EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

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THE GARGAMELLE USERS' MEETING,
Milan, 11 and 12 October, 1968

Chairman: E. Fiorini

Geneva - 23 December 1968

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Chairman's Resumé

In the meeting of the Gargamelle Users' Committee held at CERN on April 25, 1968, the need was stressed for some type of short conference, devoted only to discussions on the physics to be done with Gargamelle. The Organizing Committee, appointed on that occasion (Professors Burhop, Lagarrigue, Ramm and myself) decided that the Meeting should be held in Milan on October 10 and 11, 1968.

About one hundred people attended this meeting, and we were very pleased to see a large number of colleagues who work with other techniques, and also theorists. Their contributions to the discussions were quite essential.

The meeting was practically divided into short sections devoted to: beams for Gargamelle, neutrino physics, hadron interactions at high energy, decays of kaons, muons and antiproton phsyics, formation experiments with kaons and production experiments with pions and kaons. Each consisted of one or more general reports, followed by open discussions, which were quite brisk and did not lack some type of "contestation" (to use the words of Prof. Faissner). We are quite glad to say that we had never to cut one of them.

We reproduce here informally the reports presented at the meeting and try to include the main points that arose in the discussion.

I want to express my gratitude to the Organizing Committee, to the Physics Department of Milan University and to the National Institute for Nuclear Physics. I thank all those who contributed to the success of the meeting and particularly Dr. M. Rollier, for the organization in Milan, and Dr. D. Cundy, Secretary of the Gargamelle Users' Meeting, who collected the reports and summarized the results of the discussions.

REPORT OF THE BEAM STUDY GROUP

CERN, Geneva

1. G1(k13) AND G2(m9)

These beams are the electrostatically separated beams for $\pi^{\pm}$,$K^{\pm}$, $\bar{p}$, p in the momentum range 1.2 to 4.2 GeV/c. There has been no recent change in the situation regarding these two beams. A detailed description of their designs is given in NPA/Int. 68-4.

2. G3(u6)

Preliminary designs for the RF beam now exist in two forms. One of these uses only standard d.c. magnets whilst the other has a first stage containing pulsed quadrupoles. These two lines lie respectively to the right and to the left of the present extracted proton beam. The left-hand side solution has been considered because of its advantage with regard to the shielding of the PS. It gives, however, a reduction in the length available for the secondary beam by necessarily increasing the length of the ejected proton beam. The high-field, pulsed quadrupoles are used to allow the decrease of length without a decrease of the upper momentum limits of the beam. A comparison of all aspects of the two versions is being made.

3. G4(p6)

The report to the Track Chamber Committee edited by Prof. Fiorini recommended that G4 be constructed alongside the ν beam to provide a test beam and possibly an experimental beam for Gargamelle. The design of G4 has, therefore, been reconsidered to minimize the time needed to interchange these two beams. It is hoped to publish a detailed description of the beam soon, as an NPA Internal Report, and we only summarize here its main characteristics.

The beam uses the same target position and external proton beam as the ν experiment, although a smaller target size is required. The secondary beam is unseparated and is constructed within the ν tunnel. It uses pulsed quadrupoles and bending magnets of the type designed by B. Langeseth and his group at CERN. It is intended that these elements, 10 or 12 in number, and the 4 collimators required, be moved to the side of the tunnel during a neutrino experiment. The only problem here concerns the second reflector (R2) of the ν beam. Its present internal diameter is 20 cm and it is just possible to pass G4(p6) through its inner conductor. W. Venus has calculated provisionally that a 5% flux gain at low ν energies can be obtained by halving this diameter. However such a change would require modification of G4(p6) which would worsen the momentum resolution. Otherwise the exact spacing of the G4(p6) elements is not critical and they can be moved slightly to accommodate small changes in the ν beam. After leaving the ν tunnel the beam passes through the central pipe in the ν filter and is shaped for entry into Gargamelle. For the test version we intend using only one (pulsed) quadrupole and one (d.c.) vertical bending magnet. The exact extent of the ν filter is not yet fixed and there are three possibilities for this region:

a) the magnets are in air beyond the filter;

b) the magnets are embedded in the filter;

c) the last stage of the filter consists of machined blocks which can be moved by a crane in a few weeks.

In the horizontal plane there is a focus at the centre of Gargamelle and the dimensions of the beam never exceed 1 cm; in the vertical plane the beam diverges from a full width of about 12 cm at entry to 24 cm at exit. This is considered adequate for the test version; if a parallel beam is required then an additional (d.c.) quadrupole must be used and a greater length of ν filter must be moved.

The beam elements saturate at about 25 GeV/c; the momentum resolution is then a little better than $\pm\frac{1}{2}\%$ and the solid angle acceptance is 0.03 msr. G4 is intended primarily as a π^- beam. Particle production data at high energies is meagre but we hope to obtain an adequate flux per one extracted proton bunch for π^- momenta up to 22 GeV/c at normal PS operating conditions of 25 GeV/c (or to within 3 GeV/c of the proton momentum for other operating conditions). At low momenta the beam may be limited by three factors. Firstly, the μ^- contamination has yet to be calculated but will certainly be acceptable down to about 4 GeV/c. Secondly, the pulsed magnet power supplies would have to be modified for operation below about 6 GeV/c; this is not a difficult operation but about 6 months warning would be required. Finally at very low momenta injecting the beam into Gargamelle becomes a problem.

It may be possible to use G4 as a proton beam, either at the full PS momentum or lower. Experiments on the ejection by diffraction scattering of a small number of protons are soon to be made and, if these are successful, we will try to combine this extraction method with our pulsed-beam transport.

A study of a number of possible forms of K^0_L beam (G7-b17) has commenced.

* * *

DISCUSSION

Lagarrigue (Orsay)

I think we should consider the possibility to build a cheap beam to give π^+ around 3 GeV/c in order to study the reaction:

$$\pi^+ + p \to N^{*++} + \pi^0 + \pi^0 .$$

Miller (UCL)

When using 25 GeV/c protons it is very important to keep the number of protons down to two per picture. If there are more particles than this then many pictures are lost due to high multiplicity interactions which fill the chamber with tracks and γ rays.

At Brookhaven in the 80 in H_2-Ne experiment, 30% of the pictures were lost due to this reason when using 28 GeV/c protons.

One should think seriously about methods of shuttering the beam.

Morrison (CERN)

If one wished to have higher momentum beams, i.e. protons of 27 GeV/c and π^- of 24 GeV/c, it is possible to run the PS at 27 GeV. However, it will be unpopular.

Lagarrigue (Orsay)

I would like to suggest that there should be two K_L^0 beams, G7 and G8:

G7: K_L^0 with known momentum obtained by using a hydrogen target. This would be used to study the K_L^0 form-factors.

G8: K_L^0 without momentum definition (i.e. X_4 type beam). This type of beam could be used to study the $K_L^0 \rightarrow 2\pi^0$ decay.

Schultze (Aachen)

With respect to the momentum defined K_L^0 beam, the intensity could be improved by varying some parameters like the solid angle acceptance of the π^- used to produce the K_L^0's.

Rubbia (CERN)

One should not worry too much about the low flux in the momentum defined K_L^0 beam. At Berkeley they obtained about 100 K_L^0/pulse in a similar beam for a counter experiment.

Fiorini (Milano)

I would like to ask about the feasibility of using Gargamelle with the Interacting Storage Rings.

Lagarrigue (Orsay)

Due to questions of safety, money and perturbation of the ISR orbits we have not pursued the matter.

Rubbia (CERN)

The use of a bubble chamber with the ISR is made very difficult due to the high background level. Using the estimates of Hyams you would expect several background tracks/microsecond. I would guess that Gargamelle would be filled by background tracks during the 10 msec sensitive time.

NEUTRINO PHYSICS WITH GARGAMELLE

D.H. Perkins,
University of Oxford, England

1. EVENT RATES

Any discussion of the possible ν program with Gargamelle necessarily depends on the expected event rates both in Gargamelle and in other chambers (the BNL 7 ft, the ANL 12 ft) which will be doing similar work at about the same time (∿ 1969 - 1970). The first difficulty I encountered was that in the Fiorini report, three or four sets of event rates are quoted, often disagreeing with each other and with previous estimates -- due not to bad arithmetic but to different assumptions.

I have therefore given yet another set of numbers in Table 1. A few words of explanation are required:

i) The basic data are from the CERN 1963/1965 runs in CF_3Br. 454 ν events were observed in 220 litres fiducial volume (0.16 ton n, 0.16 ton p), using the old horn and 7.3×10^{17} protons on target. (av. intensity 5.7×10^{11} ppp). The events subdivided roughly in the proportions 30% elastic, 50% 1π, 20% ≥ 2π, strange particles, etc. For the same filling, chamber and beam, and the horn focusing negatives, the $\bar{\nu}$ rate was ∿ 10% of the ν rate.

ii) The existing focusing system at CERN, expected to yield a factor 5 enhancement in ν intensity, in fact gives a factor of order 2.5 under adverse conditions†). This conclusion is based on the propane run results; for the same number of protons on target, one obtains just over twice the number of events in C_3H_8 as in CF_3Br with the old beam for approximately the same detection mass (i.e. 1/4 the effective density and 4 times the effective volume). This is a provisional number; assuming the system is run under

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†) The adverse conditions of this experiment included: (i) a plug on a short target, (ii) 2 metres extra shielding, (iii) reduction of proton energy to 19 GeV. These three modifications were made in order to reduce the background muon flux in the spark-chamber experiment. In addition, the current in the first reflector was only 0.8 I_{max}, for safety reasons.

Table 1

Event rates of various neutrino facilities

	(a) CERN (1963/1964) per ton bound p or n	(b) Gargamelle CF_3Br	(c) Gargamelle C_3H_8 Free p	(d) BNL 7 ft H_2 p	(d) BNL 7 ft D_2 n or p	(e) ANL 12 ft H_2	(e) ANL 12 ft D_2
$\nu + n \rightarrow \mu^- + p$	600	15,000	-		750		450
$\bar{\nu} + p \rightarrow \mu^+ + n$	70	1,750	175* ($\sim$125 2C)	85 ($\sim$8 3C)		53 ($\sim$10 3C)	
$\bar{\nu} + N \rightarrow \mu^+ + \Lambda,\Sigma$	$\sim$2	$\sim$50*	$\sim$5	$\sim$3		$\sim$2	
$\nu + p \rightarrow \mu^- + p + \pi^+$	900	22,500	2,250	1,100			
$\nu + n \rightarrow \mu^- + n + \pi^+$					1,500	$\sim$700	
$\rightarrow \mu^- + p + \pi^0$	300	7,500	-	-			
$\nu + N \rightarrow \mu + N + n\pi$ ($n \geq 2$)	350	9,000*	900*	450	900	<< BNL	
$\nu + N \rightarrow \mu^- + n\pi + Y + K$	30	750	75	37	75	<< BNL	
Total ν	2,200	55,000	3,225 (p)	1,600 (p)	3,300 (n+p)	$\sim$0.2 Gargamelle free proton rate	
Total $\bar{\nu}$	220	5,500	500 (p)	150 (p)			

i) The number of events quoted are for 10^6 pulses

ii) The fiducial volumes of the various chambers are assumed to be:

Gargamelle : 6 m^3
BNL 7 ft : 4 m^3
ANL 12 ft : 12 m^3

iii) (a) and (b) refer to bound nucleons: the bound nucleon rate in Gargamelle filled with C_3H_8 is 1/3 × CF_3Br rate. (c), (d) and (e) refer to free protons or quasi-free neutrons and protons in D_2.

optimum conditions for Gargamelle one can take a factor 5. I include a penalty factor of 1.5 against Gargamelle because of the larger frontal area, and then scaled as the fiducial volume. This gives for CF_3Br filling:

$$\frac{\text{Gargamelle rate per proton in existing CERN beam (1968)}}{\text{Old NPA chamber rate in 1963/1964 beam}} \approx 90$$

It can also be hoped that the PS intensity will be improved somewhat by 1970, and I assume a factor $10^{12}/6 \times 10^{11} = 1.6$ in protons per pulse. This gives a final factor of 144. Although the repetition rate will be increased at both CERN and BNL, it is not clear to what extent the large chambers will benefit. So, I have quoted events per 10^6 pulses.

iii) To get the rate in the BNL 7 ft chamber, I have again used the penalty factor of 1.5 against the bigger frontal cross-section. The AGS intensity has always been $\simeq 2 \times$ that of the CERN PS. On the other hand we know the BNL focusing system is inherently less efficient and is underpowered. I assume these two factors will just cancel.

iv) The ANL 12 ft chamber event rate has been computed from their calculated spectrum. Essentially this spectrum gives, per m^2 averaged over the 12 ft frontal area, the same number of neutrinos per proton as the old Van der Meer spectrum averaged over the (old) CERN NPA chamber frontal area. This seems not unreasonable. The ANL spectrum is of course much softer than the CERN spectrum. Thus, ANL is at a very serious disadvantage for studying the higher-energy processes. It is also clear that, to determine form-factors (e.g. for the elastic process) in a spectrum-independent manner, one must restrict oneself to events of $E\nu > 1$ GeV say. In this case the ANL rate relative to CERN/BNL should be reduced by a factor 2.

2. SOME CONSIDERATIONS ON THE RELATIVE PROGRAMS AT CERN, BNL, ANL (1969/1970)

What essentially comes out of the table is that the expected event rates on free protons (neutrons), for the same number of pulses, under columns (c), (d) and (e) are about equal:

Gargamelle	C_3H_8 or C_3D_8	Same event rates/picture to within a factor ∿ 2 or 3
BNL 7 ft	H_2 or D_2	
ANL 12 ft	H_2 or D_2	

It is important to emphasize that the actual numbers will depend critically on the spectrum shapes, selection of events, and the proton energy chosen, and the practical performance of the focusing systems employed. The time scale refers to the interim period, before the arrival of the new linac at BNL (1971) or of the booster at CERN (1973).

On the face of it, one can therefore say that Gargamelle operated with propane, or propane with a small freon admixture, will be able to make at least a major contribution to low-energy (< 5 GeV) neutrino physics over the next two or three years. There are however other considerations than just the number of events on free protons or quasi-free neutrons. Some of these are:

i) In C_3H_8 or C_3D_8 one has the advantage that there are also events -- about four times as many -- on the bound nucleons in carbon, as well as a good γ and neutron-detection efficiency (especially in a propane-freon mixture) and the possibility of measuring proton polarization from elastic scatters on carbon.

ii) The kinematic fitting of the elastic and single pion neutrino events on free nucleons in H_2 or D_2 should certainly be superior to that in the Gargamelle events. Firstly, the intrinsic accuracy of measurement is better, and secondly, the background contributions (for those D_2 events without a visible spectator) will be very much less than in propane. The 1967 CERN propane runs indicate a carbon background of 15 ± 5% for the total cross-sections. Obviously, to get detailed information on form-factors, one needs to know the background out to high values of q^2, where the uncertainties are likely to be much greater. On the other hand, in the antineutrino studies (e.g. $\bar{\nu} + p \rightarrow n + \mu^+$) the much better neutron detection efficiency of propane compared with hydrogen is quite decisive.

iii) The usefulness of the pictures depends very much on how easy or difficult it is to analyse them. With Gargamelle one will have the complication of collaboration between several widely-spread laboratories. It is also possible that the geometrical reconstruction problems may be inherently more difficult than with the smaller BNL 7 ft chamber, for example. I do not believe anyone could honestly assess these factors at the present time.

3. ATTEMPTS TO ARRIVE AT A SUGGESTED FIRST EXPERIMENT WITH GARGAMELLE

Essentially, one has to make decisions on the beam and filling for the first Gargamelle experiments.

i) ν or $\bar{\nu}$

ii) beam length (spectrum shape)

iii) propane, propane/freon, or freon.

Obviously, (i) and (iii) can be finally decided at short notice. Fortunately, calculations show modification of the beam length (ii) to alter the spectrum shape, could produce changes in any one part of the spectrum of at most 30% in dN/dE_ν, so no long-term decision on this aspect is necessary.

Although a final choice, for a first experiment, on (i) and (iii) is neither necessary nor desirable now--remember that one is still assessing the propane run in the CERN NPA chamber--some preliminary discussion, to serve as a basis for the final choice, when it is made, is perhaps useful.

A reasonable case can probably be made out for any of the above combinations. One can however, I believe, state at the outset that to run comparable proportions of each of the three or four possible options, in say, the first 10^6 pictures, would be disastrous. What is needed is a decisive experiment, rather than a succession of explanatory surveys (which were well justified for the NPA chamber program).

The various proposals in the Fiorini report describe in some detail the processes which could be studied with each choice of sign of beam and chamber filling and there is no need to describe them again in detail. However, I have put an asterisk in the table for those reactions where Gargamelle possesses a really decisive advantage over its competitors. These are:

a) $\bar{\nu}$ run in propane. For every 10^6 pictures, one would obtain about 125 examples of the elastic reaction

$$\bar{\nu} + p \rightarrow \mu^+ + n$$

on a free proton, where the neutron direction is measured by production of an associated interaction, this providing a 2C kinematic fit. The corresponding number of events (3C fits) in the BNL chamber would be roughly an order of magnitude less, and thus hardly useful.

b) $\bar{\nu}$ run in freon. This appears to offer the only possibility, in the near future, to study hyperon production with a reasonable event rate. Probably such studies would be better deferred until the advent of the booster.

c) Highly inelastic processes†). A ν run in propane or freon would have decisive advantages over H_2/D_2 chambers in the study of the complex inelastic processes. This stems partly from the six-fold higher event rate, but more importantly from the better identification of the muon and of associated γ-rays††).

d) In the other reactions listed in the table, Gargamelle would not have decisive advantages over the hydrogen chambers, but would not necessarily be at a grave disadvantage. No one laboratory is going to obtain so many events, and be sufficiently confident about flux and background estimates, that a comparable experiment with another type of detector would not be valuable.

From these considerations it appears that one has to make a clear choice between (a) a $\bar{\nu}$ run in propane or propane/freon, where it is clear that Gargamelle has a decisive advantage for study of the elastic process, but where the number of events is small, and (b) a ν run in propane or propane/freon, where one would get many more events, but, for study of the elastic or simpler inelastic processes, one would be competing -- probably on unequal terms -- with the big hydrogen chambers. As far as I know, most potential Gargamelle users favour a <u>ν run in a propane/freon mixture</u>. Such an experiment would yield some 3000 free proton events and nearly

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†) 25 GeV operation; frequency of high-energy events is as follows:

$E_\nu > 5$ GeV	5% of total events
$E_\nu > 10$ GeV	1% of total events
Associated production	$1\frac{1}{2}$% of total events

††) In the CERN propane run, ∿25% of the events of $E_\nu > 5$ GeV were ambiguous in assignment of the negative muon.

15,000 on bound nucleons -- enough to allow several collaborating laboratories each to make a decisive contribution with a respectable number of events to analyse. One can argue about the merits of various mixtures. Table 2 indicates some typical numbers. Obviously, a moderate admixture of freon dramatically improves the γ-detection efficiency, while not impairing the momentum resolution too much. My argument here is that pure propane is already a factor 3 worse than hydrogen, and to increase this to $4\frac{1}{2}$ cannot be disastrous. On the other hand, one does not know how well in practice the theoretical momentum precision of the big chambers will be realized, so the situation may be even better. In adding freon one also dilutes the free proton concentration and impairs polarization measurements from carbon scattering, but the advantages of surer identification of the outgoing lepton, and vastly improved information content in the complex inelastic events, appear overwhelming.

Table 2

Propane/freon mixtures
(average secondary path length = average γ path length = 1.5 m)

Vol. per cent CF_3Br	Vol. per cent C_3H_8	X_0(cm)	η_{π^0}	$\Delta p/p$
100	0	11	100%	7%
20	80	39	90%	3.5%
10	90	56	77%	3.1%
0	100	102	47%	2.3%

4. OTHER NEUTRINO PROCESSES

Many other topics which could be studied in the Gargamelle neutrino film are mentioned in the Fiorini report. Some examples are:

a) Conservation of muon number and lepton number.
b) Existence of the W boson.
c) Neutral currents.
d) Time reversal invariance.
e) Tests of sum rules, PCAC etc.

Essentially (a), (b) and (c) all depend on beam characteristics and background problems, and not so much on the qualities of the detector. It does not appear that the Gargamelle experiments as such are likely to improve greatly on existing data, but more detailed studies of the beam and background problems might be rewarding. With regard to (d) and (e) the information will come as a matter of course. Since T-violating effects are likely to be extremely small in any case, it is probably not justified to prejudice the rest of the analysis by determining the type of filling purely on the basis of a possible T violation.

5. OTHER ASPECTS OF THE NEUTRINO PROGRAM

I would like to mention some important aspects of neutrino experiments which do not appear in the Fiorini report.

I have heard it recently remarked that the physics analysis of neutrino film, and the engineering of the neutrino beam itself, could be effectively decoupled. This conclusion seems to be directly contrary to all experience at CERN over the last five or six years, and I think is absolutely wrong. I would like to make a strong plea that as many of the user groups as possible get involved in the beam and background problems:

i) First let me remark that less than half the events in the film will be classed as "ν events". We do not at present understand the other half. Maybe they are due to neutrons, pions, K^0's etc., but no very detailed and systematic studies have been made.

ii) After five years of effort in CERN, no one is able to guarantee ν fluxes to better than 30%; in some regions of the spectrum the situation is much worse. It is somewhat ludicrous to go to the labour of accumulating thousands of events and accept such large uncertainties in cross-sections. There are formidable problems to be solved here, certainly comparable in magnitude to the whole of the physics film-analysis put together.

iii) Ways and means should be investigated to improve still further the neutrino flux, which at present amounts to only ≈ 1 neutrino for every 1000 protons accelerated.

iv) With the much more intense and energetic beams available at the 300 GeV machine, the burst of neutrino-produced muons emerging from the end of the main shield, and entering the detector, is likely to be of order 100 per pulse. The exact number cannot be calculated since the high-energy neutrino cross-sections are unknown. Gargamelle experiments, which will extend the range over which the energy dependence of the inelastic processes is known, will be of vital importance from this viewpoint (as well as being of very great intrinsic interest).

These are just some of the problems associated with the neutrino studies, and not simply the film analysis, where groups outside CERN could make original and possibly vital contributions.

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DISCUSSION

Musset (Ecole Polytechnique)

I am afraid one can be misled by your table. Events in complex nuclei will also be useful. If one added 10 ∿ 20% freon to the propane the measurement precision would not be seriously affected and the π^0-detection efficiency would be very high.

The number of events on free protons would only be reduced by 10 ∿ 20% and one would get ∿ 20,000 events on complex nuclei.

Perkins (Oxford)

My figures for propane are only for events on free protons. These are the events with which one will do the most physics.

I agree that the exact mixture to be used must be discussed.

Lagarrigue (Orsay)

I consider that Musset's proposal is a good solution for the first run.

Myatt (CERN)

In view of the fact that a heavy-liquid chamber has an immense advantage in the study of antineutrino physics, where most processes result in the emission of one or two neutral particles, it would be interesting to know to what extent the optimized ν beam would be non-optimum for $\bar{\nu}$'s.

Burhop (UCL)

In the light of Professor Perkin's talk one would perhaps draw the conclusion that the neutrino experiments in Gargamelle should be postponed until after the CERN PS improvement program.

Salmeron (Ecole Polytechnique)

I would like to reply to Professor Burhop's remark.

Gargamelle is a new chamber with new scanning and measurement problems. For this reason I think it is best to start with the neutrino experiment.

However, in spite of the large number of 'elastic' events produced in freon I am doubtful if they will add much to work already done by the CERN heavy-liquid and the spark chambers. This is especially true if the ν flux will still only be known to 20 $\sim$ 30%.

I imagine it would be useful to study N* production and single hyperon production. What do the theoreticians think?

Veltman (Utrecht)

I agree that the study of N* production can very usefully be extended in Gargamelle. However with respect to hyperon production one sees that the rates are still very low.

Faissner (Aachen)

Just for amusement some daring theoreticians have tried to calculate the mass of the intermediate boson. All these numbers lie around a few GeV.

NUCLEAR EFFECTS IN NEUTRINO REACTIONS ON PROPANE NUCLEI

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and
CERN, Geneva, Switzerland.

1. INTRODUCTION

In this report I intend to present a brief account of some work, which has been carried out recently, to estimate nuclear effects on reactions induced by neutrinos on light nuclei.

In fact I shall limit myself to ^{12}C nuclei, which are better known than most others and are of interest for experiments in propane: heavier nuclei — such as bromine — present a much more difficult problem and the results so far published are probably not very reliable.

2. NUCLEAR EFFECTS IN ELASTIC NEUTRINO REACTIONS

Calculations on elastic neutrino interactions on ^{12}C have been performed by Piketty$^{1)}$, Lecourtois and Piketty$^{2)}$, Franzinetti and Manfredotti$^{3)}$, Løvseth$^{4)}$, Yoshiki$^{5)}$. I am not including in this list work done on coherent scattering which is a comparatively rare process. The calculations carried out by Yoshiki are not yet available in a written form and I am unable to discuss them here.

2.1 The model used by Lecourtois and Piketty$^{1,2)}$.

This model assumes that the target nucleon is on a definite nuclear shell. The interaction of the recoiling proton with the nucleus is described by a spherical optical potential (spin-orbit coupling and terms of the same order of magnitude are neglected). The parameters of the optical potential are obtained from p-nucleus experiments. Thus the Pauli exclusion principle is automatically satisfied.

The interaction is described by an effective Hamiltonian which is correct up to terms in the second order in $|\vec{q}|/M$ where $\vec{q}$ is the three-momentum transfer from the leptons to the nucleus and M the nucleon mass*). Thus for very large $|\vec{q}|$ (say $|\vec{q}| > 0.7$ GeV/c) it fails.

They consider only events in which the proton escapes from the nucleus without interacting in it. Moreover they notice that, in the limits of the approximation they use, the differential cross-section $d^2\sigma/dq_0\, d|\vec{q}|$, plotted as a function of q_0 for fixed $|\vec{q}|$ has a shape which depends essentially on the Fermi motion of the target nucleon and not on the neutrino energy E_ν. Thus, for a fixed $|\vec{q}|$ the integral

$$\int_{q_{01}(|\vec{q}|)}^{q_{02}(|\vec{q}|)} (d^2\sigma/dq_0\, d|\vec{q}|)\, dq_0 \qquad (1)$$

contains approximately the same fraction of events for any choice of E_ν.

One can choose the two curves $q_0 = q_{01}(|\vec{q}|)$ and $q_0 = q_{02}(|\vec{q}|)$ so that for any $|\vec{q}|$ the integral (1) contains the same fraction of undistorted events. For example the curves indicated in Fig. 6a refer to propane and should contain ~95% of them. They claim that most of the inelastic events, disguised as elastic, are eliminated by this method of selection.

2.2 Løvseth's model[4]

Løvseth uses an independent particle model with a "realistic" momentum distribution. This is, in fact, a gaussian distribution of momenta given by

$$G(y) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{y} e^{-x^2/2}dx$$

with $y = (P - P_F)/\Delta$; $P_F = 0.225$ GeV/c and $\Delta = 0.075$ GeV/c. He also takes into account the Pauli principle by introducing an appropriate suppression factor. He ignores the fate of the recoil proton and calculates the q^2 distribution of the events. To do so, he averages the theoretical cross-section $d\sigma/dq^2$, for neutrino scattering on a free neutron, over the

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*) $q = (\vec{q}, iq_0)$ where $\vec{q} = \vec{p}_\nu - \vec{p}_\mu$ and $q_0 = E_\nu - E_\mu$. For all kinematical notations the reader is referred to Ref. 3.

primary neutrino spectrum $\phi(E_\nu)$ and the target momentum distribution G(y). The analysis of the events is then carried out in a standard way fitting the theoretical curve on the corresponding experimental distributions.

2.3 Monte Carlo calculations[3)]

These were carried out using a Fermi gas model of independent particles in a potential well. The depth of the well was taken equal to 38 MeV; the Fermi momentum P_F = 204 MeV/c and the Fermi gas was assumed to be at a temperature of 4 MeV. Each event was assumed to be due to the interaction on a single neutron. The proton recoil was followed through nuclear matter and its fate determined until it fell below the edge of the potential well or emerged from the nucleus. Cross-sections for proton-nucleon interactions were calculated from empirical formulae given by Metropolis et al.[6)], but the constants included in them were re-determined over more recent data.

2.4 Discussion of the results obtained in the work quoted above

Before beginning on the discussion of the work mentioned in the previous sections, a general remark is appropriate. Some of these authors[2,5)] have derived their analysis of neutrino reactions from calculations related to electron-nucleus scattering. Although there are many obvious similarities between the two processes, there is one fundamental difference: in electron scattering, the energy of the primary particle is known (or can be measured directly on each event); whereas in neutrino reaction the neutrino energy is not known and it can only be estimated from the total energy released in the reaction or from the total longitudinal momentum of the final products. Because of the difficulty in detecting neutral secondaries, there is a systematic loss in estimating the primary energy. This, in turn, introduces a systematic bias in any other parameter which is derived from the neutrino energy E_ν. Thus, what is needed, is a prediction of the distribution of measurable quantities, rather than an estimate of nuclear effects on quantities which are not directly accessible to the experimental analysis.

This point is the main difficulty encountered in Løvseth's work[5)]. He calculates the q^2 distribution $f(q^2) = \int\phi(E_\nu)dE_\nu \; d\sigma(E_\nu,q^2)/dq^2$ as distorted by nuclear effects, but still assumes that the exact q^2 can be measured and is given by

$$q^2 = 2E_\mu E_\nu (1 - \beta_\mu \cos \theta_\mu) \qquad (2)$$

(the notations are self-explanatory and, in any case are the same as in Ref. 3) whereas what is measured is

$$q^2_{vis} = 2E_\mu E_{vis} (1 - \beta_\mu \cos \theta_\mu) \qquad (3)$$

where E_{vis} is that fraction of E_ν which is associated with the charged final products of the reaction.

This effect is not large -- in general -- if one selects only elastic events which produce only a μ^- and one proton (1p events). But even for this class it plays a role at large momentum transfer $[q^2 > 1 \, (\mathrm{GeV}/c)^2]$ which should be excluded from the analysis.

Lecourtois and Piketty avoid this difficulty -- as we have seen -- by computing the partial cross-section of events in which the recoil proton emerges from a ^{12}C without interacting (the undistorted wave). This method assumes that "undistorted" events can be experimentally unambiguously identified from others: this is not always possible.

In my opinion the Monte Carlo calculation presents a number of advantages. It "generates" complete events, i.e. for each event all the parameters which define the final states are known. Thus, on them, one can see what errors are likely to interfere with experimental measurements. I shall give some examples.

One starts generating events from an assumed theoretical cross-section and an assumed neutrino spectrum*). Then one classifies the events according to the number of protons which are ejected from the ^{12}C nucleus, assuming that the energy which goes into excitation of the residual nucleus or into ejected neutrons is not visible. Then one can compare the visible energy with the original neutrino energy.

---

*) We used the cross-section given by Bell (J.S. Bell, CERN, 63-37, 1963, p.1) and the ν spectrum given by Venus (W. Venus, private communication). (See Ref. 3 for other details of the calculation).

The result is shown in Fig. 1b. Figures 1a and 1c give the equivalent scatter-diagrams for 0p or 2p events. Figures 2 and 3 tell you where the missing energy goes. E_n is the energy which goes into neutrons and E' the excitation energy absorbed by the residual nucleus, which is subsequently released into soft γ rays. If this model is correct, in 0p events the missing energy goes almost entirely to excite the residual nucleus whereas in 1p or 2p events it goes predominantly into neutrons.

The predicted proton momentum spectrum for elastic events is shown in Fig. 4 and is compared with some preliminary data from neutrino experiments in propane. Despite the small number of events plotted there, a marked difference is shown which is confirmed by later observations. Thus the model which we have used does not describe adequately the behaviour of protons in nuclear matter even if it agrees qualitatively on most of its aspects.

However, it must be pointed out that such a discrepancy is not as big as shown by the other models. In Fig. 5 we show the proton kinetic energy distribution calculated by Lecourtois and Piketty²⁾ for events in freon, compared with the experimental distribution. Several curves have been calculated for different axial vector parameters M_A *). None of them -- in particular not that one corresponding to the optimal value $M_A = 0.75$ GeV/c^2 -- agrees with the experimental results which -- once more -- contain more low-energy protons than expected from theory.

The region of discrepancy is above 200 MeV/c in both cases, i.e. where effects due to the excitation of discrete nuclear levels should be absent and the quasi-free nucleon cross-section should describe correctly the primary elementary event $\nu + n \rightarrow \mu^- + p$. Thus the discrepancy should be attributed to the interactions of protons in nuclear matter.

Løvseth has not given any proton spectrum for neutrino events. However, he has used the same model to study e-p scattering and for this process his results predict a distribution for the energy transfer which differ considerably from the experimental data. Thus I do not see any reason to prefer his method with respect to others.

---

*) They take $F_A = [1 + (q^2/M_A^2)]^{-2}$.

In Fig. 6a the predictions of Lecourtois and Piketty's method are compared with those of Manfredotti and myself. As those authors had predicted, up to three-momentum transfers of $|\vec{q}| \sim 0.7$ GeV/c about 95% of the "undistorted" events fall in the region contained by the curves defined in Eq. (1). However, also some of the distorted events fall in the same region: in fact according to the Monte Carlo calculations the sample of 1p events which would be selected by this method would contain $\sim$12% of distorted elastic events.

Finally, the following conclusions are pertinent to this question:

a) None of the nuclear models which have been used to describe lepton-nucleus scattering works really in a satisfactory way. The main discrepancy is seen in the proton momentum spectrum and also in the proton angular distribution. It lies in a region where a ν-n collision should be in fact a direct collision with an individual neutron, thus the discrepancy should be attributed to the effect of the nuclear model on the description of the subsequent interaction of the recoil proton in nuclear matter.

b) If the above is true, and also the result shown in Fig. 1b is believed, for 1p events $E_{vis} \sim E_\nu$ and thus $q^2_{vis} \sim q^2$. Then, using the q^2 distribution to determine M_A, the nuclear effects mentioned in (a) should not be important and we should get a result not too far from the true one. This conclusion seems to be confirmed by the graph of Fig. 7, where the events "generated" by the Monte Carlo were subsequently re-analysed in the same way as one would analyse real events. The χ^2 analysis of these events has a minimum for $M_A \sim 0.8$ GeV/c^2 whereas the events were generated using a cross-section with $M_A = 0.85$ GeV/c^2.

c) The discrepancy which is observed may affect our criterion for the selection of the events. However, all the results obtained by different methods indicate that the distortion introduced by the ^{12}C nucleus on the essential dynamical parameters is small in general. In fact most of the elastic events ($\gtrsim$80%) appear as 1p events, and no appreciable bias is introduced by ignoring the others.

d) We do not yet know how to make a reasonably precise estimate of the contamination of disguised inelastic events in the sample of 1π events.

3. NUCLEAR EFFECTS IN SINGLE PION PRODUCTION

To my knowledge, nuclear effects in neutrino inelastic reactions have been performed only by Manfredotti[7)]. He uses again the same model outlined in the previous section, extended to include nuclear cascades produced by 1π inelastic events in ^{12}C. He assumes that, when inside the nucleus, the pion sees a potential depth of 20 MeV.

As a test of his model, he calculates a number of distributions related to π^+-^{12}C in propane at different energies. In fact an experiment has been performed at Saclay, by the Orsay-Milan groups (see Ref. 7 for details) just to test nuclear effects in propane. In Figs. 8 and 9, the prediction of the Monte Carlo computations are compared with the experimental data at various momenta. Figure 8 contains distributions as a function of the total number of visible tracks and Fig. 9 distributions as a function of identified protons. The agreement is excellent in both cases.

Figure 10 compares pion spectra at different angles; while the forward production is fitted very well by the computed spectrum, that in the backward direction agrees less well. In Fig. 11, some preliminary data from neutrino interactions are shown. One can see that the π^+ energy distribution is in good agreement with the data from neutrino experiment. Equally good agreement is found in comparing the π^+ angular distribution (Fig. 12).

On the other hand a short disagreement is found in comparing the theoretical and experimental proton momentum distributions (Fig. 13). These protons are mainly due to nucleons produced directly in the original neutrino reactions.

The model of proton cascade was not found satisfactory in connection with elastic events either. However here the disagreement is far more pronounced and I am inclined to believe that it may be also due to the theory of neutrino inelastic reactions.

* * *

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1) C.A. Piketty, Nuovo Cimento 46, 1163, 1966.
2) A.Lecourtois and C.A. Piketty, 50A, 927 (1967).
3) C. Franzinetti and C. Manfredotti, CERN Internal Report NPA/Int. 67-30.
4) J. Løvseth, Nuovo Cimento 57, 382 (1968).
5) H. Yoshiki, private communication.
6) N. Metropolis et al., Phys.Rev. 110, 185 (1957).
7) C. Manfredotti, CERN Internal Report NPA/Int. 68-8.

* * *

DISCUSSION

Bell (CERN)

Have you considered the possibility of determining electromagnetic form-factors from complex nuclear events as a test of your kind of analysis?

Franzinetti (CERN)

Yes, but one would have to use a muon beam and no experimental material is available.

Veltman (Utrecht)

Can one measure the elastic form-factors by measurements on complex nuclei?

Franzinetti (CERN)

Up to a point, yes.

<u>Bell</u> (CERN)

Do you think the nuclear physics is under sufficient control to make it worth while piling up statistics on complex nuclei to study the elastic form-factors?

<u>Franzinetti</u> (CERN)

No.

<u>Cundy</u> (CERN)

Concerning the study of N^{*++} production on free protons in propane I would like to ask at what number of events does the systematic error from the carbon background become equal to the statistical error?

<u>Franzinetti</u> (CERN)

Calculations have shown that for the present CERN chamber 2,000 ~ ~ 3,000 events and for Gargamelle 50,000.

<u>Myatt</u> (CERN)

What is your estimate of the pion re-absorption in carbon?

<u>Franzinetti</u> (CERN)

Roughly 25% averaged over the spectrum.

<u>Myatt</u> (CERN)

Does this agree with the data from the Saclay exposure?

<u>Franzinetti</u> (CERN)

We have not compared it yet.

* * *

Figure captions

Fig. 1 : The neutrino energy (E_ν) plotted versus the energy associated with the charged particles (E_{vis}) ejected in elastic interactions

- a) for 0p events
- b) for 1p events
- c) for 2p events
- d) for $\geq$ 3p events

Fig. 2 : Distribution of the elastic events as a function of the energy going into neutrons (E_n), for different proton multiplicities.

Fig. 3 : Distribution of the events as a function of the energy going into nuclear excitation (E'), for different proton multiplicities.

Fig. 4 : Proton momentum spectra for elastic events, compared with the preliminary experimental data from the neutrino experiment in propane.

Fig. 5 : Proton energy spectrum from elastic events in freon, compared with the theoretical predictions of Lecourtois and Piketty, calculated for different values of M_A (see text and Ref. 2).

Fig. 6 : Lecourtois and Piketty's analysis of elastic events.

- a) Scatter diagrams of 1p events in which the recoil proton did not collide before emerging from the parent nucleus.
- b) Scatter diagram of events in which the recoil proton collided.

The numbers give the expected frequency of events computed by Franzinetti and Manfredotti[5].

Fig. 7 : χ^2 fit on events generated by the Monte Carlo to determine the best value for M_A.

Fig. 8 : Distribution of π^+ - ^{12}C interactions as a function of the number of visible tracks for π^+'s of 280, 380 and 1730 MeV/c.

Fig. 9 : Distribution of the same events as in Fig. 8, as a function of the number of identified protons.

Fig. 10 : Kinetic energy spectrum for π^+ produced by 195 MeV kinetic energy π^+ impinging on ^{12}C.

Fig. 11 : Cascade produced by secondary pions ejected in neutrino reactions (N^*_{33} production): kinetic energy distributions of secondary particles.

Fig. 12 : Angular distribution of the secondary particles produced as in Fig. 11.

Fig. 13 : Cascade produced by protons ejected in N^*_{33} production in ^{12}C by neutrinos. Comparison with preliminary experimental data.

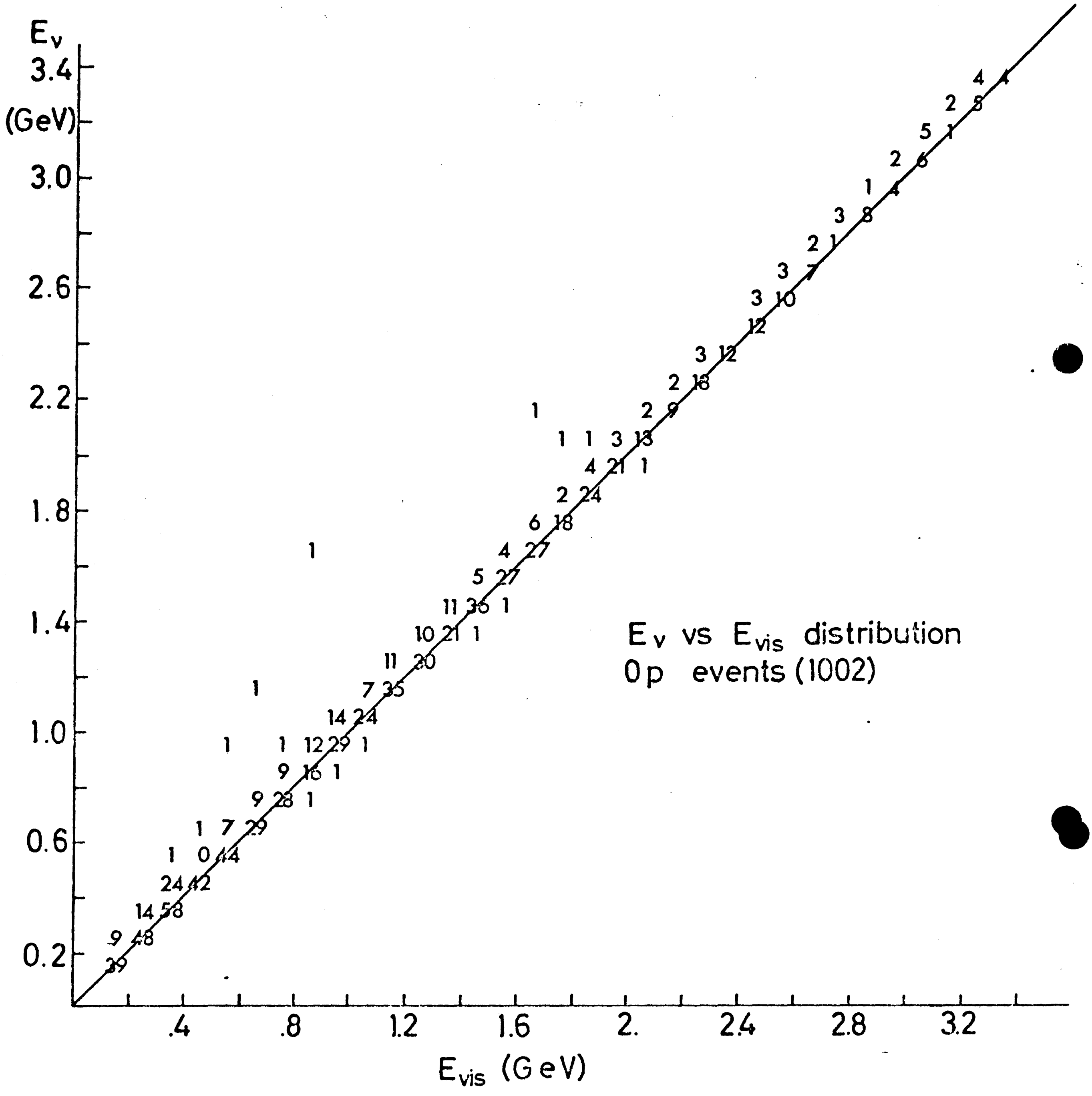

Eν
(GeV)
3.4
3.0
2.6
2.2
1.8
1.4
1.0
0.6
0.2
.4
.8
1.2
1.6
2.
2.4
2.8
3.2
Evis (GeV)
Eν vs Evis distribution
0p events (1002)
4 4
2 5
5 1
2 6
1 4
3 8
2 1
3 7
3 10
3 12
3 12
2 18
1
2 9
1 1 3 13
4 21 1
2 24
6 18
1
4 27
5 27
11 36 1
10 21 1
11 30
1
7 35
14 24
1 1 12 29 1
9 16 1
9 28 1
1 7 29
1 0 44
24 42
14 58
9 48
39

Fig. 1a

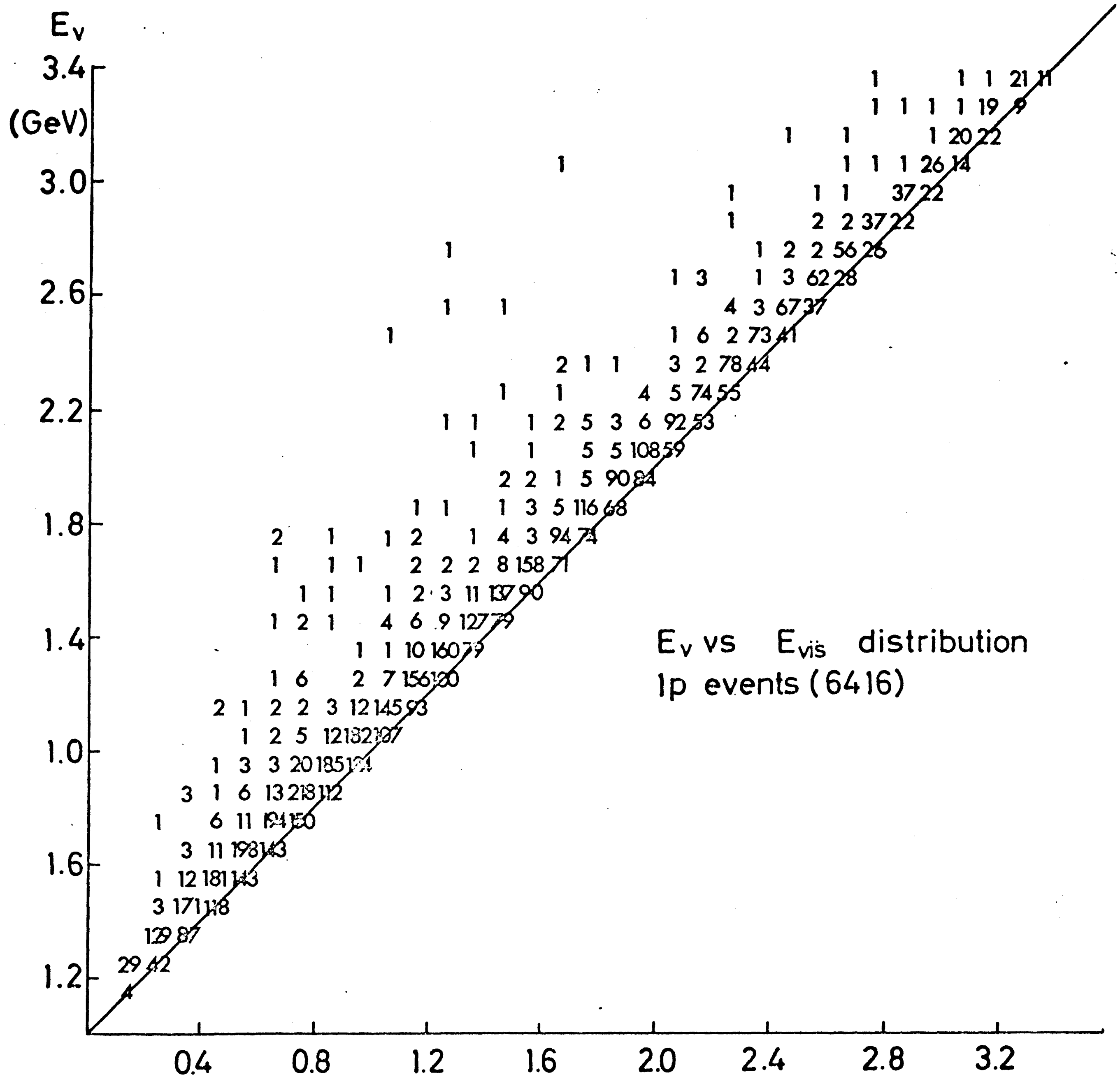

Eᵥ
(GeV)
3.4
3.0
2.6
2.2
1.8
1.4
1.0
1.6
1.2
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
Evis (GeV)
Eᵥ vs Evis distribution
1p events (6416)

Fig. 1b

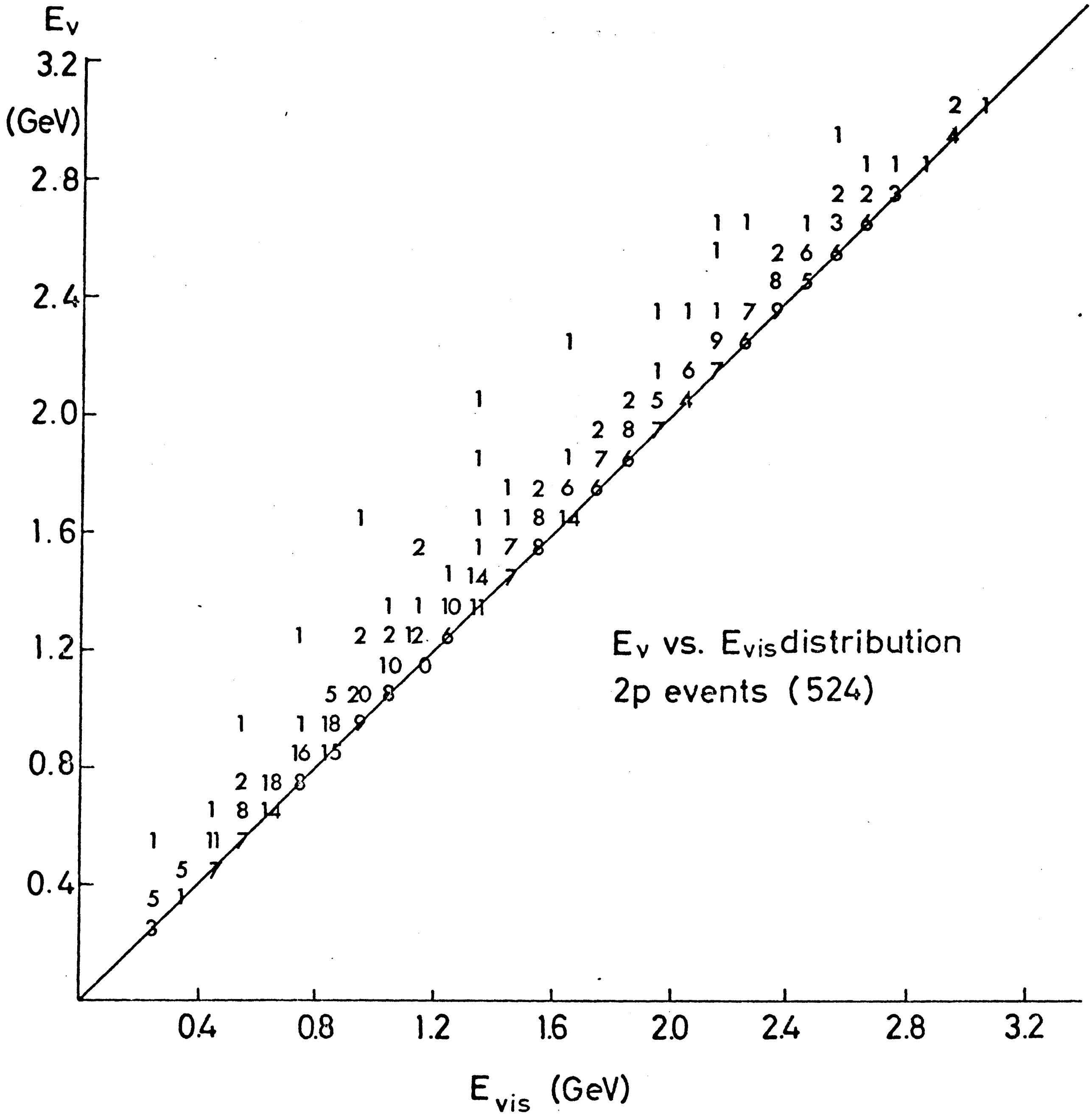

Ev
(GeV)
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
Evis (GeV)
Ev vs. Evis distribution
2p events (524)

Fig. 1c

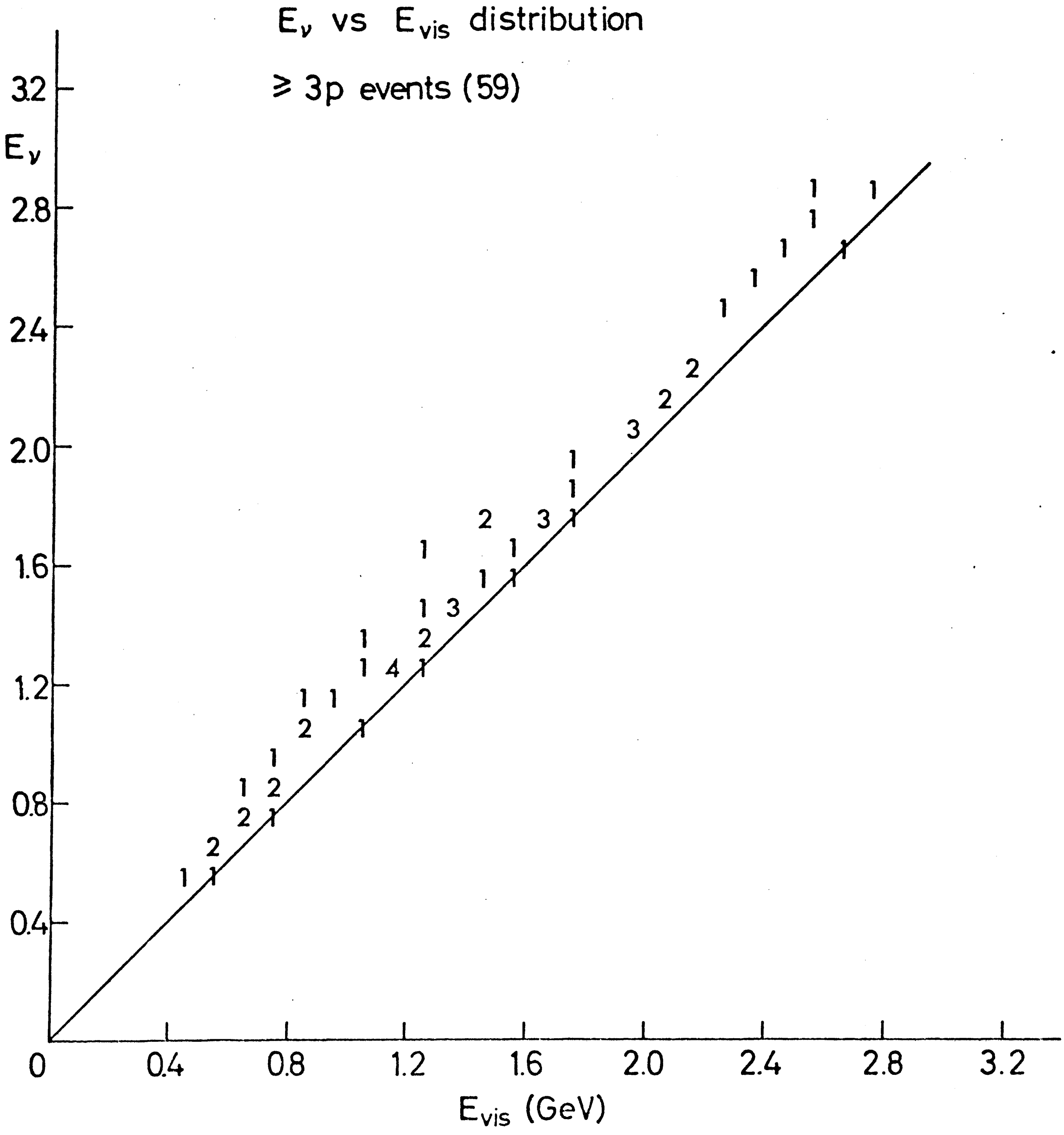

E_ν vs E_{vis} distribution
≥ 3p events (59)
E_ν
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
E_{vis} (GeV)

Fig. 1d

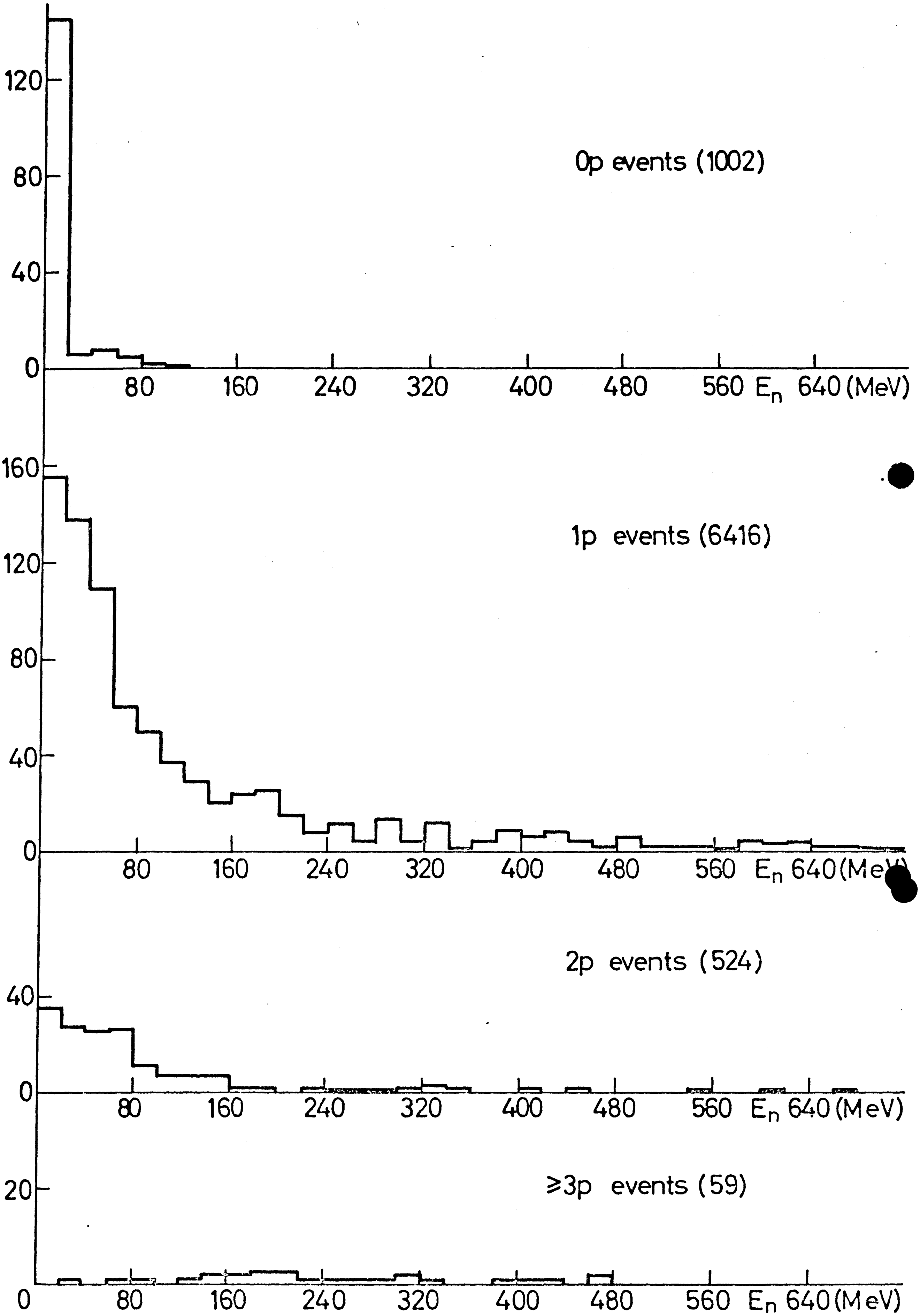

0p events (1002)
120
80
40
0
80
160
240
320
400
480
560 E_n 640 (MeV)
1p events (6416)
160
120
80
40
0
80
160
240
320
400
480
560 E_n 640 (MeV)
2p events (524)
40
0
80
160
240
320
400
480
560 E_n 640 (MeV)
≥3p events (59)
20
0
80
160
240
320
400
480
560 E_n 640 (MeV)

Fig. 2

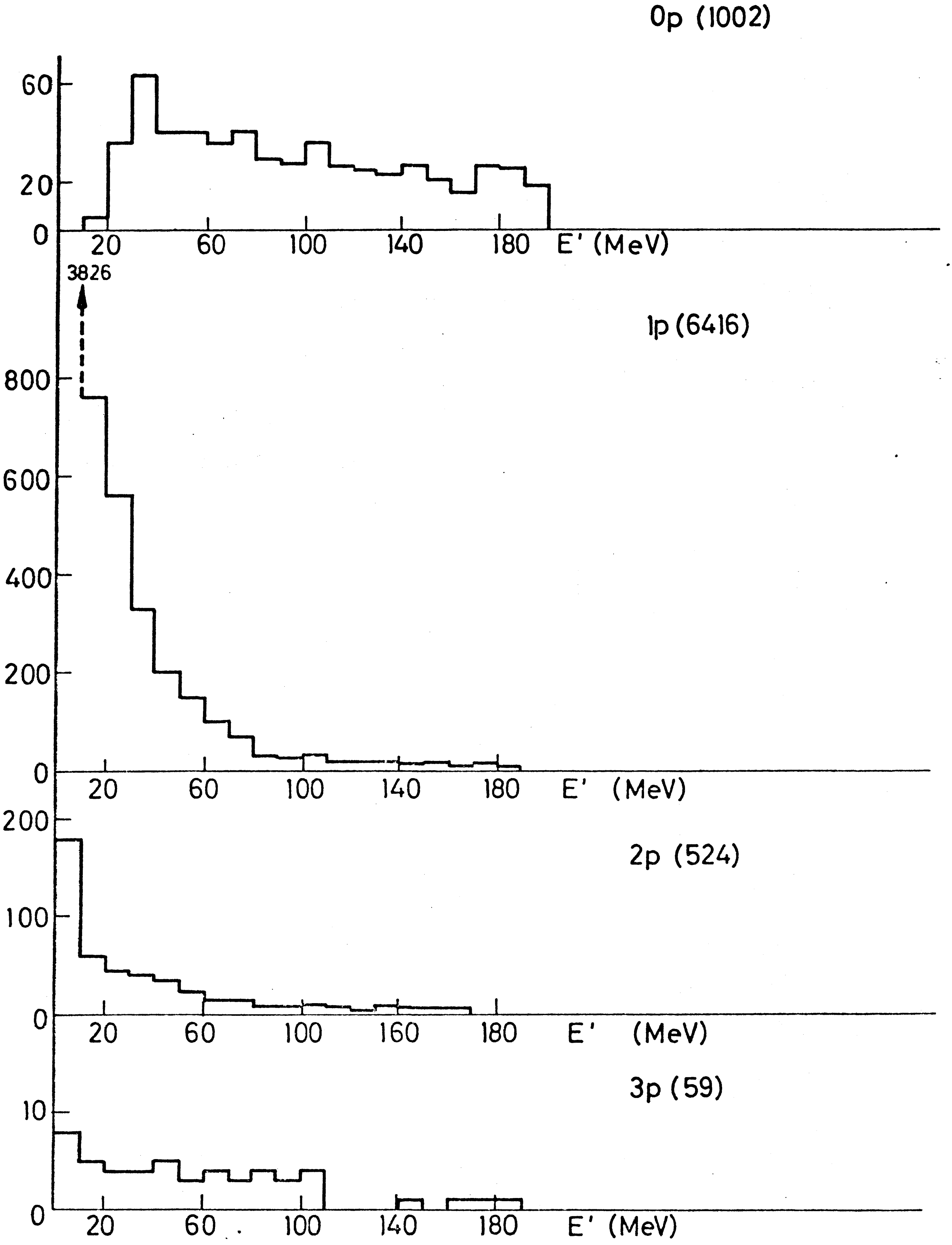

0p (1002)
60
20
0
20
60
100
140
180
E' (MeV)
3826
1p (6416)
800
600
400
200
0
20
60
100
140
180
E' (MeV)
200
2p (524)
100
0
20
60
100
160
180
E' (MeV)
3p (59)
10
0
20
60
100
140
180
E' (MeV)

Fig. 3

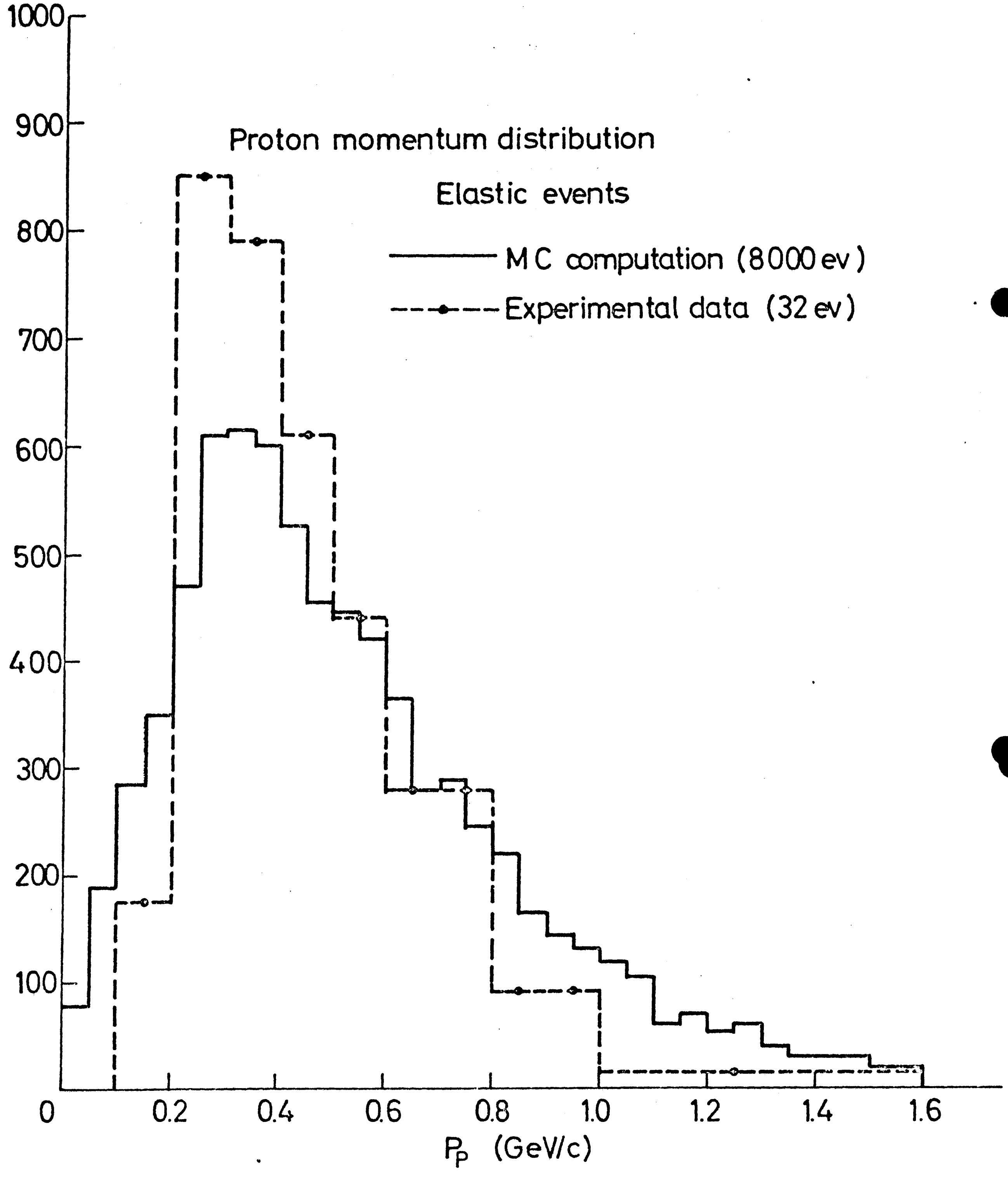

1000
900
800
700
600
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
P_P (GeV/c)
Proton momentum distribution
Elastic events
MC computation (8000 ev)
Experimental data (32 ev)

Fig. 4

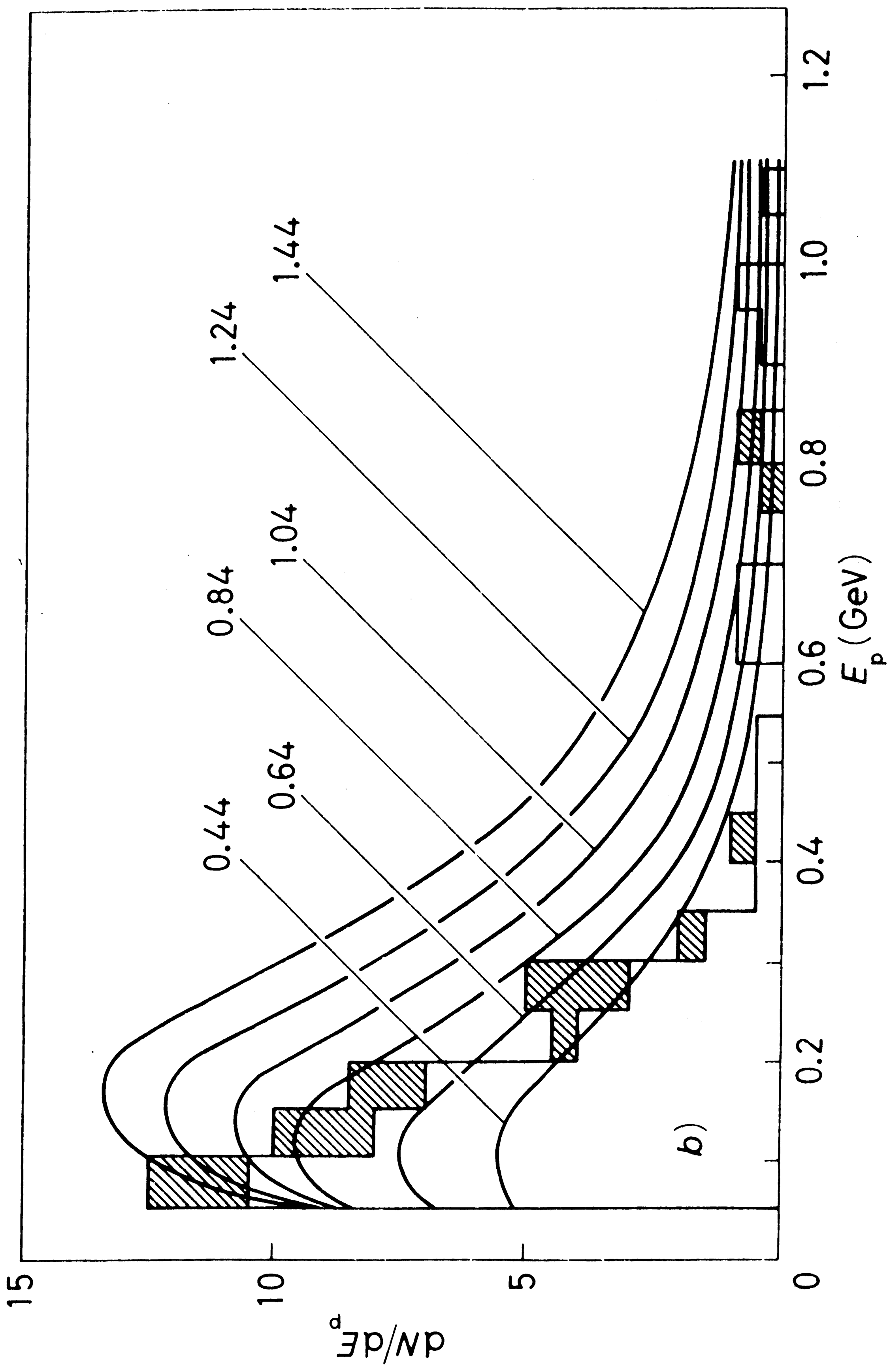
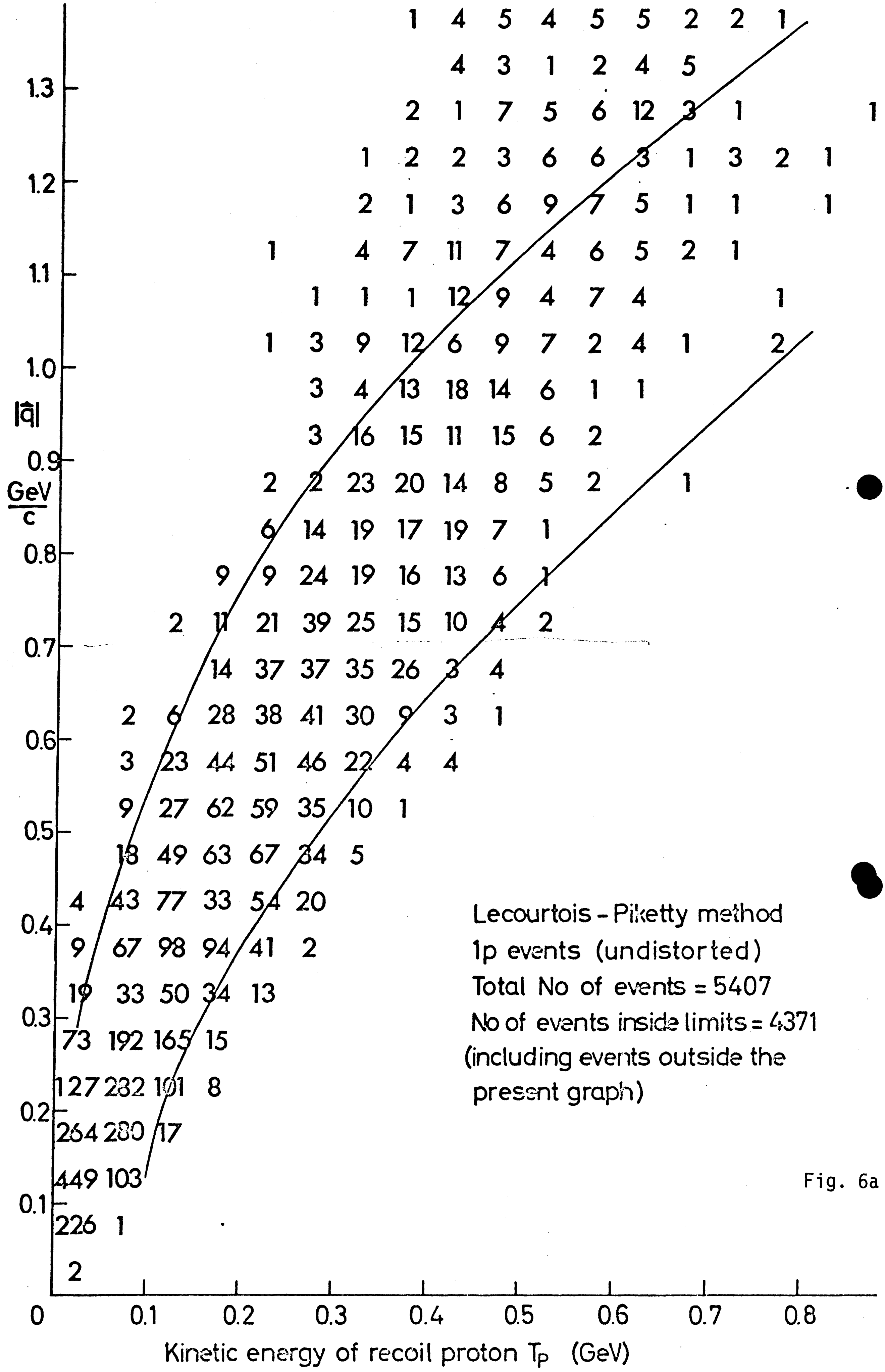
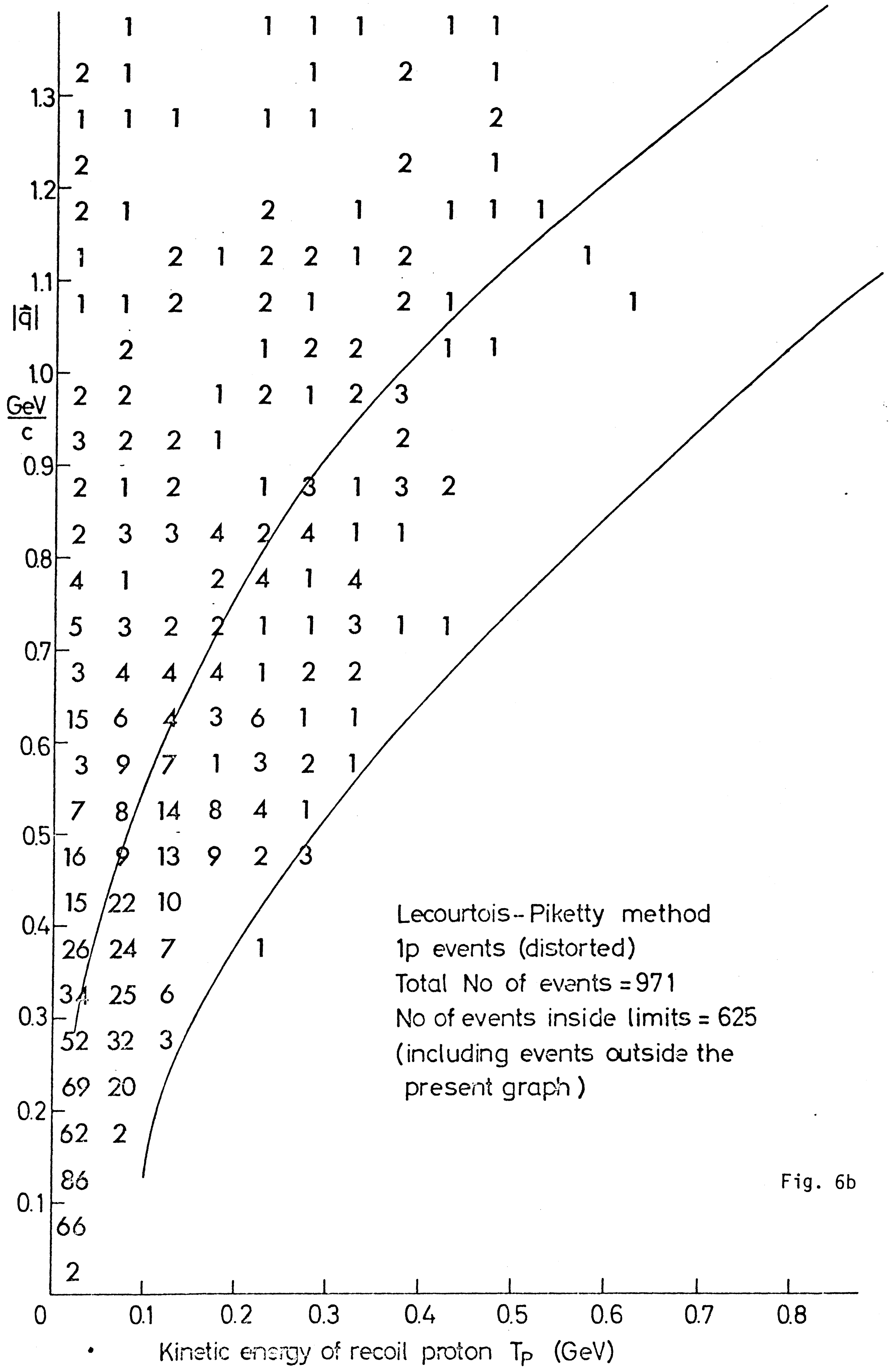


Fig. 5



Lecourtois - Pikketty method
1p events (undistorted)
Total No of events = 5407
No of events inside limits = 4371
(including events outside the present graph)

Fig. 6a



Lecourtois-Piketty method
1p events (distorted)
Total No of events = 971
No of events inside limits = 625
(including events outside the
present graph)

Fig. 6b

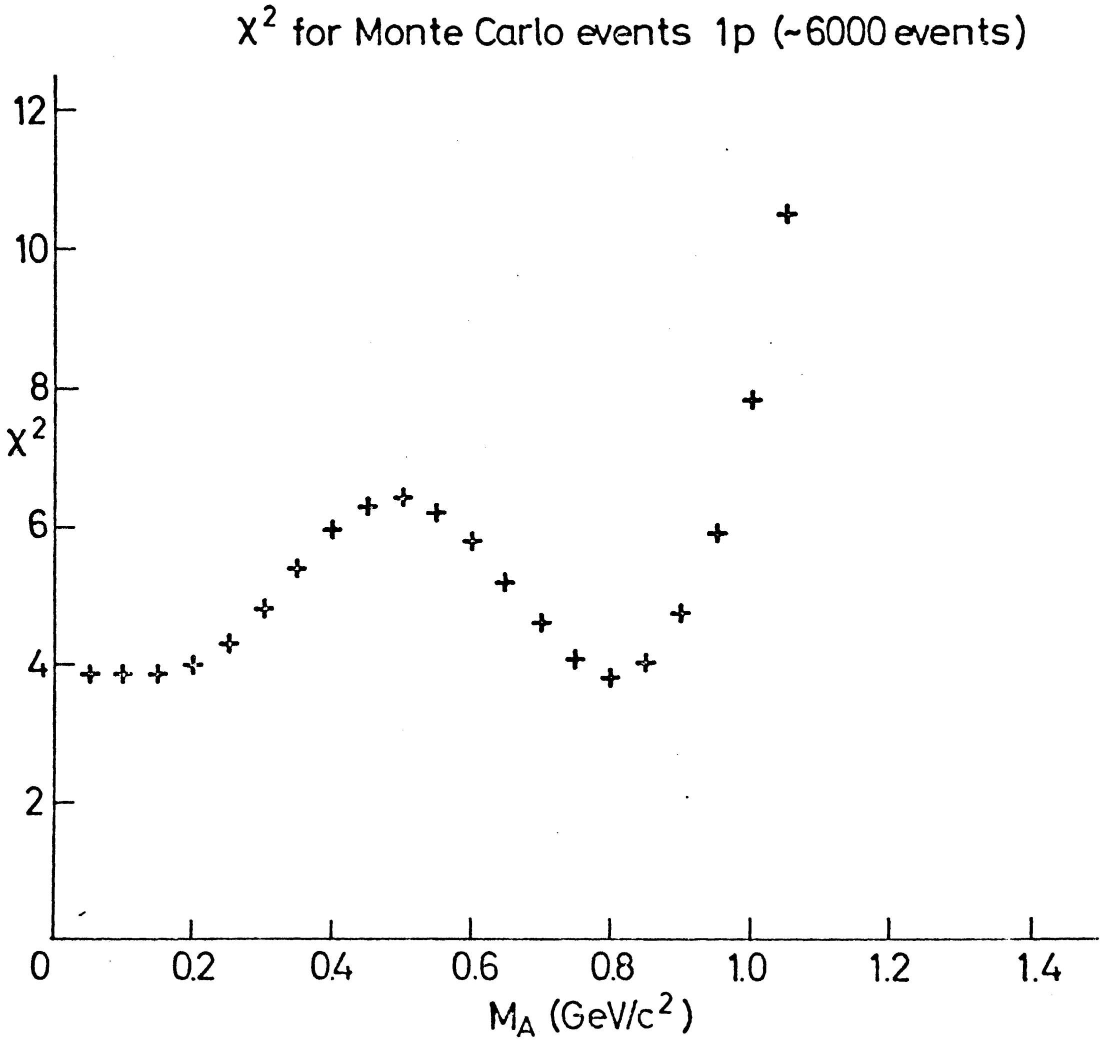

χ^2 for Monte Carlo events 1p (~6000 events)
χ^2
12
10
8
6
4
2
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
M_A (GeV/c^2)

Fig. 7

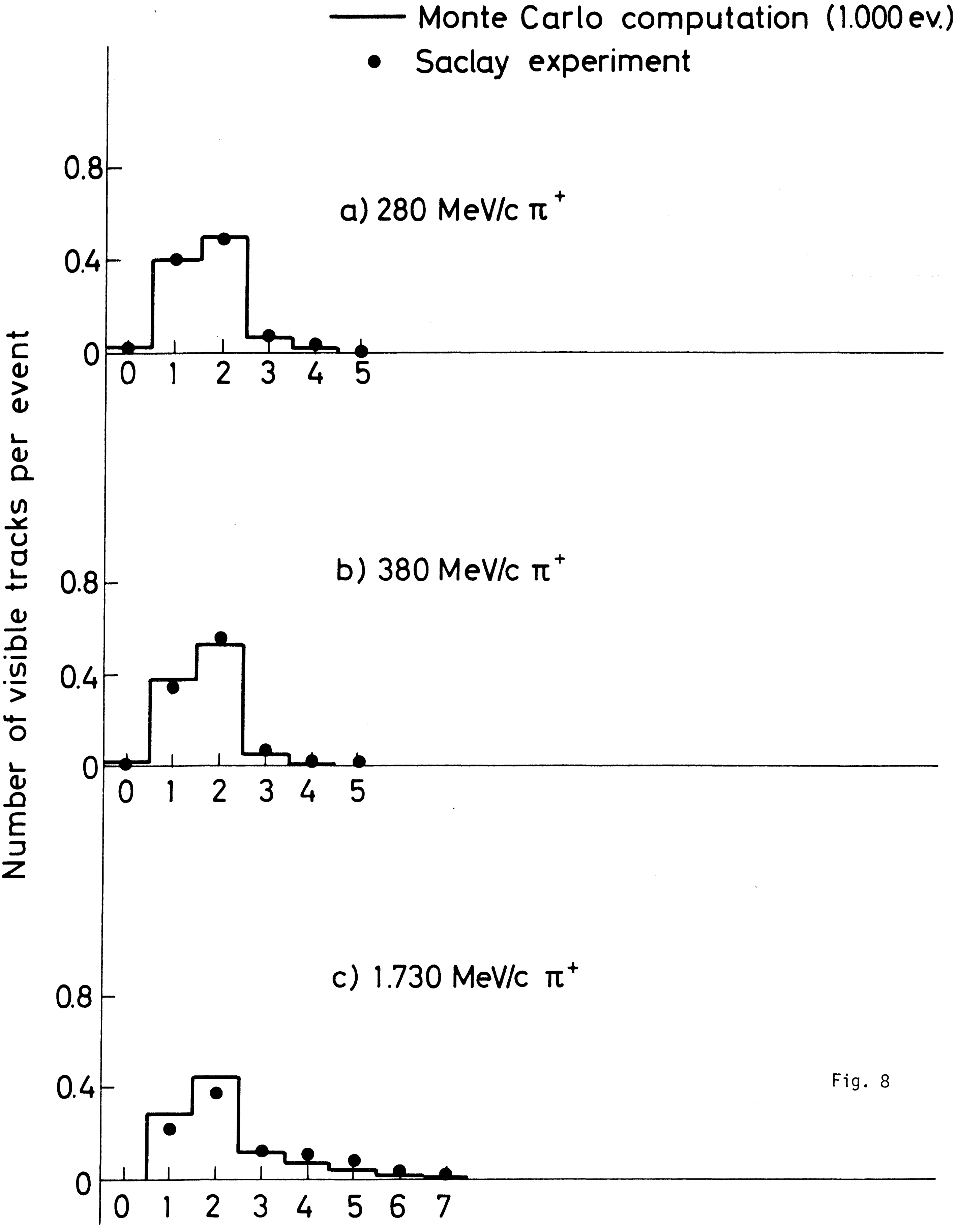

Monte Carlo computation (1.000 ev.)
● Saclay experiment
Number of visible tracks per event
a) 280 MeV/c π⁺
0.8
0.4
0
0
1
2
3
4
5
b) 380 MeV/c π⁺
0.8
0.4
0
0
1
2
3
4
5
c) 1.730 MeV/c π⁺
0.8
0.4
0
0
1
2
3
4
5
6
7

Fig. 8

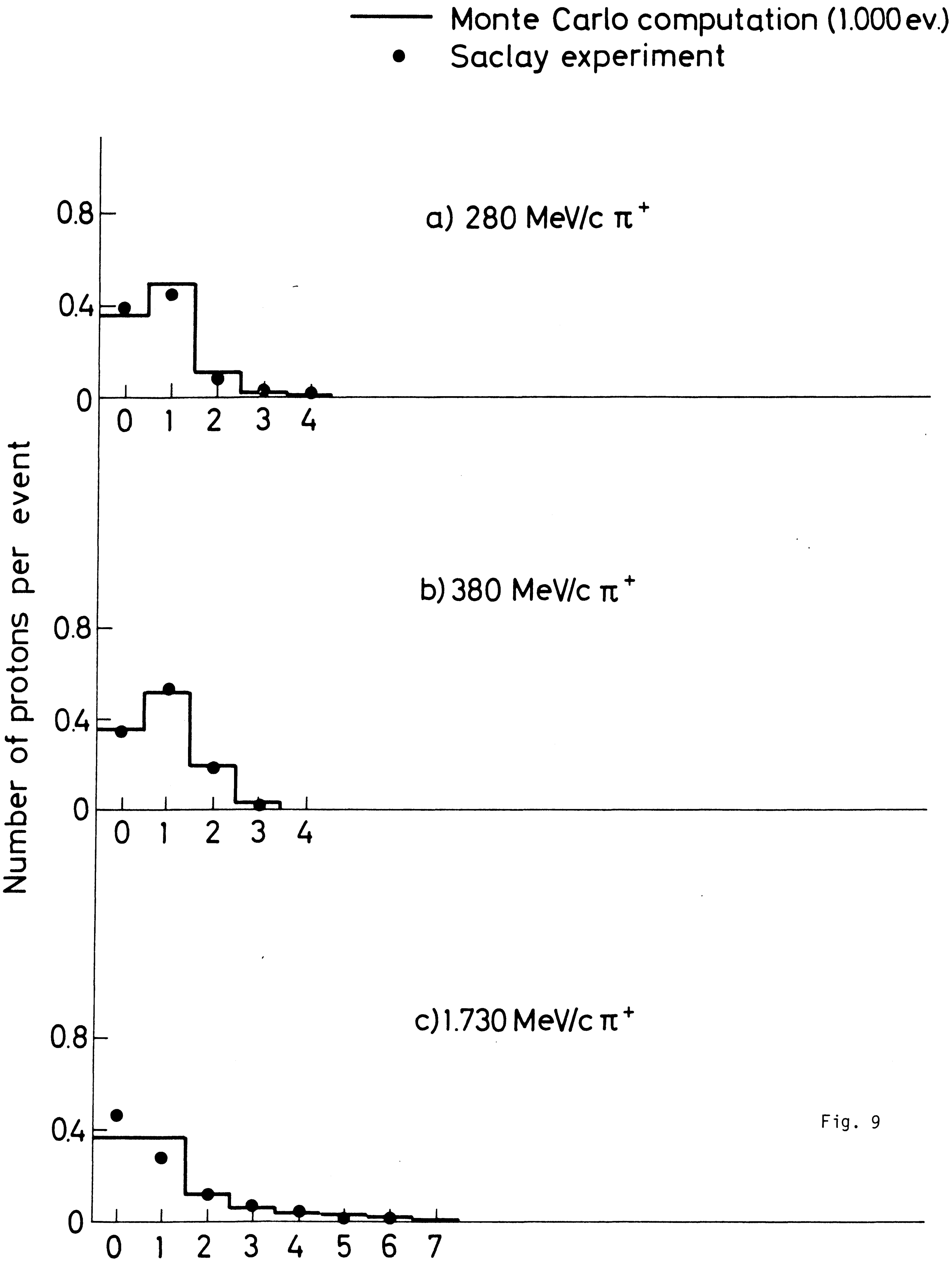

Monte Carlo computation (1.000 ev.)
● Saclay experiment
Number of protons per event
a) 280 MeV/c π^+
b) 380 MeV/c π^+
c) 1.730 MeV/c π^+
0.8
0.4
0
0
1
2
3
4
5
6
7

Fig. 9

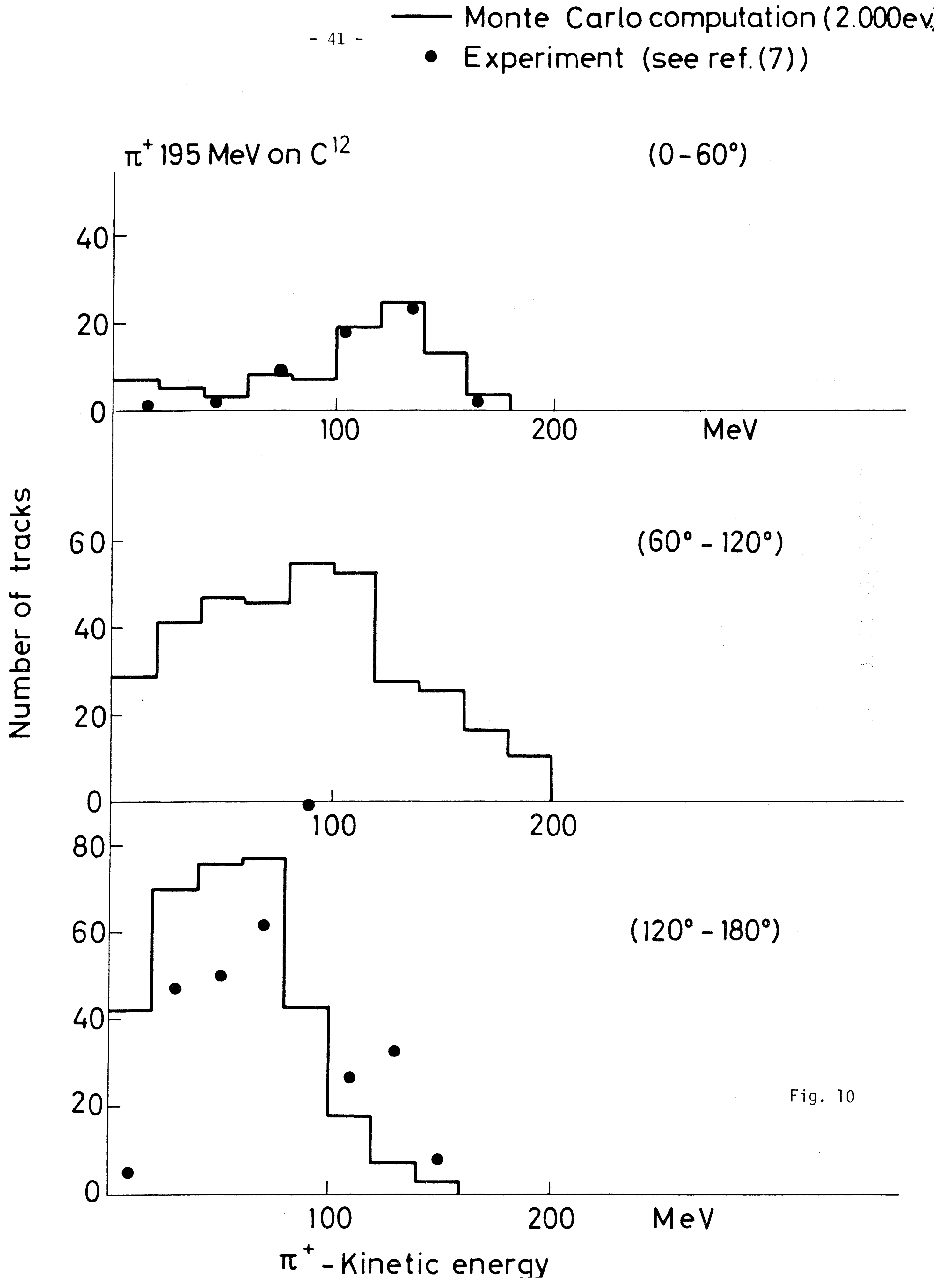

Monte Carlo computation (2.000ev
Experiment (see ref. (7))
π+ 195 MeV on C12
(0-60°)
40
20
0
100
200
MeV
Number of tracks
(60° - 120°)
60
40
20
0
100
200
80
(120° - 180°)
60
40
20
0
100
200
MeV
π+ - Kinetic energy

Fig. 10

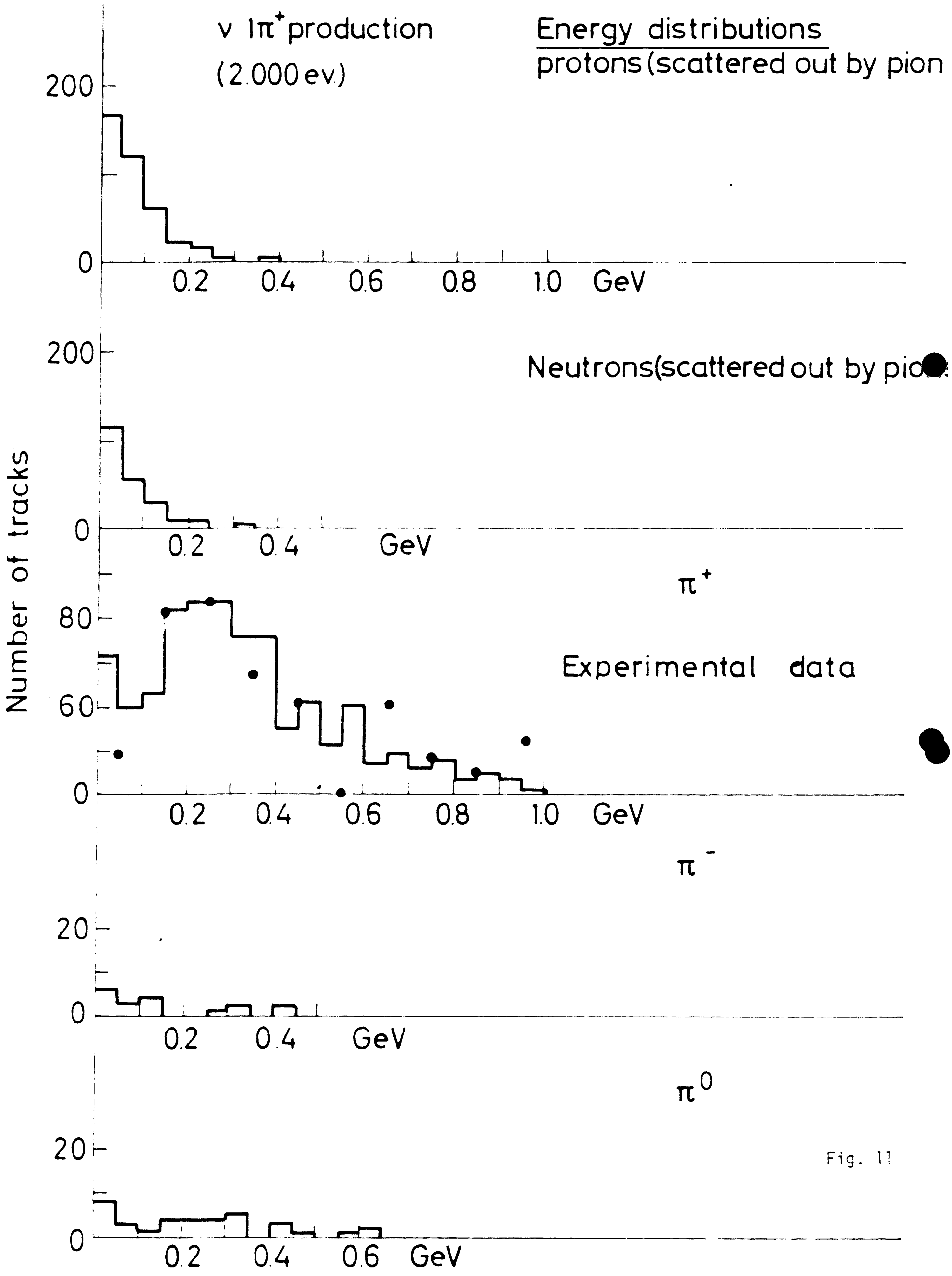

ν 1π⁺production
(2.000 ev.)
Energy distributions
protons (scattered out by pion
Neutrons(scattered out by pio
π⁺
Experimental data
π⁻
π⁰
Number of tracks
200
0
200
0
80
60
0
20
0
20
0
0.2
0.4
0.6
0.8
1.0
GeV

Fig. 11

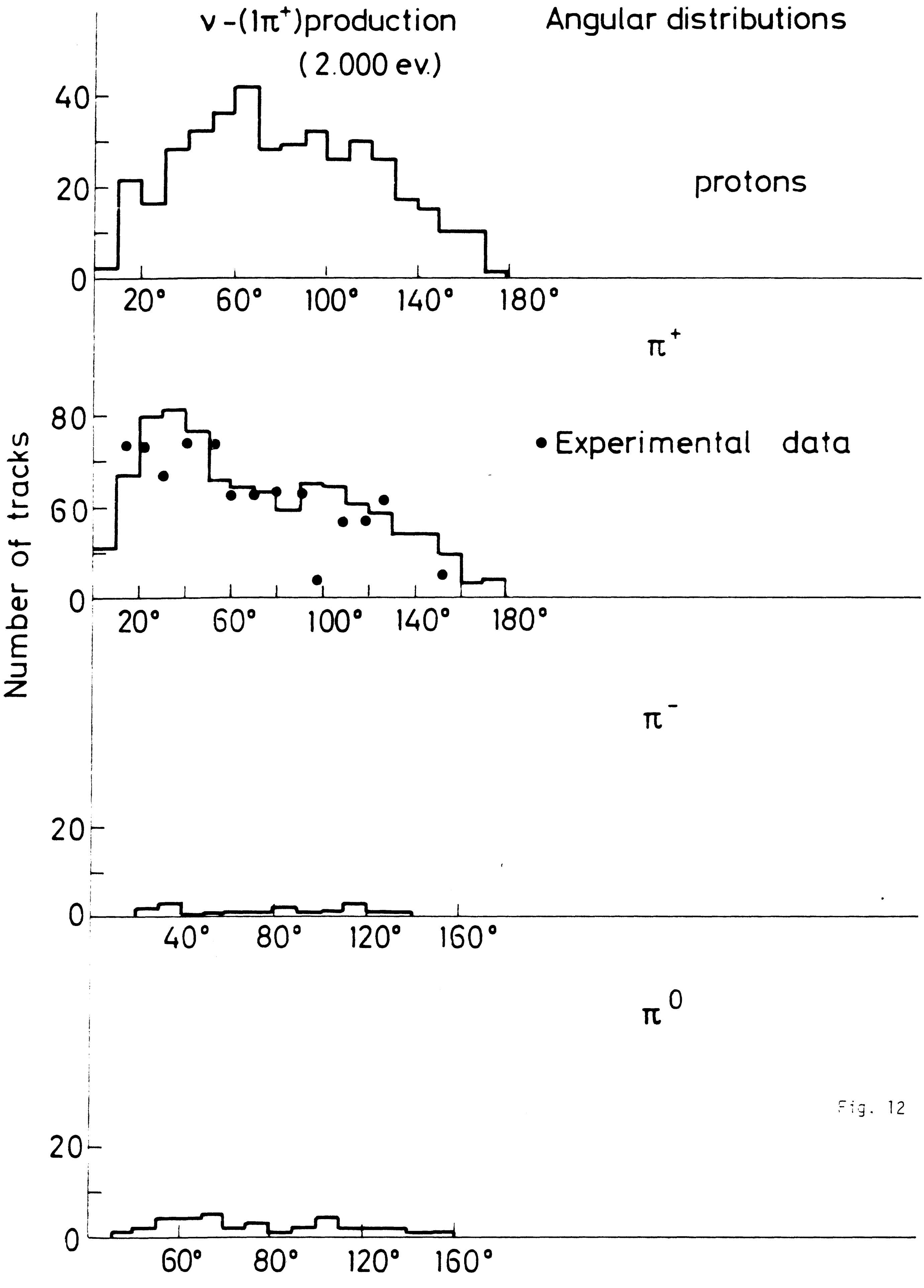

ν -(1π+)production
(2.000 ev.)
Angular distributions
protons
40
20
0
20°
60°
100°
140°
180°
π+
80
60
0
• Experimental data
20°
60°
100°
140°
180°
Number of tracks
π−
20
0
40°
80°
120°
160°
π0
20
0
60°
80°
120°
160°

Fig. 12

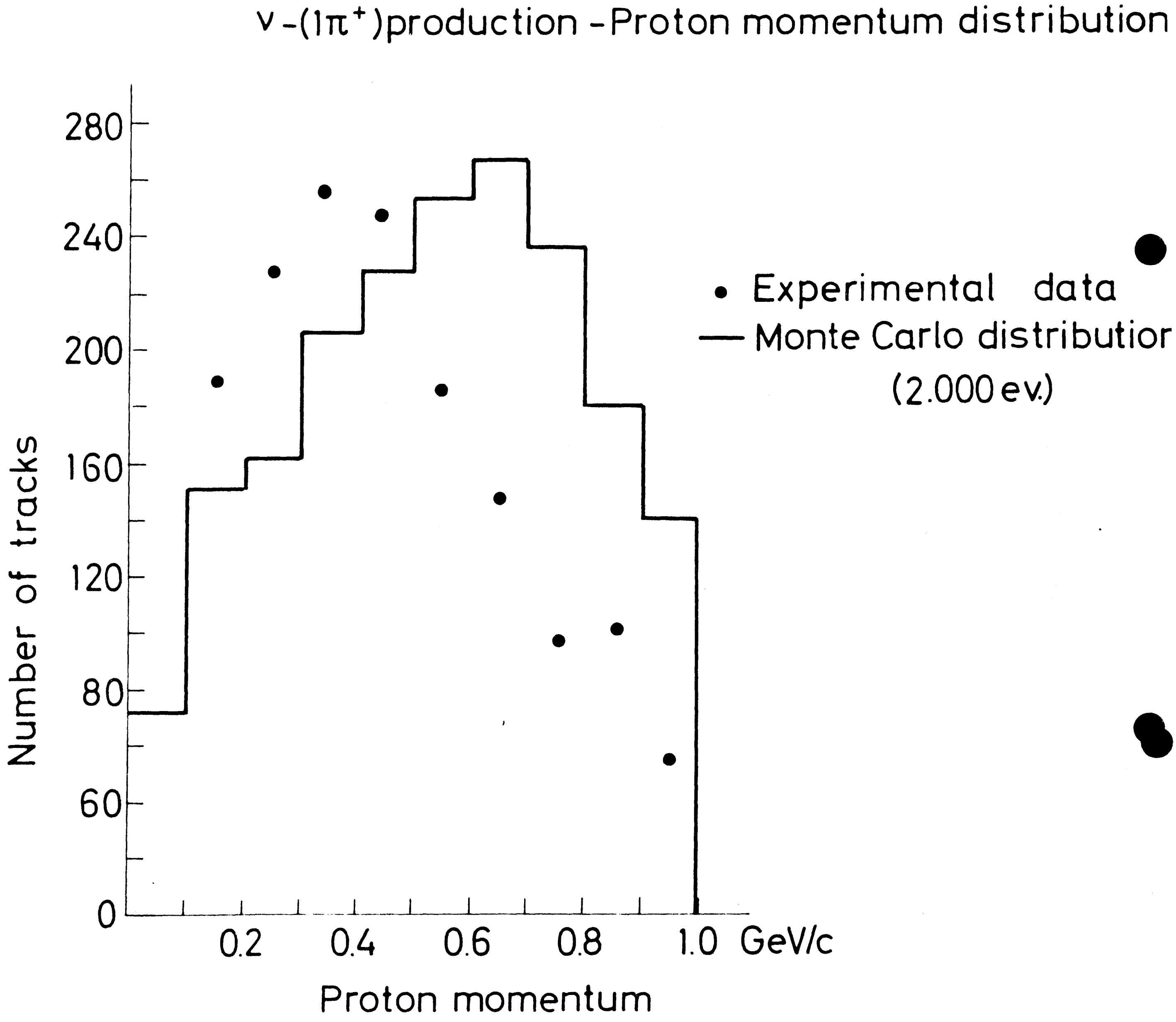

ν-(1π⁺)production - Proton momentum distribution
280
240
200
160
120
80
60
0
Number of tracks
0.2
0.4
0.6
0.8
1.0 GeV/c
Proton momentum
● Experimental data
— Monte Carlo distributior
(2.000 ev.)

Fig. 13

THE DECAY OF K MESONS

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and

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1. INTRODUCTION

Up to now, various experiments relative to the study of K decay in Gargamelle have been suggested$^{1)}$. The attention has mainly been focused upon the study of K_L^0 decays. One exception is the possibility of a simultaneous study of the 2π decay modes of K^+ and K_S^0 mesons produced by a positive kaon beam interacting directly with the nuclei of the chamber liquid. For mixtures containing propane, the possibility of observing both the creation and decay inside the chamber of K_L^0 mesons of known momentum has also been discussed. This possibility has, however, been rejected because of the very unfavourable rate of strong K_L^0 reactions with heavy nuclei, compared to useful decays$^{1)}$. All proposals relative to the study of K_L^0 decays have finally assumed that the neutral K mesons are produced in an external target. The beam is collimated so as to ensure that the subsequent decay of the kaons occurs inside a vacuum pipe placed along the chamber axis. Interest has been mainly shown in a detailed study of the vector form factors in $K_{\ell 3}^0$ decay, as well as in the measurement, in rate and interference experiments, of the complex parameter η_{00} describing CP violation in $K_L^0 \to 2\pi^0$ decays. In the future, the further experimental analysis of essentially all of the K_L^0 decay modes might eventually still be worth while. It is obvious that Gargamelle would be particularly suited for the study of $3\pi^0$, $\pi^+\pi^-\gamma$ and $\gamma\gamma$ decays. The K_L^0 decay modes are listed in Table 1.

Table 1

Expected number of K_L^0 decays in various modes
(total of 10^6 events)

Mode	Approximate number of events
$\pi^0\pi^0\pi^0$	250,000
$\pi^+\pi^-\pi^0$	120,000
$\pi\mu\nu$	270,000
$\pi e\nu$	350,000
$\pi^+\pi^-$	1500
$\pi^0\pi^0$	1000 to 4000
$\pi^+\pi^-\gamma$	<3000
$\gamma\gamma$	500

In most experiments, for instance in $K_{\ell 3}$ decay and $2\pi^0$ interference studies, the knowledge of the K_L^0 momentum is highly desirable, if not imperative. A K_L^0 beam of low momentum (∿590 MeV/c) could be produced in the reaction $\pi^- + p \rightarrow K^0 + \Lambda^0$ just below the threshold for Σ production$^{2)}$. At present, the construction of this type of beam with a workable flux (∿1K_L^0 decay in Gargamelle per burst) appears to be at the limit of the technical possibilities if the momentum bite is only a few per cent and the pipe diameter sufficiently small ($\leq$ 10 cm) to avoid important scattering effects in its walls. Experiments with monochromatic K_L^0 beams should anyhow become feasible after the introduction of the PS booster. The construction of a monochromatic K_L^0 beam is one of the projects of the Gargamelle Beam Study Group (G7 beam) and the various possibilities of design will not be reviewed here.

Apart from the use of a vacuum pipe in Gargamelle, several ideas of a technical nature have been brought to our attention:

a) The insertion of wire spark chambers inside the pipe to localize K_L^0 decay points. These chambers might be triggered for charged decays by thin scintillation counters covering the inner wall of the pipe.

b) The transformation of Gargamelle into a combination of range and momentum chambers. The pipe could be surrounded by an optically transparent bag containing a liquid of high radiation length but sensitive in the same thermodynamical conditions as the heavy freon CF_3Br which would fill the remaining volume of the chamber. A propane-ethane mixture, 70-30% by volume, has been proved to fulfil these requirements and also to have approximately the same refractive index as CF_3Br. Such an experimental set-up would allow for a high stopping power for charged particles as well as good measurement accuracy. Moreover, all π^0 decay photons would convert far from the decay region, thus reducing the probability for their misidentification as bremsstrahlung gammas from electron-positron pairs localized near the pipe wall.

Both ideas are attractive but remain still to be proved practicable. As none of the experimental proposals is explicitly relying upon these technical improvements, they will not be considered in further detail. Their possible application should, however, be kept in mind. In what follows, only the use of a decay pipe in Gargamelle, traversed by an external (monochromatic) K_L^0 beam, will be assumed throughout.

2. SEMI-LEPTONIC K_L^0 DECAYS

Since the time of the 1966 Berkeley Conference$^{3)}$, experimental data on $K_{\ell 3}$ decays have been rapidly accumulating and have mainly led to an increasing confusion concerning their significance$^{4)}$. Various aspects of $K_{\ell 3}$ decay such as energy spectra and angular correlations, $K_{\mu 3}/K_{e3}$ branching ratio and μ^+ polarization have been studied to determine the form factor ratio $\xi = f_-/f_+$ by which they are governed in the framework of the V-A theory. The results of most experiments have shown internal disagreement under the assumption that the dependence of the form factors on q^2, the square of the four-momentum transfer to the lepton system, is negligible. The meaning of these discrepancies is not well understood, but the form factor ratio ξ could possibly vary strongly with q^2 as different experimental methods are representative for different effective q^2 values. Consequently, the detailed comparison of various experimental results might be difficult and misleading as long as the exact variation of ξ with q^2 remains essentially unknown.

Recently, attempts have been made to analyse the experimental data assuming ξ to be a linear function of q^2 [5-7]. This assumption is only justified as a first approach, the published $\mu^\pm$ polarization results assuming no particular functional shape of ξ, being of poor statistical significance[6,7]. It is our feeling that, if a strong or appreciable non-linear q^2 dependence of ξ is indeed revealed by the present experiments, the main aim of future work in this field should be the determination of this dependence in a model-independent way, i.e. the analysis of the data at fixed q^2 values. Three distinct experimental pieces of information could be simultaneously studied and compared for internal consistency:

a) The μ^+ polarization in $K_{\mu3}$ decay.

b) The muon energy spectrum in $K_{\mu3}$ decay.

c) The $K_{\mu3}/K_{e3}$ branching ratio.

The foregoing remarks suggest the following analysis of the data in Gargamelle:

Selecting $K^0_{\ell3}$ decays with unambiguously identified pions, all interesting parameters listed above could be determined from an analysis of the data at given q^2 values. It is obvious that the identification probability of pions would be irrelevant. Unambiguous recognition of pions will be possible in various ways:

a) In flight, by the observation of their strong interactions.

b) At rest, depending upon their charge, through the observation of their characteristic decay (π^+-μ^+-e^+ chain) or interaction (π^- absorption star).

In a second stage of the experiment, various possible dependences of ξ on q^2, suggested by the model-independent analysis, could be adjusted to the pion energy spectrum. The recognition efficiency of pions as a function of their energy could be calibrated through a study of the $\pi^+\pi^-\pi^0$ decay mode.

In Gargamelle, leptonic and τ decays will easily be separated at the scanning stage by the correlation of converted γ rays. Taking a γ-ray conversion probability of 90% (light freon) only 1% of the τ decays will remain. This figure will be further reduced by the probability that both pion tracks have a characteristic signature and that the event fails the fit to the $K_{\mu 3}$ hypothesis. The selected sample of $K_{\ell 3}$ decays would thus be essentially free from background over the entire Dalitz plot. In order to ensure both a high $K_{\ell 3}$ event selection rate and an efficient background rejection, the density of the liquid should be chosen as high as the required measurement accuracy allows.

Apart from its high γ-conversion efficiency, Gargamelle should offer a series of advantages for the study of $K^0_{\ell 3}$ decays, in comparison with most of the previous spark-chamber and bubble-chamber experiments:

a) The 4π space angle ensures equal detection efficiencies for all kinematical configurations.

b) The big stereo angle between the cameras (60°), should provide a good distinction between muons and electrons (or positrons).

c) The angle between the optical axes and the magnetic field (30°) favours polarization measurements.

The muon decay configurations aligned along the magnetic field, and which carry the highest weight in the analysis, should be more easily reconstructed.

One inherent disadvantage of the use of a decay pipe is the fact that the pion momentum measurements are expected to be systematically biased by scattering effects in the pipe wall. In the X4 experiment, using a 2.5 mm thick aluminium pipe, single pion scatterings were estimated to affect 2.5% of the $K_{\ell 3}$ events. This number could hardly be reduced by modifying the pipe or filling its interior with helium gas (see Appendix).

Decays according to the τ mode, in which the two charged particles are stopping in the chamber could be used to investigate the importance of these effects. Detailed calculations have to be done for an actual proposal in order to estimate to what extent the accuracy of the experiment is limited by pion scatterings in the pipe wall. On the other hand, the minimum number of events required to make the experiment significant depends upon the sensitivity at given q^2 values of the various model-independent methods of analysing the data in terms of the form factor ratio ξ.

Extrapolating from the X_2 results, it appears that an unbiased sample of at least 20,000 $K_{\mu 3}$ events will be required to determine ξ to an average accuracy of 0.2 in ten bins of q^2. This number might, however, be grossly underestimated if any accuracy of this order has to be obtained on ξ for low q^2 values. Nothing like this will be available from the present generation of experiments.

3. MEASUREMENT OF $|\eta_{00}|$

The $K_L^0 \rightarrow \pi^0\pi^0$ decay rate could be measured in Gargamelle in an X_4 type of experiment$^{8)}$. After scanning for neutral K_L^0 decays, all events having a topology compatible with 4γ rays emerging from a common origin localized in a given fiducial volume of the vacuum pipe are selected. For such events, the ratio of the $3\pi^0$ background to the $2\pi^0$ signal is given by

$$R_{BS} = \left[15(1 - P)^2 + 6P(1 - P)\, p_5 + P_0^2 p_6\right] \frac{\Gamma(K_L^0 \rightarrow 3\pi^0)}{\Gamma(K_L^0 \rightarrow 2\pi^0)}$$

with

$$p_6 \simeq 0.6\, p_5^2 \ .$$

In this expression P is the combined γ conversion and detection efficiency and p_5 and p_6 are the probabilities to observe 5 or 6 γ events in which respectively 1 or 2 gammas are qualitatively indistinguishable from a bremsstrahlung on one of the remaining electron-positron pairs. In the X_4 experiment, p_5 was found to be of the order of 0.2. Extrapolating this result to a Gargamelle experiment using also CF_3Br as the chamber liquid and assuming a γ observation probability of 99%, nearly equal to the conversion probability, one expects a background to signal ratio of the order of 15. If 5 and 6 γ events would have been in all cases distinguishable from 4 γ events, the latter ratio would drop to 0.3. This example illustrates that the transformation of Gargamelle into a combined range-momentum chamber could constitute a drastic improvement for this particular experiment. A similar effect could be obtained by increasing the radius of the pipe in the fiducial decay region. This would, however, imply a proportional increase in the pipe-wall thickness and hence of the number of γ rays converted in the metal. The use of a liquid lighter then CF_3Br should be considered as it would increase the 4γ contamination arising from $3\pi^0$ decay but might decrease the background in the 5 and 6 γ configurations. The main result of an increase in the radiation length would however simply be the introduction of a scaling factor in the observed topologies of the γ-conversion points, accompanied by a relatively small improvement in the γ-pointing accuracy, of the order of the square root of the increase in radiation length.

Even with a background to signal ratio roughly equal to 15, this experiment should allow the selection of a rather clean sample of $K_L^0 \rightarrow \pi^0\pi^0$ decays, as the 4γ invariant mass distributions arising from $3\pi^0$ and $2\pi^0$ events are very different$^{8)}$. The main improvement brought about in comparison to the X_4 experiment in the reduction by nearly an order of magnitude of the background to signal ratio. This fact is of great practical importance as it offers the possibility to perform a precision measurement of $|\eta_{00}|$ using the heavy-liquid bubble-chamber technique. Indeed, only measurements of $|\eta_{00}|$ up to an accuracy of a few per cent are expected to be useful in the future, thus requiring the observation of at least a thousand $K_L^0 \rightarrow \pi^0\pi^0$ decays. The selection of such a signal would have required the measurement of 10^5 4γ candidates in the X_4 experiment. The corresponding number of events to be measured in Gargamelle is only of the order of 15,000.

4. MEASUREMENT OF THE PHASE OF η_{00}

It has been proposed to measure ϕ_{00}, the phase of η_{00}, by placing plugs of regenerating material along the pipe$^{1)}$. Using a regenerator, two basic methods are at our disposal to measure ϕ_{00}.

a) One regenerates K_S from K_L mesons in a dense regenerator and lets the short-lived component die out in free space until its 2π decay amplitude becomes comparable to that of the long-lived component.

b) One regenerates K_S from K_L in a long, diffuse regenerator, of density such that the equilibrium $K_S \rightarrow 2\pi$ decay amplitude is equal to that of K_L.

The first method requires good spatial resolution on the position of the $K^0 \rightarrow 2\pi^0$ decay point along the chamber axes. In the second type of experiment, only the total $2\pi^0$ decay rate inside the regenerator is relevant. Diffuse regenerators produce unfortunately an important incoherent background which cannot be sufficiently resolved in heavy-liquid bubble-chamber experiments in view of the poor angular resolution ($\sim 2^\circ$) on the direction of the outgoing K^0. For a continuous regenerator, the ratio R_c of incoherent to coherent regeneration at 0°, within a small solid angle $d\Omega$, is approximately given by:

$$R_c = (2N \Lambda_S \lambda^2)^{-1} d\Omega .$$

N is the number of atoms per unit volume of the regenerator, λ the K^0 wavelength, and Λ_S the K_S^0 decay length. For K_S^0 mesons of 590 MeV/c momentum ($\lambda = 2.1 \times 10^{-13}$ cm; $\Lambda = 3.1$ cm) regenerated in diffuse beryllium, R_c is found to be of the order of 2 for a 2° acceptance angle. For solid beryllium, the corresponding ratio is expected to be much lower, of the order of 0.1.

The University College London group has recently performed detailed calculations for solid carbon regenerators (density = 1.5 gm/cc) of various lengths and a K_L^0 beam momentum of 1 GeV/c. All calculations assumed $|\eta_{00}| = 2.3 \times 10^{-3}$ and f_{21}, the difference between the K and $\bar{K}$ forward scattering amplitudes, to be purely imaginary. The $2\pi^0$ decay rate is found to be maximum at the downstream face of a regenerator which is approximately 11 cm long (0.4 nsec K^0 proper time) and to become essentially constant for regenerators of length greater than 20 cm. The variation of the decay rate with time after the absorber has been investigated for various values of ϕ_{00}, considering the number of decays into the $2\pi^0$ mode occurring in 8 bins of 0.1 nsec. Sizeable interference effects only occur up to 0.6 nsec (16 cm at 1 GeV/c). The sensitivity of the experiment depends upon the variation of the number of events in each bin as a function of ϕ_{00}. At 1 GeV/c, this variation is found to be maximum in all bins for approximately 11 cm absorber thickness. Using the latter values as input to the calculations the expected number of events in each bin for various values of ϕ_{00} is shown in Table 2. The sensitivity of the experiment is seen to vary considerably as a function of ϕ_{00}. If the phase of η_{00} would be of the order of 40° (superweak model), the sensitivity of the data would unfortunately be very poor.

5. CONCLUSIONS

The advantage of Gargamelle compared to existing heavy-liquid bubble chambers regarding K_L^0 decay experiments is evident.

Table 2

Variation with distance of $K_L^0 \rightarrow 2\pi^0$ rate as a function of ϕ_{00}

ϕ_{00} (degrees)	Bin 1	Bin 2	Bin 3	Bin 4	Bin 5	Bin 6	Bin 7	Bin 8
0	1890	742	392	243	156	102	73	60
20	2110	883	454	258	151	93	70	56
40	2370	1010	496	259	138	80	58	53
60	2610	1110	515	244	118	66	51	50
80	2830	1170	504	216	95	53	45	50
100	2978	1172	469	178	70	41	42	50
120	3040	1140	407	134	47	33	41	52
140	3020	1056	335	90	28	28	43	55
160	2920	940	256	51	16	29	47	59
180	2740	800	179	22	12	34	54	63
200	2520	660	116	6	17	44	61	67
220	2260	530	74	5	29	56	70	71
240	2010	435	57	20	49	70	76	74
260	1800	377	67	48	73	84	82	74
280	1660	366	104	87	98	96	85	74
300	1590	410	163	130	121	104	86	72
320	1600	476	236	175	140	108	84	69
340	1710	604	315	213	151	108	80	65

Number in each bin for various ϕ_{00} normalized to 5000 decays for ϕ_{00} = 100°.

Time in absorber = 0.4 nsec (Carbon regenerator using 1 GeV/c K_L^0).

An experiment performed with K_L^0 mesons of known momentum to study the form factors of the $K_{\ell 3}^0$ decay mode will certainly be justified as long as the results from different experiments and different techniques are as much spread out as they are today. Even if the present discrepancies disappear, it might still remain worth while to make an accurate measurement of ξ as a function of q^2 in a model-independent way. Systematic errors seem to be no major problem, but the merit of the experiment will depend upon the final accuracy which can be reached with a limited number of pictures ($\lesssim$ 500,000).

Gargamelle would allow a reliably precise measurement of the $K_L^0 \to 2\pi^0$ decay rate without requiring an exaggerated measurement effort. The idea of transforming the chamber into a combination of range and momentum chambers appears to be particularly attractive for this experiment.

The measurement of the phase of η_{00} within a diffuse regenerator appears to be excluded in view of the high ratio of incoherent to coherent regeneration. Interference experiments with dense regenerators would be feasible, but the expected experimental resolution for ϕ_{00} depends strongly upon its value.

ACKNOWLEDGMENTS

We are grateful to Drs. V. Brisson, F. Bullock, D.C. Cundy, G. Myatt, P. Petiau, C. Rubbia and W. Venus for many comments and suggestions.

* * *

APPENDIX

STABILITY OF THICK WALLED TUBES

The critical pressure is (according to Hütte, vol. 1, p. 953)

$$P_K \sim \text{const.} \times (s/r)^3 \{1 + 50\,(r/l)^3\}$$

P_K = critical pressure   l = length

S = wall thickness   r = inner radius.

In the X_4 experiment an aluminium tube has been used with a wall thickness of 2.5 mm. This corresponds to a critical pressure of 120 atm (safety factor of 4), since a real tube is never ideally round. The critical pressure could be reduced by using a helium gas pressure inside, but this does not change the wall thickness much, if the inner radius is kept the same.

* * *

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* * *

DISCUSSION

Rousset (Ecole Polytechnique)

The $K^0_{\ell 3}$ form-factors can be studied in a non-momentum defined beam by using only the transverse momentum distribution of the decay.

Secondly the interaction lengths of $\pi^\pm$ can be determined using a $\pi^\pm$ beam in the same liquid.

Musset (Orsay)

If one pressurised the beam pipe with 15 atmospheres of helium then one could reduce the wall thickness by a factor of 4.

Cundy (CERN)

Analysis of the X_4 experiment has shown that the determination of the $K^0_{e3}/K^0_{\mu 3}$ branching ratio is limited by loss of information due to the beam pipe. You will, therefore be much worse off in Gargamelle. However, the pipe is large enough to contain a wire chamber and hence obtain detailed information on the decay apex.

Rubbia (CERN)

I am not altogether convinced that a momentum defined beam is essential. If you went to very low K^0_L momenta, i.e. <500 MeV/c I feel that the two kinematical solutions might be resolved.

MU-MESON STUDIES WITH GARGAMELLE

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.. INTRODUCTION

The basic motivation for studying μ-meson interactions is twofold; firstly to attempt to find a difference between μ mesons and electrons and secondly to use them as a tool to study electromagnetic processes.

In terms of experiments it may be possible that an individual property of the μ meson may be seen in a detailed study of the electromagnetic interaction so that experimentally the two categories may appear as one.

It should be pointed out that it is not necessary to have a μ meson in the initial state to study the weak interaction of μ mesons, for the production of μ mesons in neutrino interactions offers some of the same possibilities as in the case of the nuclear interaction of an incoming μ meson. However, there are some real advantages and differences in studying incoming μ-meson interactions to that of μ-meson production and these will be mentioned later.

2. EXPERIMENTAL STATUS

The most obvious method to search for a difference in electron and μ-meson interactions is a careful evaluation of four-momentum transfer dependence in elastic scattering on free protons. At the present time, information on cross-sections up to a few $(\mathrm{GeV}/c)^2$ four-momentum transfer, has shown that there is no apparent difference between electrons and μ mesons! In the field of elastic μ-meson scattering, bubble chambers cannot compete with other techniques because the cross-sections are very low at high four-momentum transfers.

However, the inelastic scattering processes are quite suitable to bubble-chamber techniques, principally because of the exploratory nature of the problem and its complexity. The inelastic processes (pion production) can involve several particles in the final state and hence it is more difficult to study all of the possible final-state products in a rather unbiased manner, by the counter-spark chamber techniques. Bubble chambers offer the advantage of being able to observe, with little bias, nearly all possible inelastic processes, including in some cases, those states with neutral mesons.

Recently an inelastic μ-scattering experiment was performed at CERN in the Ramm heavy-liquid chamber by the CERN, Oxford, Padova, and Wisconsin groups. A brief description and results will be given here as it relates directly to future experiments in Gargamelle. The beam of μ mesons was obtained by removing a part of the mercury plug in the neutrino shield. A small bending magnet was placed between the exit of the neutrino shielding and the bubble chamber, to give momentum dispersion to the beam. The momentum of the beam in the chamber varies from about 2.5 to 3.5 GeV/c. The track density in the chamber was varied in four steps from about 50 tracks to 150 tracks. The portion of the experiment with track densities above about 120 was not usable.

About 15,000 pictures were scanned for nuclear interactions yielding 115 events. The results are summarized in Tables . and 2.

Table 1

Descriptive Classification of Events

Type	Number of Events	
One prong (nucleon only)	58	70
Multiple prong events (nucleons only)	12	
Single-pion events		
π^+	13	30
π^-	11	
π^0 *)	6	
Two-pion events	13	
Three-pion events	1	
Strange particles (K_1^0 decay $\pi^+\pi^-$)	1	

*) This number of observed events corresponds to about 12 events when losses and conversion probabilities are included.

Table 2

μ-meson cross-sections/nucleon

Reaction	Cross-section
Total inelastic (pion production)(a)	2.0×10^{-30}
N* production(b)	1.4×10^{-30}
Multiple pion processes	0.6×10^{-30}
Upper limit of μ* production(c)	$\lesssim 4 \times 10^{-32}$

(a) Correction has been made for γ-ray conversion in estimating the number of π^0 events. No correction was made for nuclear absorption.

(b) The total N* cross-section is estimated from both π^- and π^+ decays and taking their average.

(c) This value of cross-section would correspond to one event.

The relative cross-sections for N*, single pion, two pion and ρ production agree well with photoproduction.

A comparison of the four-momentum dependence of N* production by μ mesons with theoretical predictions of Y. Nagashima*) are shown in Fig. 1. Clearly the statistics are poor, but the experimental results are in excellent agreement with theory.

A search has been made for an excited state of the μ meson. One mode of decay could be

$$\mu^* \rightarrow \mu + \gamma$$

by an electromagnetic process. Clearly if such an excited state exists it must lie above the mass of the K meson. In such case, the reaction would be very easy to detect in a bubble chamber because the μ meson

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*) Y. Nagashima, University of Rochester report UR-875-189 March 2, 1967.

would appear to scatter through a large angle, and would be accompanied by a hard γ ray. No such event was found setting an upper limit of 4×10^{-32} for the cross-section for its production.

3. PROPOSED RESEARCH WITH GARGAMELLE

As previously mentioned, the most fruitful field of research with μ mesons would seem to be the study of inelastic processes and a search for excited states of the muon. Since the field is still in an exploratory stage it would seem that even a beam with considerable momentum spread would be suitable. Such a beam almost automatically exists in connection with the neutrino facility. Perhaps one additional bending magnet ahead of the chamber would be useful, but probably not necessary, for the magnetic field of the bubble-chamber magnet would probably produce adequate dispersion. The momentum region of about 5-6 GeV/c could be studied with one or two bunches from the PS. This would give about 100 tracks per pulse. A run of 200,000 pictures would be very worthwhile, although additional pictures may be justified.

Extrapolating the above results to a 200,000 picture run in Gargamelle (100 muons/picture, 4 m fiducial track length), some 10,000 events could be expected, ∿2000 of which will be free proton events (400 free proton events per μb). Several interesting topics for study could be the following:

i) $\underline{\mu + p \rightarrow \mu + N^*}$

Several hundred interactions of this type will allow one to study the form factors of the nucleon isobar, especially in the limit of zero four-momentum transfer; here it might be possible to deduce the properties of the nucleon isobars, since the form factors have simple threshold behaviour.

In the limit $t \rightarrow 0$ the "muon production" of pions (t = mass of the virtual photon) should have the same relation to photoproduction of pions as has the electroproduction of pions, and angular correlations could be studied.

ii) $\underline{\mu + p \rightarrow \mu + N^* + \pi \text{ (soft)}}$

Adler and Weisberger suggest that this process might be used to measure indirectly the nucleon axial vector form factor. The method would be to compare the four-momentum transfer dependence of the cross-sections for $N^*\pi$ and N^* production. From photoproduction it is estimated that some 20 events of the above type on free protons could be expected per 10^6 photographs.

iii) $\mu + p \rightarrow \mu + p + \rho^0$

For this reaction the carbon events can be used as well, so that some 10-20 ρ^0's could be expected on 200,000 pictures (concluded from electroproduction of ρ^0). It should be possible to determine cross-sections, rough four-momentum transfer dependence, and the ratio with respect to charged ρ-production.

iv) $\mu + C \rightarrow C + \mu + \gamma$

There will be a few thousand bremsstrahlung gammas (which nearly all convert) with recoil momentum above 1 GeV/c, which could be sufficient to detect an anomaly in this low but at present unexplored four-momentum transfer region.

An excited state of the μ meson might be observed if it exists, in neutrino interactions. One would study the invariant mass of the γ-ray and the μ-meson system and hope to identify an excited state by a peak in this system. The background will arrive from the γ rays from π^0 decays. However in experiments involving incoming μ-meson interactions, the change in the angle of the μ meson is in general less than 5 degrees and hence the only candidates that need be considered for μ^* events are those with large angles between the incoming and outgoing μ meson. This criterion alone reduces the sample of candidates by a large factor beyond the invariant mass considerations.

On the contrary, for inelastic neutrino interactions the μ meson is not well collimated with respect to incoming neutrino direction and every event with a converted γ ray must be considered as a candidate.

These considerations as well as beam requirements make the search for excited states of the μ beam more feasible in a μ-meson beam as opposed to neutrino interactions.

To summarize, the numbers of events to be expected in a 200,000 picture run in Gargamelle filled with propane, are given in Table 3.

Table 3

Expected number of events from 200,000 pictures in Gargamelle

Type of event	Number of events
N* production	1400
Two-pion process	600
Multiple pion ≥ 3	~ 100
Strange particle	~ 100
Upper limit on μ*	1 event $\simeq 5 \times 10^{-34}$ cm^2

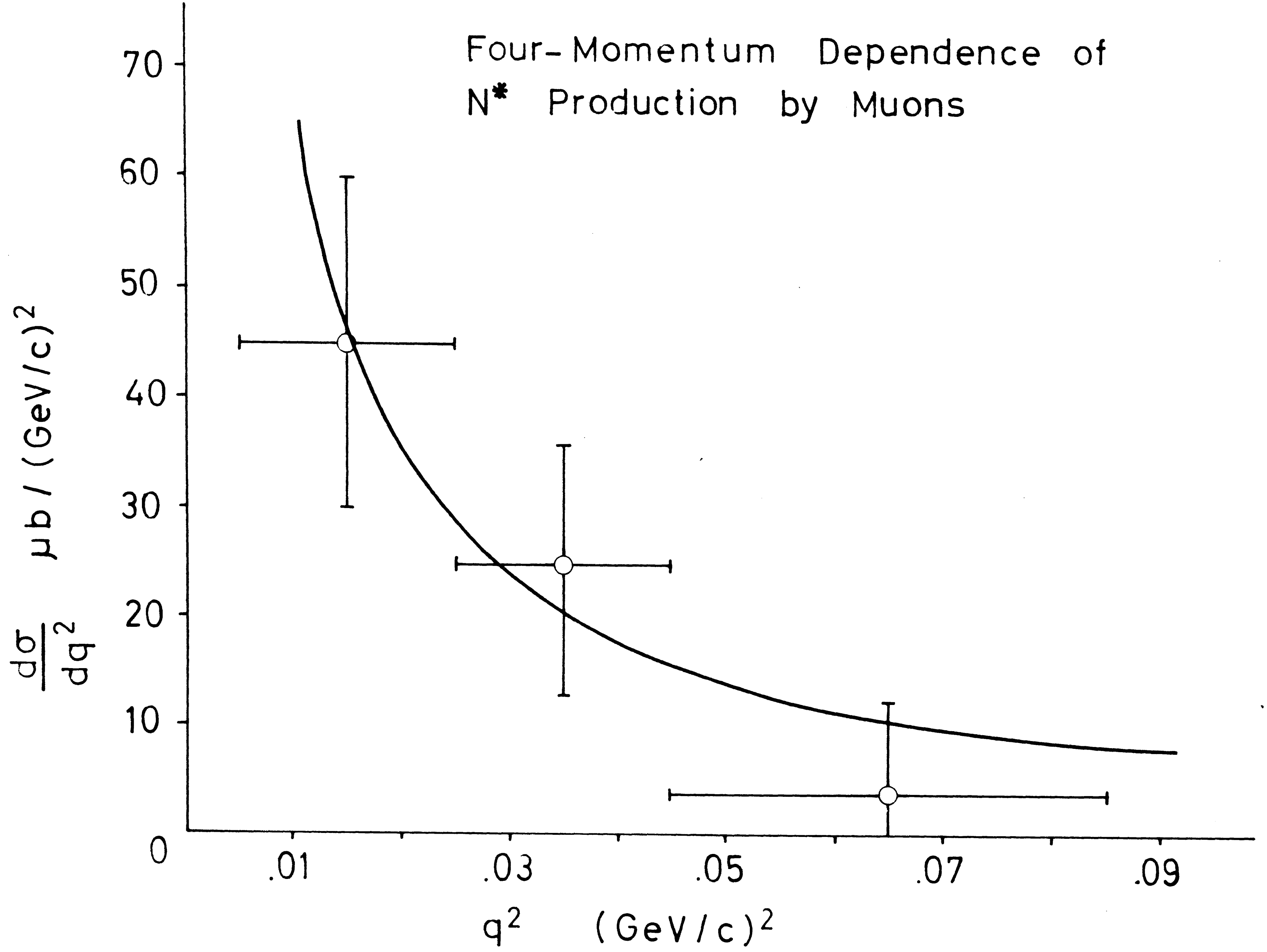
* * *

DISCUSSION

Fiorini (Milano)

I would like to remark that it seems worth while to investigate in the present neutrino pictures the possible existence of μ*, produced in the reaction

$$\nu + n \rightarrow \mu^{*-} + p$$
$$\searrow \mu + \gamma$$



Four-Momentum Dependence of
N* Production by Muons

Fig. 1

ANNIHILATION OF ANTIPROTONS AT REST WITH THE PRODUCTION OF NEUTRAL PARTICLES

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1. INTRODUCTION

Some arguments on the advantages of an experiment to study the annihilation of antiprotons with the detection of π^0's or γ rays have already been presented by some of us in a previous Gargamelle Users' Report$^{1)}$. We should consider two different types of experiment: one, annihilation of antiprotons at rest; the other, annihilation of antiprotons in flight, in each type the problems of interest being different. In this paper we are only considering annihilations at rest.

Originally, we thought of stopping the antiprotons in an expandable liquid hydrogen target placed inside a neon bubble chamber. Even if this would be the best way of doing such an experiment, a great number of technical problems have led us to consider the possibility of doing it in a heavy-liquid bubble chamber. We are mainly interested in annihilations of the antiprotons on hydrogen. It is therefore necessary to use a chamber liquid rich in propane, the propane having a loosely bound hydrogen molecule.

The success of the experiment will depend on the capture rate on the "free" hydrogen molecule. If the capture rate is too small the experiment will not be feasible. We shall come back to this problem at the end of the paper. Due to the low frequency of annihilations to final states containing kaons, we will start by studying the annihilations to pions and γ's.

2. PION PROCESSES

2.1 $3\pi^0$

In the annihilation $\bar{p}p \rightarrow 3\pi^0$ the final state interactions are dominated by the d and s waves between pairs of pions, in isospin states 0 or 2.

This channel provides a good tool to study the behaviour of these waves.

2.2 $\pi^+\pi^-\pi^0$

The annihilation $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ was studied in a hydrogen bubble chamber with a sample of 3880 events in an experiment$^{2)}$ and 1200 in another$^{3)}$. In such experiments there is a large contamination of events with two π^0's, from the annihilation $\bar{p}p \rightarrow \pi^+\pi^-\pi^0\pi^0$. In Ref. 2 for example, this contamination was estimated as (14 ± 2)%; and the fitting of the Dalitz plot is made somewhat difficult owing to the fact that the behaviour of this background is difficult to predict. Furthermore, there are some discrepancies between the results of Refs. 2 and 3. An experiment with a purer sample of events is therefore important.

2.3 $\pi^+\pi^-\pi^0\pi^0$

This channel occurs frequently in the annihilations at rest. Its analysis would complete the analysis of the channel $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-$.

2.4 $\eta^0\pi^+\pi^-$

The channel $\bar{p}p \rightarrow \eta^0\pi^+\pi^-$ was studied$^{4)}$ by using events of the types $\bar{p}p \rightarrow \pi^+\pi^-$ (missing mass) and $\bar{p}p \rightarrow \pi^+\pi^-\pi^+\pi^-\pi^0$. In the first type of events the η^0 had decayed into all neutral secondaries and was detected in the missing-mass spectrum. In the second type the η^0 was detected via the decay mode $\eta^0 \rightarrow \pi^+\pi^-\pi^0$. Only these latter events allowed a study of the Dalitz plot, because in the first events the background was too high.

The main results were:

i) rate of $\bar{p}p \rightarrow \eta^0\pi^+\pi^- = (1.26 \pm 0.13) \times 10^{-3}$ of all annihilations at rest in hydrogen;

ii)
$$\frac{\text{rate } \bar{p}p \rightarrow \eta^0\rho^0}{\text{rate } \bar{p}p \rightarrow \eta^0\pi^+\pi^-} = 0.51 \pm 0.10$$

However, the experiment can be much better done if the η^0 is detected via the decay $\eta^0 \rightarrow 2\gamma$, which corresponds to about 70% of the all η^0 decay modes. Then, the events $\bar{p}p \rightarrow \pi^+\pi^-\gamma\gamma$ would give us $\bar{p}p \rightarrow \pi^+\pi^-\pi^0$ with practically no background and allow a detailed study of "$\eta\pi$" states.

2.5 $X^0\pi^+\pi^-$

The channel $\bar{p}p \to X^0\pi^+\pi^-$ was studied[4)] by using events of the two types: $\bar{p}p \to \pi^+\pi^-\pi^+\pi^-$ (missing mass) in which the missing mass falls in the η^0 mass band and the effective mass $\pi^+\pi^-\eta^0$ falls in the X^0 mass band; and $\bar{p}p \to 3\pi^+ 3\pi^- \pi^0$, in which the effective mass $\pi^+\pi^-\pi^0$ falls in the η^0 mass band and then the effective mass $\pi^+\pi^-\eta^0$ falls in the X^0 band. The results were:

i) rate of $\bar{p}p \to X^0\pi^+\pi^- = (3.1 \pm 0.6) \times 10^{-3}$ of all antiproton annihilations at rest in hydrogen.

ii) $$\frac{\text{rate } \bar{p}p \to X^0\rho^0}{\text{rate } \bar{p}p \to X^0\pi^+\pi^-} = 0.46 \pm 0.25$$

The experiment can be much better done if the η^0 is detected via the decay mode $\eta^0 \to 2\gamma$. We would have to look for events of the type

$$\begin{array}{l} \bar{p}p \to \pi^+\pi^-X^0 \to \pi^+\pi^-\pi^+\pi^- \ 2\gamma \\ \qquad\qquad\quad \hookrightarrow \eta^0\pi^+\pi^- \\ \qquad\qquad\qquad\quad \hookrightarrow 2\gamma \end{array}$$

3. KAON PROCESSES

Among the relevant kaon production annihilations we must consider the processes involving three, four and five particles in the final state.

3.1 Three-body processes: $\bar{p}p \to K\bar{K}\pi$

They are:

$$\bar{p}p \to K_1^0 K^\pm \pi^\mp \qquad (1)$$

$$\to K_1^0 K_1^0 \pi^0 \qquad (2)$$

$$\to K_1^0 K_2^0 \pi^0 \qquad (3)$$

$$\to K^+ K^- \pi^0 \qquad (4)$$

Reaction (3) cannot be detected in a hydrogen chamber. A careful analysis of the four Dalitz plots of these reactions would give information about interactions $K\pi$ and $K\bar{K}$ in the final state[5,6)].

3.2 Four-body processes: $\bar{p}p \to K\bar{K}\pi\pi$

They are:

$$\bar{p}p \to K_1^0 K_1^0 \pi^+ \pi^- \tag{5}$$

$$\to K_1^0 K^{\pm} \pi^{\mp} \pi^0 \tag{6}$$

$$\to K_1^0 K_2^0 \pi^+ \pi^- \tag{7}$$

$$\to K_1^0 K_1^0 \pi^0 \pi^0 \tag{8}$$

$$\to K_1^0 K_2^0 \pi^0 \pi^0 \tag{9}$$

Reactions (7), (8) and (9) cannot be studied in a hydrogen bubble chamber. Note that reaction (8) corresponds to a pure state of C = +1 ($^1S_0$) and reaction (9) to a pure state of C = -1 ($^3S_1$). In reaction (9) the C^0 resonance can be produced only in the triplet state, a fact which would facilitate the determination of its quantum numbers.

3.3 Five-body processes: $\bar{p}p \to K\bar{K}\pi\pi\pi$

They are:

$$\bar{p}p \to K_1^0 K^{\pm} \pi^{\mp} \pi^- \pi^+ \tag{10}$$

$$\to K_1^0 K^{\pm} \pi^{\mp} \pi^0 \pi^0 \tag{11}$$

$$\to K_1^0 K_1^0 \pi^+ \pi^- \pi^0 \tag{12}$$

$$\bar{p}p \to K_1^0 K_2^0 \pi^+ \pi^- \pi^0 \tag{13}$$

$$\to K_1^0 K_1^0 \pi^0 \pi^0 \pi^0 \tag{14}$$

$$\to K_1^0 K_2^0 \pi^0 \pi^0 \pi^0 \tag{15}$$

Reactions (11), (13), (14) and (15) cannot be studied in a hydrogen chamber. The study of reaction (11) would allow a determination of the J^P of the E^0 resonance, specially to exclude $J^P = 1^+$.

4. FEASIBILITY OF THE EXPERIMENT

As we said in the introduction, the feasibility of the experiment depends on the fraction of antiprotons that are captured by the hydrogen of the propane molecule. In order to find out that fraction we propose to make a test run with the CERN heavy-liquid chamber, by taking some 20,000 or 30,000 photographs with about 10 antiprotons stopping per picture. We would then scan for the annihilation into two pions, having as signature two collinear pions going in opposite directions, or annihilation into $\pi^+\pi^-\pi^0(2\gamma)$, $\pi^+\pi^+\pi^-\pi^-$ giving a larger number of events. As the rate of such a process in hydrogen is well known, we can compute how many times the annihilation occurred in hydrogen.

* * *

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* * *

DISCUSSION

Rousset (Ecole Polytechnique)

Could you explain the calculations which give a figure of 2% annihilation of $\bar{p}$ on the free hydrogen in propane?

Burhop (UCL)

In emulsions K^- interactions on free hydrogen are readily distinguished by the collinearity of the secondary products. Experimentally it is found that 0.5% of all K^- interactions in emulsion occur on free hydrogen.

Calculations assuming the Fermi-Teller Z law indicate that 6% of K^- should be initially captured into an orbit around the free hydrogen and 40% around C, N, O atoms. Therefore the observed value of 0.5% K^- interactions on hydrogen show that all but 1/12 of the (K^-H) atoms lose the K^- by transfer to C, N and O atoms. If we assume the same is true for $\bar{p}$ in C_3H_8, then the initial capture rate of 25% on free hydrogen will be reduced to 2% before interaction.

Miller (UCL)

Someone has suggested $\bar{p}p$ interaction in flight. This should be good in Gargamelle since the $\bar{p}p$ cross-section is very large and hence the proportion of hydrogen interactions will be high.

Salmeron (Ecole Polytechnique)

Yes, and in fact one could inject the beam at ~ 1 GeV/c and obtain a range of interacting momenta at the same time as annihilation at rest.

Tovey (CERN)

It would seem to me that stopping $\bar{p}$ experiments in C_3H_8 are just as well done in the CERN HLBC. One will be wasting Gargamelles' great length.

Perkins (Oxford)

What is the possible time scale for these experiments? It would seem that they will be done sooner with hydrogen targets in a neon chamber.

Fiorini (Milan)

I guess that in a reasonable percentage of events like $\bar{p}p \rightarrow K_1^0 K_2^0 \pi^0 (\pi^0)$ one will be able to see the secondary interaction of the K_2^0. This allows one to determine the direction of the K_2^0 and sometimes also to have a rough estimate of the K_2^0 energy. This means one could be much more optimistic about the reconstruction of the events.

Salmeron (Ecole Polytechnique)

I am optimistic about the possibilities of the experiment but not so much about getting the pictures.

Faissner (Aachen)

Your suspected two-pion s-wave resonance has presumably an isospin $I = 0$.

Salmeron (Ecole Polytechnique)

Yes, that is just what one wants to check.

Faissner (Aachen)

This would be in agreement with some recent $\pi\pi$ phase-shift analysis which indicate a broad $J = I = 0$ resonances between 700 and 1000 MeV.

FORMATION EXPERIMENTS IN GARGAMELLE

G.W. London,
Ecole Polytechnique, Paris, France.

I will emphasize in this talk the general aspects of formation experiments and the general utility of Gargamelle as an investigating tool rather than present any actual proposals. We must remember that we are talking about experiments in $2\frac{1}{2}$-3 years at which time some of the field will have been covered and other techniques might become competitive even in the special domain of π^0 detection. Though I will make a few remarks about πp and $\bar{p}p$ formation experiments, I will concentrate on Kp formation experiments.

1. STATUS OF Y_0^* AND Y_1^* HYPERONS

In the table we see the presently known Y_0^* and Y_1^* hyperons which can be formed in Kp interactions. [See R.D. Tripp, Rapporteurs Talk, Proc. 14th International Conference on High-Energy Physics, p. 173, Vienna, 1968]

Y_0^*	Y_1^*
1405 $(1/2^-)$	1385 $(3/2^+)$
1520 $(3/2^-)$	1615 (?) ?
1670 $(1/2^-)$?	1660 $(3/2^-)$?
1690 $(3/2^-)$?	1680 (?) ?
1815 $(5/2^+)$	1750 $(1/2^-)$?
1830 $(5/2^-)$?	1770 $(5/2^-)$
2100 $(7/2^-)$	1910 $(5/2^+)$?
2350 $(9/2^+)$?	2030 $(7/2^+)$
	2250 (?)

Those resonances marked with a question mark have some questionable status which I shall now enumerate, Y_0^* first:

i) The $\Lambda\gamma$ threshold effect at 1670, for which a p-wave scattering length fits the data as adequately as an s-wave resonance, seems to have been observed strongly in $\Sigma\pi$ implying its resonant nature. This observation comes from the interference of this resonance with the D_{03} resonance at

1680 whose width from the elastic channel differs greatly with the width from the $\Sigma\pi$ channel. If you consider that this result comes from disentangling the I = 0 and I = 1 partial waves and that there is a nearby $Y_1^*(1660)$, both the $Y_0^*(1670)$ and $Y_0^*(1680)$ need further elucidation.

ii) The 1830 D_{05} resonance and 1815 F_{05} resonance [the old $Y^{0*}(1820)$] are separable via an interference term. The existence of the D_{05} resonance is only suggested by the CERN-Heidelberg-Saclay data.

iii) The J^P of the $Y_0^*(2350)$ is suggested as $9/2^+$.

iv) The $3/2^-$ $Y_1^*(1660)$ is well-established except for its branching ratios. For example, in production one finds an equal amount of $\Sigma\pi$ and $Y_0^*(1405) + \pi$ decay modes while in formation, there is almost no signal in $Y_0^*(1405)$ as compared to $\Sigma\pi$.

v) Both the $Y_1^*(1615)$ and $Y_1^*(1680)$ found in production decaying in $\Lambda\pi$ are not found in formation. A crucial point in the production experiments is the separation of Λ^0 from Σ^0.

vi) The Σ_η threshold effect at 1750, reminiscent of the Λ_η effect, is far from established as a resonance. The two published experiments disagree as to the production angular distribution near threshold while an unpublished experiment shows that this distribution is very sensitive to the fitting procedure as the fit involves deuterium in a 1C fit.

vii) The J^P of $Y_1^*(1910)$ is suggested as $7/2^+$.

viii) The J^P of the $Y_1^*(2250)$ is unknown.

2. SEPARATION OF ISOSPIN AMPLITUDES

The $\bar{K}p$ system is a mixed I = 0 and I = 1 state, while the $\bar{K}n$ system is pure I = 1. The use of deuterium is reasonable only for those final states which are well-constrained, $\Lambda^0\pi^-$ for example but not $\Sigma^-\pi^0$. There are pure isospin final states accessible to the Kp system which are the following:

$$\begin{array}{llll} I = 0 & \Lambda\gamma \quad \Sigma^0\pi^0 & \Lambda^0\pi^0\pi^0 & \Lambda^0\eta \\ I = 1 & \Sigma^0\pi^0\pi^0\ , & \Lambda^0\pi^0\pi^0\pi^0, & \Sigma^0\eta \quad . \end{array}$$

Except for the $\Lambda^0\eta$ state, each of the other final states require the observation of γ rays, especially for a partial wave analysis. Thus Gargamelle might seem an ideal tool for this type of experiment.

3. COMPETITION WITH OTHER TECHNIQUES

In $2\frac{1}{2}$ to 3 years other techniques will become competitive if not overwhelming. For example, a study of $K + \bar{p} \rightarrow \Sigma^0 + \pi^0$ using spark chambers can be very competitive if the γ directions and the Λ^0 momentum and direction (via stopping π^- and p for example) are known. The γ momenta, known to perhaps 15% in 85% propane + 15% CF_3Br, are less important than the knowledge that the target is hydrogen. In addition, if the technique of a hydrogen sensitive region surrounded by a neon-hydrogen sensitive region in the 7 ft chamber at Brookhaven is perfected, one can easily see the competition.

The point is to keep the other techniques in mind while continuing the study of Gargamelle for this type of experiment.

4. EXPERIMENTAL PROBLEMS IN HEAVY-LIQUID BUBBLE CHAMBERS

The major problem in heavy liquid is the separation of events on hydrogen-like protons. For example, the $\Sigma^0\pi^0$ experiment to be begun in the NPA chamber in January 1969 has the following difficulty.

We expect 12% of interactions on "free" protons and 44% of interactions on bound protons. A large number of the interactions on bound protons will result in visible evaporation tracks. For example, at $p_K = 15$ GeV/c in pure freon (i.e. all interactions are on bound protons) only about 25% of the interactions producing a Λ^0 and $\eta\gamma$ ($\eta \geq 2$) have no visible evaporation prongs. Thus the noise to signal ratio, <u>before fit</u> is

$$\frac{44}{12} \times \frac{1}{4} = 1$$

which we would like to reduce to 5% with the fit (6 constraints, or 3 without gamma momenta), i.e. a factor 20.

We already have some information which indicates that this reduction is possible. In a 16 GeV/c π^- experiment in freon, events with no evaporation tracks and well measurable π^+, $2\pi^-$ and proton ($\pi^- + Z \rightarrow \pi^+ + \pi^- + \pi^+ + p + Z'$) were fitted to the 4C hypothesis:

$$\pi^- + p \rightarrow \pi^- + \pi^- + \pi^+ + p \ .$$

Only 5% of the events fitted. At such a high energy the Fermi momentum plays less of a role in rejecting bound proton events than at lower energies. What seems more important is the rescattering in the nucleus which is quite difficult to calculate.

A Monte Carlo program simulating the $\Sigma^0\pi^0$ experiment on free and bound protons has been developed which will give some idea about the separability of events. If the program described by Franzinetti earlier for rescattering in the nucleus is easily adaptable to our Monte Carlo program, we will look into this.

In addition we are scanning 15 GeV/c K^- interactions in pure freon for $\Lambda n\gamma$ events ($n \geq 2$) which we will attempt to fit to $\Lambda\pi^0$, $\Sigma^0\pi^0$, etc. Finally, the definitive check of the separability of events on free and bound protons will come from the NPA experiment in which the $\Lambda^0\pi^0$ final state will be compared to hydrogen results.

5. THEORETICAL PROBLEMS IN FORMATION EXPERIMENTS

After separating a given reaction channel in centre-of-mass energy bins, the differential cross-section is fitted:

$$\frac{d\sigma}{d\Omega} = \lambda\!\!\!^{-2} \sum_{\ell=0}^{\infty} A_\ell \, P_\ell \, (\cos\Theta) \; .$$

We thus get a set of A_ℓ as a function of energy. These A_ℓ are functions of the various partial waves with both non-spin-flip and spin-flip amplitudes. For example

$$A_0 = |s_1|^2 + |p_1|^2 + 2\left[|p_3|^2 + |d_3|^2\right] + 3\left[|d_5|^2 + |f_5|^2\right] + \ldots$$

$$A_1 = 2 \,\mathrm{Re} \left[s_1^* p_1 + 2\,(S_1^* p_3 + p_1^* d_3) + \ldots\right.$$

where s, p, d ... refer to $\ell = 0, 1, 2 \ldots$ and the subscript to 2J. If both isoscalar and isovector amplitudes are present, each wave is divided in addition into its two isospin components. A non-resonant wave is parametrized in a simple but arbitrary energy-dependent way with four independent parameters. A resonant wave is parametrized by a Breit-Wigner with three independent parameters. A choice is made for each wave, the parameters varied and a minimum χ^2 is found. If there is polarization information available, this is included in the fit via the expansion

$$\vec{p}\,\frac{d\sigma}{d\Omega} = \hat{n}\,\lambda\!\!\!^{-2} \sum_{\ell=0}^{\infty} B_\ell \, p_\ell' \, (\cos\Theta)$$

where the B_ℓ are functions of the same partial waves.

The problems are the following:

i) the parametrization of the non-resonant waves is completely arbitrary.

ii) The cut-off position of a resonant amplitude far from its resonant energy is not clearly defined.

iii) An individual wave might have both resonant and non-resonant character, yet the Kp data have not been sufficient yet to investigate this, as has been found necessary in similar πp work.

6. FORMATION IN πp AND $\bar{p}p$

I would like to add a few comments about other formation experiments.

The πp system does not look particularly promising for heavy liquids. The radiative decay of N* are better inferred from photoproduction. The reaction $\pi^+ + p \rightarrow N^* \rightarrow \pi^+ + p + \gamma$ could be looked at. This could have some interest if the final state $\pi^+ p$ formed an N* and therefore we would measure the radiative decay $N^{**} \rightarrow N^* + \gamma$. I am not convinced that one would want to do an experiment uniquely for this. In any case, other techniques would be quite competitive.

The $\bar{p}p$ system could be interesting especially if mesons like S, T, U, etc., are coupled to the $\bar{p}p$ system and if certain channels necessary for the quantum number determination can be isolated.

7. PROTOTYPE PROPOSAL

In Fiorini's report to the Track Chamber Committee, there is included a proposal for a Kp formation experiment investigating the 1890-2400 MeV/c^2 centre-of-mass energy region. Let me just recall the important parameters:

i) For the $\Sigma^0\pi^0$ channel, the function $Pp(X_0)\ P_\gamma^3(X_0)$ is maximized, where Pp is the probability that an interaction is on a hydrogen-like proton and P_γ is the probability that a gamma materializes. For $X_0 = 50$ cm, we have $Pp > 20\%$ and $P_\gamma \geq 90\%$ where the potential path is 1.5 m.

iii) For a two metre fiducial volume, we investigate 150 MeV/c^2 in the centre of mass which is divided into three bins. Six useful interactions are assumed.

v) In each bin, we require 300 events and determine the unknown $\Sigma^0\pi^0$ cross-section by the average of $\Sigma^+\pi^-$ and $\Sigma^-\pi^+$ cross-sections.

iv) We thus require

P_k (transport)	Number of pictures
1.6 GeV/c	60,000
1.9	95,000
2.2	150,000
2.5	275,000

v) For the lower momenta, it might be necessary to lower the magnetic field of the chamber to get a reasonable trajectory.

* * *

DISCUSSION

Rousset

You are pessimistic about the study of the radiative N* because of photoproduction results. However I feel that we are competitive with respect to study of the $n\gamma$ and $\pi p\gamma$ decay.

PRODUCTION EXPERIMENTS WITH K$^-$ BEAMS IN GARGAMELLE: A REVIEW OF PROPOSALS

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After discussion at the Milan meeting on October 11th and 12th, and after further communication with interested parties, we feel it is worth while to produce a new version of this review. In addition to the proposals from CERN, Ecole Polytechnique and our own proposal, we have incorporated unpublished data on Ξ^0 production from Dr. C. Fisher on behalf of the Rutherford-Saclay collaboration, and from Dr. J.R. Hubbard. We are very grateful to be able to use these data.

1. K MESONS AT AROUND 2 GeV/c (G1 BEAM)

1.1 Beam momentum

The CERN, Ecole Polytechnique and UCL proposals all suggested $\sim$2.2 GeV/c. Newly available data on Ξ^0 two- and three-body production indicates that an exposure at $\sim$1.7 GeV/c would obtain a better yield of two body Ξ^0 (Fig. 1). For η' and ϕ studies a momentum above 1.95 GeV/c is essential.

1.2 Size of run

Ecole Polytechnique and UCL suggest 800,000 pictures with 8 interactions per picture. CERN suggests 500,000 pictures with 20 interactions per picture.

For experiments involving γ rays 20 interactions per picture is excessive, so all yields quoted will refer to 800,000 × 8 interactions. η, ω, Ξ^0 and Ξ^- yields are calculated at 1.7 and 2.2 GeV/c, η' and ϕ at 2.2 GeV/c only.

1.3 Mixture

80% propane, 20% CF_3Br, by volume

X_0 = 40 cm

γ-conversion probability 90%

1.4 Hydrogen interactions

After the meeting we have received Veillet's optical model calculation of inelastic cross-sections on heavy nuclei. Using this, together with a total cross-section for K^-p of 30 mb at around 2 GeV/c, we expect 1 event in 6 to be a hydrogen interaction. Veillet points out that there are few low-energy experiments against which to check his calculation, so this ratio is subject to some doubt. In the worst possible case the ratio would be 1:8.

1.5 Ξ^0 properties

We divide the estimated Ξ^0 yield into those produced on complex nuclei and those produced on hydrogen.

1.5.1 Complex Nuclei

We scale up from T8 (1.47 GeV/c in BP3)

$$\frac{160\ \mu b}{40\ \mu b} = \times\ 4\ (\pm\ 1.5)\ \text{at 1.7 GeV/c}$$

$$\frac{110\ \mu b}{40\ \mu b} = \times\ 2.7\ (\pm\ 1.0)\ \text{at 2.25 GeV/c}$$

× 8.5 for number of interactions
× 2 for γ conversion

There were 16 Ξ^0 in T8

$\therefore$ number in Gargamelle $= 16 \times 8.5 \times 2 \times 4$

$= \underline{1100 \pm 500}$ at 1.7 GeV/c

and $16 \times 8.5 \times 2 \times 2 \times 7$

$= \underline{735 \pm 270 \text{ at } 2.25}$ GeV/c .

All of these events can be used in improved lifetime and α-parameter measurements.

1.5.2 Hydrogen

Number of H interactions $= 1.1 \times 10^6$

To convert 1 or 2 γ rays, efficiency is ∿ 100%
$\Lambda \to p\pi^-$ = 67%
Rejecting Ξ^0 with length $\lesssim$ 2 cm, we keep ∿ 80%
Scanning efficiency ∿ 80%
Probability of seeing K^+ or K "signature" ∿ 33%
Cross-sections at 1.7 GeV/c

$$\left.\begin{array}{l} \Xi^0K^0 = 100 \pm 10\ \mu b \\ \Xi^0K\pi = \ \ 60 \pm 20\ \mu b \end{array}\right. = 160\ \mu b$$

So we see, at 1.7 GeV/c

$$1.1 \times 10^6 \times \frac{0.16}{30} \times 0.8 \times \frac{2}{3} \times \frac{1}{3} \times 0.8 = \underline{800}$$

split into $\underline{500 \pm 50}$ two-body H production
and $\underline{300 \pm 100}$ three-body H production.

At 2.25 GeV/c the cross-sections are

$\Xi^0 K^0 = 30 \pm 10\ \mu b$
$\Xi^0 K\pi = 80 \pm 20\ \mu b$

giving $\underline{570}$, split into

$\underline{150 \pm 50}$ two-body H production
and $\underline{420 \pm 140}$ three-body H production.

Clearly, for a study of α, β and γ parameters the better momentum is 1.7 GeV/c.

1.6 Ξ^- properties

We expect $\sim 10^4$ Ξ^- decays. This will give ~ 6 $\Xi^-\beta$ decays, but 16 were reported at Vienna. Other Ξ^- properties can be studied better in hydrogen.

1.7 Λ_β studies

About 1000 Λ_β are expected, but at this energy many channels are open and polarization will be hard to find. Romanowski's spark-chamber experiment gives $g_A/g_V = -0.23 {}^{+0.2}_{-0.33}$ as opposed to the bubble-chamber average of $-0.85 {}^{+0.14}_{-0.2}$ (Cabibbo fit wants -0.74). The two previous heavy-liquid experiments had 162 events and the error on their combined result was ±0.65 without polarization a repeat with the old heavy-liquid technique in Gargamelle will not give as good a result as the present bubble-chamber average.

1.8 Yields of mesons

Number on hydrogen, in the channel
$K^-p \to \Lambda^0$ + meson, with a visible $\Lambda^0 \to p\pi^-$
At 1.7 GeV/c

$K^-p \to \eta\Lambda^0$	$\sim 2{,}000$
$\to \omega\Lambda^0$	$\sim 25{,}000$

At 2.25 GeV/c

$K^- p \rightarrow \eta\Lambda^0$	~ 1300
$\omega\Lambda^0$	~ 9000
$\eta'\Lambda^0$	~ 2300
$\phi\Lambda^0$	~ 2100

1.9 Meson experiments

1.9.1 $\eta \rightarrow 3\pi^0$

Already reasonably well done by Ecole Polytechnique, by UCL and by Strugalski et al. etc.

1.9.2 $\eta' \rightarrow \pi^0 e^+ e^-$, $\eta' \rightarrow \eta e^+ e^-$ branching ratios

Present upper limits are $\sim 3 \times 10^{-2}$. We could get 0.15×10^{-2} and 0.23×10^{-2} respectively. A sensible by-product experiment, but Kalbfleisch at BNL will probably do it first.

1.9.3 $\eta' \rightarrow \pi^+ \pi^- \gamma$ asymmetry

400 useful events, compared with Kalbfleisch's 650. The error in asymmetry will be $\sim 6\%$. The effect if present is probably smaller than this -- as in η decays. Also, what biases are there in heavy liquid?

1.9.4 $\eta' \rightarrow \pi^+ \pi^- \gamma$ Dalitz plot analysis

Is this mode entirely ρ dominated? Our 400 events again are less than Kalbfleisch's 650, and this is one of his main concerns.

1.9.5 $\eta' \rightarrow \gamma\gamma$ search

May already have been seen in a counter experiment, but useful to check. Important for SU(3).

1.9.6 $\omega^0 \rightarrow e^+ e^-$ rate

At 1.7 GeV/c no event corresponds to 8×10^{-5} at 90% confidence level. Present limit 4×10^{-4}.

1.9.7 $\omega^0 \rightarrow \pi^0 \gamma$ rate

Present ratio $\pi^0\gamma/\text{all } \omega^0 = (9.3 \pm 0.8)\%$

Can improve to ± 0.4 at 1.7 GeV/c.

1.9.8 $\phi \to \eta\gamma$ rate

SU(3) predicts ∿90 events, although the current experimental limit indicates < 70 events, with $\eta \to \gamma\gamma$ or $\eta \to \pi^+\pi^-\pi^0$. Difficult for Kalbfleisch due to a minimum of 2γ per η. Quite an important rate in Gell-Mann, Sharp and Wagner, SU(3) - SU(6) analysis of the PVγ coupling.

1.10 $\Delta s = -\Delta Q$ from $\Sigma^+ \to e^+ \nu n$

Will have ∿70,000 Σ^+; world total is ∿85,000 $\Sigma^+ \to \pi^+ n$, with one $\Sigma^+ \to e^+ n\nu$ candidate and two $\Sigma^+ \to \mu^+ n\nu$ candidates already found. At Vienna it was said that this is comparable with expected background, perhaps due to $\Sigma^+ \to \Lambda e^+ \nu$ events with neutral decay of the Λ. In discussion at Milan, Musset argued that we expect one such $\Sigma^+ \to \Lambda e^+ \nu$ decay in the experiment. Only 1/3 of the decays are neutral and the γ rays from the neutral decay will be seen in 90% of cases. Thus the background is 1/30 event.

1.11 $|\Delta s| \neq 2$ rule

There will be 7500 signed Ξ^-. We can search for $\Xi^- \to n\pi^-$, giving a limit of 10^{-3} which is close to the present limit. H_2 can do as well. Similarly H_2 could measure all Ξ^0s with signed origins to look for $\Xi^0 \to p\pi^-$.

1.12 $K^0_S \to \pi^0\pi^0 / K^0_S \to \pi^+\pi^-$

Aubert said at Milan that this is being done in the 1.1 GeV/c K^+ film from BP3.

2. EXPERIMENTS WITH THE G3 HIGH-ENERGY RF SEPARATED BEAM

2.1 Ω^- studies

So far 25 Ω^- have been seen

13 $\to \Lambda K^-$
 8 $\to \Xi^0\pi^-$
 3 $\to \Xi^-\pi^0$
 1 either ΛK^- or $\Xi^0\pi^-$

Cross-section for producing ΛK^- mode
 = 0.9 μb at 5.5 GeV/c
 = 2.5 μb at 10 GeV/c (four events)
giving ∿ 5 μb at 10 GeV/c for all modes

Thus a 10 GeV/c experiment of 500,000 pictures with 5 interactions per picture would give

$$500{,}000 \times 5 \times \frac{0.005}{25} = 500\ \Omega^- .$$

in Ξ^0 and Ξ^- production there is strong absorption in the nucleus. One in six interactions at 1.7 GeV/c, above, is on hydrogen but we predict

$$\frac{\text{No. of } \Xi^0 \text{ on H}}{\text{No. of } \Xi^0 \text{ on nuclei}} = \frac{800}{1100}$$

This would indicate that all but 1/4 of Ξ^0 are absorbed. Presumably some high-energy Ξ particles will interact in their production nuclei to give Ω^-. This will tend to counteract the absorption of directly produced Ω^- particles. We assume, conservatively, therefore, that the 500 Ω^- mentioned above should be divided by a factor of $2\,^{+2}_{-1}$ to account for absorption and indirect production together.

Following Fournier, we will see 2/3 × (scan efficiency) of the ΛK^- and $\Xi^0\pi^-$ channels. Thus our visible Ω^- yield will be

$$500 \times \frac{1}{2} \times \frac{2}{3} \times 0.8 = \underline{130^{+130}_{-\ 60}}$$

This looks interesting, especially as we have the advantage of seeing the decay products, but we must wait for the BNL-Orsay-Milan-Berkeley-Saclay results at 10 and 13 GeV/c to see if it is realistic.

2.2 Ξ^* investigation

A 5 GeV/c K^- beam would permit Ξ^* of up to 2.75 GeV to be formed. The 1815 may be two resonances and both the 1930 and 2030 need more work. Using Gargamelle's γ-conversion efficiency we may be able to determine the ratios

$$\frac{\Xi^-\pi^0}{\Xi^0\pi^-} \text{ and } \frac{\Xi^0\pi^0}{\Xi^-\pi^+}$$

which will help in isospin determination. Also, SU(3) predicts $\Xi^*(1530) \to \Xi\gamma = 0$ for Ξ^{*-} and 2% for Ξ^{*0}. This is worth checking.

Professor Burhop pointed out that studies of Ξ^* decays in emulsion have been unsuccessful due to nuclear effects. In a high-energy experiment this should not be too serious for the 1530 ($\Gamma = 7.3$ MeV) or the 1815 ($\Gamma = 16$ MeV), though the 1930 ($\Gamma = 120$ MeV) may be vulnerable.

2.3 Neutral boson studies

$K^- p \rightarrow \Lambda$ + boson

This can be done with a 6 GeV/c beam up to boson masses of 2.4 GeV. At least 12 resonances lie between 1.6 GeV and 2.4 GeV. The least ambitious experiment could correlate γ multiplicity with mass. For some channels a complete reconstruction with π^0's would give branching ratios and isospin.

2.4 Y* studies

A study can be made of the neutral modes

$$\Sigma^0\pi^0,\ \Lambda^0\eta,\ \Lambda^0\pi^0\pi^0 \quad (I=0)$$

and

$$\Sigma^0\eta^0,\ \Lambda^0 3\pi^0,\ \Lambda^0\pi^0 \quad (I=1)\ .$$

Unless there is a highly inelastic resonance in one of these channels, formation experiments will give better statistics. Nevertheless, some new production channels will be accessible, and the Λ-Σ^0 ambiguity is resolved by seeing the γ in heavy liquid.

2.5 Coherent production of $S^{\pm}1$ bosons

This again depends on the results of the K^+ and K^- experiments in the BNL Ne-H and NPA chambers.

The primary channel of interest is

$$K^{\pm} + {}^{12}C \rightarrow (K\pi\pi)^{\pm} + {}^{12}C$$

[$K\pi$ production cannot be coherent due to spin-parity restrictions.]

Due to form factor damping, the beam momentum would preferably be $\gtrsim$ 10 GeV/c. Absorption model studies might use a carbon-neon comparison, although A = 12 and A = 20 are rather close. Justification would come if it seems that a further study of spectra and angular distributions in $K^0\pi^{\pm}\pi^0$ is likely to be fruitful. Both $K^{\pm}\pi^-\pi^0$ and $K^{\pm}\pi^0\pi^0$ are experimentally difficult. Morrison has reminded us that the latter state cannot contain ρ, so the Dalitz plot analysis may be simplified.

* * *

DISCUSSION

Rubbia (CERN)

Can you use the Gargamelle chamber as a polarization analyser? Carbon-proton scattering is a good polarization analyser in the range 80-500 MeV proton kinetic energy. This would be useful in the study of Σ and Λ decays.

Also the efficiency of double scattering will be high due to the large size of the chamber.

Burhop (UCL)

I think it is difficult to study Ξ^* production in heavy-liquid chambers unless one restricts oneself to the events on free protons. The effect of the nucleus on the secondary decay products and the resonance itself will be large.

Fournier (Orsay)

Using 12.7 GeV/c K^- we expect to see $\sim$10 Ω^- in 250,000 pictures, with 1.7 interactions/picture and an equal number of free protons and neon atoms.

At 10 GeV with 500,000 pictures and 5 interactions/picture one could expect $\sim$100 Ω^-.

Musset (Ecole Polytechnique)

The limit we will be able to set for the decay $\Sigma^+ \rightarrow n + e^+ + \nu$ will be 3×10^{-5}. I calculate that the possible background from the decay mode $\Sigma^+ \rightarrow \Lambda^0 + e^+ + \nu$ will be only 1/40 of our expected $\Sigma^+ \rightarrow n + e^+ + \nu$ limit.

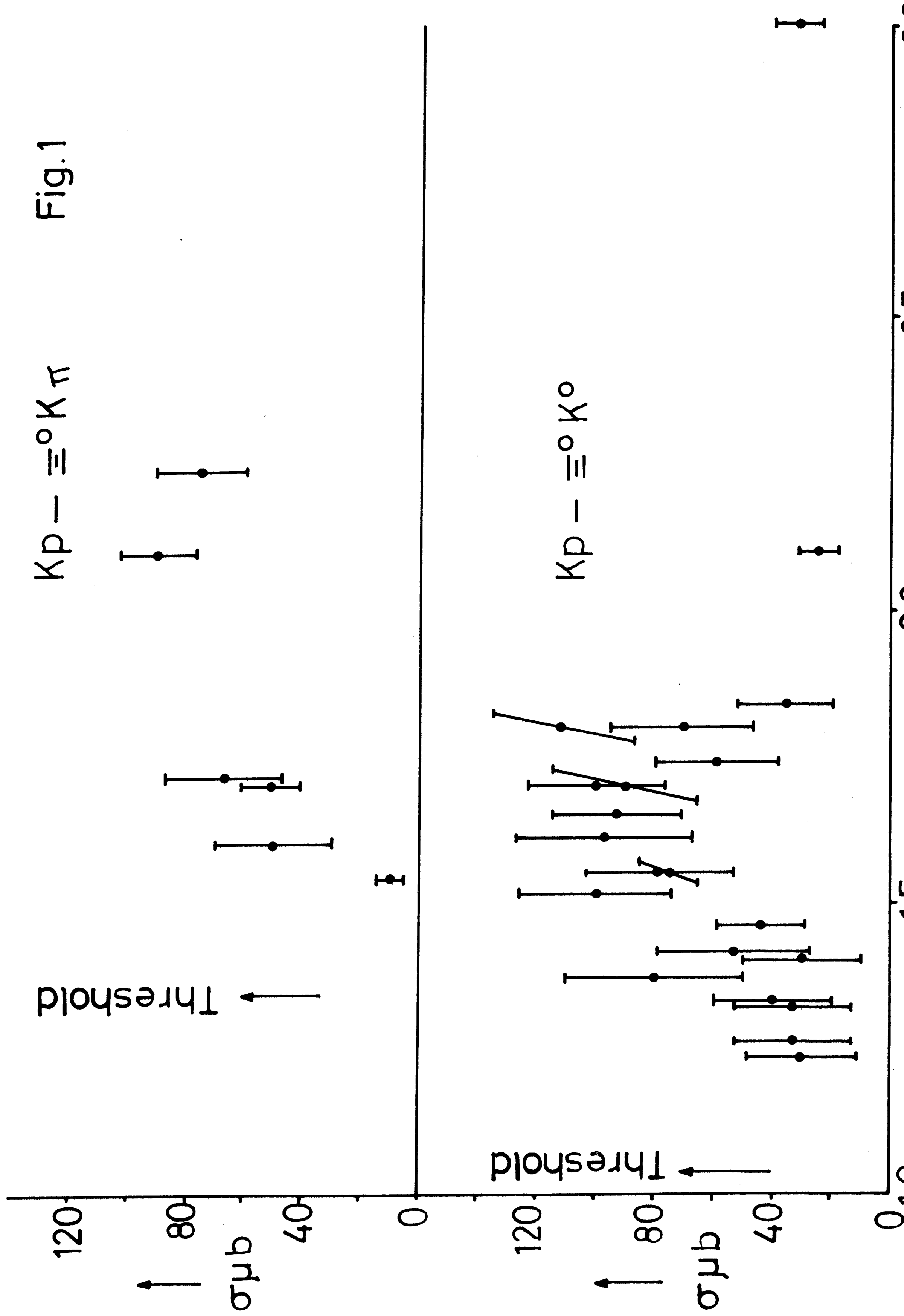
Kp — Ξ°Kπ
Kp — Ξ°K°
Threshold
Threshold
σμb
σμb
120
80
40
0
120
80
40
0
1.0
1.5
2.0
2.5
3.0
Pk - GeV/c

Fig.1

PRODUCTION EXPERIMENTS WITH PIONS

J.J. Veillet
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Orsay, France

Most of the points to be studied under this title also correspond to that of the high-energy experiments and have already been discussed in the report on hadron interactions at high energy. There are, however, a few experiments to add and I would just like to elaborate on one of the rare types of low-energy experiments which are essentially impossible in hydrogen chambers and very difficult with spark chambers. That is the study of $\pi\pi$ interaction in the reaction:

$$\pi^+ + \pi^- \rightarrow \pi^0 + \pi^0 .$$

Although it is clearly a formation reaction, one has to study it via a production reaction of the type:

$$\pi + N \rightarrow \pi^0 + \pi^0 + N'$$

assuming that this reaction can be adequately described by a one-pion exchange model, where the production reaction appears at the upper vertex. The advantage of having a whole spectrum of centre-of-mass energy for a single beam momentum is largely balanced by the difficulties due to the virtual nature of the exchanged pion. The characteristics of the real π interaction have then to be deduced by extrapolation into the physical region.

Since the two particles are identical spinless mesons, the possible spin and isospin states of the $\pi\pi$ system are the following:

$\pi^+\pi^-$	$I = 0,2$	J even	$I = 1$	J odd
$\pi^\pm\pi^0$	$I = 2$	J even	$I = 1$	J odd
$\pi^\pm\pi^\pm$	$I = 2$	J even		
$\pi^0\pi^0$	$I = 0,2$	J even		

The first three states have already been extensively studied and a complete phase-shift analysis has been achieved without the last one.

However the I = 0 phase shifts are deduced by subtraction and are not easy to extract, due to the strong dominance of the ρ resonance in the first two reactions. Different solutions are possible, depending on the particular method used. The $\pi^0\pi^0$ state will give more accessible information on the I = 0 component.

There are at least three points of interest in these I-even states:

a) The difference between the I = 0 and I = 2, J = 0 phase shifts at the K mass is important for the study of CP violation if $\eta^{\pm}$ and η^{00} are significantly different.

b) It seems clear now that no narrow ε^0 exists but it is still important to know the exact behaviour of the I = 0, J = 0 phase shift up to 1 GeV.

c) The f^0 decay into $\pi^+\pi^-$ presents an angular distribution which is not well understood. The angular distribution of the $\pi^0\pi^0$ mode should permit one to clarify this point.

More generally, very little information is available on the I = 0 $\pi\pi$ state, which is in itself interesting and essential in the understanding of the features observed in the $\pi^+\pi^-$ systems.

The most suitable reaction to study this in a heavy-liquid chamber seems to be:

$$\pi^+ + p \rightarrow N^{*33} + \pi^0 + \pi^0$$
$$\hookrightarrow p + \pi^+ .$$

Its advantages over the other possible reactions can be summarized as follows:

i) A four constraint production fit (plus two π^0 constraints) allows one to separate the hydrogen events.

ii) Momentum measurement of the π^+ and p (in most cases by range in Gargamelle) permits a good estimation of the momentum transfer.

iii) The decay angular distribution of the N* gives some tests of the OPE model.

This type of study needs obviously high statistics but, with a chamber of the size of Gargamelle, the number of pictures required is not unreasonable. First proposals are included in Fiorini's report to the Track Chamber Committee and the following characteristics can be recalled:

Liquid used : propane-freon $X_0 = 55$ cm 20% interactions on hydrogen.

Two incident energies were required: for the low mass region ($M_{\pi^0\pi^0} < 1$ GeV), an incident momentum of 2.5 GeV/c seems to be a good compromise between the requirements of low momentum transfer and high statistics, giving 1,800 $\pi^0\pi^0$ (useful events) for 300,000 pictures.

For the f^0 region, the optimum is around 5 GeV/c giving: 1000 $\pi^0\pi^0$ (500 f^0) for 300,000 pictures.

Such numbers of useful events are comparable, taking into account the absence of ρ in this channel, with the statistics obtained in the other channels by hydrogen experiments.

This experiment is probably the simplest of the low-energy production experiments with pions. Any of these experiments, as soon as it involves production of two or more π^0, is worth doing in heavy liquid. One has, however, to keep in mind that all these experiments are possible with other techniques (e.g. spark chambers, which do not seem to be better, at present, in the field of γ detection and momentum measurement.

This situation may, however, have changed by the time Gargamelle starts to operate.

* * *

DISCUSSION

Wilkin (UCL)

What is the advantage of the reaction $\pi^+ + p \rightarrow N^{*++} + \pi^0 + \pi^0$ over $\pi^- + p \rightarrow \pi^0 + \pi^0 + n$? The $\pi^0 N^{*++}$ interaction is likely to be as strong as the $\pi^0 n$ interaction. Dynamical models of the higher resonances suggest this.

Veillet (Orsay)

The reason is principally experimental. In the N* case there are more constraints and hence it will be easier to eliminate the background from complex nuclei.

I agree that the interference in the two reactions will be about the same.

Petiau (Ecole Polytechnique)

What are the number of events and mass resolutions expected for this experiment done in the CERN chamber and in Gargamelle?

Viellet (Orsay)

With a 25 cm radiation length mixture in the CERN chamber one would need twice as many pictures. The error on the mass resolution would not be doubled.

London (Ecole Polytechnique)

Would some theorist care to comment on the OPE model?

Salin (CERN)

Some unpublished Saclay results at 5 GeV/c give good agreement with the OPE model with at the most 10% contribution of A_1.

Ratti (Milano)

Dr. Salin has said that π exchange dominates at 5 GeV/c. I would like to add that the same is true at 11 GeV/c in the reaction $\pi^- + p \to \pi^0 + n$, the A_2 contribution being $\sim$20%.

Secondly I think Dr. Veillet's request is too modest. So little data exists on the study of $\pi\pi$ phase shifts in the f^0 region that a much larger exposure would be justified.

POSSIBLE EXPERIMENTS IN HADRON INTERACTIONS AT HIGH ENERGY USING GARGAMELLE

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1. INTRODUCTION

In this paper we will discuss high-energy hadron interaction experiments that could be performed in the Gargamelle bubble chamber which is a heavy liquid bubble chamber 4.5 metres in length and 1.95 metres in diameter.

Proposals for experiments with π^- have been received from CERN, Milan and Turin, with proton beams from CERN, Milan and University College, London, and with K^- beams from CERN. In this paper the proposals are not discussed individually but rather possible experiments are considered in groups in terms of the physics. There does not seem to be any obvious reason why Gargamelle should compete with hydrogen bubble chambers in experiments which can be done in hydrogen. Therefore what one wants to do is to use the particular advantages of Gargamelle which means studying especially events producing π^0's and gammas and occasionally also neutrons. The other great advantage of the heavy liquid chamber is that coherent reactions can be produced on nuclei.

2. BEAMS

The first beam for Gargamelle will be an unseparated one giving negative pions of momentum up to 22 GeV/c and protons of up to 25 GeV/c. Later other beams will be constructed to perform weak interaction experiments (not considered here) and then after several years an RF separated beam may be introduced. I would estimate that this RF beam would give positive pions from 8 to 19 GeV/c, K^+ mesons from 8 to 16 GeV/c, K^- mesons from 8 to 14 GeV/c and antiprotons from 8 to 13 GeV/c.

3. CHAMBER LIQUID AND PARTICLE DETECTION EFFICIENCY

The proposals for strong interaction studies in Gargamelle have suggested using propane as the chamber liquid. This has an interaction length of about 120 cm and radiation length of about 100 cm. The fact that the interaction length is appreciably less than the chamber length, means that the number of beam particles should be restricted to one or two. This is particularly important at high energies where there are often many secondaries which will also interact. For interactions in a fiducial region near the beam entrance, about 90% of the gamma rays produced will be detected and measurable. A large fraction of the neutrons will be observed, but is is difficult to estimate the detection efficiency.

4. USE OF GAMMA DETECTION EFFICIENCY

Particles or resonances which decay with emission of neutral pions or gammas, are candidates for study in Gargamelle. For example Ξ^0 hyperons have been observed, but rarely in hydrogen bubble chambers. One would also like to obtain direct evidence for an isospin zero mesonic resonance, σ or ε^0, which decays mainly into $\pi^0\pi^0$. It has also been proposed to investigate higher mass resonances, R, S, T and U mesons and study their decay branching ratios, particularly into channels with two or more π^0 mesons. However these high mass resonances are not easy to identify and good statistics experiments are required.

Another proposal is for a relatively simple and interesting experiment. This is to study the reactions

$$\pi^- p \rightarrow \Lambda + K^0 \qquad (1)$$

$$\rightarrow \Sigma^0 + K^0 \ . \qquad (2)$$

At high energies it is difficult to distinguish reaction (2) from the reaction

$$\pi^- p \rightarrow \Lambda + K^0 + \pi^0 \qquad (3)$$

but in Gargamelle the detection of the single gamma from the Σ^0 decay should allow the reactions (2) and (3) to be separated. One of the interests of this experiment is that from SU(3), the ratio of the cross-sections for production of Λ and Σ^0 hyperons has been predicted. Since the cross-sections for reactions (1) and (2) are small, a large number ($\sim 1/2 \times 10^6$) of photographs would be required.

There is another approach which has sometimes been used quite successfully with hydrogen bubble chambers, which is to measure all reactions instead of selecting only a few event types. An advantage of this is that one can study effects as a function of multiplicity. In hydrogen chambers partial cross-sections can only be obtained for reactions in which there is no neutral or only one neutral particle emitted. Bartke and Czyzewski have suggested a way of calculating the cross-section for the remaining channels (i.e. $\geq$ 2 neutrals); this calculation is based on considerations of phase space in Fig. 1, where the shaded areas represent the cross-sections found experimentally and the unshaded areas are the calculated ones. It may be seen that reactions corresponding to about half the total cross-section are unidentified at 10 GeV/c and this fraction increases as the energy increases. It would be interesting to have an experimental determination of the cross-sections for multi-neutral channels and to check the ideas of Bartke and Czyzewski experimentally.

5. COHERENT PRODUCTION

Most people here know roughly what is meant by coherent production. For example if a pion passes through or near a ^{12}C nucleus giving several pions, but still the ^{12}C nucleus is not broken up, then the ^{12}C nucleus is said to have reacted coherently. In this section we will first review the existing experimental knowledge on coherent interactions before considering what future experiments can be performed.

Coherent reactions can be identified experimentally by the differential cross-section $d\sigma/dt$, distribution as a function of t, the square of the four-momentum transfer. In two-body reactions it is found that for small $|t|$, the $d\sigma/dt$ distribution takes an exponential form

$$d\ /dt = \text{constant} \cdot e^{At}$$

where the slope A in a log plot is taken to be proportional to the square of the interaction radius. Consider now an experiment with high-energy pions incident on a propane bubble chamber. For coherent reactions producing for instance three pions, one would expect to observe two slopes, one for pion production on carbon and one for pion production on nucleons.

That this is so experimentally can be seen in Fig. 2 for 16 GeV/c π^- interactions. The steeper slope corresponds to coherent reactions on carbon nuclei, while the slope at large $|t|$ values corresponds to coherent reactions with hydrogen and, it is interesting to note, is about the same value as that found for elastic scattering on protons.

Another example of this is from a recent Brookhaven experiment with 28 GeV/c protons incident on a neon/hydrogen mixture. Two slopes can again be seen in Fig. 3 and the slope at large $|t|$ values is the same as that found in 28.5 GeV/c proton-proton elastic scattering. It may be concluded that a selection of events with small $|t|$ corresponds to a selection of coherent reactions.

Let us now consider the mass spectrum of the three pions produced. First we start, Fig. 4, with a typical observation from a hydrogen bubble chamber experiment. The characteristics are a broad unresolved enhancement rising rapidly from near 1.0 GeV and falling sharply between 1.3 and 1.4 GeV. This enhancement is often considered to consist of two resonances, the A_1 and A_2 mesons on top of a background (Deck effect) of uncertain shape. In addition there may be a third resonance the $A_{1.5}$ located between the A_1 at 1.1 GeV and the A_2 at 1.3 GeV. Also a further enhancement, the A_3, is observed at 1.65 GeV. In Fig. 5a the experimental three-pion mass spectrum is shown for 16 GeV/c π^- interactions in a heavy liquid for those events with such a small $|t|$ value that they are produced predominantly by coherent reactions with a heavy nucleus. A peak is seen near the A_1 mass but no peak is seen near the A_2 mass. Making a ρ selection as in Fig. 5b does not change the results. Is the peak near 1.1 GeV the A_1 resonance? In the three-pion mass distribution one expects a sharp peak somewhere near 1.1 GeV because at lower mass there is little phase space available, and at higher masses the requirement of small $|t|$ values for coherent production causes the cross-section to fall quickly with increasing mass. Hence it may be considered not proven that the 1.1 GeV peak is the A_1, although it is clear that ρ mesons are being produced. Therefore as the A_1 is still in such a confused condition it may be worthwhile to study it further.

The A_3 meson is known to decay partly into πf^0 and it may be observed in Fig. 5a, though the width is a problem. These experiments have been done using pions of 16 GeV/c, and rough calculations indicate that for coherent production the maximum three-pion mass one could get is about 1.4 GeV (but not exactly, as can be seen from Fig. 5). If the experiment were repeated at 22 GeV/c, then this maximum mass calculated is about 1.6 GeV and hence one would clearly have a better chance of studying the A_3 meson.

Although we have described coherent production, we have not discussed whether there are any rules to the change in quantum numbers from the incident particle to the outgoing system. Baryon number, isospin, strangeness and charge cannot be changed, but it seems that spin and parity can change, for example from the 0^- of the incident pion, the outgoing $\pi\rho$ system has been shown to be in a 1^+ state when in the A_1 mass region. It has been shown by Goldhaber and Goldhaber that if the target nucleus is 0^+ (such as ^{12}C and the incident particle is a meson with $J^P = 0^-$, then

$$P_f = P_i \ (-1)^J$$

where P_f and P_i are the initial and final parities and J is the change in spin. Some evidence has been presented that the above relation is valid for all spins and parities of the two initial particles. Hence if the incident particle is a pion with $J^P = 0^-$, then the outgoing system should have $J^P = 0^-, 1^+, 2^-, 3^+$ ... etc. Therefore one would expect to observe the A_1 and A_3 but not the A_2 if it has $J^P = 2^+$. That the A_2 is not observed can be seen in Fig. 6.

It would seem that in coherent production the G-parity does not change. Thus with an incident pion beam states of 3π, 5π ... may be produced coherently. This is shown in Fig. 7 where the differential cross-section distribution for 5π shows the steep rise at small $|t|$ values characteristic of coherent production. It is interesting to compare the 5π effective mass distribution found in the heavy liquid bubble chamber, Fig. 8, with that obtained in a hydrogen bubble chamber experiment, Fig. 9. It may be seen that in the heavy liquid chamber, there is a peak at low mass, 1.9 GeV, and as with the three-pion peak at 1.1 GeV, there arises the question as to whether the peak at 1.9 GeV corresponds to a resonance or to a kinematic effect. Once more it would be interesting to study this at higher incident energy and perhaps also to study the seven-pion mass and $d\sigma/dt$ distributions.

First experiments with K meson beams have recently been performed in a neon/hydrogen mixture at Brookhaven. As can be seen from the $d\sigma/dt$ distributions in Fig. 10, the sharp rise near $t = 0$ gives evidence in favour of the coherent production of the $K\pi\pi$ system. The $K\pi\pi$ effective mass distribution found in a hydrogen bubble chamber experiment at 10 GeV/c is shown in Fig. 11. This mass distribution has remarkable similarities with the 3π mass distribution in πp interactions. There is a broad peak at 1320 MeV with spin parity $J^P = 1^+$ (equivalent to the A_1), the K*(1420), shown shaded, has $J^P = 2^+$ (corresponding to the A_2), and the L meson with $J^P = 1^+, 2^-, \ldots$ is a distinct peak at higher masses (corresponding to the A_3). The $K\pi\pi$ or rather $K^*(890)\pi$ mass distribution in the heavy liquid is given in Fig. 12 and shows a broad peak at low masses, the peak being some what lower than the value of about 1320 MeV found in hydrogen bubble chamber experiments, thus raising again the question as to whether the low mass peak is a resonance or a kinematic effect. It would be interesting to pursue this question further, in particular to study the branching ratios of the K*(1320) and L meson; for this the $K^-\pi^0\pi^0$ decay mode would be most useful. The branching ratios found in heavy liquid and hydrogen bubble chambers should be compared. These experiments should be carried out at the highest available K^+ or K^- momentum.

In the reactions

$$K + p \to p + K\pi\pi$$

in hydrogen bubble chambers, there appears to be differences in the $K\pi\pi$ mass spectra between incident K^+ and K^- mesons. With K^- mesons a peak is observed at 1790 MeV (the L meson) while with K^+ mesons only a weak enhancement is observed at 1790 MeV whereas a peak is observed at 1660 MeV which has not been seen in K^-p interactions. The results found in coherent production of the $K\pi\pi$ system with high energy incident K^- and K^+ might be of considerable interest.

In the experiment performed at Brookhaven in a bubble chamber with a neon/hydrogen mixture with incident protons of 28.5 GeV/c, the resultant $p\pi^+\pi^-$ mass spectrum is shown in Fig. 13. A peak near 1470 MeV is observed. This could be the $(\frac{1}{2},\frac{1}{2})$ Roper resonance. Some 40,000 photographs with 1.5 beam tracks per photograph were analysed and gave $\sim$ 36 events in the $N^*(1470)$ enhancement. It is clear that greatly increased statistics would be welcome. In general in coherent experiments one should really have a minimum of about three to five hundred thousand photographs. With adequate statistics one might also hope to study ΛK and ΣK decay modes of any $N^*_{\frac{1}{2}}$ resonances produced.

No proposals have been made to study coherent processes with incident beams of antiprotons. While one would expect that anti-$N^*_{\frac{1}{2}}$ isobars would be produced as $N^*_{\frac{1}{2}}$ isobars are produced by proton beams, there might be some difference due to the existence of the strong annihilation channel. As the influence of annihilation on coherent production is not clear (e.g. will the $d\sigma/dt$ distribution be different?), this is probably an experiment worth trying.

There is another idea, which might be impractical, but let us at least mention it. The reaction

$$K^+p \rightarrow p\bar{\Lambda}p$$

is unusual as the cross-section is rather high ($\sim$ 10 μb) and is constant with respect to incident energy. This constancy suggests Pomeron exchange which is possibly similar to coherent production on hydrogen. The difficulty of producing a $p\bar{\Lambda}$ system by coherent production with incident K^+ mesons, is that the $p\bar{\Lambda}$ mass is rather high.

6. OTHER SUGGESTIONS

i) In hydrogen bubble chambers, with an incident beam of positive pions, the reaction

$$\pi^+ + p \rightarrow N^{*++} + (\text{neutral system})$$

is of considerable interest, the neutral system generally being a ρ^0 or

f^0. Veillet et al. have proposed studying such reactions at low energy but they are also of interest at high energy. In particular we would mention the case where an f^0 is produced. It is found, with hydrogen where $f^0 \rightarrow \pi^+\pi^-$, that the density matrix element ρ_{22} is negative by many standard deviations, which should not be possible for a diagonal element. The conventional explanation is that the f^0 interferes with the background, but no other evidence has been found. It would be of interest to study the case where the f^0 is observed in a heavy liquid bubble chamber, with $\pi^0\pi^0$ decay mode, as in this case the background might be quite different. It should be noted that the above is the only clear evidence of interference of a resonance with background in high energy (> 3 GeV) physics.

ii) With a high-energy proton beam, Λ and $\Sigma^{\pm}$ particles of ∿ 20 GeV momentum will be produced which will have a path length of about one metre before decay and hence it would be possible to investigate Λ and $\Sigma^{\pm}$ interactions. One might select all events with an observed V^0 decay as candidates for Λ or $\Sigma^{\pm}$ production.

iii) Very little is known about Ω^- mesons, only a total of about 30 having been observed in hydrogen bubble chambers, In particular their decay branching ratio is not well known. From the table below it can be seen that at high energy $\Xi\pi$ decays may be missed. With a heavy liquid bubble chamber it may be possible to establish the Ω^- decay rates.

Table 1

Number and decay mode of Ω^-

Incident K^- momentum GeV/c	ΛK	$\Xi^-\pi^0$	$\Xi^0\pi^-$
4 to 6	$6\frac{1}{2}$	3	$8\frac{1}{2}$
10	6	0	1

iv) In high-energy physics the multi-peripheral model has had considerable success. Here one draws and calculates all possible Feynmann diagrams with all possible exchanges. However if more than one Pomeron exchange is permitted per Feynmann diagram, then unitarity is violated.

The simplest reaction in which two Pomerons can be exchanged is

$$p + p \rightarrow p + f^0 + p \ .$$

In hydrogen chambers the reaction $pp \rightarrow pp\ \pi^+\pi^-$ has been studied but little f^0 signal due perhaps to background problems has been seen. It would be interesting to repeat this experiment in a heavy liquid bubble chamber where the f^0 decay into $(\pi^0\pi^0)$ is observed.

7. CONCLUSION

A number of interesting experiments have been proposed involving coherent production and detection of gamma quanta. In addition it should be remembered that until now in bubble chamber physics, the most interesting results have not been those predicted before the experiment started, but have been unexpected ones found after the experiment had been done.

DISCUSSION

Salmeron (Ecole Polytechnique)

In what interval of momentum is the cross-section for $N^*_{1/2}$ production constant in pp interactions?

Morrison (CERN)

Between 8 and 30 GeV/c, as measured in a BNL counter experiment.

Miller (UCL)

Is it not true that $K\pi$ coherent production is forbidden?

Morrison (CERN)

Yes.

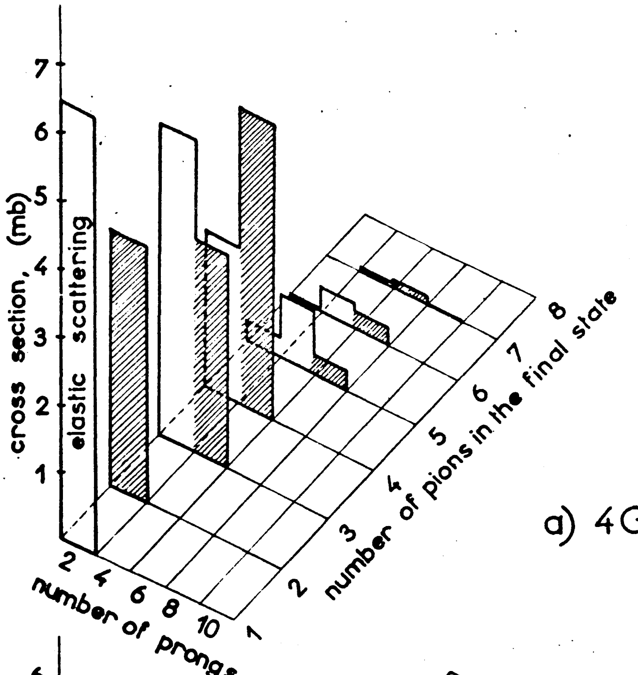
Miller (UCL)

Are you familiar with Bergers' calculation of A_1 and N*(1470) production?

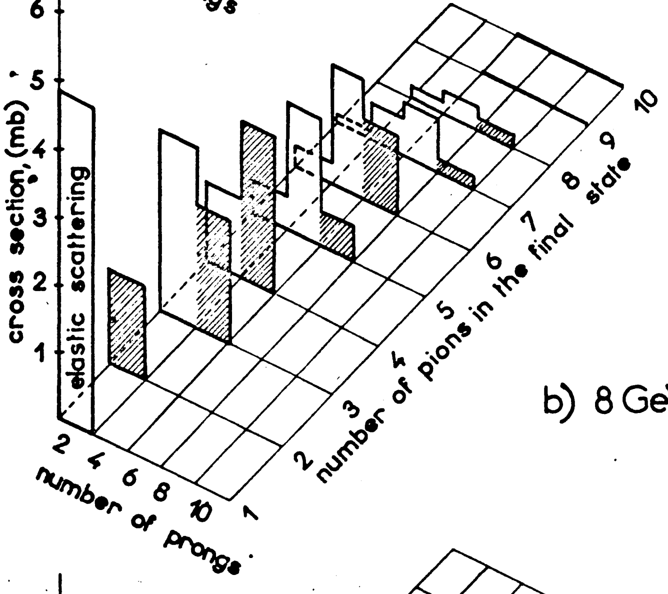
Morrison (CERN)

Yes, it fits, but I do not know what this means.

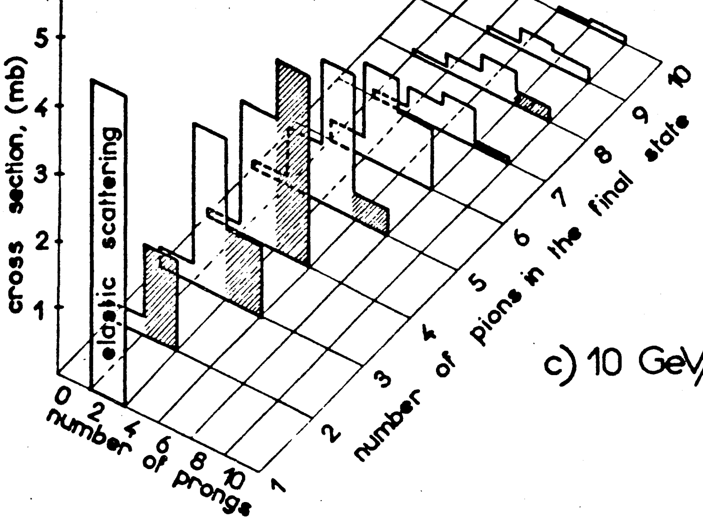
FIG. 1



a) 4 GeV/c $\pi^+ p$



b) 8 GeV/c $\pi^+ p$



c) 10 GeV/c $\pi^- p$

DIA 33318

FIG.2

16 GeV/c π^- in C_2F_5Cl

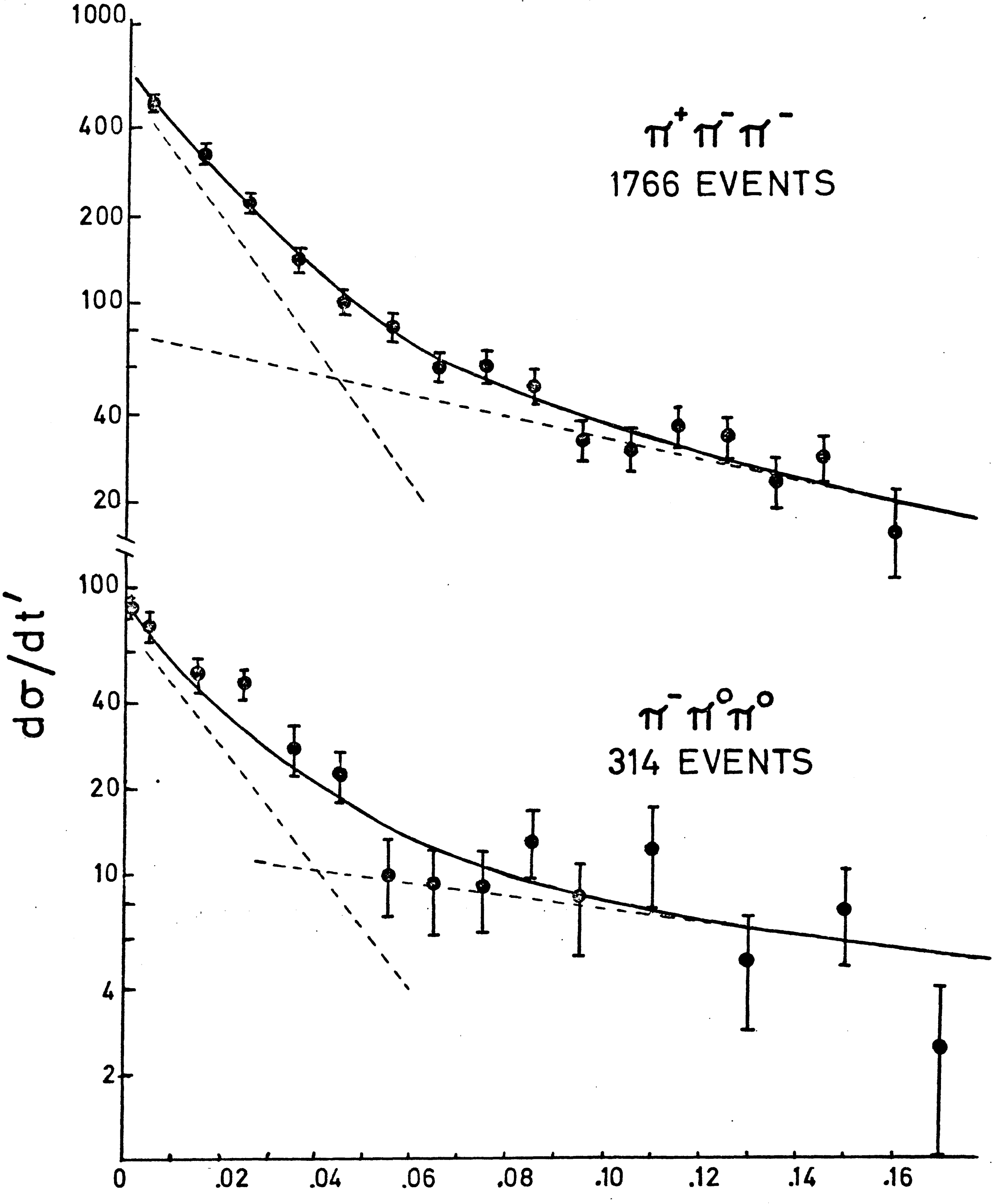


FIG. 3

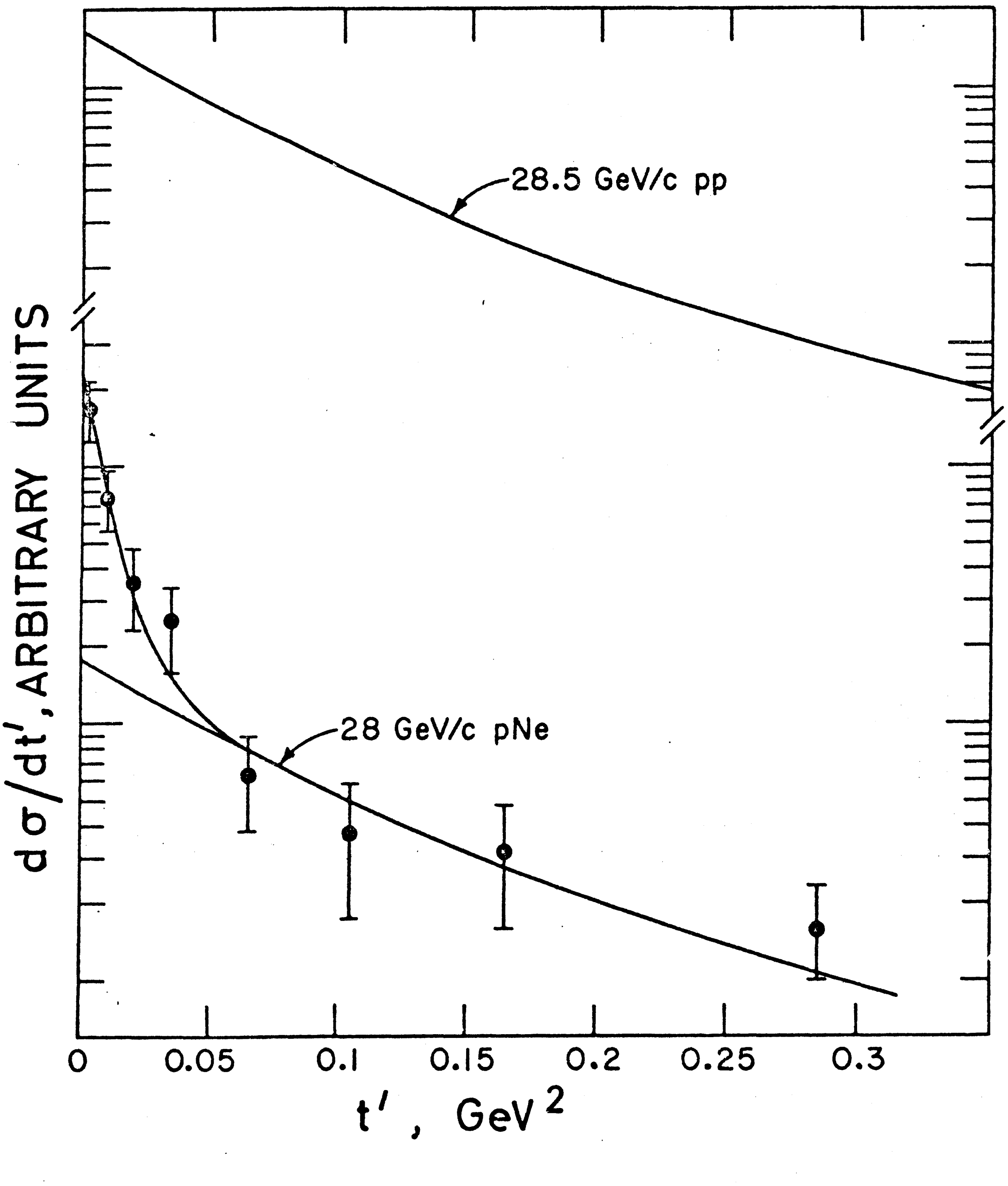

28.5 GeV/c pp
28 GeV/c pNe
dσ/dt', ARBITRARY UNITS
0
0.05
0.1
0.15
0.2
0.25
0.3
t', GeV²

FIG. 4

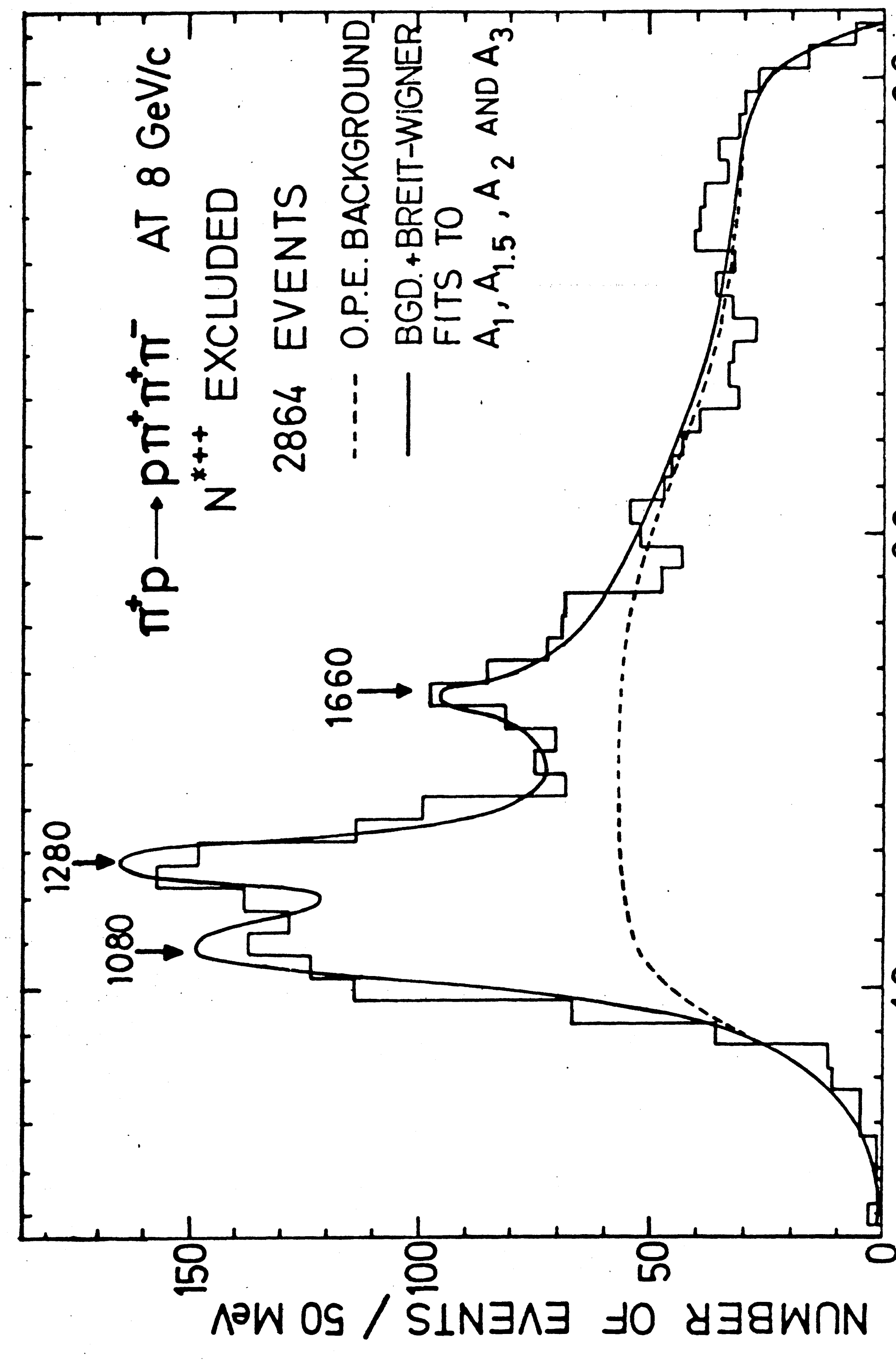

$\pi^+p \longrightarrow p\pi^+\pi^+\pi^-$ AT 8 GeV/c
N^{*++} EXCLUDED
2864 EVENTS
O.P.E. BACKGROUND
BGD.+BREIT-WIGNER FITS TO
$A_1, A_{1.5}, A_2$ AND A_3
1080
1280
1660
NUMBER OF EVENTS / 50 MeV
0
50
100
150
$(\pi^+\pi^+\pi^-)$ EFF. MASS GeV
1.0
2.0
3.0

FIG. 5

16 GeV/c π^- in C_2F_5Cl

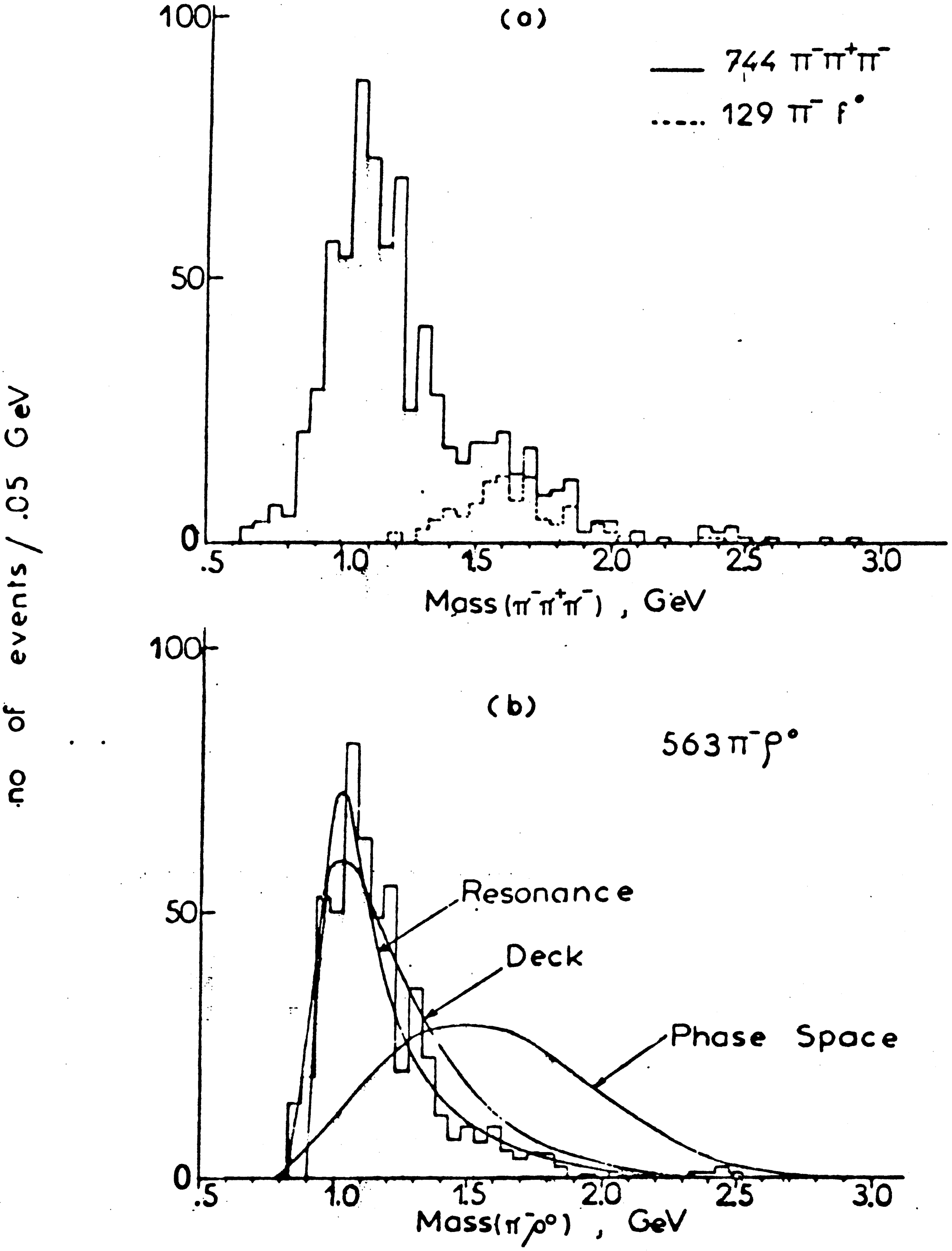


FIG.6

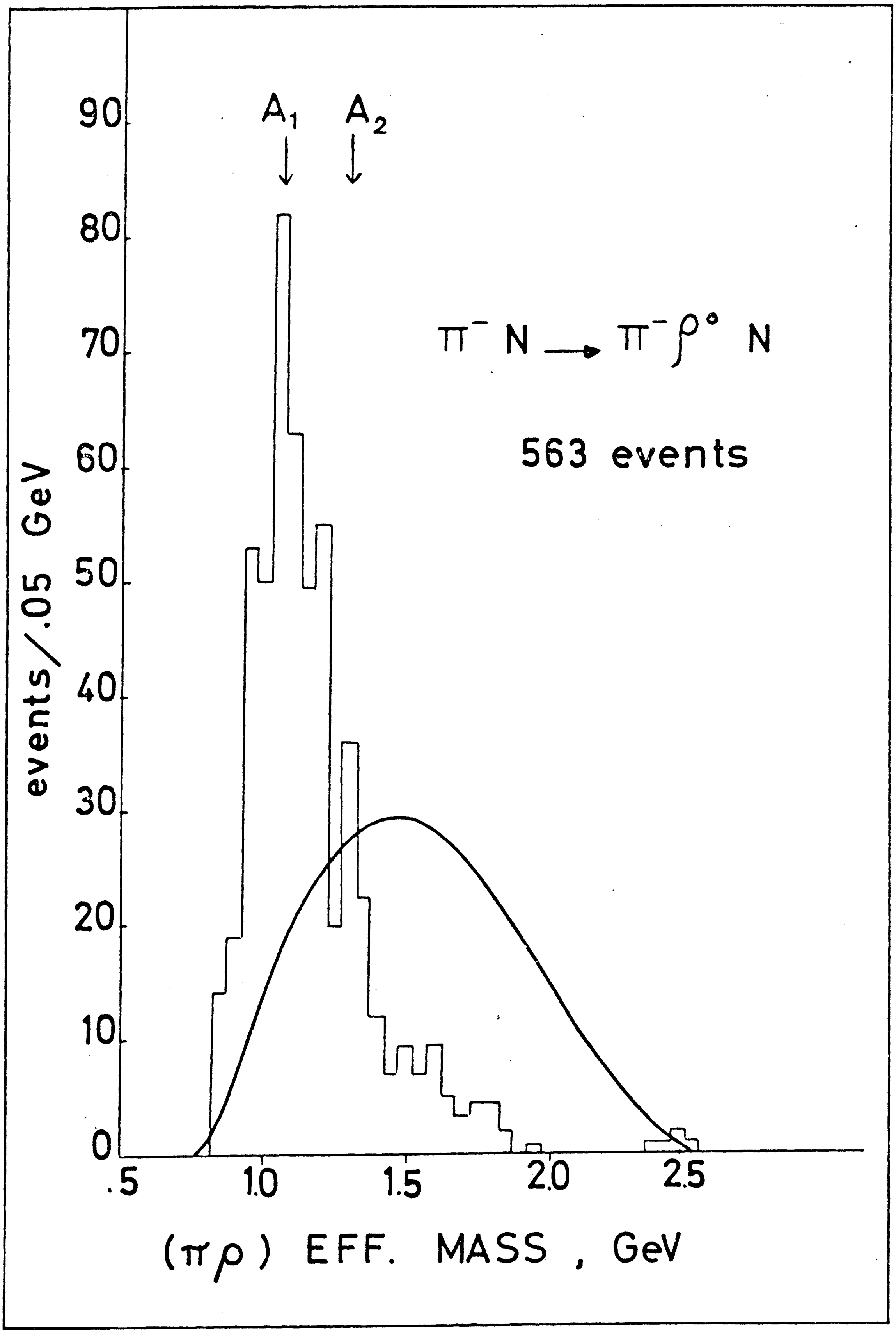

A$_1$
A$_2$
$\pi^- N \longrightarrow \pi^- \rho^\circ N$
563 events
events/.05 GeV
90
80
70
60
50
40
30
20
10
0
.5
1.0
1.5
2.0
2.5
($\pi\rho$) EFF. MASS , GeV

FIG. 7

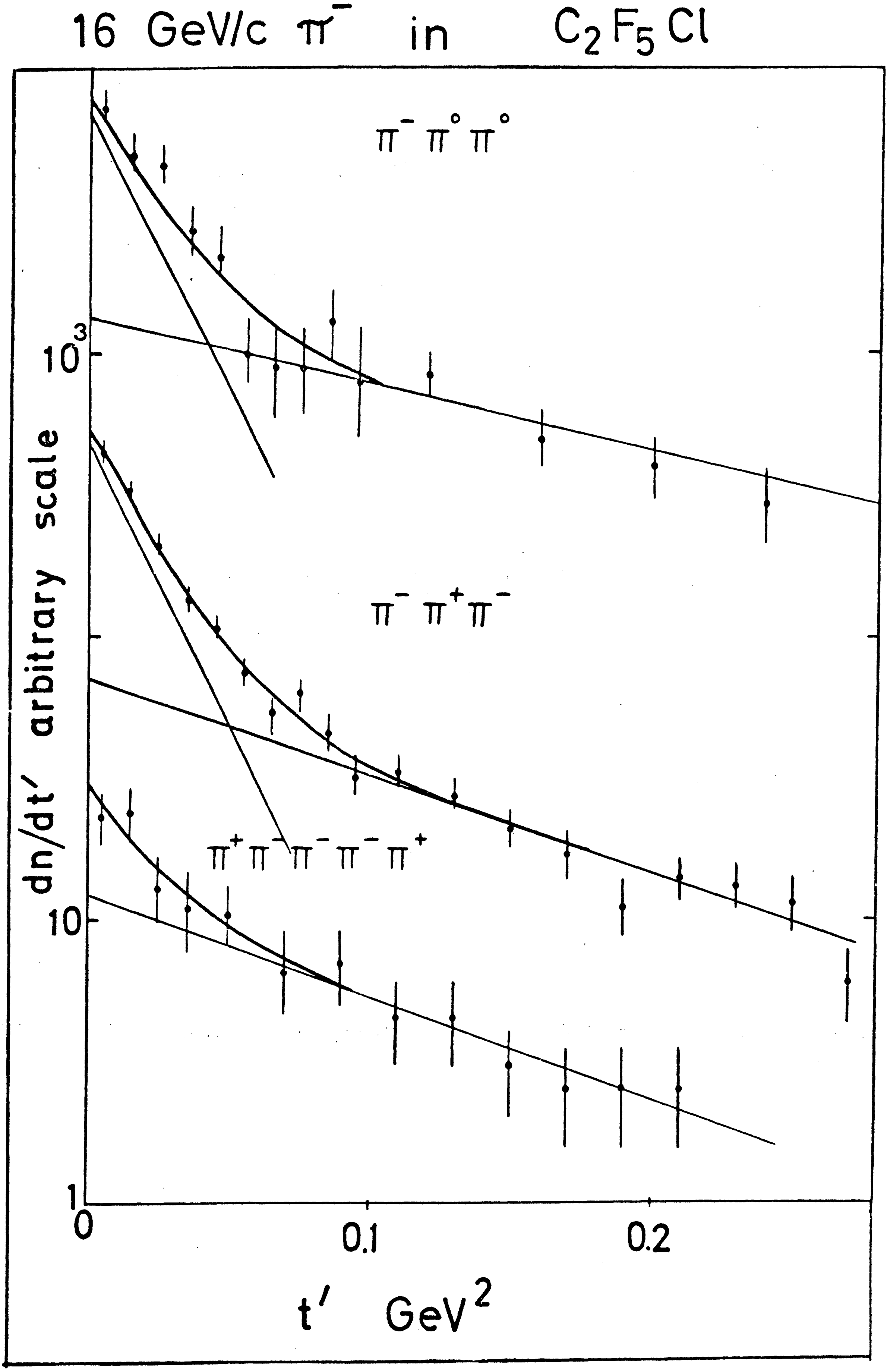

16 GeV/c π⁻ in C₂F₅Cl
π⁻ π° π°
π⁻ π⁺ π⁻
π⁺ π⁻ π⁻ π⁻ π⁺
dn/dt' arbitrary scale
10³
10
1
0
0.1
0.2
t' GeV²

FIG. 8

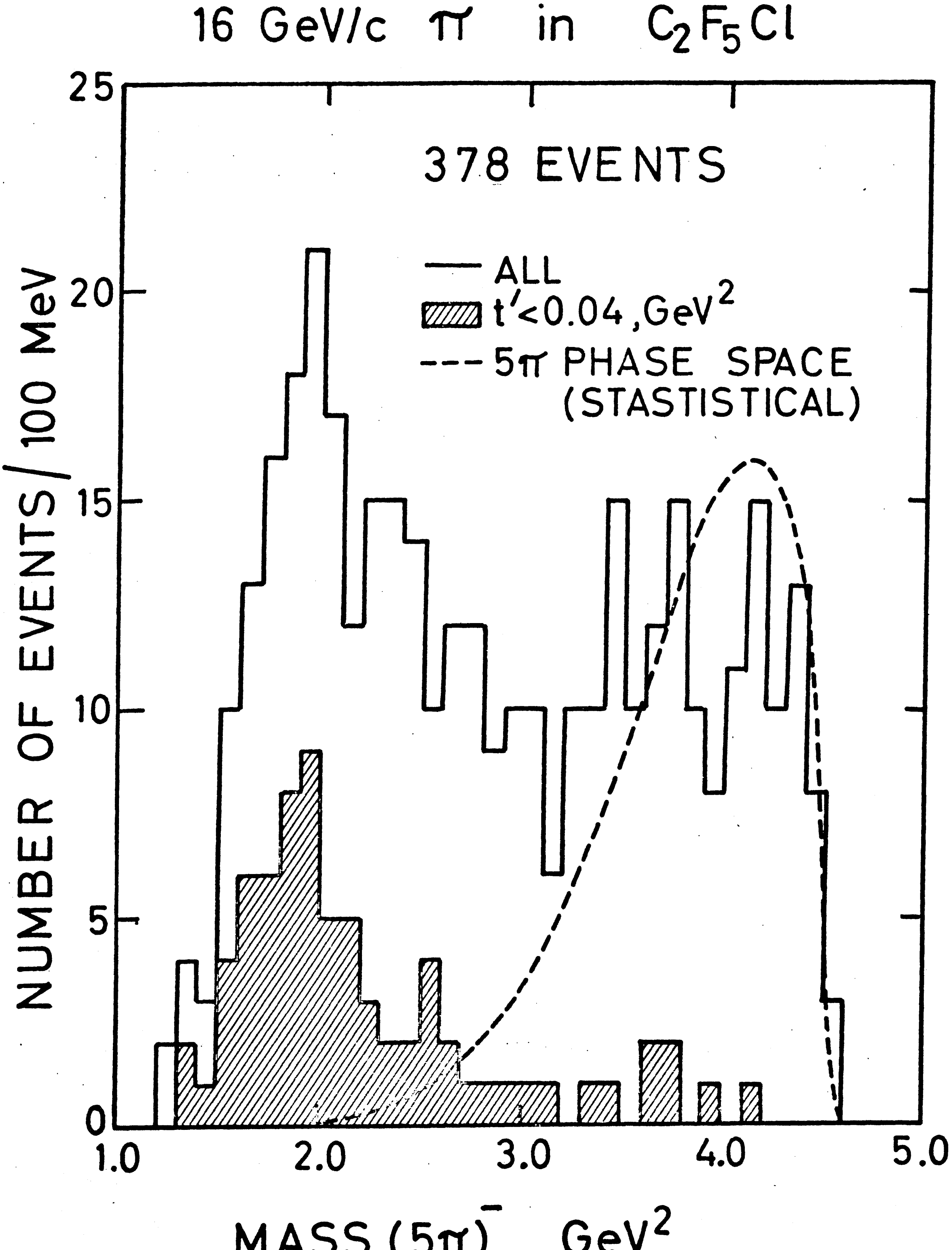
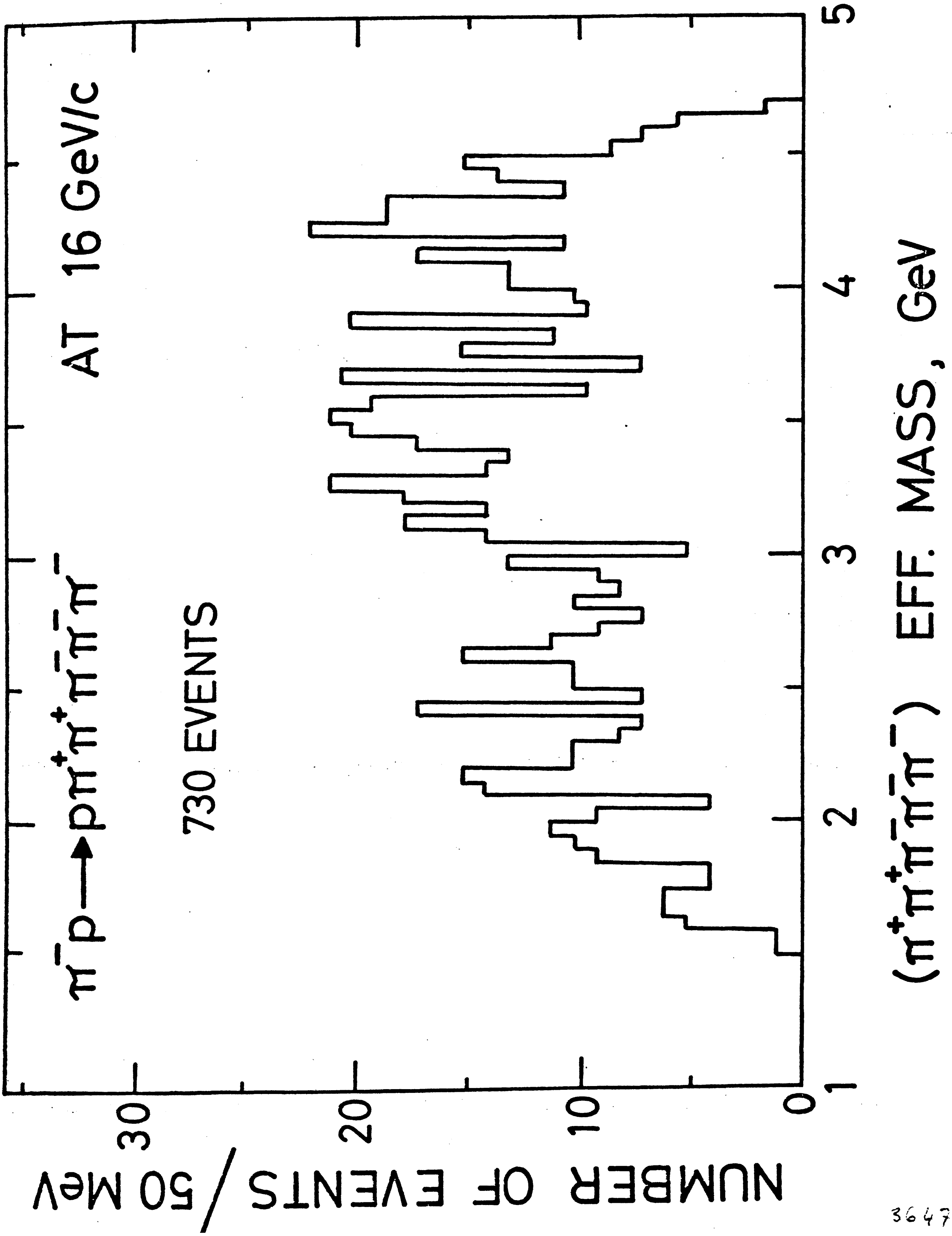
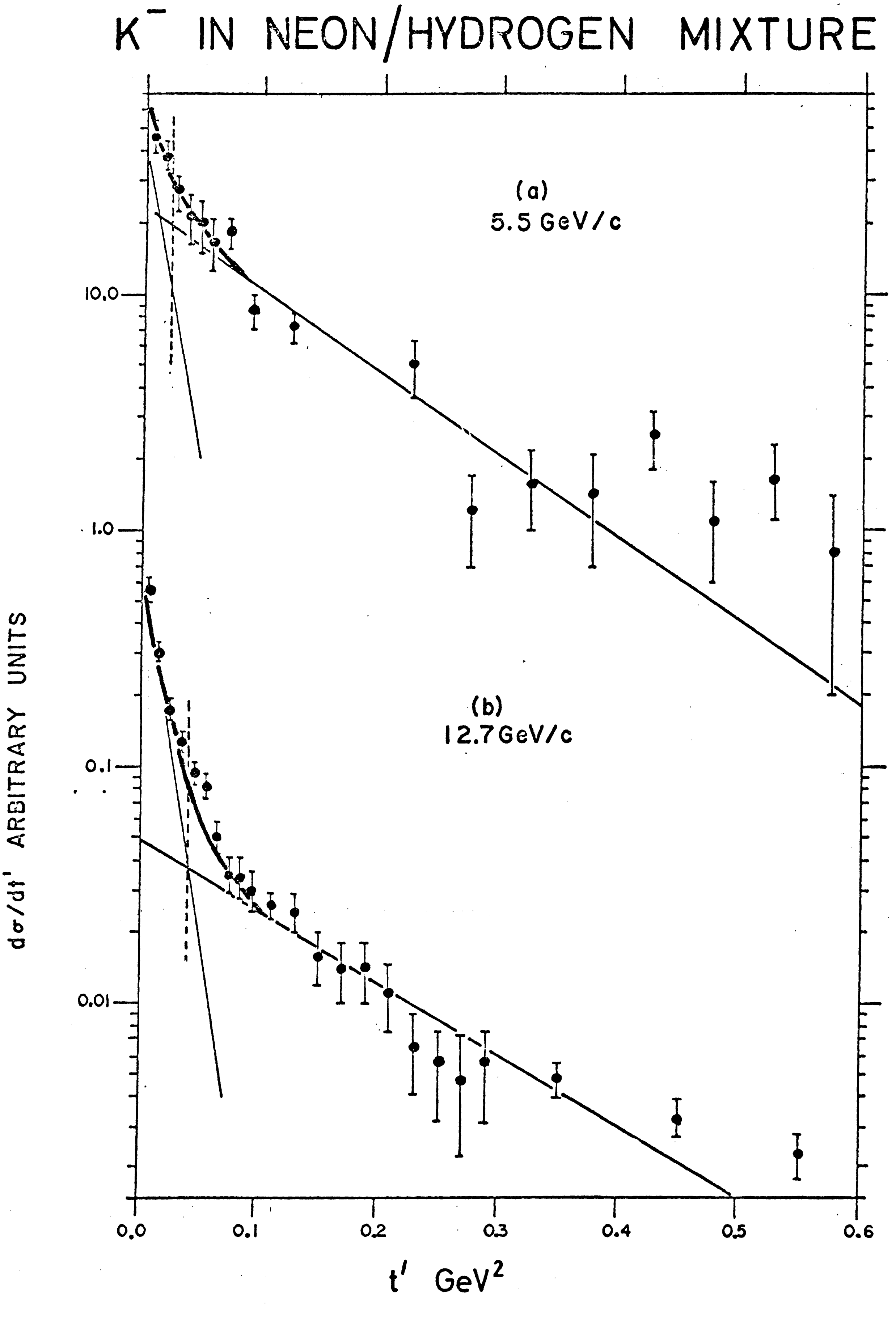

16 GeV/c π^- in C_2F_5Cl
378 EVENTS
— ALL
▨ t'<0.04 , GeV^2
--- 5π PHASE SPACE (STASTISTICAL)
NUMBER OF EVENTS / 100 MeV
25
20
15
10
5
0
1.0
2.0
3.0
4.0
5.0
MASS (5π)$^-$, GeV^2

FIG. 9


$\pi^- p \rightarrow p\pi^+\pi^+\pi^-\pi^-$
AT 16 GeV/c
730 EVENTS
1
2
3
4
5
$(\pi^+\pi^+\pi^-\pi^-)$ EFF. MASS, GeV
0
10
20
30
NUMBER OF EVENTS / 50 MeV

36479

FIG.10


K⁻ IN NEON/HYDROGEN MIXTURE
(a)
5.5 GeV/c
(b)
12.7 GeV/c
10.0
1.0
0.1
0.01
dσ/dt' ARBITRARY UNITS
0.0
0.1
0.2
0.3
0.4
0.5
0.6
t' GeV²

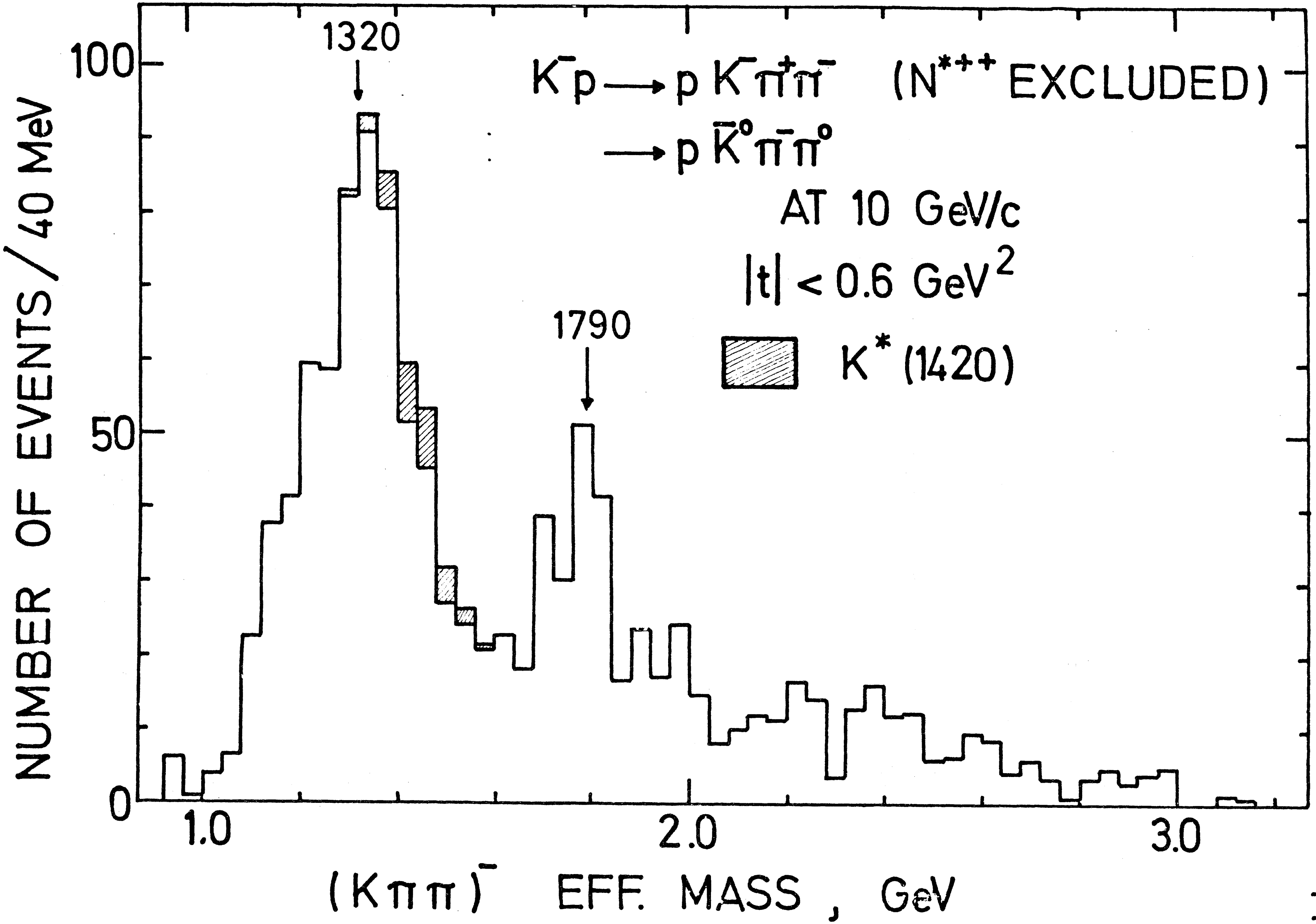

100
50
0
NUMBER OF EVENTS / 40 MeV
1320
1790
$K^-p \longrightarrow pK^-\pi^+\pi^-$ (N^{*++} EXCLUDED)
$\longrightarrow p\bar{K}^0\pi^-\pi^0$
AT 10 GeV/c
$|t| < 0.6$ GeV^2
▨ $K^*(1420)$
1.0
2.0
3.0
$(K\pi\pi)^-$ EFF. MASS , GeV

FIG.11

.1609

FIG. 12

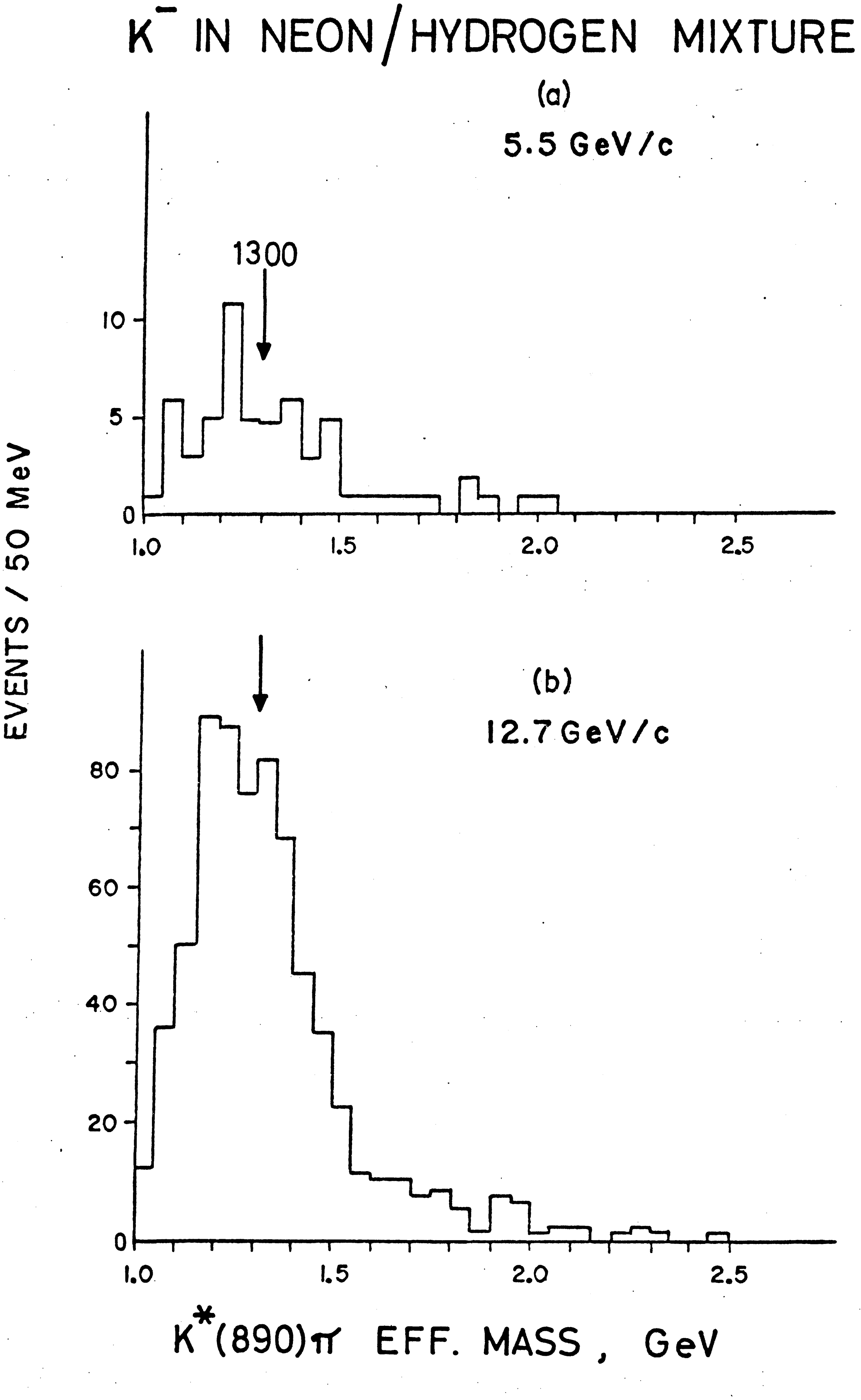
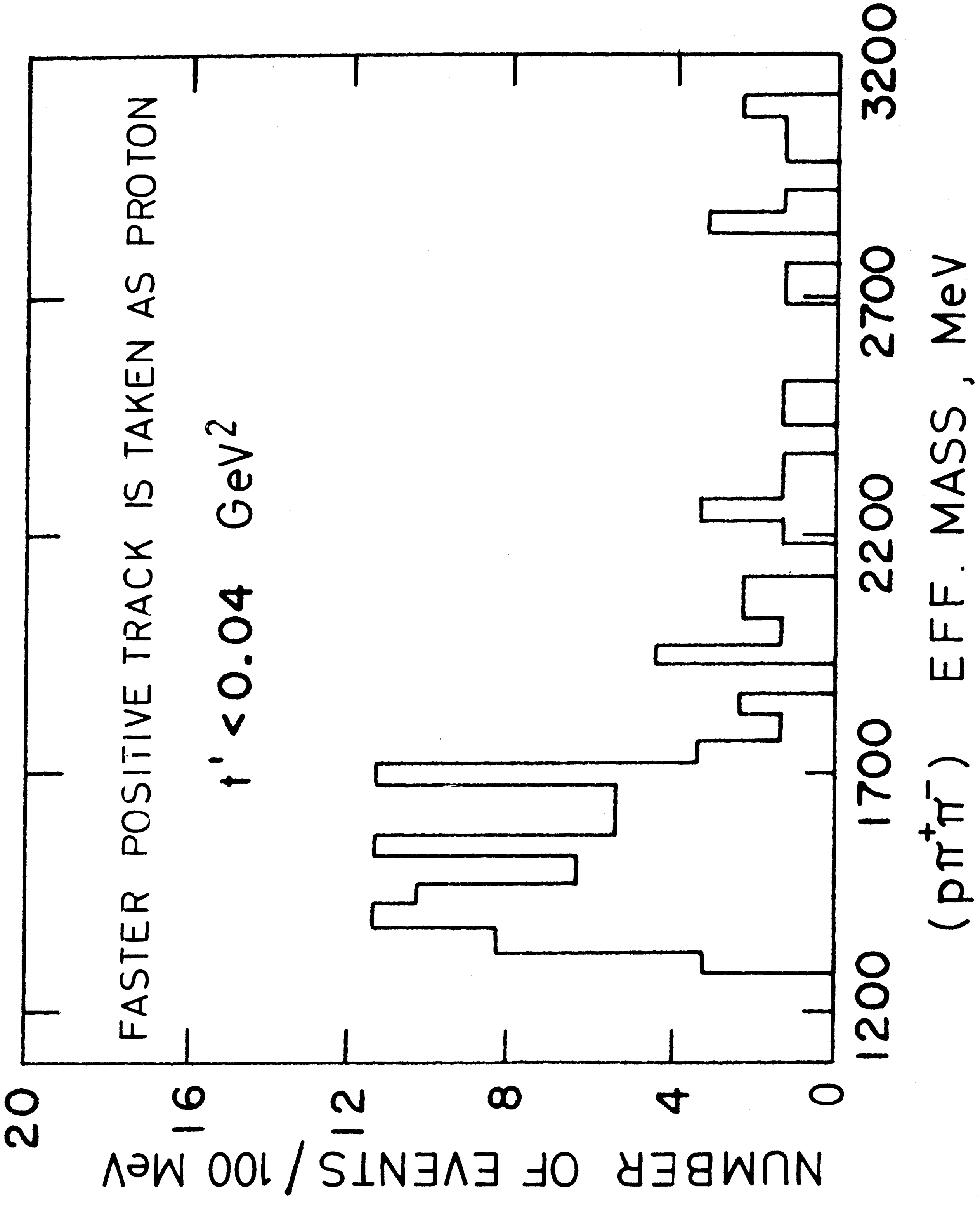

K⁻ IN NEON/HYDROGEN MIXTURE
(a)
5.5 GeV/c
1300
10
5
0
1.0
1.5
2.0
2.5
EVENTS / 50 MeV
(b)
12.7 GeV/c
80
60
40
20
0
1.0
1.5
2.0
2.5
K*(890)π EFF. MASS , GeV

FIG. 13


FASTER POSITIVE TRACK IS TAKEN AS PROTON
$t' < 0.04$ GeV^2
NUMBER OF EVENTS / 100 MeV
0
4
8
12
16
20
1200
1700
2200
2700
3200
$(p\pi^+\pi^-)$ EFF. MASS, MeV

GENERAL DISCUSSION

Prof. Fiorini	asked if the best policy was to have more meetings of this kind.
Prof. Faissner	suggested that more concrete work was needed.
Dr. Salmeron	seconded this and stated that subgroups were needed.
Prof. Fiorini	stated that these subgroups were essentially in existence and that one must make a decision on the Gargamelle program soon.
Prof. Burhop	suggested the possibility of having a study week. For example to single out the four or five promising experiments and study these in detail at a Spring School.
Prof. Lagarrigue	pointed out that the Rapporteurs were in fact making this detailed study.
Dr. Ramm	agreed that it was very important to discuss the experimental program but pointed out that in the next ν experiment it was very important to measure accurately the ν flux. In this respect help was needed from the interested outside groups.
Prof. Fiorini	asked people to send names immediately to Dr. Ramm.
Dr. Rousset	pointed out that unlike hydrogen chambers Gargamelle needed a large number of beams to do a relatively small number of experiments. As one could only have one beam at a time it was necessary to use the beam in the most efficient way.
Prof. Fiorini	thought that the Beam Study Group did this to some extent.
Prof. Faissner	thought that young physicists should be encouraged to put forward proposals.
Prof. Fiorini	closed the meeting in proposing that at the next meeting one should discuss questions such as geometry programs, projectors and the status of Gargamelle itself. However, at the meeting after this some decision on the physics program should be reached.

D.C. Cundy.

PROPOSAL FOR A ν AND $\bar{\nu}$ GARGAMELLE EXPERIMENT

Laboratoire de l'Accélérateur linéaire
Orsay, France

The Orsay group is interested in the above two experiments and the field of physics which can be covered has been already developed[1]. We would like to make some remarks which could be useful in making a reasonable choice among various experimental possibilities.

i) The existing ν data in heavy-liquid bubble chambers has allowed one to make a first analysis in the field of elastic reaction and N^{*++} production. Except for N^{*++} production it has proved difficult to extract precise information from interactions in nuclei, and in the future it is necessary to concentrate the analysis on free proton interactions. From the 1967 neutrino experiment in propane it has been seen that it is easy to extract N^{*++} hydrogen events from the carbon interactions using a 3c fit.

ii) The production of inelastic interactions with more than 1π is important and for this analysis it is essential to have good γ detection efficiency in order to isolate the various channels. This is the case for the study of $\nu + p \to \mu^- + \rho^+ + p$ [2].

Taking into account these points, we propose to use, instead of pure propane, a mixture of C_3H_8 and CF_3Br, with radiation length 60 cm (92% propane, 8% freon by volume). This is a reasonable compromise in order to obtain proton interactions and good γ-ray visibility.

We are investigating in more detail the various ν and $\bar{\nu}$ reactions and the best physics which can be made in a first experiment.

* * *

		C_3H_8	C_3H_8-CF_3Br (92%-8% by volume)
	Radiation length	106 cm	60 cm
for 1.20 m potential length	Probability to see 0γ or $1\pi^0$	0.14	0.03
	Probability to see 2γ of $1\pi^0$	0.40	0.65
	Proportion of the proton interactions	0.17	0.16

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2) B. Roe, Internal note NPA/CERN.

REMARKS CONCERNING THE PHYSICS TO BE DONE IN GARGAMELLE WITH A HIGH-ENERGY PION BEAM (G4)

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Istituto di Fisica dell'Università and
Istituto Nazionale di Fisica Nucleare, Milano, Italy

1. GENERAL FEATURES

We discuss here some physical problems concerning π^--nucleus and π^--p interactions, for which an experiment in Gargamelle would be very useful.

For this purpose the chamber would be filled by a high percentage of propane mixture. This detector allows one to study the interactions either on free protons or on complex nuclei with a good possibility to detect the γ rays. At the same time good measurements are possible for charged secondaries and electron pairs, because the multiple scattering and the bremsstrahlung effects are limited.

We assume for pure propane a collision length of 156 cm. Consequently the primary and secondary fast particles interact to a high percentage; this collision length is not strongly modified if a small quantity of heavier liquid is added. Therefore, in the following our estimations about the cross-sections and the collision length will refer to pure propane.

If we consider only the interactions which take place in one collision length after the entrance window, we obtain a number of interactions equal to 63% of primary pions. Furthermore a good γ-ray detection efficiency is obtained. In fact, because the π^0 are predominantly produced in the forward direction at this energy, we have about 2.4 radiation lengths available in the propane liquid. This corresponds to 90% of detection efficiency for a single γ ray.

Adding, for example, 10% of heavy freon (CF_3Br) to propane, the radiation length is reduced to 55 cm, increasing the detection efficiency to 99%.

From the above considerations we estimate that a high percentage of primaries and secondaries will interact in the chamber and a relevant number of gammas are present in each frame. Consequently it seems that a small number of primaries per burst (3-4) is desirable.

Moreover the greatest (∿80-90%) part of low-energy neutron (T_n < 1.0 GeV) will interact in the chamber providing an additional constraint to events with an outgoing neutron.

In such an experiment we would like to study the interactions both on nuclei (coherent and incoherent) and on single nucleons. The statistics of various kinds of interactions, <u>referring to 100,000 incident pions,</u> in the fiducial volume above indicated, are:

total number of interactions	63,000
interactions on carbon nuclei	52,500
interactions on hydrogen	10,500
inelastic collisions on carbon with coherent recoil $[t' \leq 0.027\ (\mathrm{GeV}/c)^2]$	1,200
inelastic collisions on protons (free and bound)	18,000
inelastic collisions on neutrons	12,000

The above numbers for inelastic collisions are estimated from the data obtained at 16 GeV/c in light freon¹⁾. The collisions we are particularly interested in are the inelastic collisions on nuclei with coherent recoil, and on protons. The interactions on protons are 50% on hydrogen and 50% on bound protons.

In the following sections we discuss only some particular points of interest. We can observe now that the possibility to obtain cross-sections for many different channels at this energy is a sufficient reason, in our opinion, to make such an experiment.

2. COHERENT INTERACTIONS ON NUCLEI

As it is well known, an important contribution to multipion production on nuclei at high energy is due to reactions with a coherent recoil of the nucleus, which remains in the ground state²⁾.

The states coherently produced by an incoming pseudoscalar must have J^P quantum numbers of abnormal series when they are emitted in the forward direction. At high energy a good percentage of events satisfy this condition supplying a useful tool to select only a few boson resonances.

In this way three-, five-, etc. pion states can be studied in the following reactions:

$$\pi^- + N \rightarrow \pi^- + \pi^- + \pi^+ + N \qquad (1)$$

$$\pi^- + N \rightarrow \pi^- + \pi^0 + \pi^0 + N \qquad (2)$$

$$\pi^- + N \rightarrow \pi^- + \pi^- + \pi^- + \pi^+ + \pi^+ + N \qquad (3)$$

$$\pi^- + N \rightarrow \pi^- + \pi^- + \pi^+ + \pi^0 + \pi^0 + N \qquad (4)$$

The kinematical conditions deduced from the coherence requirements limit the production of high masses. For instance for 16 GeV/c π^- incident in carbon; the form factor of a target nucleus damps the masses higher than 1.4 GeV/c^2. In our case, at 22 GeV/c incoming pion momentum, this limit is shifted to 1.65 GeV/c^2. So from the reactions (1) and (2) it should be possible to study the three-pion states: A_1 and perhaps A_3, $A_{1.5}$. The experimental determination of the branching ratio $\rho^0\pi^-/\rho^-\pi^0$ for the decay into $\rho\pi$ of A_1 enhancement can furnish an important indication about the nature of this bump (resonance or Deck effect). The interest to study the A_3 state produced in coherent interactions is primarily connected to A_3 belonging to abnormal spin-parity series. Furthermore from the value $(d\sigma/dt)_{t=0}$ it is possible to calculate the total cross-sections with the nucleon for the states coherently produced.

The interest of reactions (3) and (4) is based on the study of the 5π systems and on the possible presence of states eventually favoured by the coherent mechanism of production³⁾.

From the data available at 16 GeV/c¹⁾ we can estimate approximately the number of events expected at 22 GeV/c. The number of events we shall obtain with 100,000 incident pions is ∿650 events for reaction (1), ∿410 for reaction (2), ∿30 for reaction (3); unfortunately the cross-section for the reaction (4) is not known*⁾.

---

*) The number calculated refers to the coherent events with ($t' \leq 0.027$ GeV/c^2); for such a sample the incoherent background is $\lesssim 10\%$.

In order to obtain the desired samples of coherent reactions probably it would be necessary to measure all events without recoil proton. The number to be measured is increased by a factor 2-3 in proportion to the number of true coherent events. This factor includes the quasi-elastic interactions on neutron and incoherent reactions on nuclei without visible evaporation prongs.

However we should mention that in several neutron interactions (∿80-90%) the neutrons will interact in the chamber.

3. INTERACTIONS ON PROTONS

The interactions on free and bound protons, which we would like to study are:

Channel	Number of events expected for 100,000 primaries	
$\pi^- + p \rightarrow \pi^- + p + \pi^0$	650	(5)
$\rightarrow \pi^- + p + 2\pi^0$	1000	(6)
$\rightarrow \pi^- + p + \pi^- + \pi^+$	1000	(7)
$\rightarrow \pi^- + p + \pi^- + \pi^+ + \pi^0$	1000	(8)
$\rightarrow \pi^- + p + \eta^0 \ (\eta^0 \rightarrow \gamma\gamma)$	?	(9)
$\rightarrow n + \pi^+ + \pi^-$	800	(10)
$\rightarrow n + \pi^0 + \pi^0$	?	(11)
$\rightarrow n + \pi^+ + \pi^- + \pi^0$	1200	(12)
$\rightarrow n + \pi^0 + \pi^0 + \pi^0$	?	(13)
$\rightarrow n + 2\pi^+ + 2\pi^-$	560	(14)
$\rightarrow n + \pi^+ + \pi^- + 2\pi^0$	?	(15)
$\rightarrow n + \pi^0 + \eta^0 \ (\eta^0 \rightarrow \gamma\gamma)$	?	(16)
$\rightarrow n + \eta^0 \ (\eta^0 \rightarrow \gamma\gamma)$	?	(17)

Some of the previous reactions can be studied only in a heavy liquid bubble chamber, due to the presence of more than one neutral particle. Others could also be studied, perhaps in better conditions, in a hydrogen bubble chamber, but their availability is important for determination of the decay branching ratio of resonances and for direct comparison of invariant mass distribution of different charged states.

We discuss now some physics questions we are particularly interested in.

a) A_1 production can be studied in the negative and neutral states [channels (6), (7), (12)]. In particular the branching ratio $A_1^- \rightarrow \rho^- \pi^0 / A_1^- \rightarrow \rho^0 \pi^-$ can be determined.

The A_1^0 production can be studied, allowing the measurement of the ratio $A_1^0 \rightarrow \rho^+ \pi^- / A_1^0 \rightarrow \rho^- \pi^+$, which must be 1 if A_1 is a resonance, probably different from 1 if it is a kinematical effect, and 0 in the particular case of OPE mechanism.

b) Also A_2 can be studied in the same channels as A_1. Moreover the $\eta\pi$ decay of such a resonance can be studied either in $(\pi^+\pi^-\pi^0\pi^0)$ systems [channels (8) and (15)] and in $\gamma\gamma$ systems [channels (9) and (17)]. The possibility to detect also the last two channels allows one to increase the statistics by a factor 2.5; consequently the number of $A_2^- \rightarrow \eta^0 \pi^-$ expected for 100,000 primary is 26 4). No information exists for A_2^0.

A reasonable number of pictures would permit one to investigate other possible resonant states belonging to the normal spin parity series.

c) The recently discovered A_3 meson5) seems to decay predominantly into the $f^0\pi$ system. Moreover also the decays into $\rho\pi$ and into 3π cannot yet be excluded. From the channels (6) and (7) useful information can be derived about the branching ratio $\rho\pi / f^0\pi$. In fact possible decay of A_3^- into $\rho\pi$ can be pointed out in channel (6) with respect to predominant $f\pi$ decay.

No definite prediction is possible for the branching ratio $\pi^-\pi^-\pi^+ / \pi^-\pi^0\pi^0$.

The A_3^0 can be present in the reactions (12) and (13); similar considerations about the branching ratio of $\rho\pi$ and $f\pi$ decay can be made.

Moreover in the channel (13) only $A_3^0 \rightarrow f^0\pi^0 (\rightarrow 3\pi^0)$ and $A_3^0 \rightarrow 3\pi^0$ are present. In this system the background of $\rho\pi$ decays is suppressed. This allows a better determination of A_3 quantum numbers. Unfortunately we do not believe very much in the possibility of really obtaining a good sample in this channel.

d) Several experiments have shown some structures in the zone 1.600-1.750 GeV/c^2 decaying into two and four pions; so having G-parity +1 6). Particularly the decay into 2π, 4π, $\rho\pi\pi$, $\rho\rho$ has been observed, but it is not clear if they belong to only one or more resonances. Consequently the possibility of analysing the channels (5), (8), (10), (11), (14) and (15) under the same experimental conditions can clarify the situation. In particular we point out one question, which can be resolved only by studying at the same time reactions (8), (14) and (15).

Some hydrogen bubble-chambers experiments have shown in the $\pi^+\pi^-\pi^-\pi^0$ mass distribution a structure at 1.7 GeV/c^2 decaying into $\rho\pi\pi$ and perhaps entirely into $\rho\rho$. The structure is not present in the $2\pi^-\ 2\pi^+$ mass distribution of reaction (14). The simplest explanation of this fact rests on the hypothesis that this resonance decays entirely into $\rho\rho$. So the decay $g^0(4\pi) \rightarrow \rho^0\rho^0 \rightarrow 2\pi^+\ 2\pi^-$ is forbidden.

To confirm this we can look at the decay $g^0(4\pi) \rightarrow \pi^-\pi^0\pi^+\pi^0$. If also in this system no structure was found, then a dynamical mechanism would be favoured.

It is interesting to note that in the single OPE hypothesis the ratio $\pi^-p \rightarrow g^0(4\pi)^n/\pi^-p \rightarrow pg^-$ has to be 2:1.

Moreover in the above-discussed structures, several new resonances are present in higher mass region and named S, T and U. Very little is known about them but the study of the above-listed reactions at the proposed energy is very useful to obtain some information on their existence and decay mode.

e) To the listed channels many quasi two-body reactions contribute, for example $\pi^-p \rightarrow \rho^0 n$; $\rightarrow f^0 n$; $\omega^0 n$; $\eta^0 n$. Their dynamical behaviour can be studied at this energy and compared with several theoretical predictions. Moreover for some of them the possibility to obtain data is limited by the presence of more of one neutral particle in the final state (for example $\rightarrow \omega^0 n$, $\rightarrow \eta^0 n$).

4. MANY-BODY PROCESSES

Analysing the reactions with more than one neutral particle would provide the possibility of studying the high multiplicities in all states of charge.

Consequently the comparison with the theoretical provisions of the different models (statistical, peripheral, etc.) becomes more complete. In particular it seems important to have a comparison with the multiperipheral model and with the multi-Regge pole predictions$^{7)}$.

Another point is the study of correlation effects between pions of equal and different charges[8]. For this purpose we propose to analyse the channel

$$\pi^- + p \rightarrow 2\pi^+ + 2\pi^- + 2\pi^0 + n \qquad (18)$$

where it is possible to study not only the differences between the angular correlations in like and unlike pion pairs, but also the possible differences among the $2\pi^0$, $2\pi^+$, $2\pi^-$ pairs. In particular this last point can be important in order to clarify the nature of these correlations[9].

We have estimated obtaining 150 events/100,000 incident pions of channel (18), from the values of the cross-sections $\pi^- + p \rightarrow 3\pi^+ + 3\pi^- + n$ at 16 GeV/c[10].

5. CONCLUSIONS

From the above discussion we can conclude that many of the physical problems presented can be studied with statistics obtained from 10^6 primary pions.

This corresponds to about 250,000-300,000 pictures with 3-4 incident particles/burst.

* * *

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K. Böckmann et al., Proc. of Topical Conf. on High-Energy Collisions of Hadrons (1968), p. 611 and bibliography.

9. A. Krzywicki, private communication.

10. K. Böckmann et al., Report P N. 837/VI/PM, Warszawa 1967.

A PROPOSAL FOR A GARGAMELLE EXPERIMENT WITH A 25 GeV/c PROTON BEAM IN PROPANE

D.J. Miller,
University College London, England

1. CONDITIONS

300,000 pictures are requested with two 25 GeV/c proton tracks per picture in pure propane.

2. AIMS

i) To study the coherent production of the 1470 enhancement in $p\pi^+\pi^-$ and to find its total cross-section per nucleon. This will continue exploratory work done in a 28 GeV/c pNe experiment at Brookhaven (F.R. Huson, D.J. Miller, J.S. O'Neall, BNL preprint 12776, to be published).

ii) To analyse approximately 750 events of the type $p + p \rightarrow p + p + \pi^0 + \pi^+ + \pi^-$ with both γ-rays from the π^0 converted. This will make use of the high proportion (~ 25%) of free hydrogen interactions in pure propane. Interesting sub-channels are $p(p\omega^0)$, $p(\Delta^{++}\rho^-)$, $(p\pi^0)(p\pi^+\pi^-)$, where bracketed particles indicate possible low-mass enhancements due to diffraction dissociation.

iii) To look for coherent production of $p\pi^0$, and in particular at the 1400 enhancement in this system.

iv) To investigate other coherent nuclear channels and hydrogen channels with one or more π^0.

3. NUMBER OF PICTURES

In 60,000 pictures of the 80 in. chamber only 36 coherently produced events were seen with $p\pi^+\pi^-$ mass < 1.6 GeV. Comparing with $p + p \rightarrow p + (p\pi^+\pi^-)$, using an absorption model, it was possible to place limits of between 30 mb and 70 mb on the total cross-section per nucleon for the emerging $p\pi^+\pi^-$ state. The uncertainty came largely from the small statistics. 300,000 pictures in Gargamelle will give approximately five times as many coherent events and with careful efforts to reduce other contributions to the error it should be possible to measure this cross-section to ±8 mb.

For the $p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^0$ channel anything less than 750 events will not be worth while. The channel cross-section of ~ 1.4 mb is divided into sub-channels of 50 to 100 μb and these will have just sufficient statistics to resolve their structure.

4. CHOICE OF LIQUID - PURE PROPANE

a) The density distribution of matter within the carbon nucleus is better known than that in neon. This will make the absorption calculation more accurate. No averaging over heavy nuclei need be done if only carbon is present.

b) The proportion of visible beam interactions in propane is ~ 25%. This assumes:

i) Coherent elastic scattering from carbon is invisible to the scanner since the incoming track does not deviate, and no recoil is seen. Bellettini et al. [Nuclear Phys. 79, 609 (1966)] give the p-carbon inelastic cross-section to be 254 mb. In the pNe experiment at BNL the visible cross-section is close to the interpolated value of the inelastic cross-section, so we take σ_C (visible) = 254 mb.

ii) The BNL 28.5 GeV/c experiment [W.E. Ellis, D.J. Miller, T.W. Morris, R.S. Panvini and A.M. Thorndike, Phys. Rev. Letters 21, 697 (1968)] finds a visible pp total cross-section of 36.5 mb.

c) Too short a radiation length at high energy leads to unscannably cluttered pictures. Nearly one third of the BNL 28 GeV/c pNe pictures were rejected because of complicated interactions near beam entry. γ-ray pairs formed a major part of the complication. (A thin chamber window is also desirable for this reason.)

5. PHYSICS

a) $p\pi^+\pi^-$ coherent production exhibits the same 1470 enhancement as is seen in pp experiments. Some workers claim that this is an isobar, others such as E.L. Berger [Phys. Rev. Letters 21, 701 (1968)], explain it with a Reggeized Deck model, which of course may generate isobars through Horn-Schmidt duality. Nuclear absorption calculations, similar to those used in extracting the ρ-nucleon total cross-section from nuclear ρ photoproduction, will permit a good determination of the 1470-nucleon total cross-section. If this cross-section is around 40 mb then the 1470 behaves like a single baryon, and should be interpreted as a resonance. If the cross-section is around 70 mb then either it is a non-resonant $p\pi^+\pi^-$ (or $\Delta^{++}\pi^-$) system or it is a different kind of baryon -- perhaps made of five quarks. This experiment should be able to differentiate between the two alternatives.

Berger's double-Regge model has been able to explain most features of the BNL data, but some distributions do not fit as well as they might. With five times the statistics a good test can be made.

b) The $p + p \rightarrow p + p + \pi^+ + \pi^- + \pi^0$ channel is difficult to analyse above 20 GeV/c in hydrogen, since the π^0 missing-mass is not resolved from multi-π^0 production, and the 1C fits are therefore contaminated. The $pp\omega^0$ channel has been observed. With ~ 750 events [fast π^0 only -- another ~ 300 with slow $\pi^0 \rightarrow 2\gamma$ (seen) and perhaps 1000 with $\pi^0 \rightarrow 1\gamma$ (seen) may be worth collecting], fully constrained, a good survey of the state can be made. Higher energy points can be added to the sub-channel cross-section curves.

c) Coherent production in p + nucleus → nucleus + $p\pi^0$ was not scanned for at Brookhaven. This is a difficult channel since there is no recoil and the proton does not appear to deflect. The on-line γ-ray pointing facility of the Gargamelle scanning machines should help to identify these events. There is a bump at 1400 in $p\pi^0$ as well as in $n\pi^+$ in the 28.5 GeV/c pp experiment (Ellis et al., op. cit.) and this can be analysed in the same way as the $p\pi^+\pi^-$ enhancement. Its total nucleon cross-section can be found from the absorption model, by comparing the coherent with the pp production. The double-Regge model can also be checked.

d) Other channels include a study of the π^0 multiplicity of hydrogen interactions. This will supplement the multi-prong analysis of the Brookhaven pp experiment (P.L. Connolly, I.R. Kenyon, T.W. Morris and A.M. Thorndike, report BNL 11993, submitted to Topical Conference on High-Energy Collisions of Hadrons, CERN, Geneva, 1968; also submitted to Vienna Int. Conference on High-Energy Physics, Vienna, 1968). Other coherent channels, with strange particles or multi-pion production, doubtless exist and they may be worth surveying.

6. ADDITIONAL POINTS

a) To reduce the number of unscannable pictures (~ 1/3 at BNL) it would be desirable to use a kicker or other technique to hold the proton flux at exactly 2 particles per picture.

b) In studying coherent events a great deal depends upon the resolution of the momentum transfer from the beam to the final state particles. This resolution is largely determined by the angular errors on track directions, which in turn depend upon point precision in measurement. Thus the very best precision possible is needed at beam depth.

c) The four separate parts of the analysis could be done separately. The $p\pi^+\pi^-$ is the most important, and also the easiest to scan.

d) Useful results have been obtained by Veillet in A_1 production calculations and by others in photoproduction when data on coherent production from lead were available. A future proposal is under consideration to place a lead plate in Gargamelle for a 25 GeV/c proton experiment.

ETUDE DES DESINTEGRATIONS NON LEPTONIQUES DES MESONS K

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La compréhension des règles de sélection et de la violation de PC nécessite une connaissance très précise des rapports de branchement des désintégrations de K^+, K_S^o et K_L^o. La chambre à bulles à liquide lourd "Gargamelle" permet une amélioration très nette de la technique expérimentale actuelle.

1. DESINTEGRATIONS EN 2π DU K_S^o ET DU K^+

Plusieurs expériences sont en cours mesurant le rapport :

$$\frac{K_S^o \to \pi^o\pi^o}{K_S^o \to \pi^+\pi^-} .$$

"Gargamelle" permet de mesurer ce rapport (avec une bonne précision pour un bon choix de liquide), mais aussi, dans la même expérience :

$$R_1 = \frac{K_S^o \to \pi^o\pi^o}{\text{tous } K^o} , \quad R_2 = \frac{K_S^o \to \pi^+\pi^-}{\text{tous } K^o} , \quad R_3 = \frac{K^+ \to \pi^+\pi^o}{\text{tous } K^+} .$$

Ceci permet de tester la règle de sélection $\Delta I = 1/2$, soit par le rapport R_1/R_2, soit par le rapport $R_3/R_1 + R_2$.

Nous donnons deux méthodes pour faire cette expérience, le choix n'étant pas nécessaire dès à présent.

A. Faisceau de K^+ de 0,800 GeV/c

Longueur de radiation de 20 à 25 cm, liquide (~ 50%, ~ 50% en volume) propane-fréon CF_3Br.

Les K^o sont produits par $K^+ + n \to K^o + p$, le proton s'arrête et signe l'échange de charge. Les K^+ soit s'arrêtent, avec ou sans diffusion, soit donnent un K^0 (à 800 MeV, rapport ~ 1 entre diffusion et échange de charge). La section efficace inélastique représente quelques pour cent de la section efficace totale.

Techniquement, il faudrait rendre le faisceau G_1 compatible pour cette expérience. Un run de 120 000 photos à 2 K^+ par photo doit permettre de sélectionner 60 000 K^0, soit 10 000 $K^0_S \to \pi^0\pi^0$, dont une proportion supérieure à 90% auront trois ou quatre gammas matérialisés dans le liquide.

B. Faisceau de K^+ de 1,25 GeV/c

Même liquide que précédemment, ou X_0 légèrement plus grand pour augmenter le nombre d'événements hydrogène et la précision de mesure (étude à faire). Les K^0 sont produits dans la réaction :

$$K^+ + p \to K^0 + N^{*++} .$$

Cette réaction représente 15% de la section efficace totale (18 mb) et les productions sur hydrogène sont de l'ordre de 5%. On peut donc s'attendre à 1 événement utile pour 200 K^+. Pour réaliser cette expérience, nous proposons de prémesurer tous les événements avec un proton et un π^+. Cette prémesure sélectionnerait les événements utiles et donnerait la ligne de vol du K^0 ainsi que son impulsion, un scanning permettant le classement final.

Le faisceau G_1 sans modifications serait utilisé. Un run de 200 000 photos à 10 K^+ par photo permet une étude de plusieurs milliers de $K^0_S \to \pi^0\pi^0$. Le fait de connaître le K^0 permet des études "sous-produits", telles que les interactions de K^0 et les désintégrations en 3π du K^0_S.

Les avantages et les inconvénients des deux méthodes sont apparents. Le tableau ci-après les résume, le choix entre elles n'étant nécessaire qu'au moment du run.

P_{K^0}		Liquide	Production	Avantage principal	Inconvénient principal
A	0,8 GeV/c	$X_0 \sim 22$ cm	$K^+ + n \to K^0 + p$	peu de mesures peu de traces par photo	peu de sous-produits
B	1,25	$X_0 \sim 22$ cm ou plus grand	$K^+ + p \to K^0 + N^*$	P_{K^0} connu	mesures nombreuses

2. DESINTEGRATIONS EN 2π ET EN 3π DU K_L^0

Il n'est pas nécessaire de rappeler l'importance des mesures précises des rapports de branchement du K_L^0 en 2π et en 3π. Pour ce dernier mode en particulier, il est souhaitable de faire une analyse détaillée des diagrammes de Dalitz pour les désintégrations $\pi^+\pi^-\pi^0$ et $3\pi^0$.

L'expérience la mieux adaptée pour ces études est une expérience du type X_4, dans laquelle un flux important de K^0 traverse la chambre à l'intérieur d'un tube à vide; si l'on sélectionne les désintégrations arrivant dans le deuxième mètre de parcours, la taille de la chambre est telle que les traces chargées et les gammas seront détectés avec une grande efficacité.

Les deux paramètres dont nous disposons sont l'impulsion du faisceau et la longueur de radiation du liquide utilisé. L'importance de ces deux paramètres varie avec les modes recherchés.

2.1 Modes $\pi^+\pi^-$ et $\pi^+\pi^-\pi^0$

Si l'on admet que la mesure du premier mode n'importe pas, mais que seule son identification compte, on peut admettre une longueur de radiation courte et ne sélectionner que les modes où les deux particules chargées interagissent sans aucun γ. Par contre, la mesure précise du $\pi^+\pi^-\pi^0$ conduirait à adopter une longueur de radiation plus grande.

2.2 Modes $2\pi^0$ et $3\pi^0$

Pour étudier l'influence de la longueur de radiation et de l'impulsion du K^0, nous avons utilisé un programme de Monte Carlo dont les caractéristiques principales sont :

i) Chambre cylindrique de 2 m de diamètre et de 4 m de long.

ii) Faisceau à l'intérieur d'un tube, identique à X_4, en aluminium, de 2,5 mm d'épaisseur et de 2 cm de diamètre intérieur, l'axe de ce tube étant l'axe du cylindre.

iii) Si X est la distance entre l'entrée de la chambre et le point de désintégration, cette désintégration doit se trouver telle que :

$$0{,}60 \text{ m} < X < 1{,}20 \text{ m} ,$$

cette région nous apparaissant à priori comme l'optimum pour l'expérience envisagée.

Les conclusions de cette étude sont les suivantes :

a) Pour la matérialisation, l'impulsion du faisceau pour $P_{K^0} < 8$ GeV/c ne joue pas un rôle déterminant. La longueur de radiation est évidemment un paramètre beaucoup plus sensible, surtout pour les K^0 d'impulsion inférieure à 2 GeV/c, comme le montrent les figures 1a et 1b, où sont portées les probabilités de matérialisation de 6γ pour $3\pi^0$, de 4γ pour $2\pi^0$ et $3\pi^0$ (matérialisation pouvant avoir lieu soit dans le tube soit dans le liquide).

b) Pour mesurer les γ, il est important que le plus grand nombre de ceux-ci se matérialisent dans le liquide. Les figures 2a et 2b donnent la probabilité d'avoir $6\gamma/3\pi^0$ et $4\gamma/2\pi^0$ matérialisés dans le liquide de la chambre.
La forme de ces familles de courbes met en évidence que, pour les K^0 énergiques, la majeure partie des matérialisations sont dans l'aluminium, et que, pour les K^0 peu énergiques, une proportion importante de γ sort du volume utile pour une longueur de matérialisation de l'ordre de 55 cm. En fait, ce dernier inconvénient pourrait être minimisé si l'on utilise pour $3\pi^0$ les désintégrations à 5 et 6γ, et pour $2\pi^0$ les désintégrations à 3 et 4γ.
On peut certainement améliorer la situation en changeant la forme du tube, par exemple utiliser un cône au lieu d'un cylindre, ce qui permettrait d'augmenter l'angle avec lequel les gammas traversent l'aluminium. Une étude plus précise est nécessaire pour cela.

c) Si l'on demande, pour séparer les différents γ, un angle minimum entre leur ligne de vol, il va de soi que la probabilité d'avoir des événements utiles tombe à zéro au-delà de 4 GeV/c.

La conclusion de cette étude est que la longueur de matérialisation devra être rendue optimum (entre 11 et 30 cm) en vue de l'intérêt premier de l'expérience au moment de sa réalisation, mais surtout que les désintégrations utiles, pour les modes à π^0 exclusivement, sont les désintégrations de K^0 d'impulsions les plus basses possibles. Des désintégrations de K^0 avec $P_{K^0} > 2$ GeV/c entraînent des corrections de visibilité telles que le résultat expérimental ne pourra atteindre la précision souhaitée. Etant donné les spectres de production de K^0 par des protons de 10 à 20 GeV/c, à petit angle de production (nécessité par l'utilisation du faisceau éjecté dans la zone "Gargamelle"), une expérience utilisant ce mode de production nous semble beaucoup moins riche qu'une expérience utilisant des K^0 monocinétiques produits dans la réaction :

$$\pi^- + p \rightarrow \Lambda^0 + K^0 ,$$

même si les difficultés techniques nécessitent de retarder d'un an ou deux cette expérience. Nous souhaitons la construction d'un faisceau adéquat.

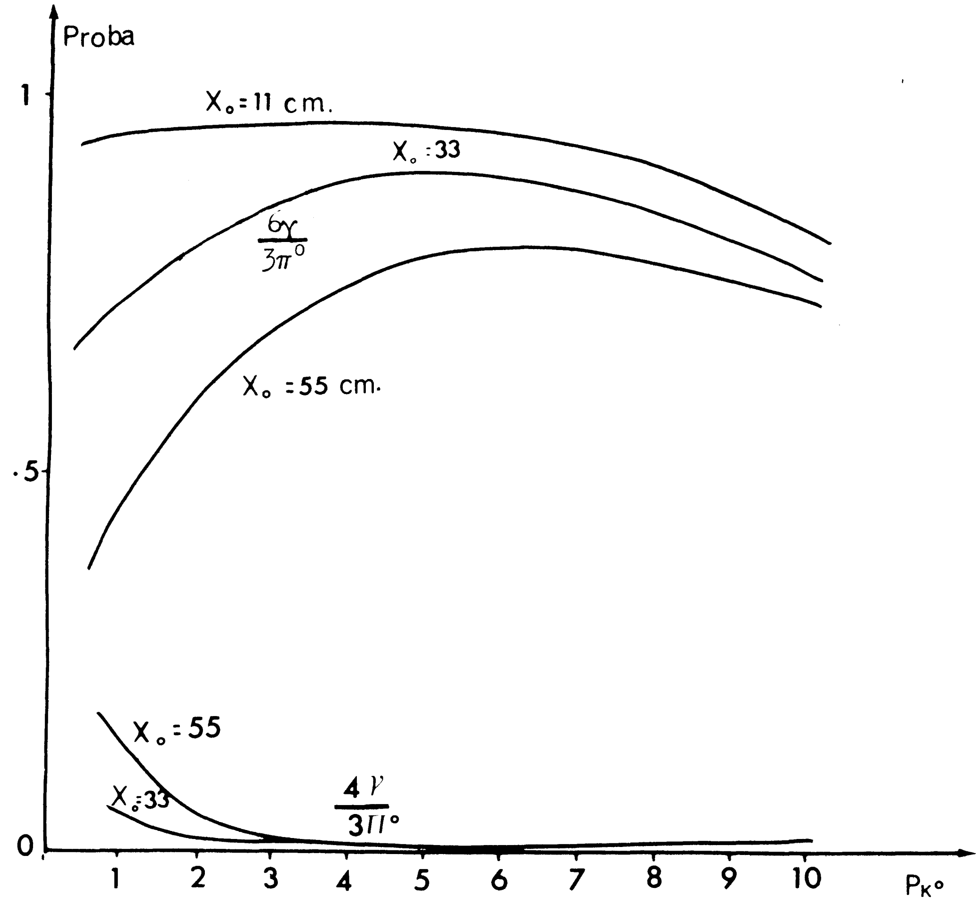
Proba
1
·5
0
X₀=11 cm.
X₀=33
6γ / 3π⁰
X₀ =55 cm.
X₀=55
X₀=33
4γ / 3π°
1
2
3
4
5
6
7
8
9
10
Pκ°

Fig. 1a

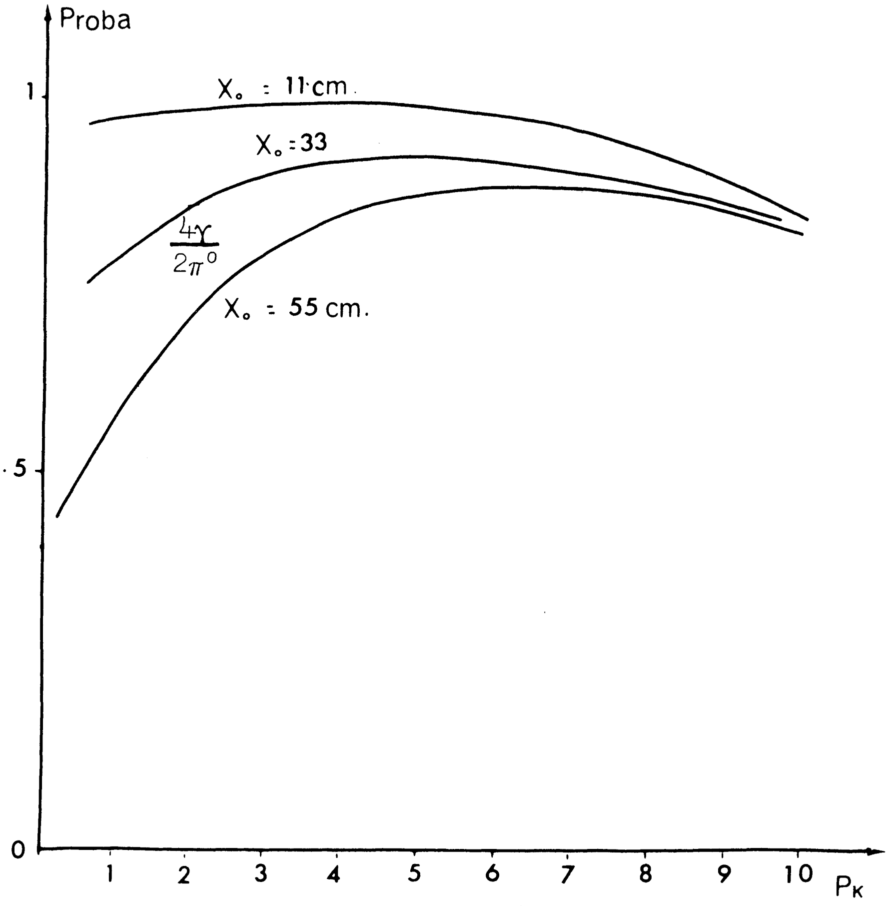
Proba
1
·5
0
X₀ = 11·cm.
X₀=33
4γ / 2π⁰
X₀ = 55 cm.
1
2
3
4
5
6
7
8
9
10
Pκ

Fig. 1b

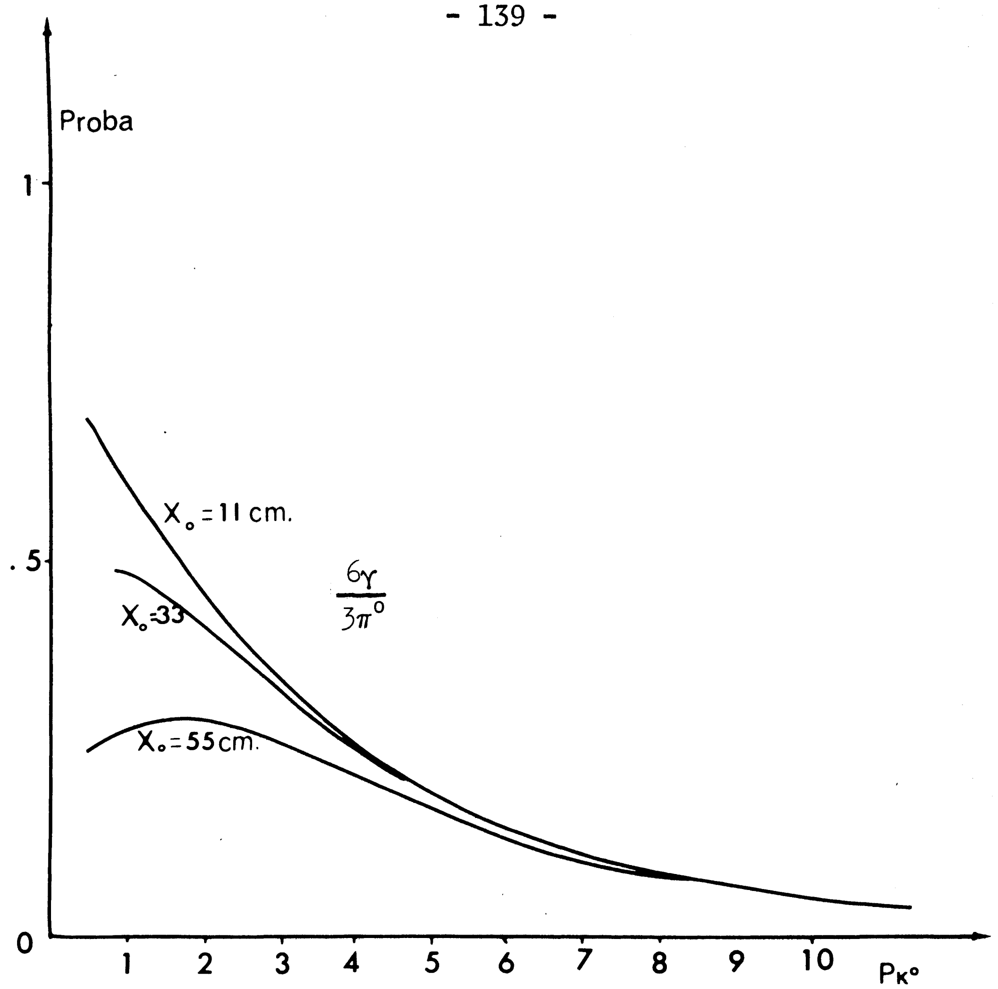
Proba
1
.5
0
$X_o = 11$ cm.
$X_o = 33$
$X_o = 55$cm.
$\frac{6\gamma}{3\pi^0}$
1
2
3
4
5
6
7
8
9
10
P_{K^o}

Fig. 2a

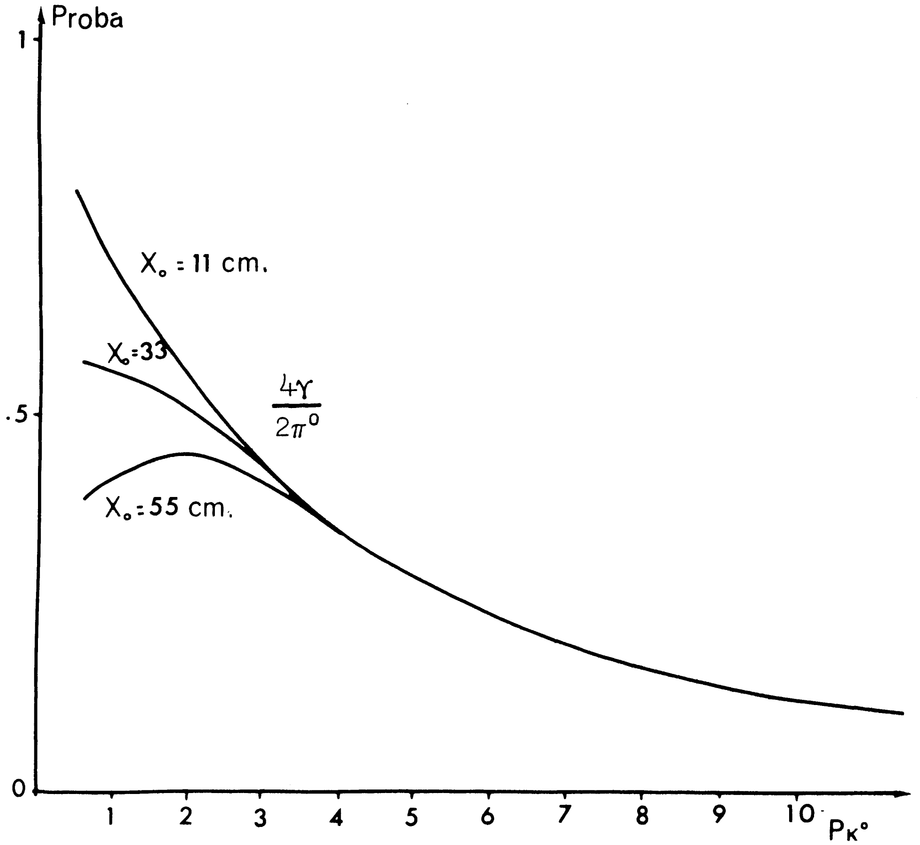
Proba
1
.5
0
$X_o = 11$ cm.
$X_o = 33$
$X_o = 55$ cm.
$\frac{4\gamma}{2\pi^0}$
1
2
3
4
5
6
7
8
9
10
P_{K^o}

Fig. 2b