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REPORT TO THE TRACK CHAMBER COMMITTEE BY THE CHAIRMAN OF THE GARGAMELLE USERS COMMITTEE

E. Fiorini

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REPORT TO THE TRACK CHAMBER COMMITTEE BY THE CHAIRMAN OF THE GARGAMELLE USERS COMMITTEE

I have been requested by the Track Chamber Committee to report on possible experiments to be done with Gargamelle with the beams which are at present being studied for this chamber.

The work on beams and experiments has been organized in the Gargamelle Users Committee in the following way:

A) A "Beam Study Group" has been requested to make a preliminary study of the feasibility and possible installation problems of the following beams:

   G1: 1 to 2.4 GeV/c electrostatic separated $K^{\pm}$, $\pi^{\pm}$, p, and $\bar{p}$ beams;

   G2: 2.4 to 4.2 GeV/c electrostatic separated $K^{\pm}$, $\pi^{\pm}$, p, and $\bar{p}$ beams;

   G3: 4-5 to 14 GeV/c RF separated $K^{\pm}$ and 4-5 to 22 GeV/c RF separated $\pi^{\pm}$ beams;

   G4: 2 to 25 GeV/c unseparated p beam and 2 to 22 GeV/c unseparated π^{-} beam;

   G5: neutrino and antineutrino beams;

   G6: a muon beam, possibly momentum analysed;

   G7: a K_2^0 beam.

   I will not enter into details regarding these beams since they are discussed in an appended report by the Beam Study Group.

B) All the groups have been requested to send me informal letters of intention, or suggestions for the future physics programme for Gargamelle. It has been stated clearly that these letters do not represent an obligation to perform the experiment, nor do they give to the proposing group any right in this sense.

The results of our request were very promising. I have received the following letters of intention and informal proposals:

- Letter of intention, by the Aachen group for future experiments with Gargamelle.

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- Letter of intention, by the Bergen Group.
- Some remarks concerning the physics to be done with Gargamelle, by the CERN-NPA Group.
- a) "Etude des annihilations d'antiprotons avec production de particules neutres", by the Collège de France and Ecole Polytechnique Groups.
  b) "Proposition d'expérience K_2^0 dans Gargamelle", by the Ecole Polytechnique Group.
  c) "Etude de la reaction $K^-p \to \Sigma^0\pi^0$ de 1,2 GeV/c à 2,4 GeV/c", by the Ecole Polytechnique Group.
  d) "Etude des mésons X^0, φ, ω, et η et des hypérons Λ, Σ, Ξ. Test de la règle $\Delta S = \Delta Q$, test de la règle $\Delta S < 2$, test de la règle $\Delta I = 1/2$", by the Ecole Polytechnique Group.
  e) "Etude du système $\pi^0\pi^0$", by the Ecole Polytechnique and Orsay Groups.
- Considerations and intentions of the Milan HLBC Group for experiments with Gargamelle.
- Study in Gargamelle of non-locality of lepton currents using a high-energy neutrino beam, by D. Perkins (Oxford).
- a) Neutrino and antineutrino physics in Gargamelle, by the Padua and Wisconsin Groups.
  b) Letter of intention on the $K^\pm$ beam, by the Padua and Wisconsin Groups.
  c) A study of inelastic meson interactions in Gargamelle, by the Padua and Wisconsin Groups.
- Interest of the Turin Bubble Chamber Group in experiments with Gargamelle.
- Experimental programme with Gargamelle, by the University College (London) Group.

Most of these letters, which are all appended to the present report, are in a very preliminary form; however, some of them contain suggestions and remarks of noticeable interest.

I would like to review briefly the future physics programmes for Gargamelle, considering all the various possible beams.

G1: 1 to 2.4 GeV/c kaon, pion, proton, and antiproton beams

Experiments with these beams have been considered by the CERN-NPA, Collège de France, Ecole Polytechnique, Padua-Wisconsin, and Turin Groups. The experiments are summarized as follows:

a) Studies of antiproton annihilations at rest with the emission of two or more particles which are undetectable in a hydrogen bubble chamber (such as π^0, γ, etc.). A mixture of 80% propane and 20% CF_3Br could yield a reasonable percentage of interactions on free protons and a 95% gamma detection efficiency.

b) A production experiment of the Y_0^* done with K^- of different momenta from 1.2 to 2.4 GeV/c in order to cover the mass region of both the 2100 and 2350 MeV resonances. A suggested mixture is 85% propane and 15% CF_3Br, with a 90% gamma detection efficiency.

c) Study of mesons and hyperons produced by K interactions in Gargamelle. One can investigate, in particular, the asymmetry in the decay $X^0 \to \pi^+\pi^-\gamma$ (C conservation), the branching ratios and the rare decay modes of X^0, ω, φ, and η, the Ξ^0 decays, and $\Lambda\beta$ decays. Tests of the $\Delta S = \Delta Q$ and $\Delta S < 2$ rules can be done by studying the decays $\Sigma^+ \to e^+ + n + \nu$ and $\Xi^- \to n\pi^-$, $\Xi^0 \to n\pi^0$, respectively. Moreover, a test of the $\Delta I = 1/2$ rule can be based on the ratio of the Ξ^0, Ξ^- lifetimes and α decay parameters.

A mixture of 80% propane and 20% CF_3Br has been suggested for these experiments.

G2: 2.4 to 4.2 GeV/c kaon, pion, proton and antiproton beams

These beams have been considered by the CERN-NPA, Ecole Polytechnique, Orsay, and Padua-Wisconsin Groups. Many of the problems to be studied are already considered in items (b) and (c) of the preceding paragraph concerning the G1 beams. A typical problem to be studied with G2 beams concerns the system $\pi^o\pi^o$ produced in the reaction $\pi^+ p \rightarrow N^{*++}\pi^o\pi^o$, which could be studied at different energies between 2.5 and 5 GeV/c to cover a wide range of $\pi^o\pi^o$ masses. A mixture of 80% propane and 20% freon could be considered (95% gamma detection efficiency).

G3: High-energy radiofrequency separated pion and kaons beams

Experiments with these beams have been considered by the CERN-NPA and Milan Groups. The interest is mostly concerned with the study of the following:

a) coherent production of K states by very high energy K^+ and K^- on nuclei;

b) production of Ω^-, of $S = -2$ and $S = -1$ baryon resonances, and of $S = 0$ bosons by high-energy K^-.

Moreover, interest in the G3 beam has been expressed by Prof. S. Ratti of the Milan Hydrogen Bubble Chamber Group, mostly for the study of reactions by very high-energy π^+ and π^-.

G4: Proton and π^- unseparated beams

The Aachen, CERN-NPA, Milan, and Turin Groups have suggested experiments with these beams which should be available for the earlier experiments with Gargamelle at CERN. The π^- beam could be operated at low energy as a "test beam", as suggested by the Aachen group, mostly in view of neutrino experiments.

At high energy the following experiments have been suggested:

a) with a π^- beam: the study of coherent production of multipion states on carbon nuclei, the production of resonances, the study of non-resonant processes, the study of the $K^o\Lambda/K^o\Sigma^o$ ratio in associated production etc.;

b) with a proton beam: the study of the production of neutral bosons in the reaction $pp \rightarrow ppM^o$ and the coherent production of baryon-meson systems.

For all of these experiments, a filling with pure propane or at least a mixture with only a small percentage of CF_3Br has been suggested.

G5: Neutrino and antineutrino beams

Experiments with these beams are by far the most popular. Expressions of interest, or suggestions, or both have been presented by the Aachen, CERN-NPA, Milan, Oxford, Padua-Wisconsin, Turin, and University College Groups. Most of the problems to be studied are concerned with the following:

a) difference between electron and muon neutrinos;

b) conservation of lepton number;

c) existence of the vector boson;

d) test of time-reversal invariance based on measurements of the polarization from decays or from scattering of particles with spin;

e) existence of neutral currents (reaction $\nu + p \rightarrow \nu + p$);

f) measurement of the total cross-sections and of the form factors from the elastic reactions $\nu + n \rightarrow \mu^- + p$ and $\bar{\nu} + p \rightarrow \mu^+ + n$ (note that the latter reaction would be overdetermined in Gargamelle in approximately 60% of the cases due to secondary neutron interactions in the chamber);

g) the same measurements as (f) from the reactions $\nu + p \rightarrow \mu^- + N^{*++}$ and $\nu + n \rightarrow \mu^- + N^{*+}$;

h) other reactions involving the $N \rightarrow N^*$ current, such as

$$\bar{\nu} + p \rightarrow \mu^+ + N^{*o}$$
$$\bar{\nu} + n \rightarrow \mu^+ + N^{*-} ;$$

i) single production of strange particles in the reactions

$$\bar{\nu} + p \rightarrow \mu^+ + \Lambda^o \quad \text{or} \quad \mu^+ + \Sigma^o$$
$$\bar{\nu} + n \rightarrow \mu^+ + \Sigma^-$$
$$\bar{\nu} + p \rightarrow \mu^+ + Y^{*o}$$
$$\bar{\nu} + n \rightarrow \mu^+ + Y^{*-}$$

These rare reactions represent a unique way of testing the validity of the Cabibbo theory, T-invariance (from the Λ decay), and the $\Delta T = 1/2$ rule from the ratios of the rates.

As far as the liquid is concerned, a filling of freon is preferable for the study of very rare events such as those listed in (i), when a greater π^0 or neutron detection efficiency and a better μ identification is desired. In all other cases a propane filling is better by far, due to the presence of free protons, to the clearer nature of the nuclear target, and to the better accuracy in the measurements of the momenta and sometimes of the polarization of the secondary particles. The use of deuterated propane has also been suggested for later investigations of interactions on quasi-free neutrons.

In the opinion of the Users, neutrino experiments have the highest priority in the physics programme for Gargamelle; they should start with neutrinos and propane filling, and follow with antineutrinos and fillings with heavier mixtures.

G6: Muon beam

Experiments with muon beams have been suggested by the CERN-NPA and Padua-Wisconsin Groups. The following reactions could be studied, amongst others:

a) $\mu^- + p \rightarrow \mu^- + N^{*+}$ to obtain the form factors of the nuclear isobar, especially in the limit $t \rightarrow 0$;
b) $\mu^- + p \rightarrow \mu^- + N^* + \pi$ to be compared with reaction (a);
c) $\mu^- + p \rightarrow \mu^- + p + \rho^0$;
d) $\mu^- + C \rightarrow \mu^- + C + \gamma$.

With a propane filling, the total number of estimated events would be of the order of one event per 100 pictures, with 100 muons per cycle.

G7: K_2^0 beam

Experiments with this beam have been suggested by the CERN-NPA, Ecole Polytechnique, and University College groups. They are mainly concerned with:

a) an improved determination of the η^{00} amplitude;

b) a test of the $\Delta I = \frac{1}{2}$ rule based on the comparison between the K^0_{e3} and K^+_{e3} decay rates;

c) an improved evaluation of the form factors in the leptonic K^0_2 decays.

These experiments could obviously be performed also with the K^0_2 beam produced in the chamber by the charge exchange interactions of K^+ with momenta of 1 GeV/c to 1.5 GeV/c (G1 beam). However, in order to obtain reasonable statistics, an experiment has been planned with a K^0_L beam crossing the chamber in a vacuum tube, similar to the X_4 experiment. The monochromatic beam would be oriented in a fixed direction by the interaction in a hydrogen target of a very intense π^- beam. A measurable K^0_2 disintegration per 10 to 20 pictures could be obtained in Gargamelle with this beam.

CONCLUSIONS

It is obvious from the large number of detailed letters received that there is great interest in performing experiments in Gargamelle.

In the last Gargamelle Users Committee, when the possible experimental programme was discussed, it was suggested that I should report the following conclusions to the Track Chamber Committee:

1) that the ν experiments in Gargamelle should have the highest priority;
2) to propose that the unseparated π^-, p beam G4 be built and given priority along with the ν experiment;
3) that the Gargamelle Area be planned in such a way that any of the proposed beams can be installed within six months.

* * *

On behalf of the Users Committee and myself, I wish to express the warmest thanks to the members of the Beam Study Group for the excellent job they have done, as well as to all groups contributing suggestions and remarks to this report. I want also to express my sincere gratitude to Dr. D. Cundy for the help he gave as Secretary of the Gargamelle Users Committee.

22 February 1968

Letter of Intention

FUTURE EXPERIMENTS WITH GARGAMELLE

H. Faissner

III. Physikalisches Institut
der Rhein.-Westf. Technischen Hochschule Aachen
Aachen, Germany.

According to the last Gargamelle Users' Committee, the expected initial physics programme will have the following form:

i) π^-,p (unseparated G4 beam)
ii) neutrinos
iii) antineutrinos.

We would like to participate in the neutrino and in the anti-neutrino experiments, as well as in a test experiment. Our interest in neutrino physics dates back several years: eight physicists now working at the Institute were amongst the co-authors at the CERN neutrino experiment 1963-65.

1. FACILITIES

Facilities to analyse Gargamelle pictures will be available in due course. The CDC 6400 of the computer centre, Aachen University, permits the running of the complete program chain. We have already the heavy-liquid versions of the CERN geometry program (DRAT) and of CERN GRIND running.

At present we are analysing the X_2 experiment and have four coordinatographs working. These are supposed to be operated on-line with a PDP 7 from Autumn 1968 onwards. The interface to our PDP 7 is already working. As a first stage we shall perform rough geometrical tests and controls of measurement procedure. Our goal is to have the full geometry on-line at a later stage.

The present coordinatographs will be replaced in the on-line system by scanning and measuring projectors for Gargamelle. A geometry program for Gargamelle will be developed in collaboration with CERN and UCL.

2. PHYSICS JUSTIFICATION

2.1 The neutrino experiment

For the neutrino experiment we favour propane for the first run to get neutrino interactions on free protons. The main justifications in this case are:

i) The study of the reaction

$$\nu + p \rightarrow N^{*++} + \mu^- .$$

We refrain from repeating the arguments put forward in many publications. The main aspects are clearly: total and differential cross-section leading to a measurement of the axial vector NN* coupling constant, and to an estimate of the relevant form factors.

ii) This run would open up the very interesting possibility of performing the Adler tests on the validity of the CVC and PCAC hypothesis using the one-pion and multipion production on free protons.

At a later stage (after the antineutrino experiment) we would support the use of deuterized propane to study the elastic neutrino reaction on quasi-free neutrons.

2.2 The antineutrino experiment obviously has to be performed in propane. There are two major objectives:

i) The detailed study of the reaction

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

off the free proton. An unambiguous identification will require detection of the neutron by nuclear interaction in propane.

ii) Elastic hyperon production:

$$\bar{\nu} + p \rightarrow \mu^+ + \Lambda^0 \qquad (1)$$

$$\rightarrow \mu^+ + \Sigma^0 \qquad (2)$$

$$\rightarrow \mu^+ + Y_1^{*0} \qquad (3)$$

Up to now only reaction (1) is observed. Considering how little is known about the strangeness-changing current, even a small number of events would be very welcome.

3. PRACTICAL CONCLUSIONS

The proposed sequence of the neutrino and antineutrino run seems to be the best choice because of technical reasons. We are preparing detailed proposals for both neutrino and antineutrino experiments.

Concerning a test experiment, we favour a test not coupled to real experiments (at least in the analysis). One should know the accuracy very well, since hydrogen events have to be separated from carbon events by measuring transverse momenta. The new geometry program has to be tested using highly constrained events. Most suitable are strange-particle decays avoiding ambiguities with Fermi momentum. A π^- beam of lowest possible momentum (2 GeV/c) seems to be desirable for such a test. For the antineutrino experiment it is essential to get a calibration of the neutron detection efficiency by nuclear interaction in propane. This is possible in the same beam using two-pion production: $\pi^- + p \rightarrow n + \pi^- + \pi^+$. We are also preparing a proposal for the test exposure.

22 February 1968

Letter of Intention

Bergen Group, Bergen, Norway.

This group has only taken part in heavy-liquid experiments. In the last three years we have collaborated with the Ecole Polytechnique, and for the time being we are working in the K^+ jet collaboration with the Ecole Polytechnique, Madrid, and Strasbourg. This experiment will be finished in 1½ years.

We are very interested in the **Garganelle** Experiments, and concerning the scanning and measurement facilities we are in contact with the NPA Division of CERN. At the end of 1969 we will be prepared for Gargamelle. From August 1968 we will contribute one physicist to the Geometry Program Group.

For the group

(signed)

Anders Haatuft
Alf Halsteinslid

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26 February 1968

SOME REMARKS CONCERNING THE PHYSICS TO BE DONE WITH GARGAMELLE

from

The CERN Heavy-Liquid Bubble Chamber Group
Geneva, Switzerland.

1. NEUTRINO PHYSICS

1.1 Introduction

This note tries to outline a possible evolution of the neutrino programme with Gargamelle, taking into account the neutrino facility which will be available and the fact that they will be the first experiments in the new chamber.

The features of this programme would be:

i) ν survey in a propane-freon mixture (1969-70).

Aims:

a) to test various hypotheses in weak interaction theory, i.e. Adler tests, locality, energy dependence of cross-section;

b) continuation of the study on weak baryonic currents;

c) detailed study of meson production processes.

A total of 10,000 events/10^6 pictures[1]).

ii) $\bar{\nu}$ survey in a propane-freon mixture (1971) essentially to study cross-sections for weak baryonic processes (in particular hyperon production).

A total of 1000 events/10^6 pictures.

iii) ν and $\bar{\nu}$ run in deuterated propane (1972) in order to produce all possible charged states on quasi-free nucleons.

Event rates would be an order of magnitude higher due to the arrival of the booster.

We will now discuss briefly the details of the various physics aspects.

1.2 Neutrino physics

1.2.1 Tests of various hypotheses in weak interaction theory

i) Energy dependence of total cross-section.

The relatively high density of propane, and the ν beam optimized also at high energies, will allow a study of total cross-sections over a wide range of energy. Only by looking at high energies and therefore at large four-momentum transfers will it be possible to test the locality of the lepton current. Locality implies that the form factors in the transition $\nu + A \rightarrow \mu^- + B$ depend only on the four-momentum transfer q^2. A dependence of cross-sections at a given q^2 and M^* value on the neutrino energy would indicate non-locality, as discussed by Lee and Yang$^{2)}$.

ii) Adler test$^{3)}$.

Tests of the PCAC and CVC hypotheses could be continued in a ν run in propane.

iii) Test of the algebra of currents.

To test the algebra of currents directly, Adler has suggested sum rules for ν interactions in the non-parallel configuration$^{4)}$. While these sum rules work only on free protons and at neutrino energies of at least 5 GeV, there are others, discussed by Kim and Ram$^{5)}$, which could be tested already at 1 GeV.

1.2.2 Continuation of the study of weak baryon currents

The most frequent weak baryonic process will be the N-N* transition. The hadronic current for N* production is described by eight unknown form factors. Various assumptions, including CVC, have been made in order to interpret the transition$^{6)}$. Only by a complete study of the cross-section, q^2 distribution, and polarization will the situation be improved.

The expected rates are

$$\sim 1000\ \nu + p \rightarrow N^{*++} + \mu^- / 10^6 \text{ pictures.}$$

It should be pointed out that the study of the energy dependence of the form factors would indicate possible breakdown of locality.

The contribution of other baryonic resonances would also be investigated.

A careful study of the elastic process $\nu + n \rightarrow \mu^- + p$ would also be made. 3000 events/10^6 pictures will occur in carbon nuclei.

1.2.3 Meson production processes (without baryon resonances)

Theoretical estimates for direct production of mesons (ρ, ω, η, X^0) have been discussed by several authors$^{7)}$. The study of weak interactions involving vector mesons will open up a completely new field of study. Roe$^{8)}$ has estimated that for ρ^+ production (produced by means of ρ diffraction scattering), about 13 events/10^6 pictures could be obtained to study the ρ-β coupling constant.

Single kaon production has not been considered at all theoretically, but is certainly allowed and should be studied.

1.3 $\bar{\nu}$ physics

At present there exist only 30 $\bar{\nu}$ bubble chamber events$^{9)}$, and therefore $\bar{\nu}$ physics is essentially an unexplored field.

1.3.1 Baryon-baryon transition

i) Elastic reaction: $\bar{\nu} + p \to \mu^+ + n$.

The event rate for this process would be ~ 100 free proton events/10^6 pictures. This data, combined with the ν data, would allow a better determination of the axial vector form-factor.

ii) Elastic hyperon and excited hyperon production.

The following interactions would take place:

$$\bar{\nu} + p \to \Lambda^0 + \mu^+$$
$$\bar{\nu} + p \to \Sigma^0 + \mu^+$$
$$\bar{\nu} + n \to \Sigma^- + \mu^+ \ .$$

Using the theoretical predictions$^{10)}$, one would expect 12 events on free protons and 36 in carbon. Though these event rates are low, the actual observation of elastic hyperon production is very important.

An equal number of Y* events can be expected allowing the qualitative study of nucleon-Y* transition, which is otherwise unobservable.

The magnitudes of the various rates is an important test of SU_3, SU_6, and $\Delta I = 1/2$ rule. In this respect the carbon events will prove very difficult to interpret, due to hyperon absorption.

iii) N* production and meson production.

As these interactions are completely analogous to the ν interactions, they are of great value because of the different charge states produced.

It is also interesting to study the suggestion to extend the Pomeranchuk theorem to neutrino interactions, i.e. to study the asymptotic limits of the following processes:

$$\nu + p \rightarrow \mu^- + \pi^+ + p$$

$$\bar{\nu} + p \rightarrow \mu^+ + \pi^- + p \; .$$

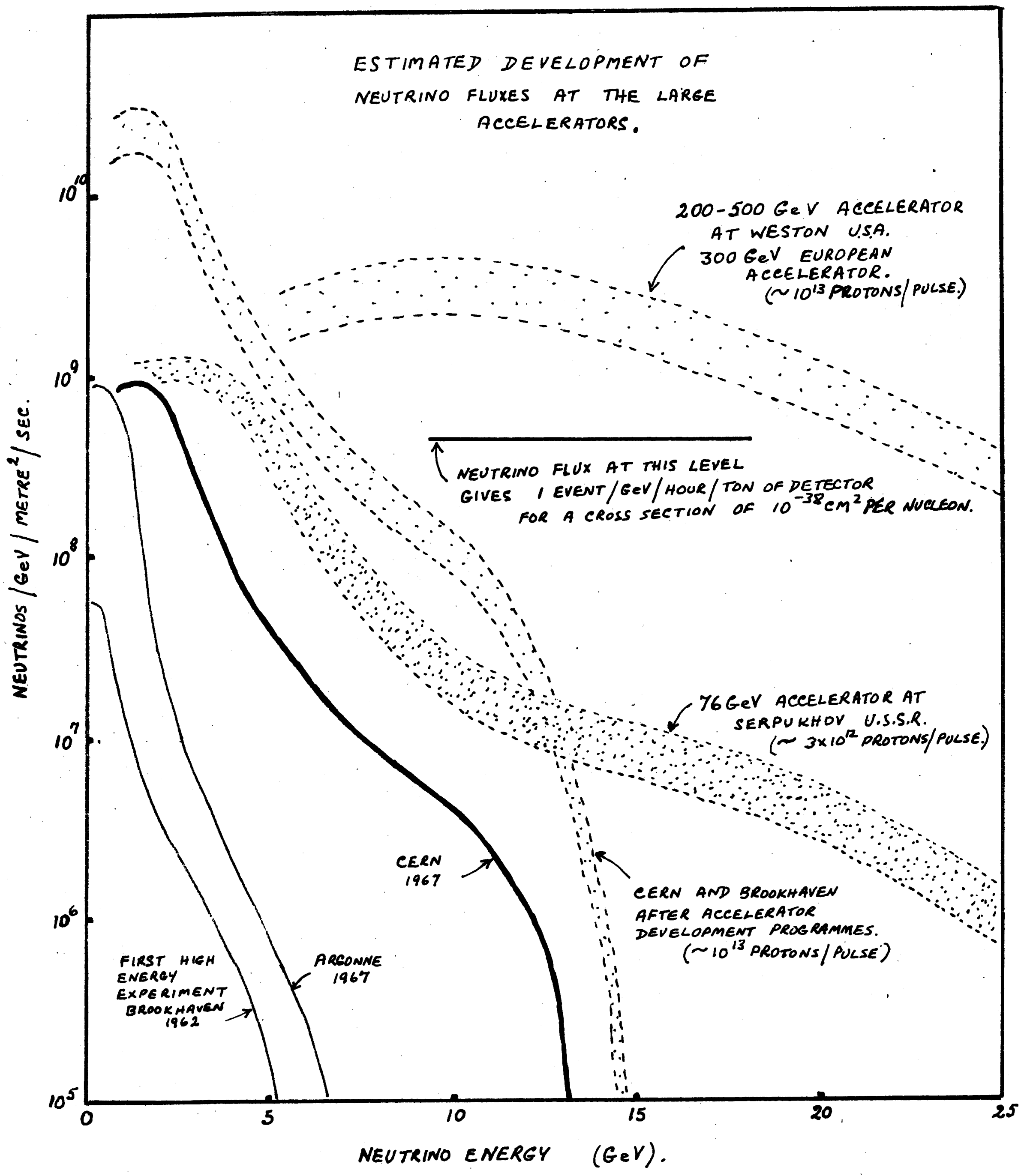
1.4 ν and $\bar{\nu}$ physics with deuterated propane

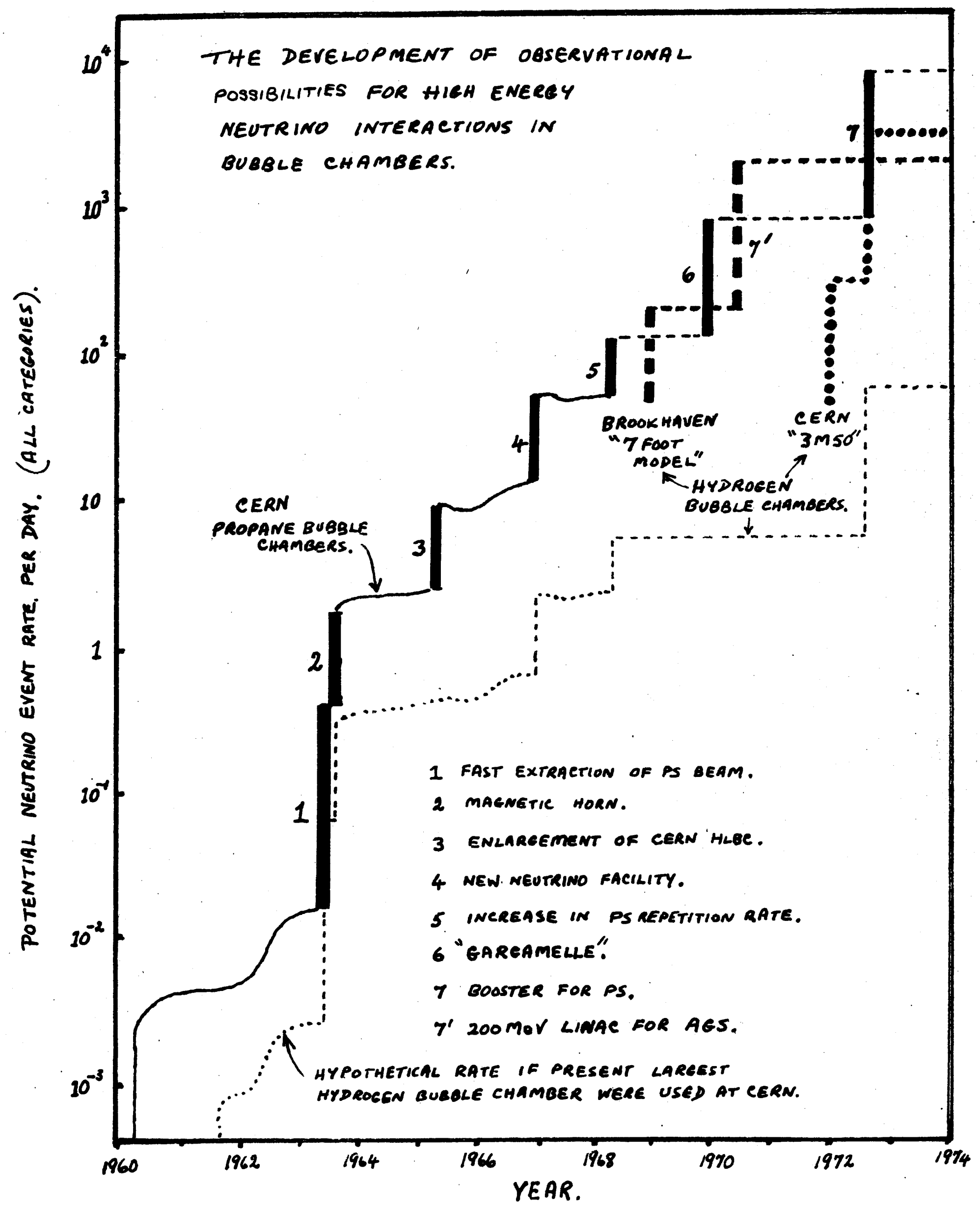
With the arrival of the booster giving an order of magnitude higher rates, in addition to studying above topics more thoroughly the following experiments will become feasible:

a) study of all elastic baryon transitions on free nucleons, thus allowing detailed study of the form factors, and meaningful tests of selection rules and symmetry schemes;

b) because of higher flux, T-invariance studies become feasible.

All interactions can be used to look for muon polarization perpendicular to the ν-μ plane. Experimentally, this requires that μ^+ from $\bar{\nu}$ must be used in order to avoid depolarization. Calculations[11)] have shown that a maximum transverse polarization of ~ 30% would be expected. Experience from $K_{\mu 3}$ studies has shown that ~ 7000 useful events are necessary to obtain a 10% accuracy in the transverse polarization. Considering that only half the $\bar{\nu}$ events will have a stopping μ^+, it would seem that ~ 14,000 $\bar{\nu}$ events or 1.4×10^6 pictures are required.


ESTIMATED DEVELOPMENT OF NEUTRINO FLUXES AT THE LARGE ACCELERATORS.


THE DEVELOPMENT OF OBSERVATIONAL POSSIBILITIES FOR HIGH ENERGY NEUTRINO INTERACTIONS IN BUBBLE CHAMBERS.
POTENTIAL NEUTRINO EVENT RATE, PER DAY. (ALL CATEGORIES).
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
1960
1962
1964
1966
1968
1970
1972
1974
YEAR.
CERN PROPANE BUBBLE CHAMBERS.
BROOKHAVEN "7 FOOT MODEL"
CERN "3M50"
HYDROGEN BUBBLE CHAMBERS.
HYPOTHETICAL RATE IF PRESENT LARGEST HYDROGEN BUBBLE CHAMBER WERE USED AT CERN.
1
2
3
4
5
6
7
7'
1 FAST EXTRACTION OF PS BEAM.
2 MAGNETIC HORN.
3 ENLARGEMENT OF CERN HLBC.
4 NEW NEUTRINO FACILITY.
5 INCREASE IN PS REPETITION RATE.
6 "GARGAMELLE".
7 BOOSTER FOR PS.
7' 200 MeV LINAC FOR AGS.

2. GARGAMELLE EXPERIMENTS IN THE PROTON AND PION BEAM G4

2.1 Coherent production and "jets"

These topics are not considered in detail here, only because they are at present being extensively studied in the CERN 1.1 m^3 HLBC and do not need additional justification. We mention only two experiments which are particularly suited to Gargamelle:

i) Classification of many-body final states. The present high-energy HBC experiments are able to fit only about 20% of all interactions due to the presence in the remainder of two or more neutrals. Gargamelle, with its high π^0 and neutron efficiency, will be able to classify these many-body final states.

ii) Multi-Regge processes in "true" three-body final states. At present, comparisons between experiment and theory at high energies are usually restricted to quasi two-body processes. Recent attempts have been made, with a little success, to study "true" three-body final states, i.e. where no pair of the three final particles are resonating. These studies form a crucial link in the extension of theories from two- to many-body events. By selecting channels inaccessible to HBC's we can contribute usefully to this field. As always at high energies, the problem will be that the number of events in any one channel is small.

2.2 Λ/K^0 ratio in associated production

We consider here the reactions

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

$$\rightarrow \Sigma^0 + K^0 . \qquad (1b)$$

Above an incident pion energy of about 5 GeV/c, experiments in HBC's cannot distinguish between Λ and Σ^0. In terms of particle exchange models, it would be most interesting to see if the ratio of reaction (1a) to reaction (1b) at low energies (R = 1.6) is maintained in the 10-20 GeV/c region. Morrison[12] has pointed out that the cross-sections for many such reactions fall off with incident momentum as a power law, whose exponent is indicative of the type of particle exchanged. A measurement of the total cross-sections of these reactions at energies well removed from the present limit at which they can be resolved will provide a good test of this observation.

The experiment would be performed by scanning for π^-p interactions with zero prongs and two visible V^0, plus any number of γ rays. It is predominantly a scanning experiment with little measurement load, which would be an advantage in the early days of Gargamelle before systems for handling large measurement loads are developed. The problem is the paucity of events. Extrapolating the extensive data of Dahl et al.[13]), then at $p_\pi = 15$ GeV/c the cross-sections for reactions (1a) and (1b) are 11 and 7 μb, respectively. Thus 10^5 interactions on free protons yield 9 and 6 events, respectively, with two visible V^0.

The main background from $\pi^-p \to (\Lambda,\Sigma)K^0\pi^0$ is expected to be about 1:1, and thus easily removable using Gargamelle's high γ-ray detection efficiency. Indeed, the measurement of these background reactions would be a by-product of the experiment.

2.3 Production and decay of neutral bosons

It would be interesting to study the reactions

$$p + p \to p + p + M^0 ,$$

where M^0 is a scalar (π^0, η^0, X^0, E^0) or vector (ρ^0, φ^0, ω^0) meson. In particular, the $\pi^0 \to 2\gamma$, $\eta^0 \to 2\gamma$, $\omega^0 \to \pi^0\gamma$ modes with all γ's converted would provide high constraint fits. At an incident momentum of 15 GeV/c, the channels

$$p + p \to p + p + \begin{matrix}\pi^0\\ \eta^0\\ \omega^0\end{matrix}$$

each have a cross-section of about 0.8 mb (i.e. 2% of all interactions), and so we could gather sufficient statistics to study production mechanisms in detail. The relative production rates of π^0/η^0 well above threshold should be related to the amount of η-X^0 or η-E^0 mixing which occurs.

2.4 Search for the $\epsilon^0(S^0)$ meson

This $\pi\pi$ resonance was originally proposed$^{14)}$ as a possible source of the anomalous forward-backward asymmetry in $\rho^0 \to \pi^+ + \pi^-$. Since then, it has been looked for in a number of experiments in each of its decay modes $\epsilon^0 \to \pi^+ + \pi^-$ and $\epsilon^0 \to \pi^0 + \pi^0$. Published results at present show evidence both for and against its existence and taken as a whole are inconclusive. A heavy-liquid bubble chamber, and in particular one of the size of Gargamelle, is well suited to an investigation of the $\pi^0\pi^0$ decay mode. Gargamelle's suitability arises from its ability to maintain a good 4γ detection efficiency even when used with a long radiation-length filling.

To get an idea of the scanning and measuring load of a useful experiment, we assume that we are using the reaction $\pi^+ + H \to \pi^+ + p + \underset{\hookrightarrow 2\pi^0}{\epsilon^0}$ at 4 GeV/c. (Use of hydrogen events might be necessary to simulate as far as possible the conditions under which the ρ^0 asymmetry anomaly has been observed.) In these circumstances, using the Durand and Chiu ϵ^0 production cross-section $[\sigma(\epsilon^0)/\sigma(\rho^0) = 0.15]$ as an upper limit, we can expect a total background of $\pi + p + 4\gamma$ (non-resonating) events of about 30:1. This ratio is optimistic because the "1" is the upper limit for ϵ^0 production and pessimistic because it takes no account of the fact that production of the ϵ^0, if it takes place, will be largely with peripheral and quasi two-body (N^{*++}, ϵ^0). This will cause greater potential path-lengths for γ's originating in ϵ^0's than for other γ's, and will allow the use at the scan-table of simple templates for picking out both π^+p and 4γ configurations of restricted invariant mass range (~ 1236 MeV and 720 MeV, respectively). As an absolute yield one could expect, from 10^5 π^+H interactions, $\lesssim 250$ completely detected $\pi^+ + H \to \pi^+ + p + \underset{\hookrightarrow 2\pi^0}{\epsilon^0}$, with a background of $\lesssim 7500$ $\pi^+ + H \to \pi^+ p + 4\gamma$ (detected).

If use were not made of the 4γ invariant mass template, the experiment could look at the $\pi^0\pi^0$ system from ~ 0.3 GeV to ~ 1.8 GeV mass (at 4 GeV/c beam momentum). At various times, several 0^+ resonances have been suggested in this range.

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3. THE POSSIBILITY OF STUDYING THE DECAYS OF K_2^0 MESONS IN THE GARGAMELLE CHAMBER

3.1 Introduction

Recently, serious problems have arisen regarding the study and interpretation of K^0 decay modes as well as in the comparison with K^+ decay. For example:

i) the value of η_{00} appears to be uncertain[15];

ii) the $|\Delta I| = 1/2$ rule appears to be violated by 3 standard deviations when comparing K^+_{e3} with K^0_{e3} decay rates[15,16];

iii) the value of the form factor ratio ξ appearing in K^0 leptonic three-body decays (as in the corresponding K^+ decays) seems to depend upon the experimental method used for its determination (branching ratio, spectra or polarization measurements)[15];

iv) the experimental results concerning the K_2^0 and K^+ decay rates into three-pion final states are also in bad agreement with the predictions of the $|\Delta I| = 1/2$ rule, assuming CP violation effects to be negligible[16,17].

Previous experiments on K_2^0 decays have been faced with several difficulties, of which we may mention:

i) a poor knowledge of the K_2^0 momenta, implying the loss of one constraint in the fitting procedures; in the case of $K^0_{\ell 3}$ decays this leads to a two-fold ambiguity in the decay kinematics;

ii) bad discrimination between pion, muon, and electron (positron) secondaries, typical of experiments performed with hydrogen bubble chambers.

3.2 Sources of momentum-defined K_2^0's

In Gargamelle, the problem of defining the K_2^0 momenta seems to be the major one, and this requirement meets fundamental difficulties.

The decays of K_2^0 mesons with well-defined momenta could be studied by two methods.

i) with the help of an external monochromatic K_2^0 beam;

ii) by producing K_2^0 mesons inside the chamber, in kinematically over-constrained reactions such as $K^+ + p \rightarrow K^0 + p + \pi^+$.

The second method requires the observation of the decays of K_2^0 mesons travelling through propane. The collision length of propane (119.3 cm) is unfortunately very small compared to the longitudinal dimension (4.8 m) of the chamber and the K_2^0 decay length (32 m at 1 GeV/c K_2^0 momentum). Supposing one produces K_2^0 mesons of 1 GeV/c momentum with an average potential path inside the chamber of the order of 3 m, roughly 15% of the K^0 mesons will leave the chamber, 80% will interact[18]) and 5% will decay. This very unfavourable interaction to decay rate makes the use of the second method very questionable, and strongly favours the use of a decay pipe and an external beam.

The solution to the problem of obtaining a monochromatic K_2^0 beam is by no means obvious.

The two-body final states of two types of primary interactions have been used up to now:

$$\pi^- + p \rightarrow \begin{cases} \Sigma^0 + K^0 & \text{(2a)} \\ \Lambda^0 + K^0 & \text{(2b)} \end{cases}$$

$$K^+ + d \rightarrow K^0 + p + p \text{ (spectator)} \ . \qquad (3)$$

Reactions (2a) and (2b) have not been separated and thus lead to the observation of two peaks in the K^0 momentum distribution. Reaction (3) has been used by Kadyk et al.[19]), but the K^0 momentum distribution obtained was spread out from 100 to 500 MeV/c while peaking at 280 MeV/c.

A possible method of obtaining a momentum-analysed K_2^0 beam is by the time-of-flight method. The method would consist of restricting oneself to 1 bunch of the PS and 1 decay/picture. The pipe through the chamber would have a particle-detecting sleeve, and hence be used to measure the time-of-flight of the K_2^0 decay.

3.3 Non-momentum defined K_2^0 beams

The use of a pipe allows one to study K_L^0 decays, and with a suitable thin regenerator also K_S^0 decays, with interference between the modes. The advantages of such an arrangement lie in the ability to study the K_L^0 decays at all (compared with 1 and 2), and in the much higher number of such decays one could, in principle, obtain. Thus, three K_L^0 decays/frame would be quite acceptable, which over a 4 m length at a momentum of 1 GeV/c implies a flux of about 30 K_L^0/pulse at the chamber. Over a wide momentum band such a number is quite possible. Restricting the momentum by, for example, using a momentum-analysed beam onto a thin hydrogen target for production, would probably reduce the flux by several orders of magnitude. Observing ~ 250,000 K_L^0 decays one would obtain, for example, ~ 750 $K_2^0 \to 2\pi^0$ decays, 60×10^3 $3\pi^0$ decays, 30×10^3 $\pi^+\pi^-\pi^0$ decays (based on presently known branching ratios). The presence of a regenerator would allow interference experiments between $K_S^0 \to 2\pi^0$ and $K_L^0 \to 2\pi^0$.

The disadvantages of a pipe are well-known. We mention

i) scattering in the walls, yielding an uncertainty in the decay point and hence in the direction of the decay products;

ii) probability of decay in the pipe, giving rise to misassignment of the decay mode. This probability is a function of both momentum and direction of the track, and so will be hard to correct for to the precision that experiments will require. If a pipe experiment were to be done, the minimum diameter pipe with minimum wall thickness would be essential.

3.4 Conclusions

We conclude that although the use of a pipe or an external monochromatic beam causes intrinsic difficulties, it is our feeling that the physics to be studied in K_2^0 decay is of sufficient importance to investigate this possibility in further detail.

4. PHYSICS IN THE MEDIUM-ENERGY K BEAM G2

4.1 Introduction

This energy region lends itself well to the properties of heavy-liquid bubble chamber, and by the time Gargamelle is in production we will have had preliminary studies in the T8, T11, and foreseen Nimrod K11 experiments.

4.2 Ξ^0 decay properties

Whereas the total number of Ξ^- particles available in the world statistics is several thousands, only a few hundred Ξ^0's exist for the determination of the decay properties. It is this lack of statistics, and the rather incomplete method of analysis used with the hydrogen chamber events, which still makes it interesting to increase by an order of magnitude the number of Ξ^0's available and thus check the $\Delta I = 1/2$ rule.

Considering a propane-freon mixture with 50 cm radiation length, then for Ξ^0's produced by ~2 GeV K^- in the two-body mode

$$K^- + p \rightarrow \Xi^0 + K^0 ,$$

the detection efficiency is the maximum possible, i.e. 23%.

Assuming that the beam could traverse two useful metres of the chamber and that 20 beam tracks, well spread out, can be obtained, then one would obtain in 5×10^5 pictures:

~1000 complete Ξ^0 K^0 20) two-body events
~1500 Ξ^0 from the pionic channels
~1000 Ξ^0 K_1^0 from the complex nuclei events.

Thus a sample of ~3000 Ξ^0 events would be available for the lifetime and α parameter studies. The 1000 two-body hydrogen events would be used to determine the β, γ parameters.

In addition, a sample of ~10^4 Ξ^- would be produced, and hence rare decays, such as $\Xi\beta$, $\Sigma^-\gamma$ could be looked for.

4.3 Neutral boson decay modes

By using the reaction $K^- + p \rightarrow \Lambda^0$ + neutral, the decay modes of the following mesons could be investigated.

i) X^0 decay modes

Taking the well-established X^0 production cross-section of 90 μb 20) at 2.2 GeV/c, then in the above exposure there would be produced ~3500 X^0 on free protons, thus giving an excellent sample for the study of the various decay modes.

ii) φ decay modes

The production cross-section of 73 μb [20] would give a sample of ~3000 φ decays.

iii) ω decay modes

A very large sample of ω mesons would be produced, ~16,000 for a production cross-section at 280 μb [20].

4.4 Λβ decay

Due to the fact that abundant $\bar{\nu}$ elastic-hyperon production is still a long way off, Λβ decay can still be considered an interesting field of research.

One could expect ~2000 Λβ decays[21], i.e. an order of magnitude more than the world sample.

The maximum analysis power is obtained if the parent Λ^0's have the maximum possible polarization. Thus, depending on the emphasis of the various other physics aspects of the K^- exposure, the K^- momentum could be adjusted to give the best polarization.

4.5 Y* production

It would be very interesting to continue the foreseen K11 work in order to study Y* decay into $\Sigma^0\pi^0$, $\Lambda\pi^0\pi^0$, and various other modes.

For example, to carry out a formation experiment between 1.5 GeV/c to 2.2 GeV/c would essentially not affect the Ξ^0 yield, but would diminish somewhat the X^0 yield.

Depending on the interest of the various topics at the time of exposure the choice between a formation or production experiment could be made.

5. PHYSICS IN THE HIGH-ENERGY K BEAM G3

5.1 Introduction

This note is intended to point out some of the more interesting experimental fields which could be investigated by means of exposures of Gargamelle to high-energy K beams. In this note we shall limit ourselves to K momenta greater than 5 GeV/c.

5.2 Production of Ω^-

The present world total of unambiguous Ω^- is 14. The paucity of events is due to the small production cross-section. Most of the observed Ω^- decay in the mode (ΛK^-) but this may be due to the fact that the ($\Xi^-\pi^0$) and ($\Xi^0\pi^-$) modes are more difficult to detect in hydrogen chambers and are also more likely to be ambiguous with other, more probable, processes. By a suitable choice of liquid, all these decay modes could be detected with high efficiency in Gargamelle. Since the decay vertex would be fully measurable, both hydrogen and heavy nucleus events are useful. Thus Gargamelle would be a very efficient instrument for studying whatever Ω^- were produced.

For decays into the mode (ΛK^-), a cross-section of 0.9 μb was found at 5.5 GeV/c 22) and 2.5 μb at 10 GeV/c 23). Thus one million K^- interactions at 10 GeV/c would give over 100 Ω^-. This would permit the principal branching ratios, lifetime, and decay parameters to be determined.

On the basis of a comparison of all available Ω^- production data, it has recently been suggested 24) that the Ω^- observed may be coming from the decay of a massive Ξ^* (mass 2.7 GeV/c^2). If this is in fact the case, it is likely that the Ω^- production cross-section in some region between 5 and 10 GeV/c is larger than those so far observed. This would permit a more rapid accumulation of events at a suitably chosen K^- momentum.

5.3 Production of S = -2 baryon resonances

Total Ξ production is a maximum for beam momenta around 2 GeV/c, but in order to search for Ξ^* resonances with masses above the three presently observed (1.530, 1.815, 1.930 GeV/c^2), higher momenta are required. A K^- beam of momentum 5 GeV/c would permit Ξ^* of up to 2.75 GeV/c^2 to be created. The good γ-conversion probability would be invaluable in assigning isobaric spin by means of the decay ratio $\Xi^-\pi^+/\Xi^0\pi^-$ and is essential for the corresponding neutral ratio $\Xi^0\pi^0/\Xi^-\pi^+$.

5.4 Investigation of S = 0 neutral bosons

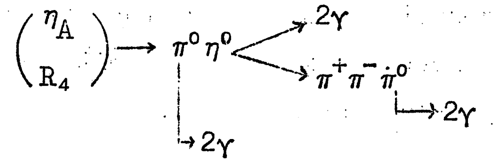
The method used is to produce the bosons in reactions of the type

$$K^- + p \rightarrow \Lambda + X^0$$

where X is any boson, and the interaction takes place on the free protons in propane or a mixture. The momentum and angle of the Λ already identify the mass of X without relying on measurement of the decay products which will usually include γ's. The feasibility of this method will be shown by currently proposed experiments at lower energy[25)].

A 7 GeV/c K^- beam would permit exploration of S = 0 bosons up to a mass of 2.4 GeV/c^2. The region of mass between 1.6 and 2.4 GeV/c^2 is at present very oonfused, with 12 fairly well-established resonances and evidence of several more. Observation of particular neutral decay modes of resonances can serve to establish their isobaric spin, and hence to check the correspondence between resonances observed at similar masses in neutral and charged modes. As an example, we will take the case of the $\eta_A(1830)$.

This resonance has been observed in the combinations $\rho^0\pi^+\pi^-$ [26)] and $K\bar{K}\pi^0$ [27)]. A negatively charged resonance R_4 at a similar mass has been observed in the missing-mass spectrometer[24)]. If the two resonances are identical, the isobaric spin must be > 0. An exposure of Gargamelle to a 5 GeV/c K^- beam could provide an appreciable number of η_A or R_4. This film could be scanned for the decay



The topology would be zero-prong or two-prong, Λ, and four (e^+e^-) pairs. The large size of Gargamelle would provide about 20% detection efficiency for all four γ's in either mode, even in pure propane. The decay $\pi\eta$ is chosen because it can only occur for an I = 1 state, and therefore its observation would prove the correspondence of the charged and neutral resonances. Furthermore, limits could be placed on the spin-parity assignment, since this decay is only allowed for $(\text{even})^+$ or $(\text{odd})^-$ J^P states.

5.5 Production of S = -1 baryon resonances

A K^- beam of momentum 5 GeV/c would permit the production of S = -1 baryon resonances of mass up to 3 GeV/c^2. In this region there are at present 20 known states. The resonances may be observed in either "production"- or "formation"-type experiments. In "production"-type experiments, the resonances are produced in association with other particles, and therefore a wide mass region may be explored at a given beam momentum. In "formation"-type experiments, the resonance is produced alone, and a range of mass is obtained by varying the beam momentum. This type of experiment is useful when it is desired to study closely a narrow mass region.

One of the principal advantages of the heavy-liquid bubble chamber is that is permits a study of neutral modes of well-defined isobaric spin. For example, the modes $\Sigma^0\pi^0$, $\Lambda\eta$, $\Lambda\pi^0\pi^0$ are $I = 0$, whereas $\Lambda\pi^0$, $\Lambda 3\pi^0$, $\Sigma^0\eta$ are $I = 1$. All these modes lead to the emission of two or more γ's and are difficult or impossible to observe in a hydrogen chamber (without plates). In general, the distinction between Λ and Σ^0 is crucial to isobaric spin assignment, and as the beam energy increases the discrimination becomes more and more difficult unless the decay γ of the Σ^0 is actually observed.

5.6 Coherent production of S = ±1 bosons

This is the so-called "diffraction-dissociation" process, and its study depending on the results of the present "jet" experiment could be one of the major contributions of heavy-liquid chambers to high-energy physics. The interactions observed are of the type:

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

where the carbon nucleus remains in its ground state. Such interactions of pions have already been observed$^{28)}$. The interesting features of this process are that the (K-pion) system is produced in only certain spin-parity states, i.e. 0^+, 1^-, 2^+, etc, and that when the spin change is non-zero the final boson has its spin oriented perpendicular to its momentum. These features make the coherent production mechanism an extemely valuable tool in determining the spins and parities of resonances.

However, the requirement that the interaction be coherent severely limits the allowed region of four-momentum transfer and thereby the range of (K-pion) masses which are accessible. The (K-pion) resonance of lowest mass so far observed is the K*(892). According to a formula given by Cocconi$^{29)}$, a K momentum of greater than 5.5 GeV/c is necessary in order to produce this resonance coherently. This therefore indicates the region of K momenta necessary for experiments which aim to exploit this process.

The evident advantages of Gargamelle in this field are that the large size permits good detection efficiency for γ's in modes such as $K^-\pi^0\pi^0$, with a fairly light liquid giving good measurability of the e^+e^- pairs. The long length will also permit accurate momentum measurements on very high energy charged tracks.

It is clear that in this type of exposure there would also be a large amount of incoherent production of (K-pion) resonances, thus permitting an exploration of the high-mass spectrum. A 5.5 GeV/c $K^{\pm}$ beam would allow incoherent production up to a (K-pion) mass of 2.4 GeV/c².

6. MUON PHYSICS IN GARGAMELLE

6.1 Précis of the results of a test run in the CERN HLBC

A short muon run in the CERN HLBC (requested in the Letter of Intention CERN/TC/COM/66-37 and carried out during the 1967 neutrino experiments) has shown the technical feasibility of investigating muon interaction in a heavy-liquid bubble chamber, using a wide-momentum-band muon beam of ~80 muons per pulse. If the muon tracks are properly distributed in the chamber, fluxes of 100 tracks per picture should be usable.

In 15,000 pictures (scanned in Oxford, Padua, Wisconsin, and CERN) containing ~1.2 × 10^6 tracks with an average momentum of 3 GeV/c, a total of 125 events were found. A sample of 108 events has been measured and analysed at Wisconsin. The events can be tabulated as follows:

Event type	Number found
Non-pionic (about 1/2 single proton recoil)	67
π^+ production	12
π^- production	11
π^0 production (γ observed)	4
2π production (all $\pi^+\pi^-$)	13
$\pi^+\pi^-\pi^+\gamma$	1

This corresponds to σ_{total}/nucleon = 4.3 μb. Including some 30 multinucleon events as inelastic [pion production and absorption in the nucleus$^{30)}$], and accounting for three times more π^0 events (γ detection efficiency ≃ 25%), a total inelastic cross-section of ~3.1 μb is found, which is in reasonable agreement with emulsion data$^{31-33)}$. The $p\pi$ invariant mass distribution indicates N*(1238) production.

6.2 Muon interactions which could be studied in Gargamelle

Extrapolating these results to a one-million picture run in Gargamelle (100 muons/picture, 4 m fiducial track length), some 50,000 events could be expected, 9,000 of which will be free proton events (2000 free proton events per μb). Several interesting topics for study could be the following:

6.2.1 $\mu + p \rightarrow \mu + N^*$

Several thousand 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 properties of the nucleon isobars, since the form factors have simple threshold behaviour³⁴⁾.

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 pions³⁵⁾, and angular correlations could be studied.

6.2.2 $\mu + p \rightarrow \mu + N^* + \pi$ (soft)

Adler and Weisberger³⁶⁾ 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 100 events of the above type on free protons could be expected per 10^6 photos.

6.2.3 $\mu + p \rightarrow \mu + p + \rho^0$

For this reaction the carbon events can be used as well, so that some 50-100 ρ^0's could be expected per 10^6 pictures (concluded from electroproduction of ρ^0 ³⁷⁾. It should be possible to determine cross-sections, rough four-momentum transfer dependence, and the ratio with respect to charged ρ-production.

6.2.4 $\mu + C \rightarrow C + \mu + \gamma$

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. Here, the advantage of the bubble chamber is that confusion between bremsstrahlung and knock-on electron gammas is reduced.

6.3 Beam facility

It should be pointed out that the test beam for the ν detectors -- used for the above-mentioned muon exposure -- could be used also for a muon experiment in Gargamelle.

By optimizing the hadron absorber (for the average muon momentum) and the target (for forward production, about one interaction length long), a fraction of the full PS intensity would be sufficient to yield several 100 muons with ≥ 8 GeV/c momentum.

These could be separated from the lower momenta by proper arrangement of two magnets in front of the chamber.

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22 février 1968

ETUDE DES ANNIHILATIONS D'ANTIPROTONS
AVEC PRODUCTION DE PARTICULES NEUTRES

Proposition d'expérience pour Gargamelle étudiée par les
groupes du Collège de France et de l'Ecole Polytechnique
la participation de A. Astier, M. Della Negra, A. Rousset et
R. Salmeron

Paris, France.

1. INTERET DE CETTE ETUDE

L'étude des annihilations d'antiprotons à l'arrêt en chambre à bulles à hydrogène ne peut être complète, car la production de deux particules neutres indétectables directement (π^0, K^0_L, γ) est très fréquente. En particulier, dans 60 % des annihilations purement pioniques, il y a émission d'au moins 2 π^0 :

$$\begin{array}{lr} \bar{p}p \rightarrow 3\pi^0, 4\pi^0, \text{ etc.} & 3.5\ \% \\ \bar{p}p \rightarrow \pi^+\pi^- + 2\pi^0, 3\pi^0 & 35\ \% \\ \bar{p}p \rightarrow \pi^+\pi^+\pi^-\pi^- + 2\pi^0, 3\pi^0 & 21\ \%\ . \end{array}$$

D'autre part, parmi les annihilations avec mésons K, les couples $K^0_L\pi^0$ et $\pi^0\pi^0$ sont assez fréquents, par exemple :

$$\begin{array}{l} \bar{p}p \rightarrow K^0_S K^0_L \pi^0 \\ \bar{p}p \rightarrow K^0 K^0 \pi^0 \pi^0\ . \end{array}$$

La chambre à bulles à liquides lourds est particulièrement bien adaptée à l'étude de ces annihilations avec particules neutres. On y bénéficie en effet des avantages suivants :

i) Détection dans l'angle solide 4π des particules émises isotropiquement dans l'annihilation d'un antiproton à l'arrêt.

ii) Détection des particules neutres : γ par les paires e^+e^-, π^0 par les 2 γ, K^0_L par interaction dans le liquide.

iii) Identification des particules $\pi^\pm$ et $K^\pm$ par leur arrêt dans la chambre.

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iv) Mesures précises des énergies des particules :

±1 % pour les particules chargées qui s'arrêtent;

±4 % pour les particules chargées par la courbure;

±12 % pour les γ .

La détermination des taux dans toutes les voies serait certainement l'objet d'un premier travail intéressant par la comparaison des modes chargés et des modes neutres.

Certaines voies présentent des intérêts tout particuliers :

1.1 Le $\pi^+\pi^-\pi^0$

Un lot très pur pourrait être obtenu permettant une analyse du diagramme de Dalitz sans contamination de $2\pi^0$, à la différence de ce qui a déjà été fait en chambre à bulles à hydrogène.

1.2 Le $3\pi^0$

La production de $\rho^{\overset{0}{\pm}}$, abondante dans le $\pi^+\pi^-\pi^0$, est ici supprimée. Il est très intéressant de voir ce qu'il restera effectivement dans le diagramme de Dalitz, le f^0 en particulier. On pourra aussi y rechercher la contribution de l'interaction $\pi\pi$ dans les états $T = 0$ ou 2.

1.3 Le $\pi^+\pi^-\pi^0\pi^0$

Cette voie est très abondante. L'étude du ρ devrait y être plus facile que dans la voie $\pi^+\pi^-\pi^+\pi^-$, car pour un ρ d'un signe donné les fausses combinaisons sont moins nombreuses.

1.4 Les systèmes $\pi^+\pi^-\gamma$ et $\pi^+\pi^+\pi^-\pi^-\gamma$

Ces voies permettent des tests de la violation de C dans les interactions électromagnétiques.

1.5 Le K^0_S-$K^0_L\pi^0$

Son étude compléterait l'analyse du diagramme de Dalitz du 3 corps $K\bar{K}\pi$ (avec les résonances $K\bar{K}$, K^*, φ, etc.).

1.6 Le $K^0_S K^0_L\pi^0\pi^0$

Le C^0 doit être produit d'une manière très pure; l'étude de ses nombres quantiques en serait très facilitée.

2. METHODE EXPERIMENTALE

Nous proposons d'utiliser Gargamelle remplie d'un mélange de propane et de fréon avec des proportions en volume respectives de 80 % - 20 %. La probabilité de détection des γ y sera égale à 95 %.

Il est préférable d'obtenir l'annihilation de l'antiproton sur un proton libre pour au moins deux raisons :

i) Utiliser un fit à la production, sans intervention de moment de Fermi, et interactions secondaires dans le noyau.

ii) Comparer les résultats avec ceux qui ont été obtenus en chambre à bulles à hydrogène : analyse de l'état S, par exemple.

Pour obtenir les annihilations sur proton libre dans Gargamelle, deux méthodes sont à priori possibles :

i) L'utilisation d'une cible à hydrogène placée à l'intérieur de Gargamelle. Mises à part quelques difficultés techniques, cette méthode a l'inconvénient de n'autoriser qu'une seule annihilation par photo et d'introduire des difficultés dans l'analyse, à cause de la non-visibilité des vertex $\bar{p}p$ et de la désintégration du K_S^o en $\pi^+\pi^-$.

ii) L'utilisation de l'hydrogène libre de la molécule de propane C_3H_8. Il est possible qu'un antiproton à l'arrêt dans le mélange s'annihile préférentiellement avec les protons de la molécule de propane. Cette question peut être facilement étudiée dans une expérience test dans la chambre à liquides lourds du CERN.

A titre d'exemple, voici quelques nombres d'événements obtenus avec 200 000 annihilations.

$3\pi^o(6\gamma)$	2 000
$\pi^+\pi^-\pi^o(2\gamma)$	10 000
$\pi^+\pi^-\pi^o\pi^o(4\gamma)$	7 000

Pour étudier plus particulièrement les modes avec mésons K, une statistique de 10^6 annihilations serait certainement nécessaire.

Enfin remarquons que les antiprotons doivent pénétrer dans Gargamelle avec un moment égal à 1 GeV/c environ. Il est possible d'étudier aussi les annihilations en vol de l'arrêt jusqu'à 1 GeV/c et de compléter ainsi ce qui sera fait dans la chambre à bulles à hydrogène dans les modes chargés.

22 février 1968

PROPOSITION D'EXPERIENCE K_2^0 DANS GARGAMELLE

Proposition d'expérience pour Gargamelle étudiée par
le groupe de l'Ecole Polytechnique avec la participation de
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Paris, France.

Il semble que les expériences en cours sur les K_2^0 ne puissent encore faire la lumière complète sur les propriétés de ces particules, surtout en ce qui concerne les facteurs de forme dans les désintégrations leptoniques $K_2^0 \to \mu^{\mp}\pi^{\pm}\nu$. La plupart des difficultés actuelles semblent provenir essentiellement de deux raisons :

i) On ne connaît pas le moment du K^0, ce qui rend problématique le choix entre les deux solutions trouvées dans le calcul de la transformation système du laboratoire → système du centre de masse du K^0, ce qui peut entraîner des biais importants pour la détermination des facteurs de forme aussi bien par l'analyse de la polarisation du μ que par l'étude de la densité du Dalitz plot.

ii) La plupart des expériences à haute statistique sur les K_2^0 sont faites en chambre à étincelles, où la probabilité de détection de l'événement varie beaucoup en fonction de la configuration, et doit être calculée très soigneusement. De plus, pour l'étude des facteurs de forme par la densité de population du Dalitz plot, les configurations les plus intéressantes ont souvent une probabilité de détection très faible dans ces expériences.

Il paraît donc intéressant d'envisager une expérience de chambre à bulles dans laquelle on observerait quelques milliers de désintégrations de K_2^0 d'énergie connue.

En ce qui concerne les désintégrations leptoniques ($K_{\mu 3}^0$, K_{e3}^0), la détection sensiblement uniforme de toutes les configurations d'événements permettrait d'espérer une bonne détermination des facteurs de forme par l'analyse de la densité du diagramme de Dalitz. D'autre part, les dimensions de la chambre sont suffisantes pour qu'un grand nombre de μ puissent s'arrêter, ce qui permettrait une étude de leur polarisation, le passage au système du centre de masse se faisant sans ambiguïté, et la composante transverse de la polarisation, en particulier, étant correctement estimée.

En ce qui concerne les désintégrations non leptoniques, l'intérêt de l'expérience est sans doute moins évident, bien que beaucoup de travail reste encore à faire, en particulier sur le mode $3\pi^0$ et sur la conservation de PC. Ce dernier point exige des K_2^0 dont le temps de vol est connu, c'est-à-dire produits dans la chambre.

Deux solutions ont été envisagées dans ce qui suit, mais aucune d'entre elles n'est extrêmement satisfaisante du point de vue de l'intensité dans l'état actuel des possibilités du faisceau :

- Production des K_2^0 dans la chambre par échange de charge de K^+ sur des protons.
- Observation des désintégrations de particules provenant d'un faisceau de K_2^0 monocinétiques, traversant la chambre à l'intérieur d'un tuyau (cf. expérience X_4).

1. PRODUCTION DE K_2^0 PAR ECHANGE DE CHARGE DANS LA CHAMBRE

Les K^+ doivent interagir sur proton libre, le mélange utilisé doit donc être aussi riche en hydrogène que possible. La réaction de production est :

$$K^+p \to K^0p\pi^+ .$$

La direction du K^0 étant connue, l'impulsion du K^0 est déterminée à la production (3C si le proton est bien mesurable), et l'on peut séparer les événements sur hydrogène.

Le propane serait *a priori* le liquide le plus favorable, mais il faut :

- arrêter le plus grand nombre possible de μ pour étudier leur polarisation;
- séparer sans erreur les π et les μ, grâce aux interactions que font les premiers.

Ceci conduit à augmenter la densité du liquide, ce qui aura aussi l'avantage d'une meilleure détection des γ dans les modes pioniques. Le mélange 50% propane - 50% CF_3Br est un compromis possible, pour lequel un μ de 500 MeV a un parcours de 2 m.

L'impulsion du faisceau de K^+ doit être comprise entre 1 et 1,5 GeV/c pour que la production d'un seul π soit maximum. Il faut la choisir aussi basse que possible (arrêt des secondaires de K_2^0 dans la chambre). La section efficace de production de K^0 est alors d'environ 5 mb, et le libre parcours correspondant dans le mélange est de 100 m. Mais la section efficace totale sur nucléon étant de l'ordre de 20 mb, il y a environ une réaction utile sur proton libre pour 40 réactions non utilisables (bien que beaucoup d'entre elles fournissent des K^0 qui seront gênants pour l'analyse).

Dans une photo où 10 K^+ traversent la chambre et y interagissent, il y aura donc 0,25 K^0 produit, donc 0,1 K_2^0 émis.

On observera la désintégration de 5% de ces K_2^0 (parcours utile 1,5 m, impulsion moyenne 0,5 GeV/c) ce qui conduit à 0,005 désintégration par photo.

Si l'on s'intéresse au mode $K_{\mu 3}$ (rapport de branchement 25%), on obtiendra donc environ un événement pour 1 000 photos. Il faut donc plusieurs millions de photos pour que l'expérience soit intéressante, et les événements utiles sont noyés dans un important bruit de fond.

En ce qui concerne le mode $\pi^+\pi^-\pi^0$ (rapport de branchement 12%), on disposerait d'un événement d'impulsion connue à la production pour 2 000 photos. Cependant, pour ce mode, la mesure des γ et la connaissance de la ligne de vol du K^0 permettent un "fit" (1C) et par conséquent la nécessité de connaître <u>a priori</u> l'impulsion est moins grande. Si l'on tient compte alors de tous les K_2^0 produits par interaction de K^+ sur les noyaux lourds du mélange, on peut espérer 5 000 désintégrations observables par million de photographies.

Pour le mode $3\pi^0$, il semble indispensable d'avoir l'information a priori de l'impulsion du K^0. En admettant une probabilité d'observer les 6γ de l'ordre de 50%, on est conduit à 500 événements observables par million de photographies.

2. FAISCEAU DE K_2^0 MONOCINETIQUE TRAVERSANT LA CHAMBRE DANS UN TUYAU

Dans cette expérience, les K_2^0 sont produits à l'extérieur de la chambre à l'aide d'un faisceau très intense de π^- monocinétiques par la réaction :

$$\pi^- p \rightarrow \Lambda^0 K^0 \quad .$$

La cible à hydrogène où a lieu la réaction est regardée sous un angle donné, de manière que l'énergie des K_2^0 émis soit bien définie. Le problème principal est encore ici un problème d'intensité.

En prenant des π^- de 1 GeV/c, et en regardant les K^0 émis à 50° dans le laboratoire (106° dans le système du centre de masse), on sélectionne des K_2^0 de 400 MeV/c. La section efficace $d\sigma/d\Omega$ est de l'ordre de 80×10^{-3} mb/sr dans le laboratoire. Le nombre de K_2^0 produits dans l'angle solide utile pour le faisceau est alors :

$$N_{K_2^0} = \frac{1}{2} \times \frac{\ell}{\lambda} \times \left(\frac{\pi r^2}{D^2}\right) \times N_{\pi^-} \;,$$

où ℓ est la longueur de la cible à hydrogène, λ le libre parcours des π pour la réaction $\Lambda^0 K^0$, r le rayon du faisceau dans la chambre, et D la distance entre la cible et le centre de la chambre.

Dans les conditions ci-dessus, on obtient $\lambda = 6 \times 10^5$ cm. En choisissant $\ell = 30$ cm, $r = 5$ cm, et $D = 500$ cm, on obtient :

$$N_{K_2^0} = 7 \times 10^{-9} N_{\pi^-} \;.$$

Il faut maintenant que ces K_2^0 arrivent dans la chambre et s'y désintègrent. Le parcours moyen de ces K^0 étant de 12 m, on obtient pour l'observation dans la chambre un facteur 0,1, ce qui donne :

$$N_{K_2^0} = 7 \times 10^{-10} N_{\pi^-} \;.$$

Avec 10^{12} protons de 30 GeV, on peut produire à 9° environ 10^{12} π^- de 1 GeV/c par steradian et par GeV/c. Si l'on suppose une acceptance de 10^{-3} steradian, on arrive donc à 10^9 π^- dans une bande de 1 GeV/c.

Or le $\Delta p/p$ du faisceau de K_2^0 est lié uniquement au $\Delta p/p$ du faisceau de π^-, car la variation de l'angle d'émission du K^0 est petite (de l'ordre du degré). Il serait souhaitable que l'impulsion des π soit définie au pire à 5% près, ce qui donnerait sur le moment du K^0 une incertitude de l'ordre de 20 MeV/c.

Il est donc nécessaire que la bande d'impulsion des π soit de l'ordre de ± 50 MeV/c, ce qui conduit à 10^8 π^-.

Ce chiffre permet donc d'espérer une désintégration de K_2^0 pour 15 photos (ou 70 000 par million de photos). Cette intensité est notablement meilleure que celle obtenue par la première méthode : un run de 300 000 photos dans ces conditions fournirait 5 000 désintégrations $K_{\mu 3}^0$.

16 février 1968

Proposition d'expérience pour Gargamelle

ETUDE DE LA REACTION $K^-p \rightarrow \Sigma^0\pi^0$ DE 1,2 GeV/c A 2,4 GeV/c

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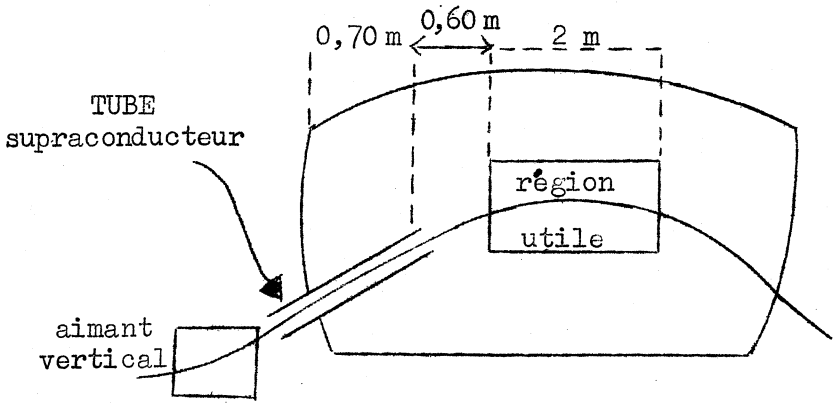
Cette expérience pourrait être une continuation de l'expérience T 133 (TCC 66-30 et TCC 67-5) qui doit être effectuée dans la chambre du NPA au cours de la période 1968-1969. C'est essentiellement une expérience de formation des resonances Y^{*0}. On sait déjà qu'il existe deux états résonants Y^{*0} aux environs de la masse 2100 correspondant à un moment de K^- égal à 1,7 GeV/c, et aux environs de la masse 2350 correspondant à un moment de K^- égal à 2,3 GeV/c.

CONDITIONS EXPERIMENTALES

L'utilisation de Gargamelle avec des faisceaux de basse énergie est difficile, car le rayon de courbure est plus petit que la dimension de la zone où règne le champ magnétique. Il est donc particulièrement indiqué d'utiliser un tube supraconducteur -- annulant le champ magnétique -- pour amener les particules à l'intérieur de Gargamelle, sur une profondeur de 70 cm environ. La longueur utile de la trajectoire du K^- sera de l'ordre de 2 mètres.



Le mélange optimal doit tenir compte d'une bonne efficacité de détection des γ, de l'ordre de 90%, et d'une proportion d'hydrogène maximale car seules les interactions hydrogène seront utiles. Un mélange de 85% propane - 15% fréon

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(en volume), de densité 0,60 et de 50 cm de longueur de radiation, semble être un bon compromis: 20% des interactions seront des interactions hydrogène, et la probabilité de matérialiser un γ sur 150 cm sera supérieure à 90%. Le ralentissement des K^- dans ce mélange sera de l'ordre de 1,5 MeV/c/cm. Les 200 cm de longueur utile permettent d'explorer une bande de moment de K^- de 300 MeV/c; quatre séries de photographies seront nécessaires pour couvrir le domaine de 1,2 à 2,4 GeV/c. Les K^- doivent parcourir 60 cm avant d'entrer dans le domaine utile, ce qui correspond à un ralentissement de 100 GeV/c. Les quatre impulsions pour les K^- sont donc 2,5, 2,2, 1,9, et 1,6 GeV/c.

En estimant les sections efficaces de la réaction $K^-p \rightarrow \Sigma^0\pi^0$ à partir des réactions $K^-p \rightarrow \Sigma^\pm\pi^\pm$, et en demandant 300 événements par intervalle de 100 MeV/c, on obtient le nombre de photos nécessaires, avec les hypothèses suivantes:

15 K^- par photo;
6 interactions utiles;
Probabilité de détection = 0,9;
Proportion d'événements hydrogène = 0,20.

60 000 photos à 1,6 GeV/c;
95 000 photos à 1,9 GeV/c;
150 000 photos à 2,2 GeV/c;
275 000 photos à 2,5 GeV/c *).
580 000 photos

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*) Voir la proposition suivante pour l'étude des mésons et d'autres réactions intéressantes dans ce dernier run.

15 février 1968

ETUDE DES MESONS X^0, φ, ω et η, ET DES HYPERONS $\Lambda\Sigma\Xi$
TEST DE LA REGLE $\Delta S = \Delta Q$, TEST DE LA REGLE $\Delta S < 2$, TEST DE LA REGLE $\Delta I = \frac{1}{2}$
(K^- de 2,25 GeV/c) *)

Proposition d'expérience sur Gargamelle discutée par
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L'étude des mésons X^0 et φ a jusqu'ici été limitée par la statistique; les sections de production sont faibles. La chambre à liquide lourd présentera l'avantage d'un taux de production élevé.

i) Les modes de branchement électromagnétiques de ces mésons sont particulièrement intéressants; leur étude implique l'observation de γ et d'électrons; ceux-ci peuvent être détectés et identifiés facilement avec une grande efficacité dans Gargamelle.

ii) Les tests de la violation de C sont particulièrement sensibles dans le cas du X^0; ils peuvent être effectués dans cette expérience.

iii) Dans une expérience optimisée pour le X^0 et le φ, des résultats peuvent être aussi obtenus pour le ω et le η.

iv) La limite de $\Delta S/\Delta Q = -1$ actuelle dans le $\Sigma^+ \rightarrow \eta e^+ \nu$ est obtenue à partir de plusieurs longues expériences. Nous pouvons dans cette expérience obtenir l'équivalent de la statistique mondiale.

v) La règle $\Delta S = 2$ est vérifiée avec précision dans la différence de masse $K_1 - K_2$ seulement. Nous pouvons espérer tester cette règle dans la recherche des processus $\Xi \rightarrow N\pi$ avec sensiblement un ordre de grandeur par rapport à la statistique mondiale.

vi) Cette expérience permettra de doubler le stock mondial de 400 000 photographies $\Lambda^0 \rightarrow p e^- \bar{\nu}$.

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*) Cette proposition est commune avec une partie de la proposition concernant l'étude de la réaction $K^- p \rightarrow \Sigma^0 \pi^0$.

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1. CONDITIONS EXPERIMENTALES

1.1 Moment du faisceau

Il correspond au maximum de section efficace de production de X^0 et de φ :

$$p = 2{,}25 \text{ GeV/c} \qquad E^* = 2{,}33 \text{ GeV}$$

$$\sigma_t(K^-p) = 29{,}5 \text{ mb} \qquad \sigma_t(K^-n) = 25 \text{ mb} .$$

1.2 Choix du mélange

Nous nous sommes proposé un mélange contenant 80% de C_3H_8 et 20% de CF_3Br. La longueur de radiation est de 39,3 cm. Tenant compte des γ de basse énergie, la longueur de matérialisation est de 55 cm. Nous avons ramené la longueur potentielle à 120 cm, pour tenir compte de la mesurabilité des γ. La probabilité de voir un γ est alors :

$$P(\gamma) = 0{,}90 \ ^{*)} .$$

La densité du liquide est 0,68 g/cm³, la longueur d'interaction ~ 2,50 cm.

1.3 Nombre d'interactions par photo

Par comparaison avec les expériences actuelles, nous avons estimé à huit le nombre d'interactions utiles dans la chambre, pour réduire le nombre de γ ambigus, soit ~ 10 K^- par photo.

2. ETUDE DES MESONS

Les sections efficaces sont estimées à partir des expériences de K^- à diverses énergies dans l'hydrogène $K^-p \rightarrow \Lambda$ méson.

Réaction	$\sigma(\mu b)$	Nombre total d'événements	Nombre d'événements à Λ vu
$K^-p \rightarrow \eta\Lambda$	55	3 220	2 100
$K^-p \rightarrow X^0\Lambda$	90	5 270	3 430
$K^-p \rightarrow \omega\Lambda$	350	20 500	14 000
$K^-p \rightarrow \varphi\Lambda$	80	4 650	3 100

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*) L'examen détaillé des différents bruits de fond semble nous indiquer que ce chiffre pourrait être plus élevé, par exemple 0,95, ce qui faciliterait la distinction entre les différents canaux. La précision de la mesure d'un γ (~ 10%) n'en serait pas affectée considérablement.

2.1 Etude du X^0

2.1.1 Test de la conservation de C

a) Asymétrie dans le mode $X^0 \rightarrow \pi^+\pi^-\gamma$ (taux de branchement 22%)

Le nombre d'événements utiles est de 610. L'erreur sur l'asymétrie est de 4% si le bruit de fond est négligeable. Le maximum théorique est de 18%.

b) Recherche des modes $X^0 \rightarrow \pi^0 e^+ e^-$, $X^0 \rightarrow \eta^0 e^+ e^-$ ($\eta \rightarrow \gamma\gamma$, $\pi^+\pi^-\pi^0$)

Pour le premier mode, l'absence d'événement correspond à une limite de 10^{-3} à 90% de confiance. Pour le second, de $1,4 \times 10^{-3}$ à 90% de confiance. Les chiffres correspondants actuels sont de l'ordre de 3×10^{-2}.

c) Recherche du mode $X^0 \rightarrow \pi^0\pi^0\gamma$

Le maximum attendu théoriquement est de 9%. Il correspond à 40 événements. L'existence d'un bruit de fond $K^- p \rightarrow \Lambda\pi^0\pi^0\pi^0$ rend l'analyse plus difficile.

2.1.2 Rapports de branchement

Les modes $X^0 \rightarrow \gamma\gamma$, $\pi^+\pi^-\gamma$ et $\rho^0\gamma$ ont été estimés théoriquement, en particulier dans le modèle de Gell-Mann, Sharp et Wagner, bien vérifié par ailleurs. Il est intéressant de tester ici le mélange $\eta \rightarrow X^0$ qui n'est actuellement connu que par la formule de masse, et qui est compliqué par l'existence du méson E.

a) Modes $X^0 \rightarrow \rho^0\gamma$, $\pi^+\pi^-\gamma$

La séparation de ces deux modes peut se faire sur 610 événements.

b) Mode $X^0 \rightarrow \gamma\gamma$

Suivant les dernières estimations, fondées sur les travaux de Dalitz et Sutherland, $\Gamma(X^0 \rightarrow \gamma\gamma) \sim 50$ GeV. Le rapport de branchement $X^0 \rightarrow \gamma\gamma / X^0 \rightarrow$ tous doit être $> 1,25\%$ en prenant la limite expérimentale $\Gamma(X^0) < 4$ MeV. On attend dans ce cas un nombre d'événements > 34.

c) Mode $X^0 \rightarrow \eta\pi\pi$

Notons simplement que l'on doit voir 130 événements en $\pi^+\pi^-\eta$, 40 événements en $\pi^0\pi^0\eta$, dont l'étude sera rendue difficile par l'existence de bruit de fond.

2.2 Etude du φ

2.2.1 Mode $\varphi \to \eta\gamma$

Les relations tirées de SU₃ relient les différentes constantes de couplage VVP au moyen de deux paramètres. On prévoit :

$$\Gamma(\varphi \to \eta\gamma) = 0{,}33 \text{ MeV} ,$$

soit 148 événements ($\eta \to \gamma\gamma$, $\pi^+\pi^-\pi^0$).

2.3 Etude du ω

2.3.1 Mode $\omega \to \pi^0\gamma$

Il est du même type que le mode précédent. Le nombre attendu d'événements est de 1 700 avec 3γ mesurés. Compte tenu de bruit de fond provenant de $\Lambda\pi^0\pi^0$, nous avons estimé l'erreur sur le rapport de branchement à 4%, alors que ce chiffre est actuellement connu à 10%.

2.3.2 Mode $\omega \to e^+e^-$

Une limite supérieure de $1{,}6 \times 10^{-4}$ à 90% de confiance correspond à 0 événement. La limite actuelle est de 4×10^{-4}.

2.4 Etude du η

2.4.1 Mode $\eta \to 3\pi^0$

On attend 310 événements de ce mode avec 6γ mesurés. La dernière expérience fournira 130 événements dans BP3. Ici aussi, le problème du bruit de fond doit être examiné.

3. ETUDES DES HYPERONS

3.1 Test de la règle $\Delta S = \Delta Q$

3.1.1 Recherche du mode $\Sigma^+ \to \eta e^+\nu$

Le nombre de Σ^+ attendus dans les réactions $K^-p \to \Sigma^+\pi^-$, $\Sigma^+\pi^-\pi^0$, $\Sigma^+\pi^+\pi^-\pi^-$ est de 70 000. L'absence d'événement correspond à une limite supérieure à 90% de confiance de :

$$3{,}4 \times 10^{-5} .$$

Ce chiffre est comparable à celui obtenu à partir de la statistique mondiale. Les bruits de fond provenant des désintégrations électroniques des K^+, des π^+, ou des Dalitz de π^0 secondaires sont négligeables ($\sim 10^{-7}$).

3.2 Test de la règle $\Delta S < 2$

3.2.1 Recherche du mode $\Xi^- \to \eta\pi^0$

Les réactions utilisables peuvent être $K^-p \to \Xi^-K^+$, $\Xi^-K^+\pi^0$, $\Xi^-K^0\pi^+$. Le nombre de Ξ^- signés par un K^0 ou un K^+ est de 7500. Un certain nombre de coupures seront nécessaires et améneront probablement la limite correspondant à l'absence d'événement à :

$$\sim 1 \times 10^{-3} .$$

La limite actuelle est de 5×10^{-3}.

3.2.2 Recherche du mode $\Xi^0 \to \eta\pi^0$

Ce mode peut être plus aisé à rechercher. On peut espérer une limite de :

$$\sim 2 \times 10^{-3} .$$

La limite actuelle est de 5×10^{-3}.

3.3 Interactions des Ξ^-

Elles n'ont pas encore été étudiées. On attend 200 interactions visibles de Ξ^- signés*).

4. DETERMINATION PRECISE DU RAPPORT DE BRANCHEMENT $K_S^0 \to 2\pi^0/K_S^0 \to \pi^+\pi^-$

Les deux mesures actuelles les plus précises de ce rapport de branchement diffèrent entre elles de 14%. Ce rapport de branchement permet de connaître la contribution $\Delta I = 3/2$ dans la désintégration $K \to 2\pi$.

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*) 150 000 Λ^0 seront produits dans cette expérience, ce qui permettra de doubler le stock mondial d'événements $\Lambda^0 \to pe^-\bar{\nu}$. Mais surtout la production de Λ^0 polarisés a été observée dans les interactions de K^- à 1,6 GeV. Si cela se confirmait pour l'énergie de K^- envisagée ici, l'étude de l'asymétrie haut-bas des produits de la désintégration $\Lambda^0 \to pe^-\bar{\nu}$ permettrait de déterminer le rapport CV/CA avec son signe.

On n'est pas ici limité par la statistique. La réaction $K^-p \rightarrow \bar{K}^0\pi^-p$ avec p à l'arrêt semble la mieux adaptée. Elle peut fournir plusieurs milliers de $K_S^0 \rightarrow 2\pi^0$ avec 4γ mesurés. 1 500 événements de chacun des deux modes fourniraient une précision de 3% sur le rapport de branchement.

26 février 1968

ETUDE DU SYSTEME $\pi^0\pi^0$

Proposition d'expérience pour Gargamelle
étudiée par les groupes d'Orsay et de l'Ecole Polytechnique
avec la participation de J.J. Veillet et F. Jacquet
Paris, France.

L'étude du système $\pi^0\pi^0$, qui n'a pas été faite de manière systématique jusqu'à maintenant, permet de compléter l'analyse de l'interaction $\pi\pi$ en fonction de l'énergie. Cette analyse n'a en effet été faite qu'à partir des systèmes chargés, et le système $\pi^0\pi^0$ est essentiel pour l'étude des amplitudes à I et J pairs. En particulier le $\rho(I = 1, J = 1)$ qui domine les interactions pour les systèmes chargés n'intervient pas dans ce cas.

Nous proposons d'analyser le système $\pi^0\pi^0$ dans la réaction $\pi^+p \rightarrow N_{33}^{*++}\pi^0\pi^0$.

La présence du N_{33}^{*++} permet d'atténuer considérablement les interférences possibles entre les interactions $\pi^0\pi^0$ et π^0-nucleon. De plus, toutes les particules sortantes peuvent être mesurées, ce qui permet, par un fit à la production, de sélectionner les événements produits sur les protons libres du liquide.

La nécessité d'avoir une grande statistique pour les faibles masses $\pi^0\pi^0$ et, d'autre part, l'intérêt de l'étude de la zone de masse du f^0, nous conduisent à choisir deux énergies :

π^+ de 2.5 GeV/c pour les faibles masses $\pi^0\pi^0$ (270 à 1000 MeV);
π^+ de 5 GeV/c pour la zone de masse du f^0.

Conditions expérimentales

Mélange proposé : 90 % de C_3H_8, 10 % de CF_3Br (proportion en volume);
Longueur de radiation : $X^0 = 55$ cm;
Proportion d'interaction sur proton libre : 20 %;
Moment du faisceau 2.5 GeV/c et 5 GeV/c;
Erreur dp/p = 0.5 %.

Avec $10\pi^+$ par photographie et 300 000 photographies pour chaque énergie de π^+ incident, on obtient :

- avec les π^+ de 2.5 GeV/c : 1800 événements $N^*\pi^0\pi^0$;
- avec les π^+ de 5 GeV/c : 1000 événements $N^*\pi^0\pi^0$ dont 500 f^0.

Ces nombres correspondent aux interactions sur proton libre. Ils sont calculés en tenant compte d'une efficacité de détection des γ de 75 %. Les sections efficaces ont été estimées à partir des données existantes en $N^*\pi^0\pi^0$ avec des π^+ de 2 GeV/c et en f^0 avec des π^+ de 4 GeV/c.

L'erreur sur l'énergie des γ est de 15 % ce qui permet une très bonne séparation des événements sur proton-libre. L'erreur sur la masse effective $\pi^0\pi^0$ après fit est de l'ordre de 20 MeV.

Ces photos permettent également l'étude du système $3\pi^0$ avec une statistique relativement importante (environ 300 événements pour chaque énergie de π^+ incident).

26 February 1968

CONSIDERATIONS CONCERNING THE EXPERIMENTS
TO BE DONE IN GARGAMELLE WITH THE G4 BEAM
(NEGATIVE PIONS OF ~ 22 GeV/c AND PROTONS OF ~ 25 GeV/c)

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1. 22 GeV/c NEGATIVE PIONS

We discuss in general terms the physics to be studied in Gargamelle with the 22 GeV/c π^- beam.

The mean free path for a 22 GeV/c π^- in propane liquid is equal to 2,2 m, i.e. all the primary interactions occur, on the average, in the two first metres after the entrance window. Consequently the probability of detection for any produced γ's is $\cong$ 0.92 within a forward cone of 15 degrees opening angle.

If we try to extrapolate the results obtained with π^- of 16 GeV/c to 22 GeV/c, we can see that the secondary pions in the low multiplicity channel are emitted in a forward cone of $\simeq 15°$ opening angle.

Consequently, the detection efficiency of γ's produced in the primary interactions is very good even in propane. If one takes into account the high number of secondary interactions in Gargamelle, it is convenient to have no more than two or three primary interactions per picture in order to avoid ambiguity in assigning γ's to the different interactions.

Consequently, we think that in this test run one should have no more than three particles/picture on an average.

The physics problems that can be studied with the 22 GeV/c beam in Gargamelle seem to be the following:

i) coherent production on carbon nuclei;
ii) the study of resonances which involve neutral π's;
iii) generally, the study of the "jets" with π^0's production.

1.1 Coherent production on carbon nuclei

As is well known, the mechanism of diffraction dissociation should be the dominant one at very high energies$^{1)}$. The requirement that qR $\lesssim$ 1 and the kinematical relation

$$|t_{\min}| = \frac{M^2 \text{ produced} - M^2 \text{ incident}}{2P \text{ incident}} = q_{\parallel}^2$$

limits the coherent production of higher masses. With 23 GeV/c π^- in carbon, this limit is ≃1600 MeV/c^2; this is not an upper limit, but the production of higher masses is suppressed by $|F(qR)|^2$, the form factor of the target nucleus. In any case, at this energy and with this nucleus it is possible to examine a larger spectrum of masses produced coherently than has been done previously.

With incident π we can study coherent production in the following channels:

$$\begin{aligned} \pi^- + {}^{12}C \rightarrow\ & {}^{12}C + \pi^- + \pi^- + \pi^+ && (1)\\ \rightarrow\ & {}^{12}C + \pi^- + \pi^0 + \pi^0 && (2)\\ \rightarrow\ & {}^{12}C + \pi^- + \pi^- + \pi^- + \pi^+ + \pi^+ && (3)\\ \rightarrow\ & {}^{12}C + \pi^- + \pi^- + \pi^+ + \pi^0 + \pi^0 . && (4) \end{aligned}$$

The results on these coherent states can be usefully compared with the same channels produced on free hydrogen or incoherently on nuclei, which can be studied at the same time [we call (1'), (2'), (3'), (4') the channels in hydrogen, corresponding to (1), (2), (3), (4), respectively]. The data will be used to investigate the following points:

i) the production of A_1, A_2, A_3, and perhaps also $A_{1.5}$ including an analysis of spin-parity and of angular correlations in comparison with similar data obtained at lower energy;

ii) the branching ratio $\rho^0\pi^-/\rho^-\pi^0$ for the decay in $\rho\pi$ of A resonances from a comparison between the first two channels on nuclei and on hydrogen;

iii) the coherent production of five π systems and the properties of the produced system.

At 16 GeV/c [2)] for the $3\pi^\pm$ coherent production on fluorine we obtain a cross-section of ~ 4 mb, and about one-eighth this value for 5π production [*)]. If we assume the same cross-sections at 23 GeV/c, the coherent productions

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[*)] We consider as coherent events only those with $t'[\sim (p\vartheta)^2 = q_\perp^2] < 0.0225\ (\mathrm{GeV}/c)^2$; in this region the incoherent background is ≲ 10%.

in the channels (1) and (3) are ~ 2% and ~ 0.25%, respectively, of the total reactions $\pi^- - {}^{12}C$ at this energy. Consequently, 10,000 $3\pi^\pm$ and 1200 $5\pi^\pm$ coherent productions corresponds to 250,000-300,000 pictures.

The statistics in channels (2) and (4) should be of the same order of magnitude. At the same time we would obtain ~ 7500 events produced on hydrogen in channels (1') and (2'), and ~ 3800 events in channels (3') and (4').

We suggest as optional also an analysis of 80,000-100,000 pictures with π^- at ~ 19 GeV/c, in order to obtain ~ 2500-3000 coherent productions on ${}^{12}C$.

A detailed study of the $3\pi^\pm$ mass spectrum in the A_1 and A_2 region produced coherently, has already been performed in part with the Heavy Liquid Bubble Chamber, and it will also be performed in part in the next experiments with spark chamber at various incident momenta as high as 16 GeV/c.

1.2 Resonance production

It seems useful to investigate in Gargamelle the following problems:

a) The decay of the A_2 resonance in $\eta\pi$ at 11 GeV/c. The cross-section of this process corresponds to ~ 28 μb [3]. In Gargamelle it would seem possible to study this process in two channels:

$$\pi^- + p \to \pi^+ + \pi^- + \pi^0 + p \qquad (5')$$

$$\to \gamma + \gamma + \pi^- + p \qquad (6')$$

and perhaps also in:

$$\to \pi^0 + \pi^0 + \pi^- + p \qquad (7')$$

$$\to \pi^+ + \pi^- + \pi^0 + \pi^0 + n \qquad (8')$$

$$\to \gamma + \gamma + \pi^0 + n . \qquad (9')$$

b) The single production of A_1^0, A_2^0, perhaps H_1^0, ω^0, η^0, and generally all resonances which can decay in $\pi^+ + \pi^- + \pi^0$. The channel to be considered is:

$$\pi^- p \to \pi^+ + \pi^- + \pi^0 + n . \qquad (10')$$

At 8 GeV/c the cross-section corresponding to this channel is 1.36 mb [4]. This research seems useful in order to investigate the production mechanism of 3π neutral resonances.

c) The $\pi^0\pi^0$ mass spectrum, for example the σ_0 and ϵ_0 study in the decay mode. If we try to extrapolate the Heavy Liquid Bubble Chamber results obtained at 6 and 16 GeV/c [5,6], we can estimate that the cross-section of the channel:

$$\pi^- + p \rightarrow \pi^0 + \pi^0 + n \qquad (11')$$

is of the order of magnitude of 0.1 mb.

d) Generally the study of resonance decays as, for instance, the R, R_1, R_2, R_3, S, T, V, etc., where the decays in neutral pions is not yet well known.

In order to have reasonable statistics in this study of resonance decays, it would be necessary to increase the number of pictures to as high as 350,000.

1.3 Study of non-resonant processes

The third proposal is the analysis of channels with production of two or more neutral particles. A general classification of the many-body final states, which is impossible in Heavy Liquid Bubble Chambers, seems very important in order to allow, for example, a general analysis of three-body final states on the basis of the double Regge-pole model or generally multiperipheral model.

2. 25 GeV/c PROTONS

We wish to add a few words about some aspects of the physics which we can study with the 25 GeV/c proton beam incident in Gargamelle.

The mean free path for 25 GeV/c protons in propane is ~ 1.4 m, and consequently the detection efficiency in Gargamelle for the produced γ's is ~ 0.95 in a cone of ~ 14°.

In this case it also seems reasonable to consider no more than two interactions per picture, i.e. no more than an average of two incident protons per picture.

We think that it is interesting to study the coherent production of protons on ^{12}C nuclei with N* or with φ^0, f^0, ω^0, etc., production. This phenomenon has only been studied on deuterium at low energies (2 GeV/c).

The N* production can be studied in the channel

$$p + {}^{12}C \rightarrow N^* + {}^{12}C \; . \tag{5}$$

In the coherent reaction the N* must have the same isotopic spin as the incident proton.

The results from channel (5) can be usefully compared with the data which can be obtained by studying at the same time the reaction:

$$p + p \rightarrow N^* + p \tag{12'}$$

already studied at incident momenta as high as 30 GeV/c [7-9].

The cross-section of $N^*_{1/2}$ production can be estimated[7] at 25 GeV/c as 0.7 mb for N*(1.40), 0.18 mb for N*(1.52), 0.568 mb for N*(1.69), and finally 0.118 mb for N*(2.19).

The mesonic resonance can be produced coherently in the channels of the type:

$$p + {}^{12}C \rightarrow \pi^+ + \pi^- + p + {}^{12}C \tag{6}$$

$$\rightarrow \pi^+ + \pi^- + \pi^0 + p + {}^{12}C \tag{7}$$

$$\rightarrow \gamma + \gamma + p + {}^{12}C \; . \tag{8}$$

In order to have reasonable statistics in these channels, one will need ~ 300,000 pictures.

* * *

From the previous remarks one can see that for the experiments with π and p at high energy, it is convenient to fill Gargamelle with propane and not with a heavier liquid. In fact, the value of the mean free path of π and p at this energy is so short that most of the primaries and the secondaries interact in the chamber. The γ-ray detection efficiency is already good with the propane; with a heavier liquid the bremsstrahlung and the multiple scattering of electrons would make difficult the measurements and the kinematic interpretation of the event.

* * *

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CONSIDERATIONS AND INTENTIONS FOR EXPERIMENTS WITH GARGAMELLE

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1. INTRODUCTION

The Milan group is very much interested in various future experiments with Gargamelle, and especially in the exposures to neutrino and antineutrino beams and to high-energy non-separated beams of pions and, eventually, protons. Obviously, we also consider other experiments such as those with low- and high-energy $K^{\pm}$, that are of great scientific interest; but here we have decided to expose only some qualitative considerations on the first two experiments in the hope that they can be of some use to the Gargamelle Users' Committee and to the Track Chamber Committee.

2. SOME CONSIDERATIONS ON NEUTRINO AND ANTINEUTRINO EXPERIMENTS

The problems to be studied with Gargamelle can be divided into two groups:

I) General questions such as the following:
   a) difference between electron and muon neutrinos;
   b) conservation of the lepton number;
   c) existence of vector bosons;
   d) validity of time reversal;
   e) existence of neutral currents, etc.

II) Studies of the weak hadronic currents, such as:
   a) $N \to N$, $N \to N^*$ and $N \to Y$ or Y^* form factors;
   b) selection rules $\Delta S = \Delta Q$, $\Delta I = 1$, or $\Delta I = \frac{1}{2}$;
   c) test on CVC and PCAC.

As far as the liquid is concerned, a filling with heavy freon would yield a higher rate of events and a higher detection efficiency for π^0, as well as a better identification of muons. On the other hand, a filling with propane is essential for the study of interactions on free protons, and allows polarization measurements of the scattering of particles with spin (such as protons) on carbon nuclei. Moreover, the measurement accuracy is much better, and the nature of the nuclear target clearer.

We will indicate for each reaction whether freon or propane is more desirable. It is clear that, in general, propane does not present substantial advantages in the study of interactions on neutrons (except for particular problems such as the tests on time reversal invariance which we will consider later), while it is essential for the study of most of the interactions on protons. One can note that for particular problems a propane chamber can even be superior to that of a H/D one. For instance, the reaction $\bar{\nu} + p \rightarrow \mu^+ + n$ cannot be kinematically determined in a hydrogen or deuterium bubble chamber; while in a propane-filled Gargamelle the reaction is overdetermined (a two-constraints fit) when the star from the neutron is detected.

2.1 Problems of type I

Let us note that for the study of problems I(a) and I(b) the choice of the mixture in the chamber is less important than a precise determination of the beam. In fact, as is well known, the presence of e^- can be due to the ν_e background (0.5%), and that of μ^+ to a background of negative particles in the focusing system (2%). We think that heavy freon would be preferable for the study of reactions (a), (b), and (c), for the following reasons:

i) the discrimination between e^- and μ^- is easier in a heavy liquid;
ii) the event rate is higher by a factor of 3.5, which is essential for detecting of rare events such as the possible production of W.

In experiments of type (d) (tests on T-invariance), the measurement of the polarization can be obtained from the decay of the muons and/or from the scattering of particles with spin (protons, for instance). However, whilst it is very improbable that the muon can stop in the chamber without losing its polarization, the probability of an elastic scattering by the secondary proton on a carbon nucleus of the propane is perhaps reasonably high. We think therefore that the use of propane should be preferred for the study of these problems.

It would also be better to use propane for experiments of type (e), where the possible existence of the reaction $\nu + p \rightarrow \nu + p$ should be investigated. Of course the detection of this reaction is extremely difficult experimentally, and requires a very good knowledge of the background events from neutrons.

2.2 Problems of type II

As is well known, the hadronic currents to be studied in neutrino interactions are mostly:

$$N \rightarrow N \quad (1)$$

$$N \rightarrow N^* \quad (2)$$

$$N \rightarrow \text{hyperon} \quad . \quad (3)$$

Let us now review the possible reactions together with the rates of events per day in Gargamelle using the present neutrino beam.

$N \rightarrow N$

a) $\nu + n \rightarrow \mu^- + p$ (98 events/day in propane and 450 events/day in CF_3Br).

From these events one can obtain

i) the measurement of the total cross-section;

ii) the form factors from the momentum transfer distribution

(for these experiments, it is preferable to use freon for the higher rate of events);

iii) a test on time reversal invariances.

For this experiment we would prefer the use of propane, as mentioned before.

b) $\bar{\nu} + p \rightarrow \mu^+ + n$ (42 ev/d in propane, of which 13 on free protons, and 112 ev/d in freon).

We would like to point out that this reaction is not overdetermined in hydrogen (0-constraint fit). It seems essential in Gargamelle to use propane and to select events on free protons associated with a neutron star. The consequent reduction of eight events per day seems justified by the importance of obtaining the total and differential cross-section for antineutrino interactions.

N → N*

c) $\nu + p \to \mu^- + N^{*++}$, $N^{*++} \to \pi^+ + p$ (190 ev/d in propane, of which 60 ev/d on free protons, and 525 ev/d in freon).

From this reaction one can obtain:

i) the total and differential cross-section;

ii) the comparison with the corresponding reaction $\nu + n \to N^{*+} + \mu^-$ (test for $\Delta I = 1$ rule).

Since this interaction is on protons it is, as usual, preferable to use propane.

d) $\nu + n \to \mu^- + N^{*+} \to \begin{cases} \pi^0 + p \\ \pi^+ + n \end{cases}$

The use of freon is preferable for higher event rate and better detection efficiency.

e) $\bar{\nu} + p \to \mu^+ + N^{*o} \to \begin{cases} n + \pi^0 \\ p + \pi^- \end{cases}$

$\bar{\nu} + n \to \mu^+ + N^{*-}$, $N^{*-} \to \pi^- + n$ (the total rate could be tentatively 50 ev/d in propane and 200 ev/d in freon).

The use of freon is preferable for the higher detection efficiency of neutral secondaries especially in the first reaction $(n + \pi^0)$.

N → Y or Y*

f) $\bar{\nu} + p \to \mu^+ + \Lambda^0$ or $\mu^+ + \Sigma^0$ (tentatively 5 ev/d in freon)

$\bar{\nu} + n \to \mu^+ + \Sigma^-$ (tentatively 2 ev/d in freon)

g) $\bar{\nu} + p \rightarrow \mu^+ + Y^{*0}$ (tentatively 10 ev/d in freon)

$\bar{\nu} + n \rightarrow \mu^+ + Y^{*-}$ (tentatively 4 ev/d in freon)

No events of types (f) or (g) have been reported up to now. These events represent a unique way of obtaining information on the weak hadronic currents with $\Delta S = 1$ at high q^2.

One can obtain:

a) a test of the validity of the Cabibbo theory;

b) a measure of the form factor [probably dominated by the K*(880) resonance];

c) a test of T-invariance from the Λ^0 decay (the transverse component of the polarization should be zero if time reversal invariance holds);

d) a test of the validity of the $\Delta I = \frac{1}{2}$ rule from the ratios $\mu^+ + \Sigma^0 / \mu^+ + \Sigma^-$ and $Y^{*0} + \mu^+ / Y^{*-} + \mu^+$.

Due to their very low cross-sections, reactions (f) and (g) should be investigated in freon.

3. CONCLUSIONS

Let us summarize our conclusions in the following table:

Best experiment in propane	Best experiments in freon
1) T-reversal invariance 2) neutral currents	1) difference between ν_e and ν_μ 2) existence of W 3) conservation of the lepton number
3) $\bar{\nu} + p \rightarrow \mu^+ + n$ (cross-sections, form factors, locality) 4) $\nu + p \rightarrow \mu^- + N^{*++}$ (form factors, $\Delta I = 1$ rule)	4) $\nu + n \rightarrow \mu^- + p$ (cross-sections, form factors, locality) 5) $\nu + n \rightarrow \mu^- + N^{*+}$ (form factors, $\Delta I = 1$ rule) 6) $\bar{\nu} + p \rightarrow \mu^+ + N^{*0}$ $\bar{\nu} + n \rightarrow \mu^+ + N^{*-}$ 7) $\bar{\nu} + \mathcal{N} \rightarrow \mu^+ +$ strange particle

The interest of the study of these reactions in the field of weak interaction physics is such that we suggest exposures of Gargamelle to neutrino and antineutrino beams, both with a propane and with a freon filling.

26 February 1968

STUDY OF NON-LOCALITY OF LEPTON CURRENTS USING A HIGH-ENERGY NEUTRINO BEAM IN GARGAMELLE

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1. INTRODUCTION

Essentially all the ν experiments proposed to date for Gargamelle are concerned with study of the structure and selection rules for hadronic weak currents. They require quite precise measurements of form-factors, etc., which will be bravely attempted in propane; in my opinion, the systematic errors in interpretation will be so severe that any substantial progress in this field (i.e. to better than the 10% level) will have to await the deployment of large H/D chambers; for example, as proposed at BNL in 1969/70. Quite apart from this, the study of hadronic weak currents does not touch the fundamental problem of the weak interaction proper, but rather the structure and renormalization effects introduced at the strong-interaction vertex.

The basic problem of the weak interactions is that there is no field theory of the lepton-lepton interaction — only a first-order prescription due to Fermi, and now 35 years old, of a local lepton current acting at a point in space-time. This recipe leads to the well-known unitarity catastrophe in ν-e scattering at (E)c.m.s. ~ 300 GeV. The presumption is that at high q^2, higher order terms introduce non-locality and damp down the cross-section, as in strong interactions. One possible means of introducing such non-locality is via the W boson (although at present even the boson theories are not renormalizable). It is clear that any search for non-local action much be made in a q^2 range above the present W mass limit (say $q^2 \geq 5$ GeV/c^2). This rules out the direct study of ν-e scattering at any accelerator presently conceived, since

$$q^2 \simeq 2m_e E_\nu = \frac{E_\nu}{1000} \text{ GeV/c}^2 .$$

The only practically feasible method of investigating high q^2 effects in the lepton current appears to be by using a heavy target, i.e. a nucleon target. Then the local hypothesis has been shown (e.g. Lee) to lead to a cross-section for the process

$$\nu + n \to \mu + \underset{\hookrightarrow \text{ SI particles}}{N^*} ,$$

expressible in terms of five structure factors. No <u>detailed</u> assumptions are involved here about the hadronic current (e.g. $\Delta I = 1$ rule, $\Delta Q/\Delta S$, G-invariance, etc.; obviously, G-invariance <u>can</u> be involved to connect elastic ν and $\bar{\nu}$ cross-sections, and so on). If one neglects the lepton mass then two factors are eliminated, and one can, for example, express a cross-section for a particular hadronic final-state mass as

$$\frac{d^2\sigma}{dq^2\,dM^{*2}} = \frac{A(q^2,M^*)}{E_\nu^2} + \frac{B(q^2,M^*)}{E_\nu} + C(q^2,M^*)$$

The existence of only three terms is a consequence of the locality assumption. It is clear that systematic checking of such formulae would be a monumental task and, one suspects, unnecessary. Physically, one would expect the breakdown of the Fermi theory to be more transparently manifest in terms of: i) a flattening-off in the rise of σ_{total} with E_ν; ii) a decline in the cross-section in a particular channel at very high energy (for example, the elastic channel, which is the 'shadow' of the inelastic processes) -- just as in strong interactions. The proposal here is therefore simply to investigate σ_{total}, and, in whatever detail possible, the differential cross-sections $d\sigma/dq^2$ appropriate to a given range of M^*, out to the highest values of E_ν and q^2 available at CERN.

2. EXPERIMENT IN FREON

The old (1963/64) CERN HLBC data showed σ_{total} rising steadily, roughly linearly with E_ν, and a q^2 distribution falling off slowly and smoothly until statistics ran out (the region covered was up to $E_\nu \sim 10$ GeV and $q^2 \sim 6$ GeV/c^2). The principal difficulties of these experiments were:

a) low statistics, on account of low flux at high E_ν and small detector mass;

b) difficulty in identifying outgoing μ^- among the assembly of up to 10 pions, kaons, etc., from the strong vertex;

c) uncertainties in the ν flux.

With the present or intended CERN beam and repetition rate, and Gargamelle filled with freon (CF_3Br), the situation would be vastly improved:

i) The decay channel could be shortened in order to optimize the ν flux for K decay (which dominates π decay for $E_\nu > 5$ GeV). Reducing the channel length and optimizing the focusing elements (possibly with redesigning) should increase the absolute flux per proton, above 5 GeV, by at least a factor of 2 — this, of course, at a small loss (30%?) in the flux below ~ 3 GeV.

ii) For an interaction half-way down the chamber, the muon, as well as the bulk of the pions, would traverse some four interaction lengths, making identification almost certain; e.g. for a $3\pi^-$ event the probability of wrong assignment would be ~ 8% only. Let me emphasize that it is precisely the very high multiplicity, high q^2 events that are interesting, and where unambiguous muon identification is vital.

iii) The event rate, as compared with CERN (63/64), could be increased by a factor

× 20 for Gargamelle versus early NPA chamber,

× 10 for improvement in beam (per sec).

The resulting improvement factor of 200 ensures that good statistics would be secured in the region E_ν = 5-10 GeV, and the effective range of E_ν and q^2 enlarged to at least 15 GeV and 20 GeV/c^2, respectively (note that QED has only been tested to $q^2 = 25$ GeV/c^2).

iv) An essential prerequisite of the experiment would be a careful study of methods of determining the ν flux at high energy. This is undoubtedly the most difficult feature of the experiment. If based on muon flux measurements, angular and energy distributions need to be determined in detail in order to obtain the kaon ν-flux.

It is important to emphasize that the target nucleon is being used only to transfer four-momentum to the lepton, and one is not interested in precise details of final-state interactions in the complex nucleus. All that is required is sure identification of the muon, its momentum and angle, and a rough (20%) measure of the energy deposited at the nucleon vertex. These quantities determine E_ν, q^2 and M^* to an acceptable accuracy (10%-20%).

3. ARGUMENT AGAINST PROPANE AND HYDROGEN

Why cannot the experiment be done in propane or propane/freon? Or hydrogen? Or neon-hydrogen?

i) Identification of the muon is imperilled. In example 2(ii) for $3\pi^-$, the probability of misidentification is increased from 8% to 40% for propane. The argument holds a fortiori for pure hydrogen or hydrogen/neon mixtures in any HBC presently conceived.

ii) The event rate in propane is reduced by a factor of 3.5, and in hydrogen by a factor of 25. It is vital to use the highest available liquid density to combat the abysmally low flux in the high-energy region.

iii) Multi-π^0 events -- and we are talking in terms of charged multiplicities up to 10, so about the same number of γ's. My argument here is that provided one does not care about the exact number of π^0's, only $\Sigma\, E_{\pi^0}$, the problem of measurement becomes easier in freon. With an average of 8-10 radiation lengths in all directions from the vertex, a measurement of the track-length integral in the whole cascade will yield an accuracy of 20% for $\Sigma\, E_{\pi^0}$. This technique could not be used in propane, and the usual confusion between bremsstrahlung and non-bremsstrahlung pairs would arise, quite apart from the fact that the probability of converting all the γ's is reduced.

To summarize, my philosophy in proposing this type of experiment is as follows:

1) It explores a region of q^2 in weak interactions where we know something new has to happen eventually. No one knows where the interesting region is, and the only way to find out is to look.

2) The 1% level studies of the common transitions $n \rightarrow p$, $n \rightarrow N^*$, $p \rightarrow \Lambda$, etc., will be done properly, in due course, by H/D chambers, or in H/D targets with neon envelopes. The heavy-liquid chamber may be able to accumulate more events but cannot possibly compete in precision. It is perhaps better to concentrate on processes where a heavy-liquid chamber can make a unique contribution.

26 February 1968

Letter of Intention

Padua and Wisconsin Groups

Gargamelle will undoubtedly be a wonderful instrument for the study of hadron physics.

We would like to emphasize the importance of certain aspects of a $K^{\pm}$ beam of relatively low momentum for the study of weak interactions.

It should be pointed out that at this moment, and perhaps also in the near future, our understanding of the most important problems relative to the weak interactions are not generally confirmed experimentally to better than 10%, namely:

a) invariance properties,
b) $\Delta S = \Delta Q$,
c) $|\Delta \vec{T}| = \frac{1}{2}$ rule,
d) form factors,
e) rare decay modes, etc.

We would suggest that the above investigation can best be accomplished by using a K^{+} beam of relatively low momentum (900-1500 MeV/c) as a source of K^{0} mesons.

This method of K^{0} production has two advantages: namely, the direction of the K^{0} is well determined by the origin vertex and the decay point; and secondly, the momentum of the K^{0} can be determined from the production vertex alone, in those cases where charge-exchange occurs on hydrogen with pion production. Furthermore, the momentum will, in general, be well determined from measurements of the decay products (because of the large size of the chamber).

Also, a K^{-} beam produces hyperons as well as neutral K mesons: it is less suited to neutral K-meson decays; on the other hand, a beam of K^{-} of relatively low momentum is a rich source of hyperons: Λ^{0}, $\Sigma^{\pm 0}$, and Ξ^{-0} particles.

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Propane would seem to be the liquid preferred because of the good accuracy of momentum measurements, the advantages of a carbon target, and the large number of free protons present. The size of the chamber is large enough to ensure a high conversion efficiency for γ-rays even in propane.

26 February 1968

Letter of Intention

NEUTRINO AND ANTINEUTRINO PHYSICS IN GARGAMELLE

Padua and Wisconsin Groups

It is clear that the field of neutrino physics will be one of the most actively pursued by those associated with Gargamelle.

At this point, it is not necessary to enumerate in detail the many problems that are of great interest; it is sufficient to mention a few:

i) ν-$\bar{\nu}$ difference in cross-section as a function of energy,
ii) strange particle production,
iii) N^*, ρ, ω, etc., production,
iv) tests of lepton conservation, etc.

Although it is clear that freon offers a substantially larger number of events than propane, it seems clear from a comparison of the last ν experiment in propane with the preceding one in freon that the high probability of absorption of produced pions, in a heavy nucleus, makes it virtually impossible to investigate the pion processes (N^*, ρ, ω, etc.). For this reason we feel the decreased number of interactions in propane is clearly offset by the increased information gained from light nuclei contained in propane.

Since there will be many groups interested in working in this field, this note is to express our interest in the subject. In particular, some members of one or the other groups may wish to spend a semester or a year at CERN or Paris working on these problems. In this way it may not be necessary to consider shipping film to the United States, as this may create problems when a large number of universities or institutes are involved in a collaboration.

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26 February 1968

Proposal for use of Gargamelle

A STUDY OF INELASTIC μ-MESON INTERACTIONS IN GARGAMELLE

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1. INTRODUCTION

With the advent of reasonably intense energetic μ-meson beams from accelerators, there has been a considerable heightening of interest in this field. The interest arises not only from the possibility of discovering some basic difference in the structures of the μ meson from that of the electron, but also in the possibility of studying virtual electromagnetic processes associated with nuclear and fundamental particle processes.

The difference between muons and electrons could be manifest in the inelastic scattering processes, as well as in the elastic process. Bubble chamber techniques are especially suitable for the study of inelastic processes, since the many and varied final states can easily be recognized and analysed. On the other hand, the cross-section for elastic scattering at high four-momentum transfer is so low that bubble chambers cannot compete with other techniques.

Up to the present time, seven experiments have been performed using μ mesons from accelerators. The counter experiment of Masek et al.[1,2] measured the elastic scattering cross-section in the region of momentum transfers from 5 F^{-2} to 18 F^{-2} (450-850 MeV/c), and found that the data fit very well, in total cross-section and in four-momentum dependence, to the electron scattering data. Likewise the experiment of Tannenbaum[3] found the same result; namely, that for four-momentum transfer in elastic scatterings in the range from 19 to 31 F^{-2} (0.860-1.100 GeV/c) the agreement with electron scattering is excellent. The experiment of Katelchuck et al.[4] gave information on lower momentum transfer again in agreement with electron scattering.

Inelastic scattering of μ mesons has been studied by two groups using emulsion techniques, and a third group using a bubble chamber. The authors who used emulsions, namely Jain and McNulty5) and Kirk et al.6), gave crude data on cross-sections for pion production and lower energy nuclear disintegration processes. The estimates for the cross-section for pion production, given by these authors, varies from 2×10^{-30} to 5×10^{-30} cm^2 per nucleon in heavy nuclei. No data are available on hydrogen. A crude estimate of the cross-sectional dependence on four-momentum transfer is shown in Fig. 1, along with the same dependence for elastic scattering. It seems that the inelastic process dominates for four-momentum transfers larger than about 0.001 $(\text{GeV}/c)^2$. No data exist on N* production in their experiments, because the interactions were in heavy nuclei.

Recently, an experiment has been performed in the CERN heavy-liquid chamber which was exposed to a beam of μ meson from the neutrino facility at CERN.

Up to the present time, the results of this experiment are unpublished7). A brief summary is given in Tables 1 and 2. Only the cross-sectional information is given here because of its relevance to the estimation of numbers and types of events to be expected in a larger chamber.

Table 1

Average No. of tracks/picture, liquid propane	50	
Total number of pictures scanned	35,000	
Total number of events	121	(only pion events included from Oxford)
Total number of pion events:	42	
single-pion events	27	(4 were π^0)
two-pion events	13	42
greater than two pions	1	
strange particles (K_1^0)	1	

Table 2

Estimated cross-sections (cm^2)

Single-pion production (including corrections for π^0 detection)	1.5×10^{-30}
Multiple pion production	6×10^{-31}
Estimate of strange particle production	$\sim 8 \times 10^{-32}$

2. PROCEDURE

The first μ-meson experiment in the large chamber must, of necessity, be rather exploratory in nature. However, the number of events in the category of pion production, N* (see Fig. 2), multiple-pion processes, as well as ρ and ω, can be estimated from the previous experiment.

Certainly, the greatest interest lies in the study of the inelastic processes on hydrogen, nevertheless, the previous experiment has shown that a great deal of information can be obtained from the interactions on carbon nuclei.

2.1 μ beams

It seems reasonable to think of μ-meson studies in Gargamelle as proceeding in two steps: namely, the first experiment could be accomplished by using a μ-meson beam of considerable momentum spread as obtained from a neutrino facility ($\Delta p/p \sim 50\%$), and a second experiment with a well-defined momentum ($\Delta p/p \cong 2\%$).

The experiments with a large momentum spread would yield total cross-section information, information on four-momentum transfer, a search for an excited state of the muon, angular correlations in the decay products from N*, ρ, and ω, etc. In spite of the uncertainty in the momentum of the incoming μ meson (obtained from entering position and direct measurements on the incoming track) the four-momentum transfer can be obtained from the visible energy and the change in the direction of the muon.

Furthermore, the spread in entering momenta would permit a study of the variation of partial cross-sections as a function of muon energy.

Clearly, a well-defined momentum beam has considerable advantages in precise determination of most of the above-mentioned quantities. However, there may be considerable advantages in proceeding from a rather simple beam for exploration to a more complex beam with more specific goals in mind.

2.2 Track density

The previous bubble chamber experiment contained photographs with μ-track densities varying from about 20 tracks/picture to as high as 120 tracks/picture. With a track density of 50 to 70, the events could easily be recognized and measured. With a track density higher than about 70 tracks/picture the events could be found, but the measurement and identification was, in about one-third of the cases, very difficult. However, it should be kept in mind that the beam was spread out over a length of about 40 cm at the point of entry in the chamber. It is clear that a beam density of 100 tracks/metre would represent an excellent compromise between obtaining the maximum number of events, and the ease of scanning and analysis. (This is true only for propane where the δ-ray production and associated electromagnetic processes do not appreciably increase the track density.)

2.3 Number of events

The numbers given in Table 3 are estimated for the following conditions:

number of pictures	200,000
number of μ/picture	100
length of μ track	3 metres
liquid	propane

Table 3

Estimated number of events on carbon

Type of reaction	Cross-section used	Number of events expected
Total pion events	2×10^{-30}	1500
Single-pion production	1.5×10^{-30}	1000
Two-pion production	6×10^{-31}	470
Greater than two pions	$\sim 5 \times 10^{-32}$	40
Strange particles	8×10^{-32}	~ 30 (observed)

The number of events on hydrogen can be estimated by dividing the numbers in the above table by 5.5.

* * *

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Fig _ 1

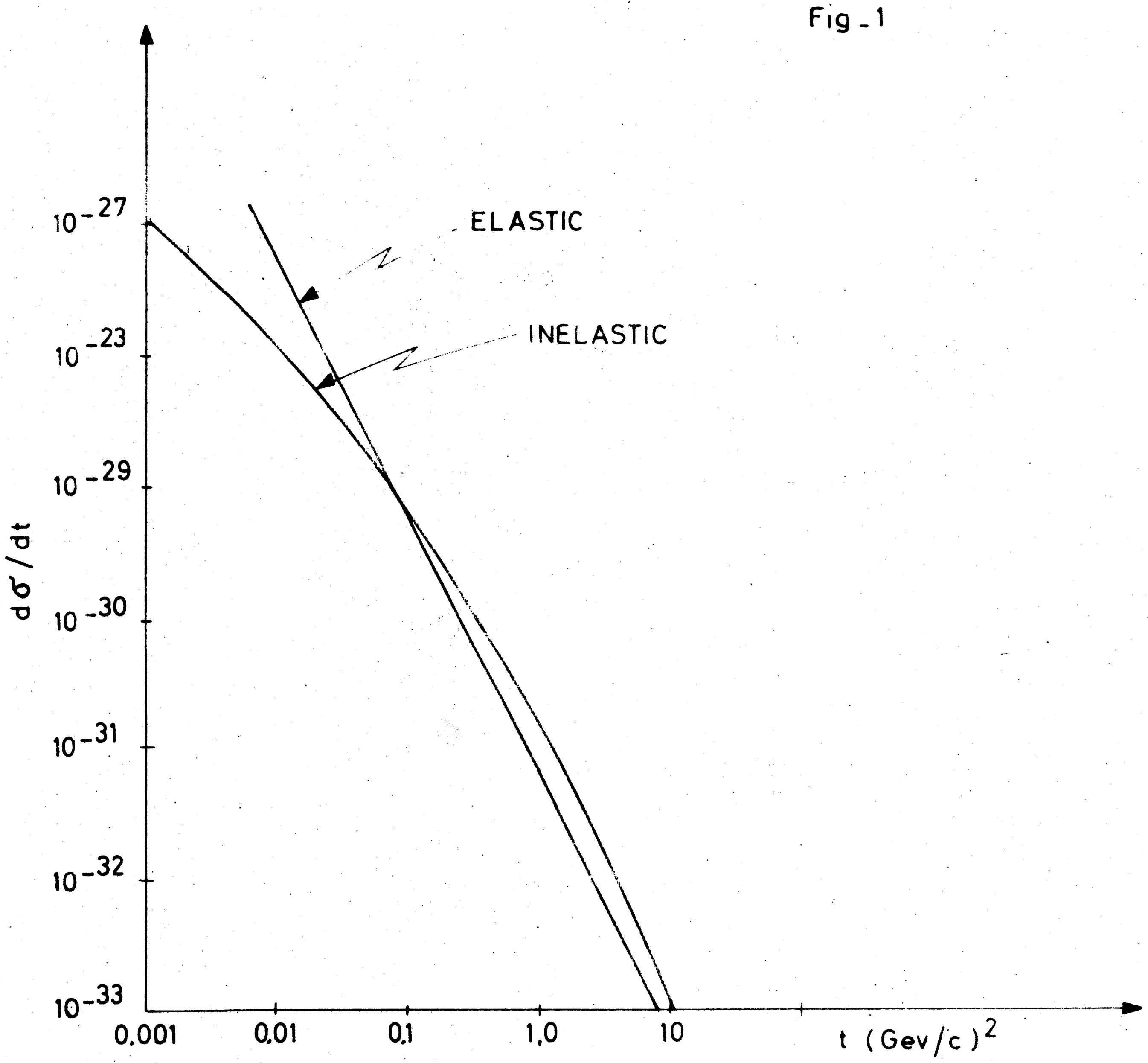

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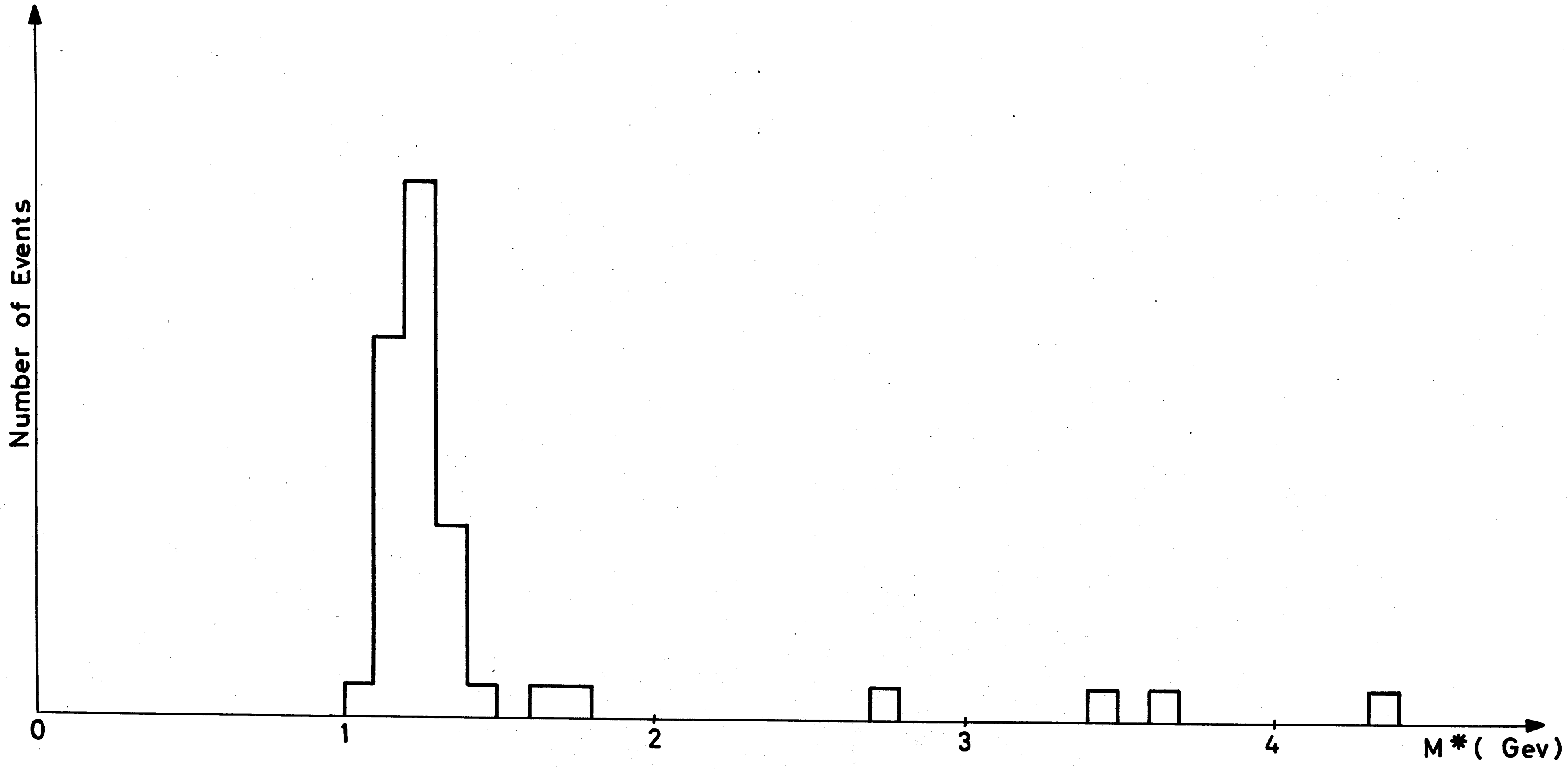
Fig. 2



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22 February 1968

INTERESTS IN EXPERIMENTS WITH GARGAMELLE

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1. INTRODUCTION

The Bubble Chamber Group of Turin University is preparing to take part in experiments using Gargamelle.

The group interested in these experiments includes eight physicists, two applied physicists, and three postgraduate students.

For the scanning of the film, the analysis, and measurements of the events, a special measuring-projector is being designed which will work with an on-line computer (IBM 1130). Reconstruction programs are being developed.

Bearing in mind the beams which will be available during the next few years for experiments with Gargamelle, we propose to study the problems listed below.

2. PROPOSED EXPERIMENTS

2.1 Experiments using the test beam and the G4 beam

2.2 Neutrino experiments

2.3 Experiments using the G1 beam

2.4 Experiments using the G3 beam.

2.1 Experiments using the test beam and the G4 beam

In the light of present knowledge, an interesting study in Gargamelle exposed to high-energy pion beams is the diffraction dissociation of the incident pions into higher mass M* states with the same value of Q, B, S, I, and G, and with J^P belonging to the series 0^-, 1^+, 2^-, etc. By G parity, these states tend to decay into 3, 5, etc., pions. Interesting work in heavy liquid has already been done with 16 GeV/c π^- beams (Orsay-Saclay-Milano-Berkeley collaboration) where the 1^+ resonance $A_1^- \to \rho\pi$ is clearly seen. For coherent production on, say, a carbon nucleus, the mass M is limited to values $2p_0 m_\pi A^{-1/3} + m_\pi^2$ = 1.4 GeV/c for p_0 = 16 GeV/c. Increasing p_0 to 22 GeV/c, as foreseen later in the Gargamelle program, extends this limit to 1.6 GeV/c^2. In this mass region there is at present an interesting problem of A_3 involving a three-pion final state. At 5 GeV/c, the Bari-Bologna-Firenze-Orsay group finds that the A_3 produced in $\pi^+ n \to pA_3^0$ decays predominantly into $\rho\pi$ as an I = 0 resonance. At 8 GeV/c the Aachen-Berlin-CERN group, and at 11 GeV/c the Genova-Hamburg-Milano-Saclay group find in $\pi^\pm p \to pA_3^\pm$ that the A_3 decays predominantly into πf^0 as an I = 1 resonance. Since the mass values are comparable, it would be interesting to search for this final state in diffractive dissociation where the $A_2(2^+)$ does not appear.

The few events thus seen decaying into five pions in the OSMB experiment have masses around 1.9 GeV/c (H.J. Lubatti, private communication) where the MM spectrometer experiment has seen a peak (S^-, 1.929 GeV/c^2). Extending p_0 to 22 GeV/c would facilitate further examination of this effect.

The mb equivalent for carbon in a propane bubble chamber (ρ = 0.41) is 595 metres. Using 5 mb for coherent production below the coherent limit, we can expect that at least 1% of the events give interesting (Δ^2 small) three-pion events, and we can estimate that 0.5% give interesting five-pion events. One should then have ~1 million pions (~100,000 pictures) entering the fiducial volume at each energy, 16 and 22 GeV/c.

Since our Gargamelle analysis system is being carefully designed to optimize the correlation and measurement of converted electron-positron pairs, we are interested in studying the neutral decay modes of many particles and resonances produced in the photos with not too many incident pions.

2.2 Neutrino experiments

Let us assume that the fiducial volume of Gargamelle is 10 m^3 [1]; that the PS and Gargamelle will permit a repetition rate of 1 pulse/per 1.5 sec. Let us neglect for the moment the fact that the beam intensity

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[1] L. Alfille, Proceedings of the International Colloquium on Bubble Chambers, Heidelberg (1967), p. 111.

2.3 G1 beam experiments

We are interested in the study of Y_0^* resonances in the channel $\Sigma^0\pi^6$; the exposure has been scheduled after the shut-down of the PS.

We propose to extend the study of production and neutral modes of decay of. Y^* resonances ($\Sigma\pi$, $\Lambda\pi$ channels) up to about 2,500 MeV mass values, using the G1 beam (K^-: 1.2 - 2.4 GeV/c) in Gargamelle.

This exposure will also make it possible to study the branching ratios of the decays of K^0 and η^c mesons, the features of Ξ^0, and Ξ^* resonances.

We point out that in order to study the $\Sigma^0\eta^0$ channel from threshold, it would be necessary to have an incident momentum of K^- as low as ~1 GeV/c.

2.4 Experiments using the G3 beam

The diffractive dissociation of incident $K^\pm$ is very useful to help disentangle the situation with the K^* resonances ($K^* \to K\pi\pi$) which one finds well presented either in the notes of G. Goldhaber for the 1967 CERN School (CERN 67-24) or in the rapporteur's talk of I. Butterworth at the Heidelberg Conference. The mass region of interest (1.2 to 1.4 GeV/c^2) is available for incident $K^\pm$ of 14 GeV/c where the coherence condition gives 1.4 GeV/c^2.

may be increased by a factor larger than 2 by the time Gargamelle will be operative.

If the above assumptions are verified, a propane-filled Gargamelle should produce more than 400 events per day; of these about 100 should be elastic events

about 100 should be elastic events
$(\nu + n \rightarrow \mu^- + p)$

" 180 should be 1π events
(of which 40 are on free protons)

" 120 inelastic events with more than 1π

Using $\bar{\nu}$, the total number of events produced per day should be about one-third of that produced using neutrinos, if the estimates of the flux obtainable for beams are correct. Assuming that in 1970 a period of 30 days will be granted for this experiment, then:

- using ν beams one expects a total yield of 12,000 events;
- using $\bar{\nu}$ beams, a total of ~4,000 events [this experiment is more difficult than the former one, due to the less favourable (signal/background) ratio].

Using a ν beam we propose

i) to study the elastic axial form factors of nucleons;
ii) to study the inelastic form factors in the region of N^*_{33} production;
iii) to study the production of many pions, that of pionic resonances and of strange particles (these should provide a test of the $\Delta Q = \Delta S$ rule);
iv) to test CVC and CPAC, following the method suggested by Adler;
v) to investigate further the possible existence of an intermediate boson and, in case of a negative result, to obtain a new lower limit for **its mass**.

Using as $\bar{\nu}$ beam (following the exposure on a ν beam)

i) to obtain a direct determination of the axial form factor by comparing the elastic cross-sections of neutrinos and antineutrinos;
ii) to determine the rate of production of hyperons;
iii) to test the $|\Delta I| = 1$ rule.

26 February 1968

EXPERIMENTAL PROGRAMME WITH GARGAMELLE

Bubble Chamber Group, University College London

1. NEUTRINO PHYSICS

1.1 General considerations

It is obvious that neutrino physics will form a very important part of the experimental programme with Gargamelle. The choice of bubble chamber liquid depends on the experiment. If the prime purpose is to search for W production, for example, it would be advantageous to use a filling of CF_3Br. The heavy liquid filling also makes possible a more definite identification of the muon. The short radiation length (11 cm) leads to large errors ($\sim$ 20%) in momentum determination for π^0 mesons (compared with 7% for C_3H_8). Errors in momentum determination of non-stopping charged particle tracks are also larger although a larger proportion will stop. For some experiments, such as the study of the relative production cross-sections for different N^* charge states, it is desirable to study interactions on free protons so that a C_3H_8 filling would be needed. In this case, however, owing to errors in momentum determination the sample of "free" proton interactions will contain a contamination of $\sim$ 25 per cent interactions on "quasi-free" protons due to interaction with nucleons bound in carbon but having a small ($<$ 100 MeV/c) transverse Fermi momentum component. The larger proportion of carbon in propane is an advantage for an experiment proposed below to look for transverse polarization of the proton perpendicular to the ν-μ plane in ν-elastic reactions. On the other hand the detection probability for neutrons is $\sim$ 60 per cent and for π^0 mesons only $\sim$ 50 per cent in propane, compared with $\sim$ 85 per cent and 100 per cent respectively for CF_3Br.

As a compromise we are proposing that a mixture (87 per cent C_3H_8 + 13 per cent CF_3Br) should be used for the bubble chamber liquid. For this mixture the radiation length is 60 cm, the π^0 detection efficiency is $\sim$ 80 per cent, the neutron detection efficiency $\sim$ 63 per cent and error on π^0 momentum determination $\sim 8\frac{1}{2}$ per cent.

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There seems to be a good case for a run using the above mixture as well as for a smaller run using a CF_3Br filling. In order to obtain comparable statistics for neutrino and antineutrino events we are proposing the following exposures that could be spread say over a period of two years :

i) 3×10^5 pictures with ν in a filling (87% C_3H_8 + 13% CF_3Br);
ii) 1.7×10^6 pictures with $\bar{\nu}$ in a filling (87% C_3H_8 + 13% CF_3Br);
iii) 1.5×10^5 pictures with ν in a filling of CF_3Br;
iv) 8.5×10^5 pictures with $\bar{\nu}$ in a filling of CF_3Br.

In order to increase the proportion of high momentum transfer interactions, (iii) and (iv) could be carried out using a neutrino beam in which the proportion of high-energy neutrinos is enhanced by decreasing the decay path of the neutrino parents or in some other way.

The figures given in the following discussion relate to the exposures (i) or (ii) above, using the mixed liquid. The experiments described in Sections 1.2, 1.3 (1.3.1, 1.3.2) could also be carried out using exposures (iii) and (iv) with a CF_3Br filling. For these exposures the event rate can be estimated approximately by multiplying the event rates given in the text by approximately 1.5.

1.2 Elastic neutrino interactions

1.2.1 Total cross-section measurements

a) $\underline{\nu + n \rightarrow \mu^- + p}$

The data expected in this case is

Total No. of useful elastic events	5,000
No. of events with $E_\nu > 2$ GeV	800
No. of events with $E_\nu > 5$ GeV	50
Improvement factor on existing world data	~ 25

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

Total No. of useful elastic events	3,000
No. of events with $E_{\bar{\nu}} > 2$ GeV	500
No. of events with $E_{\bar{\nu}} > 5$ GeV	30
Improvement factor on existing world data	~ 100

1.2.2 Form factor measurements

Existing data has enabled a study of the form factors out to $q^2 \simeq 0.8$ (GeV/c)^2 for ν and to $q^2 \simeq 0.4$ (GeV/c)^2 for $\bar{\nu}$. The proposed exposures with Gargamelle should enable the study to be extended with comparable accuracy out to $q^2 \simeq 2.5$ (GeV/c)^2 for ν and to $q^2 \simeq 2.2$ (GeV/c)^2 for $\bar{\nu}$. This assumes a form factor variation of the form $[1 + (q^2/0.64)]^{-2}$.

1.2.3 Hyperon production

No definitely established cases of Y production in the processes

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

$$\bar{\nu} + \left.\begin{matrix} n \\ p \end{matrix}\right\} \rightarrow \mu^+ + \left.\begin{matrix} \Sigma^- \\ \Sigma^0 \end{matrix}\right\}$$

have been observed. The number expected depends on the value of M in the form factor $[1 + (q^2/M^2)]^{-2}$. Even in the least favourable case about three examples would have been expected. Assuming only one had been produced in existing experiments the number to be expected in the proposed experiment would be ~ 100. The observation of a significantly smaller number would have important implications in weak interaction theory.

1.3 Events in which one pion is produced

1.3.1 Total cross-section and form factors for N^* production

The number of events available for the determination of the cross-sections

$$\nu + \left.\begin{matrix} n \\ p \end{matrix}\right\} \rightarrow N^* + \mu^-$$

$$\bar{\nu} + \left.\begin{matrix} n \\ p \end{matrix}\right\} \rightarrow N^* + \mu^+$$

will be about twice that for the elastic processes. Supposing the form factors for those processes to be known from existing data out to $q^2 = 1{,}0$ GeV/c^2 for ν and to 0.5 GeV/c^2 for $\bar{\nu}$, the Gargamelle experiment will push these limits to 3.0 (GeV/c)^2 for ν and to 2.5 (GeV/c)^2 for $\bar{\nu}$.

1.3.2 Y^* production

Approximately 200 Y^* might be expected from the process

$$\bar{\nu} + \left.\begin{matrix} n \\ p \end{matrix}\right\} \to Y_1^* + \mu^+ \ .$$

1.3.3 Branching ratios for production of different N^* and Y^* charge states

The production of N^* and Y^* is expected to occur through the following interactions involving neutrinos and antineutrinos.

$$\nu + n \to N^{*+} + \mu^- \ , \qquad (1)$$

$$\nu + p \to N^{*++} + \mu^- \ , \qquad (2)$$

$$\bar{\nu} + n \to N^{*-} + \mu^+ \ , \qquad (3)$$

$$\bar{\nu} + p \to N^{*o} + \mu^+ \ , \qquad (4)$$

$$\bar{\nu} + n \to Y_1^{*o} + \mu^+ \ , \qquad (5)$$

$$\bar{\nu} + p \to Y_1^{*o} + \mu^+ \ . \qquad (6)$$

The relative yield of N^* components is given by the $\Delta I = 1$ rule as follows:

$$\frac{\sigma(2)}{\sigma(1)} = 3 \ , \qquad \frac{\sigma(3)}{\sigma(4)} = 3$$

while the $\Delta I = \frac{1}{2}$ rule gives

$$\frac{\sigma(5)}{\sigma(6)} = 2 \ .$$

SU$_3$ gives further for high energy $\bar{\nu}$ ($E_{\bar{\nu}} \gtrsim 2$ GeV)

$$\frac{\sigma(6)}{\sigma(4)} = \frac{1}{2} \tan^2 \vartheta$$

(where ϑ is the Cabibbo angle $\simeq 0.03$).

Detailed predictions of the differential and total cross-sections for these processes have been made by Albright and Liu[1]) using SU_6 and the CVC hypothesis and a form factor parameterization of the type

$$F(q^2) = (1 + q^2/M^2)^{-n} \quad , \qquad n = 1, 2 . \qquad (7)$$

Electron scattering data give for the electromagnetic isovector form factor a parameterization of this type with $n = 2$ and $m = 0.84$ GeV.

Measurements of this type should enable specific tests to be made of:

a) Branching ratios expected on the basis of the

$$\Delta I = 1 \quad \text{and} \quad \Delta I = 1/2 \text{ rule} .$$

b) The predictions of SU_6 and the CVC hypothesis concerning the form factors for zero momentum transfer and the ratio of Y^* and N^* yields.

c) The parameterization of the form factor dependence on q^2. The topologies of the various processes are summarized below:

$$\mu^- n \pi^+ \quad \text{or} \quad \mu^- p \pi^0 \qquad (8)$$

$$\mu^- p \pi^+ \qquad (9)$$

$$\mu^+ n \pi^- \qquad (10)$$

$$\mu^+ p \pi^- \quad \text{or} \quad \mu^+ n \pi^0 \qquad (11)$$

$$\mu^+ \Lambda^0 \pi^- \qquad (12)$$

$$\mu^+ \Lambda^0 \pi^0 . \qquad (13)$$

For most events, even for high-energy neutrinos the momentum transfer will be less than 1.0 $(\text{GeV}/c)^2$. Most of this will be given to the baryon. As a result, in most of these interactions all charged particles will be identifiable making possible a good test of N^* or Y^* production.

These branching ratios cannot be determined using interactions in complex nuclei owing to secondary processes leading to charge exchange. It is necessary, therefore, to select samples of events in which the interaction is identified as taking place on a free proton. It is estimated that the sample of identified Y^* or N^* produced in interactions on free protons will consist of 150 for the ν exposure and 100 for the $\bar{\nu}$ exposure. Such a measurement would enable cross-sections for processes (9) and (11) to be determined with about the same accuracy as the total cross-section for N^* production from complex nuclei is at present known. In addition one or two examples of Y^* production in process (13) might be observed. It should be remembered, however, that owing to difficulties of separating free and bound proton production about one quarter of the events would still have been produced on bound protons so that the results would not provide a clean test of branching ratios of processes (9), (11) and (13). Processes (8), (10), (12) are not accessible to study in this way. They might be obtainable from a later experiment in deuterated propane since secondary charge-exchange processes would not be expected to be important in the deuteron. On the other hand it might be concluded that this type of experiment could better be carried out in a liquid hydrogen or deuterium chamber. If this conclusion should be reached it would offset the decision on the type of bubble chamber liquid to be used since the other experiments discussed so far could almost as well be carried out in CF_3Br resulting in a threefold increase in statistics.

1.4 Study of time reversal violation in neutrino interactions

Following a speculation by Cabibbo, an estimate has been made by Berman and Veltman$^{2)}$ of transverse muon polarization in neutrino induced interactions as a test for time reversal violation. Assuming definite SU_3 behaviour of the weak currents and of the non-leptonic Lagrangian, T-reversal violation could arise from the interference of the regular (first order) and irregular (second order) weak currents of the hadrons. Maximum effect would be obtained for a phase difference of 90^c between the two types of current.

For the elastic process

$$\nu + n \rightarrow \mu^- + p$$

and assuming this phase difference of 90° and two possible choices of one of the constants B that specifies the strength of the second order weak current term, Berman and Veltman estimated the average polarization percentages for the muon as a function of neutrino energy E_ν and of the angle ϑ between the neutrino and muon momenta in the lab. system (see Table 1). It should however be emphasised that any transverse polarization of the muon could be interpreted as evidence of T non-invariance.

Table 1

E_ν in MeV, ϑ in degrees, average polarization in %.
ϑ is the angle between muon and neutrino momentum
in the lab. system. E_ν = neutrino-energy in the lab. system.

E_ν	B = 3.71			B = 6		
ϑ	500	1000	2000	500	1000	2000
0	0	0	0	0	0	0
20	- 0.3	5.2	14	- 0.5	7.1	16
40	7	19	30	10	25	35
60	14	26	34	20	35	44
80	16.5	26	32	24	37	45
100	16	23	27	24	34	40
120	13	17.5	20	20	27	31
140	9	12	13.5	14	19	21.5
160	4.5	6	7	7.4	9.5	11

In order to measure the polarization, it is necessary:

i) that the muon should stop in the chamber, and
ii) that it should maintain its polarization until it decays.

Turning to condition (ii), of μ^- mesons captured in carbon, about one-half undergo μ^- nuclear capture before decay while the remainder retain only about 14 per cent of their polarization at the time of decay.

Since the maximum polarization expected under most favourable conditions is 40 per cent and the asymmetry factor corresponding to 100 per cent polarization is 33 per cent, the actual asymmetry expected would be only 2 per cent which would not be measurable for any neutrino flux conceivable in the near future.

For μ^+ mesons the situation is more favourable since the polarization will be maintained provided muonium formation is prevented. This will be the case if a transverse field greater than a few thousand oersted is maintained. The μ^+ will precess about the field direction. There will remain however a resultant polarization along the field direction although this will be considerably less than the polarization perpendicular to the production plane (of the order of one-half).

For an exposure of 1.7×10^6 pictures with $\bar{\nu}$ in CF_3Br, it can be estimated that approximately 300 μ^+ will stop in the chamber. 60 per cent of the stopping muons will be produced by $\bar{\nu}$ in the energy range E_ν from 0.5 to 0.75 GeV. The average polarization that would have to be measured is $\sim$ 10 per cent, corresponding to an asymmetry of 3 per cent. Clearly neutrino fluxes many orders of magnitude greater would be needed to make such an experiment practicable in Gargamelle.

Time reversal violation would also give rise to transverse polarization of the proton from the ν interaction perpendicular to the ν-μ plane. The magnitude of the effect was calculated by Fujii and Yamaguchi$^{3)}$ using the same assumptions as Berman and Veltman. For an incident neutrino of energy 940 MeV they obtained an expected polarization of around 40 per cent for a large range of proton emission directions (between 30 - 70° relative to incident neutrino direction). In principle, such polarization should be measurable in a chamber with a mixed 13 per cent CF_3Br, 87 per cent C_3H_8 filling through scattering on the carbon.

For the recoil protons, about 25 per cent will suffer an elastic scatter on carbon and the mean polarization averaged over the whole range of energy and momentum will be approximately 50 per cent. The asymmetry

$$\epsilon = \frac{I(\varphi = 0) - I(\varphi = 180°)}{I(\varphi = 0) + I(\varphi = 180°)}$$

is given by the produced P_1P_2 of the polarizations in the neutrino interaction (P_1) and in the elastic scattering (P_2). This amounts to approximately 0.2. From Section 1.2.1 above it is seen that approximately 1250 scatters of protons produced in elastic neutrino interactions should be available. With such a number of events an asymmetry of 0.2 would be measurable with errors of ± 0.03. It appears, therefore, worthwhile to attempt this experiment as a test of time reversal invariance.

Since a large proportion of the neutrino interactions will take place on a complex nucleus there will be some depolarization in leaving the nucleus. Nevertheless any evidence of polarization perpendicular to the ν-μ plane can be taken as evidence of time reversal violation. No polarization due to purely nuclear final state interactions could stimulate polarization in this direction.

Fujii and Yamaguchi also show that large polarizations would be expected (i) in the μ-ν plane, perpendicular to the direction of proton momentum and (ii) in the direction of the proton momentum. These polarizations are not related to T non-invariance however.

2. STUDY OF LONG-LIVED K^0 MESONS

2.1 Introduction

The CP violation parameters for $K_L^0 \rightarrow 2\pi$ decay have been measured with reliability only for the charged mode. The current experimental situation is

$$|\eta_{+-}| = (1.89 \pm 0.09) \times 10^{-3} \quad ; \quad \varphi_{+-} = (65 \pm 11)^\circ ,$$

$$|\eta_{00}| = 4.5 \times 10^{-3} \quad ; \quad \varphi_{00} = \text{not determined} .$$

Published work on the neutral decay mode is based on a total of about 200 events (two experiments).

Gargamelle would appear to be a particularly suitable device for looking at the neutral decay modes, and a rather modest experiment would yield 20 times the above statistics. In addition, large numbers of the other decay modes could be identified, making such an experiment a high statistics "bank" of K_L^0 decays.

2.2 Experimental conditions and yield

For the performance of regeneration type experiments determining $\varphi_{\substack{+-\\00}}$ it is essential to have control over the regenerating material. In particular the optimum amount of absorber to give a maximum interference effect depends on the value of $\varphi_{\substack{+-\\00}}$. It is also preferable to use a material for which $K^{\pm}$ scattering data are available at the momentum used so that the regeneration amplitude can be estimated. An ideal experimental arrangement would be to pass the K^0 beam (with the minimum profile attainable) along a pipe running the length of Gargamelle through the chamber liquid. This pipe should be capable of evacuation and also of containing plugs of regenerating material, or even of being filled with high pressure gas.

A similar experiment (X_4) has been performed in the CERN heavy-liquid chamber and for the purpose of unambiguously identifying decay origins inside the pipe it appears that, on average, no more than one decay per metre length is allowed. If we scale this up for Gargamelle to 4 decays per pulse then the yield of a 250,000 picture experiment is:

Decay mode	Number
$\pi^0\pi^0\pi^0$	250,000
$\pi^+\pi^-\pi^0$	120,000
$\pi\mu\nu$	270,000
$\pi e\nu$	350,000
$\pi^+\pi^-$	1,500
$\pi^0\pi^0$	4,000

The K^0 momentum distribution is probably best chosen to peak at 1 to 1.5 GeV/c. Such a momentum would give interference effects spread over a length suitable for analysis in Gargamelle. Unfortunately the $\bar{K}N$ resonances may complicate analysis of the regeneration process so it might be necessary to choose higher momentum K^0's at the expense of spreading the interference effects over a longer length of the chamber.

Since it is proposed to put the regenerating material within the chamber volume, the presence of a large neutron impurity in the beam would be undesirable. This is because the secondaries from neutron interactions in the absorber could simulate topologically both charged and neutral K^0 decays. This does not constitute a serious background to K^0's decaying well downstream of the absorber, but could complicate the analysis near to (and within) the absorber.

For reasons discussed below, there is considerable advantage in knowing the K^0 momentum accurately. An essentially monochromatic beam and freedom from neutron impurity could presumably be achieved at the same time and we would strongly advocate that the possibilities of producing a clean K_L^0 beam be investigated.

We would propose that, in addition to the 250,000 picture exposure above, designed primarily to determine φ_{00}, there should be a subsidiary run of ~ 100,000 pictures with no regeneration. This would serve to determine $|\eta_{00}|$ by monitoring the flux of K^0 with the $3\pi^0$ or $\pi^+\pi^-\pi^0$ modes. The statistical accuracy of such a determination would be 2½% assuming no background from $\pi^0\gamma\gamma$ mode (see below).

2.3 Size of K_1^0, K_2^0 interference effects

A pure K_2^0 beam incident on a block of regenerating material may be described at real time t after entry into the block by

$$\psi = e^{-iM_2' t}[\,|K_2^0> + \rho\,|K_1^0>] ,$$

where

M_2' = complex mass of K_2^0

ρ = regeneration amplitude

=

$$|\rho|\,e^{i\varphi_\rho} = \frac{\pi N}{M}\, i(f - \bar{f})\, \frac{1 - e^{-i\Delta M t}}{-\,i\Delta M} ;$$

N = number of atoms per unit volume;
M = mean mass of K^0;
$f, \bar{f}$ = forward scattering amplitudes for K^0 and $\bar{K}^0$ respectively in regenerating medium;
ΔM = $\Delta M - i(\Gamma_1/2) - i(\Gamma_2/2)$;
Δm = $m_1 - m_2$.

If $\Gamma_{1,00}$ is decay width for $K_1^0 \rightarrow 2\pi^0$ then the decay rate for this mode is

$$\frac{dN_{00}}{dt} = \Gamma_{1,00}\left[e^{-iM_2' t}(\eta_{00} + \rho)\right]^2$$

$$= [|\eta_{00}|^2 + |\rho|^2 + 2|\eta||\rho| \cos(\varphi_\rho - \varphi_{00})] . \qquad (14)$$

At time t' after leaving the block, having spent time t_1 in the block, the beam may be described by

$$\psi' = e^{-iM_2' t'}|K_2^0> + \rho_1 e^{-iM_1' t'}|K_1^0>$$

where ρ_1 is the value of the regeneration amplitude after time t_1. Then

$$\frac{dN_{00}}{dt'} = \Gamma_{1,00}\left[\eta_{00} e^{-iM_2' t'} + \rho_1 e^{-iM_1' t'}\right] ,$$

for example

$$\frac{dN_{00}}{dt'} = \Gamma_{1,00}\left[|\eta_{00}|^2 e^{-\Gamma_2 t'} + |\rho_1|^2 e^{-\Gamma_1 t'} \right.$$

$$\left. + 2|\eta_{00}||\rho_1| e^{-(\Gamma_1+\Gamma_2)t'/2} \cos(\varphi_{\rho_1} - \varphi_{00} - \Delta m t)\right] . \qquad (15)$$

Equations (14) and (15) present many possibilities for the determination of φ_{00} if the amount and arrangement of regenerator can be varied. Calculations are in progress at UCL to optimize the regenerator distribution. The periodic time, t', of the interference term in Eq. (15) is given by putting $\Delta m t_0' = 2\pi$. For a 1 GeV/c K_2^0 this gives the wavelength of the interference term to be ~ $^2/_3$ metre, so that some 5 wavelengths can be observed in Gargamelle. However, the relative amplitude of the interference effect, assuming optimum interference conditions can be achieved that is, $\varphi_{\rho ;} = \varphi_{00}$), reaches a peak at ~ $4 K_1^0$ mean lives from the absorber, that is ~ 20 cm, and is only 1% at $^2/_3$ metre. Thus one has the attractive possibility in Gargamelle of introducing further blocks of absorber within the length of the chamber, thereby "feeding" the interference and increasing the data for determining φ_{00}.

2.4 Background processes

The only significant background to the $2\pi^0$ decay is believed to come from the $3\pi^0$ mode in which 2 gammas have escaped detection. (No information is available on the rate of the CP allowed mode $K_2^0 \to \pi^0\gamma\gamma$.) The signal to noise ratio is given by

$$\frac{\text{branching ratio } (K_2^0 \to 2\pi^0)}{\text{branching ratio } (K_2^0 \to 3\pi^0)} \times \frac{\text{probability of seeing } 4\gamma/4\gamma}{\text{probability of seeing } 4\gamma/6\gamma} \,.$$

The ratio of the $2\pi^0$ to $3\pi^0$ rates is ~ 15×10^{-3}, the probability of detecting 4γ in the chamber from 4γ produced is P^4; the probability of detecting $4\gamma/6\gamma$ is $15P^4(1-P)^2$, where P is the probability of detecting one γ:

$$\text{therefore} \quad \frac{\text{signal}}{\text{noise}} = \frac{1}{(1-P)^2} \times 10^{-3} \,.$$

Clearly, this is only significant if $P \simeq 1$. If Gargamelle is filled with pure CF_3Br then it does indeed have P very close to unity since the materialization length is ~ 14 cm and a reasonable choice of fiducial volume would allow a minimum distance of ~ 5 such materialization lengths for detection in all directions, for example a detection probability of 99.33%. In this case

$$\frac{\text{signal}}{\text{noise}} = \sim 20 \,.$$

One concludes that Gargamelle with a CF_3Br filling is extremely efficient in distinguishing between $2\pi^0$ and $3\pi^0$ decay modes over a 4π solid angle. (The above may be slightly optimistic since there will be a small number of events in which 2 of the 6 gammas look like bremsstrahlung from 2 of the other gammas.)

For the $\pi^+\pi^-$ mode, the only significant background is $K_{\mu 3}$, since the $\pi^+\pi^-\pi^0$ mode will be revealed as such with high efficiency (~ 99%) by the materialization of one or both gammas. It has been estimated that pions of the energy concerned will identify themselves by stopping and decaying characteristically or by strong interaction in the chamber, with an efficiency of ~ 90%. Thus the $\pi^+\pi^-$ mode can also be investigated in this experiment and, since the parameters of this mode will presumably be well established by the time any Gargamelle experiment is mounted, those decays might provide a useful monitoring facility for the regeneration process.

2.5 Determination of K_1^0 momentum

It is necessary, for a constrained fit, to know the direction of the incident K_2^0 rather well (~ ± 2°). Then without measuring γ momentum a $K_2^0 \rightarrow 2\pi^0$ is a 1 constraint fit over 3 vertices. With γ momentum it becomes 5 constraint over 3 vertices. However, γ momenta can be determined only to about ± 25% in CF_3Br. A check on the momentum spectrum obtained for K_2^0 that decay in the $2\pi^0$ mode can be obtained from those that decay in the $\pi^+\pi^-\pi^0$ mode which is a 2 constraint fit over 2 vertices, without momentum measured.

If a substantial amount of $\pi^0\gamma\gamma$ is present then we should require momenta to be measured, otherwise, this mode is not constrained. With momenta then the event is a 4 constraint fit over 2 vertices. In the experiment of Gaillard et al.$^{4)}$ a γ momentum determination of ± 25% is claimed, and this is sufficient to reduce any background contribution from $\pi^0\gamma\gamma$ to below 4%. We conclude that we are at least in as favourable a position as this for eliminating the $\pi^0\gamma\gamma$ background.

2.6 Other studies in the experiment

2.6.1 Branching ratios

This experiment would be in a particularly favourable position to compare the branching ratios for $3\pi^0$ and $\pi^+\pi^-\pi^0$ decay modes. If CP is not violated (or only slightly violated) in decay to a T = 3 state then the rates for $3\pi^0$ to $\pi^+\pi^-\pi^0$ should be in the ratio 1.83 : 1. Experimental results to date are not accurate enough to restrict the CP non-invariant amplitude with T = 3.

The $K_{\mu 3}$ and K_{e_3} modes would be detected with high efficiency and it would be possible to determine their relative rates to a considerably higher accuracy than heretofore.

2.6.2 Radiative decays

The current upper limit to the branching ratio for $\pi^+\pi^-\gamma$ decay is $\sim 10^{-4}$; that is, in this experiment we should observe about 100, or alternatively reduce the upper limit by factor $\sim 10^2$. A large background for this mode exists from $\pi^+\pi^-\pi^0$ and using the value for P as before

$$\frac{\text{signal}}{\text{noise}} \leq \frac{1}{16} .$$

The kinematic constraints for this decay are good however (2C without momentum) so efficient rejection of background can be expected.

2.6.3 Charge asymmetry in $K_2^0 \rightarrow \pi^+\pi^-\pi^0$

Observation of a charge asymmetry in this mode would be direct evidence for CP violation. Experimental evidence to date is consistent with zero asymmetry to $\pm \sim 5\%$. In this experiment the $\pi^+\pi^-\pi^0$ mode is well detected and well constrained (2C over 2 vertices with no momenta), and an asymmetry of $< 1\%$ could be established with high statistical certainty.

3. OTHER EXPERIMENTAL PROPOSALS

Other possible experiments are being considered. These include a study of muon interactions in hydrogen and carbon. It is not clear whether Gargamelle possesses any particular advantage for this experiment. It may be that it could be carried out more easily and with a faster accumulation of statistics using electronic and spark chamber techniques.

Other types of experiments under active consideration are the study of Ξ^0 and Ω^- branching ratios and decay parameters. In experiments of this type the large dimensions of Gargamelle only offer a significant advantage over those chambers currently in use when a liquid of long radiation length is required. To illustrate this we compare the number of Ξ^0 produced and detected per incident K^- in Gargamelle to the same quantity in the much smaller UCL/RHEL heavy liquid chamber of dimensions $140 \times 50 \times 45$ cm^3. We find that with a CF_3Br filling and with the same number of incident K^-, only about 1.5 times the number of complete Ξ^0 (in which both γ's are seen) are found in Gargamelle compared to the smaller chamber. In the case of a propane filling, however, Gargamelle will accumulate such events at a rate eight times faster.

Studies of these experiments are continuing.

* * *

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PRELIMINARY STUDIES ON BEAMS FOR GARGAMELLE

Gargamelle Beam Study Group
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The purpose of this report is to describe the preliminary proposals of the Gargamelle Beam Study Group regarding beams for Gargamelle in the South-East area of the PS. We have considered physics and beam optics aspects, and make a tentative proposal for the over-all layout of the area. Members of the PS Division are in the process of making a detailed evaluation of the technical problems involved.

The aim of the study has been to provide around the ν installation, which is central to the whole area, conventional beams (K, π, p) delivering particles over a wide range of momenta, and also to consider in the same context some non-standard beams (μ, K^0).

1. CHOICE OF BEAMS

The full list of beams in the area has been taken to be:

- the ν beam (essentially already existing);
- three separated beams for the approximate momentum ranges 1.2 to 2.4 GeV/c (ES separation), 2.4 to 4.2 GeV/c (ES), and 5 to 14 GeV/c (RF - 2 cavities with variable separation);
- a muon beam;
- a K^0 beam;
- a non-separated beam (test-beam).

The code numbers of these beams are shown in Table 1.

Some omissions from this list should be explained. For the present, no low-energy K^- beam (below 1.2 GeV/c) is envisaged, as it is not yet evident that such a beam could be successfully injected into Gargamelle through its fringe field. If this were eventually possible, we would propose a suitably modified version of the K11 beam. No high momentum, electrostatically

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separated, kaon beam is proposed, so that there would be a gap in kaon momentum from about 4 to 5 GeV/c, which could be larger if the RF beam were unsatisfactory at low momenta. For this reason it is proposed that in the event that this momentum gap is a serious one, it should be possible to construct an electrostatically separated beam (momentum about 5 GeV/c) along the line of the RF beam. A further qualification to the list of beams is that the non-separated beam is proposed in spite of the fact that most of its functions could be fulfilled by the RF beam. The reason is the difference in time scales. A high-momentum beam of hadrons will probably be required as a test beam long before an RF beam could be available.

2. LAYOUT OF AREA

A number of siting problems were considered, some general and some specific to certain beams. Since the area was conceived basically for ν experiments, Gargamelle is in a fixed position behind the ν shielding (although it can be rotated through an angle of ±20°). Also the present ejected proton beam (EPB) is directly aligned towards the chamber in a narrow tunnel under a large mound of earth shielding. It has been assumed that the main bulk of the ν shielding is not to be moved, and that there will continue to be an axial hole through the fixed shielding. It would in any case be necessary to leave some shielding on the EPB axis in order to shield the low-momentum beam target (G1). It is possible either to take a beam out of the ν tunnel and round the shielding, or to keep it in the tunnel and to pass it through the shielding. Each possibility presents problems, but it is thought that these problems are surmountable, without deflecting the EPB, for all the standard beams with the exception of the RF beam. For the RF beam, a deflection of the EPB is necessary before the ν tunnel in order to obtain suitable high-energy beam optics in the given length, and to maintain compatibility with the ν beam. Care will be necessary in the design of the downstream end of the ν shielding if it is extended close to Gargamelle in order to maintain flexibility among the different beams.

From the beam optics point of view, the South-East area is, of course, symmetric about the present EPB line. The positions of the various beams will therefore be governed by other factors. These other factors have been considered in a non-detailed way, starting from the assumption that the greatest problems arise for the RF beam and that its position should therefore be fixed first. The question is then whether the RF beam should be placed on the left or on the right (looking downstream) of the present EPB. The considerations taken into account were: i) excavation near the PS ring; ii) effects on present buildings and plant; iii) effects on present access ways; iv) radiation hazards; v) ease of deflection of the present EPB to a new line. With all these things considered, it would seem preferable to have the RF beam on the right rather than on the left of the present EPB line. These two possibilities are being considered in much more detail by members of the PS Division. In the event of the choice of deflection to the right being made, then it would be logical for reasons of compatibility to place the two other separated beams (G1 and G2) on the left. On this side, the higher momentum beam of the two (G2) could make use of the already existing branch tunnel. The high-momentum unseparated beam (G4) does not enter into the discussion of left/right factors, as it is envisaged that this will be mostly within the ν tunnel and will emerge through the central hole of the shielding.

3. BEAM CHARACTERISTICS

Some of the characteristics of the beams G1 to G4 are shown in Table 2. The common assumptions made for the fluxes given are as follows: i) one bunch is 3.5×10^{10} protons; ii) the target is always copper of dimensions 2mm × 2mm × 100mm; iii) the target efficiency is 25%; iv) the beam-line transmission is 50%. For G1 and G2 it is assumed that the limiting value of the separation ratio (including chromatic aberrations) is 1.0.

G5 has not been considered, as it is expected to be essentially similar to the present ν beam. G6 and G7 do not appear in Table 2, as their study is not so far advanced as the other beams. They are, however, discussed at the end of this section. Appended to this report is a drawing showing the lines of the beams G1 to G5 as they are envisaged at present. It should be emphasized that the information on the drawing and in Table 2 is provisional only.

There follow some comments about the individual beams. The studies for the beams G1 and G2 were made by D. Simon and D. Leroy (NPA Int. 68-4).

G1: This is a single-separation-stage beam with momentum definition before and redefinition after the separation. The momentum dispersion is almost compensated through the separation stage.

The flux figures were obtained from the curves given by Jordan (CERN 65-14), and by Sanford and Wang (AGS Internal Report JRS/CLW-2).

G2: This is again a three-stage beam with a single-separation stage, definition of momentum bite before and after separation, and approximate correction of dispersion through the separator. The fluxes were obtained from the papers of Jordan, and Sanford and Wang.

Some modification of the ν branch tunnel will probably be necessary for G2 but this should involve only a small addition to the programme of work which will be necessary for the RF beam in that area.

G3: G3 is a two-cavity RF separated beam from which a continuous momentum band of particles will be available through the use of one mobile cavity. The maximum length available is about 150m, which causes some problems of beam design. The optics are not yet sufficiently fixed to allow solid angles and fluxes to be quoted. In order to obtain an idea of the fluxes expected, a rough comparison with the U3 beam is made (CERN/TC/BEAM 66-7). The solid angles accepted in the two beams should be similar but we can tolerate a larger momentum bite, which in turn leads to a larger target width. However, the chromatic aberrations will probably be worse in G3. It can thus be expected that the fluxes should be about the same in the two beams.

G4: This is an unseparated beam which, in its π^- version, has a target at the beginning of the ν tunnel. A momentum selection and recombination is made in the tunnel, using pulsed magnets, and the π^- beam then passes through the central hole of the ν shielding before being shaped by standard quadrupoles for entry into Gargamelle. The fluxes were calculated from curves given by Sanford and Wang (AGS Internal Report JRS/CLW-1) and are uncertain at high momenta.

The proton version of G4 is still being studied. The principal problem is the reduction of the flux to about 10 protons, given one whole bunch ejected. Use of an internal target would be very difficult because of the pulsed nature of the septum, EPB, and G4 magnets. The momentum of the G4 proton beam would be equal to the momentum at ejection, and the lower limit is uncertain.

G5: The details of the ν beam have not yet been considered except in recognizing the problems of compatibility that will exist. As already stated, it is not expected that there will be any radical changes in the ν beam when it is reconstructed for Gargamelle.

G6: The muon beams that are being considered are of two basic types, large and small momentum bite. The large momentum bite beam (about ±10% or more) is being studied in two forms, both of which use the ν target but which use the ν horn or a quadrupole doublet for focusing the pions. The ν-horn version has already been used in a pilot experiment, and with proper choice of shielding can provide muons in the approximate momentum range of 8-16 GeV/c. The version with quadrupole focusing provides a smaller momentum spread and a smaller muon flux. Each version requires two or three magnets between the shielding and Gargamelle to shape the beam for entry.

The low-momentum-bite version attempts to trap the muons which are produced when a pion beam decays over a long drift length in which it is parallel in both planes. Such muons can be spatially separated from the pions in the plane of a subsequent pion image. A large absorber placed at the pion image may then absorb the pions while allowing a useful fraction of the muons to pass. It is expected that the loss factor for the muons will be large and calculations are being made to determine its magnitude. Even if it proves possible to produce a useful muon flux in this way, this version of the muon beam would suffer from the disadvantage that it would require a large number of magnets, probably about the same number as in a conventional high-energy separated beam. Because of this, the possibilities are being considered of using lines in the region of G3 or G4 for this beam.

G7: There are a number of possible ways of producing K^o's for study in Gargamelle and there is no universally optimum beam. If a repeat of the X4 experiment (B11 beam) were desired (K^o_2 produced by protons; tube through chamber), it would probably be possible by using a target in the ν tunnel and passing the K^o_2 beam through the hole in the ν shielding. Other possible solutions are being studied in which K^o's are produced by the interactions of π^- or K^+, both with or without tubes in the chamber and with or without knowledge of the K^o momentum. These solutions are expected to suffer in general from low fluxes when compared with an X4 type experiment.

* * *

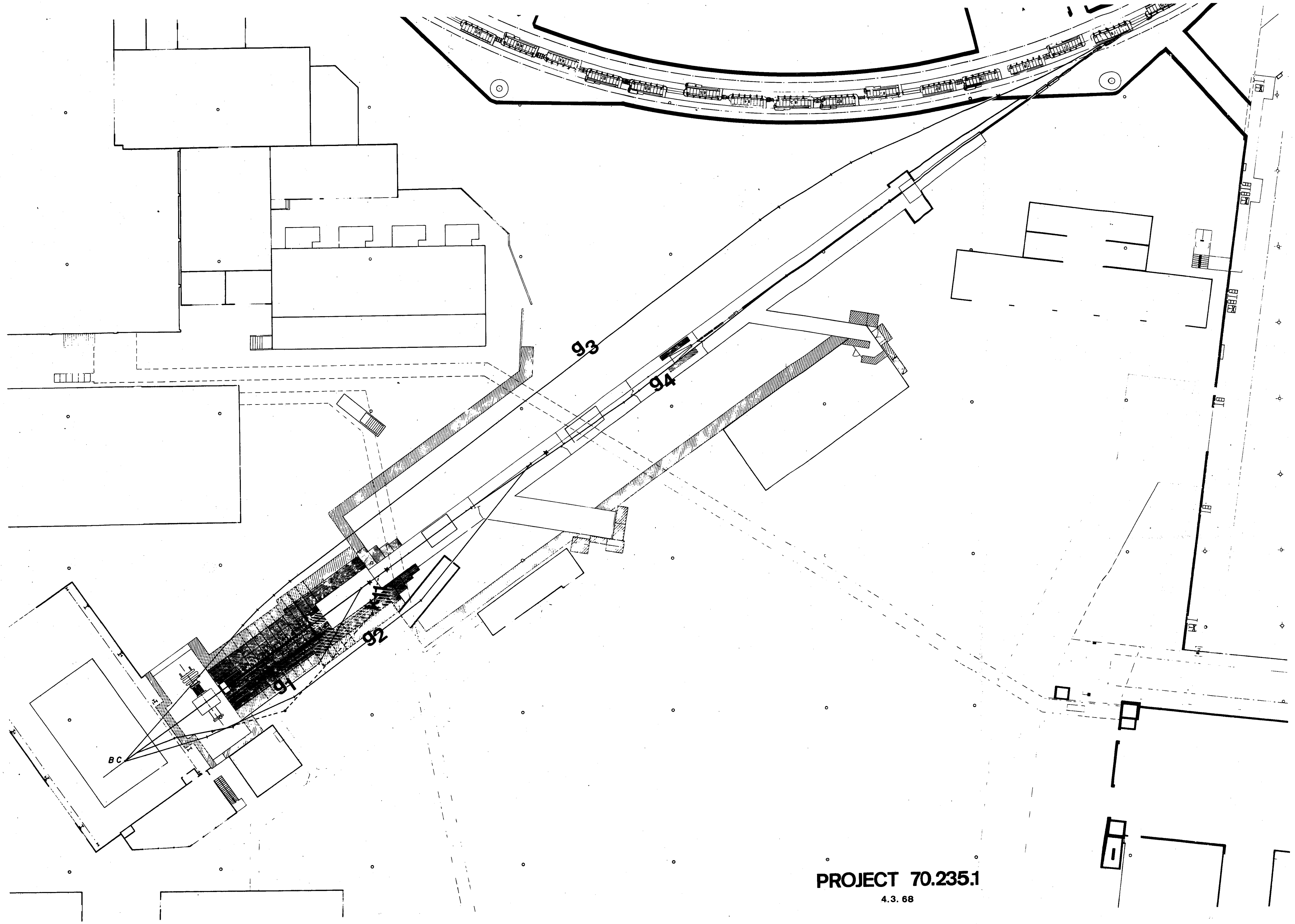
We would like to thank all the people who have helped us in this study. In particular, we are grateful to B. Langeseth, D. Leroy, D. Simon and S.N. Tovey for the work that they have contributed.

Table 1

Beam Number	Particles	Momentum (GeV/c)		Type of separation
		Lowest	Highest	
G1	$K^{\pm}$, $\pi^{\pm}$, p, $\bar{p}$	1.2	2.4	ES
G2	"	2.4	4.2	"
G3	$K^{\pm}$	5	14	RF
	$\pi^{\pm}$		22	
G4	π^{-}	2	22	None
	p	-	25	
G5	ν, $\bar{\nu}$	-	-	-
G6	μ	-	-	-
G7	K^{o}	-	-	-

Table 2

Beam	Length (m)	$\Delta p/p$ (%)	Ω (msr)	Particle	Flux/Bunch
G1	40	±½	0.58 at 1.2 Gev/c 0.11 at 2.4 Gev/c	K^-	15 at 1.2 105 at 2.4
				K^+	30 at 1.2 150 at 2.4
				$\bar{p}$	180 at 1.2 90 at 2.4
G2	75	±¾	0.2 at 2.4 0.05 at 4.2	K^-	36 at 2.4 75 at 4.2
				K^+	50 at 2.4 150 at 4.2
				p^-	230 at 2.4 110 at 4.2
G3	146	±½	-	-	-
G4	122	±0.4	0.03	π^-	600 at 2 4000 at 6 100 at 22



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