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PHYSICS I
ELECTRONICS EXPERIMENTS COMMITTEE

PROPOSAL

TO STUDY THE COHERENT 3π, 5π AND $K\pi\pi$ PRODUCTION ON NUCLEI AT THE SERPUKOV ACCELERATOR

by

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1 - Introduction

Coherent production of many pions systems in nuclear matter has so far been investigated up to 15 GeV/c primary energy(1,2,3,4,5). Some essential properties of the angular distribution and of the selection rules for the quantum number of the coherently produced systems have been established. The most striking feature of these experimental results is anyhow the low absorption cross section of the produced boson systems in nuclear matter.

Modifications of the Glauber theory(6,7,8,9) have been developped in order to explain this peculiar behaviour, but on the other hand the predictions of the models can be tested more satisfactory in the high energy limit. An experiment on coherent production at Serpukhov energies would therefore be an important step in understanding the diffractive dissociation phenomena.

From the experimental point of view the use of the "live" target technique(10) in a more refined version allows to obtain a purified sample of coherent events on Silicium also in the region of the second maximum of the angular distributions. The study of coherent production at large momentum transfers, t, is relevant in order to investigate problems related to the quantum numbers of the produced states (like helicity conservation) and to test the models mentioned above. It is to be noticed that from the results already obtained at Serpukhov with hydrogen target(11), we can expect that the non diffractive background will be depressed by a factor ∼ 4 with respect of the coherent sample from 16 to 40 GeV/c.

The physical problems we would like to investigate can be summarized in the following crucial points:

1) the previous experiments(1,3) have shown that the system of 3 and 5 pions is weakly scattered in nuclear matter. A possible explanation of this fact has been suggested first by Van Hove (6) as due to a rescattering between states of different mass of the many-pions continuum. This

theory predicts in addition a dependence of the mass spectrum on the atomic number A, and an effect on the angular distribution at fixed mass and for fixed A. However, the strong contribution of the longitudinal momentum transfer to the nuclear form factor at low energies makes the check of the predictions of the models very difficult. If the 3π system is dominated by a peak of mass around 1.1 GeV/c^2, one has the result that the product $2q_1 \lambda_{3\pi}$ (o) (which appears exponentially in the nuclear form factor) is of the order of 1 around 15 GeV/c. Therefore the effect of q_e becomes negligible only at much higher energies.

In addition from the energy dependence of $(d\sigma/dt)_{t=0}^{\pi A}$ one can learn informations about the short distance behaviour of the strong interactions (8), similarly to what one does in the problem of the strong shadowing of photons in nuclei.

Another interesting information can be directly learned from the energy dependence of the absorption cross section, as defined in the standard optical model. An energy dependence much stronger than for instance that of $\sigma_{\pi n}^{T}$ (as seems to be indicated from data at 9 and 15 GeV) (3) would imply a mechanism different from the rescattering of a definite resonant state.

2) At high energy one would be able to investigate with high efficiency 3 and also 5 particles coherent production up to 2.5 GeV/c^2 invariant mass. Therefore a good statistics would allow to obtain the cross sections of the produced systems on bound nucleons, separately for different partial waves over a large mass interval.

3) The third point concerns the possibility of studying the diffractive productions on nucleon through the coherent production on nuclei. The Glauber theory allows to extract these informations from the coherent data. In this way one

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(o) $q_1 = \sqrt{t_{min}} = \dfrac{M_{3\pi}^2 - m_\pi^2}{2p}$ is the longitudinal momentum transfer and $\lambda_{3\pi}$ is the mean-free-path of the 3π system in nuclear matter.

can avoid the difficulties in selecting in hydrogen data the diffraction contributions amongst the other channels. It has been shown in the analysis of the low energy data that this procedure is reliable(3).

2 - The experimental programme

We would like to study the coherent reactions:

$$\pi^- A \longrightarrow \pi^+ \pi^- \pi^- A \qquad (1)$$

$$\pi^- A \longrightarrow \pi^+ \pi^+ \pi^- \pi^- \pi^- A \qquad (2)$$

$$K^- A \longrightarrow \pi^+ \pi^- K^- A \qquad (3)$$

at 30 and 40 GeV/c incoming particles momenta at the Serpukhov accelerator. In (1-3) A denotes any nucleus of atomic number A. The targets we want to use and the number of coherent events we would like to collect are listed in Table I.

Due to the small fraction of K in the beam, it is planned to take separately the π and K data and to collect less statistics for the K data. On the other hand the reactions (1) and (2) are accepted at the same time by the trigger. A statistics of typically 10.000 3π events per target and per energy allows to perform a partial wave analysis per 150 MeV/c^2 mass intervals with a relative average error on the partial wave percentages of $\sim$ 5%.

As shown in Table I we plan to use a silicon detector target for a large part of the data taking. This has in fact the advantage of reducing the background level, which is relevant in particular near the second diffractive maximum (see section 3.2). Consequently we can obtain a purified sample of coherent events with a statistics $\sim$ 5 times bigger than for the other targets with 3.000 - 4.000 events in the second maximum.

3 - The experimental set-up

The experimental set-up (fig. 1) consists of:

I) the beam defining system

II) a system of scintillator counters surrounding the target and a proportional chamber (or eventually a plastic scintillator hodoscope), used to define the acceptance cone and the secondaries multiplicity

III) the Dubna magnetic spectrometer with optical spark chambers

IV) a lead glass Čerenkov counter to veto π^o's emitted at small angles and a beam killer plastic scintillator, both placed behind the magnet.

3.1 - The beam

The beam we plan to use, the 4 b beam of the Serpukhov accelerator, is a negative pion beam with a maximum flux of $\sim 10^6$ particles/burst and a top energy of 40 GeV/c (and perhaps slightly higher). It can be momentum analyzed down to $\Delta p/p \sim 0.3\%$(°). The dimensions of the beam at the target are 1 cm (horizontal) and 2 cm (vertical) FWHM, and the angular divergence is ± 1 mrad in both directions. The fractions of K^- and $\bar{p}$ at 40 GeV/c are 1,5% and 0.2% respectively.

The beam will be defined by:

i) a scintillation counter (or proportional chamber) hodoscope to measure the momentum

ii) Čerenkov counters to separate pions and kaons and to reject antiprotons

iii) a wire spark chambers hodoscope (or a special scintillation counters(12) hodoscope) to measure the incoming particles direction

iv) a standard scintillation counters telescope to be used in the trigger.

(°) The $\Delta p/p$ of 0.3% is the resolution obtained by the Kienzle group with the same beam.

3.2 - Silicon target

The Silicon target will act as a detector for the recoil in order to select the coherent events(10). The principle underlying the use of the silicon target is that, at a fixed momentum transfer the recoil nucleus releases in the detector an energy 28 times smaller than a recoiling proton.

In order to evaluate the overall performances of the target, it is necessary to take into account, in addition to the electronic noise, the Landau fluctuations on the fast particles ionization energy losses and the uncertainty about the position of the interaction inside the detector sheet.

The electronic amplification chain for this experiment has been planned and build in a proto-type, in order to fit the conflicting requirements of high resolution in the energy measurements and of short time constant operation(13). It consists of a current preamplifier plus a wide band amplifier plus a time varying filter. Its resolution, when connected with a 200 μm thick detector of 300 mm^2 of surface, is $\sim$ 20 KeV. The full width of the pulse is of the order of 100 nsec. The chain is linear up to $\sim$ 3 MeV.

The incoming and the outgoing fast particles release in the target an ionization energy of the order of 40 KeV/100 μm ± the Landau fluctuation, which is added to the recoil energy.

The best compromise between the requirements of having a good resolution in the recoil energy measurements (small thickness) and of obtaining a good evaluation of the fast particles number (large thickness), seems to be a 200 μm thick detector. With this choice the resolution on the recoil measurements is 70 KeV and the energy losses from 1, 2, 3 minimum ionizing particles are 80 ± 34, 160 ± 41, 240 ± 47 KeV, respectively. We remind that a resolution of 70 KeV in energy corresponds to 0.004 $(GeV/c)^2$ of nuclear recoil four momentum (for instance the first minimum in the $t'^{(\circ)}$ distribution for coherent processes on Si is in 0.04 - 0.05 $(GeV/c)^2$ range).

Taking into account the cross sections values for the channels 1), 2) and 3) and the trigger rate, we planned a target with ten 200 μm thick detectors, connected with ten independent amplification chains.

To select the coherent events, both the following requirements should be fulfilled:

1 - a) no more than one detector must give a pulse corresponding to an energy higher than three (or five) fast particles crossing it. In fact the recoiling nucleus range is always on the order of few μm, while easily a proton recoil escapes from the thin sheet, where the interaction took place. This requirement rejects most of the incoherent interactions with a recoiling proton;

b) the detectors preceeding the one where the coherent interaction took place must give a pulse corresponding to an energy consistent, within the errors, with one relativistic particle crossing it; the detector where the interaction took place should give a pulse consistent with at least one fast particle and all the following detectors should give a pulse consistent with three (five) relativistic particles.

2 - The recoil energy E_{si} measured in the target should be consistent, within the errors, with the energy E_{kin} coming from the kinematical fit of the interaction, using the measurements of the secondary tracks in the magnetic spark chambers. On the basis of the detectors resolution and of the measurements' precision, (see § 4), it is possible to state that this last requirement allows to reduce to background due to incoherent interactions where only neutrons are emitted ($E_{si} < E_{kin}$)

(°) t' is defined as $t - t_{min}$

and those where the emitted protons (recoils or evaporation) do not cross more than one detector ($E_{si} < E_{kin}$).

From Monte Carlo calculations, the incoherent background, after the requirement 1) + 2) have been applied, is expected to be reduced of a factor ∿ 2 in the range 0 - 0.03 $(GeV/c)^2$ and to be practically suppressed between 0.05 and 0.08 $(GeV/c)^2$. (The remaining incoherent background after this selection is expected to be ∼ 1% in the region of the second maximum).

Due to the short time constant operation of the electronic chain it could be possible to use the target selection directly in the trigger, namely for the point 1 a).

3.3 - Selection of the secondaries multiplicity

The target is surrounded by a cylindrical scintillator R which provides a veto for the fast recoil protons and the charged secondaries emitted at large angles. A lead-scintillator sandwich, S_1, also surrounds the target and is used to veto large angle γ -rays. S_2 and S_3 are lead scintillator sandwiches which define an acceptance cone 30° wide, by rejecting charged particles and γ 's emitted at an angle greater than 15°.

A proportional wire chamber P, positioned before R (see fig. 1) selects a multiplicity greater than 2 (°).

A lead glass Cerenkov, $\check{C}$, placed behind the spectrometer is covered by an anticoincidence, A_3, and is used to veto small angle π^0's.

The final trigger signature for a coherent event is

$$(B_1 . \bar{A}_1 . \bar{A}_2 . \bar{K}) \;.\; (\bar{R} . \bar{S}_1 . \bar{S}_2 . \bar{S}_3 . P[\geqslant 3]\;) \;.\; (\bar{A}_3\ \check{C})$$

where K is the signal from the beam killer counter.

(°) Eventually it is foreseen to use a plastic scintillator hodoscope.

3.4 - The Dubna magnetic spectrometer

The useful volume of the magnet is H x W x L = = 1,3 x 1,5 x 5 m^3. The magnetic field intensity ranges between 17 and 21 KGauss. 50 units of optical spark chambers with 2 cm gap, in groups of ten, fill the magnet aperture. Each unit consists of 2 Al electrodes, 3 mm thick, with a central window, normally 600 mm in diameter and 57 μm thick. One copper diaphram per unit (8 mm thick) is placed in the region around the central window. The spark chambers allow a flux of 2 x 10^5 particles/sec and they can be pulsed ar a rate $\leq$ 10/sec. The expected multiparticle efficiency is $>$ 90% for $n \leq 5$.

Two stereo views are taken at an angle of 16°. The cameras use 35 mm film, with a picture length of 170 mm. Their repetition time is $\sim$ 100 msec.

4 - Acceptances and resolution

The geometrical efficiency has been evaluated by tracing in the Dubna spectrometer Monte Carlo events produced with slopes of $d\sigma/dt$ typical for the coherent reactions on nuclei.

In order to have a good geometrical reconstruction, we assume to use for the tracks' measurement only the central window (57 μm Al thick) of the optical spark chambers. With respect to the original diameter of 60 cm for the central window, the windows from the 7th to 16th units of spark chambers have to be enlarged up to a maximum diameter of 100 cm: (corresponding to a target placed 60 - 70 cm upstream the first plate (see fig. 1)): this is relevant to meet the requirements of high efficiency and good resolution for high invariant masses of the produced system.

In this geometry the acceptance cone is 30° and the minimum measurable track length is $\sim$ 140 cm (corresponding to a minimum of 8 sparks' pairs). The geometrical efficiencies for reactions (1-3) are shown in fig. 2 as a function of the invariant mass. The acceptance for reactions (1) and (3) is $\sim$ 90% at 1.1 GeV mass and $\sim$ 80% at 2.5 GeV/c^2; for reaction (2) it varies between 75% at 1.8 GeV/c^2 and $\sim$ 55% at 3 GeV/c^2 invariant mass.

The experimental mass resolution has been estimated from momentum and angle resolution using the results of analogous experiments (e.g. ref. (14)) and the parameters of the Dubna spectrometer.

It turns out that a relative mass resolution better than 2% can be achieved up to 2.5 GeV/c^2 invariant mass. Nevertheless it seems difficult to reject by a 1 c fit the events with 3 or 5 charged secondaries and one additional π^0 with a momentum $<$ 2 GeV/c. But this class of events can be rejected either by the trigger (S_1, S_2, S_3 scintillators) or at scanning level due to the high γ-conversion efficiency in the copper diaphragms.

5 - Trigger rates

The rates of 3π, 5π, $K\pi\pi$ coherent productions and those of the reactions that will give background triggers have been evaluated by extrapolating to 40 GeV/c the cross sections obtained from spark chambers$^{(1,2,3)}$ and heavy liquid bubble chamber $^{(5)}$ experiments at 15 GeV/c incident momenta. The procedure used is the following:

a) The coherent 3π production cross sections for incident pions at 30 and 40 GeV/c have been obtained multiplying the cross sections obtained from the experiments at 15 GeV/c by factors 1.8 and 2.5 respectively. By the same procedure the 5π coherent production cross sections have been calculated to be 10% and 15% of the 3π cross sections at 30 and 40 GeV/c. These factors have been obtained by interpolating the data from nuclear emulsion at very high energy$^{(15)}$.

b) The ratio of the cross sections of different channels have been extrapolated to higher energy by reducing the rates of the channels with exchanged mesons with respect of the diffractive one following a p^{-2} low, in agreement with the results obtained on hydrogen at Serpukhov(11). The incoherent background had been studied also by means of the cascade model developed by V.S. Barashenkov et al.(16).

The reactions contributing to the background are the incoherent channels with 3π, 5π and $K\pi\pi$ systems, the same channels with additional π^0's and processes with charged multiplicity different from the wanted ones.

The expected coherent cross sections and trigger cross sections at 30 and 40 GeV/c π and K incident momenta are listed in table II for typical nuclear targets.

In the case of the reactions (1) and (2) triggered in the same time, because of the large π intensity the thickness of the target is not critical. The thicknesses of the various targets, quoted in table II, have been evaluated in such a way that the average $\Delta\vartheta$ due to the target multiple scattering corresponds to 0.25 mrad for a particle of 10 GeV/c (i.e. negligeable with respect to the error due to the measurements). It is to be noticed that with a flux of $2\cdot 10^5\ \pi$/burst the trigger (5 - 10 per burst) is saturated anyway.

For the K beam, due to the lack of the intensity and in order to have a reasonable running time, we have to use for media and heavy nuclei target thicknesses 4 times larger. Nevertheless the $\Delta\vartheta$ corresponding to the multiple scattering is still smaller than the error due to the geometrical reconstruction.

6 = Time request and other remarks

The data-taking time, needed in order to collect the data shown in table I, is 550 hours at 30 GeV/c plus 400 hours at 40 GeV/c. The conservative figures of 5 event/burst in average and of 50% trigger efficiency have been used for this estimate. In addition ~200 hours are needed for the tests of the set-up.

The spectrometer is now completed and has been tested now in Dubna.

The data-taking starts at the beginning of 1974 and it should be completed by the middle 1975.

During the fall of 1973 we plan to test in Italy and at CERN part of the equipment, i.e. the Silicon detector target and the trigger system. Therefore 2 weeks in a low energy test beam at the CERN PS (e.g. t_1) are required for calibration and a running time of 2 weeks in a higher energy high intensity beam (~ 50.000 particles/burst) is needed for the final check of the system before this is brought to Serpukhov.

The pictures will be measured in Dubna, Warsaw and in Italy (at the National Centre of Bologna).

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TABLE I

NUMBER OF COHERENT EVENTS/TARGET/ENERGY

	$\pi A \rightarrow 3\pi A$	$\pi A \rightarrow 5\pi A$		$K A \rightarrow K 2\pi A$
Target	30 and 40 GeV/c	30 GeV/c	40 GeV/c	30 and 40 GeV/c
Be^{9}	10,000	1,000	1,500	5,000
C^{12}	10,000	1,000	1,500	---
Si^{28}	50,000	5,000	7,500	10,000
Ti^{48}	10,000	1,000	1,500	---
Cu^{63}	10,000	1,000	1,500	5,000
Ag^{107}	10,000	1,000	1,500	5,000
Ta^{181}	10,000	1,000	1,500	---
Pb^{208}	10,000	1,000	1,500	5,000

TABLE II

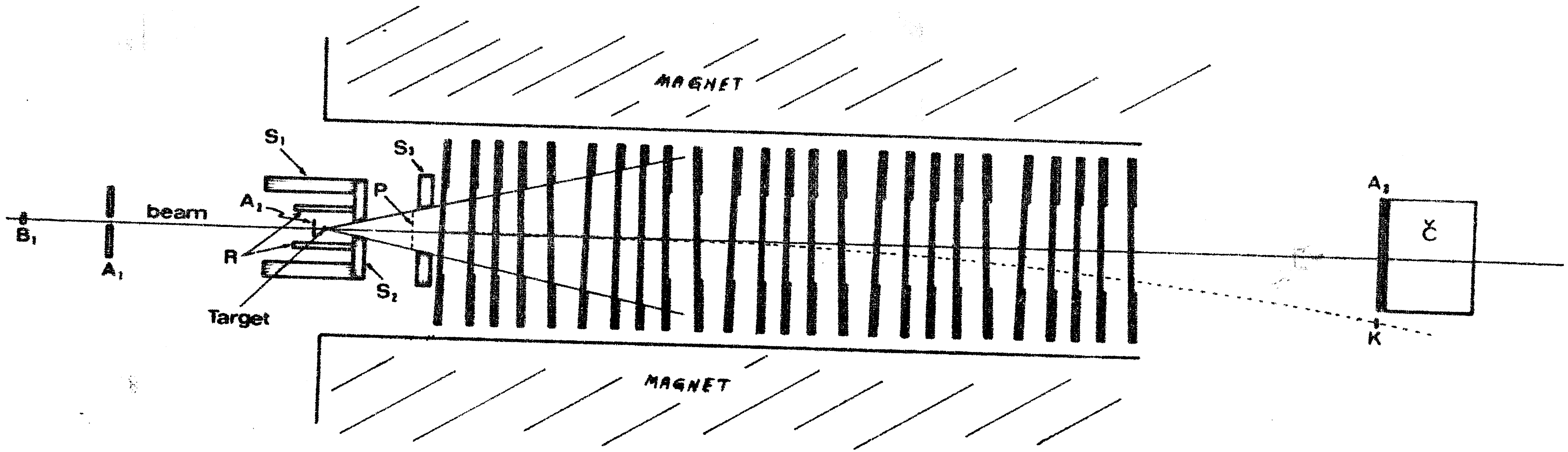
Target	Thicknesses (cm)		Coh. cross sections (mb)		Trigger cross sect. (mb)		Rate/π		Rate/K	
	π	K	30 GeV/c	40 GeV/c	30	40	30	40	30	40
Be^{9}	3.2	9.6	3.6	4.4	12.5	15.5	5x10^{-3}	6.2x10^{-3}	15x10^{-3}	18.6x10^{-3}
Si^{28}(°)	0.2	0.2	8.2	10	24.5	30	0.25x10^{-3}	0.30x10^{-3}	0.25x10^{-3}	0.30x10^{-3}
Cu^{63}	0.13	0.4	14	17	36	41	0.4x10^{-3}	0.5x10^{-3}	1.20x10^{-3}	1.50x10^{-3}
Pb^{208}	0.15	0.15	15	19	36	44	0.06x10^{-3}	0.07x10^{-3}	0.18x10^{-3}	0.21x10^{-3}

(°) The thickness of the silicon detectors live target is limited by practical reasons.

FIGURE CAPTIONS

Fig. 1 - Side view of the experimental set-up

Fig. 2 - Geometrical acceptance for reactions (1-3) as a function of the invariant mass.



TRIGGER : $(B_1 \cdot \bar{A}_1 \cdot \bar{A}_2 \cdot \bar{K}) \cdot (\bar{R} \cdot \bar{S}_1 \cdot \bar{S}_2 \cdot \bar{S}_3 \cdot P[2,3]) \cdot (\overline{\bar{A}_3 \cdot \check{C}})$

Fig. 1

EFFICIENCY FOR AN ACCEPTANCE ANGLE $\alpha = \pm 15°$

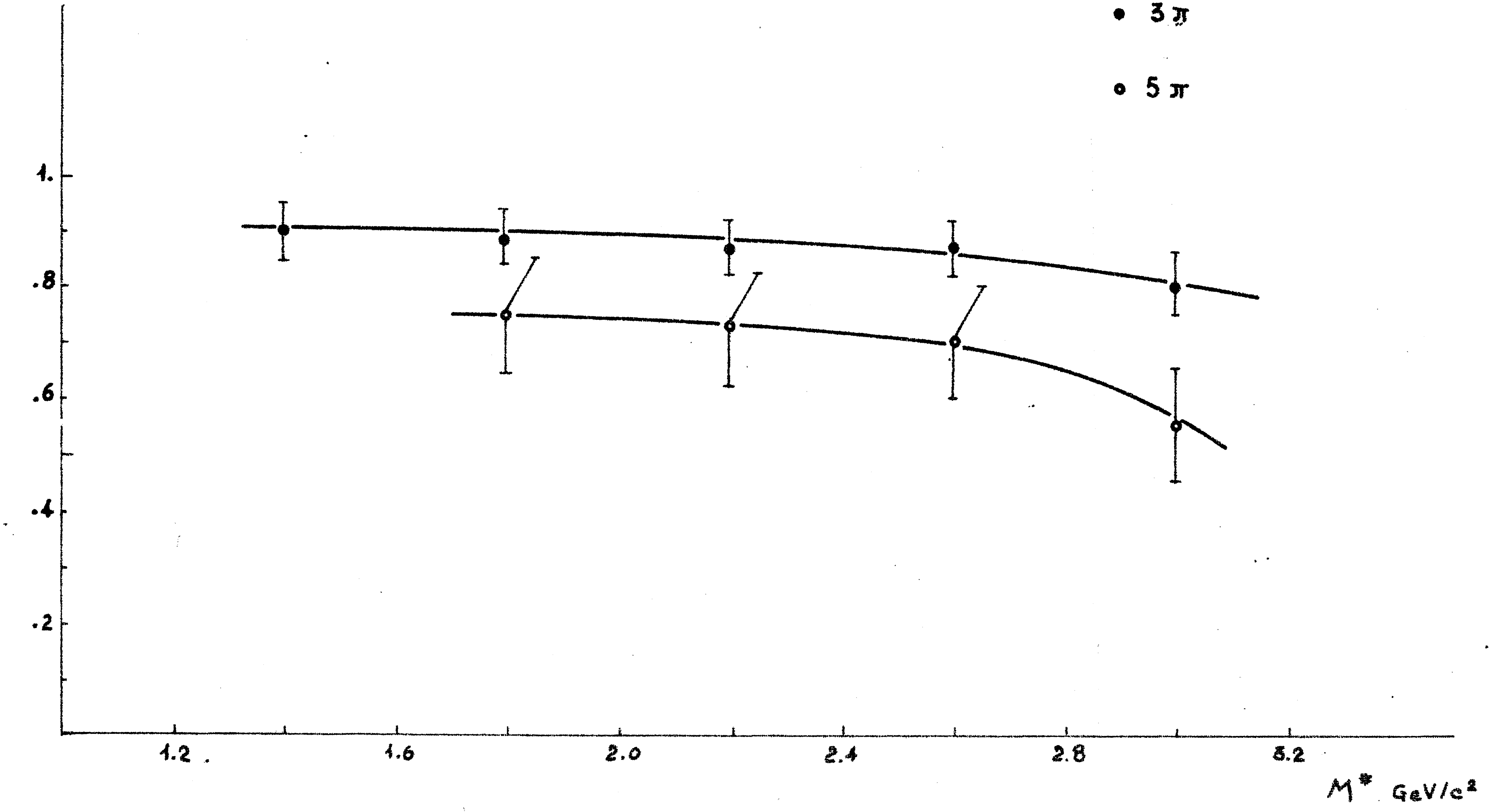


Fig. 2