NAL PROPOSAL No. 125

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PROPOSAL TO STUDY π^-p REACTIONS AT 60 and 200 GeV/c IN THE 30 INCH HYDROGEN BUBBLE CHAMBER AT NAL

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SUMMARY

A request is made for 50,000 photographs of 60 GeV/c π^- and 50,000 photographs of 200 GeV/c π^- in the Argonne 30 inch hydrogen bubble chamber at N.A.L. Reasons are given explaining how good physics can be done with this chamber. This experiment is a natural extension of the work of the group and will be of great usefulness in preparing for experiments with the CERN II accelerator.

DROM/ah

1. INTRODUCTION

The problem of extracting interesting physics results from bubble chamber photographs of a high energy beam (200 GeV/c) in a relatively small chamber (30 inches) is not simple but is a situation that we have previously met in 1960 in studying $\simeq$ 20 GeV/c beams in a 30 cm chamber. This experience, plus our work at the highest available energy since, leads us to believe that we can obtain worthwhile physics, quickly, from a fairly small number of photographs taken at NAL.

We submit here a proposal to study high energy π^-p interactions in the Argonne 30" hydrogen bubble chamber at the National Accelerator Laboratory, Batavia, USA.

We wish to study (a) what happens at high energy and (b) the variation with energy of the phenomenon observed. The request is for two energies, 60 and 200 GeV/c, with 50,000 photographs at each energy.

Apart from the obvious interest deriving from working in an unexplored energy range, the study of hadron interactions of these high energies is of particular meaning to us for the following reasons:

(a) This work is a most valuable preparation for experiments at similar energies to be performed with the future CERN 300 GeV accelerator.

(b) Our group has more than ten years of experience in research at the highest available energies in hydrogen bubble chambers. The Data Summary Tapes that have been established or will be completed by the end of this year are:

8 GeV/c π^+p (70,000 events) Aachen-Berlin-CERN-Cracow-Warsaw Collaboration.

10 GeV/c K^-p (250,000 events) Aachen-Berlin-CERN-London-Vienna Collaboration.

16 GeV/c π^-p (95,000 events) Aachen-Berlin-Bonn-CERN-Cracow-Heidelberg-Warsaw Collaboration.

16 GeV/c π^+p (150,000 events) Aachen-Bonn-CERN-Cracow-Heidelberg-Warsaw Collaboration.

Subject to agreement with our Collaborators, all these results shall be readily available for comparison with the results at NAL, at 60 and 200 GeV/c.

In addition, during the first half of this year we have taken or will take :

16 GeV/c π^+p (500,000 photographs) Aachen-Bonn-CERN-Cracow-Warsaw Collaboration.

16 GeV/c K^-p (300,000 photographs) Aachen-CERN-London-Vienna Collaboration.

24 GeV/c π^+p (150,000 photographs) Brookhaven-CERN-Wisconsin Collaboration.

In general we have repeatedly found that the understanding of our data on one experiment has been greatly helped by doing the same analysis on other experiments at different energies or with different beam particles.

2. EXPERIMENTAL CONDITIONS

The present proposal assumes operation with the "bare" Argonne chamber, i.e. with no electronic detectors and auxilliary magnets to improve momentum and angular resolutions. Though these facilities would allow one to tackle more elaborate problems, we believe that valuable results can be obtained, in the early stage of NAL operation, even with the "bare" chamber.

It is assumed that the incoming pion beam will have a momentum resolution $\Delta p/p$ of the order of 1:1000 and a density of 10 to 15 tracks per photograph.

3. SCANNING AND MEASURING

The photographs shall be scanned for all topologies.

The number of events of all types expected is of about 25,000 at each energy.

All events shall be measured on H.P.D., which seems to be the most consistently accurate machine at present. At CERN, 10 pre-measuring tables and two H.P.D. machines are presently in operation for bubble chamber experiments.

In discussing the experiment, we shall consider physical results that can be obtained without attempting kinematic fitting. We feel, however, that four-constraint reactions might be studied by kinematic fitting at least at 60 GeV/c, if necessary by treating them as three-constraint reactions (in general only one very energetic track will be present).

4. PRINCIPLES OF THE ANALYSIS

The situation we are meeting when planning to put high momentum beams through a 30" chamber with a field of 32 KG is, however, not a new one. It is similar, in fact, to that met at CERN in 1960, when beams of 16 GeV/c π^- and 24 GeV/c protons were studied in a hydrogen bubble chamber 30 cm in diameter with a 15 KG field. Looking back, it is gratifying to see that valuable results were obtained at that time [1,2]. Since then, we have gained considerably in experience and theoretical understanding, but the main lessons learned ten years ago are still valid and still are the main basis for attacking today's problems:

(1) A variety of interesting results can be obtained by measuring only low momentum secondaries, which are the tracks that we can measure with relatively small errors. At the energies we are considering, the pions with $p_T < 1$ GeV/c, emitted backwards in the interaction centre of mass, have low laboratory momentum. Also protons which are peripheral - i.e. have small $|t|$ values, have correspondingly low lab. momenta.

(2) Many general characteristics of high energy interactions can be studied, which are either independent of measurements or do not require precise measurements of all tracks. Detailed discussions of the physical results expected are in Sections 5 and 6.

5. PHYSICAL RESULTS EXPECTED FOR TWO BODY INELASTIC CHANNELS

5.1 Missing mass to the proton

Protons with momentum up to 1.5 GeV/c can be identified by ionisation. Their momentum is measured by their range up to 300-400 MeV/c with the precision of ~ 1 MeV and by curvature at higher momenta (at 1 GeV/c, $\Delta p \simeq 15$ MeV/c). The angular resolution $\Delta\Theta$ varies from ~ 7 m rad at low momenta to ~ 1 mrad at ~ 1 GeV/c.

Considering the reaction

$$\pi^- + p \rightarrow p + X ,$$

if the momentum and angle in the laboratory of the proton are known, then the Missing Mass, M_x, is uniquely determined. Values of M_x as a function of the proton momentum and angle are given in figs. 1 and 2 for π^- beams of 60 and 200 GeV/c. The interesting question is the error on M_x. This has been calculated using the errors on the proton momentum and angle which were found experimentally from IEP measurements of photographs of the CERN 2m hydrogen bubble chamber. The resultant errors ΔM_x on the Missing Mass are plotted as functions of the proton momentum in figs.3 and 4 for 60 and 200 GeV/c $\pi^- p$ interactions, respectively. For much of the physics that we wish to do, errors in M_x of $\simeq$ 100 MeV are acceptable. It can be seen in figs.3 and 4, that for $M_x \simeq 1$ GeV such values of ΔM_x are obtainable at small $|t|$ values, where are most of the events. At very high mass values (6 to 10 GeV), the effect of the Jacobian peak is felt and the error, ΔM_x, becomes small($\lesssim$ 20 MeV). Although it may be unlikely to find any narrow peak in this high mass range with our statistics, we will look and perhaps try to combine data from other experiments.

We can thus perform, by selecting and measuring accurately the proton, a single-arm spectrometer experiment, which has the advantage, over similar counter experiments, that at least the number of charged pions present is known.

To predict what the M_x spectra should look like at 60 and 200 GeV/c, we start from the results obtained for 16 GeV/c π^-p interactions, where kinematic fitting is possible. Fig. 5 shows the (2π) (3π), (4π) and (5π) mass distributions in the reactions

$$\pi^-p \rightarrow p + n\pi, \text{ with } n = 2\text{-}5. \qquad (1)$$

It may be seen that for values of M_x below 1 GeV, only the (2π) system contributes and what is observed is mainly the rho-meson in the reaction

$$\pi^-p \rightarrow p + \rho^-. \qquad (2)$$

The peak in the (3π) mass distribution at 1.2 GeV has almost no contribution from the (4π) and (5π) systems, (whose thresholds are higher) and is thus attributed to the reaction

$$\pi^-p \rightarrow p\, A_1 . \qquad (3)$$

On the basis of our present knowledge on the production mechanisms of two-body channels, we would venture to predict at 200 GeV/c M_x spectra more or less like the curves in fig. 5.

Reaction (2) which is believed to proceed by π or ω exchange, should in fact have a cross section that decreases with increasing lab. momentum as

$$\sigma = \text{const.}\ p_L^{-n} , \qquad (4)$$

with n = 1.5-2. Therefore, at 200 GeV/c, we would expect practically no events below 1 GeV. The peak at 1.2 GeV in the (3π) mass distribution, attributed to reaction (3) which is interpreted as a diffractive process, is instead expected to remain practically independent of the incoming momentum (in formula (4) n is about 0.2 at present accelerator energies

The (4π) and (5π) spectra are expected to receed to still higher masses. For (4π) systems, where diffraction dissociation is not possible, the cross sections should decrease with $n \simeq 2$. For (5π) systems the possibility of so far unknown diffractive peaks at higher masses exists and this is an interesting question to investigate by comparing results at 16, 60 and 200 GeV/c.

In conclusion, at 200 GeV/c we would expect:

(1) In the M_x of the two prong events: practically no events at around 750 MeV due to $(\pi^-\pi^0)$ and a broad peak at ~ 1.2 GeV due to the $(\pi^-\pi^0\pi^0)$ decay mode of the A_1 meson.

(2) In the M_x of four prong events: a broad peak at 1.2 GeV due to the $(\pi^-\pi^+\pi^-)$ decay mode of the A_1 and, possibly, other enhancements at higher masses due to the diffraction dissociation into $(\pi^-\pi^+\pi^-)$ or $(\pi^-\pi^+\pi^-\pi^0\pi^0)$.

The physical results to be obtained are:

(a) A value for the cross section for the diffractive process $\pi^-p \to p\,A_1^-$ at 60 and at 200 GeV/c. If these were found to be comparable to the values obtained at present accelerator energies, our present ideas on Diffraction Dissociation would be verified.

(b) New "diffraction dissociation" enhancements at masses higher than the A_1 and A_3 may be discovered and their cross sections measured.

(c) From comparison of enhancements around 1.2 GeV/c in two and four-prong M_x spectra, the branching ratio $(\pi^-\pi^0\pi^0)/(\pi^-\pi^+\pi^-)$ for the A_1 meson can be determined.

(d) A value, or an upper limit, can be obtained for the cross section of the reaction $\pi^-p \to p\rho^-$ at 60 and at 200 GeV/c.

The study of the energy dependence of this cross section is particularly interesting, as both π and ω exchanges are possible. Regge pole models predict $\sigma = \text{const}\ s^{-n}$ with $n = 2 - 2\,\alpha(0)$, which gives $n = 1$ for ρ_2, A_2 or ω exchange and $n \simeq 2$ for π-exchange. For energies up to 25 GeV/c no indication has so far been obtained for different s-dependence in reactions dominated by scalar and vector meson exchanges [3].

5.2 Study of the diffraction dissociation of the proton

An approach similar to that described in 5.1 can be used to study the isobar mass spectrum. In fig. 6 are shown the $(B\pi)$, $(B2\pi)$, $(B3\pi)$ and $(B4\pi)$ mass spectra, where B stands for baryon, obtained at 16 GeV/c. It may be seen that if one wishes to study isobars of mass below $\simeq$ 1.8 GeV, only the $(B\pi)$ and $(B2\pi)$ masses contribute. For the $(B2\pi)$ mass spectrum, the most important channel is

$$\pi^- p \rightarrow p\, \pi^+ \pi^- \pi^- \tag{5}$$

and here we study the $(p\pi^+\pi^-)$ mass spectrum, assuming that the proton undergoes diffraction dissociation into $(p\pi^+\pi^-)$. It is expected that these three particles, $(p, \pi^+$ and $\pi^-)$ will all be produced with low momentum in the laboratory so that their effective mass can be accurately measured. We will only have a lower limit on the momentum of the other, or "bachelor", π^-, but its angles can be measured and this should allow some separation of reaction (5) from similar reactions with one or more π^o's. The $(p\,\pi^+\pi^-)$ mass distribution with small four-momentum transfer, could then be studied.

5.3 Double pomeron exchange

One of the most interesting questions in connection with pomeron exchange is the existence, or non-existence. of reactions of double pomeron exchange. For example, in the reaction

$$\pi^- p \rightarrow \pi^- (\pi^+\pi^-)\, p, \tag{6}$$

the pions in parentheses would be produced practically at rest in the collision centre-of-mass (pionisation), while the other π^- and the p would be produced strongly forwards and backwards, respectively.

This longitudinal momentum configuration is not separate from

$$\pi^- p \rightarrow \pi^- (\pi^+ \pi^- p) \tag{7}$$

and

$$\pi^- p \rightarrow (\pi^+ \pi^- \pi^-) p \tag{8}$$

at present accelerator energies, but it is expected to be at 100-200 GeV/c. The proton and the two pions at rest should be accurately measurable, so that only the momentum of the forward pion is unmeasurable. As in 5.2, we can thus expect to get 3C-fits for these reactions.

6. RESULTS EXPECTED FOR MANY BODY REACTIONS

6.1 Multiplicity of charged prongs

Topologic cross sections will be determined and their variation with energy studied. The present information is summarized in fig. 7. It may be seen that the four prong cross section tends to be constant, probably because of the predominance of diffractive processes, while the two prong cross section decreases steeply. Since an appreciable Pomeron-exchange contribution is expected also in the two-prong channels, it would be interesting to see whether this cross section flattens off at high energies.

The dependence of the average charged multiplicity on the primary energy E can be determined. There is doubt, at present, as to whether it varies as log E or $E^{1/4}$.

Wroblewski [4] has pointed out that if ℓ is the number of charged prongs, then $\sigma_{\ell+2} = \frac{1}{2} \sigma_\ell$ at present accelerator energies. It would be interesting to check this surprising result at higher energies.

It has been found that the charged multiplicity distribution at a given energy (for present accelerator results) follows approximately a Poisson distribution. However, the result is not free from contradictions and should be checked at higher energies. The new formulation of Czyzewski and Rybicki [5] in which the dispersion is also included seems the best description of multiplicity distributions, but needs checking at ≃ 100 GeV/c.

6.2 Angular distribution of secondary particles

The study of the lab. angular distribution of the secondary particles has produced interesting results at cosmic ray energies. By plotting the distribution of the function log tan Θ, which has convenient transformation properties , evidence has been found for two well separated particle accumulations (also called Fireballs).

6.3 Comparison of the forwards and bakcwards cones

More precise information on this subject can be obtained when the particles produced forward and backward in the collision centre of mass are separated, and comparisons are made of the properties of the forward and backward cones. Of particular interest is the correlation between the multiplicities in the two cases, i.e. the multiplicity distribution in the forward cone as a function of the multiplicity in the backward cone. Very preliminary results at the Intersecting Storage Rings at CERN seem to indicate that high multiplicity in the forward cone tends to be associated with similarly high multiplicity in the backward cone. Results of this kind are valuable for comparison with models of high energy interactions.

Comparison of longitudinal and transverse momentum spectra in the two cones, at the two energies, would also be interesting.

6.4 Study of inclusive reactions

We consider reactions of the type

$$A\ B \rightarrow (C_1 C_2 \ldots C_\ell)\ (C_{\ell+1}, \ldots C_n)$$

where only secondaries C_1 to C_ℓ are measured and the other particles are grouped together as a missing mass.

(a) In the simplest case, $\ell = 1$, we have single-arm-spectrometer-type experiments. Protons can be selected, for momenta $p_{LAB} < 1.5$ GeV/c or positive pions emitted backwards in the c.m. system with small p_T or negative pions of all momenta (assuming that all negative tracks are negative pions). Distributions of p_{LAB}, p_L^*, p_T^*, t can be studied. The distributions of the Feynman variable $x = p_L^*/p^*_{inc}$ at different energies can be compared to look for scaling effects.

Particle C_1 can also be a lambda. Lambda production at present accelerator energies has a cross section of about 1 mb, i.e. approximately 4% of the events contain a lambda. The proportion of lambda events may be higher at 60-200 GeV/c. In general the lambdas will have rather low momenta in the laboratory system and will be identified up to several GeV/c by kinematic fitting. The results should be unbiassed. A study of the missing mass to the lambda, given sufficient statistics, would be most interesting, for comparison with the results on the missing mass to the proton, and to results at lower energies.

(b) In the case of $\ell = 2$ and 3, in reaction (6), correlations among the measured particles can be studied. At 60-200 GeV/c it will be almost always possible to measure two or three particles well enough to know their four vectors. The method is to plot the two or three Feynman variables $x_i = p_i^*/p_{inc}^*$ against one another, which ones, depends on the analysis wanted. As pointed out by Van Hove [6], the measured quantity is then

$$F = |M|^2 \, \delta\left(\sum_i^{\ell} \vec{p}_i^{\,*}\right) \delta\left(s^{\frac{1}{2}} - \sum_i^{\ell} E_i^*\right) + \sum_i \int |M|^2 \, \delta\left(\sum_i^{n_c} \vec{p}_i^{\,*}\right) \delta\left(s^{\frac{1}{2}} - \sum_i^{n_c} E_i\right) \prod_i^{n_c} d\vec{p}_i / E$$

where the first terms is the exclusive collision $A\,B \rightarrow C_1 + \ldots\ldots C_\ell$ and the second term sums over all the channels $A\,B \rightarrow C_1 \ldots\ldots C_\ell \, C_{\ell+1} \ldots C_{n_c}$. The advantage of this approach is that the function F is equivalent to the result of a two or three-arm spectrometer and is, therefore, integrated over fewer variables than in a one-arm spectrometer. In particular, the correlations among the measured particle are not lost. This type of analysis is being performed at 16 GeV/c [7] but higher energy is needed for comparison.

6.5 Study of the mirror system

Protons of low laboratory momentum are peripheral. The information obtained from them can be further exploited by using the "Mirror System" of Dubrotin and Slavatinsky [8].

Corresponding to the protons that are very backwards, there must exist another group of particles which are very forwards and also near the elastic limit - these being "leading particles" or "fragments" in the language of Yang and his collaborators. The corresponding particle in the "mirror" system has a total energy, E^{mirror}, in the laboratory system given by

$$E^{mirror} = (Eo/M) . (E_L - \beta_o . p_L \cos \theta_L)$$

where E_o, M and β_o are the total energy, mass and velocity of the incident proton and E_L, p_L and θ_L are the total energy, momentum and angle of the emitted particle in the laboratory system. This type of analysis was already performed [1] in 1961 where results for 16 GeV/c $\pi^- p$ and 24 GeV/c pp collisions are compared as shown in fig. 8. Therefore, in the $\pi^- p$ reaction, we wereconsidering protons of 107.5 GeV interacting with pion targets. For 60 and 200 GeV incident pions, this would correspond to protons of 400 and 1350 GeV interacting with pion targets. It would be interesting to compare our results at different pion momenta and with results from other experiments (bubble chamber and counter) of proton-proton reactions.

7. UNEXPECTED PHYSICS

In Sections 5 and 6 we have described the type of physics that we can reasonably expect to do, but in going to higher energies we have always found new features that were unexpected.

8. COLLABORATION

Although this proposal comes from a group with a reasonable number of physicists, mostly experienced in high energy physics and capable of analysing quickly the photographs requested, we feel that this experiment should be performed in collaboration with one or more North American groups. It may be noted that in studying 24 GeV/c π^+ we are already involved in a transatlantic collaboration.

9. NUMBER OF PHOTOGRAPHS

We believe that with the relatively small number of photographs requested we can do good physics. Naturally, higher statistics would be an advantage and this could be achieved either by having more pictures or by working in collaboration with other groups.

10. CHOICE OF BEAM ENERGY

The choice indicated is somewhat arbitrary: 60 GeV/c is an energy high in comparison with the present 10-25 GeV/c, yet low enough for extrapolation of the present information to be still meaningful and for kinematic fitting to be still feasible, at least for 4C-reactions; 200 GeV/c is close to the highest energy available in the early stage of NAL operation. If for technical reasons other energies were more convenient, the proposal may be corrected. If higher energies than 200 GeV/c become available, we would be interested.

11. FUNDS

(a) Adequate funds will be available for travel and other activities connected with the proposed experiment.

(b) In view of the budget cuts in CERN I, considerable funds could not be made available for a bubble chamber experiment with counters, for a single experiment. However, if it were decided that this technique of using counters with bubble chambers should be employed with the CERN II accelerator, then the position may be reconsidered.

12. POSSIBLE EXTENSIONS OF EXPERIMENT

We are convinced that good physics can be obtained with the "bare" 30 inch chamber, using beams of 60 and 200 GeV/c. However, more information would be obtainable from detectors and additional magnets arranged before and after the bubble chamber. Should it be possible in the future to have these facilities, we would be interested in collaborating in such an experiment and we would have the technical capacity to use the additional information quickly.

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FIGURE CAPTIONS

1. Lab. momentum of the recoil proton vs. its lab. emission angle for $\pi^- p$ reactions at 60 GeV/c, for various values of the missing mass to the proton, M_x.

2. Lab. momentum of the recoil proton vs. its lab. emission angle for $\pi^- p$ reactions at 200 GeV/c, for various values of the missing mass to the proton, M_x.

3. Values of the error in the missing mass, ΔM_x, as functions of the lab. momentum of the recoil proton, for different values of the missing mass M_x, at 60 GeV/c.

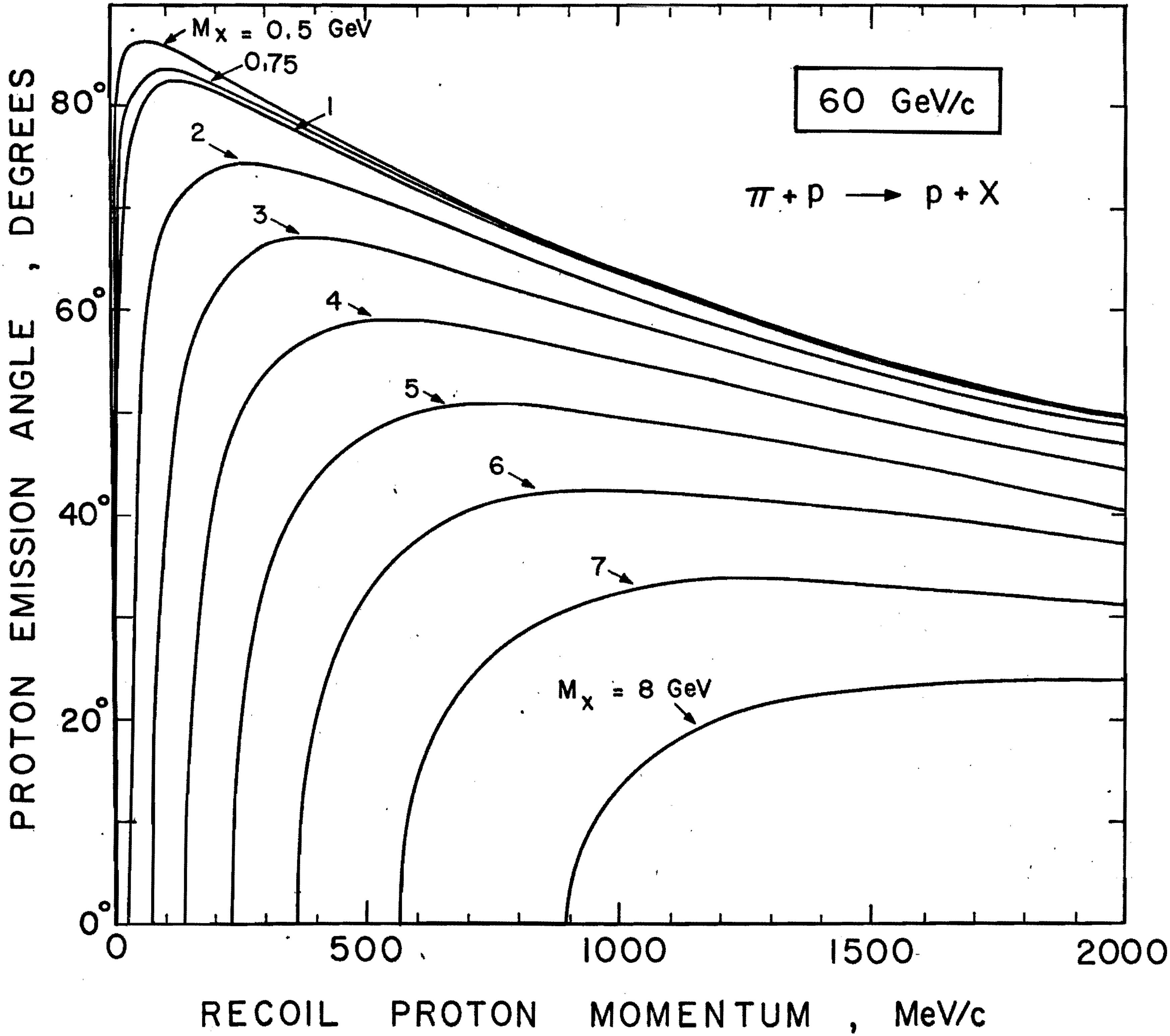
4. Values of the error in the missing mass, ΔM_x, as functions of the lab. momentum of the recoil proton, for different values of the missing mass M_x, at 200 GeV/c.

5. Experimental results for the effective mass spectra of (2π), (3π), (4π) and (5π) in the reactions $\pi^- p \rightarrow p + (n\pi)$ at 16 GeV/c and the spectra that might be expected at 200 GeV/c (dashed curves).

6. Experimental results for the effective mass spectra of $(B\pi)$, $(B2\pi)$, $(B3\pi)$ and $(B4\pi)$, where B is a baryon, in the reactions $\pi^- p \rightarrow \pi^- + (B + n\pi)$ at 16 GeV/c.

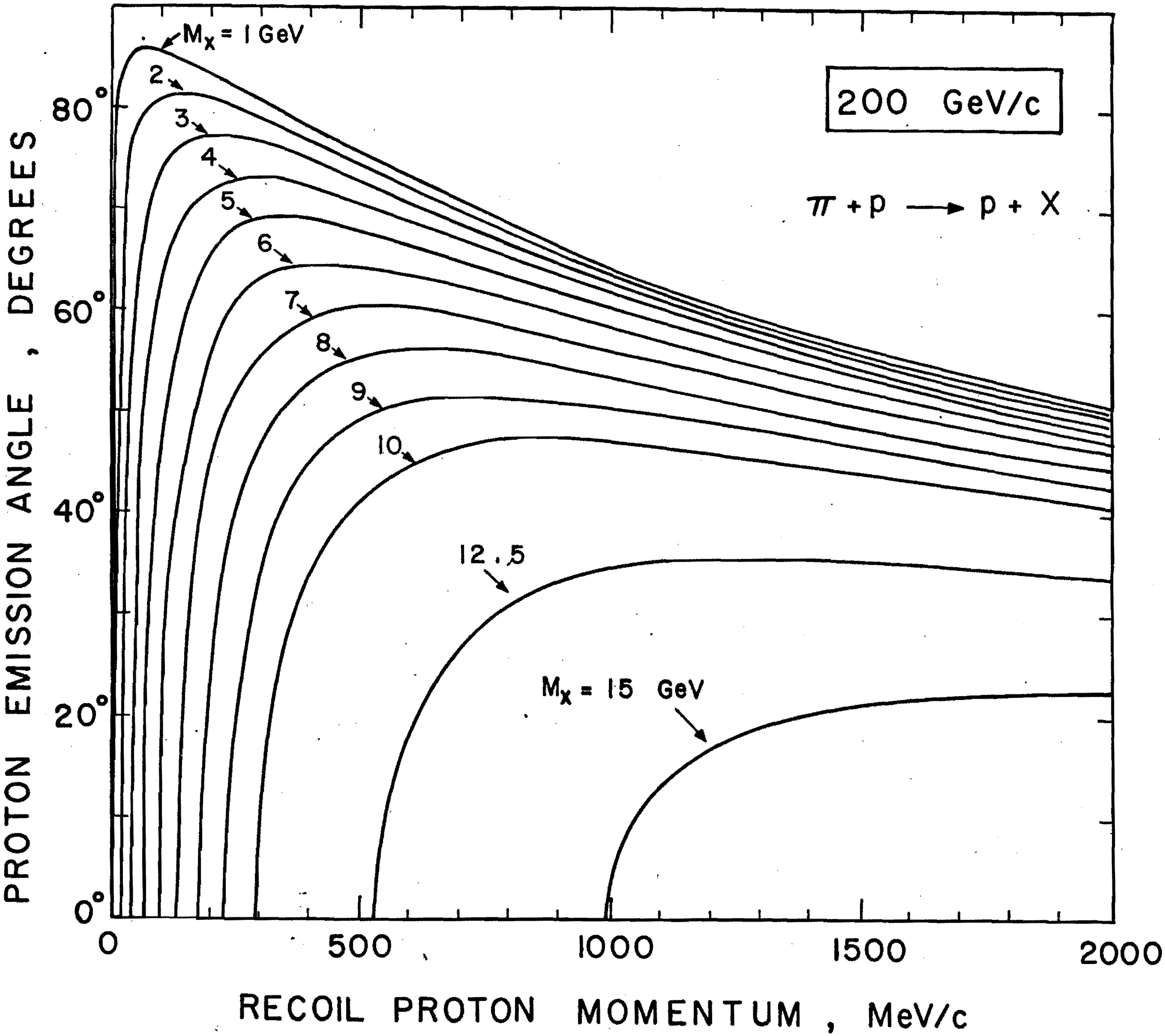
7. Variations of the topologic cross sections for $\pi^- p$ interactions as functions of the lab. momentum of the incoming pion.

8. From 16 GeV/c $\pi^- p$ and 24 GeV/c pp interactions, the energy of the proton in the "mirror" system is shown.



M_X = 0.5 GeV
0.75
1
2
3
4
5
6
7
M_X = 8 GeV
60 GeV/c
$\pi + p \longrightarrow p + X$
PROTON EMISSION ANGLE , DEGREES
80°
60°
40°
20°
0°
0
500
1000
1500
2000
RECOIL PROTON MOMENTUM , MeV/c

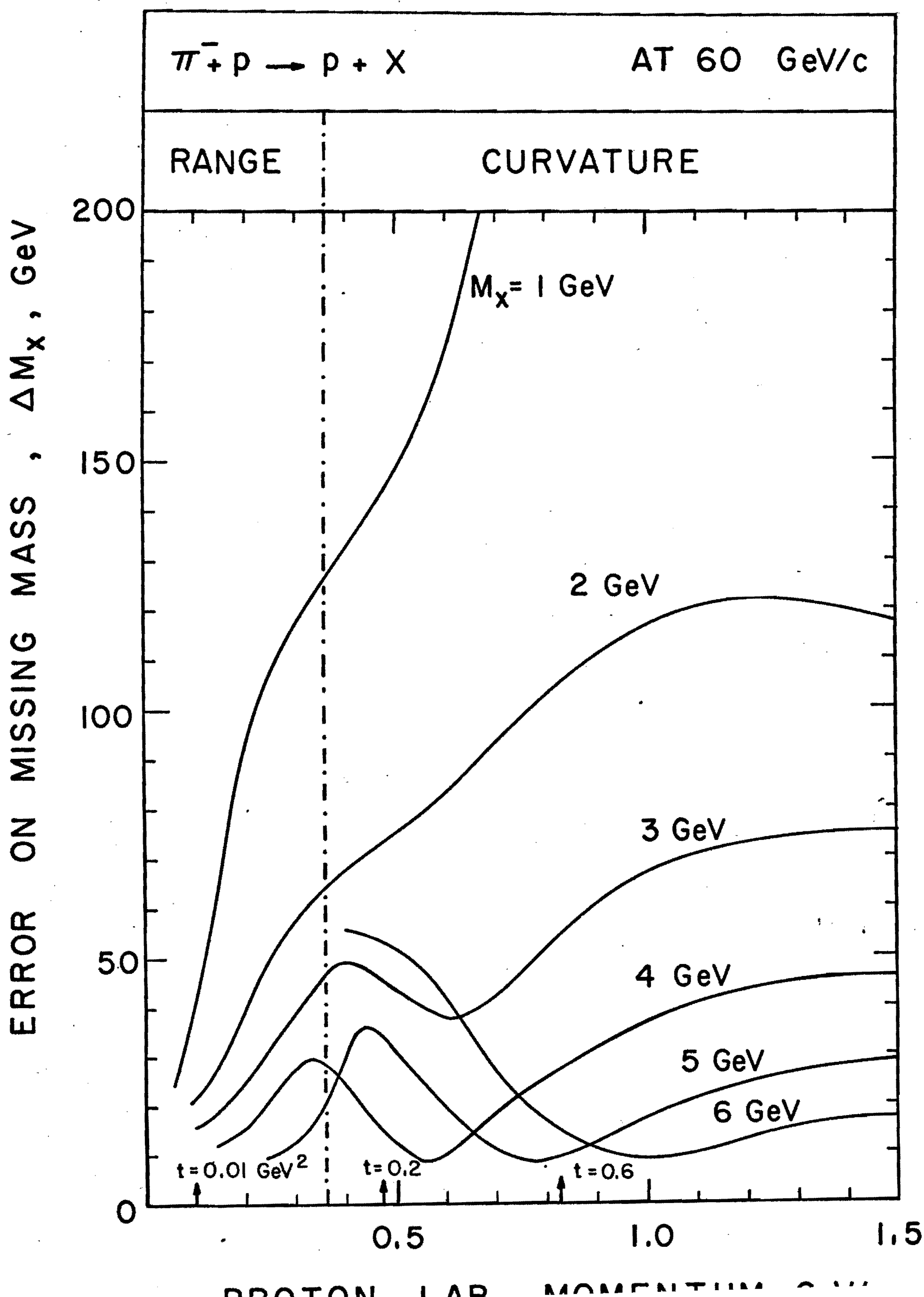
Fig. 1



200 GeV/c
π + p ⟶ p + X
M_X = 1 GeV
2
3
4
5
6
7
8
9
10
12.5
M_X = 15 GeV
PROTON EMISSION ANGLE, DEGREES
0°
20°
40°
60°
80°
RECOIL PROTON MOMENTUM, MeV/c
0
500
1000
1500
2000

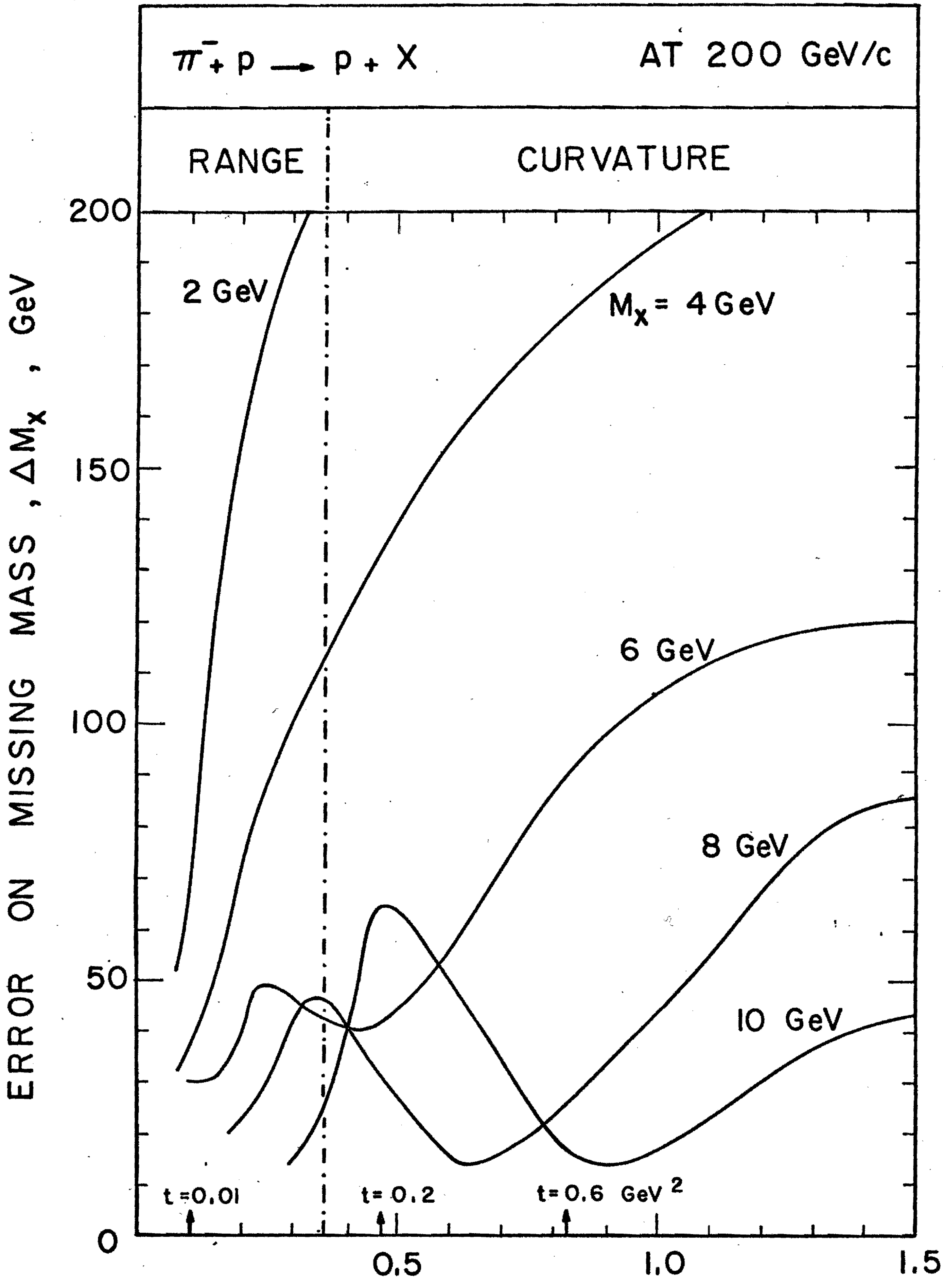
Fig. 2

Fig. 3



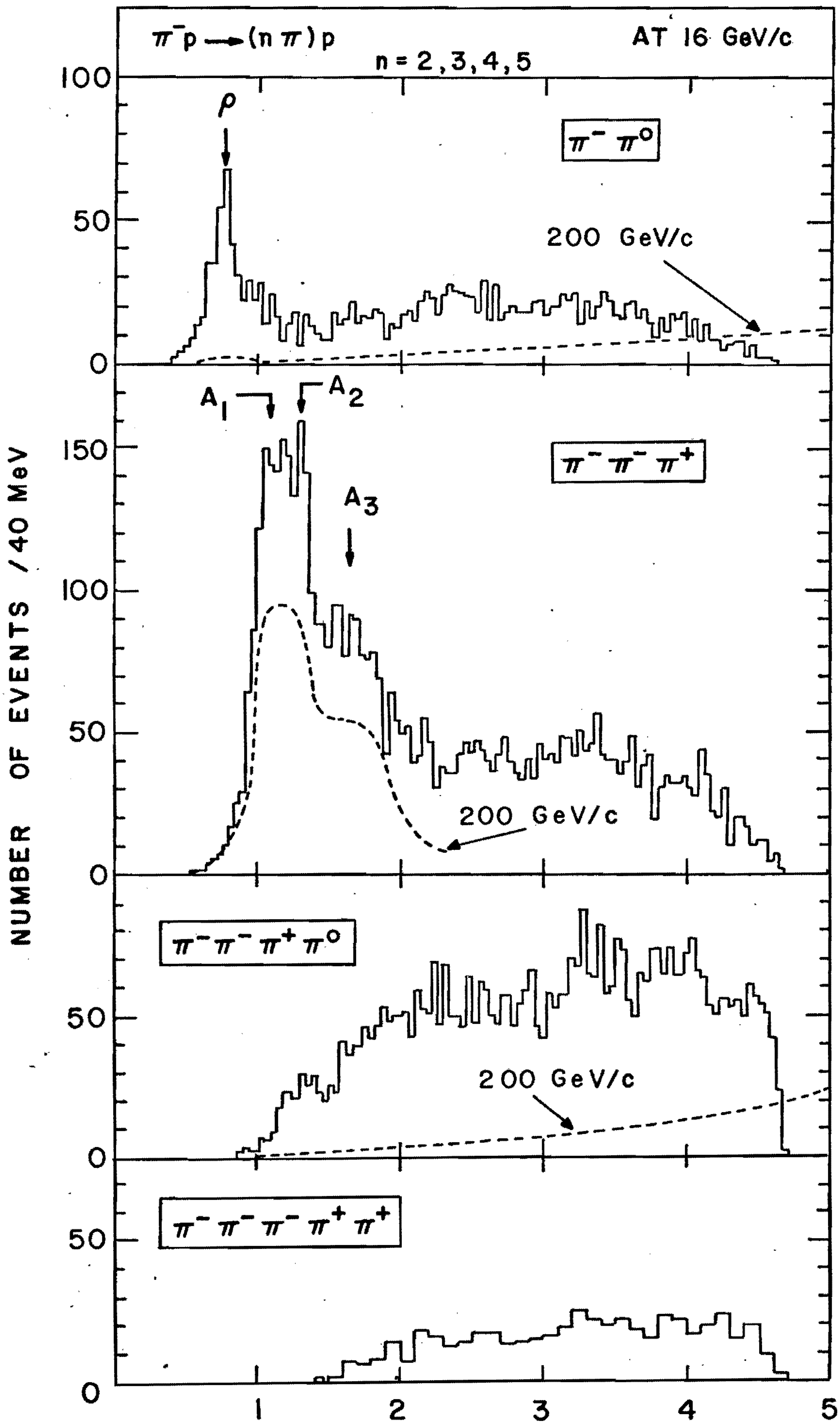
$\pi^- + p \longrightarrow p + X$
AT 60 GeV/c
RANGE
CURVATURE
ERROR ON MISSING MASS, ΔM_x, GeV
200
150
100
50
0
M_x= 1 GeV
2 GeV
3 GeV
4 GeV
5 GeV
6 GeV
t=0.01 GeV^2
t=0.2
t=0.6
0.5
1.0
1.5

Fig. 4



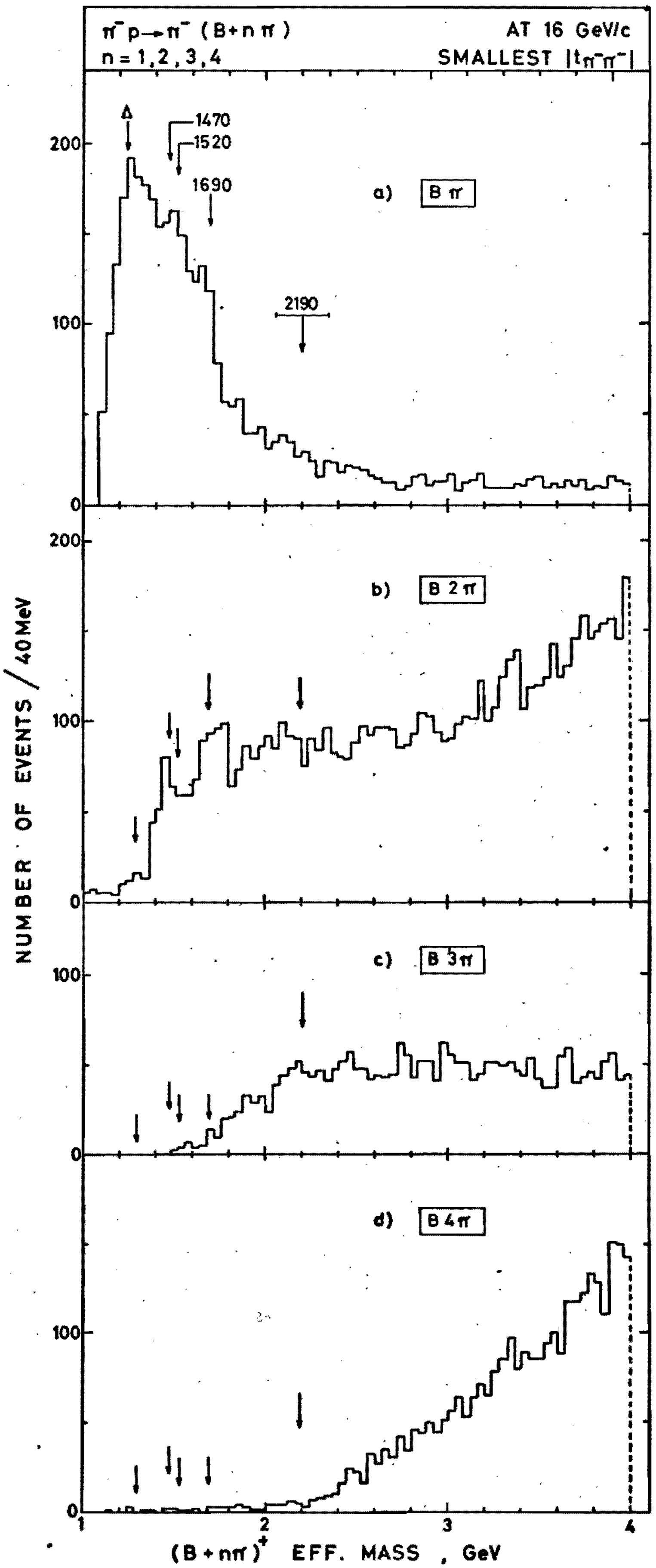
π⁻ + p → p + X
AT 200 GeV/c
RANGE
CURVATURE
2 GeV
Mx = 4 GeV
6 GeV
8 GeV
10 GeV
t = 0.01
t = 0.2
t = 0.6 GeV 2
ERROR ON MISSING MASS, ΔMx, GeV
200
150
100
50
0
0.5
1.0
1.5

Fig. 5



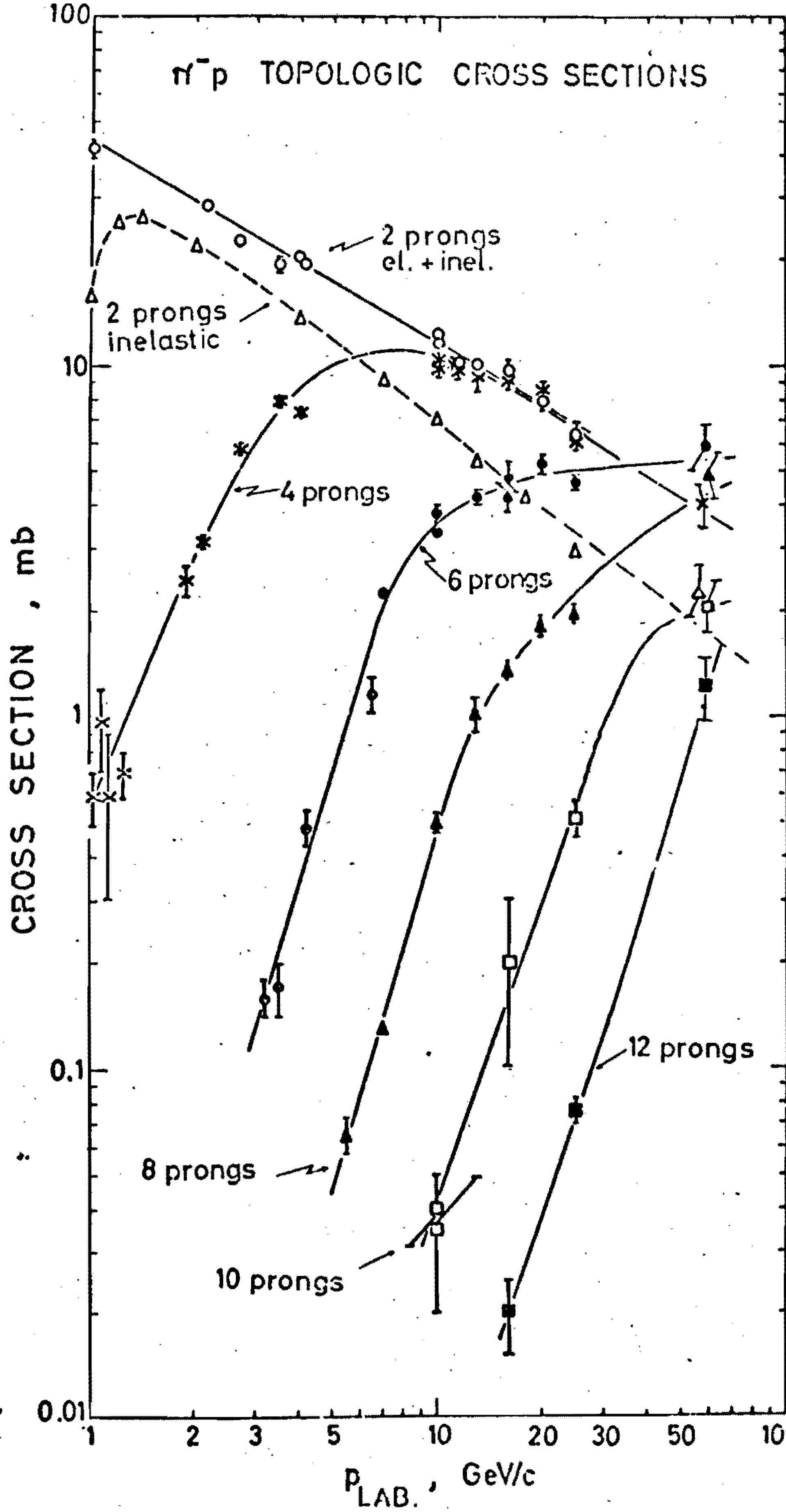
π⁻p → (nπ)p
AT 16 GeV/c
n = 2,3,4,5
NUMBER OF EVENTS /40 MeV
ρ
π⁻ π⁰
200 GeV/c
A1
A2
A3
π⁻ π⁻ π⁺
200 GeV/c
π⁻π⁻π⁺π⁰
200 GeV/c
π⁻π⁻π⁻π⁺π⁺
0
50
100
150
1
2
3
4
5

Fig. 6



π⁻p → π⁻ (B+nπ)
n = 1,2,3,4
AT 16 GeV/c
SMALLEST |t π⁻π⁻|
Δ
1470
1520
1690
2190
a) Bπ
b) B 2π
c) B 3π
d) B 4π
NUMBER OF EVENTS / 40 MeV
0
100
200
1
2
3
4
(B+nπ)⁺ EFF. MASS , GeV

Fig. 7



π⁻p TOPOLOGIC CROSS SECTIONS
2 prongs el. + inel.
2 prongs inelastic
4 prongs
6 prongs
8 prongs
10 prongs
12 prongs
CROSS SECTION , mb
P LAB. , GeV/c
100
10
1
0.1
0.01
1
2
3
5
10
20
30
50
100

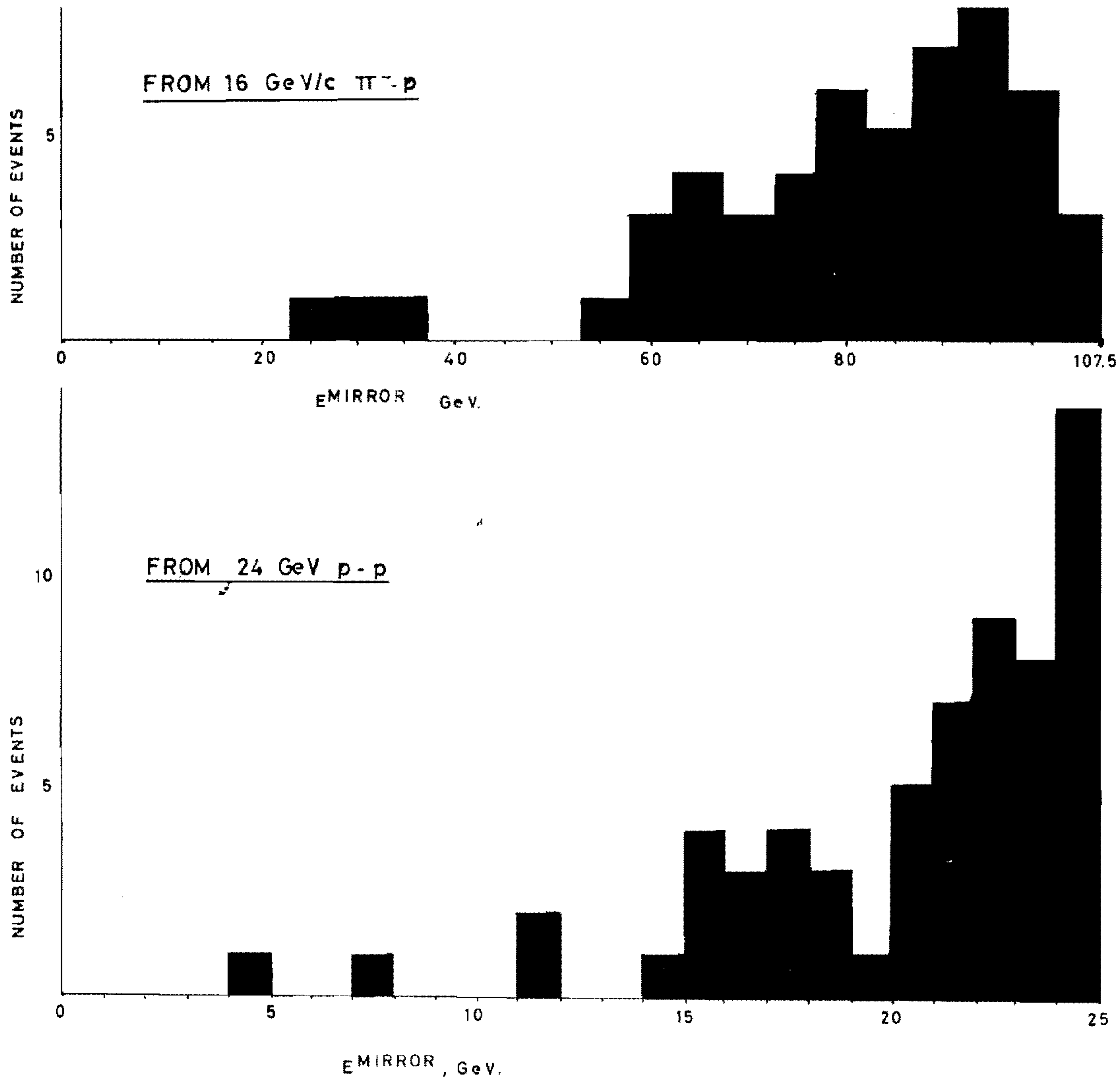

FROM 16 GeV/c π⁻-p
NUMBER OF EVENTS
5
0
20
40
60
80
107.5
EMIRROR GeV.
FROM 24 GeV p-p
NUMBER OF EVENTS
10
5
0
5
10
15
20
25
EMIRROR, GeV.

Fig. 8

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PERIPHERAL OR « QUASI-ELASTIC » INTERACTIONS OF 24 GeV PROTONS AND 16 GeV/c NEGATIVE PIONS IN HYDROGEN

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INTRODUCTION -

It has been found by Ashmore et al [1] that in the interactions of protons of about 20 GeV with protons, there are inelastic interactions which are almost elastic. These have been variously described as "quasi-elastic interactions", "glancing collisions" or as examples of peripheral processes. The effect actually observed with a counter arrangement was a peak in the cross-section for the production of protons at about only one GeV below the expected energy for an elastic event. It may be expected that these processes are mainly due to interactions involving the creation of only one pion, i.e.

$$p + p \longrightarrow \begin{cases} p + p + \pi^{\circ} \\ p + \pi^{+} + n \end{cases} \qquad (1)$$

In a hydrogen bubble chamber such interactions will be observed as an event called a two prong event, in which two charged particles leave the interaction vertex. Here we report the results of measurements made on a projection table of two prong events obtained in the CERN 32 cm diameter hydrogen bubble chamber with a beam of 24 GeV protons. The two-prong events were separated into elastic and inelastic events using kinematic critaria ; only the inelastic events are considered here. To identify the prongs as pions or protons, measurements were made of the ionision by the Mean Cap Length method. It was found possible to classify all particles of less than 1.5 GeV/c and to identify some up to 2 GeV/c momentum.

At present there is no experimental evidence on the possible existance of "glancing collisions" or "quasi-elastic" processes in pion-proton interactions ; a subject of some interest as it would lead to interpretation in terms of π-π cross-sections. Thus two prong-events produced in the CERN 32 cm hydrogen chamber by a beam of 16 GeV/c negative pions were measured and the results of the analysis of the inelastic events only are presented here.

A first account of this work has been reported [2] and many of the graphs presented there will not be repeated here.

INELASTIC TWO-PRONG EVENTS IN 24 GeV p-p INTERACTIONS -

In figure 1 is shown the angular distribution in the C.M. system of the identified protons and of the non-identified prongs which were assumed to be protons. It can be seen that there is a very strong backwards-forwards peaking with an additional small bump near Cos $\vartheta^* = +0.85$ which can be accounted for as due to positive pions which had been assumed to be protons. From this and other graphs, it may be presumed that the sub-class of two-prong events chosen for study here represent a fairly clean sample in which there are very few events with multiple pion production.

To help in understanding the results, it was found very useful to plot the transverse momentum, p_T, against the Centre of Mass Longitudinal momentum, P_L^*. This plot is a semi-circular area. The initial positions of the two protons would correspond to the 2 points $P_T = 0$, $P_L^* = \pm 3.36$ GeV/c. The points correspording to each prong must lie within a semi-circle. Elastic events would lie on the edge of this circle. The "quasi-elastic" protons observed by Ashmore et al [1] would appear as points very near the elastic limit in the forward direction, or more exactly they would be very near the initial point, $P_T = 0$, $P_L^* = +3.36$ GeV/c. Lines of equal values of Cos ϑ^* will appear as radial lines.

CENTRE OF MASS ANGULAR DISTRIBUTION OF TWO PRONG INELASTIC EVENTS IN 24 GeV PROTON - PROTON INTERACTIONS.

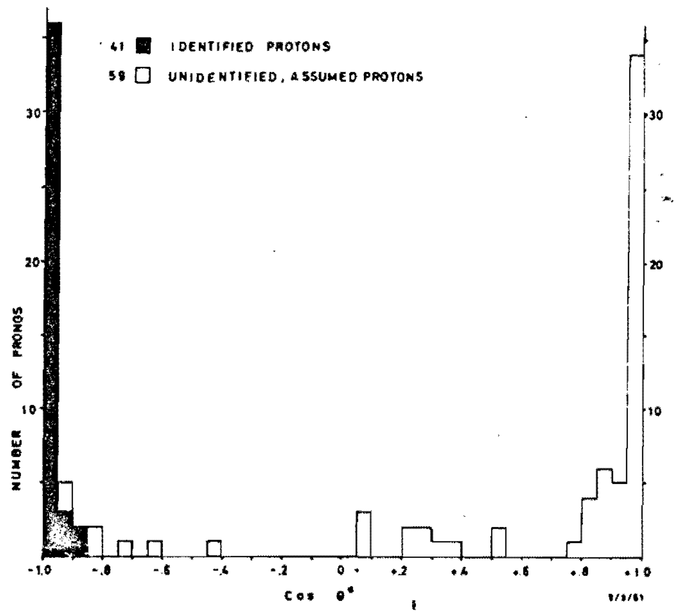


Figure 1

The important point is that since the incident and the target particle are identical, this plot must be symmetrical in the forwards and backwards quadrants. Thus for any distribution of points which is found experimentally in the backwards directions, there must be a corresponding distribution in the forwards direction. That is it is possible to measure low momentum tracks emitted at large angles (i.e. backwards in the C.M. system) and hence deduce the results for high momentum tracks at small angles (i.e. forwards in the C.M. system) which would normally be difficult to measure. The resultant plot for the backwards quadrant is shown in figure 2. All the prongs have been identified except three ; from symmetry arguments these three are probably pions. It can be seen that the protons are grouped strongly backwards and many of them are almost elastic. The pions are grouped towards $P_L^* = 0$. A striking feature of figure 2 is that the transverse momentum is always small. If we consider only P_L^*, the resultant histograms for protons and pions is shown in figure 3.

Corresponding to the protons that are very backwards, there must exist another group which are very forwards and also near the elastic limit, that is are similar to the "quasi-elastic" events found by Ashmore et al [1]. This corresponding forward particle is the "mirror" particle described by Dubrotin and Slavatinsky [3], the total energy in the laboratory system of this mirror particle is given by :

$$E^{mirror} = \frac{E_o}{M} (E_L - \beta_o . p_L \cos\vartheta_L) \qquad (2)$$

where E_o, M and β_o are the total energy, mass and velocity of the incident proton and E_L, p_L and ϑ_L are the total energy, momentum angle of the emitted particle all in the laboratory system.

The distribution of mirror energies is shown in figure 4. Due to the small number of events, the values have been grouped in large intervals of one GeV width for a typical measurement error of one degree and of 50 MeV/c out of a total momentum of about 400 MeV/c, the corresponding error in E^{mirror} is about 0.2 GeV. Thus the method is capable of high resolution if more events had been measured. In figure 4, it can be seen that there are many inelastic events giving protons of almost the elastic limit value. The peak of the proton cross-section is almost one GeV below the maximum possible value of 25 GeV. There were very few events that could correspond to the excitation of the (3/2, 3/2) resonance.

C.M. LONGITUDINAL MOMENTUM DISTRIBUTION OF INELASTIC TWO PRONG EVENTS IN 24 GEV PROTON-PROTON INTERACTIONS.

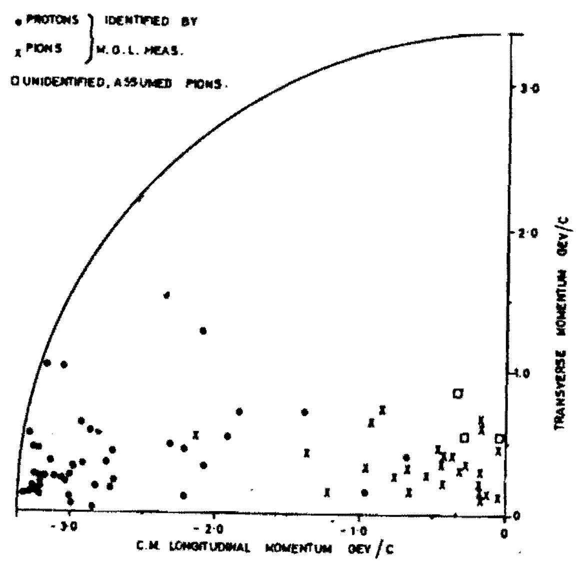


Figure 2

C.M. LONGITUDINAL MOMENTUM DISTRIBUTIONS OF INELASTIC TWO PRONG EVENTS IN 24 GeV PROTON-PROTON INTERACTIONS.

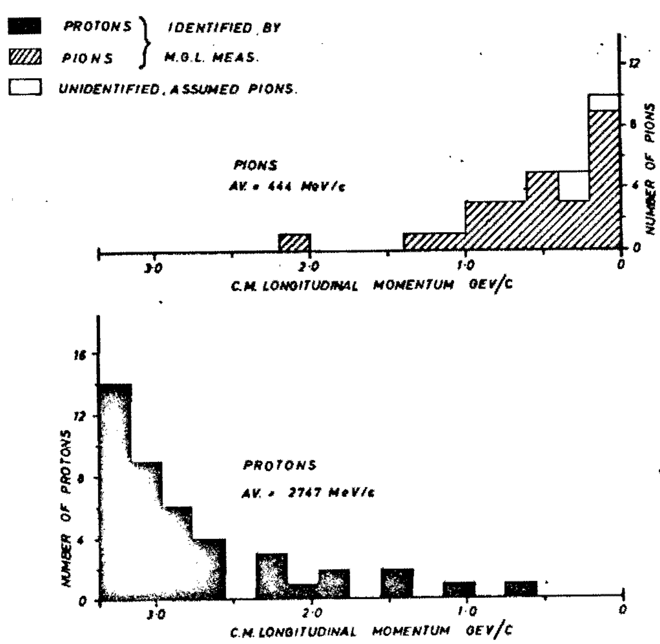


Figure 3

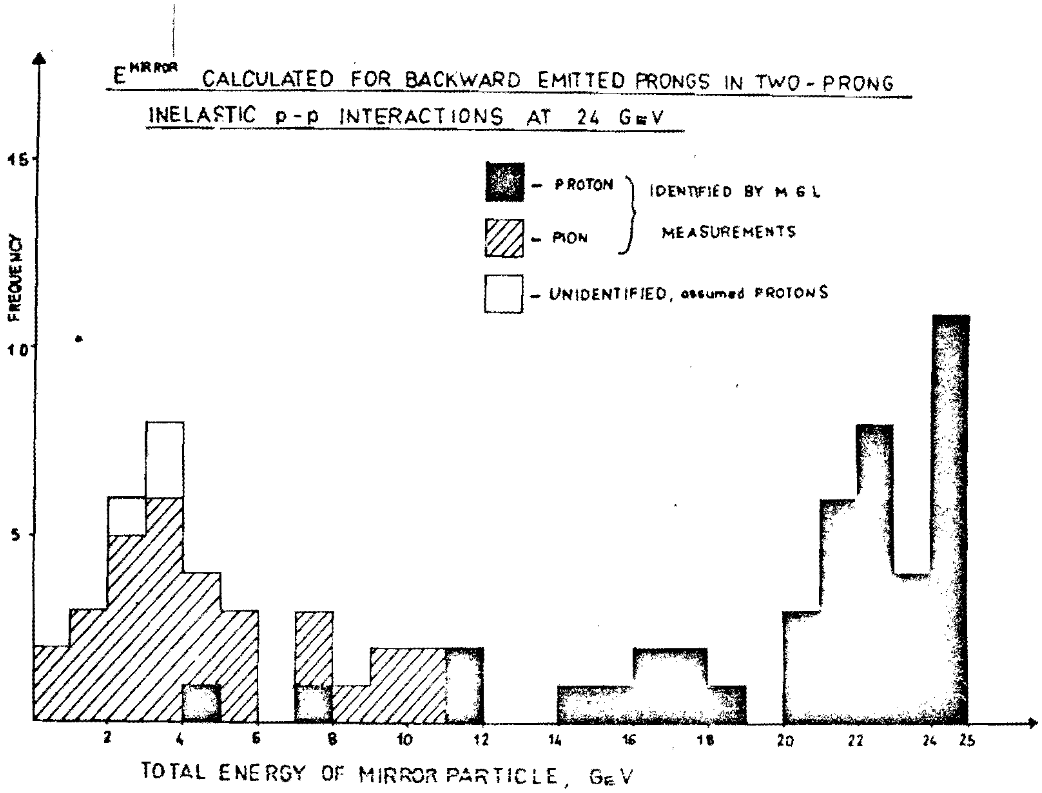


Figure 4

This "quasi-elastic bump" has been explained in terms of a diffraction disintegration by Good and Walker [4] or as a diffraction scattering on a virtual pion by Amati, Peyrou and Prentki, independently. These two descriptions are in fact the same process explained in different terms. The first quantative description of the process has been given by Drell and Hiida [5] who explain that the dominant Feynmann graph is :

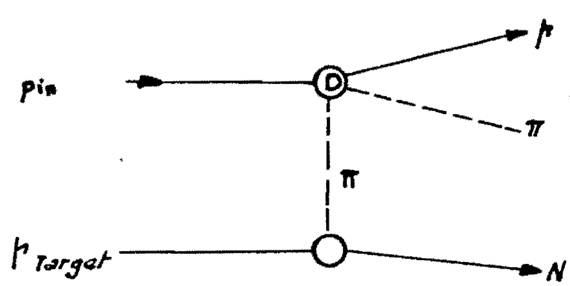


Figure 5

where a D has been written in the top vertex to indicate that it is a diffraction scattering process. Since it is a diffraction process the outgoing fast nucleon must be a proton and cannot be a neutron. It was found by Drell and Hiida that the cross-section for this graph had a large enhancement factor when the pion produced was very slow in laboratory.

If one equates the peak in the E^{mirror} distribution with this Feynmann graph, then the cross-section for this graph will be 3 mb. However, this graph is not symmetrical, that is one proton is forwards while a pion and a nucleon are backwards. Since the proton-proton interaction is symmetrical, there must exist a corresponding graph in which the target proton makes the diffraction scattering. In this graph the pion and a nucleon will go forwards, the nucleon with about 18 GeV energy. Thus in the E^{mirror} distribution one should expect to see not only a group near 24 GeV, but also a broad group at about 18 GeV. Now the nucleon near 18 GeV can be either a proton or a neutron, and from charge independence there should be two neutrons to one proton. Hence the group in E^{mirror} near 18 GeV should be only one third the size of the peak near 24 GeV. There are too few events in figure 4 to test this, but Professor Peyrou in his report to this conference will present a graph of E^{mirror} showing this work combined with the measurements of the Birmingham, Imperial College London and Oxford groups, where a second group near 18 GeV becomes clearer.

Thus the Feynmann graph of figure 5 and its mirror graph must contribute together 6 mb out of a total inelastic cross-section of about 31 mb.

INELASTIC TWO-PRONG EVENTS IN 16 GeV/c π^--p INTERACTIONS -

Although some useful results may have been obtained from the study of p-p interactions, more interesting results can be found from π^--p interactions since the π-π interaction may be involved. One experimental advantage is that the two particles have opposite signs so that if the high momentum track is negative it may be assumed to be a pion.

As before two-prong events only were measured and the elastic ones were separated off. The C.M. angular distribution of the negative particles is shown in figure 6 where it can be seen that there is a strong forward peaking suggesting that there are few events which are of the multi-pion production type. In figure 7 these negative particles are given on a P_T, P_L^* plot. Since as before, the P_T is always small, the plot of P_L^* is also given. The most striking feature of this graph is that there appear to be two groups of π^-, one with very forward particles and a second group near $P_L^* = 0$, but slightly forwards.

The P_T - P_L^* plot and the P_L^* histograms for the positive particles are given in figures 8 and 9 where it can be seen that the protons are grouped strongly backwards, but perhaps not quite so close to the elastic limit as in figure 2 for the p-p interactions. The positive pions are grouped near $P_L^* = 0$, but slightly backwards.

Perhaps the most interesting result is given by studying the correlation between the P_L^* values for two particles. This is done in figure 10 where the P_L^* value for negative particle lies on the X-axis while that for the posivite particle is given on the vertical axis, so that each event is represented by a square on the plot, and the square is shaded according to the identification of the positive particle ; it was assumed that the unidentified negative particles are pions.

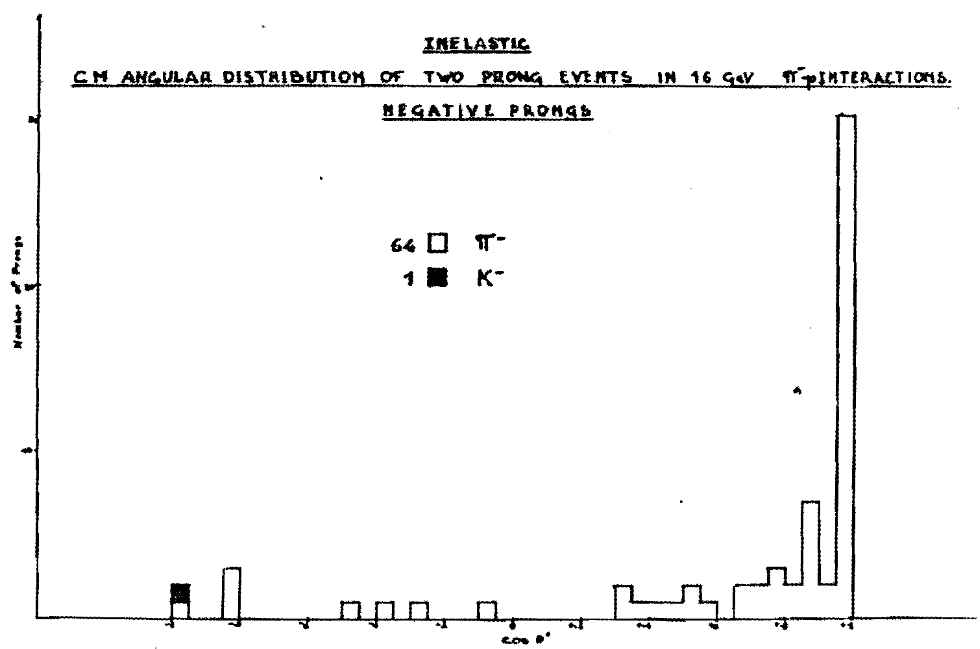


Figure 6

C.M. MOMENTUM DISTRIBUTIONS OF INELASTIC TWO PRONG EVENTS IN 16 GEV/C π^-p INTERACTIONS NEGATIVE PRONGS

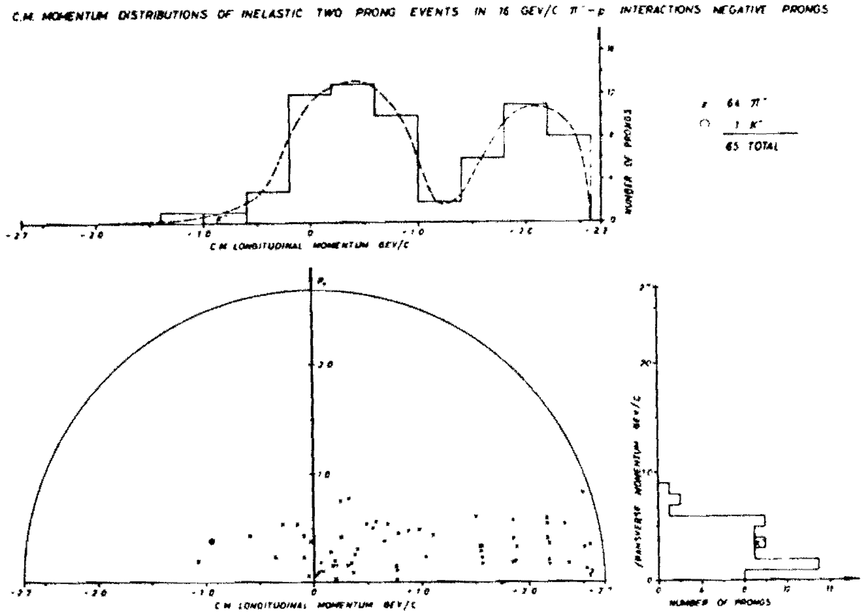


Figure 7

C.M. LONGITUDINAL MOMENTUM DISTRIBUTION OF INELASTIC TWO PRONG EVENTS IN 16 GeV/c π^-p INTERACTIONS

POSITIVE PRONGS

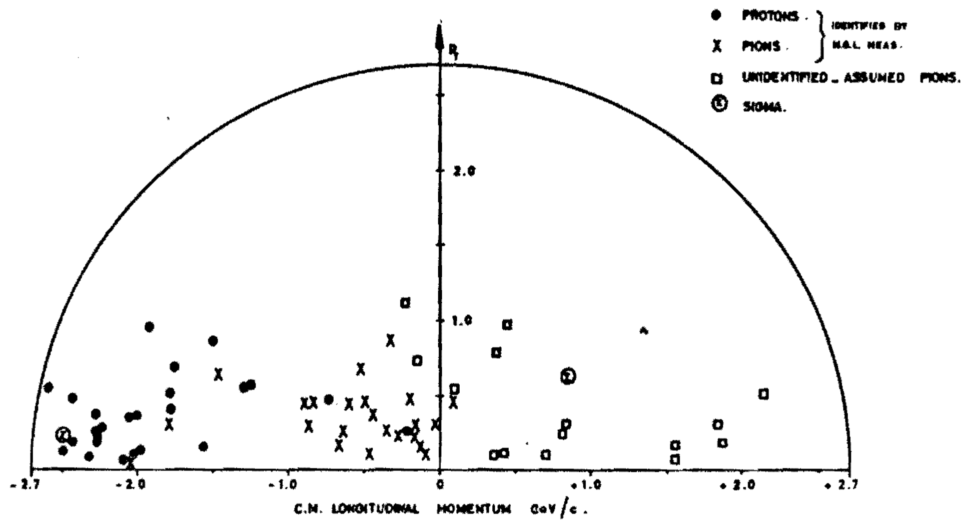


Figure 8

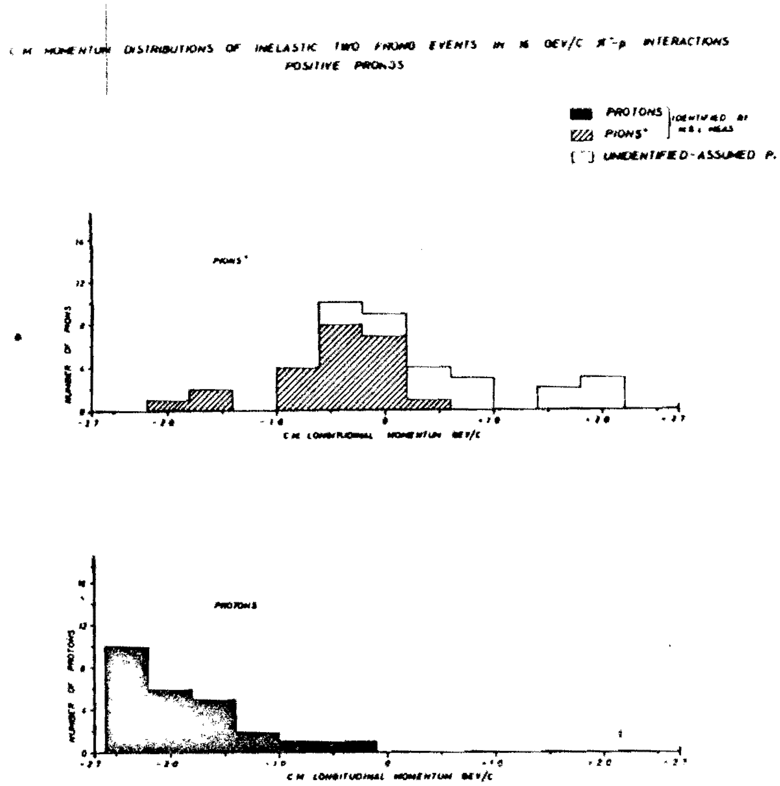


Figure 9

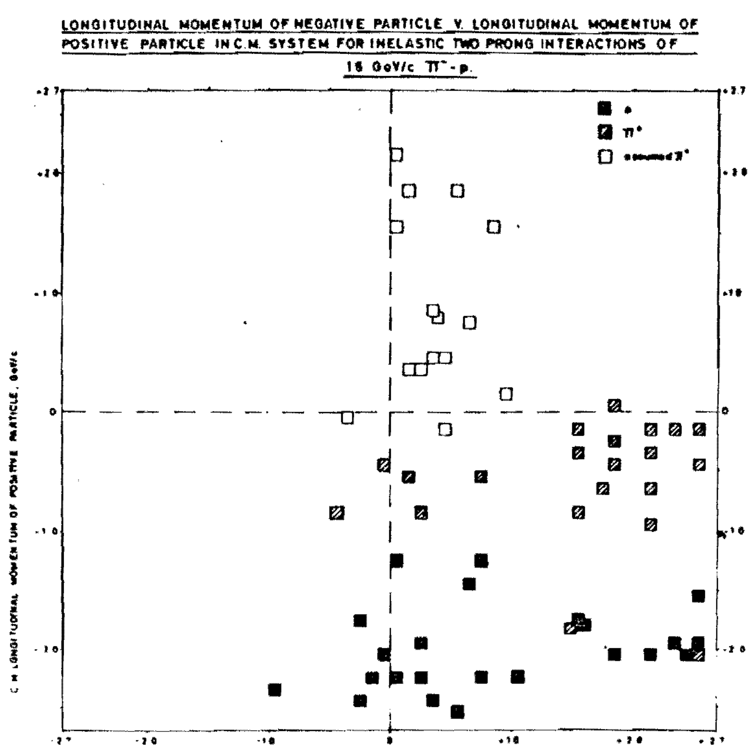
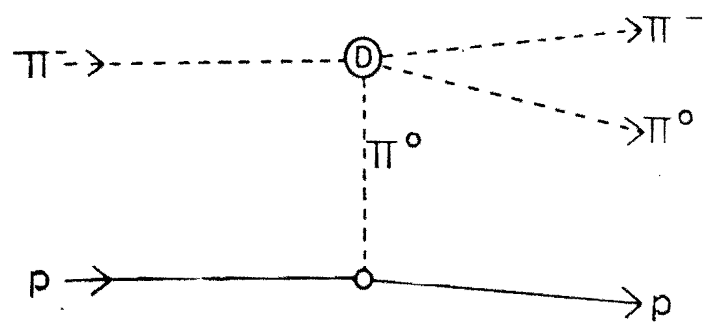
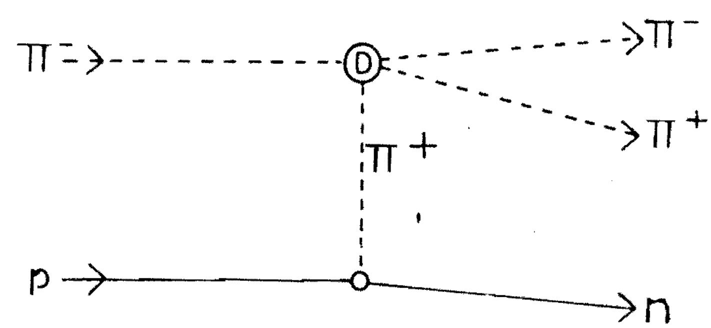


Figure 10



TYPE A



TYPE B

Figure 11

It can be seen in figure 10 that there is a large group of events which have a fast π^- prong (where the π^- has a P_L^* value of more than 1.4 GeV/c) together with a backward emitted proton or π^+. This group of events we may interpret as being due to diffraction scattering of the incident π^- on a virtual pion of the proton, and the enhancement factors which Drell and Hiida [5] described for the p-p interaction may be expected to operate here. The relevant Feynmann graphs are shown in figure 11, these being two graphs according as the virtual pion exchanged is a π^0 or a π^+. For charge independence we may expect that the ratio of graph A to graph B should be 1/2. Here we find 8 events with a proton and 16 with a π^+. The cross-section for these two graphs is about 2 /4 mb. From this Drell [6] has calculated the π-π total cross-section, obtaining a value of about 30 mb.

It is interesting to note that there exists a group of 5 events whose positive prong has a higher momentum (in the lab and in the C.M. system) than the negative prong. The positive prong cannot be very forward as the negative prong is also fowards in the C.M. system. Although one may speculate (double charge exchange ?) no further evidence is available.

There is also a large group of events which have a slow proton associated with a π^- which has a P_L^* value of near zero or slightly positive (lower centre of figure 10). At lower pion energies where such a backwards peaking of the protons is found, it is conventional to show that this is not in agreement with a phase space calculation but can be accounted for by means of a π-π resonance. Here we would like to suggest a different approach. The results which have been found in the π-p C.M. system must also be true in any laboratory system. In particular they must be true in the system in which the proton is the incident particle and the pion is at rest and is free ; (that is this is the "mirror" system to our normal pion-proton system). The incident proton must have the same velocity as a 16 GeV/c pion, and hence has a total energy of 107.5 GeV. We will now assume that the incident proton makes a diffraction scattering on a virtual pion associated with the real pion. To do this, two pions must now be emitted from the bottom vertex. The Feynmann graph for this is figure 12 :

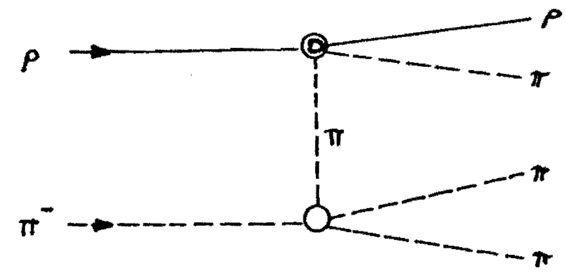


Figure 12

Or we may write :

$$\pi^- + p \longrightarrow \pi^- + p + \pi + \pi \tag{2}$$

Here it will be seen that two pions and not one have been created and hence it may be expected that the outgoing proton should not be so nearly elastic as it was in the proton-proton case. That this is so may be best seen by comparing the mirror energy of the "recoil" proton in π^--p and in p-p interactions. This is done in figure 13 where it may be seen that the shape of the two curves is quite different. While the peak of the "mirror" protons in the π-p interaction is of high energy it is not near the maximum value as it was in the p-p system.

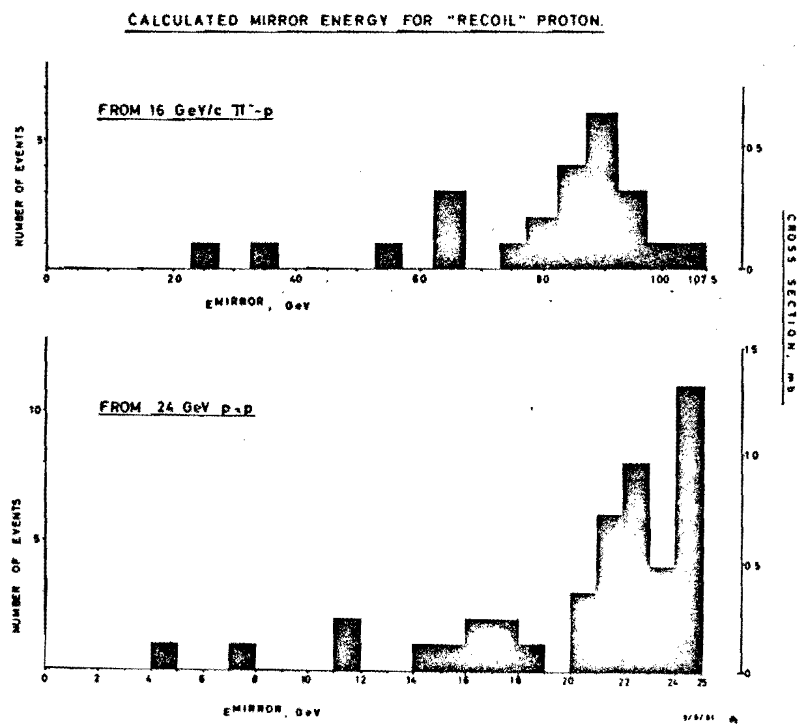


Figure 13

The cross-section for the graph of figure 12 should be about one to two millibarns, a correction being necessary for the case where all three pions are charged so that the interaction will appear as a 4-prong event. It may be commented that if our interpretation is correct then the cross-section for proton-proton elastic scattering at 107.5 GeV is not zero.

It is of course not excluded that π-π resonances also contribute strongly to enhancement of the channel represented by figure 12, however, we would suggest the enhancement given by the diffraction scattering of the proton on the virtual pion may also be important.

It may be noted that all three pions of eqn. (2) will tend to be forwards in our laboratory system.

FURTHER COMMENT ON THE 24 GeV p-p INTERACTIONS -

As the two prongs are both positively charged, it is not possible to plot the correlations between the two prongs on a figure corresponding to figure 10 for the π^--p interactions. The best that can be done is to plot each event with its X-coordinate given by the higher value of P_L^* and its Y-axis by the lower value of P_L^*. Thus all points must lie below a line through the origin at 45°. This plot is given in figure 14, but it is rather difficult to understand this figure as due to the difficulty of measuring momenta of about 20 GeV, it should be expected that there must be overlapping between those cases where the high value of P_L^* is due to the diffraction scattering of the incident proton or is due to the recoil nucleon being a proton of about 18 GeV in the laboratory system. It may easily be shown that one would expect that the lower momentum particles associated with the high value of P_L^* should be equally probably π^+ or protons. If we take all events with a P_L^* value of greater than +2.0 GeV/c then the associated particles are 14 protons and 12 identified or assumed pions.

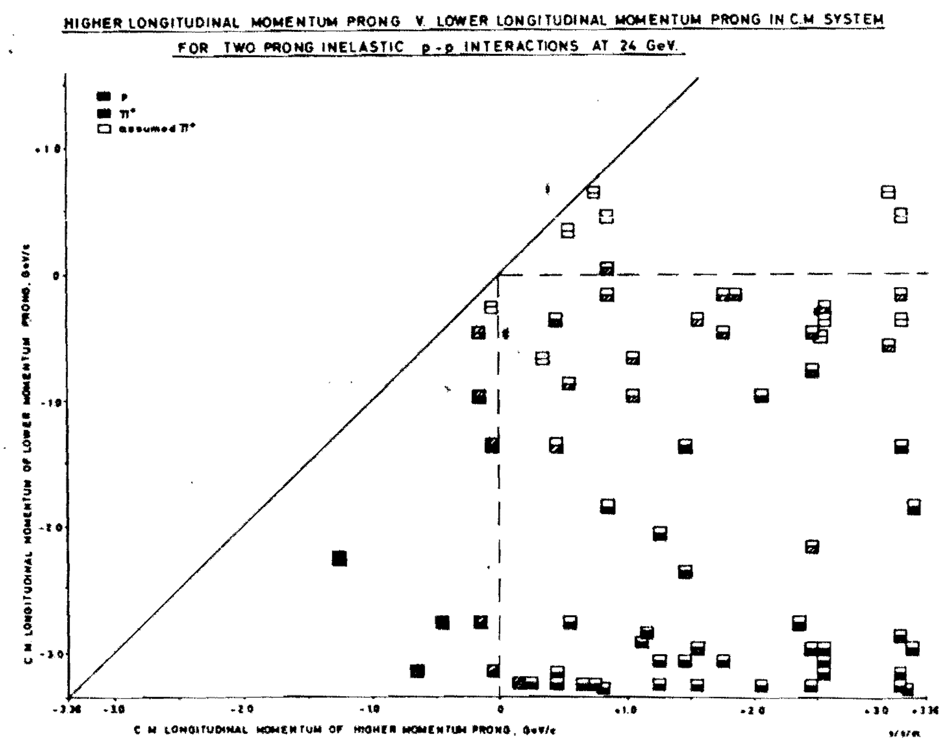


Figure 14

CONCLUSIONS -

It has been demonstrated that the method of making accurate measurements of low momentum tracks can give detailed information about high energy interactions particularly if the idea of the "mirror" particle or mirror system is used.

The integrated cross-section for the "quasi-elastic" bump found by Ashmore et al is about 3 mb giving a total of about 6 mb for the assumed one pion exchange process of the diffraction scattering of a proton on a virtual pion.

In the π^--p interactions two types of interactions have been distinguished. Firstly one group where the incident π^- keeps its identify and this is assumed to be due to diffraction scattering of a pion on a virtual pion. The cross-section for this process is about 2 /4 mb. The total π-π cross-section deduced by Drell is about 30 mb. The second group may be interpreted as the diffraction scattering of the proton by a virtual pion associated with the incident pion. The cross-section for this process being about 1 to 2 mb.

ACKNOWLEDGEMENTS -

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