A PROGRESS REPORT AND UPDATED REQUEST FOR TIME TO COMPLETE E-268,

AN EXPERIMENT TO MEASURE THE INCLUSIVE REACTIONS

$\pi^- p \rightarrow (\pi^0, \eta, \omega, \ldots) + X$ and $pp \rightarrow (\pi^0, \eta, \omega, \ldots) + X$

IN THE HIGH P_T REGION.

October 11, 1974

By running parasitically with E-51 and E-8 in the M2 beam we have demonstrated the feasibility of performing the measurements described in our original proposal*, we have obtained some rough but interesting new information about the high p_T reactions produced by π^-, and we have sharpened our ideas about the principal objectives for the experiment.

In this report we describe the preliminary results obtained to date and we request approval for the running time necessary to complete the experiment.

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* E-268 Proposal, "A PROPOSAL TO STUDY MESON PRODUCTION AT LARGE P_T WITH A γ-RAY DETECTOR," A. Barnes, K.-W. Lai, J. Mellema, A.V. Tollestrup, R.L. Walker, O. Dahl, R. Johnson, R. Kenney, and M. Pripstein.

I. Introduction.

While carrying out a feasibility study for Experiment E-268, we have obtained a limited amount of data on the reactions

$$\pi^- p \to \pi^0 X \qquad (1a)$$

$$\pi^- p \to \eta X \qquad (1b)$$

with 100 and 200 GeV incident π^-, and on

$$pp \to \pi^0 X \qquad (2a)$$

$$pp \to \eta X \qquad (2b)$$

for 300 GeV incident protons.

These preliminary data will be presented in Section II of this report. They were obtained with 10^9 incident particles for each of three samples during parasitic running with E-51 and E-8. The kinematic regions explored in these three sets of data are summarized below:

Beam	p_T Range	Range in Laboratory Angle	Range in CM Angle
100 GeV/c π^-	$1.6 \leq p_T \leq 4$ GeV/c	30 mr - 65 mr	25° - 51°
200 GeV/c π^-	$1.6 \leq p_T \leq 4$ GeV/c	30 mr - 65 mr	33° - 68°
300 GeV/c p	$1.6 \leq p_T \leq 3.5$ GeV/c	30 mr - 65 mr	42° - 79°

The data presented here are equivalent to what would be obtained in about five hours of prime running time in the M2 beam with 200 GeV/c π^- and even fewer hours with 100 GeV/c π^- or 300 GeV/c protons.

Experiment 268 was proposed in order to achieve the following physics goals:

1. To make an accurate comparison between reactions such as (1) and (2) with different incoming (and outgoing) particles out to $p_T \simeq 5$ GeV/c.
2. To investigate inclusive production at large p_T over a wide angular range ($20° \lesssim \theta_{CM} \lesssim 110°$).
3. To utilize the unique features of our γ-ray detector in identifying and distinguishing between π^o, η, ω, and other neutral mesons which decay into all γ-rays. A measurement of ω production at large p_T would be particularly interesting, since vector meson decays are a possible source of the observed copious muon production at large p_T.

These goals nicely complement existing information on high p_T inclusive production. Whereas the ISR[1] and Chicago-Princeton[2] results span a wide range in incident energy and p_T, they are confined to a single initial state (nucleon-nucleon) and a small range of θ_{CM} near 90°. The only existing large p_T data away from $\theta_{CM} = 90°$ comes from the British Scandinavian Group's measurement at 59.40° at the ISR[3] and the Fermilab internal target experiment[4] which looks at single γ's produced in pp interactions out to $p_T \simeq 4$ GeV/c.

As a result of our parasitic running and a comparison of our preliminary results with other high p_T data, we have become aware of some important advantages of our experiment:

1. Since we use a liquid H_2 target and are able to count the number of incident particles, we should be able to measure the cross sections of reactions (1) and (2) with better normalization (5 - 10% expected uncertainty) than most if not all previous measurements at large p_T. The ratios between corresponding reactions in (1) and (2) should be determined with an even smaller normalization error.
2. The angular range of $20° \lesssim \theta_{CM} \lesssim 110°$ is covered in two overlapping settings of the apparatus, so that we can investigate the angular

dependence of the invariant cross section, essentially unaffected by point-to-point normalization errors.

3. The energy resolution of our detector is approximately independent of whether or not a $(\pi^o, \eta, \ldots)$ is accompanied by other γ-rays or charged particles. Good energy (and hence p_T) resolutions for both categories of events is essential, since the cross section is a steep function of p_T.

These advantages are specially significant in view of our present ideas as to what may be the most important information to come from the present experiment. The general purpose of experiments at high p_T is to learn something about the structure of hadrons and, in particular, about their constituents, if there are any. It seems likely that the observable data which may be most easily and directly related to the hadron structure (quarks??) are not the s-dependence or p_T dependence of the cross section for a given reaction, but the detailed differences in the cross sections for different incident particles and different final particles. In any constituent model of the hadrons, the different structure of π and N, for example, should lead to definite predictions about the differences in angular distributions, p_T dependence and other characteristics of the cross section for incident π^- compared to incident protons.

For these reasons we expect that a comparison of results for different particles will be very revealing. However, to be significant, such a comparison will require high accuracy in the measurements, including relative normalizations. We expect to be able to achieve the required accuracy in the present experiment.

In comparing results for different particles it might be interesting to include reactions produced by incident K mesons. The flux of K^+ at 100 GeV is sufficient to make possible limited measurements of K^+p reactions. In fact, if the K^+p cross section were appreciably greater than that for pp, it might be necessary to identify the K^+p in order to eliminate these background reactions. These questions concerning kaons[5)] and the possible redesign of our Cerenkov counter so as to detect K's are under consideration.

II. Preliminary Results.

The data presented in this section are based on samples of "unaccompanied" π^o's and η's (i.e., events in which no appreciable energy is deposited in the detector by additional γ's or charged particles), obtained with our three beam settings. In computing $E\, d^3\sigma/dp^3$, an estimated correction has been applied to compensate for the neglect of the "accompanied" events. The Appendix details our progress to date in the recovery of accompanied events and explains the approximate loss correction used in our cross section calculations. However, some uncertainty remains as to the variation of this correction with p_T, θ_{CM}, incident momentum and initial state. Until we sort out these effects in our analysis, we feel that our preliminary cross sections are not good to better than about 30%. There is also an uncertainty of a few per cent in our p_T scale since we have not yet tuned up our gain calibration programs for the present experiment.

Selection of π^o's and η's for the data shown here has been made using our on-line analysis programs which gave the $(\text{mass})^2$ distributions shown in Fig. 1. Better mass resolution can be achieved by more detailed fitting of the data from the detector as described and illustrated in the Appendix. However this improved analysis procedure has not yet been applied to the major portion of the data.

In Fig. 2 our preliminary data on $pp \to \pi^o X$ at 300 GeV/c are shown together with a small sample of preliminary data on $pp \to \pi^o X$ at the same energy and angle from Experiment E-63A (J.K. Walker et al.).[6] The two experiments agree reasonably well. In Figures 2-6, subjectively drawn straight lines are shown to indicate the trend of the data.

Because our results agree with those of E-63A for 300 GeV protons, we may be justified in using other data from the latter experiment to compare with our $\pi^- p$ data at energies where we have not yet made measurements of the pp reactions. Thus in Fig. 3 we show our data on $\pi^- p \rightarrow \pi^o X$ at 200 GeV compared with a sample of data from E-63A on $pp \rightarrow \pi^o X$ at the same energy and angle. We see that there is a significant, though not large, difference in the slopes of the curves for incident π^- and incident protons producing π^o's.

In figure 4 we compare our data at 100 and 200 GeV for the reaction, $\pi^- p \rightarrow \pi^o X$. (The 200 GeV data are the same as shown in figure 3.) We see that the cross section falls less rapidly with increasing p_T for the higher energy data, in agreement with other measurements in the high p_T region.

In figure 5 our preliminary data on $\pi^- p \rightarrow \eta X$ at 100 and 200 GeV are shown together with the data on $\pi^- p \rightarrow \pi^o X$ at 200 GeV. The π^o and η data for 300 GeV incident protons are compared in figure 6. More accurate data on the η inclusive reactions are needed before we can draw firm conclusions concerning the behavior of these cross sections.

Before leaving this section on preliminary results, we should mention the status of ω's in our present data. We have not observed any significant mass peak in the ω region. However, the calculated efficiency for detecting ω's in the $\pi^o\gamma$ decay mode for the experimental configuration used during the parasitic running is rather low and the branching ratio for the $\pi^o\gamma$ decay mode is only 9 or 10%. A numerical estimate of the number of ω's which should have been observed in the present data sample indicates that we would not have seen a noticeable ω signal unless the cross section for ω production were several times that for π^o's.

III. Proposed Run Plan.

In Table 1 we list the relative amounts of running time to be allocated to each desired incident momentum and beam polarity and for each angular region. The proposed run plan would be to complete the experiment in two three-week running periods of reasonable accelerator operation. (We may submit a later request for an additional two-week run to study 300 GeV/c incident pions when 400 GeV protons are being targeted in the Meson Lab.)

Each three-week run would be devoted to a particular θ_{CM} region, with the proton and pion data being taken in the same setting of the apparatus for each incident momentum, thus permitting a direct comparison of the cross sections for reactions (1) and (2).

We estimate that there are typically 250 useful hours of data-taking in a three-week period, making a total of about 500 hours of running for the two periods. Given a run of this duration, we expect to have a sensitivity of about 3×10^4 events/μb for each angle setting and beam polarity at 100 and 200 GeV/c. At these two energies we would thus have for each of the eight configurations a factor of about fifteen greater sensitivity than for the preliminary 100 or 200 GeV/c data in Section II. The 300 GeV diffracted proton running would enable us to collect data with the highest energy presently available in the Meson Lab and with significantly higher incident intensity. Here we hope to have a sensitivity of a few times 10^5 events/μb; this should provide, at each angle, more than a factor of 100 times greater statistics than the 300 GeV data reported in Section II.

Table I.

Relative Amounts of Running Time for Various Experimental Configurations.

	θ_{CM} 45°			θ_{CM} 90°		
	Position	π^-	p	Position	π^-	p
100 GeV/c	1	0.6	0.4	4	0.6	0.4
200 GeV/c	2	1.0	0.3	5	1.0	0.3
300 GeV/c	3	*	0.5	6	*	0.5

* Possibly to be requested later with a value of about 1.0.

Appendix: Analysis of Multi-Photon Events.

The identification of an "accompanied" π^o or η is dependent on our ability to isolate each γ-ray in the detector and determine its energy and (X,Y) coordinate. The information available is the X and Y projections of the energy deposited in the detector. Each γ-ray shower projection has a characteristic shape which is very nearly independent of energy. A procedure has been developed to fit the X and Y energy projections to a superposition of shower shapes, such that the energy and coordinate of each shower are determined in the fit. There are then two separate matching problems to be solved. First, the information from the X and Y fits must be combined so that each peak in X is paired with its correct counterpart in Y. Second, from among the γ-rays now identified we must select the pair which come from a π^o or η. We shall discuss this latter question first, using a small sub-sample of our 200 GeV/c π^- data collected with a trigger requirement that $p_T \gtrsim 1.3$ GeV/c.

For each pair of γ-rays we compute p_T and the invariant mass. Figures 7(a-c) show the invariant mass squared distribution of all γ-ray pairs for events where $N_\gamma = 2$, 3, and 4, respectively. A π^o signal appears in each distribution, although the background increases rapidly with N_γ. Because the energy calibration of the detector has not yet been applied to these events, the π^o peak is shifted below the expected value of $M^2_{\pi^o} = 0.0182$ GeV^2. The next series of plots, Figs. 7(d-f), show the invariant mass squared, selecting the pair of γ-rays in each event with the largest p_T and requiring $p_T > 1$ GeV/c. Of course, the $N_\gamma = 2$ spectrum is essentially unchanged, while the $N_\gamma = 3$ and $N_\gamma = 4$ show a significant reduction in background. Figures 7(g-j) are mass squared plots again taking the largest p_T but now requiring $p_T > 2$ GeV/c. Here the signal-to-noise ratio seems still better. Figures 7(k-m) show the mass squared for the 2γ events in the η region. The η signal is enhanced by selecting events with $p_T > 1.5$ GeV/c.

By selecting the γ-pair with largest p_T, we are sometimes taking the wrong pair and losing a desired π^o. To estimate the size of this loss, we have studied the mass spectrum of γ-pairs with the second largest p_T. This plot (not shown) indicates that only about 4% of the π^o's with $p_T < 2$ GeV/c were missed in the original pairings and probably a smaller percentage were lost for $p_T > 2$ GeV/c

The π^o production as a function of γ multiplicity in the detector breaks down as follows (errors are statistical only):

	$p_T > 1$ GeV/c	$p_T > 2$ GeV/c
2γ	(80 ± 1)%	(84 ± 3)%
3γ	(17 ± 1)%	(13 ± 3)%
4γ	(3 ± 0.3)%	(2 ± 1)%
$\geq 5\gamma$	<1%	≳1%

Since the 2γ events have a large majority of the π^o events and since the breakdown has no strong dependence on p_T, we expect that the analysis in Section II is not too far wrong even though it ignores multi-gamma events.

The ambiguities in matching the X and Y projections of an event are still under study. Fortunately, approximately 80% of the high p_T π^o's are in the 2γ category for which the matching ambiguity is irrelevant in the determination of mass and p_T. Furthermore, after preliminary analysis of 3γ and 4γ events we believe that less than 30% of the high p_T π^o's present in these events will be lost because of difficulties in resolving them.

Therefore errors in the cross section from these problems with multigamma events are not expected to be serious. Furthermore, since γ multiplicity appears to be a weak function of p_T, the correction for X-Y mismatch will not vary rapidly with p_T, although the data indicate that the fraction of ambiguous events decreases at larger p_T.

References

1. F.W. Büsser et al., Phys. Lett. 46B, 471 (1973). (CCR)

   B. Alper et al., Phys. Lett. 44B, 521 (1973). (British-Scandinavian)

   M. Banner et al., Phys. Lett. 44B, 537 (1973). (Saclay-Strassbourg)

2. J.W. Cronin et al., Phys. Rev. Lett. 31, 719 (1973); also see

   J.A. Appel et al., Phys. Rev. Lett. 33, 719 (1974).

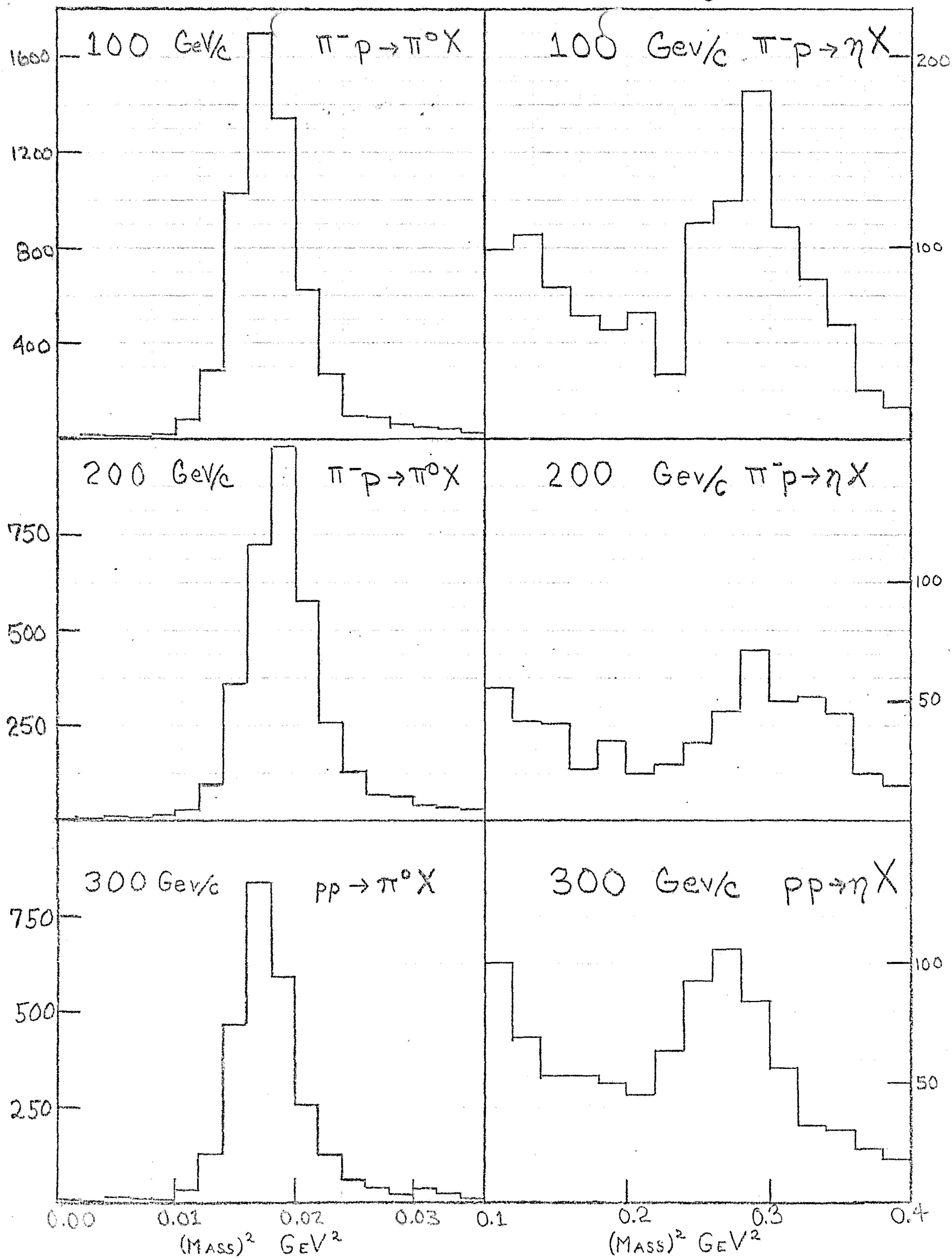
3. B. Alper et al., op. cit.

4. D.C. Carey et al., Phys. Rev. Lett. 33, 327 (1974). (E-63A)

5. We are indebted to J.K. Walker for calling our attention to these questions concerning K mesons.

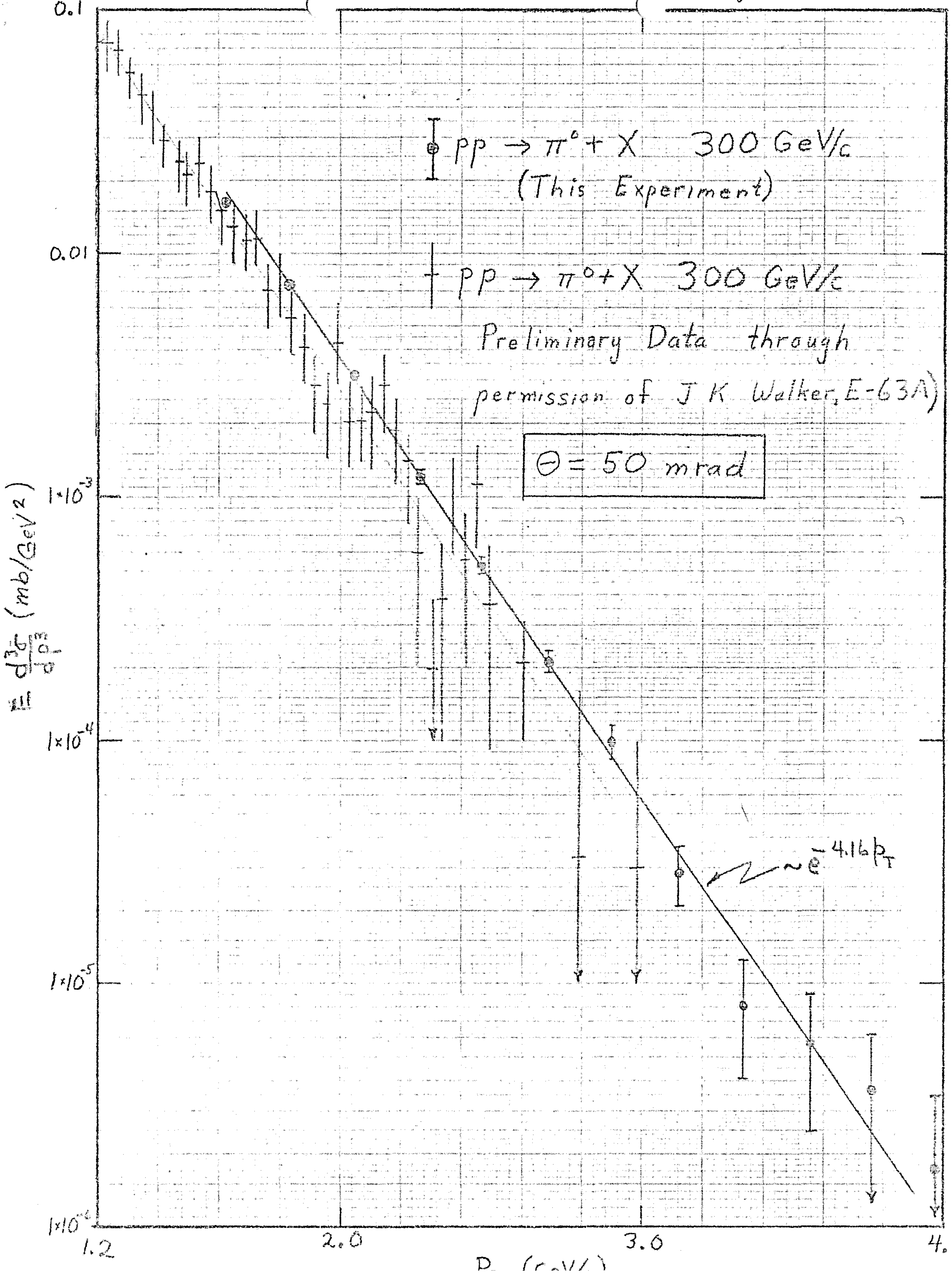
6. J.K. Walker, private communication.

Fig. 1



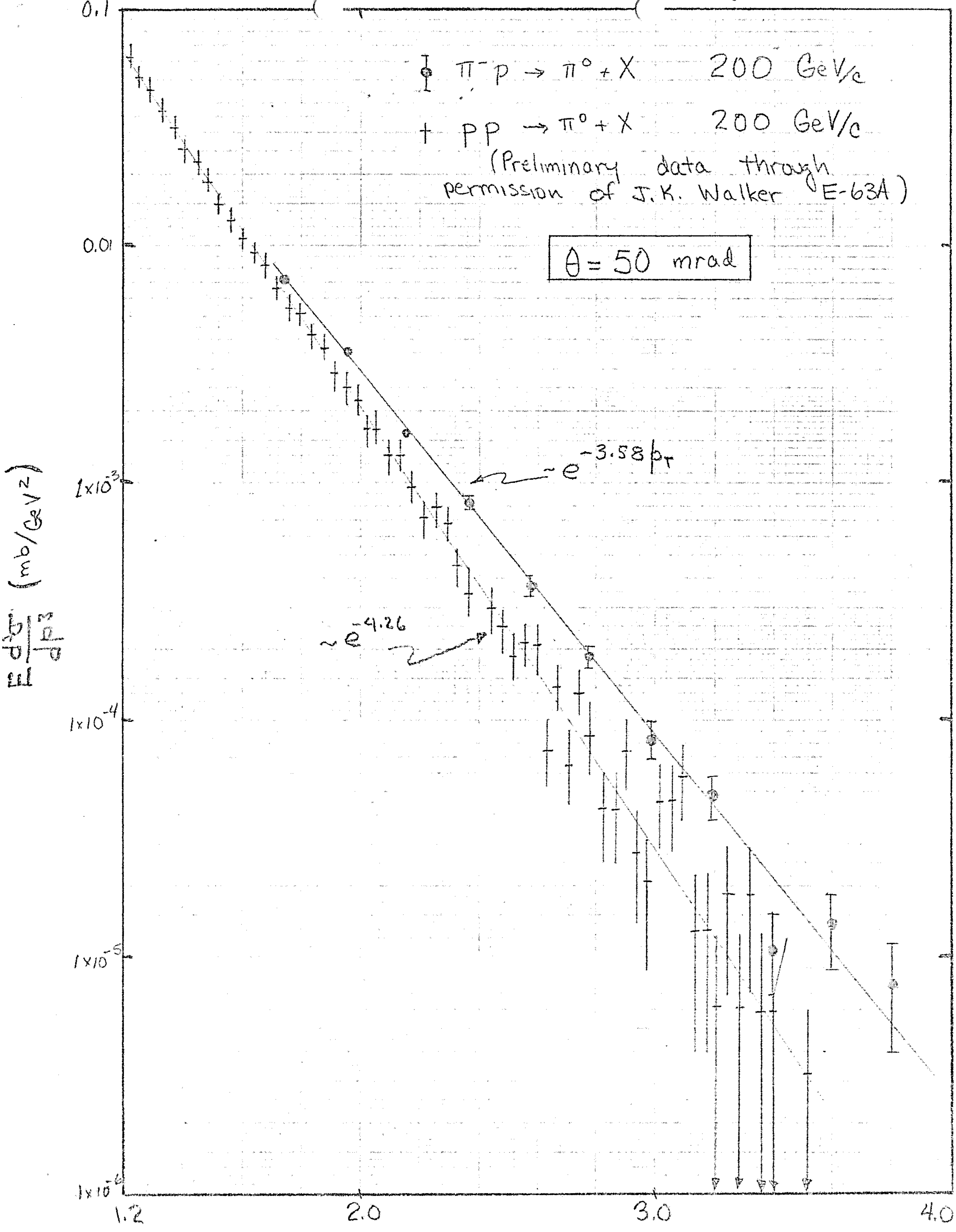
100 GeV/c $\pi^-p \to \pi^0 X$
100 GeV/c $\pi^-p \to \eta X$
1600
1200
800
400
200
100
200 GeV/c $\pi^-p \to \pi^0 X$
200 GeV/c $\pi^-p \to \eta X$
750
500
250
100
50
300 GeV/c $pp \to \pi^0 X$
300 GeV/c $pp \to \eta X$
750
500
250
100
50
0.00
0.01
0.02
0.03
0.1
0.2
0.3
0.4
(Mass)² GeV²
(Mass)² GeV²

Fig. 2



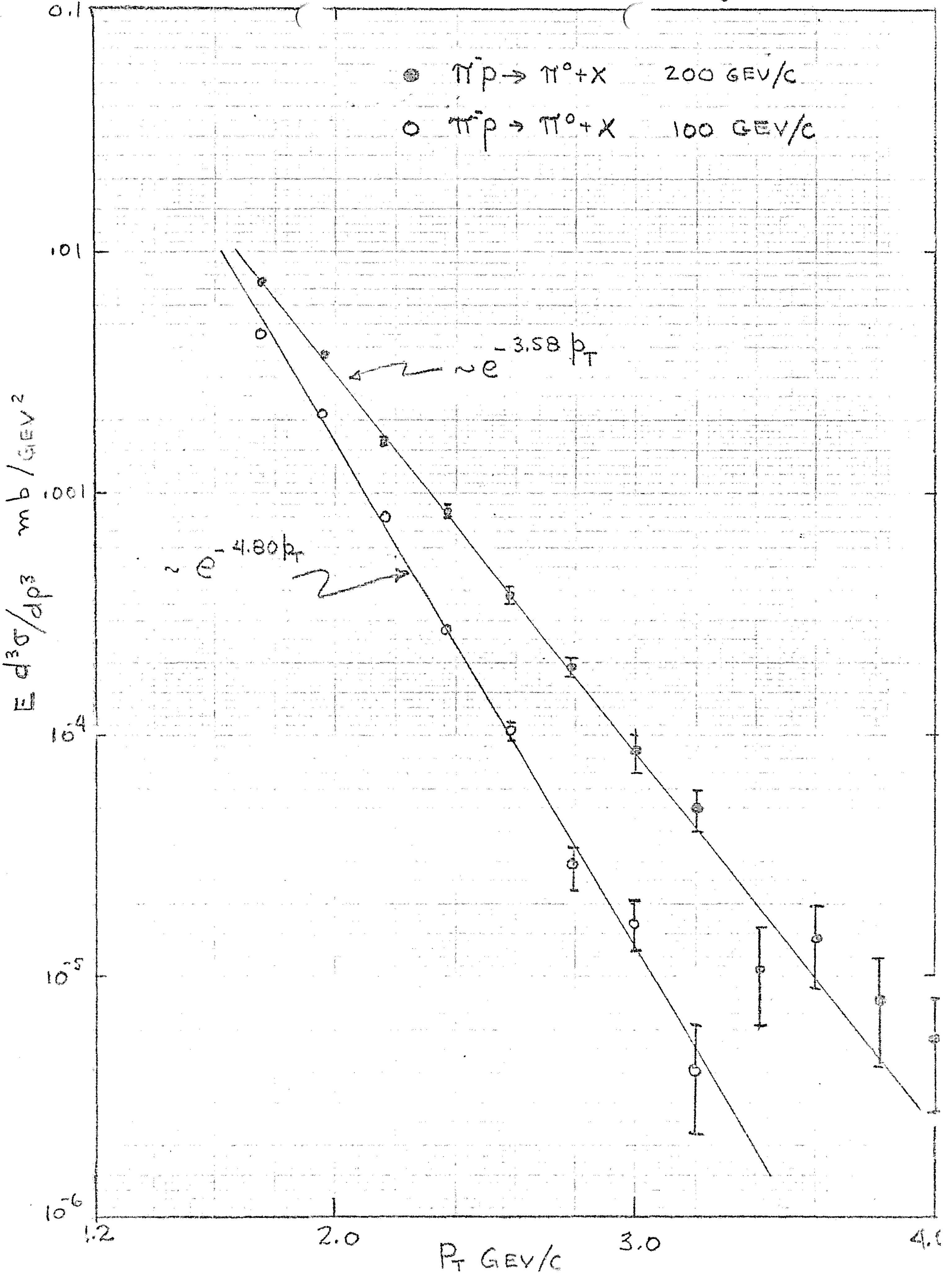
pp → π° + X 300 GeV/c
(This Experiment)
pp → π° + X 300 GeV/c
Preliminary Data through
permission of J K Walker, E-63A)
Θ = 50 mrad
~e^-4.16 p_T
0.1
0.01
1×10^-3
1×10^-4
1×10^-5
1×10^-6
1.2
2.0
3.0
4.
E d³σ/dp³ (mb/GeV²)
P_T (GeV/c)

Fig. 3



π⁻p → π° + X 200 GeV/c
pp → π° + X 200 GeV/c
(Preliminary data through permission of J.K. Walker E-63A)
θ = 50 mrad
~e^-3.58 pT
~e^-4.26
E d³σ/dp³ (mb/GeV²)
0.1
0.01
1×10⁻³
1×10⁻⁴
1×10⁻⁵
1×10⁻⁶
1.2
2.0
3.0
4.0

Fig. 4



π⁻p → π⁰ + X 200 GEV/c
π⁻p → π⁰ + X 100 GEV/c
~e^{-3.58 p_T}
~e^{-4.80 p_T}
E d³σ/dp³ mb/GEV²
0.1
10⁻¹
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
1.2
2.0
3.0
4.0
P_T GEV/c

Fig. 5

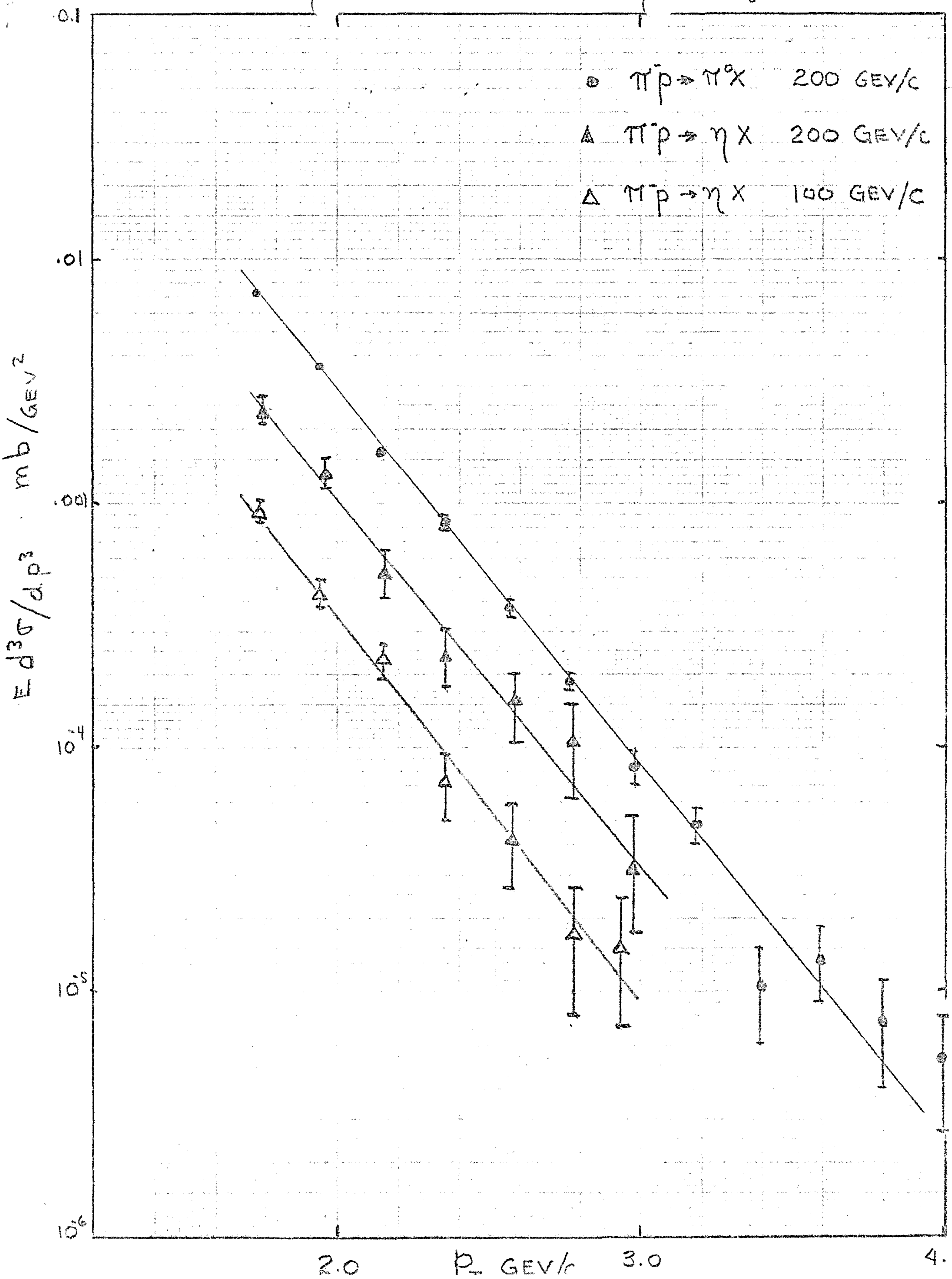

π⁻p → π°X 200 GEV/c
π⁻p → ηX 200 GEV/c
π⁻p → ηX 100 GEV/c
$E\,d^3\sigma/dp^3$ mb/GEV²
0.1
.01
.001
10⁻⁴
10⁻⁵
10⁻⁶
2.0
3.0
4.
p_T GEV/c

Fig. 6

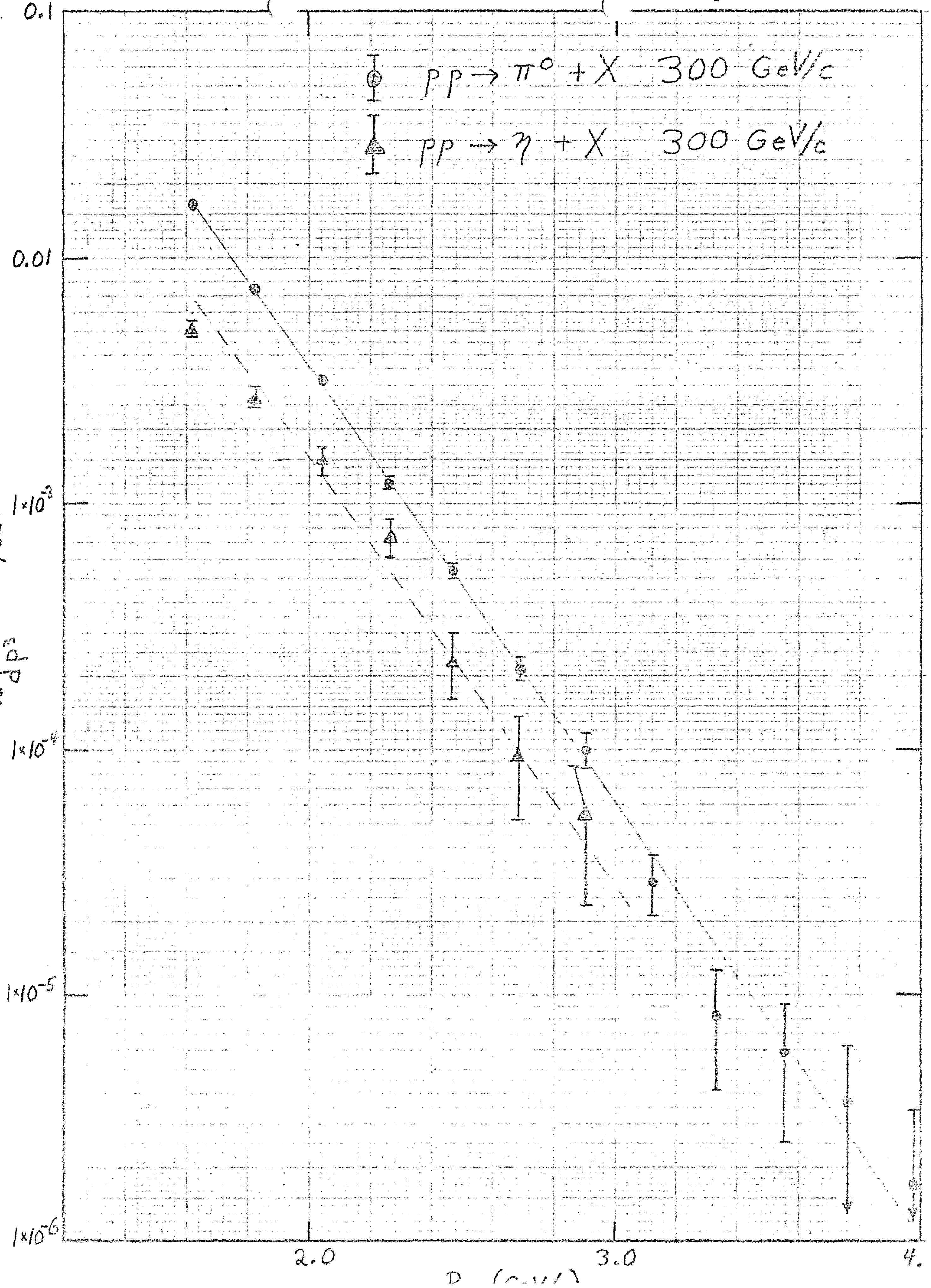
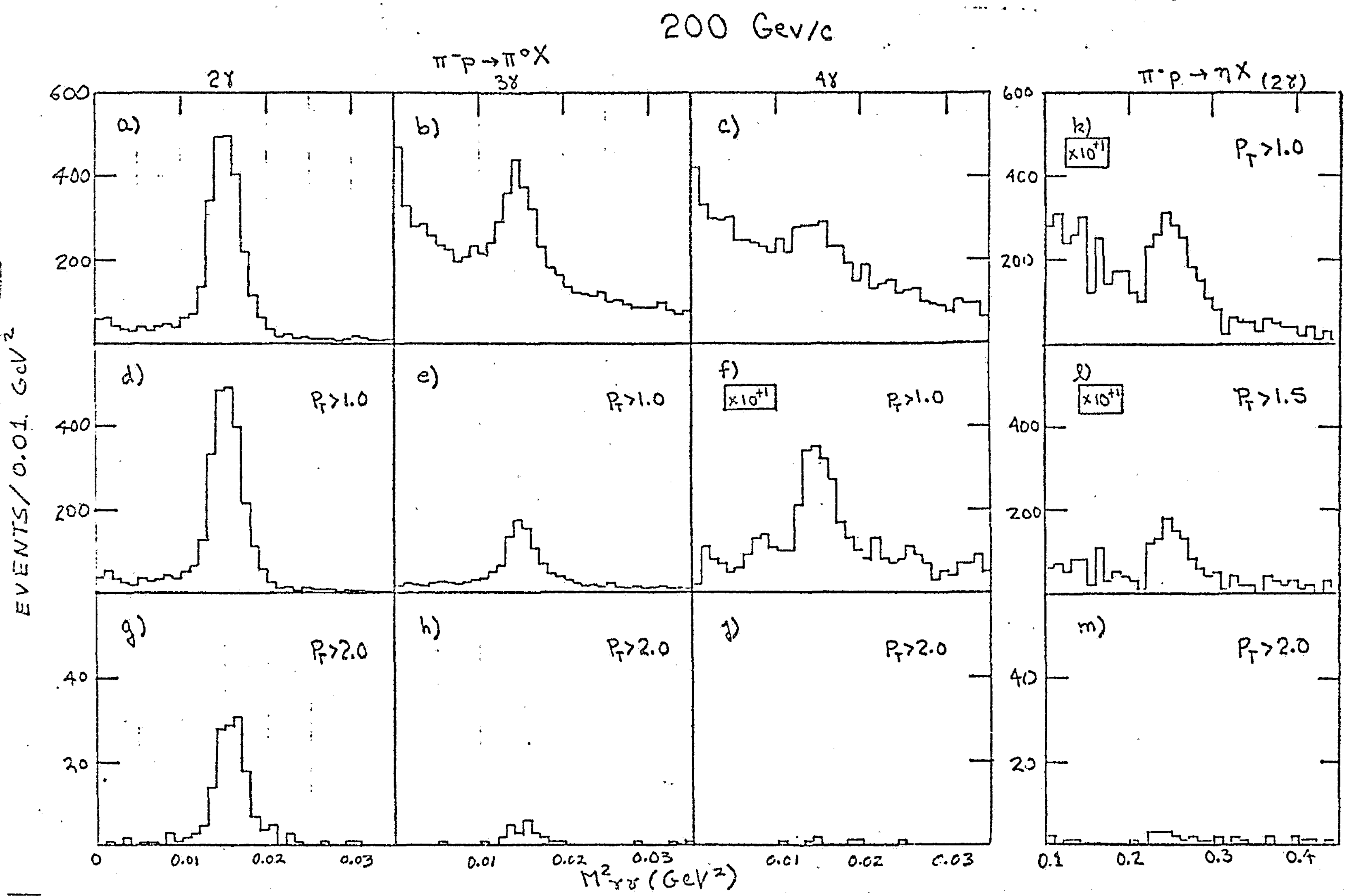

pp → π⁰ + X 300 GeV/c
pp → η + X 300 GeV/c
0.1
0.01
1×10⁻³
1×10⁻⁴
1×10⁻⁵
1×10⁻⁶
E d³σ/dp³ mb/GeV²
2.0
3.0
4.

Fig 7


200 Gev/c
π⁻p → π°X
2γ
3γ
4γ
π⁻p → ηX (2γ)
EVENTS/0.01 GeV²
a)
b)
c)
d)
e)
f)
g)
h)
j)
k)
l)
m)
×10⁺¹
P_T>1.0
P_T>1.5
P_T>2.0
M²γγ (GeV²)