

PROGRESS REPORT -- EXPERIMENTS 331/444

Mu-Pair Production by π^+ , π^- , and Protons in the
Chicago-Cyclotron Spectrometer

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I. INTRODUCTION

The data-taking phase of E-331 was concluded on 22 March 1976, after a test run in June 1975 and a 3 month run from December 1975 - March 1976. Since that time, we have been analyzing the data acquired, and have completed the analysis of the June 1975 data. The first results from last June (150 GeV/c π^+ -Be and p-Be Collisions) have been discussed at conferences¹ and published in Phys. Rev. Letters.² Preliminary results of the run just completed (225 GeV Collisions of π^+ , π^- , and protons with Carbon and Tin Targets) have been described at the Washington APS meeting³, and contributions have been sent to the Tbilisi conference. At this time 25% of the data have been analyzed, and some features are already emerging, as will be discussed below. The bulk of the primary analysis, which reconstructs all events, and catalogues the high-mass pairs and multi-muon events, should be completed by the end of June and reported at Tbilisi.

For the pairs with masses below ~ 1 GeV/c, additional analysis using Multi-wire Proportional Chambers in the beam and upstream of the hadron absorber to improve resolution, is underway and should be finished by the end of the summer.

II. PLANNING OF E-444

At present we are engaged in constructing the additional components of the apparatus needed to handle the higher intensities of E-444, and should be ready to run by the end of the year. Two new graduate students, Cathy Newman of Chicago, and Gary Hogan of Princeton, have joined our group to work on E-444.

The physics issues of E-444 have, if anything, become more exciting with the measurements of high-mass lepton-pairs by Columbia-FNAL (E-288) and Princeton-Chicago (300/325) groups, which are interpreted as parton-antiparton annihilations. In E-444, by comparing the continuum μ pairs from π^+ , π^- , and protons to a very high accuracy, one can find definitively whether fractionally charged partons are annihilating. We can also measure the parton structure functions of pions from the X and p_{\perp} distributions of the continuum events.

For the π^+/π^- comparison, E-444 will reach Fermilab's ultimate limit of precision. The spectrometer acceptance is as large as feasible and the beam intensity of 10^7 /sec is the highest at which Cherenkov counters can resolve π^+ from protons. Only an RF separated beam could obviate this.

We are very anxious to get started on this experiment, which also can search for new particles to a $\sim 10^{-37}$ cm²/event at $M \lesssim 15$ GeV. A new large hodoscope is being built to be placed downstream of the Chicago Cyclotron Magnet to suppress low-mass μ pairs to the level needed, and we are building a segmented target to increase the yield while maintaining

good mass resolution. A third beam Cherenkov has been built to join the two we provided for our last run. We are now negotiating our agreement with the Research Division and the Neutrino Department, and strongly request to be scheduled for installation soon after the end of the present muon period. The new targeting system in the muon decay pipe would suffice for setup and some data-taking with positive beam; the triplet train is required to provide $10^7 \pi^-$ /burst for the negative run.

III. PHYSICS RESULTS OF E-331

A. Production of New Particles

In Table I we summarize our exposure in the mass range above 1 GeV/c, listing as a figure of merit the expected number of J events obtained under various running conditions. Features of this data are discussed below.

1. J(3.1)

At 150 GeV, our published results for $p + \text{Be} \rightarrow J + X$ and $\pi^+ + \text{Be} \rightarrow J + X$ are shown in Fig. 1. One sees a significant difference in the distribution in Feynman - X between π^+ -induced and p-induced J's. The absolute total cross sections reflect a high production rate from π^+ collisions.

At 225 GeV/c, we have obtained so far (25% of the data on π^+ and p, most of the π^- data) the raw samples shown in Fig. 2. Comparing π^+ vs π^- induced J's, one sees very similar X-dependences (see Fig. 3). Comparing π vs p induced J's we find the p_{\perp} -distributions to be identical, the x-distribution of π -induced events again to be broader. The final π^+ and π^- samples will each contain more than 400 J events, the proton sample more than 2000.

The actual form of the p_{\perp} spectrum of J production has a large influence on the yield of direct single leptons when the p_{\perp} of the lepton becomes

larger than about 3 GeV/c. For the sample of 225 GeV/c p-induced J events analyzed so far it begins to appear (see Fig. 4) that the parametrization

$$\frac{1}{p_{\perp}} \frac{d\sigma}{dp_{\perp}} \propto e^{-bp_{\perp}^2}, \text{ with } b \sim 0.70 \text{ GeV}^{-2}$$

is superior to the form often used up to now, viz.

$$\frac{1}{p_{\perp}} \frac{d\sigma}{dp_{\perp}} \propto e^{-cp_{\perp}}, \text{ with } c = 1.7 \text{ GeV}^{-1}.$$

The full sample will show conclusively which of these, if either, is the best description.

2. $\psi(3.7)$

Intriguingly this particle seems to be produced by π^{-} and π^{+} beams, but is not as yet evident in the proton-induced sample. (See Fig. 2)

3. Vector Meson Production (ρ , ω , ϕ)

To improve resolution, at low masses, we have used MWPC planes upstream of the absorber and halfway through it. Only the data from the June run at 150 GeV/c has been analyzed including information from these planes. The 225 GeV/c analysis is in progress. A mass spectrum is shown in Fig. 5. The ϕ is clearly resolved; the peak at 750 MeV/c is narrower than what would come from $\rho \rightarrow \mu\mu$ alone, so a comparable ω contribution must be present. The differential cross-sections for ρ , ω , and ϕ have been obtained as functions of x and p_{\perp} , satisfying the forms $\frac{1}{p_{\perp}} \frac{d\sigma}{dp_{\perp} dx} = A(1-x)^b e^{-cp_{\perp}}$, for example, (Fig. 6). The total cross-sections obtained are shown in Table 2. These results are just being submitted for publication. Greatly improved statistics for ρ , ω , ϕ production have been obtained in the 225 GeV/c run, as well as a sample of π^{-} induced events. The spectrometer acceptance is much larger at low x_F at 225 GeV, and more uniform than at 150 GeV.

IV. STUDY OF NON-RESONANT μ -PAIRS

A. $1.8 < M_{\mu\mu} < 2.6$ GeV

In the mass range 1.8 GeV/c - 2.6 GeV/c, where there are no known resonant sources of μ -pairs, we have accumulated sufficient events to compare the π^+ vs π^- production cross sections to about 10%. Models of parton-antiparton annihilation as the source of these pairs would predict

$$\frac{\sigma(\pi^+ C \rightarrow \mu\mu + X)}{\sigma(\pi^- C \rightarrow \mu\mu + X)} = 1.6$$

in this mass range. The p_{\perp} and X distributions of the continuum are also very useful in constraining such models. This measurement will be greatly improved in E-444.

B. $M \lesssim 0.6$ GeV

Below the ρ - ω peak of Fig. 5, there is a substantial continuum, which persists down to the threshold of $M = 2 M_{\mu}$. We are still estimating the fraction of these events coming from secondary processes (Bethe Heitler, ρ production in the absorber which is misidentified as originating in the target etc.), to see if there remains significant primary production.

V. CONTRIBUTION OF μ -PAIRS TO THE DIRECT SINGLE LEPTON CROSS-SECTION

Within the kinematical limits of our μ -pair measurements ($0 < p_{\perp} \lesssim 4$) GeV/c, ($M_{\mu\mu}$ from threshold up to and including the J(3.1)) we can obtain the inclusive single lepton cross-section originating from μ -pairs.

A complete survey has been carried out over a wide range of x and p_{\perp} of the single muon where we have actually measured the cross-sections of all significant parent μ -pairs. The results are being submitted for publication.

VI. MULTI-MUON EVENTS

So far we have analyzed only the multi-muon events from last June, where the sample was very small. Only one high-mass event was seen, where a J was accompanied by a low p_{\perp} muon. With the new sample, we shall be able to say, to a cross section limit of better than 10^{-35} cm², (.1% of J production) whether interesting 3 or 4 μ events are produced. This analysis will be reported at Tbilisi for most of our 225 GeV sample.

REFERENCES

1. J. E. Pilcher, 1975 Lepton-Photon Conference, Stanford Univ., August 1975, p. 207.
A. J. S. Smith, in Particles and Fields, H. J. Lubatti, P. M. Mockett, Editors, Univ. of Washington, Seattle 1975, p. 169.
K. T. McDonald, Invited Paper, New York APS Meeting 1976.
G. H. Sanders, Vanderbilt Conference, March 1976.
2. K. J. Anderson et.al., Phys. Rev. Letters 36, 237 (1976).
3. G. G. Henry et.al.; K. J. Anderson et.al.; J. G. Branson et.al.; K. T. McDonald et.al.; Bull Am. Phys. Soc. II 21, 567 (1976).

TABLE I

SUMMARY OF DATA ACQUIRED IN E-331

A. ALL DATA (Number of J(3.1) Events Is Used To Indicate Sensitivity)

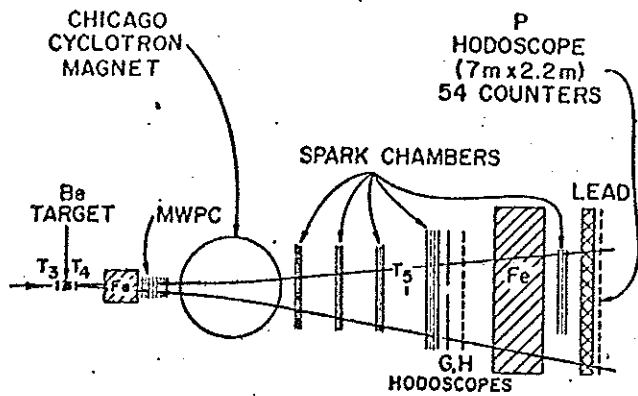
Run	P _{BEAM} (GeV/c)	Target	Number of J/ψ		
			π ⁺ Induced	π ⁻ Induced	p - Induced
June 1975	150	Be	63	-	67
Winter 75-76	225	C	600	350	1200
	225	Sn	100	-	300

B. DATA WITH FORWARD CHAMBERS ACTIVE

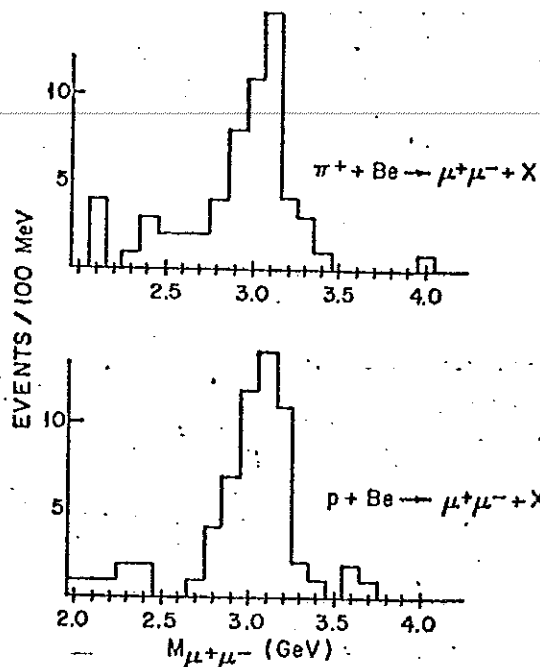
(For Better Resolution To Study Masses < 1.5 GeV)

The number of $\rho + \omega$ events is shown for each running condition.

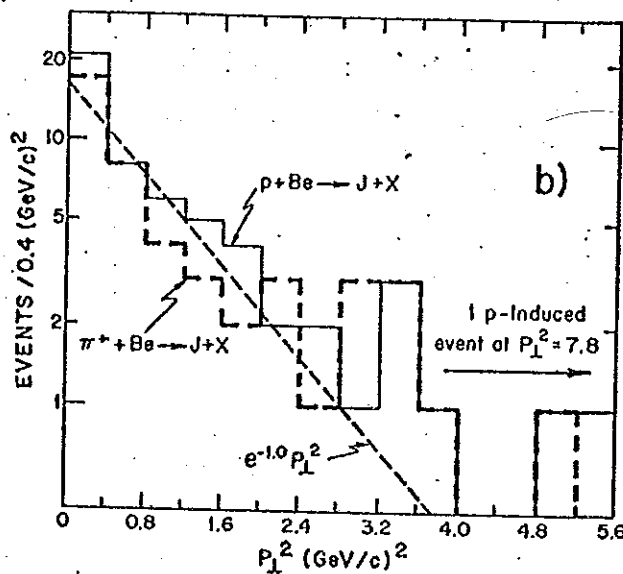
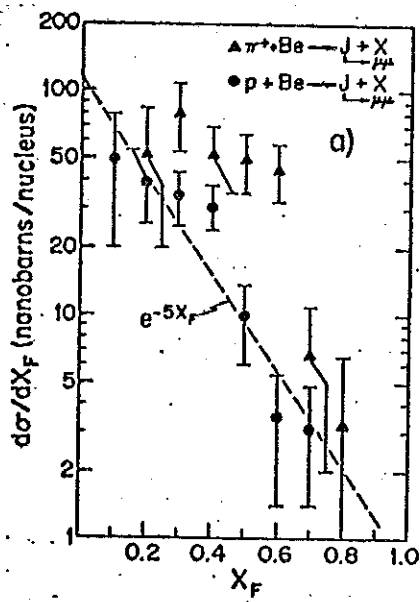
June 1975	150	Be	600	-	1200
Winter 75-76	225	C	3000	6000	6000



The spectrometer.



Mass spectra, uncorrected for spectrometer acceptance.



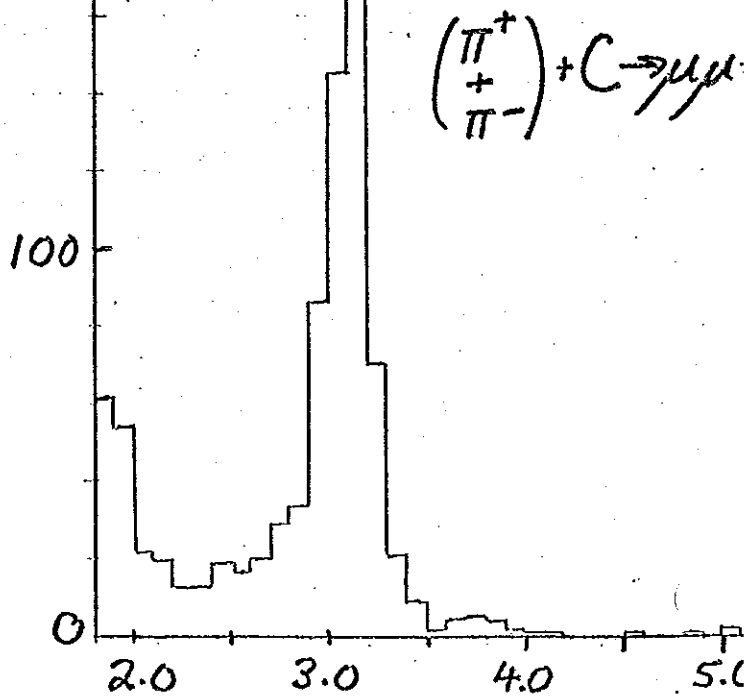
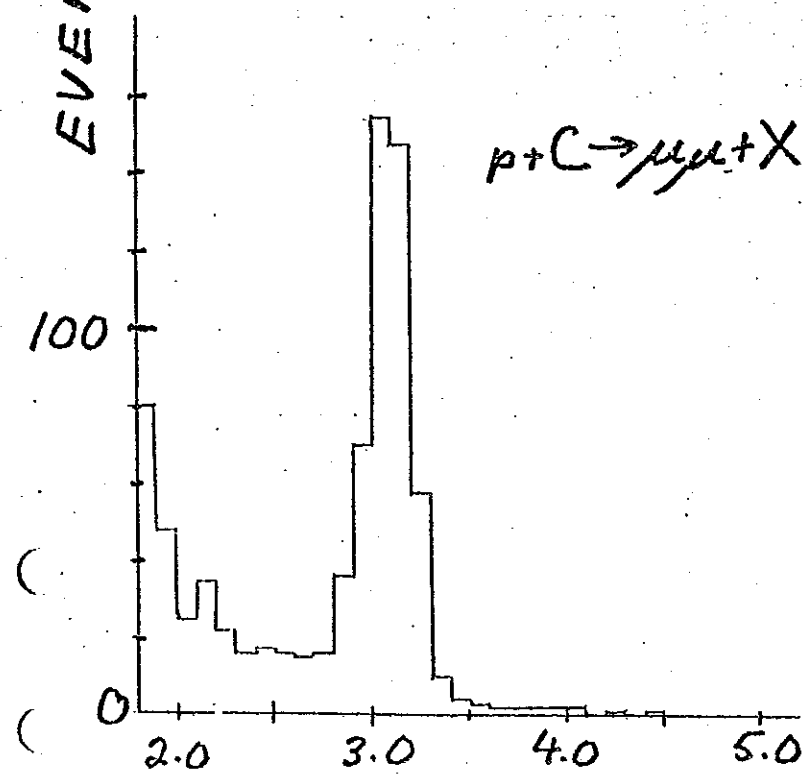
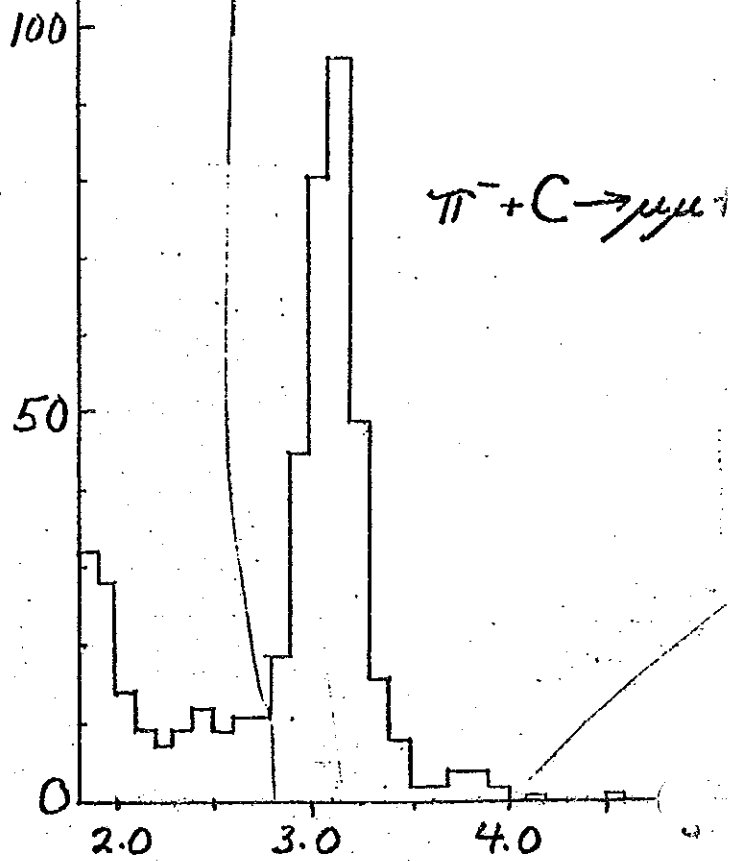
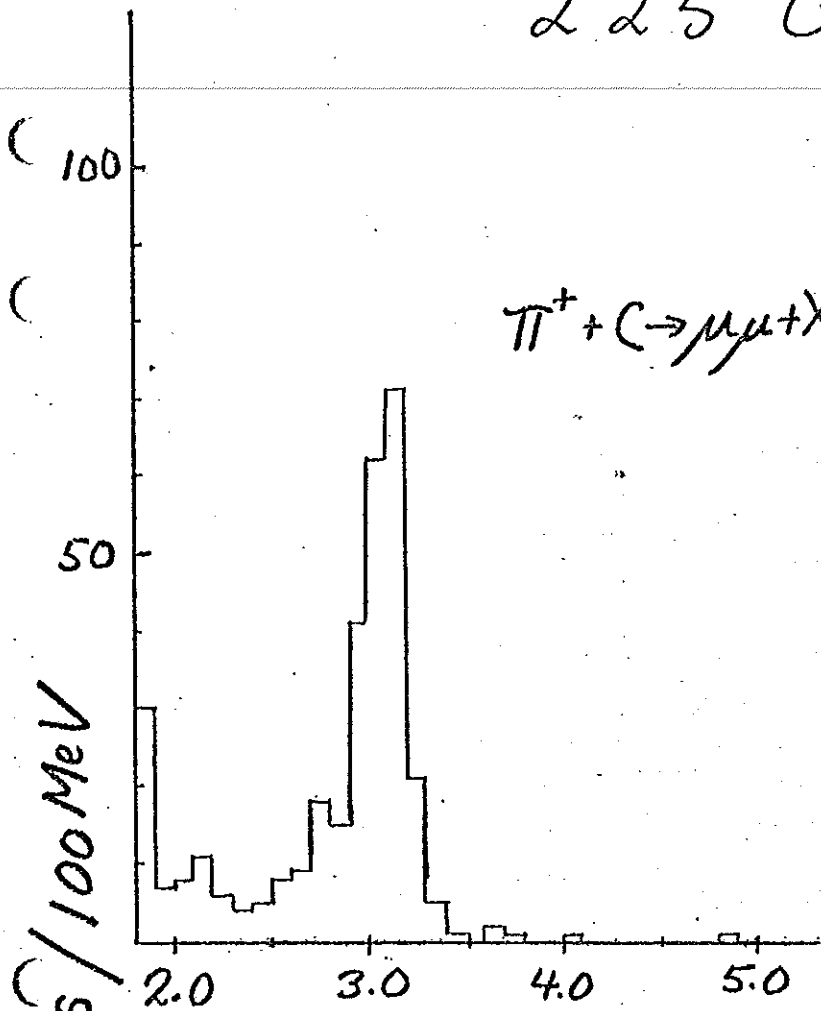
(a) Cross sections for J production by π^+ and protons. (b) Relative distributions in p_{\perp}^2 for J production, uncorrected for acceptance. [The acceptance is uniform in p_{\perp}^2 to within $\pm 10\%$ out to p_{\perp}^2 of 3 (GeV/c) 2 .]

Absolute cross sections for μ -pair production at 150 GeV/c incident momentum. Upper limits are for 90% confidence. Statistical and systematic errors are included.

Charge state	Mass range (GeV/c 2)	Range of x_F	$\sigma(p + Be \rightarrow \mu^+ \mu^- + X)$		$\sigma(\pi^+ + Be \rightarrow \mu^+ \mu^- + X)$	
			(nb/nucleus)	(nb/nucleon)	(nb/nucleus)	(nb/nucleon)
+-	2.0-2.6	0.05-1.0	2.4 ± 0.9	0.27 ± 0.10	11 ± 4	1.3 ± 0.5
+- (J)	2.6-3.5	0.05-1.0	17 ± 4	1.9 ± 0.4	29 ± 6	3.2 ± 0.7
+-	3.5-4.1	0.20-1.0	1.0 ± 0.6	0.11 ± 0.07	< 4.0	< 0.44
++	2.0-4.1	0.20-1.0	< 1.3	< 0.15	< 2.4	< 0.27
--	2.0-4.1	0.20-1.0	< 0.75	< 0.08	< 2.4	< 0.27
++, +-, --	4.1-10	0.4-0.6	< 0.84	< 0.09	< 2.8	< 0.31

FIGURE 1. FIRST RESULTS, JUNE '75 TEST RUN

225 GeV



$M_{\mu\mu}$ (GeV)

FIGURE 2

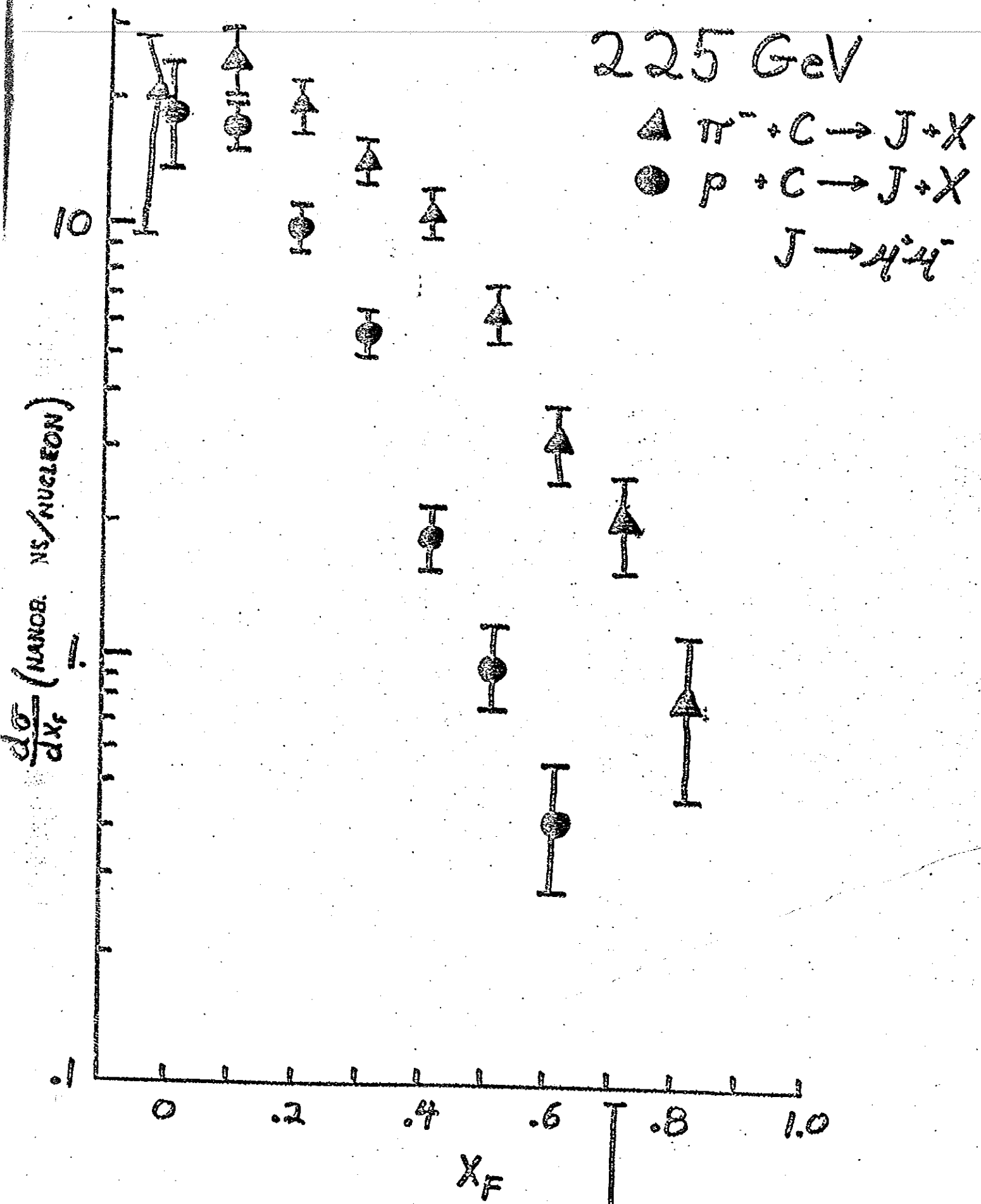


FIGURE 3

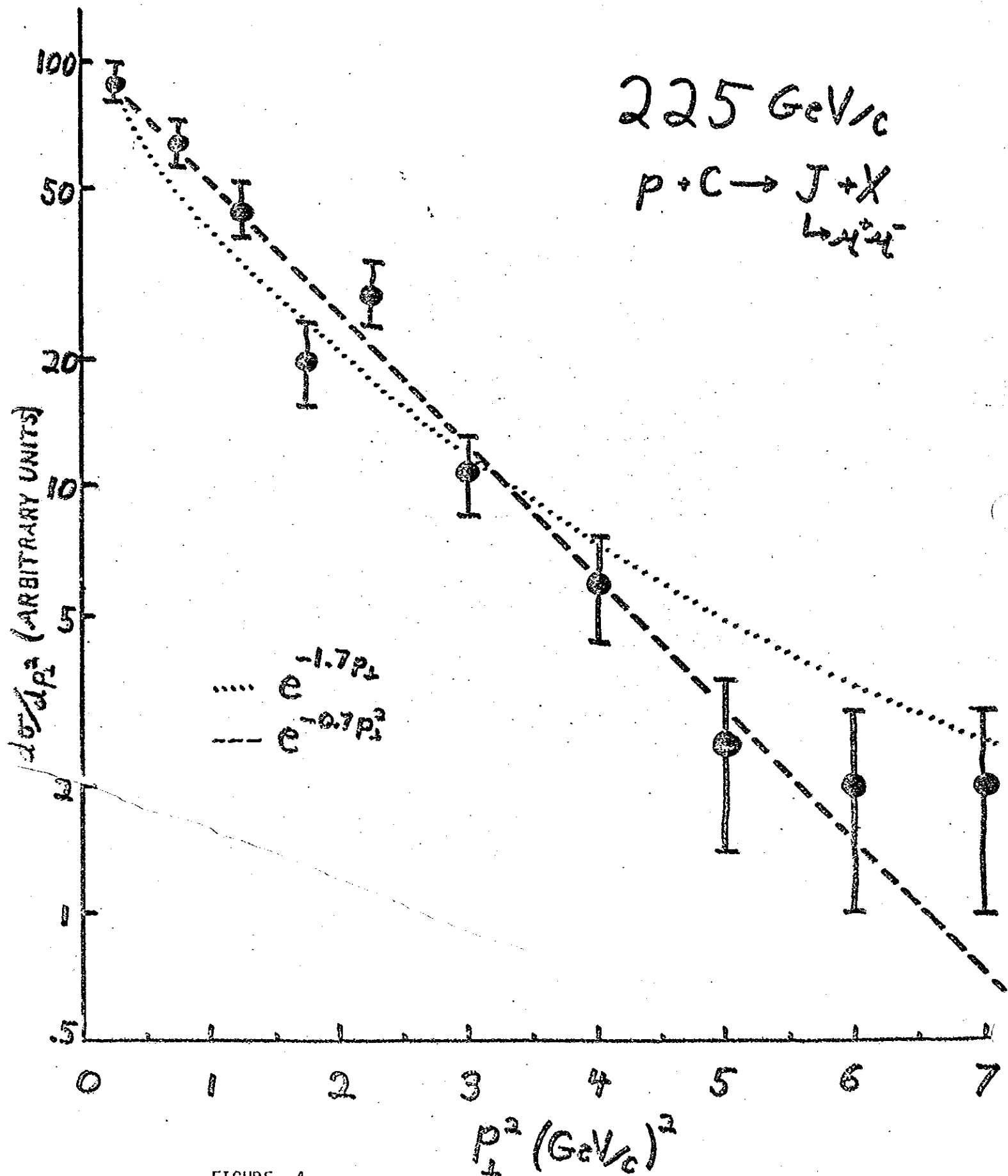


FIGURE 4

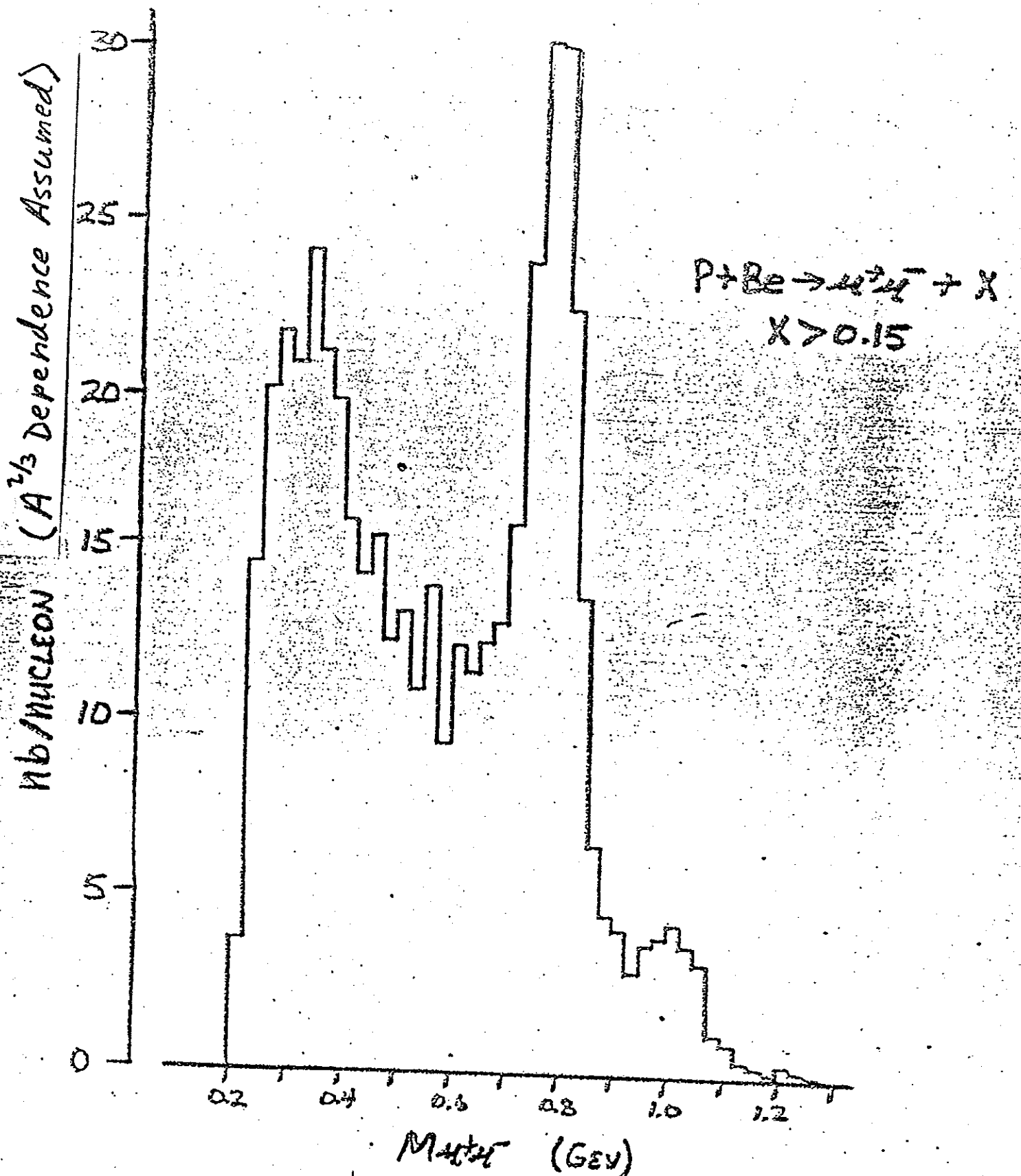


FIGURE 5

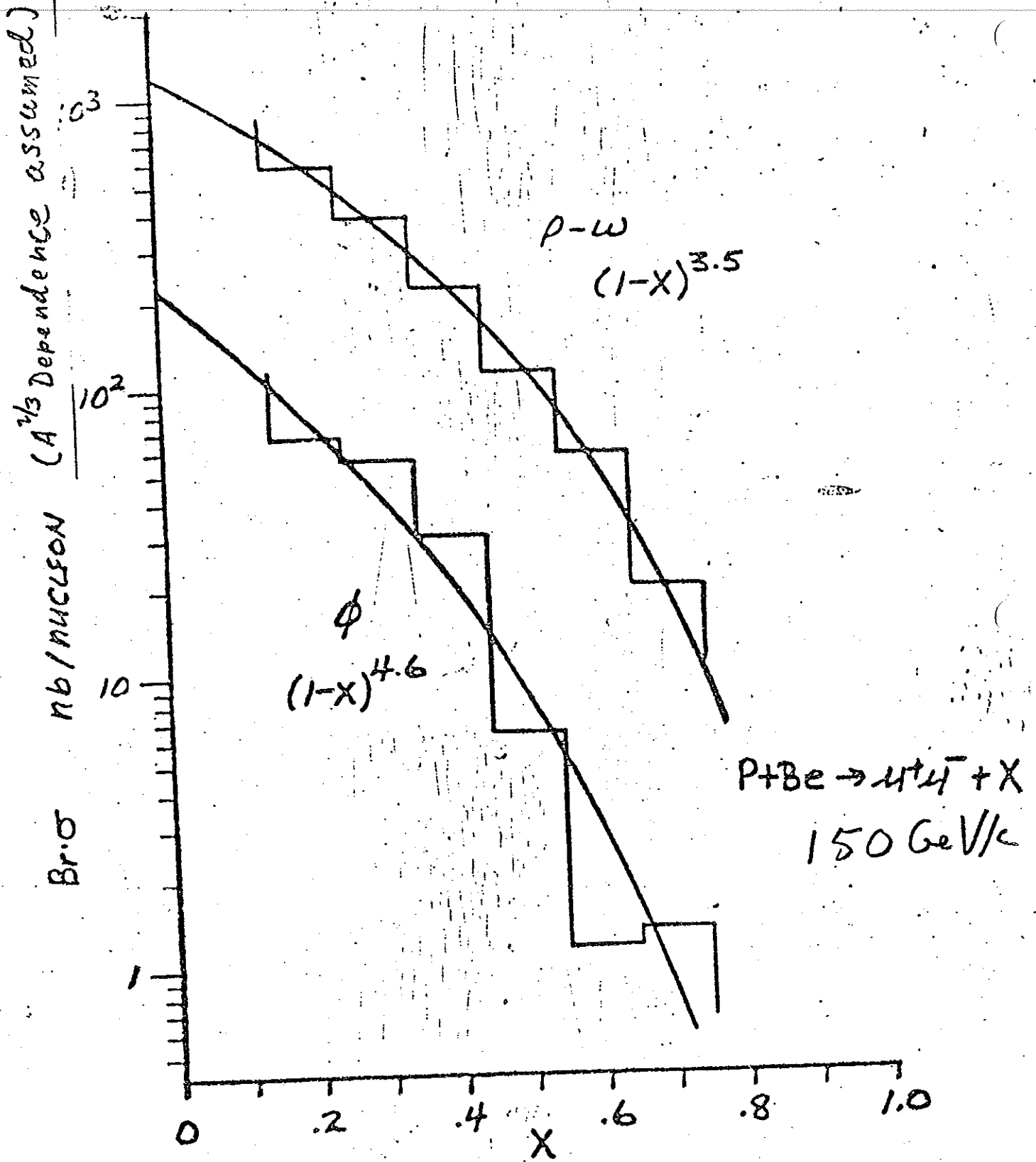


FIGURE 6a

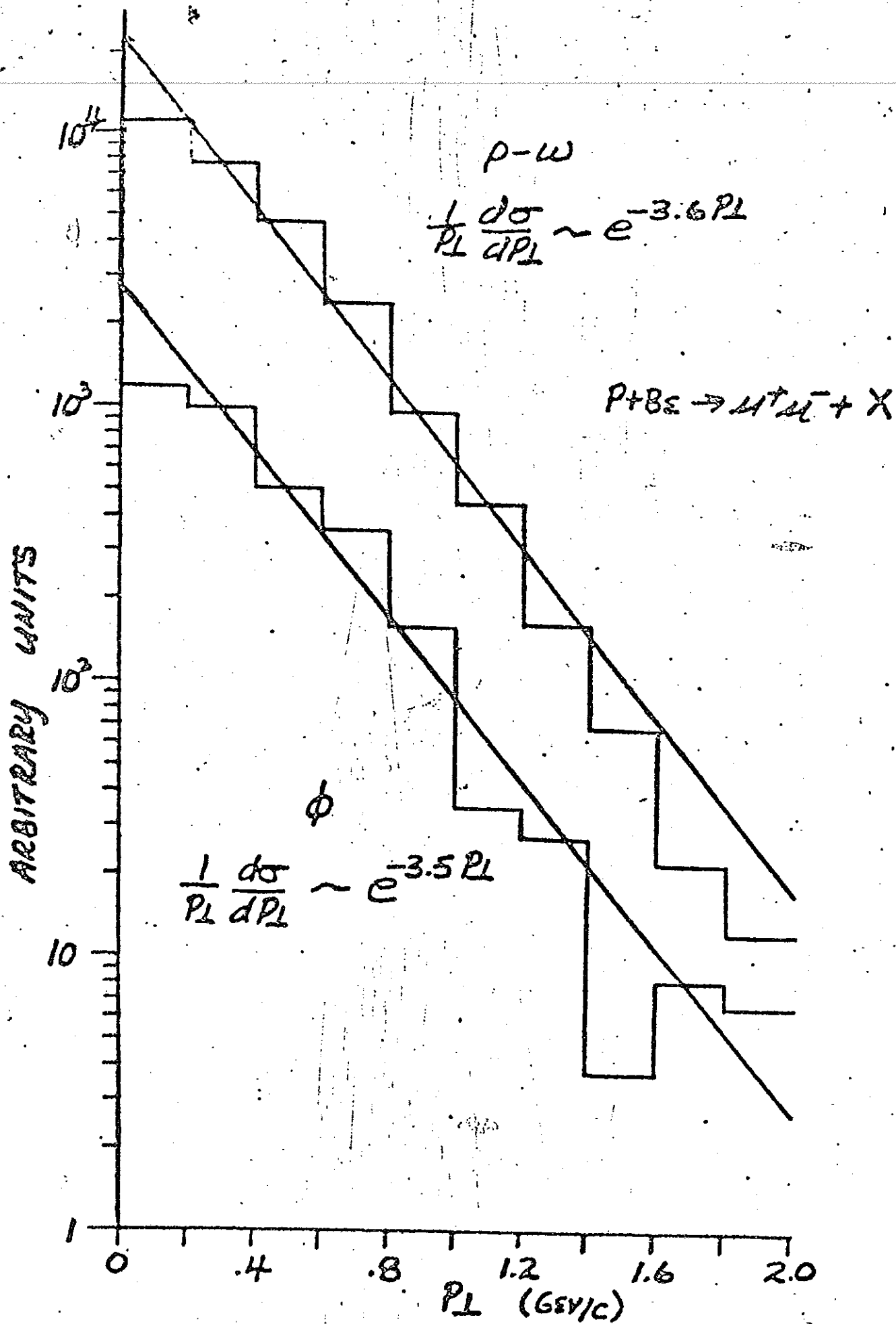


FIGURE 6b

