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BY

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Features of Diffraction Dissociation of Neutrons in np Collisions at Fermilab Energies[§]

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We present preliminary results from an investigation of the reaction $n+p \rightarrow (p\pi^-)+p$ for neutron momenta in the range of 50 GeV/c to 300 GeV/c. The data display a strong correlation between the mass of the $p\pi^-$ system and the four-momentum transferred in the production. Cross sections for producing low-mass $(p\pi^-)$ systems are independent of energy to within 10% accuracy.

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We have measured the dissociation of neutrons into ($p\pi^-$) systems using a variety of nuclear targets ranging from hydrogen to uranium. The data are from an experiment performed in the 1 mrad M-3 neutral-beam line of the Fermi National Accelerator Laboratory. In this letter we will discuss the properties of the dissociation process as observed using a hydrogen target. We report, in particular, on the reaction:

$$n + p \rightarrow (p\pi^-) + p \qquad (1)$$

for neutron momenta between 50 GeV/c and 300 GeV/c.[1]

A schematic diagram of the apparatus is given in Fig. 1a. The hydrogen target consists of a cylindrical high-pressure vessel. (Data was taken at operating gas pressures of 750 psi and 1250 psi.) The active target region is 20 inches in length and 3.5 inches in diameter; it is defined by a thin veto counter (A_1) at the upstream end, by a downstream counter (S), and by a set of sixteen plastic scintillator strips, each 20 inches long, 1/4 inch thick and 11/16 inch wide, positioned azimuthally about the active region at a distance of 1-3/4 inches from the beam axis. (See Fig. 1b.) All of the scintillators are contained within the high pressure volume and are connected optically through acrylic light pipes to photomultiplier tubes located outside of the high-pressure vessel.[2] Photomultiplier signals from both ends of each of the sixteen azimuthal scintillator strips are pulse-height analyzed, and this information is used off line to calculate the spatial location of the interaction vertex point, as well as to obtain a measure of the energy of the recoil proton in reaction (1).

A total of 30 spark chamber planes, read out magnetostrictively at both ends of each of the planes, provided substantial redundancy checks for background rejection; the effective spatial resolution of the chambers was ±0.3 mm.

Trigger requirements were designed to strongly favor reaction (1) and to suppress multiparticle production processes. The trigger was satisfied under the following conditions: (1) no charged particle entered the target region (A_1 counter), (2) only one of the sixteen azimuthal scintillation counters surrounding the target region had a signal, (3) at least one charged particle emerged from the sensitive region of the hydrogen target, activating the S counter, (4) no charged (or converted neutral) particle was detected in any of the lead/scintillator sandwich veto counters which were located downstream of the target, and positioned so as to shadow the magnet aperture, and (5) two of the six H1-hodoscope elements immediately downstream of the magnet were activated.

A typical run consisted of 20,000 triggers taken over an eight-hour period. Periodic runs were also taken with an empty target. A PDP-15 DEC computer was used to monitor the performance of the apparatus and to transfer data to magnetic tape for off-line analysis. A total of ~400,000 triggers were collected in the experiment; the data from about half of these will be presented in this report.

Spatial reconstruction, performed off line, provided vector-momentum information for the two charged tracks of the ($p\pi^-$) "V" entering the magnet aperture. Over 80% of all triggers yielded acceptable reconstructed V's. The distribution in the azimuthal angle between the reconstructed momentum vector of the V and the center of the activated scintillation counter around the target region (that signal being generated by the recoiling proton) is displayed in Fig. 1c. The distribution in Φ is observed to peak at 180°, indicating the presence of a substantial signal for reaction (1). The peak has the expected width of ~22.5° (the angle subtended by an azimuthal target counter) and a signal to background ratio of ~5/1. In the data to be presented we have imposed a cut-off band on Φ centered at 180° (i.e., 180±15°). To correct for contamination[3] of our $pp\pi^-$ final state, we have subtracted from the data in the signal band of $165°<\Phi<195°$ (45,000 events, or ~¼ of the reconstructed V's) the data in the sum of the background bands: $195°<\Phi<210°$ and $150°<\Phi<165°$ (8,000 events). A small subtraction (~2%) for target-empty was also applied to the data. Additional background suppression of the $n\pi^+\pi^-p$ final state was provided through the rejection of events which contained neutral-particle-initiated large pulse heights in the neutron calorimeter, located downstream of the apparatus. The calorimeter subtended an angle of ±1 mrad in both horizontal and vertical directions.

The acceptance of the apparatus for $p\pi^-$ masses (M) below 2 GeV was a smooth function of all dynamic variables; typically the efficiency was ~70%, being limited mainly by the 8-inch vertical aperture of the magnet. (The horizontal aperture was 24 inches.) The magnet provided a transverse bend of 1 GeV/c.

Figure 2 displays the mass distributions for the momentum analyzed $(p\pi^-)$ V's satisfying the acceptance criteria of reaction (1). The data are presented as a function of the square of the four-momentum transfer (t) between the incident neutron and the produced $(p\pi^-)$ V. (The experiment is not sensitive for $|t| < 0.02\ GeV^2$. This is because at such small momentum transfers the recoil proton does not have sufficient momentum (~120 MeV/c) to emerge from the central target region and activate one of the azimuthal counters as required to satisfy the trigger.) Corrections have been made for geometrical losses using a Monte Carlo program. (The efficiency for M<1.55 GeV is large and consequently we believe that the corrections at low mass are reliable; the results for

$M \gtrsim 1.55$ GeV, although qualitatively correct, may change in detail with subsequent analysis.) The mass spectra are observed to have structure near 1.5 GeV and 1.68 GeV, particularly at the larger values of t. Because our experimental mass resolution is $\lesssim 15$ MeV (standard deviation), the absence of narrow peaks suggests that the mass spectrum consists of an overlap of intrinsically broad states.

Distributions in t for various regions of $(p\pi^-)$ mass are given in Fig. 3. The rapid variation of the t-distributions with mass, a characteristic of diffraction-production phenomena, is clearly evident in the data.[4] It is interesting that all the t-spectra appear to be consistent with an exp (4.5 t) dependence for $|t| \gtrsim 0.4$ GeV^2. Table I presents the results of a simple exponential parameterization of the t-spectrum as a function of the $(p\pi^-)$ mass. The dependence of the slope parameter on mass is similar to that observed at lower energies.[4]

Finally, in Fig. 4 we present the energy dependence observed for reaction (1) for the production of small $(p\pi^-)$ masses. (The data have been integrated over $.02 < |t| < 1.00$ GeV^2.) The neutron momentum spectrum required for the calculation of the energy dependence was extracted from our results for production of $(p\pi^-)$ systems in the nuclear Coulomb field of lead.[5]
It has been suggested that the cross section for processes such as reaction (1) falls with increasing energy as $s^{-0.4}$;[6] our data for $1.25 < M < 1.45$ GeV are essentially energy independent and consequently do not support such a strong s-dependence for the cross section. Despite this observed lack of energy dependence we point out that our cross sections are nevertheless approximately a factor of 1.5-2.0 smaller than those previously measured in the 10-30 GeV/c momentum band.[6]

To summarize our findings, we have measured with excellent mass and t resolution the dependence of the slope of the t distribution on mass for neutron dissociation into the two-body $p\pi^-$ final state. At small t we observe a variation of the slope parameter with the mass of the $p\pi^-$ system similar to that found at lower energies. Fine structure is observed in the $p\pi^-$ mass distribution, particularly at large t values. These general features of the data have been interpreted previously in terms of the dominance of low spin s-channel helicity non-flip production amplitudes at small ($p\pi^-$) mass, and the emergence of higher spin helicity-flip terms for larger mass values.(7) The pertinence of such arguments will be discussed in the following letter.

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References

1. The properties of the neutral beam have been discussed previously by M. Longo et al, University of Michigan Report UM HE 74-18 (1974). The neutron spectrum has an average momentum of ~200 GeV/c, with a peak value at ~240 GeV/c.

2. A report describing the design and performance of the target assembly is in preparation.

3. We believe that the main source of background is from neutron dissociation into $p\pi^-\pi^0$ systems. We expect this background to be at a level of ~10% for the $p\pi^-$ signal.

4. See the summary of J. Rushbrooke in Proc. of III Intl. Conf. on Multiplarticle Dynamics, Zakopane (1972). A. Bialas et al, eds.

5. See T. Ferbel in Proc. of the Intl. School of Subnuclear Physics - Erice (1975), A. Zichichi, ed. The neutron momentum spectrum extracted from our Pb data is consistent with the results given in Ref. 1.

6. E. Nagy et al, Contribution to the XVII International Conference on High Energy Physics, London (1974). The relevant information from the ISR is contained in the report of A. Diddens which appears in the Proceedings, J. R. Smith ed. For data at low energies see J. Hanlon et al, Vanderbilt Report VAND-HEP 74(2) (1974).

7. For a discussion of these class of models see G. Kane, Acta Phys. Pol <u>B3</u>, 845 (1972).

Table I

Slope of the t distribution as a function of mass

Mass Interval (GeV)	Slope[a] (GeV^{-2})
< 1.25	19.1 ± 0.9
1.25 - 1.35	15.0 ± 0.7
1.35 - 1.45	12.8 ± 0.6
1.45 - 1.55	6.8 ± 0.7
1.55 - 1.65	4.9 ± 0.6
1.65 - 1.75	4.2 ± 0.6
1.75 - 2.00	4.2 ± 0.8

(a) Value of the parameter b from a fit of the data to the form exp(bt). The range of |t| in the fit was 0.04 to 0.16 GeV^2 for the first four mass bands and .04 to 0.5 GeV^2 for the last three mass regions.

Figure Captions

1. (a) Overall sketch of the apparatus.

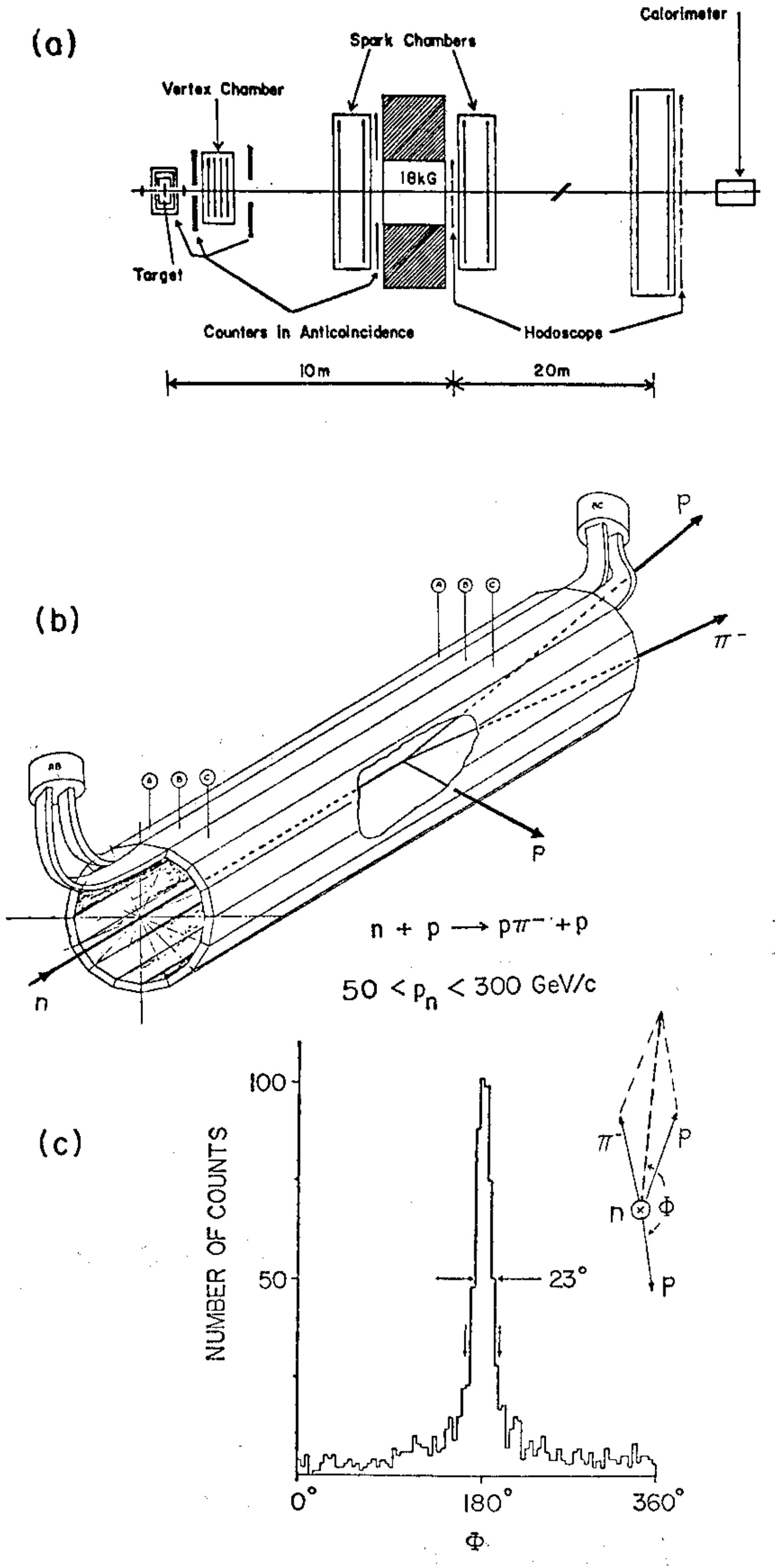
   (b) Schematic drawing of the 16 scintillator elements which are located azimuthally about the interaction region.

   (c) The distribution in the azimuth between the reconstructed vector momentum of the $(p\pi^-)$ V and the center of the azimuthal counter activating the trigger.

2. Mass spectra of $p\pi^-$ pairs, integrated over a 50-300 GeV/c neutron momentum band, displayed as a function of t. (a), (b) and (c) correspond to $|t|$-bands of 0.02-0.08, 0.08-0.20 and 0.20-1.00 GeV^2, respectively.

3. Distributions in $|t|$ for seven mass bands of the $p\pi^-$ system: <1.25, 1.25-1.35, 1.35-1.45, 1.45-1.55, 1.55-1.65, 1.65-1.75, and 1.75-2.0 GeV.

4. Energy dependence of the cross section for reaction (1) for two low-mass intervals. Data are shown integrated over $0.02 < |t| < 1.0 GeV^2$. The absolute normalization is uncertain by about ±20%.



(a)
Calorimeter
Spark Chambers
Vertex Chamber
18kG
Target
Counters in Anticoincidence
Hodoscope
10m
20m
(b)
p
π⁻
p
n
n + p ⟶ pπ⁻ + p
50 < p_n < 300 GeV/c
(c)
NUMBER OF COUNTS
100
50
23°
0°
180°
360°
Φ
π⁻
p
n
Φ
p

Fig 1

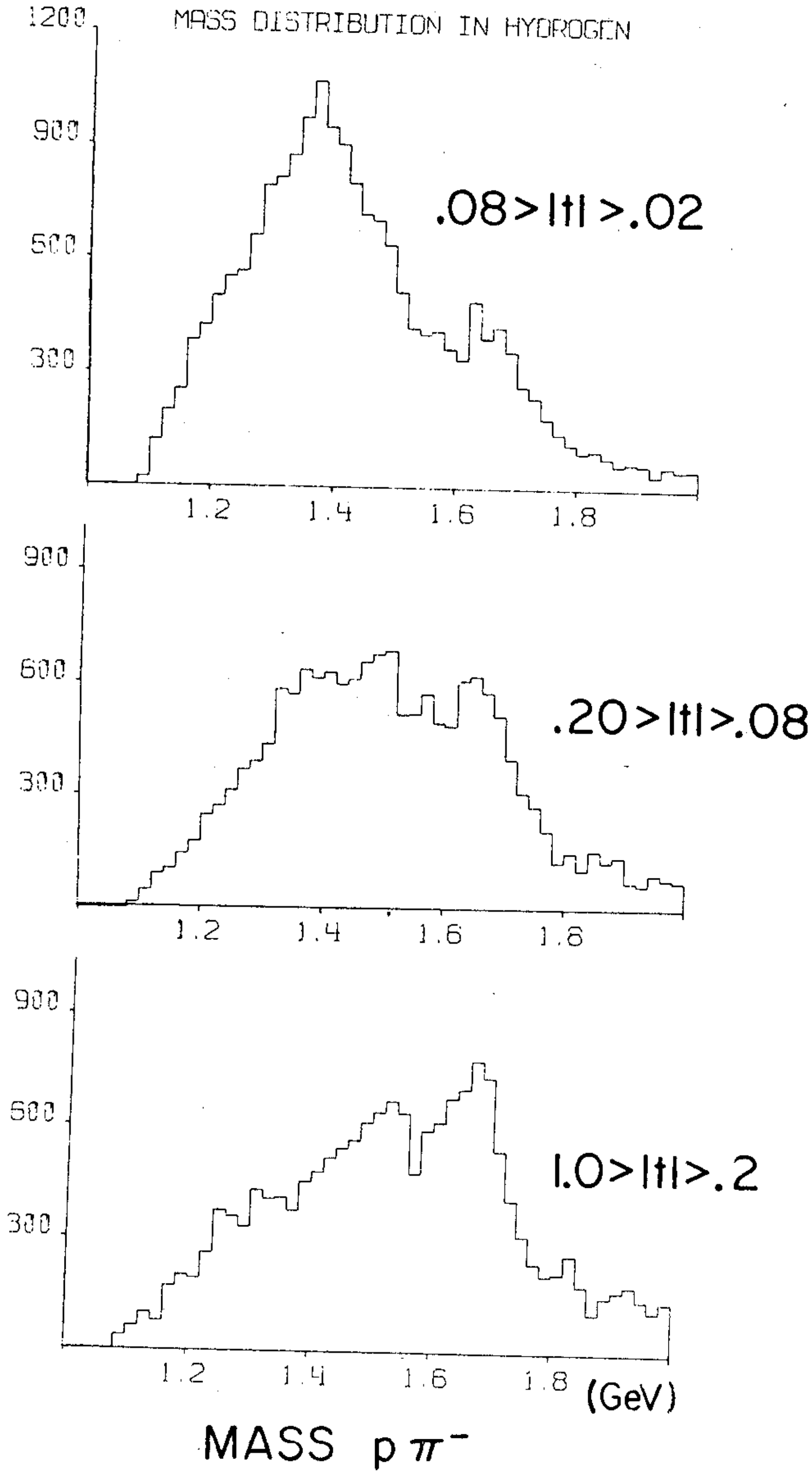
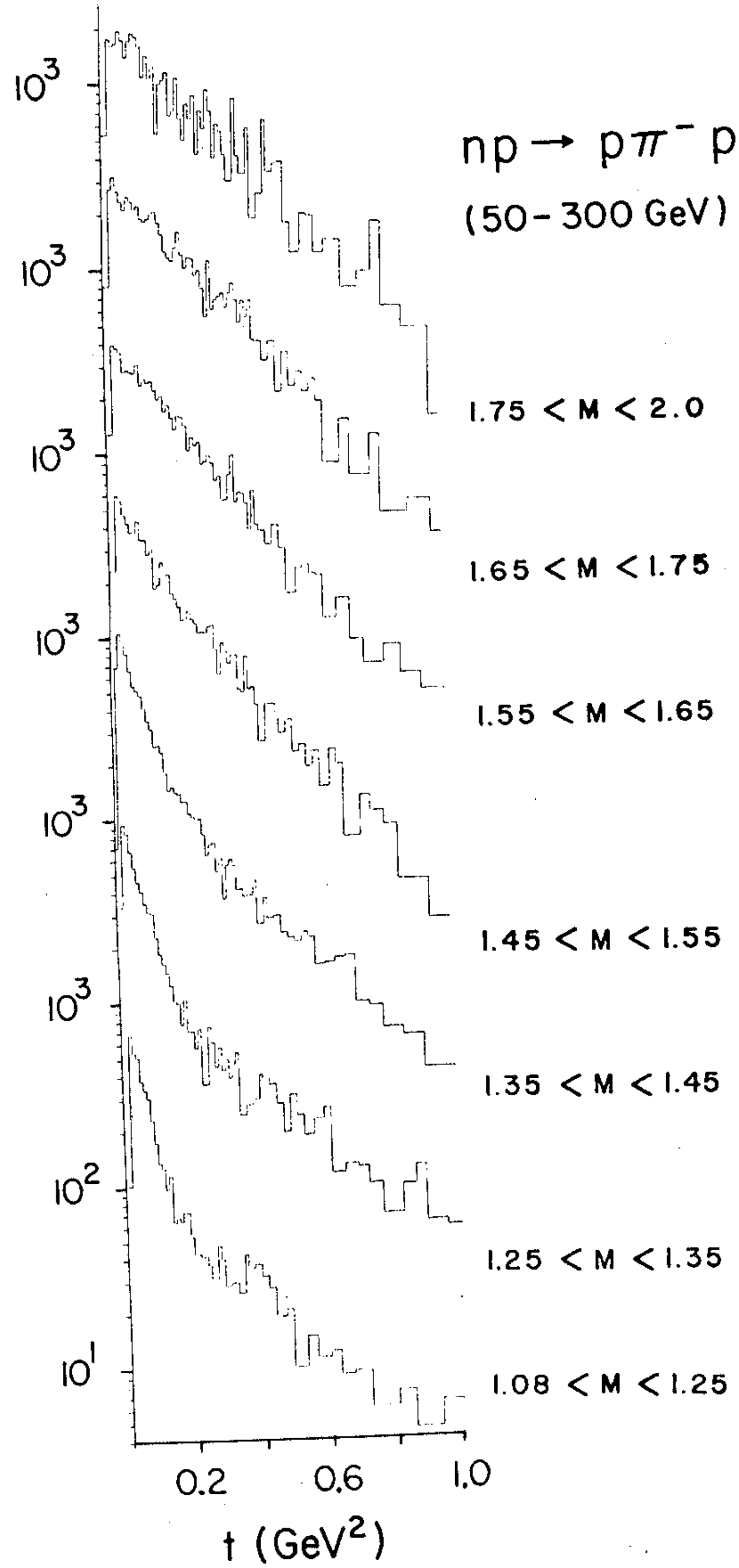
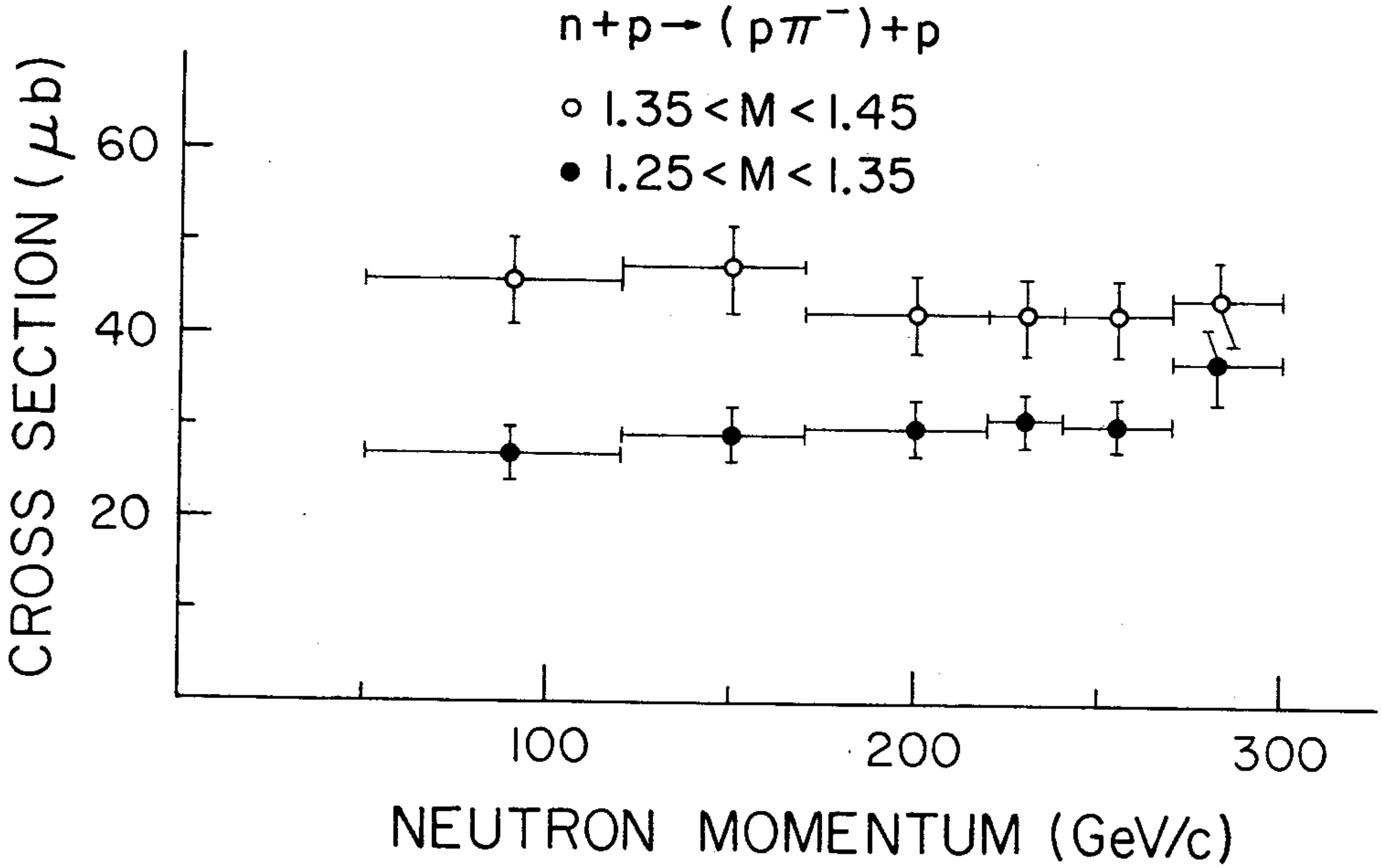

MASS DISTRIBUTION IN HYDROGEN
1200
900
600
300
.08>|t|>.02
1.2
1.4
1.6
1.8
900
600
300
.20>|t|>.08
1.2
1.4
1.6
1.8
900
600
300
1.0>|t|>.2
1.2
1.4
1.6
1.8
(GeV)
MASS pπ⁻

Fig 2



np → pπ⁻ p
(50-300 GeV)
10³
10³
10³
10³
10³
10³
10²
10¹
1.75 < M < 2.0
1.65 < M < 1.75
1.55 < M < 1.65
1.45 < M < 1.55
1.35 < M < 1.45
1.25 < M < 1.35
1.08 < M < 1.25
0.2
0.6
1.0
t (GeV²)

Fig 3



n+p→(pπ⁻)+p
○ 1.35<M<1.45
● 1.25<M<1.35
CROSS SECTION (μb)
60
40
20
100
200
300
NEUTRON MOMENTUM (GeV/c)

Fig 4

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