FERMILAB PROPOSAL No. 303

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NAL 15 Foot Hydrogen Bubble Chamber Proposal
Diffraction Dissociation of Neutrons on Hydrogen

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Summary of Proposal:

10^5 photographs of the 15 foot bubble chamber exposed to a proposed neutron beam using a primary 300 GeV/c proton beam.

Spokesman: J. Vander Velde (Until August, 1974 please contact A. Seidl in reference to this proposal).

ABSTRACT

We propose to measure the s and t dependence and decay angular distributions of certain exclusive final states produced in np interactions. The principal reactions of interest are $np \rightarrow p\pi^- p$ and $np \rightarrow p\pi^-\pi^+\pi^- p$. These reactions, which are principal contributors to diffractive dissociation of the nucleon, will be studied from ~50 to ~250 GeV/c, assuming a 300 GeV/c primary proton beam. The bubble chamber is particularly well suited to study certain quantities of theoretical interest such as the low t behavior and decay angular distributions of the diffractively produced system. The long path length available in the 15 foot bubble chamber is particularly advantageous both for obtaining high statistics and for measuring the momentum of high momentum particles. We request a 100,000 picture exposure of the 15 foot bubble chamber with $\sim 2 \times 10^4$ protons on a production target (see sections II and III). This would yield ~250,000 inelastic interactions, ~2400 $np \rightarrow p\pi^- p$ events, and ~4000 $np \rightarrow p\pi^-\pi^+\pi^- p$ events in an 8 foot fiducial volume.

I. Physics Justification

Several counter and bubble chamber experiments at NAL and at the ISR have given evidence for a diffractive inelastic component in pp and πp interactions. This phenomenom, presumedly connected with similar observations at lower energies, is loosely referred to as diffraction dissociation. It contributes approximately 15% of the total cross section at high energies and is confined primarily to events with low charged multiplicities. (1,2). The separation of the diffractive peak is more easily done at the higher energies but, in spite of this, the experimental and theoretical details of its nature remain largely uncertain after the "first round" high energy experiments. It is clear that more and different kinds of experiments are needed before much more theoretical progress can be made.

We plan to study the <u>details of a particular set of final states</u> which contribute to neutron diffraction dissociation on hydrogen.

$np \rightarrow (p\pi^-)p \quad (\sigma \approx 0.3 \text{ mb. for } M^2 \leq 10 \text{ GeV}^2)$

$np \rightarrow (p\pi^-\pi^+\pi^-)p \quad (\sigma \approx 0.5 \text{ mb. for } M^2 \leq 10 \text{ GeV}^2)$

etc.

(See appendix for methods used in estimating cross sections.) The first of these reactions we estimate makes up approximately 10% to 20% of the total diffractive dissociation of the neutron at NAL energies it is also representative of the simplest class of inelastic reactions, single pion production, and therefore presumably needs to be understood if we are to understand diffraction dissociation in general.

The second and additional reactions are of interest in studying "high mass diffraction"; their energy dependence are of particular importance. In general the above set of neutron final states complements similar "4C" events involving <u>even</u> numbers of produced pions which can be studied in pp interactions (e.g. $pp \to pp\pi^+\pi^-$)

We list below some of the particular physics and/or experimental advantages of the proposed experiment.

1. In the reaction $np \to p\pi^- p$ one can study single pion production with no elastic contamination as one has for the corresponding reaction $pp \to p\pi^\circ p$. This can be crucial at small t since the elastic cross section is an order of magnitude larger than the inelastic cross section.

2. The 3 constraint fit in $np \to p\pi^- p$ will allow a much cleaner separation than one could hope to do in the 1 constraint fits to $pp \to n\pi^+ p$ or $pp \to p\pi^\circ p$.

3. It is true that similar final states can be fitted in pd reactions but this is disadvantageous because one must see the spectator proton in order to make the corresponding 4C fit in deuterium with reasonable confidence. This necessitates throwing away 3/4 of the interactions off of neutrons; and the event rate is lower to begin with in deuterium, since 1/2 of the interactions are on protrons and it is interactions per picture that limits the event rate.

Deuterium also suffers from the usual difficulties in knowing how to define t, in handling the ambiguity of which proton was the "spectator", and in taking into account the Pauli exclusion principle, etc. These effects are particularly serious for small t ($-t \lesssim 0.02$ GeV^2) whereas we believe it is crucial to measure the t dependence in this region.

The percentage of time the two final state protons can get confused in a deuterium experiment can be seen in Fig. 1. This data comes from an AGS experiment by our group, studying the $np \to p\pi^- p$ reaction using 25 GeV/c deuterons on hydrogen. We note that with a 25 GeV/c deuteron beam the momentum of a typical spectator proton is 12.5 GeV/c. As usual we define the spectator proton (p_s) as the slowest proton in the deuteron rest frame. This leaves considerable overlap with the "decay" proton (p_n), as can be seen from the figure. It is well known that this ambiguity and the Pauli exclusion principle cause serious problems if one wants to look at the behavior for $-t \lesssim 0.02$. Clearly the p_s-p_n ambiguity also has some effects on the $p\pi^-$ decay angular distribution.

4. There will soon be high energy data available from counter experiments on coherent $n \to p\pi^-$ off heavier nuclei. Our hydrogen data will complement these experiments nicely. In particular we can explore the region $-t > 0.05$ GeV^2 which is not possible off heavy nuclei because of the increasing incoherent background. Clearly the region $-t > 0.05$ must be studied as well as the very low region. Our experiment will cover the whole t region up to $-t \approx 1$ GeV^2.

5. Similar counter experiments on hydrogen can be contemplated but one is faced with not seeing the proton recoil for $-t \lesssim 0.1$ GeV^2 and hence the 3C fit can't be made. The bubble chamber also has its usual advantages in uniform coverage of the solid angle for the decaying $p\pi^-$ system. Moreover, since the cross section for $np \to p\pi^- p$ is approximately 0.3 mb. one can compile reasonable statistics with the bubble chamber.

In brief we believe that the present proposal is the most (if not the only) reliable way to achieve a detailed study of the important contribution of single pion production to inelastic diffractive processes, especially in regards to the small t behavior. We can cover the region $-t \approx 0$, with a resolution of $\delta t \approx 0.002$ GeV^2 at $-t = 0.01$ GeV^2, and with uniform detection efficiency out to $-t \approx 1.0$ GeV^2 (where statistics begin to limit us).

Secondary Objectives

1. We intend to study the charge exchange reaction

$$np \to p\Delta^\circ \quad \hookrightarrow p\pi^-$$

as a function of energy. We have detected a clear signal for this in our 25 GeV/c dp experiment (see Fig. 2). We should be able to measure the energy dependence up to about 100-200 GeV/c provided the cross section falls no faster than $\sim p^{-1}_{lab}$.

2. It is important to know the energy dependence near "threshold" of the higher states like $np \to p\pi^-\pi^+\pi^-p$ in trying to understand so-called "high mass diffraction". One wants to see how they rise (and fall?) with beam energy and to what extent they are controlled by t_{min} effects, etc.

3. The inclusive reaction $np \to p$ + anything can be studied in the usual way by measuring the recoil, counting charged prongs in the $n \to$ "anything" system, etc. (Note the "slow" proton is at the opposite vertex here as compared to a pd experiment). One expects the inclusive recoil proton spectrum to be very similar to the pp case, but one can search for differences, and in particular get a good measure of the single pion contribution near $|x|=1$. There is an experimental difficulty with this inclusive measurement

since one doesn't know the beam momentum for each event. However we note that one gets a precise measurement of x even without this, since with no approximations

$$1-|x| = \frac{1}{m} (p_{\parallel}/\beta - T)$$

where m, $p_{\parallel}$, and T are the mass, longitudinal momentum, and kinetic energy of the recoiling proton <u>in the lab.</u> The only dependence on the beam energy comes from β, the velocity of the center of mass in the laboratory; $1/\beta \approx 1 + {}^{m}/p_{beam}$.

Thus we can write

$$1-|x| \approx \frac{1}{m} (p_{\parallel} - T \quad) + p_{\parallel} \;/p_{beam}$$

Keeping only the first (infinite energy) term we see we thereby only make an error in x of the size $p_{\parallel} \;/p_{beam}$ and even this can be estimated for each event.

By the use of ionization and energy loss we can identify protons up to $p_{lab} \approx 1$ GeV/c. Since $p_{\parallel} \;< 0.1$ GeV/c when $1-|x| \lesssim 0.1$ and $p_{\parallel} \;\lesssim 1$ GeV/c in the region where protons can be identified <u>we have a negligible error in measuring x as long as $p_{beam} \gtrsim 30$ GeV/c.</u>

The error in x introduced by the inaccuracy in the recoil protons angle, scaling up from the 30 inch chamber, will be $\delta\, x \approx 0.01$. Thus we can measure $d\sigma/dxdp_T^2$, averaged over the neutron spectrum, to compare with the corresponding pp measurements. What cannot be done of course is to convert x to $M^2 (M^2 \approx m^2 + s\ (1-|x|)\ )$ on an event-by-event basis. Nonetheless, $d\sigma/dxdp_T^2$ for np→ anything + p is important to measure; it cannot be done easily in pd since one has to measure the momentum of the outgoing fast proton with an error of ≈ 1% in order to achieve the same accuracy in x.

II. Neutron Flux

In order to extract the best physics out of the above described measurements one should have an absolute measurement of the neutron energy spectrum. This we propose to measure by means of a neutron calorimeter.

For purposes of the proposal the neutron flux can be estimated by assuming it equals the measured $pp \rightarrow p$ production in the range $0.1 < |x| < 0.9$ (and letting it drop rapidly to zero for $0.9 < |x| < 1.0$). Using NAL bubble chamber measurements of the proton flux near $p_T^2 = 0$ we can parameterize

$$\begin{pmatrix} pp \rightarrow n \\ 0.1 < x < 0.9 \end{pmatrix} \quad E \frac{d\sigma}{d^3p} \approx 30 e^{-6p_T^2} \text{ mb./GeV}^2$$

Likewise we parameterize, for $pp \rightarrow K_L^\circ$

$$(pp \rightarrow K_L^\circ) \quad E \frac{d\sigma}{d^3p} \approx 3 e^{-5p_T^2} e^{-5x} \text{ mb./GeV}^2$$

The latter expression is based on NAL bubble chamber measurements of the cross section for $pp \rightarrow K_s^\circ$. Using these forms one can calculate the flux $d\sigma/dx$ (in the Lab) inside an acceptance half angle $\theta_\circ$ from the target:

$$d\sigma/dx \approx \pi \, (P_\circ \theta_\circ)^2 \; R_\circ(x) \; x \text{ mb}$$

where $P_\circ$ = proton beam momentum and

$$R_\circ (x) = E \frac{d\sigma}{d^3p} \Big| \; p_T^2 = 0$$

The above formula is a good approximation as long as $(P_\circ\theta_\circ)^2 << {}^1/b$, where b is the slope in the gaussion approximation to the p_T dependence of the cross section. For our case we use $(P_\circ\theta_\circ)^2 = 0.0036$ and ${}^1/b \approx 0.2$, so the results are insensitive to the exact values of b.

The results of these calculations for $P_\circ = 300$ GeV/c and $\theta_\circ = 0.2$ mr. are shown as the solid curves in Figure 3. We estimate these flux calculation are correct to within about a factor of 2. We see that we expect a triangular neutron spectrum (with the peak at the high momentum end). This agrees approximately with the observed shape of neutron beams at lower energies and the observed shape seen by Longo et al., in the meson Lab. We also see that the K_L° flux is a negligable fraction of the neutron flux everywhere. The dashed curves are the predicted fluxes at 1 mr. for the same solid angle ($\Delta\Omega$ = .125 μ sr) as above.

III. Beam Construction

The details of constructing a neutron beam will be considered in conjunction with the NAL staff. However, two possibilities that use much of the existing hadron beam suggest themselves. First of all the present hadron beam has both a vertical and horizontal focus in enclosure 111. The insertion of a production target and a standard beam line bending magnet with power supply in enclosure 111 would create a neutral secondary beam with the charged primary and secondary beams being dissipated in the berm. A collimator $\sim$ 1 in. in diameter followed by a cleanup bending magnet in enclosure 113 could then be used to define the neutron beam. According to our flux estimates $\sim 2 \times 10^4$ protons on a $\sim$ .15 interaction length target would give us $\sim$ 10 neutrons in the bubble chamber in the momentum range 30-250 GeV/c. The other possibility is to place a production target in enclosure 109 before the last bending magnet. At an incident proton momentum of 300 GeV/c the remaining bending magnets give sufficient bend so that we can take off a neutral beam at a small production angle. The last bending magnet could be used to sweep out charged particles. The collimators in enclosure 111 would then define a neutral beam with the final cleanup being done in enclosure 113. The disadvantage of the latter method is that at present there is no focus in enclosure 109. However, there appear to be sufficient upstream beam elements so that acceptable targeting should be possible. In either case we would require a beam monitor to measure the number of protons on target.

IV. Mass and t Resolution in $np \rightarrow p\pi^- p$

In order to estimate the resolution we have assumed a setting error in space of 300μ a magnetic field of 30 kg and between 1 and 2 meters of measured track length on the high momentum tracks. Using a Monte Carlo calculation the measured mass resolution of a 1.5 GeV/c^2 $p\pi^-$ system whose momentum in the lab is 200 GeV/c is 100 MeV/c^2 full width at half max. The measured momentum resolution is 20 GeV/c full width at half max. We estimate that after making the 3C fits these inaccuracies will decrease by approximately a factor of 2.

The resolution in t, for low t, is determined by the accuracy with which one can measure the length of stopping protons. We estimate that we can measure the length of a 0.5 cm proton to 0.15 cm this yields a δt of ~ 0.0025 GeV^2 at a $-t$ of 0.013 GeV^2.

V. Scanning, Measuring, Computing, and Manpower

We expect to devote the equivalent of two full time physicists, plus one graduate student to this experiment. We have a Polly measuring machine which is becoming operational plus, at present, 1 manual measuring machine adapted to the 15' film format. By fall of 1974 two additional manual machines will have been adapted.

Geometric reconstruction and kinematic fitting programs for 15' measurements are presently being developed for our ν experiments and will be available for use in this experiment. Additional analysis programs have already been developed for use with our 60, 100 and 400 GeV/c pp exposures in the 30" chamber. All computing will be done on a departmental owned PDP 10.

In order to extract the $np \to p\pi^- p$ events we expect to measure ~ 50 K 3 prong interactions which will take between 6 months and a year using Polly for one shift/day. We thus expect to have preliminary results on the entire data sample less than 1 year after obtaining the film. Results on a partial data sample will of course be available at an earlier date.

Appendix

We have used two methods of estimating the cross section for the reaction $np \rightarrow p\pi^- p$. First of all the measured two prong single diffractive cross section in pp reactions in the 100-200 GeV/c range is ~ 1.5 mb. (1,2). In addition the average number of π° produced with two charged particles is ~ 1.5. If we assume that the π° multiplicity distribution is Poisson, the cross section for $pp \rightarrow pn\pi^+$ is ~ 0.33 mb. Since a diffractively produced $N\pi$ system is in an $I = 1/2$ state the cross section for $np \rightarrow p\pi^- p$ is also ~ 0.33 mb. Secondly the cross section for $pp \rightarrow pp\pi^+\pi^-$ has been measured at both 100 and 200 GeV/c and is found to be primarily diffractive and falling as $p^{-0.37}$. If we assume that $np \rightarrow p\pi^- p$ has the same dependence on the incident momentum as $pp \rightarrow pp\pi^+\pi^-$, the $np \rightarrow p\pi^- p$ cross section at 100 GeV/c is ~ 0.32 mb. scaling from Morris et al., at 28.5 GeV/c (3).

In order to estimate the cross section for $np \rightarrow p\pi^-\pi^+\pi^- p$ we note the cross sections for $pp \rightarrow pn\pi^+\pi^+\pi^-$ and $pp \rightarrow pp\pi^\circ\pi^+\pi^-$ are approximately equal for $p_{lab} \gtrsim 10$ GeV/c (4). We therefore assume that $\sigma_{np \rightarrow p\pi^-\pi^+\pi^- p} \approx \frac{1}{2}\,\sigma_{pp \rightarrow pn\pi^+\pi^+\pi^-}$ and has the same energy dependence as $pp \rightarrow pp\pi^+\pi^-$. The yields $\sigma_{np \rightarrow p\pi^-\pi^+\pi^- p}$ $\approx .5$ mb.

Footnotes

1. J. W. Chapman et al., Phys. Rev. Lett 32 257 (1974).
2. J. Whitmore, Experimental Results on Strong Interactions in the NAL Bubble Chamber, and references therein (submitted to Physics Reports).
3. J. W. Morris et al., BNL 14 904 (1970).
4. O. Benary et al., (Particle Data Group), NN and ND Interactions (above 0.5 GeV/c) - A compilation.

Figure Captions

1. Momentum vector diagram of a typical $dp \rightarrow p_s p_n \pi^- p$ event in the deuteron rest frame, and momentum distributions of p_s (spectator) and p_n (proton from neutron diffraction) in the deuteron rest frame. The curve is a Hulthen distribution with $\alpha = 45.5$ MeV/c, $\beta = 7.0\alpha$, normalized to 2320 events.

2. Invariant mass of the $p_p\pi^-$ system for events with $M(p_p\pi^-) < M(p_n\pi^-)$ where p_p is the recoiling target proton and p_n is the proton from neutron diffraction.

3. Neutral particle flux estimates for an incident proton momentum of 300 GeV/c and 0 mr production angle (solid curves) and 1mr production angles (dashed curves).

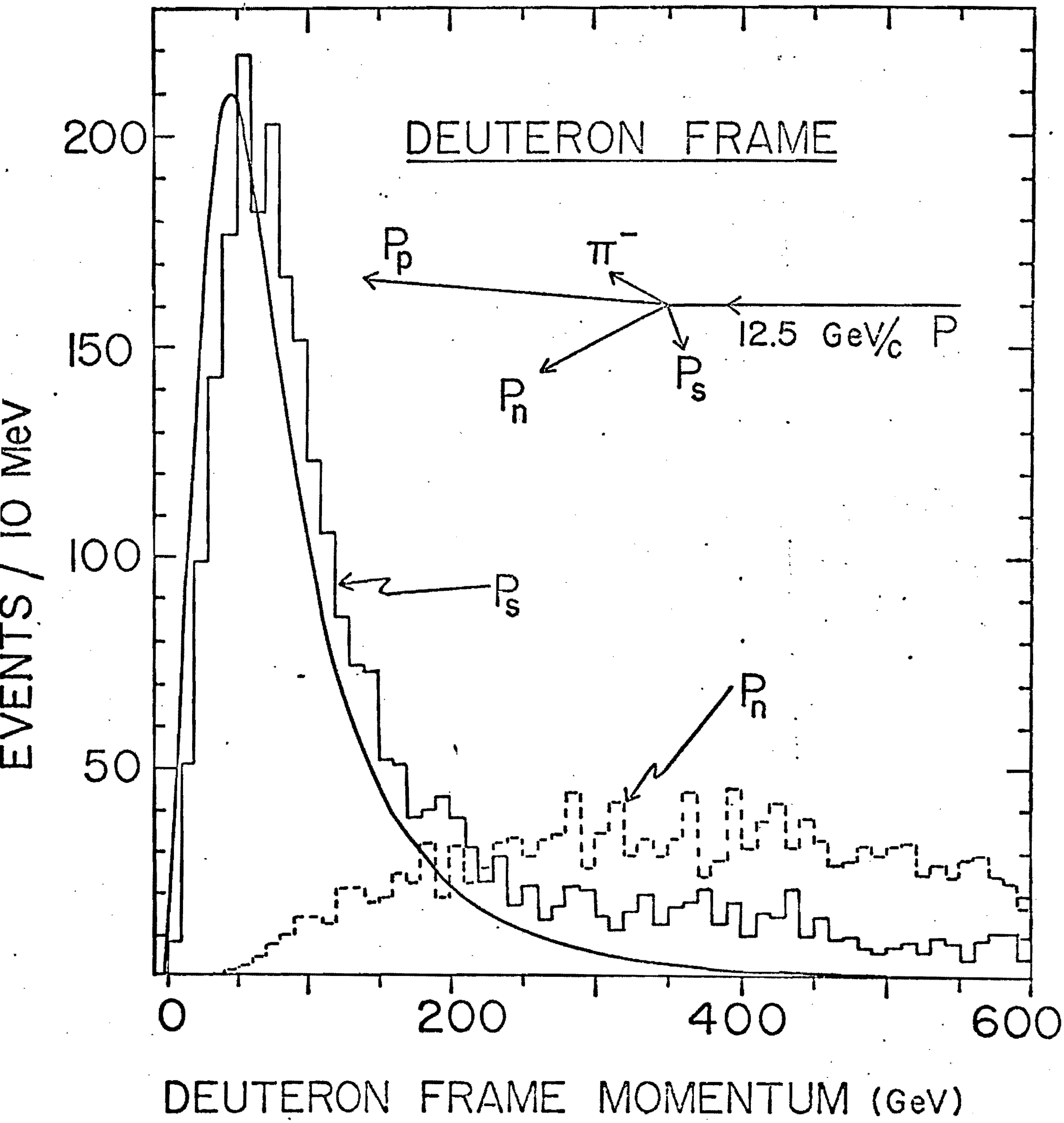
DEUTERON FRAME
P_p
π^-
12.5 GeV/c P
P_s
P_n
P_s
P_n
EVENTS / 10 MeV
200
150
100
50
0
200
400
600
DEUTERON FRAME MOMENTUM (GeV)

Figure 1

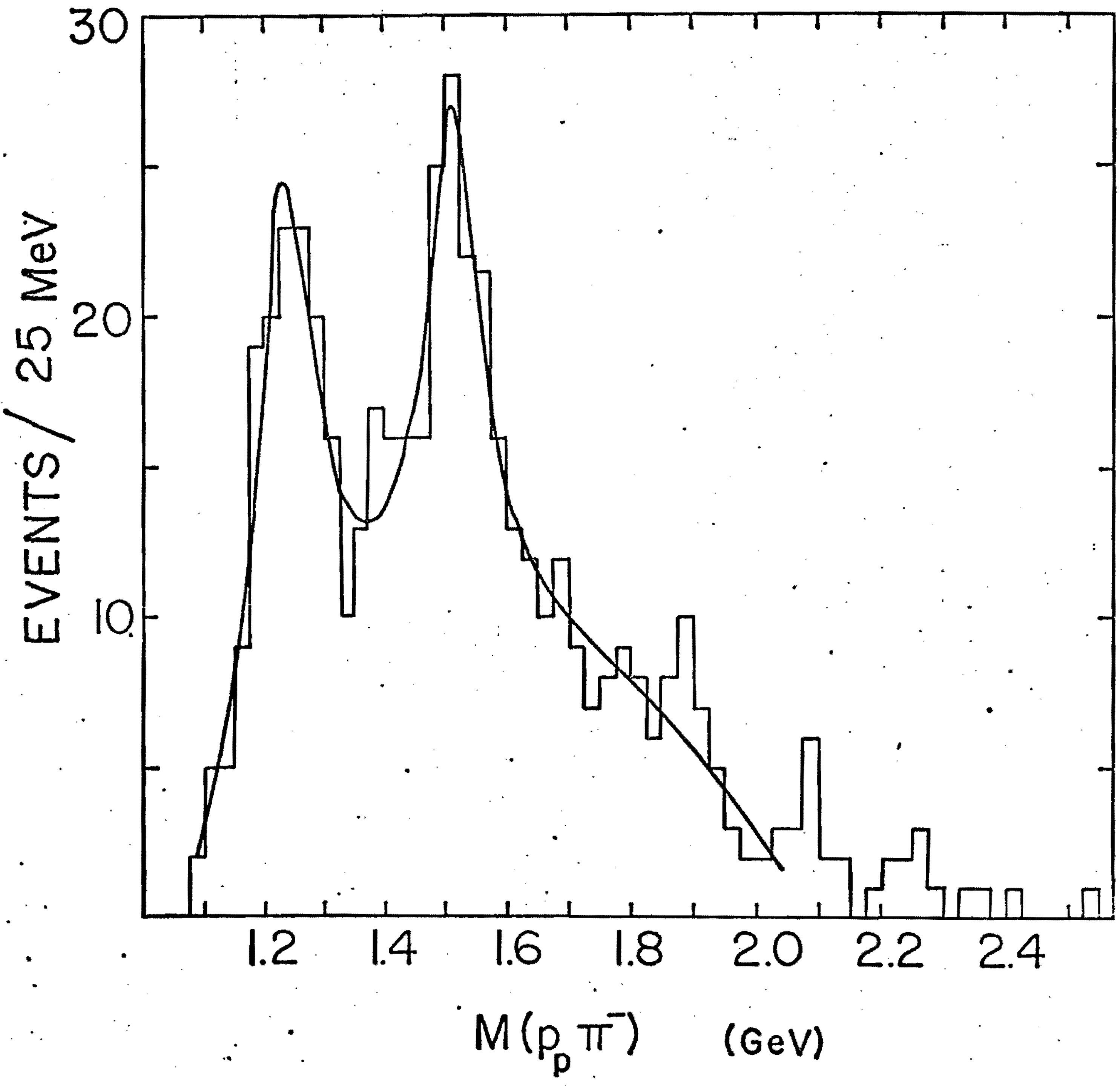

Figure 2

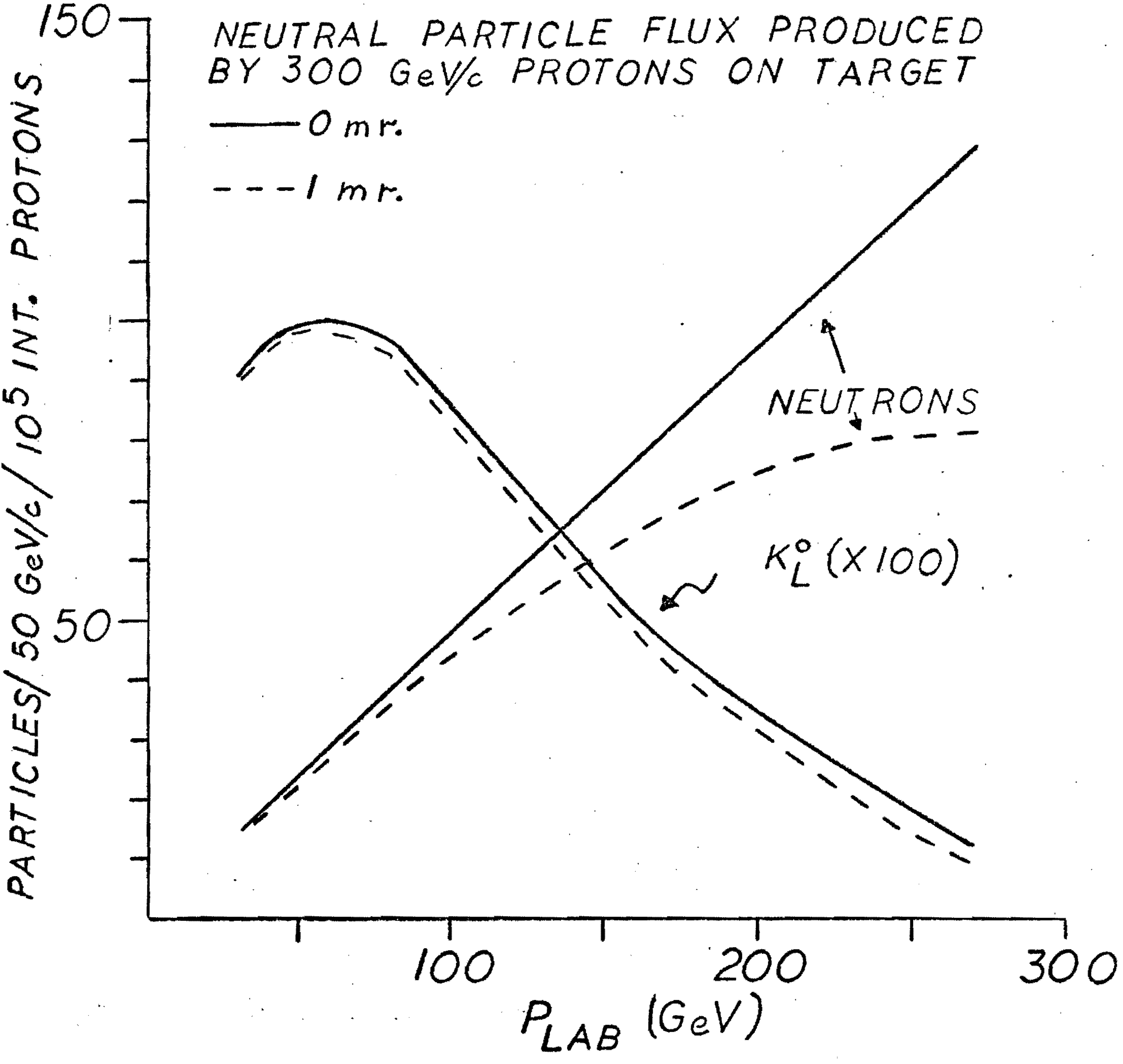
NEUTRAL PARTICLE FLUX PRODUCED
BY 300 GeV/c PROTONS ON TARGET
0 mr.
1 mr.
NEUTRONS
K_L^0 (X100)
150
50
PARTICLES/50 GeV/c/10^5 INT. PROTONS
100
200
300
P_{LAB} (GeV)

Figure 3