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Authors

Birge, Robert
Ely, Robert
Gidal, George
et al.

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University of California

Ernest O. Lawrence Radiation Laboratory

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Robert Birge, Robert Ely, George Gidal,
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Robert Birge, Robert Ely, George Gidal,
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Lawrence Radiation Laboratory
University of California
Berkeley, California

(Presented by Robert W. Birge)

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We report on the analysis of 503 $n\,n \to n\,p\,\pi^-$ events in the momentum region p_n = 1.7 to 2.3 GeV/c. In addition to providing a detailed test of charge symmetry, this study also shows the feasibility of observing n-n reactions at a well-defined energy in the GeV region.

The Brookhaven National Laboratory 20-inch bubble chamber, filled with deuterium, was exposed to a 3.68 GeV/c separated deuteron beam at the alternating gradient synchrotron. We scanned for interactions with three visible emergent singly charged particles, $2p + \pi^-$. Most of these are examples of the reaction $d\,d \to ppp\,n\,\pi^-$, in which the proton from the target deuteron is too short to be visible (< 90 MeV/c), and hence is identified as a spectator. These events were constrained to the reaction

$$d\,n \to p\,p\,\pi^- n\,. \qquad (1)$$

The assumption that the neutron was at rest made possible a one constraint fit. The n-n reactions were identified by having $\chi^2 \leq 3$, and by the presence of a proton of momentum less than 120 MeV/c in the rest frame of the beam deuteron. We called this proton a "high-energy spectator". Figure 1 shows the transverse-momentum distribution of the high-energy spectator proton; it follows closely the Hulthén form of the deuteron wave function.

*Work done under the auspices of the U.S. Atomic Energy Commission.

In the analysis of the n-n reactions, the measured values of the proton and pion momentum were used, and the outgoing neutron momentum was inferred from energy-momentum conservation in reaction (1). The assumption that the target neutron was at rest introduced an uncertainty of 0 to 90 MeV/c in the neutron momentum, in addition to the usual measurement errors. For each event, the energy in the n-n c.m. system was calculated from the momenta of the three outgoing particles. We restricted our study of the c.m. total-energy interval 2.317 to 2.517 GeV: the corresponding neutron mean laboratory momentum is 1.9 GeV/c.

Figure 2 shows the proton and neutron angular distributions in the n-n c.m. system. These are strongly peaked forward and backward, indicating that the reaction is predominantly peripheral. This peaking is expected if the reaction goes mainly through the exchange of a single virtual pion. There are then two possible diagrams for the reaction (Fig. 3). Chew and Low have shown that the one-pion-exchange (OPE) reaction occurs primarily at low values of Δ^2, the square of the 4-momentum of the virtual pion;[1] in the nonphysical limit $\Delta^2 \rightarrow -\mu^2$ (μ is the pion mass), the cross section goes as $\Delta^2/(\Delta^2+\mu^2)^2$. The predominance of small 4-momentum transfers is reflected in the angular distributions.

Figure 4 shows the $(\pi^- n)$ and $(\pi^- p)$ effective-mass distributions. The reaction is clearly dominated by N^{*-} production--that is, by diagram (a). This dominance follows from simple isotopic-spin considerations and is further evidenced by the fact that the proton angular distribution is more peaked than that of the neutron (Fig. 2). The distributions in Fig. 4 are consistent with the assumption that the reaction goes entirely via N^* production in the proportion 9:1 for diagrams (a) and (b). When the data is fitted with the usual invariant three-body phase space and an S-wave Breit-Wigner form, the N^{*-} parameters which give the best fit are $M = 1219$ MeV, $\Gamma = 125$ MeV. These values are presented as a parameterization of the data and not as an estimate of the N^{*-} parameters, since the assumption of a phase-space distribution is not valid for peripheral interactions.

As a test of charge symmetry we compare our data with a recent study of 1414 $p\,p \rightarrow p\,n\,\pi^+$ events at 1.12 GeV/c.[2] The charge symmetric p-p angular distributions are shown as the dotted lines in Fig. 2. Here the n-n data shows a possible depletion of the two extreme boxes. This is probably because we may miss n-n events at $\Delta^2 \rightarrow 0$. At Δ^2 near zero, the recoil of a target nucleon may be invisible, and a recoiling beam nucleon is indistinguishable from a high-energy spectator proton.

Figure 5 shows the proton kinetic energy in the laboratory. This is also in agreement with one-pion exchange according to diagram (a). The sharp peak at low energy corresponds to pion emission by the target neutron, and the broader peak at high energy is due to pion emission by the beam neutron. The broadening is a consequence of the transformation from the beam neutron rest system to the laboratory. The OPE model of Ferrari and Sellari predicts the form of this distribution.[3,4] They assume that the Chew-Low formula for a nucleon scattering on a virtual pion is valid in the physical region, and also that diagram (b) can be neglected. By introducing a single empirical pionic form factor for the nucleon, they achieve agreement with p-p data over the entire range of proton laboratory energies from 1.0 to 3.0 GeV. The smooth curve in Fig. 5 is the distribution predicted by the Ferrari and Sellari model, using the same empirical form factor which fits the p-p data. Agreement of our distribution with this empirical fit to the p-p data confirms charge symmetry.

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FIGURE LEGENDS

Fig. 1. Distribution in transverse momentum, p_T, of spectator protons in the beam deuterons. The smooth curve is the Fourier transform of the Hulthén wave function, folded into the transverse plane.

Fig. 2. Center-of-mass angular distributions of (a) protons, and (b) neutrons in $nn \rightarrow np\pi^-$. The dotted lines are (a) neutrons and (b) protons in $pp \rightarrow pn\pi^+$.

Fig. 3. Feynman diagrams for single-pion exchange in the reaction $nn \rightarrow np\pi^-$.

Fig. 4. Effective-mass distributions (a) for ($\pi^- n$) and (b) for ($\pi^- p$). The smooth curves are calculated on the assumption that N^{*-} and N^{*0} are produced in the ratio 9:1.

Fig. 5. Proton kinetic-energy spectrum in the laboratory. The smooth curve is the distribution predicted by the Ferrari and Sellari OPE model, using the form factor which gives a best fit to the p-p data.

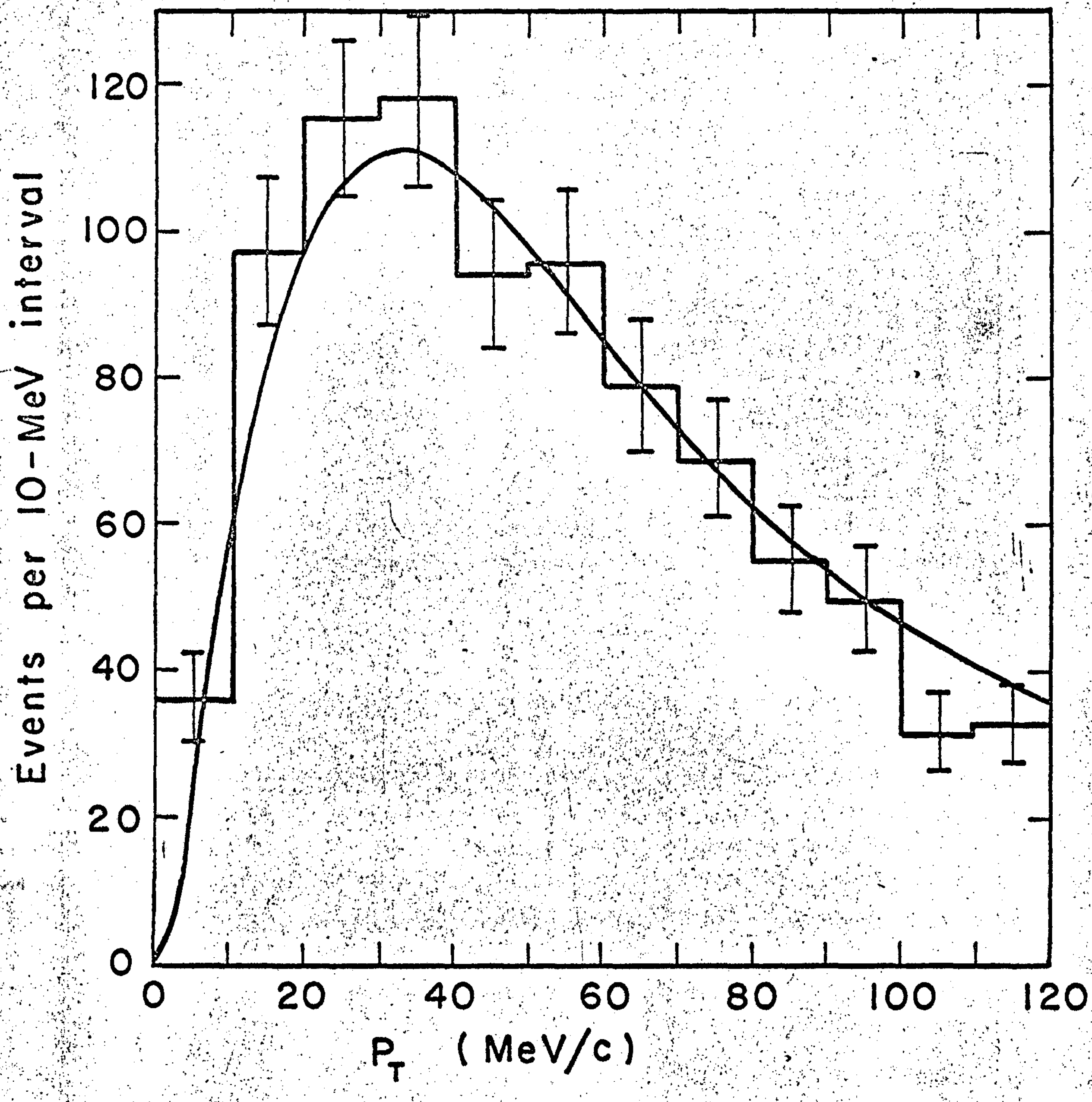

Fig. 1

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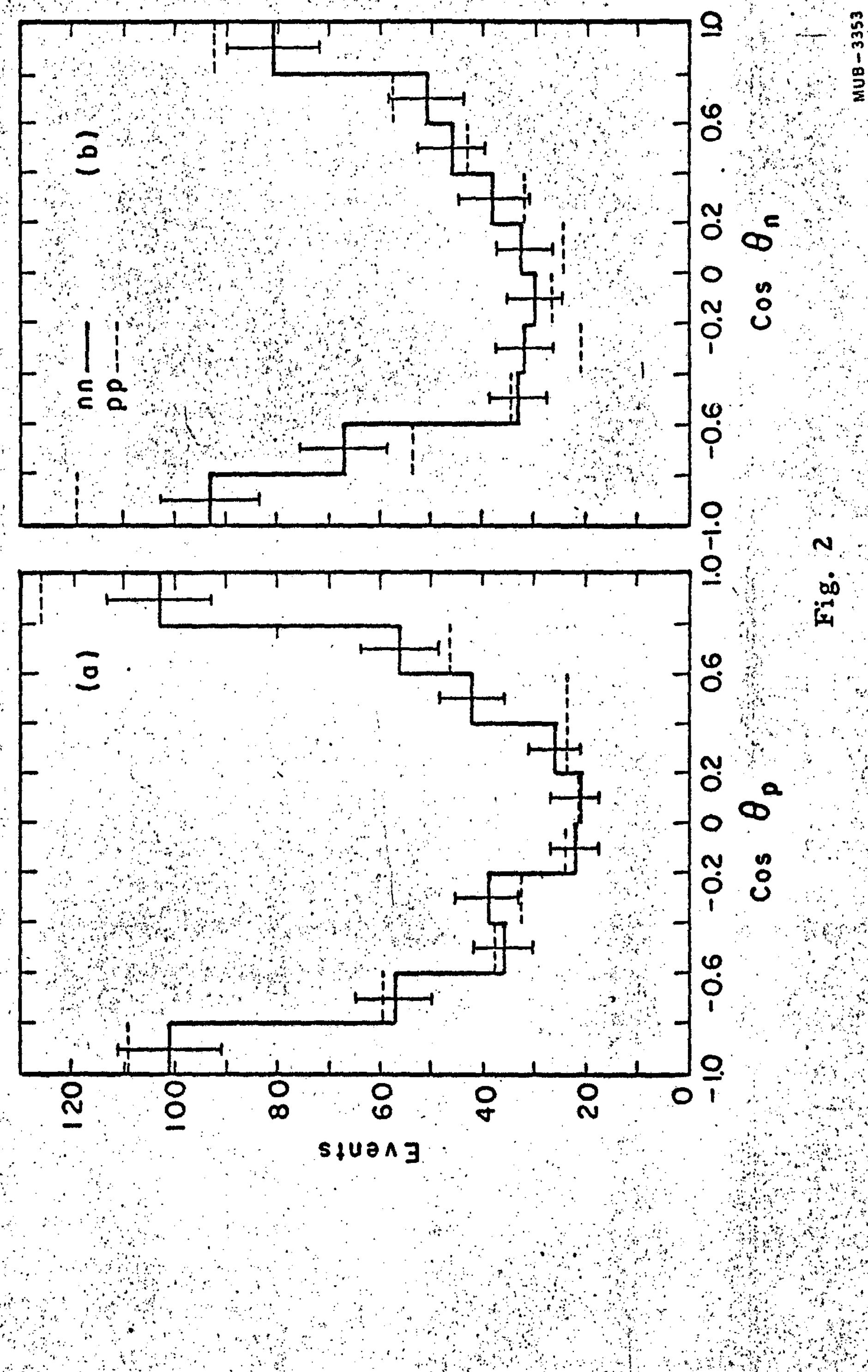
(a)
(b)
nn
pp
Events
Cos θp
Cos θn
120
100
80
60
40
20
0
-1.0
-0.6
-0.2
0
0.2
0.6
1.0
MUB-3353

Fig. 2

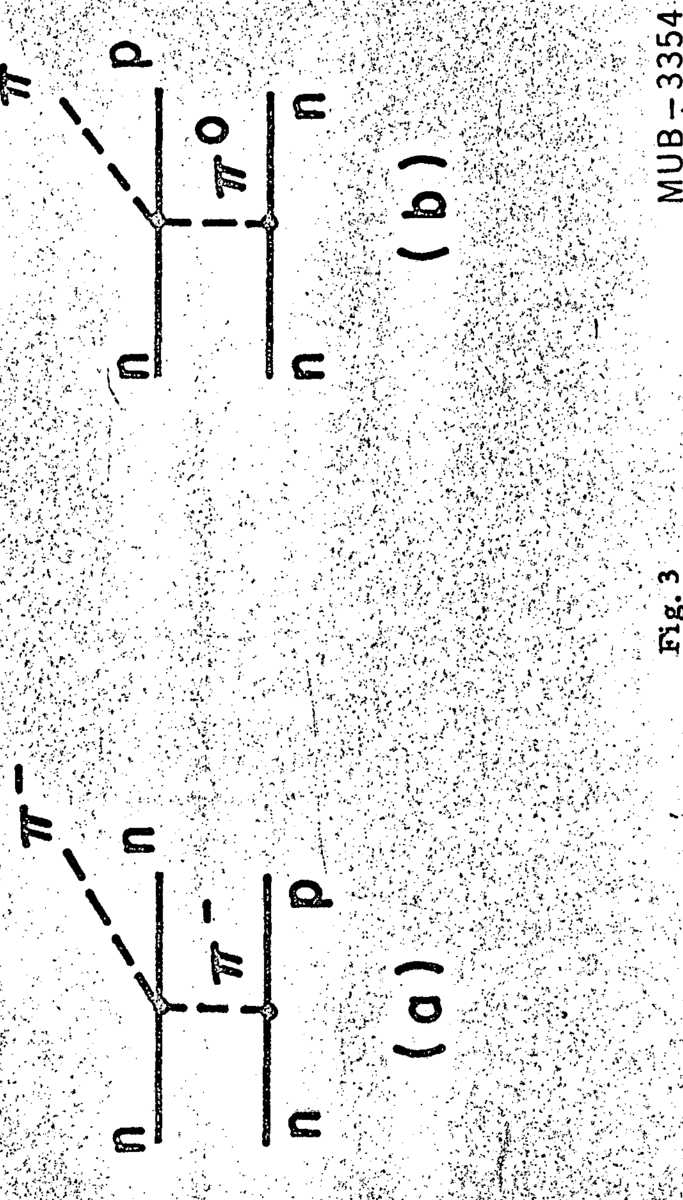

Fig. 3

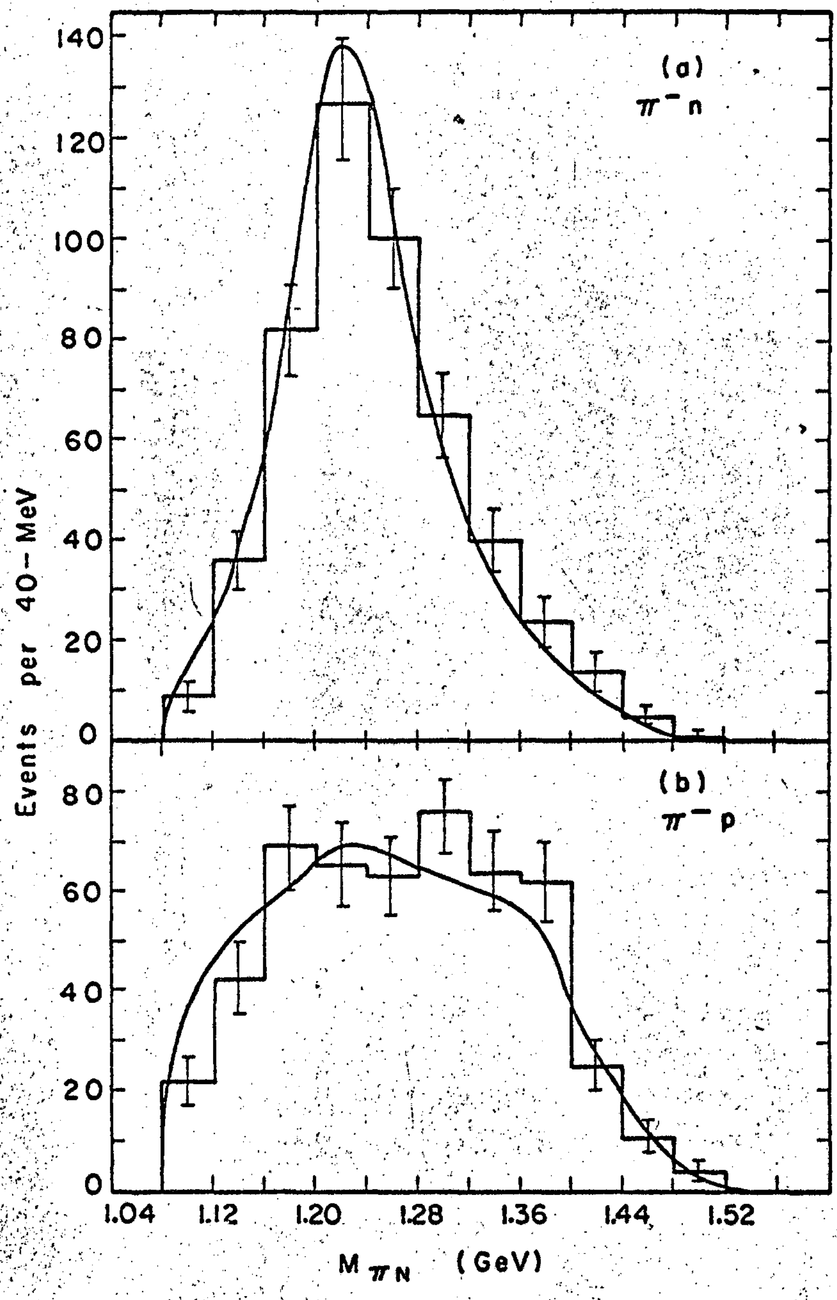

Fig. 4

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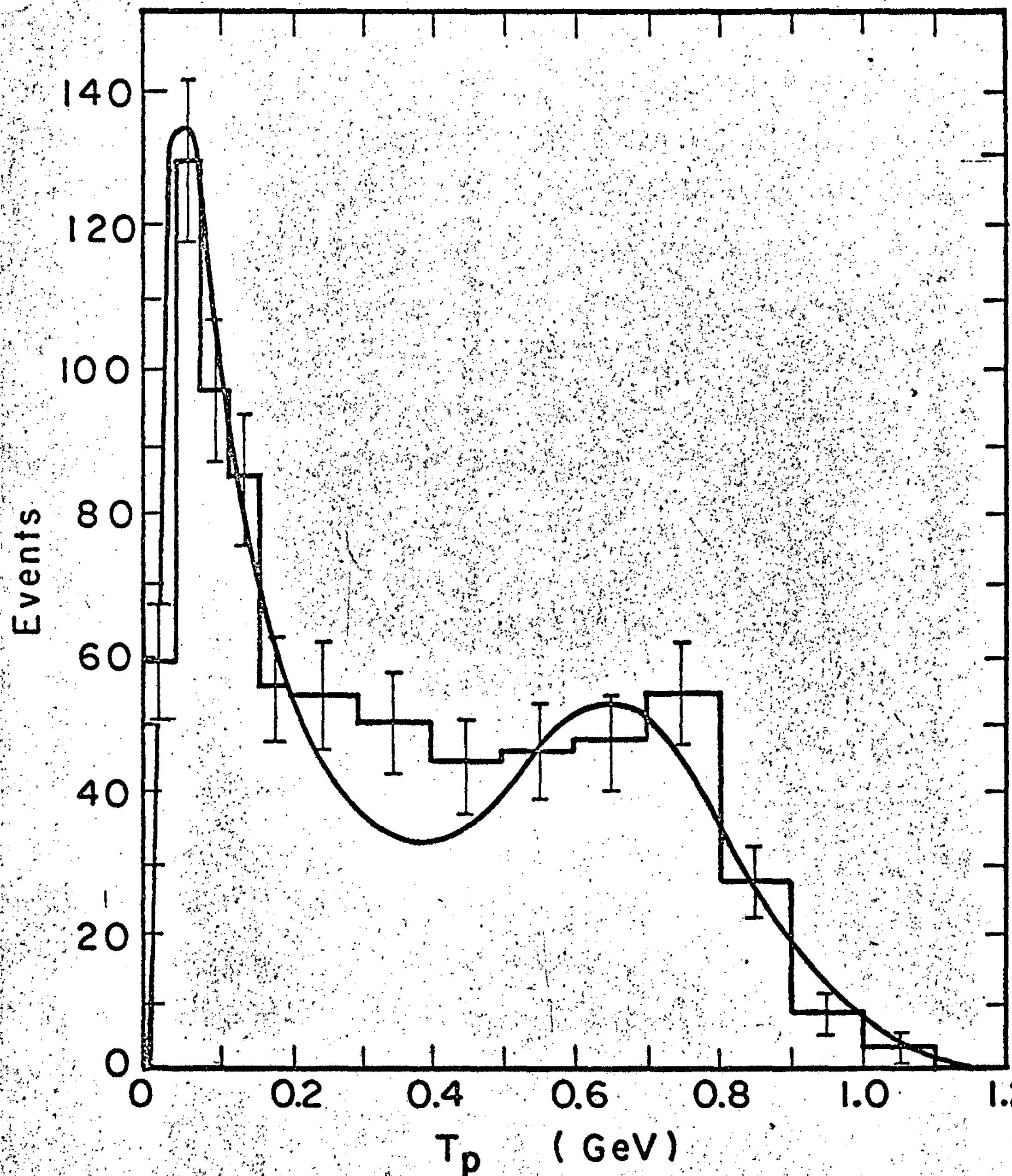

Fig. 5

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