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by

H.C. Dehne, J. Díaz, K. Strömer, A. Schmitt, and W.P. Swanson
Physikalisches Staatsinstitut
II. Institut für Experimentalphysik, Hamburg

and

I. Borecka, G. Knies, and G. Wolf
Deutsches Elektronen-Synchrotron DESY, Hamburg

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In a study of pp interactions at 10.01 GeV/c in the Saclay 81 cm hydrogen bubble chamber at the CERN PS, interactions with two outgoing charged particles have been analyzed in 30 000 pictures. Using a χ^2 criterion and ionization information for track momenta less than 1.7 GeV/c, a total of 801 events were found which fitted the Reaction

$$(1) \qquad pp \rightarrow pn\pi^+$$

We have used the program FAKE[1] to check our measuring and hypothesis selection procedure. It was found that events having a π^+ in the backward hemisphere (with respect to the beam direction) in the overall c.m. system constitute a highly pure sample (contamination $<$ (10 $\pm$ 5)%). Only these events have been used for the analysis (341 events). Due to the symmetry of the initial state, no biases are introduced by this procedure. All cross sections given have been correspondingly corrected and hence refer to the total Reaction (1). The total cross section for Reaction (1) is 3.7 $\pm$ 0.4 mb.

Figure 1 shows a Chew-Low plot of the $p\pi^+$ invariant mass $M_{p\pi^+}$ versus Δ^2_{min}. Here Δ^2_{min} is the smaller of the two possible values of the four momentum transfer squared between the outgoing $p\pi^+$ system and either of the initial state protons. There is a marked accumulation of events at small momentum transfers and strong $N^{*++}(1236)$ production. Other features of Reaction (1) will be discussed elsewhere. A superposition of a Breit-Wigner distribution for the $N^{*++}_{(1236)}$ and Lorentz invariant phase space modified by a factor $e^{-3.2\Delta^2_0}$ (where Δ^2_0 is the minimum value of Δ^2 kinematically allowed for a given $p\pi^+$ mass) were fitted to the $p\pi^+$ mass distribution. From this fit we obtain for the process

$$(1a) \qquad pp \rightarrow N^{*++}_{(1236)}\, n$$

a cross section of 1.2 $\pm$ 0.2 mb.

Fig. 2 shows the differential cross section $\frac{d\sigma}{d\Delta^2_{min}}$ for events with $M_{p\pi^+}$ inside (a) and outside (b) the isobar region.

Fig. 3 shows the $p\pi^+$ mass distribution for small values of Δ^2_{min}. The decay angular distribution of the N^{*++} in its CM system with respect to the incident proton direction in the process (1a) has been investigated in terms of the elements ρ_{ik} of the N^* spin-space density matrix[2]. Table I shows the values of ρ_{ik} determined for events with 1.125 GeV $< M_{p\pi^+} <$ 1.325 GeV and $\Delta^2_{min} < 0.3$ GeV^2.

Reaction (1) has already been investigated by various authors for laboratory momenta of the incoming proton up to 5.5 GeV/c[3)-8)].

Reaction (1) and especially (1a) is a suitable reaction for testing the one-pion exchange model (OPEM) since the πNN coupling constant and the differential cross sections for πN elastic scattering are known.

Ferrari and Selleri[3] have applied an OPEM with the form factor approach to data of Reaction (1) between 1.7 - 3.7 GeV/c[3),4),5)]. From a fit to these data they determined the unknown correction functions which enter into the calculation, and achieved quantitative agreement with these experiments. We used these correction functions to obtain the predictions of this model at 10 GeV/c. Since these correction functions contain no adjustable parameter, a comparison with our data constitutes a direct check of the Ferrari-Selleri approach.

There are four OPE diagrams which contribute to Reaction (1)

(See Fig. 4). Explicit calculation of diagrams (2) and (4) showed that their contribution could be neglected compared to diagrams (1) and (3). Diagram (1) leads to the following cross section

$$(2)\qquad \frac{d^2\sigma}{dM^2_{p\pi^+}\, d\Delta^2} = \frac{1}{\pi}\frac{G^2}{s(s-4M^2)} A^2\,(M_{p\pi^+},\ \Delta^2)\,\frac{\Delta^2}{(\Delta^2+\mu^2)^2}\,M_{p\pi^+}|\vec{q}|\,\sigma_{\pi^+p}(M_{p\pi^+})$$

$$s = (p_1+p_2)^2 \qquad \Delta^2 = -\,(p_2-n)^2$$

p_1, p_2 and n are four momentum vectors of the respective particles (see Fig. 4)

M = nucleon mass, μ = pion mass, G^2 = 14.4

$\bar{q}$ = three momentum of the π^+ in the π^+p C.M. system,

σ_{π^+p} = total cross section for elastic π^+p scattering.

For $M_{p\pi^+} <$ 1.45 GeV, the function $A(M_{p\pi^+},\ \Delta^2)$ is given by

$$(3)\qquad A(M_{p\pi^+},\ \Delta^2) = \frac{f_1{}^+(M_{p\pi^+},\Delta^2)}{f_1{}^+(M_{p\pi^+})}\left(0.28 + \frac{0.72}{1+\dfrac{\Delta^2+\mu^2}{4.73\,\mu^2}}\right)$$

where $f_1{}^+(M_{p\pi^+},\Delta^2)\ /\ f_1{}^+(M_{p\pi^+})$ is defined by Eq. (4.1) of Ref. 9*).

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*) A different form of the correction was given in a later paper[10), but it would lead to the same numerical conclusions.

For $M_{p\pi^+} > 1.45$ GeV/c^2, we used Eq. (4.10) of Ref. 3:

$$(4) \quad A\,(M_{p\pi^+}, \Delta^2) = \left(1 + \frac{\Delta^2 + \mu^2}{\gamma}\right)^{-1},$$

with $\gamma = 30\,\mu^2$ [11])

The same contribution comes from Diagram (3), if Δ^2 is taken to mean $\Delta^2 = -(p_1-n)^2$.

For comparison with our data we have neglected possible interference terms between diagrams (1) and (3).

The prediction of this OPE model for $d\sigma/d\Delta^2_{min}$ and $d\sigma/dM_{p\pi^+}$ for small momentum transfers is shown by the curves in Fig. 2 and 3. Although the theoretical curves are in qualitative agreement with the data, the agreement is worse than at lower energies.

A best fit to the differential cross section outside the N^* region ($M_{p\pi^+} > 1.325$ GeV, Fig. 2b) and for $\Delta^2_{min} < 0.5$ GeV^2 leads to a value $\gamma = 15\,\mu^2$.

According to this OPE model the spin-space density matrix elements given in Table I should all be zero. This is not in agreement with our experimental results.

Our data can also be compared with the OPEM with absorptive corrections. Alexander et al.[8]) have measured Reaction (1) at a proton momentum of 5.5 GeV/c and compared their results for the process (1a) (N^*-production) with OPE with absorption. They obtained agreement with their data after properly adjusting a parameter γ' describing the final state n - N^* scattering. Taking the same value for the absorption parameter $\gamma' = 0.12$, we can obtain a prediction at our momentum of 10 GeV/c. This prediction is also shown in Fig. 2a. It is in reasonable agreement with our data. Table I contains also the predictions for the N^* decay matrix elements ρ_{ik} from the absorption model as given in Ref. 8). Our experimental values favour the result of the absorption OPE model over the form factor model.

Conclusion: OPE model calculations for the reaction $pp \rightarrow N^{*++}n$ can be compared with experiments for incident proton momenta from 1.7 GeV/c up to 10 GeV/c. The OPE calculations with absorption or form factor corrections adjusted from lower energy experiments are able to predict the differential cross section at 10 GeV/c to better than a factor of two. This result is independent of the specific form used for the correction function describing the low energy data, provided that this function is independent of the primary energy. The use of absorptive corrections instead of form factors leads to a better agreement with the data especially for the N^*-decay angular distribution.

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Abstract:

The reaction $pp \rightarrow pn\pi^+$ and the process $pp \rightarrow N^{*++}_{(1238)}n$ have been measured at 10 GeV/c. The OPEM is compared with the isobar production and agreement with the data is better than a factor of two.

TABLE I

Spin-space density matrix elements for Reaction (1a).

	Experimental Values $1.125 < M(p\pi^+) < 1.325$ GeV $\Delta^2_{min} < 0.3$ GeV^2	Prediction with Absorptions-Model according to Ref. 8	OPE
ρ_{33}	0.29 ± 0.07	0.12	0
Re $\rho_{3,-1}$	-0.08 ± 0.07	0.04	0
Re $\rho_{3,1}$	-0.10 ± 0.06	0.03	0

References

(1) G.R. Lynch, UCRL 10335 (1962)
E. Raubold, Fake Manual, (Hamburg, 1966, unpublished). The Raubold version of FAKE contains modifications in the method of error handling.

(2) K. Gottfried and J.D. Jackson, Nuovo Cimento 33, 309 (1964).

(3) E. Pickup, D.K. Robinson, and E.O. Salant, Phys. Rev. 125, 2691 (1962).

(4) E.L. Hart, R.I. Louttit, T.W. Morris, W.J. Willis, and S.S. Yamamoto, Phys. Rev. 126, 747 (1962).

(5) D.V. Bugg, A.J. Oxley, J.A. Zoll, J.G. Rushbrooke, V.E. Barnes, J.B. Kinson, W.P. Dodd, G.A. Doran, and L. Riddiford, Phys. Rev. 133, B1017 (1964).

(6) J. Kidd, L. Mandelli, V. Pelosi, S. Ratti, L. Tallone, M. Dameri, C. Grosso, and G. Tomasini, XIII-th Intern. Conf. on High Energy Physics, Berkeley, 1966 (unpublished), and S. Ratti private communications.

(7) A.B. Eisner, E.L. Hart, R.I. Louttit, and T.W. Morris, Phys. Rev. 138, B670 (1965).

(8) G. Alexander, O. Benary, B. Haber, N. Kidron, A. Shapira, G. Yekutieli, and E. Gotsman, Phys. Rev. 144, 1122 (1966); G. Alexander, O. Benary, G. Czapek, B. Haber, N. Kidron, B. Reuter, A. Shapira, E. Simonopoulou, and G. Yekutieli, Weizmann Institute of Science, Preprint.

(9) E. Ferrari, Nuovo Cimento 27, 1450 (1963).

(10) F. Selleri, Proceedings of the 1964 Boulder Conference on High Energy Physics, (Boulder, 1965) pg. 183; F. Selleri, Nuovo Cimento 40, 236 (1965).

(11) O. Czyzewski, B. Escoubès, Y. Goldschmidt-Clermont, M. Guinea-Moorhead, T. Hofmokl, D.R.O. Morrison, and S. de Unamuno-Escoubès. International Conference on High Energy Physics at Dubna, Vol. I, pg. 148 (1964).

Figure Captions

Fig. 1a Scatter plot of the invariant mass of the $\pi^+ p$ system, $M_{p\pi^+}$, versus the minimum four-momentum transfer to the $p\pi^+$ system, $\Delta^2_{min}(p/p\pi^+)$

1b Projection of the data in Fig. 1a on the $M_{p\pi^+}$ axis.

Fig. 2a Four-momentum transfer distribution $\Delta^2_{min}(p,p\pi^+)$ for events with $1.125 < M_{p\pi^+} \leqslant 1.325$. The curves show the predictions of the OPEM with form factor and absorption corrections respectively.

2b Four-momentum transfer distribution $\Delta^2_{min}(p,p\pi^+)$ for events with $M_{p\pi^+} > 1.325$ GeV. The curve shows the prediction of the OPEM with form factor corrections ($\gamma = 30\ m^2_\pi$, see Text).

Fig. 3 Invariant mass distribution of the $p\pi^+$ system for events with a minimum four-momentum transfer (a) $\Delta^2_{min}(p/p\pi^+) <$ 0.3 GeV^2, (b) $\Delta^2_{min}(p/p\pi^+) <$ 0.1 GeV^2.
The curves show the predictions of the OPEM with form factor corrections.

Fig. 4 One-pion-exchange diagrams for Reaction (1).

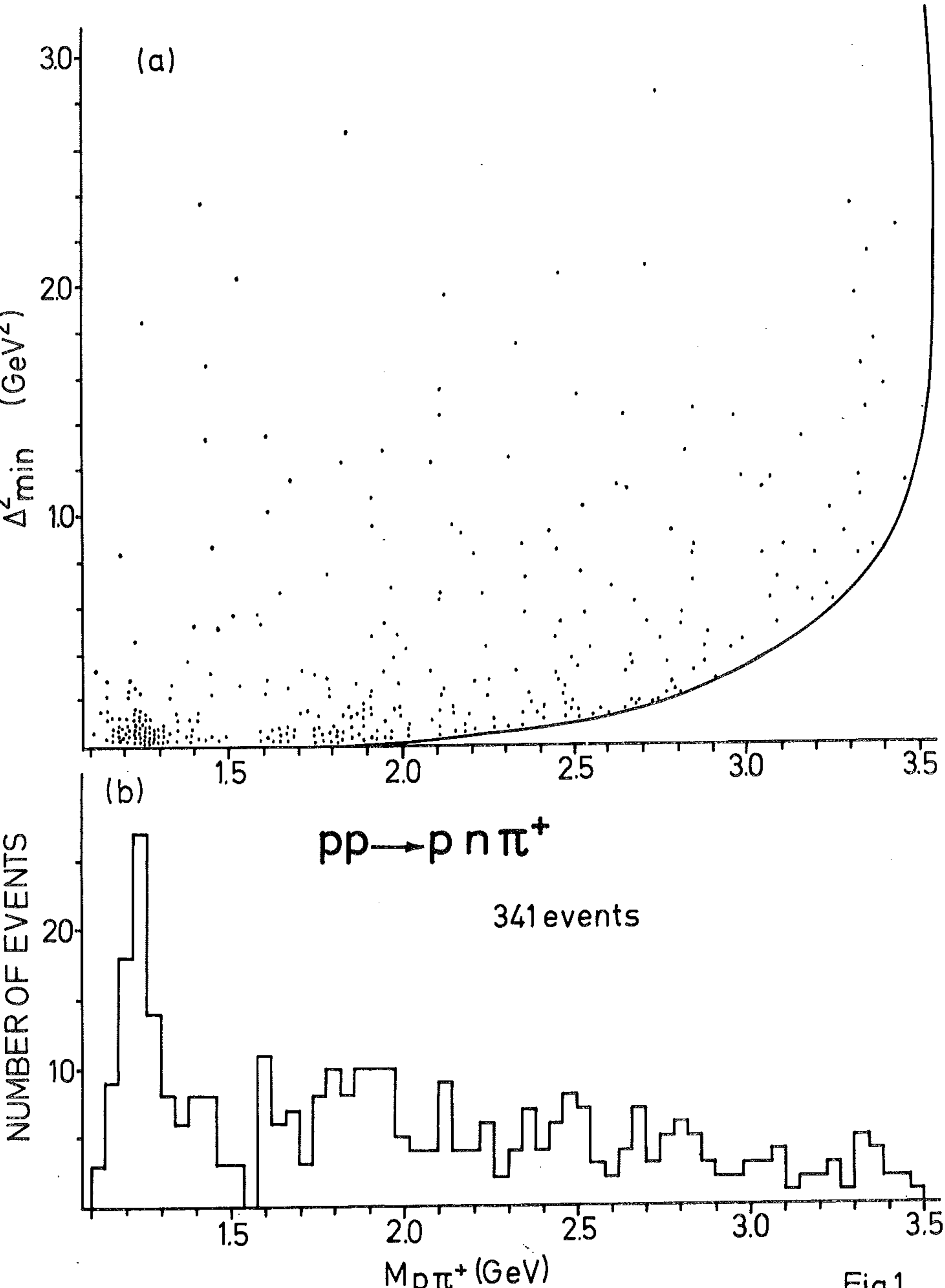
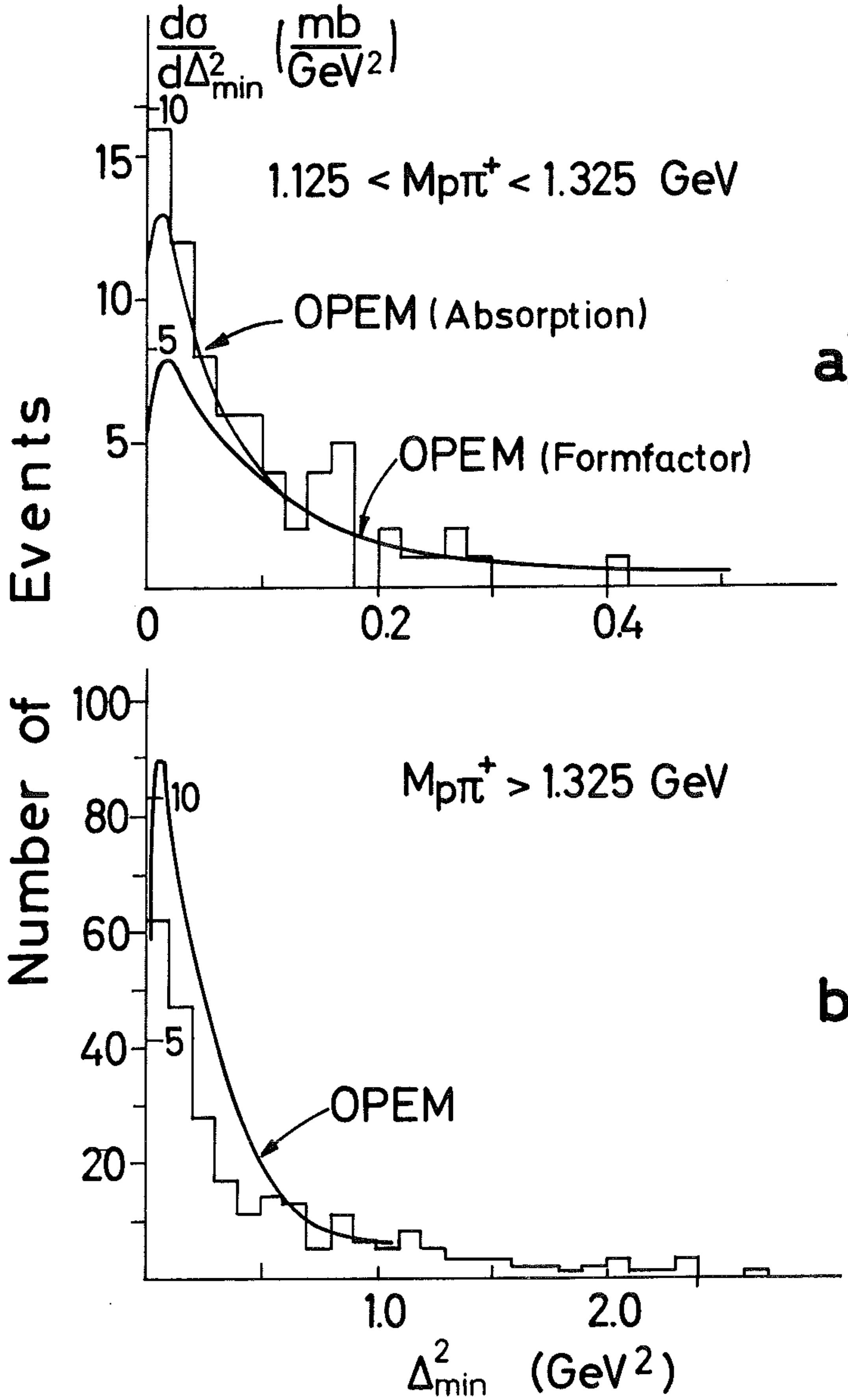
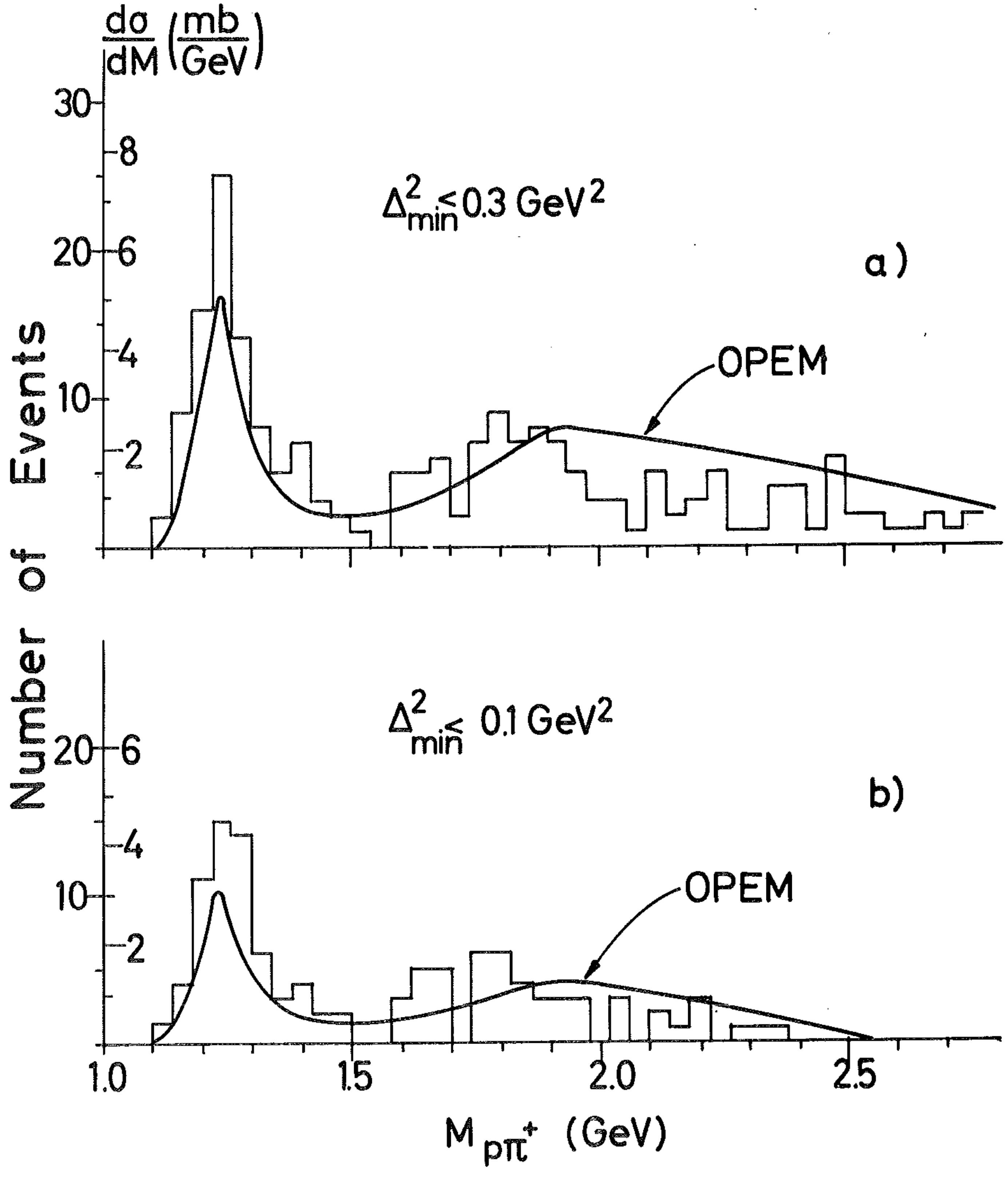

(a)
3.0
2.0
1.0
Δ^2_{min} (GeV^2)
1.5
2.0
2.5
3.0
3.5
(b)
pp → p n π⁺
341 events
NUMBER OF EVENTS
20
10
1.5
2.0
2.5
3.0
3.5
Mpπ⁺ (GeV)

Fig.1



dσ/dΔ²min (mb/GeV²)
10
15
1.125 < Mpπ⁺ < 1.325 GeV
10
OPEM (Absorption)
5
a)
5
OPEM (Formfactor)
Number of Events
0
0.2
0.4
100
Mpπ⁺ > 1.325 GeV
80
10
60
b)
40
5
OPEM
20
1.0
2.0
Δ²min (GeV²)

Fig. 2



dσ/dM (mb/GeV)
Number of Events
30
8
20
6
10
4
2
Δ²min ≤ 0.3 GeV²
a)
OPEM
Δ²min ≤ 0.1 GeV²
b)
OPEM
1.0
1.5
2.0
2.5
M pπ⁺ (GeV)

Fig.3

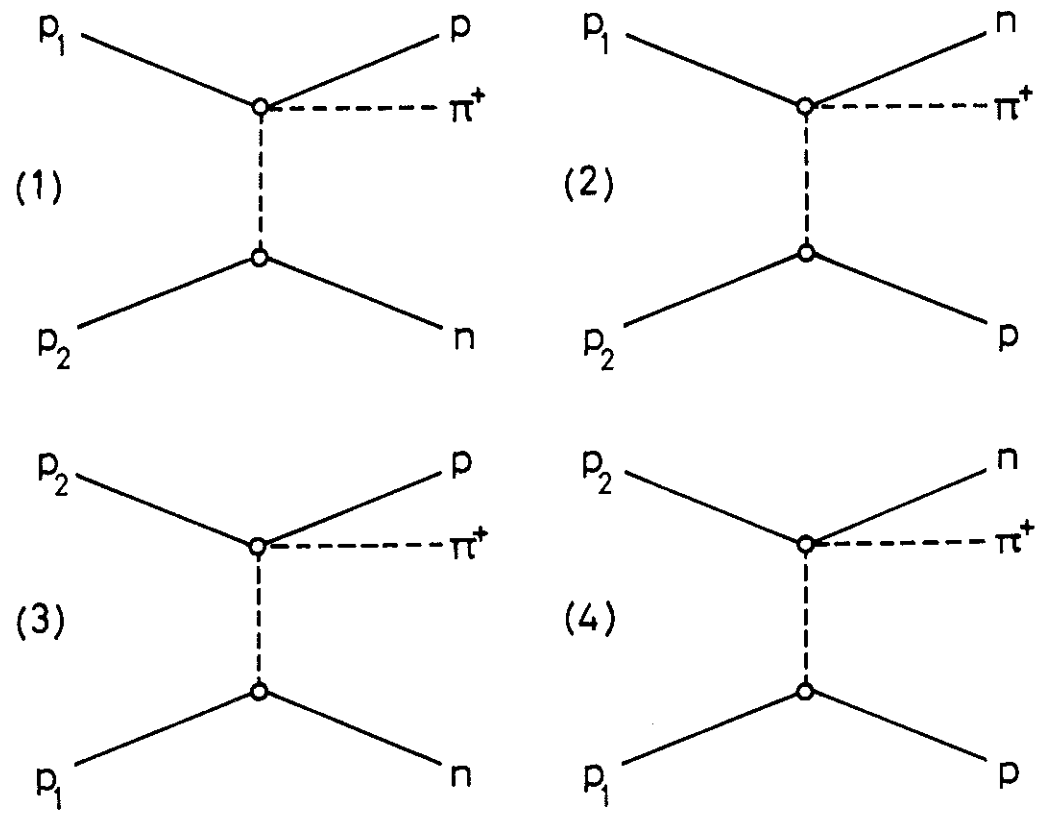


Fig. 4