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OBSERVATION OF NEUTRON-NEUTRON INTERACTIONS WITH DOUBLE DIFFRACTION DISSOCIATION AT THE ISR

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ABSTRACT

Neutron-neutron interactions have been observed at the CERN ISR with deuteron colliding beams. The double diffraction dissociation process $nn \rightarrow (p\pi^-)(p\pi^-)$ has been measured with the Split Field Magnet at $\sqrt{s} = 26$ GeV detecting all final state particles, including the two spectator protons. Mass and t distributions are presented and compared with corresponding spectra observed in single neutron diffraction in the same energy range with supporting evidence for factorization. The cross-section of the process is 11.5 ± 2.8 μb and can be directly related to the corresponding value for double diffraction dissociation of protons in the same energy range.

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Double diffraction dissociation, in which both incident particles are excited through the exchange of vacuum quantum numbers only, has recently been observed in proton-proton collisions [1] and investigated in some detail at the ISR [2]. Although representing a small fraction of the total diffractive cross-section, these processes allow detailed investigation of the dynamics of diffraction by comparison with corresponding processes of single proton diffractive excitation.

From previous experiments, no results had been obtained either on neutron-proton or neutron-neutron double diffraction, in contrast with the many results available in pn interactions up to the highest accelerator energies. In particular, very little was known about high-energy nn collisions, due to the experimental difficulties which arise with conventional accelerators for both beams and targets.

Colliding deuteron beams, as recently obtained at the CERN Intersecting Storage Rings, besides offering several experimental advantages [3] associated with fast moving deuterons, provide a new and versatile tool for studying nn interactions, thus filling the gap of the possible two-nucleon initial states. For incoherent reactions, detection of two symmetric spectator protons in the final state labels the break-up of both colliding deuterons, thus allowing a complete knowledge of the nn initial state.

In this letter we report preliminary results on the first measurement of double neutron diffraction dissociation in the reaction

$$nn \to (p\pi^-)\ (p\pi^-)\ , \qquad (1)$$

where the two spectator protons have been omitted in the notation. The data come from about 40 h of test runs in which luminosity reached the value of 0.18 $\mu b^{-1}\ sec^{-1}$; the integrated luminosity corresponding to our data sample is about 5300 μb^{-1}. The measurement was carried out with the Split Field Magnet detector (SFM) at the ISR.

The study of reaction (1) as the first stage of an investigation on nn processes is motivated by several considerations, the most immediate being the simplicity of the experimental detection of the symmetric double $(p\pi^-)$ system. Direct information on the production mechanisms can be inferred from the comparison of reaction (1) with single neutron diffraction dissociation

$$np \to (p\pi^-)p \qquad (2)$$

also measured at the ISR [3] in pd collisions with the same technique and apparatus within days of the dd run on which we report here. In addition, reaction (1) yields new information on the processes of double diffraction of nucleons which can be compared with pp data [2] collected at the ISR with the same Split Field Magnet detector.

The symmetric SFM setup [4], complemented by the small-angle detection capabilities in the downstream compensating magnets, allows a very efficient detection of both spectator protons with an over-all acceptance in excess of 95% for 26 GeV/c deuteron beams. This tags the interaction of two quasi-monochromatic neutrons at a c.m. energy of about 26 GeV, with an 8% spread due to Lorentz-expanded Fermi momentum distributions. The reconstructed neutron momenta in the deuteron rest frame follow closely the prediction of the Hulthèn wave function for all values of the momentum. We place a fiducial cut on this quantity at 0.3 GeV/c.

Similarly the neutron angular distributions in the d rest frame are uniform, as expected from the well-known s-wave composition of the deuteron wave function. In this case the asymmetry of kinematical origin introduced by the invariant Møller flux factor is compensated by the symmetry of the neutron motions in the two-deuteron initial state.

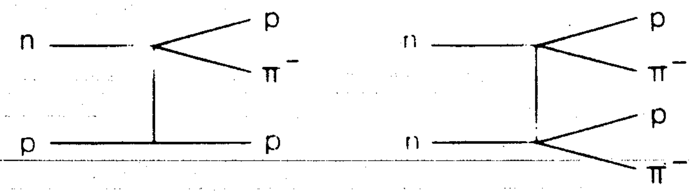
Reconstruction of events and selection of the sample using a 4C fit to reaction (1) indicate negligible background contributions, as supported by the source and χ^2 distributions. No ambiguity arises between spectators and neutron-like protons, given their substantially different momentum spectra. Figure 1 shows the two distributions in the laboratory; a normalized Monte Carlo calculation indicates that on the basis of momentum arguments alone*) the spectator identification is ambiguous in less than 4% of the cases.

The combined mass distribution of the two $(p\pi^-)$ systems from the 858 fitted events is shown in Fig. 2. The usual low mass enhancement, concentrated below 2 GeV, dominates the mass spectrum and some structures appear at the positions of the known $N^{*0}(1470)$ and $N^{*0}(1688)$ isobars. This behaviour is very similar to what is observed in single neutron dissociation [5] at FNAL and, apart from statistical fluctuations, the distribution is almost identical to the corresponding mass spectrum observed in single neutron diffraction dissociation [3] at the ISR. This similarity can be interpreted in terms of factorization, since the dissociating neutron at one vertex of the reaction appears to be completely independent of the nature of the other nucleon vertex, be it an "elastically" scattered proton or another dissociating neutron.

The same qualitative behaviour of the mass spectrum is displayed by two-body single proton dissociation at ISR energies [6] in the diffractive process, which is charge-symmetric to reaction (1) (at the neutron vertex). In particular, the steep drop of the mass distributions around 2 GeV seems to be a common feature of few-body diffractive processes.

*) The spectator is identified as the proton with fitted momentum closest to the nominal central value, equal to half the beam momentum.

When comparing single and double neutron dissociation having a common $n \to p\pi^-$ vertex



one expects the t-distributions to be sensitively dependent on the nature of the non-common vertex. These distributions should reflect the substantial slope difference between the differential cross-sections of elastic scattering and single dissociation. Figure 3a shows the differential distribution integrated over all final state $(p\pi^-)$ masses. The forward peak is considerably shallower than in single diffraction and the structure which develops around 0.3 GeV^2 is much more pronounced. From the slope observed in single neutron diffraction [3], $b_D = 8.2 \pm 0.3\ GeV^{-2}$, and assuming similarity of slope behaviour among pp, pn and nn elastic scattering, one would predict for the double diffractive forward slope [7] b_{DD}:

$$b_{DD} = 2 \times 8.2 - [8.23 + 0.556\ \ln(s_{nn})] \qquad (3)$$

One gets $b_{DD} = 4.5 \pm 0.6\ GeV^{-2}$, in good agreement with the experimental value $b_{DD} = 4.1 \pm 0.6\ GeV^{-2}$.

The forward slope is known to be a rather steep function of the produced mass in single diffraction and is observed to have an even steeper dependence on final-state masses in double proton diffraction [2], as expected from factorization arguments.

This feature is observed also in double neutron diffraction, as shown in Fig. 3b; here $(p\pi^-)$ masses close to threshold have been selected in either of the two dissociated systems. Structures in t also become more evident with decreasing mass. In this case a clear dip-maximum structure develops at small four-momentum transfer, thus supporting the already observed tendency of double diffraction differential distributions [2] to display complex behaviours with greater clarity than single diffractive data.

A preliminary value for the cross-section of reaction (1) is $\sigma_{DD} = 11.5 \pm 2.8\ \mu b$; a 2.3% correction for each colliding deuteron, due to the fiducial cut on the spectator momentum, and a 5% correction due to Glauber screening have been taken into account. Most of the error is due to the systematic uncertainty in the absolute scale of the over-all detection efficiency and of the luminosity measurement.

This cross-section can be compared with that for single neutron diffraction dissociation (2). Applying factorization to predict the single diffractive cross-section σ_{SD} from our measured value of σ_{DD} and extrapolating to $\sqrt{s} \simeq 37$ GeV with a $p_L^{-0.4}$ dependence*), one obtains $\sigma_{SD} = 214 \pm 27$ μb in good agreement with the measured value $\sigma_{SD} = 182 \pm 45$ μb [3].

One may also compare σ_{DD} for reaction (1) with the double diffractive cross-section for

$$pp \to (p\pi^+\pi^-)\ (p\pi^+\pi^-)\ , \tag{4}$$

which is ∿ 5 μb over the ISR energy range [2]. Under the assumption that the elasticity values for isobars in the low mass range hold over the two-body and three-body diffractive mass spectra one would expect

$$\frac{\sigma_{DD}(N\pi)}{\sigma_{DD}(N\pi\pi)} \simeq \left[\frac{\Gamma(N^* \to N\pi)}{\Gamma(N^* \to N\pi\pi)}\right]^2 = 2\text{-}3$$

which accounts for the observed ratio of the double diffractive cross-section.

In summary, exclusive nn double diffraction has been detected and measured in a preliminary investigation on neutron dissociation processes at the ISR. As for pp double diffraction dissociation, simple factorization predictions on mass spectra and slopes of differential t distributions seem to be supported by the data. In addition, well resolved structures appear in the four-momentum transfer distributions to a greater extent than in single diffractive processes. All these features, together with the observed value of the total cross-section, indicate a common behaviour of the processes of double diffraction dissociation of nucleons both in two-body and in three-body final states.

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*) This dependence fits the existing data on both $pp \to p(n\pi^+)$ and $pn \to p(p\pi^-)$ [6,11].

REFERENCES

[1] R. Webb et al., Phys. Letters 55B, (1975) 336; Phys. Letters 55B, (1975) 491.
A. Firestone et al., Phys. Rev. D 12 (1975) 15.

[2] M. Cavalli-Sforza et al., Nuovo Cimento Letters 14 (1975) 345; Nuovo Cimento Letters 14 (1975) 353; Nuovo Cimento Letters 14 (1975) 359.

[3] G.C. Mantovani et al., First results on neutron diffraction dissociation at the ISR (to be published in Phys. Letters B).

[4] R. Bouclier et al., Nuclear Instrum. Methods 115 (1975) 235.

[5] J. Biel et al., Phys. Rev. Letters 36 (1976) 504.

[6] H. de Kerret et al., Phys. Letters 63B (1976) 477.

[7] Y. Akimov et al., Phys. Rev. D 12 (1975) 3399.

[8] G. Kane, Acta Phys. Polon. B3, (1972) 845.

[9] S. Humble, Nuclear Phys. B76 (1974) 137.

[10] E.L. Berger, report ANL-HEP-PR-75-06 (1975).
E.L. Berger and P. Pirilä, report ANL-HEP-PR-75-27 (1975).

[11] Scandinavian Bubble Chamber Collaboration, Nuclear Phys. B87 (1975) 426.
A. Babaev et al., Diffraction dissociation of neutron into ($p\pi^-$) on protons in the momentum range 35 to 65 GeV/c (submitted to Nuclear Phys.)

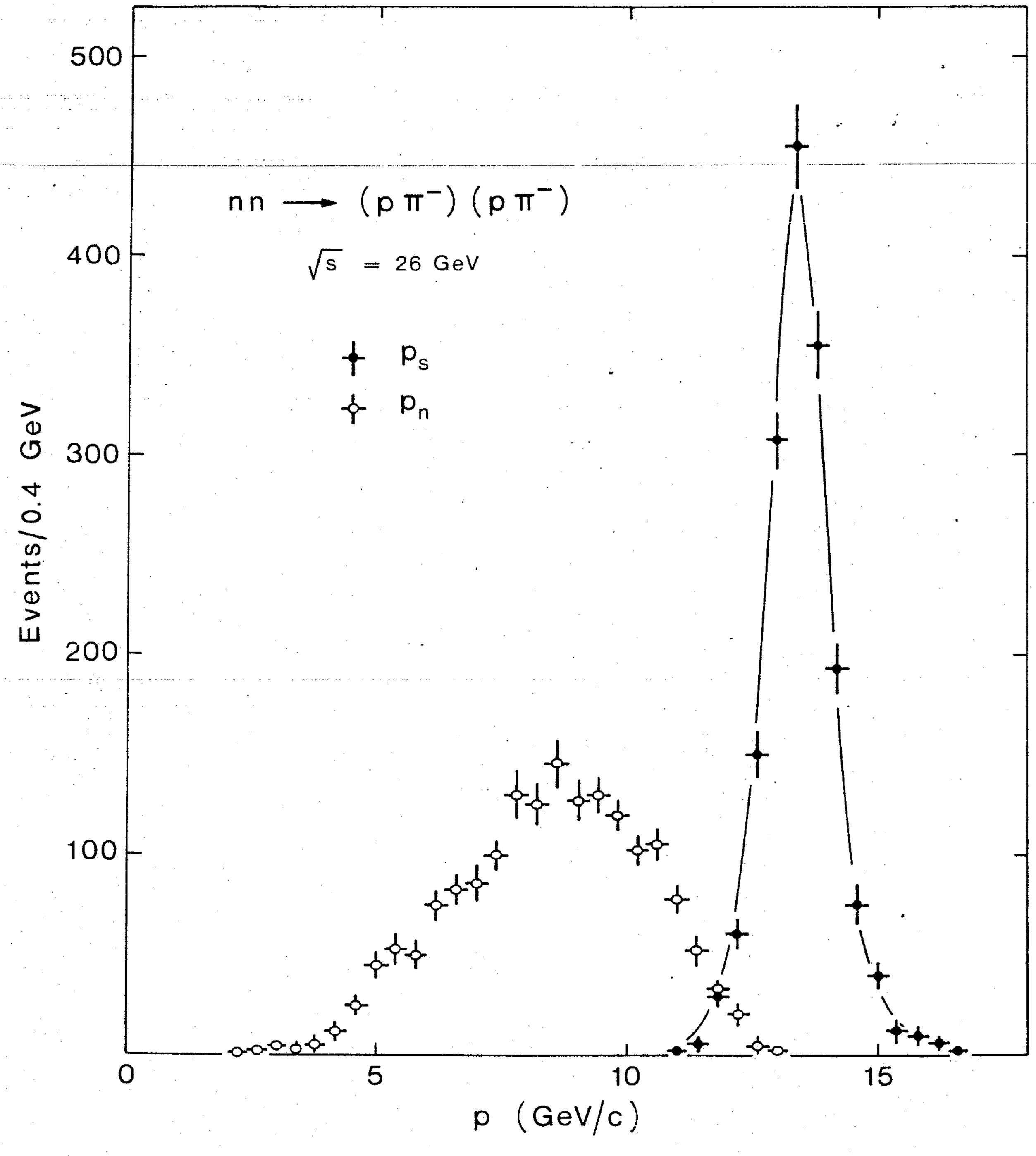
Figure captions

Fig. 1 : Momentum distributions in the laboratory of the spectator and of the neutron-like proton in reaction (2). Both dissociated systems contribute to this plot. The peak at half the beam momentum is due to the spectator protons and is in agreement with a Hulthèn momentum distribution Lorentz-transformed to the laboratory system (full line).

Fig. 2 : Mass spectrum of the two $(p\pi^-)$ systems in double neutron diffraction [reaction (2)]. (a.u. = arbitrary units).

Fig. 3 : a) Differential t distribution integrated over all $(p\pi^-)$ masses for reaction (2). (a.u. = arbitrary units).

b) Differential t distribution for events having at least one of the two $(p\pi^-)$ systems with mass below 1.3 GeV.



nn ⟶ (p π⁻) (p π⁻)
√s = 26 GeV
p_s
p_n
Events/0.4 GeV
500
400
300
200
100
0
5
10
15
p (GeV/c)

Fig. 1

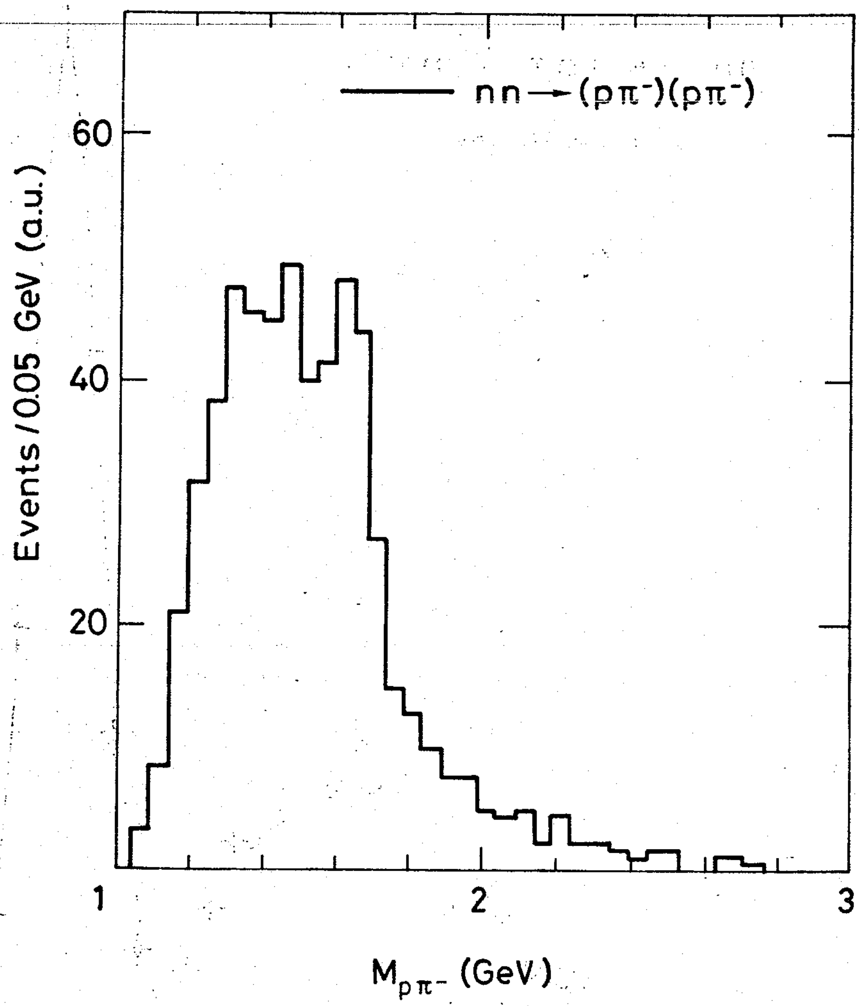


Fig. 2

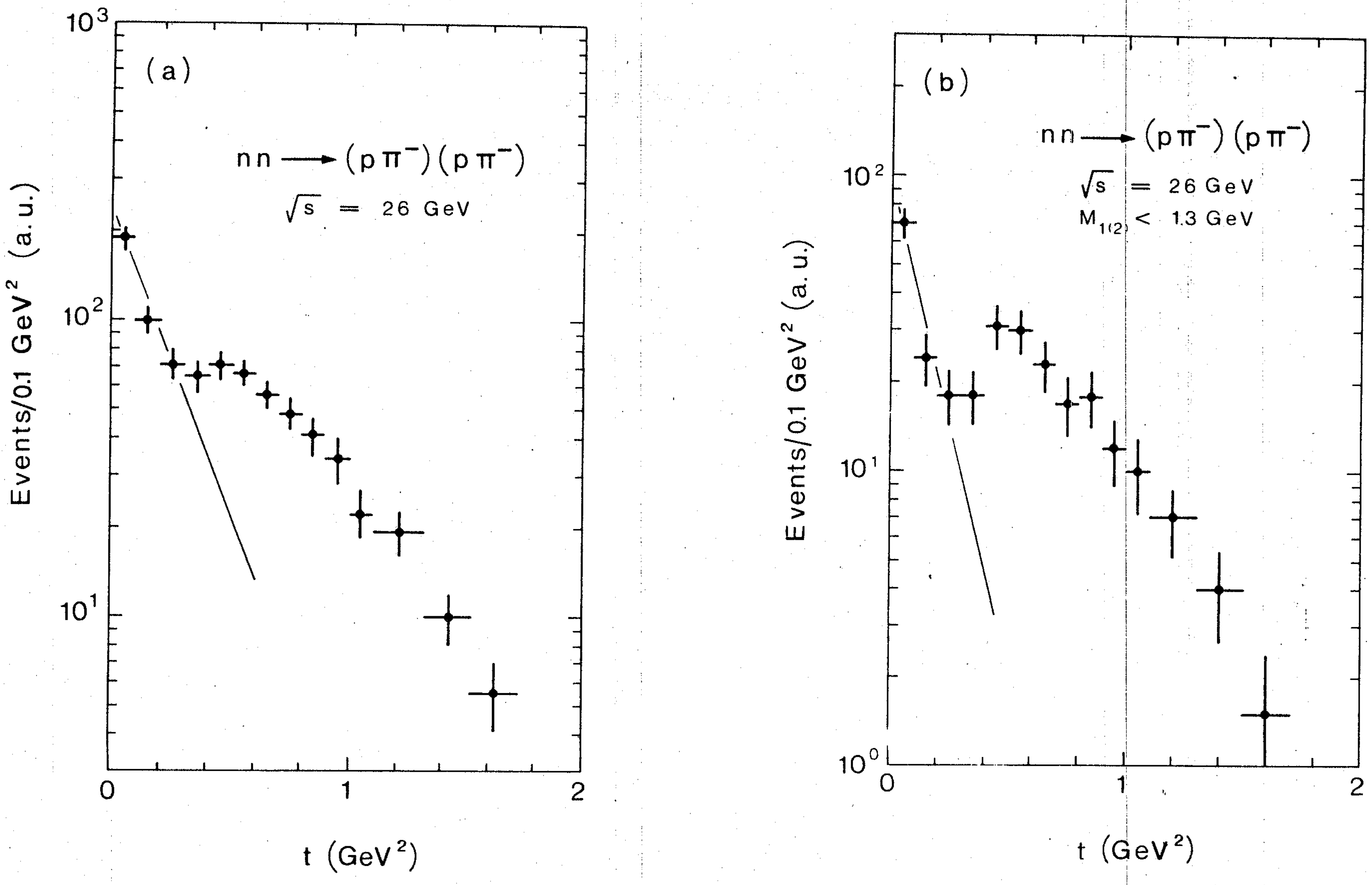

(a)
nn ⟶ (pπ⁻)(pπ⁻)
√s = 26 GeV
Events/0.1 GeV² (a.u.)
t (GeV²)
(b)
nn ⟶ (pπ⁻)(pπ⁻)
√s = 26 GeV
M1(2) < 1.3 GeV
Events/0.1 GeV² (a.u.)
t (GeV²)

Fig. 3