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NEW RESULTS ON NUCLEON DOUBLE DIFFRACTION AT THE CERN ISR

G. Goggi*)

CERN, Geneva, Switzerland

M. Cavalli-Sforza**), C. Conta, M. Fraternali, F. Impellizzeri, G.C. Mantovani, F. Pastore, A. Rimoldi and B. Rossini

Istituto di Fisica Nucleare dell'Università di Pavia and INFN, Sezione di Pavia, Italy

ABSTRACT

Results on exclusive double diffraction dissociation in ($N\pi$) and ($N\pi\pi$) final states are reported for neutron-neutron interactions at $\sqrt{s}$ = 26.4 GeV and for proton-neutron interactions at $\sqrt{s}$ = 37.2 GeV. The data have been obtained at the CERN Intersecting Storage Rings using the Split Field Magnet detector with proton-deuteron and deuteron-deuteron colliding beams. Factorization is shown to be verified to a very high degree in both mass- and t-differential cross-sections. The data confirm the previously observed rise in the proton-proton double diffractive cross-section as a function of c.m. energy.

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*) On leave from the Istituto di Fisica Nucleare, Università di Pavia and INFN, Sezione di Pavia, Italy.

**) Present address: Princeton University, Princeton, NJ, USA.

The recent observation [1] at the CERN Intersecting Storage Rings (ISR) of a substantial increase at high energy of the cross-section for proton-proton double diffraction in the process

$$pp \to (p\pi^+\pi^-)(p\pi^+\pi^-) \quad (1)$$

raises several questions relevant to the understanding of the nature of the Pomeron and of the diffraction dissociation mechanism.

In the usual exchange picture, diffractive amplitudes are thought to be factorizable, and this property is expected to hold even when relaxing [2] the assumption of a dominant trajectory. A detailed connection between single and double diffraction can nevertheless be difficult, in view of the observation [3] of a pronounced local breakdown of factorization in a t-dependent comparison between elastic and inelastic diffractive cross-sections in pp collisions. This breakdown, however, could be attributed to an essential difference in the impact parameter description of elastic and inelastic diffraction [4]. Therefore significant tests for factorizing amplitudes are best performed in the absence of elastic-like vertices on differential distributions of purely inelastic diffractive processes, for which similar impact parameter structures can be assumed.

A second major problem is represented by the energy dependence of inelastic diffractive amplitudes, which is still largely unknown, since no consistent set of measurements of single diffractive cross-sections is at present available at ISR energies and the extrapolation of lower energy trends into the rising cross-sections régime can be seriously misleading. It is therefore of great interest to obtain better experimental limits on the s-dependence of double diffraction on the widest set of homogeneous independent measurements obtained at the ISR [1].

In this paper we extend our previous study of double diffraction in reaction (1) to the exclusive two- and three-body final states involving neutron diffraction in the processes

$$nn \to (p\pi^-)(p\pi^-) \quad (2)$$

$$pn \to (p\pi^+\pi^-)(p\pi^-) \quad (3)$$

from new data taken at the CERN ISR with 26 GeV/c deuteron-deuteron and proton deuteron colliding beams*). These results allow stringent tests of Pomeron factorization on the whole differential mass- and four-momentum transfer distributions among similar inelastic diffractive reactions and provide new information on the cross-section rise observed [1] for proton double diffraction over the ISR energy range.

Reactions (2) and (3) have been measured with the Split Field Magnet (SFM) detector at c.m. energies in the nucleon-nucleon system of 26.4 GeV and 37.2 GeV, respectively, for 26.6 GeV/c incident beams. Details on the data samples are given in table 1. The SFM detector has been described elsewhere [6]: it is essentially composed of two symmetric forward magnetic spectrometers equipped with multiwire proportional chambers; two smaller downstream compensator magnets with additional chambers allow magnetic analysis also on particles at very small angles to the beams.

Details on triggers, event selection and reconstruction, and on the Monte Carlo simulation have been described in previous papers [1,7]. In the deuteron arm(s) a highly efficient detection of the spectator proton in the compensator magnet(s) [7,8] allowed a complete determination of the incoming neutron vector momentum. After a four-constraint kinematical fit, events corresponding to a confidence level larger than 1% were retained. As for reaction (1), no appreciable phase space cuts are present in the final sample and background contaminations are below the 2% level. For each dissociating neutron in reactions (2) and (3), a 5% shadow correction and 2.3% correction accounting for undetected spectator proton momenta in the wave function tail were applied. An over-all scale uncertainty of ±12% due to systematical effects was estimated for the cross-section values.

The invariant mass spectra at the two vertices of reaction (3) are shown in figs. 1a and b. They display the distinctive features of $(N\pi)$ and $(N\pi\pi)$ diffractive excitation with strong signals at the N(1688) mass superimposed on

*) Preliminary data on reaction (2) obtained during a short test run have already been published [5]. They are not included in the present analysis of the subsequent complete experiment.

Figure 2a shows the differential cross-section of reaction (2) measured up to $-t = 2.0\ (\mathrm{GeV}/c)^2$. It is clear that the t-dependence of the differential cross-section cannot be satisfactorily described with a simple exponential parametrization. The curve is a fit to the data with a peripheral impact-parameter profile model [10]. Also shown is the same fit for reaction (1) at $\sqrt{s} = 23$ GeV.

The absolute prediction of Eq. (6) is compared with the data of reaction (3) in fig. 2b *). Factorization for diffractive processes with no elastic vertices seems to be satisfied to a very high degree throughout the entire range of four-momentum transfer explored (χ^2/d.f. = 0.76).

For the purpose of comparing total cross-sections of all reactions (1) to (3), thereby obtaining new information on the energy dependence of double diffraction measured for reaction (1), a model-independent ratio of the total diffractive cross-sections in two- and three-body final states $\eta = \sigma(N \to N\pi)/\sigma(N \to N\pi\pi)$ is needed, owing to the large and different continuum contributions to the two mass spectra. The previous analysis and the data in fig. 2 imply a very good agreement among all three double diffractive cross-sections, but the cross-section values for reactions (2) and (3) are not linearly independent in the comparison with reaction (1) if one uses only data from our experiment**). An independent value for η can be obtained from isospin analyses of hadron-induced ($N\pi$) and ($N\pi\pi$) proton dissociation. These values are remarkably energy independent in the 30 GeV energy range [11]; taking a weighted average and applying the proper isospin coefficients, one obtains

$$\frac{\sigma(n \to p\pi^-)}{\sigma(p \to p\pi^+\pi^-)} = 1.20 \pm 0.12 \qquad (p_{tot} < 30\ \mathrm{GeV}/c)\ .$$

This value is in excellent agreement with the corresponding value [12,13] 1.21 ± 0.50 at 1000 GeV/c.

*) Owing to the energy difference at which reactions (2) and (3) have been measured, a small correction factor due to the observed energy dependence of the double diffractive cross-section [1] has been taken into account.

**) The values of η calculated from reactions (2) and (3) are 1.28 ± 0.06 at $\sqrt{s} = 26$ GeV and 1.27 ± 0.18 at $\sqrt{s} = 37$ GeV.

substantially different continuum distributions, with the two-body system peaking at lower masses than the three-body one.

Factorization in terms of invariant mass differential cross-sections predicts invariance of the mass distribution at one vertex for a given final-state configuration, irrespective of reaction type at the other vertex. This corresponds in our case to the requirement of unity ratios (for normalized cross-sections)

$$R_{ij}(M) = \frac{d\sigma/dM_i}{d\sigma/dM_j} ,$$

where the indexes refer to the appropriate reaction numbers (1) to (5) and M is the invariant mass of the $(N\pi)$ or $(N\pi\pi)$ system, according to the case.

In order to test this hypothesis, data have also been used on the single diffractive reactions:

$$pp \rightarrow p(p\pi^+\pi^-) \qquad \sqrt{s} = 53 \text{ GeV} \qquad (4)$$

$$pn \rightarrow p(p\pi^-) \qquad \sqrt{s} = 37 \text{ GeV} , \qquad (5)$$

measured during the same experiment [5]. As a consequence, the same acceptance factors, besides being smooth functions of M, appear in both numerator and denominator of R_{ij} and hence cancel out.

Figures 1c to f show quantitatively that the excitation properties of $(N\pi)$ and $(N\pi\pi)$ systems are identical in single, double (symmetric) diffraction and in the asymmetric case of reaction (3).

In the case just discussed the integration over four-momentum transfer washes out the effect of possible structures in the t-distribution contributed by the elastic vertex, since they appear at very low relative cross-section levels [3,9]. Approaching factorization from a t-dependent standpoint, we compare in the following the differential cross-sections for diffraction dissociation at both reaction vertices. The prediction for this case is

$$\frac{d\sigma}{dt}\left[pn \rightarrow (p\pi^+\pi^-)(p\pi^-)\right] = \left\{\frac{d\sigma}{dt}\left[pp \rightarrow (p\pi^+\pi^-)(p\pi^+\pi^-)\right]\frac{d\sigma}{dt}\left[nn \rightarrow (p\pi^-)(p\pi^-)\right]\right\}^{1/2} . \qquad (6)$$

Applying this factor to our data from reactions (2) and (3), we get equivalent cross-sections for reaction (1) at $\sqrt{s}$ = 26.4 and $\sqrt{s}$ = 37.2 GeV as shown in fig. 3. The errors given are quadratic combinations of statistical and systematic uncertainties. The new points are in good agreement with the previously measured ones for symmetric double proton excitation. Fitting the seven points to the function $\sigma = a + b \ln s$, we get a cross-section rising by (51 ± 5)% in the s-range 544 GeV^2 to 3878 GeV^2 *). The corresponding rise for the five points of reaction (1) was (55 ± 7)% in the same energy interval.

In conclusion, the ($N \to N\pi$) and ($N \to N\pi\pi$) exclusive diffractive excitation mass spectra appear to obey strict factorization for single and double diffraction processes. This in turn implies a remarkable invariance of the resonance to continuum ratio in the dissociated systems. A similar strong validity of factorization is observed when comparing double diffractive processes as a function of four-momentum transfer up to $-t = 2.0$ $(GeV/c)^2$. The diffractive production mechanisms therefore show definite factorization properties with respect to different incident particles, different final state topologies, and between single and double dissociation. The cross-section rise observed in symmetric double proton excitation is confirmed by new data on neutron-proton and neutron-neutron double diffraction.

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*) If the last point at $\sqrt{s}$ = 63 GeV is ignored the cross-section rise becomes (46 ± 5)% over the entire s-range. Introducing the exponent of a $(\ln s)^{\alpha}$ term as a free parameter the fit over seven points yields α consistent with 1.

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Table 1

Parameters of the data samples from reactions (2) and (3)

Reaction	$\sqrt{s}$ (GeV)	p_{lab} (GeV)	No. of events	$\int \mathscr{L}\, dt$ (μb^{-1})	Systematic uncertainty	σ (μb)
$nn \to (p\pi^-)(p\pi^-)$	26.4	371	1543	13277	12%	8.39 ± 0.96
$pn \to (p\pi^+\pi^-)(p\pi^-)$	37.2	738	785	8223	12%	7.72 ± 0.90

Figure captions

Fig. 1 : a) Mass distribution at the neutron vertex of reaction (3).

b) Mass distribution at the proton vertex.

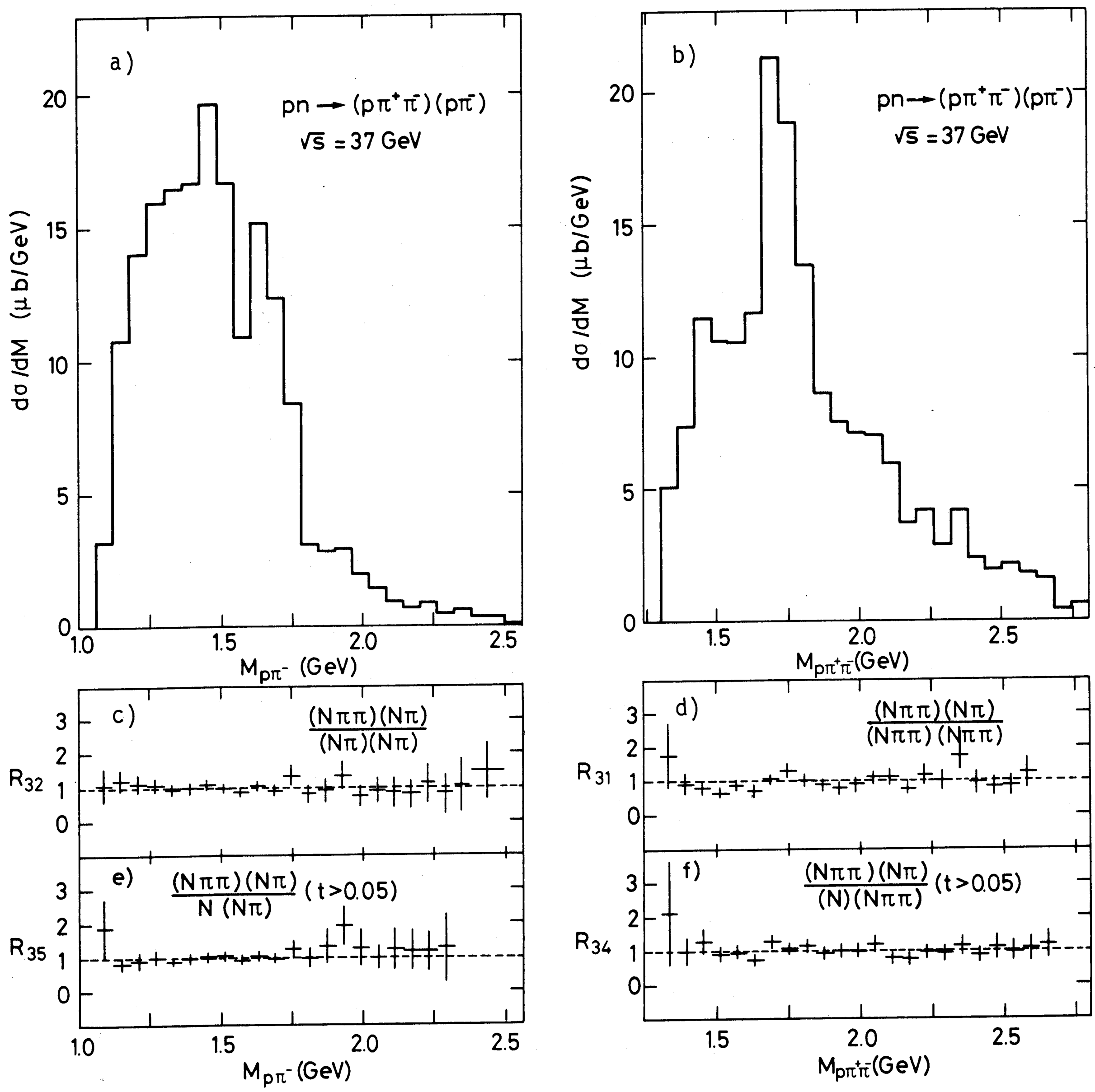
c),d) Ratio of the mass distributions in (a) and (b) to the corresponding normalized distributions of symmetric double diffraction, reactions (1) and (2).

e),f) Ratio of the mass distributions in (a) and (b) to the corresponding normalized distributions of single diffraction, reactions (4) and (5). The experimental t-cut $[-t > 0.05\ (\mathrm{GeV}/c)^2]$ for the data of the denominators has been applied also to the data in the numerators.

Fig. 2 : a) Differential cross-section for double neutron diffraction, reaction (2). The solid line is a fit to the data (see text). Also shown (displaced by a factor of 2) is the same type of fit for previous results of double proton diffraction, reaction (1).

b) Differential cross-section for pn double diffraction, reaction (3). The solid line is the absolute factorization prediction from the data in fig. 2a and eq. (6).

Fig. 3 : Total cross-section for reaction (1) as a function of equivalent laboratory momentum. New data deduced from reactions (2) and (3) are also shown. The solid line is a ln (s) fit to all seven points.



a)
pn → (pπ⁺π⁻)(pπ⁻)
√s = 37 GeV
dσ/dM (μb/GeV)
M_pπ⁻ (GeV)
b)
pn → (pπ⁺π⁻)(pπ⁻)
√s = 37 GeV
dσ/dM (μb/GeV)
M_pπ⁺π⁻ (GeV)
c)
(Nππ)(Nπ) / (Nπ)(Nπ)
R32
d)
(Nππ)(Nπ) / (Nππ)(Nππ)
R31
e)
(Nππ)(Nπ) / N (Nπ) (t>0.05)
R35
M_pπ⁻ (GeV)
f)
(Nππ)(Nπ) / (N)(Nππ) (t>0.05)
R34
M_pπ⁺π⁻ (GeV)

Fig. 1

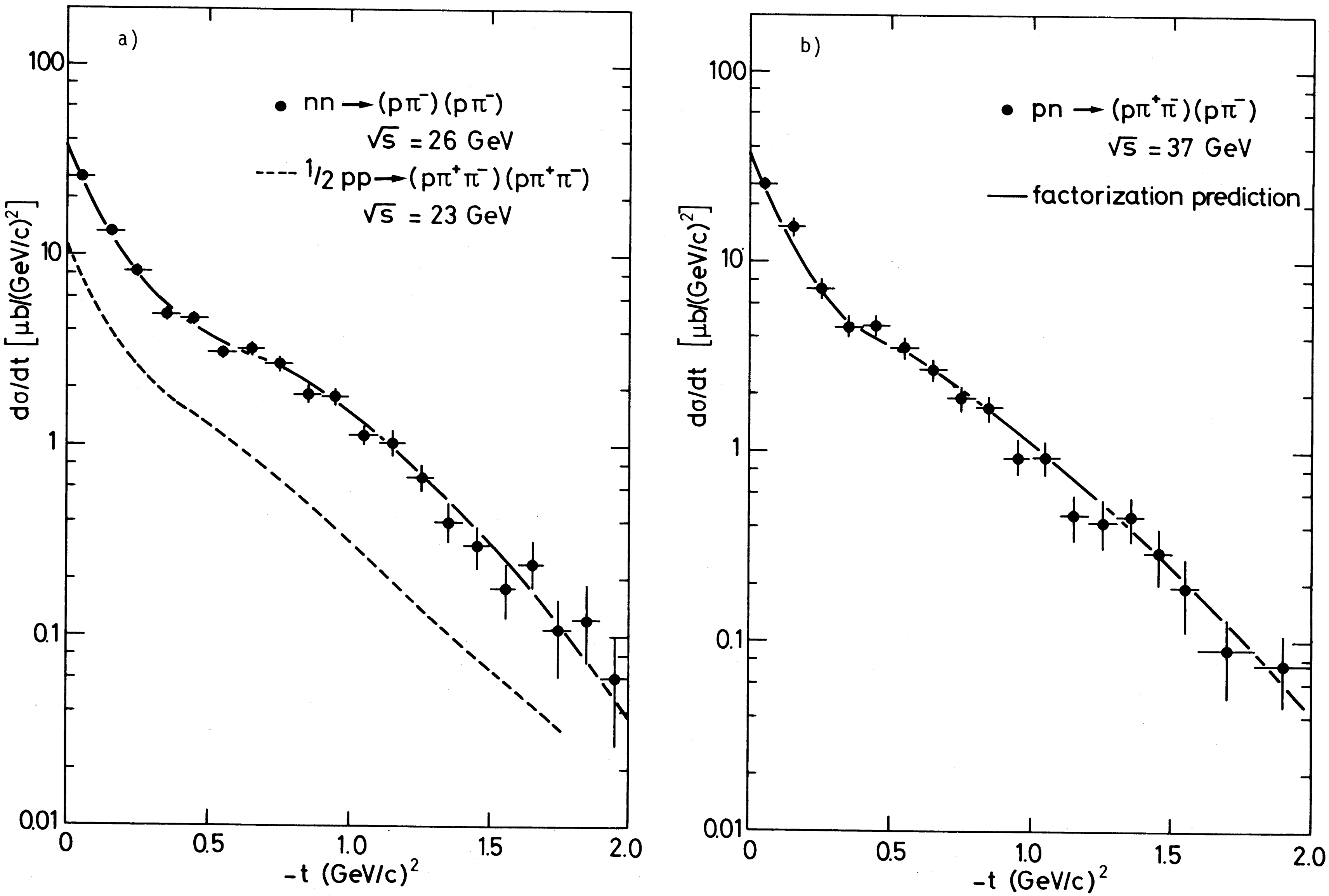

a)
nn → (pπ⁻)(pπ⁻)
√s = 26 GeV
1/2 pp → (pπ⁺π⁻)(pπ⁺π⁻)
√s = 23 GeV
b)
pn → (pπ⁺π⁻)(pπ⁻)
√s = 37 GeV
factorization prediction
dσ/dt [μb/(GeV/c)²]
-t (GeV/c)²

Fig. 2

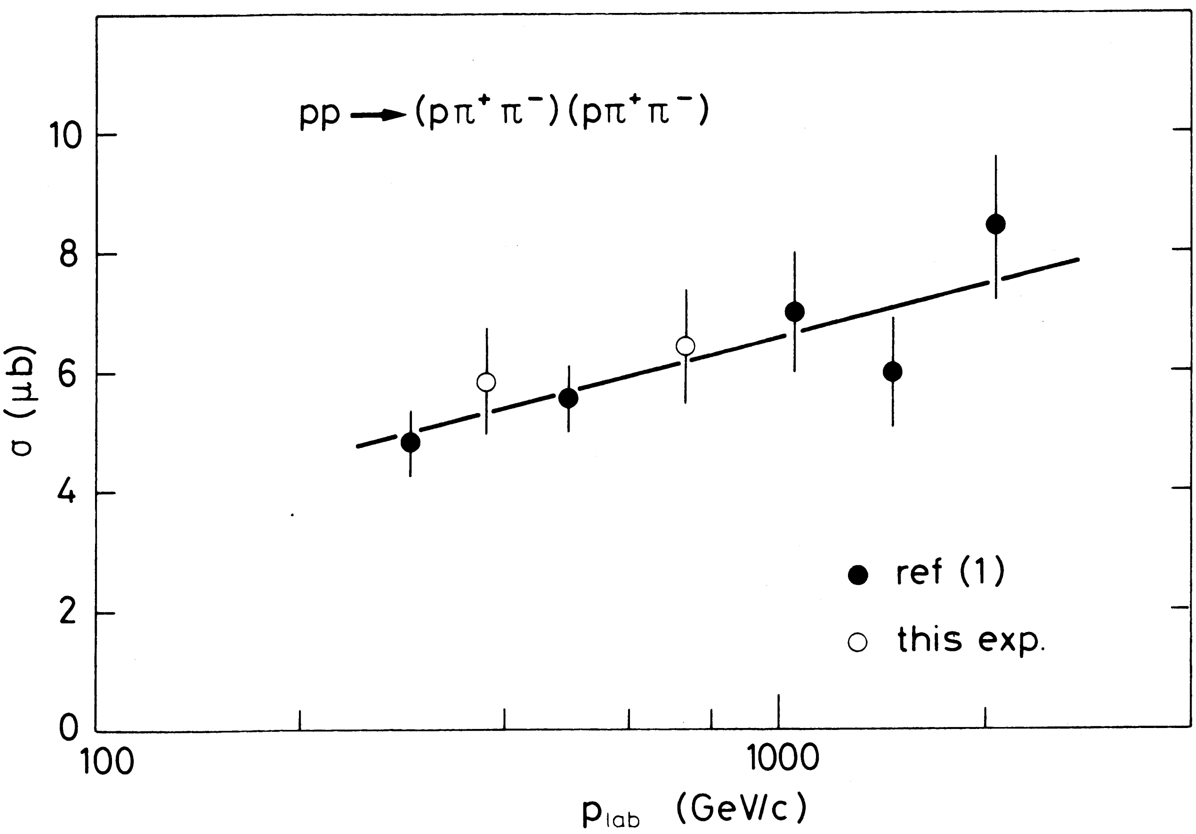


Fig. 3