STUDY OF EXCLUSIVE NEUTRON REACTIONS AND COHERENT DEUTERON PROCESSES AT THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

Preliminary results from an experiment studying proton-deuteron (pd) and deuteron-deuteron (dd) coherent and incoherent interactions at the ISR are presented. Total and differential cross-sections of various diffractive channels are shown, together with some features of mass spectra and decay angular distributions of the produced systems. Experimental data on pd and dd elastic scattering are compared with the Glauber model predictions.

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The successful storage of deuteron beams in the CERN Intersecting Storage Rings (ISR) has opened up an interesting new subject of investigation; pd and dd collisions in fact provide a versatile tool for studying inelastic neutron interactions at very high energy, while pd and dd elastic scattering and coherent nucleon dissociation processes are of special interest in view of the speculations on the space-time evolution of hadronic matter during the collision inside a particularly simple nucleus.

For the study of neutron interactions, deuteron beams represent a source of quasi-monochromatic neutrons. A measurement of the spectator proton vector momentum specifies completely the neutron initial state, thus virtually providing a tagged neutron beam. With a neutron initial state one can study nucleon diffraction dissociation into a two-body charged ($p\pi^-$) final state which represents the simplest configuration for the analysis of the production mechanisms.

By requiring the presence of an undissociated deuteron in the final state, one tags coherent reactions characterized by pure isoscalar exchange, achieving a stronger signature for diffractive processes. A comparison of the pure $I = \frac{1}{2}$ dissociated final states with those produced in pp collisions may provide information on the non-diffractive mechanisms still present at ISR energies.

At moderate t-values ($|t| \simeq 0.3$ GeV^2), rescattering terms dominate the behaviour of the coherent differential cross-sections, as described by the Glauber theory[1]. At very high energy one may expect deviations from the simple Glauber approach[2], when in the primary collision the nucleon is excited into an inelastic intermediate state, which propagates through the deuteron. At the ISR the spectrum of nucleon excitation has been observed[3] to extend to very large masses ($M^2/s \lesssim 0.1$), which should give particular relevance to inelastic propagator diagrams. Since the rescattering time is now extremely short with respect to the characteristic evolution time of these systems, rescattering can act as a probe of the space-time properties of hadronic matter and of unstable hadron interactions[4]. The same arguments also hold for elastic pd and dd scattering, for which data in the rescattering region are missing at these energies.

With pd and dd colliding beams of 26.6 and 31.5 GeV/c we have investigated the single and double diffractive reactions:

$$pn \rightarrow p(p\pi^-) \quad \text{at} \quad \sqrt{s} = 37 \text{ GeV} \tag{1}$$

$$pn \rightarrow (p\pi^+\pi^-)(p\pi^-) \quad \text{at} \quad \sqrt{s} = 37 \text{ GeV} \tag{2}$$

$$nn \rightarrow (p\pi^-)(p\pi^-) \quad \text{at} \quad \sqrt{s} = 27 \text{ GeV} . \tag{3}$$

Together with the data that we previously collected in pp interactions on the reactions

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

$$pp \rightarrow (p\pi^+\pi^-)(p\pi^+\pi^-) \quad \text{at} \quad \sqrt{s} = 23 \text{ to } 63 \text{ GeV} , \tag{5}$$

we aim to get a relative complete picture of nucleon diffraction in the ISR energy range with a large amount of complementary information from correlated channels, allowing for cross-checks and for several independent factorization tests.

In addition we have taken data on the coherent diffractive reactions:

$$pd \rightarrow (p\pi^+\pi^-)d \quad \text{at} \quad \sqrt{s} = 53 \text{ GeV} \tag{6}$$

$$nd \rightarrow (p\pi^-)d \quad \text{at} \quad \sqrt{s} = 37 \text{ GeV} \tag{7}$$

and on pd and dd elastic scattering at $\sqrt{s}$ = 53 and 63 GeV.

It is worth pointing out that comparisons among similar reactions can be performed in our experiment using data samples which are homogeneous in terms of energy, acceptance corrections, and general performance of the apparatus.

The apparatus used is the Split Field Magnet detector, consisting of two forward telescopes equipped with 23 proportional chambers[5]. For details concerning the whole experimental procedure we refer to already published papers[6]. In the following we shall limit ourselves to considering some aspects of the physical results.

The results obtained so far, though still preliminary, concern total and differential cross-sections and general features of the produced mass spectra and of the decay angular distributions.

1. TOTAL DIFFRACTIVE CROSS-SECTIONS

Our results on nucleon diffractive excitation, both coherent and incoherent, contribute to considerably extend the energy range in which these processes have been measured.

If we compare different diffraction dissociation channels, the general picture of the cross-section energy dependence seems to contradict a simple universal behaviour (Fig. 1). In fact, while the diffractive production of $N^*(1680)$ extracted from the available data seems to be essentially constant at high energy (p_{lab} = = 10-1000 GeV/c), the total cross-sections for single nucleon diffraction dissociation are still compatible with a slow decrease of the type $p_{lab}^{-(0.25-0.3)}$. On the other hand, our recent results[7] on double proton diffractive excitation [reaction (5)] show a strong increase of the total cross-section over the ISR energy range.

We remark, however, that the high-energy data are still too scanty to exclude a change of regime in the s-dependence of single diffractive excitation at ISR-FNAL energies.

2. DIFFERENTIAL CROSS-SECTIONS

The differential cross-sections for (incoherent) single and double neutron diffraction dissociation are shown in Fig. 2. Both present a structure at $|t| \simeq 0.3$ GeV^2, which is more pronounced in the double diffraction case. This structure develops into a local minimum when masses close to threshold are selected. These features can indicate a substantial peripheral non-spin-flip contribution at low masses or, alternatively, strong absorption in a Deck model description of the data[8].

Strong slope-mass correlation is observed in both reactions. An example for the single diffraction case is shown in Fig. 3. Preliminary tests, both in terms of total cross-sections and of forward differential slopes, are in good agreement with factorization, as usual.

3. COHERENT DISSOCIATION PROCESSES

An example of differential cross-section for a coherent reaction is shown in Fig. 4. The comparison with similar data at low energy[9] shows shrinkage of the forward peak from 12.5 to 750 GeV/c.

By investigating the differential cross-section of coherent nucleon diffraction [reactions (6-7)] in specific mass bands, it is possible to extract the (N^*N) total cross-section by comparison with the predictions of Glauber calculations including the (N^*N) rescattering term. The relevant diagrams are shown in Fig. 5.

A very preliminary evaluation of the interaction cross-section σ_{N^*N} of the $N^*(1680)$ has been obtained by comparing the experimental data on reaction (7) in the mass band 1.55-1.8 GeV, with various theoretical evaluations à la Glauber in which σ_{N^*N} was considered as a free parameter. There is indication that at ISR energies the estimated value for σ_{N^*N} is about $1/2\sigma_{NN}$, as also found by Edelstein et al. at 22.5 GeV/c [10].

4. MASS SPECTRA

In both two-body ($p\pi^-$) and three-body ($p\pi^+\pi^-$) diffractive mass spectra there is evidence of resonance contributions [particularly $N^*(1680)$] over a low-mass continuum, which is generally interpreted in terms of Deck model contributions[8]. Figure 6 shows a comparison of mass spectra for two-body coherent and incoherent final states. An enrichment of the low-mass continuum is expected and in fact observed in coherent diffraction dissociation because of the steeper t-dependence of the differential cross-section, dominated by the deuteron form factor, and of the role of the slope-mass correlation.

One way to investigate the dynamics of the dissociation mechanisms is the study of correlations in the decay angular distributions of the produced systems. The two-dimensional distributions in the ($\cos\theta - \phi$) plane of the Gottfried-Jackson system show evidence for the presence of both pion and baryon exchange Deck terms. This is a general feature of the diffractive reactions and seems to be somewhat enhanced in the coherent channels. Figure 7 shows one such distribution for coherently produced ($p\pi^+\pi^-$) systems. Numerical fits are in progress, in order to determine the relative weights of the various contributions in the different channels. Also Deck-type calculations of the rescattering terms in coherent diffraction on deuterons are known to be in progress[11].

5. PROTON-DEUTERON AND DEUTERON-DEUTERON ELASTIC SCATTERING

Preliminary Glauber model calculations of pd and dd elastic scattering at ISR energies have been performed for comparison with our experimental data.

In pd elastic scattering the Glauber theory foresees that the dip due to the interference between the single and double scattering terms is filled by the contribution of the deuteron quadrupole form factor. The situation is different in dd scattering since, owing to the presence of an "abnormal" rescattering term, the interference dip is expected at a lower t-value ($|t| \simeq 0.18$ GeV^2), where the quadrupole form factor contribution is much smaller[12].

A good agreement with the Glauber predictions can be observed in Fig. 8 where a sample of our pd data at $\sqrt{s} = 53$ GeV is shown. In Fig. 9 we compare a sample of dd elastic scattering data at $\sqrt{s} = 63$ GeV with the predicted differential cross-section. As in the previous case the agreement is good, particularly in the single scattering region, and the expected dip is observed around $|t| = 0.18$ GeV^2. Acceptance and resolution calculations are at present being refined in order to improve the details in the interference and double-scattering regions.

We observe, on the other hand, that the available low-energy data[13], besides being in general agreement with the predictions, display in detail systematic discrepancies with the Glauber theory in the multiple scattering region.

The extension of the standard Glauber calculations to include the rescattering of inelastic intermediate states, on the basis of the inclusive diffractive spectra measured at the ISR, is at present in progress.

6. CONCLUSIONS

The data of our experiment, although still incomplete, already fit into a rather consistent picture of nucleon diffraction; however, at the same time they leave open important questions which concern, in particular: a) the s-dependence of the total cross-sections of different diffractive processes; b) the relative importance of the various Deck graphs and resonant contributions; c) the peripheral nature of the dominant s-channel non-spin-flip amplitude. A preliminary extraction of σ_{N^*N} from coherent diffractive data is consistent with other experiments at low energy. Elastic pd and dd scattering data show a general agreement with the predictions of the standard Glauber model. In particular the expected interference dip in dd elastic scattering has been observed.

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Figure captions

Fig. 1 : Energy dependence of various diffractive channels investigated in this experiment. Full lines are hand-drawn.

Fig. 2 : Differential cross-sections for single (incoherent) and double neutron diffraction dissociation.

Fig. 3 : Forward slope versus mass in single (incoherent) neutron diffraction dissociation.

Fig. 4 : Differential cross-section for coherent proton diffraction dissociation $pd \to (p\pi^+\pi^-)d$ at $\sqrt{s}$ = 53 GeV (p_{lab} = 750 GeV/c) compared with data at p_{lab} = 12.5 GeV/c.

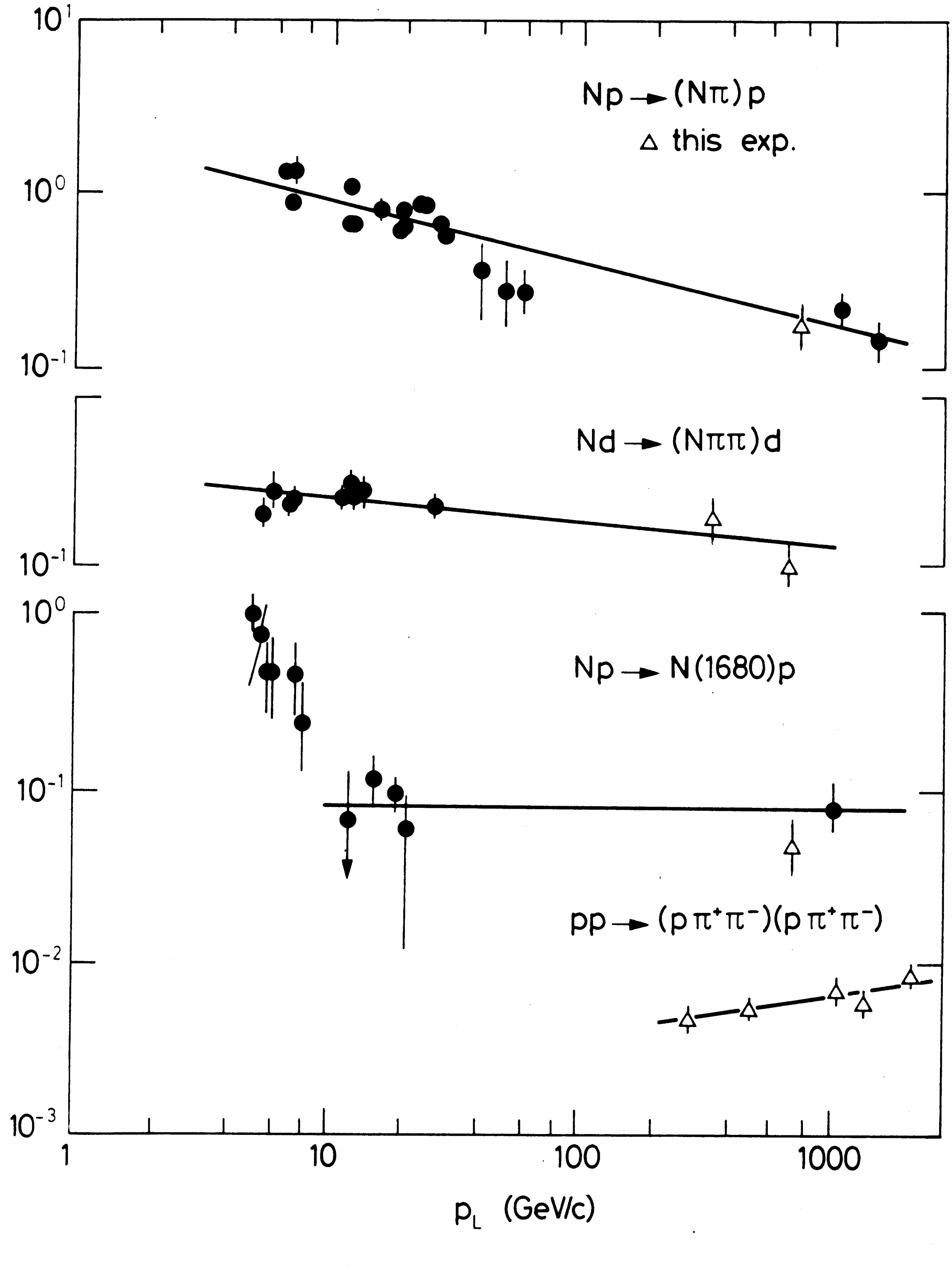
Fig. 5 : Relevant diagrams contributing to coherent nucleon diffraction dissociation.

Fig. 6 : Mass spectra of the $(p\pi^-)$ system in coherent and incoherent single neutron diffraction dissociation.

Fig. 7 : Two-dimensional distribution in the $(\cos\theta - \phi)$ plane of the Gottfried-Jackson system for the decay of coherently produced $(p\pi^+\pi^-)$ states.

Fig. 8 : Differential cross-section of pd elastic scattering compared with standard Glauber prediction at $\sqrt{s}$ = 53 GeV.

Fig. 9 : Differential cross-section of dd elastic scattering compared with standard Glauber prediction at $\sqrt{s}$ = 63 GeV.



Np → (Nπ) p
△ this exp.
Nd → (Nππ) d
Np → N(1680)p
pp → (pπ⁺π⁻)(pπ⁺π⁻)
10¹
10⁰
10⁻¹
10⁻¹
10⁰
10⁻¹
10⁻²
10⁻³
1
10
100
1000
p_L (GeV/c)

Fig. 1

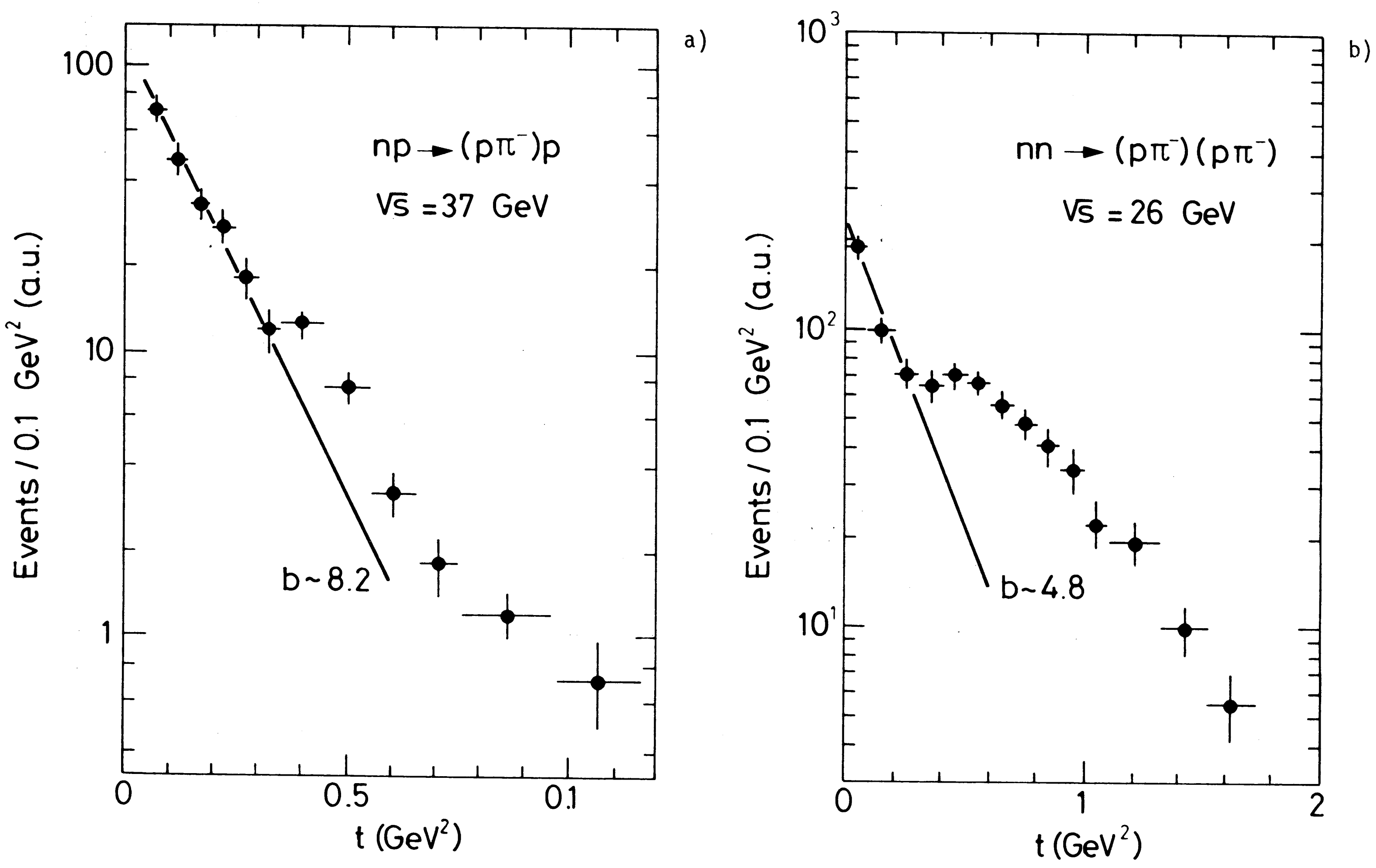

a)
np → (pπ⁻)p
√s = 37 GeV
b ~ 8.2
Events / 0.1 GeV² (a.u.)
t (GeV²)
b)
nn → (pπ⁻)(pπ⁻)
√s = 26 GeV
b ~ 4.8
Events / 0.1 GeV² (a.u.)
t (GeV²)

Fig. 2

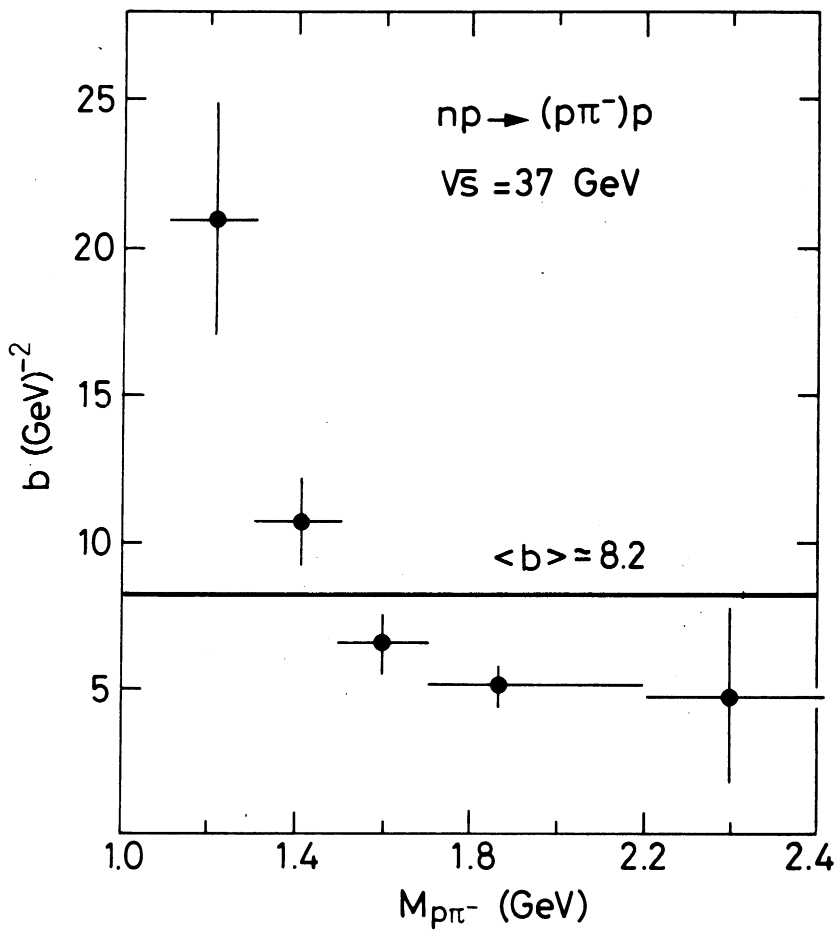
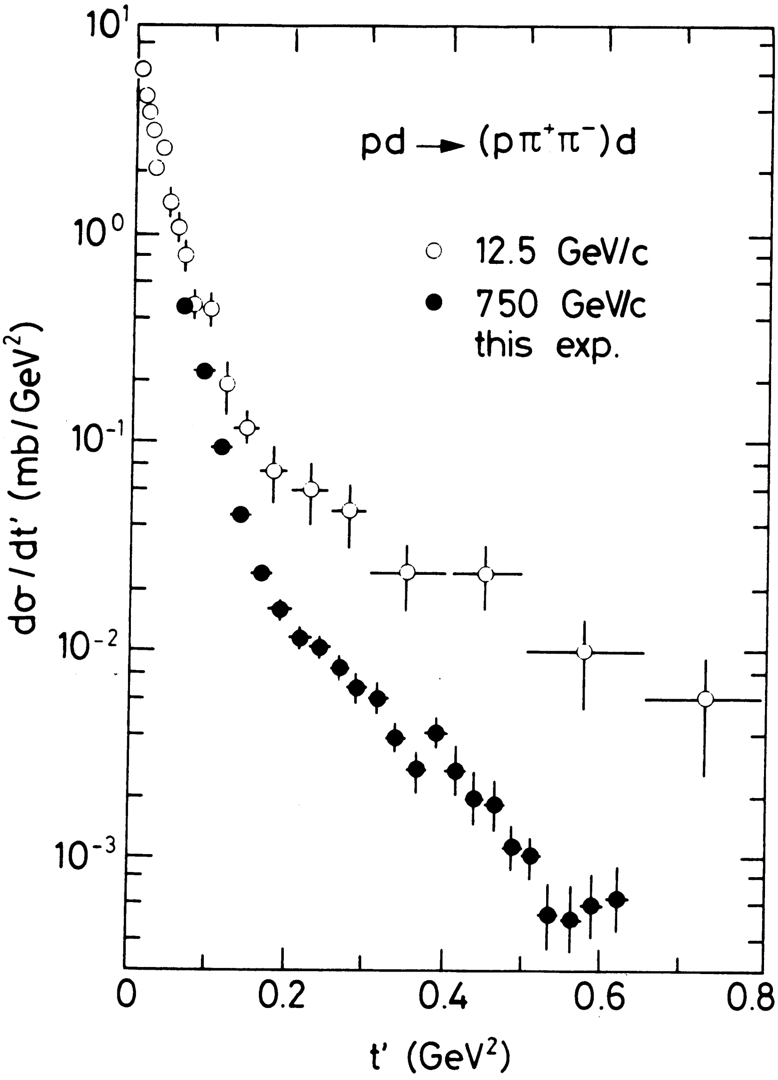
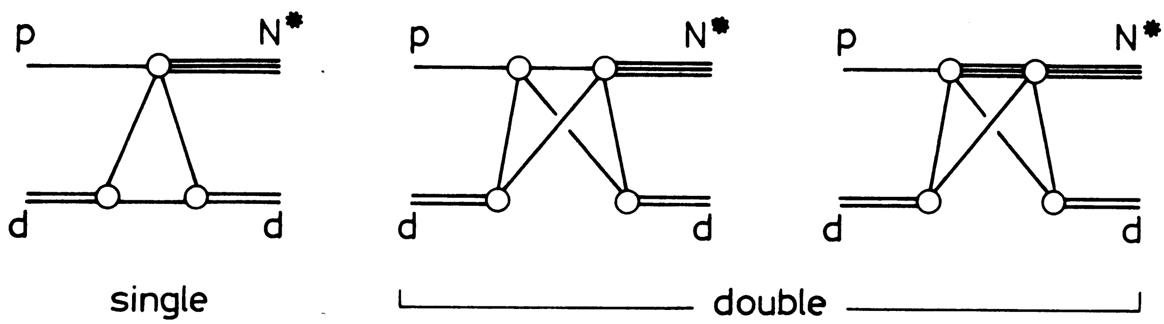


Fig. 3



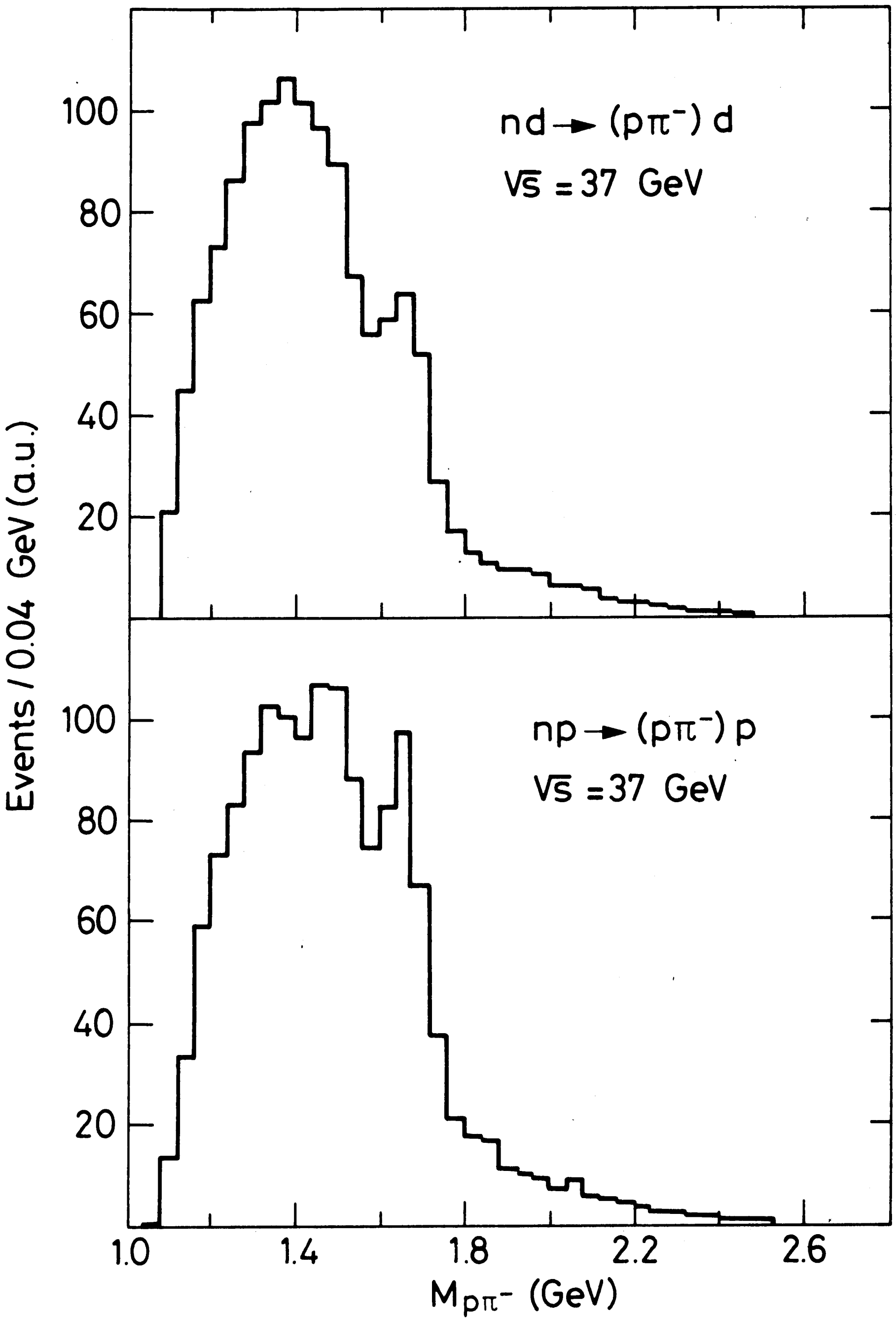
pd → (pπ⁺π⁻)d
12.5 GeV/c
750 GeV/c
this exp.
dσ/dt' (mb/GeV²)
t' (GeV²)

Fig. 4



p
N*
d
d
single
double

Fig. 5



nd → (pπ⁻) d
√s = 37 GeV
np → (pπ⁻) p
√s = 37 GeV
Events / 0.04 GeV (a.u.)
100
80
60
40
20
1.0
1.4
1.8
2.2
2.6
M pπ⁻ (GeV)

Fig. 6

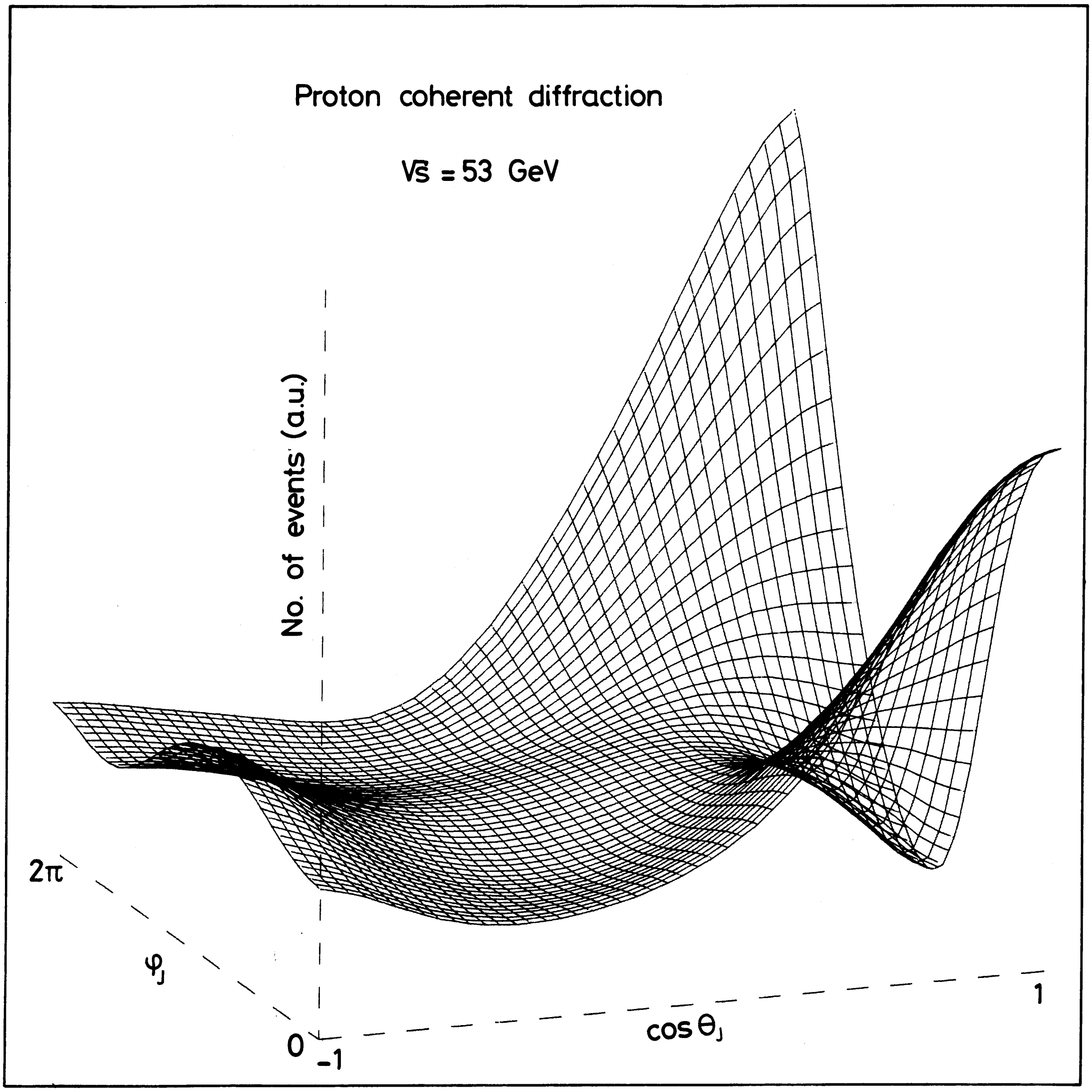
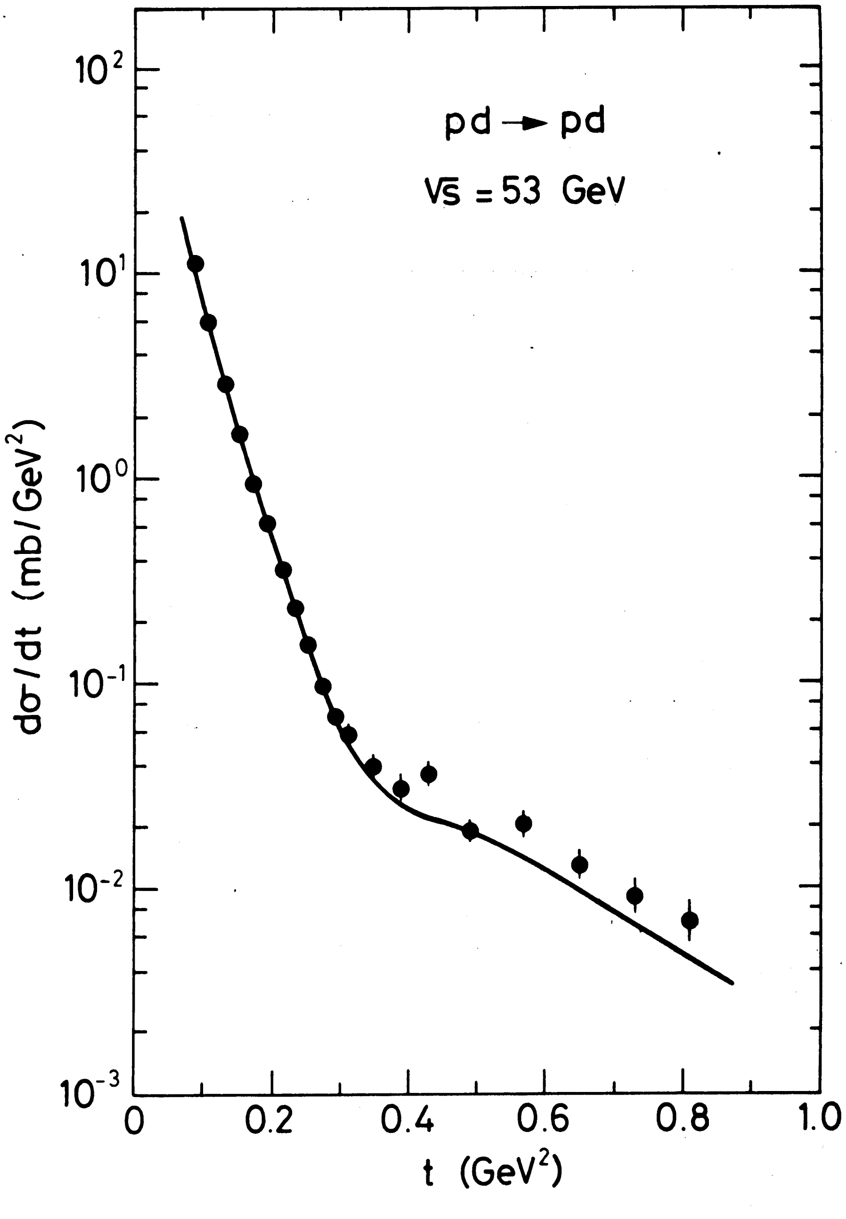
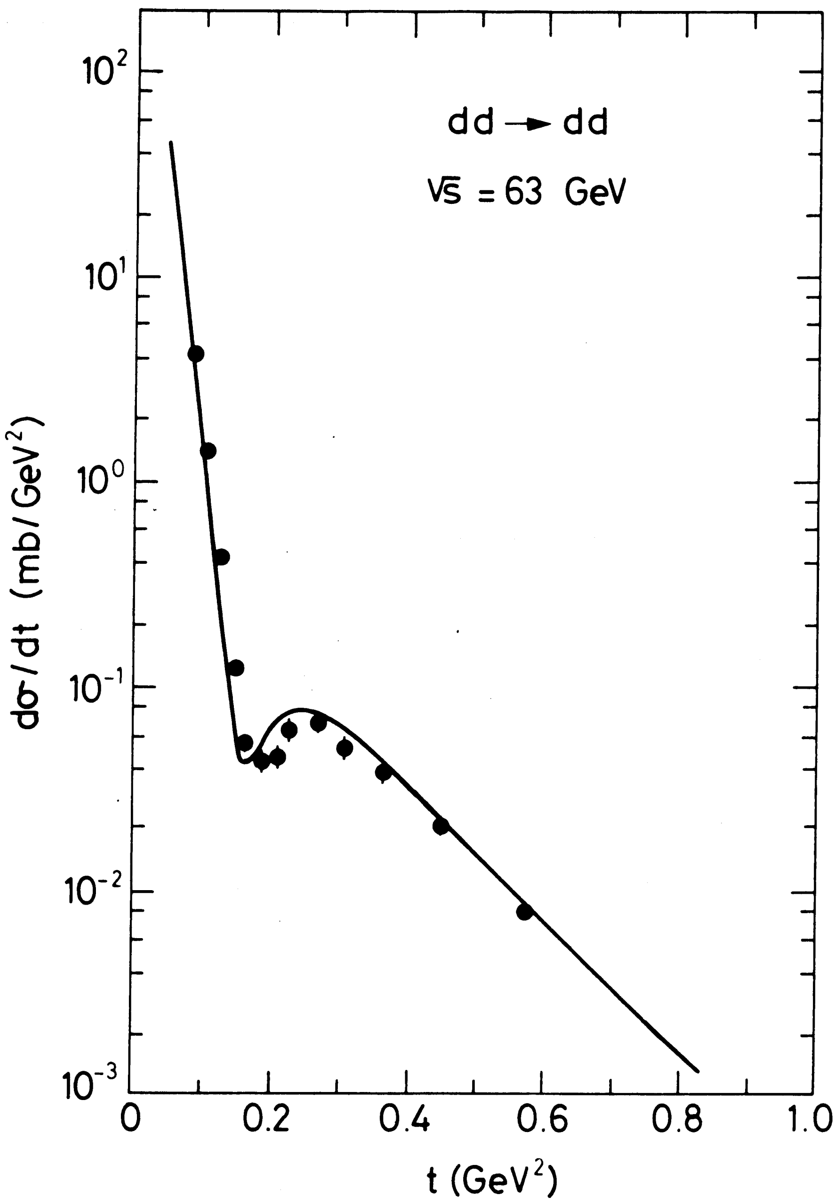

Proton coherent diffraction
√s = 53 GeV
No. of events (a.u.)
2π
φJ
0
-1
cos ΘJ
1

Fig. 7



pd → pd
√s = 53 GeV
dσ/dt (mb/GeV²)
t (GeV²)
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
0
0.2
0.4
0.6
0.8
1.0

Fig. 8



dd → dd
√s = 63 GeV
10^2
10^1
10^0
10^-1
10^-2
10^-3
dσ/dt (mb/GeV^2)
0
0.2
0.4
0.6
0.8
1.0
t (GeV^2)

Fig. 9