

STUDY OF CHARGE-EXCHANGE DOUBLE DISSOCIATION OF PROTONS
AT THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

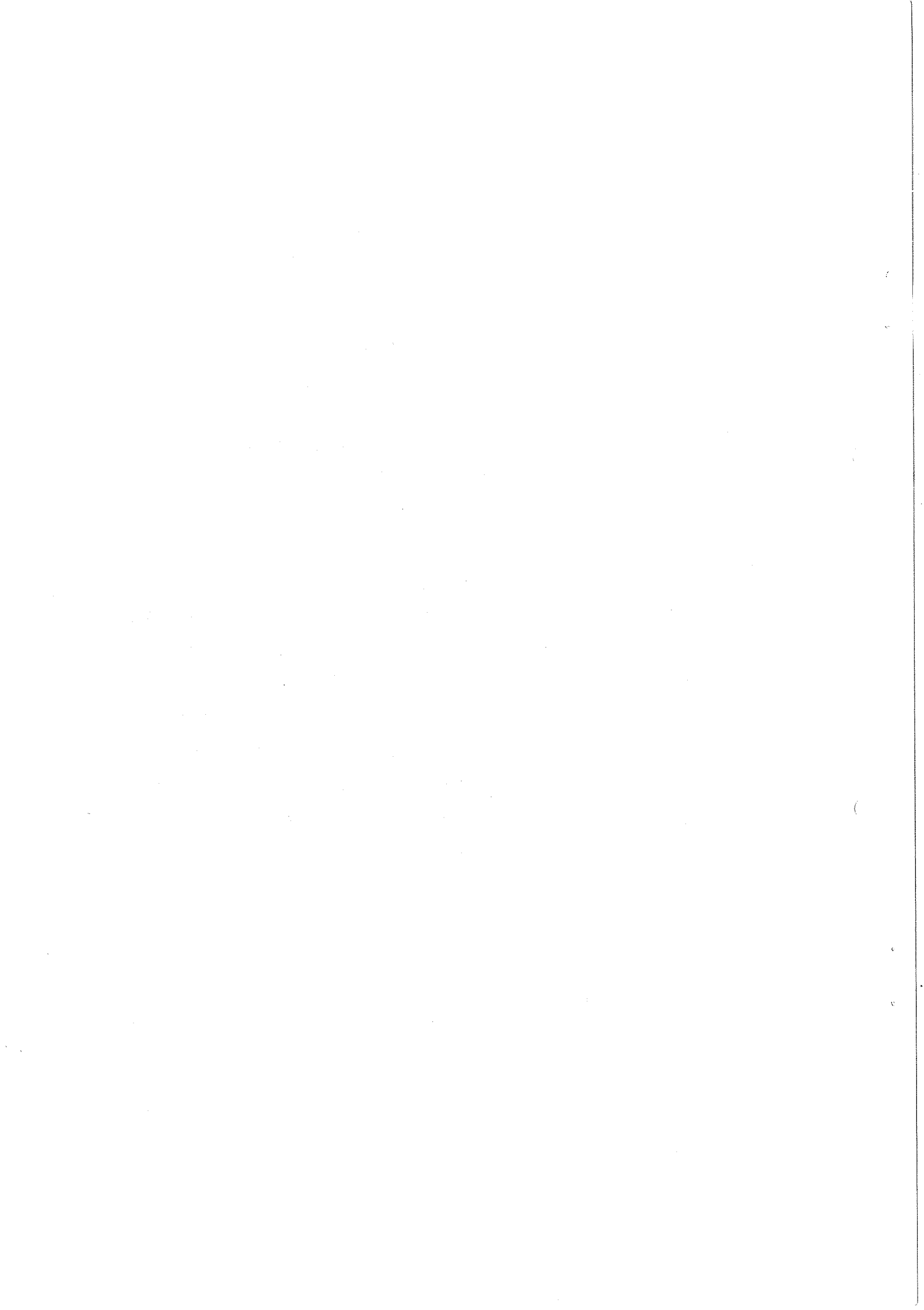
We have measured the charge-exchange reaction $pp \rightarrow (p\pi^+)(p\pi^-)$ at $\sqrt{s} = 23, 31, 45, 53,$ and 63 GeV at the ISR, using the Split Field Magnet detector. The data are characterized by a sharp forward peak of width 0.02 (GeV/c)², followed by a much gentler slope at higher $|t|$; sizeable Δ^{++} , Δ^0 , and N^0 production is observed in the $(N\pi)$ mass spectra. Two different components are present in the data following power-law energy dependences of the type p_{lab}^{-n} with $n_1 = -1.63 \pm 0.13$ and $n_2 = -0.96 \pm 0.07$, respectively, indicating the onset of mechanisms in competition with pion exchange at ISR energies.

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The study of nucleon charge-exchange scattering, both in the "quasi-elastic" np backward scattering [1] and in the inelastic processes involving Δ production [2], has led to a rather clear picture of the dominant π -exchange mechanism, whose features appear to totally control the data up to Fermilab/SPS energies. In fact, the energy dependence of the cross-sections obeys power laws of the type $\sigma \sim p_{\text{lab}}^{-n}$ with $n = 1.5-2$, in good agreement with a simple Regge-pole prediction $p_{\text{lab}}^{2\alpha_0-2}$ with a π intercept close to zero, and the shapes of the differential cross-sections appear dominated by a sharp forward spike of width $|t| \sim m_{\pi}^2$. With increasing energy higher-lying trajectories, in particular ρ and A_2 , are expected to give increasingly important contributions to the channels involving isospin exchange and eventually to dominate over the exchange of a simple pion [3]. This behaviour would manifest itself through a significant change in the shape and energy dependence of the differential cross-section $d\sigma/dt$. Since an exchange-degenerate ($\rho + A_2$) exchange amplitude, because of its $s^{1/2}$ behaviour, is expected to compete with pion exchange beyond the 100 GeV/c region, it is of particular interest to analyse the details of charge-exchange reactions in the ISR energy range.

In the course of the experiment on double diffraction dissociation in proton-proton collisions at the ISR, on which we reported in the preceding letter [4], data were also collected on the charge-exchange process



in which both colliding protons are excited to a low-mass ($N\pi$) system. This allows a comparison of the energy dependence of different reaction mechanisms at the highest available energies, minimizing apparatus-dependent systematic effects. We report here the first results on reaction (1) obtained at all five standard ISR energies, corresponding to an equivalent momentum range from 280 GeV/c to 2060 GeV/c. The data were taken simultaneously with those of the mentioned diffractive reaction with a very similar experimental procedure.

The apparatus, consisting of the full proportional-wire Split Field Magnet (SFM) detector system [5], provided complete solid-angle coverage for charged particle

tracking and momentum analysis. It was separated into two forward symmetric acceptance regions, surrounded by the rest of the sensitive volume. These two complementary regions accepted events corresponding to the excitation of both colliding protons to rather low-mass systems at small to moderate momentum transfers, i.e. at the opposite ends of the rapidity interval available at each energy. An inspection of the relevant rapidity distributions and a comparison of the measured mass and t -distributions with the acceptance limits defined in the apparatus show that a totally unambiguous selection of events from reaction (1) and, in general, of double dissociation processes, can be easily performed at the ISR.

A two-step trigger, at fast and slow levels, was used as described in more detail in Ref. 4. The fast trigger only required a beam-beam interaction signature; a slower set of conditions was then applied, specifying the event topology by means of hodoscope information from groups of 32 wires in the forward telescope MWPCs. In particular, final states were required i) to be within two symmetrical forward cones, the rest of the detector vetoing more centrally produced particles, ii) to contain at least one high momentum particle, iii) to fall within a track multiplicity window in each forward telescope. The aperture of the forward cones was such as to assure complete acceptance for $p\pi^+$ and $p\pi^-$ systems with invariant masses ≤ 3 GeV and produced with $|t| \leq 2$ (GeV/c)². The multiplicity conditions were optimized taking into account the strong spatial correlation in the $(N\pi)$ systems, dominated by Δ^{++} production at one vertex and containing a sizeable fraction of Δ^0 at the other. Both Monte Carlo studies and real data distributions from preliminary runs at all five ISR energies led to a widening of the topological acceptance criteria, with inclusion of triggers with single track candidates. In this way, the data sample included some contamination from high- t elastic events, which however were easily rejected by off-line filtering. This filtering required, with the full resolution of the proportional chambers, the presence of at least two separate track candidates in each telescope and preceded the standard SFM pattern recognition and reconstruction chain [6]. The final sample of events was then obtained by means of a 4C kinematical fit.

Events having χ^2 -probability greater than 0.01 were kept in the analysis; distributions of unfitted quantities, such as transverse momentum balance or coplanarity*), showed only minor background contributions, to the 5% level, to be subtracted from the data sample.

Luminosity measurements were obtained by collecting monitor counts during data taking. The monitor calibrations, at least one at each energy, are the same as in the previous paper [4]. Acceptance calculations were performed with a Monte Carlo program simulating in great detail apparatus geometry and performance, secondary interactions of final-state particles, and the trigger conditions specific to reaction (1). The efficiency for each two-body final-state system in reaction (1) was completely described in terms of M , t , and the two decay angles in the Jackson frame. The same considerations apply to apparatus performance, running conditions, and backgrounds as for the double diffraction measurement [4]. The same arguments also hold about the absence of acceptance cuts down to the kinematical boundaries of reaction (1). This proves particularly valuable when studying the behaviour of the forward peak in the differential cross-section.

The number of fitted events, integrated luminosities, and acceptance values at each energy are given in Table 1.

Figure 1 shows the differential t -distribution at $\sqrt{s} = 23$ GeV, where the largest event sample is available. A fit to the data with an incoherent sum of two exponentials in the form

$$\frac{d\sigma}{dt} = A_1 e^{b_1 t} + A_2 e^{b_2 t} \quad (2)$$

shows a sharp forward peak with slope $b_1 = 4.85 \pm 2.7$ (GeV/c) $^{-2}$, strongly suggestive of a close pion pole, smoothly merging into a gentler exponential with slope $b_2 = 7.6 \pm 0.4$ (GeV/c) $^{-2}$. This behaviour is qualitatively the same at all five energies, although the relative size of the two components in Eq. (2) appears to be energy dependent.

*) It is worth while pointing out that any coplanarity selection must be approached in a t -dependent way when dealing with sharply forward-peaked reactions, such as π -exchange processes. This is due to the increasingly strong correlation between $|t|$ and the error on the measured coplanarity angle for vanishing production angles.

The mass distributions of the ($p\pi^+$) and ($p\pi^-$) systems shown in Fig. 2 display clear resonant structures. The ($p\pi^+$) mass spectrum is dominated by Δ^{++} production^{*}): a one-dimensional fit to this distribution yields an almost energy-independent fraction of about 70% Δ^{++} . The ($p\pi^-$) mass spectrum shows Δ^0 production, as well as enhancements in the $N^0(1520)$ and $N^0(1688)$ regions. The mass distributions appear substantially unaffected by a t -cut at 0.1 (GeV/c)^2 , which indicates that the two components observed in the differential cross-section lead to essentially identical final states.

The total cross-section of reaction (1) is given in Table 1. Systematic uncertainties arise from absolute luminosity calibrations due to the machine working conditions (Table 1); a 10% error is due to the choice of our acceptance parametrization and a further 6% arises from comparisons between properties of simulated and real events. Systematic and statistical errors were combined in quadrature; a 15% over-all scale uncertainty is not included in the quoted figures.

The energy dependence of the total cross-section (Fig. 3a) can be fitted with a power-law behaviour $\sigma \sim p_{\text{lab}}^{-n}$ with $n = 1.25 \pm 0.08$. This value of n sensibly close to one arises from the different energy dependence of the two contributions in Eq. (2). If we identify the forward peak with pion exchange and the higher- t region with ($\rho + A_2$) exchange, we have, in fact,

$$\sigma_{\pi} = \int \left(\frac{d\sigma}{dt} \right)_{\pi} dt \sim p_{\text{lab}}^{-1.63 \pm 0.13}, \quad \sigma_{\rho} = \int \left(\frac{d\sigma}{dt} \right)_{\rho} dt \sim p_{\text{lab}}^{-0.96 \pm 0.07}. \quad (3)$$

A normalization-independent study of the two relative contributions can be made by plotting the ratio of the two integrals as a function of equivalent laboratory momentum (Fig. 3b). The ratio $\sigma_{\rho}/\sigma_{\pi}$ is observed to rise as $p_{\text{lab}}^{0.73 \pm 0.15}$ and is equal to unity around $p_{\text{lab}} = 500 \text{ GeV/c}$. The latter exponent has a theoretical upper limit of one, which would correspond to a simple pion pole without absorption corrections^{**}).

^{*}) For ($p\pi^+$) masses greater than 1.4 GeV the distribution is somewhat distorted by wrong proton-pion assignments.

^{**}) In this extreme case the sum of π^- - and ρ -exchange terms, weighted in accordance with the $\sigma_{\rho}/\sigma_{\pi}$ ratio measured at $\sqrt{s} = 23 \text{ GeV}$, would yield an over-all approximate $p_{\text{lab}}^{-1.35}$ dependence, to be compared with our experimental value $n = 1.25$ for the total cross-section of reaction (1).

In conclusion, the cross-section of the charge-exchange double dissociation process (1) in the ISR energy range shows a clear transition régime, with $(\rho + A_2)$ exchange becoming progressively dominant over π exchange. In spite of the steep decrease with energy of the pion component of the differential cross-section, the sharp π -associated forward peak is observed up to the highest energy measured.

Acknowledgements

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Table 1

\sqrt{s} (GeV)	Equiv. Plab (GeV/c)	No. of events	$\int \mathcal{L} dt$ (μb^{-1})	$\bar{\epsilon}$ (%)	Systematic uncertainty $\int \mathcal{L} dt$ (%)	σ_T (μb)
23	287	2499	8845	8.0	7	3.54 ± 0.50
31	490	446	2605	7.5	5	2.28 ± 0.32
45	1057	632	15228	5.1	10	0.81 ± 0.13
53	1470	410	24623	3.5	10	0.47 ± 0.08
63	2060	485	46582	3.2	5	0.32 ± 0.05

Figure captions

- Fig. 1 : Differential cross-section of reaction (1) at $\sqrt{s} = 23$ GeV. The solid line is a fit to the data according to Eq. (2). Also shown are the contributions of the two separate components.
- Fig. 2 : Mass distributions of a) $p\pi^+$ and b) $p\pi^-$ systems at $\sqrt{s} = 23$ GeV.
- Fig. 3 : a) Total cross-section of reaction (1) as a function of equivalent laboratory momentum. A power-law fit to the data is shown together with a p_{lab}^{-2} extrapolation of the π -exchange integrated cross-section at $\sqrt{s} = 23$ GeV (dashed line).
- b) Ratio of the ρ -exchange to π -exchange integrated cross-sections [Eq. (3)] as a function of p_{lab} .

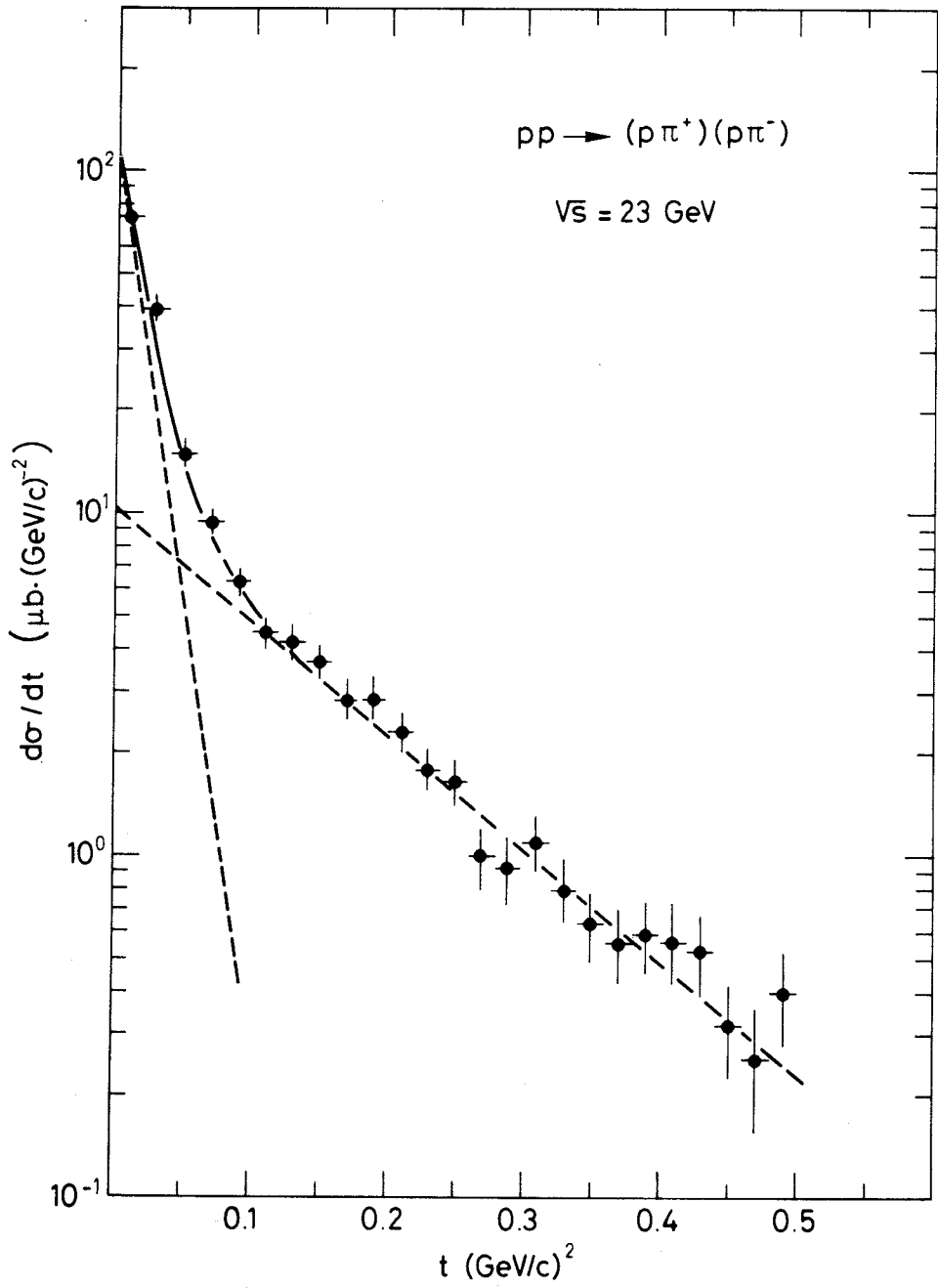


Fig. 1

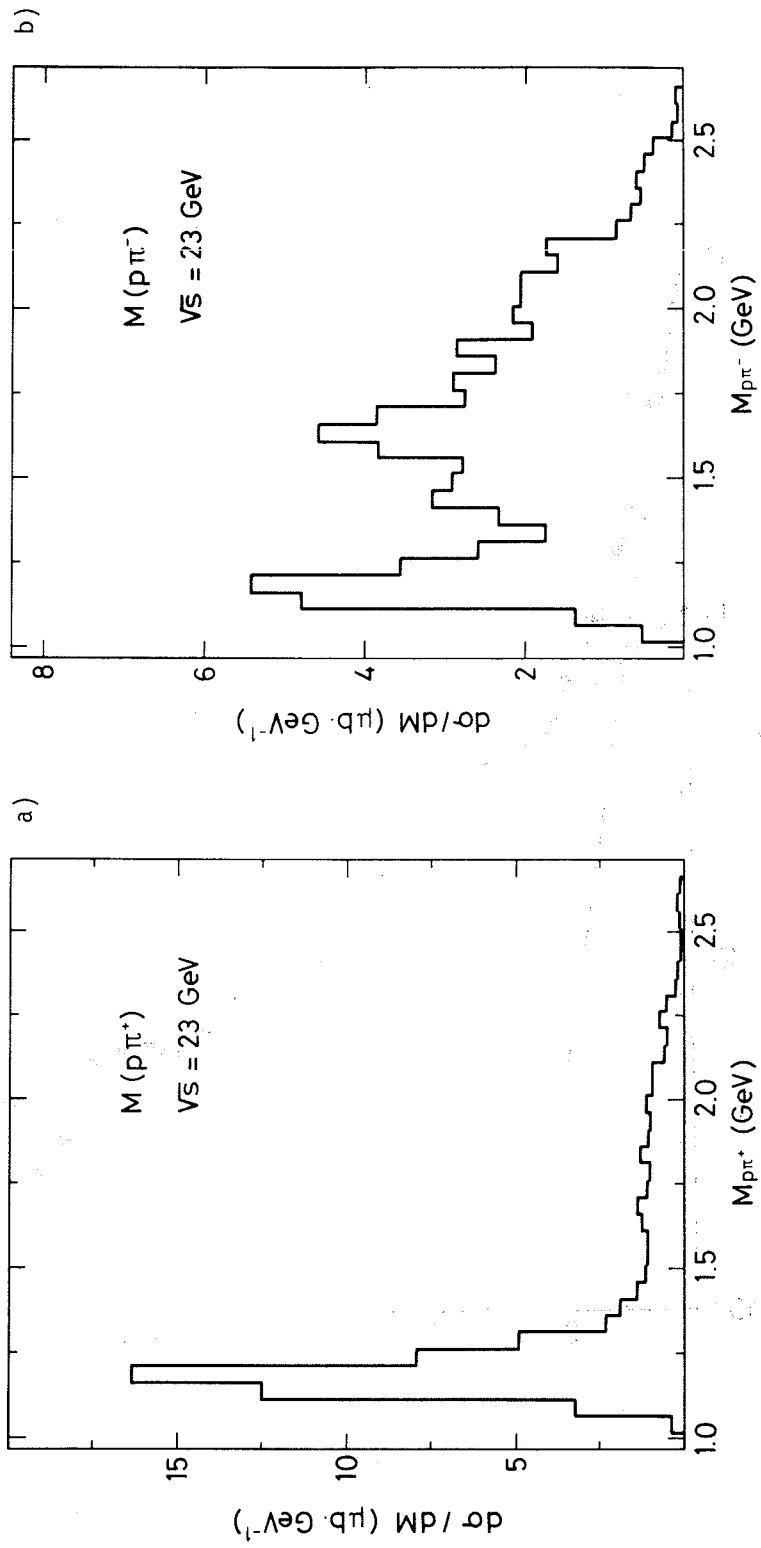


Fig. 2

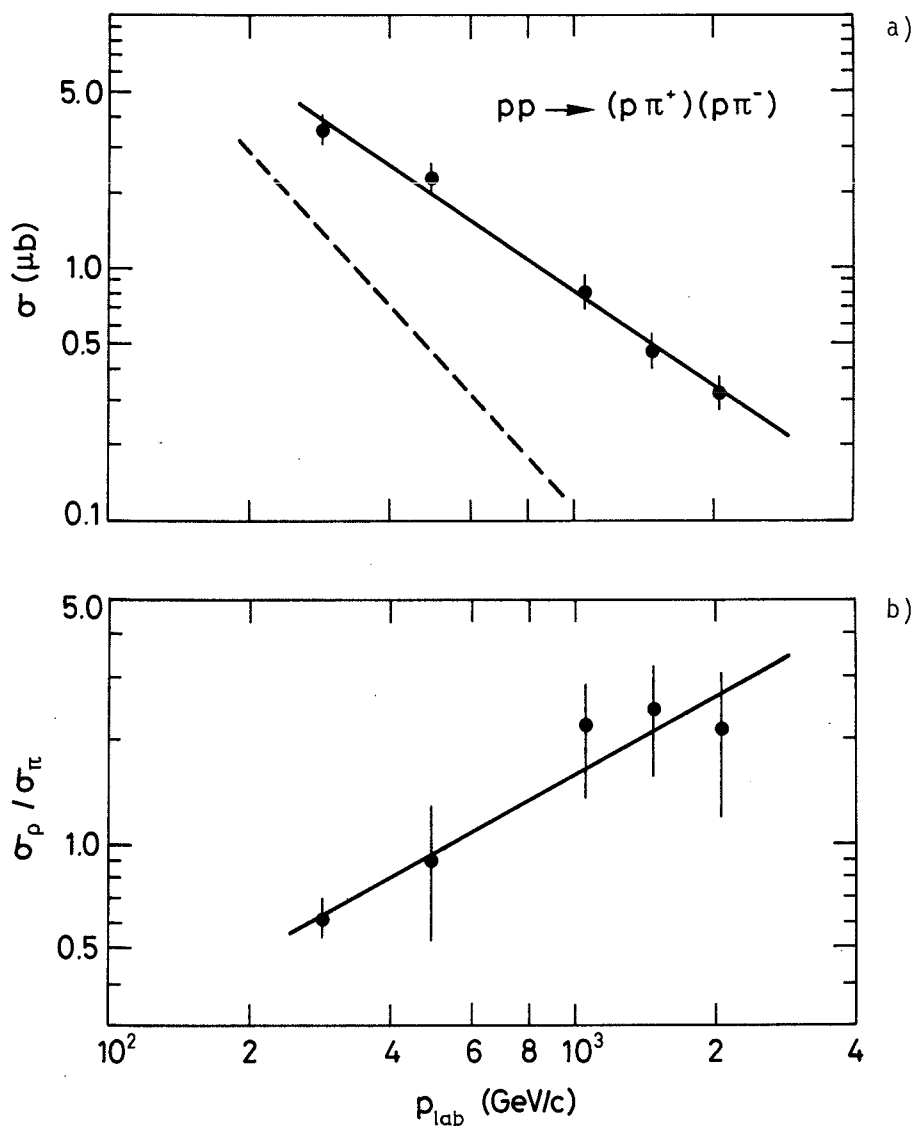


Fig. 3

