

THE s-DEPENDENCE OF DOUBLE DIFFRACTION DISSOCIATION OF PROTONS
AT THE CERN INTERSECTING STORAGE RINGS

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ABSTRACT

We report results on a new measurement of the double diffractive reaction $pp \rightarrow (p\pi^+\pi^-)(p\pi^+\pi^-)$ at the ISR obtained with the Split Field Magnet detector. Experimental procedures and data analysis are discussed in detail. The cross-section measured at the five standard ISR energies exhibits an increase of $(55 \pm 7)\%$ in the s-range from 549 to 3892 GeV².

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Double diffraction dissociation of protons has been identified at the CERN Intersecting Storage Rings (ISR) both in semi-inclusive [1] and in exclusive [2] final states. Our previous measurements [2] showed the main features of mass- and t-distributions together with their factorization properties, but the limitations of apparatus and running time did not allow the investigation in detail of the s-dependence of the cross-section over the full ISR energy range.

In this paper we report the results of a new cross-section measurement*) of double diffraction of protons covering the full energy range available at the ISR.

The reaction studied, as in Ref. 2, is the symmetric excitation of both colliding protons to the all-charged final state

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

detected in the opposite arms of the Split Field Magnet (SFM) detector system.

The data were taken at the five ISR energies in a sequence of several runs, all of them particularly homogeneous in terms of apparatus performance; during the runs repeated calibrations of the normalization constants were also performed.

The complete SFM detector, equipped with $\sim 70,000$ proportional wires, allows charged-particle detection and momentum analysis over essentially 4π sr [3]. In this experiment events were detected in opposite cones within the two forward telescopes, the remaining sensitive volume of the detector being used to reject processes with charged particles in the central rapidity region.

The trigger involved a two-step selection: a fast level, requiring beam-beam interaction, and a slower level, making use of memory signals from groups of 32 wires each [4]. This second decision level applied three kinds of conditions:

i) the geometrical constraints defining the acceptance cones, ii) the presence of at least one high-momentum particle in each forward cone, iii) a set of hit patterns, defining multiplicity windows for track candidates in each telescope. The aperture of the acceptance cones was set by Monte Carlo simulation to accept all $(p\pi^+\pi^-)$ systems up to invariant masses of 3.5 GeV and four-momentum transfers up to $2 (\text{GeV}/c)^2$.

*) Earlier data, from which the previously published [2] results were obtained, have not been included in the present analysis.

Analysis of the raw data provided positive tests on detector behaviour, telescope and trigger symmetry, and background stability, showing great consistency among all the runs.

The events were reconstructed off-line through a chain of analysis programs performing pattern recognition, geometrical reconstruction, and topology selection [5]. The surviving events were submitted to a 4C kinematical fit. χ^2 and χ^2 -probability distributions were found very close to the expected ones. In the final sample only events having χ^2 -probability greater than 0.01 were accepted. The average resolutions on mass and four-momentum transfer are about 12 MeV and 0.015 (GeV/c)^2 , respectively, at all energies.

A clear diffractive signature is displayed by the reconstructed events, as indicated in Fig. 1, where the c.m. rapidity distributions of the final state ($p\pi^+\pi^-$) systems and of the individual particles are shown. The two systems are separated by a large rapidity gap at all ISR energies; the experimental rapidity distributions for all particles are not affected by the acceptance limits associated with our trigger, also shown.

The over-all acceptance for reaction (1), including the detector geometry and the trigger and pattern recognition efficiency, was calculated with a sequence of Monte Carlo and tracking programs [5], followed by the same reconstruction chain as for the real events. The detection efficiency was studied for single ($p\pi^+\pi^-$) systems and then factorized, given the complete symmetry of the apparatus. Events were generated according to a sequential two-body decay $N^* \rightarrow \Delta\pi \rightarrow N\pi\pi$, with a highly detailed description of the detector geometry, including simulation of beam dispersion parameters, decays of reaction products and their secondary interactions, clusters, and chamber behaviour. Integrating over the Δ decay angles, the acceptance is described by a four-dimensional function of the ($p\pi^+\pi^-$) invariant mass, the four-momentum transfer, and the two Jackson angles of the $N^* \rightarrow \Delta\pi$ decay. The sensitivity of the detection efficiency to the details of the decay models was checked for different Δ decay distributions: the two extreme

assumptions of a flat*) or a $(1 + 3 \cos^2 \theta)$ behaviour were found to differ by no more than 6% at all energies.

The acceptance was found to be a smooth and uniform function of the four kinematic variables of our parametrization at all energies. The decay kinematics of reaction (1), leading mainly to low average momenta in the fully dissociated final state, accounts for the absence of distortions down to $t' = 0$ and mass threshold, also in the presence of small dead regions which accommodate the ISR vacuum pipes.

The cross-section normalization was obtained by collecting monitor counts simultaneously with data-taking from two counter hodoscopes placed downstream of the SFM forward spectrometers. Two other sets of counters provided additional monitors.

Absolute calibrations of all the monitors were performed at least once at each energy with the Van der Meer method [7] and found consistent within 2%.

The integrated luminosity at all energies, together with the systematic uncertainty due to the machine operating conditions, is shown in Table 1.

The acceptance parametrization was systematically investigated and the uncertainty evaluated at each energy (Table 1); the details of the Monte Carlo model were also studied in its ability to reproduce track and background parameters of real data, which introduces a further 6% uncertainty.

The total cross-section of reaction (1) is given in Table 1. The quoted errors are quadratic combinations of statistical and systematic uncertainties; they do not include an over-all 15% scale uncertainty. The dependence of the cross-section on equivalent beam momentum is shown in Fig. 2.

We observe a continuous increase of the double diffractive cross-section between 280 GeV/c and 2060 GeV/c; a parametrization of the form $\sigma = A + B \ln s$ indicates a rise of $(55 \pm 7)\%$ over the full ISR energy range.

A comparison of the s -dependence of exclusive double and single diffraction cross-sections is made difficult by the scarcity of measurements on single diffractive processes in the full ISR energy range. Extrapolations from the

*) Experimental data on $(p\pi^+\pi^-)$ decays indicate that the angular distributions of $(p\pi^+)$ subsystems in the Δ mass band are nearly isotropic (see, for example, Ref. 6).

$p_{\text{lab}} \approx 10\text{-}30$ GeV/c region would suggest a slowly decreasing power-law régime for single diffractive reactions, in marked contrast with the s -dependence we observe in double diffraction. The few measurements of single nucleon diffraction available from Fermilab and ISR are, however, not incompatible with a different energy régime in this region. In this spirit, it is interesting to observe that the trend of our result shows a remarkable similarity with the rise of single inclusive diffraction dissociation systematically investigated at the ISR [8]. The inclusive cross-section integrated over M^2/s from $-\infty$ to 0.05 shows, in fact, a rise of $(15 \pm 5)\%$ over the s -range 549 to 1464 GeV², or $(30 \pm 10)\%$ over the full ISR s -range. When confining the mass of the excited system to values closer to the ones typical of exclusive diffraction (i.e. $M^2/s \leq 0.01$), the cross-section rise is found to be as large as 70% *).

Further analysis of our double diffraction data is in progress, particularly in connection with a geometrical description of the observed cross-section rise.

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*) These figures are a $\ln s$ extrapolation from results in the interval $s = 549$ GeV² to $s = 1464$ GeV².

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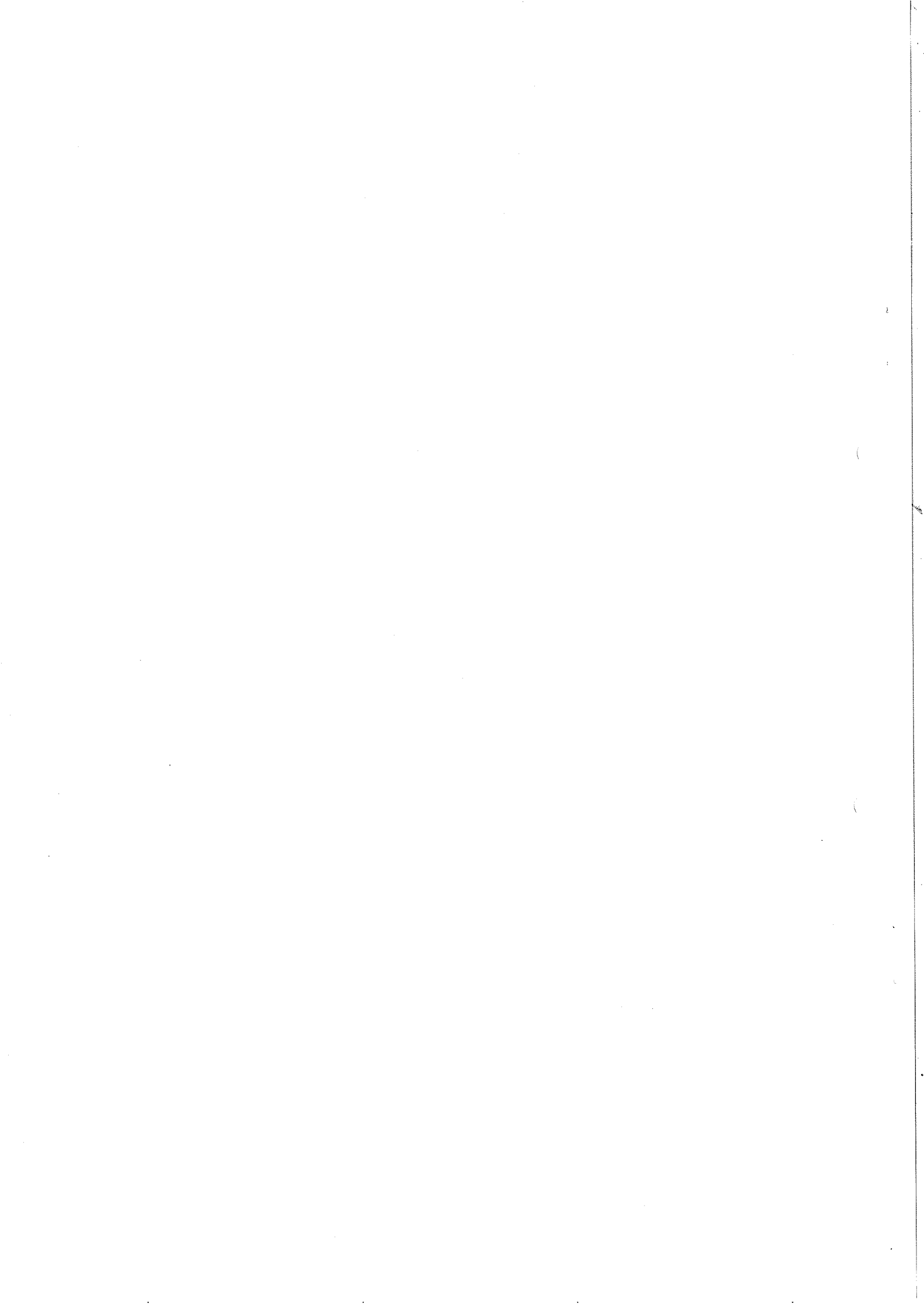
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Table 1

| \sqrt{s} (GeV) | Equiv. Plab (GeV/c) | No. of events | $\int \mathcal{L} dt$ (μb^{-1}) | $\bar{\epsilon}$ (%) | Systematic uncertainty $\int \mathcal{L} dt$ (%) | Systematic uncertainty $\bar{\epsilon}$ (%) | σ_T (μb) |
|---------------------|---------------------------|------------------|---|-------------------------|---|--|---------------------------------|
| 23 | 287 | 2265 | 10798 | 4.4 | 7 | 6 | 4.82 ± 0.56 |
| 31 | 490 | 3497 | 18791 | 3.4 | 5 | 6 | 5.53 ± 0.59 |
| 45 | 1057 | 2032 | 17831 | 1.6 | 10 | 8 | 6.99 ± 1.04 |
| 53 | 1470 | 3944 | 51555 | 1.3 | 10 | 9 | 5.96 ± 0.93 |
| 63 | 2060 | 1535 | 23075 | 0.8 | 5 | 9 | 8.41 ± 1.16 |

Figure captions

- Fig. 1 : Rapidity distributions of a) $(p\pi^+\pi^-)$ systems and b) all final state particles at the lowest ISR energy $\sqrt{s} \approx 23$ GeV. Arrows indicate the lower limits of the acceptance (see text).
- Fig. 2 : Total cross-section of reaction (1) as a function of equivalent laboratory momentum. The line represents a $\ln s$ fit to the data.



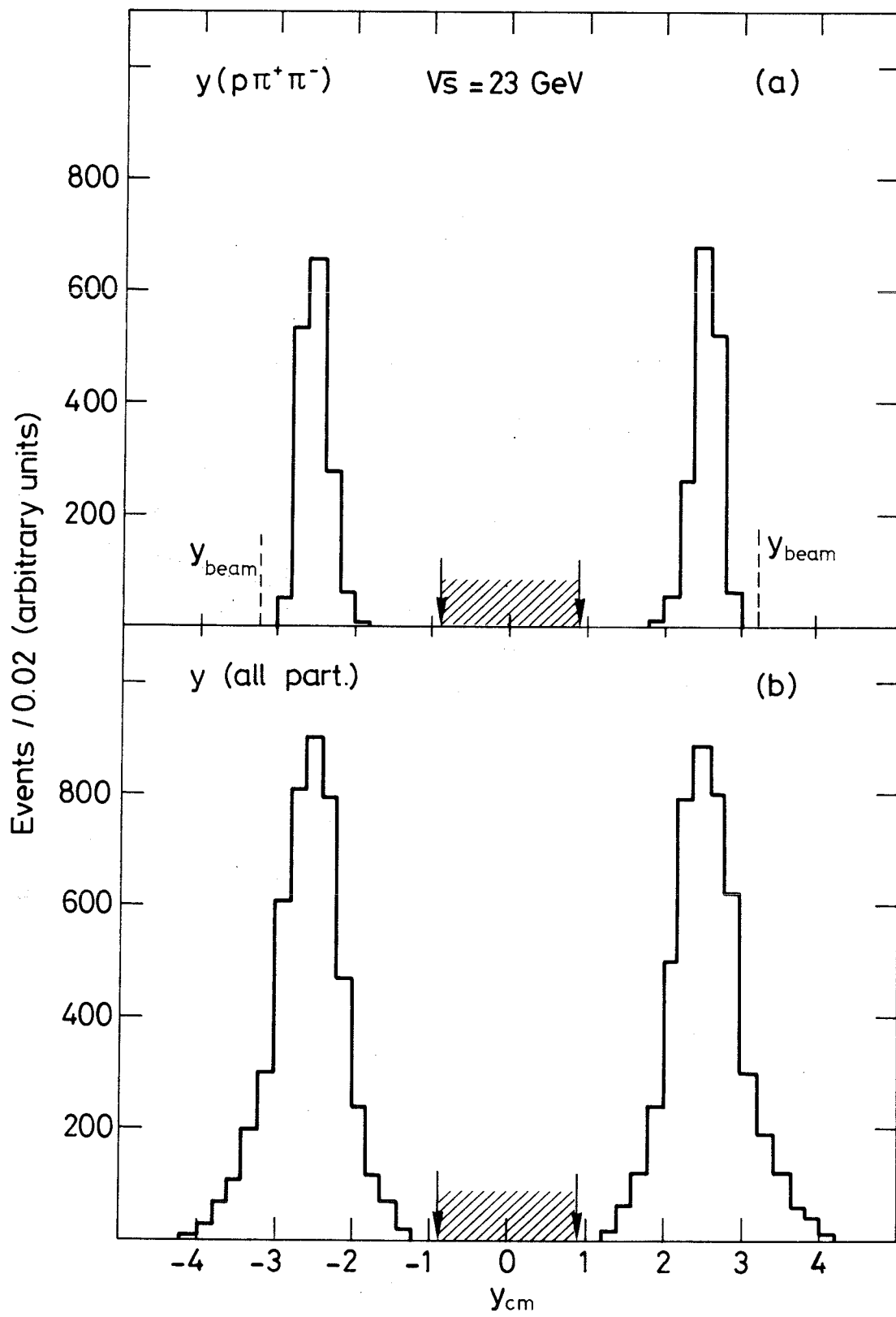


Fig. 1

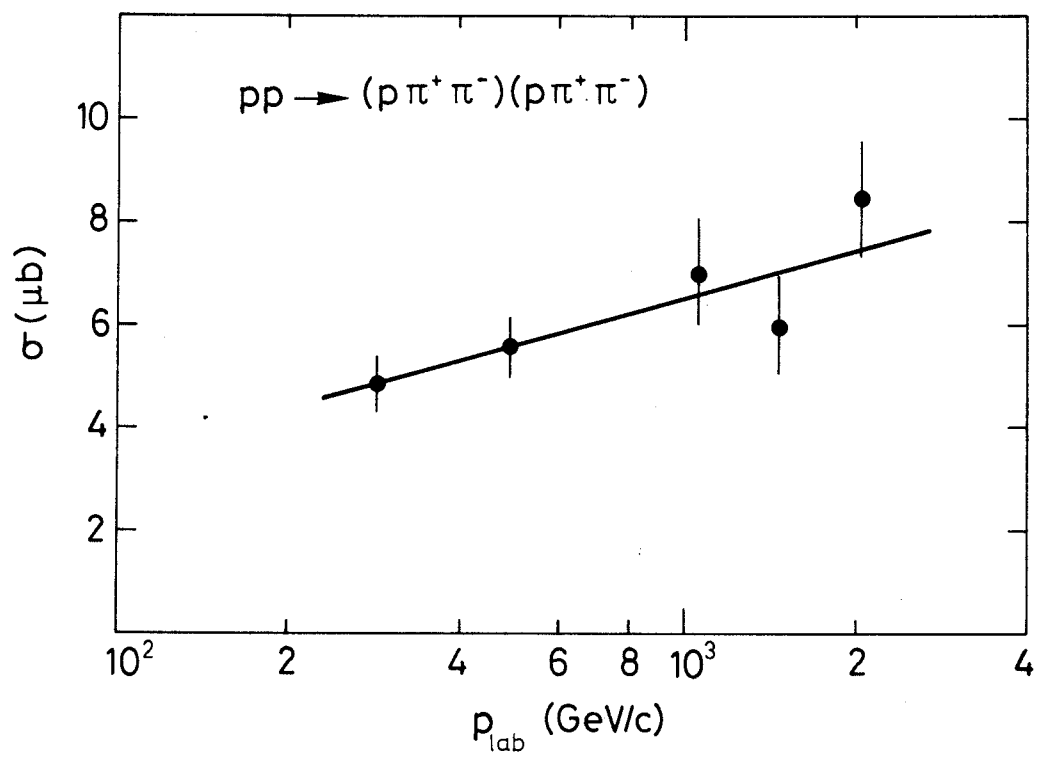


Fig. 2