A MEASUREMENT OF THE CROSS SECTION OF THE REACTION $pp \to n\Delta^{++}(1232)$ AT ISR ENERGIES

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ABSTRACT

A measurement of the cross section of the charge-exchange reaction $pp \to \Delta^{++}(1232)n$ at $\sqrt{s}$ = 23, 31 and 45 GeV at the CERN-ISR is reported. The energy dependence continues to follow a power law p_{lab}^{-n} with n = 1.94±0.03 indicating dominance of one-pion exchange at the lowest ISR energy; there is some evidence for deviation from this at the higher ISR energies.

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It has been found that the total cross section of the charge-exchange reaction

$$p + p \rightarrow \Delta^{++}(1232) + n \qquad (1)$$

decreases approximately like p_{lab}^{-2} in the low energy accelerator region[1]. The reaction is fairly well understood in terms of a single-(modified) pion exchange model[2]. A question still to be answered is whether one-pion exchange would dominate the reaction at ISR energies. Contributions of ρ and A_2-exchange would manifest themselves by a less rapid energy dependence of their cross section, in the form of p_{lab}^{-1}.

We report here new results on the reaction $pp \rightarrow (p\pi^+)n$, obtained at $\sqrt{s}$ = 23, 31 and 45 GeV using the Split Field Magnet detector (SFM)[3] at the CERN Intersecting Storage Rings (ISR), and discuss the s-dependence of the cross section.

The present experiment utilizes the forward telescope with proportional wire chambers, and two neutron detectors[4], consisting of a carbon converter plate (40 x 40 cm^2) of 10 cm thickness and multi-wire proportional chambers to measure the neutron impact point. The neutron detectors are positioned at 9 m from the beam intersection; they detect neutrons within an angular range of 0 to 23 mrad with an efficiency varying from 4% to 6% with the neutron momentum and impact point. The SFM magnetic field ranges from 0.5 to 1.0 T, resulting in an average momentum resolution of about ±7% for the mean proton momentum of reaction (1) and a mass resolution of ΔM = 20 MeV/c^2 at the Δ-mass.

Events are selected in two steps; a fast trigger requires at least one charged particle in one of the telescopes, using fast signals from the wire chambers, and a neutron conversion in the opposite hemisphere. A slow trigger selects events using memory levels of groups of wires[5] with a decision time of about 2 μsec. It requires two charged particles in one telescope and no charged particle in the opposite, neutron-side, telescope. The charged particles are not identified. The events are passed off-line through a chain of three analysis programs: A track recognition program selects events with two positive particles and a reconstructed neutron impact. A geometrical fit in the magnetic field gives directions and momenta of the positive particles and their common vertex from which the neutron direction is calculated. A kinematical fit with 3 constraints is performed assuming that the higher momentum positive particle is the proton and the other one is the pion of reaction (1)*).

In order to separate genuine events of reaction (1) from the large background we have examined the distribution of events in the transverse components of missing momentum, calculated by imposing energy conservation. The missing longitudinal momentum can be very large due to its poorer measurement and hence does not discriminate between events of reaction (1) and background. We observe an accumulation of events around zero missing momentum and invariant mass $M(p\pi^+) = 1232$ MeV/c^2 which we attribute to reaction (1), and a broader distribution due to background. We select events satisfying the following criteria

(i) invariant mass 1155 MeV/c^2 < $M(p\pi^+)$ < 1325 MeV/c^2;

(ii) missing transverse momentum in the plane of magnetic deflection $|\Delta p_x| < 100$ MeV/c;

(iii) proton emitted backwards in the Gottfried-Jackson reference system, $\cos \Theta_J < 0$,

and obtain a distribution of events in the other component of missing transverse momentum, Δp_z, perpendicular to the plane of magnetic deflection as shown in figure 1 for $\sqrt{s}$ = 23, 31 and 45 GeV. There is clear evidence for an accumulation of events around $\Delta p_z = 0$, which we attribute to reaction (1) and a broader distribution due to background.

The forward hemisphere of the Gottfried-Jackson reference system is much more strongly contaminated with background. In particular, we note that the signal to background ratio is quickly decreasing for $\cos \Theta_J > 0$ as the energy $\sqrt{s}$ is increased, whereas in the backward hemisphere, $\cos \Theta_J < 0$, it is increasing. The broad background distribution in figure 1 can be extrapolated linearly under the peak and subtracted; the number of

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*) This choice is always correct for $(p\pi^+)$ masses below 1340 MeV.

genuine events thus obtained is given in table 1. We note that the background distribution is broadening as $\sqrt{s}$ is increased, thus reducing the uncertainty due to its subtraction. At $\sqrt{s}$ = 23 GeV the signal to background ratio is acceptable over the whole phase space of reaction (1); after subtraction of background in Δp_z and correction for the relative geometrical acceptance for $\cos \Theta_J < 0$ and $\cos \Theta_J > 0$ we find equal numbers of events of reaction (1) in both hemispheres. Non-resonant contributions to the selected mass range are known to be small[1)] and have not been subtracted.

The observed number of events must be corrected for the geometrical acceptance of the detector, for the neutron detection efficiency, for loss of events due to absorption and scattering in the vacuum tube and in the frames of the wire chambers, and normalized by the integrated luminosity of the ISR to obtain cross sections. The geometrical acceptance of the detector has been calculated using Monte Carlo methods. Events were generated using a parametrization of the four-fold differential cross section which fully describes reaction (1):

(i) the dependence in four-momentum transfer t by exp(12t), compatible with the data at all three energies;

(ii) a Breit-Wigner distribution of invariant mass around 1232 MeV/c^2 with a width[6)] of 110 MeV/c^2;

(iii) a decay angular distribution in the Jackson frame according to $(1 + 3 \cos^2\Theta_J)$, independent of the azimuthal angle Φ_J, following a simple one-pion exchange description as observed at lower energies[1)].

The experimental and the calculated distributions have been compared in these variables; we estimate a ±15% uncertainty in the cross section due to the choice of parametrization.

All details and obstacles of the vacuum tube and of the detectors are carefully simulated and the reliability of the absorption and scattering correction has been tested for elastic proton-proton scattering in the same data runs[7)]. We estimate a remaining systematic uncertainty in the cross section of ±14%. The neutron detection efficiency has been calibrated in a neutron beam[4]; its stability was cross checked by protons with a resulting uncertainty in the cross sections of ±10%. Trigger losses contribute ±10% uncertainty. Adding all uncertainties in quadrature the systematic error is estimated to be ±25%. Values of the overall acceptance thus evaluated and the accepted range of four-momentum transfer t are given in table 1.

The absolute normalization is obtained by collecting monitor counts simultaneously with data taking. A scintillation counter monitor has been calibrated using the Van der Meer method[8]. The integrated luminosity at each energy and the observed total cross section are given in table 1; systematic and statistical errors have been added in quadruture. The total cross section as a function of equivalent beam momentum is shown in figure 2 together with earlier results at lower energies[1].

We observe a continuing decrease of the cross section, approximately as p^{-2}, from 2.8 GeV/c to the lowest ISR energy of 280 GeV/c equivalent momentum. A fit to a form

$$\sigma = a \cdot p_{lab}^{-n} \qquad (2)$$

gives n = 1.94±0.03, suggesting that one-pion exchange is dominant in this energy interval. At the higher ISR energies we observe cross sections which are larger than expected on the basis of relation (2). However, in view of the large background subtraction and small statistics a firm conclusion would require further investigation.

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$\sqrt{s}$ [GeV]	equivalent p_{lab} [GeV]	integrated luminosity [10^6/mb]	t-range [GeV^2]	overall acceptance [%]	observed number of events	total cross-section [μb]	$\sigma_{expected}$ [μb] (a)
23	280	16.4	0-0.07	0.099	26 ± 9	1.60 ± 0.68	1.4
31	510	8.87	0-0.13	0.136	20 ± 6	1.66 ± 0.65	0.53
45	1090	90.42	0-0.27	0.050	23 ± 7	0.50 ± 0.20	0.12

TABLE I

(a) Estimate of the cross-section from a fit to low energy data, reference 1.

FIGURE CAPTIONS

Figure 1 - Observed distributions in a transverse component of missing momentum, $|\Delta p_z|$. Events have invariant mass in the range $1155 < M(\pi^+ p) < 1325$ MeV/c^2 and $|\Delta p_x| < 100$ MeV/c. The observed number of events attributed to reaction (1) is given.

Figure 2 - Total cross section for charge-exchange $pp \to n\Delta^{++}(1232)$ as a function of equivalent beam momentum. The solid line represents a fit to the data between 2.8 GeV/c and 280 GeV/c.

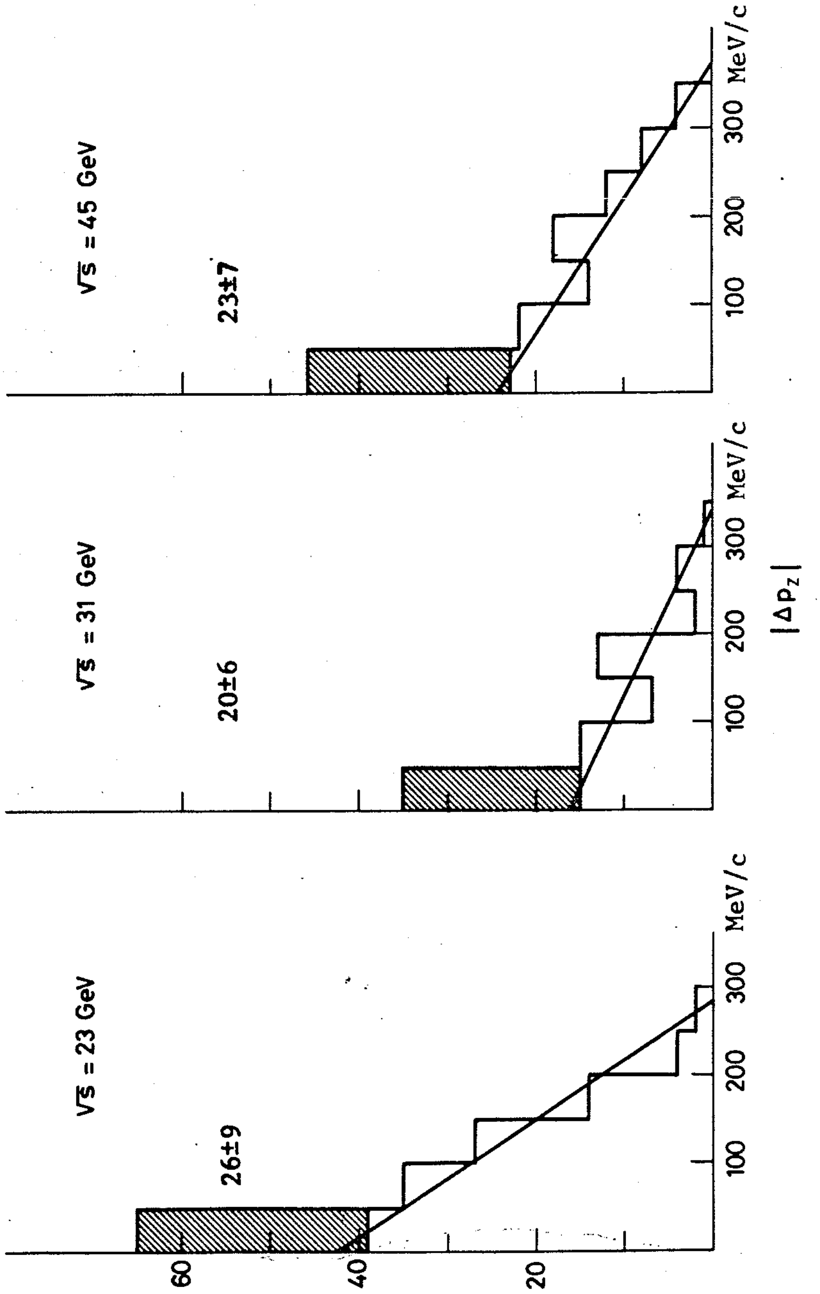

Figure 1

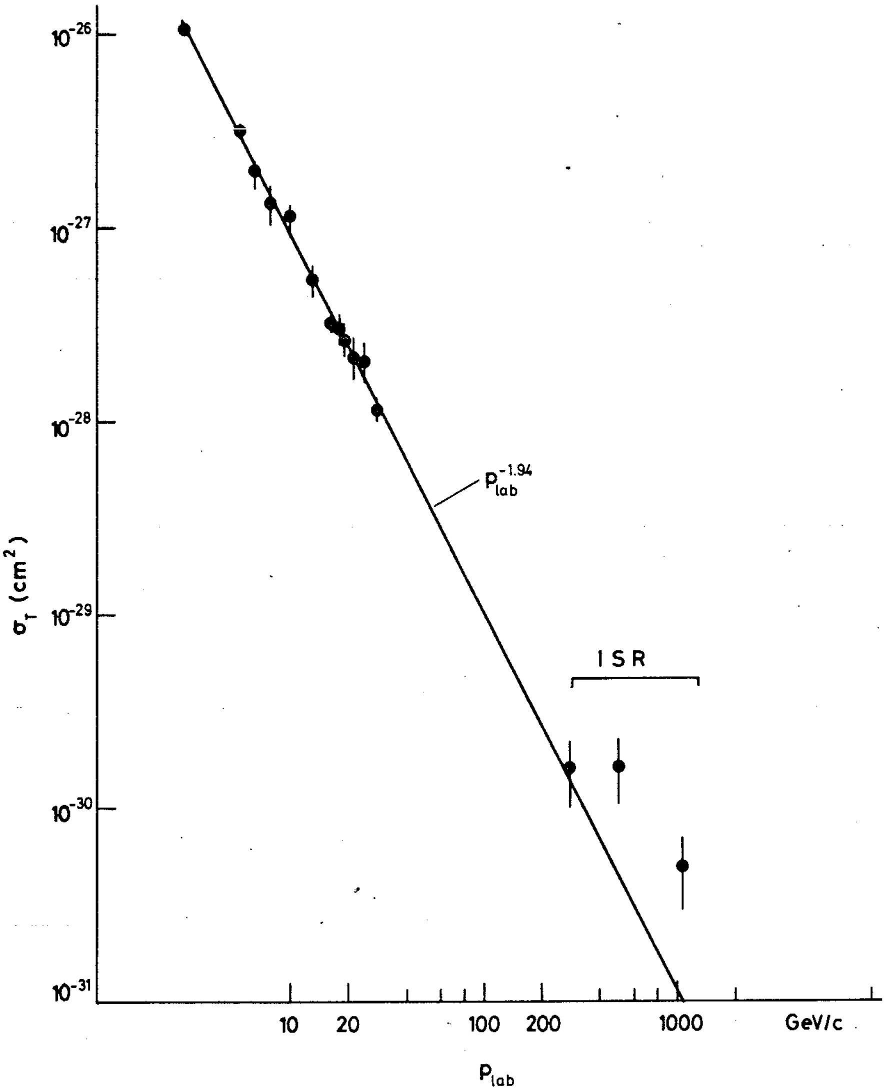
10^{-26}
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
σ_T (cm^2)
$p_{lab}^{-1.94}$
I S R
10
20
100
200
1000
GeV/c
P_{lab}

Figure 2