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ISOLATION OF ISOSCALAR EXCHANGE IN $\pi^{\pm} + p \rightarrow \rho^{\pm} + p$ AT 15 GeV/c*

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ABSTRACT

We have extracted $d\sigma/dt$ and the ρ density matrix elements ρ^{H}_{oo} and $\rho^{H}_{1,-1}$ for isoscalar t-channel exchange in $\pi^{\pm} + p \rightarrow \rho^{\pm} + p$ at 15.0 GeV/c. The total I = 0 contribution to σ for $0 \leq |t| \leq 1.0$ (GeV/c)^2 is 24 ± 10 μb. The momentum dependence of the natural and unnatural parity components has been fit to $\sigma = K\, P_{Lab}^{-n}$ with n(natural parity) = 1.4 ± 0.3 and n(unnatural parity) = 2.2 ± 0.5.

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The isoscalar (I = 0) t-channel exchange mechanisms contributing to the reactions

$$\pi^{\pm} + p \rightarrow \rho^{\pm} + p \qquad (1)$$

can be isolated at high energy by the following relation[1, 2]:

$$\frac{d\sigma}{dt}(I=0) = \frac{1}{2}\left[\frac{d\sigma}{dt}(\pi^{+} p \rightarrow \rho^{+} p) + \frac{d\sigma}{dt}(\pi^{-} p \rightarrow \rho^{-} p) - \frac{d\sigma}{dt}(\pi^{-} p \rightarrow \rho^{o} n)\right] \qquad (2)$$

This equation also holds if each $d\sigma/dt$ is replaced by $\rho_{ij}\, d\sigma/dt$ where ρ_{ij} is a spin density matrix element of the ρ meson. In this letter we use our recent measurements[3] of reactions (1) and of $\pi^{-} + p \rightarrow \rho^{o} + n$ to determine the isoscalar contribution at 15.0 GeV/c beam momentum.

It has generally been assumed that the major isoscalar contribution would be from the exchange of an ω meson--this being the smallest mass meson known with the required quantum numbers $I^G(J)^P = 0^-(1)^{-1}$. For future use we remind the reader that the ω is a so-called natural parity particle since $P = + (-1)^J$. This assumption has been roughly verified[4-7], but a recent set of measurements[4,5] at a laboratory momentum of 2.7 GeV/c indicates that in the small-t region a pure ω-exchange mechanism is not sufficient. The inclusion of other natural parity exchange mechanisms, such as higher mass exchange particles, does not remove the discrepancy. Some isoscalar contribution from an unnatural parity ($P = -(-1)^J$) exchange mechanism with $G = -1$ appears to be required. There is no generally accepted meson with the required properties, so that two-particle exchange mechanisms must be assumed. If this last assumption is correct then it is expected that this two-particle exchange contribution would decrease more rapidly with energy than the natural parity isoscalar exchange contribution. In this letter we extract both the natural and unnatural parity contributions at 15 GeV/c. We then examine the momentum dependence of these contributions to test the ideas we have just outlined.

The examination of the validity of a particular exchange mechanism explanation of a reaction is hampered by our lack of an exact theory. We can use the various absorption corrected Regge models, but it is perhaps best to use the more general considerations of Cohen-Tannoudji et al.[8] and Ader et al.[9] These considerations lead to certain requirements on the behavior of the density matrix elements, ρ_{ij}, and on $\rho_{ij}\, d\sigma/dt$, if elementary particles of fixed spin or Regge trajectories of fixed signature are exchanged in the t-channel. Specifically we observe that the natural parity t-channel exchange contribution is given to order 1/s by the combination

$$(\rho_{11} + \rho_{1,-1}) \frac{d\sigma}{dt} \tag{3a}$$

and that for pure natural parity exchange

$$\rho^H_{oo} \simeq 0.0 \tag{3b}$$

$$\rho^H_{1,-1} \simeq 0.5$$

Here the superscript H denotes the helicity frame.

To begin the analysis we present in Fig. 1 the density matrix elements for $\pi^\pm + p \rightarrow \rho^\pm + p$ taken from our recent measurements[3]. We have already given[3] the corresponding values of $d\sigma/dt$. We obtained the corresponding values for $\pi^- + p \rightarrow \rho^o + n$ with the same optical spark chamber apparatus[3] used to study the charged ρ reactions. The only change made was to alter the electronic event selection criterion to select events with two charged particles and no γ rays in the final state. Events fitting the reaction $\pi^- + p \rightarrow \rho^o + n$ were then selected in the conventional way--the vector momenta of both charged pions having been measured. The neutron was not detected, leading to a one-constraint fit. In this manner 817 events were obtained. The ρ^o density matrix elements are also shown in Fig. 1. To obtain ρ^H_{oo} and $d\sigma/dt$ we have made an s-wave subtraction by the following procedure: for each t bin we fit to the $\pi\pi$ invariant mass distribution a relativistic Breit-Wigner

(Γ = 160 MeV) plus a slowly varying background. The s-wave in each bin was identified with the background term and varied in size from 7 to 15%.

Our ρ^o data is in overall agreement with the results of Bulos et al.[10], also at 15.0 GeV/c, with small differences in some of the density matrix elements. This supplies a valuable check of our normalization procedures.

The isoscalar contributions are presented in Fig. 2; $d\sigma/dt$ (I = 0) is seen to have a forward peak. We find the isoscalar cross section for $0 \leq |t| \leq 1.0$ (GeV/c)^2 to be [11,12]

$$\int_0^1 \frac{d\sigma}{dt} (I = 0)\ d|t| = 24 \pm 10\,\mu b. \tag{4}$$

We have included our estimated systematic error as well as the statistical error in (4). Since we are using Eq. (2) to calculate a relatively small cross section the effect of systematic errors can be large. To illustrate this, for each data point of $d\sigma/dt$ (I = 0) in Fig. 2 our estimate of the systematic error is shown as a bar, to the ends of which are added the statistical error. Our systematic error has approximately equal contributions from normalization effects which are t-independent, from uncertainties in our acceptance corrections which may have a weak t-dependence, and from uncertainties in our subtraction of contaminations[3] in the low-t region $|t| < .08$(GeV/c)^2. This cross section is in agreement, within errors, with that found at 16.0 GeV/c in a hydrogen bubble chamber experiment.[7]

We also show in Fig. 2 ρ^H_{oo} (I = 0) and $\rho^H_{1,-1}$ (I = 0). We find ρ^H_{oo} consistent with 0 for the entire t range $0 \leq |t| \leq 1.0$ (GeV/c)^2. This agrees with the simple ω-exchange prediction (3b). However $\rho^H_{1,-1}$ tends to be less than 0.5.

To investigate further we use (3a) to separate the natural and unnatural parity contributions to the isoscalar cross section. We have used data at 2.67 GeV/c[4,5], 6.0 GeV/c[6], and our data at 15.0 GeV/c to determine the energy dependence of these components. We have fit this data (Fig. 3) and the total I = 0 cross section data with the form $\sigma = K P_{Lab}^{-n}$ obtaining

$$\begin{aligned} n(\text{natural parity}) &= 1.4 \pm 0.3 \\ n(\text{unnatural parity}) &= 2.2 \pm 0.5 \\ n(I = 0) &= 1.7 \pm 0.3 \end{aligned} \tag{5}$$

This non-zero unnatural parity component may be explained by a two-particle exchange mechanism. An alternative explanation might be absorption. In this case the condition (3b) that $\rho_{oo}^{H} \approx 0$ for pure natural parity exchange would still hold as absorptive mechanisms are thought to conserve s-channel helicity. At 15.0 GeV/c we find

$$\int_{o}^{1} \rho_{oo}^{H} \frac{d\sigma}{dt}(I=0)\, d\,|t| = 2 \pm 5\ \mu b\ . \tag{6}$$

Crennell et al.[6] obtain about 15 ± 20 μb at 6.0 GeV/c. Michael and Gidal,[4] on the other hand, find about 75 ± 20 μb at 2.67 GeV/c, clear evidence of a non-absorptive effect. While the statistics are not sufficient for a conclusive statement, it seems likely on the basis of the data from all three energies that we are indeed observing non-absorptive contributions to the unnatural parity component of $d\sigma/dt\,(I=0)$ which decrease with energy roughly as P_{Lab}^{-2}.

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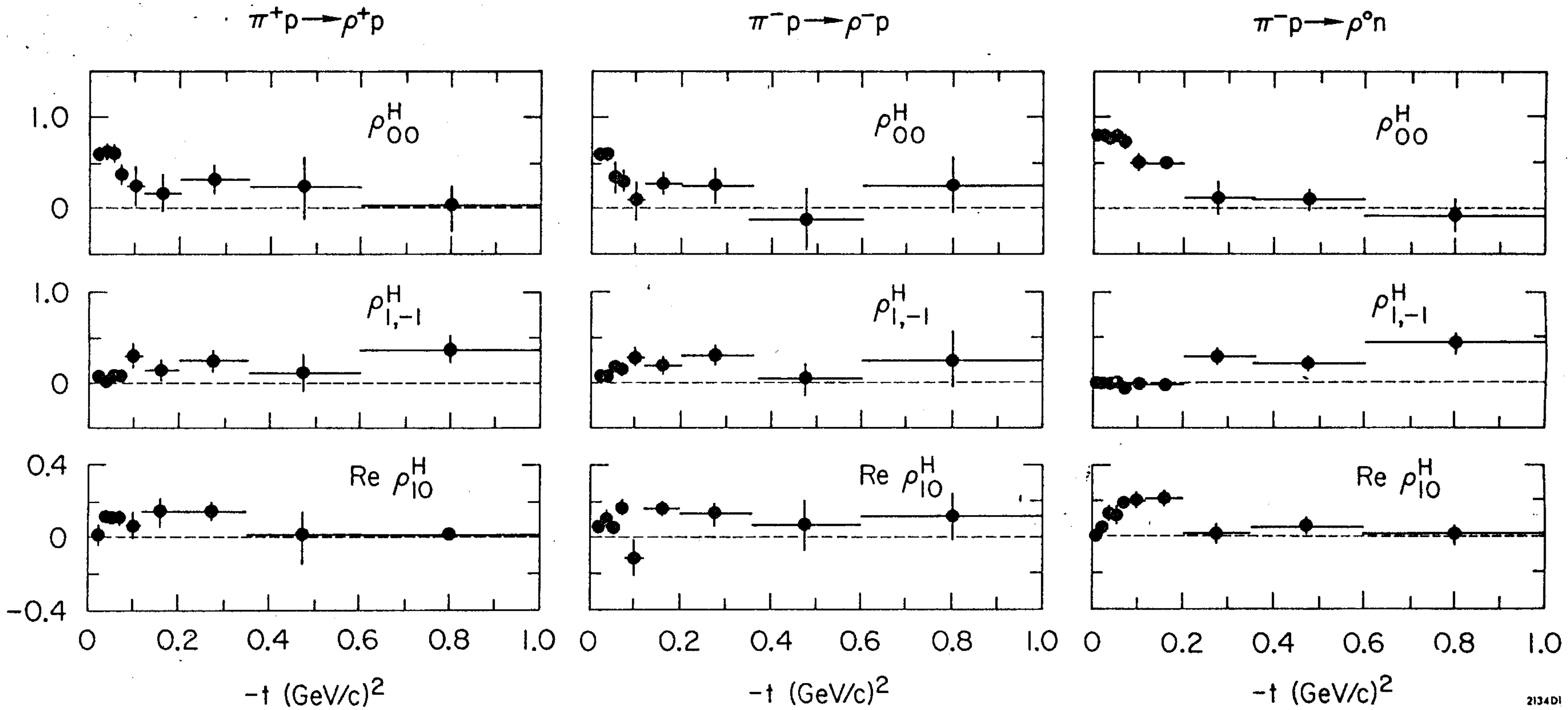
11. We have restricted our investigation to the low and medium t region, $0 \leq |t| \leq 1.0\ (GeV/c)^2$, to avoid complications such as u-channel exchanges.
12. We have used the ρ^0 cross section data of Ref. 10 in the bin $.030 \leq |t| \leq .045\ (GeV/c)^2$ because of a severe fluctuation in our own data. Our ρ^0 cross section is in good agreement with that of Ref. 10 in all other bins in the region $0 \leq |t| \leq 0.3\ (GeV/c)^2$.

FIGURE CAPTIONS

1. ρ density matrix at 15.0 GeV/c

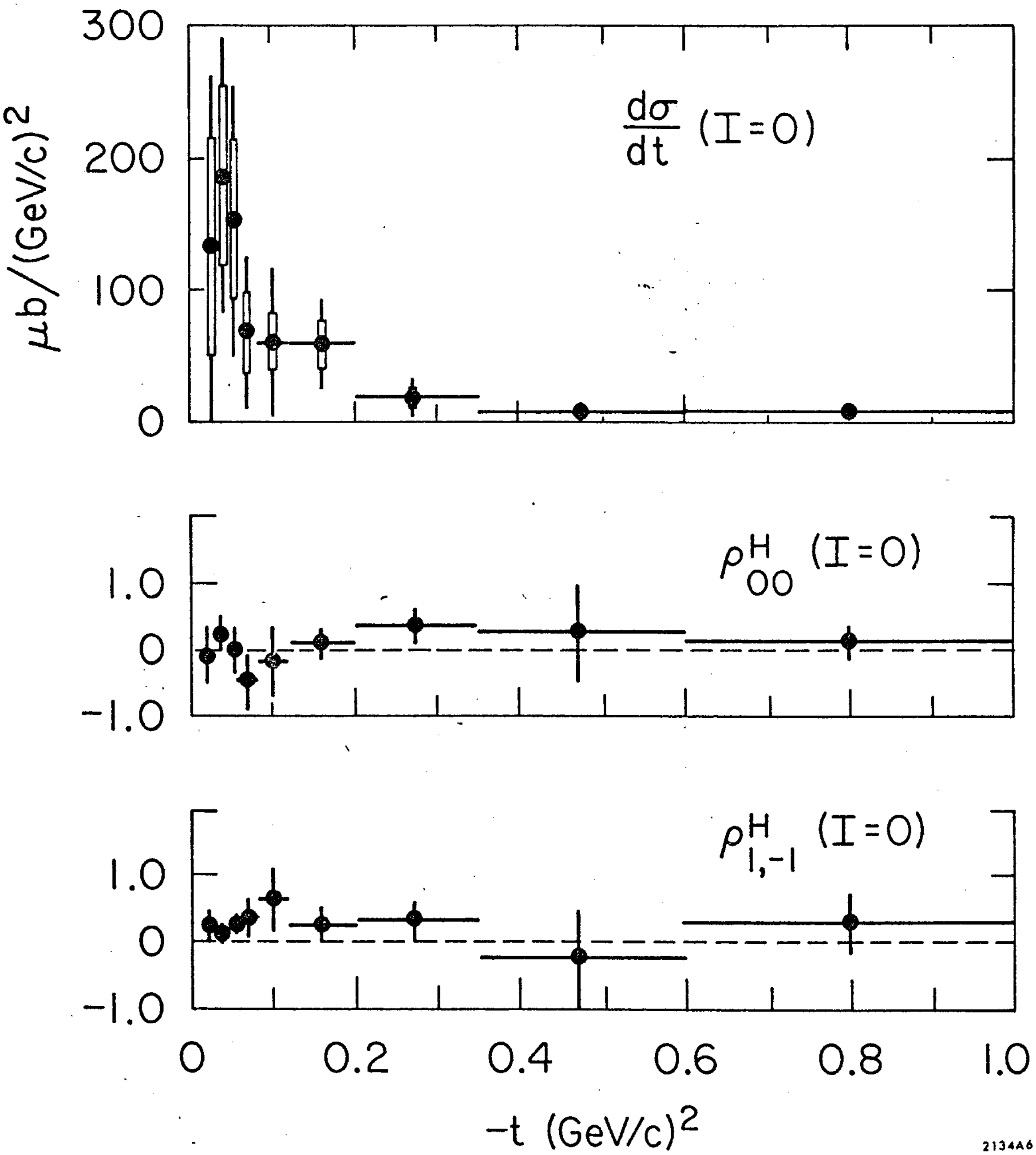
2. The isoscalar components of the differential cross section and ρ density matrix elements. For $d\sigma/dt$ ($I = 0$) the systematic errors are illustrated by the bars; the statistical errors are added on the ends. Only statistical errors are shown for the density matrix elements.

3. The natural and unnatural parity components of the isoscalar cross section for $0 \leq |t| \leq 1.0$ $(GeV/c)^2$ as a function of laboratory momentum. The errors here include our estimate of systematic uncertainties.



π⁺p → ρ⁺p
π⁻p → ρ⁻p
π⁻p → ρ°n
ρ^H_{00}
$\rho^H_{1,-1}$
Re ρ^H_{10}
1.0
0
0.4
-0.4
0
0.2
0.4
0.6
0.8
1.0
-t (GeV/c)²
2134D1

Fig. 1



300
200
100
0
μb/(GeV/c)²
dσ/dt (I=0)
1.0
0
−1.0
ρ^H_00 (I=0)
1.0
0
−1.0
ρ^H_1,−1 (I=0)
0
0.2
0.4
0.6
0.8
1.0
−t (GeV/c)²
2134A6

Fig. 2

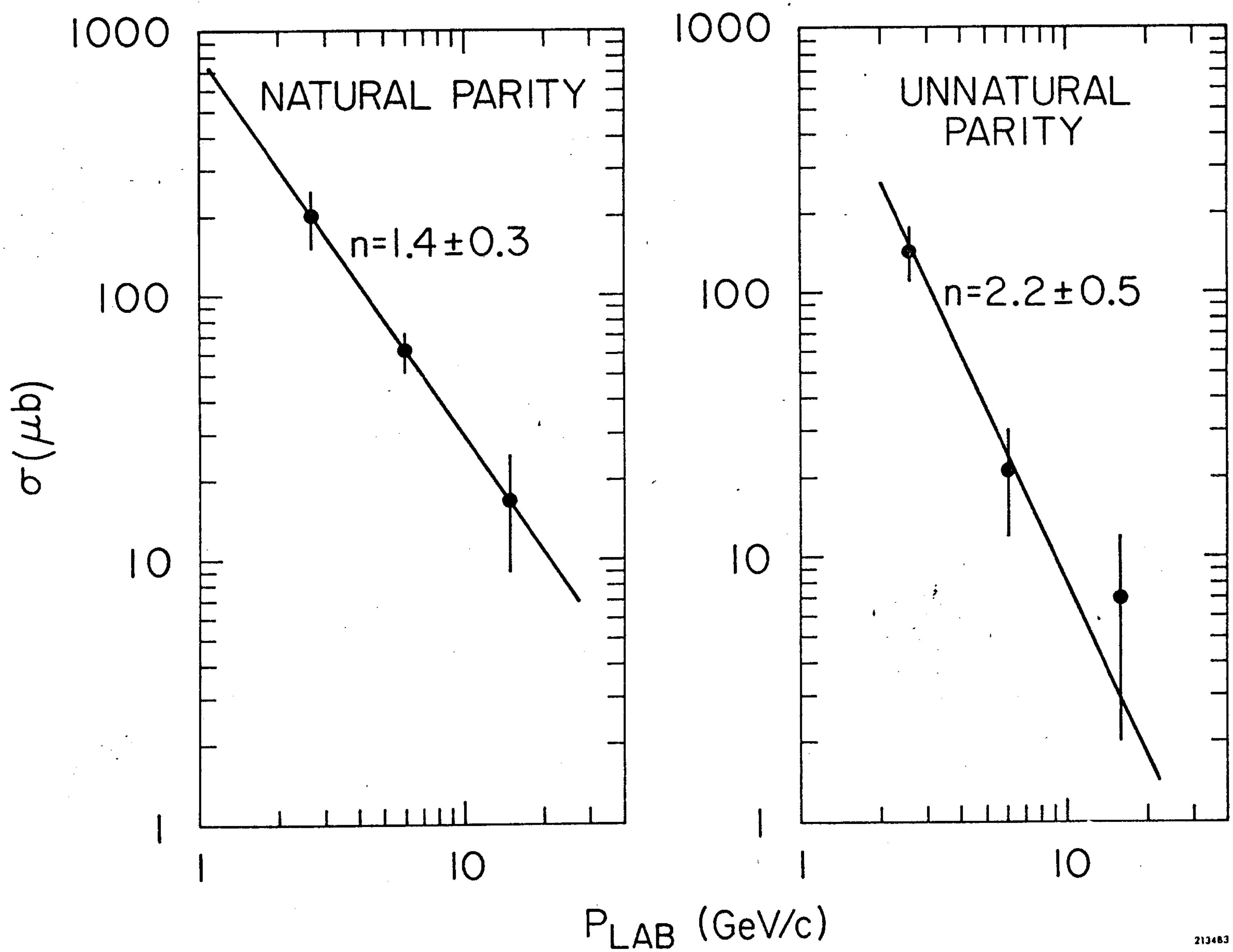

1000
100
10
1
σ(μb)
NATURAL PARITY
n=1.4±0.3
UNNATURAL
PARITY
n=2.2±0.5
1
10
P LAB (GeV/c)
213483

Fig. 3