HIGH-ENERGY NUCLEON-NUCLEON TOTAL CROSS SECTIONS

A. N. Diddens, E. Lillethun, G. Manning,* A. E. Taylor,* T. G. Walker,† and A. M. Wetherell
CERN, Geneva, Switzerland
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This Letter reports the results of an experiment aimed at filling a gap in the present knowledge of nucleon-nucleon total cross sections. Transmission measurements of "p-n" and p-p total cross sections, including diffraction scattering, at momenta between 3.3 and 7.8 GeV/c were performed. Here "p-n" stands for $(p$-$d)$ - $(p$-$p)$. The "p-n" total cross section is found to be constant, and the same as that at higher energies.

The experiment was essentially the same as that described by Ashmore et al.[1] The proton beam used was an elastically scattered beam from the CERN proton synchrotron. It was momentum selected and its energy varied by changing the operating cycle of the synchrotron. It was found possible to run the accelerator in a stable and reliable manner at proton kinetic energies as low as 2.5 GeV.

The experimental apparatus consisted of two 2-cm diameter scintillators ~9 m apart, defining the beam after momentum analysis, followed by the absorber and then seven transmission counters subtending half-angles between 6 and 45 mrad at the center of the absorber. The angles were chosen by consideration of the beam divergence, the multiple scattering[2] in the absorber, and the width of the diffraction pattern at the energies used. Absorbers of D_2O and H_2O were used in the "p-n" determinations and CH_2 and C for the p-p cross sections; all of the absorbers were about a radiation length in thickness.

The cross sections measured for each solid angle were corrected for multiple Coulomb scattering[2] and for random coincidences, which were measured continuously. The latter correction never exceeded 1 mb. A linear extrapolation to zero solid angle was made using those points which corresponded to the region of the diffraction pattern in which such an extrapolation was expected to be linear. The total cross sections obtained are given in Table I and are compared with those of other experiments in Fig. 1. The errors quoted are mainly statistical. The last column in the table gives the difference $\sigma_{tot}(p$-$p)$ - σ_{tot}("p-n"). At higher momenta, between 10 and 24 GeV/c, Ashmore et al.[1] have measured this difference to be 3 ± 1 mb.

Table I. Measured cross sections.

Momentum (GeV/c)	Total cross section $\sigma_{tot}(p$-$p)$ (mb)	σ_{tot}("p-n") (mb)	Difference $\sigma_{tot}(p$-$p)$ σ_{tot}("p-n") (mb)
3.27	47.1 ±0.9	37.1 ±1.3	10.0 ±1.6
4.51	42.1 ±0.7	36.8 ±0.9	5.3 ±1.1
5.83	41.6 ±0.6	37.0 ±0.8	4.6 ±1.0
7.75	41.6 ±1.1	37.6 ±1.6	4.0 ±1.9

The p-p points measured in this experiment are in good agreement with the measurements of Longo and Moyer,[3] von Dardel et al.,[4] Ashmore et al.,[1] and Lindenbaum et al.,[5] although the 3.27-GeV/c point appears to be somewhat high.

The neutron cross-section measurements of Chen et al.[6] and Ashmore et al.[1] are of the "p-n" type and can be compared directly with the present one (see Fig. 1). It is seen that there is little energy variation from 3 GeV/c upwards. To obtain the n-p total cross section, the "p-n" points have to be corrected for the shadowing effect of the accompanying proton in the deuteron. This shadowing correction has been calculated by Glauber.[7] In the approximation of the proton-neutron separation in the deuteron, r, being large compared to the interaction radius, and for a purely imaginary nucleon-nucleon scattering amplitude, the result is

$$\Delta\sigma = \sigma_{tot}(n\text{-}p) - \sigma_{tot}(\text{“}p\text{-}n\text{”})$$

$$= (1/4\pi)\sigma_{tot}(p\text{-}p)\sigma_{tot}(n\text{-}p)\langle r^{-2}\rangle_d.$$

This correction is about 4 mb, taking $\langle r^{-2}\rangle = (1.7\ \text{F})^{-2}$.

Figure 2 is a comparison of p-p, $\bar{p}$-p, and corrected "p-n" cross sections. Smooth curves have been drawn through the experimental points. Above 2 GeV/c only two direct n-p measurements have been made. The point of Coor et al.[8] at 2.1 GeV/c lies 5 mb above the curve; the point of Atkinson et al.[9] lies 8 mb below the curve. The quoted uncertainties in their measurements are 1.8 and 1.6 mb, respectively.

The figure shows that, above 3 GeV/c, the

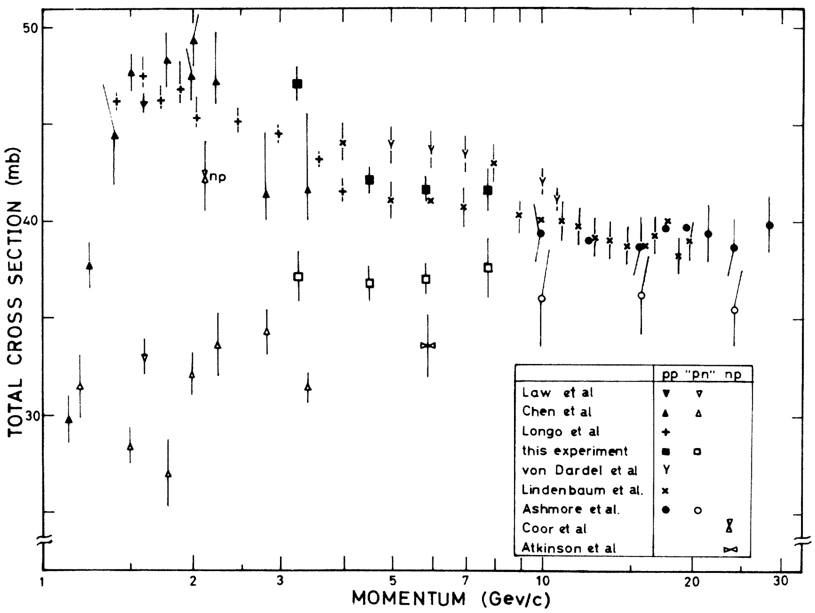

FIG. 1. Nucleon-nucleon total cross sections. The data are taken from this experiment and from references 1, 3-6, 8, 9, and 11.

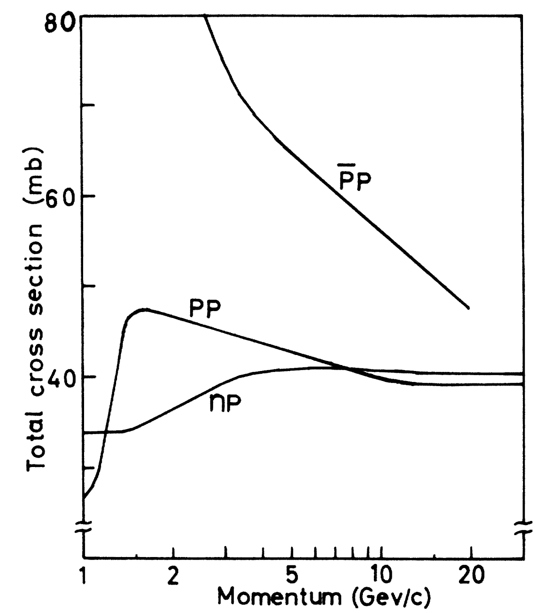

FIG. 2. Trend of p-p, $\bar{p}$-p, and n-p total cross sections. The n-p cross section has been obtained by correcting the "p-n" cross sections for the shadowing effect.

n-p cross section thus obtained has little energy variation and that it is not significantly different from the p-p cross section.

The p-p, $\bar{p}$-p, and n-p cross sections in this energy range have been discussed recently by Udgaonkar.[10] The fact that above 3 GeV/c, $\sigma_{\text{tot}}(p\text{-}p)-\sigma_{\text{tot}}(n\text{-}p)\approx 0$, and is much smaller than $\sigma_{\text{tot}}(\bar{p}\text{-}p)-\sigma_{\text{tot}}(p\text{-}p)$, is in conflict with a statement by Udgaonkar based on the single value of Atkinson et al. In the context of Udgaonkar's analysis, our results indicate that the contributions to the cross sections of the Regge poles due to the π and ρ mesons are small compared to the contributions from the ω and η poles.

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*On leave of absence from the Atomic Energy Research Establishment, Harwell, England.

†On leave of absence from National Institute for Research in Nuclear Science, Harwell, England.

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EXPERIMENTAL CROSS SECTION FOR $\pi\pi \rightarrow K\bar{K}$ *

A. R. Erwin, G. A. Hoyer, R. H. March, W. D. Walker, and T. P. Wangler
University of Wisconsin, Madison, Wisconsin and Brookhaven National Laboratory, Upton, New York
(Received June 6, 1962)

For some time there has been theoretical interest in scattering channels other than $\pi\pi \rightarrow \pi\pi$ because of their possible contributions to the nucleon form factors.[1,2] Recent experimental success in observing $\pi\pi \rightarrow \pi\pi$ scattering in peripheral collisions has led some authors to suggest that the same methods may give information concerning other channels.[3] We report here an experiment which gives rough values for isospin dependence and cross sections in the reaction $\pi\pi \rightarrow K\bar{K}$.

The experiment involves looking for K pairs produced in peripheral π^-p collisions at 1.89 BeV/c and 2.10 BeV/c in the Adair 14-in. hydrogen bubble chamber. The three possible reactions are:

$$\pi^- + p \rightarrow K^0 + \bar{K}^0 + n, \qquad (1)$$

$$\pi^- + p \rightarrow K^- + K^0 + p, \qquad (2)$$

$$\pi^- + p \rightarrow K^+ + K^- + n. \qquad (3)$$

High-energy π^- experiments at CERN have shown that K mesons produced in pairs tend to peak forward in the center-of-mass system indicating that a peripheral collision may be involved.[4] Center-of-mass angular distributions for the recoil nucleon of reactions (1) and (2) of our experiment are shown in Fig. 1(a). The fact that the nucleon prefers the backward direction after the reaction suggests collisions with high impact parameters.

We will now attempt to show that our limited data for reactions (1) and (2) are consistent with the one-pion-exchange model of Chew and Low.[5,6] For one-pion exchange we expect the observed differential cross section described by the diagram in Fig. 2(a) to be[7]

$$\frac{d^2\sigma}{d\Delta^2 dm^*} = \frac{f^2}{\pi}\frac{km^{*2}}{q_{iL}^{\;2}}\bar{\sigma}_{K\bar{K}}(m^*)\frac{\Delta^2}{\mu^2}\frac{1}{(\Delta^2+\mu^2)^2} \times \begin{cases} 1 \text{ for } \pi^0 \text{ exchange} \\ 2 \text{ for } \pi^+ \text{ exchange}, \end{cases} \qquad (4)$$

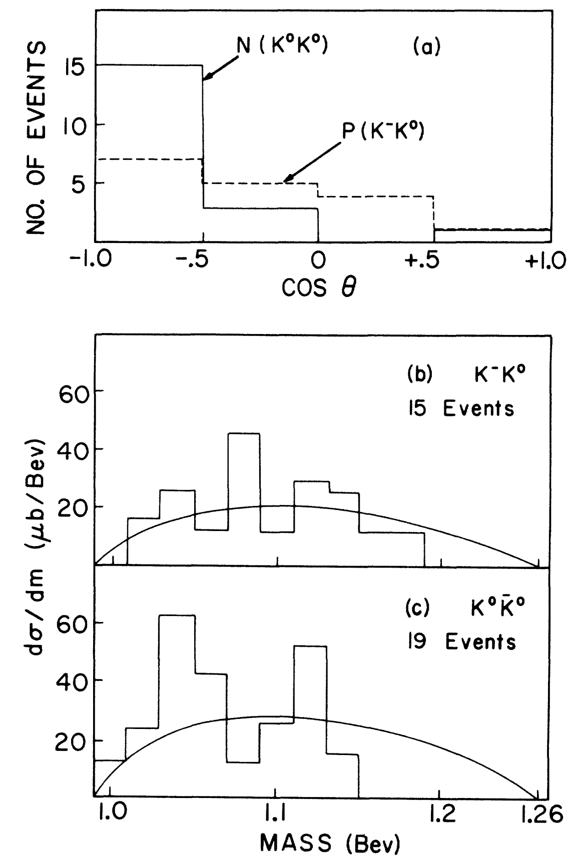

FIG. 1. (a) Center-of-mass angular distributions for the nucleon. Solid curve is for reaction (1). Dashed curve is for reaction (2). (b) Cross section for K^-K^0p events in which all three final particles are observed vs total energy of the K^-K^0 system. (c) Cross section for $K^0\bar{K}^0n$ events in which two $K_1^{\,0}$ decays are observed vs total energy of the $K^0\bar{K}^0$ system. The smooth curves in (b) and (c) represent phase space modified by the momentum distribution of the beam and detection efficiency.

where m^* is the invariant mass of the $K\bar{K}$ system, k is the momentum of one K meson in the $K\bar{K}$ system, Δ is the invariant momentum transfer to the nucleon, $\bar{\sigma}_{K\bar{K}}(m^*)$ is some average over