TOTAL CROSS SECTIONS OF $\pi^{\pm}$, $K^{\pm}$, p AND $\bar{p}$ ON PROTONS AND DEUTERONS BETWEEN 200 AND 370 GeV/*c*

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Total cross sections of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ on protons and deuterons have been measured at 6 momenta between 200 and 370 GeV/*c*.

We report here an extension of our earlier measurements [1,2,3] (referred to here as I, II and III respectively) of hadron total cross sections to incident beam momenta of 370 GeV/*c*. The higher momenta were achieved by the upgrading of the M1 beam in the Meson Laboratory at Fermilab [4,5] where the experiment was carried out, and the availability of 400 GeV/*c* protons on the Meson Laboratory target. The experimental arrangement was essentially identical to that described in III, except for the following modifications: (i) The number of muons in the incident beam was determined by penetration through 6.1 m of steel. (ii) For most data below 280 GeV/*c*, incident particles were identified using two gas differential Cerenkov counters [6] with radiator lengths of 16 and 32 m and respective Cerenkov angles of 15 and 7.5 mr. For 310 GeV/*c* and above, the two counters were combined into one with radiator length of 48 m and Cerenkov angle of 5 mr in order to obtain the additional resolution required. (iii) The distance from target to transmission counters in I, II and III, at a momentum of P(GeV/*c*), was $0.30P$ (meters), while in this experiment it was reduced to $0.23P$ (meters) because of space limitations.

Data analysis was carried out similarly to that described previously except for changes necessitated by modification (iii) above. Data taken at 200 GeV/*c*, at a distance of 60 m (and thus with each transmission counter covering the same t range as before) were in excellent agreement with those obtained previously: e g. to ~0.05% in the pp case. With the reduced distance, the individual counters did not cover the same t ranges as in III, and there was therefore some uncertainty about which counters to include in the extrapolation fit. In the few cases where the results were dependent on the choice of counters, we used that set of counters in the extrapolation which gave a result closest to that obtained in III in the overlapping momentum region; in the case of σ_{pd}, where there was the largest sensitivity to this effect (~0.5%), we normalized the cross sections in the overlap region to give agreement with III. As in III, the extrapolation procedure was verified using proportional wire chambers [7]. Our procedure extrapolated the fit to the partial cross sections from $-t = 0.015$ $(\mathrm{GeV}/c)^2$ to $-t = 0$. In the case of $\bar{p}p$ scattering at 280 GeV/*c*, the proportion-

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Table 1
Total cross sections in millibarns measured in this experiment, and combined with those of ref. [3] where appropriate See text for definitions of $\langle r^{-2}\rangle$ and α. Any entry in this table supercedes the corresponding entry in table I of ref [3] Only momentum dependent errors are given.

	Momentum in GeV/c						
	200	240	280	310	340	370	α
σ_{pp}	38.98 ± 0.04	39.24 ± 0.04	39.42 ± 0.04	39.59 ± 0.06	39.69 ± 0.07	39.77 ± 0.06	–
σ_{pd}	73.99 ± 0.07	74.42 ± 0.07	74.61 ± 0.07	74.96 ± 0.10	75.02 ± 0.12	75.35 ± 0.11	–
σ_{pn}	39.27 ± 0.05	39.50 ± 0.06	39.53 ± 0.05	39.75 ± 0.07	39.72 ± 0.10	40.01 ± 0.08	–
$\sigma_{\bar{p}p}$	41.51 ± 0.15	41.90 ± 0.20	41.91 ± 0.21	–	–	–	–
$\sigma_{\bar{p}d}$	78.32 ± 0.28	78.46 ± 0.29	78.40 ± 0.31	–	–	–	–
$\sigma_{\bar{p}n}$	41.62 ± 0.23	41.39 ± 0.34	41.30 ± 0.38	–	–	–	–
σ_{K^+p}	19.91 ± 0.11	20.22 ± 0.06	20.45 ± 0.07	20.67 ± 0.15	–	–	–
σ_{K^+d}	38.42 ± 0.10	39.32 ± 0.10	39.76 ± 0.10	40.14 ± 0.21	–	–	–
σ_{K^+n}	19.72 ± 0.11	20.37 ± 0.09	20.61 ± 0.10	20.80 ± 0.26	–	–	–
σ_{K^-p}	20.79 ± 0.05	21.30 ± 0.07	21.32 ± 0.08	21.45 ± 0.12	–	–	–
σ_{K^-d}	40.00 ± 0.10	40.50 ± 0.09	40.85 ± 0.10	41.13 ± 0.15	–	–	–
σ_{K^-n}	20.52 ± 0.08	20.55 ± 0.09	20.90 ± 0.11	21.07 ± 0.18	–	–	–
σ_{π^+p}	23.78 ± 0.04	24.10 ± 0.07	24.43 ± 0.10	24.50 ± 0.10	24.62 ± 0.14	–	–
σ_{π^+d}	46.26 ± 0.08	46.88 ± 0.10	47.18 ± 0.14	47.24 ± 0.15	47.45 ± 0.20	–	–
σ_{π^-p}	24.34 ± 0.04	24.61 ± 0.04	24.78 ± 0.06	24.90 ± 0.08	25.08 ± 0.08	25.25 ± 0.09	–
σ_{π^-d}	46.32 ± 0.07	46.91 ± 0.07	47.05 ± 0.09	47.34 ± 0.11	47.68 ± 0.12	47.89 ± 0.15	–
$\sigma_{\bar{p}p} - \sigma_{pp}$	2.53 ± 0.11	2.66 ± 0.18	2.49 ± 0.19	–	–	–	0.43 ± 0.02
$\sigma_{\bar{p}d} - \sigma_{pd}$	4.33 ± 0.18	4.04 ± 0.26	3.79 ± 0.29	–	–	–	0.43 ± 0.02
$\sigma_{\bar{p}n} - \sigma_{pn}$	2.35 ± 0.24	1.89 ± 0.34	1.77 ± 0.38	–	–	–	0.40 ± 0.04
$\sigma_{K^-p} - \sigma_{K^+p}$	0.88 ± 0.08	1.08 ± 0.07	0.87 ± 0.09	0.77 ± 0.18	–	–	0.44 ± 0.03
$\sigma_{K^-d} - \sigma_{K^+d}$	1.58 ± 0.10	1.18 ± 0.10	1.09 ± 0.11	0.98 ± 0.25	–	–	0.39 ± 0.03
$\sigma_{K^-n} - \sigma_{K^+n}$	0.80 ± 0.14	0.18 ± 0.13	0.29 ± 0.15	0.27 ± 0.32	–	–	0.31 ± 0.10
$\sigma_{\pi^-p} - \sigma_{\pi^+p}$	0.56 ± 0.04	0.51 ± 0.06	0.35 ± 0.08	0.40 ± 0.08	0.46 ± 0.13	–	0.54 ± 0.03
$\sigma_{\pi^-d}/\sigma_{\pi^+d}$	1.001 ± 0.002	1.001 ± 0.003	0.997 ± 0.004	1.002 ± 0.004	1.005 ± 0.005	–	–
$\langle r^{-2}\rangle$ (mb^{-1})	0.040	0.039	0.043	0.043	0.043	–	–

al wire chamber data, which allowed measurements to smaller values of $-t$, showed that there was no rapid change in partial cross section slope down to at least $-t \approx 0.006$ (GeV/c)^2.

Several cross sections measured in III were repeated here, and there was good agreement between the new data and those of III.

Based on the reproducibility of the data and upon the uncertainty in extrapolation procedure we estimate the momentum dependent systematic uncertainty in p and $\bar{p}$ cross sections to be between ± 0.1% and ± 0.2% in addition to the statistical error. For pions and kaons, the estimated systematic uncertainty was increased to between ± 0.2% and ± 0.3% as a result of uncertainties in the muon contamination. A momentum independent systematic scale error in the absolute magnitude of the cross sections is introduced by uncertainties in the form of extrapolation and in the hydrogen and deuterium

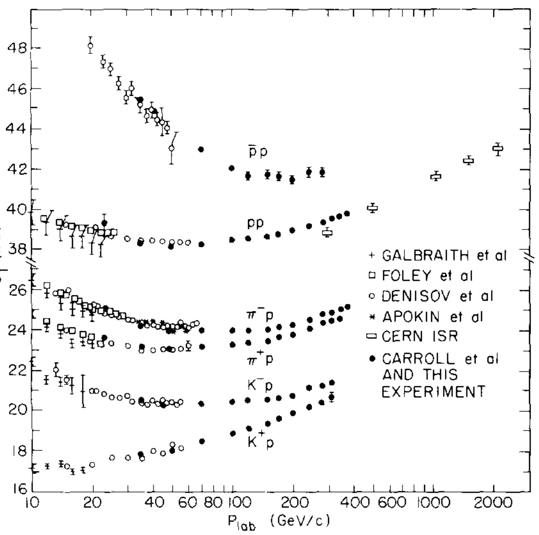
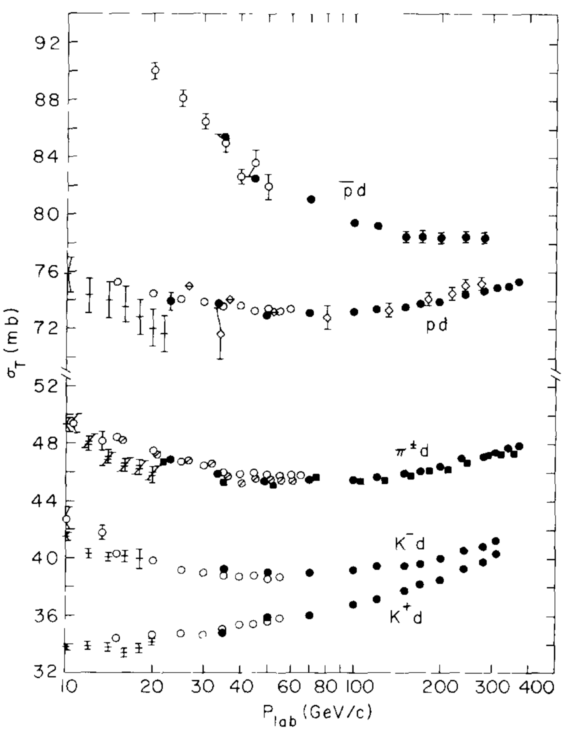


Fig. 1. Total cross sections on protons; only momentum dependent errors are shown. Data in figs. 1, 2 and 3 are from this experiment and refs. [3,8–18]. Additional earlier data is given in ref [3].

densities and contaminations. It is estimated to be ± 0.4% for protons and ± 0.7% for deuterons. The systematic scale error for deuterons was determined from the consistency of these measurements and those of III.

Results of this experiment are given in table 1 and also displayed in figs. 1 and 2, together with previous data [3,8–18] Only momentum dependent errors are given. Where measurements made in III have been repeated in the present experiment, we have combined the two measurements, so that any entry in table 1 supercedes the corresponding entry in table I of III. This is done in order to correctly combine both the statistical and systematic uncertainties in the two experiments.

Cross sections for target neutrons have been obtained from those on protons and deuterons using the



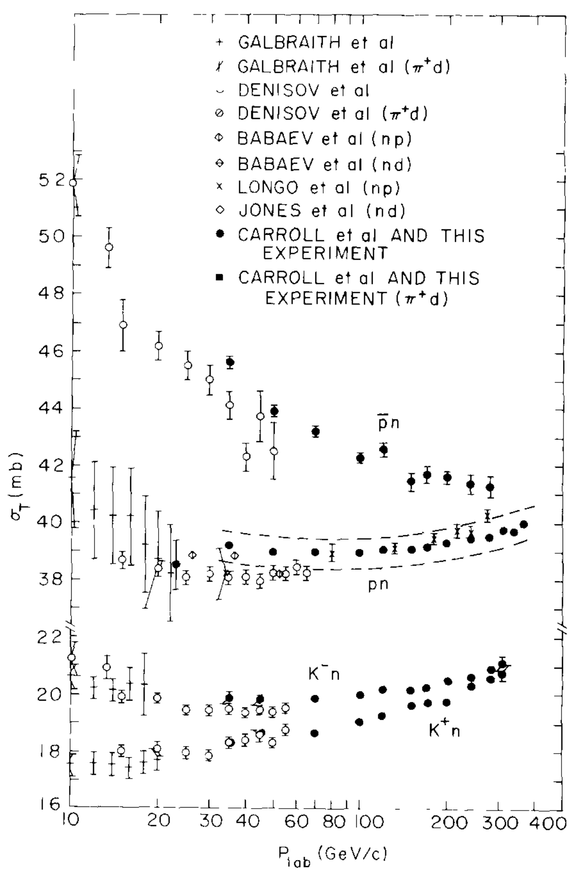


Fig. 2. Total cross sections on deuterons on neutrons. Only momentum dependent errors are shown The upper and lower dashed curves represent the pn cross sections assuming $\langle r^{-2} \rangle$ = 0.039 and 0.031 mb^{-1} respectively.

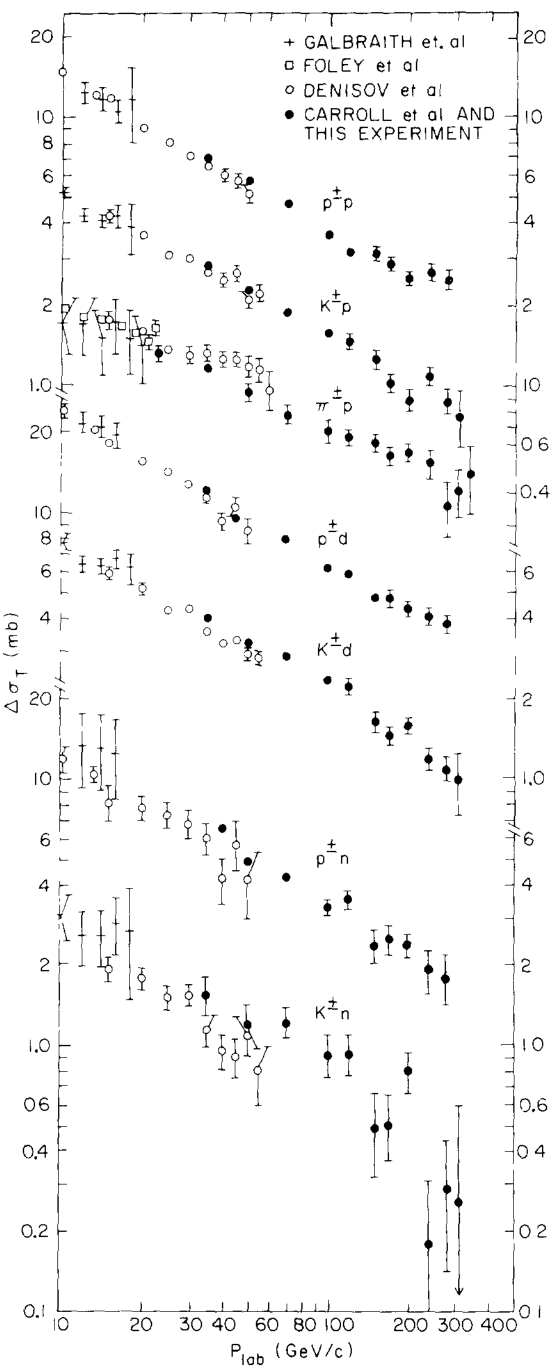


Fig. 3. Antiparticle–particle total cross section differences

Glauber–Wilkin procedure [19,20]; the parameter $\langle r^{-2}\rangle$ derived from pion cross sections on protons and deuterons is given in table 1. To provide consistency over the range 23 to 370 GeV/c measured in III and this experiment, we derive neutron cross sections using $\langle r^{-2}\rangle$ of 0.039 mb^{-1} for pions and kaons, and 0.035 mb^{-1} for protons and antiprotons. As we noted in III, it must be stressed that the adequacy of this procedure for deriving neutron cross sections has been frequently questioned [21], so we again emphasize that caution should be exercised in drawing conclusions on neutron cross sections from these data As an illustration, fig 2 shows the effect on the pn cross section of a variation in $\langle r^{-2}\rangle$ of ± 0 004 mb^{-1}. Reasonable changes in the parameter $\langle r^{-2}\rangle$, however, do not appreciably affect the momentum dependence of the neutron cross sections.

The new data above 200 GeV/c for all cross sections extrapolate well from the data of III, and continue the trends observed there. In particular, the p̄p cross section appears momentum independent above ~120 GeV/c; this is consistent with the behavior of all other cross sections where the cross sections, after falling with increasing momentum, reach a minimum before rising again

The simple power law dependence of the antiparticle–particle differences observed in I, II and III continues to hold at the higher momenta measured here, as shown in fig. 3. Fitting the data of III and this experiment only (from 23 to 370 GeV/c) with the form $As^{\alpha-1}$, we obtain the values of α given in table 1

The ratio $\sigma_{\pi^-d}/\sigma_{\pi^+d}$, which should be unity if charge symmetry is valid, is given in table 1; it is always consistent with 1, and averages 1.0008 ± 0.0014.

In conclusion, we have measured hadron total cross sections up to 370 GeV/c. The trends observed previously [3] continue to hold. Conclusions drawn on comparisons of the earlier data with various relations given by quark and Regge pole models (e.g. [13,22]) remain valid.

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