#4 dupl

PUB-74-152-E
E-0104

#4

HE UM 74-22

Neutron-Proton Total Cross Sections from 40 to 280 GeV/c*

Michael J. Longo, Cyril A. Ayre, H. Richard Gustafson
Lawrence W. Jones, P.V. Ramana Murthy+ and Patrick Skubic

Department of Physics
University of Michigan
Ann Arbor, Michigan 48104

and

Bruce Cork

Lawrence Berkeley Laboratory

June, 1974

---

*Work supported by the National Science Foundation and the Atomic Energy Commission

+On leave from Tata Institute for Fundamental Research, Bombay, India.

Abstract

We present results of measurements of the n-p total cross section between 30 and 280 GeV/c. The measurements were carried out with a neutron beam using the standard transmission technique and a liquid hydrogen target. A total absorption calorimeter was used to determine the neutron energy. Our measurements, which have an accuracy ~1%, tie on smoothly with lower energy n-p data. They indicate a smooth rise of approx. 1.5 mb between 30 and 280 GeV/c. The n-p and p-p cross sections seem to be nearly equal in this range. The combined n-p and p-p data above 20 GeV/c are well fitted by the expression $\sigma = 38.4 + 0.85|\ln(s/95|^{1.47}$ mb.

In this article we present results of a series of measurements of neutron-proton total cross sections from 30 to 280 GeV/c. The measurements were carried out in a neutron beam at the Fermi National Accelerator Laboratory. The standard transmission technique was employed with a 1.2 m liquid hydrogen target. A total absorption ionization calorimeter was used to detect the neutrons and measure their energy.

The neutron beam was taken off at an angle of 1 mr from a beryllium target in the external proton beam. Most of the data were taken with an incident proton momentum of 300 GeV/c; some data were also taken with 200 GeV/c protons. The beam was defined by a steel collimator 1.58 mm in diameter, placed 198 m from the production target. Sweeping magnets before and after the defining collimator removed charged particles from the beam. Two lead filters, one 5 cm thick ahead of the defining collimator and the other 1.3 cm thick following the collimator, removed most of the high-energy γ's. The neutron spectrum peaked strongly near 230 GeV/c. Below about 100 GeV/c, the beam contained a significant admixture of $\bar{n}$'s, K°'s and γ's.[1]

The experimental arrangement is shown schematically in Figure 1. Relative beam intensity was measured by two monitor telescopes placed in the beam just ahead of the hydrogen target. Each telescope consisted of a veto counter followed by a 1.6 mm thick lucite converter and 3 small scintillation counters in triple coincidence. The liquid hydrogen target was a flask 1.2 m long and 5 cm in diameter operated near atmospheric pressure. Mounted next to the target in the same vacuum jacket was an evacuated dummy target. During data taking the two targets were interchanged about once per minute. The length of the target was found to be 121.53 ± 0.03 cm at liquid hydrogen temperature.[2] The target pressure was monitored continuously so that the hydrogen density could be determined accurately. Sufficient time elapsed between filling the target and taking data to insure that the ortho-to-parahydrogen transition was complete. Hydrogen density and vapor pressure data were taken from a recent NBS compilation.[3] The uncertainty in the final cross sections due to uncertainties in the target length, density, hydrogen purity, and other target properties is estimated to be <0.2%.

The ratio of the beam transmitted by the hydrogen target to that by the dummy target, was measured by placing a 1.25 cm iron converter in the beam, followed by 7 circular transmission counters and a total absorption calorimeter (see Fig. 1). The transmission counters D_1-D_7 ranged from about 1 to 5 cm in radius, compared to the beam radius of approx. 0.2 cm. The smallest counter was in contact with the iron converter and the largest was about 1.3 cm away. Charged particles formed by neutron interactions in the iron converter tend to go nearly along the direction of the incident neutron so that the transmission counters saw a charged particle distribution which closely approximated the distribution of transmitted neutrons at the iron converter.[4]

The calorimeter was placed just downstream of the transmission counters and provided a measure of the energy of the incident neutron. The calorimeter and its properties are discussed in Ref. 5. Briefly, it consisted of 30 iron plates, each 30 g cm^{-2} thick, interspersed with 30 scintillators. The light output from the scintillators was optically added and brought to four RCA 8575 phototubes. The summed output pulse from these was roughly proportional to the energy of the incident neutron. Measurements taken with a monoenergetic proton beam show that the calorimeter had an energy resolution (std. deviation) of 12 GeV at 200 GeV and 17 GeV at 300 GeV.

A total of 64 coincidences of various kinds were scaled and recorded. Most of these were of the type $\bar{A}_o\bar{A}_1D_jD_{j+1}C_i$, where A_o and A_1 are the veto counters shown in Fig. 1 and C_i represents a pulse from one of seven discriminators which were set to trigger only if the pulse height from the calorimeter exceeded some minimum δ_i. The δ_i corresponded to energies deposited in the calorimeter of approx. 14, 52, 104, 154, 206, 231, and 252 GeV/c. The neutron spectrum could thus be divided into the 7 momentum ranges given in Table 1 by subtracting counts in successive momentum bins (e.g., $A_oA_1D_jD_{j+1}C_i - A_oA_1D_jD_{j+1}C_{i-1}$). The other scaler channels recorded the beam monitors, accidental coincidences of various kinds, singles rates, proton beam intensity, etc.

The scaler counts were recorded on magnetic tape after every beam pulse. This allowed later editing of occasional bad beam pulses. Data were taken in "runs" lasting from 30 to 90 minutes.

For each run the pulse-to-pulse variations in scaler/monitor ratios were checked. These were consistent with expected statistical fluctuations in most cases; if not, a larger error was assigned or the data were rejected. The final sample includes data from 80 runs with 300 GeV/c incident protons and 40 runs with 200 GeV/c protons. Over the course of the measurements, which spanned about 10 months, accelerator performance (in particular, duty cycle and beam stability) improved markedly. Despite the wide range of conditions the measured cross sections showed a high degree of consistency after small corrections for a rate effect were made as discussed below.

Corrections to the cross sections were ~1% except for the lowest momentum bin. These are described below and numerical values are given in Table 1.

Rate Effects: Because we are making cuts on the neutron pulse-height spectrum to determine the neutron energy, any shift in the pulse-height spectrum between target empty and target full will cause a systematic error in the cross sections. Some variation of the cross sections with beam rate was observed. This was due to pileup of pulses from the calorimeter[6] which occurs more frequently with the target empty. This effect is expected to give an error which is a nearly linear function of beam rate. Corrections were made by extrapolating the cross sections linearly to zero rate. Table 1 gives typical values for this correction.

Finite Solid Angle: The measured cross sections were extrapolated to zero solid angle in the usual way. The smallest counter subtended an extremely small solid angle so this correction was quite small as shown in Table 1.

Beam Contamination: The lowest three energy bins contained a non-negligible admixture of K°'s. The procedure for determining the fraction of K°'s in the beam and the K° total cross sections is described in Ref. 1. The lowest energy bin also contained a significant admixture of γ's and $\bar{n}$'s . The $\bar{n}/n$ ratio was assumed to be the same as the $\bar{p}/p$ ratio in a similar charged beam.[7] Because this assumption is open to question, a large uncertainty was assigned to this correction.

The final cross sections are given in Table 1. The assigned errors include the statistical errors and the uncertainties in the rate corrections, the extrapolation to zero solid angle, and the beam contamination, all combined in quadrature. Our results are compared to available n-p data[8] and p-p data[9] in Figure 2. Our data tie on smoothly with the lower energy n-p data. They indicate a smooth rise of about 1.5 mb in the np total cross section between 50 and 280 GeV/c. In general, the n-p and p-p total cross sections seem to be approx. equal over the range 30 to 300 GeV/c. Our highest energy n-p points agree fairly well with the p-p total cross sections at 200 and 300 GeV/c measured previously by our group.[10] The combined n-p and p-p data above 20 GeV/c can be well fitted with the expression $\sigma = 38.4 + 0.85\,|\ln(s/95)|^{1.47}$ mb.

We would like to express our gratitude to the NAL staff for their help and cooperation. We also wish to thank F. Ringia, D. Koch, J. Stone, J. Chanowski and C. DeHaven for their invaluable help in various aspects of the experiment.

References and Footnotes

1. For a detailed description of the beam see, M.J. Longo *et al*., "Characteristics of the M-3 Neutral Beam at NAL", UM HE 74-18 (unpublished).
2. The target length was measured at room temperature and at liquid nitrogen temperature. Since the flask was made of a known aluminum alloy, the length at hydrogen temperature could be easily calculated from thermal expansion data. The change in length from nitrogen to hydrogen temperature was only 0.02%.
3. H.M. Roder *et al*., Nat'l Bureau of Standards Technical Note 641, August 1973 (unpublished).
4. Because of the finite opening angle of the cone containing the charged secondaries, the effective size of the transmission counters was somewhat larger than their geometrical size. The effective size was determined by scanning the beam stepwise across the iron converter. This gave the probability of detecting a neutron vs. distance from the beam axis.
5. L.W. Jones *et al*., UM HE 73-24, to be published in Nucl. Instr. and Meth.
6. This is a partial coincidence of two pulses from the calorimeter which shifts one or both pulses to a higher energy bin.
7. W.F. Baker *et al*., "Measurement of $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ Production by 200 and 300 GeV/c Protons," N.A.L. Preprint (unpublished).

8. Serpukhov neutron beam data: A. Babaev *et al*., ITEP-11, to be published in Phys. Lett. Serpukhov (pd-pp) data: Yu. P. Gorin *et al*., Sov. J. Nucl. Phys. 17, 157 (1973).

9. References to the p-p total cross section data are given in Ref. 10. The 300 GeV/c bubble chamber measurement of Dao *et al*. has been revised to 40.68±0.55 mb (A. Firestone *et al*., CALT-68-438.)

10. H.R. Gustafson *et al*., Phys. Rev. Lett. 32, 441 (1974).

Figure Captions

1. Schematic of experimental arrangement. Not to scale.
2. n-p and p-p total cross sections. Not all the data below 60 GeV/c are shown.

Table Caption

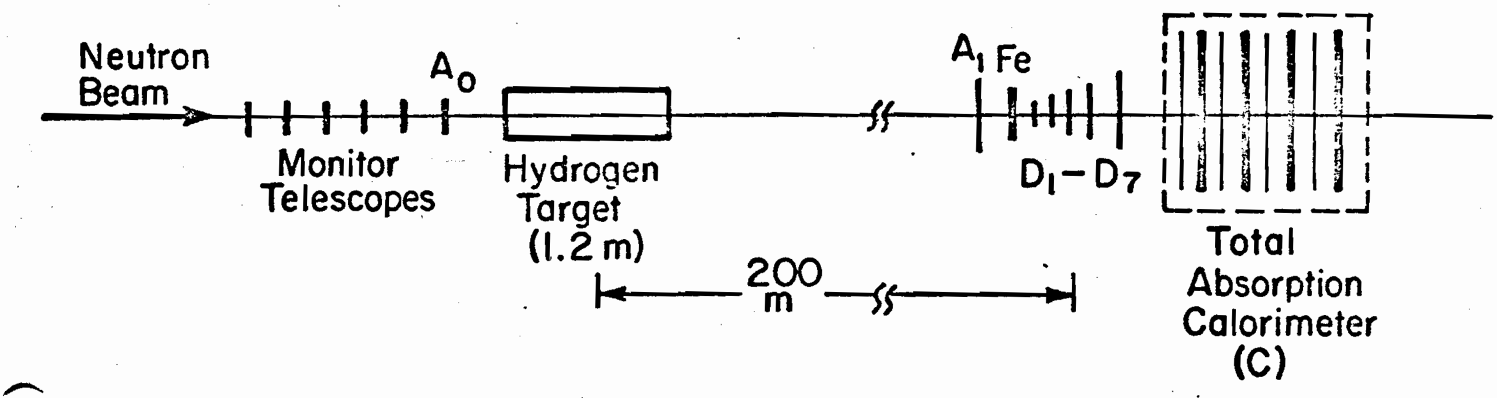
Table 1. Measured cross sections and corrections. Measurements marked with (*) were taken with an accelerator energy of 200 GeV.

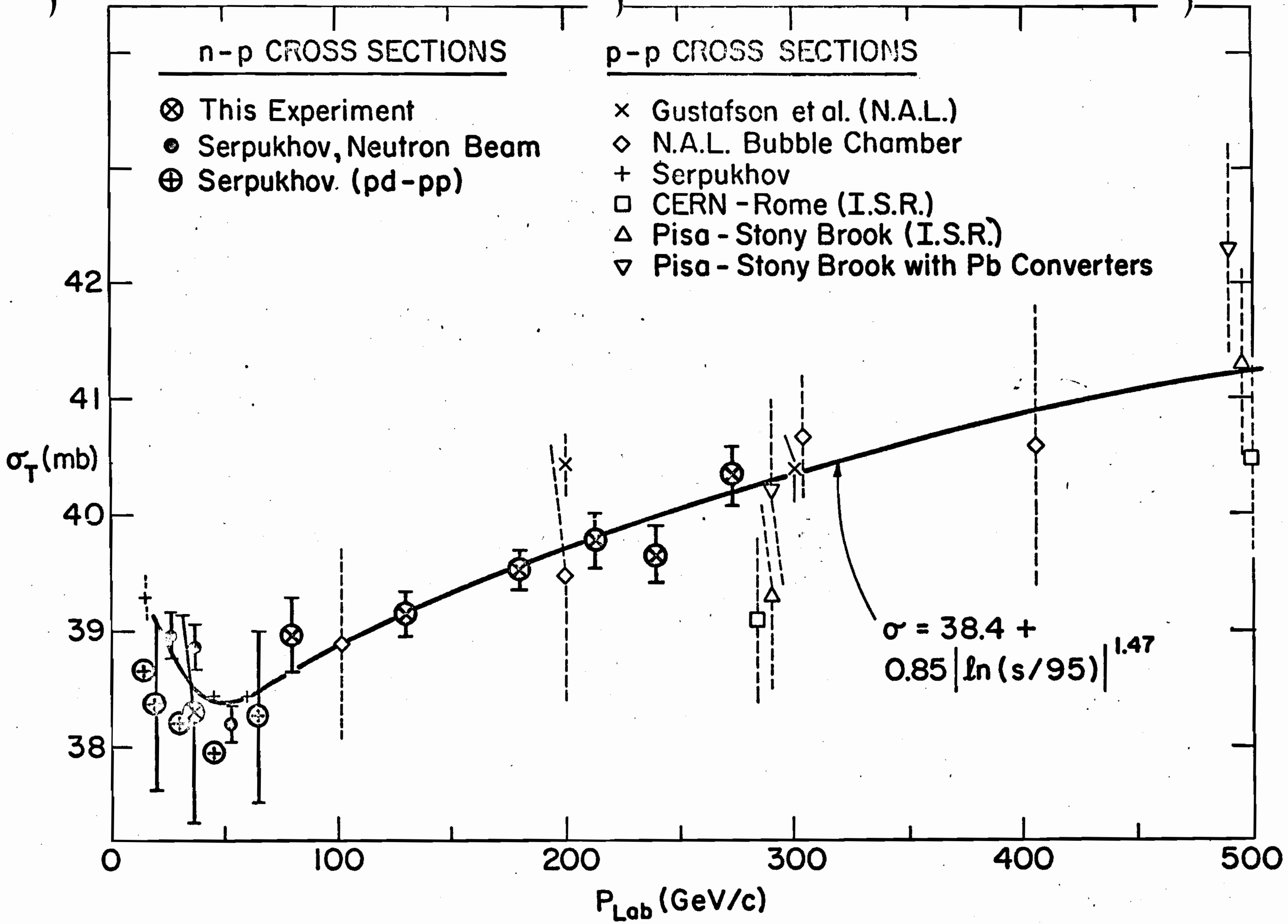
Table 1 - Cross Sections and Corrections

Momentum Range			σ $(D_1D_2)^\dagger$ mb	Typ. Rate Correction	Extrap. to zero solid angle	Beam Contam. Corr.	Total Cross section (mb)	Average
Min.	Max.	Mean						
252	300	273 GeV/c	40.20±0.22	(-0.8)	+0.12±0.06		40.32±0.23	
231	252	240	39.58±0.23	(0)	+0.08±0.04		39.66±0.24	
206	231	215	39.71±0.23	(+0.2)	+0.08±0.04		39.79±0.24	
154	206	180	39.55±0.19	(+0.3)	+0.07±0.04		39.62±0.20	39.52±0.18
154	206	175*	39.17±0.36	(-0.4)	+0.04±0.02		39.21±0.36	
104	154	131	38.78±0.22	(+0.25)	+0.09±0.05	+0.27±0.08	39.14±0.24	39.17±0.19
104	154	133*	39.10±0.30	(+0.25)	+0.06±0.03	+0.05±0.04	39.21±0.30	
52	104	80	37.56±0.25	(+0.3)	+0.11±0.06	+1.35±0.37	39.02±0.45	38.98±0.33
52	104	80*	38.30±0.34	(+0.25)	+0.22±0.07	+0.43±0.20	38.95±0.40	
14	52	34	34.52±0.38	(+0.20)	+0.37±0.15	+2.95±0.81	37.84±0.91	38.2±0.9
14	52	34*	35.09±0.60	(+0.15)	+1.5±0.35	+2.23±0.84	38.82±1.09	

† Corrected for rate effects.

* Taken with a 200 GeV proton beam.


Neutron Beam
Monitor Telescopes
A0
Hydrogen Target (1.2 m)
200 m
A1 Fe
D1 – D7
Total Absorption Calorimeter (C)


n-p CROSS SECTIONS
⊗ This Experiment
● Serpukhov, Neutron Beam
⊕ Serpukhov (pd-pp)
p-p CROSS SECTIONS
× Gustafson et al. (N.A.L.)
◇ N.A.L. Bubble Chamber
+ Serpukhov
□ CERN - Rome (I.S.R.)
△ Pisa - Stony Brook (I.S.R.)
▽ Pisa - Stony Brook with Pb Converters
$\sigma = 38.4 + 0.85\left|\ln(s/95)\right|^{1.47}$
σ_T (mb)
42
41
40
39
38
0
100
200
300
400
500
P_{Lab} (GeV/c)