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TOTAL CROSS SECTION FOR NEUTRINO CHARGED CURRENT INTERACTIONS AT 3 GeV AND 9 GeV

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ABSTRACT

Average total cross sections are given for neutrino charged current interactions at neutrino energies of 2.87 GeV and 9.05 GeV. The ratios $\langle\sigma\rangle/\langle E\rangle$ are 0.69 ± 0.05 and 0.61 ± 0.06 in units of 10^{-38} cm^2/GeV/nucleon respectively. The errors include both statistical and systematic uncertainties.

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An exposure of the CERN heavy liquid bubble chamber, Gargamelle, filled with a light propane-freon mixture ($\rho = 0.518\ g/cm^3$) to the wide-band neutrino beam (fig. 1) at the CERN Proton Synchrotron (CPS) yielded 2500 neutrino induced charged current interactions above 1.5 GeV neutrino energy. 264 events have more than 6 GeV, and hence are induced by neutrinos from kaon decay. The corresponding total neutrino fluxes were determined from the continuous measurement of the muon flux distributions in the neutrino shielding during the experiment.

These data are used to determine total cross sections, $\langle\sigma\rangle$, averaged over the neutrino spectrum above 1.5 GeV at an average energy, $\langle E \rangle$, of 2.87 GeV, and above 6 GeV at $\langle E \rangle = 9.05$ GeV. Cross sections determined in this way have less uncertainties due to corrections for missing energy, neutrino spectrum shape, deconvolution, etc., than if they are measured as a function of energy.

All events observed during the double scanning of 109 000 photographs, taken during good beam conditions, were retained if the interaction vertex occurred inside the 3 m^3 fiducial volume and there was at least one negative muon candidate present. A negative muon candidate was signalled by a track leaving the visible volume without interaction or coming to rest with subsequent decay or capture.

Event energies were measured by track curvature or range. Some 4% of the tracks interacted too early to allow a good curvature measurement. In these cases the particle's energy was estimated from measurements of the secondary particles or, if this was not possible, assigning the average hadron energy (500 MeV) to the track. All visible gammas and neutral strange particles pointing to the vertex were included, but secondary neutron interactions were ignored. Ambiguous positive tracks (π^+, p) were defined [1] as protons if the momentum was greater than 1 GeV/c, otherwise as pions. About 16% genuine protons - mainly between 0.8 and 1 GeV/c - are thus misclassified as pions.

In order to reduce the background induced by incoming charged and neutral hadrons or neutrinos via the neutral current, events were only retained if the total longitudinal momentum was in excess of 0.6 GeV/c and the total visible energy greater than 1.5 GeV. A total of 2500 events remained after the application of these cuts. The remaining background was estimated using events with no muon candidate but an identified π^- and the known π^- detection efficiency (49 ± 2)% [2].

In general the visible energy is an underestimate of the real energy, and the event sample has to be corrected to account for this. The corrections due to missing gammas and neutrons were small, since in this type of analysis only the narrow energy region around the cut in visible energy is affected. The number of events lost due to missing neutrons and gammas was estimated from the channels $\mu^- pX$ and $\mu^- \gamma X$ respectively, the gamma detection efficiency being (58 ± 2)% [2]. A further small correction was applied for the above mentioned misclassified protons. The results of these corrections are shown in table 1, together with the final event samples.

The neutrino flux traversing the fiducial volume of Gargamelle was determined from the muon flux distributions measured in six transverse gaps in the neutrino shielding (fig. 1), using arrays of solid state detectors, and recorded continuously during the experiment by a computerized data acquisition system [3]. A Monte-Carlo program [4] was used to predict the muon fluxes in the shielding and the corresponding neutrino flux traversing Gargamelle using the beam parameters (fig. 1) and the π and K production data measured at 24 GeV/c proton momentum in thin targets [5] and extrapolated to 26 GeV/c. The predicted muon intensity distribution was fitted to the measured distribution varying the input parent spectrum within reasonable limits thereby yielding the neutrino energy spectrum which extended up to ~ 16 GeV and peaked at 1.75 GeV (fig. 2).

The absolute neutrino flux above 1.5 GeV, determined from the total number of muons, was $(1.45 \pm 0.09) \times 10^{15}$ neutrinos/m^2 averaged over the area of the fiducial volume [2]. The error of ± 6% is due to uncertainties in the calibration of the muon flux detectors [4]. Above 6 GeV the flux was $(5.83 \pm 0.47) \times 10^{13}$ neutrinos/m^2 where the error (± 8%) includes additional uncertainties in the K/π ratio from production measurement errors and thick target effects.

The average neutrino energies above 1.5 GeV and 6 GeV are (2.87 ± 0.03) GeV and (9.05 ± 0.09) GeV respectively. The errors include the uncertainty in the shape of the neutrino spectrum due to the combined errors in the muon range-energy relation and the density of the neutrino shielding.

The resulting cross sections - corrected for the neutron to proton ratio, 0.79, of the propane-freon mixture (0.8) using $\sigma^{\nu n}/\sigma^{\nu p} = 2.08 \pm 0.15$ [1] - are shown in table 2. Also given are the ratios $\alpha = \langle \sigma \rangle / \langle E \rangle$. They are shown in fig. 3 together with the slopes of σ versus E obtained in most previous experiments [6 - 12] by one-parameter fits. The curve in fig. 3 represents a quantum chromodynamical calculation [13(a)], extended towards lower neutrino energies [13(b)]. It describes the trend of the data which within about 15%, are also consistent with no energy dependence.

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(b) Private communication by K.J.F. Gaemers (1979).

TABLE 1

Event samples and corrections

E_{min} (GeV)	Selected sample	Background	Corrections			Final sample
			Neutron	Gamma	(π^+, p) amb.	
1.5	2500	$-(38 \pm 10)$	68 ± 8	47 ± 5	$-(55 \pm 10)$	2522 ± 60
6.0	264	$-(2 \pm 0.5)$	9.5 ± 1.5	16.5 ± 2	$-(2 \pm 0.5)$	286 ± 20

TABLE 2

Total cross section per nucleon for an isoscalar target

E_{min} (GeV)	$\langle E_\nu \rangle$ (GeV)	$\langle \sigma \rangle$ (10^{-38} cm^2/nucleon)	$\alpha = \langle \sigma \rangle / \langle E \rangle$ (10^{-38} cm^2/GeV/nucleon)
1.5	2.87 ± 0.03	1.98 ± 0.12	0.69 ± 0.05
6	9.05 ± 0.09	5.55 ± 0.56	0.61 ± 0.06

FIGURE CAPTIONS

Fig. 1 Layout of the Gargamelle CPS-neutrino experiment. Proton momentum: 26 GeV/c. Target: 1.3 m long Be rod. Focusing currents: 300 kA in the first lens ("horn"), 400 kA in the second lens ("R2"). Total decay path length: 70 m. Shielding thickness: 22 m. Muon flux measurement gaps are in 2.4, 3.2, 4.8, 6.4, 8.8, 11.2 m depths corresponding to minimum muon energies of 2.9, 4.0, 6.2, 8.4, 11.9, 15.4 GeV respectively.

Fig. 2 The fitted neutrino energy spectrum.

Fig. 3 Comparison of the ratios $\alpha = \langle\sigma\rangle/\langle E\rangle$ for various experiments. Where possible the total error and the error excluding the flux normalization uncertainty are indicated. The ν_K point of the BEBC experiment is normalized to the same K/π ratio as used by the CDHS experiment.

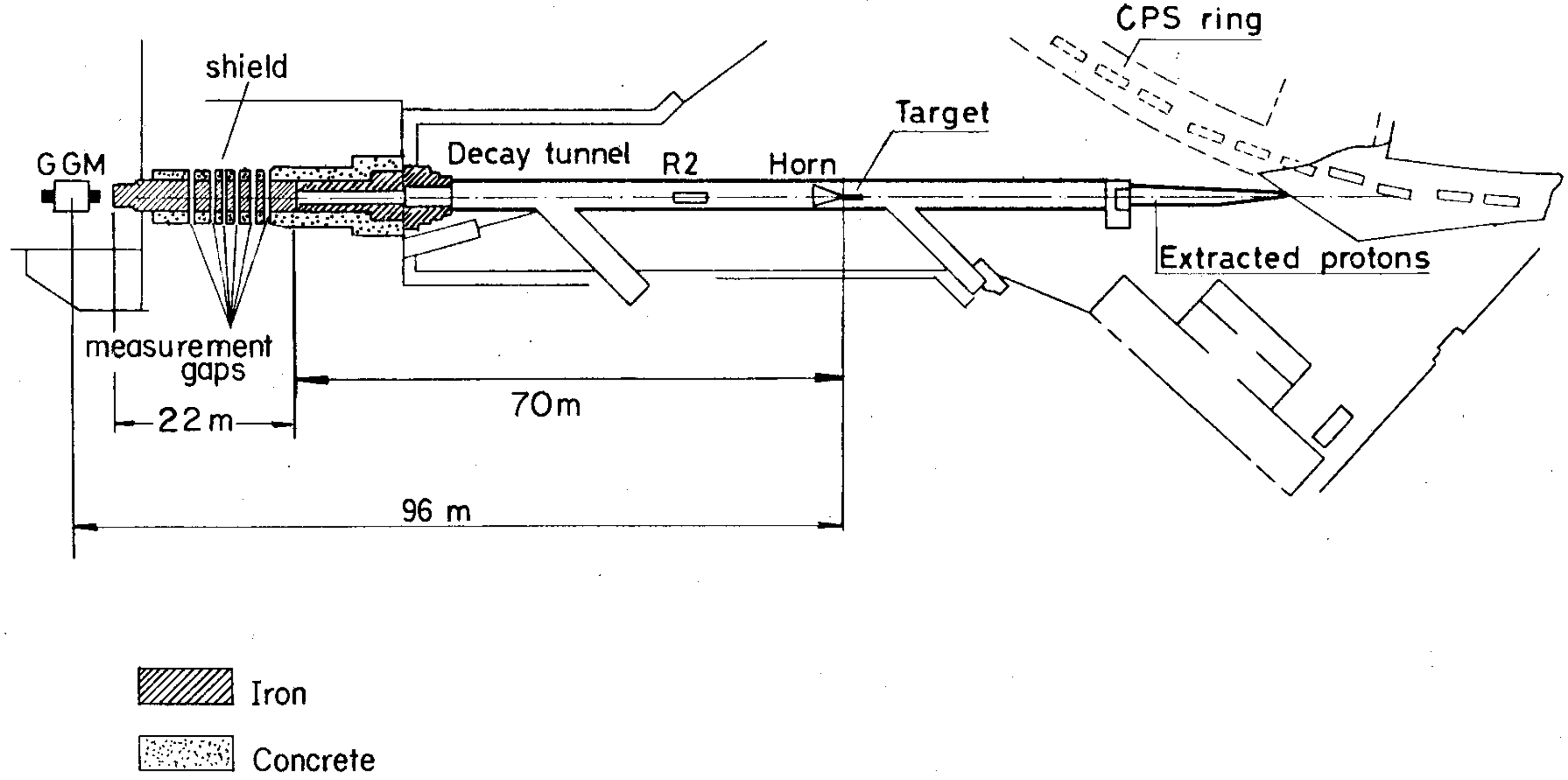
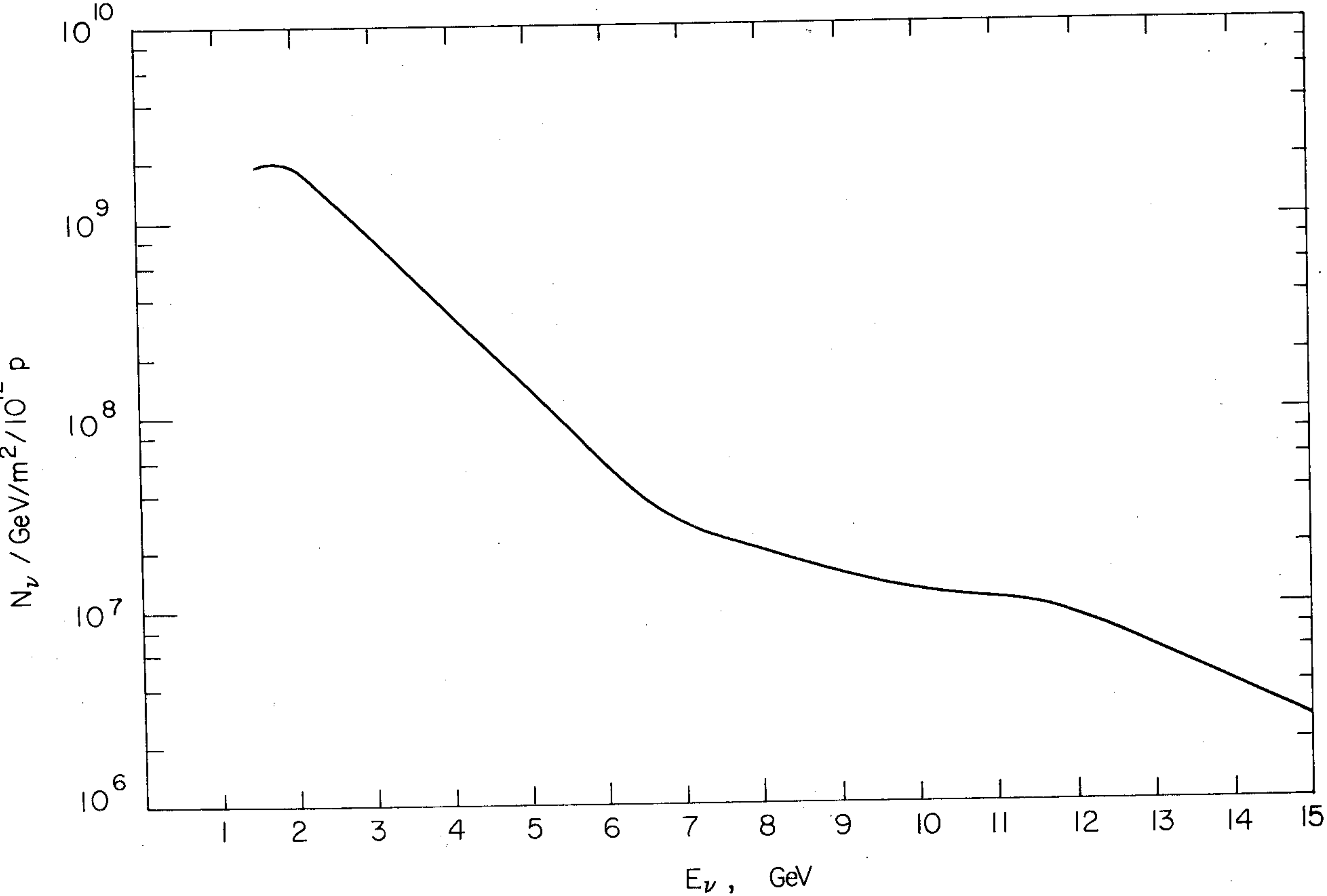
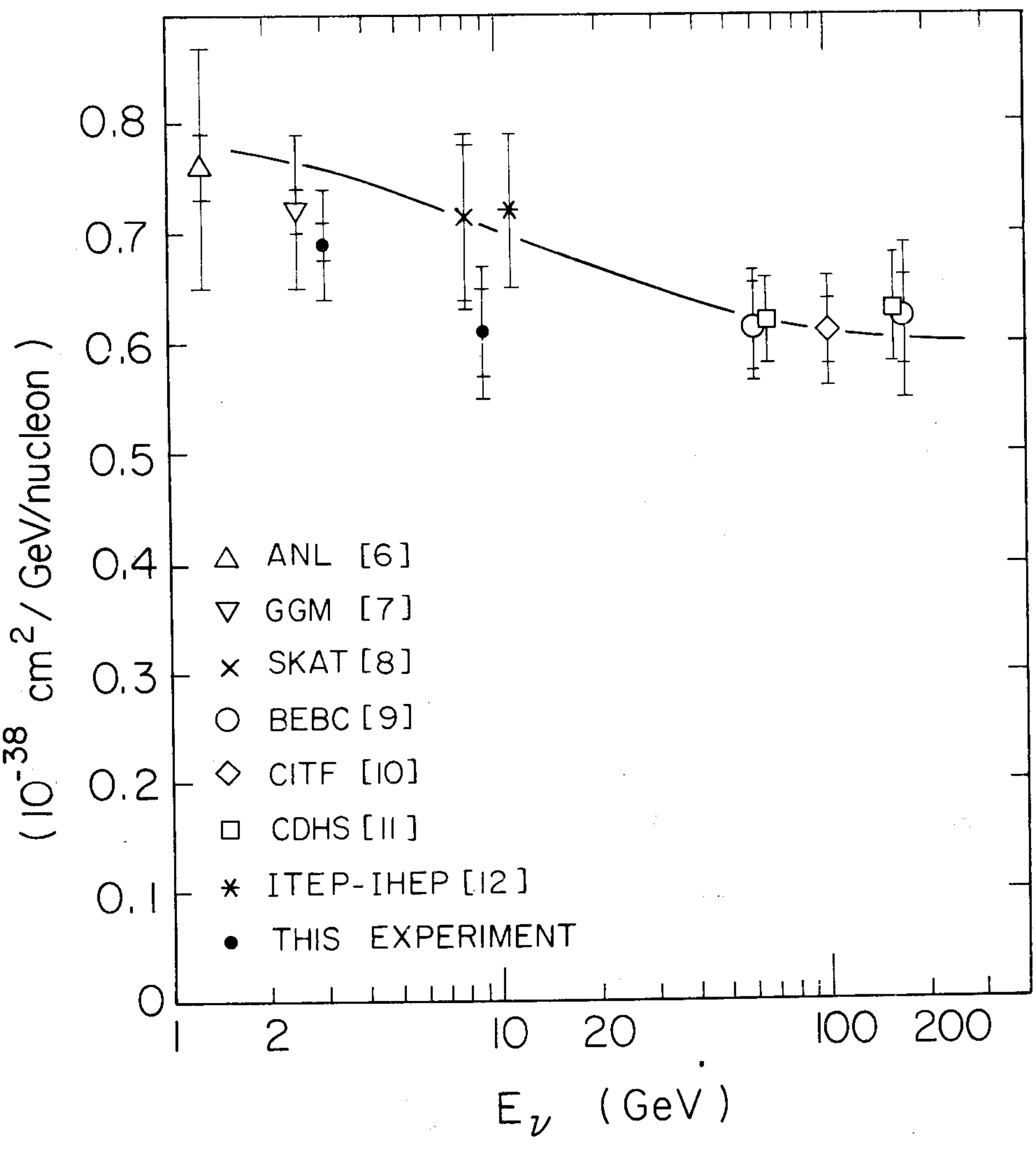

CPS ring
shield
Target
GGM
Decay tunnel
R2
Horn
Extracted protons
measurement gaps
70m
22 m
96 m
Iron
Concrete

Fig. 1



10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
N_ν / GeV/m^2/10^{12} p
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
E_ν , GeV

Fig. 2



0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
(10^-38 cm^2 / GeV/nucleon)
ANL [6]
GGM [7]
SKAT [8]
BEBC [9]
CITF [10]
CDHS [11]
ITEP-IHEP [12]
THIS EXPERIMENT
1
2
10
20
100
200
E_ν (GeV)

Fig. 3