DEPENDENCE OF ν-NUCLEUS CROSS SECTIONS ON THE MASS NUMBER *

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1. INTRODUCTION

According to optical model predictions by Bell [1] on the physical behaviour of virtual pions inside nuclear matter, and with a theorem by Adler [2], which connects neutrino cross sections to pion cross sections, neutrino cross sections for nuclei should under certain kinematical conditions be partially supressed relative to A-times the neutrino-nucleon cross sections. The kinematical conditions are a) parallel configuration between incoming and outgoing lepton, b) small four-momentum transfer q^2 $(q^2 = 2 E_\nu E_\mu (1 - \cos\theta_{\nu\mu}) - m_\mu^2)$, c) large inelasticity $E_\nu - E_\mu$.

The theoretical limits on these quantities are difficult to predict in a quantitative way, and should be regarded as highly approximate estimates. They are

$$\text{a)}\quad \theta_\mu < 20^\circ, \qquad \text{b)}\quad q^2 < 0.1(\text{GeV/c})^2, \qquad \text{c)}\quad \left(\frac{m_\pi}{p_\pi}\right) < 1.$$

The "elastic" channel $\nu + n \to p + \mu^-$ is excluded from the effect. This problem has also been discussed by Løvseth and Frøyland [3] and by Stodolsky [4]. Due to these conditions, the supression effect is expected to occur in only a small fraction of all ν-interactions.

An experiment has been carried out in the new improved CERN neutrino beam, using a multisandwich like arrangement of Pb, Fe, Al and C-targets and spark chambers. The experimental setup is unable to distinguish kinematical details of an event and therefore no reliable separation of elastic and inelastic

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events can be made. The quantities, which could be measured were the muon angle θ_μ and the muon momentum p_μ or a minimum momentum p_μ^{min}. These allowed to estimate the average q^2 for a certain class of events. Due to the relative simplicity of the experimental setup the inelasticity of an event cannot be determined. A detector showing more details of an event still would not reveal reabsorption effects in the same nucleus, however.

In the following we wish to present approximately 80 % of the data, which have been collected in our spark chamber arrangement. The run was done in parallel with a propane bubble chamber exposure.

A cross section ratio between lead (40 cm thick Pb wall) and aluminium (spark chamber plates) has been reported by Holder [5], who used experimental material collected during the 1964 CERN neutrino run.

2. EXPERIMENTAL ARRANGEMENT AND RUNNING CONDITIONS

The experimental arrangement is shown schematically in Fig. 1. The target chamber consists of four carbon targets (each 16 cm thick), four Pb-targets (each 5 cm) and one Fe-target (5 cm) in the middle and one Al-target (16 cm) at the end. They are arranged in the sequence Pb-C-Pb-C-Fe-C-Pb-C-Pb-Al. Optical spark chambers with two gaps are placed between successive targets, as well as in front and back of the entire assembly. Immediately behind the target chamber there are two trigger counters, separated by 5 cm of iron. This main setup is followed by an 80 cm thick concrete wall and by two 15 cm thick magnetized (17 kGauss) iron plates and several spark chambers. The target chamber is 220 cm long, 190 cm deep and 160 cm high. The whole setup, including the magnetized iron plates, has a stopping power for muons of 1.8 GeV for the first target and 1.2 GeV for the last target. In the total run appr. 4000 events have been collected in a fiducial area of 2.2 m^2 and a muon angle up to 29^o. The neutrino run was done with an external proton beam of 21 GeV/c momentum, a boron carbide target, an improved magnetic horn [6)], and two additional focusing elements [7)]. The neutrino spectrum has its intensity maximum in a broad band between 0.5 and 2.5 GeV [8)]. Since the different targets were exposed to the same beam for cross sections ratio determinations, it was not necessary to monitor the beam for this experiment. The apex distributions in all targets of the neutrino events have shown an almost uniform distribution, when corrected for the trigger geometry. No geometrical corrections for the sandwich ratios are necessary for the sample of events presented here.

3. ERROR SOURCES AND LIMITATIONS

The following possible error sources had to be estimated or determined experimentally:

3.1 Wrong target assignment to a neutrino event due to inefficient spark chamber operation

A continuous check on the spark efficiency of all spark chambers was provided by the presence of muon tracks traversing the whole chamber originating from neutrino interactions in the bubble chamber magnet. The average spark efficiency in the two-gap spark chamber was 99 % for at least one spark firing, and 95 % for both sparks firing. Thanks to the two 90^o stereo pictures one spark firing is already sufficient to guarantee a correct target assignment, i.e. to eliminate single spurious sparks which do not belong to a track. Additional spark efficiency tests were made regularly during the run with "horizontal" cosmic ray tracks.

3.2 Wrong target assignment to a neutrino event due to backward-going tracks

Backward-going tracks in a neutrino interaction (due to pions, protons, γ-rays) can shift the true apex to the previous target in cases where no event apex is seen. A study was made in which the lateral spark displacement was determined in both views of the first double spark relative to the track direction, as defined by the following sparks. From the observed number of displaced sparks, wrong target assignments owing to this effect must be less frequent than 2 %, if a uniform angular distribution of backward-going tracks is assumed.

3.3 Incoming tracks

In order to ensure that no particle entering the target chamber from outside is erronously taken as an apex event, it was necessary to reduce the target area from 3.0 m^2 to a fiducial area of 2.2 m^2. Under this condition the backward extrapolation of all tracks with angle smaller than 29° (the angular limit introduced in the presented sample) to the previous spark chamber still fall well inside its sensitive area.

3.4 Neutron events

For the sample of neutrino events presented here the track which triggers the spark chamber must visibly traverse at least four geometrical mean free paths. This condition reduces to a negligible level possible triggers due to high energy neutrons which originate mainly from neutrino interactions, because the hadrons will be absorbed before reaching the trigger counters.

3.5 Neutrino events occuring in the Al-plates of the spark chambers

A background which needs correction is caused by neutrino interactions in the thick-plate Al spark chambers, each chamber representing 4.0 gr/cm^2 of material. The correction to the Pb to C-ratios (assuming A-proportionality) amounts to 6 % and has been applied to the present data.

3.6 Pion or proton triggers

In principle it is possible that a pion or proton with angle smaller than the chosen angular limit, would trigger the chamber instead of the muon, the muon being at a larger angle than the limit. Such events should, according to the angular limit criterion, not be counted in the sample. Again the requirement of at least four geometrical mean free paths for the triggering track eliminates this error source.

3.7 Multiple scattering

Multiple scattering in the lead targets affects the muon emission angle by $\pm 2^{\circ}$ for 1 GeV muons. This effect can alter the cross section ratios due to an introduction of a maximum angle of 29° by not more than 2 %. Single scattering can be neglected.

3.8 Coulomb interaction

The Coulomb interaction of the muon with a heavy nucleus could influence cross section ratio. Estimations of this effect are under study.

4. EXPERIMENTAL RESULTS

Fig. 2 shows the experimental cross section ratios Pb/C, Fe/C and Pb/Al normalised to unity for A-proportionality and for the conditions $\theta_{\mu} < 29^{\circ}$; $p_{\mu} > 1.0$ GeV/c. An estimated average four momentum transfer q^2 is 0.3 (GeV/c)^2. Also shown is a line for $A^{2/3}$-proportionality. Due to the different neutron to proton ratios in the various targets, there is an additional uncertainty indicated by the shaded band in Fig. 2. For the elastic channel, by lepton conservation, only the neutron ratio should be taken. For N*-production, which is a dominating inelastic channel, the reaction occurs three times more frequent on protons than on neutrons and therefore rather the proton ratios should be taken. The upper limit corresponds to a 30 % elastic admixture in the sample and otherwise A-proportionality, the lower line to 100 % N*-production. The true value however, if there is no supression effect present should be rather close to 1.0. The data presented in Fig. 2 are given in Table 1.

Table 1

Cross Section Ratios R for Various Elements for Events with $\theta_\mu < 29^\circ$ and $p_\mu > 1.0$ GeV/c

	R	Total number of events
Pb/C	1.05 ± 0.05	2'156
Fe/C	0.90 ± 0.09	416
Pb/Al	0.92 ± 0.07	693

The quoted errors in Table 1 are statistical errors from the number of events only. The Pb/C and Fe/C ratios do not need a trigger geometry correction due to the sandwich like arrangement. However, the Pb/Al ratio had to be corrected by 6 %.

Holder [5)] has reported a value for Pb/Al for events with $p_\mu > 0.65$ GeV/c and $\theta_\mu < 26^\circ$ of R = 1.14 ± 0.14.

In Fig. 3 is shown the Pb/C ratio in dependence of the muon angle θ_μ. The estimated average q^2 for the two smallest angular intervalls $0^\circ < \theta_\mu < 3^\circ$ and $3^\circ < \theta_\mu < 5^\circ$ are $q^2 \sim 0.05$ and ~ 0.10 $(GeV/c)^2$ respectively. The shaded areas correspond to ± 1 standard deviations of the ratios.

In conclusion, for neutrino events with $p_\mu > 1.0$ GeV/c and $q^2 \sim 0.3$ $(GeV/c)^2$ no supression effect is observed in agreement with theory. Also in the sample of small θ_μ ($\theta_\mu < 5^o$) containing appr. 200 events (Fig. 3) and $q^2 \leq 0.1$ $(GeV/c)^2$ within the relatively large statistical error no deviation from A-proportionality can be seen. A sample including still smaller muon momenta is under study. Special care however must be given to the estimation of some of the mentioned background effects.

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FIGURE CAPTIONS

Fig. 1 Experimental arrangement

Fig. 2 Pb/C, Fe/C and Pb/Al ratios for $\theta_\mu < 29^\circ$ and $p_\mu > 1.0$ GeV/c. (Solid line $A^{2/3}$-proportionality, lower line of shaded band N*-production only, upper line of shaded band 30 % elastic contribution otherwise A-proportionality)

Fig. 3 Pb/C ratio versus θ_μ for $p_\mu > 1.0$ GeV/c.

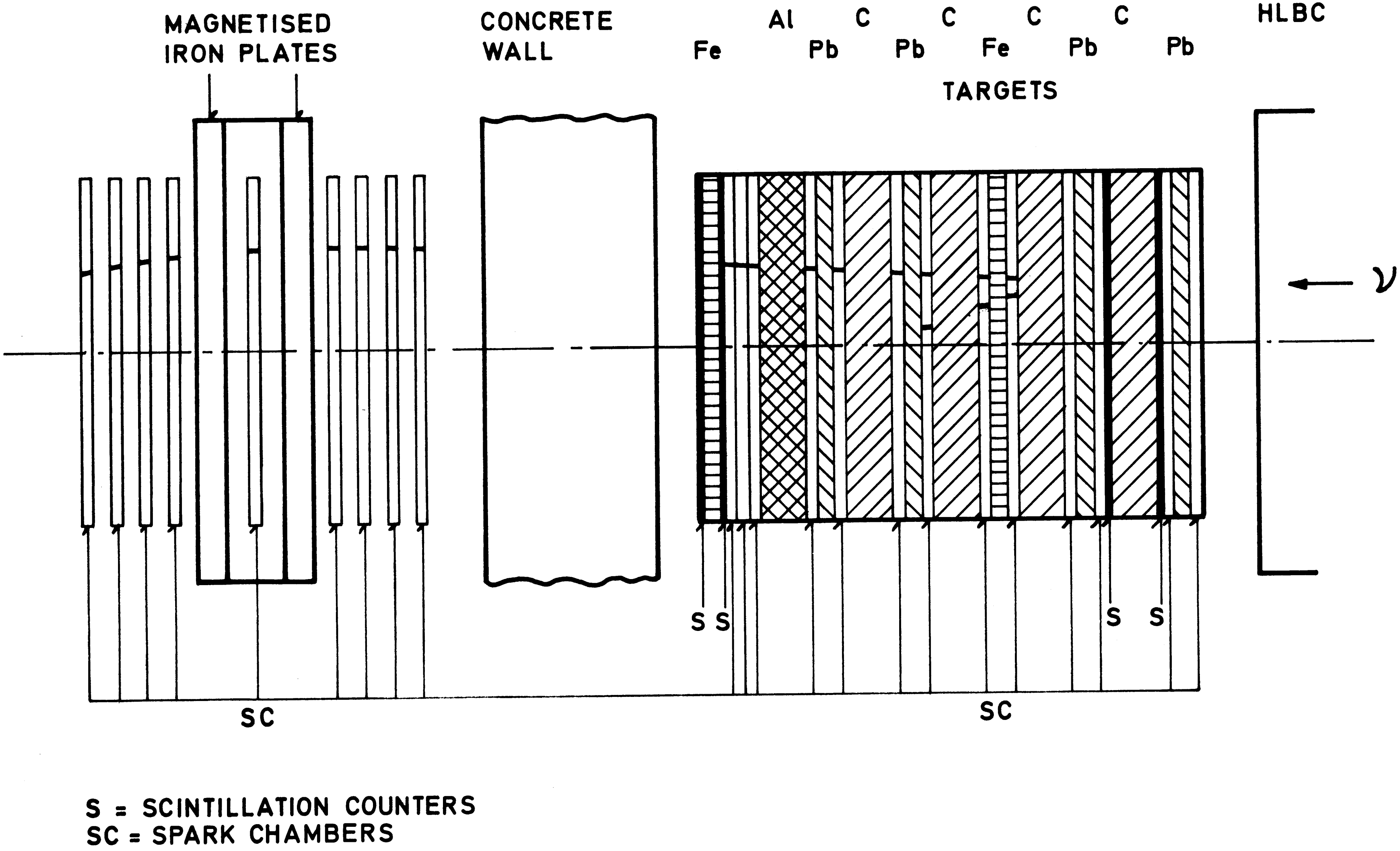

FIG. 1

ARRANGEMENT OF NEUTRINO EXPERIMENT

Number of Event Ratio

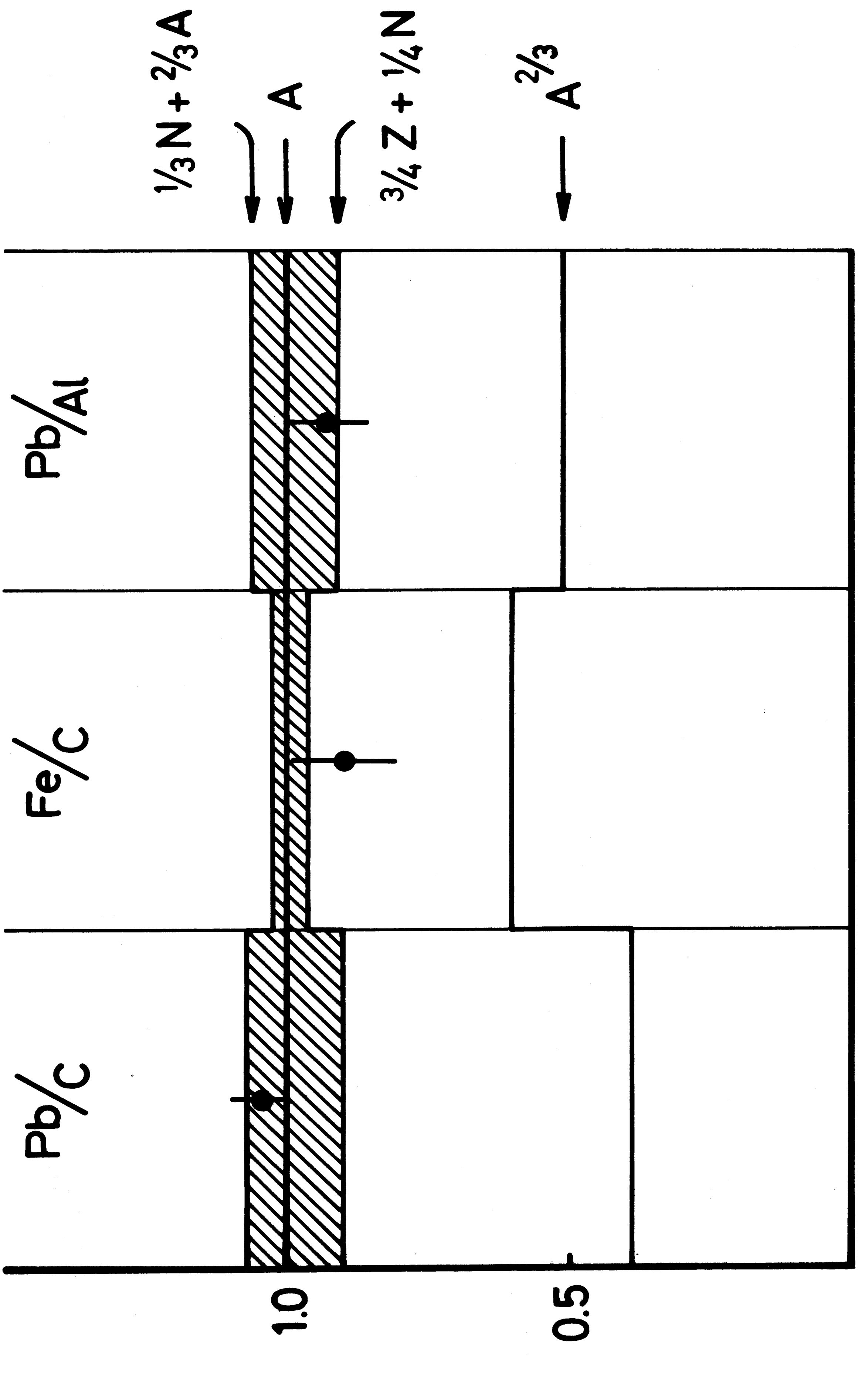

Fig.2 $\theta_\mu < 29°$, $\bar{q}^2 \sim 0.3\ (\mathrm{GeV}/c)^2$, $P_\mu > 1.0\ \mathrm{GeV}/c$

Lead to Carbon Ratio

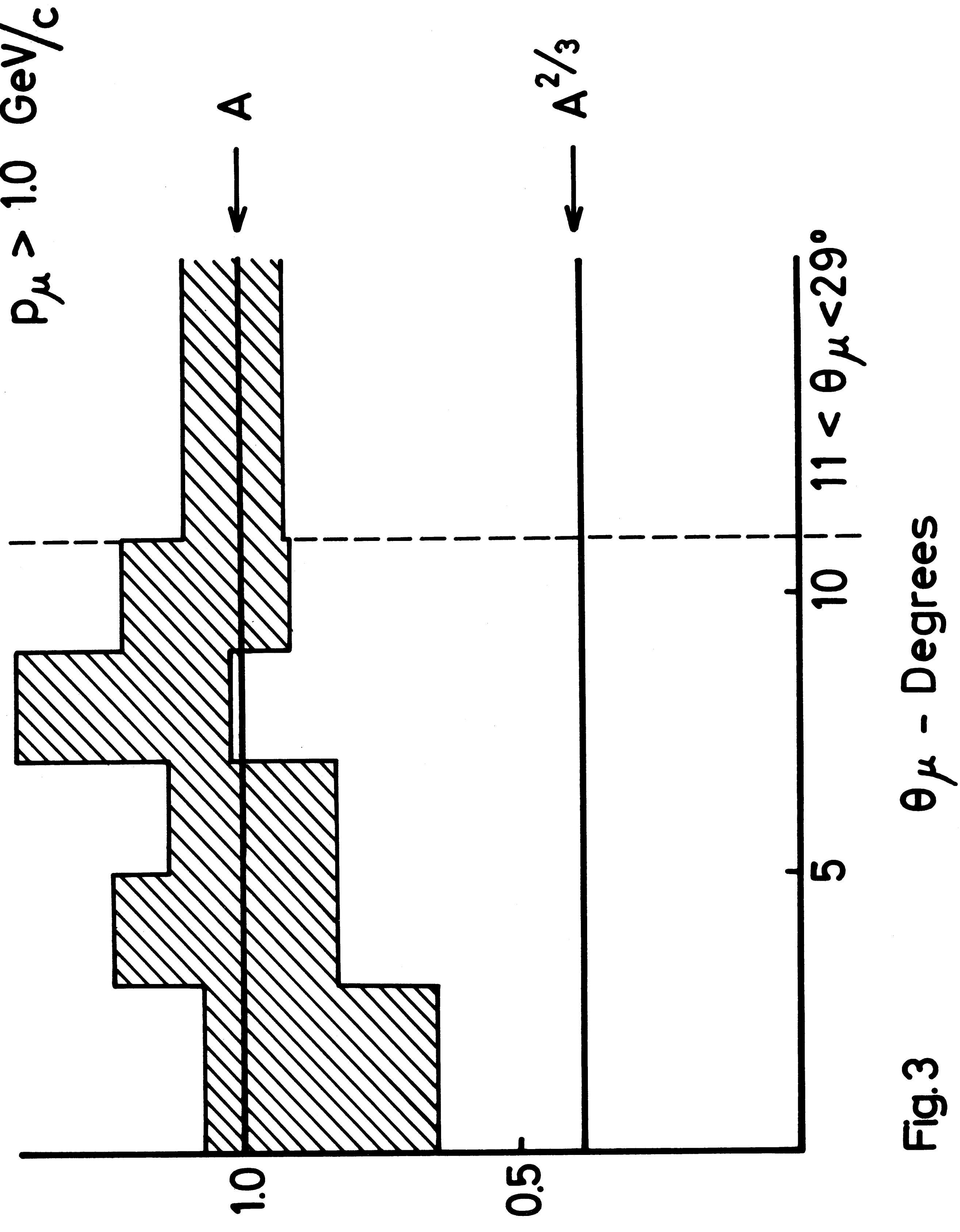

Fig.3