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ON THE QUASI-ELASTIC NEUTRINO REACTION IN DEUTERIUM  
IN THE FORWARD DIRECTION

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A B S T R A C T

Forward cross-section of the reaction  $\nu + d \rightarrow \mu^- + p + p$  is studied under different assumptions. It is shown that a value  $E^{-2}(d\sigma/d\Omega) \simeq 0.27 \cdot 10^{-38} \text{ cm}^2 \text{ sr}^{-1} \text{ GeV}^{-2}$  is expected independent of the incident neutrino spectrum shape. Relativistic effects and one-pion exchange contributions have been estimated.

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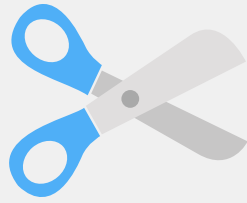
In a recent paper <sup>1)</sup> the differential cross-section of the reaction  $\nu + d \rightarrow \mu^- + p + p$  is calculated at fixed four-momentum transfer square  $q^2$ , the reason being that  $d\sigma/dq^2$  is almost independent of the incident neutrino energy  $E$  for small  $|q^2|$  [see Tables II to V of Ref. 1]. By measuring energies of the muon  $E'$  and one of the protons  $E_1$ , the corresponding angles  $\theta$ ,  $\alpha$  with the incident neutrino direction and the angle  $\phi$  between these two planes (see Fig. 1) it is possible to know the neutrino energy  $E$ , then  $q^2$ , and to obtain results independent of the form of the incident spectrum. The use of final state three-body kinematics leads to the value  $d\sigma/dq^2 = 0$  for  $(-q^2)_{\min} \simeq 0$ , because then the muon spectrum vanishes, but this phase space effect is not noticeable for  $-q^2 \geq 0.004 \text{ GeV}^2$  when the results are compared to closure approximation with free neutron kinematics.

The behaviour of the cross-section for very small values of  $|q^2|$  can be seen studying this process near the forward direction, a zone of great interest due to the apparent experimental absence of the exclusion principle in the results of Kustom et al. <sup>2)</sup>. It is necessary to clarify the situation in order that the quasi-elastic form factors can be measured by experiments on deuterium [see Ref. 3) for the present situation].

As the final and initial state hadronic masses are different, one may ask whether the Adler theorem can be applied to relate the muon spectrum to the pion absorption cross-section for  $\pi^+ d \rightarrow pp$ . Unfortunately this latter relationship only holds if  $q^0 \gg \sqrt{-q^2}$ , where  $q^0 = E - E'$ , whereas the leading contribution to the muon spectrum in the quasi-elastic neutrino reaction arises from the smallest values of  $q^0$ . In the forward direction, the relation  $-q^2 \simeq m^2 q^0/E$  can be written in this zone of  $q^0$  and therefore  $|\vec{q}|^2 \simeq q^{02}(1 + (m^2/Eq^0))$ . For  $q_0 \simeq \text{few } B$ , where  $B$  is the binding energy of the deuteron, it is hard to neglect the second term; for higher values of  $q^0$  the muon spectrum does not contribute practically to the cross-section  $d\sigma/d\Omega$ .

In the forward direction a dependence  $E^2$  in the differential cross-section  $d\sigma/d\Omega$  is expected. Then  $E^{-2}(d\sigma/d\Omega)$  will give results independent of the neutrino spectrum shape. As we are concerned with very small values of  $-q^2$  and  $q^0$ , the leading insertions of the hadronic current  $J_\mu$  correspond to the ones given in Fig. 2 and  $p_1 \leftrightarrow p_2$ . A correction is given by the interaction between the two protons, but the result is not sensitive to it, if one integrates over the muon spectrum. The other correction corresponds to the insertion of the current in the blob, Fig. 3a,





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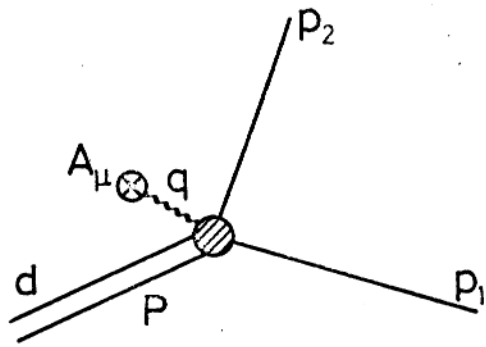


FIG. 3a

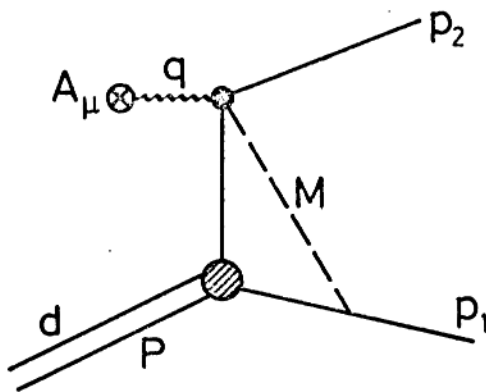


FIG. 3b



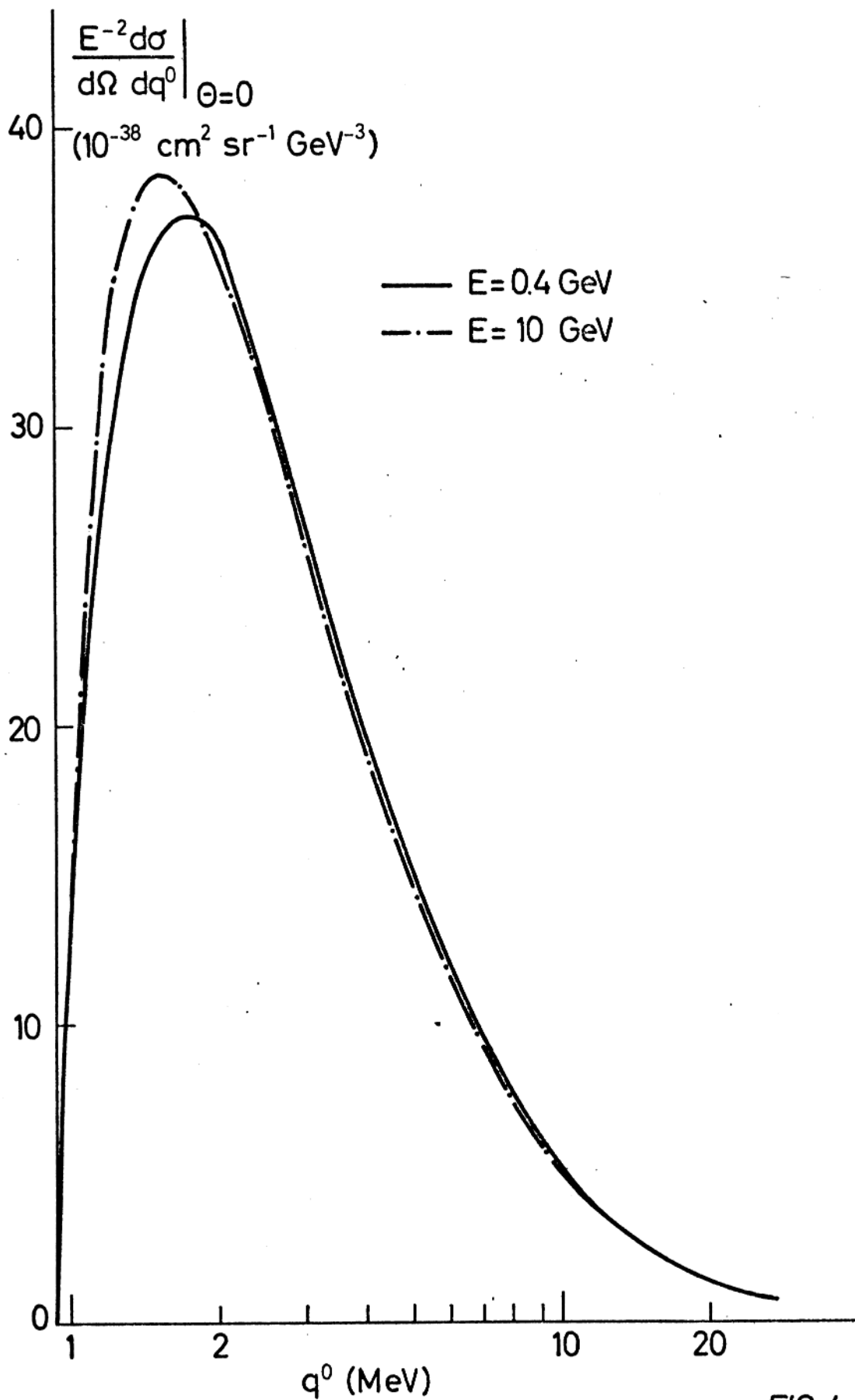


FIG.4



