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REEXAMINATION OF DEUTERON CROSS SECTIONS AND THE I = 0 K^+N ENHANCEMENT AT 1.15 BeV/c

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REEXAMINATION OF DEUTERON CROSS SECTIONS AND THE $I = 0$ K^+N ENHANCEMENT AT 1.15 BeV/c*

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ABSTRACT

The observed peak in the K^+d total cross section at 1.2 GeV/c is reexamined in light of the anomalous breakdown of the Glauber-Wilkin approximation observed by Carter et al. at 820 MeV/c in a πd and $\pi^{\pm}p$ total cross section comparison. It is suggested that the peak in the K^+d total cross section could be due to a small effect involving the entire deuteron (~ 2 mb), rather than to a pronounced peak (~ 5-6 mb) in the K^+N $I = 0$ cross section. Examples of possible consequences in other deuteron reactions are discussed.

Cool et al.[1] and more recently Bugg et al.[2] have carried out precise K^+p and K^+d total cross section measurements. These measurements showed a peak in the K^+p cross section at $P_K \approx 1.25$ GeV/c as well as a more pronounced peak in the K^+d cross section at $P_K \approx 1.2$ GeV/c. The "conventional" analysis (to be described below) of these data leads to a large sharp peak (~ 5-6 mb) in σ_0 the $I = 0$ K^+N cross section, which has been tentatively interpreted as a Z_0^*--a positive strangeness hyperon of mass 1865 MeV. Here it must be noted that the question whether or not such a particle exists is of a considerable interest since in the framework of SU(3) classification it cannot be accommodated in the well-established $\underline{8}$ and $\underline{10}$ baryon representations but rather in the $\underline{10}^*$ representation and is thus what has been referred to as an "exotic" particle.[3] In terms of the quark picture it cannot be represented by a qqq system but rather requires at least the structure of $qqqq\bar{q}$.

To emphasize the problems in the determination of σ_0, we present a brief description of the conventional analysis of the K^+p and K^+d data. In such an analysis one assumes the impulse approximation as well as the Glauber-Wilkin "shading" effect[4] in order to evaluate the "folded" K^+n cross section "σ"(K^+n) from the relation

$$"\sigma"(K^+n) = \sigma(K^+d) - "\sigma"(K^+p) + \sigma_{GW} . \qquad (1)$$

Here $\sigma(K^+d)$ is the measured K^+d cross section, "σ"(K^+p) is the measured K^+p cross section folded into the nucleon momentum distribution in deuterium as given by the Hulthén or similar wave function and σ_{GW} is the Glauber-Wilkin shading effect, a measure of how much the deuterium cross section is reduced from the sum of the folded proton and neutron cross sections.[5] The $I = 0$ K^+-nucleon cross section is then given by:

$$"\sigma_0" = 2"\sigma"(K^+n) - "\sigma"(K^+p)$$
$$= 2\sigma(K^+d) - 3"\sigma"(K^+p) + 2\sigma_{GW} \quad (2)$$

which finally yields σ_0 on unfolding.

In following the above procedure, any anomaly that occurs in $\sigma(K^+d)$, and which is not present in the "σ"(K^+p) is directly ascribed to "σ"(K^+n) and propagated in a magnified form to σ_0. Furthermore, any inaccuracy in σ_{GW} is similarly included and magnified. Here the magnification results from the factor two in Eq. (2) and is further enhanced by the unfolding calculation. It is the purpose of this note to point out that the observed peak in $\sigma(K^+d)$ could be due to a relatively small (~ 2 mb) effect involving the entire deuteron rather than to a very pronounced peak (~ 5-6 mb) in σ_0 as has been suggested.[1,2]

In a recent counter experiment of total pion cross sections Carter et al.[6] have demonstrated that the Glauber-Wilkin approximation is inadequate for pion momenta below 1 GeV/c. Here it is worthwhile to emphasize that Glauber has repeatedly warned that the standard expression for σ_{GW} may not be valid at all incident momentum regions.[7] Carter et al. have carried out a high precision total cross-section measurement for the reactions π^+p, π^+d, π^-p and π^-d from 0.5 to 2.65 GeV/c laboratory momentum. Assuming charge independence, an experimental measure of the shading effect is then given by:

$$\Delta\sigma = "\sigma"(\pi^+p) + "\sigma"(\pi^-p) - \frac{1}{2}[\sigma(\pi^+d) + \sigma(\pi^-d)] \quad . \quad (3)$$

Here $\sigma(\pi^+d)$ and $\sigma(\pi^-d)$ are expected to be equal--actually small differences have been observed[6] which are ascribed to Coulomb effects[8] and need not concern us here. The experimental value of $\Delta\sigma$ shows that by and large there is a shading effect and that for pion momenta between 1 to 2.5 GeV/c the results are compatible with the Glauber-Wilkin approximation, although some small deviations are present. The striking feature of the data is however a very strong deviation over a small region around $P_\pi = 820$ MeV/c for which $\Delta\sigma$ becomes negative; that is, the πd cross section becomes larger than the sum of the folded $\pi^+ p$ and $\pi^- p$ cross sections. Carter et al. expressed their results by determining an empirical value for $\langle r^{-2} \rangle_d$ the constant in the Glauber-Wilkin correction, as function of P_π. The phenomenon around $P_\pi = 820$ MeV/c then corresponds to a negative value for $\langle r^{-2} \rangle_d$ (≈ -0.26 mb^{-1}) indicative of the fact that we are not dealing with a "shading" but rather an enhancement.

On the basis of the present results we cannot be sure of the origin of this effect. Thus it could be a manifestation of our lack of understanding of the deuteron primarily due to a breakdown of: (a) the spectator model, (b) the Glauber-Wilkin shading correction, or (c) a deficiency in the folding procedure which makes itself felt in the vicinity of a rapidly varying cross section.[9] Alternatively the effect observed by Carter et al. could be due to an intrinsic property of the np system at specific mass values such as (d) the <u>production</u> of an $I = 1$ or 0 state (or states) in the mass region 2380 to 2440 MeV, or finally (e) the <u>formation</u> of an $I = 1$ state (or states)[10] in the mass region 2520 to 2580 MeV. In any case it appears to be an effect which involves the entire deuteron in one way or another and should thus be considered in terms of the kinematics of the incident particle and the <u>deuteron</u>. The interesting question is whether a corresponding phenomenon can occur in another experimental situation and what form it would take.

This depends of course on which is the correct interpretation. In each of the cases (a) to (e) some anomaly could occur for other incident particles on deuterium (see below). If case (c) is correct a similar phenomenon could manifest itself in the vicinity of rapidly varying cross sections for other reactions on deuterium. For case (d) we would expect anomalies in (free) np scattering and if $I = 1$ state(s) are involved in pp scattering as well, at laboratory momenta in the region 1860 to 2030 MeV/c. For case (e) we would expect anomalies in pp scattering for proton laboratory momenta of 2260 to 2440 MeV/c.

We wish to point out that in cases (a), (b) and (d) an analogous effect can occur in the K^+d reaction at the position of the 1.2 GeV/c peak and of a magnitude which qualitatively accounts for the observed peak. Our point can be most readily understood if for the sake of discussion we interpret the effect as in case (d) as the initial rise from threshold and subsequent drop off in the cross section $\sigma_\pi(d')$ for the production by pions of a state (or states) d' according to:

$$\pi^\pm + d \rightarrow \pi^\pm + d' \quad . \tag{4}$$

For a different incident particle x we would then expect d' production to occur to some extent according to:

$$x + d \rightarrow x + d' \quad . \tag{5}$$

Here the question of the nature of the state d' is not clear. In particular whether d' does or does not correspond to one or more resonances (as in case (d)) can only be settled by detailed studies of the reaction products.[11] Our discussion should be equally valid if the effect represents the breakdown of the approximations applied to the deuteron as in cases (a) and (b). The relevant kinematical quantity for which one can compare different incident particles is:

$$E = E_{xd} - m_x \tag{6}$$

where E_{xd} is the total energy in the xd center of mass. This is simply the Q value for the reaction plus m_d. In the region of interest E runs from $\approx$ 2380 MeV to $\approx$ 2500 MeV.

Table I lists our estimate of $\sigma_\pi(d')$ from the data of Carter et al. as a function of E as well as the corresponding laboratory momenta for incident γ rays or electrons, pions, kaons, and protons. Our estimate of $\sigma_\pi(d')$ is obtained from $\sigma_\pi(d') = \sigma_{GW} - \Delta\sigma$ where σ_{GW} given in Table I was calculated for the value $\langle r^{-2}\rangle_d = 0.02\ (\text{mb})^{-1}$ which is the experimental average value obtained by Carter et al. for $P_\pi \geqq 1.0$ GeV/c. This estimate is subject to considerable uncertainties as it uses σ_{GW} in a region where its validity is very doubtful, in particular at the lower end of the interval for which the Wilkin correction becomes large as the real part of the forward scattering amplitude Re f(0) becomes large.[11] We have thus limited our estimate of $\sigma_\pi(d')$ to the region over which $\Delta\sigma$ is negative. For this region we can consider $|\Delta\sigma|$ as a lower limit to $\sigma_\pi(d')$.

On the basis of our assumption we would thus expect an anomaly in $\sigma(xd)$ at the momentum values P_x, corresponding to E, of magnitude $\alpha\sigma_\pi(d')$ where α represents the ratio of the d' production rate for particle x to that for a pion.

If we apply these ideas to the K^+d system we find that for $\alpha \cong 0.7$ the peak in "σ"(K^+n) can be ascribed to $\sigma_{K^+}(d')$ and that on this reinterpretation of the data no significant peak occurs in the $I = 0$ K^+ nucleon system at 1.15 BeV/c. This is illustrated in Fig. 1. We get qualitatively the same result if we use the empirical values of $\langle r^{-2}\rangle_d$ as determined by Carter et al.

for the Glauber-Wilkin correction and assume that they are characteristic of the deuteron, i.e., the energy E, and do not depend on the incident particle.

If the ideas discussed above are correct then for cases (a), (b) and (d) other corresponding effects could be observable for different incident particles on deuterium at the momenta listed in Table I. Thus

a possible test is for example a comparison between the np cross sections measured directly $\sigma(np)$ and the pn cross section deduced from pp and pd measurement $\sigma(pn)_d$. Some of the presently available pp and pd and free np measurements are given in Fig. 2. Using the above mentioned conventional analysis, Bugg et al.[12] have deduced the corresponding pn cross section and $\sigma_o(NN)$ the $I = 0$ nucleon-nucleon cross section shown in Fig. 2c. The proton momentum P_p corresponding to the center of the observed anomaly in the πd system is ~ 1620 MeV/c. At this momentum there is a dip in $\sigma(pn)_d$ and a pronounced dip in $\sigma_o(NN)$ (see curves in Fig. 2). On the basis of our discussion one could thus expect $\sigma(np)$ to lie lower than $\sigma(pn)_d$. If this is indeed observed, the reduction in $\sigma_o(NN)$ would be considerably more pronounced. Our very crude estimate of this effect on the assumption that $\alpha = 1$ is indicated by the dashed curves in Fig. 2c.

To carry out such a test considerably more precise free np cross sections would be needed, in particular in the region near the dip. It is noteworthy that the very marked difference between $\sigma(pp)$ the $I = 1$ NN cross section and $\sigma_o(NN)$ can be readily interpreted in terms of dropping elastic cross sections and rising inelastic cross sections. In the $I = 1$ case the rapid rise in $\sigma(pp)$ at 1000-1500 MeV/c can be ascribed to the onset of the process $pp \rightarrow N\Delta(1236)$. For the $I = 0$ case Δ production is forbidden by I spin conservation. Thus here the inelastic process proceeds via $pn \rightarrow NN^*_{1/2}$, where $N^*_{1/2}$ stands for the first few $I = 1/2$ baryon resonances. This effect sets in at a higher momentum over the region 1600-2400 MeV/c and does not give as rapid, or as large, a rise in the cross section.

Another example would be the comparison of the K^+n cross section with the charge symmetric K^op cross section. Here, however, we have traded the difficulties encountered with deuterium targets for the difficulties inherent in using a K_2^o beam which then involves $\overline{K}^o$ interactions as well. These are probably even more formidable and are not likely to yield a quantitative test in the near future.

Finally we have also considered the $\overline{N}N$ and $\overline{K}N$ data.[16] For these cross sections one needs the interactions on deuterium for the determination of both σ_o and σ_1. In principle one could test the ideas presented in this note by performing precise $\overline{n}p$ and $\overline{K}^op$ total cross section measurements. However, due to the obvious difficulties in obtaining a useful $\overline{n}$ beam and the particle mixture nature of the K_2^o-meson here again it seems unlikely that these experiments can be realized in the near future.

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FOOTNOTES AND REFERENCES

*Work supported by the U. S. Atomic Energy Commission.

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5. Here σ_{GW} is a positive quantity, given by $\sigma_{GW} = Q\langle r^{-2}\rangle_d/4\pi$ and $Q_{KN} = \sigma(K^+p)\sigma(K^+n)(1 - \gamma_p\gamma_n) - \frac{1}{2}[\sigma(K^+p) - \sigma(K^+n)]^2 + \frac{1}{2}[\gamma_p\sigma(K^+p) - \gamma_n\sigma(K^+n)]^2$, where $\gamma = \mathrm{Re}\, f(0)/\mathrm{Im}\, f(0)$; similar equations are given by Wilkin in Ref. 4 for the πN system.

6. A. A. Carter, K. F. Riley, R. J. Tapper, D. V. Bugg, R. S. Gilmore, K. M. Knight, D. C. Slater, G. H. Stafford, E. J. N. Wilson, J. D. Davies, J. D. Dowell, P. M. Hattersley, R. J. Homer and A. W. O'Dell, Phys. Rev. 168, 1457 (1968).

7. See for example, R. Glauber in High Energy Physics and Nuclear Structure, G. Alexander, editor (North Holland Publishing Co., 1967), p. 311.

8. D. V. Bugg and N. Cottingham, Rutherford Laboratory Report RPP/H/30 (1967).

9. We have repeated the analysis of Carter et al. using the Hulthén wave function in momentum space with an empirical tail extending to 400 MeV/c matched to a typical experimental spectator distribution. We find that

even in this extreme case the effect at P_π = 820 MeV/c did not change substantially. Similar calculations have also been tried by T. Kycia and C. Wilkin (private communication).

10. Here it should be noted that a d_1^* which could correspond to an N-Δ structure can occur in formation or production in the $\pi^\pm d$ reaction; however, a d_0^* which could correspond to an $N\text{-}N^*_{1/2}(1400)$ structure can occur in production only.

11. In this connection it is interesting to note that evidence for a recoiling d^* has been obtained by Bellettini et al. [Physics Letters 18, 167 (1965)] in a 19.3-GeV/c pd experiment. The mass of the possible d^* was found to be 2330±10 MeV with a width Γ = 200±20 MeV, corresponding to a structure of a nucleon and $N^*_{1/2}(1400)$. The question of the existence of d^* resonances in SU(6) theory has been examined by F. J. Dyson and N. H. Xuong [Phys. Rev. Letters 13, 815 (1964)], for example.

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Table I. Estimate of $\sigma_\pi(d')$ from data of Carter et al.[6] as a function of E. Corresponding laboratory momenta for electrons, K mesons, and protons are also shown.

	Cross sections (mb)		Laboratory momentum in MeV/c for various incident particles			
E (MeV)	Estimate of $\sigma_\pi(d')$	σ_{GW} (folded)	γ or e	π	K	p
2380	1.5	1.6	573	736	1093	1493
2390	1.9	1.5	586	750	1109	1514
2400	2.2	1.4	599	764	1126	1534
2410	2.4	1.3	611	778	1143	1555
2420	2.5	1.2	624	791	1160	1576
2430	2.6	1.2	637	805	1177	1597
2440	2.6	1.2	650	819	1194	1618
2450	2.6	1.3	663	833	1211	1639
2460	2.6	1.3	676	847	1228	1659
2470	2.4	1.4	689	861	1245	1680
2480	2.2	1.5	703	875	1262	1701
2490	1.9	1.5	716	890	1279	1722
2500	1.6	1.6	729	904	1296	1743

FIGURE LEGENDS

Fig. 1. Total K^+p and K^+d cross sections taken from Refs. 1 and 2. Smooth curves are the $I = 0$ part of the KN cross section $\sigma_0(KN)$ as given in Refs. 1 and 2. The dashed curve represents our estimate of the behavior of $\sigma_0(KN)$ arrived at on the assumption that the peak in $\sigma(K^+d)$ is due to an effect involving the entire deuteron. Here small oscillations in this curve due to the unfolding procedure have been smoothed out.

Fig. 2. (a) Total pp and pd cross sections taken from Refs. 12-14. (b) Total $\sigma(pn)_d$ cross section and total $\sigma_0(NN)$ cross section as given in Ref. 12 deduced from pp and pd cross section measurements. The dashed curves represent our estimate for the behavior of $\sigma(np)$ and $\sigma_0(NN)$ on the assumption that part of $\sigma(pd)$ is due to an effect involving the entire deuteron. The experimental points are np cross-section measurements obtained from neutron beams compiled in Ref. 15.

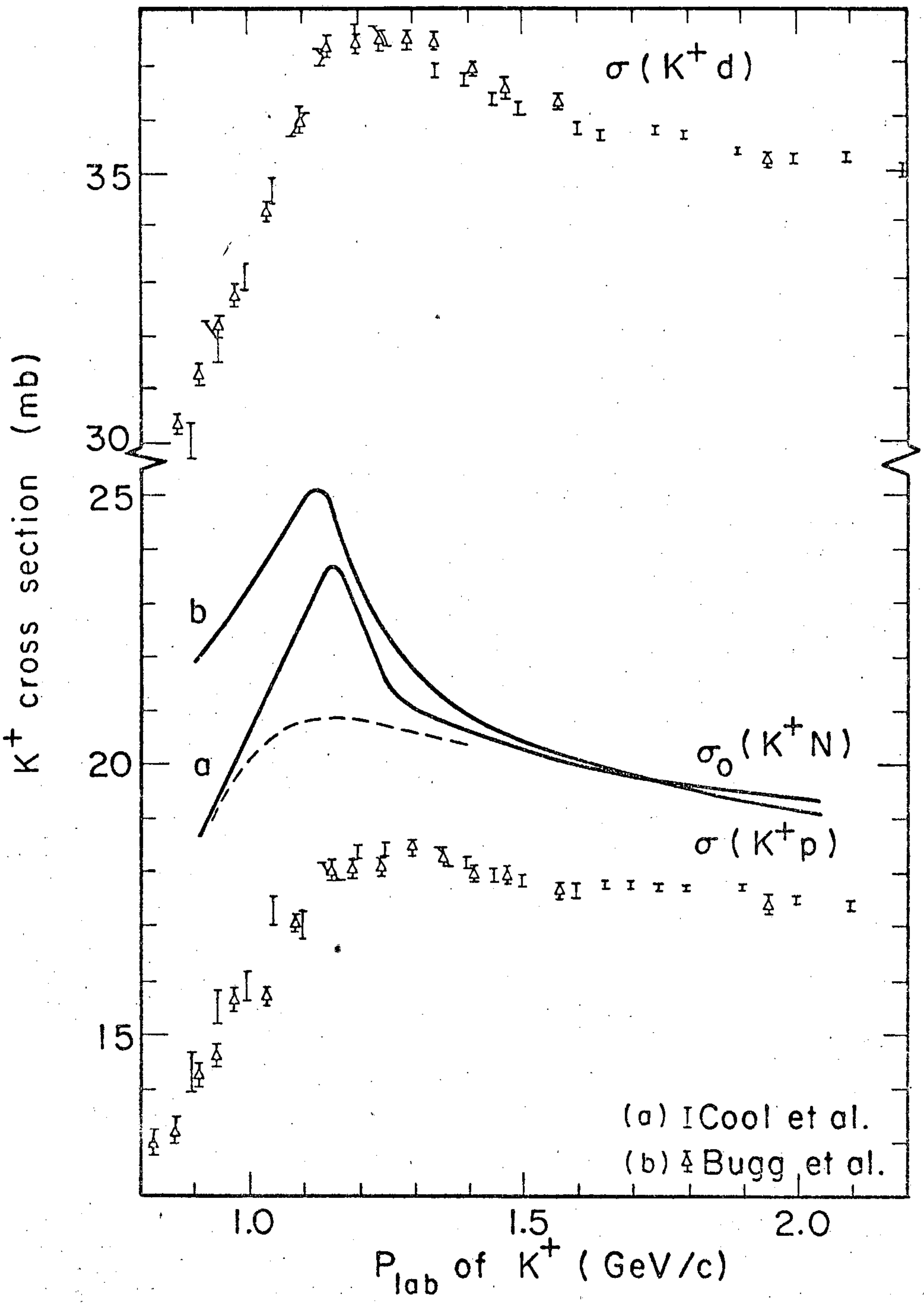

Fig. 1

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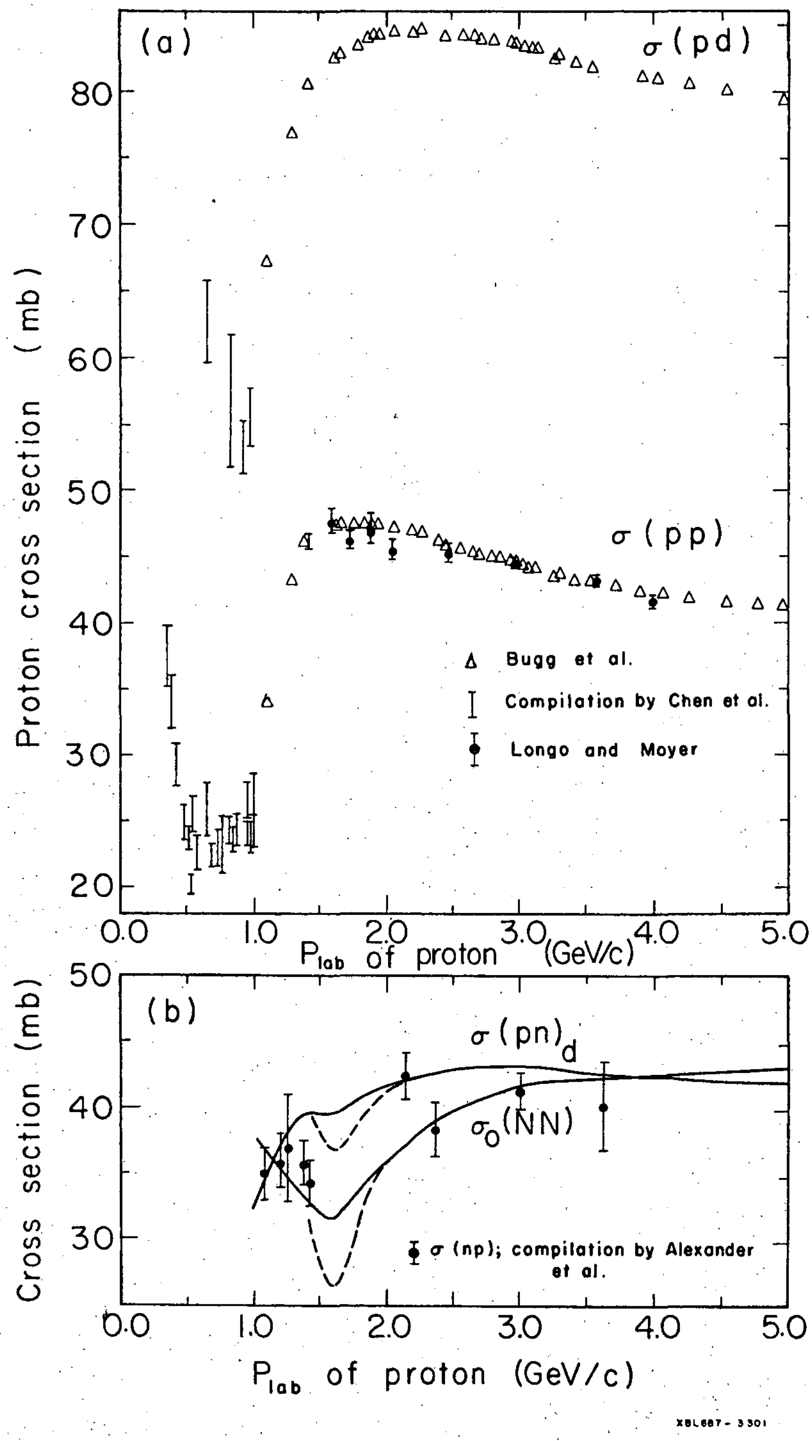
(a)
σ (pd)
σ (pp)
Proton cross section (mb)
80
70
60
50
40
30
20
Bugg et al.
Compilation by Chen et al.
Longo and Moyer
0.0
1.0
2.0
3.0
4.0
5.0
P_{lab} of proton (GeV/c)
(b)
$\sigma(pn)_d$
$\sigma_0(NN)$
Cross section (mb)
σ (np); compilation by Alexander et al.
P_{lab} of proton (GeV/c)
XBL687-3301

Fig. 2