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DISCLAIMER

OBSERVATION OF HIGH MOMENTUM PROTONS FROM LIMITING TARGET FRAGMENTATION*

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ABSTRACT

We report on measurements of the inclusive distributions of protons produced at 180° in the momentum range $0.3 \leq p \leq 1.0$ GeV/c. Proton, alpha, carbon, and argon beams in the range of kinetic energies $0.4 \leq T \leq 2.1$ GeV/n (4.89 GeV for protons) were incident on C, Al, Cu, Sn, and Pb targets. The dependences of the cross sections on the projectile and target mass and on the incident energy are presented. Limiting behavior is found at energies above 1. - 2. GeV/n. Features suggestive of nuclear correlations are discussed.

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Nuclear collisions are studied with the hope of learning details of nuclear structure or reaction mechanisms in the collisions. Precise measurement of (e,e'), (e,e'p), (p,2p), and (γ,p)[1] reactions have provided much information on the distributions of nucleon momenta inside nuclei up to 300-400 MeV/c. Predictions using known single particle wavefunctions are in good agreement with the data. Attempts to relate the large momenta observed in (γ,p)[2] and backward (p,p')[3] reactions directly to high internal momenta indicate the presence of high momentum components in nuclei far above those expected from single particle wavefunctions. A quasi-elastic description was used[4] to relate backward momenta from the (p,p') reactions to internal momenta. It was stated that production from nuclei could result only from the internal motion of nucleons since backward production is forbidden in free nucleon-nucleon collisions. The difficulties involved in extracting information on high internal momenta, which are associated with deviations from mean field motion in the nucleus, have been pointed out by Gottfried.[5] In addition, Amado and Woloshyn[6] have shown that final state interactions do not permit a simple interpretation of the backward momenta in the (p,p') reactions.[3] The determination of large internal momenta is still a fundamental experimental and theoretical problem. Nevertheless, the high momenta observed in these types of reactions provide valuable information on the production mechanisms, and possibly on internal momentum distributions.

We have recently concluded a systematic study of the inclusive distributions of high momentum protons produced at 180° using the full range of beams and energies available from the Bevalac facility. Earlier measurements[7] at angles $\theta_{lab} \geq 120°$ using high energy ν, γ, π, and p beams revealed that the shapes of the spectra of protons in the momentum interval $0.3 \leq p \leq 1.0$ GeV/c were insensitive to the type of the projectile and its energy. We find that at the lower incident energies, the cross sections rise rapidly with increasing bombarding energy. However, we also find that beyond 1.-2. GeV/n, the distributions in the momentum region $0.4 \leq p \leq 1.0$ GeV/c become relatively insensitive to the further increase of the incident energy. In comparison, projectile fragmentation studies found that fragment distributions for $p \leq 400$ MeV/c in the projectile frame already became limiting somewhere between beam energies 0.4 and 1.05 GeV/n.(8) Projectile fragmentation studies together with target fragmentation measurements provide systematic data spanning the two momentum ranges $0. \leq p \leq .4$ GeV/c and $0.4 \leq p \leq 1.0$ GeV/c. We find that the limiting proton distributions encompassing these two momentum ranges are approximated better by two distinct overlapping Gaussians rather than by a single Gaussian. In this parametrization, both Gaussians have a mean at zero momentum. The second Gaussian, which has a larger dispersion, starts to dominate in the region 300-400 MeV/c. Results from theoretical investigations suggest that the second Gaussian is a manifestation of nuclear correlations.

The experiment was performed at the LBL Bevalac. The beams used were (0.8, 1.05, 2.1, 3.5, 4.89) GeV protons, (1.05, 2.1) GeV/n alphas, (0.4, 1.05, 2.1) GeV/n carbon, and (1.05, 1.83) GeV/n argon. The targets were C, Al, Cu, Sn, and Pb. Protons at 180^0 were measured in the momentum range $0.3 \leq p \leq 1.0$ GeV/c with a magnetic spectrometer. Details of the apparatus are reported in Ref. 9. We estimate the overall absolute uncertainties in the inclusive cross sections to be ±15 percent.

The energy dependence of the cross sections is shown in Fig. 1. Results from other experiments at 90 MeV,(10) 600 MeV,(3) 7.71 GeV,(11) and 400 GeV(12) have been included. The data indicates limiting behavior of the distributions in the range of momenta $0.4 \leq p \leq 1.0$ GeV/c starting between 1.0

and 2.0 GeV/n. A slight rise is found however in the 400 GeV data measured at 160°. The spectrum at 90 MeV, commonly attributed to pre-equilibrium decay[13] at low energies, has an elastic kinematic limit at 392 MeV/c. A lack of dependence of the proton cross sections on the incident energy is exhibited in data for all targets with proton beams having kinetic energies $T \geq 2.0$ GeV, strongly suggestive that limiting target fragmentation[14] has set in. The hypothesis of limiting fragmentation states that the cross sections for the production of target fragments in the lab and projectile fragments in the projectile rest frame become independent of incident energy. The energy ranges spanned by the heavier projectiles are not as extensive but the features of the data are similar.

The dependence of the proton production cross sections on projectile mass for a carbon target at an incident energy of 1.05 GeV/n is shown in Fig. 2. The shapes of the proton spectra in the momentum range $0.4 \leq p \leq 1.0$ GeV/c are seen to be roughly independent of projectile mass. Plotted in the same figure (in the projectile rest frame) are data from Papp[15] for C+C⇒p(2.5°) at 1.05 GeV/n. The break found in the C+C⇒p data at about 350 MeV/c is similar to that found in extracted momentum distributions from (γ,p)[2] data. Recent theoretical investigations[16-18] show that the internal momentum distributions in nuclei can be approximated by two overlapping Gaussians when short range correlations are included. The low momentum Gaussian is dominated by the single particle characteristics of the momentum distributions and the second Gaussian emerges when short range correlations are considered. The solid line is a double Gaussian parametrization of the C+C⇒p data. If the internal momentum distributions are indeed correctly specified by the models, then one is led to conjecture that the shapes of the measured distributions in the momentum region $0.4 \leq p \leq 1.0$ GeV/c are a consequence of the presence of nuclear correlations.

In order to further study the dependence of these cross sections on projectile and target mass and energy, we have parametrized our data in the momentum range $0.4 \leq p \leq 1.0$ GeV/c in the form $d\sigma/dp^3 = \sigma_T/((\sqrt{2\pi})^3\alpha^3) \times e^{-(p^2/2\alpha^2)}$ (where $\sigma_T = \int(d\sigma/dp^3)d^3p$). The fits are good for incident kinetic energies $T \geq 1.05$ GeV/n having typical uncertainties of ±5 MeV/c for α and ±10 percent for σ_T. The dependence of α on the target and projectile masses is shown in Fig. 3(a). The mass dependences are relatively weak. The dependence on incident energy is more dramatic and the limiting nature of the cross sections is reflected in this dependence. A limiting value of 220±10 MeV/c is indicated by data at various backward angles and energies above 5 GeV.[7,11,12] For comparison, the distributions in the low momentum region $p \leq 400$ MeV/c, where one would expect the first Gaussian, should be well described by the formulation of Goldhaber[19] which has been successful in describing fragment momenta from projectile fragmentation. Employing Fermi momentum values from quasi-elastic electron scattering measurements,[20] one gets correspondingly smaller values of α in this low momentum region ranging from 76 MeV/c for Li to 119 MeV/c for Pb. For the higher momentum region, the dependence of σ_T on the masses at 1.05 GeV/n incident energy is shown in Fig. 3(b). An approximate $A_p^{2/3}A_t^{4/3}$ (p = proj, t = tgt) dependence is found for σ_T at 1.05 GeV/n and 2.1 GeV/n. The A_p dependence is expected in a limiting fragmentation model[21] where the projectile is seen as a contracted disk by the target nucleus. In such a model, one could interpret the measured momenta as reflecting information of the target. The A_t dependence argues against incoherent collisions and indicates the involvement of more than one target nucleon in backward nucleon production. Inclusive proton data in the fragmentation region from p+d and p+α reactions[22,23] show a similar break in the distributions at about 300 MeV/c. This would argue against a multiple scattering cascade as the dominant mechanism, at least for light nuclei. Definitive theoretical work on the contributions of multiple scattering is, however, still necessary to justify this conclusion.

It has been noted[8] that results of measurements of fast backward target fragments and fast forward projectile fragments indicate the presence of short range structure. Of the various approaches[4,24-33] to parametrize these data, very attractive are models which include scattering with correlated nucleons. A model by Fujita and Hüfner[24] includes both initial correlations between nucleons in the target and final correlations between two nucleons. The final state interaction with the rest of the A-2 nucleons is however neglected. Fujita has extended this model to include multiple correlations.[34] The improved model describes well the incident energy dependence of backward proton spectra in the region $0.4 \leq p \leq 1.0$ GeV/c for the intermediate energy range 0.6 to 1.0 GeV. Theoretical work by Frankfurt and Strikman[29] and Yukawa and Furui[30] indicate that backward spectra induced by high energy probes are mainly composed of spectator nucleons from the breakup of correlated pairs in the nucleus. As such, these backward nucleons potentially reflect direct information of the nuclear wavefunction.

In conclusion, we find that our data spans a transition region wherein the inclusive distributions of protons in the momentum range $0.4 \leq p \leq 1.0$ GeV/c are found to exhibit limiting behavior. The data, together with recent theoretical descriptions of internal momentum distributions in nuclei and reaction mechanisms involving correlated nucleons, strongly suggest that the limiting shapes of the measured spectra are related to the presence of correlations in the nucleus.

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FIGURE CAPTIONS

Fig. 1. Proton inclusive distributions; △, ◆, ○ this expt.; ▣ Ref. 12; ▼ Ref. 11; —— Ref. 3; ---- Ref. 10.

Fig. 2. Proton inclusive distributions; ● Ref. 15, plotted in the rest frame of the projectile; ▼, ◇, □ this expt., plotted in the lab frame; — double Gaussian representation of C + C → p data (solid points) with values of parameters indicated in N(P).

Fig. 3. (a) ◆ energy dependence of α, ○ target dependence of α, □ projectile dependence of α where A denotes both A_p and A_t (b) plot of parameter σ_T vs. $A_p^{2/3}A_t^{4/3}$, solid line shows trend expected if dependence of σ_T is $A_p^{2/3}A_t$.

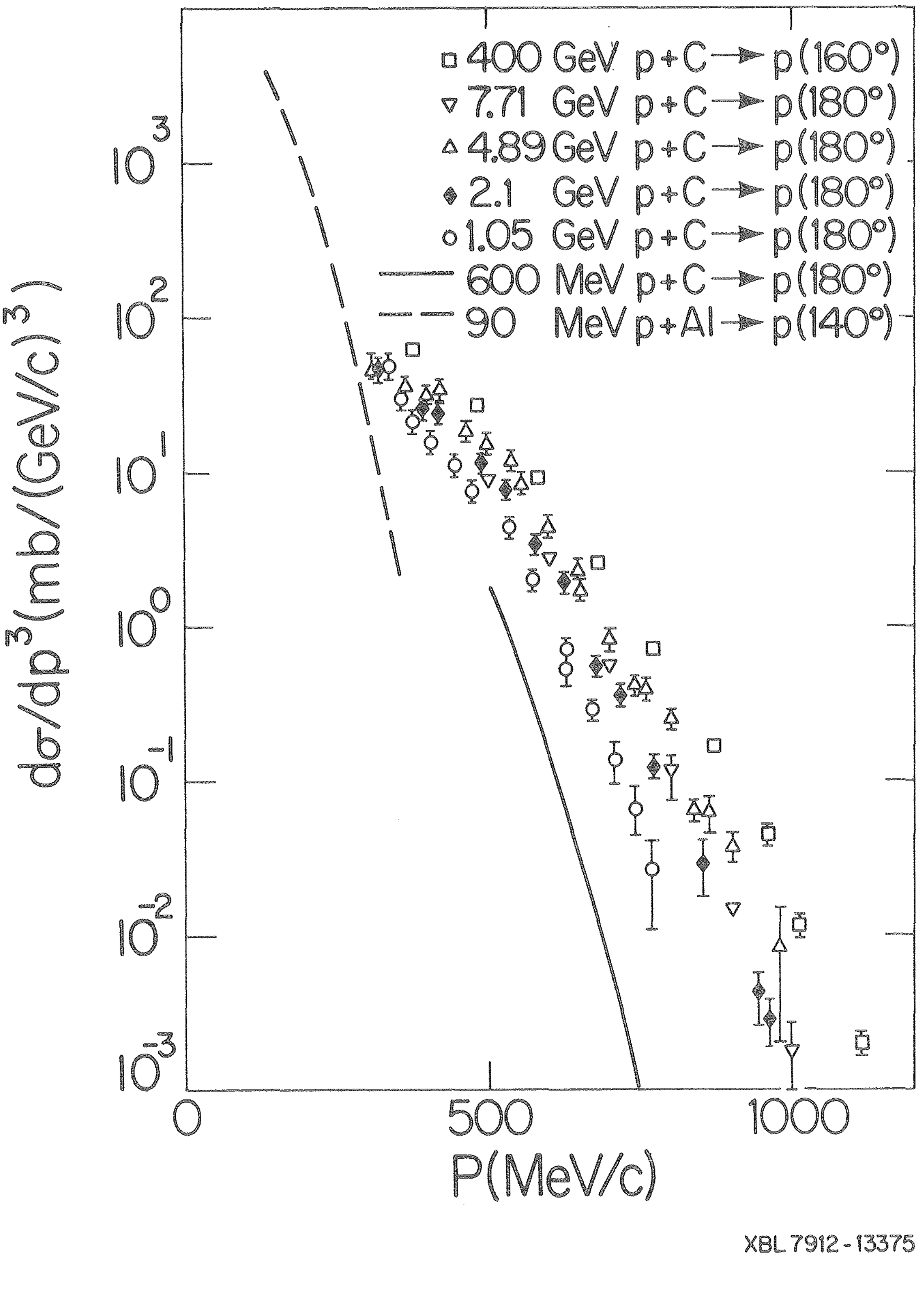
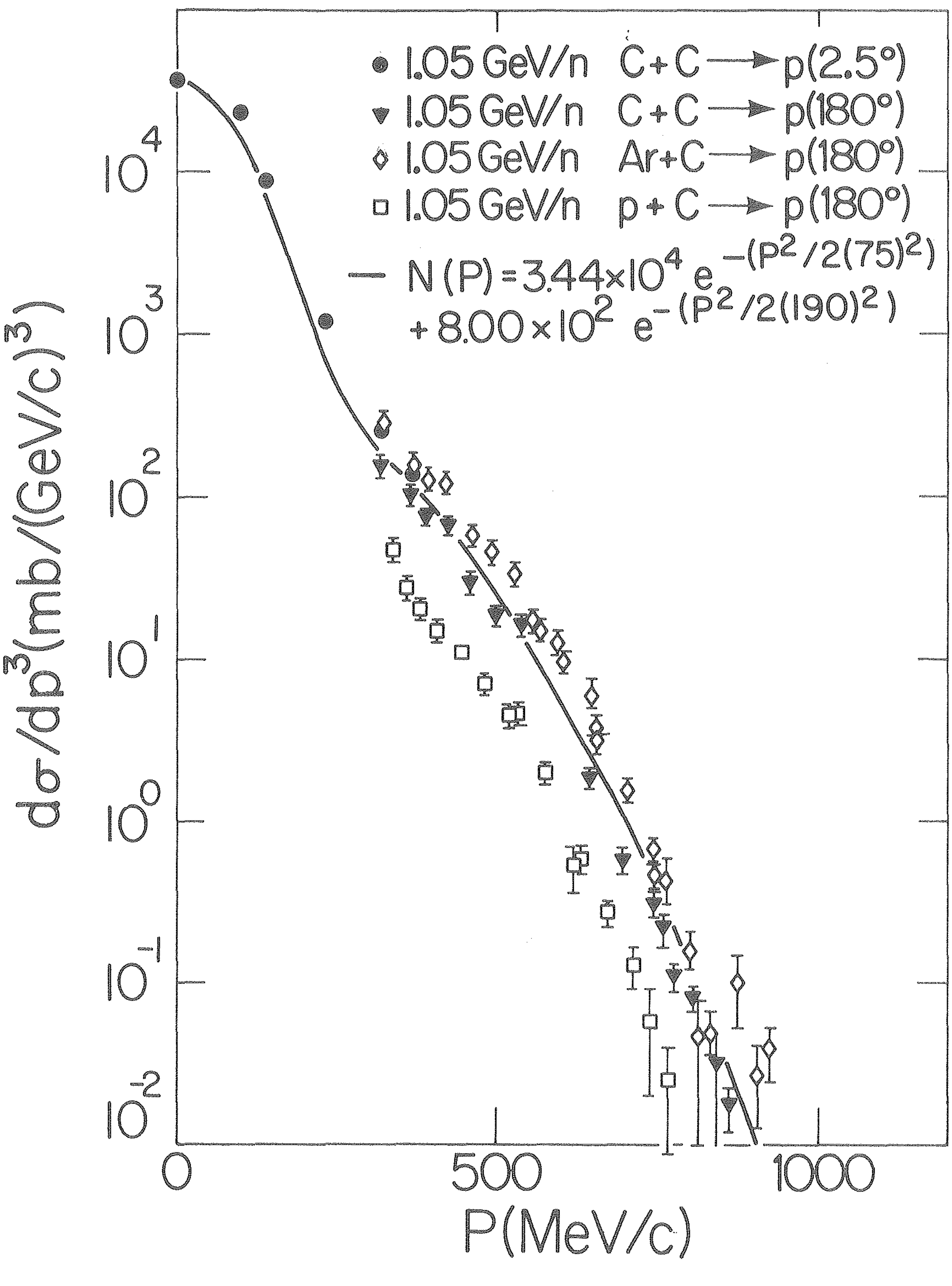

400 GeV p+C → p(160°)
7.71 GeV p+C → p(180°)
4.89 GeV p+C → p(180°)
2.1 GeV p+C → p(180°)
1.05 GeV p+C → p(180°)
600 MeV p+C → p(180°)
90 MeV p+Al → p(140°)
dσ/dp³(mb/(GeV/c)³)
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁻³
0
500
1000
P(MeV/c)
XBL 7912-13375

Fig. 1



XBL 7912-13374

Fig. 2

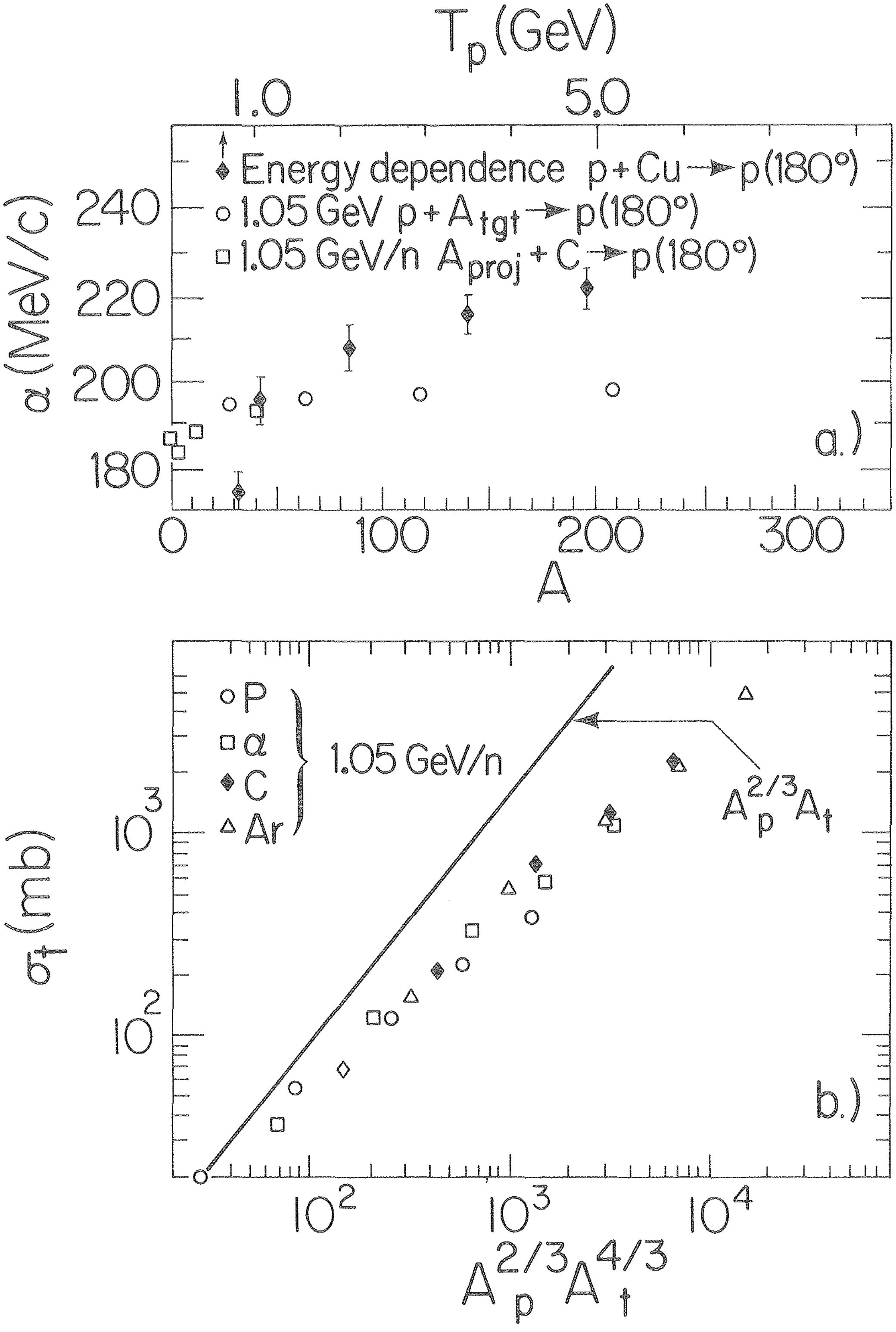


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Fig. 3