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On scaling in the projectile-fragmentation regime at cosmic-ray energies

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We point out that three is a non-negligible electromagnetic contribution to the projectile-fragmentation regime in inelastic nucleon-air collisions at cosmic-ray energies. This must be subtracted before conclusions can be drawn concerning the hypothesis of limiting fragmentation in hadronic (nucleon-nucleon) collisions.

INTRODUCTION

The hypothesis of limiting fragmentation (HLF),[1] namely that, in hadronic collisions, the cross section for the emission of any particle into a fixed volume of momentum space in the projectile or the target rest frame approaches a constant value at asymptotic energies, has been tested repeatedly in the GeV-TeV range.[2,3] The conlcusion from accelerator data appears to be that the HLF is broken, but in a way that is consistent with Mueller-Regge phenomenology. The situation above 1 TeV is not so clear. Results from the CERN SPS $\bar{p}p$ collider indicate a clear violation of Feynman scaling[4] for *central* production,[5] in essential agreement with trends from lower energies;[3] however, measurements in the fragmentation region are still inconclusive.[6] Data from cosmic-ray experiments are somewhat contradictory, in that certain measurements in the projectile-fragmentation region suggest a substantial violation of the HLF (the cross section *drops* as the collision energy increases),[7] while other results appear to be consistent with the HLF.[8] The cosmic-ray data are based primarily on proton-air, or rather p-${}^{14}_{7}$N collisions. Because of the large radiative width of the $\Delta(1236)$, that is the $\Delta^+(1236)\to p+\gamma$ process,[9] and the fact that inelastic electomagnetic cross sections rise substantially with incident beam energy,[10] we have investigated whether production in the nuclear Coulomb field through the Primakoff mechanism[10] provides a measurable contribution to the projectile-fragementation regime.

CALCULATION

Inelastic production in the Coulomb field of a target of charge Z in p-Z collisions, shown schematically in Fig. 1, is given by[11]

$$\frac{d\sigma}{dM^2dt}=\frac{Z^2\alpha}{\pi}\frac{\sigma_{\gamma p}(M)}{M^2-m_p{}^2}\frac{t-t_0}{t^2}|F(t)|^2\ , \tag{1}$$

where M is the mass of the produced hadronic system; t is the square of the four-momentum transferred to the nucleus (in our metric $t=p^2-E^2>0$); t_0 is the minimum value of t required to produce the mass M; $\sigma_{\gamma p}(M)$ is the total inelastic cross section for γp collisions at the γp center-of-mass energy $E=M$; α is the fine-structure constant; $|F(t)|^2$ is the electromagnetic form factor of the nucleus, which can be taken approximately as $\exp(-85t)$.

The cross section for Eq. (1) peaks essentially at $t=2t_0$, which corresponds to a production angle $\theta\simeq 0°$. The form

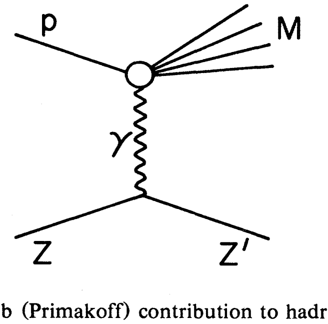

FIG. 1. Coulomb (Primakoff) contribution to hadroproduction.

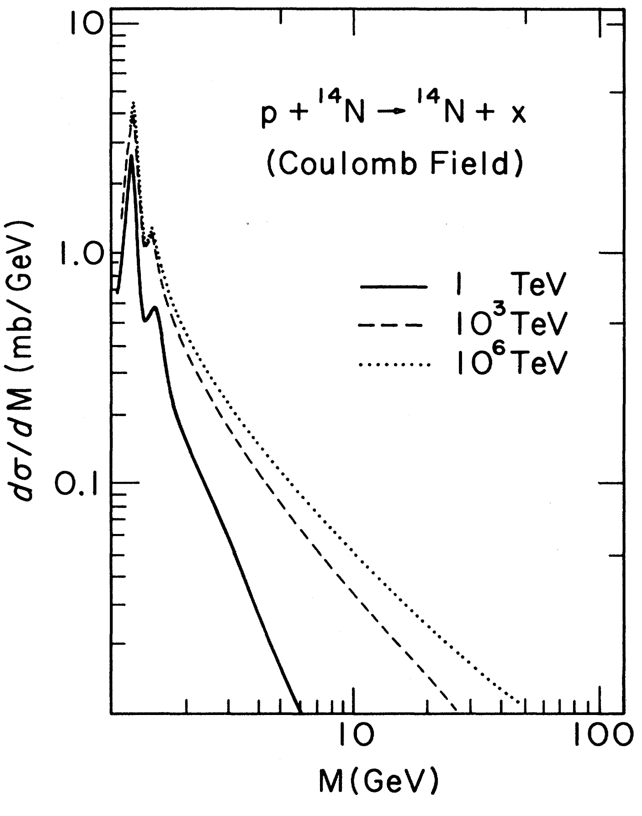

FIG. 2. Mass dependence of electromagnetic production as a function of incident proton energy.

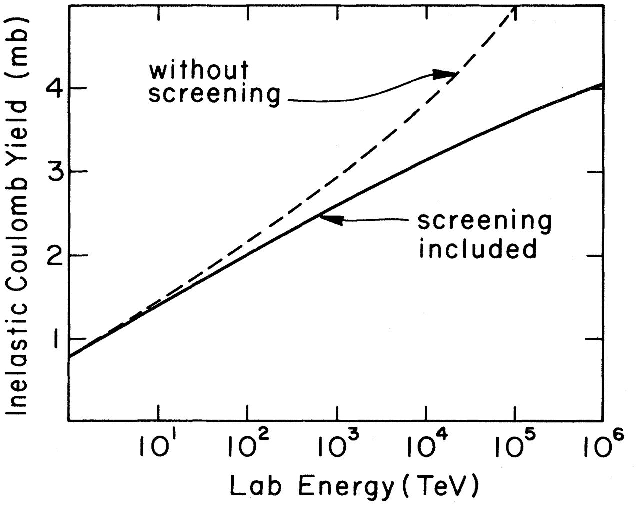

FIG. 3. Integrated yield for the Coulombic contribution to inelastic production as a function of incident proton energy. The calculations are shown with and without electron-screening corrections.

factor at such small values of t can be taken to equal unity.

We have integrated Eq. (1), over t, using the measured value[9] of $\sigma_{\gamma p}(M)$ in Eq. (1), assuming a constant cross section of 110 μb beyond the measured range of $M > 20$ GeV. The integration was performed from $t = t_0$ to $t = 0.05$ GeV^2, which corresponds to essentially the full range of Coulomb production. For energies $\gtrsim 1$ TeV, where electron screening of the nuclear field can become important, we have modified the calculation to take account of the electron distribution for the nitrogen atom.[12] The production cross section, as a function of M, is shown in Fig. 2 for several incident proton energies. The cross section integrated over M is shown as a function of laboratory energy in Fig. 3.

CONCLUSION

The calculated absolute cross section for inelastic Coulomb production in proton-air collisions is relatively small. It corresponds to $\sim 0.5\%$ of the inelastic total cross section. Moreover, this contribution is peaked at small dissociation masses and, consequently, at low multiplicities. For most purposes, therefore, this electromagnetic source of hadroproduction can be ignored. However, essentially the entire contribution is restricted to a rather narrow region of phase space, namely the projectile fragmentation regime of very forward rapidities, and the yield increases with incident energy. Consequently, this Coulomb contribution must be subtracted from proton-air data before the question of the validity of the HLF in hadronic collisions can be properly addressed. Although data on nuclear collisions are sparse, we will attempt to estimate below the overall size of the electromagnetic effect relative to hadronic production in the projectile-fragmentation region.

The total nuclear diffraction dissociation cross section at Fermilab and CERN ISR energies ($\lesssim 1$ TeV) is about 3 mb (per nucleon).[3] For exclusive channels, the diffractive yield remains constant or drops somewhat with increasing energy,[13] and the dependence on target material is approximately linear with nucleon number.[14] The inclusive cross section for diffractive excitation appears to rise somewhat in the Fermilab or ISR regime;[15] the target dependence in inclusive production is weak and not well known ($\sim A^{0.5}$).[16] At smallest production angles (and low dissociation masses) the Coulomb yield in Fig. 3 is definitely non-negligible; in fact, it dominates the cross section. For large dissociation masses, the relative importance of the Coulomb contribution is difficult to gauge because there is not enough information available on inclusive nuclear diffraction production, particularly at energies $\gtrsim 0.5$ TeV. Roughly speaking, however, we can assume that the Coulombic contribution to proton-air collisions will be restricted to $\sim 10\%$ of the rapidity range and correspond to $\sim 5\%$ of strong production. If the diffraction yield does not increase much with energy (or starts to decrease), then the fraction of the production cross section at small angles that can be attributed to electromagnetic sources for $\gtrsim 10^3$ TeV may increase to a substantial fraction of strong production. Consequently, we believe that the electromagnetic contribution should be subtracted from proton-air data prior to evaluating the success of the HLF.

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