CONSEQUENCES OF THE "BREMSSTRAHLUNG ANALOGY" FOR PARTICLE PRODUCTION ON NUCLEI

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Particle spectra in hadron-nucleus collisions are discussed using the bremsstrahlung analogy. The following features are expected at high energies: (a) a plateau in rapidity higher than that observed in hydrogen, (b) an inelasticity increasing with increasing nuclear number and (c) independence of nuclear effects from the primary energy.

1. Introduction

The bremsstrahlung analogy [1] appears to be rather successful in describing many aspects of particle production in high energy hadron collisions [1, 2, 3]. Furthermore, as emphasized recently in Ref. [4] it is also able to naturally explain the fundamental fact observed in particle production on nuclei, the absence of a high energy cascade inside nuclear matter.

It therefore seems interesting to look into some of the specific consequences of this picture for hadron-nucleus collisions. The present paper is an attempt in this direction.

2. Formation zone

Let us first recall the explanation which the bremsstrahlung analogy provides for the absence of a high-energy cascade [4]. It is based on the concept of the "formation zone" [5, 6, 7]. According to this idea, the distance in the laboratory necessary for the

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emission of a field quantum k in the high-energy bremsstrahlung process should be on the order of

$$\tau = \frac{1}{\omega - k_{\|} v} \approx \frac{2k_{\|}}{(Mx)^2 + k_{\perp}^2 + \mu^2} \approx \frac{2\omega}{k_{\perp}^2 + \mu^2}, \tag{1}$$

where ω and $k_{\|}$ are the energy and the longitudinal component of the momentum of the emitted particle in the laboratory system and v and M are velocity and mass of the projectile. Furthermore, μ is the mass of the emitted quantum and $x = k_{\|}/E$, E being the incident energy.

If τ is larger than the nuclear diameter, the particles are emitted during a time long compared to the traversal of the nucleus and thus are only weakly sensitive to nature of the target. It might be said that the secondaries are formed outside the nucleus. In particular we do not expect any intra-nuclear cascade. Consequently for all particles which satisfy the condition

$$\tau > 2R, \tag{2}$$

where R is the nuclear radius, we can consider the production from nuclei to be described by exactly the same mechanism, although not necessarily with the same parameters, as in nucleon-nucleon collisions. A simple calculation [4] shows that the condition (2) is satisfied for the majority of particles emitted in collisions at energies of a few hundred GeV. Only particles from the target fragmentation region and/or particles emitted with large transverse momenta can be strongly affected by the actual nuclear number by possible cascading phenomena. The emission of all other particles, since they have a formation zone which is greater than the nuclear dimensions, should have the properties suggested by the bremsstrahlung analogy [1]: a plateau in rapidity and moderate inelasticity.

We stress that an important feature of Eq. (1) is that the formation zone is essentially independent of the energy of the primary. Therefore such features as the transition from the cascading to noncascading or the change in A behaviour with transverse momentum, should take place at the *same* lab. energy and angle of the seconadry for *all* incident energies, once the energy is high enough to make x small.

3. *The rapidity distribution of the produced particles*

From the preceding discussion it follows that, apart from fragmentation regions, the rapidity distribution should have a "plateau" analogous to the one observed in nucleon--nucleon collisions. It is not possible, unfortunately, to predict the density in rapidity of particles in the plateau: the density depends on details of the interaction which are presently unknown. It seems very likely, however, that density is larger than that in nucleon--nucleon collisions. Indeed, since the projectile passes through more material it seems natural to expect that the state of the system suffers a greater alteration leading to somewhat more radiation, i.e. higher plateau.

Thus we expect asymptotically three regions in the rapidity plot: the plateau which can be somewhat higher than that in nucleon-nucleon collisions, the backward fragmentation region of the nucleus where cascading effects can occur and the forward fragmentation region. Fig. 1 shows this highly idealized rapidity distribution.

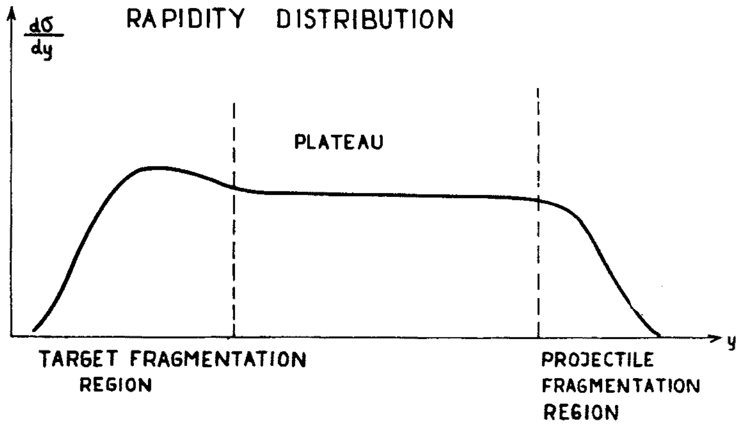

Fig. 1. Schematic rapidity distribution for hadron-nucleus collision at very high energy

The shape of this distribution in the projectile fragmentation region will be affected through energy and momentum conservation by the increased density of the plateau and therefore will not be exactly the same as in hydrogen. Qualitatively we expect that at larger densities in rapidity, i.e. heavier nuclei, the effects on the projectile fragmentation

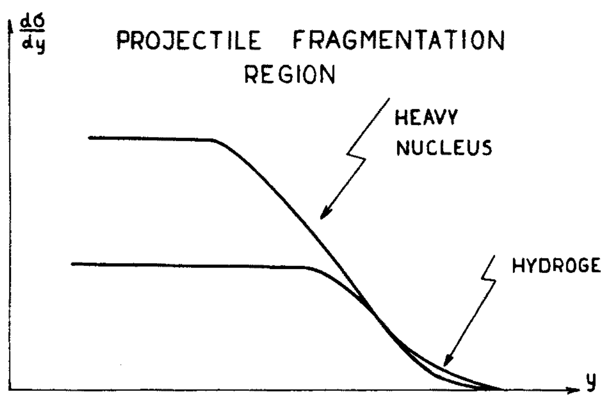

Fig. 2. Expected behaviour of projectile fragmentation region for nuclear and hydrogen targets

region to become greater, as illustrated in Fig. 2. Indeed, high multiplicity events in general do not contain many fast particles. Thus we expect the projectile fragmentation region to be depopulated and departure from the plateau to start at rapidities smaller than in nucleon-nucleon collision at the same energy. This expectation appears to be confirmed by the data [8, 9, 12, 13].

4. *The leading particle distribution*

The leading particle distribution is of decisive importance in distinguishing various models of multiproduction on nuclei. As shown in Ref. [1] the leading particle distribution in the bremsstrahlung analogy is determined by the density of particles in the plateau. The generalization of this idea to take into account the experimentally observed multiplicity distribution leads to the following formula [3] for the leading particle spectrum

$$\frac{1}{\sigma}\frac{d\sigma}{dx} = \frac{1}{\lambda_0}\int \psi(\lambda/\lambda_0)(1-x)^{\lambda-1}\lambda d\lambda, \tag{3}$$

where λ_0 is the average density in the plateau region and $\psi(z)$ is the KNO function [11] describing the multiplicity distribution. The resulting curve agrees with the data on hydrogen [3]. In Fig. 3 the expected distribution is plotted for different nuclei using the experimentally determined KNO function[1] and average multiplicities[2] for nuclei.

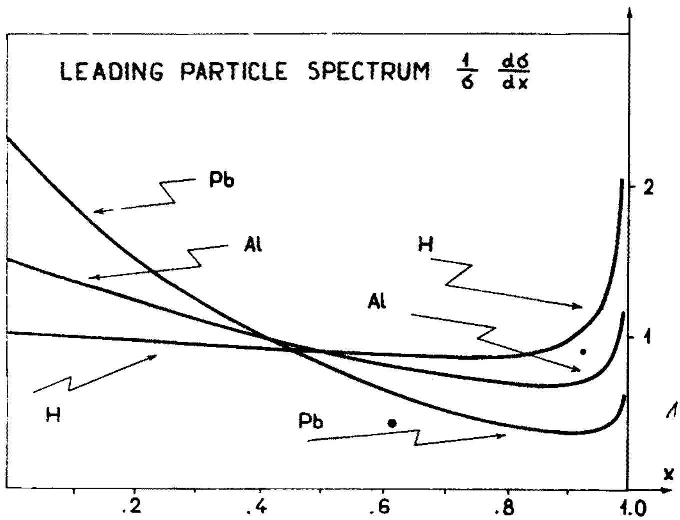

Fig. 3. Leading Particle Spectrum for several targets

We see that although the leading particle spectrum on nuclei is similar to that on protons, the spectra shift gradually to smaller x, reflecting the slowly rising multiplicity in the central region, which leads to a greater inelasticity. This kind of leading particle spectrum[3] is different, for example, from that expected from the parton model [14]. In the parton model the leading particle spectrum should be *exactly* the same on all targets since the leading partons do not interact with the nucleus. We stress that this growing

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[1] Similarly as in Ref. [3] we used the Møller fit [11]. This appears to be very good description of hadron-nucleus multiplicity distribution (see e.g. Ref. [12]).

[2] The empirical formula [13. 8] $\bar{n}_A = \frac{1}{2}(\bar{\nu}+1)\bar{n}_H$ was used.

[3] Since the rapidity plateau is not well-developed at energies now available, the curves shown in Fig. 3 are only approximate. However, if KNO scaling holds at asymptotic energies, the approximation should be reasonable.

inelasticity with nuclear size is inextricably connected with the increasing density in the plateau: the plateau cannot increase without removing a fraction of the energy carried by the proton. Similarly, if the leading particle spectrum does not change, no energy can be added to the plateau.

5. *Summary*

In conclusion the salient points of our discussion are the following:

1. The "Formation Zone" seems to give a correct description of where in transverse momentum and rapidity the secondary spectrum will be strongly affected by the nuclear number of the target and where not [8, 13, 15]. Since the formation zone depends only (essentially) on the secondary the pattern should be essentially energy independent once it has set in.

2. In general we expect the central region in rapidity, the plateau, to be somewhat higher the larger the nucleus. Since the length of this region in rapidity grows indefinitely with energy, there are long range correlations, which can grow stronger with nuclear size.

3. The leading particle spectrum is expected to be qualitatively but not *quantitatively* similar on nuclei and hydrogen, as shown in Fig. 3. A definite trend towards greater inelasticity on heavier nuclei is expected.

As far as we know these claims are consistent with the availabe data. We look forward to their eventual verification or refutation with interest.

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