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HIGH ENERGY HADRON-NUCLEUS SCATTERING

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Abstract

We describe theoretical expectations for hadron-nucleus scattering at high energy if the basic hadron-hadron interaction is due to Regge poles and cuts arising in multiperipheral or soft field theory models. Experiments at Fermilab may provide a critical test of such models.

The scattering of high energy hadrons off nuclear targets offers new possibilities for testing models of hadron-hadron scattering and, as emphasized by Gottfried[1], may provide otherwise unavailable information on the time scales involved in hadronic interactions. In this note we shall report on some of the general features of hadron-nucleus scattering implied by a softened field theory or multiperipheral model[2] of Regge poles and cuts, leaving the detailed arguments for another publication. This model accounts, at least qualitatively, for the observed behavior of hadron-hadron scattering at small momentum transfers and furthermore automatically contains the large time scales required by the SLAC data on inelastic electron scattering.[3] An analysis of hadron-nucleus scattering in soft field theory models has been given by Kancheli[4] and by Lehmann and Winbow[5],

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but we shall emphasize the critical role of certain Regge cut effects and how the relation between total, elastic and inclusive cross sections may provide a decisive test of the model.

Consider first an elastic hadron-hadron scattering amplitude given by single Regge pole exchange, which in the ϕ^3 model (any other soft theory model without vector mesons is equivalent for our purposes) is represented by a sum of ladder graphs. In order to have a simple space-time interpretation with on-mass-shell intermediate states it is convenient to work in old-fashioned (time-ordered) perturbation theory where at high energy in the laboratory frame a ladder graph takes the form shown in Fig. 1. In principle there is a sum of graphs, one for each ordering of the vertices, but since most of the internal lines carry a large momentum all orderings but that shown are suppressed by powers of p.(6) The lifetimes of the various intermediate states can be estimated by the uncertainity principle to be* $0(p/m^2)$ for the first few intermediate states, decreasing to $0(1/m)$ for those adjoining the interaction with the target. The physical picture associated with this graph(7) is that the projectile begins to emit fast quanta and then a large time and distance interval $0(p/m^2)$ later, slow quanta have appeared and these can interact directly with the target. After a further time and distance interval $0(p/m^2)$ the virtual quanta have recombined and the scattering event is complete. There are two types of two-Reggeon cuts (two-ladder graphs). The projectile may split into two fast secondaries which independently emit ladders, then a time $0(p/m^2)$ later both ladders interact with the target within a time $0(1/m)$ of each other, and after a further time $0(p/m^2)$ the two ladders recombine into the outgoing projectile. This is just the Mandelstam graph. Alternatively, the projectile may emit one ladder which interacts with the

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* m can be interpreted as an average transverse cluster mass, and we expect $m = 0(1\ \mathrm{GeV})$.

target and then recombines (after a time $0(p/m^2)$), and then emits a second ladder which interacts with the target and recombines. The second case, the AFS graph, is clearly zero since the projectile is already far past the target before beginning to emit the second ladder. However, if there were a second target a distance at least $0(p/m^2)$ downstream of the first, then this last statement is false and an AFS - like graph need not vanish.

Now consider hadron-nucleus scattering with $p/m^2 \gg R$, the nuclear radius. For a large nucleus it is a good approximation to work at a single impact parameter and then multiply by πR^2. Again, if the projectile is to interact it must begin to emit one or more Reggeon ladders a distance $0(p/m^2)$ before reaching the nucleus. The nucleus now has hadrons distributed over a distance 0(R) and any virtual particle with momentum $k \leq 0(m^2 R)$ can, and in general will, interact repeatedly with the nucleus through AFS - like rescattering. Since the elastic scattering amplitude in impact parameter is bounded by a constant, the strength of this latter interaction cannot grow as a power of R however. Thus the full scattering amplitude has a Regge form for the virtual particles with $p \geq k \gtrsim 0(m^2 R)$ and a constant dependence for the lower momentum components, and we find

$$\sigma_{tot} = \pi R^2 \left[c_1 \left(\frac{p}{m^2 R} \right)^{\alpha - 1} + c_2 \left(\frac{p}{m^2 R} \right)^{2\alpha - 2} + \dots \right]$$

with $c_i = 0(1)$. The coupling of Regge cuts to a nucleus can be larger than to a hadron, but cannot be enhanced by powers of R. Because of the long time scales of interactions, the Glauber expansion[8] is inapplicable.

We thus expect a single-particle inclusive cross section of the form shown in Fig. 2: a nucleus fragmentation region where rescattering and some cascading can occur, a central region(if the energy is sufficiently high) and a projectile fragmentation region.

The height of the cross section in the central region and the shape in the projectile fragmentation region need not be the same as for a hadron target due to possibly stronger Regge cuts. The height of the central plateau is tightly correlated with the elastic cross section, as we now discuss. First we take the simple example of allowing only one- and two-Reggeon exchanges; then the AKG cutting rules[9], which depend critically on the long time scales typical of a softened field theory model[10], imply that the relative strengths of total, diffraction dissociation (including elastic) and one- and two-Reggeon final state cross sections are, respectively, $\sigma_{tot} = A_1 - A_2$, $\sigma_{DD} = A_2$, $\sigma_1 = A_1 - 4A_2$, and $\sigma_2 = 2A_2$, where $A_1(-A_2)$ is the imaginary part of the one- (two-) Reggeon amplitude. Suppose we wish to maximize $r \equiv \sigma_{DD}/\sigma_{tot}$, a ratio which tends to $\frac{1}{2}$ for large nuclei at lower energies. This entails maximizing A_2, but we are constrained to keep $\sigma_1 \geq 0$ or $A_2 \leq \frac{1}{4} A_1$. If we assume that hadron-hadron scattering is dominated by single-Reggeon exchange, and define

$$R_c = \left[\left(\frac{1}{\sigma_{inel}} \frac{d\sigma}{dy} \right)_{nucleus} \Bigg/ \left(\frac{1}{\sigma_{inel}} \frac{d\sigma}{dy} \right)_{hadron} \right]_{central\ region} ,$$

where $\sigma_{inel} \equiv \sigma_{tot} - \sigma_{DD}$, then at the maximum we have $r = \frac{1}{3}$ and $R_c = 2$. Similarly, if we allow one-, two-, and three-Reggeon exchange we can reach $r = \frac{3}{7}$, but only if $R_c = 3$. Thus a large elastic cross section implies a large inclusive particle density. In general we can show that when multiple Regge cuts (but no Reggeon interactions) are allowed, if

$$\frac{1}{2} \frac{1 - 2^{2-n}}{1 - 2^{1-n}} < r < \frac{1}{2} \frac{1 - 2^{1-n}}{1 - 2^{-n}}$$

then

$$R_c \geq n + 1 + \frac{2^{n-1}(2r-1)}{1 - r}$$

When n becomes large, which in configuration space corresponds to a high density of particles at each rapidity and impact parameter, then Reggeon interactions are presumably non-negligible and the bound is not strictly true. However if experiments reveal a distinct central region with $R_c \approx 1 - 2$, together with $r \not\approx \frac{1}{2}$, then softened field theory models of models of Regge behavior are in doubt.

The planar dual string model of hadron-hadron scattering offers a contrasting behavior. Here, an interaction between an incident (hadron) string and a single nucleon is essentially instantaneous, so that on a nuclear target the string can interact successively with each nucleon at its impact parameter and the Glauber expansion can be safely applied. One finds $\sigma_{tot} = 2\pi R^2$, $r = \frac{1}{2}$ and $R_c = 1$. When dual loops are included these results may change; in particular, loops are essential in describing the excess particle production and rescattering in the nucleus fragmentation region. Nevertheless, if experiment rules out a softened field theory description, a string model may provide an attractive alternative.

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Figure Captions

Fig. 1 A Regge pole in old-fashioned perturbation theory, depicted at high energy in the rest frame of P.

Fig. 2 The inclusive particle density for nuclear and hadron targets.

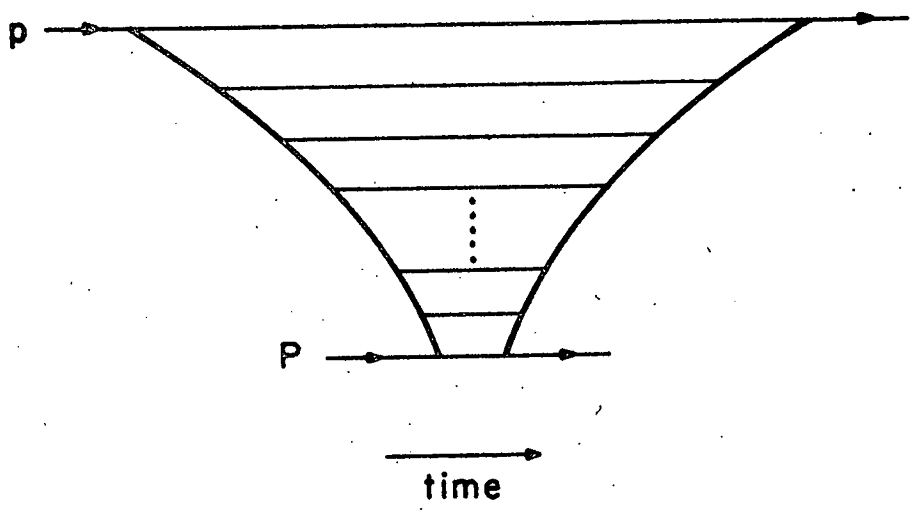
p
P
time

Fig. 1

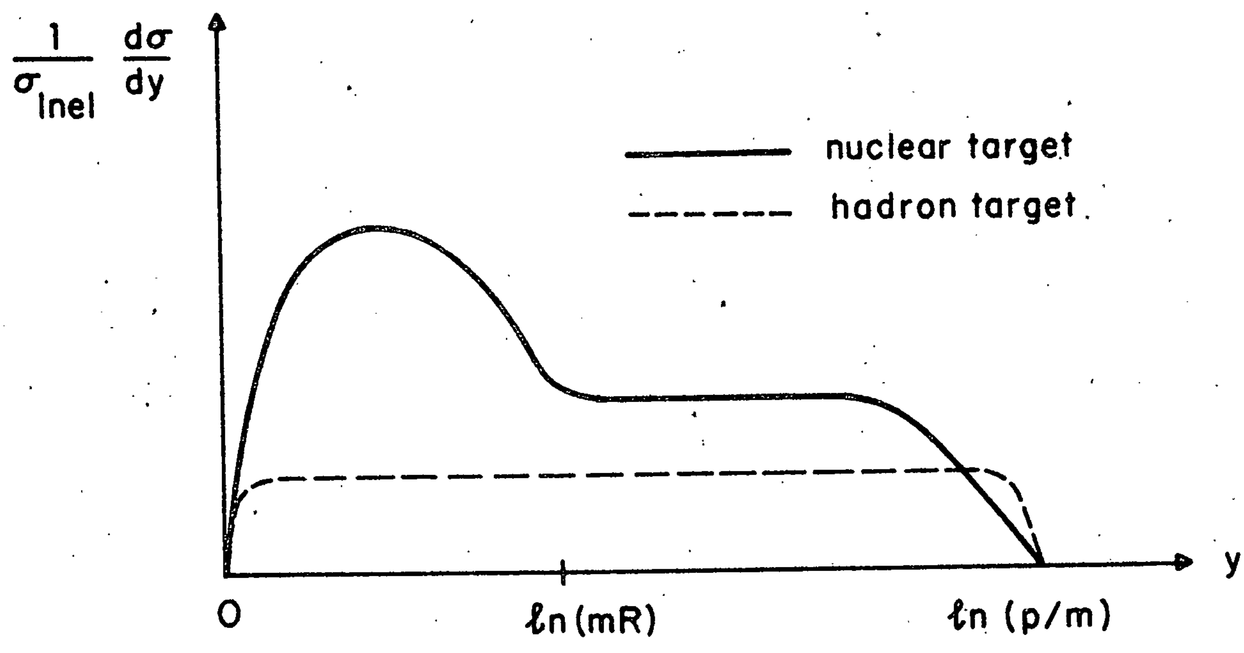
$\frac{1}{\sigma_{Inel}} \frac{d\sigma}{dy}$
nuclear target
hadron target
y
0
ℓn (mR)
ℓn (p/m)

Fig. 2

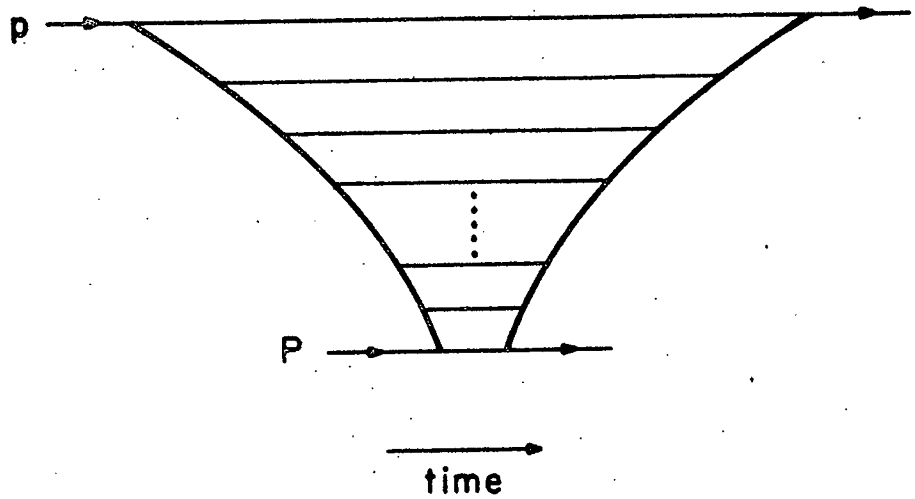
p
P
time

Fig. 1

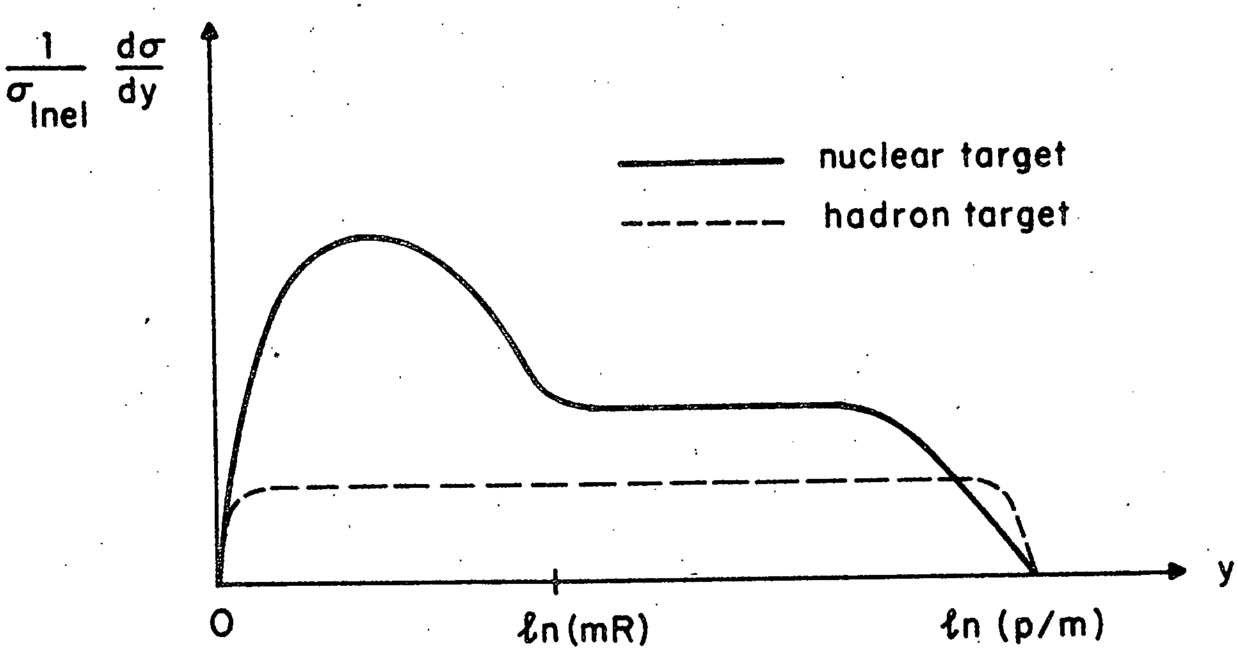
$\frac{1}{\sigma_{Inel}} \frac{d\sigma}{dy}$
nuclear target
hadron target
y
0
ℓn(mR)
ℓn (p/m)

Fig. 2