Hard color coherent phenomena

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We consider hard color coherent phenomena which can be probed at FNAL collider.

1. Introduction

During the last few years a number of hard color coherent phenomena was discovered which can be legitimately calculated in QCD: pion dissociation into 2 jets observed in [1] is consistent with predictions of [2], HERA data for exclusive production of mesons in DIS initiated by longitudinally polarized photons are consistent with predictions of [3]. These processes allow both to study the interaction of small color dipoles with hadrons at high energies and hence probe break down of the DGLAP approximation as well as to study hadron wave functions in the minimal Fock space configurations.

2. Hard exclusive diffraction

2.1. Diffraction into three jets

It is possible that a nucleon (meson) has a significant amplitude to be in a configuration where valence partons are localized in a small transverse area together with the rest of the partons. These configurations are usually referred to as *minimal* Fock space configurations - $|3q\rangle$ ($|q\bar{q}\rangle$). Hadrons in such a configuration occupy a small transverse area with a larger probability than in the case of nonminimal configurations, because, e.g. the long range pion field is very weak. Therefore, such initial configurations are expected to interact with other hadrons, even at high energy, with a small cross-section. However for the fixed transverse size, b, this cross section is proportional to the gluon density at $Q^2 \sim 10/b^2$ and hence rapidly increases with increase of energy. At sufficiently high energies this growth should be tamed not to violate unitarity constraints, for the recent discussion see [4].

In the case of the "elastic scattering" of such a proton configuration off another proton, this three-quark system with large relative momenta should preferentially diffractively dissociate into a system of three jets with large transverse momenta $p_{Ti} \sim \pi\, b^{-1}$, where b is the transverse size of the minimal configuration. Kinematics of the process is presented at the lego plot of Fig.1.

The production cross-section for the three jets can be estimated to leading order in $(\alpha_s \ln M^2_{3jet})$. As in the case of diffractive vector meson production in deep inelastic scattering, the cross-section is proportional to the square of the gluon density in the nucleon at $x \approx M^2_{3jets}/s$, and virtuality $\sim p^2_{T\ jet}$[5]. The distribution over the fractions of the momentum carried by the jets is proportional to the square of the light cone wave function of the $|3q\rangle$ configuration. Hence the diffraction of a proton into three jets provides important information about the short-distance quark structure of the proton, and also provides unique information about the longitudinal momentum distribution in the $|3q\rangle$ configuration. From an analysis of diffraction data [5,6], numerical estimates for $\sqrt{s} = 2$ TeV lead to a value of the cross-section integrated over everything except a $p_{T\ jet}$ threshold for one jet,

$$\sigma_{3\ jets} \sim (10^{-5} - 10^{-6}) \left(\frac{5 \text{ GeV}}{p_{T\ jet}}\right)^8 \text{mb}. \qquad (1)$$

The probability of the $|3q\rangle$ configuration is estimated using a phenomenological fit to the probability of configurations of different interaction strengths in a nucleon (cf. [5,6]).

Another interesting group of hard processes is proton diffraction into 2 high p_T jets and one collinear jet. These processes are dominated by parton configurations when only 2 quarks in the projectile proton are close to each other, i.e., have large transverse momenta. Such quark configurations are relevant for estimates of proton decay rates. The wave function describing such a configuration can be measured in the double-diffraction process where each of the protons fragments into 3 high p_t jets: $pp \to jet(k_t) + jet(-k_t - q_t) + jet(q_t) + jet(l_t) + jet(-l_t - r_t) + jet(r_t)$.

2.2. Tagged-pion diffraction dissociation

Reactions containing a very forward neutron or a Δ-isobar can be dominated by the scattering off the pion cloud of the nucleon. In this way the proton beam is effectively converted into a pion beam; the leading baryon is effectively a pion tag. A necessary condition that one-pion exchange dominates this process is that the transverse momentum of the forward baryon be small compared to 300 MeV and, in the case of the Δ,

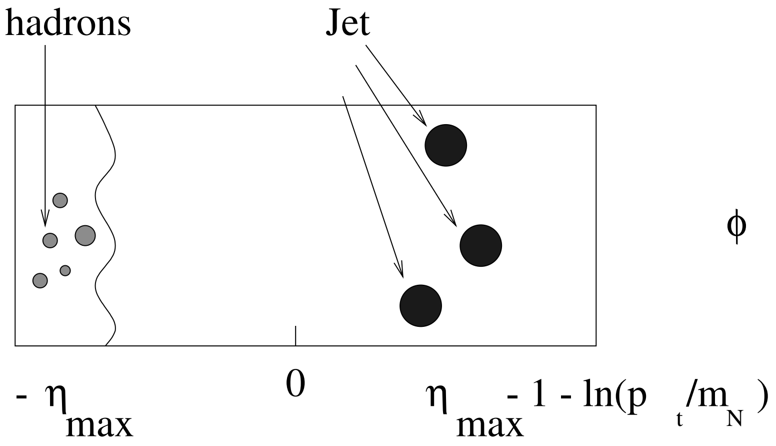

Figure 1. LEGO plot for diffraction of proton into three jets

that its x_F exceed 0.9. The precise condition is

$$|t| = (\frac{M_B^2}{x_F} - m_N^2)(1 - x_F) + \frac{k_t^2}{x_F} \leq 0.1\mathrm{GeV}^2. \quad (2)$$

One must still deal with absorptive corrections due to the simultaneous interactions of the projectile with a nucleon and a pion. These are expected to be corrections no larger than a factor two.

Two types of processes would be of special interest:

Pion diffraction into two jets:

In analogy with the process of nucleon diffraction into three jets it is expected that a pion can dissociate into two jets in the process $\pi + p \to jet_1 + jet_2 + p$ [7,2] (Fig. 2).

The cross-section for this process has a similar structure [2]: due to the rapid increase of the gluon density with energy one expects the cross-section for pion diffraction into two jets to be much larger than in the case of the fixed target experiment E791 at FNAL which has just reported first evidence for this effect [1].

Two $\to$ three hard reactions:

It is also interesting to study large $|t|$ elastic scattering off the pion cloud in a number of reactions [8].

$$pp \to B(p_{T\ B}) + \pi(p_{T\ \pi}) + p(p_{T\ p}), \quad (3)$$

for $B = N, \Delta$, $x_F(B) \geq 0.9$, $p_{T\ B} \sim 0$, and $p_{T\ \pi} \sim -p_{T\ p} \gg 1$ GeV, which corresponds to the proton elastic scattering off the pion cloud. Although the flux of such pions in the proton is only $\sim 1\%$, at large $|t| \approx p_{T\ p}^2$ the cross-section for elastic πp scattering is expected to be substantially larger than the cross-section for elastic pp scattering. [1] Hence the cross-sections for reaction (3) and elastic pp scattering at $|t|$ larger than 10 GeV^2 should be comparable.

One may also consider elastic scattering of two pions in processes like

$$pp \to B(p_{T\ B}) + \pi(p_{T\ \pi}) + \pi(p_{T\ \pi'}) + B'(p_{T\ B'}) \quad (4)$$

for $B, B' = N, \Delta$, $x_B, x_{B'} \geq 0.9$, $p_{T\ B} \sim p_{T\ B'} \sim 0$, and $p_{T\ \pi} \sim -p_{T\ \pi'} \gg 1$ GeV. Again the much slower decrease of the $\pi\pi$ elastic scattering with $|t|$ helps to compensate the small probability of finding both nucleons in configurations with pions.

Many generalizations of such processes can be estimated. These include channels with strange particles in the final state like

$$pp \to (\Lambda K^+, \Sigma^+ K^0) + p$$

as well as kinematics for which the transverse momentum of the proton is balanced by a baryon, not a meson. Such processes are of interest, both for the study of high-energy scattering and for the structure of color correlations in hadrons, especially in relation to the question of intrinsic strangeness in nucleons, see e.g. [10]. Note that at sufficiently large $|t|$, where the colliding-hadron configurations are sufficiently small for the applicability of perturbative QCD, new factorization relations are expected to be valid relating these processes with analogous exclusive DIS processes.

3. Diffractive hard factorization

In difference from the case of deep inelastic scattering there is no reason for applicability of the factor-

[1] The high-energy data on large $|t|$ πp elastic scattering [9] are consistent with this expectation.

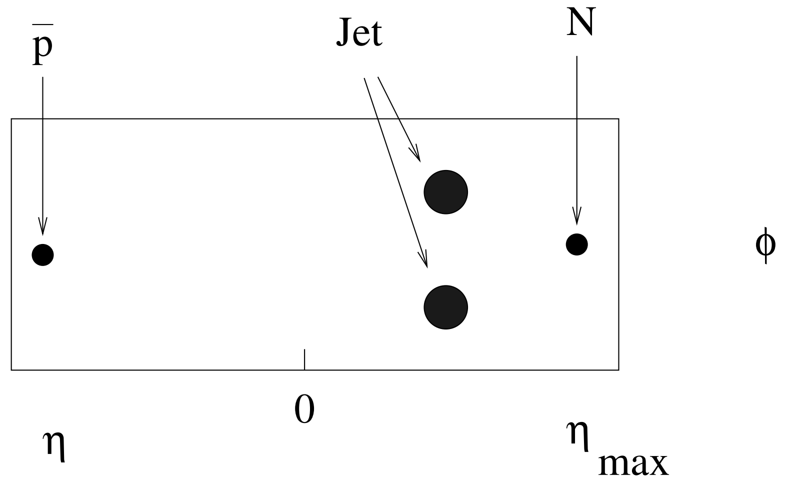

Figure 2. LEGO plot for the tagged 2 jet production

ization theorem for diffractive scattering. Hence it is convenient to represent the measured cross-section as a factorizing cross-section times a suppression factor:

$$\sigma_{\rm true} = \sigma_{\rm fact}(x_N, x_{I\!P}) \times S(x_{I\!P}, t, s). \quad (5)$$

Estimates of the value of S typically give a value $S \sim \frac{1}{10}$.

S may actually be a slowly varying, but rather complicated function of initial energy, $x_{I\!P}$, t, and x_N. For example, one can expect that it will decrease with an increase of $\sigma_{tot}(pp)$ (stronger spectator effects), increase with increasing $|t|$ (selection of more weakly interacting configurations in the intact nucleon [11]), and increase as x_N becomes large (due to a selection of smaller size configurations in N) (N is the nucleon which diffracted inelasticly).

It would be also interesting to study diffraction to inelastic low-mass final states B in the process:

$$p(p_1) + p(p_2) \rightarrow ({\rm jet}_1 + {\rm jet}_2 + X) + B \quad (6)$$

which may select configurations with an interaction strength rather different from the average one. Several examples of interesting channels are the aforementioned $B = n\pi^+, p\pi^+\pi^-$ and ΛK^+, each of which can be studied as a function of p_T of the produced jets for fixed $t \sim 0$. A hard factorization combined with Regge factorization would lead to

$$\frac{\sigma(p(p_1) + p(p_2) \rightarrow ({\rm jet}_1 + {\rm jet}_2 + X) + B)}{\sigma(p(p_1) + p(p_2) \rightarrow ({\rm jet}_1 + {\rm jet}_2 + X) + p)} = \frac{\sigma(p(p_1) + p(p_2) \rightarrow p + B)}{\sigma(p(p_1) + p(p_2) \rightarrow p + p)} \quad (7)$$

It is natural to expect that at least for large enough p_T this factorization would be broken, with the cross-section of diffractive jet production in the inelastic diffraction channel substantially enhanced compared to the expectations of Eq.(7).

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