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COLOR TRANSPARENCY AND PION VALENCE QUARK DISTRIBUTIONS FROM DI-JET EVENTS IN FERMILAB E791

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Diffractive, exclusive di-jet events produced by 500 GeV/c π^- scattered off nuclei were used to measure their A-dependence, and to make the first direct measurement of the valence-quark momentum distribution in pions. Data on the latter are compared to two limiting predictions for the pion light-cone wave-function. The results show that the asymptotic wave-function of perturbative QCD describes the data well for Q^2 of 10 GeV^2 and above. The measured A-dependence is consistent with observation of point-like configurations in the pion and color-transparency calculations.

1 Introduction

Color transparency (CT) is the name given to the prediction that the color fields of QCD cancel for physically-small singlet systems of quarks and gluons.[1] This color neutrality (or color screening) should lead to the suppression of initial and final state interactions of the small-sized systems in hard processes.[2] Observing color transparency requires that point-like configurations (PLC's) are formed and that the energies are high enough so that expansion of the PLC does not occur while traversing the target[3,4,5] (the "frozen" approximation). We use the A-dependence of di-jet production to test for the existence of PLC's in coherent interactions with nuclei.

Given that we find such exclusive di-jet, PLC interactions, we can use these to measure the valence quark distribution in pions. Here, we summarize two papers being submitted to Phys. Rev. Lett.[6].

2 Data Set and Event Selection

From a 10% subset of the Fermilab E791[7] 2×10^{10} recorded interactions, a selection was made to find those which had exclusively two-jets recoiling *coherently* from the carbon and platinum targets. On-line, only a single incident pion was allowed in the resolving time of the calorimeters and a loose minimum transverse energy requirement was made. Off-line, further selection was made by demanding that at least 90% of the incident pion momentum appear in charged particles with a total charge equal to -1. Using the JADE algorithm[8] optimized for di-jet finding, only events with two jets in the final state were accepted. The jets had to be back-to-back in the plane transverse to the beam within 20 degrees.

For each two-jet event, we calculated the transverse momentum of each jet with respect to the beam axis (k_t), the di-jet transverse momentum above the minimum for that di-jet mass (q_t), and the di-jet invariant mass (M_{di-j}). The di-jet invariant mass is related by simple kinematics to the quarks' longitudinal momentum fractions (x) in the pion infinite momentum frame: $M^2_{di-j} = k_t^2/[x(1-x)]$. To assure clean selection of high-mass di-jet events, a minimum k_t of 1.2 GeV/c is required. The distribution of events vs x gives the square of the valence-quark wave-function, assuming that each of the two jets is a measure of the quark from which it came.

The size of a $|q\bar{q}\rangle$ system which produces di-jets with $k_t > 1.5$ GeV/c can be estimated as $1/Q \leq 0.1\,\mathrm{fm}$ where $Q^2 \sim M^2_{di-j} \sim 4k_t^2 \sim 10$ GeV$^2/c^2$. The distance that the $|q\bar{q}\rangle$ system travels before it expands appreciably, the coherence length, is given by $\ell_c \sim$

Table 1. Experimental results and color-transparency (CT) predictions[10] for α values in coherent pion dissociation off nuclei vs k_t.

k_t GeV/c	α	$\Delta\alpha$	α (CT)
$1.25 - 1.5$	1.64	$+0.06$ -0.12	1.25
$1.5 - 2.0$	1.52	± 0.12	1.45
$2.0 - 2.5$	1.55	± 0.16	1.60

$(2p_{\rm lab})/(M^2_{di-j} - m^2_\pi)$ [3] which is ~ 10 fm for $M_{di-j} \sim 5$ GeV/c^2. Therefore, we expect that the di-jet signal events selected in this analysis evolve from point-like configurations which will exhibit color transparency.[9,10]

3 Coherent Scattering and Color Transparency

We derive the numbers of produced di-jet events in the data for each target in three k_t bins by integrating over the coherent diffractive terms in fits of the MC-smeared distributions to the q_t^2 distributions of the di-jet events. Using the resulting yields and the known target thicknesses, we determine the ratio of cross sections for diffractive dissociation on platinum and carbon. The exponents α are then calculated using the cross section dependence $\sigma \propto A^\alpha$. The α values are listed in Table 1, as are CT theoretical predictions[10]. The α's are consistent with those predictions and above $k_t = 1.5$ GeV/c, clearly inconsistent with α values like those in $\sigma \propto A^{2/3}$ for incoherent scattering observed in other hadronic interactions.

4 Pion Light-Cone Wave-Function

The pion wave-function can be expanded in terms of Fock states:

$$\Psi = \alpha|q\bar{q}\rangle + \beta|q\bar{q}g\rangle + \gamma|q\bar{q}gg\rangle + \cdots . \qquad (1)$$

For interactions in which pions transfer momentum to other particles over sufficiently short distances (for sufficiently high Q^2), the first component should be dominant.[11]

Table 2. Asymptotic (a_{as}) and CZ (a_{CZ}) wave-function contributions in fits of the data.

k_t GeV/c	a_{as}	$\Delta_{a_{as}}$	a_{CZ}	$\Delta_{a_{CZ}}$
1.25 - 1.5	0.64	+0.14 -0.12	0.36	-$\Delta_{a_{as}}$
1.5 - 2.5	1.00	+0.10 -0.14	0.00	-$\Delta_{a_{as}}$

The pion light-cone wave-function is predicted[9,12,13] by perturbative QCD for asymptoticly large Q^2 to be

$$\Phi_{asy}(x) = \sqrt{3}x(1-x). \qquad (2)$$

Using QCD sum rules, at low Q^2 Chernyak and Zhitnitsky (CZ) proposed[14]

$$\Phi_{CZ}(x) = 5\sqrt{3}(1-x)(1-2x)^2, \qquad (3)$$

where x is the usual fractional momentum carried by the quark. In the measurements, we use $x = p_{jet1}/(p_{jet1} + p_{jet2})$.

For measurement of the pion wave-function, we used data from the platinum target only, since it has a sharp diffractive distribution and low background. We used events with $q_t^2 < 0.015$ GeV/c^2. In order to get a measure of the correspondence between the experimental results and the calculated light-cone wave-functions, we fit the results with a linear combination of squares of the two MC-smeared wave-functions. This assumes an incoherent combination of the two wave functions and that the evolution of the CZ function is slow (as stated in Ref. 14). The coefficients a_{as} and a_{CZ} representing the contributions of the asymptotic and CZ functions, respectively, are listed in Table 2. The results for the higher k_t window show clearly that the asymptotic wave-function describes the data very well. Thus, for $k_t > 1.5$ GeV/c, which translates to $Q^2 \sim 10$ (GeV/$c)^2$, the perturbative QCD approach that led to construction of the asymptotic wave-function is reasonable. The distribution in the lower window is consistent with a significant contribution from the CZ wave-function.

The k_t dependence of diffractive di-jets is an observable that can show how well the perturbative calculations describe the data. As shown in Ref. 10, assuming interaction via two gluon exchange and slowly-varying ϕ_{as} leads to $\frac{d\sigma}{dk_t} \sim (k_t)^n$, with n = - 6. For our data, the region above $k_t \sim 1.8$ GeV/c can be fit with $n = -6.5 \pm 2.0$ with $\chi^2/dof = 0.8$, consistent with perturbative QCD predictions. This supports the evaluation of the light-cone wave-function at large k_t.

5 Summary

We have observed pion scattering events which exhibit A^α dependence consistent with color transparency for coherent diffractive di-jet production off nuclei. These events exhibit k_t dependence transitioning from non-perturbative to the perturbative regime. In addition, using the events from the platinum target, we have made the first direct measurement of valence quark distribution in the pion. This wave-function is consistent with dominance of asymptotic form for k_t above $\sim 1.5\ GeV/c$ ($Q^2 \sim 10\ GeV^2$).

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