Color Transparency and Pion Valence Quark Distributions from Di-Jet Events in Fermilab E791

Jeffrey A. Appel, Fermilab

For the Fermilab E791 Collaboration

ICHEP 2000 - PA-02 Soft Interaction Processes

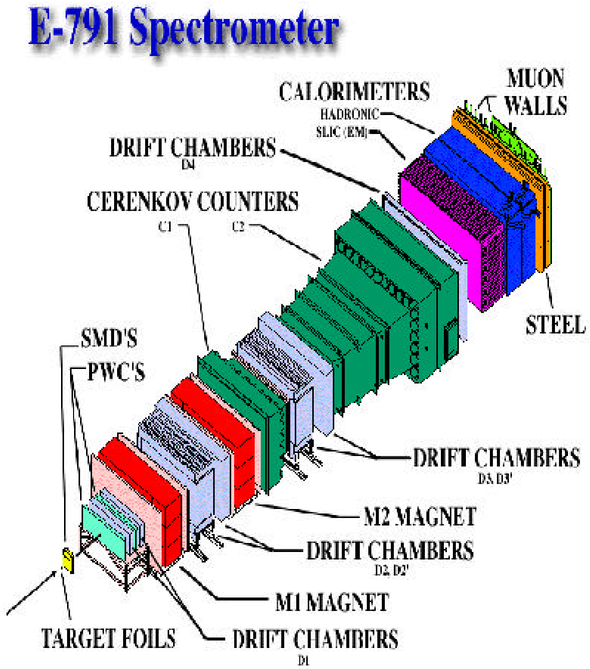
Osaka, Japan

July 29, 2000

Abstract

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.

Fermilab E791 Apparatus



Fermilab E791 Collaboration

CBPF, Rio de Janeiro, Brazil
University of California – Santa Cruz
University of Cincinnati
CINVESTAV, Mexico
Fermilab
Illinois Institute of Technology
Kansas State University
University of Massassachusetts
University of Mississippi – Oxford
Universidad Autonoma de Puebla
University of South Carolina
Stanford University
Tel Aviv University
Tufts University
University of Wisconsin
Yale University

On-Line Trigger and Data Set

Loose on-line trigger requirements:

Minimum transverse energy (~ 3 GeV) in calorimeters

Single incident pion

Recorded 2 x 10^{10} events (50 Terabytes on 20,000 8 mm tapes).

Off-line, event selection continued with a single pass through data.

Only 10% of the data was examined for the di-jet analysis presented here.

Di-Jet Event Selection – Off-Line

Almost all momentum carried by charged particles (> 90% of beam).

Total charge equal to beam charge ($\Sigma Q = -1$).

Interaction clearly originated in one of the five targets (1 Pt, 4 C).

Exclusively two jets in the event, with jets defined using the JADE algorithm (definition optimized for di-jet event finding).

Minimum jet transverse momentum (clear jet separation) > 1.25 GeV/*c*.

Two jets required to be back-to-back within 20^{o} in transverse plane.

Pion Wave Function

Expansion in terms of Fock states:

Ψ = | q anti-q > + | q anti-q g > + | q anti-q g g > + …

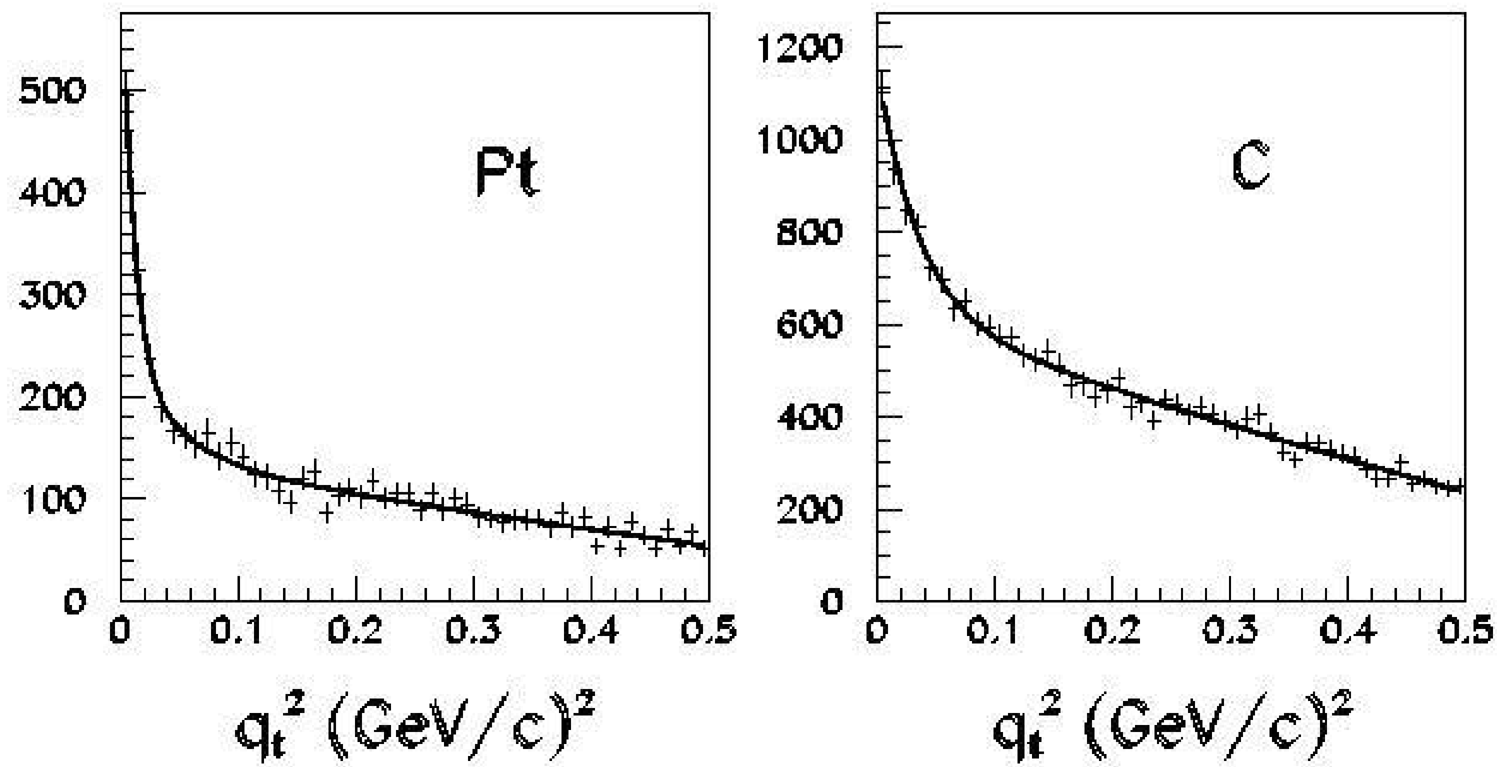
Valence component |q anti-q > dominant at high Q^2.

Other terms suppressed by powers of $1/Q^2$ for each additional parton.

Selection of scattering events due to coherent exclusive production of di-jets off nuclei allows us to focus on the valence component of the above expansion, and ask if that component approaches point-like configuration as predicted.

Scattering from Pt and C

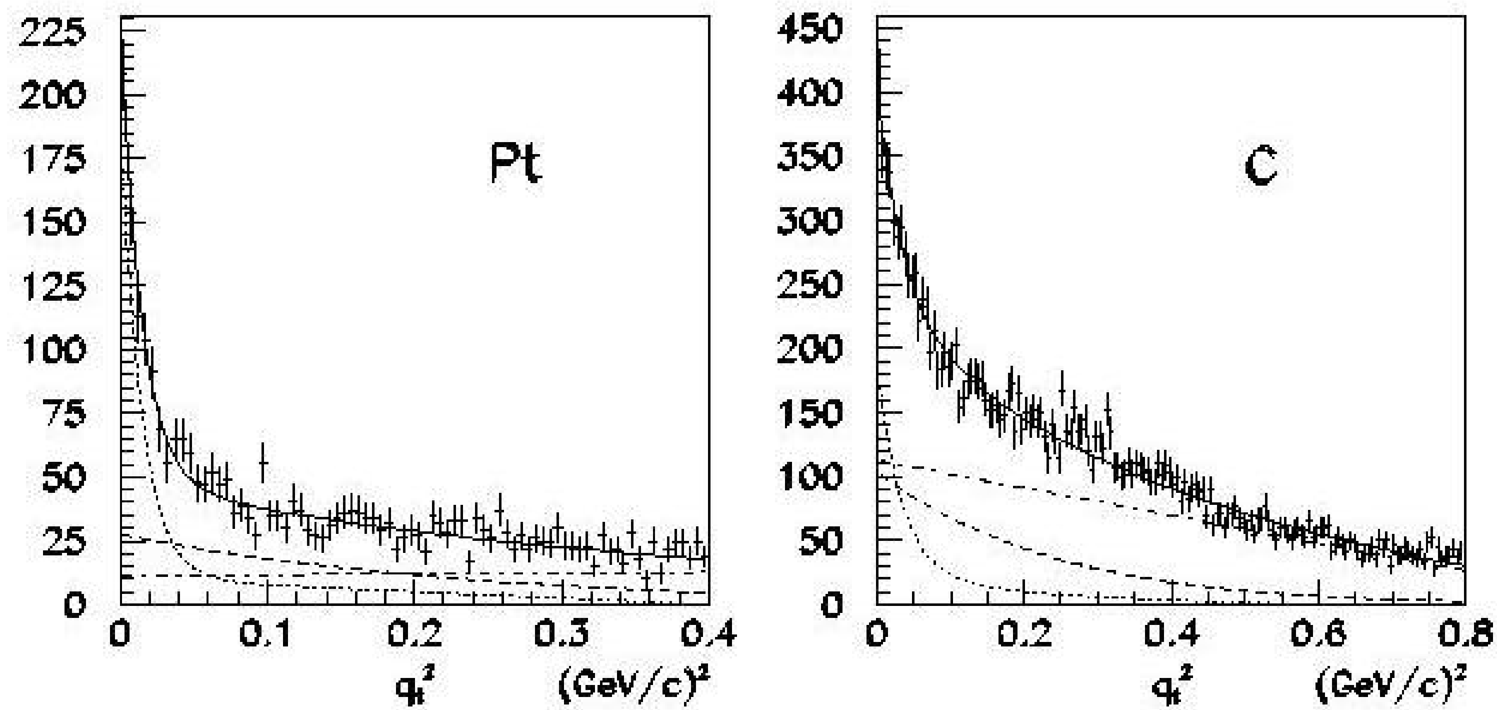
500 GeV/*c* π^- incident, jet transversed momentum > 1.25 GeV/*c*



Each coherent peak ~ e^{-bt} with b ~ square of the nuclear radius

$$q_t^2 = - t + t_{min}$$

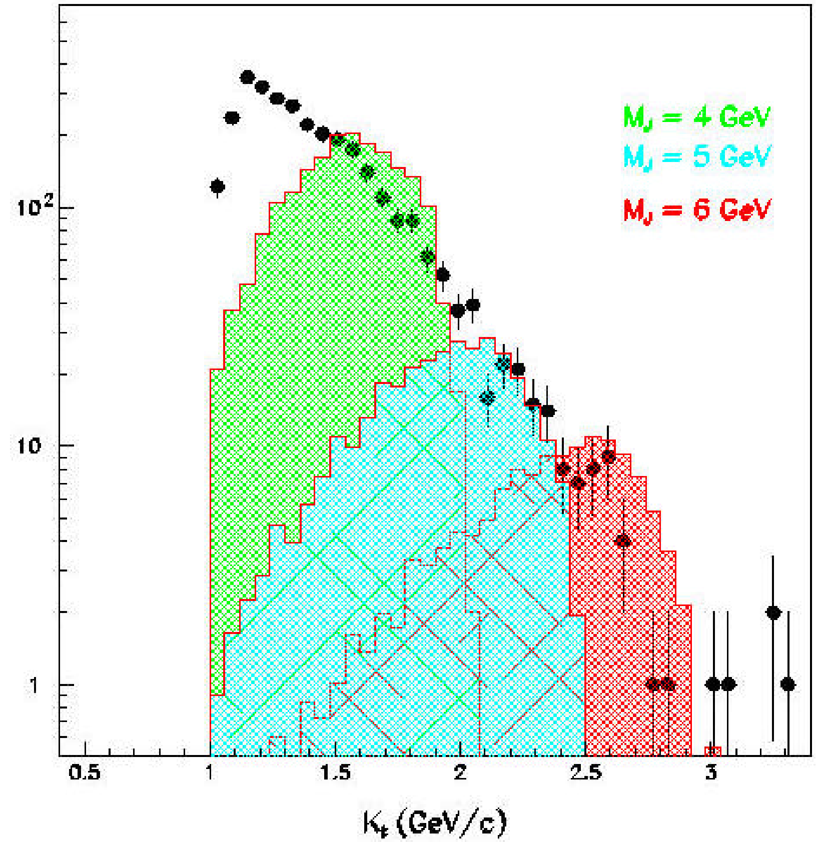
Coherent Scattering Contribution



Example of k_t bin 1.5 - 2.0 GeV/*c*. Shapes for coherent peak and incoherent nucleon scattering from MC simulation of detector.

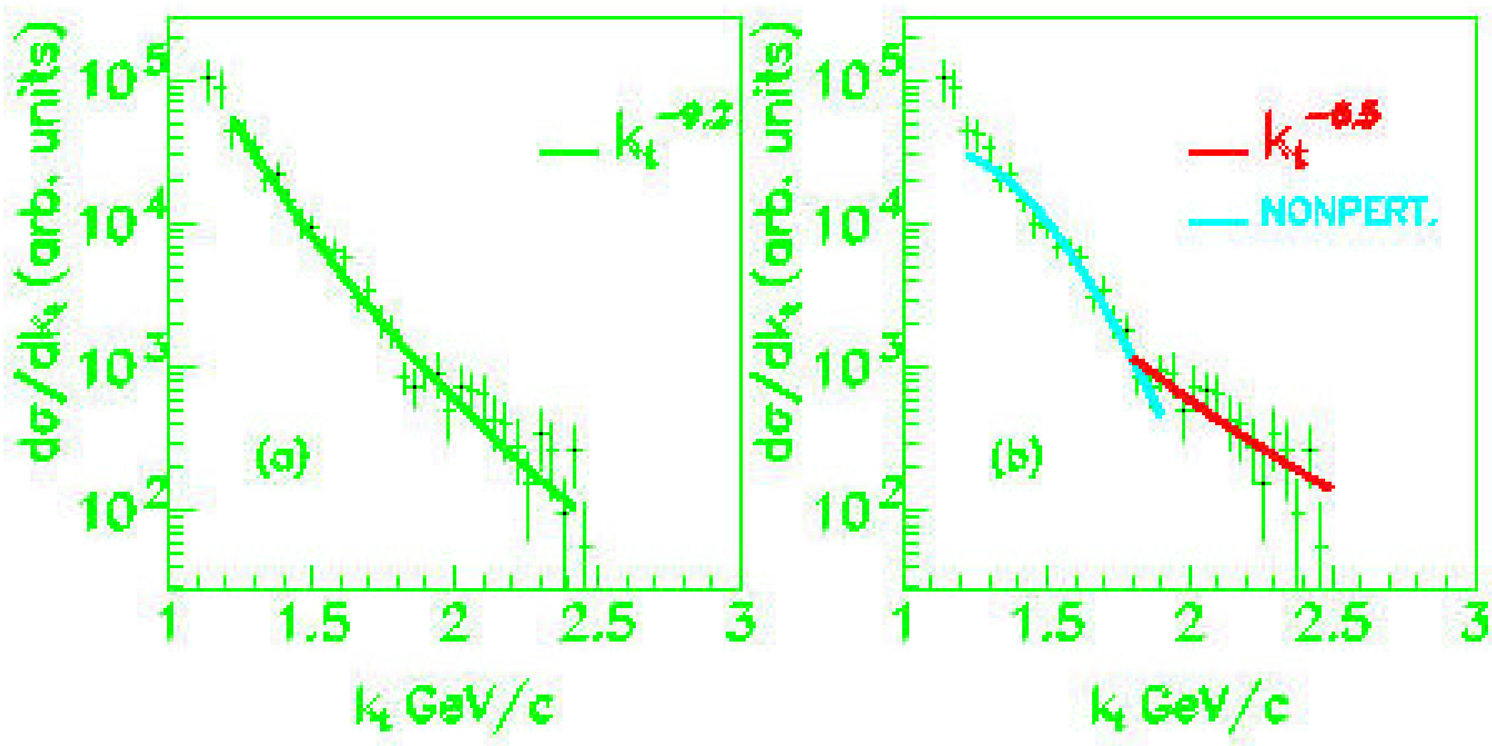
Di-Jet Effective Mass

$$M_{di\text{-}jet}^2 = k_t^2/[x(1-x)]$$



3 different MC samples (varied di-jet masses) used to study model sensitivity – combined as a model for the final result

Diffractive Di-Jets vs k_t



Perturbative expectation: $d\sigma/dk_t \sim k_t^{-6}$. Fit gives $k_t^{(-9.2 \pm 0.4 \pm 0.3)}$ with $\chi^2/\text{dof} = 1.0$,

and $k_t^{(-6.5 \pm 2.0)}$ for k_t above 1.8 GeV/*c* with $\chi^2/\text{dof} = 0.8$.

Nonperturbative fit $\sim (k_t^2 - 2\beta k_t^4 + \beta^2 k_t^6)\exp(-2\beta k_t^2)$ below k_t = 1.8 GeV/*c* gives

$\beta = 1.78 \pm 0.05(\text{stat.}) \pm 0.10(\text{sys})$ with $\chi^2/\text{dof} = 1.1$

Di-Jet Production k_t Predictions

For q anti-q component of pion interacting with two gluons from the target, Frankfurt, Miller, and Strikman (Phys. Lett. **B304**, 1, 1999) predicted:

$$d\sigma/dk_t^2 \sim |\, \alpha_s(k_t^2)\, x_{Bj}\, G(x_{Bj}, k_t^2)\,|^2 \;\; |\, d^2/dk_t^2\, \psi(x, k_t^2)\,|^2 \qquad (1)$$

where ψ is the light-cone wave function of the pion.

At large k_t,

$$\psi \sim \phi / k_t^2 \qquad (2)$$

with ϕ a slow function of k_t. (e.g., the asymptotic wave function – see later in talk), and given the weak k_t dependence of α_s and that

$$\alpha_s(k_t^2)\;\; G(x_{Bj}, k_t^2) \sim k_t^{1/2} \qquad (3)$$

then

$$d\sigma/dk_t \sim k_t^{-6} \qquad (4)$$

For the lower k_t region,

$$\psi \sim \exp(-\beta k_t^2) \qquad (5)$$

And using (1) and (3), we get:

$$d\sigma/dk_t \sim (k_t^2 - 2\,\beta\, k_t^4 + \beta^2\, k_t^6)\, \exp(-2\beta k_t^2) \qquad (6)$$

A-Dependence

A^{α} for $d\sigma/dt$ predicted to be A^2 at $t = 0$ and infinite energy.

Corresponds to $\sigma \sim A^{4/3}$ for $\langle R \rangle \sim A^{1/3}$, $\sim A^{1.45}$ for

$\langle R_{Pt} \rangle = 5.27$ fm and $\langle R_C \rangle = 2.44$ fm.

Measured alpha values for σ come from correction of data to

infinite energy via t_{min} correction.

k_t Bin (GeV/*c*)	α	C-T predicted α
1.25 – 1.50	$1.64 \pm 0.05^{+0.06}_{-0.12}$	1.25
1.50 – 2.00	$1.52 \pm 0.09 \pm 0.12$	1.45
2.00 – 2.50	$1.55 \pm 0.11 \pm 0.16$	1.65

Systematic errors dominated by di-jet mass model and acceptance sensitivity to possibly different C and Pt di-jet mass distributions.

Return to Pion Wave Function

Expansion in terms of Fock states:

$\Psi = |\, q \text{ anti-}q > \; + \; |\, q \text{ anti-}q \;\; g > \; + \; |\, q \text{ anti-}q \;\; g\, g > \; + \; \ldots$

Perturbative QCD prediction for asymptotic (large Q^2)[1-3]:

$\phi_{asy}(x) = \sqrt{3}\, x\, (\, 1 - x\,)$ and

from QCD sum rules, at low Q^2 Chernyak and Zhitnitsky proposed[4]:

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

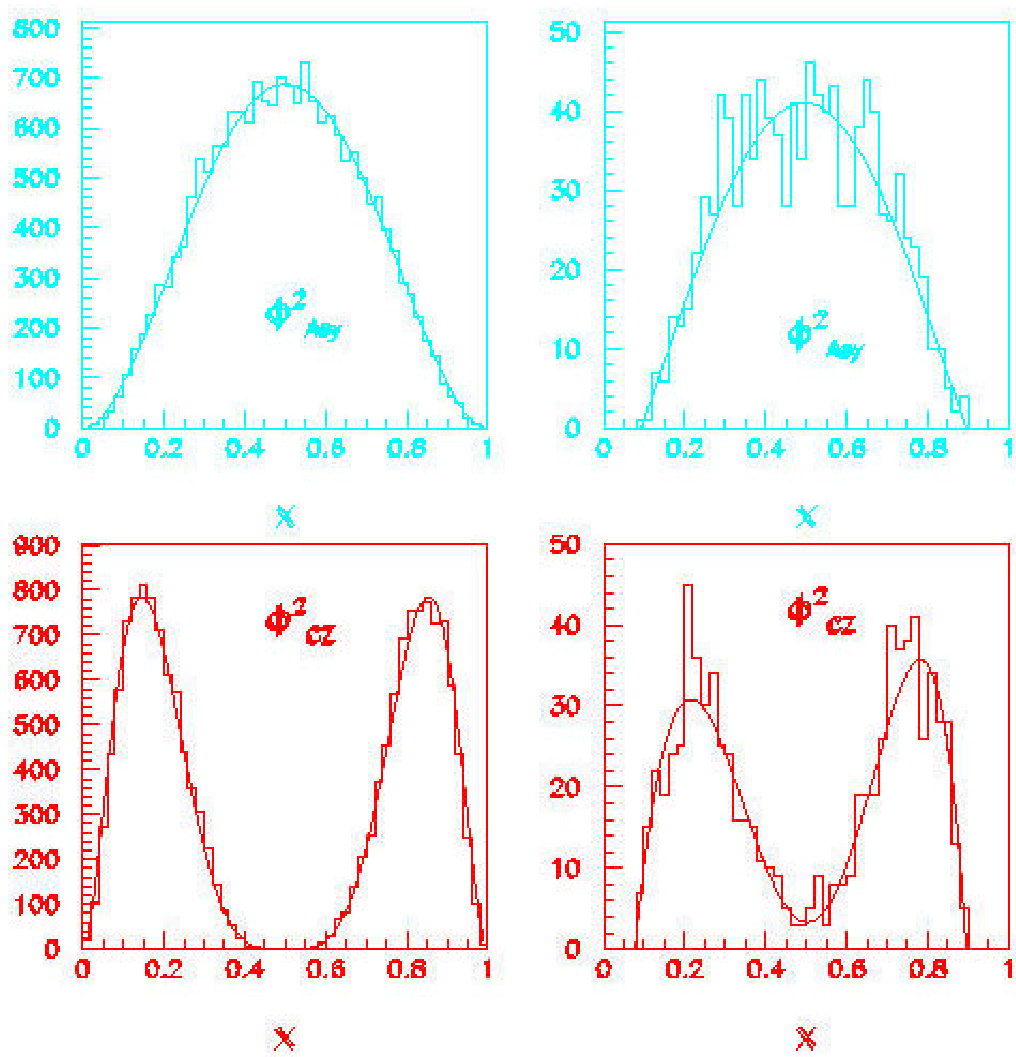
where x is the usual fractional momentum carried by the quark. In the measurements, we use $x = p_{jet1}/(p_{jet1} + p_{jet2})$ and MC modeling.

1. S.J. Brodsky and G.P. Lepage, Phys. Rev. D22, 2157 (1980).
2. A.V. Efremov and A.D. Radyushkin, Theor. Math. Phys. **42**, 97 (1980)
3. G. Bertsch, S.J. Brodsky, A.S. Goldhaber, and J. Gunion, Phys. Rev. Lett. **47**, 297 (1981).
4. V.L. Cernyak and A.R. Zhitnitsky, Phys. Rep. **112**, 173 (1984).

Two Predictions for Wave Function

Asymptotic

High Q^2 Limit



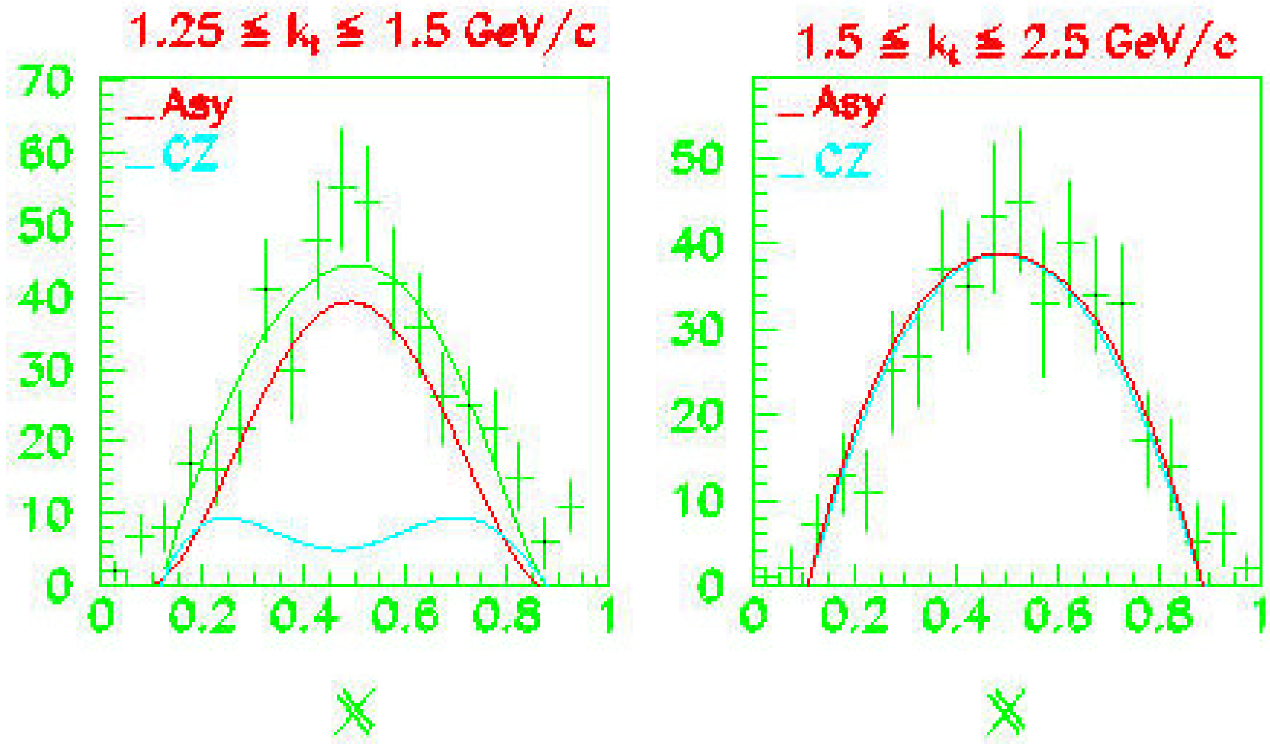
Cernyak-Zhitnitsky

Low Q^2 Limit

Quark Level

Detected Di-Jets

Fits to x Distributions in Two k_t Bins



k_t Bin (GeV/*c*)	Fraction Asy.	Fraction CZ
1.25 – 1.50	$0.64 \pm 0.12\ ^{+0.07}_{-0.01}$	$0.36 \pm 0.12\ ^{+0.01}_{-0.07}$
1.50 – 2.50	$1.00 \pm 0.10\ ^{+0.00}_{-0.10}$	$0.00 \pm 0.10\ ^{+0.10}_{-0.00}$

Summary

Observed pion scattering events which:

Exhibit A^{α} dependence consistent with color transparency for coherent diffractive di-jet production off nuclei.

Exhibit k_t dependence transitioning from non-perturbative to perturbative regimes.

Allow first direct measurement of valence quark distribution in pion, which is consistent with dominance of asymptotic form for k_t above ~ 1.5 GeV/*c* (Q^2 ~ 10 GeV^2).

Acknowledgements

To S.J. Brodsky, L. Frankfurt, G.A. Miller, and M. Strikman for many fruitful discussions.

To the staffs of Fermilab and all the participating institutions for their assistance.

To the Brazilian Conselho Nacional de Desenvolvimento Científico e Technológio, the Mexican Consejo Nacional de Ciencia y Technologica, the Israeli Academy of Sciences and Humanities, the US Department of Energy, the US-Israel Binational Science Foundation, and the US National Science Foundation for support.