# Hadronic Form Factor in Space and Time-Like Regions

- The form factor in AdS/QCD is the overlap of the normalizable modes dual to the incoming and outgoing hadron $\Phi_I$ and $\Phi_F$ and the non-normalizable mode $J$, dual to the external source (hadron spin $\sigma$):

$$F(Q^2)_{I\to F} = R^{3+2\sigma}\int_0^\infty \frac{dz}{z^{3+2\sigma}}\, e^{(3+2\sigma)A(z)}\Phi_F(z)\, J(Q,z)\, \Phi_I(z)$$
$$\simeq R^{3+2\sigma}\int_0^{z_o} \frac{dz}{z^{3+2\sigma}}\, \Phi_F(z)\, J(Q,z)\, \Phi_I(z),$$

- $J(Q,z)$ has the limiting value 1 at zero momentum transfer, $F(0)=1$, and has as boundary limit the external current, $A^\mu = \epsilon^\mu e^{iQ\cdot x} J(Q,z)$. Thus:

$$\lim_{Q\to 0} J(Q,z) = \lim_{z\to 0} J(Q,z) = 1.$$

- Solution to the AdS Wave equation with boundary conditions at $Q=0$ and $z\to 0$:

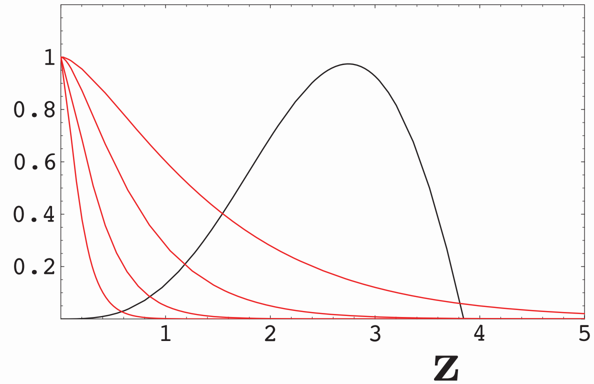
$$J(Q,z) = zQK_1(zQ).$$

Polchinski and Strassler, hep-th/0209211; Hong, Yong and Strassler, hep-th/0409118.

- Propagation of external perturbation suppressed inside AdS.

- At large enough $Q \sim r/R^2$, the interaction occurs in the large-$r$ conformal region. Important contribution to the FF integral from the boundary near $z \sim 1/Q$.

$$\mathbf{J}(\mathbf{Q}, \mathbf{z}), \quad \mathbf{\Phi}(\mathbf{z})$$

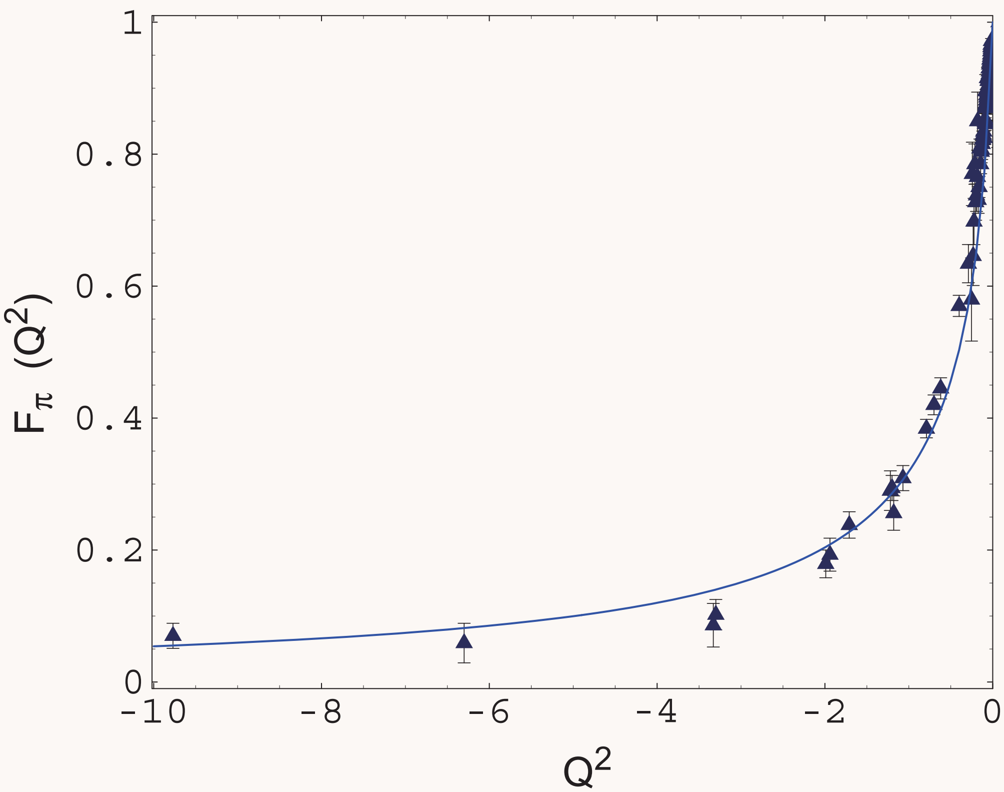



- Consider a specific AdS mode $\Phi^{(n)}$ dual to an $n$ partonic Fock state $|n\rangle$. At small $z$, $\Phi^{(n)}$ scales as $\Phi^{(n)} \sim z^{\Delta_n}$. Thus:

$$F(Q^2) \to \left[\frac{1}{Q^2}\right]^{\tau-1},$$

General result from AdS/CFT

where $\tau = \Delta_n - \sigma_n$, $\sigma_n = \sum_{i=1}^{n} \sigma_i$. The twist is equal to the number of partons, $\tau = n$.




Space-like pion form factor in holographic model for $\Lambda_{QCD} = 0.2$ GeV.

*No distinction between Feynman large-x and high transverse momenta regimes*

- Consider the spin non-flip form factors in the infinite wall approximation

$$
\begin{aligned}
F_+(Q^2) &= g_+ R^3 \int \frac{dz}{z^3}\, J(Q,z)\, |\psi_+(z)|^2, \\
F_-(Q^2) &= g_- R^3 \int \frac{dz}{z^3}\, J(Q,z)\, |\psi_-(z)|^2,
\end{aligned}
$$

where the effective charges $g_+$ and $g_-$ are determined from the spin-flavor structure of the theory.

- Choose the struck quark to have $S^z = +1/2$. The two AdS solutions $\psi_+(z)$ and $\psi_-(z)$ correspond to nucleons with $J^z = +1/2$ and $-1/2$.

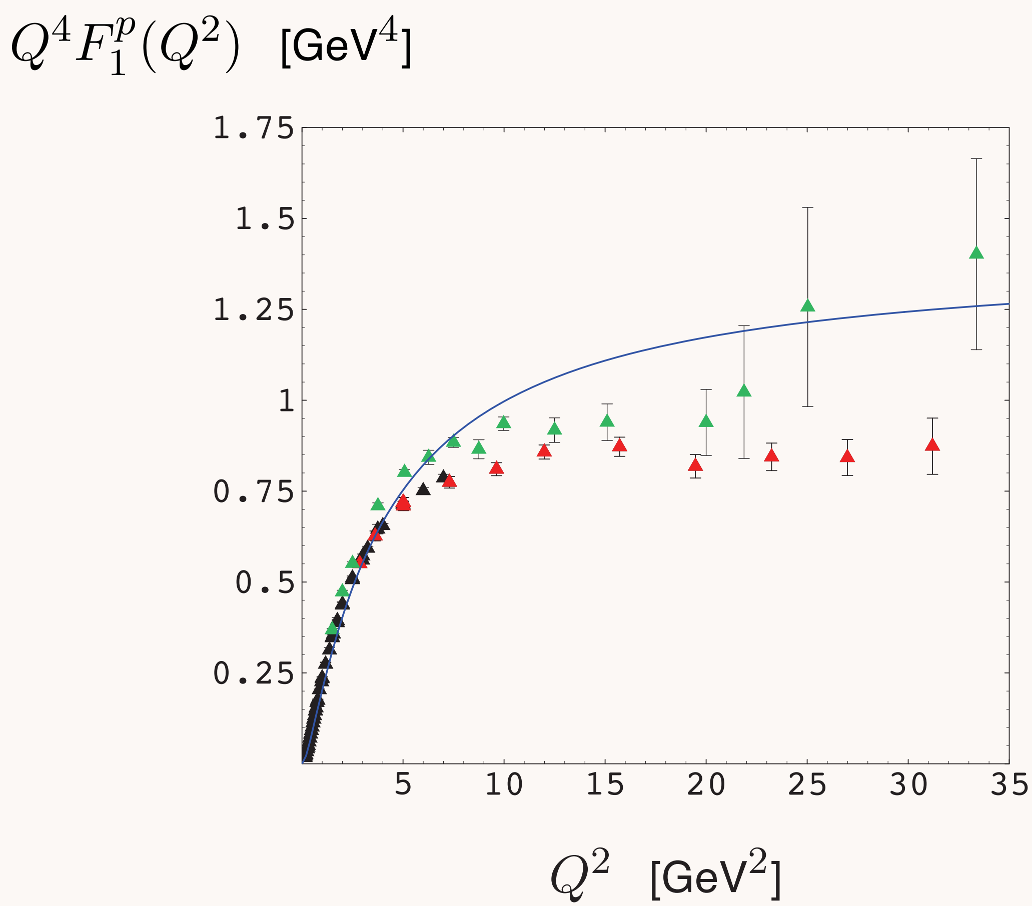
- For $SU(6)$ spin-flavor symmetry

$$
\begin{aligned}
F_1^p(Q^2) &= R^3 \int \frac{dz}{z^3}\, J(Q,z) |\psi_+(z)|^2, \\
F_1^n(Q^2) &= -\frac{1}{3} R^3 \int \frac{dz}{z^3}\, J(Q,z)\, \left[|\psi_+(z)|^2 - |\psi_-(z)|^2\right],
\end{aligned}
$$

where $F_1^p(0) = 1,\; F_1^n(0) = 0$.

- Large $Q$ power scaling: $F_1(Q^2) \to \left[1/Q^2\right]^2$.

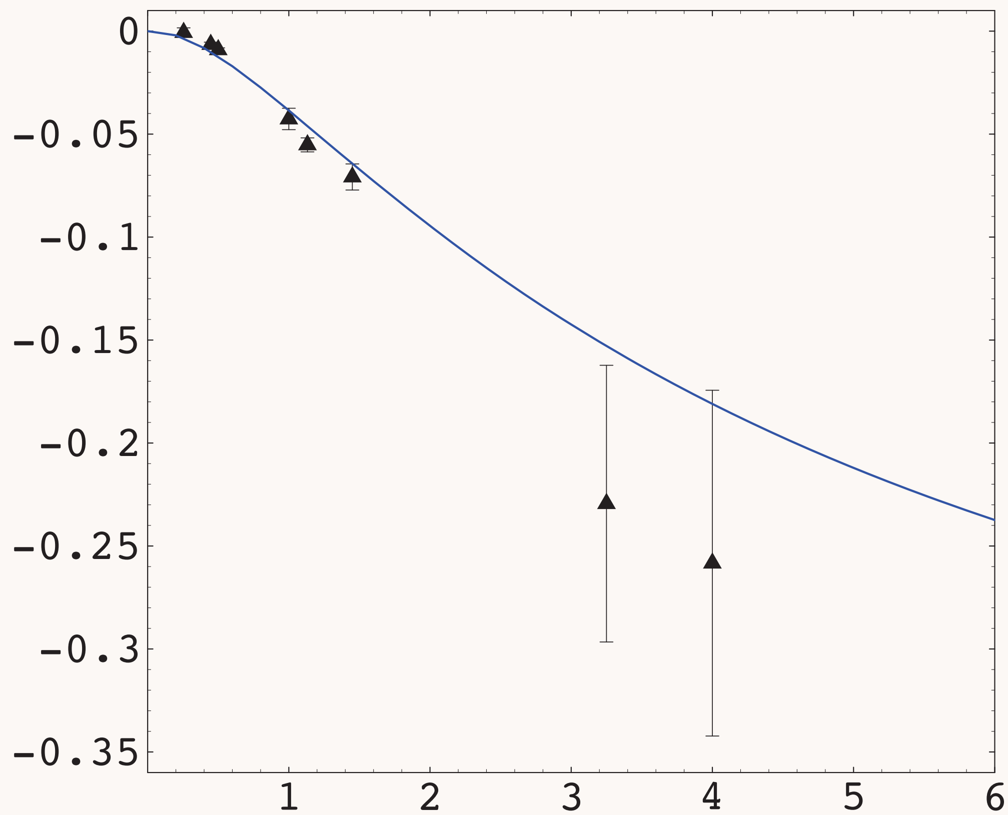
## Dirac Proton Form Factor $F_1^p$




Prediction for $Q^4 F_1^p(Q^2)$ for $\Lambda_{\rm QCD} = 0.21$ GeV in the infinite wall approximation
from Kirk (superimposed green points assuming $G_E^p = G_M^p$): P. N. Kirk *et al.*, Phys. Rev. D **8** (1973) 63.

$Q^4 F_1^n(Q^2)$ [GeV$^4$]

Dirac Neutron Form Factor $F_1^n$




$Q^2$ [GeV$^2$]

Prediction for $Q^4 F_1^n(Q^2)$ for $\Lambda_{QCD} = 0.21$ GeV in the infinite wall approximation.

# Drell-Yan West formula for Form Factor of meson

$$F(q^2) = \sum_q e_q \int_0^1 dx \int \frac{d^2\vec{k}_\perp}{16\pi^3} \; \psi^*_{P'}(x, \vec{k}_\perp + (1-x)\vec{q}_\perp) \; \psi_P(x, \vec{k}_\perp).$$

## In Impact Space:

$$F(q^2) = 4\pi \int_0^1 dx \int \; d^2\vec{b}_\perp \; e^{i\vec{b}_\perp \cdot \vec{q}_\perp} \left|\widetilde{\psi}(x,b)\right|^2$$

$$= 8\pi^2 \int_0^1 dx \int_0^\infty b \; db \; J_0\left(bqx\right) \; \left|\widetilde{\psi}(x,b)\right|^2,$$

For a two-parton state, the light-front wave function is effectively cutoff at

$$\vec{b}_\perp^2 \simeq \frac{1}{x(1-x)\Lambda^2_{\rm QCD}},$$

## Change Integration variable to: $\zeta = |\vec{b}_\perp|\sqrt{x(1-x)}$

$$F_{IS}(Q^2) = 8\pi^2 \int_0^1 \frac{dx}{x(1-x)} \int_0^{\Lambda^{-1}_{\rm QCD}} \zeta \; d\zeta \; J_0\left(\frac{\zeta Q x}{\sqrt{x(1-x)}}\right) \; \left|\widetilde{\psi}(x,\zeta)\right|^2,$$

- Change the integration variable $\zeta = |\vec{b}_\perp|\sqrt{x(1-x)}$

$$F(Q^2) = 2\pi \int_0^1 \frac{dx}{x(1-x)} \int_0^{\zeta_{max}=\Lambda^{-1}_{\rm QCD}} \zeta \, d\zeta \, J_0\left(\frac{\zeta Q x}{\sqrt{x(1-x)}}\right) \left|\widetilde{\psi}(x,\zeta)\right|^2,$$

- Compare with AdS form factor for arbitrary $Q$. Find:

$$J(Q,\zeta) = \int_0^1 dx J_0\left(\frac{\zeta Q x}{\sqrt{x(1-x)}}\right) = \zeta Q K_1(\zeta Q),$$

the solution for the electromagnetic potential in AdS space, and

*Recover AdS/CFT formula !*

$$\boxed{\widetilde{\psi}(x,\vec{b}_\perp) = \frac{\Lambda_{\rm QCD}}{\sqrt{\pi} J_1(\beta_{0,1})} \sqrt{x(1-x)} J_0\left(\sqrt{x(1-x)}|\vec{b}_\perp|\beta_{0,1}\Lambda_{QCD}\right) \theta\left(\vec{b}_\perp^{\,2} \le \frac{\Lambda^{-2}_{\rm QCD}}{x(1-x)}\right)}$$

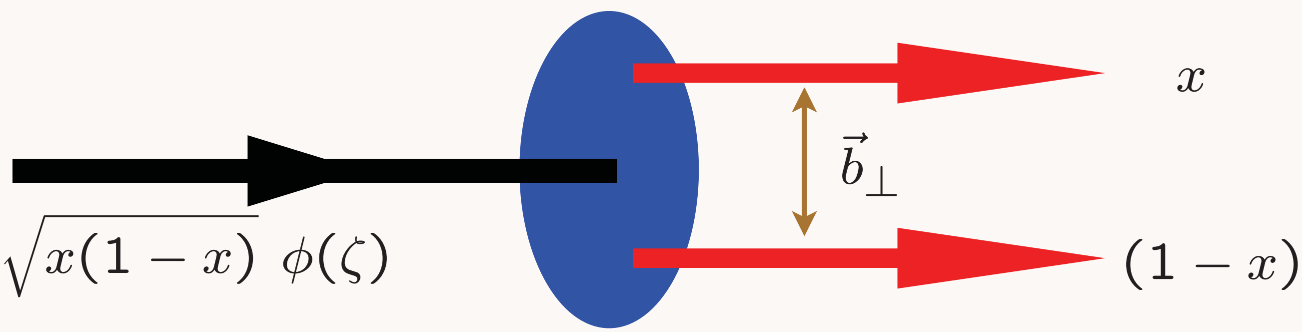
the holographic LFWF for the valence Fock state of the pion $\psi_{\overline{q}q/\pi}$.

- The variable $\zeta$, $0 \le \zeta \le \Lambda^{-1}_{QCD}$, represents the scale of the invariant separation between quarks and is also the holographic coordinate $\zeta = z$ !

Similar in form to Radyushkin model

# Mapping between LF(3+1) and AdS$_5$

| LF(3+1) | | AdS$_5$ |
| --- | --- | --- |
| $\psi(x, \vec{b}_\perp)$ | $\Longleftrightarrow$ | $\phi(z)$ |
| $\zeta = \sqrt{x(1-x)\vec{b}_\perp^2}$ | $\Longleftrightarrow$ | $z$ |




$$\psi(x, \vec{b}_\perp) = \sqrt{x(1-x)}\ \phi(\zeta)$$

# AdS/CFT and Light-Front Wavefunctions

- Light-Front Wavefunctions can be determined by matching functional dependence in fifth dimension to scaling in impact space.

$$\left[z^2\,\partial_z^2 - (d-1)z\,\partial_z + z^2\,\mathcal{M}^2 - (\mu R)^2\right] f(z) = 0,$$

$$z \to \zeta = b\sqrt{x(1-x)}$$

de Teramond and sjb

- High transverse momentum behavior matches (mod logs) PQCD LFWF with orbital: Belitsky, Ji, Yuan

- Perfect match of LF and AdS/CFT formulae for form factors

G. de Teramond and sjb

# Map AdS/CFT to 3+1 LF Theory

Effective radial equation:

$$\left[-\frac{d^2}{d\zeta^2} + V(\zeta)\right]\phi(\zeta) = \mathcal{M}^2\phi(\zeta)$$

$$\zeta^2 = x(1-x)\mathbf{b}_\perp^2.$$

Effective conformal potential:

$$V(\zeta) = -\frac{1-4L^2}{4\zeta^2}.$$

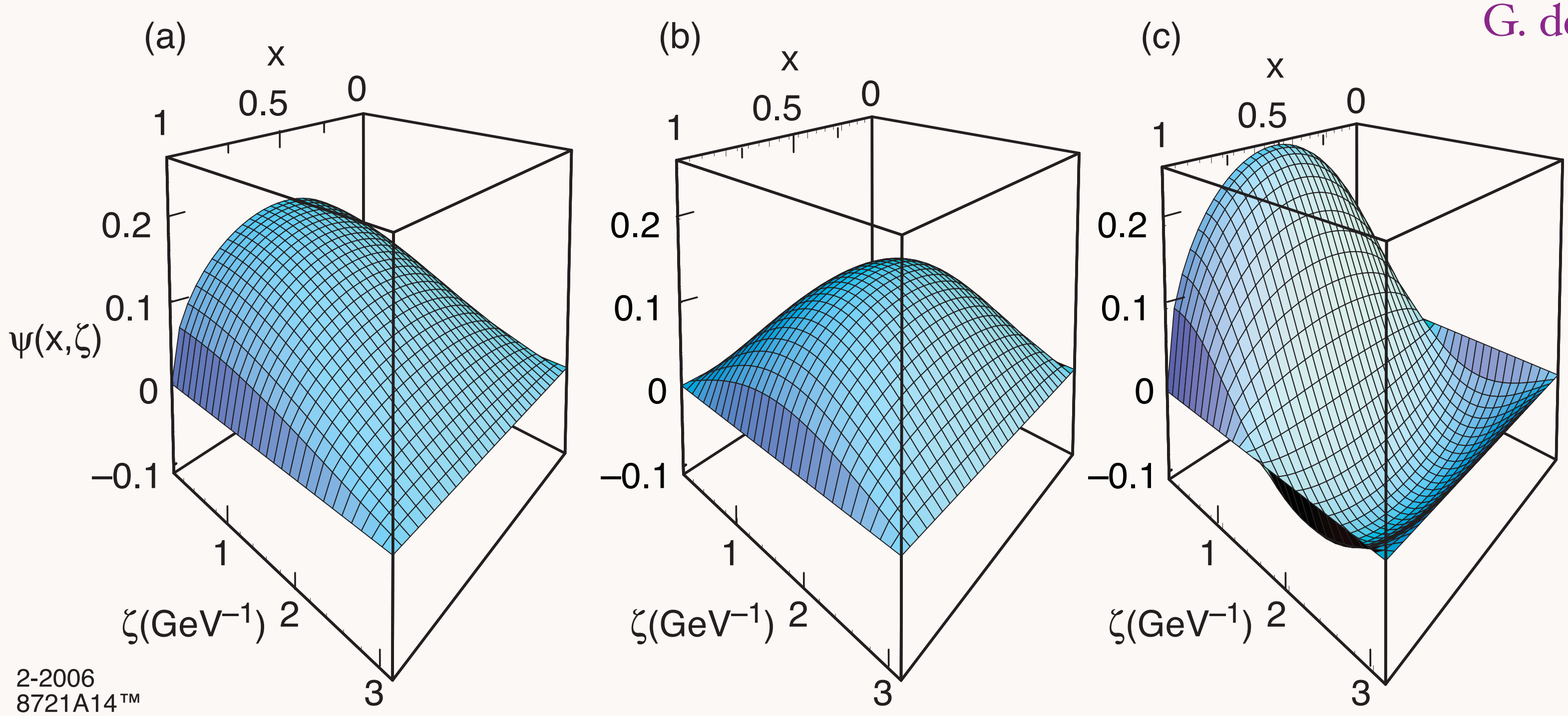
General solution:

$$\widetilde{\psi}_{L,k}(x,\vec{b}_\perp) = B_{L,k}\sqrt{x(1-x)}$$

$$\mathbf{X} \quad J_L\left(\sqrt{x(1-x)}|\vec{b}_\perp|\beta_{L,k}\Lambda_{QCD}\right)\theta\left(\vec{b}_\perp^{\,2} \le \frac{\Lambda_{QCD}^{-2}}{x(1-x)}\right),$$

# AdS/CFT Prediction for Meson LFWF

G. de Teramond
SJB



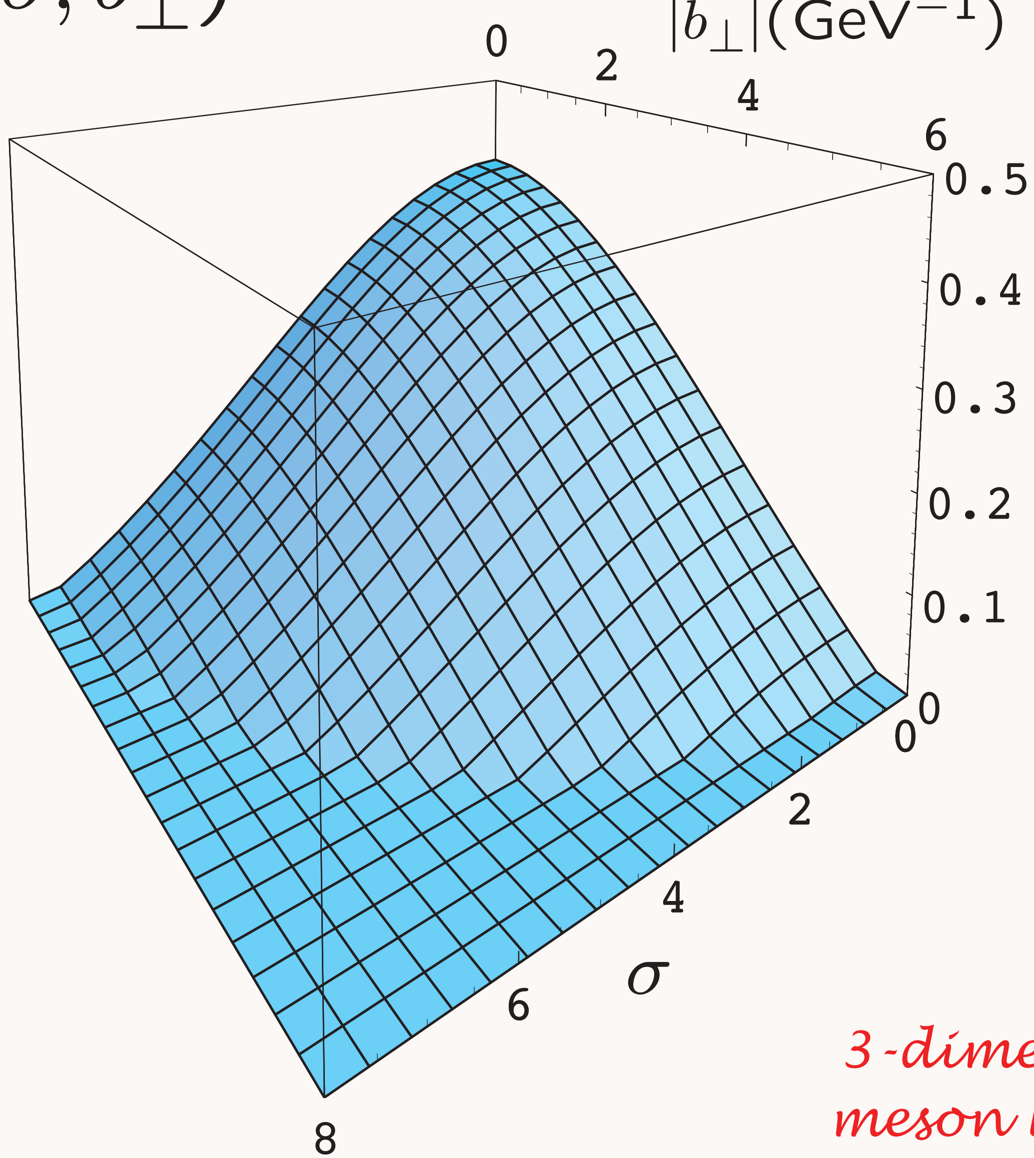

Two-parton holographic LFWF in impact space $\widetilde{\psi}(x,\zeta)$ for $\Lambda_{QCD} = 0.32$ GeV: (a) ground state $L=0,\ k=1$; (b) first orbital exited state $L=1,\ k=1$; (c) first radial exited state $L=0,\ k=2$. The variable $\zeta$ is the holographic variable $z=\zeta=|b_\perp|\sqrt{x(1-x)}$.

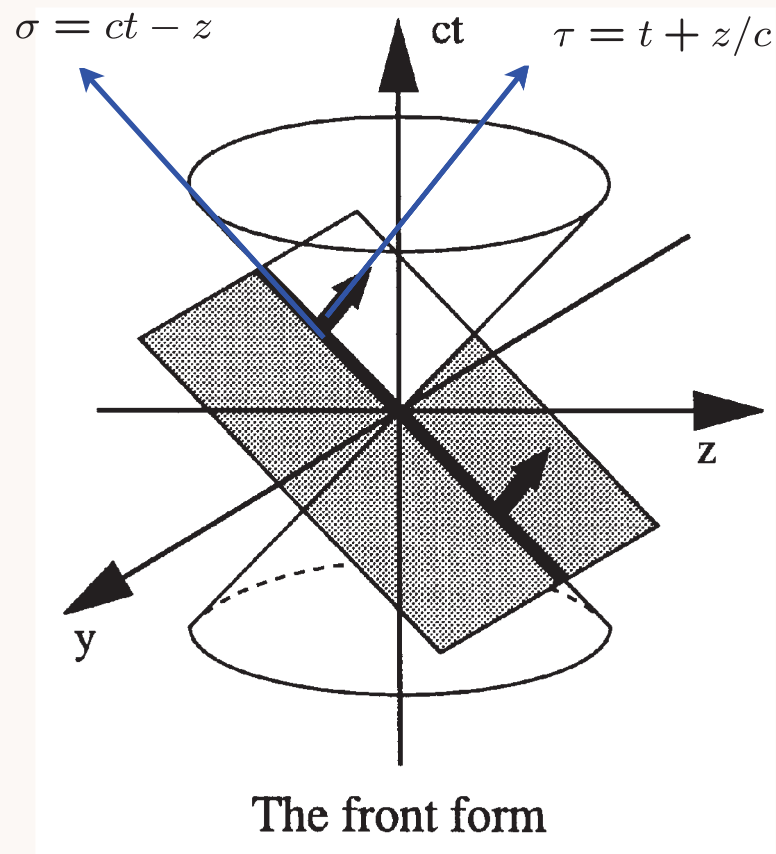
$$\widetilde{\psi}(x,\zeta) = \frac{\Lambda_{\rm QCD}}{\sqrt{\pi}J_1(\beta_{0,1})}\sqrt{x(1-x)}J_0\left(\zeta\beta_{0,1}\Lambda_{QCD}\right)\theta\left(z \le \Lambda^{-1}_{\rm QCD}\right)$$

# AdS/CFT Holographic Model

G. de Teramond
SJB

$\psi(\sigma, b_\perp)$




*3-dimensional photograph: meson LFWF at fixed LF Time*

# Evaluation of QCD Matrix Elements: Example $f_\pi$

- Pion decay constant defined by the matrix element of EW current $J_W^+$:

$$\left\langle 0 \left| \overline{\psi}_u \gamma^+ (1-\gamma_5) \psi_d \right| \pi^- \right\rangle = i\sqrt{2} P^+ f_\pi ,$$

with

$$\left| \pi^- \right\rangle = \left| d\overline{u} \right\rangle = \frac{1}{\sqrt{N_C}} \frac{1}{\sqrt{2}} \sum_{c=1}^{N_C} \left( b^\dagger_{c\, d\downarrow} d^\dagger_{c\, u\uparrow} - b^\dagger_{c\, d\uparrow} d^\dagger_{c\, u\downarrow} \right) \left| 0 \right\rangle .$$

- Use light-cone expression:

$$f_\pi = 2\sqrt{N_C} \int_0^1 dx \int \frac{d^2 \vec{k}_\perp}{16\pi^3} \, \psi_{\overline{q}q/\pi}(x, k_\perp) .$$

Lepage and Brodsky, Phys. Rev. D **22**, 2157 (1980)

- Find:

$$f_\pi = \frac{\sqrt{3}\Lambda_{\rm QCD}}{8 J_1(\beta_{0,1})} = 83.4 \,\text{Mev},$$

for $\Lambda_{\rm QCD} = 0.2$ GeV.

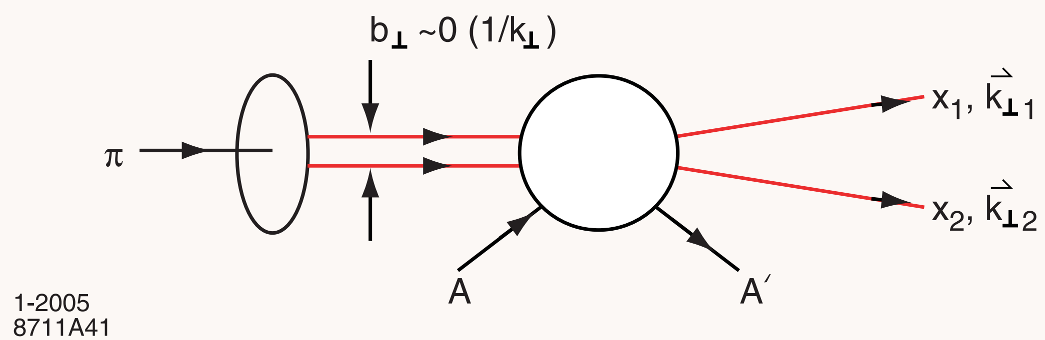
Experiment: $f_\pi = 92.4$ Mev.

# Use Diffraction to Resolve Hadron Substructure

- Measure Light-Front Wavefunctions
- Test AdS/CFT predictions
- Novel Aspects of Hadron Wavefunctions: Intrinsic Charm, Hidden Color, Color Transparency/Opaqueness
- Diffractive Di-Jet Production
- Nuclear Shadowing and Antishadowing
- New Mechanism for Higgs Production

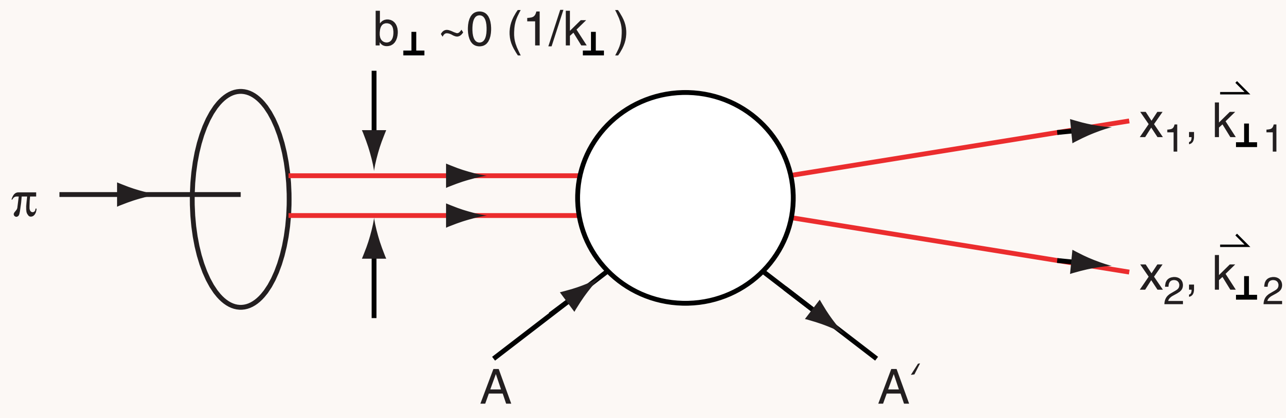
# Diffractive Dissociation of Pion

E791 Ashery et al.

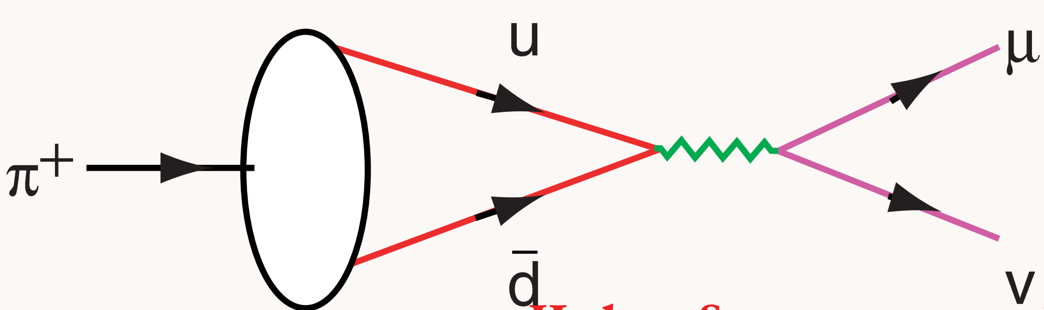



Measure Light-Front Wavefunction of Pion
Two-gluon Exchange
Minimal momentum transfer to nucleus
Nucleus left Intact

# Fluctuation of a Pion to a Compact Color Dipole State

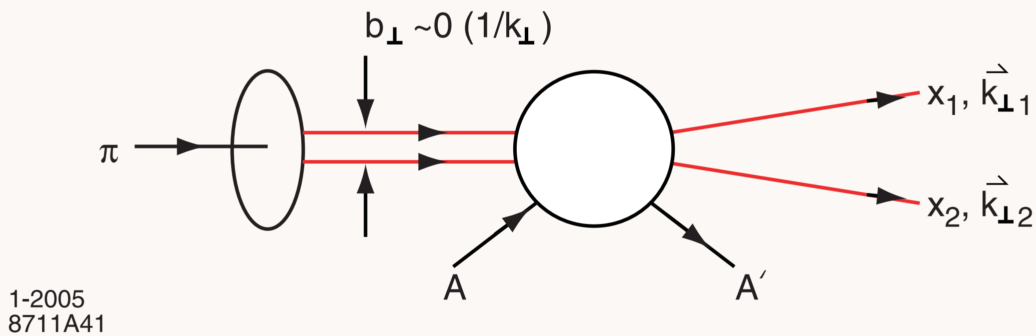



Color-Transparent Fock State For High Transverse Momentum Di-Jets




Same Fock State Determines Weak Decay

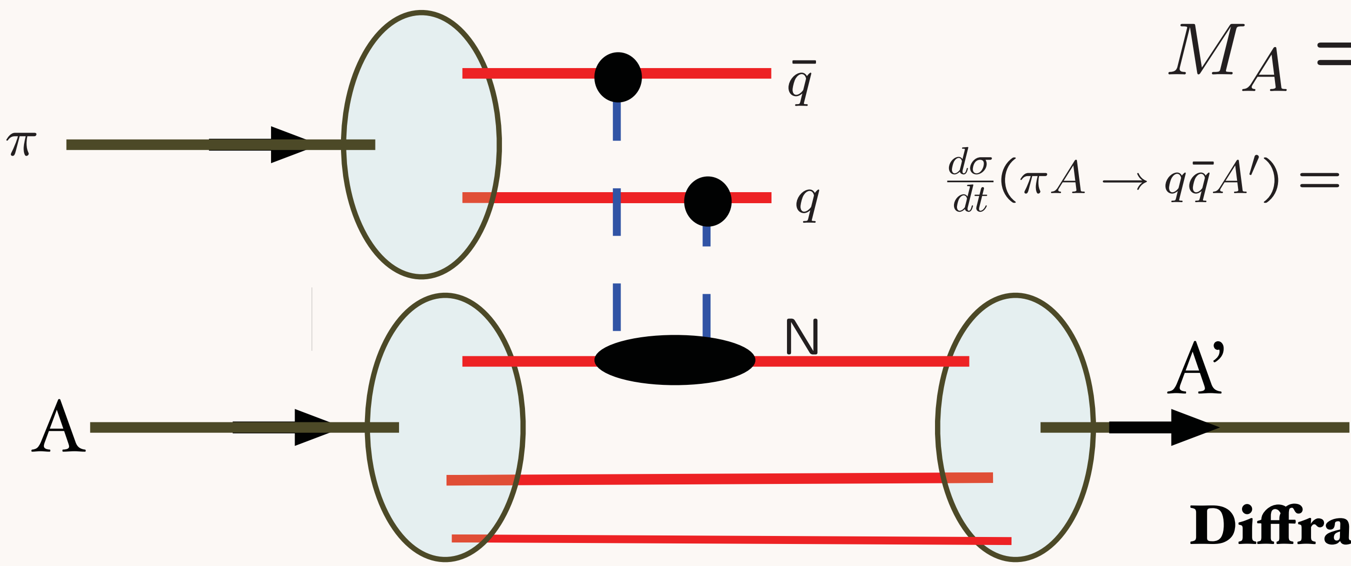
# Key Ingredients in Ashery Experiment




Brodsky Mueller Frankfurt Miller Strikman

*Small color-dipole moment pion not absorbed; interacts with each nucleon coherently*

*QCD COLOR Transparency*




$$M_A = A\ M_N$$

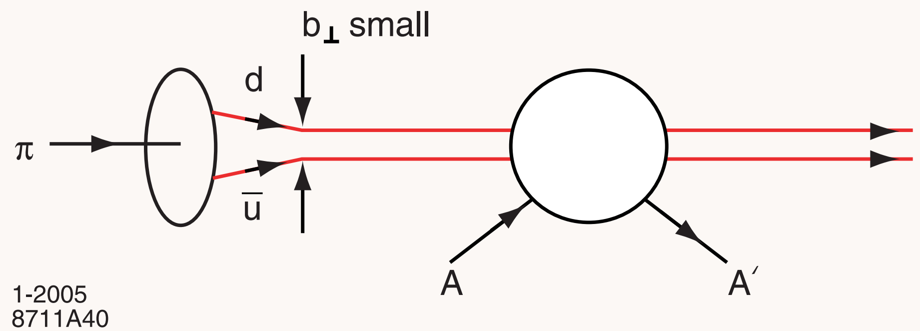
$$\frac{d\sigma}{dt}(\pi A \to q\bar{q}A') = A^2\ \frac{d\sigma}{dt}(\pi N \to q\bar{q}N')\ F^2_A(t)$$

**Target left intact**

**Diffraction, Rapidity gap**

# Fluctuation of a Pion to a Compact Color Dipole State

Small Size Pion Can Interact Coherently on Each Nucleon of Nucleus




Diffractive Dijet Cross Section Color Transparent

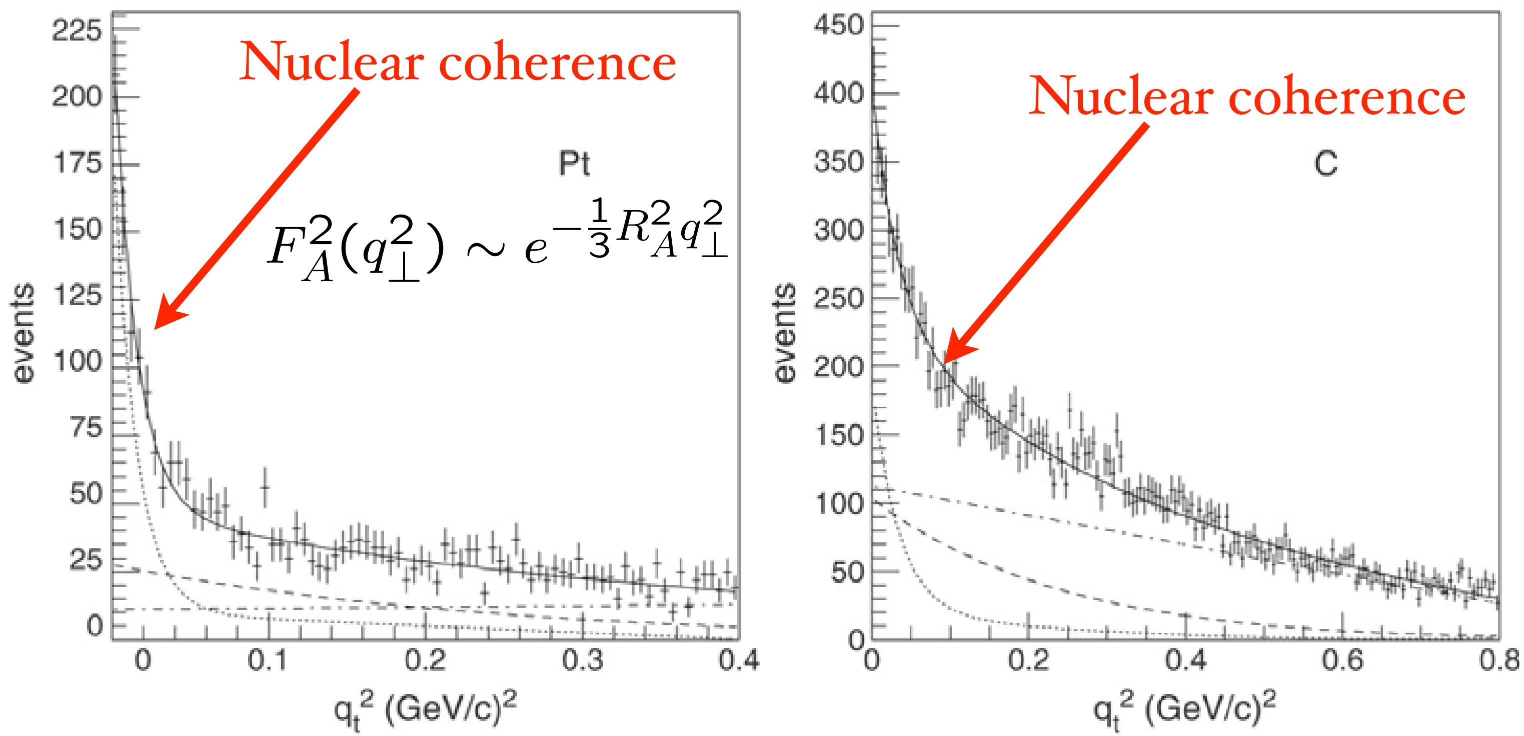
$$M(\pi A \to JetJetA') = A^1 M(\pi N \to JetJetN') F_A(t)$$
$$d\sigma/dt(\pi A \to JetJetA') =$$
$$A^2 d\sigma/dt(\pi N \to JetJetN') |F_A(t)|^2$$
$$\sigma \propto \frac{A^2}{R_A^2} \sim A^{4/3}$$

- **Fully coherent interactions between pion and nucleons.**
- **Emerging Di-Jets do not interact with nucleus.**

$$\mathcal{M}(\mathcal{A}) = \mathcal{A} \cdot \mathcal{M}(\mathcal{N})$$

$$\frac{d\sigma}{dq_t^2} \propto A^2 \quad q_t^2 \sim 0$$

$$\sigma \propto A^{4/3}$$



# Ashery E791:
# Measure pion LFWF in diffractive dijet production
# Confirms color transparency !

Mueller, sjb; Bertsch et al; Frankfurt, Miller, Strikman

A-Dependence results: $\sigma \propto A^{\alpha}$

| $k_t$ range (GeV/c) | $\alpha$ | $\alpha$ (CT) |
|---|---|---|
| $1.25 < k_t < 1.5$ | 1.64 +0.06 -0.12 | 1.25 |
| $1.5 < k_t < 2.0$ | $1.52 \pm 0.12$ | 1.45 |
| $2.0 < k_t < 2.5$ | $1.55 \pm 0.16$ | 1.60 |

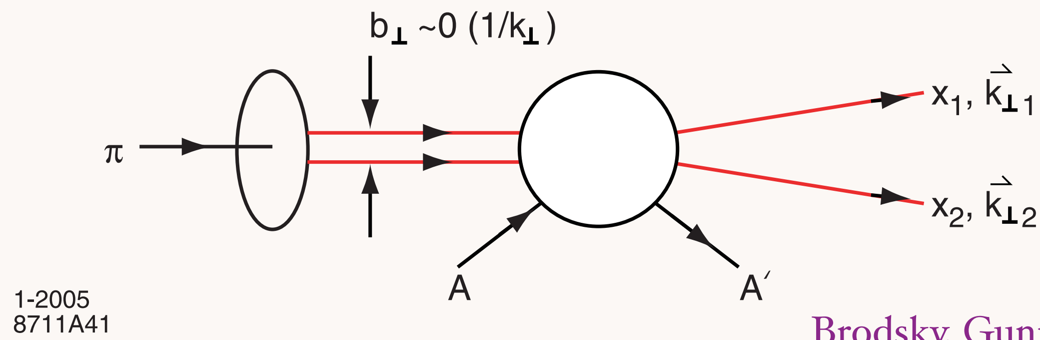
$\alpha$ (Incoh.) = $0.70 \pm 0.1$

Conventional Glauber Theory Ruled Out !

Factor of 7

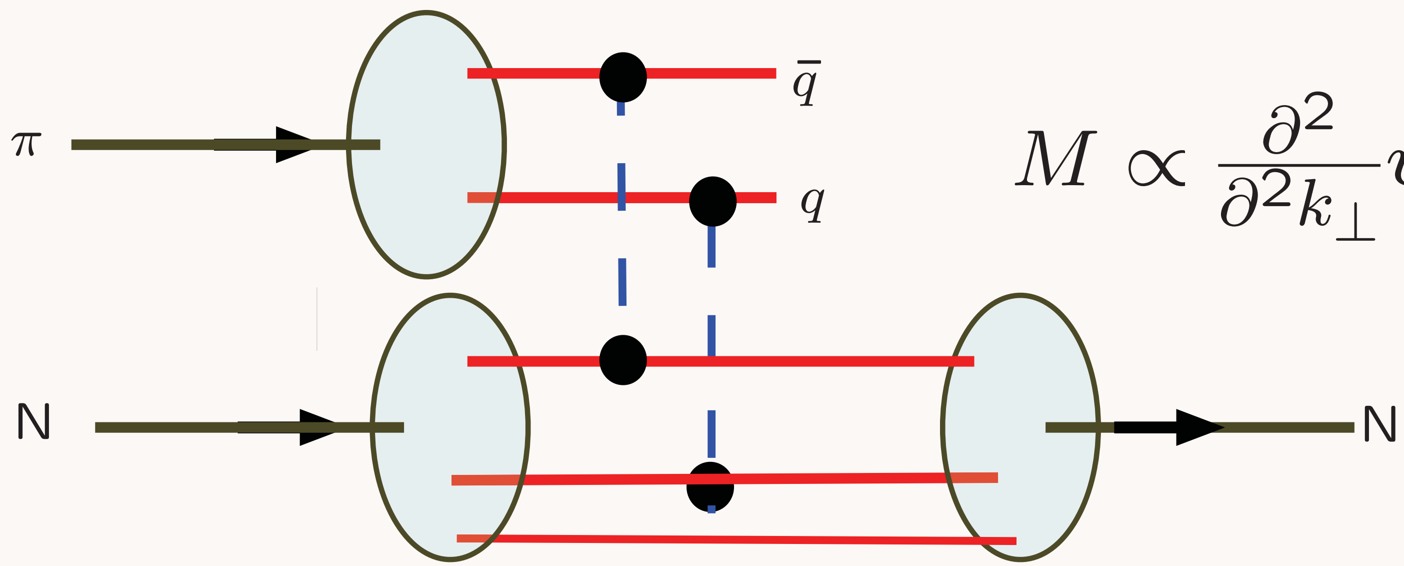
FermiLab E791
Ashery et al

# Key Ingredients in Ashery Experiment

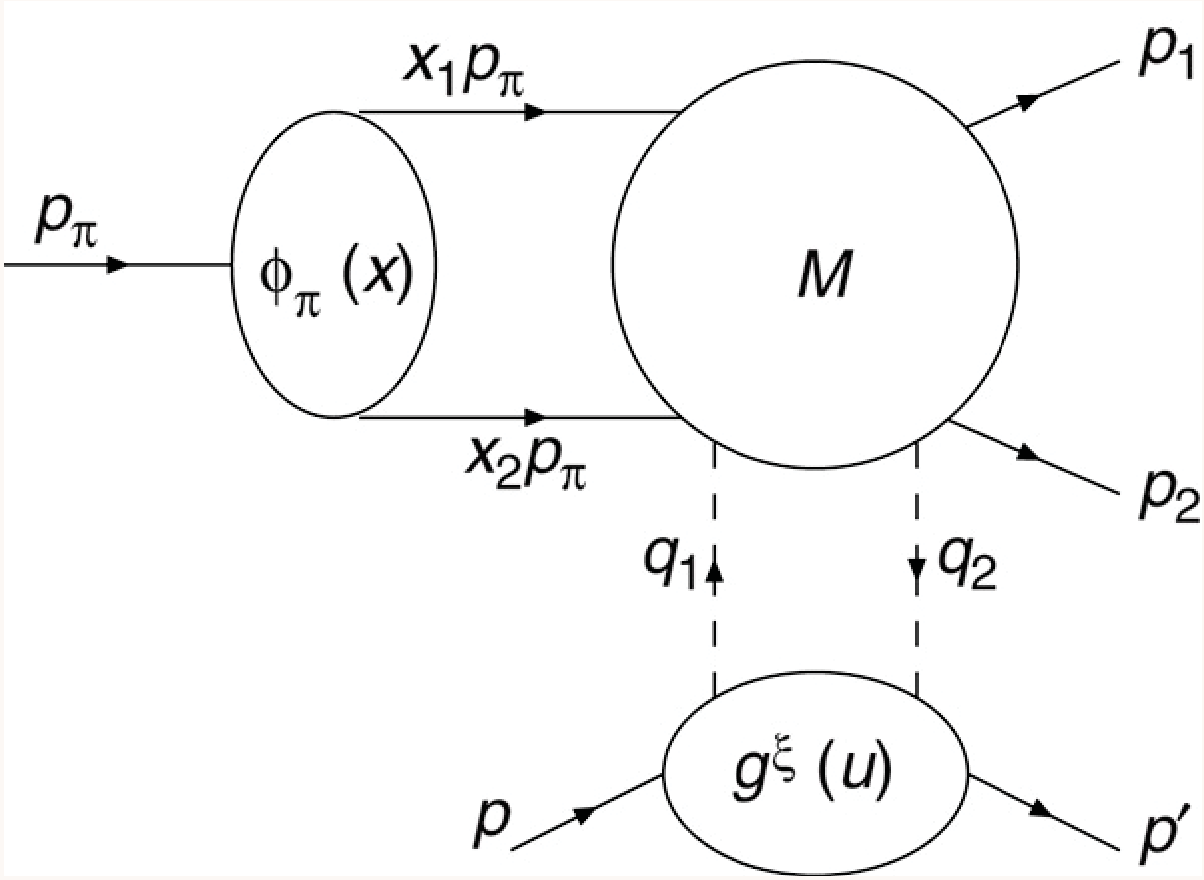



Brodsky, Gunion, Frankfurt, Mueller, Strikman
Frankfurt, Miller, Strikman

## Two-gluon exchange measures the second derivative of the pion light-front wavefunction




$$M \propto \frac{\partial^2}{\partial^2 k_\perp}\psi_\pi(x, k_\perp)$$




x

*gluons measure size of color dipole*

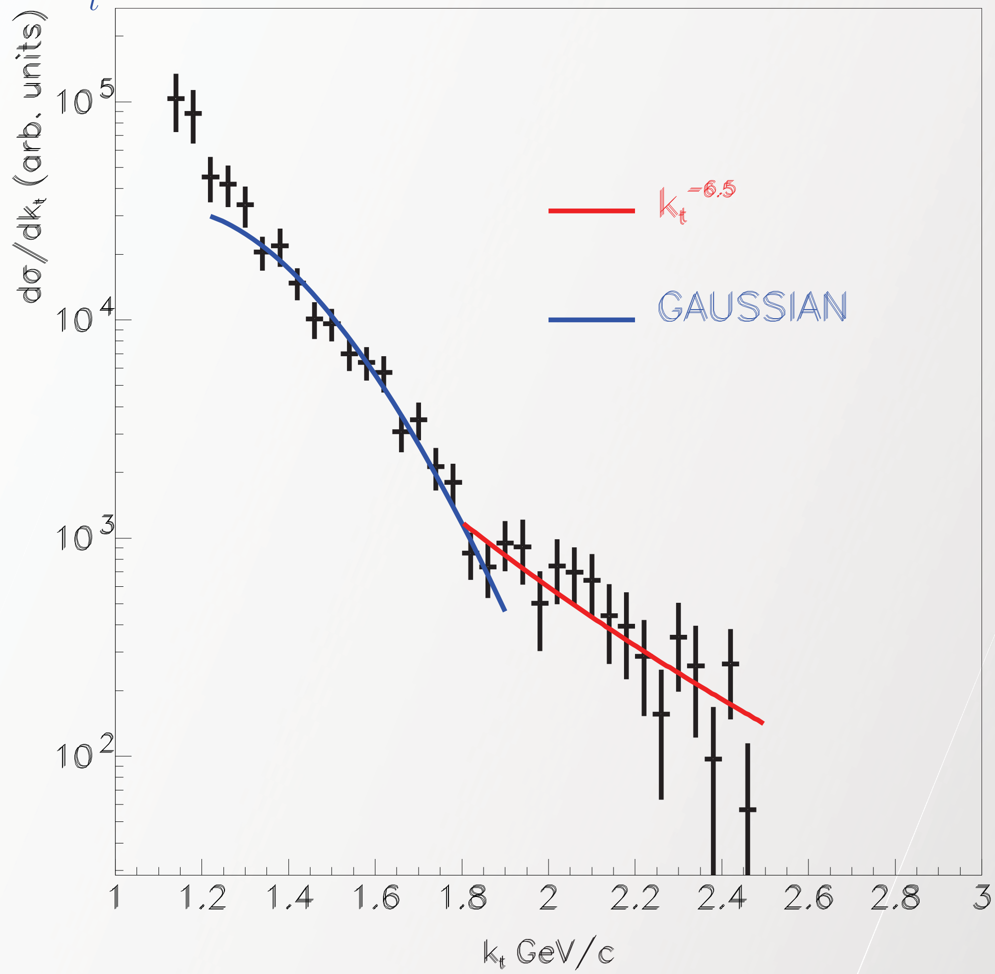
1-x

$$\frac{d\sigma}{dk_t^2} \propto |\alpha_s(k_t^2) x_N G(u, k_t^2)|^2 \left| \frac{\partial^2}{\partial k_t^2} \psi(x, k_t) \right|^2$$

# THE $k_t$ DEPENDENCE OF DI-JETS YIELD

$$\frac{d\sigma}{dk_t^2} \propto \left|\alpha_s(k_t^2) G(x, k_t^2)\right|^2 \left|\frac{\partial^2}{\partial k_t^2}\psi(u, k_t)\right|^2$$

**With** $\psi \sim \frac{\phi}{k_t^2}$**, weak** $\phi(k_t^2)$ **and** $\alpha_s(k_t^2)$ **dependences and** $G(x, k_t^2) \sim k_t^{1/2} : \frac{d\sigma}{dk_t} \sim k_t^{-6}$



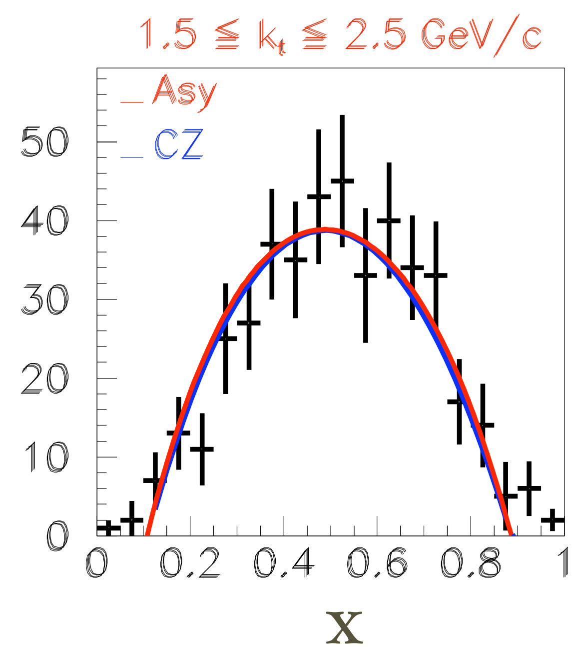

*High Transverse momentum dependence consistent with PQCD*

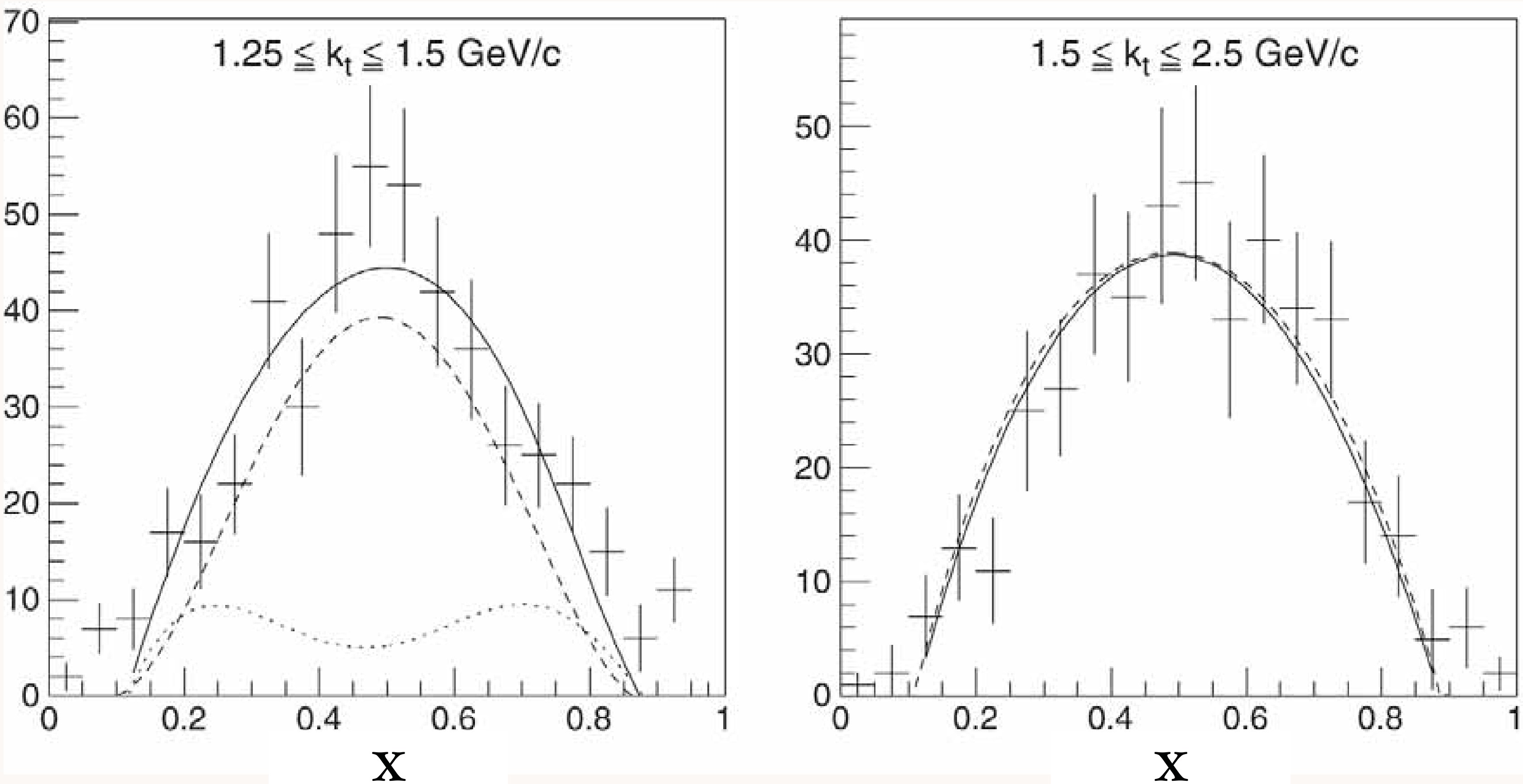
# Diffractive Dissociation of a Pion into Dijets

$$\pi A \rightarrow Jet\,Jet\,A'$$

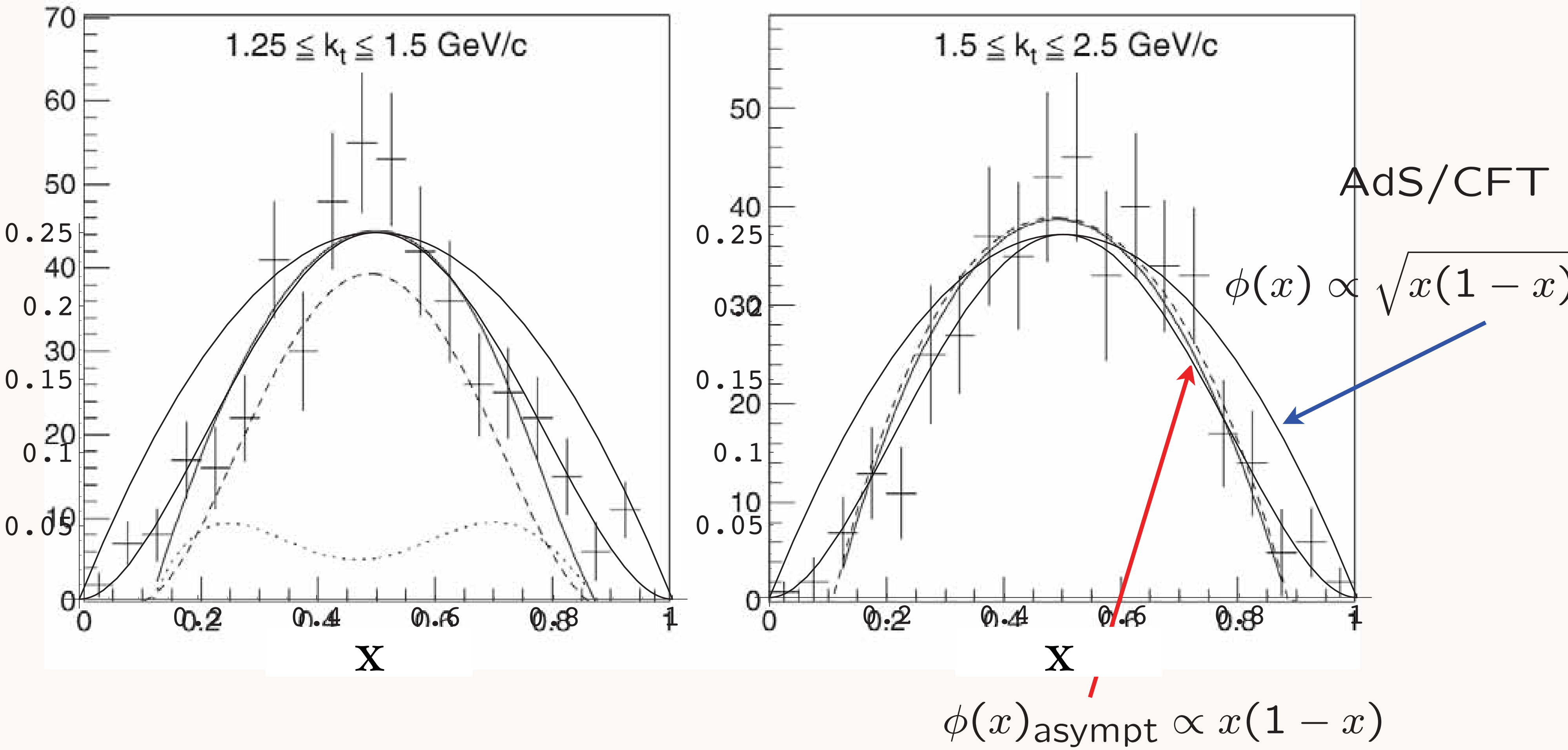
$$\psi^{\pi}_{q\bar{q}}(x, \vec{k}_\perp)$$

- E789 Fermilab Experiment Ashery et al
- 500 GeV pions collide on nuclei keeping it intact
- Measure momentum of two jets
- Study momentum distributions of pion LF wavefunction





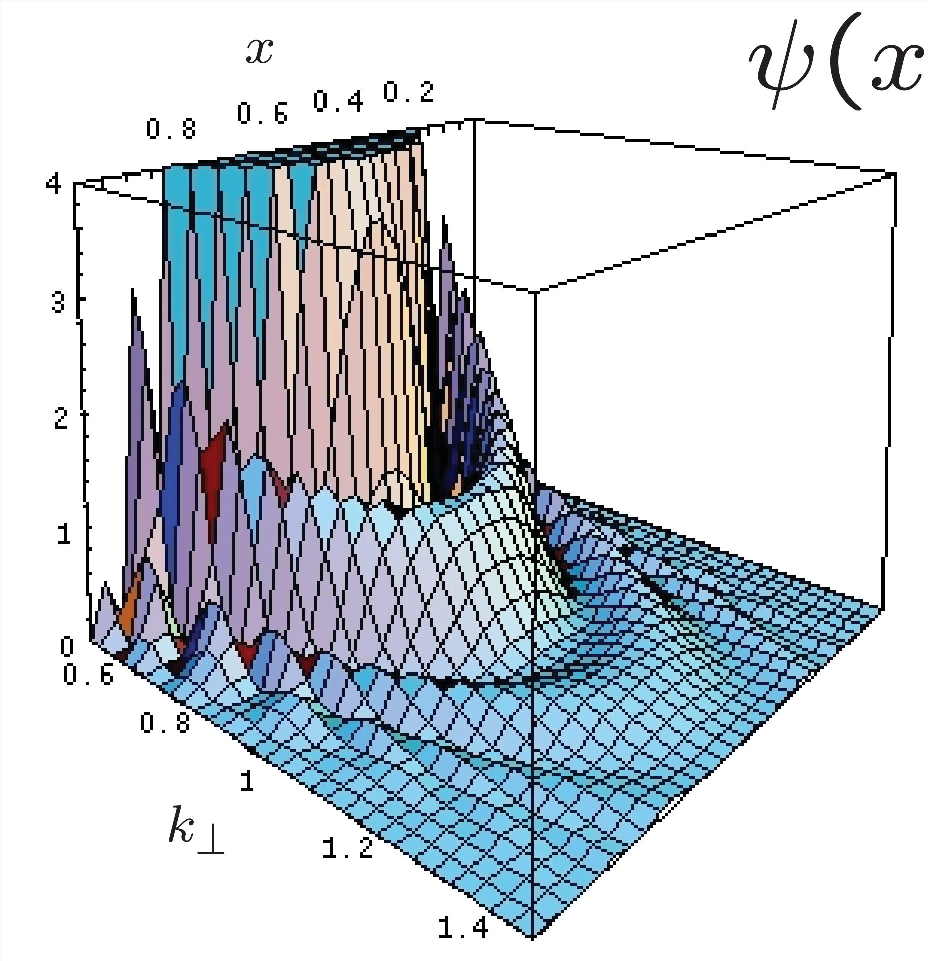

The x distribution of diffractive dijets from the platinum target for $1.25 \leq k_t \leq 1.5$ GeV/$c$ (left) and for $1.5 \leq k_t \leq 2.5$ GeV/$c$ (right). The solid line is a fit to a combination of the asymptotic and CZ distribution amplitudes. The dashed line shows the contribution from the asymptotic function and the dotted line that of the CZ function.

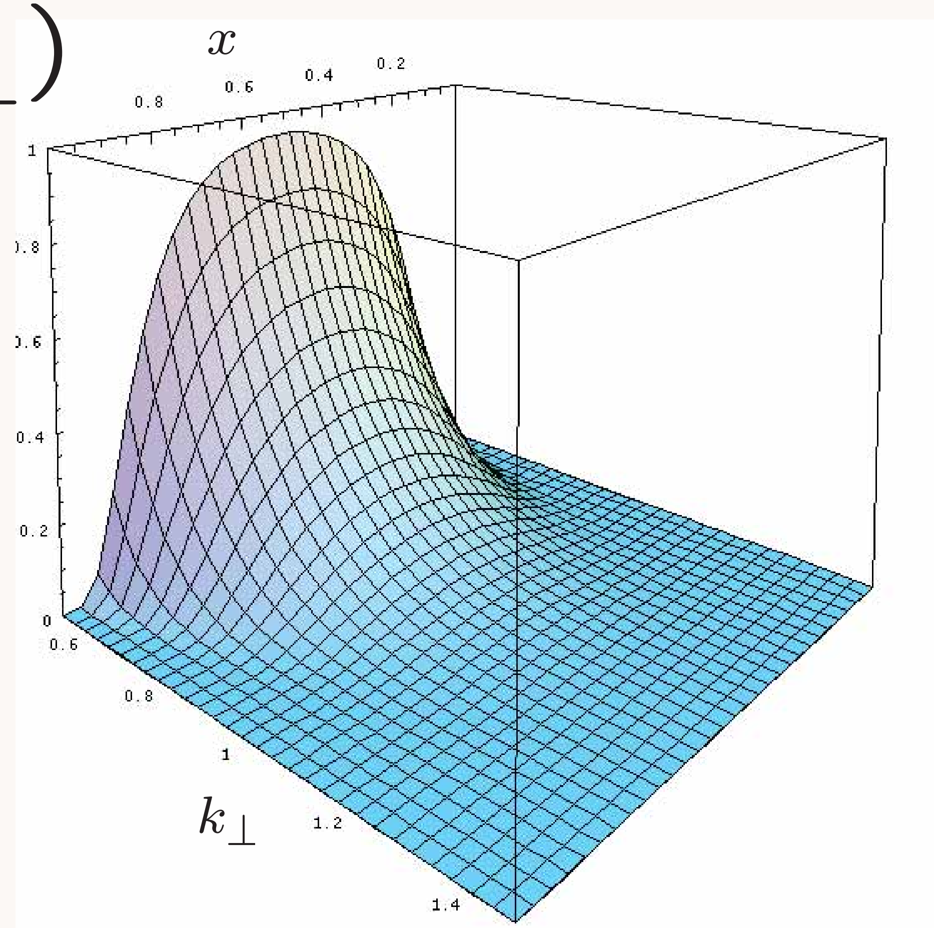



**The x distribution** of diffractive dijets from the platinum target for $1.25 \leq k_t \leq 1.5$ GeV/$c$ (left) and for $1.5 \leq k_t \leq 2.5$ GeV/$c$ (right). The solid line is a fit to a combination of the asymptotic and CZ distribution amplitudes. The dashed line shows the contribution from the asymptotic function and the dotted line that of the CZ function.

# Predictions from AdS/CFT

$$\psi(x, k_\perp)$$



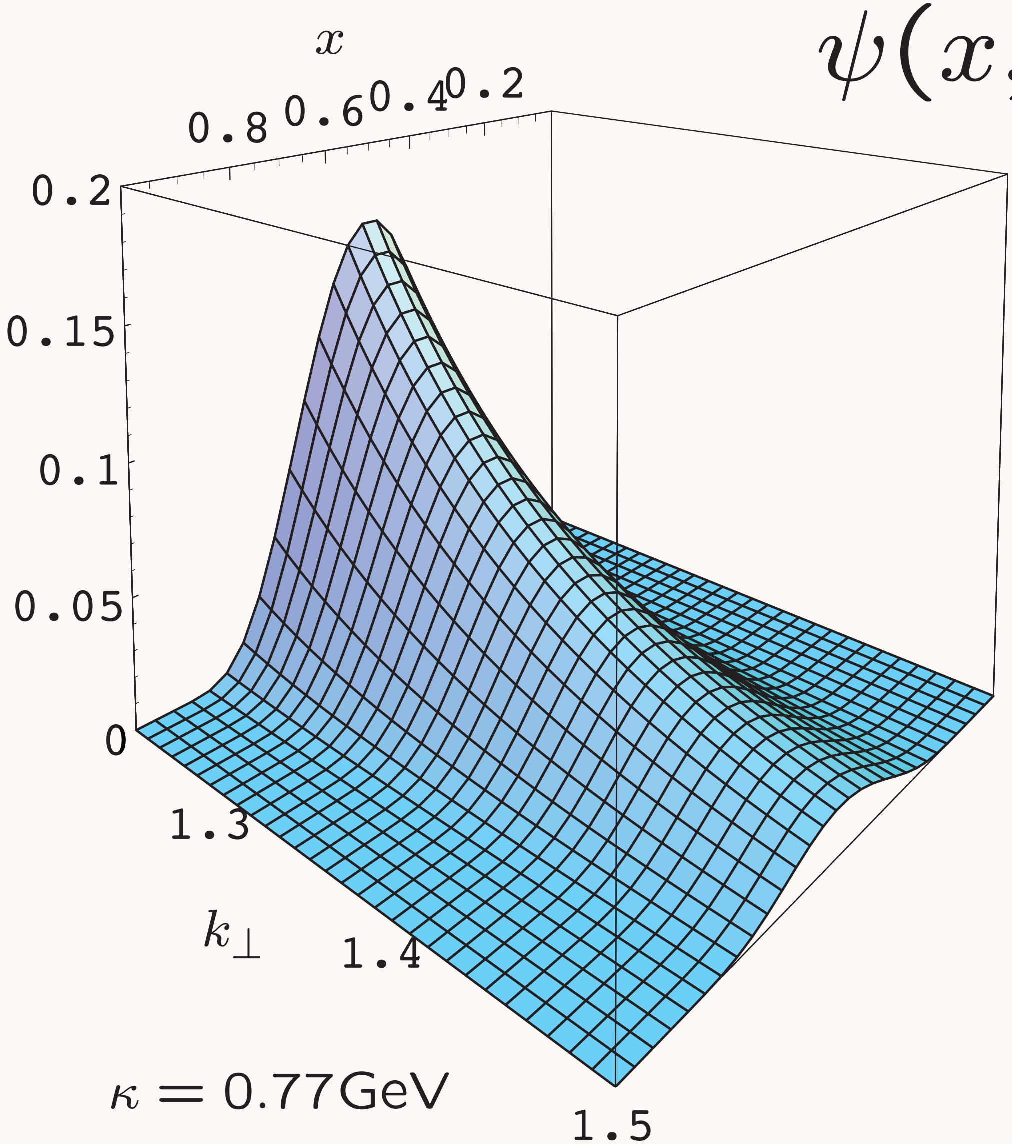




truncated space: needs smoothing

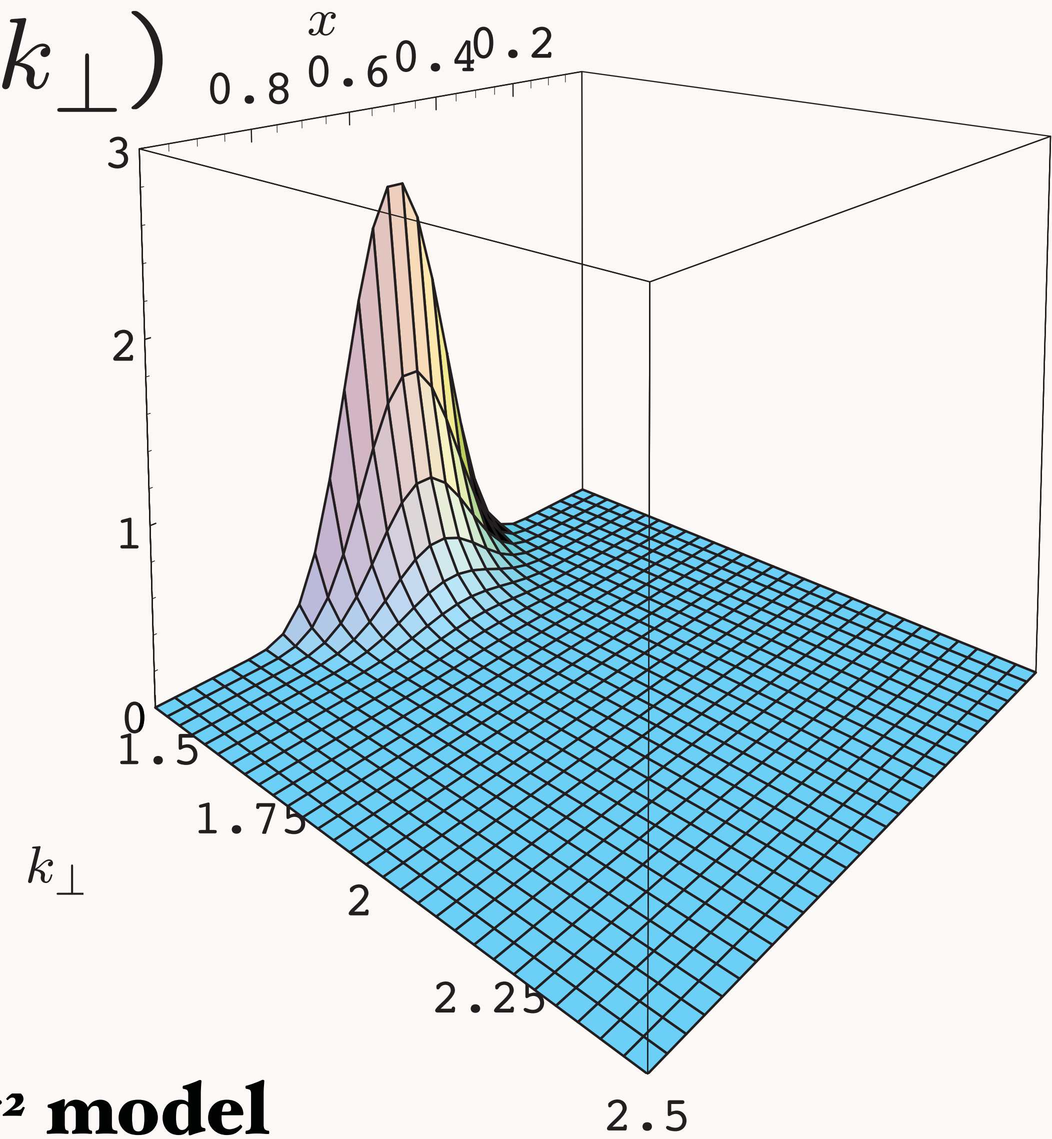
"oscillator" $z^2$

# Predictions from AdS/CFT

$$\psi(x, k_\perp)$$

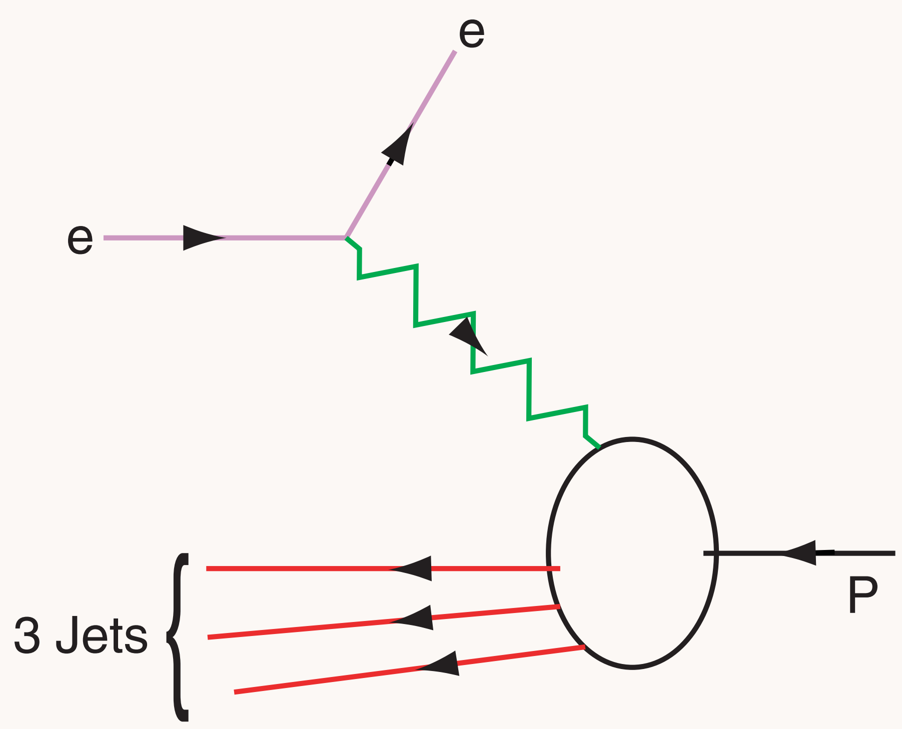



$\kappa = 0.77 \text{GeV}$




**z² model**

# Coulomb-Dissociate Proton to Three Jets at HERA




Frankfurt
Strikman
Miller

Measure $\Psi_{qqq}(x_i, \vec{k}_{\perp i})$ valence wavefunction of proton

# AdS/CFT and QCD

Bottom-Up Approach

- Nonperturbative derivation of dimensional counting rules of hard exclusive glueball scattering for gauge theories with mass gap dual to string theories in warped space:

  Polchinski and Strassler, hep-th/0109174.

- Deep inelastic structure functions at small $x$:

  Polchinski and Strassler, hep-th/0209211.

- Derivation of power falloff of hadronic light-front Fock wave functions, including orbital angular momentum, matching short distance behavior with string modes at AdS boundary:

  Brodsky and de Téramond, hep-th/0310227.

E. van Beveren et al.

- Low lying hadron spectra, chiral symmetry breaking and hadron couplings in AdS/QCD:

  Boschi-Filho and Braga, hep-th/0212207; de Téramond and Brodsky, hep-th/0501022; Erlich, Katz, Son and Stephanov, hep-ph/0501128; Hong, Yong and Strassler, hep-th/0501197; Da Rold and Pomarol, hep-ph/0501218; Hirn and Sanz, hep-ph/0507049; Boschi-Filho, Braga and Carrion, arXiv:hep-th/0507063; Katz, Lewandowski and Schwartz, arXiv:hep-ph/0510388.

- Gluonium spectrum (top-bottom):

  Csaki, Ooguri, Oz and Terning, hep-th/9806021; de Mello Kock, Jevicki, Mihailescu and Nuñez, hep-th/9806125; Csaki, Oz, Russo and Terning, hep-th/9810186; Minahan, hep-th/9811156; Brower, Mathur and Tan, hep-th/0003115, Caceres and Nuñez, hep-th/0506051.

- D3/D7 branes (top-bottom):

  Karch and Katz, hep-th/0205236; Karch, Katz and Weiner, hep-th/0211107; Kruczenski, Mateos, Myers and Winters, hep-th/0311270; Sakai and Sonnenschein, hep-th/0305049; Babington, Erdmenger, Evans, Guralnik and Kirsch, hep-th/0312263; Nuñez, Paredes and Ramallo, hep-th/0311201; Hong, Yoon and Strassler, hep-th/0312071; hep-th/0409118; Kruczenski, Pando Zayas, Sonnenschein and Vaman, hep-th/0410035; Sakai and Sugimoto, hep-th/0412141; Paredes and Talavera, hep-th/0412260; Kirsh and Vaman, hep-th/0505164; Apreda, Erdmenger and Evans, hep-th/0509219; Casero, Paredes and Sonnenschein, hep-th/0510110.

- Other aspects of high energy scattering in warped spaces:

  Giddings, hep-th/0203004; Andreev and Siegel, hep-th/0410131; Siopsis, hep-th/0503245.

- Strongly coupled quark-gluon plasma ($\eta/s = 1/4\pi$):

  Policastro, Son and Starinets, hep-th/0104066; Kang and Nastase, hep-th/0410173 . . .

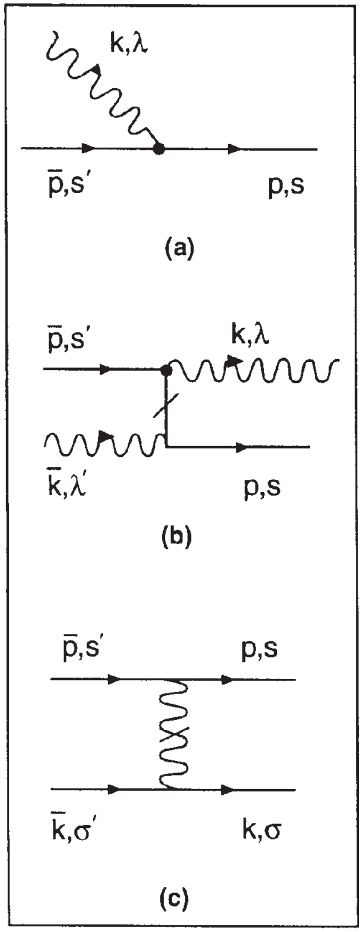
# Solving the LF Heisenberg Eqn.

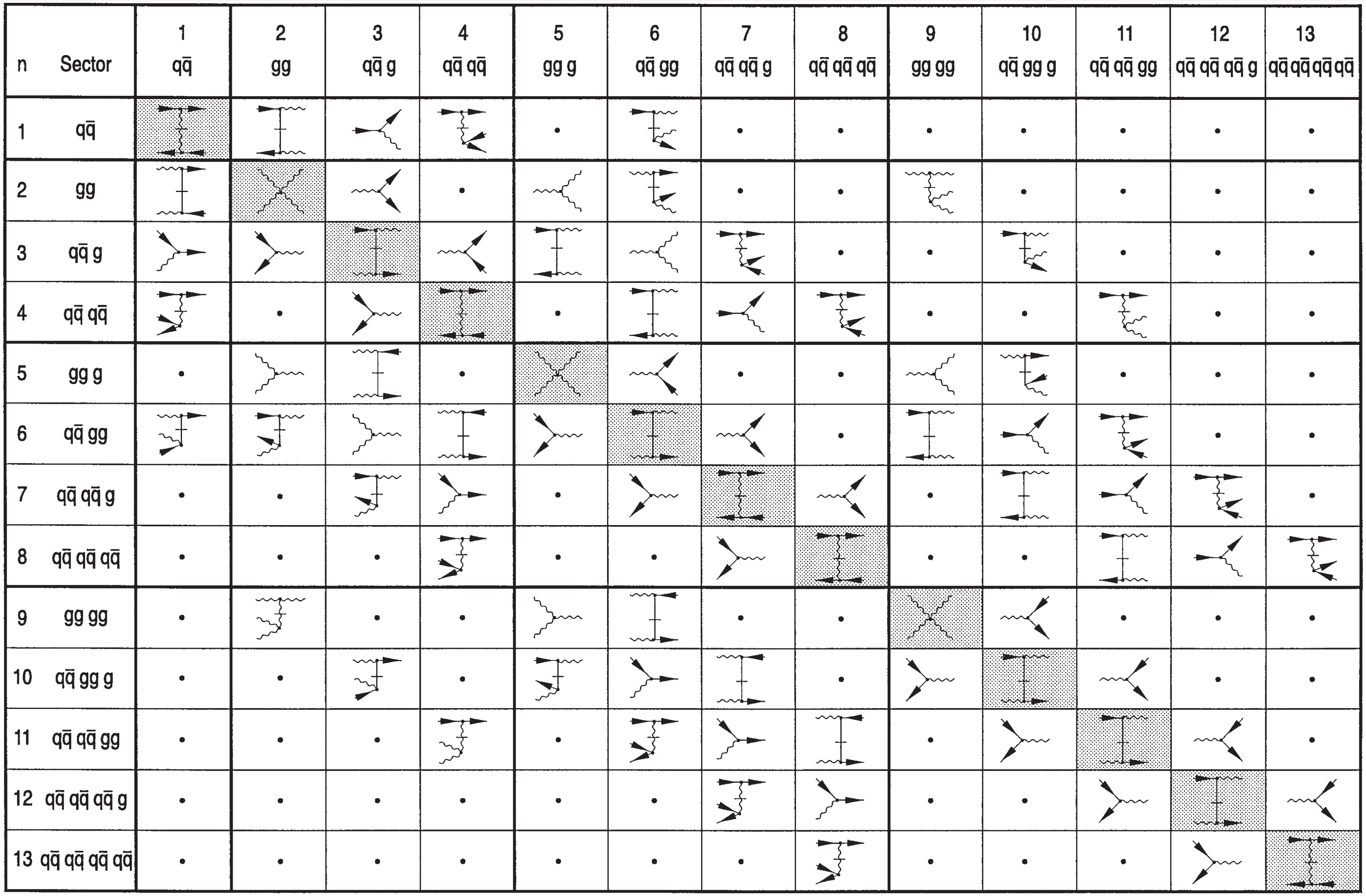
- Discretized Light-Cone Quantization (DLCQ) Pauli, sjb
  Minkowski space !
- Many 1+1 model field theories completely solved using DLCQ Hornbostel, Pauli, sjb; Klebanov
- UV Regularization: 3+ 1 Pauli Villars Hiller, McCartor, sjb
- Transverse Lattice Bardeen, Peterson,Rabinovici, Burkardt, Dalley
- Bethe-Salpeter/Dyson-Schwinger at fixed LF time
- Angular Structure of Solutions known Karmanov, Hwang, sjb
- Use AdS/CFT model solutions as starting point! Vary, sjb

# Light-Front QCD Heisenberg Equation

$$H_{LC}^{QCD}|\Psi_h\rangle = \mathcal{M}_h^2\,|\Psi_h\rangle$$

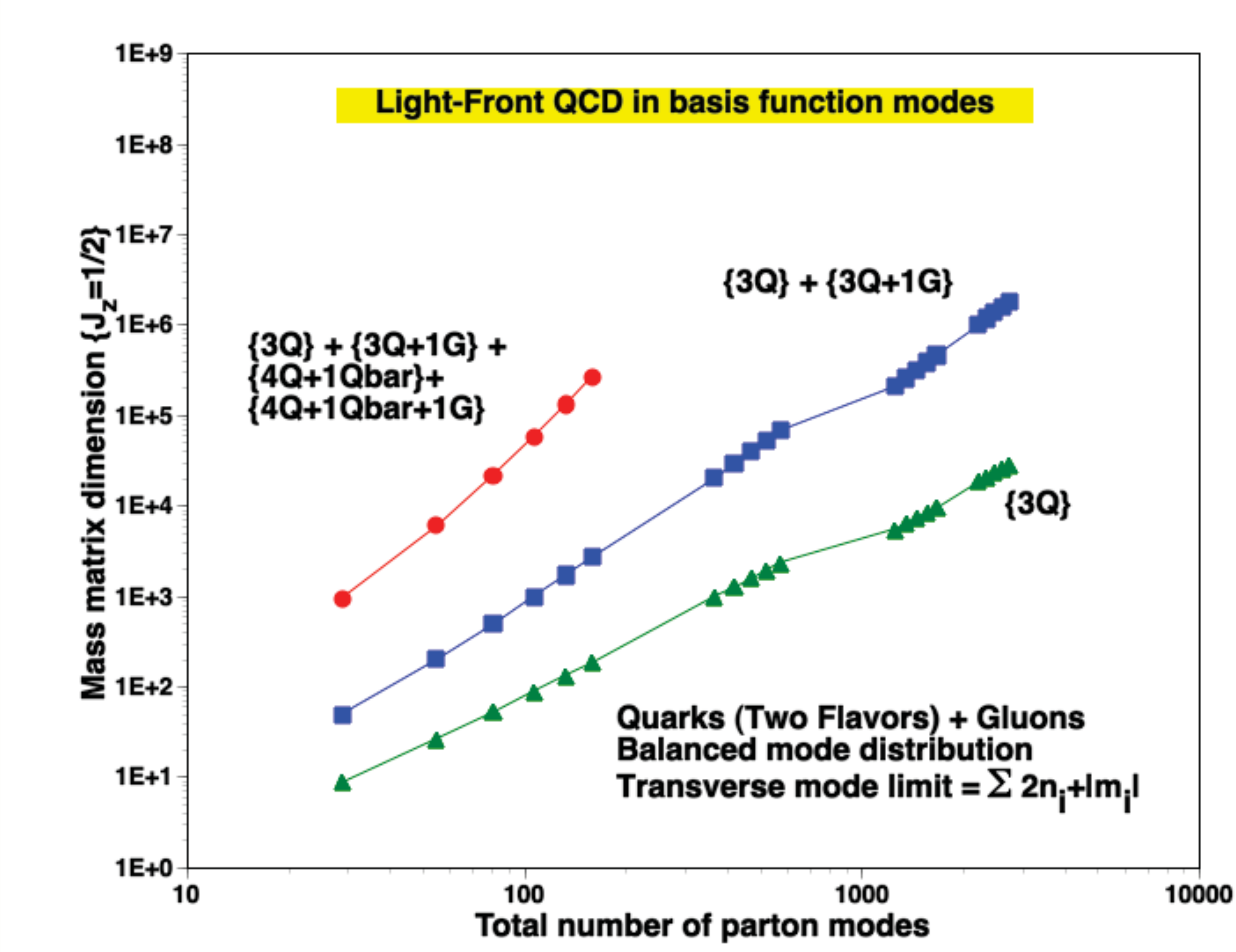
# DLCQ




Pauli, Pinsky, sjb

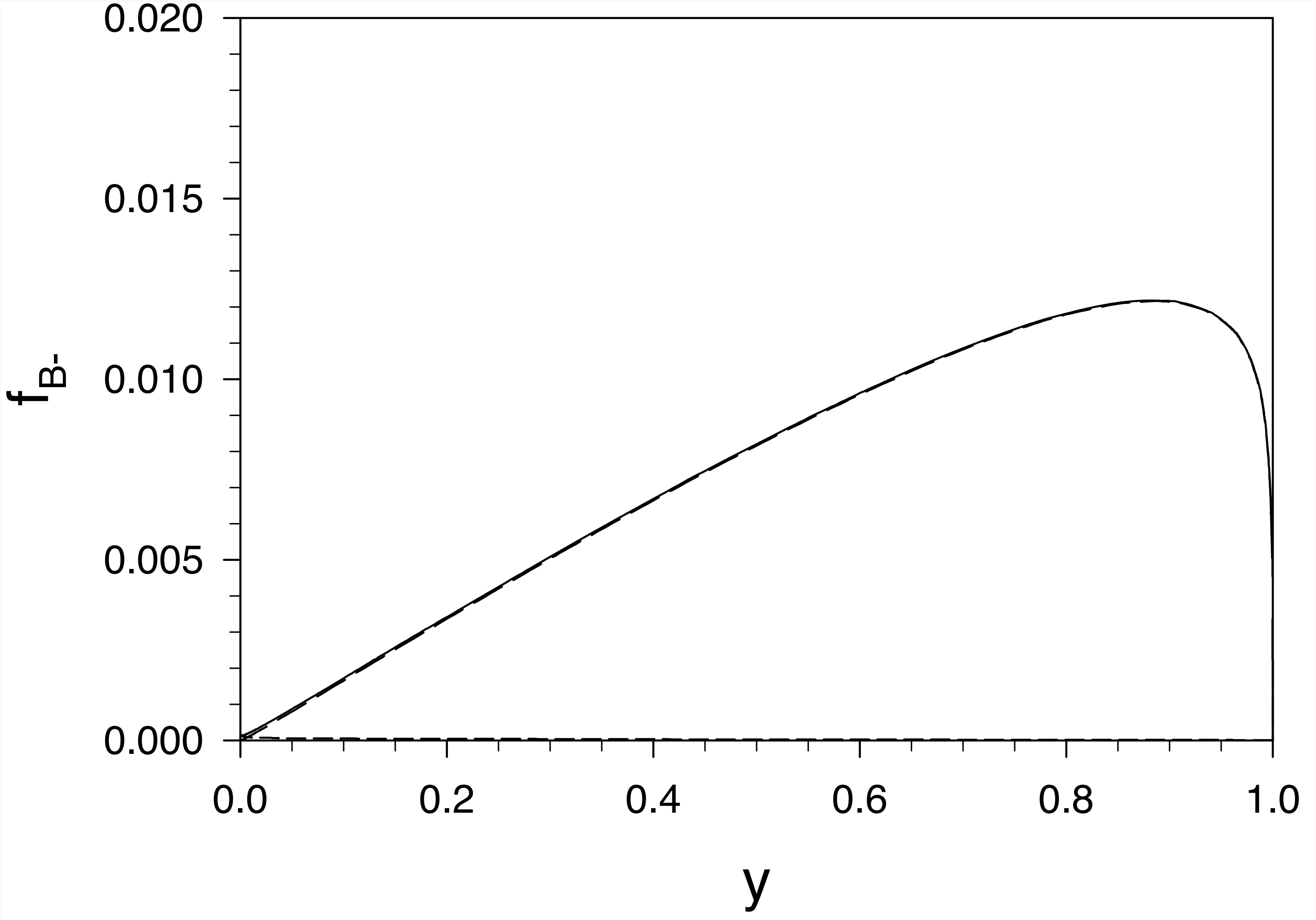
# Use AdS/CFT basis (complete and orthonormal) to diagonalize LF QCD Hamiltonian




J. Vary et al

## *Structure function of boson constituent in 3+1 Yukawa theory*

### Three-particle Fock state truncation




Pauli-Villars Regularization

Hiller, McCartor, sjb

# New Perspectives on QCD from AdS/CFT

- Holographic Model from AdS/CFT : Confinement at large distances and conformal behavior at short distances
- AdS/CFT predicts Light-front wavefunctions: Fundamental description of hadrons at amplitude level
- AdS/CFT: gluonium (gg) , meson (q $\bar{q}$), and baryon (qqq) spectra
- **Quark-interchange dominates scattering amplitudes**

# Why is quark-interchange dominant over gluon exchange?

Example: $M(K^+p \to K^+p) \propto \frac{1}{ut^2}$

Exchange of common $u$ quark

$M_{QIM} = \int d^2k_\perp dx \ \psi^\dagger_C \psi^\dagger_D \Delta \psi_A \psi_B$

Holographic model (Classical level):

Hadrons enter 5th dimension of $AdS_5$

Quarks travel freely within cavity as long as separation $z < z_0 = \frac{1}{\Lambda_{QCD}}$

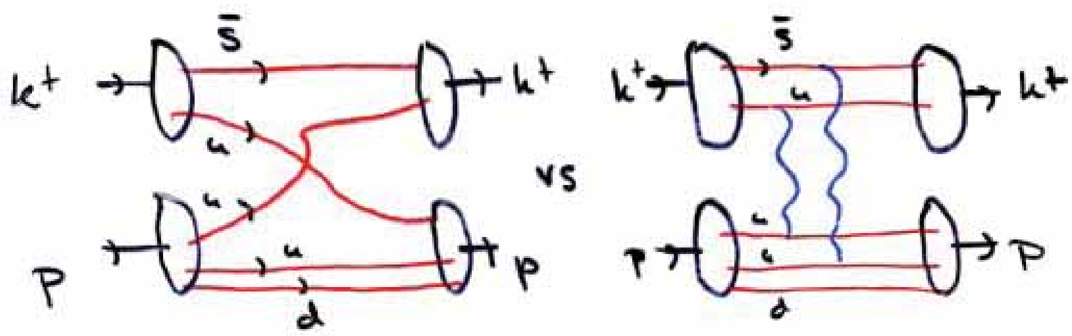
LFWFs obey conformal symmetry producing quark counting rules.

Angular Distribution $-t/s = \frac{1}{2}(1-\cos\theta_{cm})$

$$\frac{d\sigma}{dt} = \frac{1}{s^{n_{TOT}-2}} F(t/s)$$

Blankenbecler, Gunion, sjb

determined by scattering mechanism




Quark Interchange     gluon exchange

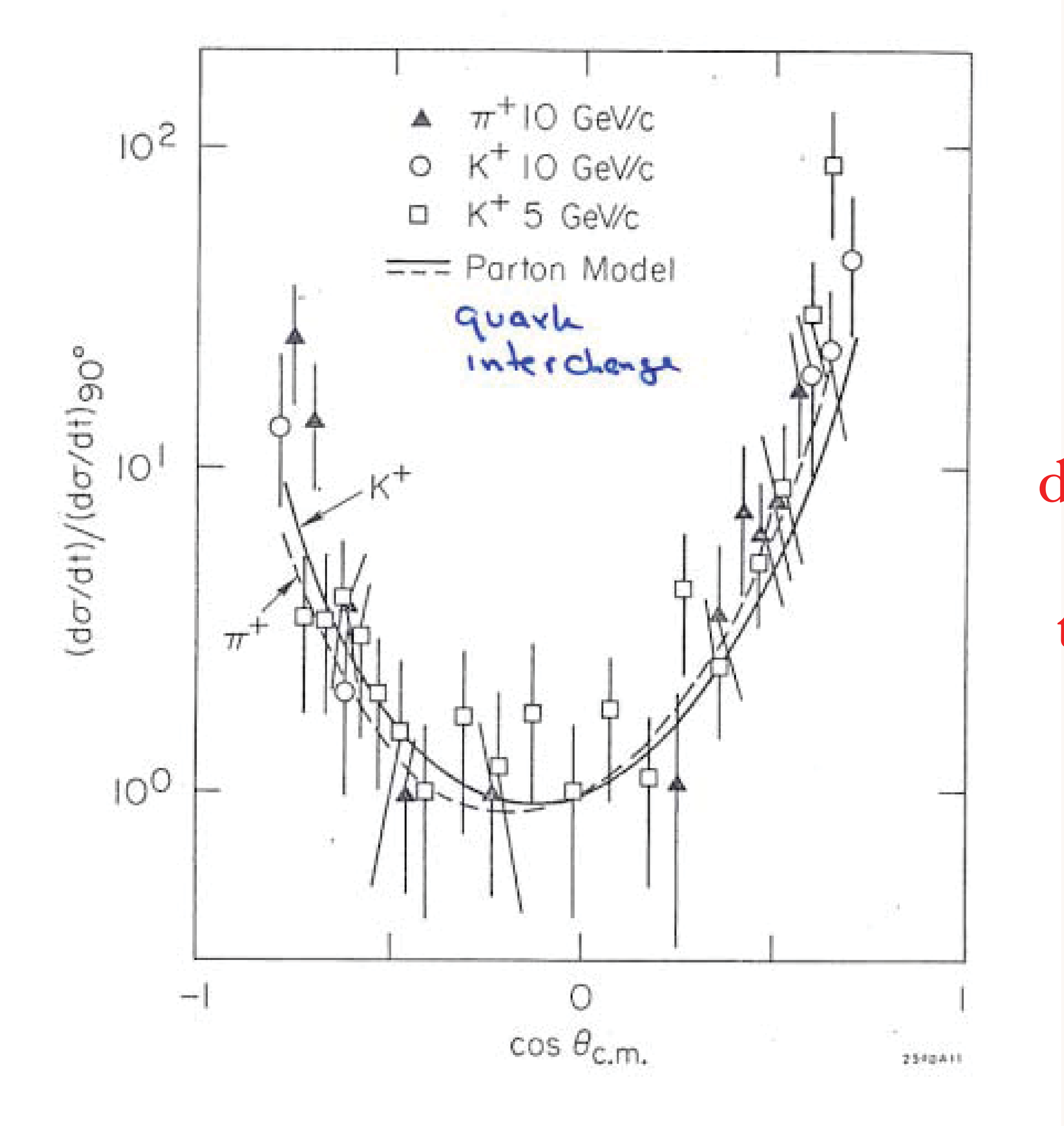
analogous to spin exchange in atom-atom scattering     Van der Waals

# MIT Bag Model predicts dominance of quark interchange: deTar

Large $N_c$: Quark Interchange Dominant

$$\mathcal{M} \sim \frac{1}{u}\frac{1}{t^2}$$

t' Hooft limit, AdS/CFT




AdS/CFT explains why quark interchange is dominant interaction at high momentum transfer in exclusive reactions

# Formula for quark interchange using LFWFs

Blankenbecler, Gunion, sjb; Sivers

$$M_{FI} = \langle \psi_F | E - K | \psi_I \rangle$$
$$\equiv \langle \psi_F | \Delta | \psi_I \rangle$$
$$= \frac{1}{2(2\pi)^3} \int d^2k \int_0^1 \frac{dx}{x^2(1-x)^2} \Delta \psi_C(\vec{k}_\perp - x\vec{r}_\perp, x) \psi_D(\vec{k}_\perp + (1-x)\vec{q}_\perp, x) \psi_A(\vec{k}_\perp - x\vec{r}_\perp + (1-x)\vec{q}_\perp, x) \psi_B(\vec{k}_\perp, x)$$

where

$$\Delta = s - M_A{}^2 - M_B{}^2 - K_a - K_b - K_c - K_d$$
$$= M_A{}^2 + M_B{}^2 - S_A(\vec{k}_\perp + (1-x)\vec{q}_\perp - x\vec{r}_\perp, x) - S_B(\vec{k}_\perp, x)$$
$$= M_C{}^2 + M_D{}^2 - S_C(\vec{k}_\perp - x\vec{r}_\perp, x) - S_D(\vec{k}_\perp + (1-x)\vec{q}_\perp, x) .$$

# *New Perspectives for QCD from AdS/CFT*

- LFWFs: Fundamental description of hadrons at amplitude level
- Holographic Model from AdS/CFT : Confinement at large distances and conformal behavior at short distances
- Model for LFWFs, meson and baryon spectra: many applications!
- New basis for diagonalizing Light-Front Hamiltonian
- Physics similar to MIT bag model, but covariant. No problem with support $0 < x < 1$.
- Quark Interchange dominant force at short distances

# Essential to test QCD

- GSI antiprotons
- 12 GeV Jlab
- J-PARC
- BaBar/Belle: ISR, two-gamma, timelike DVCS
- RHIC/LHC Nuclear Collisions; LHCb; forward heavy quarks, higgs
- photon-photon collider at the ILC
- electron-proton, electron-nucleus collisions