Holographic Model

AdS/CFT prediction for meson LFWF

Guy de Teramond
SJB

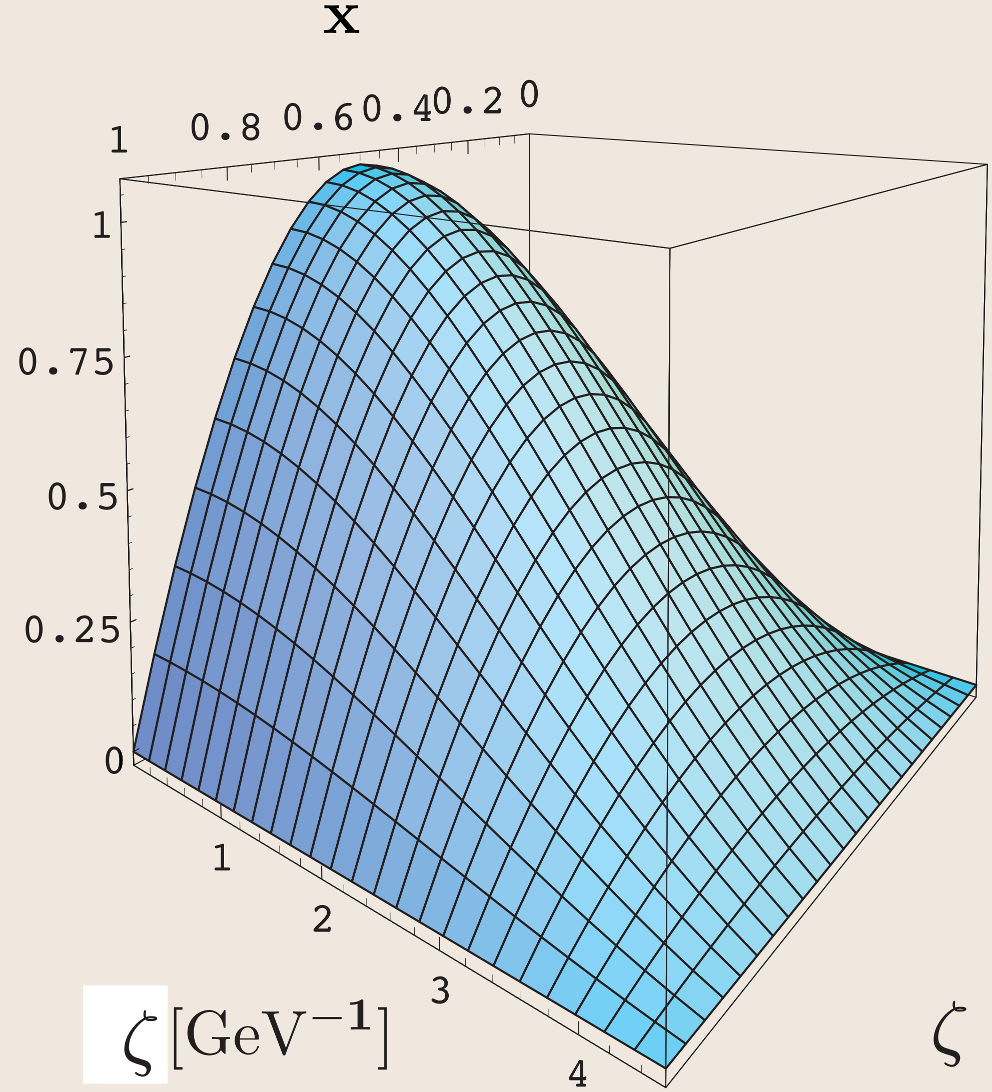
$$\widetilde{\psi}_L(x, \vec{b}_\perp) = C_L \frac{J_{1+L}\left(|\vec{b}_\perp|\sqrt{x(1-x)}\ \beta_{1+L,k}\Lambda_{\rm QCD}\right)}{|\vec{b}_\perp|}.$$

At large $k_\perp$ the LFWF has the scaling behavior

$$\sqrt{x(1-x)}\ \psi(x, \vec{k}_\perp) \to \left[\frac{|\vec{k}_\perp|}{\sqrt{x(1-x)}}\right]^L \left[\frac{x(1-x)}{\vec{k}_\perp^2}\right]^{1+L},$$

BL convention

$$\sqrt{x(1-x)}\psi(\mathbf{x},\mathbf{b})$$



AdS/CFT prediction for meson LFWF

Holographic Model

Guy de Teramond
SJB

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

Two-parton ground state LFWF in impact space $\psi(x,b)$ for a for $n=2,\ell=0,k=1$.

BL convention

Holographic Model

Guy de Teramond
SJB

AdS/CFT prediction for meson LFWF

$$\sqrt{x(1-x)} \quad \widetilde{\psi}_L(x, \vec{b}_\perp)$$

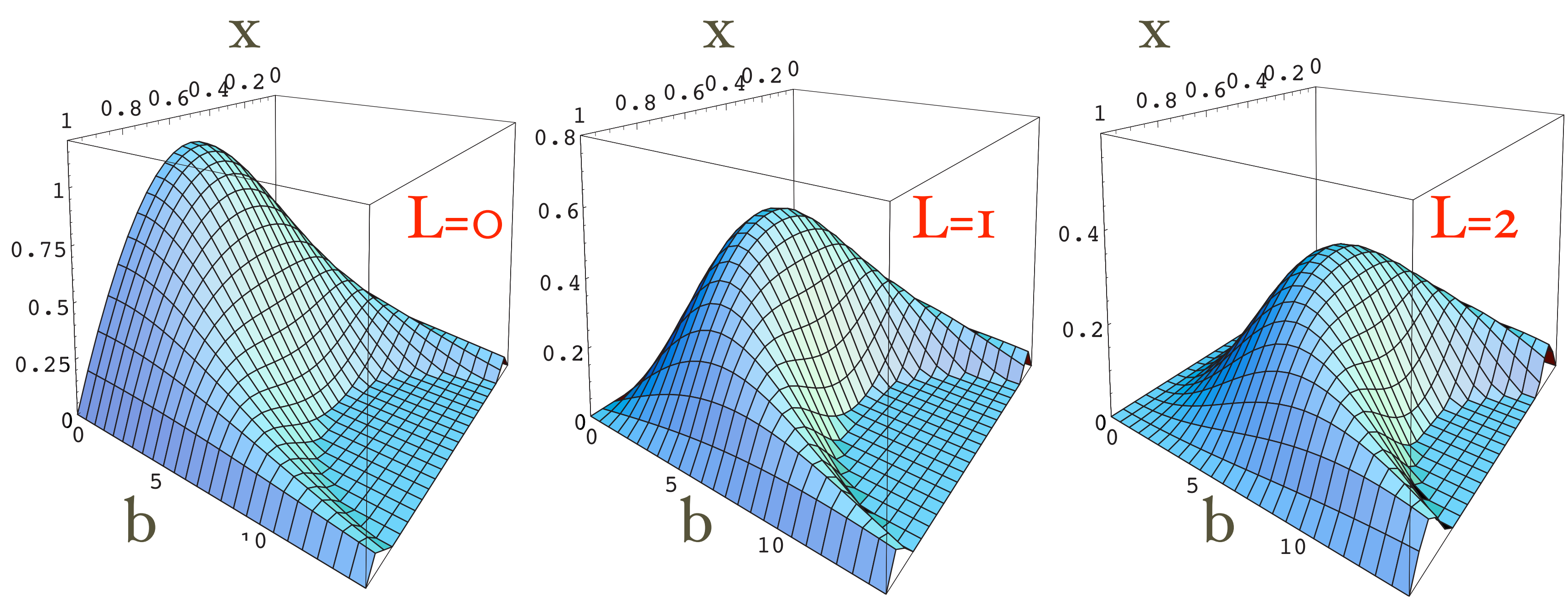


Figure 1: Two-parton bound state light-front wave function $\widetilde{\psi}_L(x, \vec{b}_\perp)$ as function of the constituents longitudinal momentum fraction x and $1-x$ and the impact space relative coordinate $\vec{b}_\perp$ in a holographic QCD model. The results for the ground state ($L = 0$) are shown in (a). The predictions for first orbital exited states ($L = 1$ and $L = 2$) are shown in (b) and (c) respectively.

BL convention

$$\left|\Psi_h(P^+, \vec{P}_\perp)\right\rangle = \sum_{n,\lambda_i} \int \; [dx_i \; d^2\vec{k}_{\perp i}] \; \psi_{n/h}(x_i, \vec{k}_{\perp i}, \lambda_i) \; |n : x_i P^+, x_i \vec{P}_\perp + \vec{k}_{\perp i}, \lambda_i\rangle$$

Conformal Behavior:

$$\psi_{n/h}(\vec{k}_\perp) \to (k_\perp)^\ell \left[\frac{1}{\vec{k}^2_\perp}\right]^{n+\delta_n+\ell-1} .$$

PQCD: Ji, Ma, Yuan

AdS/CFT : de Teramond, Sjb

Model Form

$$\psi_{n/h}(x_i, \vec{k}_{\perp i}, \lambda_i, l_{zi}) \sim \frac{(g_s \; N_C)^{\frac{1}{2}(n-1)}}{\sqrt{N}_C} \prod_{i=1}^{n-1} (k^\pm_{i\perp})^{|l_{zi}|} \left[\frac{\Lambda_o}{\mathcal{M}^2 - \sum_i \frac{\vec{k}^2_{\perp i} + m_i^2}{x_i} + \Lambda_o^2}\right]^{n+|l_z|-1}$$

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
- No ggg bound states

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

$$M_{QIM} = \int d^2k_\perp dx\ \psi_C^\dagger \psi_D^\dagger \Delta \psi_A \psi_B$$

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.

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

$$\Delta = s - M_A{}^2 - M_B{}^2 - K_a - K_b - K_c - K_d$$

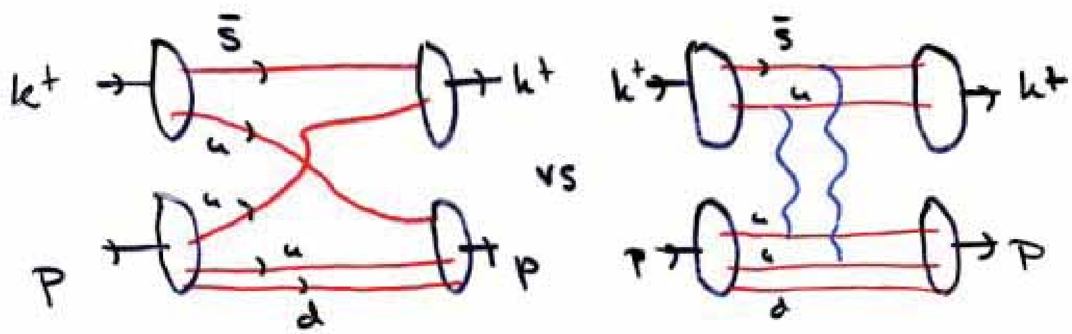
$$= M_A{}^2 + M_B{}^2 - S_A(\vec{k}_\perp + (1-x)\vec{q}_\perp - x\vec{r}_\perp, x) - S_B(\vec{k}_\perp, x)$$

$$= M_C{}^2 + M_D{}^2 - S_C(\vec{k}_\perp - x\vec{r}_\perp, x) - S_D(\vec{k}_\perp + (1-x)\vec{q}_\perp, x) .$$

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

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

determined by scattering mechanism



Quark Interchange — gluon exchange

↗ analogous to spin exchange in atom - atom scattering

Van der Waals

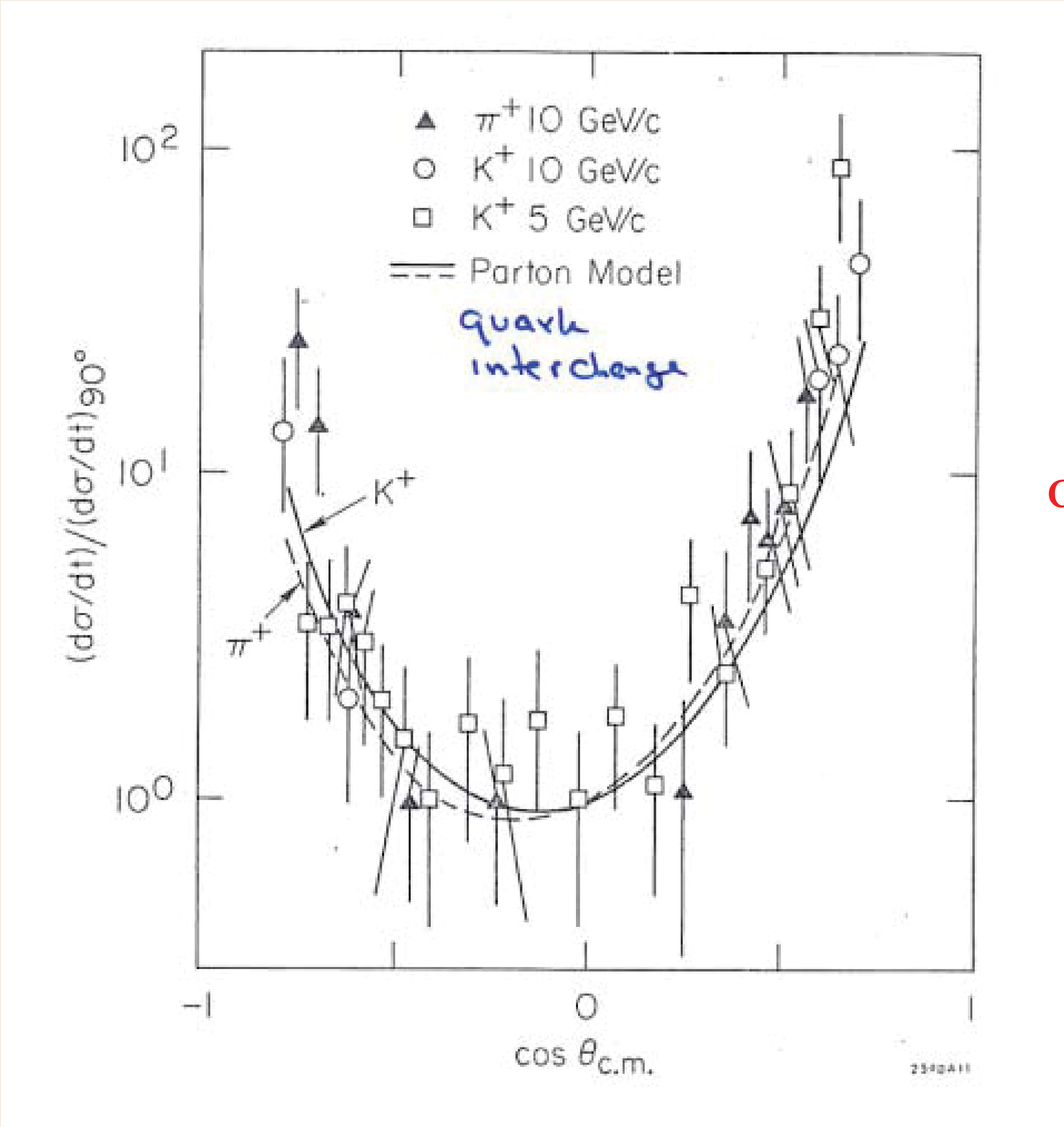
Large N_c: Quark Interchange Dominant

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

't Hooft Limit, AdS/CFT

Blankenbecler, Gunion, sjb

MIT Bag Model predicts dominance of quark interchange: deTar

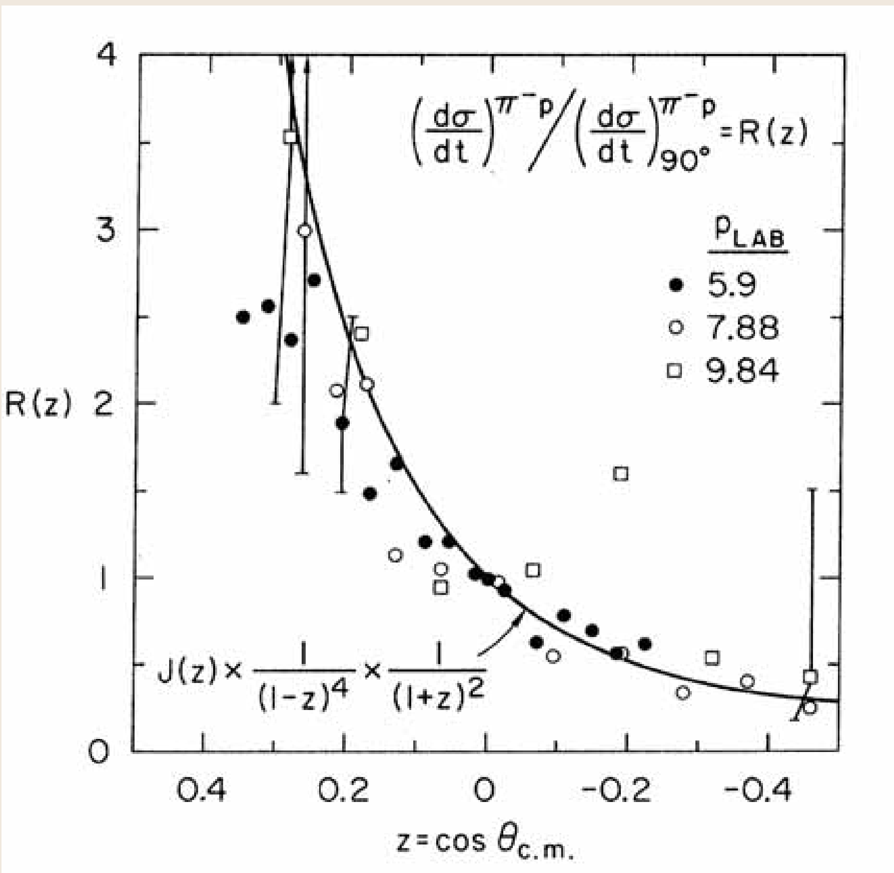


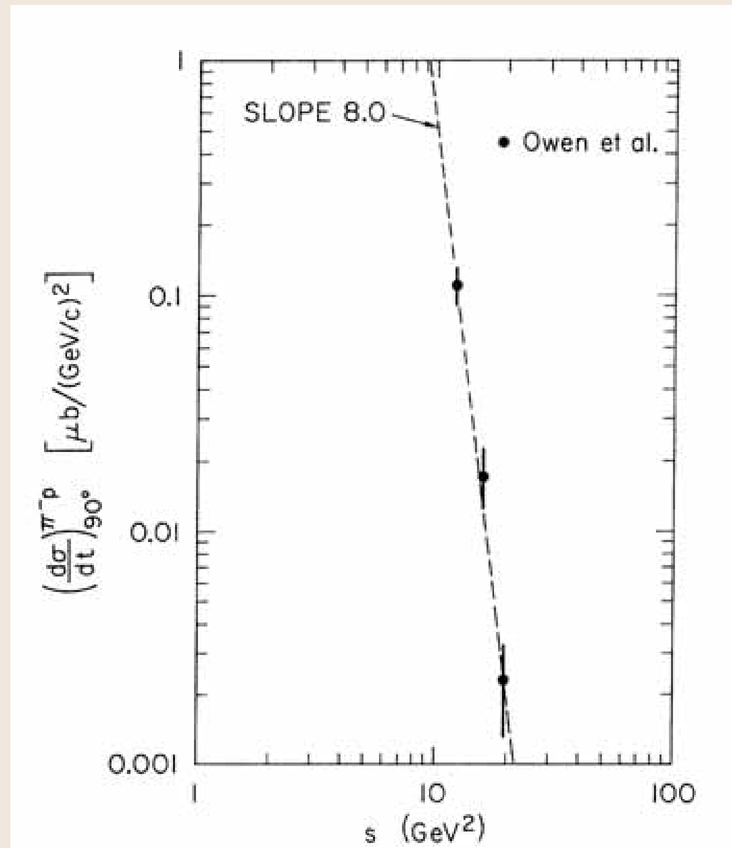
AdS/CFT explains why quark interchange is dominant interaction at high momentum transfer in exclusive reactions

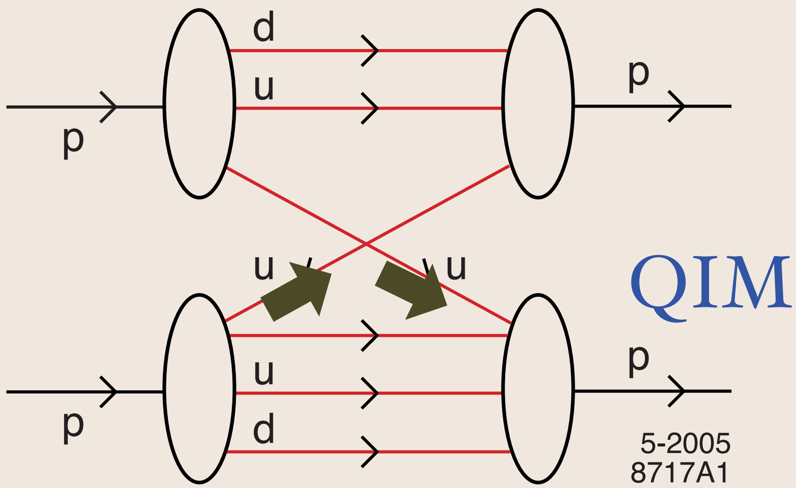
$$M_{FI} = \langle \psi_F | E - K | \psi_I \rangle$$
$$\equiv \langle \psi_F | \Delta | \psi_I \rangle$$
$$= \frac{1}{2(2\pi)^3} \int d^2k \int_0^1 \frac{dx}{x^2(1-x)^2} \Delta \psi_C(\vec{k}_\perp - x\vec{r}_\perp, x) \psi_D(\vec{k}_\perp + (1-x)\vec{q}_\perp, x) \psi_A(\vec{k}_\perp - x\vec{r}_\perp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

where

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







$$\frac{d\sigma}{dt}(pp \to pp) = C\,\frac{F_p^{\,2}(t)F_p^{\,2}(u)}{s^2}$$

$$\frac{d\sigma}{dt} = \frac{1}{s^{10}} f(\theta_{c.m.})\,, \quad f(\theta_{c.m.}) \sim \left(\frac{1}{1-\cos^2\theta}\right)^4 .$$

The biggest failure of the interchange mechanism is in the spin correlation. For all angles we predict from Table I

$$A_{nn} = \frac{1}{3}\,\frac{1-(\frac{3}{31})^2\chi^2}{1+\frac{1}{3}(\frac{3}{31})^2\chi^2}\,, \qquad (3.11)$$

where

$$\chi = \frac{f(\theta)-f(\pi-\theta)}{f(\theta)+f(\pi-\theta)}\,.$$

Thus A_{nn} is predicted to be within 2% of $\frac{1}{3}$ even when $\chi = 1$ [$\chi = 0$ for the form in Eq. (3.6)]. The data clearly indicate that A_{nn} is not a constant near $\frac{1}{3}$.

Our expectation, then, is that there is an additional amplitude which strongly interferes with the quark-interchange contributions at Argonne energies; most plausibly, the quark-interchange contribution is dominant at asymptotic t and u, and the interfering amplitude is most important at low t and u. As we shall discuss below, the behavior of A_{ll} and A_{ss} in the interference region can play an important role in sorting out the possible subasymptotic contributions.

These results for the quark-interchange model have also been obtained by Farrar, Gottlieb, Sivers, and Thomas,[12] who also consider the possibility that nonperturbative effects (quark-quark scattering via instantons) can explain the data.

$$\frac{d\sigma}{dt}(pp \to pp) = \frac{F(t/s)}{s^{9.7 \pm 0.5}}$$

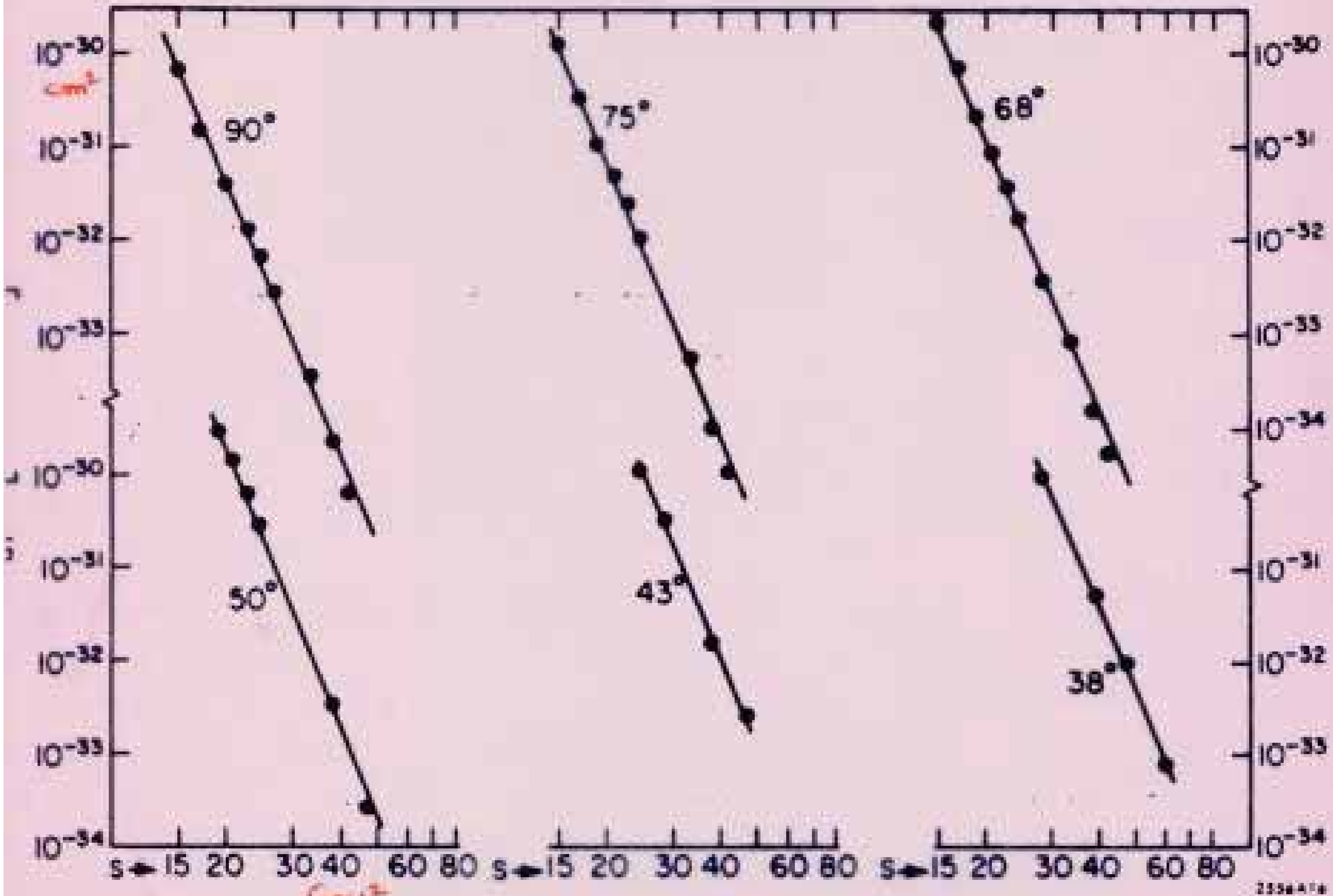


Figure 22. Test of fixed θ_{CM} scaling for elastic *pp* scattering. The data compilation is Landshoff and Polkinghorne.

Light-Front QCD Phenomenology

- Hidden color, Intrinsic glue, sea, Color Transparency
- Near Conformal Behavior of LFWFs at Short Distances; PQCD constraints
- Vanishing anomalous gravitomagnetic moment
- Relation between edm and anomalous magnetic moment
- Cluster Decomposition Theorem for relativistic systems
- OPE: DGLAP, ERBL evolution; invariant mass scheme

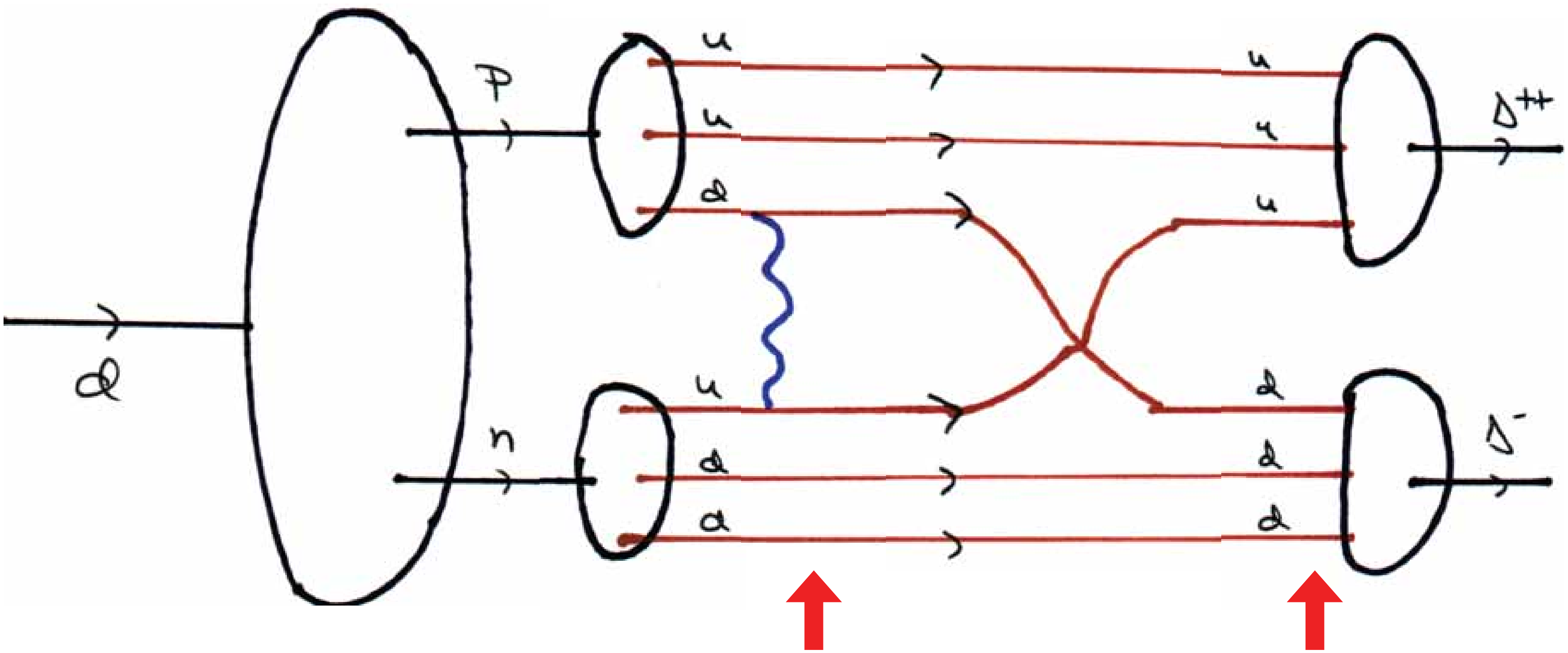
Hidden Color in QCD

Lepage, Ji, sjb

- Deuteron six quark wavefunction:
- 5 color-singlet combinations of 6 color-triplets -- one state is |n p>
- Components evolve towards equality at short distances
- Hidden color states dominate deuteron form factor and photodisintegration at high momentum transfer
- Predict $\frac{d\sigma}{dt}(\gamma d \to \Delta^{++}\Delta^{-}) \simeq \frac{d\sigma}{dt}(\gamma d \to pn)$ at high Q^2

Ratio = 2/5 for asymptotic wf

Structure of Deuteron in QCD



Hidden Color Fock State

Delta-Delta Fock State

Insights for QCD from AdS/CFT

The evolution equation for six-quark systems in which the constituents have the light-cone longitudinal momentum fractions x_i ($i = 1, 2, \ldots, 6$) can be obtained from a generalization of the proton (three-quark) case.[2] A nontrivial extension is the calculation of the color factor, C_d, of six-quark systems[5] (see below). Since in leading order only pairwise interactions, with transverse momentum Q, occur between quarks, the evolution equation for the six-quark system becomes $\{[dy] = \delta(1 - \sum_{i=1}^{6} y_i)\prod_{i=1}^{6} dy_i$, $C_F = (n_c^2 - 1)/2n_c = \frac{4}{3}$, $\beta = 11 - \frac{2}{3}n_f$, and n_f is the effective number of flavors$\}$

$$\prod_{k=1}^{6} x_k \left[\frac{\partial}{\partial \xi} + \frac{3C_F}{\beta}\right] \tilde{\Phi}(x_i, Q) = -\frac{C_d}{\beta} \int_0^1 [dy] V(x_i, y_i)\, \tilde{\Phi}(y_i, Q),$$

$$\xi(Q^2) = \frac{\beta}{4\pi} \int_{Q_0^2}^{Q^2} \frac{dk^2}{k^2} \alpha_s(k^2) \sim \ln\left(\frac{\ln(Q^2/\Lambda^2)}{\ln(Q_0^2/\Lambda^2)}\right).$$

$$V(x_i, y_i) = 2 \prod_{k=1}^{6} x_k \sum_{i \neq j}^{6} \theta(y_i - x_i) \prod_{l \neq i, j}^{6} \delta(x_l - y_l) \frac{y_j}{x_j} \left(\frac{\delta_{h_i \bar{h}_j}}{x_i + x_j} + \frac{\Delta}{y_i - x_i}\right)$$

where $\delta_{h_i \bar{h}_j} = 1$ (0) when the helicities of the constituents $\{i, j\}$ are antiparallel (parallel). The infrared singularity at $x_i = y_i$ is cancelled by the factor $\Delta \tilde{\Phi}(y_i, Q) = \tilde{\Phi}(y_i, Q) - \tilde{\Phi}(x_i, Q)$ since the deuteron is a color singlet.

Quantum Chromodynamic Predictions for the Deuteron Form Factor

$$F_d(Q^2) = \int_0^1 [dx][dy]\varphi_d^{\dagger}(y,Q) \times T_H^{6q+\gamma^*\to 6q}(x,y,Q)\varphi_d(x,Q), \quad (1)$$

where the hard-scattering amplitude

$$T_H^{6q+\gamma^*\to 6q} = [\alpha_s(Q^2)/Q^2]^5 t(x,y) \times [1+O(\alpha_s(Q^2))] \quad (2)$$

gives the probability amplitude for scattering six quarks collinear with the initial to the final deuteron momentum and

$$\varphi_d(x_i,Q) \propto \int^{k_{\perp i}<Q}[d^2k_\perp]\psi_{qqq\,qqq}(x_i,\vec{k}_{\perp i}) \quad (3)$$

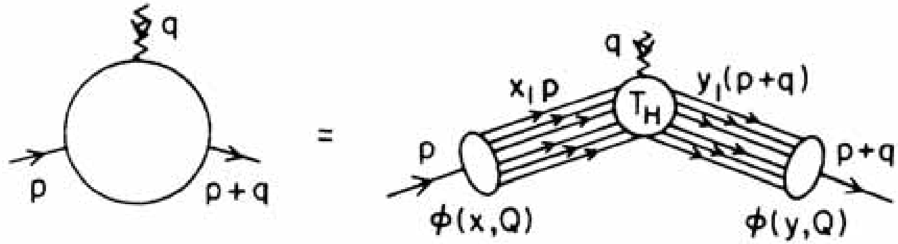


FIG. 1. The general structure of the deuteron form factor at large Q^2.

Ji, Lepage, sjb

QCD Prediction for Deuteron Form Factor

$$F_d(Q^2) = \left[\frac{\alpha_s(Q^2)}{Q^2}\right]^5 \sum_{m,n} d_{mn} \left(\ln \frac{Q^2}{\Lambda^2}\right)^{-\gamma_n{}^d - \gamma_m{}^d} \left[1 + O\left(\alpha_s(Q^2), \frac{m}{Q}\right)\right]$$

Define "Reduced" Form Factor

$$f_d(Q^2) \equiv \frac{F_d(Q^2)}{F_N{}^2(Q^2/4)} .$$

Same large momentum transfer behavior as pion form factor

$$f_d(Q^2) \sim \frac{\alpha_s(Q^2)}{Q^2} \left(\ln \frac{Q^2}{\Lambda^2}\right)^{-(2/5)\, C_F/\beta}$$

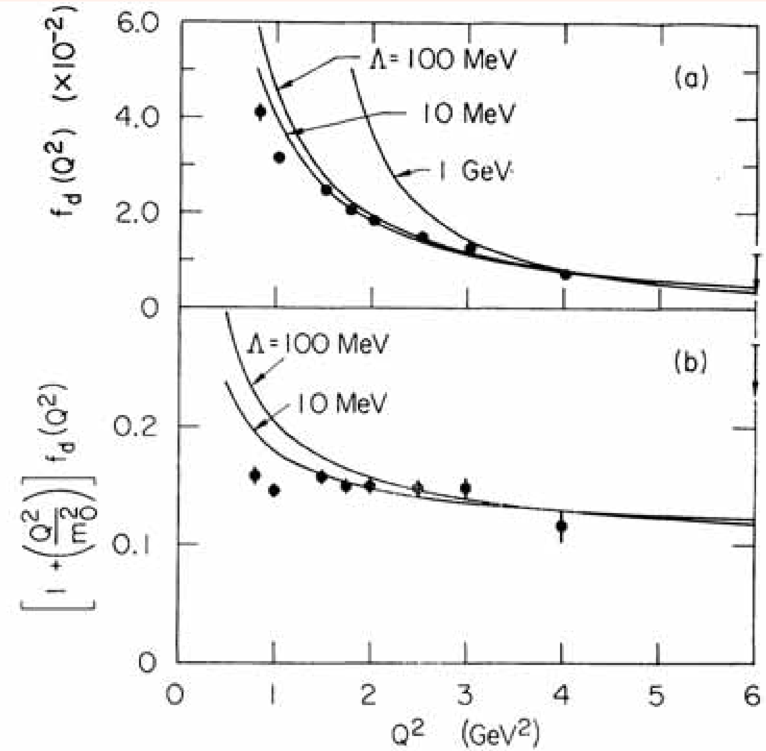
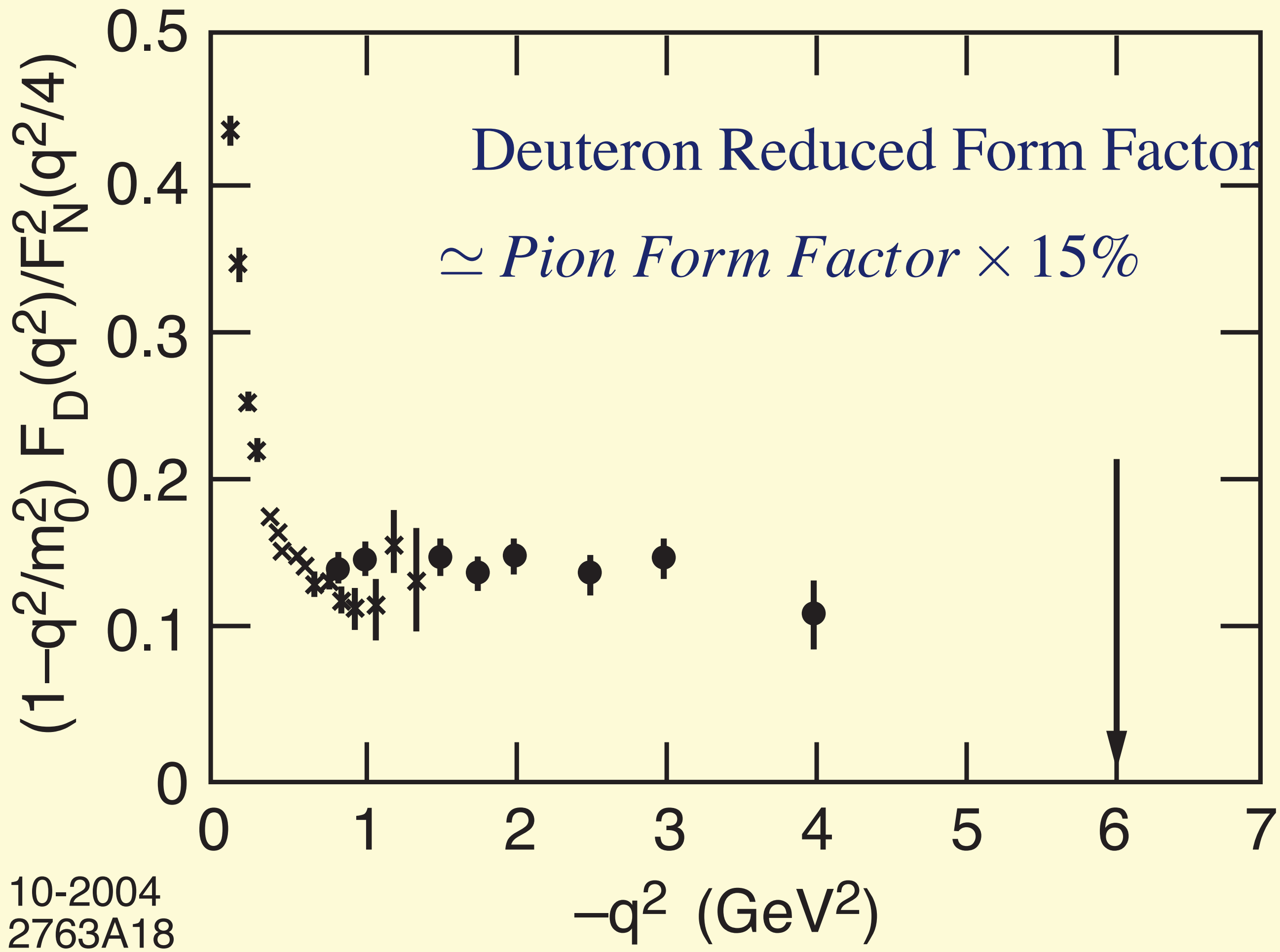


FIG. 2. (a) Comparison of the asymptotic QCD prediction $f_d(Q^2) \propto (1/Q^2)[\ln(Q^2/\Lambda^2)]^{-1-(2/5)C_F/\beta}$ with final data of Ref. 10 for the reduced deuteron form factor, where $F_N(Q^2) = [1 + Q^2/(0.71\ \text{GeV}^2)]^{-2}$. The normalization is fixed at the $Q^2 = 4$ GeV^2 data point. (b) Comparison of the prediction $[1 + (Q^2/m_0{}^2)] f_d(Q^2) \propto [\ln(Q^2/\Lambda^2)]^{-1-(2/5)C_F/\beta}$ with the above data. The value $m_0{}^2 = 0.28$ GeV^2 is used (Ref. 8).



- 15% Hidden Color in the Deuteron

Test Hidden Color of Deuteron

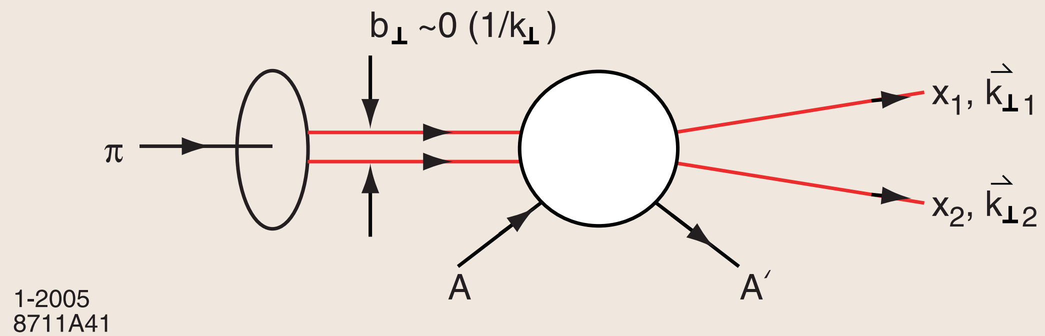
- Diffractive, Coulomb Dissociation to $\Delta^{++}\,\Delta^{-}$
- Photodisintegration of Deuteron to $\Delta^{++}\,\Delta^{-}$
- Connection to EMC
- Deuteron not simply n + p

Use Diffraction to Resolve Hadron Substructure

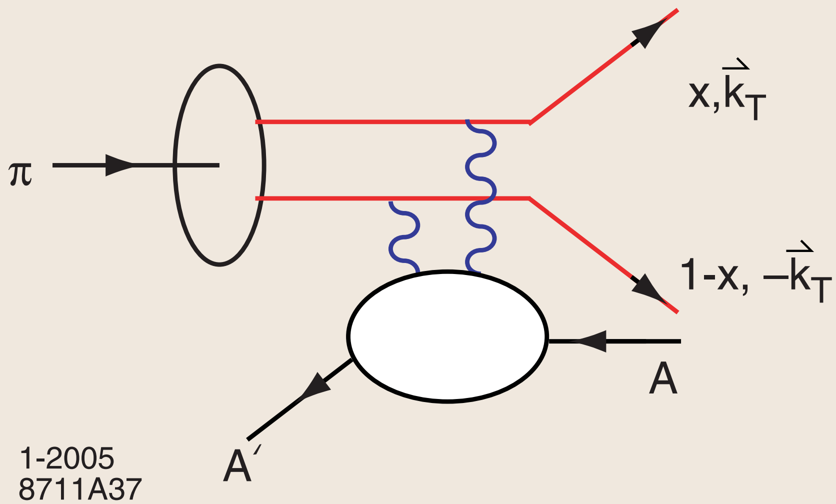
- Measure Light-Front Wavefunctions
- Test AdS/CFT predictions
- Novel Aspects of Hadron Wavefunctions: Intrinsic Charm, Hidden Color, Color Transparency/Opaqueness
- Diffractive Di-Jet Production
- Nuclear Shadowing and Antishadowing
- New Mechanism for Higgs Production

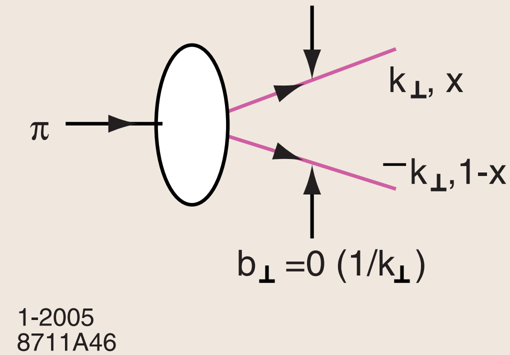
Diffractive Dissociation of Pion

E791 Ashery et al.



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

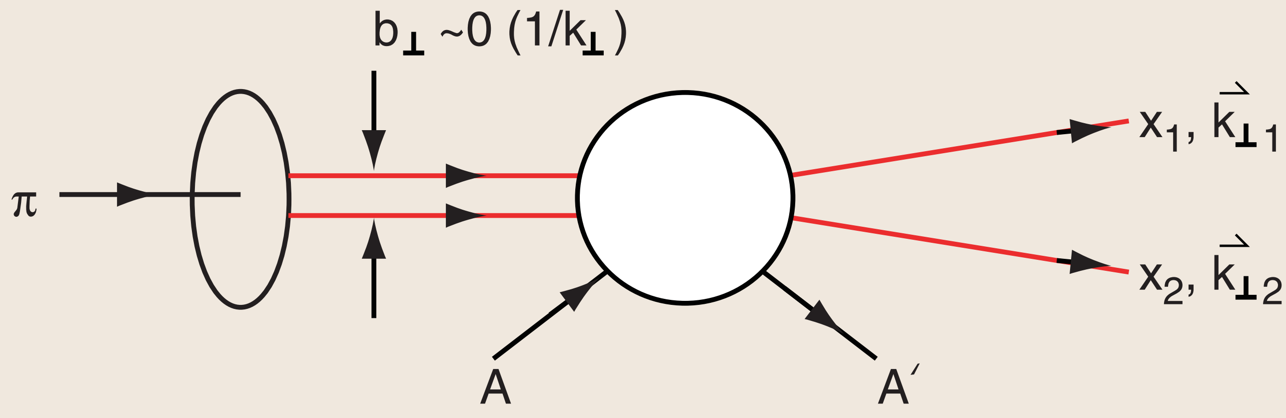




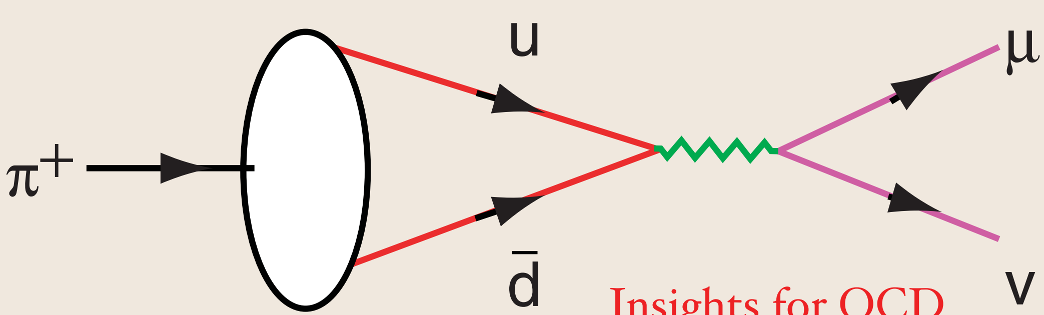
- Small Size Pion Valence Fock State
- Color Transparent
- E791 Fermilab Experiment

See: D. Ashery Talk

Fluctuation of a Pion to a Compact Color Dipole State



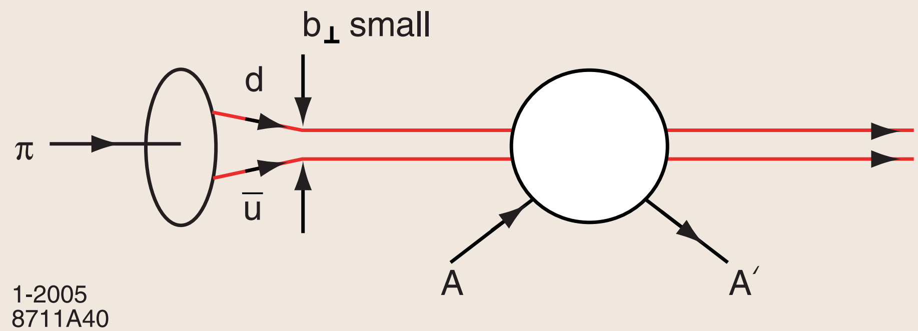
Color-Transparent Fock State For High Transverse Momentum Di-Jets



Same Fock State Determines Weak Decay

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.**

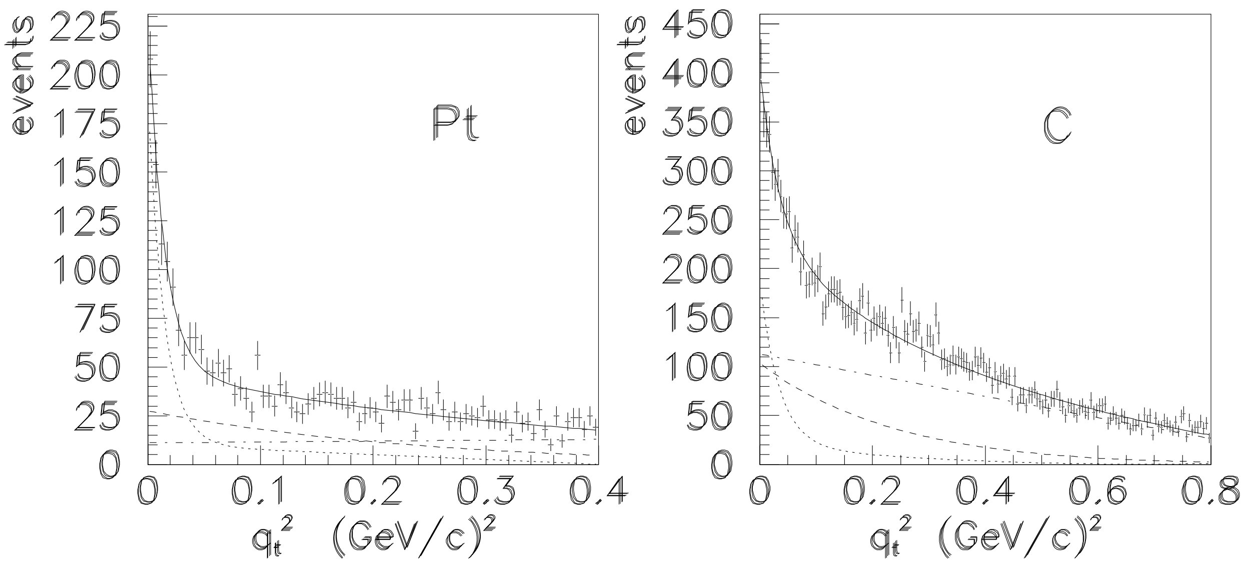
- **Emerging Di-Jets do not interact with nucleus.**

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

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

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

E791 Collaboration, E. Aitala *et al.*, Phys. Rev. Lett. 86, 4773 (2001)



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)	α	α (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

α (Incoh.) = 0.70 $\pm$ 0.1

Conventional Glauber Theory Ruled Out !

Factor of 7

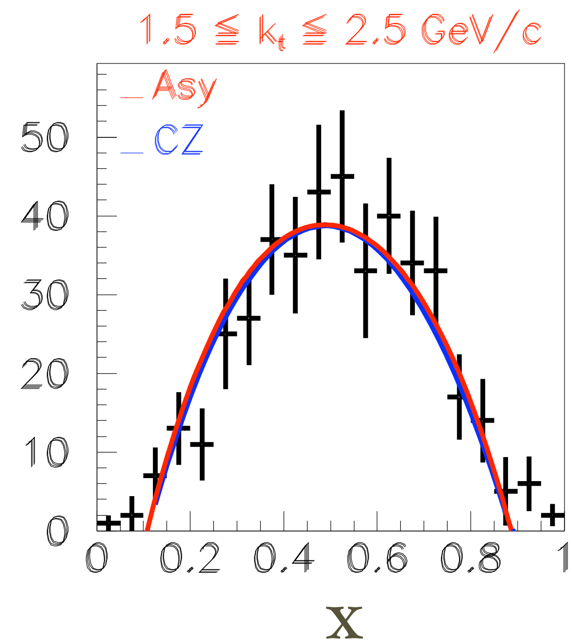
FermiLab E791
Ashery et al

Diffractive Dissociation of a Pion into Dijets

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

- 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

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



Diffractive Dissociation of Pion into Di-Jets

- Verify Color Transparency
- Pion Interacts coherently on each nucleon of nucleus!

$M \propto A, \; \sigma \propto A^2$

- Pion Distribution similar to Asymptotic Form

$$\psi(x, k_\perp) \propto x(1-x)$$

May be broader at endpoints

- Scaling in transverse momentum consistent with PQCD

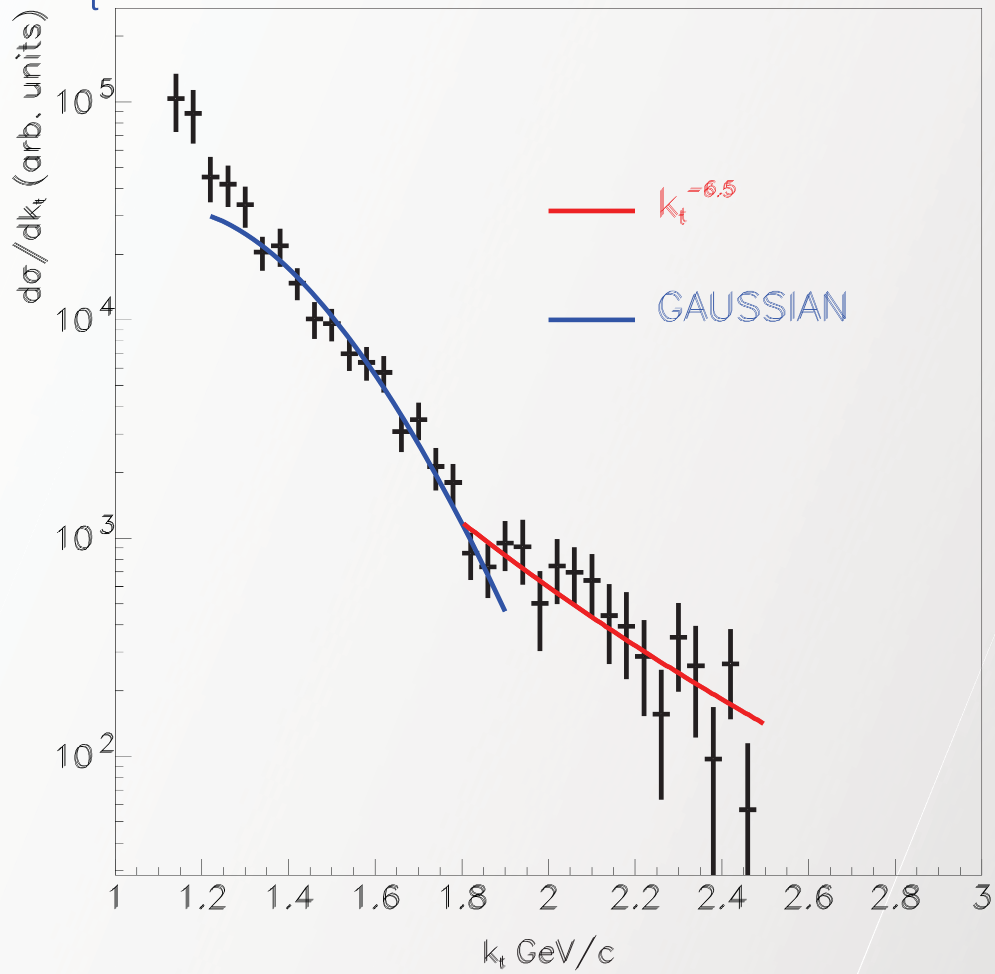
New program at ZEUS

- Diffractive dijet production from photon
- Diffractive dipion production

THE k_t DEPENDENCE OF DI-JETS YIELD

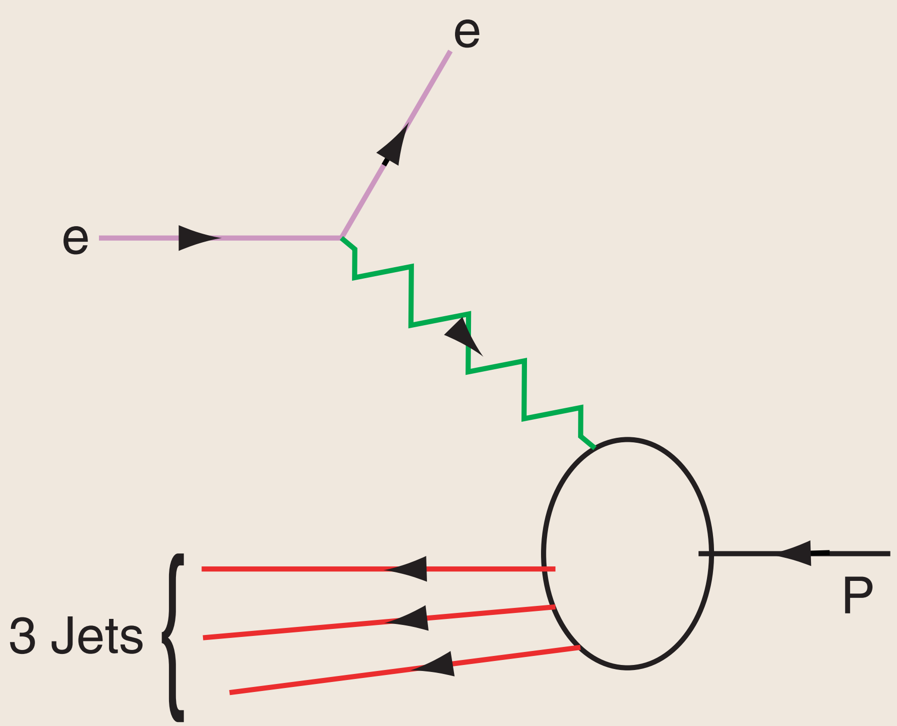
$$\frac{d\sigma}{dk_t^2} \propto \left|\alpha_s(k_t^2) G(x, k_t^2)\right|^2 \left|\frac{\partial^2}{\partial k_t^2}\psi(u, k_t)\right|^2$$

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/ AdS/CFT

Coulomb Dissociate Proton to Three Jets at HERA



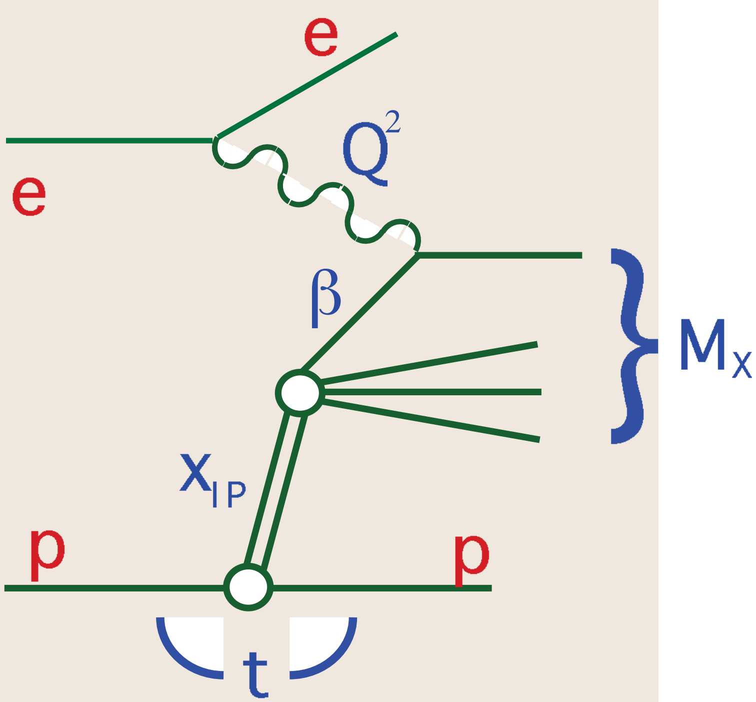
Frankfurt
Strikman
Miller

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

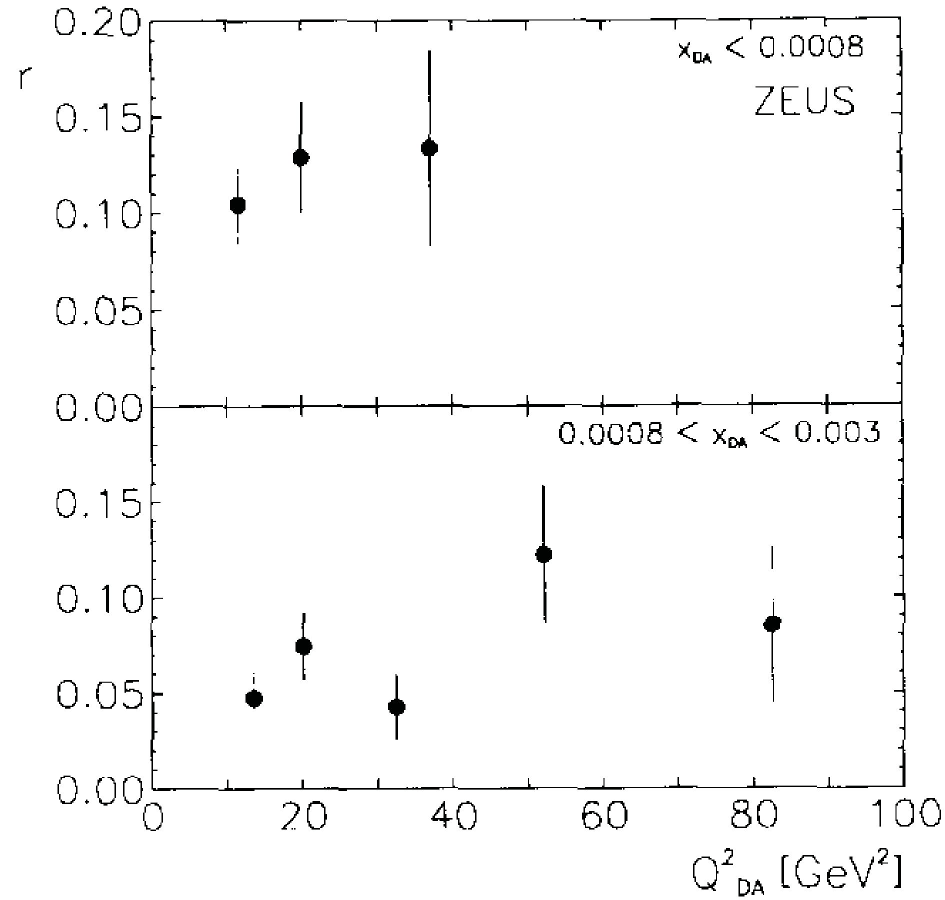
Hard Diffraction from Rescattering

- Diffractive DIS: New Insight into Final State Interactions in QCD
- Origin of Hard Pomeron
- Structure Functions not Probability Distributions
- T-odd Single-Spin Asymmetries
- Diffractive dijets/ trijets
- Color Transparency, Color Opaqueness

Remarkable observation at HERA



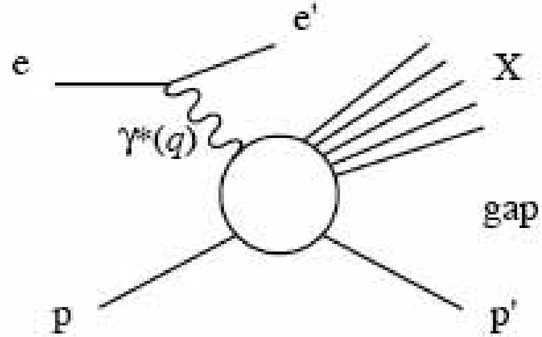
10% of DIS events are diffractive !



Fraction r of events with a large rapidity gap, $\eta_{\max} < 1.5$, as a function of $Q^2_{\rm DA}$ for two ranges of $x_{\rm DA}$. No acceptance corrections have been applied.

M. Derrick et al. [ZEUS Collaboration], Phys. Lett. B 315, 481 (1993).

DDIS

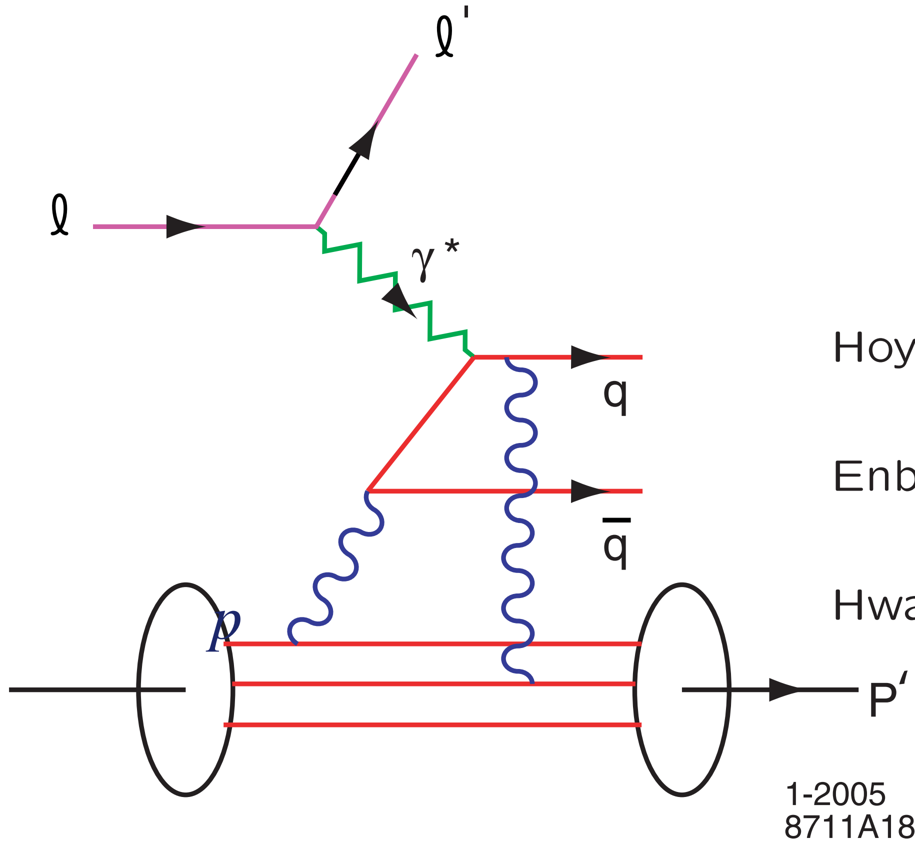


- In a large fraction ($\sim$ 10–15%) of DIS events, the proton escapes intact, keeping a large fraction of its initial momentum
- This leaves a large *rapidity gap* between the proton and the produced particles
- The t-channel exchange must be *color singlet* → a pomeron??

Enberg

Diffractive Deep Inelastic Lepton-Proton Scattering

Final State Interaction Produces Diffractive DIS

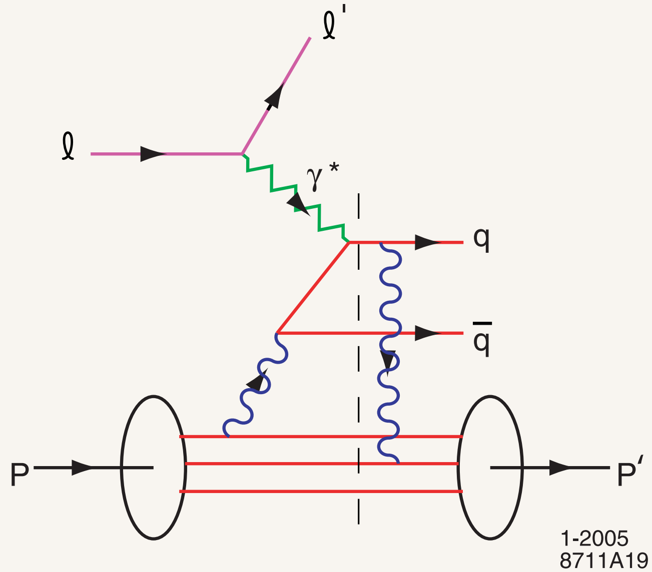


Quark Rescattering

Hoyer, Marchal, Peigne, Sannino, SJB (BHM

Enberg, Hoyer, Ingelman, SJB

Hwang, Schmidt, SJB

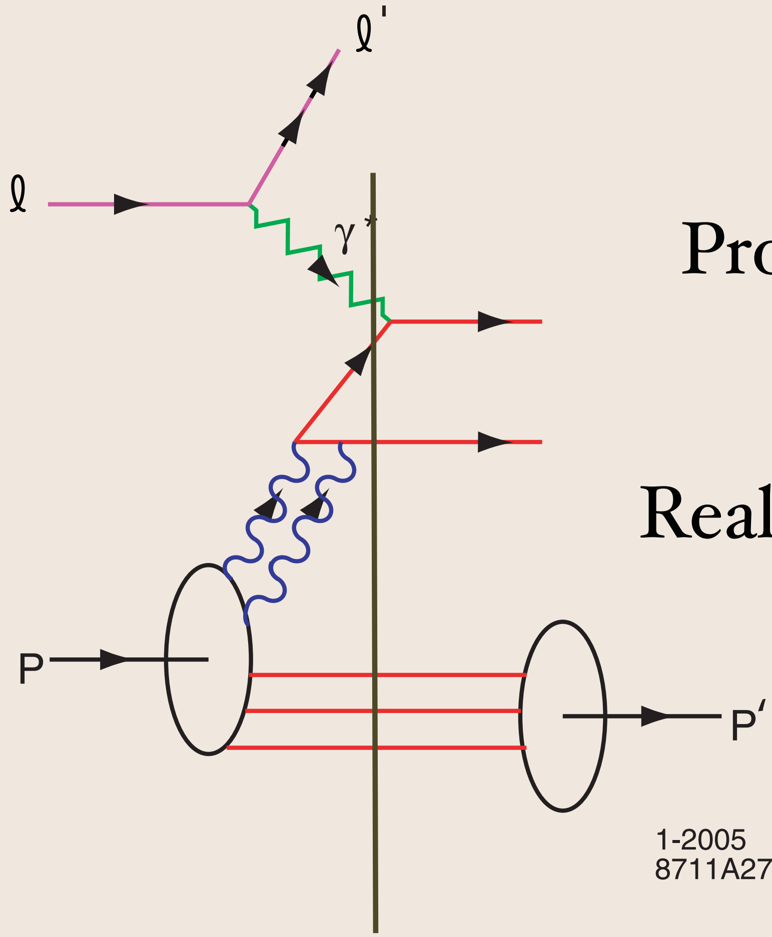


Integration over on-shell domain produces phase i

Need Imaginary Phase to Generate Pomeron

Need Imaginary Phase to Generate T-Odd Single-Spin Asymmetry

Physics of FSI not in Wavefunction of Target



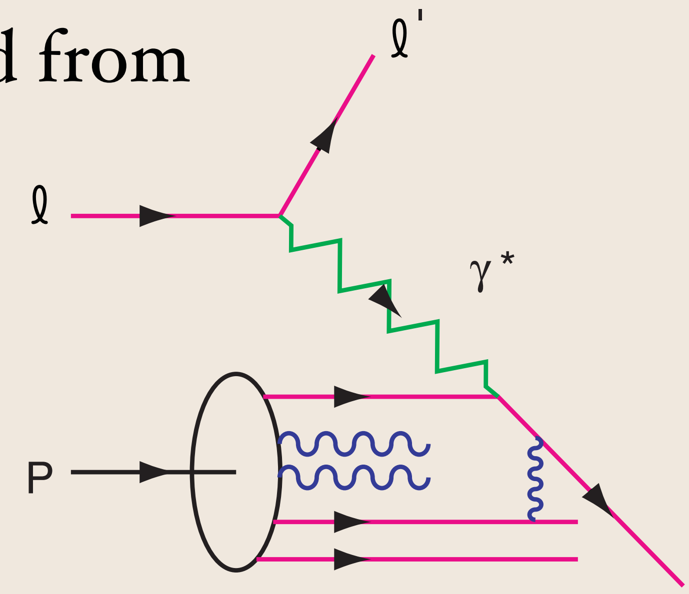
Problem: Wrong Phase

Real; should be imaginary

Pomeron is not a constituent of proton!

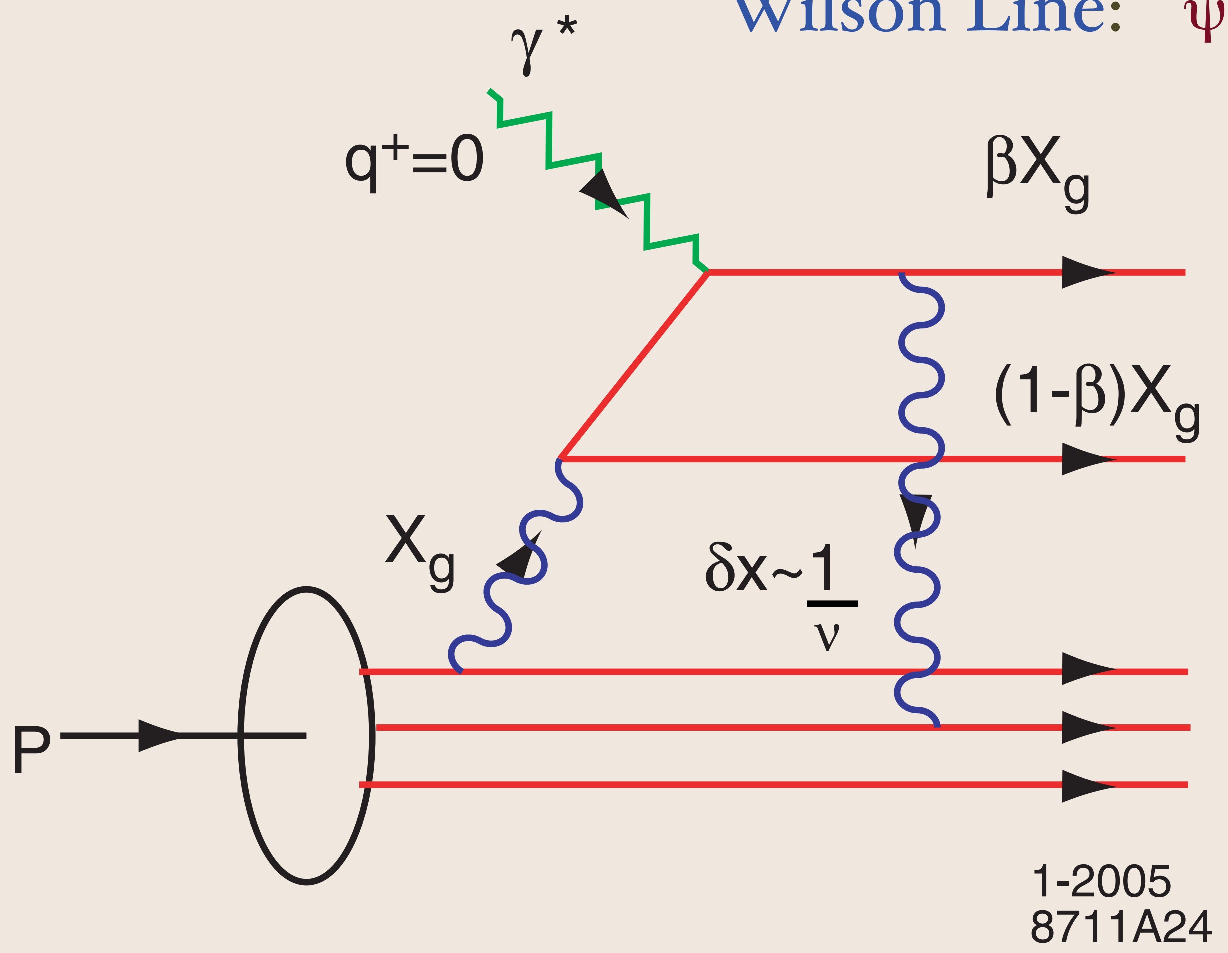
Need Final State Interactions !

- Quarks Reinteract in Final State
- Analogous to Coulomb phases, but not unitary
- Observable effects: DDIS, SSI, shadowing, antishadowing
- Structure functions cannot be computed from LFWFs computed in isolation
- Wilson line not 1 even in lcg



QCD Mechanism for Rapidity Gaps

Wilson Line: $\overline{\psi}(y) \int_0^y dx\, e^{iA(x)\cdot dx}\, \psi(0)$



QCD at The Amplitude Level

- Light-Front Fock Expansions
- LFWFs boost invariant
- Direct connection to form factors, structure functions, distribution amplitudes, GPDs
- Higher Twist Correlations
- Orbital Angular Momentum
- Validated in QED, Bethe-Salpeter
- AdS/CFT Holographic Model

Physics of Rescattering

- Diffractive DIS: New Insight into Final State Interactions in QCD
- Origin of Hard Pomeron
- Structure Functions not Probability Distributions
- T-odd SSAs, Shadowing, Antishadowing
- Diffractive dijets/ trijets, doubly diffractive Higgs
- Novel Effects: Color Transparency, Color Opaqueness, Intrinsic Charm, Odderon

Compute LFWFs from First Principles

- Very difficult using Euclidean lattice
- Discretized light-cone quantization: Diagonalize light-cone Hamiltonian
- Bethe-Salpeter Dyson-Schwinger Equations
- Transverse lattice
- AdS/CFT guidance: Initial Approximation

New Perspectives for QCD from AdS/CFT

- LFWFs: Fundamental description of hadrons at amplitude level
- QCD is Nearly Conformal
- Holographic Model from AdS/CFT : Confinement at large distances and conformal behavior at short distances
- Model for LFWFs, meson and baryon spectra
- Physics similar to MIT bag model, but covariant. No problem with support $0 < x < 1$.
- Quark Interchange dominant force at short distances

Outlook

- Only one scale Λ_{QCD} determines hadronic spectrum (slightly different for mesons and baryons).
- Ratio of Nucleon to Delta trajectories determined by zeroes of Bessel functions.
- String modes dual to baryons extrapolate to three fermion fields at zero separation in the AdS boundary.
- Only dimension $3, \frac{9}{2}$ and 4 states $\overline{q}q$, qqq, and gg appear in the duality at the classical level!
- Non-zero orbital angular momentum and higher Fock-states require introduction of quantum fluctuations.
- Simple description of space and time-like structure of hadronic form factors.
- Dominance of quark-interchange in hard exclusive processes emerges naturally from the classical duality of the holographic model. Modified by gluonic quantum fluctuations.
- Covariant version of the bag model with confinement and conformal symmetry.

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

QCD

- Basic theory underlying all of hadron and nuclear physics
- Remarkable Phenomena: Confinement, Diffractive DIS, Chiral Symmetry Breaking, QGP, Hidden Color, Intrinsic Heavy Quarks, Color Transparency
- New Effects from orbital angular momentum + ISI and FSI --> SSA's
- QCD at the amplitude level: LFWFs
- New insights from conformal theory: ADS/CFT
- Conformal Template and Commensurate Scale Relations; Elimination of renormalization scale ambiguities
- Zero color limit
- Exploration of QCD just beginning!