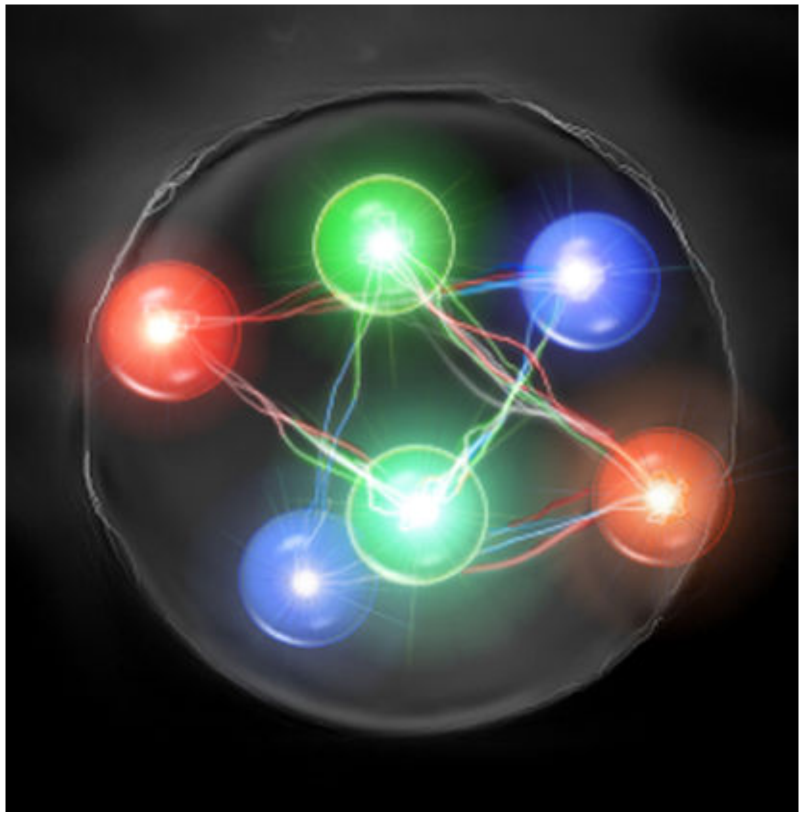
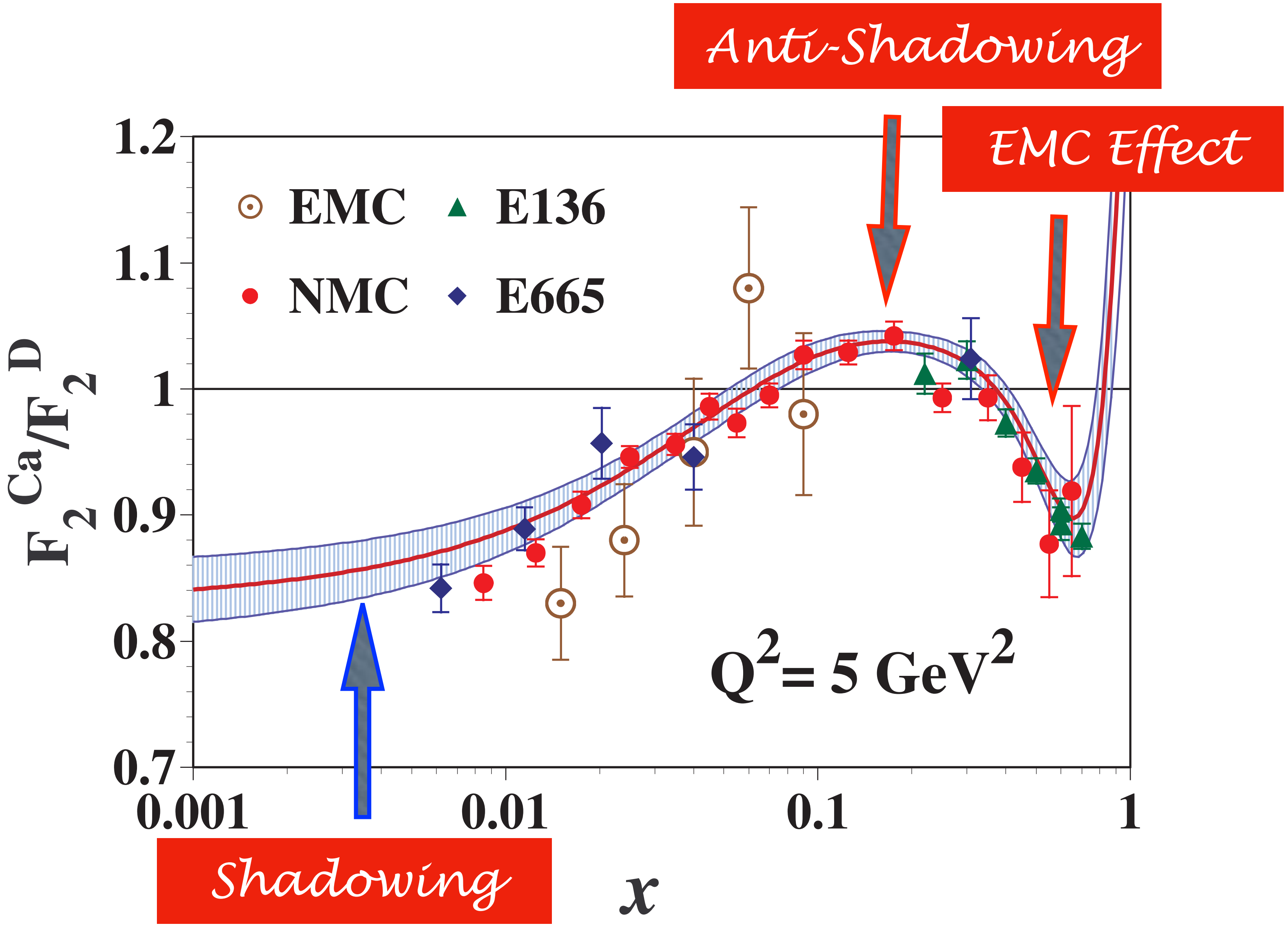
Novel QCD Features of Nuclei



Hidden Color



Stan Brodsky

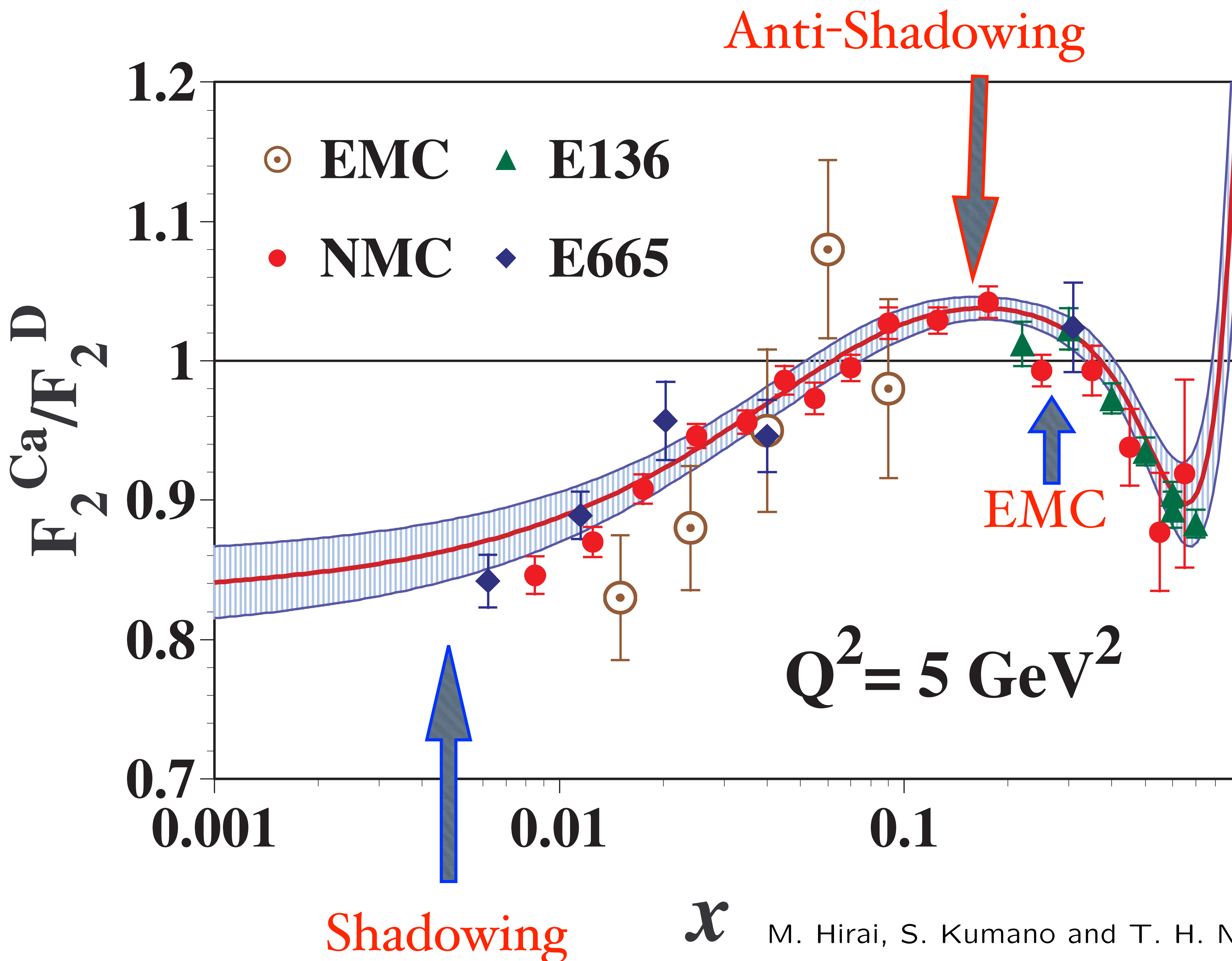
SLAC NATIONAL ACCELERATOR LABORATORY

LELAND STANFORD JUNIOR UNIVERSITY · DIE LUFT DER FREIHEIT WEHT · 1891

GHP-APS

8th Workshop of the APS Topical Group on Hadronic Physics

Denver
Wednesday, 10 April 2019



M. Hirai, S. Kumano and T. H. Nagai,
"Nuclear parton distribution functions
and their uncertainties,"
Phys. Rev. C **70**, 044905 (2004)
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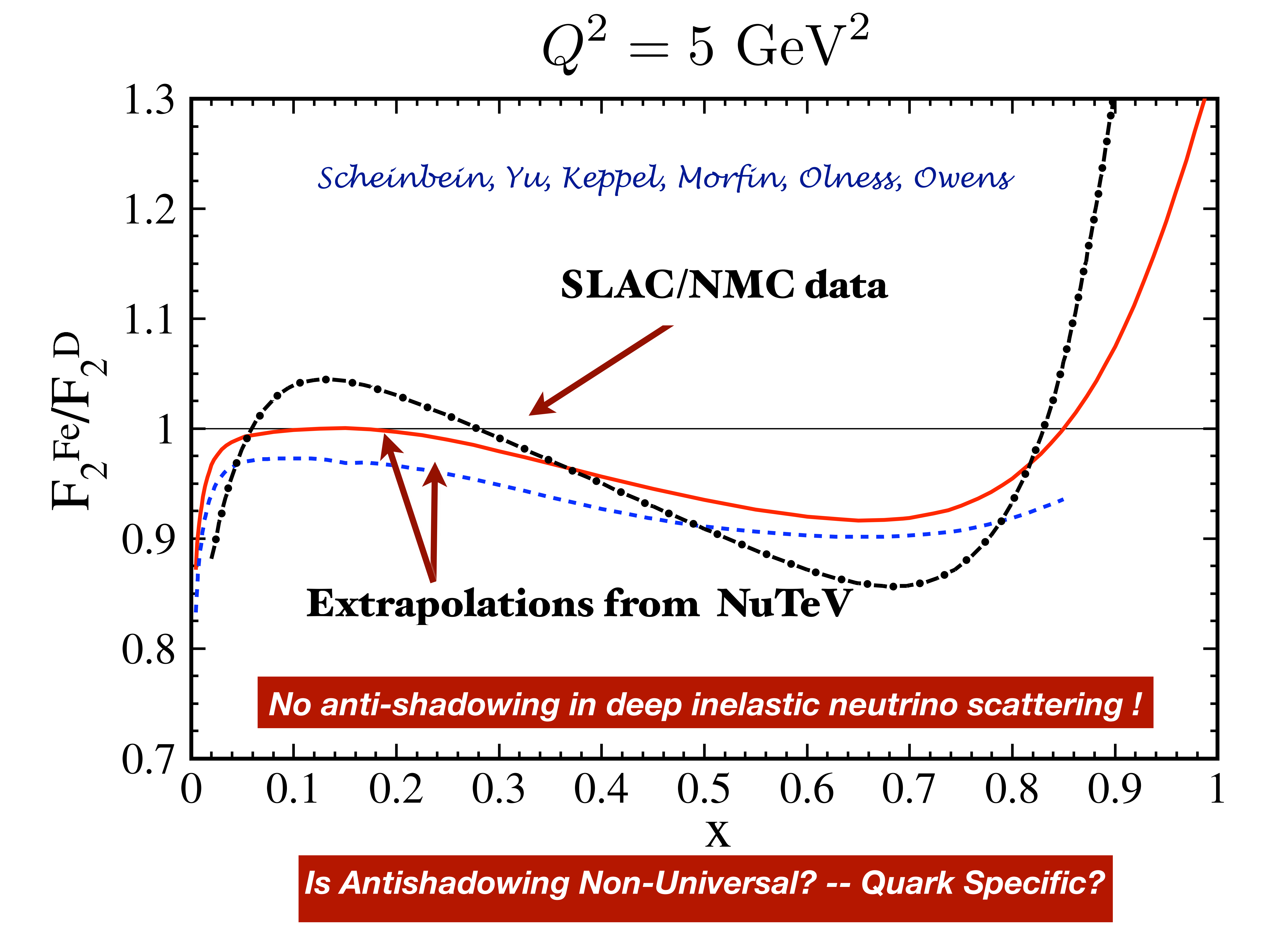
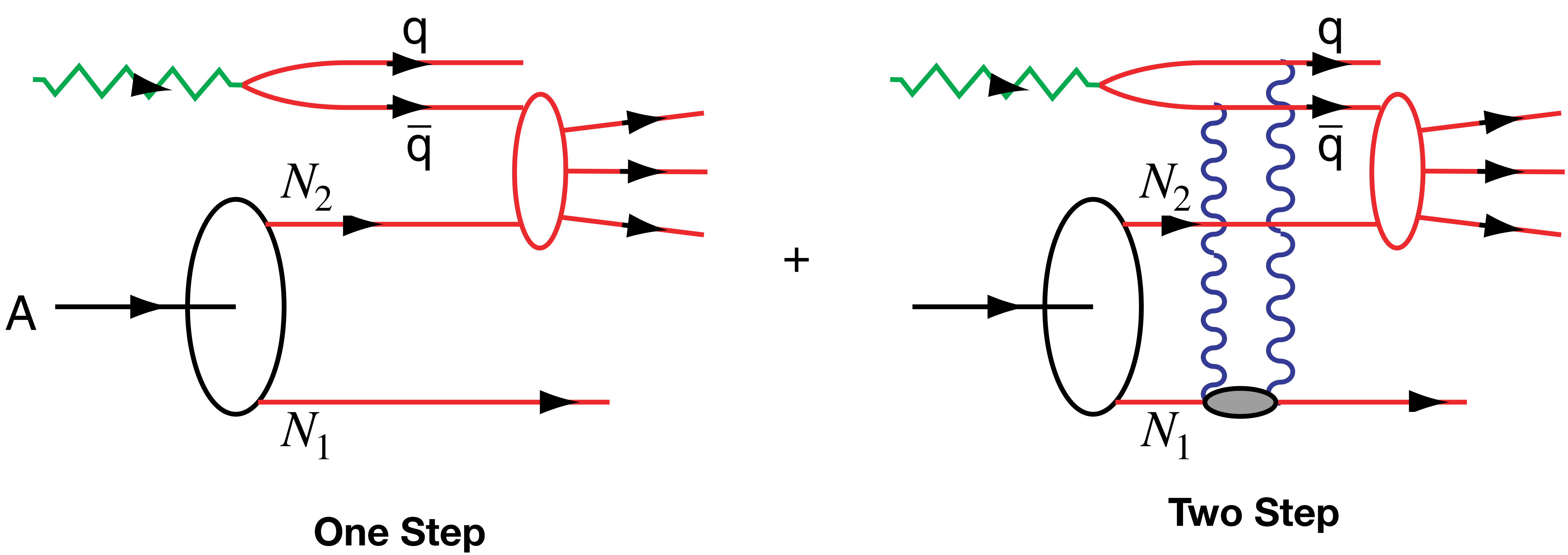


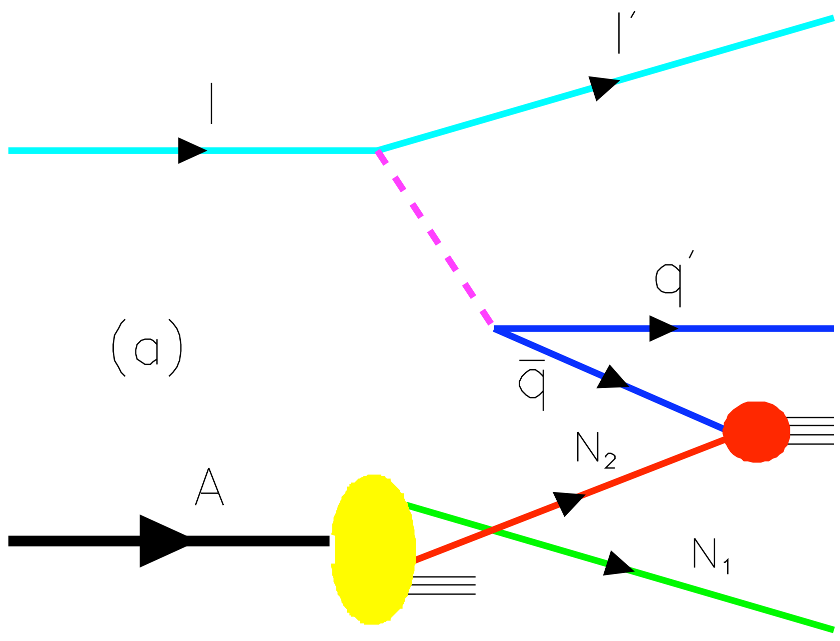
$Q^2 = 5\ \mathrm{GeV}^2$
Scheinbein, Yu, Keppel, Morfin, Olness, Owens
SLAC/NMC data
Extrapolations from NuTeV
No anti-shadowing in deep inelastic neutrino scattering !
F_2^{Fe}/F_2^{D}
x
1.3
1.2
1.1
1
0.9
0.8
0.7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Is Antishadowing Non-Universal? -- Quark Specific?

Stodolsky
Pumplin, sjb
Gribov

Theory of Nuclear Shadowing in DIS

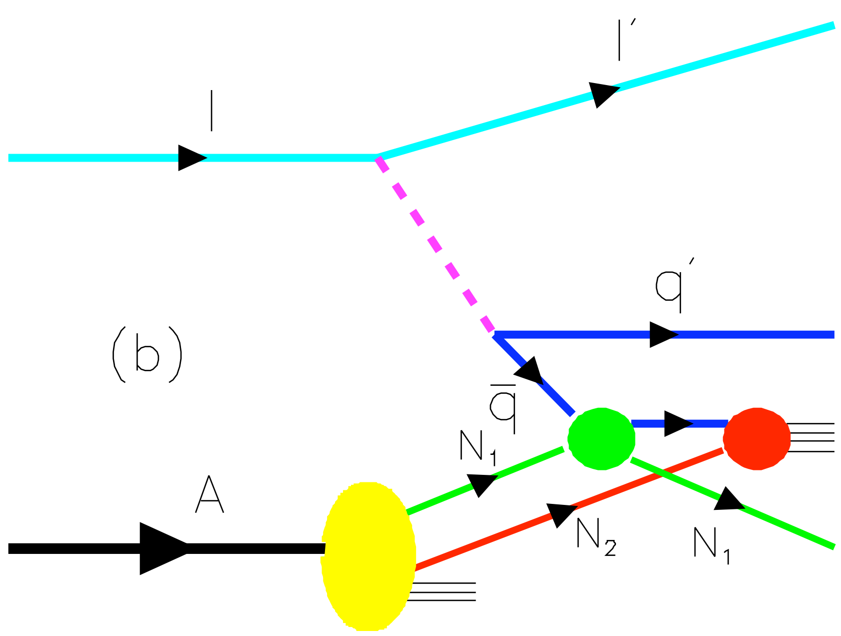


Shadowing depends on understanding leading twist-diffraction in DIS



The one-step and two-step processes in DIS on a nucleus.

Coherence at small Bjorken x_B :
$1/Mx_B = 2\nu/Q^2 \geq L_A$.



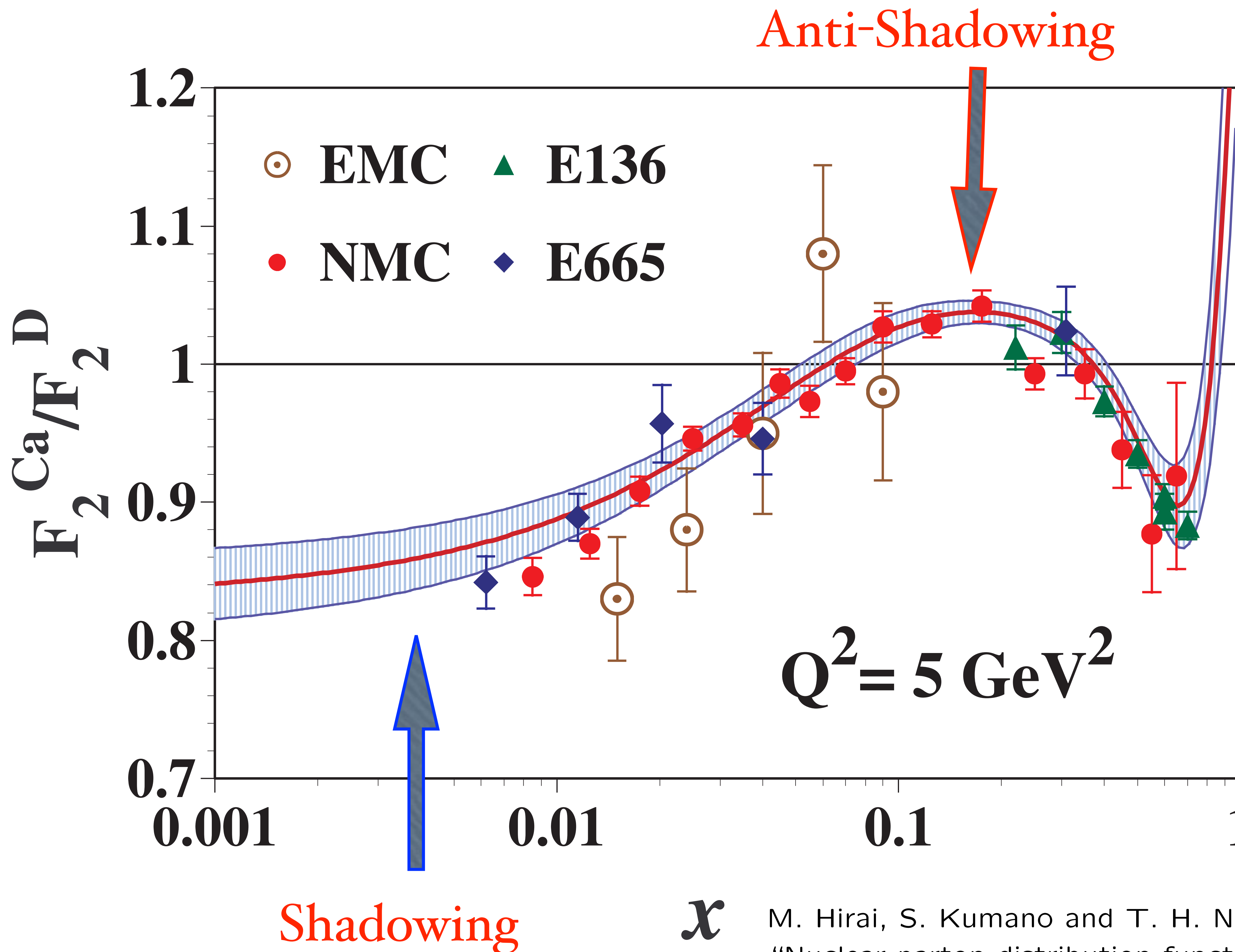
If the scattering on nucleon N_1 is via pomeron exchange, the one-step and two-step amplitudes are opposite in phase, thus diminishing the $\overline{q}$ flux reaching N_2.

$\rightarrow$ Shadowing of the DIS nuclear structure functions.

Diffraction via Pomeron gives destructive interference!

Shadowing

Shadowing depends on understanding leading twist-diffraction in DIS



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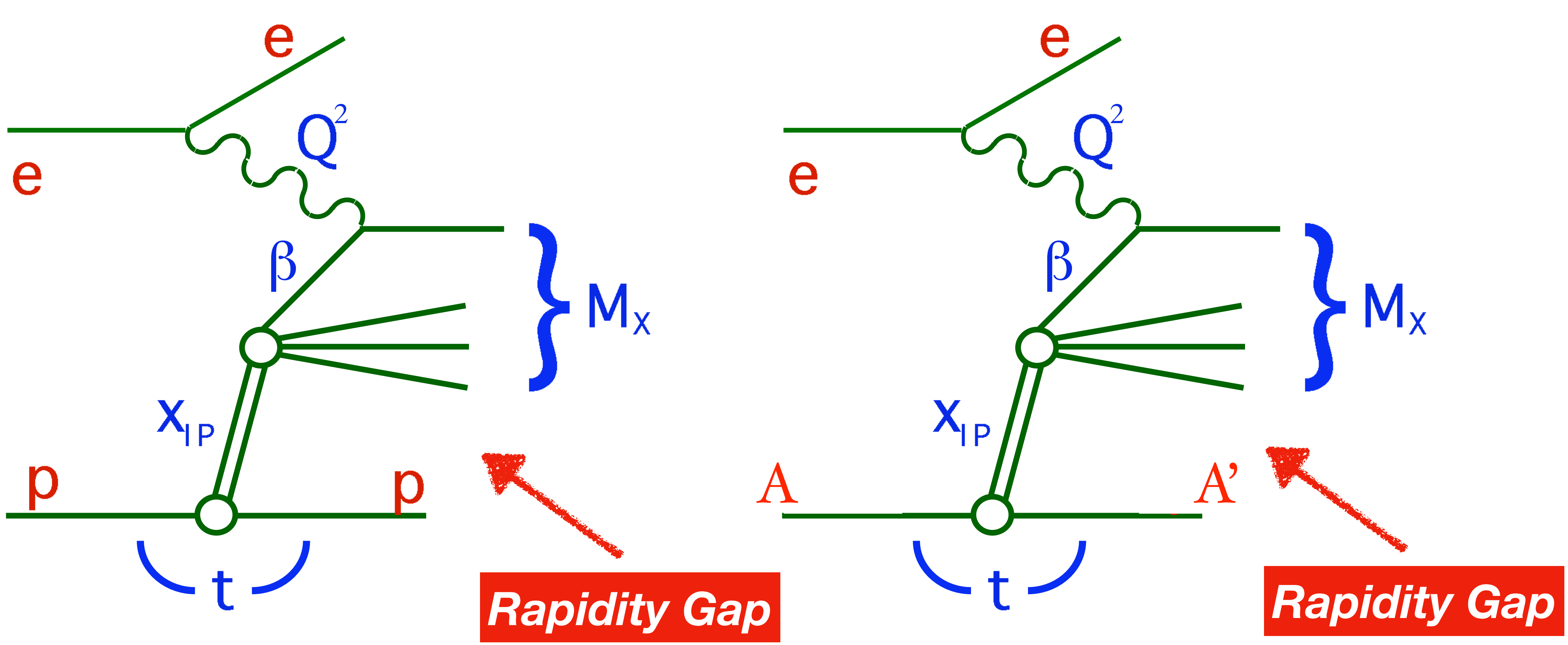
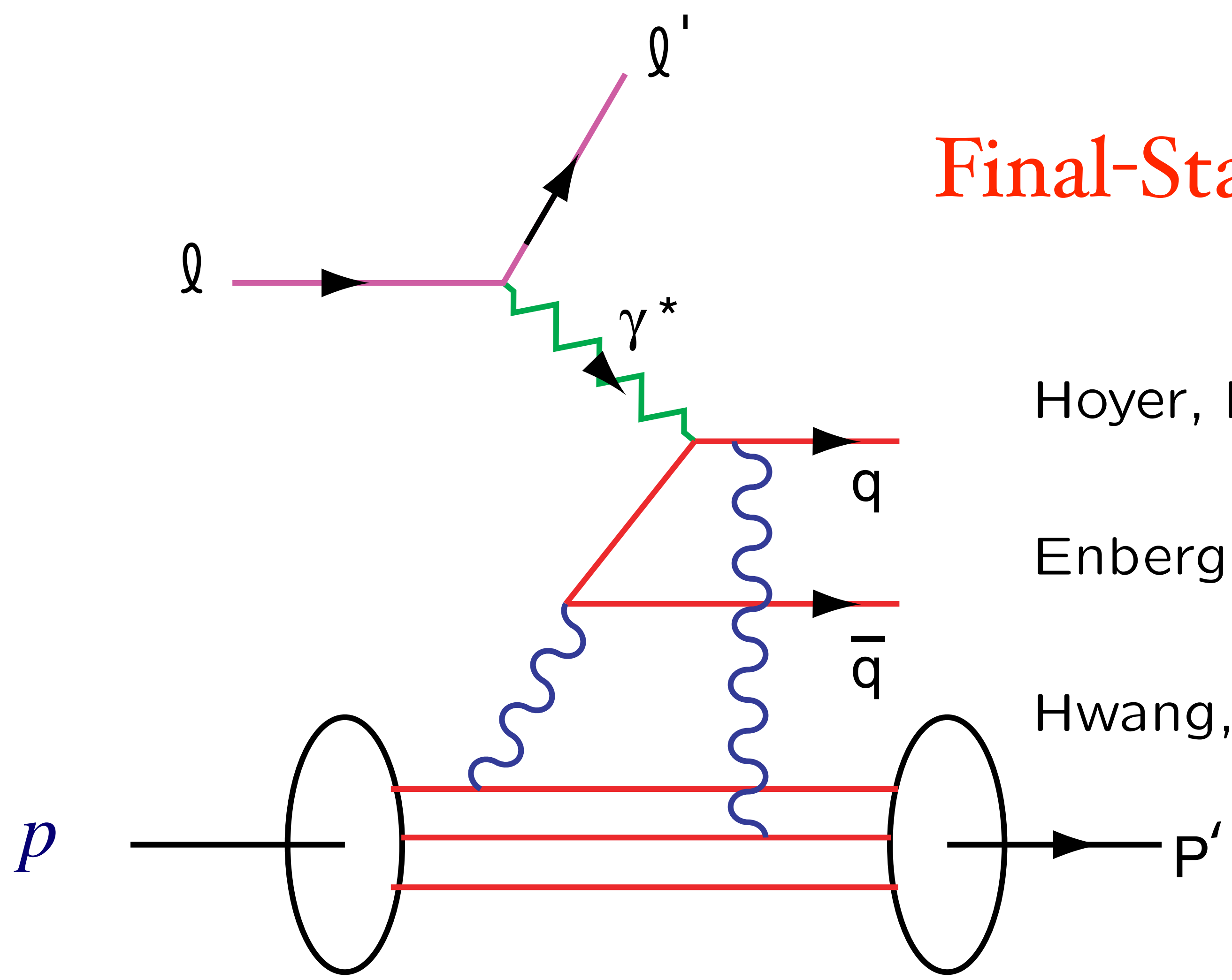
Diffractive Deep Inelastic Scattering

Diffractive DIS $ep \to epX$ where there is a large rapidity gap and the target nucleon remains intact probes the final state interaction of the scattered quark with the spectator system via gluon exchange.

Diffractive DIS on nuclei $eA \to e' AX$ and hard diffractive reactions such as $\gamma^* A \to VA$ can occur coherently leaving the nucleus intact.



Diffractive Structure Function



Final-State Quark Rescattering

Hoyer, Marchal, Peigne, Sannino, SJB (BHMPS)

Enberg, Hoyer, Ingelman, SJB

Hwang, Schmidt, SJB

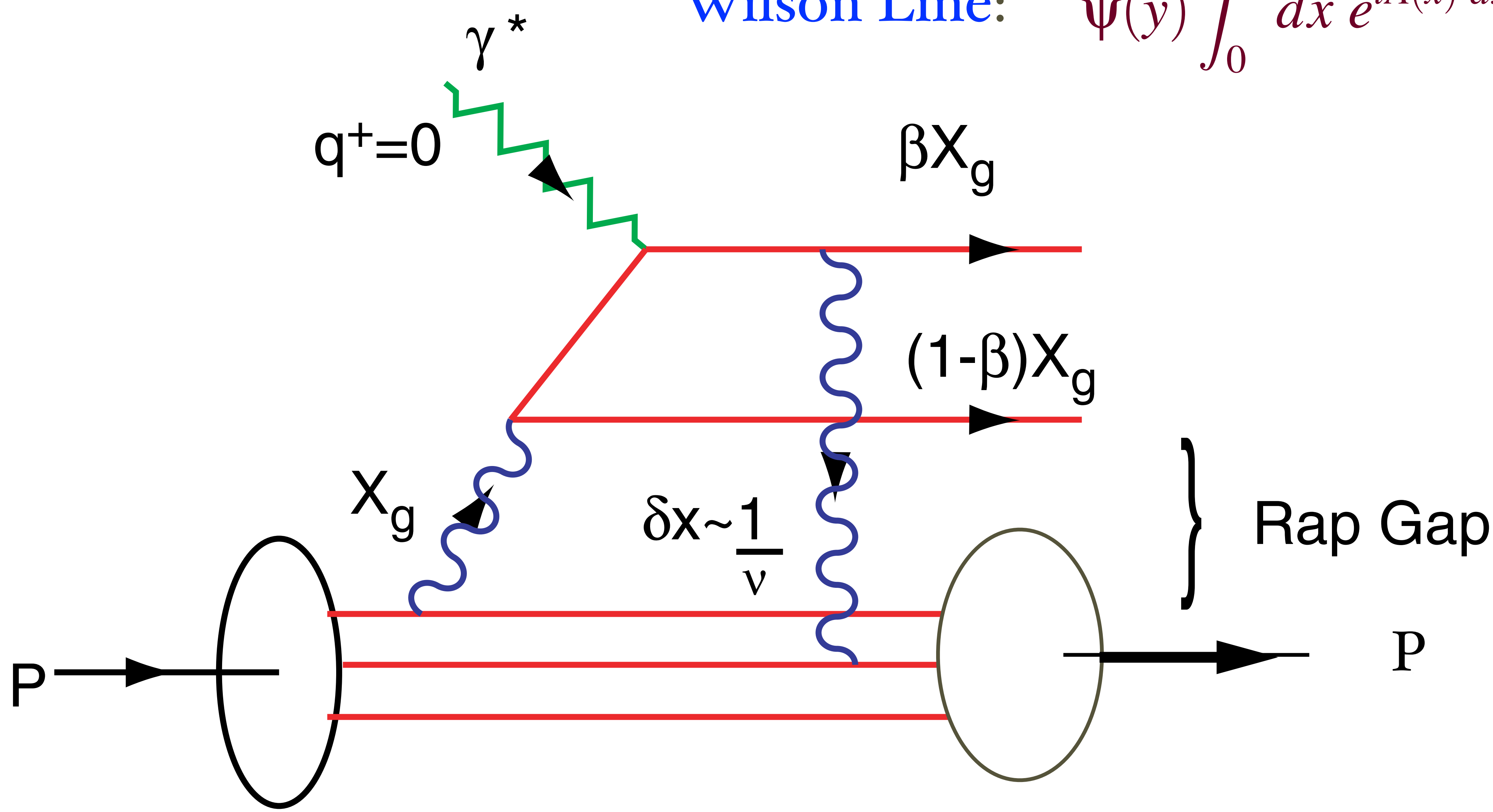
Low-Nussinov model of Pomeron

Same final-state interaction produces Sivers Effect

Hoyer, Marchal, Peigne, Sannino, sjb

QCD Mechanism for Rapidity Gaps

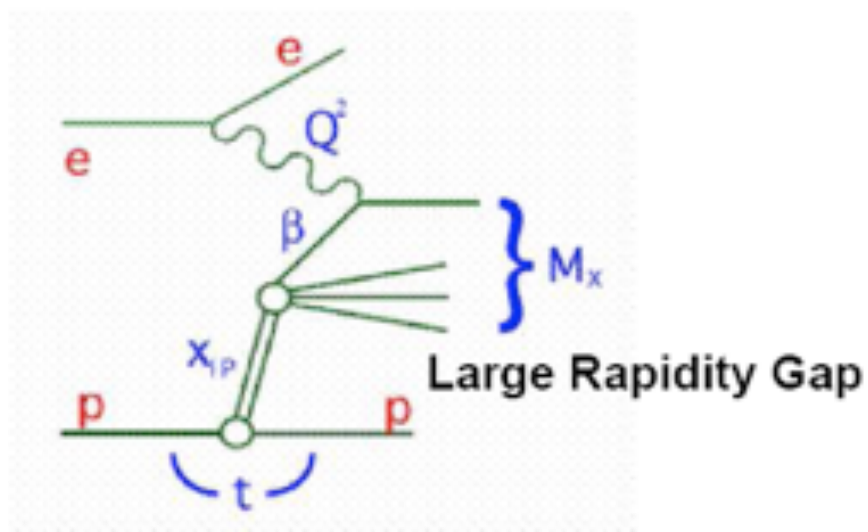
Wilson Line: $\overline{\psi}(y) \int_0^y dx\, e^{iA(x)\cdot dx}\, \psi(0)$



Reproduces lab-frame color dipole approach
DDIS: Input for leading twist nuclear shadowing

DDIS: Diffractive Deep Inelastic Scattering de Roeck

Diffractive Structure Function F_2^D



Diffractive inclusive cross section

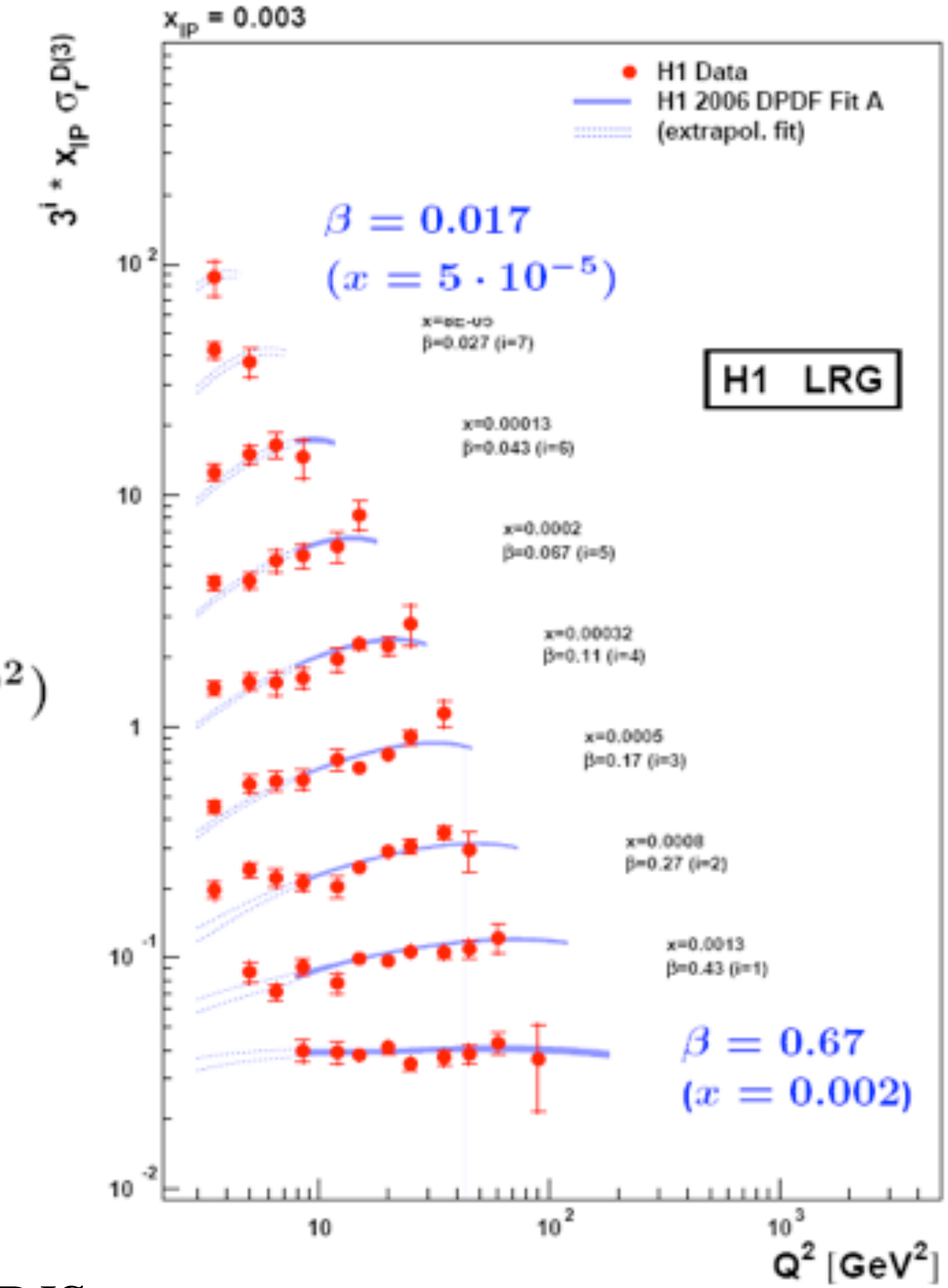
$$\frac{d^3\sigma_{NC}^{diff}}{dx_{I\!P}\, d\beta\, dQ^2} \propto \frac{2\pi\alpha^2}{xQ^4} F_2^{D(3)}(x_{I\!P}, \beta, Q^2)$$

$$F_2^D(x_{I\!P}, \beta, Q^2) = f(x_{I\!P}) \cdot F_2^{I\!P}(\beta, Q^2)$$

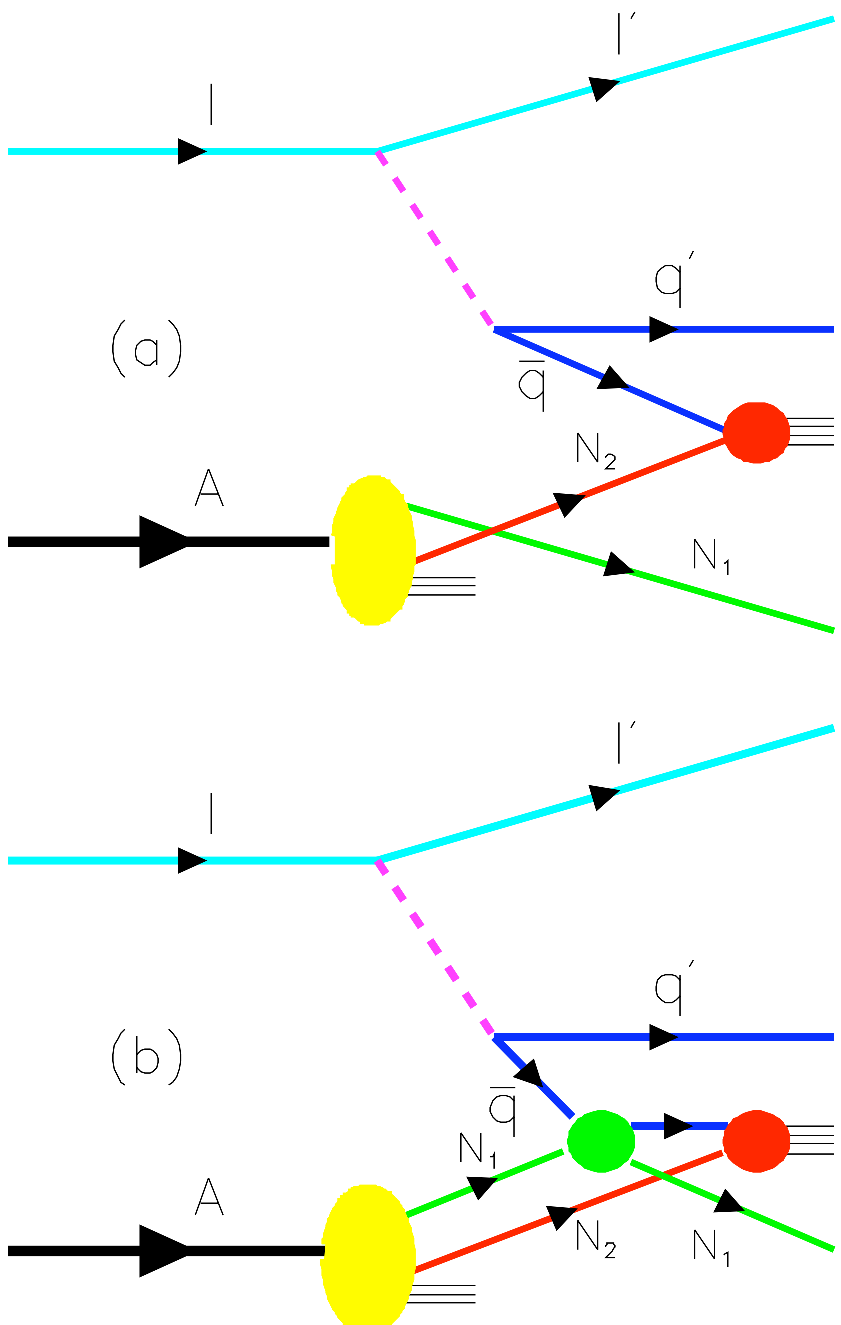
extract DPDF and $xg(x)$ from scaling violation

Large kinematic domain $3 < Q^2 < 1600\ \mathrm{GeV}^2$

Precise measurements *sys 5%, stat 5–20 %*



DDIS ~ 10 % of DIS rate



The one-step and two-step processes in DIS on a nucleus.

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$1/Mx_B = 2\nu/Q^2 \geq L_A$.

If the scattering on nucleon N_1 is via pomeron exchange, the one-step and two-step amplitudes are opposite in phase, thus diminishing the $\overline{q}$ flux reaching N_2.

Interior nucleons shadowed

→ Shadowing of the DIS nuclear structure functions.

Observed HERA DDIS produces nuclear shadowing

Single-spin asymmetries

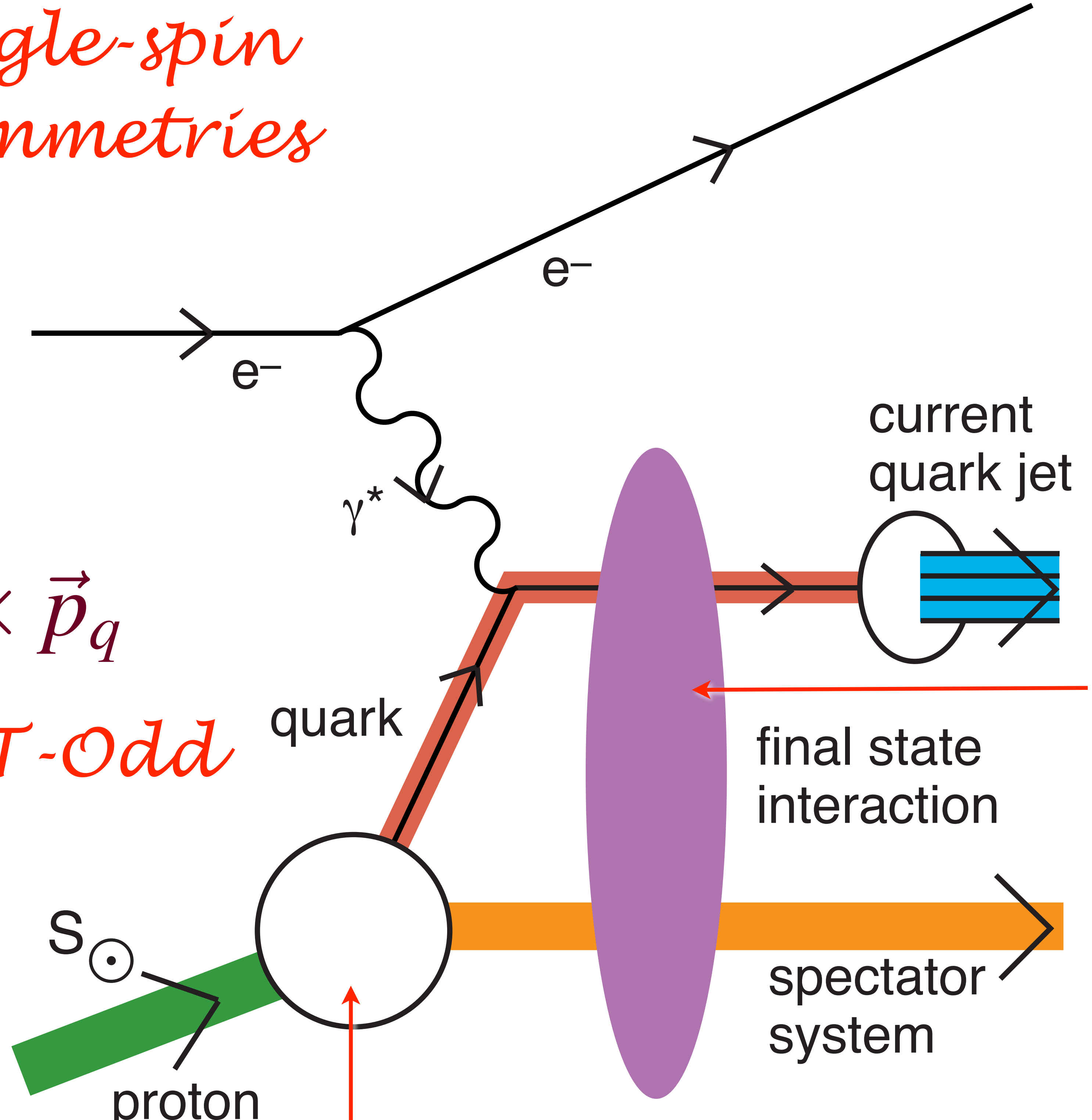
Leading Twist Sivers Effect

Hwang, Schmidt, sjb

Collins, Burkardt, Ji, Yuan. Pasquini, ...

$$i\ \vec{S}_p \cdot \vec{q} \times \vec{p}_q$$

Pseudo- T-Odd



QCD S- and P- Coulomb Phases --Wilson Line

"Lensing Effect"

"Lensing" involves soft scales

Light-Front Wavefunction S and P- Waves!

Leading-Twist Rescattering Violates pQCD Factorization!

Sign reversal in DY!

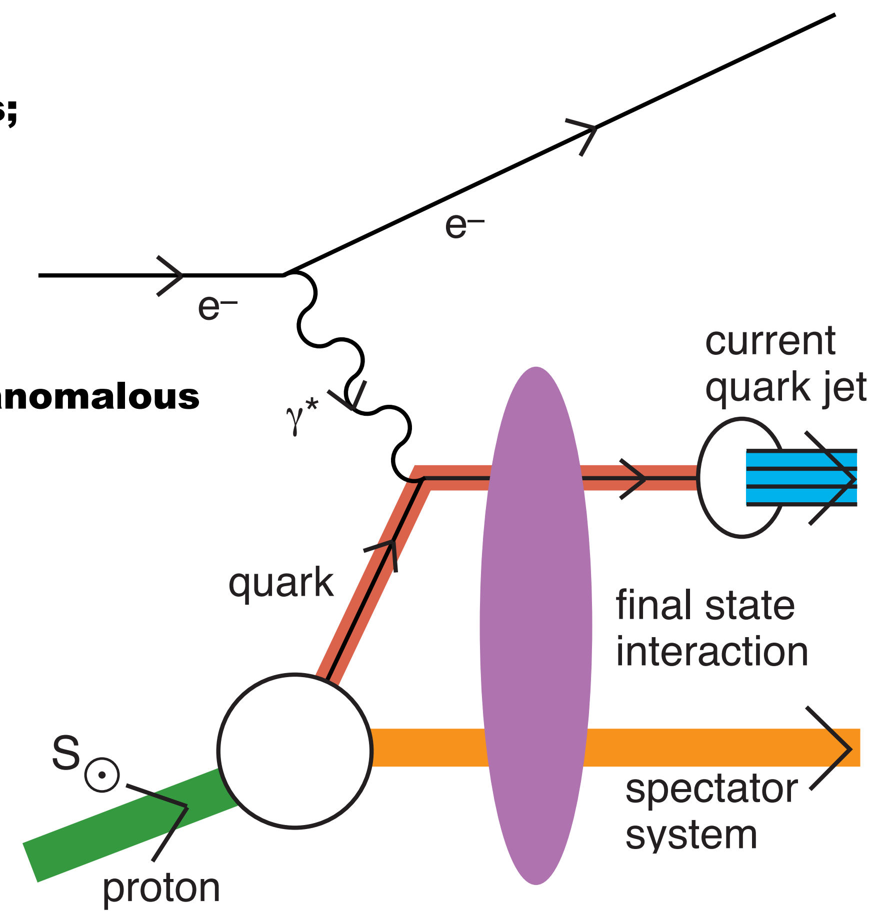
Violates Conventional Wisdom!

Final-State Interactions Produce Pseudo T-Odd (Sivers Effect)

Hwang, Schmidt, sjb
Collins

$$\mathbf{i}\ \vec{S} \cdot \vec{p}_{jet} \times \vec{q}$$

- **Leading-Twist Bjorken Scaling!**
- **Requires nonzero orbital angular momentum of quark**
- **Arises from the interference of Final-State QCD Coulomb phases in S- and P- waves;**
- **Wilson line effect -- lc gauge prescription**
- **Relate to the quark contribution to the target proton anomalous magnetic moment and final-state QCD phases**
- **QCD phase at soft scale!**
- **New window to QCD coupling and running gluon mass in the IR**
- **QED S and P Coulomb phases infinite -- difference of phases finite!**
- **Alternate: Retarded and Advanced Gauge: Augmented LFWFs**

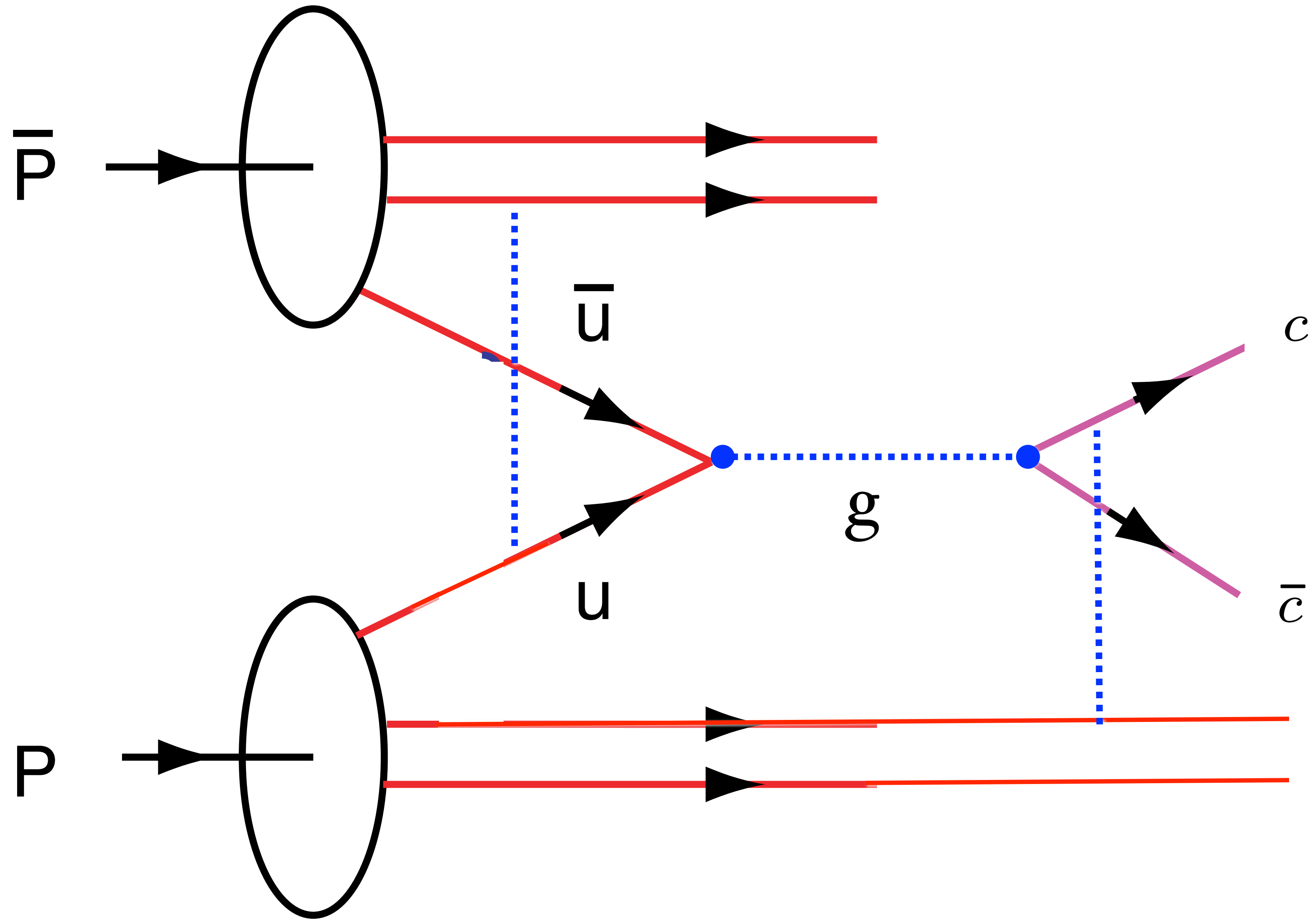


Dae Sung Hwang, Yuri V. Kovchegov,
Ivan Schmidt, Matthew D. Sievert, sjb

Pasquini, Xiao, Yuan, sjb

Mulders, Boer   **Qiu, Sterman**

See also: Collins and Qiu



Problem for factorization when both ISI and FSI occur

Double Initial-State Interactions generate anomalous $\cos 2\phi$

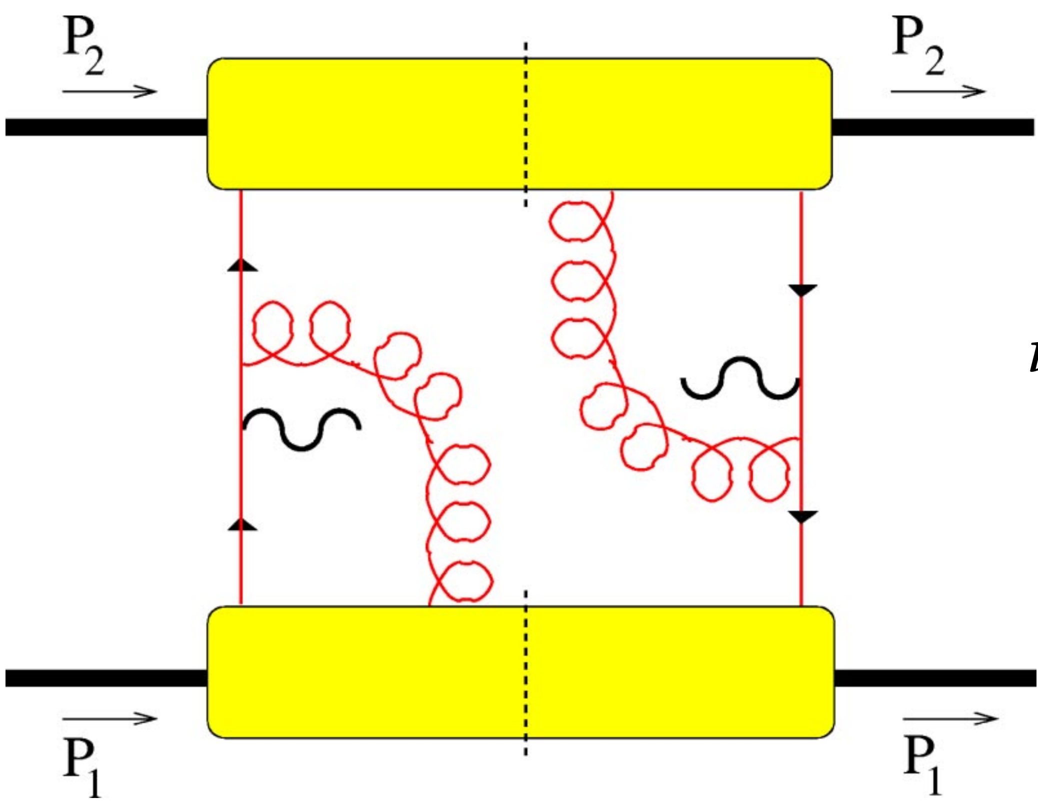
Boer, Hwang, sjb

Drell-Yan planar correlations

$$\frac{1}{\sigma}\frac{d\sigma}{d\Omega} \propto \left(1 + \lambda \cos^2\theta + \mu \sin 2\theta \cos\phi + \frac{\nu}{2}\sin^2\theta \cos 2\phi\right)$$

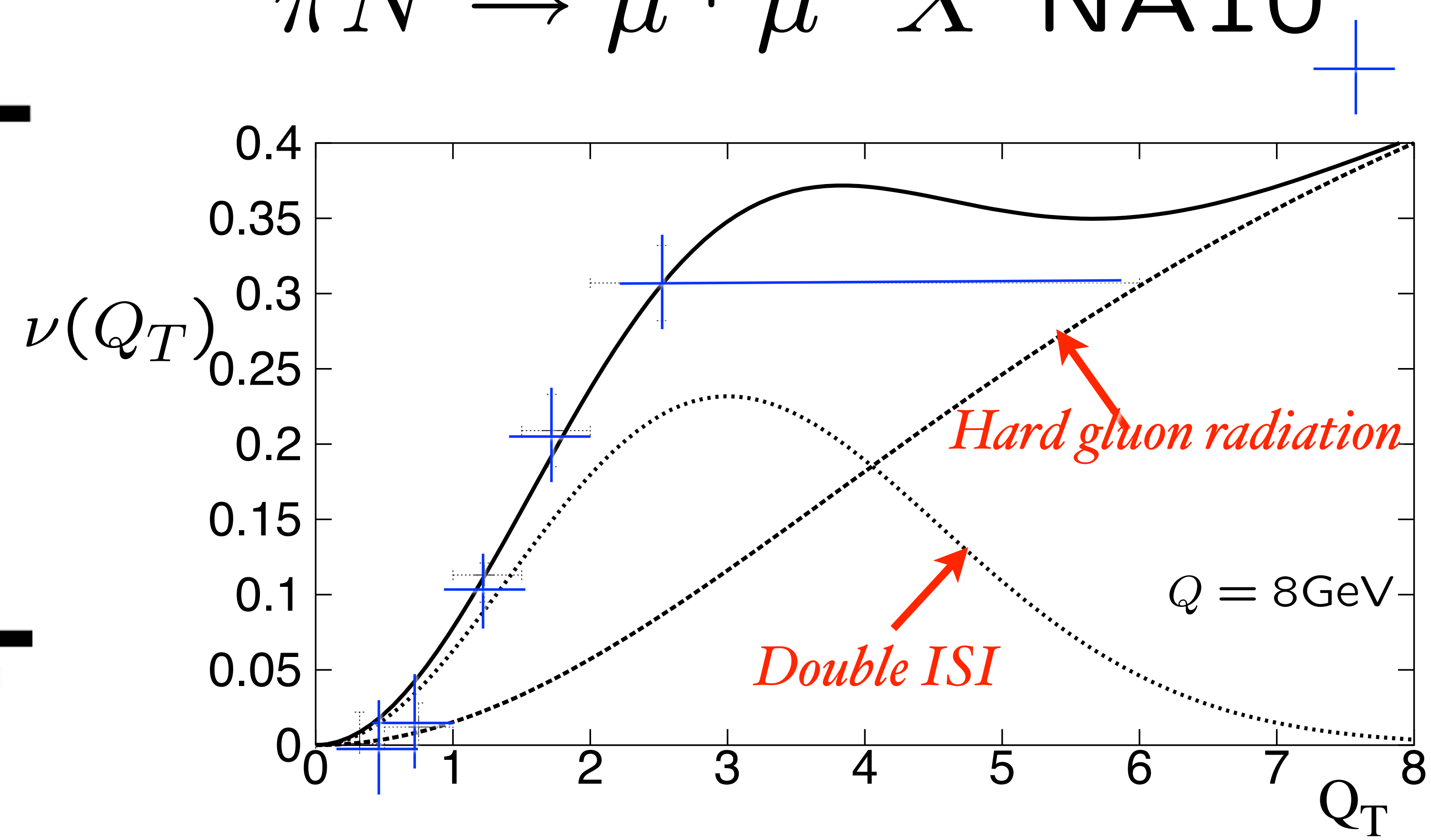
PQCD Factorization (Lam Tung): $1 - \lambda - 2\nu = 0$

$$\frac{\nu}{2} \propto h_1^{\perp}(\pi)\, h_1^{\perp}(N)$$



Violates Lam-Tung relation!

$\pi N \to \mu^+\mu^- X$ NA10

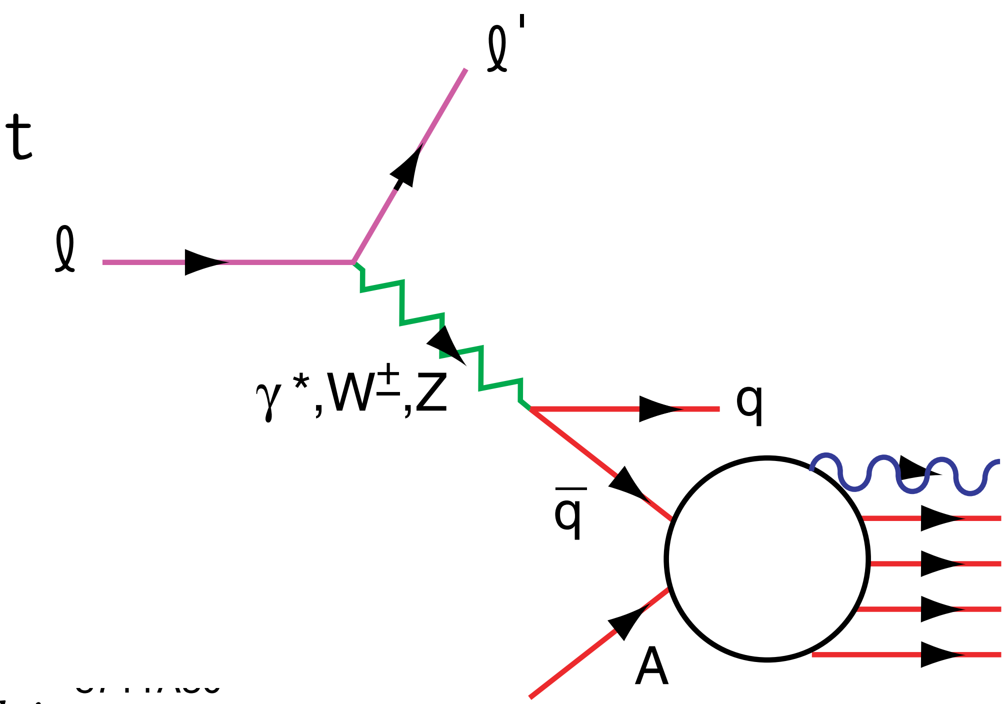


Model: Boer,

Origin of Regge Behavior of Deep Inelastic Structure Functions

$$F_{2p}(x) - F_{2n}(x) \propto x^{1/2}$$

Antiquark interacts with target nucleus at energy $\widehat{s} \propto \frac{1}{x_{bj}}$



Regge contribution: $\sigma_{\bar{q}N} \sim \widehat{s}^{\alpha_R - 1}$

Nonsinglet Kuti-Weisskoff $F_{2p} - F_{2n} \propto \sqrt{x_{bj}}$ at small x_{bj}.

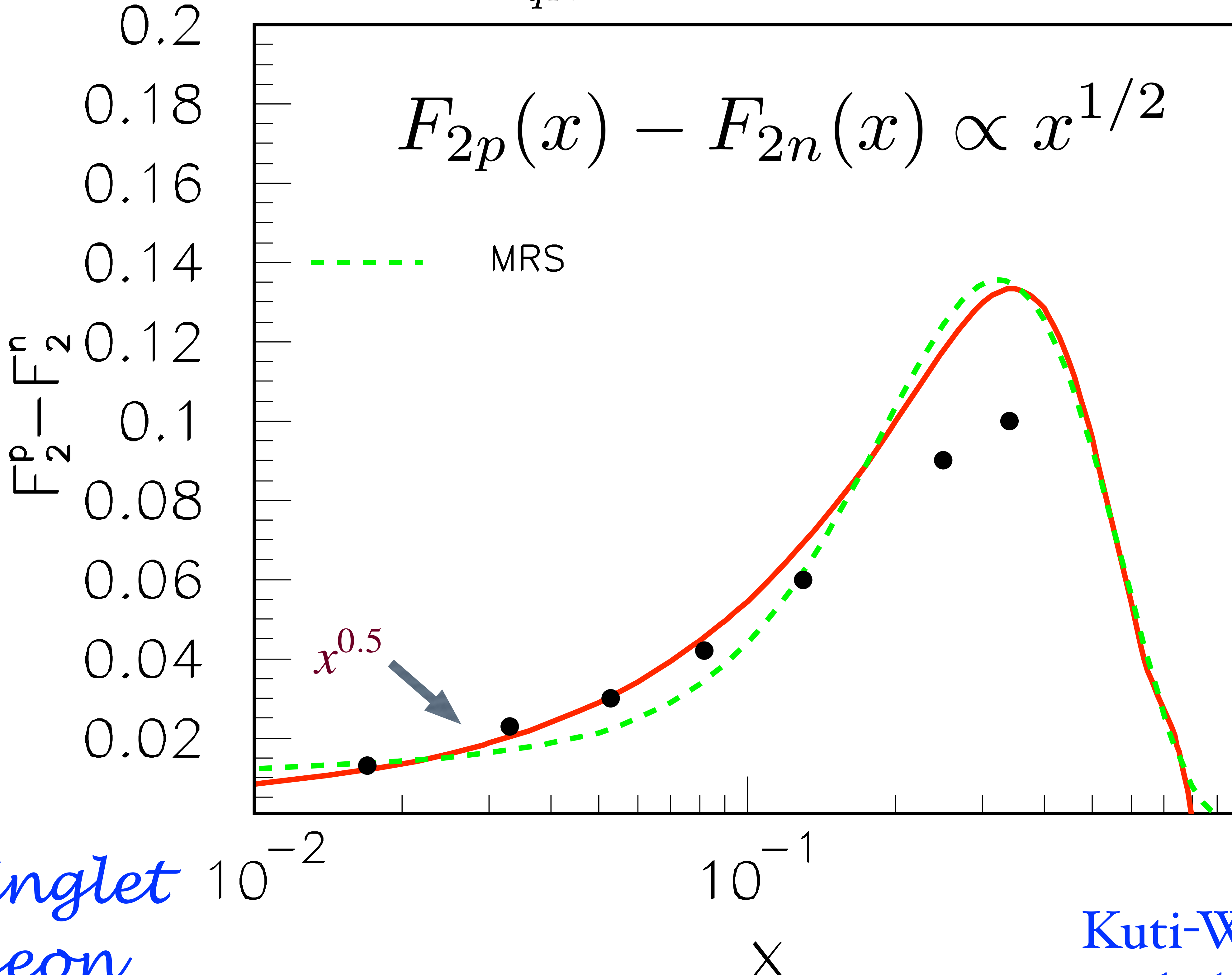
Shadowing of $\sigma_{\bar{q}M}$ produces shadowing of nuclear structure function.

Landshoff, Polkinghorne, Short

Close, Gunion, sjb

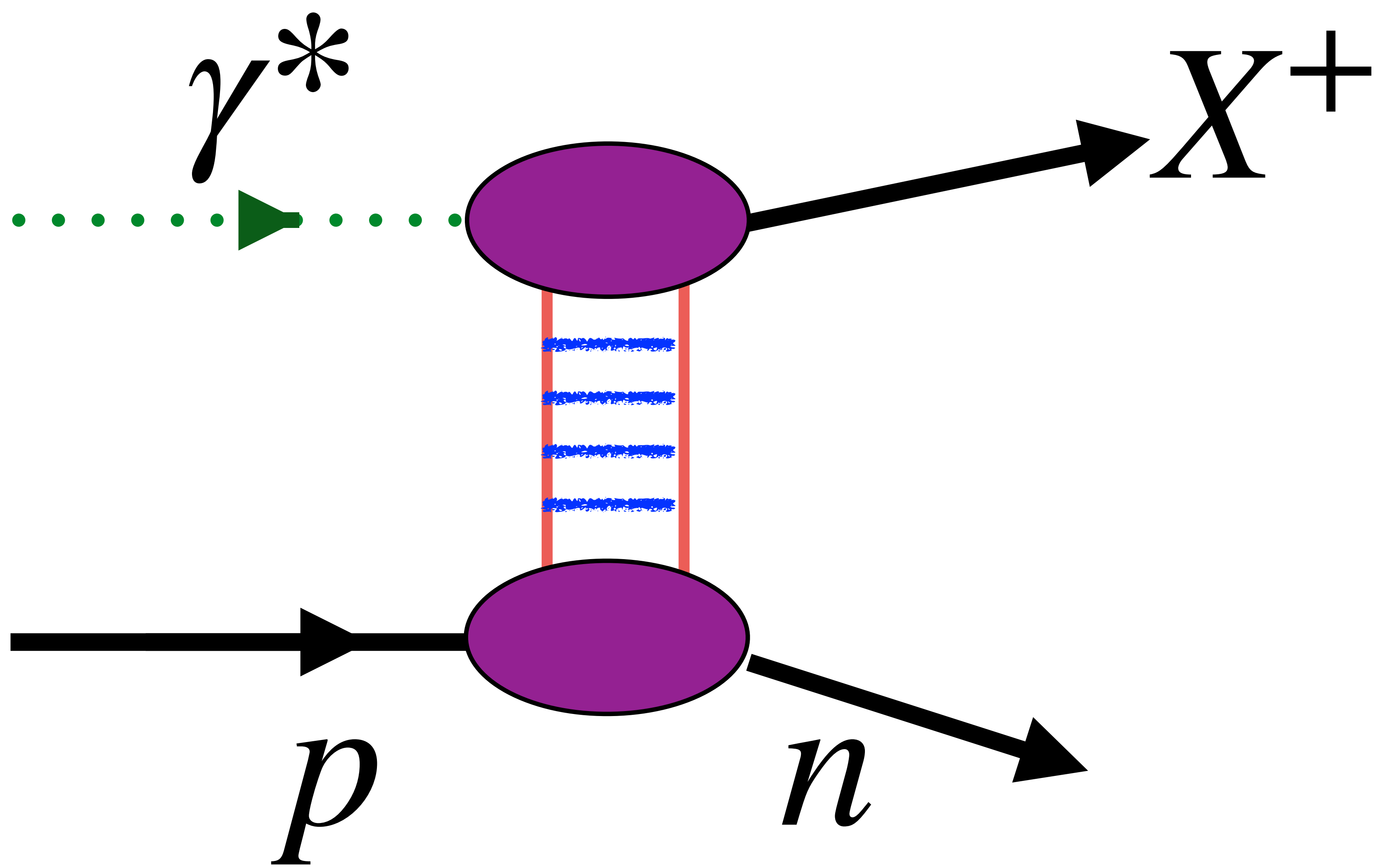
Schmidt, Yang, Lu, sjb

Regge contribution: $\sigma_{\bar{q}N} \sim \hat{s}^{\alpha_R - 1}$ $\alpha_R \simeq 1/2$



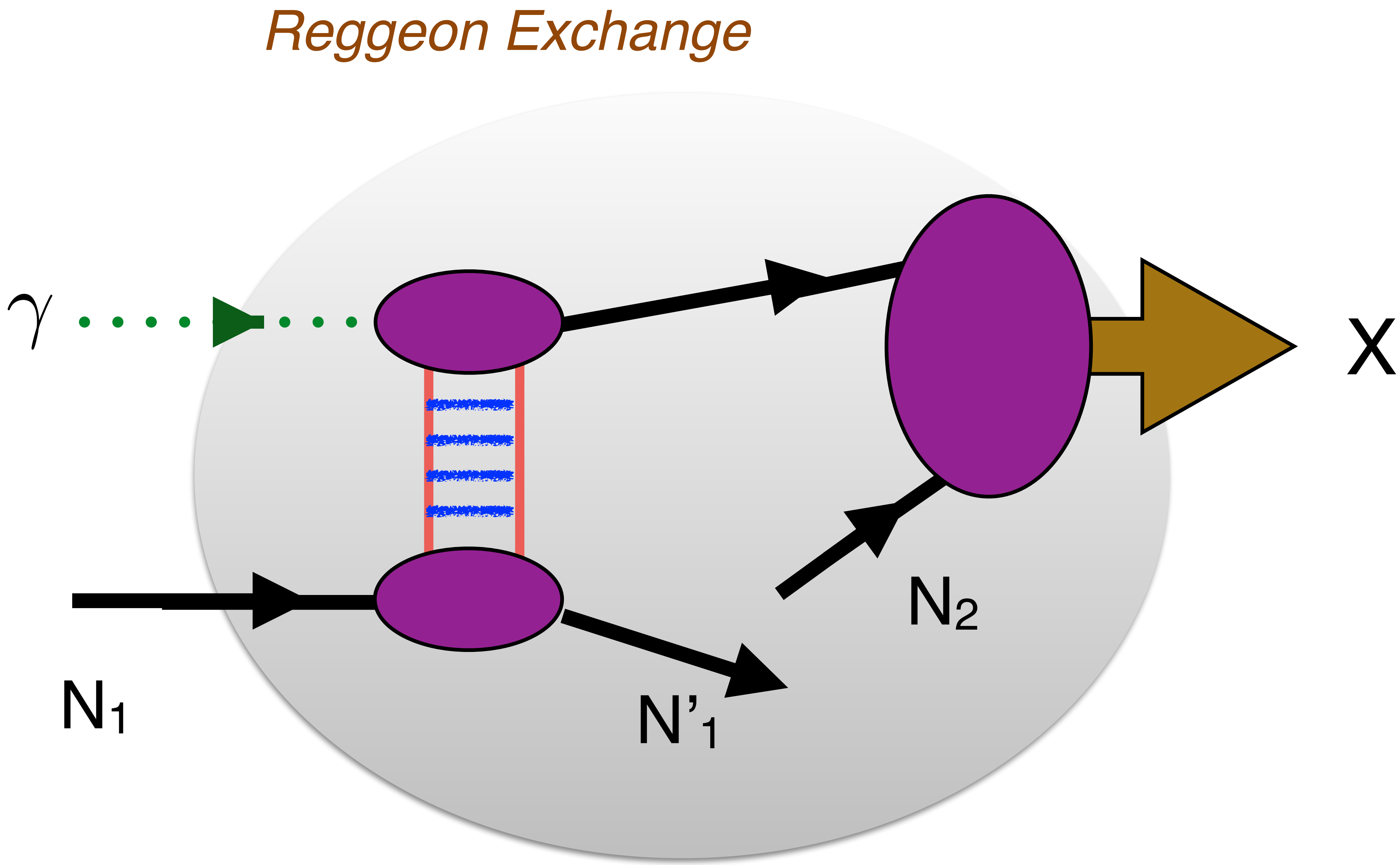
Non-singlet Reggeon Exchange

Kuti-Weisskopf behavior



Reggeon Exchange Contribution to Charge-Exchange DDIS

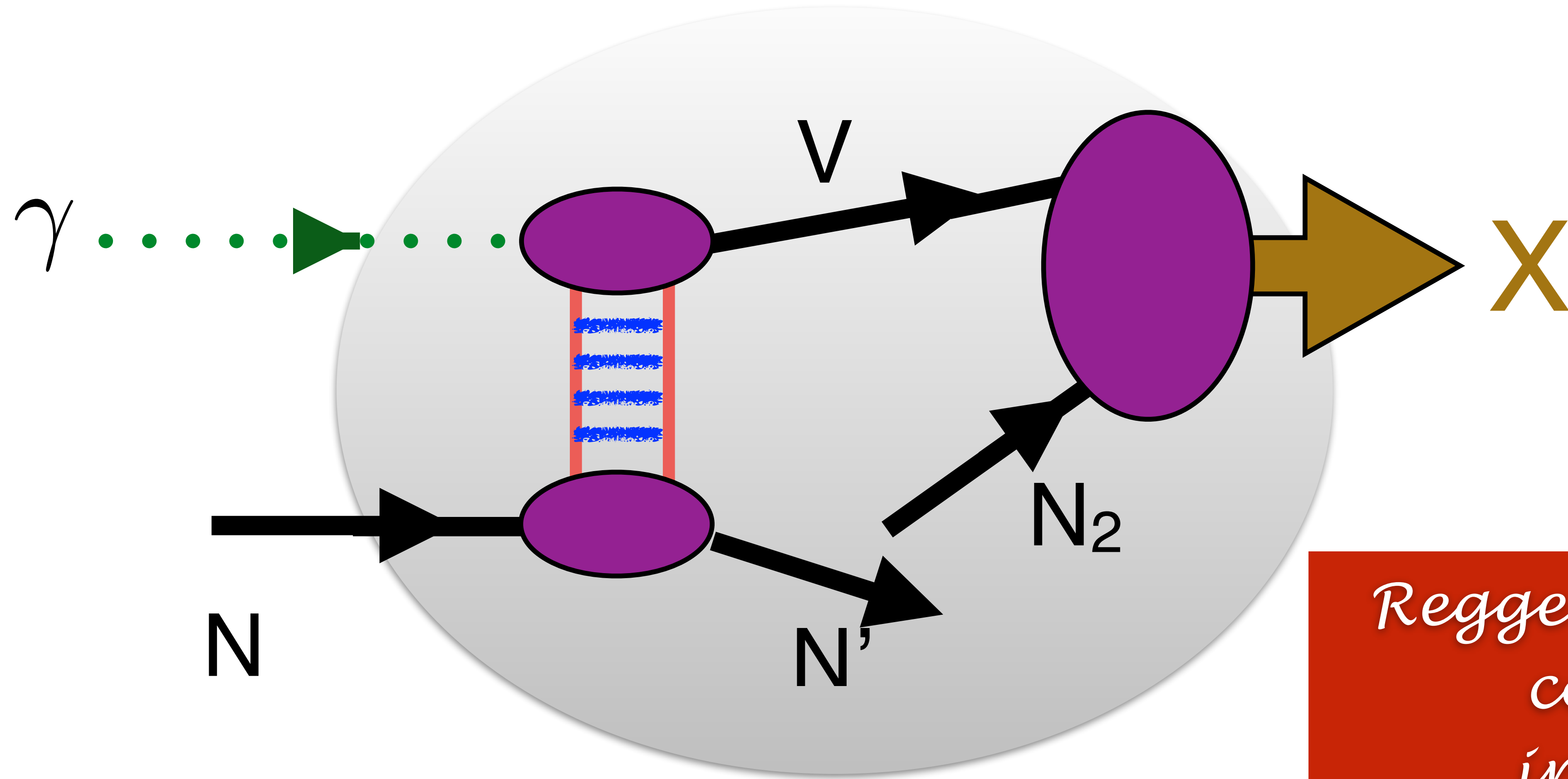
Two-step Glauber process



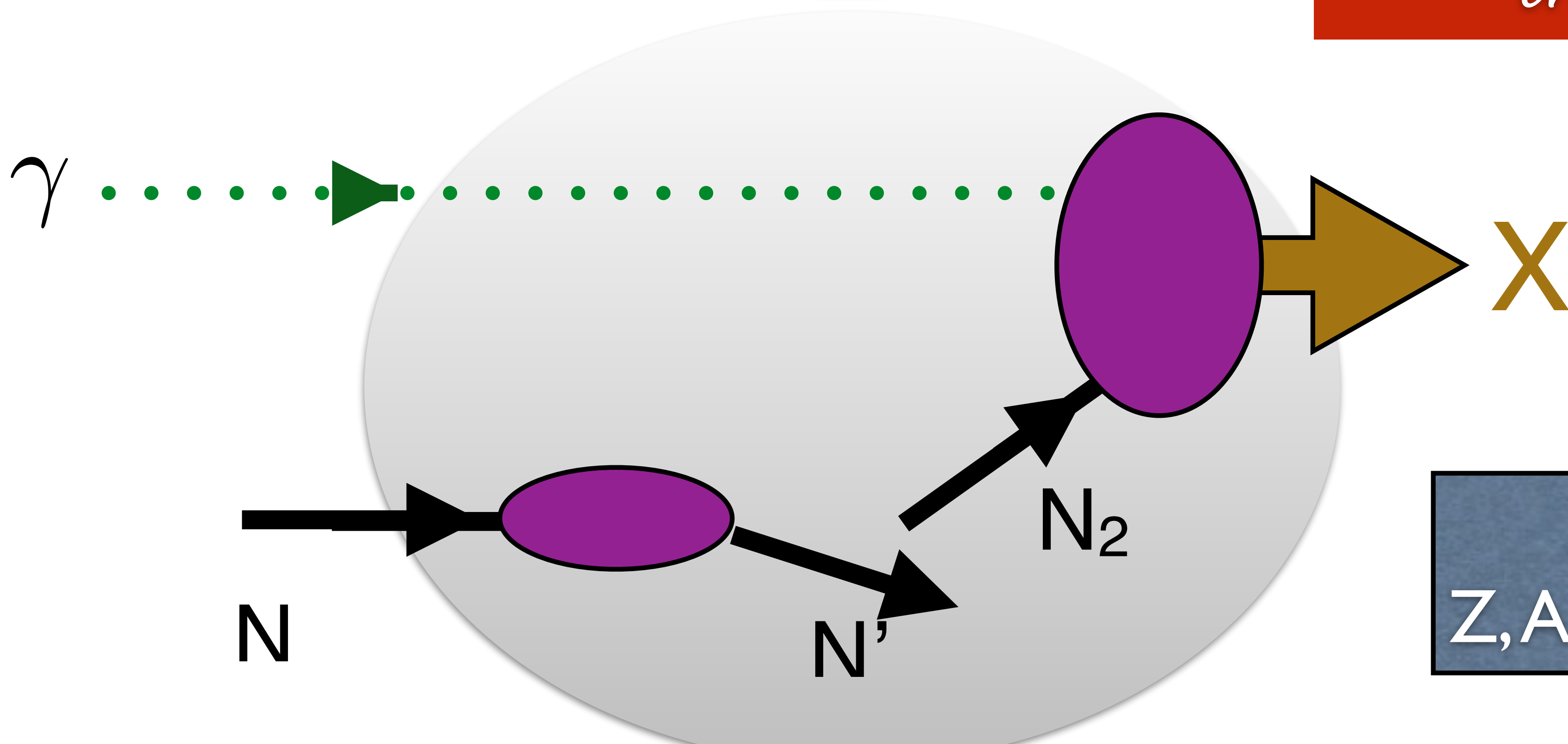
Can give constructive interference !

Two-step and One-Step Glauber processes

Reggeon Exchange on N_1



Regge Phase can give constructive interference!



Anomalous Z,A-Z dependence

Reggeon Exchange

Regge contribution: $\sigma_{\bar{q}N} \sim \hat{s}^{\alpha_R - 1}$ $\alpha_R \simeq 1/2$

Phase of two-step amplitude relative to one step:

$$\frac{1}{\sqrt{2}}(1 - i) \times i = \frac{1}{\sqrt{2}}(i + 1)$$

Constructive Interference

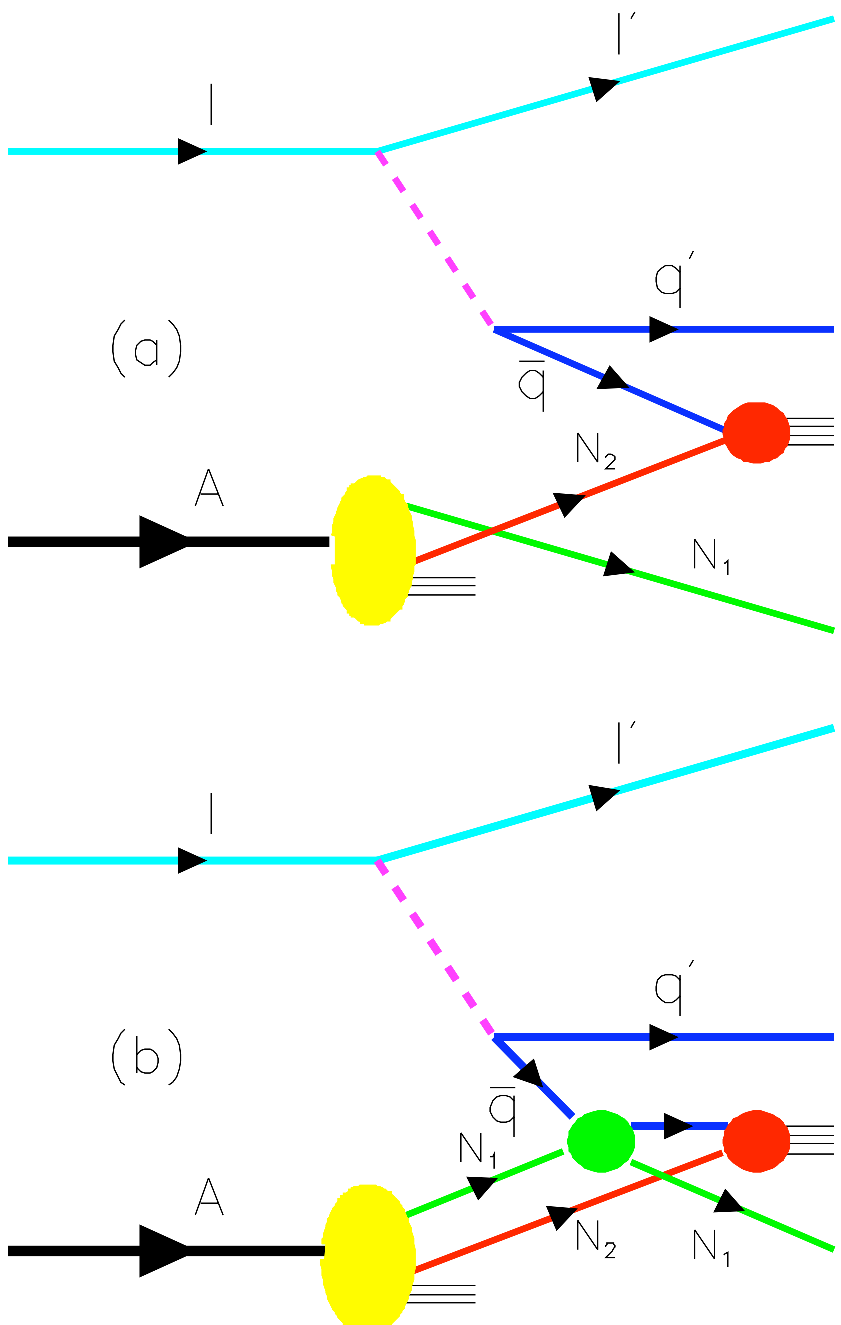
Depends on quark flavor!

Thus antishadowing is not universal

Different for couplings of $\gamma^*, Z^0, W^\pm$

Test: Tagged Drell-Yan

Schmidt, Lu, Yang, sjb



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Regge

If the scattering on nucleon N_1 is via ~~pomeron~~ exchange, the one-step and two-step amplitudes are ~~opposite in phase, thus diminishing the $\bar{q}$ flux reaching N_2.~~

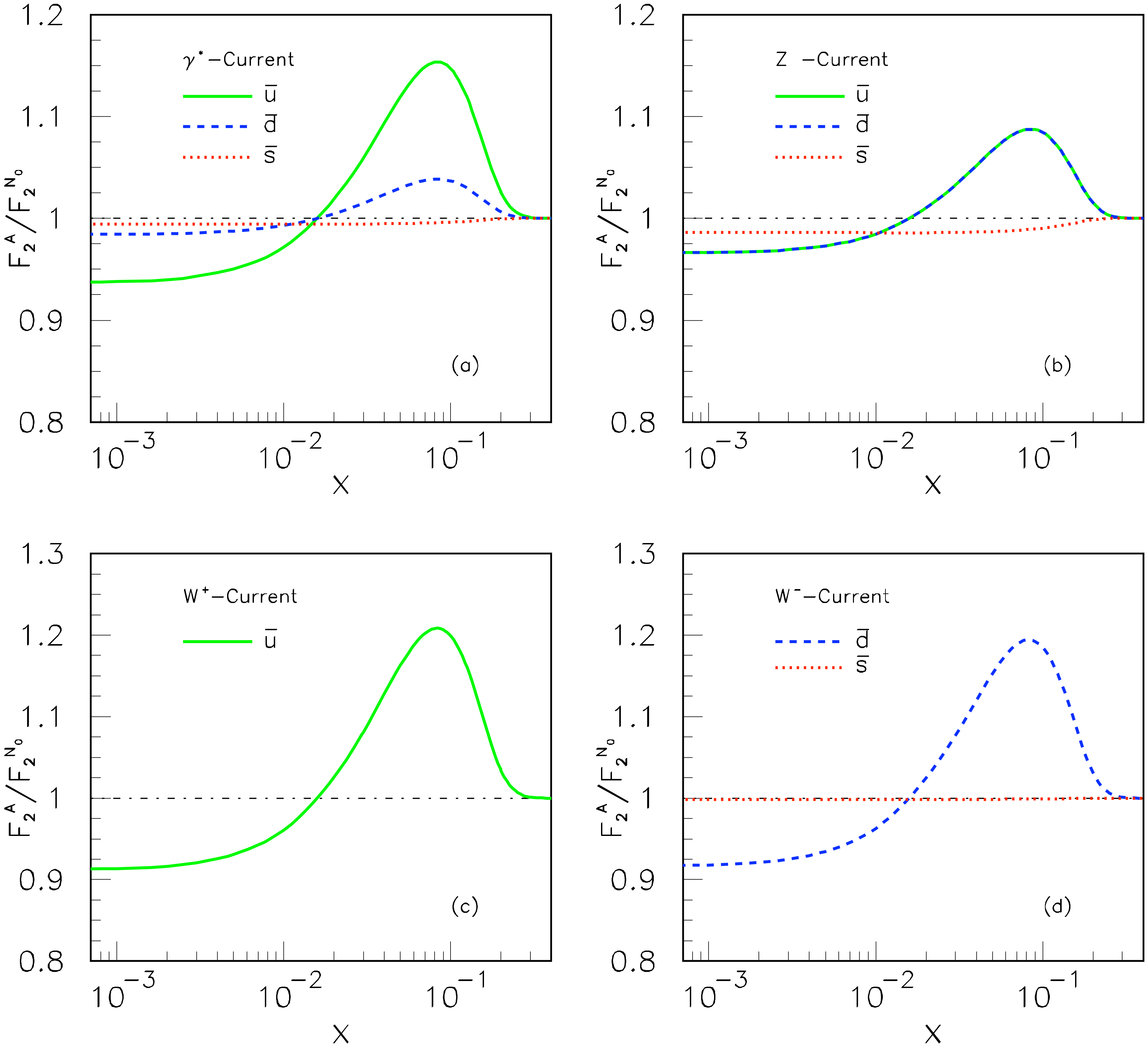
constructive in phase

thus ***increasing*** the flux reaching N_2

Interior nucleons anti-shadowed

Regge Exchange in DDIS produces nuclear anti-shadowing

Lu, Schmidt, Yang; sjb



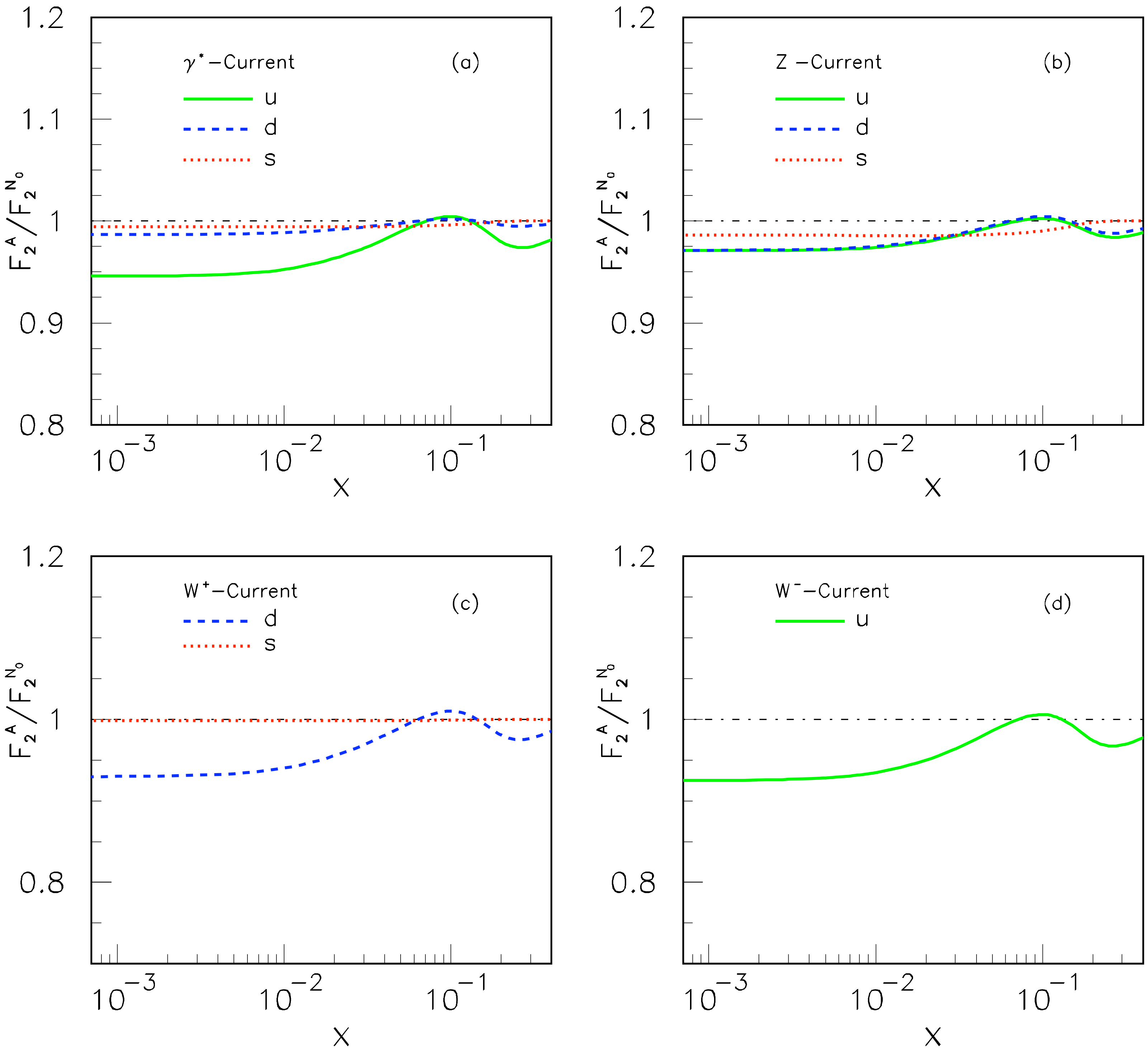
Modifies NuTeV extraction of

$\sin^2 \theta_W$

Test in flavor-tagged DIS at the EIC

Nuclear Antishadowing is flavor dependent not universal !

Shadowing and Antishadowing of DIS Structure Functions



S. J. Brodsky, I. Schmidt and J. J. Yang, "Nuclear Antishadowing in Neutrino Deep Inelastic Scattering," Phys. Rev. D 70, 116003 (2004) [arXiv:hep-ph/0409279].

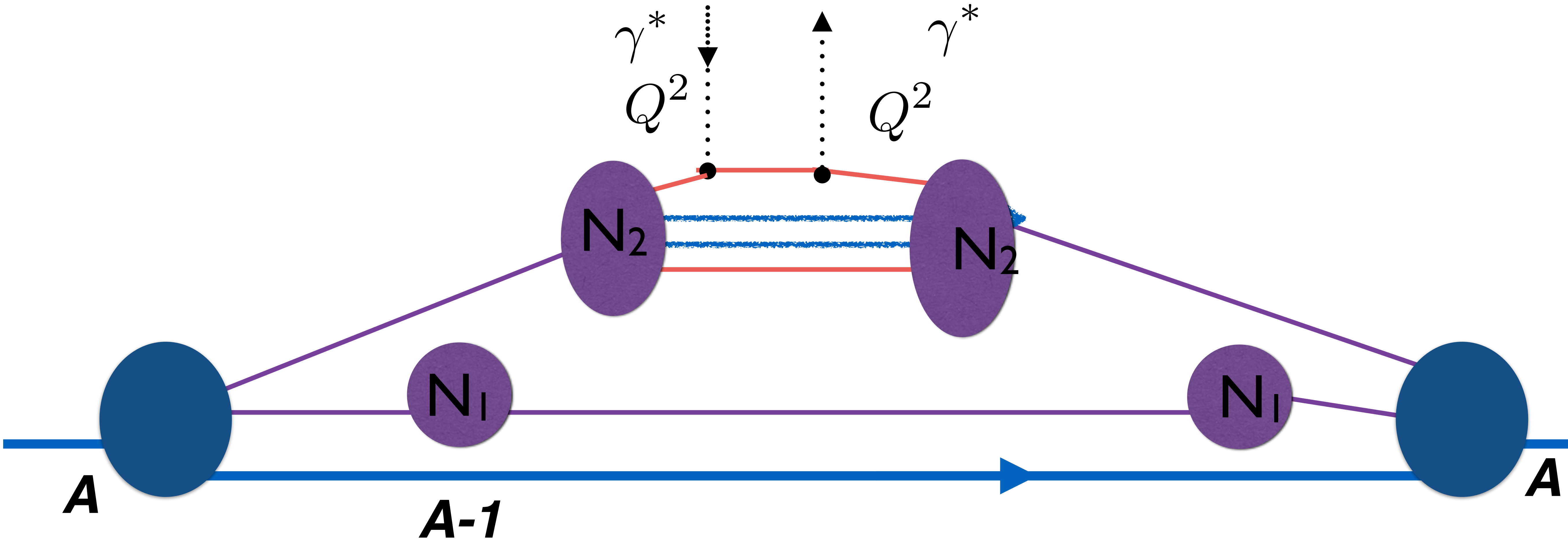
Modifies NuTeV extraction of $\sin^2\theta_W$

Test in flavor-tagged lepton-nucleus collisions

Handbag Diagram

$q^+ = 0 \quad q_\perp^2 = Q^2 = -q^2$

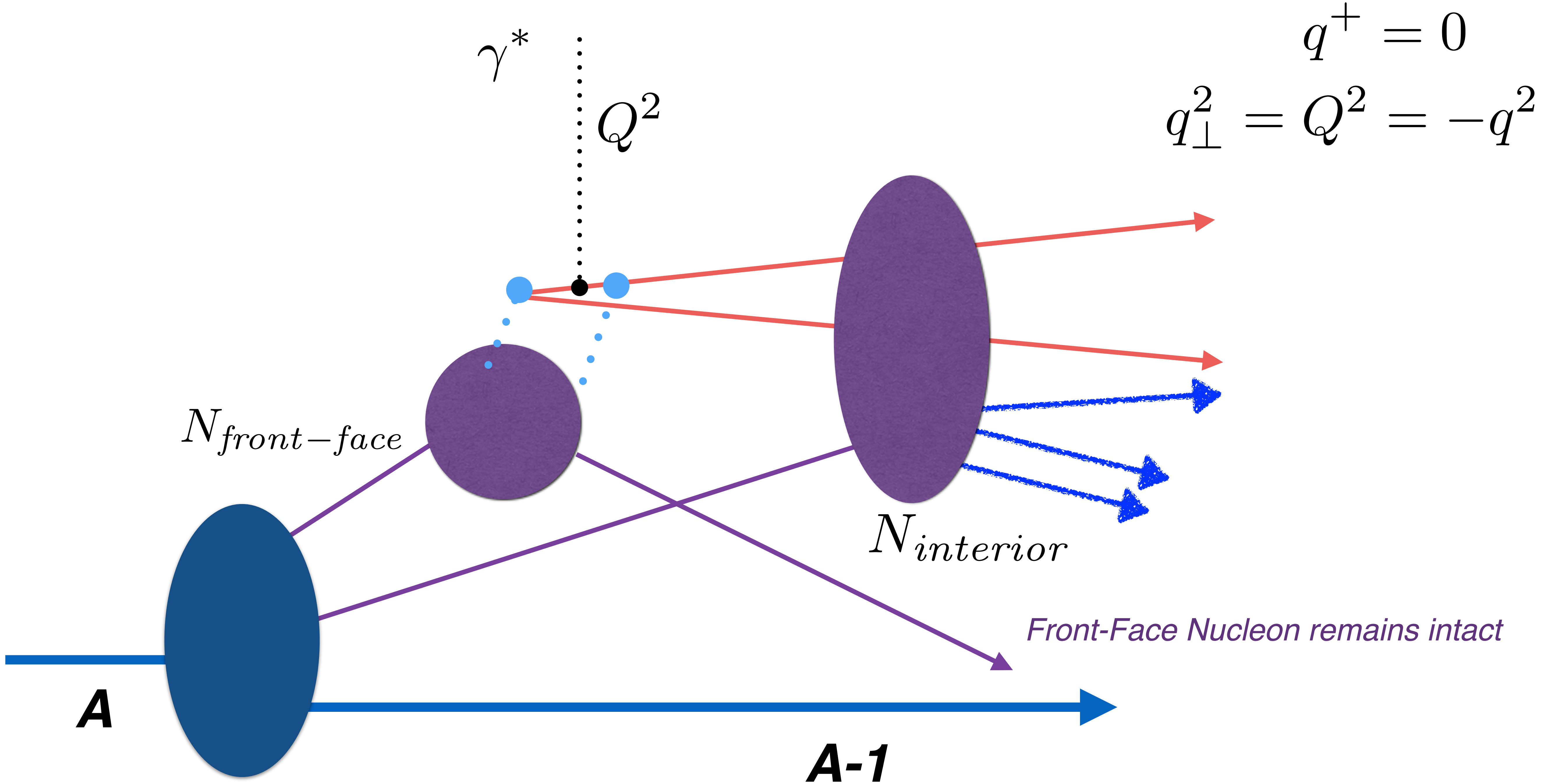
Unitarity: Cut gives DIS Cross Section



$$\text{Double Virtual Compton Scattering } \gamma^* A \to \gamma^* A$$

Reduces to matrix element of local operator: Sum Rules

LFWFs are real for stable hadrons, nuclei

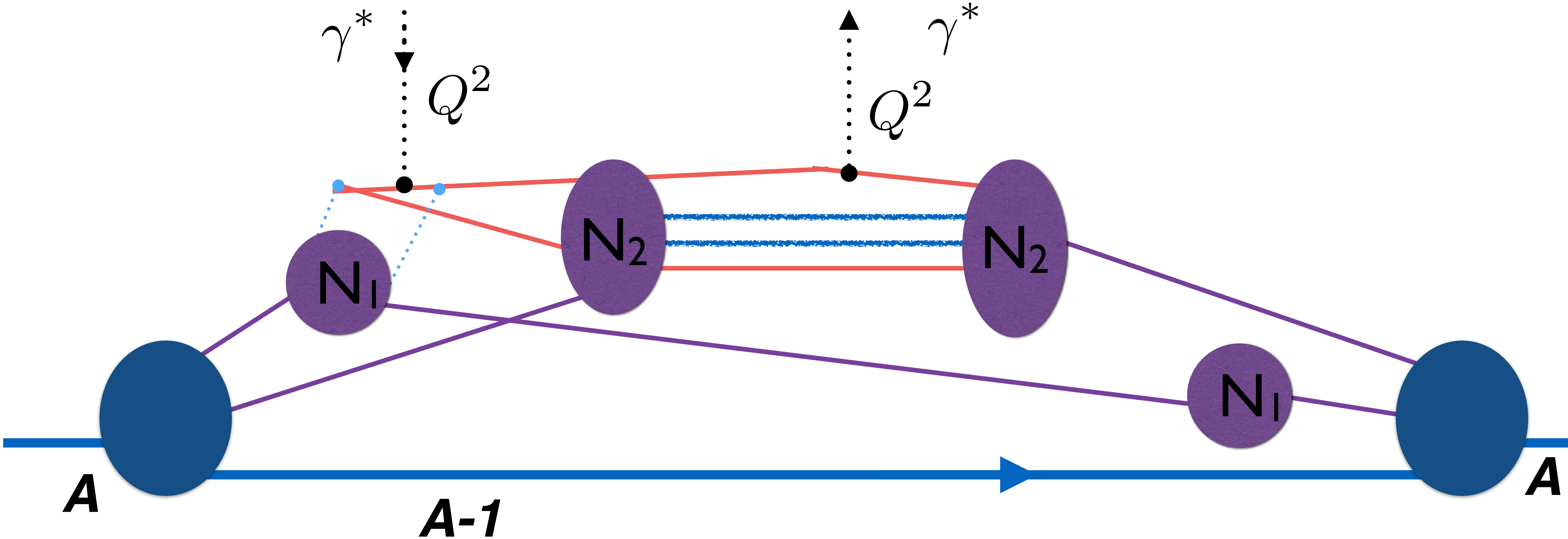


Two-Step Process in the $q^+=0$ Parton Model Frame

Illustrates the LF time sequence

$$q^+ = 0 \quad q_\perp^2 = Q^2 = -q^2$$

Illustrates the LF time sequence



Front-Face Nucleon N_1 struck

Front-Face Nucleon N_1 not struck

One-Step / Two-Step Interference

Study Double Virtual Compton Scattering $\gamma^* A \to \gamma^* A$

Cannot reduce to matrix element of local operator! No Sum Rules!

LFWFs are real for stable hadrons, nuclei

Liuti, sjb

Is Antishadowing in DIS Non-Universal, Flavor-Dependent?

Do Nuclear PDFS Obey Momentum and other Sum Rules?

I. A. Schmidt, SJB

$$|p,S_z>=\sum_{n=3}\Psi_n(x_i,\vec{k}_{\perp i},\lambda_i)|n;\vec{k}_{\perp_i},\lambda_i>$$

sum over states with n=3, 4, ...constituents

The Light Front Fock State Wavefunctions

$$\Psi_n(x_i,\vec{k}_{\perp i},\lambda_i)$$

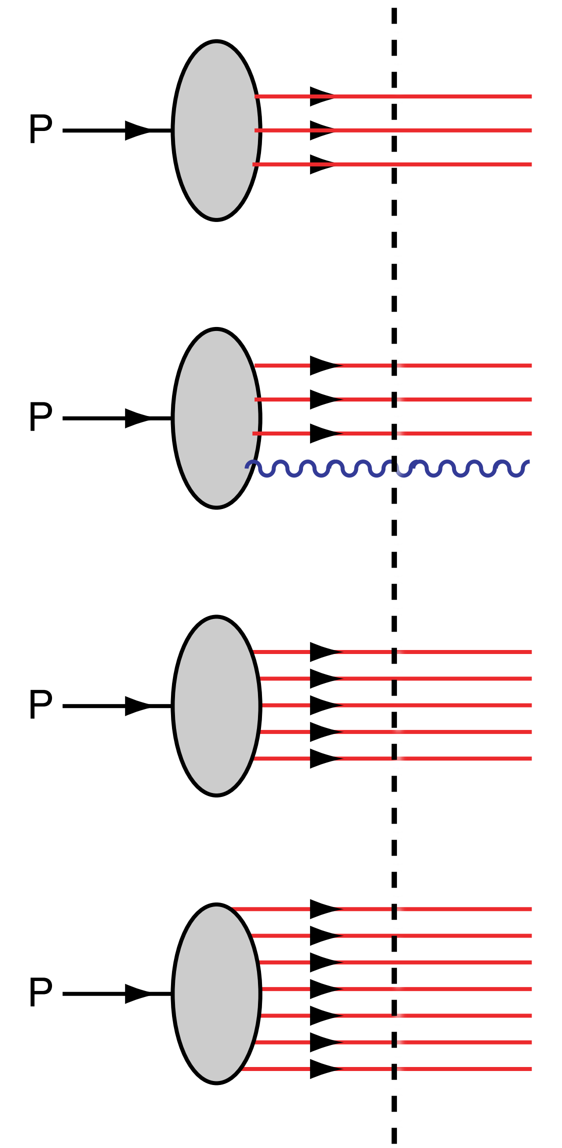
are boost invariant; they are independent of the hadron's energy and momentum P^μ.

The light-cone momentum fractions

$$x_i=\frac{k_i^+}{p^+}=\frac{k_i^0+k_i^z}{P^0+P^z}$$

are boost invariant.

$$\sum_i^n k_i^+=P^+,\ \sum_i^n x_i=1,\ \sum_i^n \vec{k}_i^\perp=\vec{0}^\perp.$$



Fixed LF time

Intrinsic heavy quarks
s(x), c(x), b(x) at high x !

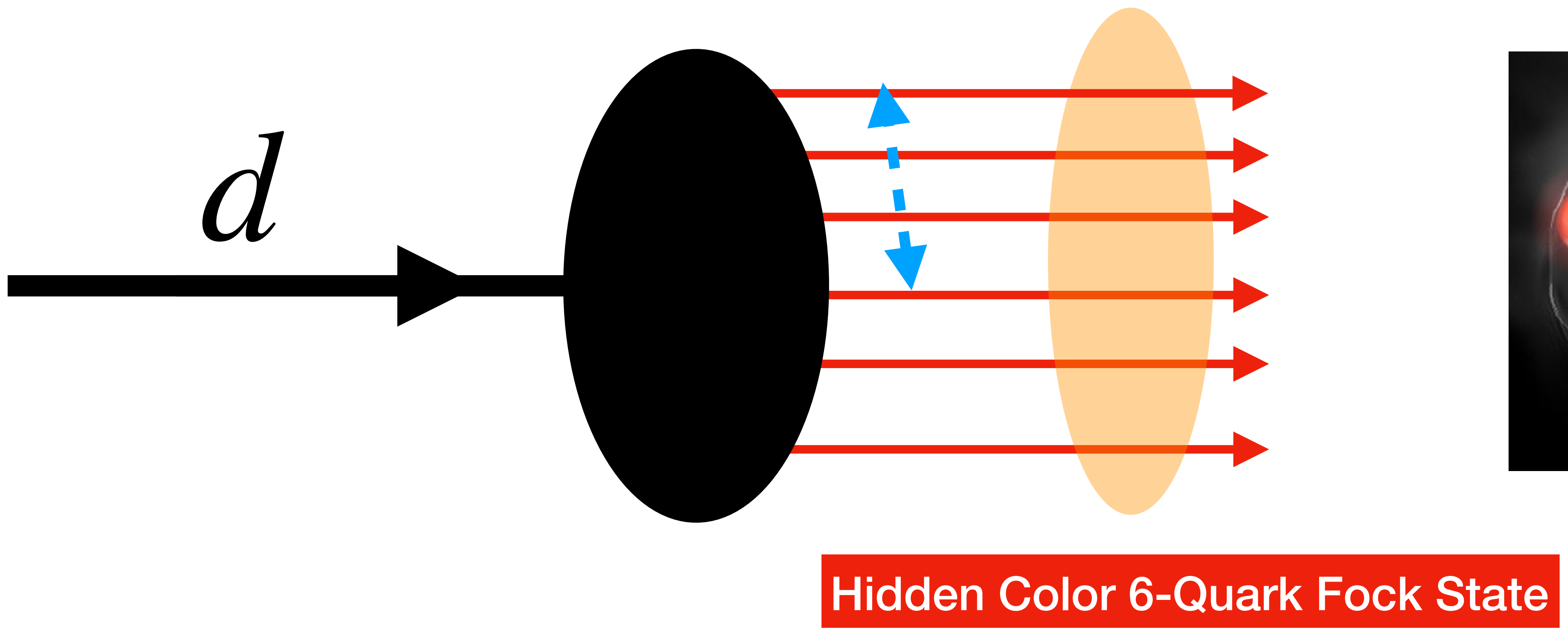
$\bar{s}(x)\neq s(x)$
$\bar{u}(x)\neq \bar{d}(x)$

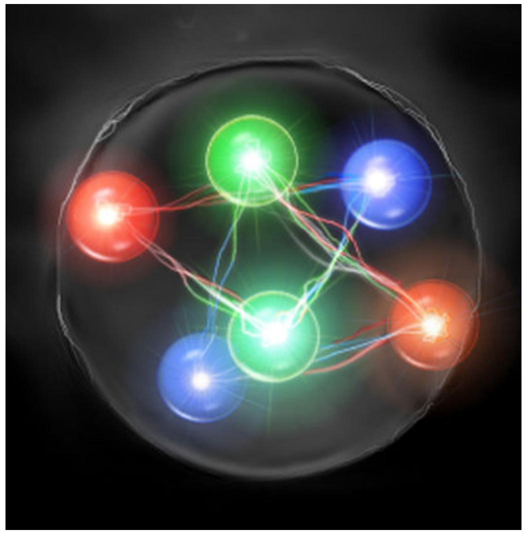
Deuteron: Hidden Color

Hidden Color in QCD

- Deuteron: Five color-singlet combinations of 6 color-triplets

- One Fock state is n p nucleon clusters, one state is Δ Δ





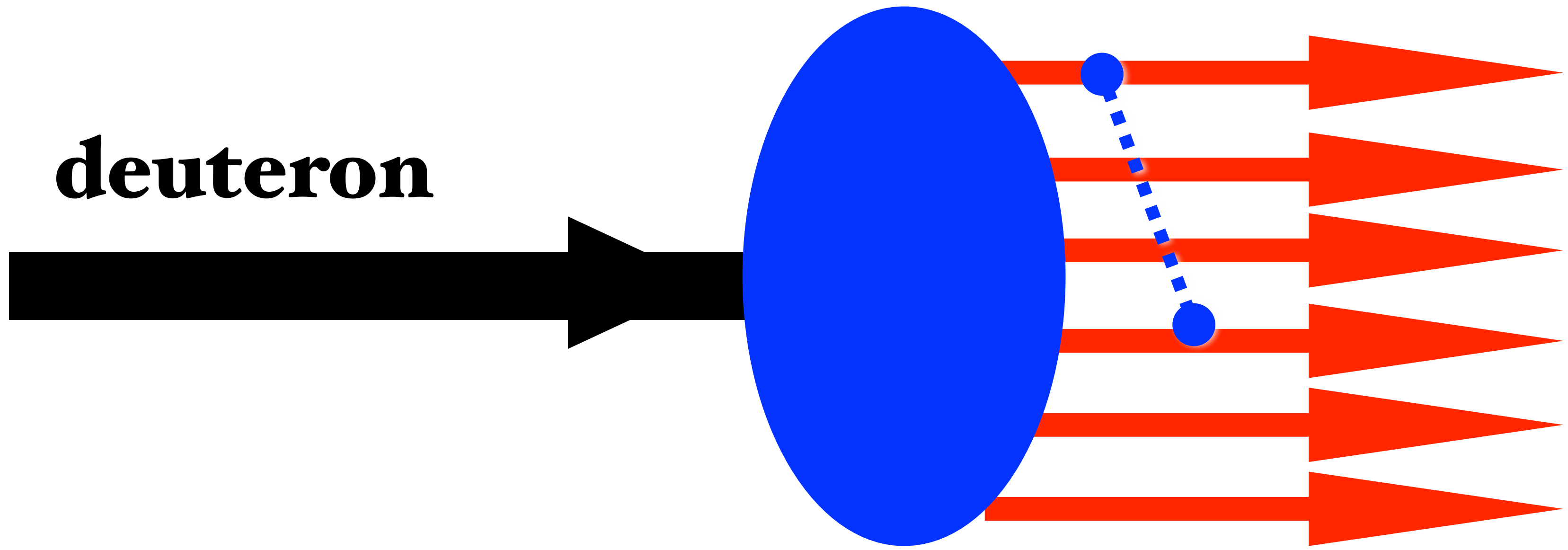
Rigorous Feature of QCD!

Lepage, Ji, sjb

pQCD Evolution of 5 color-singlet Fock states

Lepage, Ji, sjb

$$\Psi^{\mathbf{d}}_n(x_i, \vec{k}_{\perp i}, \lambda_i)$$



$$\sum_i^n \vec{k}_{\perp i} = \vec{0}_\perp$$

$$\sum_i^n x_i = 1$$

$$\Phi_n(x_i, Q) = \int^{k^2_{\perp i} < Q^2} \Pi' d^2 k_{\perp j} \psi_n(x_i, \vec{k}_{\perp j})$$

5 X 5 Matrix Evolution Equation for deuteron distribution amplitude

Hidden Color in QCD

Lepage, Ji, sjb

- Deuteron: six-quark wavefunction
- ERBL Evolution of deuteron distribution amplitude $\phi_D(x_i, Q^2)$
- 5 color-singlet combinations of 6 color-triplets -- one state is |n p>
- Components of deuteron distribution amplitude evolve towards equality at short distances:

$$\phi_D(x_i, Q^2) \to C x_1 x_2 x_3 x_4 x_5 x_6$$

- Hidden color states dominate deuteron form factor and photo-disintegration at high momentum transfer

$$\frac{d\sigma}{dt}(\gamma d \longrightarrow \Delta^{++}\Delta^{-}) \simeq \frac{d\sigma}{dt}(\gamma d \longrightarrow pn) \text{ at high } Q^2$$

Hidden Color of Deuteron

Deuteron six-quark state has five color-singlet configurations, only one of which is n-p.

Asymptotic Solution has Expansion

$$\psi_{[6]\{33\}} = \left(\frac{1}{9}\right)^{1/2} \psi_{NN} + \left(\frac{4}{45}\right)^{1/2} \psi_{\Delta\Delta} + \left(\frac{4}{5}\right)^{1/2} \psi_{CC}$$

ERBL Evolution: Transition to Delta-Delta

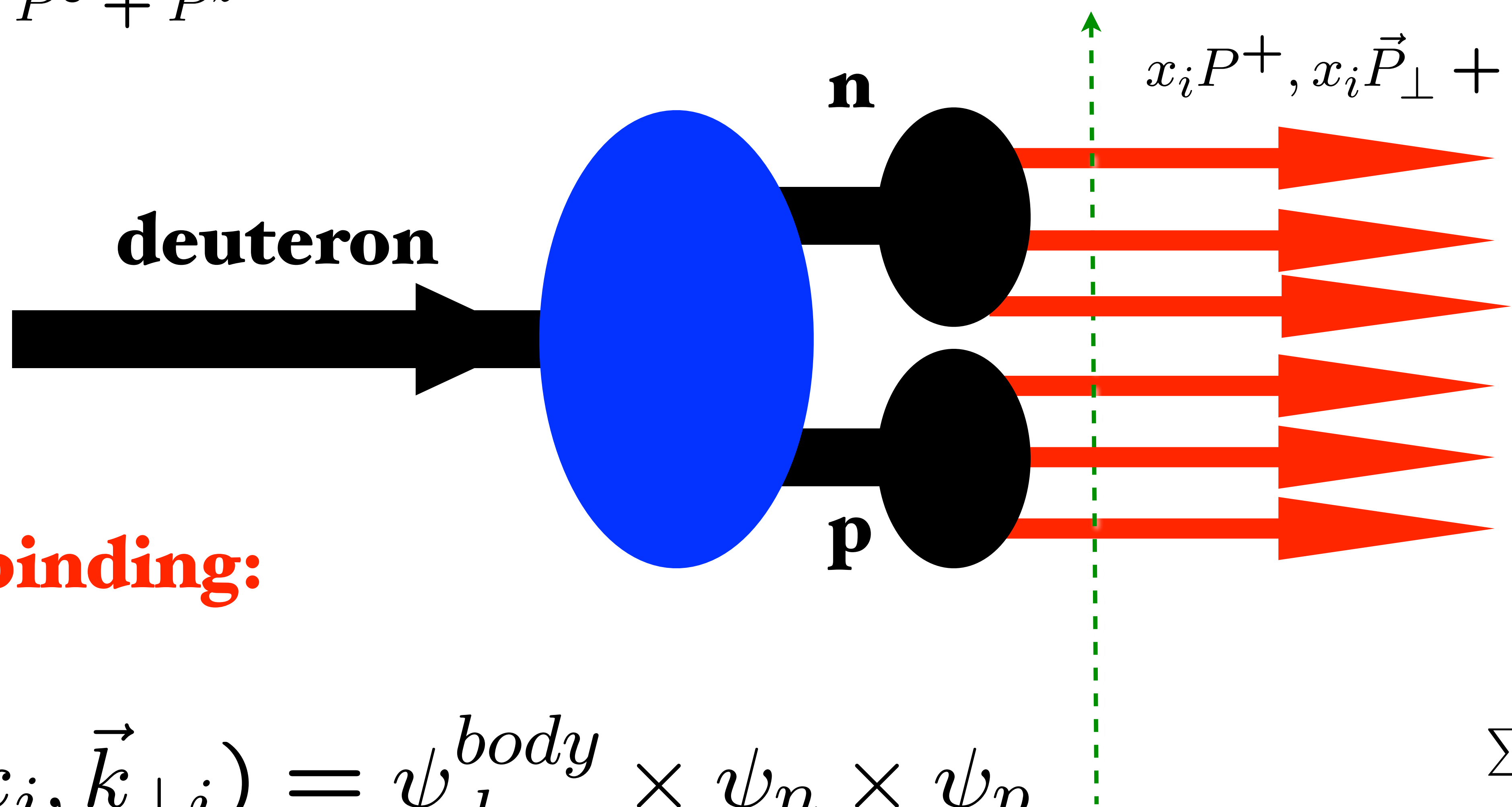
Lepage, Ji, sjb

$P^+ = P^0 + P^z$

Fixed $\tau = t + z/c$

$x_i P^+, x_i \vec{P}_\perp + \vec{k}_{\perp i}$

$P^+, \vec{P}_\perp$



Weak binding:

$$\psi_d(x_i, \vec{k}_{\perp i}) = \psi_d^{body} \times \psi_n \times \psi_p$$

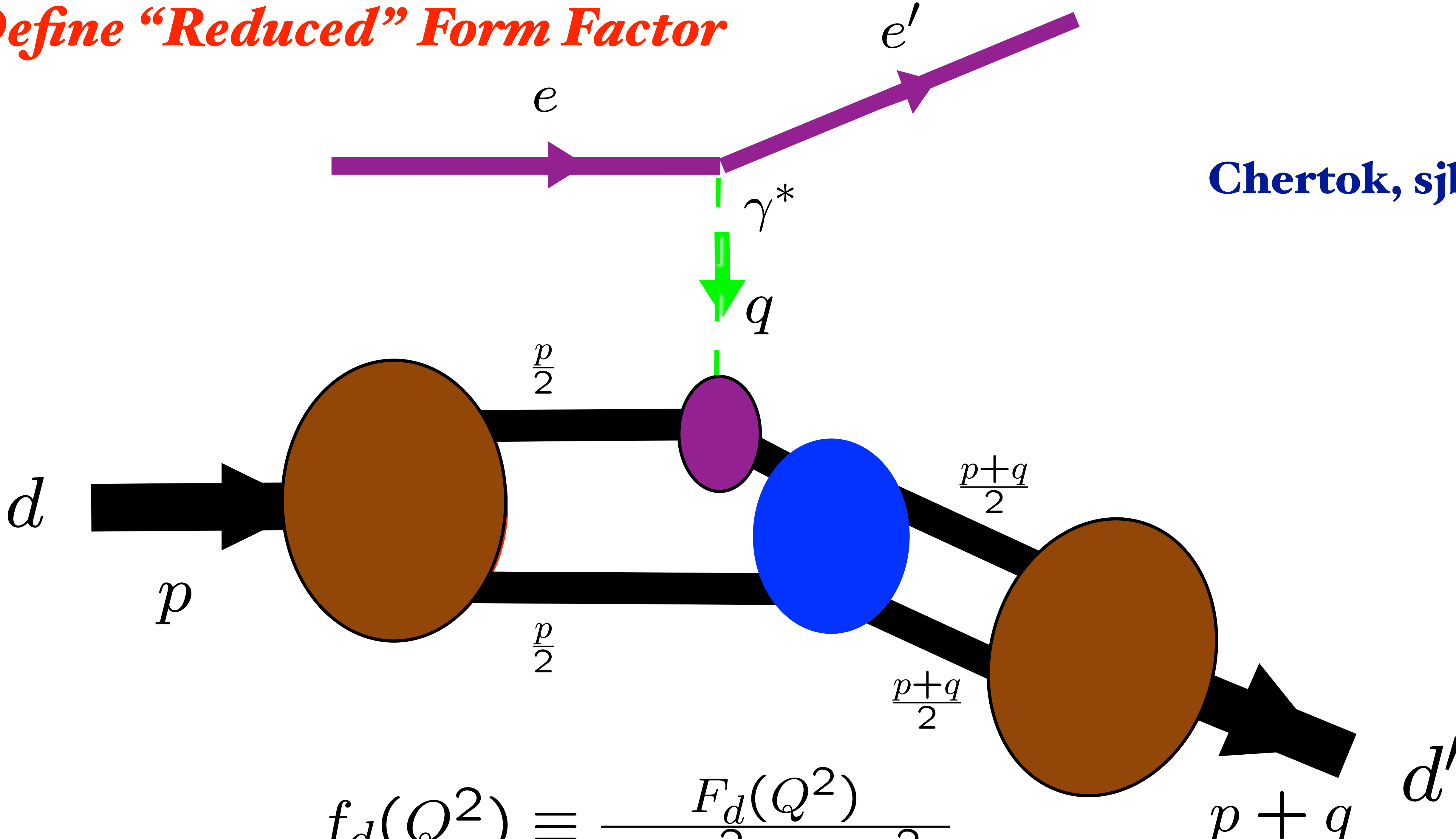
$\sum_i^n x_i = 1$

$\sum_i^n \vec{k}_{\perp i} = \vec{0}_\perp$

Nuclear Physics:
Two color-singlet combinations of three 3_C

Define "Reduced" Form Factor

Chertok, sjb



$$f_d(Q^2) \equiv \frac{F_d(Q^2)}{F_p(\frac{Q^2}{4})F_n(\frac{Q^2}{4})}$$

Elastic electron-deuteron scattering

$$\text{Predict } f_d(Q^2) \to \frac{1}{Q^2}$$

QCD Prediction for Deuteron Form Factor

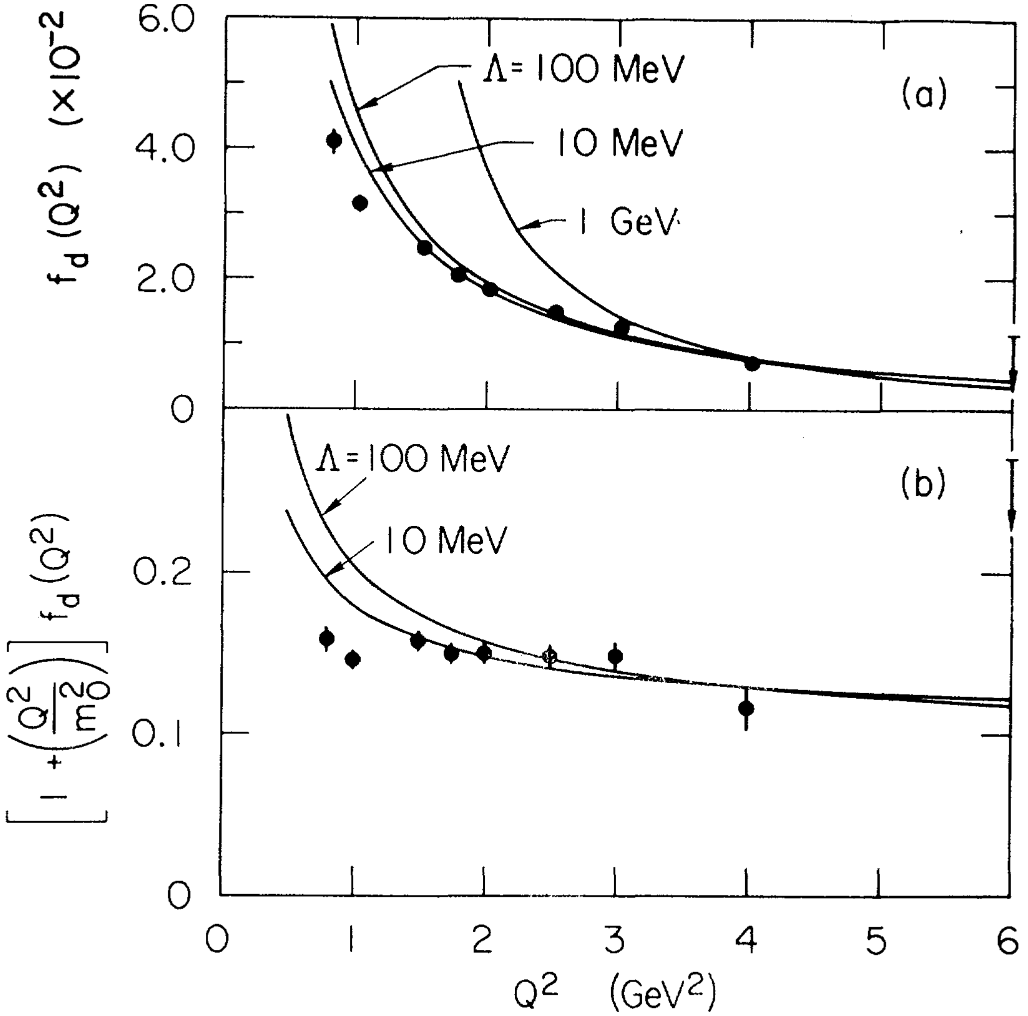
Lepage, Ji, sjb

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

Define "Reduced" Form Factor

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

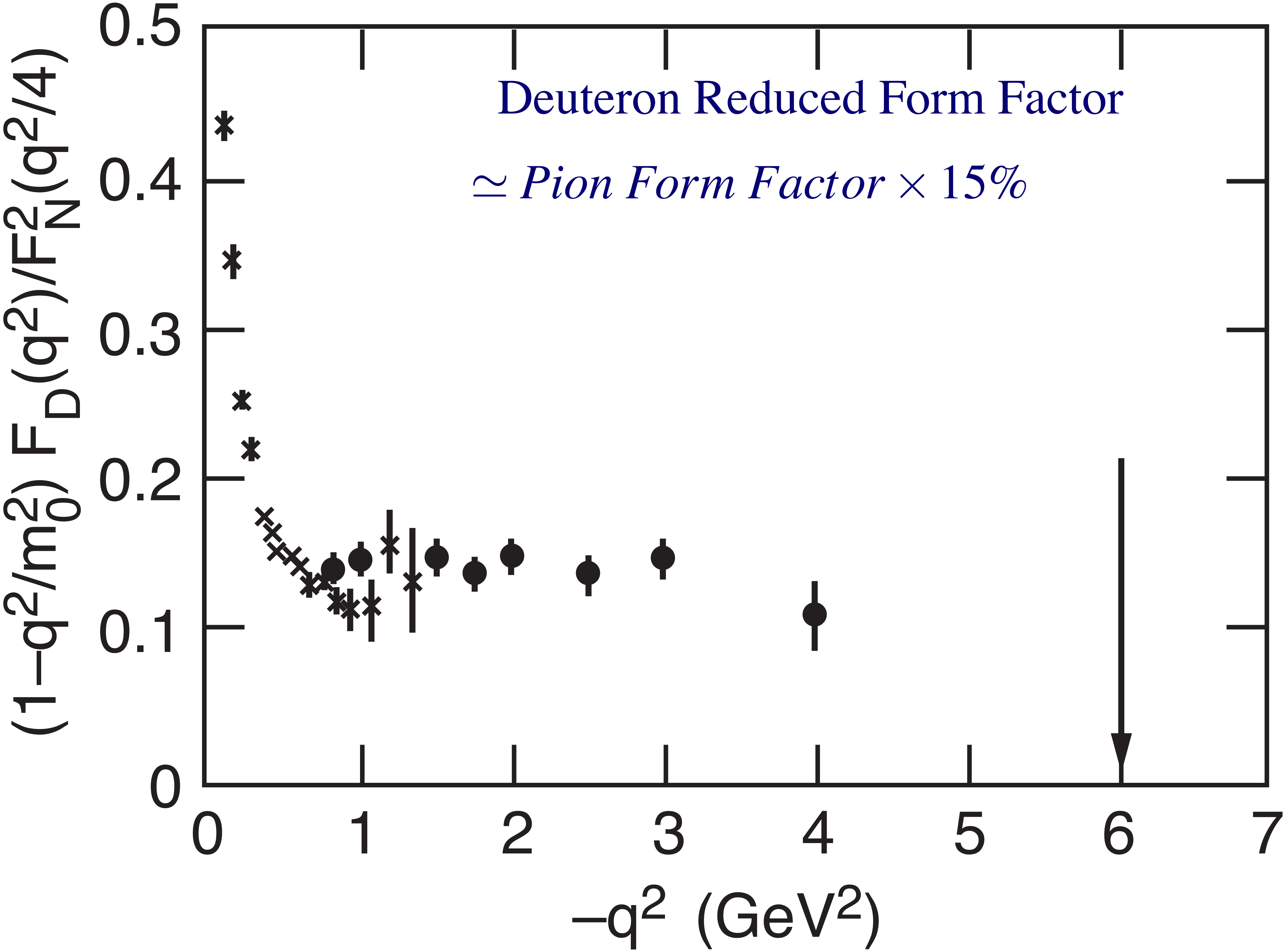
$$f_d(Q^2) \sim \frac{\alpha_s(Q^2)}{Q^2} \left(\ln \frac{Q^2}{\Lambda^2}\right)^{-(2/5)\, C_F/\beta}$$



(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 $Q^2 = 4\ \text{GeV}^2$ 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 $m_0^{\,2} = 0.28\ \text{GeV}^2$ is used

Same large momentum transfer behavior as pion form factor

Chertok, sjb



$$Predict\ f_d(Q^2) \to \frac{1}{Q^2}$$

Lepage, Ji, sjb

Hidden Color in QCD

Study the Deuteron as a QCD Object

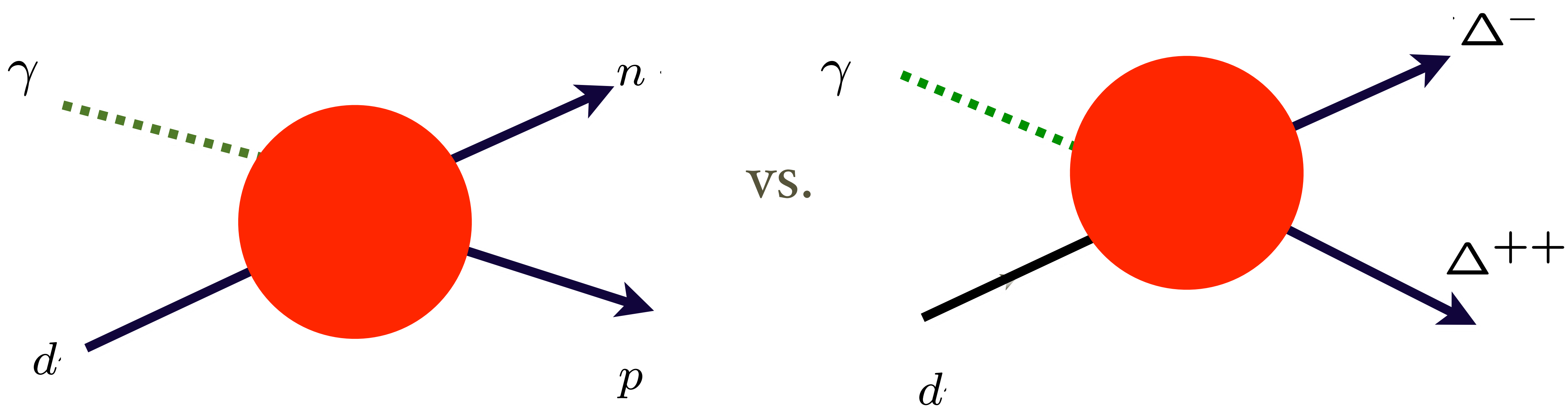
- Deuteron six-quark wavefunction
- 5 color-singlet combinations of 6 color-triplets -- only one state is |n p>
- Components evolve towards equality at short distances
- Hidden color states dominate deuteron form factor and photo-disintegration at high momentum transfer
- Dominance at x > 1
- Predict $\frac{d\sigma}{dt}(\gamma d \to \Delta^{++}\Delta^{-}) \simeq \frac{d\sigma}{dt}(\gamma d \to pn)$ at high Q^2

Test of Hidden Color in Deuteron Photo-Disintegration

$$R = \frac{\frac{d\sigma}{dt}(\gamma d \to \Delta^{++}\Delta^{--})}{\frac{d\sigma}{dt}(\gamma d \to pn)}$$

Ratio predicted to approach 2:5

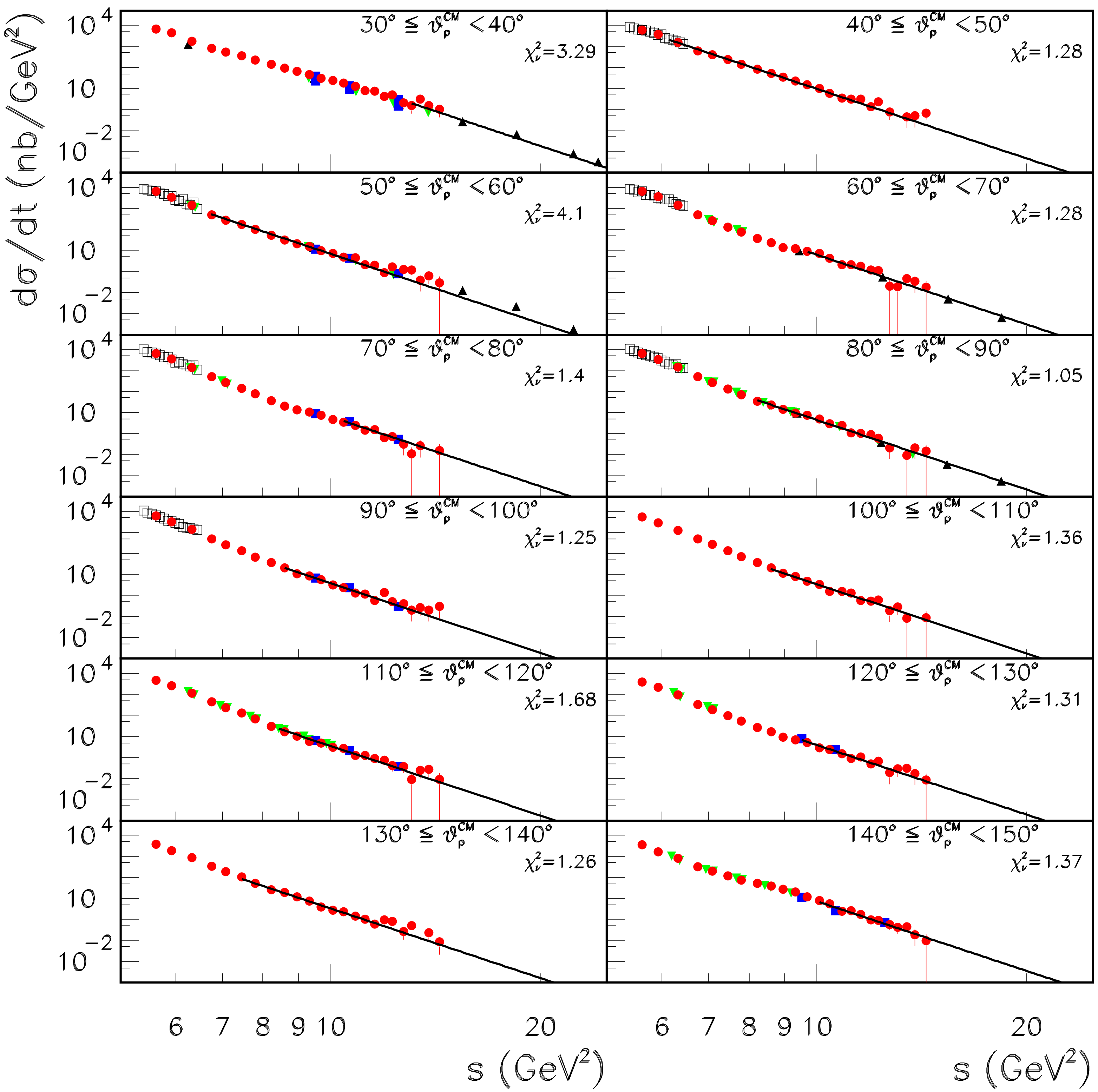
Ratio should grow with transverse momentum as the hidden color component of the deuteron grows in strength.



Possible contribution from pion charge exchange at small t.

Deuteron Photodisintegration

Dimensional Counting Rules



$$\gamma D \to np$$

PQCD and AdS/CFT:

$$s^{n_{tot}-2}\frac{d\sigma}{dt}(A+B\to C+D) = F_{A+B\to C+D}(\theta_{CM})$$

Conformal invariance at high momentum transfers!

$n_{tot} - 2 =$ (1 + 6 + 3+ 3) - 2 = 11

$$s^{11}\frac{d\sigma}{dt}(\gamma D \to np) = F(\theta_{CM})$$

Check of CCR

$\gamma d \rightarrow np$

P.Rossi et al, P.R.L. 94, 012301 (2005)

Fit of $d\sigma/dt$ data for the central angles and $P_T \geq 1.1$ GeV/c with

$A\ s^{-11}$

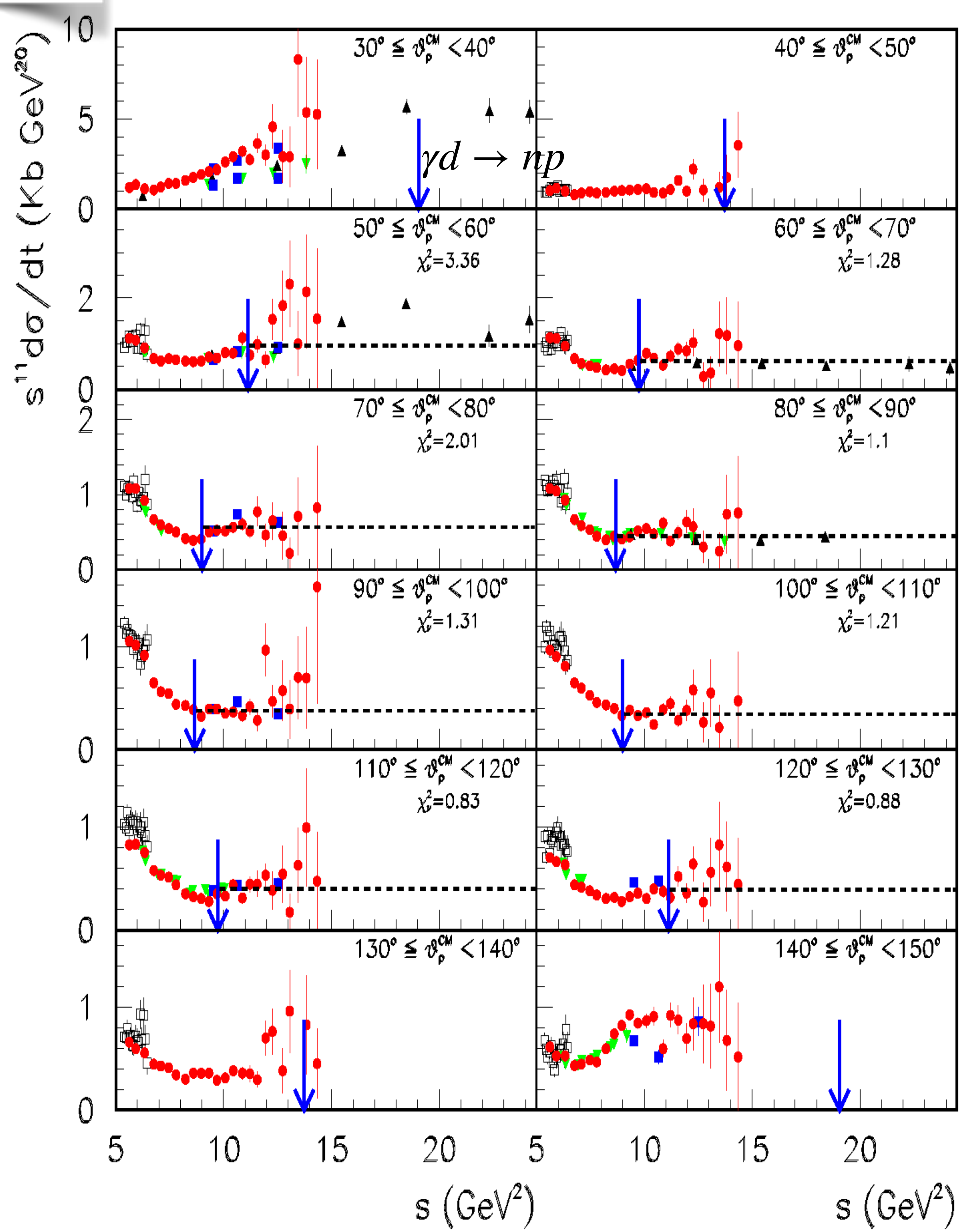
For all but two of the fits

$\chi^2 \leq 1.34$

- Better χ^2 at 55° and 75° if different data sets are renormalized to each other
- No data at $P_T \geq 1.1$ GeV/c at forward and backward angles
- Clear s^{-11} behavior for last 3 points at 35°

Data consistent with CCR

$$s^{11}\frac{d\sigma}{dt}(\gamma d \rightarrow np) = F(\theta_{CM})$$

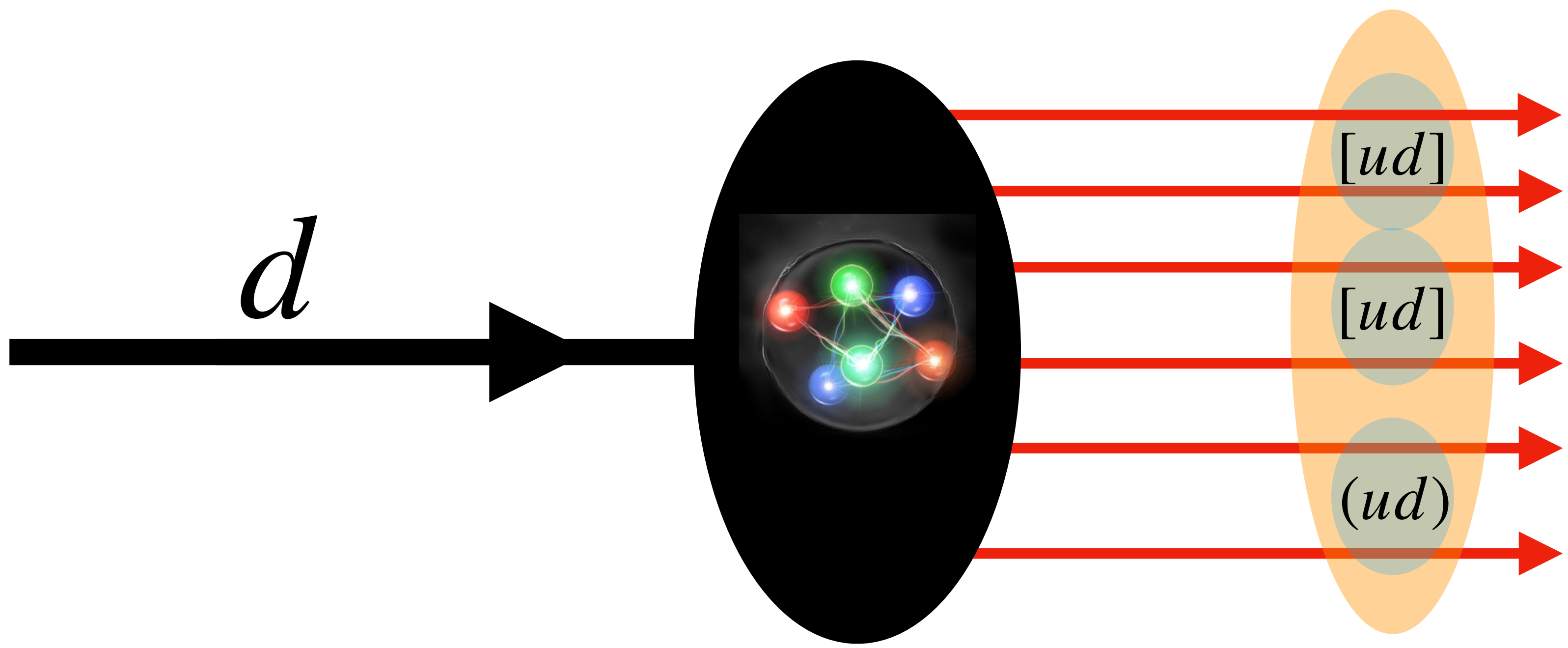


Hidden Color in QCD

- Deuteron: Five color-singlet combinations of 6 color-triplets
- one state is |n p>, one state is Δ Δ

Lepage, Ji, sjb

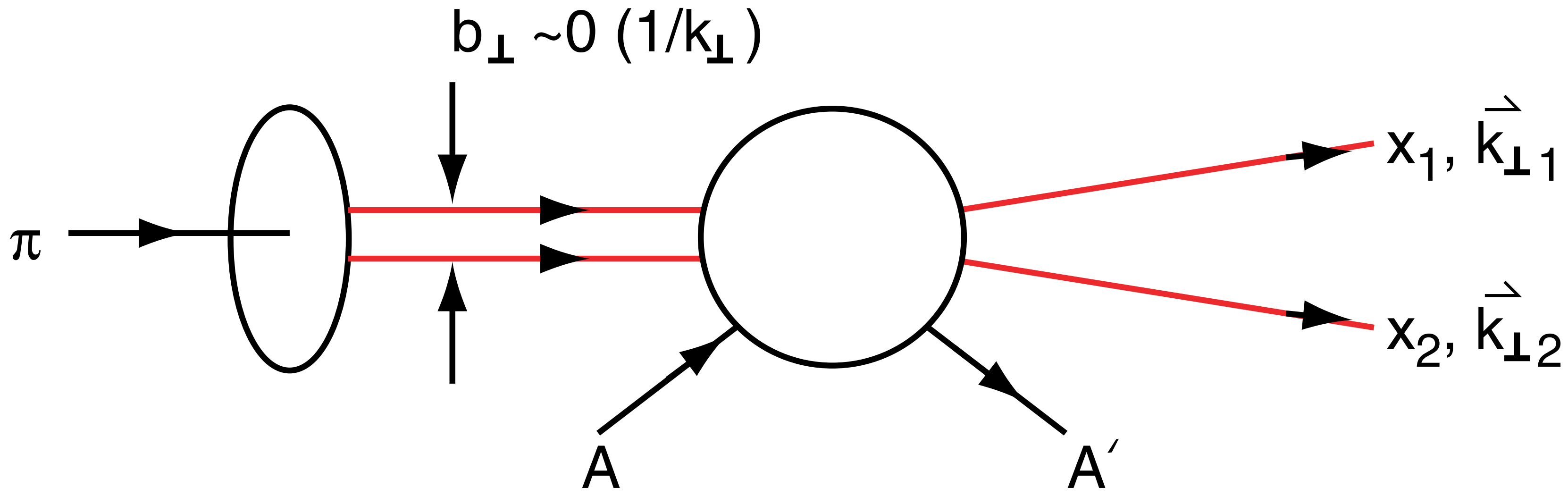
- One state is a J=1 Hexaquark



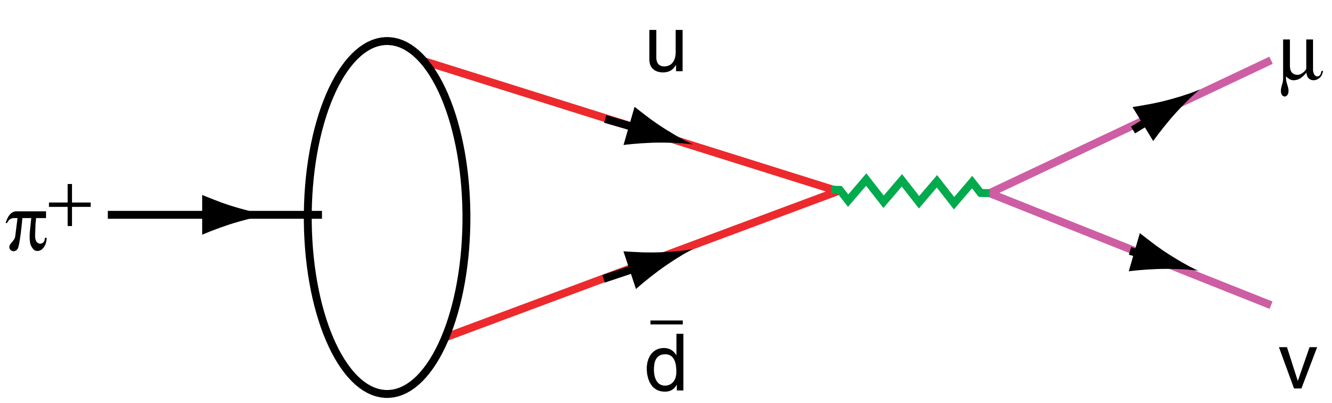
$J = 1$ **Hexaquark** $|(ud)[ud][ud]>$

$Three\ \bar{3}_C\ diquarks : S = 1(ud), S = 0[ud]$

Fluctuation of a Pion to a Compact Color Dipole State

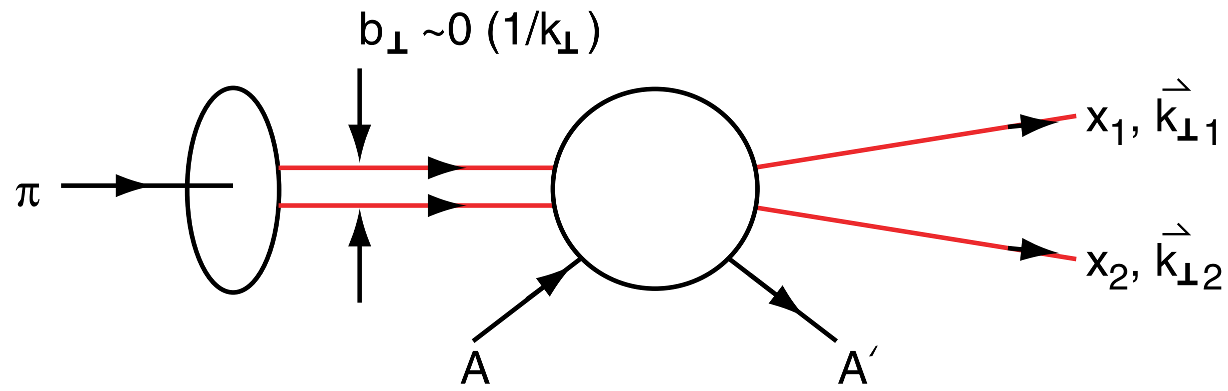


Color - Transparent Fock State Produces High Transverse Momentum Di-Jets



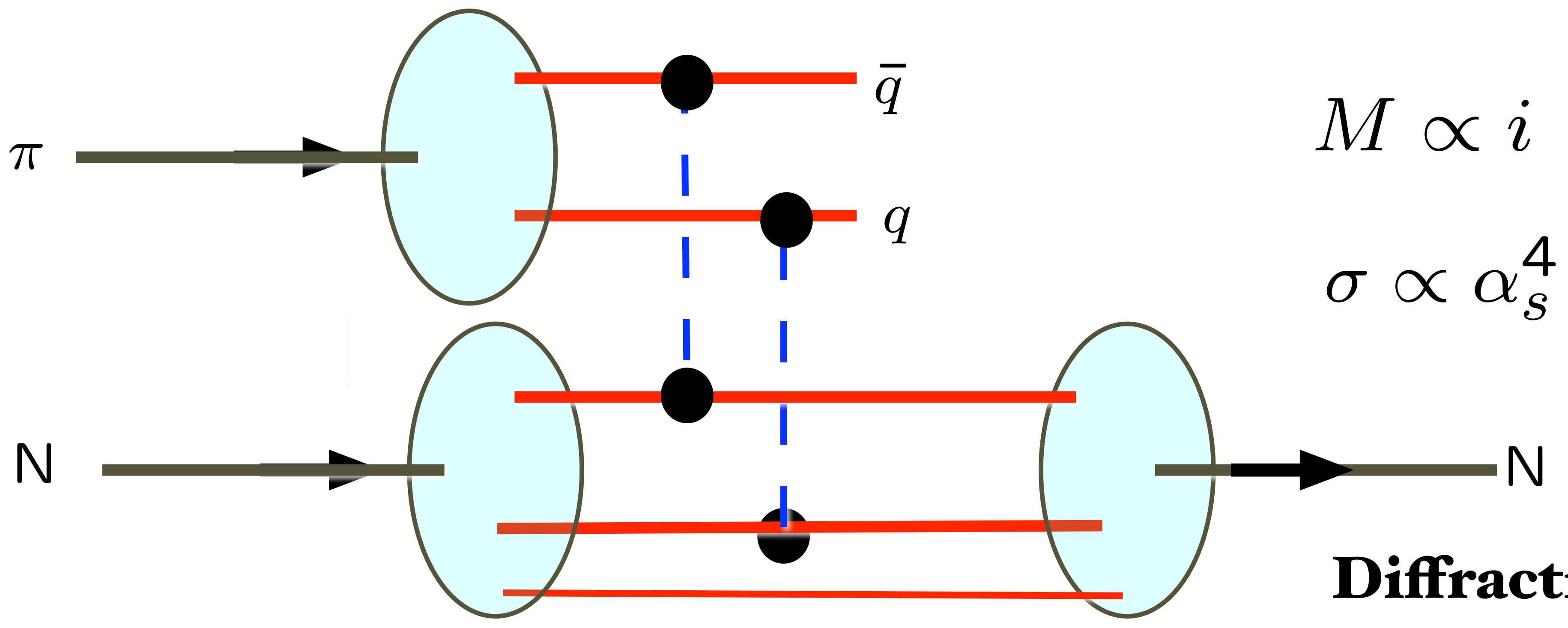
Same Fock State Determines Weak Decay

Key Ingredients in Ashery Experiment



Low Nussinov

Two-gluon exchange gives imaginary amplitude proportional to energy, constant diffractive cross sections



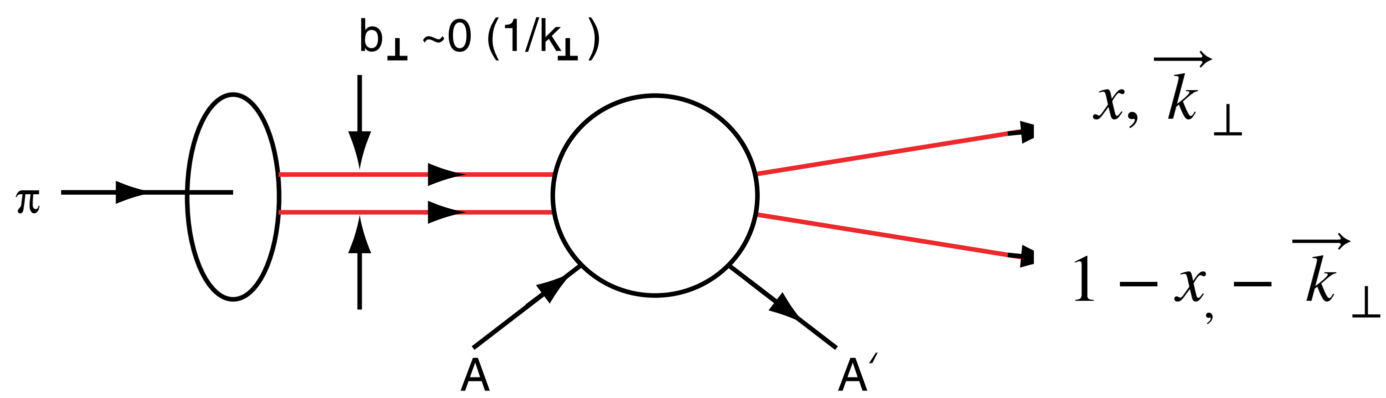
$$M \propto i\ s\ \alpha_s^2\ b_\perp^\pi\ b_\perp^N$$

$$\sigma \propto \alpha_s^4\ (b_\perp^\pi)^2\ (b_\perp^N)^2$$

Target left intact

Diffraction, Rapidity gap

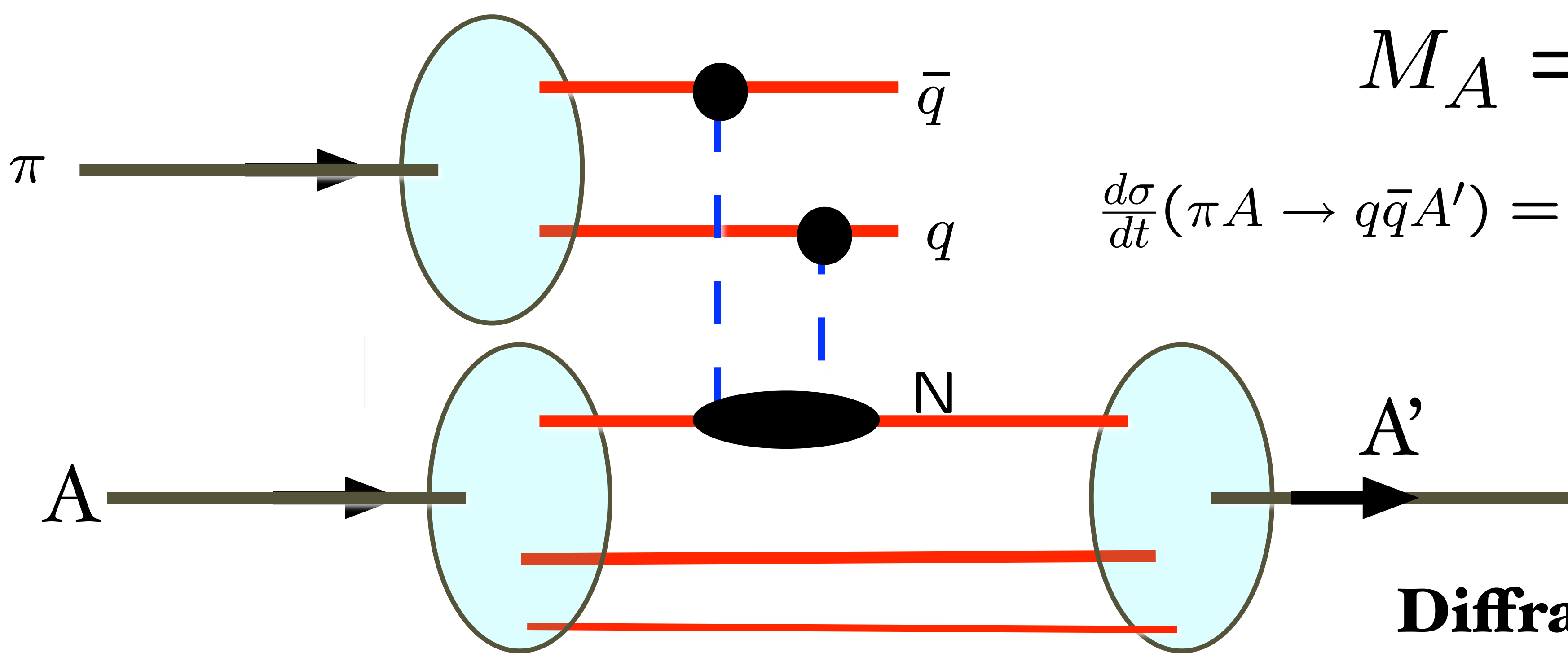
Key Ingredients in Ashery Experiment



Brodsky Mueller
Frankfurt Miller
Strikman

Small color-dipole moment pion not absorbed; interacts with <u>each</u> nucleon coherently

<u>QCD COLOR Transparency</u>

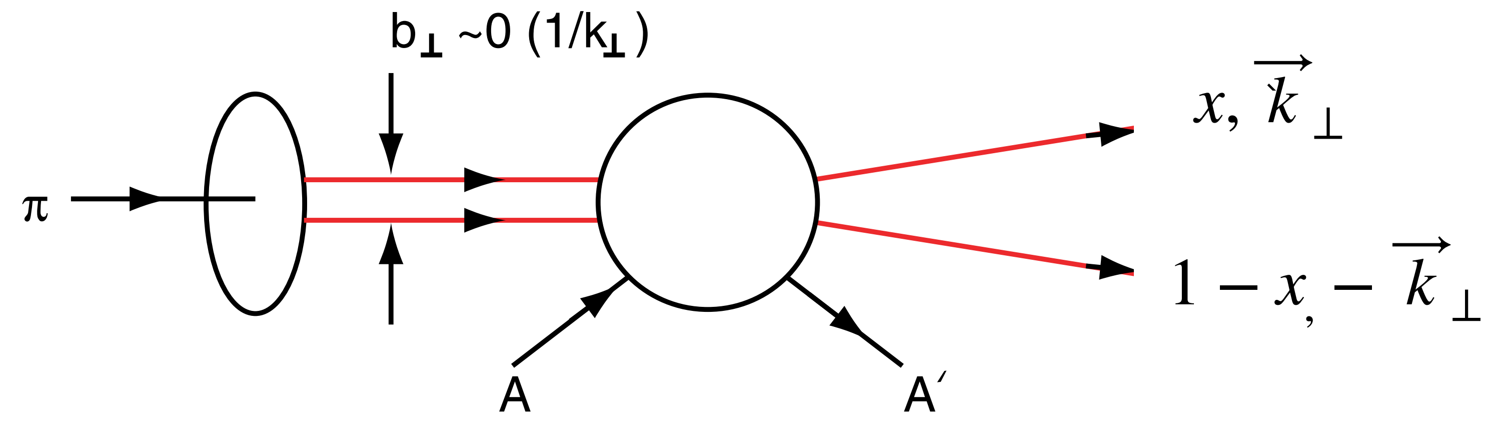


$$M_A = A\ M_N$$

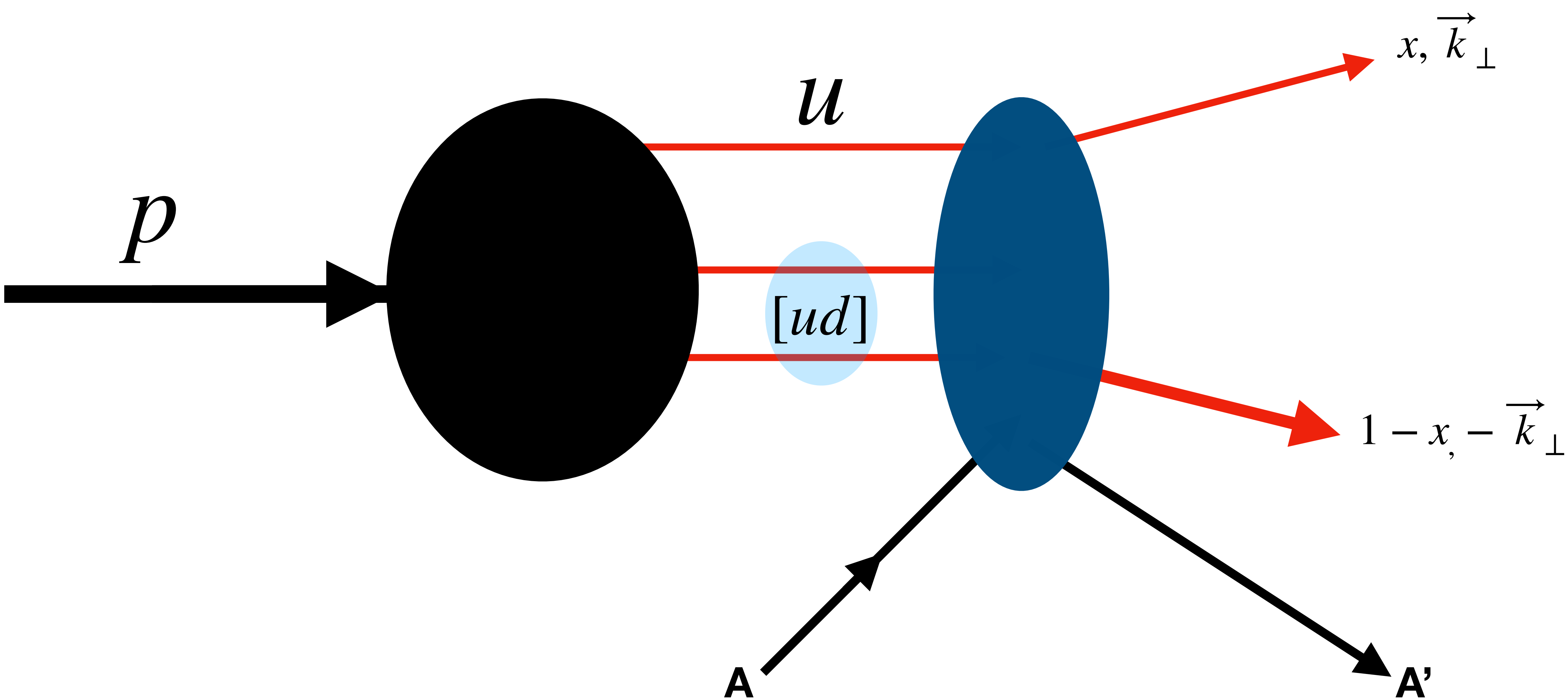
$$\frac{d\sigma}{dt}(\pi A \to q\bar{q}A') = A^2\ \frac{d\sigma}{dt}(\pi N \to q\bar{q}N')\ F^2_A(t)$$

Target left intact

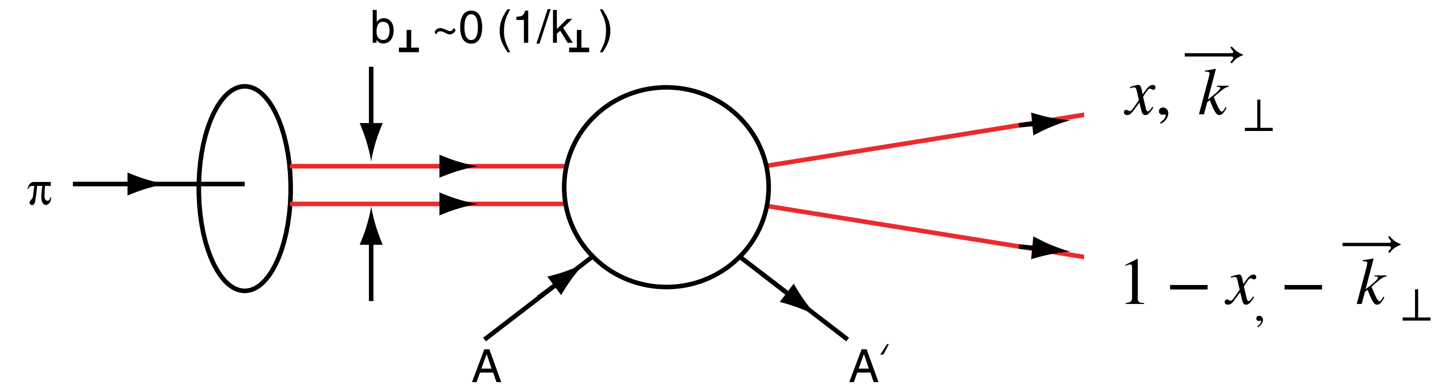
Diffraction, Rapidity gap



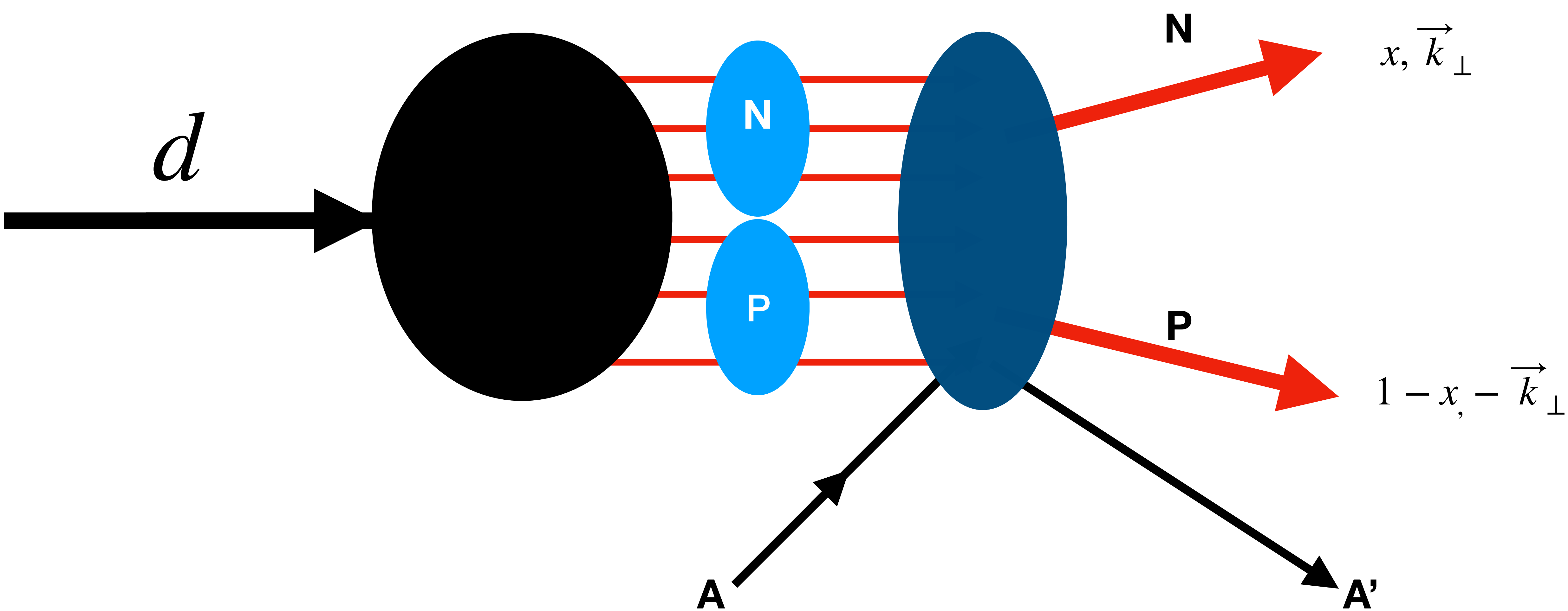
Dissociate proton Fock state to two jets



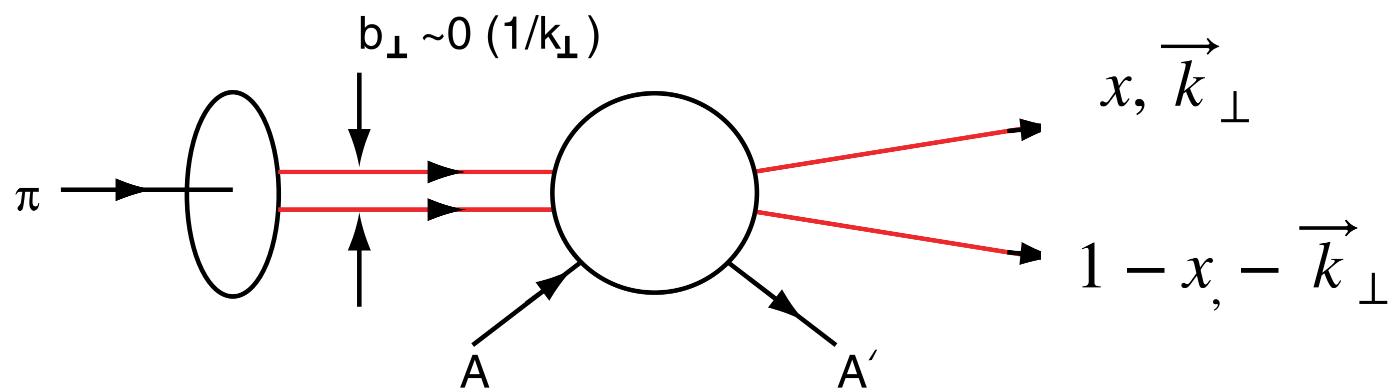
Measure frame-independent proton quark-diquark light-front wavefunction $\Psi_p^{u[ud]}(x, \vec{k}_\perp)$



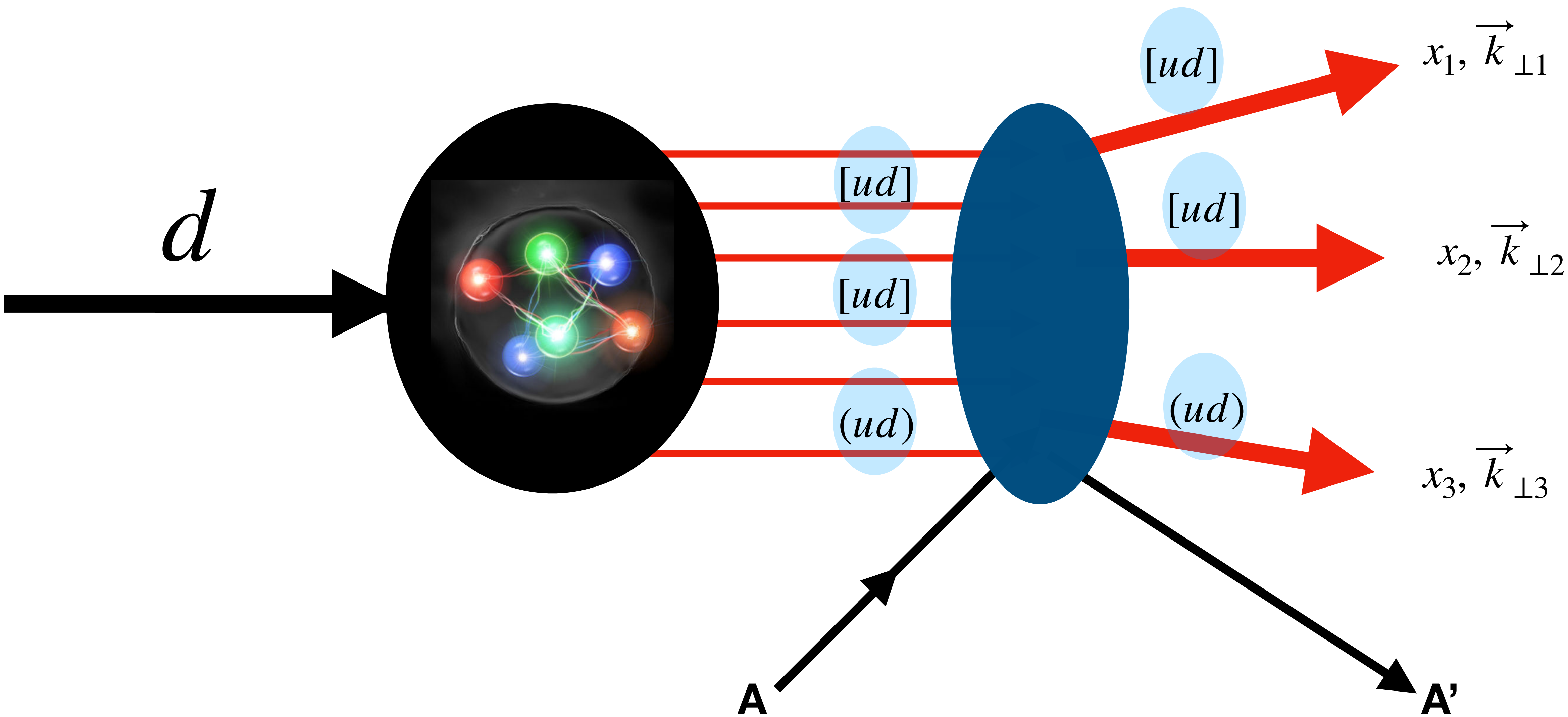
Dissociate deuteron Fock state to two nucleons



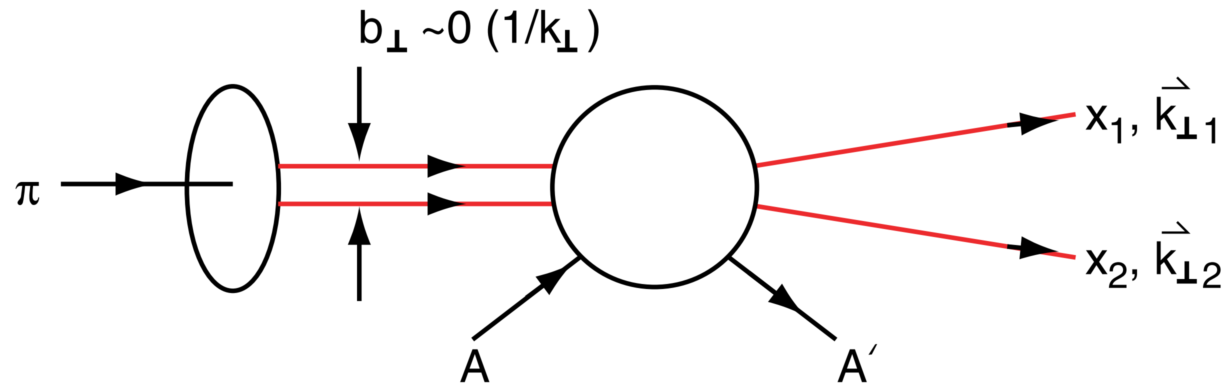
Measure frame-independent deuteron light-front wavefunction $\Psi_d^{NP}(x, \vec{k}_\perp)$



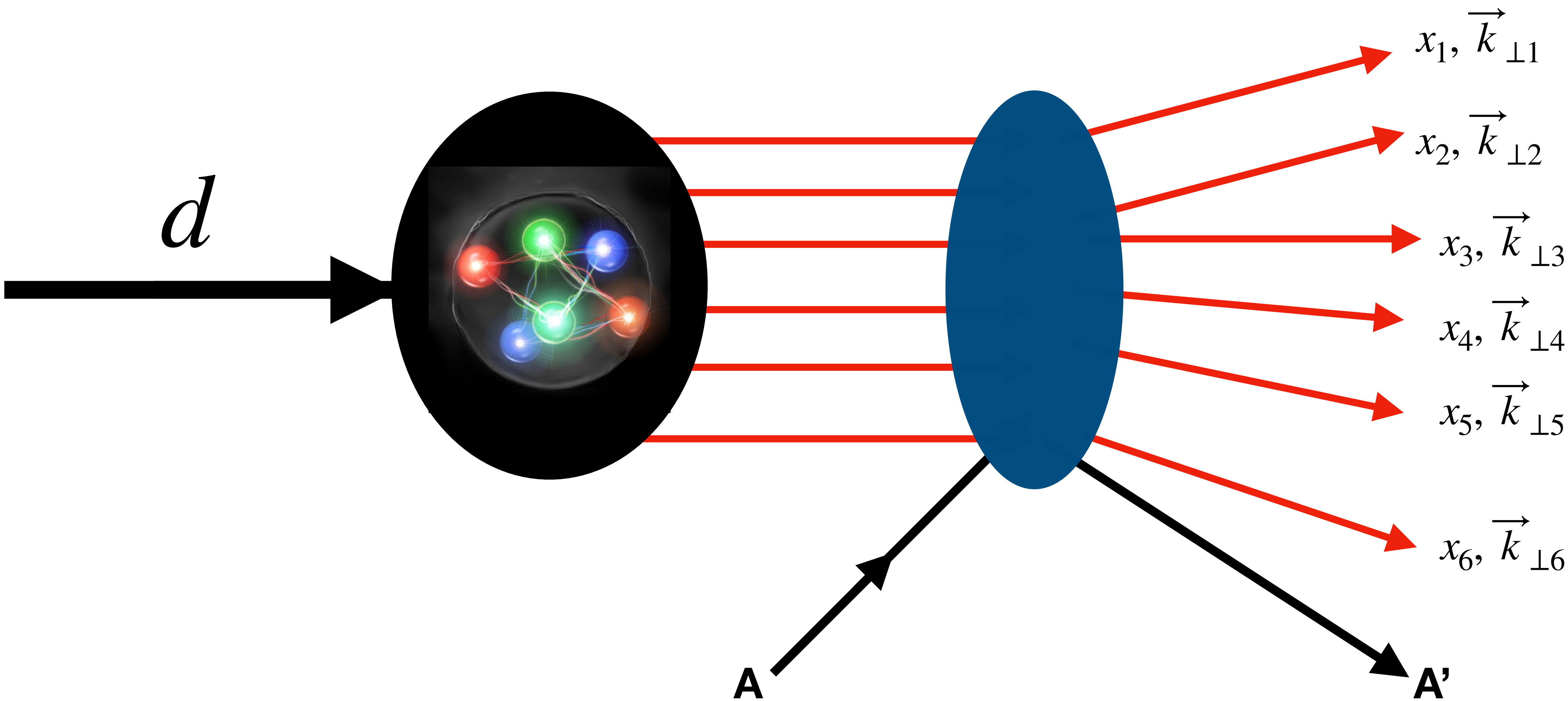
Dissociate hidden-color deuteron hexaquark Fock state to three diquark jets



Measure frame-independent deuteron light-front wavefunction $\Psi_d^{\mathbf{Hexaquark}}(x, \vec{k}_\perp)$



Dissociate hidden color deuteron Fock state to six quark jets



Measure frame-independent deuteron light-front wavefunction

What is measured!

Static	Dynamic
Square of Target LFWFs	Modified by Rescattering: ISI & FSI
No Wilson Line	Contains Wilson Line, Phases
Probability Distributions	No Probabilistic Interpretation
Process-Independent	Process-Dependent - From Collision
T-even Observables	T-Odd (Sivers, Boer-Mulders, etc.)
No Shadowing, Anti-Shadowing	Shadowing, Anti-Shadowing, Saturation
Sum Rules: Momentum and J^z	Sum Rules Not Proven !
DGLAP Evolution; mod. at large x	DGLAP Evolution
No Diffractive DIS	Hard Pomeron and Odderon Diffractive DIS

Hwang, Schmidt, sjb,

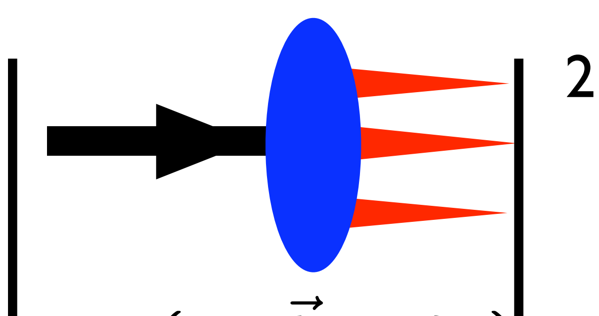
Mulders, Boer

Qiu, Sterman

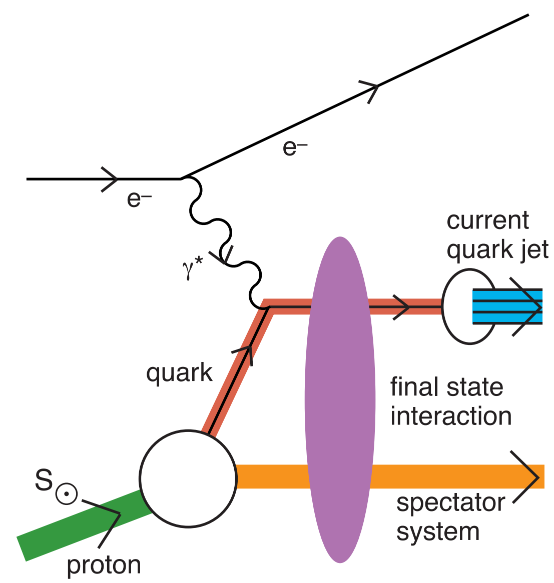
Collins, Qiu

Pasquini, Xiao, Yuan, sjb

Liuti, sjb



$$\left|\Psi_n(x_i, \vec{k}_{\perp i}, \lambda_i)\right|^2$$



One of the most interesting aspects of neutrino-nucleus DIS measurements is the apparent absence of antishadowing of the nuclear parton distributions, in direct contradiction to electron-nucleus and muon-nucleus measurements.

Implications:

(1) anti-shadowing may be flavor specific.

(2) This can be tested in flavor-tagged semi-inclusive deep inelastic lepton scattering.

(3) antishadowing cannot compensate for shadowing in the momentum sum rule

(5) the momentum sum rule may in fact be inapplicable for the nuclear pdf,

(6) the standard operator product analysis can fail for nuclei because of shadowing and antishadowing.

(7) Implications of these issues for nuclear pdfs in QCD based on Glauber-Gribov theory

(9) Important connections to leading-twist diffractive DIS.

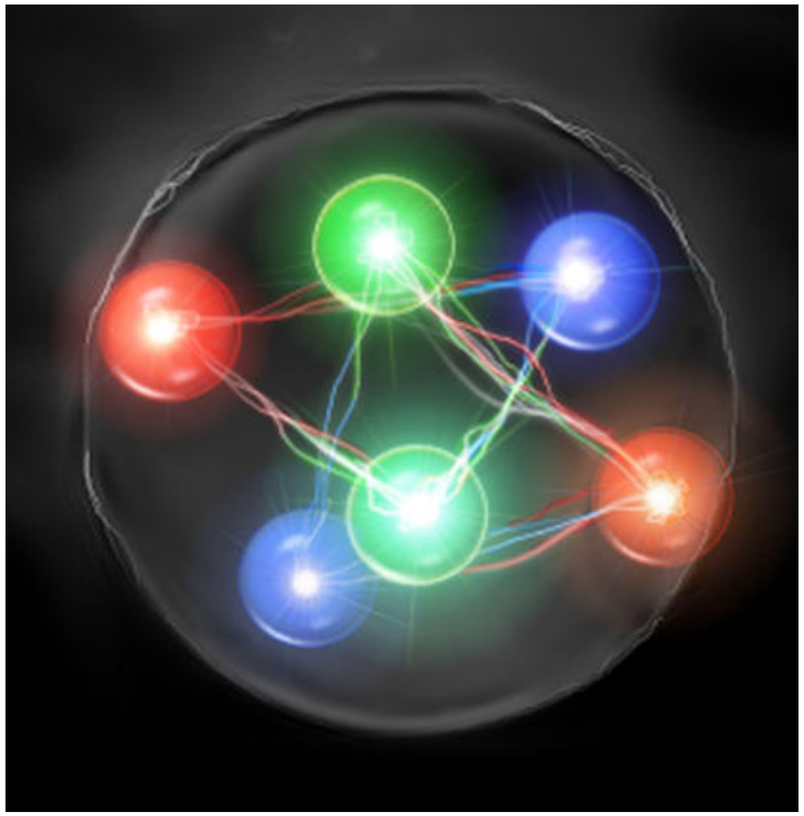
Novel Effects Derived from Light-Front Wavefunctions

- Color Transparency
- Intrinsic heavy quarks at high x $c(x), b(x)$
- Asymmetries $s(x) \neq \bar{s}(x), \bar{u}(x) \neq \bar{d}(x)$
- Spin correlations, counting rules at x to 1
- Diffractive deep inelastic scattering $ep \to epX$
- Nuclear Effects: Hidden Color

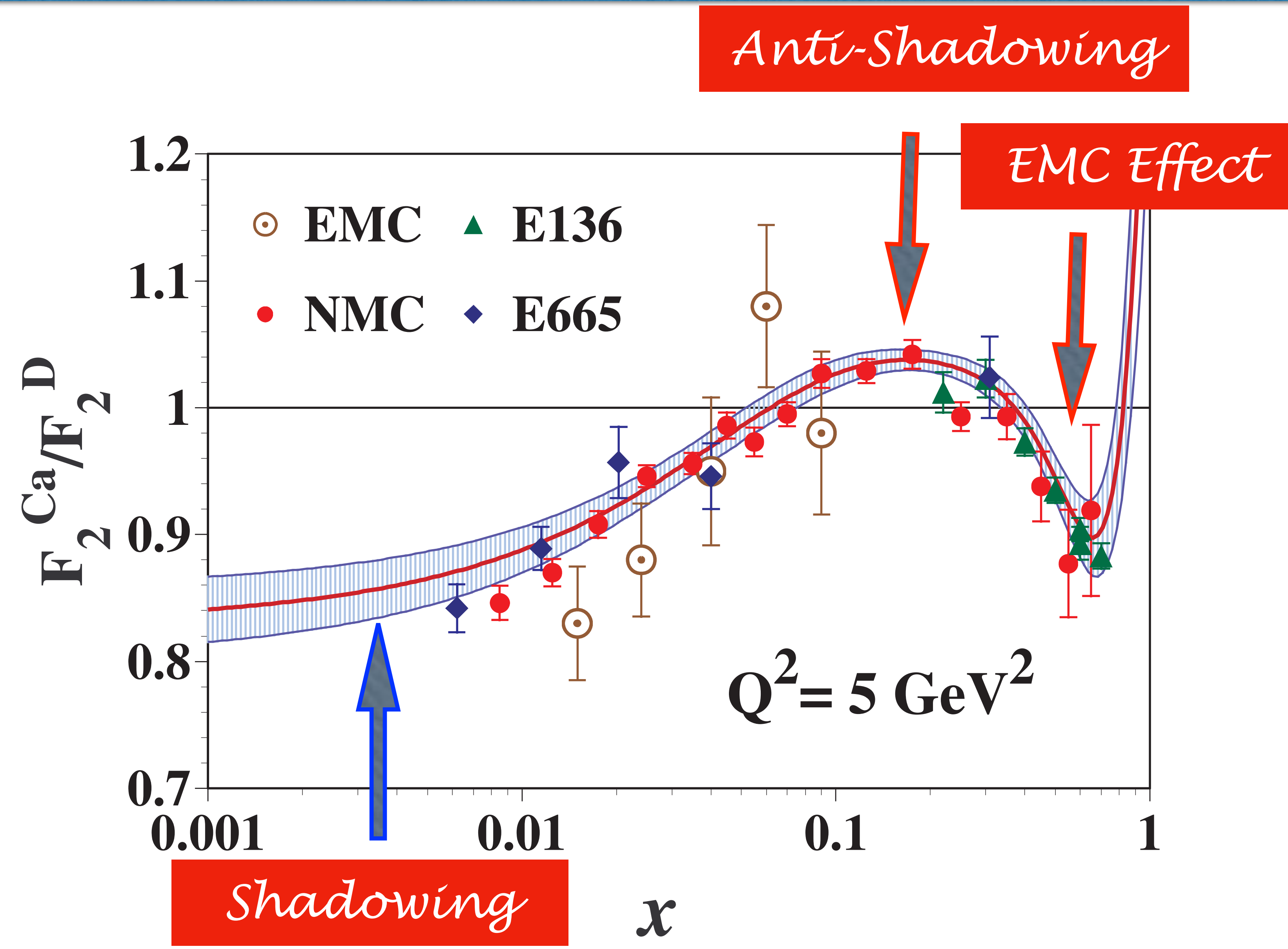
QCD Myths

- **Anti-Shadowing is Universal: Nuclear PDF Sum Rules!**
- **ISI and FSI are higher twist effects and universal**
- **High transverse momentum hadrons arise only from jet fragmentation -- baryon anomaly!**
- **heavy quarks only from gluon splitting**
- **renormalization scale cannot be fixed**
- **QCD condensates are vacuum effects**
- **Infrared Slavery**
- **Nuclei are composites of nucleons only**
- **Real part of DVCS arbitrary**

Novel QCD Features of Nuclei



Hidden Color



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GHP-APS

8th Workshop of the APS Topical Group on Hadronic Physics

Denver
Wednesday, 10 April 2019