Hadrons Fluctuate in Particle Number

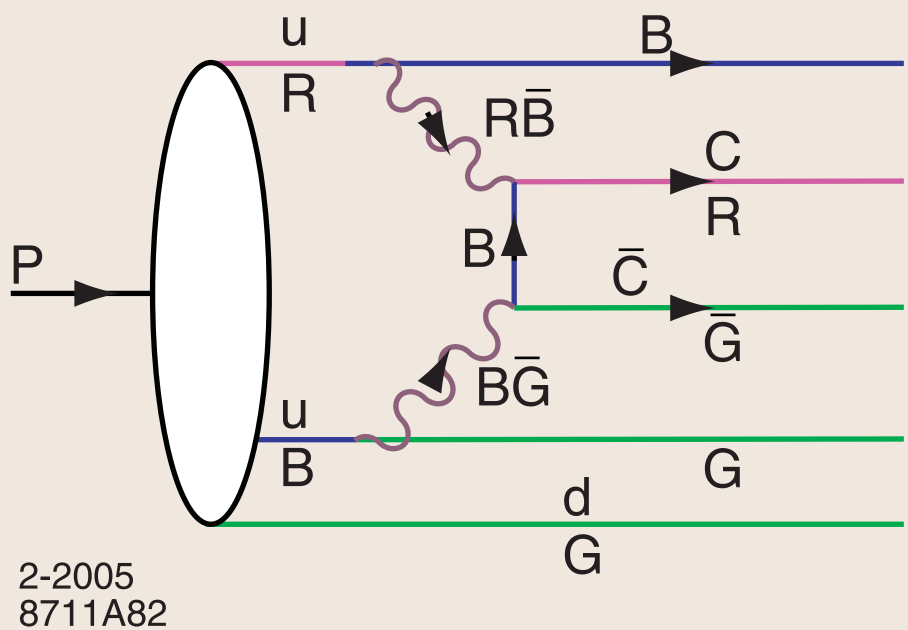
- Proton Fock States

$$|uud>, |uudg>, |uuds\bar{s}>, |uudc\bar{c}>, |uudb\bar{b}> \cdots$$

- Strange and Anti-Strange Quarks not Symmetric

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

- "Intrinsic Charm": High momentum heavy quarks
- "Hidden Color": Deuteron not always p + n
- Orbital Angular Momentum Fluctuations - Anomalous Magnetic Moment



$|uudc\bar{c}>$ Fluctuation in Proton

QCD: Probability $\frac{\sim\Lambda^2_{QCD}}{M^2_Q}$

OPE derivation - M.Polyakov et al.

High x charm

$c\bar{c}$ in Color Octet

Distribution peaks at equal rapidity (velocity)

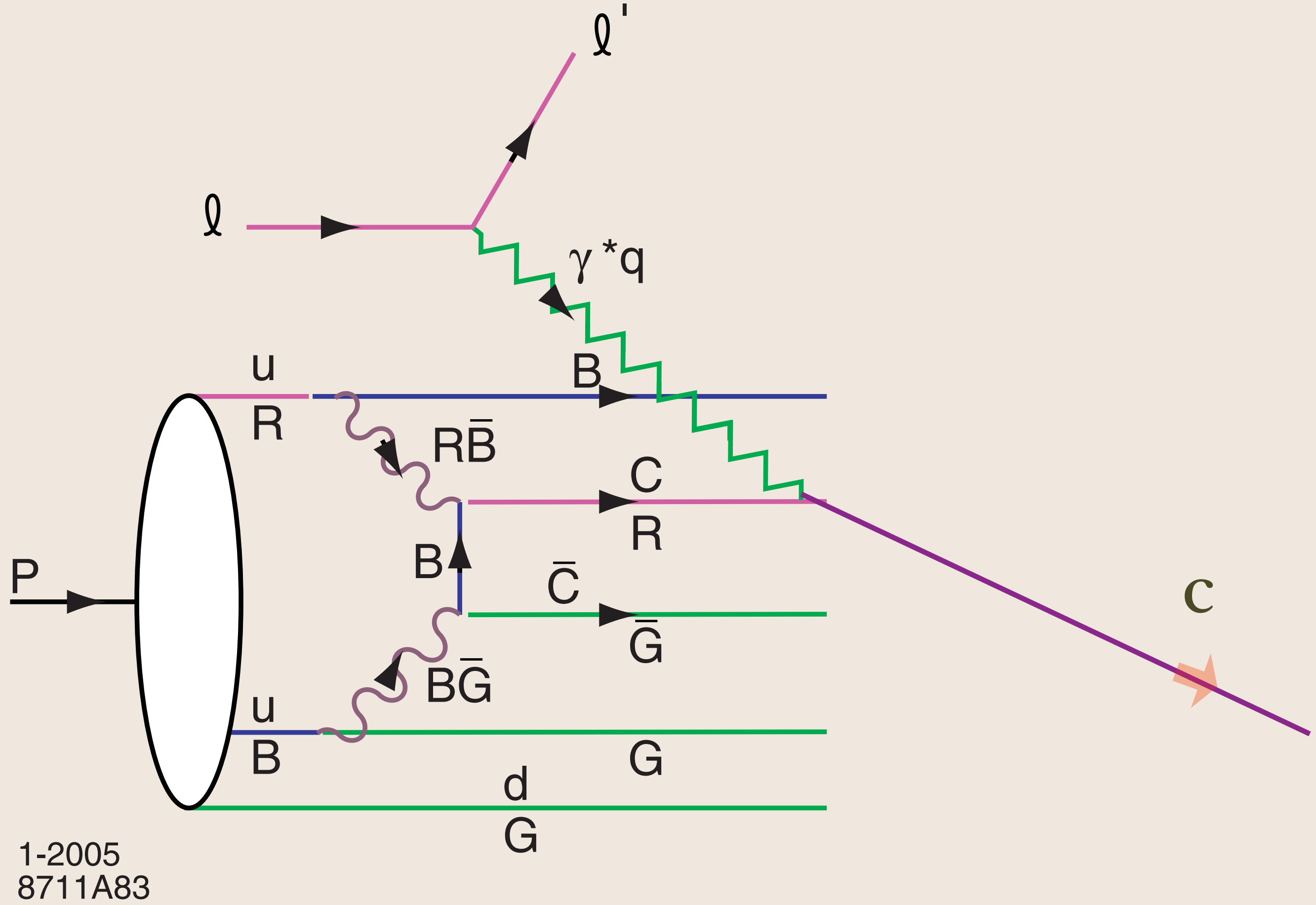
Therefore heavy particles carry the largest momentum fractions

In contrast:

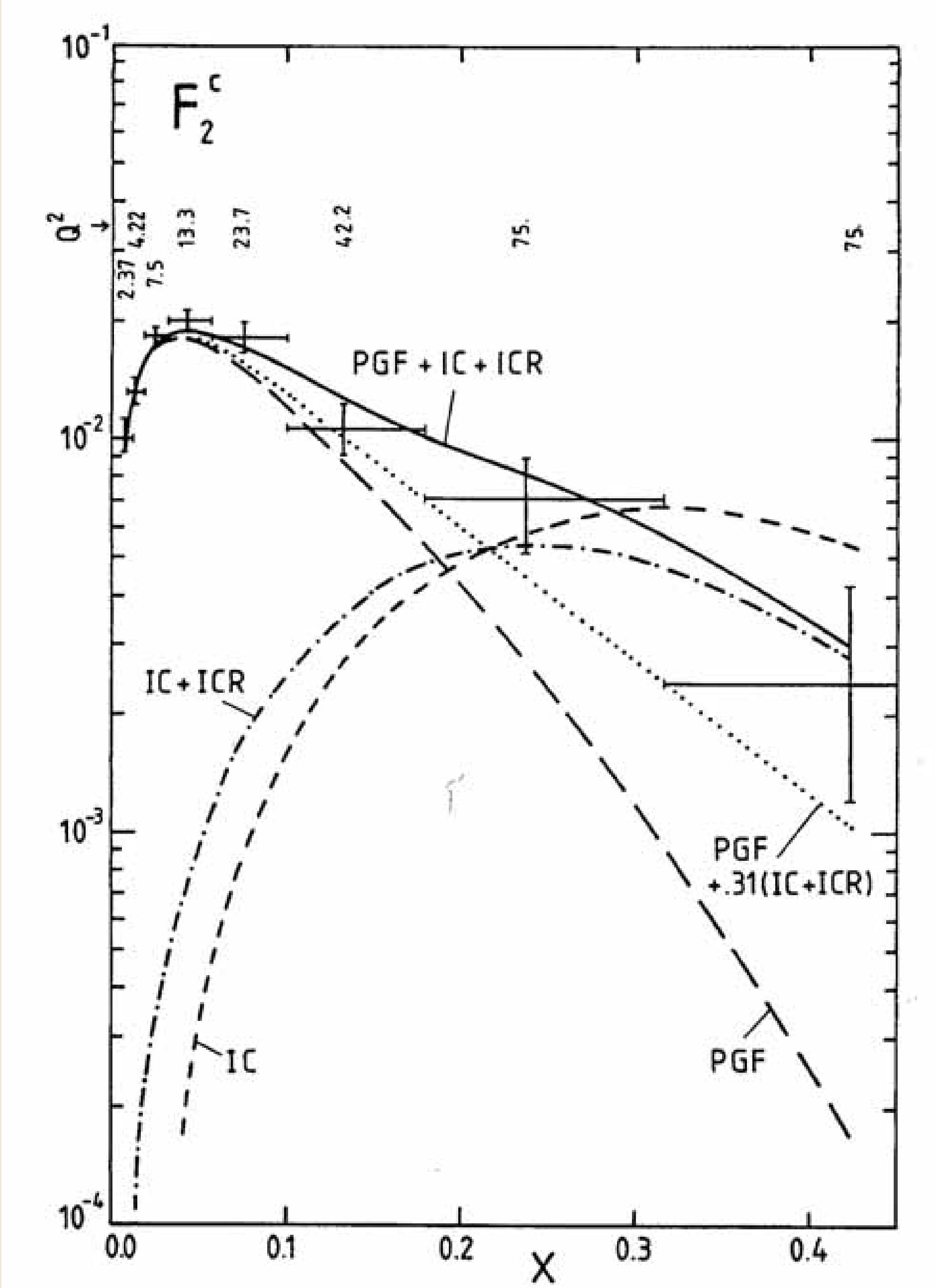
$|e^+e^-\ell^+\ell^->$ Fluctuation in Positronium

QED: Probability $\frac{\sim(m_e\alpha)^4}{M^4_\ell}$

Measure c(x) in Deep Inelastic Lepton-Proton Scattering

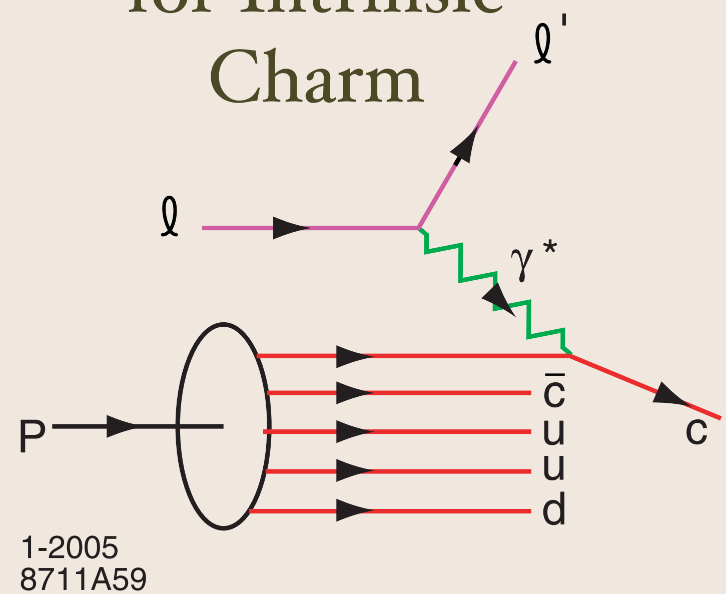


Hoyer, Peterson, SJB



Measurement of Charm Structure Function

Evidence for Intrinsic Charm



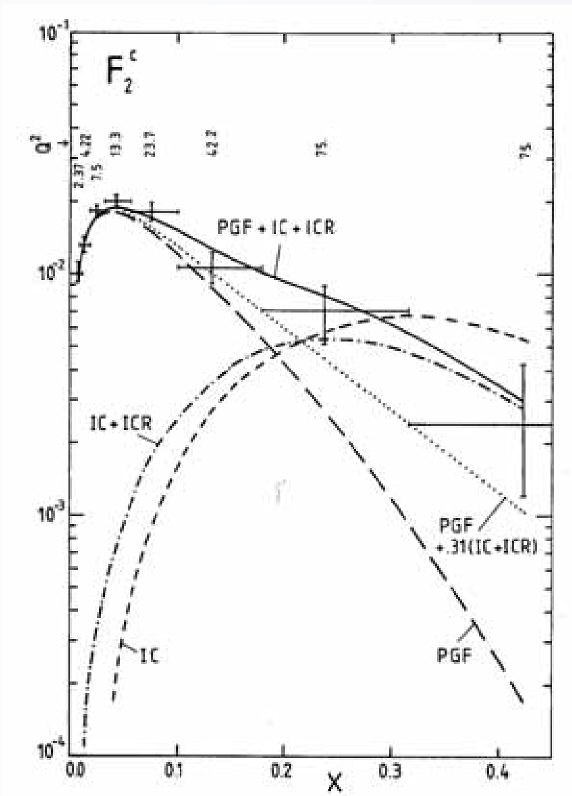
J. J. Aubert et al. [European Muon Collaboration], "Production Of Charmed Particles In 250-Gev Mu+ - Iron Interactions," Nucl. Phys. B 213, 31 (1983).

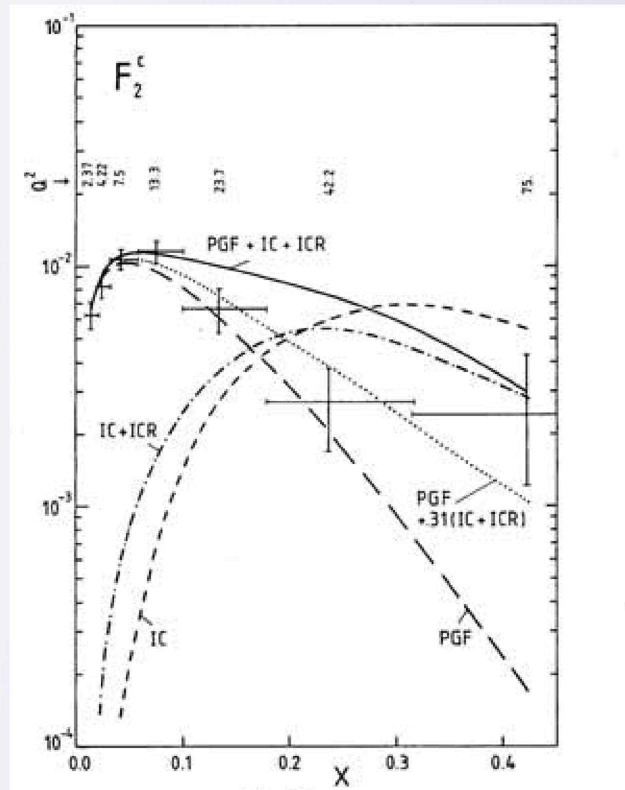
EMC Measurements of the Charm Structure Function

Photon Gluon Fusion Factor 30 too small !

J. J. Aubert et al. [European Muon Collaboration], "Production Of Charmed Particles In 250-Gev Mu+ - Iron Interactions," Nucl. Phys. B 213, 31 (1983).

1% IC





Analysis by
E. Hoffmann and R. Moore, Z. Phys. C 20, 71 (1983).

- EMC data: $c(x, Q^2) > 30 \times$ DGLAP
  $Q^2 = 75$ GeV^2, $x = 0.42$

- High x_F $pp \to J/\psi X$ NA3

- High x_F $pp \to J/\psi J/\psi X$ NA3

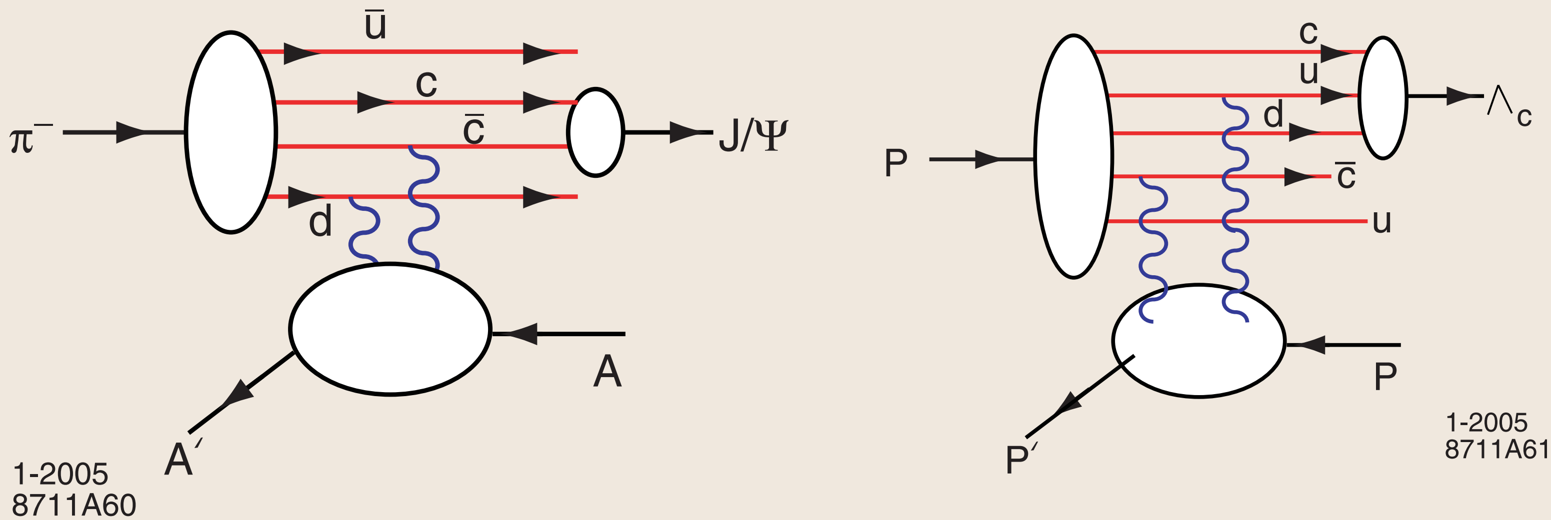
- High x_F $pp \to \Lambda_c X$ ISR

- High x_F $pp \to \Lambda_b X$ ISR

- High x_F $pp \to \Xi(ccd) X$ (SELEX)

Key QCD Experiment at J-PARC

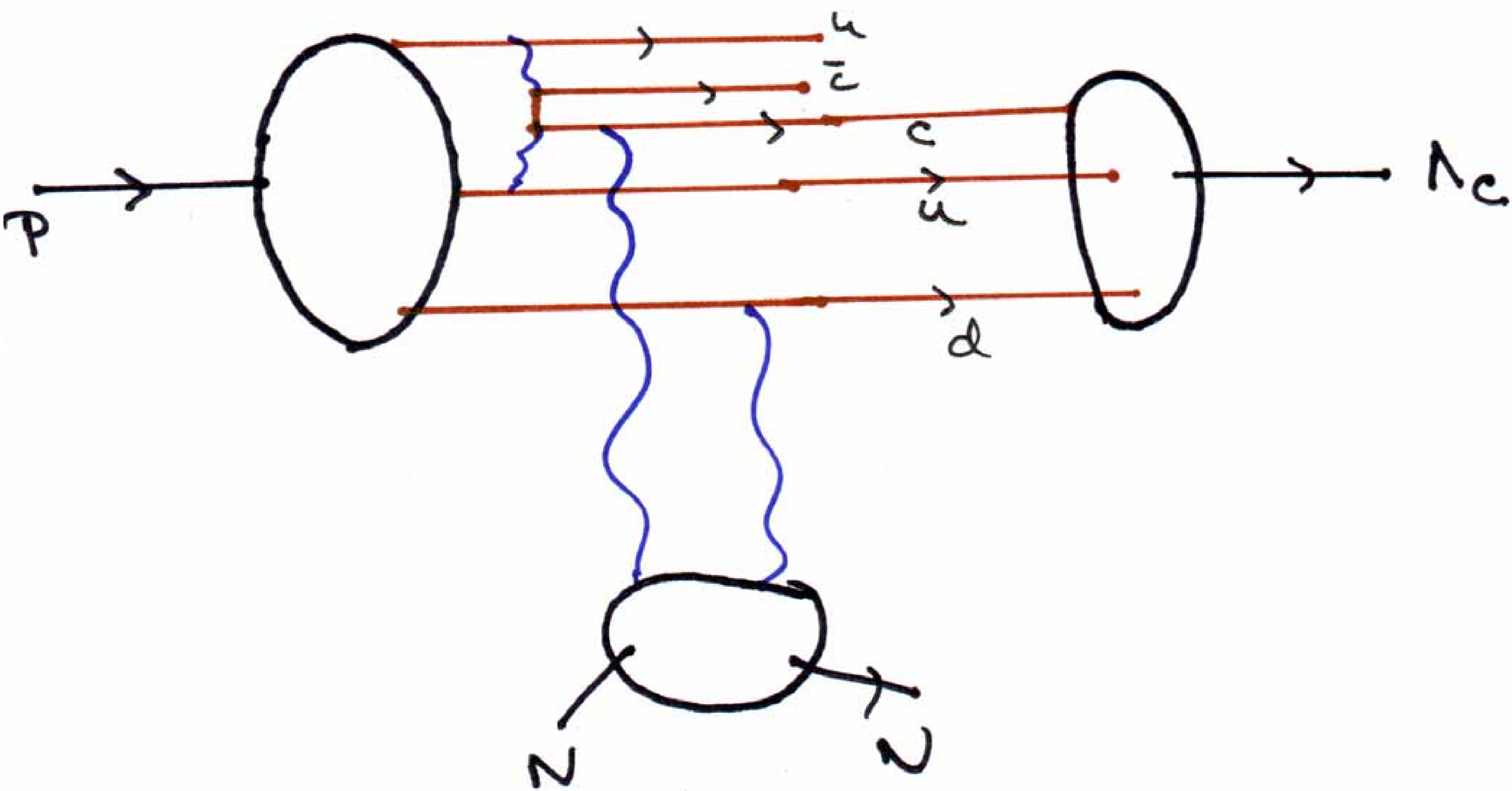
Diffractive Dissociation of Intrinsic Charm



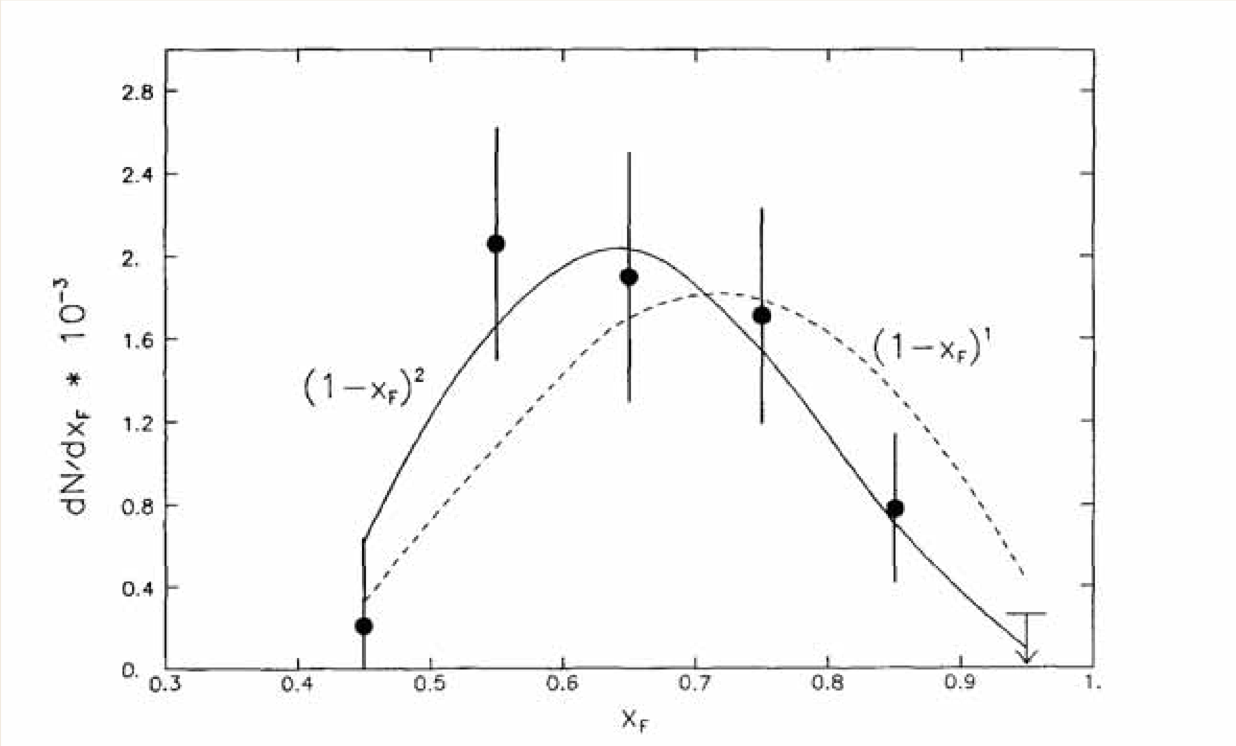
Coalescence of Comoving Charm and Valence Quarks
Produce J/ψ, Λ_c and other Charm Hadrons at High x_F

$p\ p \to p\Lambda_c X$

Diffractive Dissociation of Intrinsic Charm



Production of Charm Hadrons at the ISR

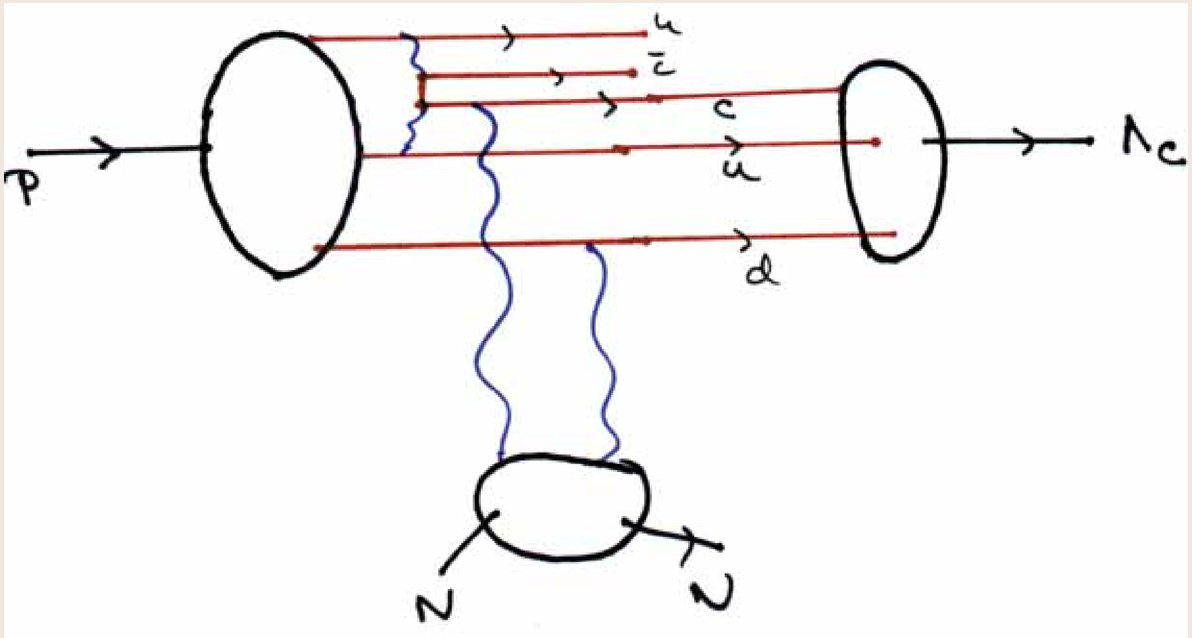


P. M. Chauvat et al. [R608 Collaboration],
"Production of Λ_C With Large x_F At The ISR,"
Phys. Lett. B 199, 304 (1987).
$pp \to p\Lambda_C X$

Key QCD Experiment at J-PARC

Measure diffractive open charm production at forward x_F

$$\frac{d\sigma}{dt dx_F}(pp \to p + \Lambda_C + X)$$



$$\mathcal{M}^2 \geq 16 \text{ GeV}^2$$

$$s = 80 \text{ GeV}^2$$

$$\Delta p_L = \frac{\mathcal{M}^2 - 1 \text{ GeV}^2}{2E_{lab}} \geq 0.4 \text{ GeV}$$

Important Test of Intrinsic Charm

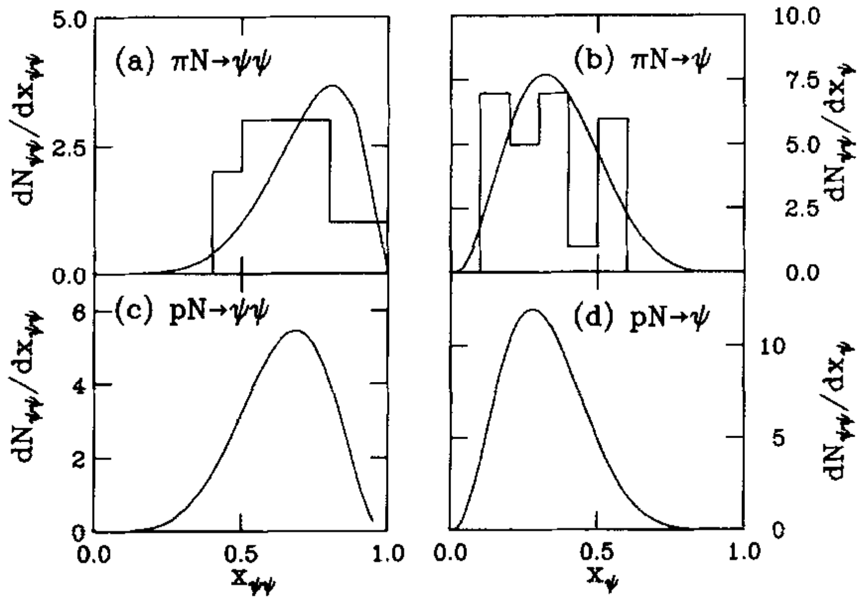


Fig. 3. The $\psi\psi$ pair distributions are shown in (a) and (c) for the pion and proton projectiles. Similarly, the distributions of J/ψ's from the pairs are shown in (b) and (d). Our calculations are compared with the $\pi^- N$ data at 150 and 280 GeV/c [1]. The $x_{\psi\psi}$ distributions are normalized to the number of pairs from both pion beams (a) and the number of pairs from the 400 GeV proton measurement (c). The number of single J/ψ's is twice the number of pairs.

NA3 Data

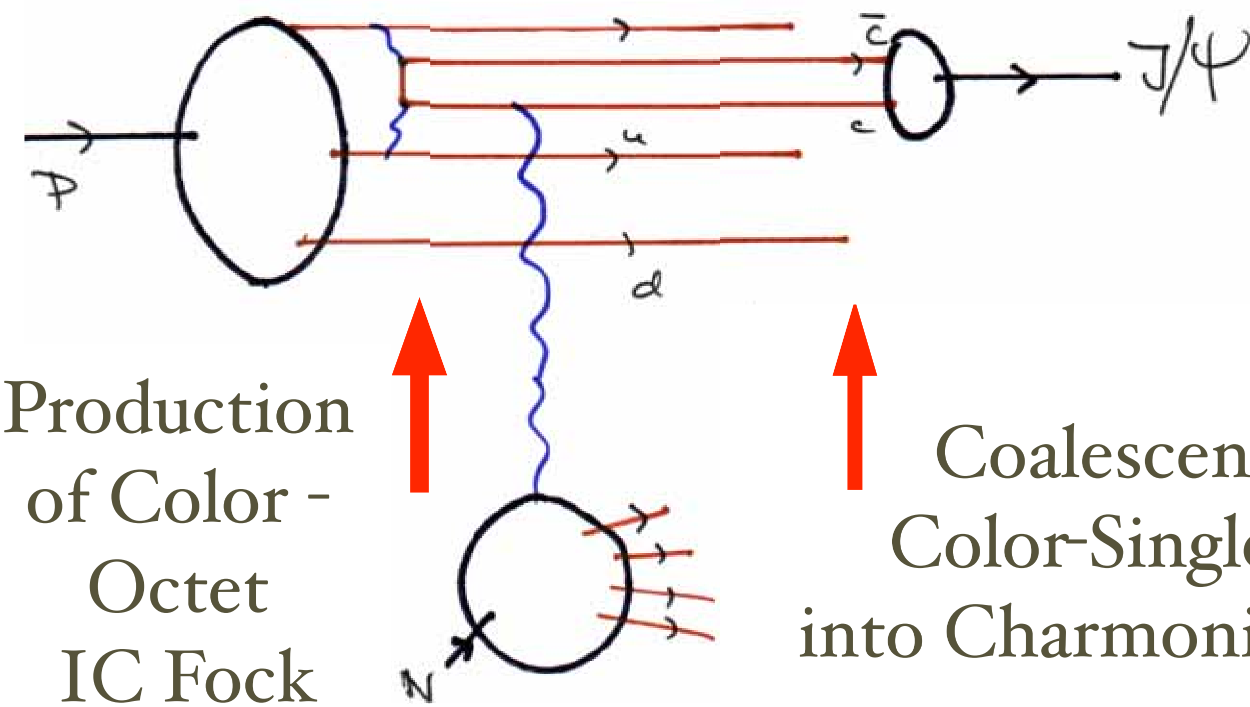
$\pi A \to J/\psi J/\psi X$

Intrinsic charm contribution to double quarkonium hadroproduction ★

R. Vogt [a], S.J. Brodsky [b]

The probability distribution for a general n-parti intrinsic $c\bar{c}$ Fock state as a function of x and $\boldsymbol{k}_T$ written as

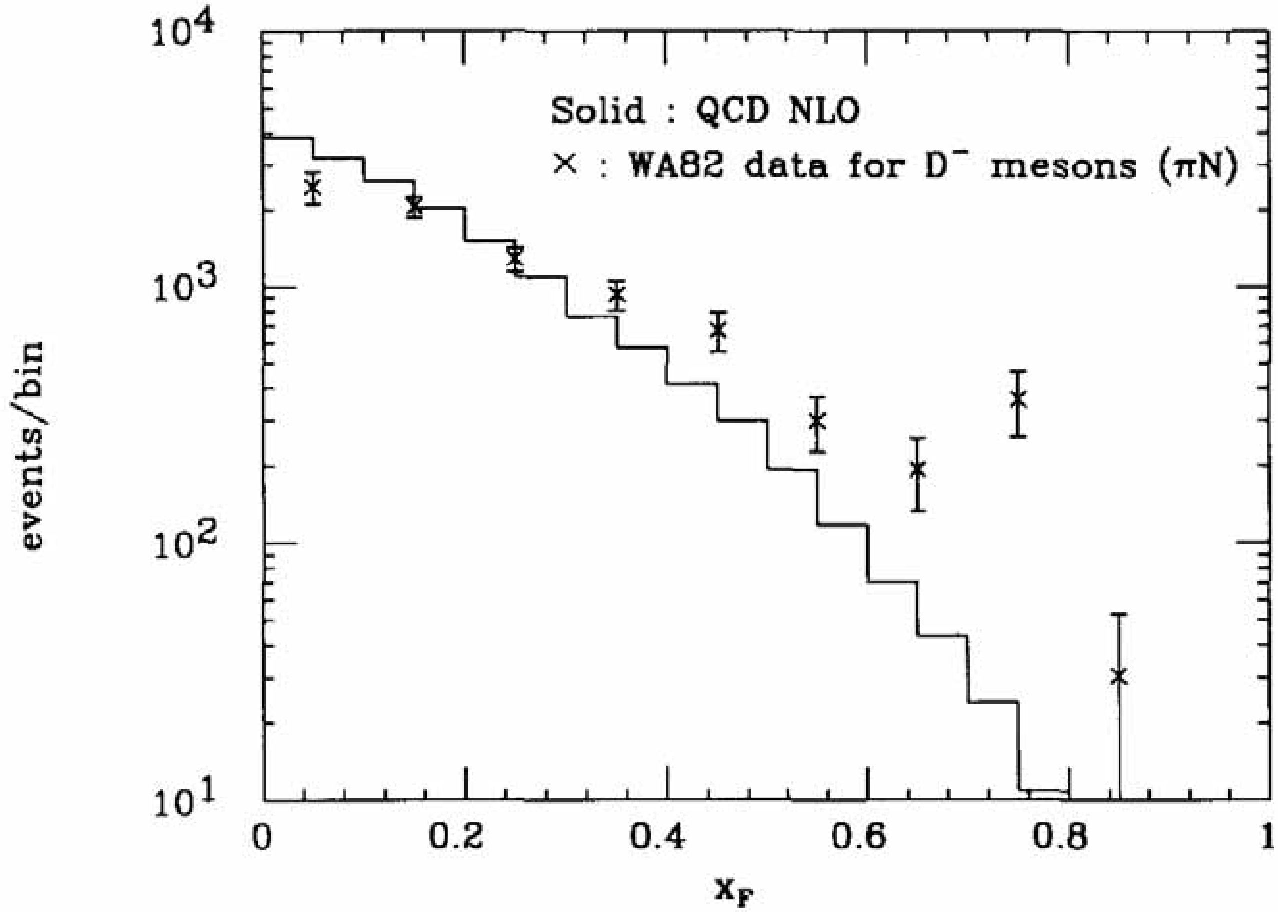
$$\frac{dP_{\rm ic}}{\prod_{i=1}^n dx_i d^2 k_{T,i}} = N_n \alpha_s^4(M_{c\bar{c}}) \frac{\delta(\sum_{i=1}^n \boldsymbol{k}_{T,i})\delta(1-\sum_{i=1}^n x_i)}{(m_h^2 - \sum_{i=1}^n (m_{T,i}^2/x_i))^2},$$



Production of Color - Octet IC Fock State

Coalescence of Color-Singlet Pair into Charmonium State

Scattering on Nucleon via one Gluon



S. Frixione, M. L. Mangano, P. Nason and G. Ridolfi, "Heavy-Quark Production,"
Adv. Ser. Direct. High Energy Phys. 15, 609 (1998) [arXiv:hep-ph/9702287].

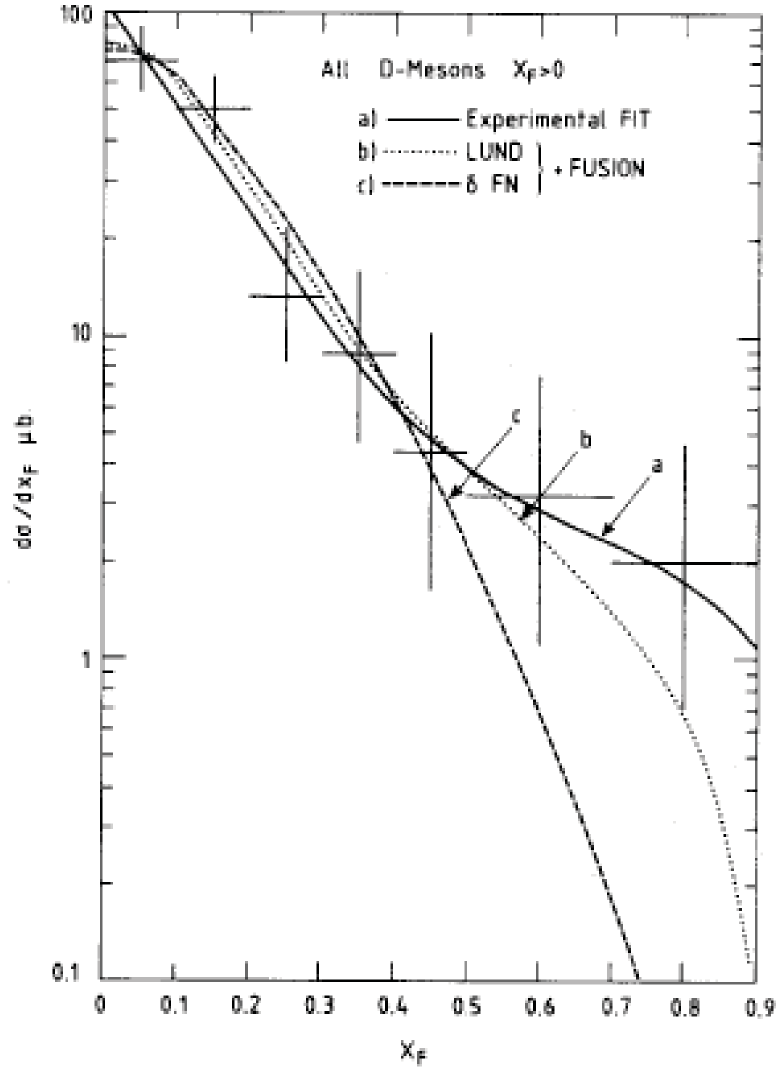


Fig. 1. The differential distribution x_F for all D mesons having $x_F > 0$. Curve (a) is the two-component fit to the data as described in the text. Curve (b) is the prediction of the Lund fusion calculation. Curve (c) is the prediction of the bare QCD fusion calculation (δ-function fragmentation). Note that both theoretical curves have been normalised to the observed total cross section for $x_F > 0$.

M. Aguilar-Benitez et al.
[NA27 Collaboration],
"Inclusive Properties Of *D* Mesons
Produced In 360-GeV πp Interaction
Phys. Lett. B 161, 400 (1985).

- IC Explains Anomalous $\alpha(x_F)$ not $\alpha(x_2)$ dependence of $pA \to J/\psi X$ (Mueller, Gunion, Tang, SJB)

- Color Octet IC Explains $A^{2/3}$ behavior at high x_F (NA3, Fermilab) (Kopeliovitch, Schmidt, Soffer, SJB)

- IC Explains $J/\psi \to \rho\pi$ puzzle (Karliner, SJB)

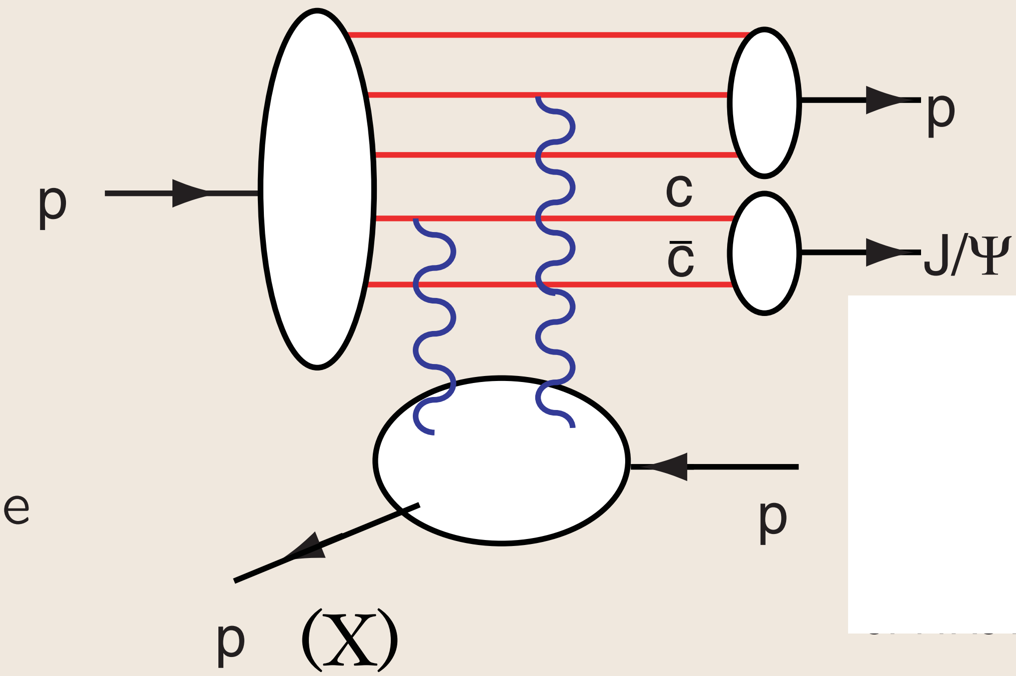
- IC leads to new effects in B decay (Gardner, SJB)

Key QCD Experiment at J-PARC

Measure diffractive hidden charm production at forward x_F

$$\frac{d\sigma}{dt_1 dt_2 dx_F}(pp \to p + J/\psi + p)$$

$$\frac{d\sigma}{dt dx_F}(pp \to p + J/\psi + X)$$



Anomalous nuclear dependence

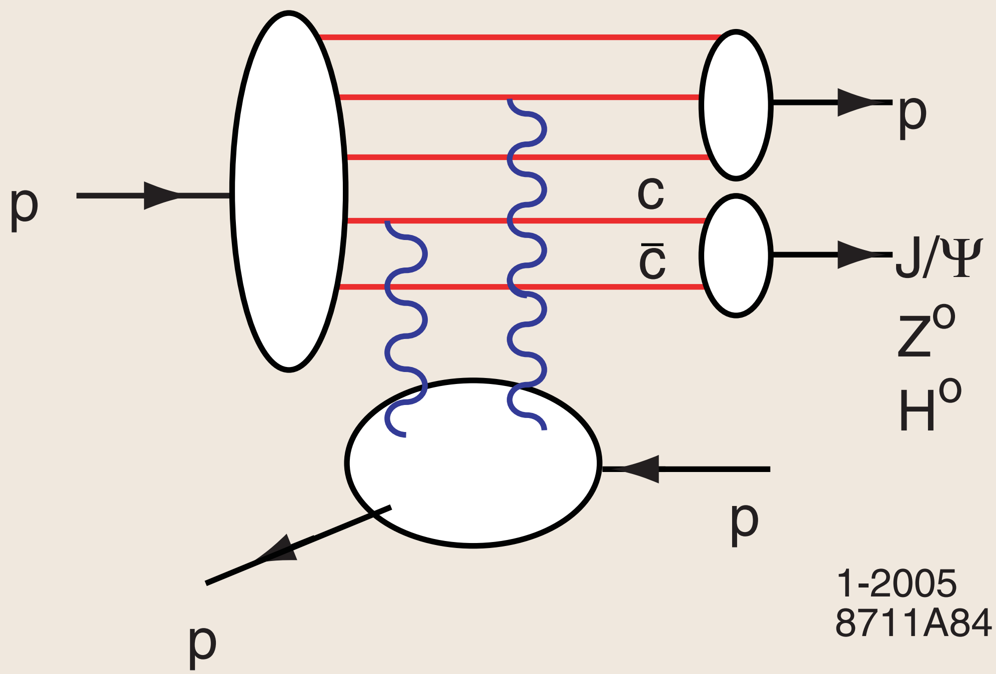
$$\frac{d\sigma}{dx_F}(pA \to J/\psi + X)$$

$A^{\alpha(x_2)}$ versus $A^{\alpha(x_F)}$

Important Tests of Intrinsic Charm

Key QCD Experiment at J-PARC

Intrinsic Charm Mechanism for Double Diffraction



$$\mathrm{p\,p} \to J/\psi\; p\; p$$

$$x_{J/\psi} = x_c + x_{\bar{c}}$$

High x_F !

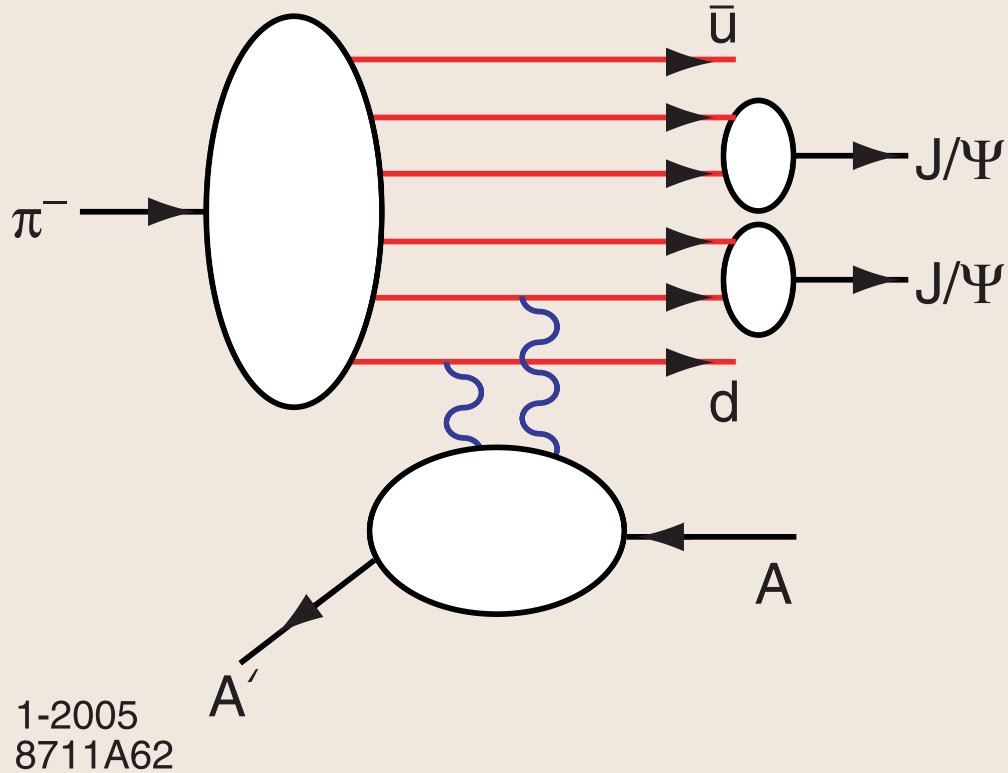
Kopeliovitch, Schmidt, Soffer, sjb

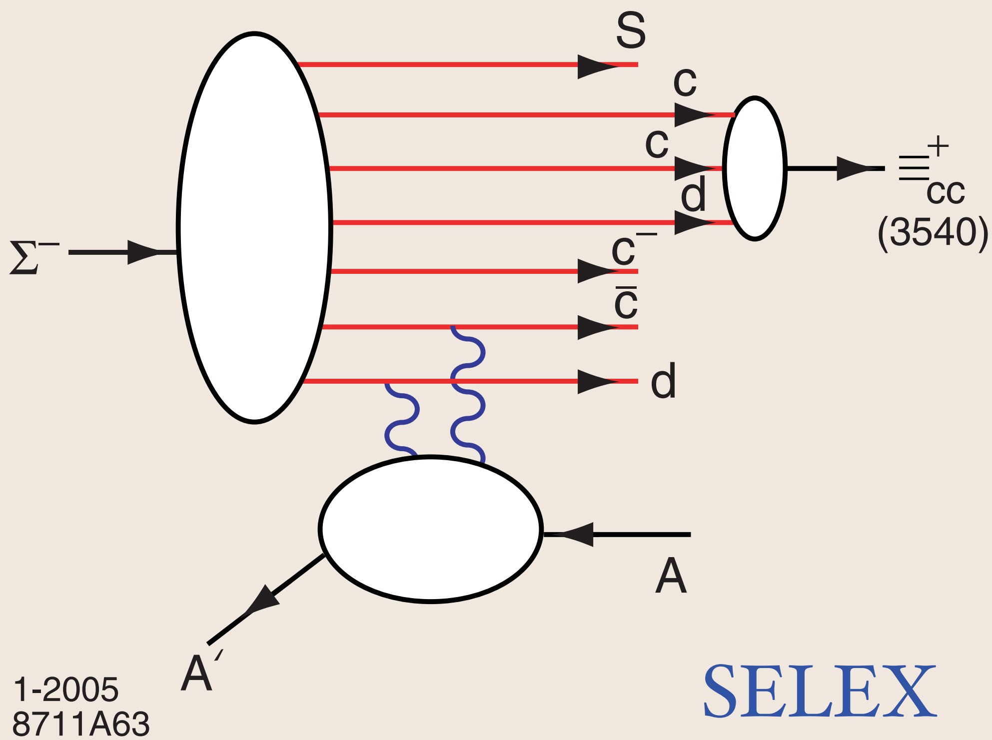
Possible J-PARC experiment

Intrinsic $c\bar{c}$ pair formed in color octet 8_C in proton wavefunction Large Color Dipole

Collision produces color-singlet J/ψ through color exchange

Production of Two Charmonia at High x_F





SELEX

Production of a Double-Charm Baryon

Nuclear Dependence of Quarkonium Production

NA3 data for $\frac{d\sigma}{dx_F}(p(\pi)A \to J/\psi X)$: hard A^1 and "diffractive" $A^{2/3}$ components

Diffractive contribution extends to large x_F

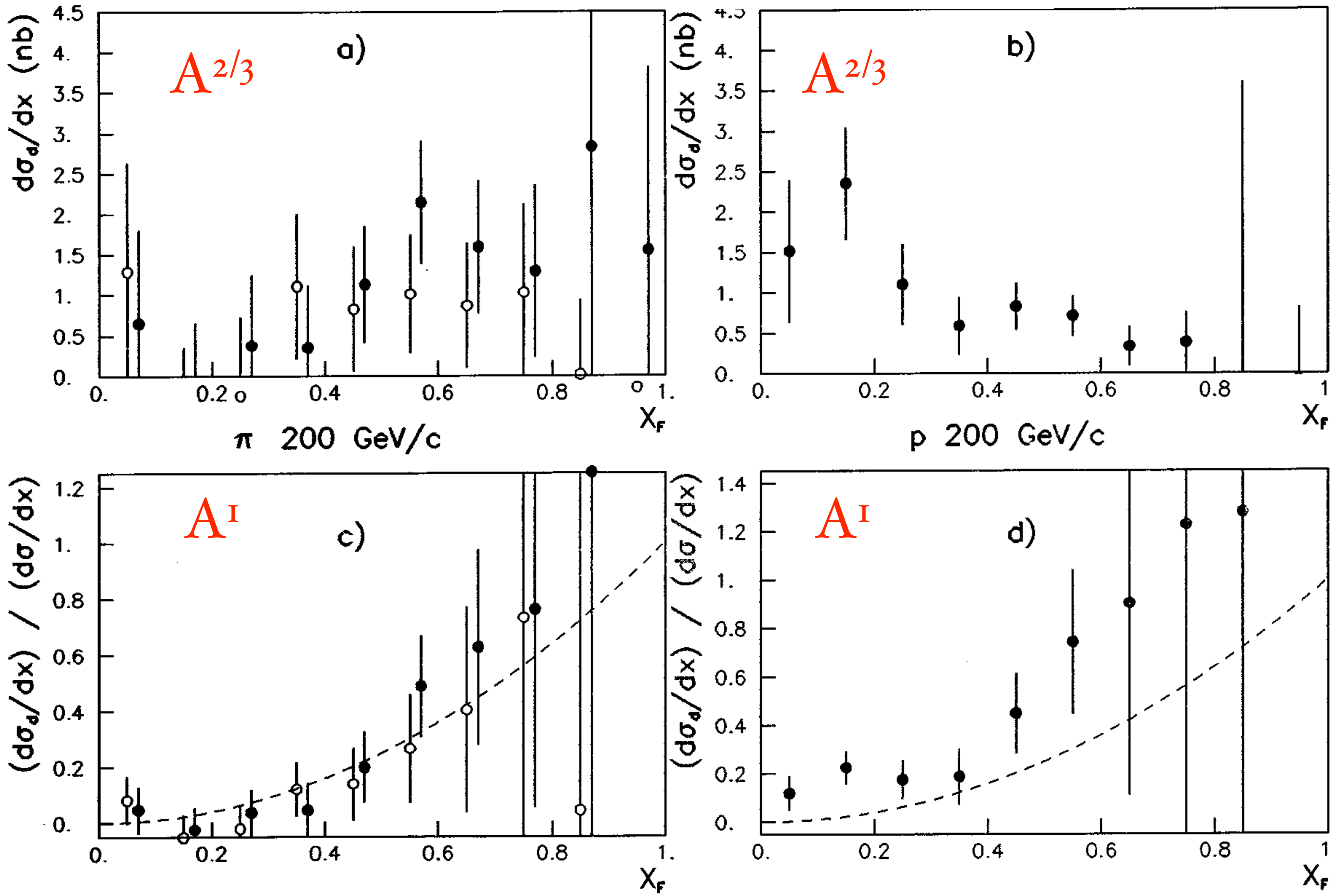
$A^{\alpha(x_F)}$ not $A^{\alpha(x_2)}$: PQCD Factorization Violated!

Seen at Sepurkhov

EXPERIMENTAL J/ψ HADRONIC PRODUCTION FROM 150 TO 280 GeV/c

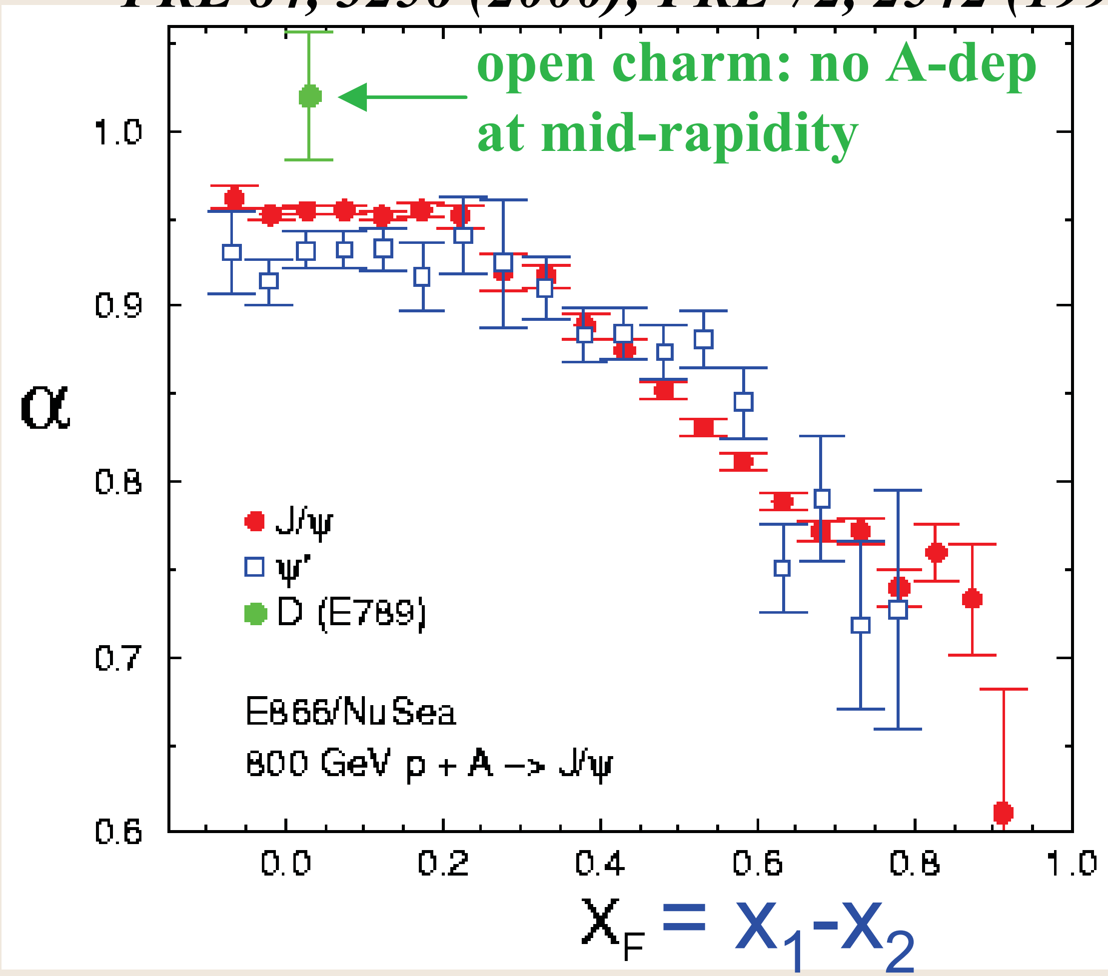
CERN-EP/83-86
June 29th, 1983

NA3 COLLABORATION



800 GeV p-A (FNAL) $\sigma_A = \sigma_p * A^\alpha$

PRL 84, 3256 (2000); PRL 72, 2542 (1994)



Remarkably Strong Nuclear Dependence for Fast Charmonium

M. Leitch

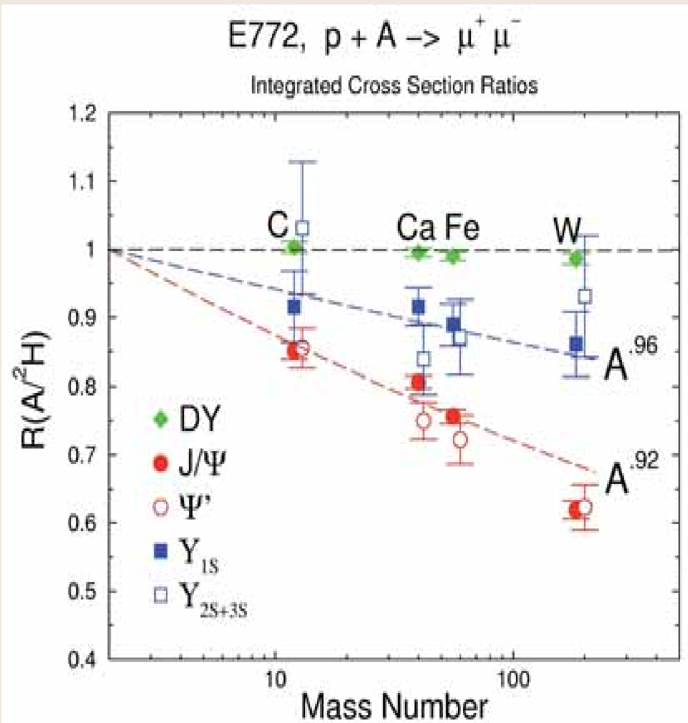
Nuclear effects in Quarkonium production

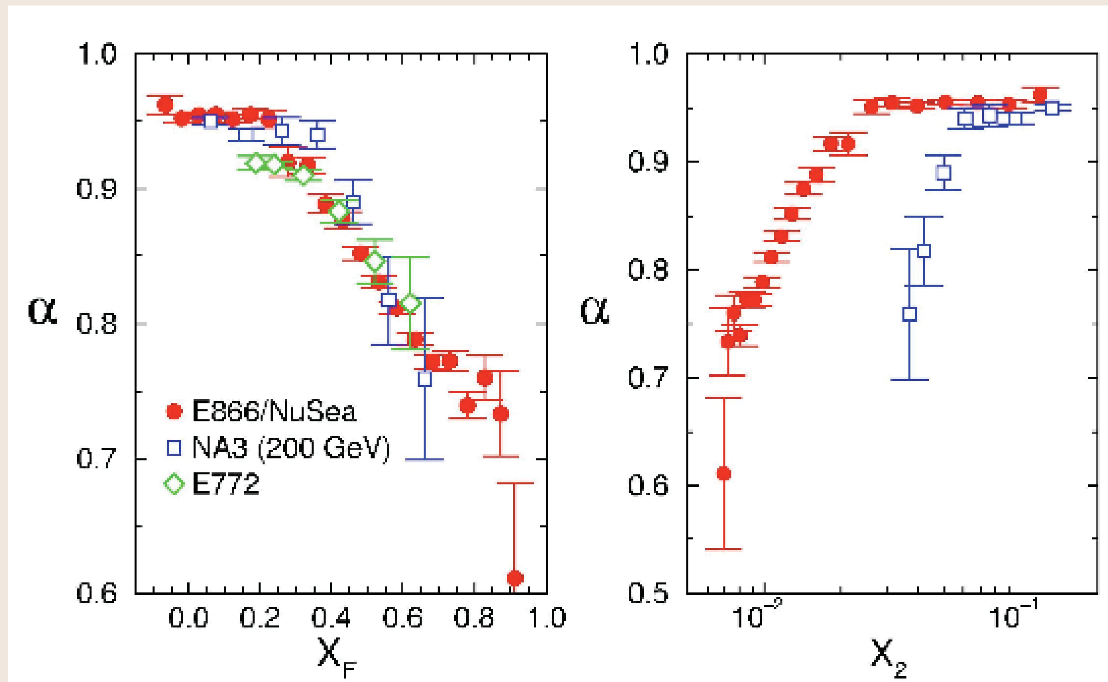
$p + A$ at $s^{1/2} = 38.8$ GeV

$\sigma(p+A) = A^{\alpha}\,\sigma(p+N)$

E772 data

Strong x_F - dependence



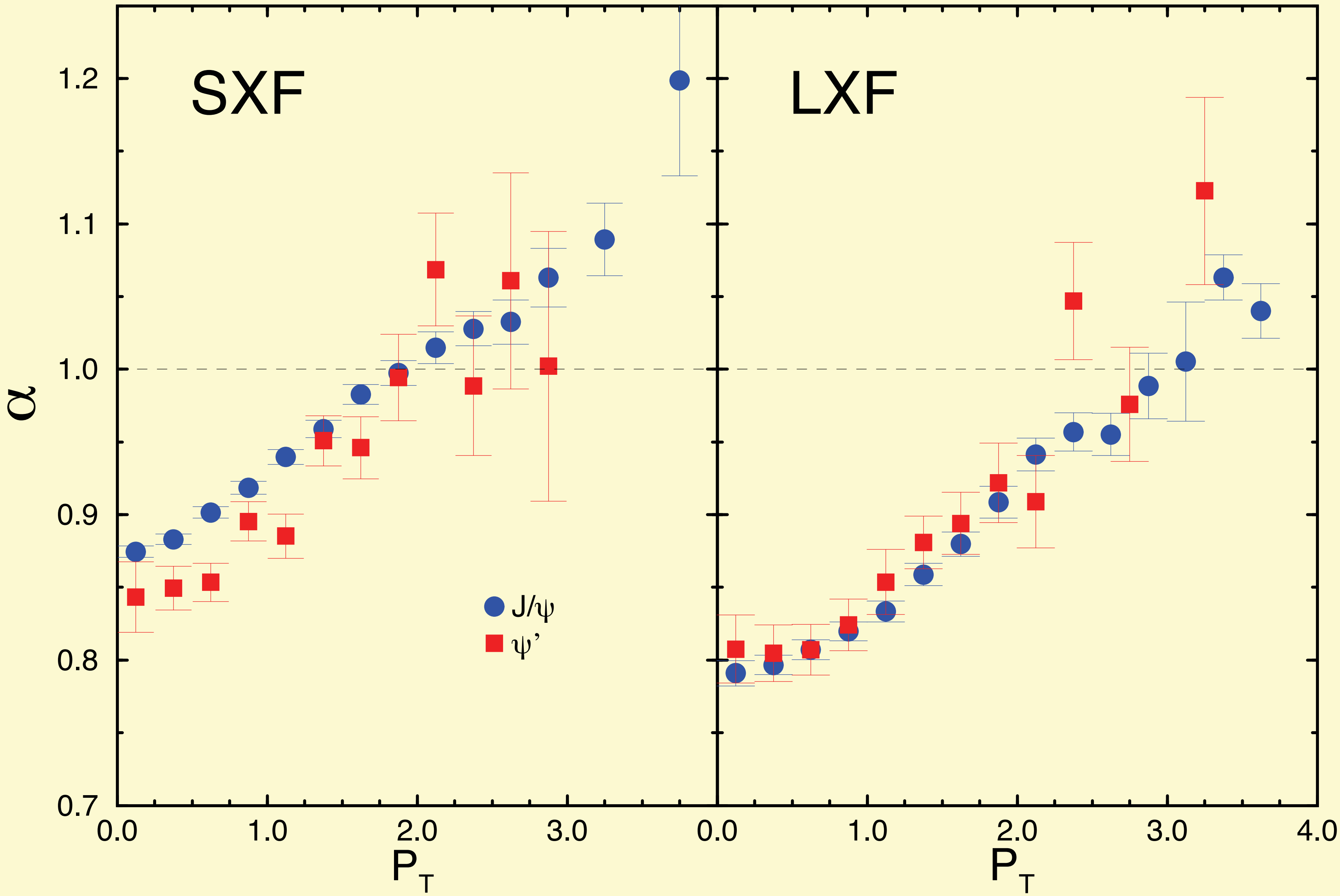


Nuclear effects scale with x_F, not x_2 !!!

M.Leitch

800 GeV p + A -> J/ψ

E866/NuSea Preliminary, $\sigma_A = \sigma_p * A^{\alpha}$

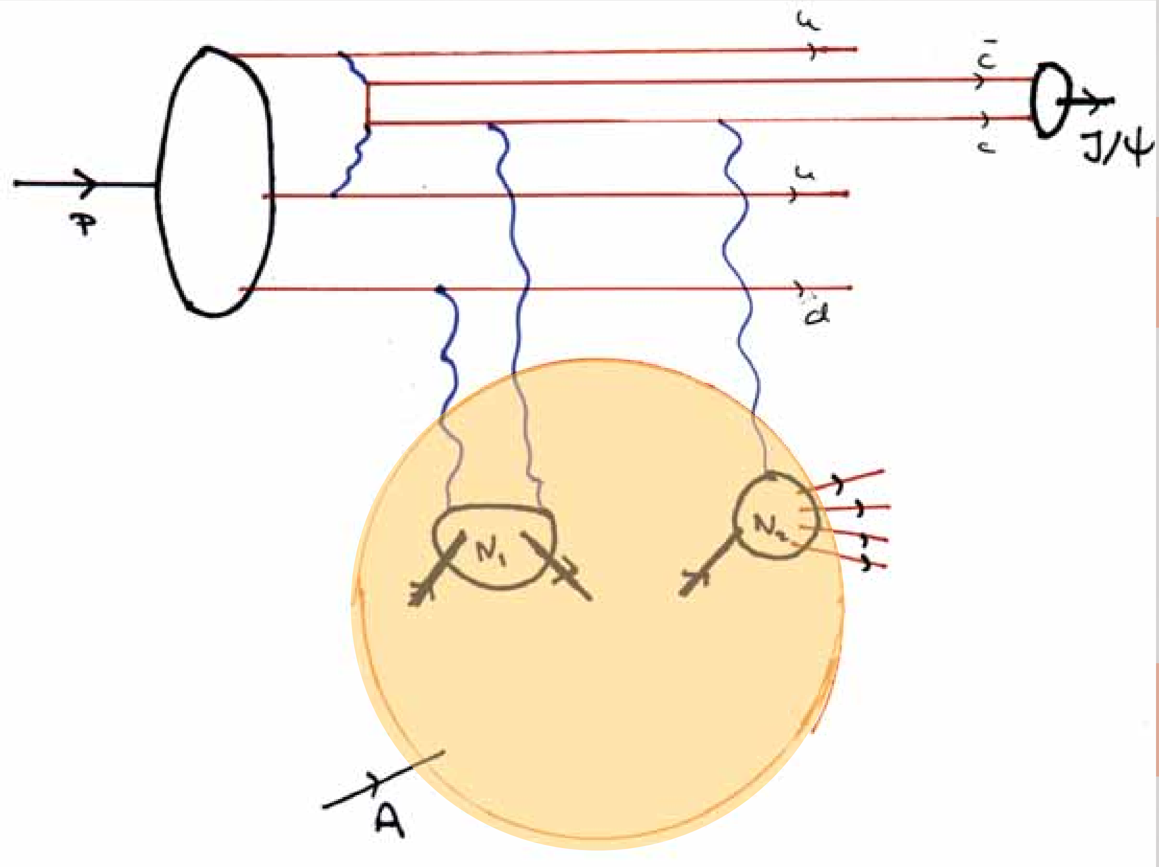


Key QCD Experiment at J-PARC

Measure Nuclear Dependence of $J/\psi, \eta_c$
open charm production production

Understand breakdown
of QCD Factorization

Intrinsic Charm, Color Octet Dipole Physics,
Energy Loss Mechanisms



Shadowing of $pA \to J/\Psi X$

J/Ψ Production on Front Surface
No Absorption of Propagating J/Ψ
$\sigma(p + A \to J/\Psi + X) \propto A^{2/3}$

Elastic scattering of IC Fock state:
$|[uud]_{8_C}[c\bar{c}]_{8_C} > + N_1 \to |[uud]_{8_C}[c\bar{c}]_{8_C} > + N_1$
followed by:
$|[uud]_{8_C}[c\bar{c}]_{8_C} > + N_2 \to J/\Psi + X$
Depleted flux on downstream nucleons

Key QCD Experiment at J-PARC

Measure nuclear shadowing, antishadowing at J-PARC in Drell-Yan reactions

$$pA \to \ell^+\ell^- X$$

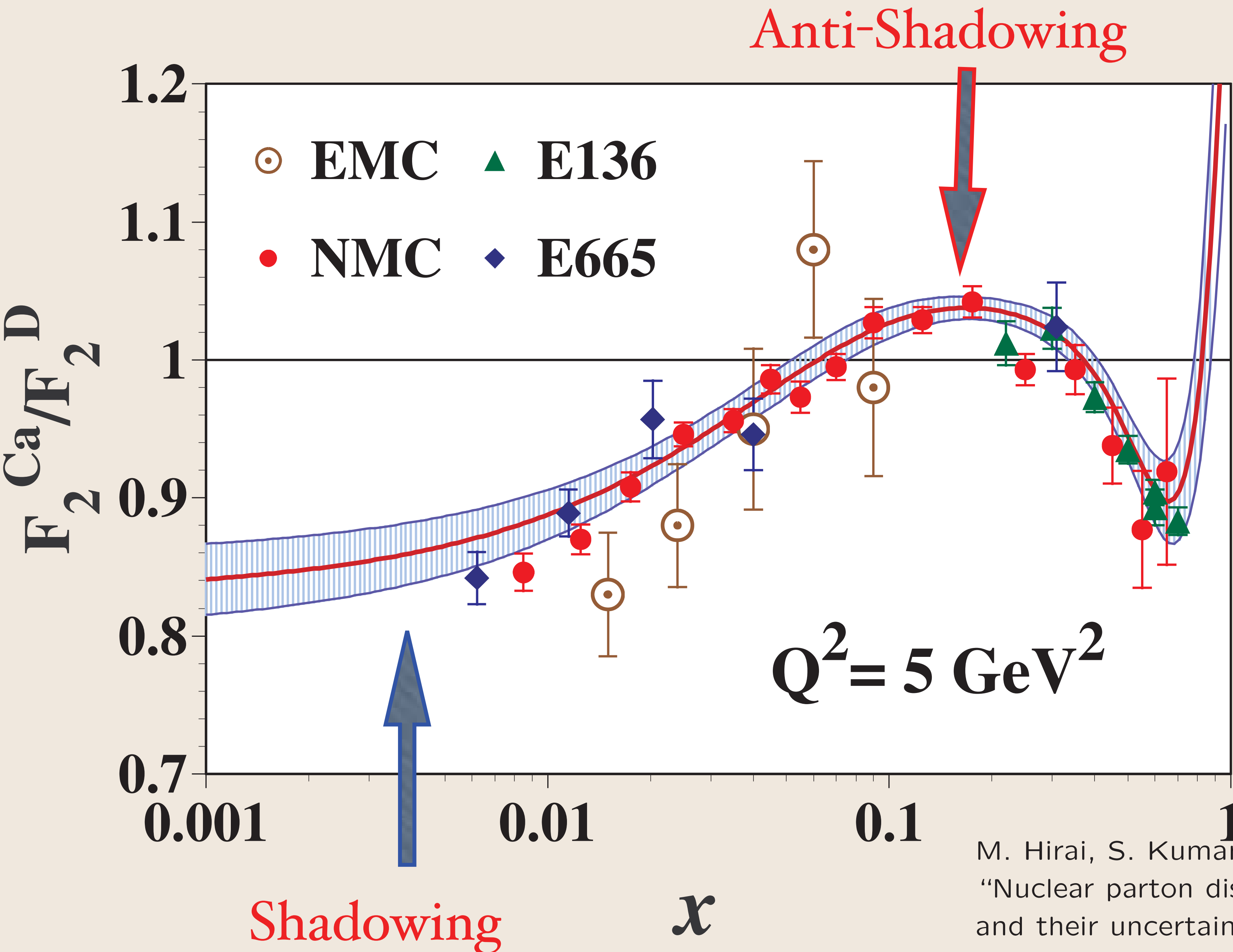
$$Q^2 = x_1 x_2 s \qquad x_1 x_2 = .05, x_F = x_1 - x_2$$

$$A^{\alpha(x_1)} = \frac{2\frac{d\sigma}{dQ^2 dx_F}(pA \to \ell^+\ell^- X)}{A\frac{d\sigma}{dQ^2 dx_F}(pd \to \ell^+\ell^- X)}$$

Higher twist effects at high x_F:

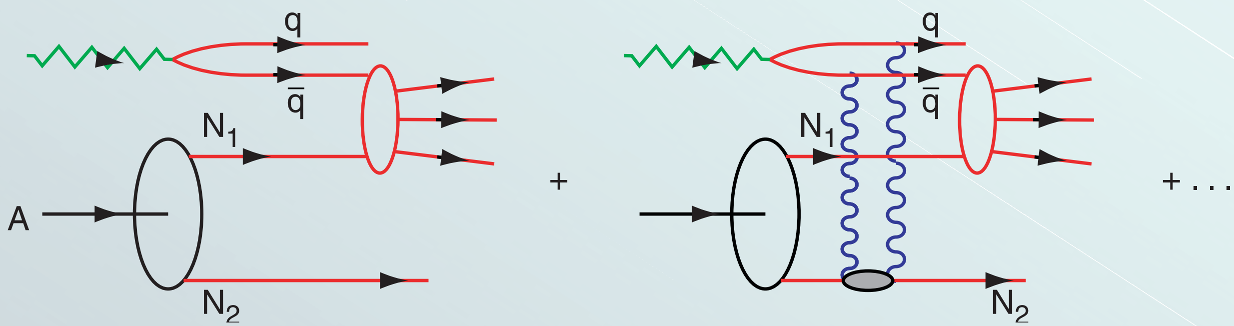
Deviations from $(1 + \cos^2\theta)$

$\cos 2\phi$ correlation.



M. Hirai, S. Kumano and T. H. Nagai, "Nuclear parton distribution functions and their uncertainties," Phys. Rev. C **70**, 044905 (2004) [arXiv:hep-ph/0404093].

Origin of Nuclear Shadowing in Glauber - Gribov Theory



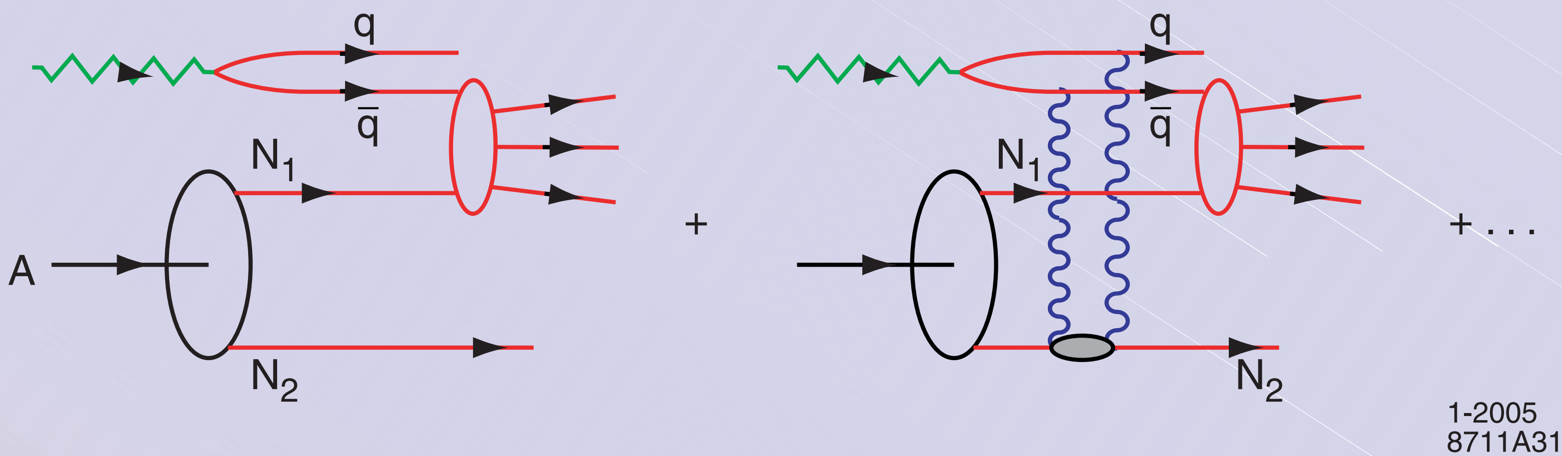
Interference of one-step and two-step processes

Interaction on upstream nucleon diffractive

Phase i X i = - 1 produces destructive interference

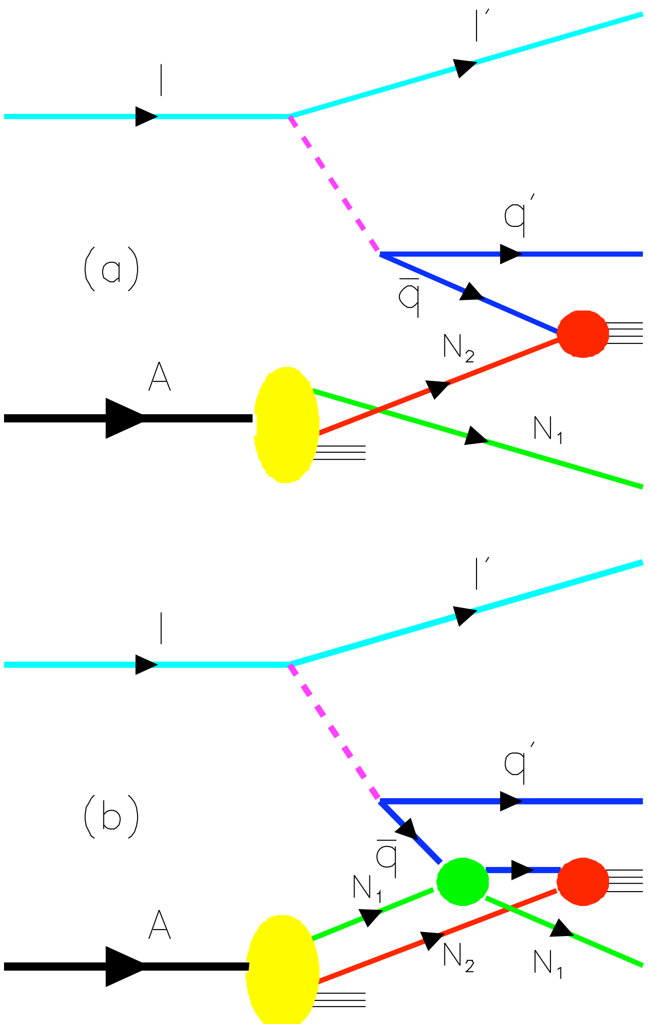
No Flux reaches down stream nucleon

Nuclear Shadowing in QCD



Nuclear Shadowing not included in nuclear LFWF !

Connection to DDIS



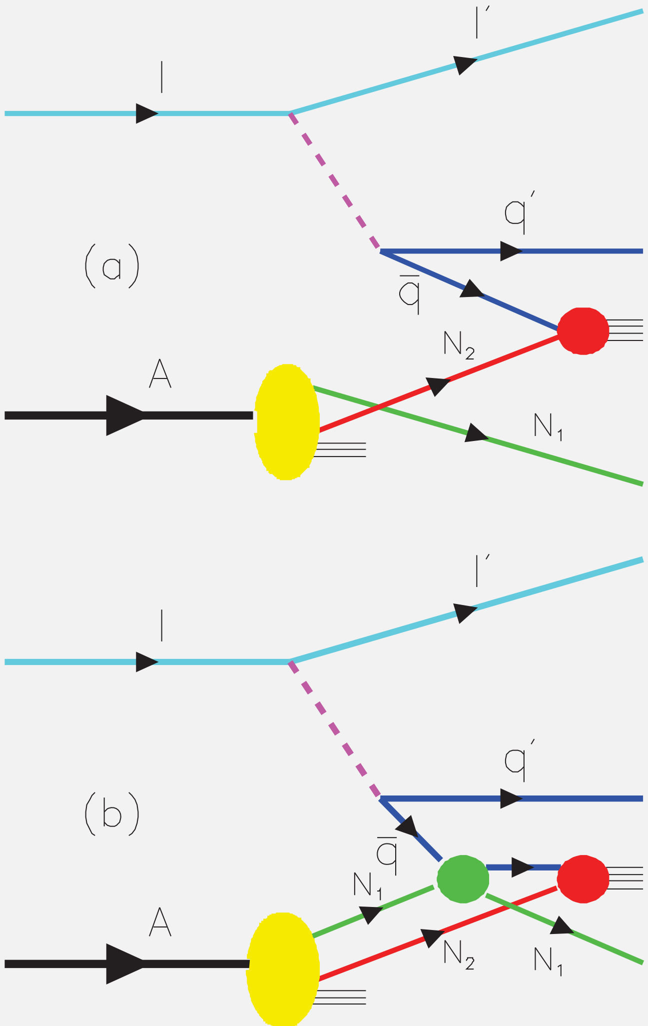
The one-step and two-step processes in DIS on a nucleus.

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 $\bar{q}$ flux reaching N_2.

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

Kowalski: HERA DDIS produces observed nuclear shadowing



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

If the scattering on nucleon N_1 is via $C=-$ Reggeon or Odderon exchange, the one-step and two-step amplitudes are constructive in phase, enhancing the $\bar{q}$ flux reaching N_2

$\rightarrow$ Antishadowing of the DIS nuclear structure functions

Reggeon Exchange

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

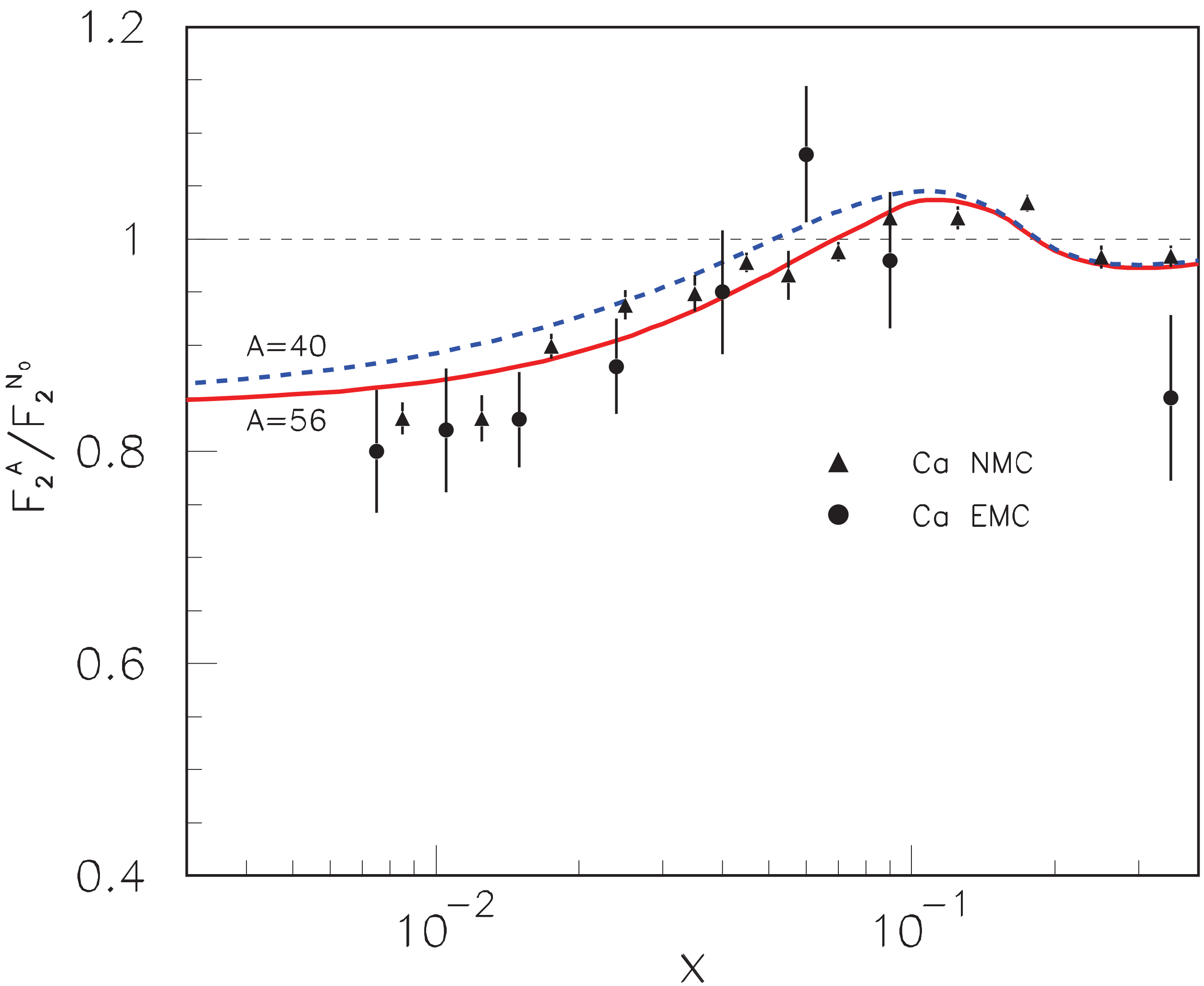
Different for couplings of $\gamma^*, Z^0, W^\pm$

Shadowing and Antishadowing in Lepton-Nucleus Scattering

- Shadowing: Destructive Interference
of Two-Step and One-Step Processes
Pomeron Exchange

- Antishadowing: Constructive Interference
of Two-Step and One-Step Processes!
Reggeon and Odderon Exchange

- Antishadowing is Not Universal!
Electromagnetic and weak currents:
different nuclear effects !
Potentially significant for NuTeV Anomaly}



The nuclear shadowing and antishadowing effects at $\langle Q^2 \rangle = 1\ \text{GeV}^2$.

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].

Shadowing and Antishadowing in Lepton-Nucleus Scattering

- Shadowing and Antishadowing in DIS arise from interference of multi-nucleon processes in nucleus

Phases!

- Not due to nuclear wavefunction
Wavefunction of stable nucleus is real.
Effect of multi-scattering of $q\overline{q}$ in nucleus.

- Bjorken Scaling :
Interference requires leading-twist diffractive DIS processes

See: Talk by I. Schmidt

Estimate 20% effect on extraction of $\sin^2\theta_W$ for NuTeV

Need new experimental studies of antishadowing in

- Parity-violating DIS
- Spin Dependent DIS
- Charged and Neutral Current DIS

Key QCD Experiment at J-PARC

Measure nuclear shadowing, antishadowing at J-PARC in Drell-Yan reactions

$$pA \rightarrow \ell^+ \ell^- X$$

$$Q^2 = x_1 x_2 s \qquad x_1 x_2 = .05, x_F = x_1 - x_2$$

$$A^{\alpha(x_1)} = \frac{2\frac{d\sigma}{dQ^2 dx_F}(pA \rightarrow \ell^+ \ell^- X)}{A\frac{d\sigma}{dQ^2 dx_F}(pd \rightarrow \ell^+ \ell^- X)}$$

Higher twist effects at high x_F:

Deviations from $(1 + \cos^2\theta)$

$\cos 2\phi$ correlation.

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

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

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

Hadron Dynamics at the Amplitude Level

- DIS studies have primarily focussed on probability distributions: integrated and unintegrated
- We need to determine hadron wavefunctions!
- Test QCD at the amplitude level!
- Phases, multi-parton correlations, spin, angular momentum

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.

New Perspectives on QCD Phenomena from AdS/CFT

- AdS/CFT: Duality between string theory in Anti-de Sitter Space and Conformal Field Theory

- New Way to Implement Conformal Symmetry

- Holographic Model: Conformal Symmetry at Short Distances, Confinement at large distances

- Remarkable predictions for hadronic spectra, wavefunctions, interactions

- Dominance of Quark Interchange in Hard Exclusive Processes

- AdS/CFT provides novel insights into the quark structure of hadrons

- J-PARC: Novel Tests of AdS/CFT Predictions

Essential to test QCD

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

Novel Tests of QCD at J-PARC

$E^p_{lab} = 50$ GeV Polarized proton Beam Secondary Beams

- Characteristic momentum scale of QCD: 300 MeV
- Many Tests of AdS/CFT predictions possible
- Exclusive channels: Conformal scaling laws, quark-interchange
- pp scattering: fundamental aspects of nuclear force
- Color transparency: Coherent color effects
- Nuclear Effects, Hidden Color, Anti-Shadowing
- Anomalous heavy quark phenomena
- Spin Effects: A_N, A_{NN}