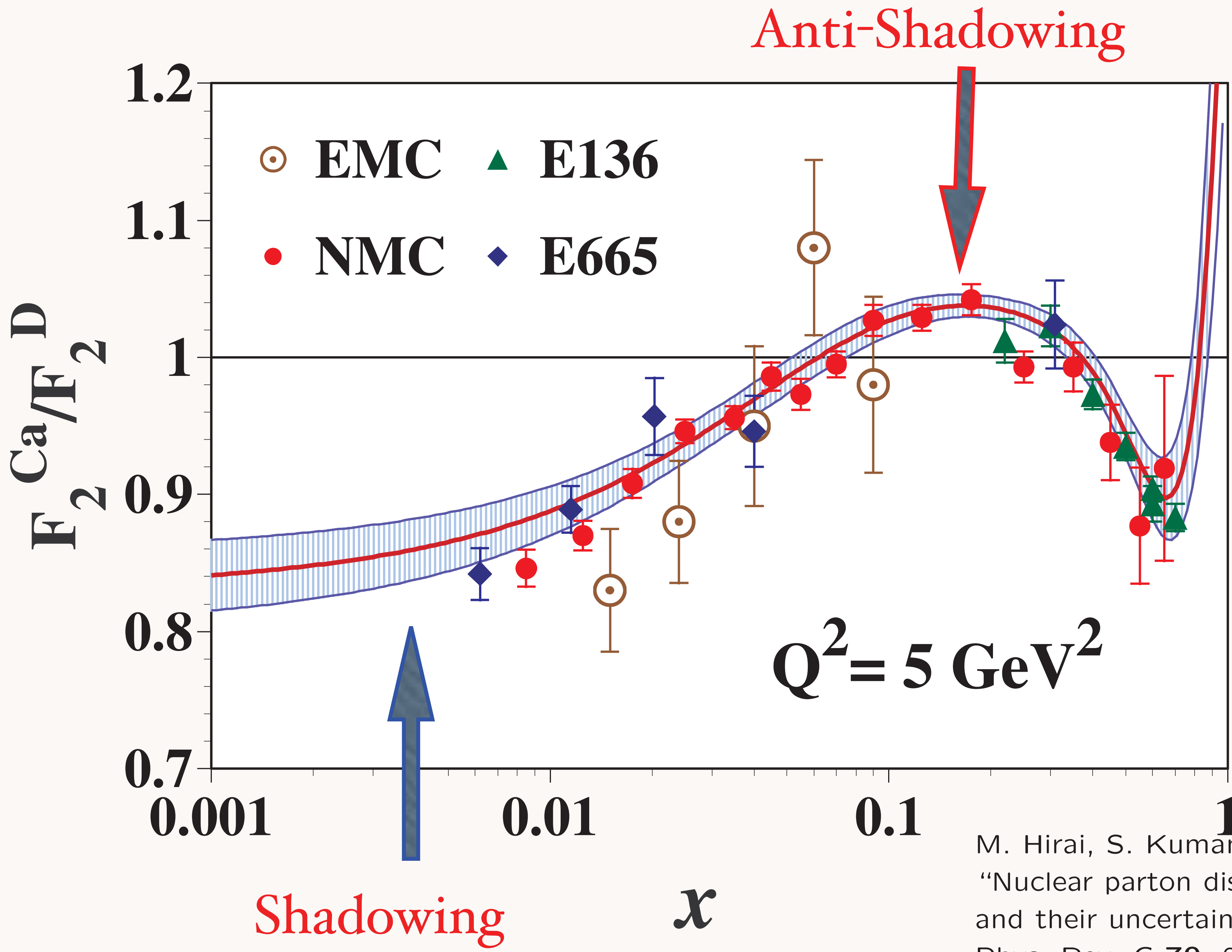
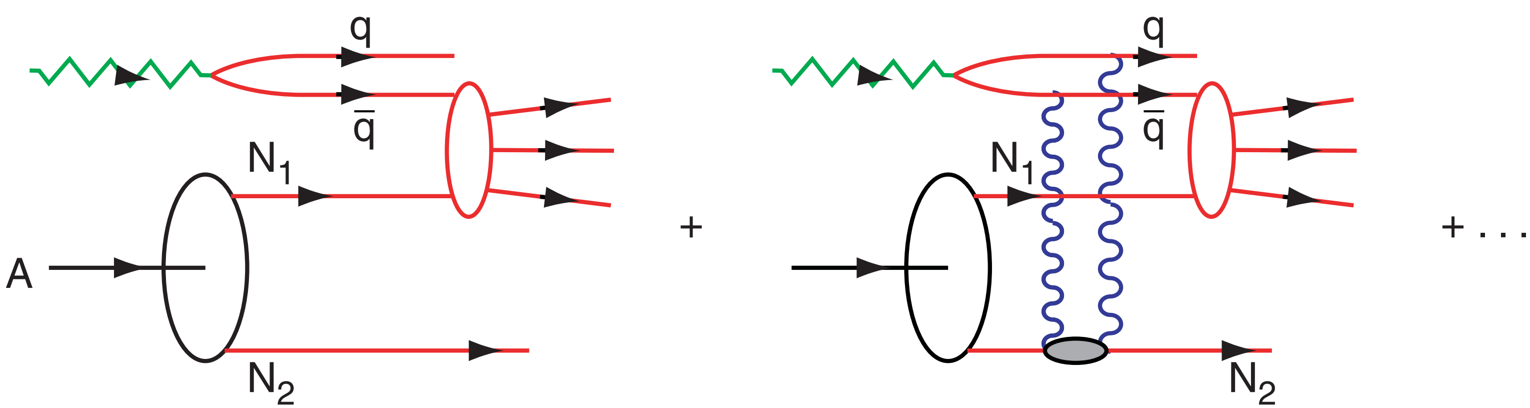


M. Hirai, S. Kumano and T. H. Nagai, "Nuclear parton distribution functions and their uncertainties," Phys. Rev. C **70**, 044905 (2004) [arXiv:hep-ph/0404093].

Stodolsky
Pumplin, sjb
Gribov

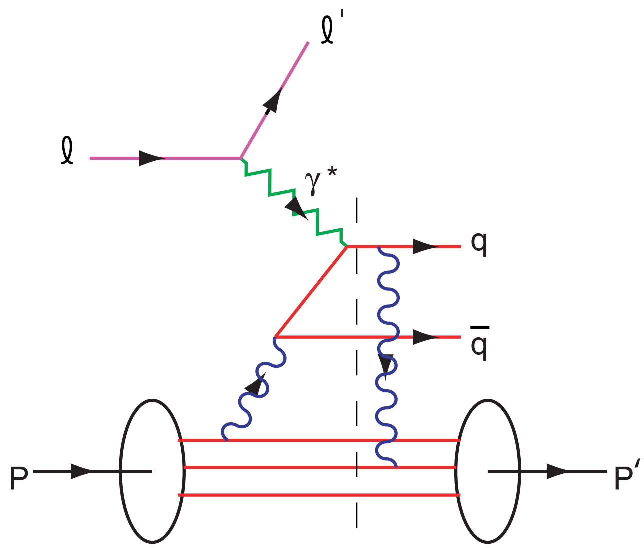
Nuclear Shadowing in QCD



Shadowing depends on understanding leading twist-diffraction in DIS

Nuclear Shadowing not included in nuclear LFWF !

Dynamical effect due to virtual photon interacting in nucleus



Shadowing depends on leading-twist DDIS

Integration over on-shell domain produces phase i

Need Imaginary Phase to Generate Pomeron

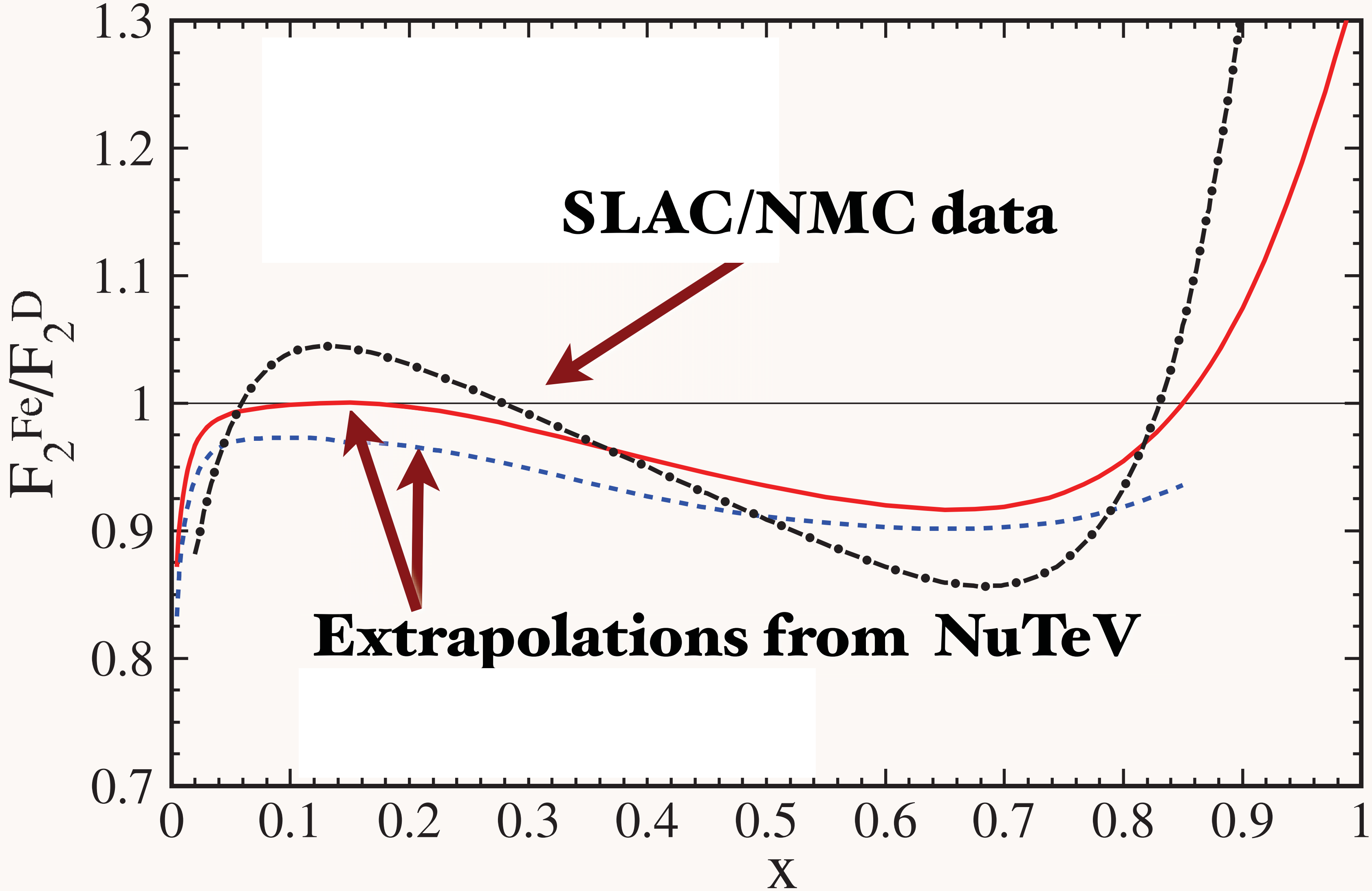
Need Imaginary Phase to Generate T-Odd Single-Spin Asymmetry

Physics of FSI not in Wavefunction of Target

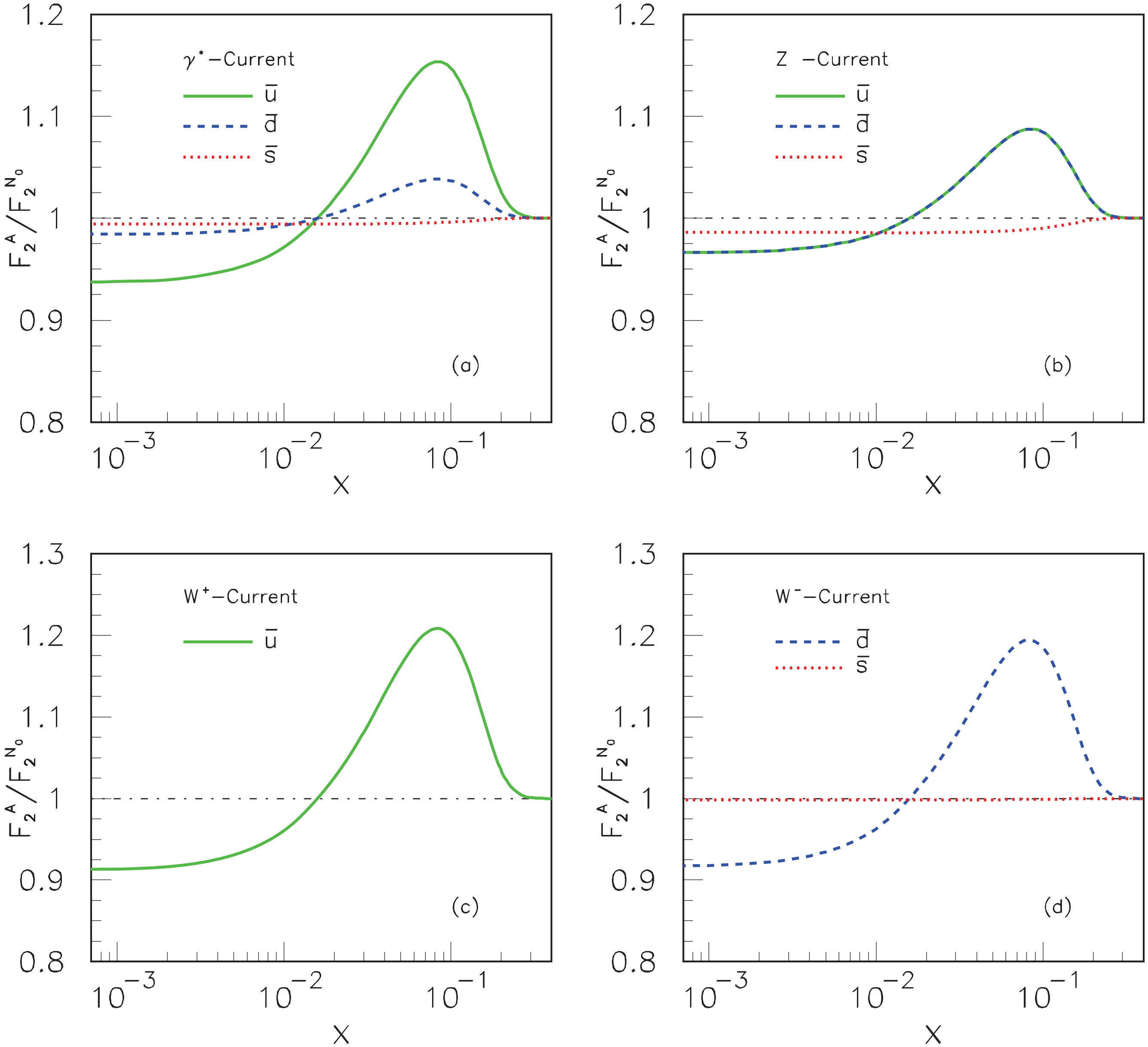
Antishadowing (Reggeon exchange) is not universal!

Schmidt, Yang, sjb

$Q^2 = 5\ \mathrm{GeV}^2$



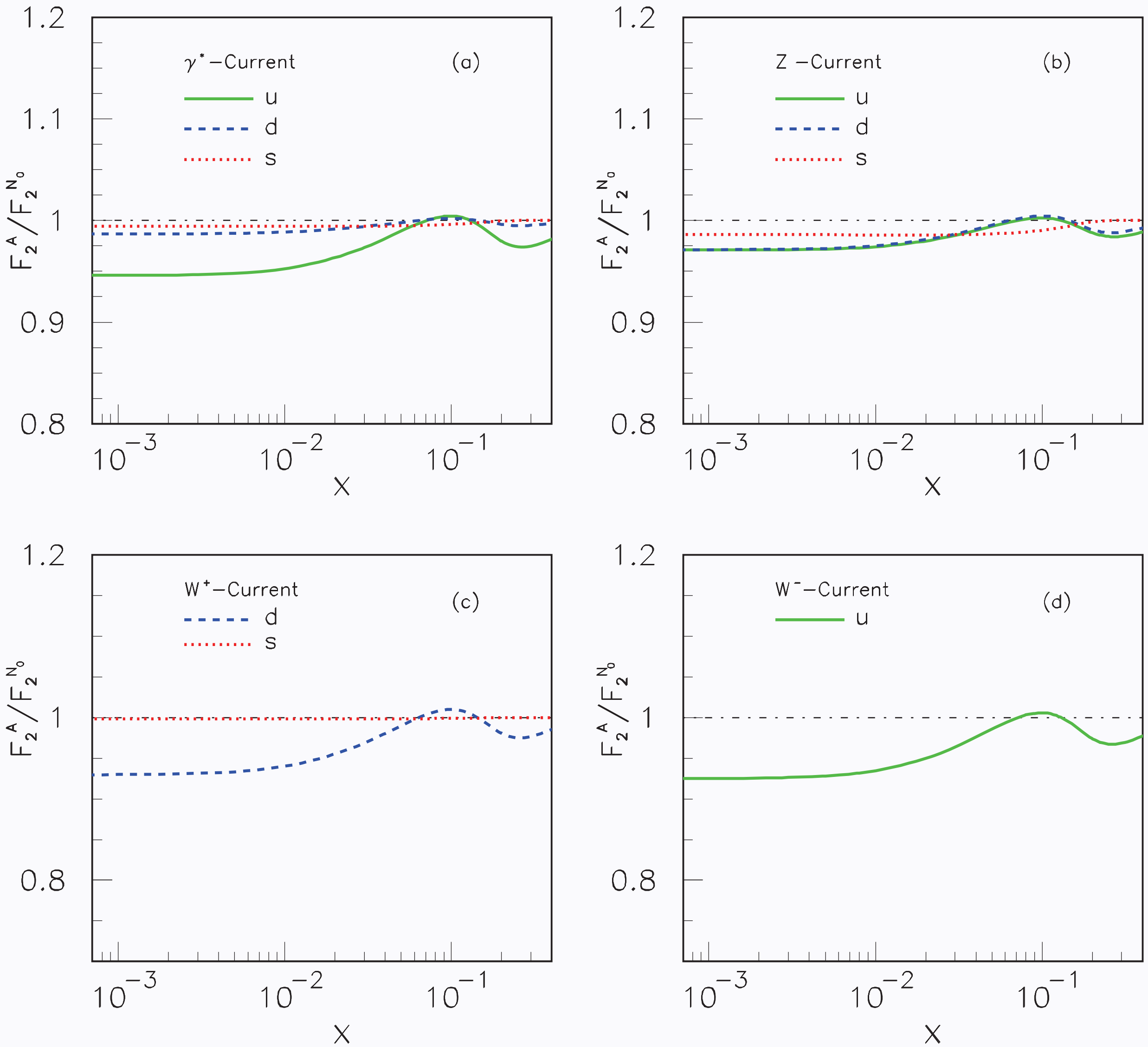
Scheinbein, Yu, Keppel, Morfin, Olness, Owens



Schmidt, Yang; sjb

Nuclear Antishadowing not universal !

Shadowing and Antishadowing of DIS Structure Functions

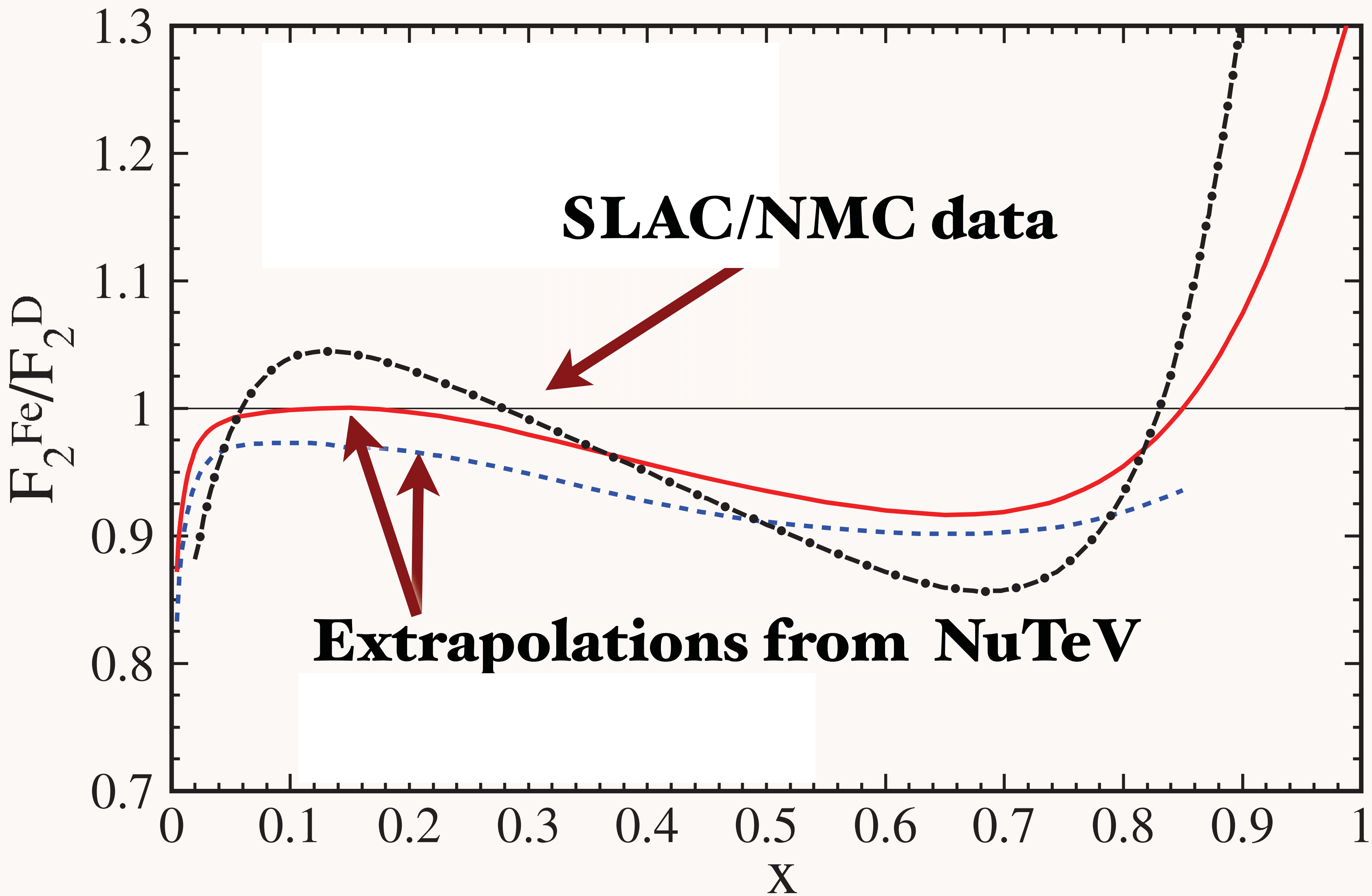


S. J. Brodsky, I. Schmidt and J. J. Yang, "Nuclear Antishadowing in Neutrino Deep Inelastic Scattering," Phys. Rev. D 70, 116003 (2004) [arXiv:hep-ph/0409279].

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

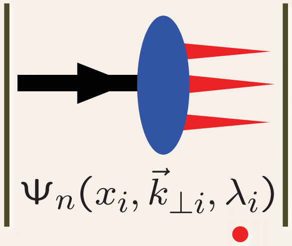
Test in flavor-tagged lepton-nucleus collisions

$Q^2 = 5 \text{ GeV}^2$



Scheinbein, Yu, Keppel, Morfin, Olness, Owens

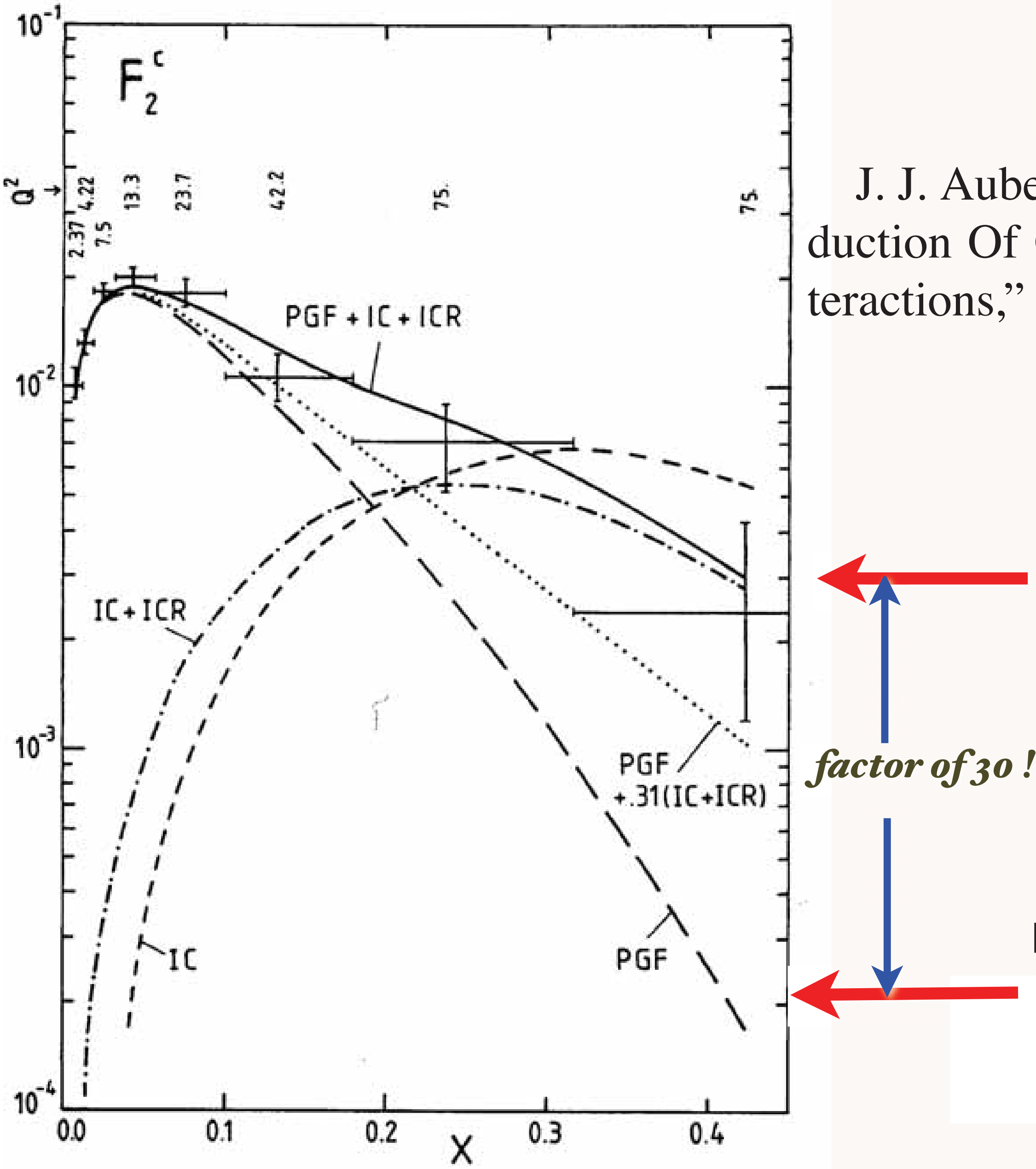
Static vs. Dynamic Structure Functions



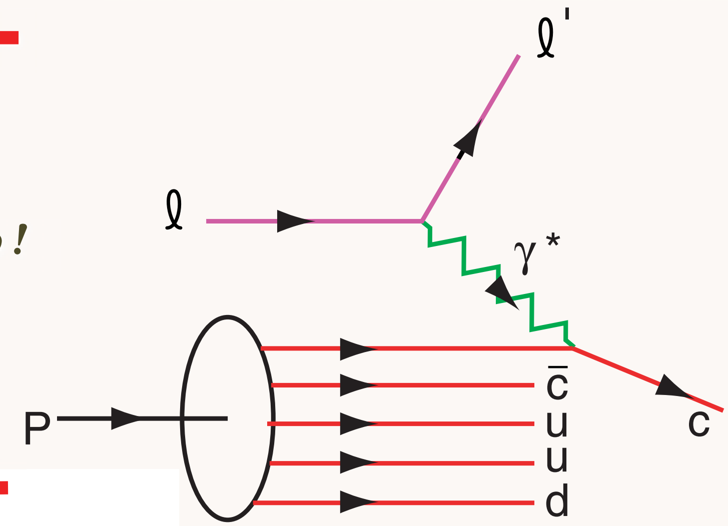
Static	Dynamic
Square of Target LFWFs	Modified by Rescattering: ISI & FSI
No Wilson Line	Contains Wilson Line, Phases
Probability Distributions	No Probabilistic Interpretation
Process-Independent	Process-Dependent - From Collision
T-even Observables	T-Odd (Sivers, Boer-Mulders, etc.)
No Shadowing, Anti-Shadowing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

Measurement of Charm Structure Function

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

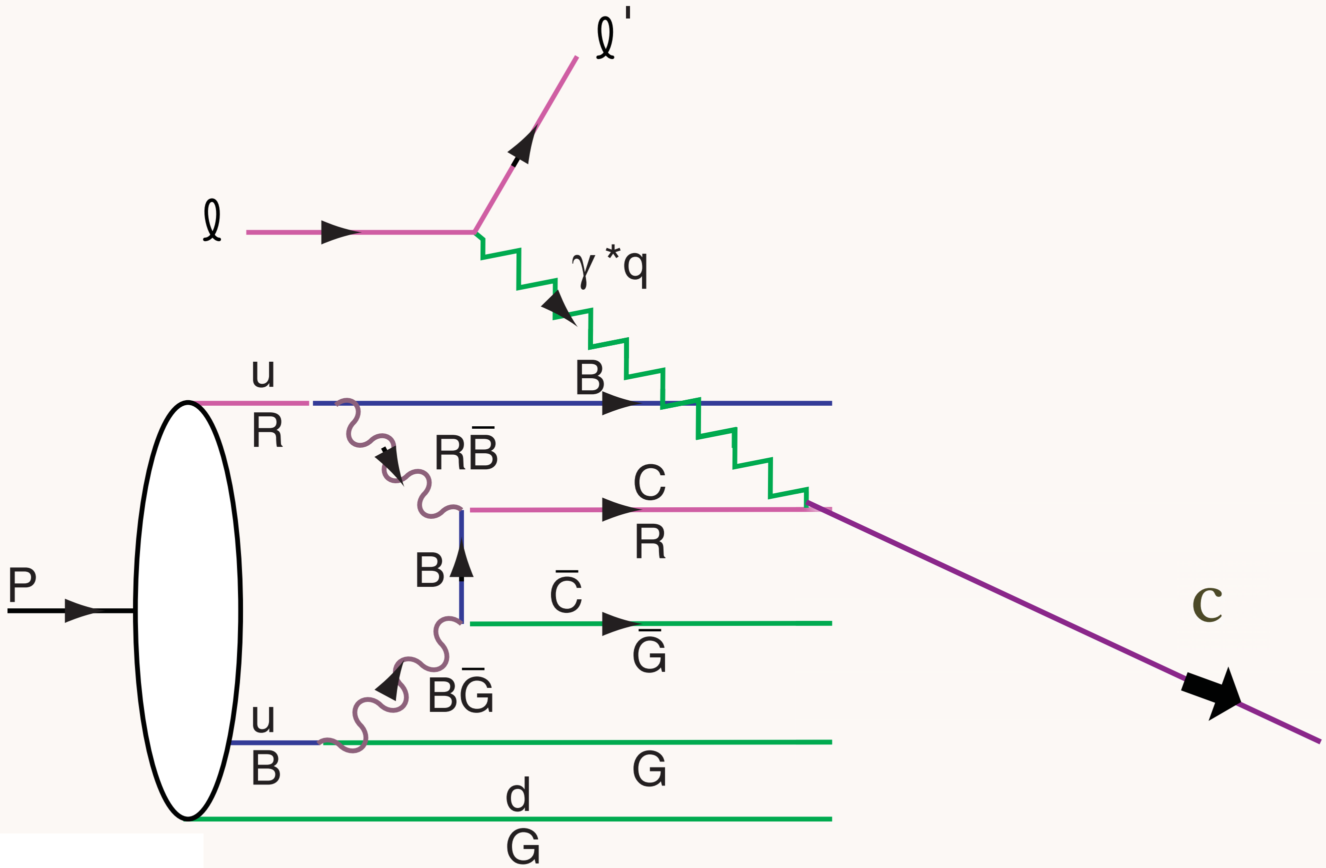


First Evidence for Intrinsic Charm



DGLAP / Photon-Gluon Fusion: factor of 30 too small

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



Hoyer, Peterson, SJB

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

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

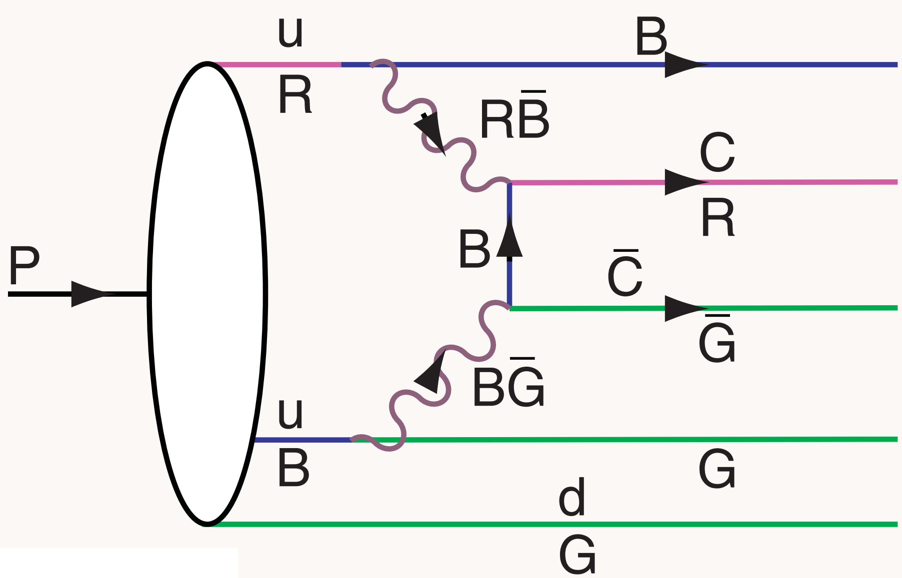
- High x_F $pp \to J/\psi J/\psi X$

- High x_F $pp \to \Lambda_c X$

- High x_F $pp \to \Lambda_b X$

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

IC Structure Function: Critical Test of QCD



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

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

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

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

OPE derivation - M.Polyakov et al.

$< p|\frac{G^3_{\mu\nu}}{m^2_Q}|p >$ vs. $< p|\frac{F^4_{\mu\nu}}{m^4_\ell}|p >$

$c\bar{c}$ in Color Octet

Distribution peaks at equal rapidity (velocity)
Therefore heavy particles carry the largest momentum fractions

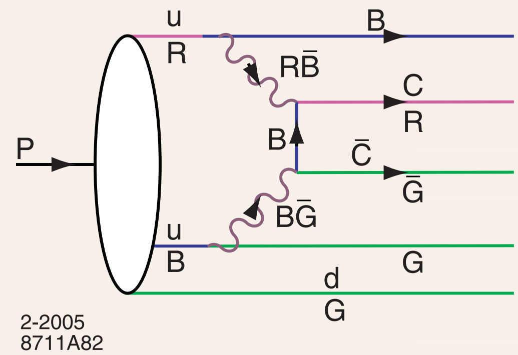
$$\hat{x}_i = \frac{m_{\perp i}}{\sum_j^n m_{\perp j}}$$

High x charm!

Hoyer, Peterson, Sakai, sjb

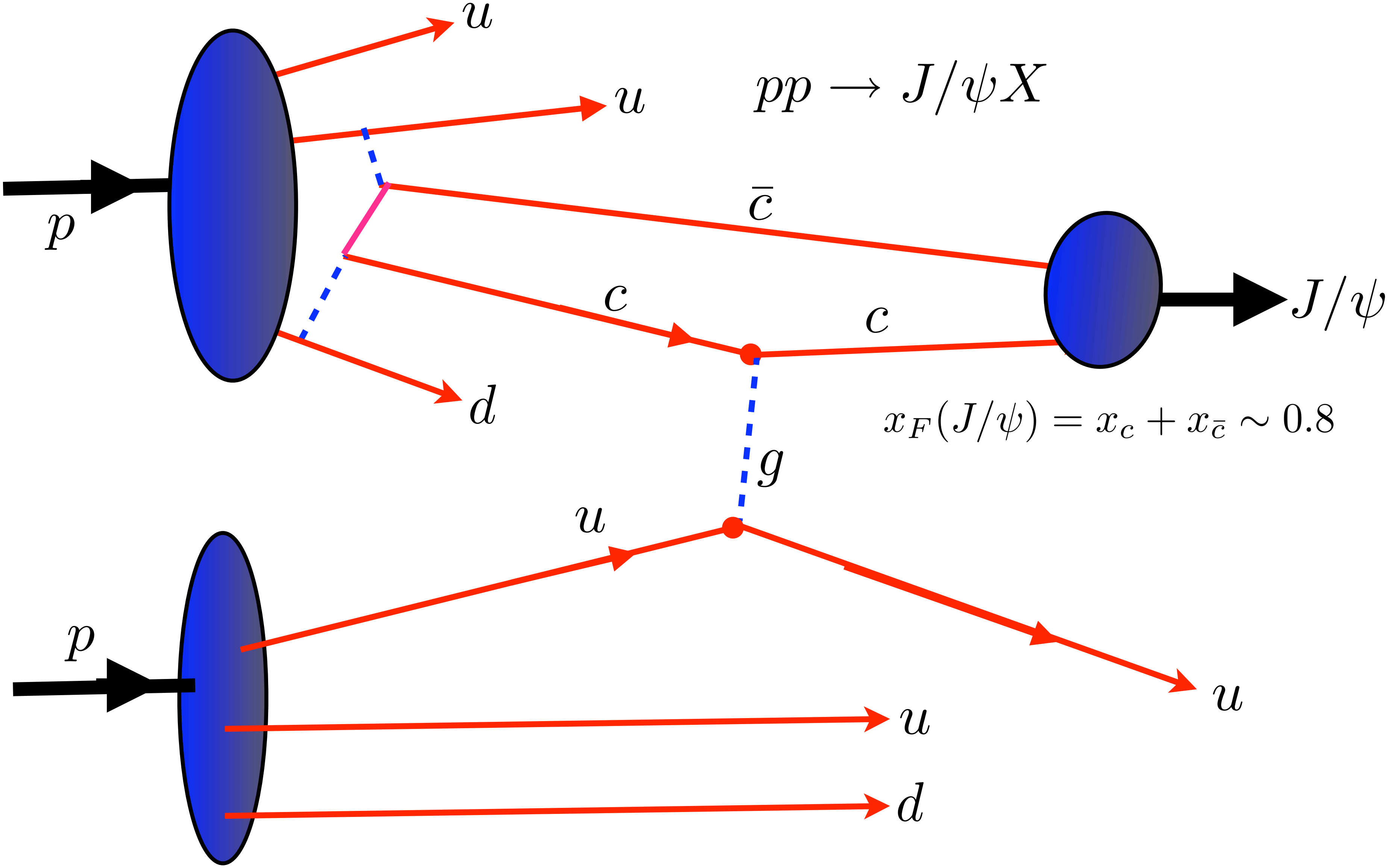
Hoyer, Peterson, Sakai, sjb

Intrinsic Heavy-Quark Fock States



- Rigorous prediction of QCD, OPE
- Color-Octet Color-Octet Fock State!
- Probability $P_{Q\bar{Q}} \propto \frac{1}{M_Q^2}$ $P_{Q\bar{Q}Q\bar{Q}} \sim \alpha_s^2 P_{Q\bar{Q}}$ $P_{c\bar{c}/p} \simeq 1\%$
- Large Effect at high x
- Greatly increases kinematics of colliders such as Higgs production (Kopeliovich, Schmidt, Soffer, sjb)
- Severely underestimated in conventional parameterizations of heavy quark distributions (Pumplin, Tung)
- Many empirical tests

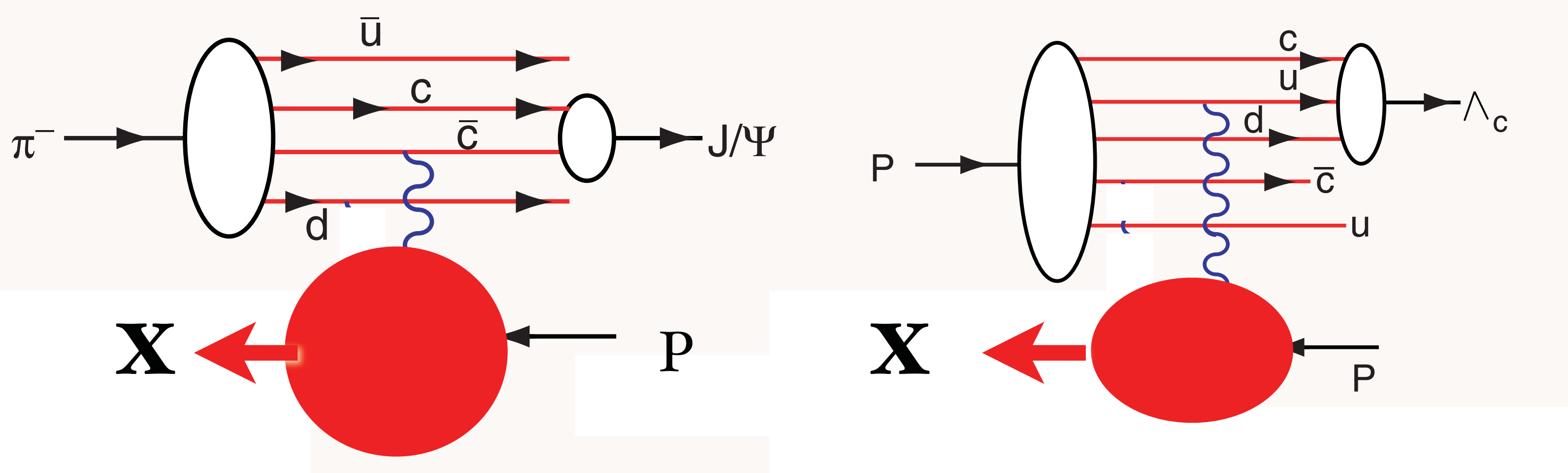
Intrinsic Heavy Quark Contribution to Quarkonium Hadroproduction at High x_F



Maximal Wavefunction Strength at Minimal Invariant Mass : Equal Rapidity

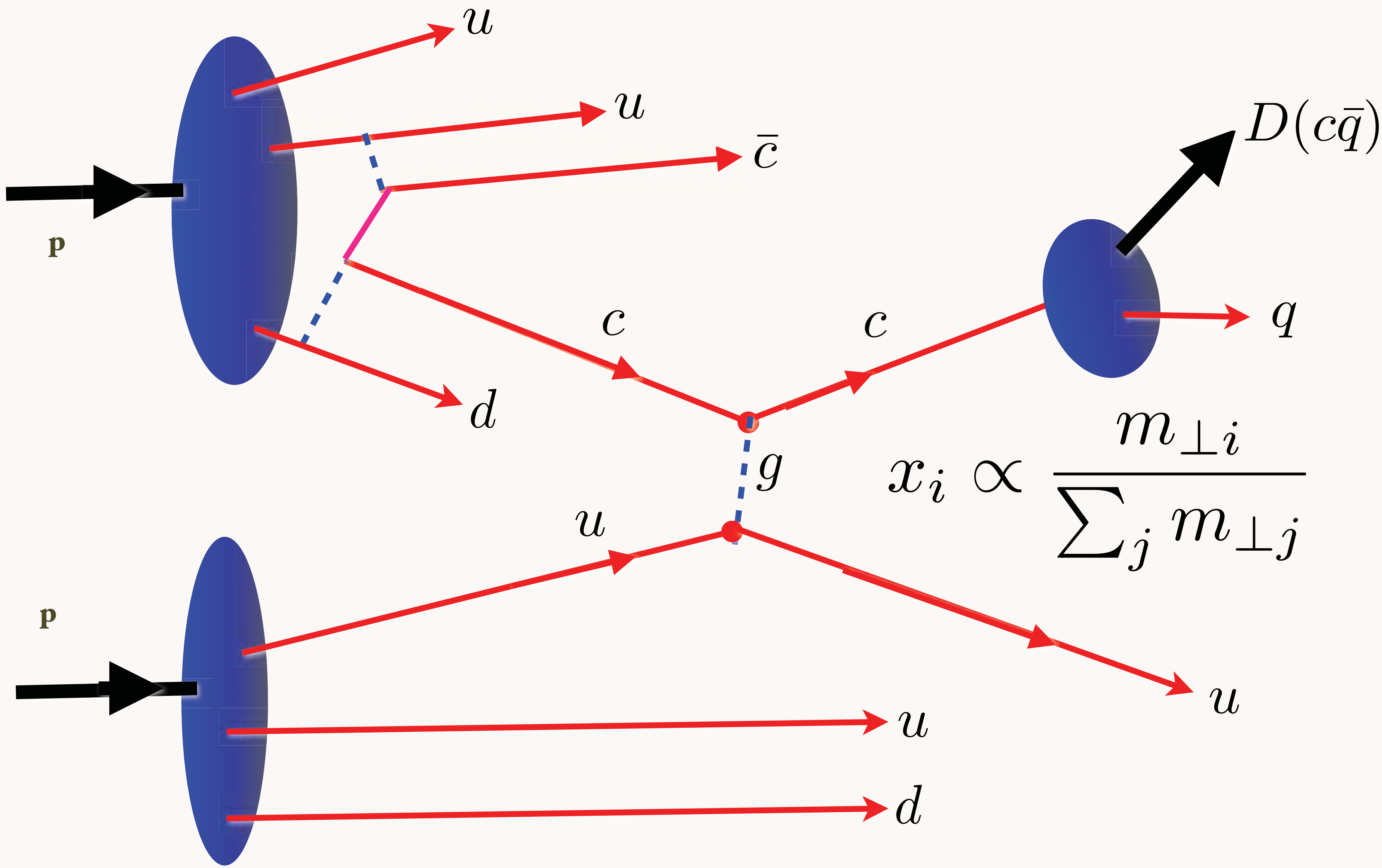
$$x_i \propto \frac{m_{\perp i}}{\sum_j m_{\perp j}}$$

Leading Hadron Production from Intrinsic Charm



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

Intrinsic Heavy Quark Fock States at High x



$$x_i \propto \frac{m_{\perp i}}{\sum_j m_{\perp j}}$$

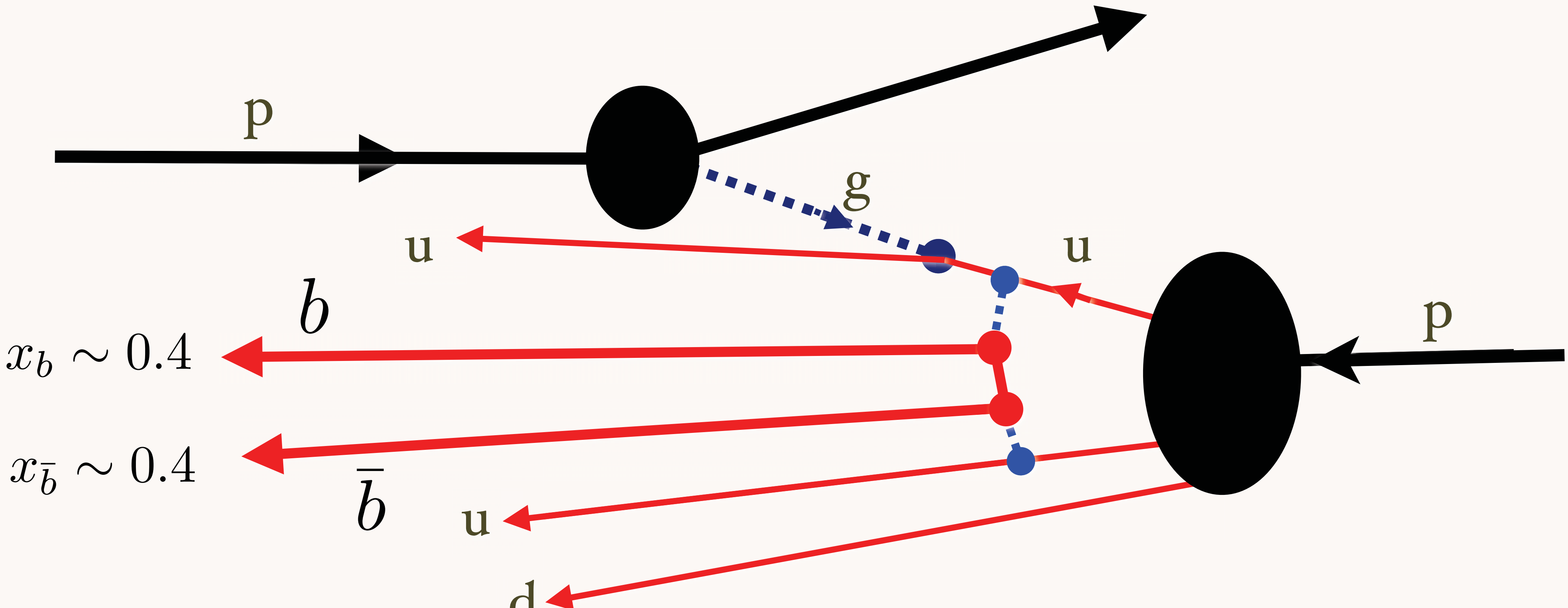
Maximal Wavefunction Strength at Minimal Invariant Mass : Equal Rapidity

Excitation of Intrinsic Heavy Quarks in Proton

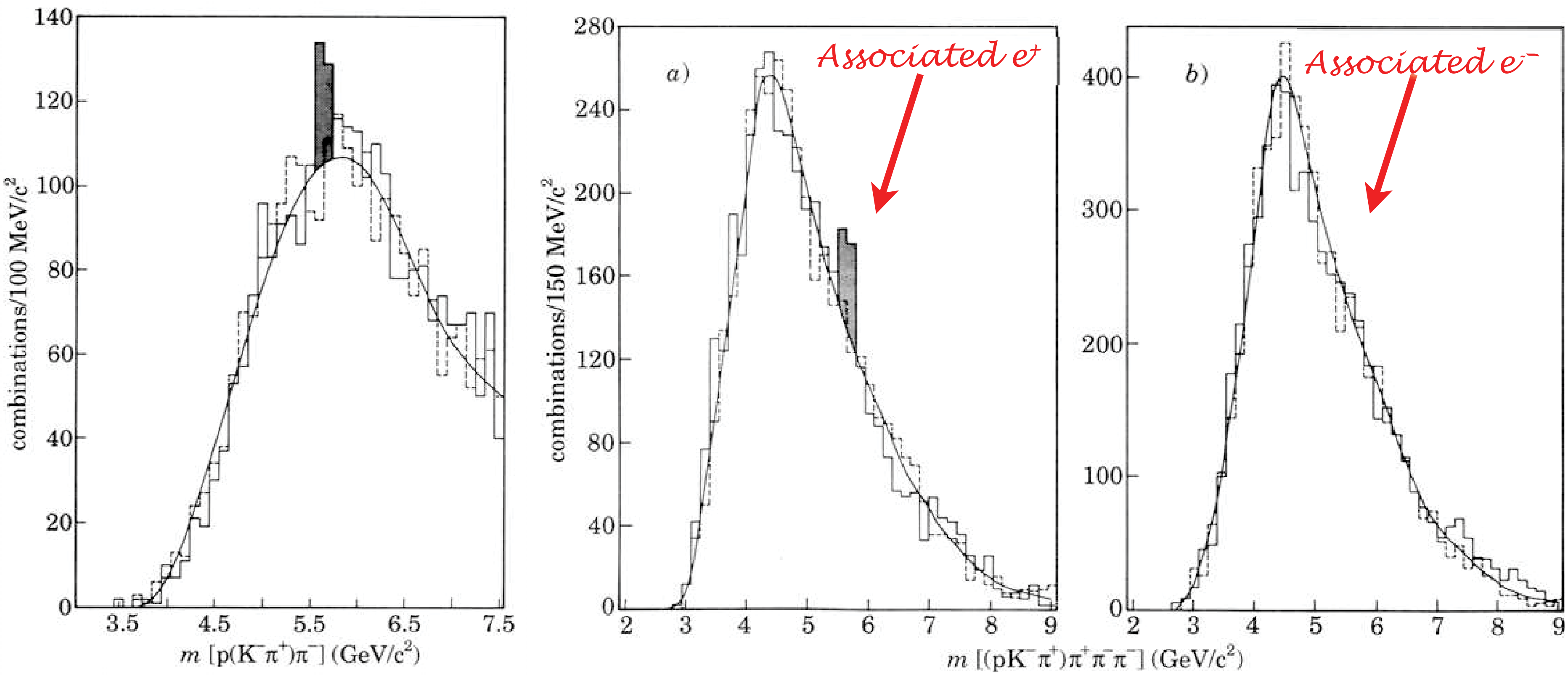
Amplitude maximal at small invariant mass, equal rapidity

$$x_i \sim \frac{m_{\perp i}}{\sum_j^n m_{\perp j}}$$

Produce forward, high x_F
$\Upsilon(b\bar{b}), \Lambda_b(bud), B^+(\bar{b}u), B^0(\bar{b}d)$



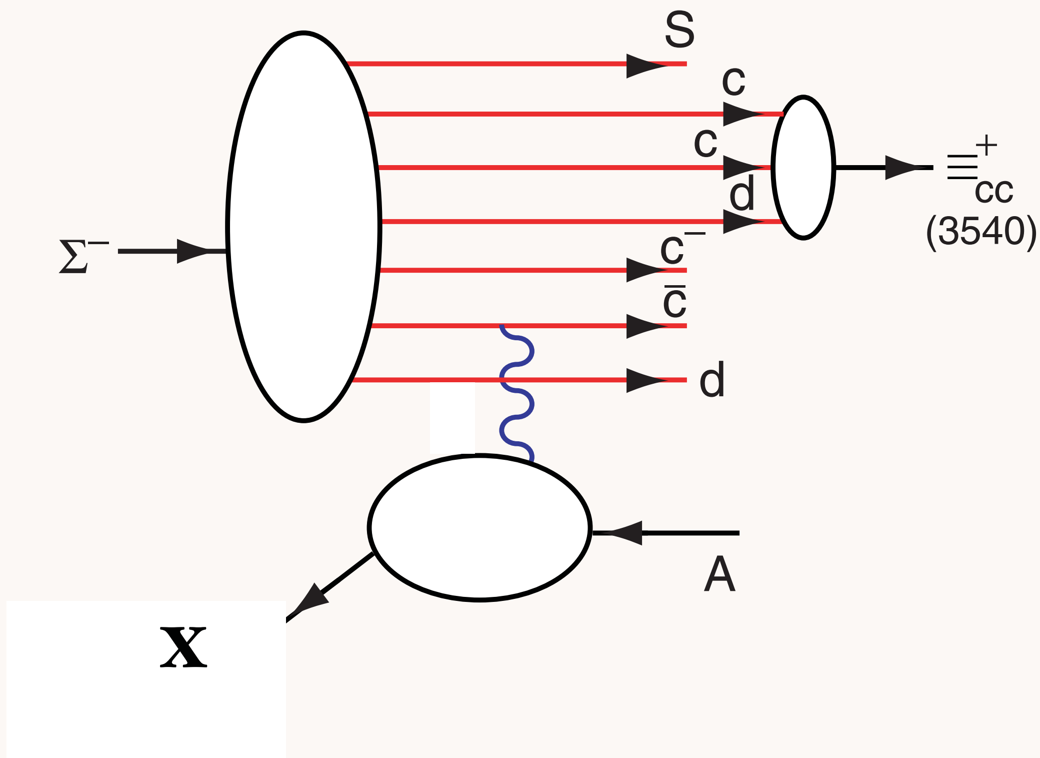
CERN-ISR R422 (Split Field Magnet), 1988/1991



$\Lambda_b^0 \to pD^0\pi^-$

$\Lambda_b^0 \to \Lambda_c^+\pi^+\pi^-\pi^-$

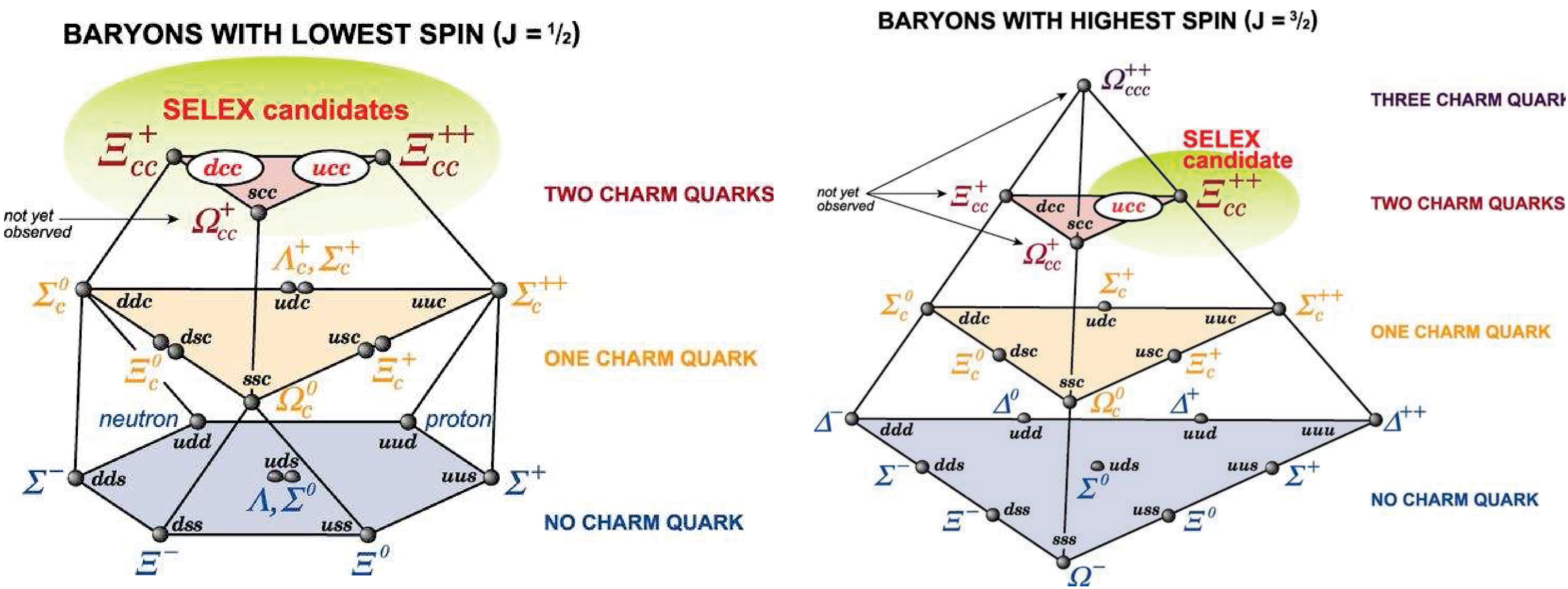
Il Nuovo Cimento 104, 1787



Production of a Double-Charm Baryon

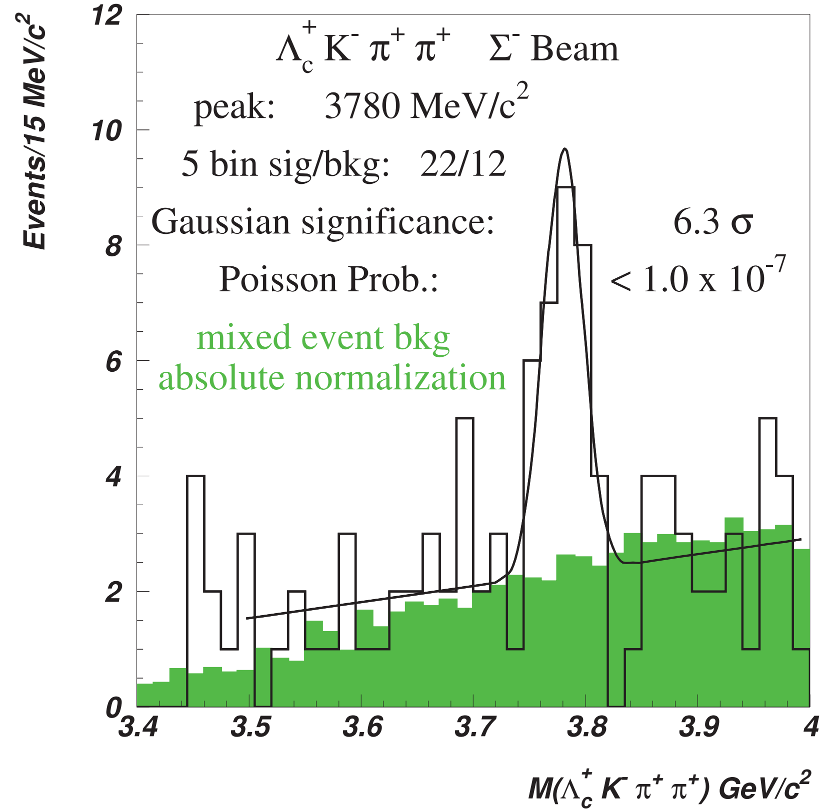
SELEX high x_F $< x_F >= 0.33$

Doubly Charmed Baryons

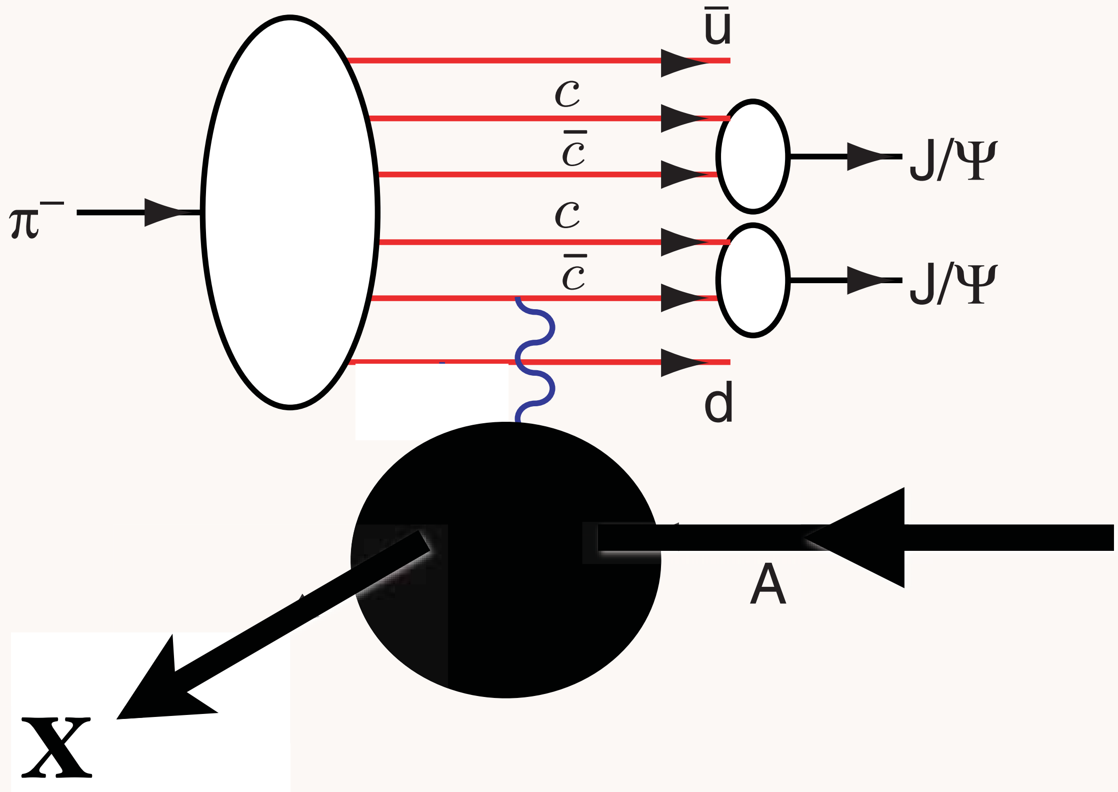


$\Xi_{cc}(3780)^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$

- Re-Analyzed Data
- Restrict to Σ^-–Beam
- Peak wider than Resolution
- Half decay to $\Xi_{cc}^+(3520)$
- Still working on Details



Production of Two Charmonia at High x_F



All events have $x^F_{\psi\psi} > 0.4$!

Excludes `color drag' model

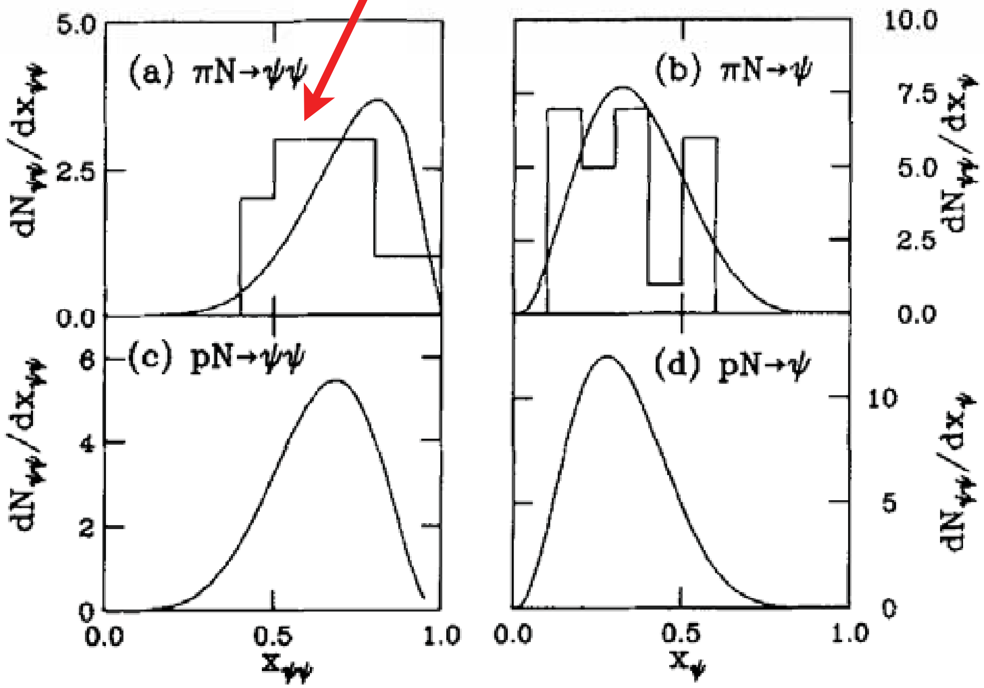


Fig. 3. The $\psi\psi$ pair distributions are shown in (a) and (c) for the pion and proton projectiles. Similarly, the distributions of J/ψ's from the pairs are shown in (b) and (d). Our calculations are compared with the $\pi^- N$ data at 150 and 280 GeV/c [1]. The $x_{\psi\psi}$ distributions are normalized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

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

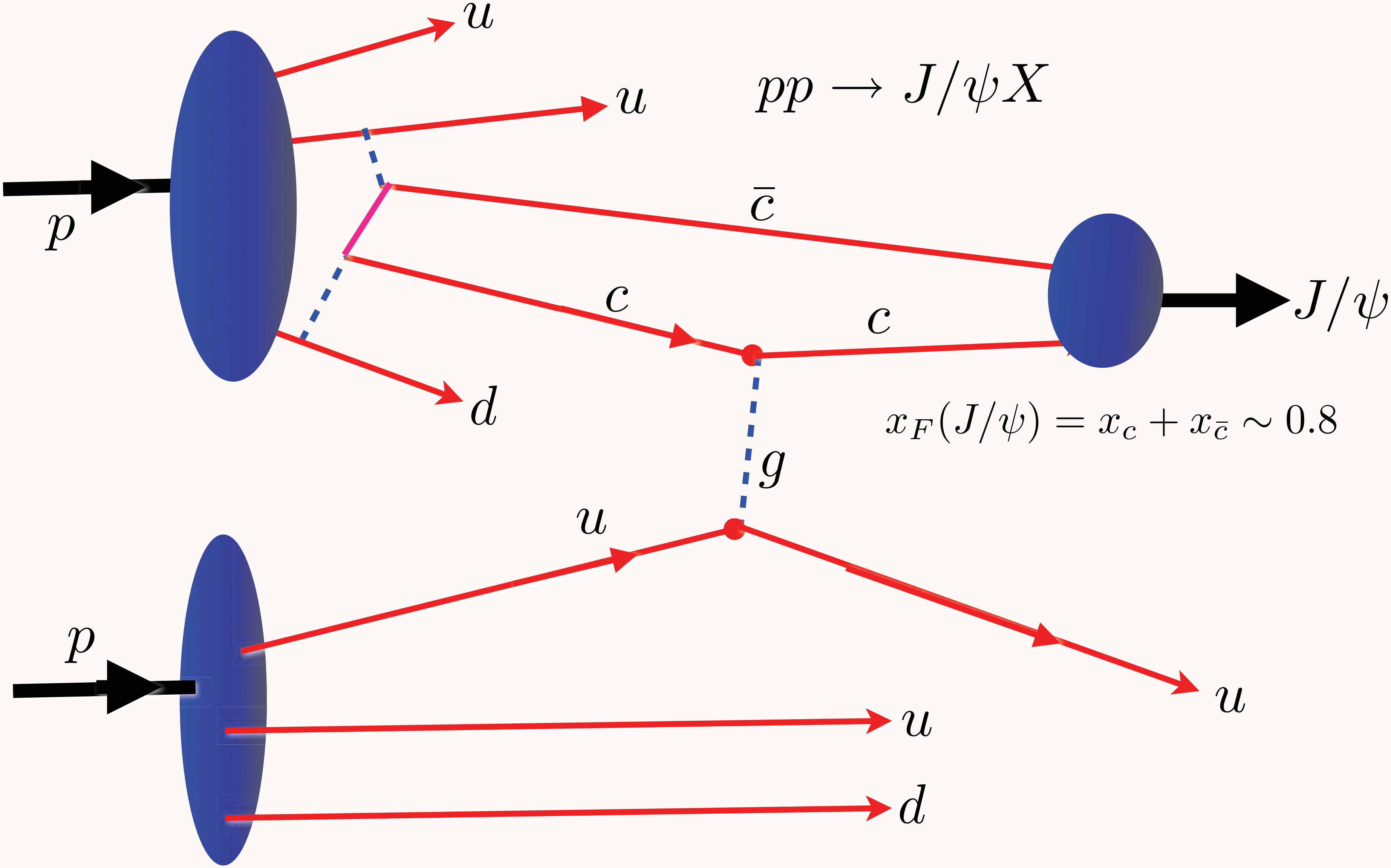
Intrinsic charm contribution to double quarkonium hadroproduction ★

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 k_T written as

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

Intrinsic Heavy Quark Contribution to Quarkonium Hadroproduction at High x_F



$$x_i \propto \frac{m_{\perp i}}{\sum_j m_{\perp j}}$$

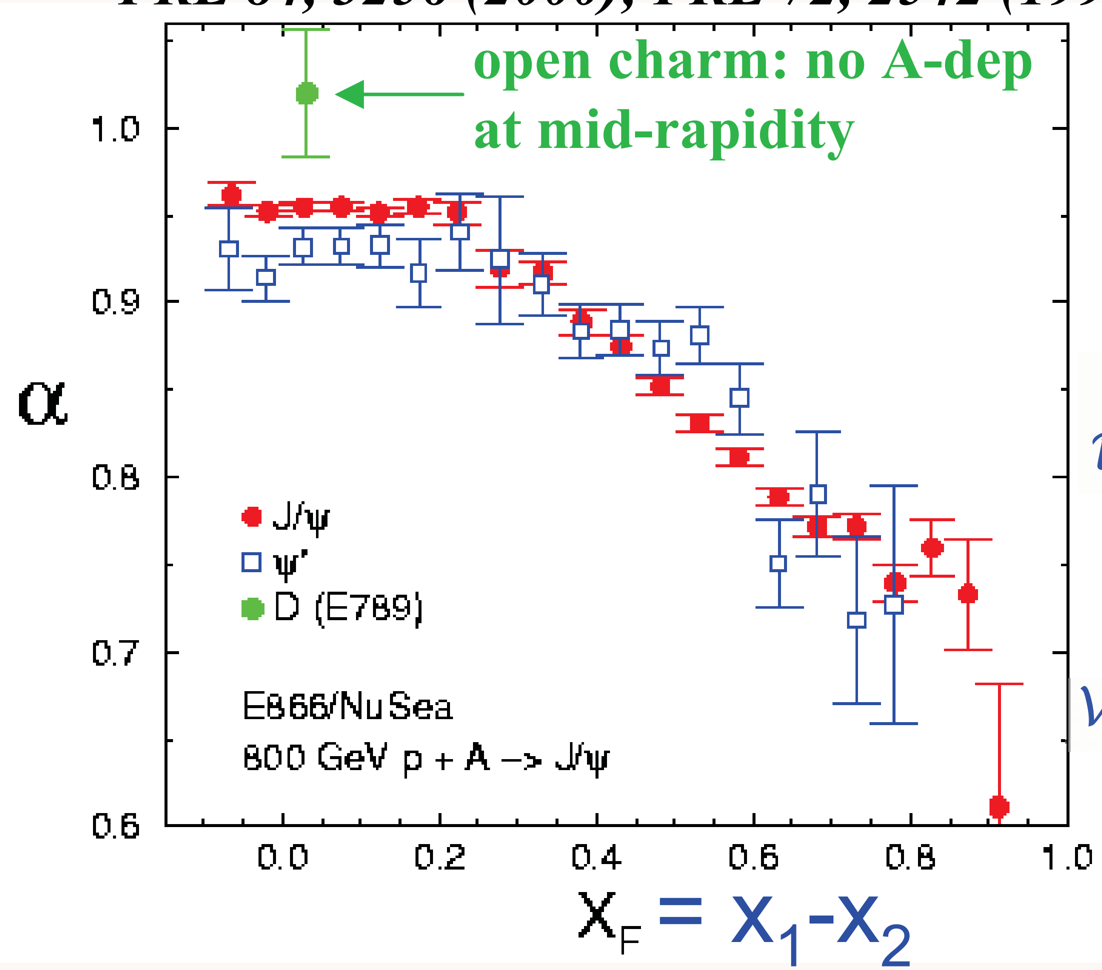
Maximal Wavefunction Strength at Minimal Invariant Mass : Equal Rapidity

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

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

M. Leitch

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



Remarkably Strong Nuclear Dependence for Fast Charmonium

Violation of PQCD Factorization!

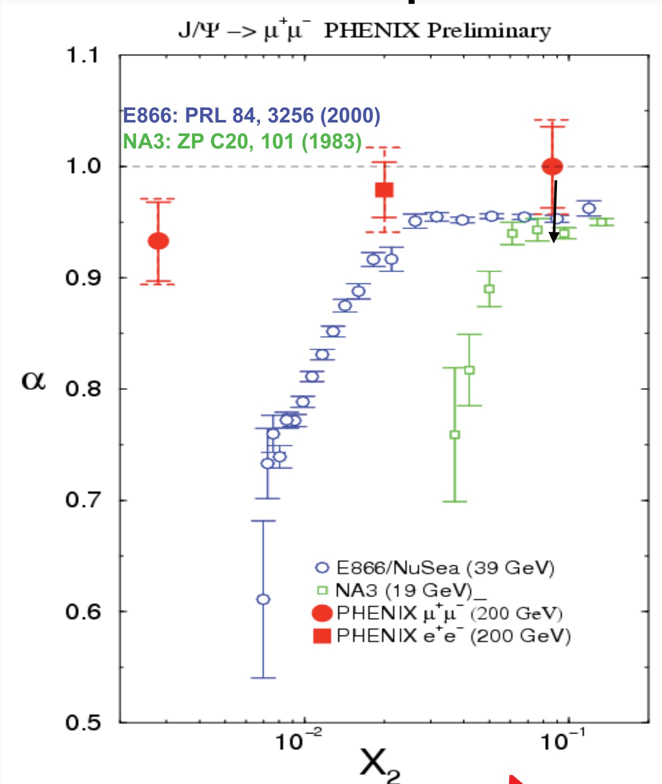
Violation of factorization in charm hadroproduction.

P. Hoyer, M. Vanttinen (Helsinki U.) , U. Sukhatme (Illinois U., Chicago) . HU-TFT-90-14, May 1990. 7pp.
Published in Phys.Lett.B246:217-220,1990

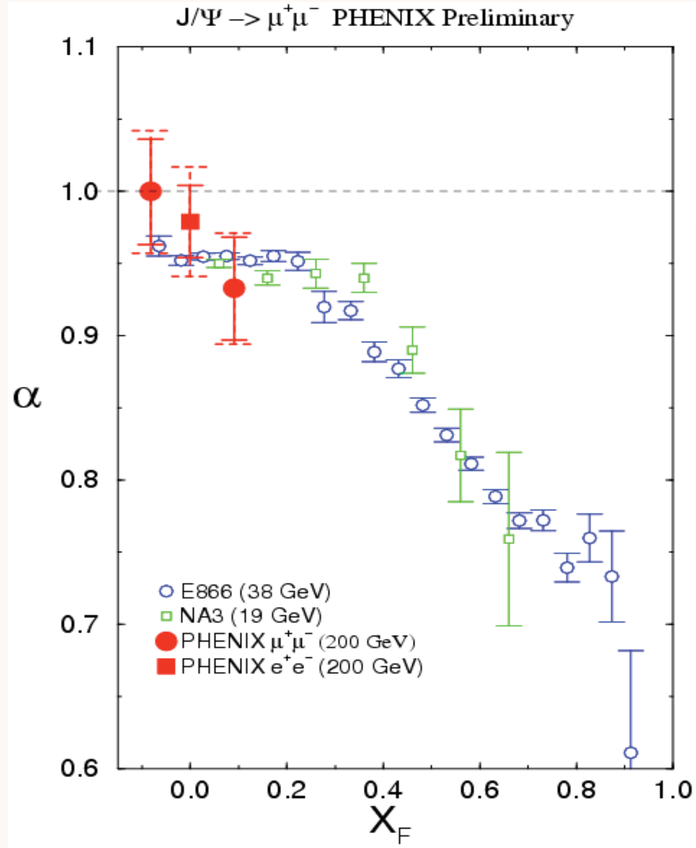
J/ψ nuclear dependence vrs rapidity, x_{Au}, x_F

M.Leitch

PHENIX compared to lower energy measurements



Klein,Vogt, PRL 91:142301,2003
Kopeliovich, NP A696:669,2001



Huge "absorption" effect at large xF

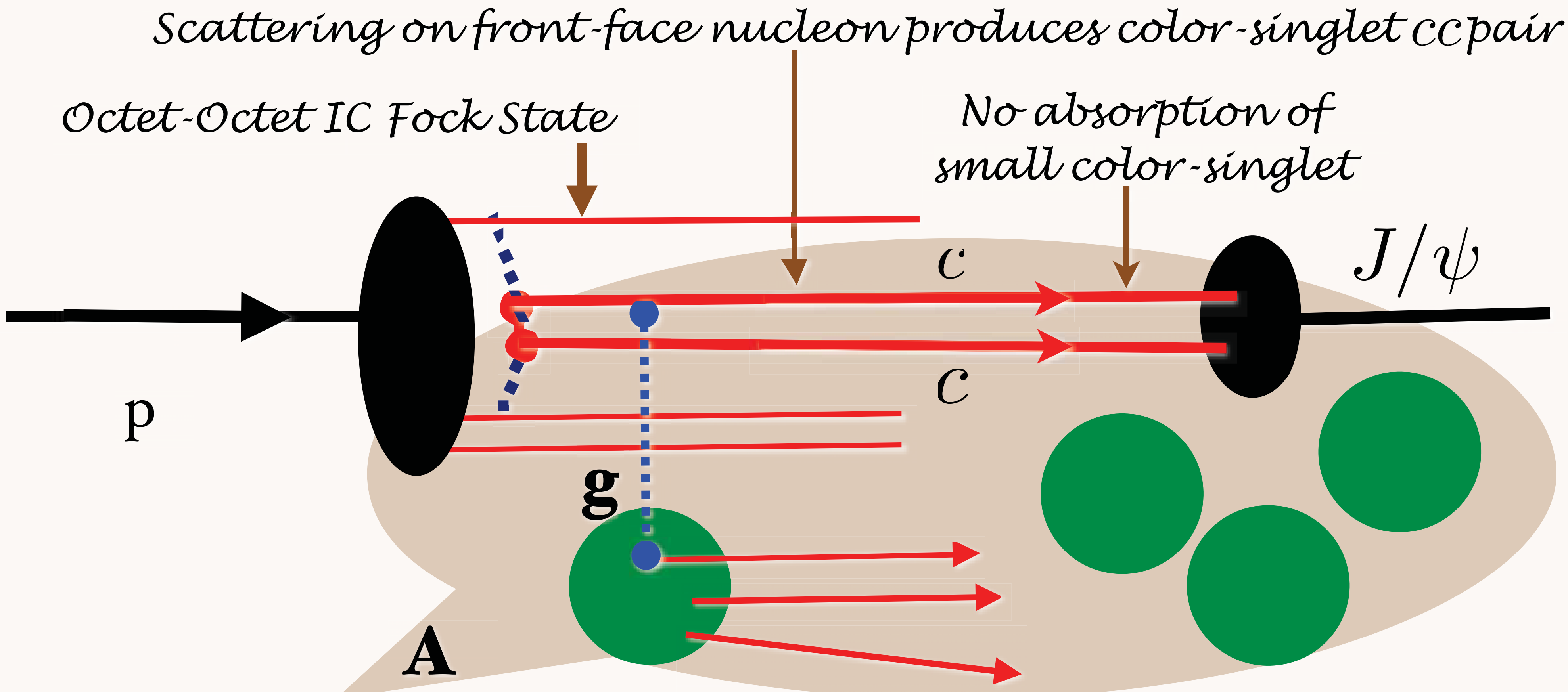
Violates PQCD factorization!

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

Hoyer, Sukhatme, Vanttinen

Kopeliovich, Schmidt, Soffer, sjb

Color-Opaque IC Fock state interacts on nuclear front surface

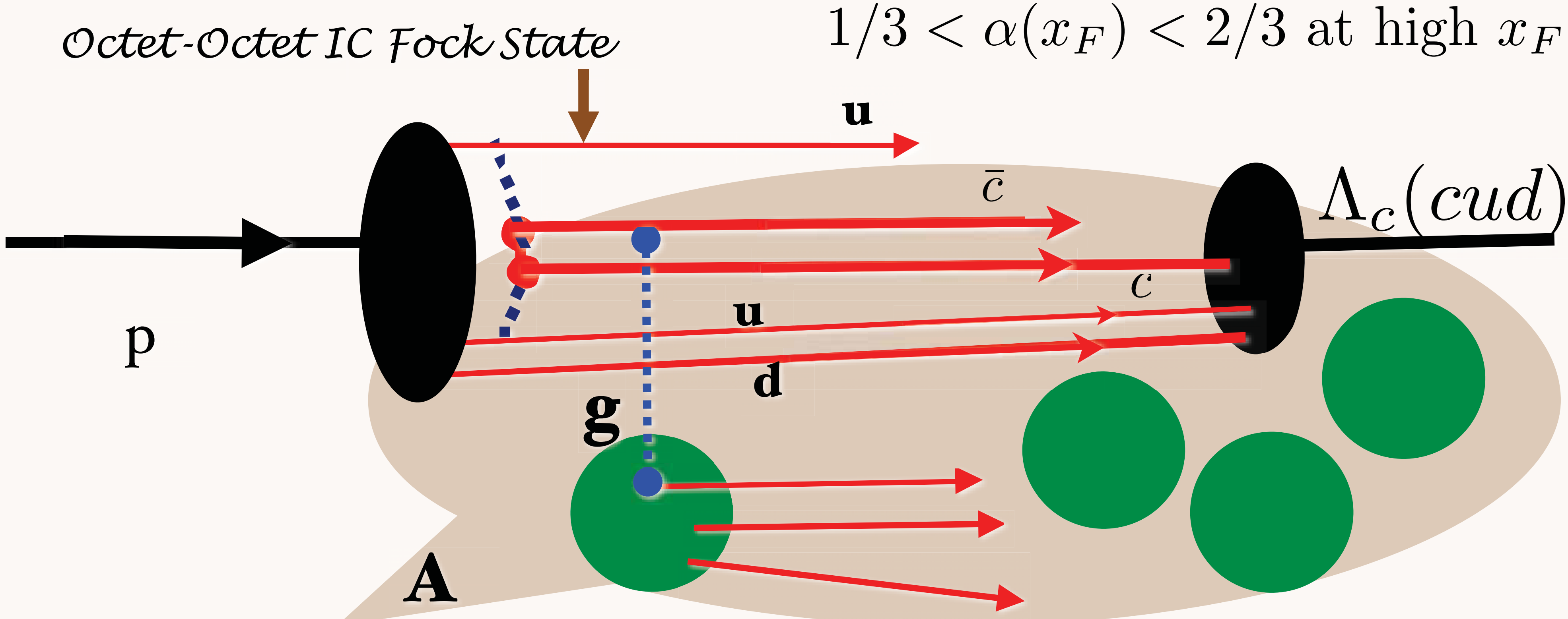


$$\frac{d\sigma}{dx_F}(pA \to J/\psi X) = A^{2/3} \times \frac{d\sigma}{dx_F}(pN \to J/\psi X)$$

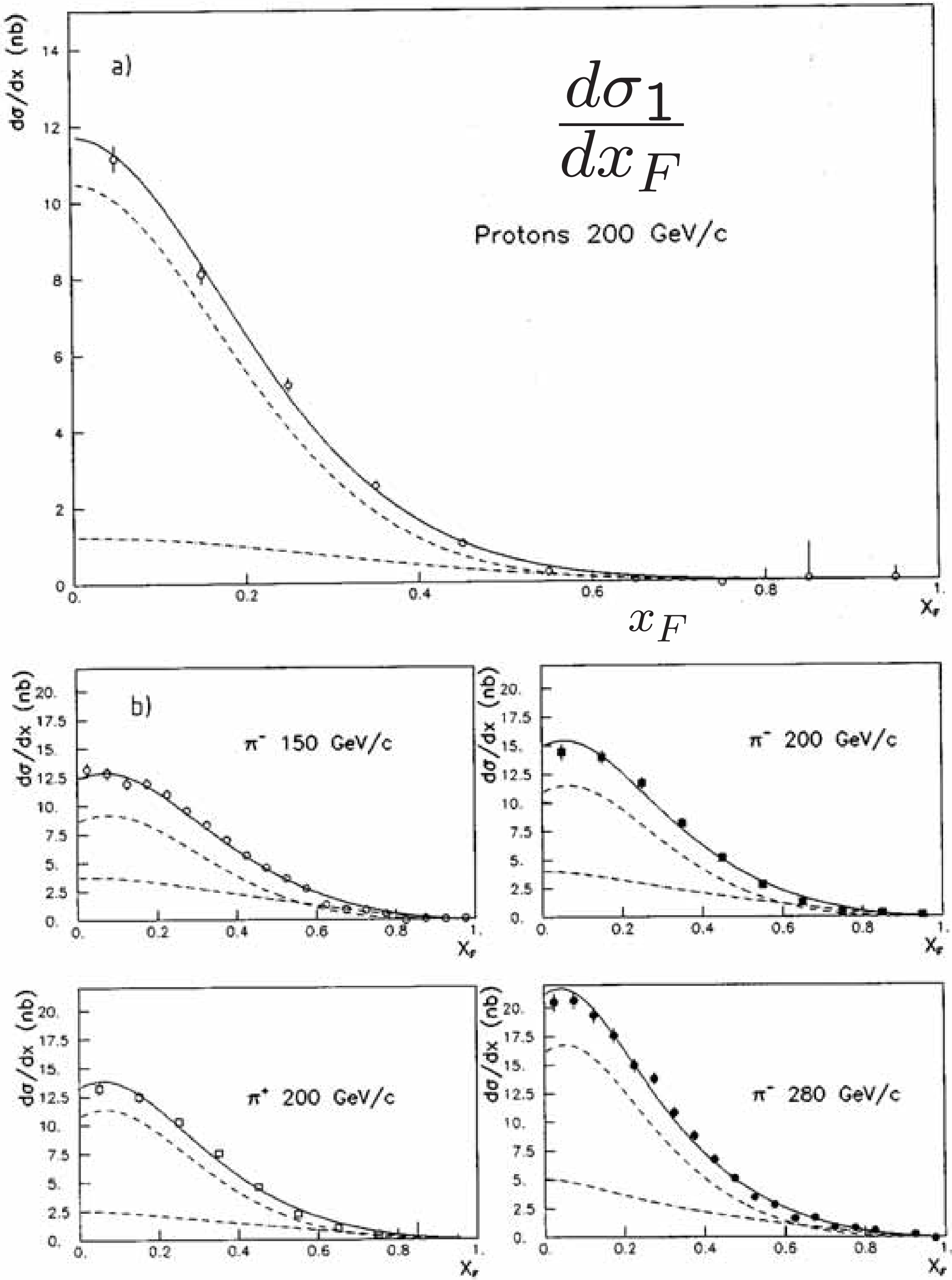
Color-Opaque IC Fock state interacts on nuclear front surface

$$\frac{d\sigma}{dx_F}(pA \to \Lambda_c X) = A^{\alpha(x_F)} \frac{d\sigma}{dx_F}(pN \to \Lambda_c X)$$

$1/3 < \alpha(x_F) < 2/3$ at high x_F



Reconciles ISR and Fixed Target Measurements!



J. Badier et al, NA3

Two Components

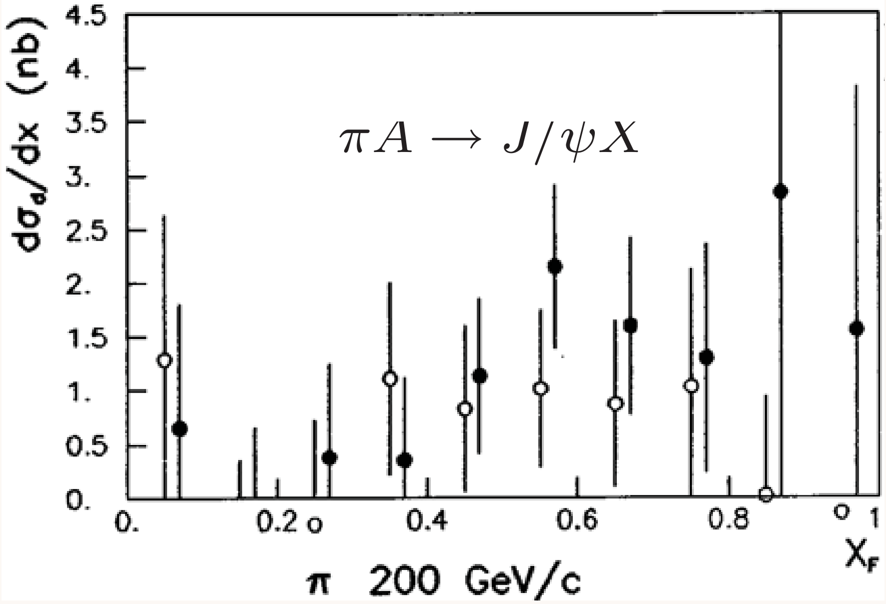
$$\frac{d\sigma}{dx_F}(pA \to J/\psi X) = A^1 \frac{d\sigma_1}{dx_F} + A^{2/3} \frac{d\sigma_{2/3}}{dx_F}$$

A^1 component

Identify with Fusion

Conventional PQCD subprocesses

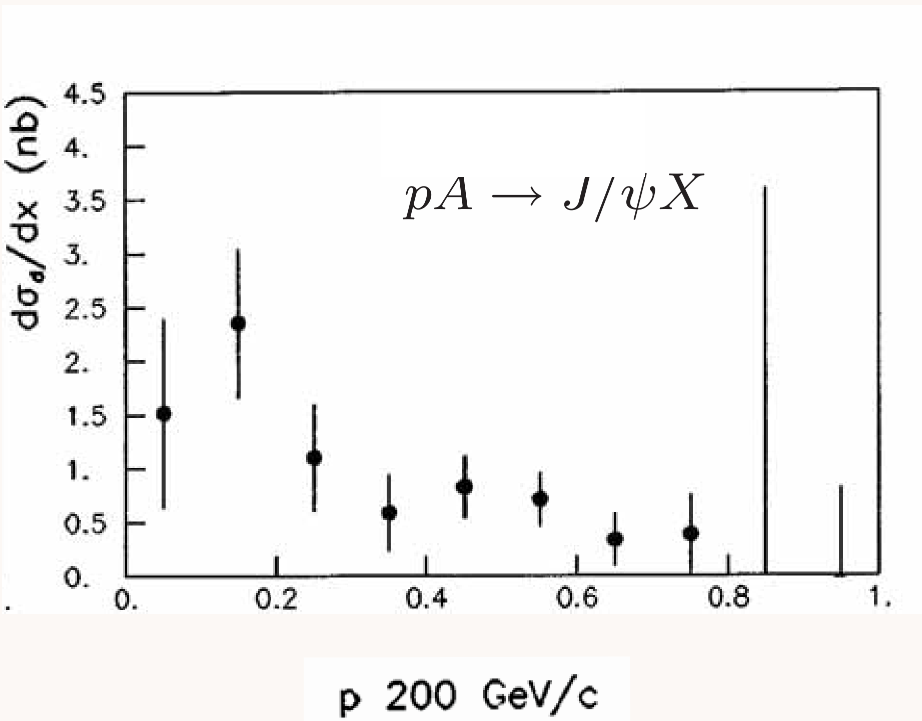
$$\frac{d\sigma_1}{dx_F}(\pi A \to J/\psi X)$$



J. Badier et al, NA3

$$\frac{d\sigma}{dx_F}(pA \to J/\psi X) = A^1 \frac{d\sigma_1}{dx_F} + A^{2/3} \frac{d\sigma_{2/3}}{dx_F}$$

$A^{2/3}$ component



Identify with IC
High x_F

Remarkably Flat Distribution

Excess beyond conventional PQCD subprocesses

- 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)

Color Opaqueness

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

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

Higgs production at x_F = 0.8

PHYSICAL REVIEW D **73,** 113005 (2006)

Diffractive Higgs production from intrinsic heavy flavors in the proton

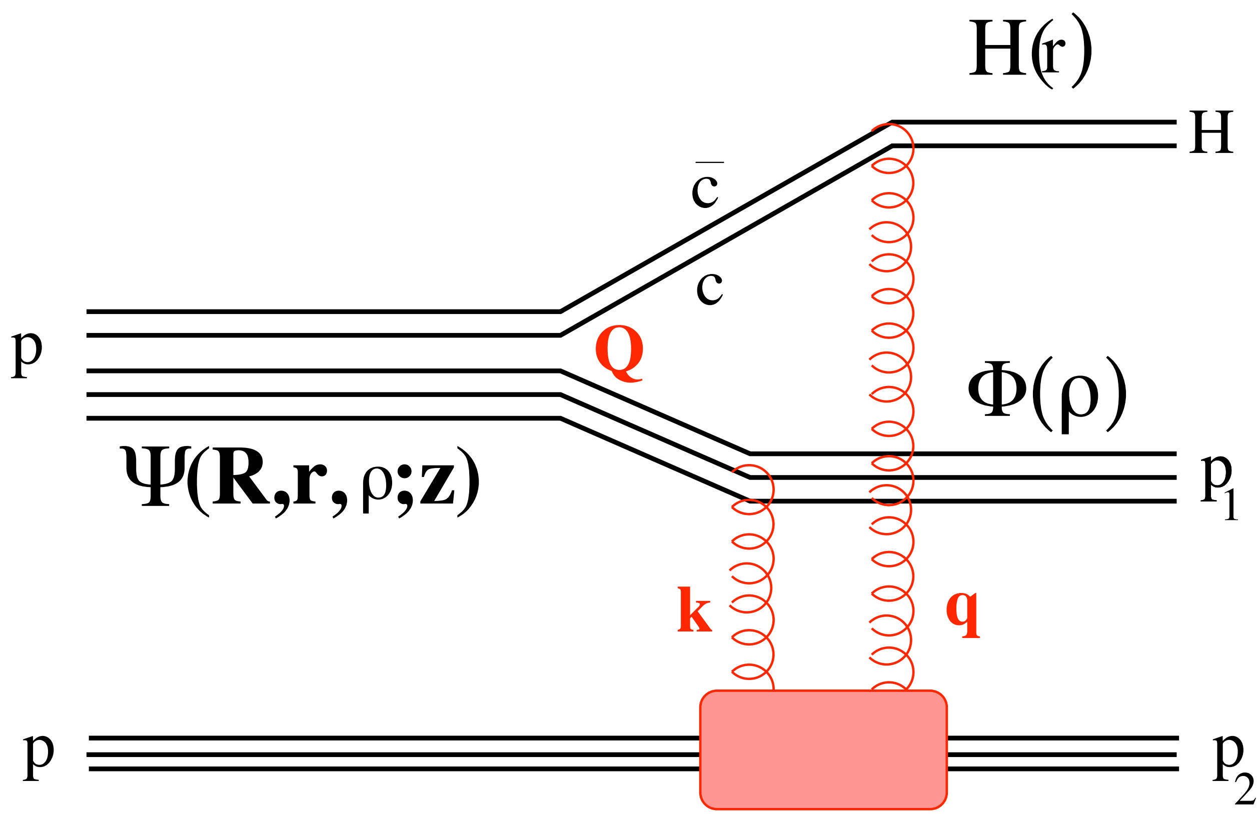
Stanley J. Brodsky,[1,*] Boris Kopeliovich,[2,†] Ivan Schmidt,[2,‡] and Jacques Soffer[3,§]

Higgs Hadroproduction at Large Feynman x

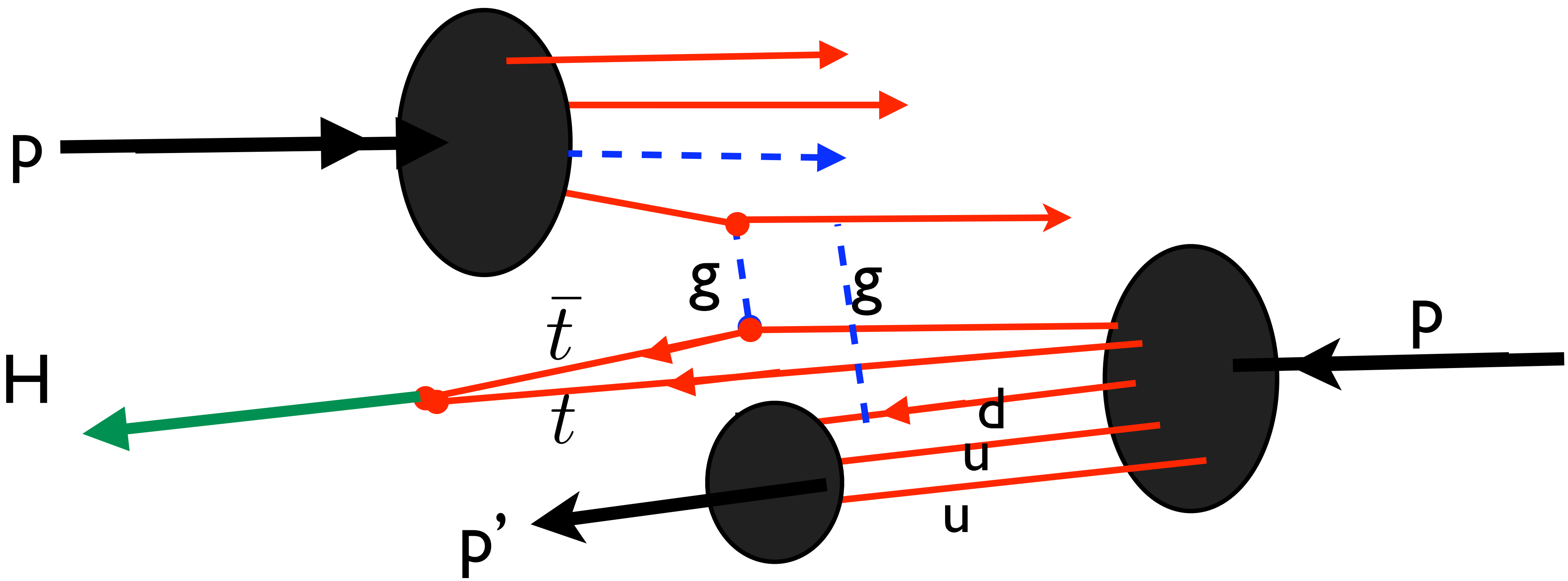
Stanley J. Brodsky[*a], Alfred Scharff Goldhaber[†a,b], Boris Z. Kopeliovich[‡c,d], Ivan Schmidt[§c]

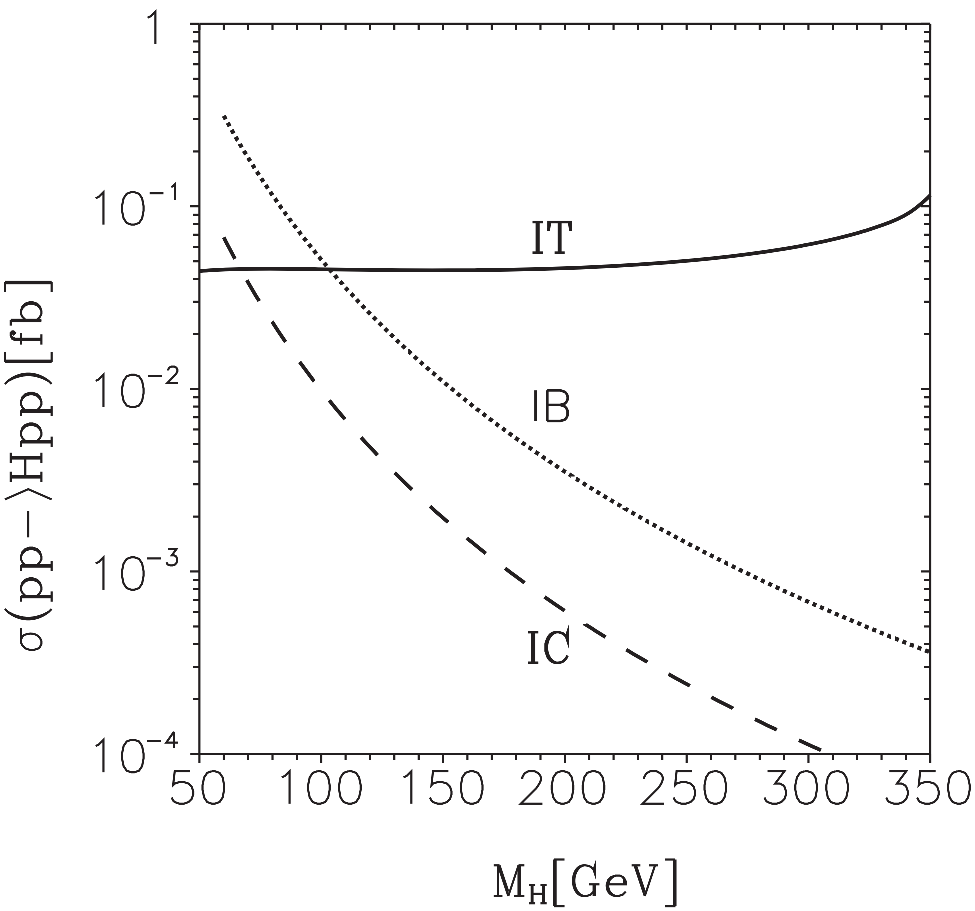
To be published in Nuclear Physics B

$$\frac{d\sigma(pp \to ppH)}{dx_2 d^2 p_1 d^2 p_2} = \frac{1}{(1-x_2)16\pi^2} |A(x_2, \vec{p}_1, \vec{p}_2)|^2$$



Diffractive Higgs Hadroproduction at High x_F from Intrinsic Heavy Quarks





The cross section of the reaction $pp \to Hp + p$ as a function of the Higgs mass. Contributions of IC (dashed line), IB (dotted line), and IT (solid line).

Why is Intrinsic Charm Important for Flavor Physics?

- New perspective on fundamental nonperturbative hadron structure
- Charm structure function at high x
- Dominates high x_F charm and charmonium production
- Hadroproduction of new heavy quark states such as ccu, ccd at high x_F
- Intrinsic charm -- long distance contribution to penguin mechanisms for weak decay
- Novel Nuclear Effects from color structure of IC, Heavy Ion Collisions
- New mechanisms for high x_F Higgs hadroproduction
- Dynamics of b production: LHCb
- Fixed target program at LHC: produce bbb states

Novel Aspects of High p_T QCD

- Anti-Shadowing not universal
- Hadronization at the Amplitude Level
- AdS/QCD Light-Front Wavefunctions
- Fixed-x_T scaling laws
- Multiple renormalization scales
- Initial and Final-State Scattering Effects
- Intrinsic Heavy Quark Fock States
- Direct Higher-Twist Subprocesses and Color Transparency
- Diffractive Reactions at Leading Twist

Novel Aspects of QCD

- Heavy quark distributions do not derive exclusively from DGLAP or gluon splitting -- component intrinsic to hadron wavefunction: Higgs at high x_F

- Initial and final-state interactions are not power suppressed in hard QCD reactions

- LFWFS are universal, but measured nuclear parton distributions are not universal -- antishadowing is flavor dependent

- Hadroproduction at large transverse momentum does not derive exclusively from 2 to 2 scattering subprocesses

- DDIS Rescattering: Sivers Effect: Breakdown of Leading-Twist Factorization
- Physics of Hard Pomeron
- Measure Fundamental Hadron Wavefunction via Di-jet and Tri-jet Fragmentation
- Origin of Leading Twist Shadowing
- Non-Universal Antishadowing
- Heavy quark structure functions at high x
- Higgs production at large xF
- Hadroproduction of new heavy quark states such as ccu, ccd at high x_F
- Novel Nuclear Effects from color structure of IC
- Fixed target program at LHC: produce bbb states
- Direct Hadroproduction at high pT