Importance of *e+D* scattering at a collider

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Overview

- Why the deuteron?
- Nuclear effects from low to high x
    - beyond obvious LHeC strength
- Proton/neutron tagging
- Diffraction
    - Only touched upon inthis talk

Why deuteron?

- **Deuteron as effective neutron beam**

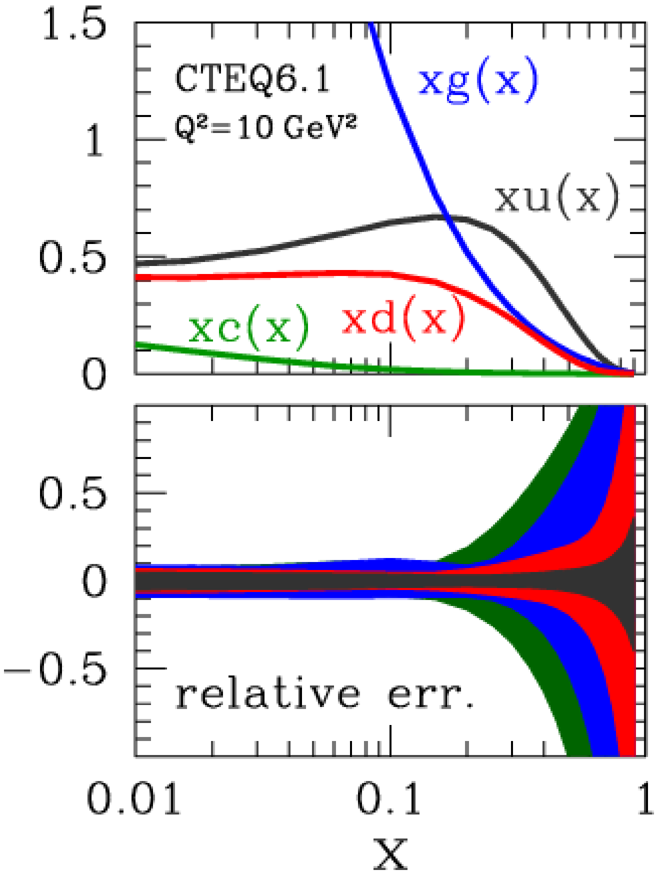
- Quark flavor decomposition

$$F_2(p) \propto 4u + d$$

$$F_2(n) \propto u + 4d$$

- Particularly important at large *x*
  - Large d-quark uncertainty
  - *d/u* ratio at x → 1 probes non perturbative proton structure

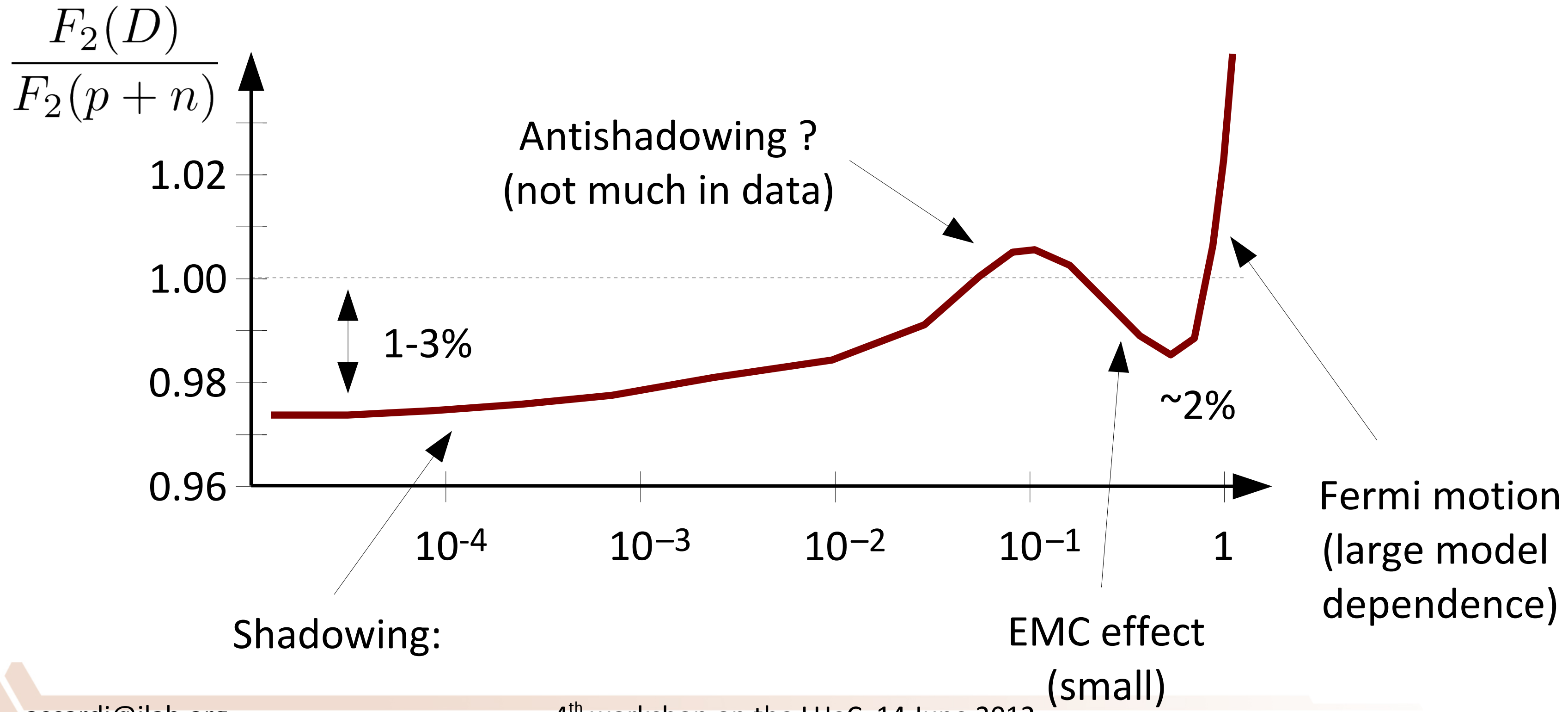
Accardi et al. [CTEQ-JLab collab.] PRD84(2011)



- At $x \lesssim 10^{-2}$ sea quarks dominate, expect $F_2(p) \approx F_2(n)$

Why deuteron?

- **As baseline for nuclear PDFs**
  - $F_2(A)/F_2(D)$ is measured: approx. correct for isospin, remove syst.
    - Ideally, $F_2(A)/[ZF_2(p)+(A-Z)F_2(n)]$
  - But $F_2(D) \neq F_2(p)+F_2(n)$, need to measure it



Antishadowing ?
(not much in data)

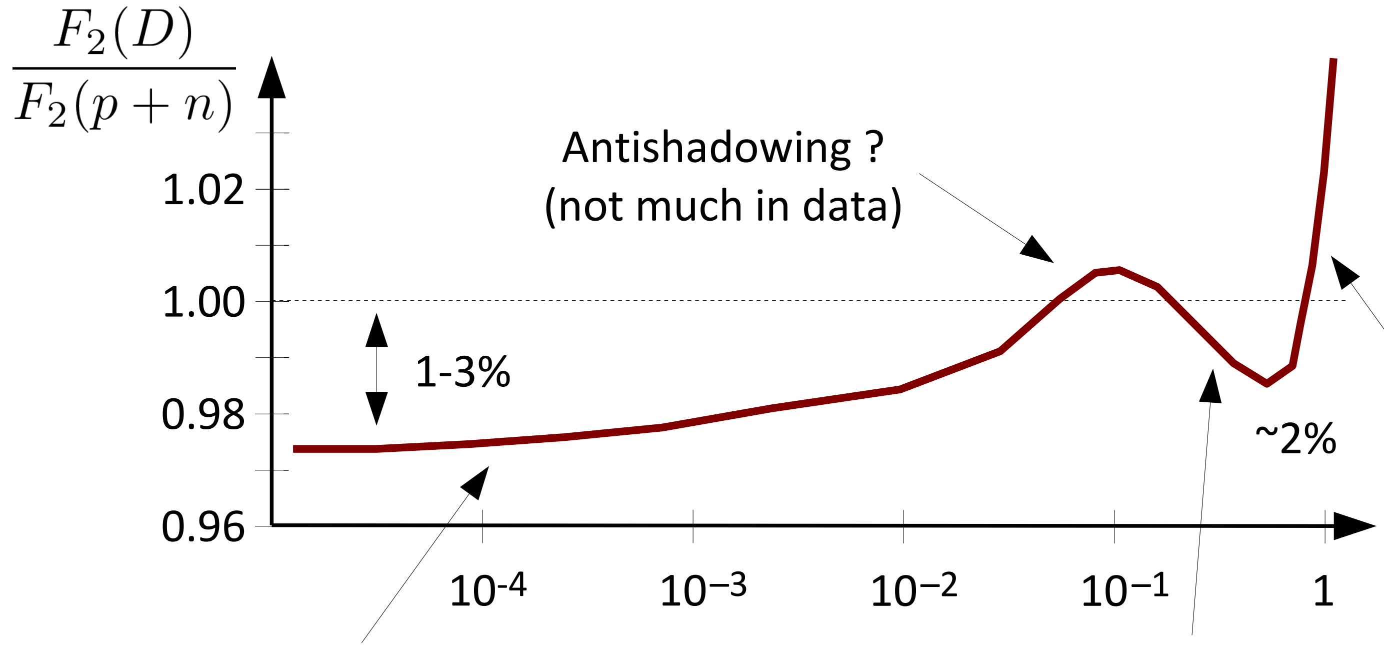
Shadowing:

EMC effect
(small)

Fermi motion
(large model
dependence)

Why deuteron?

- **The simplest nucleus:**
  - Nuclear few-body calculations of *p*, *n* wave function available
  - Testbed for nuclear effects calculations and modeling



Antishadowing ?
(not much in data)

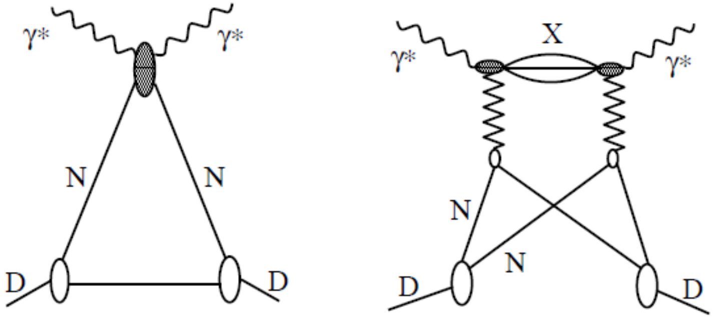
Shadowing:

EMC effect
(small)

Fermi motion
(large model
dependence)

Nuclear effects 1 - shadowing

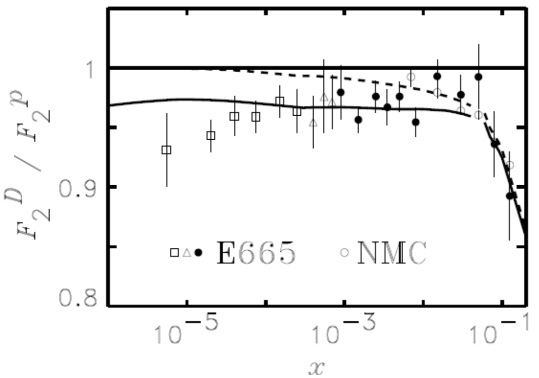
- **Nuclear shadowing**
  - Double scattering only
  - At low x << 0.01 , Glauber-Gribov, no model dependency
  - Connection to diffraction (on *p* and *n*)



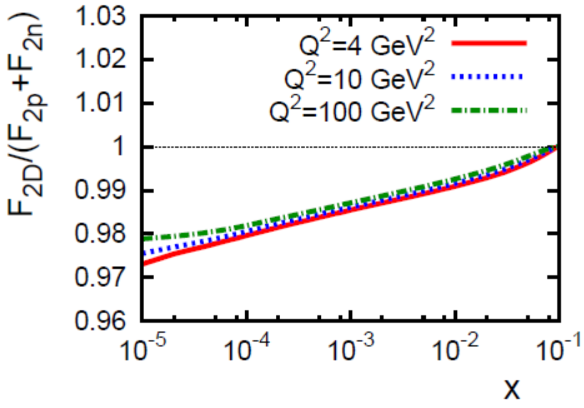
Badelek, Kwiecinsky, NPB370(1992)

- All implementations: 1-3% shadowing at $10^{-5} < x < 10^{-2}$
  - Main uncertainty: deuteron wave function

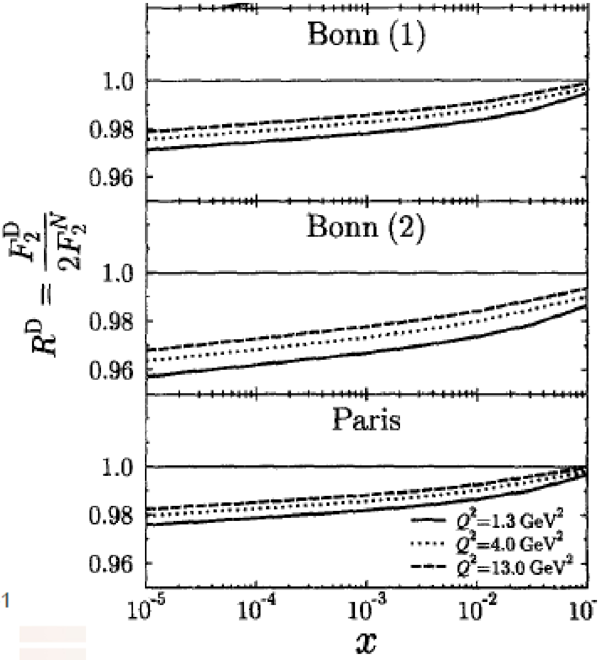
Melnitchouk, Thomas, 1995



Guzey et al. 2011



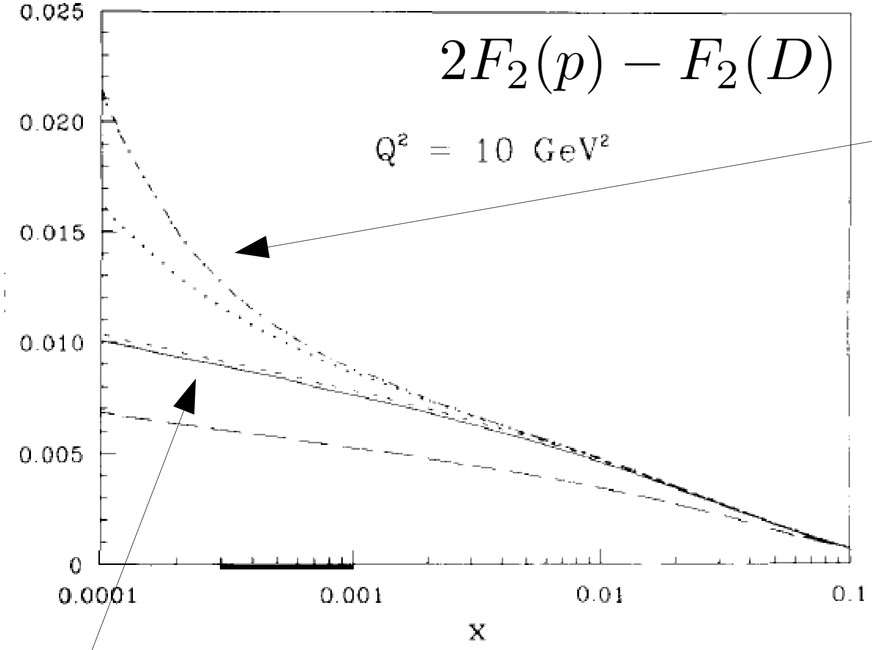
Piller et al. 1995



Nuclear effects 1 - shadowing

- **Shadowing + gluon recombinations**

Badelek, Kwiecinsky, NPB370(1992)



With recombination
(2 different gluon PDF)

→ more shadowing

Without recombination

Nuclear effects 1 - shadowing

- **Shadowing + gluon recombinations**

Test shadowing calculations in controlled setting

→ approach to saturation

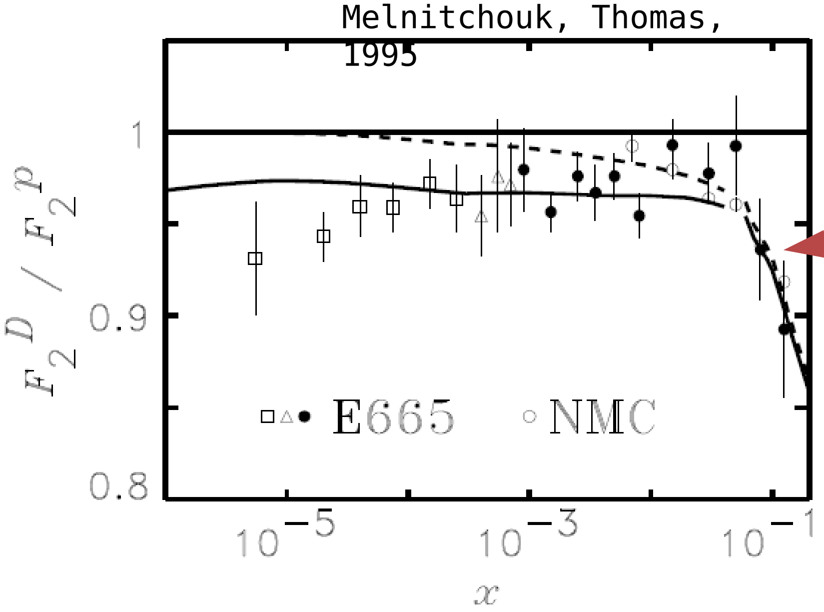
→ Access to diffractive $F_2^D(n)$

bination
gluons)

Without recombination

Nuclear effects 2 - antishadowing

- **Antishadowing**
  - Not obvious in data because $F_2(p) \neq F_2(n)$ at $x \gtrsim 0.01$
  - The baseline is not 1



- **Needs direct measurements of $F_2(n)$**
  - Proton tagging, see later
  - Data exist from BoNuS at *x* > 0.3, low *Q*; lower *x*, higher *Q* at JLab12

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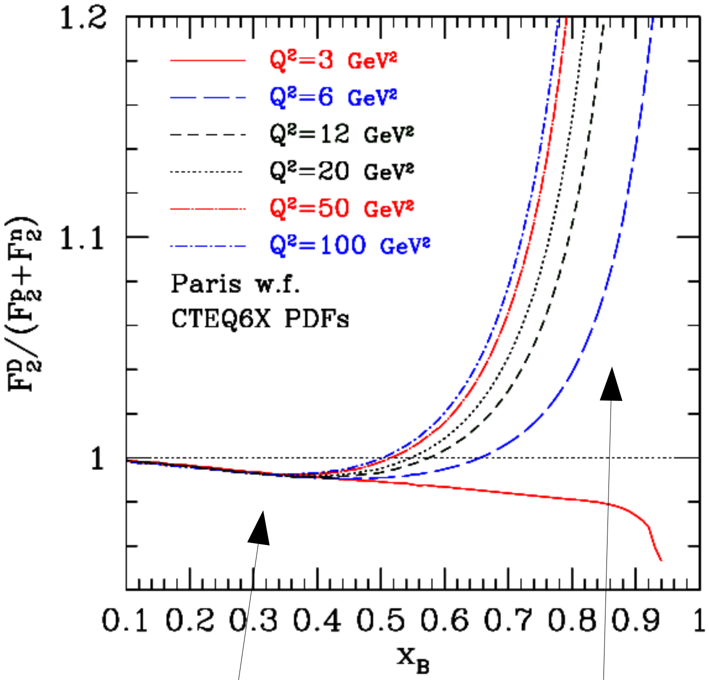
Nuclear effects 3 – EMC, Binding, Fermi motion

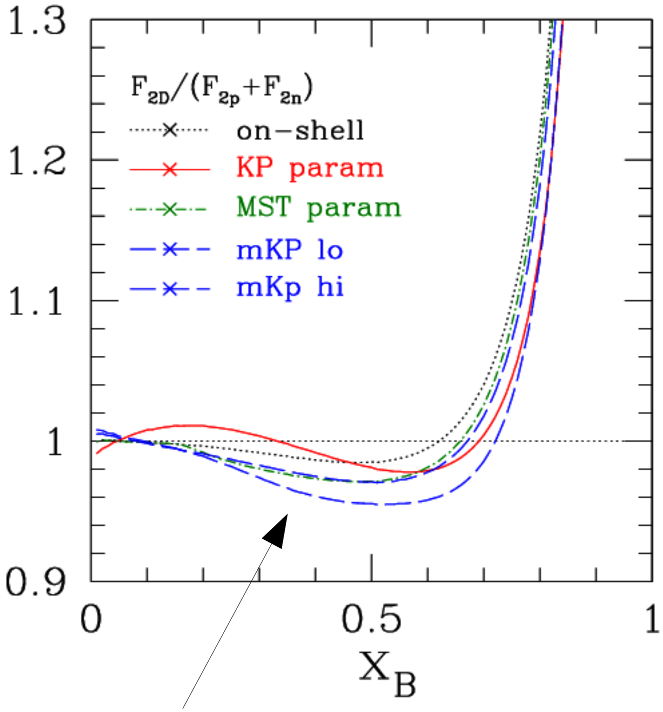
- Origin of EMC effect still a mystery after 30 years:
  - x > 0.1 is a complex region
  - many theoretical uncertainties

Accardi et al. [CTEQ-JLab collab.] PRD84(2011)



1/Q^2 effects:

- Higher twists
- Target Mass
- p^2/Q^2 effects



Nucleon off-shellness effects

Binding

Fermi motion

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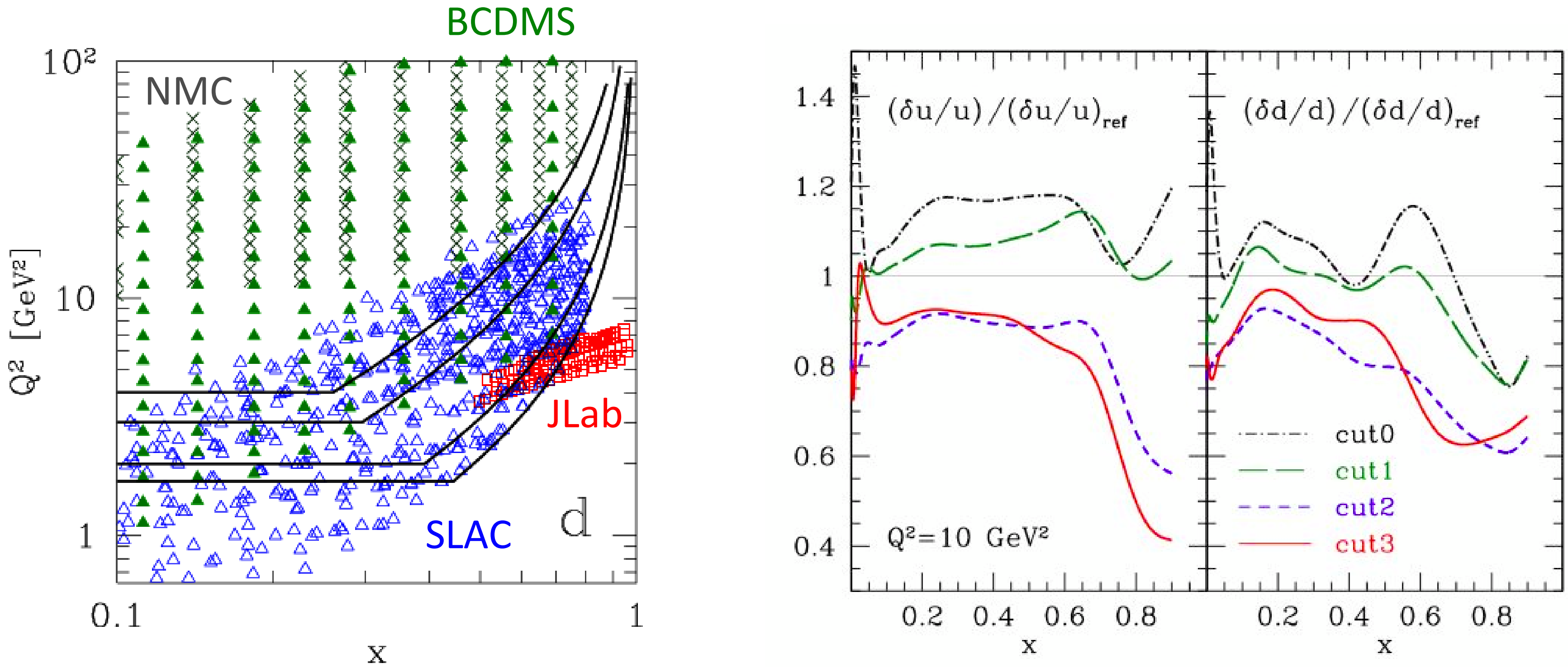
Nuclear effects 3 - EMC, Binding, Fermi motion

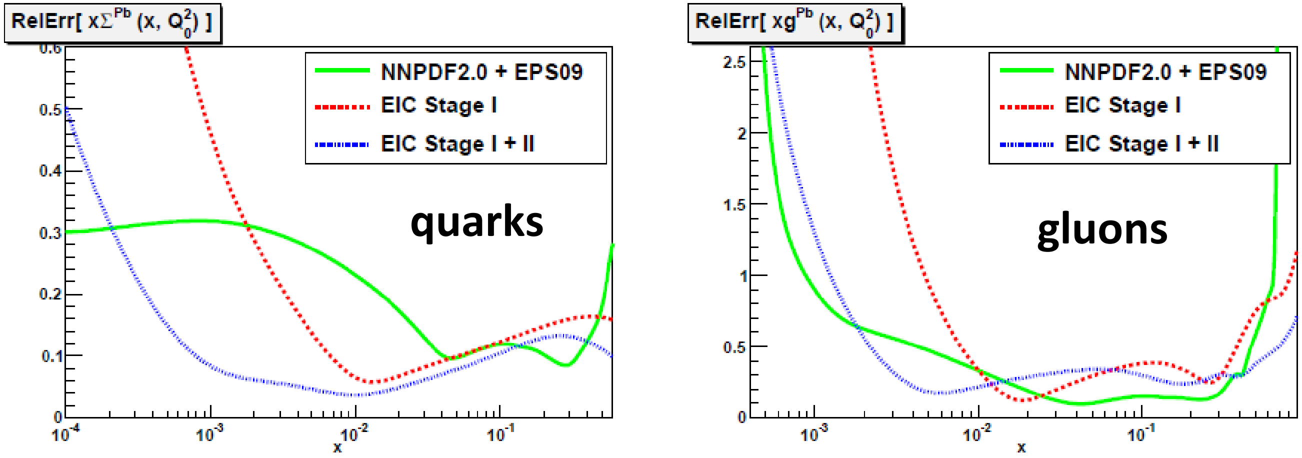
- Important for:
  - Fit of *d* quark at large *x* Accardi et al. [CTEQ-JLab] PRD84(2011)
  - Constraining nucl. corrections, when compared to free proton data (for example, p+p → W(Z)+X, PVDIS, ...) Accardi, ECT*, May 2012



Accardi et al. [CTEQ-JLab] PRD81(2010)

Nuclear effects 3 - EMC, Binding, Fermi motion

- Not impossible to have good data at a collider
  - For example at EIC, 1 year of data at L = 4 fb^{-1} for 5+3 energies



Accardi, Guzey, Rojo, arXiv:1106.383

- Advantage: large Q^2 leverage
  - Suppress $1/Q^2$ power corrections
  - Gluon EMC effect via scaling violation of F_2
    - This may be as revolutionary as original quark EMC effect

Nuclear effects 3 - EMC, Binding, Fermi motion

- ☐ Not impossible to have good data at a collider
  - F es

_d_ quark at large x

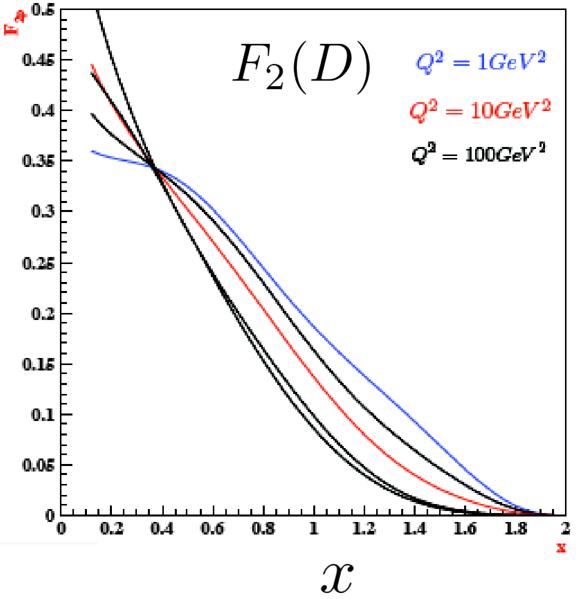
Test of nuclear corrections

Gluon EMC effect

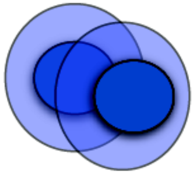
- ☐ Adva
  - Suppress 1/Q power corrections
  - Gluon EMC effect via scaling violation of F_2
    - This may be as revolutionary as original quark EMC effect

Nuclear effects 4 - superfast quarks

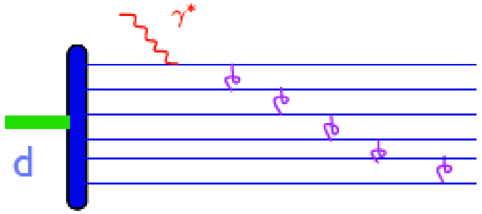
Sargsian et al JPG29 (2003)



- ☐ F2(D) can go to *x* > 1 at large Q2:
  - **“superfast quarks”**
- ☐ Scatter on faster-than-average nucleon
  - Probe short-range *NN* potential

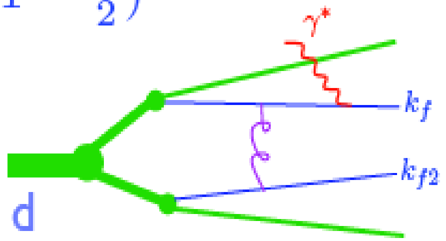


- ☐ Scattering on exotica
  - e.g., 6-quark bags



$$F_{2,(6q)} \sim (1 - \frac{x}{2})^{10}$$

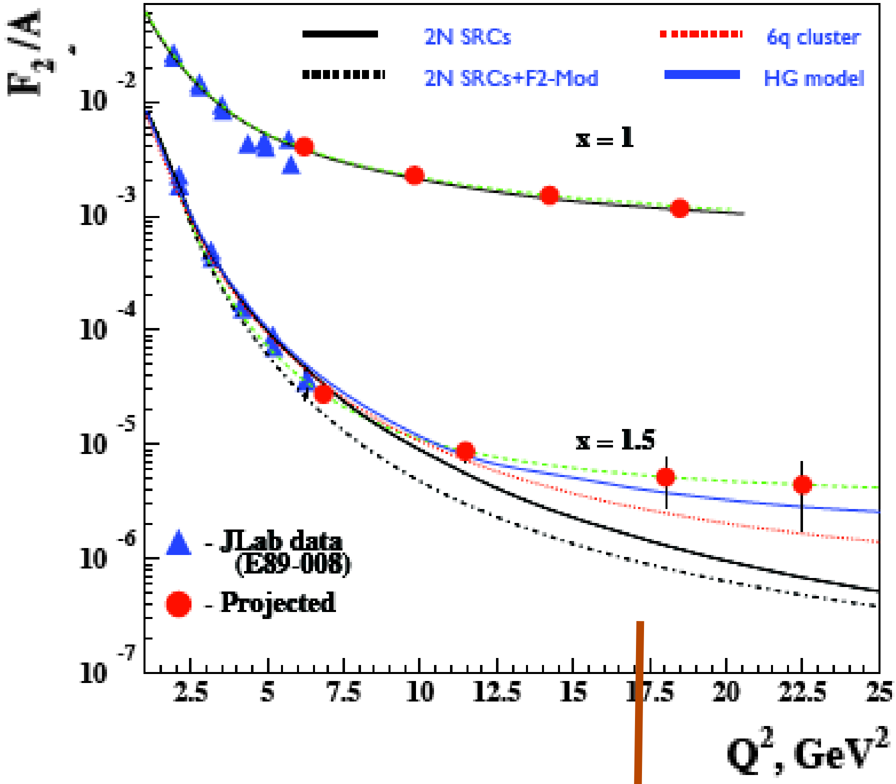
- ☐ Novel QCD mechanisms
  - Hard-gluon exchange?



Nuclear effects 4 - superfast quarks

- **Signatures**

M.Sargsian

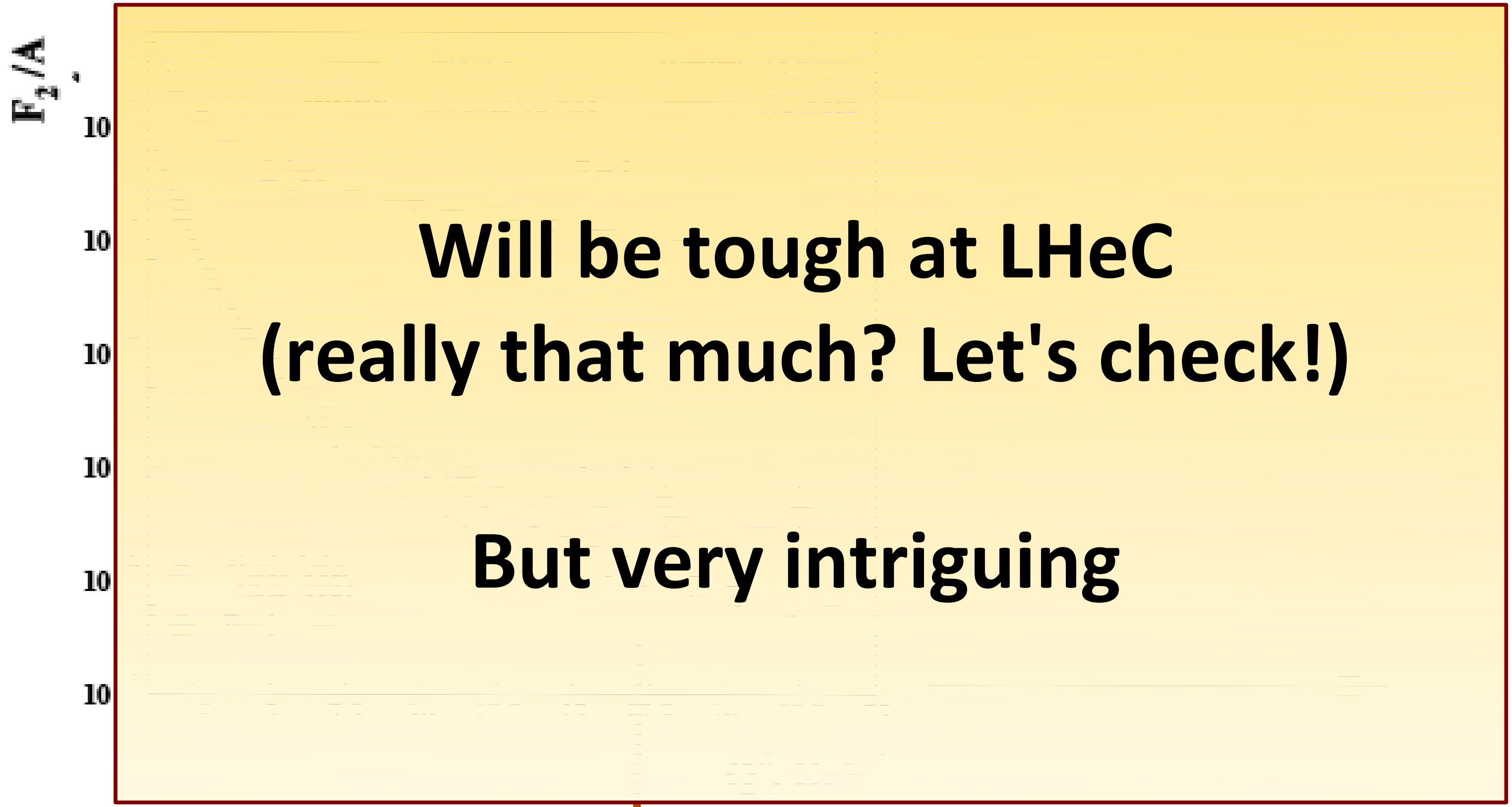


EIC, LHeC:

larger x, larger Q^2

Nuclear effects 4 - superfast quarks

- **Signatures**

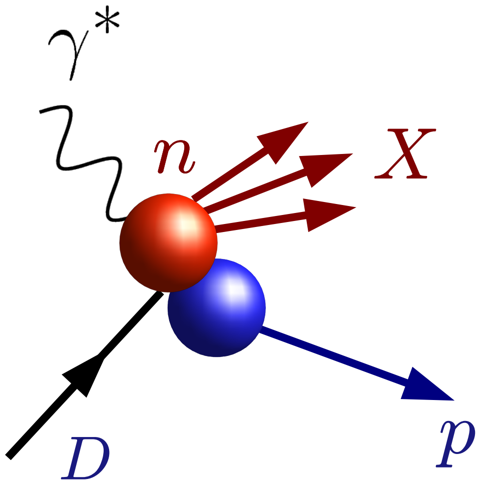


Will be tough at LHeC
(really that much? Let's check!)

But very intriguing

EIC, LHeC:
larger x, larger Q^2

Nucleon tagging



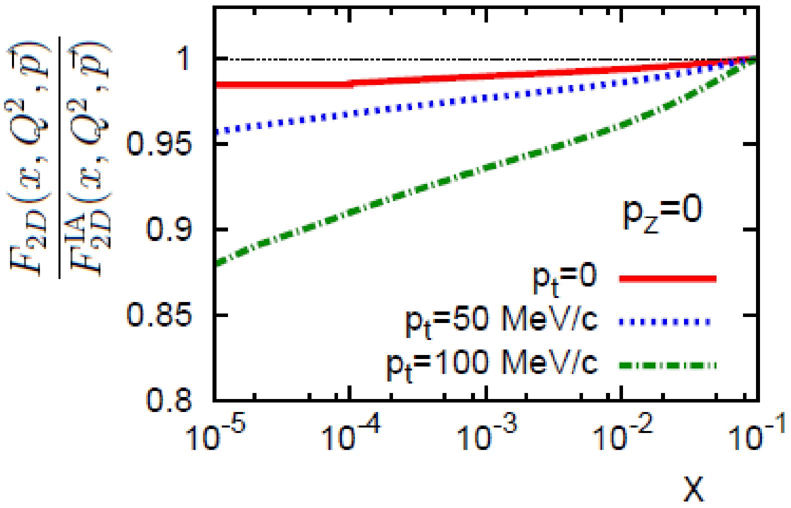
- **Proton tagging: scattering on neutron**

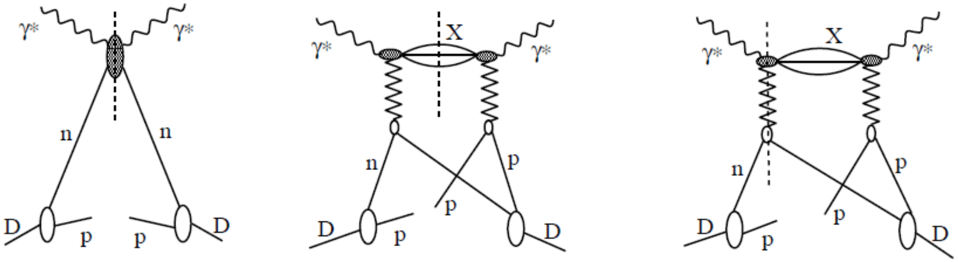
$$F_2 = F_2(x, Q^2, \vec{p})$$

$$\vec{p} = \text{spectator momentum}$$

  - But: shadowing, binding, off-shellness, F. motion...

- **Small x: shadowing corrections**
  - Minimized when $\vec{p} \approx 0$
  - Diffraction on “quasi-free neutrons”



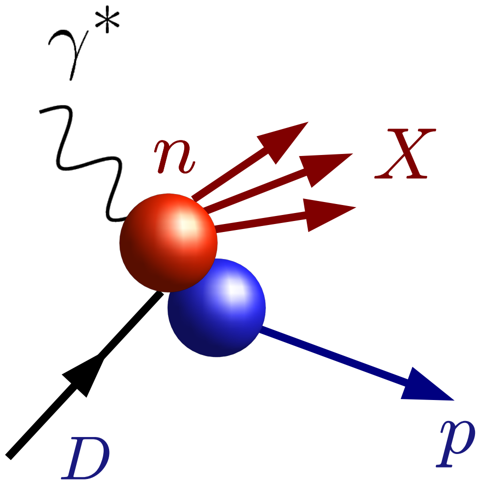


Nucleon tagging

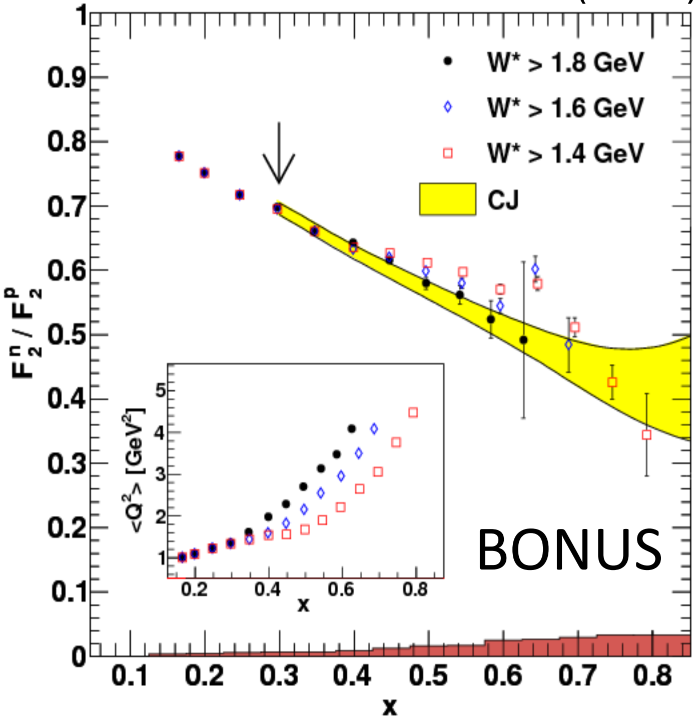
- **Small x: Final State Interactions**
  - Minimized for:
    - Spectators anti-parallel to γ^*
    - Slow protons
  - “quasi-free neutrons”

- Minimizing nuclear w.f. uncertainty
  - Take suitable ratios of F_2

- **Neutron tagging**:
  in-medium modifications
  - By comparing tagged to free protons



Baillie et al. PRL108(2012)



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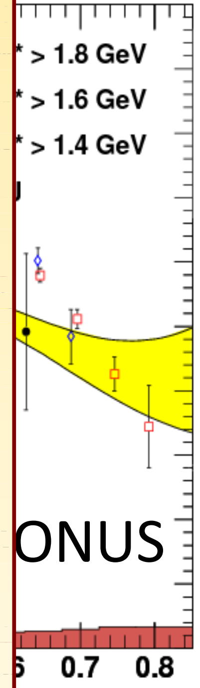
108(2012)



Collider ideal for nucleon tagging, especially neutron

CHALLENGE: good control and resolution of spectator momentum

BUT:

Neutron DIS, diffraction

Baseline for antishad. in *D*

Free vs. bound, off-shell protons

…

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Summary: why deuteron?

- Flavor separation, baseline for nuclear PDF fits
- Nuclear effects from low to high x
  - Verify shadowing calculations, approach to sat., $F_2^D(n)$
  - Bound nucleons without $1/Q^2$ corrections
  - “Superfast quarks”
- Proton/neutron tagging
  - DIS, diffraction on neutrons
  - Free vs. bound, off-shell protons
- Diffraction (not covered in this talk)
  - Coherent, breakup, incoherent