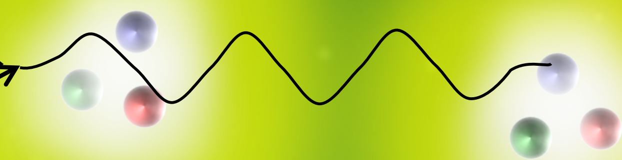
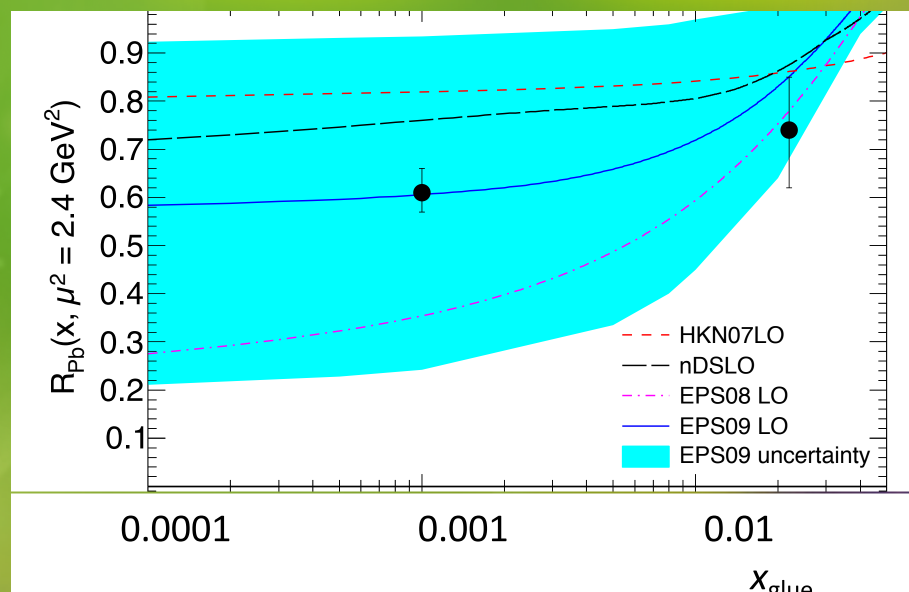
Nuclear Dynamics Probed by DIS: IV

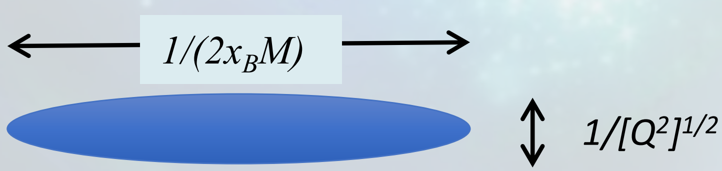
- $x_{Bj} < 0.05$: "Shadowing"
- Coherent diffractive scattering from ≥ 2 nucleons
  - Interference is destructive by virtue of NN antisymmetry
  - NN pair must be in-line
    - Transverse resolution $1/Q^2$ post-selects nuclear state
  - Shadowing is a ~100% effect on the ~10% of DIS events that are diffractive
  - Nuclear gluon suppression observed in LHC ultra-peripheral collisions
    - Photon cloud of forward moving Pb nucleus collides with gluons in backward moving Pb nucleus.

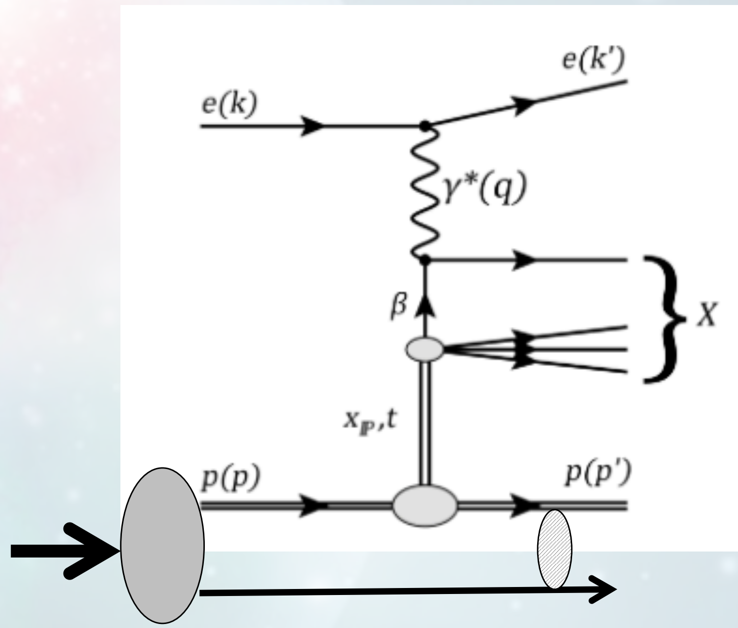




DIS V. Nuclear Initial and Final States in Diffractive DIS: Double spectator tagging

- Incoherent Diffraction: A clean probe of multi-nucleon dynamics.
  - Only low-energy NN, NNN... Final state Interactions
- Event-by-event initial & final state:
  - Elliptical source ≥ 2 nucleons





Color-neutral
$\delta b > 1/[Q^2]^{1/2}$
No FSI!

Destructive Interference: active/spectator in NN pair

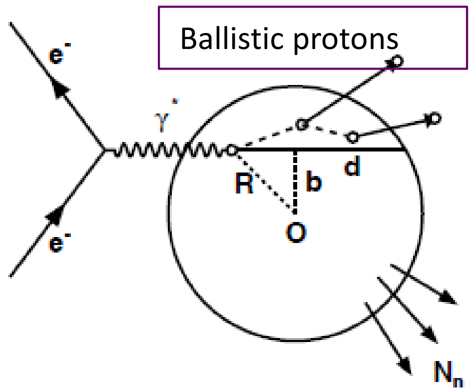
DVES on Deuteron
(V = Vector meson…)

- Coherent *d(e,e'd V)*
  - Tensor polarized beam: Observe quark-gluon structure of tensor interaction.
- Incoherent *d(e,e'pnV)*
  - *Miller, Sievert, Rajugopalan,* [*www.arXiv.org/1512.03111*](http://www.arXiv.org/1512.03111)
  - Low mass NN final state ≈ independent nucleons
  - High mass NN final state → probe quark-gluon distribution of interacting NN pair

MDBaker, ECA, Lee, Zhang eRD17

Zheng, Aschenauer, Lee, EPJA **50**

Geometry tagging (w/o shadowing)

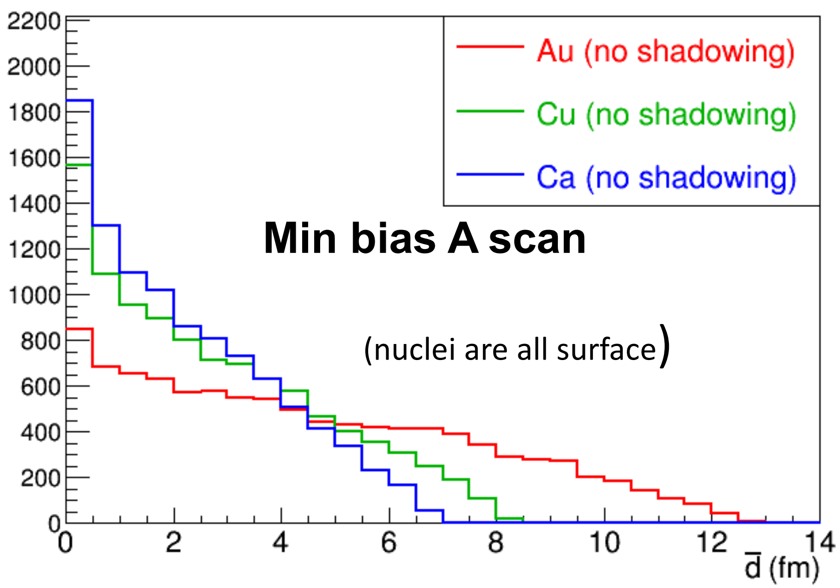


Intra-nuclear cascading increases with d (forward particle production)

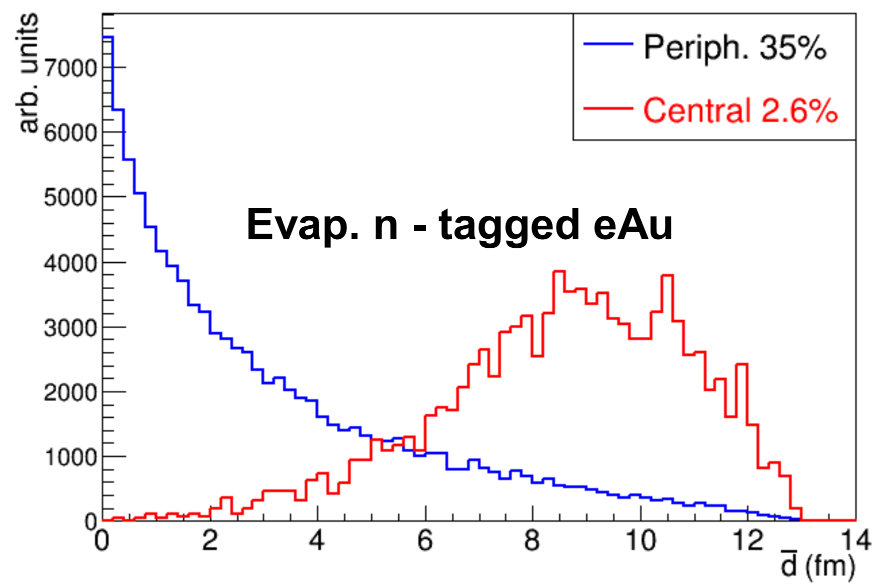
Leads to more evaporation of nucleons from excited nucleus (very forward)

JLab LDRD FY2017 project
Nadel-Turonski, Baker *et al*

Role of ballistic nucleons:
Lappi, Mäntysaari,
R. Venugopalan, PRL **114**



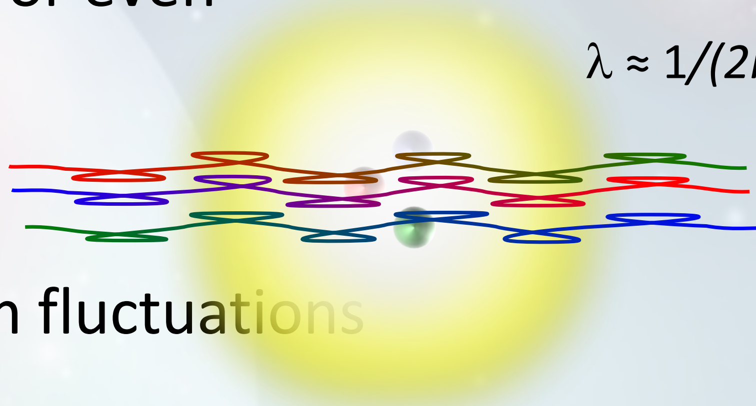
Tagged eAu (samples scaled to same area)

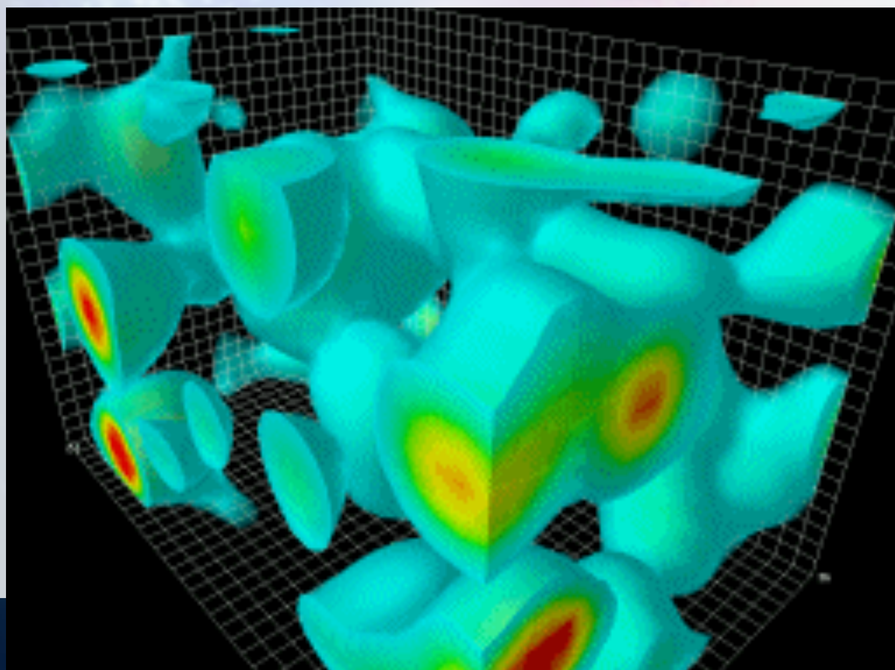


DIS VI. $x_{Bj} \ll 0.1$

- DIS probes fluctuations with coherence length λ much greater than nucleon or even nuclear size.
- Precursor to saturation
- Low energy probes cannot distinguish these from vacuum fluctuations

$\lambda \approx 1/(2Mx_{Bj})$





Animations at

www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/index.html

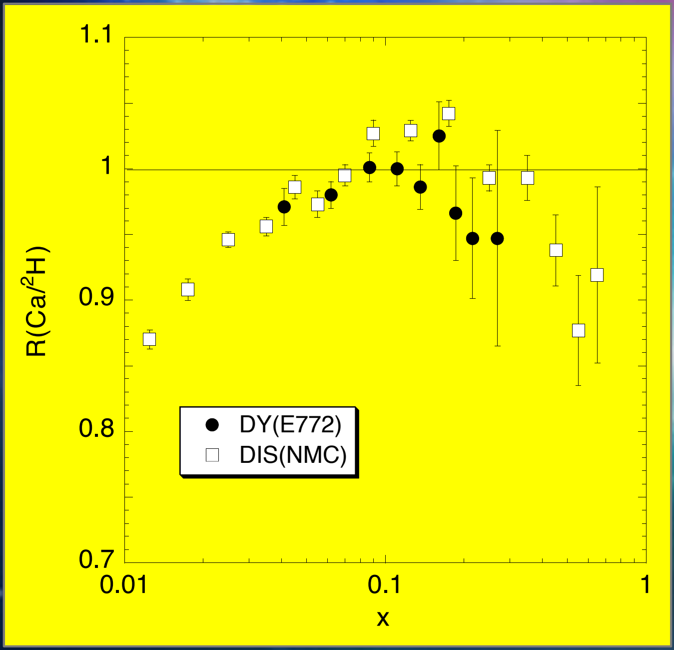
Conclusion

- A High Luminosity Polarized Electron Ion Collider is an unprecedented tool to quantitatively explore the quark-gluon dynamics of
  - the Origin of the Mass of mesons and baryons
  - The Creation of Mass as a quark or gluon propagates through cold QCD matter
    - Vacuum
    - Nucleus
  - Nuclear Binding
    - NN Force
    - NNN Force
- These are exciting, challenging questions.
  - We can make progress
  - These emergent phenomena will resonate with the larger scientific community

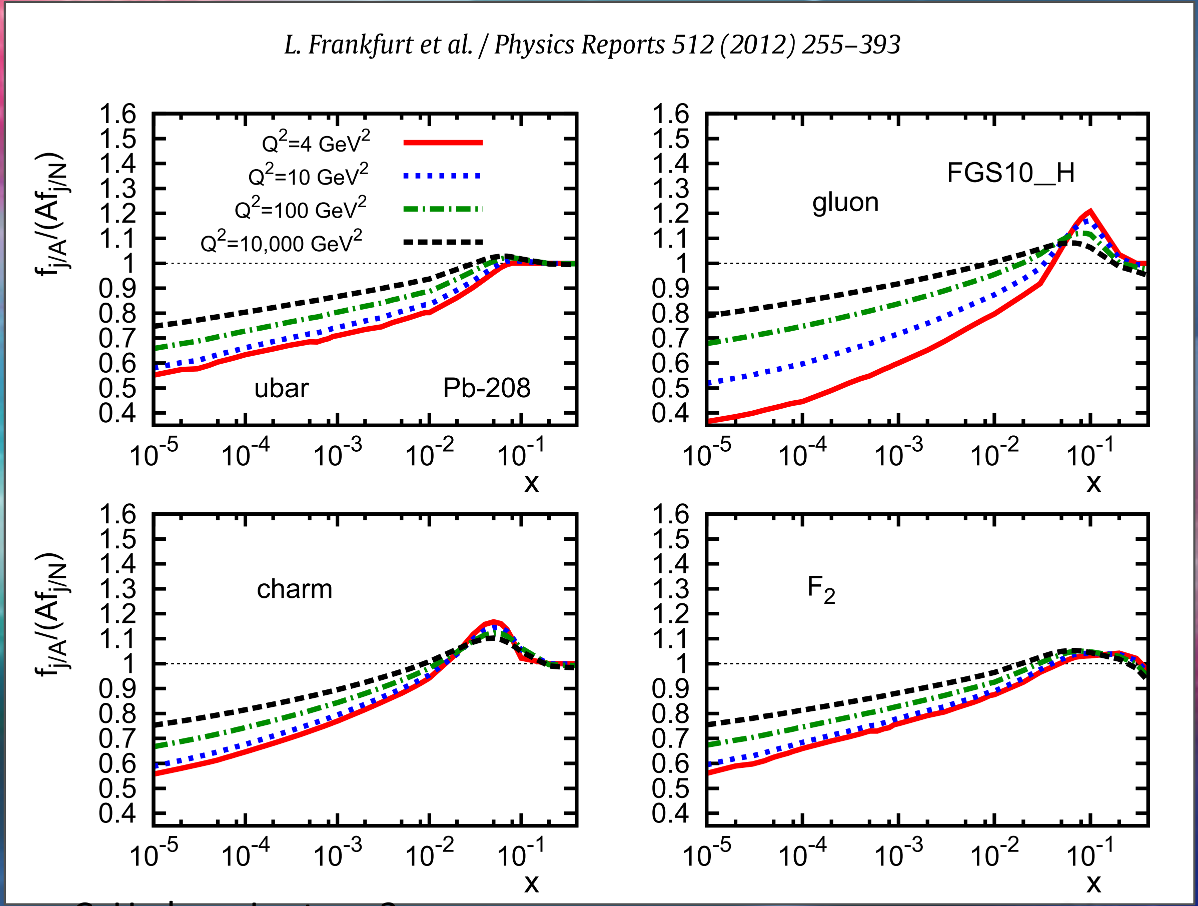
Backup Slides

EMC Effect': Anti-Shadowing

- Anti-shadowing is not anti-quarks! FermiLab Drell-Yan E722



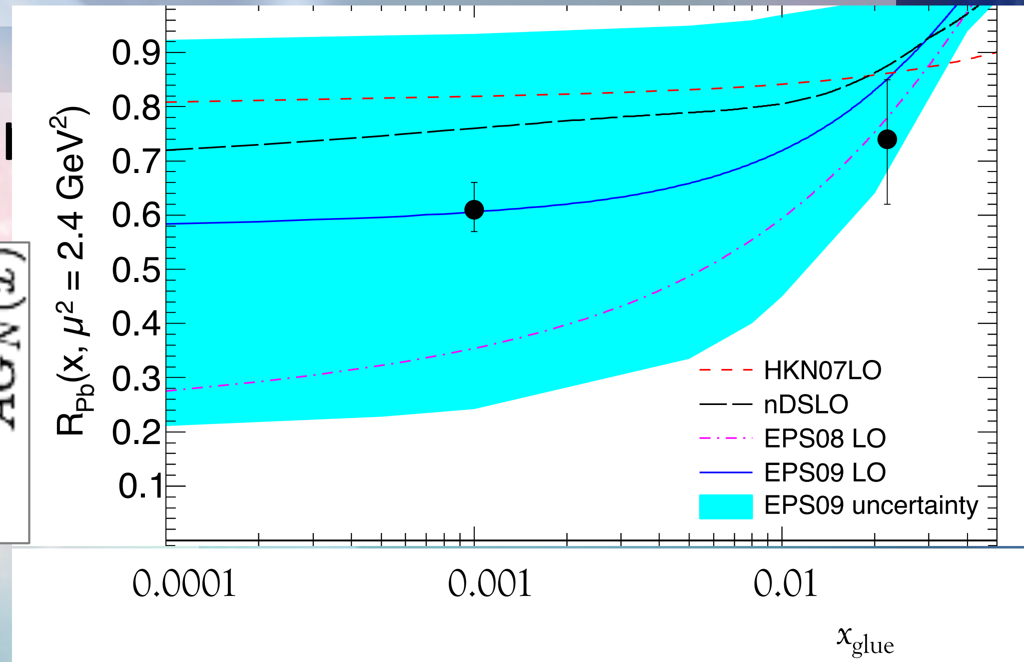
- Anti-shadowing is glue

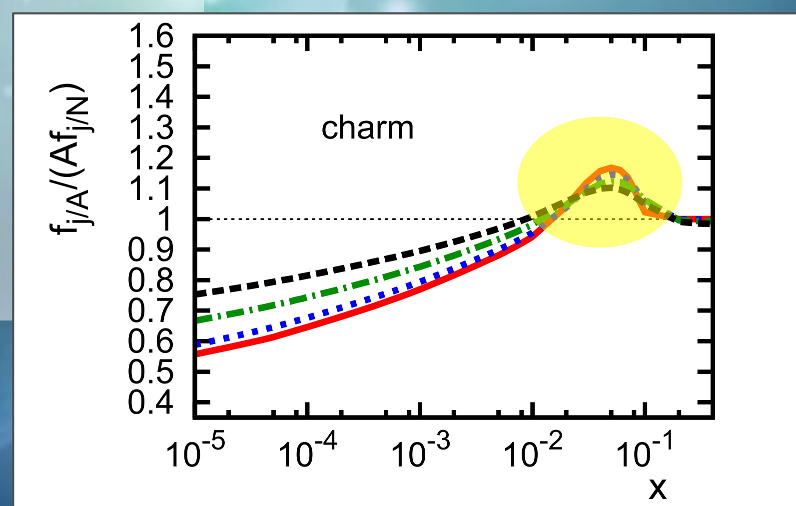


Gluons & Nuclear Binding

- Shadowing (coherent gluo[n] from NN, NNN ...)
  - ALICE PLB**718** (213) ultra-peripheral AA→ AA J/Ψ ...CMS 2016 Fig. from Guzey, Zhalov, arXiv.org/ 1404.6101
  - x = 0.001 — 0.01
- Expectation of gluonic anti-shadowing at $x \approx 0.1$

$$R = \frac{G_A(x)}{A G_N(x)}$$





Spectator Tagging

- Spectator Tagging:

$$p_R = p_p^{\{+,\perp,-\}} = \left[\frac{\alpha}{2}P_D^+, \mathbf{p}_{R\perp}, \frac{M^2}{\alpha P_D^+}\right] \approx P_D^\mu/2$$

- Impulse Approximation:

$$p_n^2 = (P_D - p_R)^2 = t = M_n^2 + t'$$

$$-t' > M_D B + B^2/2 = 4.1 \cdot 10^{-3}\ \mathrm{GeV}^2$$

- In Deuteron rest-frame:

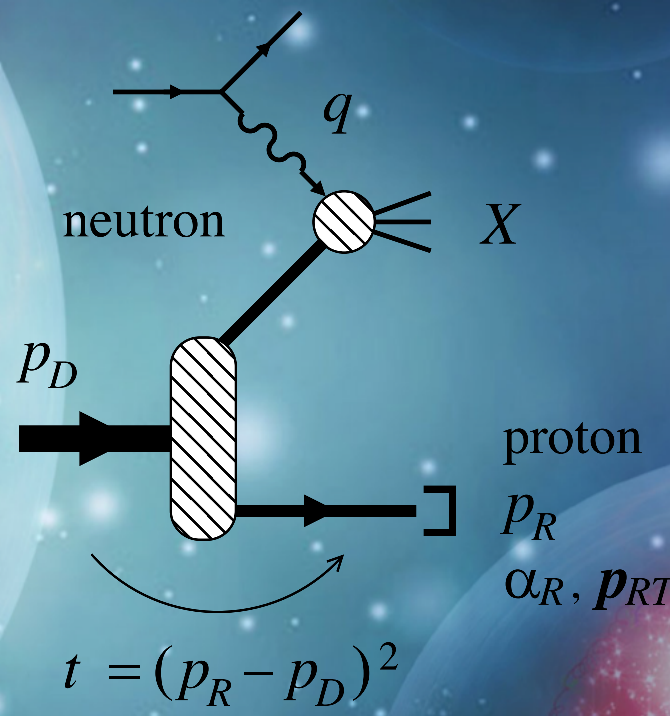
$$\mathbf{p}_p \to \tfrac{(\alpha-1)}{2} M_N \hat{z} + \mathbf{p}_\perp$$

for $\alpha \approx 1$ and $|\mathbf{p}_\perp| << M_N$

- In Collider Frame:

$$\mathbf{p}_p \approx \tfrac{1}{2}\mathbf{P}_D + \mathbf{p}_\perp$$

$$\mathbf{p}_p \approx \tfrac{\alpha}{2}\mathbf{P}_D + \mathbf{p}_\perp$$



On-Shell Extrapolation

- Spectator Tagging in Impulse Approximation:

$$p_n^2 = (P_D - p_R)^2 = t = M_n^2 + t'$$

$$-t' > M_D B + B^2/2 = 4.1 \cdot 10^{-3}\ \text{GeV}^2$$

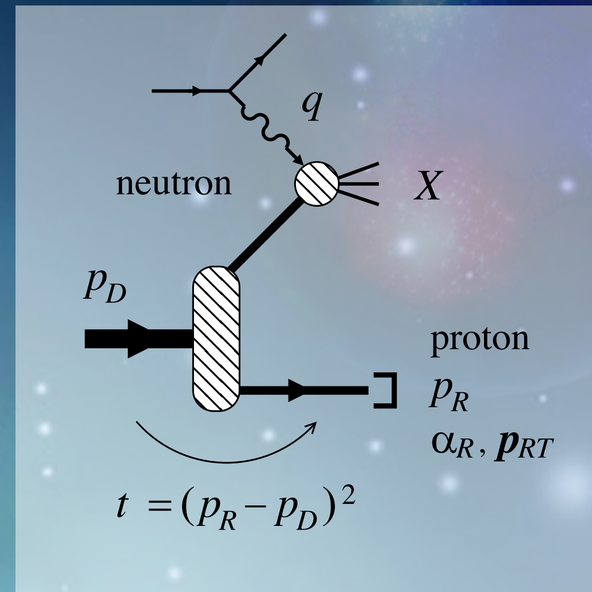
- Example on-shell extrapolation

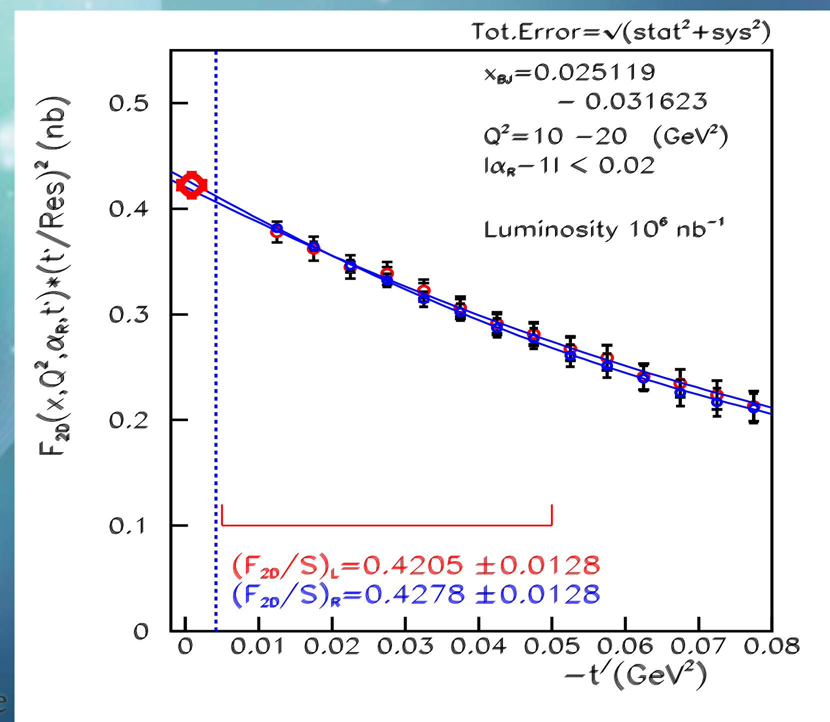
$$k_e \otimes P_D = 5 \otimes 100\ (\text{GeV/c})^2$$

$$\int \mathcal{L} dt = 1\,/\,\text{fb}$$

$$x_{\text{Bj}} \in [0.025, 0.032],\ \ Q^2 \in [10, 20]\ \text{GeV}^2$$

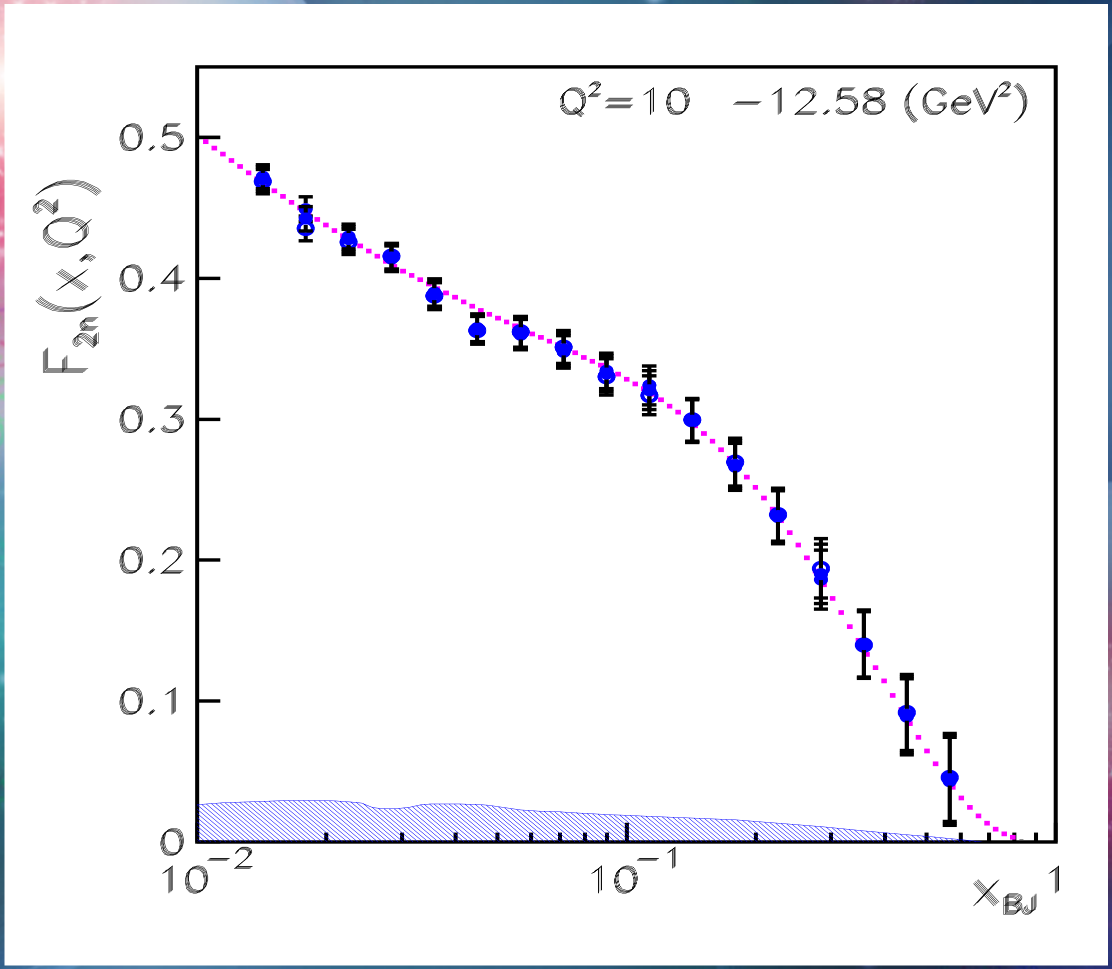
$0.98 \leq \alpha < 1$ $\quad$ $1.0 < \alpha \leq 1.02$





Neutron F_2 from on-shell Extrapolation

- A sample bin in Q^2
  - Error bars are statistical
  - Error band is systematic error from assumed 10% uncertainty in incident beam emittance
- Radiative effects not yet included.
- QCD Evolution not yet included.



Neutron Spin Structure

Longitudinal Double Spin Asymmetry on the Neutron

x-dependence at fixed Q^2 — Q^2-dependence at fixed *x*