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SPIN PHYSICS AT THE ELECTRON ION COLLIDER:

THE JLEIC DETECTOR CONCEPT

Charles E. Hyde

Old Dominion University

Norfolk VA

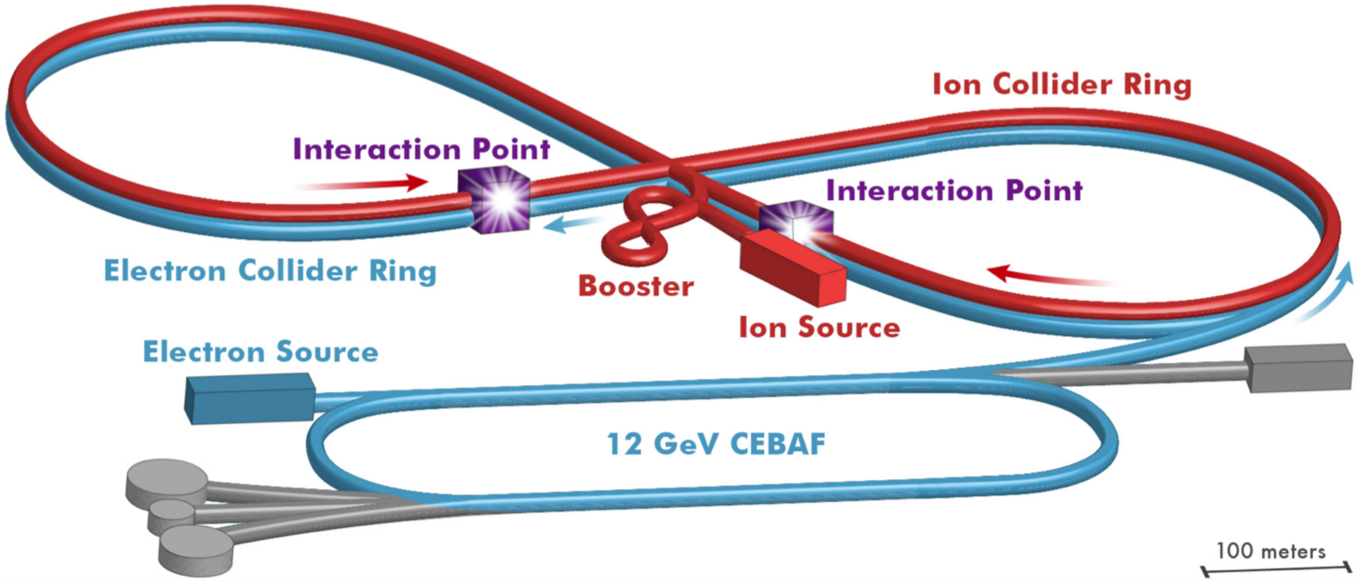
chyde@odu.edu

EIC @ Jefferson Lab

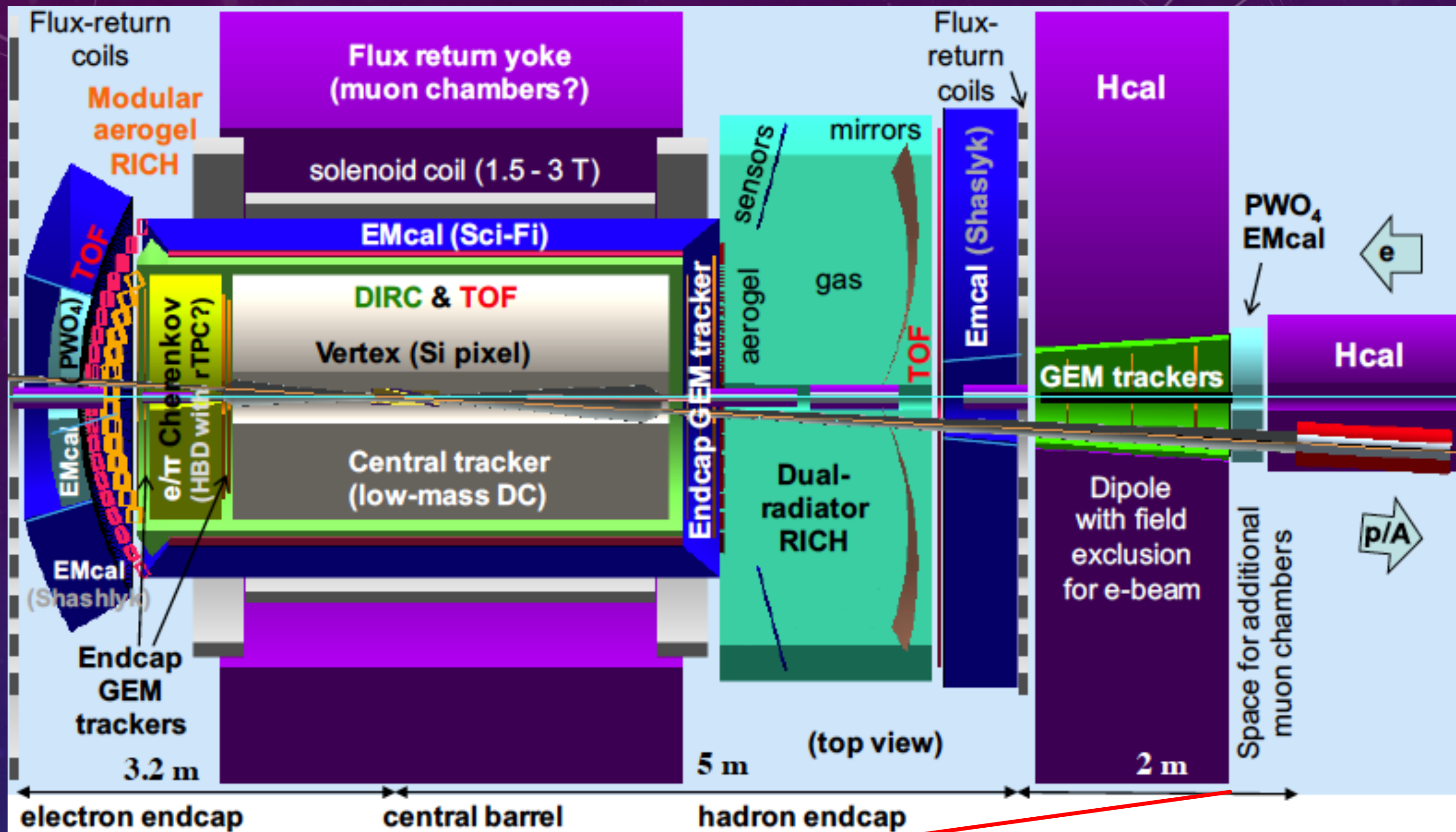
3-10 GeV $e^{-} \otimes$ $Z\bullet(20\text{-}100\ GeV/c)$ ions

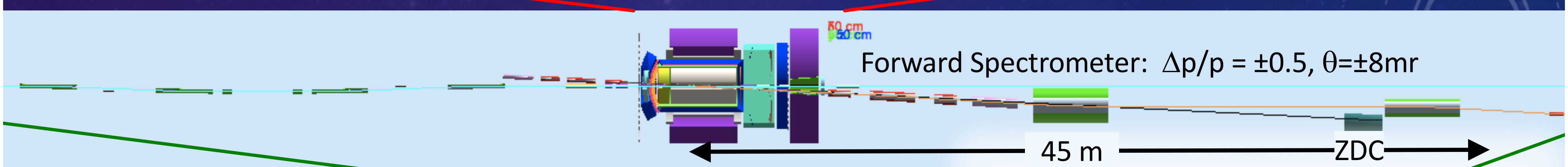
Longitudinal and Transverse Polarized

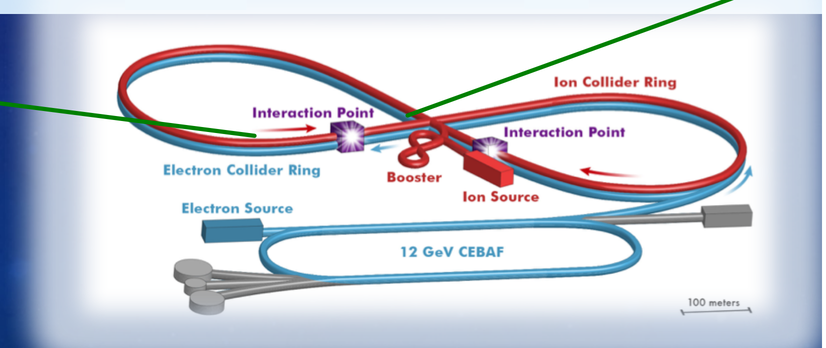
p, d, ^{3}He, ^{7}Li, … Tensor polarized *d*



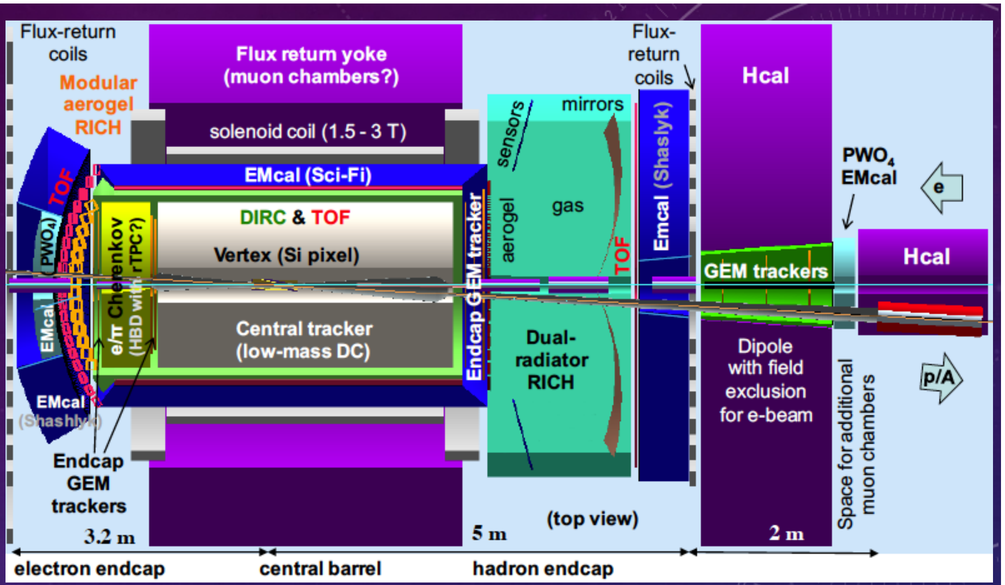
JLEIC Full Acceptance Detector





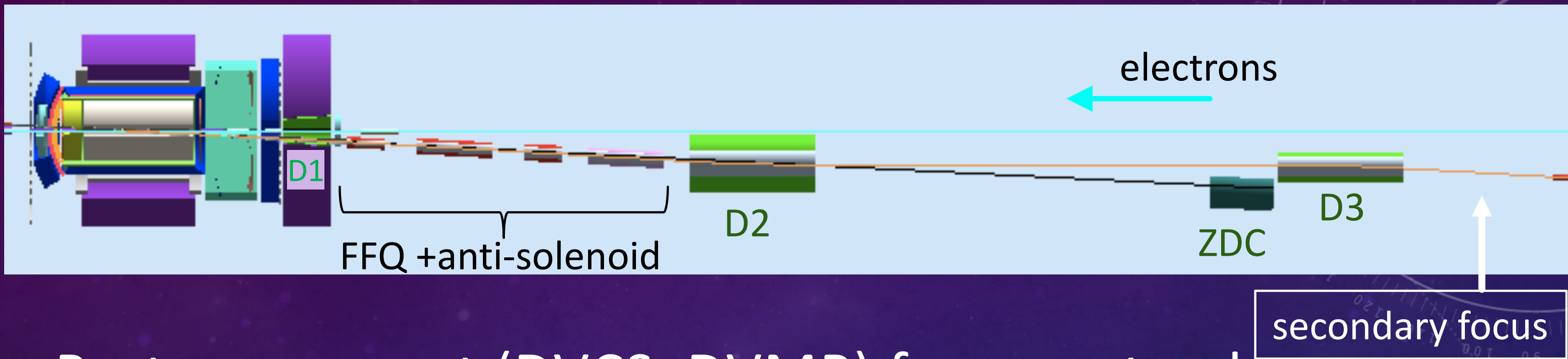


Particle I.D.
Central Detector



- Electron Endcap: (p < 10 GeV)
  - *e/π:* EMCal ($PbWO_4$, Shashlyk) ⊗ Hadron Blind (Cherenkov)
  - *π/K/p:* Modular Aerogel RICH (mRICH) ⊕ TOF
- Barrel Region:
  - *e/π:* EMCal (Shashlyk or SciFi) ⊗ DIRC (0.7—1.0 GeV/c)
  - *π/K: DIRC (p < 6 GeV/c…R&D)* ⊗ *TOF (80 ps, p ≤ 1.5 GeV/c)*
- *Ion Endcap*
  - *π/K: TOF (p<2.4 GeV)* ⊗ *Dual (Aerogel/Gas) RICH (p<50 GeV/c)*
  - *e/γ/μ/π: EMCal (Shashlyk)* ⊗ *HCal*

Ion-Downstream Spectrometer & ZDC

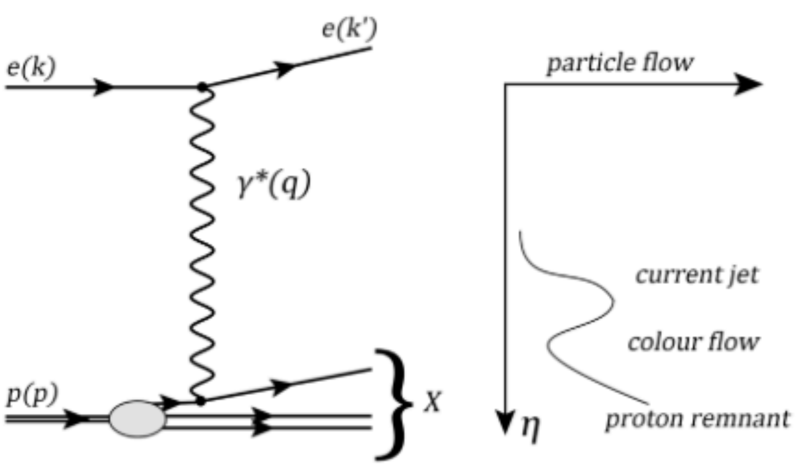


- Proton remnant (DVCS, DVMP) from proton beam
  - Focus at IP+45 m
    - Dispersion ~ 1m/100%, Magnification ~ –0.5
    - 300µm resolution → $\sigma(p)/p = 3 \bullet 10^{-4}$ = Beam rms
    - 300µm resolution over 2m → $\sigma(\theta_{IP}) = 0.3$ mrad = Beam rms
  - FFQ acceptance (6T pole field) ~± 8 mrad
- Neutron remnant, ZDC acceptance ± 10mrad
  - High performance HCal:
    - $\sigma(E)/E$ ~30%[1 GeV/E]$^{1/2}$, $\sigma(\theta) < 0.3$mrad

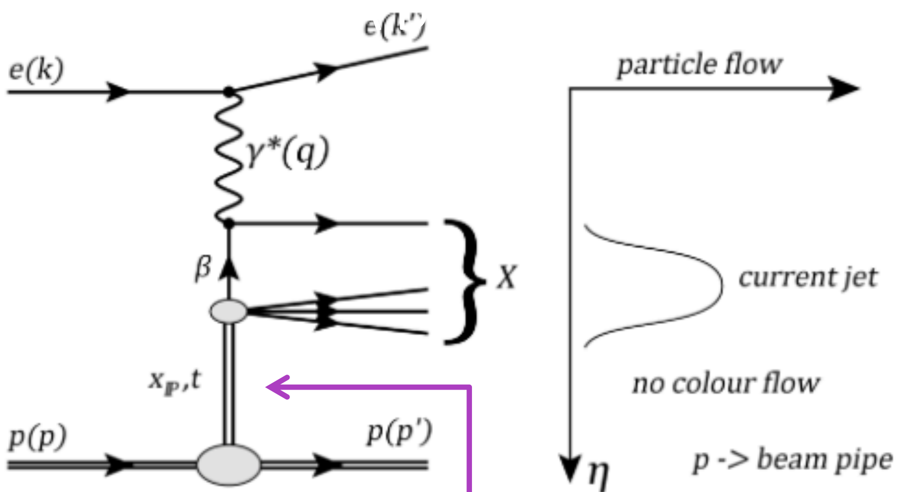
Final States:

DIS → Diffractive DIS → Deep Virtual Exclusive Scattering

Deep Inelastic Scattering (DIS)



Diffractive Scattering (DDIS)



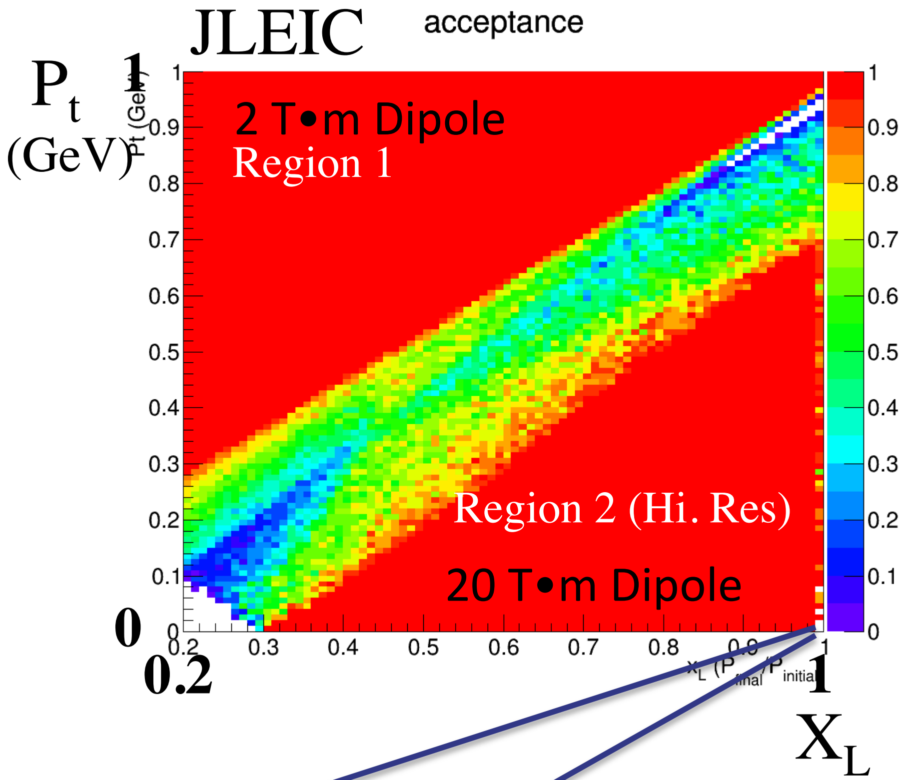
Rapidity Gap: Δη ≥ 2

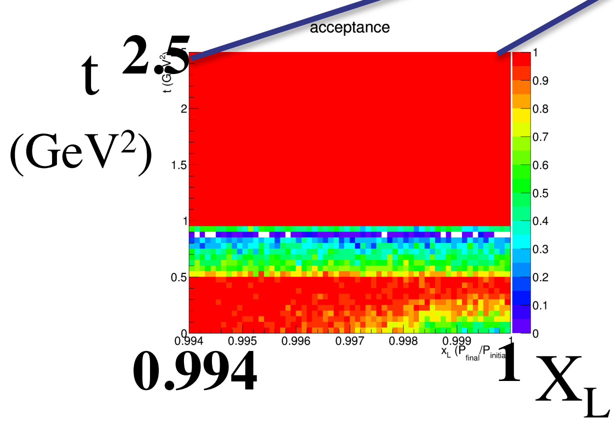
Proton Remnant:

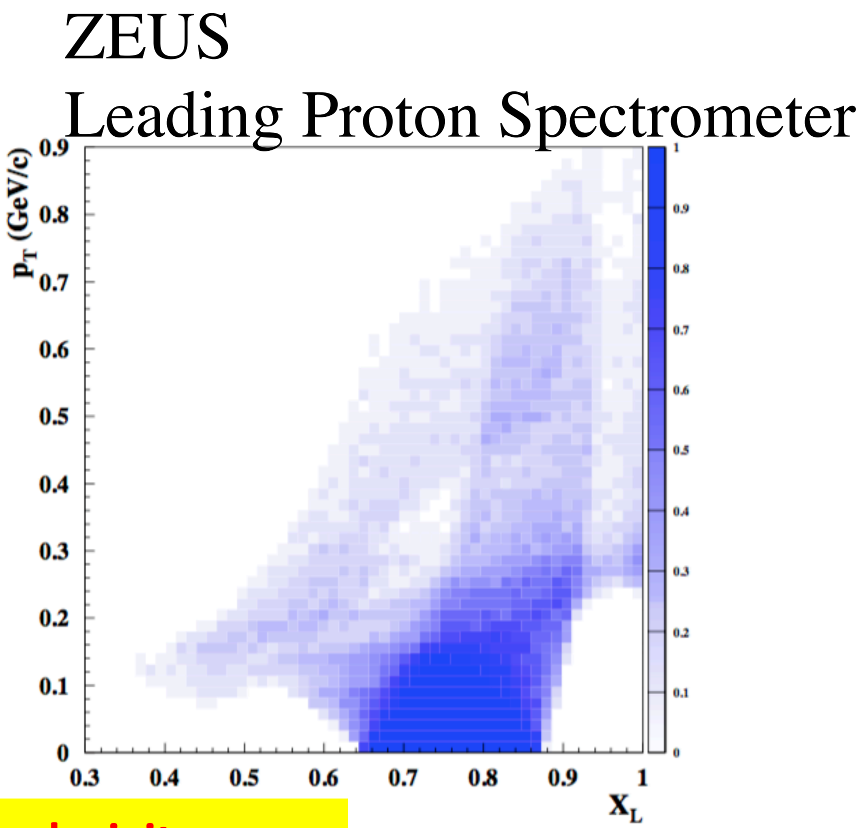
- Di-quark/ tetra-quark color triplet
- Color octet

~10% of HERA events

Acceptance for p' in DDIS







Tagging essential for exclusivity

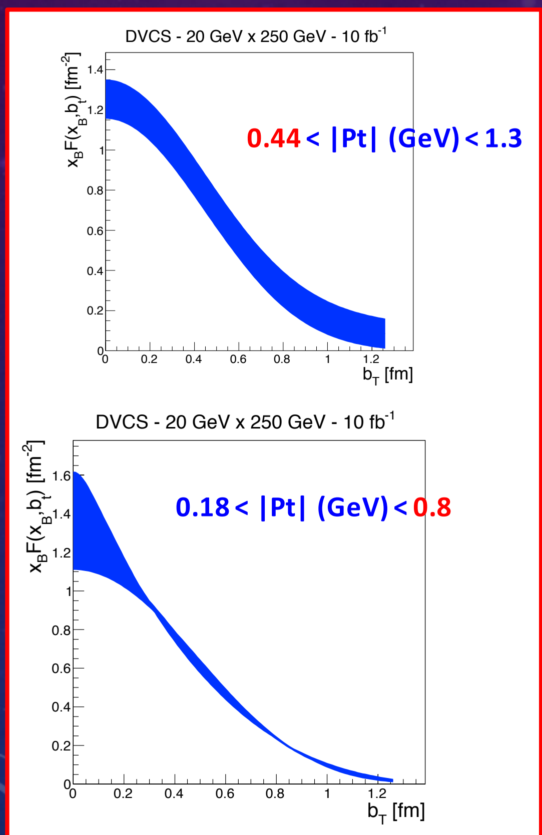
Acceptance in diffractive peak (X_L>~.98)

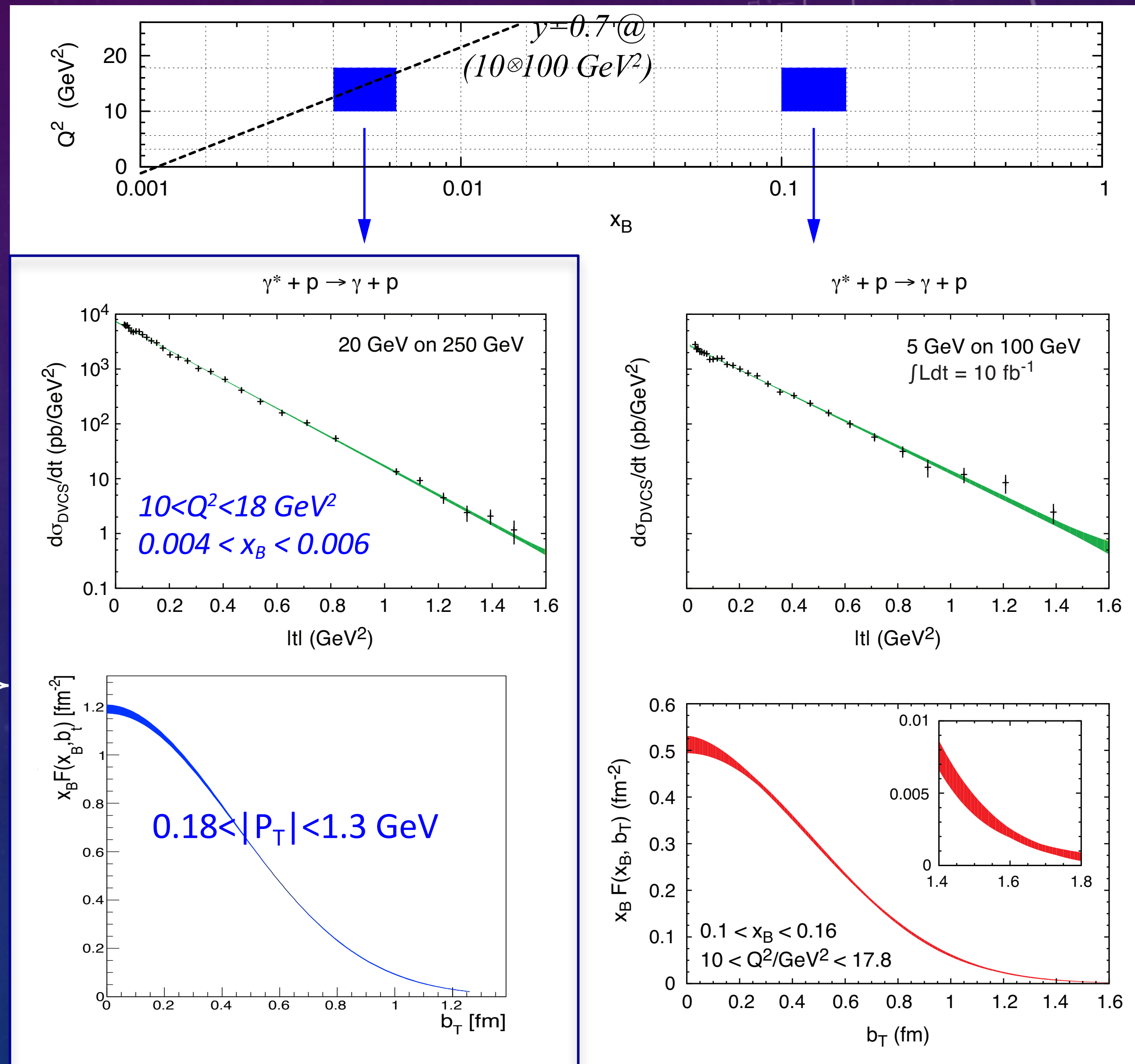
ZEUS: ~2%

JLEIC: ~100%

Deep Virtual Exclusive Scattering Transverse Spatial Imaging *vs.* x_{Bj}

- Detector Acceptance
  - eRHIC: new IR design: $0.18 \le p_T$
  - JLEIC: Far-Forward spectr. $0.0 \le p_T$ for $x_{Bj} > 0.003$





Nuclear DIS Final State with an EIC

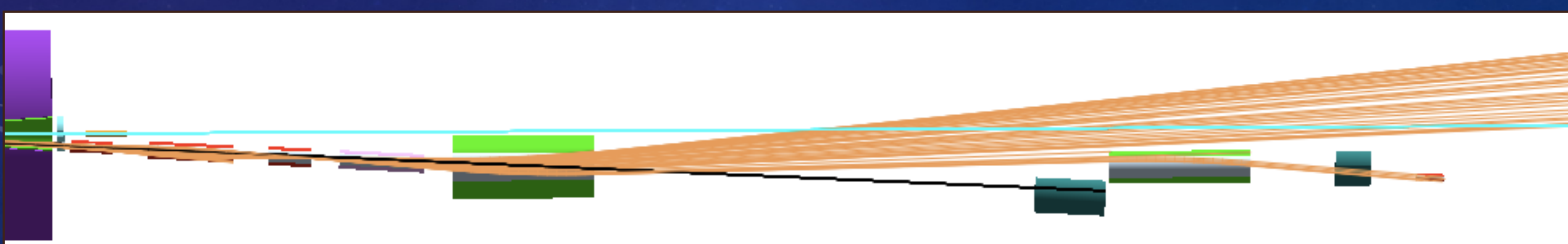
- Naïve spectator kinematics:

$$p_i^{[+,T,-]} = \left[\frac{\alpha_i}{A}P_A^+, \mathbf{p}_{i,T}, p_i^-\right]$$

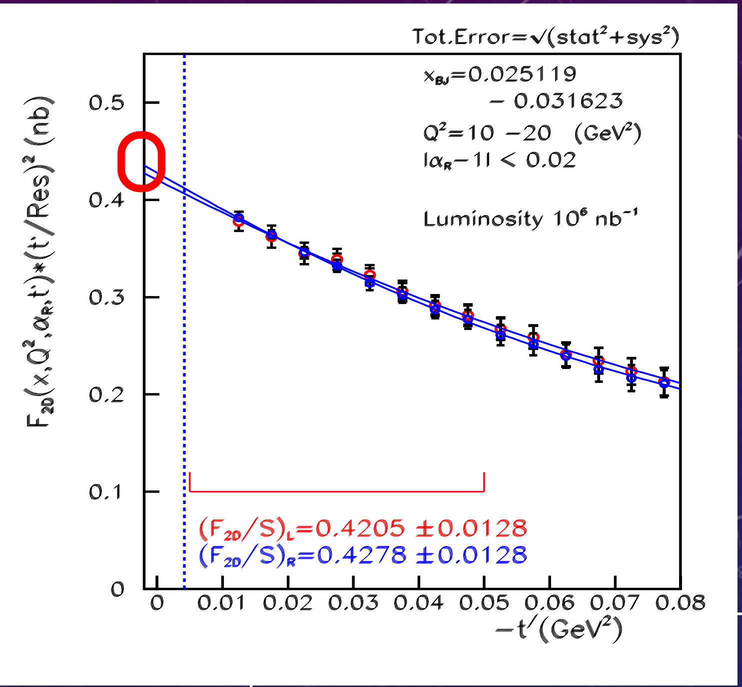
$$p_i^- = \frac{M^2 + \mathbf{p}_{i,T}^2}{2\alpha_i P_A^+/A}$$

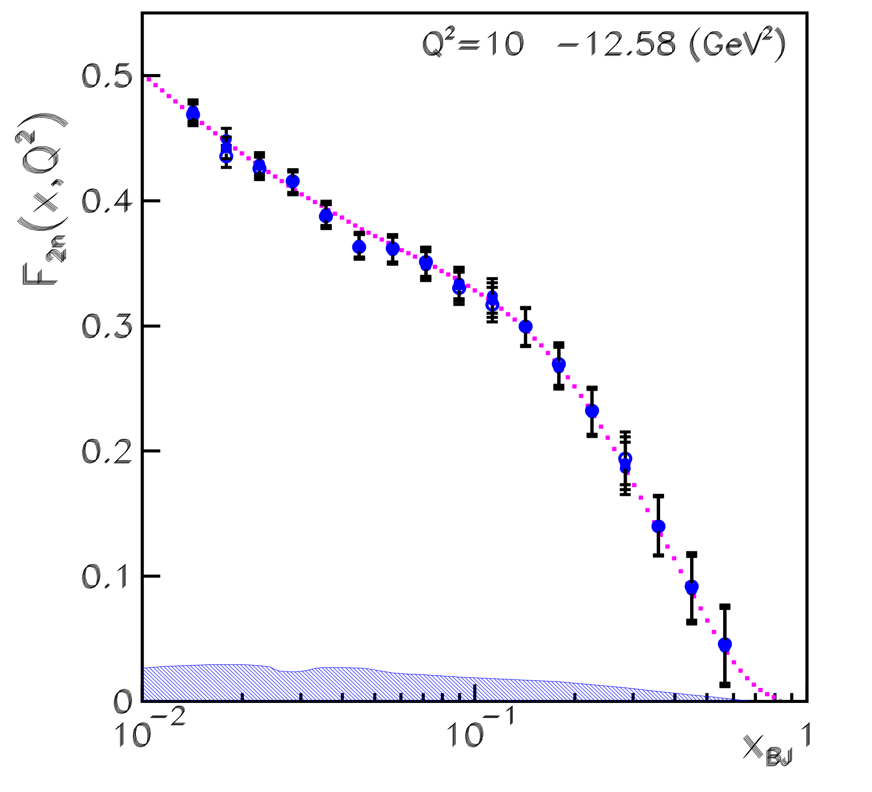
$$\sum_{i=1}^{A} \alpha_i = A, \qquad \sum_{i=1}^{A} \mathbf{p}_{i,T} = 0$$

- Fermi gas: $|\alpha_i - 1| \gtrsim p_F/M \approx 0.25$ $\qquad \mathbf{p}_{i,T} \leq p_F$
- In a deuteron of momentum *100 GeV/c,* spectator neutron or proton has laboratory momenta $(p_{||}, p_T) \approx [\alpha_i(50\ GeV/c),\ \mathbf{p}_{i,T}]$
    - Proton Spectator Forward Tagging!



$F_{2n}(x_B,Q^2)$ from Proton Spectator-Tagging on the Deuteron



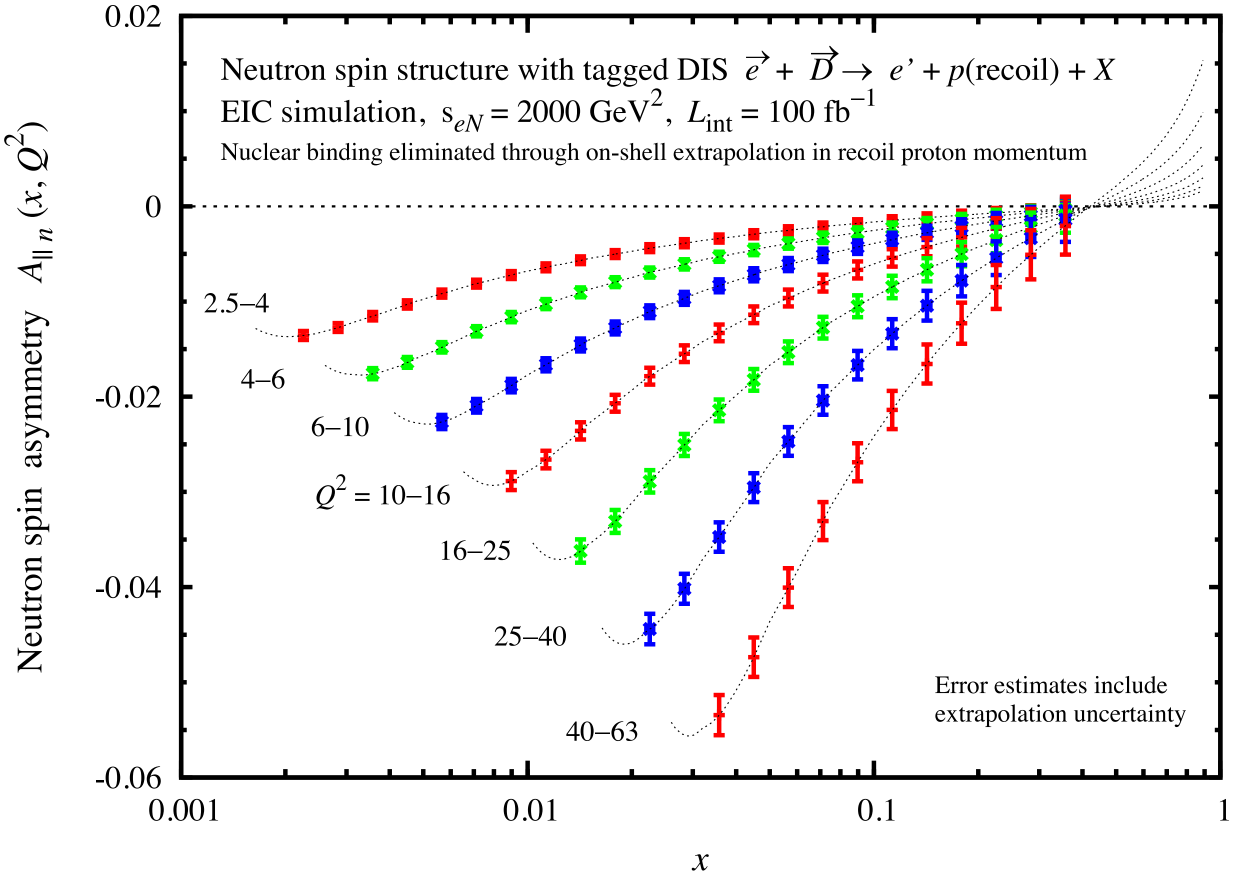


- $-t' = M_n^2-(P_D-p_S)^2$
  $-t' > 2MB_D + B_D^2$
  $-t' > 0.004\ GeV^2$

- Statistical Errors and systematic band from beam smearing
- Radiative effects not included

Neutron Spin Structure Functions: $\vec{d}(\vec{e},e'p_S)\,X$

- Statistical & Systematic Errors from On-Shell Extrapolation



$$A_{\parallel n} = \frac{\sigma(+-) - \sigma(++)}{\sigma(+-) + \sigma(++)}$$

$$= D\,\frac{g_1}{F_1} + \ldots$$

$$D = \frac{y(2-y)}{2 - 2y + y^2}$$

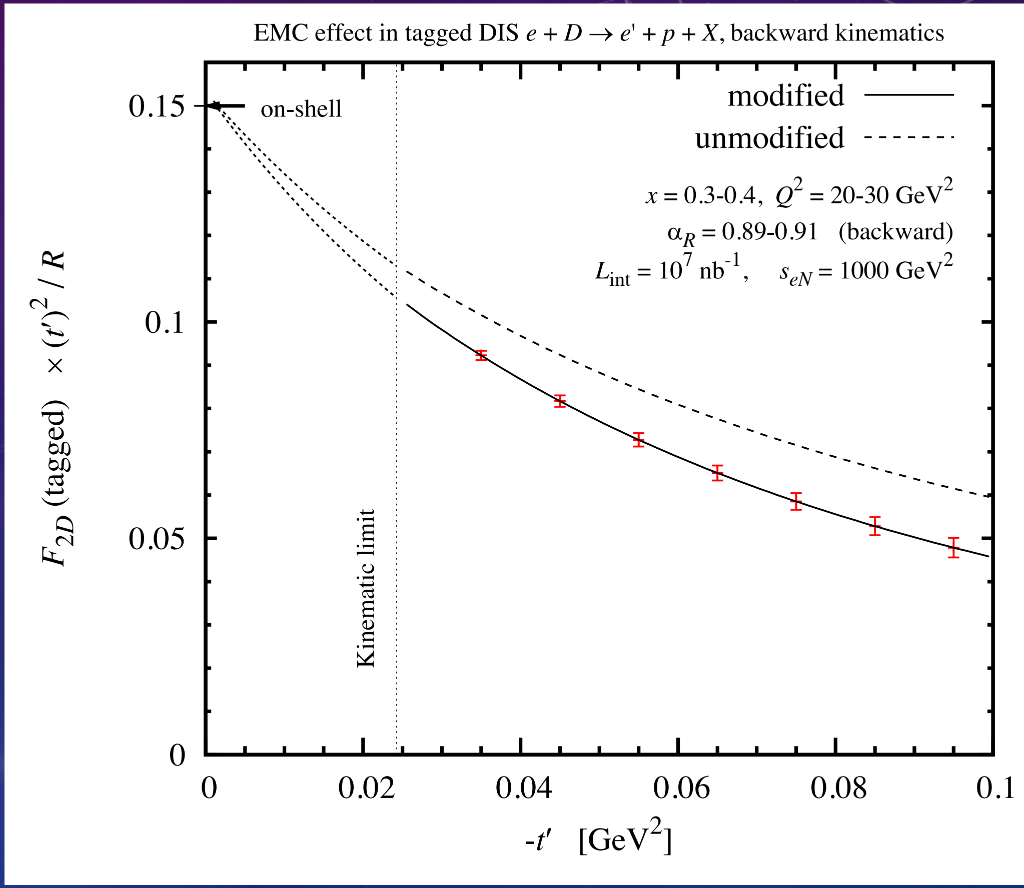
depolarization factor

$$y = \frac{Q^2}{x s_{eN}}$$

The EMC Effect in the Deuteron

In a given bin in *(x_{Bj}, Q^2)*:

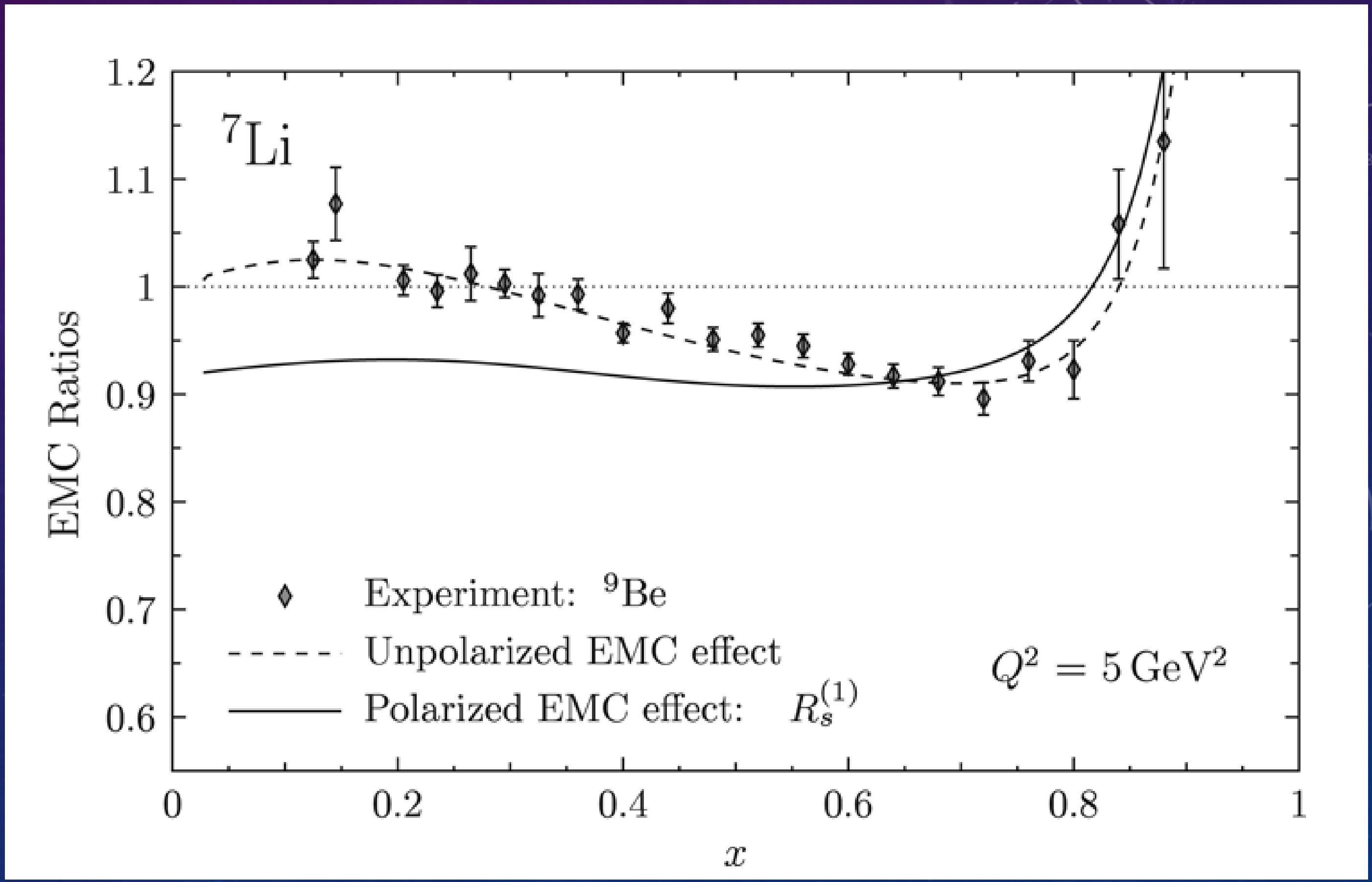
- First extrapolate to the on-shell point with data $\alpha \approx 1$
- Compare IA (dashed) with pseudo- data (solid) at 'large' negative $\alpha - 1$
  - $\alpha < 1$ minimizes FSI
  - EMC Effect modeled via t'-dependent form factor
- Illustrated Luminosity is 10 / fb



Polarized EMC Effect

I. Cloet, et al, PLB **642** (2006)210

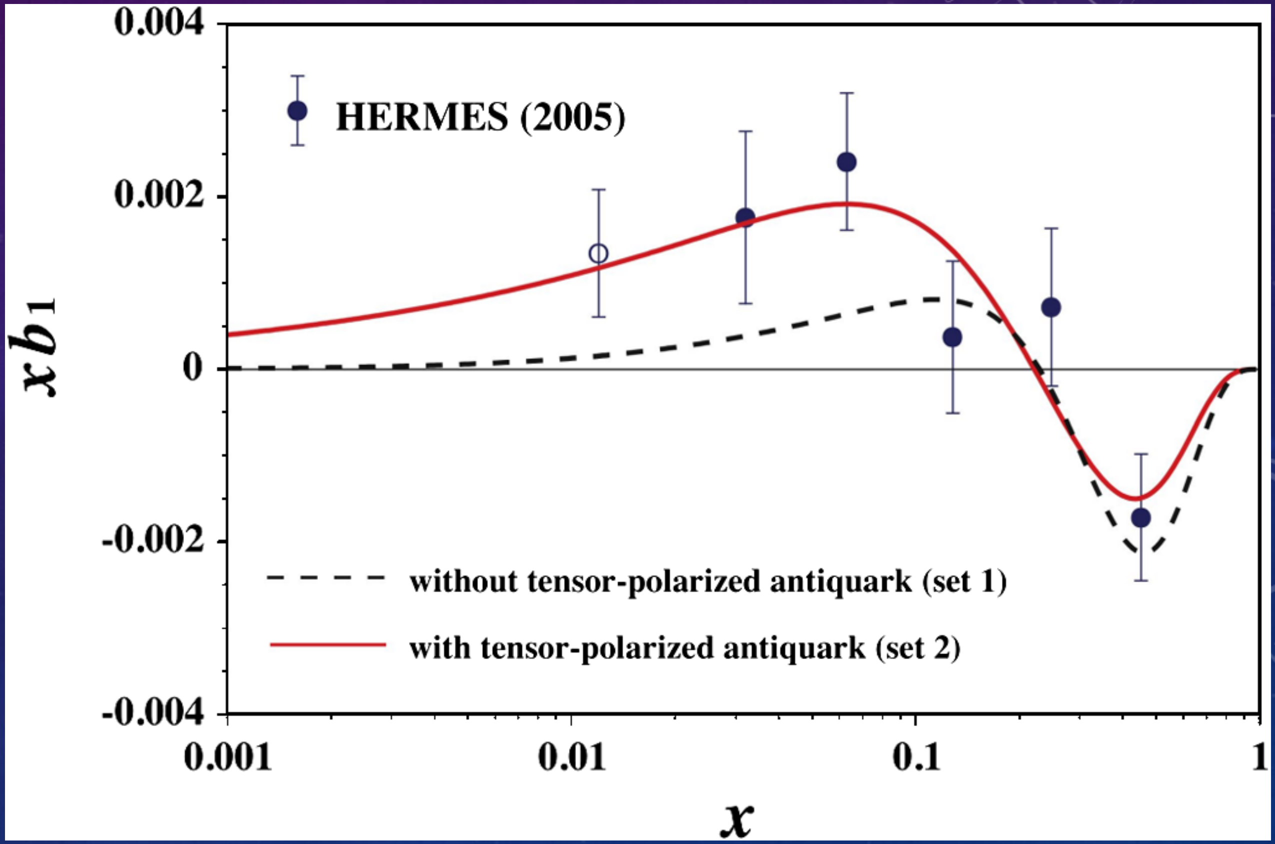
- $g_{1p}^{\text{in Medium}} / g_{1p}^{\text{Free}}$



Deuteron Tensor Polarization in DIS

- Quark–Anti-quark–gluon structure of the NN tensor force

- HERMES data
- Theory: S. Kumano, PRD **82** 017501



DVES on Deuteron

- 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 spatial size of interacting pair

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 and spin of mesons and baryons
  - The creation of mass as a quark or gluon propagates through cold QCD matter
    - Vacuum
    - Nucleus
  - Spin Isospin dependence of Nuclear Binding
    - NN Force
    - NNN Force?
- These are exciting, challenging questions.
  - We can make progress
  - This will resonate with the larger scientific community

BACKUP SLIDES

JLEIC IP Beamline Optics Design

- Full Conceptual Design
  (field profiles, physical dimensions):
  - Final focus Quad blocks,
  - (electron, ion), (upstream, downstream)
  - Solenoid (with fringe field)
  - Large ion-downstream dipole (D2)
- Design in process:
  - Small (6 mrad) ion-downstream dipole (D1) and electron-beam flux exclusion

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:

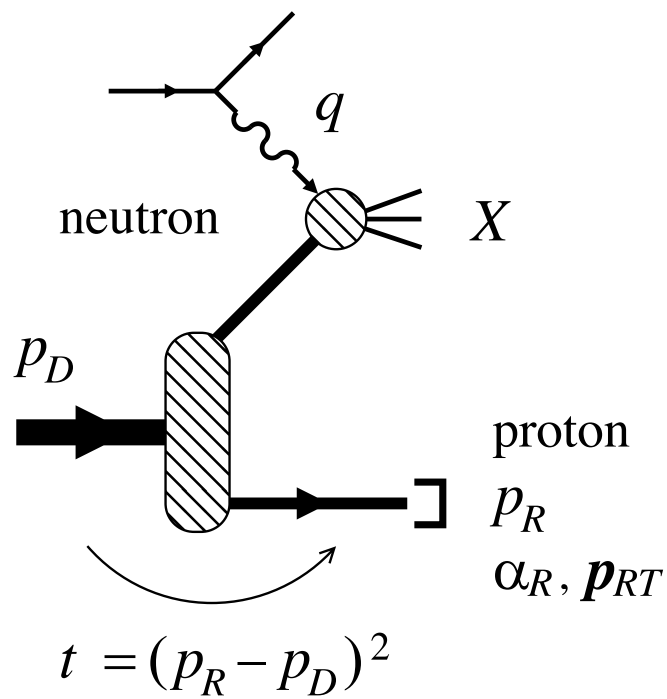
$$\mathbf{p}_p \to \frac{(\alpha-1)}{2} M_N \hat{z} + \mathbf{p}_\perp$$

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

- In Collider Frame:

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

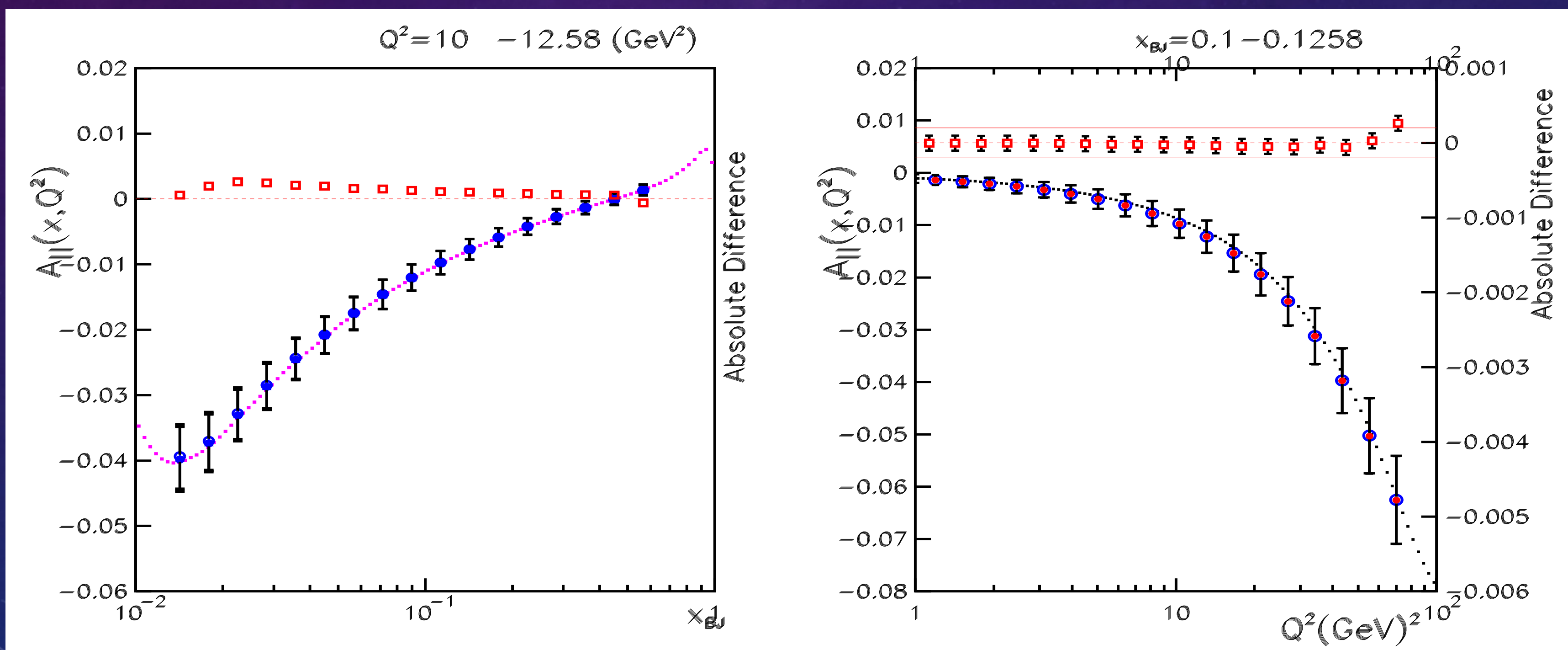
$$\mathbf{p}_p \approx \tfrac{\alpha}{2}\mathbf{P}_D + \mathbf{p}_\perp$$



Neutron Spin Structure

- Longitudinal Double Spin Asymmetry on the Neutron

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



Spin & Particle ID:

- Semi Inclusive DIS (SIDIS):
  - Flavor tagging in EIC covers a wide range in *(x_B, Q^2, z, k_T, ϕ_S)*
  - 3-D momentum imaging (TMDs), Transversity, Tensor Charge…
  - $K_S^0 \rightarrow \pi^+\pi^-$ i.d. from vertex tracker, with forward boost
- Diffractive DIS: Forward tagging of diffracted beam
- Exclusive processes:
  - p(e,e'γ p), p(e,e'V p), p(e,e'π^+n), p(e,e'K^+ *Λ*), p(e,e' K_S^0 Σ^+)
  - Longitudinal and transverse polarized ion beams:
    - Separate Vector *H, E,* Axial *Ȟ, Ế* Compton Form Factors
  - Meson flavor & spin → vector/axial and flavor/gluon