# Physics with a low/medium energy EIC

C. Weiss (JLab), DIS2009 Future Facilities, 28–Apr–09
with R. Ent, T. Horn, Ch. Hyde, P. Turonski + JLab CASA group

- Several key issues in nucleon structure require/favor kinematics $x \sim 10^{-1}$, $Q^2 \leq 20 - 30\,\text{GeV}^2$
  - Transverse imaging of nucleon with GPDs
  - Orbital angular momentum $L_q$ and $\boldsymbol{p}_T$ dependence
  - Flavor decomposition in semi-inclusive DIS

- What collider energies do we need to address them?
  - CM energy, luminosity
  - Detectability: Angular distributions, particle ID, energy resolution ←

- New high–luminosity medium–energy EIC concept at JLab

  $\mathcal{L} = \text{few} \times 10^{34}\,\text{cm}^{-2}\,\text{s}^{-1}, \quad E_e/E_p = 5/30 - 60\,\text{GeV}$

# Context

- Traditional EIC assumption: Common machine
  for small–$x$ physics and nucleon structure

- Recently: Detailed process simulations, emerging detector concepts.
  Many nucleon structure issues favor lower, more symmetric energies!

- "Staging:" Several medium–energy EIC options discussed

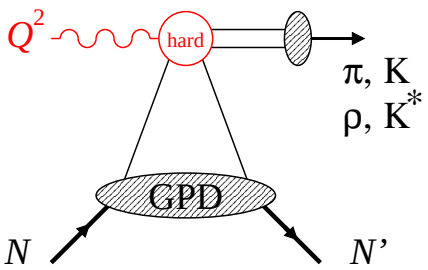
  Staged eRHIC: 2/250 or 4/250 GeV
  Medium–energy EIC at JLab: 5/30 – 5/60 GeV

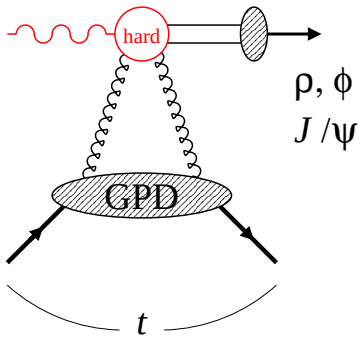
  . . . Should address distinct physics program!

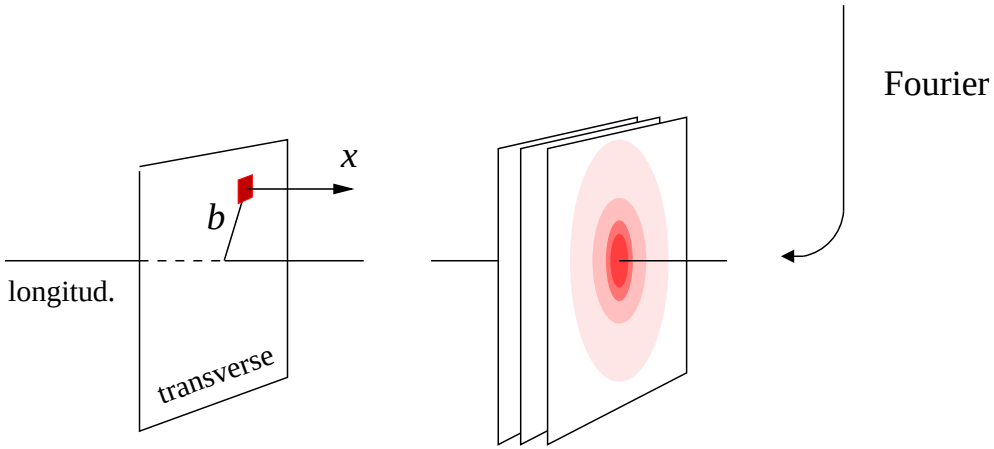
- Low–energy collider ideas

  ENC at GSI
  JLab–COSY ring–ring collider and other studies

# Transverse imaging: GPDs




- Exclusive meson production: Generalized parton distributions

| | |
|---|---|
| $J/\psi, \phi$ | gluon |
| $\rho^0$ | gluon, singlet q. |
| $\pi, K, \rho^+, K^*$ | non-singlet quark |

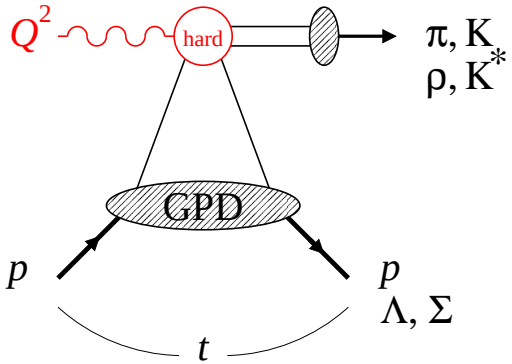
- Transverse spatial distribution of quarks/gluon in nucleon

$\rightarrow$ Nucleon structure in QCD: Valence quarks, pion cloud

$\rightarrow$ High–energy $pp$ at LHC: Transverse geometry

$\rightarrow$ Saturation: $b$–dependence, QCD dipole model

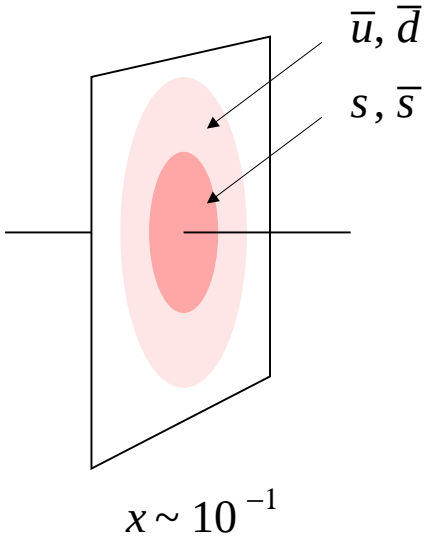
# Transverse imaging: Non–singlet quarks




- Transverse distribution of quark flavor/charge/helicity from exclusive $\pi, K, \rho^+, K^*, \ldots$

  $\rightarrow$ QCD vacuum structure, chiral dynamics

  $\rightarrow$ valence quark structure



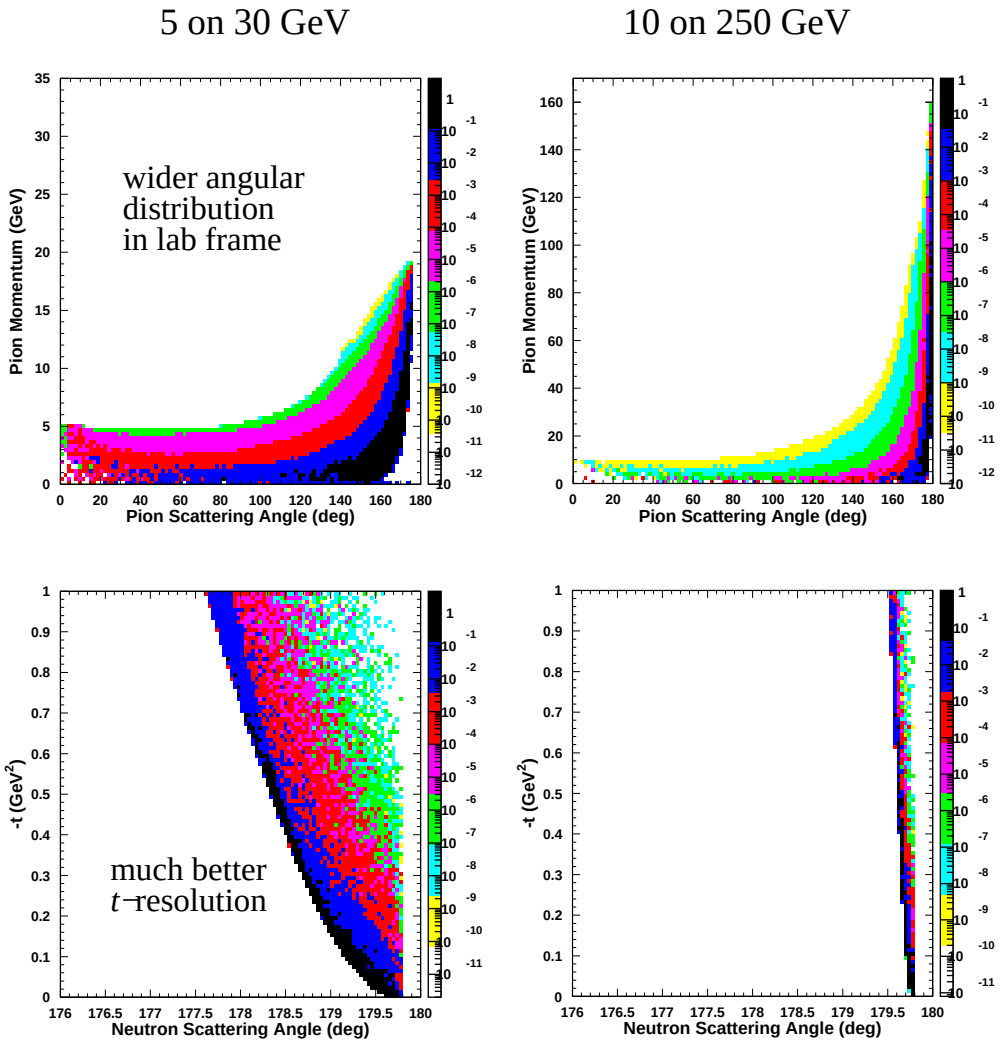

- Experimental requirements

| | |
|---|---|
| $x \sim 10^{-1}$ | Non-diffractive processes, cross secs drop with energy |
| $Q^2 < 20\,\text{GeV}^2$ | limited range |
| $L \sim 10^{34}$ | cross secs $\sim$ 1–10 pb, drop with $Q^2$ |

$+$ exclusivity, $t$–resolution $\leftarrow$

EIC: Want non–singlet quark imaging at $x \sim 0.1$

# Transverse imaging: EIC simulations

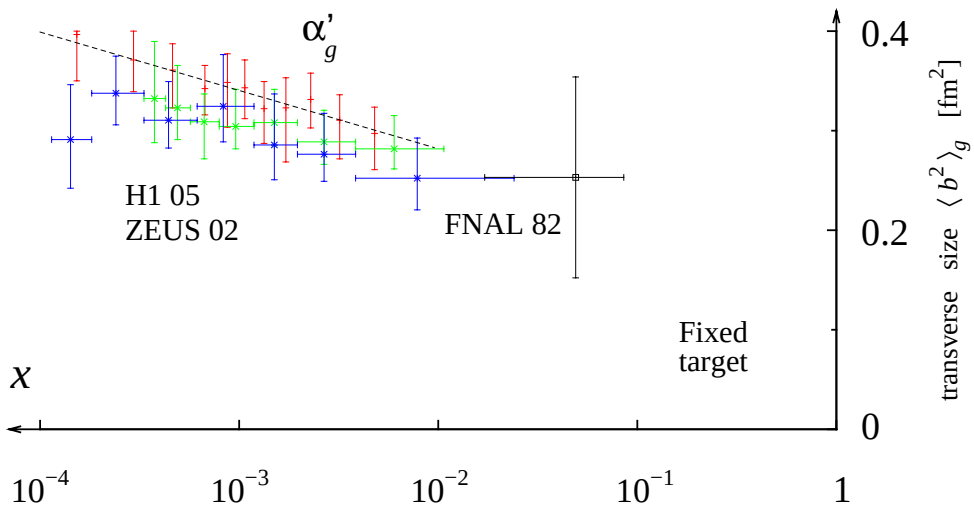


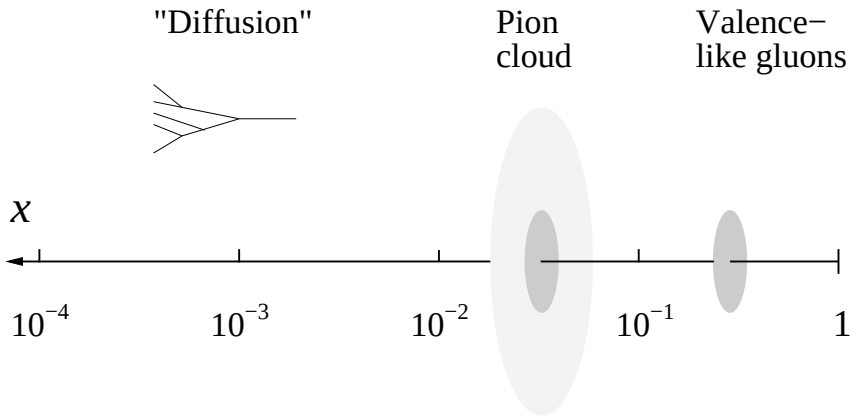

T. Horn et al. 2008

- Here: Exclusive production $ep \to e'\pi^+ n$
- Lower–energy, symmetric collider
  - $\to$ wider $\pi^+$ angular distribution: Detection, angular resolution
  - $\to$ wider recoil $n$ distribution: $t$–resolution
- Next step: Detector simulations

Exclusive processes: Much better prospects with lower–energy, more symmetric EIC

# Transverse imaging: Gluons




- Transverse distribution of gluons from exclusive $J/\psi$

  | | |
  |---|---|
  | $x \leq 10^{-2}$ | HERA H1, ZEUS<br>FNAL 82 |
  | larger $x$ | fixed–target |

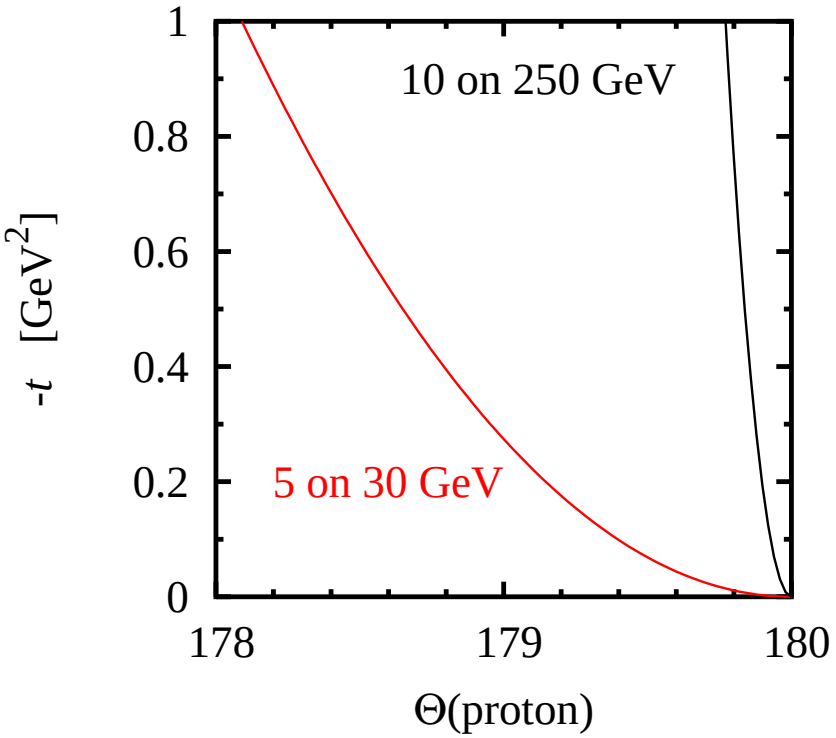
- EIC expectations

  Cover region $10^{-2} < x < 0.3$
  $W < 30$ GeV
  $\rightarrow$ Valence structure
  $\rightarrow$ Hard procs in $pp$ at LHC

  Exclusivity, $t$–resolution:
  Recoil proton detection

EIC: Want gluon imaging
up to valence region $x \sim 0.3$

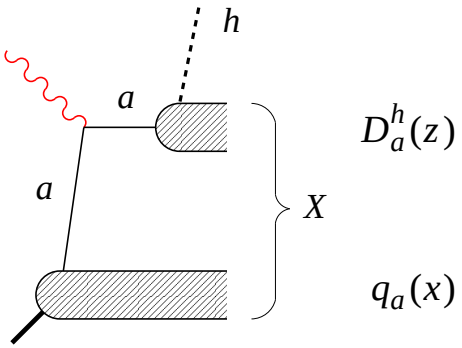
# Transverse imaging: Gluons

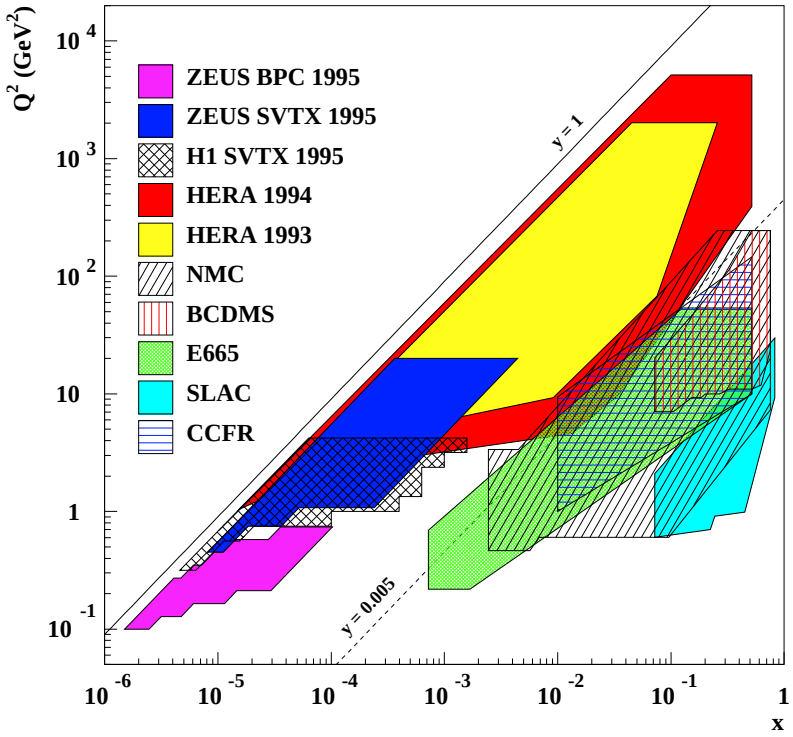



- Exclusive $\gamma p \to J/\psi + p$:
  Much wider angular spread
  of recoil proton
  at lower energies:
  $-t \sim E_p^2(\Theta - 180°)^2$

EIC: Better $t$–resolution
with low–energy option

# Flavor decomposition in semi-inclusive DIS



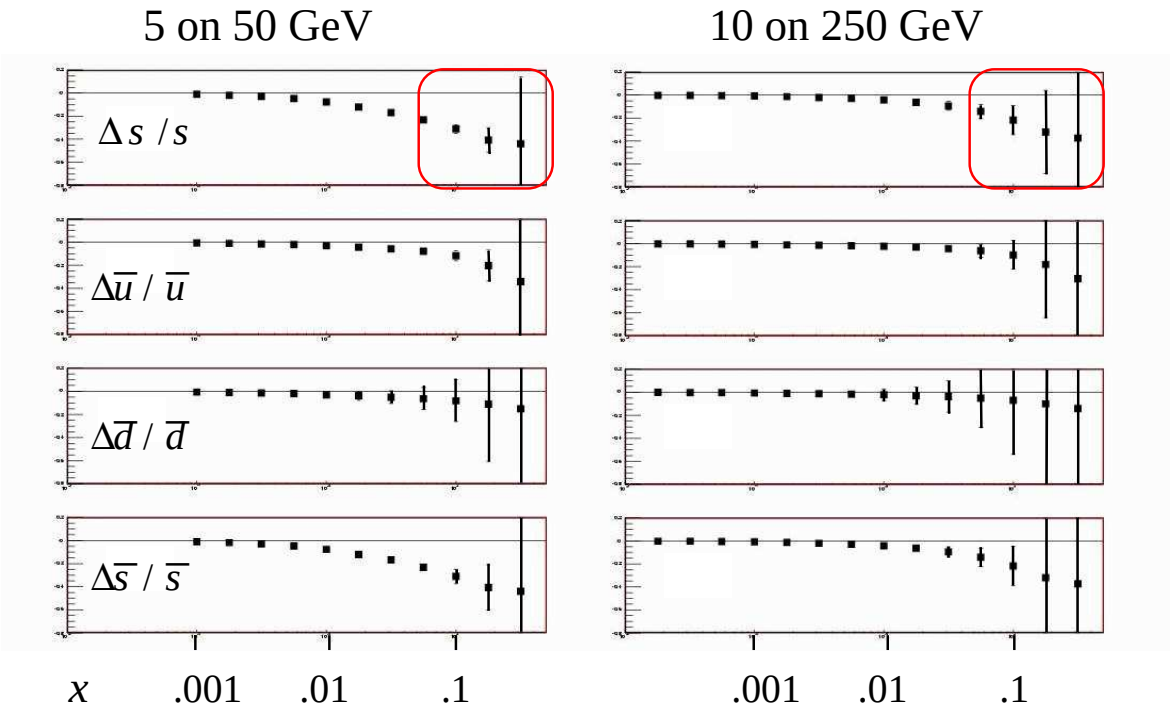

- Fragmentation process tags flavor of active quark in DIS
- Want sensitivity at $x \geq 10^{-1}$

  $\dfrac{\Delta q(x)}{q(x)}$ relative polarization

  $\dfrac{\bar{d} - \bar{u}}{\bar{d} + \bar{u}}$ rel. flavor asymmetry

- Difficult to access with high–energy collider: $y > y_{\min}$

# Flavor decomposition: EIC simulations




E. Kinney, J. Seele, 2007+

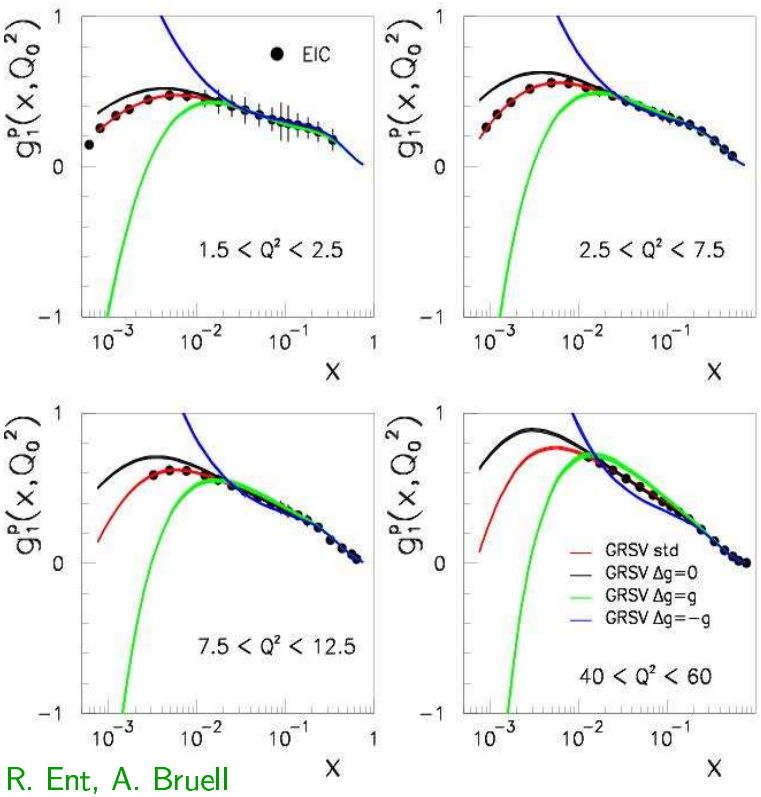
- Accessible ideally with medium–energy EIC

  → Much better statistics at $x \geq 0.1$

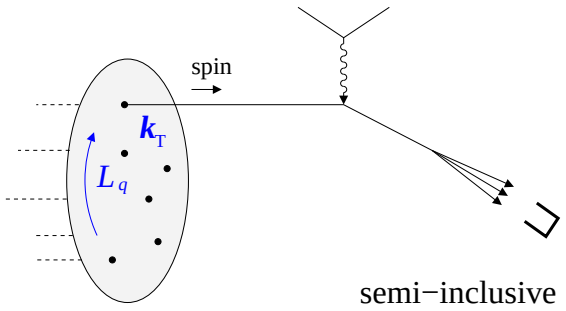
  → Good particle ID range of $E_h =$ 1-10 GeV suited to relevant range of $z = E_h/\nu$

Flavor decomposition in SIDIS favors medium–energy EIC

# Spin: From $\Delta G$ to $L_q$




R. Ent, A. Bruell




- $\Delta G$ interesting in its own right:
  Requires $Q^2$–dependence,
  wide kinematic coverage
  $\rightarrow$ high–energy EIC

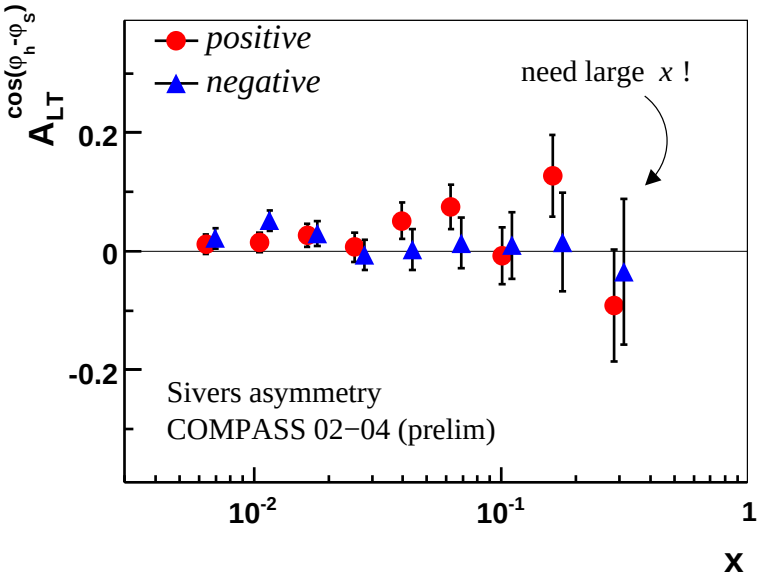
  How much will be needed after
  JLab12 + COMPASS + RHIC Spin?

- Expected $\Delta G$ small, probably will not account for nucleon spin!

  $\rightarrow$ Orbital ang. momentum $L_q, L_g$?

- Semi–inclusive DIS: $\boldsymbol{k}_T$ dependence
  - Indirect access to $L_q$
  - Progress in theory, interpretation
  - Requires $x \geq 0.1$

# Spin: $k_T$ dependence in SIDIS



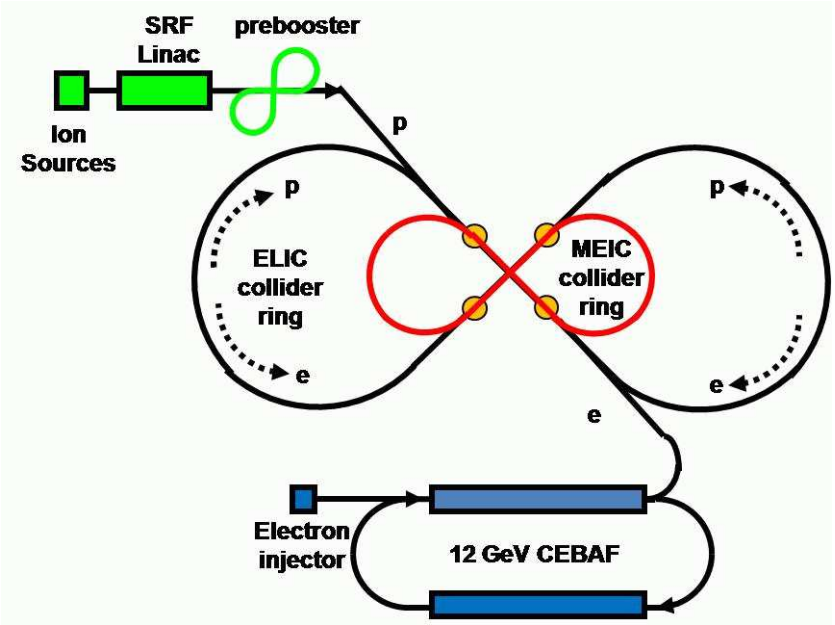

- $k_T$ dependent structures live at $x \geq 0.1$
  - Accessible ideally with medium–energy EIC
  - Good PID in relevant $z$–range $0.2 < z < 0.7$

- $J_q$ from GPDs? Model–dependent, but perhaps progress with JLab12. . .

$$\int dx\, x\, [H + E]\,(x, \xi; t) \rightarrow \text{large } x!$$

Orbital angular momentum observables require $x \geq 0.1$

# High–luminosity medium–energy EIC at JLab




| | | |
|---|---|---|
| Energy | $E_e/E_p$ | $= 5/30 - 60$ GeV |
| | $s_{ep}$ | $= 600 - 1200$ GeV$^2$ |
| Luminosity | few $\times$ $10^{34}$ cm$^{-2}$ s$^{-1}$ | |
| Circumf. | $\sim$ 600 m | |
| Polarization, nuclear beams | | |

- Conceptual development on–going, 1st version presented to EIC Advisory Committee Feb–09
- Rich physics program in nucleon structure/nuclear physics
  - Transverse nucleon imaging
  - Orbital angular momentum, $\boldsymbol{k}_T$ dep.
  - Flavor decomposition: Sea quarks, polarization
  - Nuclei in QCD: Gluonic structure, coherent processes, transparency
- Possible stage to high–energy ELIC, but distinct physics program!

# Summary

- Many nucleon structure applications favor medium–energy EIC
  - Transverse nucleon imaging
  - Orbital angular momentum $L_q$
  - Flavor decomposition
- JLab medium–energy EIC: Promising new development!
  - Significant progress during last 3 months
  - Hope to expand efforts. . .
- Needed: Further discussion, detailed simulations