Higher twist and Dihadron Fragmentation

IR2@EIC: Science and Instrumentation of the 2nd IR for the EIC

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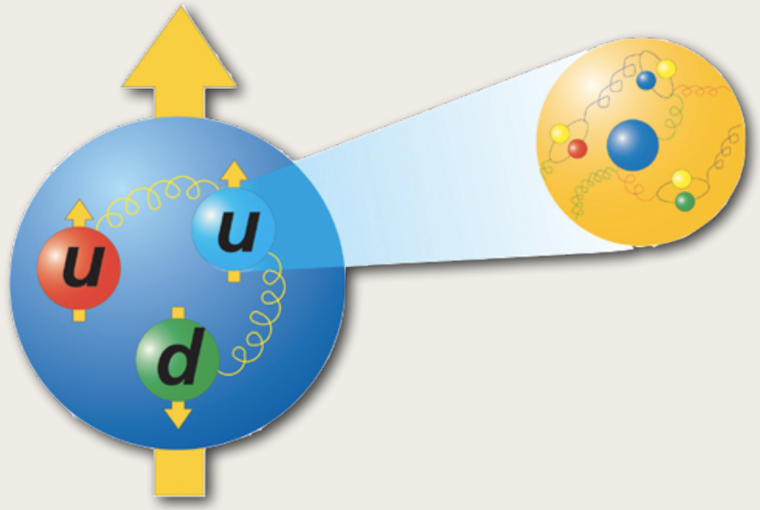
The interaction

Collinear picture of hadrons:

- leading twist: mid- to high-energies
  - inclusion of nonperturbative QCD
- higher twists: suppressed but not necessarily small
  - extra degrees of freedom



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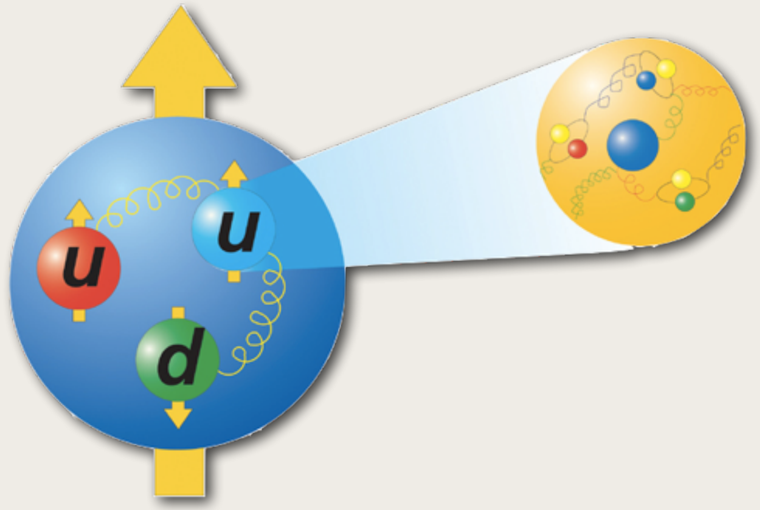

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Core of the nonperturbative dynamics

in genuine twist-3 effects:

- mass terms
- sigma terms
- quark-gluon-quark interaction
- zero modes

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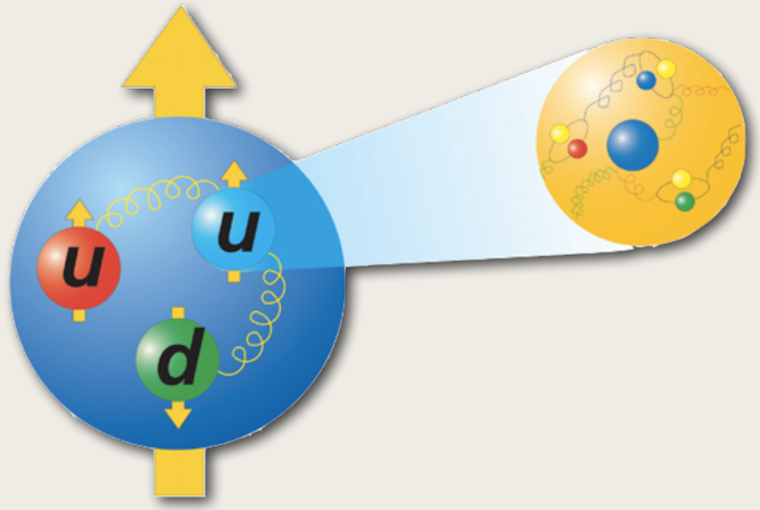

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Address questions, e.g.,

the origin of the proton mass or

transverse forces on quark.

Collinear picture

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \left\langle PS|\bar{\psi}(0)\gamma_\mu \psi(\lambda n)|PS\right\rangle = 2\left\{f_1(x)p_\mu + M^2 f_4(x) n_\mu\right\},$$

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \left\langle PS|\bar{\psi}(0)\gamma_\mu\gamma_5 \psi(\lambda n)|PS\right\rangle = 2\left\{g_1(x)p_\mu S\cdot n + g_T(x) S_{\perp\mu} + M^2 g_3(x) n_\mu S\cdot n\right\},$$

$$\int \frac{d\lambda}{2\pi} e^{i\lambda x} \left\langle PS|\bar{\psi}(0)\psi(\lambda n)|PS\right\rangle = 2e(x),$$

twist-2 PDFs

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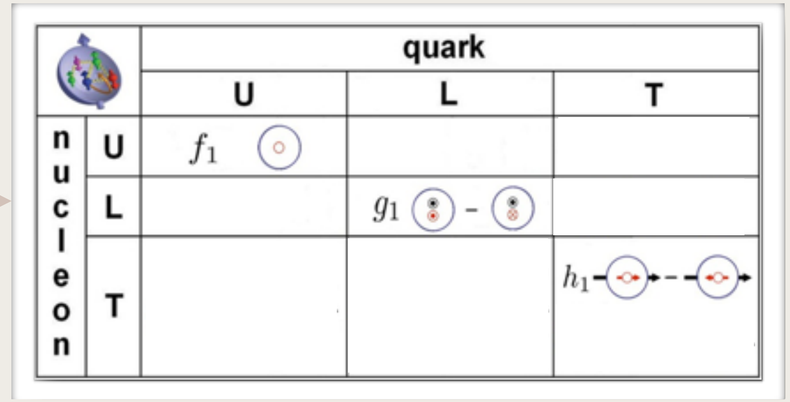

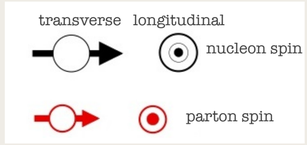

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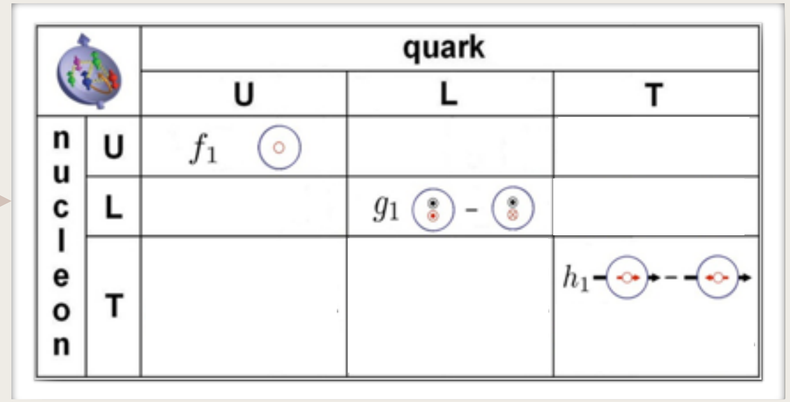
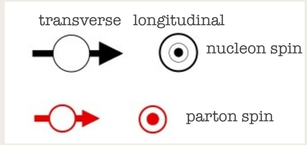
twist-2 PDFs

twist-3 PDFs





Multi-parton distributions at the EIC

Large range of Q^2 values, includes smallish x regions

Sandbox for factorization and evolution studies

Complementary to fixed-target experiments (HERMES, CLAS,…)

Golden channel

- fully inclusive DIS: $A_{LT} \Rightarrow g_T$

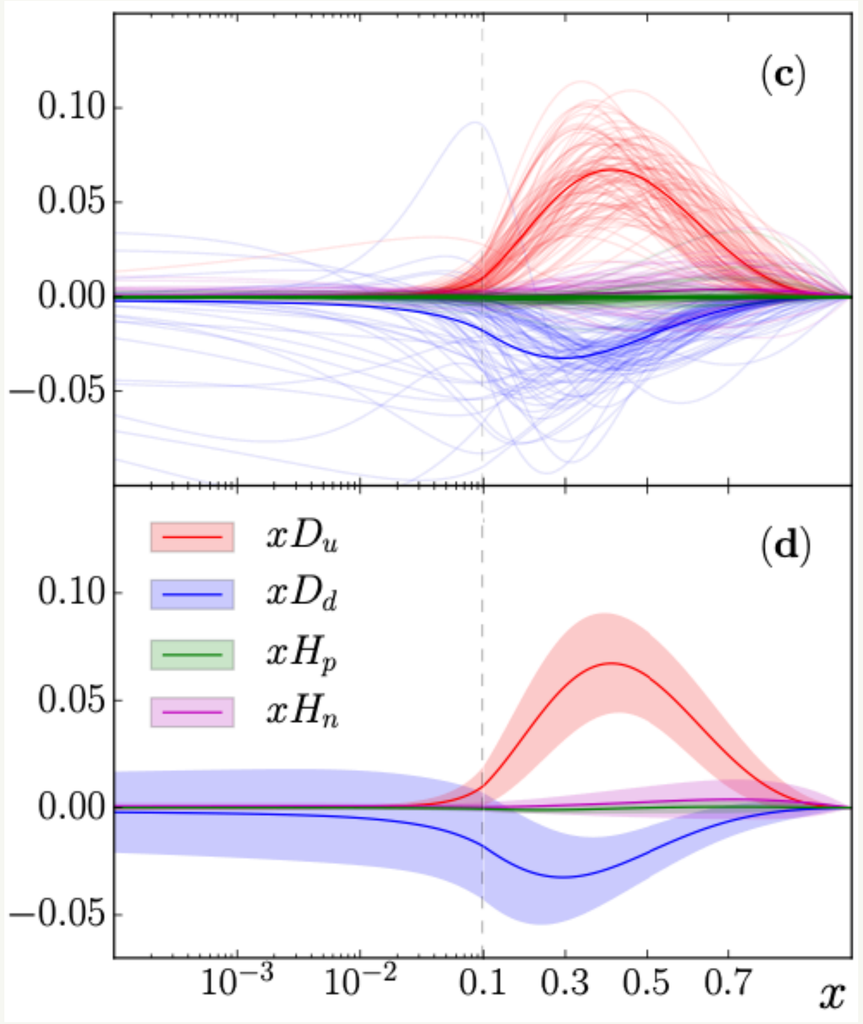
Silver channel

- semi-inclusive DIS: $A_{LU} \Rightarrow e$

- **Collinear observables.**
- Plethora of interesting TMD, GPD higher-twist observables not considered here
- subWG: Avakian, Burkardt, AC, Gamberg, Pitonyak, Sato, Schweitzer, Vossen

Extraction of $g_T(x)$

- **global fit** of g_1 & g_2 by JAM [PRD93]
  - world data + CLAS ($W^2>4GeV^2$) +TMC
- kinematic reduction to twist-2 PDFs: Wandzura-Wilczek approximation
- beyond WW
  - ➡ quark-gluon-quark interaction
  - ➡ zero modes
- constrained by D related to g_2
  - ➡ constrained by sum rules
  - ➡ sum rules for genuine contribution: d_2

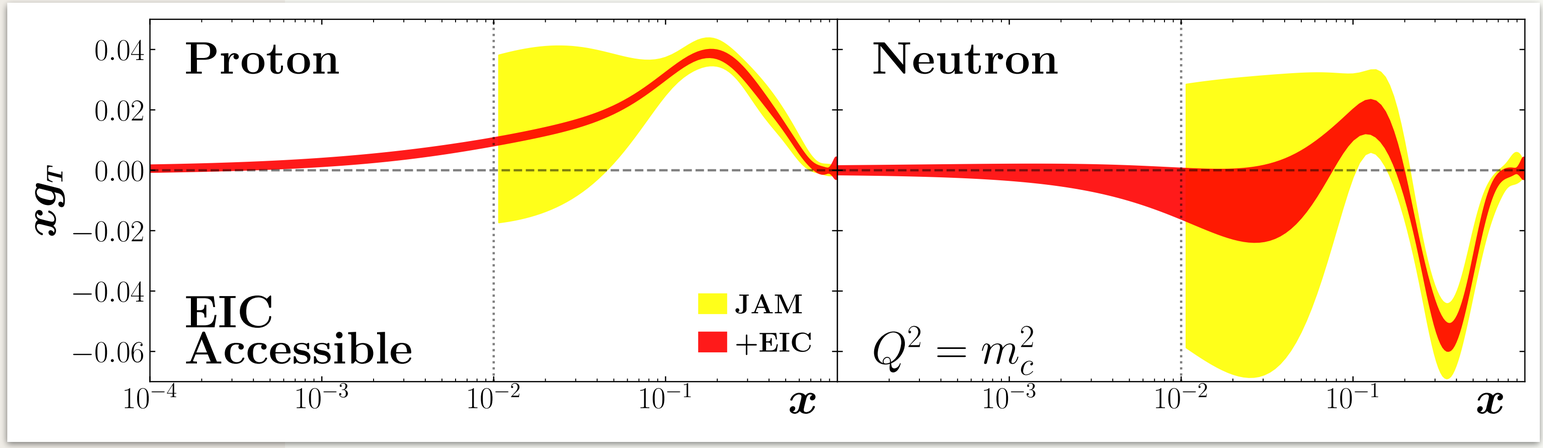


Adapted from Nobuo Sato's explanations

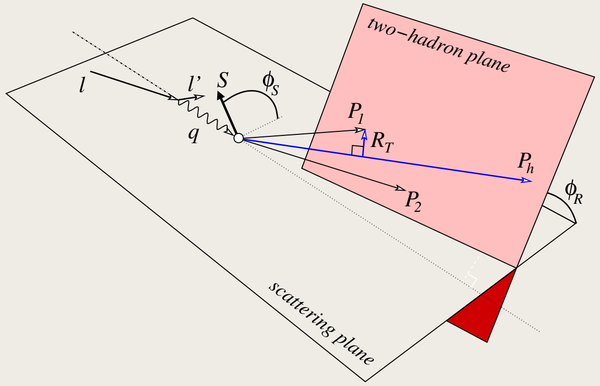
Golden: $g_T(x)$

Accessible through fully DIS

- $g_T = g_1 + g_2$
- JAM+EIC: $g_T = g_T^{WW} + \tilde{g}_T$
- hints of non-vanishing twist-3 effect in DIS
  - extend to genuine twist-3 with EIC
  - study the scale dependence/factorization
  - complementarity of x range
- Projections: expected error EIC with proton, deuteron & helium target



Collinear PDFs in SIDIS



e.g. [Bacchetta & Radici, PRD69]

Pinpoint partners for chiral-odd PDFs

- Dihadron Fragmentation Functions can be chiral-odd
- Phenomenologically tested for the twist-2 transversity PDF
  - extracted in e^+e^- at Belle [A.C., Bacchetta, Radici & Bianconi, PRD85]
  - collinear extraction of the transversity PDF [Bacchetta, AC & Radici, PRL107 and follow-ups]

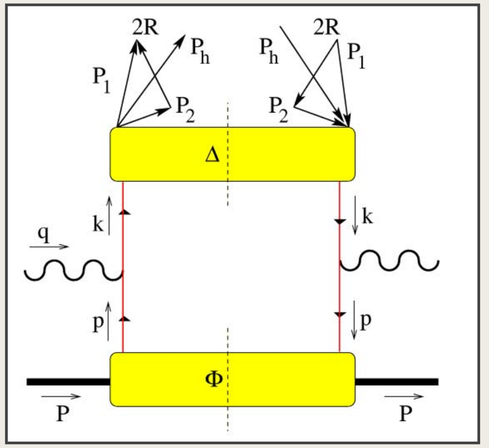
See Nobuo Sato's talk

  - we get the ratio R that is universal (transportable) *up to evolution effects*

$$R(z, M_h) = \frac{|\boldsymbol{R}|}{M_h} \frac{H_1^{\sphericalangle u}(z, M_h; Q_0^2)}{D_1^u(z, M_h; Q_0^2)}$$

chiral-odd DiFF

unpolarized DiFF



Extraction of e(x)

- e^+e^- from Belle & SIDIS proton target from
  - CLAS [PRL126 (2021)]
  - CLAS12 [2101.04842]

  } non-vanishing twist-3 effects
- Preliminary point-by-point extraction [1405.7659]
- Sketch:

$$A_{LU} \propto \frac{\text{twist-3 PDF} \times \boxed{\dfrac{\text{twist-2 FF} + \text{twist-2 PDF}}{\text{unpolarized}}} \times \text{twist-3 FF}}{}$$

known twist-2 quantities

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known twist-2 quantities

$$e^q(x) = e^q_{\rm loc}(x) + e^q_{\rm gen}(x) + e^q_{\rm mass}(x)$$

$$\tilde{G}^{\sphericalangle} = \text{genuine twist-3}$$

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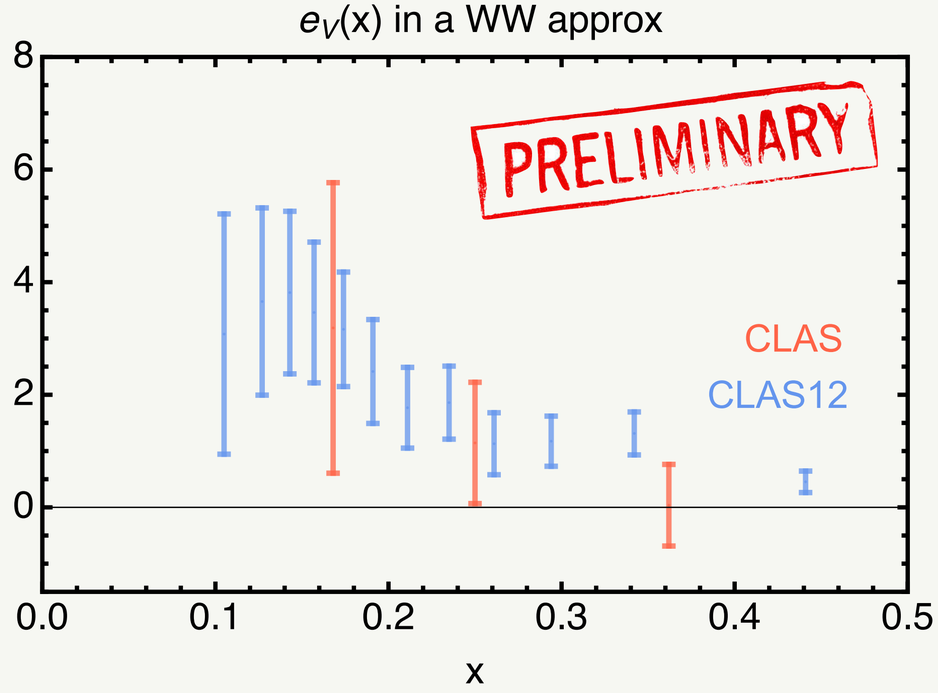

Warnings:

- "WW" approximation: e(x) × twist-2 DiFF term
- update of [1405.7659]

Extraction of e(x)

- Preliminary extraction update: [1405.7659]
- Fit, work in progress [Avakian, AC, López, Miramontes, Mirazita]
- Physical content:

$$e^q(x) = e^q_{\rm loc}(x) + e^q_{\rm gen}(x) + e^q_{\rm mass}(x)$$

"local" term

genuine qGq interaction

quark mass term
proportional to twist-2 PDFs
not quite WW-like

$$\int_{-1}^{1} dx\, e^q(x,Q^2) = \sigma_q(Q^2)$$

$$\mathcal{M}_n[e^q_{\rm mass}] = \frac{m_q}{M_{\rm N}} \times \begin{cases} 0 & \text{for } n=1 \\ \mathcal{M}_{n-1}[f_1^q] & \text{for } n>1 \end{cases}$$

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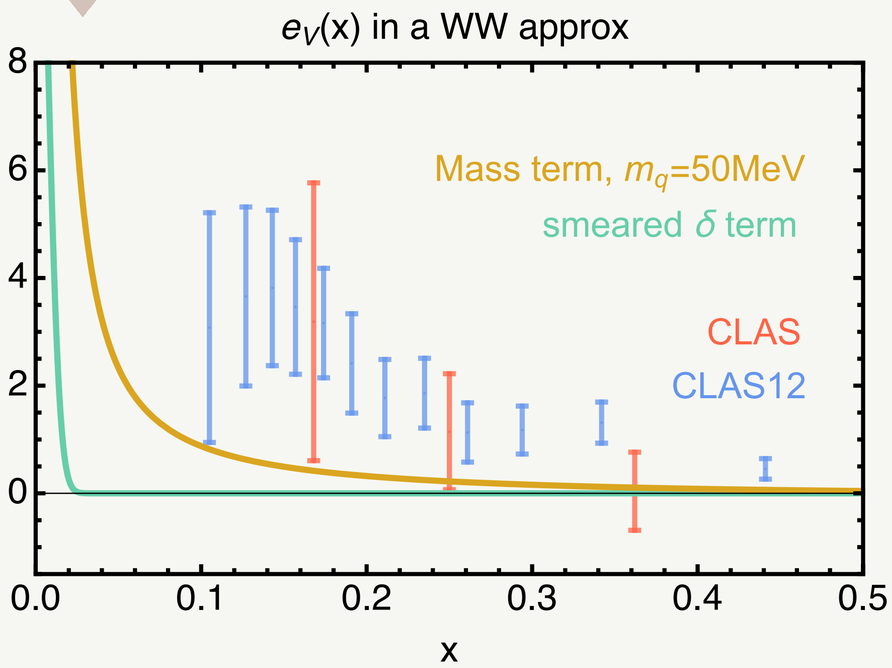
Some nonperturbative effects expected in the small(ish)-x region



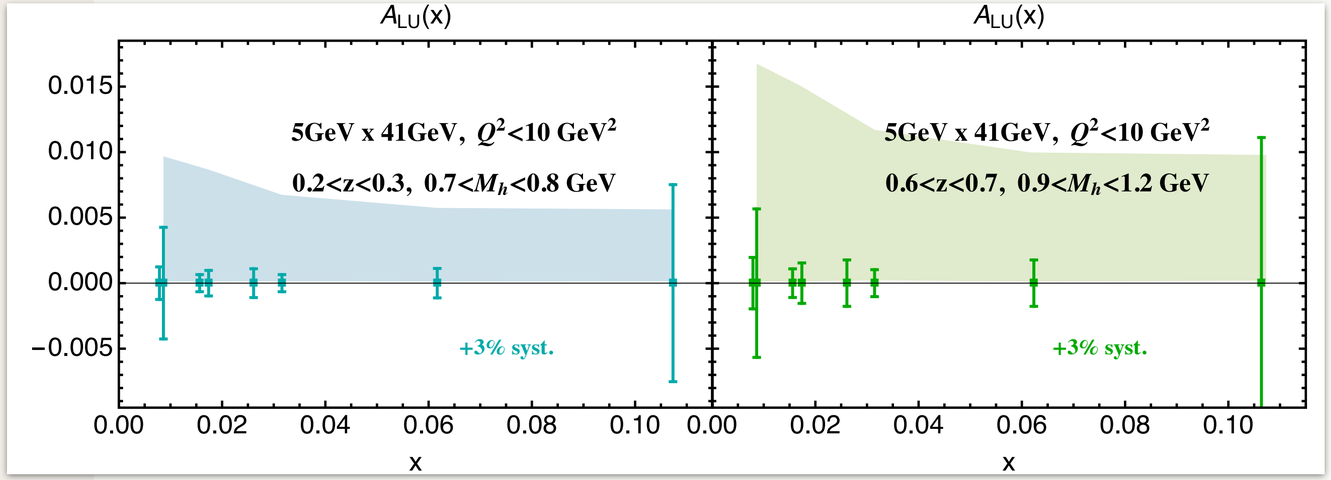
Schematic models for illustration purpose only!

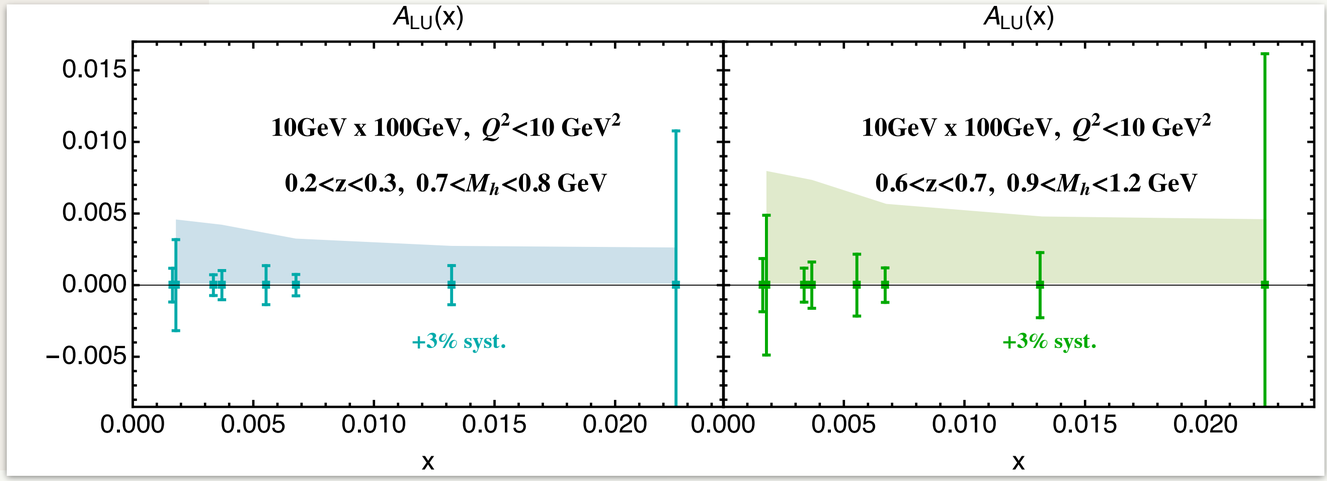
Update of [1405.7659]

Silver: e(x)

Accessible through DiFF SIDIS: A_{LU}

- EIC error projections (from transversity studies)
- Models × DiFFs predictions
  - LC model [Pasquini & Rodini, PLB 788]
  - made-up mass-term contribution with m_q=300MeV
- span in Q^2 suitable for evolution studies
- complementary small-x range
  - small asymmetries
  - caution…

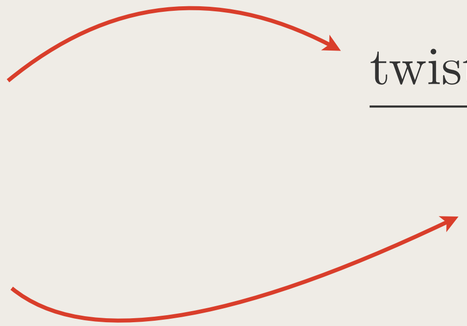




Roadmap for an access of multi-parton distributions

Technical points

- evolution over ratios:
  - no cancellation expected for twist-3 numerators
  - study of evolution for genuine twist 3
  - study of factorization
- denominator for low Q^2:
  - study of multiplicities (ex: CLAS12 [Soto, Mirazita et al…])
- rôle of unpolarized PDFs at low Q^2



$$\frac{\text{twist-3 PDF}(\times\text{twist-2 FF})}{\text{unpolarized}}$$

Dihadron specifics

- upgraded version of DiFFs
- rôle of twist-3 fragmentation
- asymmetry & flavor combinations

  ⇒ complementarity of observables: e.g. A_{UL}

Conclusions

Access to multi-parton dynamics through genuine twist-3 contributions at the EIC

- highlight on twist-3 collinear PDFs, specifically: g_T and e
- challenge for global (and not so global) analyses
- unveil aspects of hadron dynamics: nonperturbative picture
- IR2@EIC: necessary coverage in (x,Q^2) to go to the next level

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- A_N studies
- Lambda related asymmetries
- TMD-PDF twist relations

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Long way

- efforts will need *peoplepower*
- coordination of efforts from many fronts