Study the Nuclear Effects of TMDs and Fragmentation Functions

using SIDIS and Drell-Yan Processes

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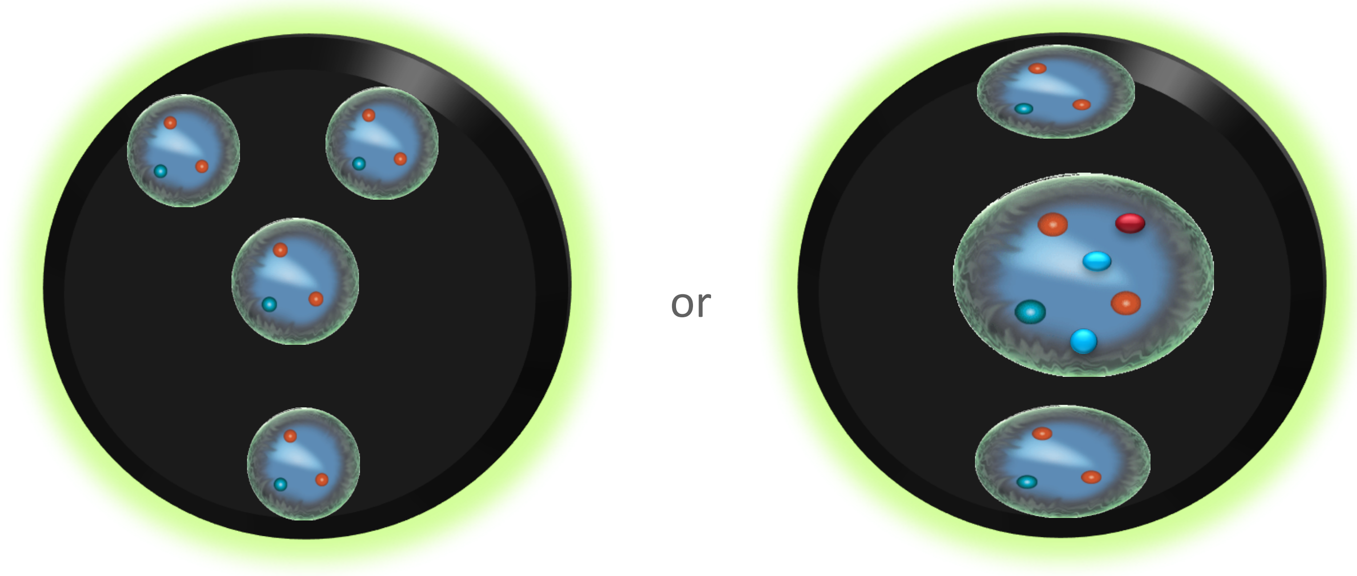
Our Visual Images of a Nucleus



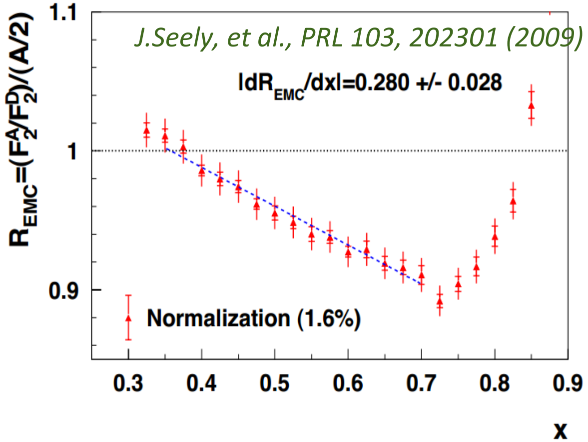
- How are protons and neutrons bounded together into nuclei?
- Are protons and neutrons behave differently when they are free and when they are bounded?

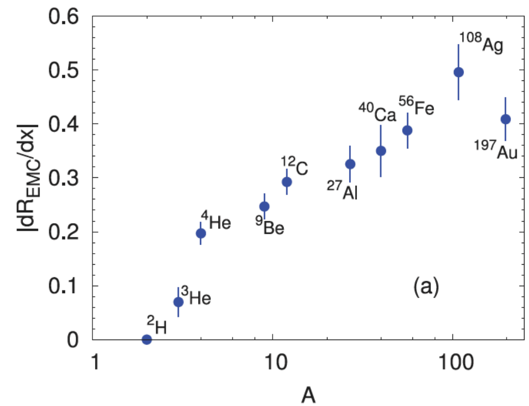
Are the nucleon distribution functions different from the one in nuclei?
(e.g, not just PDF, but also TMD, Fragmentation Function, GPD and even Wigner Distributions)

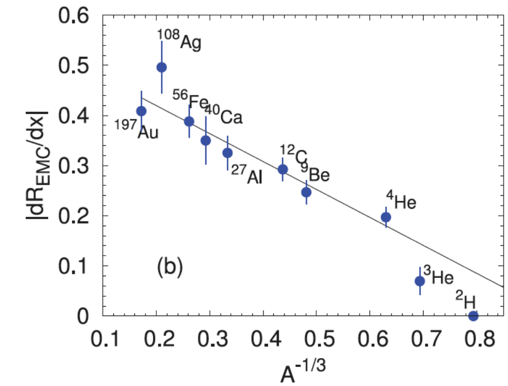
Medium Modification on the Longitudinal Direction!

- EMC Effect on PDFs: *J. Arrington et al. PRC 86, 065204 (2012)*

- **EMC Effect:** A nucleon's structure function (F_2) is modified when placed in different nuclei

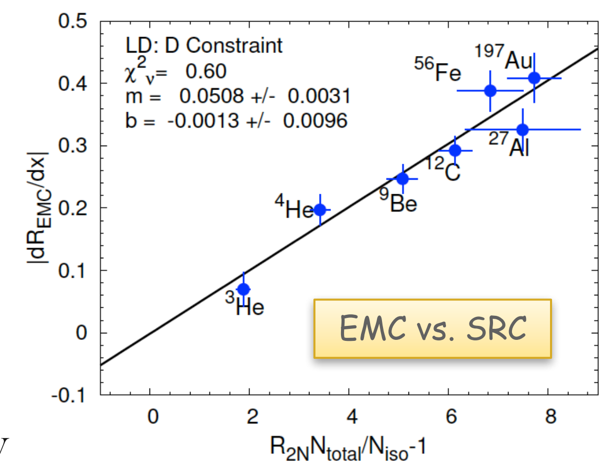






- Discovered in 1980s; Still don't fully understand the origin
- Strong A dependence:
- Connection to Short-Range Correlations (SRCs):

  the nucleon is modified within a high-density configuration?



- Active experimental programs to continue pursuing this issue at Jlab-12GeV

  (Tritium Experiments, many Hall-C experiments), EIC and SeaQuest

Medium Modification on the Transverse Direction?

- "Facts":

  - The SIDIS "effective-neutron" data from the Deuteron or He3 target should carry medium modification effect;

    To early to worry about such effect due to the limited experimental accuracy of existing data
  - In SIDIS, the modification effect comes from both the TMDs and the Fragmentation Functions (FF);
  - FFs measured from (e+,e-) are not ideally the same as ones in nuclei (even in the free proton and neutron!)

- Questions:
  - Maybe the reason that we still don't understand the EMC effect is because we only look at 1D-PDF?

    A nucleon is a rigid and compact 3D object described by a 5D Wigner Distribution;
  - Is the Transversity (h_1) larger or smaller than g_1?

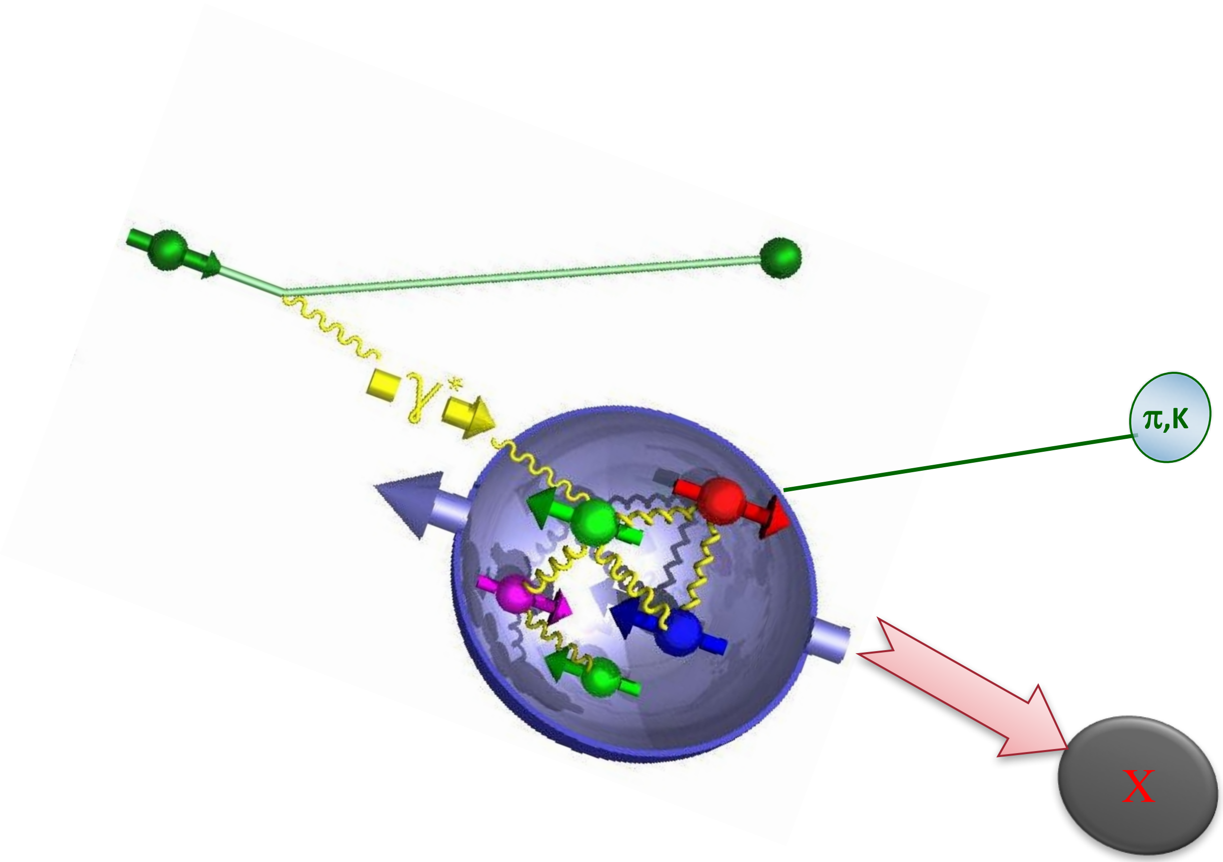
    Theoretical calculation indicates a large modification effect on g_1 than f_1 *(I. Cloet, PRL 95, 052302, 2005)*
  - Is a nucleon more easier to be modified along the transverse direction (stronger modification effect on TMD)?
  - A new way to study orbital angular momentum in nuclei?

    (Y.V. Kovchegov, M.D. Sievert, Nuclear Physics B 903 (2016) 164–203)

- Is it too early to worry about medium modification on TMD (and GPD as well)?

  EMC effect in PDFs was discovered >30 years ago and is still not fully understood.

SIDIS Process



Medium Modification in SIDIS

- Extended to the 3D Dimension (unpolarized case):

- In 1D study, we detect different hadrons to tag quark flavors
- In 3D study, we also measure the additional quantities:
  - ✓ Longitudinal momentum of the detected hadron (“z”)
  - ✓ Transverse momentum and of the detected hadron “P_T”
  - ✓ Azimuthal angle of the hadron (“ϕ_h”)
  - ✓ For polarization measurement, also measure “ϕ_S”
- At leading order, the unpolarized cross section:

$$\frac{d\sigma^h}{dx\,dy\,dz\,d^2\mathbf{P_T}} = \frac{4\pi\alpha^2 s}{Q^4}\left(1-y+\frac{y^2}{2}\right)\sum_q e_q^2[f_1^q \otimes D_{1q}^h],$$

$$[\ldots \otimes \ldots] = \int d^2p_T\, d^2k_T\, \delta^{(2)}\left(\mathbf{p_T} - \frac{\mathbf{P_T}}{z} - \mathbf{k_T}\right)[\ldots].$$

SIDIS Process

$$P_T = \frac{p \cdot P_h}{|q^2|} = p_{h\perp}$$

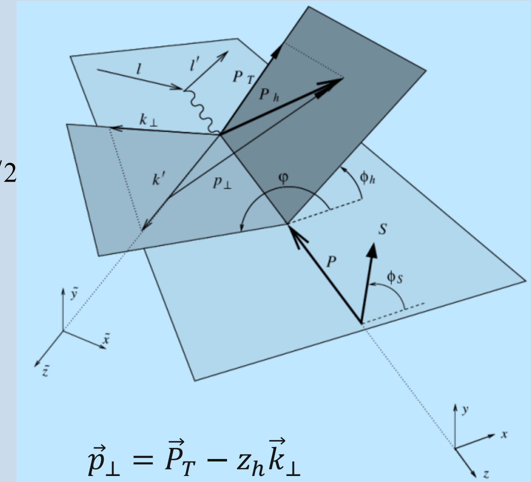
$$q = l - l'$$

$$Q^2 = -q^2 = 4E_l E_{l'} \sin^2\theta/2$$

$$x_B = \frac{Q^2}{2M\nu} = \frac{q \cdot P}{M}$$

$$y = \frac{E_l - E_{l'}}{E_l} = \frac{q \cdot P}{l \cdot P}$$

$$z = \frac{P \cdot P_h}{P \cdot q}$$



- With Gaussian Approximation: *PRD 71 074006 (2005)*

$$\langle k_\perp^2 \rangle = 0.25\,(\mathrm{GeV}/c)^2 \qquad \langle p_\perp^2 \rangle = 0.20\,(\mathrm{GeV}/c)^2$$

$$f_q(x, k_\perp) = f_q(x)\frac{1}{\pi\langle k_\perp^2\rangle} e^{-k_\perp^2/\langle k_\perp^2\rangle} \qquad D_q^h(z, p_\perp) = D_q^h(z)\frac{1}{\pi\langle p_\perp^2\rangle} e^{-p_\perp^2/\langle p_\perp^2\rangle}$$

$$\langle P_T^2 \rangle = \langle p_\perp^2 \rangle + z_h^2 \langle k_\perp^2 \rangle$$

$$\boldsymbol{p}_\perp = \boldsymbol{P}_T - z_h \boldsymbol{k}_\perp + \mathcal{O}\left(\frac{k_\perp^2}{Q^2}\right)$$

Integrating over $\boldsymbol{k}_\perp$(not an experimental observable), we have the unpolarized SIDIS cross section

Cahn Effect

$$\frac{d^5\sigma^{\ell p \to \ell h X}}{dx_B\, dQ^2\, dz_h\, d^2\boldsymbol{P}_T} \simeq \sum_q \frac{2\pi\alpha^2 e_q^2}{Q^4} f_q(x_B) D_q^h(z_h)\left[1 + (1-y)^2 - 4\frac{(2-y)\sqrt{1-y}\langle k_\perp^2\rangle z_h P_T}{\langle P_T^2\rangle Q}\cos\phi_h\right]\frac{1}{\pi\langle P_T^2\rangle} e^{-P_T^2/\langle P_T^2\rangle}$$

And we also can add the Boer-Mulder Term (very small):

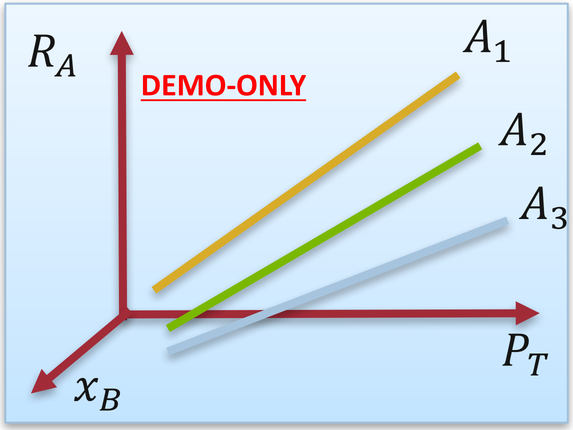
$$\frac{d^5\sigma^{\ell p \to \ell h X}}{dx_B\, dQ^2\, dz_h\, d^2\boldsymbol{P}_T} = A + B\cos\phi_h + C\cos 2\phi_h$$

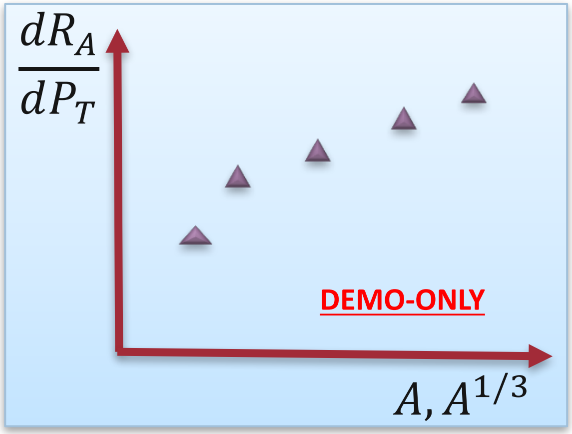
Medium Modification in SIDIS

- Study the A-dependence of the transverse momenta ($\boldsymbol{P}_T$, $\boldsymbol{k}_\perp$, *and* $\boldsymbol{p}_\perp$) distributions:
  - Before applying the Factorization Theorem (model safe)
  - Fin bins in (Q^2, x, z, P_T) for D2 and heavy nuclei
  - Take XS ratios to study the changes of correlations in A's

$$R_A(Q^2, x, z, P_T) = \frac{\sigma_A^h(Q^2, x, z, P_T)}{\sigma_{D2}^h(Q^2, x, z, P_T)}$$

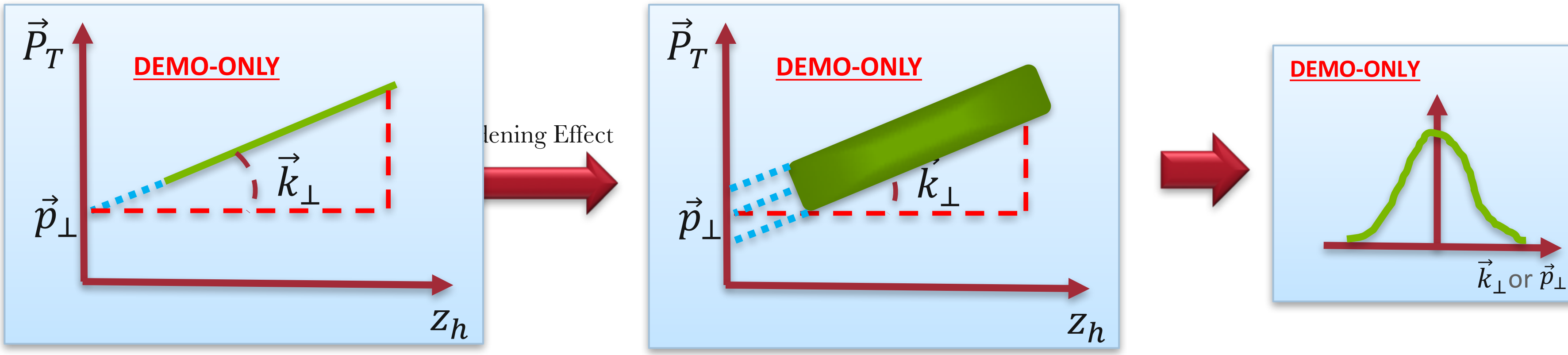
  - Their slopes (if linear) as functions of A or $A^{1/3}$
  - Exam their z dependences





Medium Modification in SIDIS

- Extraction of $\boldsymbol{k_\perp}$ *and* $\boldsymbol{p_\perp}$ distributions (A ***Rosenbluth*** style of extraction):
  - In the Parton Model : $\vec{P}_T = \vec{p}_\perp + z_h \vec{k}_\perp + O(\frac{k_\perp^2}{Q^2})$, approximately a linear correlation (not 100% correct in full QCD)
  - When $z_h \rightarrow 0$, we can extract the distributions (or moments) of $\vec{p}_\perp$ in different nuclei.
  - The slope gives the ("relative") distributions (or moments) of $\vec{k}_\perp$ in different nuclei.



To be interesting to see:

- The widths of in different nuclei compared to D2. i.e., From $\vec{k}_\perp$, does the quark shrink or enlarge when the nuclear number A is changing? And, from $\vec{p}_\perp$, does the quark shrink or enlarge after it is struck out?
- By extracting the first and higher moments, can we determine whether the transverse momentum distributions are like Gaussian shapes or something else?

- We can further study the XS ratios as functions of $\boldsymbol{k_\perp}$ and $\boldsymbol{p_\perp}$, and see their medium effect in TMD and FF separately by fixing one quantity while studying the other .

$$R_{A/D}(Q^2, x, z, P_T) = \frac{\sigma_A^h(Q^2, x, z, P_T)}{\sigma_{D2}^h(Q^2, x, z, P_T)} = R_{A/D}^{TMD}(Q^2, x, \vec{k}_\perp) \cdot R_{A/D}^{FF}(Q^2, x, \vec{p}_\perp)$$

Medium Modification in SIDIS

- Measuring Medium Modification Effect of Boer-Mulder TMD & FF:

  - When probing p_T dependence, the SIDIS cross section with **unpolarized** nuclei contains angular dependent terms:

$$\sigma \propto A + B \cdot \cos(\phi_h) + F_{UU}^{\cos(2\phi_h)} \cdot \cos(2\phi_h)$$

  - The $\cos(2\phi_h)$ dependence module gives the BM convoluted by Collins Fragmentations:

$$F_{UU,A}^{\cos(2\phi_h)}(x, z, p_T, Q^2) \propto \langle\cos(2\phi_h)\rangle_{UU,A} \propto h_{1,A}^{\perp}(x, k_\perp, Q^2) \otimes H_{1,A}^{\perp}(z, p_\perp, Q^2)$$

  - We can separated them by mapping out the x & z dependence, e.g.:

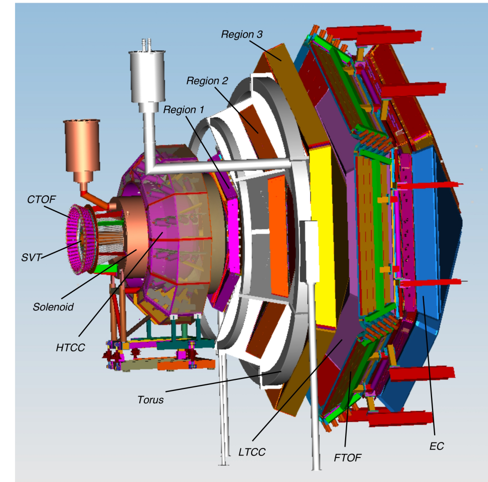
$$R_{\frac{A}{D}}^{\cos(2\phi_h)}(x, z, p_T, Q^2) = \frac{F_{UU}^{\cos(2\phi_h)}(A, x, z, p_T, Q^2)}{F_{UU}^{\cos(2\phi_h)}(^2D, x, z, p_T, Q^2)} = R_{A/D}^{BM}(x, p_T, Q^2) \otimes R_{A/D}^{FF}(z, p_T, Q^2)$$

  - With the parton model, one can use the approximated relationship, $\vec{P}_T = \vec{p}_\perp + z_h \vec{k}_\perp$, to study the medium modification effects of BM TMDs and Collins-FF seprately at the same time!

  - At the bottom line, we can safely study the correlations of $\cos(2\phi)\ vs.\ P_T$ in different nuclei, before worry about the theory issues, such as the factorization region.

New Study with CLAS12

- First Nuclear TMD measurement with CLAS12 in Hall-B:



  - Existing approved experiments (Run-Group B, D and E) contains all unpolarized targets we need to study SIDIS from light to heavy nuclei
  - Developing a new run-group proposal on top of these to perform the first measurement of nuclear TMD and Fragmentation Functions (Z. Ye, H. Avakian, K. Hafidi)
  - Working closely with theorists who are performing the first calculation of Unpolarized TMD, Boer-Mulders TMD and others in nuclei. (I. Cloet, Xin-Nian Wang, and Z.T Liang)
  - Will extend the study to polarized target to study nuclear medium modified g1-TMD
  - Would be pioneering study on nuclear-TMD before EIC

E12-07-104	Neutron magnetic form factor	Gilfoyle	A-	30	90	Neutron detector RICH (1 sector) Forward tagger	11	B K. Hafidi	liquid D_2 target
PR12-11-109 (a)	Dihadron DIS production	Avakian	-	-					
E12-09-007a	Study of partonic distributions in SIDIS kaon production	Hafidi	A-	56					
E12-09-008	Boer-Mulders asymmetry in K SIDIS w/ H and D targets	Contalbrigo	A-	TBA					
E12-11-003	DVCS on neutron target	Niccolai	A	90					
E12-06-106	Color transparency in exclusive vector meson production	Hafidi	B+	60	60		11	D	Nuclear
E12-06-117	Quark propagation and hadron formation	Brooks	A-	60	60		11	E	Nuclear

We also can have similar study on SoLID (more statistics, lower uncertainties).

New Study with CLAS12

- Simulation Study:

- Beam energy, E0 = 8.8 and 11 GeV
- Targets:
  a) D2 (totally 90 PAC days, plus approved E12-11-003 and other CLAS12 Run-Group B experiments)
  b) H1, D2, C12, Fe56, Sn119 (totally 60 PAC days, with 40+ days of production data taken, together with approved E12-06-106)
  c) N14, Ar40, Kr85, Au197 (totally 60 PAC days, assuming 10 days for each target, together with approved E12-06-117)

- Hadrons: detecting all pions and kaons

Rate (KHz)	pi+	pi-	K+	K-
C12	1.16	0.43	0.34	0.16

- Acceptance:
  electrons: 6.5 < theta < 40 degrees, 0< phi < 360 *80% (Gaps between six sectors)
  hadrons: 5.0 < theta < 40 degrees, 0< phi < 360 *80% (Gaps between six sectors)

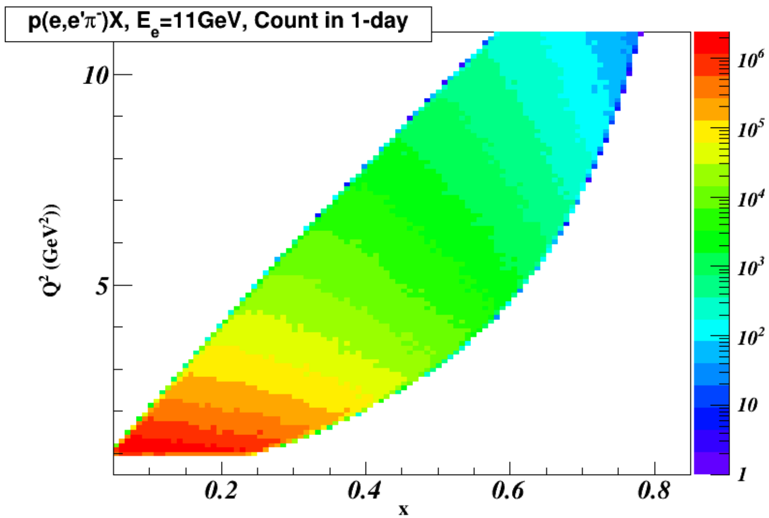
- Using unpolarized SIDIS generator developed for SoLID to generate MC events

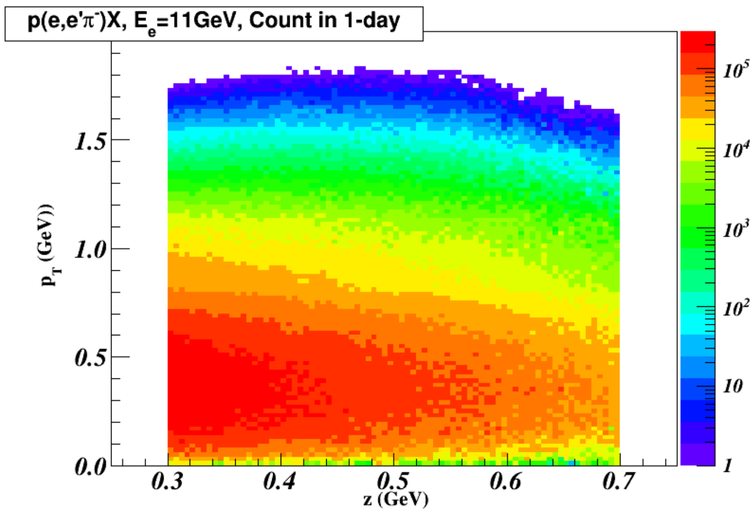
- Using CLAS12-FastMC to build in the CLAS12 acceptance; Assuming 85% totally detector efficiency

- Using the maximum CLAS12 luminosity (1e35/A cm-2 s-1, note: scaled by the nuclear number A)

New Study with CLAS12

- Binning of MC Data (Binning method as demo):





- Bin the Q2 and z first, by defining the following boundaries:

  $Q^2[5] = [1.0,\ 2.0, 3.5, 5.5, 10.0]\ GeV^2, \qquad z[7] = [0.3, 0.35, 0.4, 0.45, 0.5, 0.6, 0.7]$

- Further bin the data on pT and x:

  $p_T[\leq 9] = [0.0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6] GeV/c$

  Note: merge a bin to its larger bins until the total events >= 1e5 (before binning on x)

  $x_B[N]$ = [from 0.0 to 1.0, step=0.02], increase the step size if the total events in the bin is <1e4

- Projected results (see plots on next few slides):

  a) Choose C12 target as examples (other targets should have similar statistical budges)

  b) Each projected data file has the detected hadron (pi+,pi-, K+, K-), and in which (Q2, z) bin

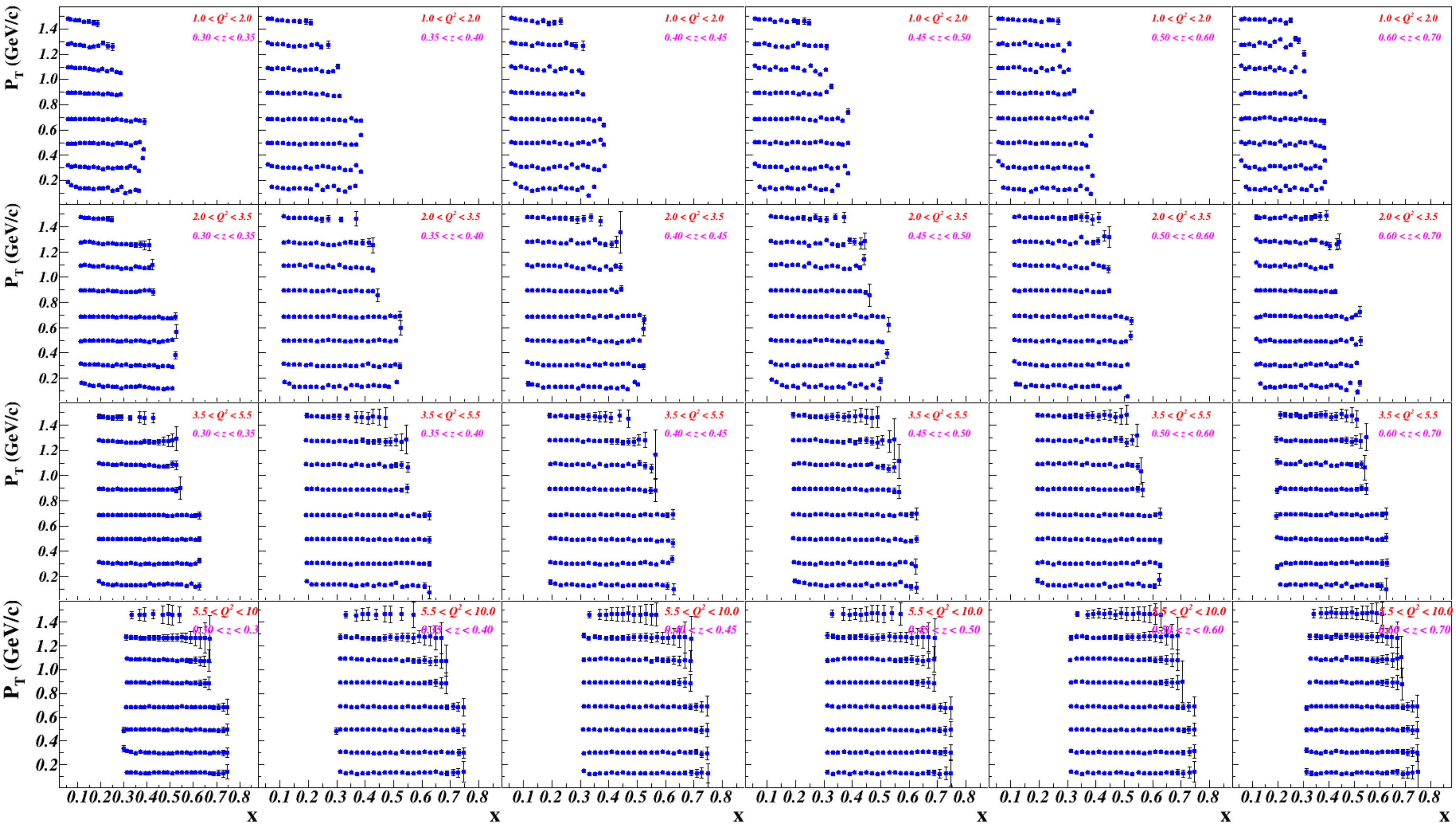
  c) Statistical error delta_stat = 1./sqrt(N_exp_count)

  d) No central values of any observables. Need theoretical inputs

New Study with CLAS12

- Projected Data Coverage and Statistical Accuracy:

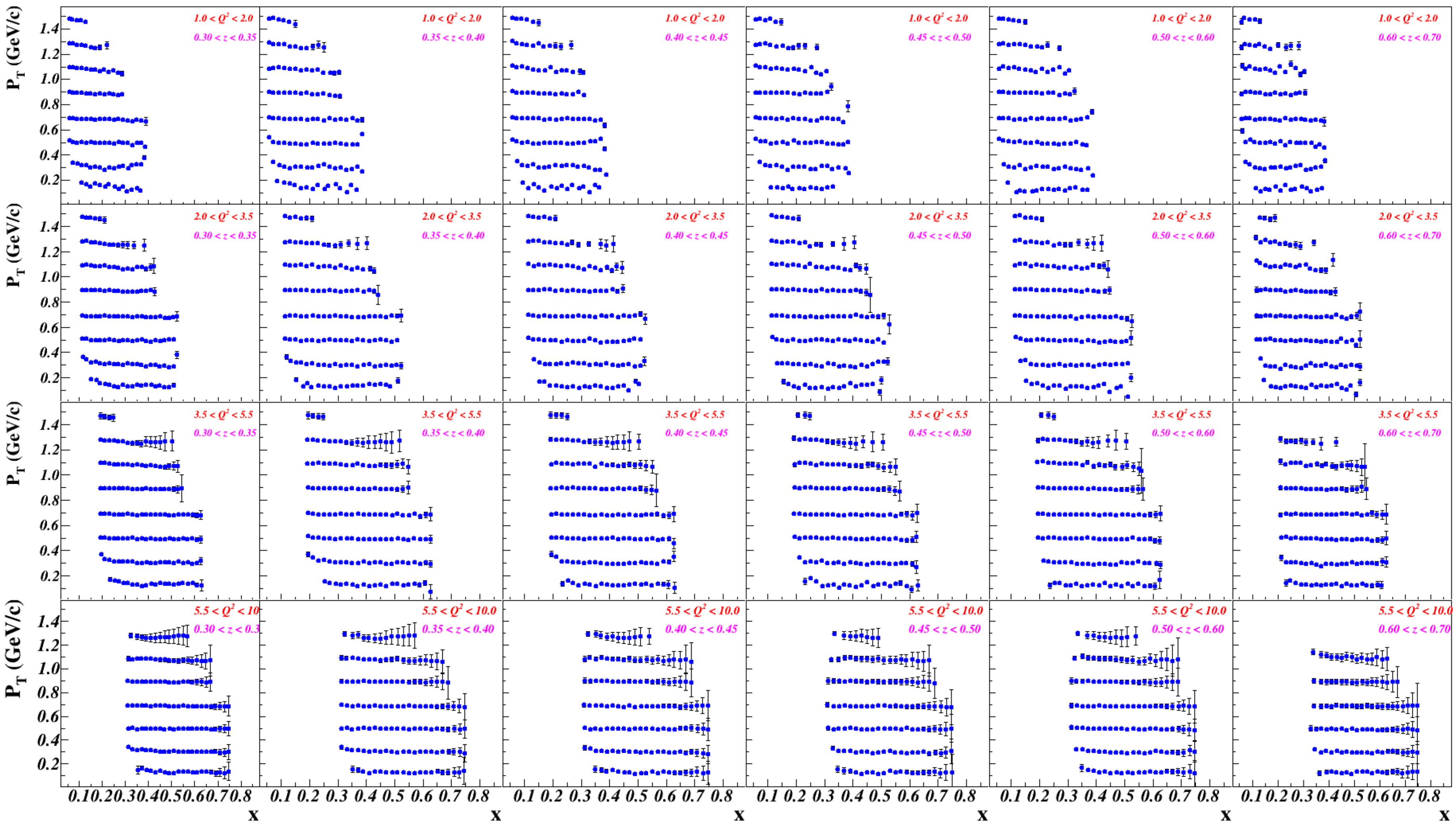
$$^{12}C(e,e'\pi^+)X$$



New Study with CLAS12

- Projected Data Coverage and Statistical Accuracy:

$$^{12}C(e, e'\pi^-)X$$



New Study with CLAS12

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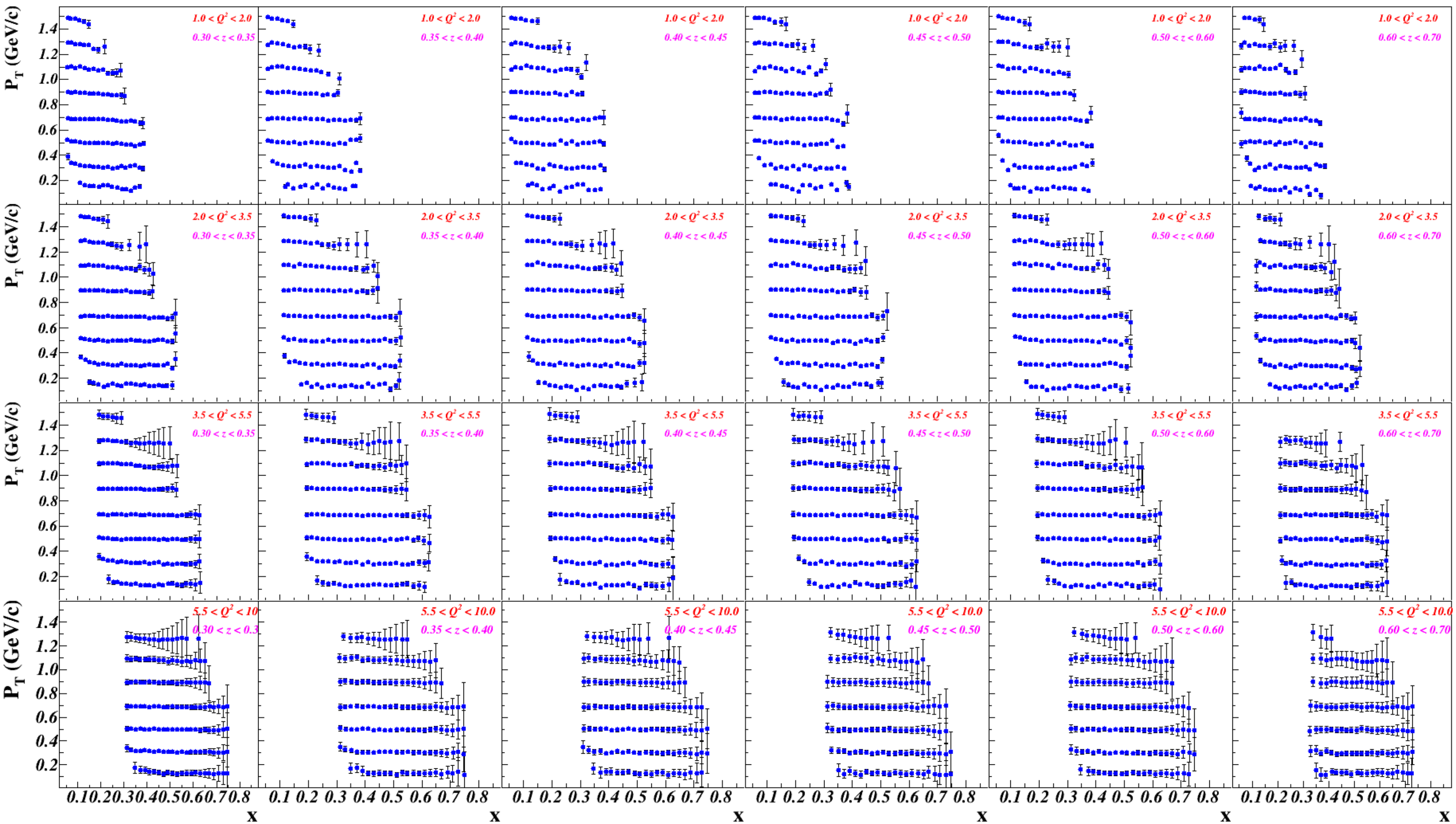
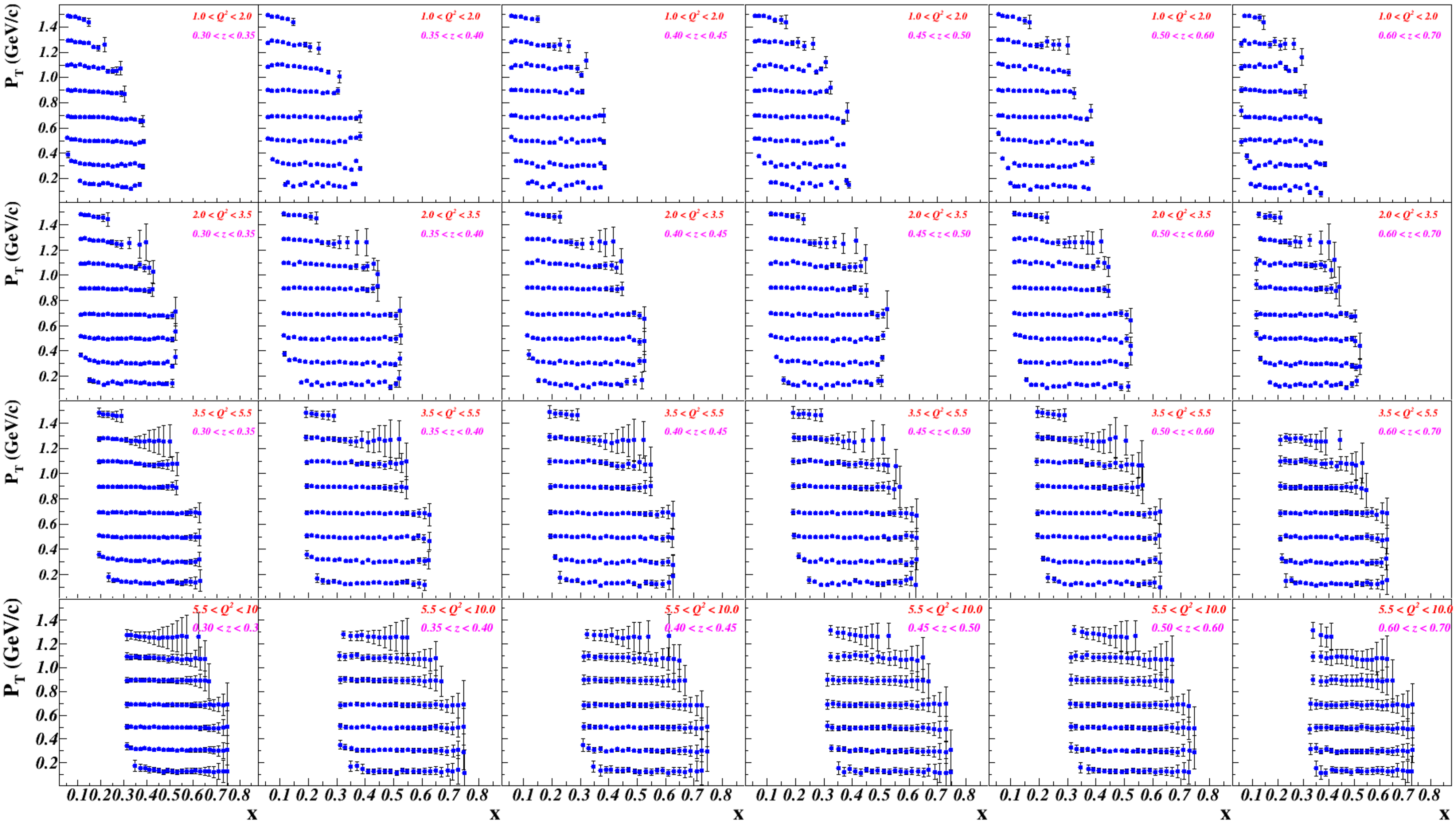


New Study with CLAS12

- Projected Data Coverage and Statistical Accuracy:

$${}^{12}C(e, e'K^{-})X$$



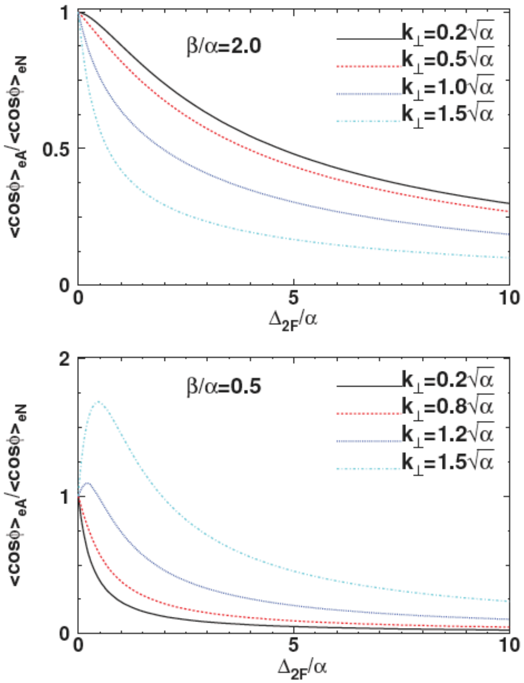
Drell-Yan Process

Medium Modification in SIDIS

- Some works done by Xin-Nian Wang et. al

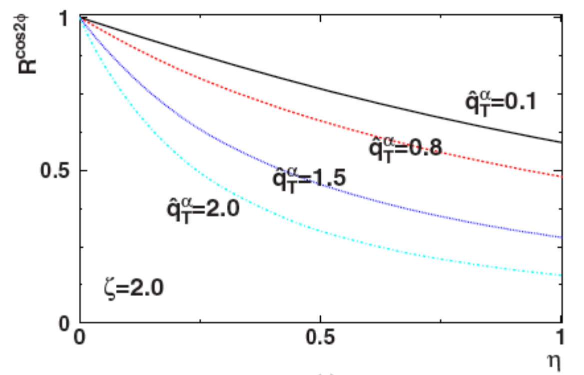
Unpolarized SIDIS: PHYSICAL REVIEW C 81, 065211 (2010)

$$\frac{\langle\langle\cos\phi_h\rangle\rangle_{eA}}{\langle\langle\cos\phi_h\rangle\rangle_{eN}} = \sqrt{\frac{\beta z^2 + \alpha_F}{(\beta + \Delta_{2F})z^2 + \alpha_F}}$$

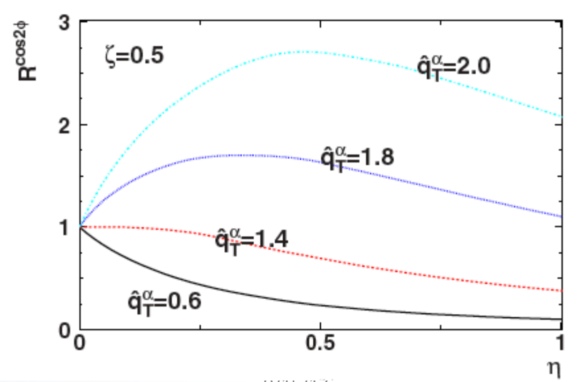


Unpolarized Drell-Yan:
PHYSICAL REVIEW C 89, 035204(2014)

$$R^{\sin 2\phi} \equiv \frac{A_{NA}^{\sin 2\phi}}{A_{NN}^{\sin 2\phi}} = \frac{(2\alpha + \Delta_{2F})(\sigma_1 + \beta)^3}{2\alpha(\sigma_1 + \beta + \Delta_{2F})^3} \times e^{-\frac{(\sigma_1+\beta-2\alpha)(\sigma_1+\beta+2\alpha+\Delta_{2F})\Delta_{2F}}{2\alpha(2\alpha+\Delta_{2F})(\sigma_1+\beta)(\sigma_1+\beta+\Delta_{2F})}\vec{q}_T^{\,2}},$$



(a)



Medium Modification on TMD

- Measuring medium modification effect of TMD via Drell-Yan

- Boer-Mulders TMD from unpolarized Drell-Yan, e.g. SeaQuest:

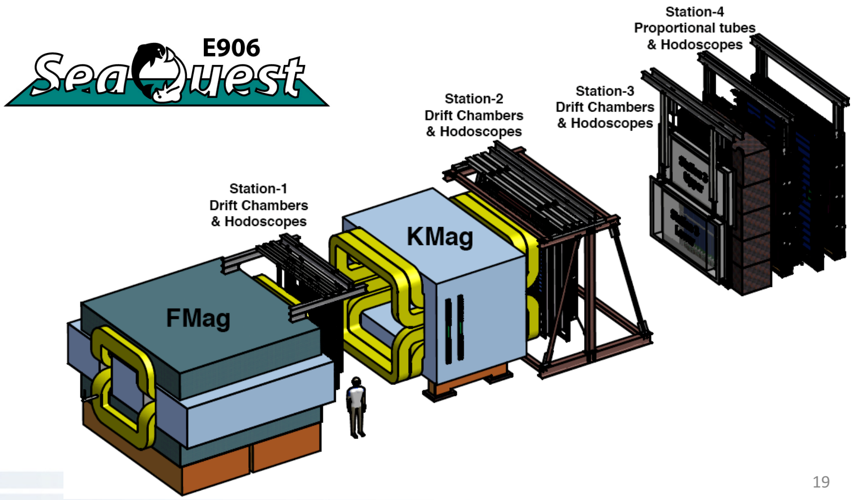
$$p + A \longrightarrow l^+ + l^- + X \quad \Rightarrow \quad \nu(\boldsymbol{A}) = \frac{2F_{UU}^{cos2\phi}}{F_{UU}^1 + F_{UU}^2} \propto \frac{h_1^{\perp q}(x_b) \cdot h_1^{\perp,\bar{q}}(x_t, A)}{f_1^q(x_b) \cdot f_1^{\bar{q}}(x_t, A)}$$

Sensitive to ***sea-quarks*** Boer-Mulders TMDs in heavy nuclei

- SeaQuest has been taking the data and continues accumulating more statistics
- ✓ Unpolarized targets (^{1}H, ^{2}D, ^{12}C, ^{56}Fe, and ^{184}W, *add more?)*
- ✓ The current data analysis of Boer-Mulders TMD is only focusing on 1D and ^{2}D, but straightforward to extend to heavier targets
- ✓ ***Data Exist! Will be a pioneering study***

Challenge: corrections of the acceptance effect?

Require sophisticated Monte-Carlo simulation.

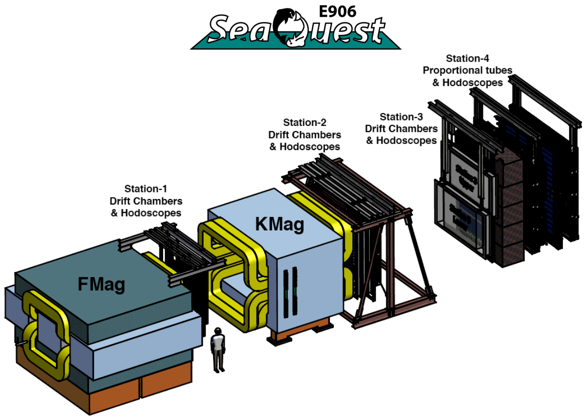


Medium Modification on TMD

➢ Measuring medium modification effect of TMD via Drell-Yan

❑ Sivers TMD from polarized proton-beam Drell-Yan (E1027)

$$A_{TU}(p^{\uparrow\downarrow} + A \rightarrow l^{+} + \bar{l}^{-} + X) \Rightarrow A_{TU}^{sin\phi_S} \propto \frac{f_1^{\bar{q}}(x_b) \cdot f_{1T}^{\perp q}(x_t, A)}{f_1^{q}(x_b) \cdot f_1^{\bar{q}}(x_t, A)}$$



- ✓ Sensitive to the Sivers-TMD of ***valance quark***
- ✓ Polarization is relative during the collision
- ✓ Can probe the medium modified Sivers TMD in the targets
- ✓ Study the modification of orbital angular momentum in heavy nuclei
- X ***SIDIS experiments (including EIC) are unlikely to study such effect***

❑ Also, from meson induced or anti-proton Drell-Yan (COMPASS, AFTER@LHC, PAX@FAIR, J-PAC)

Polarized DY, particularly with polarized anti-proton to light and heavy nucleus, would be more ideal to study nuclear TMD since a quark-TMD is convoluted with an anti-quark TMD.

Drawback:

- Drell-Yan process has generally low production rates, while TMD study requires good statistics and good precision
- Anti-Proton DY may not be able to provide high enough luminosity and good beam quality
- Pion DY requires good understanding of the pion-PDFs which are poor measured currently

Backup Slides

Medium Modification in SIDIS

➢ Measuring medium modification effect of unpolarized 1D-PDF & 1D-FF:

- As an "unrealistic" example, using free proton and free neutron, and measuring their charge-asymmetry ratio (1D-PDF & FF):

$e + N \longrightarrow e' + h^{\pm,0} + X$

$$\frac{d\sigma^h}{dxdydz} \propto \sum_q e_q^2 [f_1^q(x) \cdot D_q^h(z)] \Rightarrow \begin{aligned} D^{fav} &= D_u^{\pi^+} = D_{\bar{d}}^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-}, \\ D^{unfav} &= D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_u^{\pi^-} = D_{\bar{d}}^{\pi^-}, \end{aligned}$$

- First order approximations:

$$\begin{aligned}
N_p^{\pi^+} &\propto e_u^2 u(x) D^{fav}(z) + e_u^2 \bar{u}(x) D^{unf}(z) + e_d^2 d(x) D^{unf}(z) + e_d^2 \bar{d}(x) D^{fav}(z) + e_s^2 s(x) D^s(z) + e_s^2 \bar{s}(x) D^s(z) \\
N_p^{\pi^-} &\propto e_u^2 u(x) D^{unf}(z) + e_u^2 \bar{u}(x) D^{fav}(z) + e_d^2 d(x) D^{fav}(z) + e_d^2 \bar{d}(x) D^{unf}(z) + e_s^2 s(x) D^s(z) + e_s^2 \bar{s}(x) D^s(z) \\
N_n^{\pi^+} &\propto e_u^2 d(x) D^{fav}(z) + e_u^2 \bar{d}(x) D^{unf}(z) + e_d^2 u(x) D^{unf}(z) + e_d^2 \bar{u}(x) D^{fav}(z) + e_s^2 s(x) D^s(z) + e_s^2 \bar{s}(x) D^s(z) \\
N_n^{\pi^-} &\propto e_u^2 d(x) D^{unf}(z) + e_u^2 \bar{d}(x) D^{fav}(z) + e_d^2 u(x) D^{fav}(z) + e_d^2 \bar{u}(x) D^{unf}(z) + e_s^2 s(x) D^s(z) + e_s^2 \bar{s}(x) D^s(z)
\end{aligned}$$

- Get rid of the strangeness contribution by looking at the charge difference:

$$\begin{aligned}
N_p^{\pi^+} - N_p^{\pi^-} &\propto [e_u^2 \cdot [u(x) - \bar{u}(x)] - e_d^2 \cdot [d(x) - \bar{d}(x)]] \cdot [D^{fav} - D^{unf}] \\
N_n^{\pi^+} - N_n^{\pi^-} &\propto [e_u^2 \cdot [d(x) - \bar{d}(x)] - e_d^2 \cdot [u(x) - \bar{u}(x)]] \cdot [D^{fav} - D^{unf}]
\end{aligned}$$

- Get rid of the Fragmentation Function by taking the ratio of the charge differences:

$$R_{pn}^{\pi^{+-}} = \frac{N_p^{\pi^+} - N_p^{\pi^-}}{N_n^{\pi^+} - N_n^{\pi^-}} = \frac{e_u^2 \cdot [u(x) - \bar{u}(x)] - e_d^2 \cdot [d(x) - \bar{d}(x)]}{e_u^2 \cdot [d(x) - \bar{d}(x)] - e_d^2 \cdot [u(x) - \bar{u}(x)]}$$

- Directly measure the valance-like quark flavors:

$$\frac{d_v(x)}{u_v(x)} = \frac{d(x) - \bar{d}(x)}{u(x) - \bar{u}(x)} = \frac{e_u^2 + e_d^2 \cdot R_{pn}^{\pi^{+-}}}{e_u^2 \cdot R_{pn}^{\pi^{+-}} + e_d^2} = \frac{4 + R_{pn}^{\pi^{+-}}}{1 + 4R_{pn}^{\pi^{+-}}}$$

With mirror nuclei (He3 and H3, A=3), we can study the dv/dv in a A nucleus

Medium Modification in SIDIS

➢ Measuring medium modification effect of unpolarized 1D-PDF & 1D-FF:

- Kaon Detection ($K^+ = u\bar{s}, K^- = \overline{us}$):

$$N_p^{K^+} \propto e_u^2 u(x) D^{fav}(z) + e_u^2 \bar{u}(x) D^{unf}(z) + e_d^2 d(x) D^s(z) + e_d^2 \bar{d}(x) D^s(z) + e_s^2 s(x) D^{unf}(z) + e_s^2 \bar{s}(x) D^{fav}(z)$$
$$N_p^{K^-} \propto e_u^2 u(x) D^{unf}(z) + e_u^2 \bar{u}(x) D^{fav}(z) + e_d^2 d(x) D^s(z) + e_d^2 \bar{d}(x) D^s(z) + e_s^2 s(x) D^{fav}(z) + e_s^2 \bar{s}(x) D^{unf}(z)$$
$$N_n^{K^+} \propto e_u^2 d(x) D^{fav}(z) + e_u^2 \bar{d}(x) D^{unf}(z) + e_d^2 u(x) D^s(z) + e_d^2 \bar{u}(x) D^s(z) + e_s^2 s(x) D^{unf}(z) + e_s^2 \bar{s}(x) D^{fav}(z)$$
$$N_n^{K^-} \propto e_u^2 d(x) D^{unf}(z) + e_u^2 \bar{d}(x) D^{fav}(z) + e_d^2 u(x) D^s(z) + e_d^2 \bar{u}(x) D^s(z) + e_s^2 s(x) D^{fav}(z) + e_s^2 \bar{s}(x) D^{unf}(z)$$

- Remove the d-quark contribution by taking the charge difference:

$$N_p^{K^+} - N_p^{K^-} \propto [e_u^2 \cdot [u(x) - \bar{u}(x)] - e_s^2 \cdot [s(x) - \bar{s}(x)]] \cdot [D^{fav} - D^{unf}]$$
$$N_p^{K^-} - N_p^{K^-} \propto [e_u^2 \cdot [d(x) - \bar{d}(x)] - e_s^2 \cdot [s(x) - \bar{s}(x)]] \cdot [D^{fav} - D^{unf}]$$

- The ratio of the charge differences between a free proton and a free neutron:

$$R_{pn}^{K^{+-}} = \frac{N_p^{K^+} - N_p^{K^-}}{N_n^{K^+} - N_n^{K^-}} = \frac{e_u^2 \cdot [u(x) - \bar{u}(x)] - e_s^2 \cdot [s(x) - \bar{s}(x)]}{e_u^2 \cdot [d(x) - \bar{d}(x)] - e_s^2 \cdot [s(x) - \bar{s}(x)]} = \frac{1 - \frac{e_s^2}{e_u^2} R_{u_v}^S}{R_{u_v}^{d_v} - \frac{e_s^2}{e_u^2} R_{u_v}^S}$$

Medium Modification in SIDIS

- Extended to the heavy nuclei: $e + A \longrightarrow e' + h^{\pm,0} + X$
  - Both the PDFs and FFs are A-dependent!

$$N_A^{\pi^+} - N_A^{\pi^-} \propto [(u_A - \bar{u}_A)(Ze_u^2 - Ne_d^2) - (d_A - \bar{d}_A)(Ze_d^2 - Ne_u^2)] \cdot (D_A^{fav} - D_A^{unfav})$$

  - Using Deuteron and any Heavy nuclei: $R_{A/D}^{\pi^{+-}} = \dfrac{N_A^{\pi^+} - N_A^{\pi^-}}{N_D^{\pi^+} - N_D^{\pi^-}} = A(x) \cdot B(z),$ drop out Q2 dependent temperately

$$A(x) = \frac{(u_A - \bar{u}_A)(Ze_u^2 - Ne_d^2) - (d_A - \bar{d}_A)(Ze_d^2 - Ne_u^2)}{(u_D - \bar{u}_D)(e_u^2 - e_d^2) - (d_D - \bar{d}_D)(e_d^2 - e_u^2)}$$

$$B(z) = \frac{D_A^{fav} - D_A^{unfav}}{D_D^{fav} - D_D^{unfav}}$$

For symmetry nuclei (Z=N):

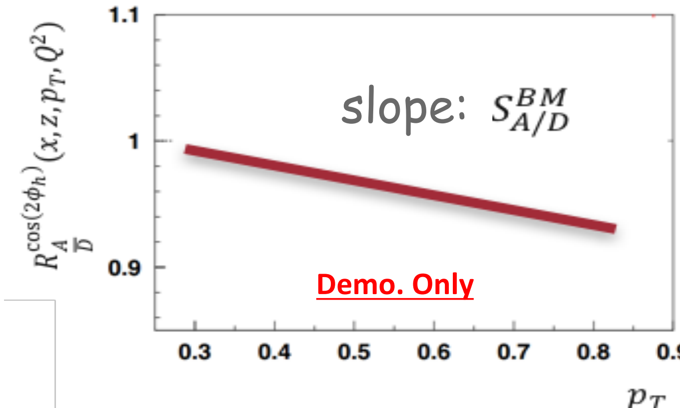
$$A(x)|_{Z=N} = \frac{A}{2}\frac{(u_A - \bar{u}_A) - (d_A - \bar{d}_A)}{(u_D - \bar{u}_D) - (d_D - \bar{d}_D)} = \frac{A}{2}\frac{u_{v,A} - d_{v,A}}{u_{v,D} - d_{v,D}}|_{Z=N}$$

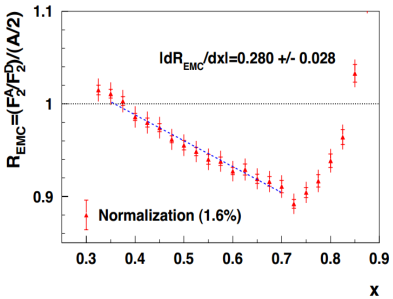
✓ The ratio can be factorized into x-dependence (1D-PDFs) and z-dependence (1D-FFs)

Medium Modification in SIDIS

- More crazy ideal → Testing the origin of medium modification effect:
  - If BM is modified in different nuclei, we should be able to see a "EMC-Like" slop (e.g., vs. p_T)

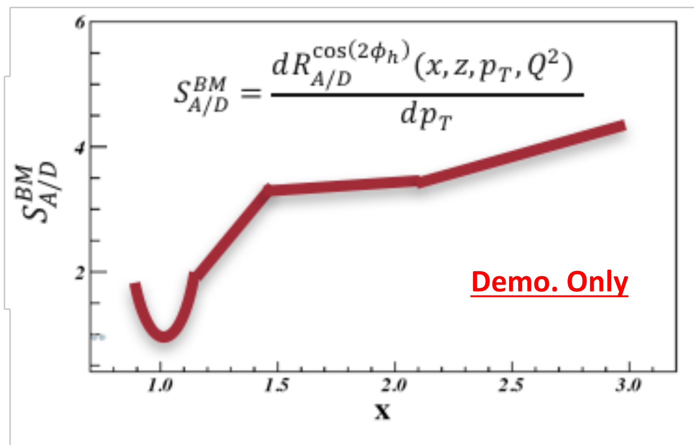
EMC-Like Slope?



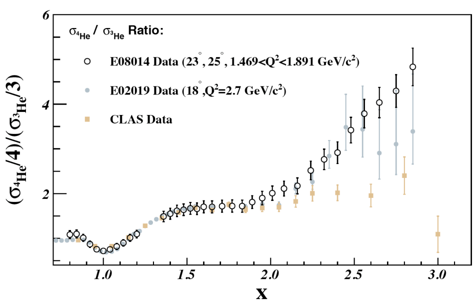


  - If the modification is due to the high density configuration (SRC), we can see "scaling" at x>1

Connect to SRC?



Z. Ye, to be submitted to PRL soon



  - Will be striking if we can see any of these hints, but they are very hard to measure
  - Require **very very high luminosity** and larger acceptance devices (SoLID, luminosity updated CLAS12 and EIC)