SIDIS Experiments with A=3 Nuclei

Zhihong Ye

清華大學
Tsinghua University

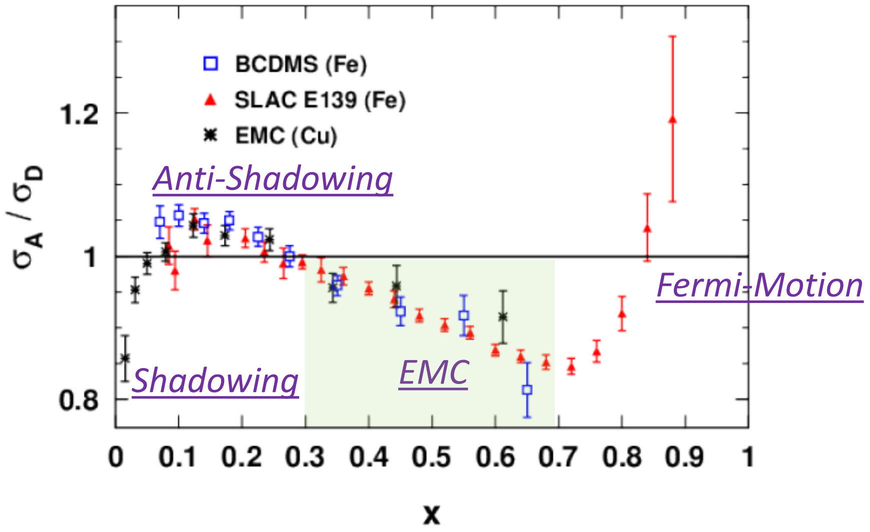
On behalf of the spokespeople:
D. Dutta, D. Gaskell, O. Hen, D. Meekins, D. Nguyen, L. Weinstein*, J. R. West, Z. Ye

06/04/2021, CLAS Collaboration Meeting

Flavor-Dependent EMC Effect

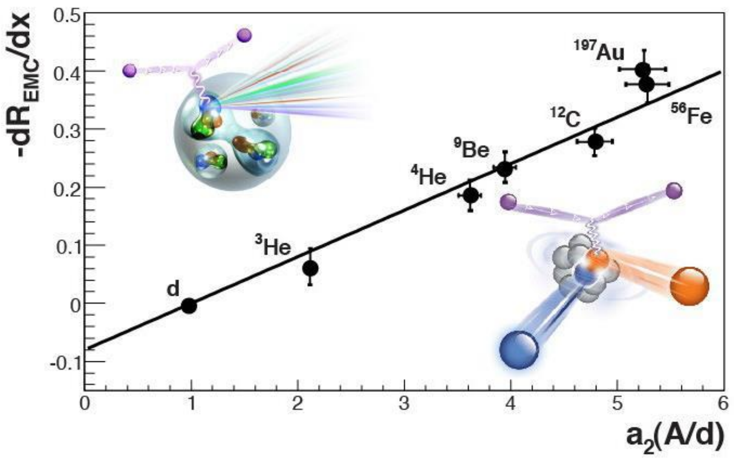
➢ What is the EMC Effect?

❖ The ratio of inclusive DIS cross-section between a nucleus-A to the deuteron drops linearly in 0.3<x<0.7



- Requires nucleon structure modification
- No accepted explanation
- New experimental techniques are needed

❖ EMC slope proportional to number of short range correlated (SRC) pairs:



L. Weinstein et al, PRL 106, 052301 (2011)
O. Hen et al, RMP

What are Short-Range Correlations?

- SRC pairs are predominantly pn
- Nucleons in SRC pairs are at high relative momentum
- Overlapping?

❖ Outstanding Question: Which nucleons are modified?
- All nucleons are equally modified by the mean field; Or,
- Only nucleons in SRC pairs are modified,
  i.e. in asymmetric nuclei, minority nucleons are more modified?

Flavor-Dependent EMC Effect

➢ What is the EMC Effect?

❖ More questions related to the EMC effect:

- Isospin dependence for the same A?
- Flavor-dependence?
- EMC effects in sea-quarks?

Need new observables beyond inclusive DIS

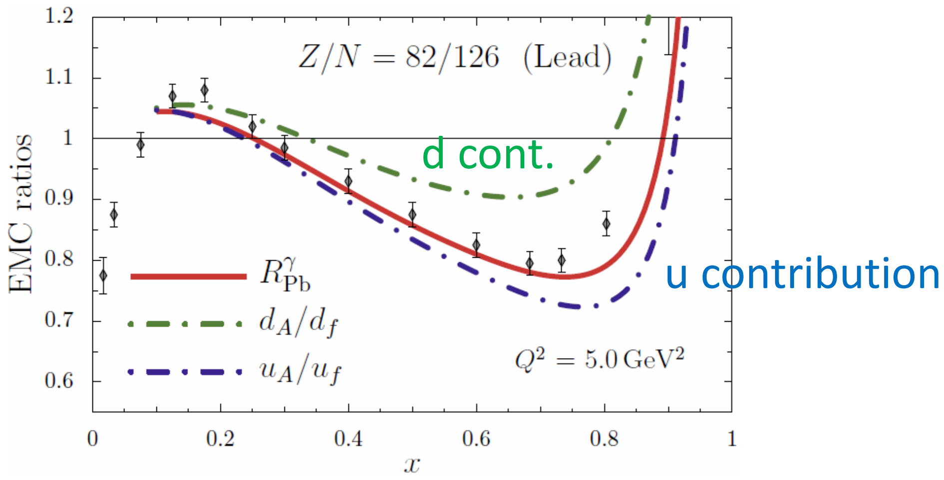
Need wide kinematic ranges (Jlab + EIC)

- Connection to lower-x phenomena (the integrated momentum has to be conserved)?

❖ Theoretical calculation of Gold nPDF indicates a flavor-dependent EMC effect

In $Z \neq N$, different medium effect on u- and d- quark:

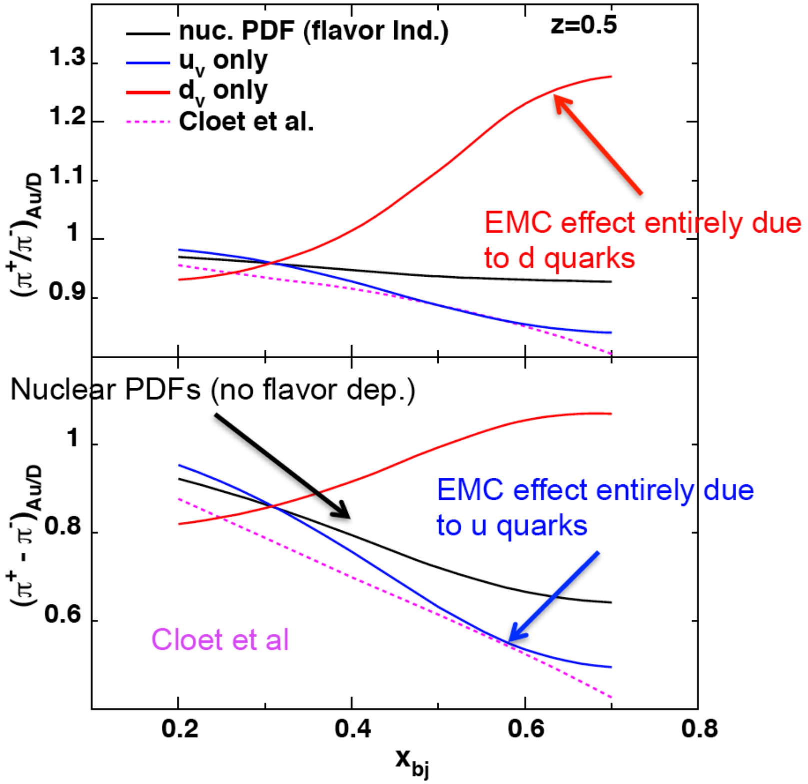
✓ If N>Z, u-quark is more "bound"
✓ If N<Z, d-quark is more "bound"



I. Cloet, et al, PRL 109, 182301 (2012); PRL 102, 252301 (2009)]

$$\frac{Au(\pi^+/\pi^-)}{d(\pi^+/\pi^-)}$$

$$\frac{Au(\pi^+ - \pi^-)}{d(\pi^+ - \pi^-)}$$



❖ New experimental observables: SIDIS with nuclear targets!

Semi-Inclusive DIS Measurement with Nuclei

- SIDIS kinematics:

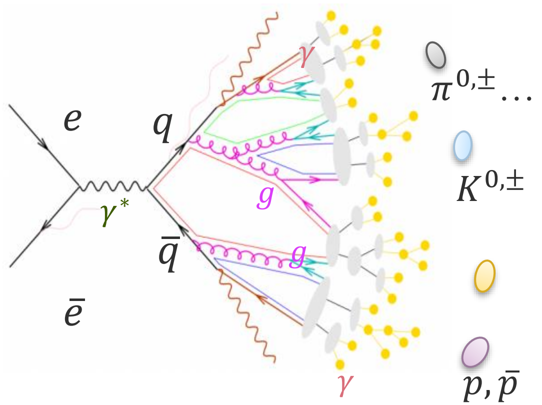
❖ Unpolarized SIDIS Cross Section (LO, P_T integrated):

$$\frac{d\sigma^h}{dxdydz} = \frac{4\pi\alpha^2 s}{Q^4}\left(1 - y + \frac{y^2}{2}\right) \sum_q e_q^2 [\boxed{f_1^q(x)}\, \boxed{D_q^h(z)}]$$

Unpolarized PDF (from DIS)

Unpolarized Fragmentation Function (FF)

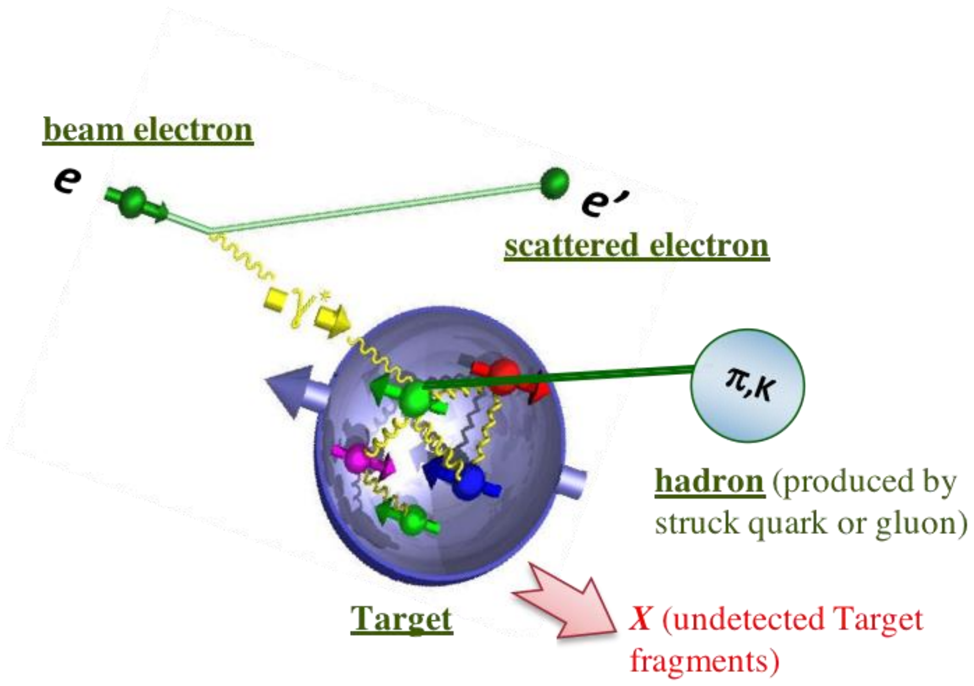
❖ Fragmentation Functions (FF):



- ✓ Describe the process of the struck quark fragmenting into a hadron
- ✓ Normally obtained from ($e + e^- \longrightarrow h^\pm + X$) data (e.g., BELLE)
- ✓ Can also be extracted from SIDIS by measuring the multiplicity:

$$M(Q^2, z) = \frac{\sigma_{SIDIS}}{\sigma_{DIS}} \simeq \frac{\sum_q e_q^2 f_1^q(Q^2, x) \cdot D_q^h(Q^2, z)}{\sum_q e_q^2 f_1^q(Q^2, x)}$$

Compared with PDFs which are well-measured, FFs are still poorly known.



$$x_B = \frac{Q^2}{2M\nu} = \frac{q \cdot P}{M} \qquad z = \frac{E_h}{\nu} = \frac{P \cdot P_h}{P \cdot q}$$

$$y = \frac{\nu}{E_l} = \frac{q \cdot P}{l \cdot P} \qquad P_T = \frac{p \cdot P_h}{|q^2|} = p_{h\perp}$$

Semi-Inclusive DIS Measurement with Nuclei

- SIDIS kinematics:
  - ❖ The proton's SIDIS yield in pion production:

$$Y_p^{\pi^\pm}(x,z) \propto F_{p,UU}^{\pi^\pm} = e_u^2 \cdot u(x) \cdot D_u^{\pi^\pm}(z) + e_u^2 \cdot \bar{u}(x) \cdot D_{\bar{u}}^{\pi^\pm}(z) + e_d^2 \cdot d(x) \cdot D_d^{\pi^\pm}(z) + e_d^2 \cdot \bar{d}(x) \cdot D_{\bar{d}}^{\pi^\pm}(z) + e_s^2 \cdot s(x) \cdot D_s^{\pi^\pm}(z) + e_s^2 \cdot \bar{s}(x) \cdot D_{\bar{s}}^{\pi^\pm}(z),$$

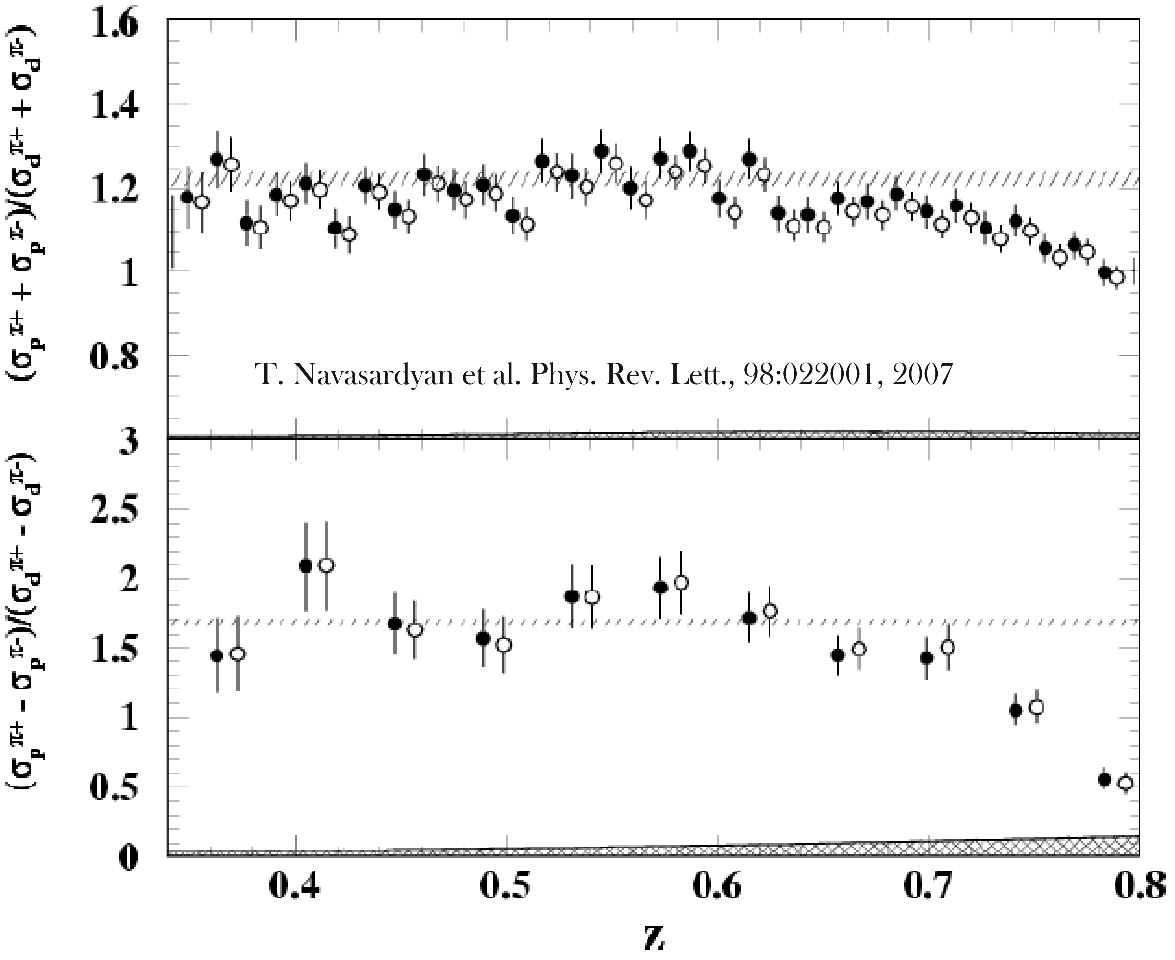
  - ❖ The Yield-Sum and Yield-Difference between pi+ and pi-:

$$Y_p^{\pi^+} + Y_p^{\pi^-} \propto [e_u^2 \cdot (u+\bar{u}) + e_d^2 \cdot (d+\bar{d})] \cdot [D^{fav} + D^{unf}]$$
$$Y_n^{\pi^+} + Y_n^{\pi^-} \propto [e_u^2 \cdot (d+\bar{d}) + e_d^2 \cdot (u+\bar{u})] \cdot [D^{fav} + D^{unf}]$$
$$Y_p^{\pi^+} - Y_p^{\pi^-} \propto [e_u^2 \cdot (u-\bar{u}) - e_d^2 \cdot (d-\bar{d})] \cdot [D^{fav} - D^{unf}]$$
$$Y_n^{\pi^+} - Y_n^{\pi^-} \propto [e_u^2 \cdot (d-\bar{d}) - e_d^2 \cdot (u-\bar{u})] \cdot [D^{fav} - D^{unf}]$$

  - ❖ FFs cancel in LO in Ratios of Yield-Sum and Yield-Difference

$$R_{p/n}^{\pi,\pm}(x,z) = \frac{(Y_p^{\pi^+} \pm Y_p^{\pi^-})}{(Y_n^{\pi^+} \pm Y_n^{\pi^-})} = \frac{4(u\pm\bar{u}) \pm (d\pm\bar{d})}{4(d\pm\bar{d}) \pm (u\pm\bar{u})}$$

- ❖ Simplified Leading-Order formulas show the sensitivities of physics observables
  - ✓ Hall-C E10-108 data (H1 vs D2) shows no strong z-dependence, indicating that LO is working at certain levels.



- ❖ More sophisticated global analysis are generally carried out by theorists to perform with measured SIDIS cross sections.

Semi-Inclusive DIS Measurement with Nuclei

- **Study Medium-Modification Effects of PDFs via SIDIS:**
  - Unpolarized SIDIS Cross Section (LO, P_T integrated):

$$\frac{d\sigma^h}{dxdydz} = \frac{4\pi\alpha^2 s}{Q^4}\left(1 - y + \frac{y^2}{2}\right)\sum_q e_q^2 \boxed{f_1^q(x)}\, \boxed{D_q^h(z)}$$

Unpolarized nuclear PDF (nPDF)

Unpolarized nuclear Fragmentation Function (nFF)

$$u_A = \frac{Z\tilde{u} + N\tilde{d}}{A},\ d_A = \frac{Z\tilde{d} + N\tilde{u}}{A},\ s_A = s,$$

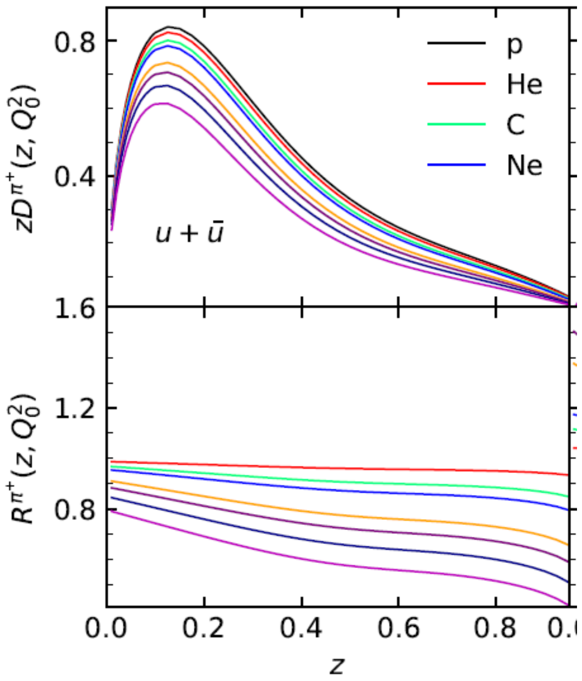
- Ratios between two nuclei:

$$R^{\pi,\pm}_{A_1/A_2}(x,z) = \frac{(Y^{\pi^+}_{A_1} \pm Y^{\pi^-}_{A_1})/A_1}{(Y^{\pi^+}_{A_2} \pm Y^{\pi^-}_{A_2})/A_2}$$

$$= \frac{4(u_{A_1} \pm \bar{u}_{A_1}) \pm (d_{A_1} \pm \bar{d}_{A_1})}{4(u_{A_2} \pm \bar{u}_{A_2}) \pm (d_{A_2} \pm \bar{d}_{A_2})} \cdot \frac{D^{fav}_{A_1} \pm D^{unfav}_{A_1}}{D^{fav}_{A_2} \pm D^{unfav}_{A_2}}$$

$A^{\pi,\pm}_{A_1/A_2}(x)$ $B^{\pi,\pm}_{A_1/A_2}(z)$

Strangeness contribution is ignored in Yield-Sum-Ratio while cancelled in Yield-Different-Ratio while



- FFs are also significantly modified in heavy nuclei

Pia Zurita, arXiv:2101.01088

- Pros:
  - Sensitive to the flavor-contents of the DIS reaction
  - Sensitive to the 3D structure of the nucleus (nTMDs, nFFs)
- Cons:
  - Nuclear structure uncertainties
  - Fragmentation Function uncertainties
    - Not well known
    - Must measure in a valid current fragmentation region
  - Hadronization uncertainties
  - Limited detector ranges (e.g, pT coverage)
  - Complicated theoretical corrections for SIDIS

- How to take advantage of the pros while minimizing the cons?

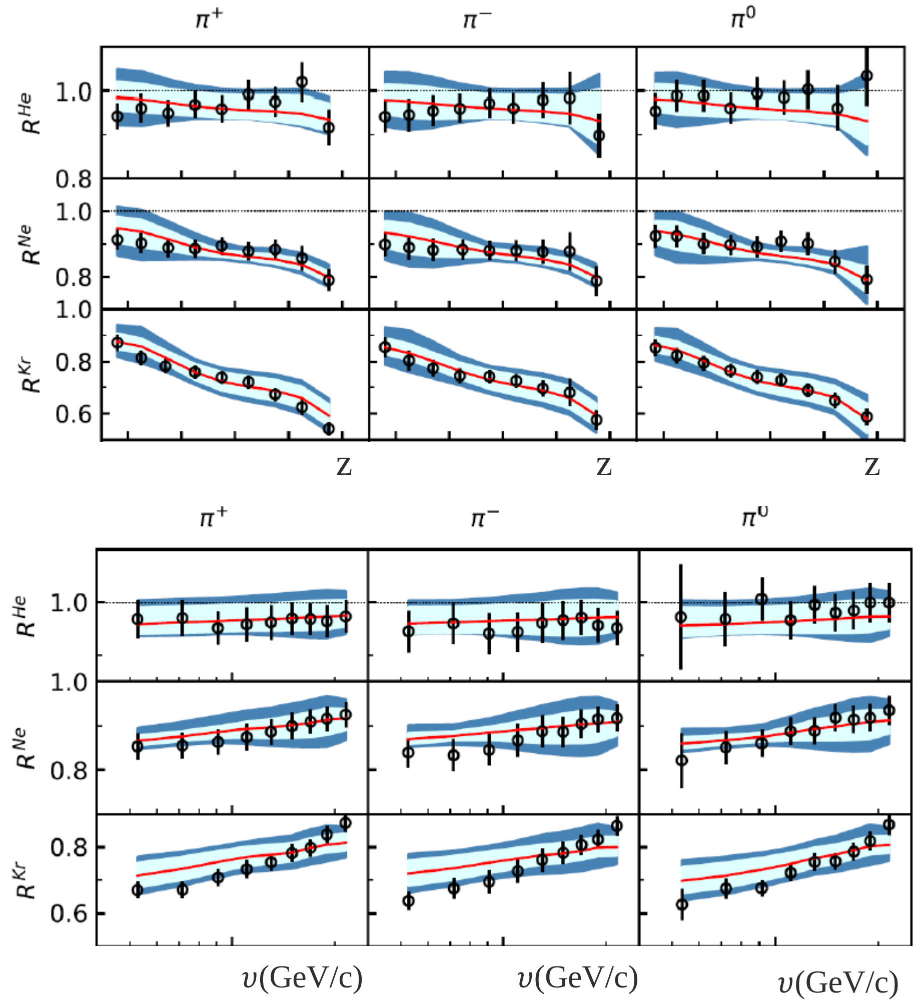
Why we study A=3 Nuclei

➢ Tritium and Helium-3:

- ❖ Use the Mirror nuclei to minimize cons
  - ✓ Exact nuclear calculations possible (assuming an NN potential)
  - ✓ The EMC effect is small but still significant
  - ✓ SIDIS fragmentation functions
    - ✓ Should be similar in the mirror nuclei
    - ✓ should mostly cancel in ratios
  - ✓ Nuclear hadronization effects should be small

- ❖ Small (~ 5+/-3% at high-z) medium effects on He4's nFFs (Pia Zurita, arXiv:2101.01088)
- ❖ Should be even smaller in A=3 (calculation in progress by Pia Zurita)

Super-ratio of the multiplicity-ratios between A and D2



Y-axis

$$R_A^h(\nu, z, Q^2, p_T^2) = \frac{\left(\frac{N^h(\nu,z,Q^2,p_T^2)}{N^e(\nu,Q^2)}\right)_A}{\left(\frac{N^h(\nu,z,Q^2,p_T^2)}{N^e(\nu,Q^2)}\right)_d}$$

Semi-Inclusive DIS Measurement with A=3 Nuclei

- Flavor-Dependent EMC Effect in A=3:

  - Measure SIDIS pion-ratios of D2, H3 and He3

$$R^{\pi,\pm}_{A_1/A_2}(x,z) = \frac{(Y^{\pi^+}_{A_1} \pm Y^{\pi^-}_{A_1})/A_1}{(Y^{\pi^+}_{A_2} \pm Y^{\pi^-}_{A_2})/A_2}$$

$$= \frac{4(u_{A_1} \pm \bar{u}_{A_1}) \pm (d_{A_1} \pm \bar{d}_{A_1})}{4(u_{A_2} \pm \bar{u}_{A_2}) \pm (d_{A_2} \pm \bar{d}_{A_2})} \cdot \frac{D^{fav}_{A_1} \pm D^{unfav}_{A_1}}{D^{fav}_{A_2} \pm D^{unfav}_{A_2}}$$

$$A^{\pi,\pm}_{A_1/A_2}(x) \qquad B^{\pi,\pm}_{A_1/A_2}(z)$$

  - The nFF in A=3 are likely to be the same and very close to D2 (small medium effects), so:

$$B^{\pi,\pm}_{H/T}(z) \simeq B^{\pi,\pm}_{H/D}(z) \simeq B^{\pi,\pm}_{T/D}(z) \simeq 1$$

"D" as D2
"T" as "H3"
"H" as "He3"

  - Can also be measured independently from the ratio of the multiplicity-sum and –difference:

$$M^h(z) = \frac{\sigma_{SIDIS}}{\sigma_{DIS}} \propto \frac{\sum_q e_q^2 f_1^q(x) \cdot D_q^h(z)}{\sum_q e_q^2 f_1^q(x)}$$

$$\Rightarrow \quad B^{\pi,+}_{A/D}(z) = \frac{M^{\pi^+}_A + M^{\pi^-}_A}{M^{\pi^+}_D + M^{\pi^-}_D} = \frac{D^{fav}_A + D^{unfav}_A}{D^{fav}_D + D^{unfav}_D}$$

  - While the FF contribution being controlled, the SIDIS ratios (H3/D2 vs He3/D2) can get access to the flavor-dependent EMC effect

$$R^{\pi,+}_{H/D}(x) \simeq \frac{4(u_H+\bar{u}_H)+(d_H+\bar{d}_H)}{5(u+\bar{u})+5(d+\bar{d})} = \frac{9(u_{p,H}+\bar{u}_{p,H})+6(d_{p,H}+\bar{d}_{p,H})}{5(u+\bar{u})+5(d+\bar{d})},$$

$$R^{\pi,-}_{H/D}(x) \simeq \frac{4(u_H-\bar{u}_H)-(d_H-\bar{d}_H)}{3(u-\bar{u})+3(d-\bar{d})} = \frac{7(u_{p,H}-\bar{u}_{p,H})+2(d_{p,H}-\bar{d}_{p,H})}{3(u-\bar{u})+3(d-\bar{d})},$$

$$R^{\pi,+}_{T/D}(x) \simeq \frac{4(u_T+\bar{u}_T)+(d_T+\bar{d}_T)}{5(u+\bar{u})+5(d+\bar{d})} = \frac{6(u_{p,T}+\bar{u}_{p,T})+9(d_{p,T}+\bar{d}_{p,T})}{5(u+\bar{u})+5(d+\bar{d})},$$

$$R^{\pi,-}_{T/D}(x) \simeq \frac{4(u_T-\bar{u}_T)-(d_T-\bar{d}_T)}{3(u-\bar{u})+3(d-\bar{d})} = \frac{2(u_{p,T}-\bar{u}_{p,T})+7(d_{p,T}-\bar{d}_{p,T})}{3(u-\bar{u})+3(d-\bar{d})},$$

Two opposite assumptions to be tested:

- EMC effect is only A-dependent:
  - $u_{p,H} = u_{p,T}$
  - *p*,*n* equally modified
- EMC effect based on SRC pairs
  - $u_{p,H} = d_{n,T}$
  - *p* more modified in 3H, *n* in 3He

(e,e’) DIS Measurement with A=3 Nuclei (MARATHON)

- Used as Effective “free-Neutrons” to Study Partonic Structure:
  - New MARATHON Results (arXiv:2104.05850)

$$F_{H3} = F_{\tilde{p}} \otimes f_p^{H3} + 2F_{\tilde{n}} \otimes f_n^{H3}$$

$$F_{He3} = 2F_{\tilde{p}} \otimes f_p^{He3} + F_{\tilde{n}} \otimes f_n^{He3}$$

$$\rightarrow \frac{F_2^n}{F_2^p} = \frac{2\mathcal{R} - F_2^{^3\mathrm{He}}/F_2^{^3\mathrm{H}}}{2F_2^{^3\mathrm{He}}/F_2^{^3\mathrm{H}} - \mathcal{R}}$$

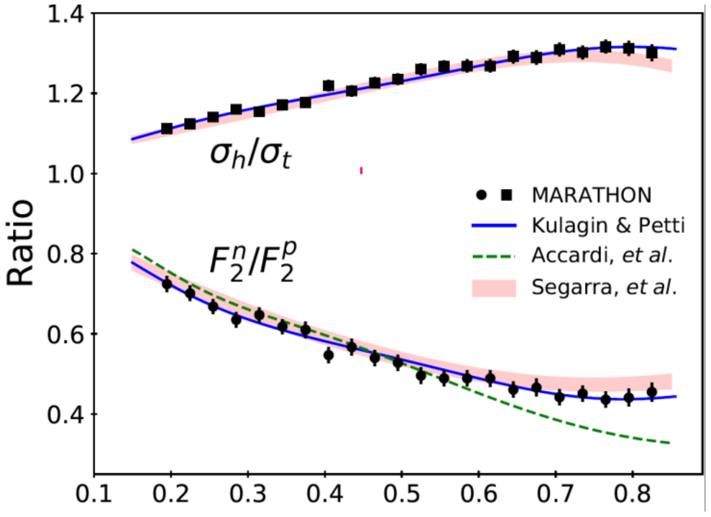
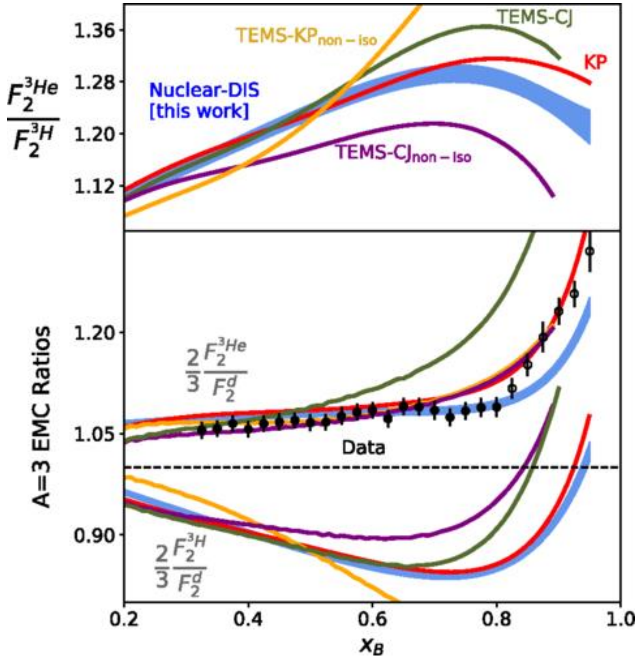


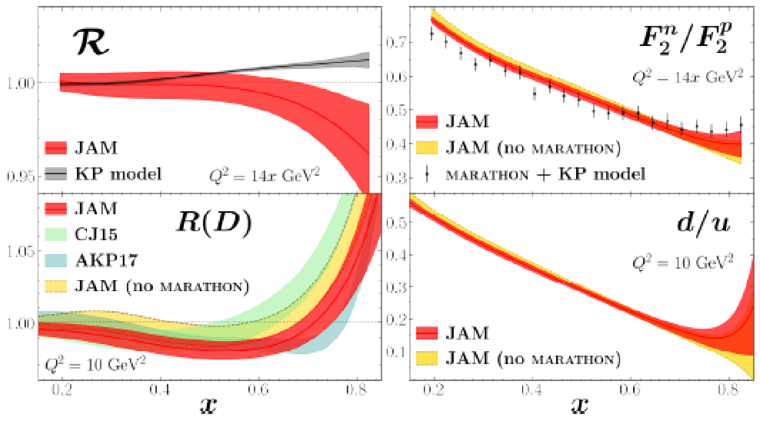
Figure is replotted by T. Kutz using the same result

- However, there are significant nuclear and off-shell nucleon corrections for extracting d/u from the inclusive data

E. P. Segarra, et. al. Phys. Rev. Lett. 124, 092002
arXiv:2104.07130v1



C. Cocuzza, et. al., arXiv:2104.06946v1



- We need to more directly measure whether u or d quark distributions are more modified in nuclei!

Semi-Inclusive DIS Measurement with A=3 Nuclei

- SIDIS between H3 and He3 (as "effective-free" nucleons):
  - If EMC effect is only A-dependent:
    - Like MARATHON, we can use H3 and He3 to study PDFs in nucleons
  - The FFs should be similar and mostly cancel in the ratios $D_H^{fav,unf} = D_T^{fav,unf}$
  - Direct probe of d/u (besides PVDIS)

$$R_{H/T}^{\pi,+} = \frac{9(u+\bar{u}) + 6(d+\bar{d})}{6(u+\bar{u}) + 9(d+\bar{d})}$$

$$R_{H/T}^{\pi,-} = \frac{7(u-\bar{u}) + 2(d-\bar{d})}{2(u-\bar{u}) + 7(d-\bar{d})}$$

$$\Rightarrow$$

$$\frac{d+\bar{d}}{u+\bar{u}} = \frac{9 - 6R_{H/T}^{\pi,+}}{9R_{H/T}^{\pi,+} - 6}$$

$$\frac{d-\bar{d}}{u-\bar{u}} = \frac{7 - 2R_{H/T}^{\pi,-}}{7R_{H/T}^{\pi,-} - 2}.$$

  - At high-x:

$$\frac{d}{u} \simeq \frac{9 - 6R_{H/T}^{\pi,+}}{9R_{H/T}^{\pi,+} - 6} = \frac{7 - 2R_{H/T}^{\pi,-}}{7R_{H/T}^{\pi,-} - 2}, \text{ when } x \to 1$$

Semi-Inclusive DIS Measurement with A=3 Nuclei

- Nuclear Effects in A=3 → from 1D to 3D:
  - The SIDIS SF with additional P_T dependence:

Unpolarized TMD *Unpolarized FF*

$$F_{UU}(x,z,P_T) = \sum_q e_q^2 [f_1^q(x,k_\perp) \otimes D_q^h(z,q_T)]$$

  - P_T is the only experimental quantity lined to intrinsic transverse components of the quark:

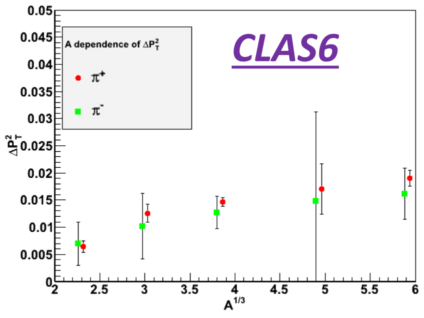
$$\vec{P}_T = z\vec{k}_\perp + \vec{q}_T + O(k_\perp^2/Q^2)$$

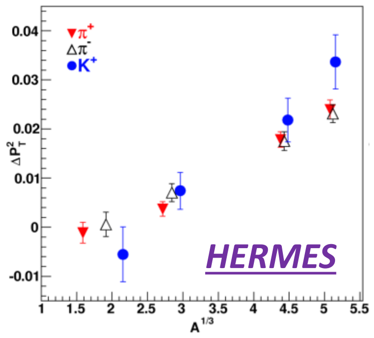
  - Actual P_T distribution is not well-known, Gaussian ansatz are commonly used:

$$f_1^q(x,k_T) = f_1^q(x)\frac{1}{\pi < k_T^2 >}exp(-\frac{k_T^2}{< k_T^2 >}),$$

$$D_1^q(z,q_T) = D_1^q(z)\frac{1}{\pi < q_T^2 >}exp(-\frac{q_T^2}{< q_T^2 >}),$$

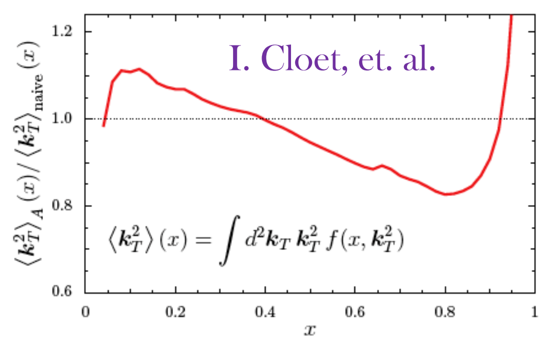
  - P_T broadening measured to study Hadronization:





3D TMD/FF in A=3

- ✓ Mapping out the realistic P_T distribution is crucial to the TMD program
  →H3 and He3 as "effective-free" nucleons in SIDIS to decouple P_T distributions for individual quark-flavor
- ✓ High precision 4D(Q2, x, z, pT) binning SIDIS data can access unpolarized TMDs and FFs in A=2 & 3 system
  →Extremely important for TMD measurements with polarized targets at JLab and on EIC
- ✓ Explore the medium-modification effects in the transverse directions (both TMDs and FFs)
  →A more comprehensive way of study the nuclear effect in 3D!



- ✓ Also allow us to test the Factorization and study the Hadron attenuation in light-nuclei

Semi-Inclusive DIS Measurement with A=3 Nuclei

- From MARATHON to Tritium-SIDIS

LOI12-19-005

Title: "Next Generation Tritium Experiments in CLAS12"

Spokespersons: D. Gaskell, D.W. Higinbotham, D. Meekins (Jlab), O. Hen (MIT), D. Dutta (Mississippi State), L.B. Weinstein (Old Dominion), Z. Ye (ANL), S. Sirca, M. Mihovilovic (U. Ljubljana)

PAC47 Report

Issues: The main technical issue is the use of tritium in CLAS12 as target material. The highly successful program completed in Hall A was a logistical tour de force. The geometry of the CLAS12 detector will impose new constraints on the target design and operation. The LOI states that there will be cost savings since certain R&D efforts will not need to be repeated. However, those will be at least partially offset by new requirements needed for Hall B. As stated in the LOI, a new target cell that is better matched to the cylindrical symmetry of CLAS12 will have to be designed, engineered and tested. The TAC report lists issues that will need to be dealt with.

✓New Tritium-SRC Experiment, E12-20-005, has been approved with new Tritium-Target system

Summary: A program of SIDIS experiments on A=2 and A=3 nuclei would form a natural and important component of the JLab 12 GeV program on light nuclei. It would also fit in well into the framework of mapping the full 3D partonic structure of nuclei.

For a full proposal the physics motivation must be made stronger. It will be specifically helpful if more detailed theoretical work is included together with usual experimental details. The high-x SIDIS program will complement the analysis of data from the existing inclusive experiments, but a stronger case is needed in identifying observables in SIDIS that would **not** be possible to extract otherwise. This may include the possibility of detecting kaons in the final state as potential tag on the nuclear dependence of strange quark distributions in the nucleon.

The Measurement

- Propose to run in CLAS12 with standard setup:
  - Targets: D2/H3/He3, with the same target system in the approved Tritium-SRC proposal (**E12-20-005**)

Material	Tritium	Al Windows	Be Window	Total
Length(g/cm^2)	0.085	0.21	0.037	0.33
Luminosity	3.54×10^{34}	8.42×10^{34}	1.54×10^{34}	1.35×10^{35}

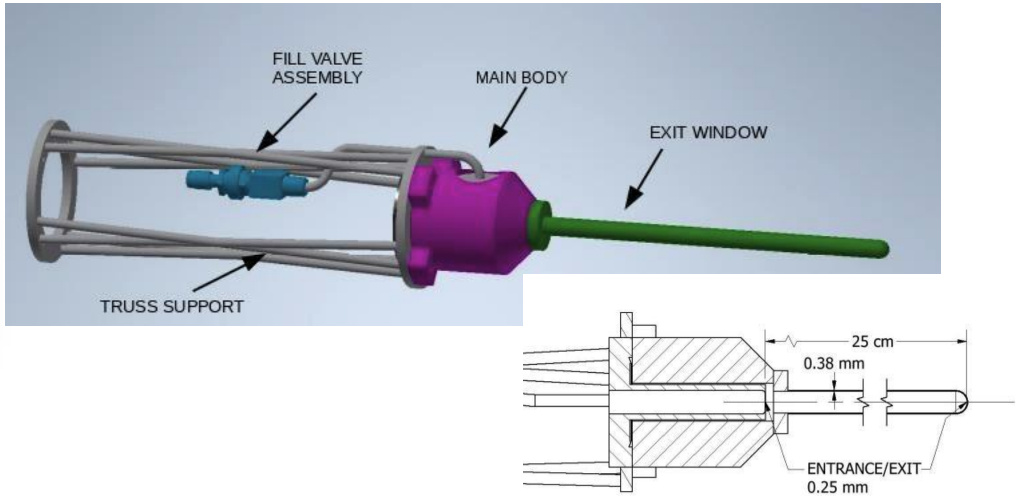
  - Beam-Time request:

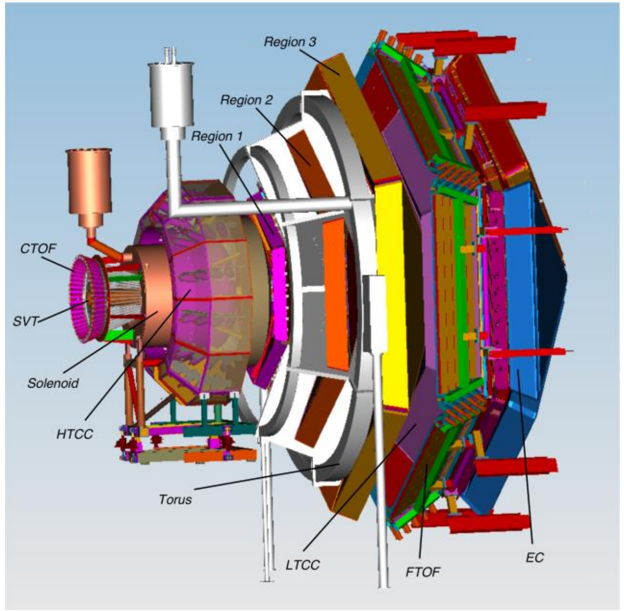
Target:	^{2}D	^{3}He	^{3}H	Total
Measurement Days (10.6 GeV)	10	20	20	50
Calibration: Luminosity, dummy, H				5
Target Changes				2
Torus polarity reversals				1
			Total at 10.6 GeV:	58

  - Error budget:

	Sectors	Tracking	Vertex	Fiducial	Acceptance
Uncertainty (%)	0.34	0.13	0.16	0.41	0.1

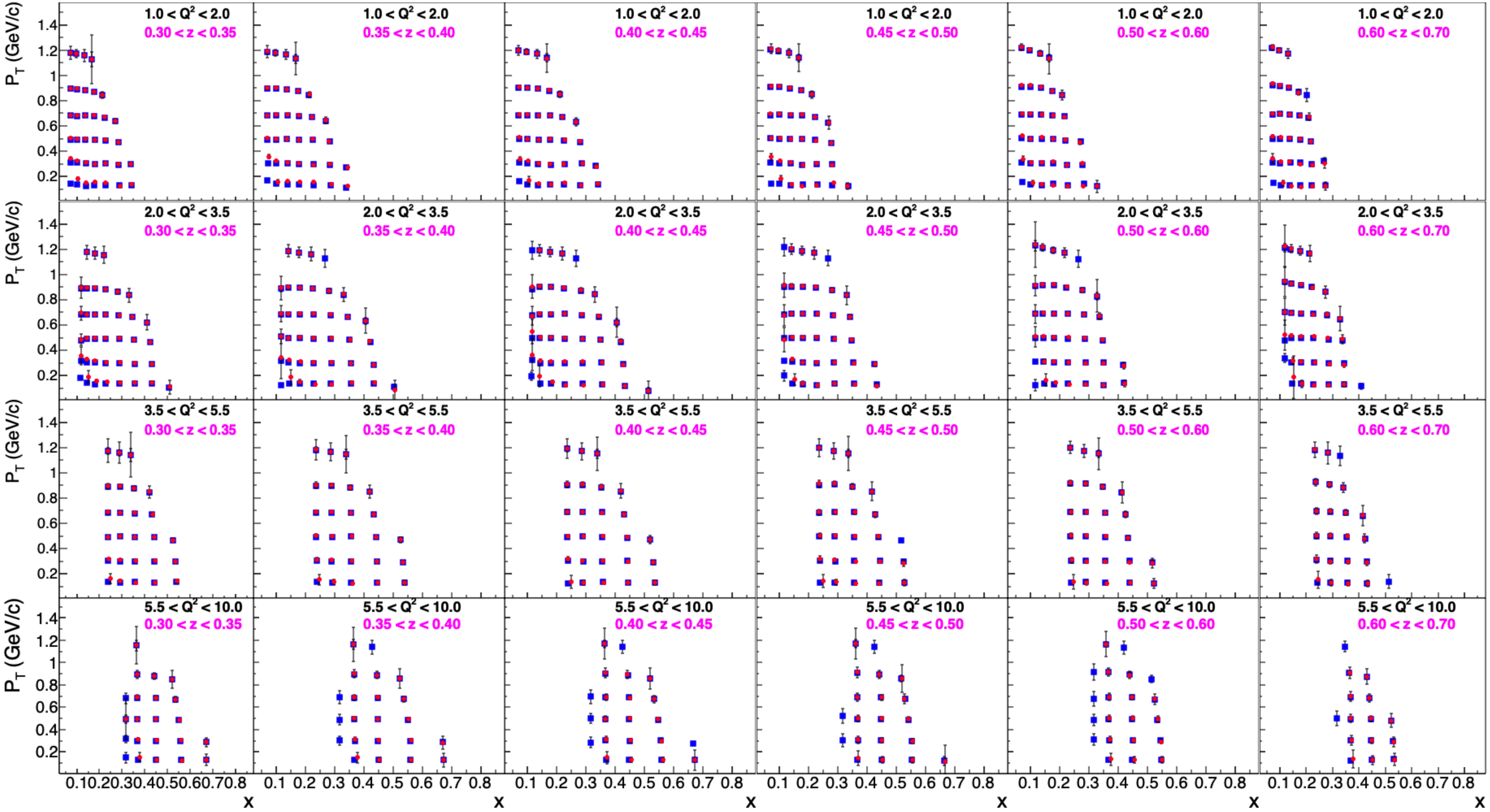
  - Detected scattered electrons and pions (also kaons if full-size RICH is available)
    - Flip the Torus field often to minimize the different acceptance of π^+, π^-
  - Kinematic cuts:
    - $Q^2 > 1$ GeV^2, $W > 2$ GeV, $0.1 < y < 0.85$, $0.3 < z < 0.7$
  - Bin the data in 4D (Q^2, x, z, P_T)





Semi-Inclusive DIS Measurement with A=3 Nuclei

➢ Projected Results of A=3 in SIDIS: Pion Data 4D Binning



Blue → π^+
Red → π^-

Semi-Inclusive DIS Measurement with A=3 Nuclei

- Projected Results of A=3 in SIDIS :

  - This experiment is mostly data-driven (lack of existing theoretical predictions)

  - **More sophisticated theoretical predictions are underway:**
    - ✓ Chris Cocuzza, Nobuo Sato, Wally Melnitchouk, et.al (NLO SIDIS Structure-Functions based on arXiv:2104.06946)
    - ✓ Jennifer Rittenhouse West, et. al, based on diquark-models, arXiv:2009.06968, Nucl. Phys. A 1007:122134
    - ✓ Pia Zurita, NLO SIDIS Structure-Functions, based on arxiv:2101.01088
    - ✓ Ian Cloet, et. al.

  - Models used in this simulation:
    - CJ15-LO as free-PDFs
    - KP Model calculated for MARATHON analysis (A-dependent, some off-shell effect built in, no isospin effect)
    - SLAC-fit from J. Gomez (Phys. Rev. D 49, 4348) + 5% addition slope to match the Hall-C data (A-dependence only)
    - "Toy-Model" for the extreme case → the EMC effect (from SLAC-fit for A=3) is only contributed by u- or d-quark

✓ 100% u-quark contribution

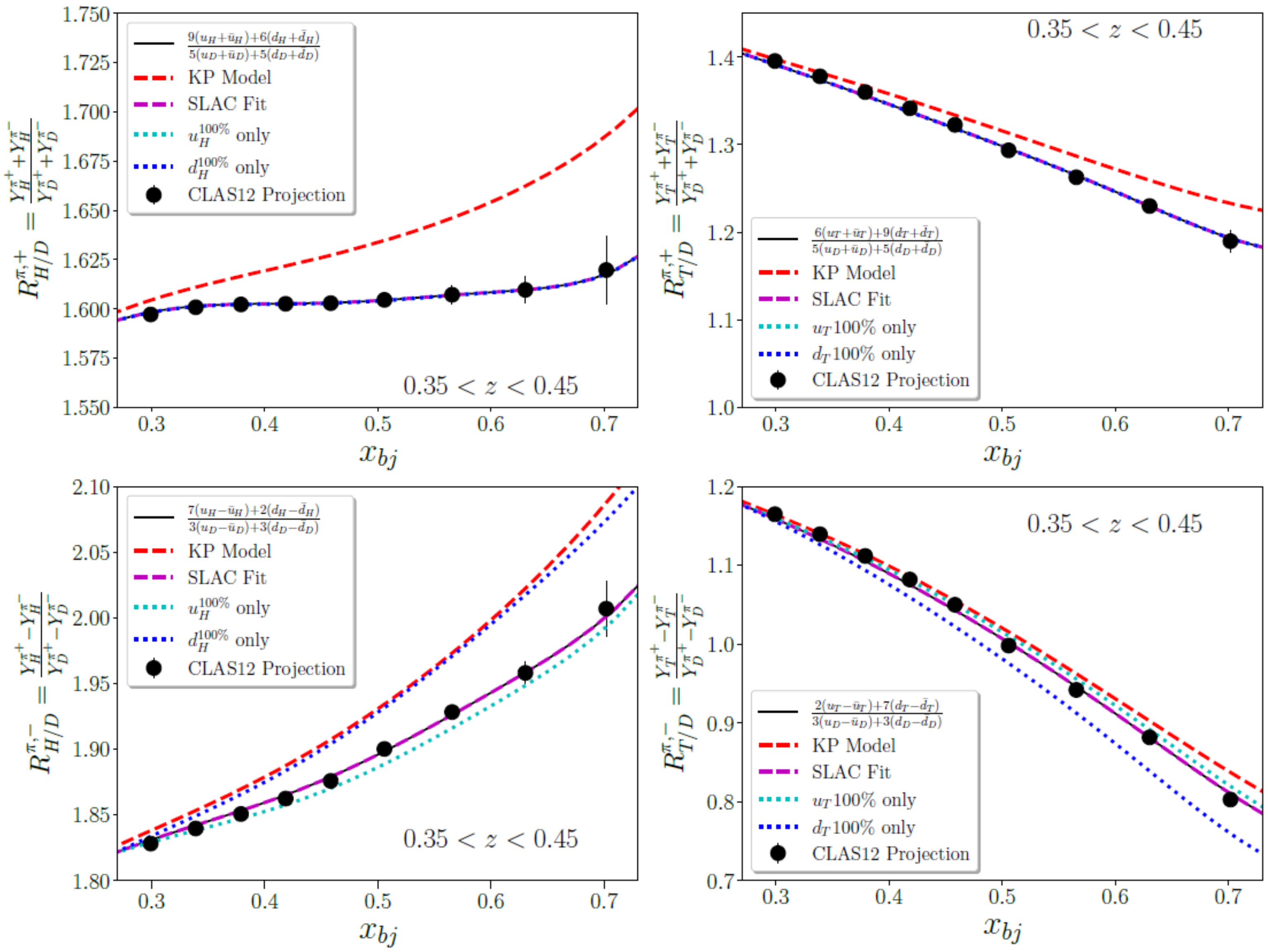
$$F_2^{A,SLAC} = (Ze_u^2 + Ne_d^2)(u_{p,A}^{100\%} + \bar{u}) + (Ze_d^2 + Ne_u^2)(d + \bar{d}) + (Z+N)e_s^2(s+\bar{s}),$$

✓ 100% d-quark contribution

$$F_2^{A,SLAC} = (Ze_d^2 + Ne_u^2)(d_{p,A}^{100\%} + \bar{d}) + (Ze_u^2 + Ne_d^2)(u + \bar{u}) + (Z+N)e_s^2(s+\bar{s}),$$

Semi-Inclusive DIS Measurement with A=3 Nuclei

➢ Projected Results of A=3 in SIDIS → Flavor Dependent EMC Effect



❖ Integrating P_T and fix z-bins

❖ Models used:

- CJ15-LO as free-PDFs
- KP Model calculated for MARATHON analysis (A-dependent, some off-shell effects built in, no isospin effect)
- SLAC-fit from J. Gomez (Phys. Rev. D 49, 4348) + 5% addition slope to match the Hall-C data (A-dependence)
- Toy Model: u-quark dominates ($u_{100\%}$), and d-quark dominates ($d_{100\%}$)

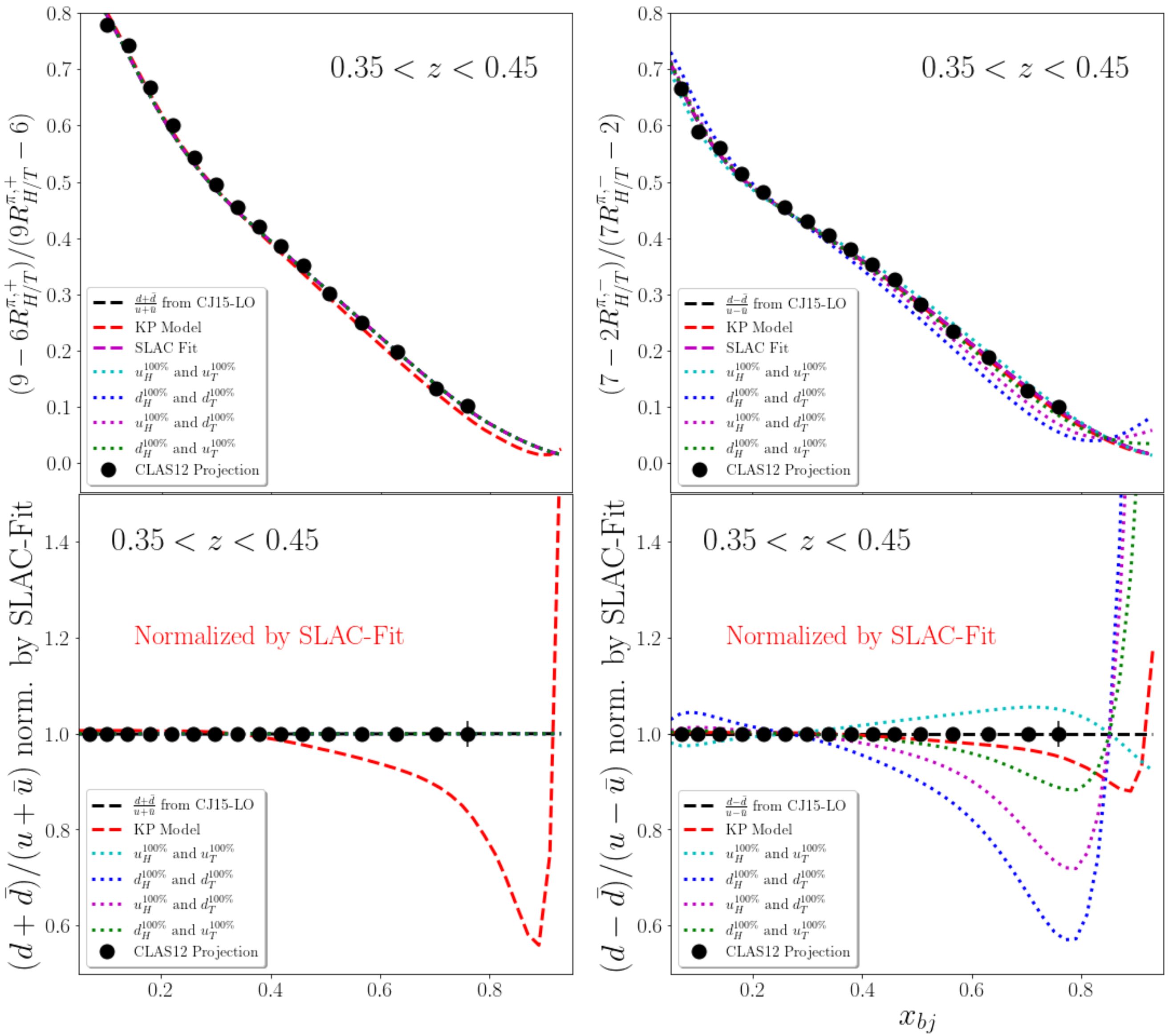
✓ EMC effect has a strong cancellation effect in the Yield-Sum ratio(except KP-model)

✓ Flavor-dependent EMC effect in different models can be distinguished in the Yield-Sum ratio

Semi-Inclusive DIS Measurement with A=3 Nuclei

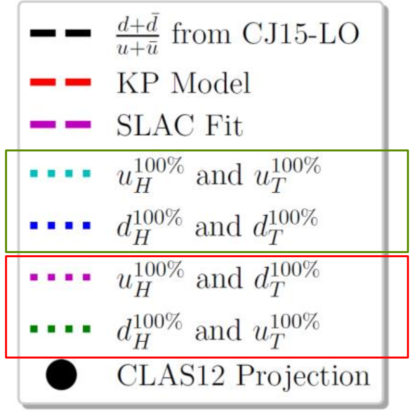
- **Projected Results of A=3 in SIDIS** → d/u projection:
  - Integrating P_T and fix z-bins (Q2 varies with x)
    - Statistical errors are tiny, only assume overall 2% systematic uncertainty
    - Has not account for limited P_T coverage (which is assumed to be omitted by integration)

✓ EMC effect has a strong cancellation effect in the Yield-Sum ratio(except KP-model)
✓ Flavor-dependent EMC effect in different models can be distinguished in the Yield-Sum ratio



A-dependence only

Isospin-dependence



Other Physics Opportunities as a Run-Group

- Parasitic Run: Kaon production in SIDIS with H3 and He3:

  - Assign the FFs to s-quarks:

$$D_u^{K^+} = D_{\bar{s}}^{K^+} = D_s^{K^-} = D_{\bar{u}}^{K^-} = D_K^{fav},$$
$$D_s^{K^+} = D_{\bar{u}}^{K^+} = D_u^{K^-} = D_{\bar{s}}^{K^-} = D_K^{unfav}$$
$$D_d^{K^\pm} = D_{\bar{d}}^{K^\pm} = D_s^K.$$

  - Measure the charge difference in kaon production:

$$\frac{d-\bar{d}}{u-\bar{u}} = \frac{7-2R_{H/T}^{\pi,-}}{7R_{H/T}^{\pi,-}-2}.$$

$$R_K^- = \frac{F_{UU}^{^3He,K^+} - F_{UU}^{^3He,K^-}}{F_{UU}^{^3H,K^+} - F_{UU}^{^3H,K^-}} = \frac{8(u-\bar{u})+4(d-\bar{d})-3(s-\bar{s})}{4(u-\bar{u})+8(d-\bar{d})-3(s-\bar{s})},$$

$$\frac{s-\bar{s}}{u-\bar{u}} = \frac{4(R_K^- - 2)}{3(R_K^- - 1)}\left(1 + \frac{2R_K^- - 1}{R_K^- - 2}\boxed{\frac{d-\bar{d}}{u-\bar{u}}}\right)$$

<u>A direct test of the strangeness symmetry:</u>

$$\delta_{s=\bar{s}} = R_K^- - \frac{4R_\pi^- + 1}{4 + R_\pi^-} = 0, if\ s = \bar{s}$$

  - When comparing A=3 and D2, probe the possible medium effect in strangeness that has not been observed yet!
  - Require a full working RICH detector
  - Require ultra-high luminosity and experimental precision (not the primary goal of this experiment)

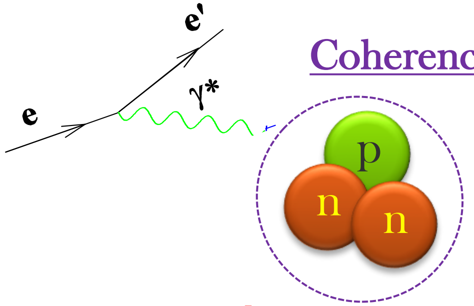
Other Physics Opportunities as a Run-Group

- Parasitic Run: DVCS measurement on H3 and He3:
  - First measurement of DVCS off He4 nucleus (1-GPD)

    First step toward accessing the 3-D partonic structures of nuclei

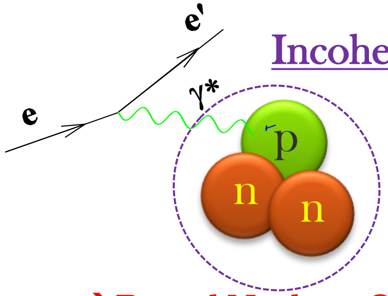
    (M. Hattawy et al. Phys. Rev. Lett. 119, 202004 (2017))

  - DVCS off He3 and H3 (4 GPD for spin ½ targets):



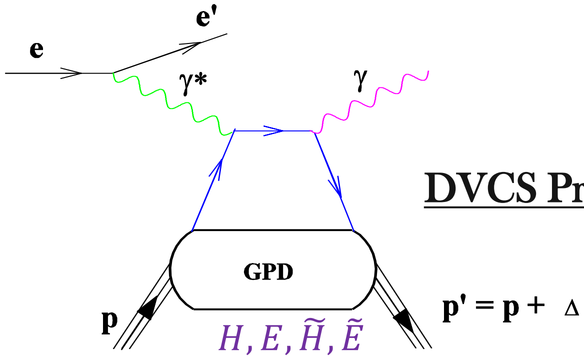
Coherence

→Nuclear-GPD



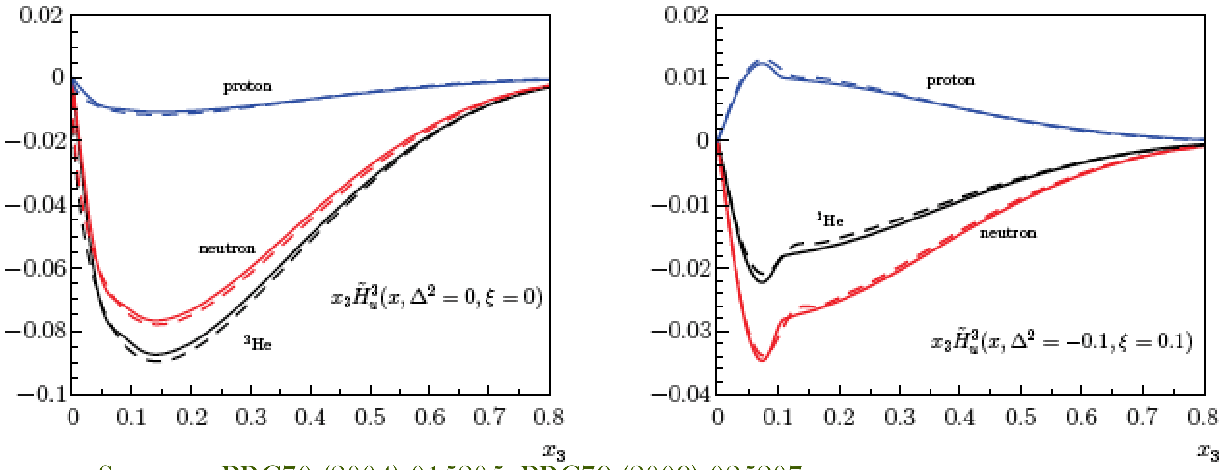
Incoherence

→Bound Nucleon-GPD



DVCS Process

$$H_q^A(x,\xi,\Delta^2) \simeq \sum_N \int \frac{d\bar{z}}{\bar{z}} h_N^A(\bar{z},\xi,\Delta^2) H_q^N\left(\frac{x}{\bar{z}},\frac{\xi}{\bar{z}},\Delta^2\right)$$



Scopetta, PRC70 (2004) 015205; PRC79 (2009) 025207;
Rinadli and Scopetta, PRC87 (2013) 035208; arXiv:1401.1350 (2014)

  - Advantage of using DVCS off He3 & H3:
    - ✓ Neutron-contribution dominates in He3-GPDs
    - ✓ Sensitive to GPD-E (orbital angular momentum)
    - ✓ Use H3 to isolate pure neutron/proton contributions
    - ✓ Get access to the flavor-dependence GPDs

      $$H_u^{He3} = H_d^{H3}$$

    - ✓ Medium Modification Effect in GPDs

- In collaboration with Silvia Niccolai, Alex Camsonne to explore this run-group proposal
- Welcome new collaborators
- Strong theory support needed!

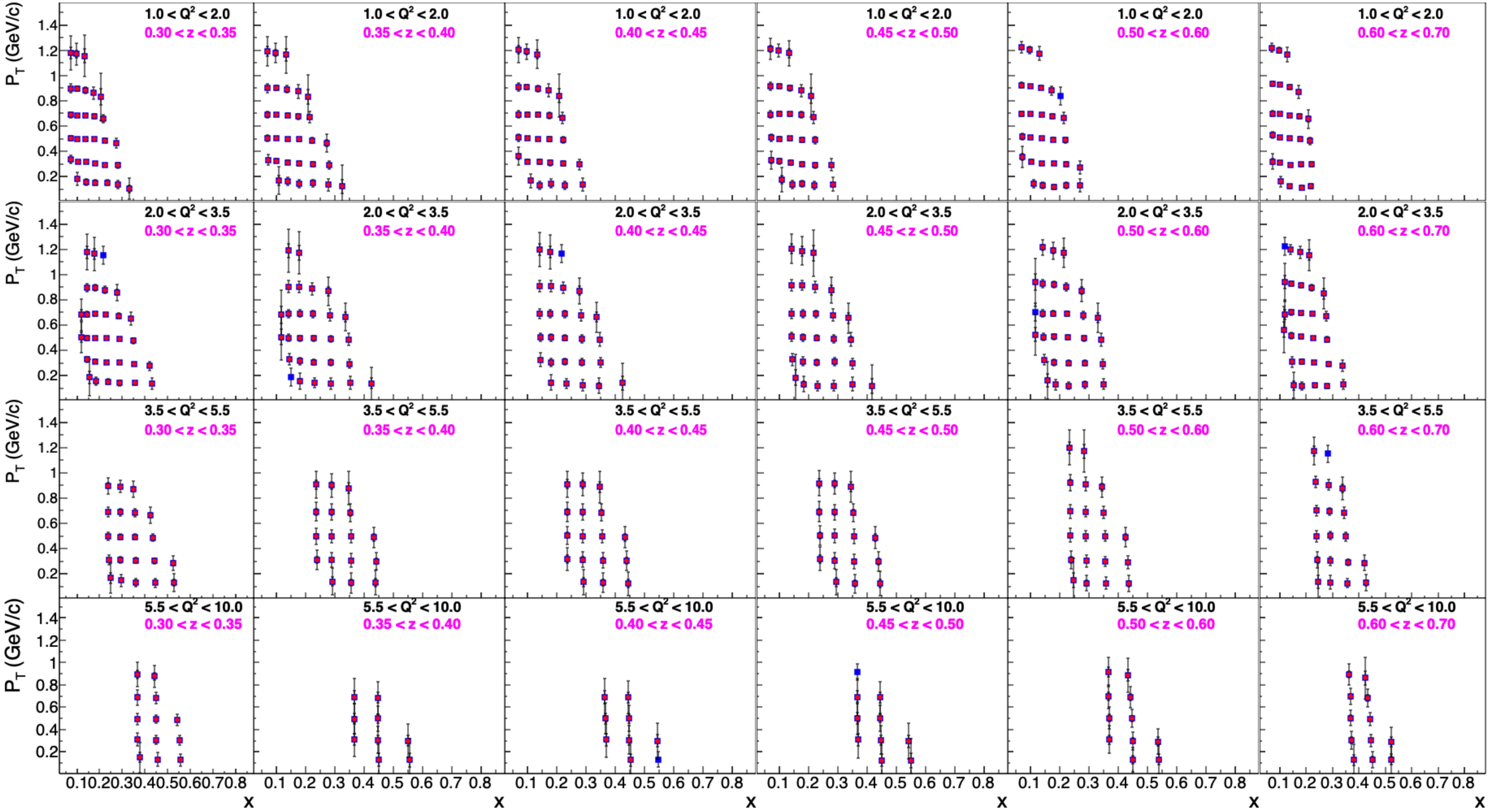
Summary

- No accepted explanation of the EMC effect → need new observables
- Measure SIDIS ratios of $(e, e'\pi^+)$ and $(e, e'\pi^-)$ in D2, H3 and He3
  - ✓ Flavor-dependent EMC effect study
  - ✓ Nuclear effect on the fragmentation functions (FFs)
  - ✓ Direct measurement of d/u
  - ✓ Measurement of unpolarized TMDs and FFs, and their nuclear effects in 3D(x, z, P_T)
  - ✓ Use approved CLAS12 Tritium target system
- Ongoing theoretical support from theorists (ready before PAC defense)
- Study strangeness contents via Kaon-Production in SIDIS when the RICH becomes available
- DVCS in A=3 can be run in parallel to study flavor-dependent GPDs and nuclear-GPDs in A=3 system

BACKUP

Semi-Inclusive DIS Measurement with A=3 Nuclei

➢ Projected Results of A=3 in SIDIS: Kaon Data 4D Binning



Blue → K+
Red → K-