Unpolarized EMC and Anti-Shadowing Effects

exploring w/ 22GeV CEBAF

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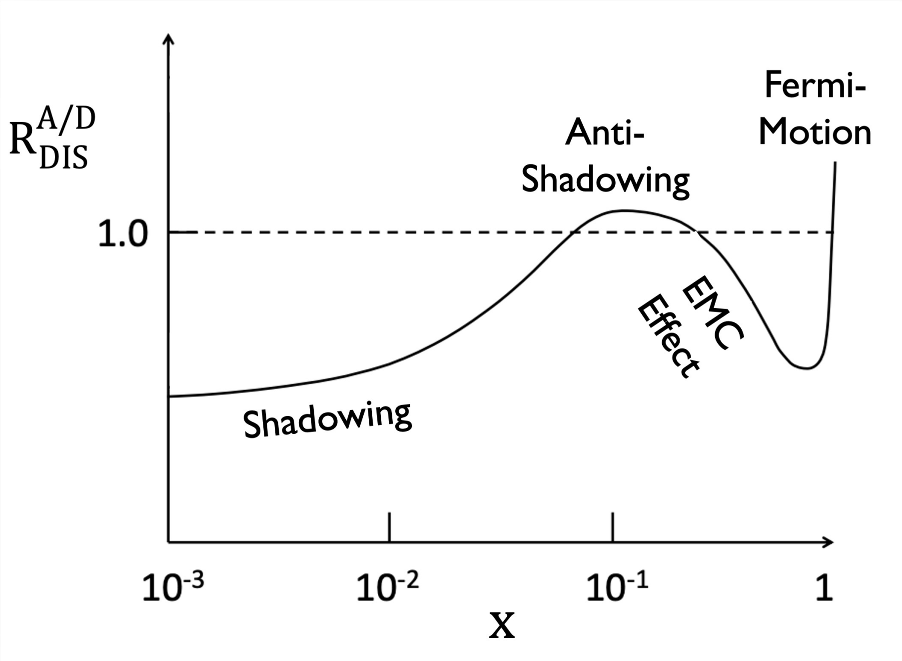
01/23-25/2023, Jlab at 22 GeV Workshop

Partons in Nuclei

➢Four Regions

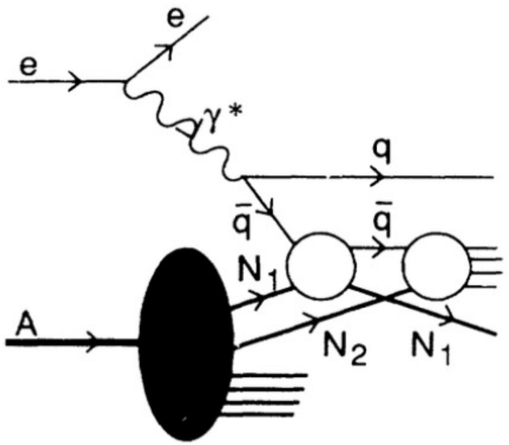


Geesaman, Saito, Thomas, Ann. Rev. Nucl. Part. Sci.45, 337 (1995)
Norton, Rept.Prog.Phys. 66 (2003) 1253-1297

- ❑ **Fermi-Motion**:
  - ✓ Bound nucleons moving in nuclear medium (offshell, smearing, …)
  - ✓ Easily understood, hard to calculate!
  - ✓ Recent discussion on A=2,3

    Alekhin, Kulagin, Petti, PRD 96, 054005 (2017)
    C. Cocuzza, et. al., PRL 127, 242001
    Segarra et. al. PRL 124, 092002 (2020)

- ❑ **Shadowing:**
  - ✓ multiple-scattering (diffractive)
  - ✓ models various (especially when treating along w/ anti-shadowing & EMC)

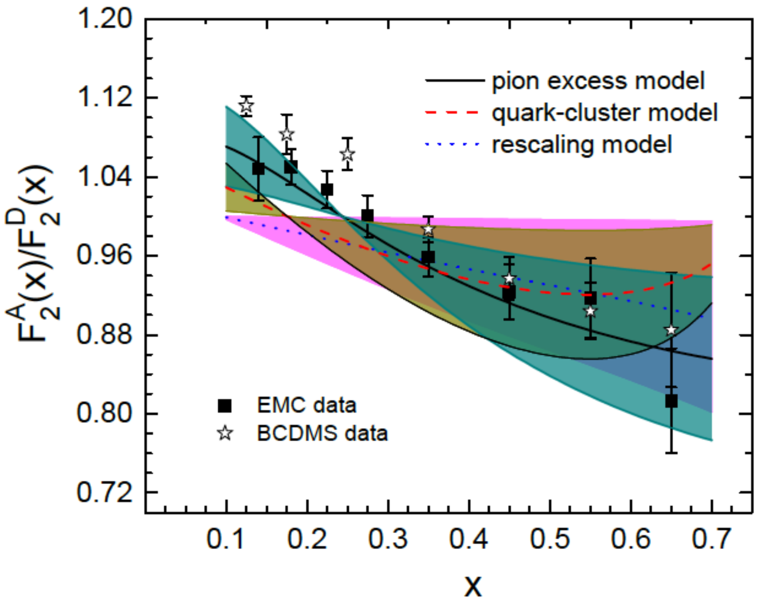


- ❑ **Anti-Shadowing？？**
- ❑ **EMC？？**

Partons in Nuclei

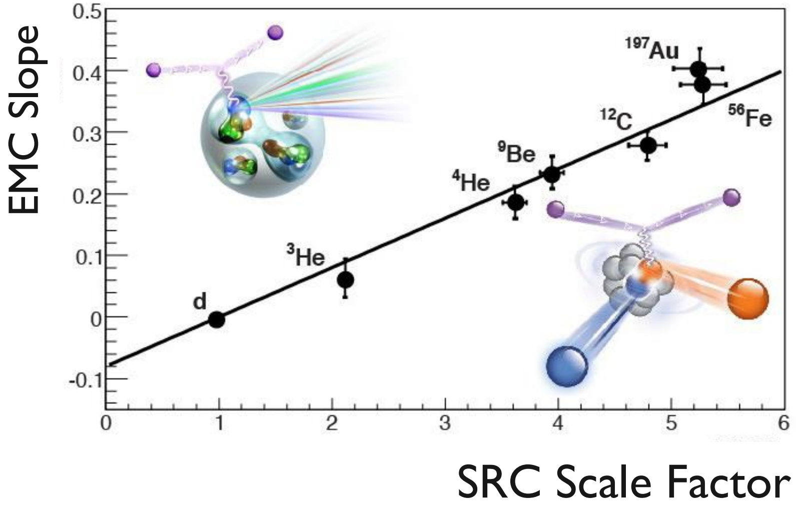
➢ EMC Effect:

- ❑ EMC: The ratio of inclusive DIS cross-section between a nucleus-A to the deuteron drops linearly in $0.3<x<0.7$
  Phys.Lett.B 123 (1983) 275-278
- ❑ Modeling:
  - ✓ Rescaling of quark & gluon sizes
  - ✓ Mean-Field (MIT bag, NJL …)
  - ✓ Multi-quark clusters (6-quark bag)



C. Gong, B.Q. Ma, Phys.Rev.C 97 (2018) 6, 065207

- ❑ Related to short range correlated (SRC) pairs:

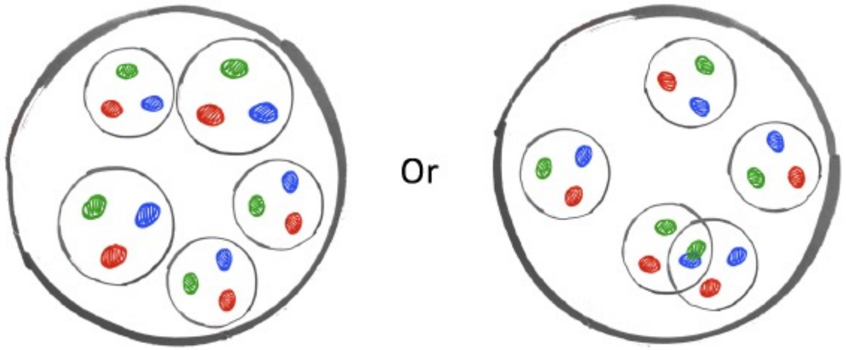


L.Weinstein et al, PRL 106, 052301 (2011)

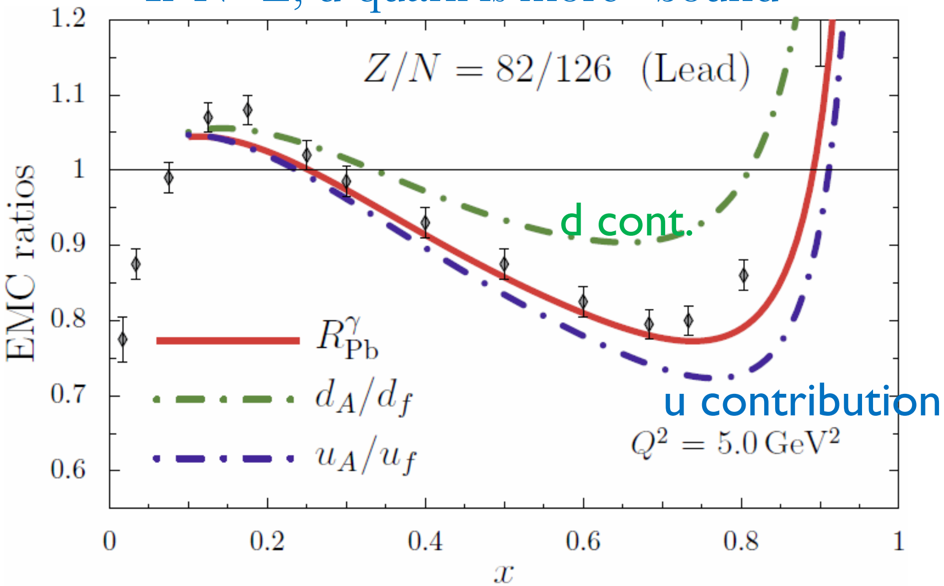
- ❑ Which nucleons are modified?

2017 – Modified Nucleons

Drawing stealed from G. Miller

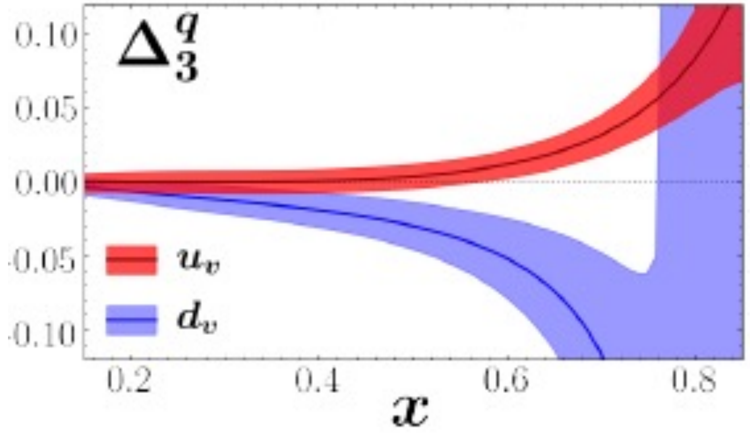


- ➢ EMC Effect:
  - ❑ Mean-field model indicates flavor-dependence
    - ✓ If N>Z, u-quark is more "bound"
    - ✓ If N<Z, d-quark is more "bound"

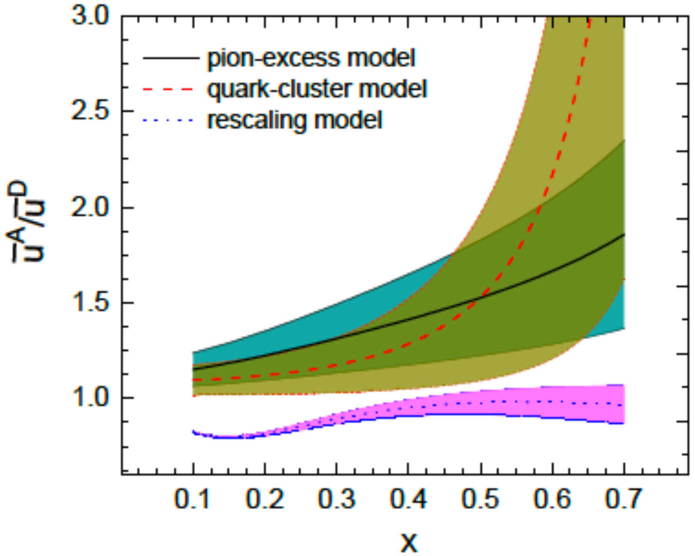


I. Cloet, et al, PRL 109, 182301 (2012)
PRL 102, 252301 (2009)

- ❑ JAM Model predicts u and d-quark modified differently in H3 and He3



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



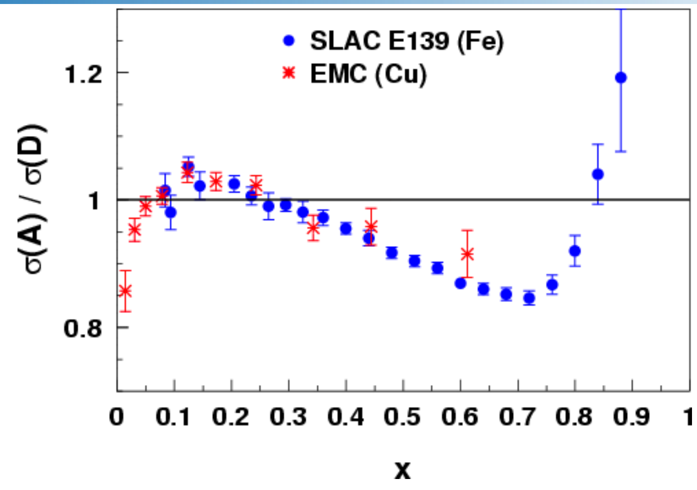
- ❑ EMC effect in sea-quarks (unseen experimentally)?

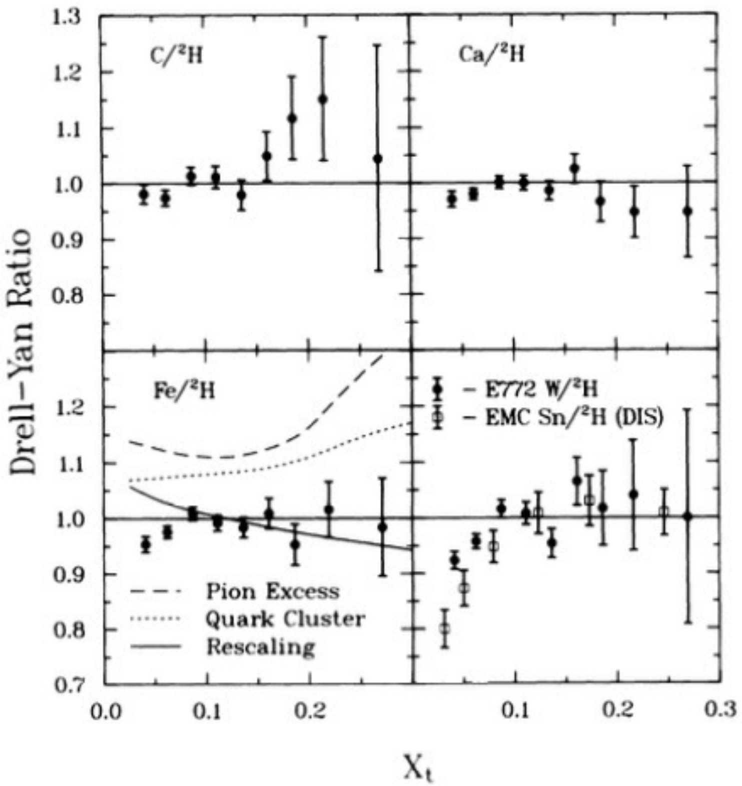
C. Gong, B.Q. Ma, Phys.Rev.C 97 (2018) 6, 065207

Partons in Nuclei

➢Anti-Shadowing

- ❑ Even poorly known
  - Recover momentum loss from EMC & shadowing is not a good explanation!
- ❑ May have richer physics info
  - connection with nuclear force?
- ❑ Unsettled theoretical explanations
  - Deffractive process (multiple-scattering)?
  - Rescaling (enlarged confiment sizes)?
  - 6-quark bag?
  - …





- ❑ "No" anti-shadowing in sea quarks
  - Strong flavor-dependence?

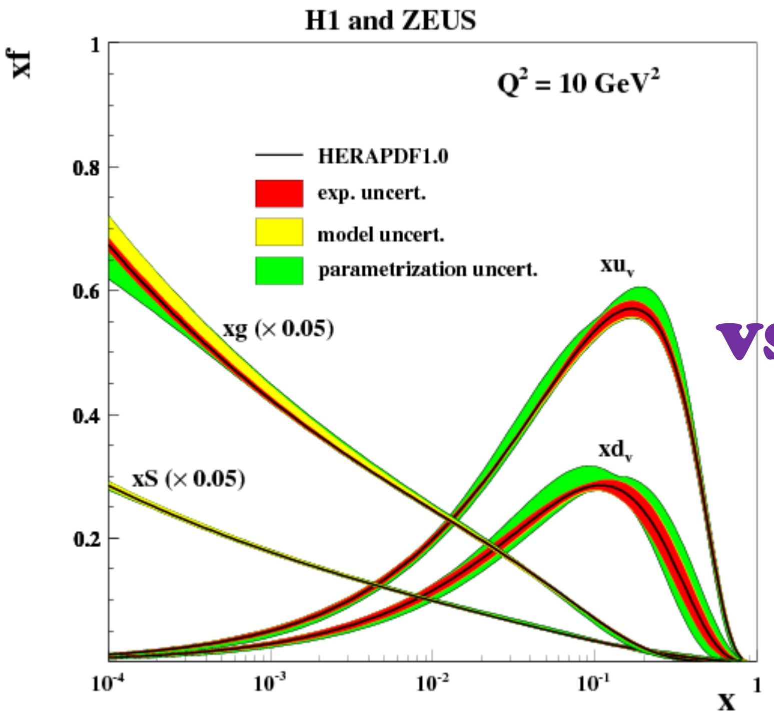
Drell-Yan, E772, PRL. 64 (1990) 2479-2482

- ❑ May only exists in σ_L^{DIS} →gluons only?

Frankfurt, Guzey, Strikeman PRC 95 055208 (2017), Guzey, et.al, PRC86,045201 (2012)

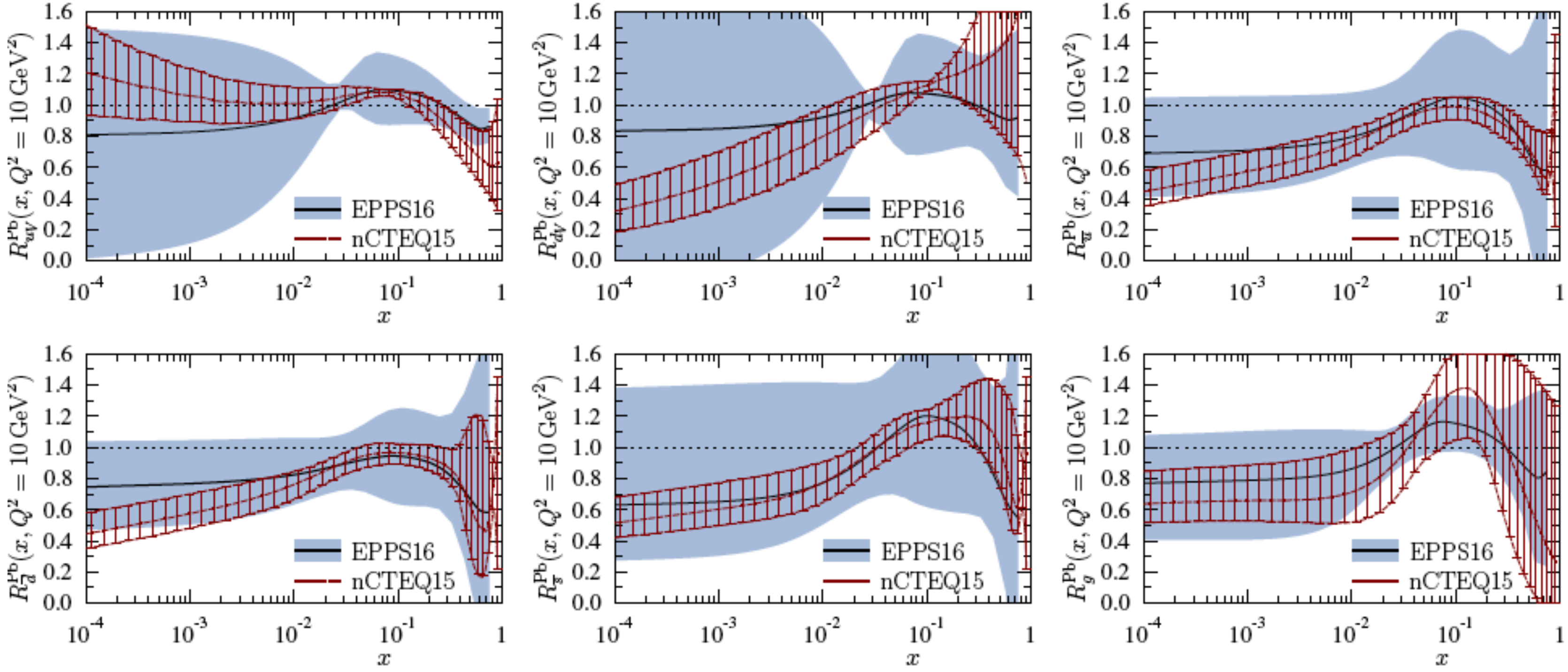
➢Nuclear PDF

- ❑ Data unprecise; Limited A-coverage
- ❑ Many assumption made in global fit (e.g., flavor-independence, isospin-symmetry)
- ❑ Plenty rooms to improve!



Free nucleon PDF

vs



EPPS16 Nuclear PDF

Eur. Phys. J. C (2017) 77:163

➢Future Measurements

Jlab11GeV

- ❑ Inclusive DIS: many have been done,
  - with "smarter" nuclei pairs, e.g. Ca48&Ca40, H3&He3
  - Synergic check of EMC-SRC connection?
  - A-dependence of R($^{\sigma_L}/_{\sigma_T}$)
  - Polarized nuclear target?
  - Beam-Asymmetry?
- ❑ PVDIS
  - Conditionally approved SoLID experiment w/ Ca48/Ca40

Jlab22GeV & EIC

- ❑ Nucleon-tagging DIS (T. Kutz's talk)
- ❑ Flavor-tagging Semi-Inclusive DIS (SIDIS)
  - Multiple hadron final states: π , $K, p, \bar{p}, \Lambda, \bar{\Lambda}$, ...
  - Nuclear TMDs

This talk!

- ❑ Exclusive Reactions
  - DVCS/DVMP with D2/H3/He3/He4
  - Nuclear GPDs

- ❑ Neutrinio scattering
- ❑ Drell-Yan (COMPASS-II)
- ❑ pA (CERN)

Semi-Inclusive DIS (SIDIS)

➢ SIDIS in eA :

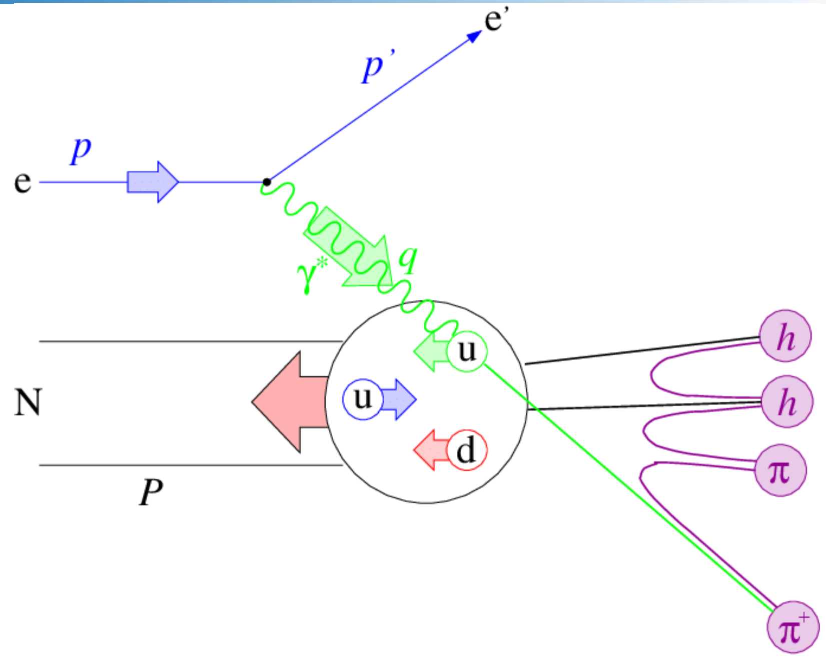
❑ XS at Colinear, Leading-Order

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

Nuclear Fragmentation Function (nFF)

Nuclear PDF (nPDF)

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

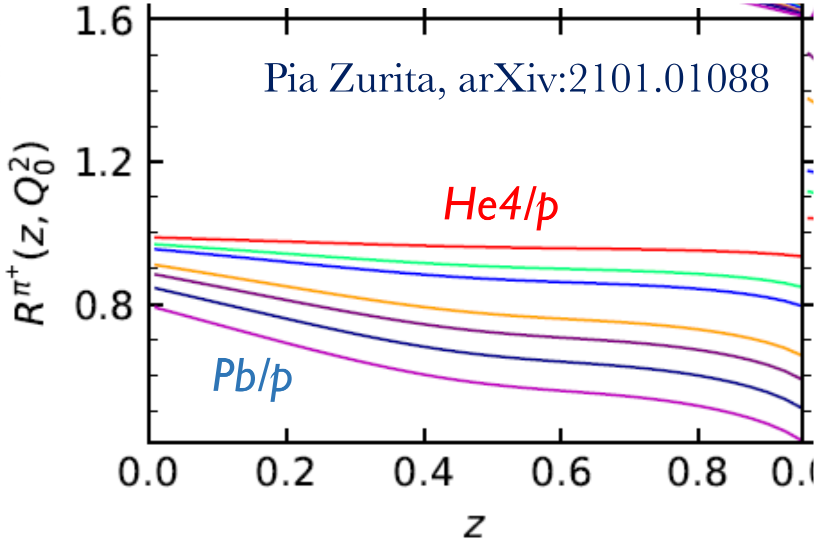


❑ Ratio of charge differences

$$R_{A/D}^{\pi^+ + \pi^-}(x, z, Q^2) = \frac{N_A^{\pi^+} + N_A^{\pi^-}}{N_D^{\pi^+} + N_D^{\pi^-}} = \frac{1}{5} \frac{(4Z+N)(u_A + \bar{u}_A) + (Z+4N)(d_A + \bar{d}_A)}{(u_D + \bar{u}_D) + (d_D + \bar{d}_D)} \cdot \frac{D_A^{fav} + D_A^{unfav}}{D_D^{fav} + D_D^{unfav}}$$

$$R_{A/D}^{\pi^+ - \pi^-}(x, z, Q^2) = \frac{N_A^{\pi^+} - N_A^{\pi^-}}{N_D^{\pi^+} - N_D^{\pi^-}} = \frac{1}{3} \frac{(4Z-N)u_v^A - (Z-4N)d_v^A}{u_v^D + d_v^D} \cdot \frac{D_A^{fav} - D_A^{unfav}}{D_D^{fav} - D_D^{unfav}}$$

nFF Ratios

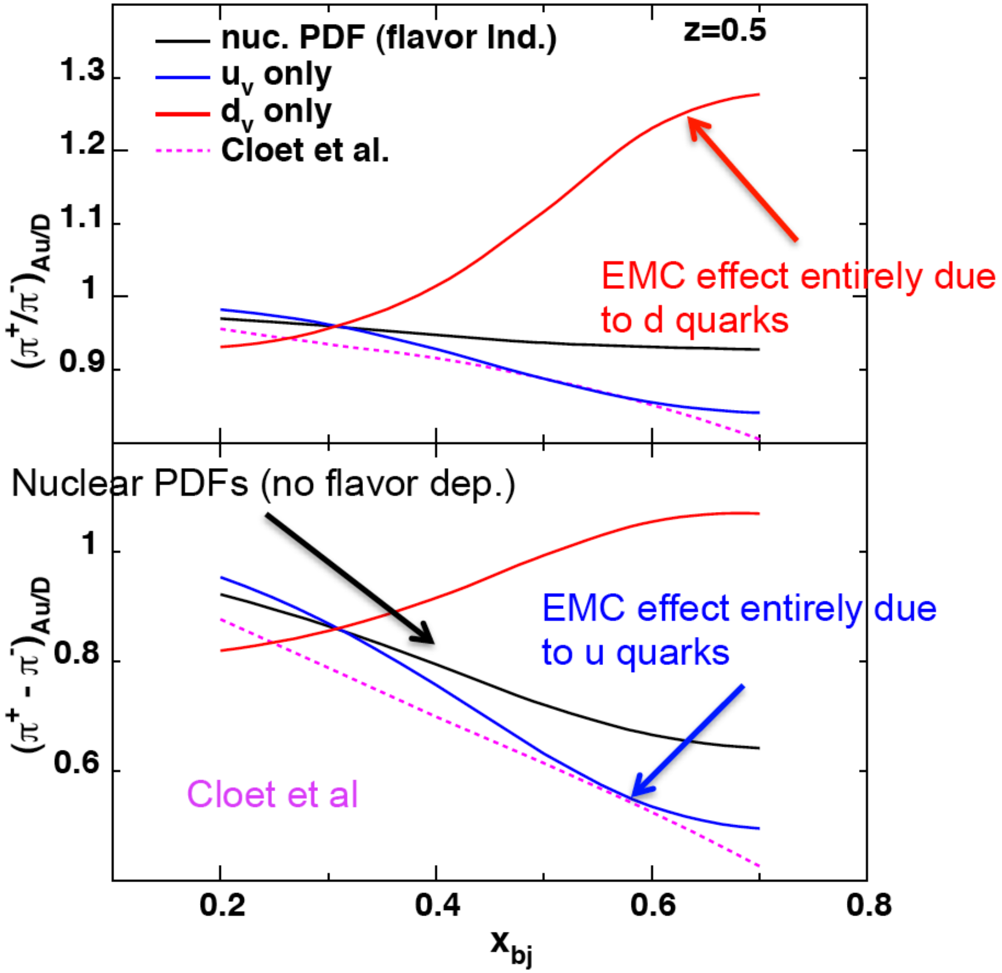


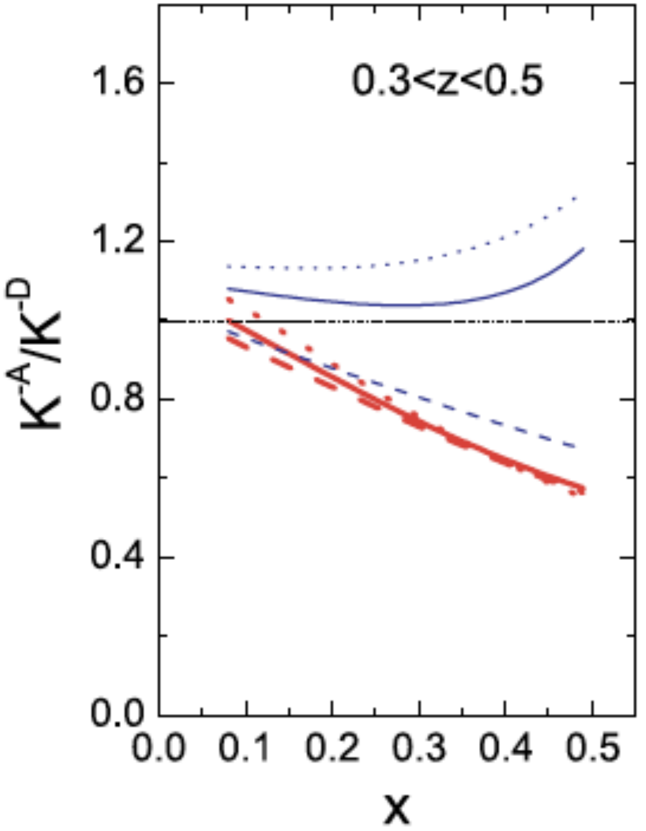
❑ FFs are also significantly modified in heavy nuclei

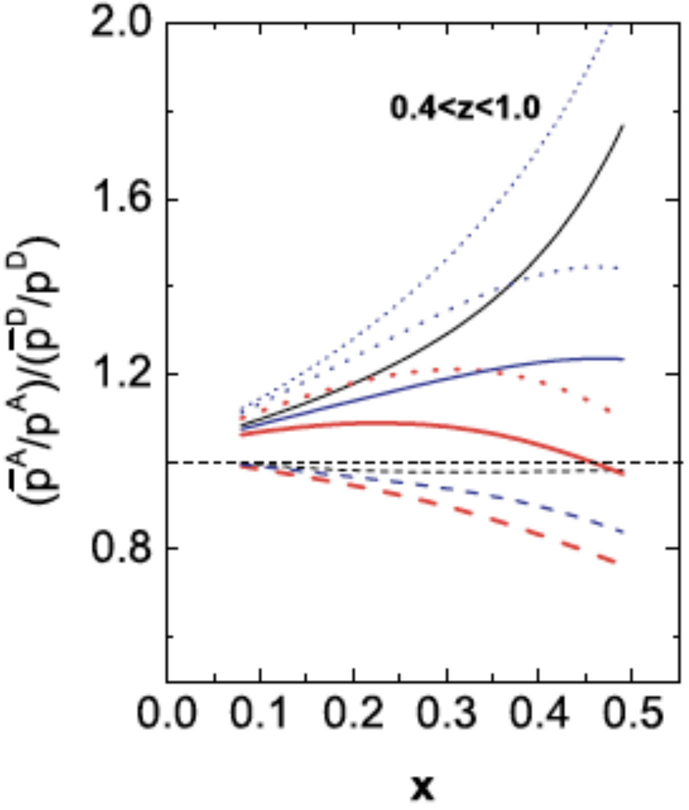
✓ Need to decouple from nPDF study

Semi-Inclusive DIS (SIDIS)

- SIDIS in eA:
  - Super-ratios of hadron/anti-hadron production in SIDIS magnify EMC signals
  - Suggest flavor-dependence w/ different hadrons-productions



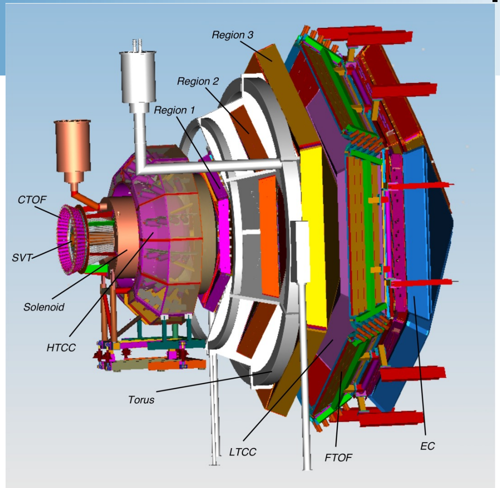




J. Lu, B.Q. Ma PRC 74, 055202 (2006)

C. Gong, B.Q. Ma, PRC 97 (2018) 6, 065207

Semi-Inclusive DIS (SIDIS)



➢ SIDIS in eA:

- ❑ A list of approved CLAS12 experiments to study Hadronization
  - ✓ Beam energy, E0 = 8.8 and 11 GeV
  - ✓ Targets: H1, D2, C12, N14, Ar40, Fe56, Kr85, Sn119, Au197
  - ✓ Hadrons: detecting all pions and kaons
  - ✓ Wide acceptance and 4D (Q2, x, z, P_T) binning

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					
E12-06-117	Quark propagation and hadron formation	Brooks	A-	60	60		11	E	Nuclear

- ❑ Global analysis to systematically extract nPDF and nFF from precise eA SIDIS data

- ❑ A parallel analysis to extract 3D info of nuclei?
  - Run-group experiment was proposed by R. Dupre, Z. Meziani et. al. and approved

Semi-Inclusive DIS (SIDIS)

- SIDIS in eA:
  - However, there are pros and cons:

Pros:
- Sensitive to flavor-contents by detecting different hadron types
- Access 3D info by measuring P_T distributions

Cons:
- Common challenges for all SIDIS (w/ nucleons and nuclei):
  - Factorization regions not well defined
  - FF poorly known
  - Theoretical Corrections
    - High-twist , Target Mass, Radiative, ...
- Additional for Nuclei-SIDIS:
  - Nuclear structure
  - Hadronization

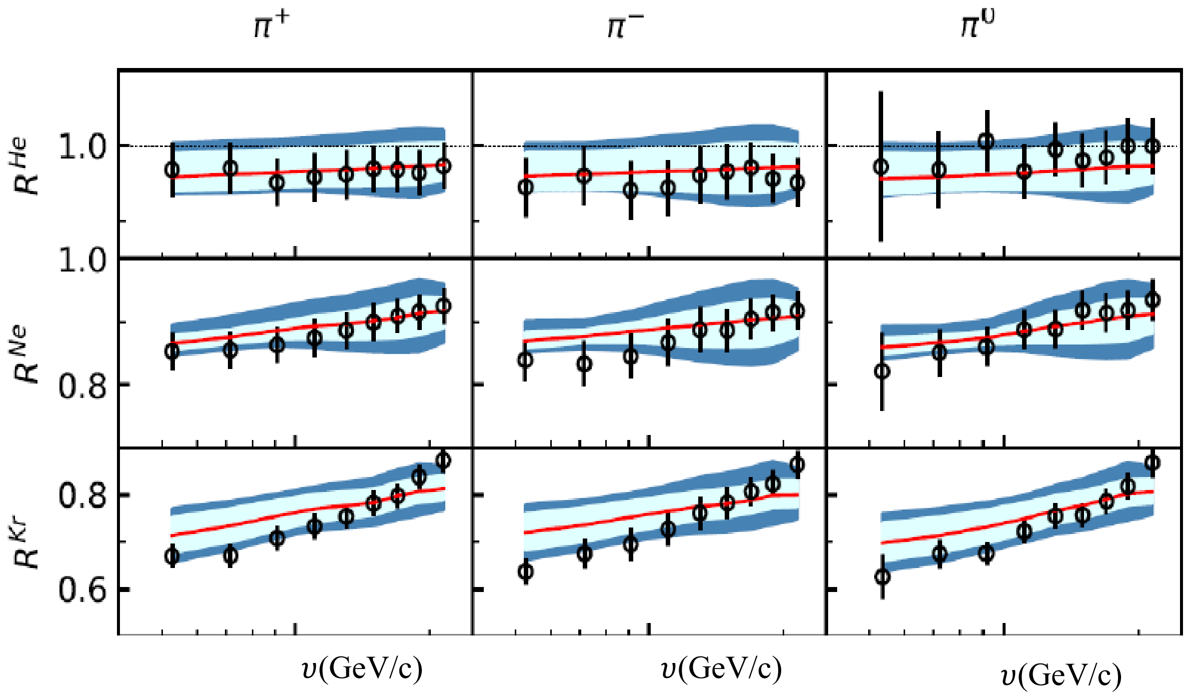
Semi-Inclusive DIS (SIDIS)

➢ Study nPDF with SIDIS:

- ❑ Start with light nuclei, e.g. He3 and H3:
  - ✓ Nuclear calculations possible
  - ✓ Measurable EMC effect
  - ✓ Small hadronization effects
  - ✓ Fragmentation functions
    - o Expected small nuclear effect
    - o Similar in the mirror nuclei

❑ A bridge between free-nucleons and heavy nuclei

(Pia Zurita, arXiv:2101.01088)



Small (~ 5% at high-z) effects on He4's nFFs
→ Safe to ignore medium effect of nFF in A=2, 3

Semi-Inclusive DIS (SIDIS)

➢C12-21-004 Experiment

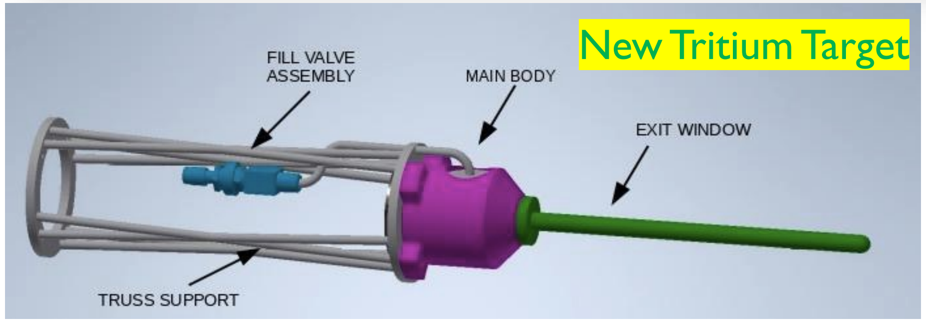
SIDIS Measurement of A=3 Nuclei with CLAS12 in Hall-B

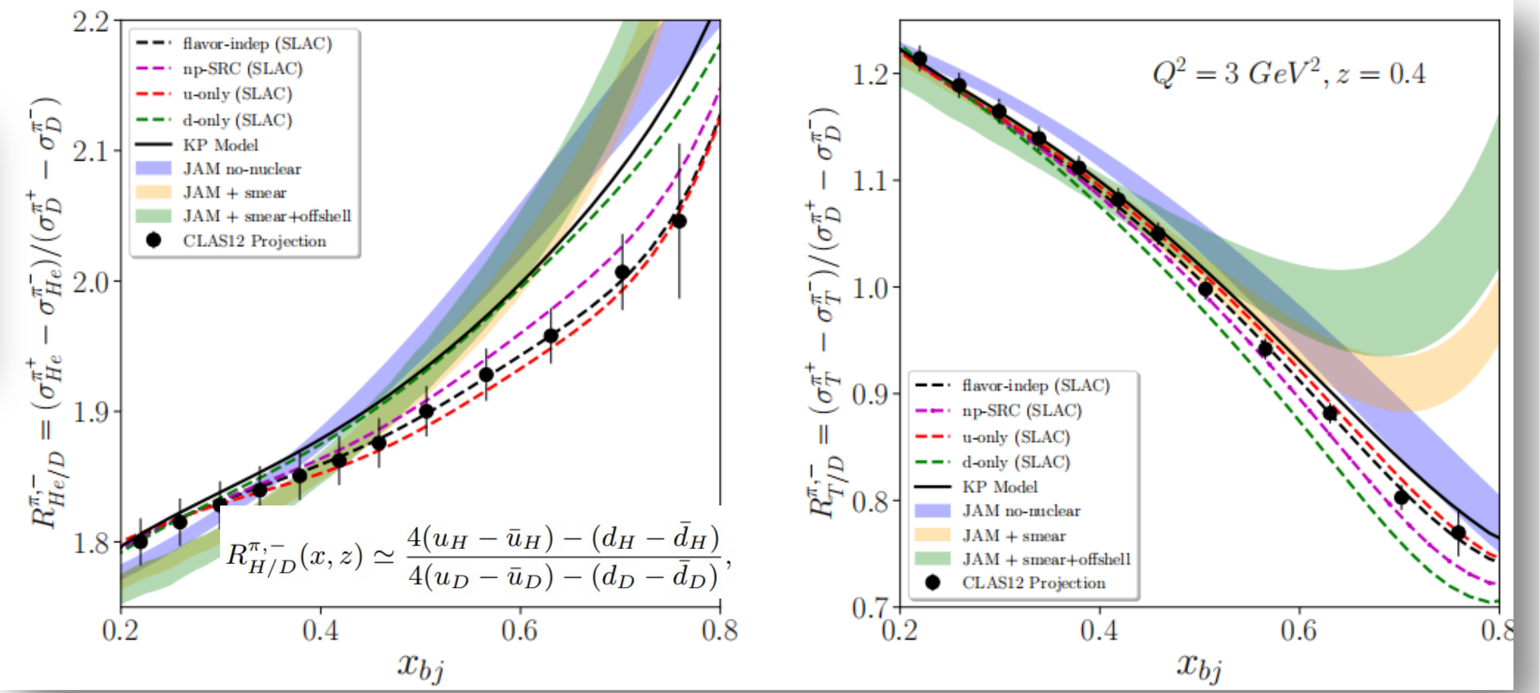
Conditionally approved in PAC49

On behalf of the spokespeople:

D. Dutta, D. Gaskell, O. Hen, D. Meekins, D. Nguyen, L. Weinstein*, J. R. West, Z. Ye,

and the CLAS Collaboration





- ❑ **Physics Topics:**
  - ✓ Flavor-Dependent EMC
  - ✓ d/u at high-x
  - ✓ Factorization in light nuclei
  - ✓ Hadronization in light Nuclei
  - ✓ TMD and FF in A=3

- ❑ Targets: D2/H3/He3 with 10.6 GeV unpolarized beam
  - ✓ New Tritium target system (same as 2nd Tritium-SRC)
  - ✓ Standard CLAS12 setup
  - ✓ Detecting electrons, pions and kaons
- ❑ "Conditionally" approved
  - ▪ Seek theorists' helps to prove A=3 can minimize these challenges
  - ▪ Ask to provide projections on A=3 nTMD and nFF

11GeV to 22GeV

➢ How energy upgrade helps?

Pros:

- Sensitive to flavor-contents by detecting different hadron types
- Access 3D info by measuring P_T distributions

Cons:

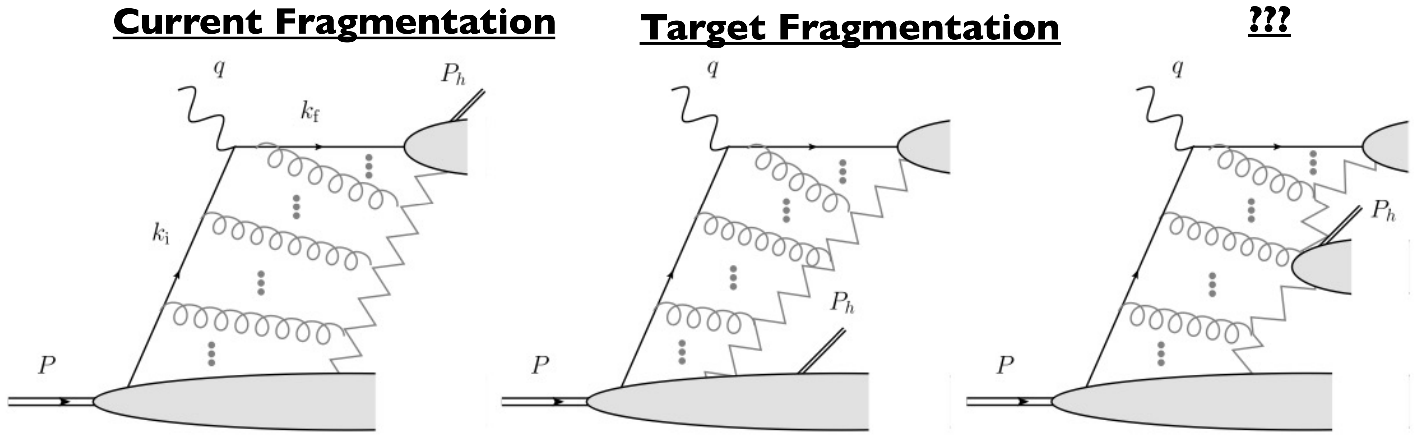
- Common challenges for all SIDIS (w/ nucleons and nuclei):
  - Factorization regions not well defined
  - FF poorly known
  - Theoretical Corrections
    - High-twist , Target Mass, Radiative, ...
- Additional for Nuclei-SIDIS:
  - Nuclear structure
  - Hadronization

Should learn a lot from all 11GeV-SIDIS data

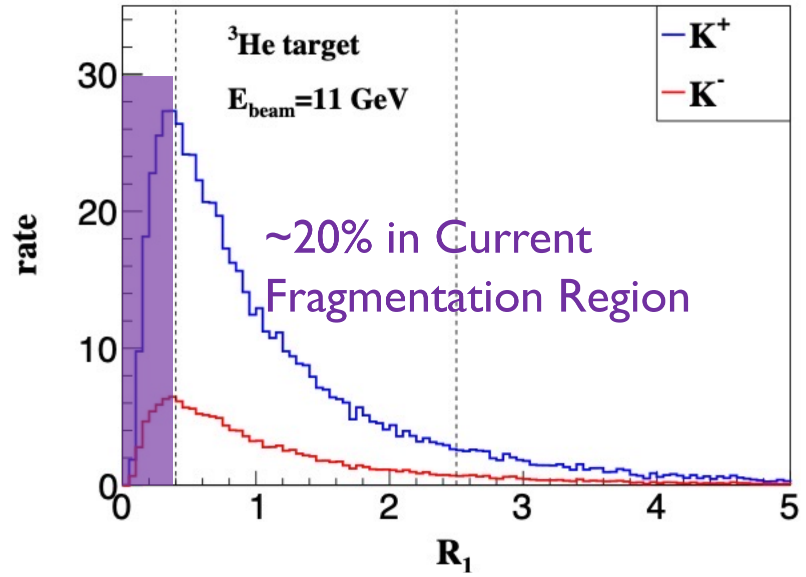
Easier with 22GeV?

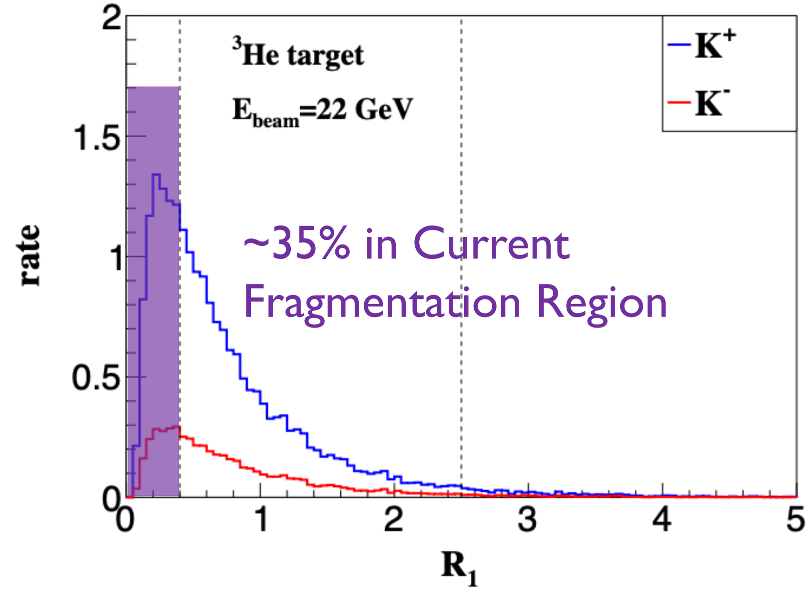
11GeV to 22GeV

➢How energy upgrade helps?



✓ Factorizable!



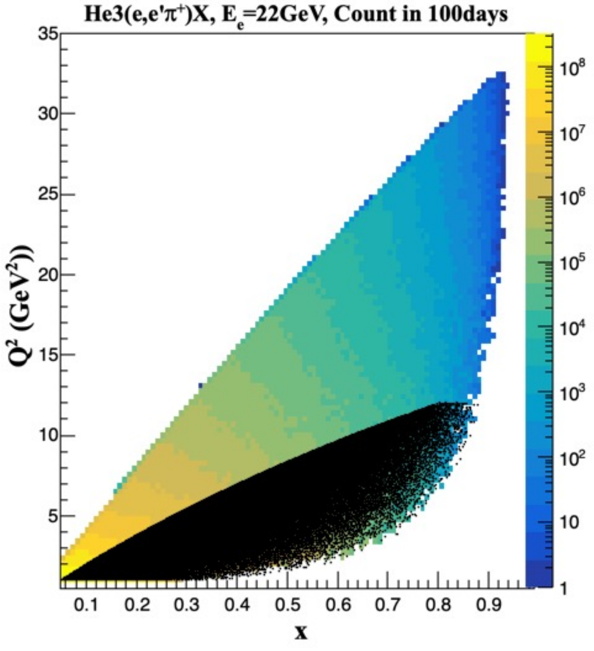


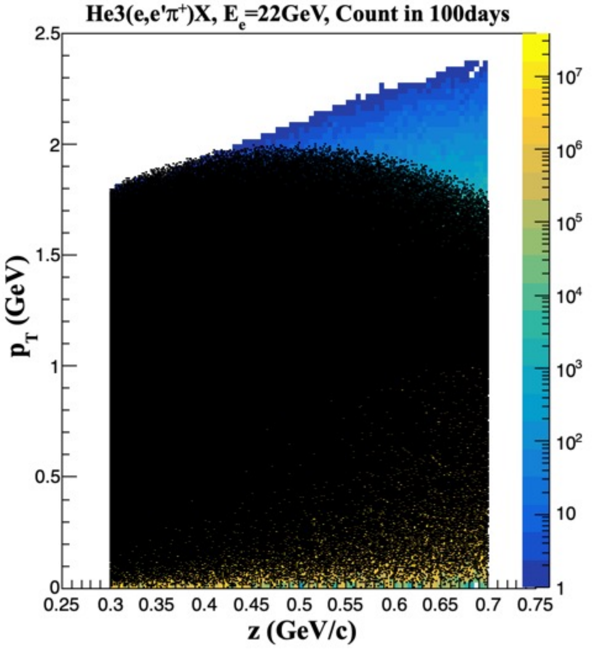
- Current fragmentation region is not clearly defined
- Model estimation: Boglione, et. al. Phys. Lett. B 766, 245 (2017)
  - At 11GeV, 70% pions and 20% kaons are valid.
  - At 22 GeV, 35% kaons are valid; also cleaner for pions with eA
- Open up kaon phase-space (tight at 11GeV/c), maybe lambda or heavier?

(credit to T.B. Liu, based on Boglione, et. al.

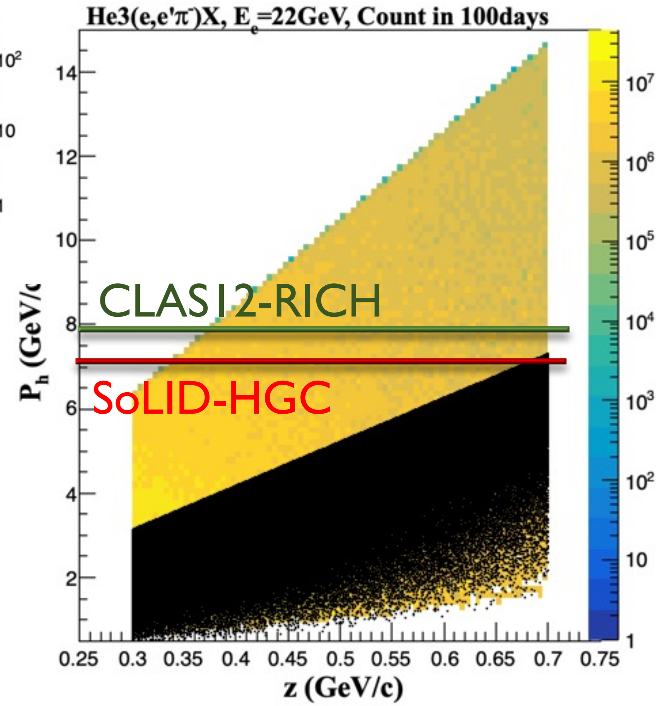
11GeV to 22GeV

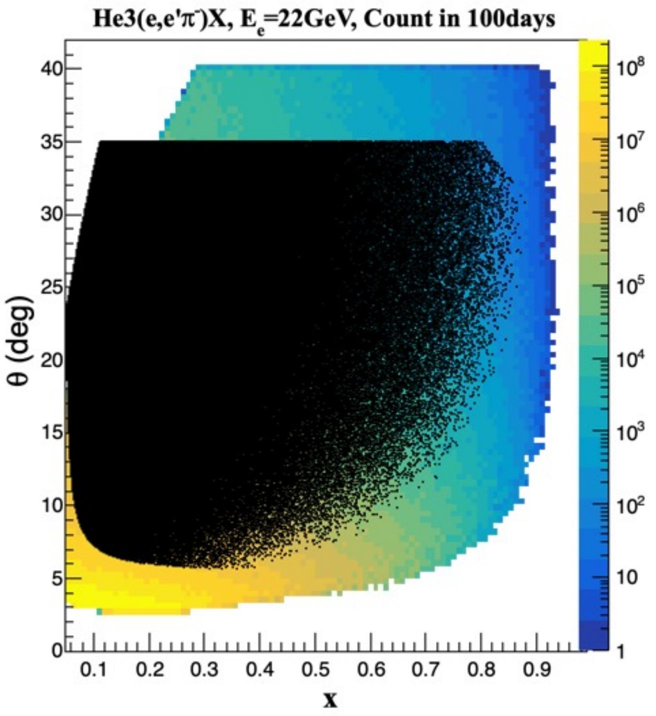
➢Larger Phase-Space





Back dots→11GeV
Color dots→22GeV

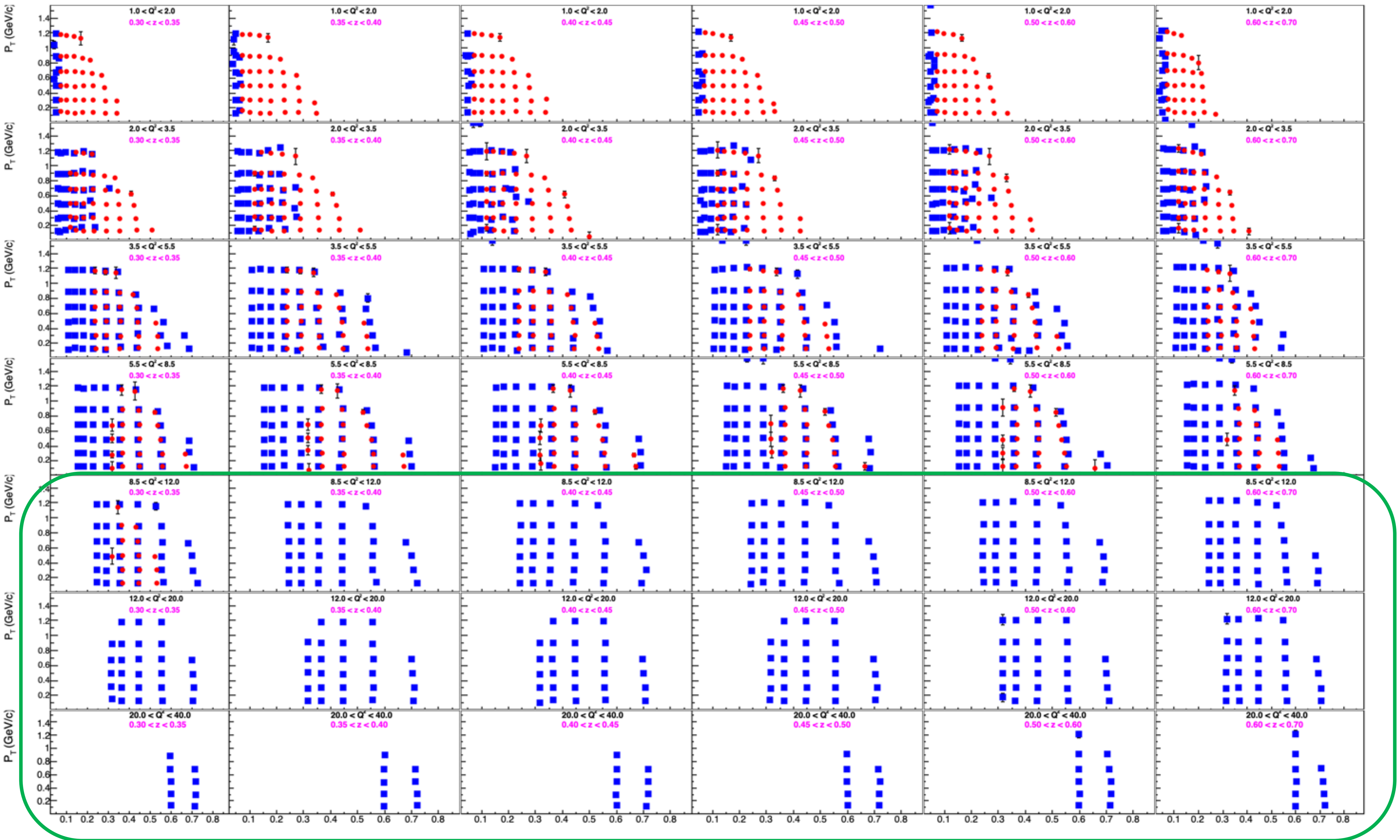




- ❑ Assuming updated CLAS12/SoLID detectors cover the entire acceptance

11GeV to 22GeV

Pio-SIDIS Projection



- 11GeV
- 22GeV

→4π-detector (CLAS12 & SoLID)

→Lumi~10^{35}cm^{-2}s^{-1},

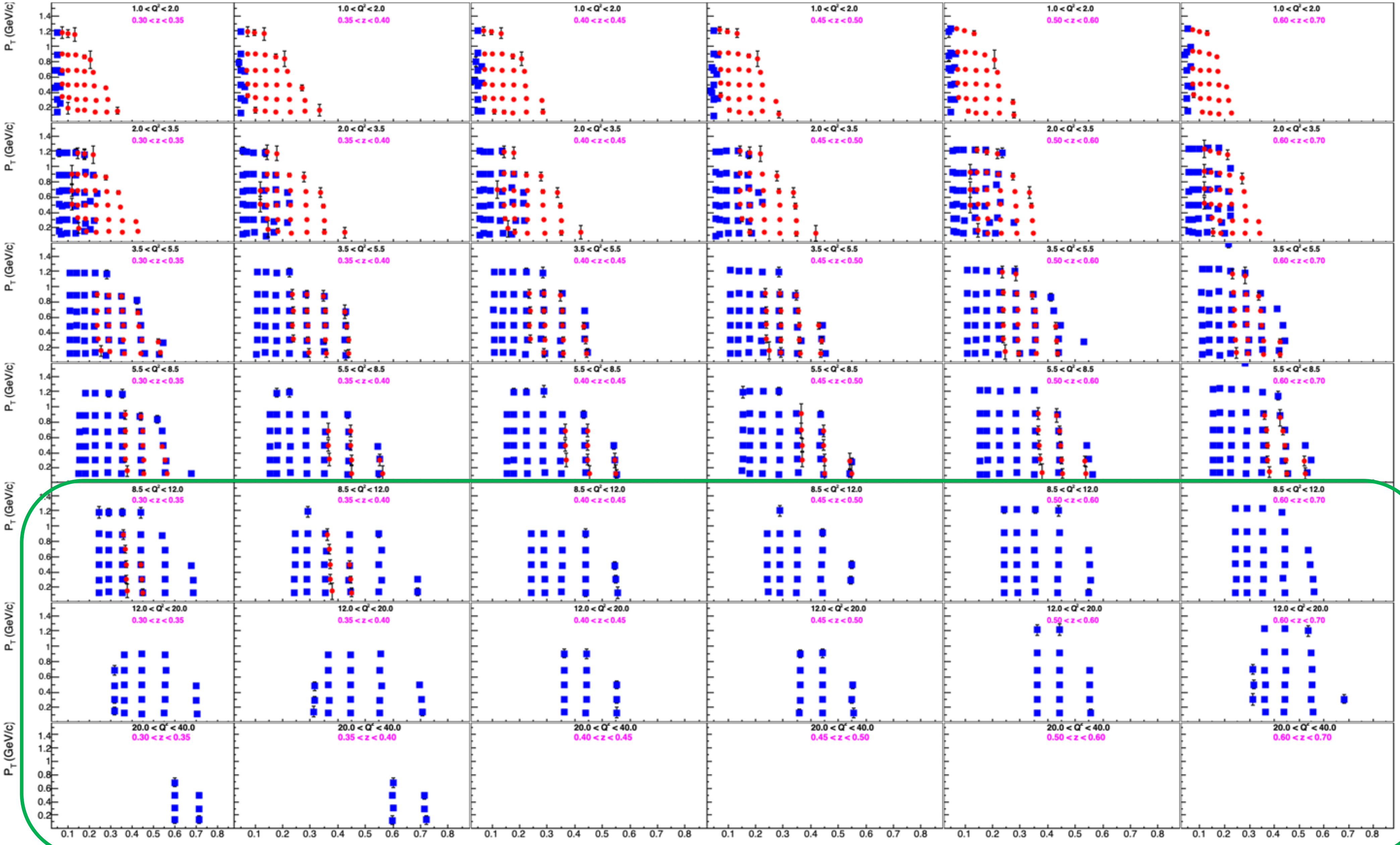
→100-days

11GeV to 22GeV

Kaon-SIDIS Projection

- 11GeV
- 22GeV

→4π-detector (CLAS12 & SoLID)
→Lumi~10^{35}cm^{-2}s^{-1},
→100-days



11GeV to 22GeV

Proton-SIDIS Projection

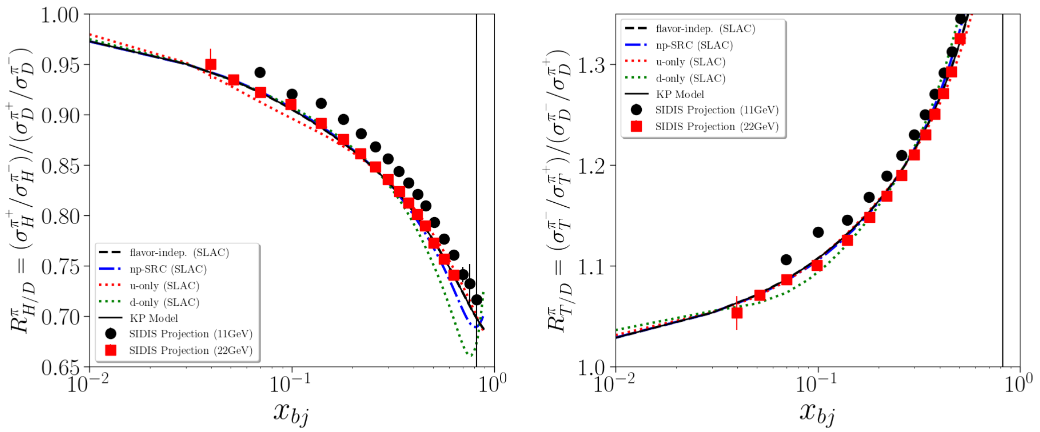
- Proton
- Anti-Proton

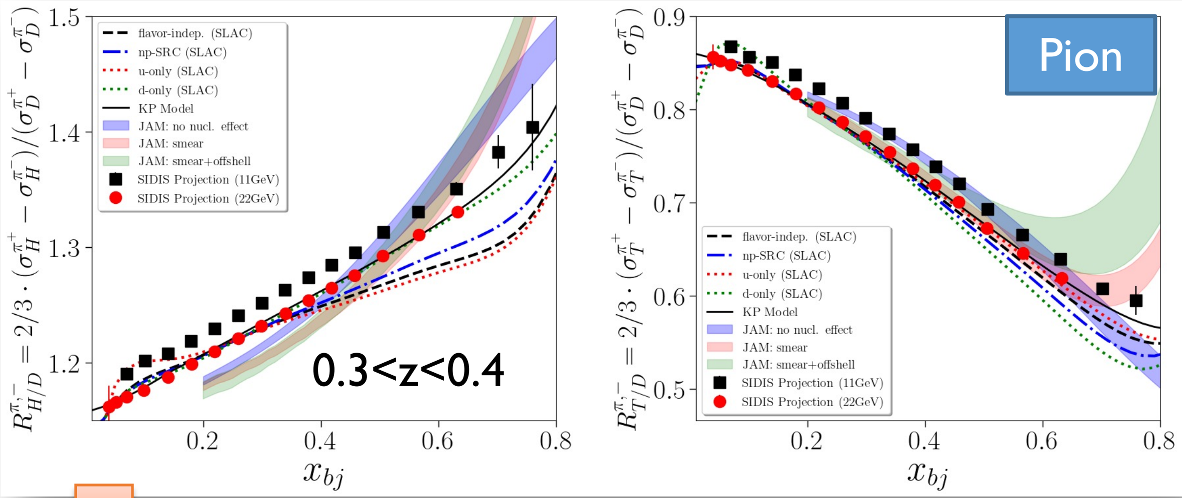
→4π-detector (CLAS12 & SoLID)
→Lumi~10^{35}cm^{-2}s^{-1},
→100-days

11GeV to 22GeV

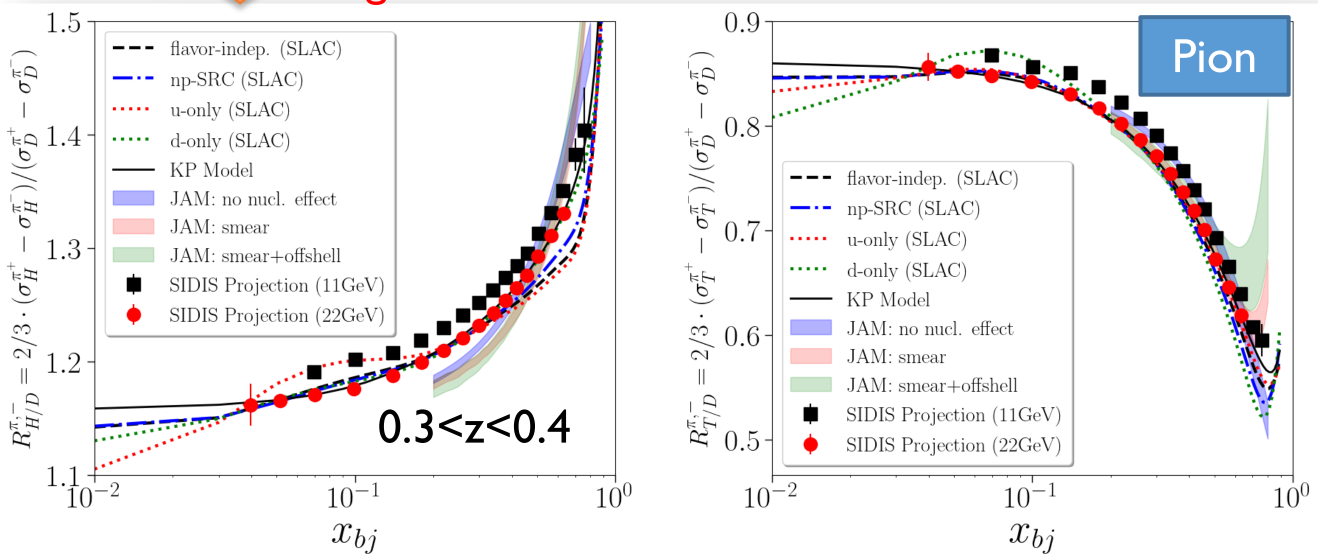
➢eA SIDIS w/ mutiple Hadron-Production

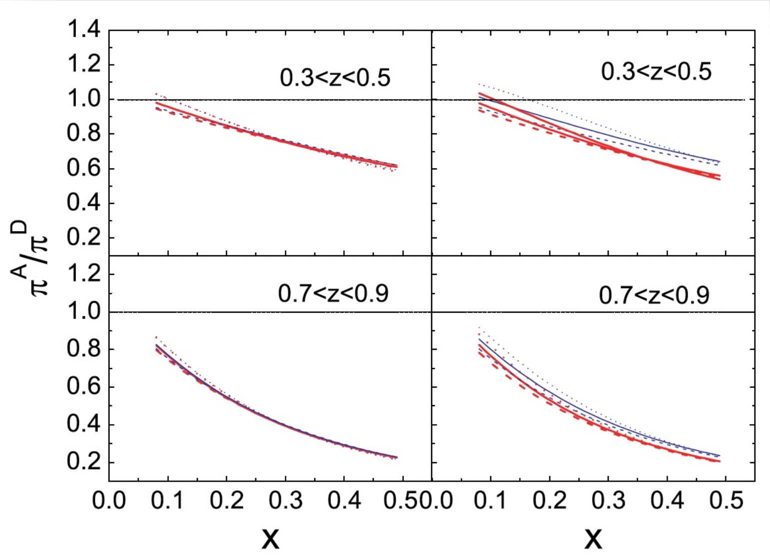
- ❑ Fully decouple flavor-dependent EMC & Antishadowing in A=3





Log-scale





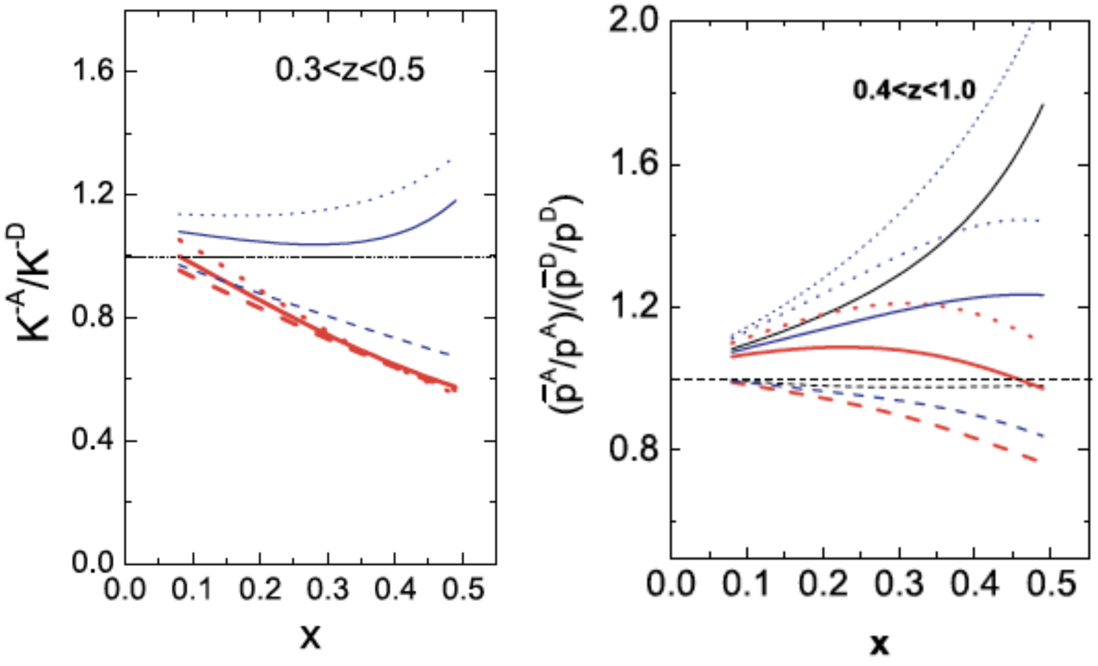
J. Lu, B.Q. Ma
PRC 74, 055202 (2006)

11GeV to 22GeV

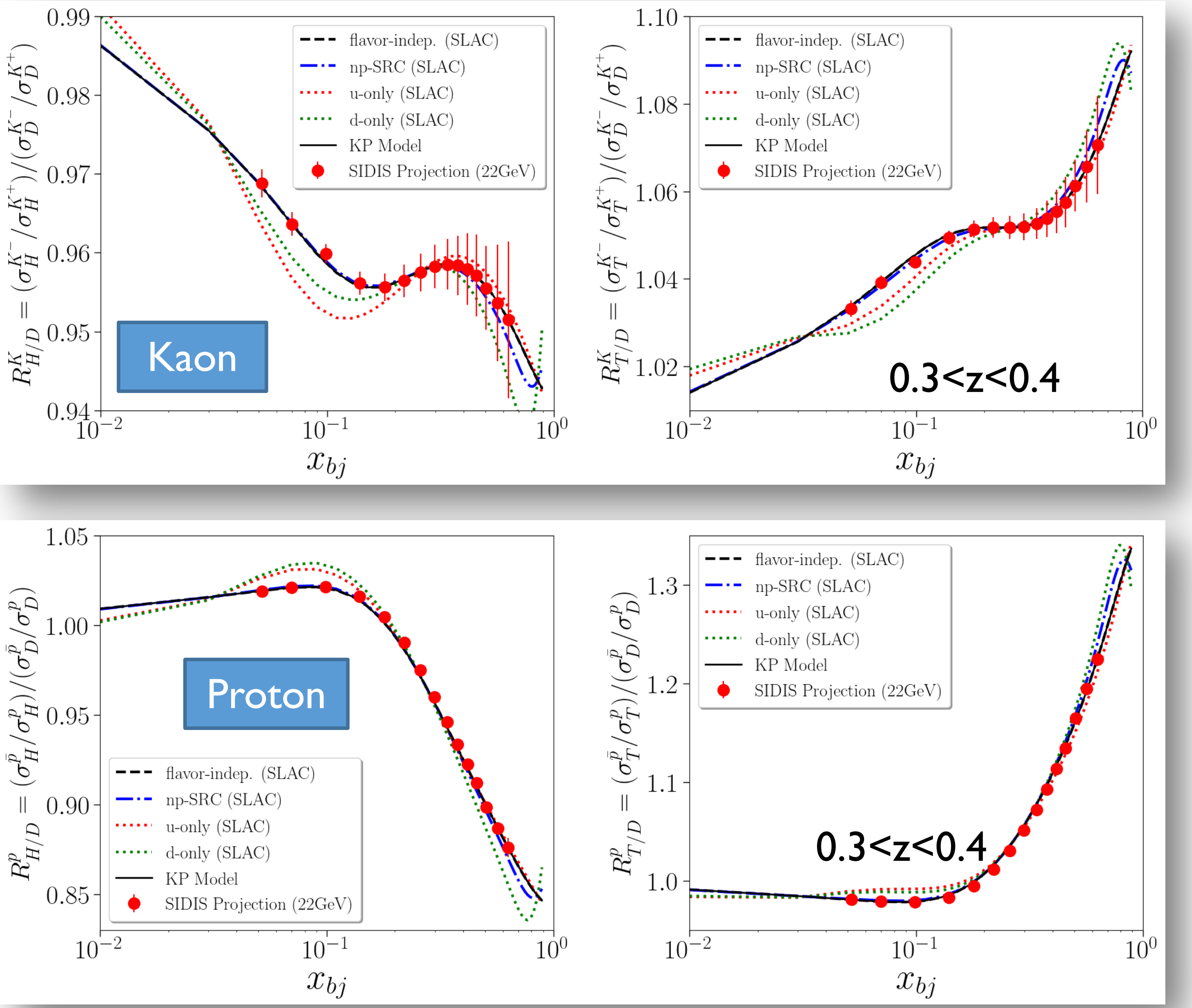
➢eA SIDIS w/ mutiple Hadron-Production

- ❑ Fully decouple flavor-dependent EMC & Antishadowing in A=3

- ❑ To do: implement more theoretical predictions



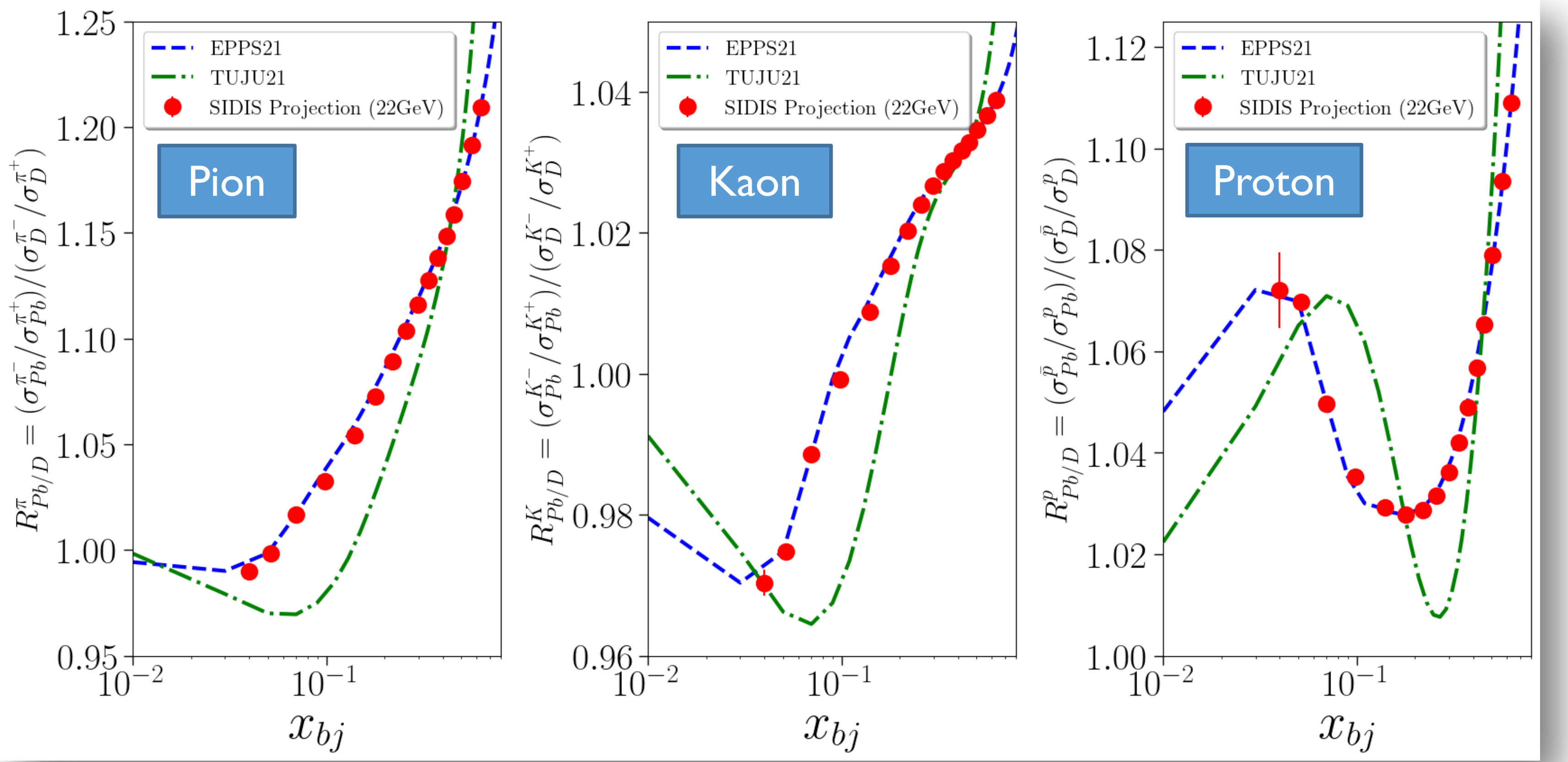
J. Lu, B.Q. Ma PRC 74, 055202 (2006)



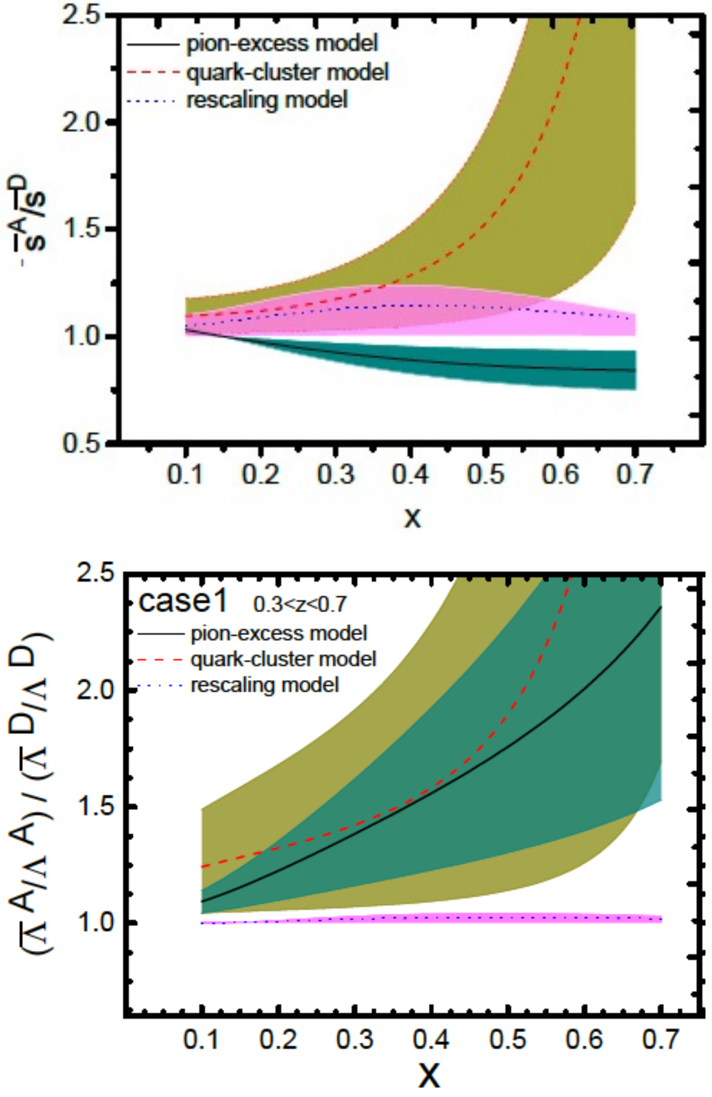
11GeV to 22GeV

➢eA SIDIS w/ mutiple Hadron-Production

- ❑ A-dependence from light to heavy nulcei



C. Gong, B.Q. Ma,
PRC 97 (2018) 6, 065207



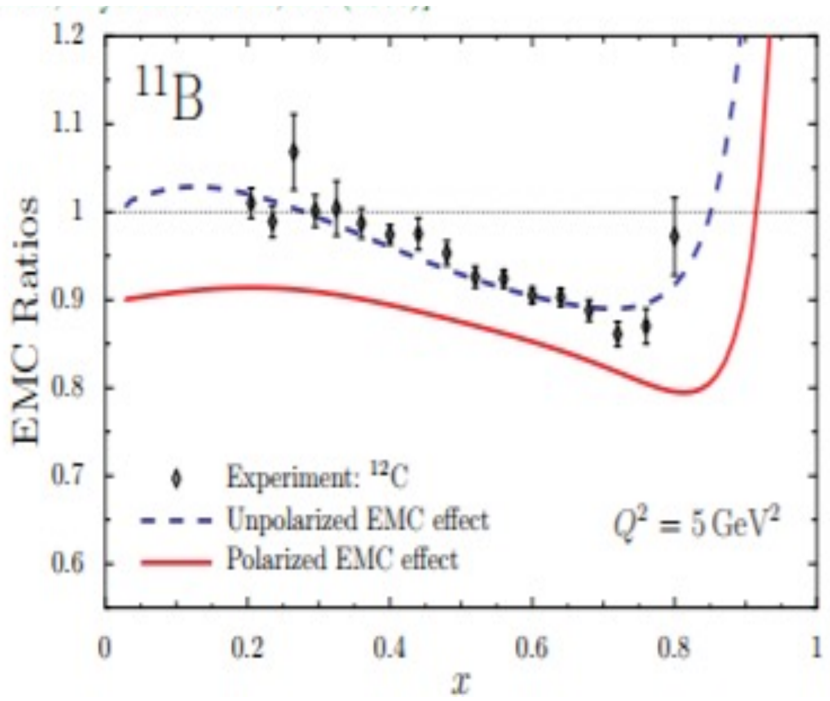
- ❑ EMC & Antishadowing in strange-quarks via Lambda-Production? (ongoing projection)

11GeV to 22GeV

➢ From 1D to 3D?

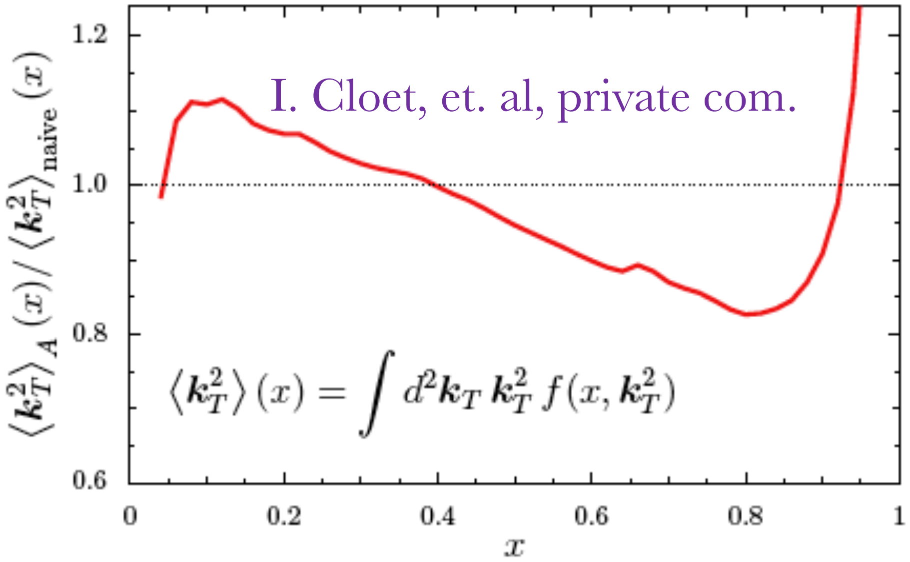
❑ Models suggest polarized PDFs in Nuclei are modified!

- Modification of quark-spin in nuclei?



I. Cloet, PRL 95, 052302, 2005); PLB 642, 210(2006)

❑ Transverse momentum distributions also likely modified



❑ To fully understand EMC effect → Nuclear effect in 3D!

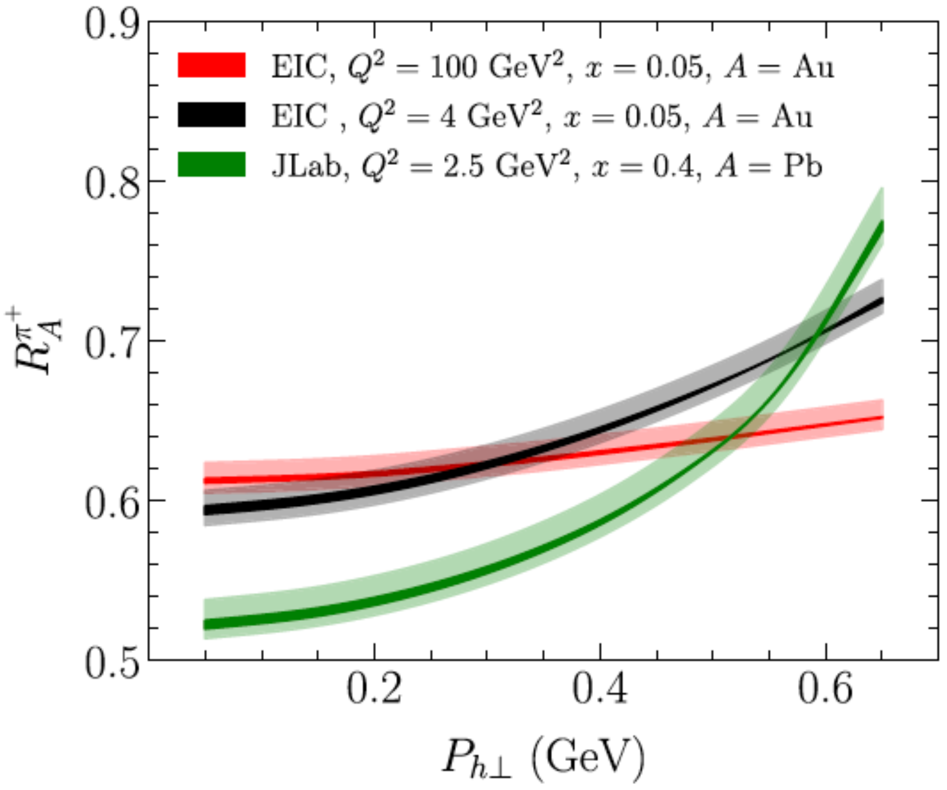
✓ Measuring pT distribution

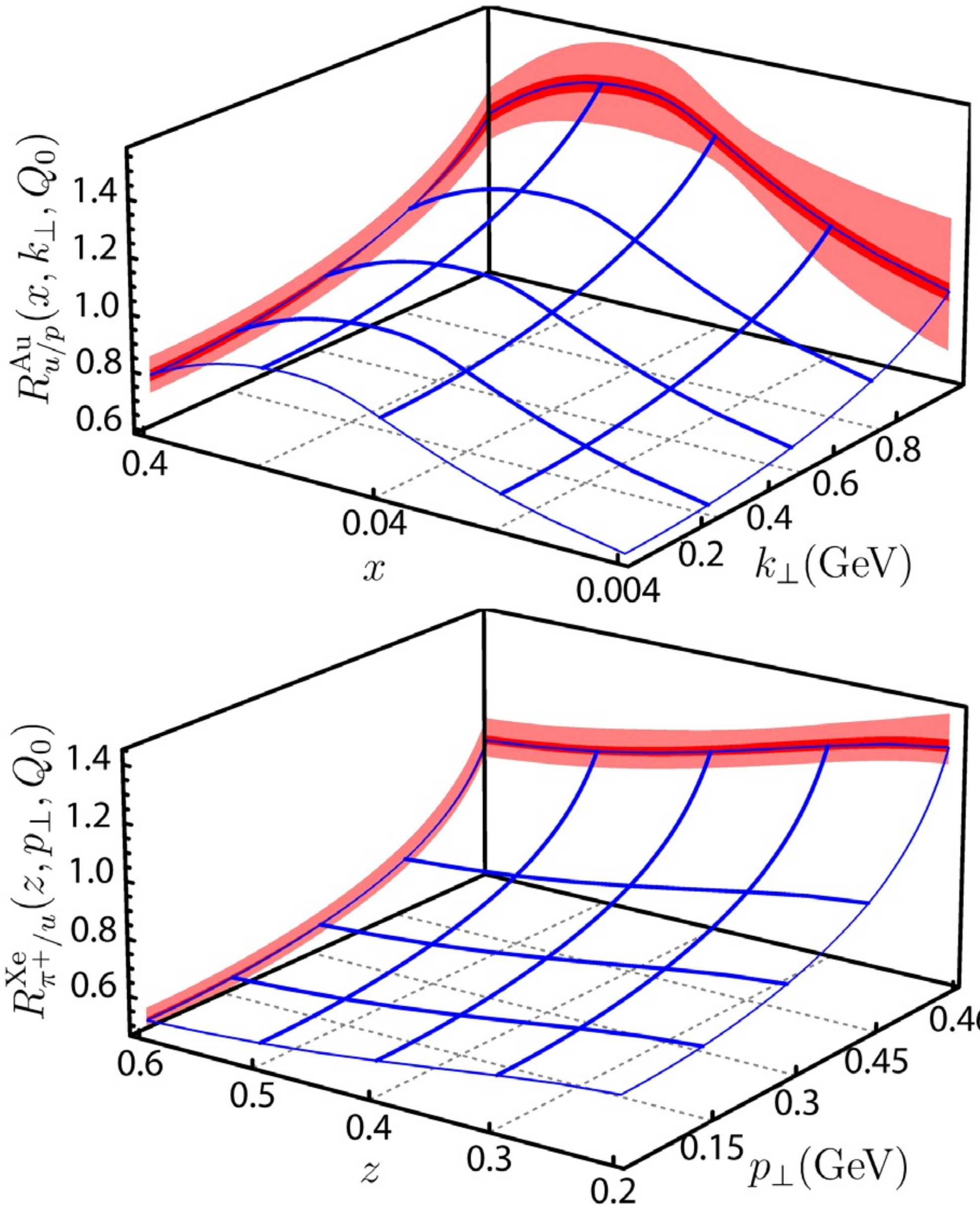
$$F_{UU}(x,z,P_T) = \sum_q e_q^2 [f_1^q(x,K_\perp) \otimes D_q^h(z,q_T)]$$

Unpolarized TMD *Unpolarized FF*

➢ From 1D to 3D?

- ❑ First global analysis of nTMD
  M. Alrashed et. al. PRL 129 (2022) 24, 242001



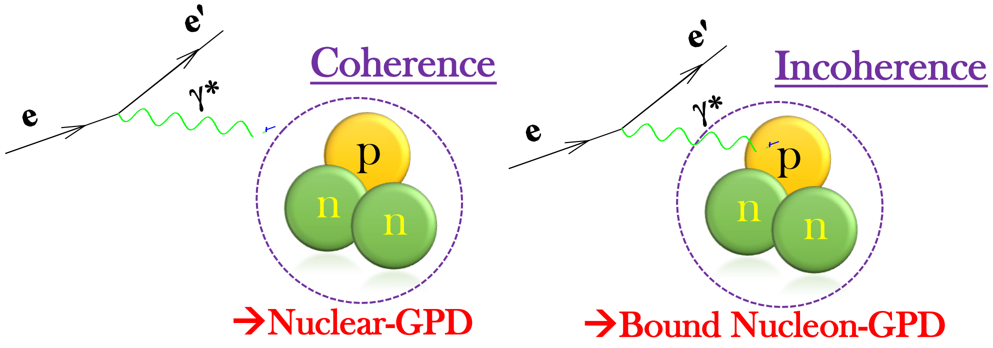


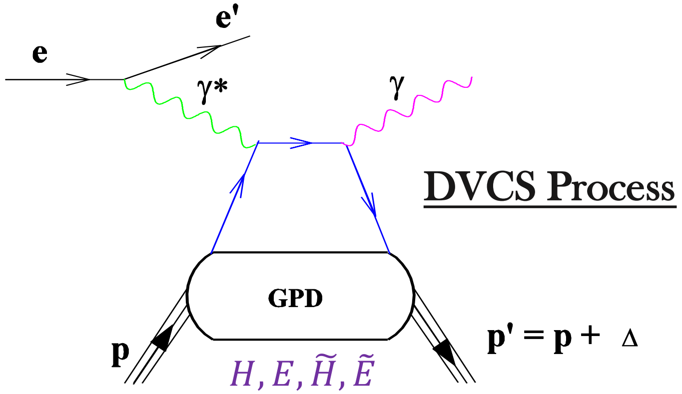
- ❑ Full 3D Projections@Jlab 11/GeV22GeV for A=3, C12&Pb are available → needed to be plotted properly

11GeV to 22GeV

➢ From 1D to 3D?

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





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

- ❑ 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

- ❑ Run in parallel with C12-21-004 A=3 SIDIS (no additional beam time)
- ❑ Projection (11GeV & 22GeV) ongoing

Summary

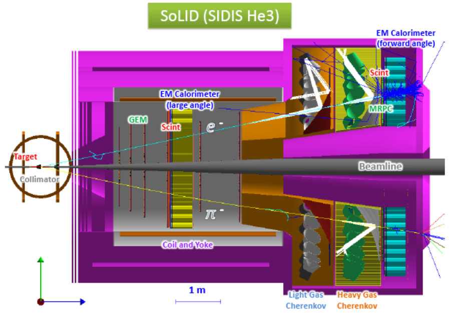
- Origins of EMC and anti-shadowing effects are still largely unknown
  - EMC vs SRC → how nucleons are modified?
  - Flavor-dependence of u and d?
  - Effects in sea & gluon?
- Poor experimental precision (mostly inclusive-DIS)
  - Need more precise data, mutiple techniques
  - Theoretical guidances
- SIDIS with multiple hadron-production at Jlab 22 GeV
  - Phase-space, fragmentation regions, corrections
  - Pions, kaons, proton and lambda production →Flavor-tagging
  - Measuring EMC & Anti-shadowing in 3D: nPDF → nTMD & nFF & nGPD

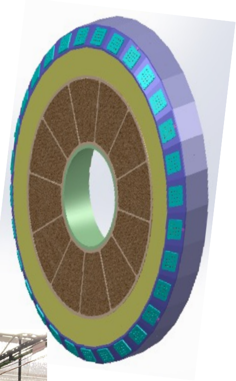
Backup

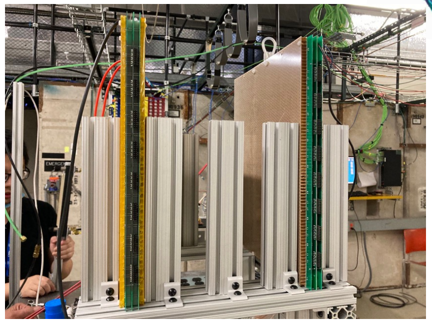
11GeV to 22GeV

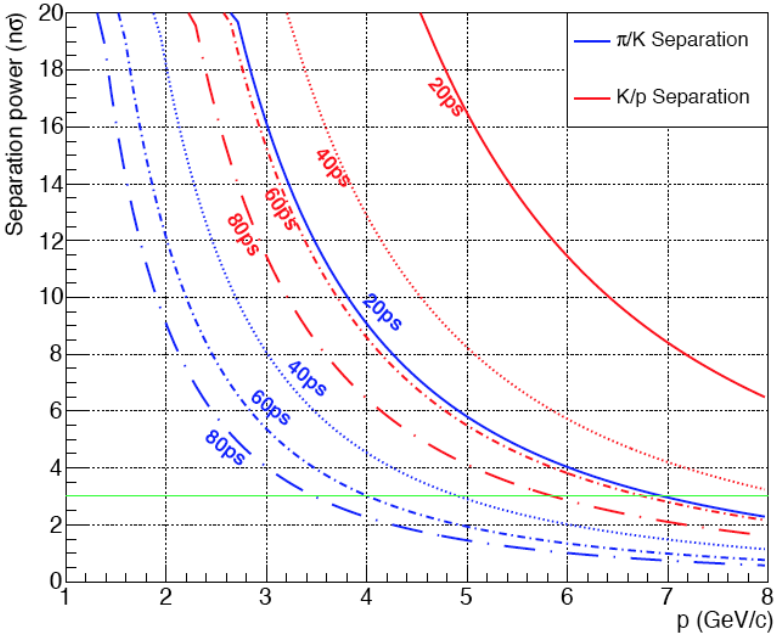
➢Need Detector Upgrade?

- ❑ At high-energy, particles go more forward!
- ❑ Scattered electrons at lower x go to small angles
  - ✓ Need high-granuity & high-resolution Ecal
  - ✓ Need good tracking reconstruction
  - ✓ Background & radiation
- ❑ Need to seprate more hadrons at high momenta
- ❑ SoLID Heavy-Gas Chernekov and MRPC-TOF:Pi/K separation up to 7 GeV/c









- ❑ CLAS12-RICH: Pi/K separation up to 8 GeV/c

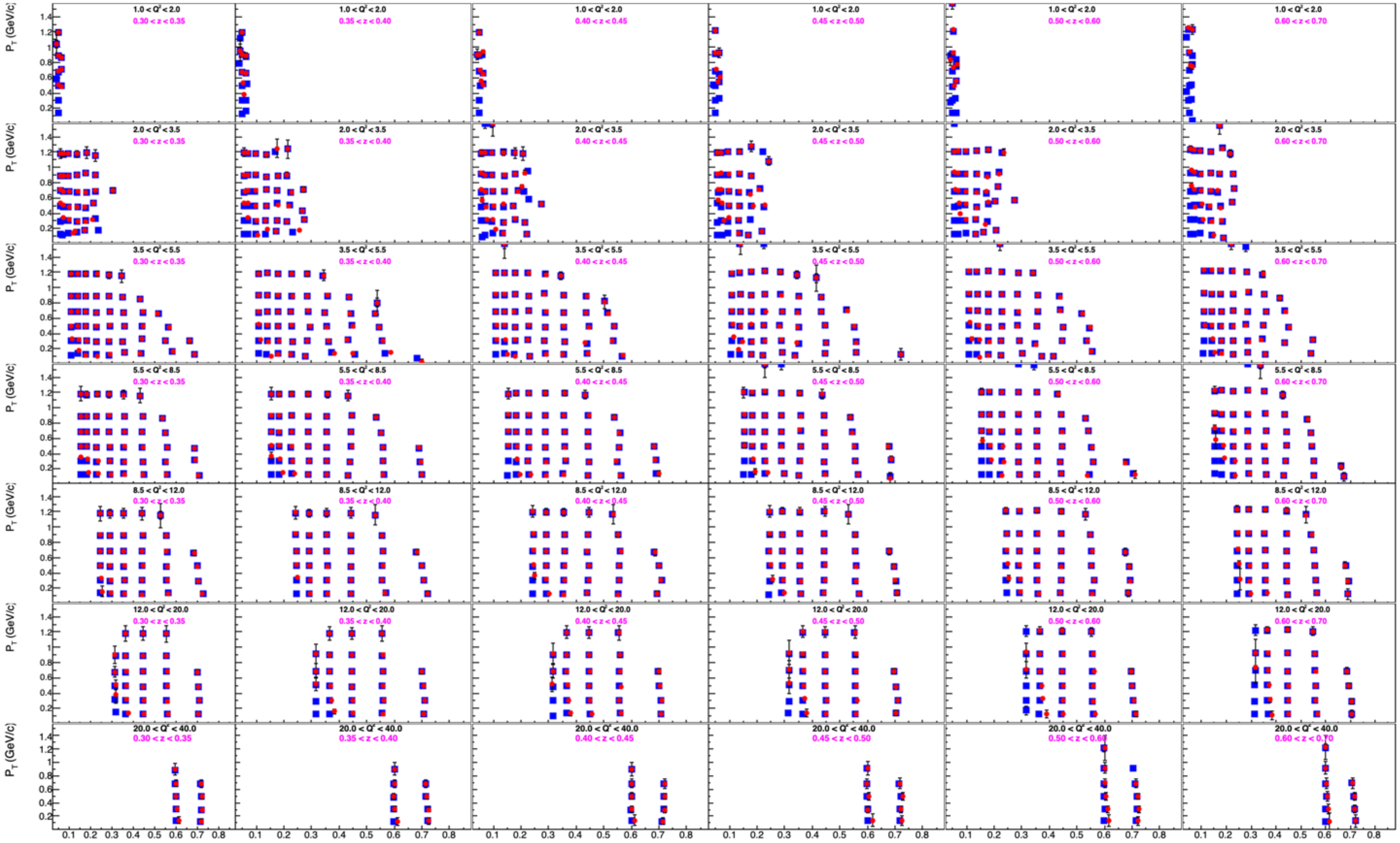
- ❑ CLAS12 & SoLID need detector upgrade for more forward partcles and PID at higher momenta (14GeV/c)

11GeV to 22GeV

➢Need Detector Upgrade?

Pion-SIDIS Projection

- CLAS12/SoLID
- More Open Geometry



11GeV to 22GeV

➢Need Detector Upgrade?

Kaon-SIDIS Projection

- CLAS12/SoLID
- More Open Geometry

11GeV to 22GeV

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

- Gaussian ansatz are commonly used but imprecise:
  - P_T Broadening to Actual distribution → Precision needed!

- 4D(Q2, x, z, P_T) SIDIS data off nuclei with multiple hadron states
  - ✓ Decouple P_T distributions for individual flavor
  - ✓ Access unpolarized nTMDs and nFFs
  - ✓ Study Hadron Attenuation in light-nuclei
  - ✓ Medium-modification effects in the transverse directions

➢ From 1D to 3D?

- The unpolarized SIDIS cross section w/ additional azimuthal dependence:

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

$$= A + B\cos\phi_h + C\cos 2\phi_h$$

Cahn Boer-Mulder

❖ If we consider the Boer-Mulder Term (very small):

- A-dependence of the $\cos(\phi_h)$ azimuthal term:

$$\langle\cos\phi\rangle_{UU} = -\frac{|\vec{k}_\perp|}{Q}\frac{B(y)}{A(y)}\frac{x_B f^\perp(x_B,k_\perp)}{f_1(x_B,k_\perp)}$$

Twsist-3

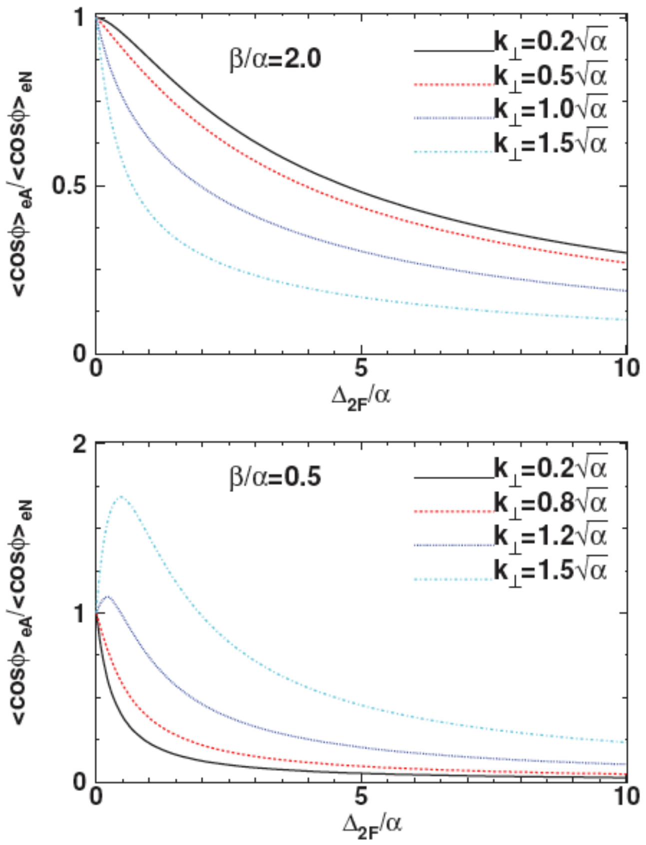
$$f_q^A(x,k_\perp) \approx \frac{A}{\pi(\alpha+\Delta_{2F})} f_q^N(x) e^{-\vec{k}_\perp^2/(\alpha+\Delta_{2F})},$$

$$f_{q\perp}^A(x,k_\perp) \approx \frac{A\beta}{\pi(\beta+\Delta_{2F})^2} f_{q\perp}^N(x) e^{-\vec{k}_\perp^2/(\beta+\Delta_{2F})}.$$

p_T width

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

broadening

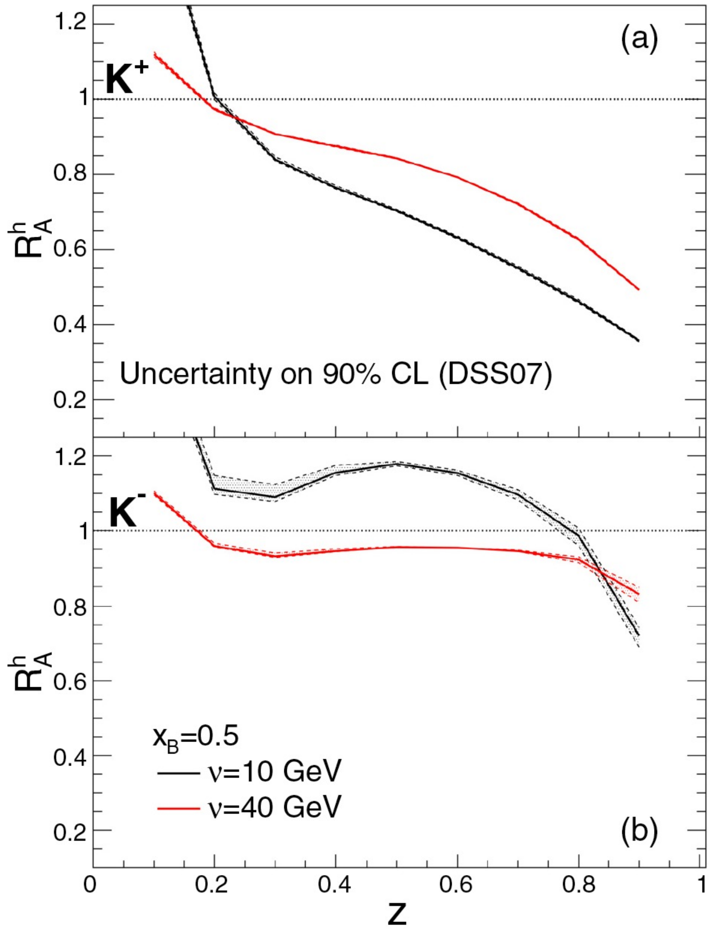


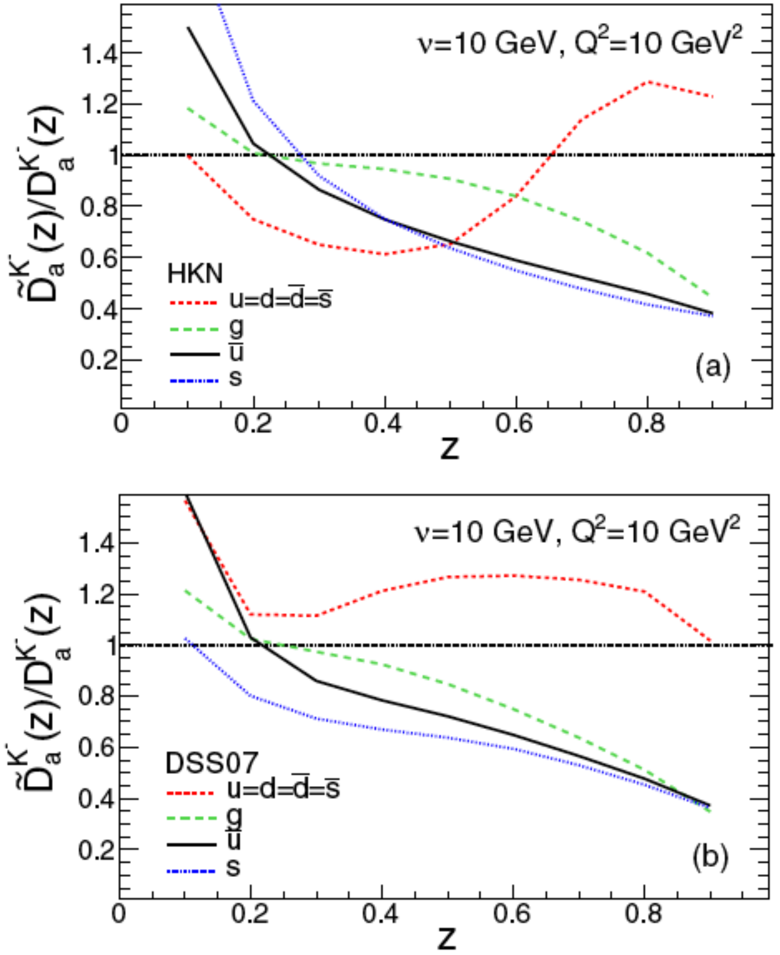
Gao, Liang, Wang RPC 81, 065211 (2010)

11GeV to 22GeV

➢ How energy update helps?

❑ Study flavor-dependence of Medium effect of FF





N Chang, et. al. PRC92, 055207 (2015)

W. Deng and X.-N Wang PRC 81, 024902 (2010)

nPDF with SIDIS

➢SIDIS with PT measurements

- XS-Sum and XS-Difference between $\pi^+$and π^- (Factorization, LO, P_T integrated):

$$\frac{d\sigma_A^h}{dx dQ^2 dz} = \frac{4\pi\alpha^2 s}{Q^4}(1 - y + \frac{y^2}{2}) \sum_q e_q^2 f_1^{A,q}(x) \cdot D_{A,q}^h(z),$$

$$(\sigma_A^{\pi^+} \pm \sigma_A^{\pi^-})/A \propto [4(u_A \pm \bar{u}_A) \pm (d_A \pm \bar{d}_A)] \cdot [D_A^{fav} \pm D_A^{unf}],$$

Simplify the FFs:

$$D_u^{\pi^+} = D_{\bar{d}}^{\pi^+} = D_d^{\pi^-} = D_{\bar{u}}^{\pi^-} \equiv D^{\text{fav}},$$
$$D_d^{\pi^+} = D_{\bar{u}}^{\pi^+} = D_u^{\pi^-} = D_{\bar{d}}^{\pi^-} \equiv D^{\text{unfav}},$$

- Super-Ratios between two nuclei:

$$R_{A_1/A_2}^{\pi,\pm}(x,z) = \frac{(\sigma_{A_1}^{\pi^+} \pm \sigma_{A_1}^{\pi^-})/A_1}{(\sigma_{A_2}^{\pi^+} \pm \sigma_{A_2}^{\pi^-})/A_2}$$
$$= \frac{4(u_{A_1} \pm \bar{u}_{A_1}) \pm (d_{A_1} \pm \bar{d}_{A_1})}{4(u_{A_2} \pm \bar{u}_{A_2}) \pm (d_{A_2} \pm \bar{d}_{A_2})} \cdot \frac{D_{A_1}^{fav} \pm D_{A_1}^{unfav}}{D_{A_2}^{fav} \pm D_{A_2}^{unfav}} = A_{A_1/A_2}^{\pi,\pm}(x) \cdot B_{A_1/A_2}^{\pi,\pm}(z),$$

- FF-term can be independently measured: $B_{A/D}^{\pi,+}(z) = \frac{M_A^{\pi+} + M_A^{\pi-}}{M_D^{\pi+} + M_D^{\pi-}} = \frac{D_A^{fav} + D_A^{unfav}}{D_D^{fav} + D_D^{unfav}}$

✓ SIDIS with Nuclei are able to study nPDF and nFF (but global analysis needed for QCD effect)

Flavor-Dependence EMC Effect

➢ Flavor-Dependent EMC Effect in A=3:

❖ The Super-Ratios are uniquely sensitive to the PDF-contribution:

- ✓ If N>Z, u-quark is more modified → Tritium?
- ✓ If N<Z, d-quark is more modified → Helium-3?

$$R^{\pi,+}_{H/D}(x) \simeq \frac{4(u_H + \bar{u}_H) + (d_H + \bar{d}_H)}{5(u + \bar{u}) + 5(d + \bar{d})} \qquad R^{\pi,+}_{T/D}(x) \simeq \frac{4(u_T + \bar{u}_T) + (d_T + \bar{d}_T)}{5(u + \bar{u}) + 5(d + \bar{d})}$$

$$R^{\pi,-}_{H/D}(x) \simeq \frac{4(u_H - \bar{u}_H) - (d_H - \bar{d}_H)}{3(u - \bar{u}) + 3(d - \bar{d})} \qquad R^{\pi,-}_{T/D}(x) \simeq \frac{4(u_T - \bar{u}_T) - (d_T - \bar{d}_T)}{3(u - \bar{u}) + 3(d - \bar{d})}$$

- EMC effect on all nucleons:

$$u_{T,Adep} = \frac{\tilde{u} + 2\tilde{d}}{3}, \quad d_{T,Adep} = \frac{\tilde{d} + 2\tilde{u}}{3},$$
$$u_{H,Adep} = \frac{2\tilde{u} + \tilde{d}}{3}, \quad d_{H,Adep} = \frac{2\tilde{d} + \tilde{u}}{3},$$

- EMC effect only on SRC pairs

$$u_{T,SRC} = \frac{\tilde{u} + \tilde{d} + d}{3}, \quad d_{T,SRC} = \frac{\tilde{d} + \tilde{u} + u}{3},$$
$$u_{H,SRC} = \frac{\tilde{u} + \tilde{d} + u}{3}, \quad d_{H,SRC} = \frac{\tilde{d} + \tilde{u} + d}{3},$$

SIDIS with Heavy Nuclei

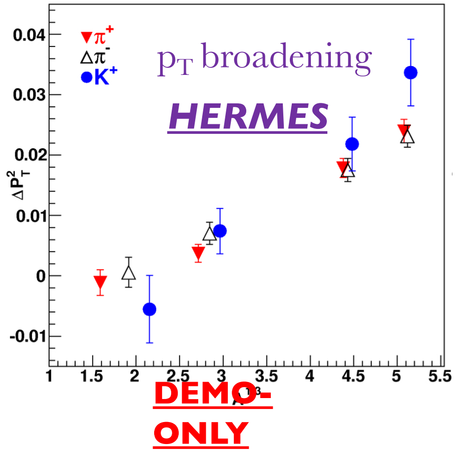
➢ Nuclear 3D Tomography:

❖ 4D-binning (Q^2, x, z, P_T) in SIDIS for light and heavy nuclei

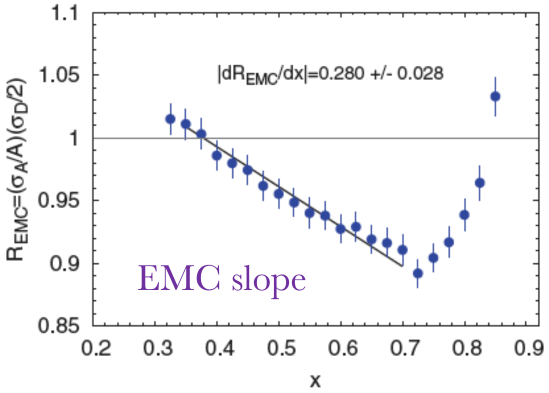
❖ Study the A-dependence of PDF and PDF in medium

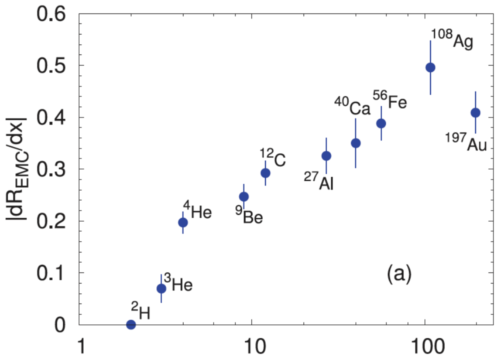
$$B^{h+}_{A/D}(z,p_T) = \frac{M^h_A(z,p_T)}{M^h_D(z,p_T)} = \frac{(N^{h+}_A + N^{h^-}_A)/N_A}{(N^{h^+}_D + N^{h^-}_D)/N_D}$$

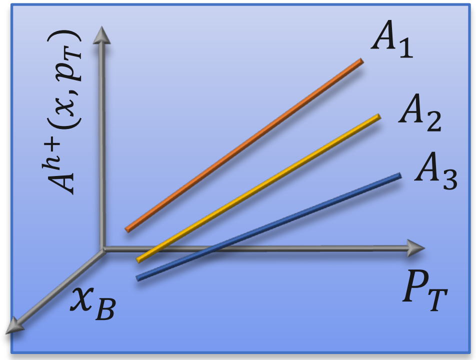
$$R^{h^+ + h^-}_{A/D}(x,z,p_T) = \frac{N^{h^+}_A + N^{h^-}_A}{N^{h^+}_D + N^{h^-}_D} = A^{h+}(x,p_T) \otimes B^{h+}(z,p_T)$$



❖ Look at the p_T dependence (not just broadening)





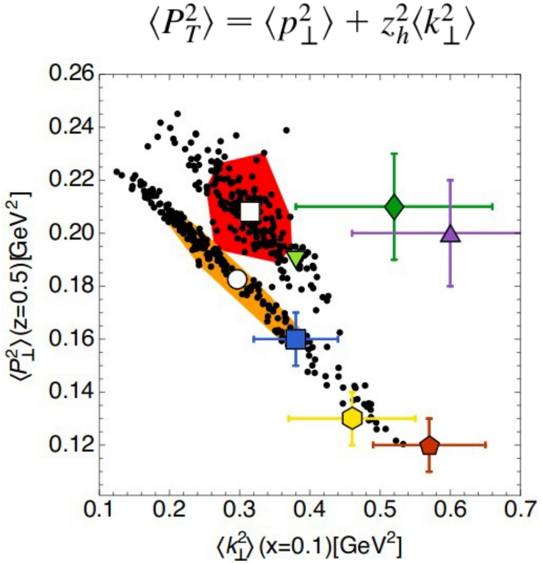


EMC ratio in 2D?

✓ A comprehensive way to study nuclear-effect in QCD

SIDIS with Heavy Nuclei

➢ Nuclear 3D Tomography:

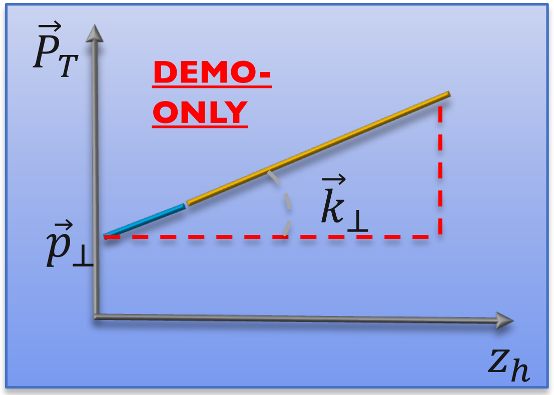


❖ Possible to extraction of $\boldsymbol{k_\perp}$ ***and*** $\boldsymbol{p_\perp}$ distributions:

$$\vec{P}_T = \vec{p}_\perp + z_h\vec{k}_\perp + O\left(\frac{k_\perp^2}{Q^2}\right),$$ not 100% correct in full QCD but roughly hold

✓ Extrapolation to $z_h \rightarrow 0$ to extract the distributions of $\vec{p}_\perp$

✓ The slope gives the ("relative") distributions of $\vec{k}_\perp$



❖ By comparing the distributions of extracted $\vec{p}_\perp$ and $\vec{k}_\perp$ in different nuclei:

- From $\vec{k}_\perp$, does the quark shrink or enlarge when A is larger?
- From $\vec{p}_\perp$, does the quark shrink or enlarge after it is struck out?
- Is the Gaussian Ansatz hold for $\vec{p}_\perp$ and $\vec{k}_\perp$ in all nuclei?