2D Correlations in Nuclear DIS with EG2 Data

Dr. Sebouh J. Paul
on behalf of the CLAS12 collaboration

University of California, Riverside

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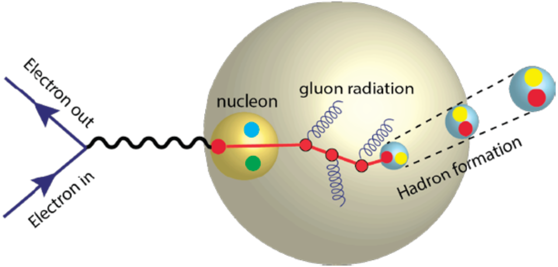
Introduction/Motivation

- What happens when a fast moving quark moves through a nucleus?
- Struck quark → primary hadron



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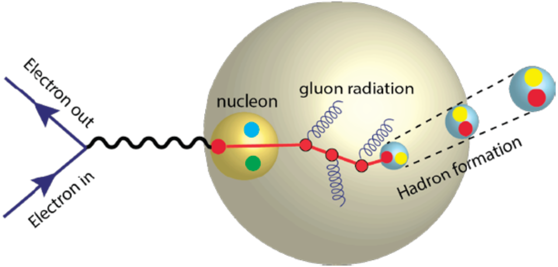
- Struck quark $\rightarrow$ primary hadron
- Final-state interactions $\rightarrow$ secondary-hadron cascade



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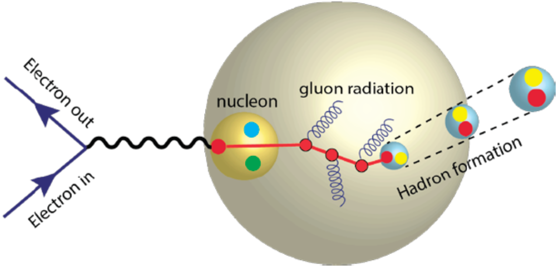
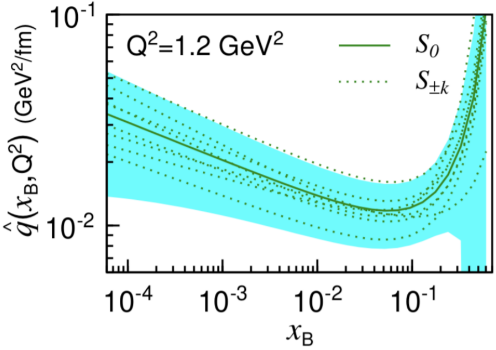


Motivation: constrain transport-parameters of nuclei, e.g:

The $\hat{q}(x, Q^2)$ transport parameter: "broadening/energy loss per unit length".

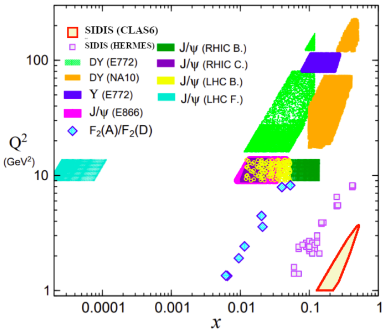


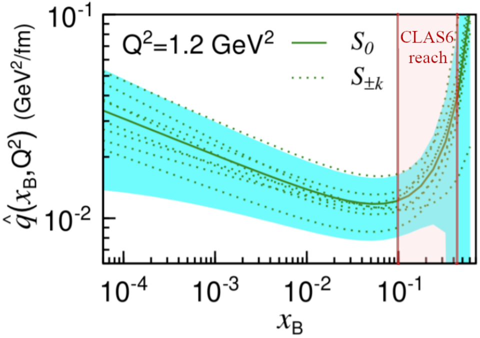
- Large uncertainties, especially at large x region.
- Sharp increase at large-x (larger nuclear effects) are predicted.
- Weak rise with decreasing x below $x \approx 0.1$

Motivations: Cold Nuclear-Matter Effects

A global extraction of $\hat{q}$ transport parameter, which dictates strength of CNM effects.
Ru et al. PRD 103, 031901 (2021)

Figure 1.5: Summary of world data that has been used to constrain cold nuclear matter effects

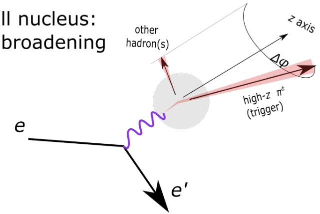




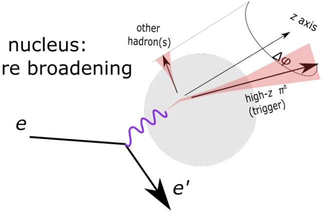
CLAS data can be used to constrain high-x dependence of $\hat{q}$.
Useful baseline for lower-x measurements.

qhat and di-hadron azimuthal correlation

Small nucleus:
less broadening



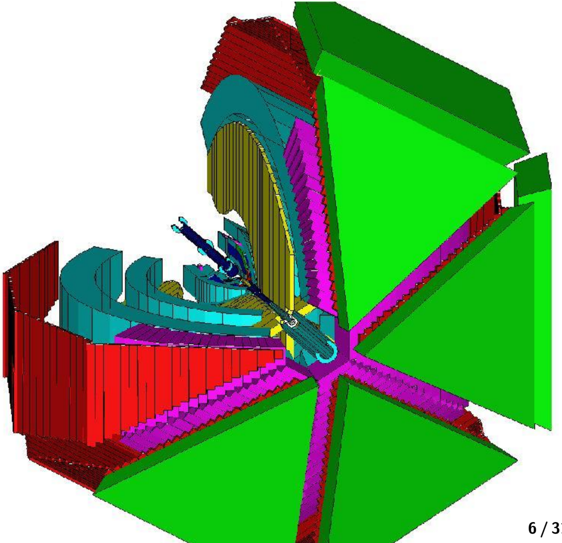
Big nucleus:
more broadening



- How can $\hat{q}$ be constrained by azimuthal correlations?
- In bigger nuclei, the hadrons encounter more material $\rightarrow$ correlations smear out more

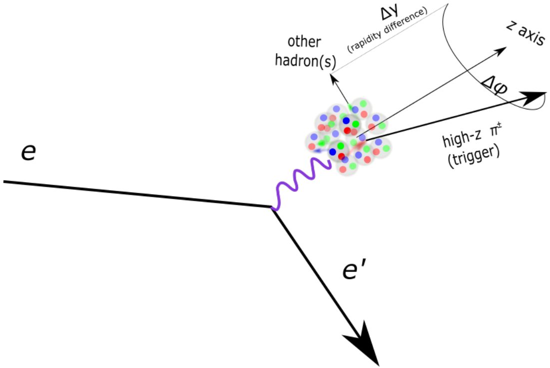
Dataset/Experimental Setup

- EG2 data from CLAS6
- $E_{beam} = 5.014$ GeV
- deuterium target in tandem with nuclear targets: C, Fe and Pb
- Setup minimizes systematic uncertainties for nuclear-to-deuterium ratios



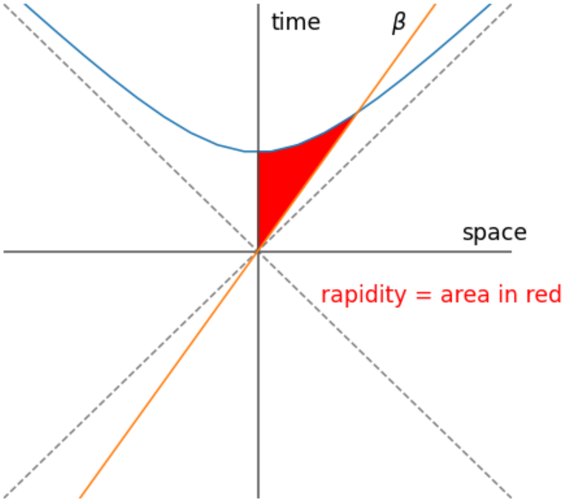
Kinematics and definitions

- We look at events with a scattered electron, a high-z pion (trigger) and another hadron (associated)
- Results are presented in the $\gamma^* p$ CM frame as a function of
  - $\Delta\phi$: difference in azimuthal angle
  - Δy: difference in rapidity ($y = \frac{1}{2} \ln \frac{E+p_z}{E-p_z}$)



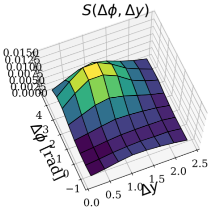
What is rapidity?

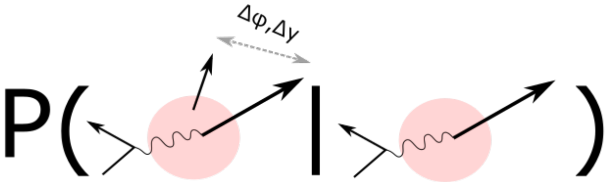
- A measure of boosted-ness along a given axis.
- in our case the γ^* axis
- $y = \frac{1}{2} \ln \frac{E+p_z}{E-p_z}$
- Δy: differences in rapidity are invariant under boosts along the chosen axis.

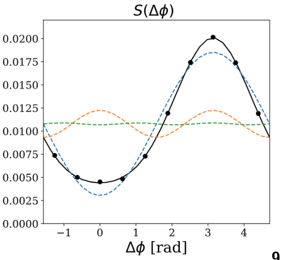


What is a correlation function?

- Probability, given one hadron's (ϕ, y), of finding another hadron some $(\Delta\phi, \Delta y)$ away
- Related to same-event yield, $\frac{1}{N_{\mathrm{trig}}} \frac{dN_{\mathrm{pair}}}{d\Delta\phi d\Delta y}$
- Includes pair-acceptance corrections
- Analogous to galactic correlation function used in cosmology

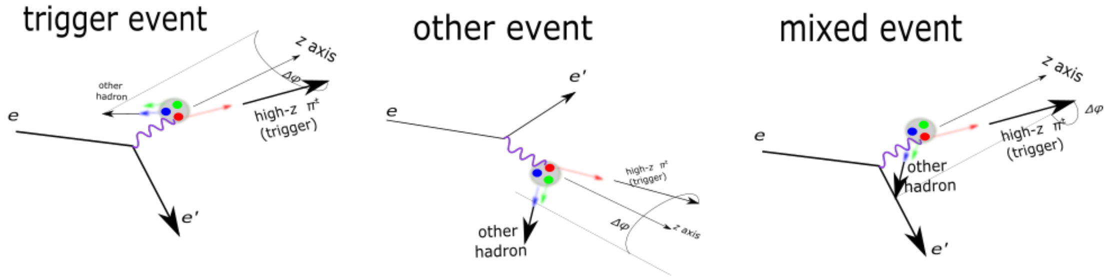






Pair-acceptance correction

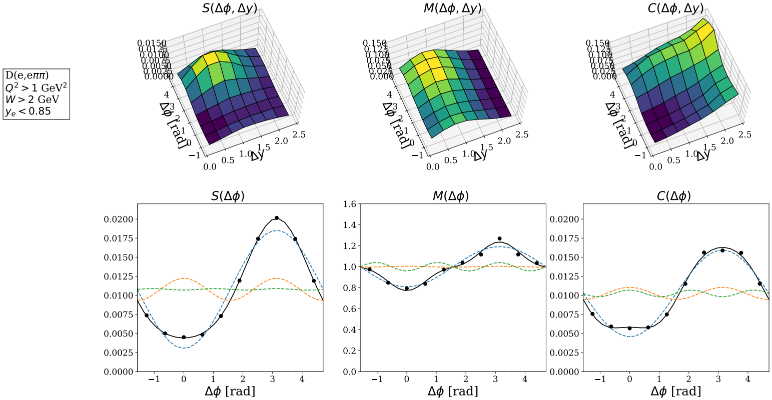
- Event mixing is performed to correct for pair-acceptance effects in a data-driven way.
- This method was used previously in CLAS12 and tested with an independent, MC-based correction, providing similar results*
- this nearly cancels when taking deuteron/nucleus ratios.



*S. Paul "Long-range two-particle correlations in DIS with CLAS12", DIS 2021.

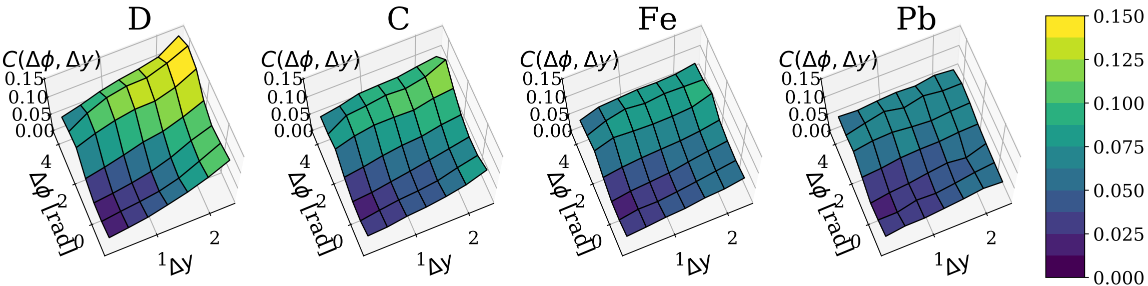
Correlation function: $\pi\pi$ pairs from D

- $S(\Delta\phi, \Delta y) = \frac{1}{N_{\mathrm{trig}}} \frac{dN_{\mathrm{pairs}}}{d\Delta\phi\Delta y}$
- $M(\Delta\phi, \Delta y) = \frac{1}{N_{\mathrm{mix}}} \frac{dN_{\mathrm{mix}}}{d\Delta\phi\Delta y}$
- $C(\Delta\phi, \Delta y) = \frac{S(\Delta\phi,\Delta y)}{M(\Delta\phi,\Delta y)}$



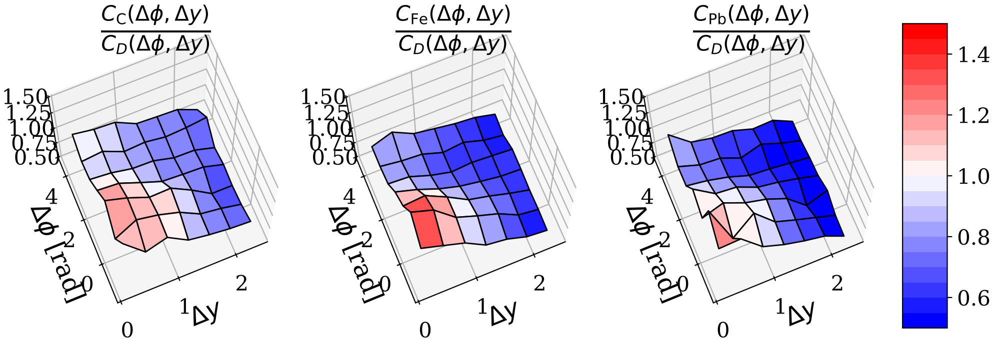
All nuclei, $\pi\pi$.

- Similar general shape for all targets
- Suppression visible for heavier nuclei



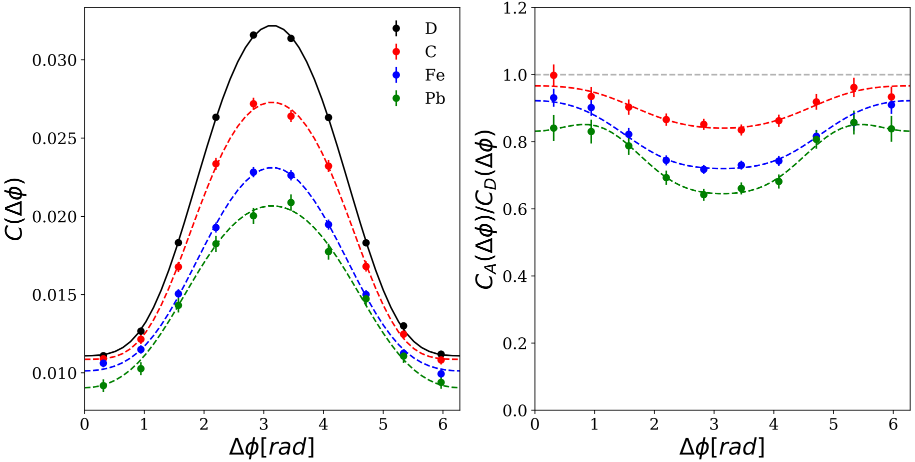
All nuclei, $\pi\pi$.

- Taking C_A/C_D ratio shows an enhancement at $\Delta\phi, \Delta y$ near 0
- Suppression everywhere else

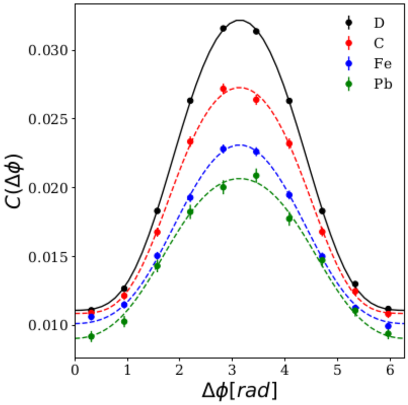


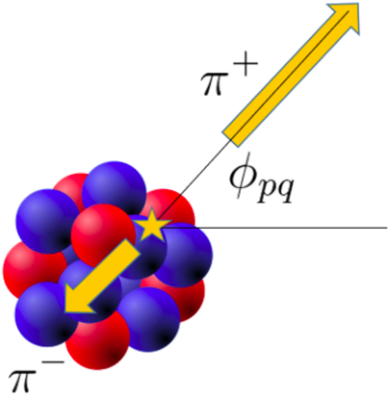
All nuclei, $\pi\pi$.

Increased broadening and suppression with heavier nuclei.

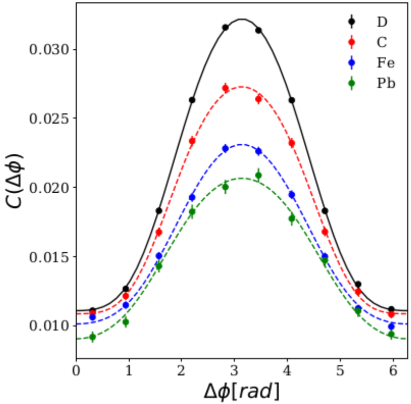


First evidence of suppression and broadening of two-pion correlation function in e-A DIS

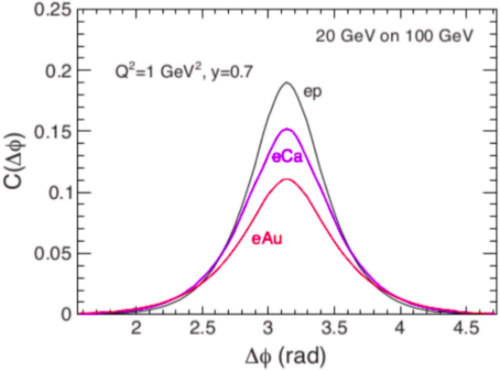




CLAS



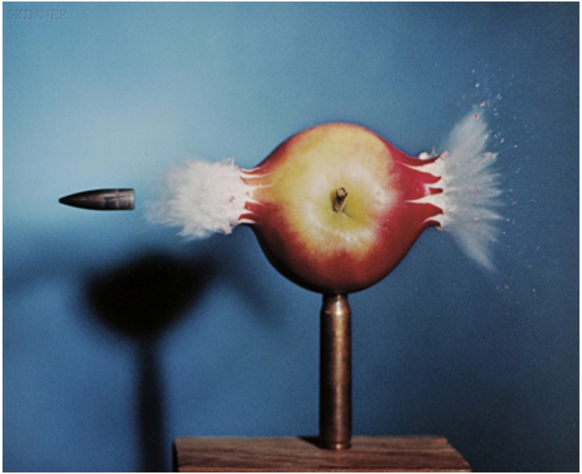
EIC



Same system, same observable, same Q2, different x range

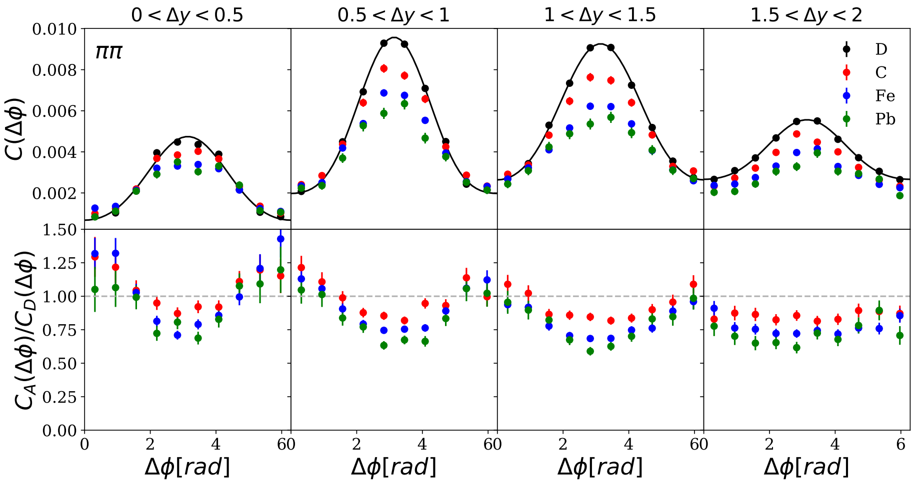
What do we gain from measuring Δy?

- Nuclear debris expected to show up near the high-z pion direction (azimuthal and rapidity)
- Medium-response to the “fast quark”.



All nuclei, $\pi\pi$. Δy slices

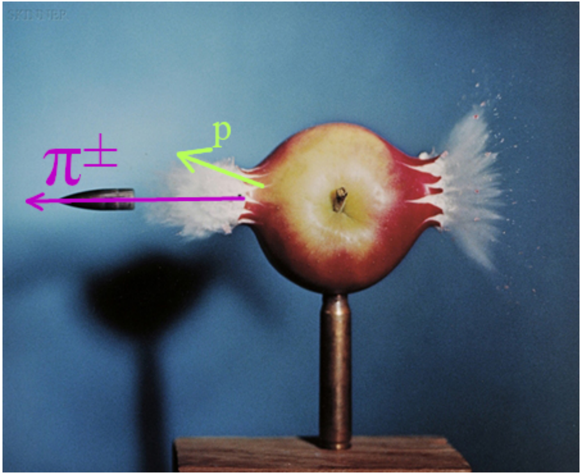
- Suppression factor is flatter at larger Δy.



Motivation for proton measurement

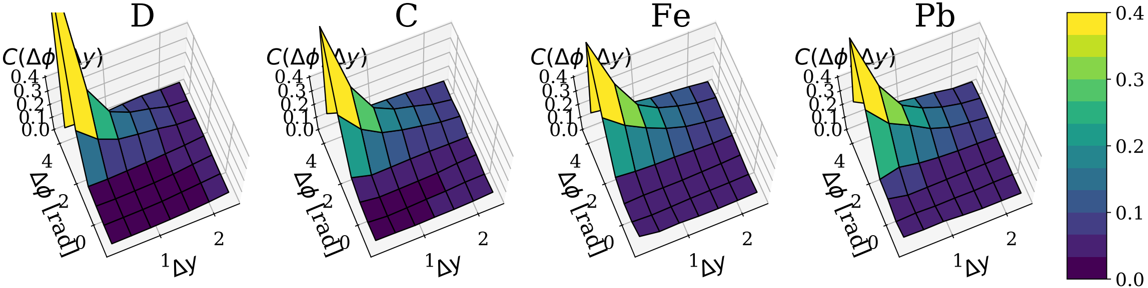
At least two forms of proton production:

- part of the recoiling diquark system (this is already observed in *ep* DIS)
- protons knocked out of the nucleus by the fast-moving quark (pure nuclear effect!)



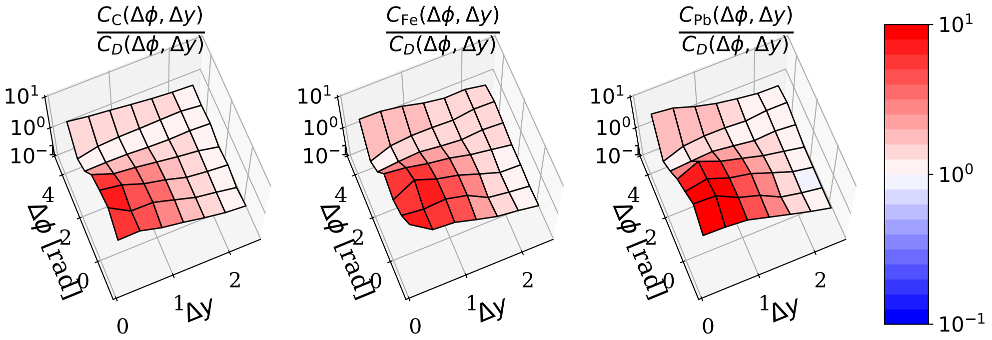
All nuclei, πp.

- Similar general shape for all targets
- Spike near $\Delta\phi = \pi$, $\Delta y = 0$



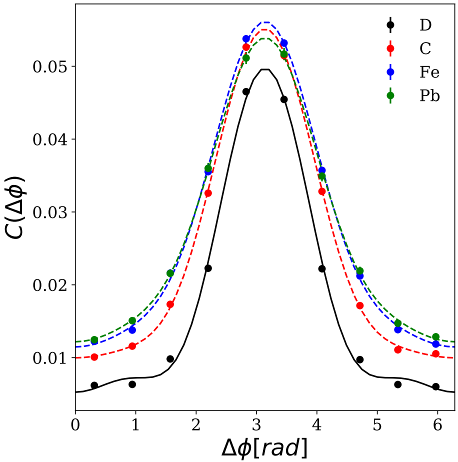
All nuclei, πp.

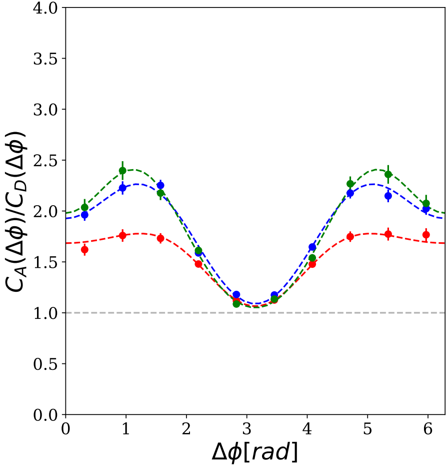
- HUGE enhancement at $\Delta\phi, \Delta y$ near 0,0 (Note the log scale!)
- Slight suppression at $\Delta\phi = \pi$, $\Delta y = 0$ (smaller spike)
- Mild enhancement virtually everywhere else.



All nuclei, πp.

Not only is the 1D correlation function broadened, but also enhanced!





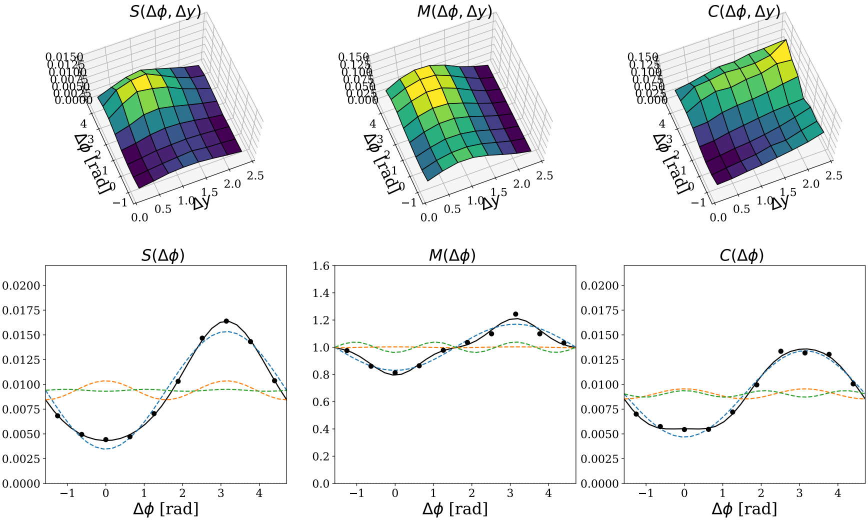
Conclusions

- Two-particle correlation functions in nuclear DIS provide a poweful tool to constrain cold nuclear-matter effects. “How does the nucleus react to a fast-moving quark?”
- Back-to-back azimuthal topology sensitive to broadening due to multiple scattering of quarks (hadrons) in nuclei.
- CLAS6 data provide good coverage at high-x, where nuclear effects (encapsulated by transport parameter $\hat{q}(x, Q^2)$) are predicted to increase.
- Useful reference/baseline for future EIC studies
- 2-pion events:
    - Fewer secondary pions are produced per trigger hadron in larger nuclear targets
    - Suppression and broadening of correlation function observed, with larger effects for heavier targets
- pion-proton events:
    - Broadening observed, but rates are enhanced, rather than suppressed, in heavy targets

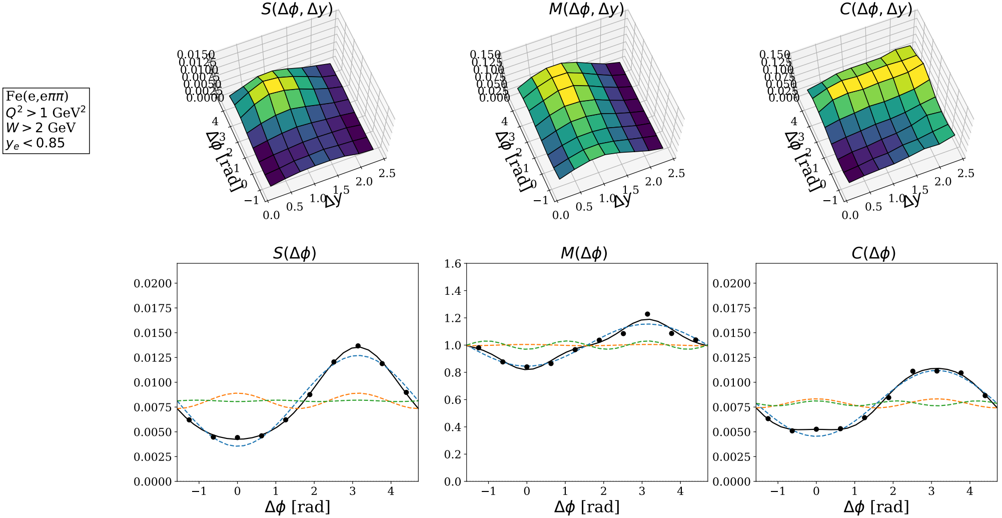
BACKUP SLIDES

Correlation function: $\pi\pi$ pairs from C

C(e,e$\pi\pi$)
$Q^2 > 1$ GeV^2
$W > 2$ GeV
$y_e < 0.85$

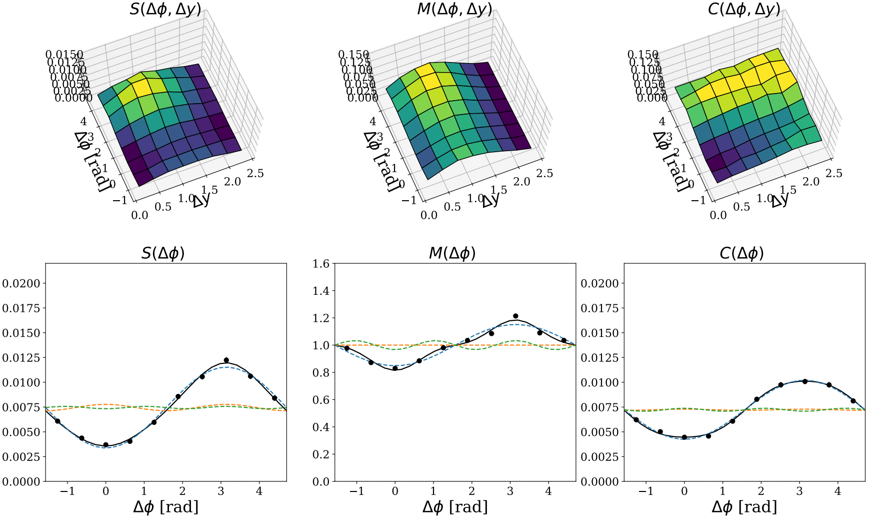


Correlation function: $\pi\pi$ pairs from Fe

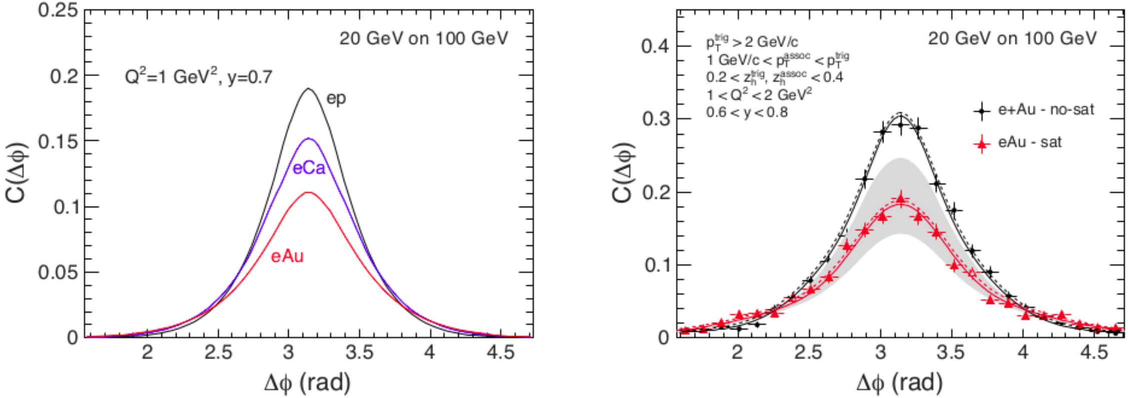


Correlation function: $\pi\pi$ pairs from Pb

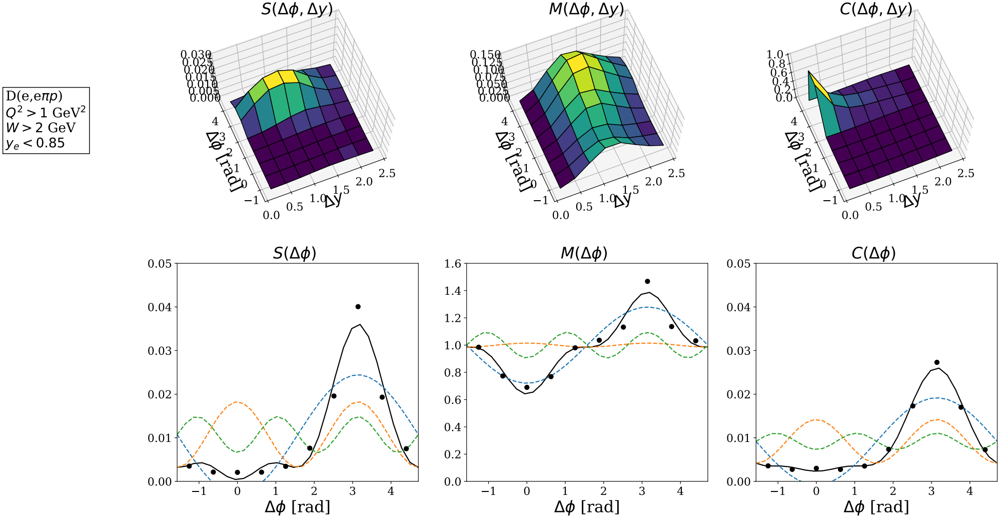
Pb(e,e$\pi\pi$)
$Q^2 > 1$ GeV^2
$W > 2$ GeV
$y_e < 0.85$



- CLAS6 data may test CNM models at high$-x$, which is important reference for future EIC data (projection shown below).



Correlation function: πp pairs from D



Correlation function: πp pairs from C

C(e,eπp)
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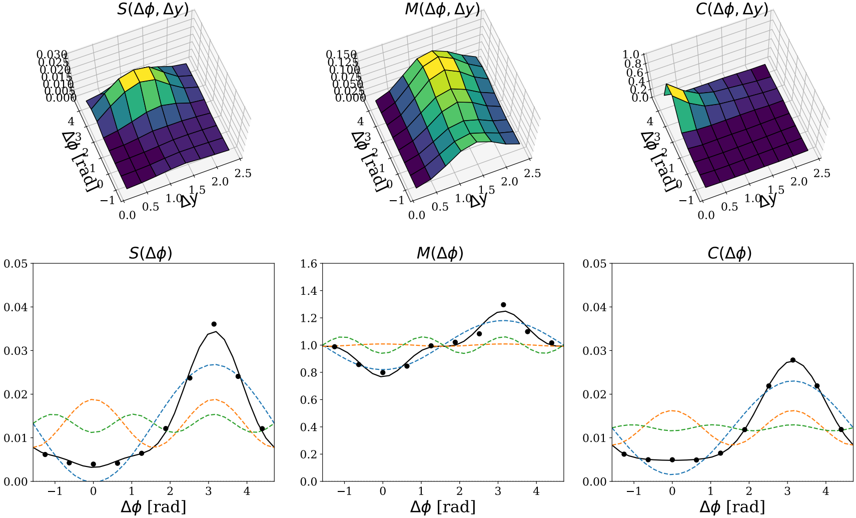

Correlation function: πp pairs from Fe

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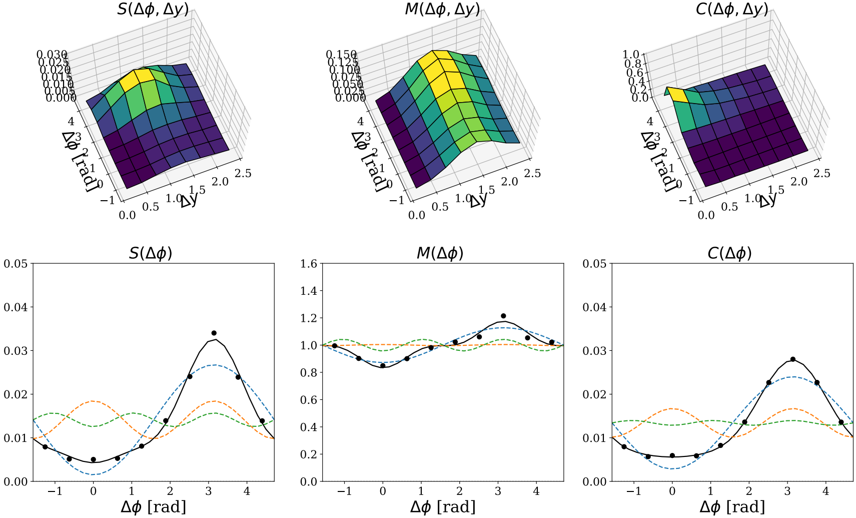

Correlation function: πp pairs from Pb

Pb(e,eπp)
$Q^2 > 1$ GeV^2
$W > 2$ GeV
$y_e < 0.85$