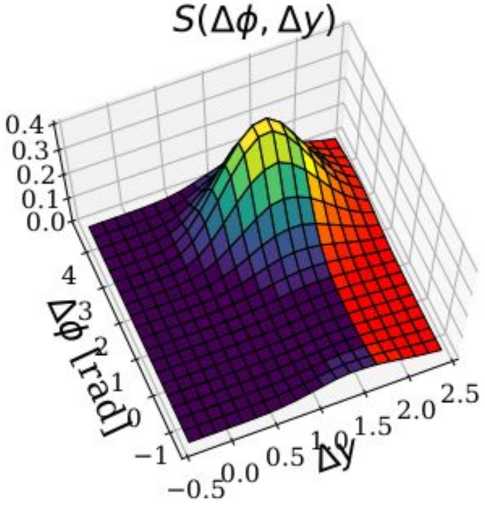
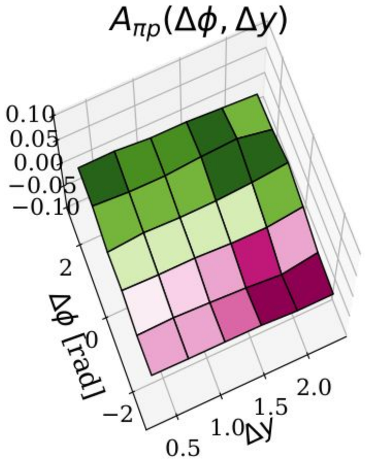
Hadronization studies in DIS

Miguel Arratia,
On behalf of the CLAS collaboration





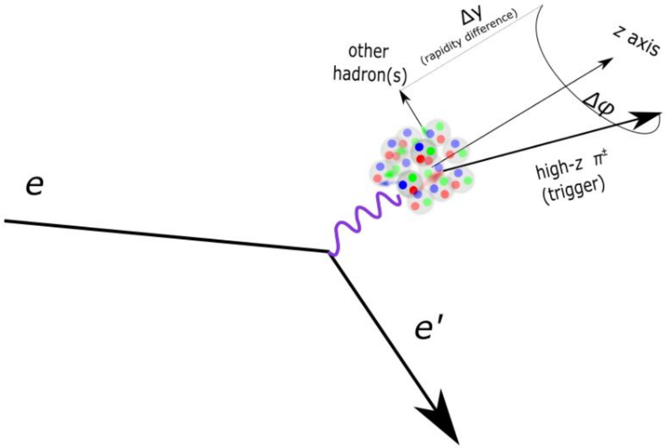
The Future of CT and Hadronization Studies at JLab and beyond, June 2021

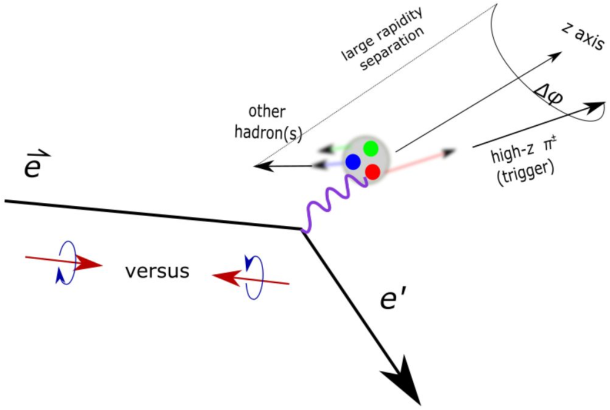
Outline

- Hadronization studies in nuclear DIS

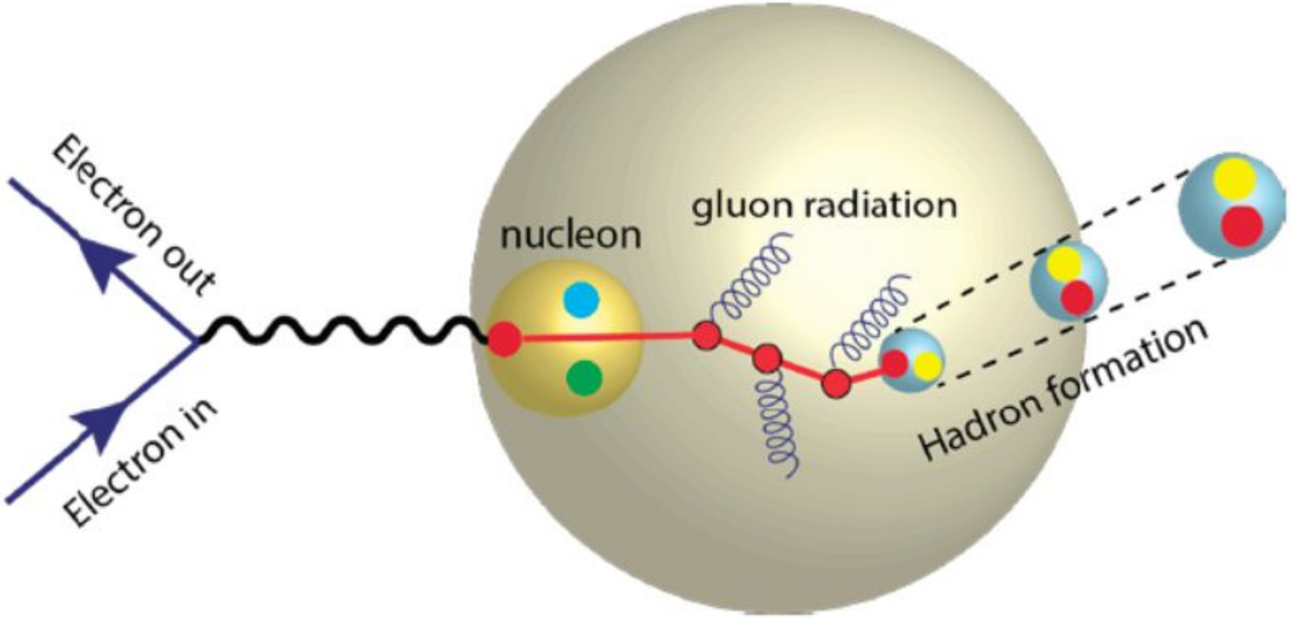
- Hadronization studies in unpolarized and polarized ep DIS.

- Future prospects

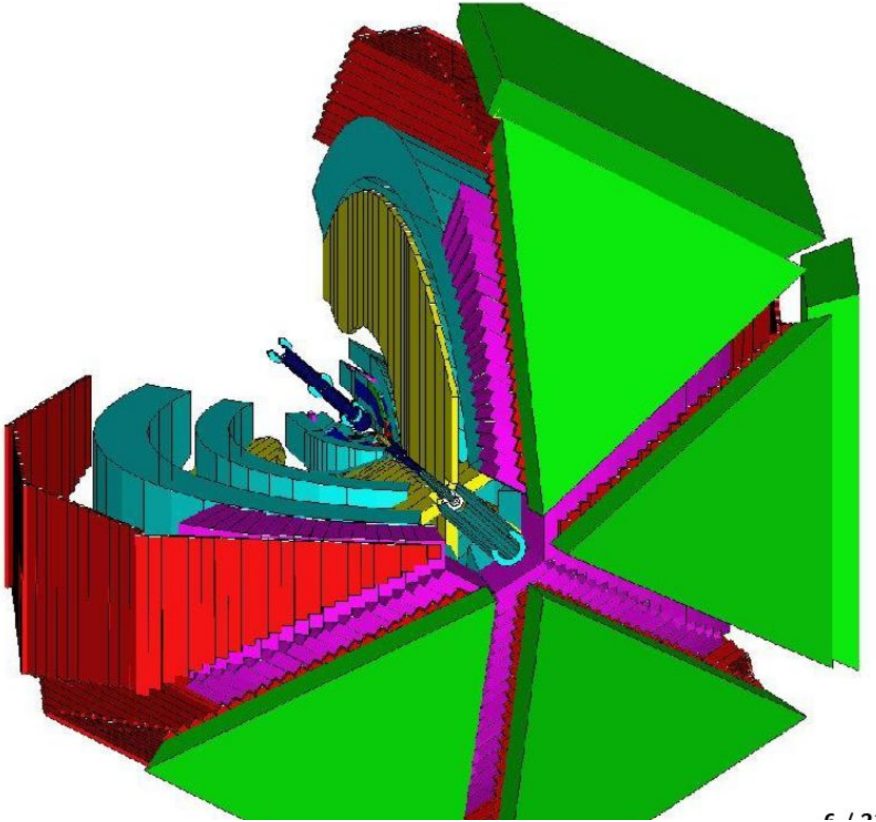




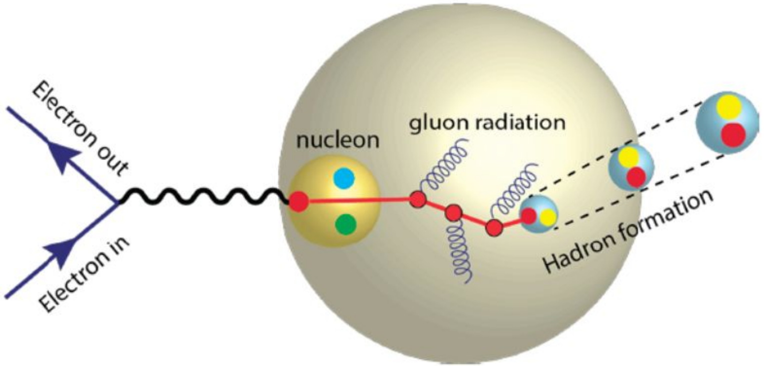
How does the nucleus react to a fast moving quark?



- 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

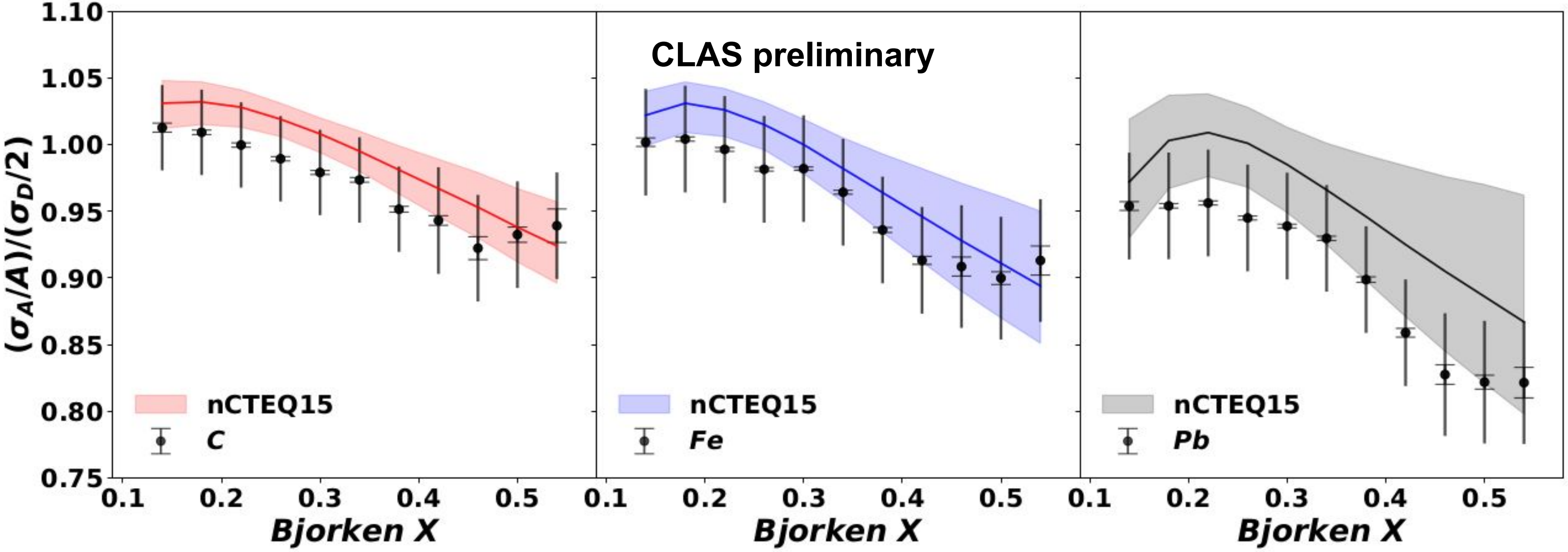


Nuclear modification factor



$$R_h(\nu, Q^2, z, p_T^2) = \frac{N_h^A(\nu, Q^2, z, p_T^2)/N_e^A(\nu, Q^2)}{N_h^D(\nu, Q^2, z, p_T^2)/N_e^D(\nu, Q^2)}.$$

EMC ratio, Q2>1 GeV2, W>2 GeV.

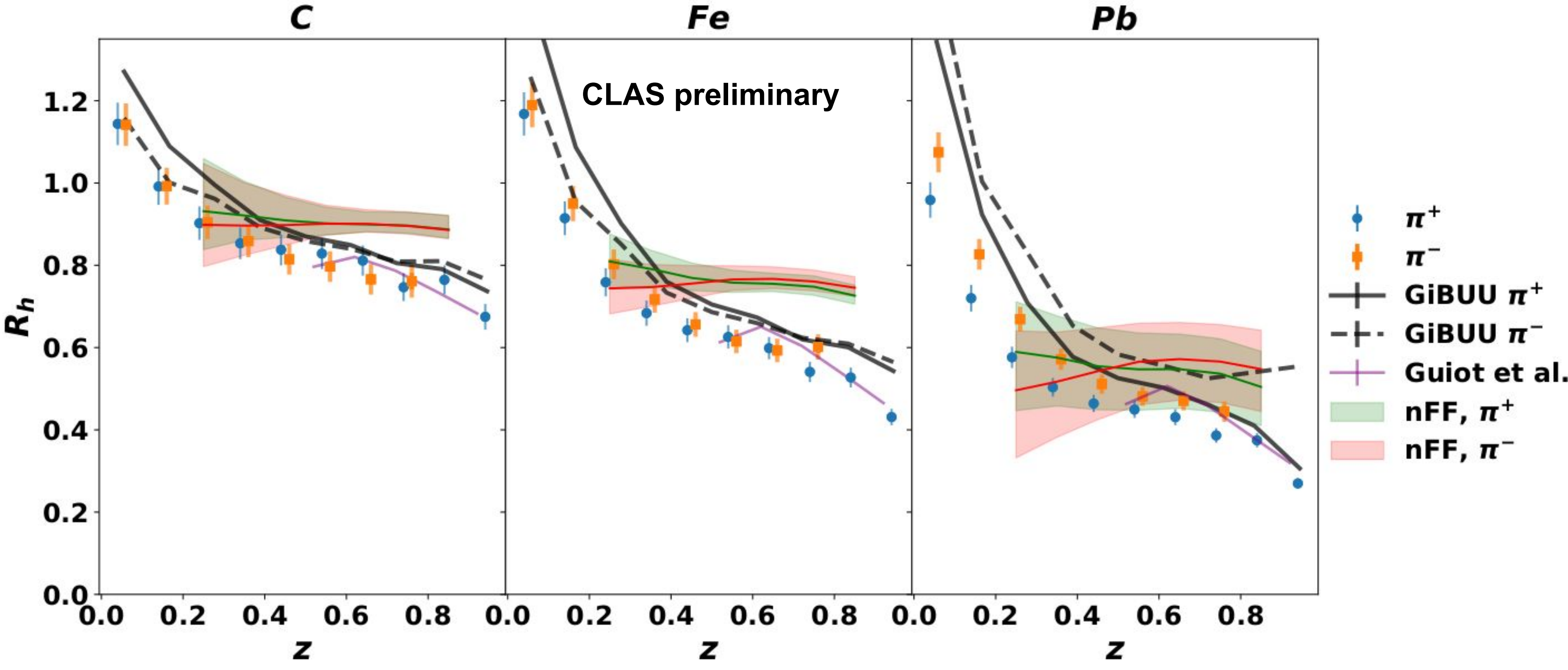


-Extends previous CLAS results to lower Q2.

-Still consistent with nPDFs, even well outside their region of applicability.

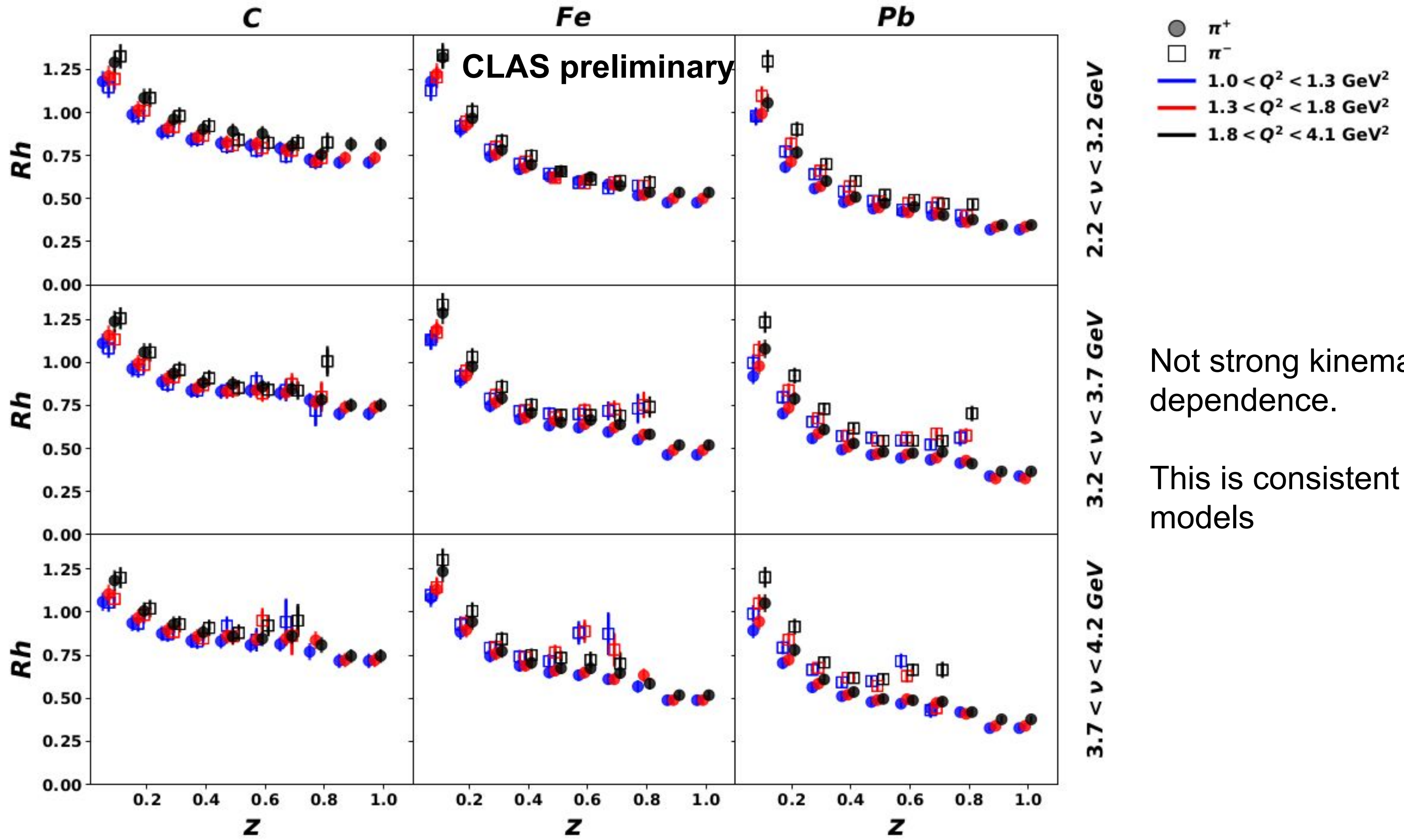
- New constraints on Q2 dependence of EMC ratio?

Multiplicity ratios



Both pions consistent results for C and Fe;~10% difference in Pb.
Strong z dependence, predicted by GiBUU, and absorption model but not nuclear FF calculation (NLO)

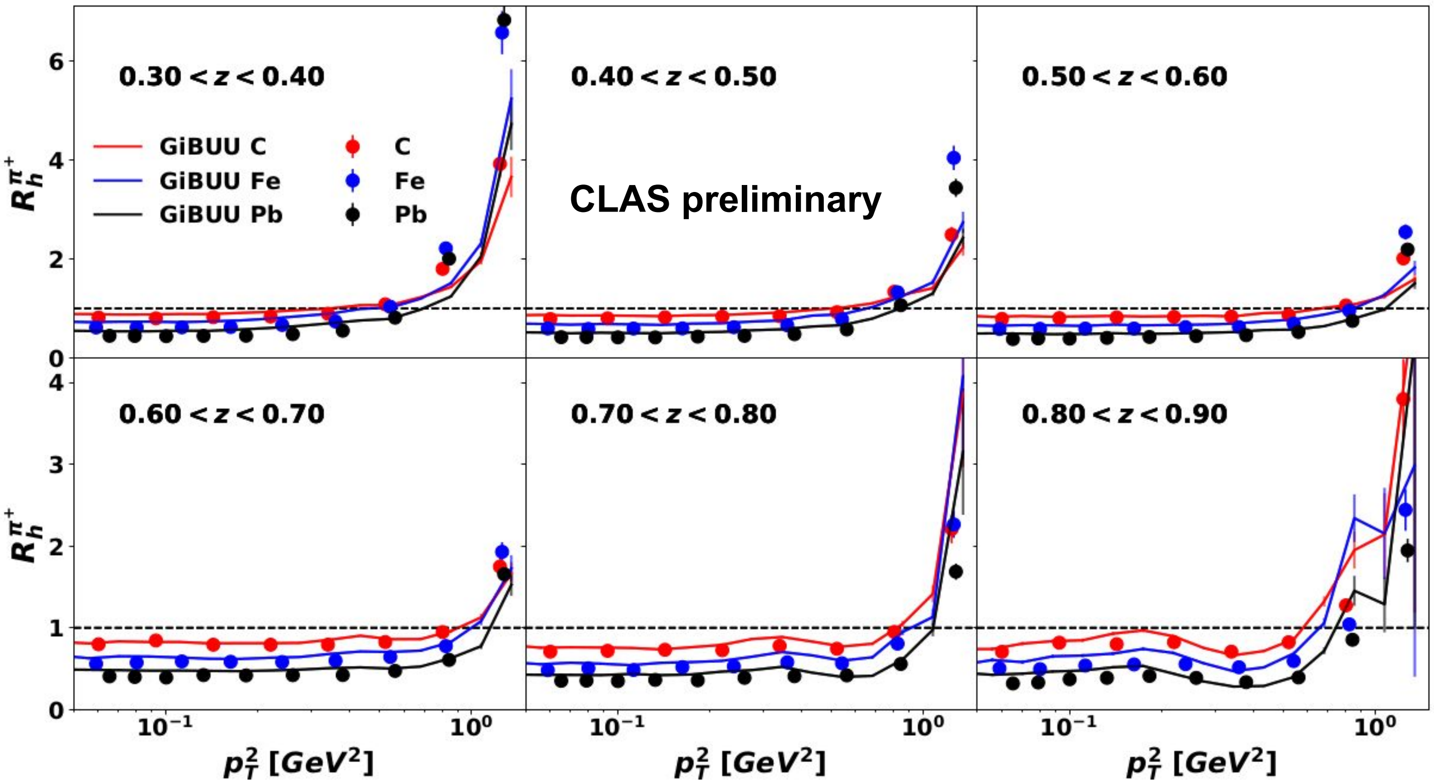
Multiplicity ratios (3D)



Not strong kinematic dependence.

This is consistent with models

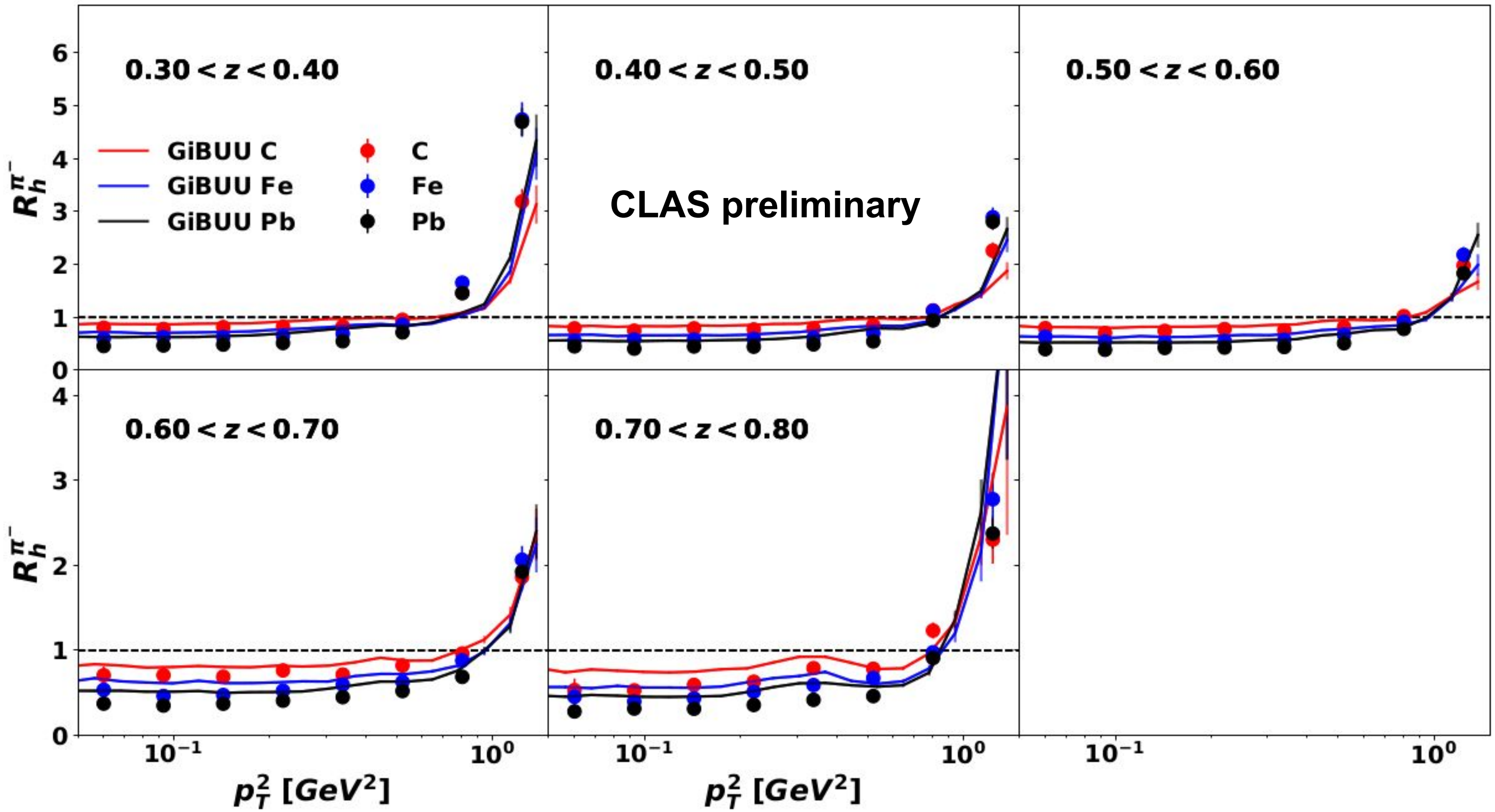
Multiplicity ratios (pi+ transverse-momentum dependence)



“Cronin-like enhancement”?

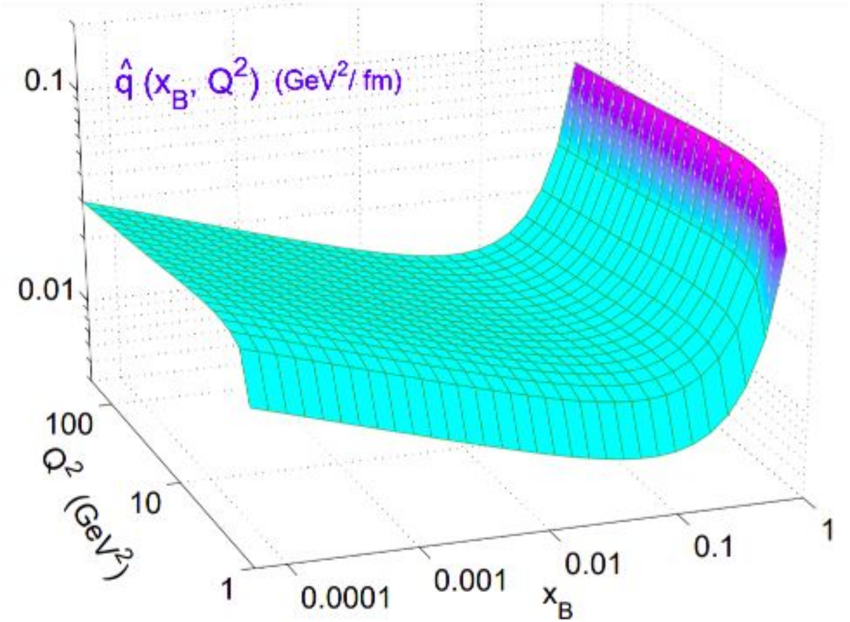
Non-trivial z dependence, qualitatively described by GiBUU

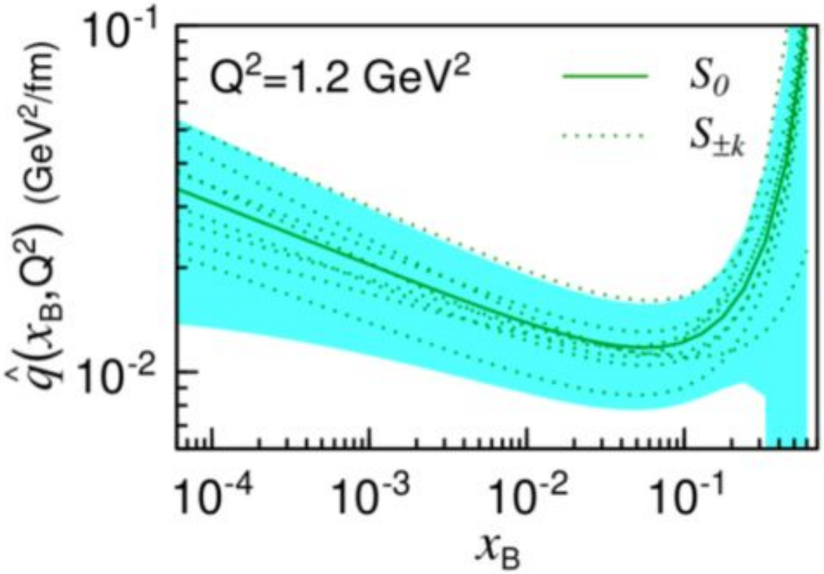
Qualitatively similar results for pi-



Potential impact of this data in future global analyzes?

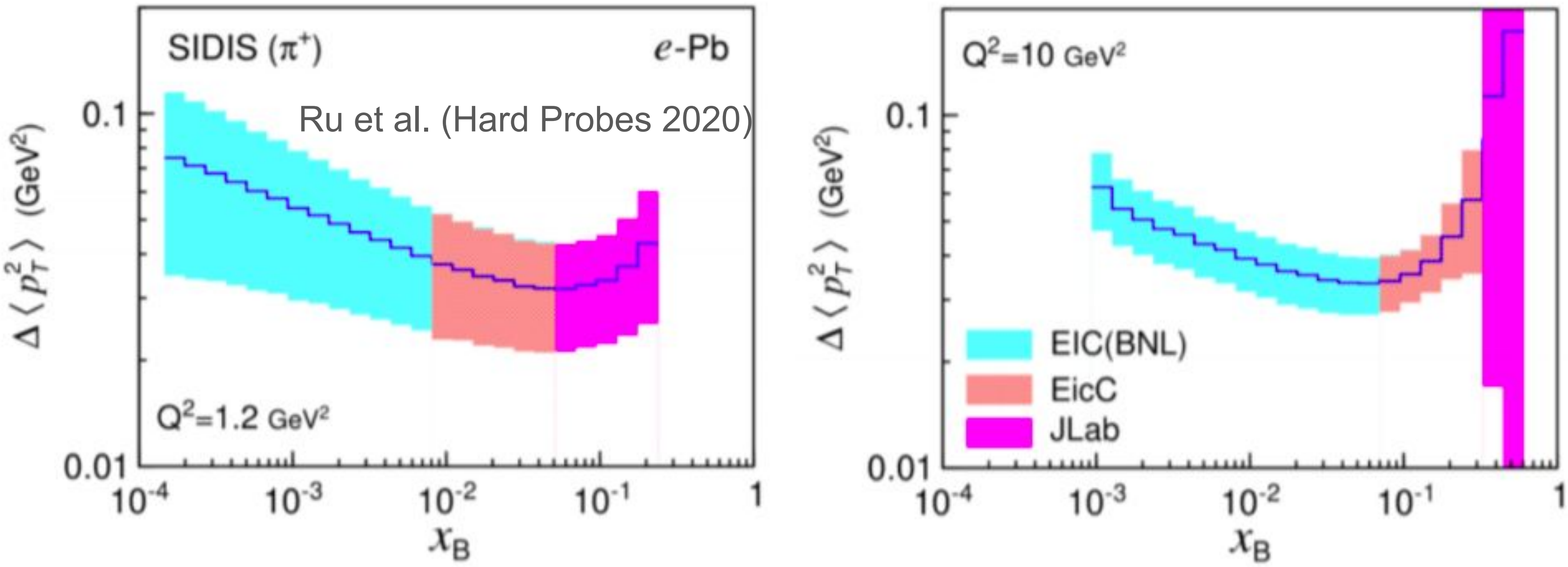
For example, it could be used to constrain “transport parameters of nuclei”





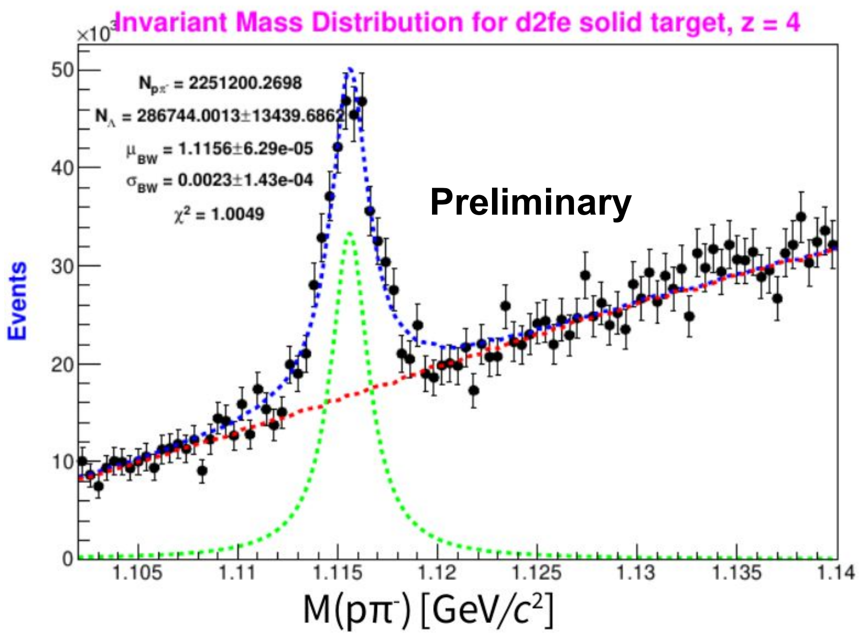
Ru et al. PRD 103, 031901 (2021)

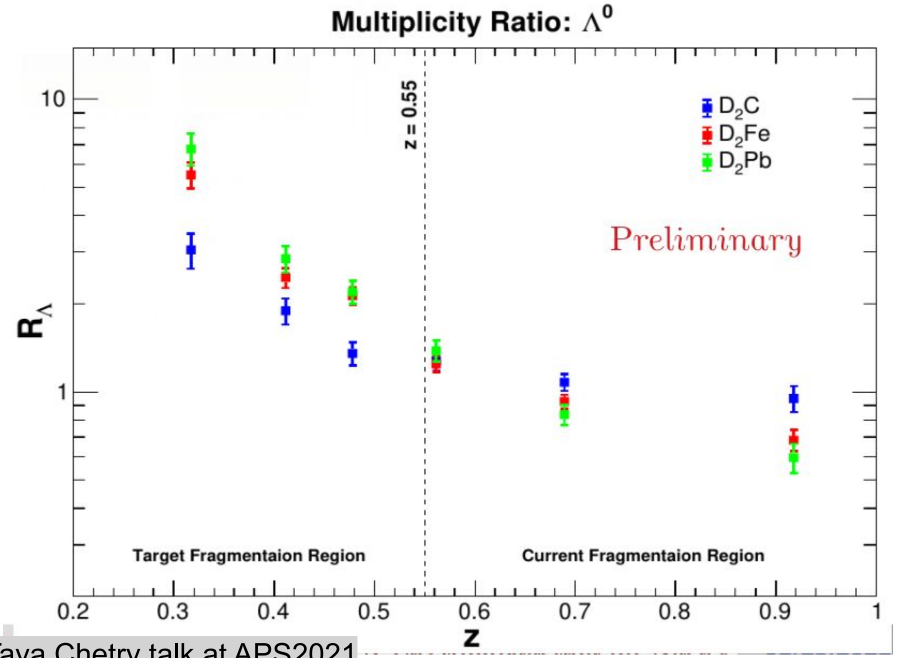
CLAS and CLAS12 coverage will complement and provide crucial baseline for future measurements at EIC



Predictions for transverse momentum broadening, which are dedicated in their framework by q.
Predictions for other observables posible and ongoing

CLAS will soon yield baryon measurements:



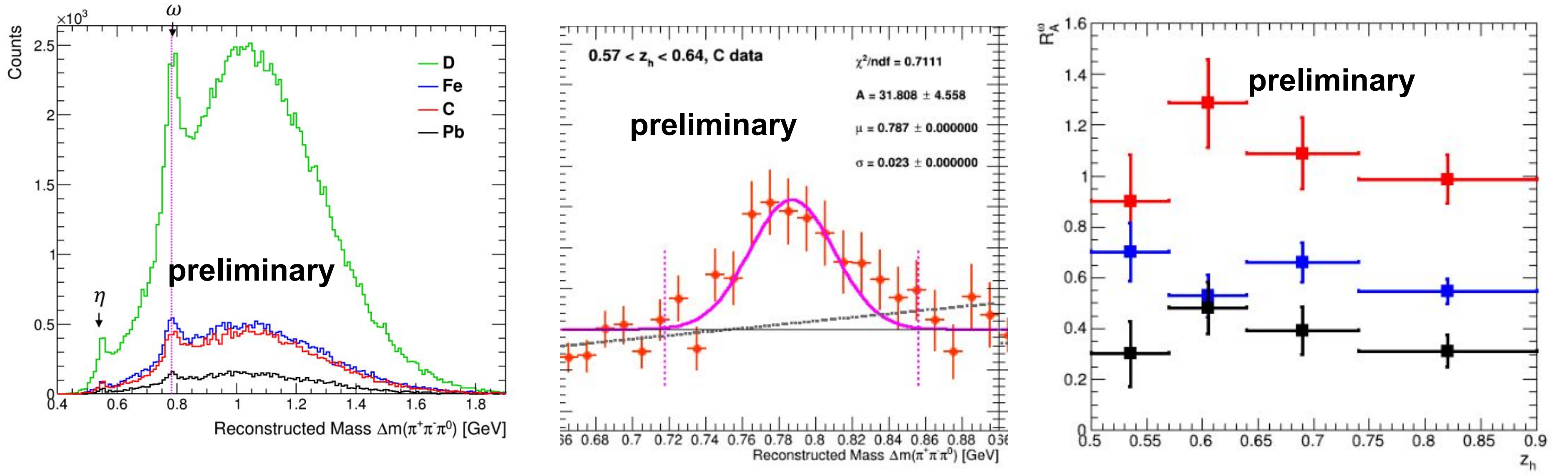


Taya Chetry talk at APS2021

Defying “standard” explanations of “knockout” protons

CLAS will soon yield baryon measurements:

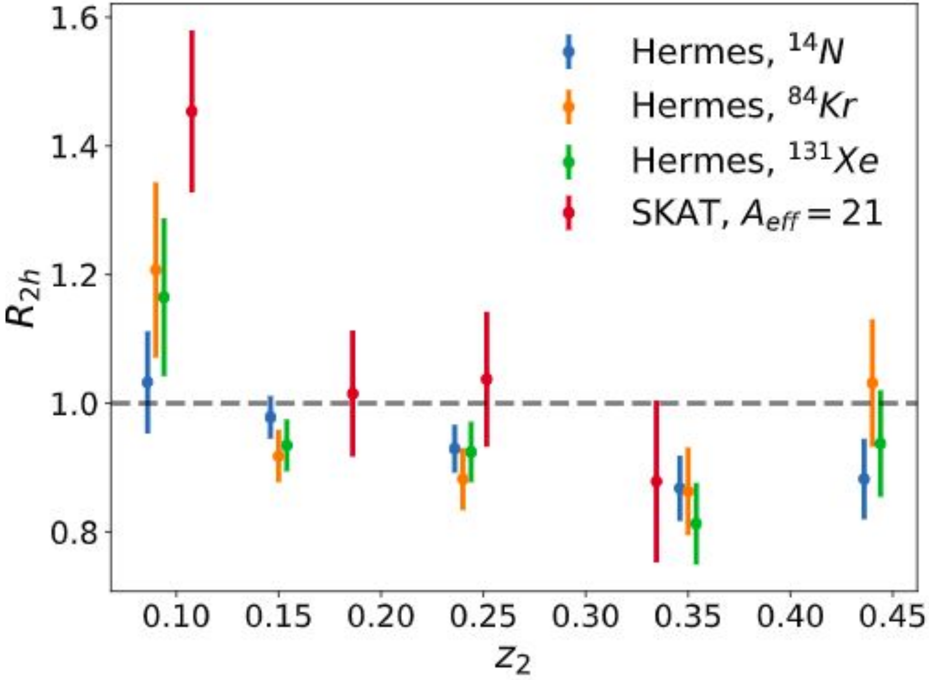
Andres Bosquez talk at APS2021



Unprecedented omega, eta measurements coming
Also rather accurate proton measurements

What is next? Di-hadron measurements with CLAS

$$R_{2h}(z_2) = \frac{M_h^A(z_2|z_1 > 0.5)/M_h^A(z_1 > 0.5)}{M_h^D(z_2|z_1 > 0.5)/M_h^D(z_1 > 0.5)} \equiv C_A/C_D.$$

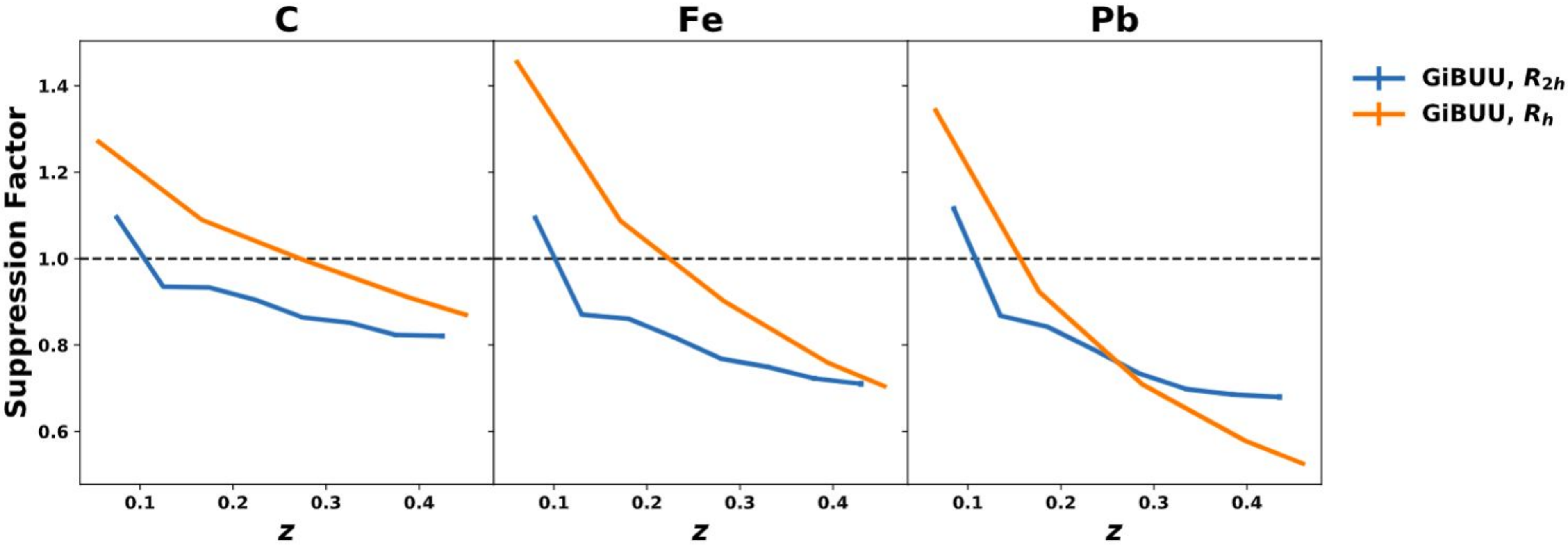


- CLAS data will yield far better precision than HERMES
- Double-hadron measurement constraints “correlations” induced by nuclear effects.
- Higher discrimination power for models than single hadron measurements

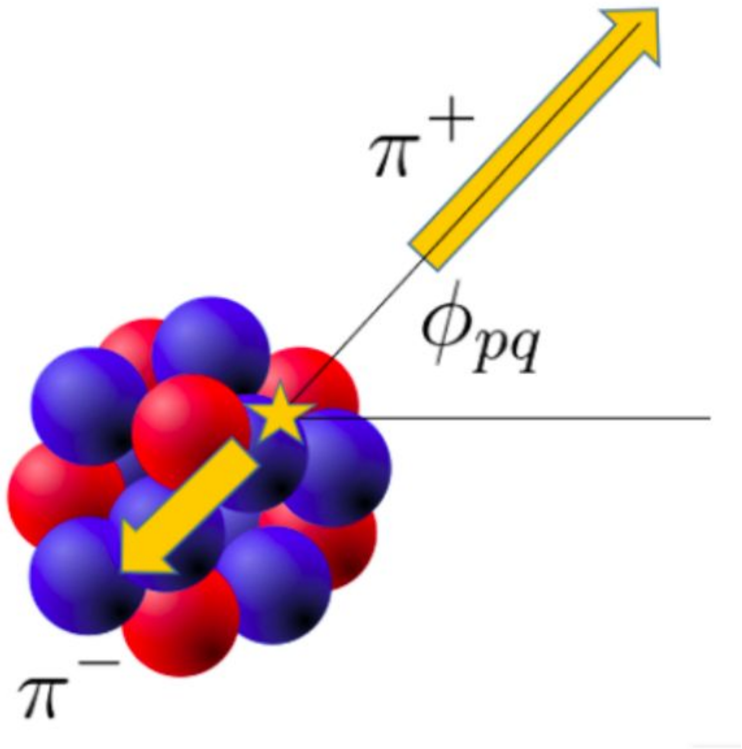
GiBUU calculations for CLAS 5 GeV data

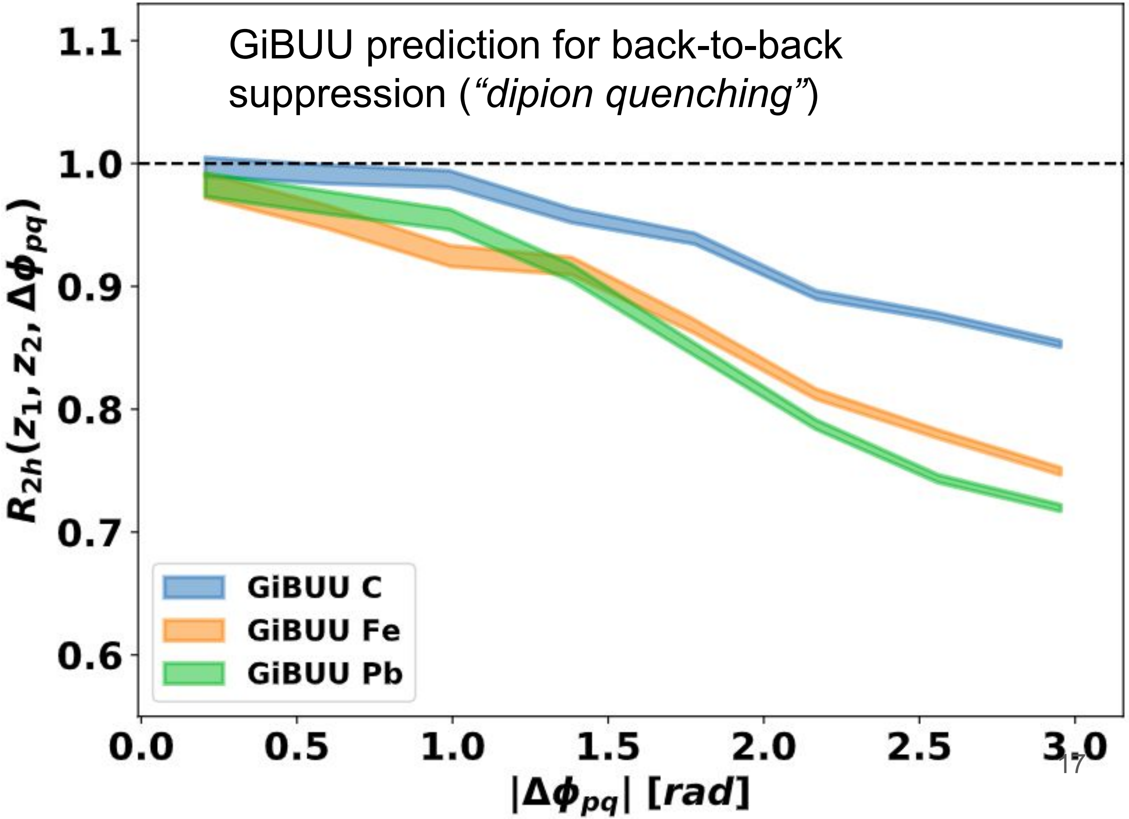
Double-hadron vs single-hadron suppression factors

In absence of correlations induced by nuclear effects, it should holds that $R_{2h} = R_h$



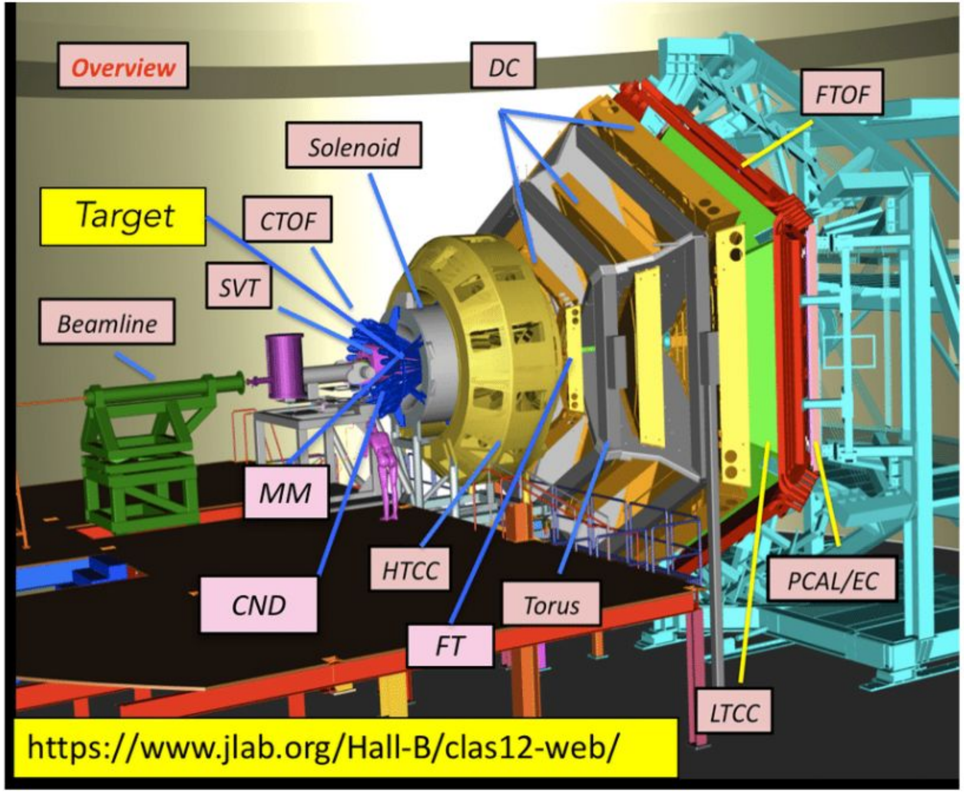
Next step: azimuthal correlation.

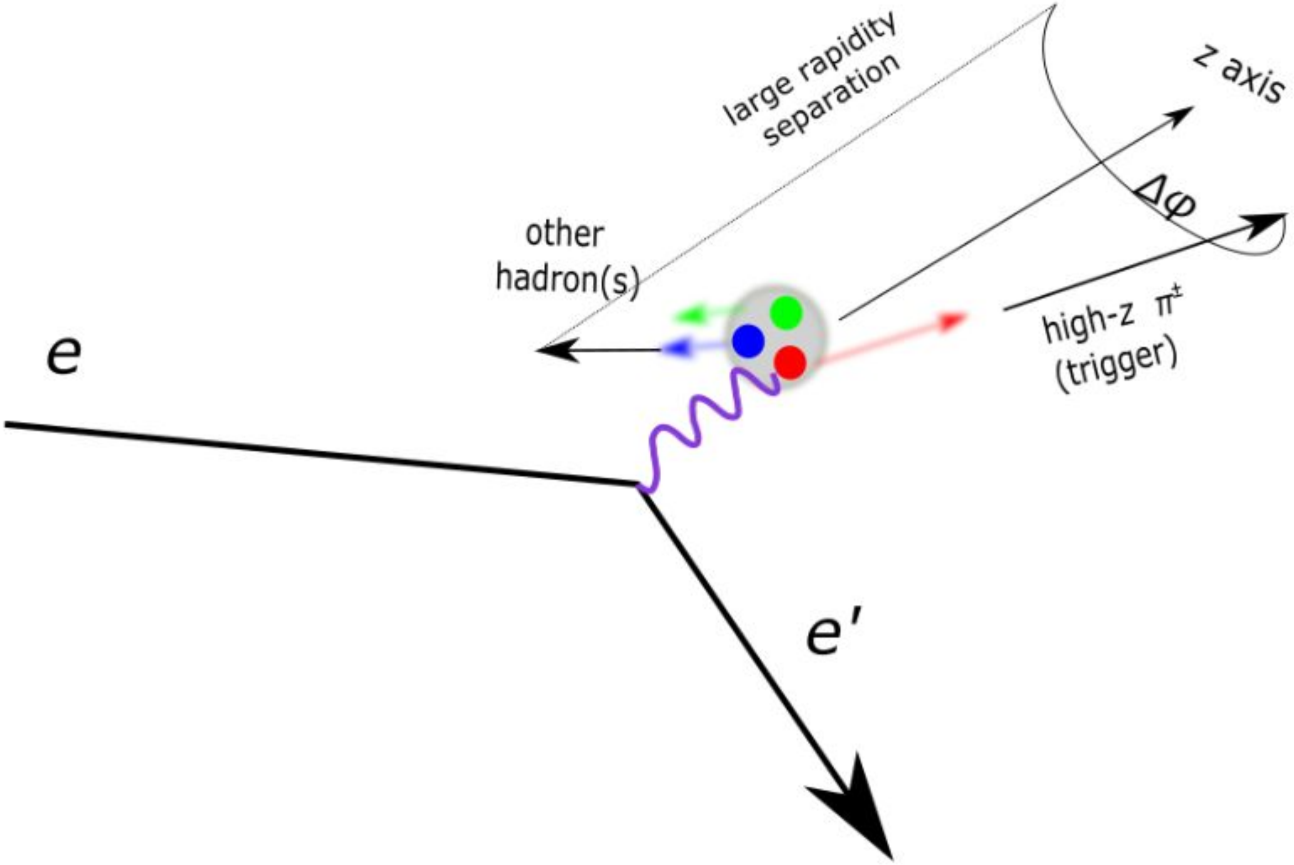




CLAS12

- Data taken using CLAS12 spectrometer
- $E_{beam} = 10.6$ GeV
- liquid hydrogen target
- Only tracks in forward detector $5^\circ < \theta < 45^\circ$ were used




large rapidity separation
z axis
Δφ
other hadron(s)
high-z π±
(trigger)
e
e′

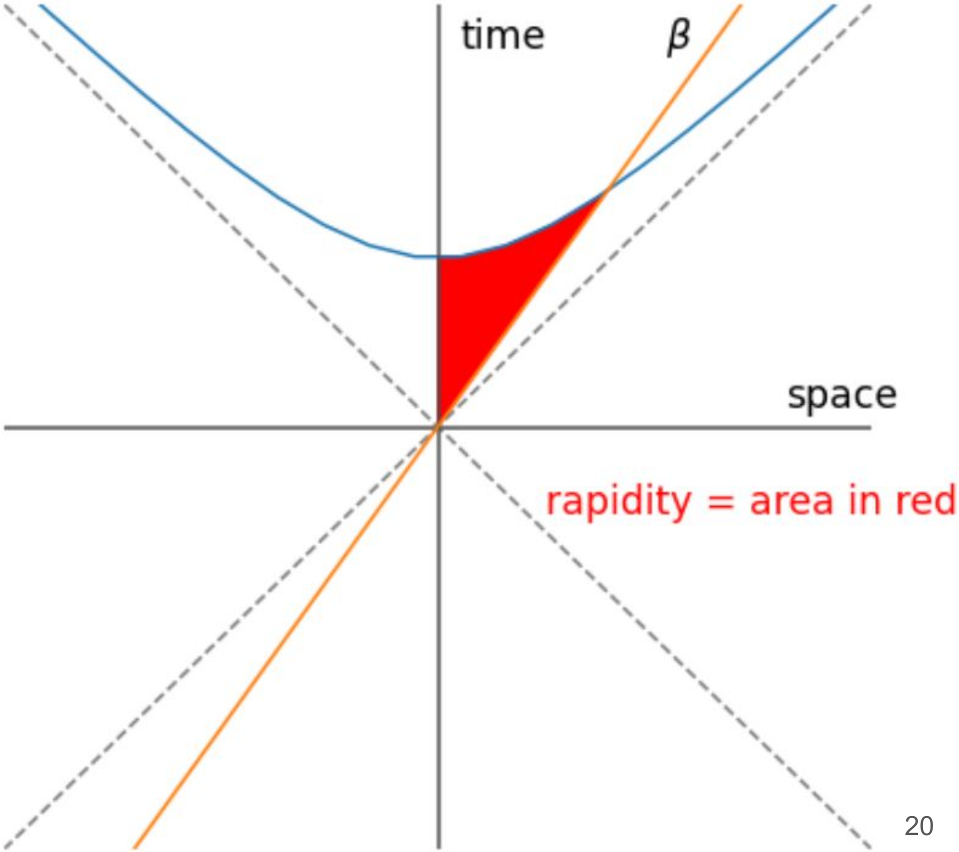
What is rapidity?

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.



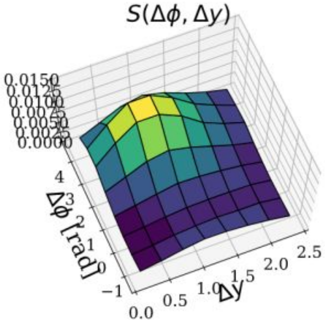
What is a correlation function? (never measured in DIS)

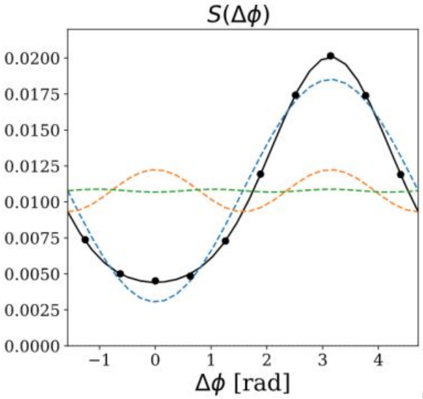
Probability, given one hadron's (ϕ, y), of finding another hadron some $(\Delta\phi, \Delta y)$ away

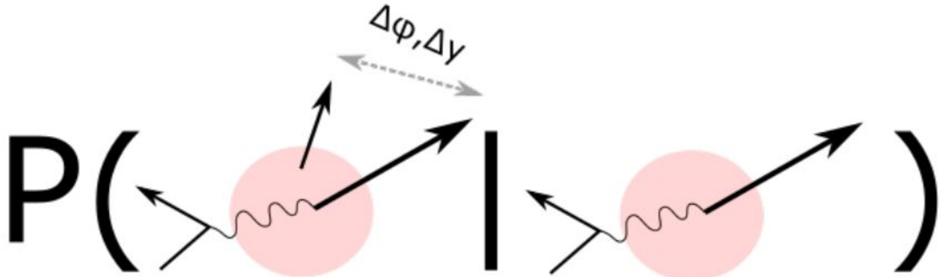
Related to same-event yield, $\frac{1}{N_{\mathrm{trig}}} \frac{dN_{\mathrm{pair}}}{d\Delta\phi d\Delta y}$

Includes pair-acceptance corrections

Analogous to galactic correlation function used in cosmology

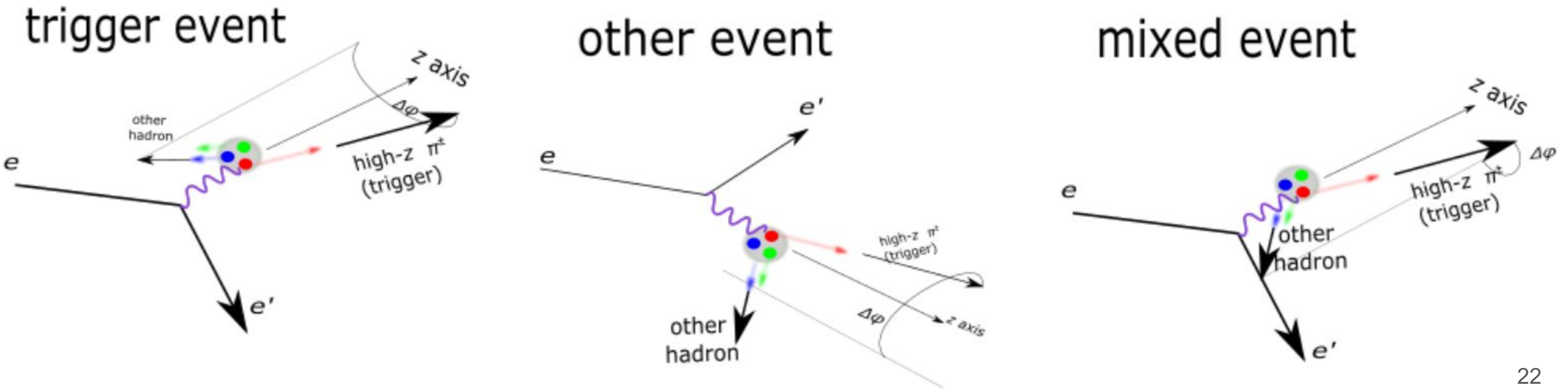




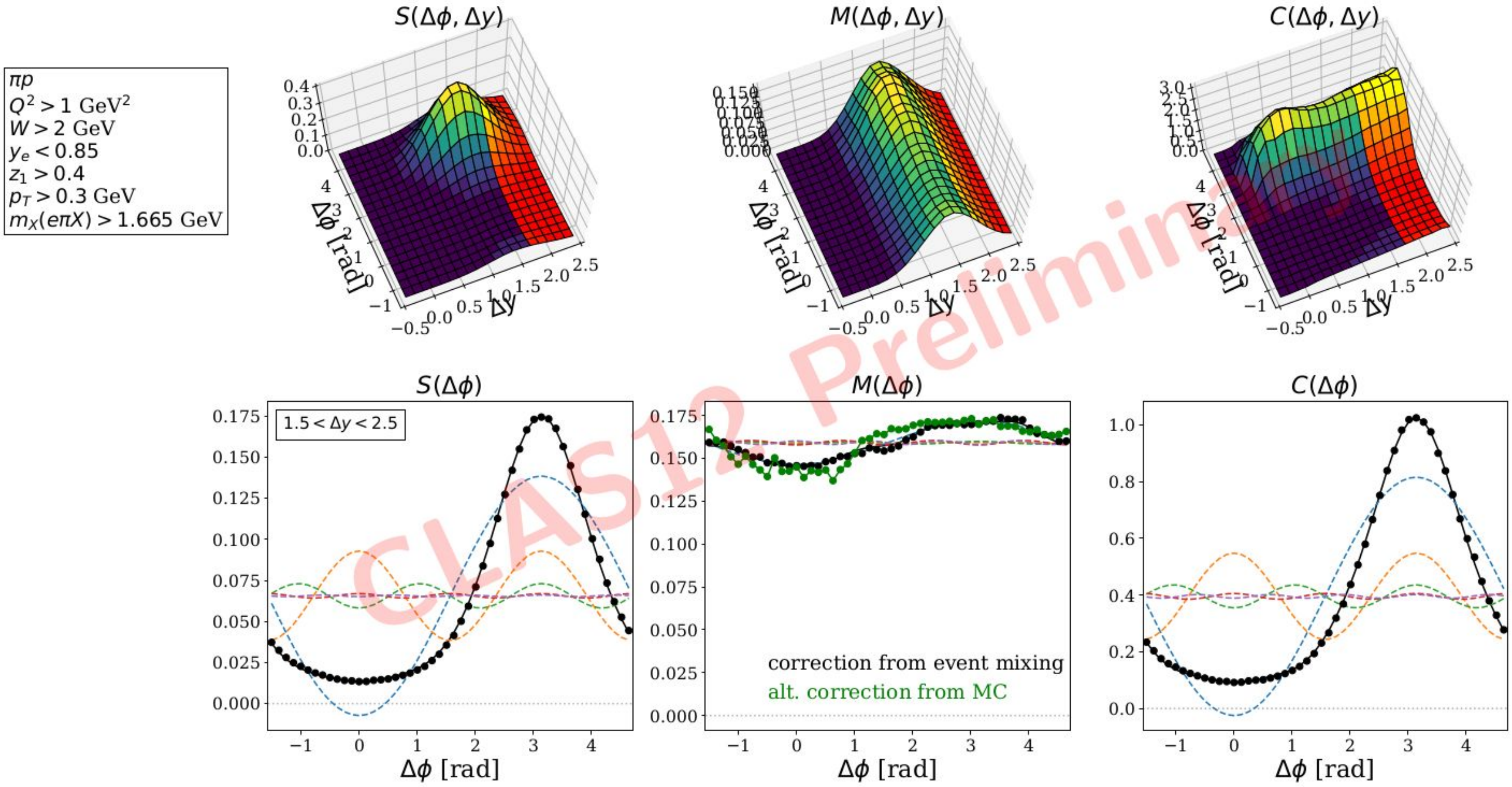


Data-driven way to correct for pair acceptance

- Event mixing is performed to correct for pair-acceptance effects in a data-driven way.
- This method is tested with an independent, MC-based correction, providing similar results.

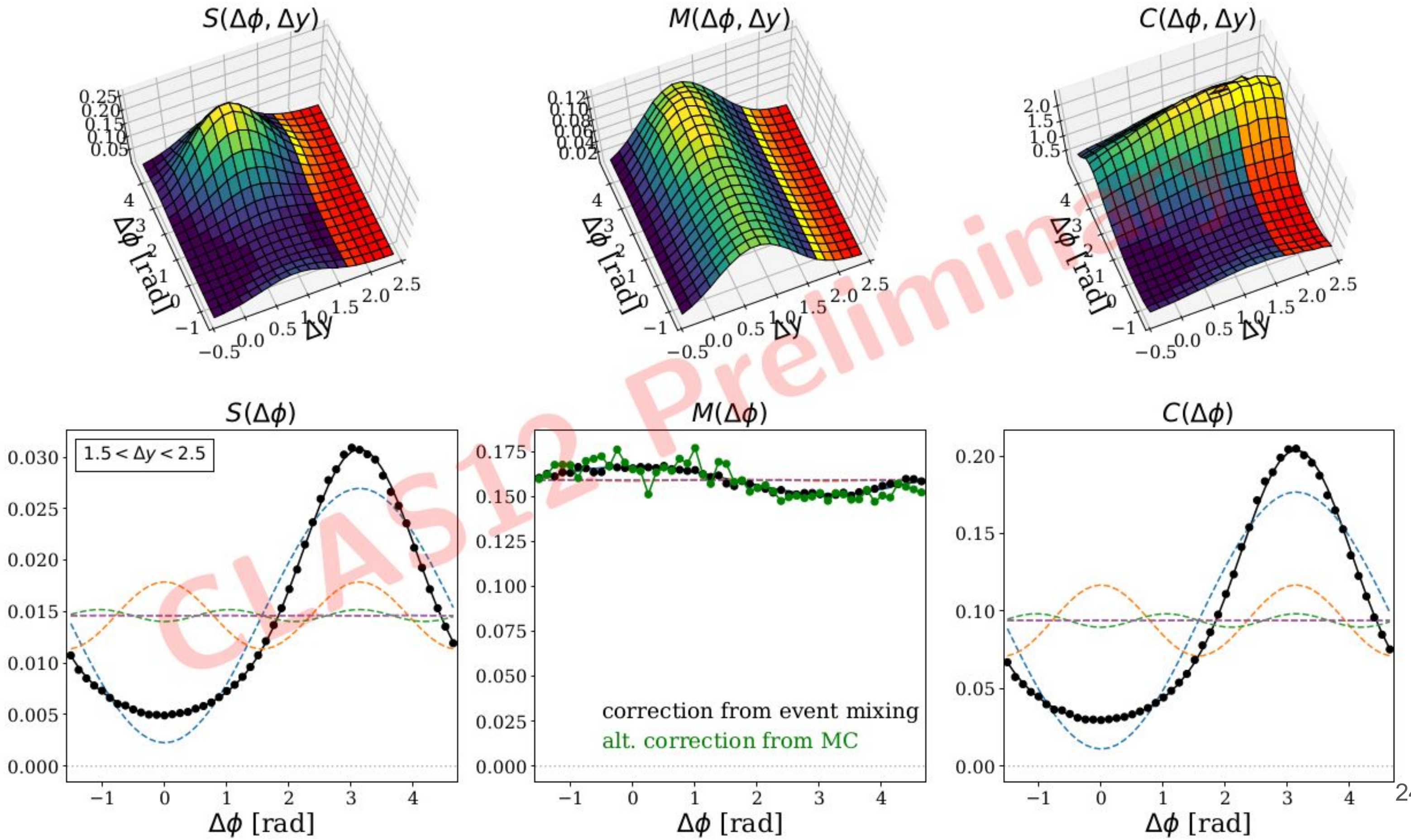


Pion-proton correlation function with CLAS12



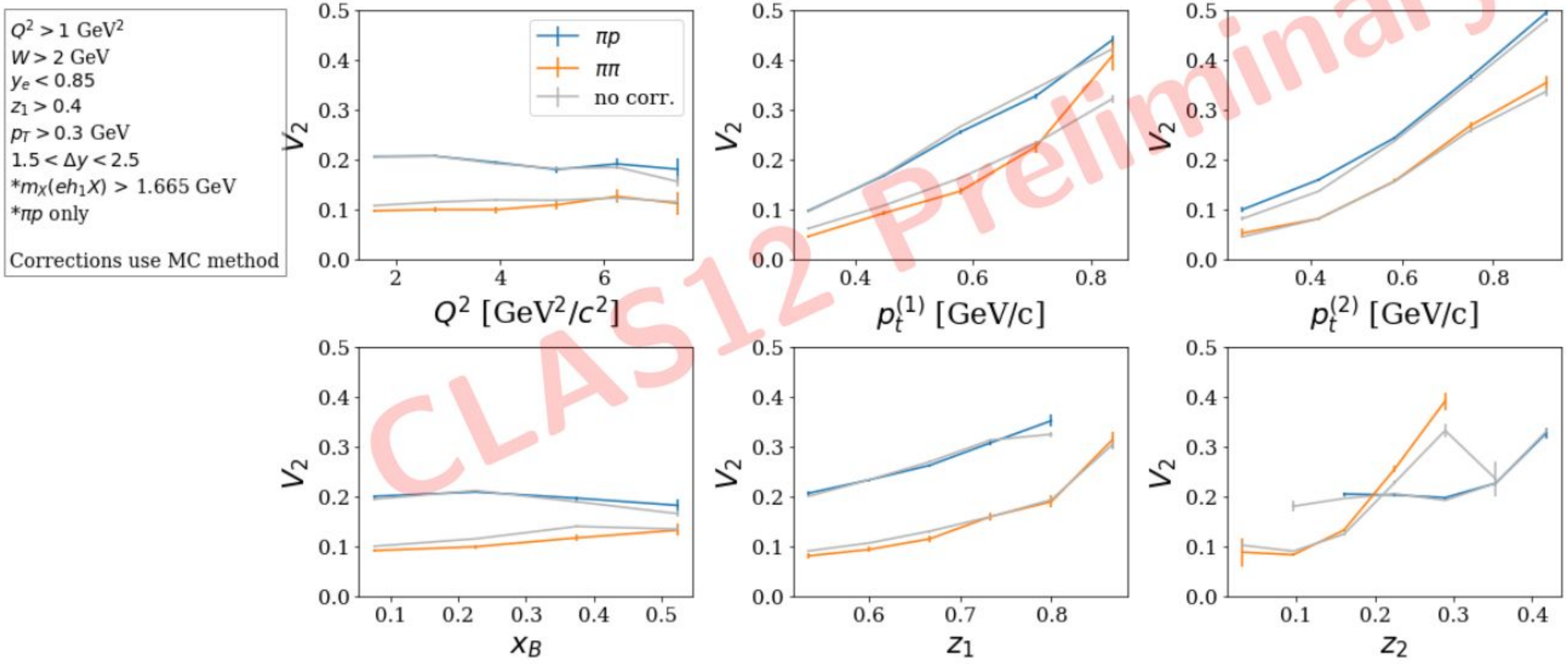
Dipion correlation functions with CLAS12

$\pi\pi$
$p_T > 0.3$ GeV
$Q^2 > 1$ GeV^2
$W > 2$ GeV
$y_e < 0.85$
$z_1 > 0.4$
$p_T > 0.3$ GeV



Fourier fit: $C(\Delta\phi) = A(1 + 2\sum_n V_n \cos(n\Delta\phi))$

These data can constrain target fracture functions.

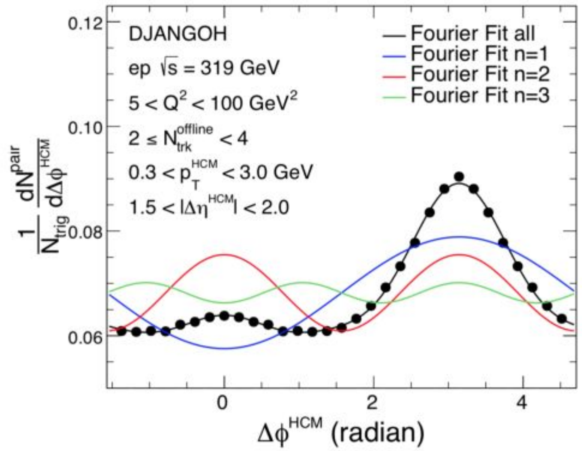


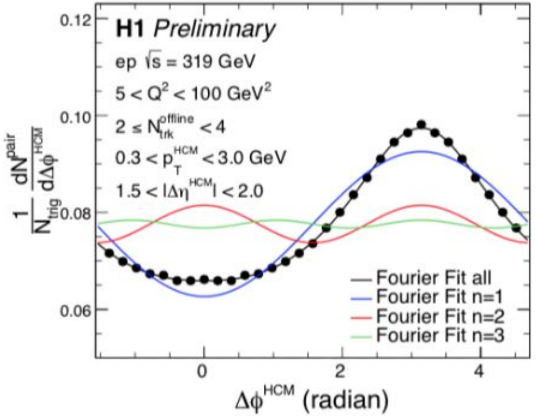
Large p_T and z dependence, weak x_B and Q^2 dependence.

“Ridge” search in “extremely small systems”

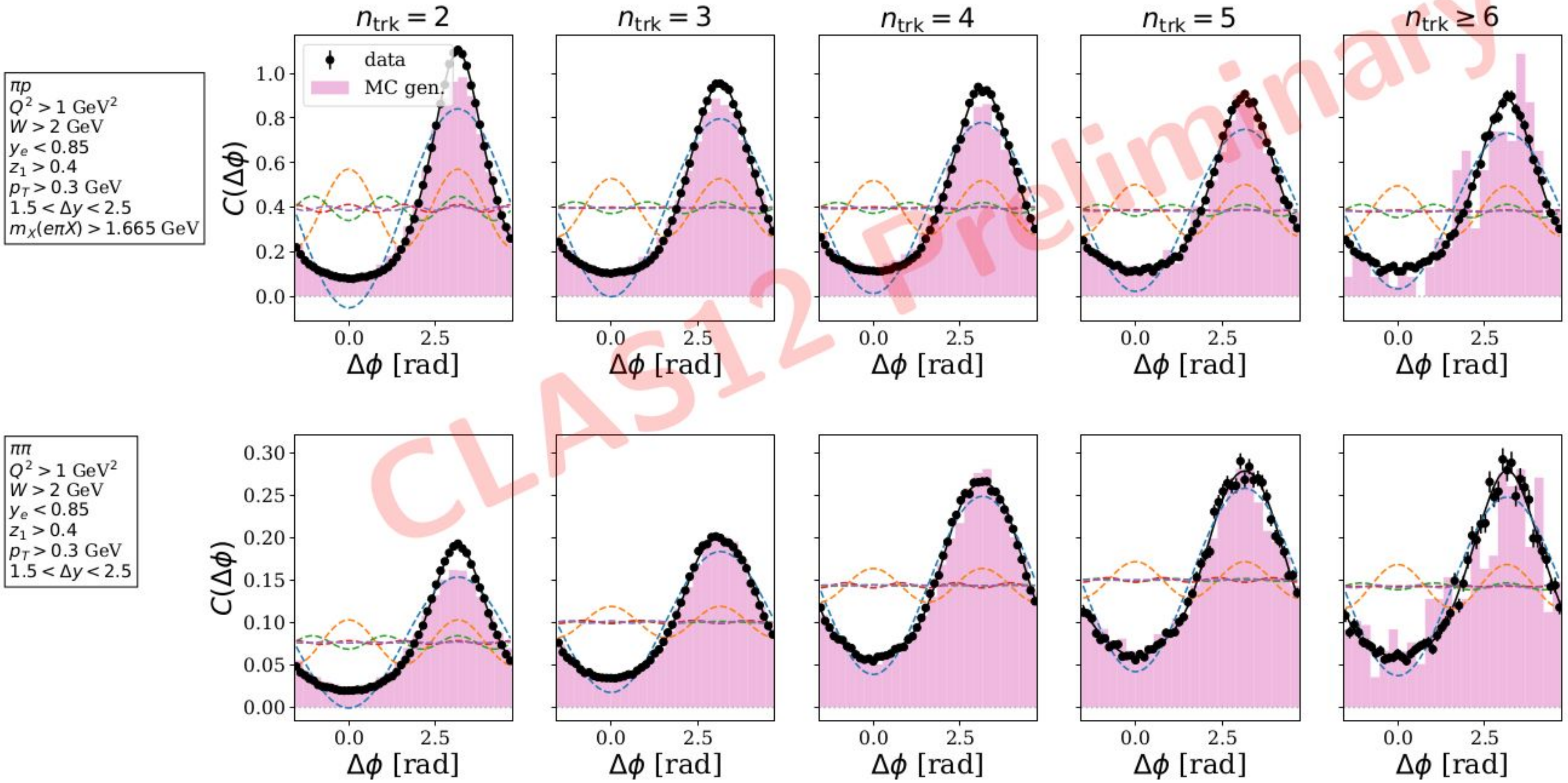
In some other experiments (and predicted models), a secondary peak (the “ridge”) is observed at $\Delta\phi = 0$, persisting at large rapidity separation

Upper limits have been set/are being set at ALEPH [1], and HERA [2] for low multiplicity.

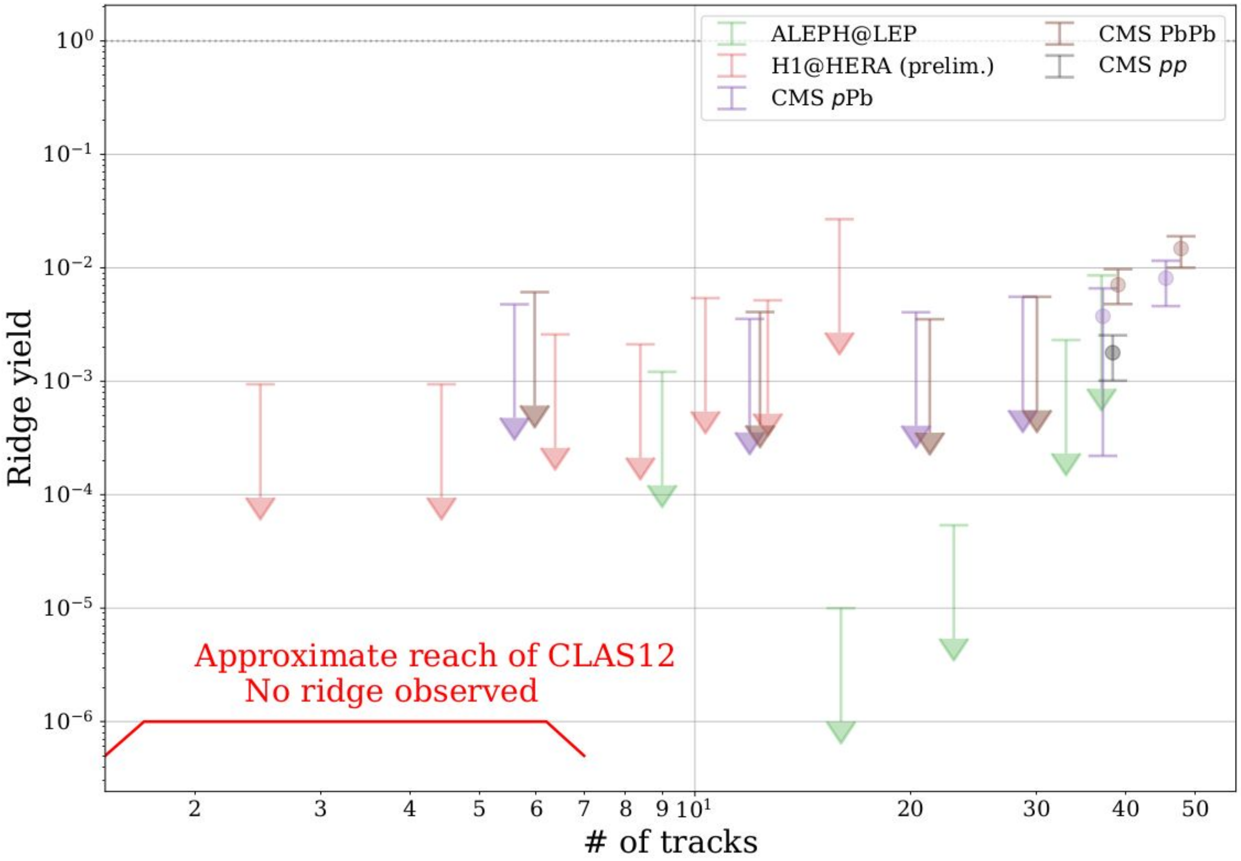




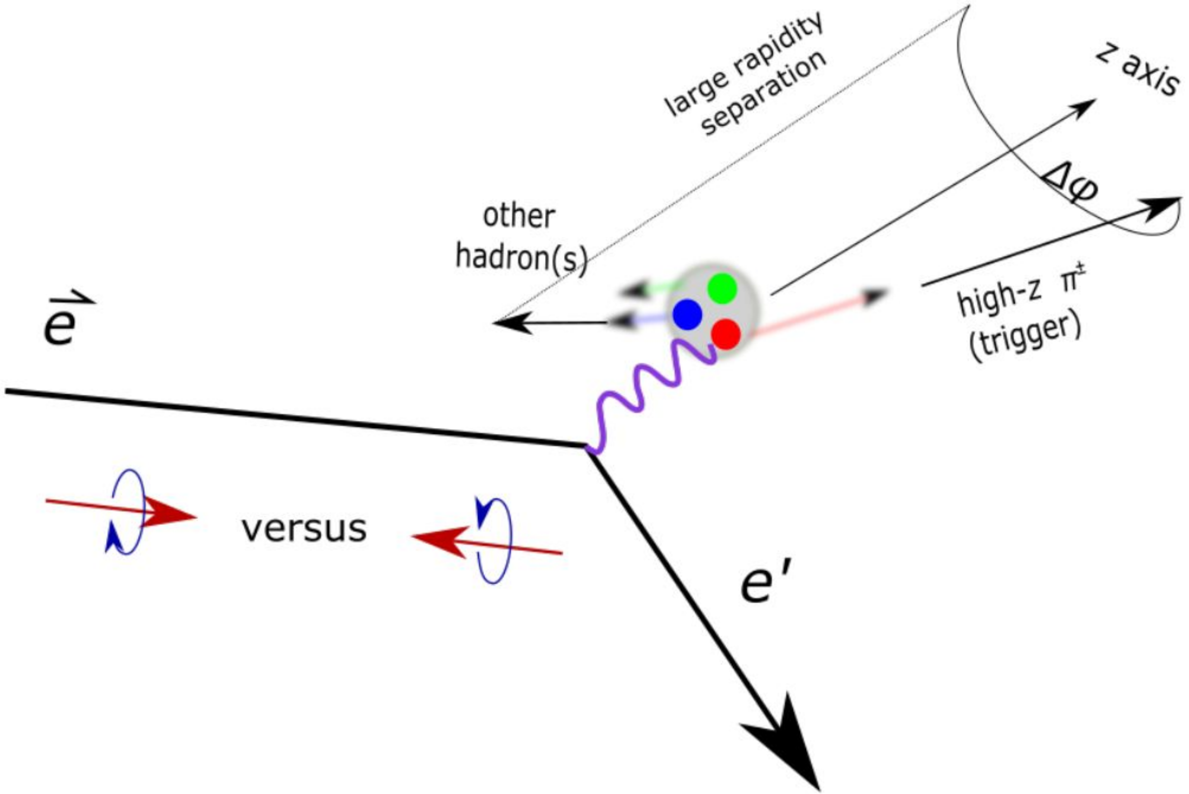
Seach for "ridge", i.e peak at $\Delta\phi = 0$, in intervals of track multiplicity (tracks in range $3 < \theta < 40$). **No signal observed**



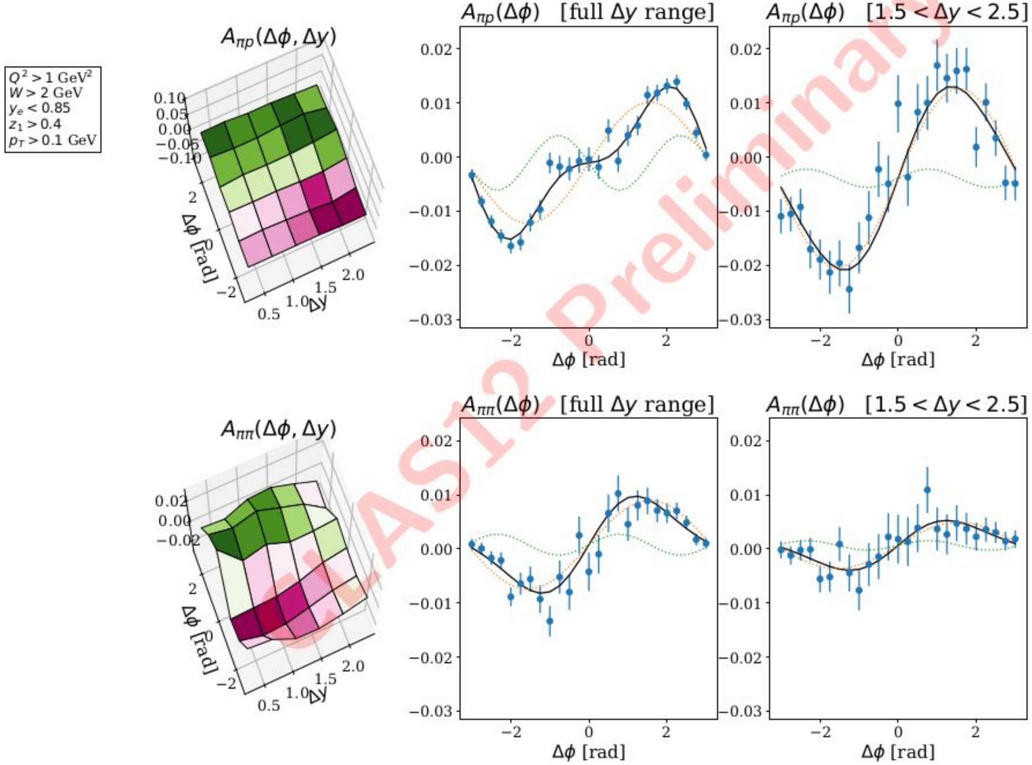
Prospects of new limits for “Ridge” in “extremely small systems”



What if we add polarization?

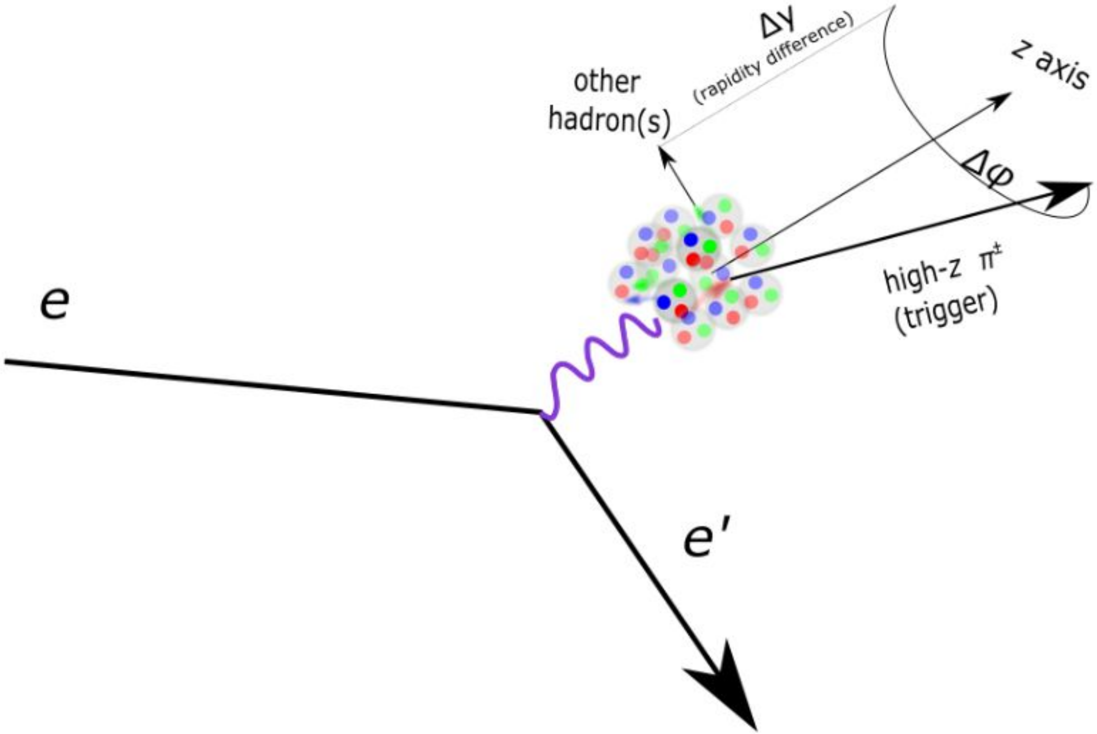


Helicity asymmetry $A = \frac{S_+ - S_-}{S_+ + S_-} / P_e$

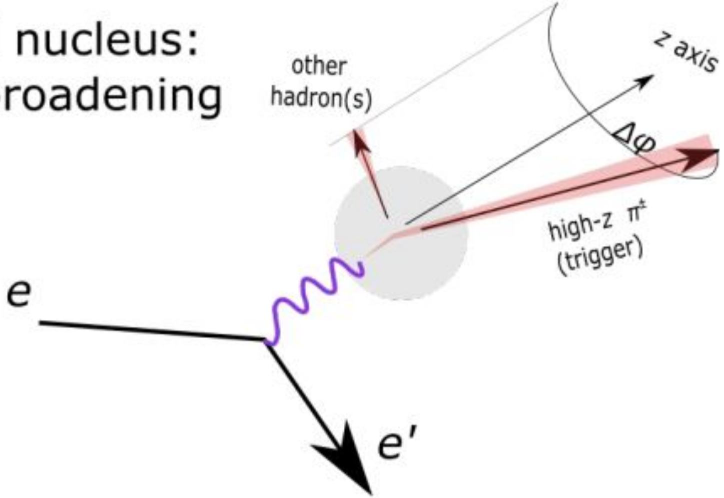


- Long-range spin correlations between struck quark and proton remnant.
- Significant Δ y dependence.

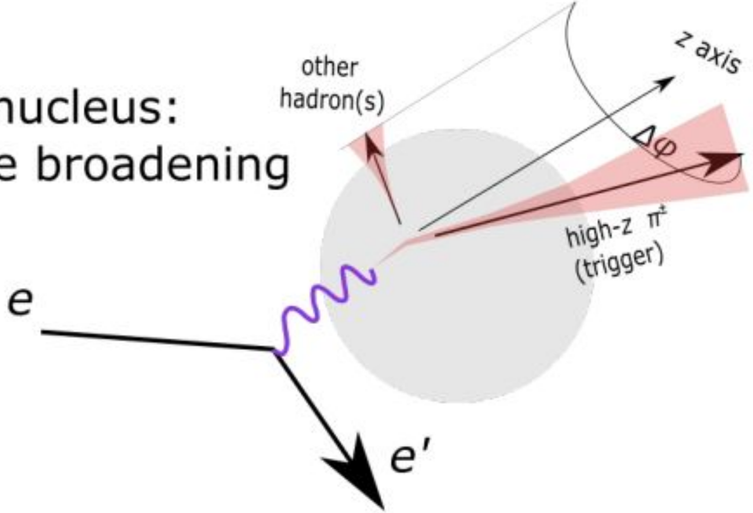
Coming soon: Nuclear 2D correlations



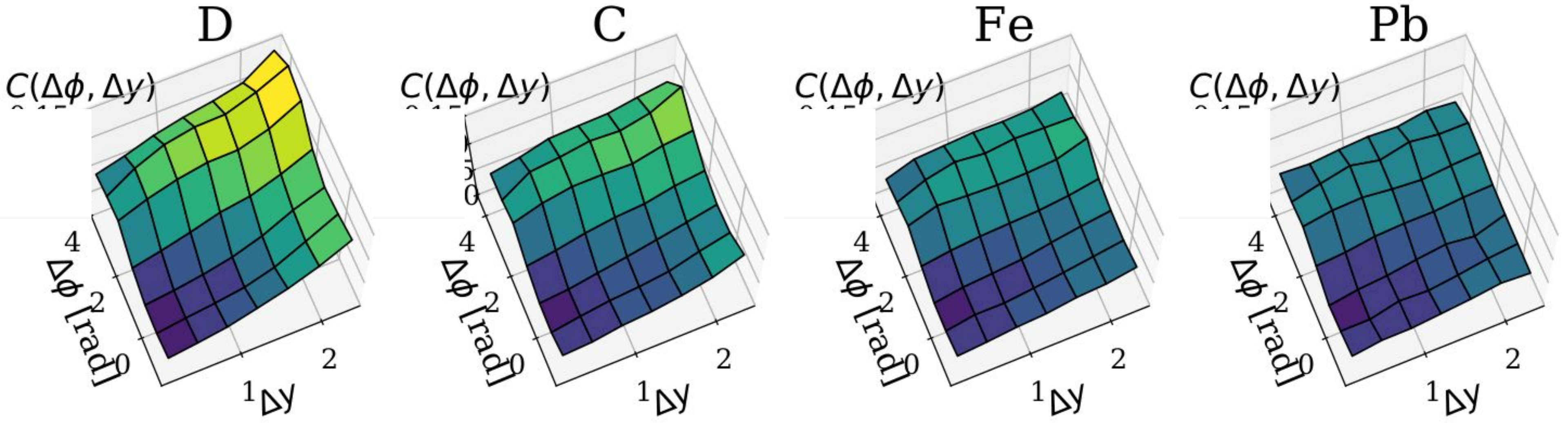
Small nucleus: less broadening



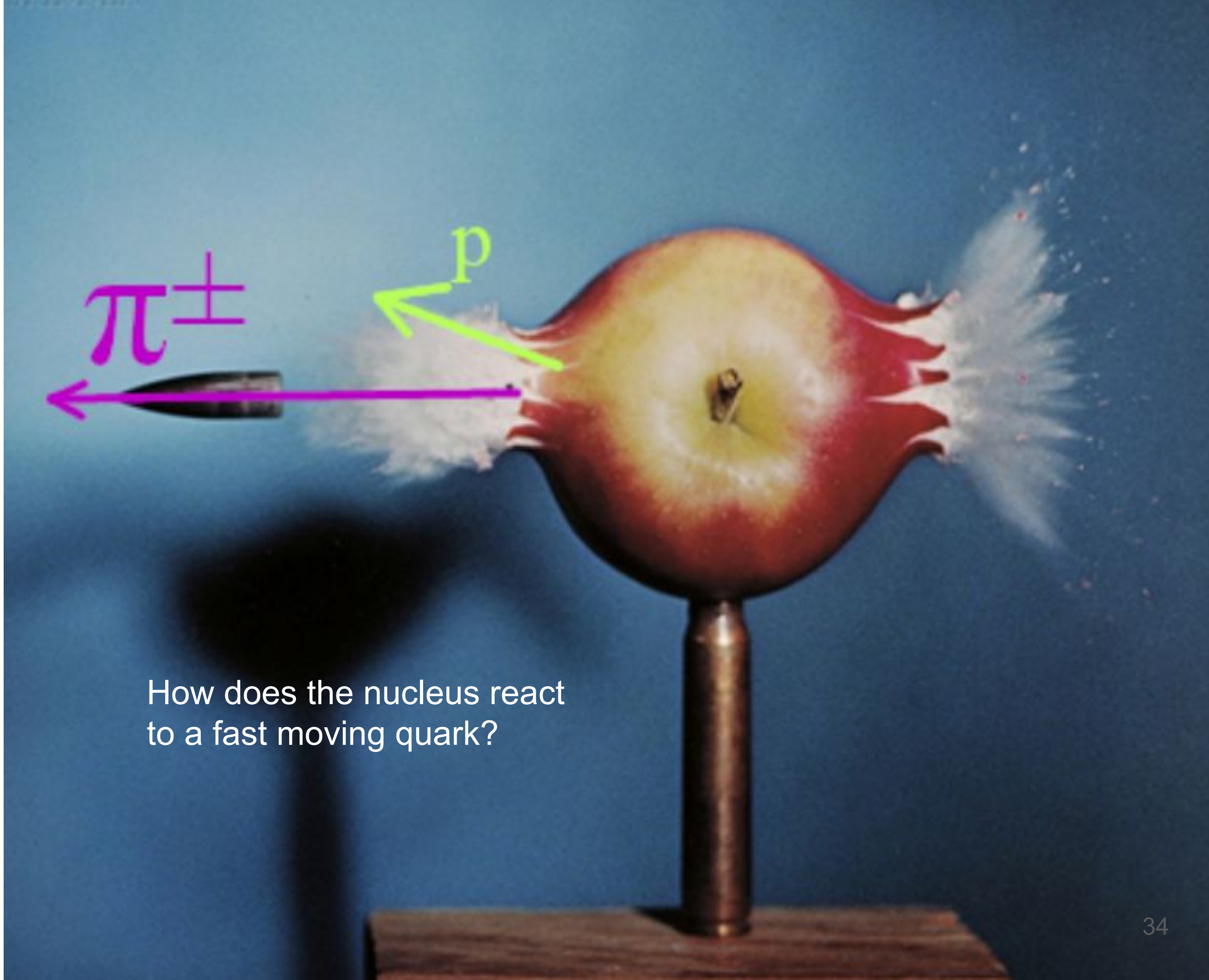
Big nucleus: more broadening



Coming soon: Nuclear 2D correlations



Coming soon: “medium response” studies



Summary

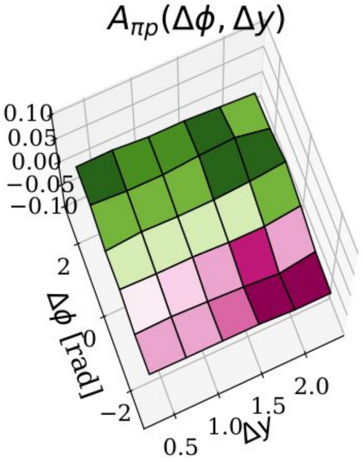
- CLAS results on nuclear DIS precise and accurate 3D data for pions, which provides hiigh discrimination power for widely varying model assumptions.

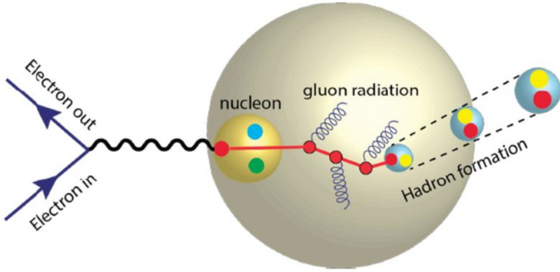
- CLAS will also yield new baryon results that challenge “standard” explanations.

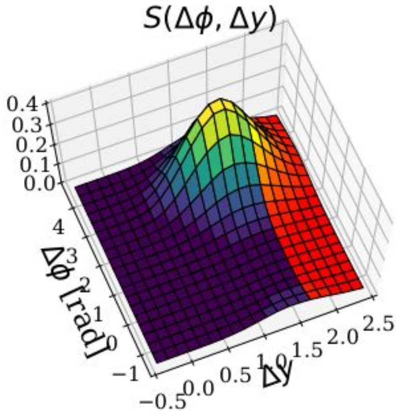
- CLAS large acceptance makes it very suitable for hadronization studies with 2D correlation functions, which have never been measured before in DIS.

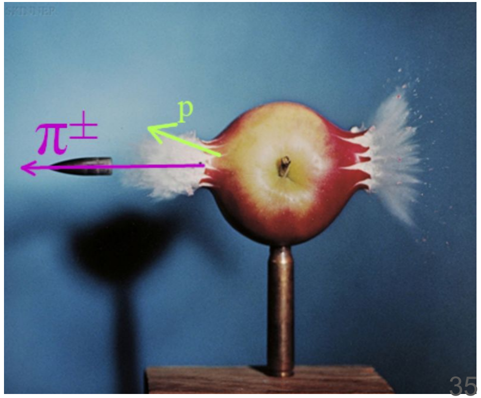
- These are revealing new aspects of hadronization (diquark-quark spin correlations, etc) and the nuclear response to a fast moving quark.

- CLAS12 high-energy nuclear data has great potential, approved experiments recently upheld by PAC48.









Backup

GiBUU predictions for CLAS12