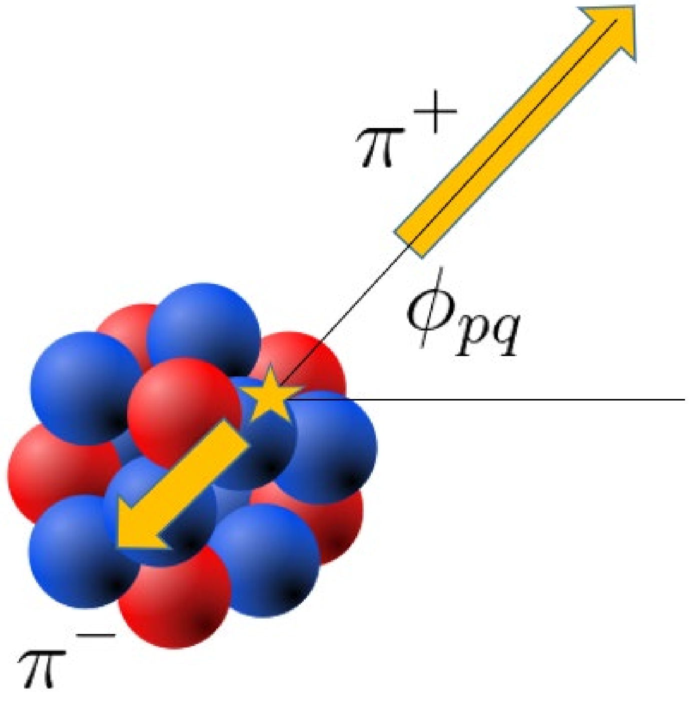
Proposal for PAC48: "Dihadron measurements in electron-nucleus scattering with CLAS12"

Miguel Arratia,* Sebouh Paul, and Sean Preins
University of California, Riverside, CA†

William K. Brooks, Hayk Hakobyan, Ahmed El Alaoui,* and Jorge Lopez, Taisiya Mineeva
Universidad Técnica Federico Santa María, Valparaíso, Chile.

Kyungseon Joo* and Saman Bastami, Richard Capobianco, Stefan Diehl, Francois-Xavier Girod, Kyungseon Joo, Andrey Kim, Valerii Klimenko, R. Santos, Peter Schweitzer, Paul Stoler, Kemal Tezgin
University of Connecticut, Storrs, CT



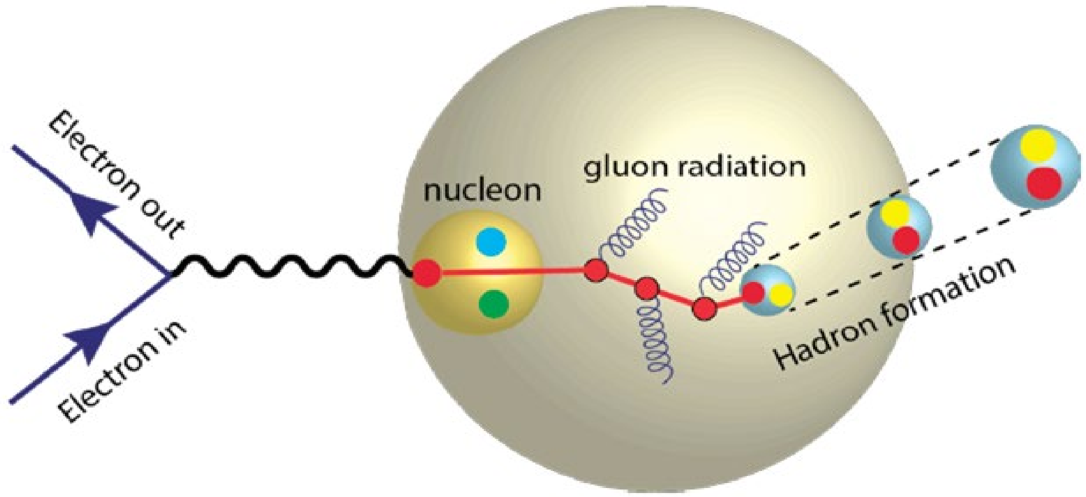
Abstract

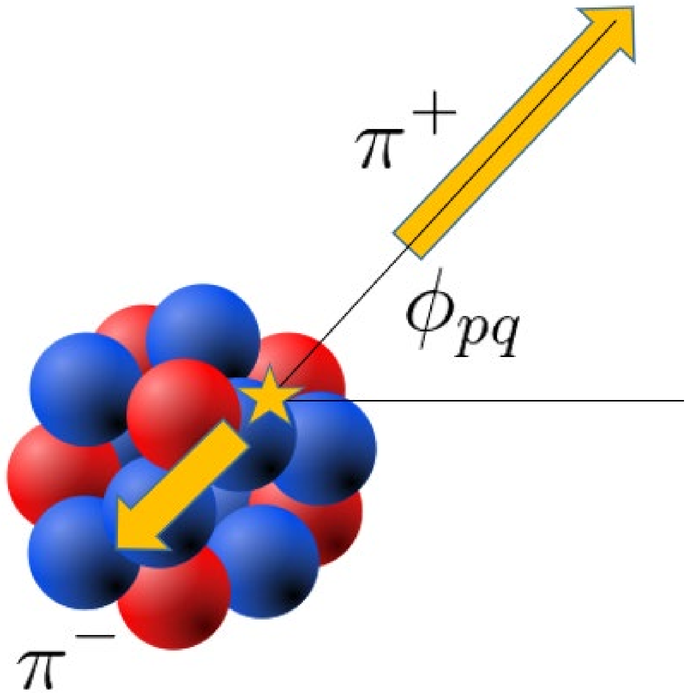
We propose a new CLAS12 program based on studies of dihadron angular correlations in nuclear I
which have never been measured before. This proposal builds on the recently observed suppression of b

Addition to Run Group E.

Motivation:

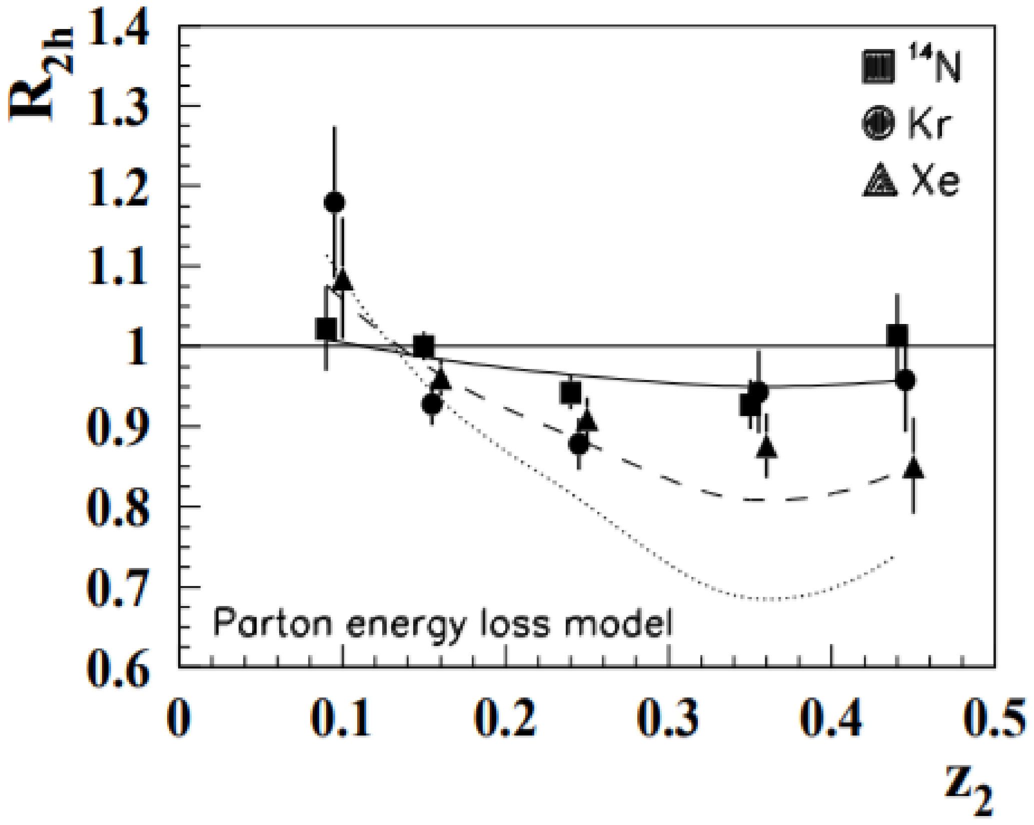
Studies of dihadron production in nuclei complements single hadron-studies and allow us to test correlations induced by nuclear effects





Double-Hadron Leptoproduction in the Nuclear Medium

A. Airapetian *et al.* (HERMES Collaboration)
Phys. Rev. Lett. **96**, 162301 – Published 25 April 2006

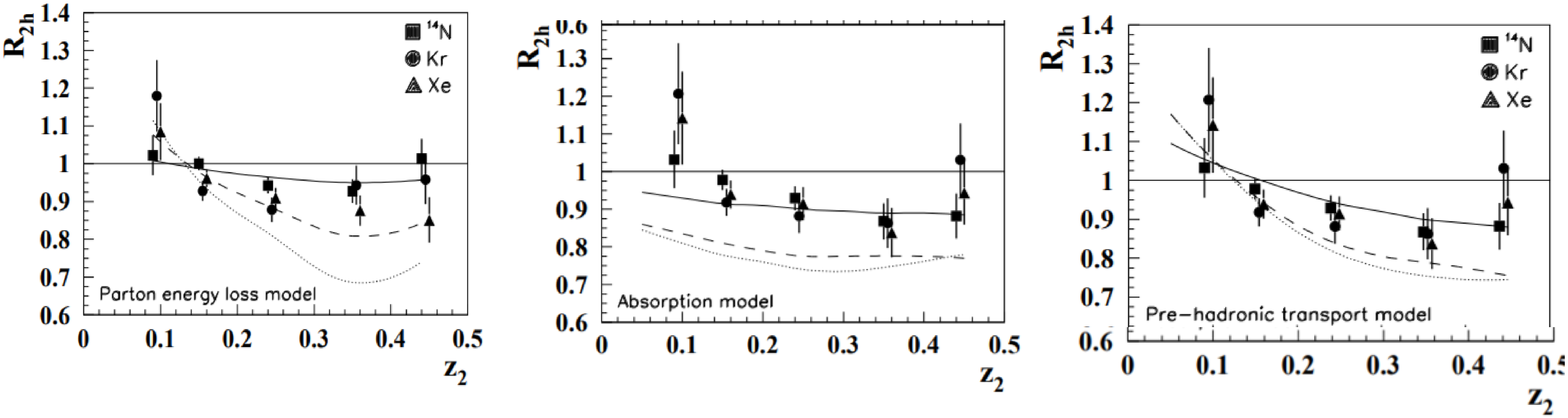


Conditional suppression factor

$$R_{2h}(z_2) = \frac{\left(\frac{dN^{z_1>0.5}(z_2)/dz_2}{N^{z_1>0.5}}\right)_A}{\left(\frac{dN^{z_1>0.5}(z_2)/dz_2}{N^{z_1>0.5}}\right)_D},$$

- Sensitive to correlated nuclear effects.
- Potential for model discrimination.

We will extend these measurements, keeping the goal of discriminating against several competing models.



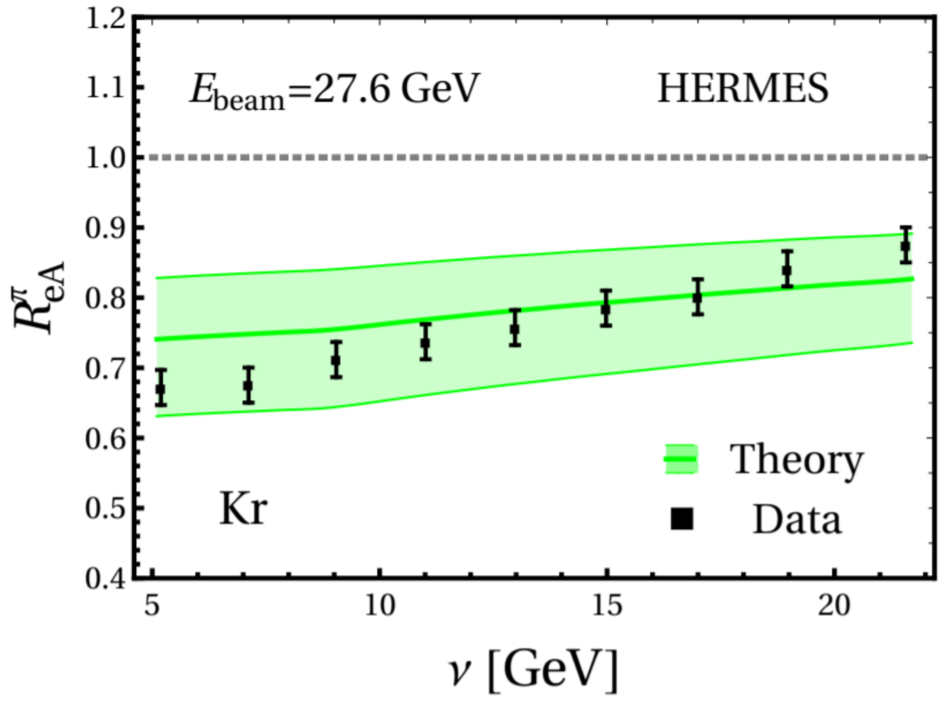
Our goal is *not* to a priori pick one model and “interpret” our data with it.

All bets are off!

do not take my word for it, check a recent theory paper:

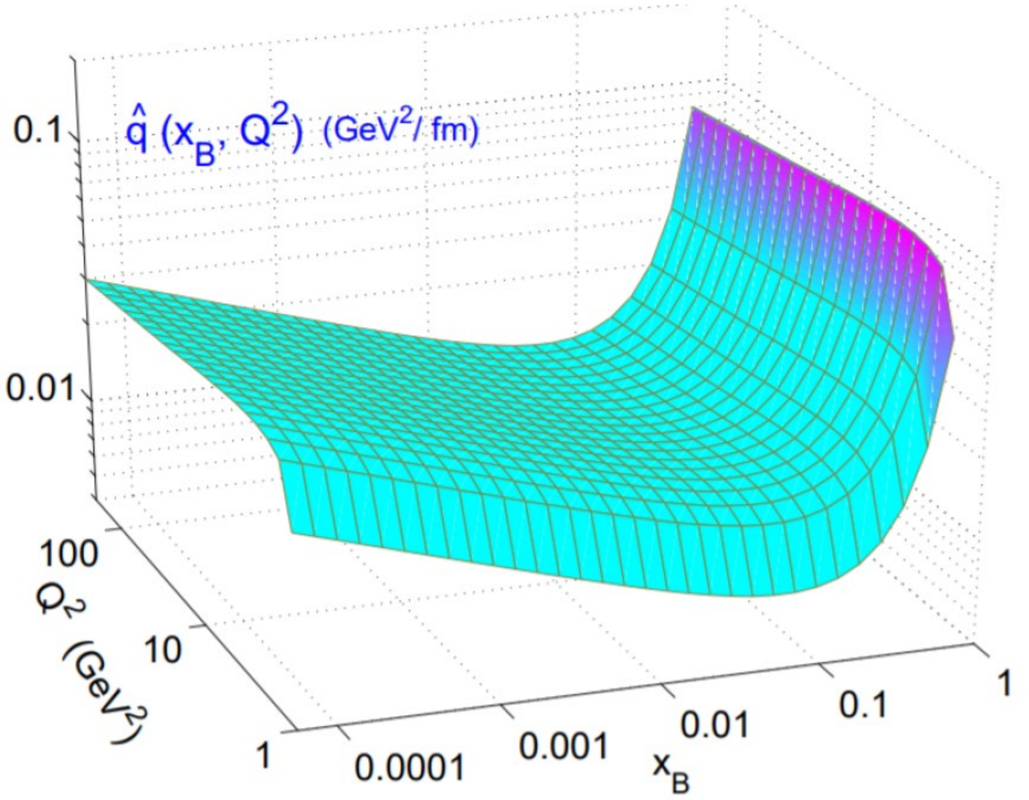
arXiv:2007.10994, **July 21**, Li, Liu, Vitev
"Heavy meson tomography of cold nuclear matter at the electron-ion collider"

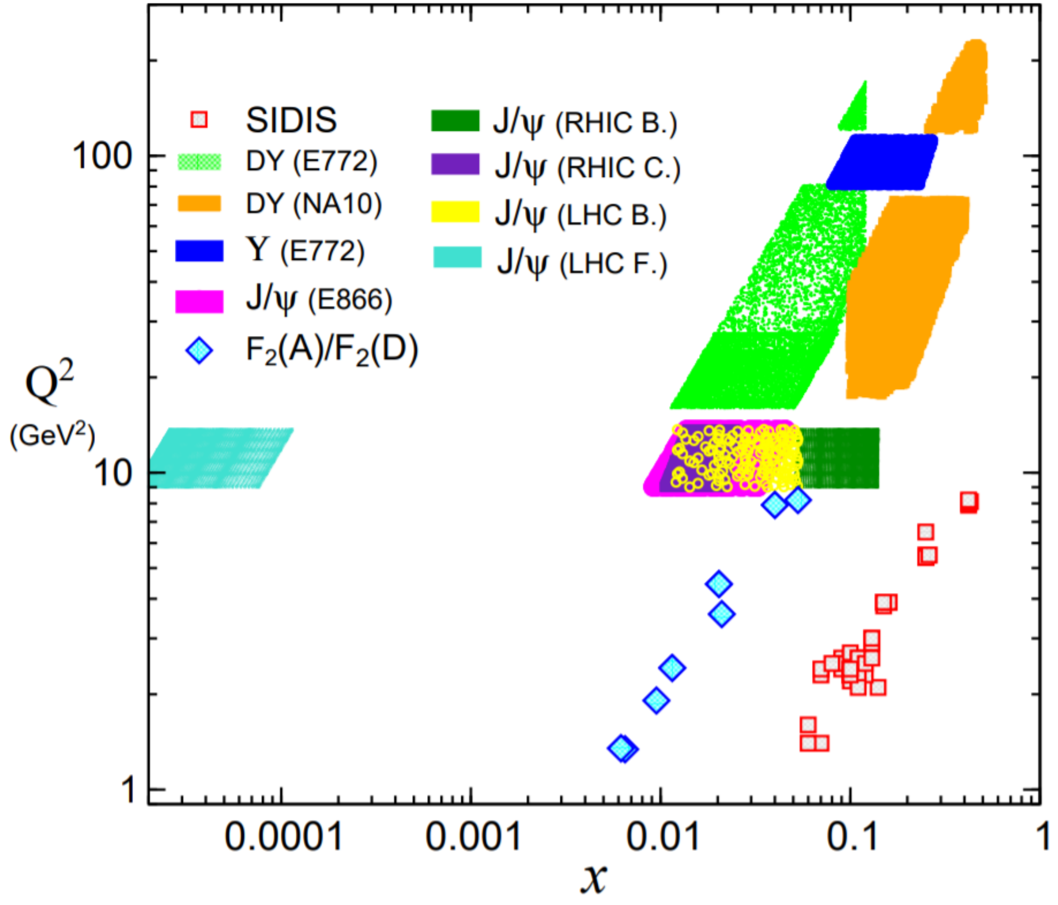
The HERMES Collaboration e+A results have advanced our understanding of particle production in the nuclear environment, but a number of open questions still remain. The transport coefficients extracted from data using different energy loss approaches differ by up to an order of magnitude [8, 9]. More importantly, fundamentally different assumptions about the time scales involved in the process of hadronization and the nature of nuclear attenuation - inelastic parton scattering versus hadron absorption - give equally good description of the light meson multiplicities' quench-



Example of recent theory/pheno development

"A global extraction of the jet transport coefficient in cold nuclear matter"
Ru et al. arXiv:1907.11808v1

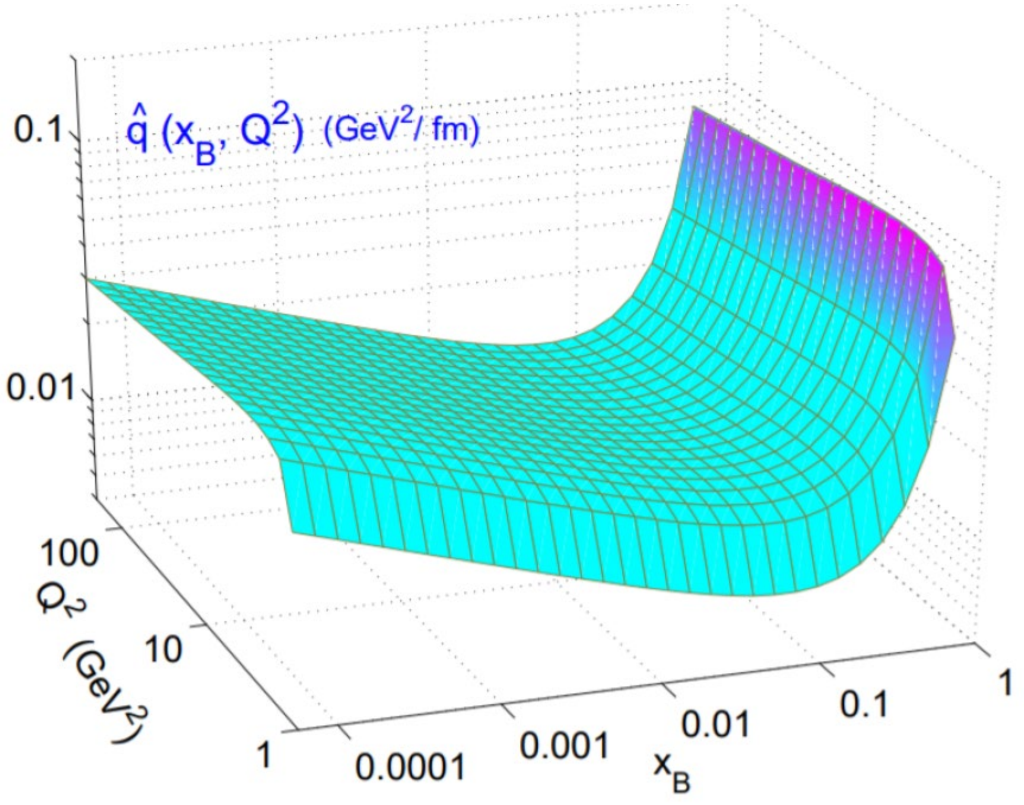


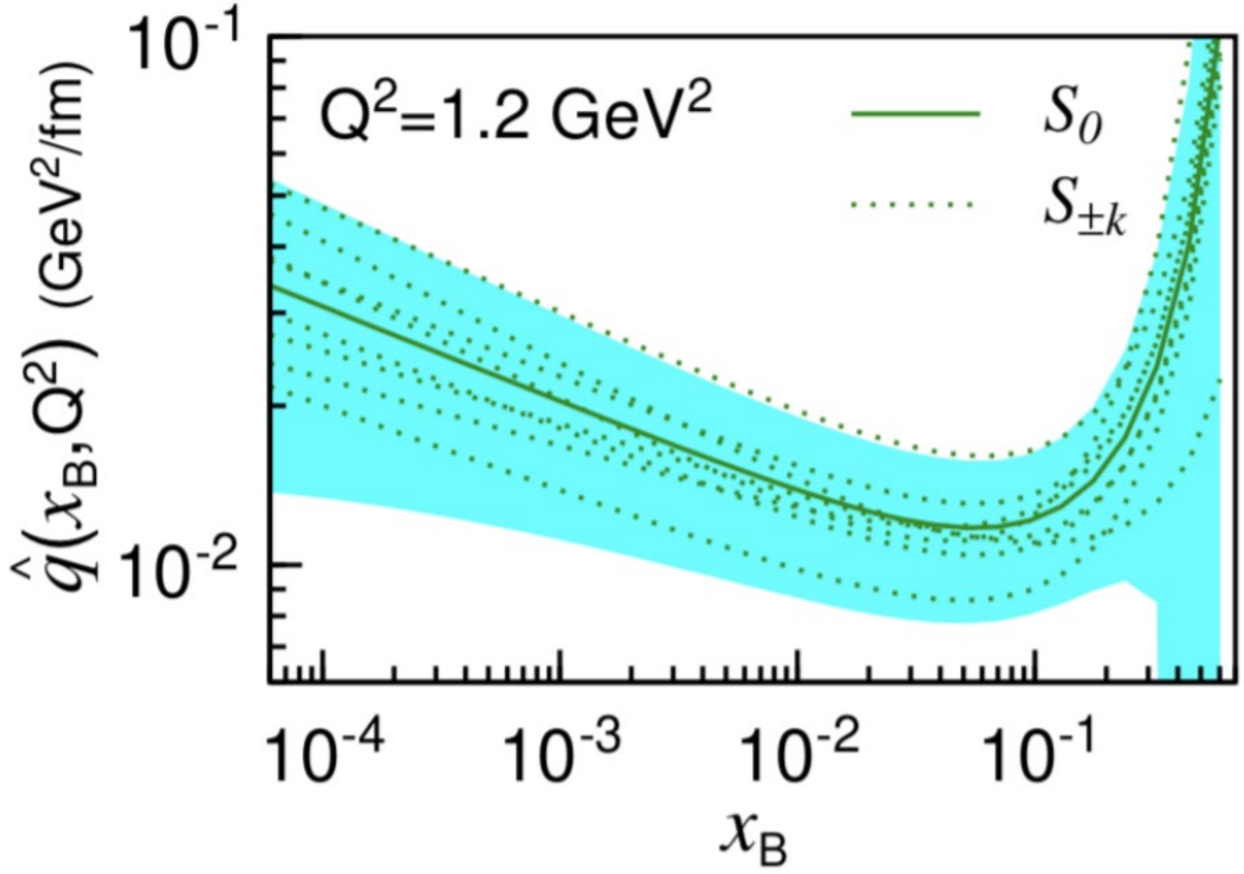


SIDIS data comes from HERMES

Transport coefficient of nuclei

qhat sets dictates transverse-momentum-broadening per unit length

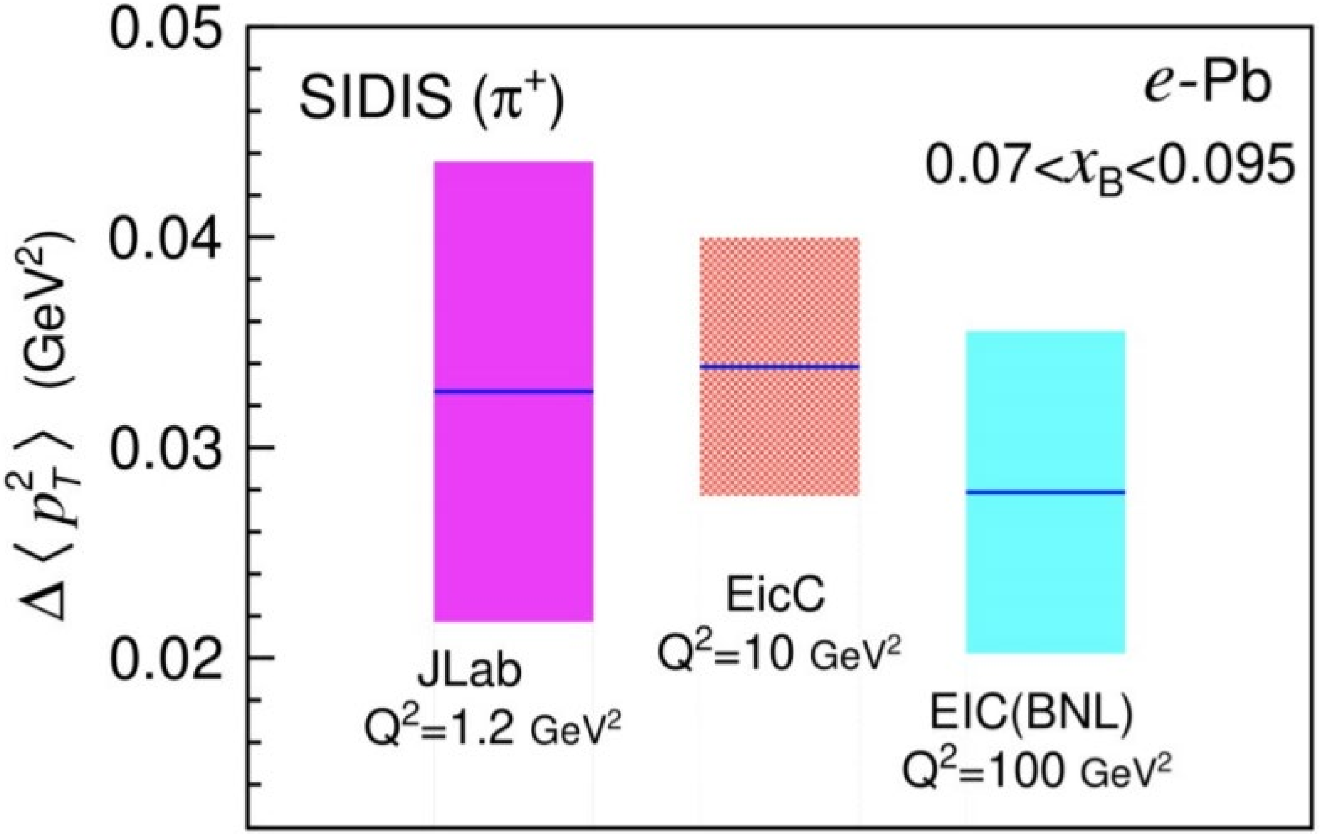


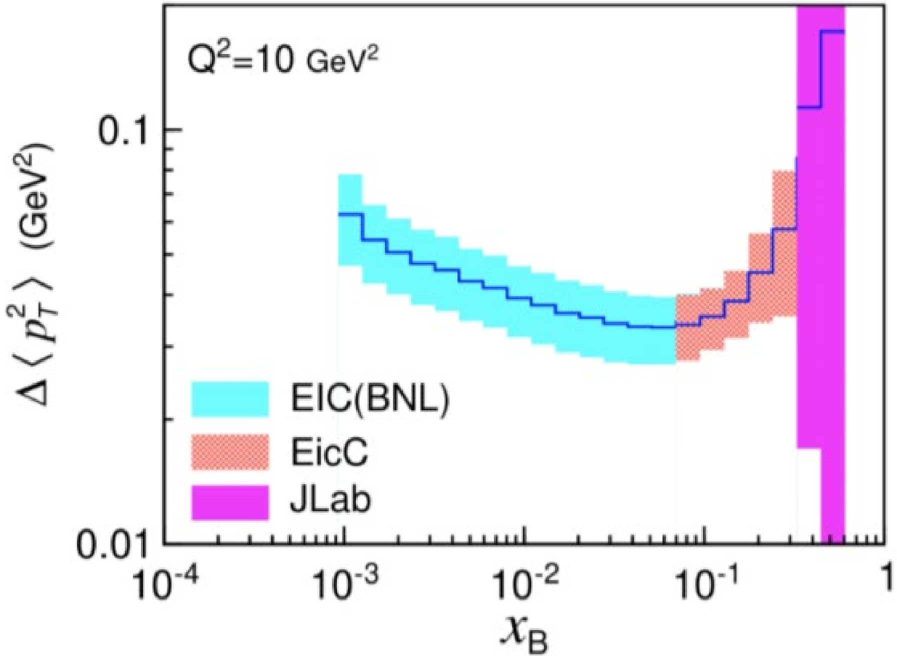


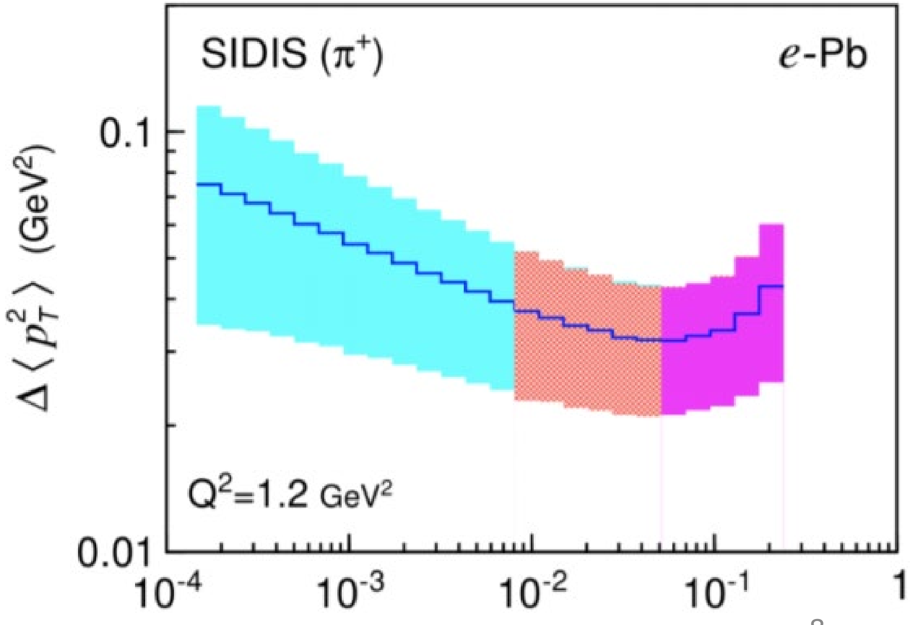
- CLAS12 data could have tremendous impact on these global analyzes.
- Main channels are transverse-momentum broadening of single-hadrons, as well as broadening of back-to-back hadrons.

Complementarity with EICs

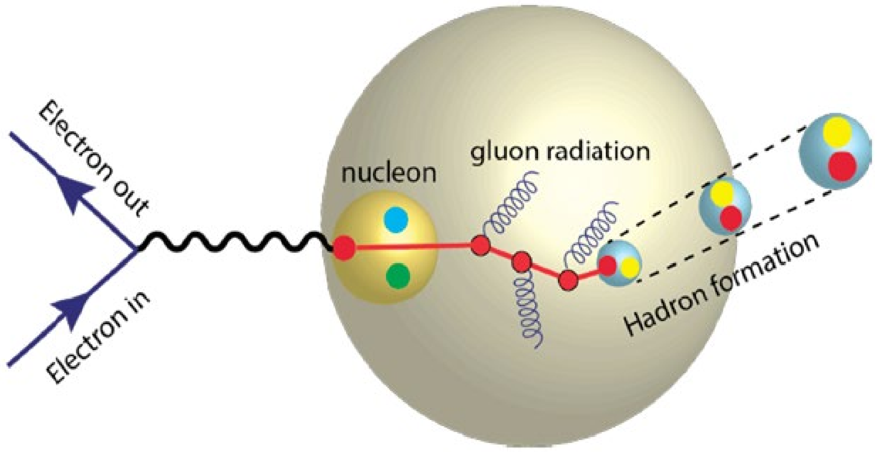
From Peng Ru, Hard Probes 2020



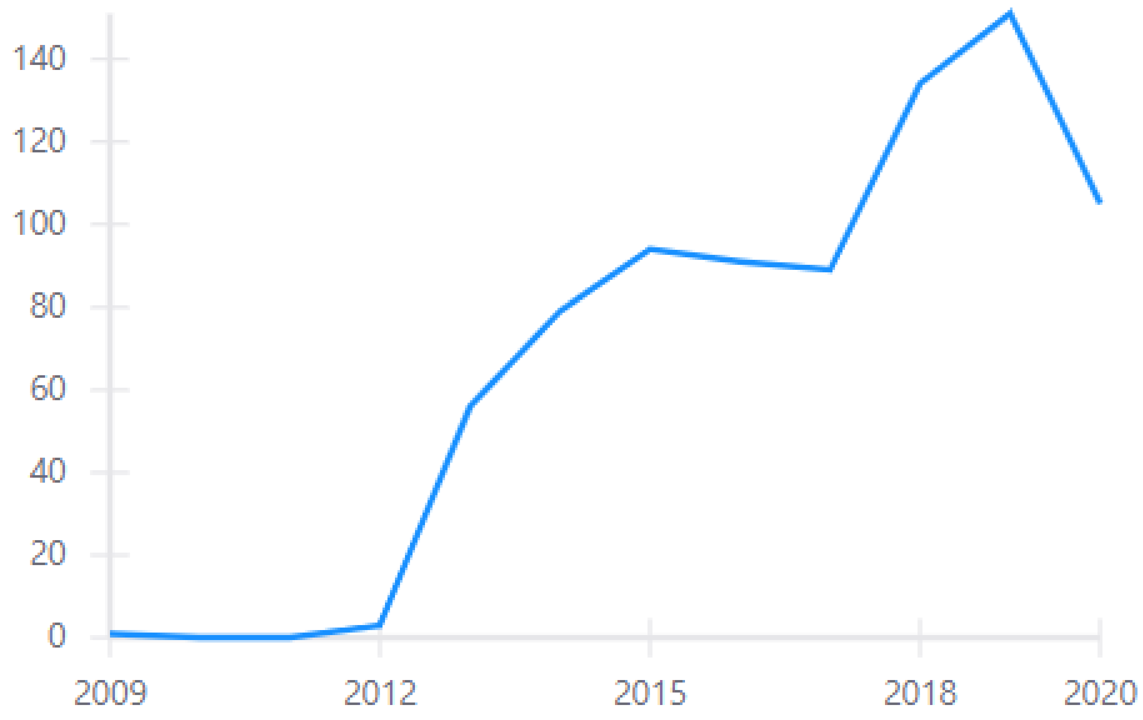




The field of hadronization in nuclei (one of the four EIC science pillars) is poised to get a boost…



Citations per year of EIC White paper

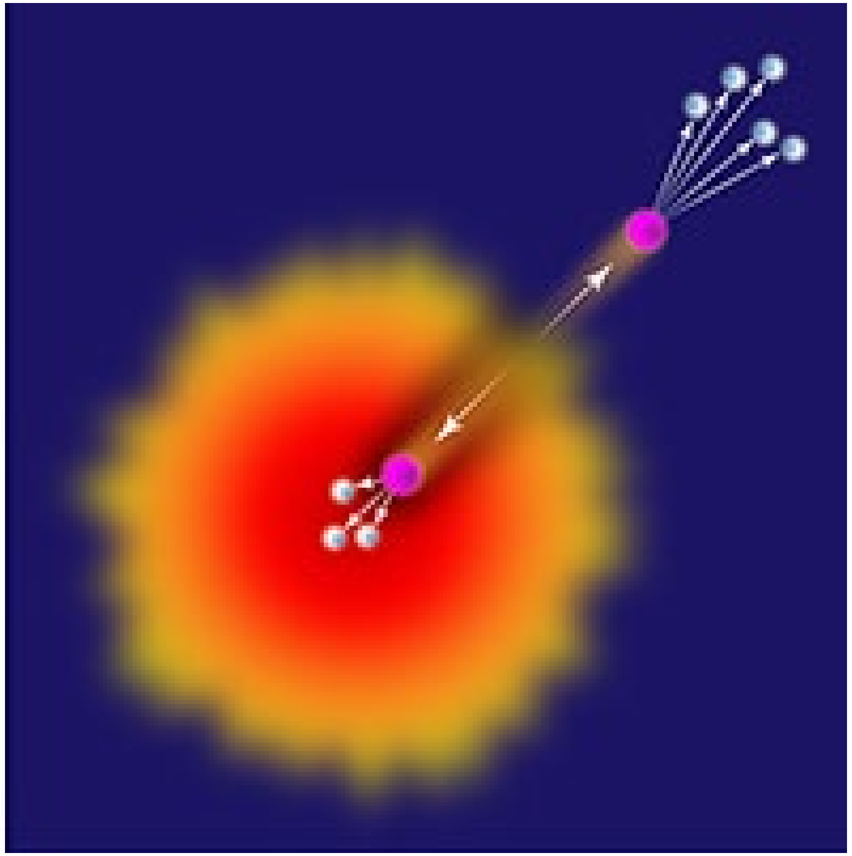


- Large acceptance of CLAS12 presents a unique opportunity. These are "must-do" measurements. A "pathfinder" for EIC.

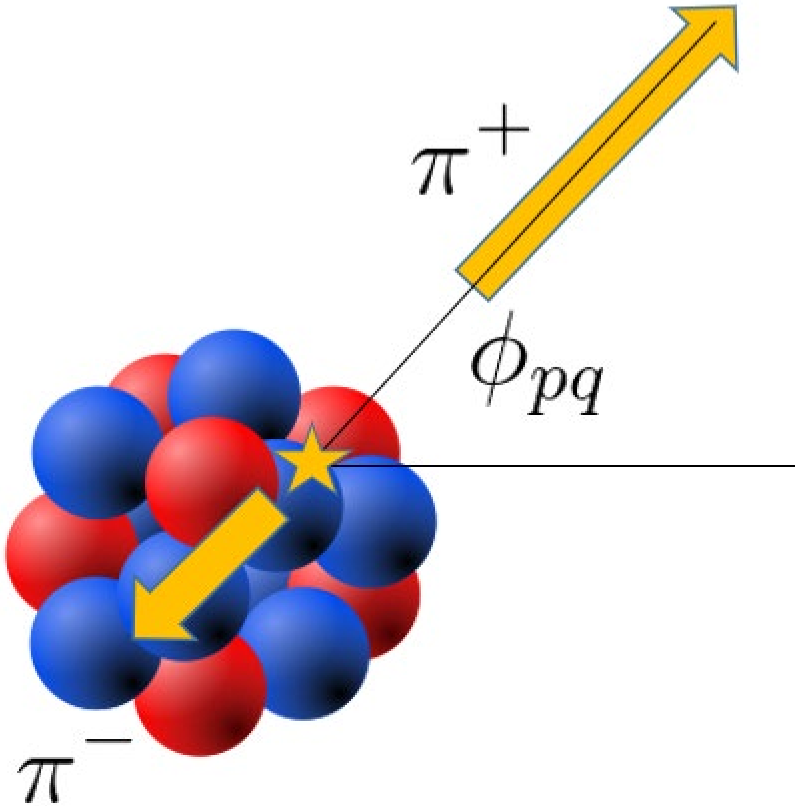
- The sooner the e-A runs gets on the schedule, the higher the impact will be.

We want to perform a measurement that is iconic in the study of hot nuclear matter, but for the study of cold nuclear matter

HOT QCD Matter

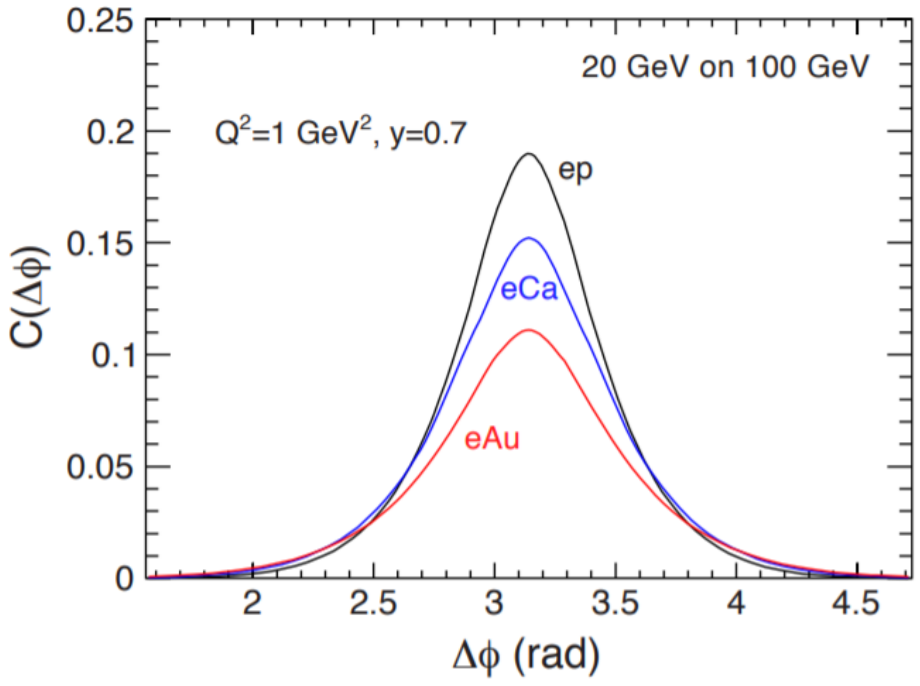


COLD QCD Matter

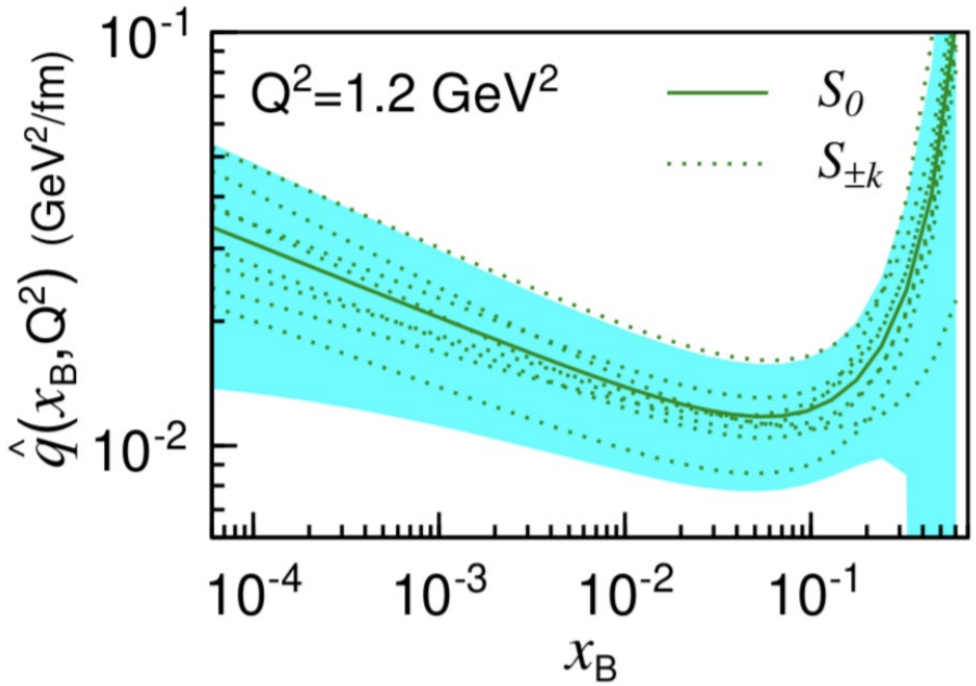


“Cold-nuclear matter” effects are the main background for gluon-saturation searches

Gluon saturation signal

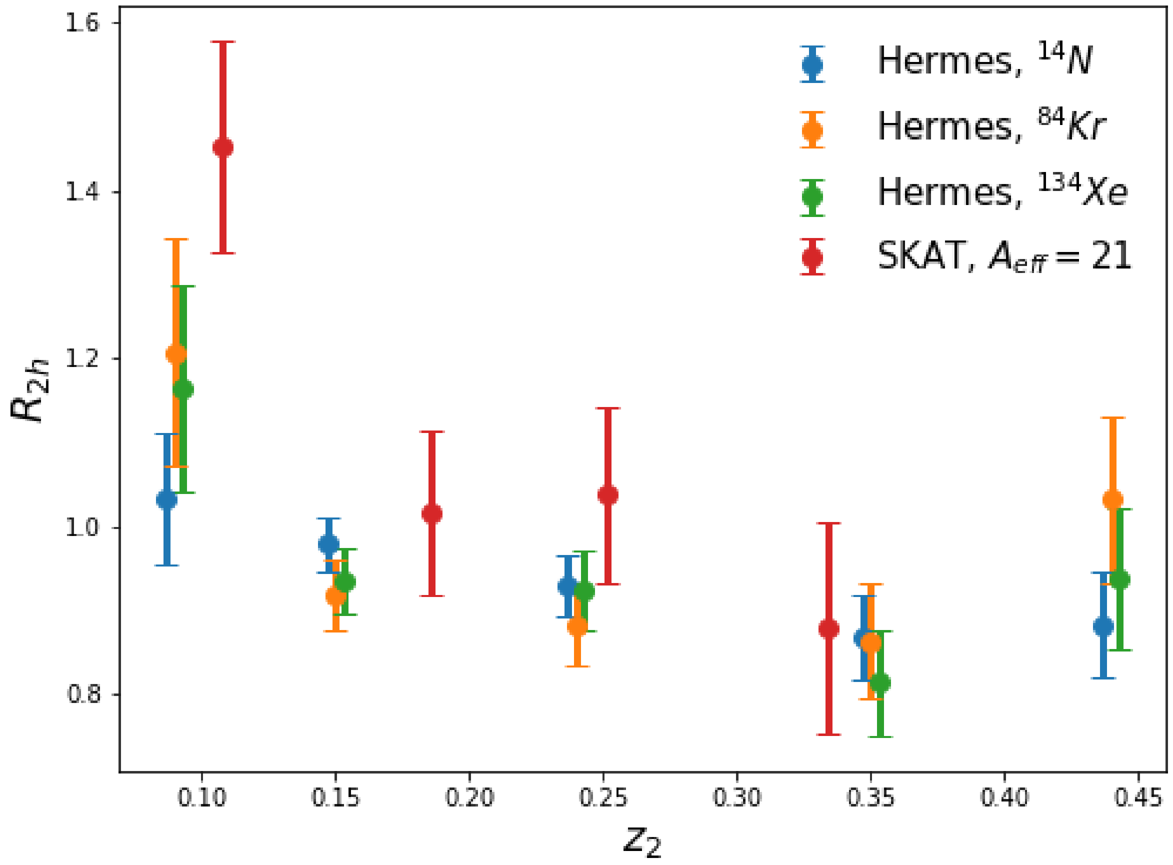


Background



- Main channel for gluon-satutarion search at EIC is dihadron azimuthal correlation
- Note the kinematics (low Q2), and note x-dependence of qhat is rather weak.

Previous measurements



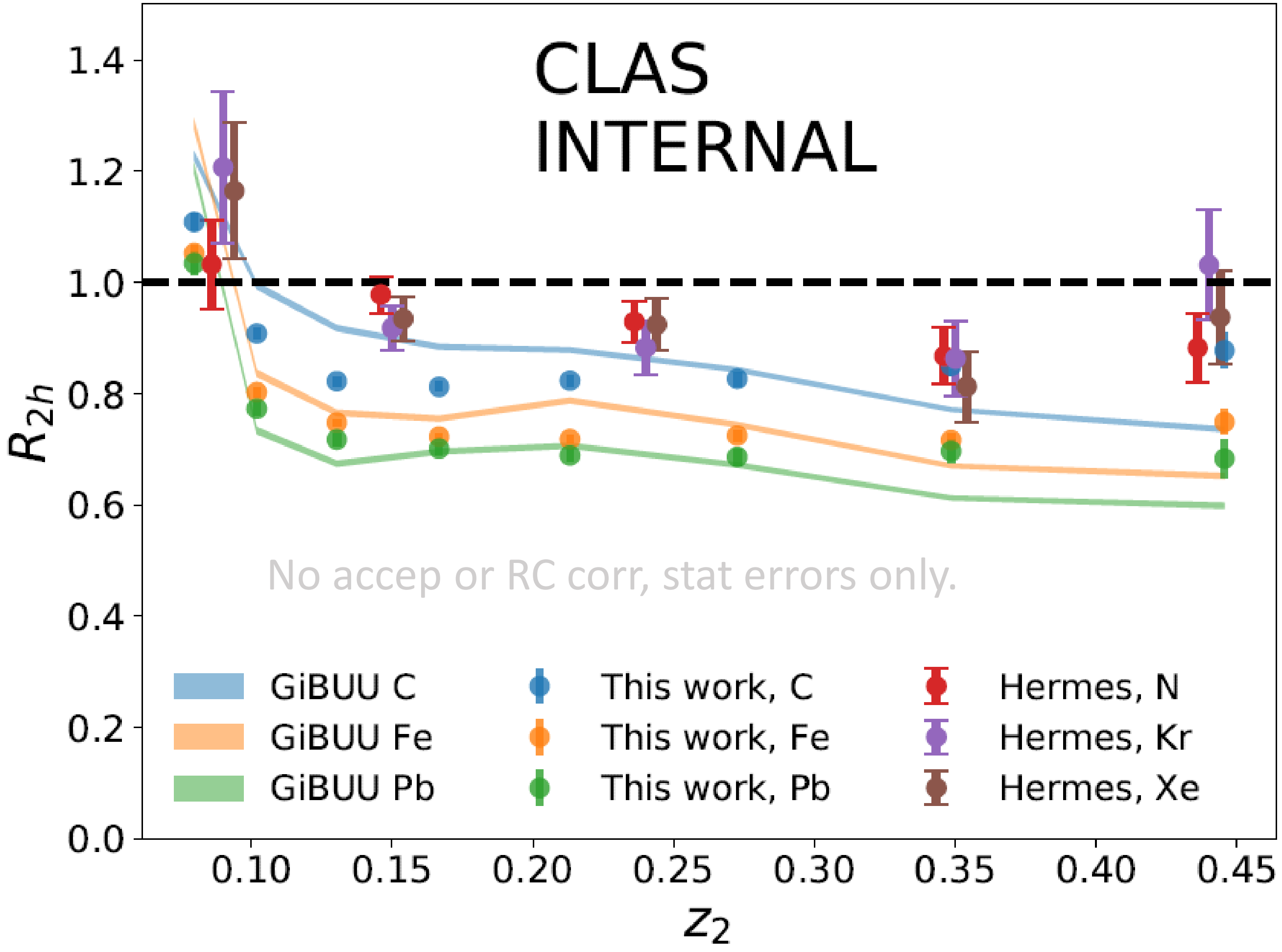
$$R_{2h}(z_2) = \frac{N_h^A(z_2|z_1 > 0.5)/N_h^A(z_1 > 0.5)}{N_h^D(z_2|z_1 > 0.5)/N_h^D(z_1 > 0.5)}$$

- No A dependence within uncertainties. (this was unexpected)
- Much reduced A-dependence than single-hadron measurements
- Agreement of e-A and nu-A experiments within uncertainties, even if kinematics differs
- Hint of enhancement at low-z. Hint of tendency to approach unity at high-z
- Unidentified hadrons for both cases.

- "Double-hadron Leptoproduction in the Nuclear Medium" *Phys. Rev. Lett. 96 (2006) 162301 , HERMES Collaboration.*
- "A study of the double hadron neutrino production on nuclei" *Phys.Atom.Nucl.74:246-252,2011, N.M. Agababyan et al.*

Preview: 5 GeV data

$$R_{2h}(z_2) = \frac{N_h^A(z_2|z_1 > 0.5)/N_h^A(z_1 > 0.5)}{N_h^D(z_2|z_1 > 0.5)/N_h^D(z_1 > 0.5)}$$



https://gibuu.hepforge.org/trac/wiki

The GiBUU project

The **GiBUU project** provides a unified theory and transport framework in the MeV and GeV energy regimes for

- **elementary reactions on nuclei**, as e.g.
  - **electron** + A,
  - **photon** + A,
  - **neutrino** + A ,
  - **hadron** + A (especially **pion** + A and **proton** + A)
- and for **heavy-ion collisions**,

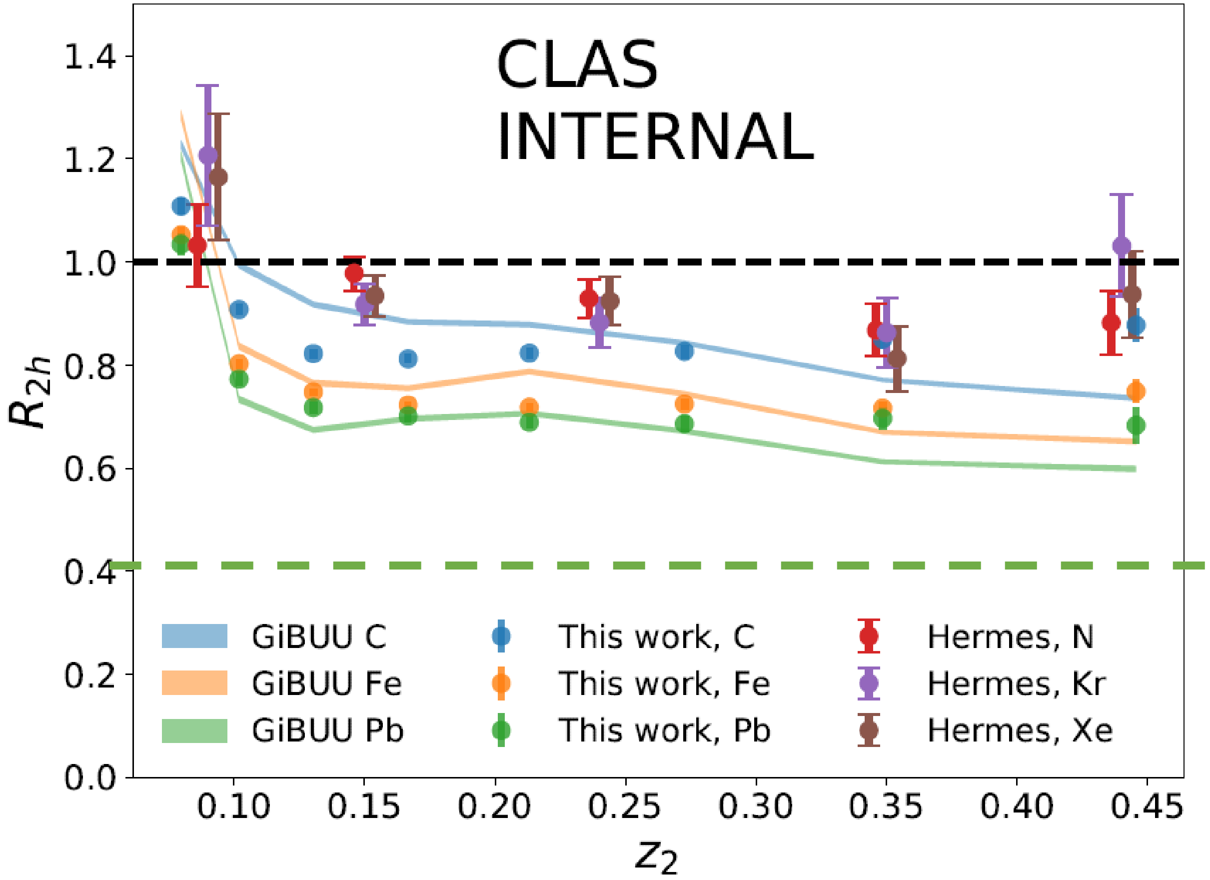
using the same physics input and code. The GiBUU code provides a full dynamical description of the reaction and delivers the complete final state of an event; it can thus be used as an **event generator**. The source code is freely available.

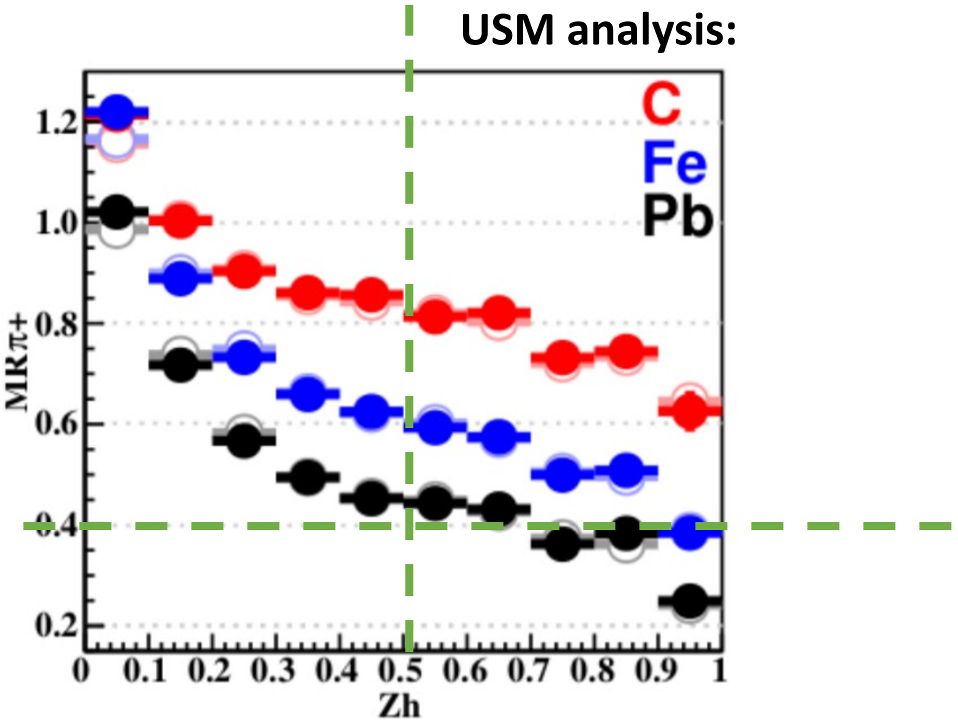
For all the reactions, the flow of particles is modeled within a Boltzmann-Uehling-Uhlenbeck (BUU) framework. The relevant degrees of freedom are **mesons** and **baryons**, which propagate in mean fields and scatter according to cross sections which are applicable to the energy range of a few 10 MeV to about 40 GeV. In the higher energy regimes the concept of **pre-hadronic** interactions is implemented in order to realize *color transparency* and *formation time* effects. For a general overview of the model, its theoretical basis as well as many

News

- 3. June 2020: *patch 7:* bugfix pion-BG for antiNC, position output in ROOT files
- 3. March 2020: *patch 6:* antiparticles in FinalEvents.dat; Collision List
- 10. Dec. 2019: *patch 5:* bugfix for A+A collisions
- 5. Nov. 2019: *patch 4:* minor corrections for CLAS
- 5. Aug. 2019: *patch 3:* minor bugfix for reading fluxes
- 16. April 2019: *patch 2:* DUNE fluxes updated

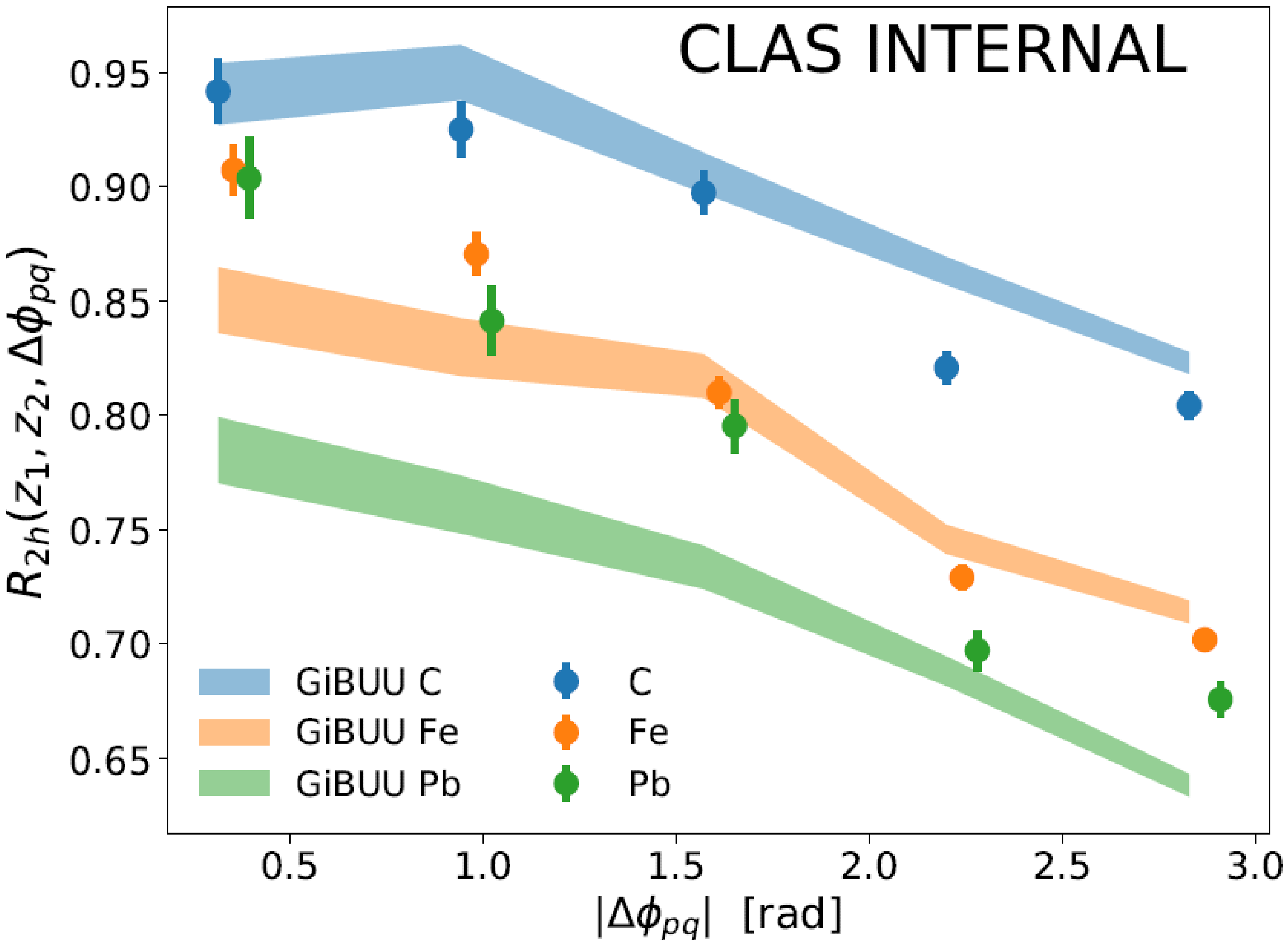
Double-hadron v single-hadron modification

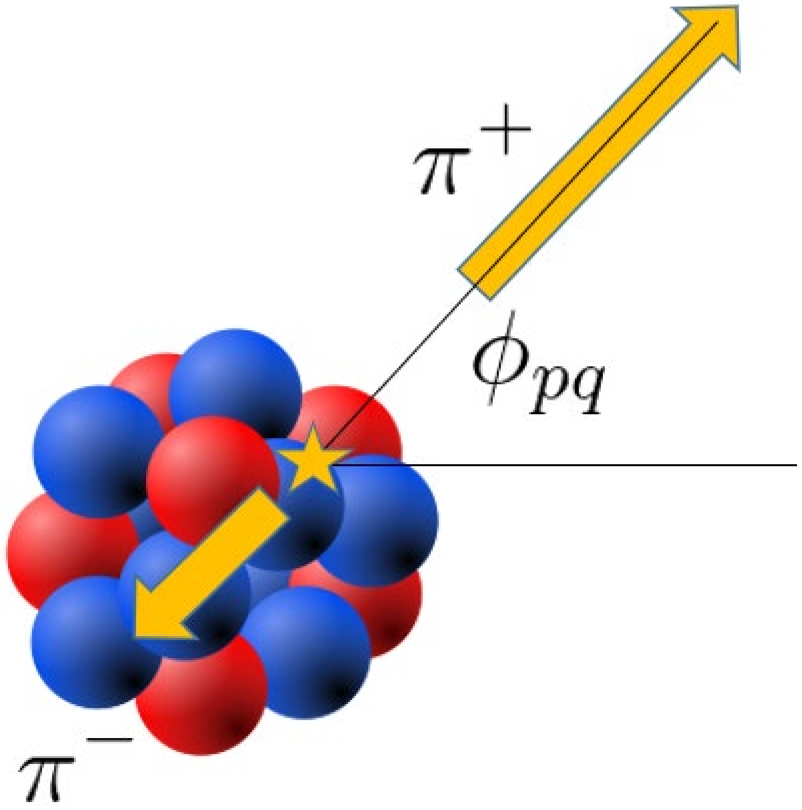




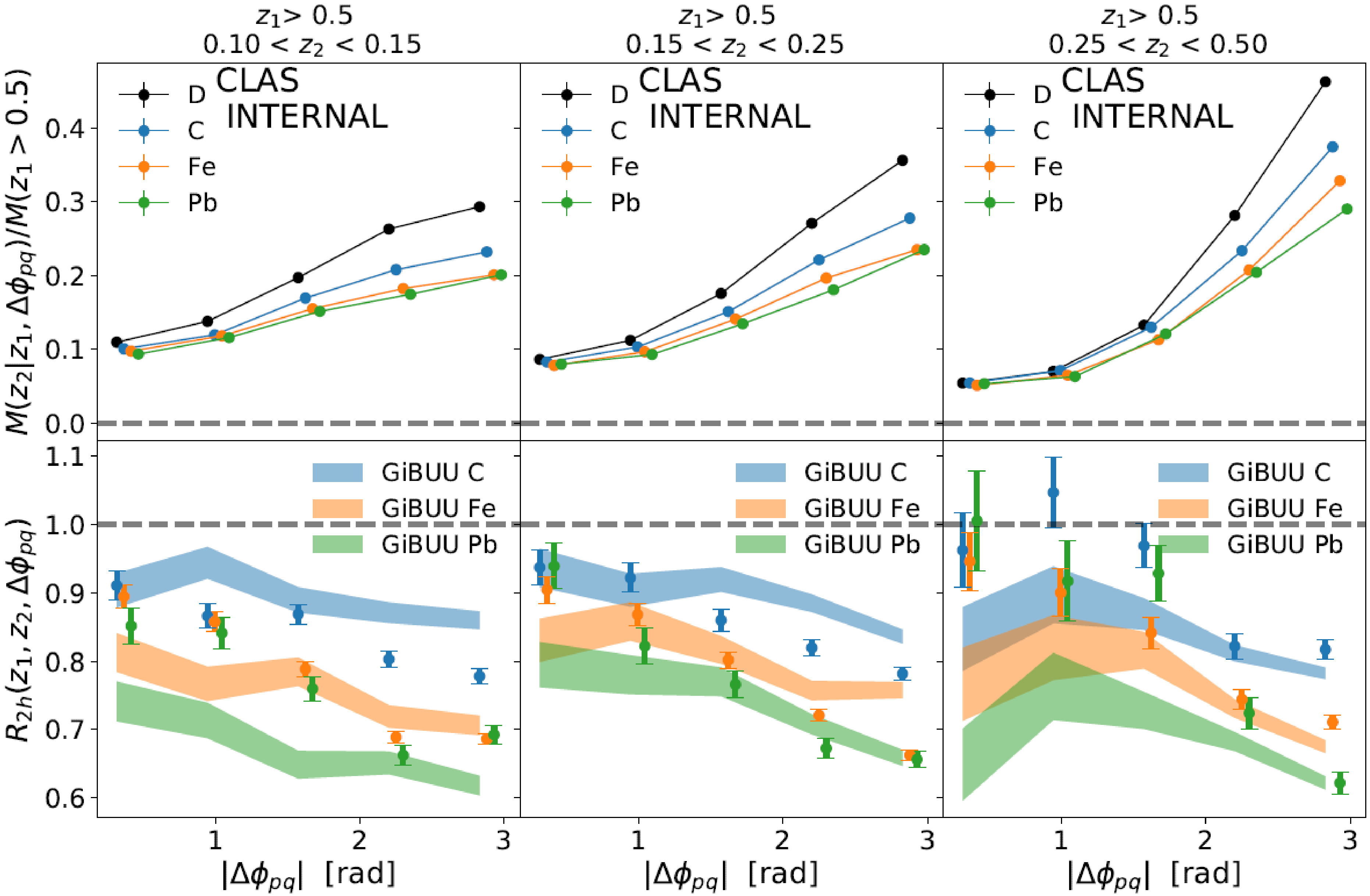
- Less suppression for conditional events (evidence of correlated effects)
- Much reduced A-dependence.
- Combination offers great discrimination power for competing models

Azimuthal correlation



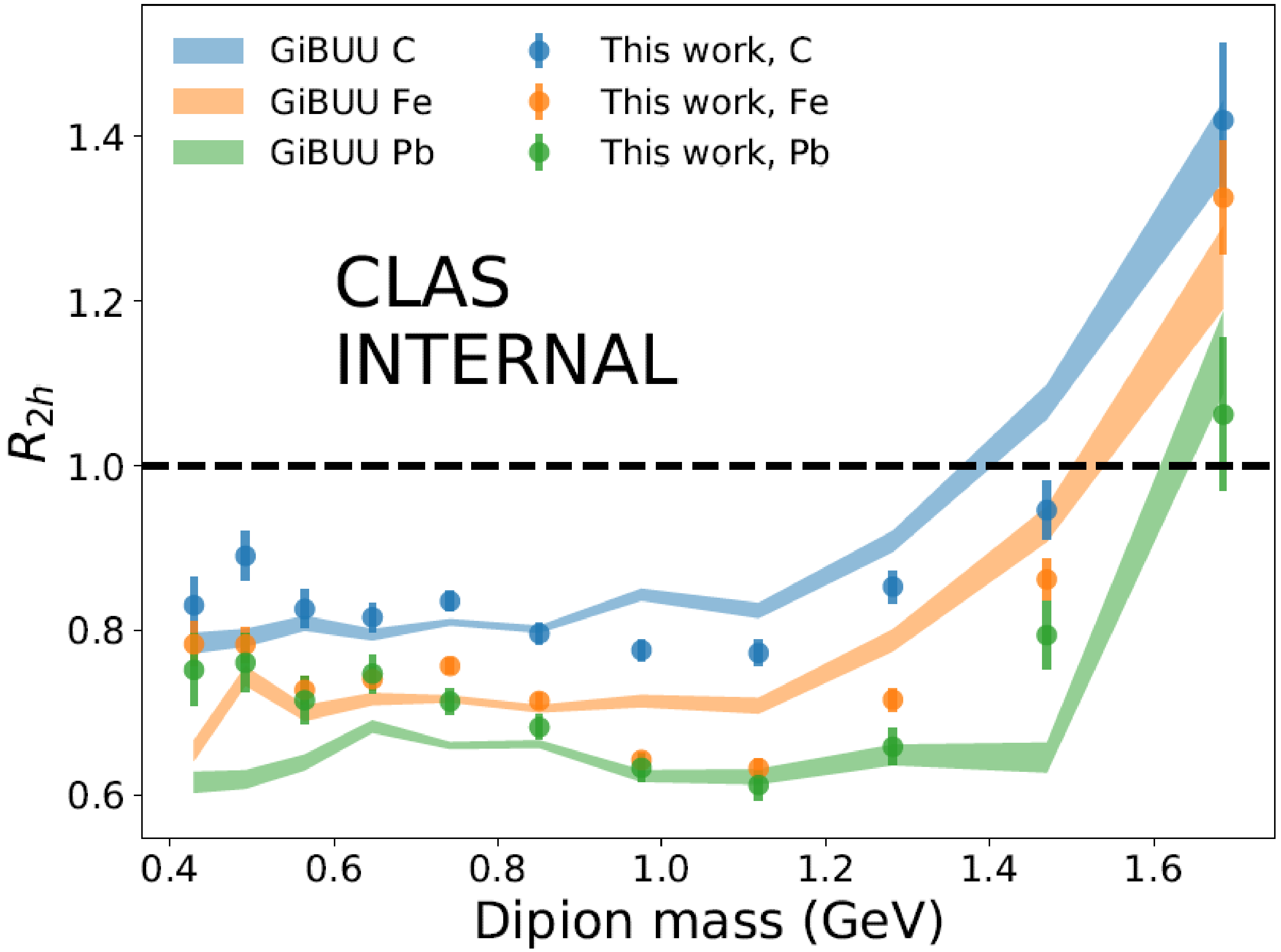


No accep or RC corr, stat errors only.

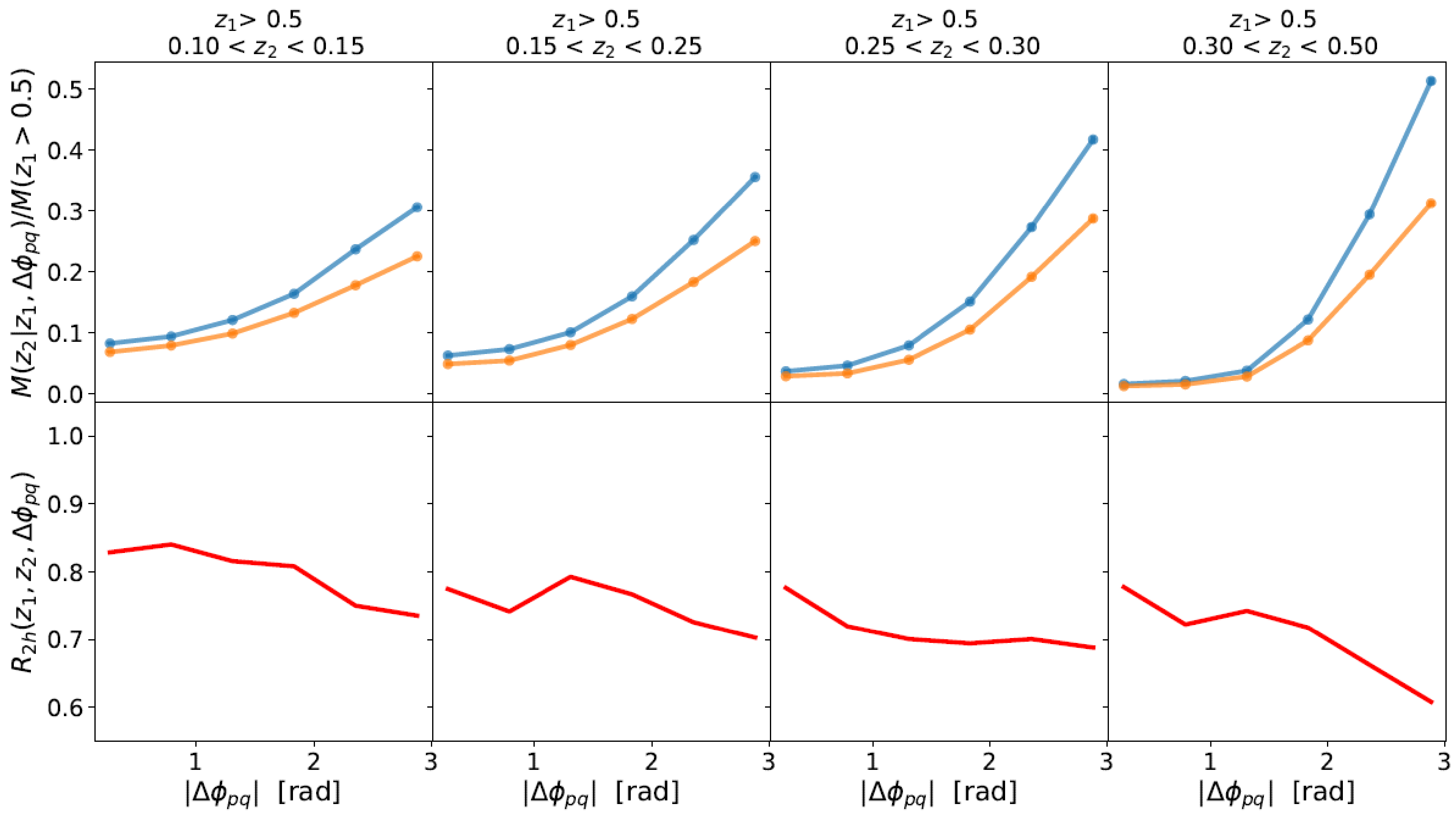


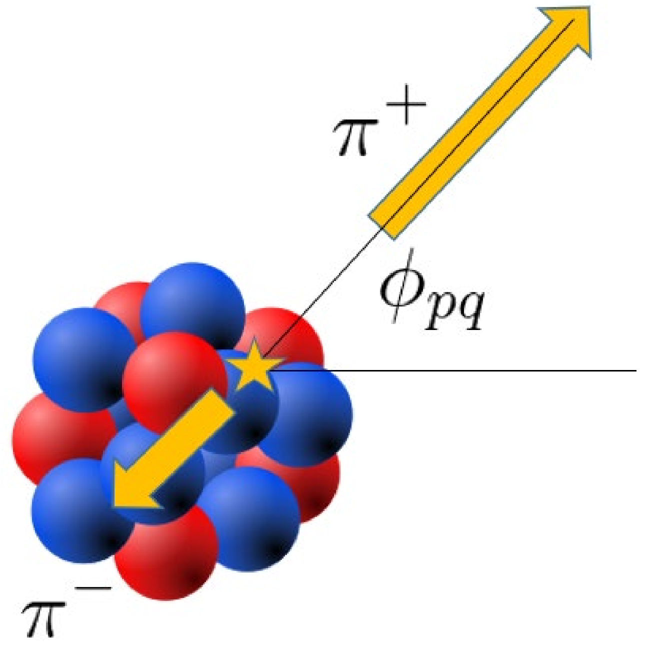
EG2 data hints interesting effects, larger kinematic reach and higher luminosity is required to study it in detail.

Mass dependence



Predictions for 11 GeV





At our request , GiBUU authors added geometrical information in their MC

https://gibuu.hepforge.org/trac/wiki

News

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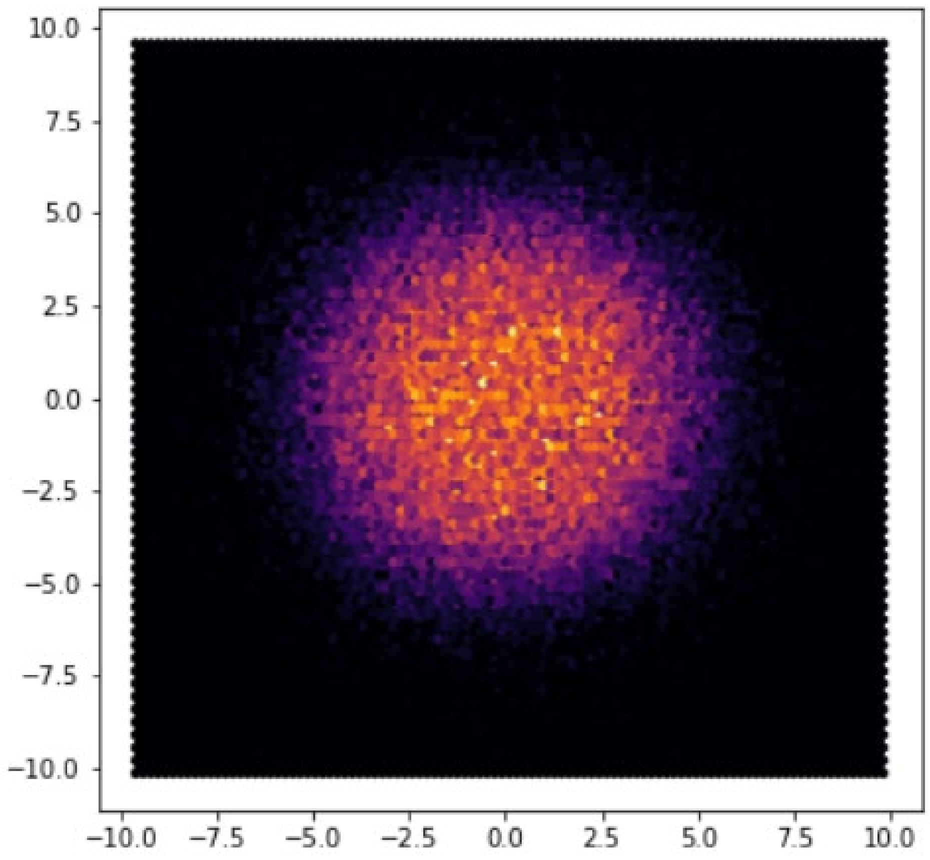
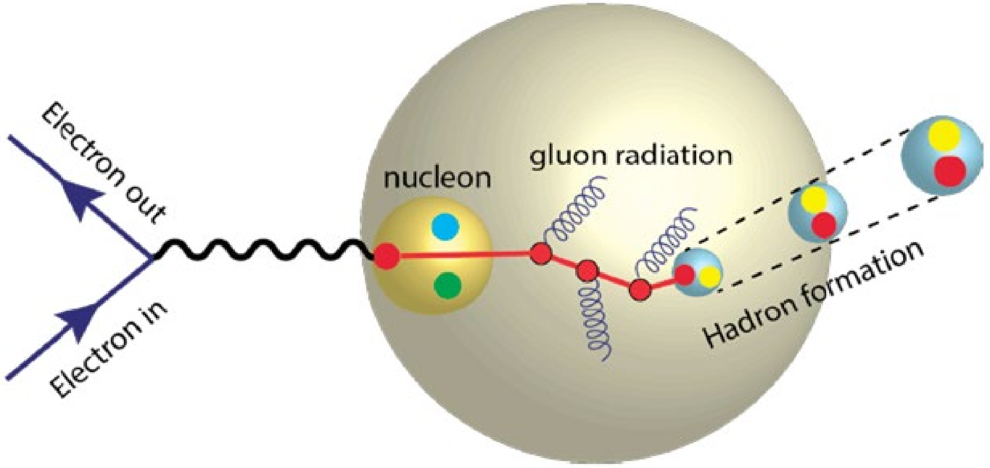
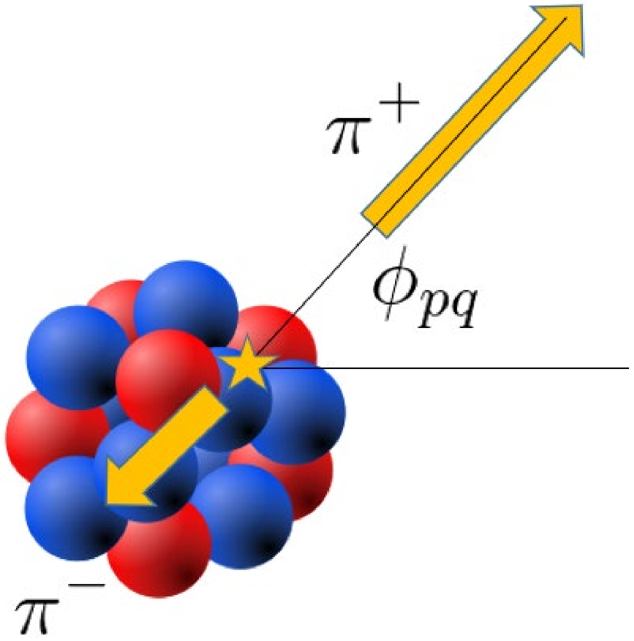
Within this model, we might explore in more detail the observed azimuthal correlation, perhaps supporting “surface bias” explanation. (work in progress)



Summary

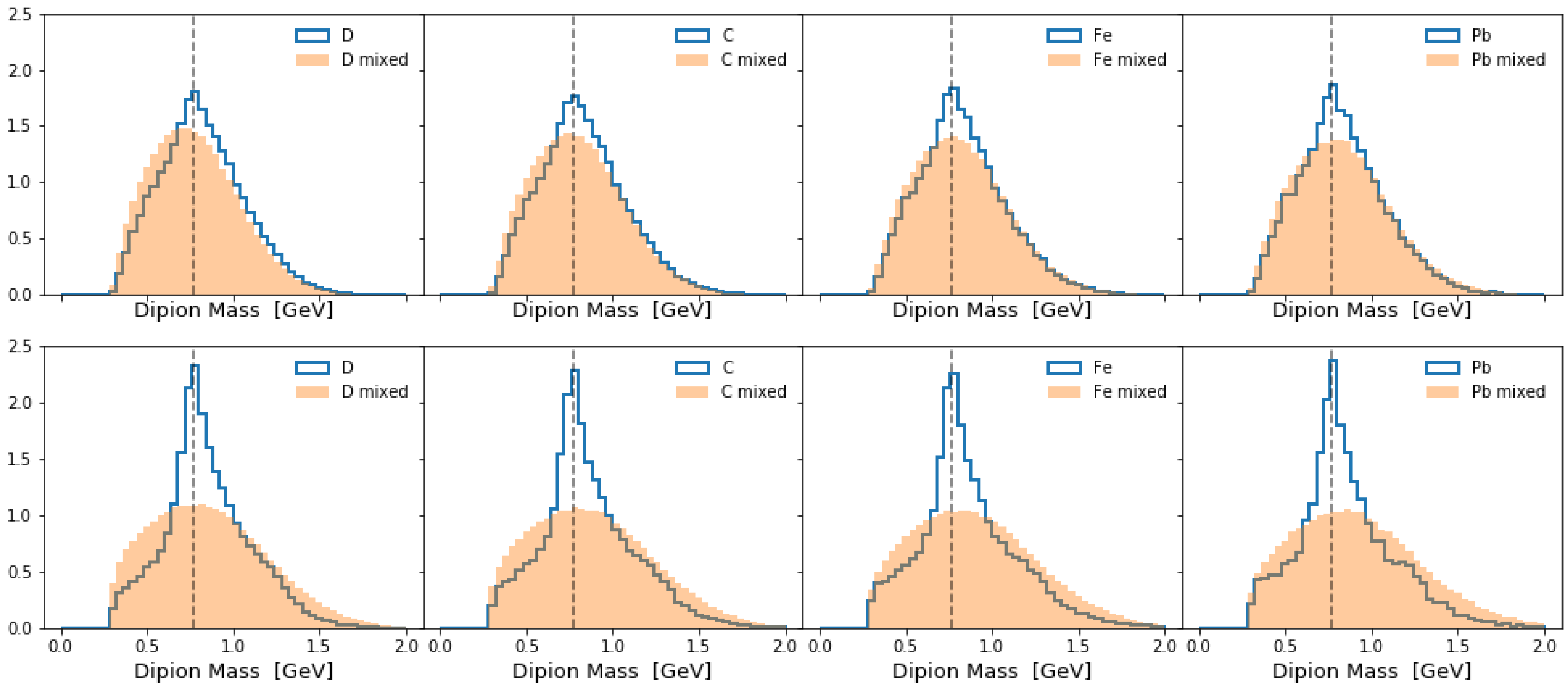
- We will carry out dihadron measurements in nuclear DIS. In particular, dihadron angular correlations (for the first time ever). This is a run addition for run group E.
- Dihadron measurements will complement single-hadron studies and allow us to:
  - Strongly tests of a plethora of competing models
  - Constrain fundamental QCD parameters.
- Program offers potential as pathfinder for EIC, complentary kinematics. 11 GeV beam data is essential. CLAS12 is the only game in town.
- Field is hot and will get hotter. We need nuclear data with CLAS12 asap.





Backup

On exclusive rhos:

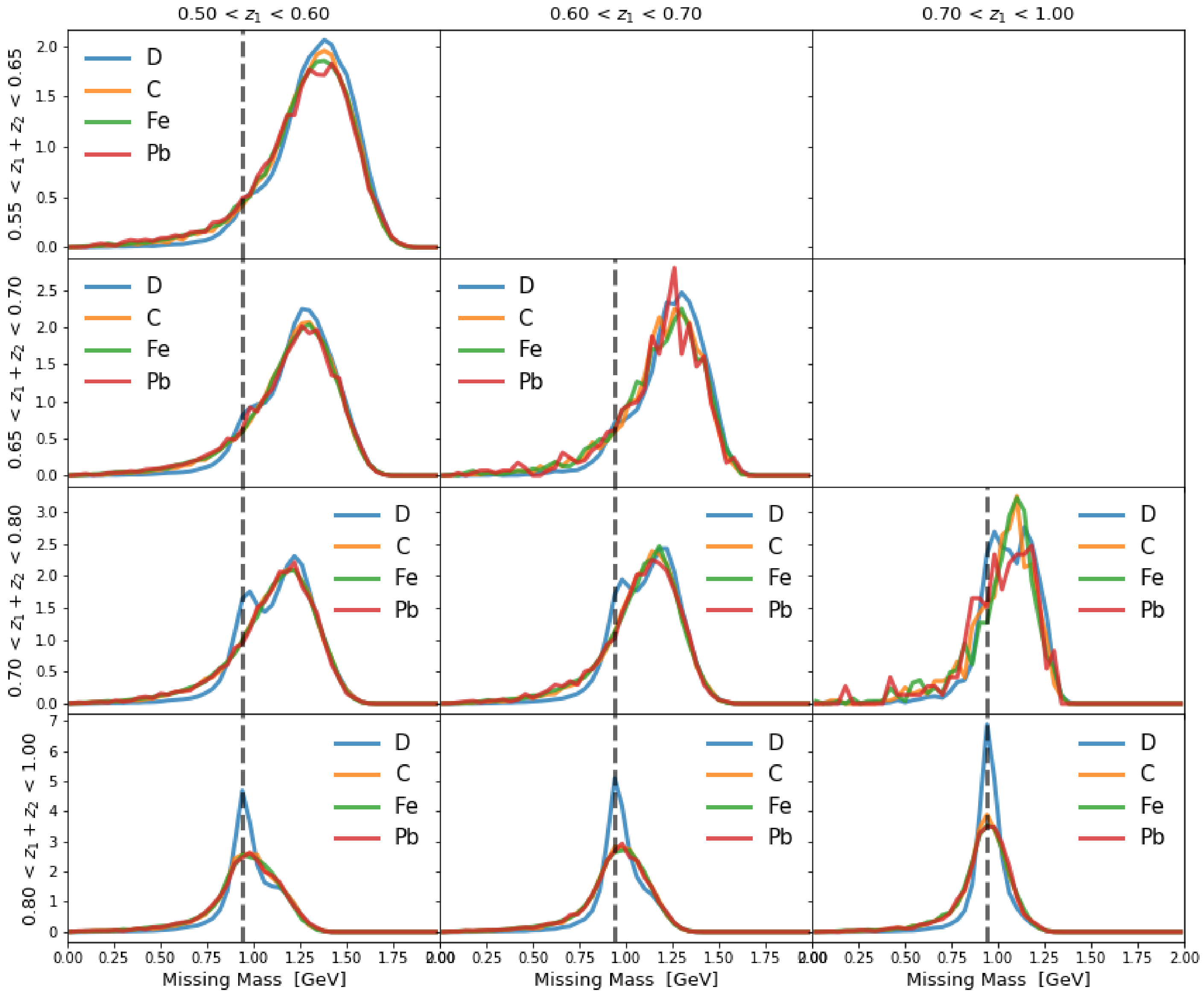


Z1+z2 < 0.8

Z1+z2 > 0.8

- Clearly the exclusive rho(770) production is significant for for ztot >0.8.
- Rather than trying to remove , we will present differential results and let theorists interpret (note we do not observe anything dramatic at z->1 or rho(770) mass)

Missing mass



- As expected, exclusive limit show a peak at nucleon mass (for deuterium target)
- Note that this variable is not useful for nuclear targets, due to Fermi motion

Event selection, kinematics, PID

- **HERMES (e-A):**
  Event selection: Q2> 1 GeV,
  W>2 GeV, y<0.85,
  nu> 7 GeV
  Average kinematics:
  <Q2> = 2.4 GeV2,
  <nu> = 17.7 GeV.
  Targets : Ne, Kr, Xe.

  Statistics limited.
  No PID

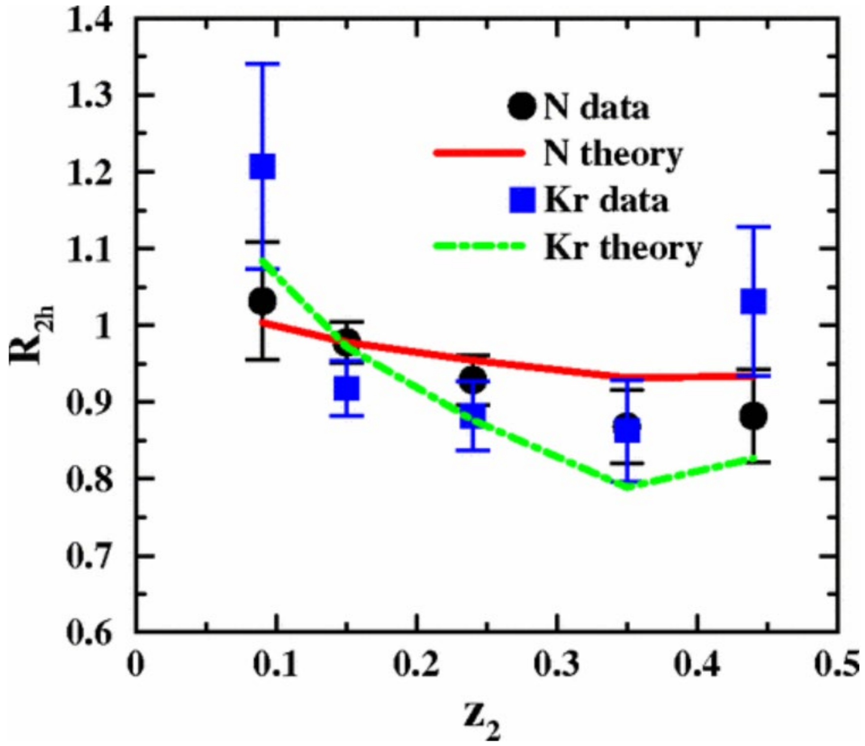
- **SKAT (nu-A):**
  Event selection: Q2> 1 GeV,
  W>2 GeV, y<0.85
  Average kinematics:
  <Q2> = 2.7 GeV2.
  <W> = 2.9 GeV,
  <nu> = 5.8 GeV

  Target: A_eff = 21
  (Bubble Chamber)
  Statistics limited
  No PID

“Modified Dihadron Fragmentation Functions in Hot and Nuclear Matter”

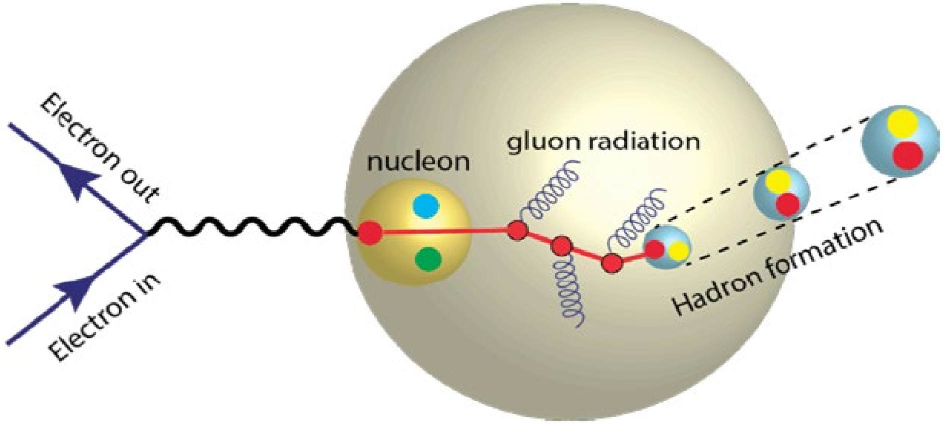
Phys. Rev. Lett. 99, 152301

A. Majumder, Enke Wang, and Xin-Nian Wang



“The suppression of R2h at large z2 with atomic number is quite small compared to the suppression of the single fragmentation function…
the effect of induced gluon radiation or quark energy loss is mainly borne by the single spectra of the leading hadron.”

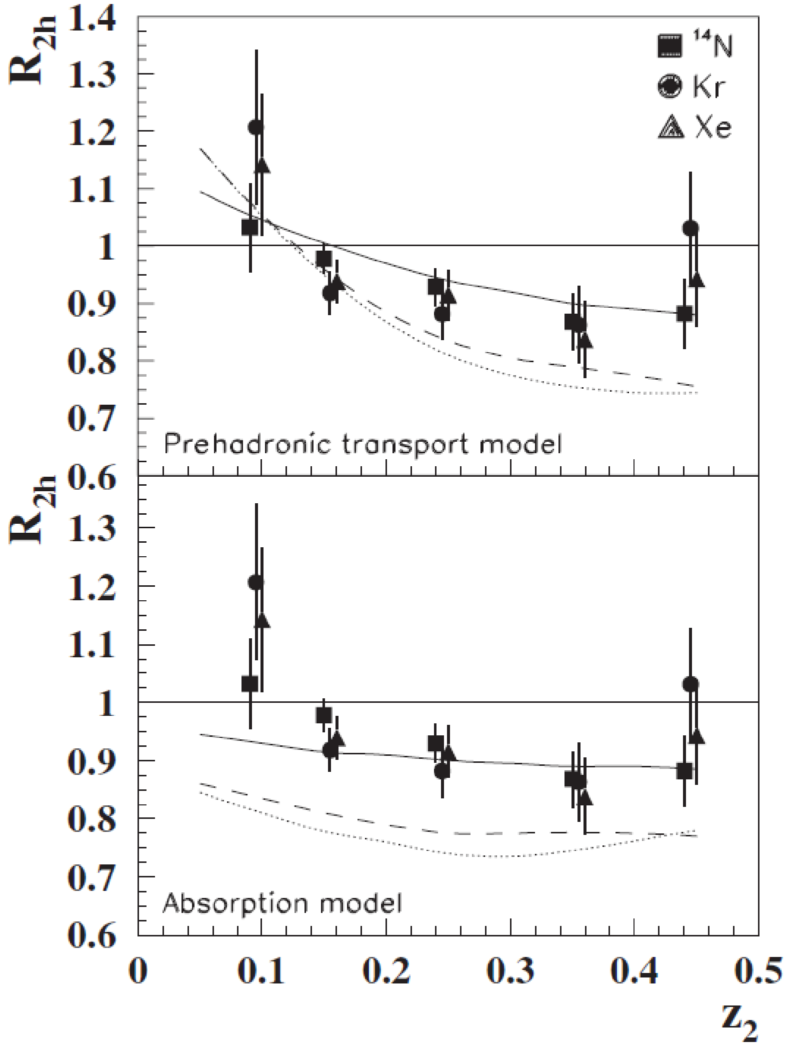
“At small z2, the modified di-hadron FF rises above its vacuum counterpart more than the modified single FF. This is due to the new contribution where each of the detected hadron emanates from the independent fragmentation of the quark and the radiated gluon”



“On the electroproduction of nuclei”.

Eur. Phys. J. A. 32 213-218 (2007)
K. Fialkowski, R. Wit

“The absorption models overestimate the effects, especially for heavier targets, in all the considered z-range. The transport model fares better, but it does not reflect the two most striking features of the data: the similarity of the results for all nuclei and the apparent disappearance of the absorption effects as z2->0.5”



Revised absorption model with geometric correlations

"On the electroproduction of nuclei". Eur. Phys. J. A. 32 213-218 (2007)

"Due to the strong nuclear abortion of the fast "trigger" hadron, the cut on z discriminate against the selection of a hit nucleon in the front part of the nucleus. Therefore, on average, the other hadrons will be absorbed less strongly than in a typical event"

"We expect that the secondary collisions of the hadrons originating from the string breaking with other nucleons produced extra hadrons. This enhances the spectra for low z values and may even result in values of Rh above one."

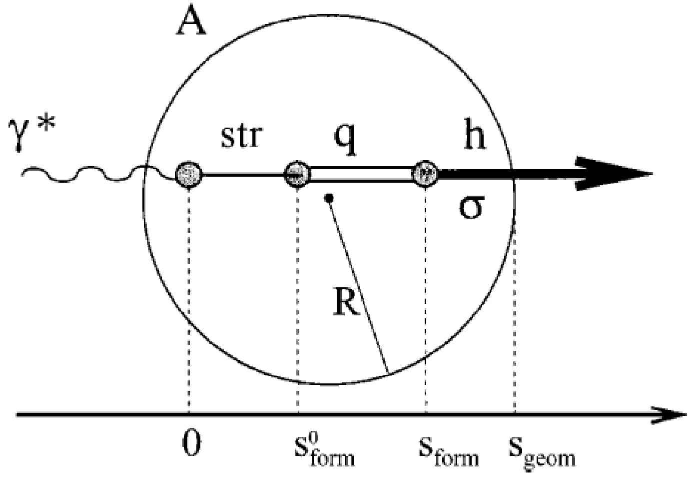


Fig. 1. The schematic picture of the string formation, string breaking and hadron formation inside a nucleus. The distances are measured from the string formation point.

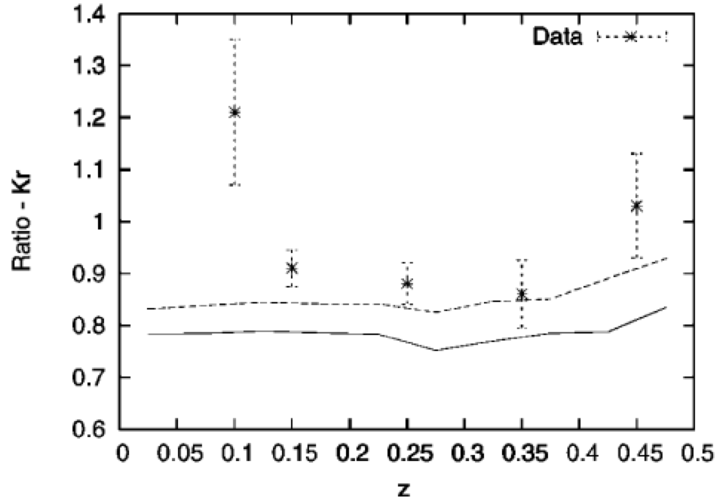
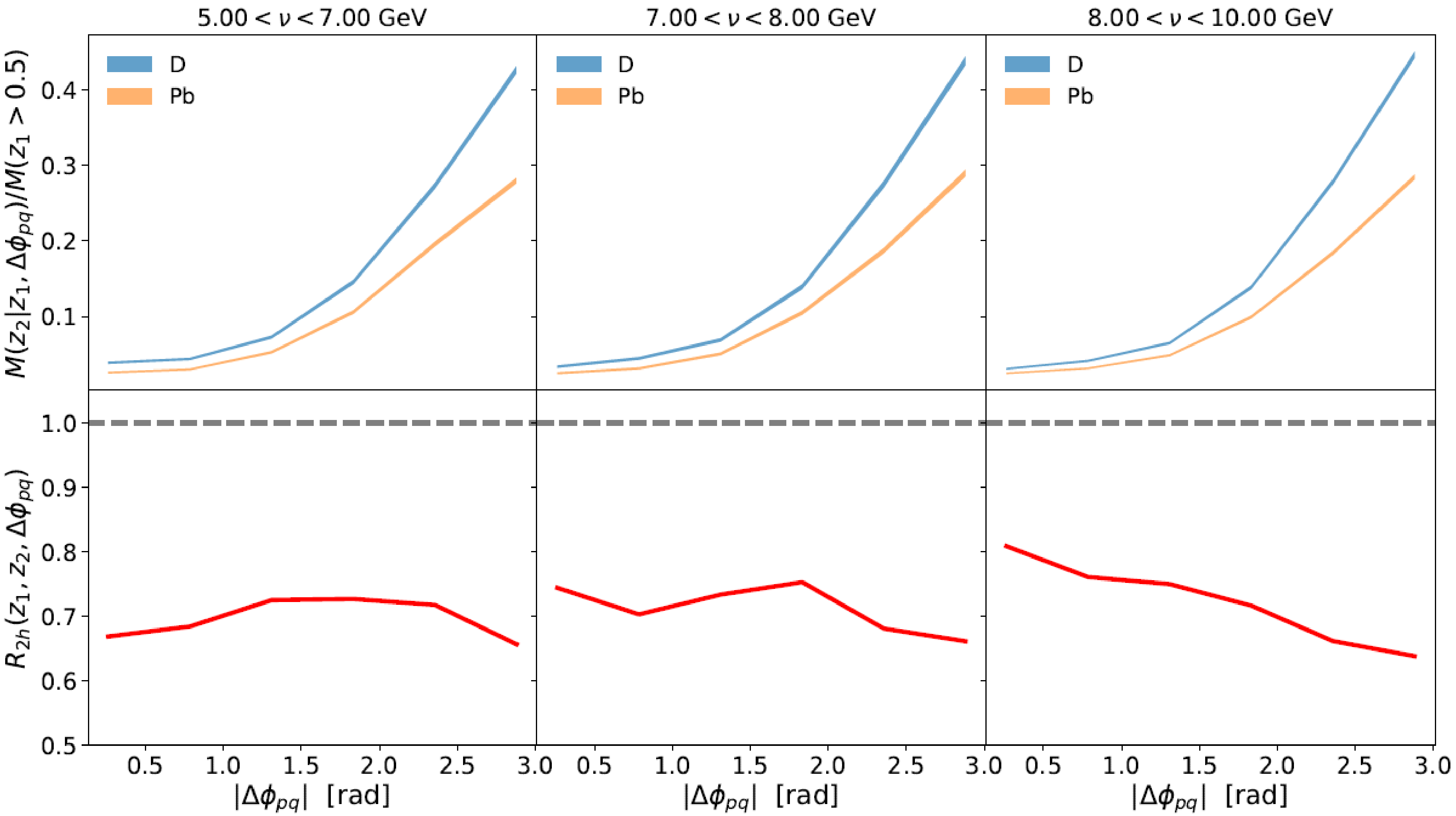


Fig. 6. The experimental ratio of the conditional charged hadrons z-spectra for krypton and deuterium [3] (asterisks with error bars) compared with the model calculations for $\tau_r = 0.8\,\mathrm{fm}/c$ (broken line) and the results of the event generation without proper correlations (solid line).

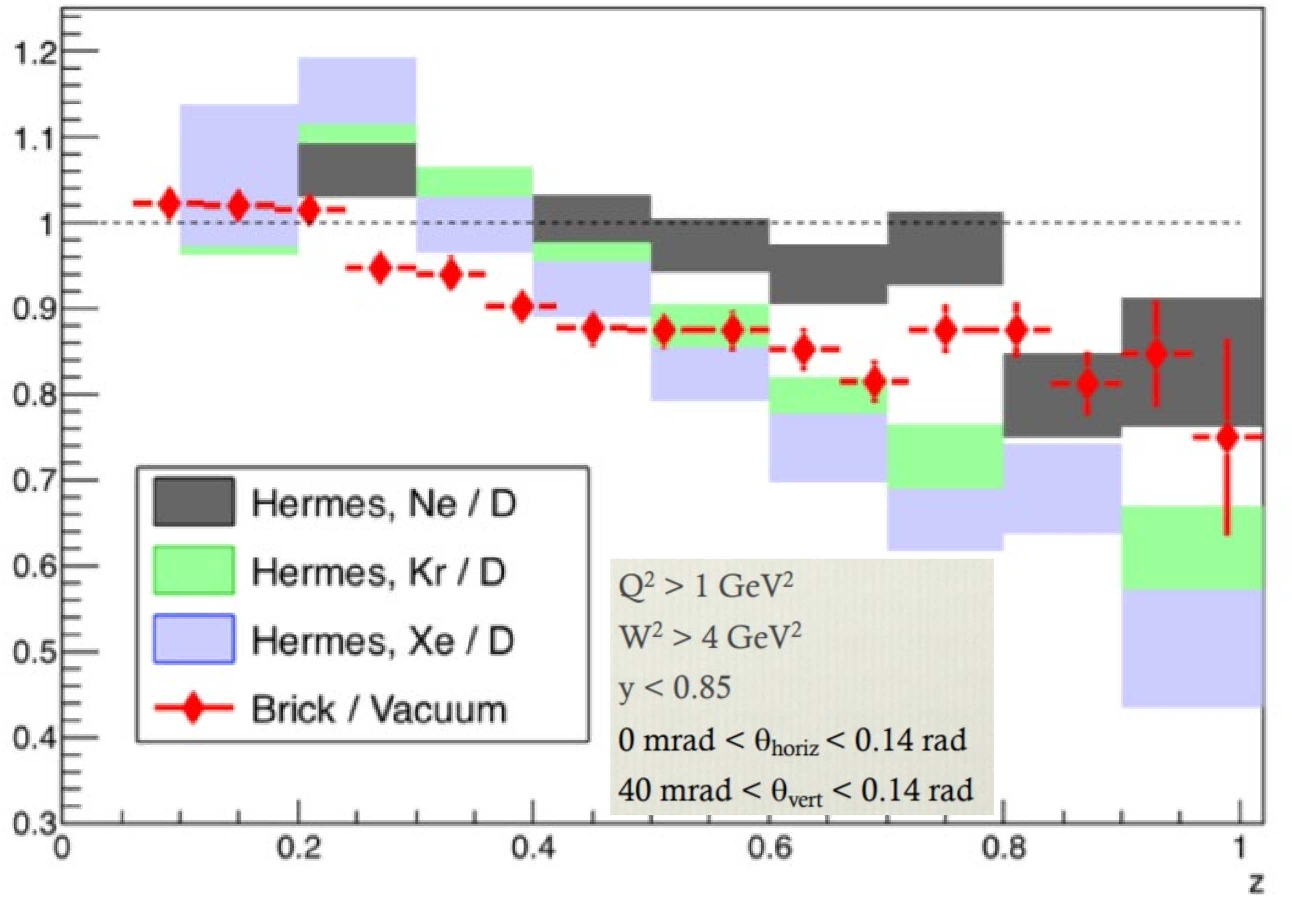
Predictions for 11 GeV



I bet that sophisticated MC generators and QCD theory will soon be available for e-A physics, e.g:

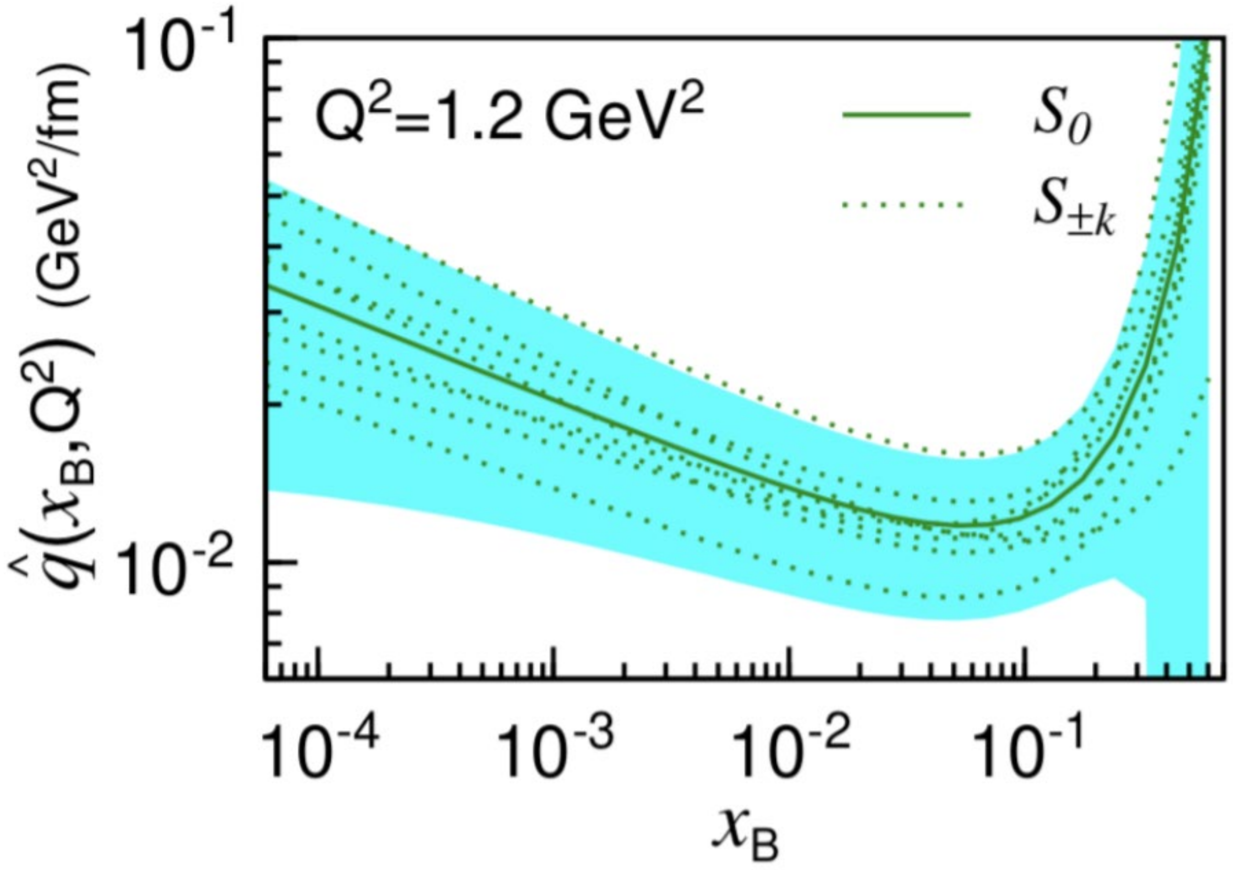
JETSCAPE

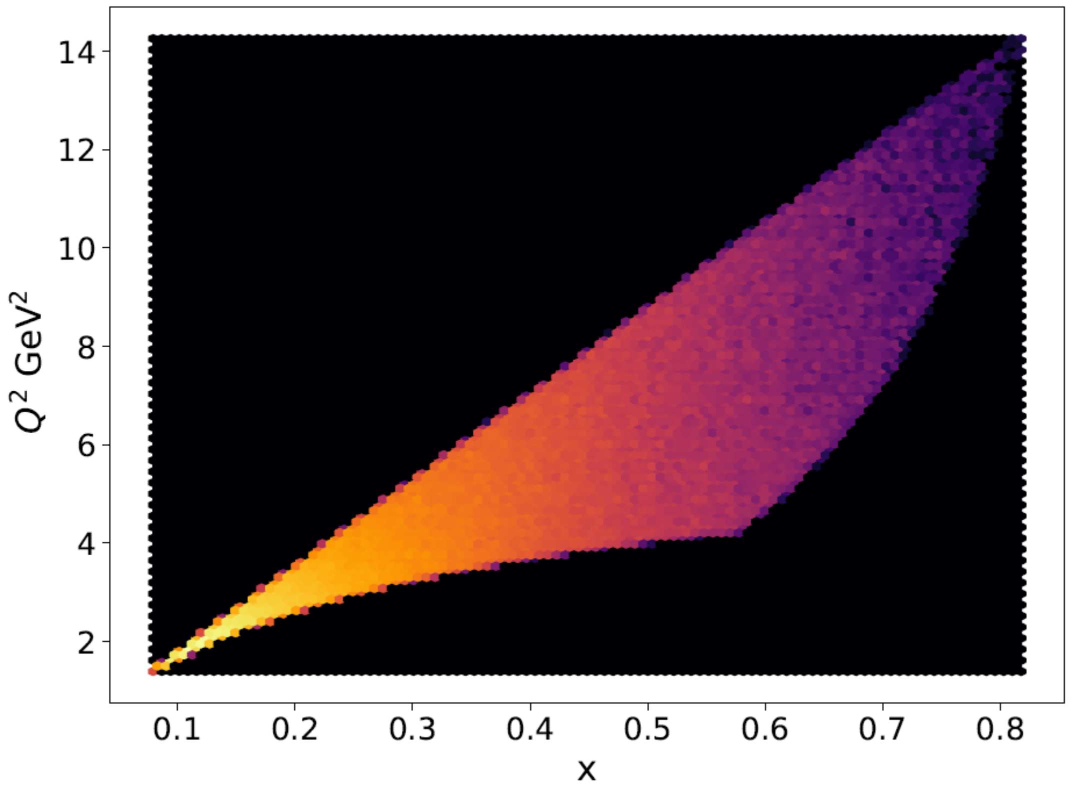
http://jetscape.org/



they do not shy away from fixed-target energies: (early work)

CLAS12 covers terra incognita





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