Flavor and Spin Effects in Anti-Shadowing

Will Brooks

Workshop on

Science at Mid x: Anti-shadowing and the Role of the Sea

July 23, 2022

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UNIVERSIDAD TECNICA FEDERICO SANTA MARIA

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Outline

- “Polarized EMC effect” and…
- **Modification of spin structure functions in the antishadowing region (main topic)**
- Multidimensional hadronization analysis of heavy flavor meson production from nuclei

The EMC Effect in Spin Structure Functions

https://www.jlab.org/exp_prog/proposals/14/PR12-14-001.pdf

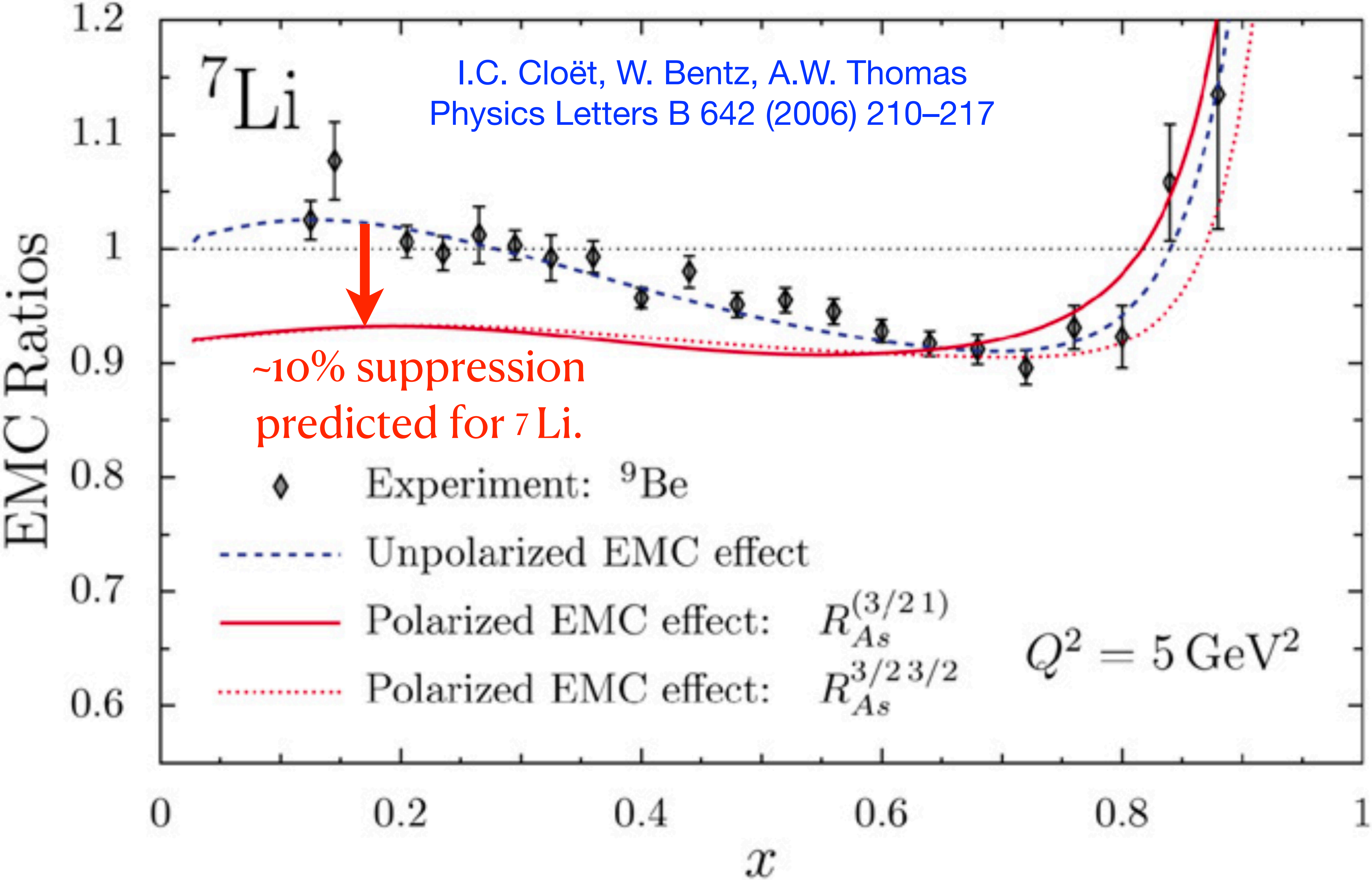
S. Kuhn, W. Brooks

It has been known for more than 35 years that the basic structure functions of protons and neutrons are modified inside nuclei. This has been observed in many measurements over the decades, including recent experiments at JLab. However, ***no experiment has ever searched for this effect in the spin structure functions***.

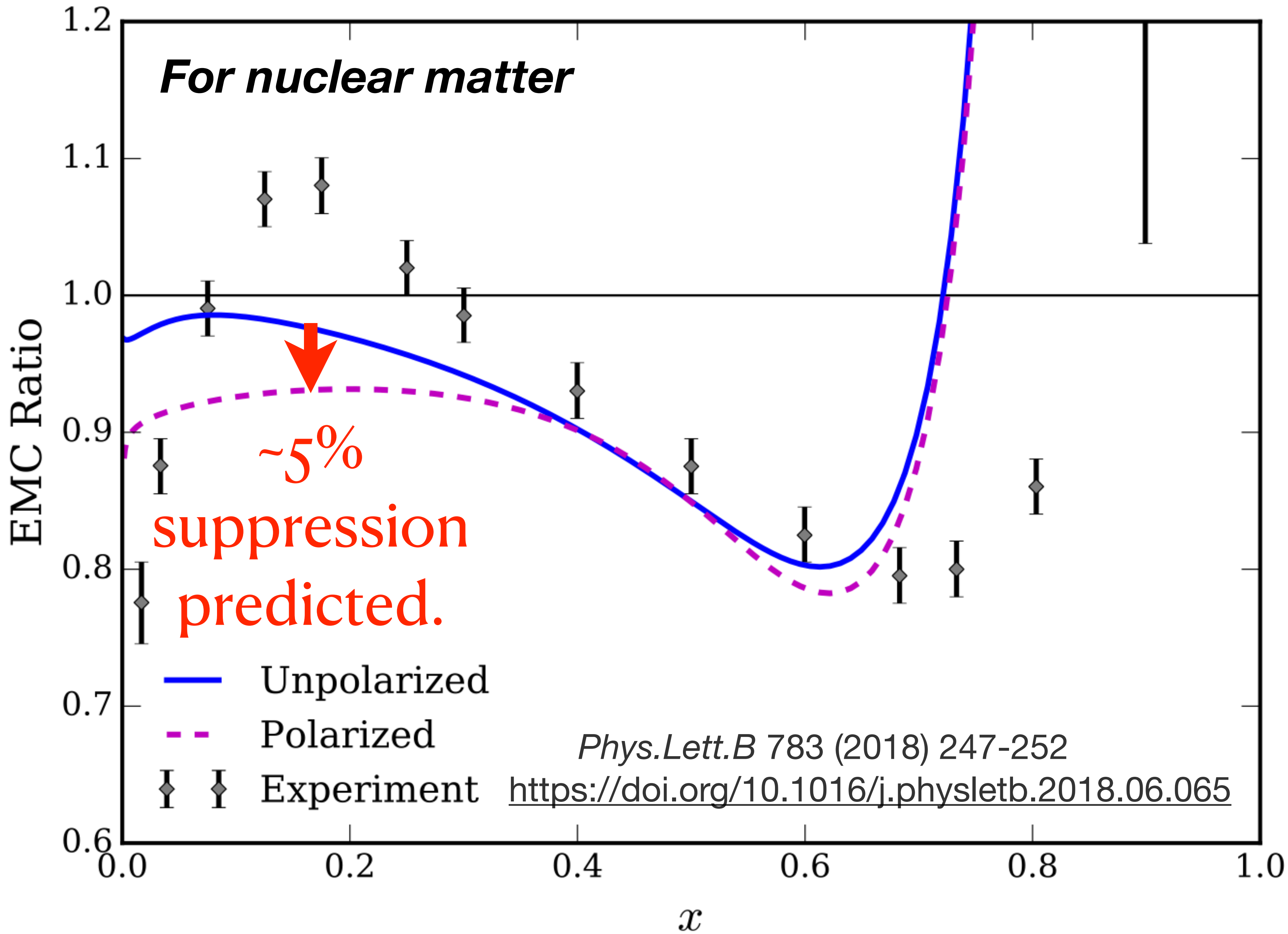
We can repeat this study at 20+ GeV. But, this talk is supposed to be about things that are completely **new**. That would be:

Modification of Spin Structure Functions in the Antishadowing Region! MSA? MoSSFAR?

Theory results in the antishadowing region



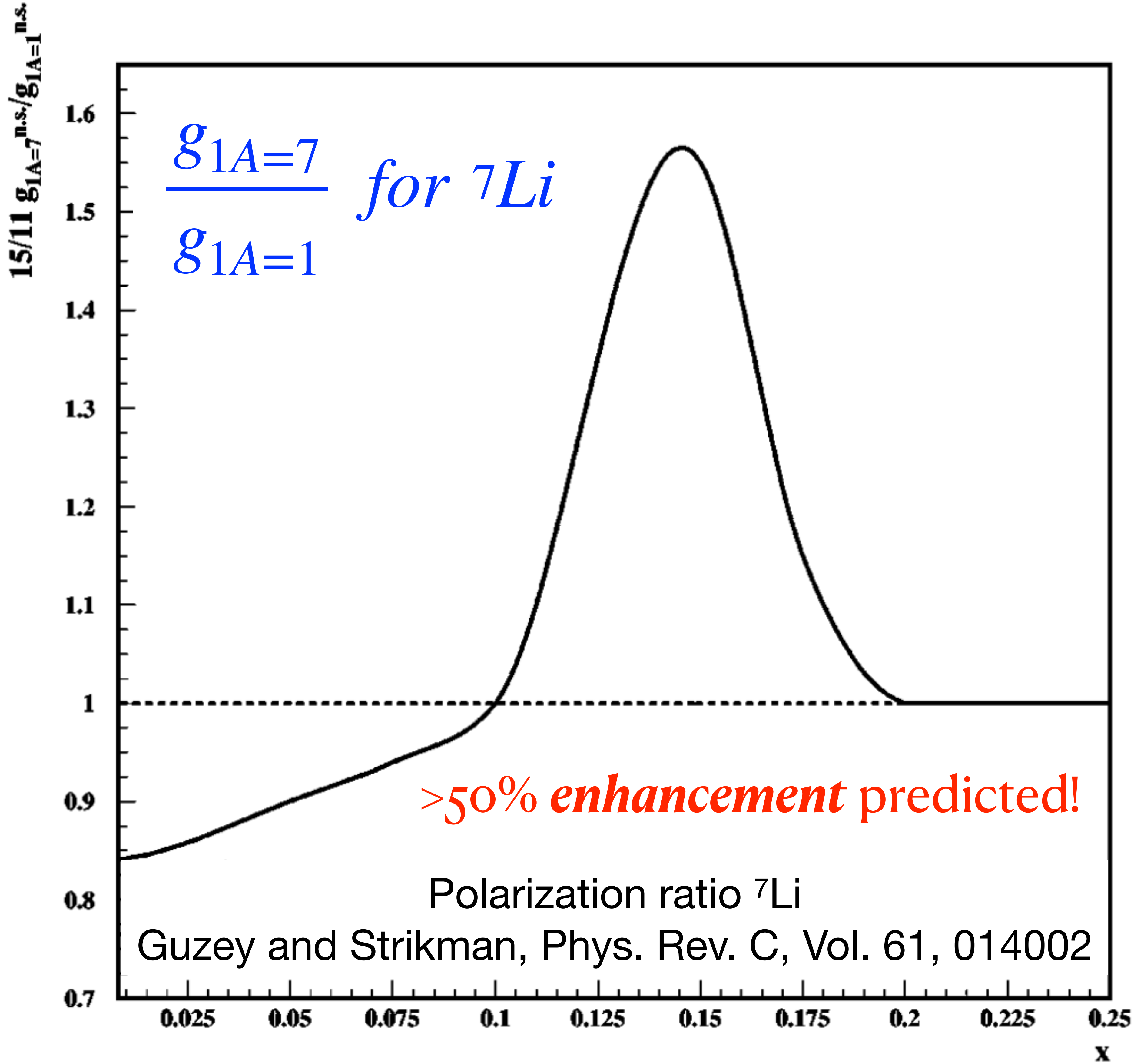
Theory results in the antishadowing region



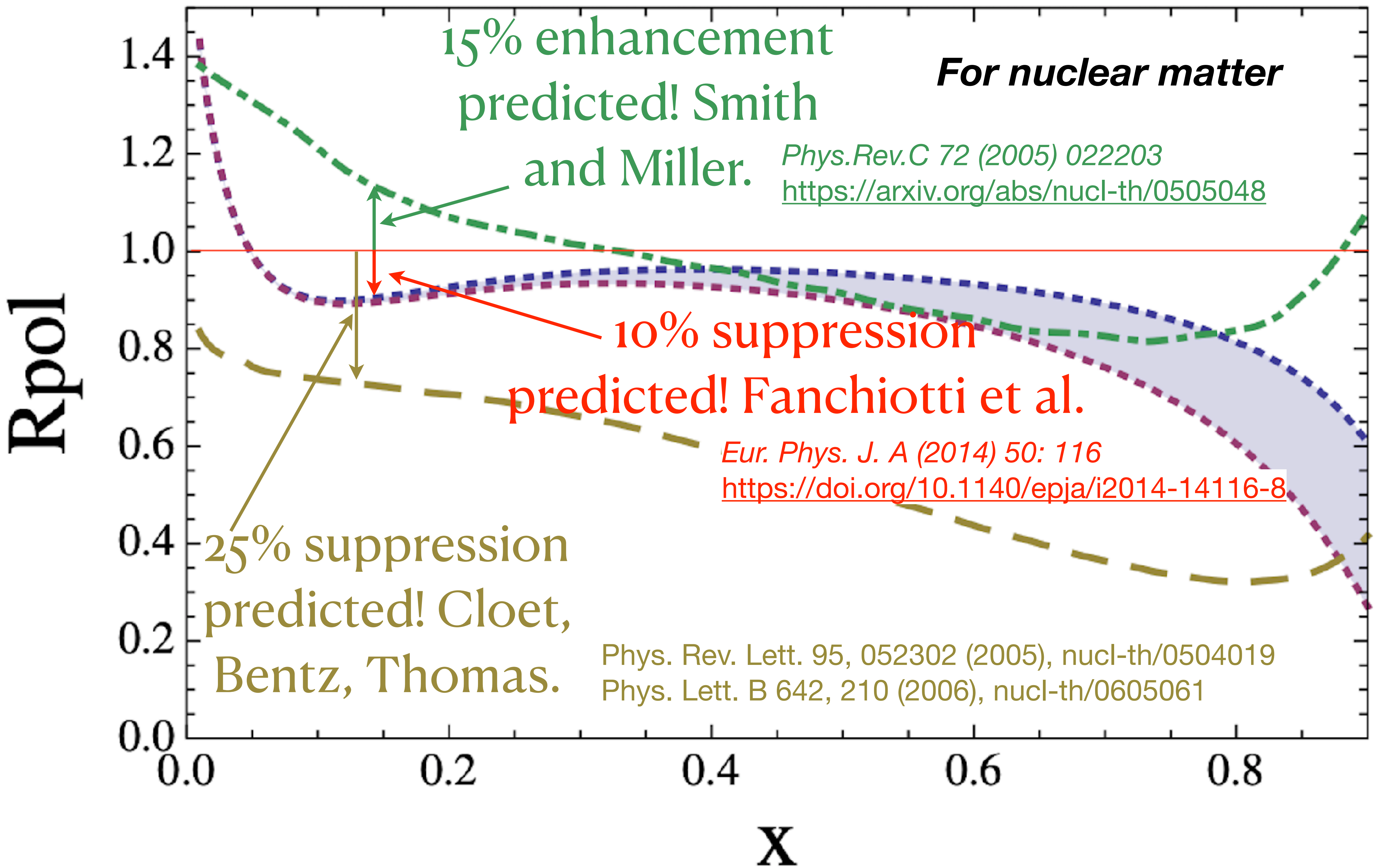
Unpolarized (blue solid line) and polarized (purple dashed line) EMC effect in the QMC model. The results are evolved to $Q^2 = 10\ GeV^2$.

Stephen Tronchin, Hrayr H. Matevosyan, Anthony W. Thomas

Theory results in the antishadowing region



Theory results in the antishadowing region



Huner Fanchiotti, Carlos A. García Canal, Tatiana Tarutina, and Vicente Vento

To first approximation, the study of MSA at 22 GeV could use the same target and same techniques as the Polarized EMC Effect experiment, just at lower x_{Bj}. For now I assume that is true, but, to be explored:

- The CLAS12 polarized target requires rastering to avoid local depolarization. The 22 GeV beam will presumably have a bigger spot size at the target location (experts should comment). Perhaps it will be half a millimeter sigma? Maybe the bigger spot size will actually be beneficial in terms of reducing local heating.
- The vertex resolution needs to be good enough to separate scattering from the two target cells (to be described later).
- To use the full CLAS22 luminosity of 1E37 is a challenge. More on this later.

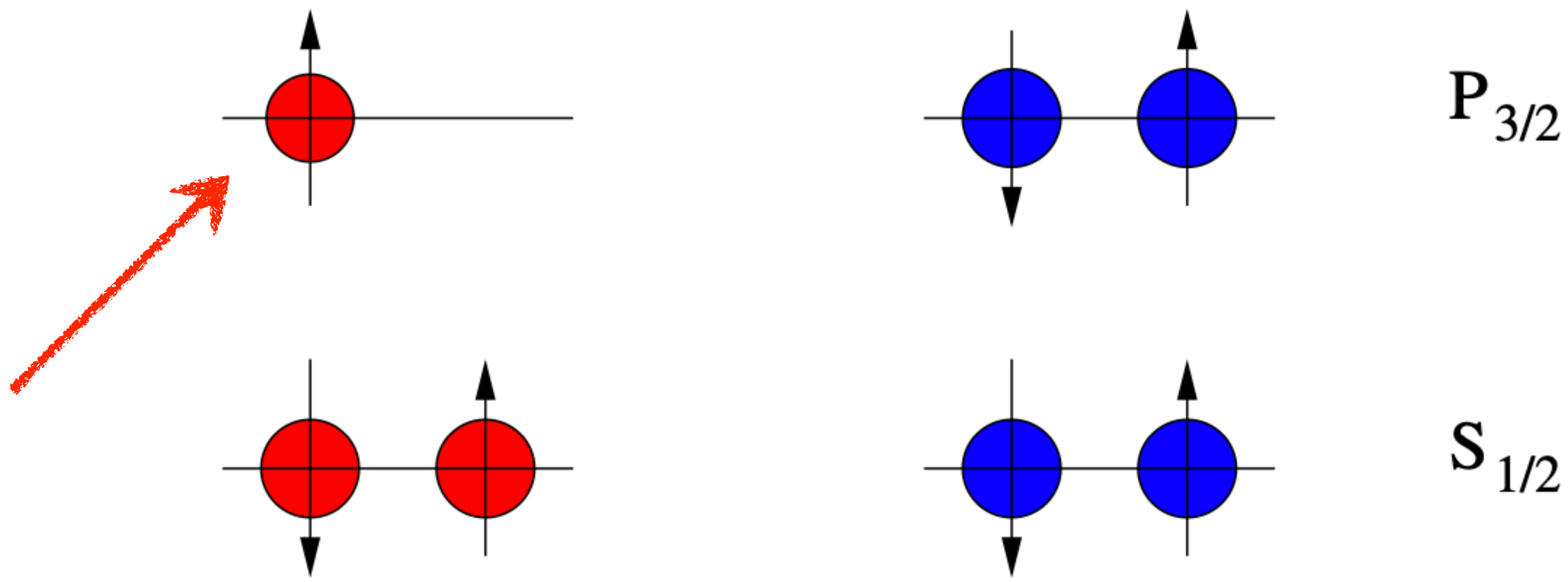
The strategy

We chose the nucleus ^{7}Li because of its unique nuclear structure. In polarized ^{7}Li, **one proton** carries **nearly all of the polarization**. Thus it is a polarized proton embedded in a nuclear medium.

We chose to have two target cells, in order to gain best control of systematic uncertainties by having polarized ^{7}Li and polarized H simultaneously.

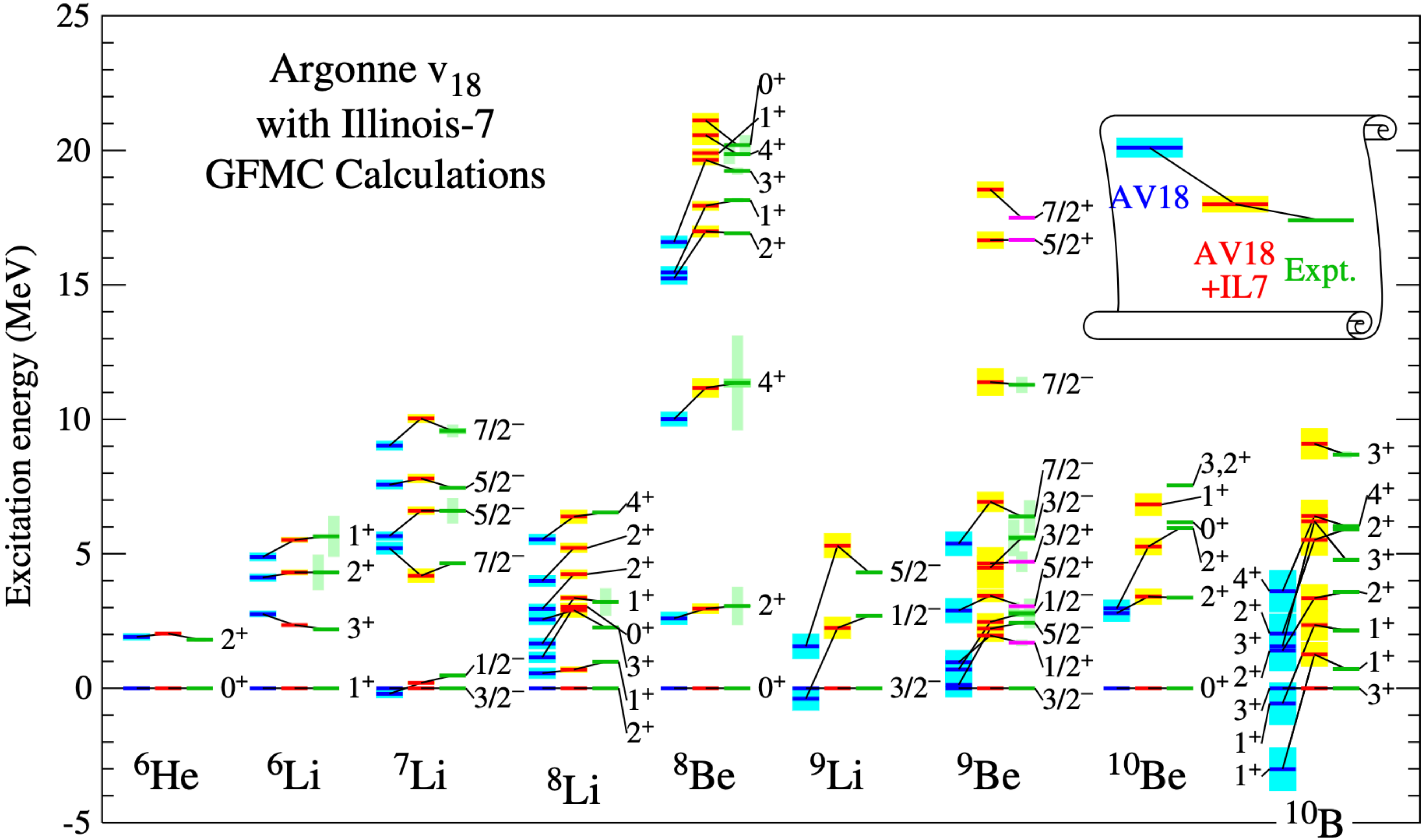
We take advantage of 99% of existing polarized target infrastructure for CLAS12. The polarized target will be scheduled for installation at 22 GeV.

Shell model picture of ^{7}Li



86.6% of the ^{7}Li nuclear polarization is carried by the unpaired proton.

This result is quantitatively confirmed by detailed Green Function Monte Carlo calculations.



GFMC excitation energies of light nuclei for the AV18 and AV18 + IL7 Hamiltonians compared to experiment.

[REVIEWS OF MODERN PHYSICS, VOLUME 87, JULY–SEPTEMBER 2015, p. 1067]

Target sample considerations

To reduce systematic uncertainties, we measure polarized ^{6}LiH and ^{7}LiD simultaneously in two separate cells.

Max Thickness: 2% of X_0: 0.02*97 cm = 2 cm = **160 g/cm^2**

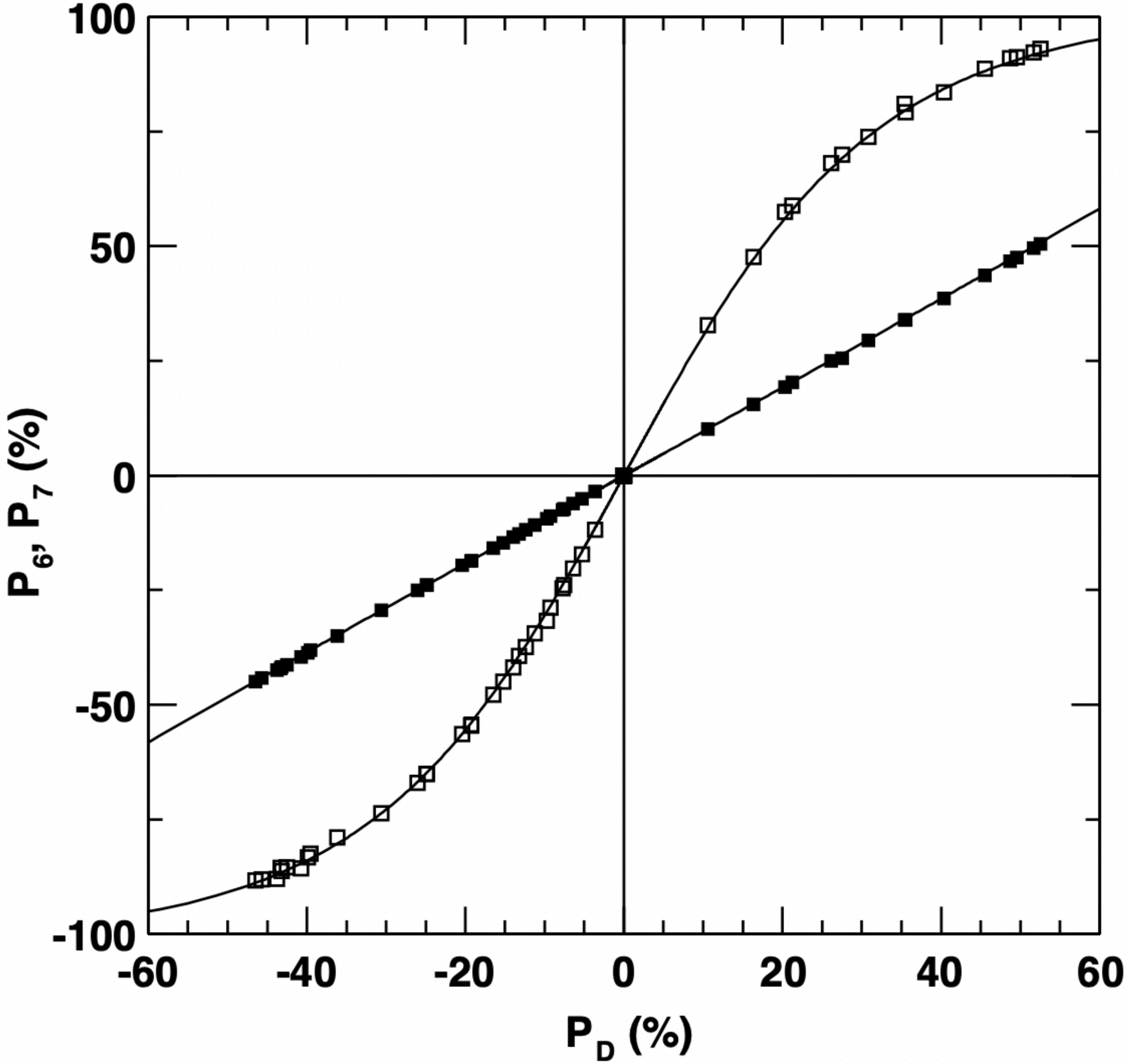
(Compare ammonia: 5 cm*0.82 g/cm^3 = 4 g/cm^2)

Chris Keith: radiation resistance of ^{7}Li not well known, but ^{6}Li is is 2-5 times more radiation resistant than NH_3.

At 2 MeV/(g/cm^2), power deposit in a LiH target of 160 g/cm^2 with 10 nA of beam would be **3.2 W** at a luminosity of 6x10^{36} / cm^2/s.

The effects due to beam current: heating by power deposition, radiation damage, and depolarization, need to be optimized, but it seems likely a favorable combination could be found.

E.g., **1 cm, 5 nA, 1.5x10^{36} /cm^2/s**, seems feasible.



Relationship between the measured polarizations of ^{7}Li (open symbols) and ^{6}Li relative to deuterium as found by COMPASS Collaboration. Lines are Equal Spin Temperature calculations.

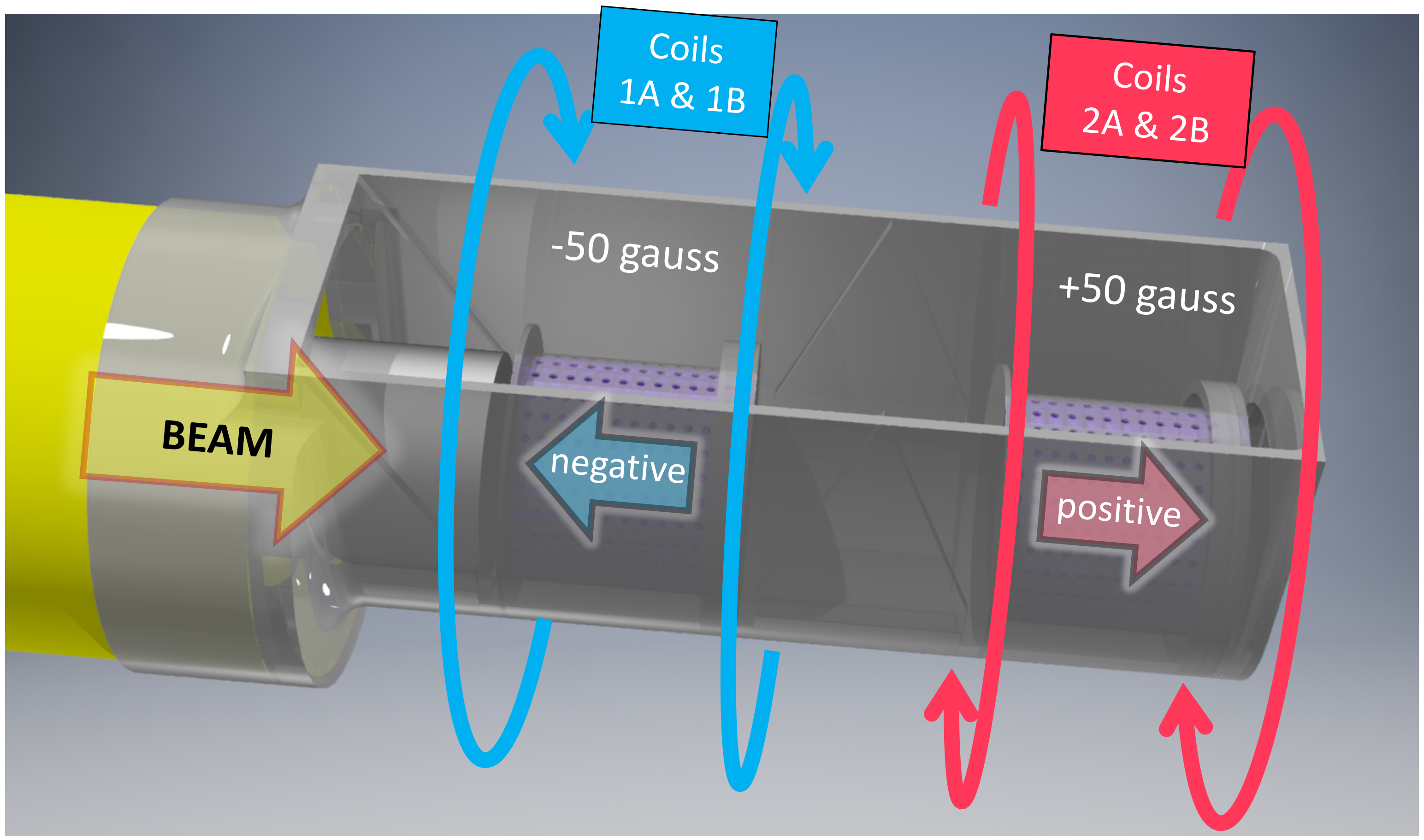
Double-cell Polarization

Can we polarize two samples at once, in opposite directions?
Small coils inside target cryostat shift the 5 T polarizing field:

- Upstream sample -50 gauss
- Downstream sample +50 gauss

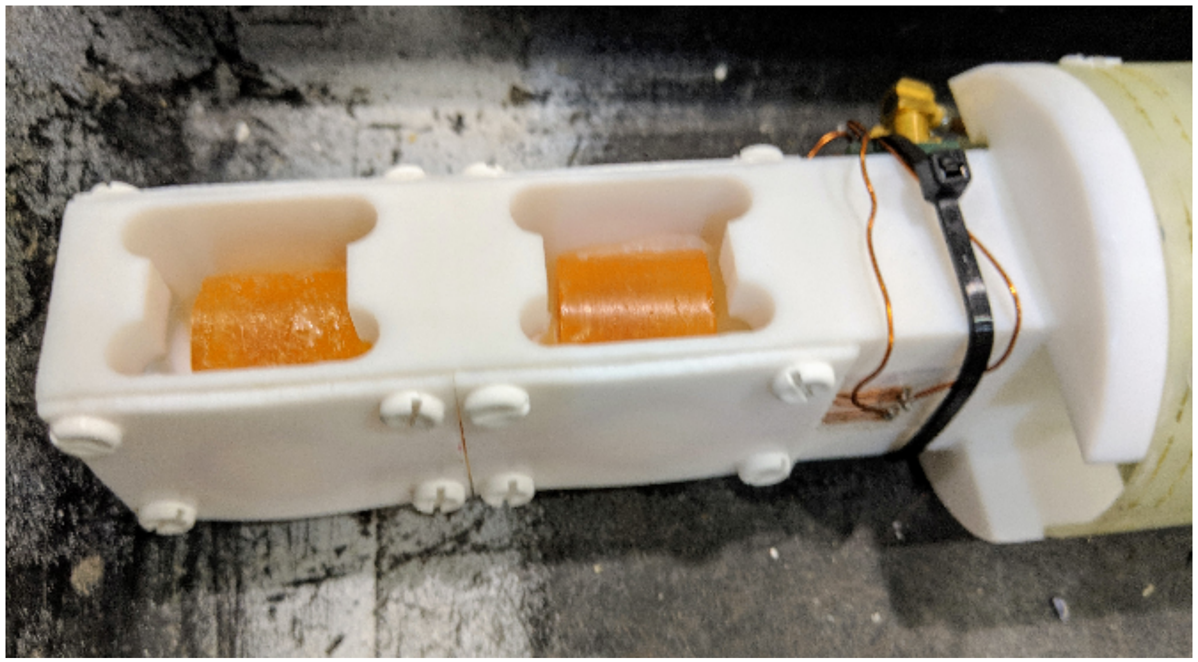
Microwave frequency halfway between the normal (+) and (-) polarization frequencies:

- ➢ high field sample will polarize (+)
- ➢ low field sample will polarize (-)

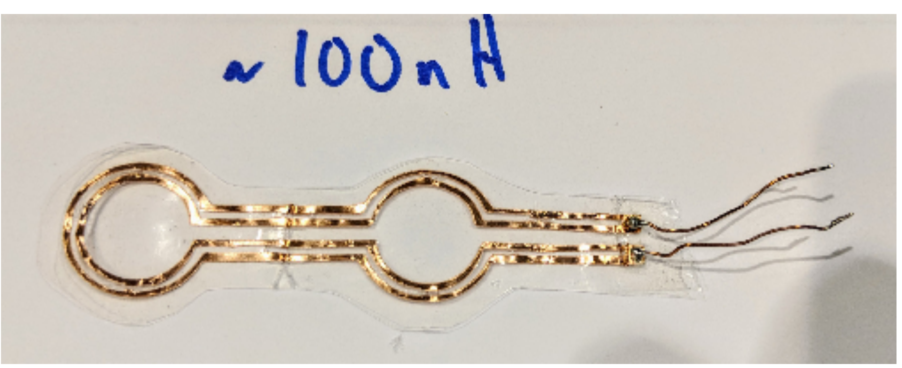


Double-cell Polarization

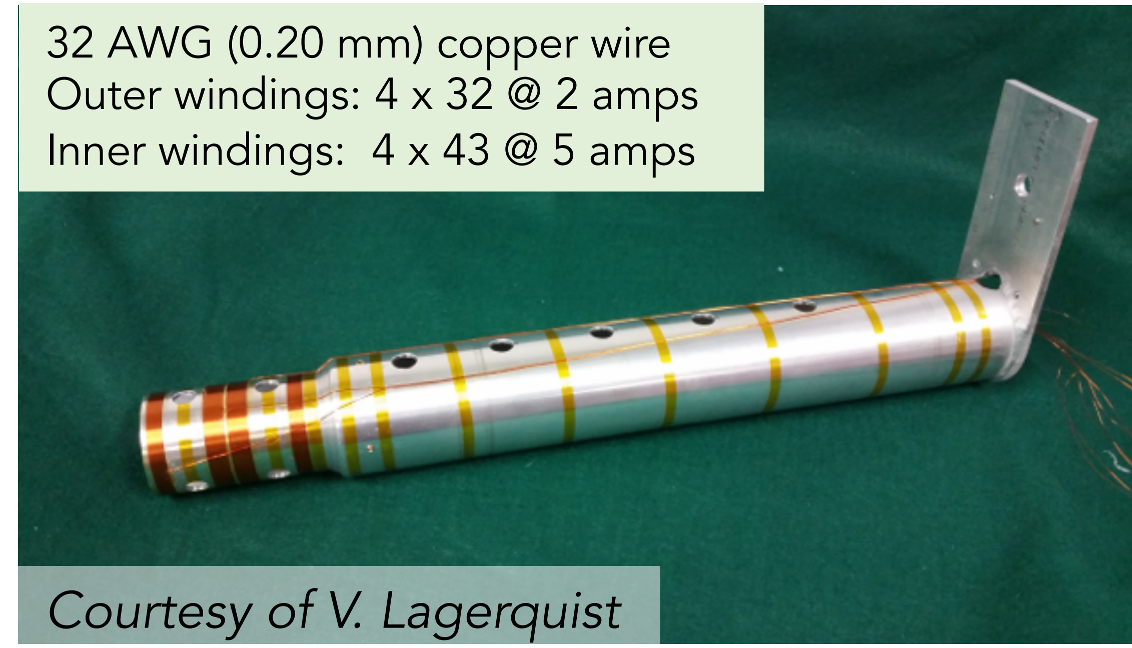
Proof-of-principle tests performed at 77 K and 5 T using TEMPO-doped polymer



Courtesy of J. Maxwell



- Two samples
- One NMR coil

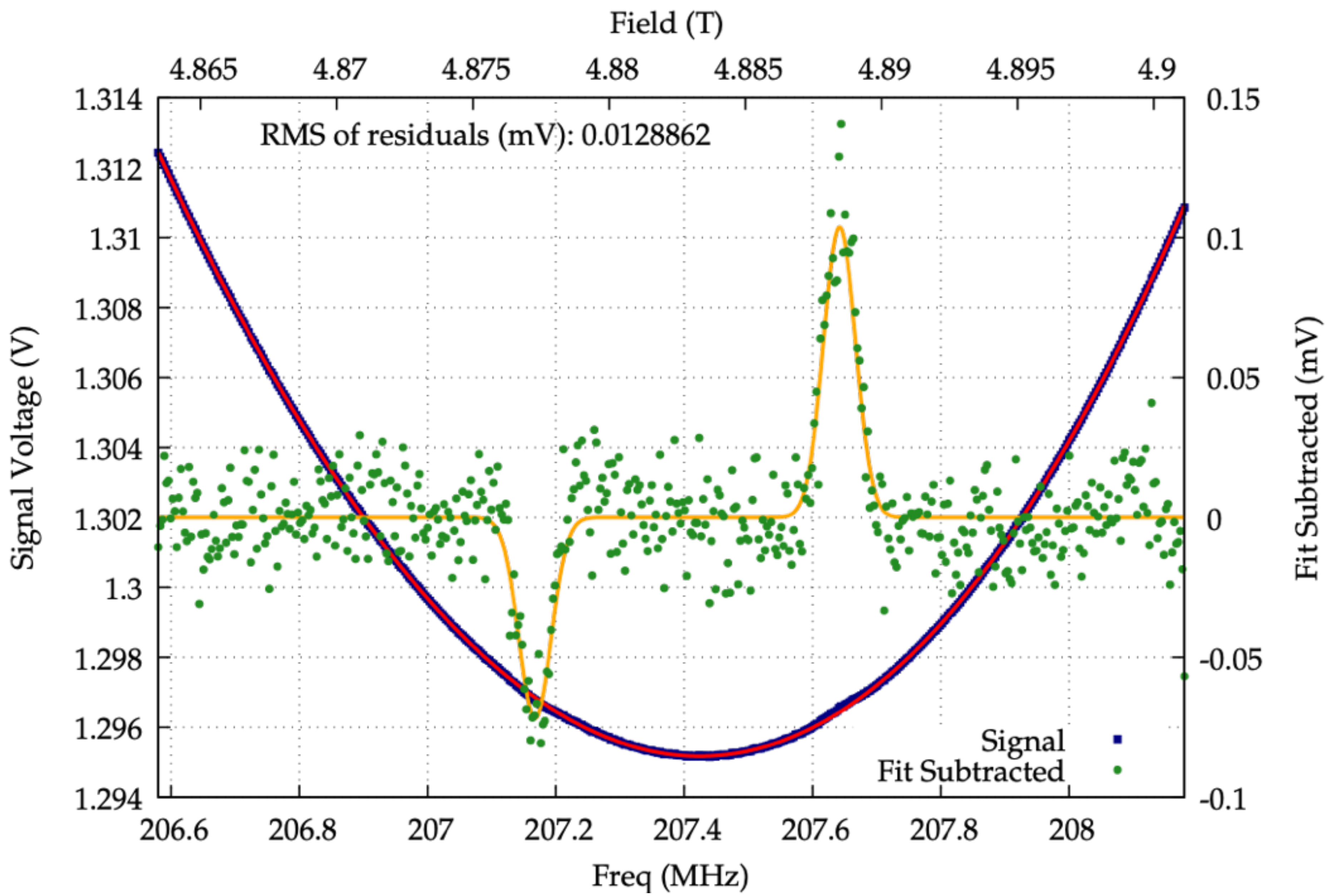


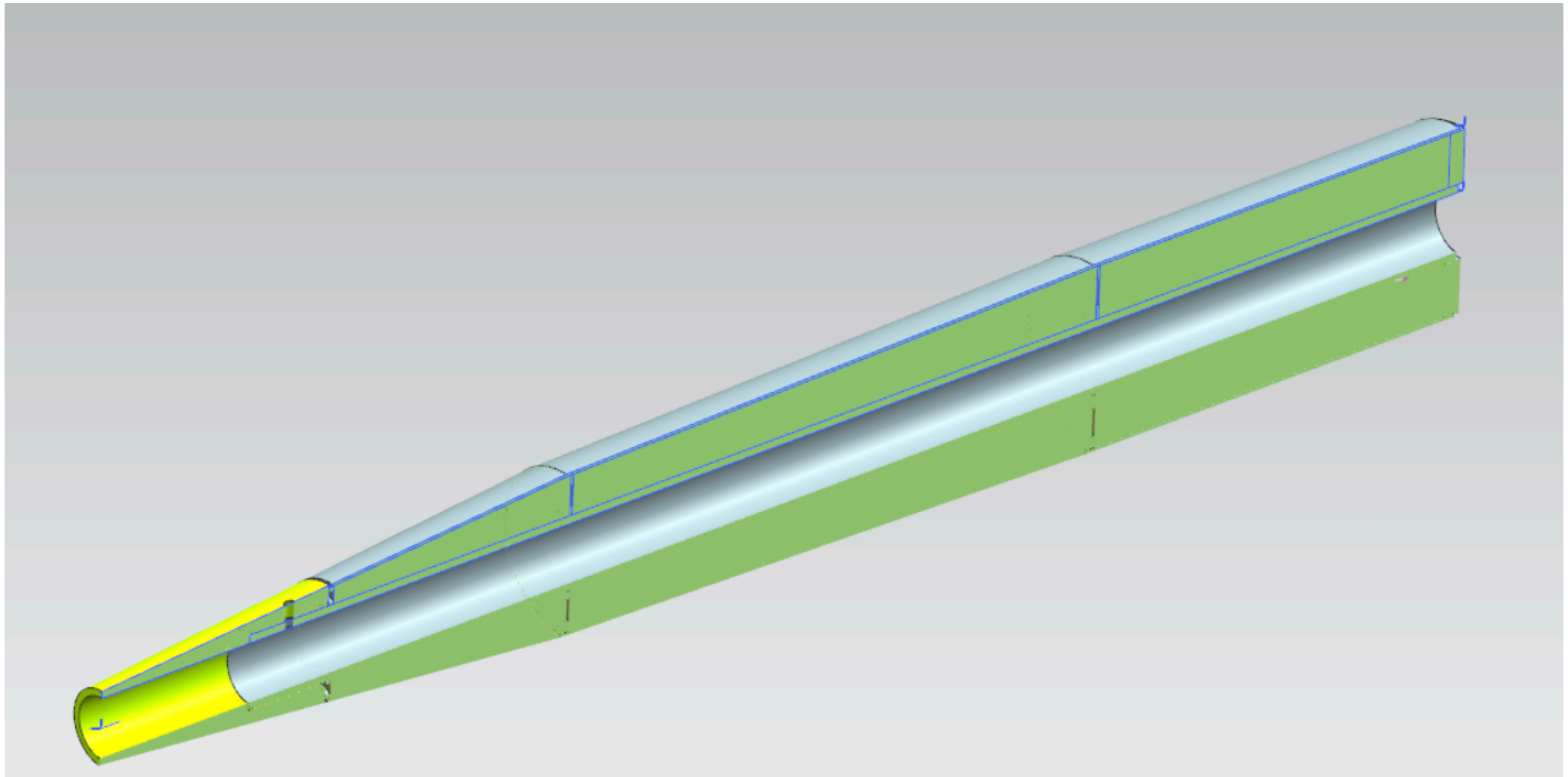
5 T solenoid used for FROST

Double-cell Polarization

Proof-of-principle tests performed at 77 K and 5 T using TEMPO-doped polymer

Success!



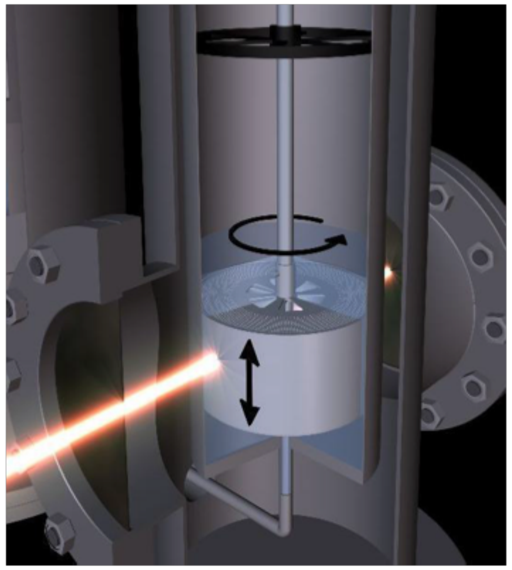


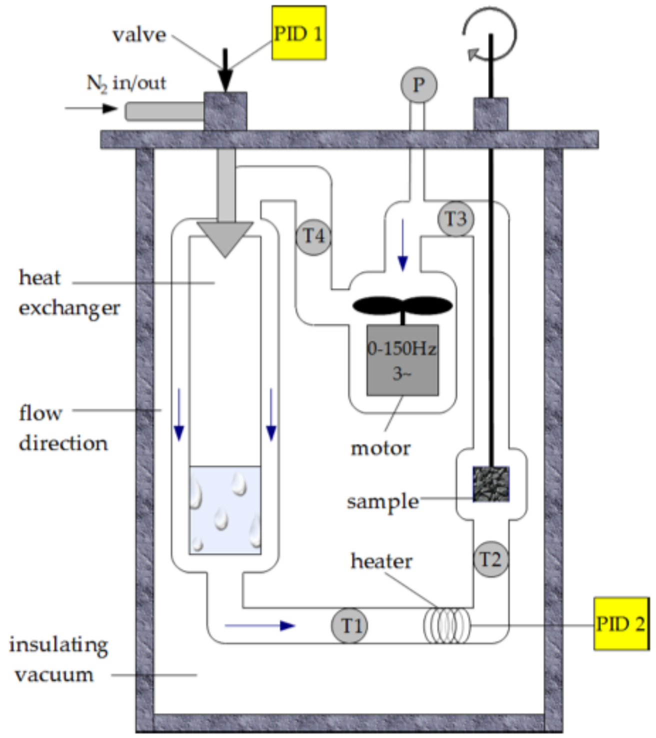
- New tungsten Møller electron shield for use with rastered beam on a polarized target.
- Optimized to contain the electromagnetic background produced by the electron beam as far as 1 cm off the nominal beam axis, to accommodate rastering.
- RG-G will use a configuration with the Forward Tagger (FT) removed and this new Møller shield installed, to be able to run with the highest luminosity possible.

DNP of Lithium Hydride

Under 1K/5T conditions, 7Li has been polarized to about 80% and 6Li to 30%.

Optimal polarization requires pre-irradiating the samples in a narrow temperature band around 185 K.





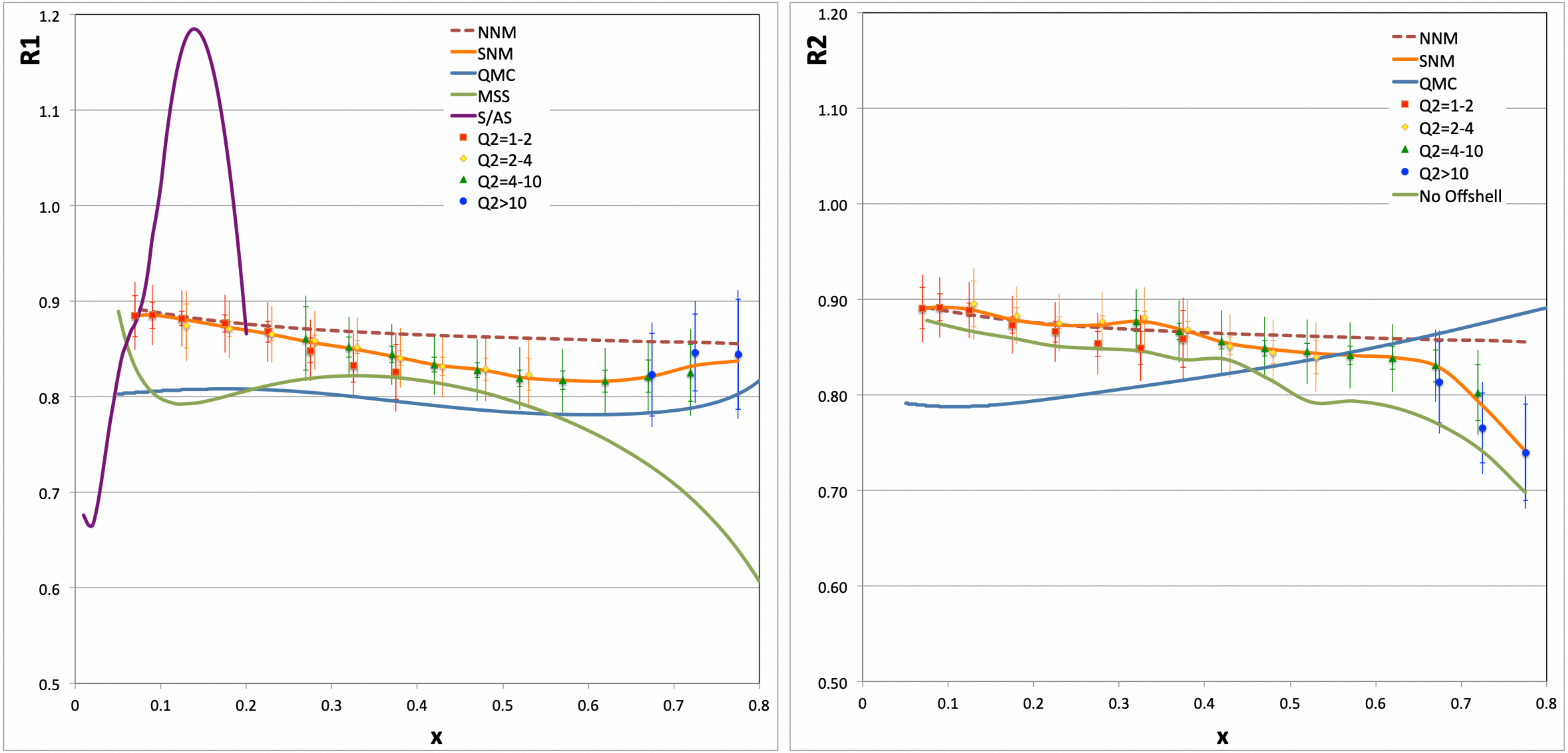
This can be performed at the UITF, using a custom-built, variable-temperature irradiation cryostat.

Photos and drawings: Scott Reeve, U. Bonn.

Upgrade Injector Test Facility: UITF at JLab

See X. Li et al., NIM A Volume 1039, 11 September 2022, 167093.

Anticipated Uncertainties (representative, from pEMC)



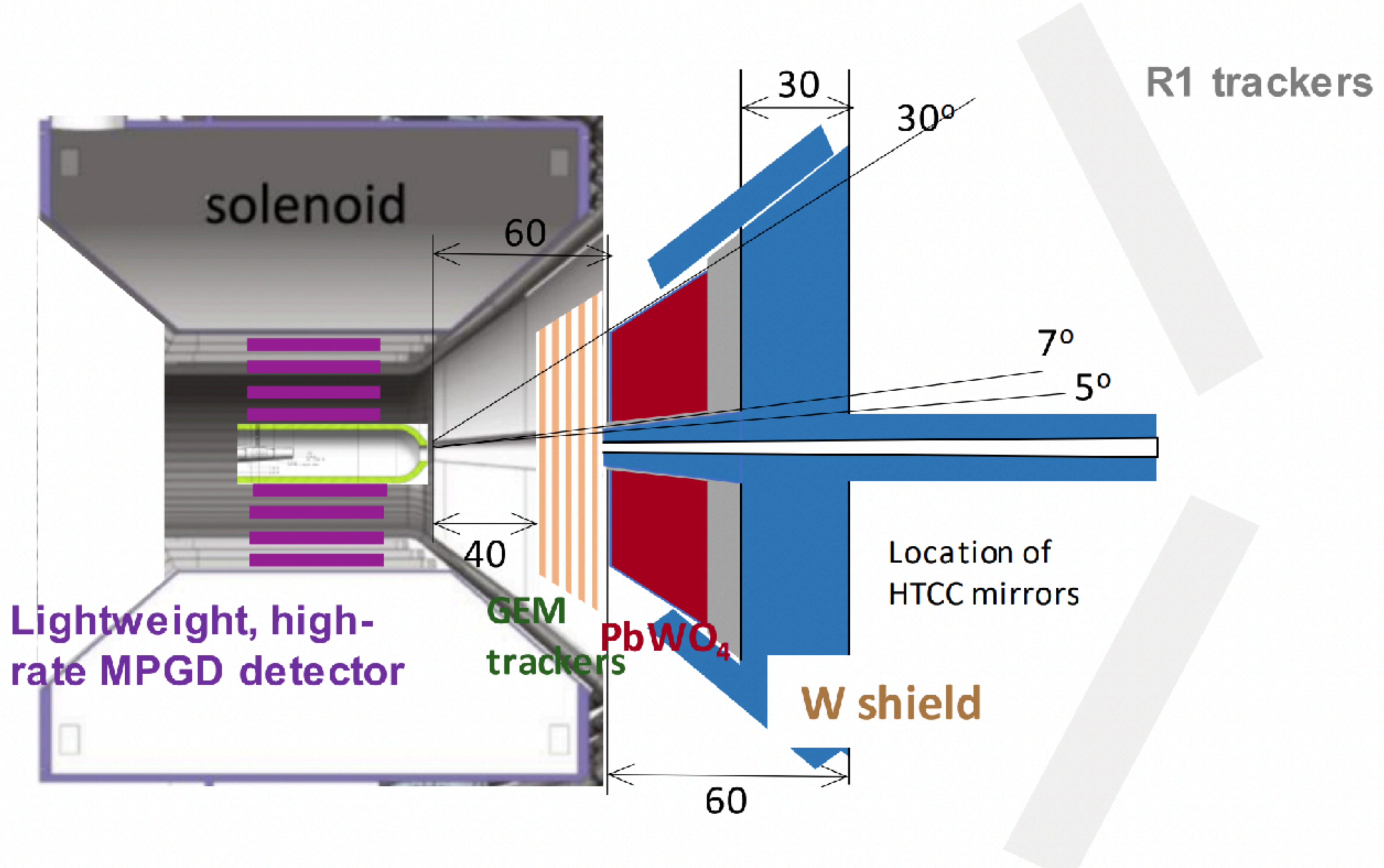
Ratio R_1 of cross section differences for double polarized ^{7}Li(e,e') over p(e,e') for several different models. Ratio R_2 of the parallel double spin asymmetry $A_{||}$ for ^{7}Li(e,e') over p(e,e), normalized by "naïve " unpolarized structure function ratio for ^{7}Li over hydrogen.

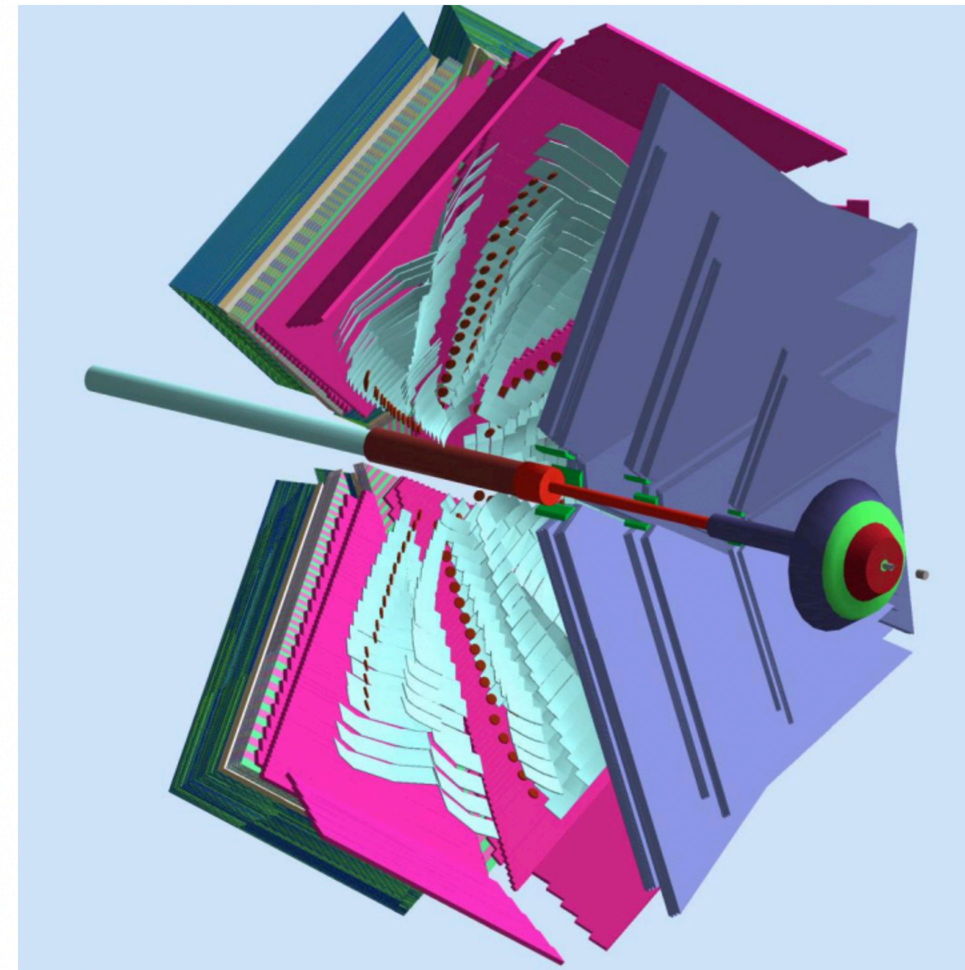
(NNM = naïve nuclear model, SNM = standard nuclear model, QMC = Quark-meson coupling model, MSS = modified sea scheme, S/AS = shadowing/antishadowing model).

Point-to-point systematic uncertainties added in quadrature to the statistical ones (with horizontal bars). An overall scale uncertainty of about 4% is not shown.

CLAS12: intended upgrades to 22 GeV

- Near-term upgrade to double luminosity capability (~3 years)
- Longer-term upgrade to two orders of magnitude luminosity capability, enhanced PID (7-10 years)
- µRWell an enabling technology in these plans





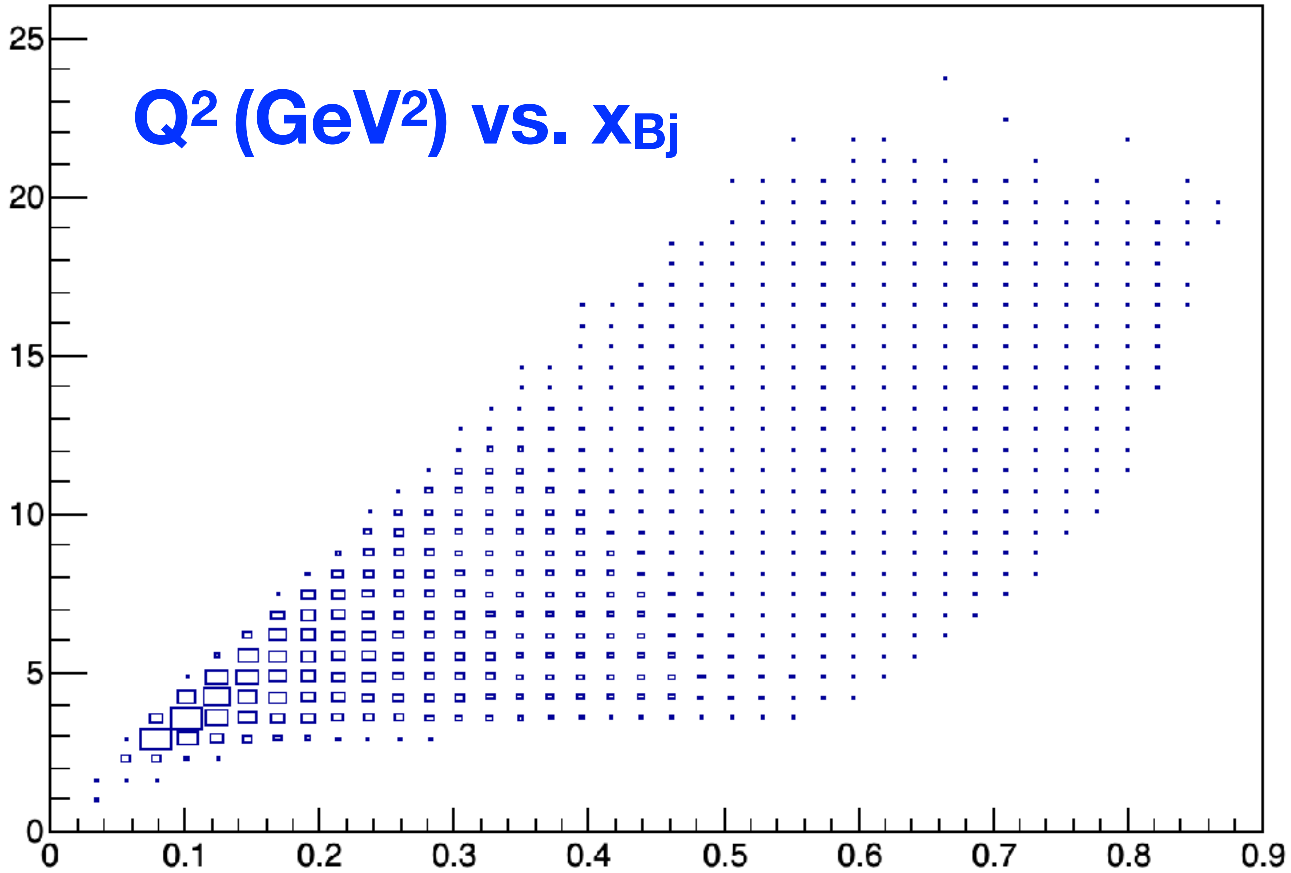
https://indico.jlab.org/event/472/contributions/9014/attachments/7329/10133/clas12_hi-lumi_collmeeting.pdf

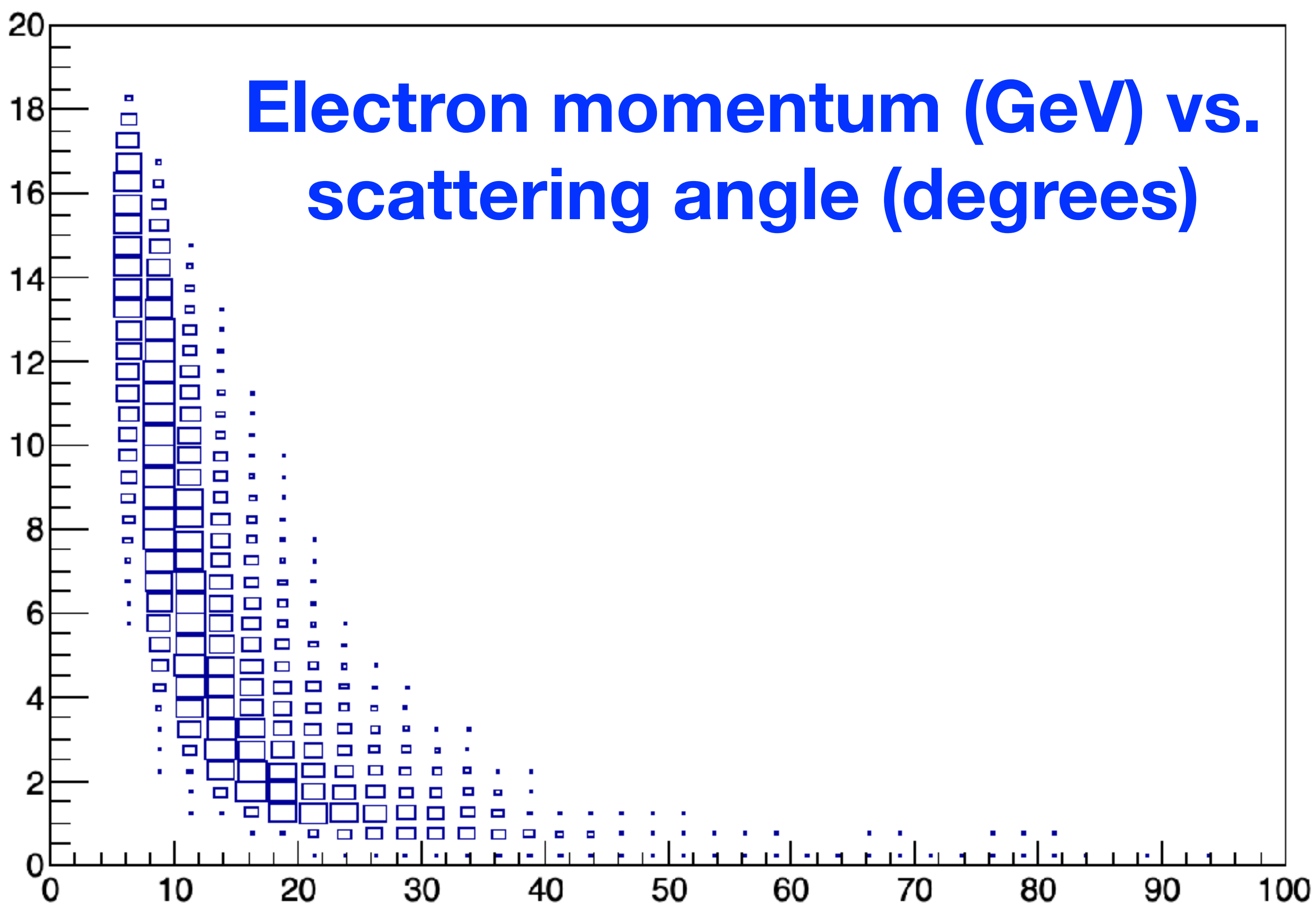
https://indico.jlab.org/event/536/contributions/9714/attachments/7952/11184/DDVCS_CLAS_Colab_June2022.pdf

22 GeV Simulations of CLAS12 with Polarized Target and Fiducial Cuts

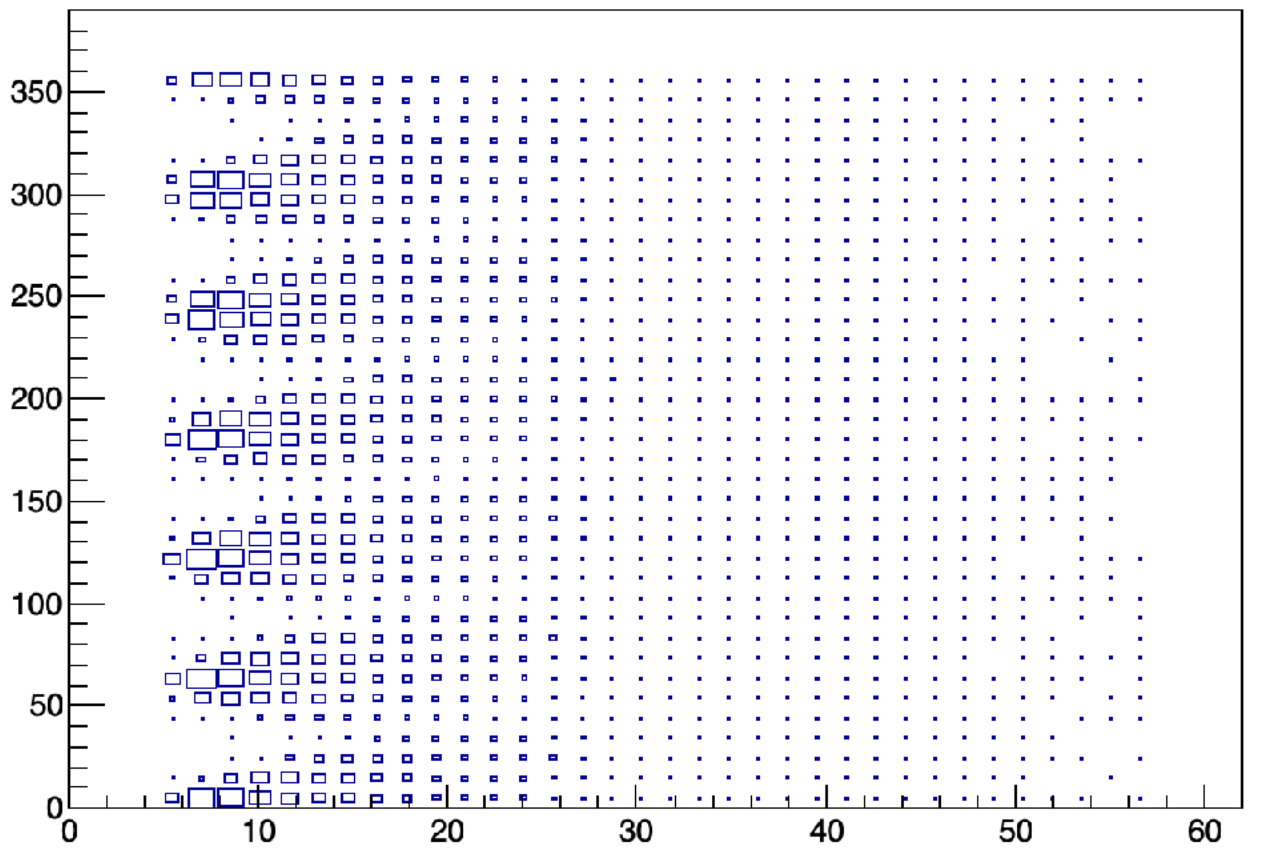
Inbending electrons

Simulation files from Harut Avakian (JLab) and Timothy Hayward (UConn)





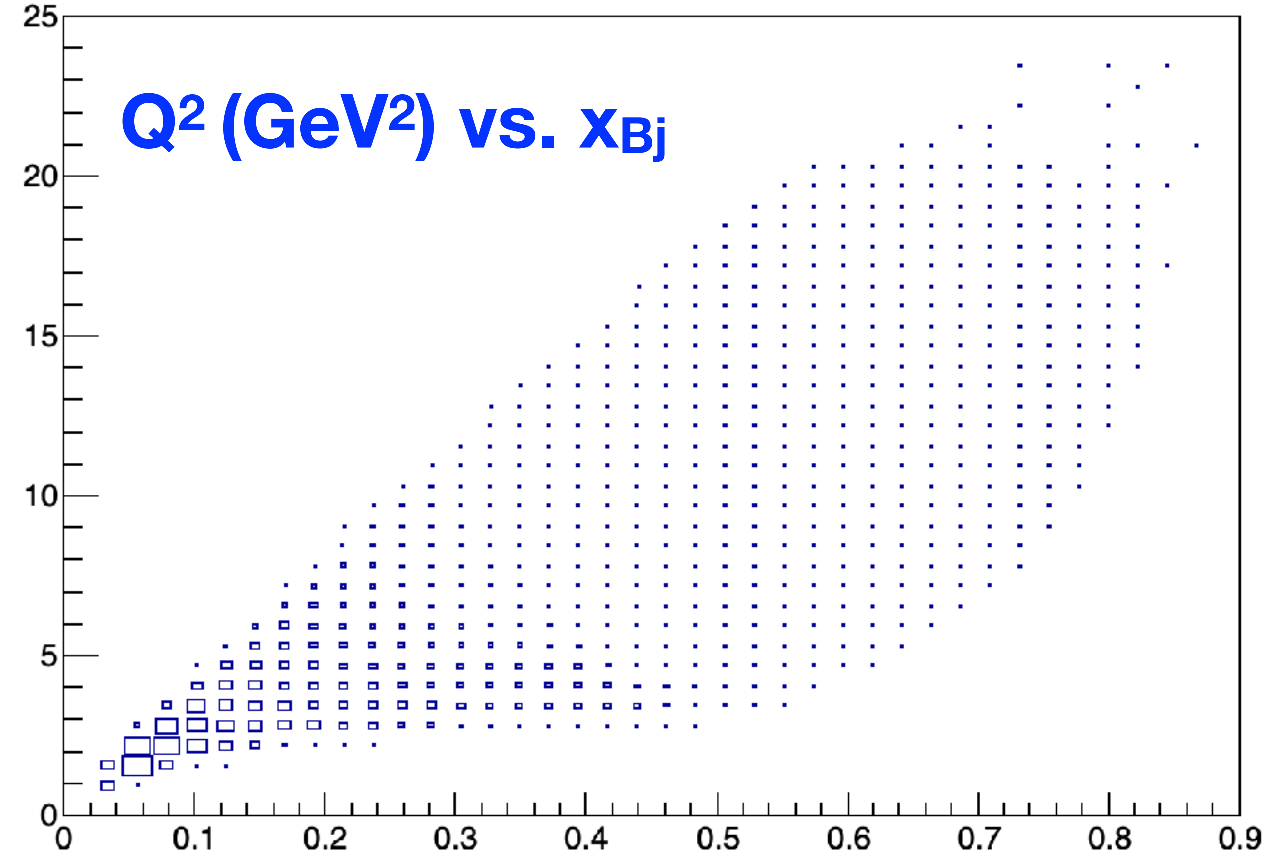
Electron azimuthal angle vs. polar angle (degrees)

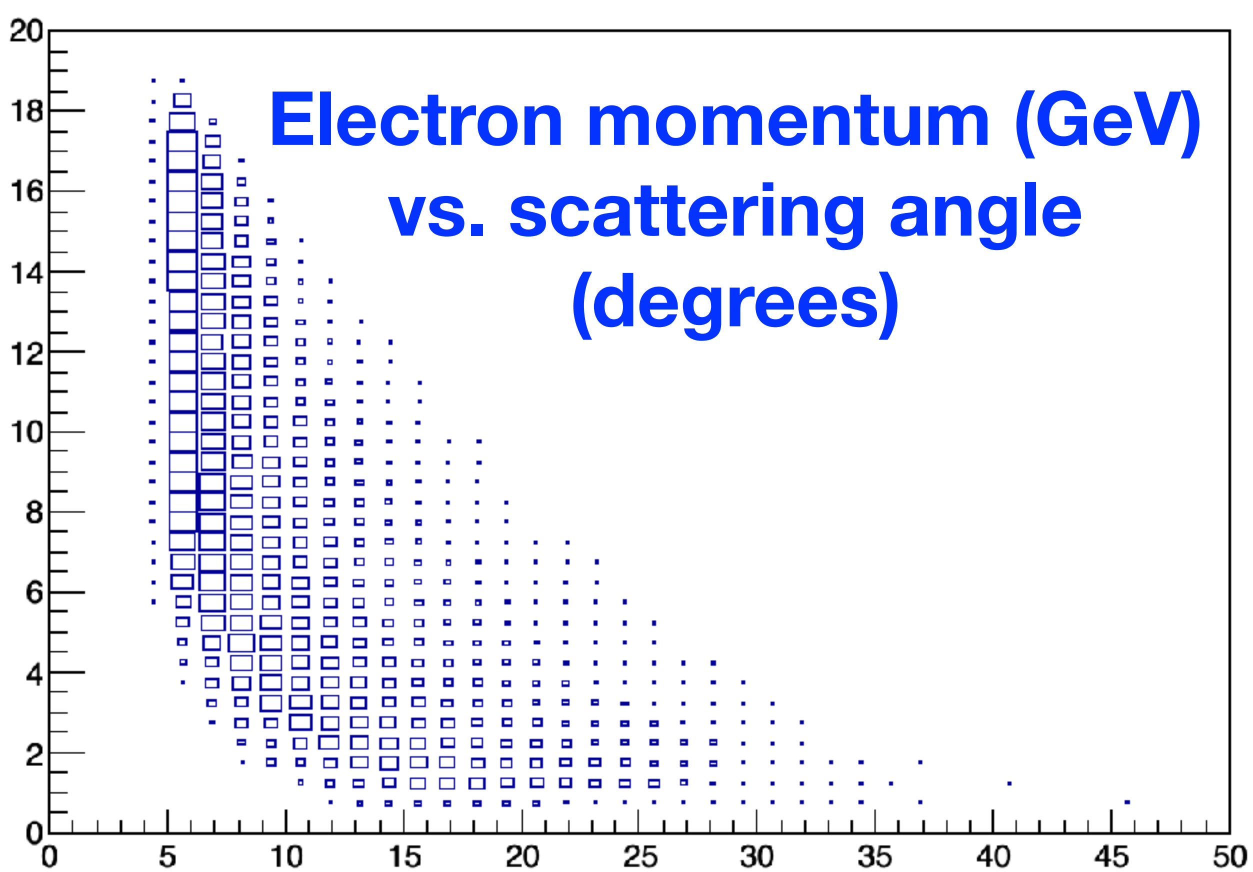


22 GeV Simulations of CLAS12 with Polarized Target and Fiducial Cuts

Outbending electrons

Simulation files from Harut Avakian (JLab) and Timothy Hayward (UConn)





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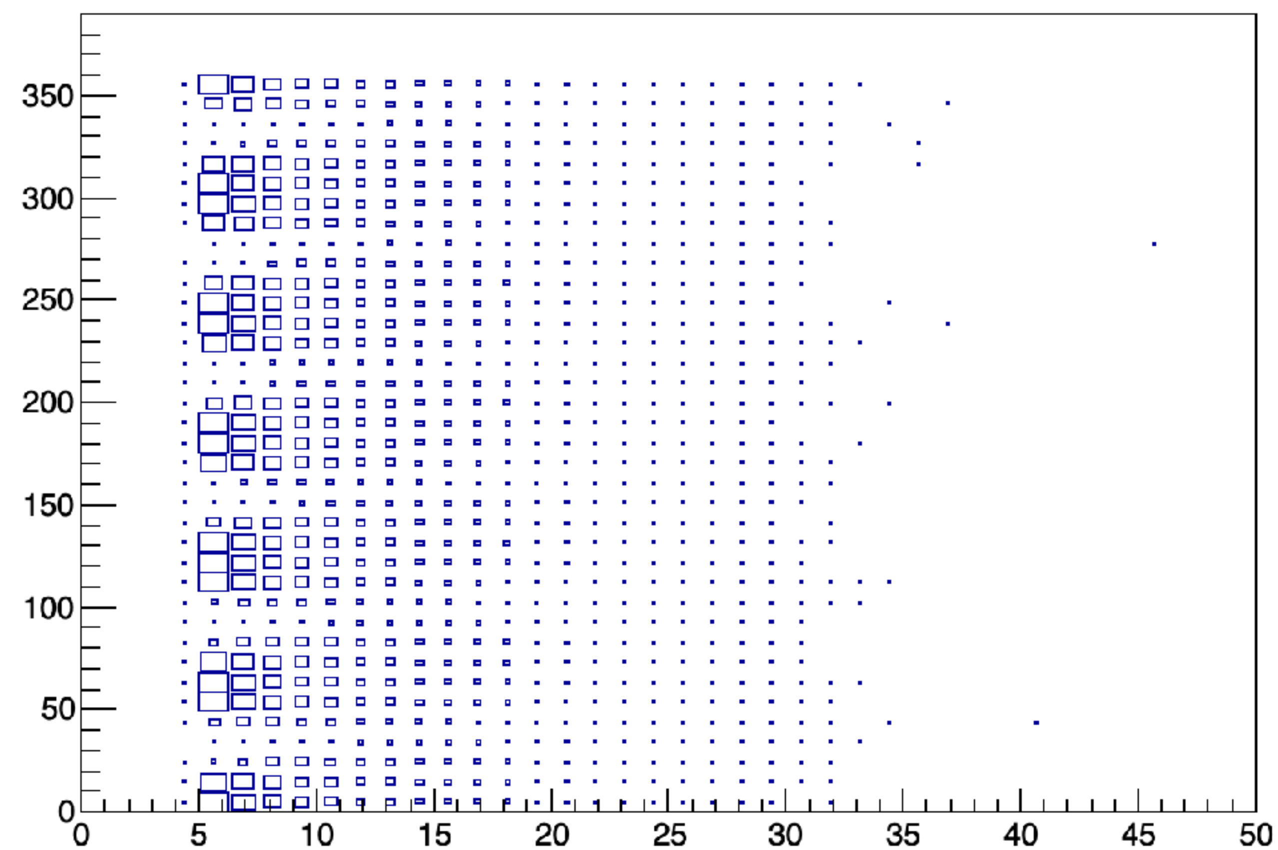
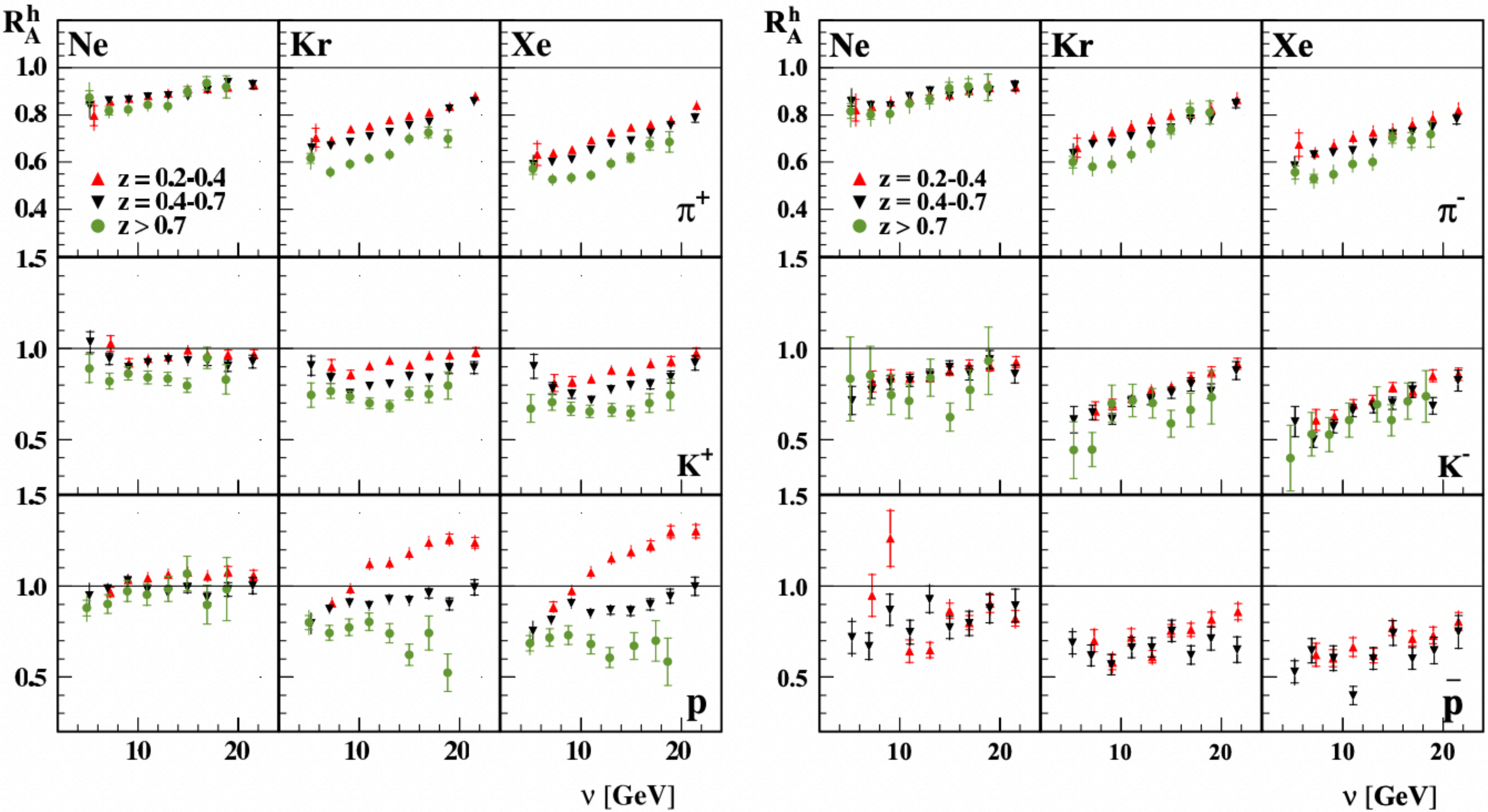


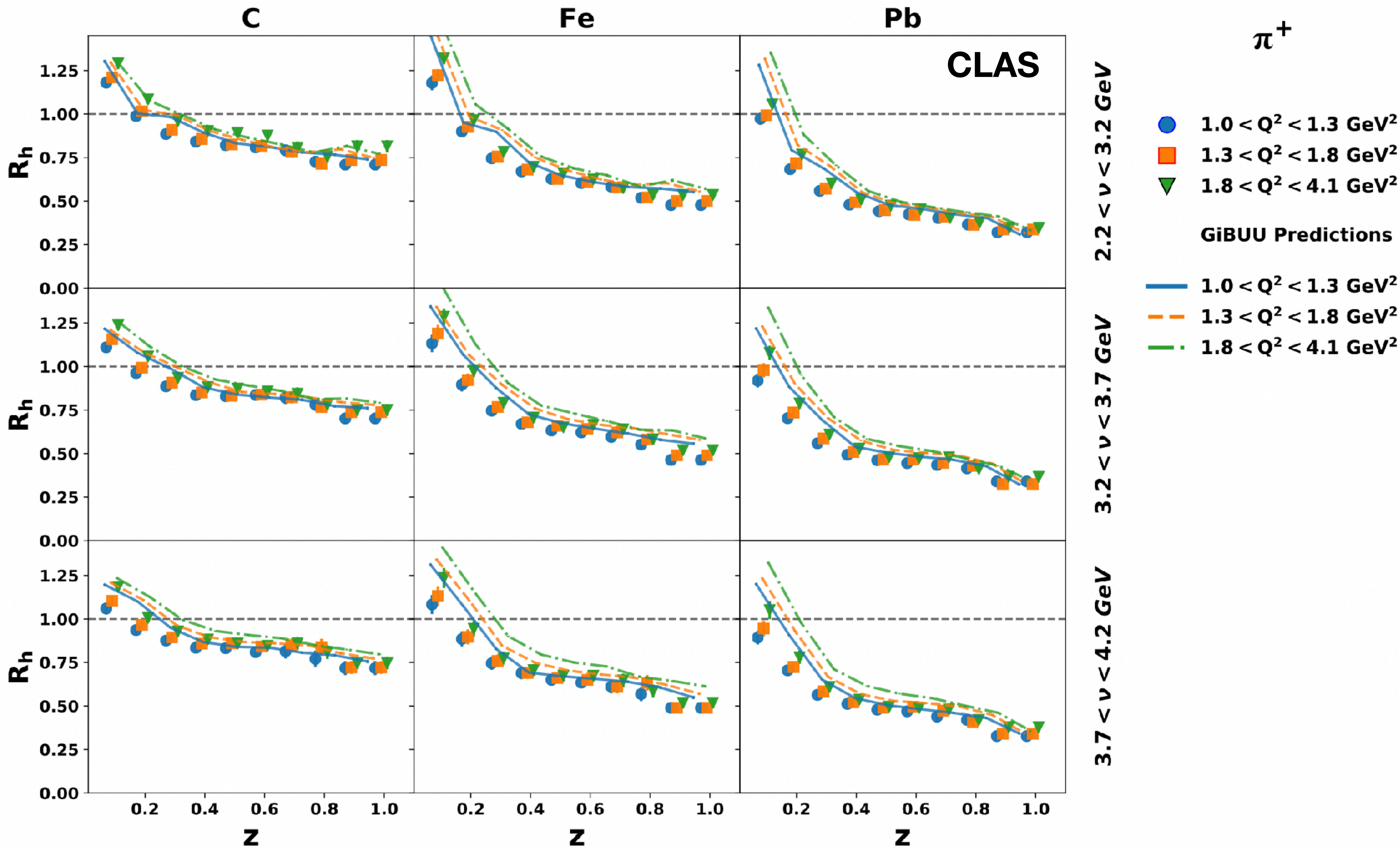
Evolution of Multidimensional Studies of Hadronization in Nuclei

Charged hadron multiplicity ratios - 2D analysis, HERMES
Eur. Phys. J. A (2011) 47: 113



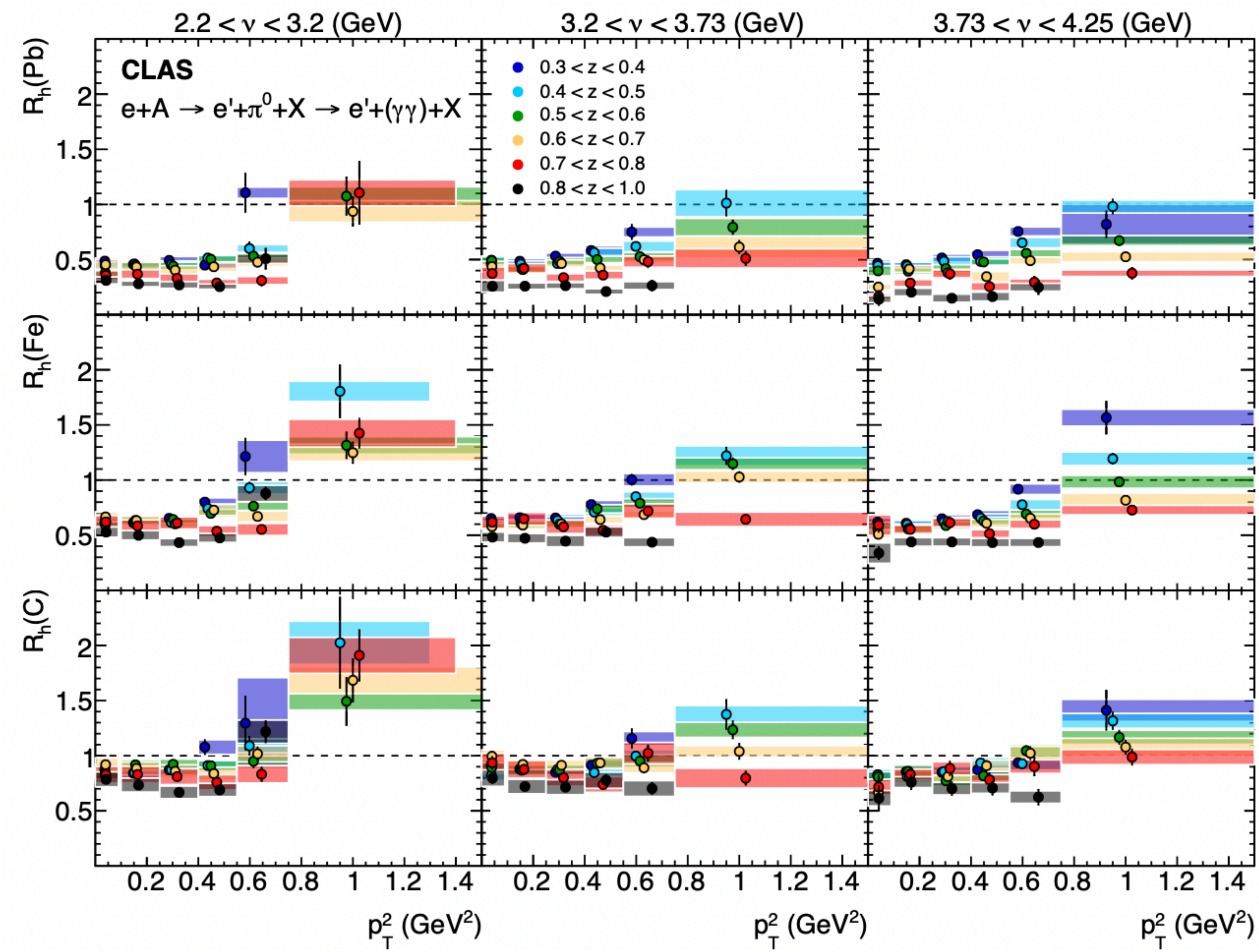
First observation of multidimensional dependence of multiplicity ratios.

Charged pion multiplicity ratios - 3D analysis in CLAS
Phys. Rev. C 105, 015201, (2022)



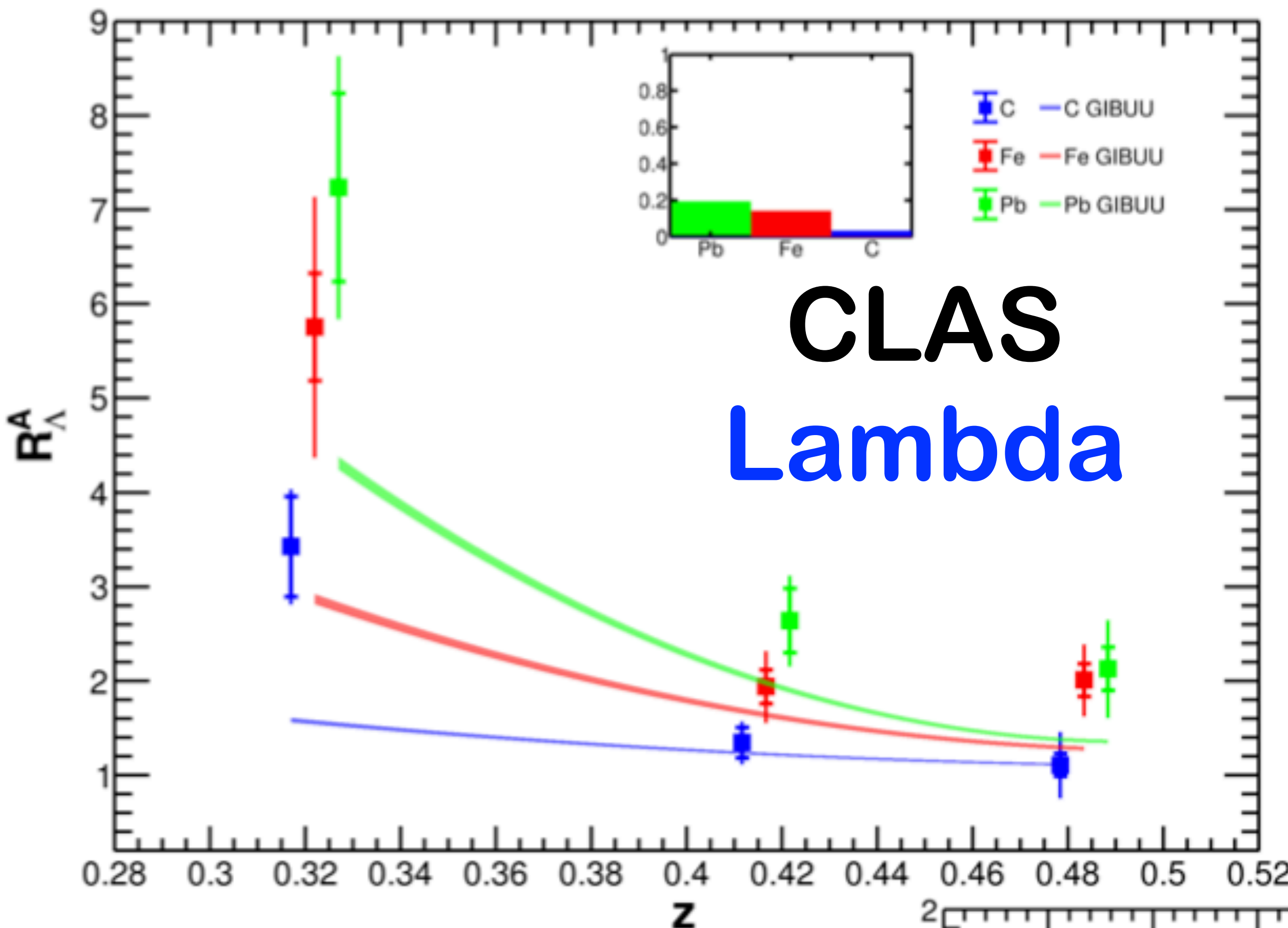
First three-dimensional study of hadronic multiplicity ratios. (4D at 12 GeV))

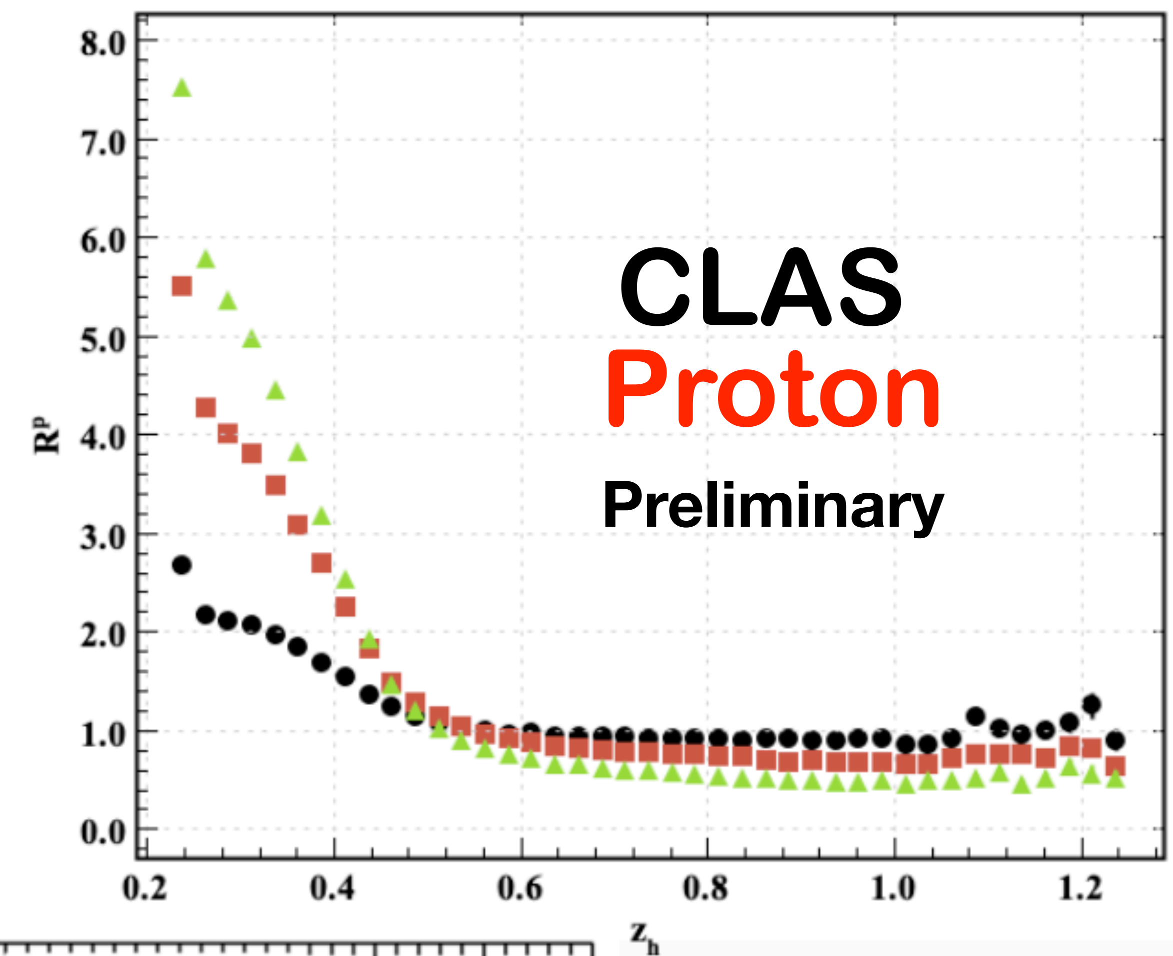
Neutral pion multiplicity ratios - 3D analysis in CLAS
Paper under internal review (2022)



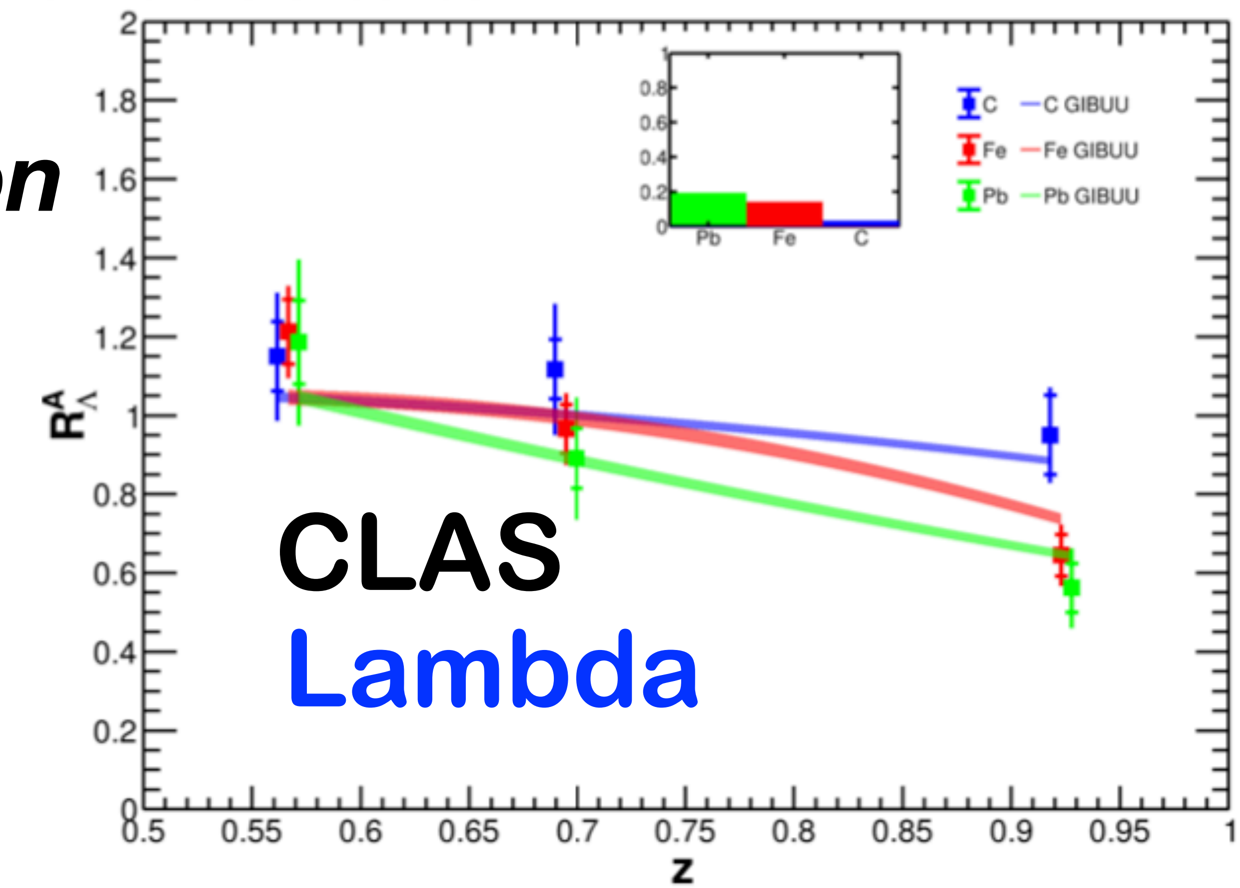
First multi-dimensional study of π_0 multiplicity ratios. (4D at 12 GeV))

Baryon multiplicity ratios in CLAS (2022)



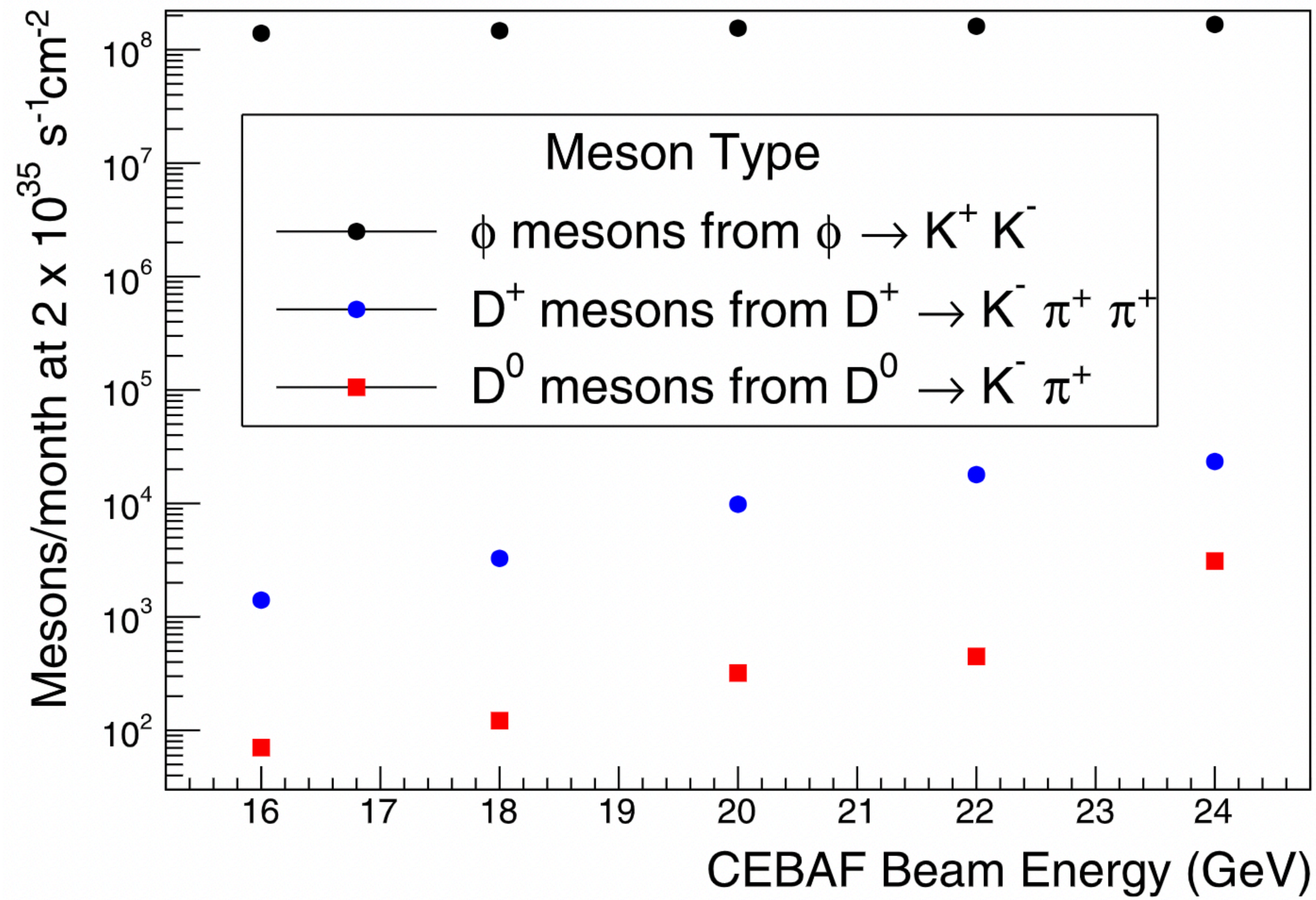


First lambda baryon
multiplicity ratio
1D now
2D in CLAS12



Proton
multiplicity ratio (3D now, 4D in CLAS12)

Multidimensional hadronization analysis of **heavy flavor meson** production from nuclei at 24 GeV in CLAS



- Two and three dimensional analysis of phi meson hadronization! (1D at 12 GeV)
- One and two dimensional analysis of D mesons

J. Arrington, M. Battaglieri, A. Boehnlein et al.
Progress in Particle and Nuclear Physics 2022 (in press)

Conclusions

- A feasible and very interesting measurement of medium-modified structure functions is feasible in the anti-shadowing region.
- It offers a mechanism of testing models that is new and complementary to the planned polarization measurement in the EMC region as well as the unpolarized measurements.
- The theoretical predictions from various models range from suppression to large enhancements.
- It can be argued that models which survive testing in the EMC reason may still be eliminated in the anti-shadowing region, where new interference phenomena will emerge.