Medium-modified spin structure functions in the EMC and anti-shadowing regions

Will Brooks

Science at the Luminosity Frontier: Jefferson Lab at 22 GeV

January 25, 2023

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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 spin structure functions***.

We will perform this study with 11 GeV beam. We can repeat this study at 20+ GeV. What will be new? Antishadowing region!

Modification of Spin Structure Functions in the Anti-shadowing Region

The experiment was reviewed in 2020

Its scientific rating was upgraded to A-

Read this document to understand theory ingredients:

https://www.dropbox.com/s/dnwp7weufiskrc0/10pageWriteup.pdf?dl=0

CLAS12 Run Group G Jeopardy Update Document

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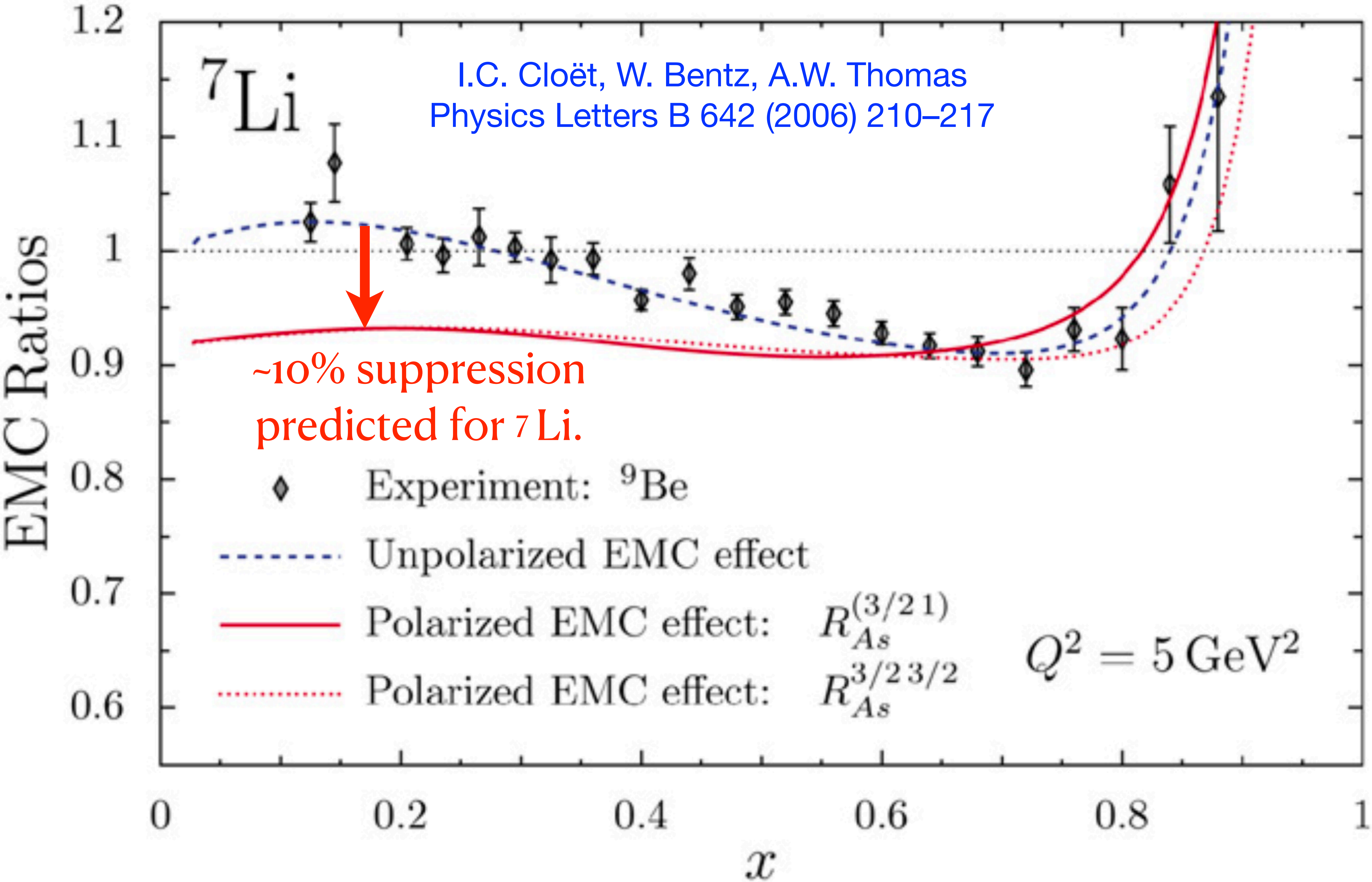
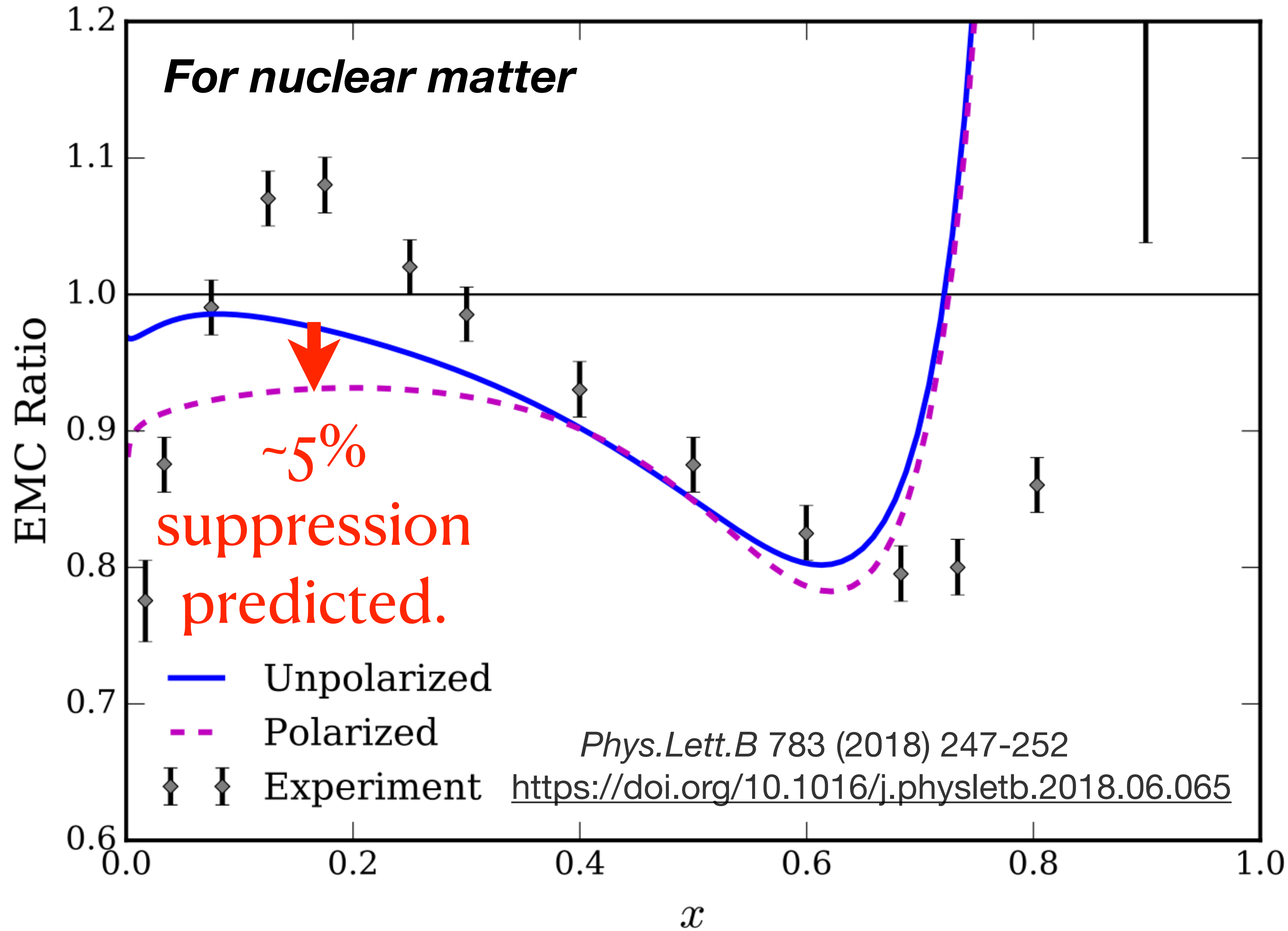
(Dated: June 20, 2020)

Theory results in EMC and antishadowing regions



Theory results in EMC and antishadowing regions

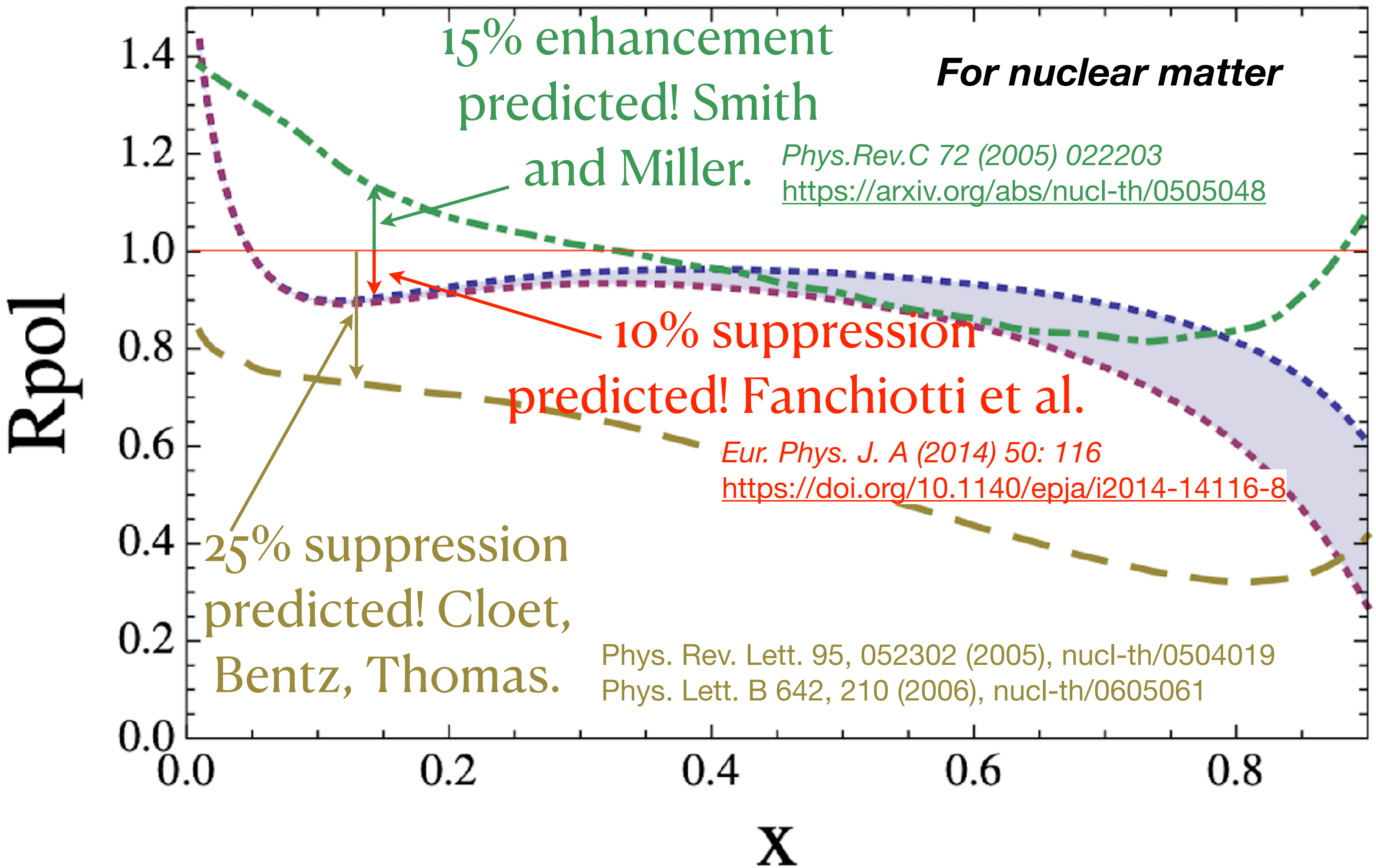


2018 paper

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 EMC and antishadowing regions



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

Glauber-Gribov Picture in DIS

- γ^*, W, Z produces a colored $q\bar{q}$ dipole pair
- Dipole can interact diffractively or inelastically on nucleons
- **Interference** of diffractive amplitudes from Pomeron exchange on upstream nucleons causes shadowing of γ^* interactions on the downstream nucleons.
- Coherence between processes on **two nucleons** separated by a distance d requires:

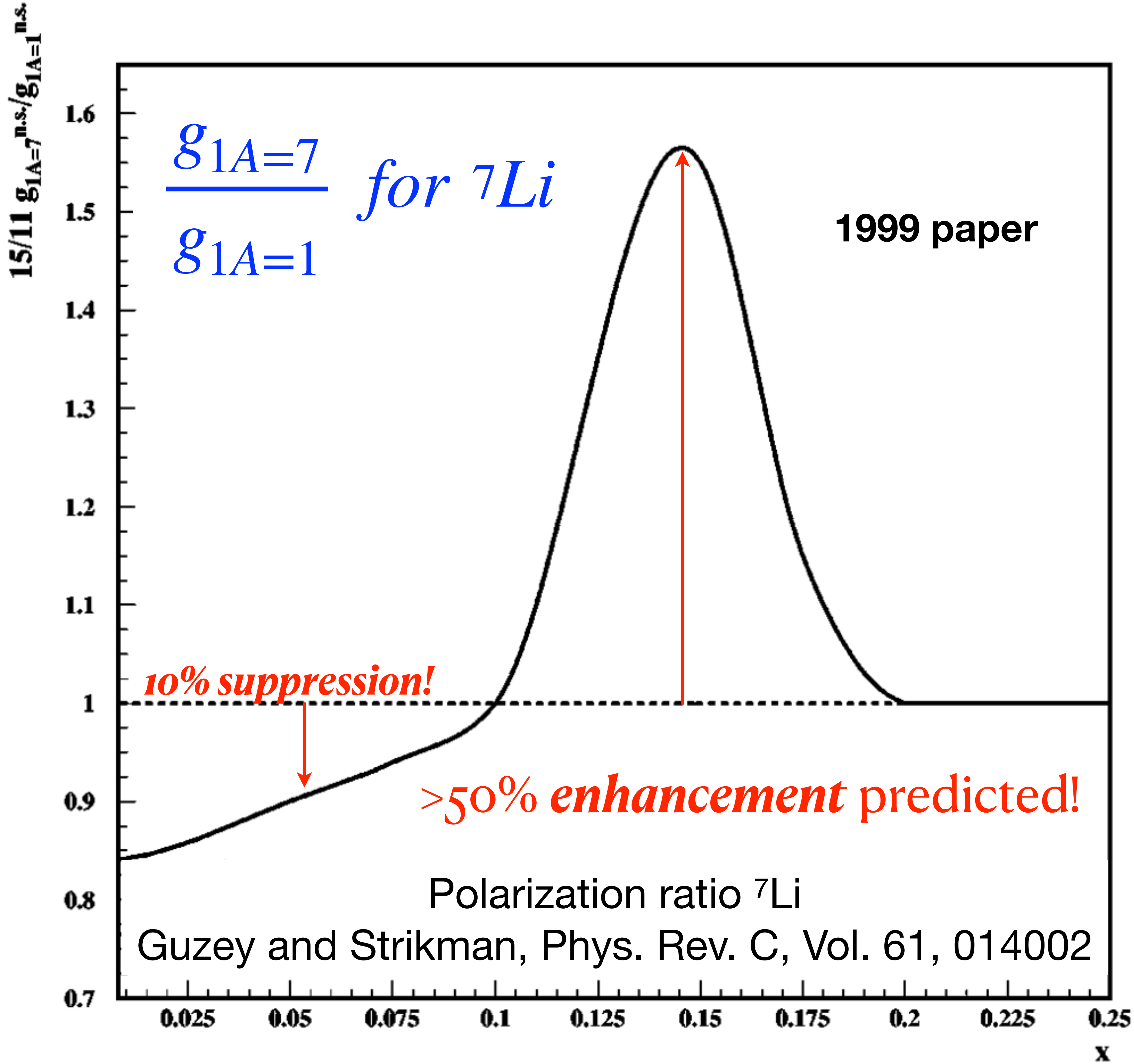
$$\frac{1}{Mx_{Bj}} = \frac{2\nu}{Q^2} = d$$

(x_{Bj}=0.1 means d= 2.2 fm)

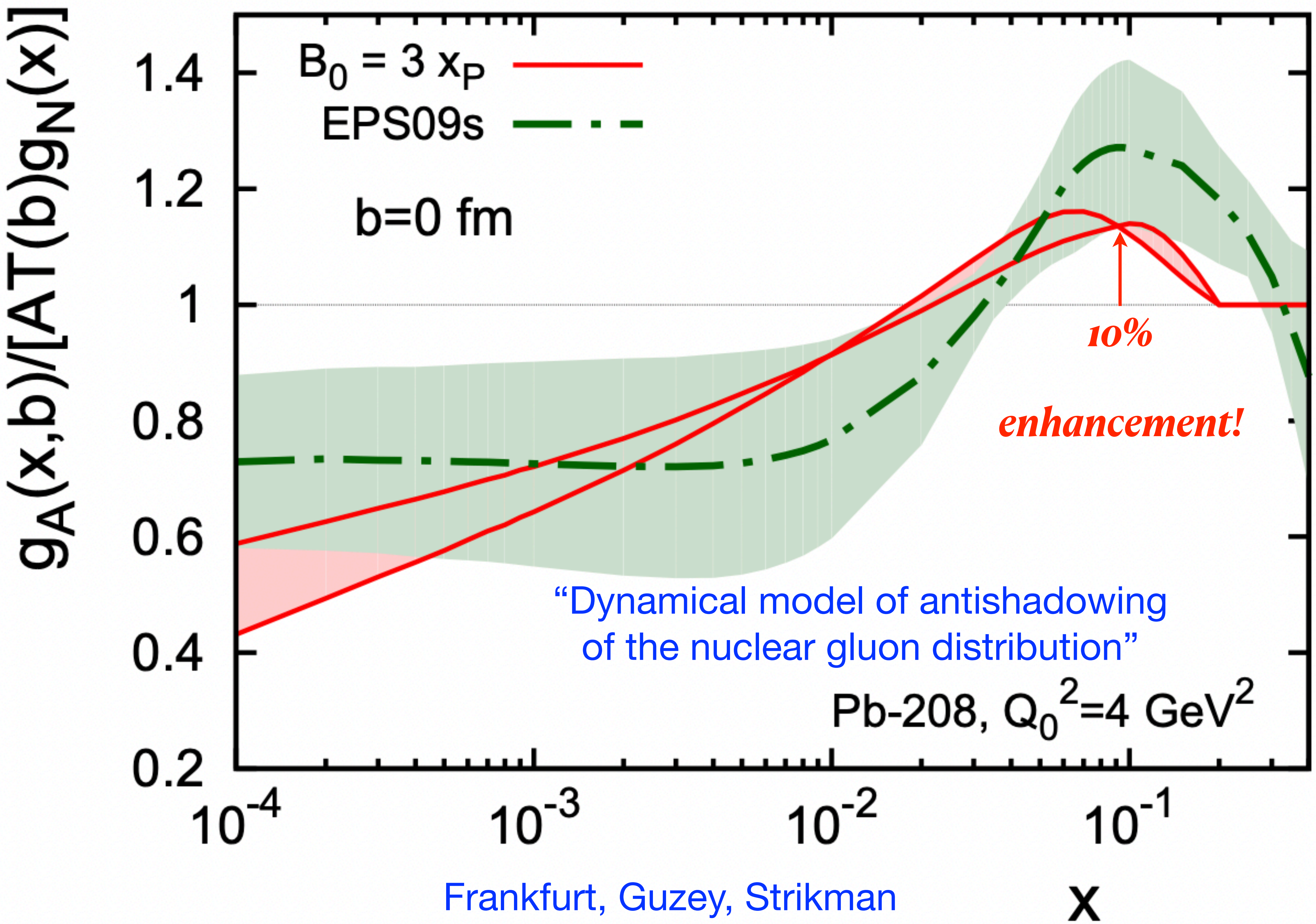
This is **less** than the separation between nucleons in nucleus.
So coherent processes **will** happen in antishadowing region and below.

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.70.116003

Theory results in the antishadowing region



Theory results in the antishadowing region



Frankfurt, Guzey, Strikman
Phys. Rev. C 95, 055208 (2017)
https://doi.org/10.1103/PhysRevC.95.055208

2017 paper

Experimental measurements

Study of Modification of Spin Structure Functions in the Antishadowing Region (MSA) at 22 GeV could use the same target and same techniques as the Polarized EMC Effect experiment, just at lower x_{Bj}. To be explored:

- The CLAS12 polarized target requires rastering to avoid local depolarization and heating. Beam spot size at 22 GeV? Moller electron multiple scattering in target captured well enough? More study needed.
- The vertex resolution needs to be good enough to separate scattering from the two target cells (to be described later).
- We may not be able to make use of full 10^{37} /s/cm^2 luminosity due to limitations of refrigerator power, depolarization, and radiation damage to target (details to follow).

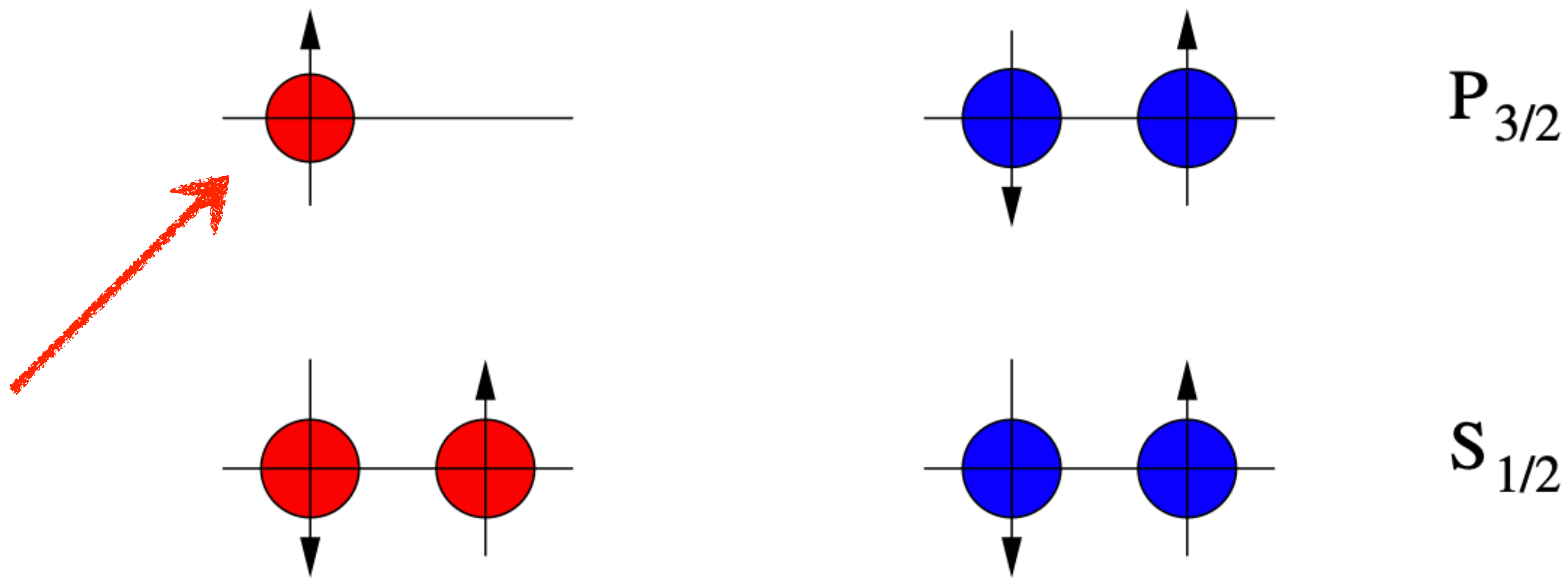
The strategy

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.

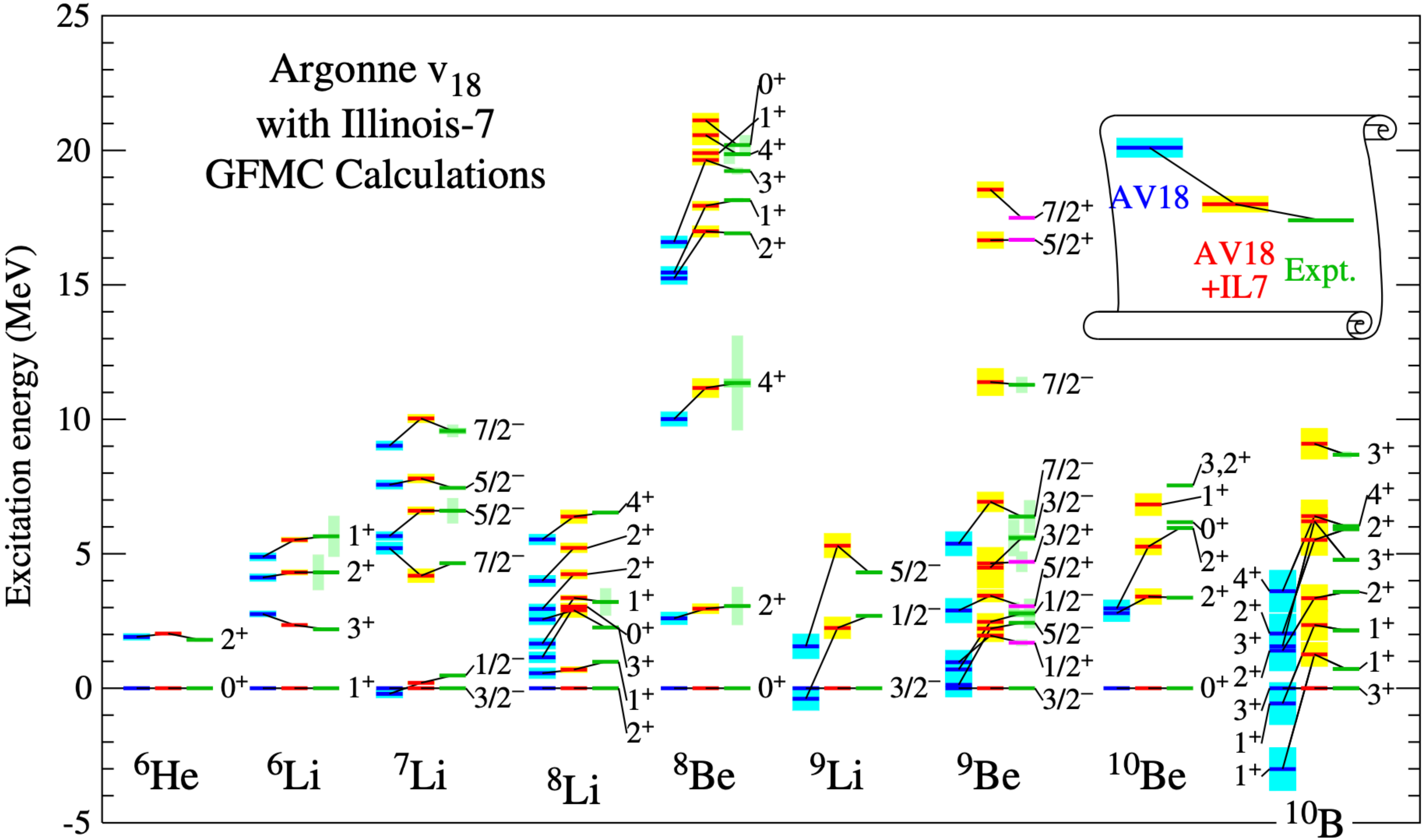
We take advantage of 99% of existing polarized target infrastructure for CLAS12. The polarized target will be scheduled for installation at 22 GeV.

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 (compacted powder) considerations

To reduce systematic uncertainties, we measure polarized ^{6}LiH and ^{7}LiD simultaneously in two separate locations along the beamline, with trim coils to adjust NMR frequency.

Max Thickness: 2% of X_0: 0.02*97 cm = 2 cm = **1.6 g/cm^2**

(Compare ammonia: 5 cm*0.82 g/cm^3 = 4 g/cm^2, packing fraction ~0.6). 2 cm = E.g. two ~1 cm disks, spaced 3 cm.

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

Power deposit in a LiH target of 1.6 g/cm^2 would be **~2.4 W** at a luminosity of 10^{37} /cm^2/s. Requires refrigerator upgrade? also replacement/ annealing every few hours at best. Too risky?

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., a good compromise: **1 + 1 cm, 10^{36} /cm^2/s, 270 nA**

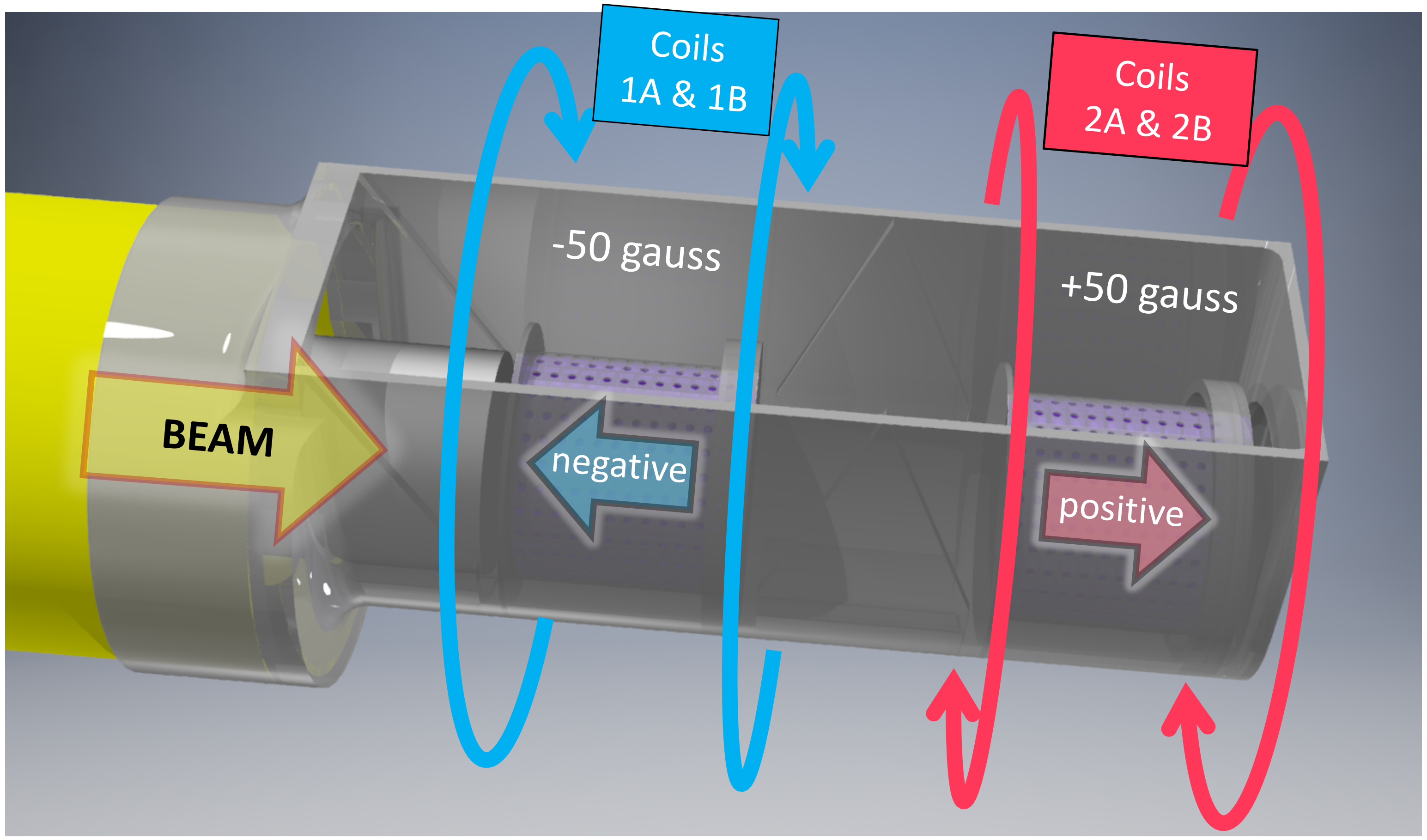
Double-cell Polarization

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

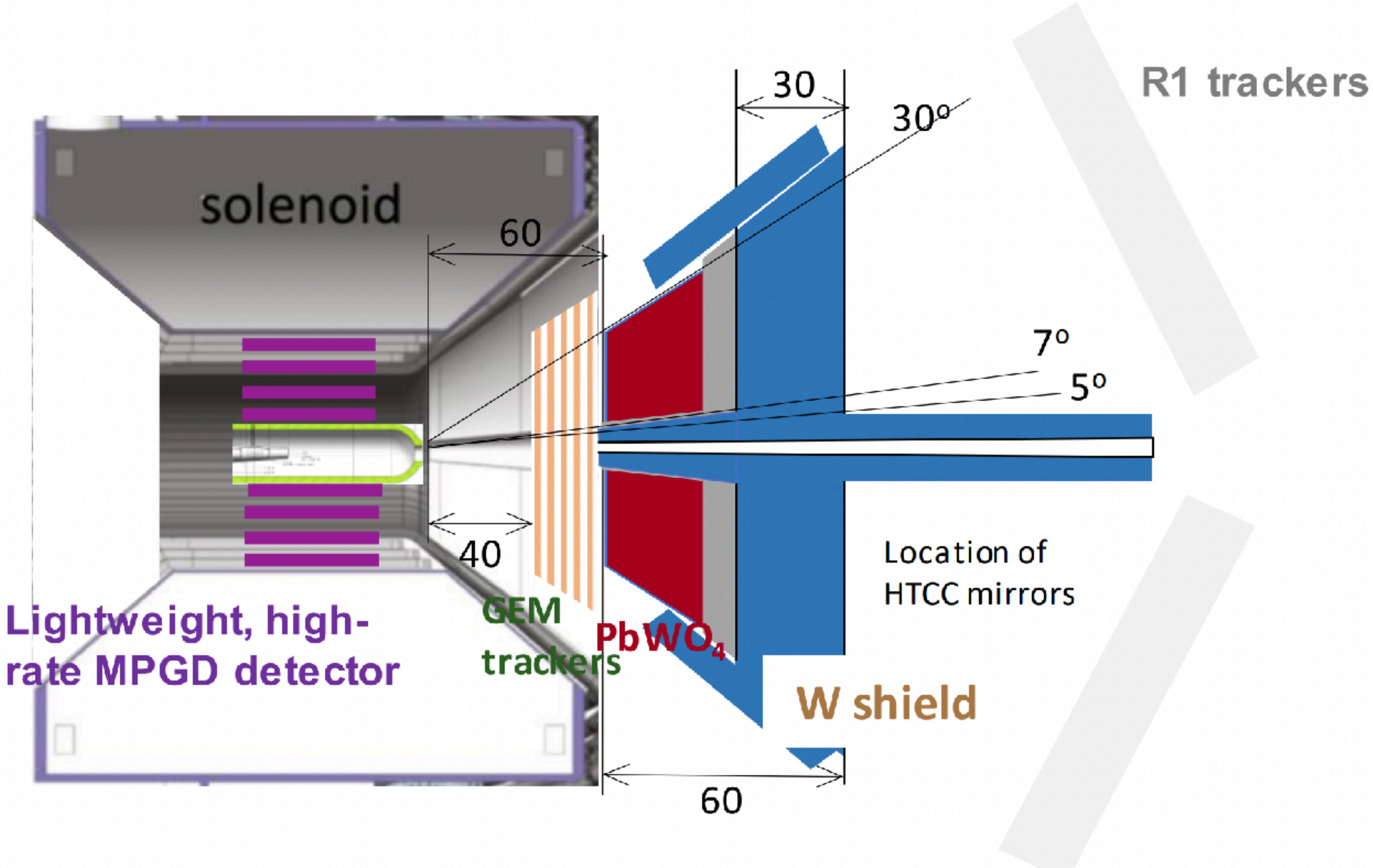
Microwave frequency halfway between the normal (+) and (-) polarization frequencies:

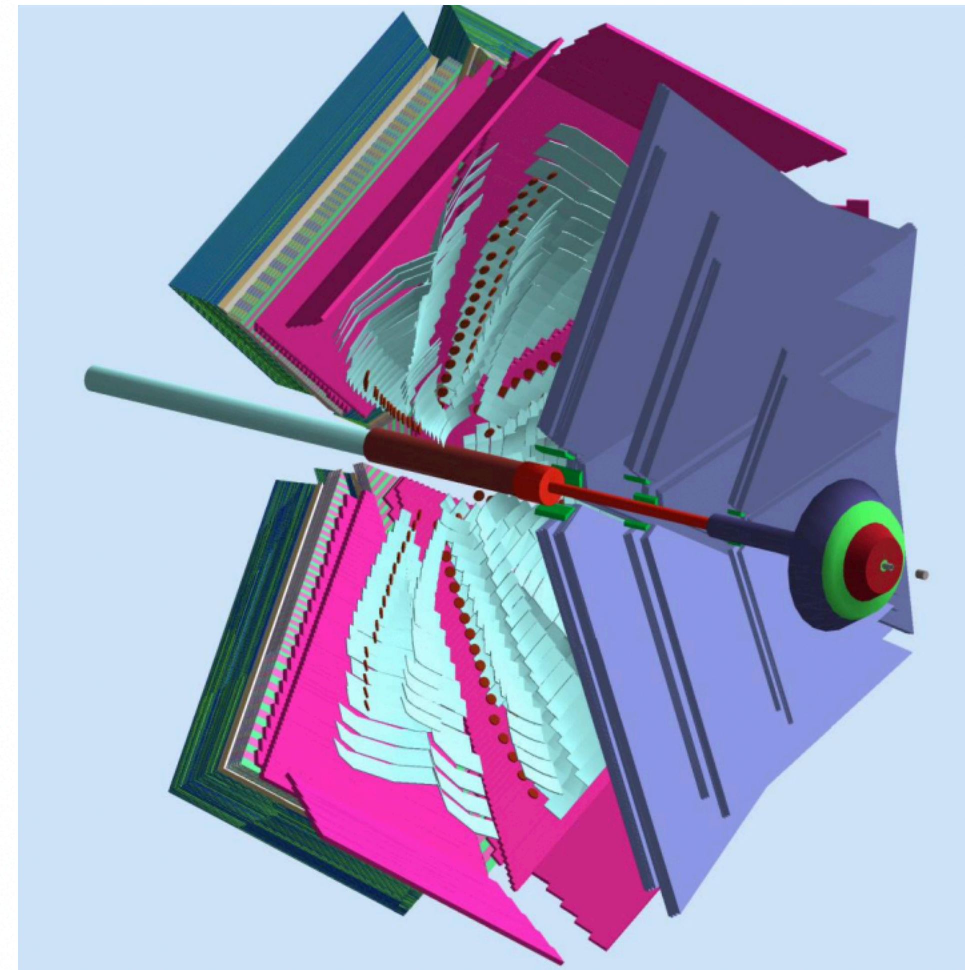
- high field sample will polarize (+)
- low field sample will polarize (-)



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

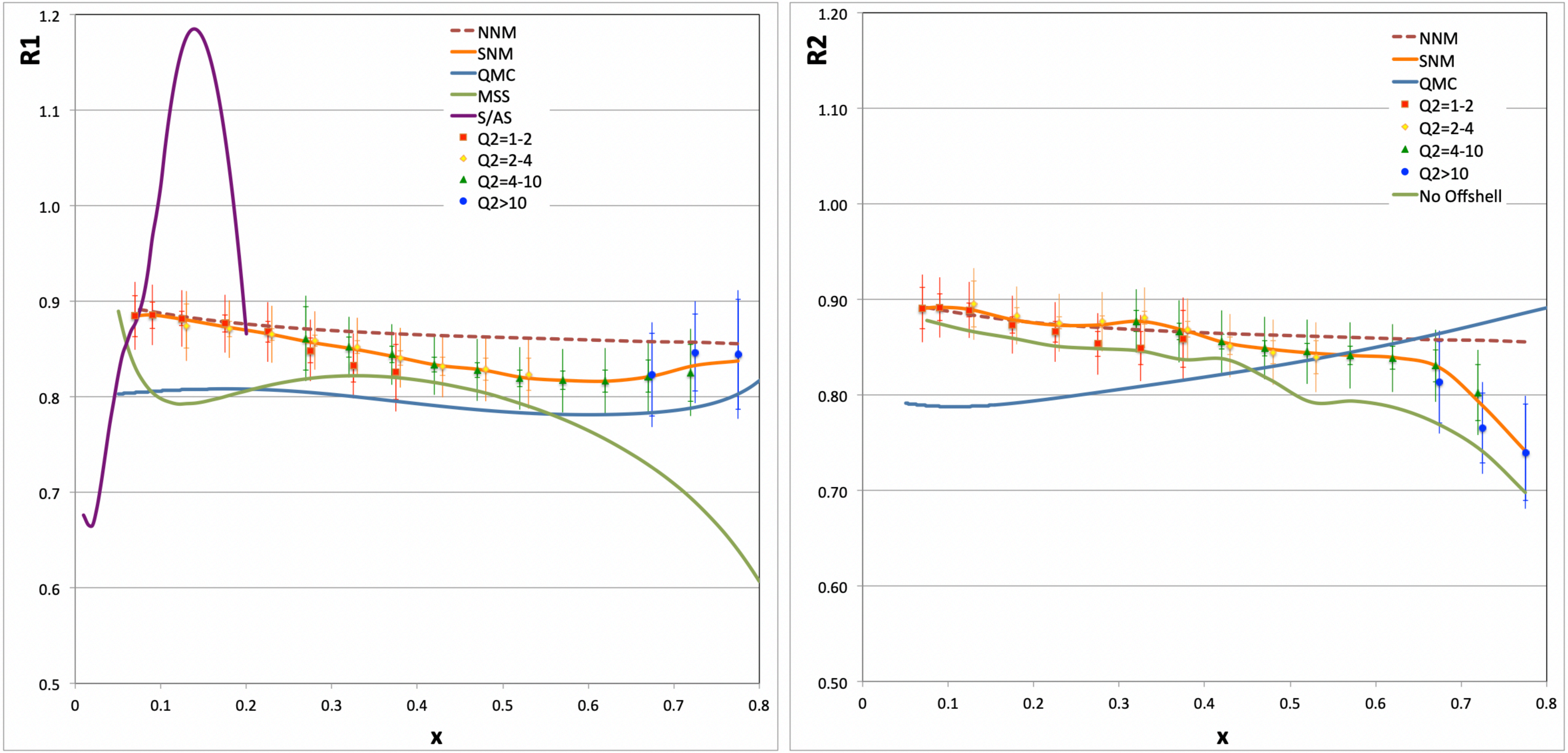




https://indico.jlab.org/event/472/contributions/9014/attachments/7329/10133/clas12_hi-lumi_collmeeting.pdf

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

Anticipated Uncertainties (representative, from pEMC)

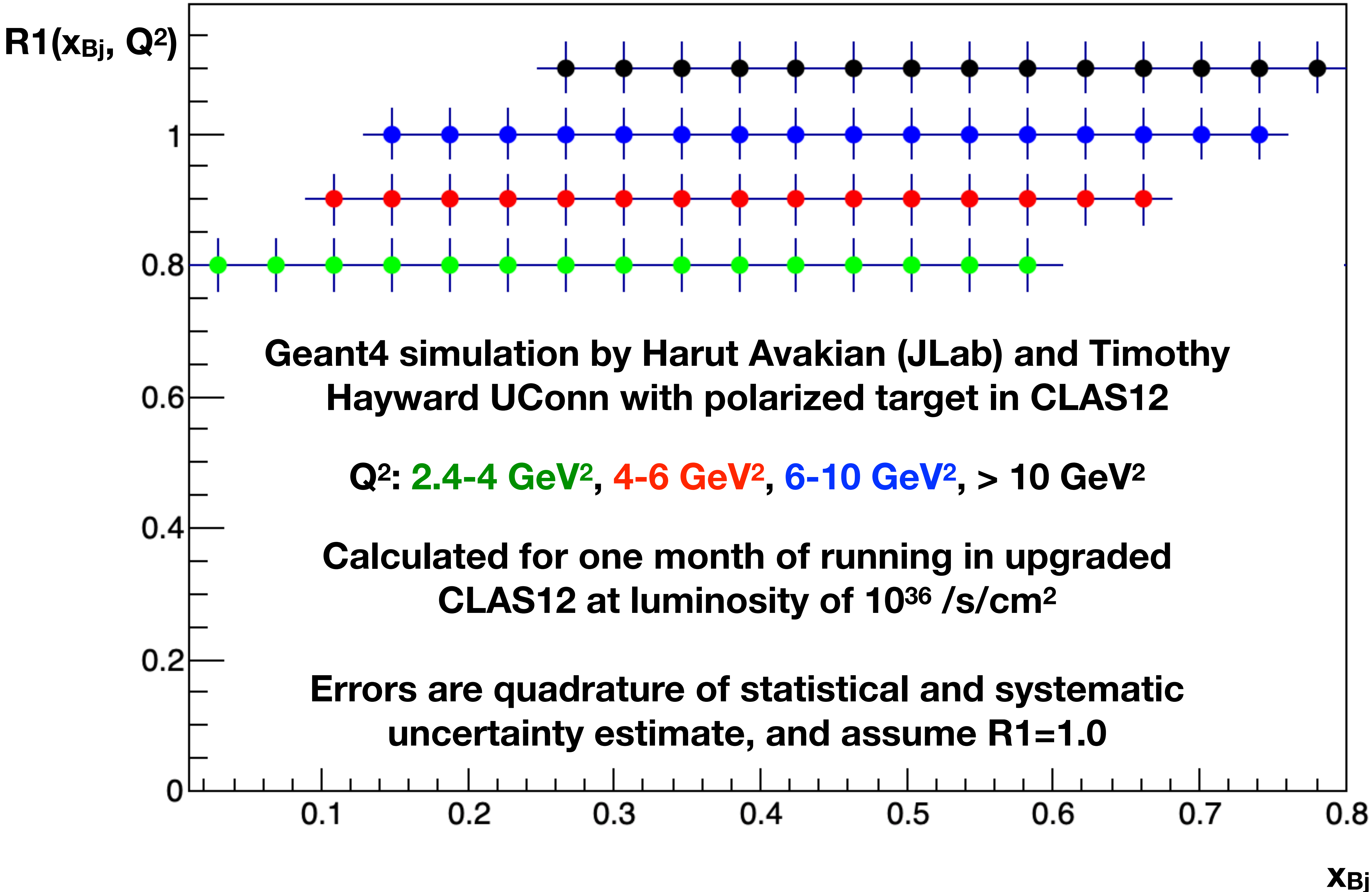


Ratio R_1 of cross section differences for double polarized ^{7}Li(e,e') over p(e,e') for several different models. Ratio R_2 of the parallel double spin asymmetry $A_{\|}$ for ^{7}Li(e,e') over p(e,e), normalized by "naïve " unpolarized structure function ratio for ^{7}Li over hydrogen.

(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.

Anticipated results at 22 GeV JLab



Conclusions

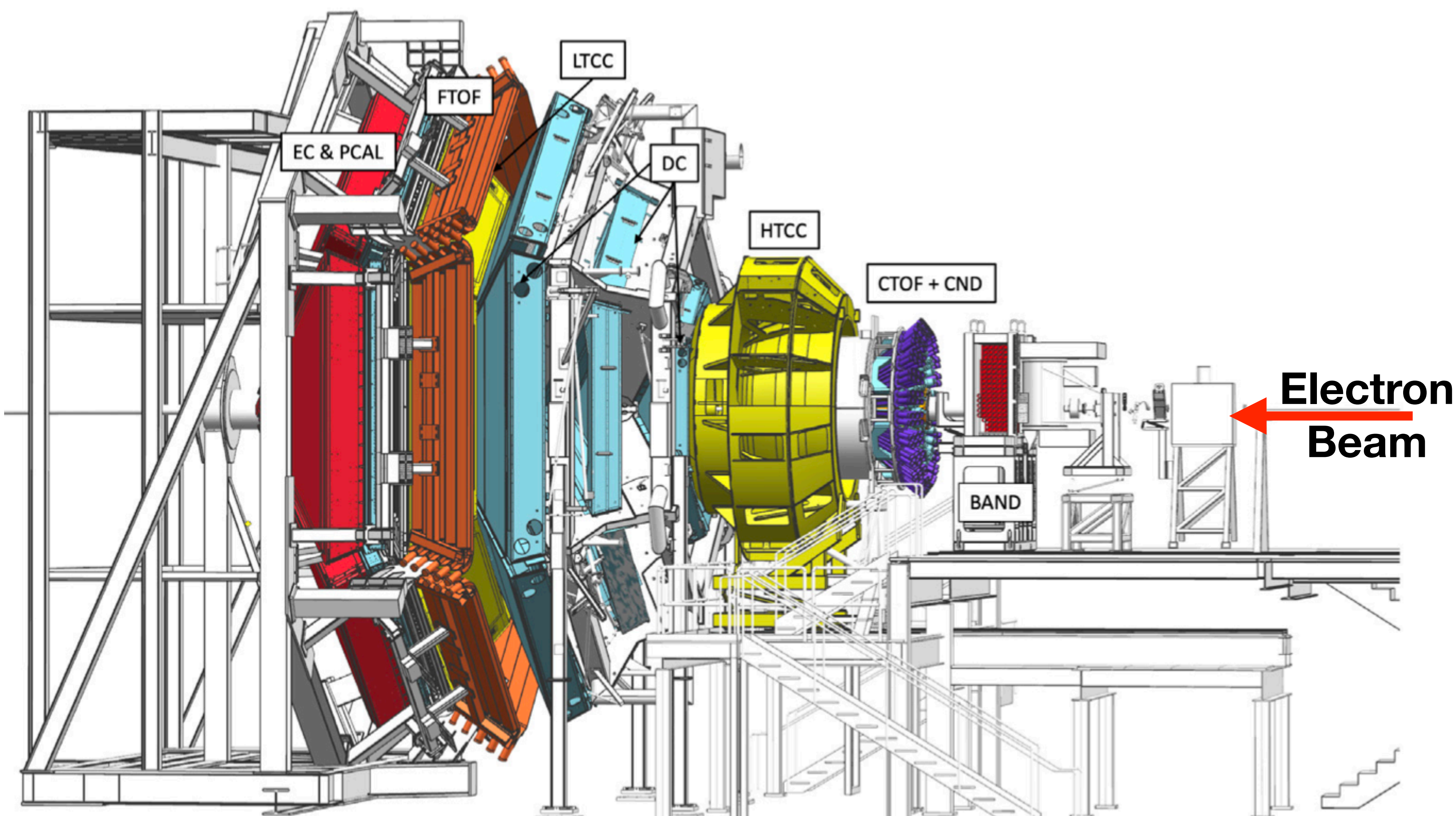
- A very interesting measurement of medium-modified structure functions is feasible in the anti-shadowing region.
- This offers a mechanism of testing models that is new and complementary to the planned polarization measurement in the EMC region and to unpolarized EMC studies.
- The theoretical predictions from various models range from 25% suppression to 50% enhancement.
- It can be argued that models which survive testing in the EMC region may still be eliminated in the anti-shadowing region, where new interference phenomena will emerge.

Backup slides

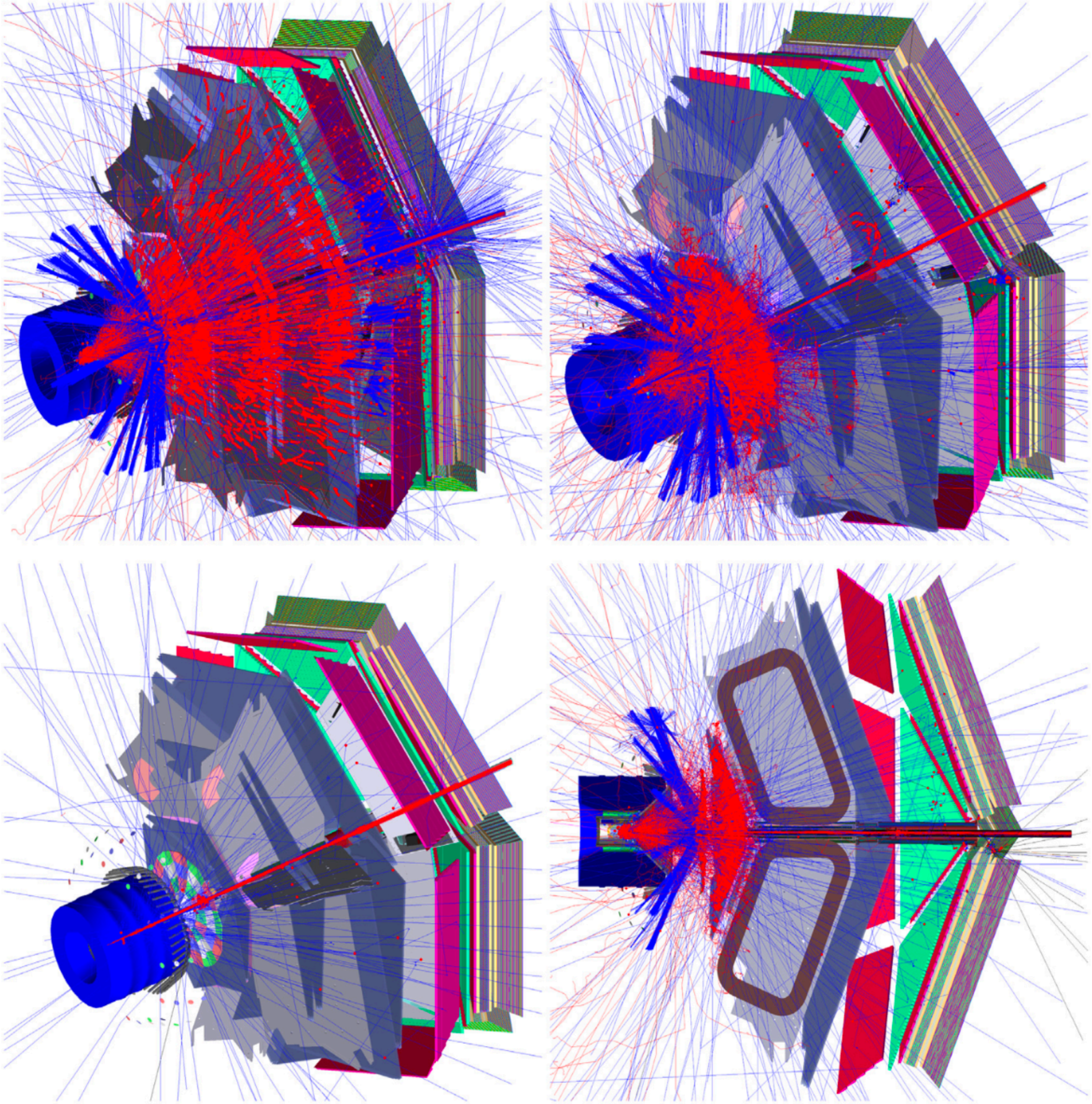
The CLAS12 Spectrometer

- The 11 GeV measurements described will be carried out in the CLAS12 spectrometer.

- The 22 GeV measurements would use an upgraded CLAS12

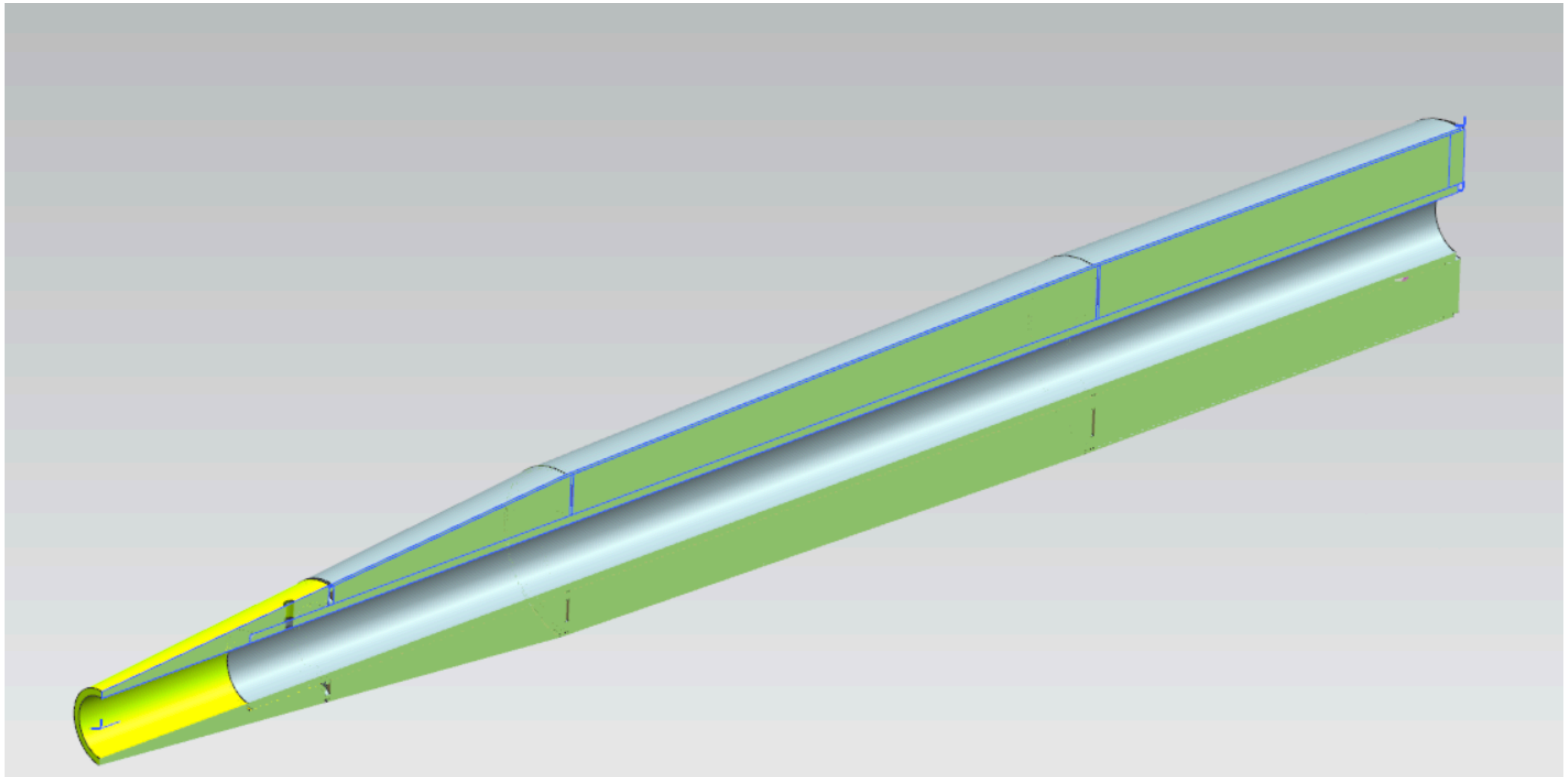


Why we talk about Møller electrons



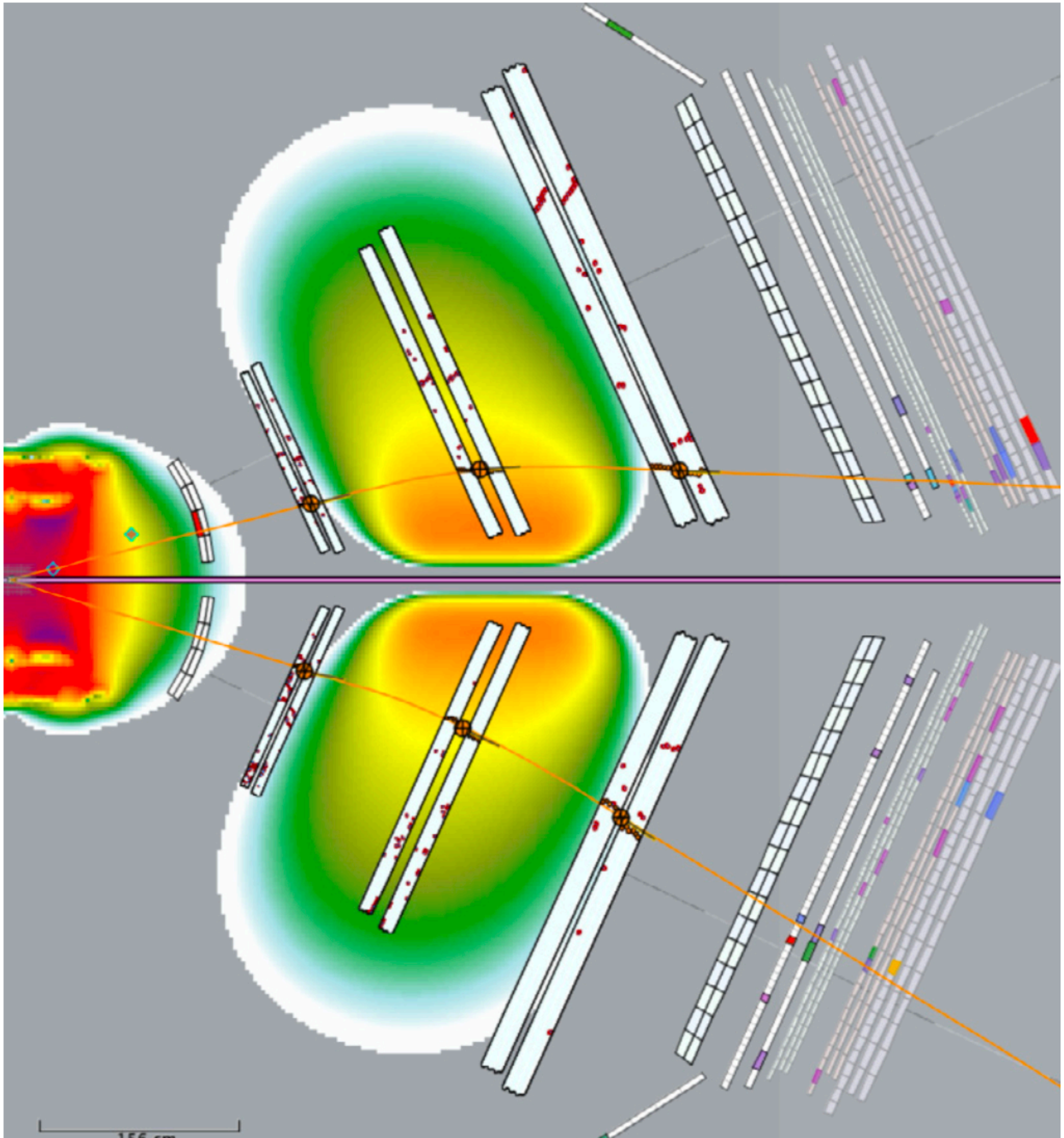
1) Fixed target experiment, where the target material is made of atoms (with electrons!)
2) Open detector design

Nuclear Inst. and Methods in Physics Research, A 959 (2020) 163419



- 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.

Present-Day CLAS12 Spectrometer



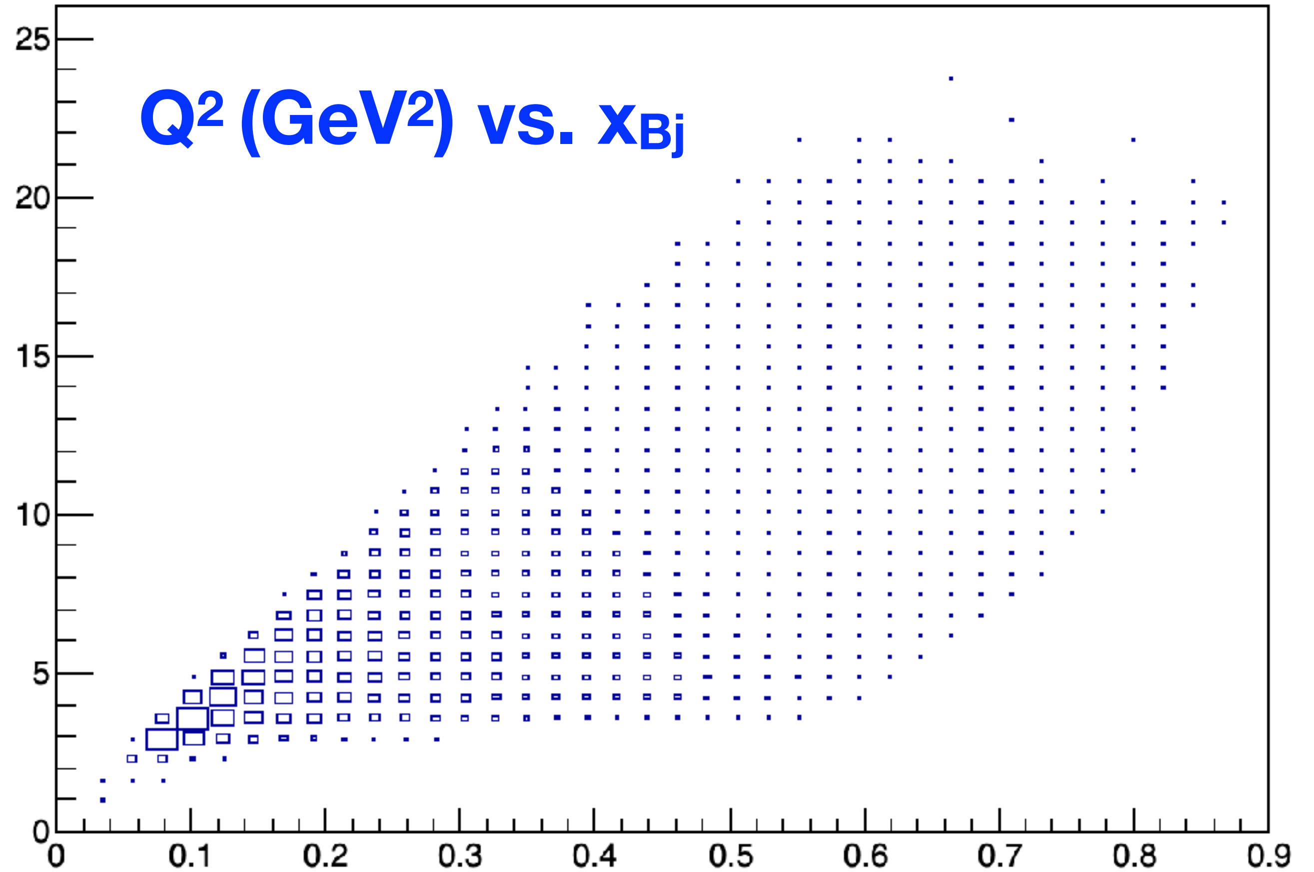
Scattered Electron
("inbending")

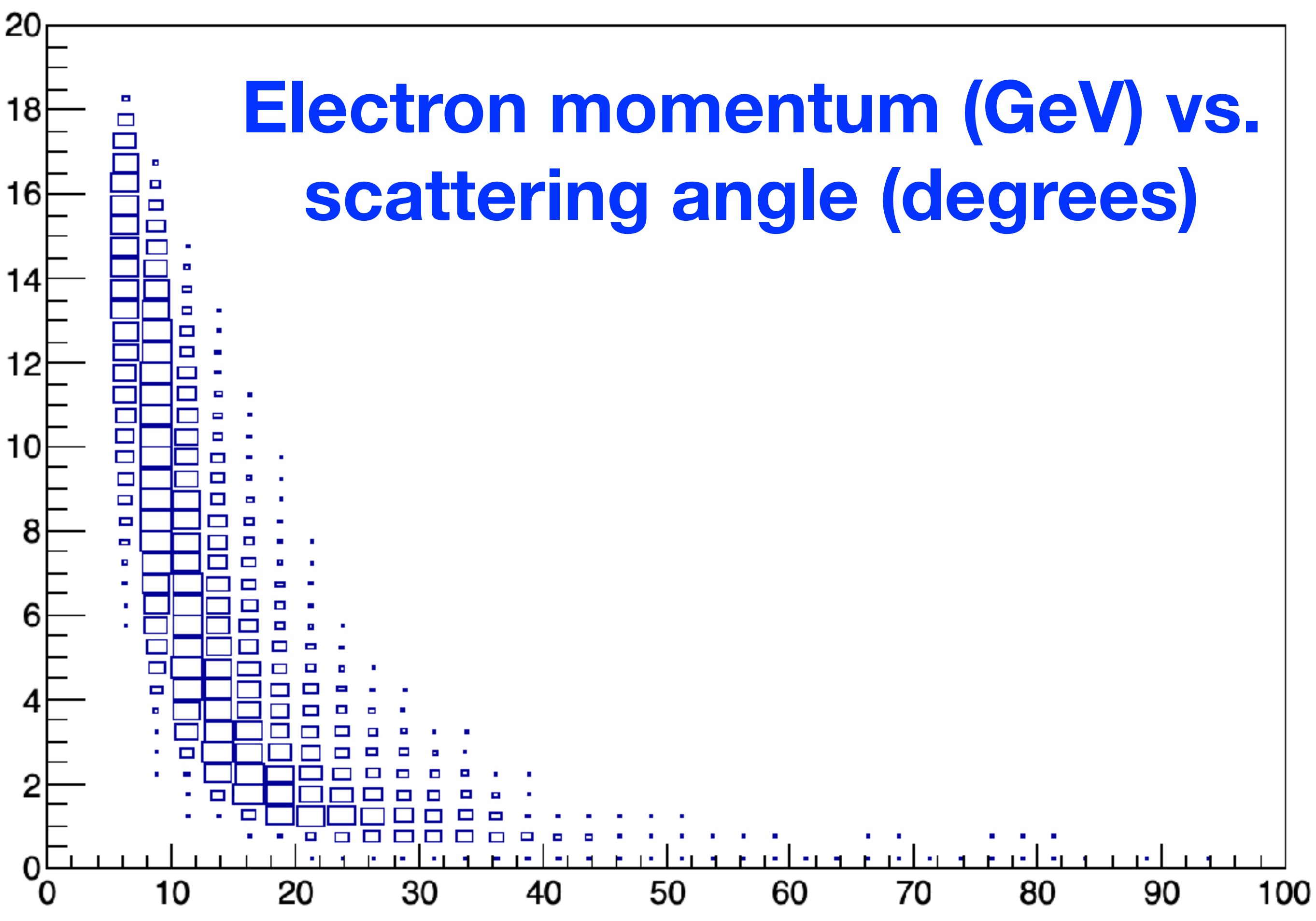
Positive Particle
("outbending")

22 GeV Simulations of CLAS12 with Polarized Target and Fiducial Cuts

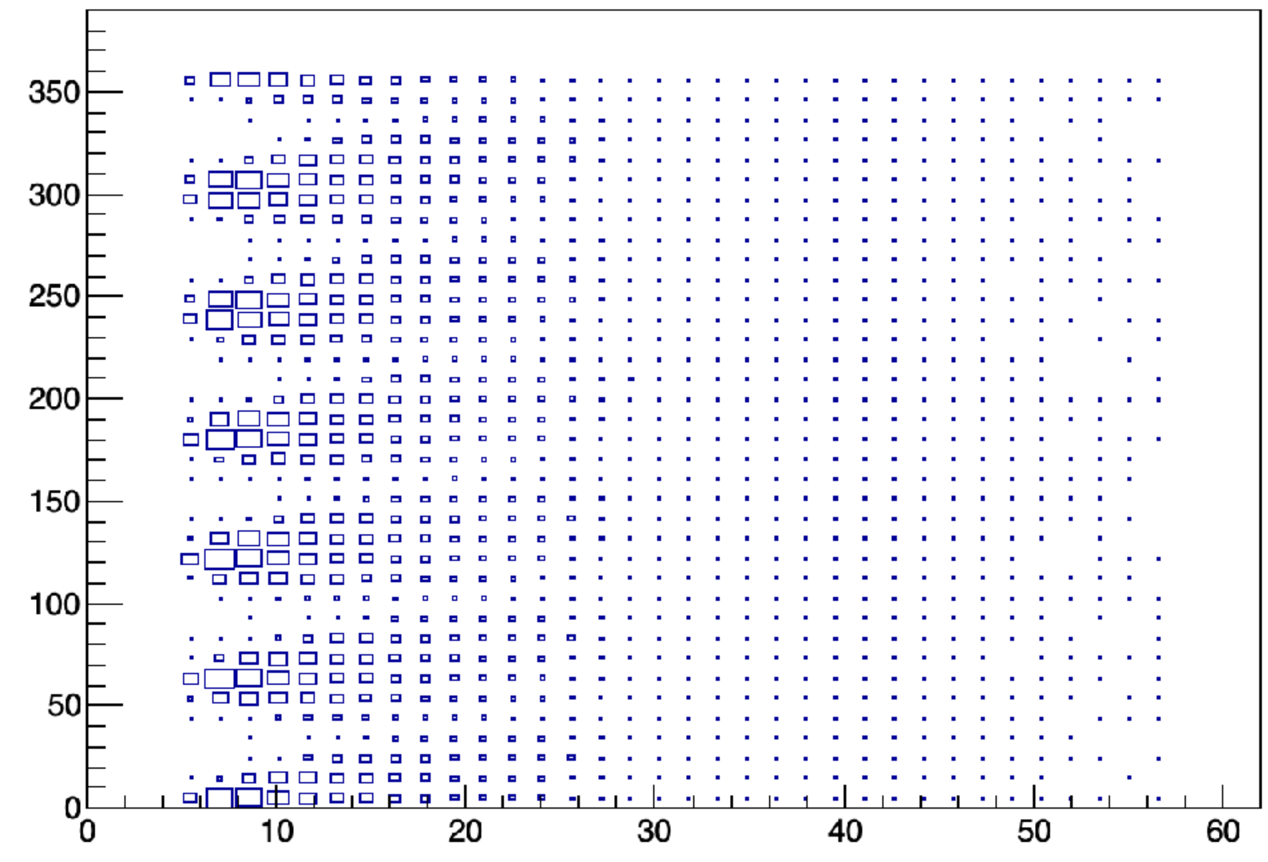
Inbending electrons

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



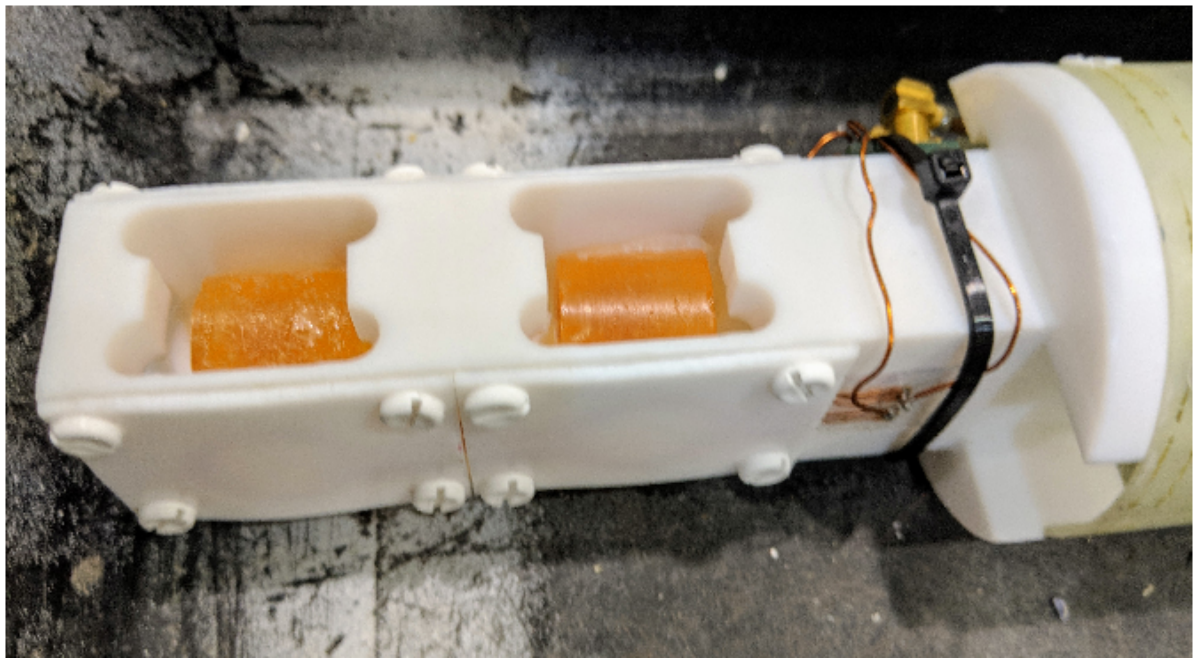


Electron azimuthal angle vs. polar angle (degrees)

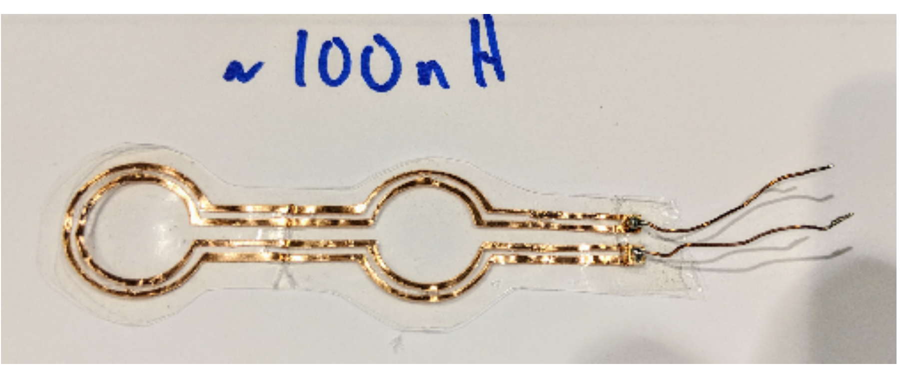


Double-cell Polarization

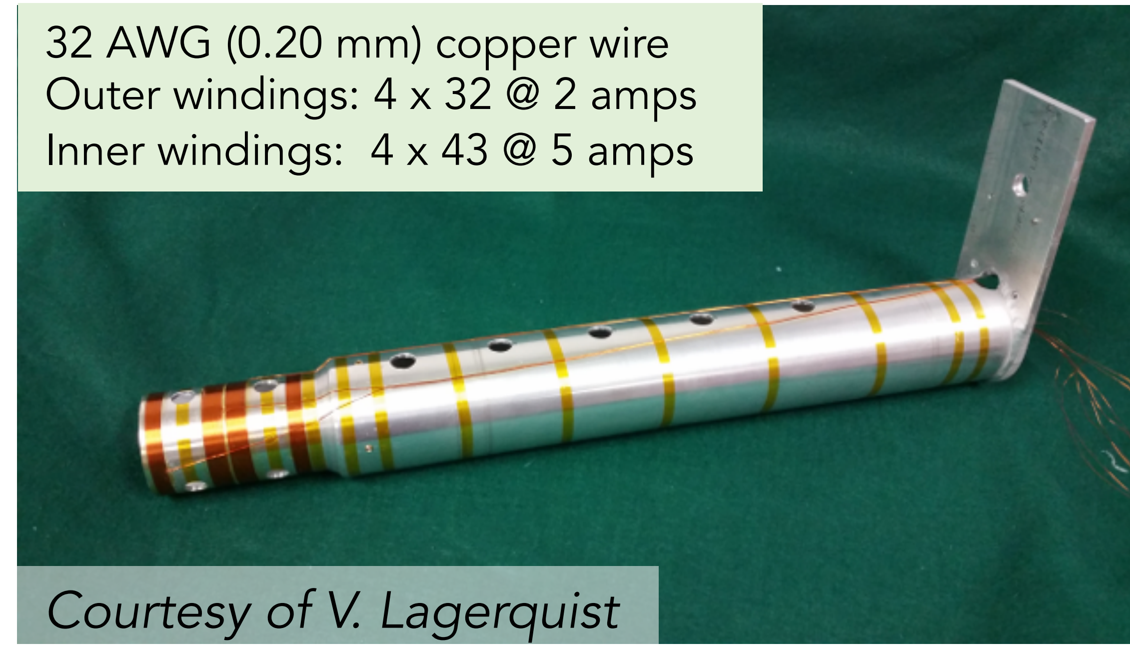
Proof-of-principle tests performed at 77 K and 5 T using TEMPO-doped polymer



Courtesy of J. Maxwell



- Two samples
- One NMR coil



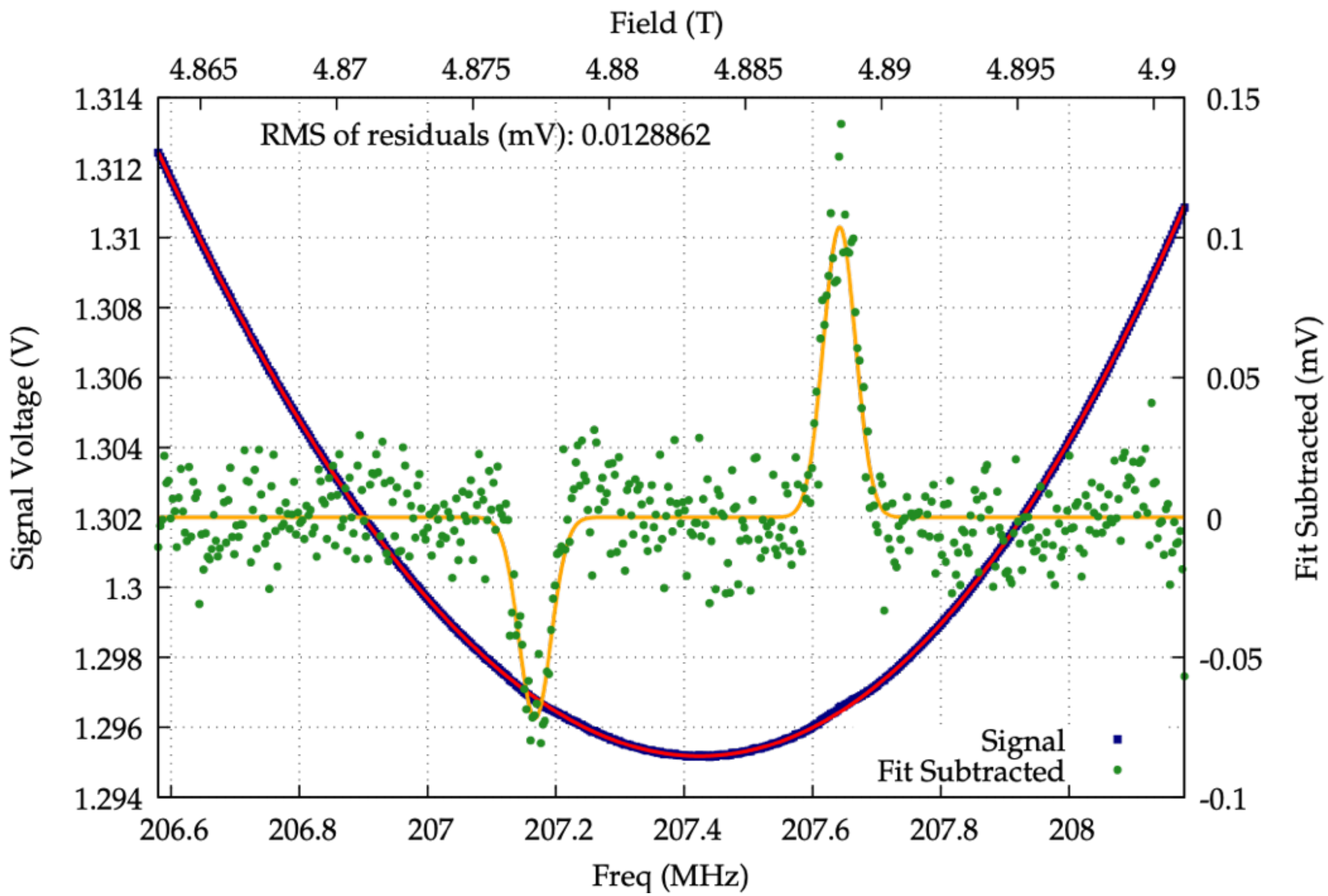
Courtesy of V. Lagerquist

5 T solenoid used for FROST

Double-cell Polarization

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

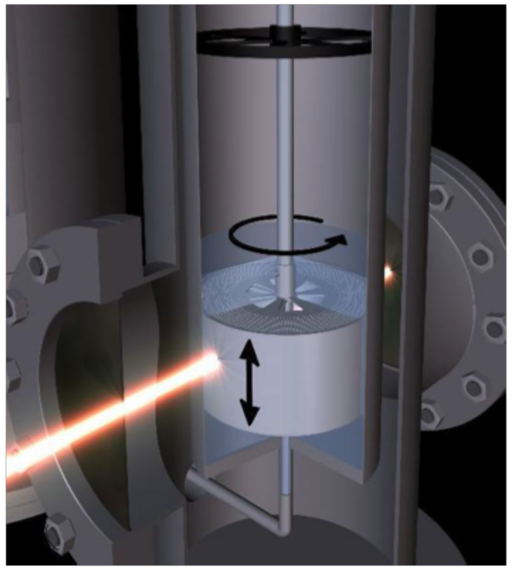
Success!

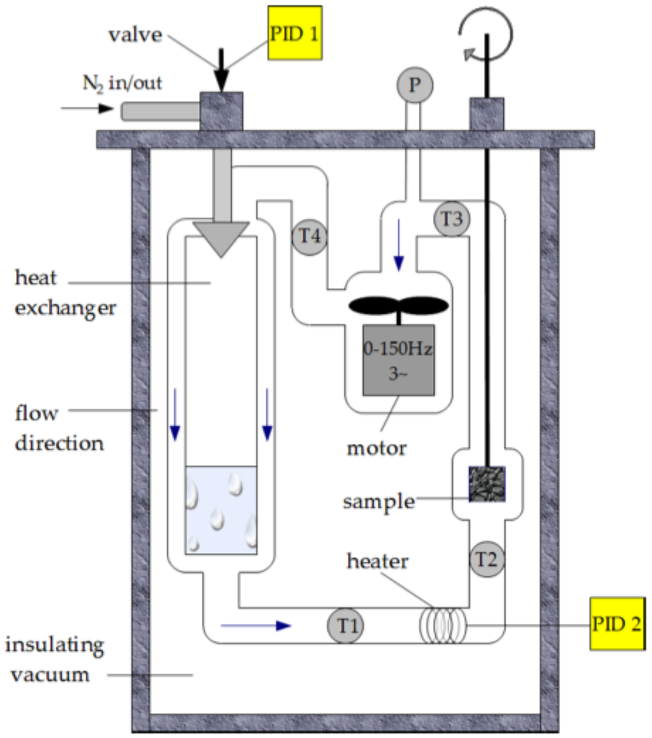


DNP of Lithium Hydride

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.

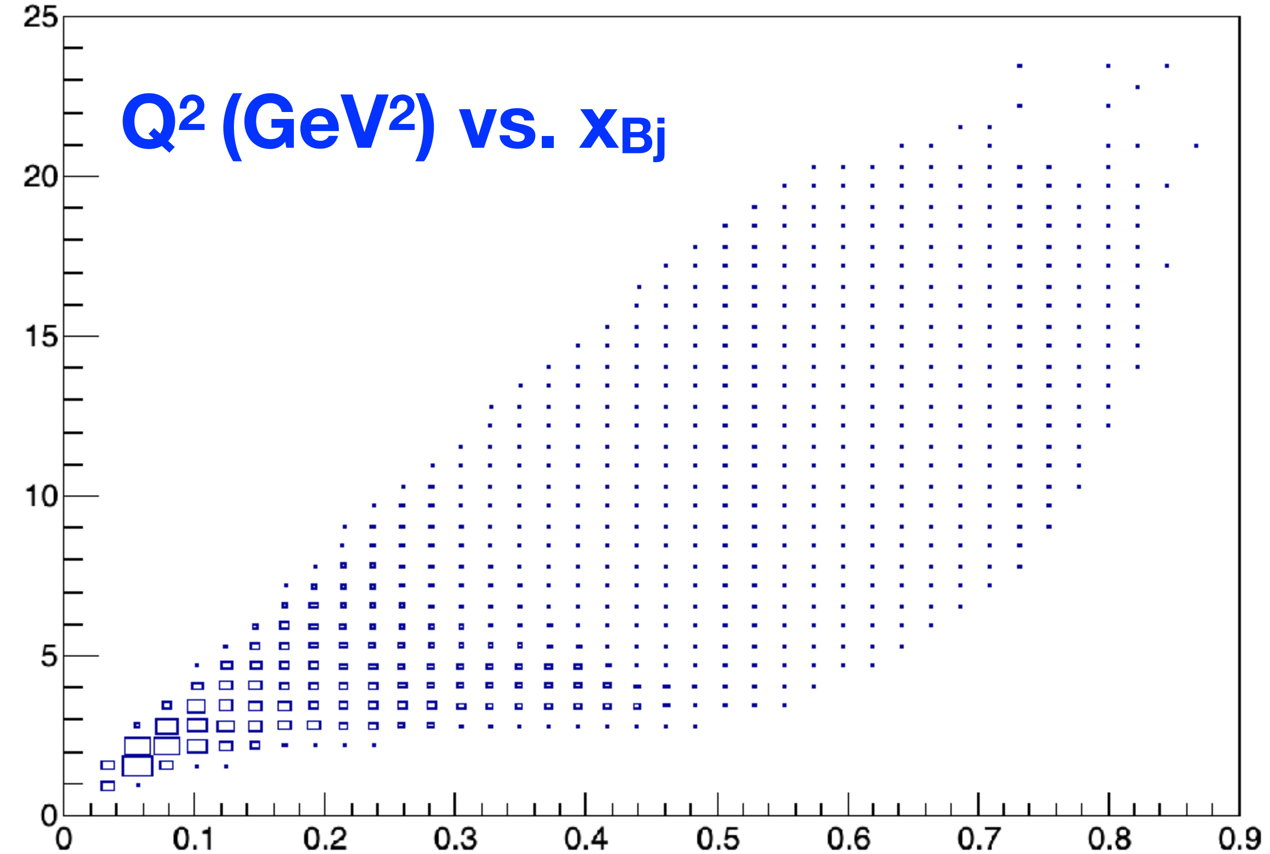
Upgrade Injector Test Facility: UITF at JLab

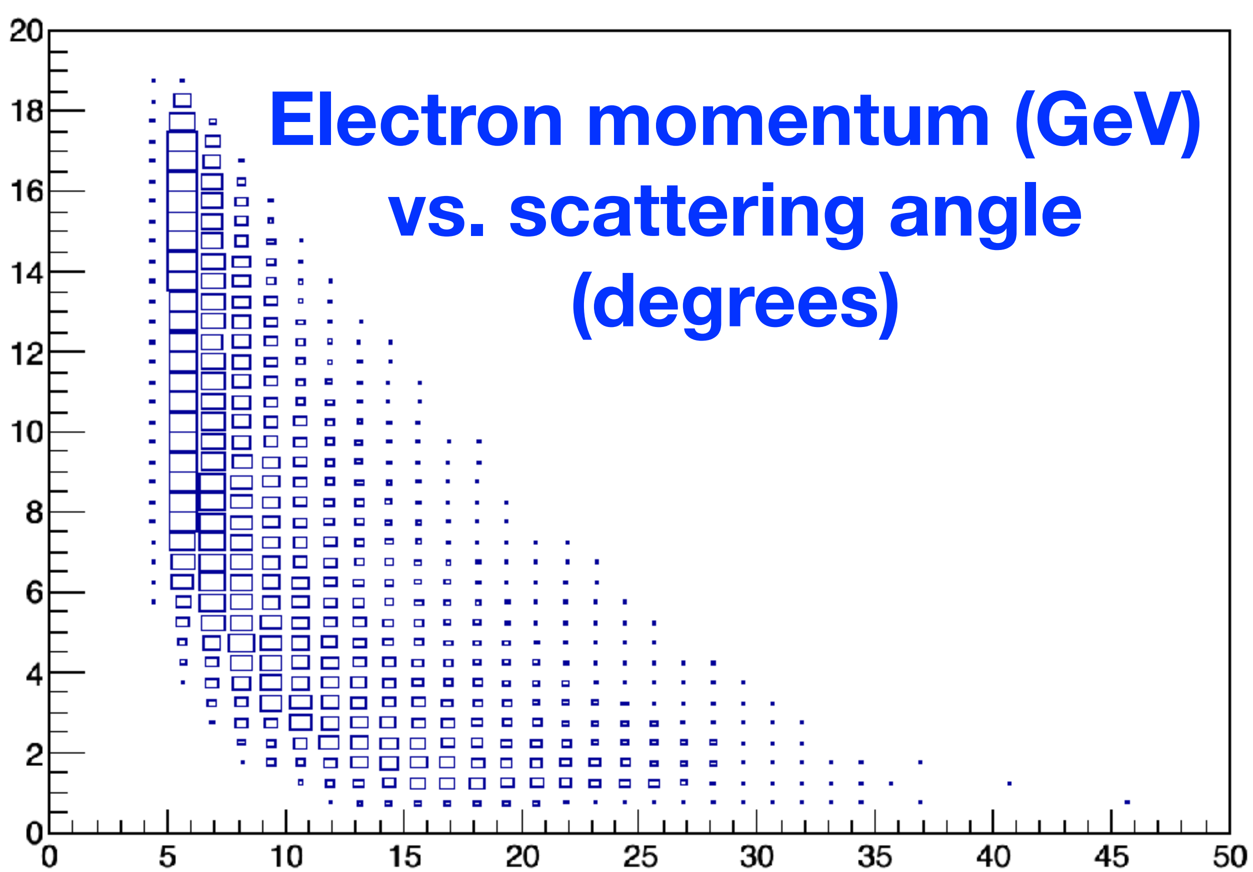
See X. Li et al., NIM A Volume 1039, 11 September 2022, 167093.

22 GeV Simulations of CLAS12 with Polarized Target and Fiducial Cuts

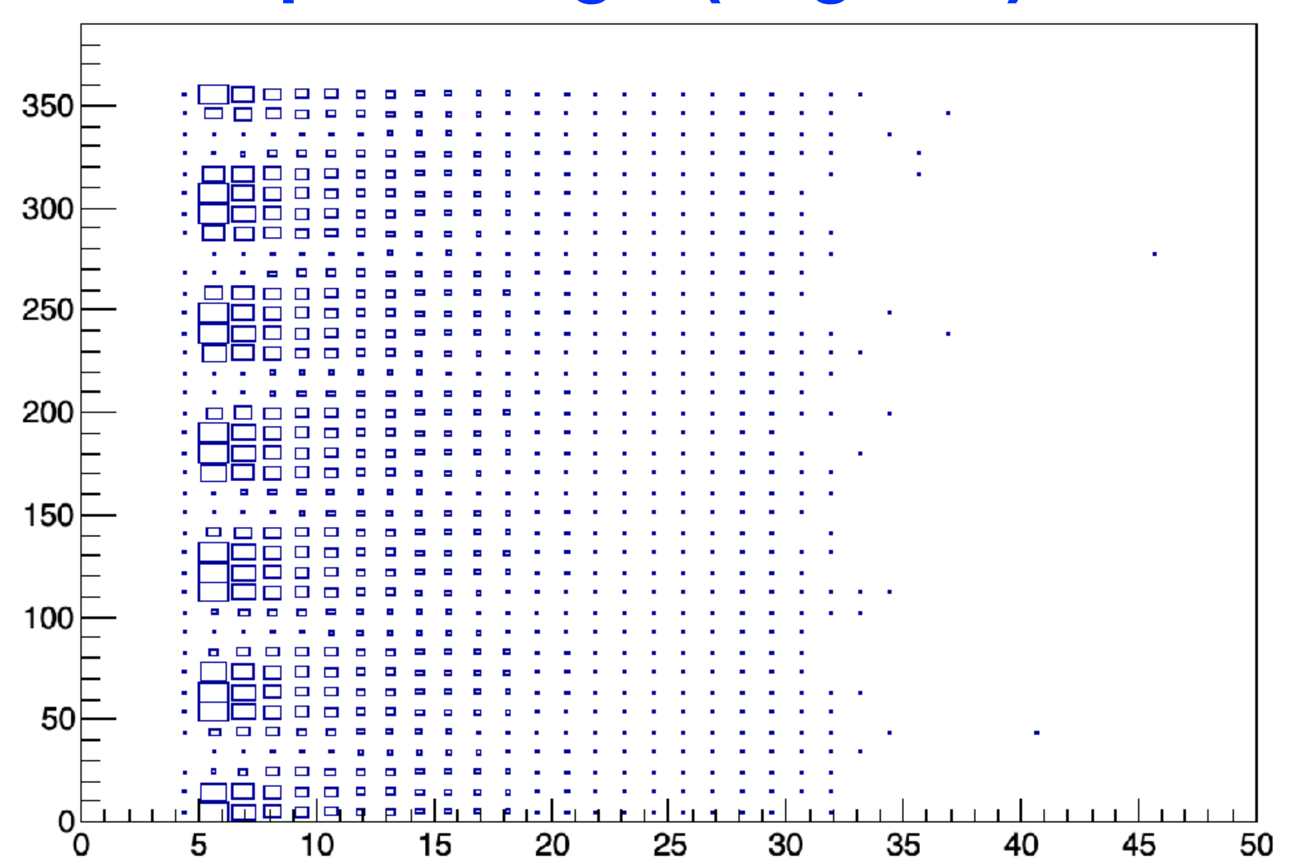
Inbending electrons

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

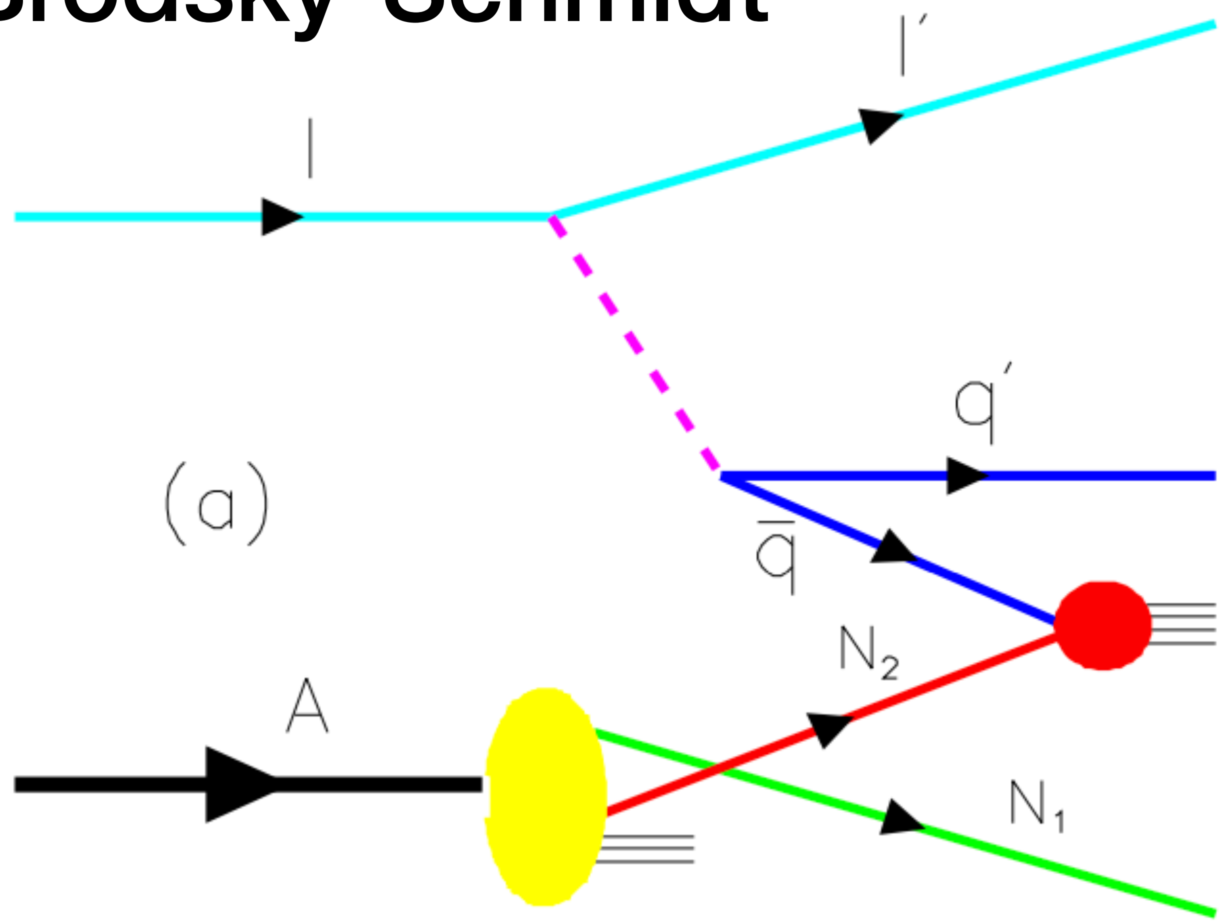




Electron azimuthal angle vs. polar angle (degrees)



Brodsky-Schmidt

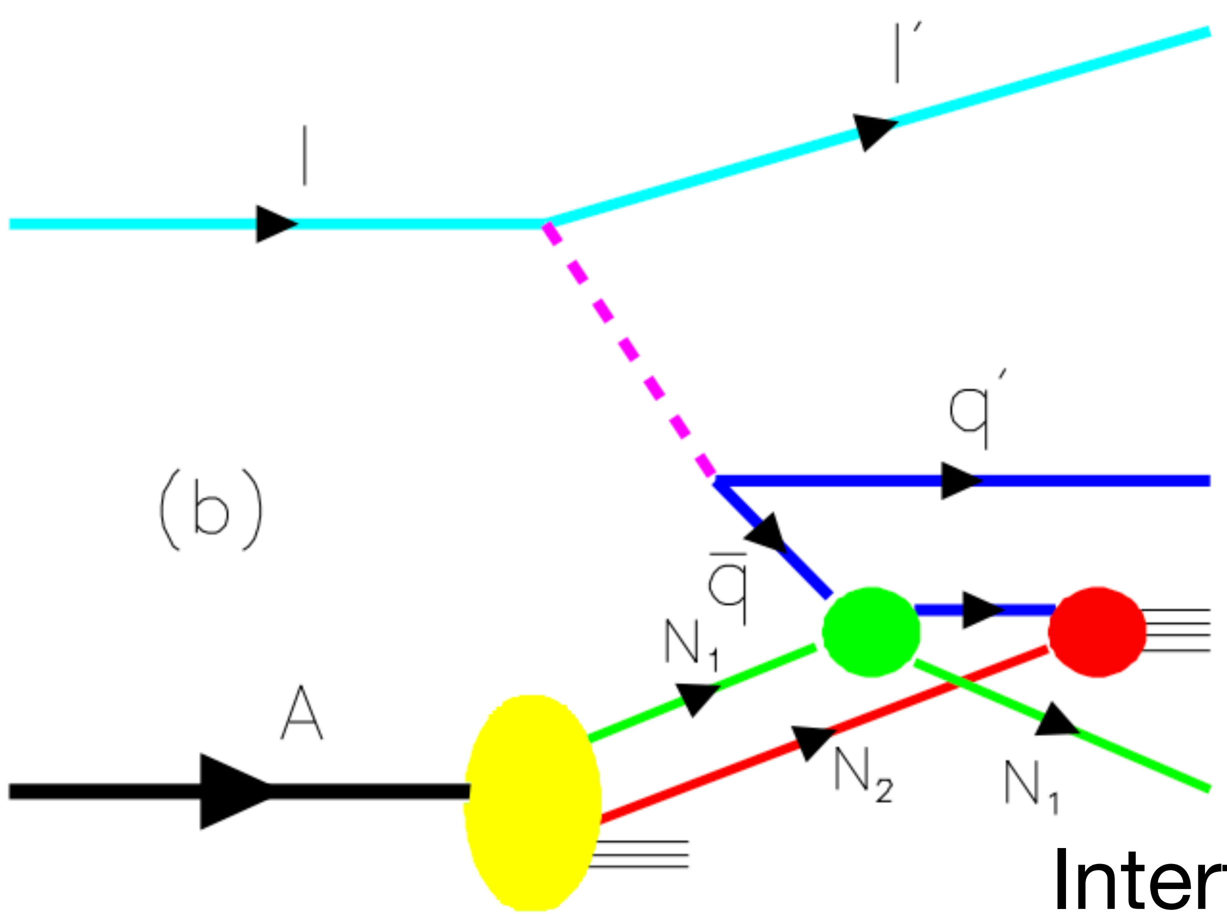


Single-step process

Exchange boson fluctuates into $q\bar{q}$ pair

The $\bar{q}$ interacts strongly with nucleon N_2 from the nucleus A

Nucleon N_1 is a spectator



Two-step process

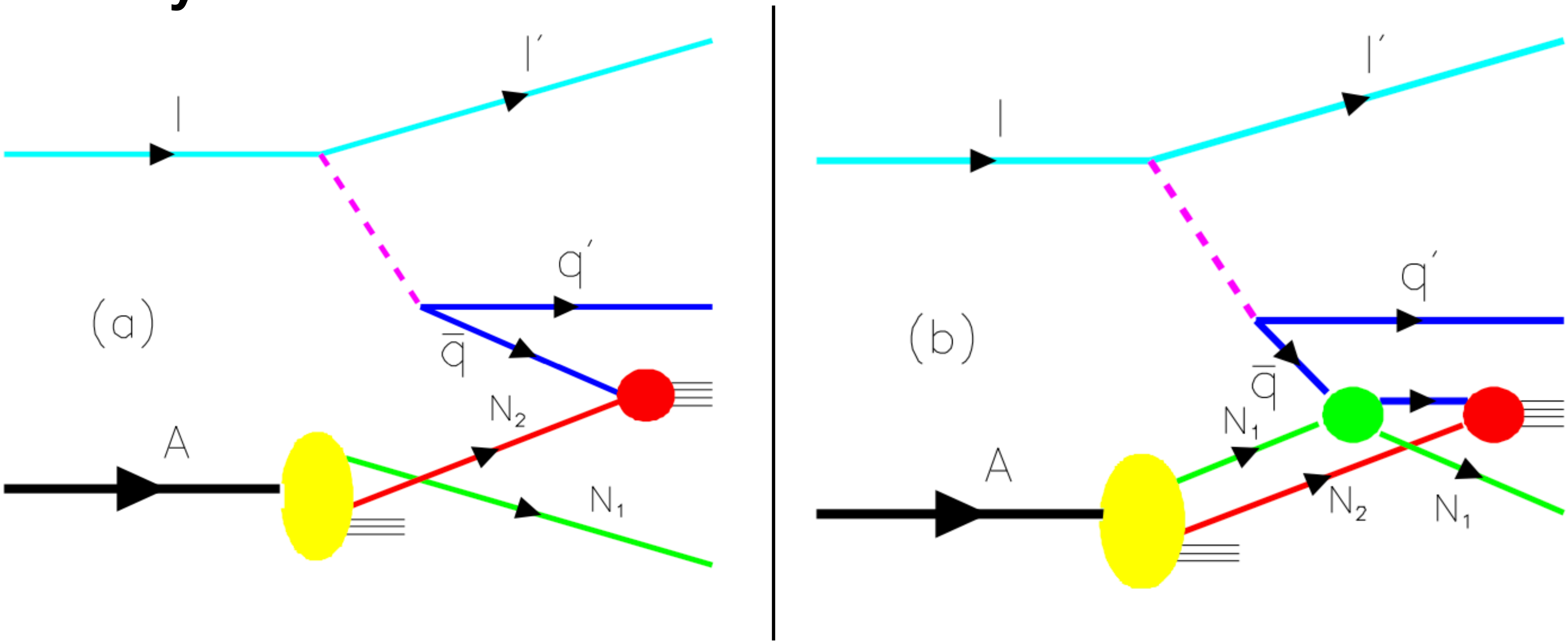
Exchange boson fluctuates into $q\bar{q}$ pair

The $\bar{q}$ interacts *softly* with nucleon N_1 by pomeron exchange, then goes on to interact strongly with N_2

Nucleon N_1 emerges intact

Interference between the two processes!

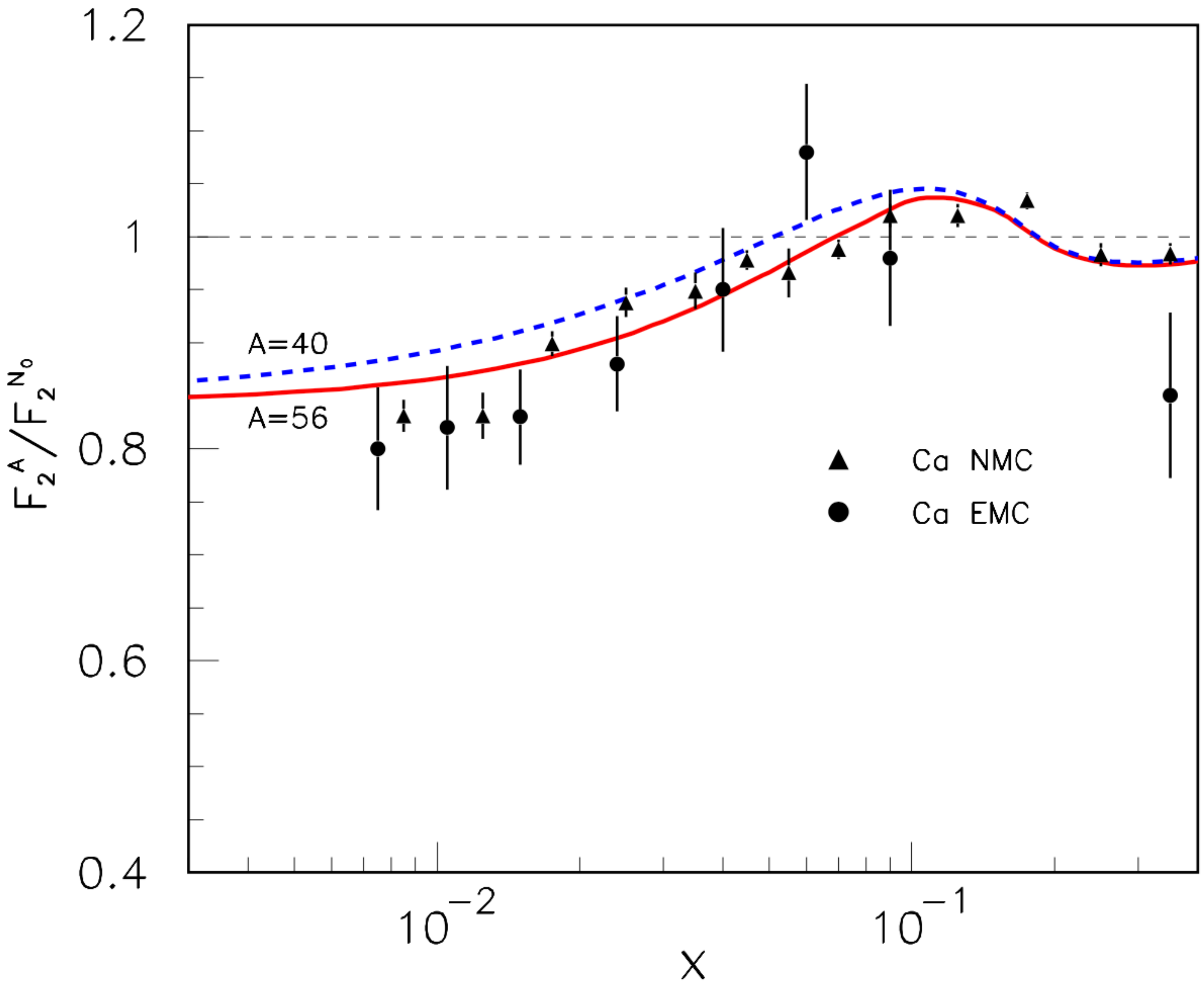
Brodsky-Schmidt



The one-step (a) and two-step (b) processes in DIS on a nucleus. If the scattering on nucleon N_1 is via Pomeron exchange, the one-step and two-step amplitudes are **opposite in phase**, thus diminishing the $\bar{q}$ flux reaching N_2. This causes **shadowing** of the charge and neutral current nuclear structure functions.

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.70.116003

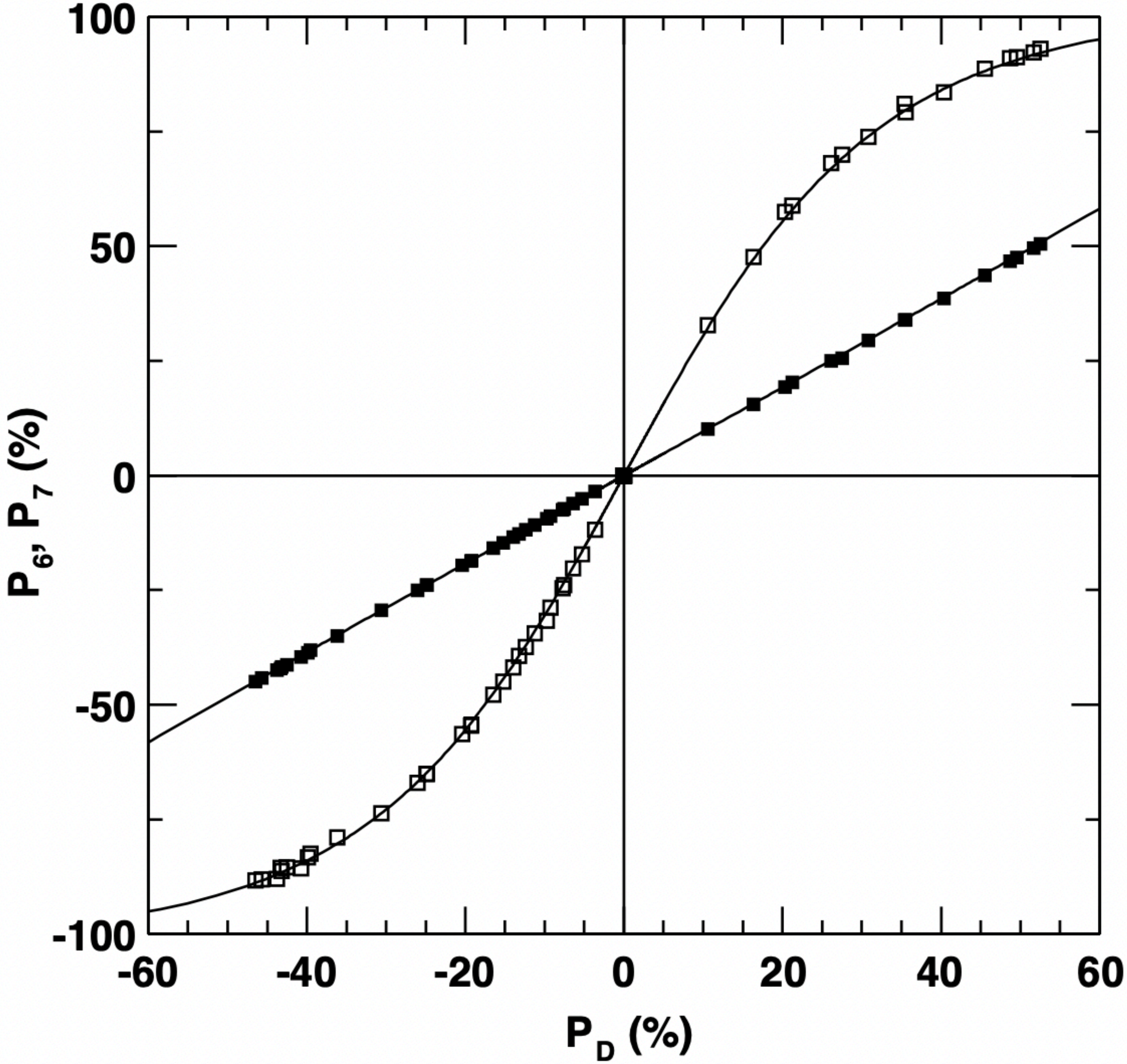
Brodsky-Schmidt: Pomeron, Reggion, Odderon



- Introducing the Reggion and the Odderon creates the possibility of having **constructive** interference, producing **anti-shadowing**.

- No polarization prediction yet in this approach

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.70.116003



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.

Glauber-Gribov Picture in DIS

- The Diffractive contribution to DIS (DDIS) where the nucleon absorbing a pomeron remains intact, is a constant fraction of the total DIS rate ➙ that process is *leading twist*.

- Bjorken scaling of DDIS was observed at HERA.

https://journals.aps.org/prd/abstract/10.1103/PhysRevD.70.116003