Tagged EMC Measurements at EIC

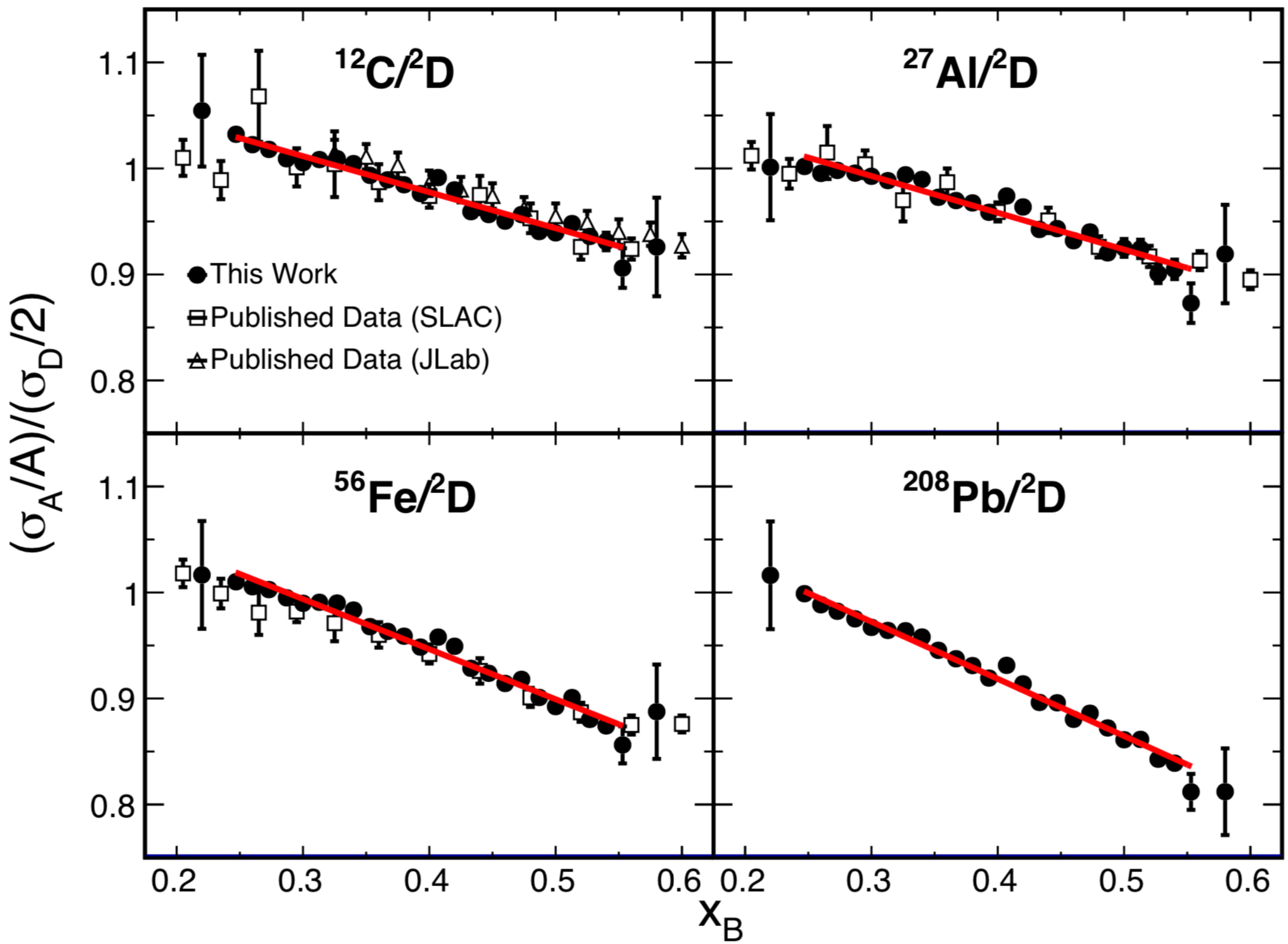
Florian Hauenstein,
EIC Workshop
01/23/20

Overview

- EMC-SRC Recap
- Tagged DIS-SRC
  - JLab12
  - EIC
- Status of EIC simulations
- Outlook and Summary

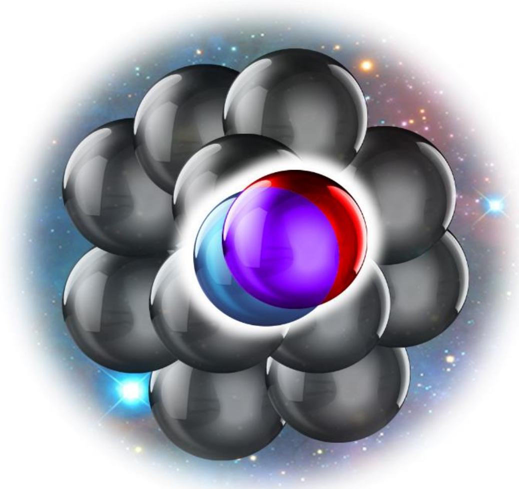
EMC Effect in Different Nuclei

B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)

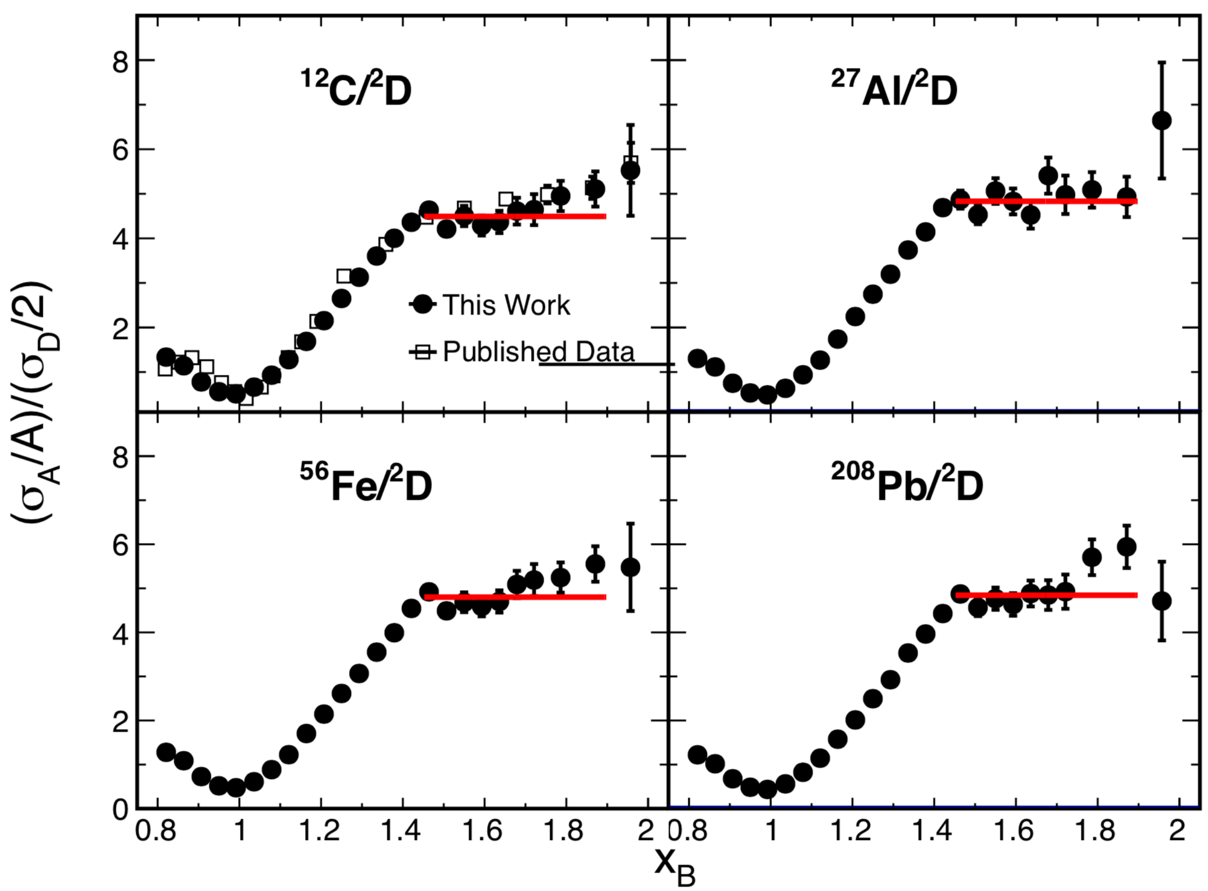


SRC Recap (see talks yesterday)

https://indico.bnl.gov/event/6799/timetable/#20200122



- Nucleon pairs that are close together in the nucleus
- *high relative* and *lower c.m.* momentum compared to the Fermi momentum $\mathbf{k_F}$



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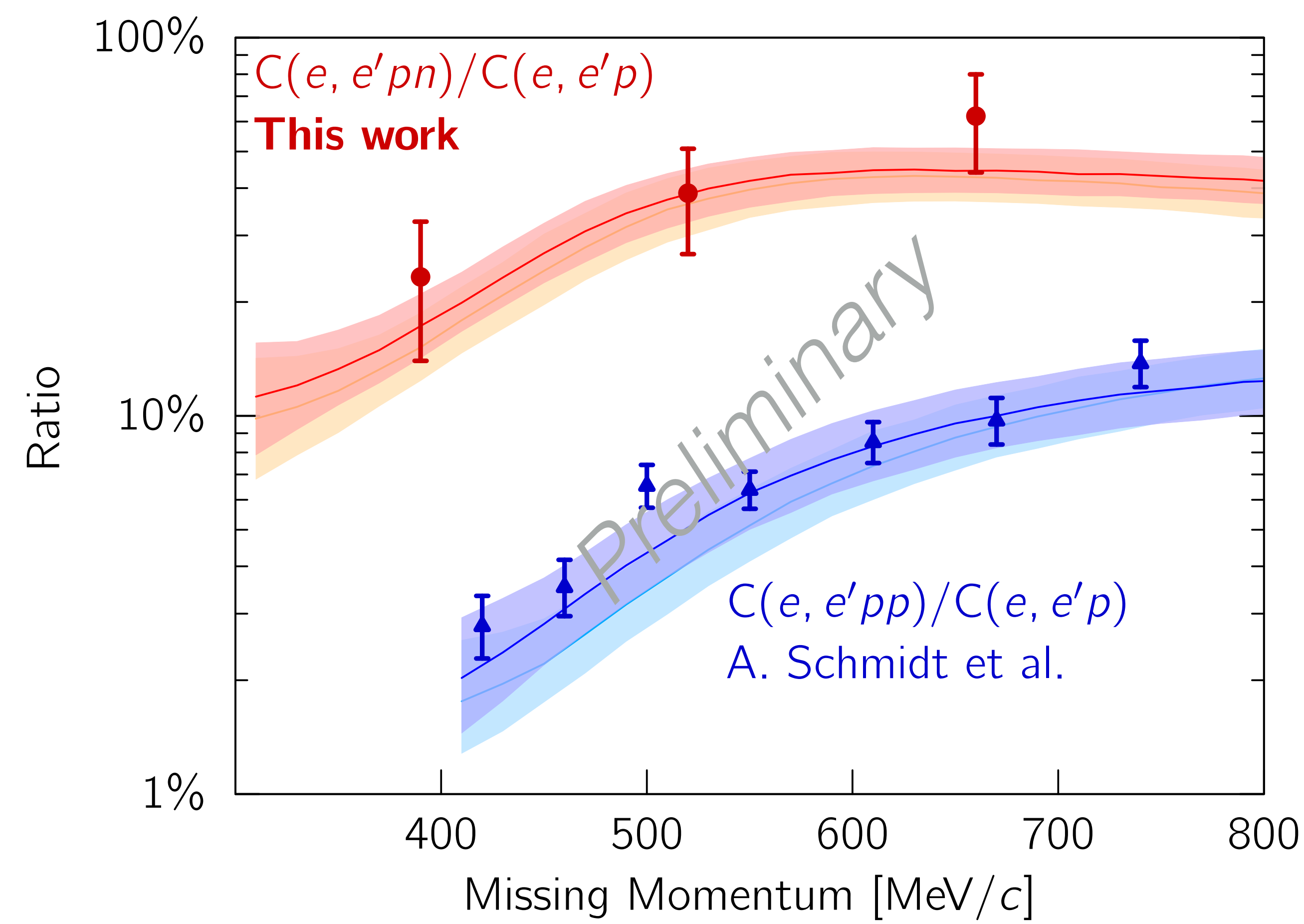
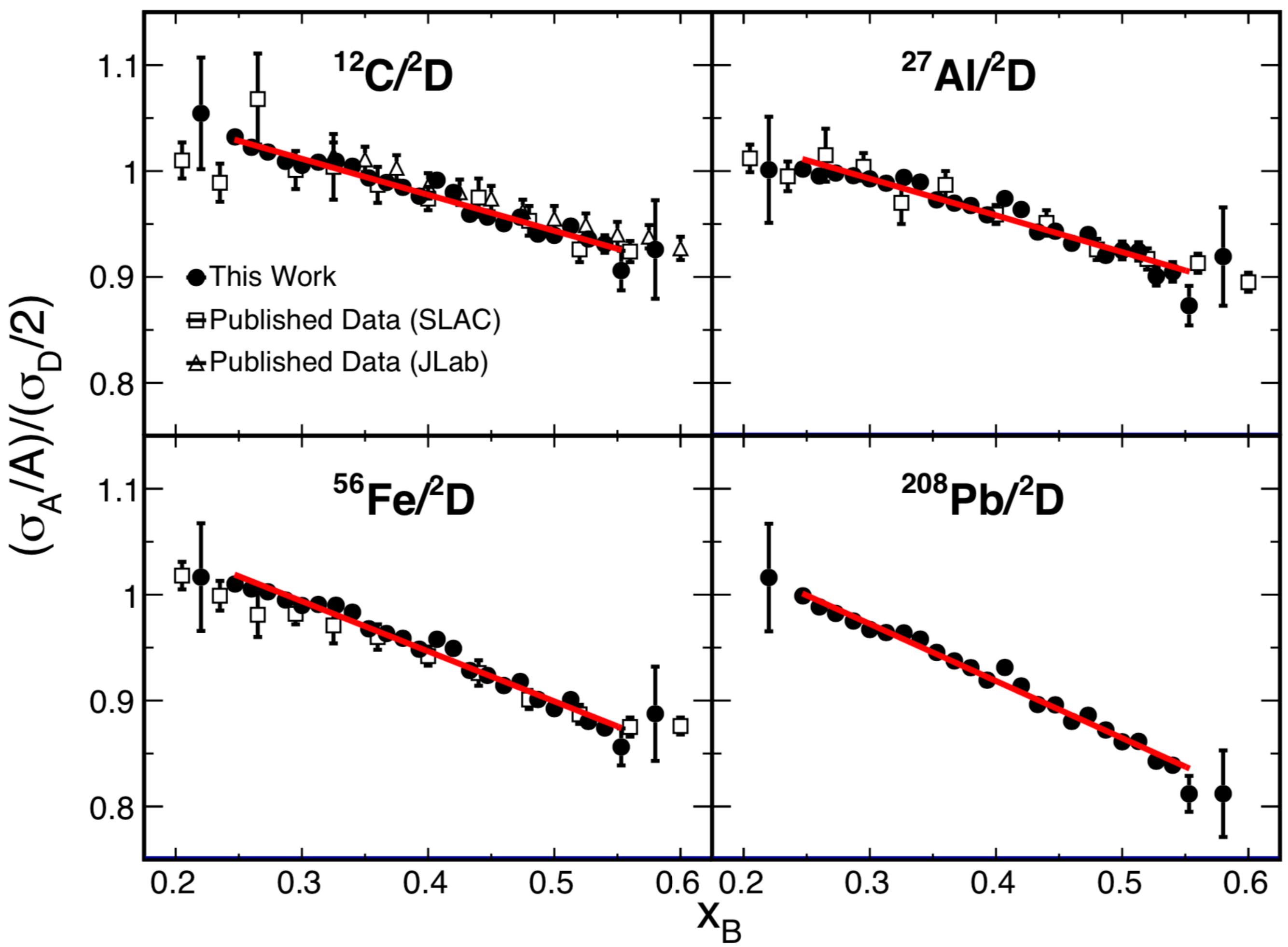


from Jackson Pybus' talk

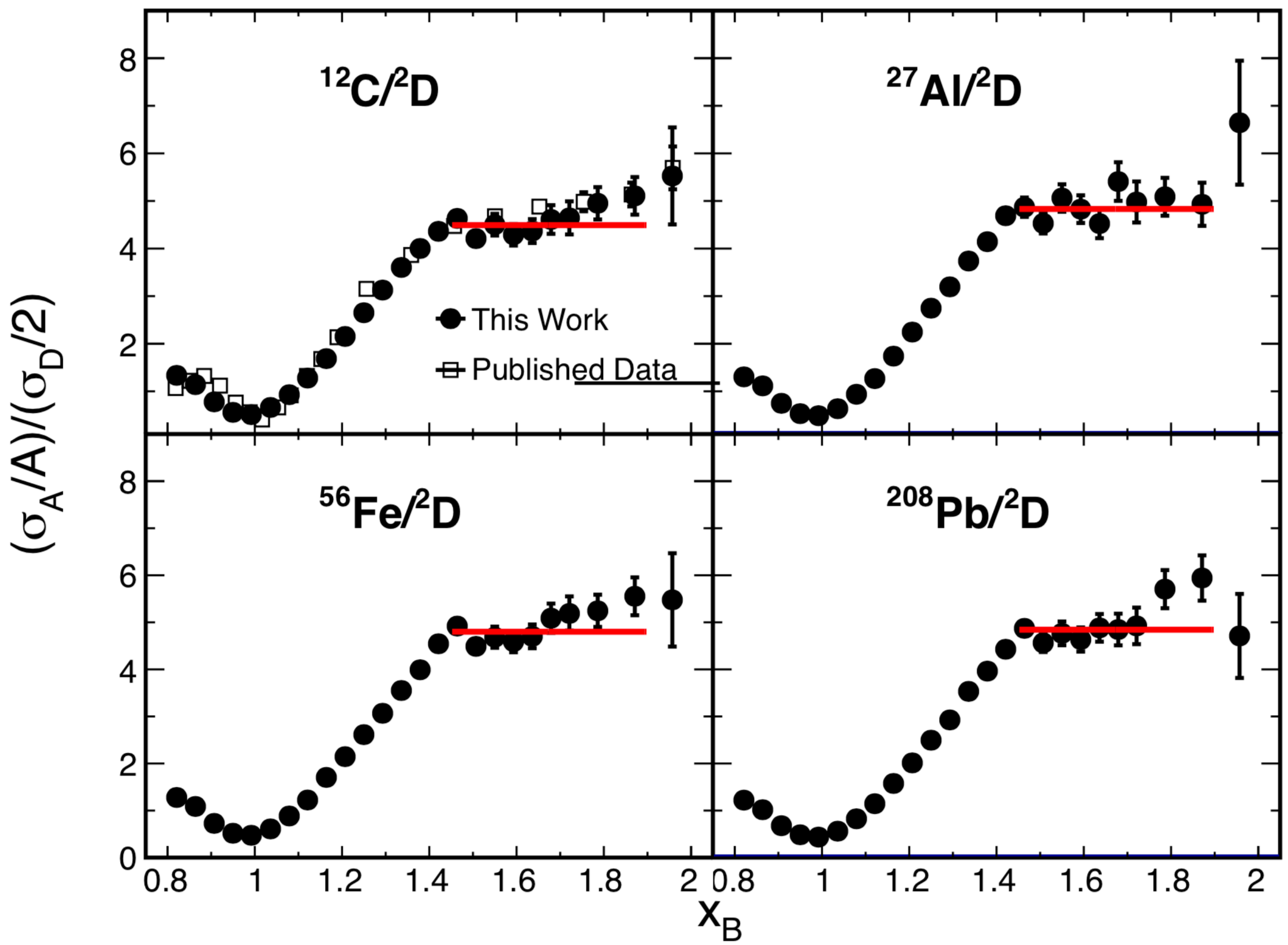
EMC - SRC correlation

B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)

DIS



Quasi-Elastic

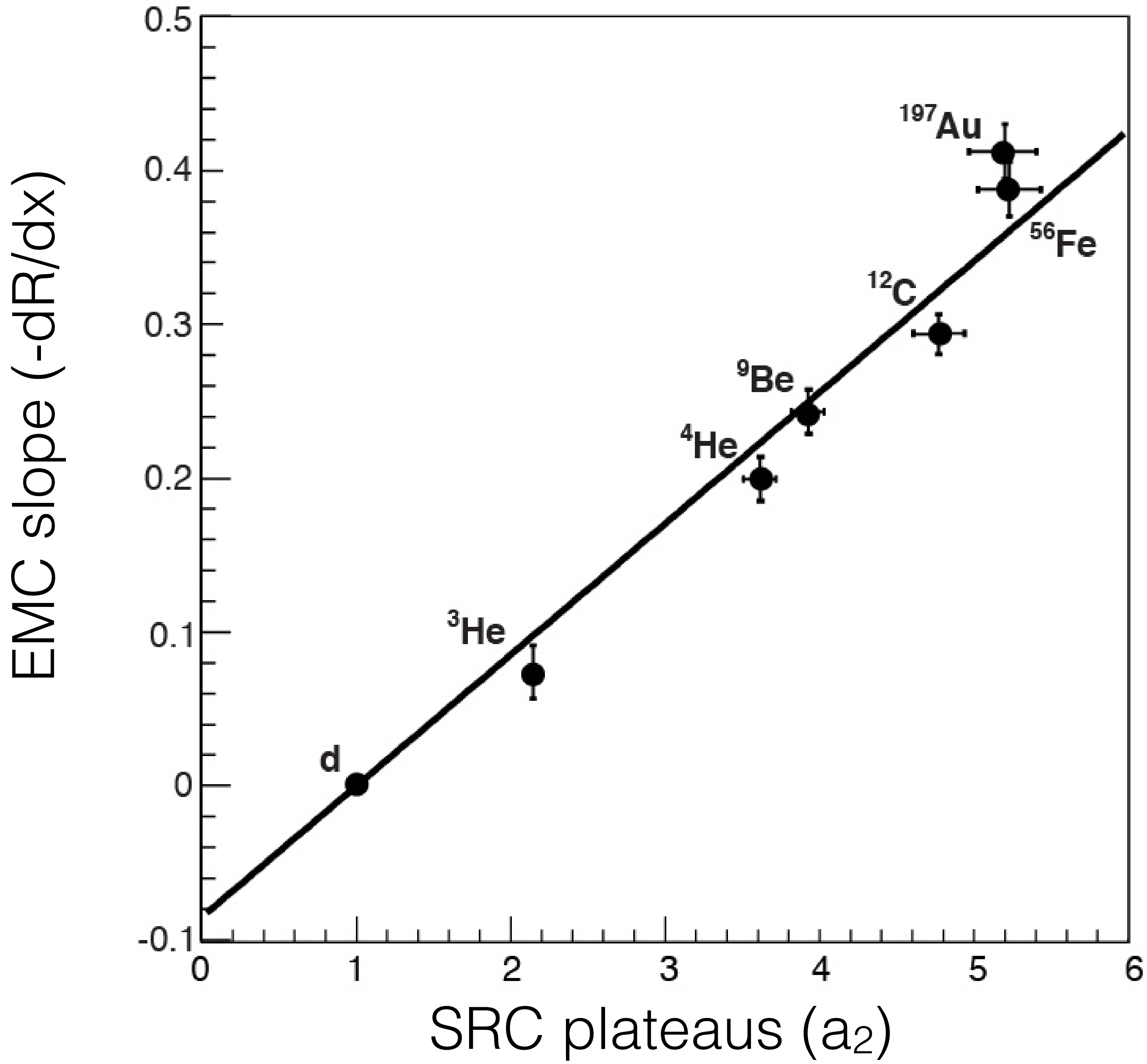


—> EMC slope

—> SRC plateaus (a_2)

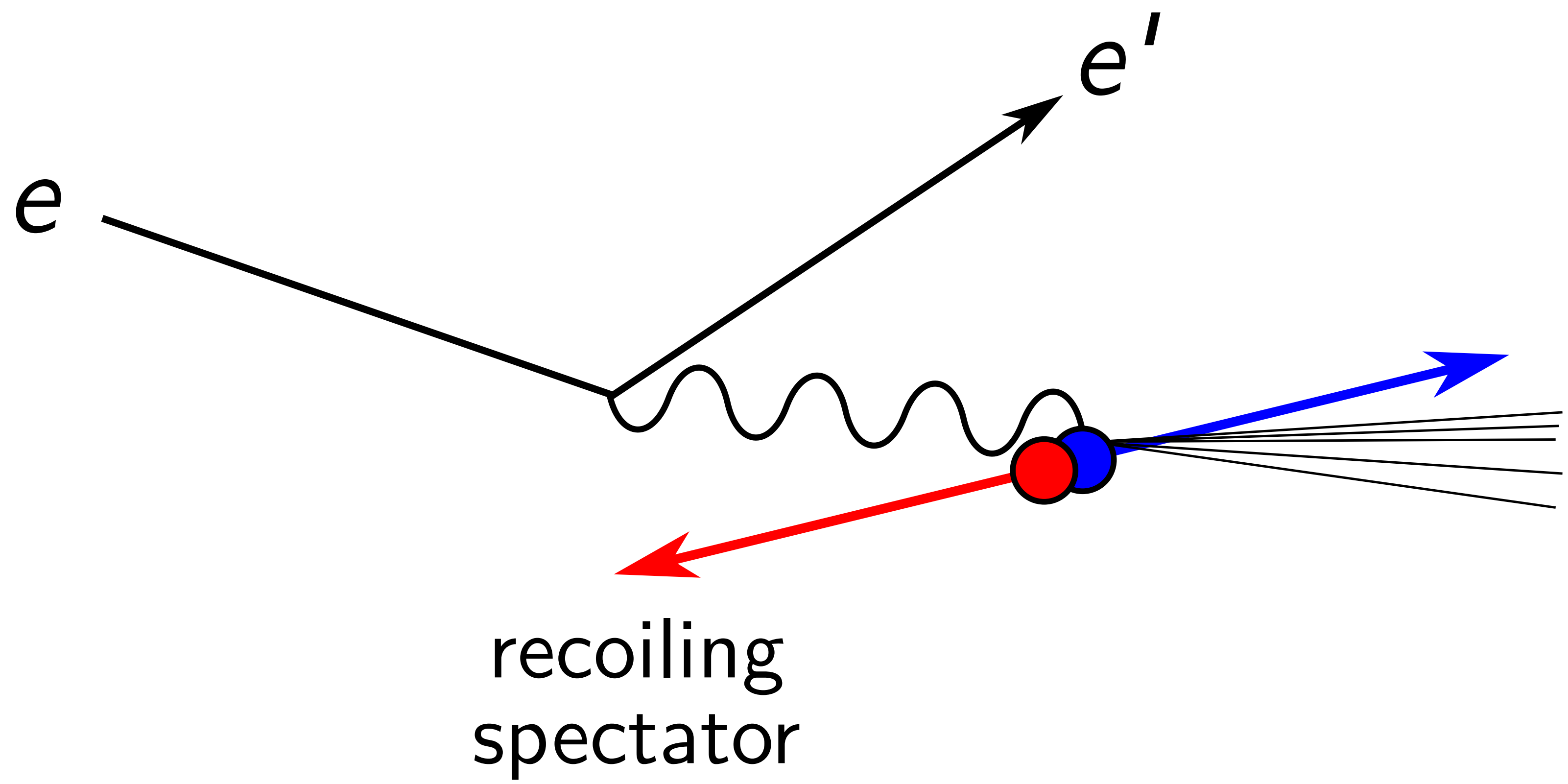
EMC - SRC Correlation

Weinstein et al., PRL 106, 052301 (2011), Hen et al.,PRC 85, 047301(2012)



- Are high-momentum nucleons responsible for the EMC effect?

Tagged DIS on Deuterium



- “Tag“ interacting nucleon by measuring spectator
- How does the bound nucleon structure function depend on bound nucleon virtuality $v = p^2 - m^2$
- Explaining the EMC effect

Tagged DIS: What will be measured

- Measuring cross section ratios to minimize uncertainties

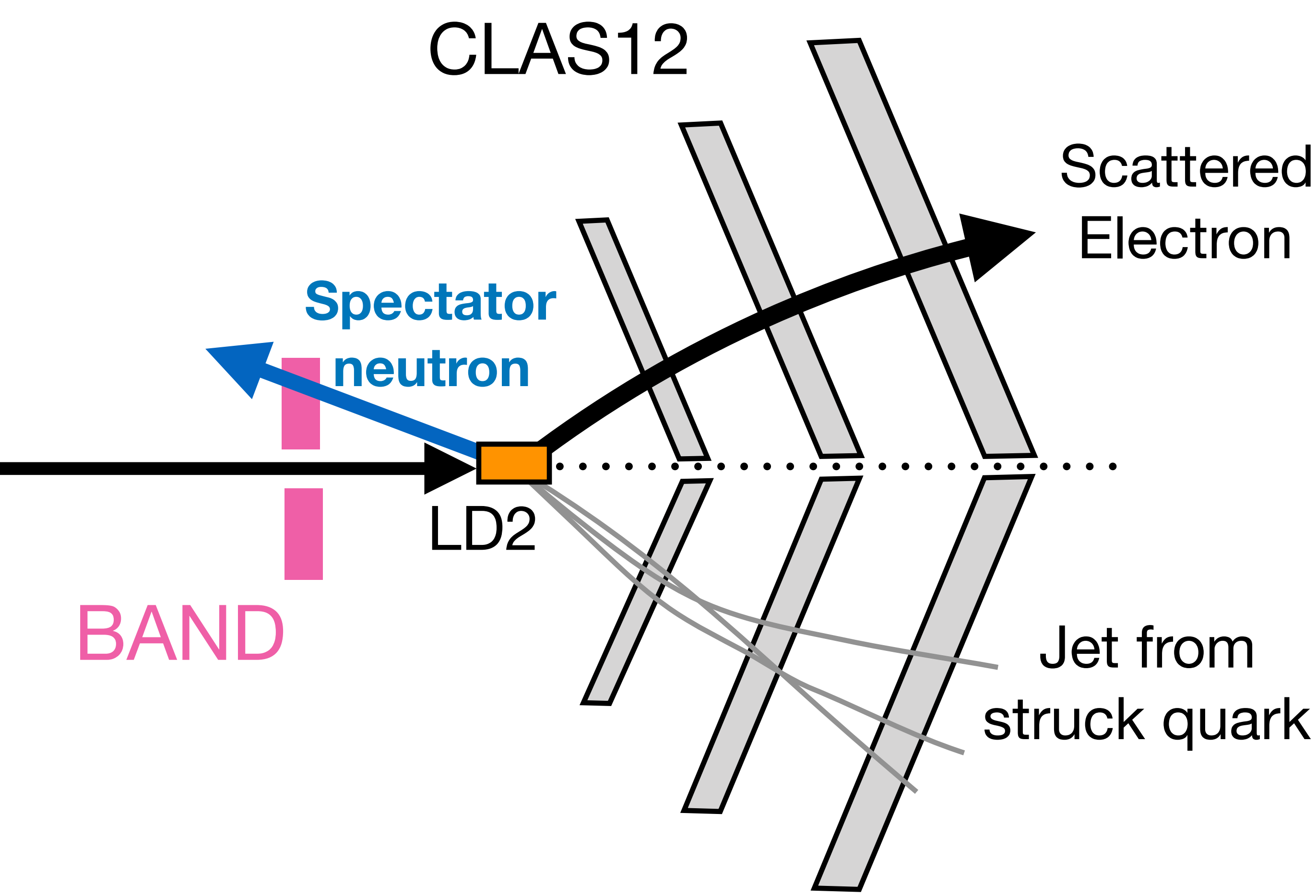
$$\frac{F_2^{\text{bound}}(x'_{\text{high}}, Q_1^2, \alpha_s)}{F_2^{\text{free}}(x_{\text{high}}, Q_1^2)} = \boxed{\frac{\sigma_{DIS}(x'_{\text{high}}, Q_1^2, \alpha_s)}{\sigma_{DIS}(x'_{\text{low}}, Q_2^2, \alpha_s)}} \cdot \boxed{\frac{\sigma_{DIS}^{\text{free}}(x_{\text{low}}, Q_2^2)}{\sigma_{DIS}^{\text{free}}(x_{\text{high}}, Q_1^2)}}$$

measurement theory

- minimal FSI $\theta_{rq} > 107^{\circ}$
- $x' = x$ for moving nucleon $= Q^2/(2p \cdot q)$

Tagged DIS at JLab

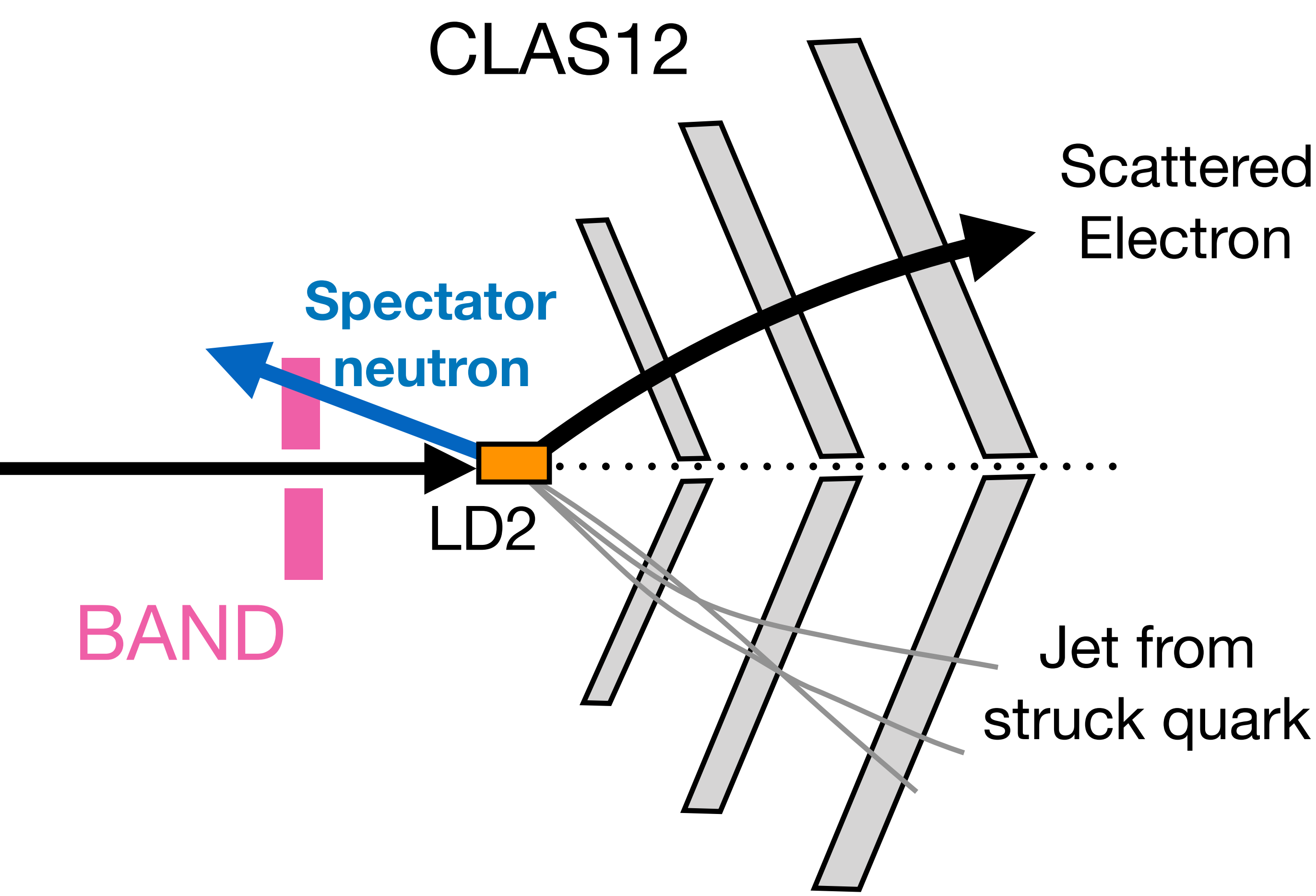
Hall B:
CLAS 12 + Backward Angle Neutron Detector (BAND)



- Took first data in Spring 19
- Taking more data now

Tagged DIS at JLab

Hall B:
CLAS 12 + Backward Angle Neutron Detector (BAND)



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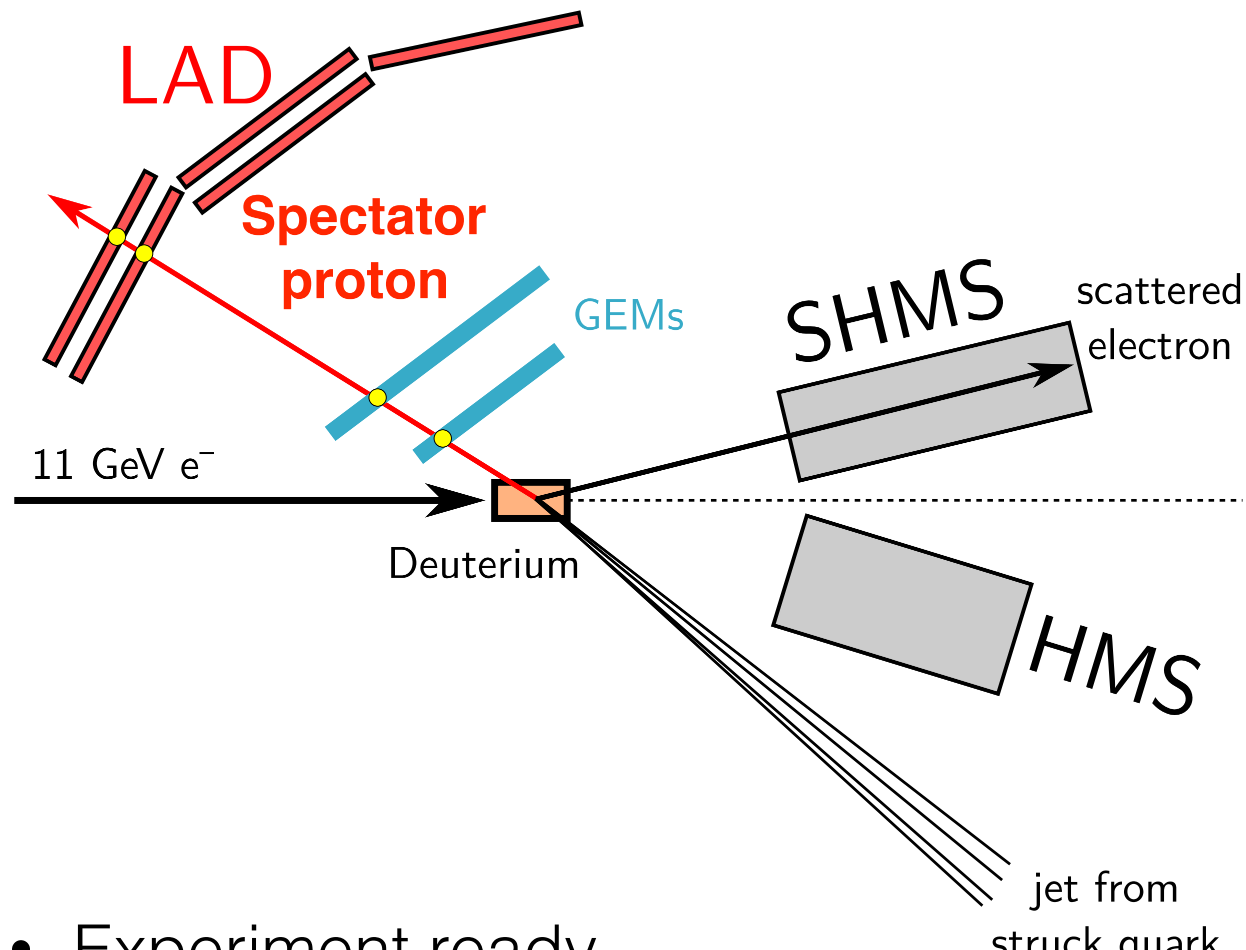
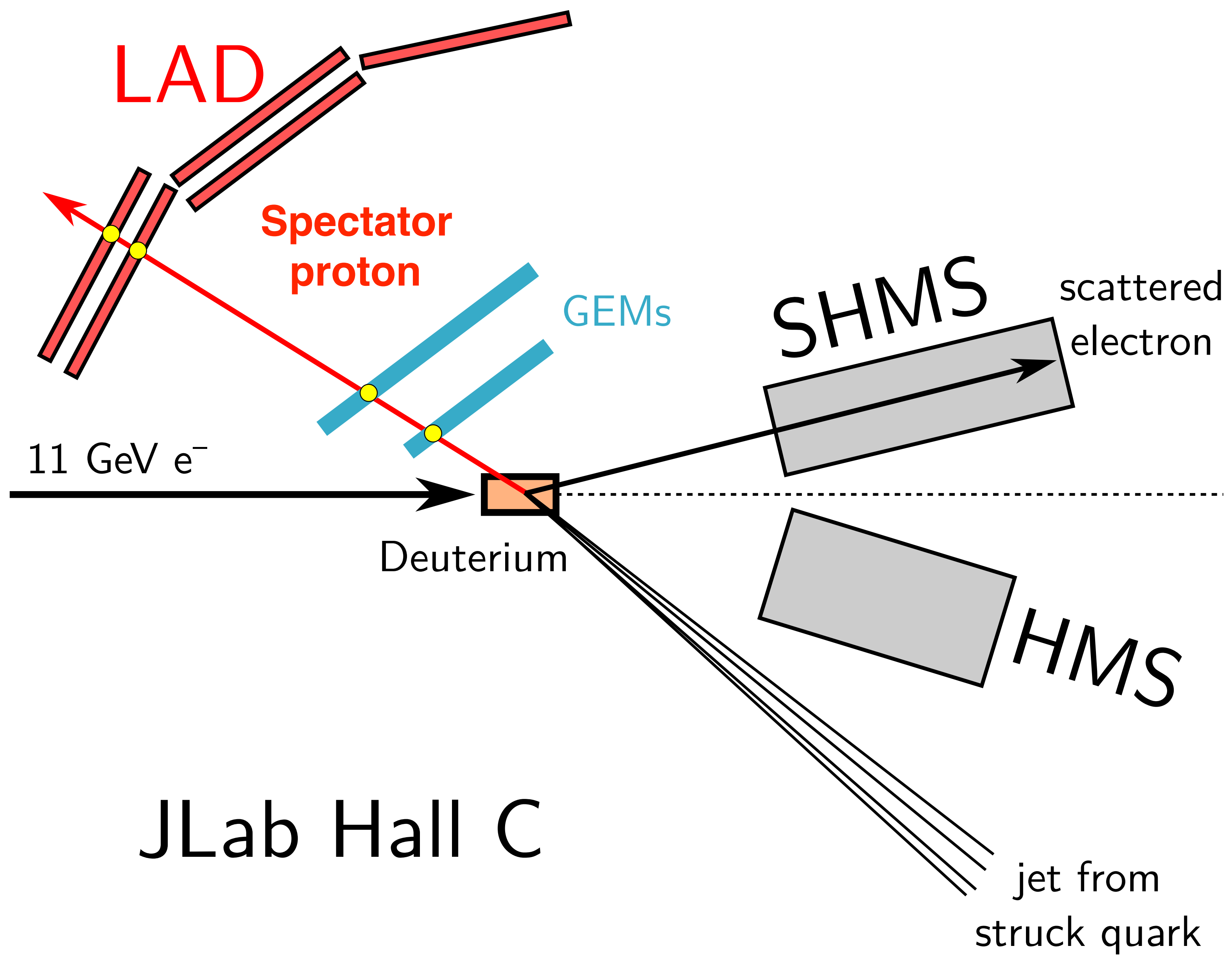
Hall C:
SHMS/HMS + Large Angle Detector (LAD)

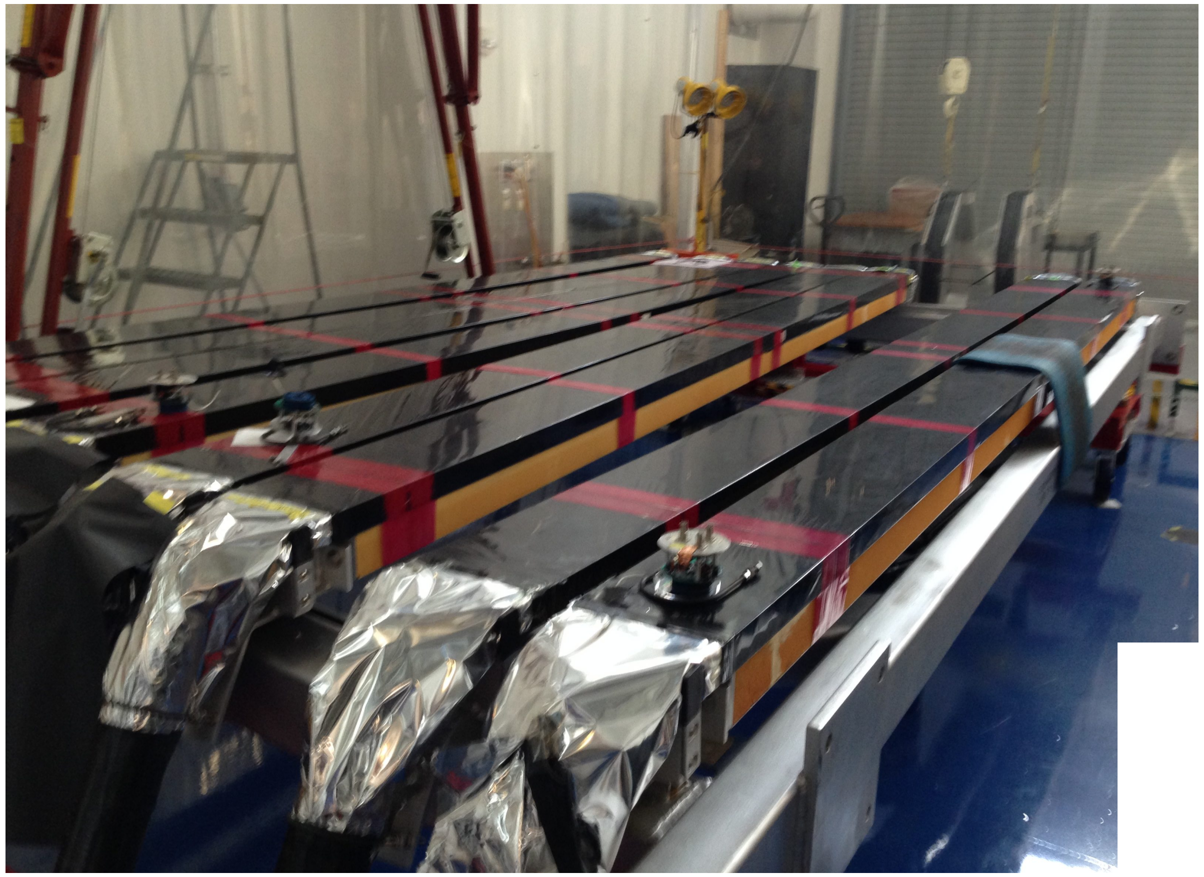


- Experiment ready
- GEMs from PRAD experiment
- Run in 2022?

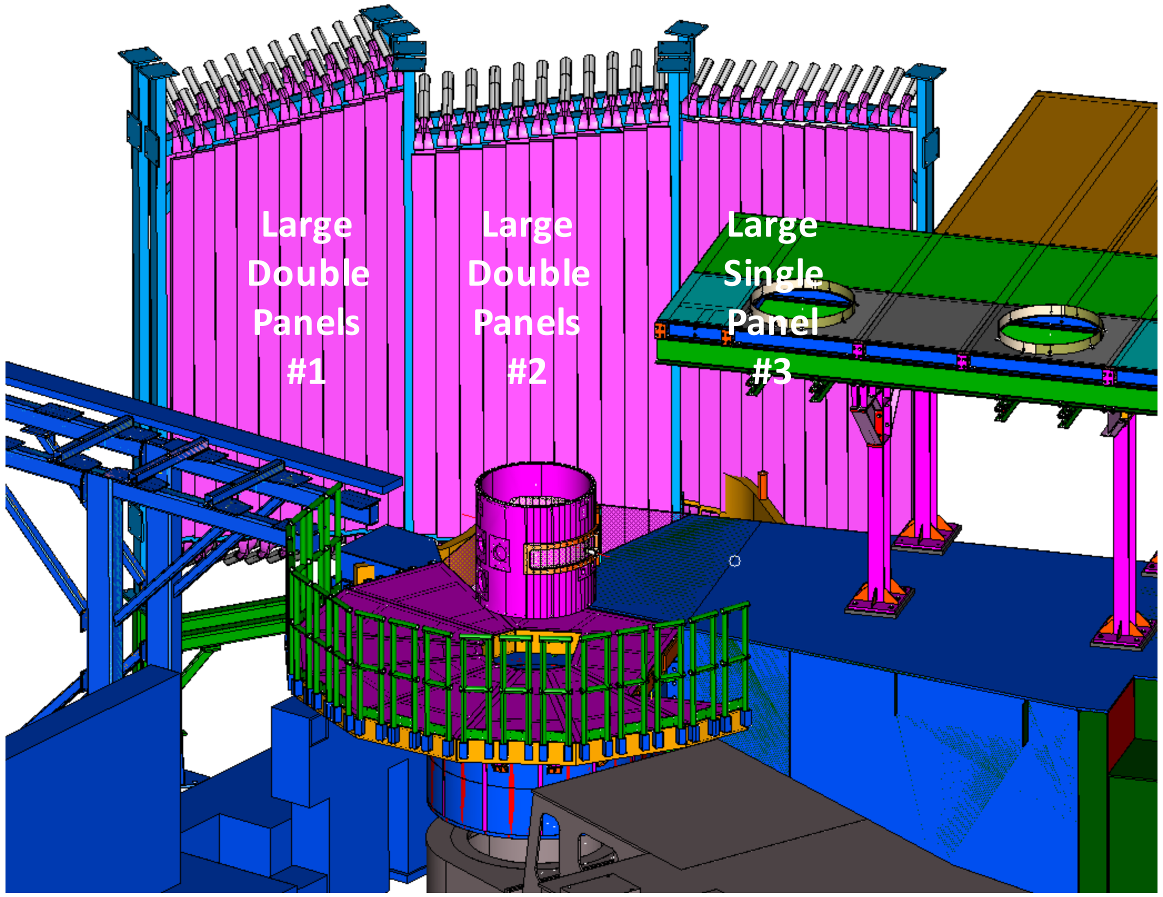
LAD in Hall-C


LAD
Spectator
proton
GEMs
SHMS
scattered
electron
11 GeV e⁻
Deuterium
HMS
JLab Hall C
jet from
struck quark

LAD - Refurbished CLAS6 Scintillators



- 4m long, 5 panels, 55 bars
- 6m away from the target
- coverage 90 - 157 degree
- ~200ps time resolution



LAD - BAND Comparison

BAND:

- ~ 10^{35} $cm^{-2}s^{-1}$ luminosity
- No tracking of neutrons
- Some regions with high material between target and BAND
- x' coverage: 0.2 - 0.5

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LAD:

- ~ 10^{36} $cm^{-2}s^{-1}$ luminosity
- Proton tracking with GEMs
- Low material budget between target and LAD
- x' coverage: 0.2 - 0.6

LAD - BAND Comparison

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- Proton tracking with GEMs
- Low material budget between target and LAD
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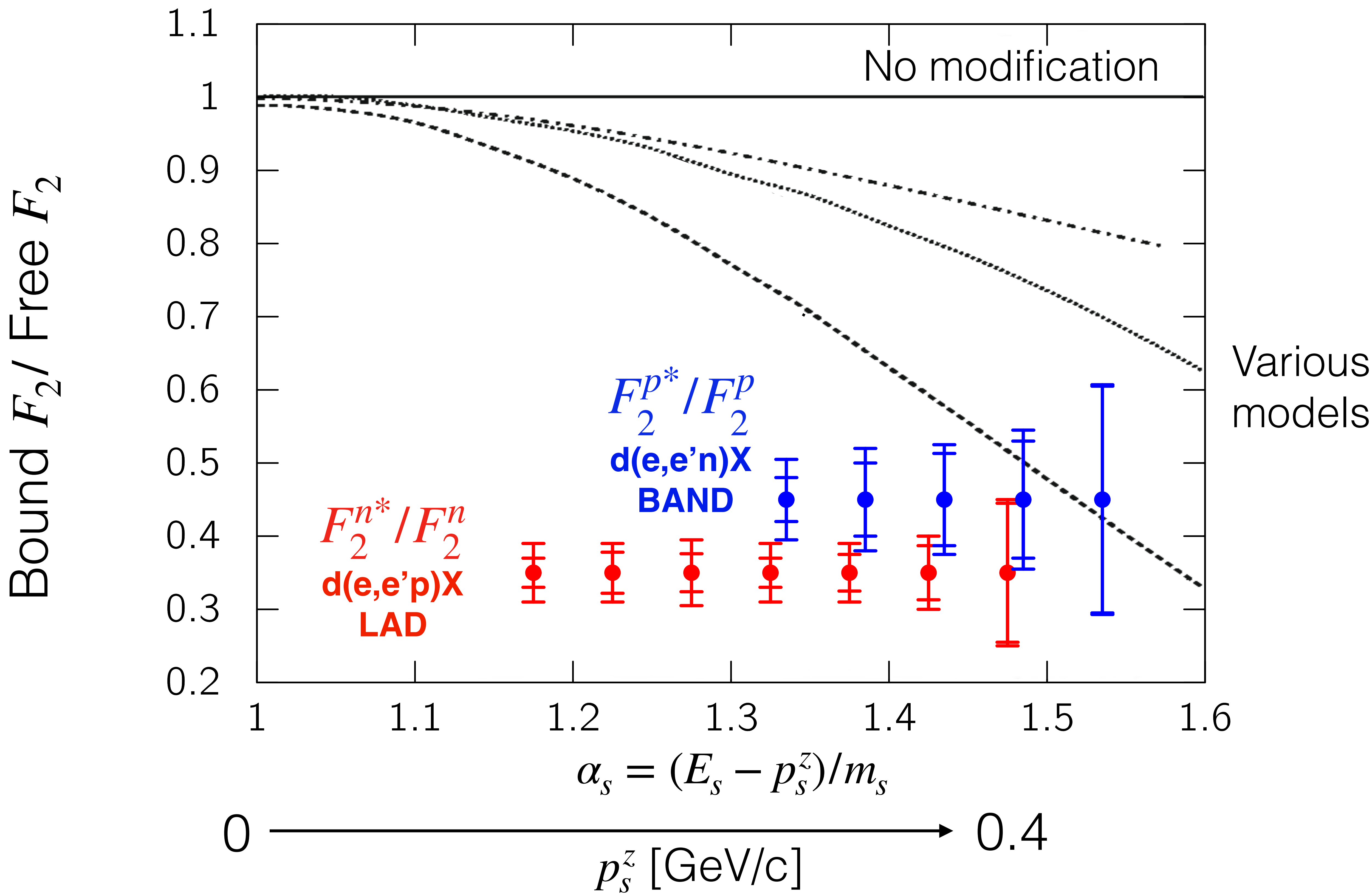
LAD wins!

—> reduced (accidental) background
—> higher luminosity
—> higher x' coverage

DIS Recoil Tagging d(e,e'N)X - Expected Results



Tagged DIS at EIC

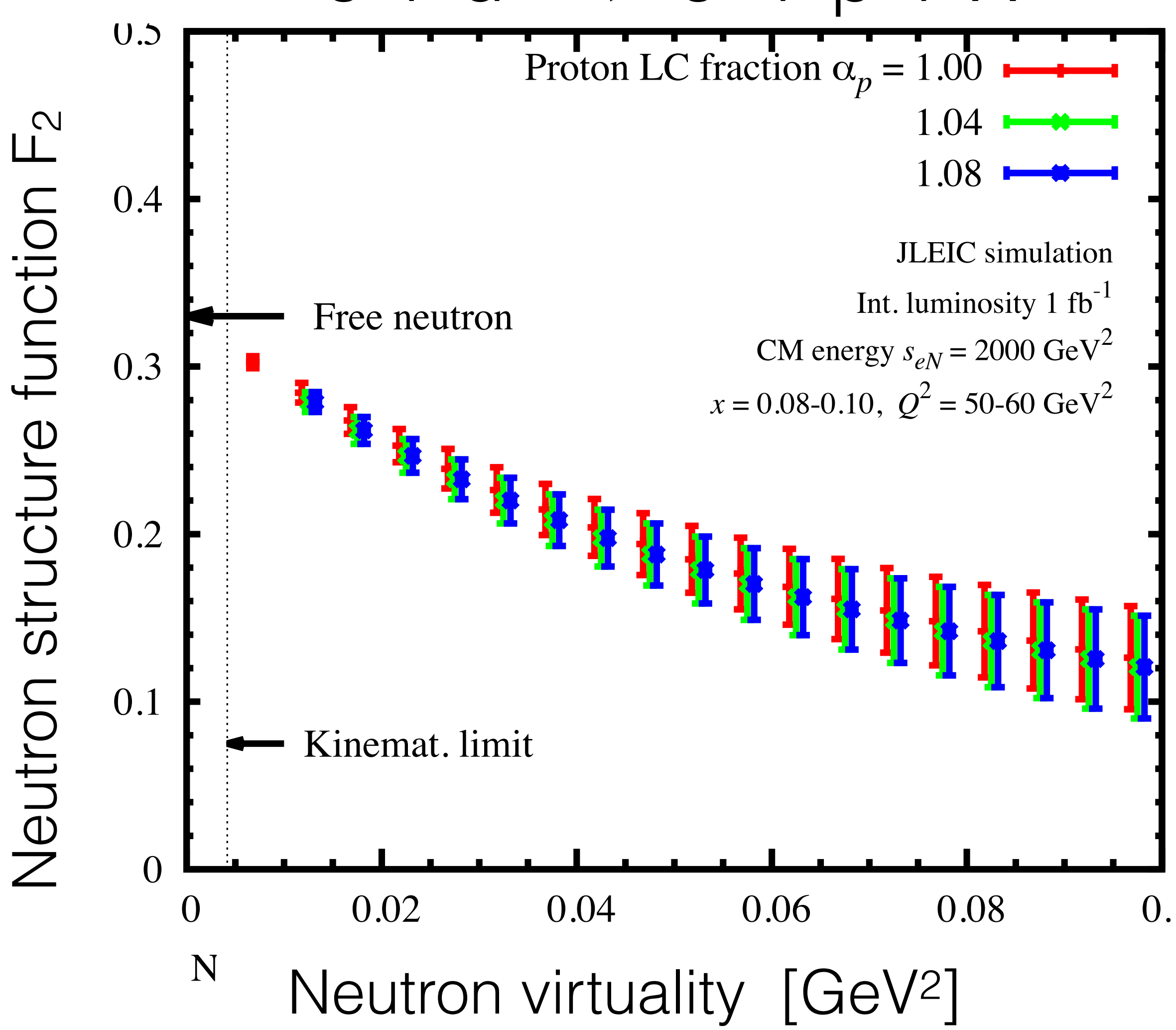
Jefferson Labs' LDRD project (2014/15)
``*Physics potential of polarized light ions with EIC@JLab*"

Webpage: https://www.jlab.org/theory/tag/

- Polarized deuterons (vector/tensor)
- A > 2 nuclei
- Proton and Neutron tagging
- Exclusive processes

- Advantages at EIC
  - Detection of low momentum recoils
  - Higher Q^2
  - Possible detection of A-2 system

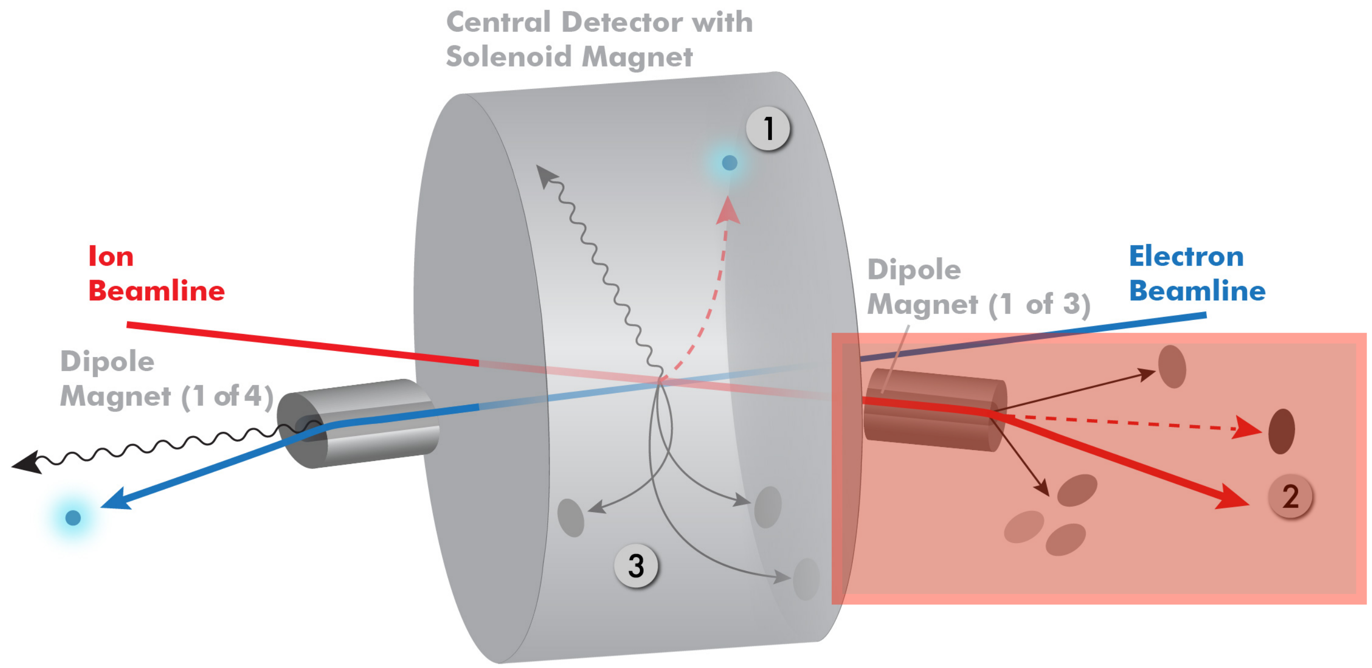
e + d —> e' + p + X



Detection in Forward Ion Direction

- Detection demanding
  - need good resolutions
  - particles down to $p_T = 0$ GeV/c
  - neutral detection

- Detectors
  - roman pots
  - zero degree calorimeter
  - tracking detectors



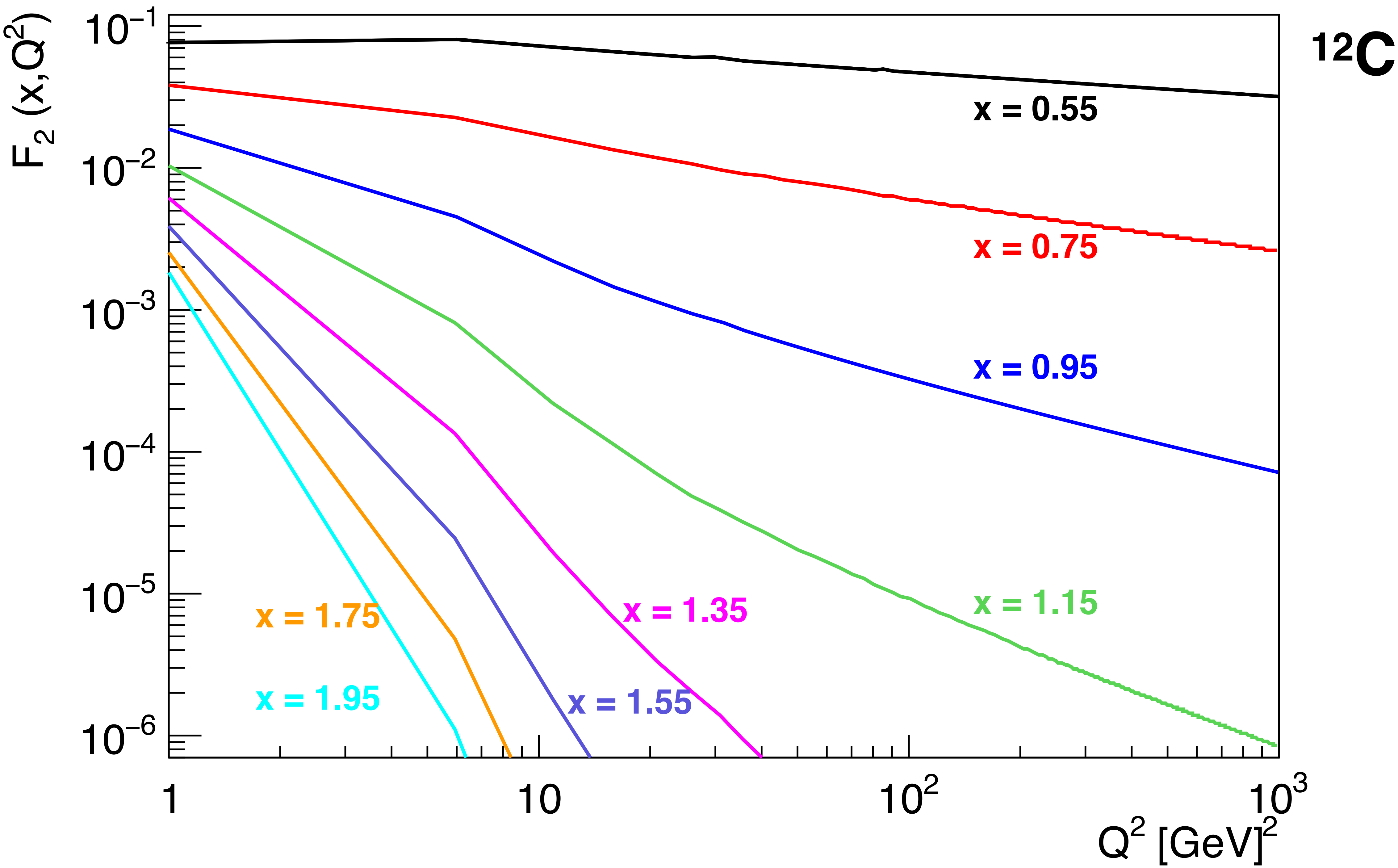
``Tagged SRC for medium and heavy ions at EIC'' (LDRD1912)

- Feasibility of tagged SRC in DIS
  - Rates
  - Resolution
  - Detector requirements (focus on forward direction)
  - Required beam energies

- Tools
  - BeAGLE - eA event generator
  - g4e - Geant4 simulation for EIC

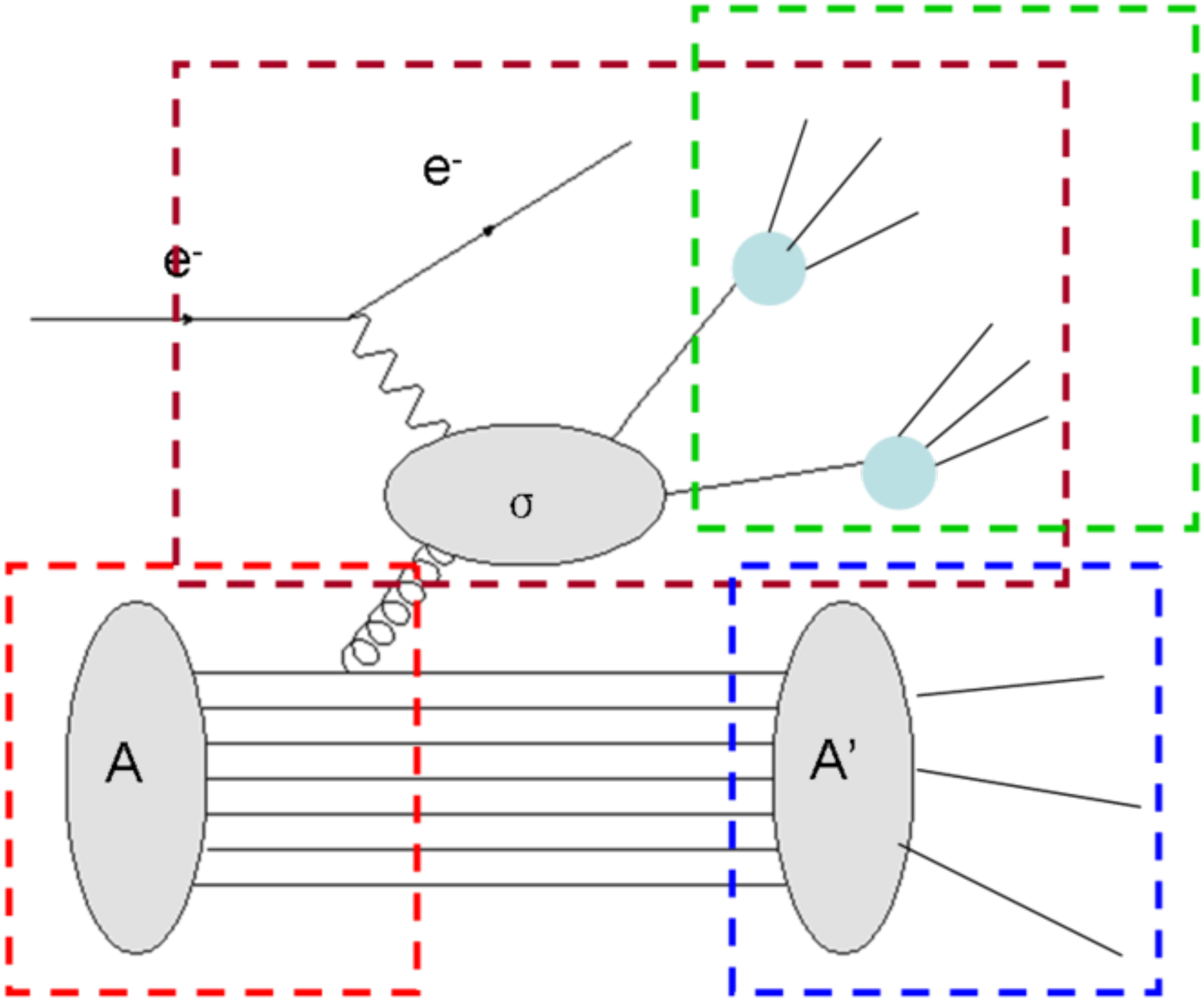
DIS Rates for High-x

based on super-fast quark yield parametrization,
N. Fomin PRL 105, 212502 (2010)
(alternative model: J. Freese et al. Phys. Rev. D 99, 114019)



BeAGLE - Benchmark eA Generator for LEptoproduction

Mark Baker, E. Aschenauer, J.H. Lee, L. Zheng

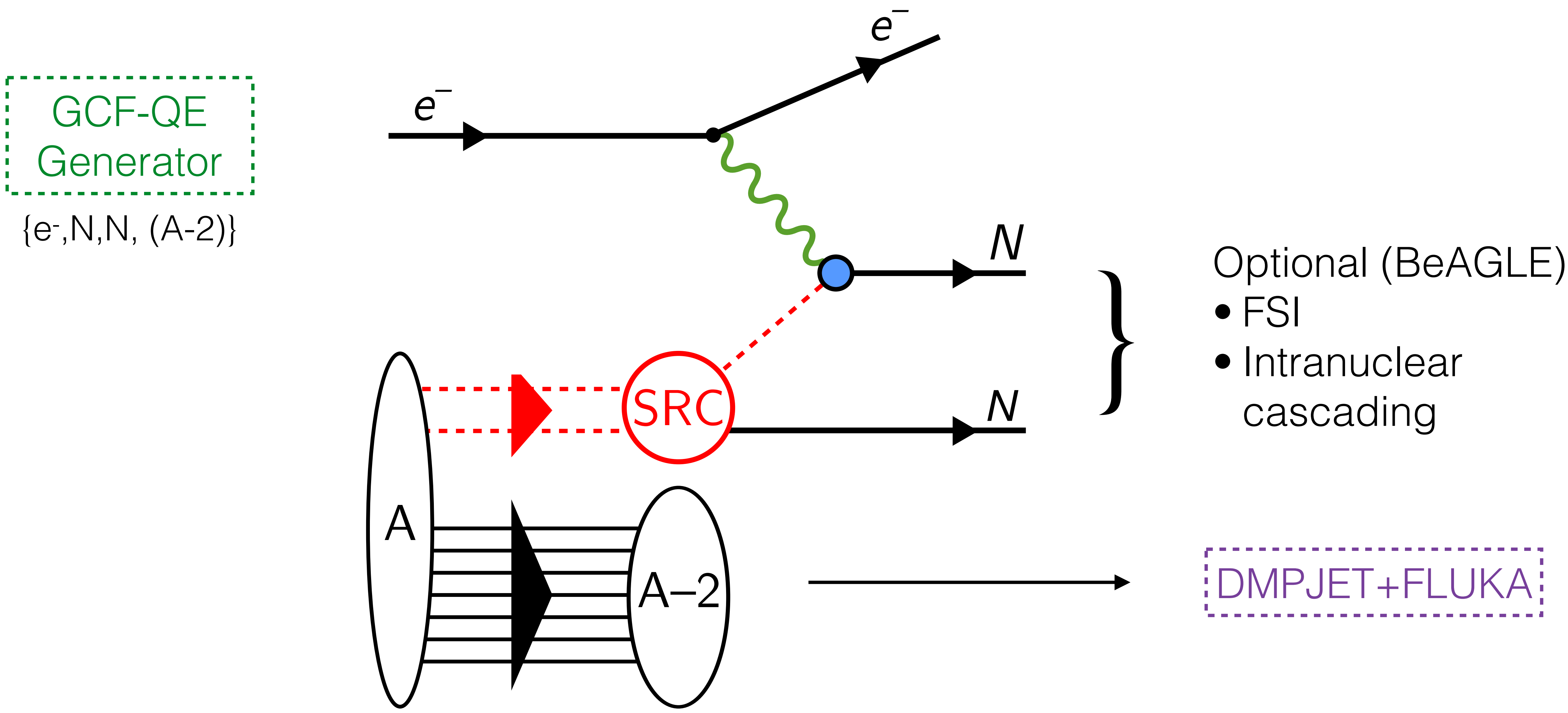


Merger of
- PYTHIA 6 (hard interaction)
- Energy loss of partons: PyQM
- Nuclear environment
  - DPMJET
  - nPDF from EPS09
- Nuclear evaporation by DPMJET3+FLUKA

https://wiki.bnl.gov/eic/index.php/BeAGLE

SRCs in BeAGLE

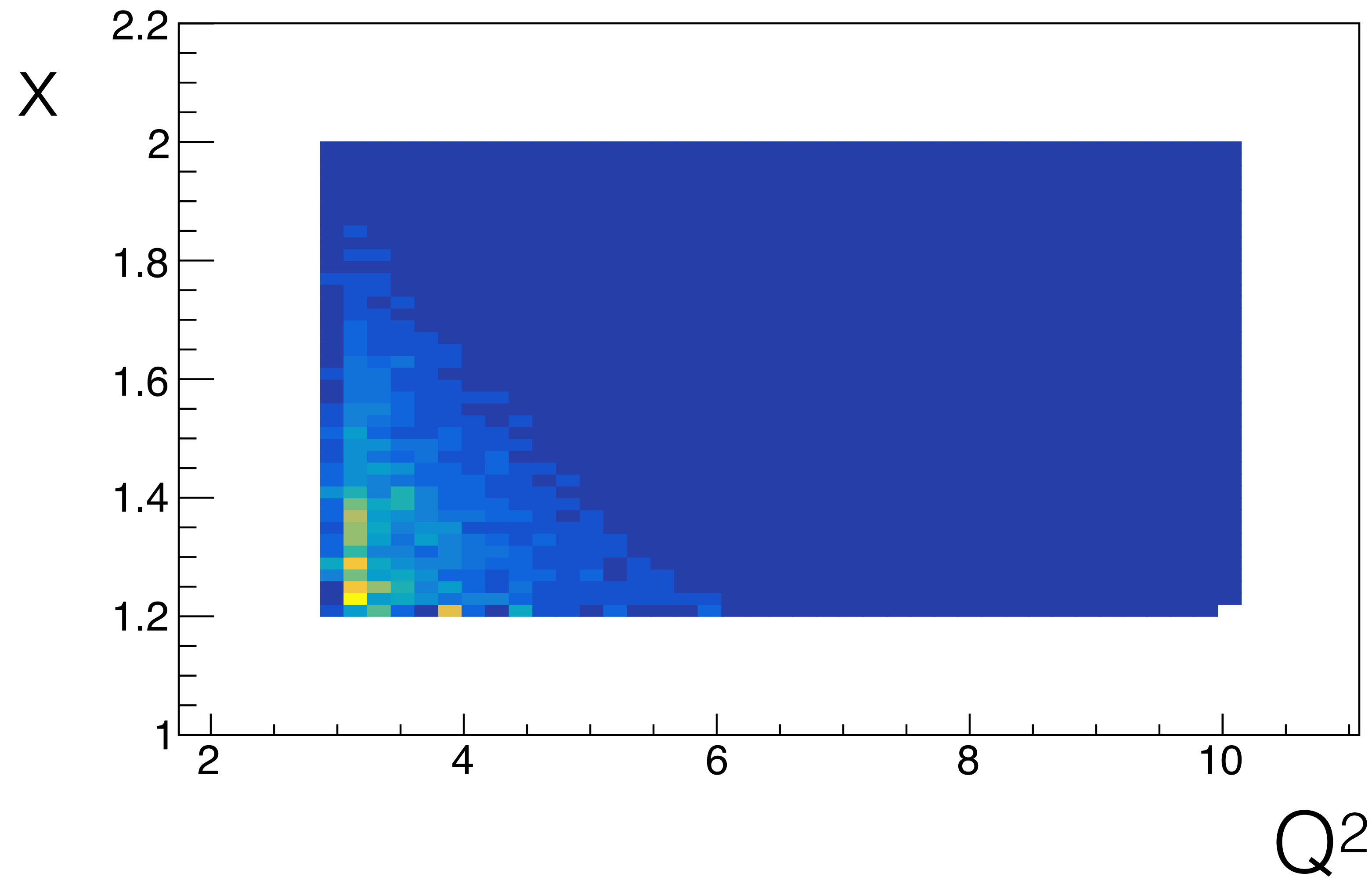
- SRC-DIS in development
  - scaling from deuterium
  - SRC-EMC model
- GCF-Quasielastic (QE) implemented
- (A-2)-system handled by DPMJET3+FLUKA



Quasi-Elastic SRC Simulations for EIC

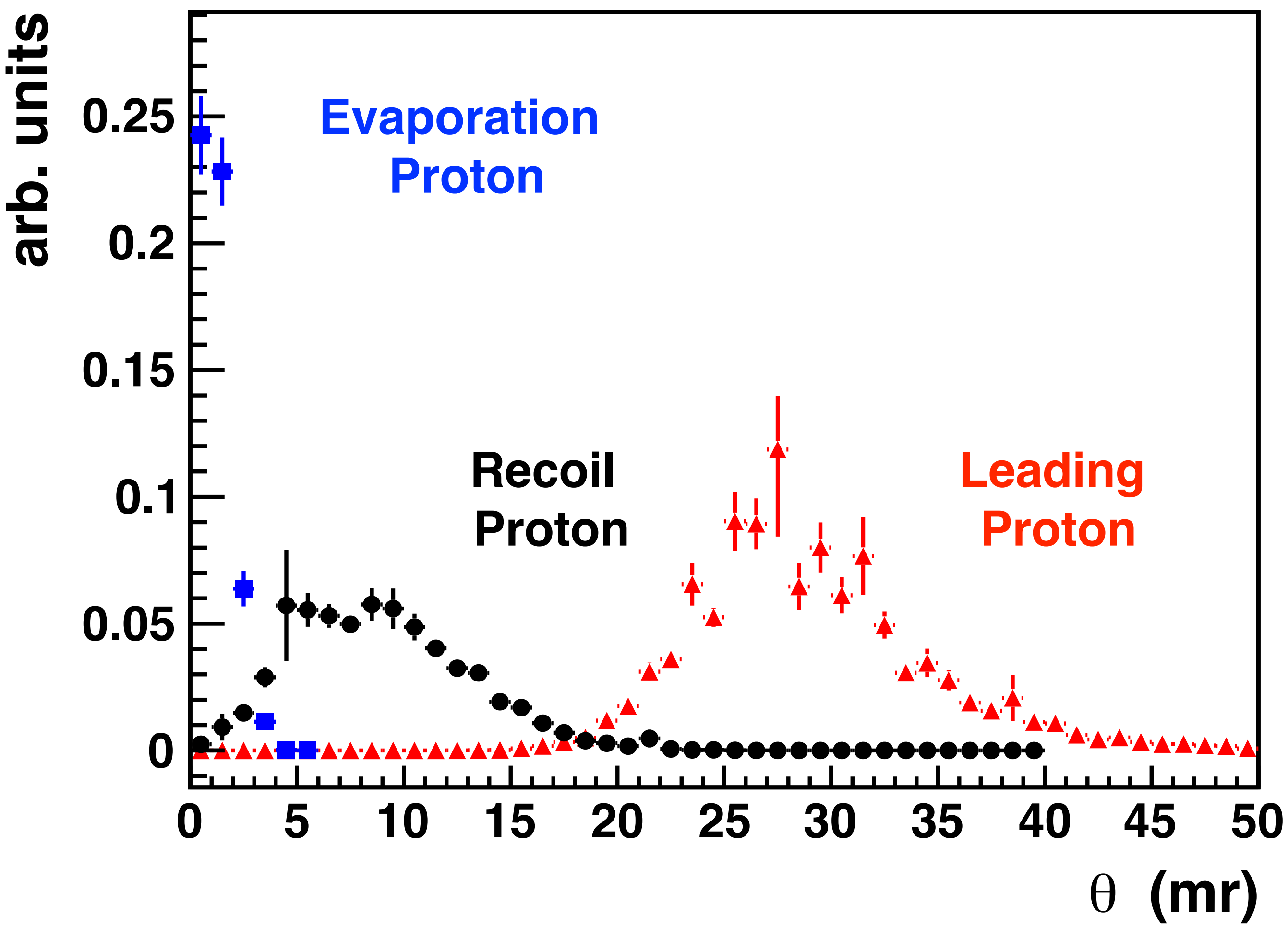
- 5 GeV electrons and 50 GeV carbon head-on
- Interaction point crossing angle applied individually
  - 25 mrad for eRHIC
  - 50 mrad for JLEIC
- Separation of leading, recoil and evaporation nucleons

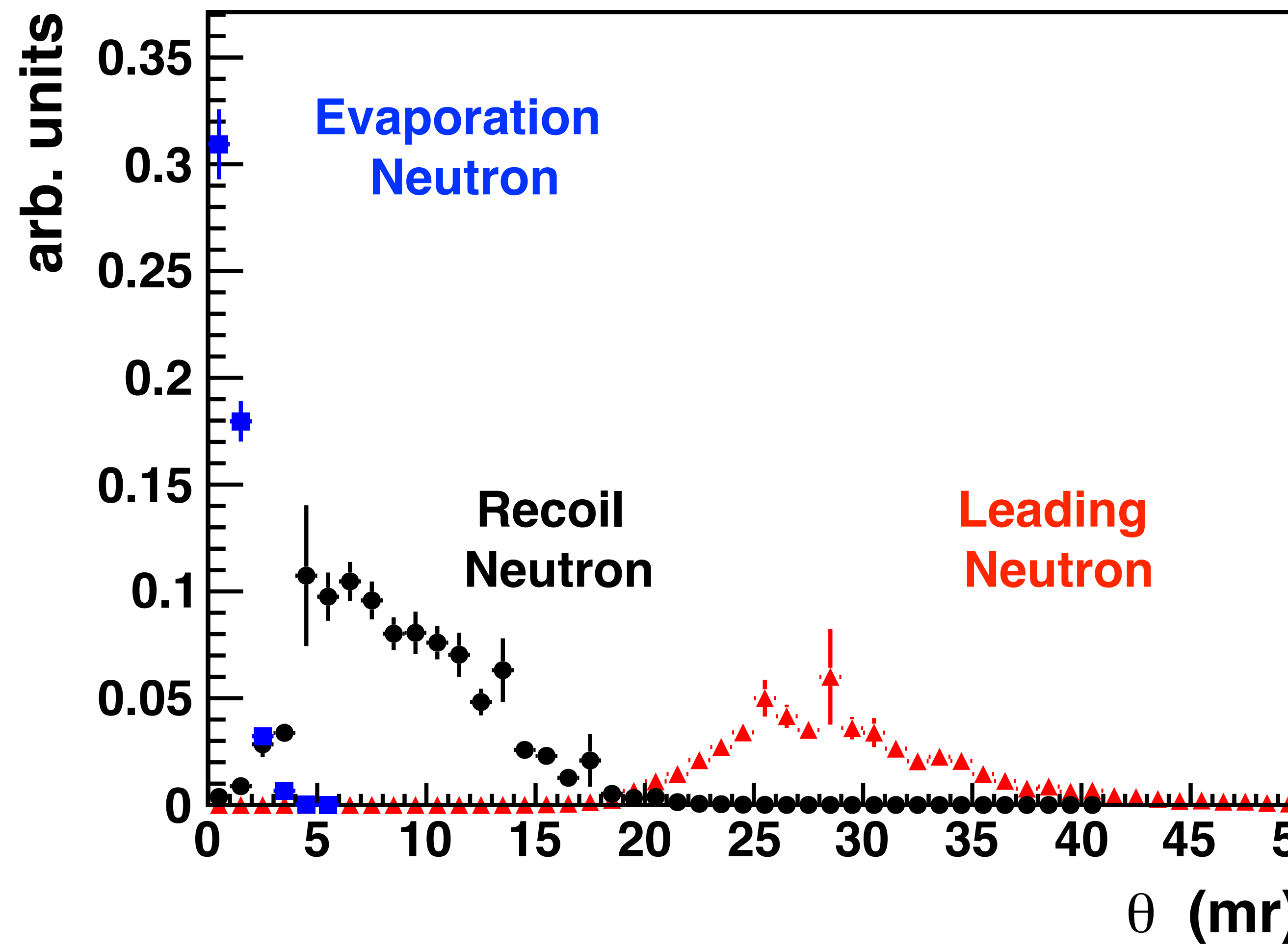
Quasi elastic selection
- **$Q^2 > 3$**
- **x > 1.2 cut**



QE Simulation Results (no crossing angle)

e + C (5 GeV + 50 GeV)



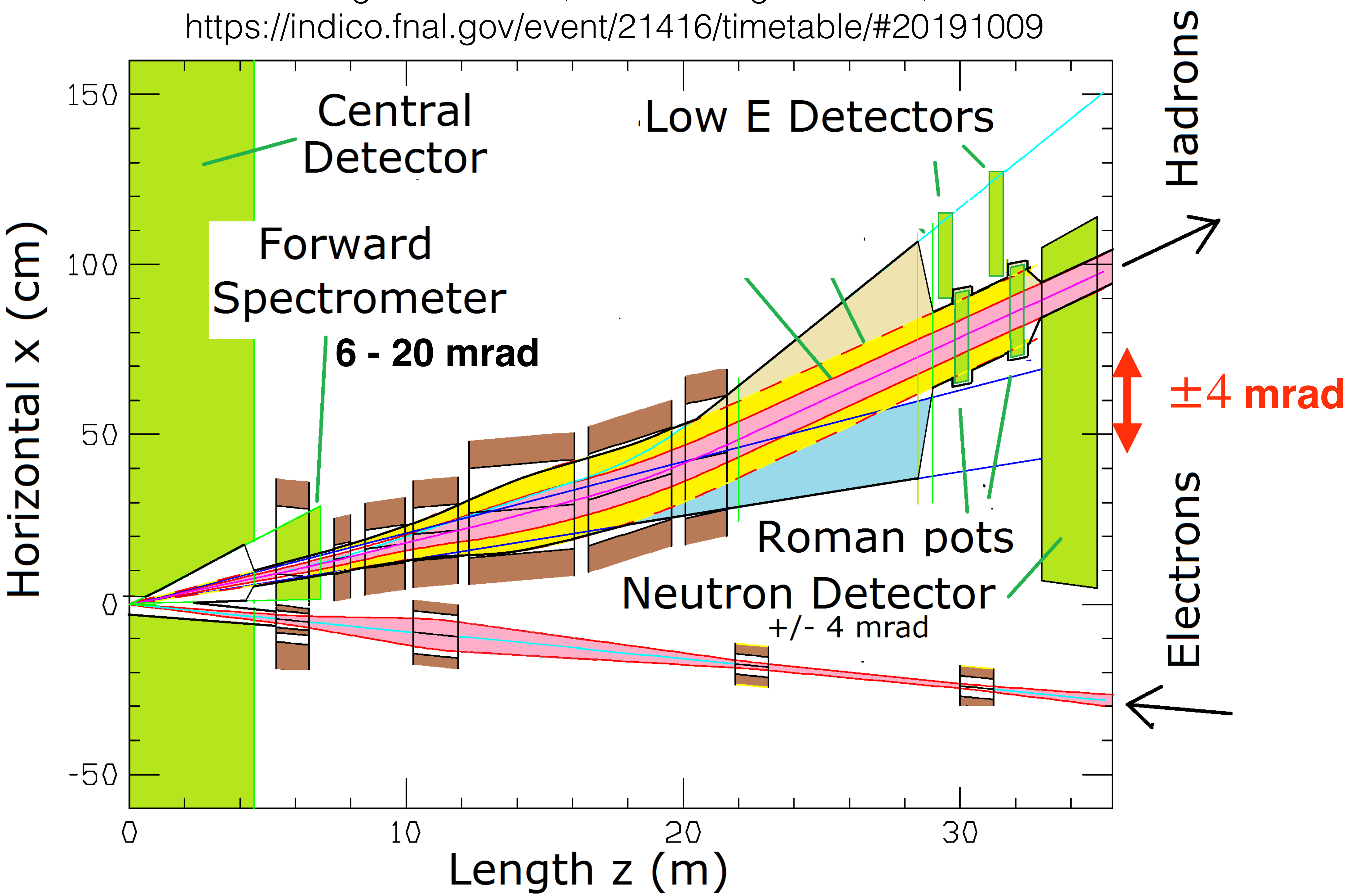


- Leading, recoil, evaporation nucleons well separated
- Assume similar separation of evaporation and recoil nucleons for SRC-DIS

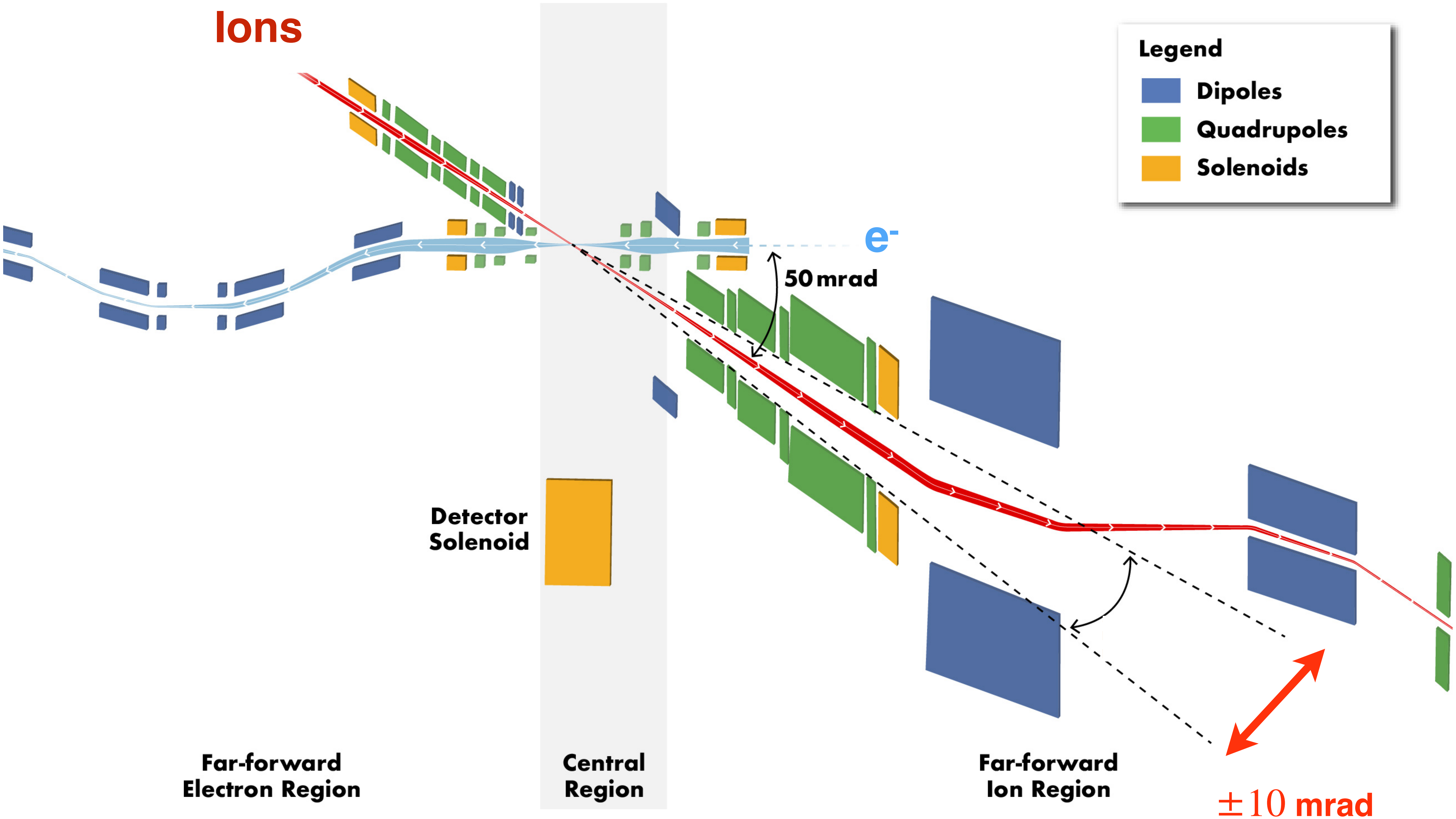
Note: Plots without FSI and intranuclear cascading

eRHIC Interaction Point

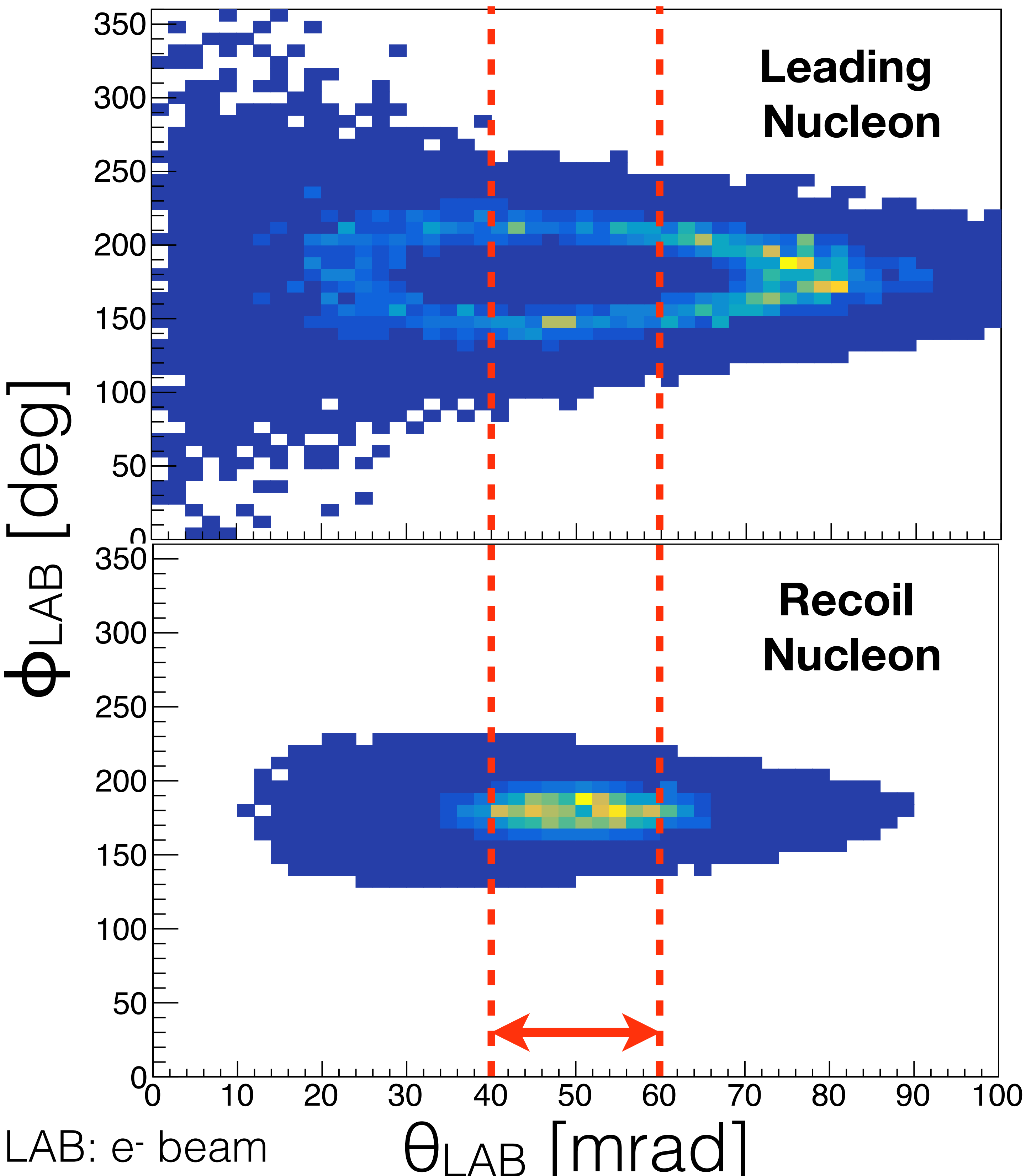
Holger Witter talk, EIC meeting Oct 2019,
https://indico.fnal.gov/event/21416/timetable/#20191009



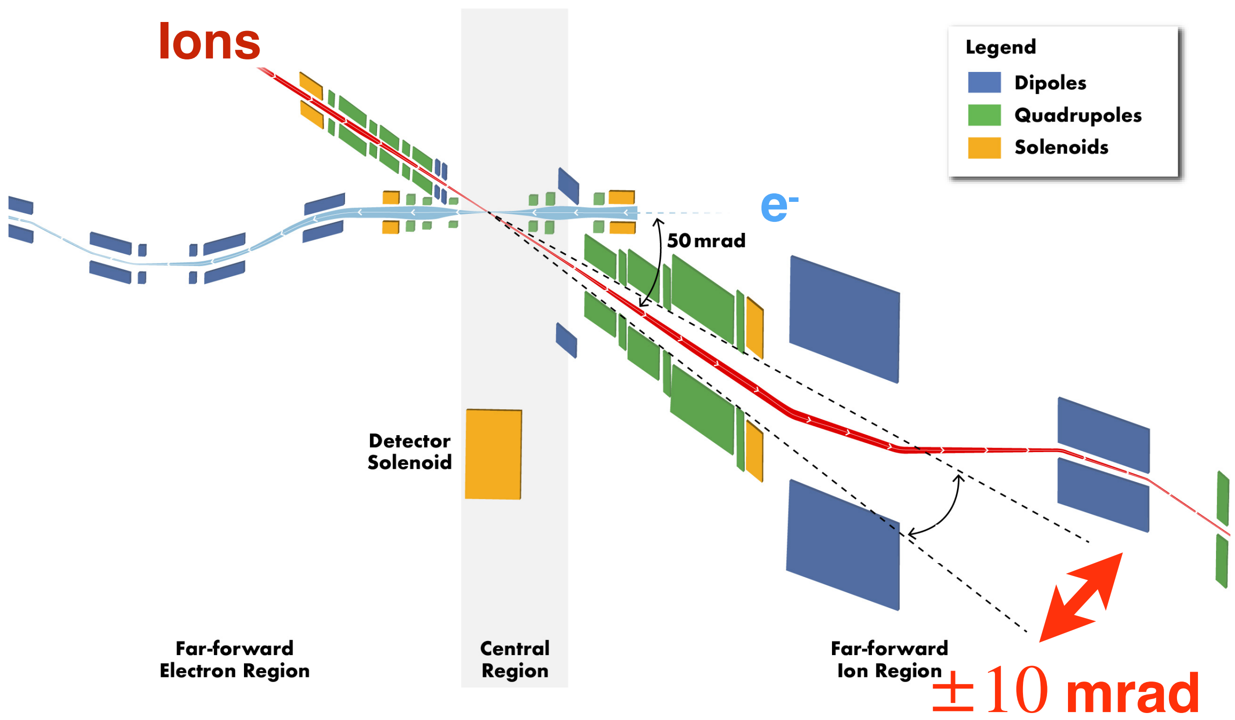
JLEIC Interaction Point Design



JLEIC IP: 50 mrad crossing angle

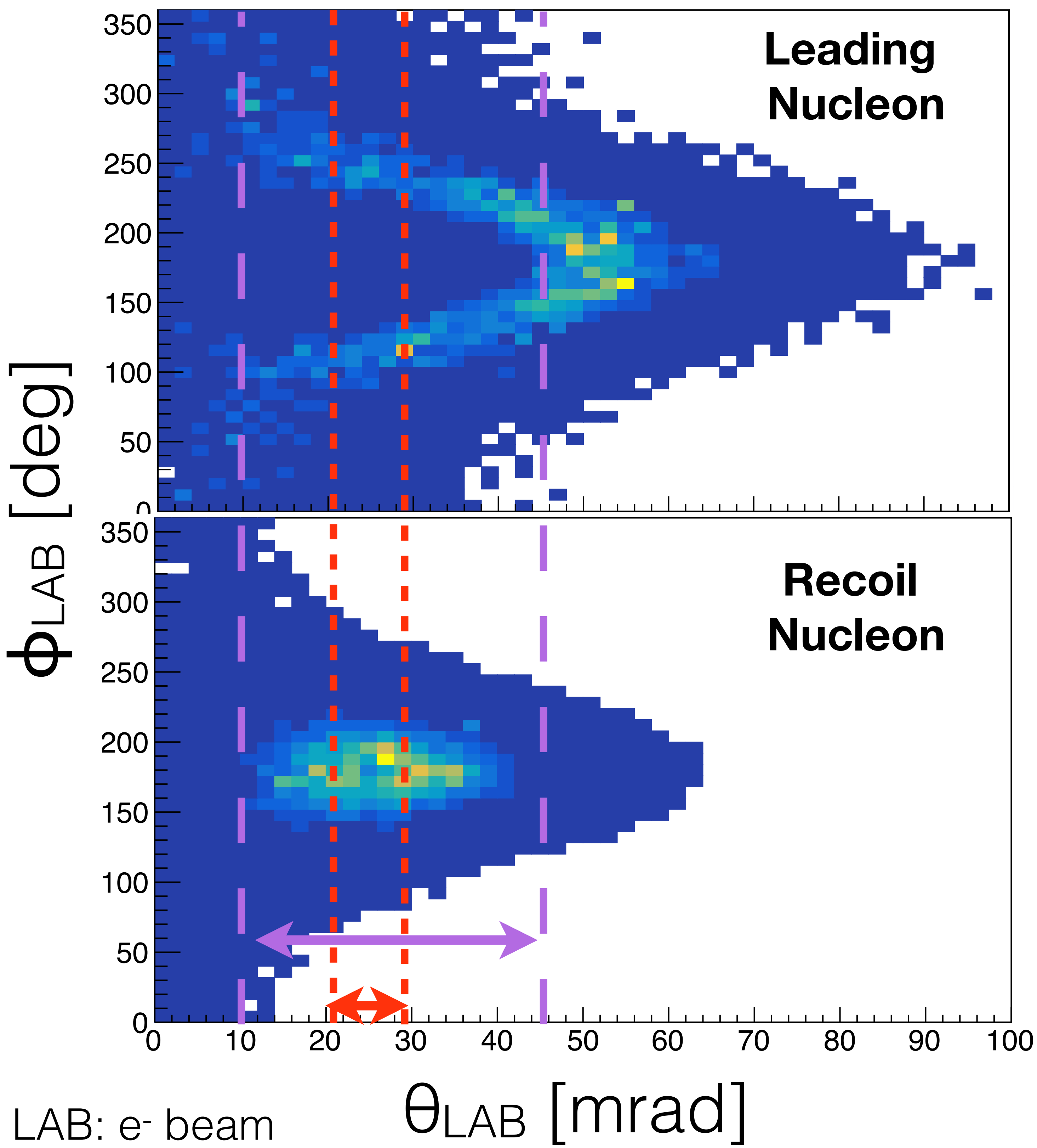


LAB: e- beam

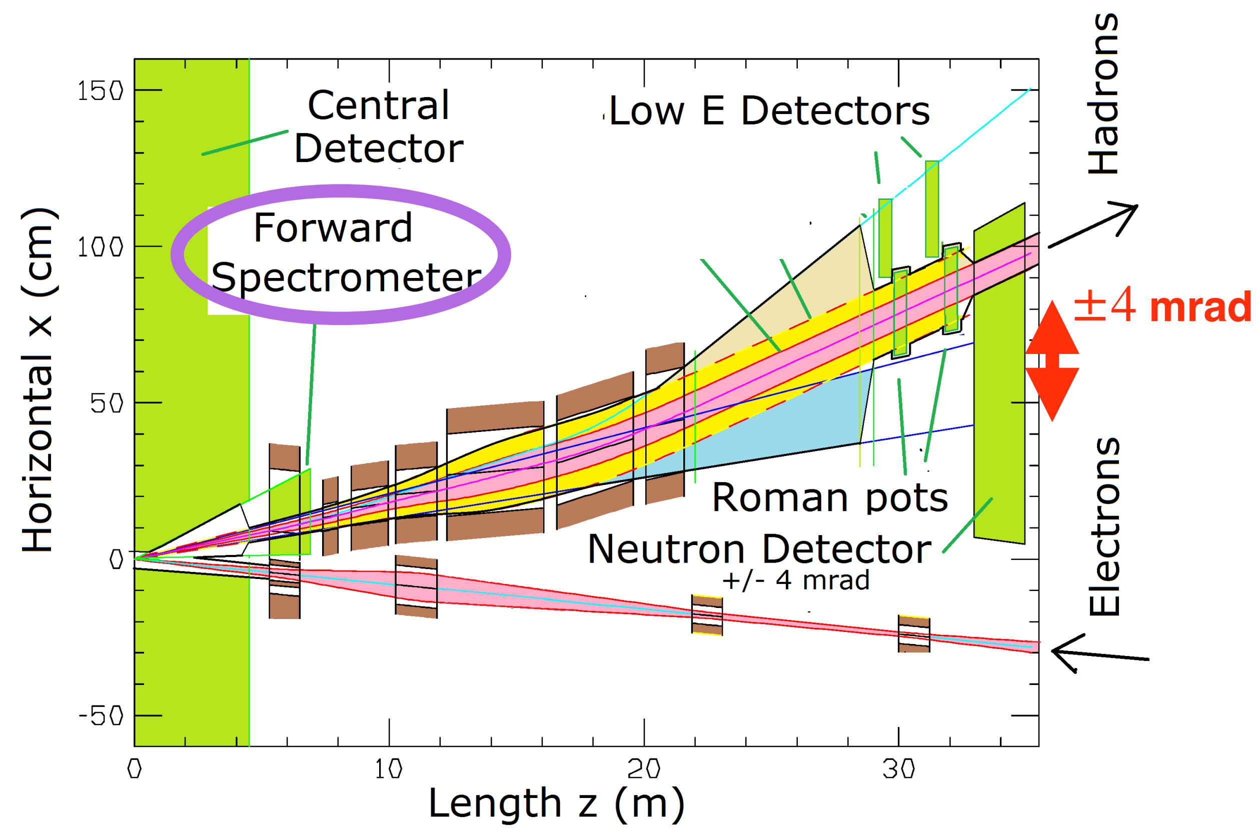


- Recoil nucleons within magnet aperture
  - all neutrons detectable
  - proton detection more difficult

eRHIC IP: 25 mrad crossing angle



LAB: e^- beam



- Recoil nucleons covered by forward spectrometer and forward direction detectors
- **<u>Ongoing:</u> Implementation of IP into g4e —> Detailed simulations**

Summary and Outlook

- EMC-SRC correlation from electron scattering
- Tagged SRC physics possibilities at EIC
  - Recoils nucleons well separated
  - Detection of recoils in both IP designs
  - Requirements for beam energies moderate

Near term:

- GCF-QE events processed through g4e
- Simulation of DIS-SRC events
- Study of FSI and intra nuclear cascading effects
- Detector requirements
- Resolutions

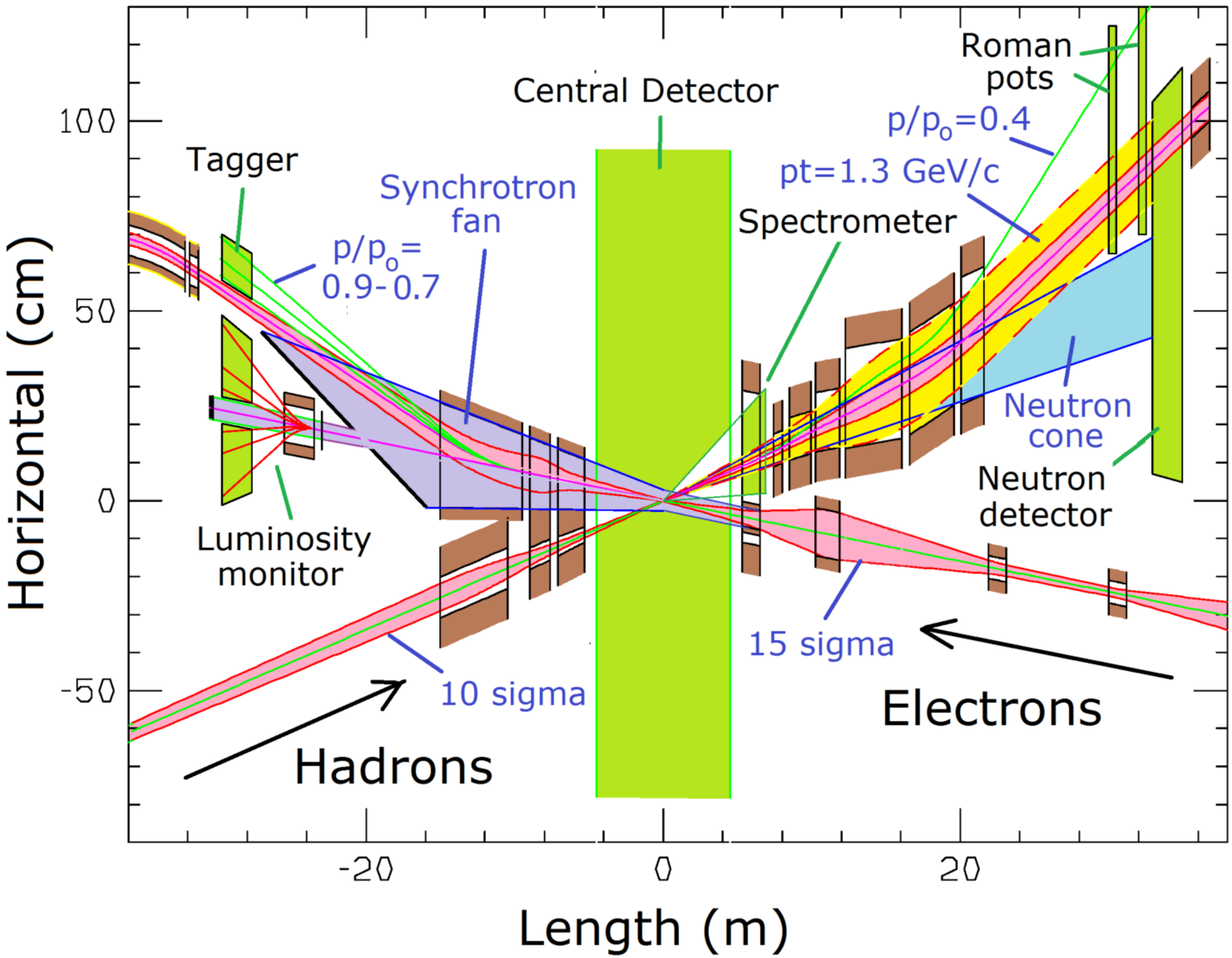
Far term:

- Yellow report section

Back up slides

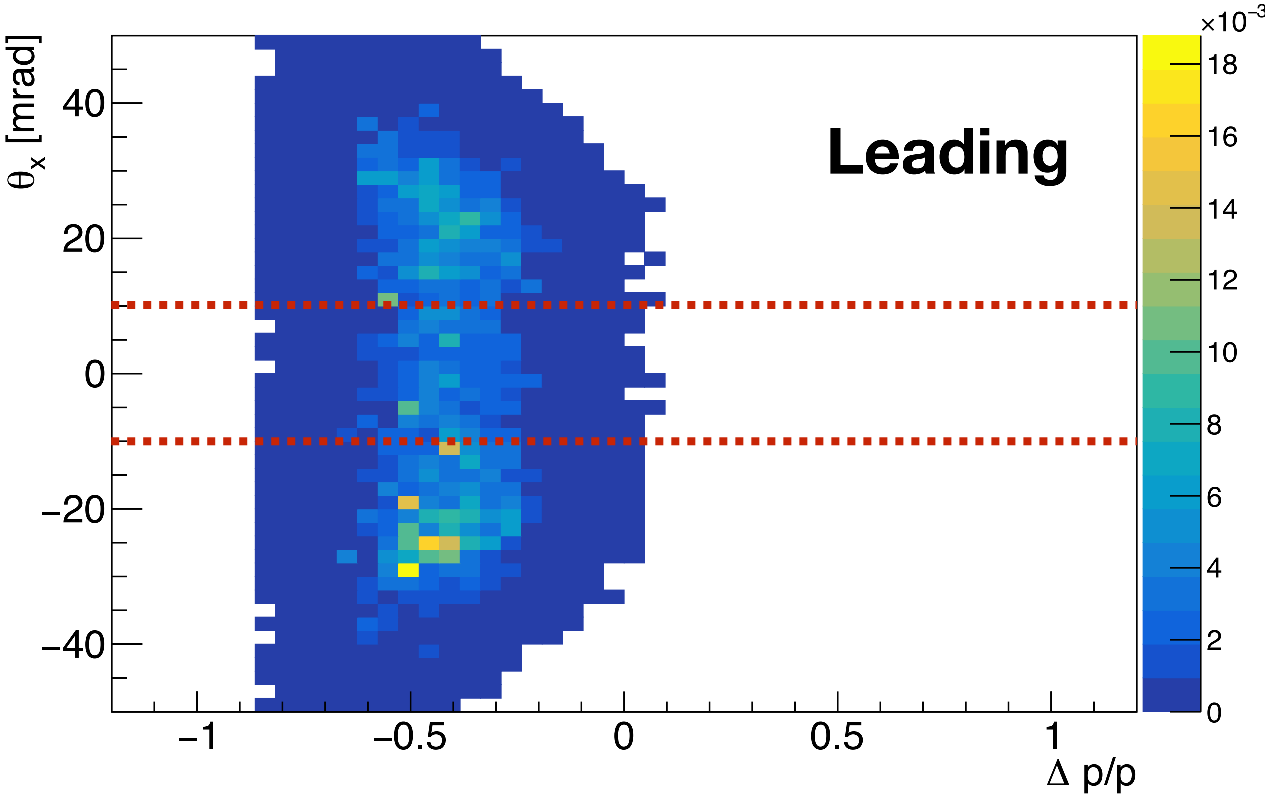
eRHIC Full Interaction Region

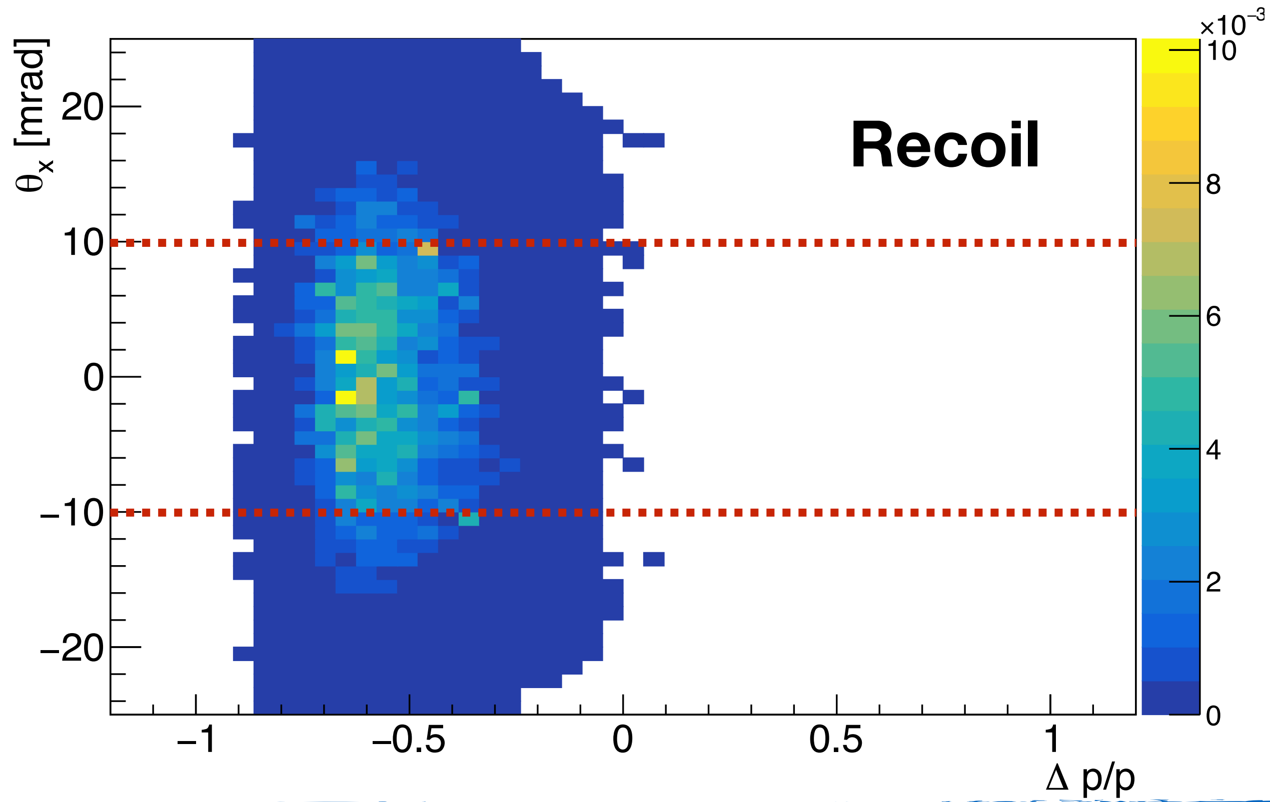
Holger Witte talk, EIC meeting Oct 2019



Quasi-elastic SRCs - Beam Rigidity

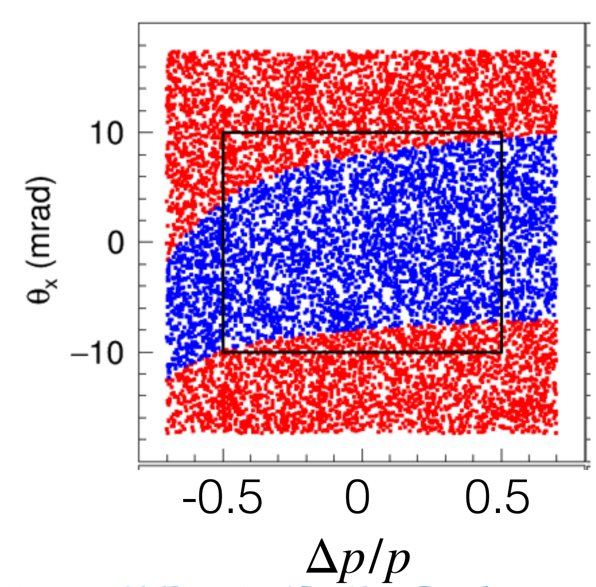
(JL)EIC e+C, 5x50 GeV², QE selection cuts





$$\frac{\Delta p}{p} = \frac{\Delta B\rho}{B\rho_{ion}} = \frac{(Z/A)_{ion} \cdot p_f - p_{ion}}{p_{ion}}$$

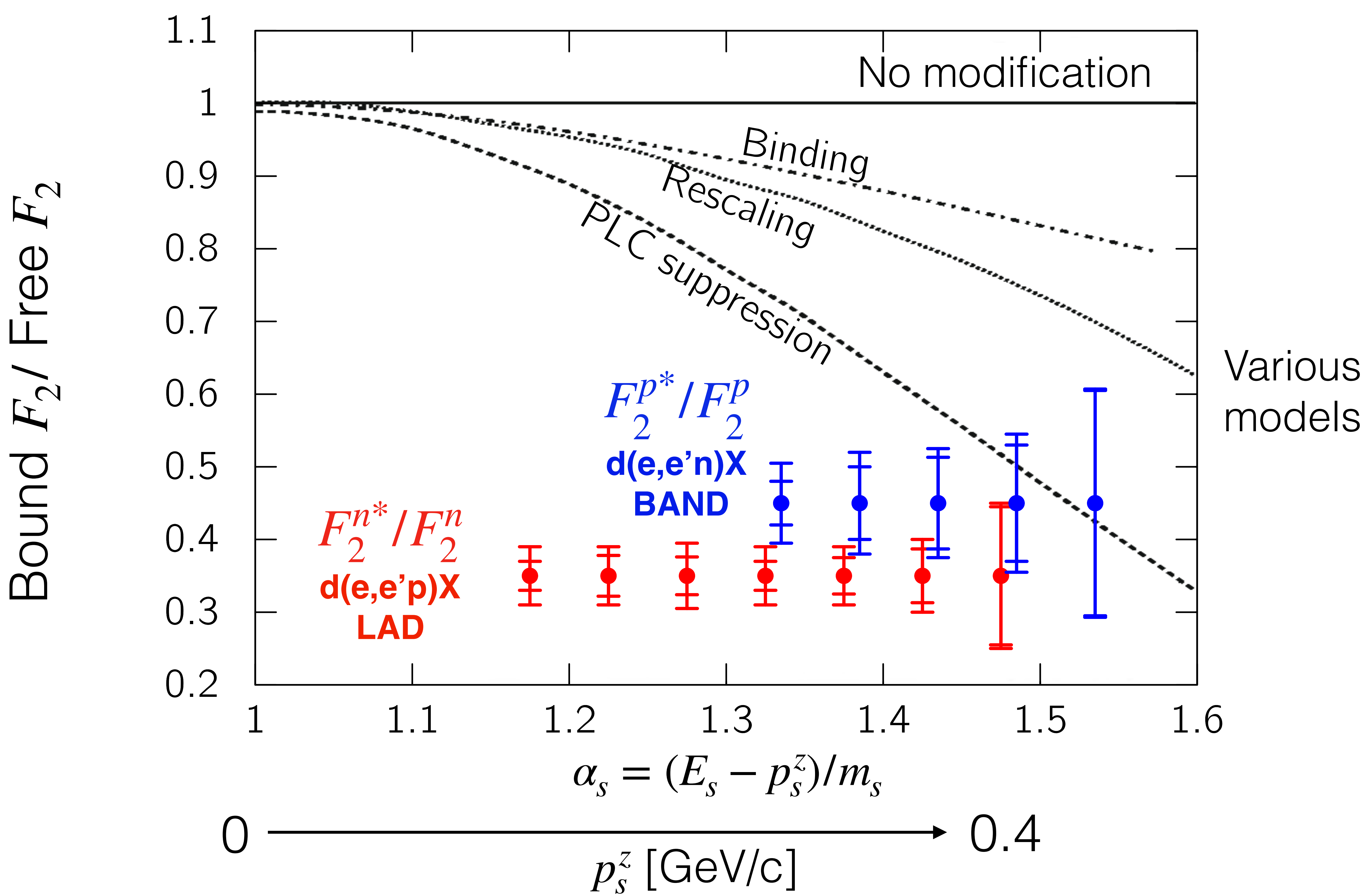
- Recoils close to ion direction
- Rigidity below 0 as expected
- Rigidity for recoils smaller than for leading
- Coverage for $\Delta p/p < -0.5$ challenging



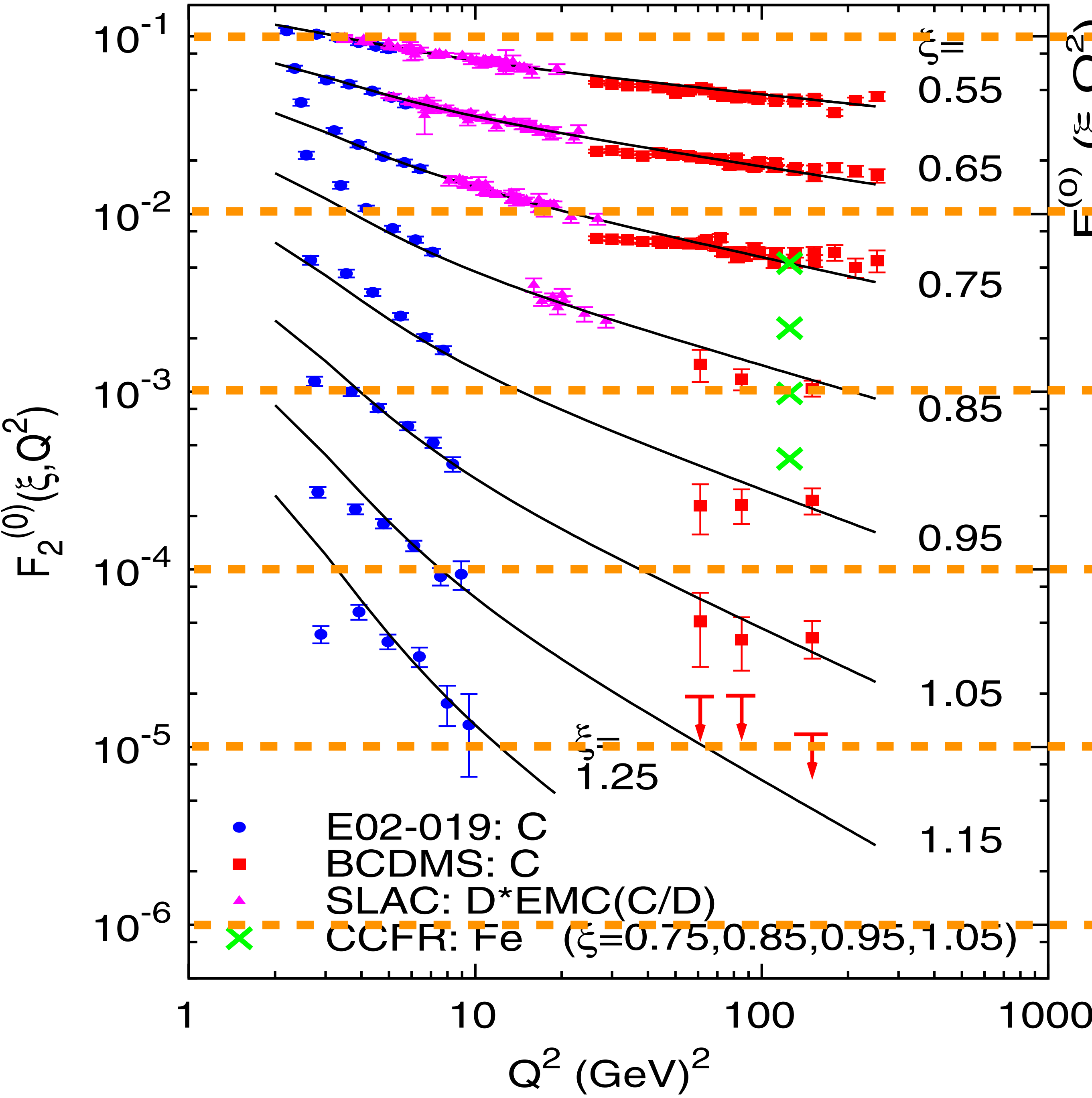
from V. Morozov CFNS Summer School 2019

Quad aperture at 6T

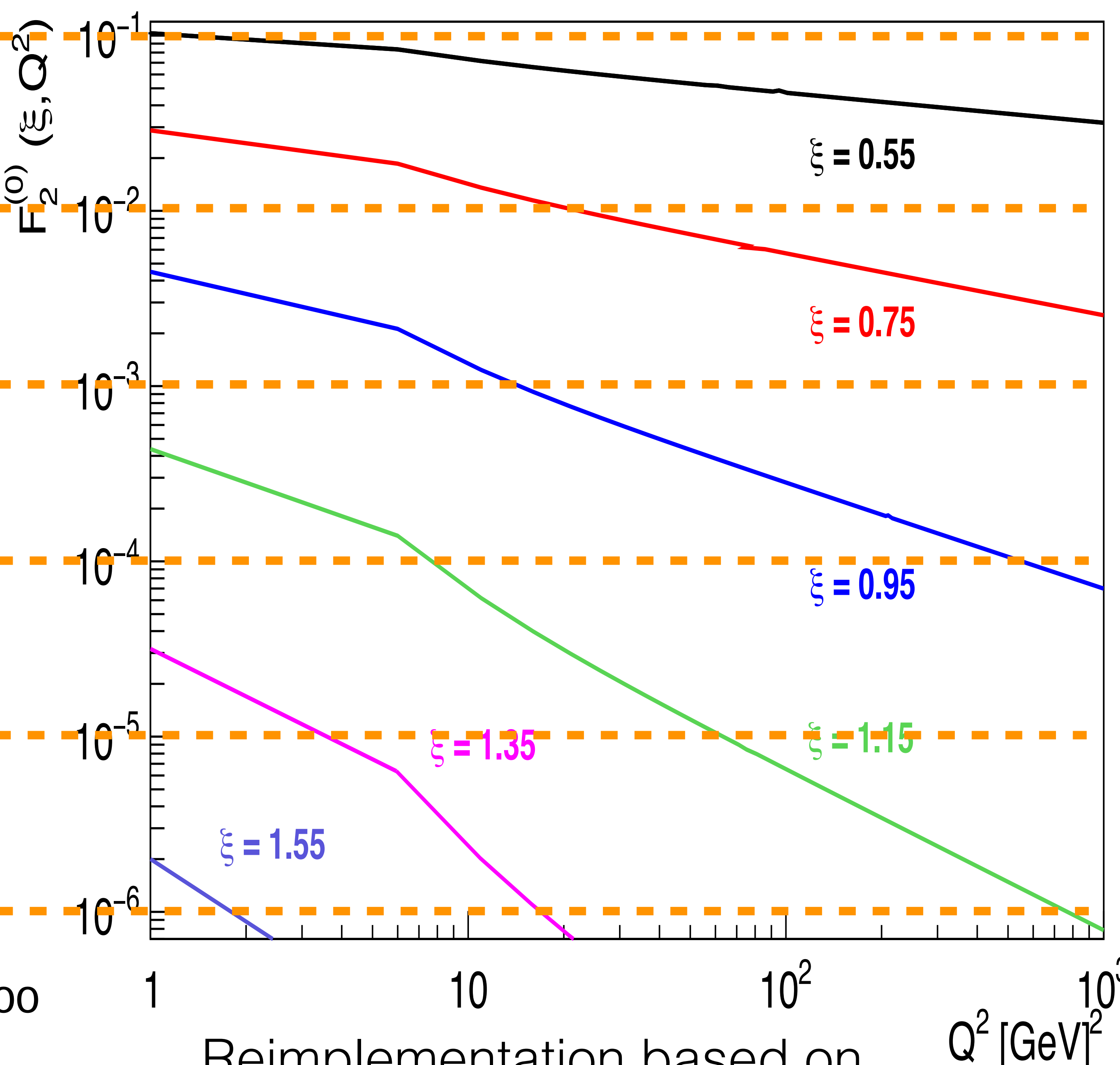
DIS Recoil Tagging d(e,e'N)X - Expected Results



F_2 from N. Fomin Paper and Reimplementation



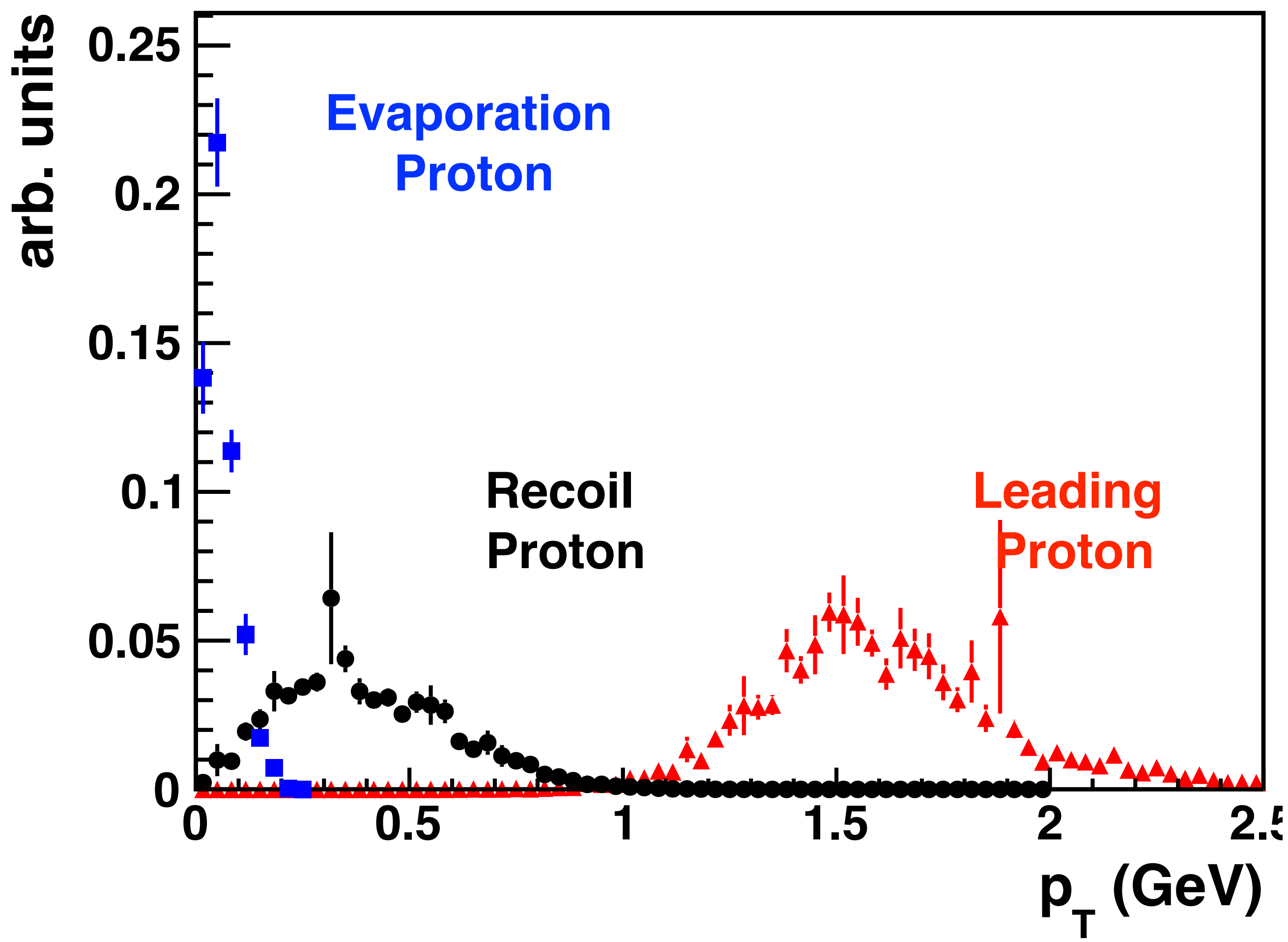
N. Fomin PRL 105, 212502 (2010

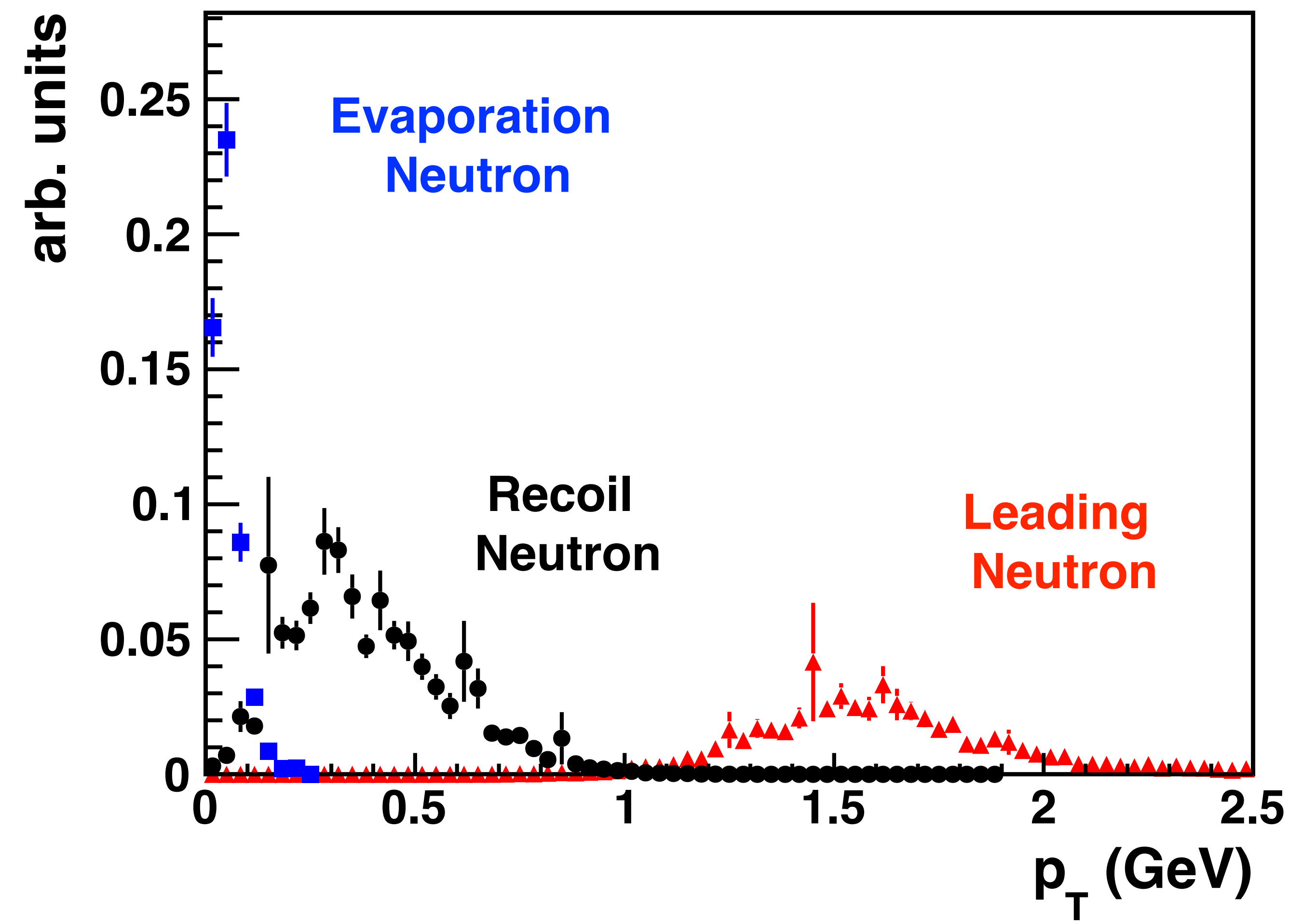


Reimplementation based on N. Fomin scripts

QE Simulation Results (no crossing angle)

e + C (5 GeV + 50 GeV)





- Leading, recoil, evaporation nucleons well separated
- Expecting similar separation of evaporation and recoil nucleons for DIS

Note: This results are without FSI and intranuclear cascading

LAD - Experimental Conditions

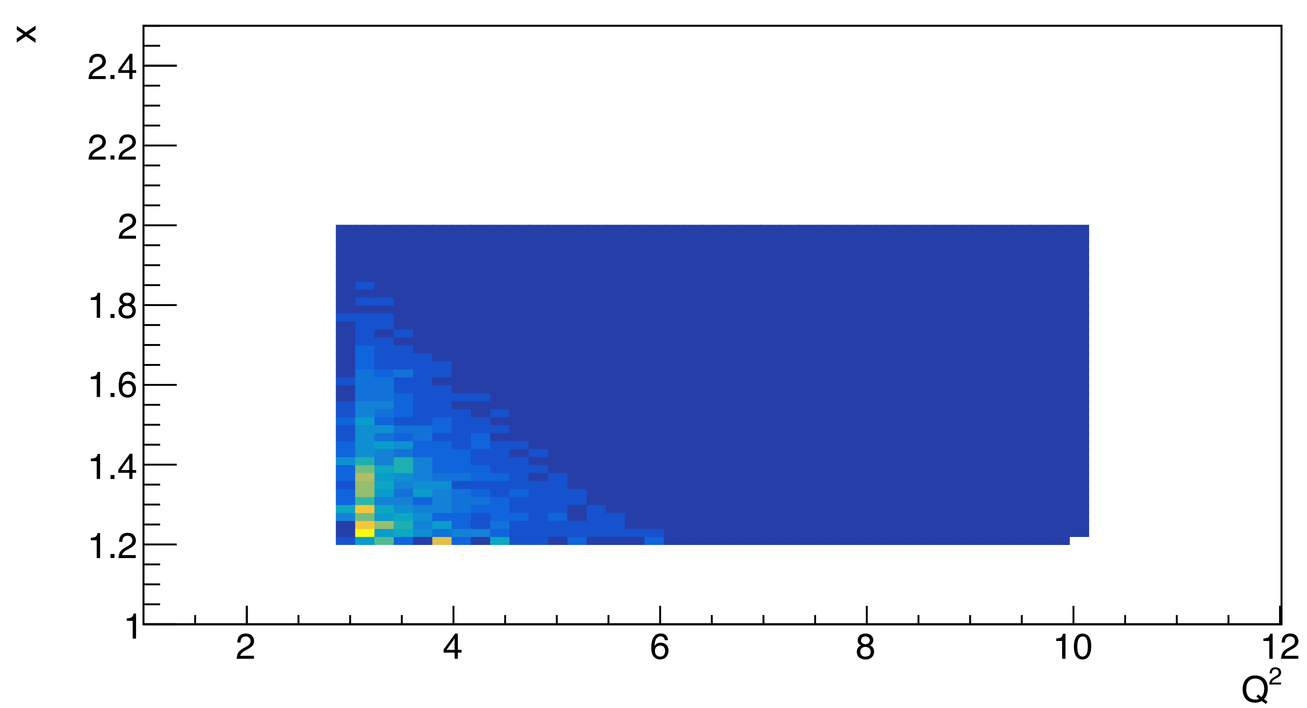
- 11 GeV electron beam
- Extended LD_2 target
- Approved for ~34 PAC days
- 10^{36} $cm^{-2}s^{-1}$ luminosity (10x larger than BAND in HallB)
- Low and high x’ settings in both HallC spectrometers

QE Event Handling Procedure

- GCF-QE output of electrons with P_e = 537 GeV on Carbon (fixed target)
- Process through BeAGLE and convert to ROOT-file

- **Fixed target events to collider events**
  - Boost from lab to c.m.s with fixed target kinematics (P_e = 537 GeV)
  - Boost from c.m.s to collider lab with e+C (5x50[40]) beams
- **Add crossing angle via**
  - Boost along x-axis with beta = 0.025
  - Rotate along y-axis by -0.025 mrad

Check of Q2 and x distribution (Q^2 > 3 and x > 1.2 cut)



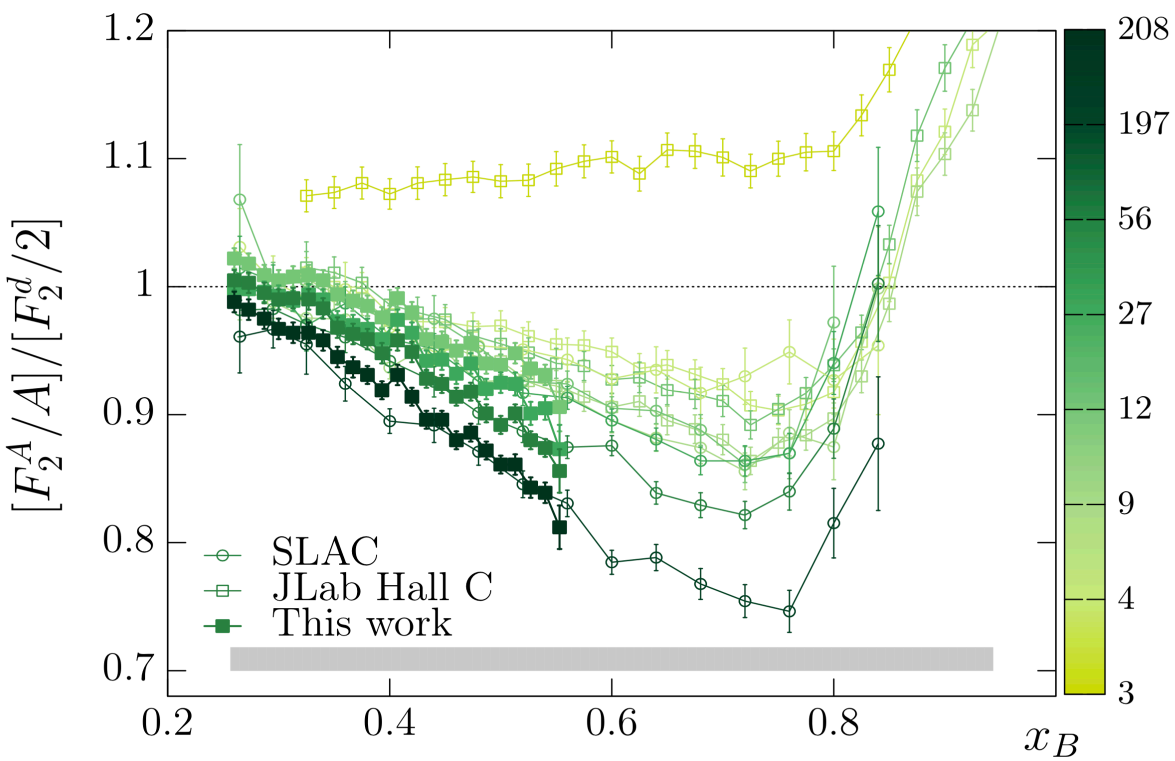
SRC-EMC Model and Universal function

B. Schmookler et al., Nature 566, 354 (2019)

- Data driven approach
- Modification of F_2 by np-SRC pairs (neglect nn and pp pairs)

$$F_2^A = \quad ZF_2^p + NF_2^n \quad + n_{SRC}^A(\Delta F_2^p + \Delta F_2^n)$$

Bound = ``Quasi-free" + Modified SRC



SRC-EMC Model and Universal function (2)

B. Schmookler et al., Nature 566, 354 (2019)

- Data driven approach
- Modification of F_2 by np-SRC pairs (neglect nn and pp pairs)

$$F_2^A = \quad ZF_2^p + NF_2^n \quad + n_{SRC}^A(\Delta F_2^p + \Delta F_2^n)$$

Bound = ``Quasi-free" + Modified SRC

F_2^n not well constrained but solve by

- $F_2^d = F_2^p + F_2^n + n_{SRC}^d(\Delta F_2^p + \Delta F_2^n)$
- $a_2 = \frac{2}{N} n_{SRC}^A / n_{SRC}^d$

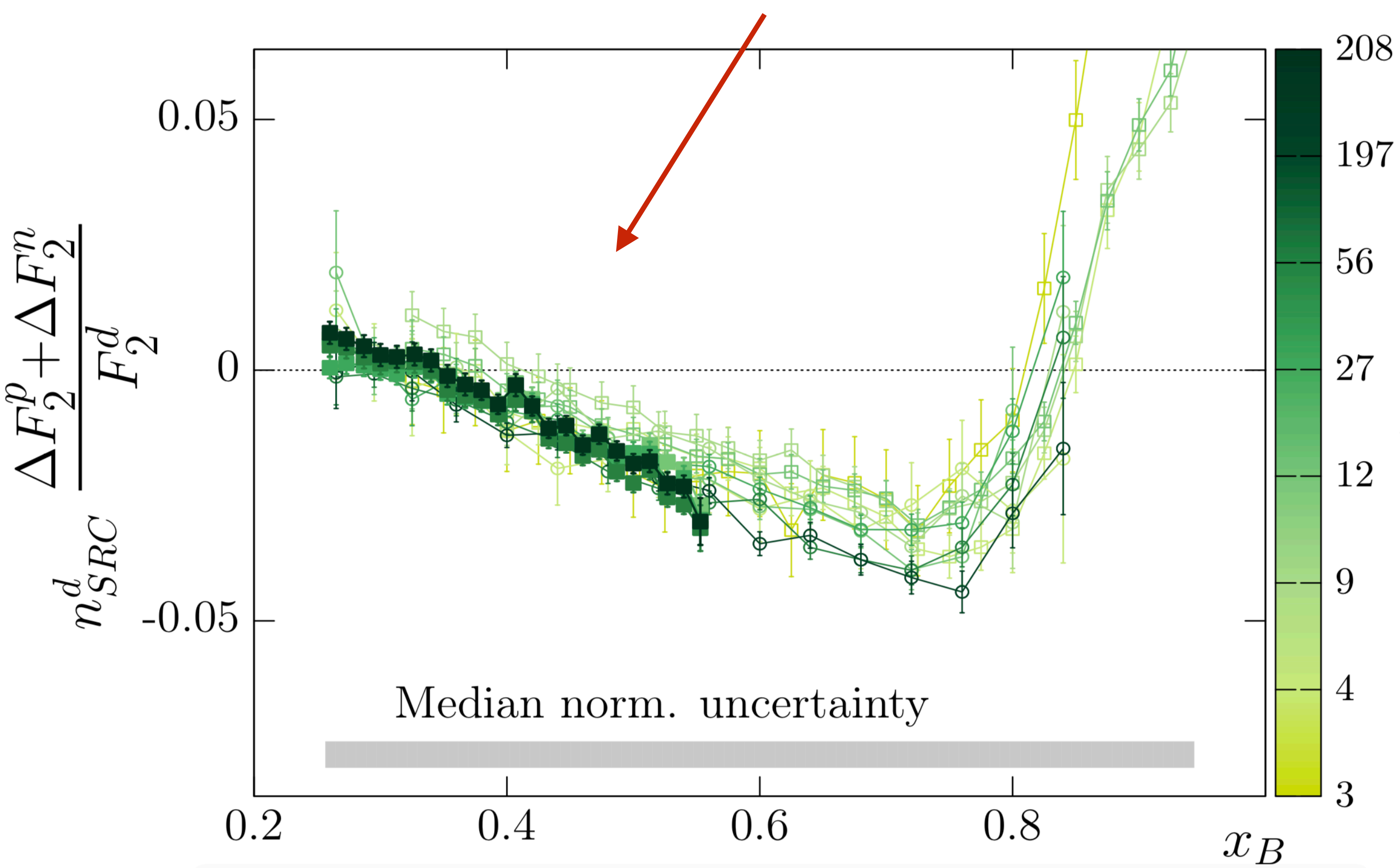
SRC-EMC Model and Universal function (3)

B. Schmookler et al., Nature 566, 354 (2019)

$$\boxed{n^d_{SRC}\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d}} = \boxed{\frac{\frac{F_2^A}{F_2^d} - (Z-N)\frac{F_2^p}{F_2^d} - N}{\frac{A}{2}a_2 - N}}$$

Universal function

Nucleus Dependent



—> Can be used for DIS event generators

QE Simulation Results (no crossing angle)