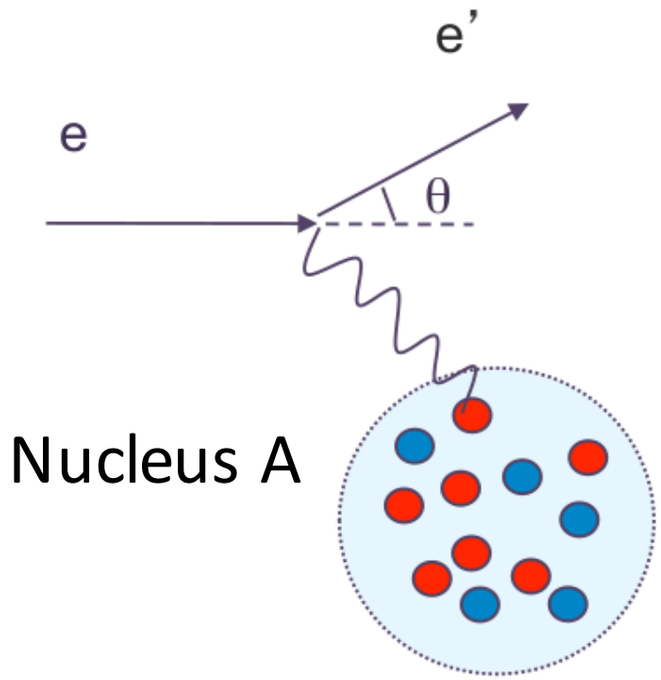
SRC and EMC Experimental Overview and Simulation Studies

Florian Hauenstein,
Old Dominion University
CFNS & RBRC Workshop
09/24/19

Deep Inelastic Scattering (DIS)



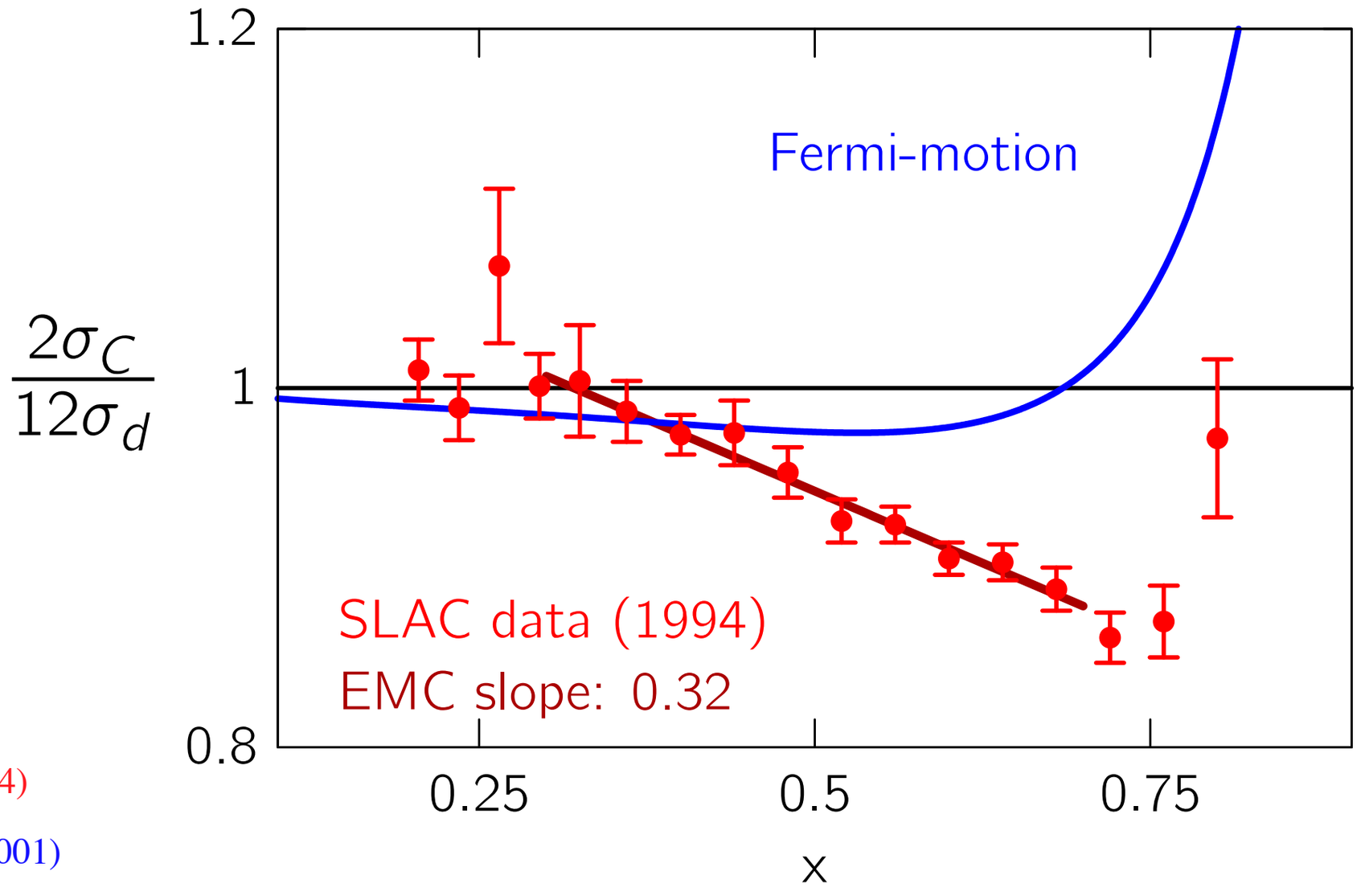
$$x_B = \frac{Q^2}{2m\omega}$$

$$Q^2 = 4E_0 E \sin^2\left(\frac{\theta}{2}\right)$$

$$\omega = E - E'$$

$$\frac{d\sigma}{d\Omega dE'} = \left(\frac{2\alpha E'}{Q^2}\right)^2 \times \left(\frac{1}{\nu}F_2 + \frac{2}{m}F_1 \tan^2\frac{\theta}{2}\right)$$

The EMC Effect in DIS Scattering



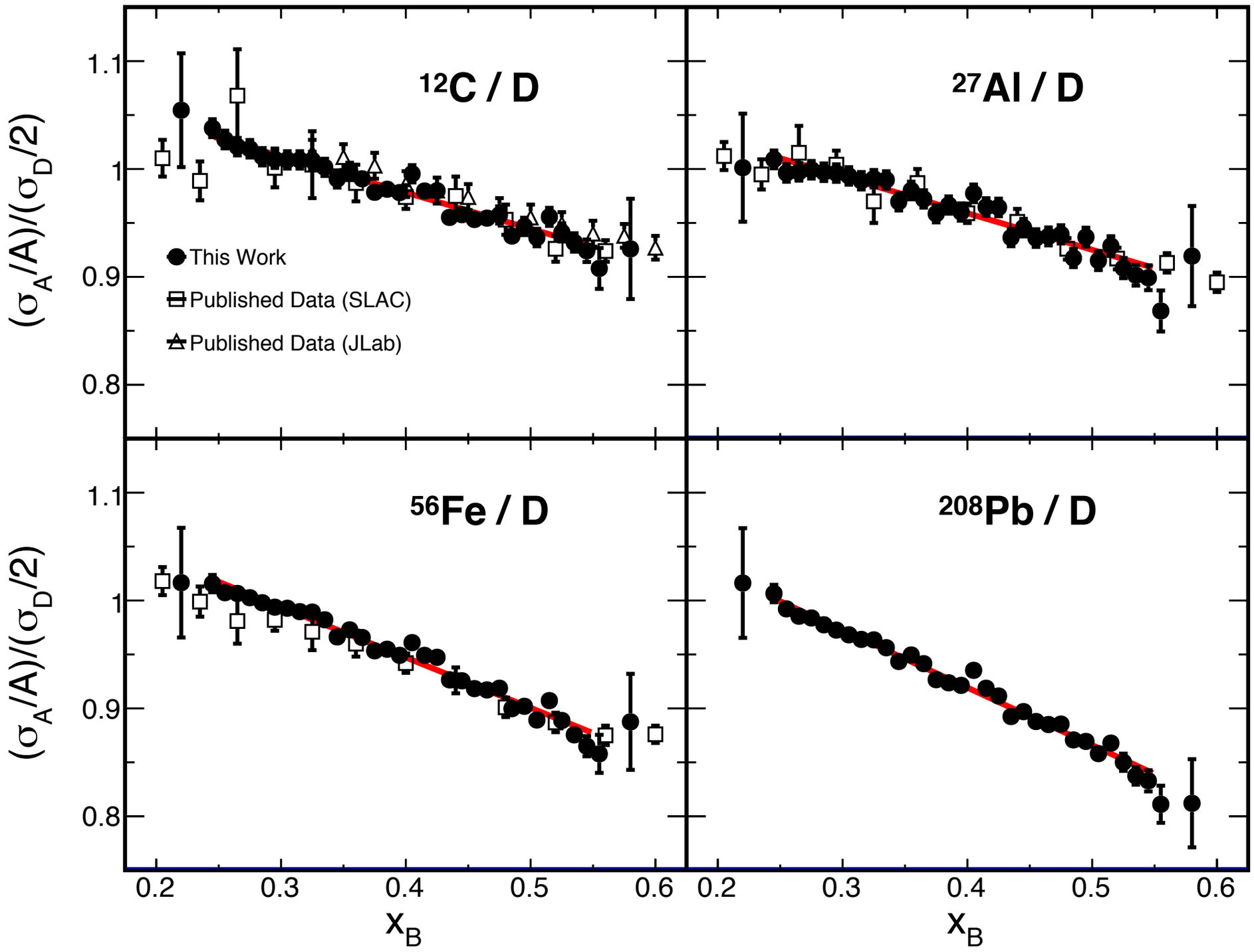
PRD 49, 4338 (1994)

PRC 65, 015211 (2001)

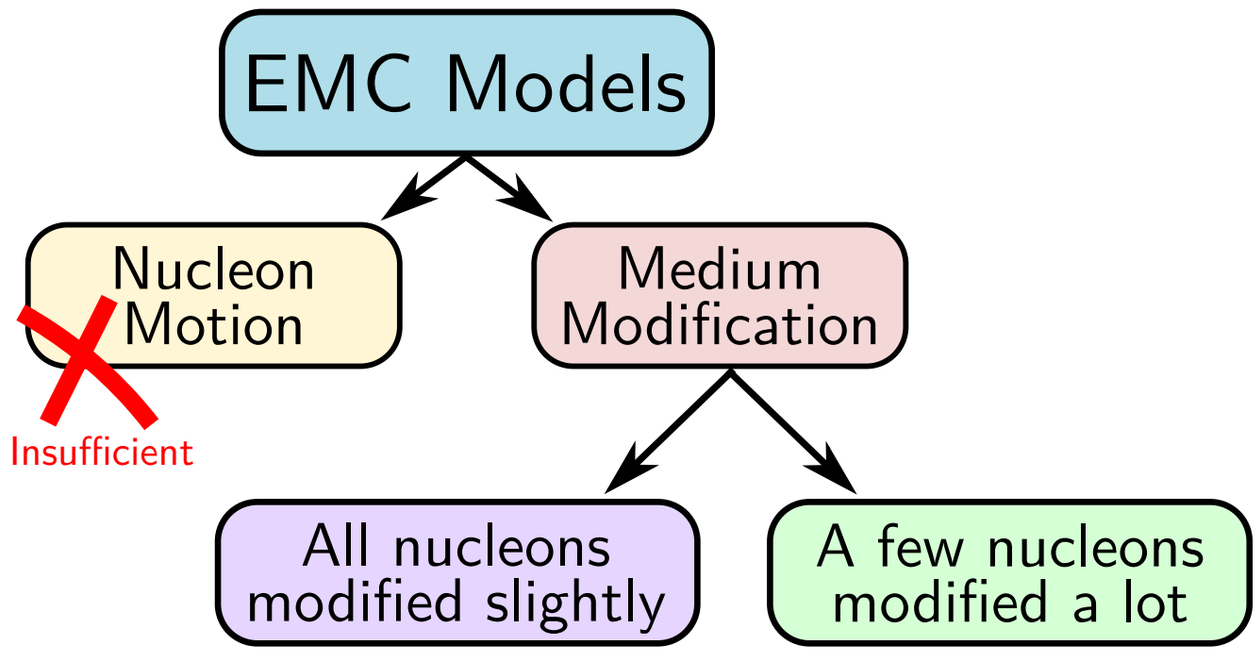
Quark distributions (F_2) in nucleons bound in nuclei different to distributions in free nucleons, here: $F_2^C \neq 6 * F_2^d$

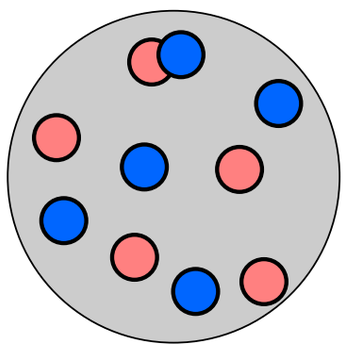
EMC Effect in Different Nuclei

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

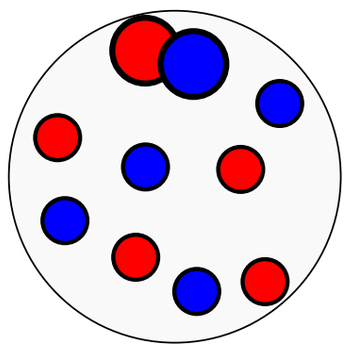


EMC Models



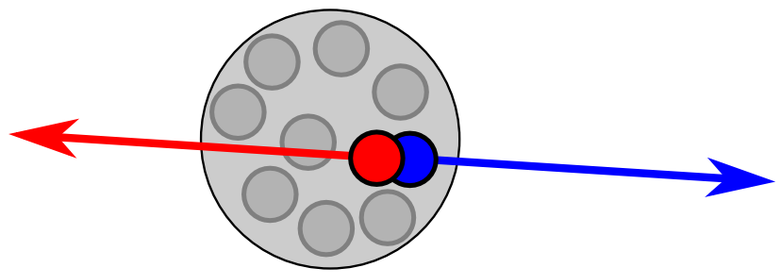


Mean Field Modifications



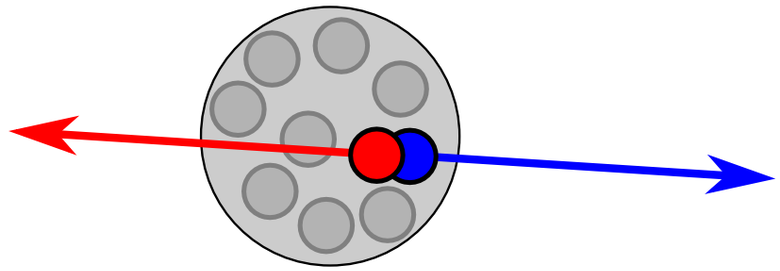
Short Range Correlations (SRC)

Short Range Correlations



- NN pair with
  - **large relative momentum > 300 MeV/c**
  - **small c.m momentum**
- ~20% of nucleons in nuclei

Short Range Correlations



- NN pair with
  - **large relative momentum > 300 MeV/c**
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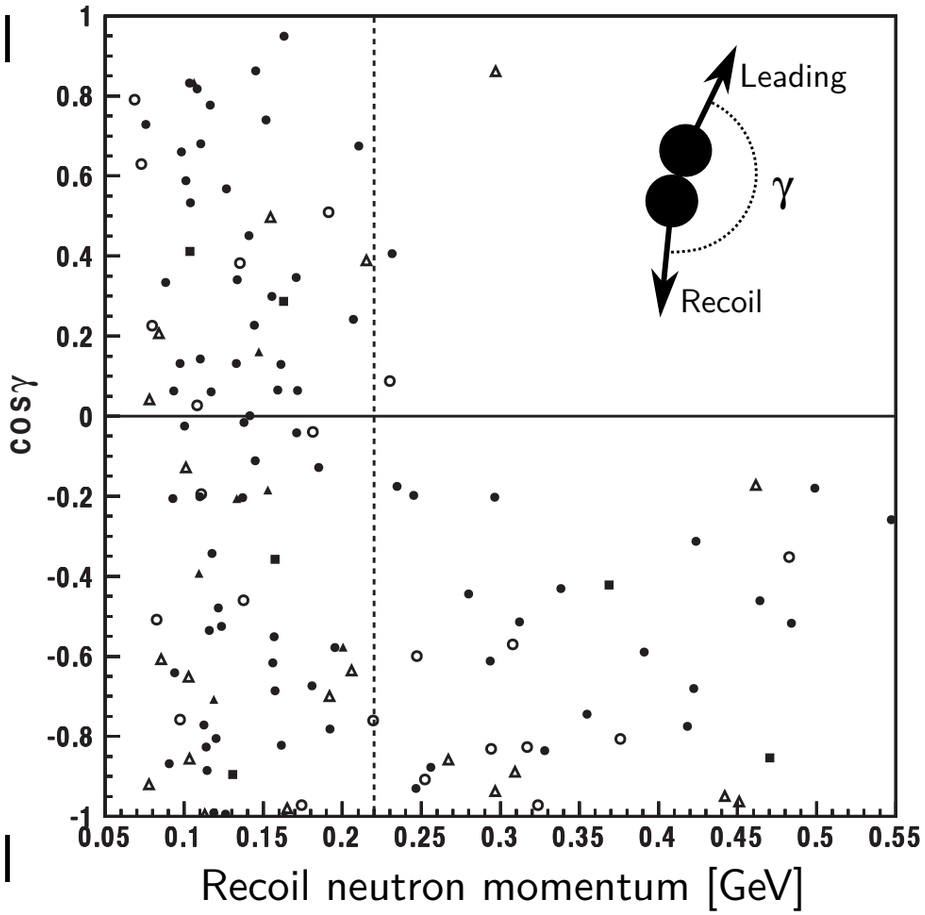
- ~20% of nucleons in nuclei

parallel

anti-parallel

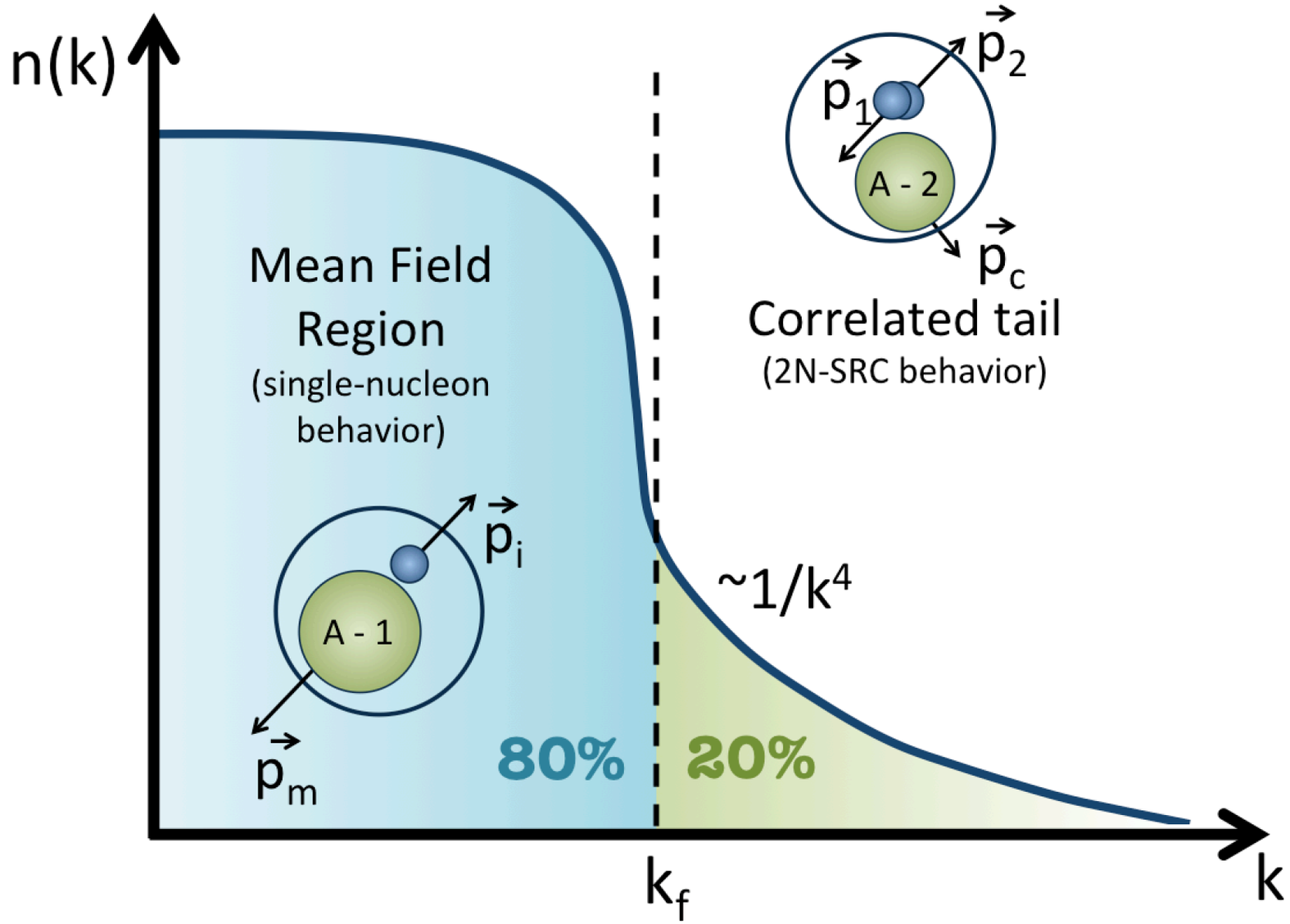


E. Piasetzky et al., PRL 97, 162504 (2006)

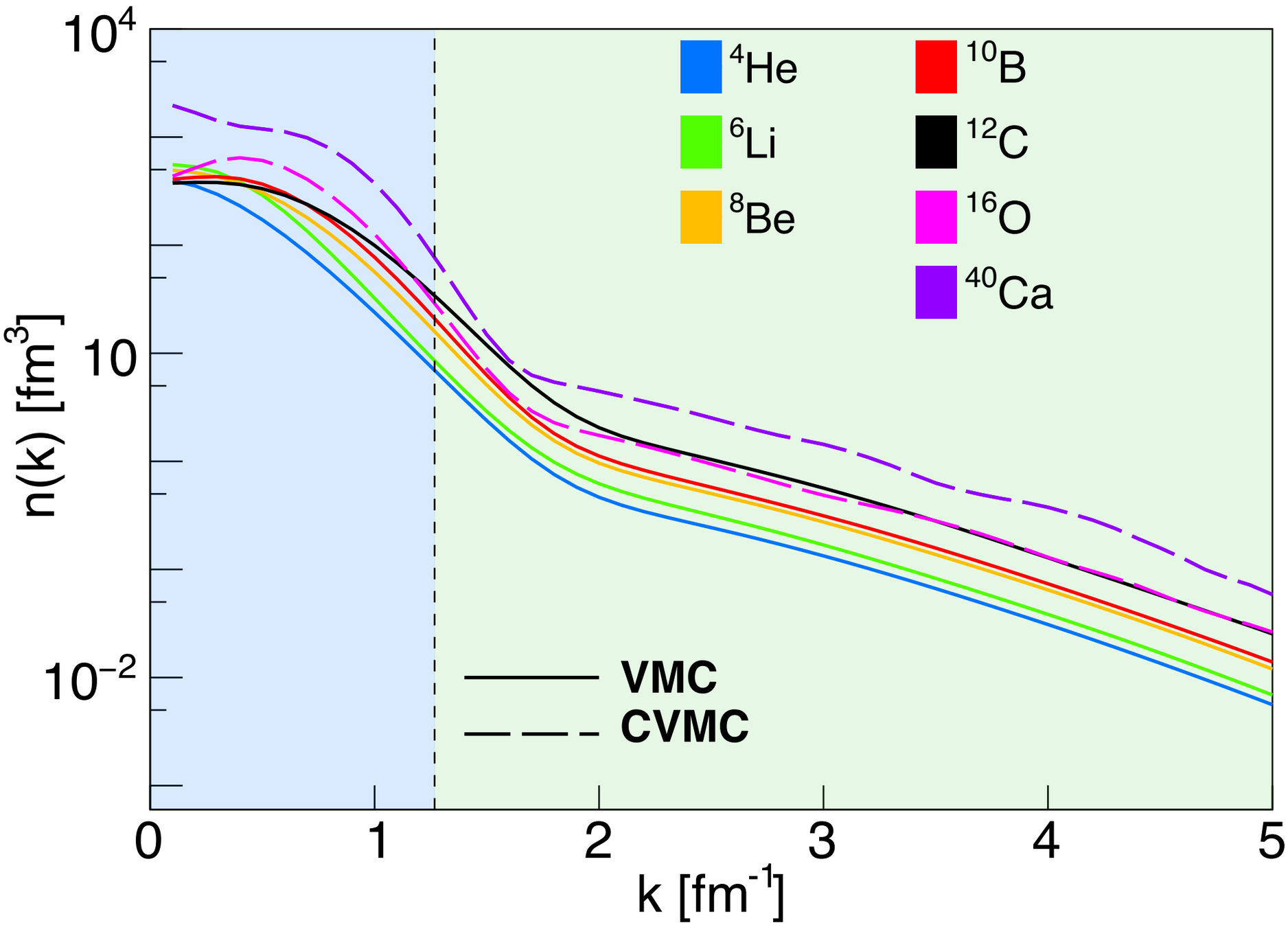
p scattering from Carbon

- always a correlated partner
- Anti-parallel momentum

Nucleon Momentum Distribution

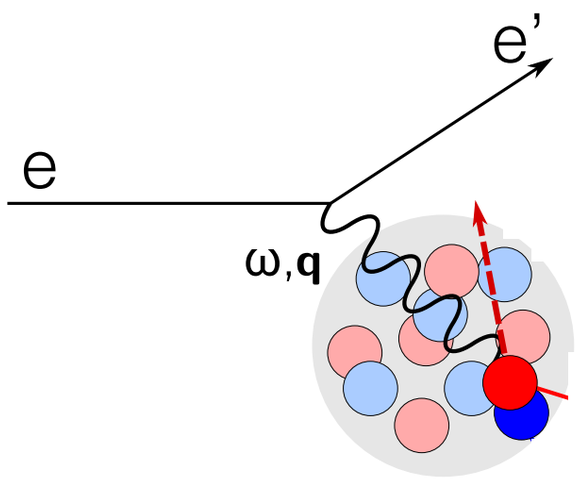


Universality of High Momentum Tail

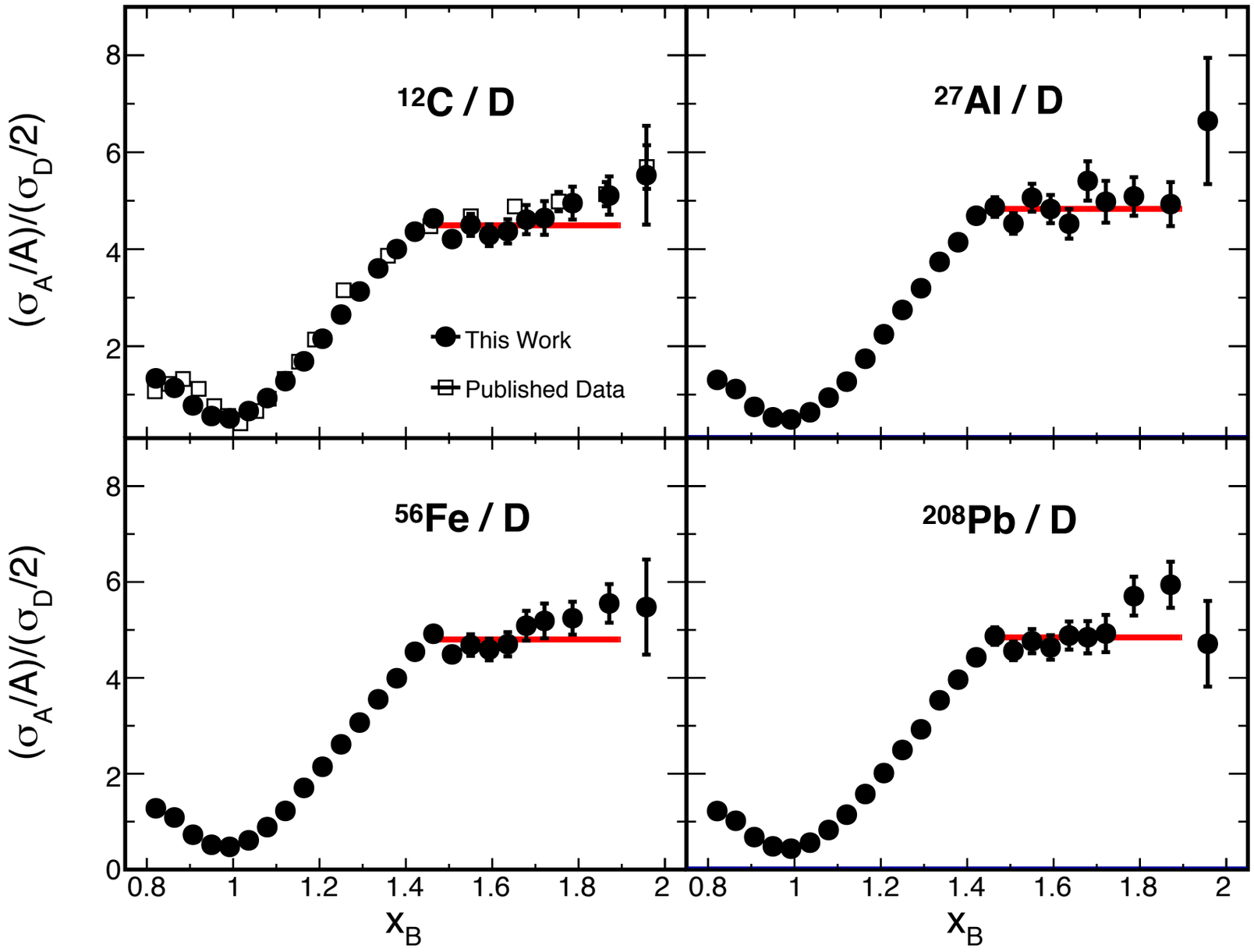


B. Wiringa, https://www.phy.anl.gov/theory/research/QMCresults.html

SRCs in Inclusive Scattering

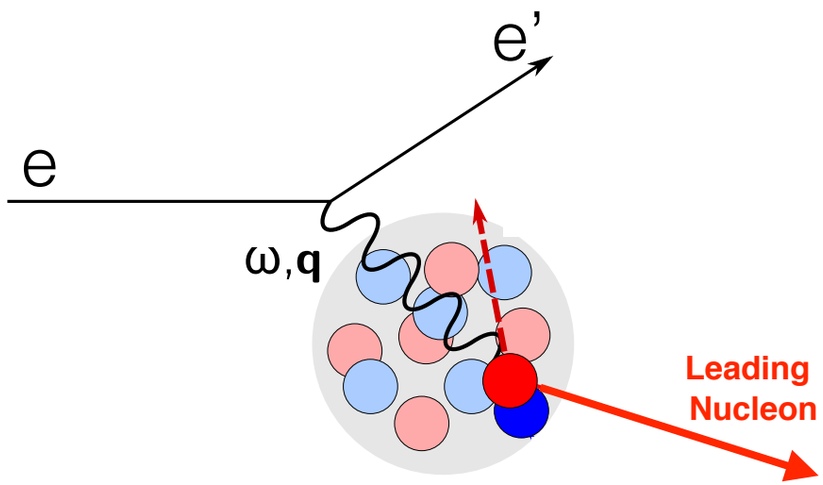


B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)

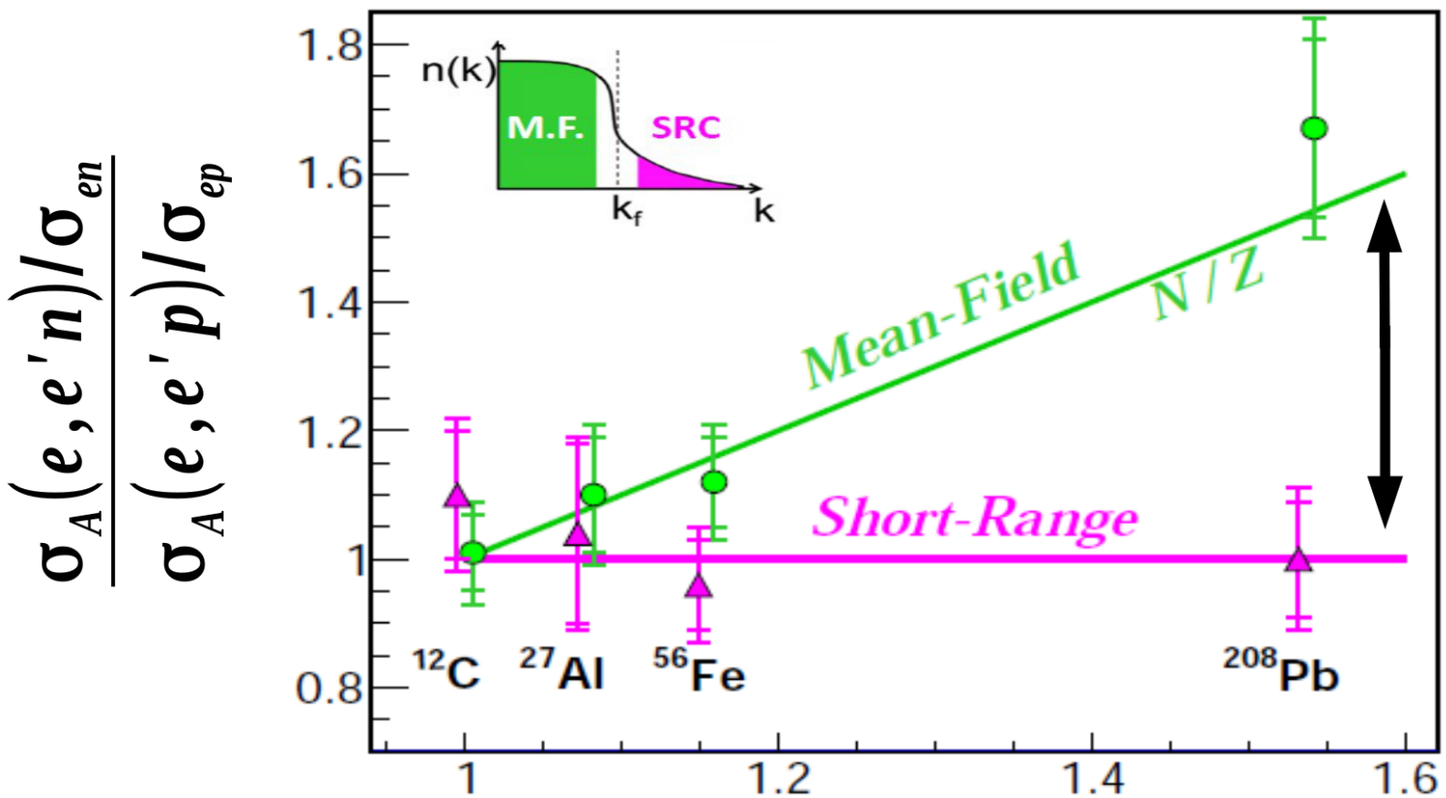


- Quasi-Elastic scattering
- Plateaus due to SRCs

SRCs in Exclusive Scattering

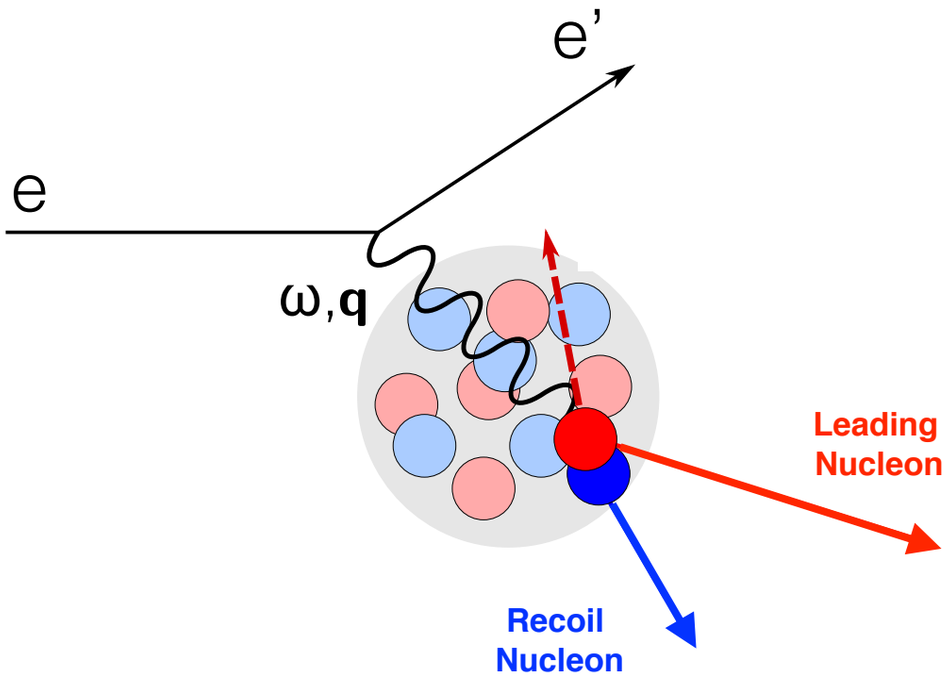


Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

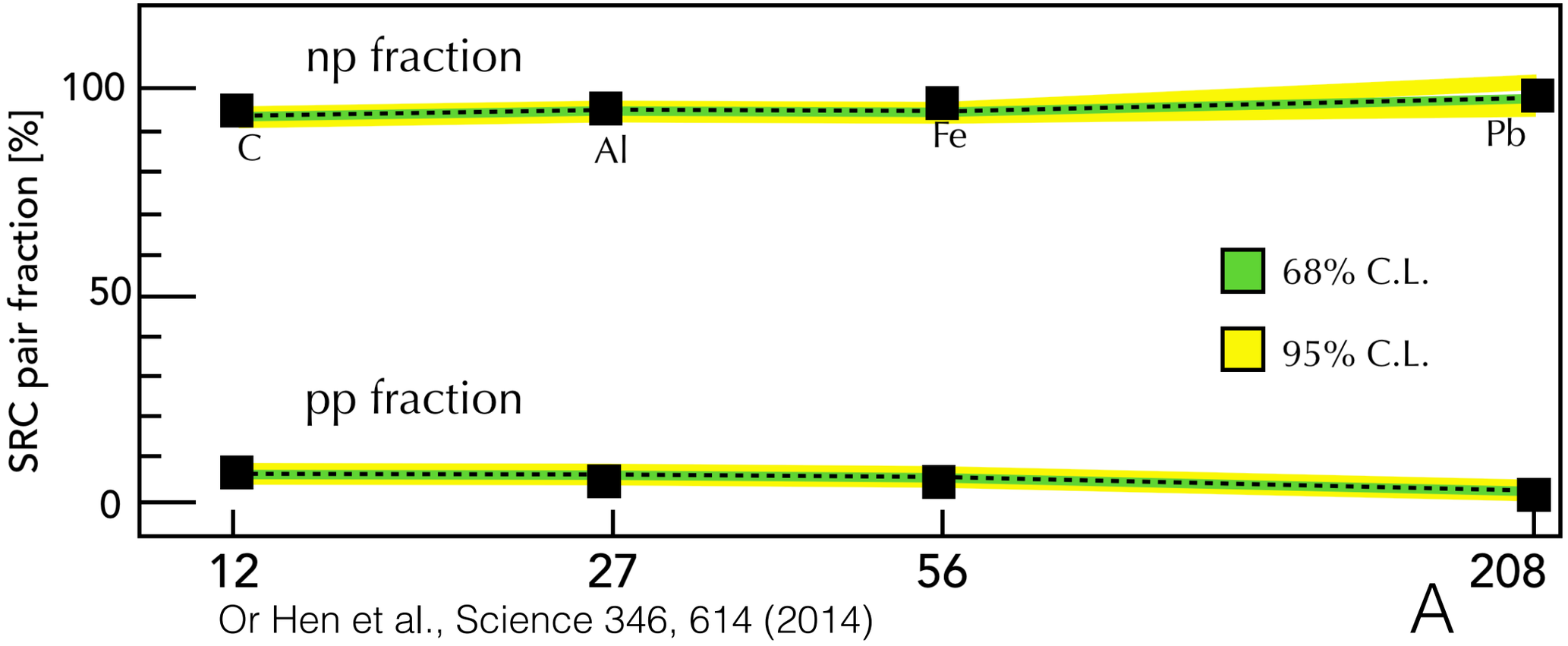


- (e'p) and (e'n) measurements
- Indication of np-dominance for SRC pairs

np-Dominance

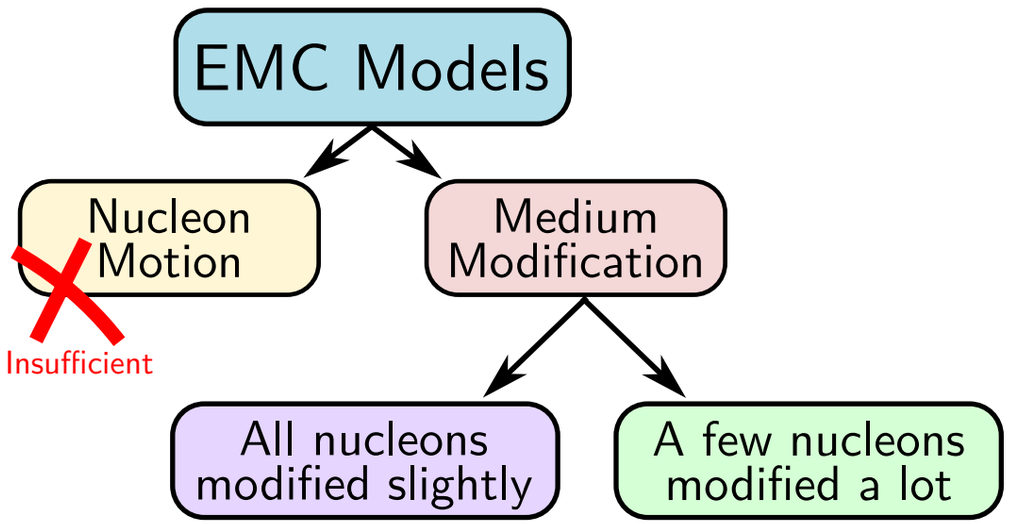


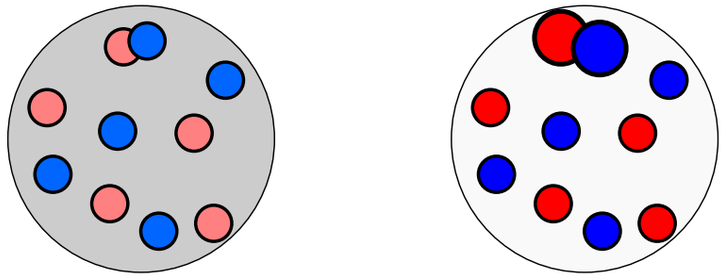
- (e'pp) & (e'np) measurements
- Probability for np pairs about ~18 larger than for pp pairs



Or Hen et al., Science 346, 614 (2014)

To Review: EMC and SRC



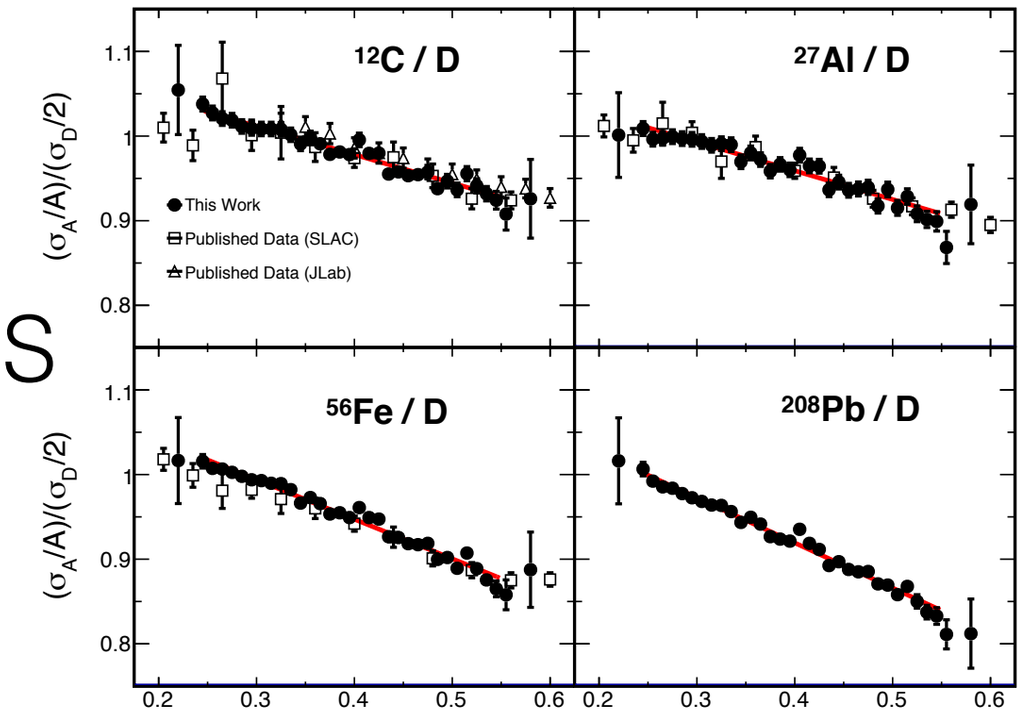


Mean Field Modifications

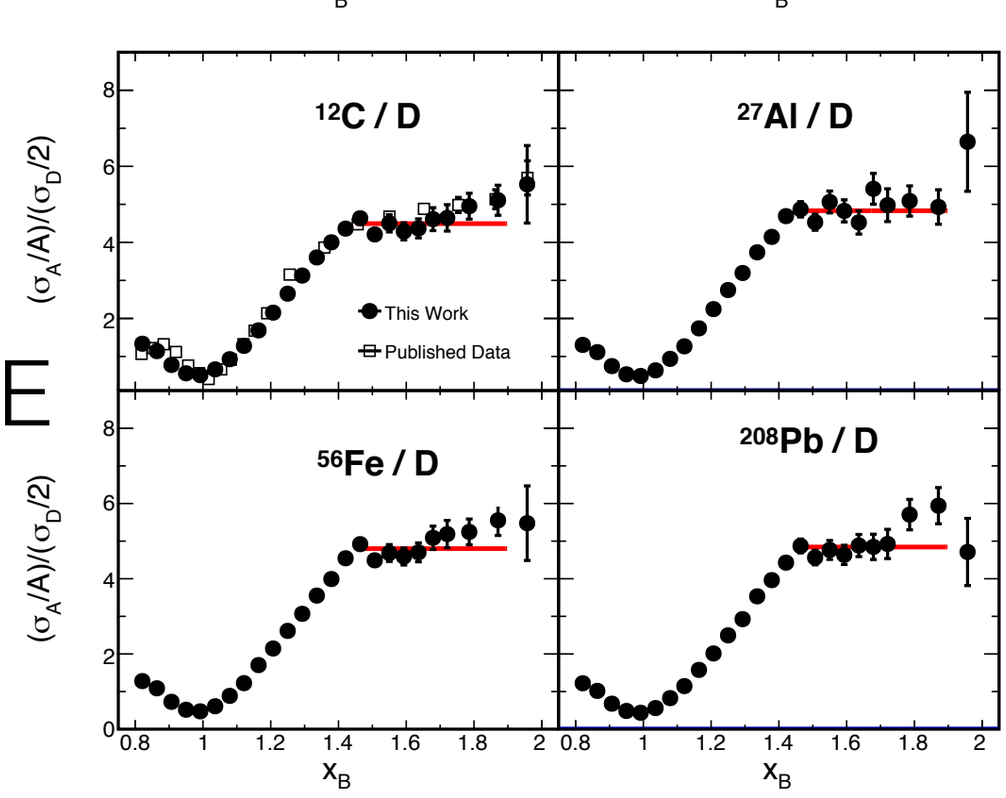
Short Range Correlations (SRC)

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

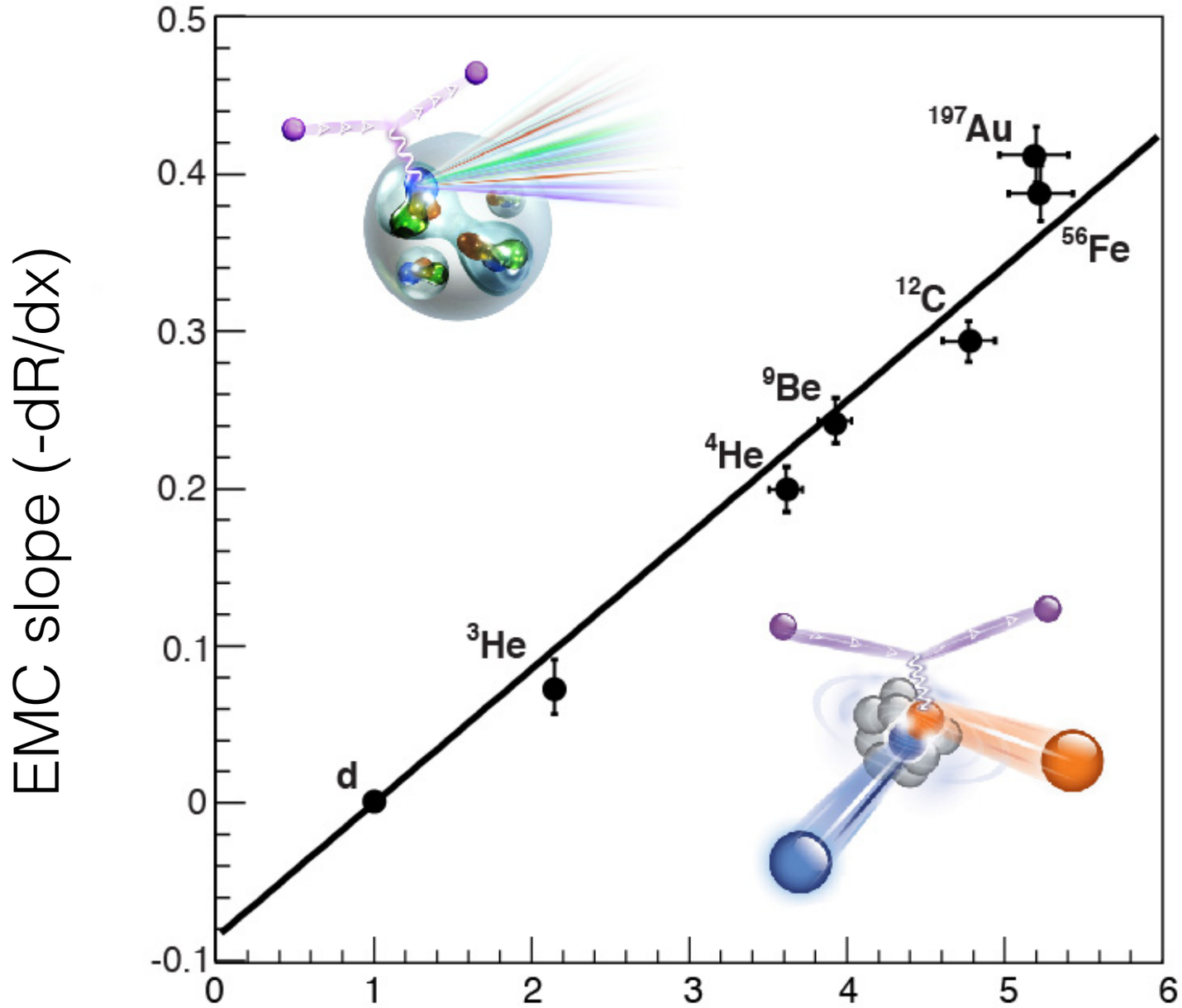
DIS



QE



EMC and SRC Correlation



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

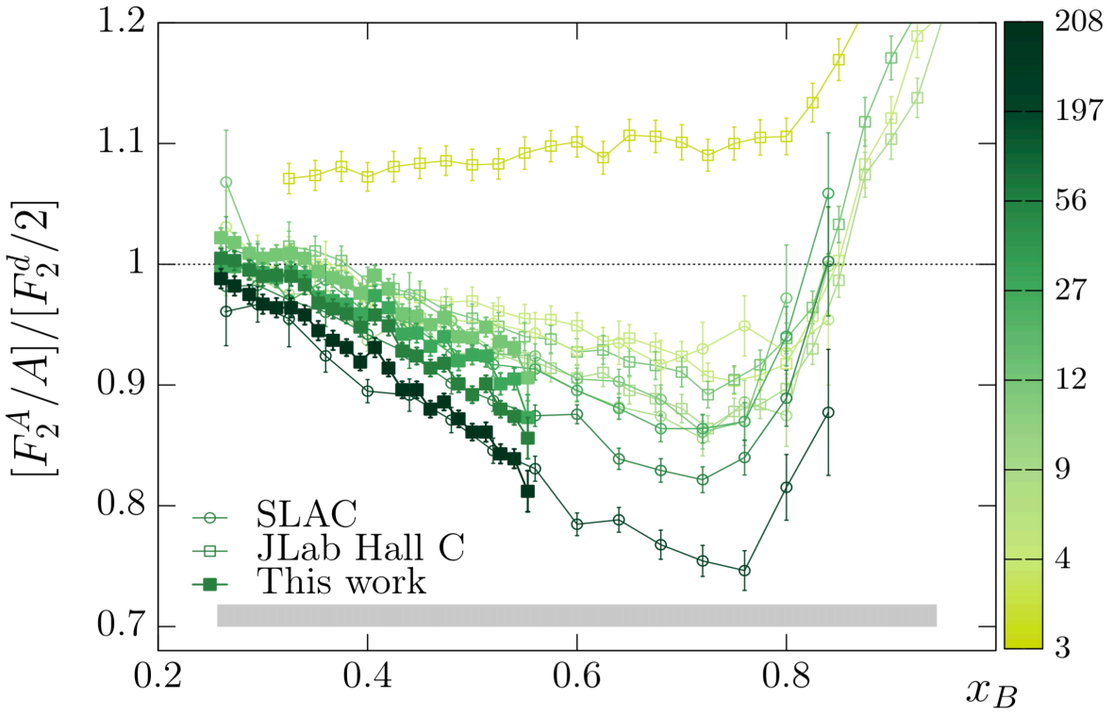
SRC-EMC Model and Universal function

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

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

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

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)

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

Bound = ``Quasi-free“ + Modified SRC

F_2^n not well constrained but solve by

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

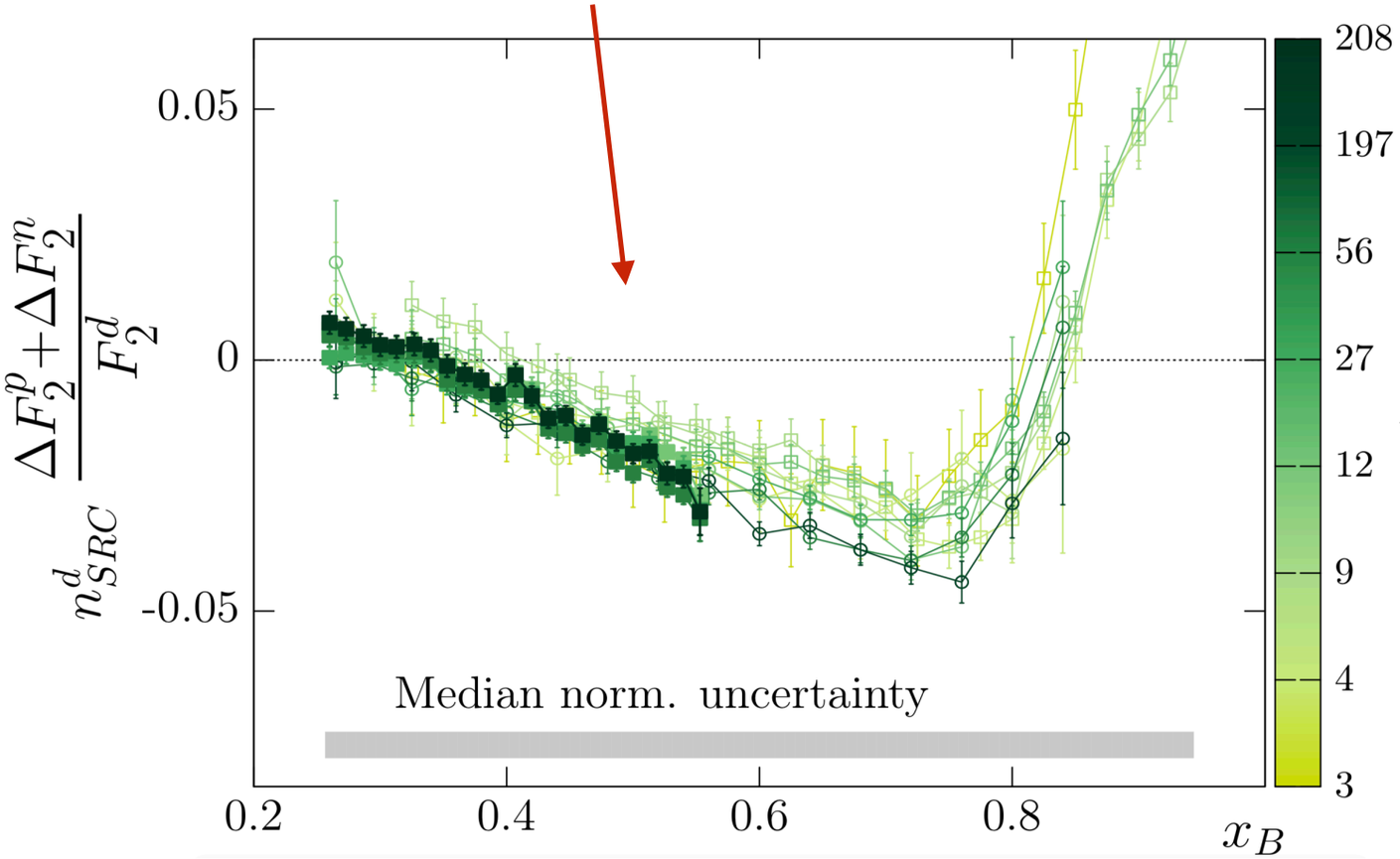
SRC-EMC Model and Universal function (3)

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

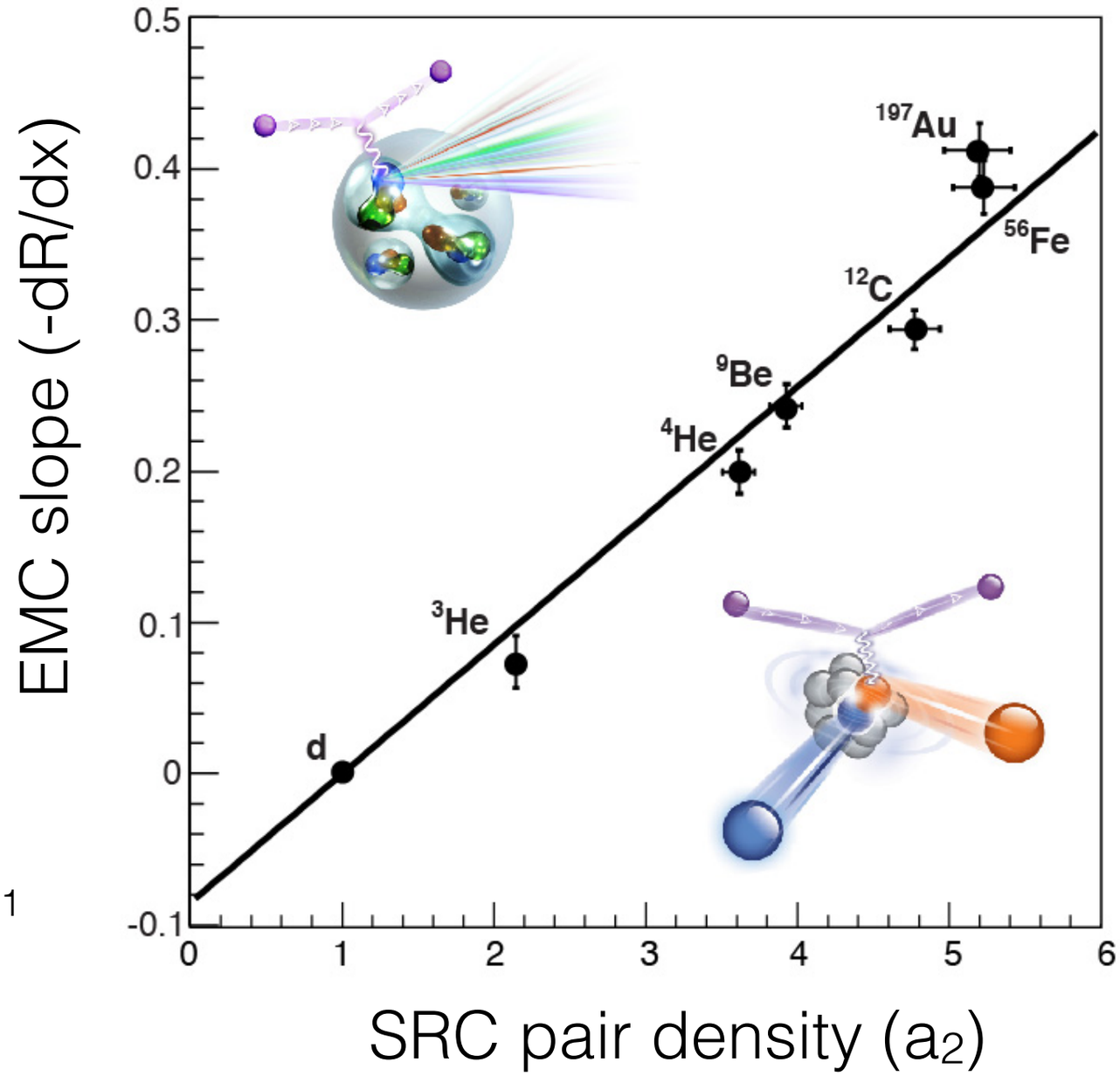
$$n_{SRC}^{d}\frac{\Delta F_2^p + \Delta F_2^n}{F_2^d} = \frac{\frac{F_2^A}{F_2^d} - (Z-N)\frac{F_2^p}{F_2^d} - N}{\frac{A}{2}a_2 - N}$$

Universal function

Nucleus Dependent



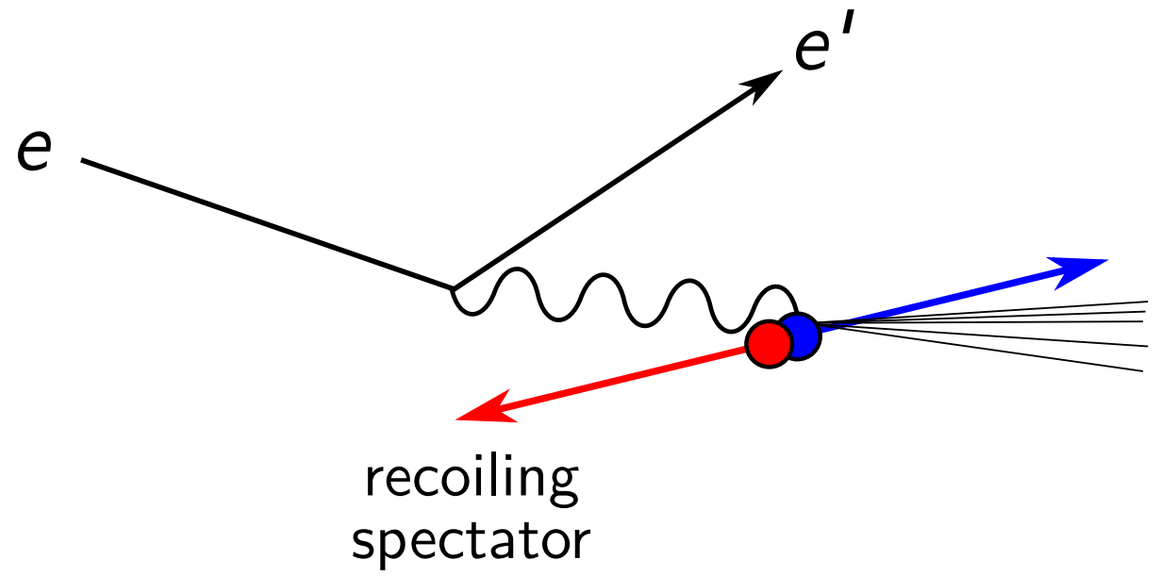
EMC and SRC Correlation



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

- Are high-momentum nucleons responsible for the EMC effect?
- Does nucleon modification depend on nucleon momentum?

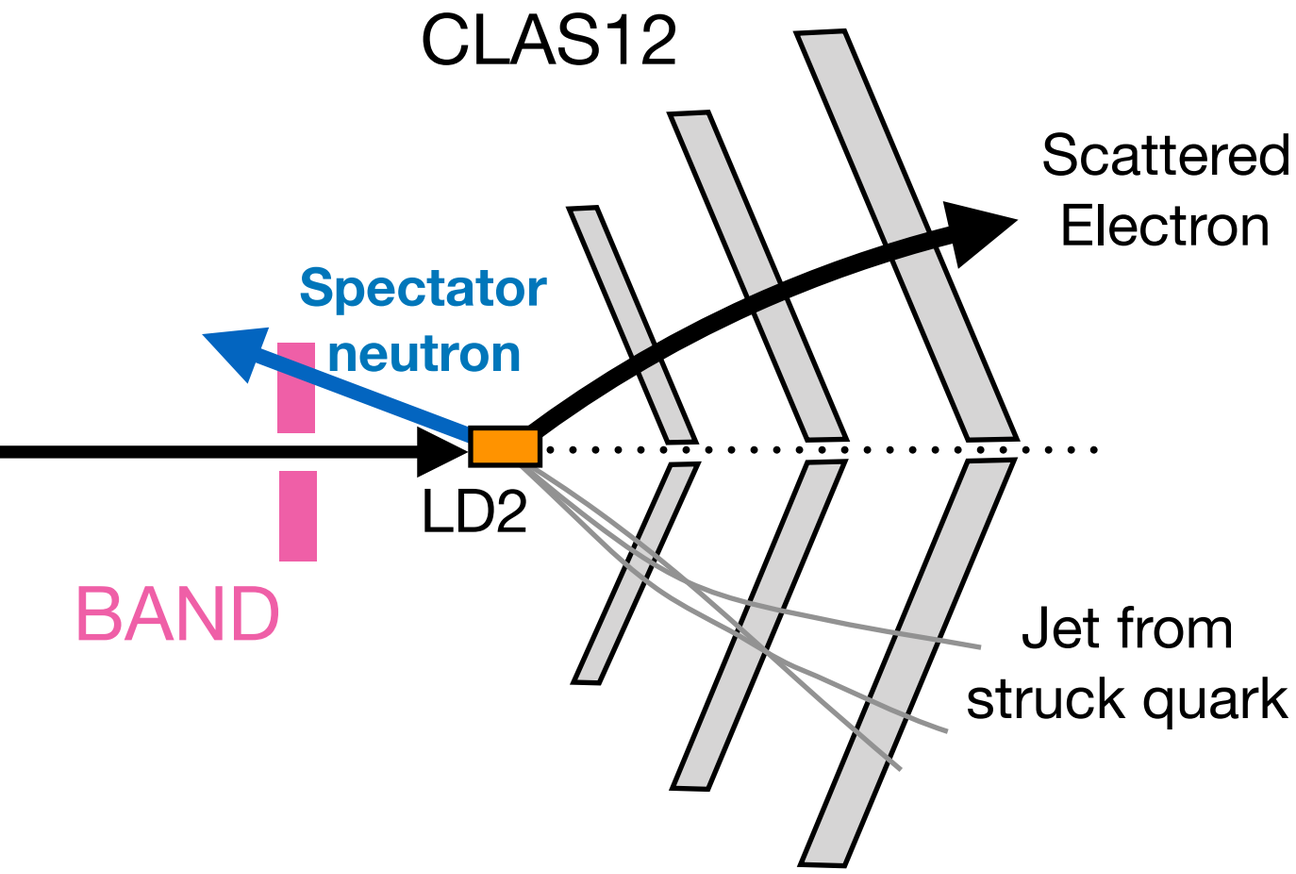
Tagged DIS on Deuterium



- “Tag“ interacting nucleon by measuring spectator
- How does the bound nucleon structure function depend on nucleon momentum?
- Explaining the EMC effect

Tagged DIS at JLab

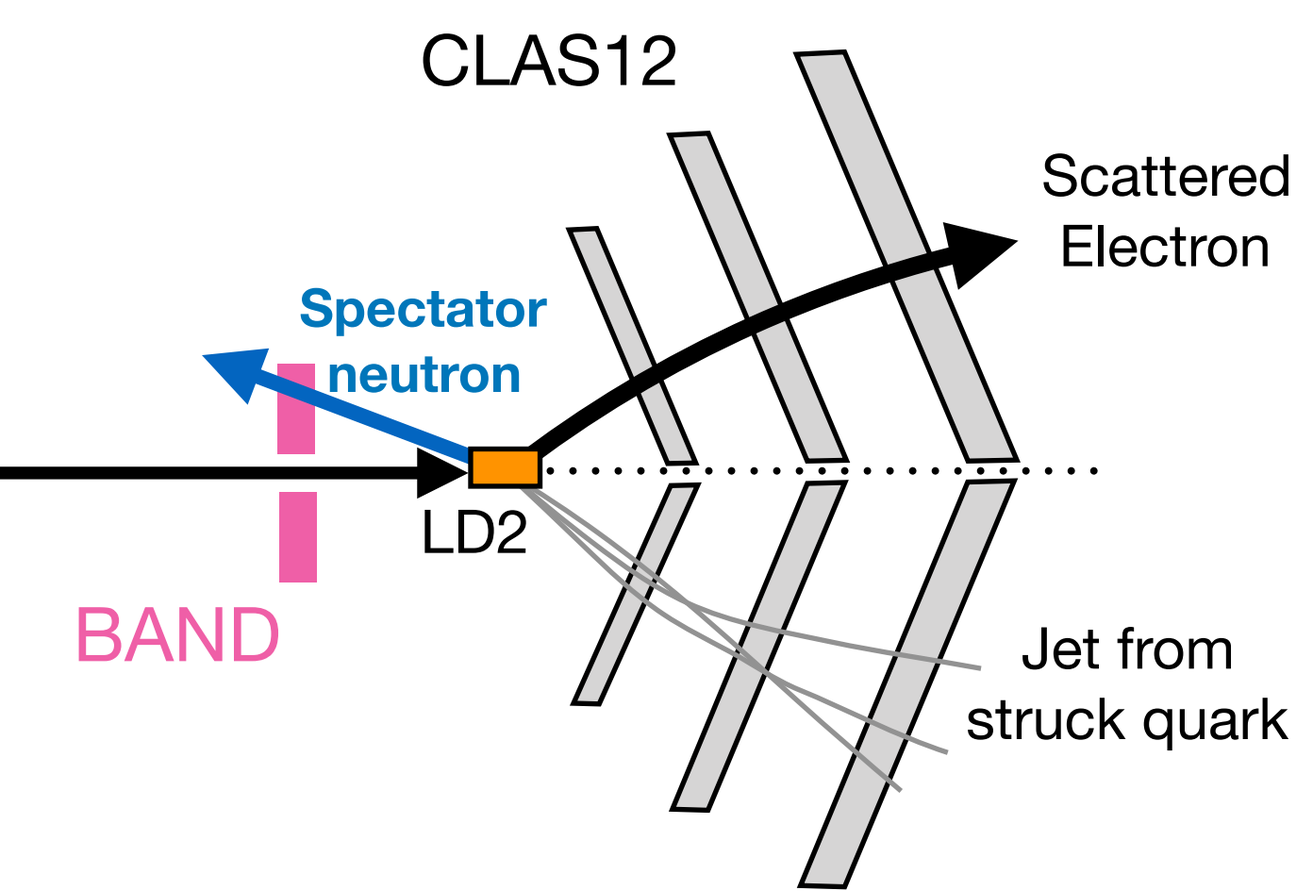
Hall B:
CLAS 12 + Backward Angle Neutron Detector (BAND)



- Took first data in Spring 19
- More to come in Fall 19

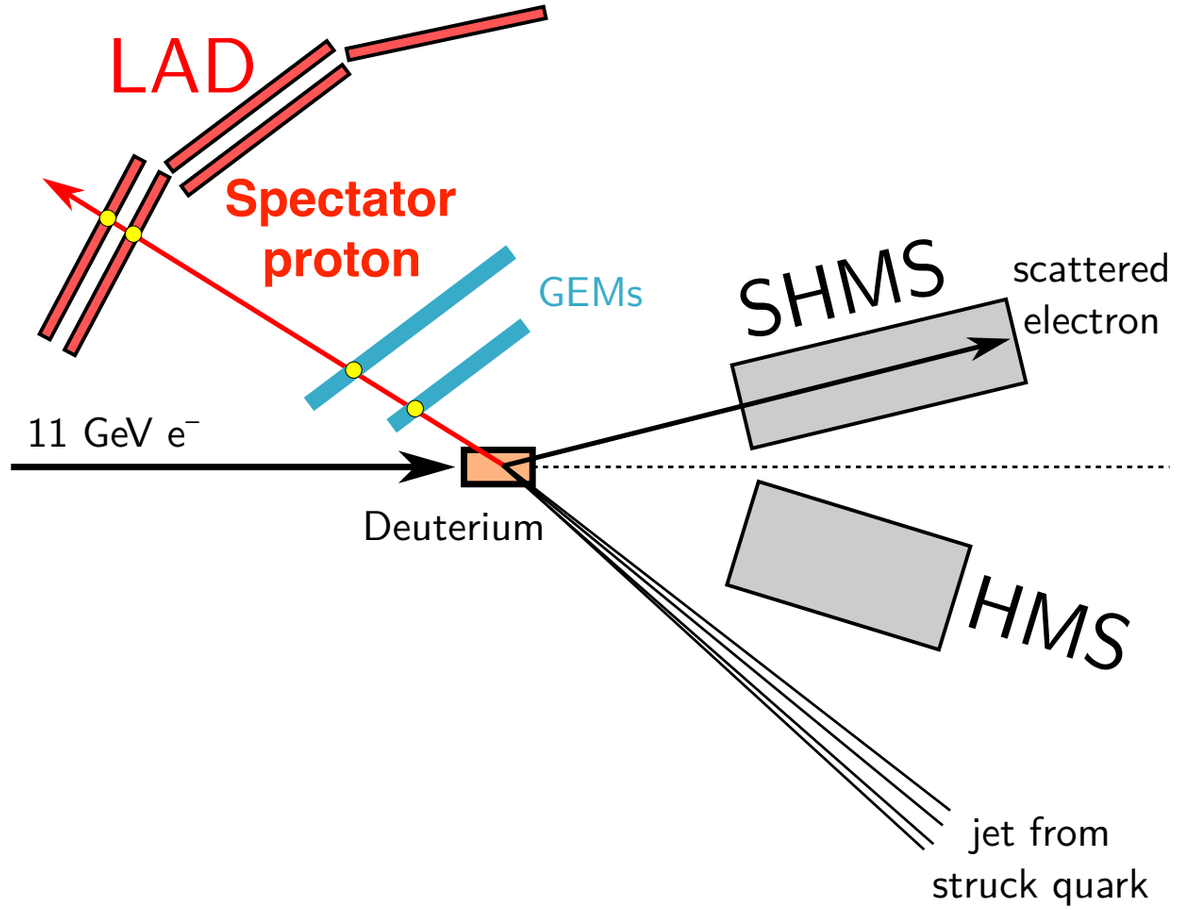
Tagged DIS at JLab

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



- Took first data in Spring 19
- More to come in Fall 19

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

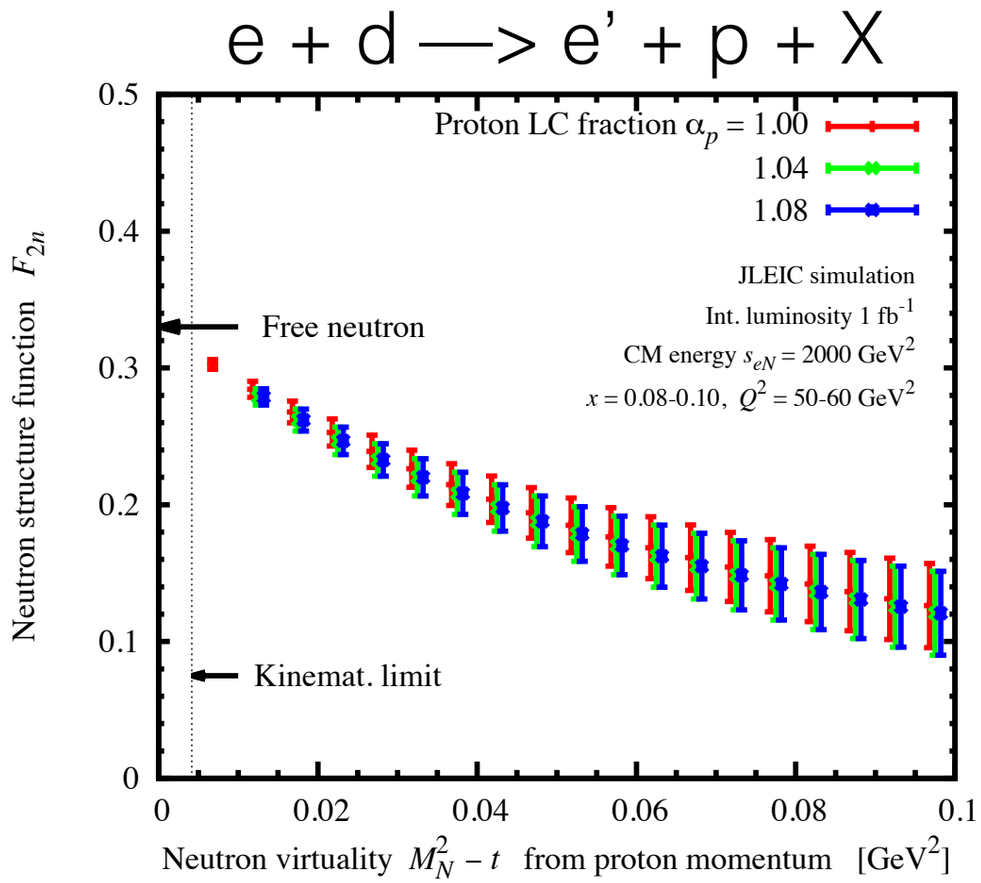


- LAD built, GEMs to be build
- Run in 2021?

Tagged DIS at EIC

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

- Detecting of recoil particles in forward direction
  - up to low angles, full acceptance
  - over a wide range of momenta
- Possible detection of A-2 system



Jefferson Labs' LDRD project (2014/15)

``*Physics potential of polarized light ions with EIC@JLab*"

C. Weiss, D. Higinbotham, P. Nadel-Turonski, W. Cosyn, V. Guzey,
Ch. Hyde, K. Park, M. Sargsian, M. Strikman

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

—> see Christian Weiss talk

Tagged SRC at EIC

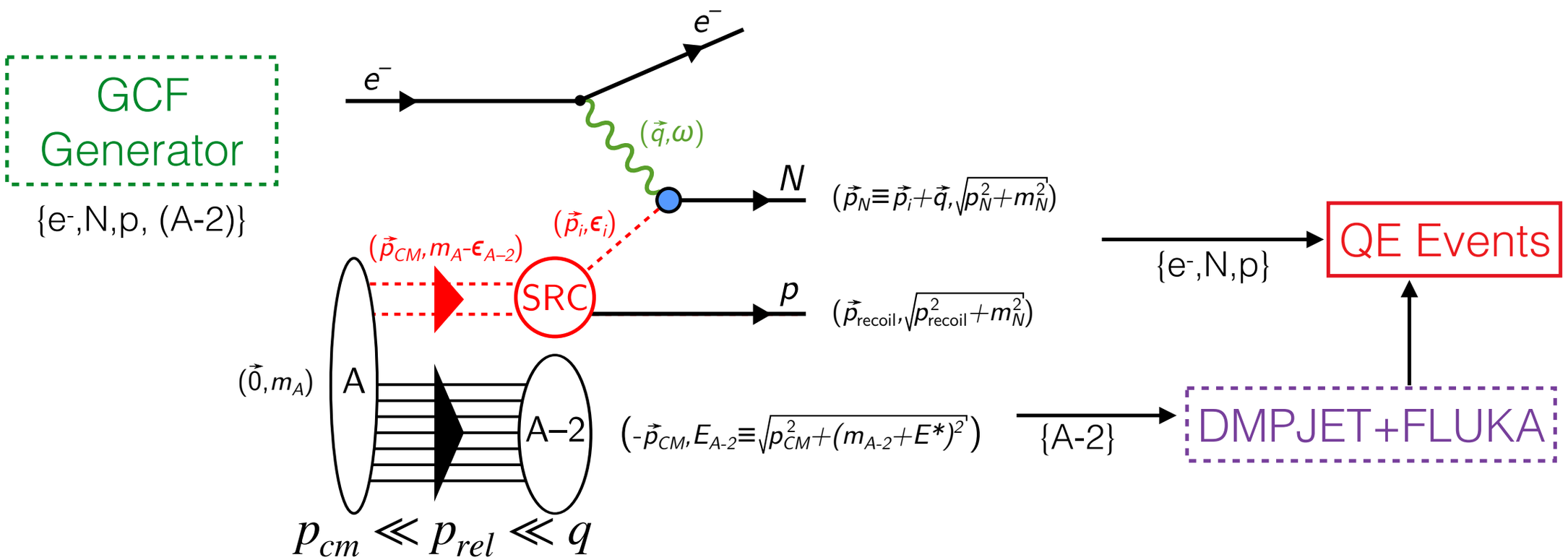
``Tagged SRCs for medium and heavy ions at the EIC“ (LDRD1912):
D. Higinbotham, V. Morozov, M. Baker, F. Hauenstein, A. Deshpande, O. Hen, C. Hyde, A. Schmidt, B. Schmookler, Z. Tu, P. Nadel- Turonski, L. Zheng

—> see Pawel Nadel-Turonski's talk

- Feasibility of tagged SRCs physics at (JL)EIC
  - Rates at high x
  - Resolution at high x
  - Beam energies
- Physics Reach
- Simulation and Modeling
  - BeAGLE - eA event generator for EIC
  - Implementing SRCs in BeAGLE
  - EIC detector requirements
  - Reconstruction methods

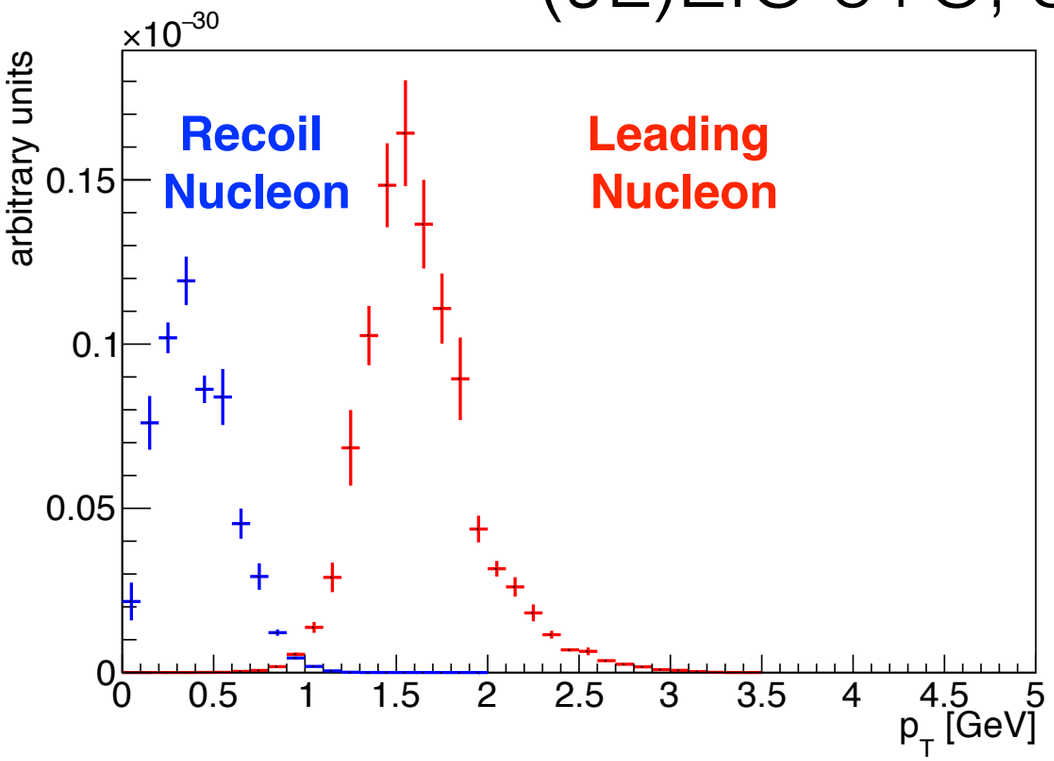
Short Range Correlations and BeAGLE

- Input to BeAGLE:
  - DIS events based on SRC driven EMC model
  - Quasi-Elastic SRC events from Generalized Contact Formalism (GCF) generator (see Axel Schmidt talk (http://www.mit.edu/~src_emc/fri/schmidt_20190322.pdf))
  - (A-2)-system handled by DPMJET3+FLUKA
- LDRD Project: Focus on e+C and e+Pb simulations

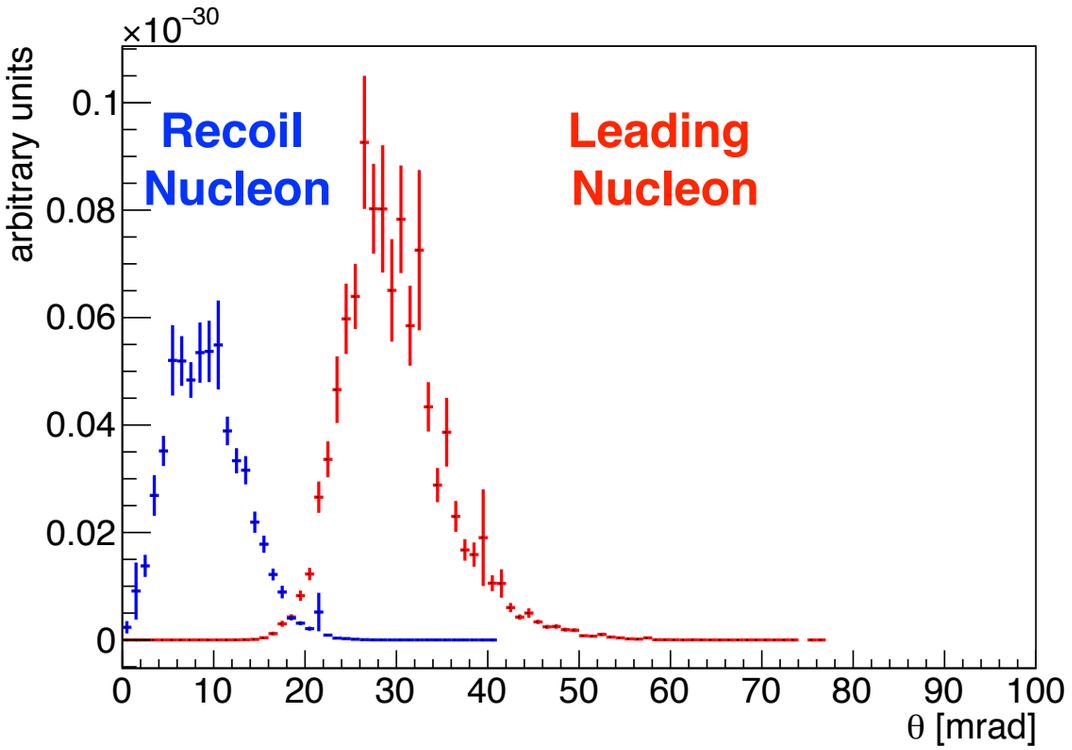


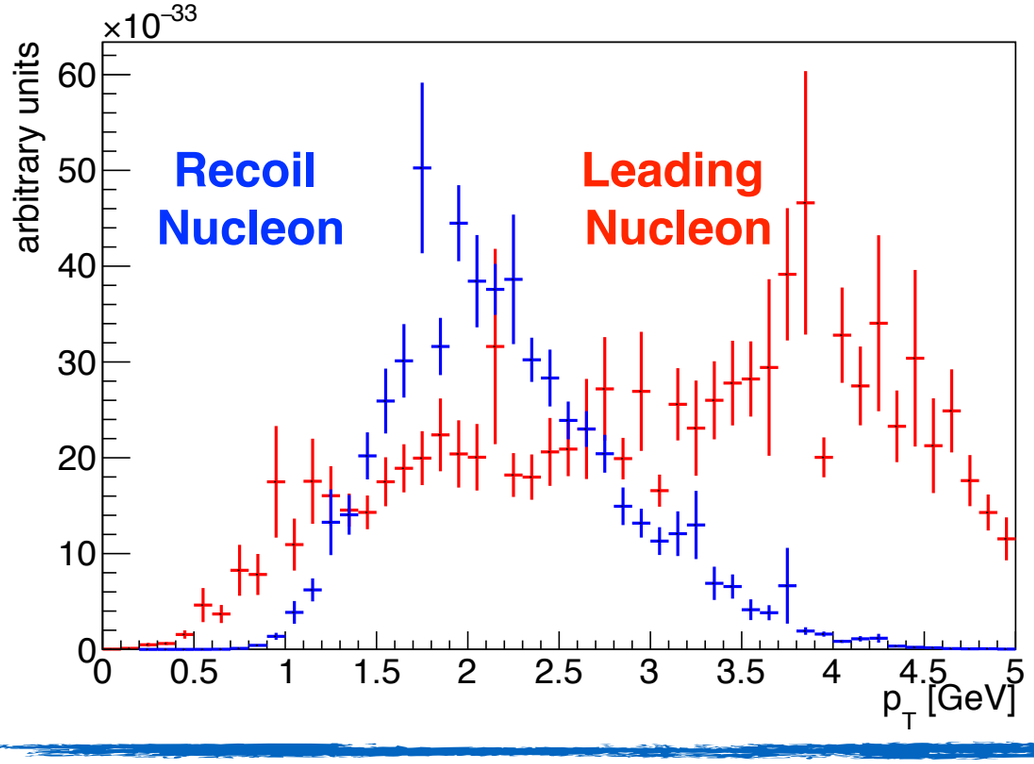
Quasielastic Simulation Results

(JL)EIC e+C, 5x50 GeV^2, QE selection cuts

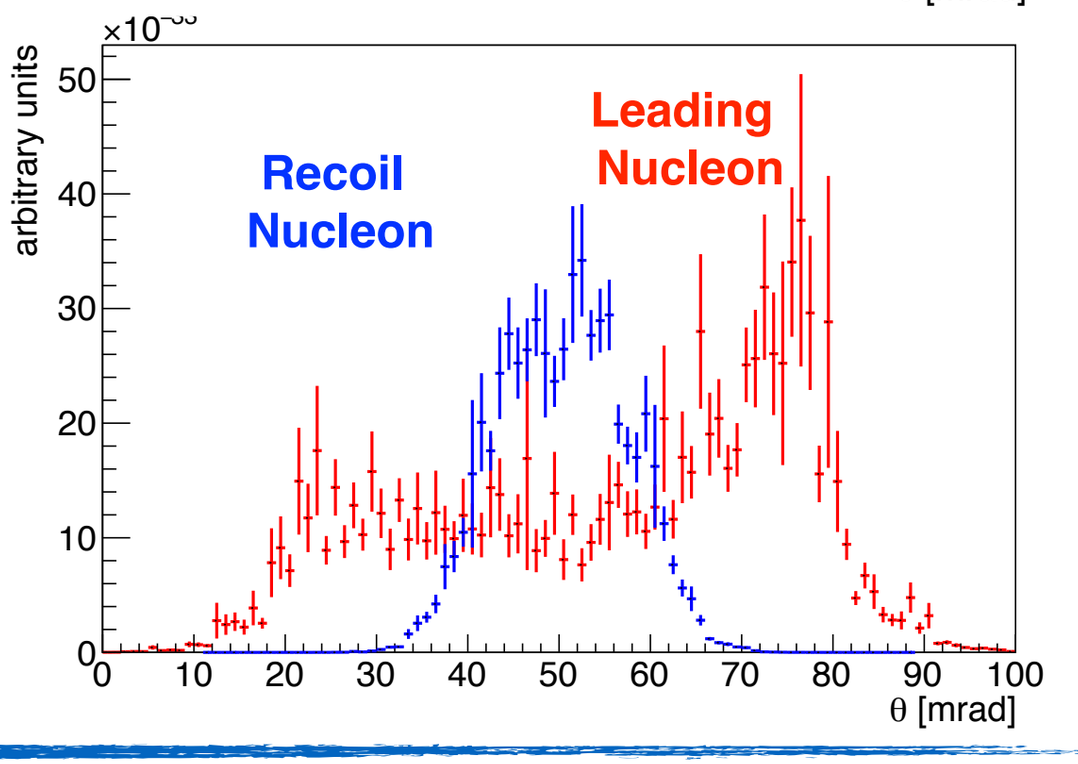


no crossing angle



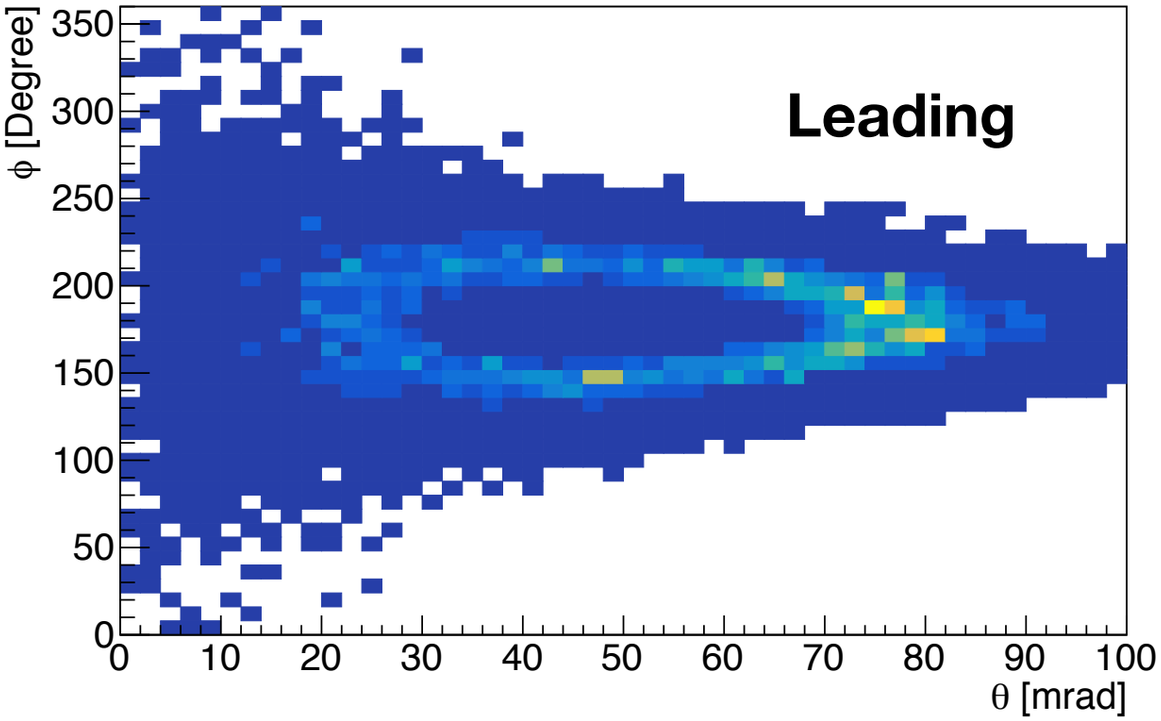


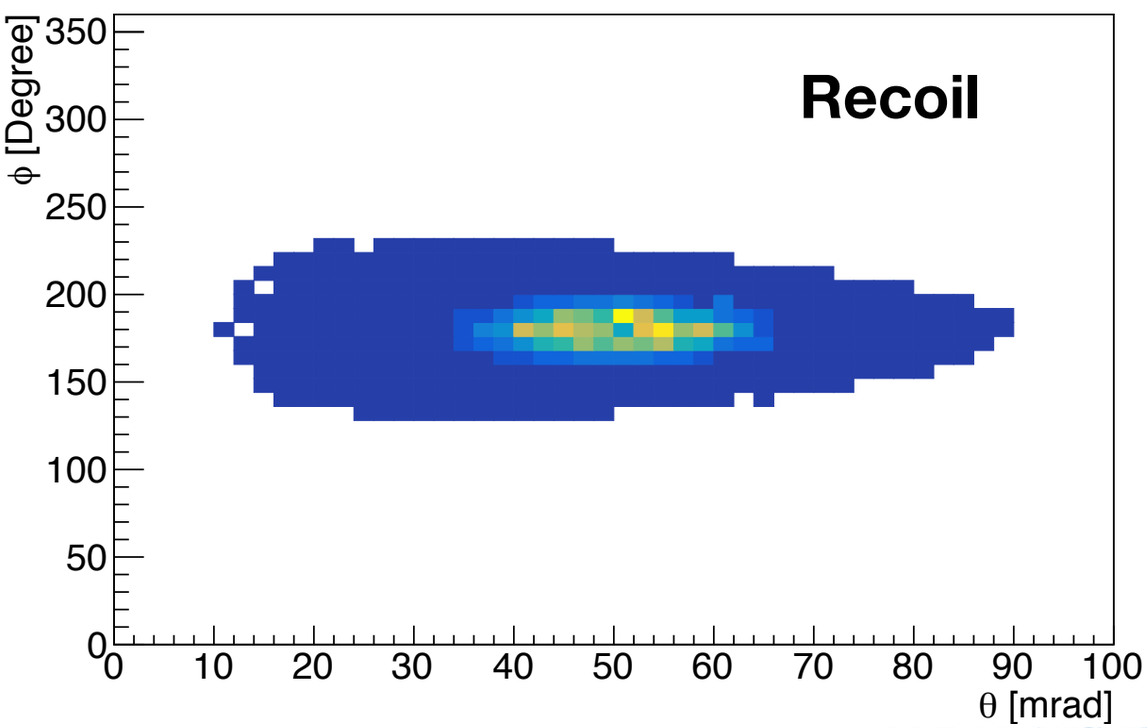
50 mrad crossing angle



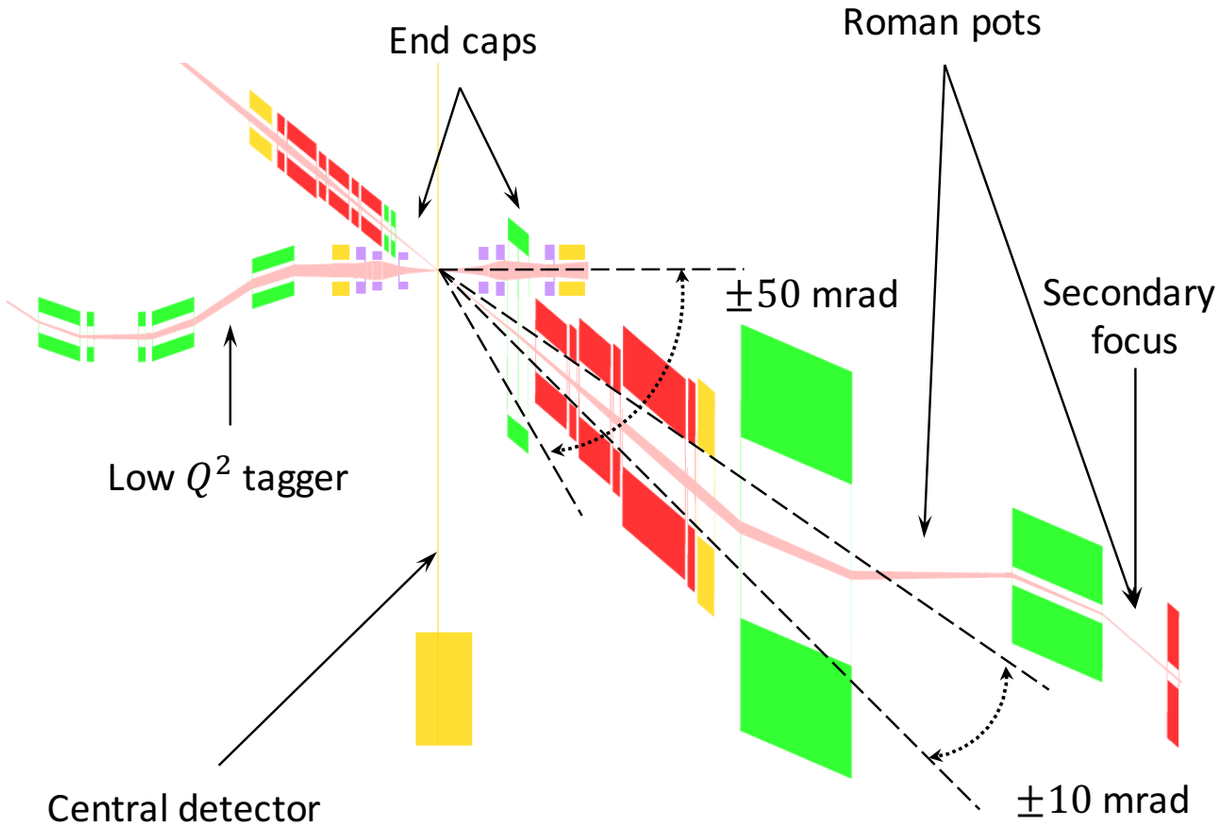
Quasielastic SRCs: $\phi - \theta$

(JL)EIC e+C, 5x50 GeV^2, QE selection cuts





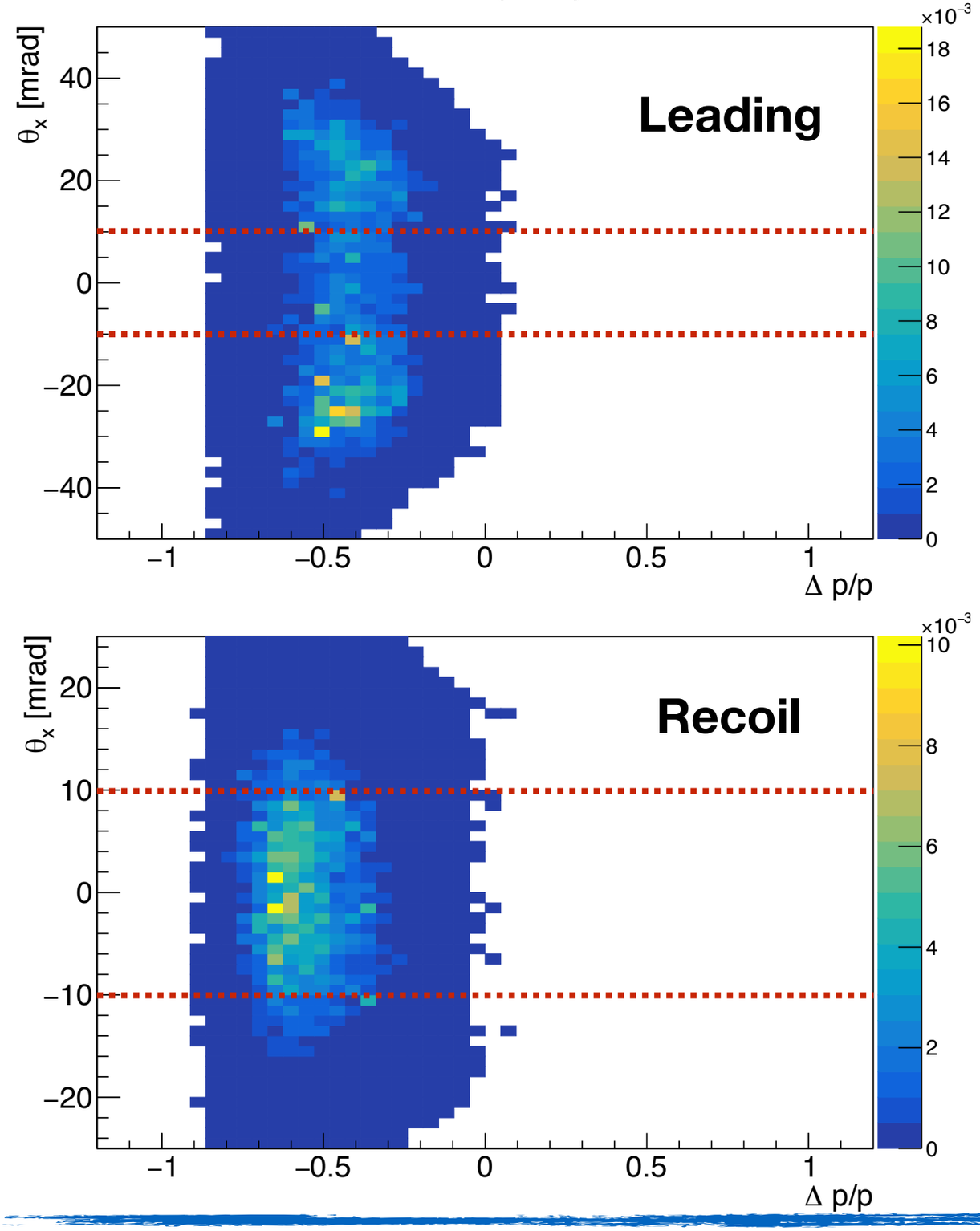
(JL)EIC forward ion direction



- ± 10 mrad acceptance —> zero degree detectors
- up to ± 50 mrad within magnet (not full ϕ due to first electron dipole)

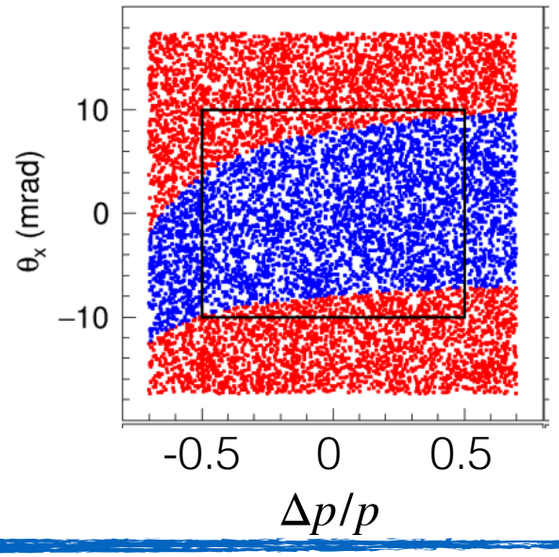
Quasielastic SRCs - Beam Rigidity

(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

Summary and Outlook

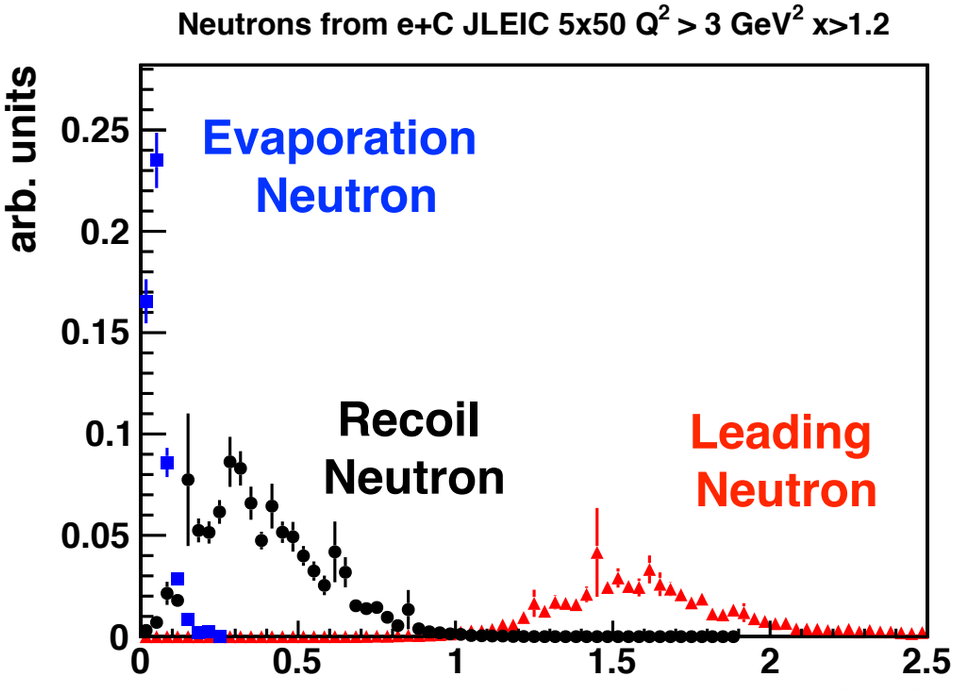
- EMC-SRC correlation from electron scattering
- Tagged DIS measurement at JLab to explain EMC effect
  - Measurement of F_2^p with CLAS12 plus BAND
  - Measurement of F_2^n in Hall C with LAD (2021?)
- SRC physics possibilities at (JL)EIC
  - LDRD project
    - First simulation results from QE-SRCs

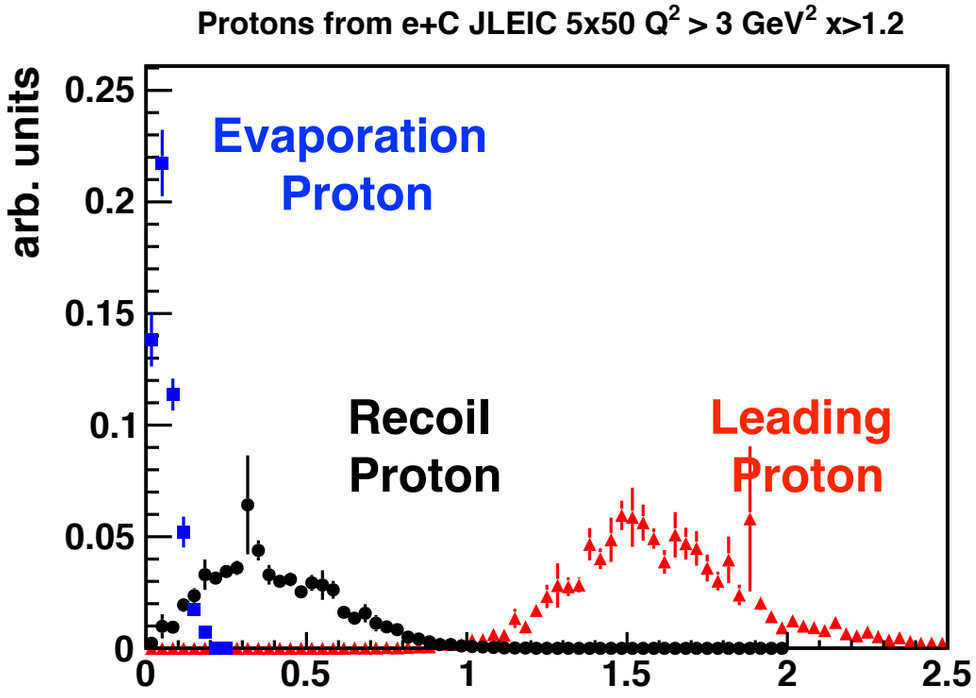
Near term:

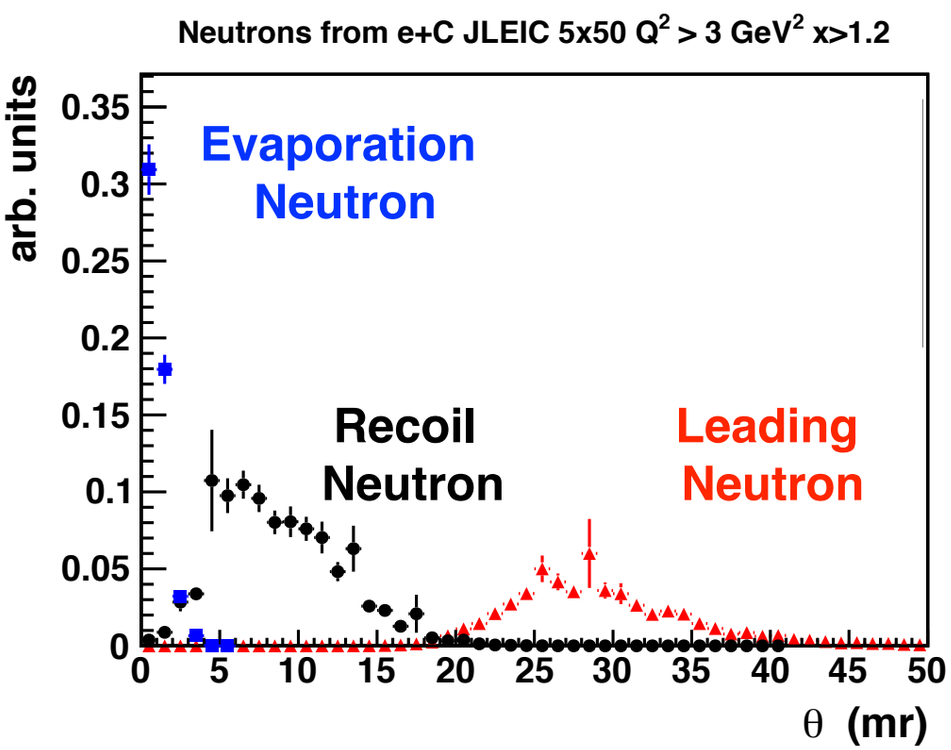
- Continuation of EIC-LDRD project
  - Simulation of DIS event from SRC-EMC model
  - Effects of FSI and intranuclear cascading
  - Detector requirements in forward ion direction

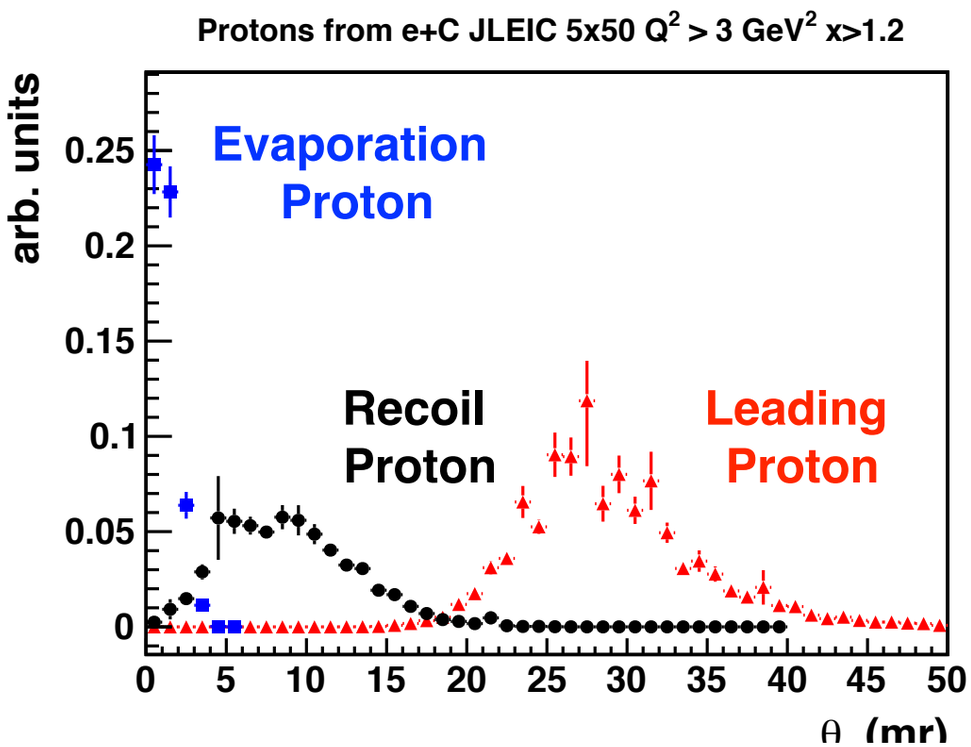
Back up slides

QE Simulation Results (no crossing angle)

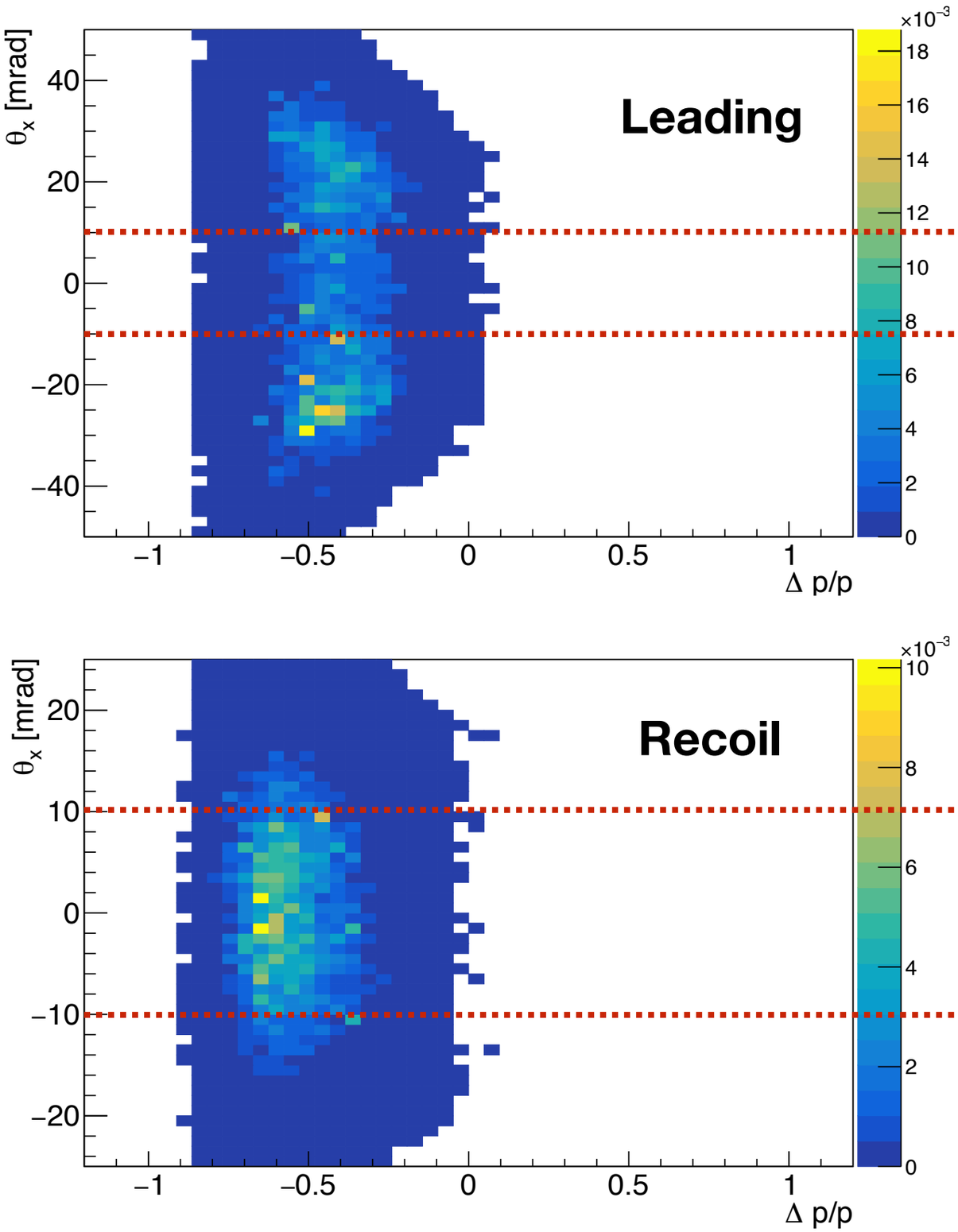


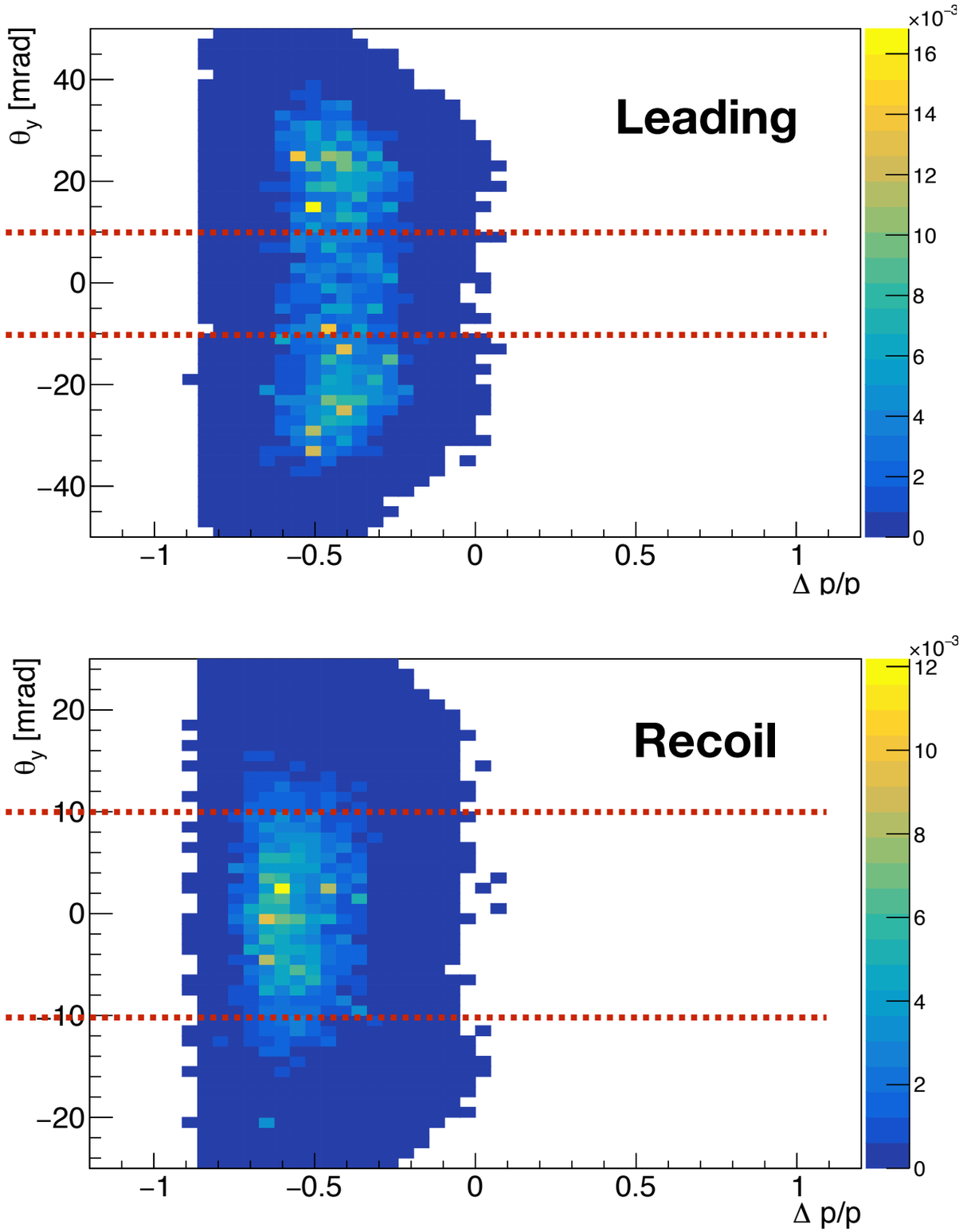






Quasielastic SRCs - Beam Rigitidity



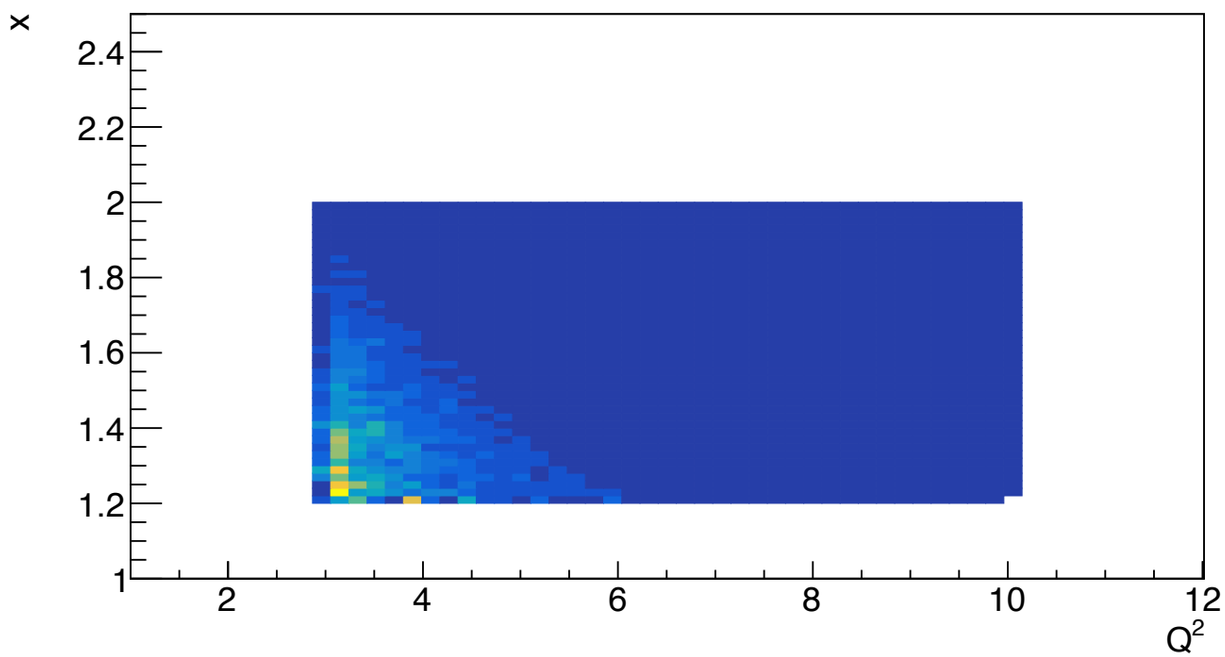


QE Event Handling Procedure

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

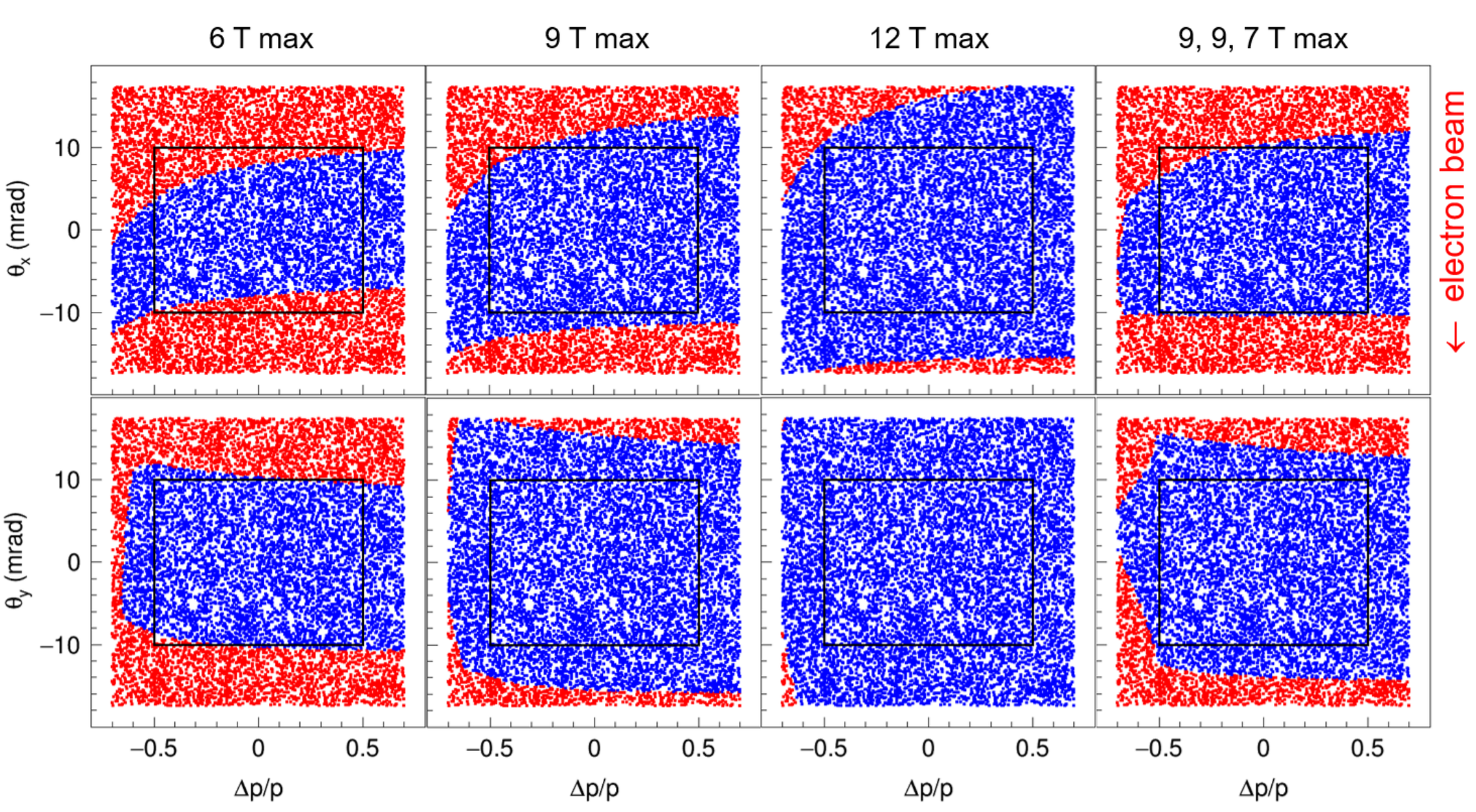
- **Fixed target events to collider events**
  - Boost from lab to c.m.s with fixed target kinematics (P_e = 537 GeV)
  - Boost from c.m.s to collider lab with e+C (5x50[40]) beams
- **Add crossing angle via**
  - Boost along x-axis with beta = 0.025
  - Rotate along y-axis by -0.025 mrad

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



Far-forward Acceptance Simulation

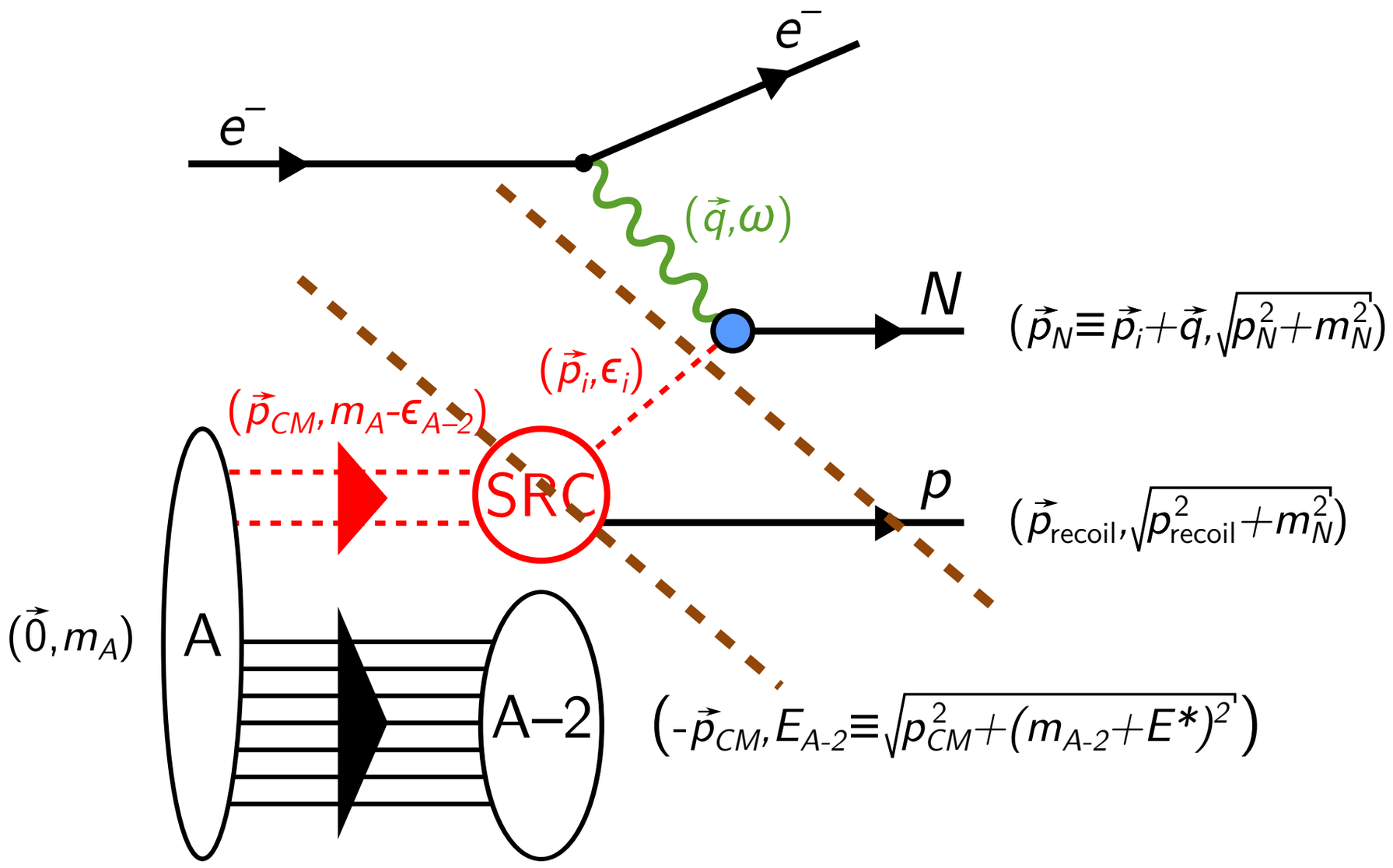
from V. Morozov CFNS Summer School 2019



- Uniform particle distribution ±0.7 in $\Delta p/p$
- Accepted particles are in blue

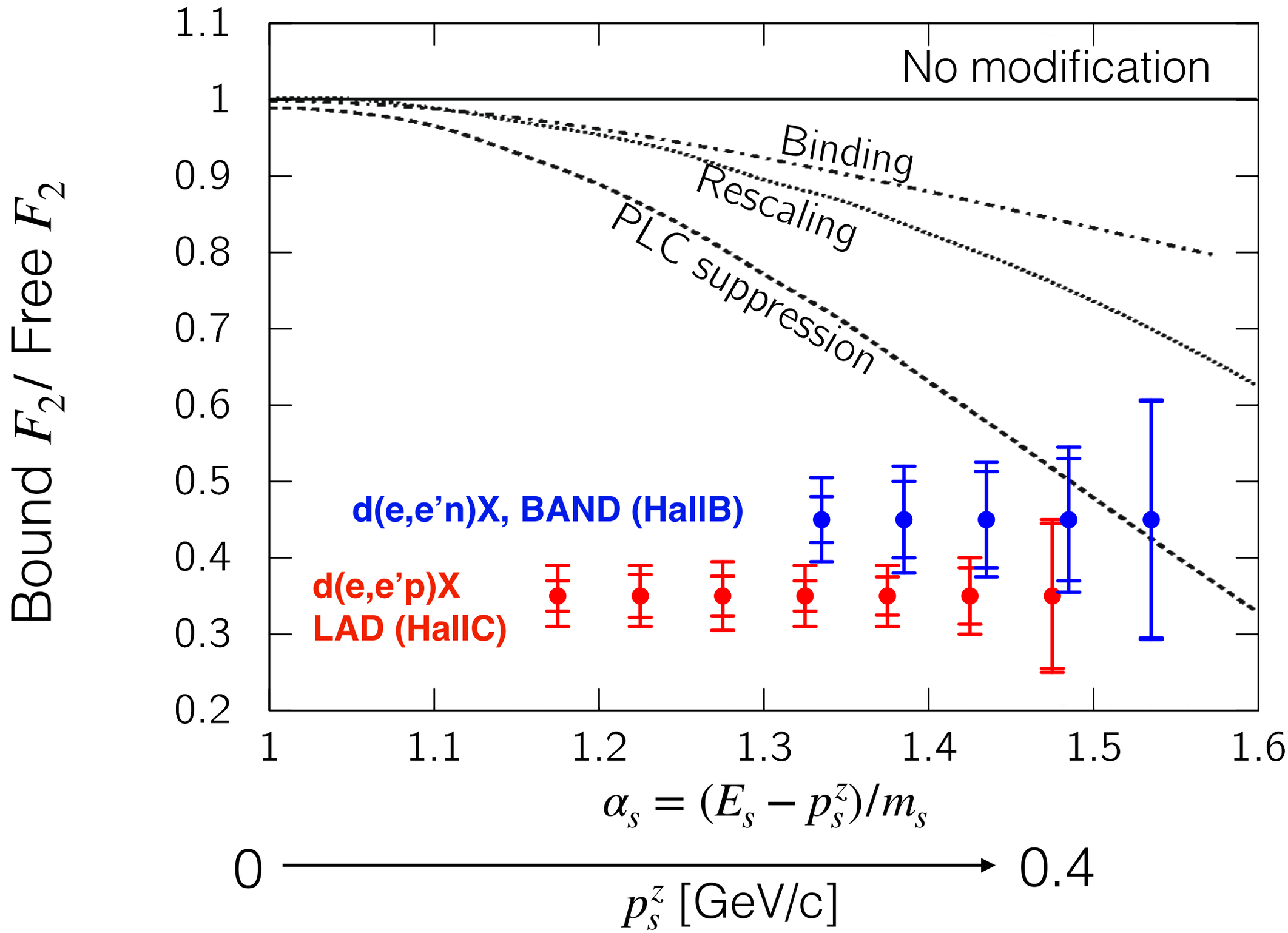
GCF-QE Diagram

Fully Plane-Wave Reaction

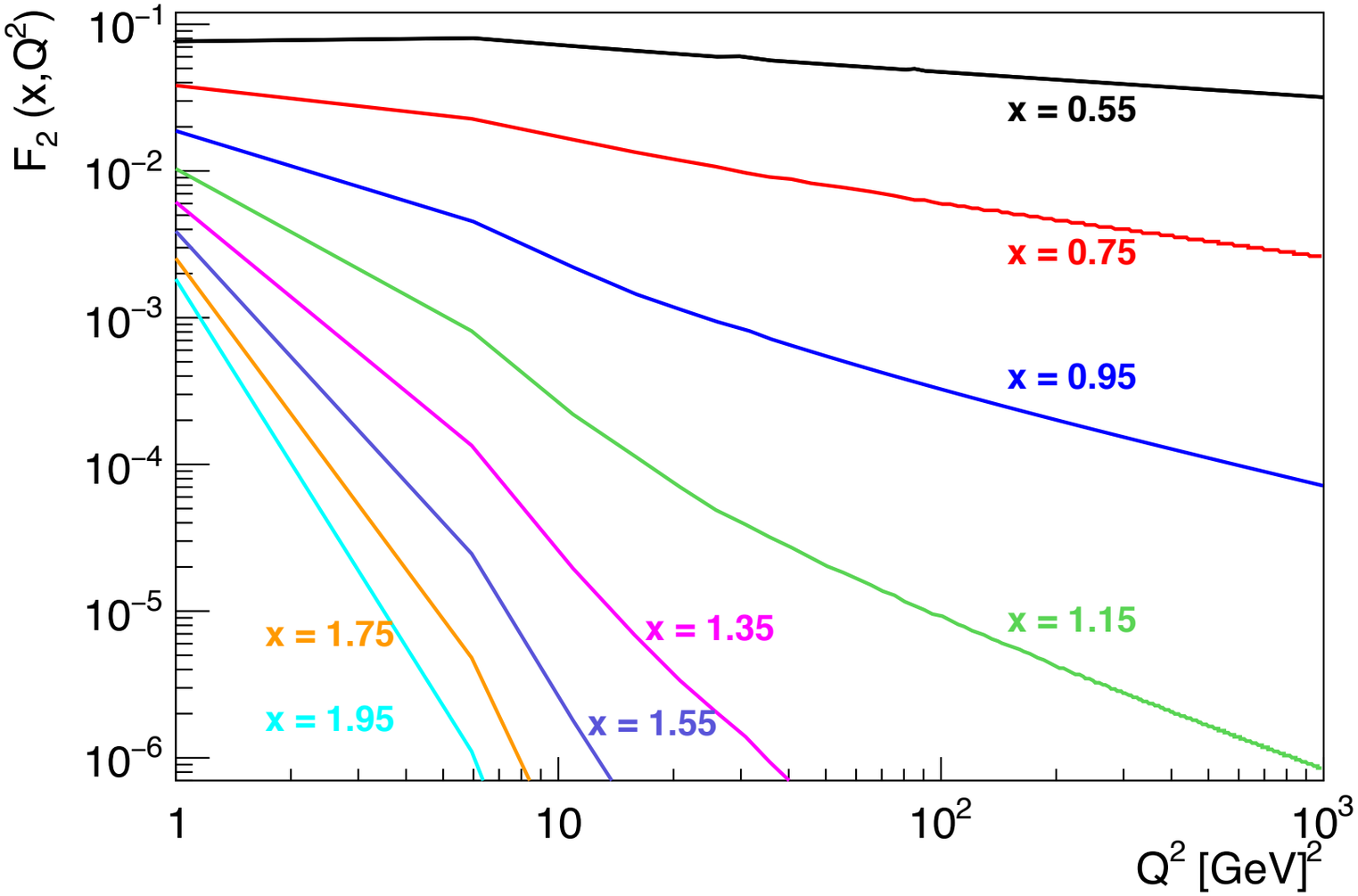


Scale separation: $p_{cm} \ll p_{rel} \ll q$

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



DIS Rate Estimates from F_2 Parametrization

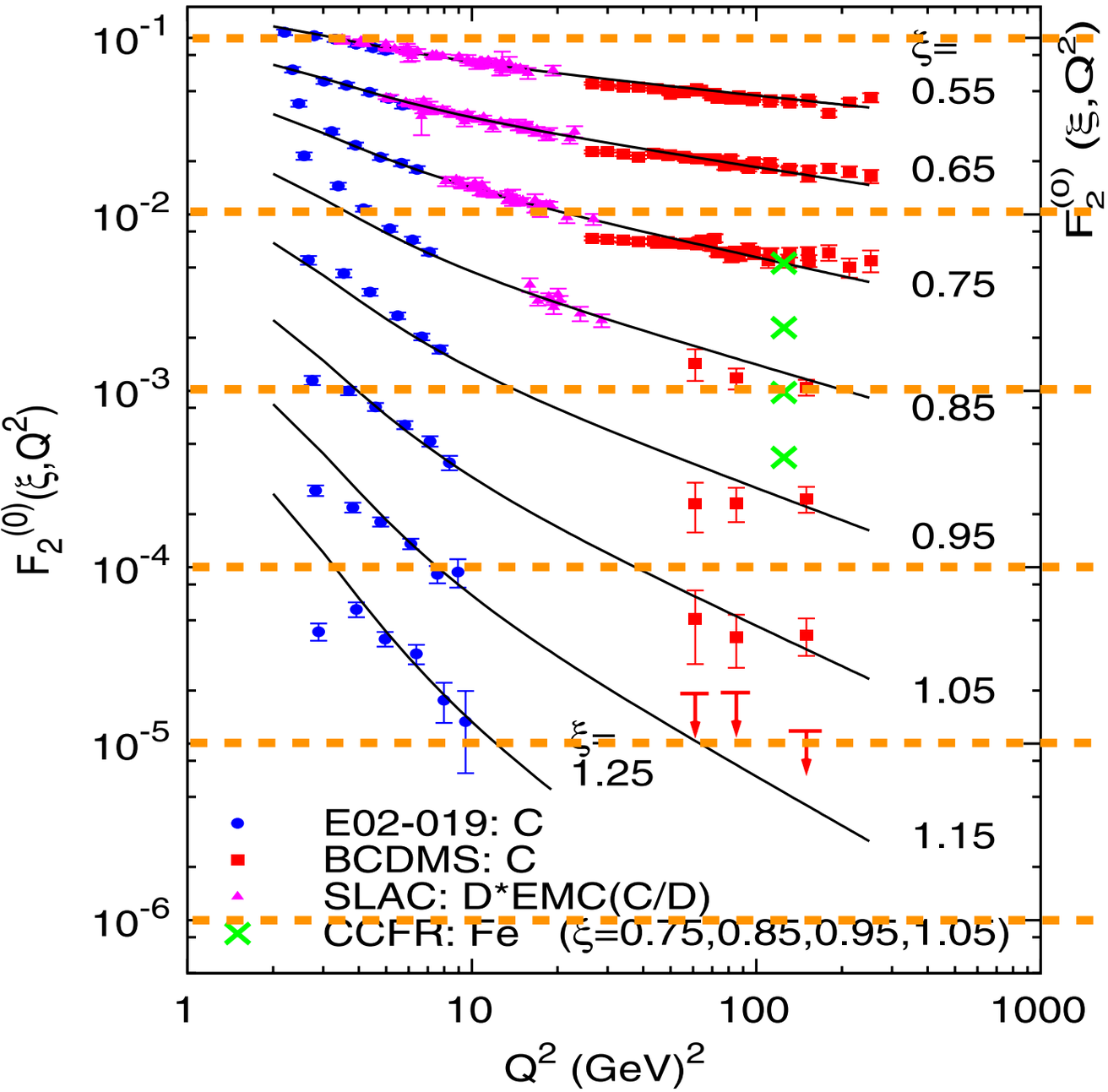


- Measuring EMC effect at high Q^2 easy —> high rate
- SRC (x >1) at high Q^2 challenging but non zero rate

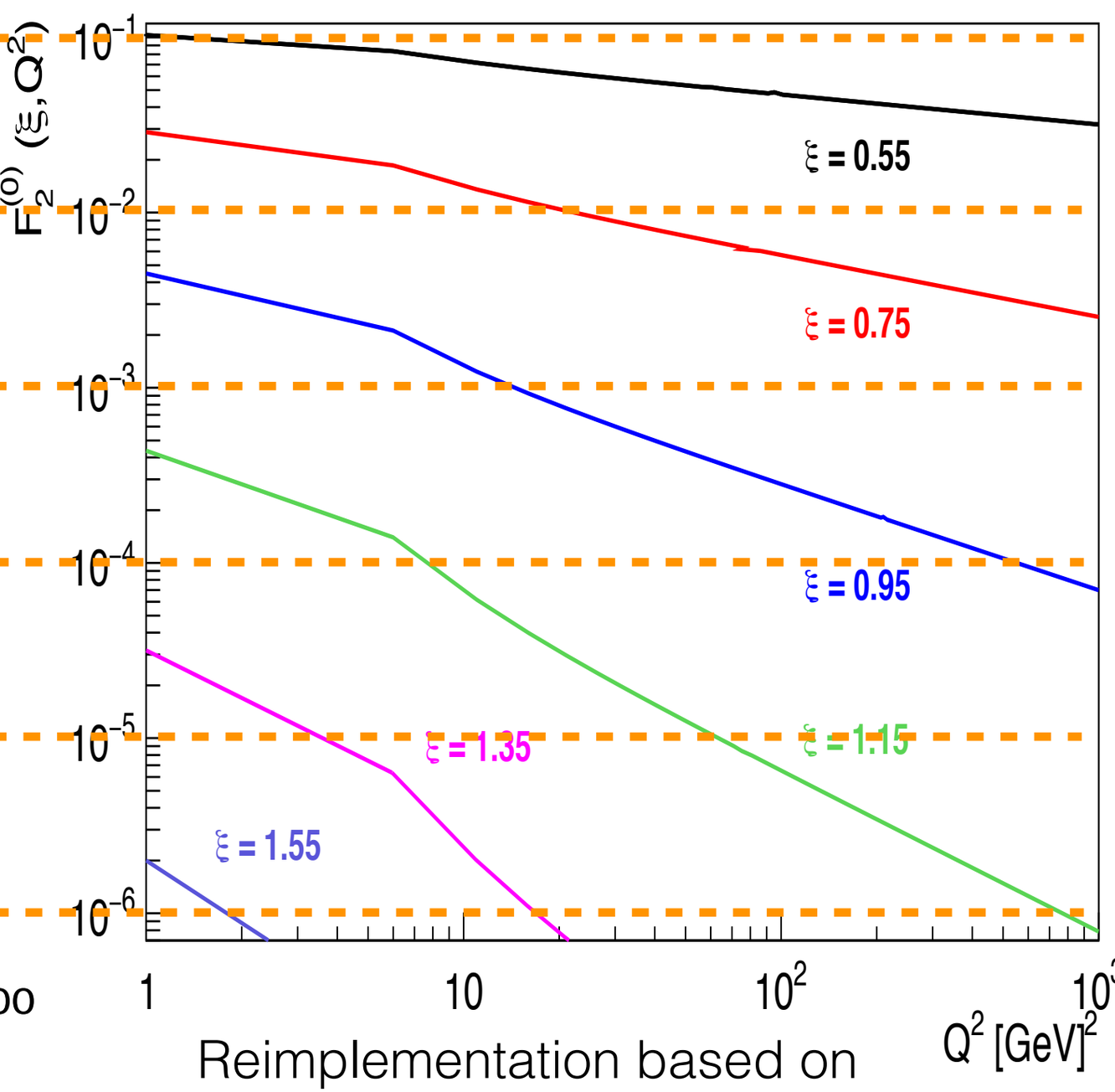
$F_2(x,Q^2)$ based on super-fast quark yield parametrization, N. Fomin PRL 105, 212502 (2010)

alternative model: J. Freese et al. Phys. Rev. D 99, 114019

F_2 from N. Fomin Paper and Reimplementation

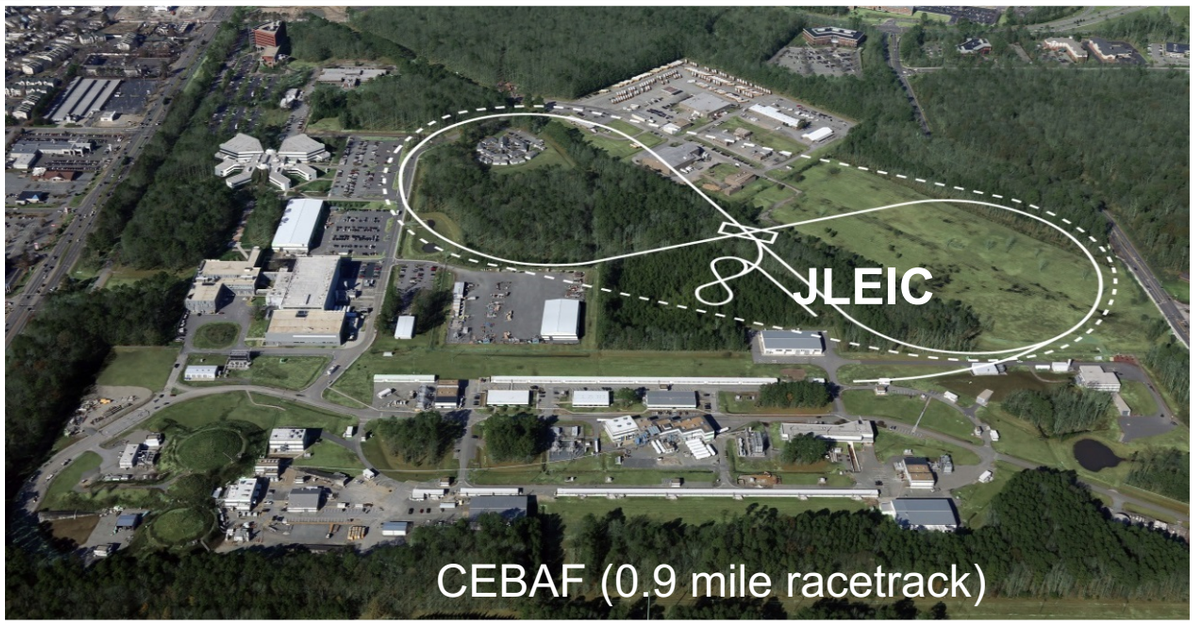


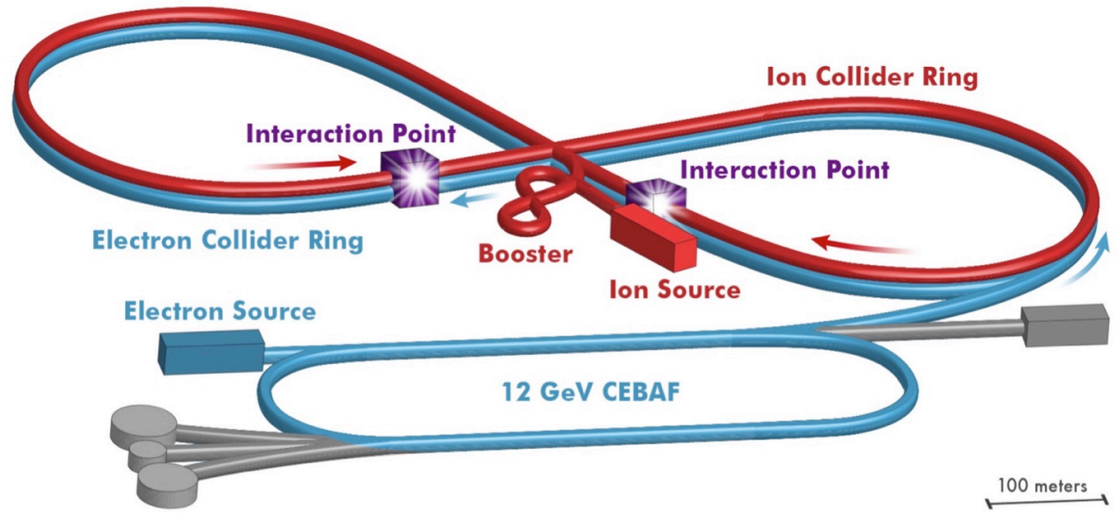
N. Fomin PRL 105, 212502 (2010



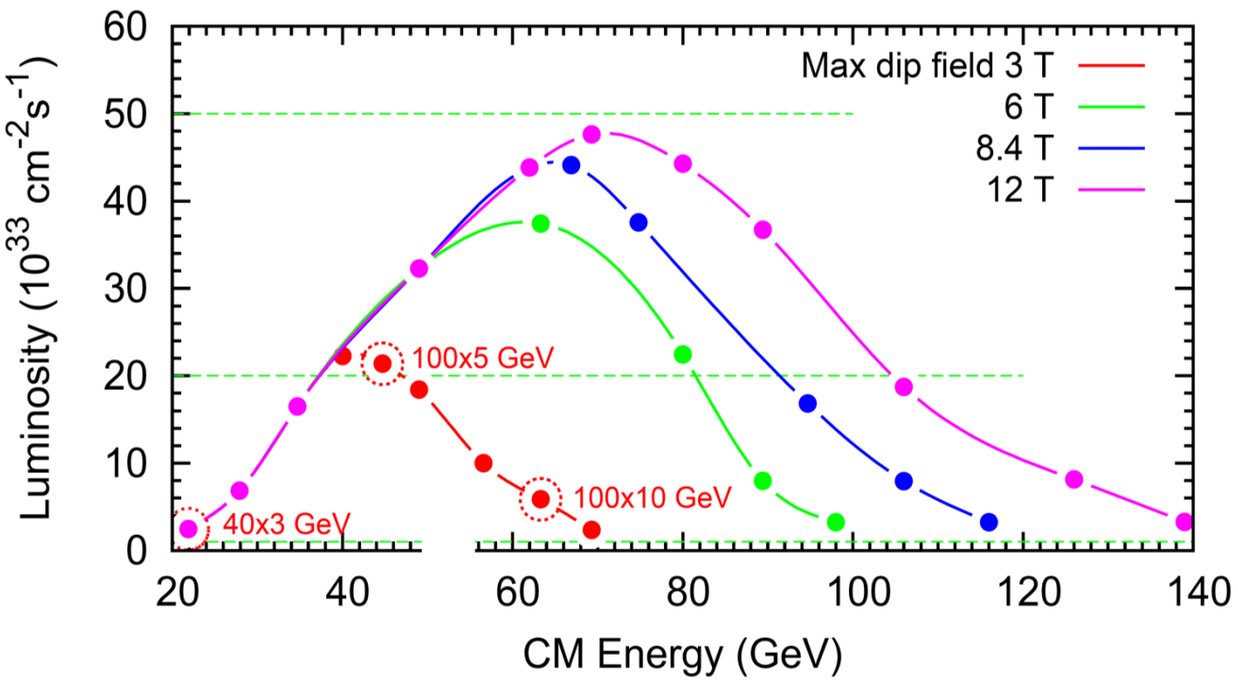
Reimplementation based on N. Fomin scripts

(JL)EIC Overview



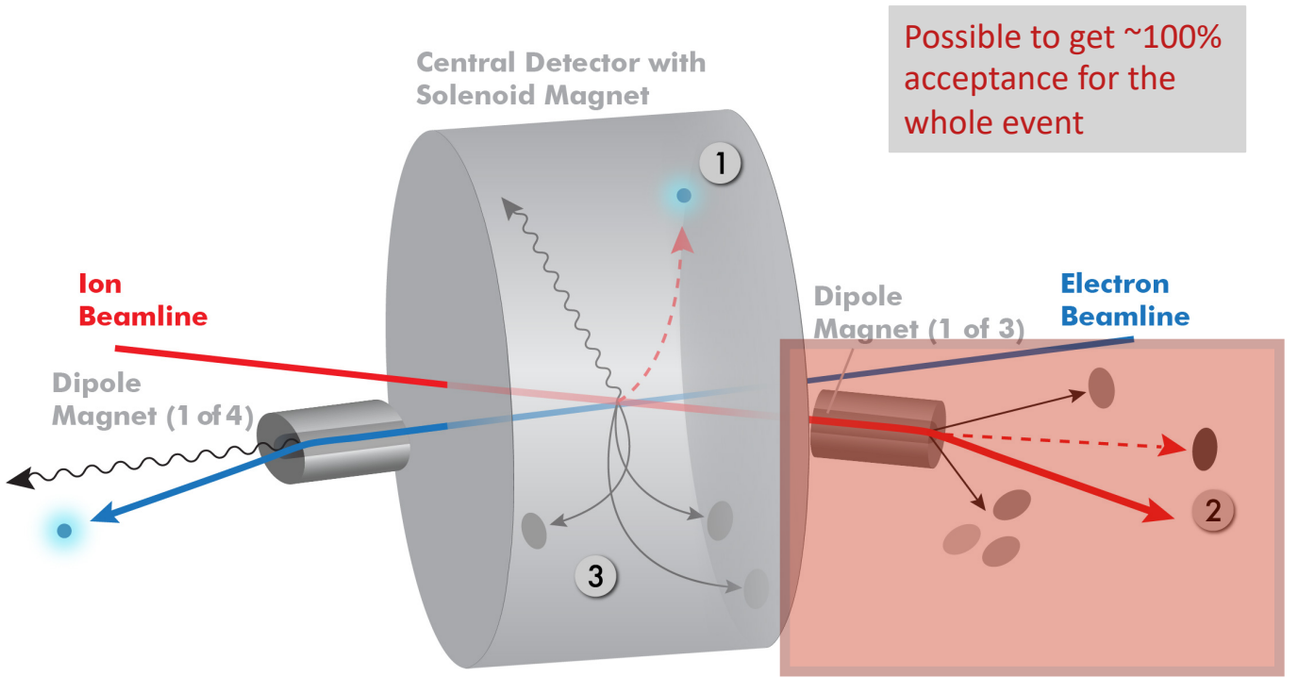


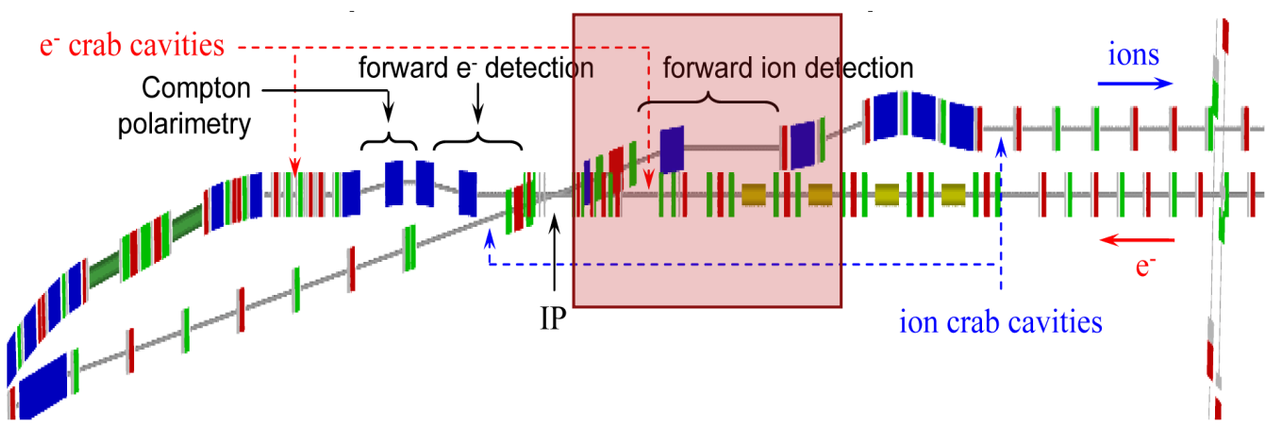
- Figure 8 shape design
- Luminosity 10^{33} - 10^{34} cm^{-2} s^{-1} (1000x HERA)
- 12 GeV e^- 5GeV (lumi max) on 200 GeV p



from M. Diefenthaler HUGS talk 2019

(JL)EIC Ion Detection

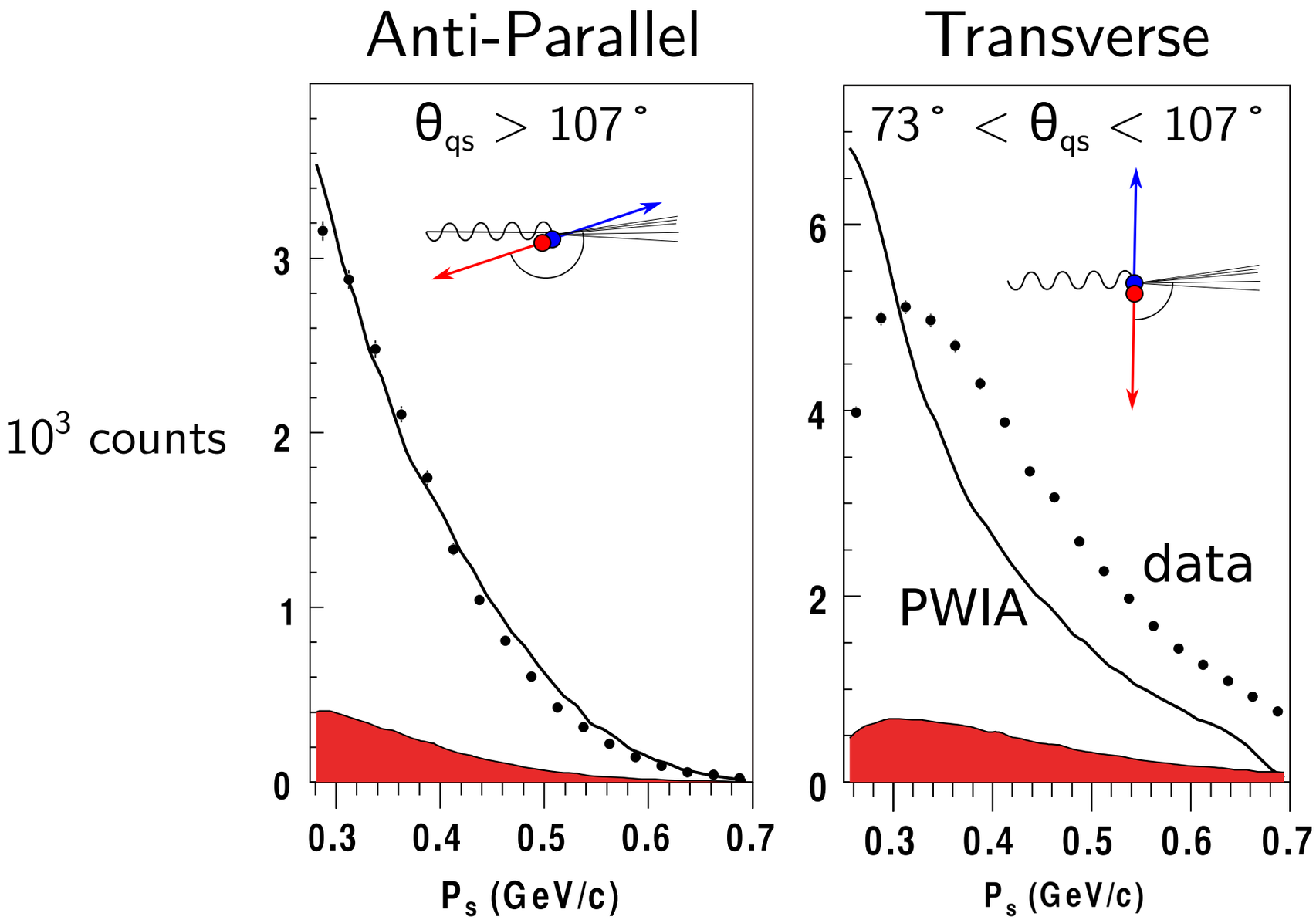




- Forward detection of recoil baryons and target fragments
- Detection demanding
  - Need good resolutions
  - Particles down to p_T = 0 GeV/c
  - Neutral detection
  - Ion PID
- Detectors
  - Roman pots
  - Zero degree calorimeter
  - Tracking detectors

FSI in Tagged DIS

DEEPS showed little FSI at back angles.



Klimenko et al., PRC 73 035212 (2006)