Tagged Short Range Correlations for Medium to Heavy Ions

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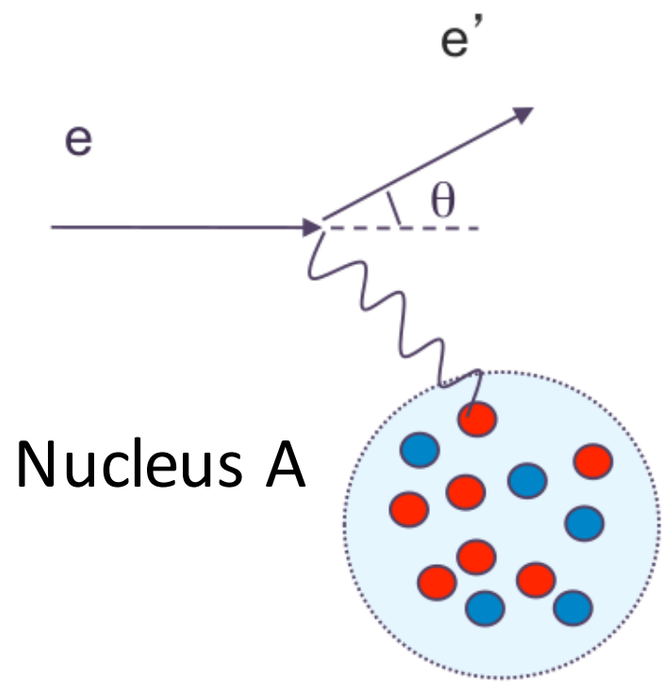
Old Dominion University
ICNFP 2019
08/24/19

OLD DOMINION
UNIVERSITY

Deep Inelastic Scattering (DIS)



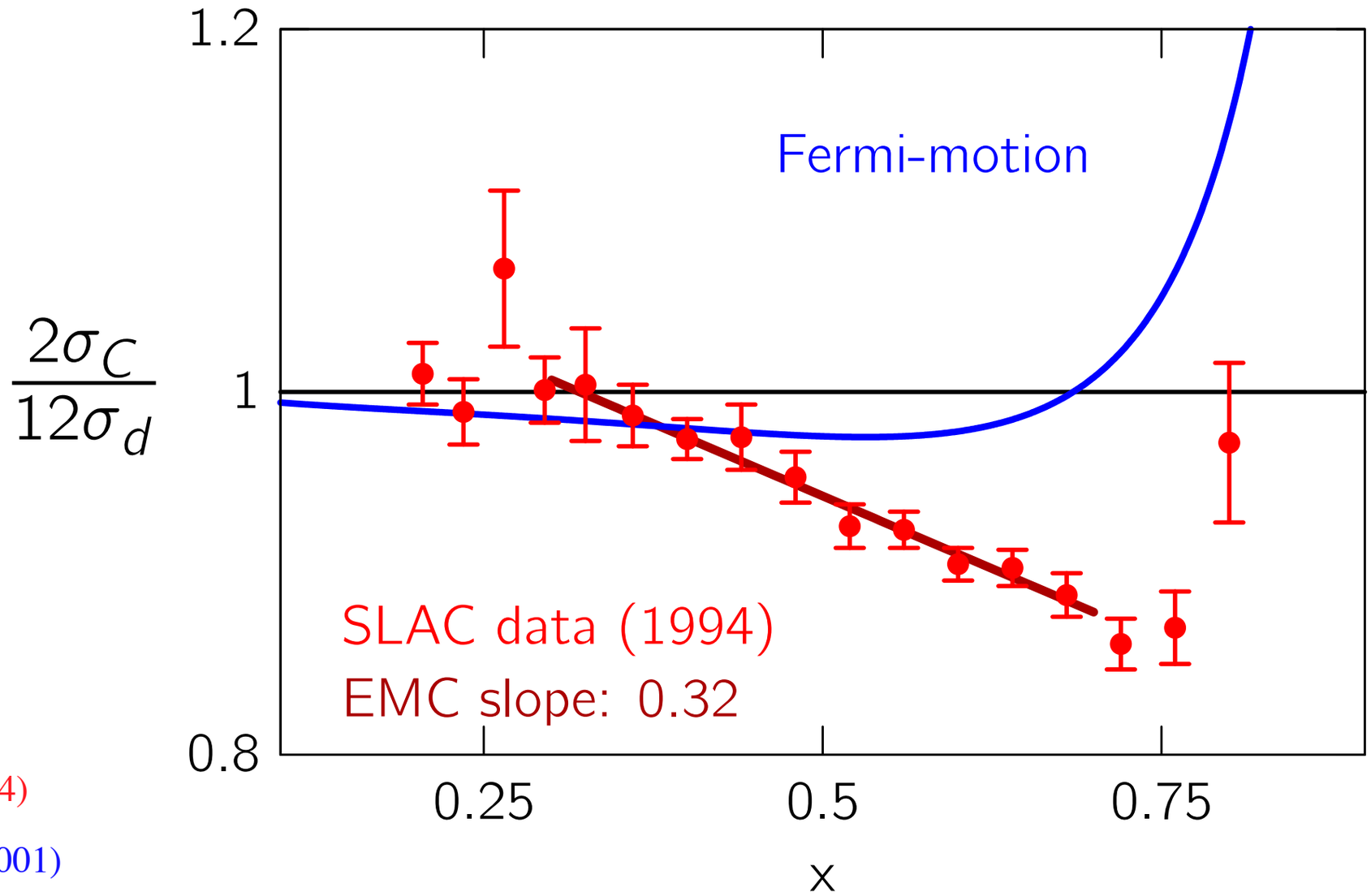
$$x_B = \frac{Q^2}{2m\omega}$$

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

$$\omega = E - E'$$

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

The EMC Effect in DIS Scattering



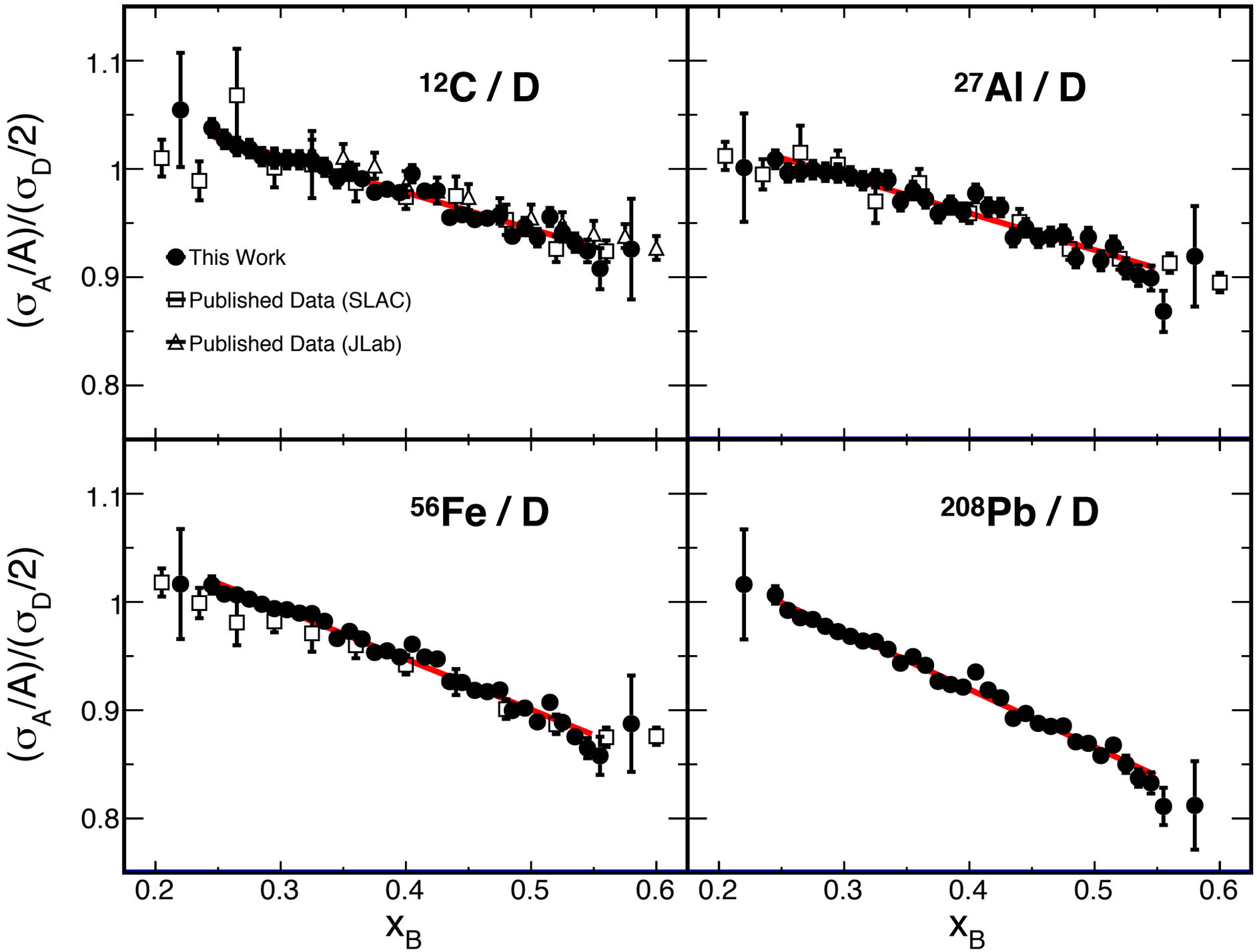
PRD 49, 4338 (1994)

PRC 65, 015211 (2001)

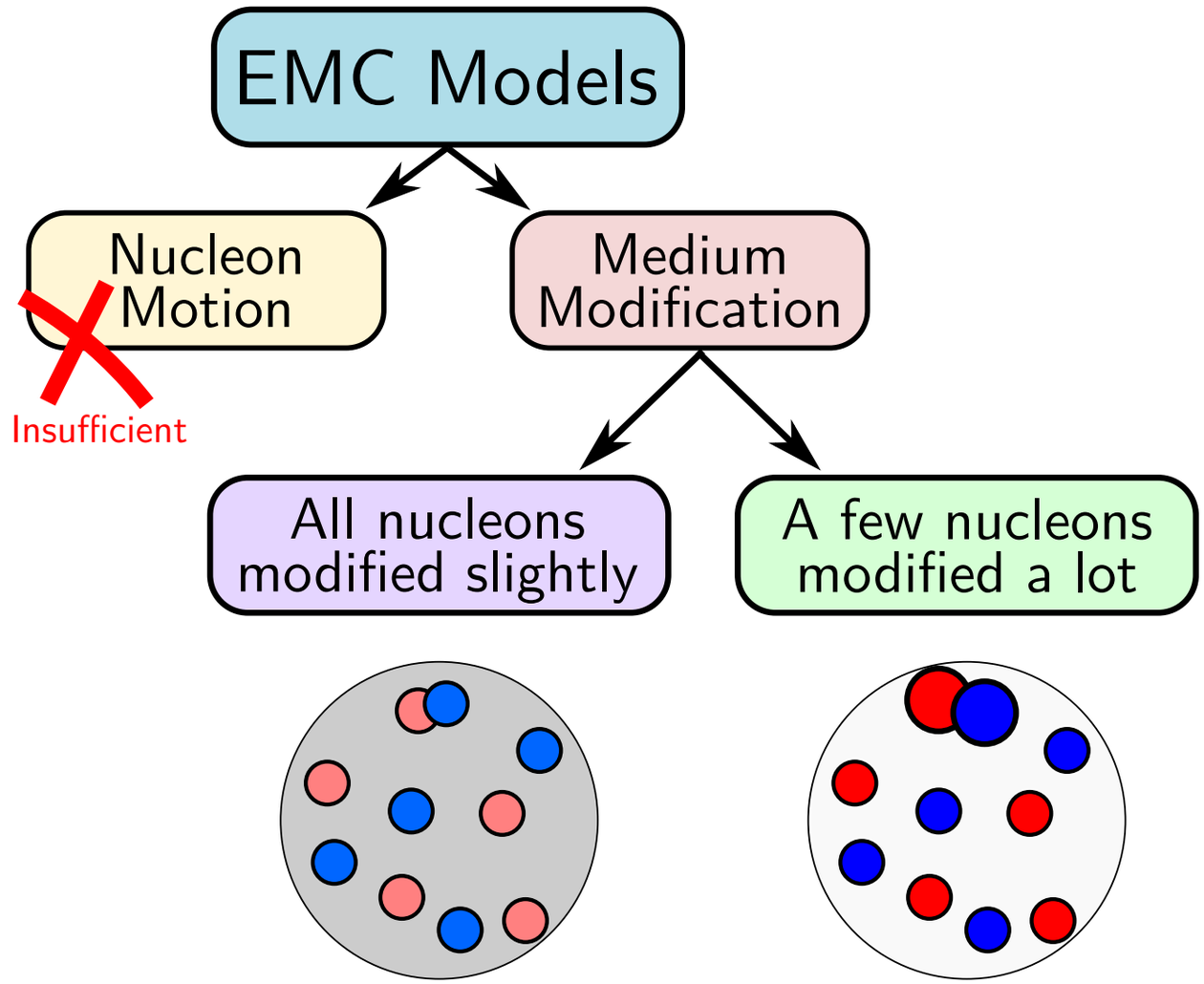
Quark distributions (F_2) in nucleons bound in nuclei different to distributions in free nucleons, here: $F_2^C \neq 6 * F_2^d$

EMC Effect in Different Nuclei

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



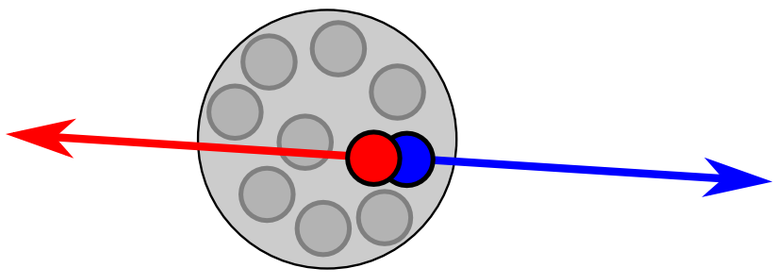
EMC Models



Mean Field Modifications

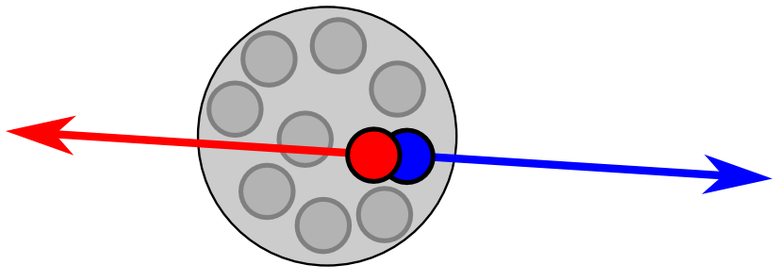
Short Range Correlations (SRC)

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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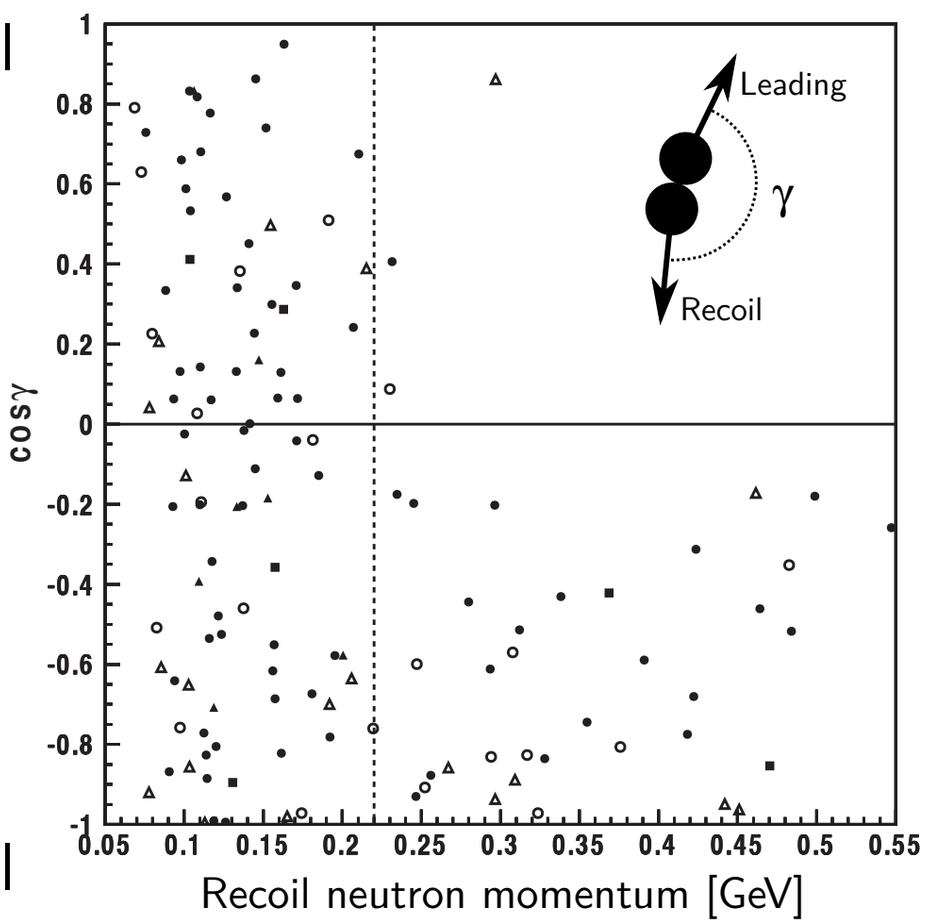
parallel

anti-parallel

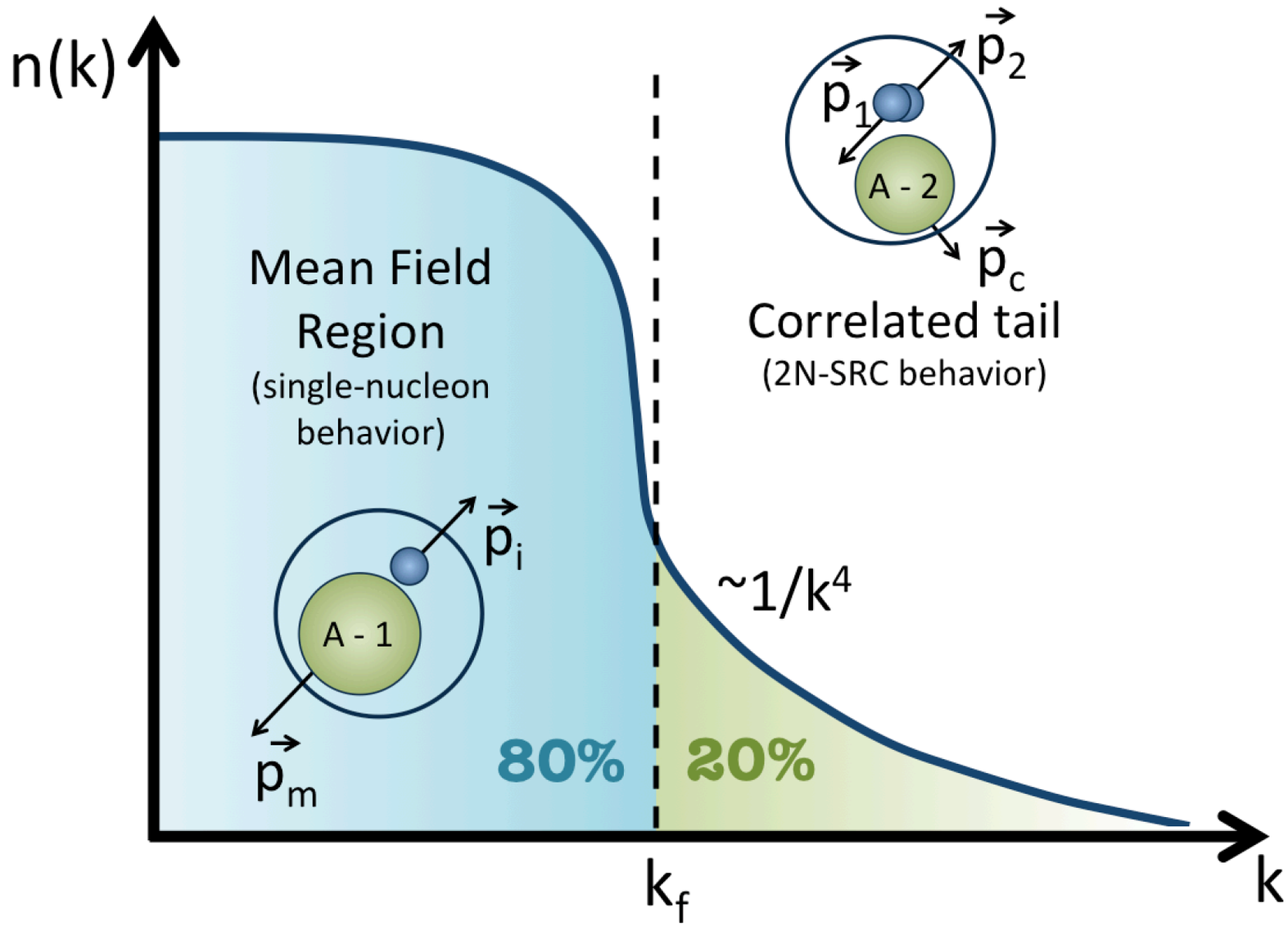


E. Piasetzky et al., PRL 97, 162504 (2006)

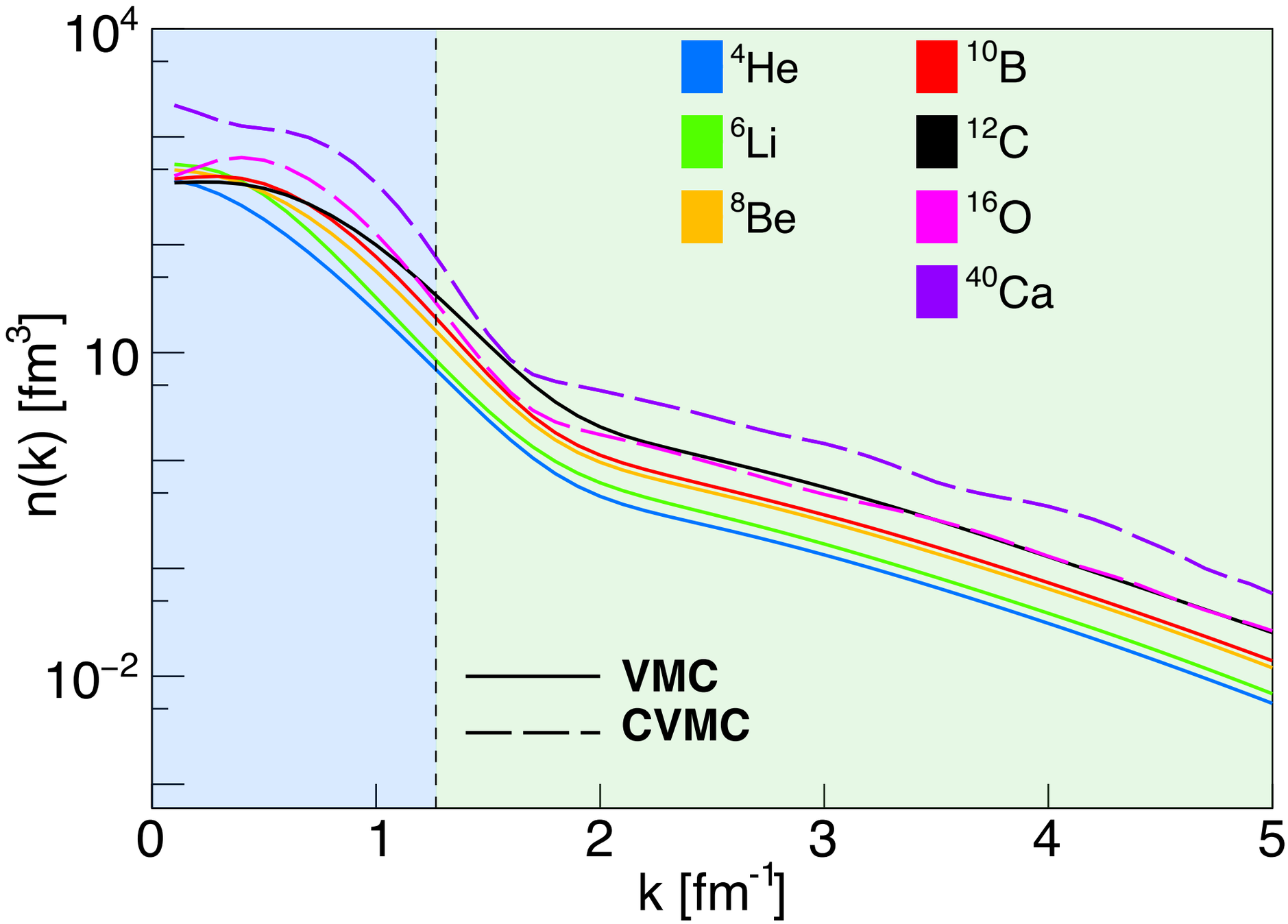
p scattering from Carbon

- always a correlated partner
- Anti-parallel momentum

Nucleon Momentum Distribution

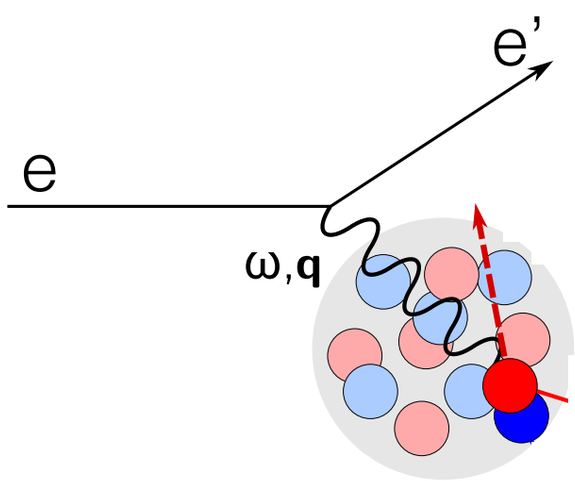


Universality of High Momentum Tail

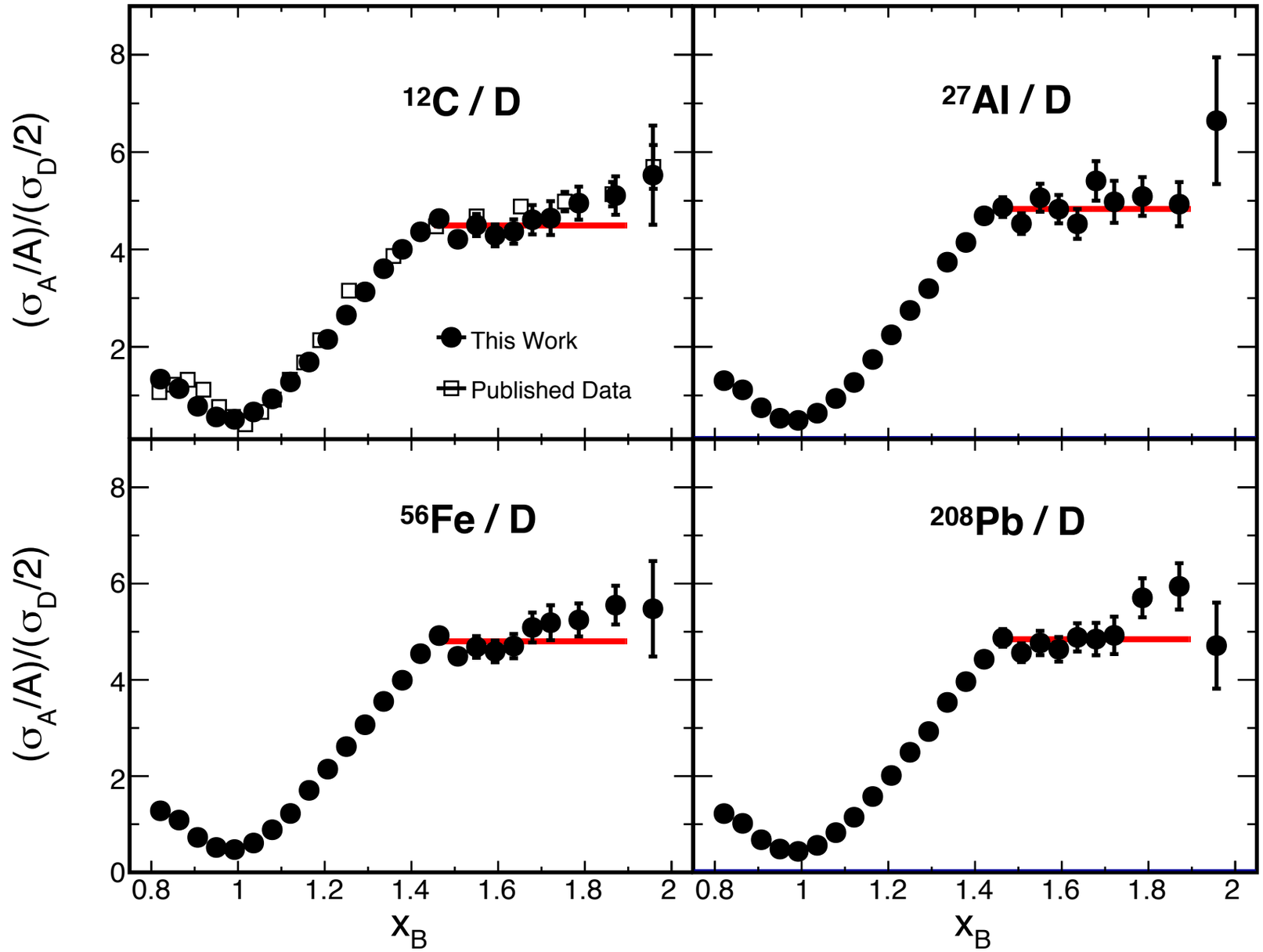


B. Wiringa, https://www.phy.anl.gov/theory/research/QMCresults.html

SRCs in Inclusive Scattering

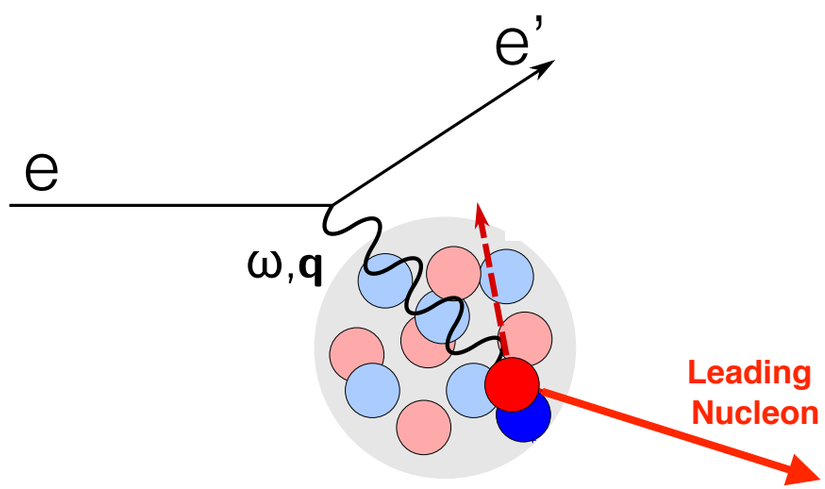


B. Schmookler et al. (CLAS collaboration), Nature 566, 354 (2019)

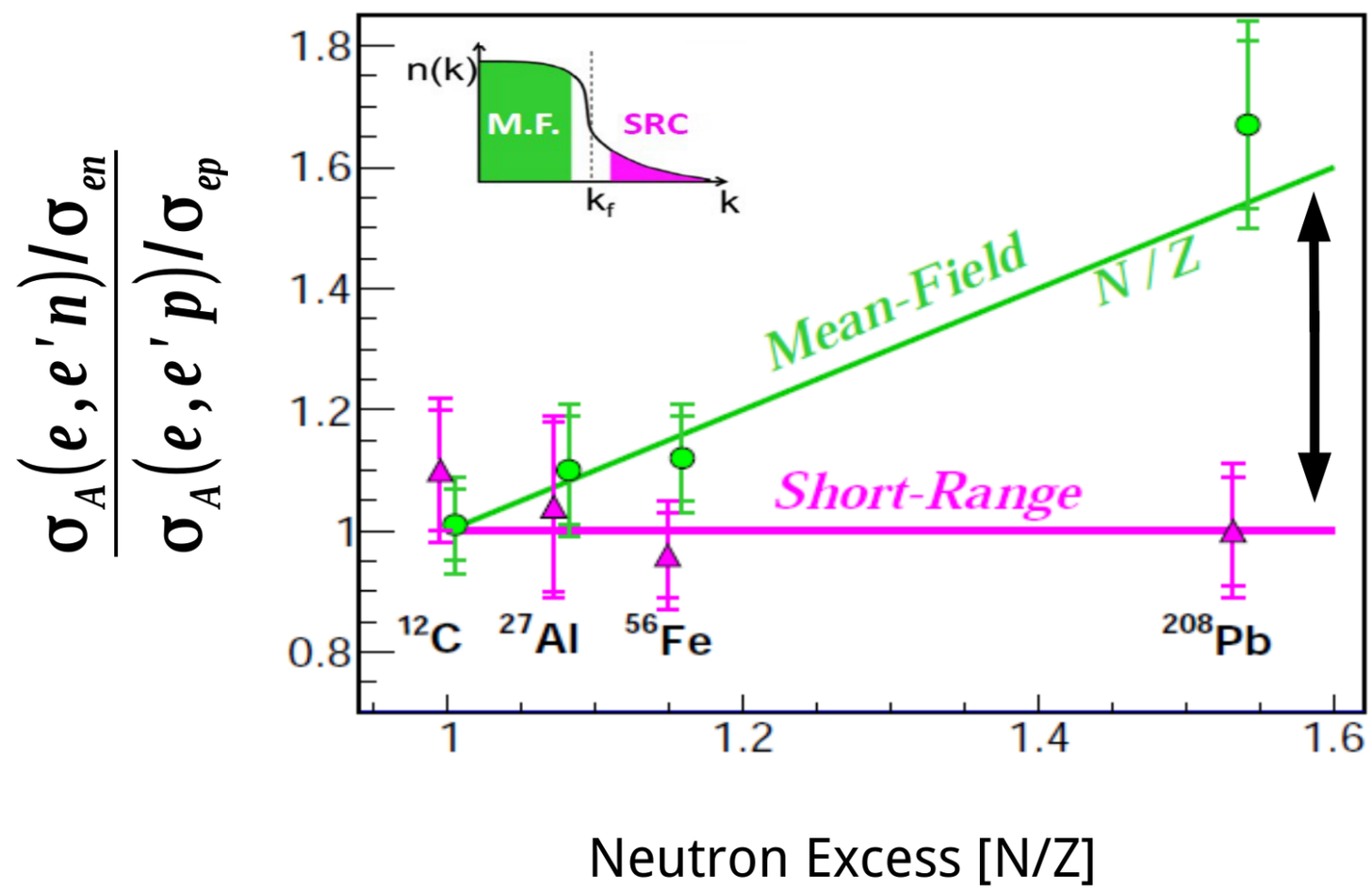


- Quasi-Elastic scattering
- Plateaus due to SRCs

SRCs in Exclusive Scattering

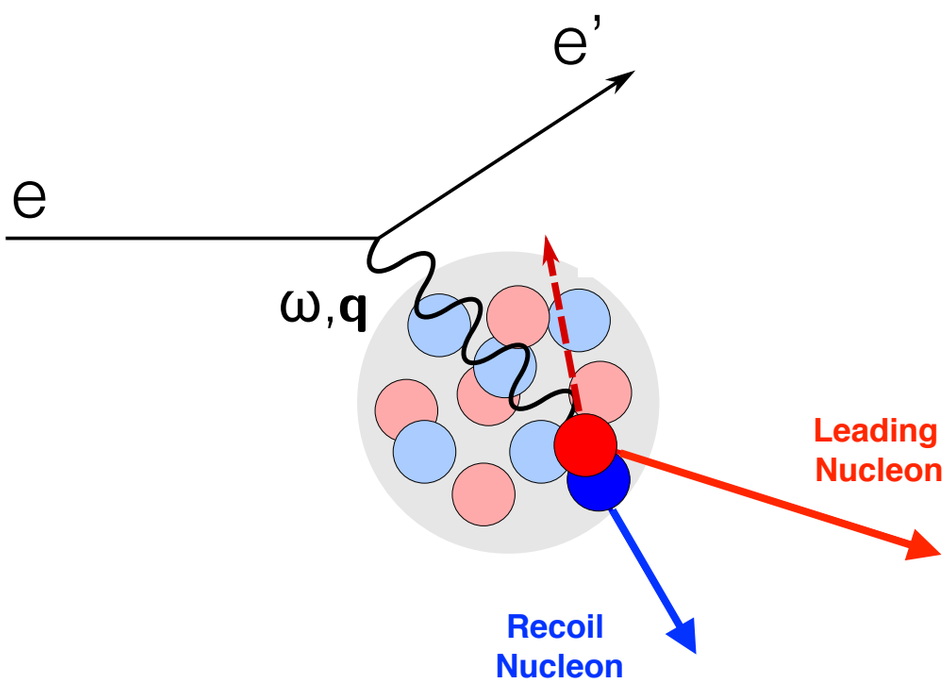


Duer et al. (CLAS collaboration), Nature 560, 617 (2018)

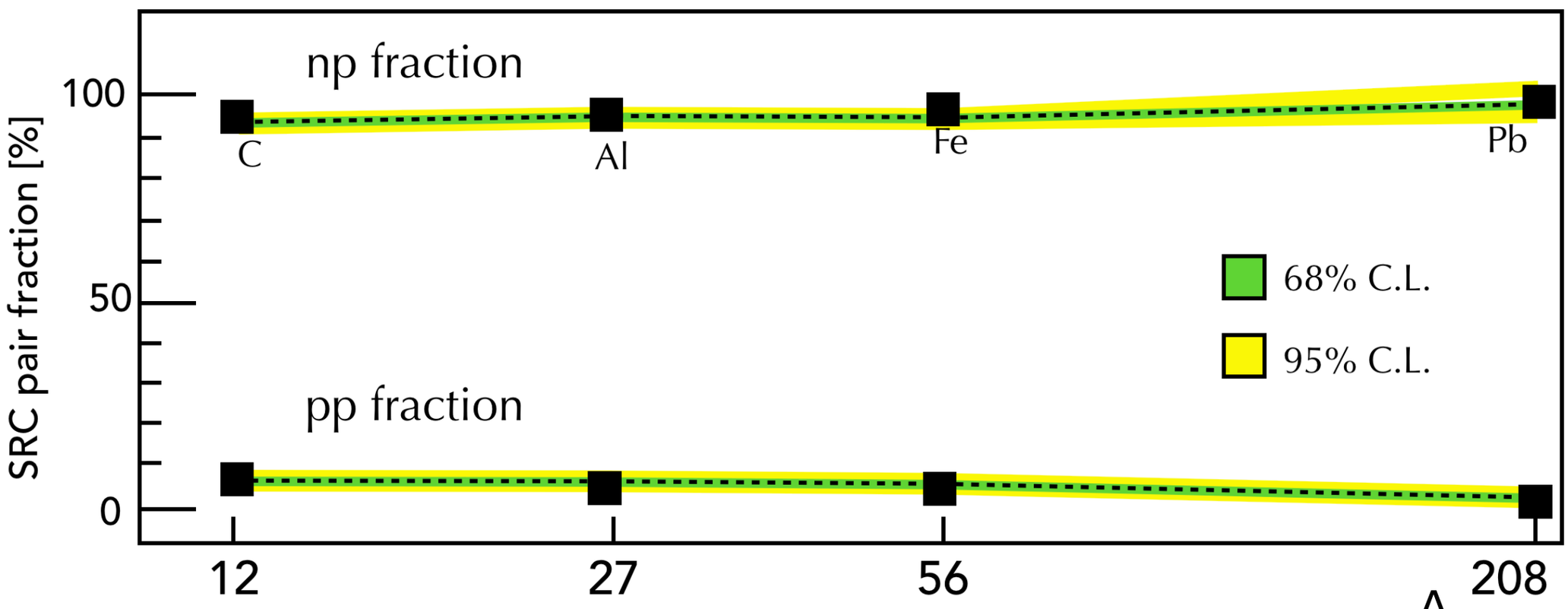


- (e'p) and (e'n) measurements
- Indication of np-dominance for SRC pairs

np-Dominance

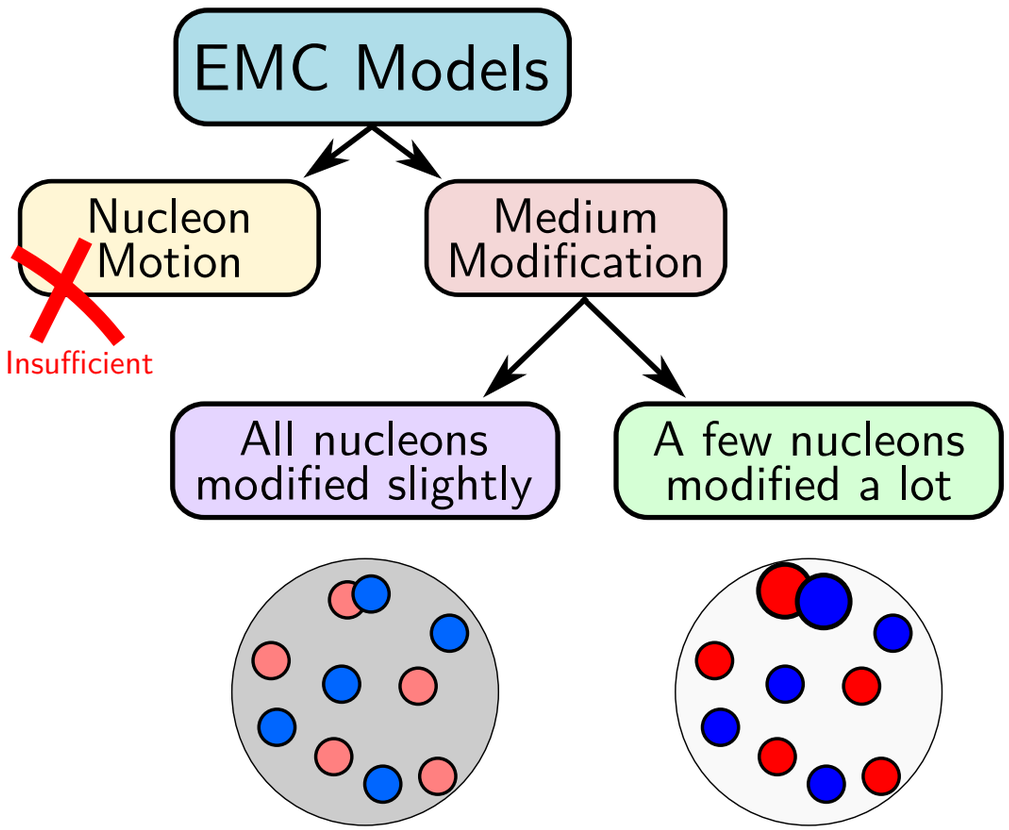


- (e'pp) & (e'np) measurements
- Probability for np pairs about ~18 larger than for pp pairs



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

To Review: EMC and SRC

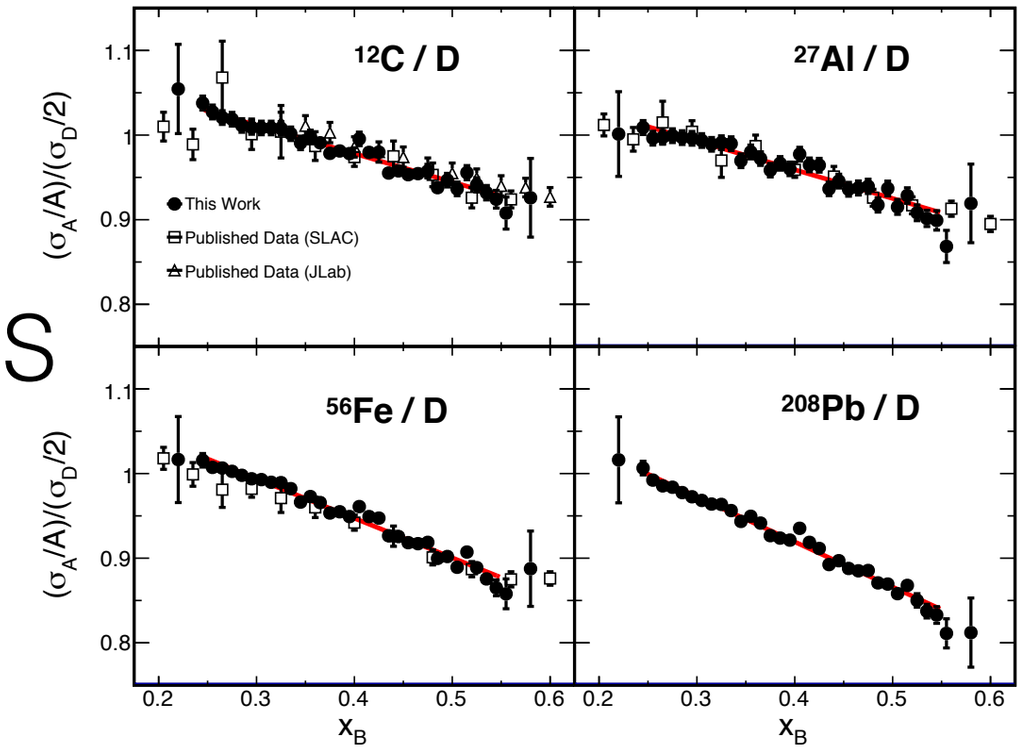


Mean Field Modifications

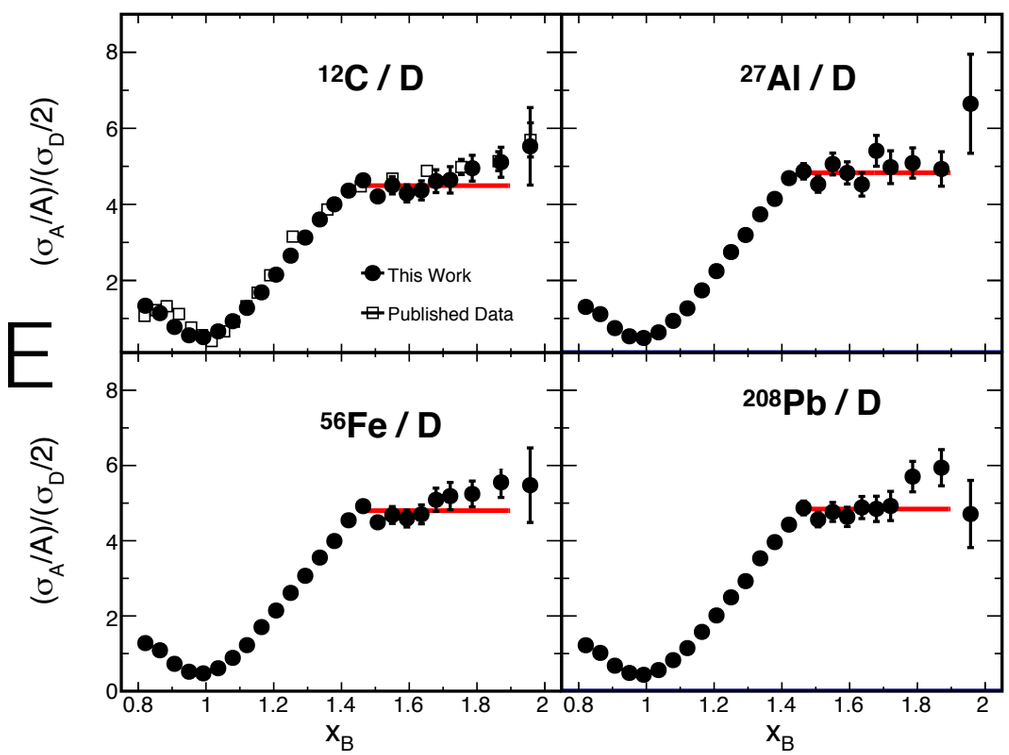
Short Range Correlations (SRC)

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

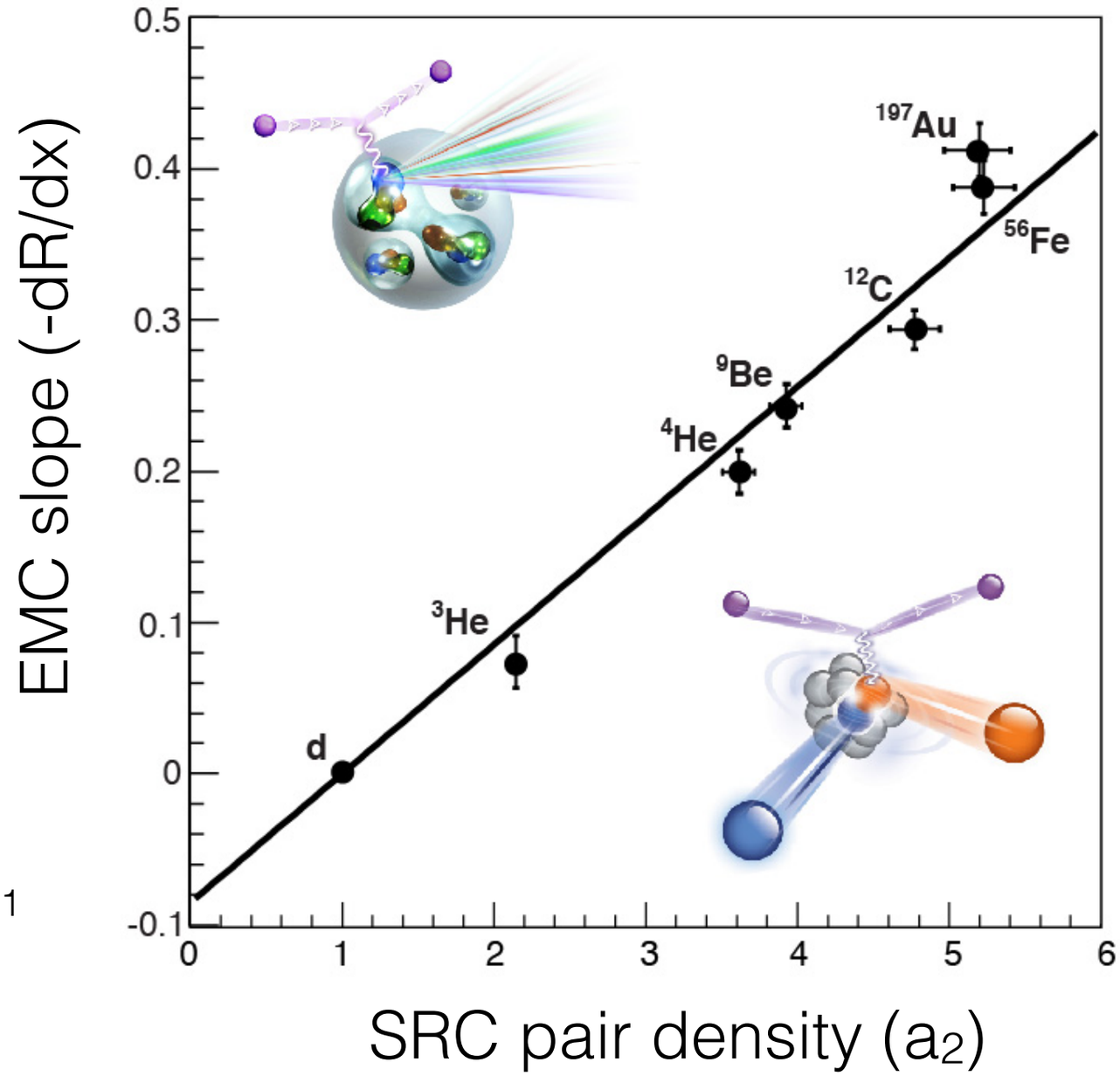
DIS



QE



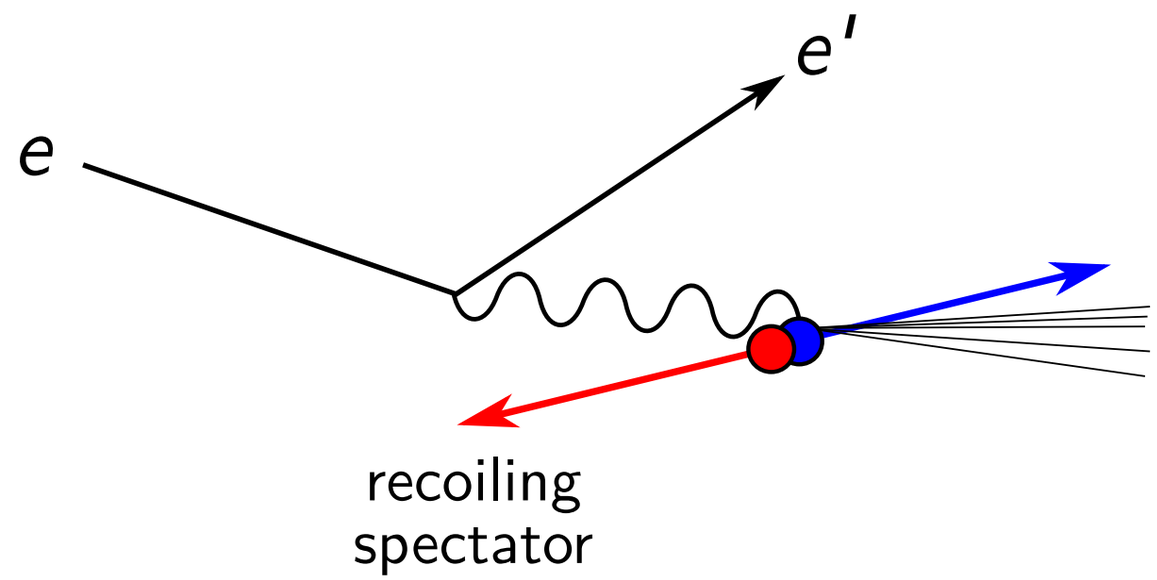
EMC and SRC Correlation



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

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

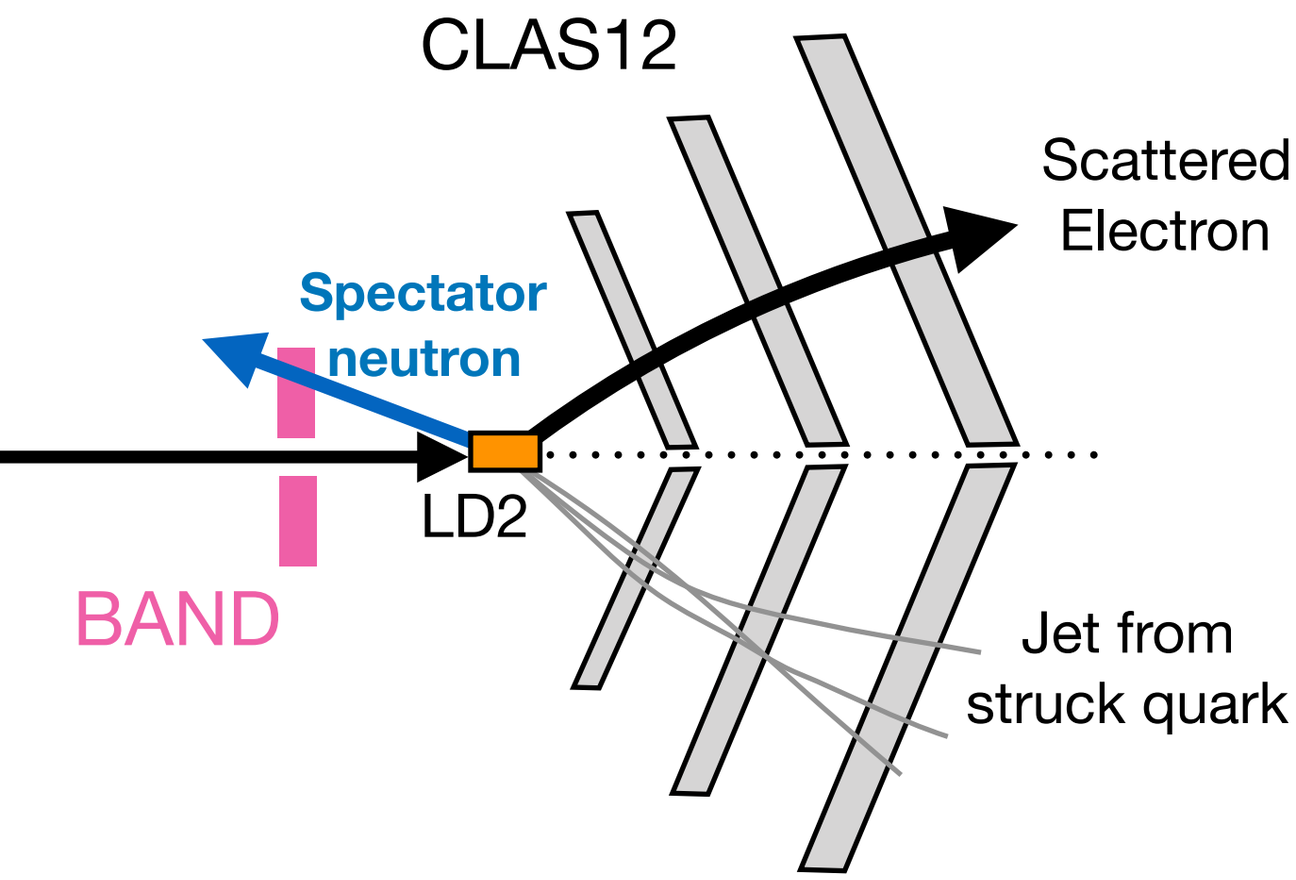
Tagged DIS on Deuterium



- “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)

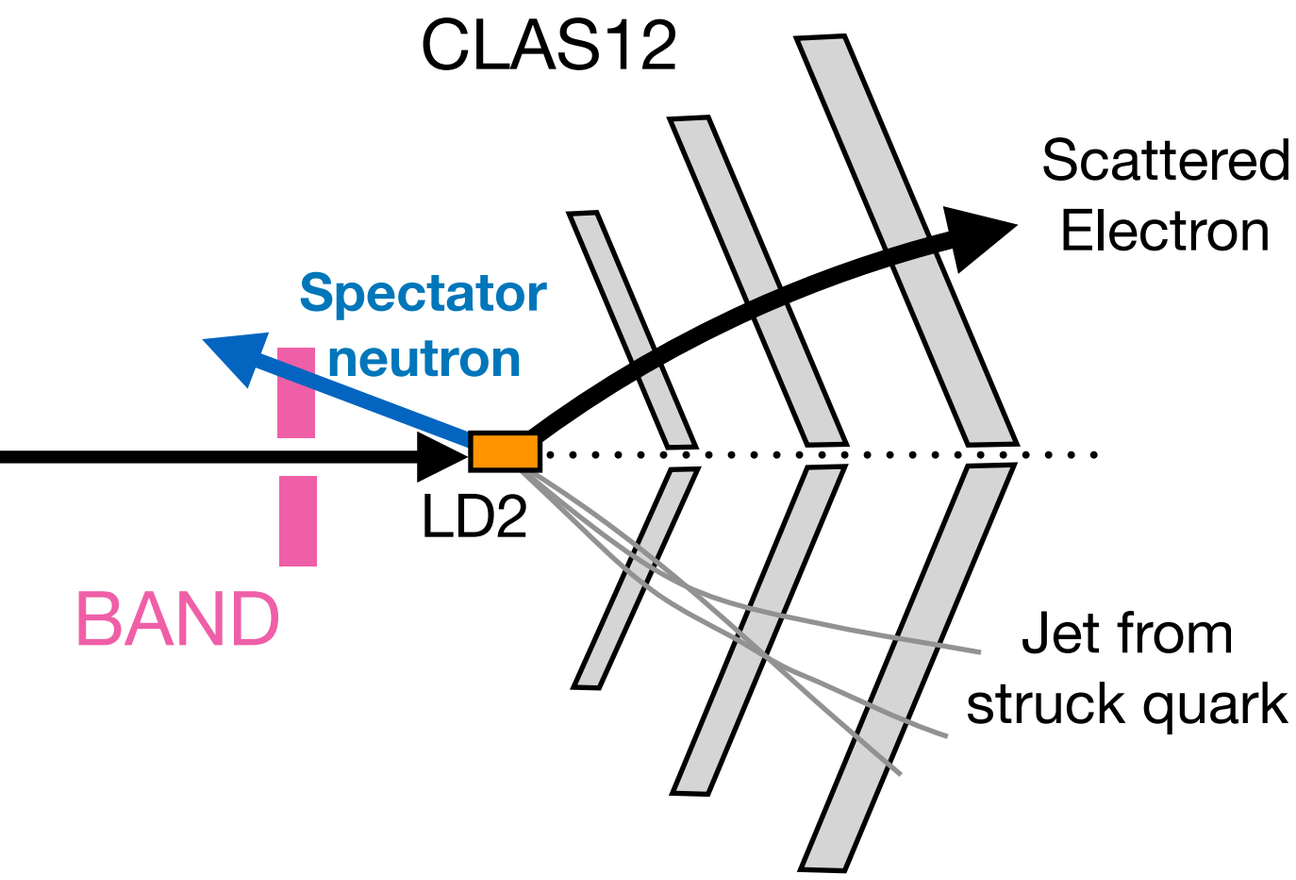


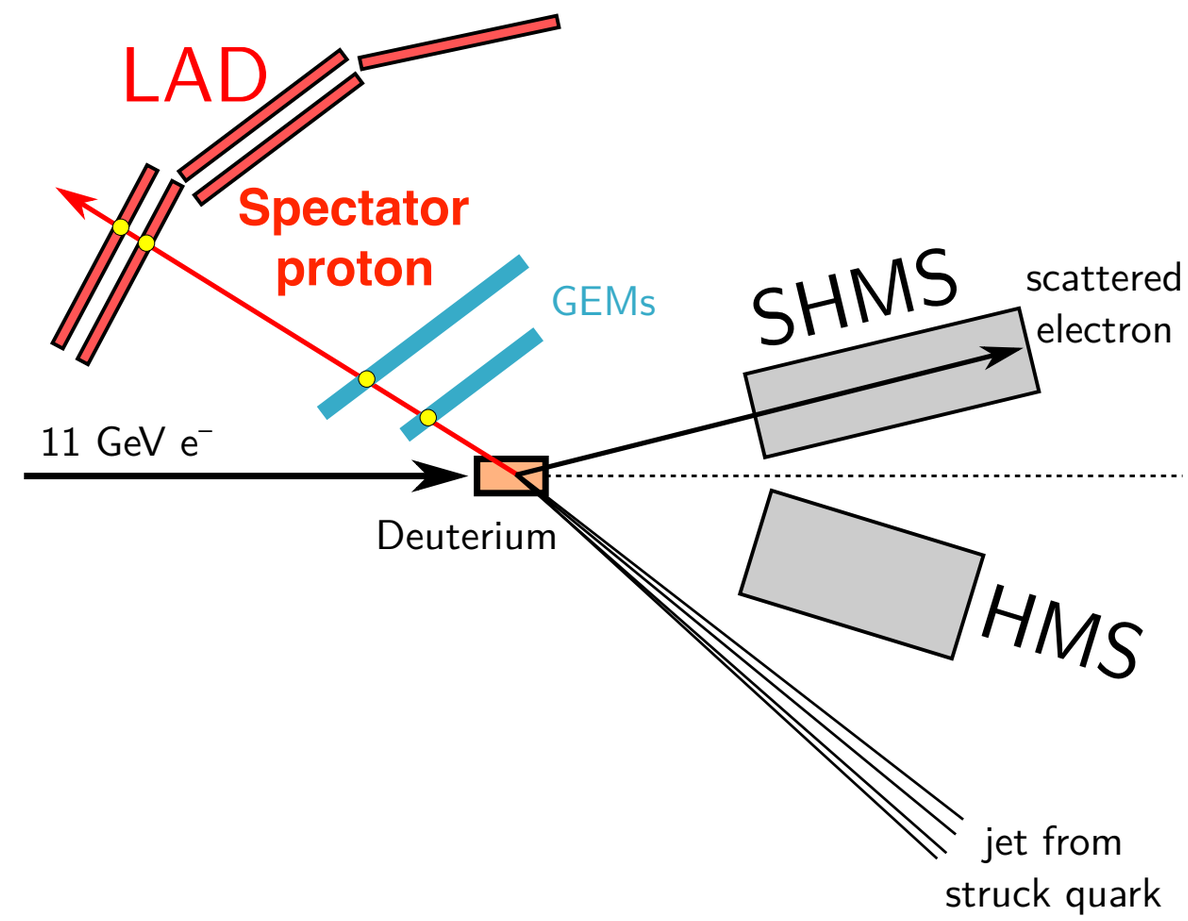
- Took first data in Spring 19
- More to come in Fall 19

Tagged DIS at JLab

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

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

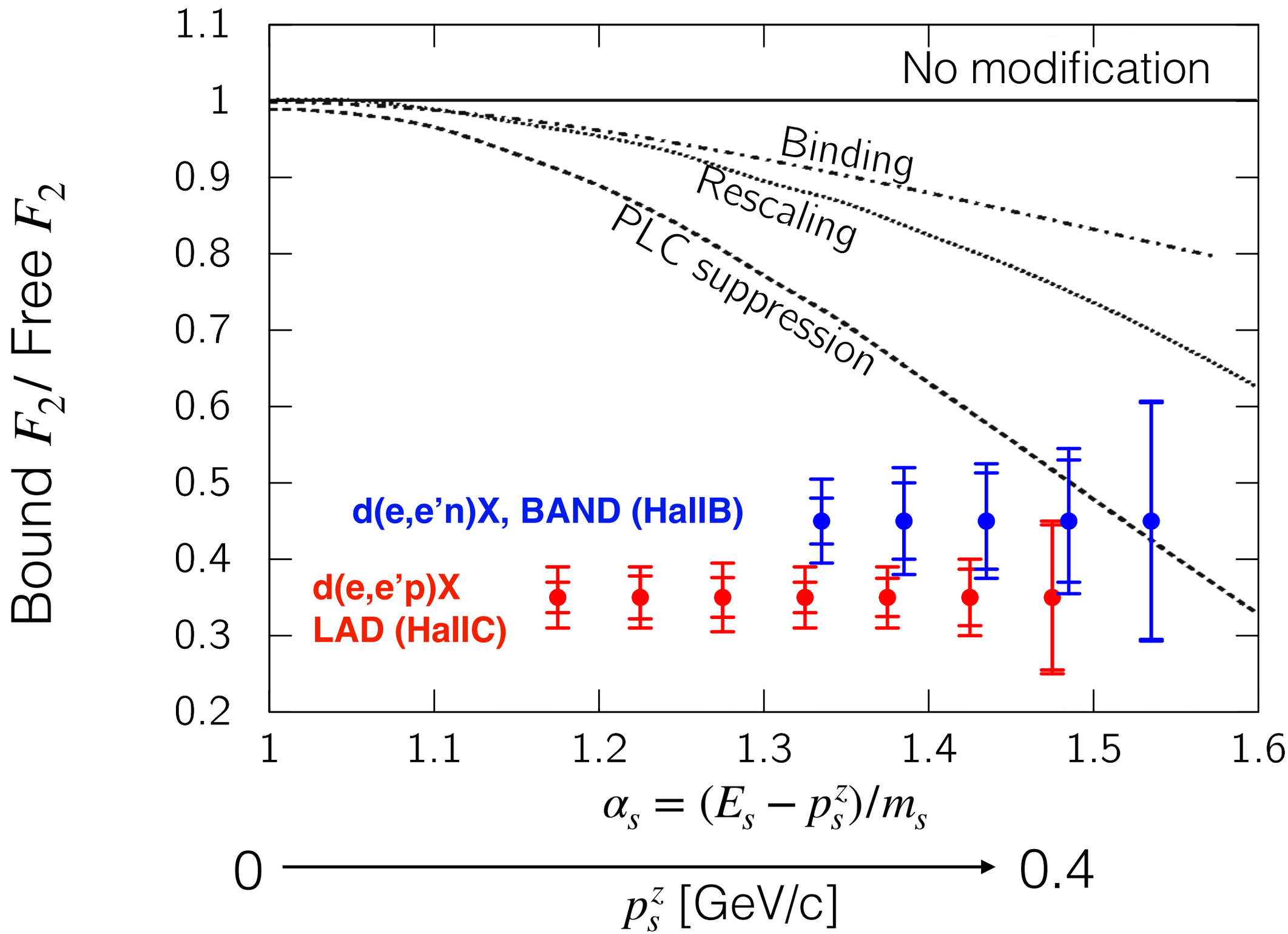




- Took first data in Spring 19
- More to come in Fall 19

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

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

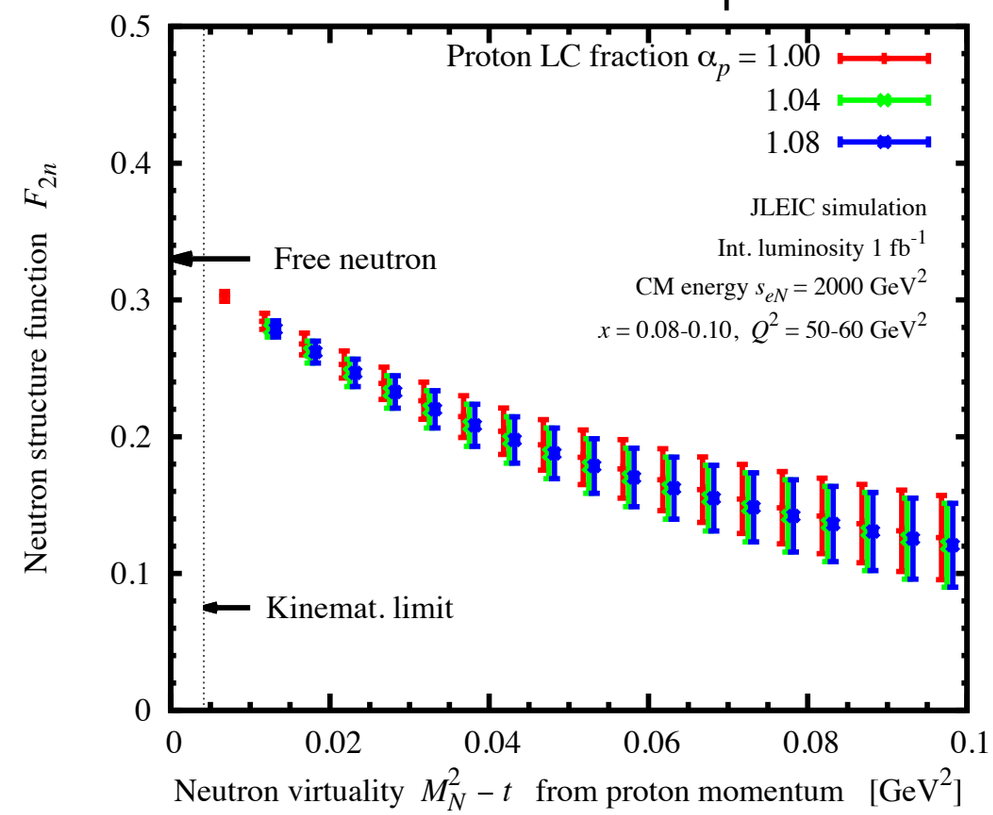


Tagged DIS at EIC

- 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

e + d —> e' + p + X



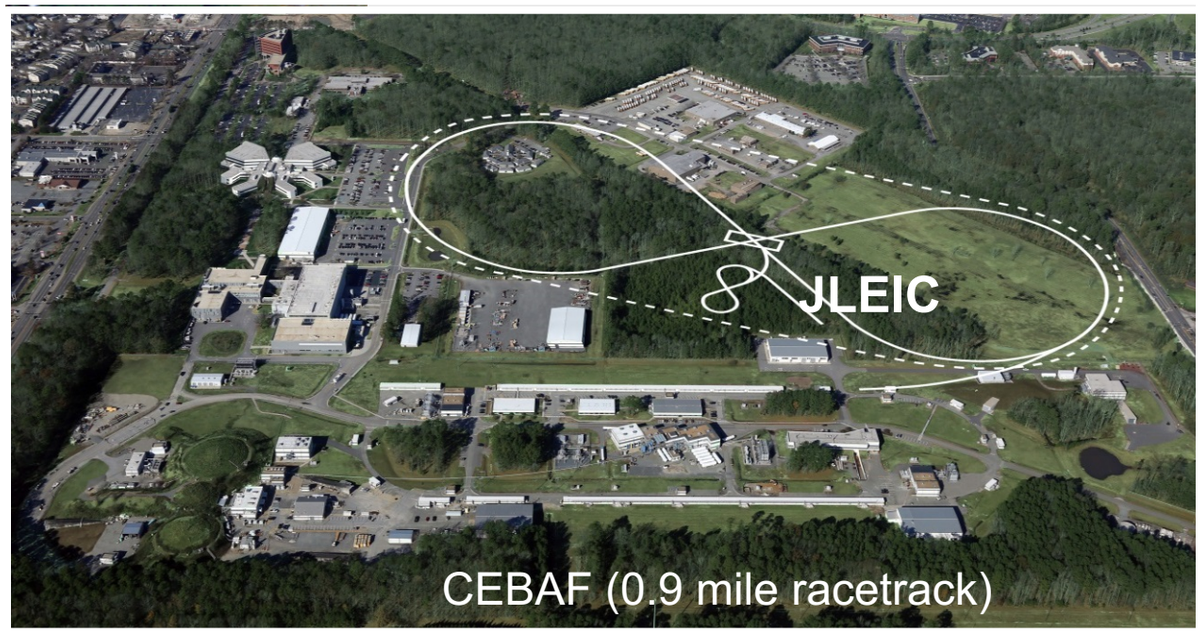
Jefferson Labs' LDRD project (2014/15)

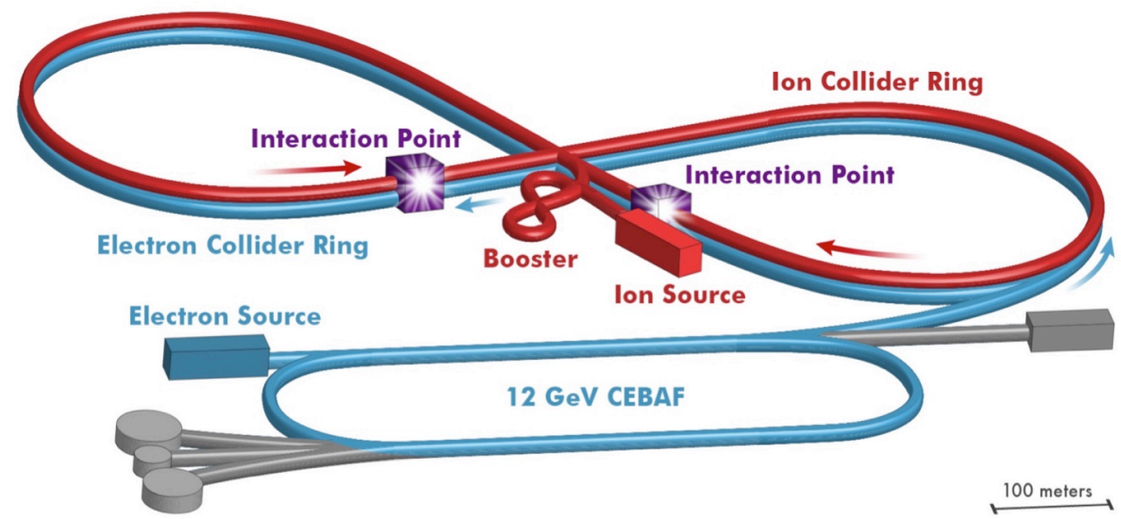
``*Physics potential of polarized light ions with EIC@JLab*"

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

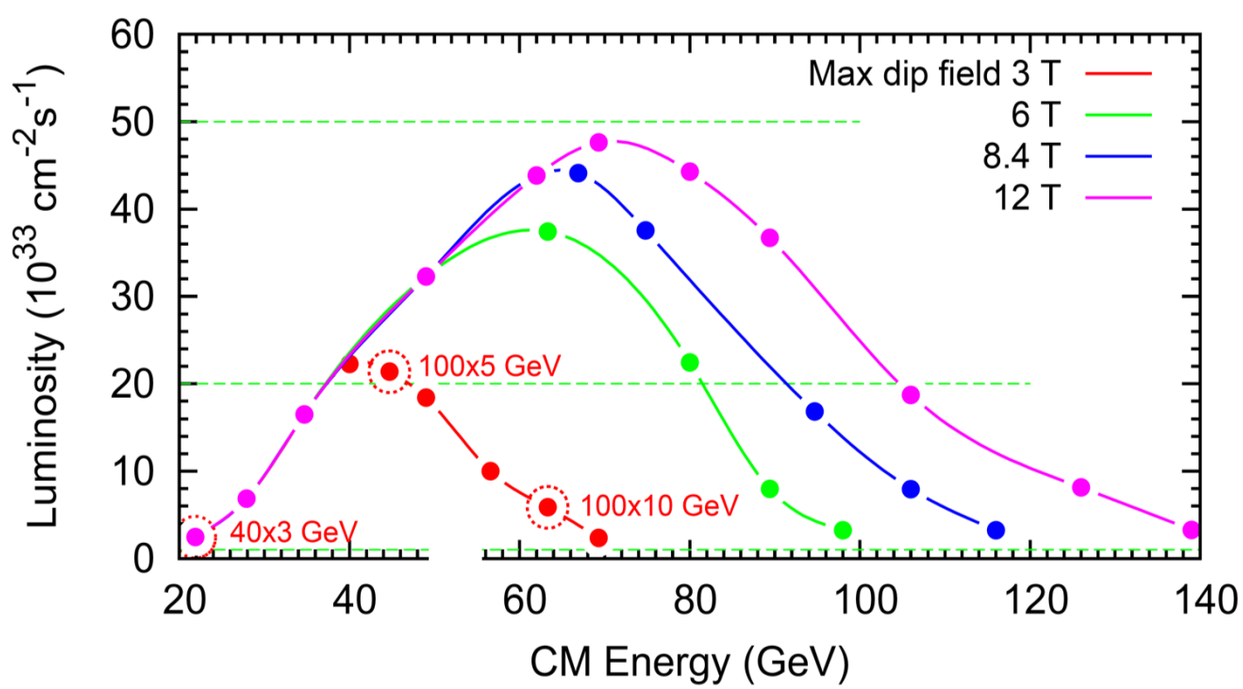
Webpage: https://www.jlab.org/theory/tag/

(JL)EIC Overview



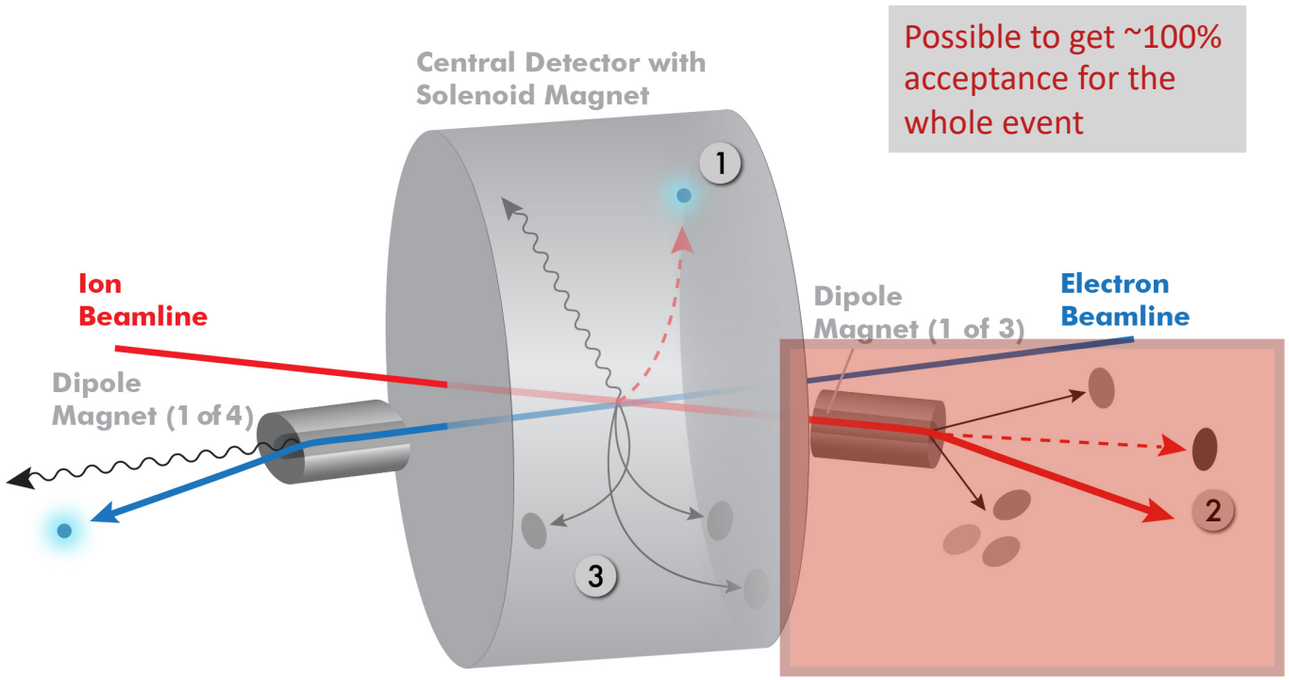


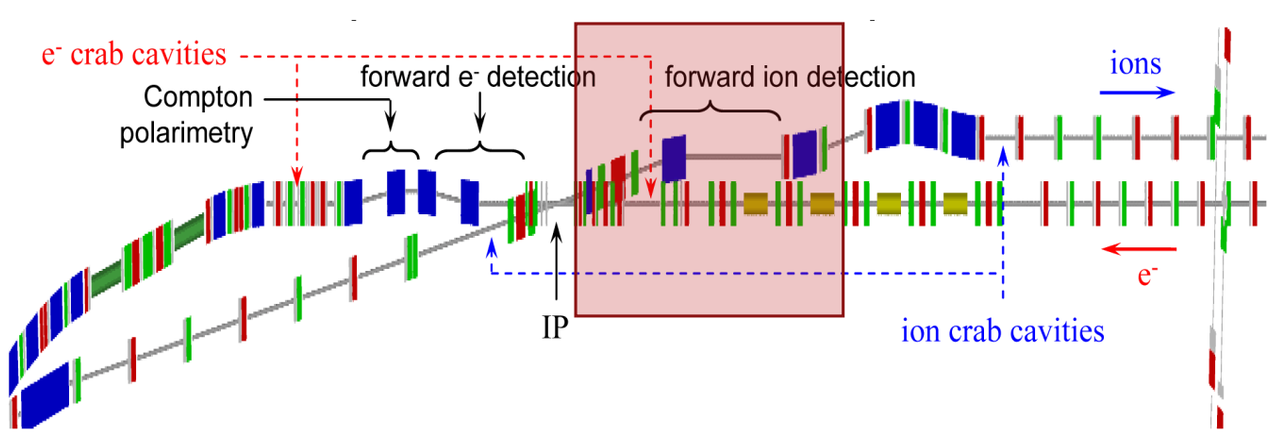
- Figure 8 shape design
- Luminosity 10^{33} - 10^{34} cm^{-2} s^{-1} (1000x HERA)
- 12 GeV e^- 5GeV (lumi max) on 200 GeV p



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

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

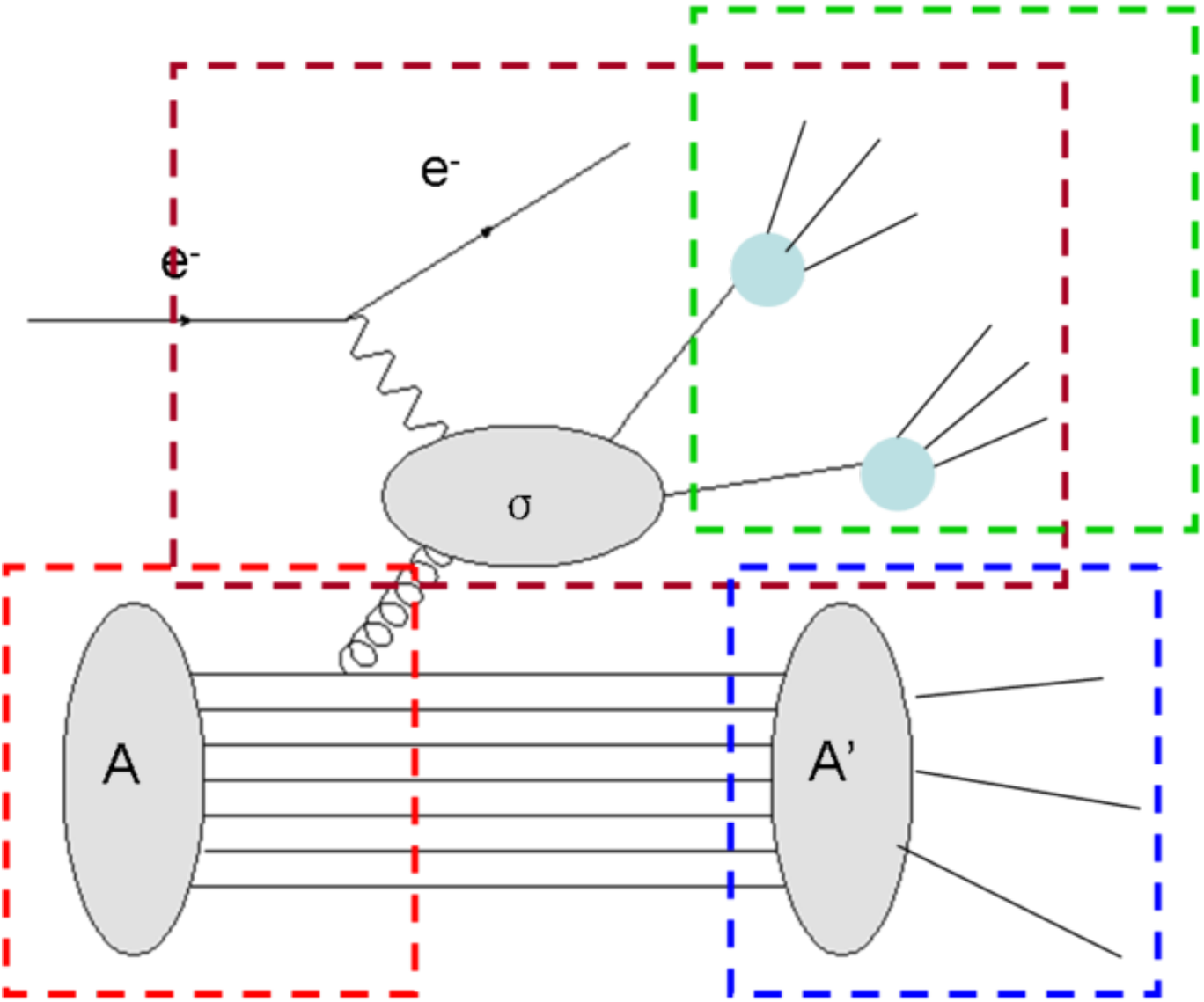
- Feasibility of tagged SRCs physics at (JL)EIC
  - Rates at high x
  - Resolution at high x
  - Beam energies

- Physics Reach

- Simulation and Modeling
  - BeAGLE - eA event generator for EIC
  - Implementing SRCs in BeAGLE
  - EIC detector requirements
  - Reconstruction methods

BeAGLE - Benchmark eA Generator for LEptoproduction

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



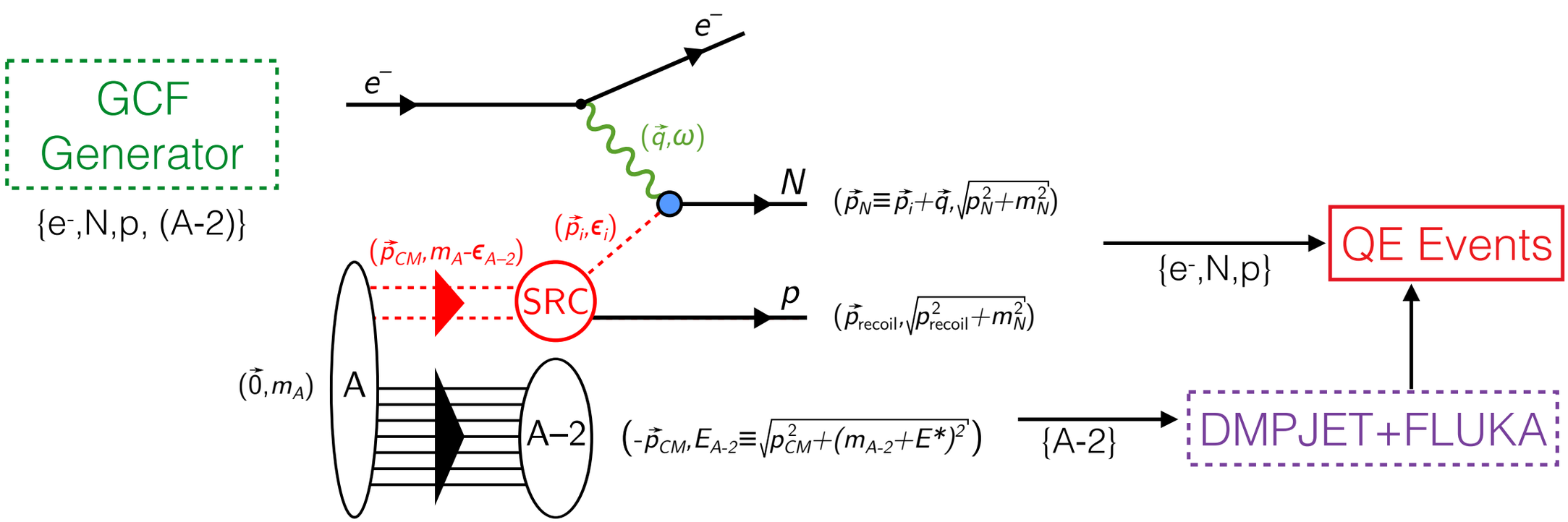
Merger of

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

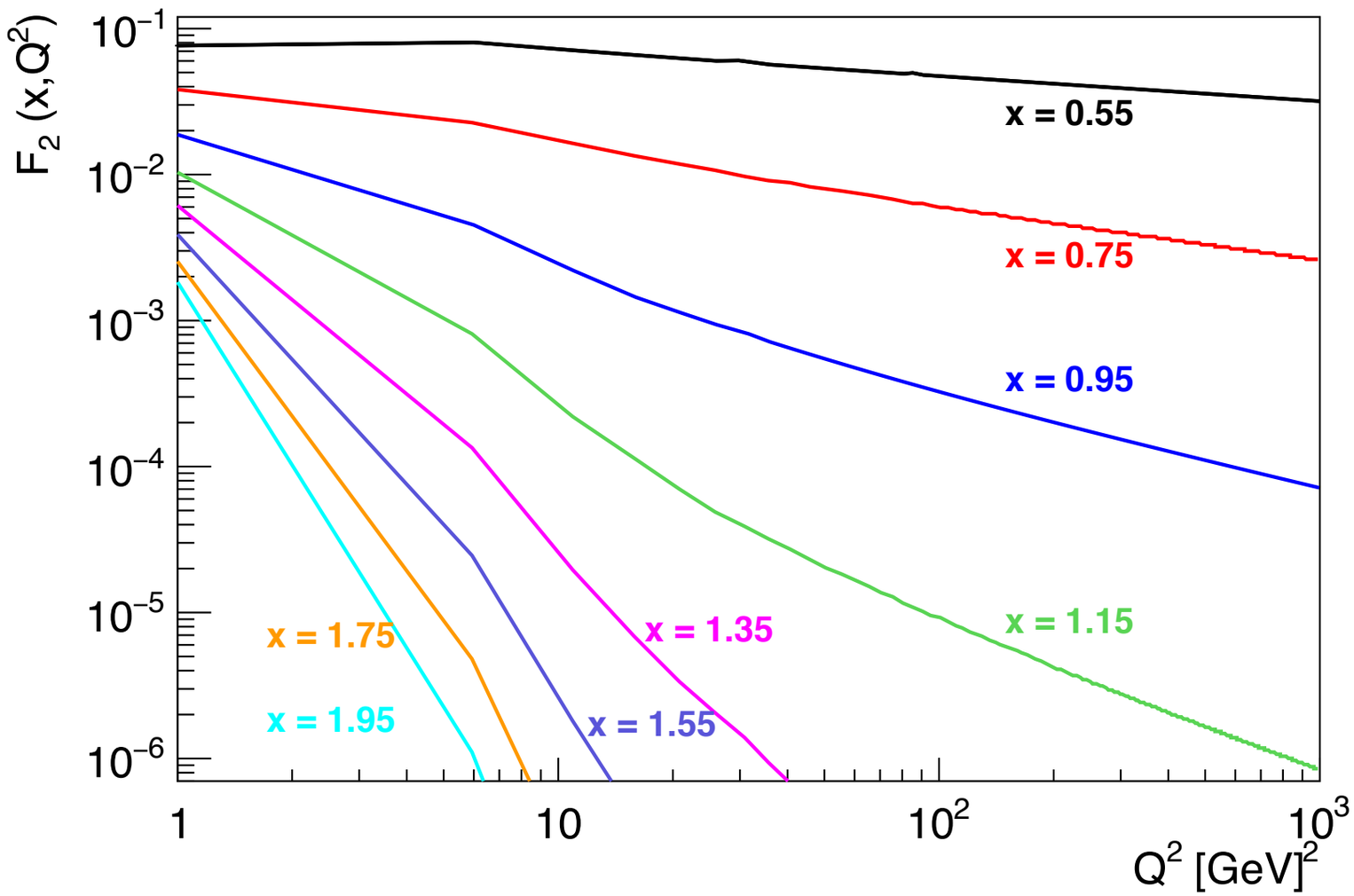
https://wiki.bnl.gov/eic/index.php/BeAGLE

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
  - (A-2)-system handled by DPMJET3+FLUKA
- LDRD Project: Focus on e+C and e+Pb simulations



DIS Rate Estimates from F_2 Parametrization



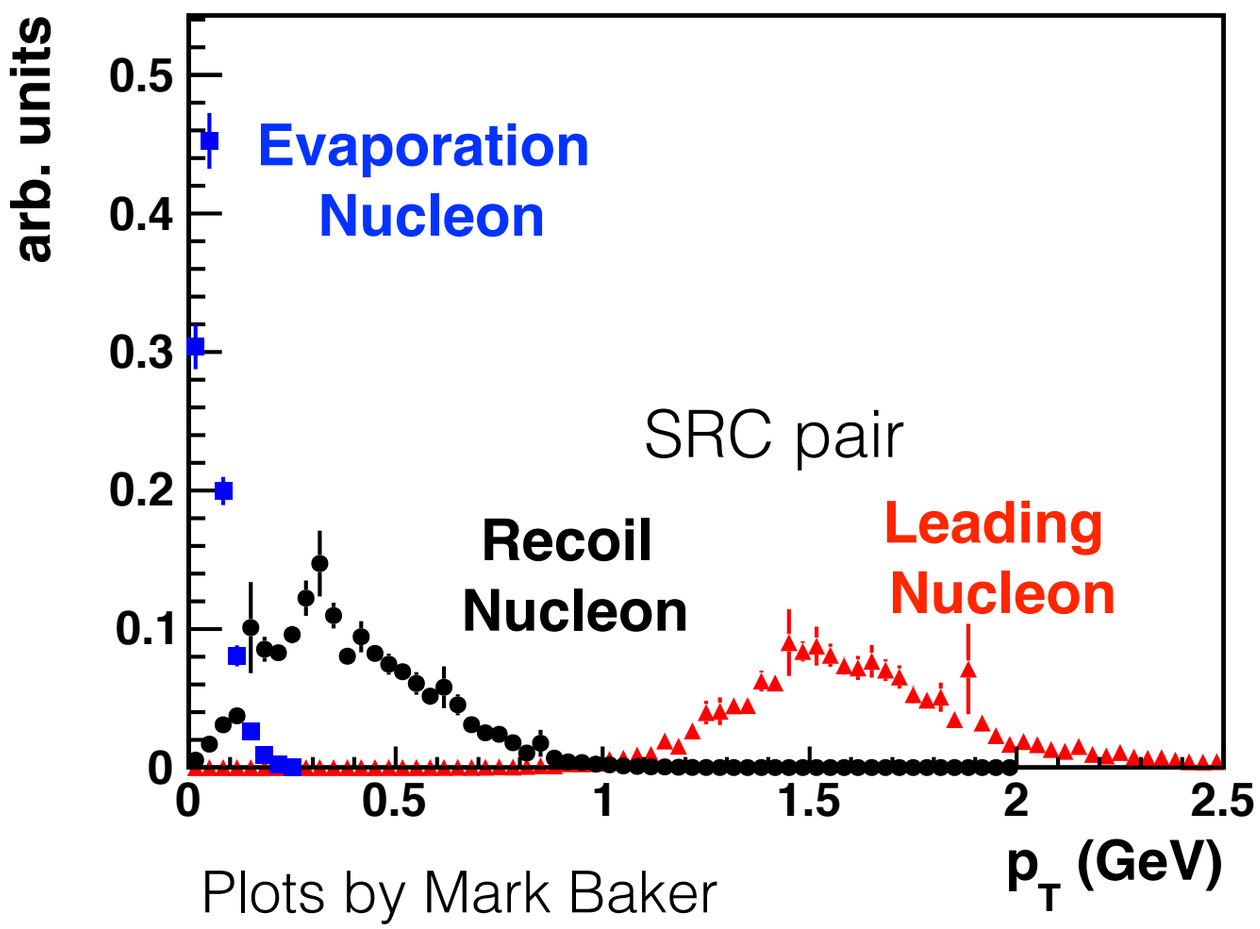
- Measuring EMC effect at high Q^2 easy —> high rate
- SRC (x >1) at high Q^2 challenging but non zero rate

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

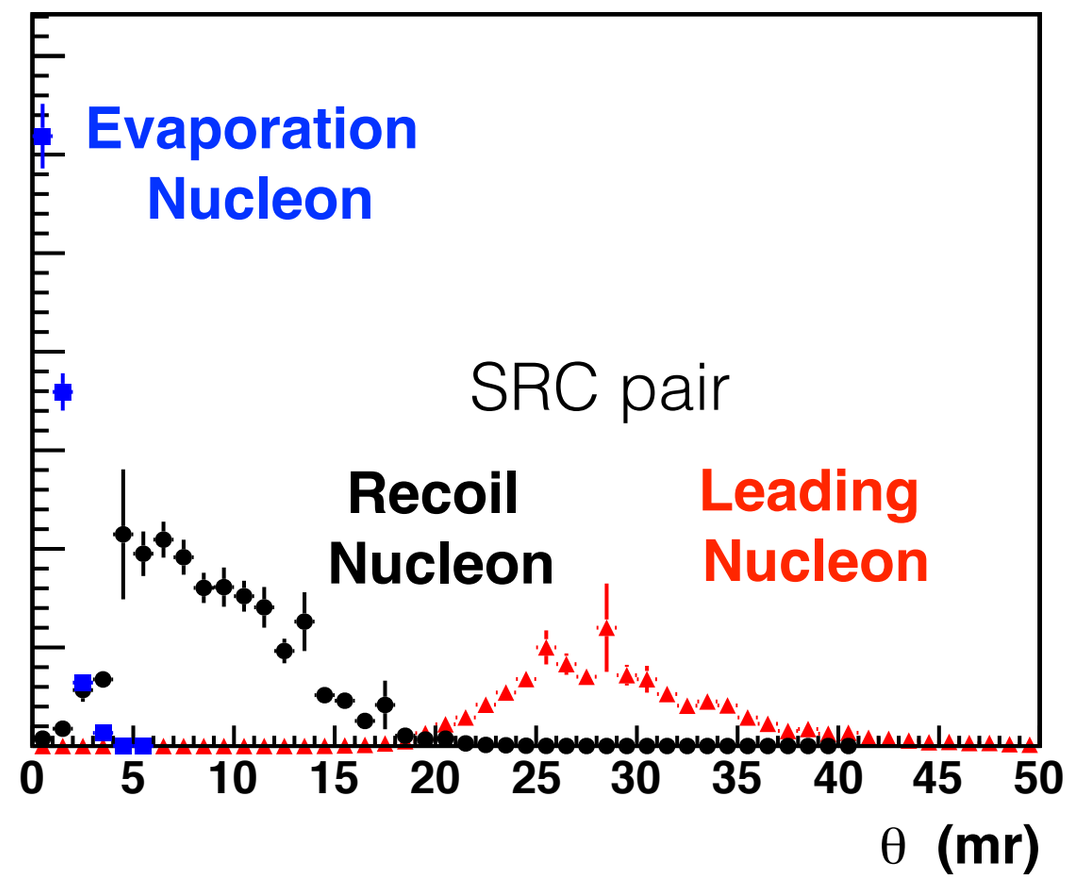
alternative model: J. Freese et al. Phys. Rev. D 99, 114019

Quasielastic Simulation Results

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



Plots by Mark Baker



- Leading, Recoil and Evaporation Nucleons well separated
- Recoil nucleons in challenging 5 -15 mrad detection region

Summary and Outlook

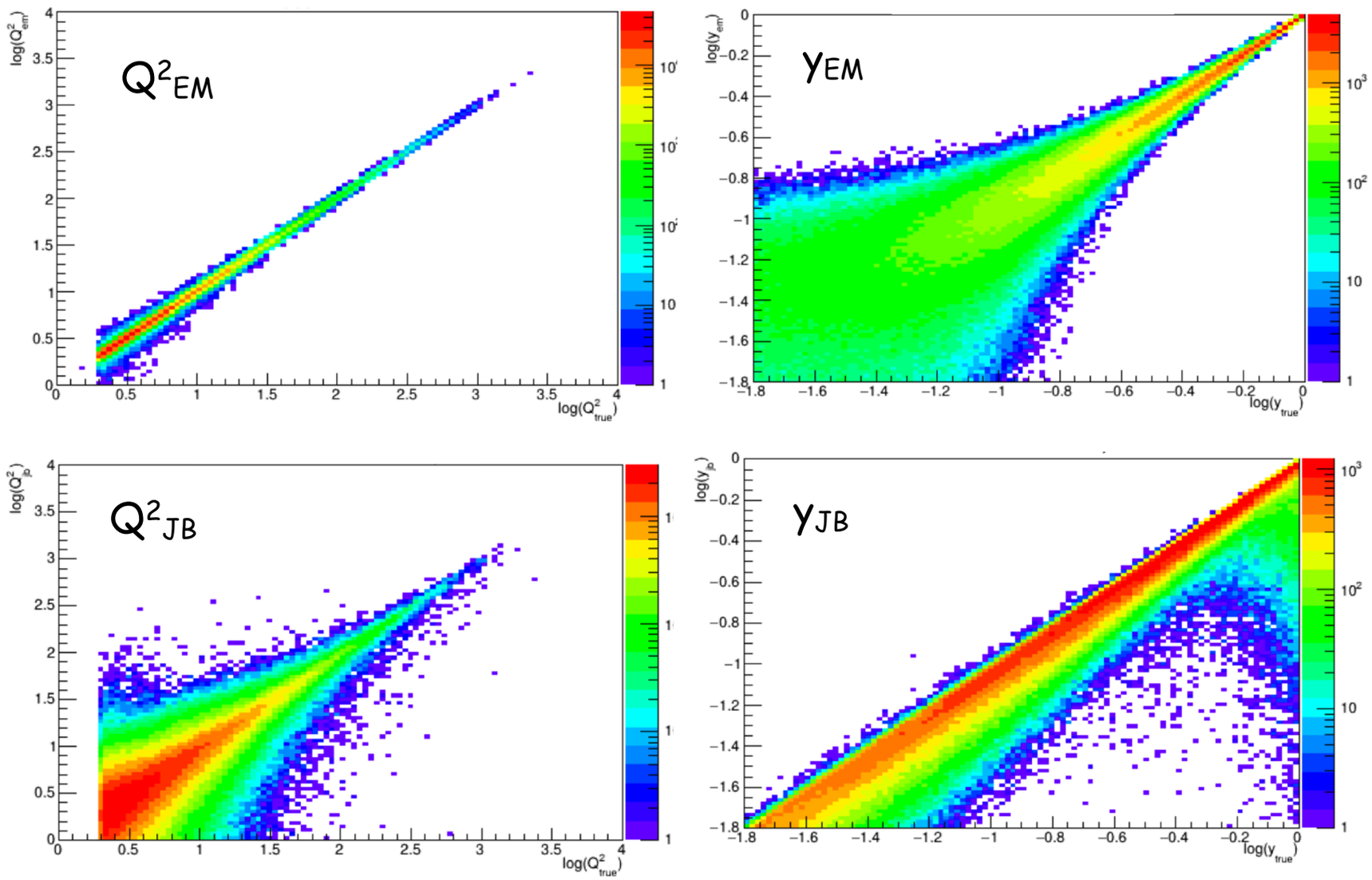
- EMC-SRC correlation from electron scattering
- Tagged DIS measurement at JLab to explain EMC effect
  - Measurement of F_2^p with CLAS12 plus BAND
  - Measurement of F_2^n in Hall C with LAD (2021?)
- SRC physics possibilities at (JL)EIC
  - LDRD project
  - First simulation results promising

Near term:

- Continuation of EIC-LDRD project
  - Simulation of DIS event from SRC-EMC model
  - Effects of FSI and intranuclear cascading
  - Resolution requirements

Back up slides

Resolution for x and Q^2 in ep



Electron Only Method

$$Q_e^2 = 4EE' \cos^2(\theta/2)$$

$$= \frac{p_{t,e}^2}{1 - y_e}$$

Jacquet-Blondel Method

$$Q_{JB}^2 = \frac{(\sum_i p_{x,i})^2 + (\sum_i p_{y,i})^2}{1 - y_{JB}}$$

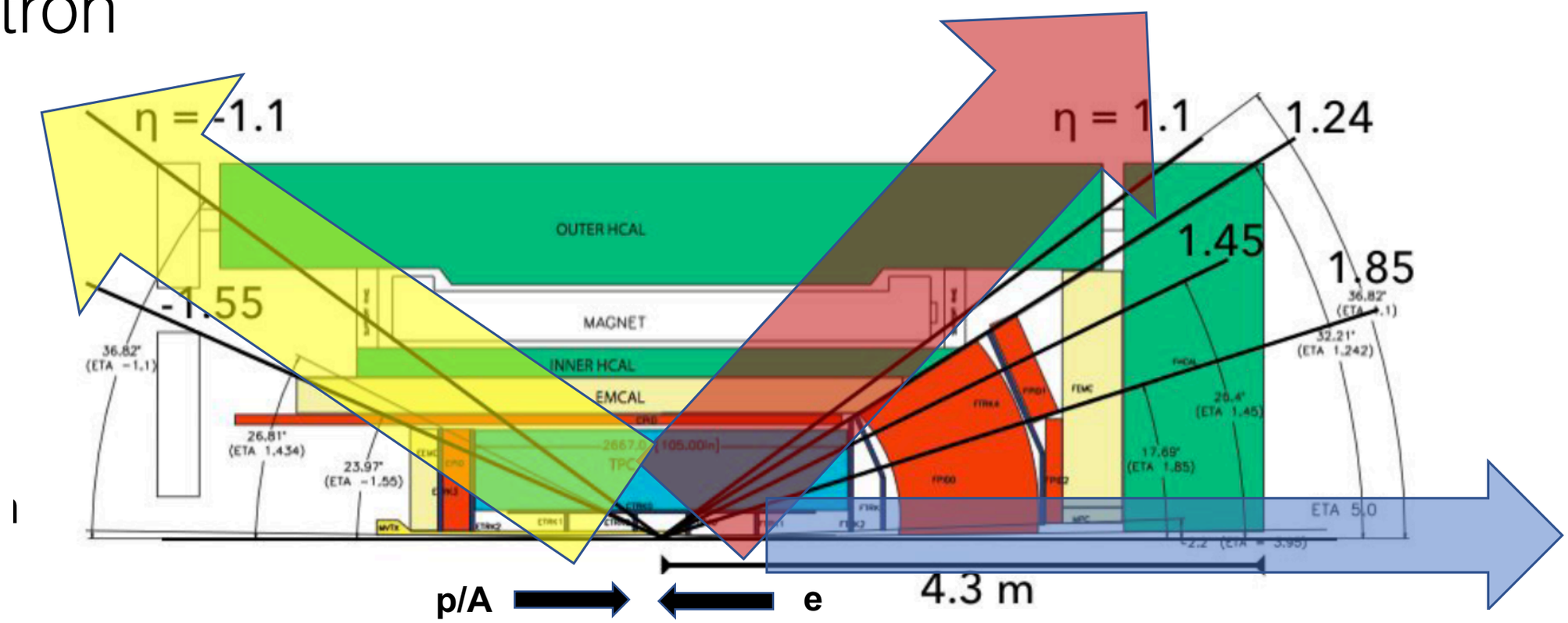
$$= \frac{p_{t,h}^2}{1 - y_{JB}}$$

- For electron only, worse low y (high-x) resolution
- For JB method, low y better but low Q^2 worse
- Need a more general approach (e.g. kinematic fitting) for eA in general, and high-x in particular

EIC Detector

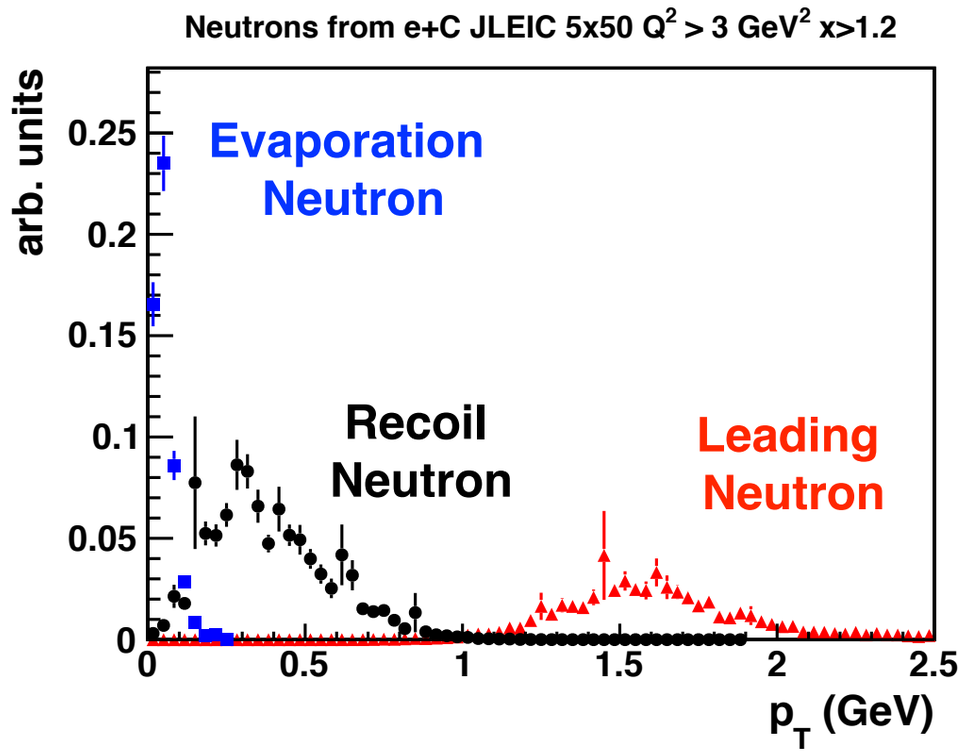
Scattered electron

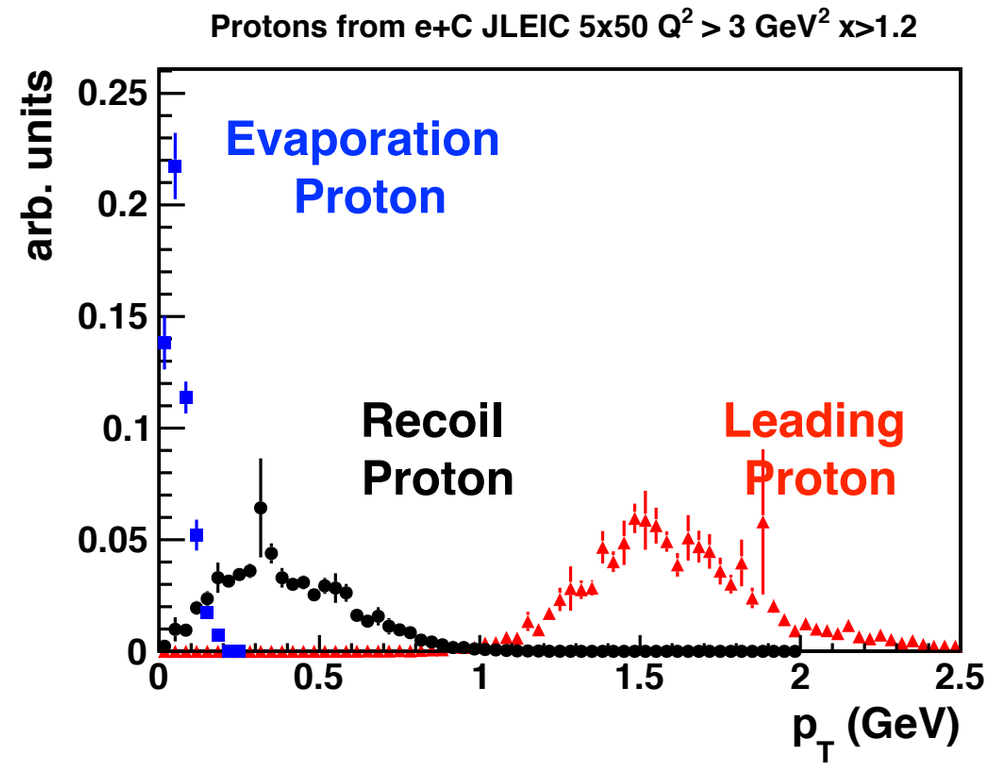
Current jet (or hadron)

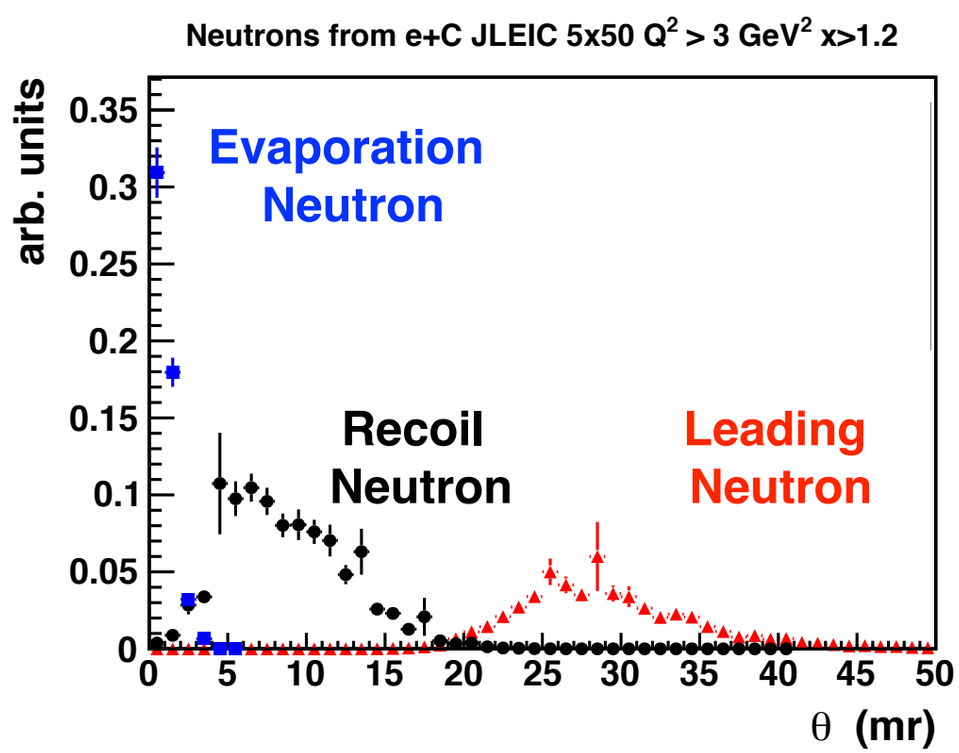


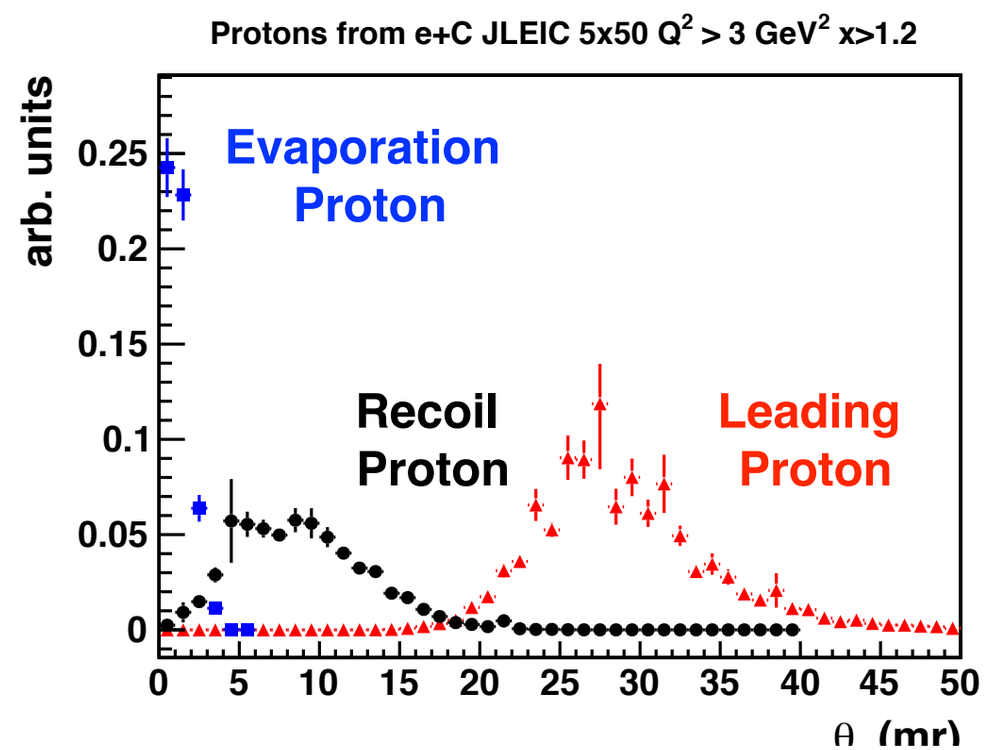
Target fragments

QE Simulation Results

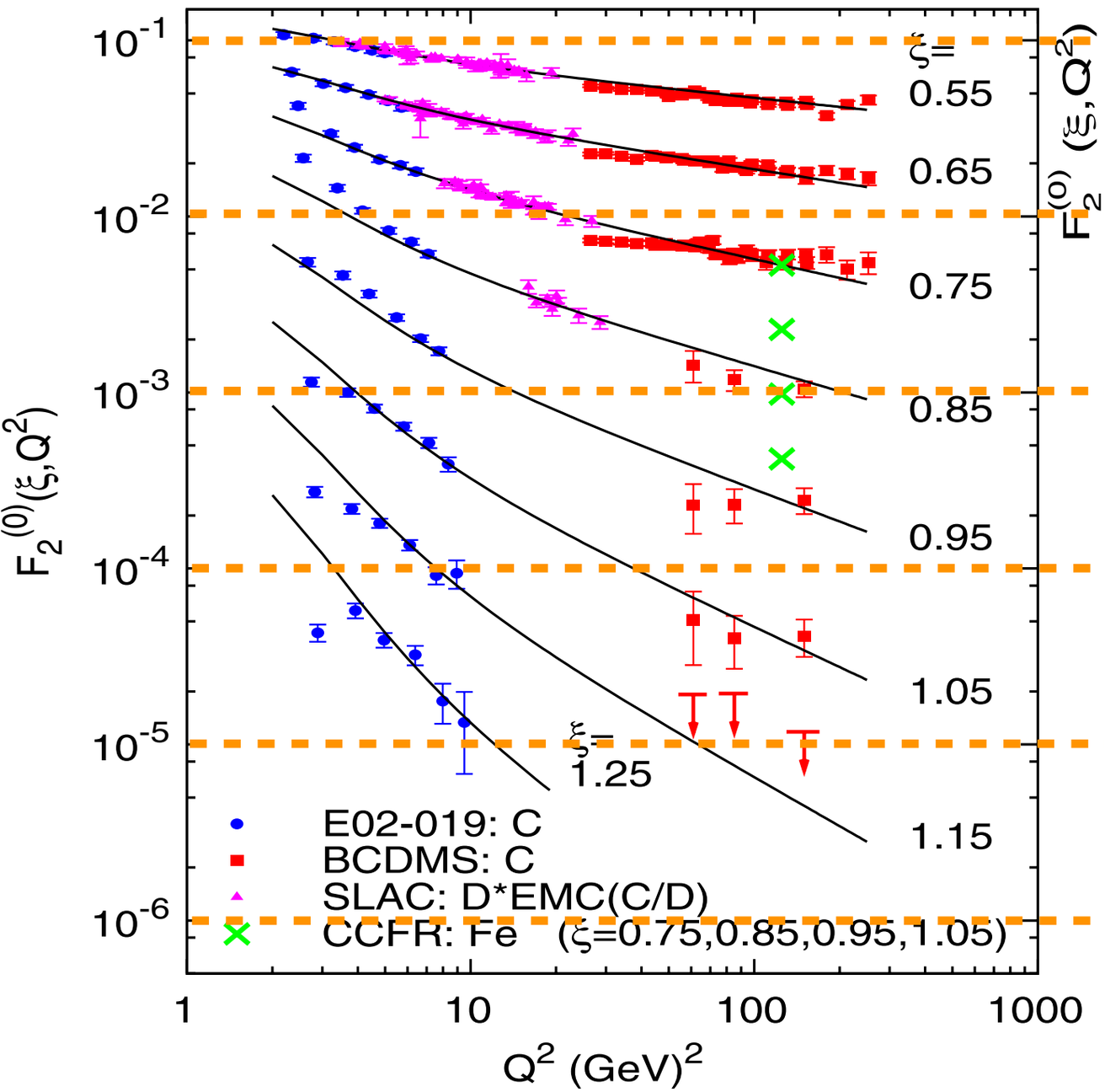




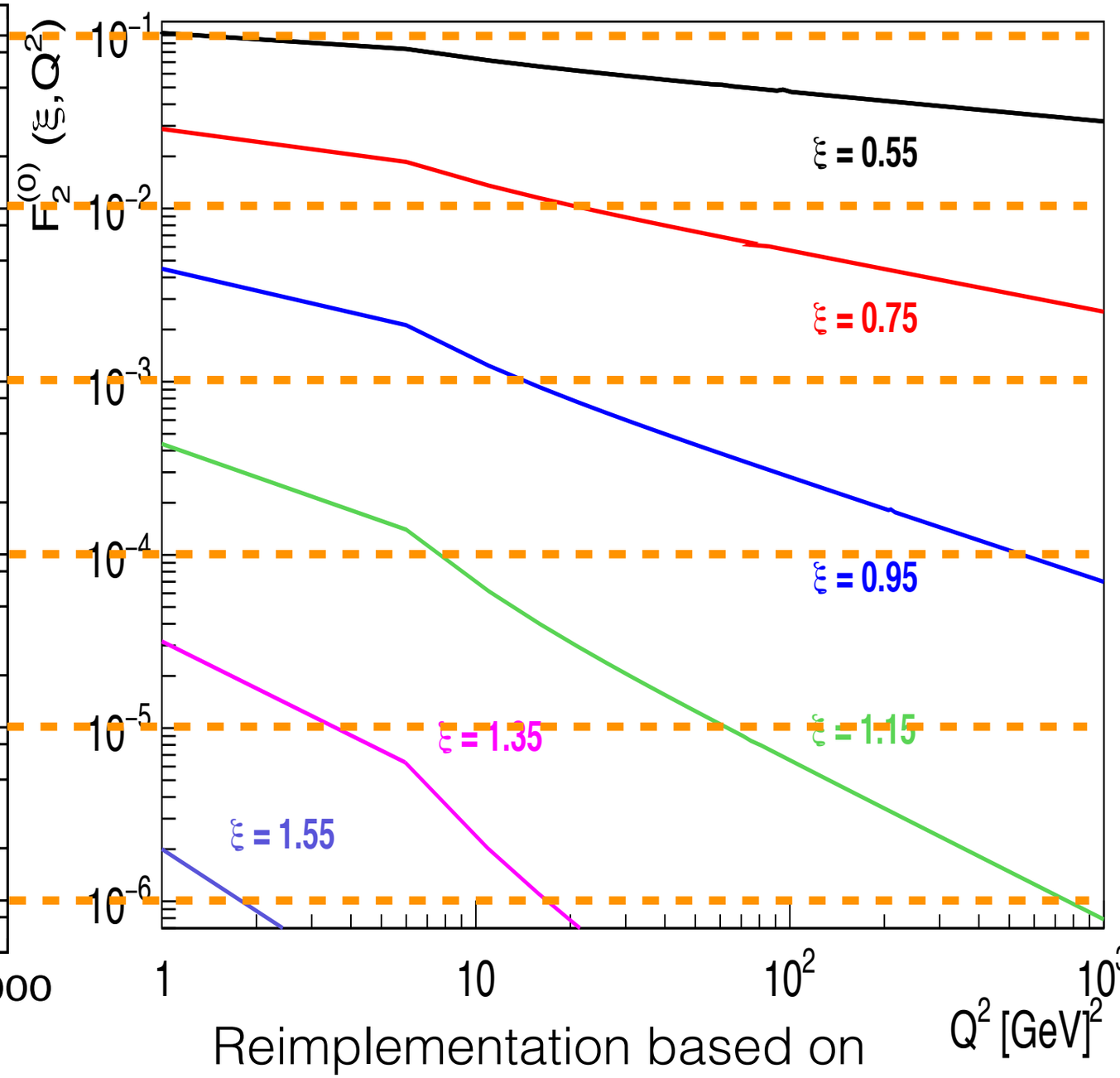




F_2 from N. Fomin Paper and Reimplementation



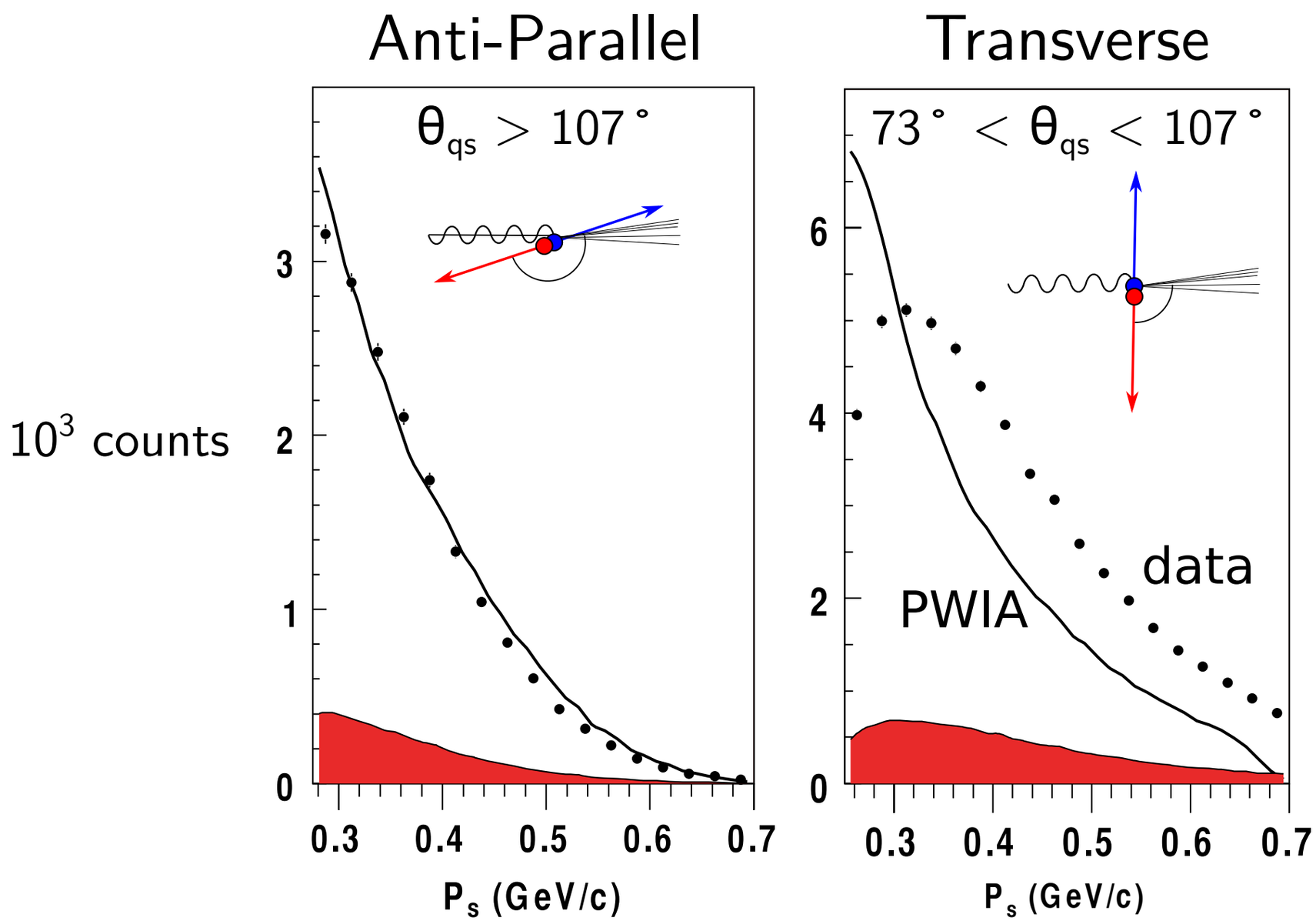
N. Fomin PRL 105, 212502 (2010



Reimplementation based on N. Fomin scripts

FSI in Tagged DIS

DEEPS showed little FSI at back angles.

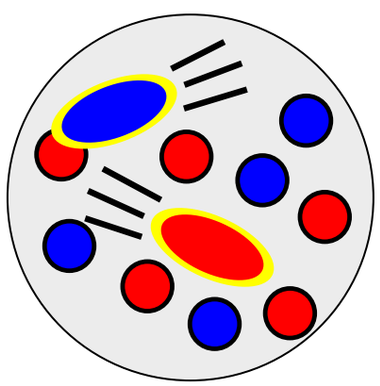


Klimenko et al., PRC 73 035212 (2006)

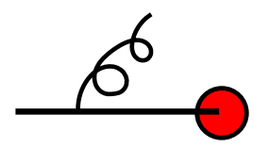
Theories

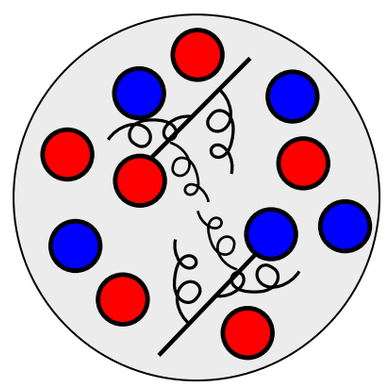
Binding

Free 

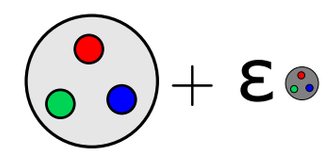
Bound 

Rescaling

Free 

Bound 

Point-like Configuration Suppression

Free 

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