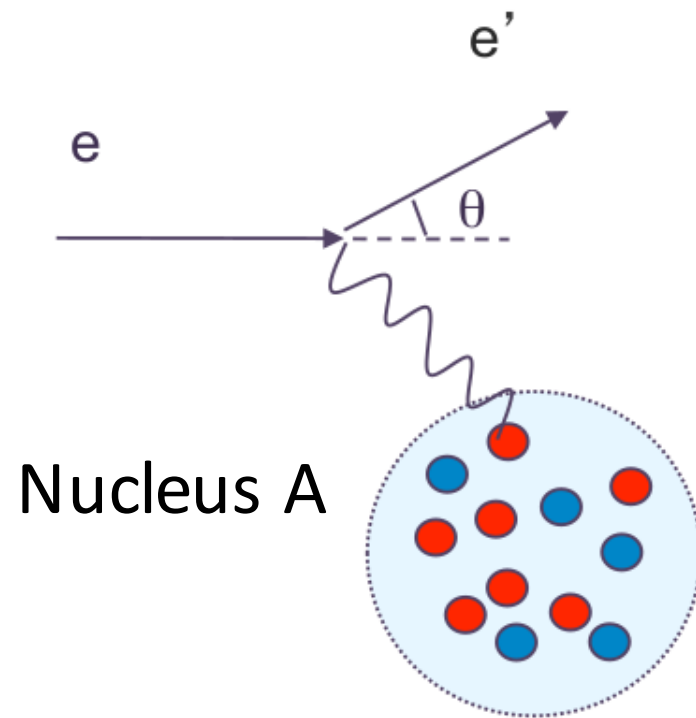


Short Range Correlations and Tagged Deep Inelastic Scattering

Florian Hauenstein,
Old Dominion University
User Group Meeting 2019
06/25/19



Deep Inelastic Scattering (DIS)



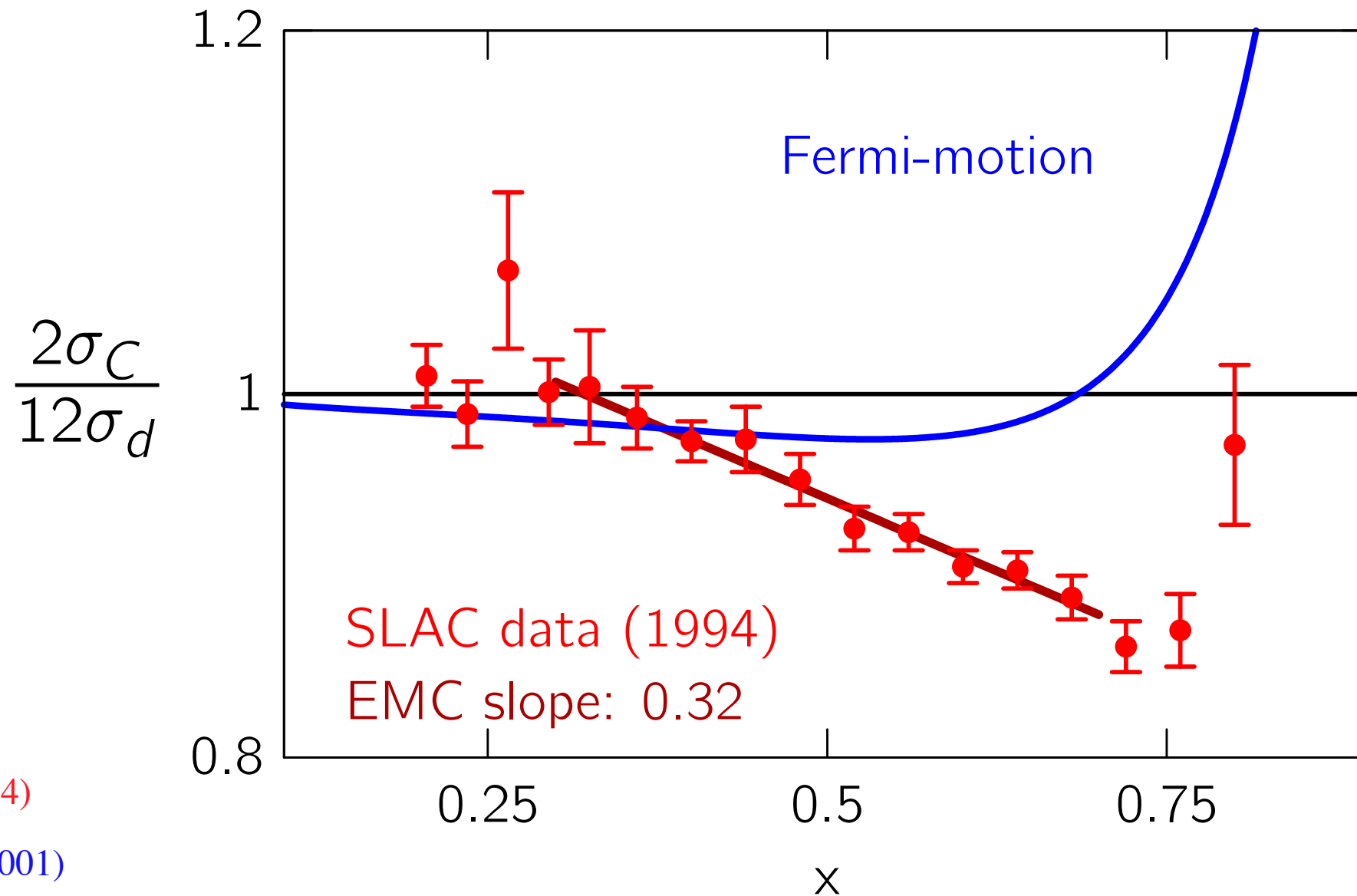
$$x_B = \frac{Q^2}{2m\omega}$$

$$Q^2 = 4E_0E \sin^2\left(\frac{\theta}{2}\right)$$

$$\omega = E - E'$$

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

The EMC Effect in DIS Scattering



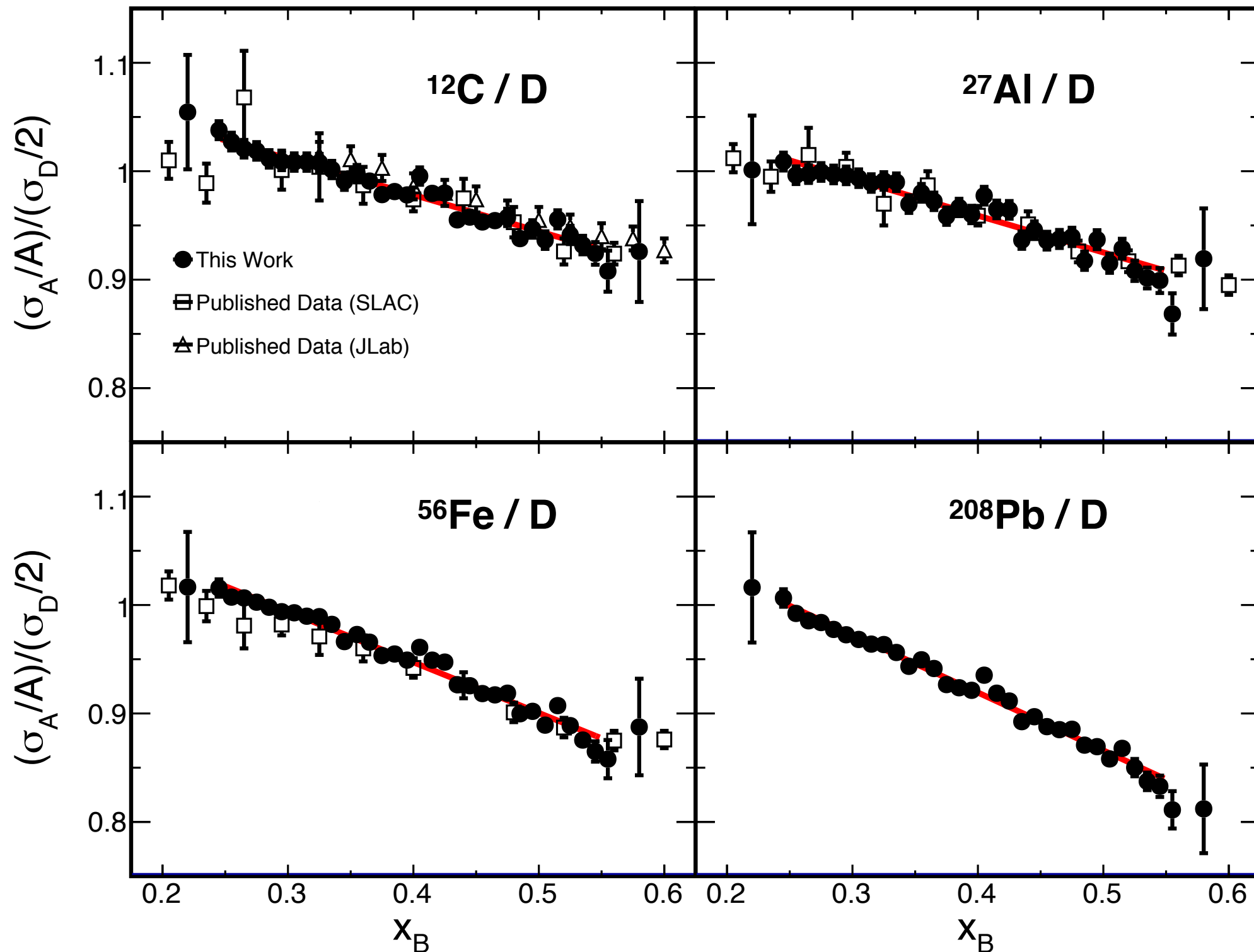
PRD 49, 4338 (1994)

PRC 65, 015211 (2001)

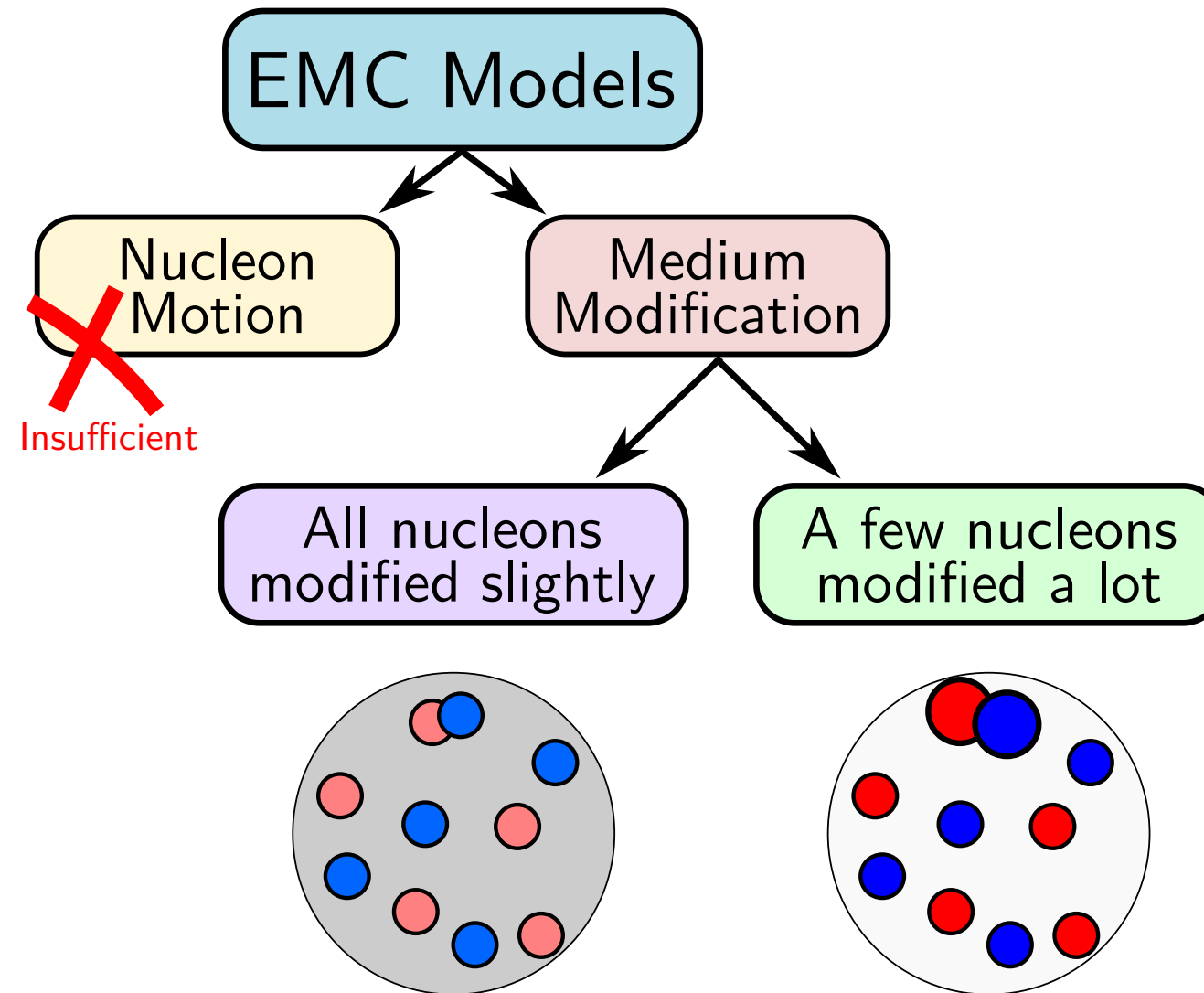
Quark distributions (F_2) in nucleons bound in nuclei different to distributions in free nucleons, here: $F_2^C \neq 6 * F_2^d$

EMC Effect in Different Nuclei

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



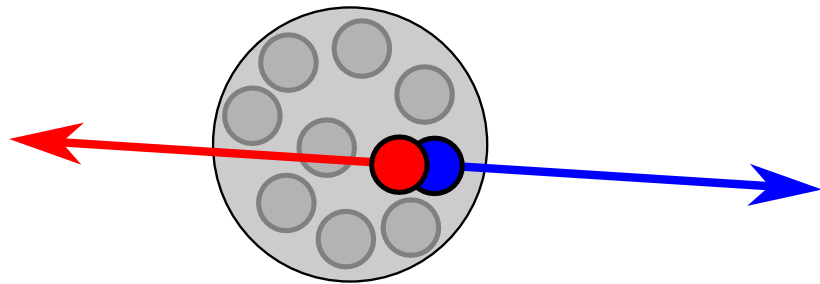
EMC Models



Mean Field
Modifications

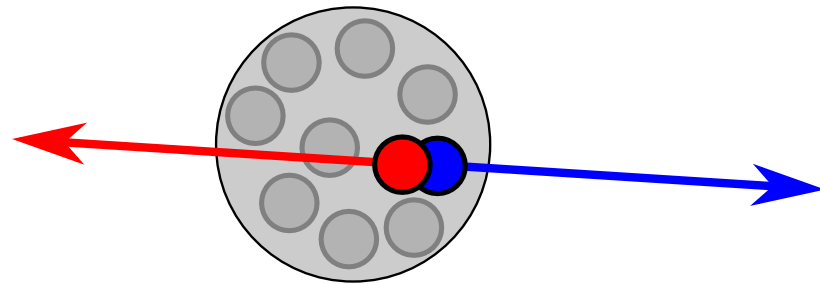
Short Range Correlations
(SRC)

Short Range Correlations

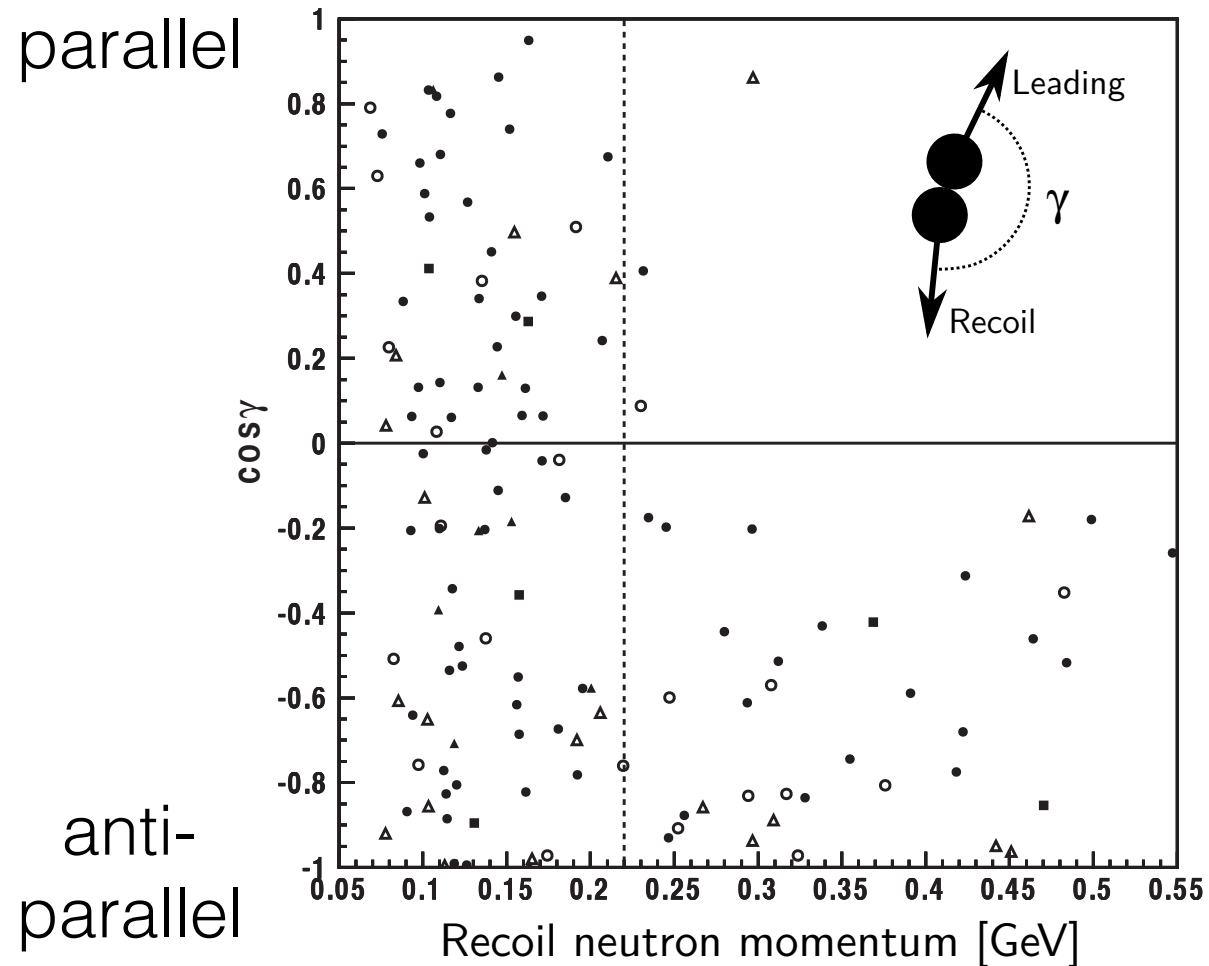


- NN pair with
 - **large relative momentum**
 $> 300 \text{ MeV}/c$
 - **small c.m momentum**
- $\sim 20\%$ of nucleons in nuclei

Short Range Correlations



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

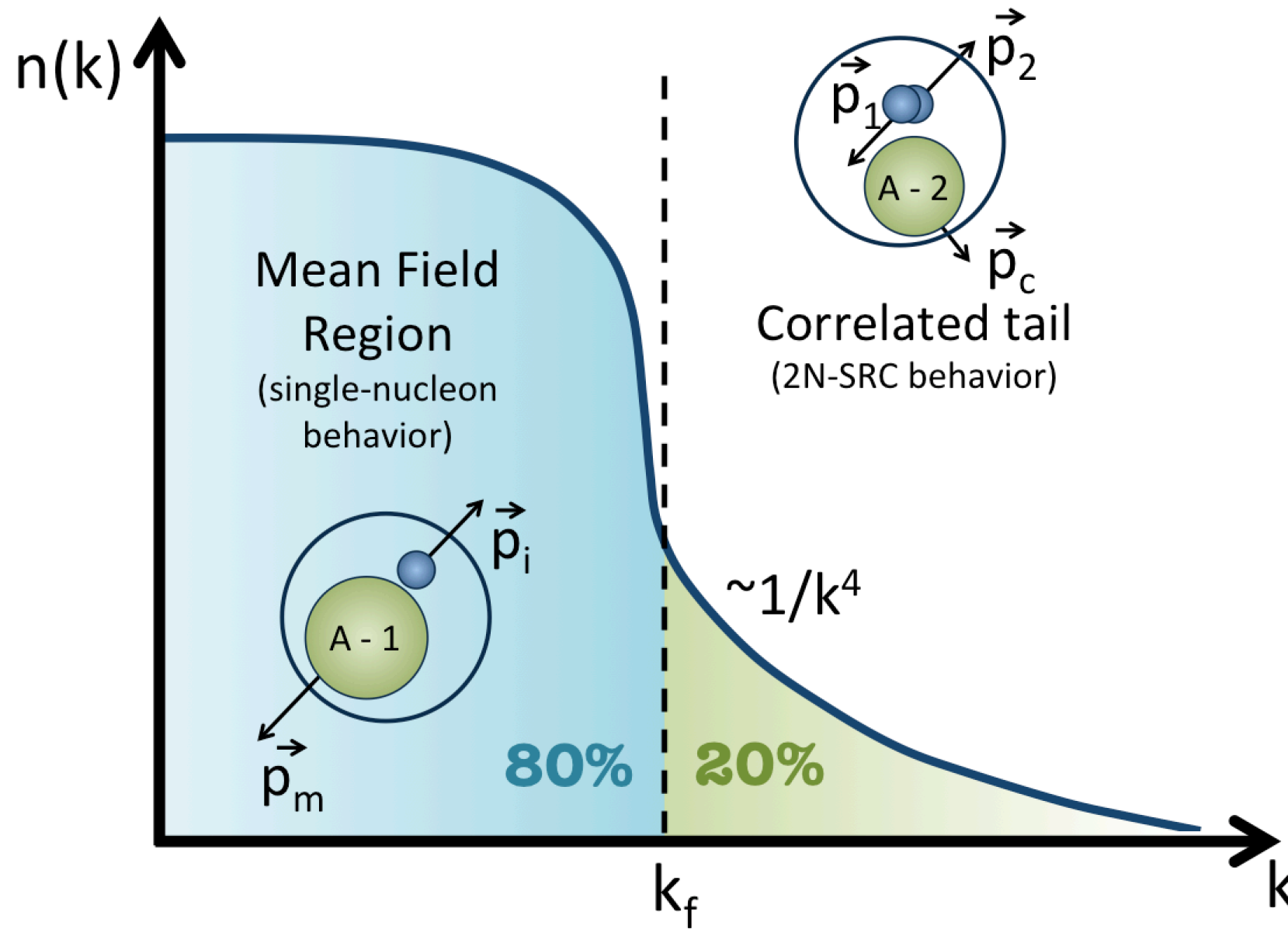


p scattering from Carbon

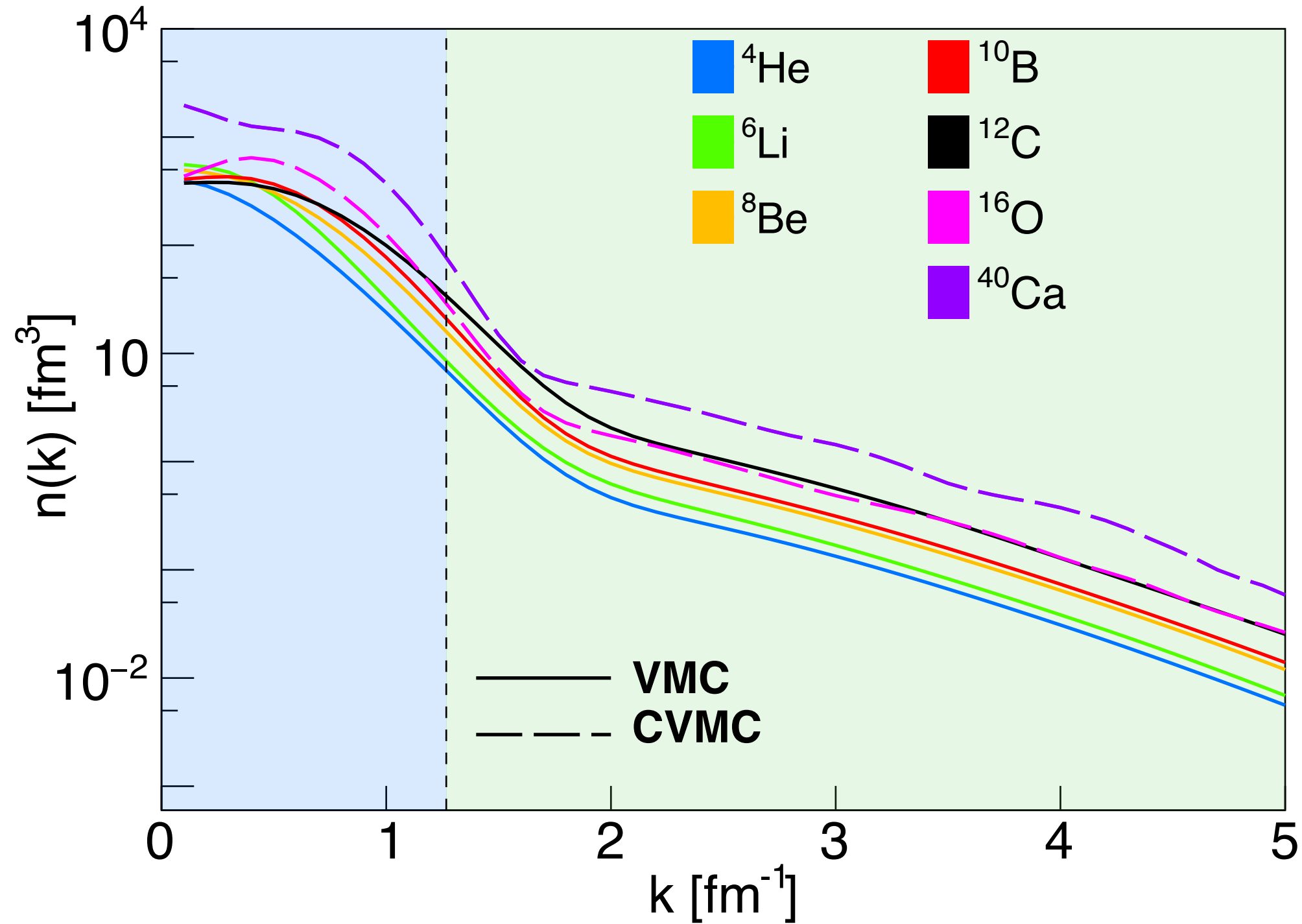
- always a correlated partner
- Anti-parallel momentum

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

Nucleon Momentum Distribution



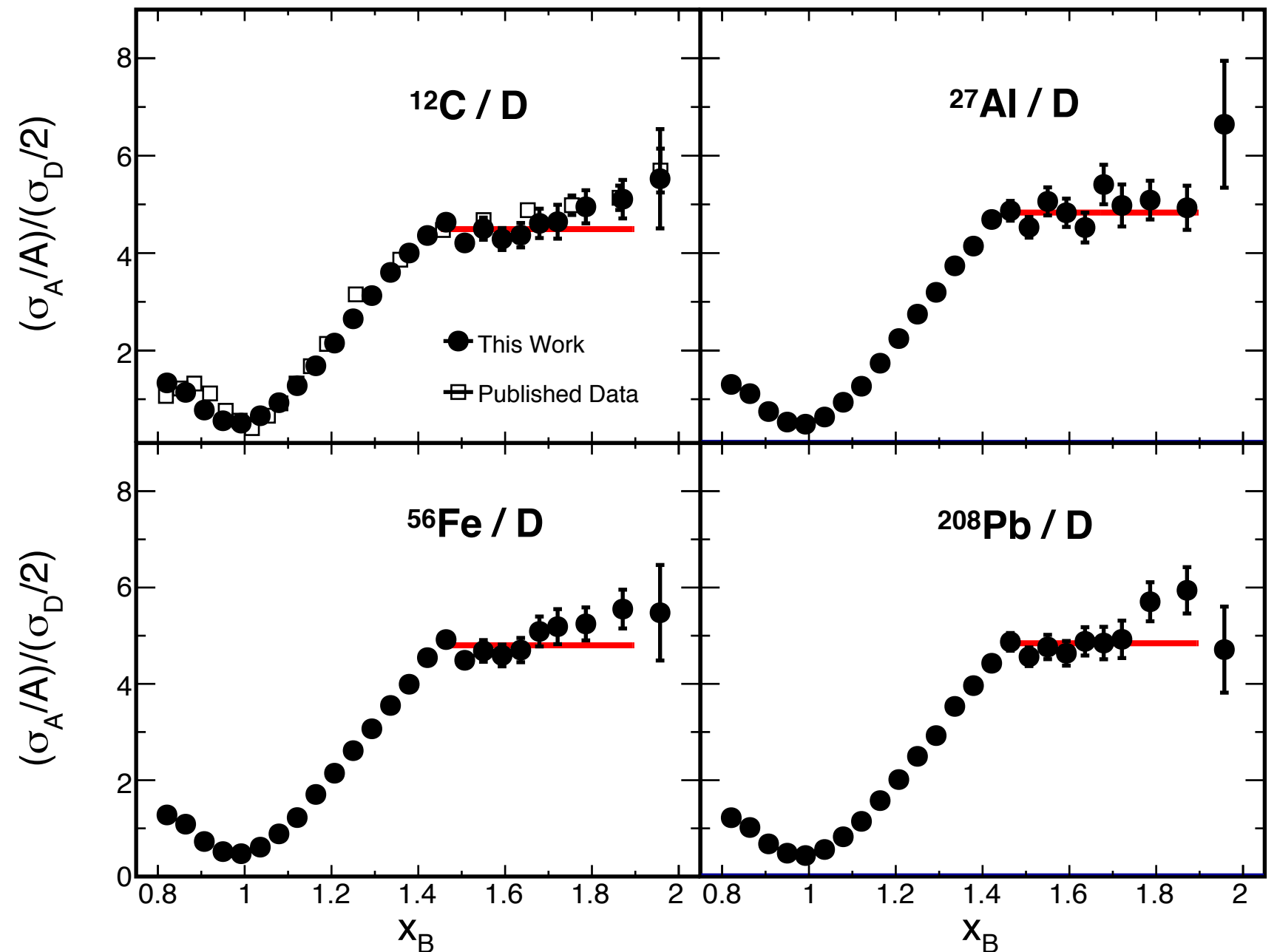
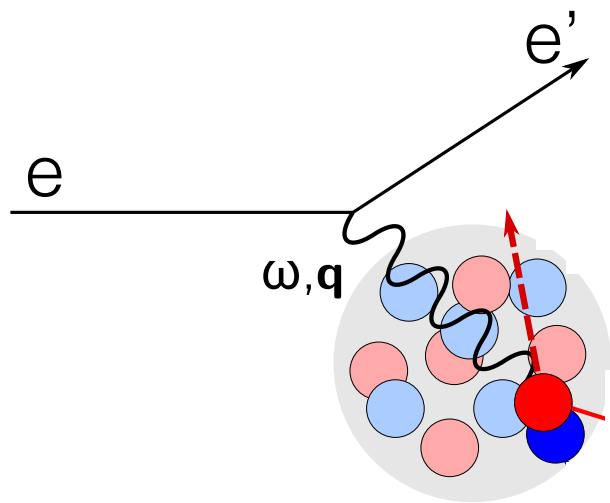
Universality of High Momentum Tail



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

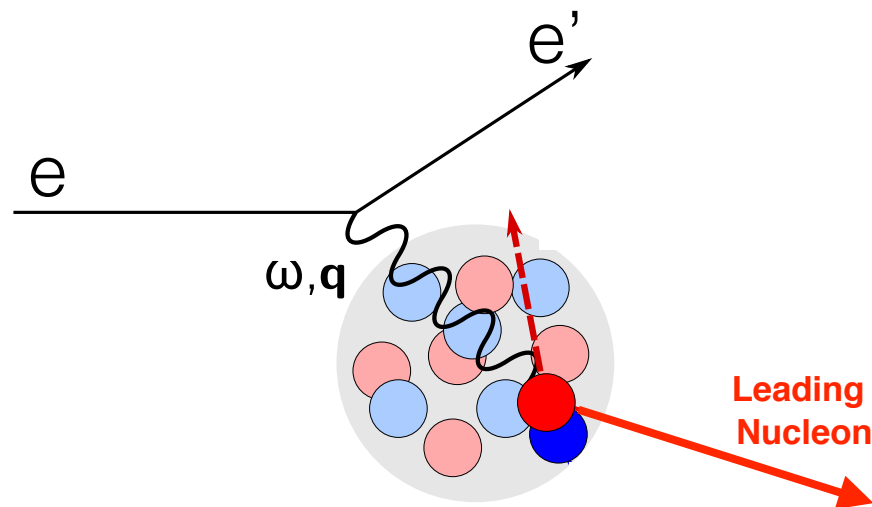
SRCs in Inclusive Scattering

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



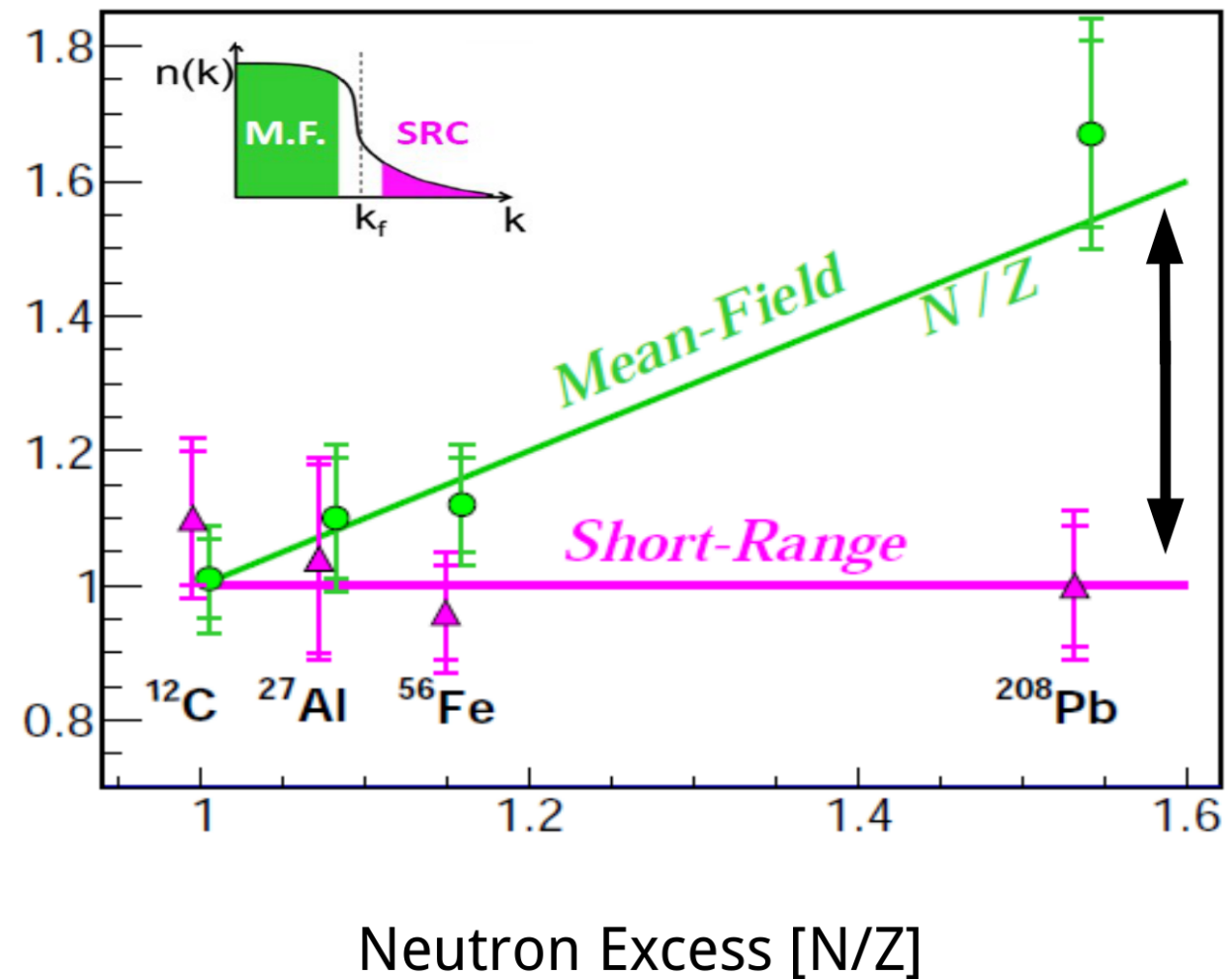
- Quasi-Elastic scattering
- Plateaus due to SRCs

SRCs in Exclusive Scattering



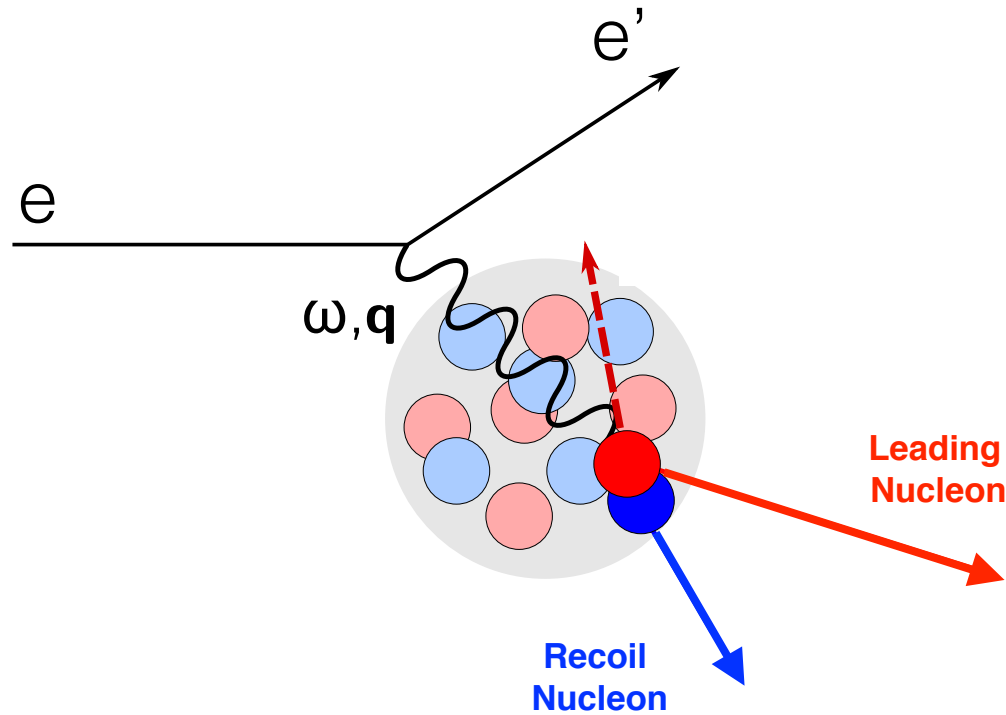
$$\frac{\sigma_A(e, e'n)/\sigma_{en}}{\sigma_A(e, e'p)/\sigma_{ep}}$$

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

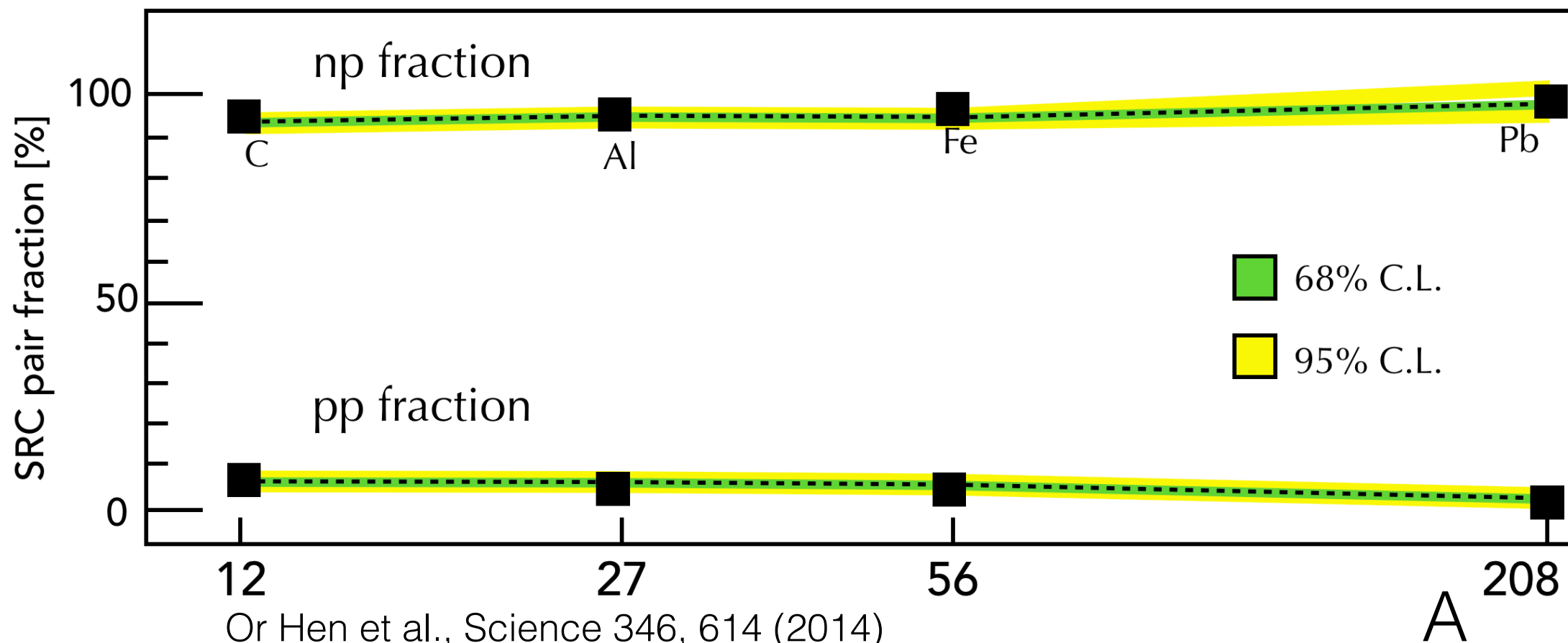


- (e'p) and (e'n) measurements
- Indication of np-dominance for SRC pairs

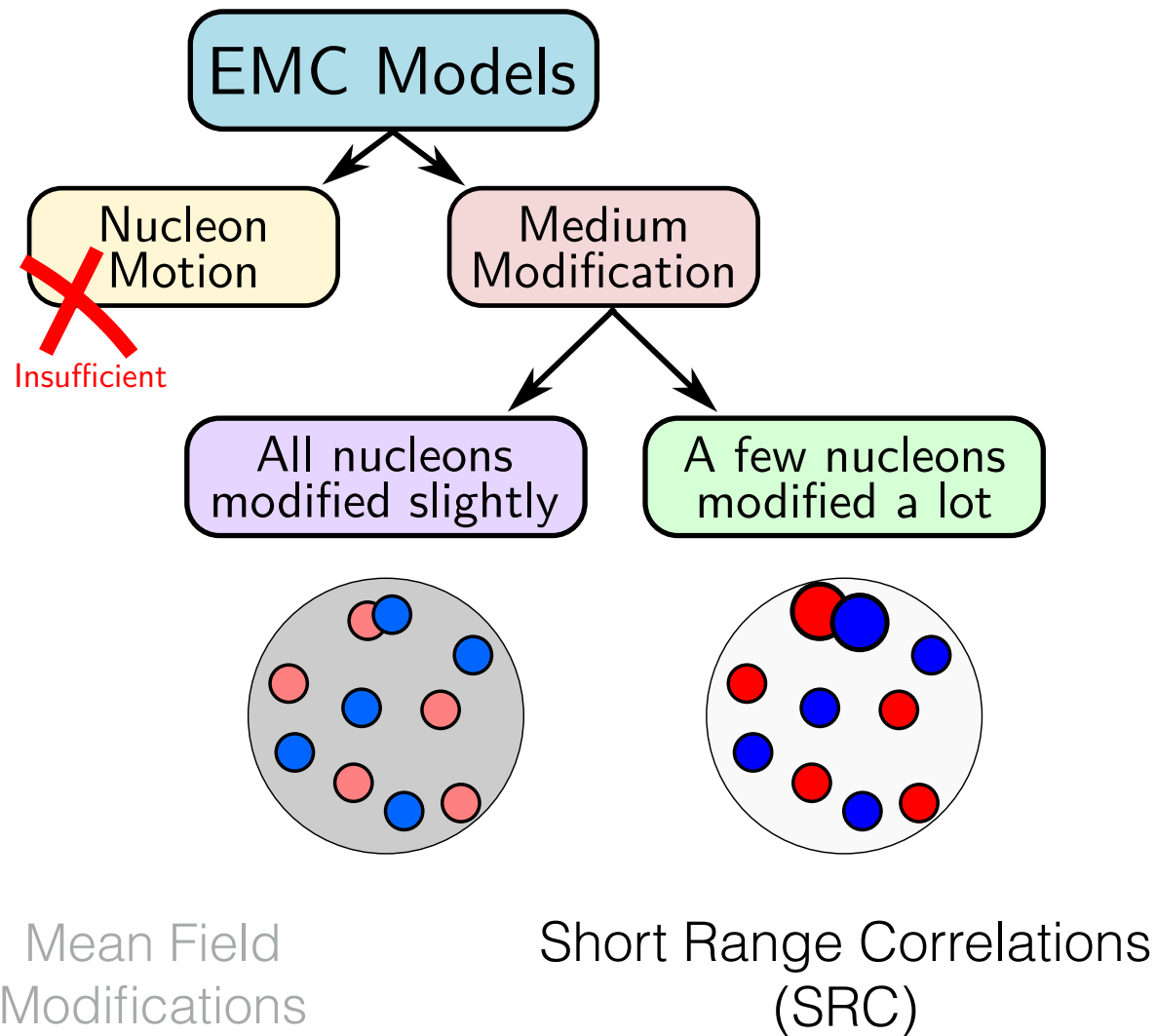
np-Dominance



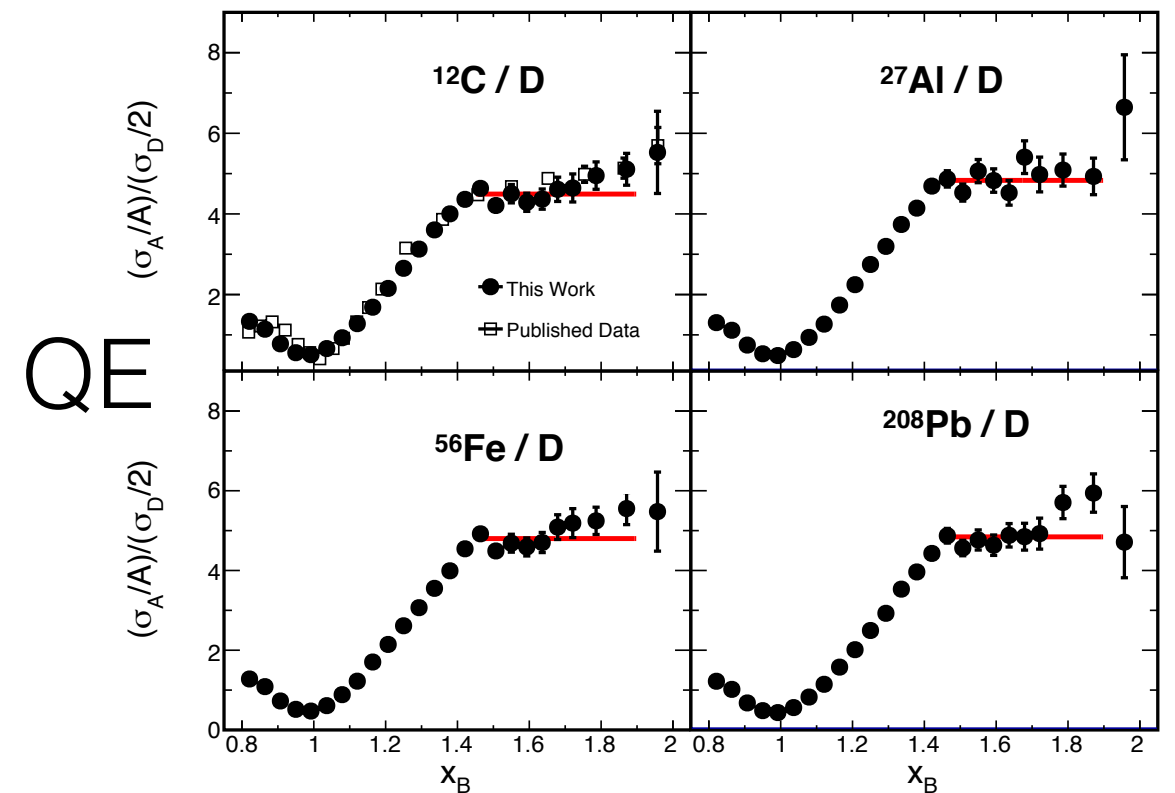
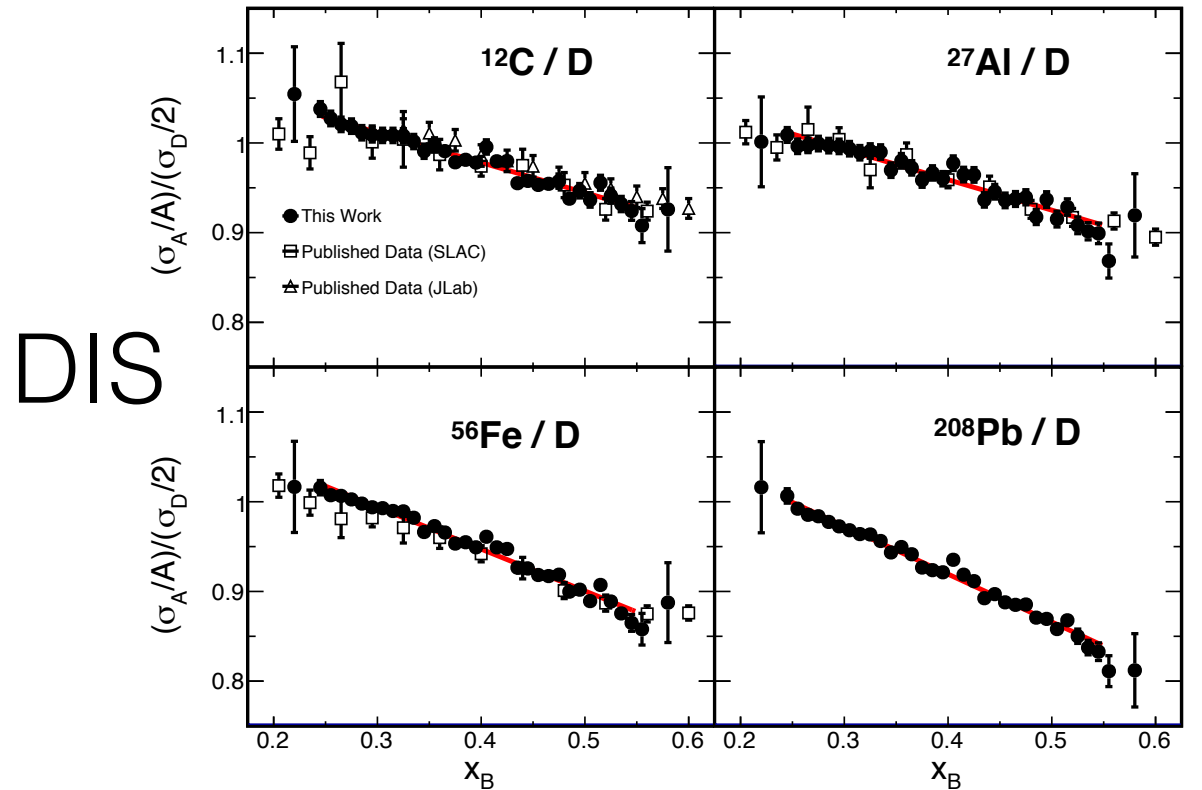
- $(e'pp)$ & $(e'np)$ measurements
- Probability for np pairs about ~ 18 larger than for pp pairs



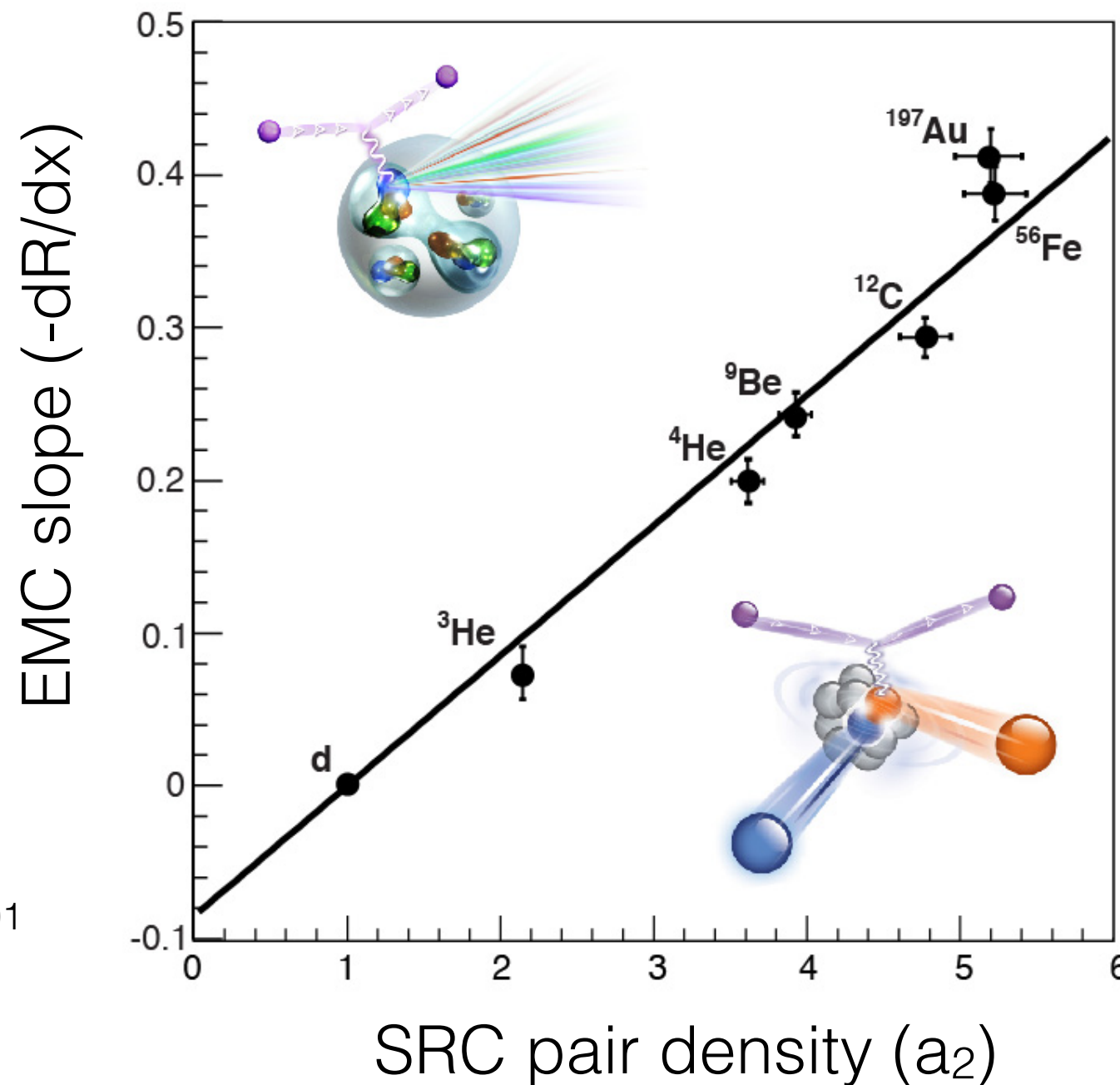
To Review: EMC and SRC



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



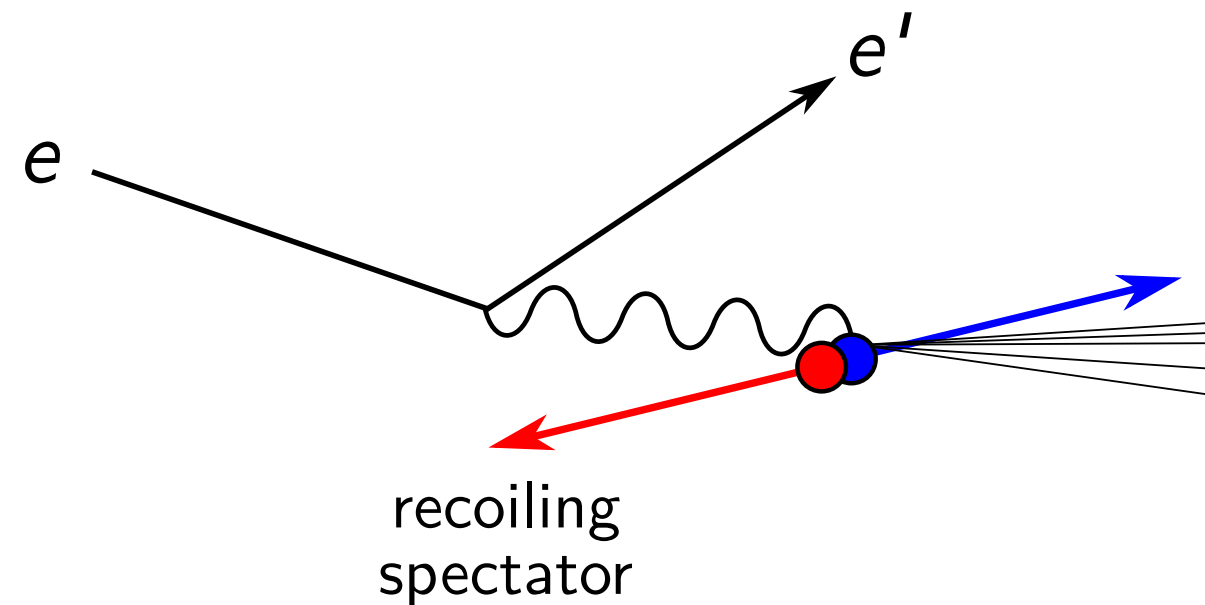
EMC and SRC Correlation



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

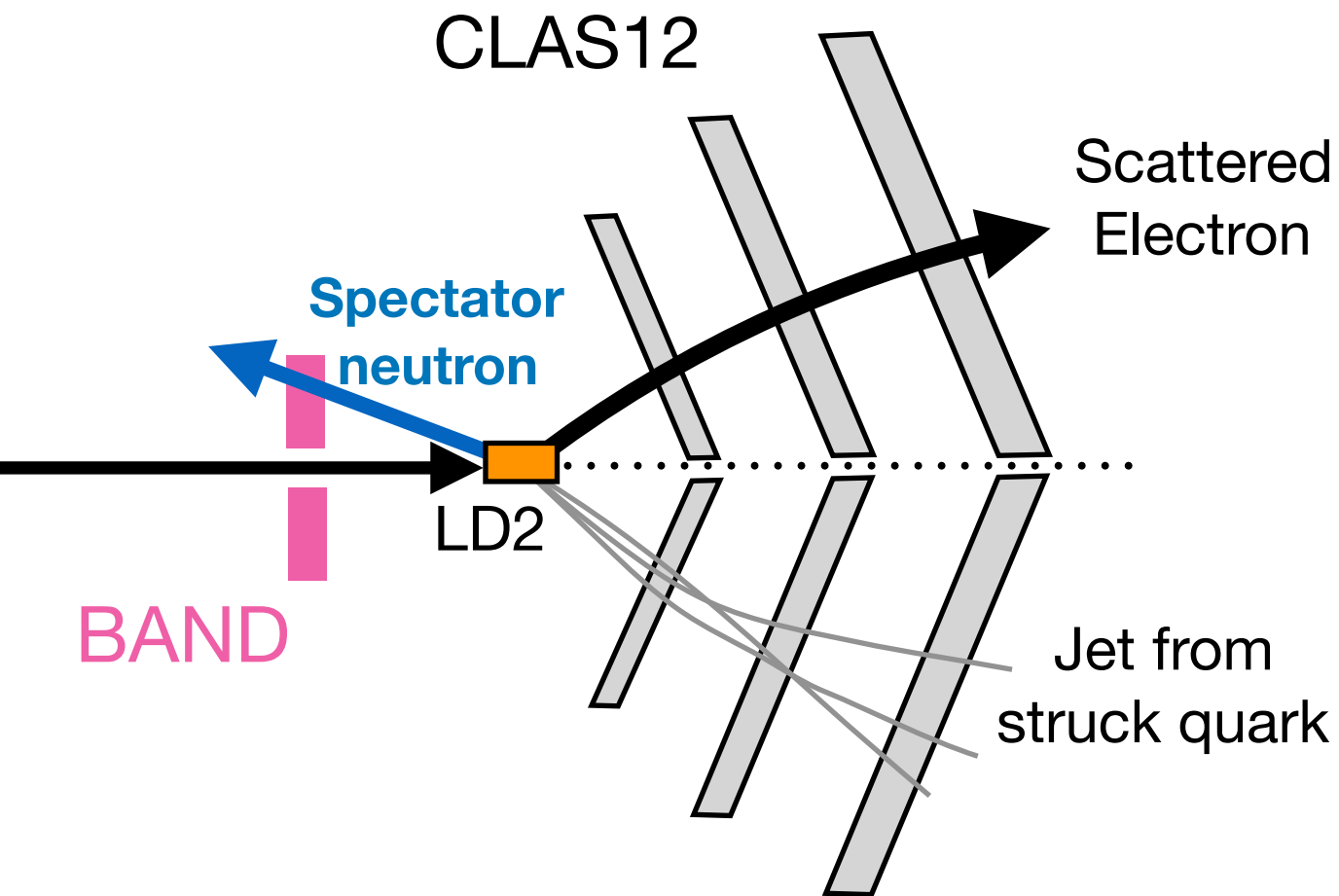


- “Tag” interacting nucleon by measuring spectator
- How does the bound nucleon structure function depend on nucleon momentum?
- Explaining the EMC effect

Tagged DIS at JLab

Hall B:

CLAS 12 + Backward Angle
Neutron Detector (BAND)

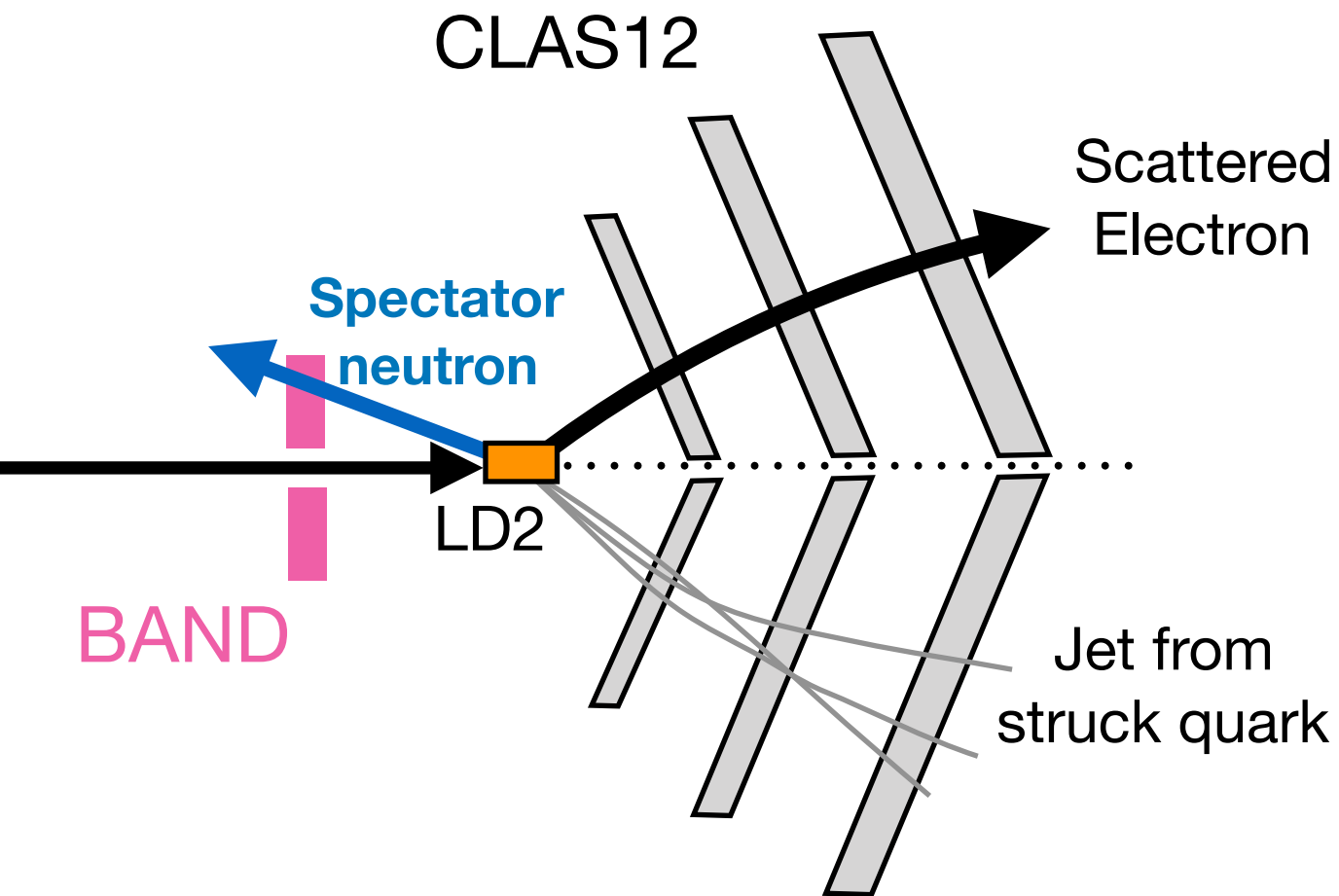


- Took first data in Spring 19
- More to come in Fall 19

Tagged DIS at JLab

Hall B:

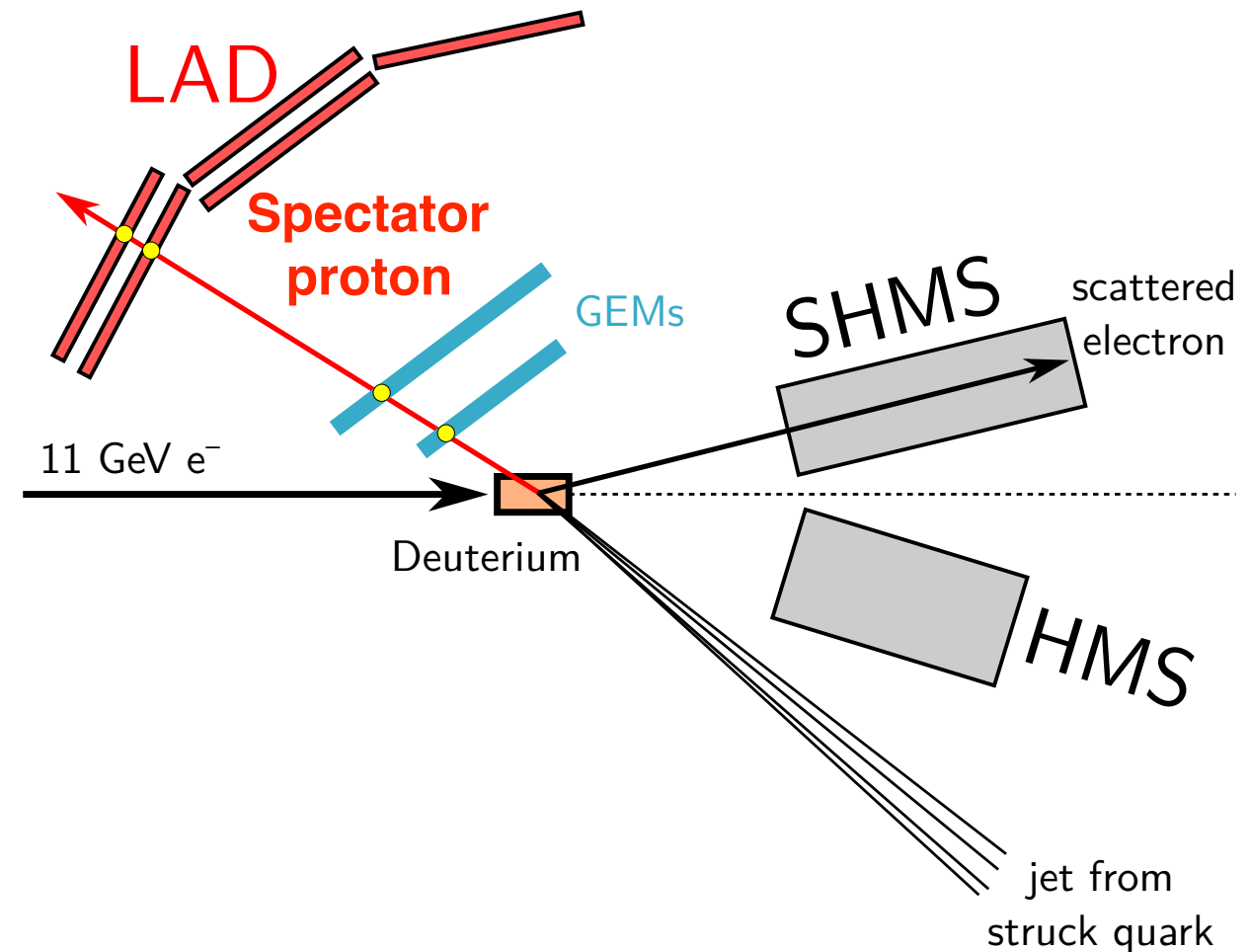
CLAS 12 + Backward Angle Neutron Detector (BAND)



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

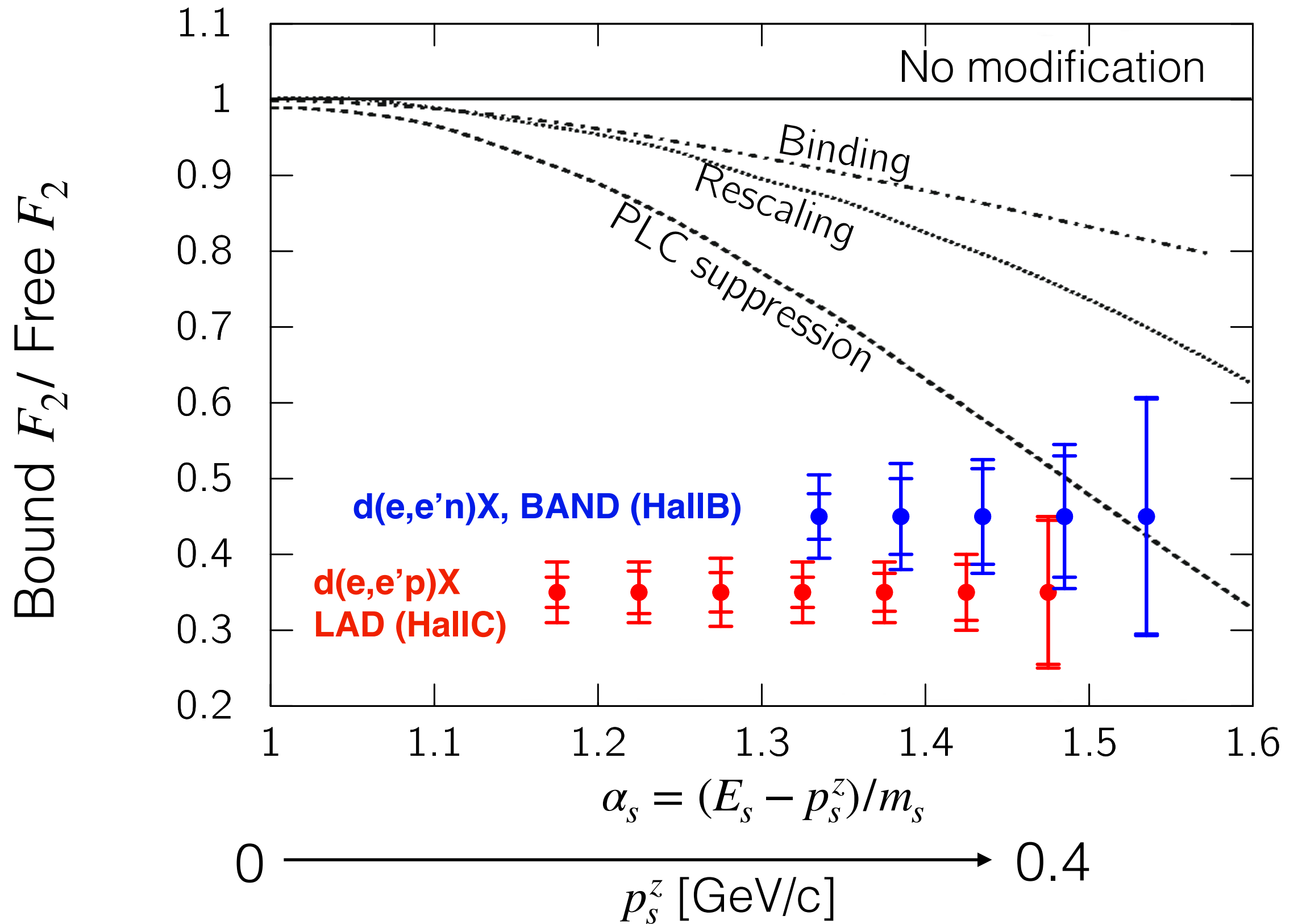
Hall C:

SHMS/HMS + Large Angle Detector (LAD)

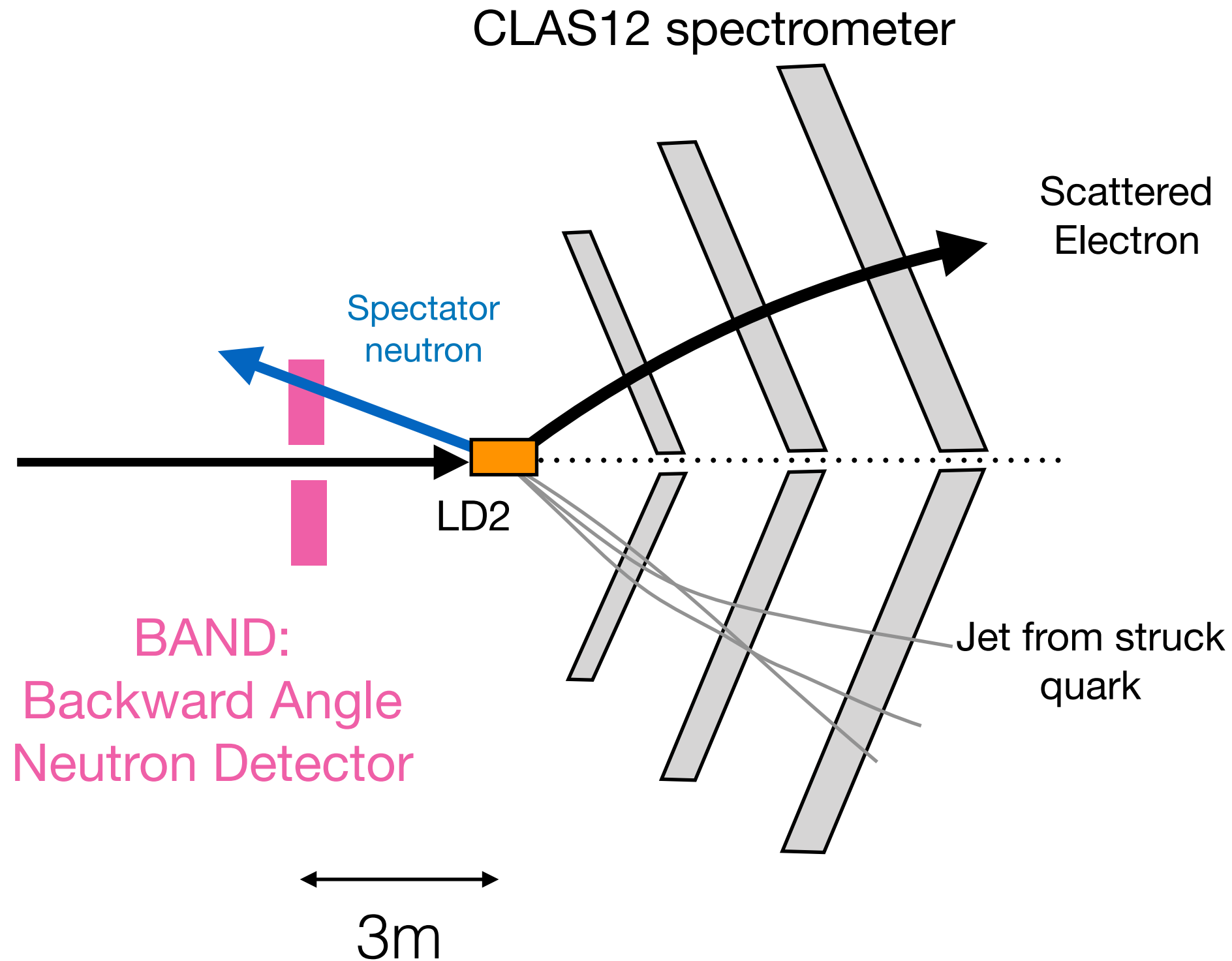


- LAD built, GEMs to be build
- Run in 2021?

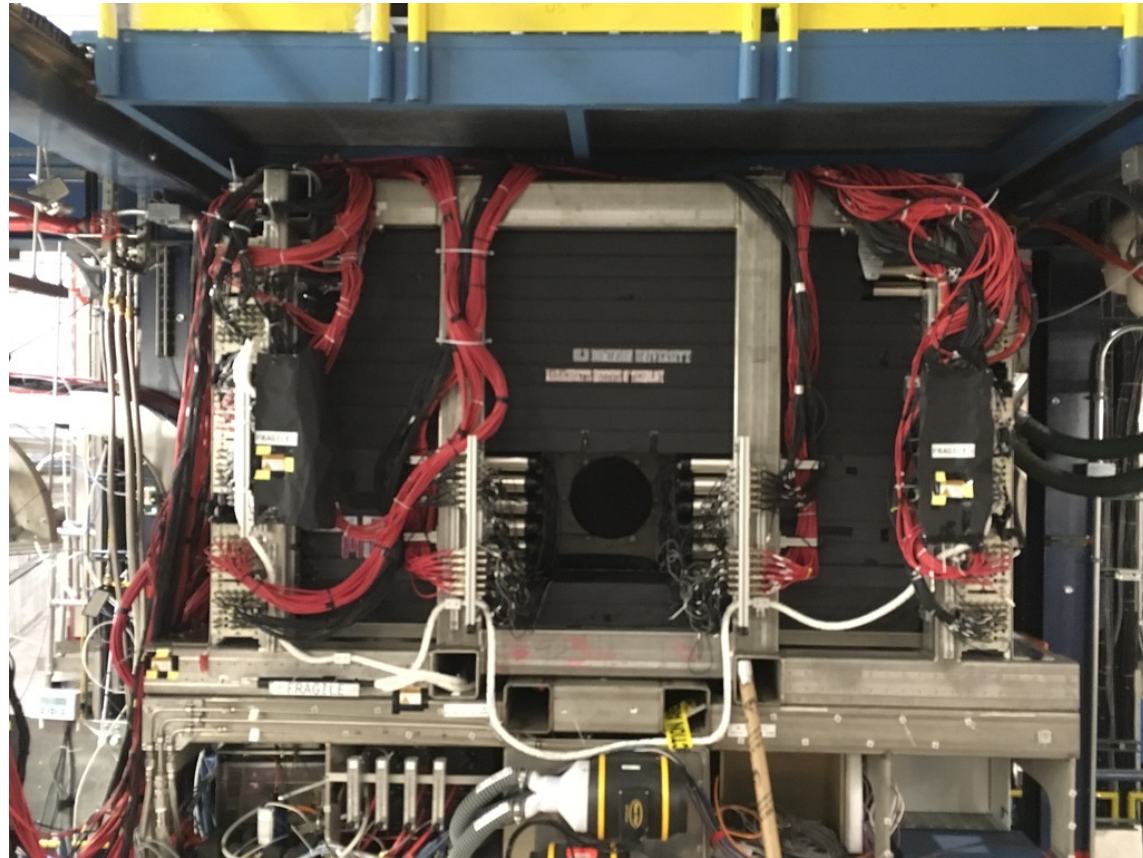
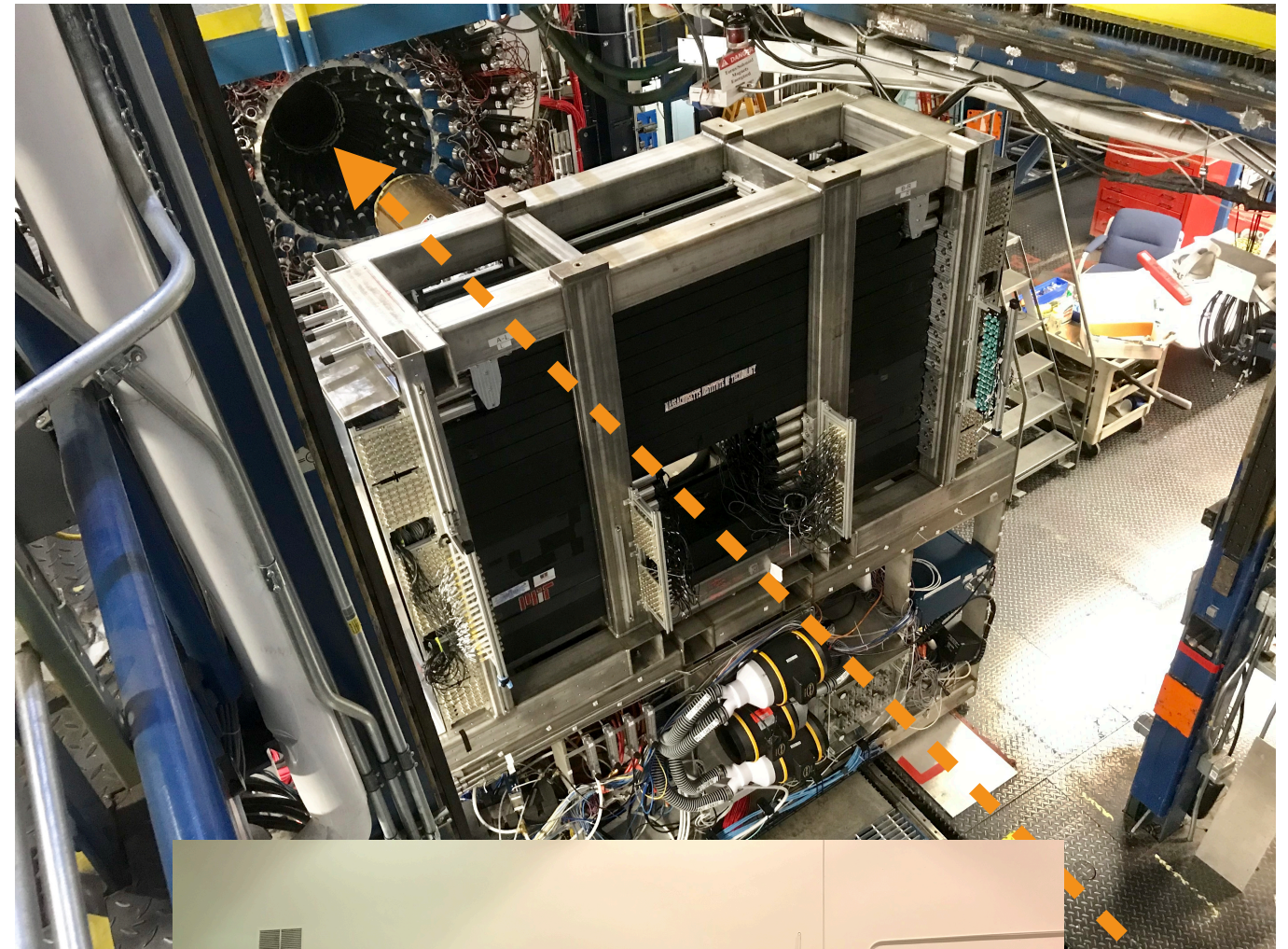
DIS Recoil Tagging $d(e,e'N)X$ - Expected Results



BAND in HallB



BAND in Hall B

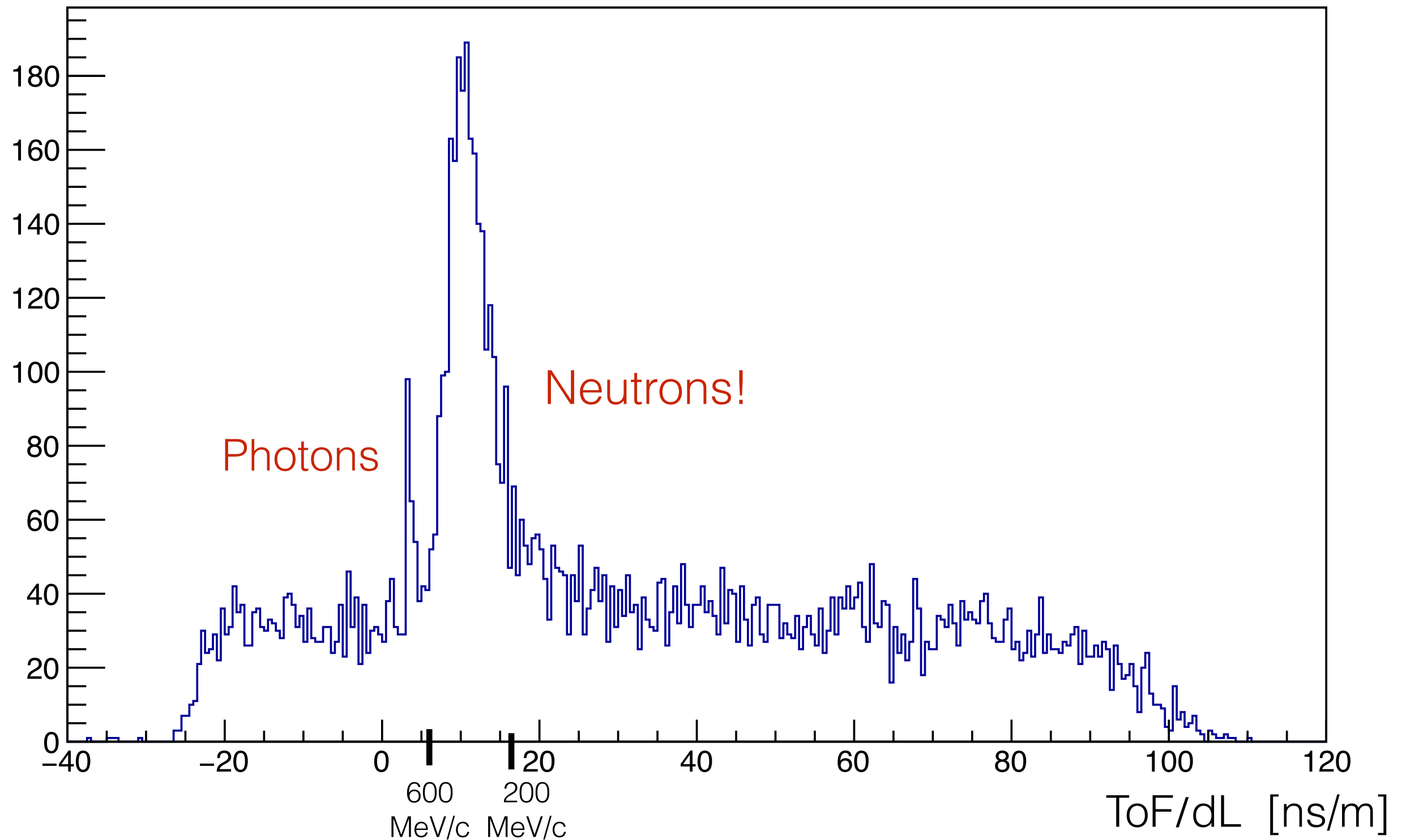




... we didn't

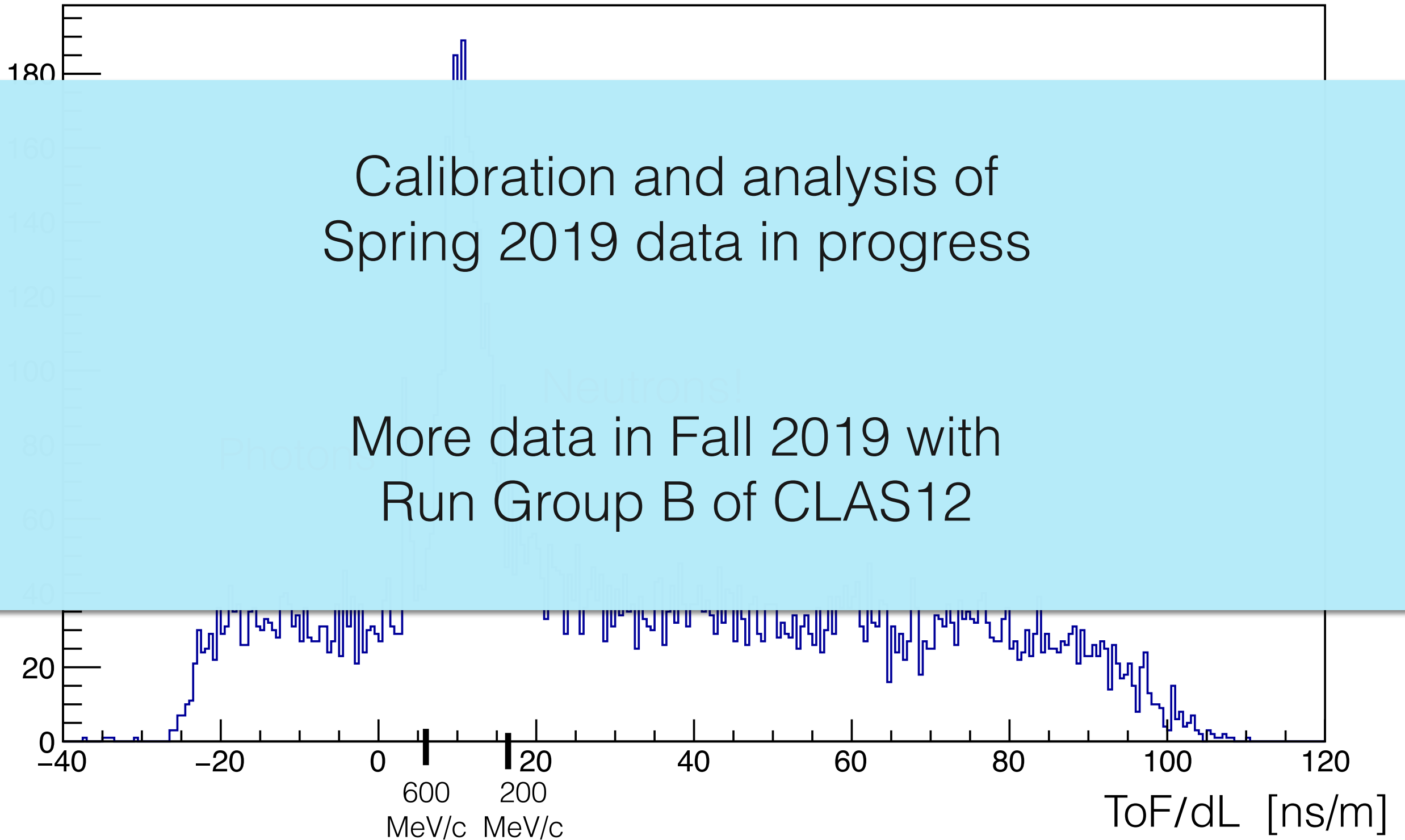
BAND Time-of-Flight/m Spectrum

50nA beam, electron cuts ($Q^2 > 2 \text{ GeV}$, $W > 2.2 \text{ GeV}$)



BAND Time-of-Flight/m Spectrum

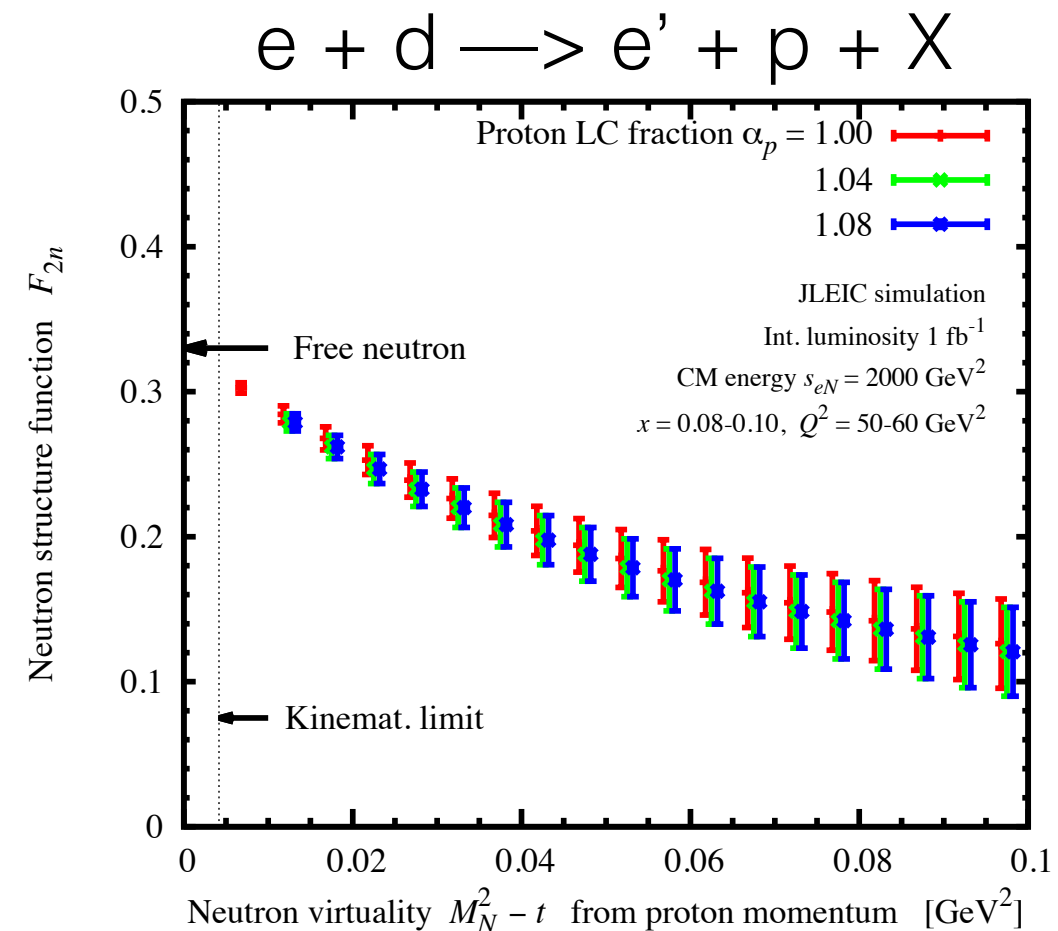
50nA beam, electron cuts ($Q^2 > 2 \text{ GeV}$, $W > 2.2 \text{ GeV}$)



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/>

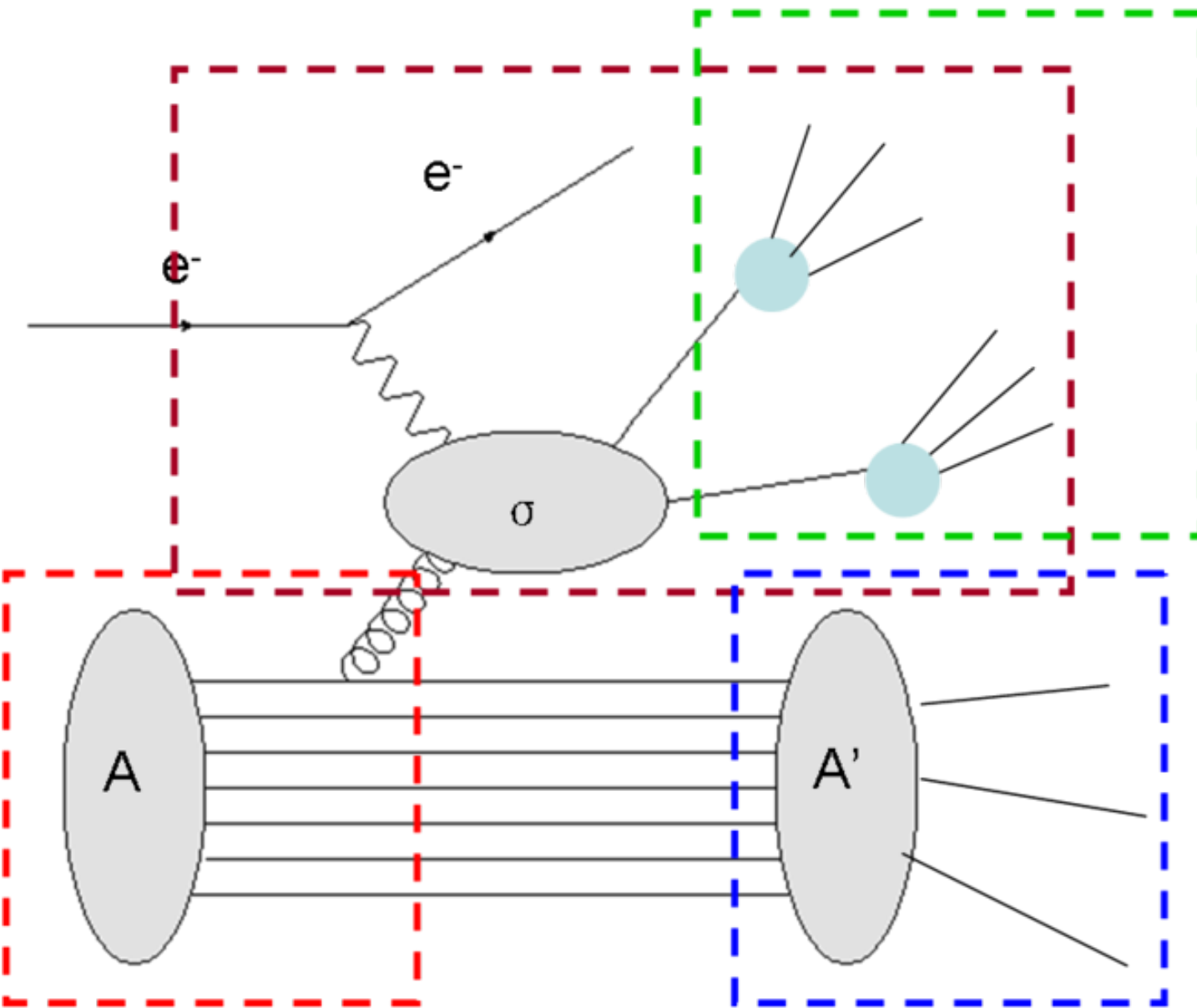
Tagged SRC at EIC

“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 LEptonproduction

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



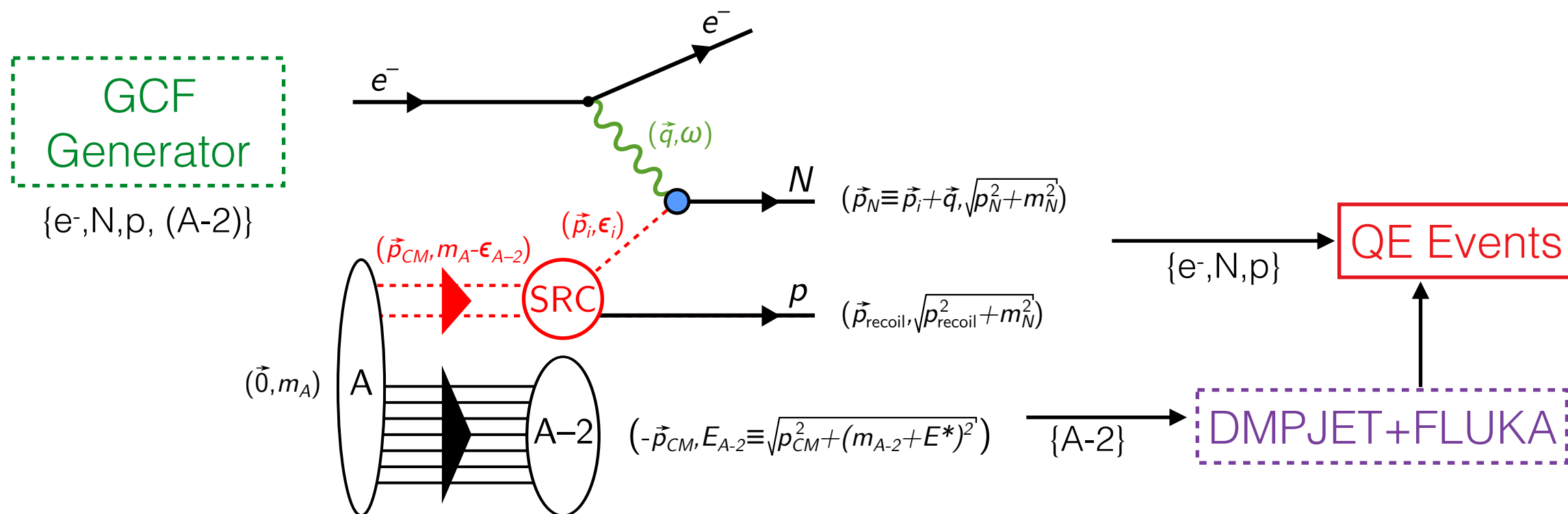
Merger of

- 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>

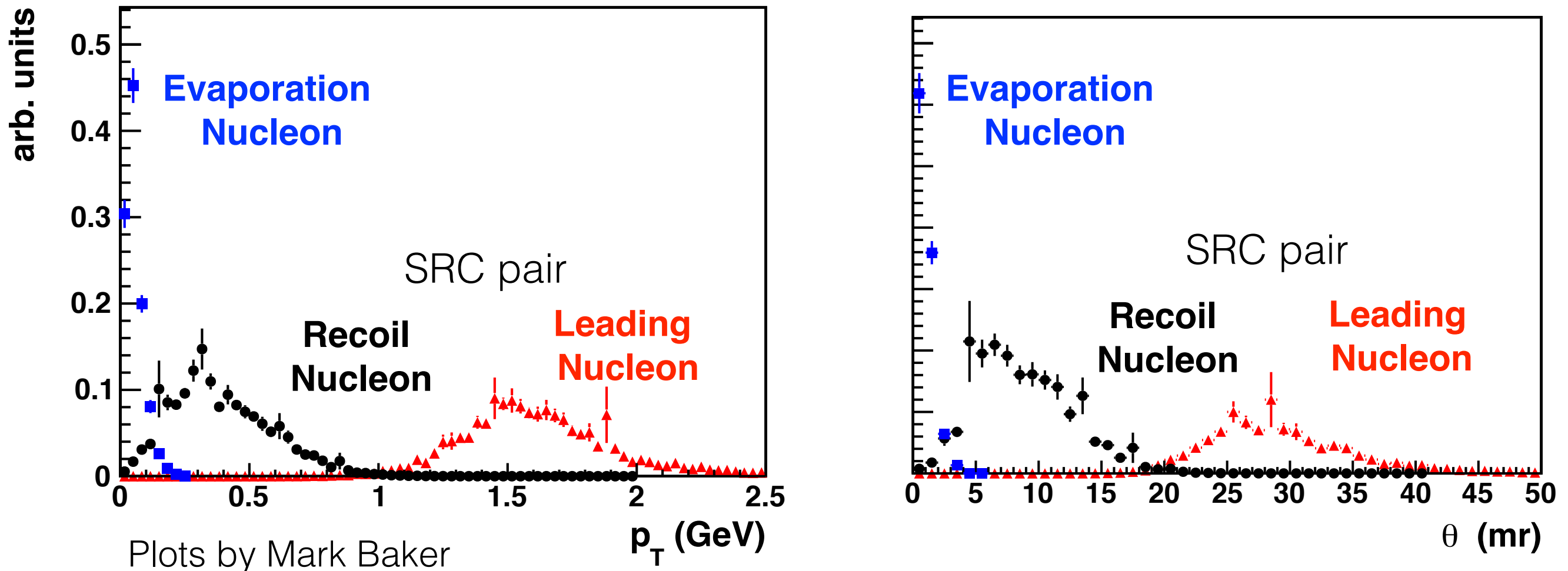
Short Range Correlations and BeAGLE

- Input to BeAGLE:
 - DIS events based on SRC driven EMC model
 - Quasi-Elastic SRC events from Generalized Contact Formalism (GCF) generator (see Rey Cruz-Torres talk)
- (A-2)-system handled by DPMJET3+FLUKA
- LDRD Project: Focus on e+C and e+Pb simulations



QE Simulation Results

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



- 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

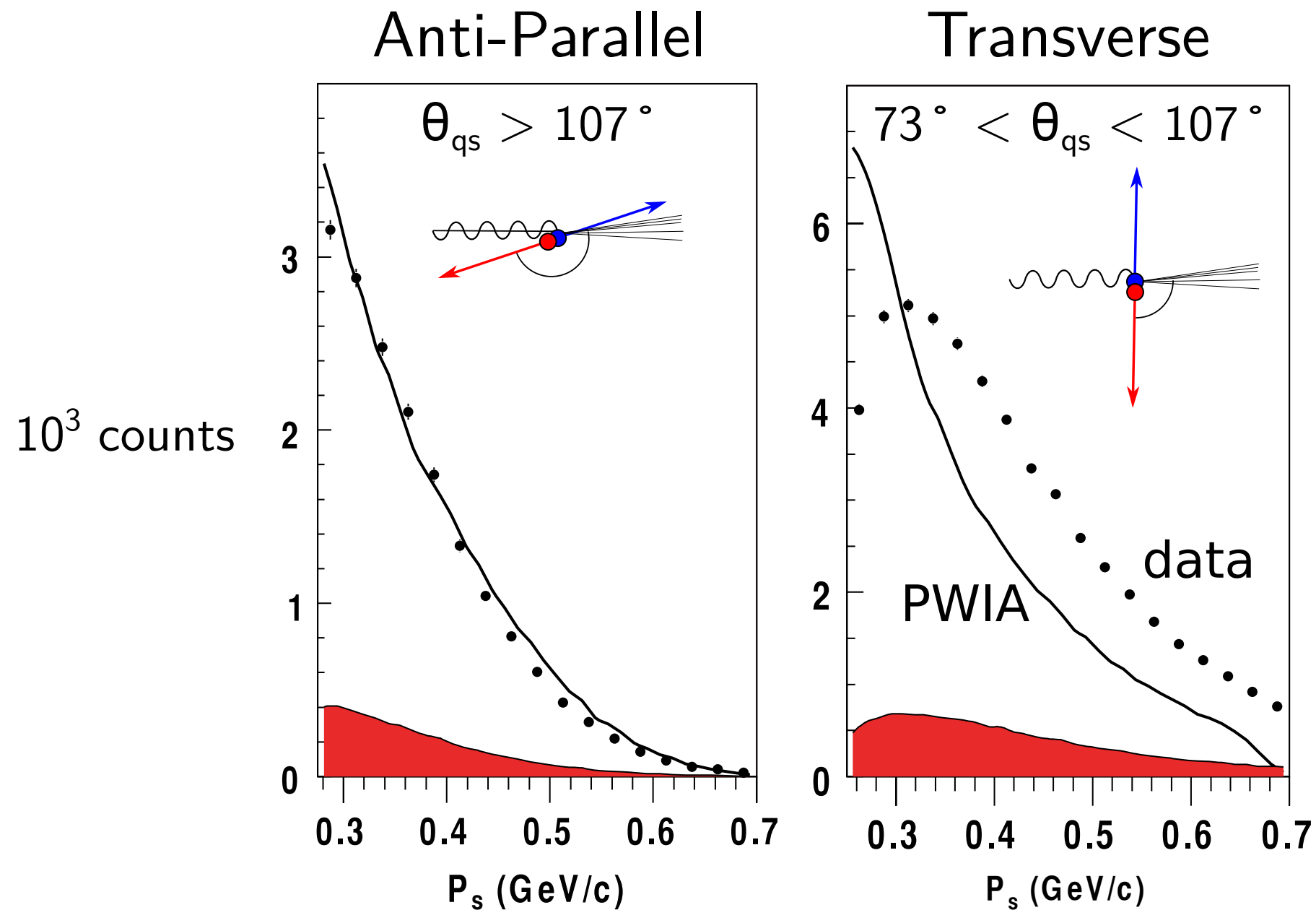
Near term:

- Analysis of CLAS12/BAND data
- Continuation of EIC-LDRD project
 - Simulation of DIS event from SRC-EMC model
 - Effects of FSI and intranuclear cascading
 - Resolution requirements

Back up slides

FSI in Tagged DIS

DEEPS showed little FSI at back angles.



Klimenko et al., PRC 73 035212 (2006)

What will be measured

- Measuring cross section ratios to minimize uncertainties
- Choose kinematics with minimal FSI $\theta_{rq} > 107^\circ$

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

measurement
theory

- $x' = x$ for moving nucleon = $Q^2/(2p \cdot q)$
- $x'_{\text{high}} > 0.45$
- no EMC effect at $0.25 \leq x'_{\text{low}} \leq 0.35$

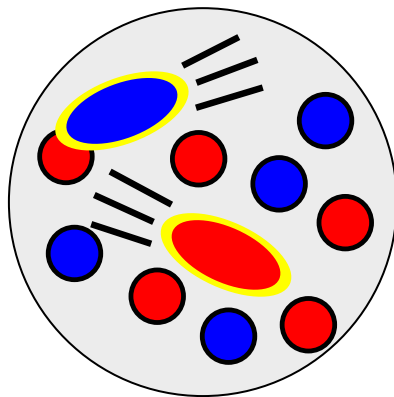
Theories

Binding

Free

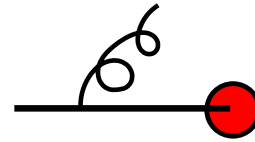


Bound

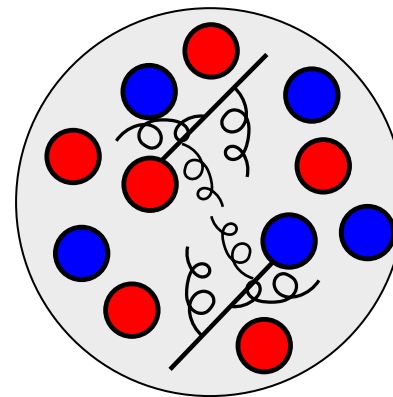


Rescaling

Free

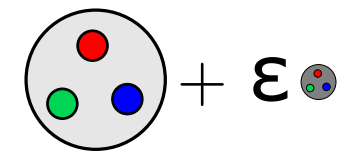


Bound

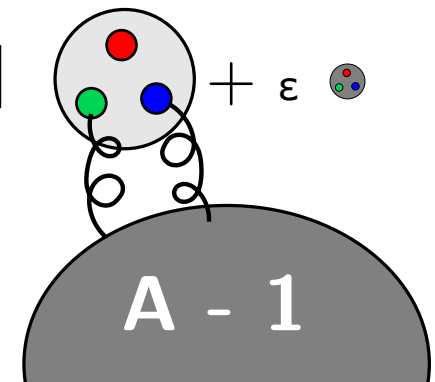


Point-like Configuration
Suppression

Free

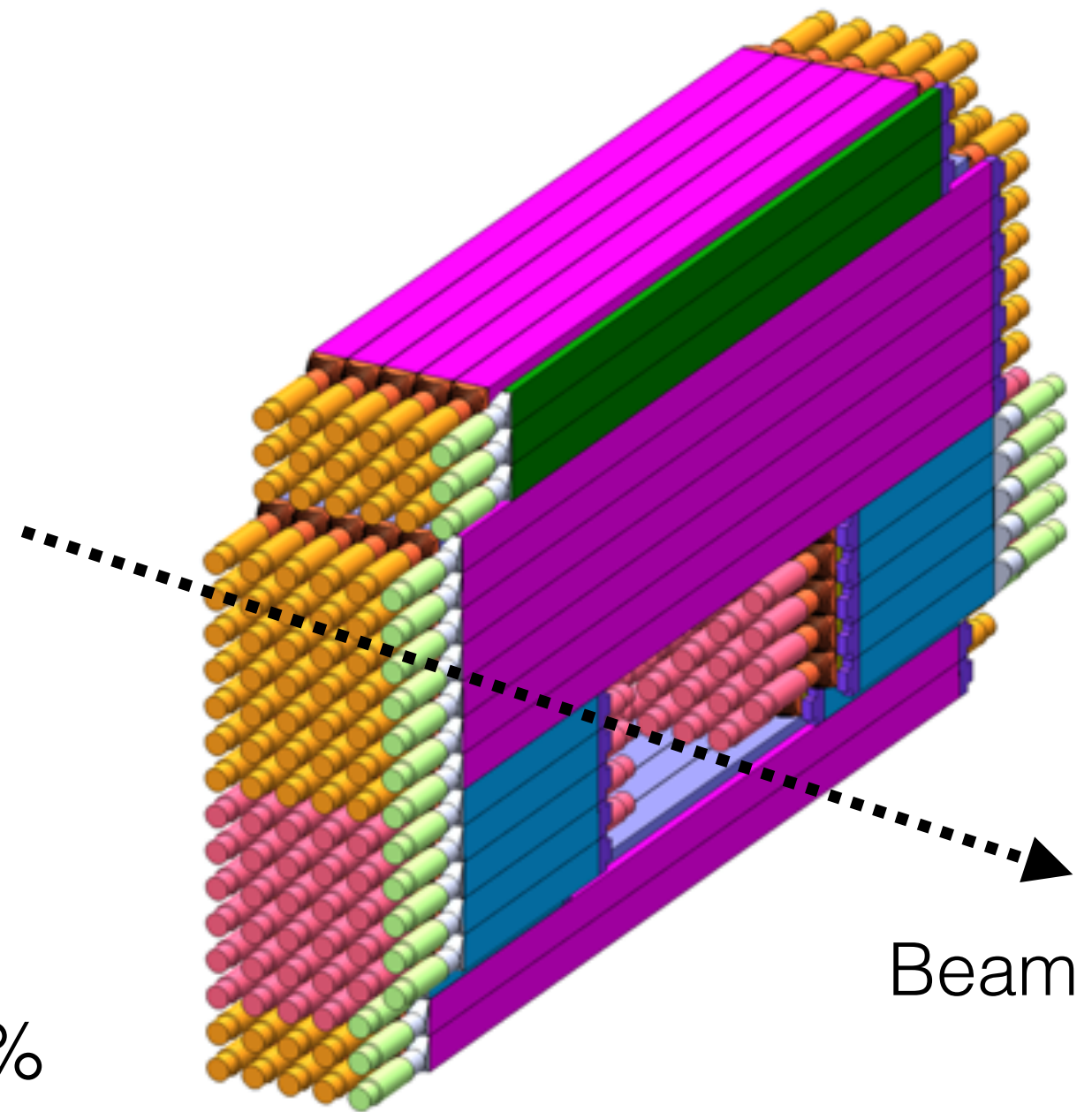


Bound



Overview of BAND

- 5 layers thick (36cm total) with veto layer (1cm thick)
- 140 scintillator bars
- Bar resolutions < 200 ps
- 3 meters upstream of target, coverage in $\theta \sim 155\text{-}176^\circ$
- Design neutron efficiency $\sim 35\%$ and momentum resolution $\sim 1.5\%$
- Laser system for calibrations

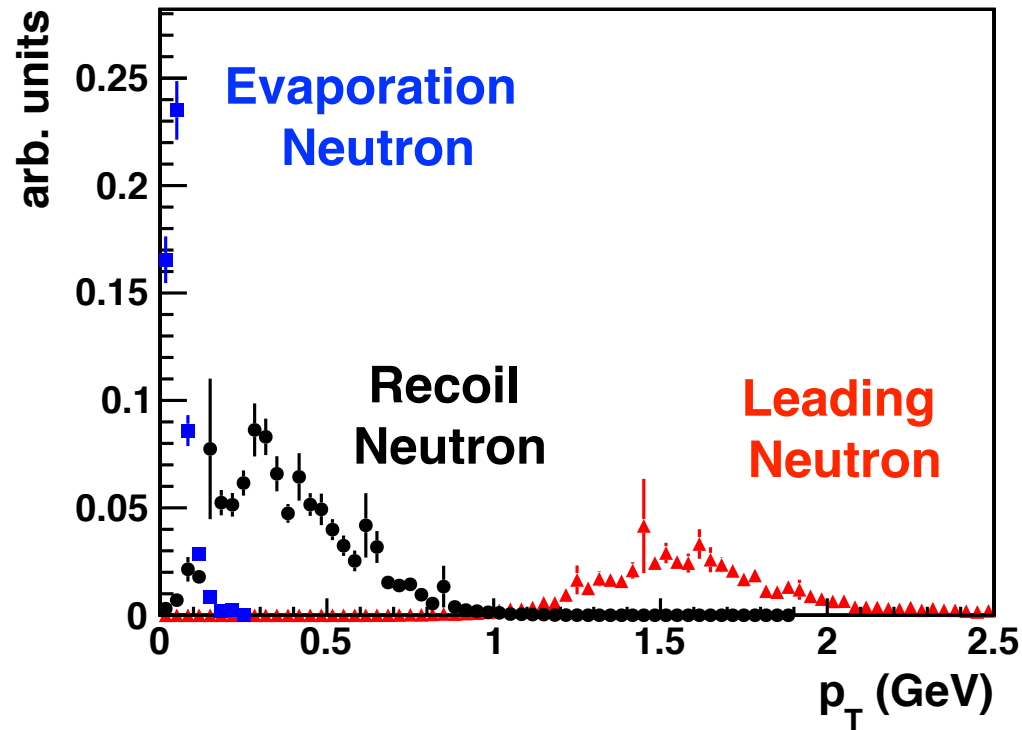


BAND Experimental Conditions

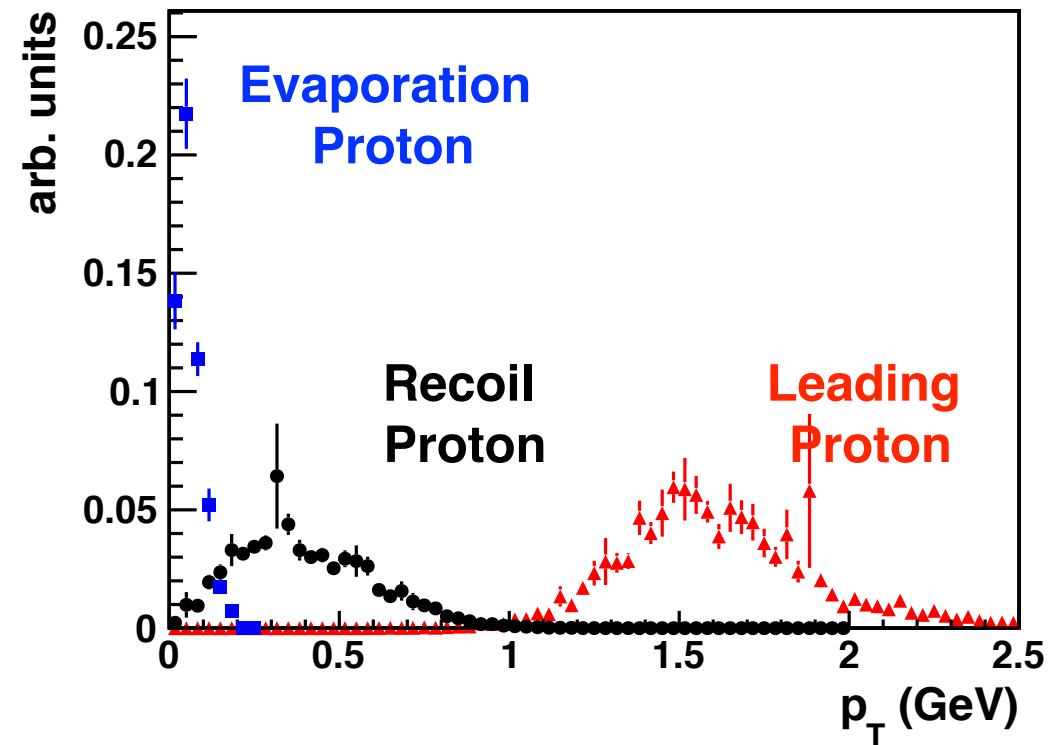
- Data taking during Run Group B of CLAS12
- Approved for 180 days (90 PAC days)
- ~50% of approved beam time in spring and fall 2019
- 11 GeV electron beam
- 10^{35} cm⁻²s⁻¹ luminosity
- Scattered e' in CLAS12

QE Simulation Results

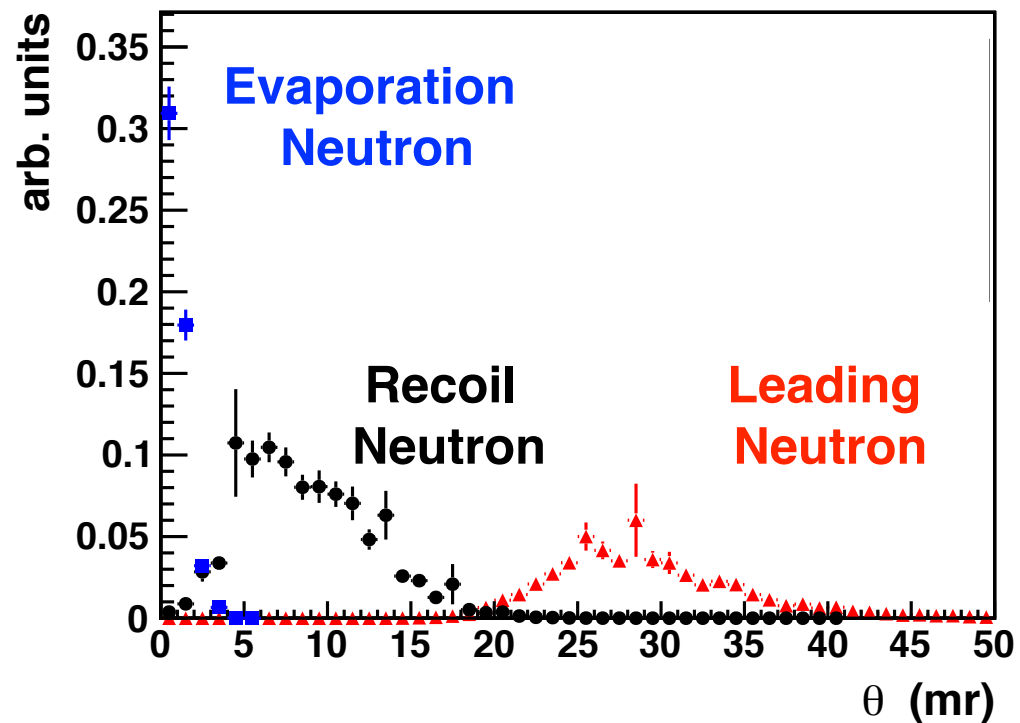
Neutrons from e+C JLEIC 5x50 $Q^2 > 3 \text{ GeV}^2$ $x > 1.2$



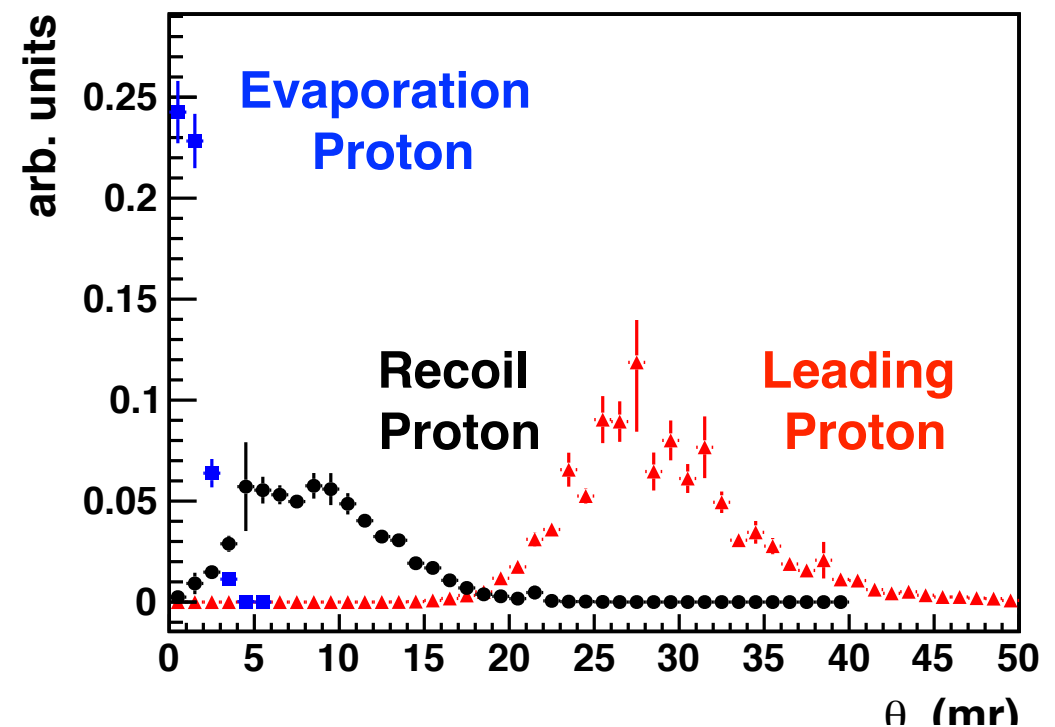
Protons from e+C JLEIC 5x50 $Q^2 > 3 \text{ GeV}^2$ $x > 1.2$



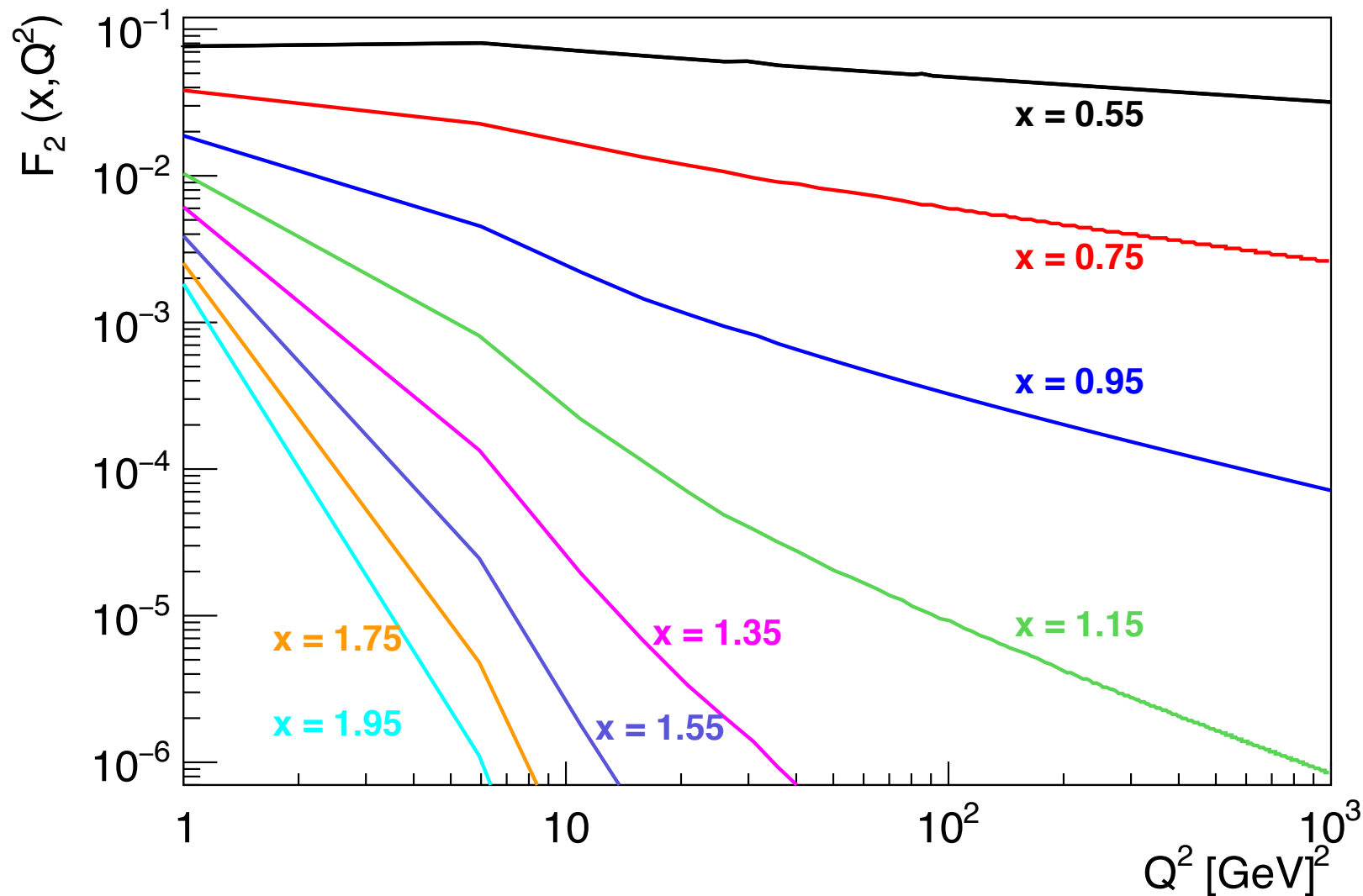
Neutrons from e+C JLEIC 5x50 $Q^2 > 3 \text{ GeV}^2$ $x > 1.2$



Protons from e+C JLEIC 5x50 $Q^2 > 3 \text{ GeV}^2$ $x > 1.2$



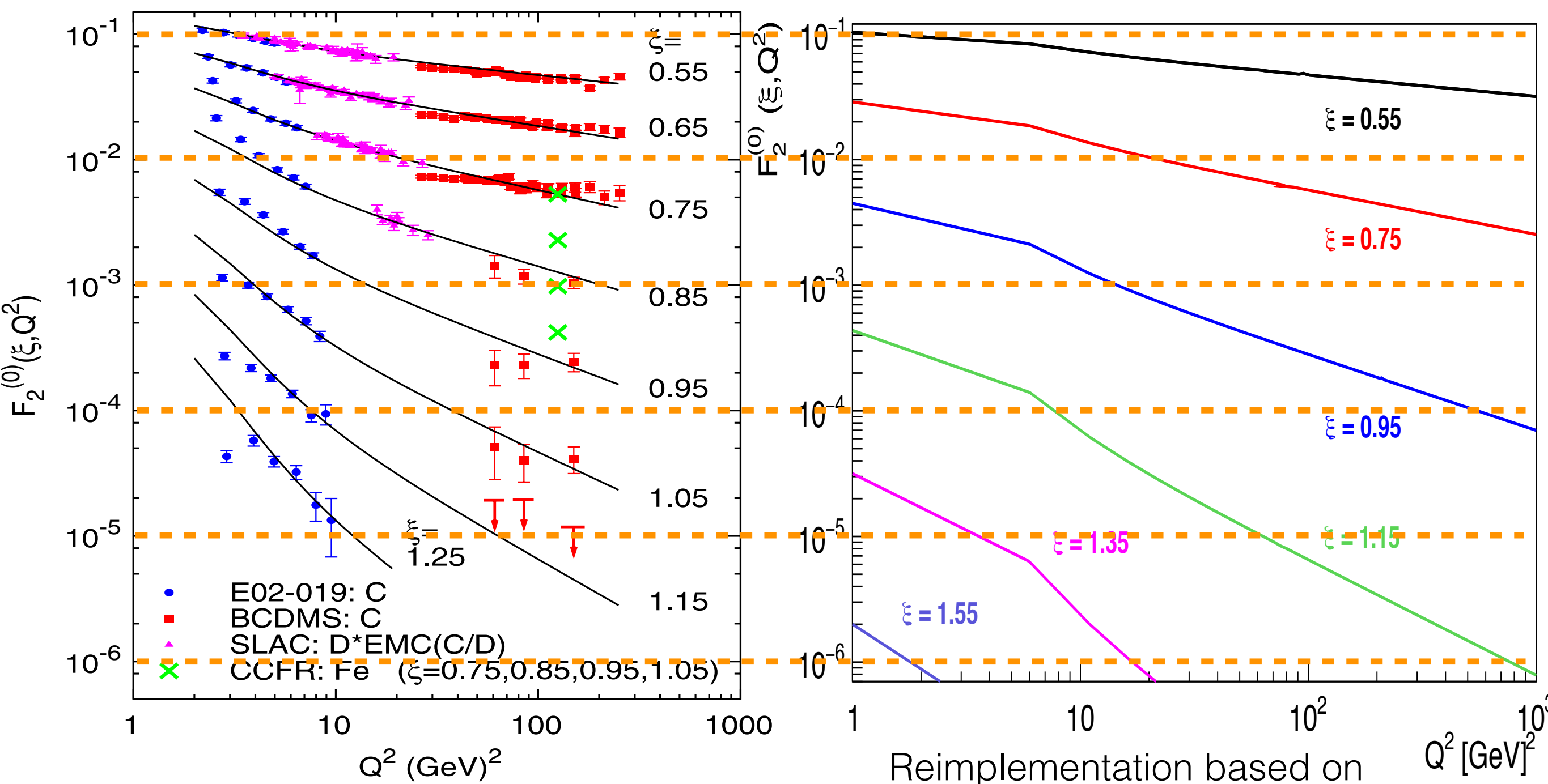
Rate Estimates from F_2 Parametrization



- Measuring EMC effect at high Q^2 easy \rightarrow 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)

F₂ from N. Fomin Paper and Reimplementation



N. Fomin PRL 105, 212502 (2010)

Reimplementation based on N. Fomin scripts