Measurements of low energy recoils with ALERT and CLAS12

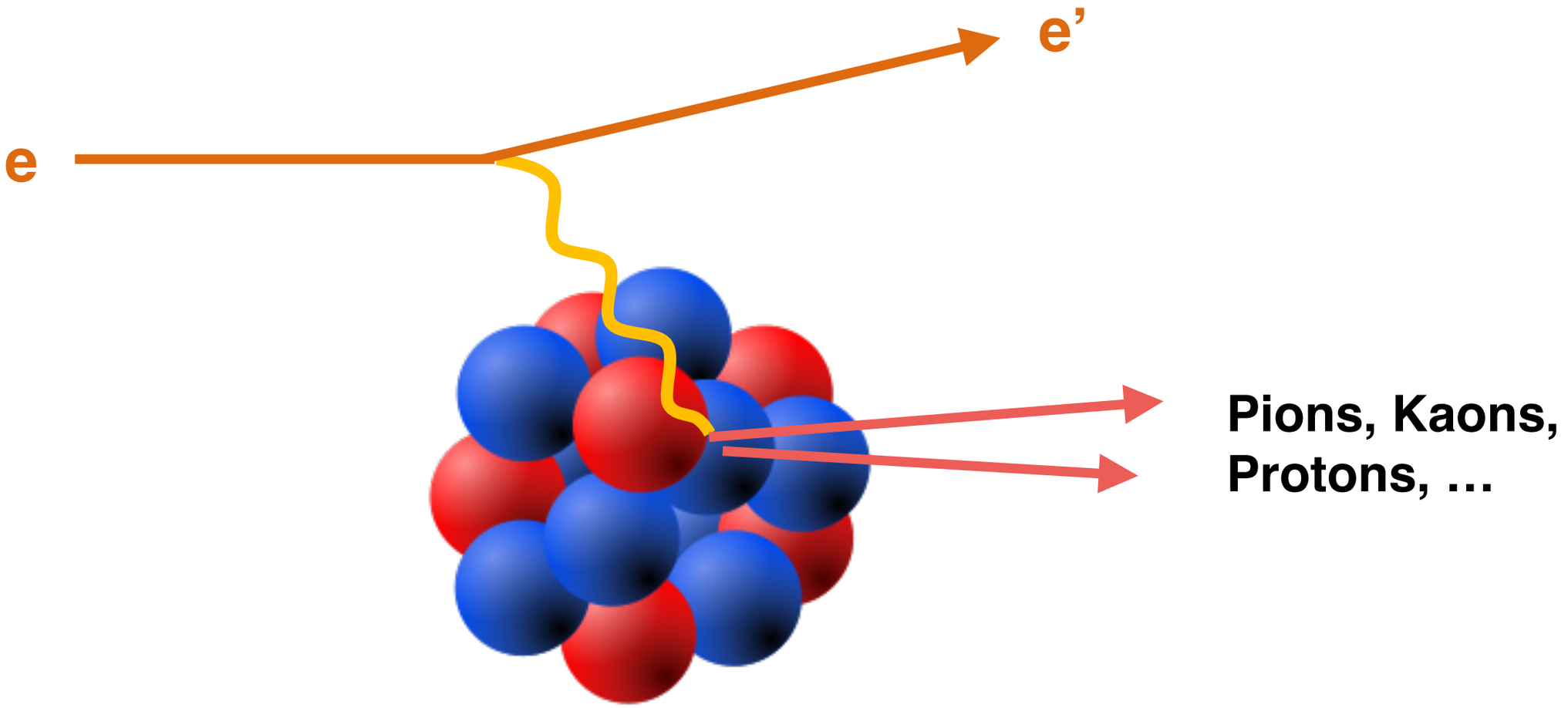
Florian Hauenstein

Photonuclear Reactions Workshop

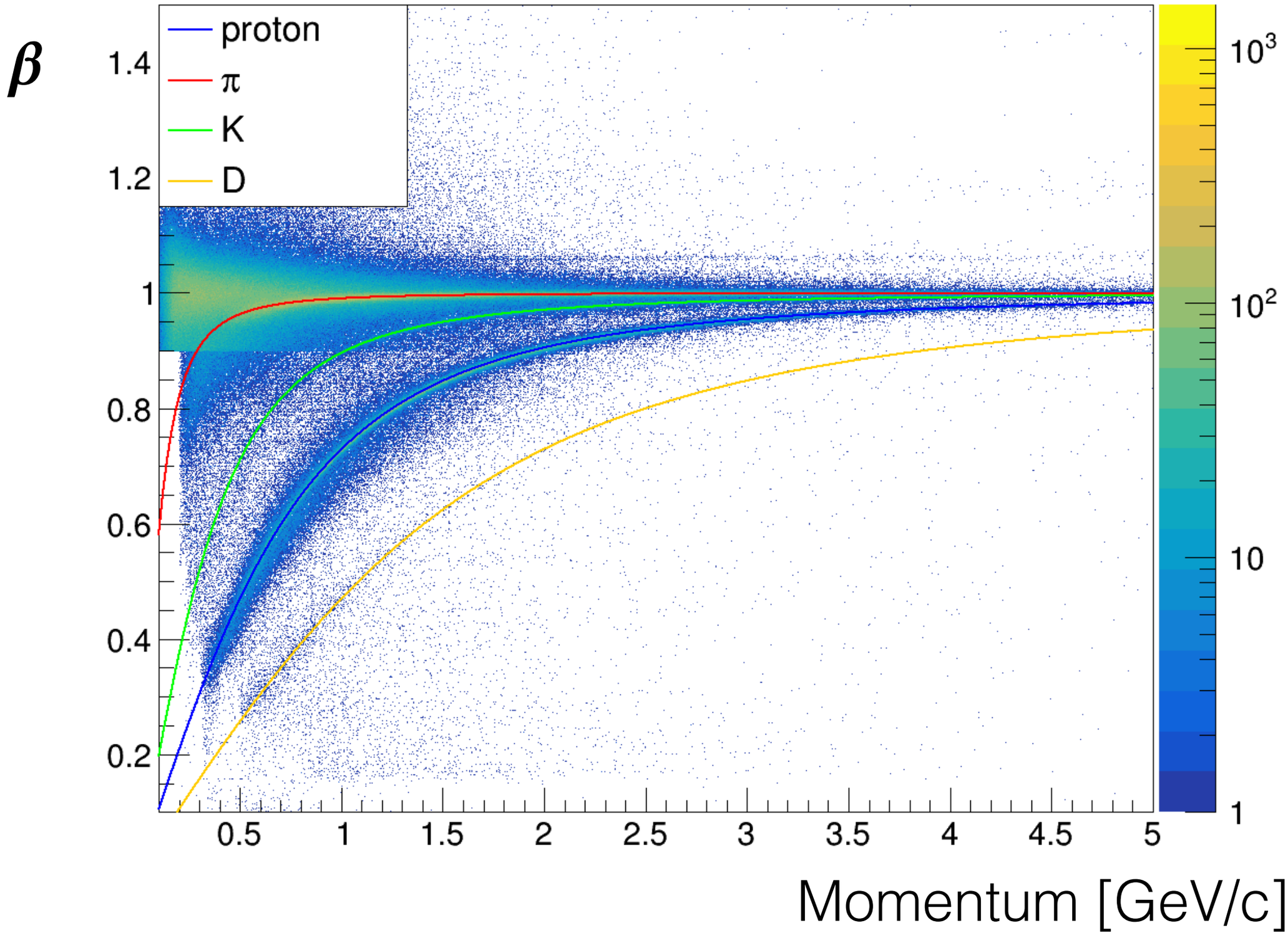
08/08/24

Jefferson Lab

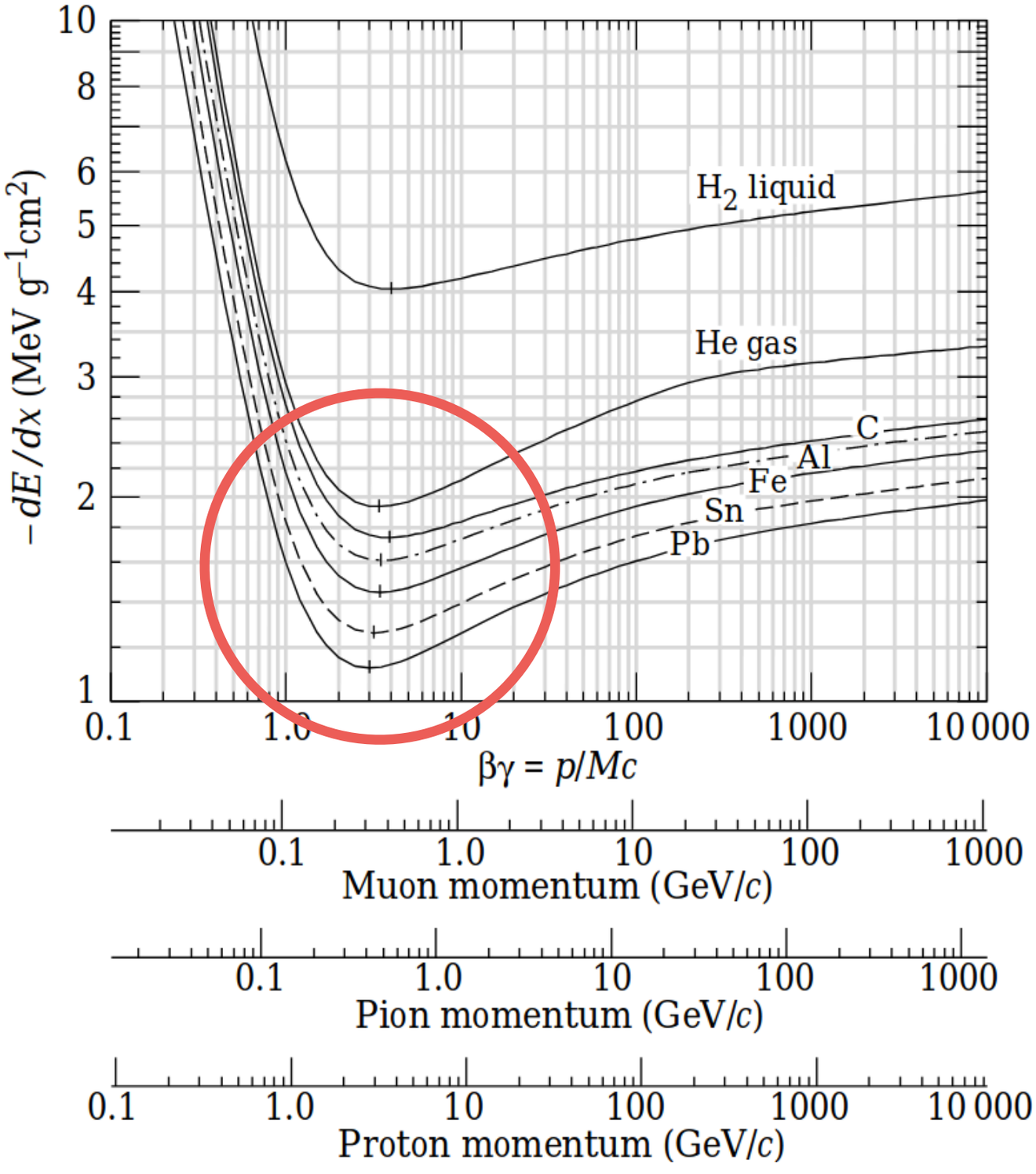
Usual Electron Scattering on Nuclei (at Jlab)



Charge Particles in a Detector (CLAS12)

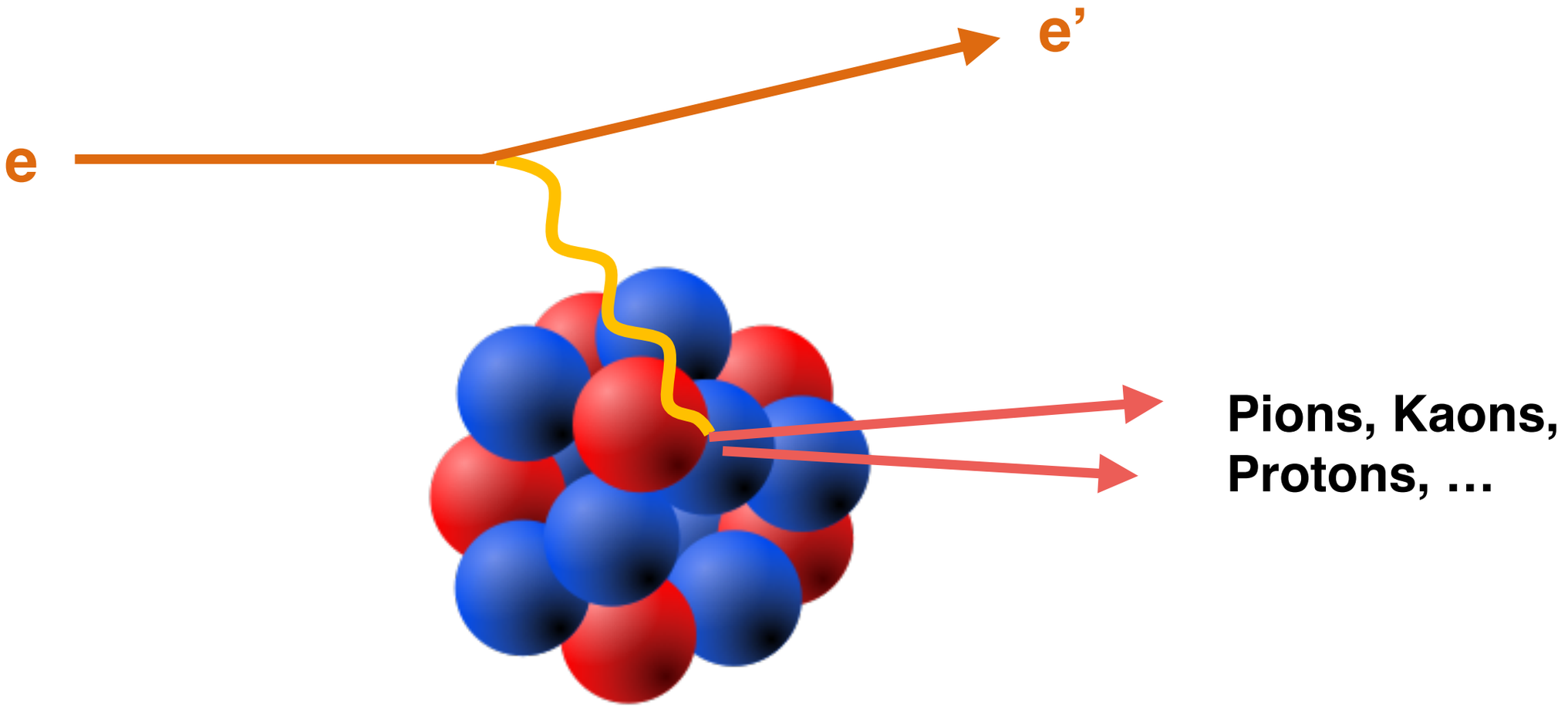


Usually Minimum Ionizing Particles



Source: PDG

Usual Electron Scattering on Nuclei (at Jlab)



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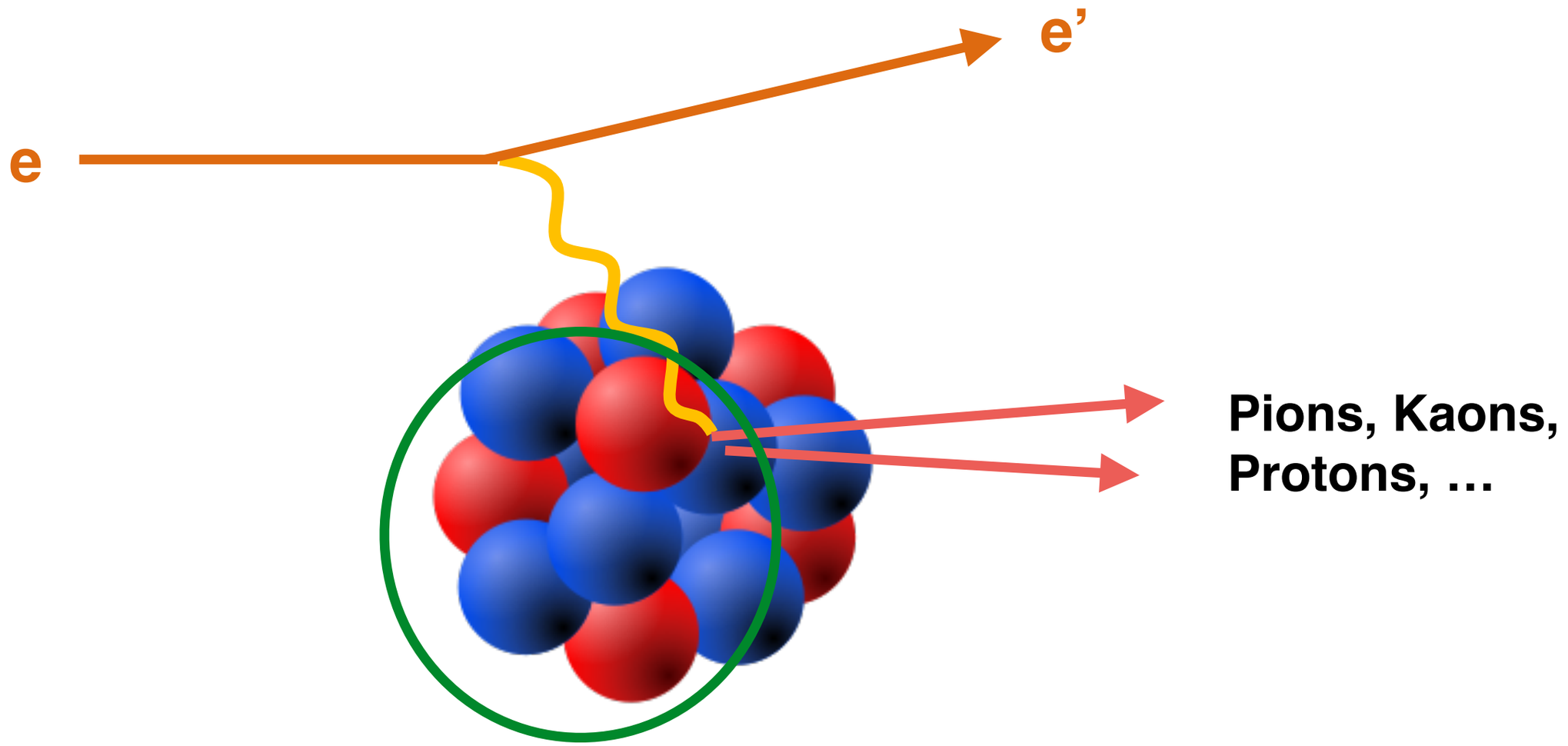

- Detecting remaining nucleus gives (depending on reaction)
  - information about initially struck nucleon
  - selection of specific initial states
  - fully exclusive reactions
  - understanding and suppression of nuclear effects

Let’s look at the Simplest Nucleus - Deuteron

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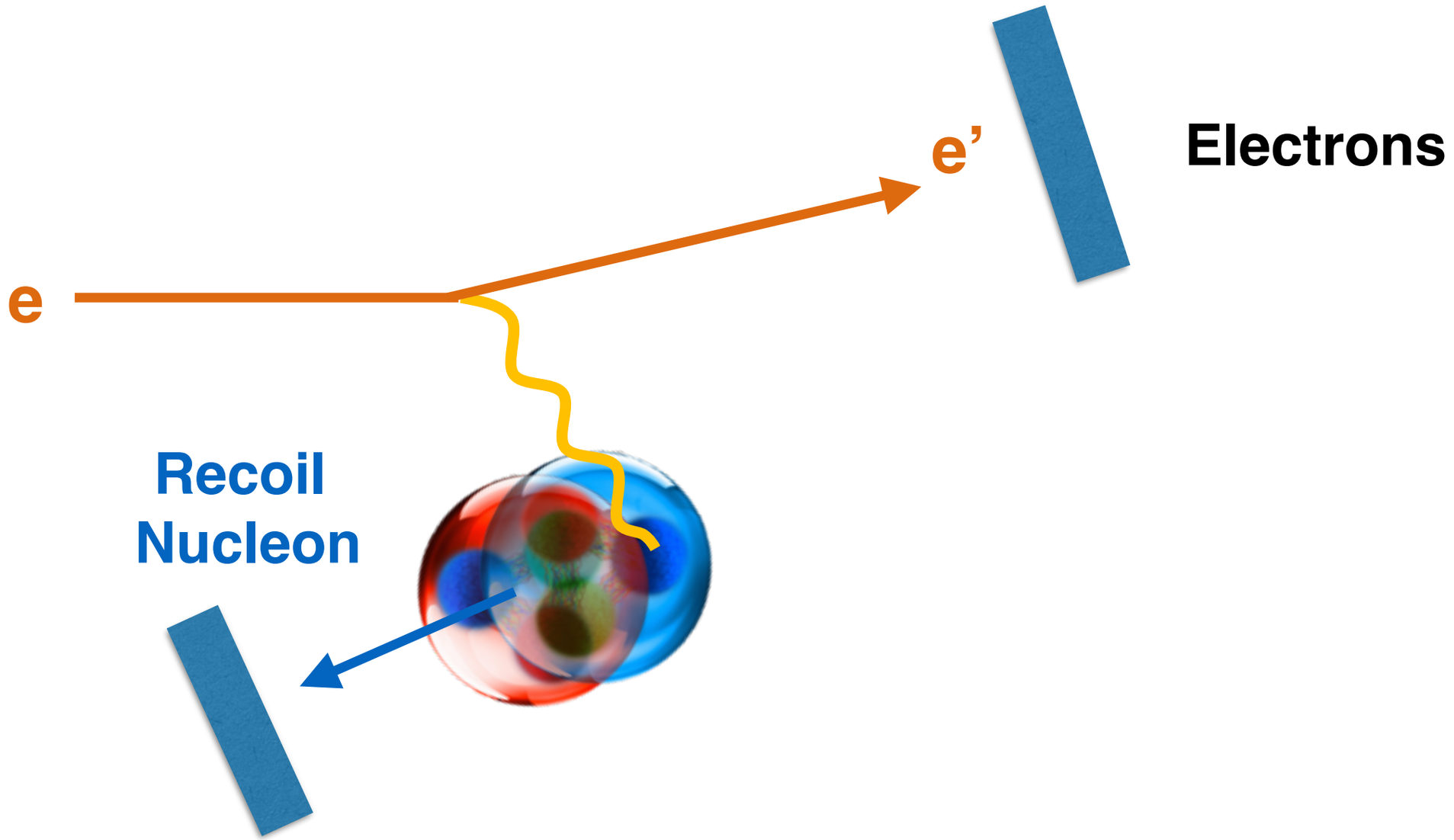

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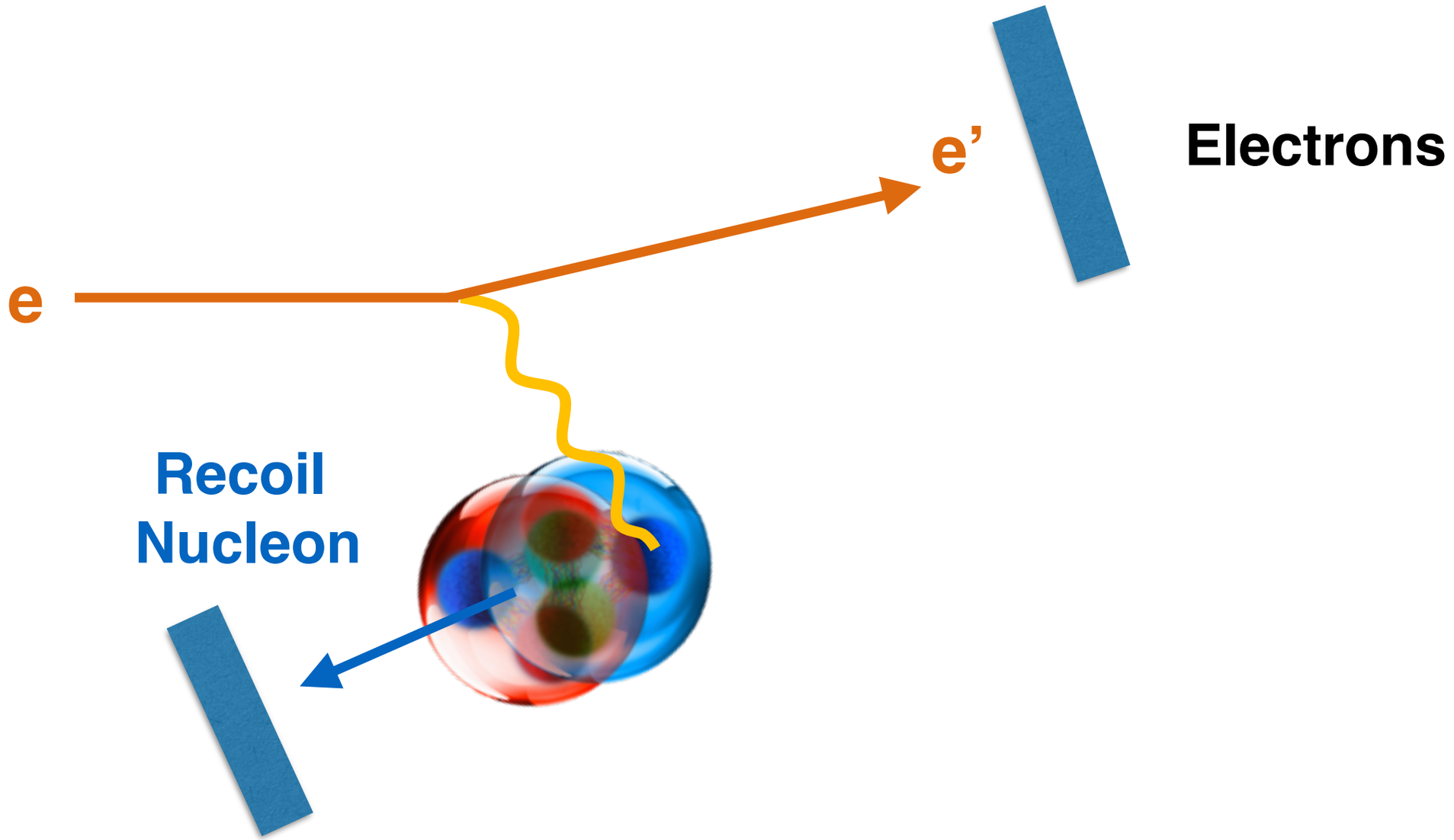
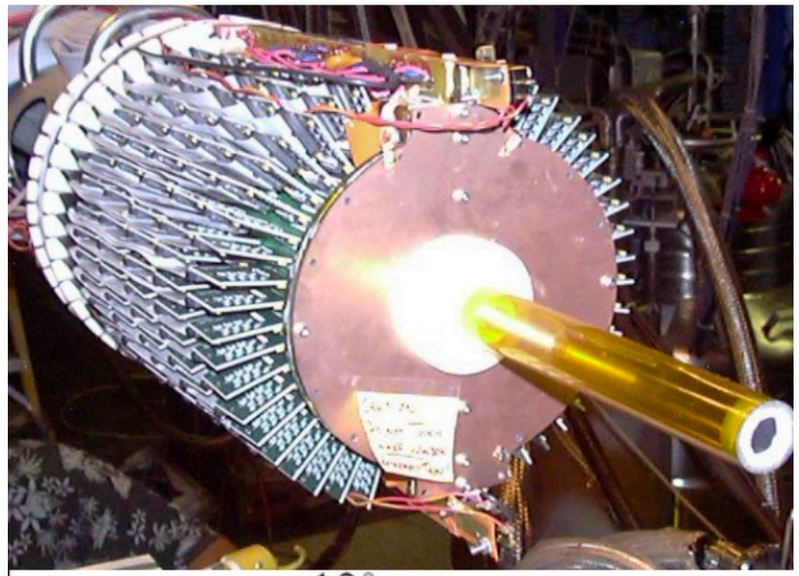


- Tag interaction by recoil
- Most importantly: **Free Neutron Target!**

BONUS Experiment at Jefferson Lab

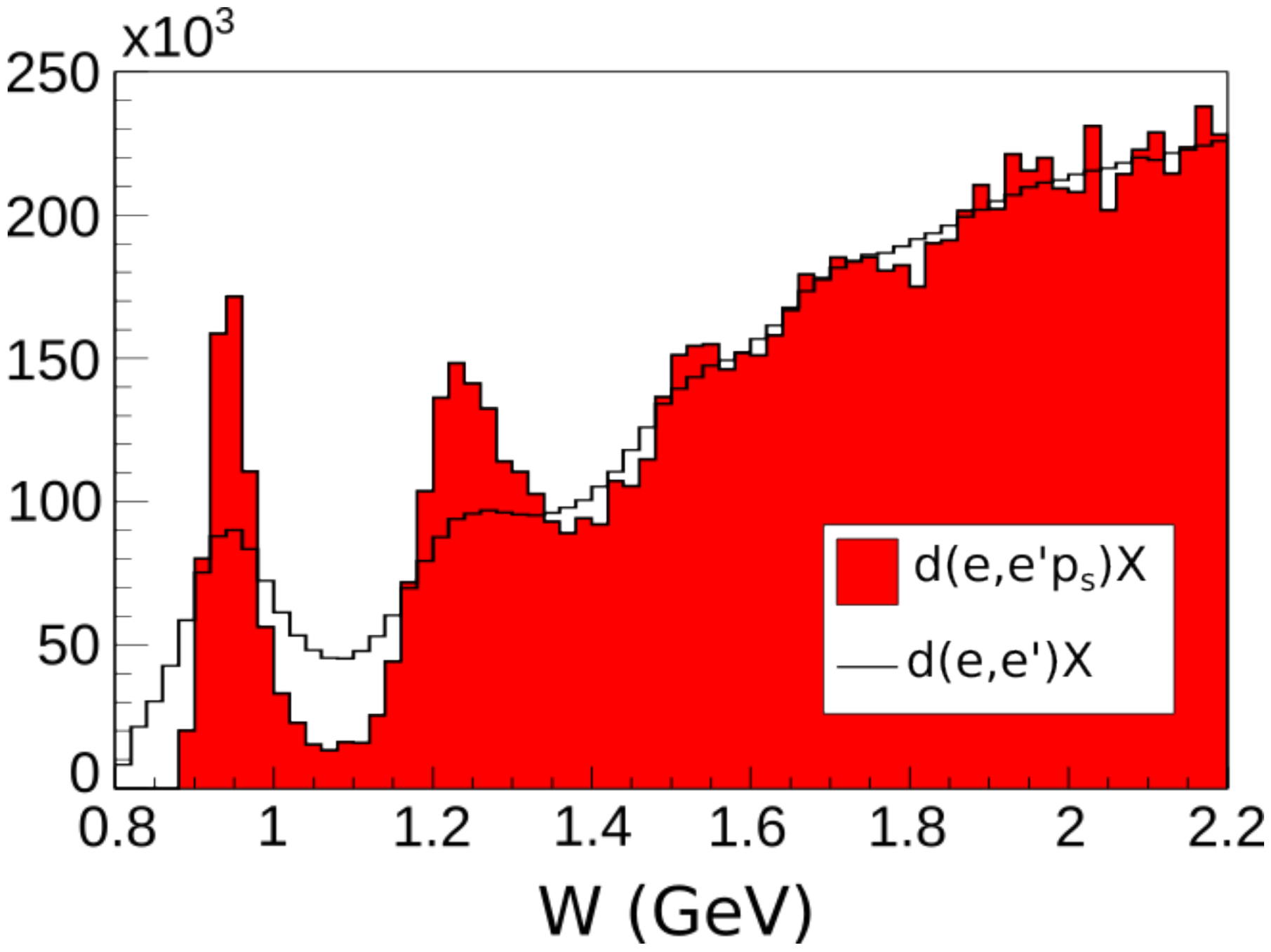
- BONUS detector
  - small radial time projection chamber
  - minimal material in the detector
  - as low as 60 MeV/c protons
- Rest - CLAS spectrometer

- Goal: Study free neutron structure function



H. Fenker *et al.* NIM **A592**, 273 (2008)

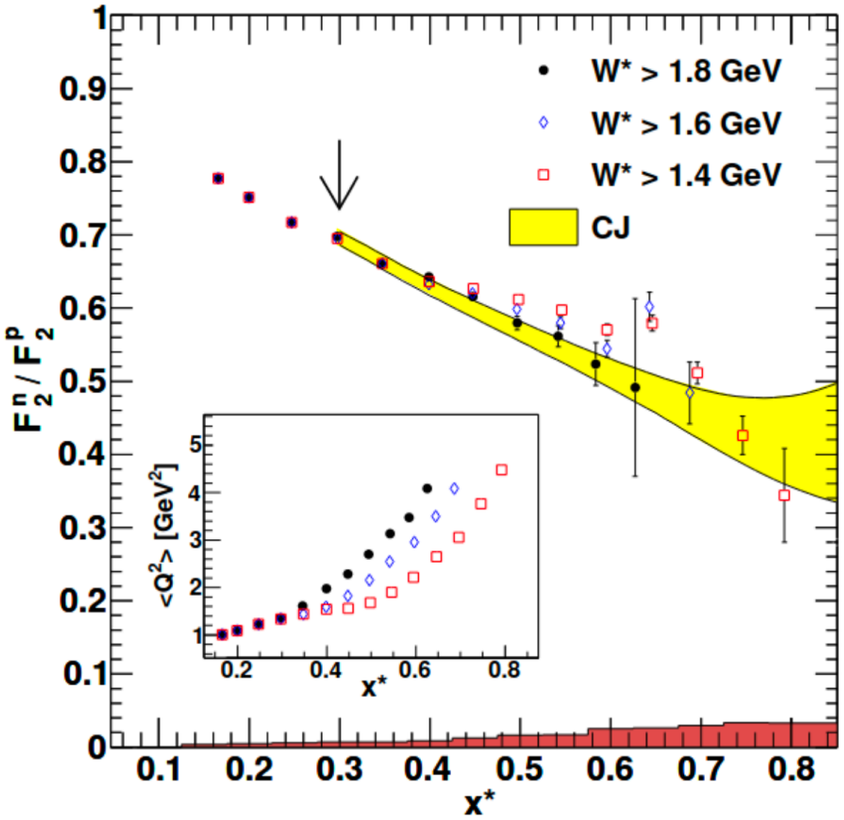
Tagging Worked - Improve of Kinematics



N. Baillie *et al.* (The CLAS Collaboration), Phys. Rev. Lett. **108**, 142001 (2012)

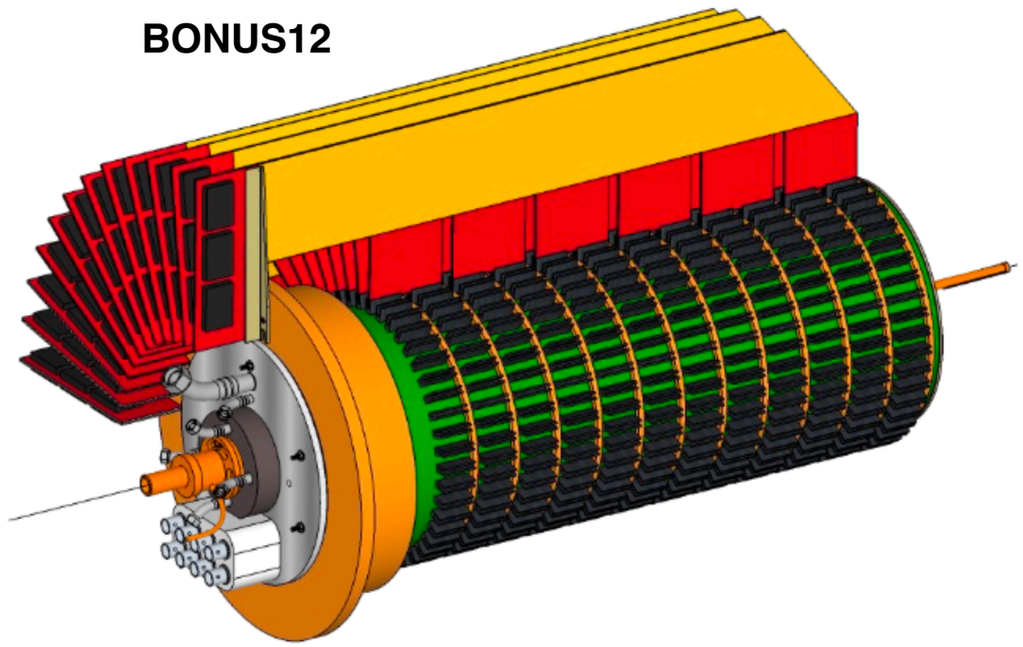
From BONUS to BONUS12

N. Baillie *et al.,* Phys. Rev. Lett. **108**, 142001



- BONUS: Measurement of neutron F_2
  - Free of nuclear effects
  - Unique data for fits of parton distribution functions

- BONUS12 experiment
  - Improved detector
    - less material inside
    - faster electronics
  - Higher electron beam energy
  - Analysis in progress



I. Albayrak *et al.,* NIM **A1062**, 169190 (2024)

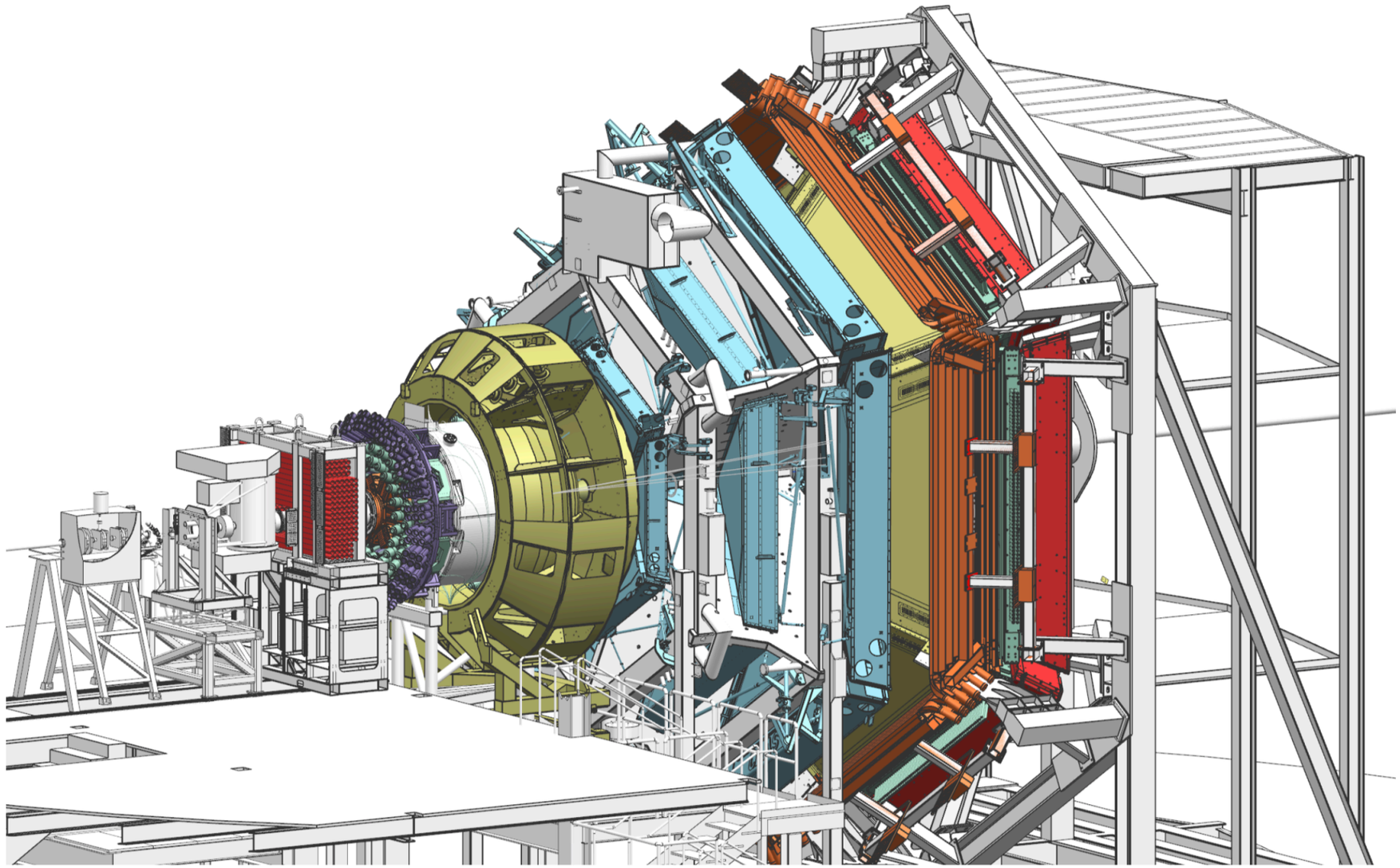
Can We also Detect Recoil Nuclei?

Can We also Detect Recoil Nuclei?

- Yes!

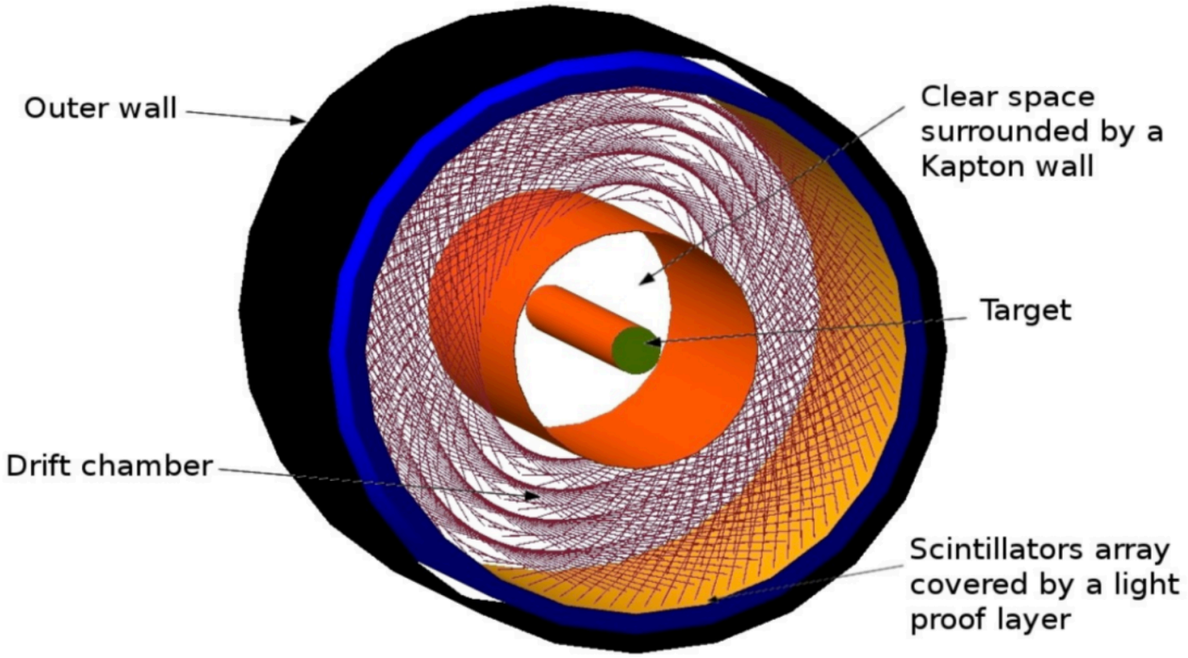
- But
  - light nuclei to have enough momentum
  - detector close to target with thin walls
  - “material-free” detectors

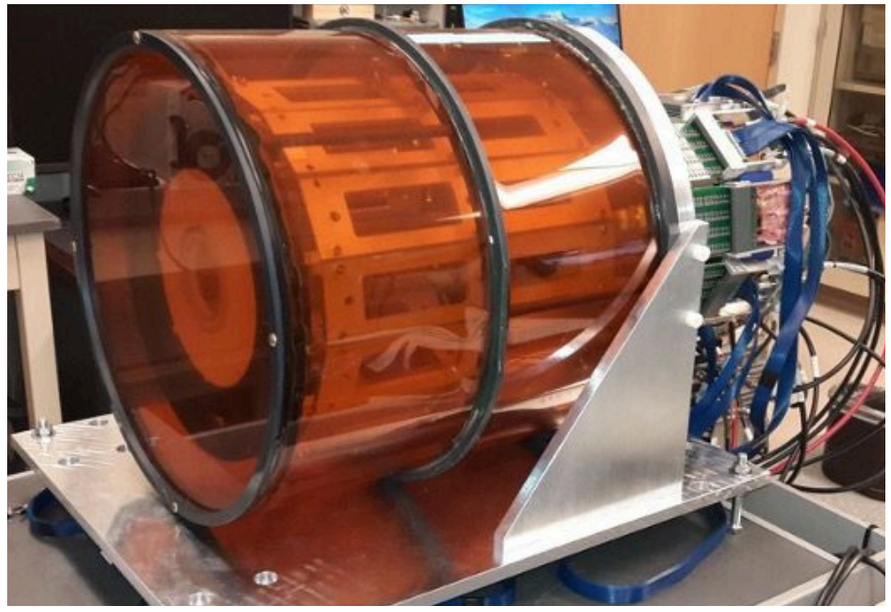
CLAS12 at Jefferson Lab HallB



- Spectrometer with solenoid and torus fields
- ~4π acceptance
- Neutral and charged particle detection
- No detection of recoils below 200 MeV/c

ALERT: A Low Energy Recoil Tracker



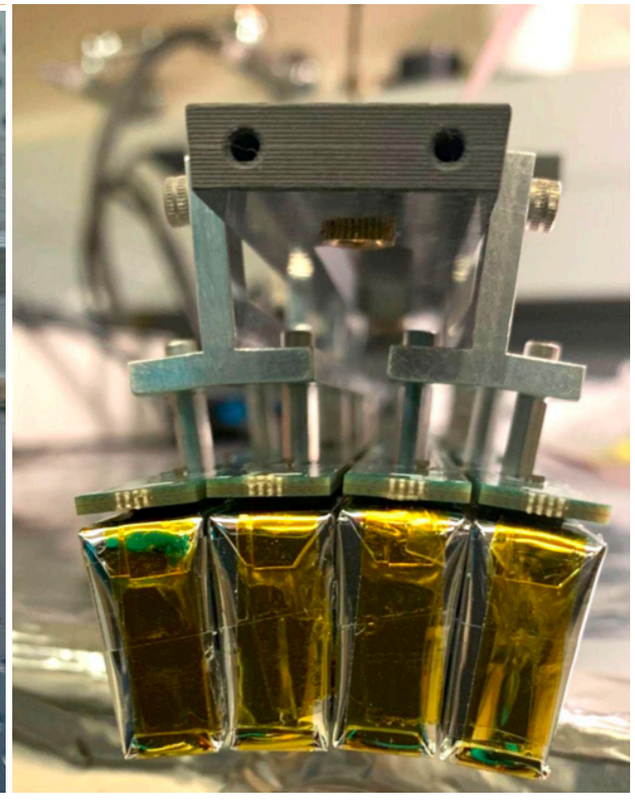


~0.5m

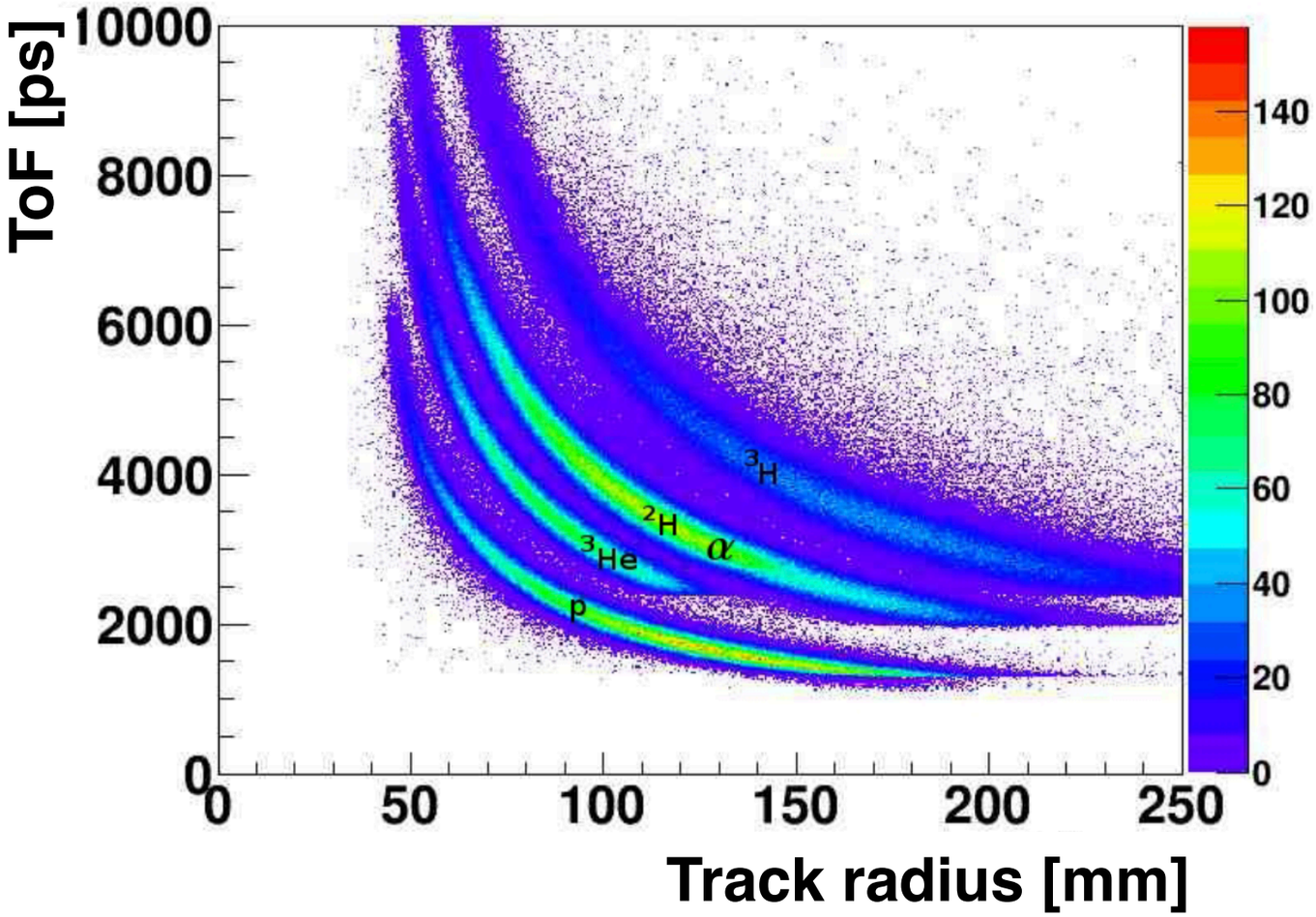
- Hyperbolic drift chamber
- Time-of-flight array
- Large angular acceptance
  - 25-160° polar
  - ~340° azimuthal
- Blind to minimum ionizing particles
- Recoils
  - deuteron: 100 - 300 MeV/c
  - triton:120 - 300 MeV/c
  - He-4

DC

TOF



ALERT PID of Recoil Nuclei



- well separated p, ^{3}He, d/^{4}He and ^{3}H bands

Figures courtesy of W. Armstrong, CLAS collaboration meeting June 2023

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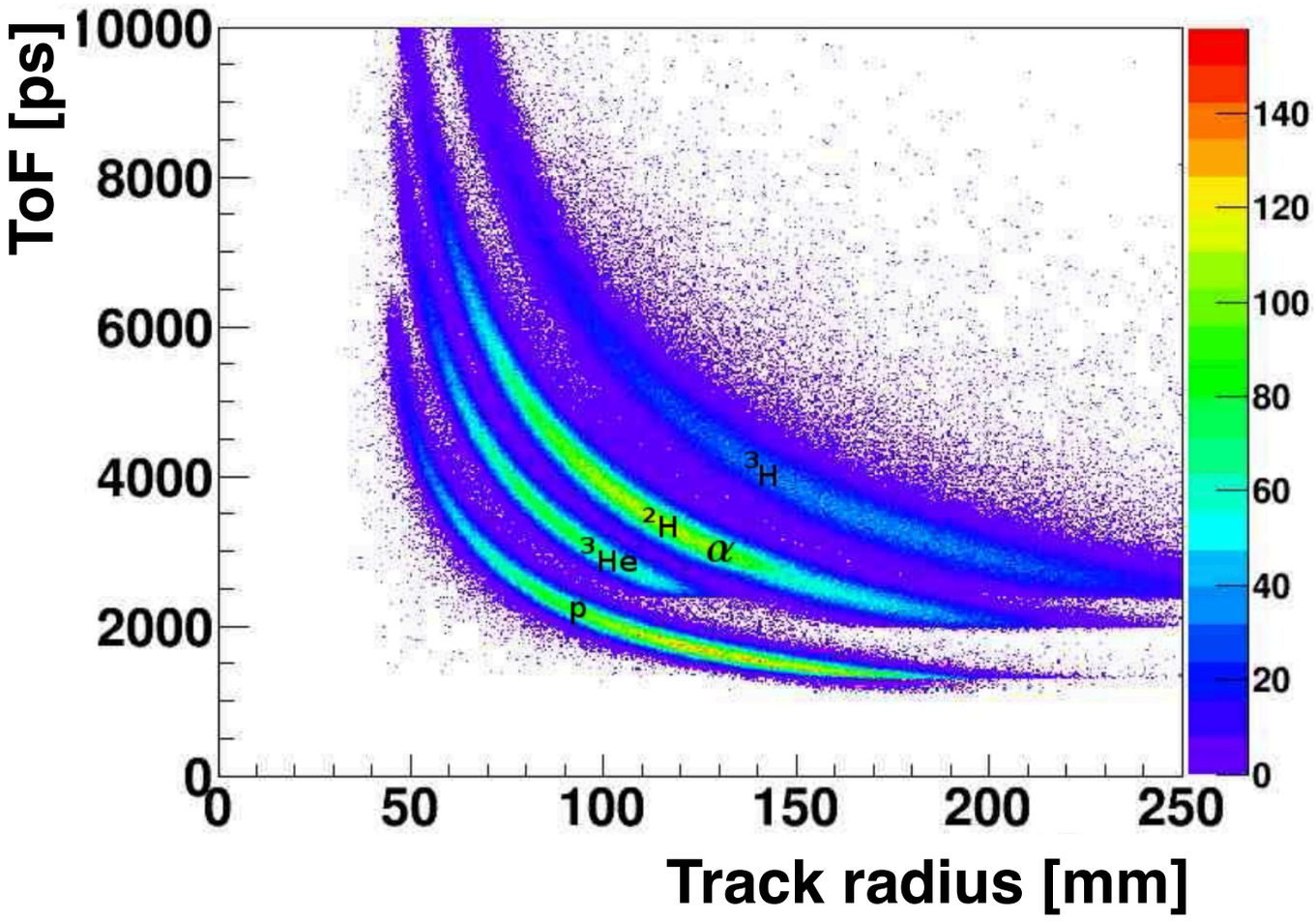
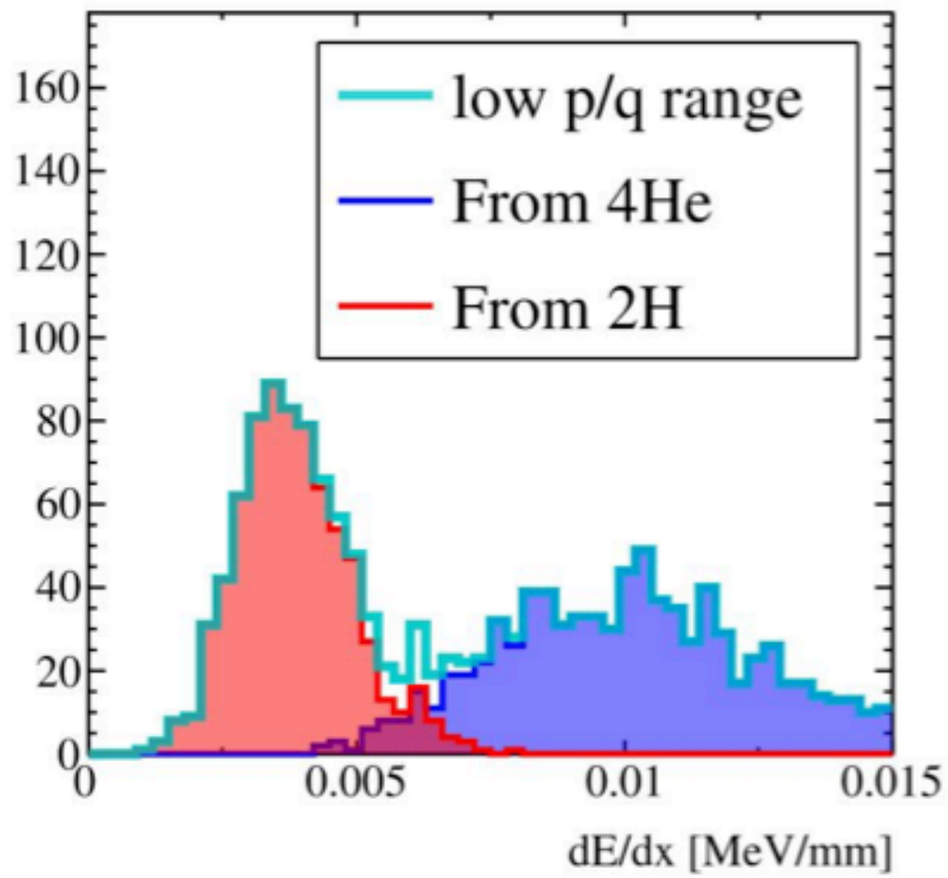


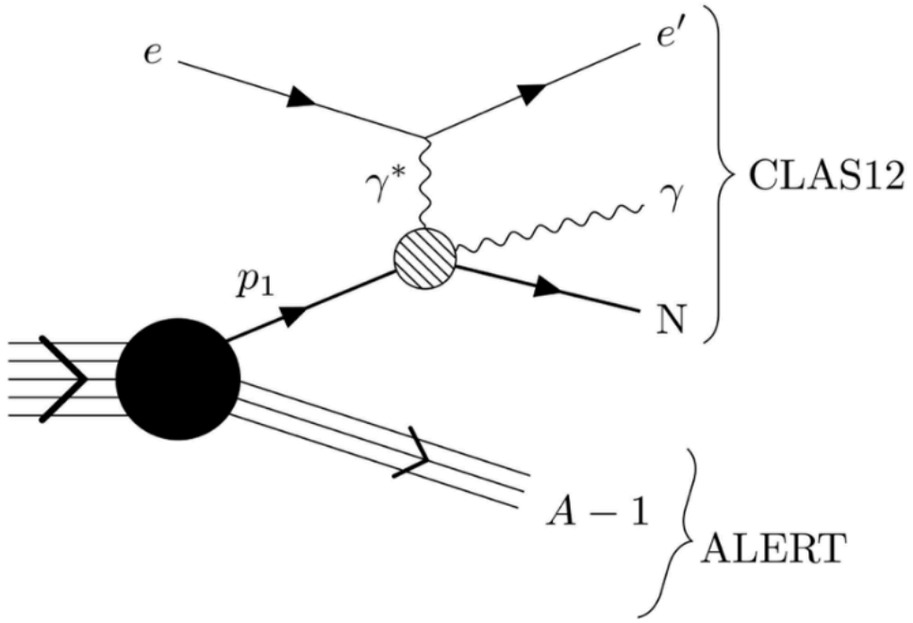


- well separated p, ^{3}He, d/^{4}He and ^{3}H bands
- d and 4He seperation via dE/dx

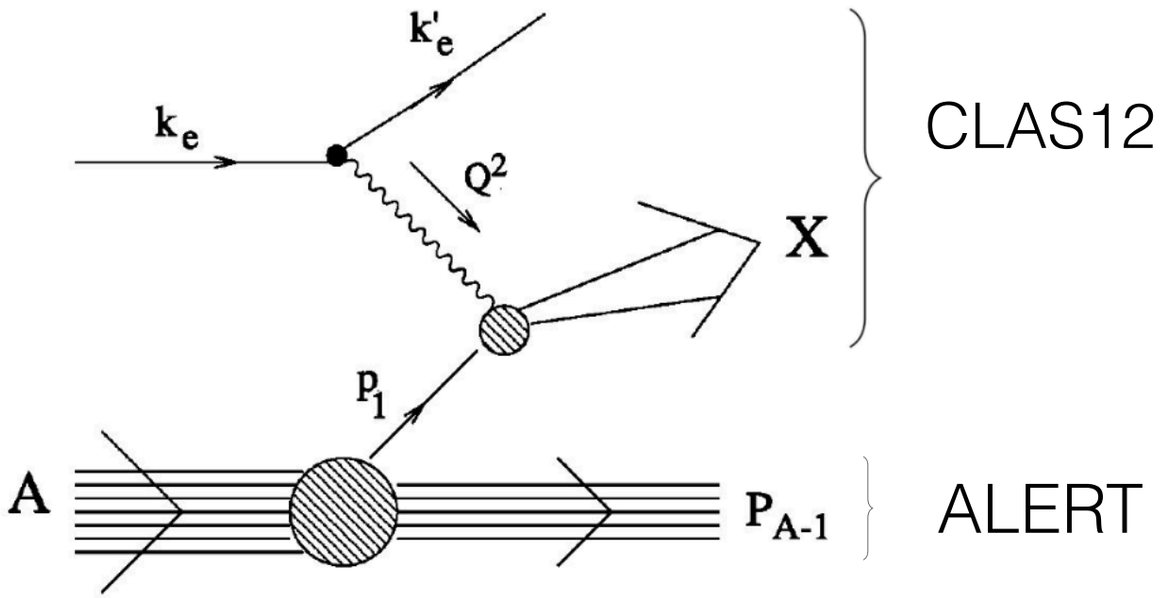
Figures courtesy of W. Armstrong, CLAS collaboration meeting June 2023

Physics with ALERT

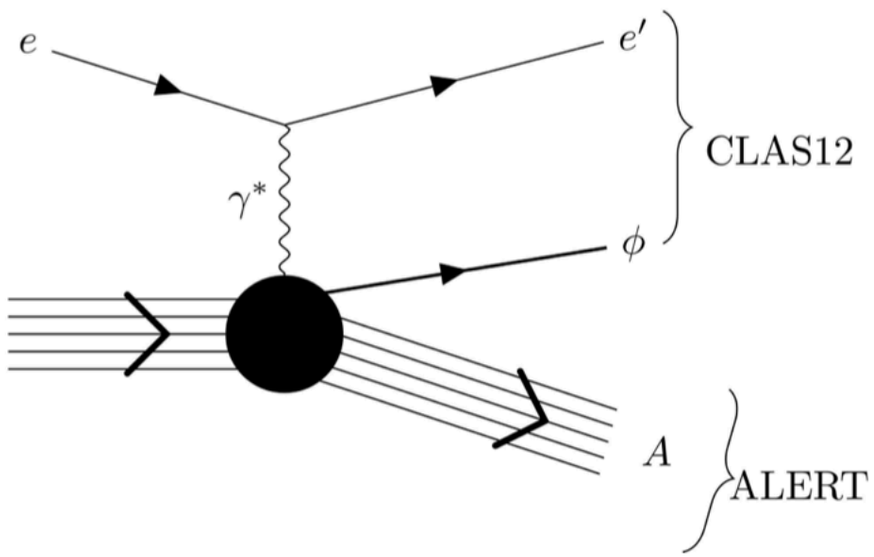
Tagged DVCS



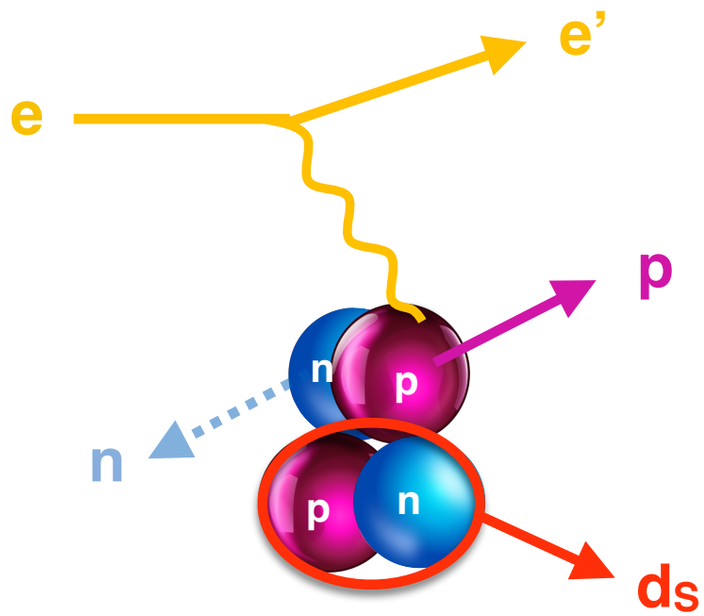
Tagged EMC



Nuclear GPDs



Tagged SRCs



Physics with ALERT

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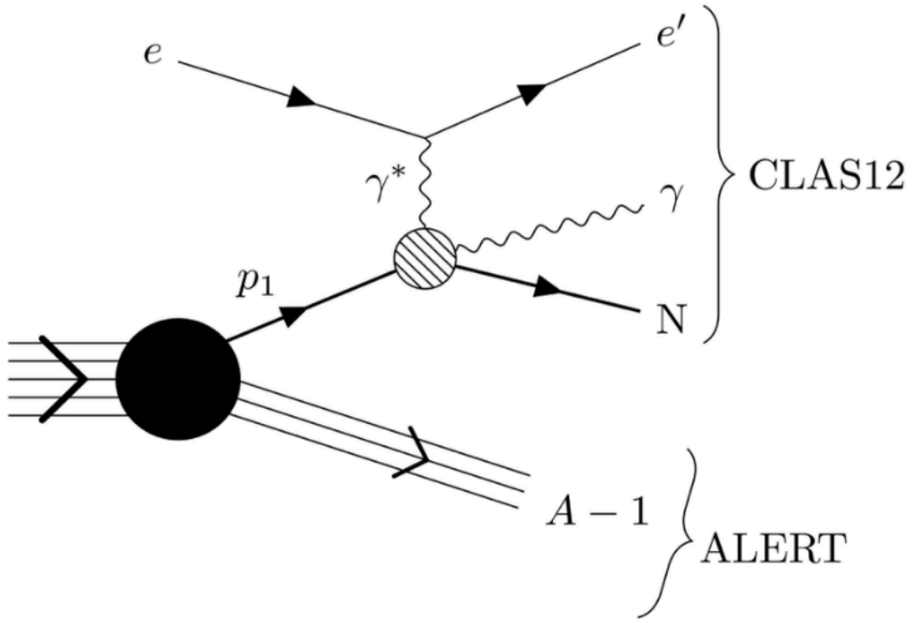

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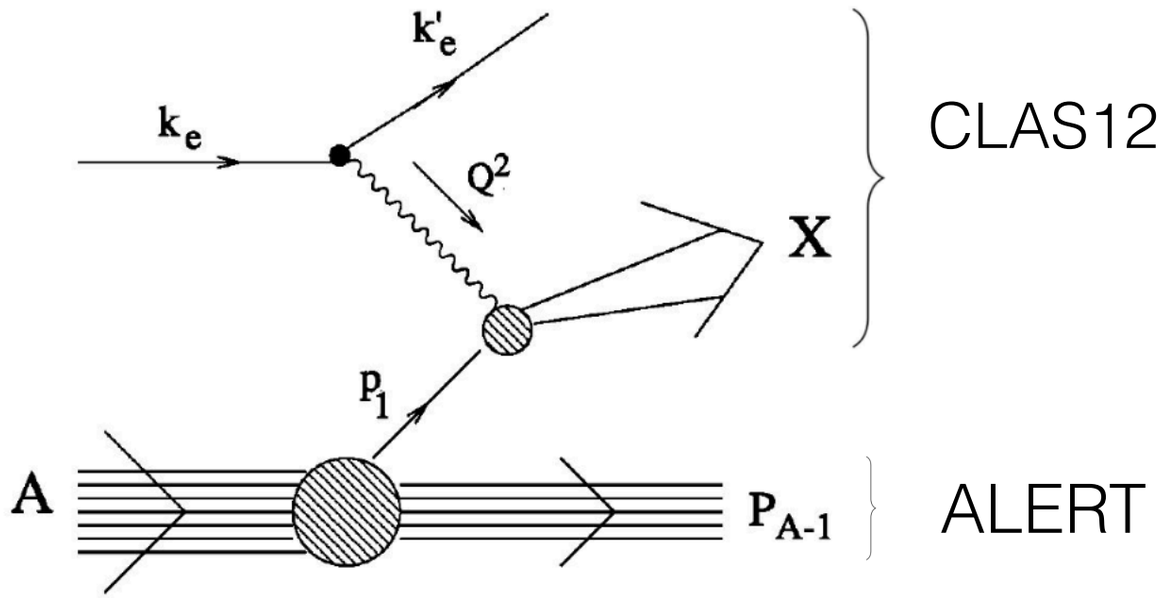

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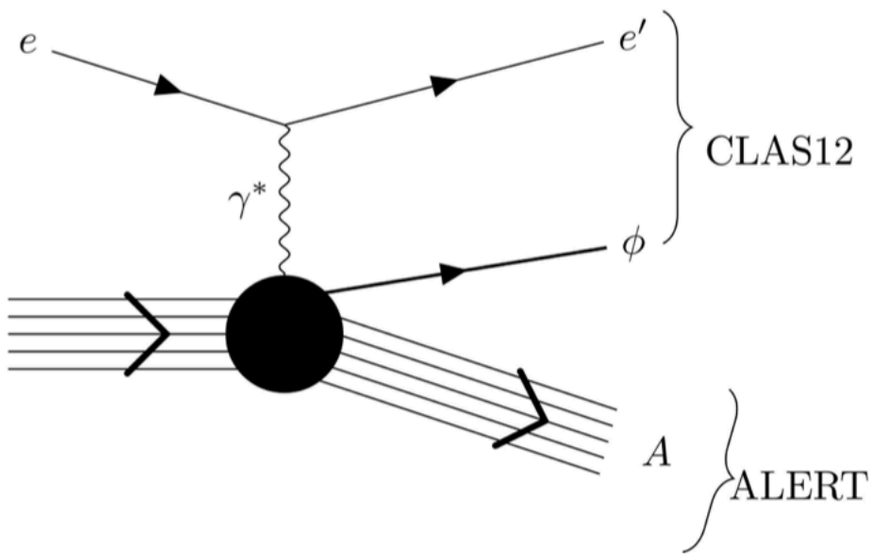

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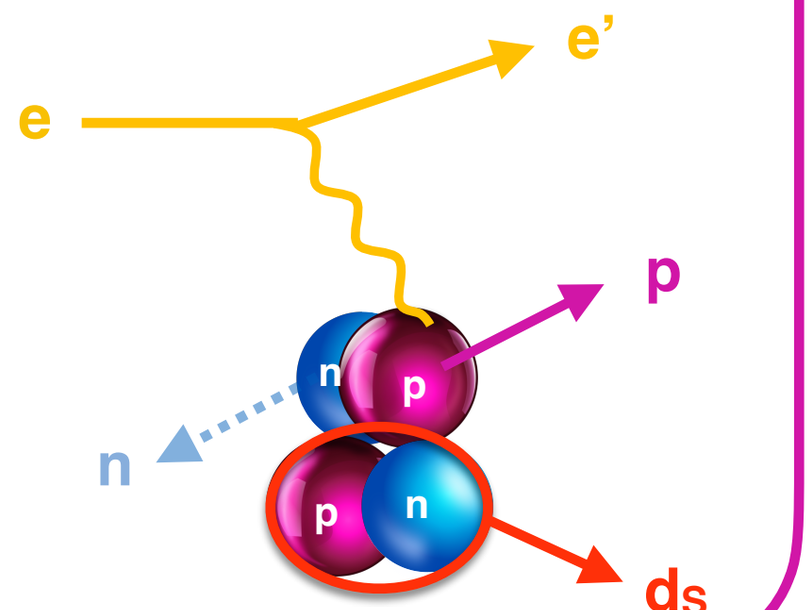
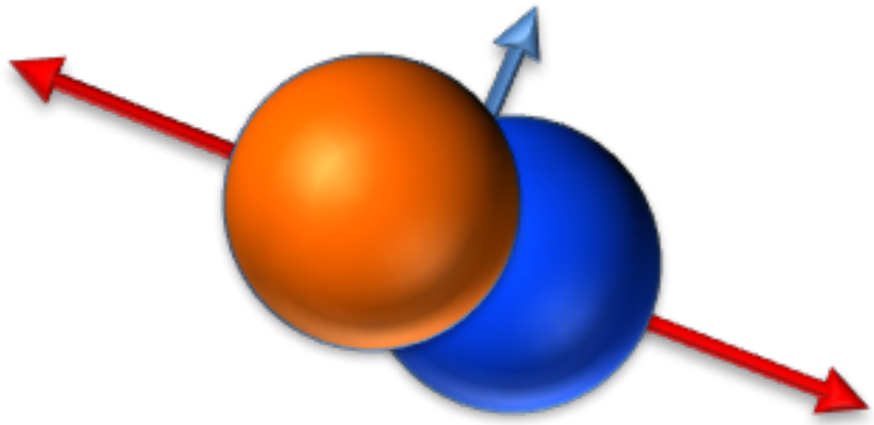
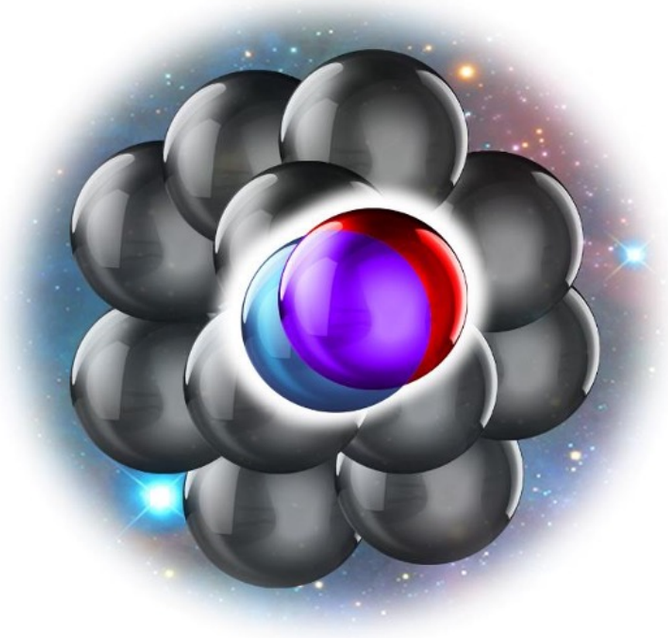


Short-Range Correlations (SRC)

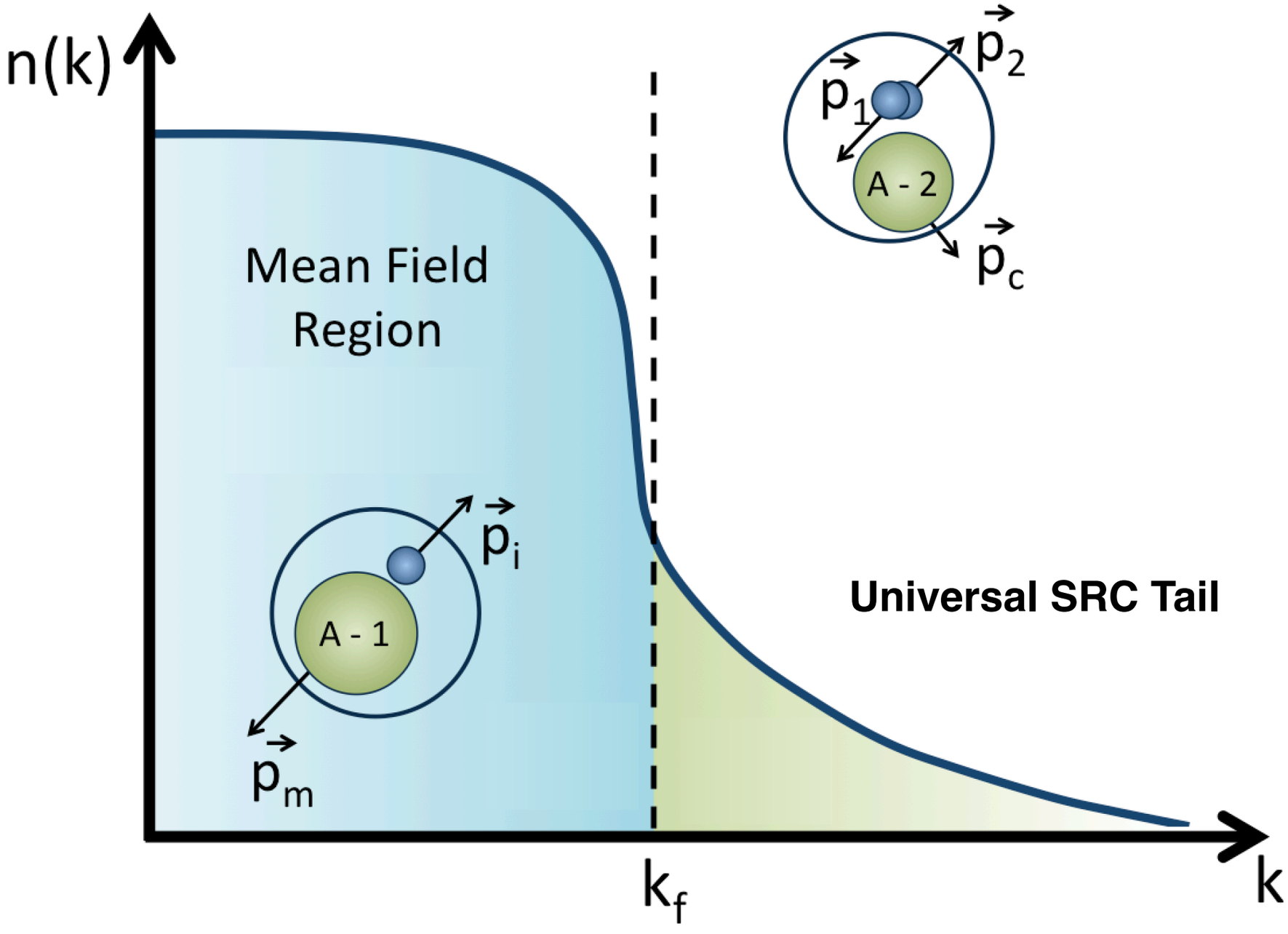
<u>Correlated Nucleon pair with:</u>

- high relative momentum
  > Fermi momentum
- lower c.m momentum



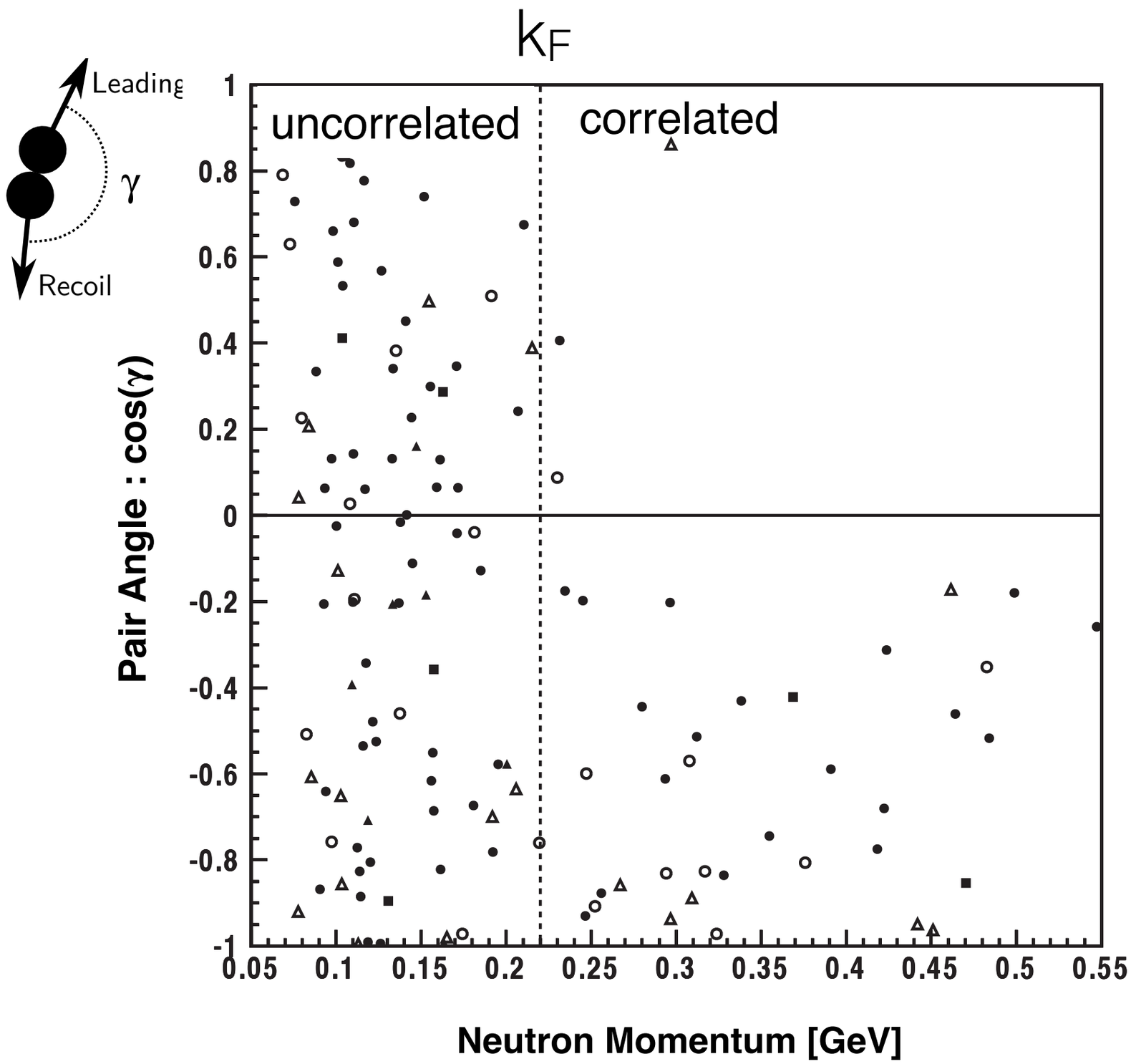


Mean-field to SRC Transition



Mean-field to SRC Transition

PRL 97 (2006), PLB 453 (1999), PRL 90 (2003)



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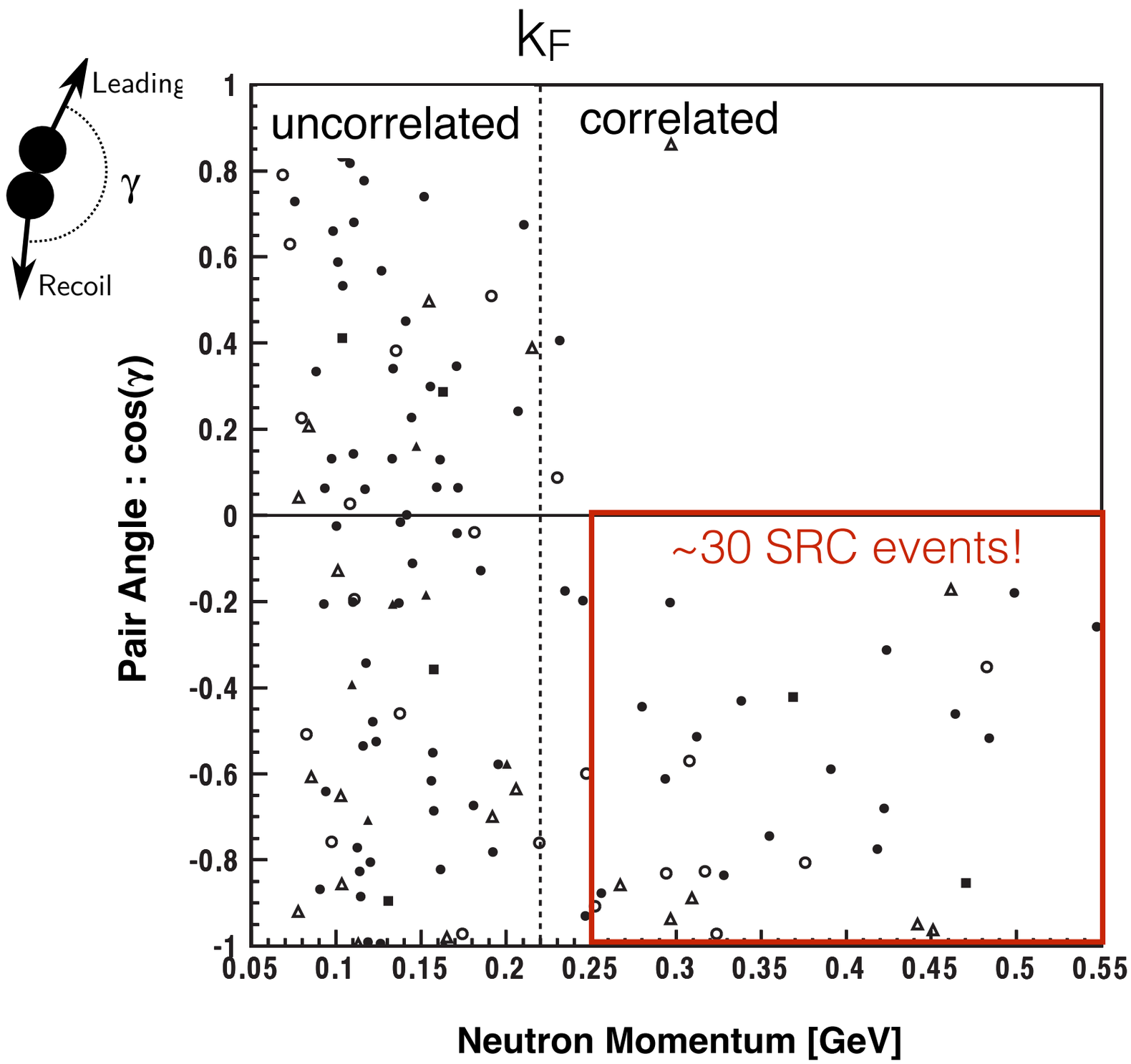
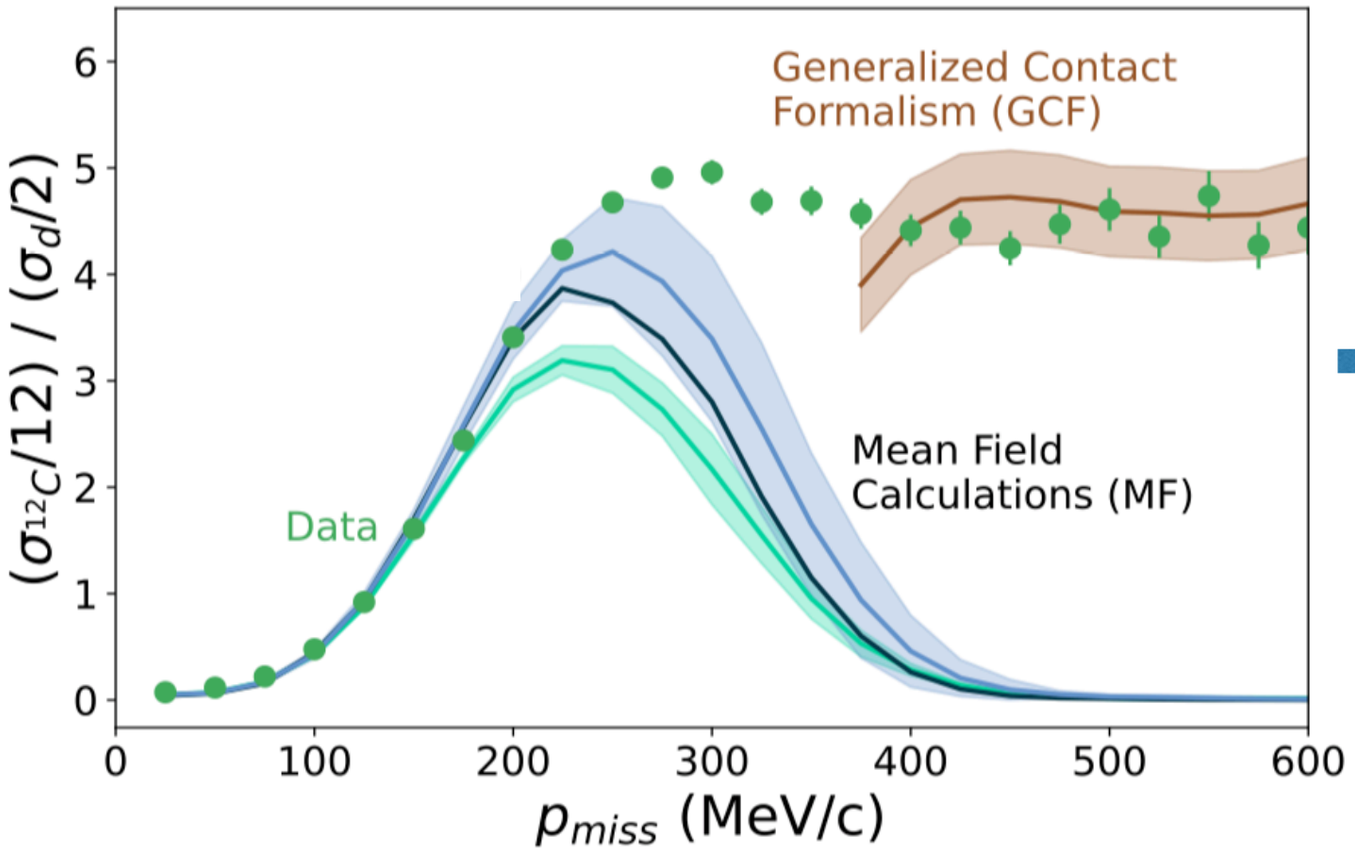
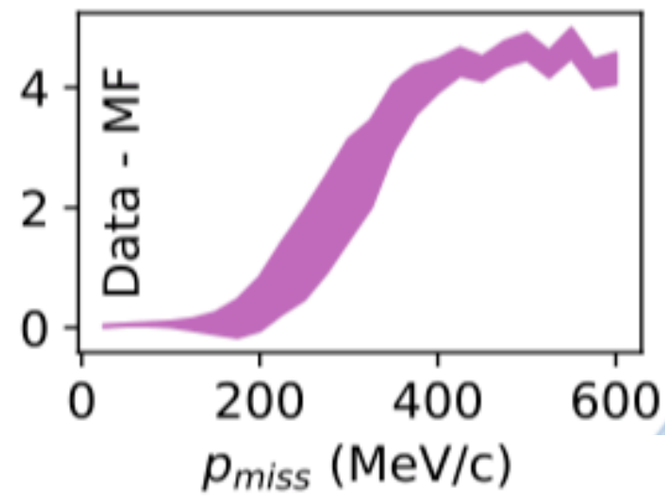


Mapping of Transition

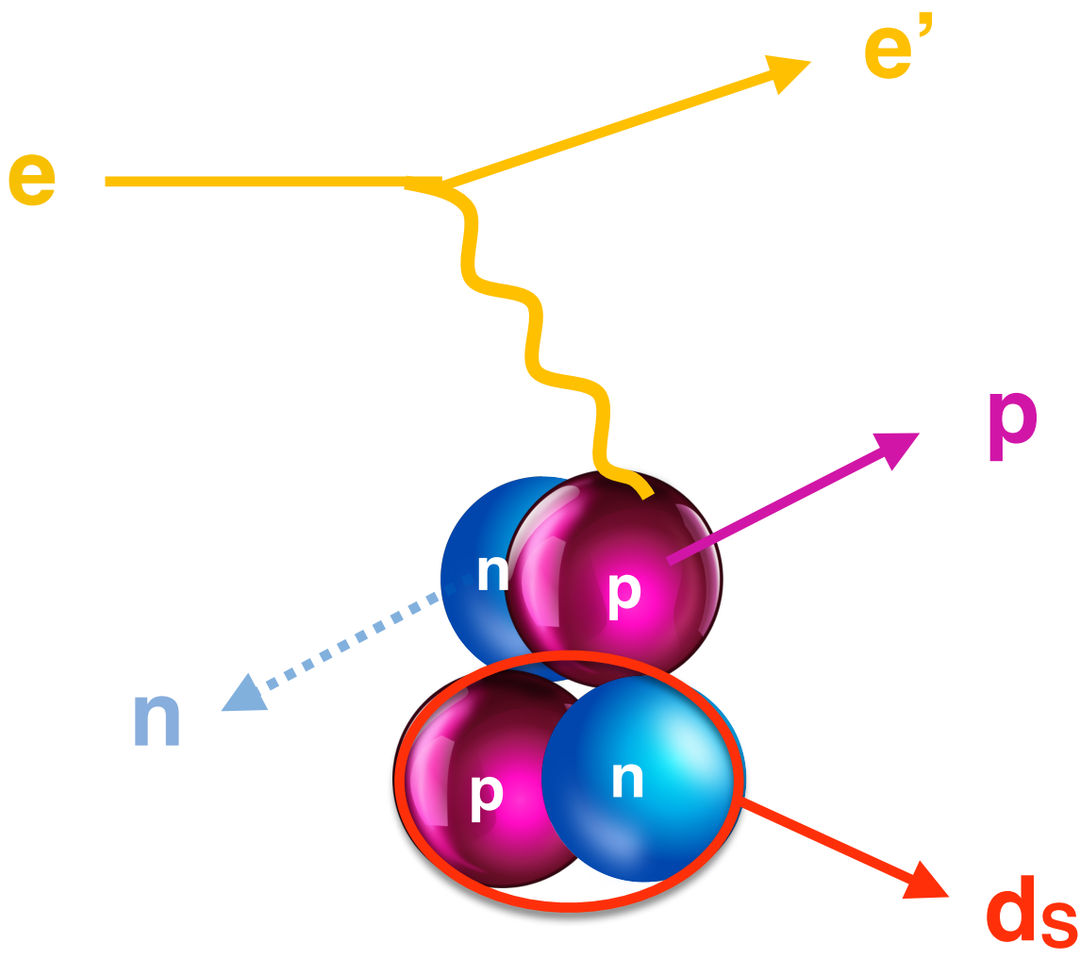
PRC 107, L061301 (2023)



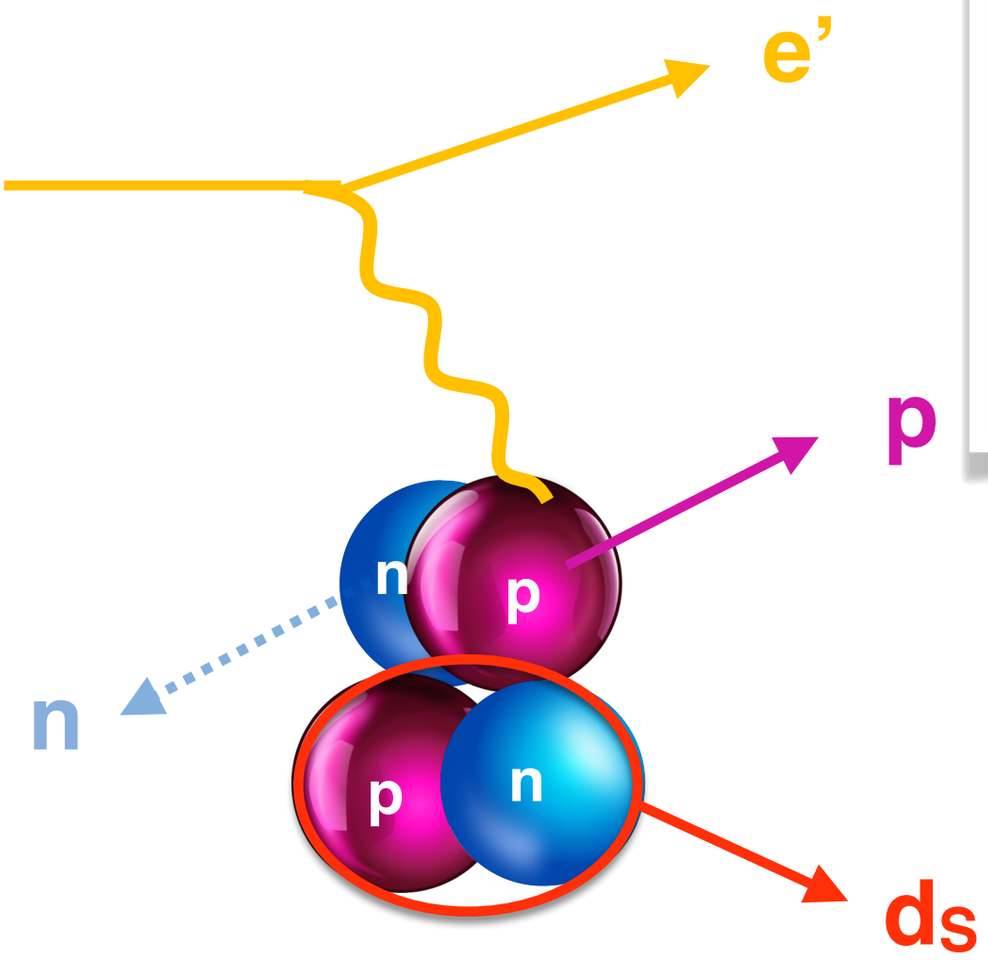


- Model dependent interpretation of (e,e'p) data
- Scaling onset shift to higher momenta not ruled out
- Implications for all effective SRC modeling!

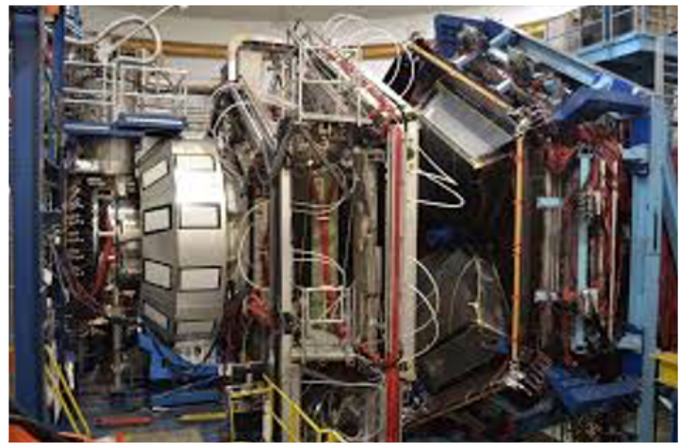
Main Channel ^{4}He(e,e'pd$_S$)n



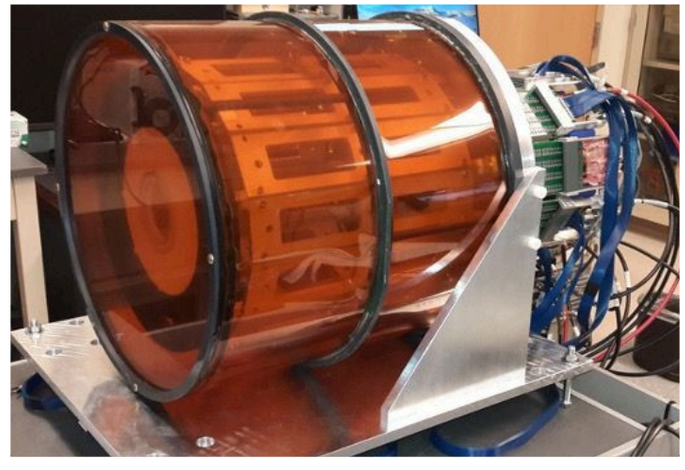
Main Channel ^{4}He(e,e'pd$_S$)n



CLAS12

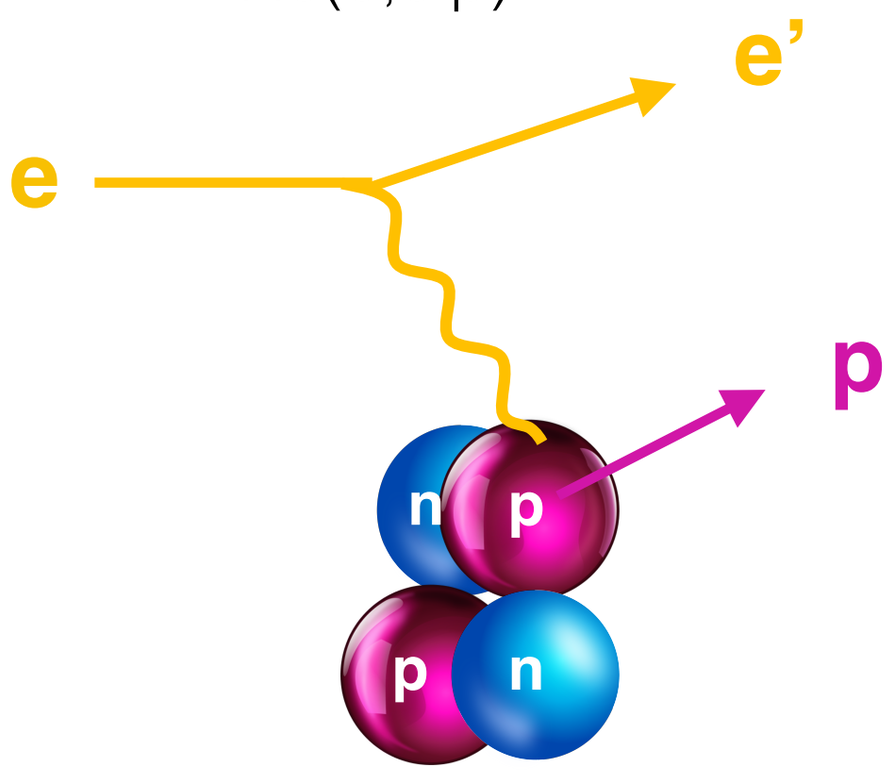


ALERT

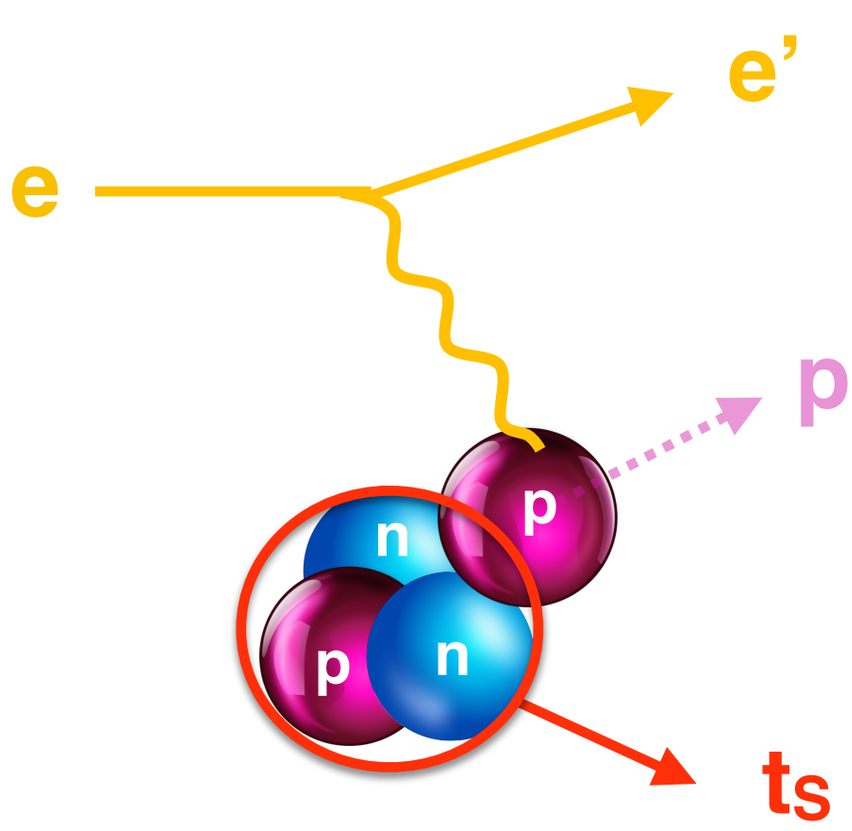


Other Channels

^{4}He(e,e'p)

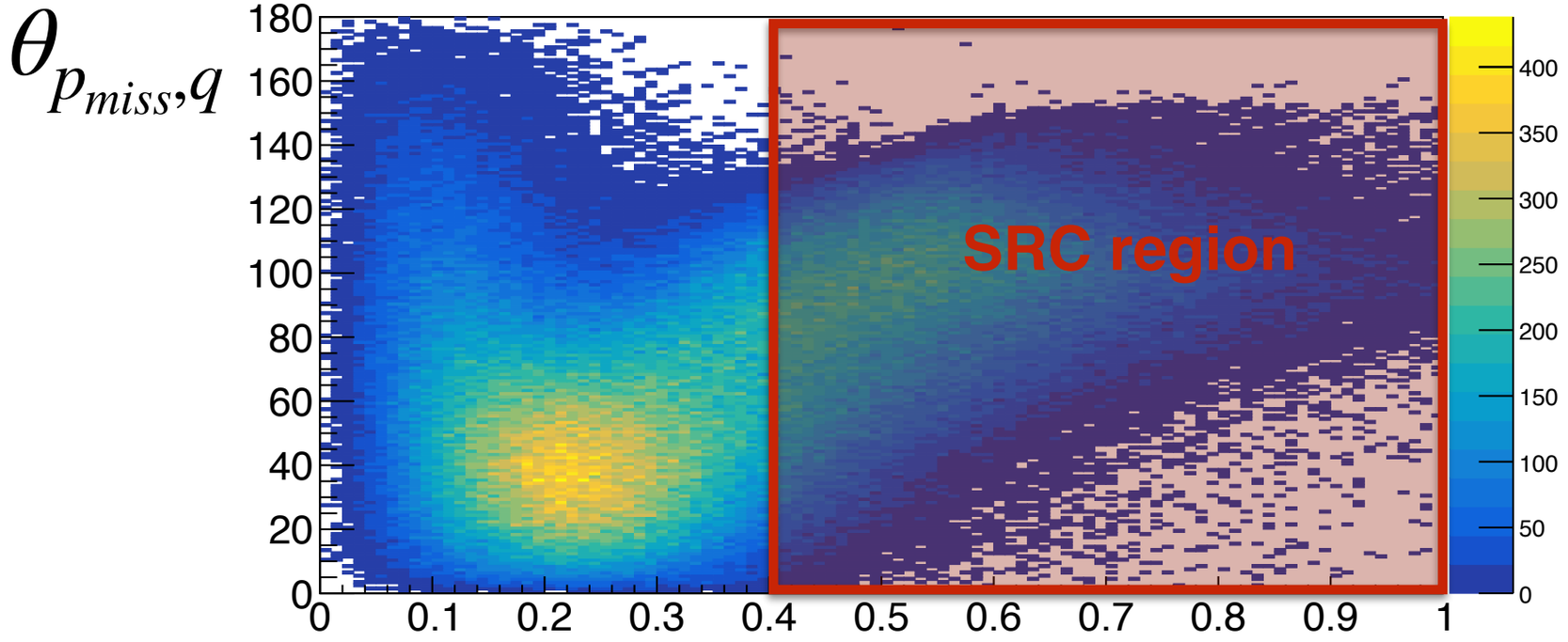


^{4}He(e,e't$_s$)p



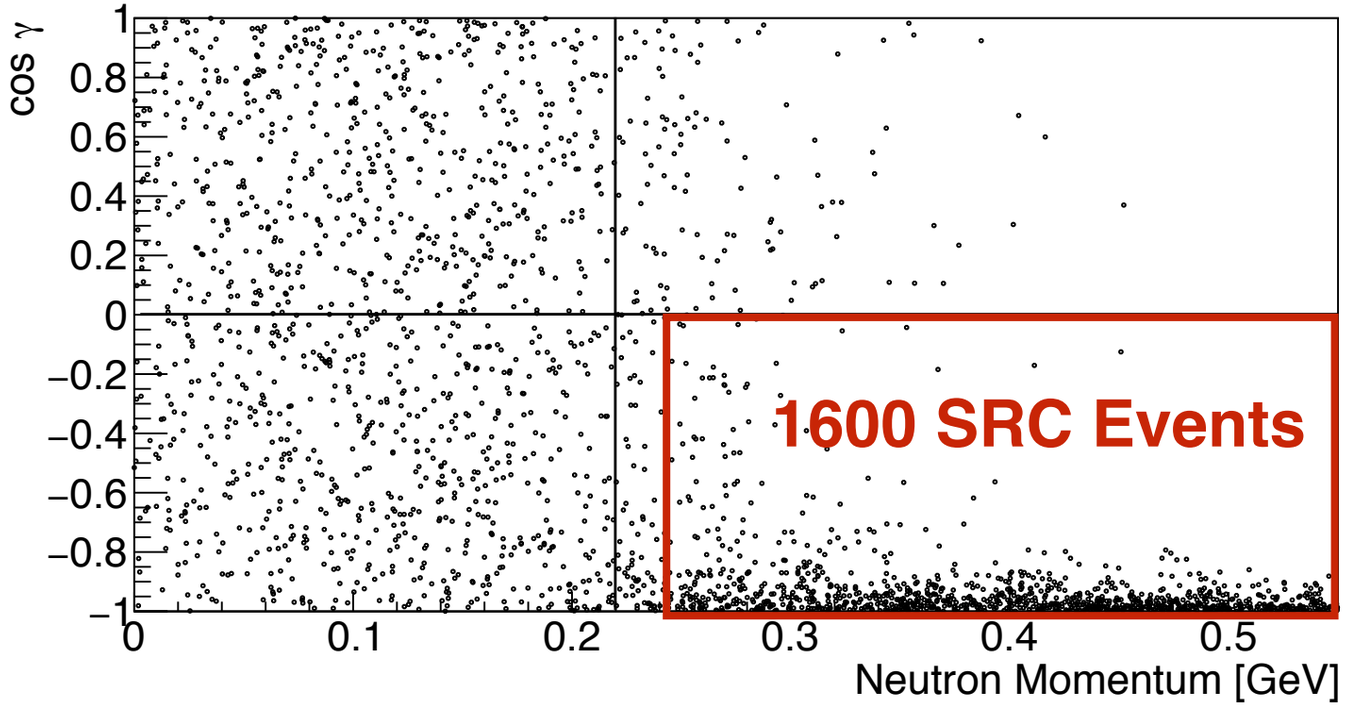
Rate Estimates

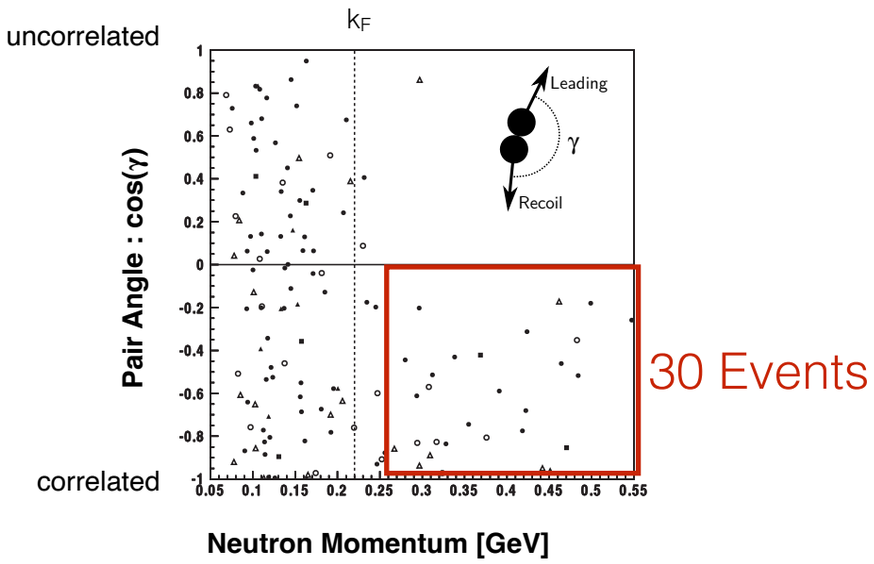
- Measured CLAS12 rates from ^{4}He(e,e'p) data, scaled to ALERT luminosity
- SRC events selection cuts from previous analysis
- Account for recoil ion tagging efficiency



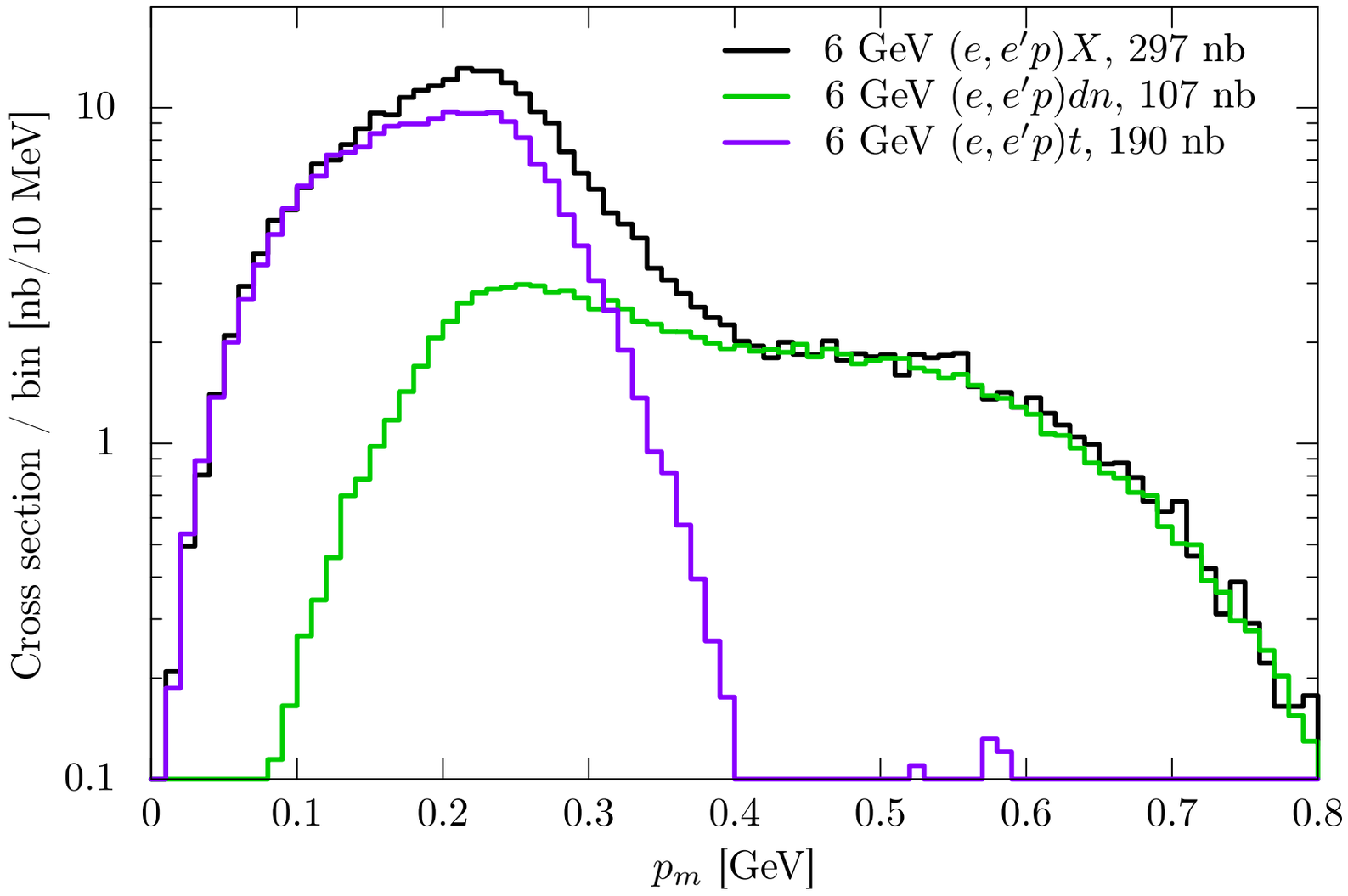
- 1600 SRC events with deuteron tagging
- 34 days beam time

Projected Results: ^{4}He(e,e'd$_s$p)n





Bonus: Validation of ^{4}He Models



- Simulations with Plane-Wave-Impulse-Approximation
  - ^{4}He spectral function (N. Rocco and A. Lovato)
  - Two-body and three-body breakup
- Triton momentum acceptance ~120 - 300 MeV/c

Summary

- Measuring recoil nuclei is a great tool to study reactions
  - selection of initial states
  - suppression of backgrounds
- ALERT detects p, d, ^{3}H, ^{3}He and ^{4}He recoils
- Expect interesting new physics results
  - Tagged DVCS and EMC
  - Nuclear Generalized Parton Distributions
  - Transition region from mean-field to SRC regime with high statistics
- Experiment will run next year

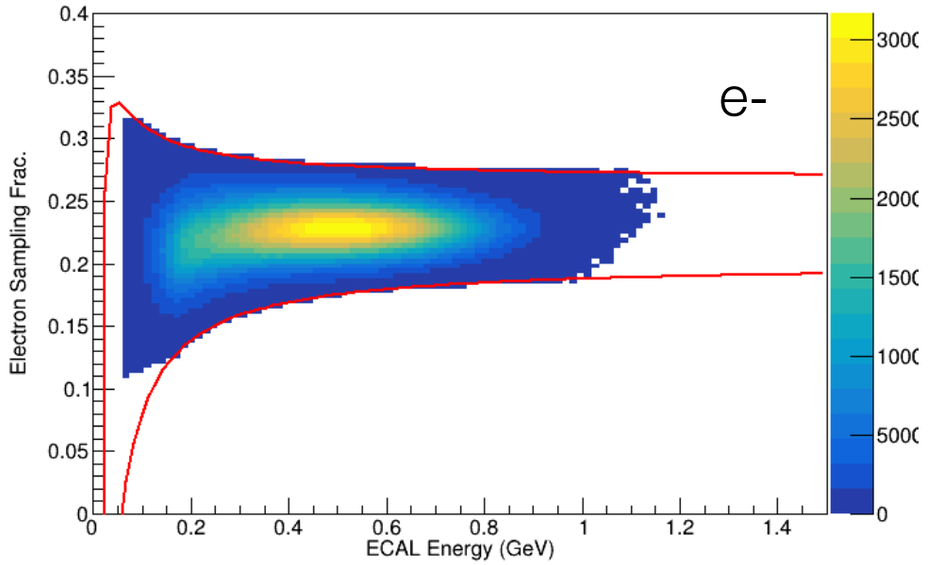
Backup slides

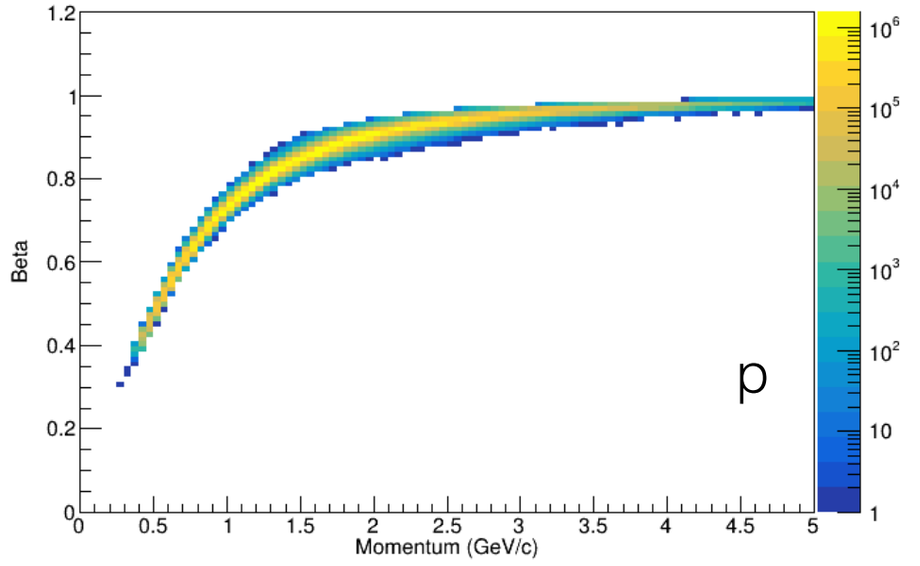
RGM (e,e'p) Event Selection

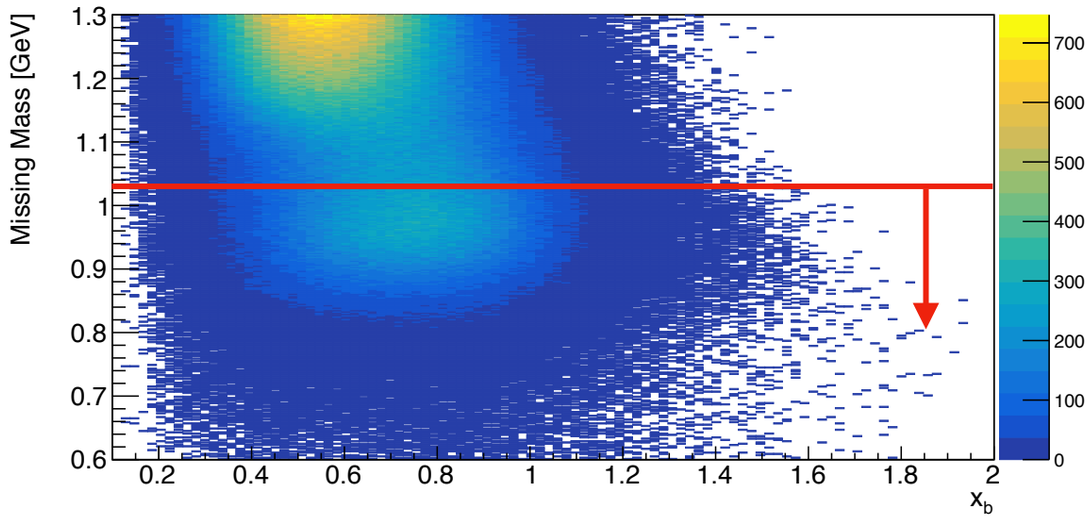
- Electron in Forward Detector
  - Calorimeter sampling fraction cut
  - PCAL fiducials

- Proton in Forward Detector
  - PID 2212
  - χ^2 PID < 3

- Kinematic Cuts for Quasi-elastic selection
  - $Q^2 > 1.2$ GeV^2
  - $\theta_{pq} < 25°$
  - $|p|/|q| > 0.6$
  - $M_{miss} < 1.03$ GeV (assuming stationary pair with deuteron mass)

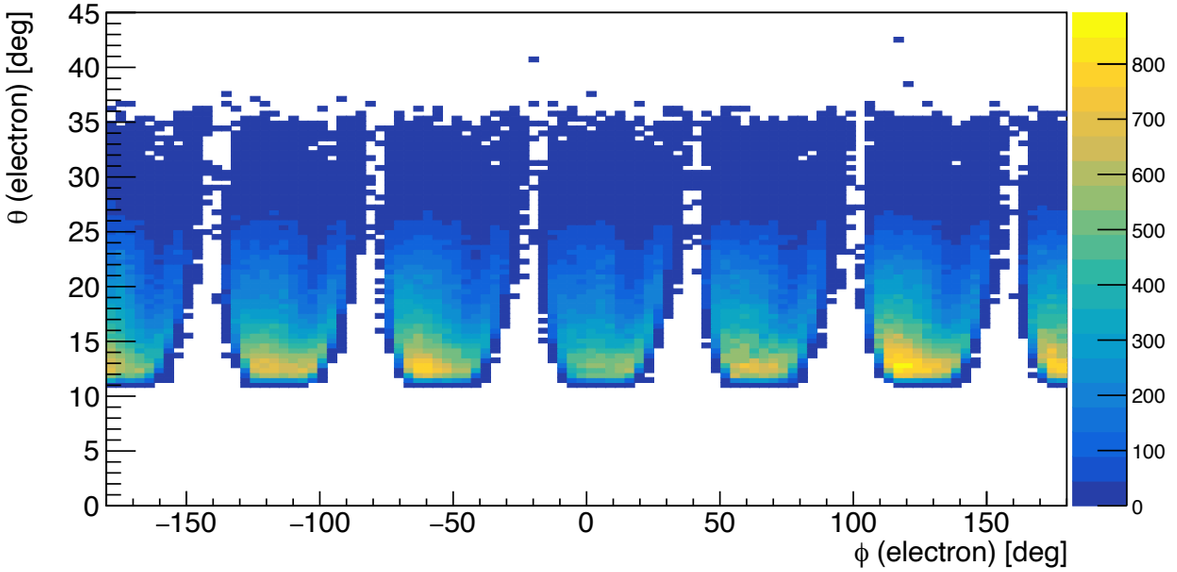


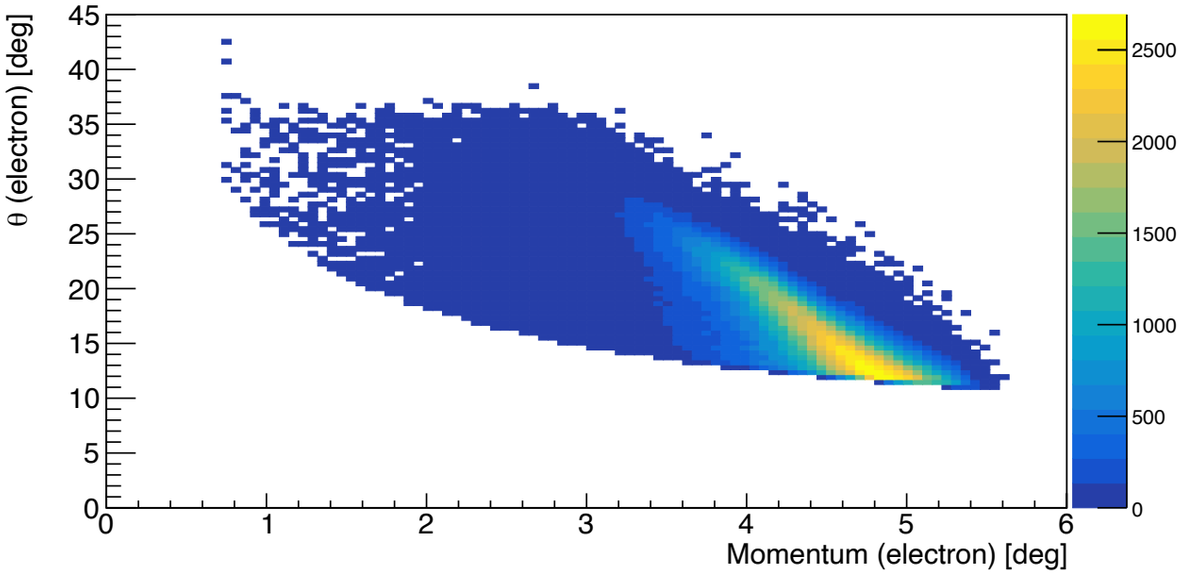




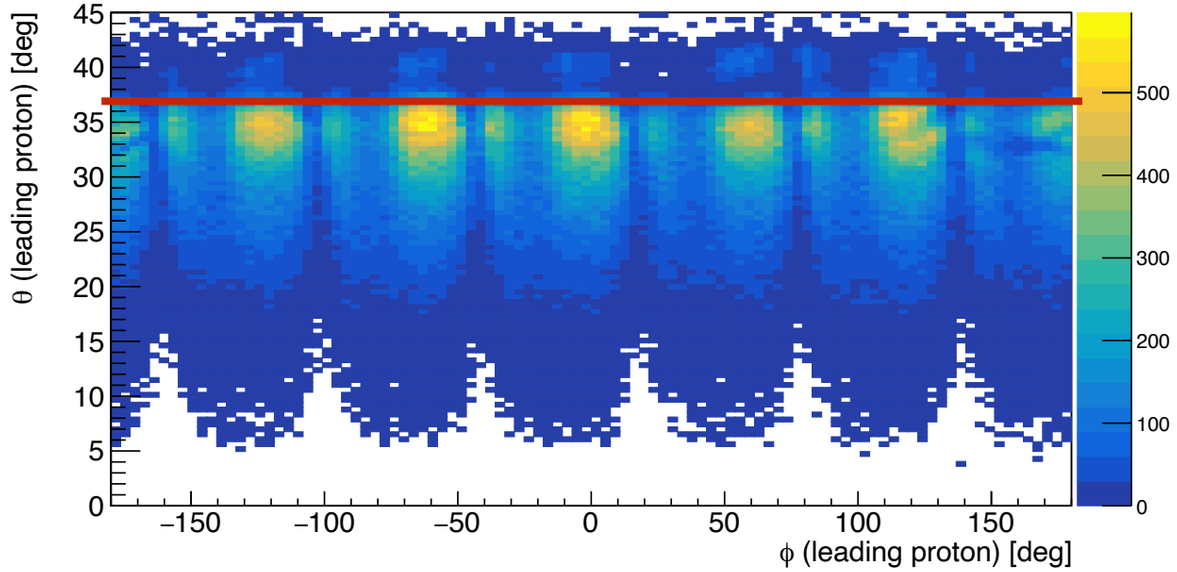
Electron and Proton Distributions

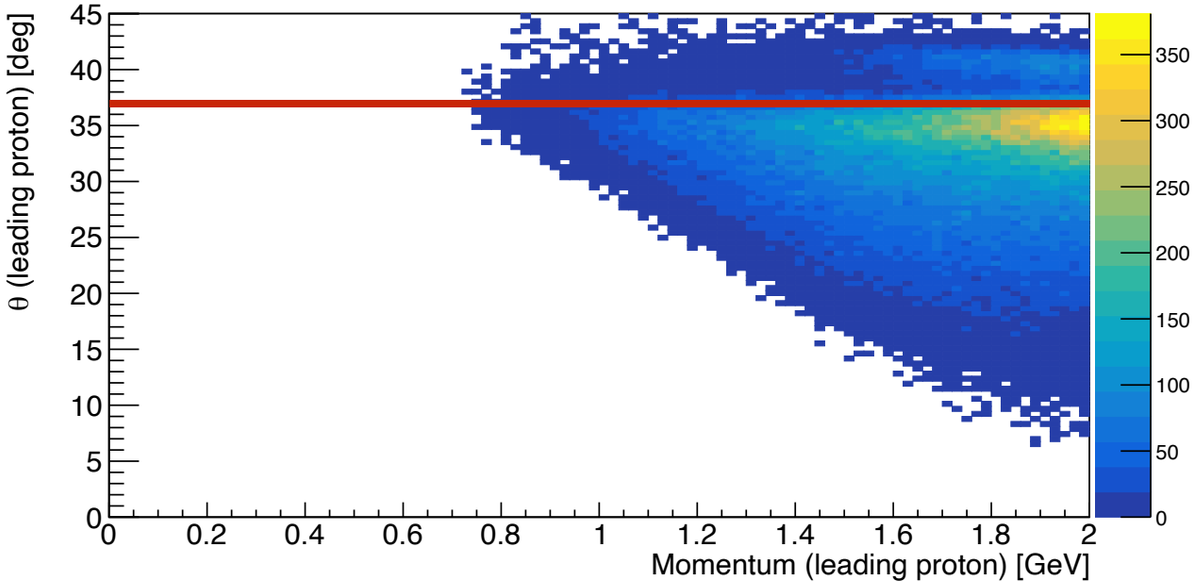
Electrons





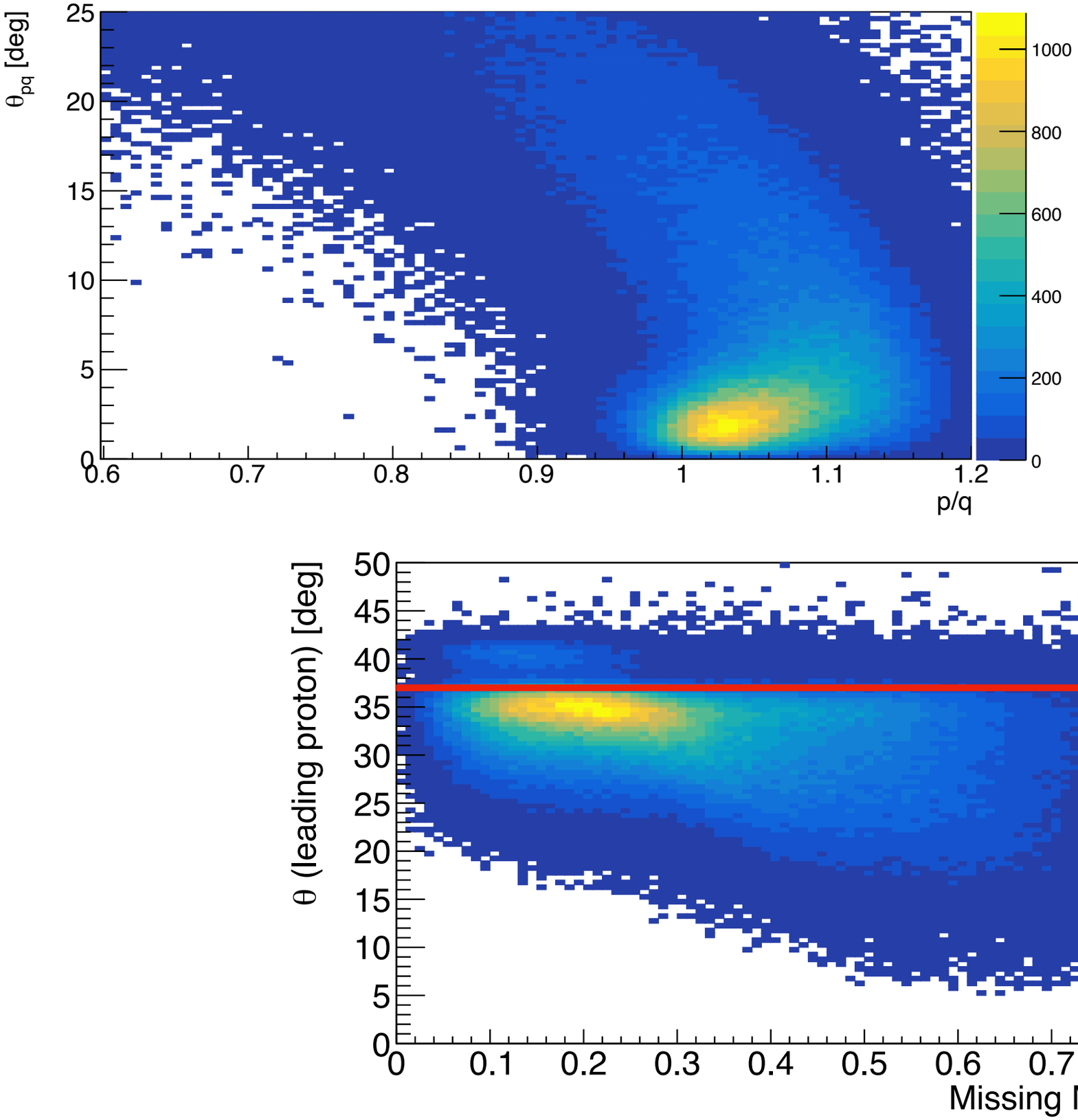
Protons





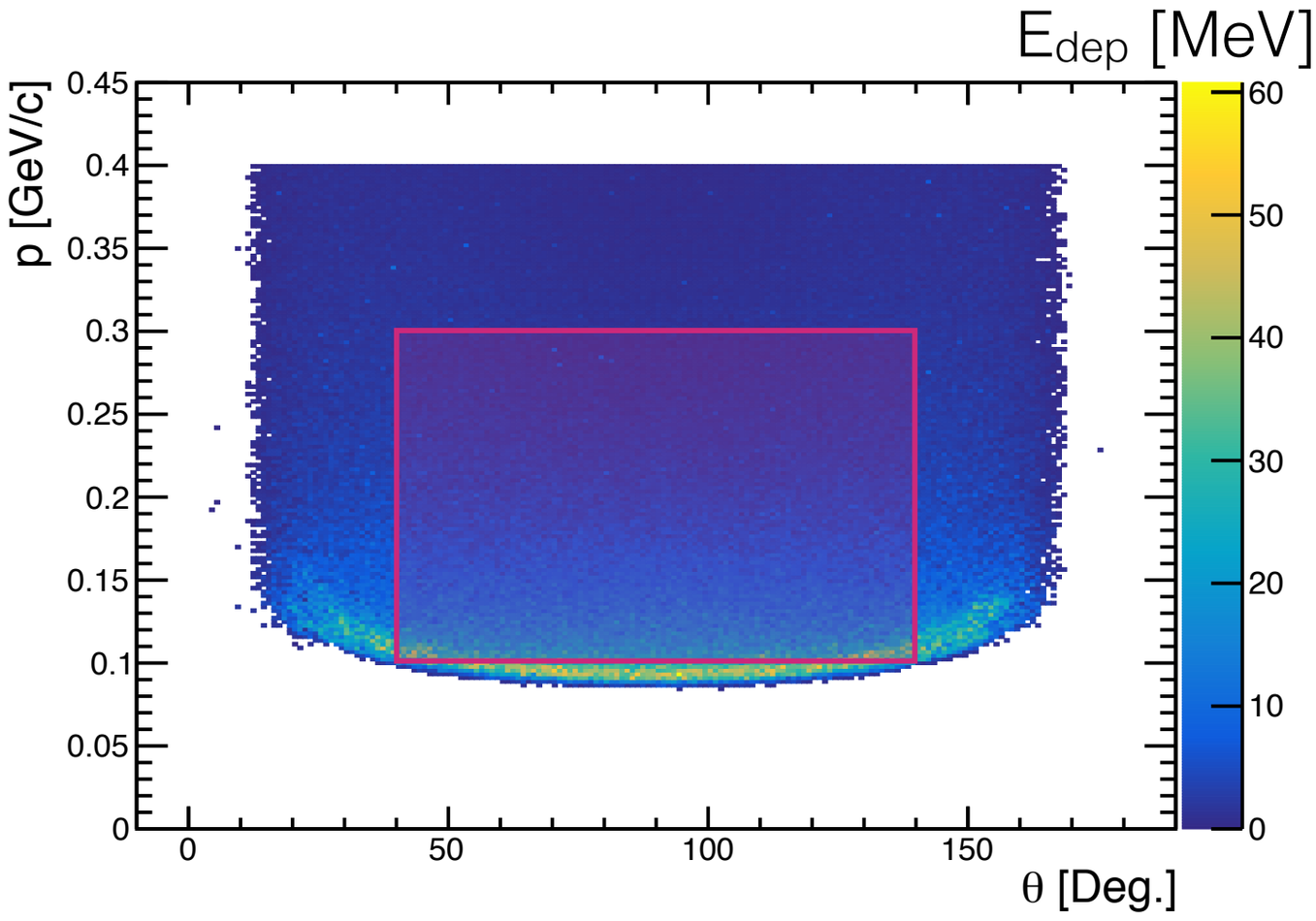
- Standard 6-fold sector structure of CLAS12
- Additional proton scattering angle cut $\theta_p < 37°$ to ensure proton only in forward detector

Other Kinematic Distributions



Deuteron Acceptance (1)

- Uniformly generated deuterons
  - 0-400 MeV/c momenta
  - 0-180° polar angle
  - 0-360° azimuthal angle

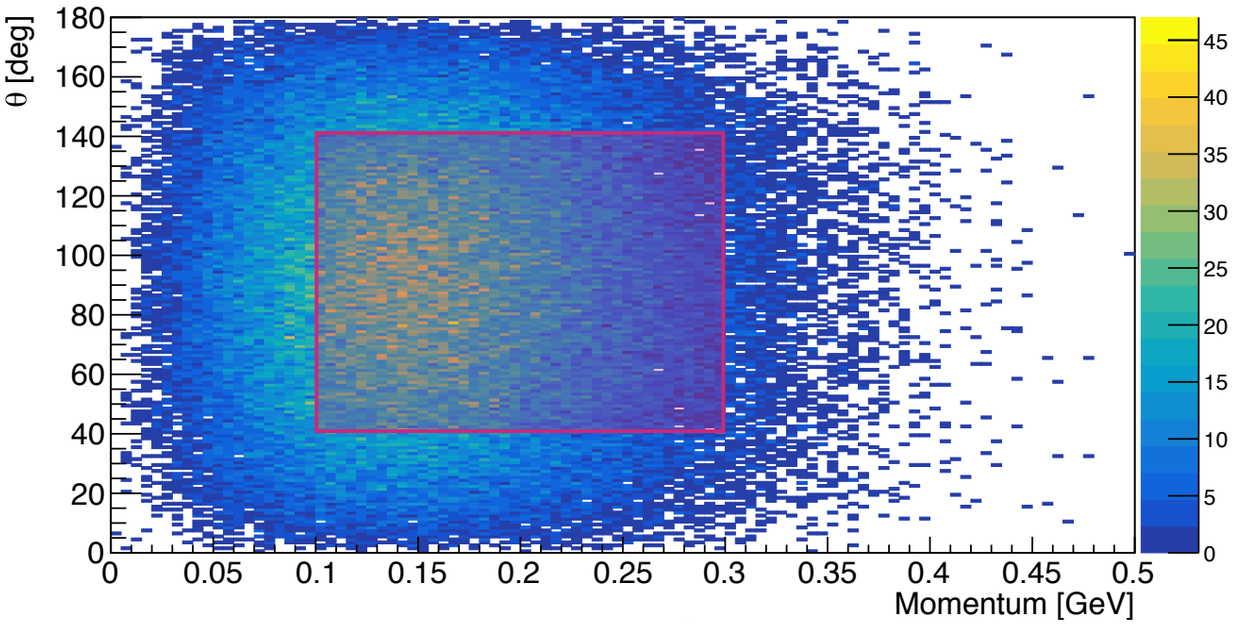


- Events through GEMC (ALERT only)
  - Accept event if hit in all DC layers
  - No explicit track reconstruction

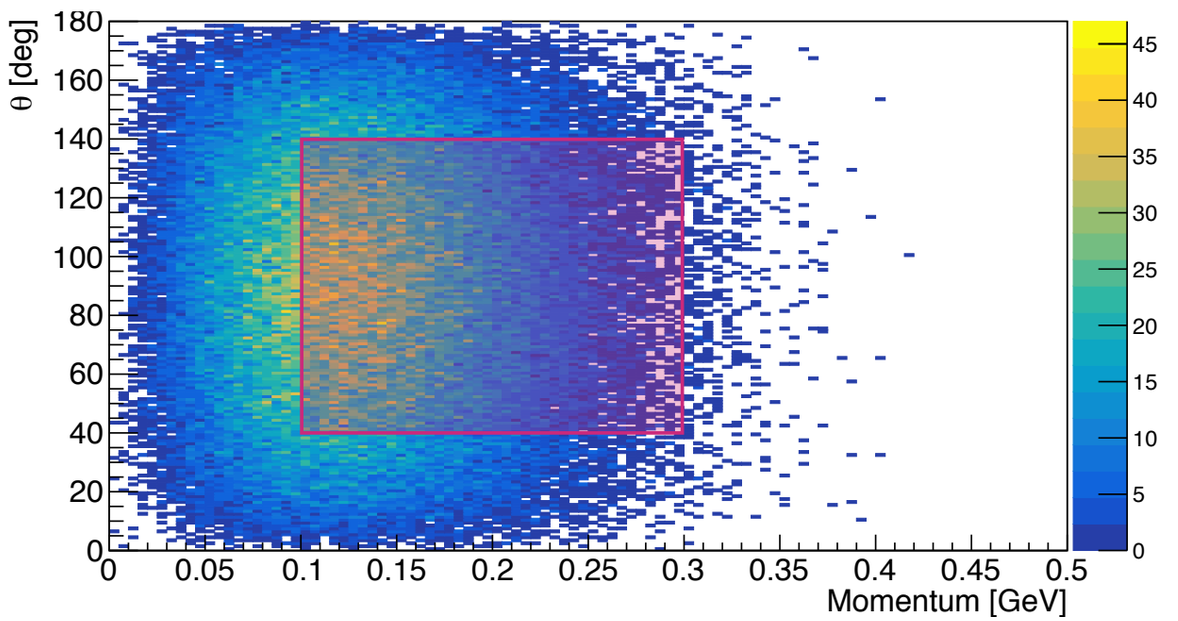
- Select conservative range with high efficiency for acceptance determination
  - 100 - 300 MeV/c
  - 40° -140°

Deuteron Acceptance (2)

- Simulated deuterons from ^{4}He(e,e'pd$_S$)n
  - isotropically emitted
  - deuteron momentum (= np-pair cms momentum) sampled from Gaussian
  - checked different values: σ = 100 MeV/c [PRL 113 (2014)] and σ = 84 MeV/c [PRC 89 (2014)]



σ = 100 MeV/c



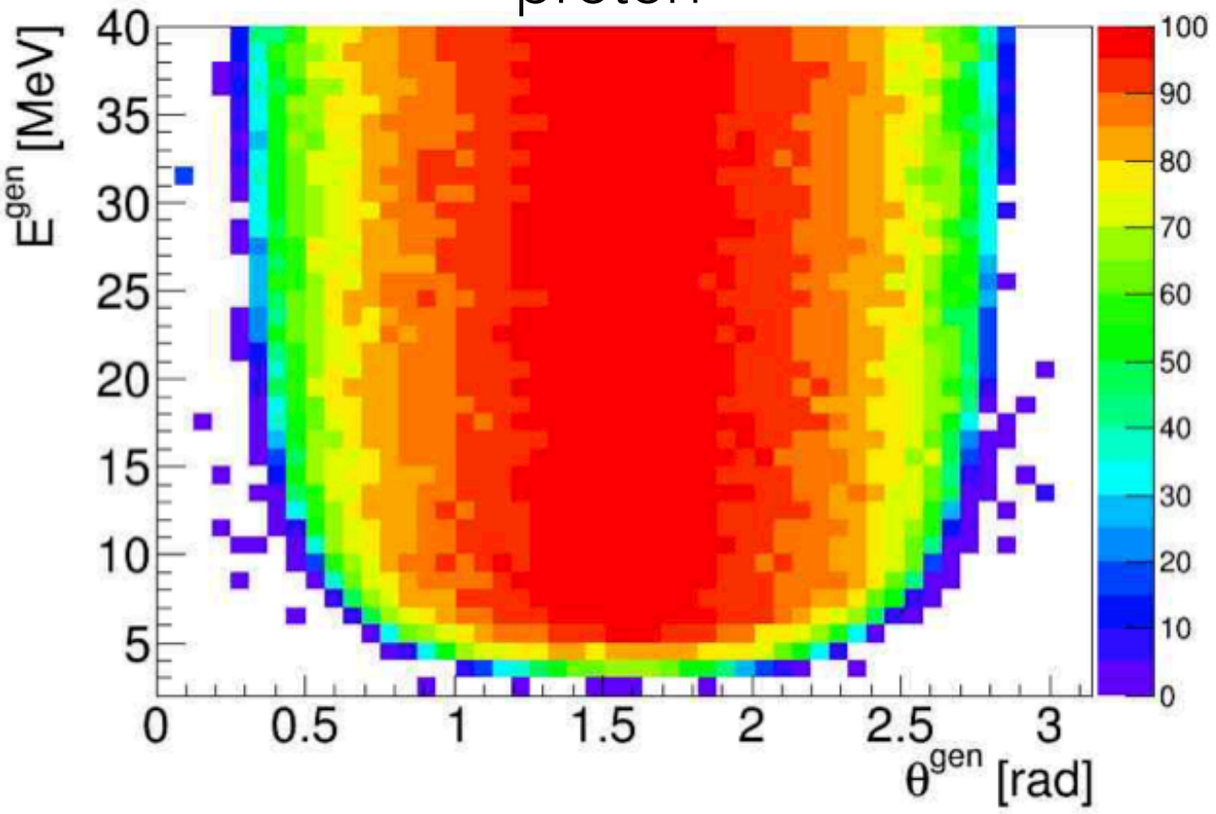
σ = 84 MeV/c

- More spread in momentum for larger σ (expected)
- 59% (100 MeV/c) or 53% (84 MeV/c) events in (conservative) ALERT acceptance box

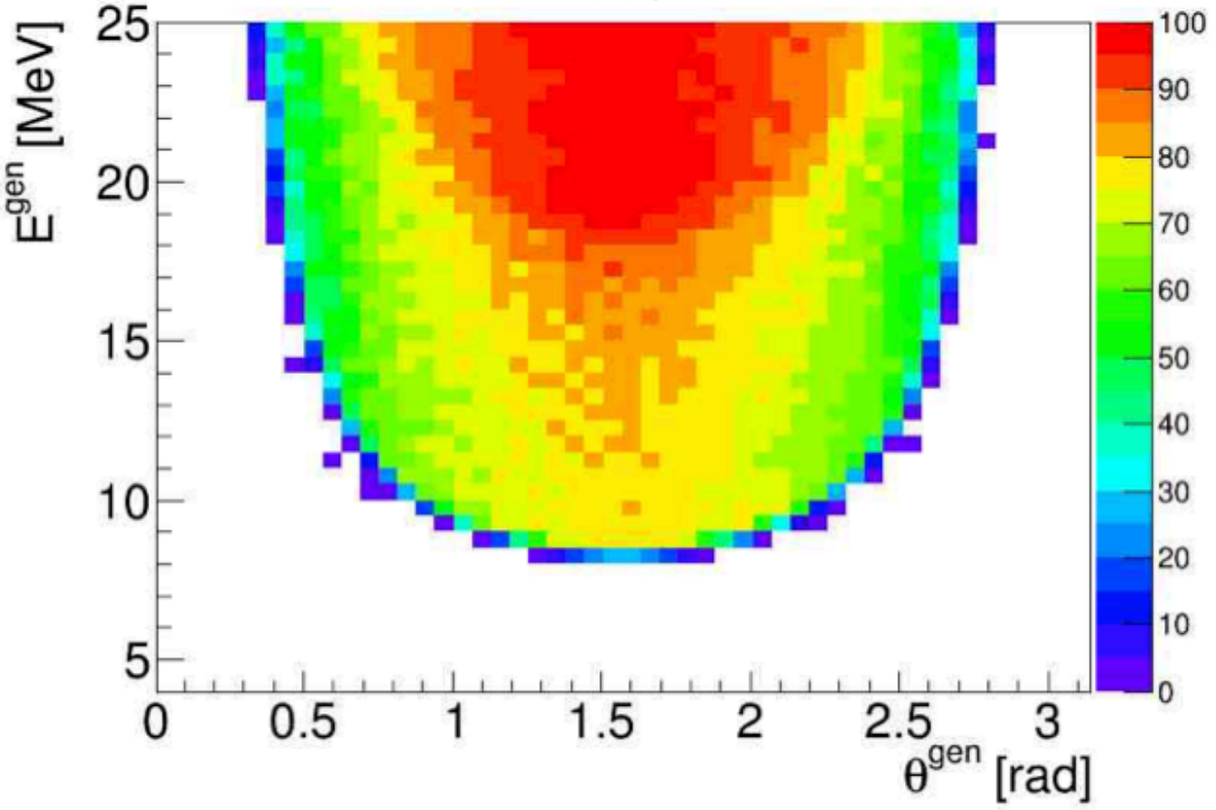
- For rate estimate: conservative **deuteron acceptance factor = 0.5**

Comparison Acceptances

proton

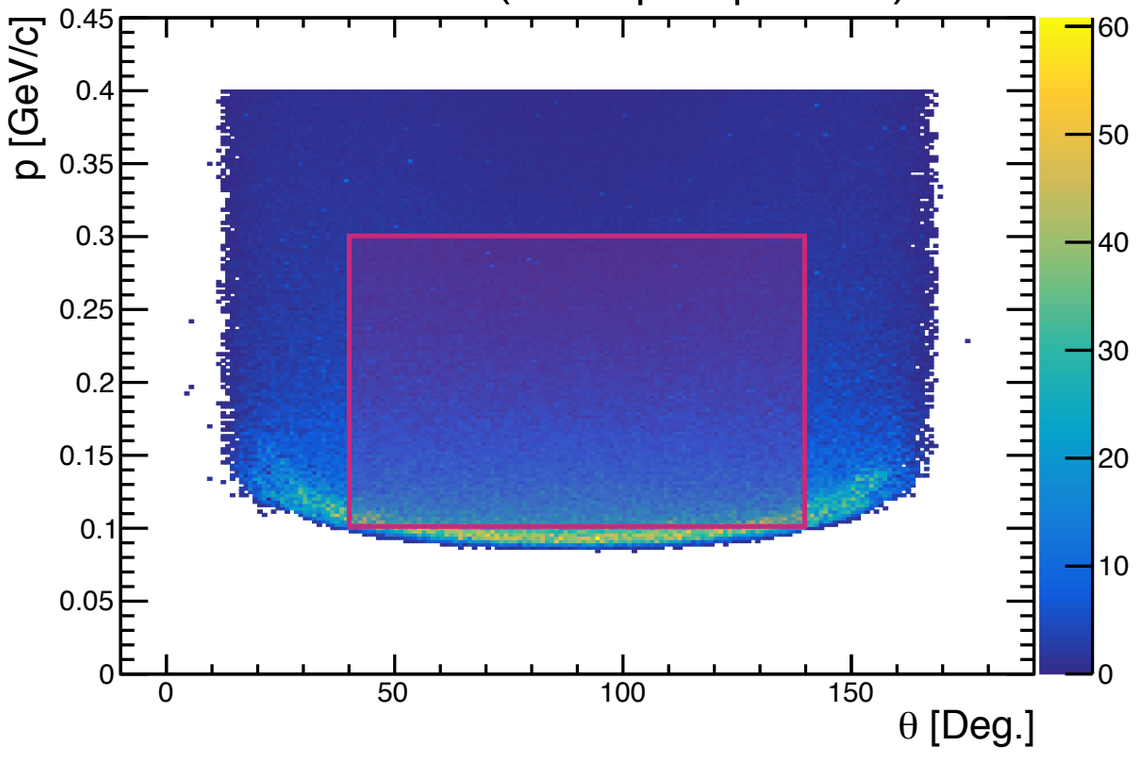


^{4}He



- Acceptances consistent with previous simulations from approved ALERT proposal E12-17-012 (https://misportal.jlab.org/pacProposals/proposals/1338/attachments/98370/Proposal.pdf)

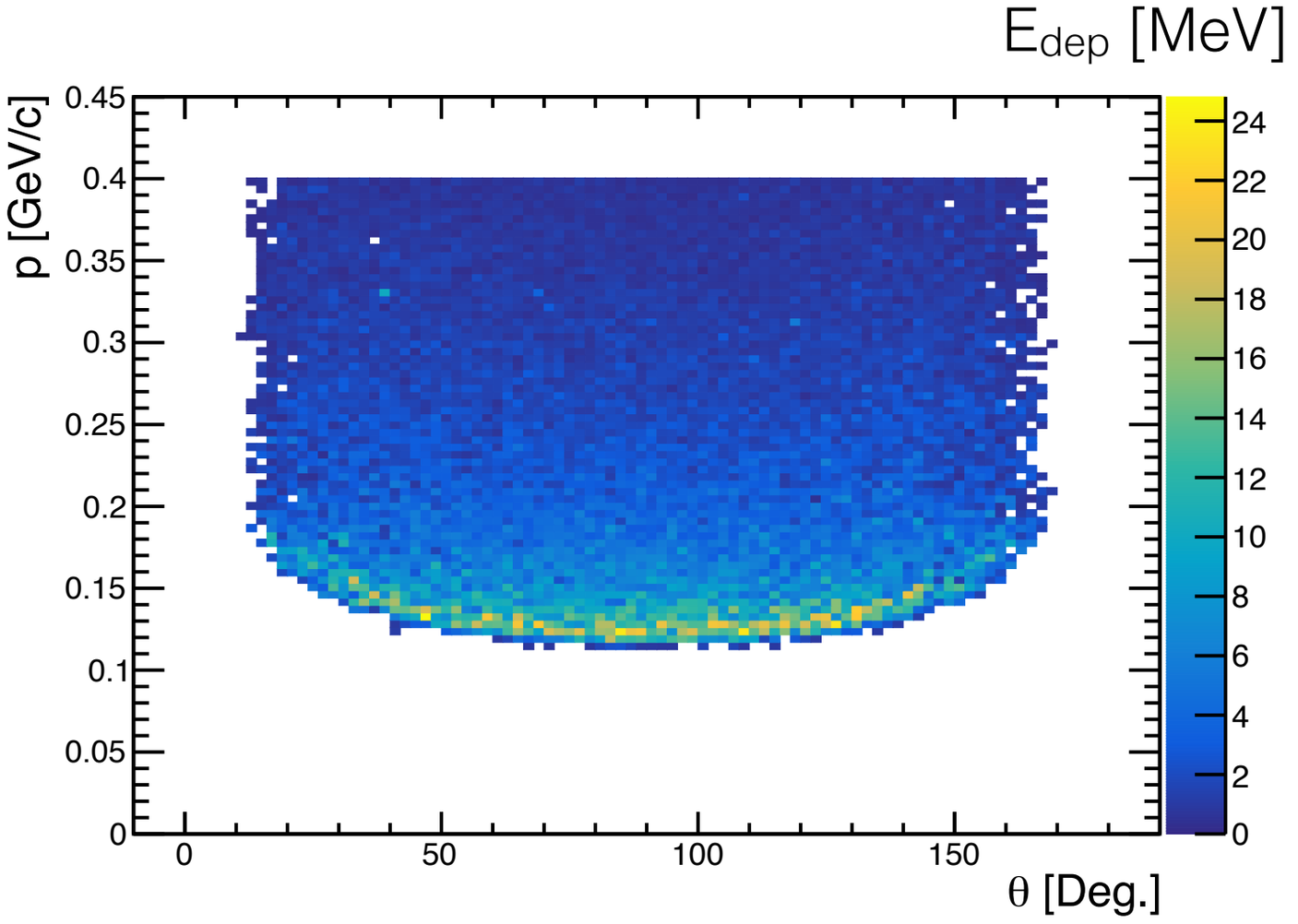
Deuteron (this proposal)



Triton ALERT Acceptance

- Uniformly generated tritons
  - 0-400 MeV/c momenta
  - 0-180° polar angle
  - 0-360° azimuthal angle

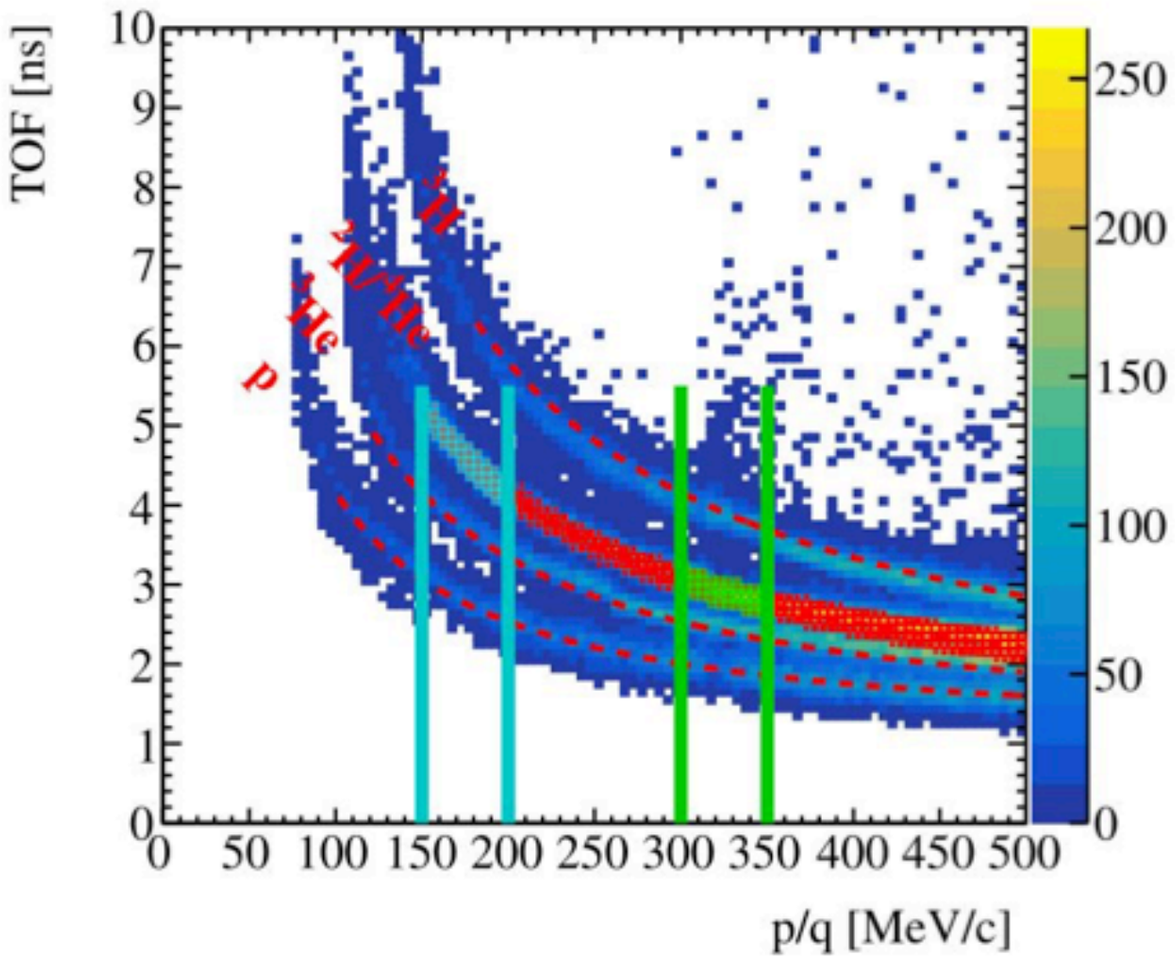
- Events through GEMC (ALERT only)
  - Accept event if hit in all DC layers
  - No explicit track reconstruction



- Similar acceptance range than deuterons —> can detect tritons from 120-300 MeV/c

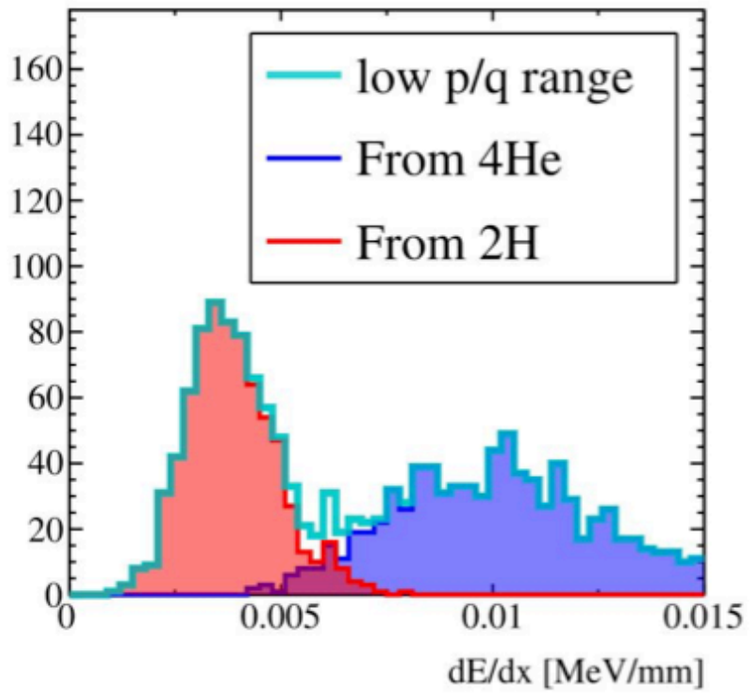
ALERT PID

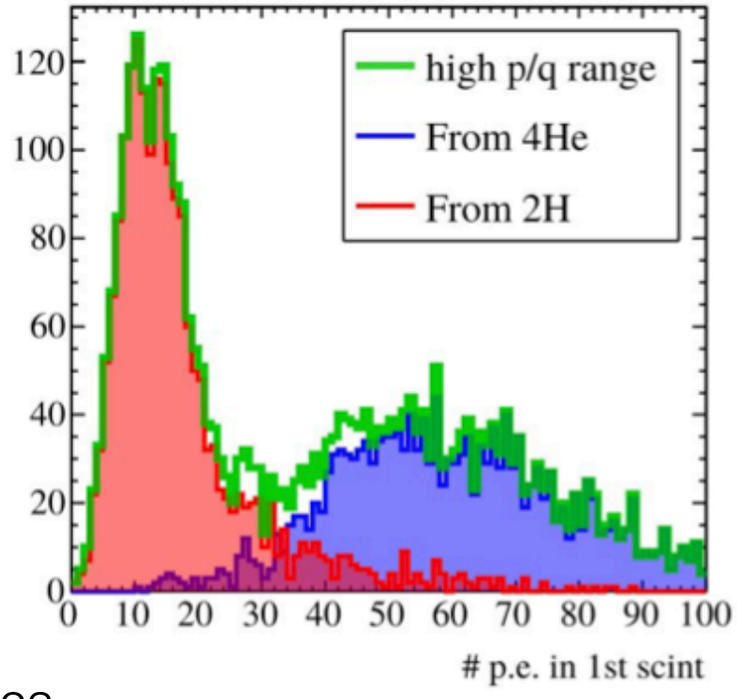
- PID from ToF (<150ps resolution)



- well separated p, ^{3}He, d/^{4}He and ^{3}H bands

- d and 4He seperation via dE/dx

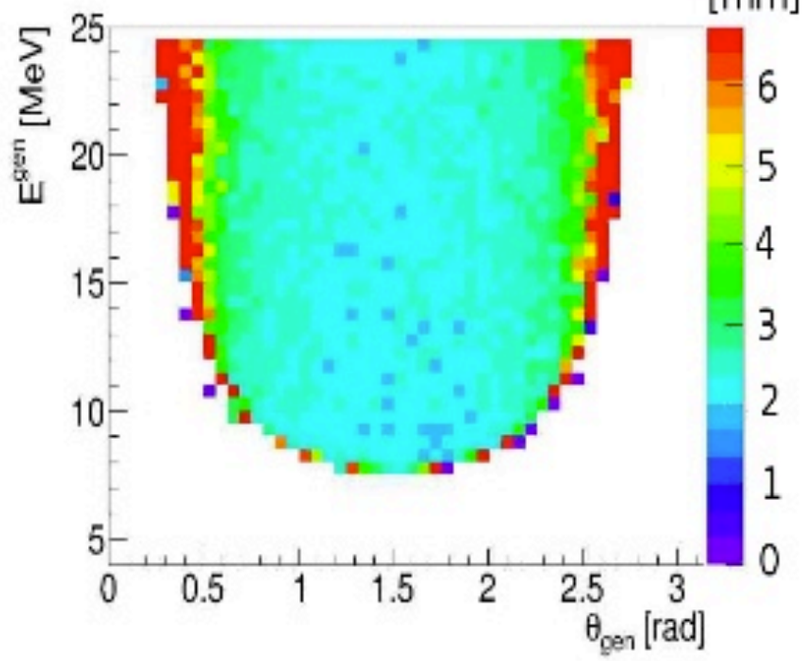




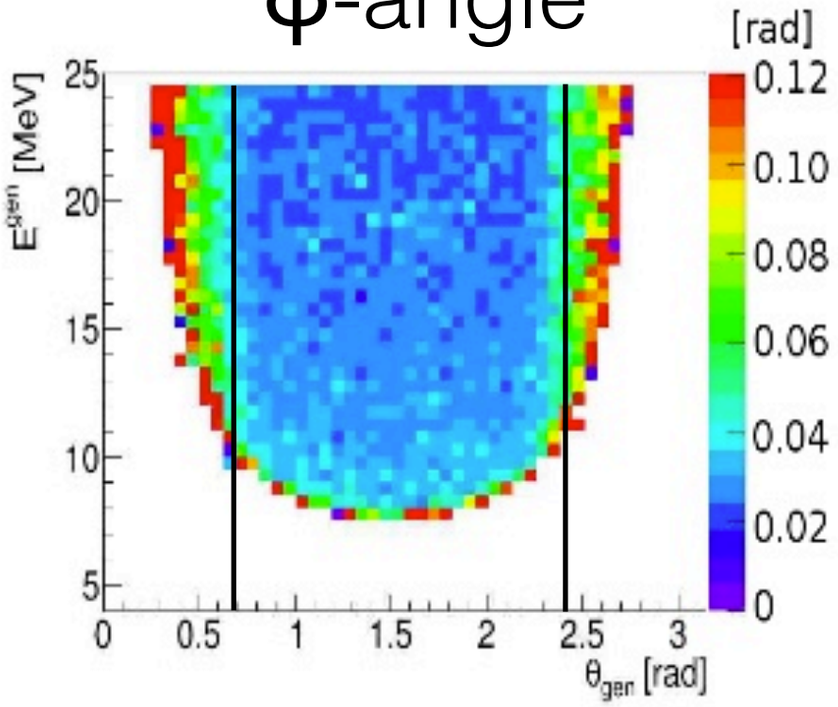
Figures courtesy of W. Armstrong, CLAS collaboration meeting June 2023

Expected ALERT Resolutions ^{4}He

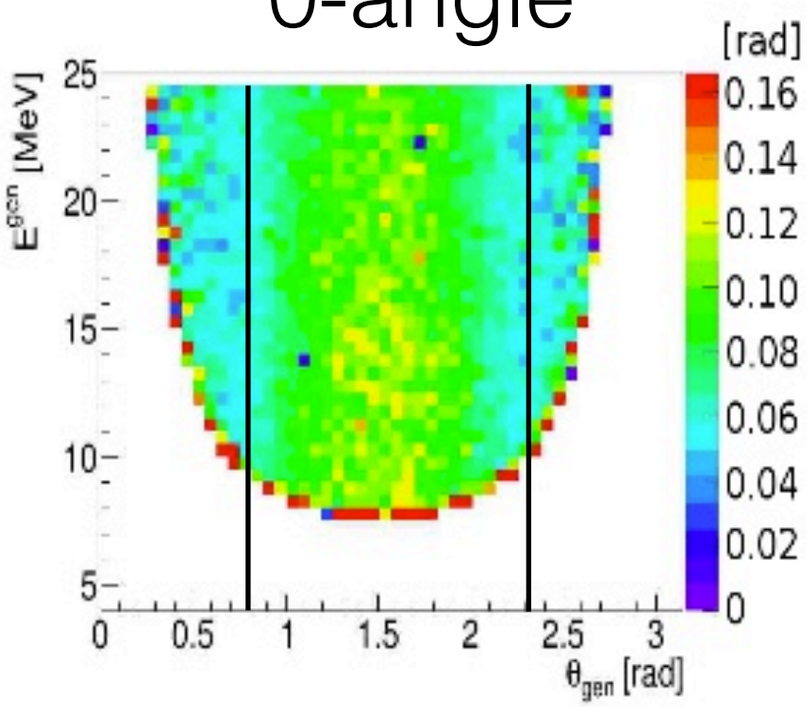
z-vertex



ϕ-angle



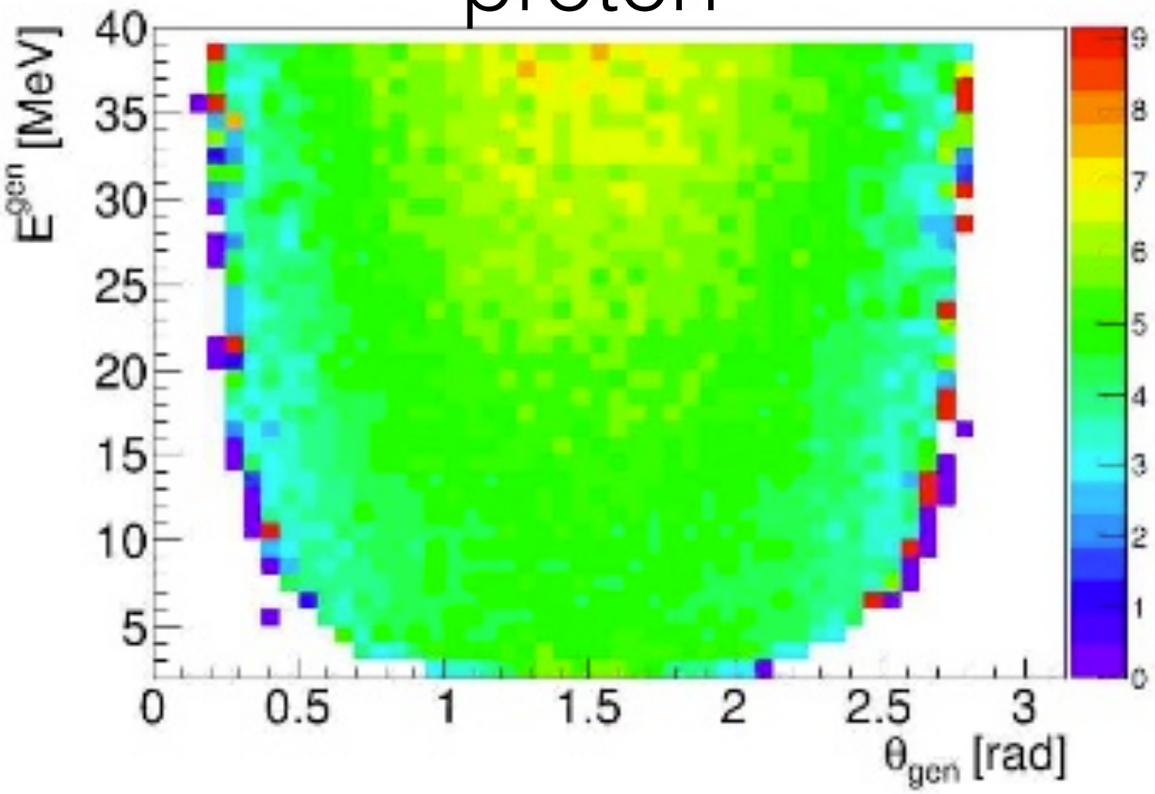
θ-angle



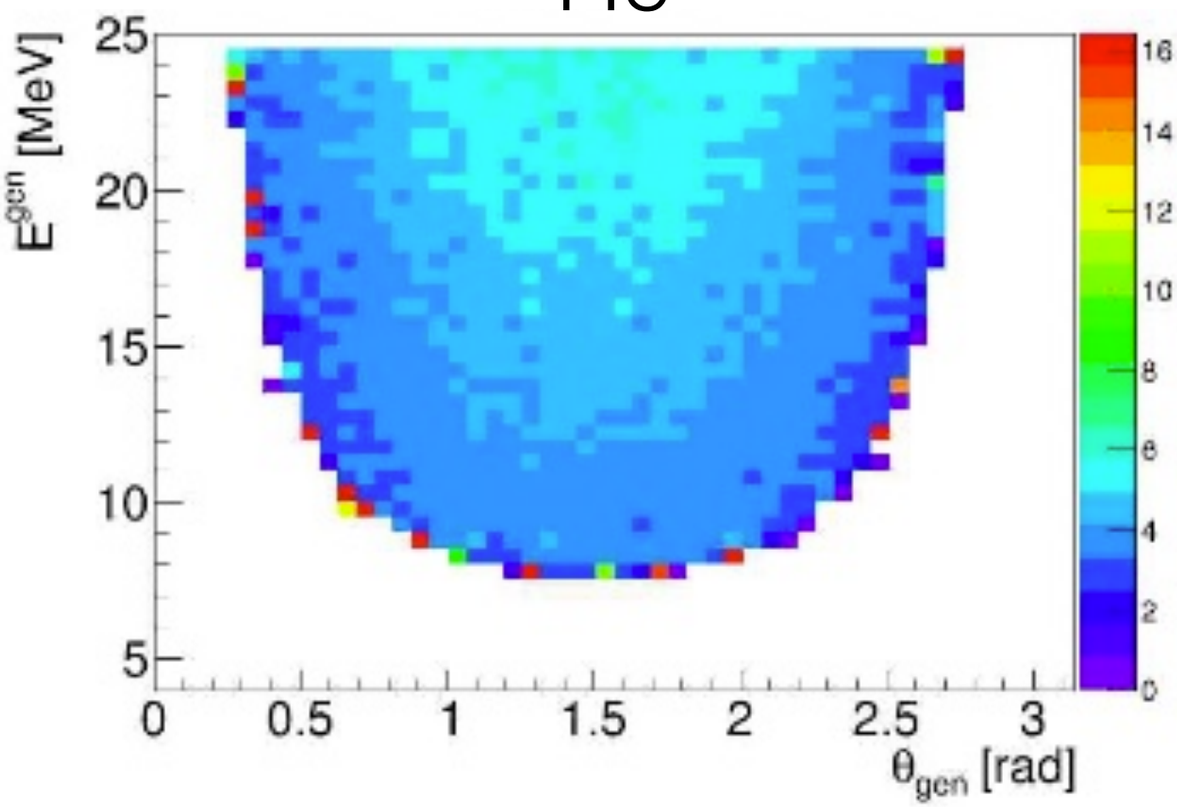
- Resolutions from approved ALERT proposal E12-17-012 (https://misportal.jlab.org/pacProposals/proposals/1338/attachments/98370/Proposal.pdf)
- Assumed resolutions for deuterons/tritons within acceptance
  - ϕ = 0.1 rad
  - θ = 0.1 rad

ALERT Momentum Resolutions

proton



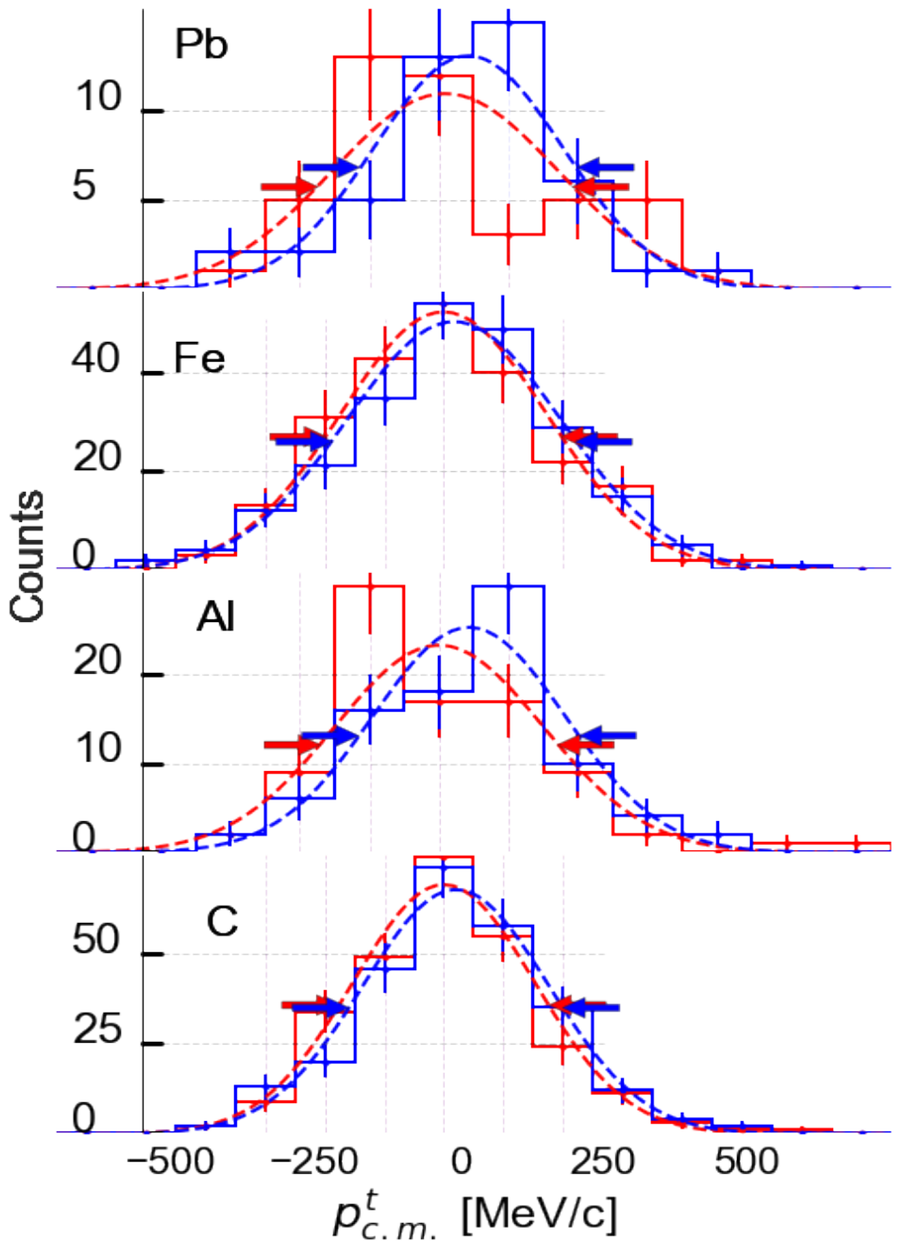
^{4}He



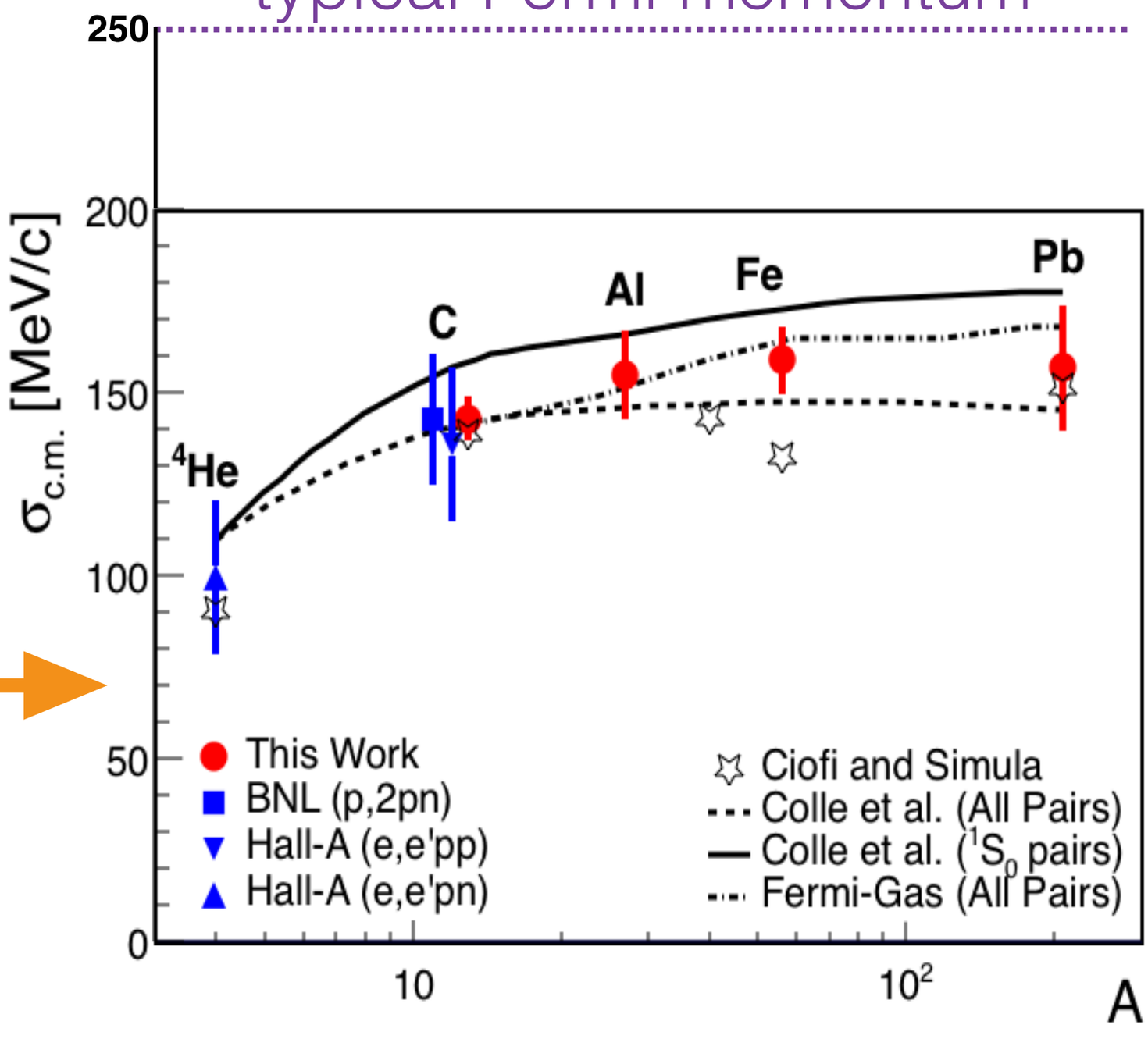
- Resolutions from approved ALERT proposal E12-17-012 (https://misportal.jlab.org/pacProposals/proposals/1338/attachments/98370/Proposal.pdf)
- Assumed resolution for deuterons/tritons will be between protons and 4He —> ~4%

SRC pair - center of mass momentum

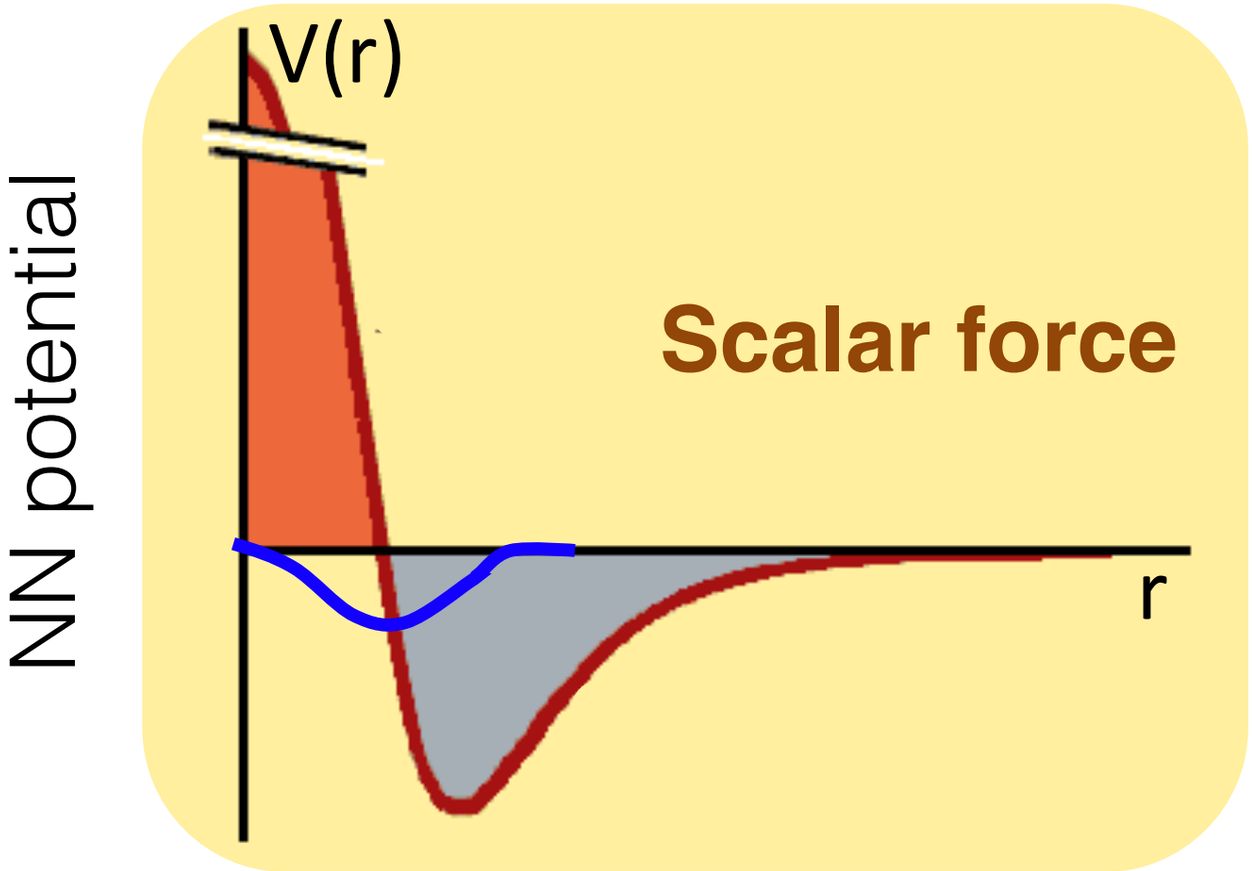
E. Cohen et al.(CLAS collaboration), PRL (2018)



typical Fermi momentum

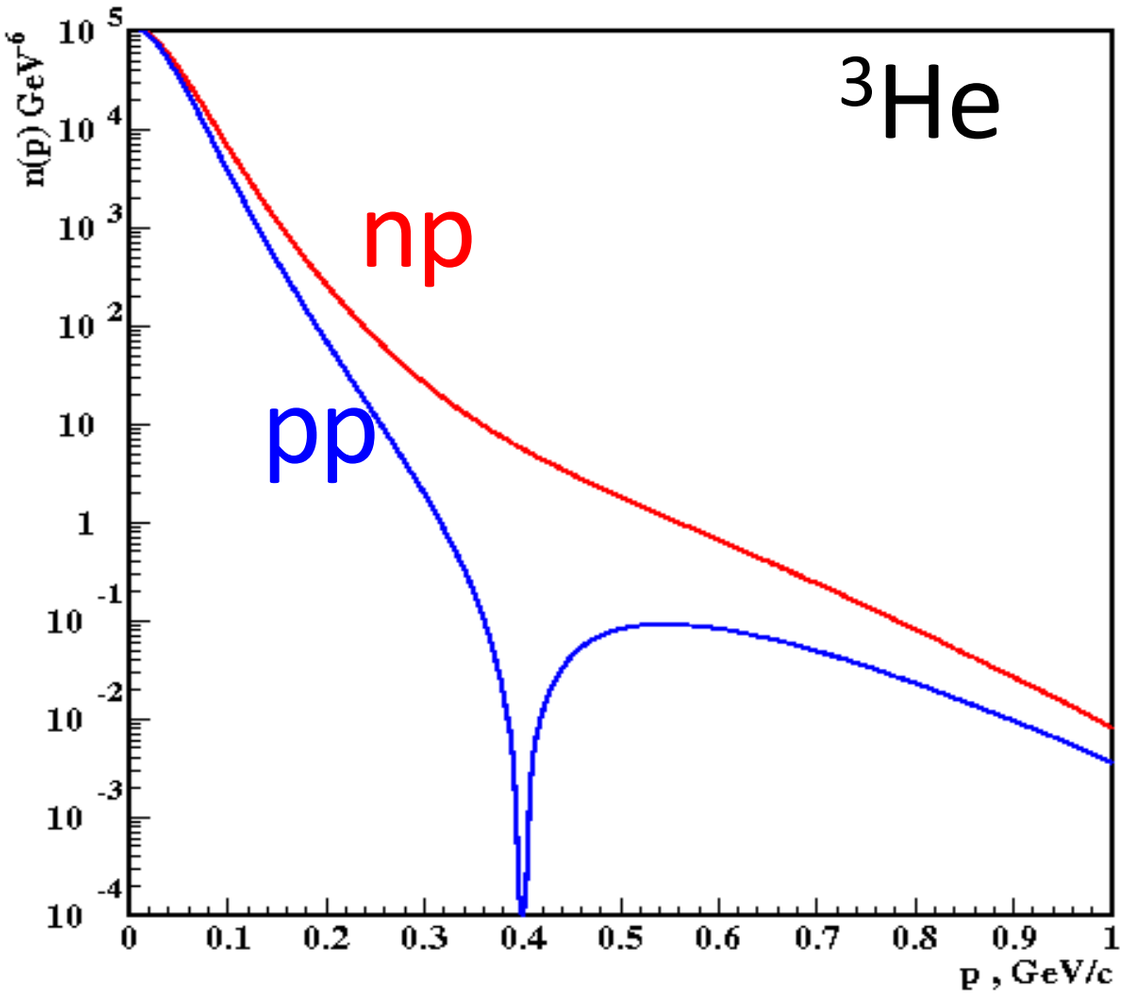


np-Dominance from Tensor Force

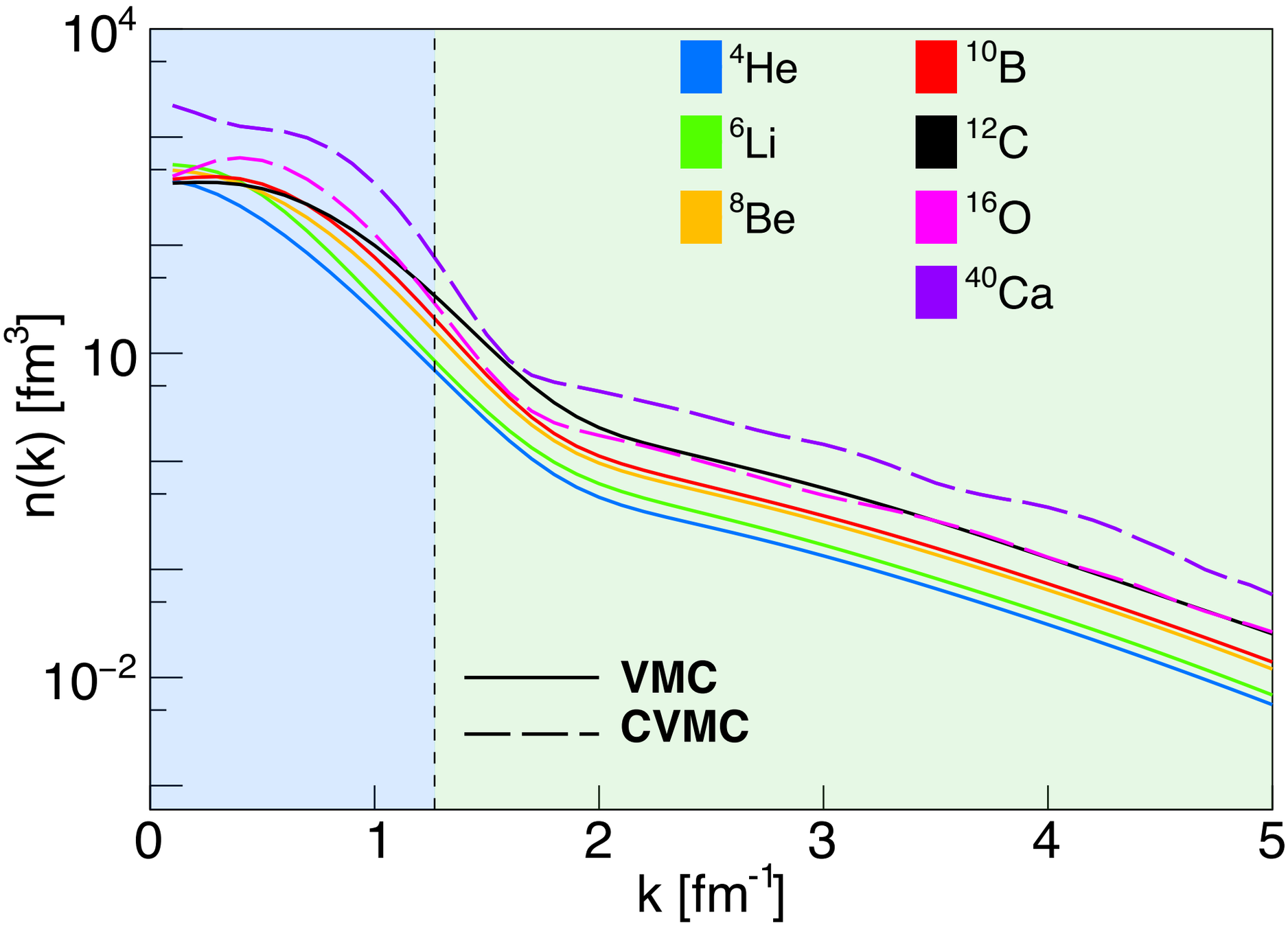


Tensor force
Short-Range attraction

Sargsian et al., PRC (2005)

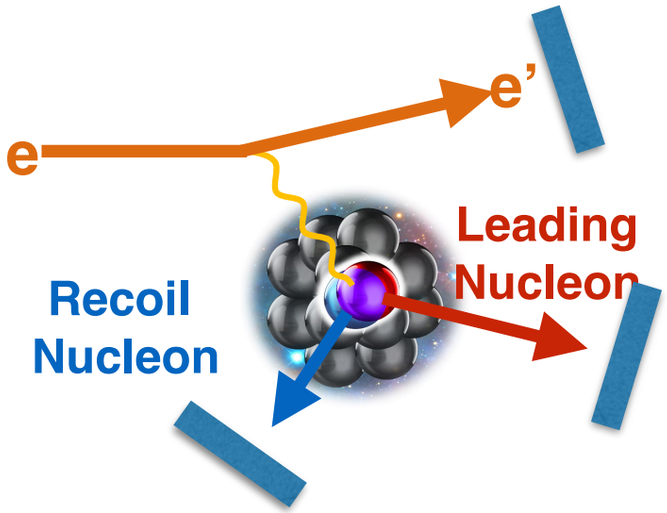


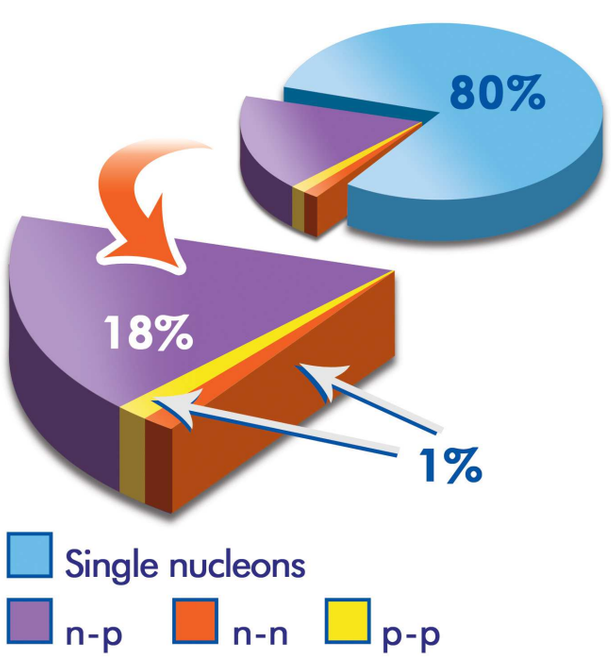
Universality of High Momentum Tail



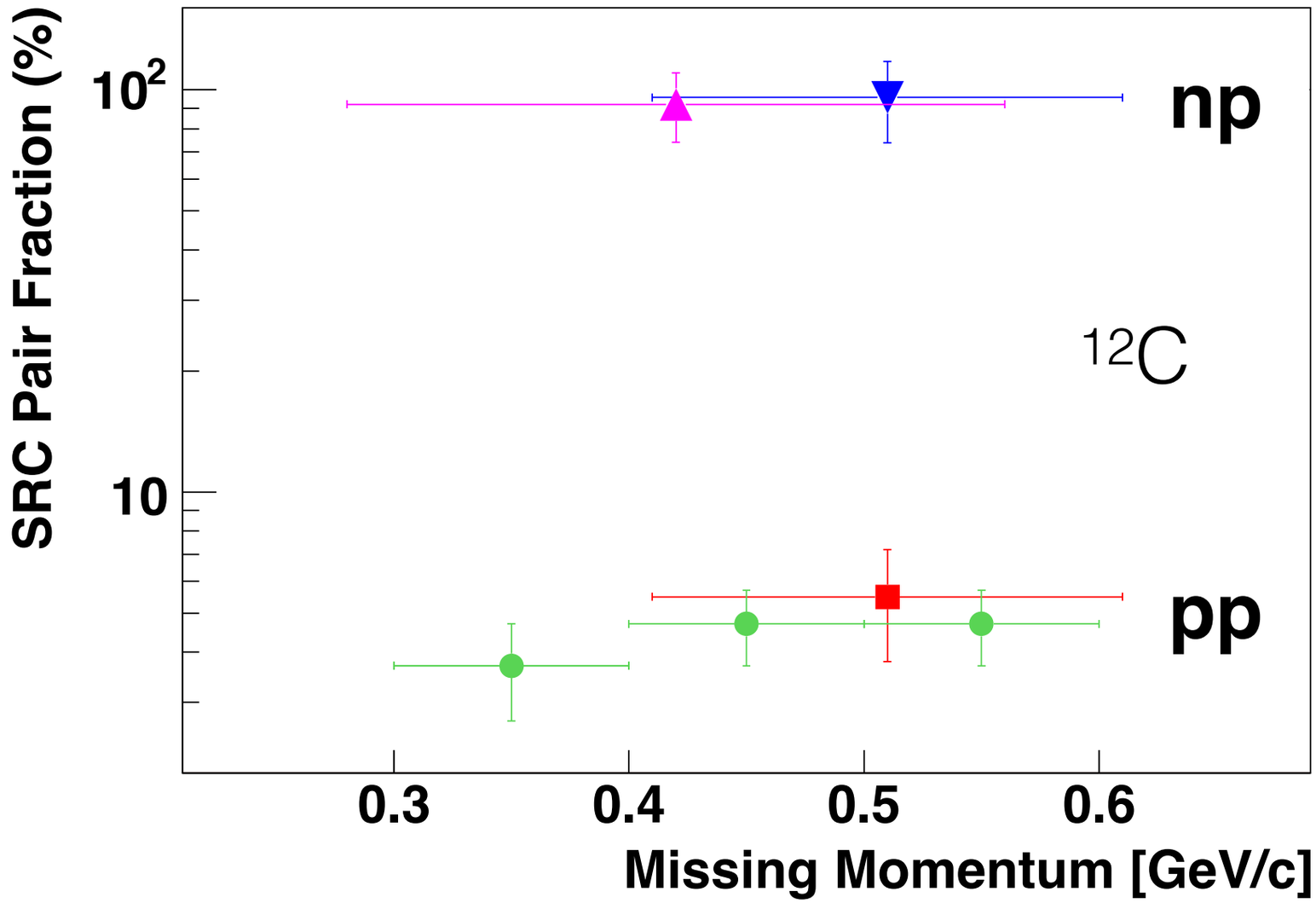
B. Wiringa, https://www.phy.anl.gov/theory/research/QMCresults.html

np-Dominance





- Far more np pairs than pp pairs
- Similar in all nuclei



Piasetzky, PRL (2006), Shneor, PRL (2007), Subedi, Science (2008), Korover, PRL (2014), Hen , Science (2014), Duer, Nature (2018), Duer, PRL (2019), Schmidt, Nature (2020), Korover (2020) Review: Hen RMP (2017)