

Exclusive Measurements of SRC in He with ALERT

Florian Hauenstein

5th International Workshop on Quantitative
Challenges in SRC and EMC Research

06/10/26

 **Jefferson Lab**

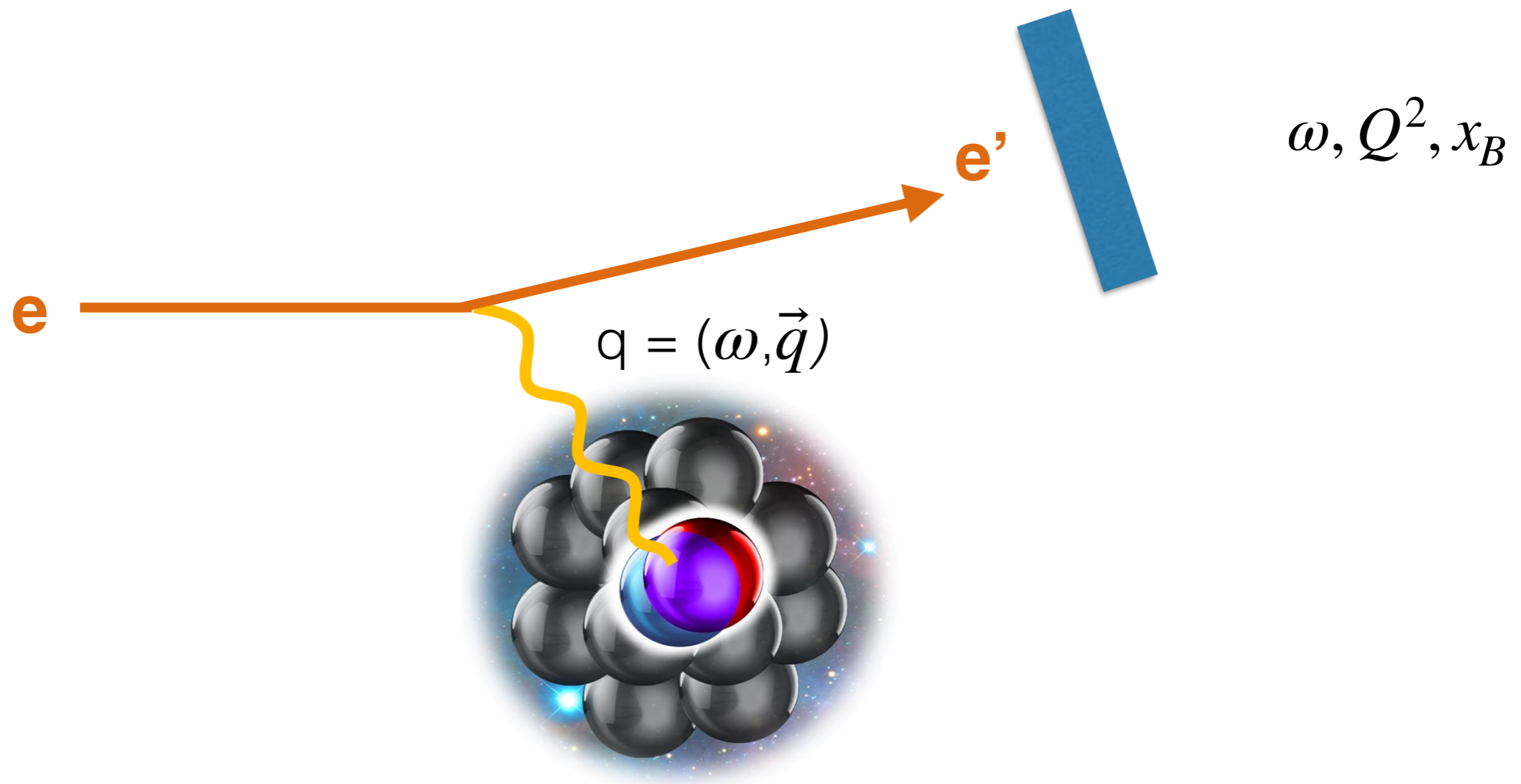


 The logo for Tsinghua University, featuring the Chinese characters '清華大學' in a stylized purple font above the English name 'Tsinghua University' in a smaller purple font.

 The logo for the University of Paris-Saclay, featuring the word 'université' in a purple serif font above 'PARIS-SACLAY' in a purple sans-serif font.

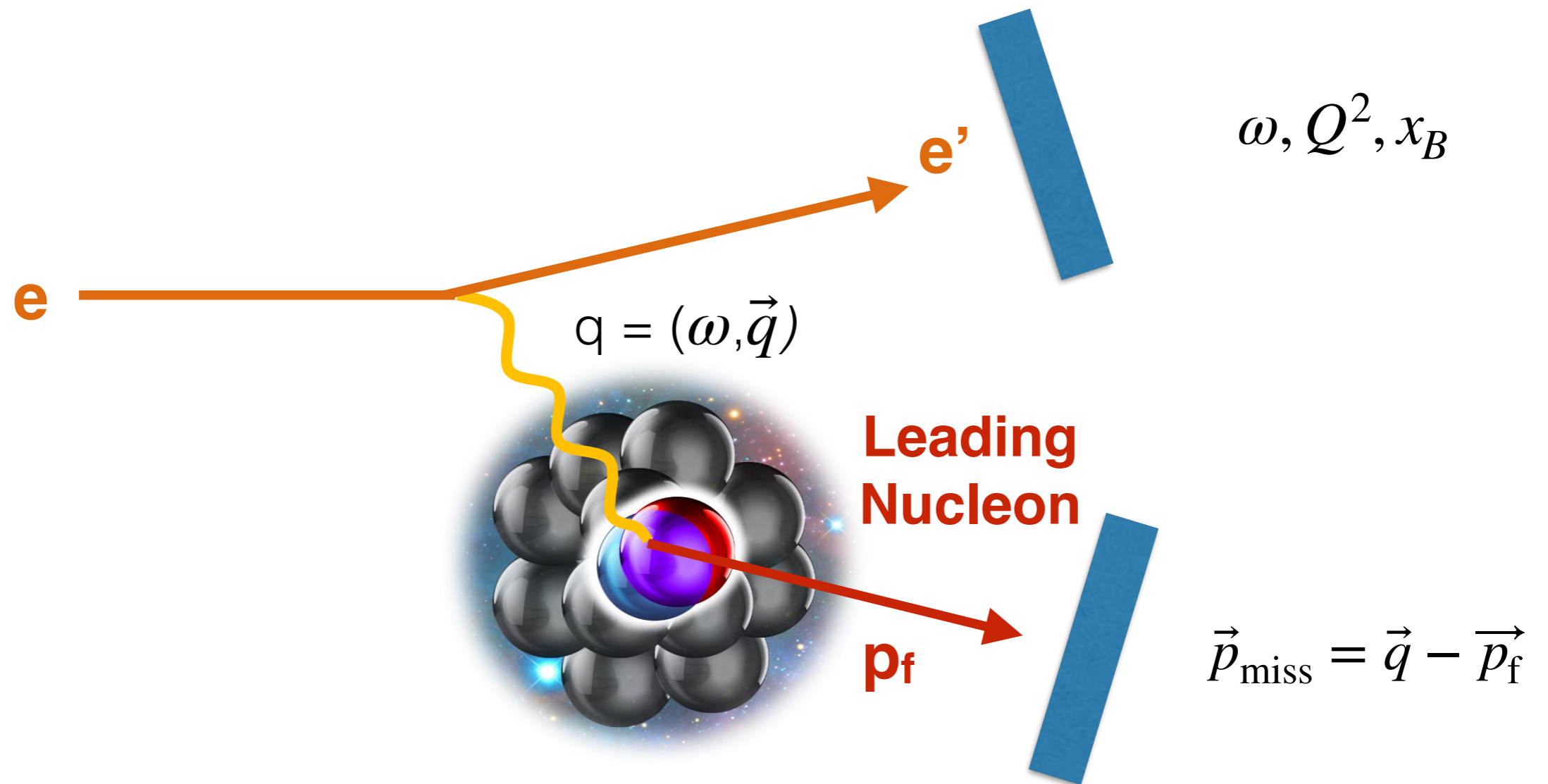


Usual Electron Scattering off SRC pair



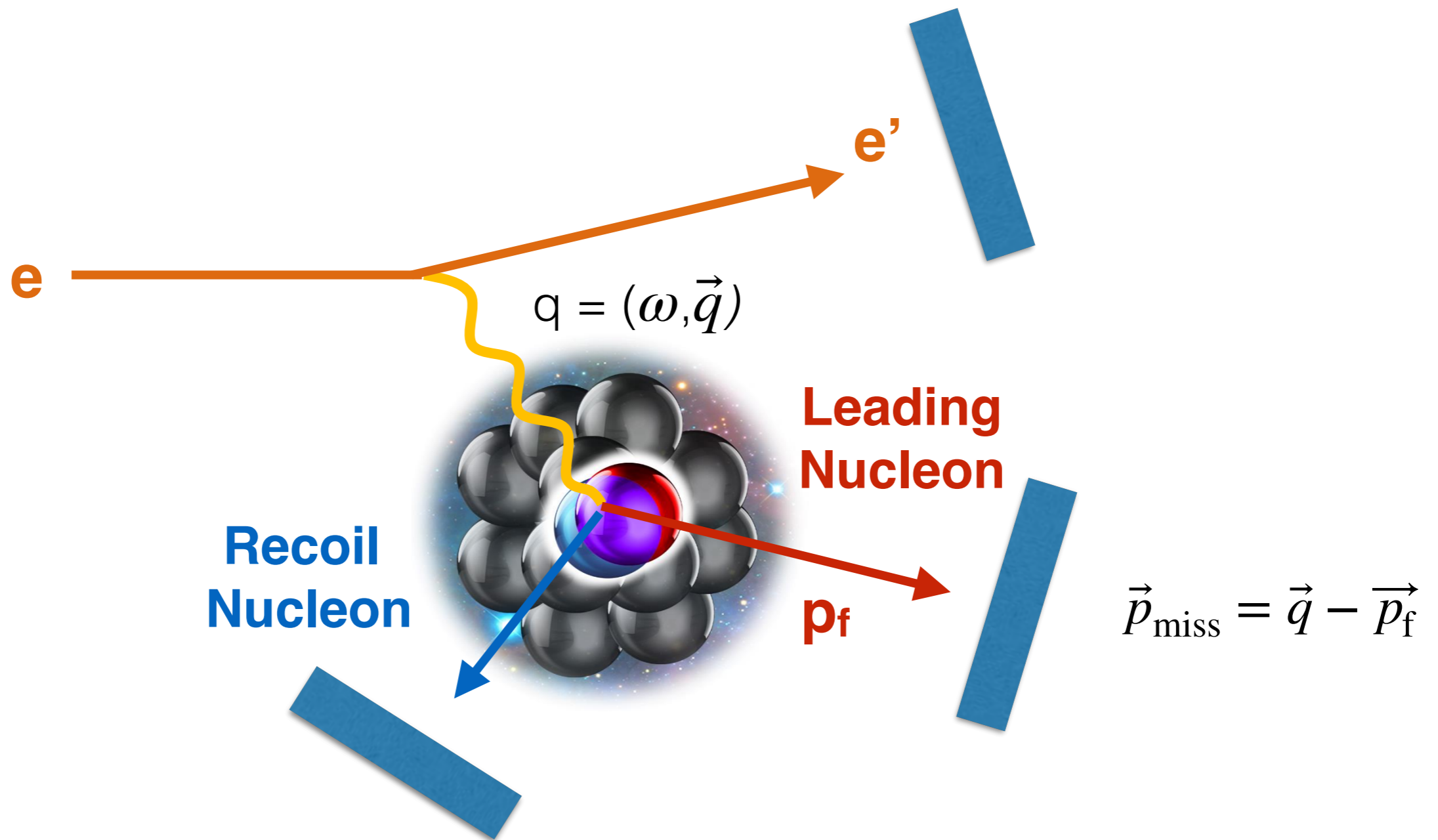
- (e,e') inclusive

Usual Electron Scattering off SRC pair



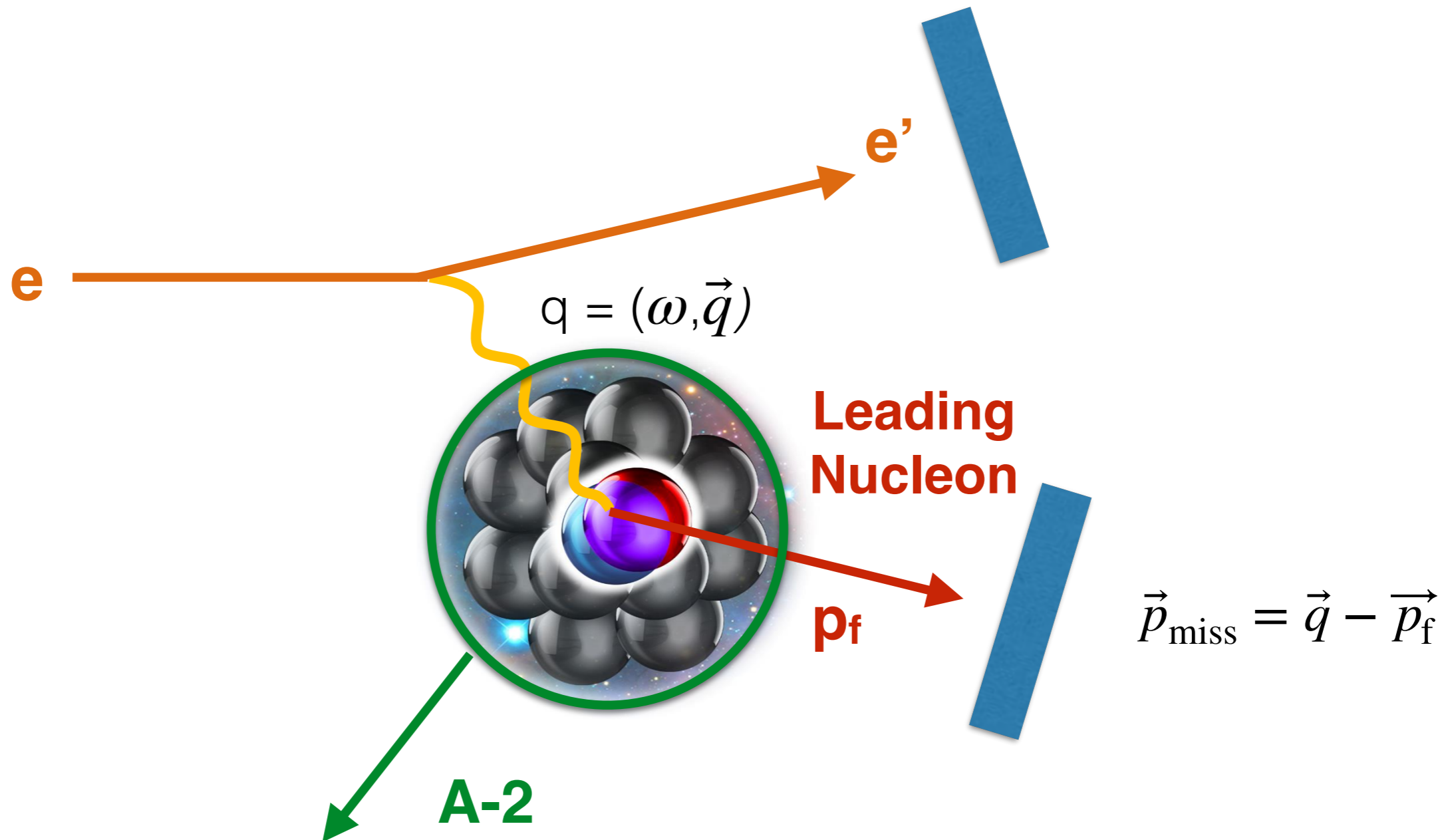
- (e, e') inclusive
- $(e, e'N)$

Usual Electron Scattering off SRC pair



- (e, e') inclusive
- $(e, e'N)$
- $(e, e'NN)$

Usual Electron Scattering off SRC pair



- Detection of remaining nucleus gives (depending on reaction)
 - fully exclusive reaction
 - selection of specific initial states
 - understanding and suppression of nuclear effects

Usual Electron Scattering off SRC pair

Can we detect recoil nuclei in fixed-target experiments?

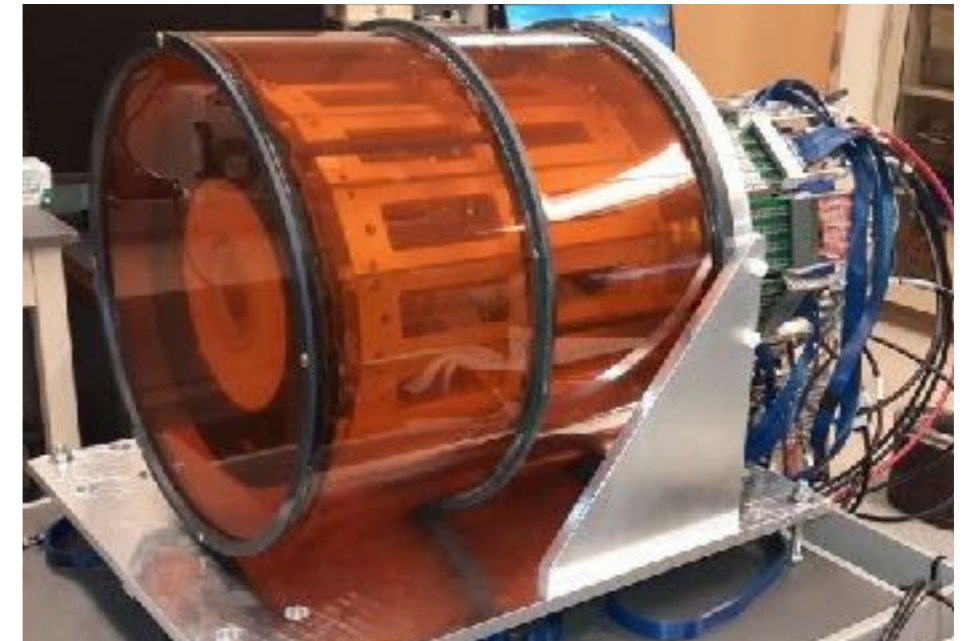
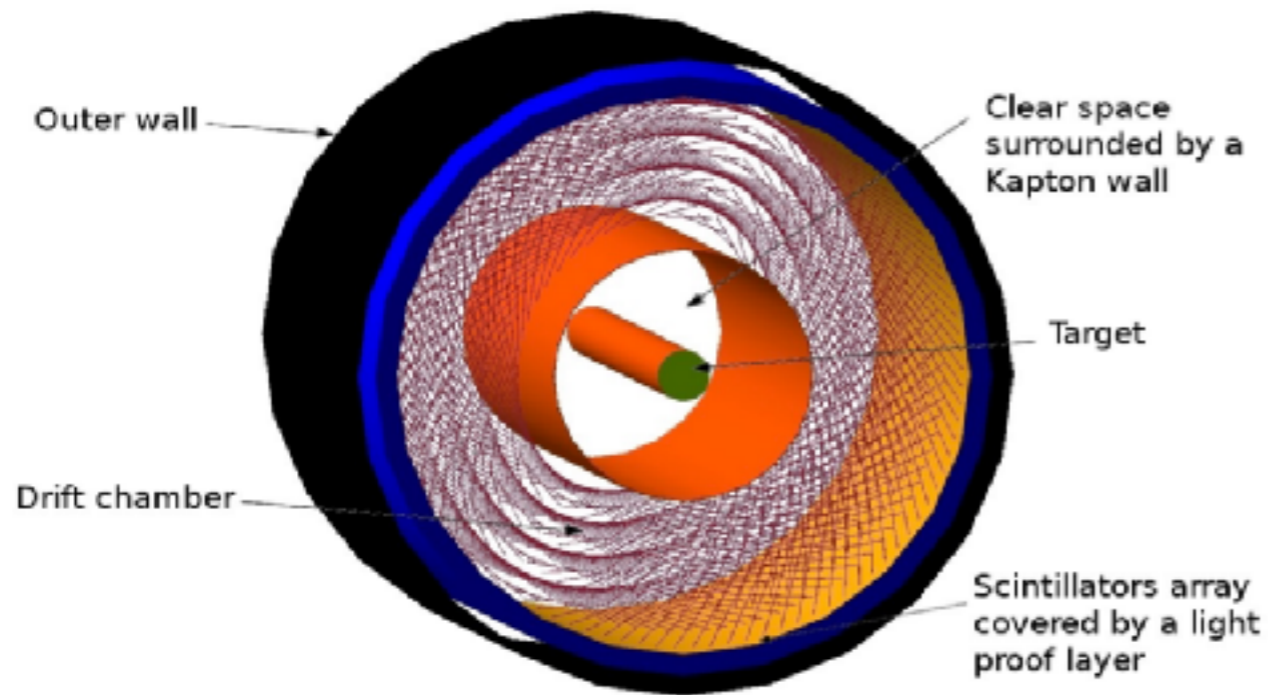
Yes! But

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

Solution

Novel ALERT Detector

ALERT: A Low Energy Recoil Tracker



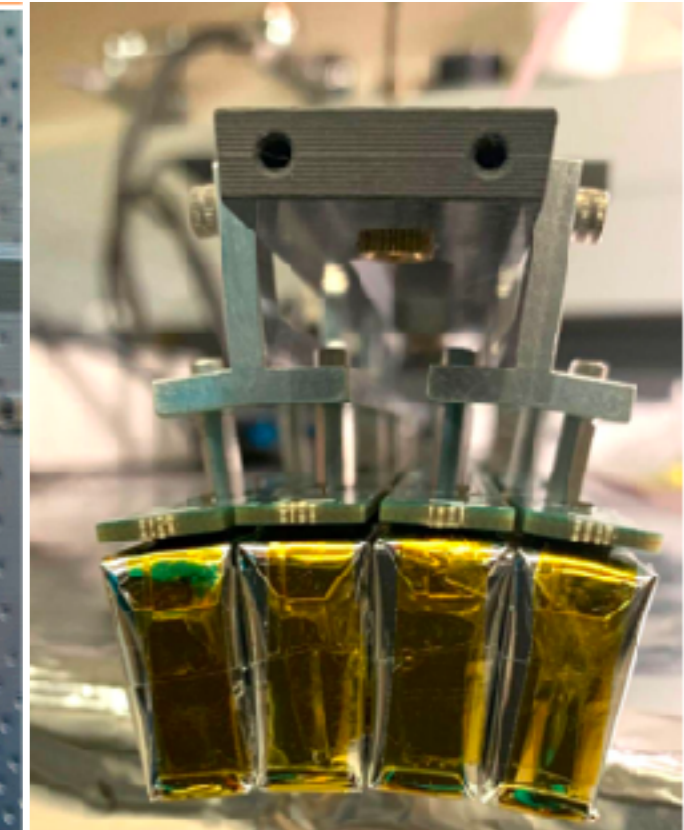
~0.5m

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

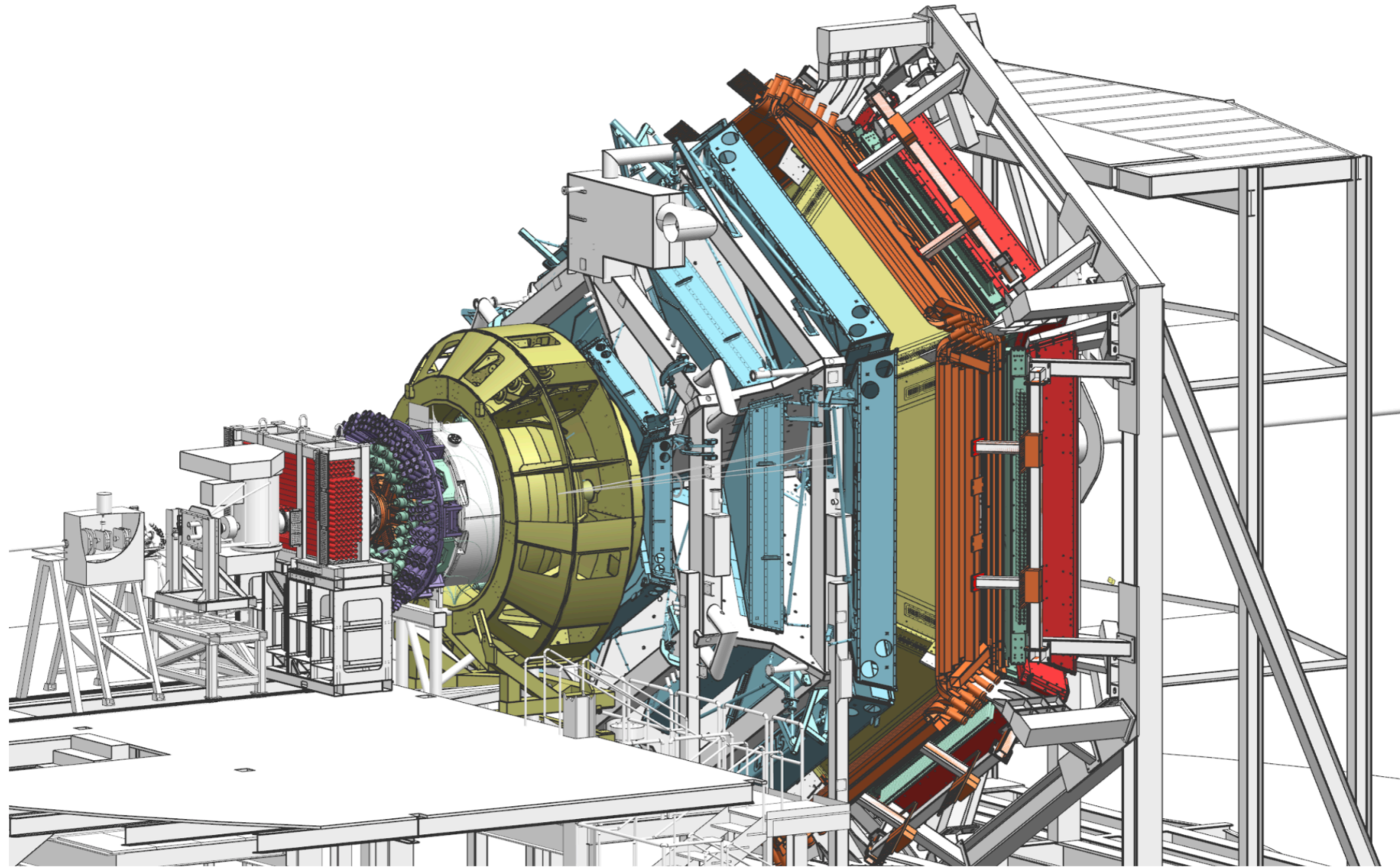
DC



TOF



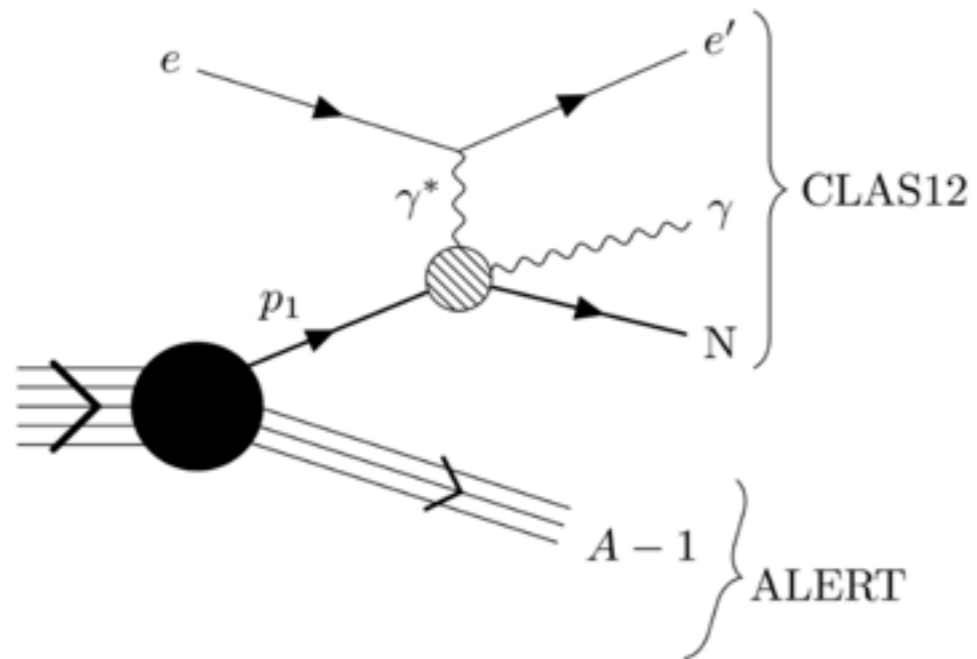
CLAS12 at Jefferson Lab Hall B



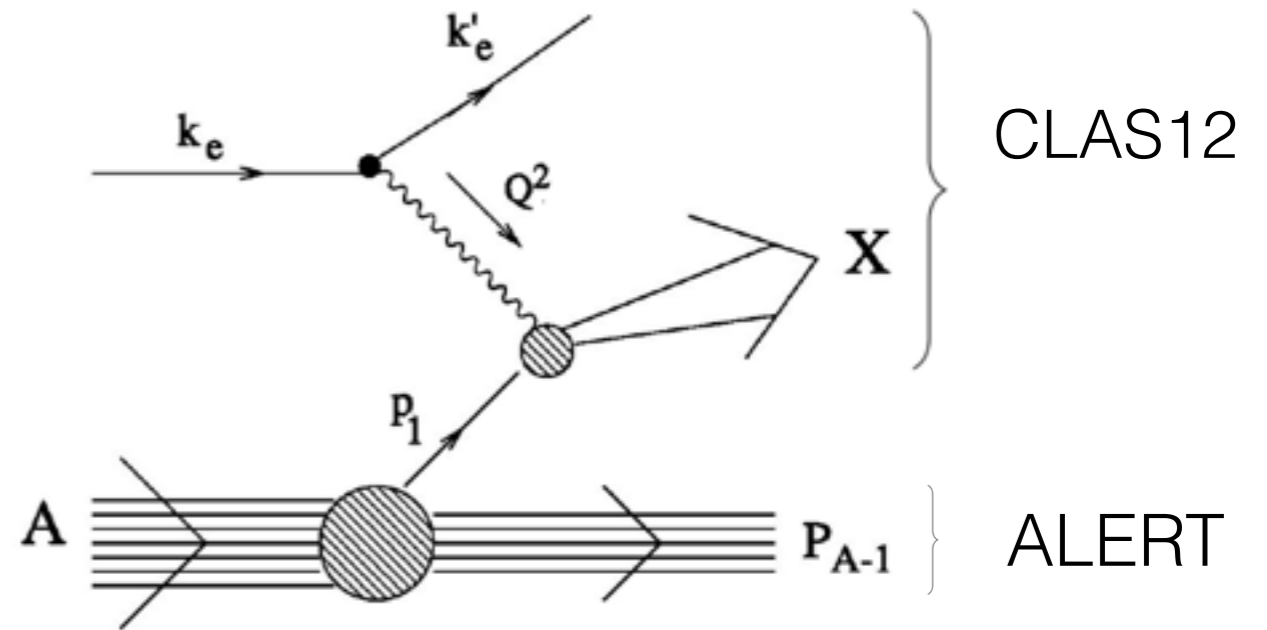
- Spectrometer with solenoid and torus fields
- $\sim 4\pi$ acceptance
- Neutral and charged particle detection
- Central tracker within solenoid field replaced with ALERT

Physics with ALERT

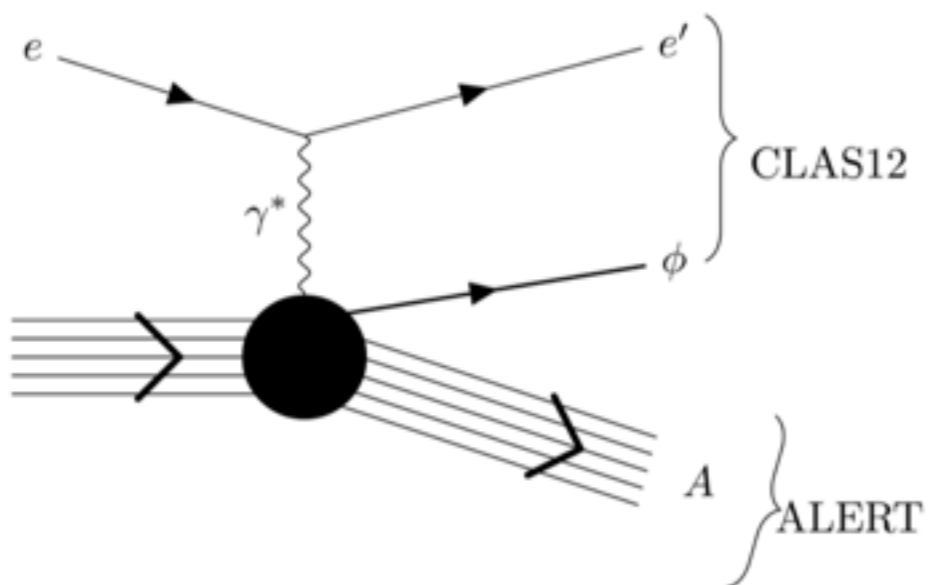
Tagged DVCS



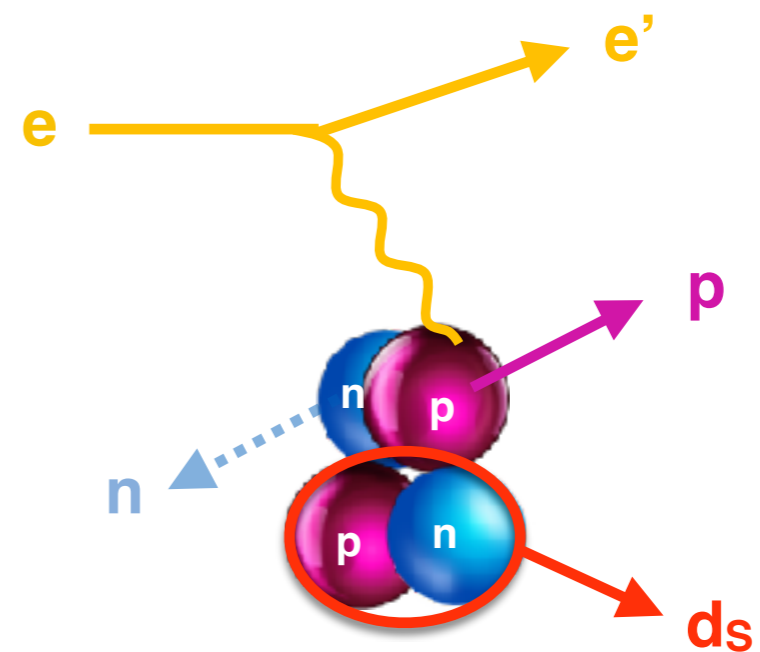
Tagged EMC



Nuclear GPDs

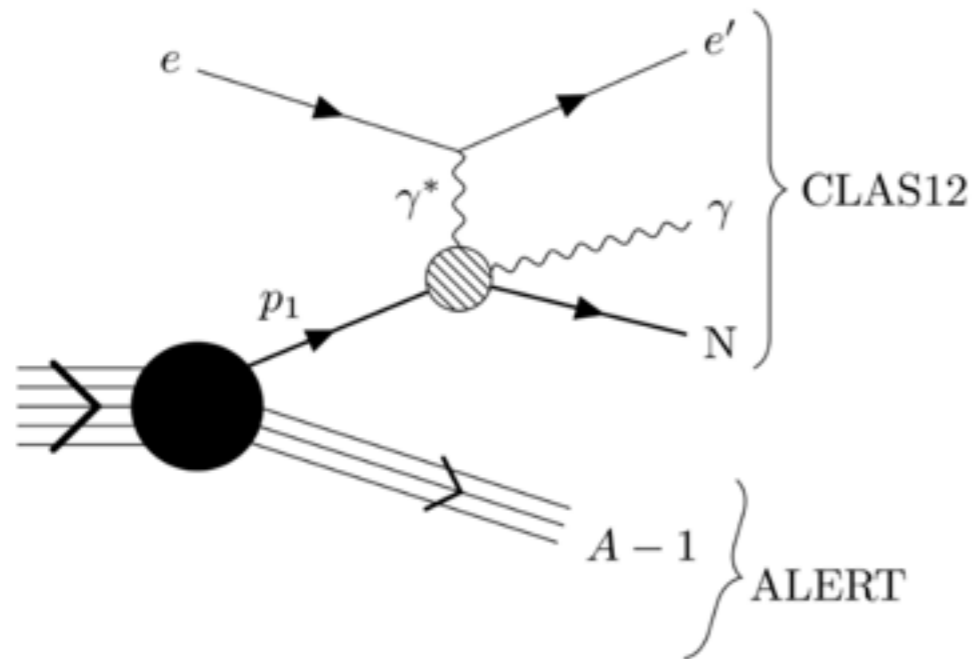


Tagged SRCs

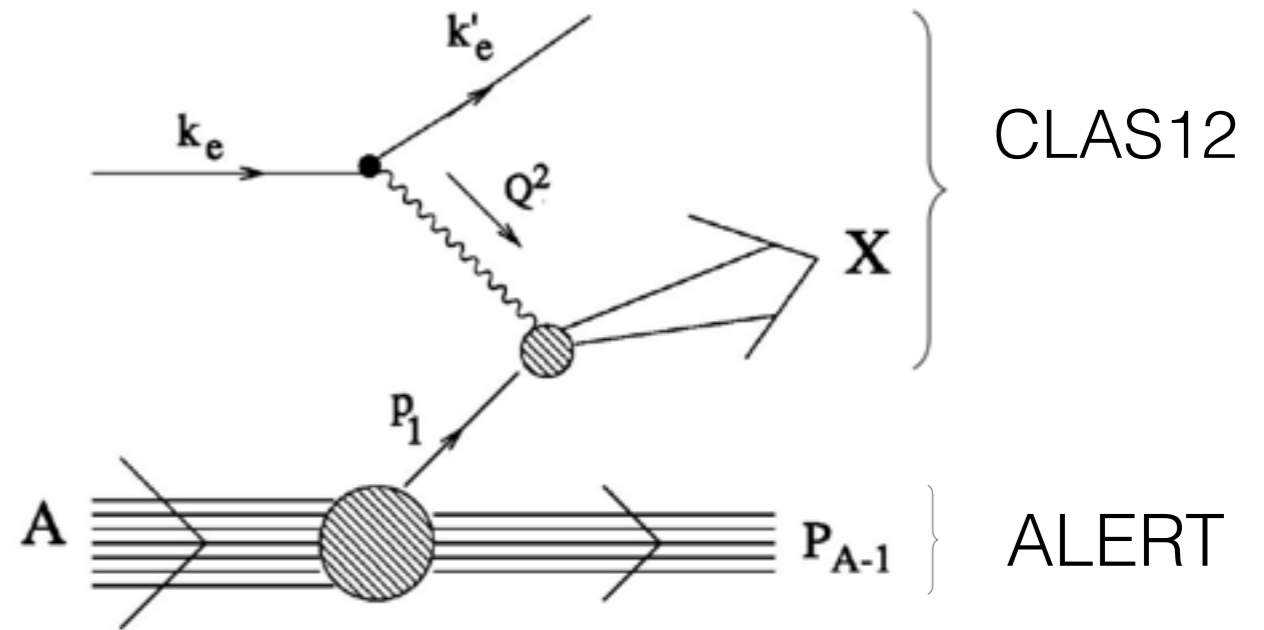


Physics with ALERT

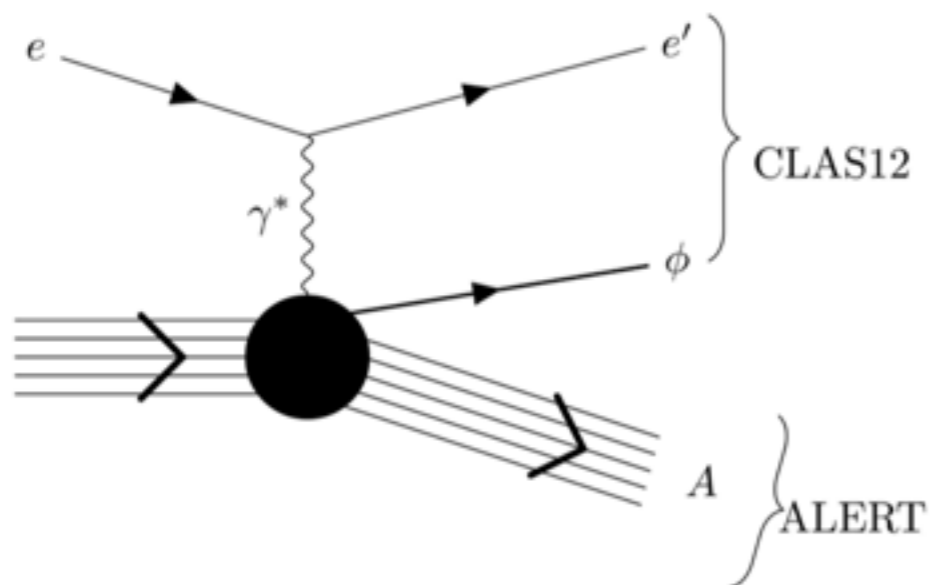
Tagged DVCS



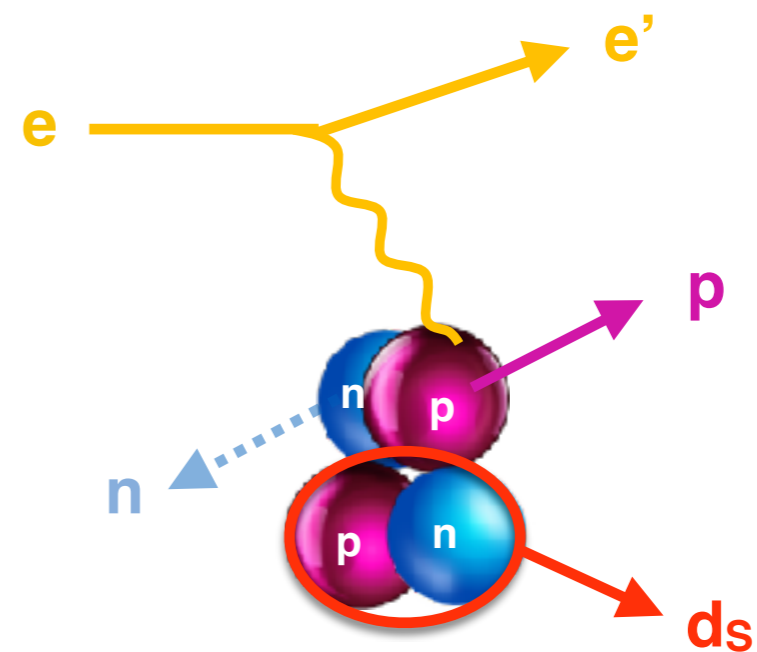
Tagged EMC



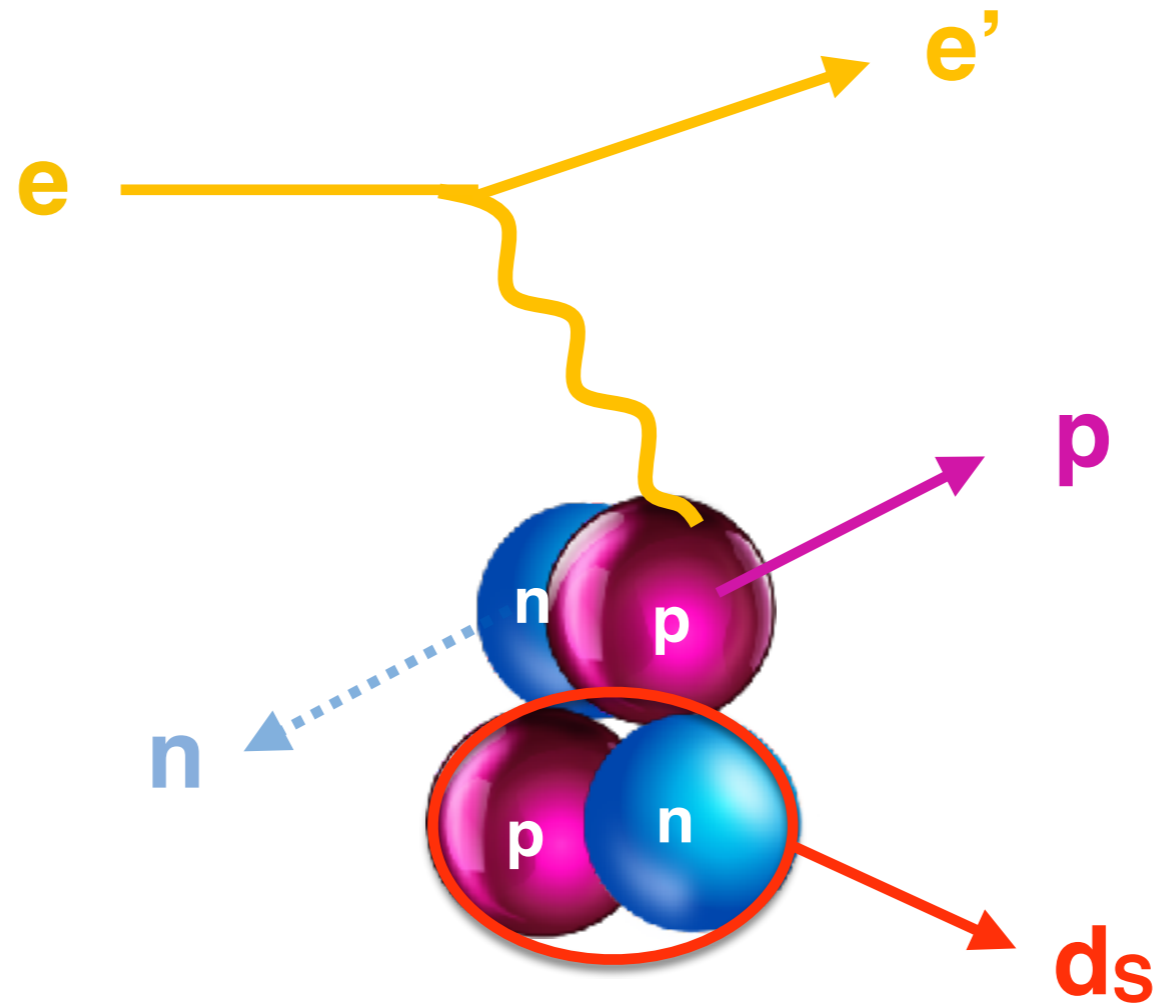
Nuclear GPDs



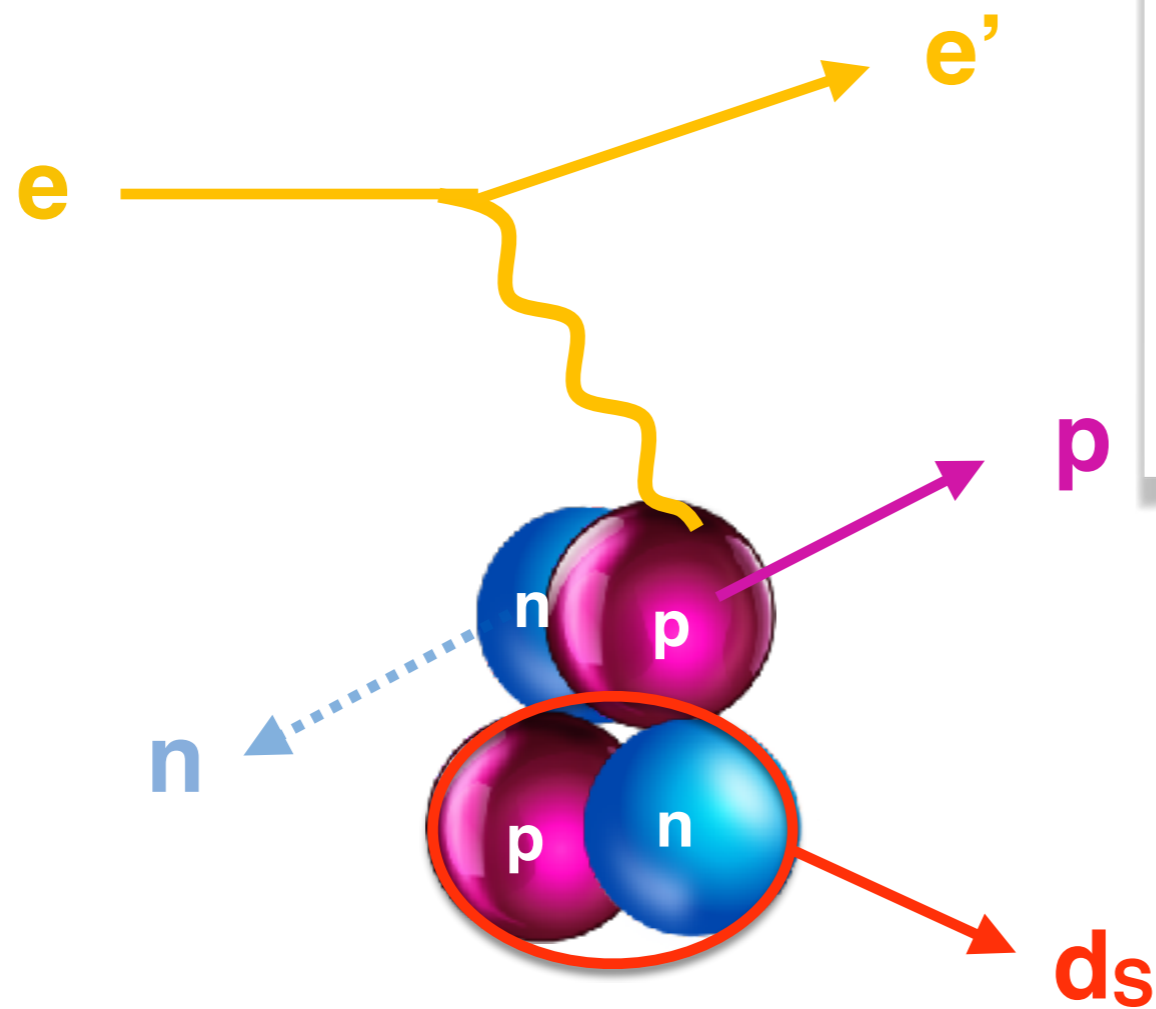
Tagged SRCs



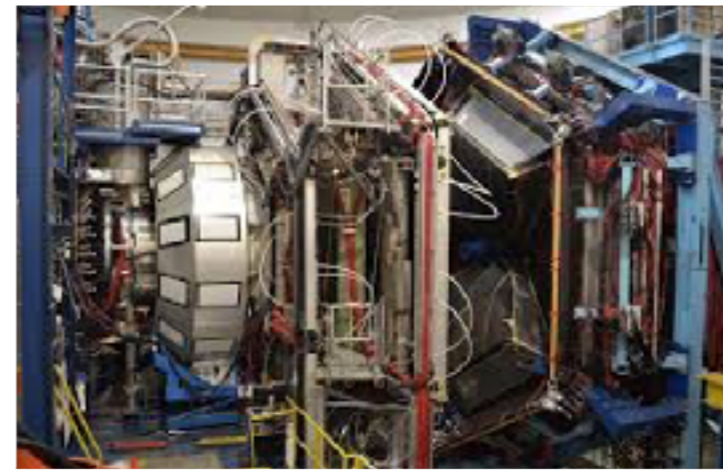
Main Channel ${}^4\text{He}(e, e'pd_s)n$



Main Channel ${}^4\text{He}(e, e'pd_s)n$



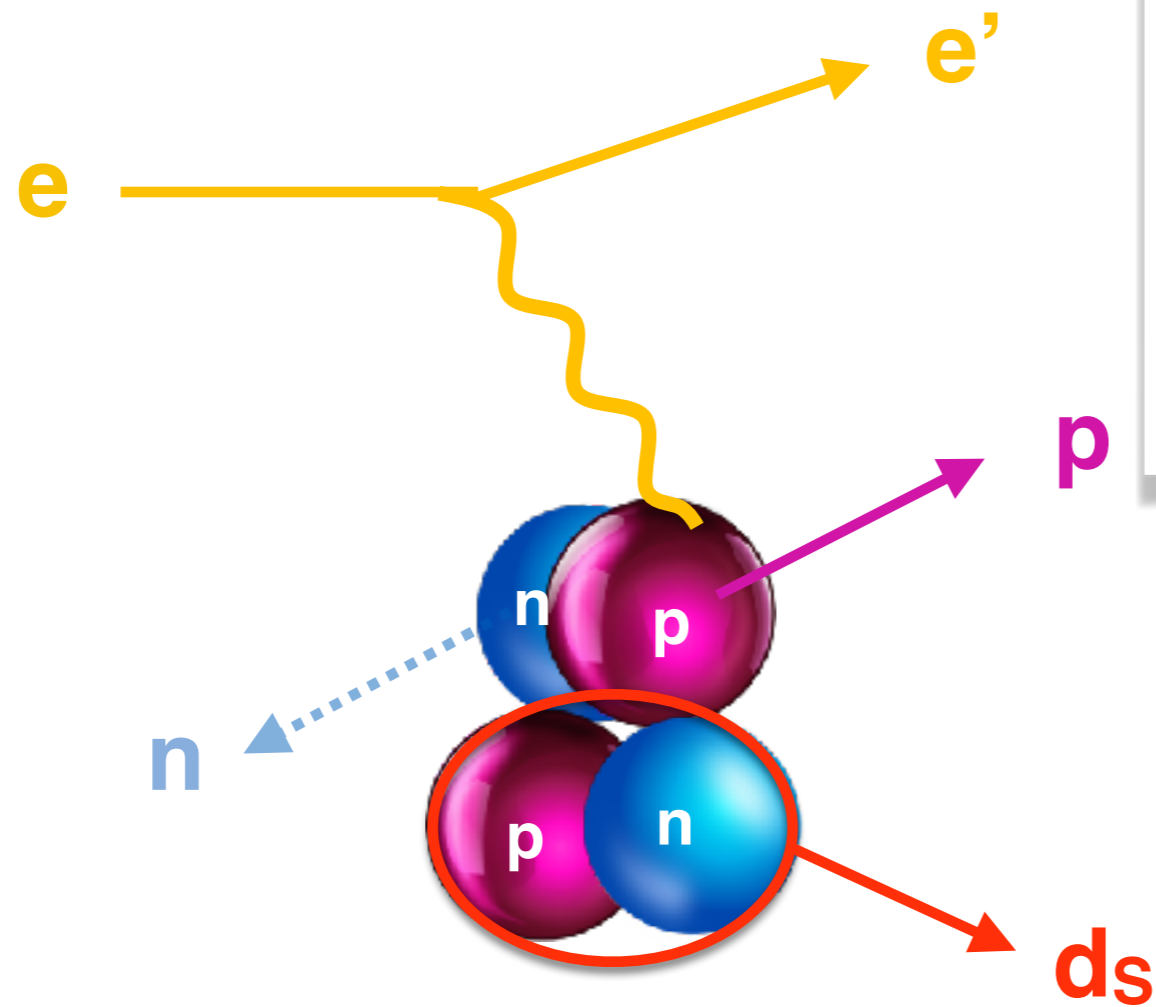
CLAS12



ALERT



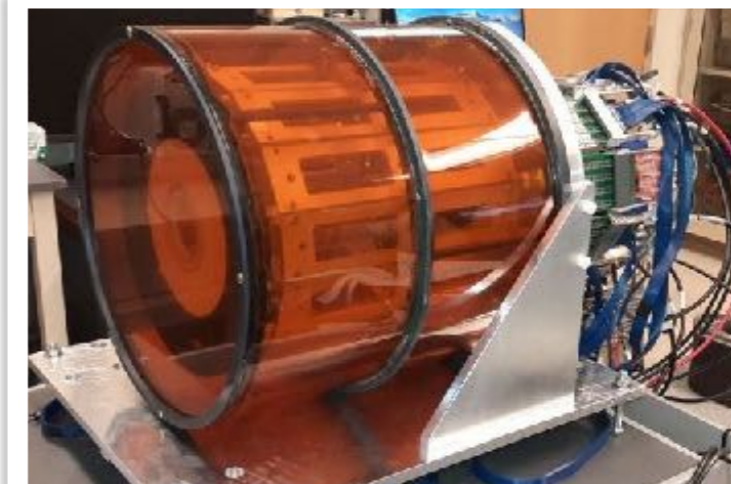
Main Channel ${}^4\text{He}(e, e' p d s) n$



CLAS12



ALERT

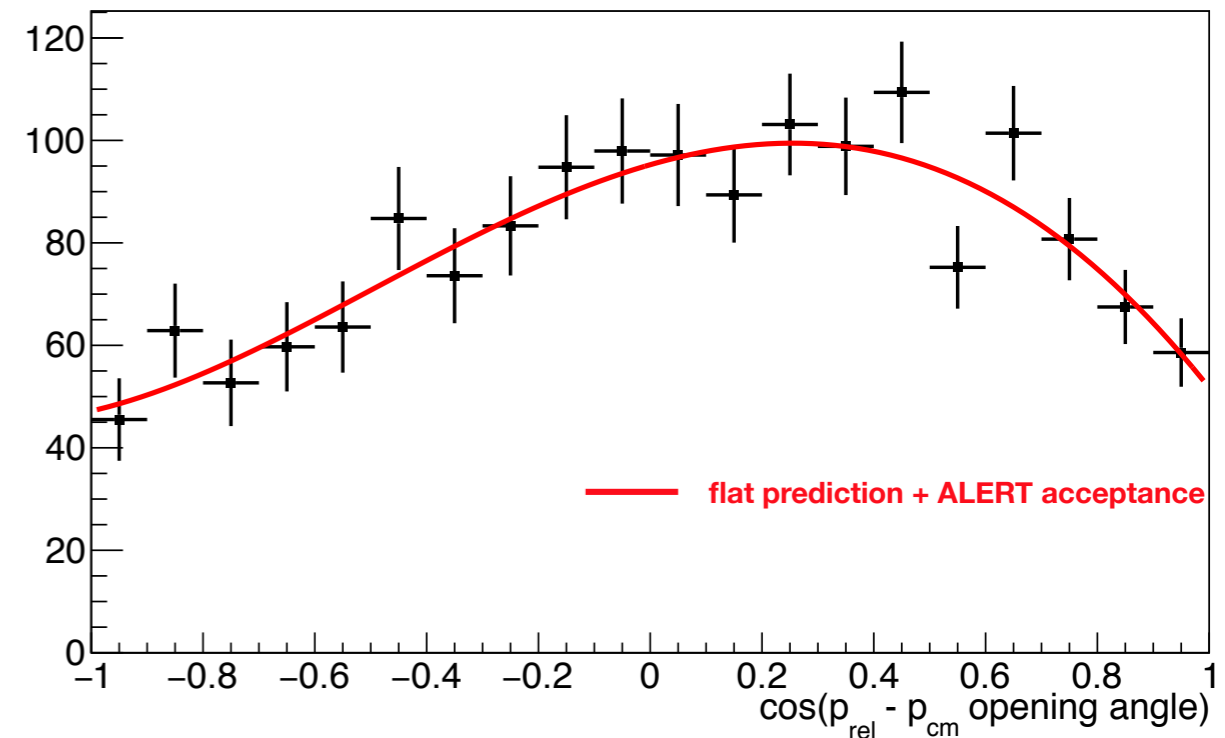


Experimental Details

- Took data last year for 34 days
- Beam energy 6.4 GeV
- Luminosity: $3 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$
- $\sim 290 \text{mC}$ collected charge

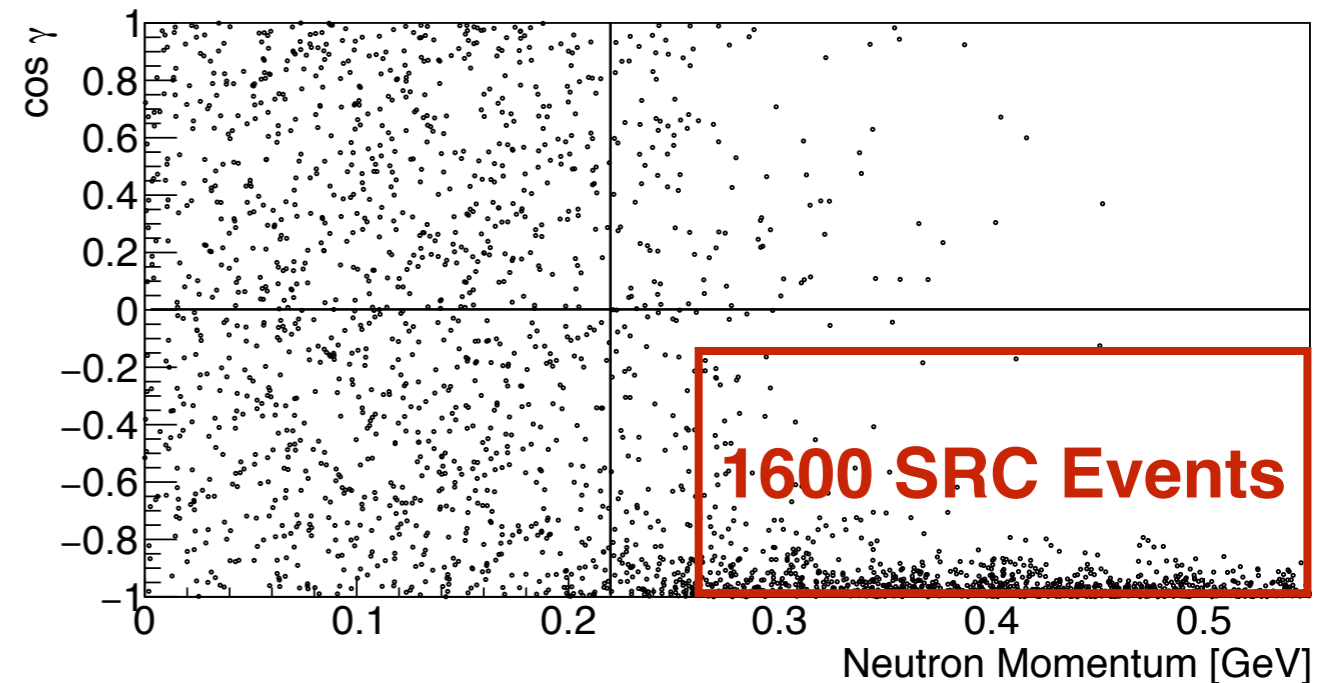
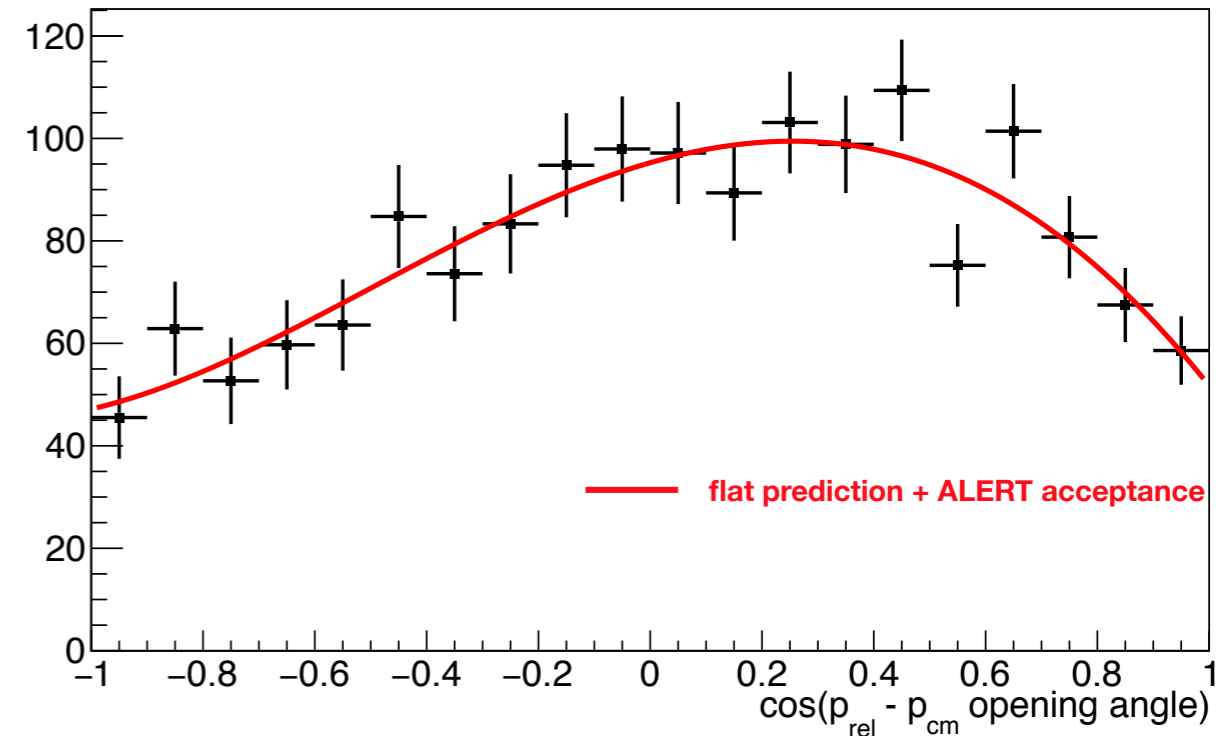
Goals and Projected Results

- **Test of Factorization between A-2 and pair**
 - ~1600 SRC events from ${}^4\text{He}(e, e'pd_s)n$
 - Based on flat prediction folded with ALERT deuteron acceptance



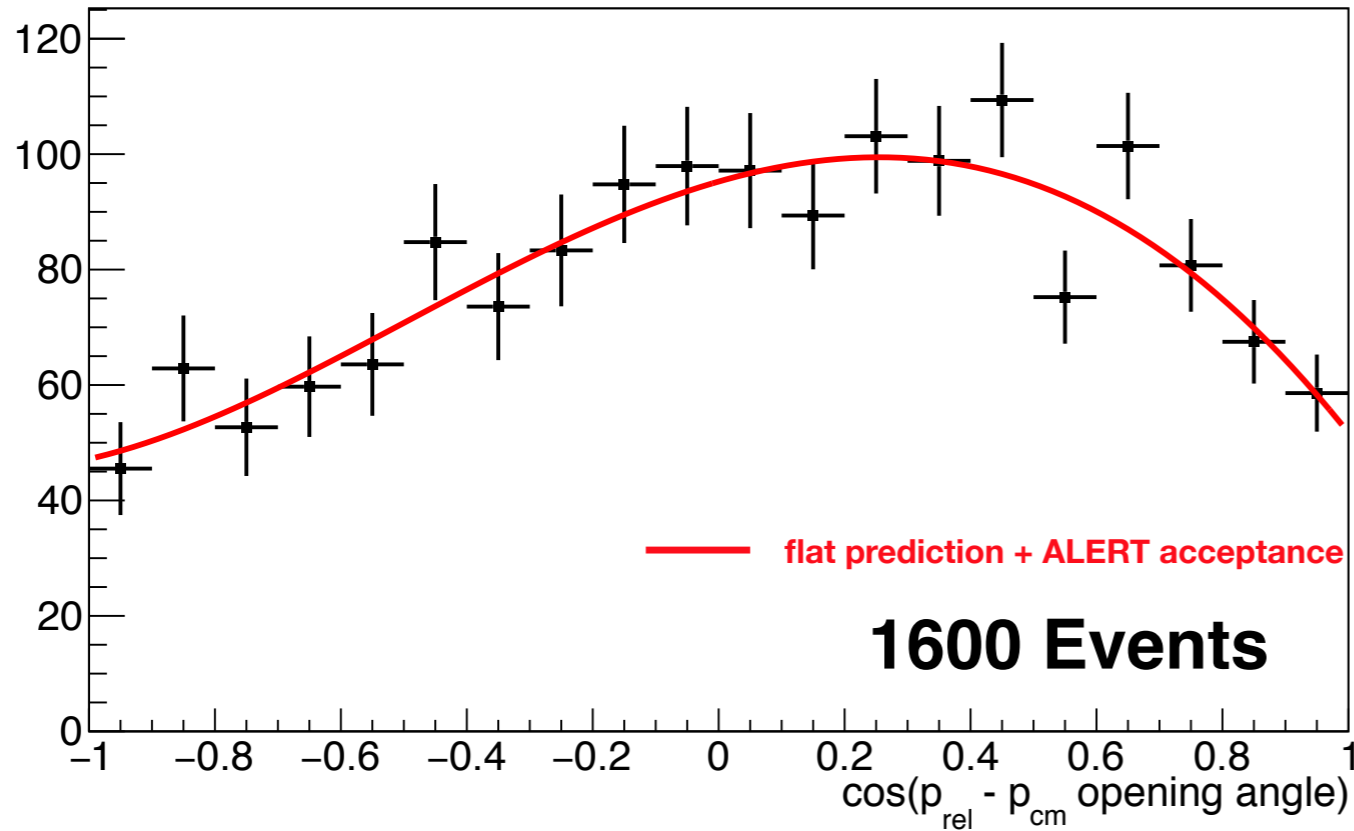
Goals and Projected Results

- **Test of Factorization between A-2 and pair**
 - ~1600 SRC events from ${}^4\text{He}(e,e'pd_s)n$
 - Based on flat prediction folded with ALERT deuteron acceptance
- **Mapping of Mean-field to SRC Transition**
 - ~1600 SRC events from ${}^4\text{He}(e,e'pd_s)n$
 - Similar or more uncorrelated MF events
 - Order of magnitudes more than previous data

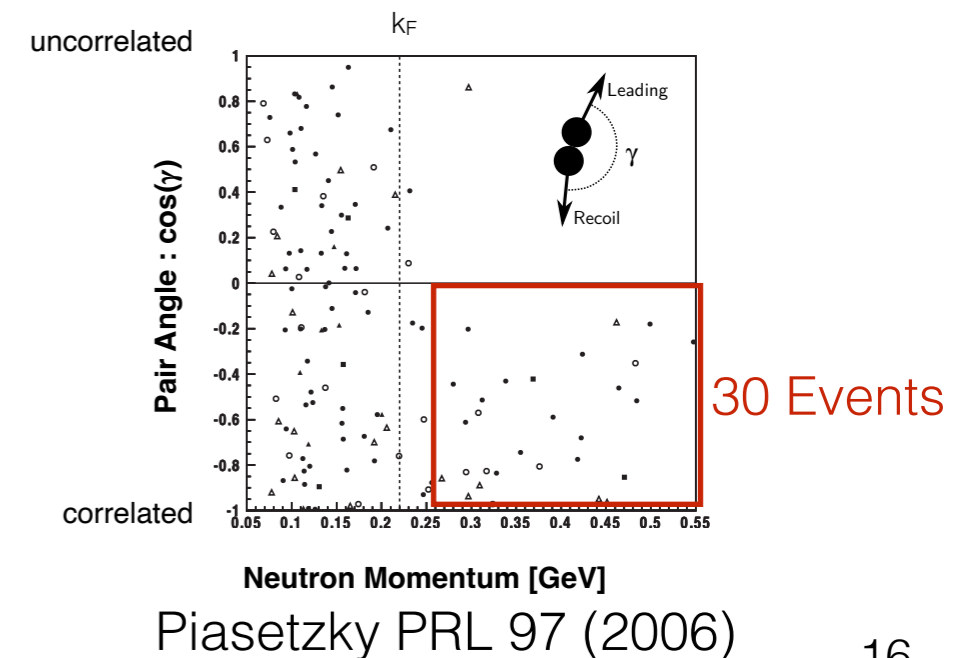
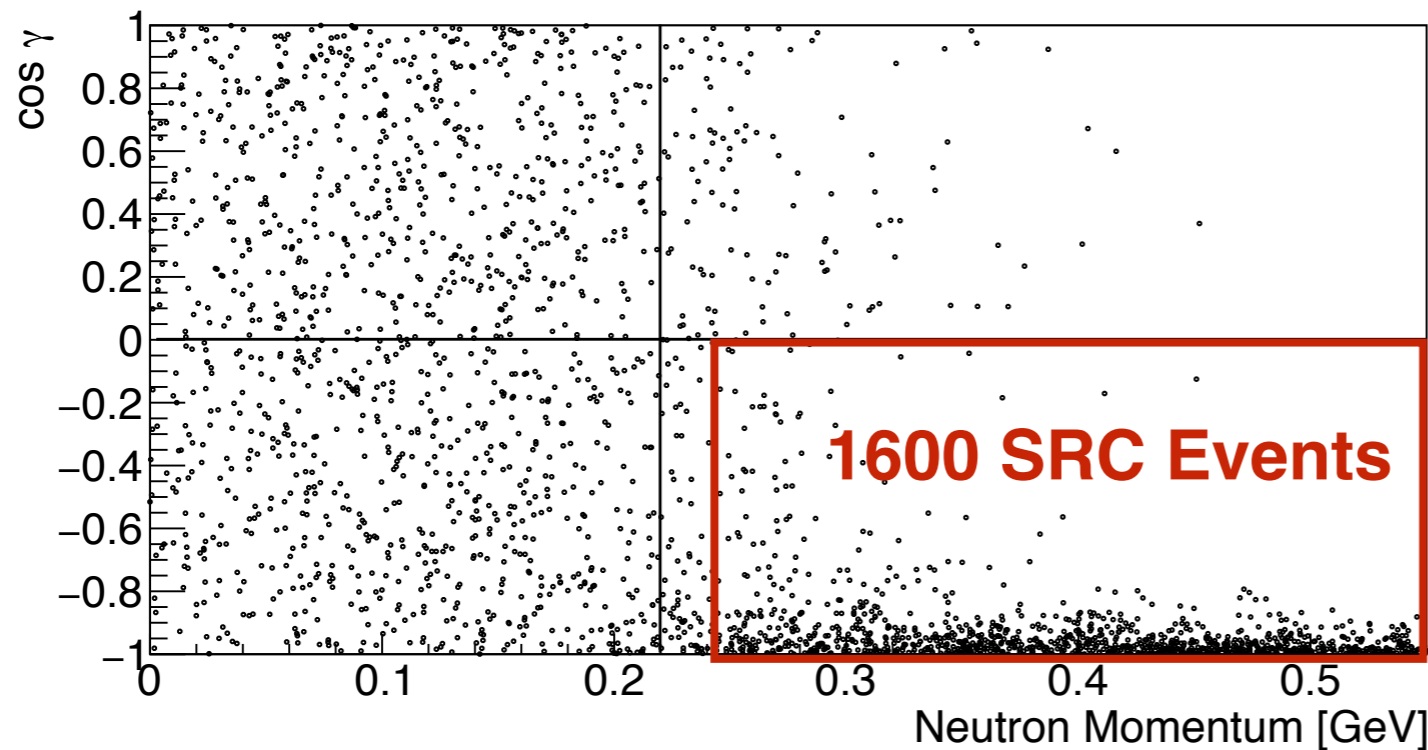
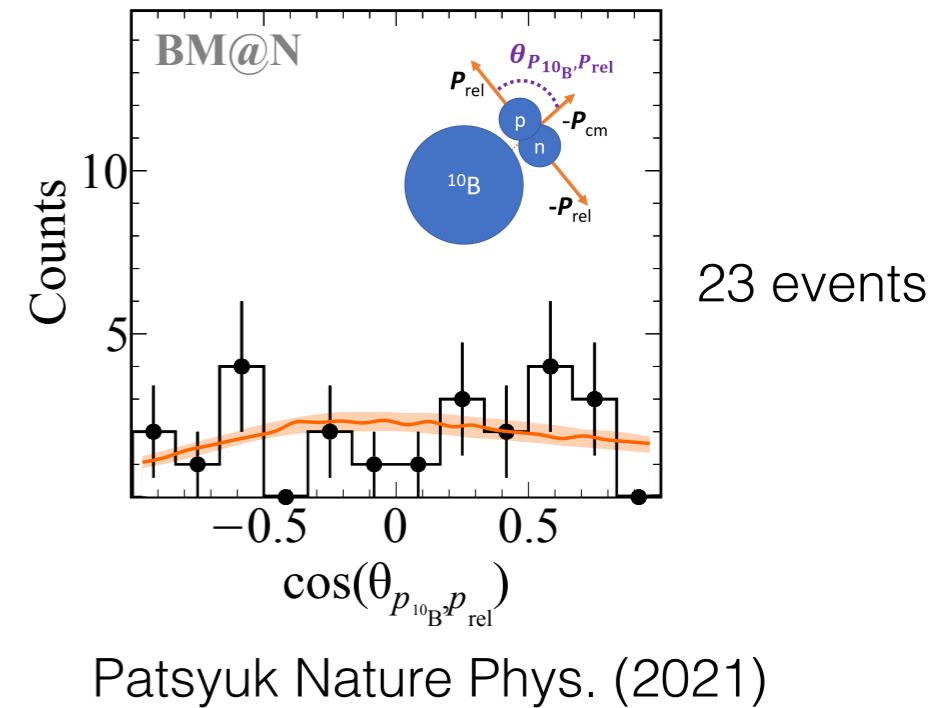


Projected Results: ${}^4\text{He}(e,e'd_{sp})n$

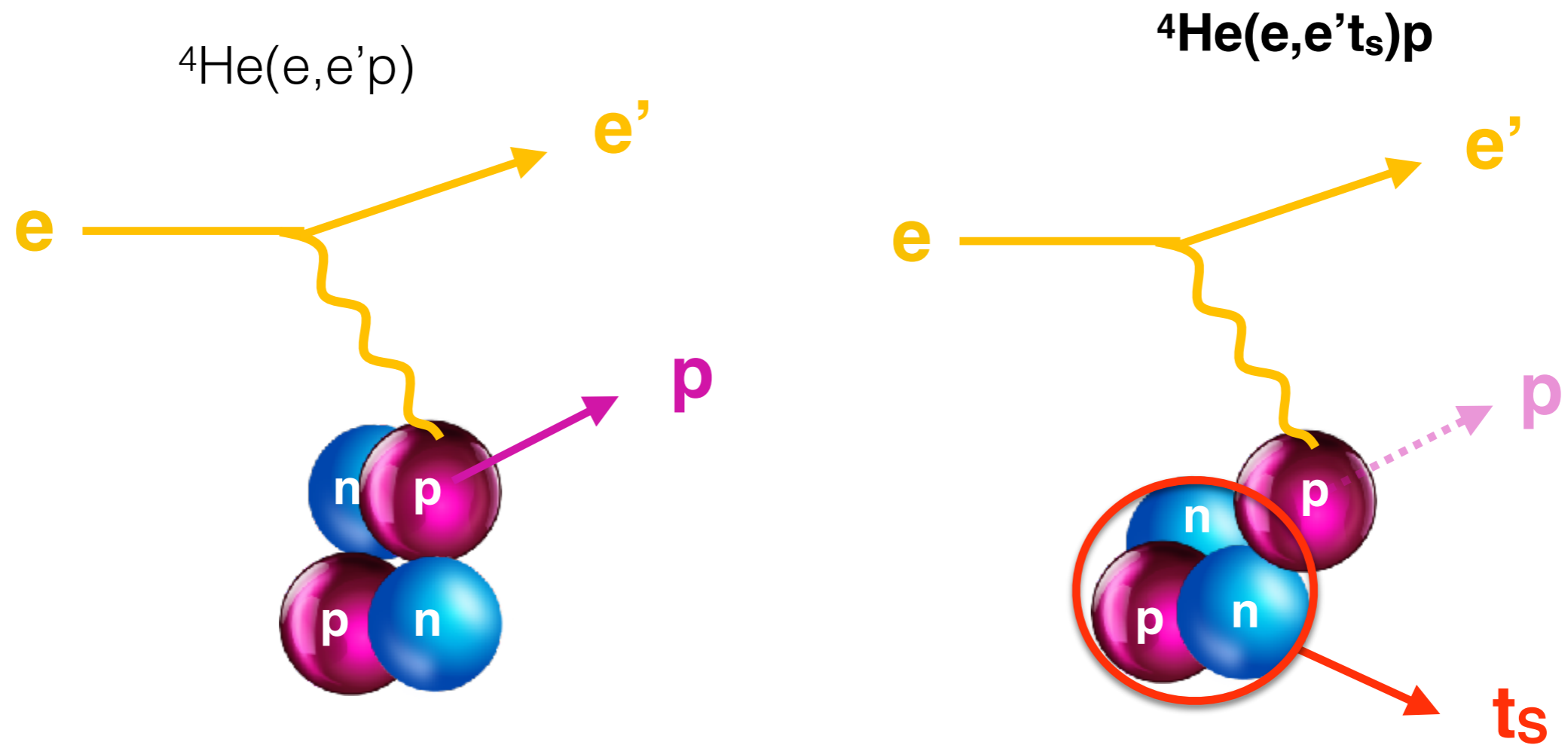
This Proposal



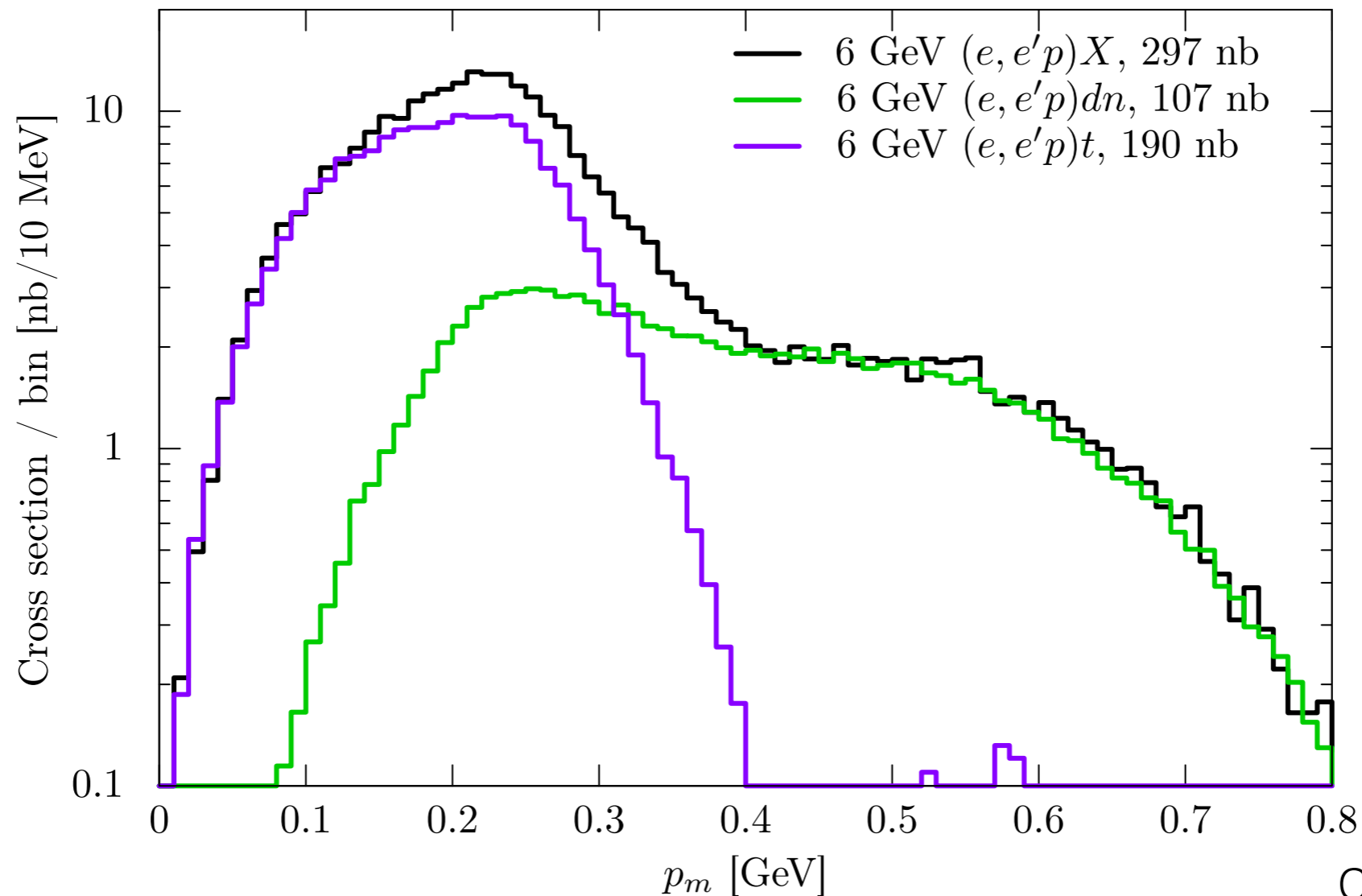
Previous Experiments



Other Channels



Bonus: Validation of ^4He Models



Courtesy of A. Schmidt

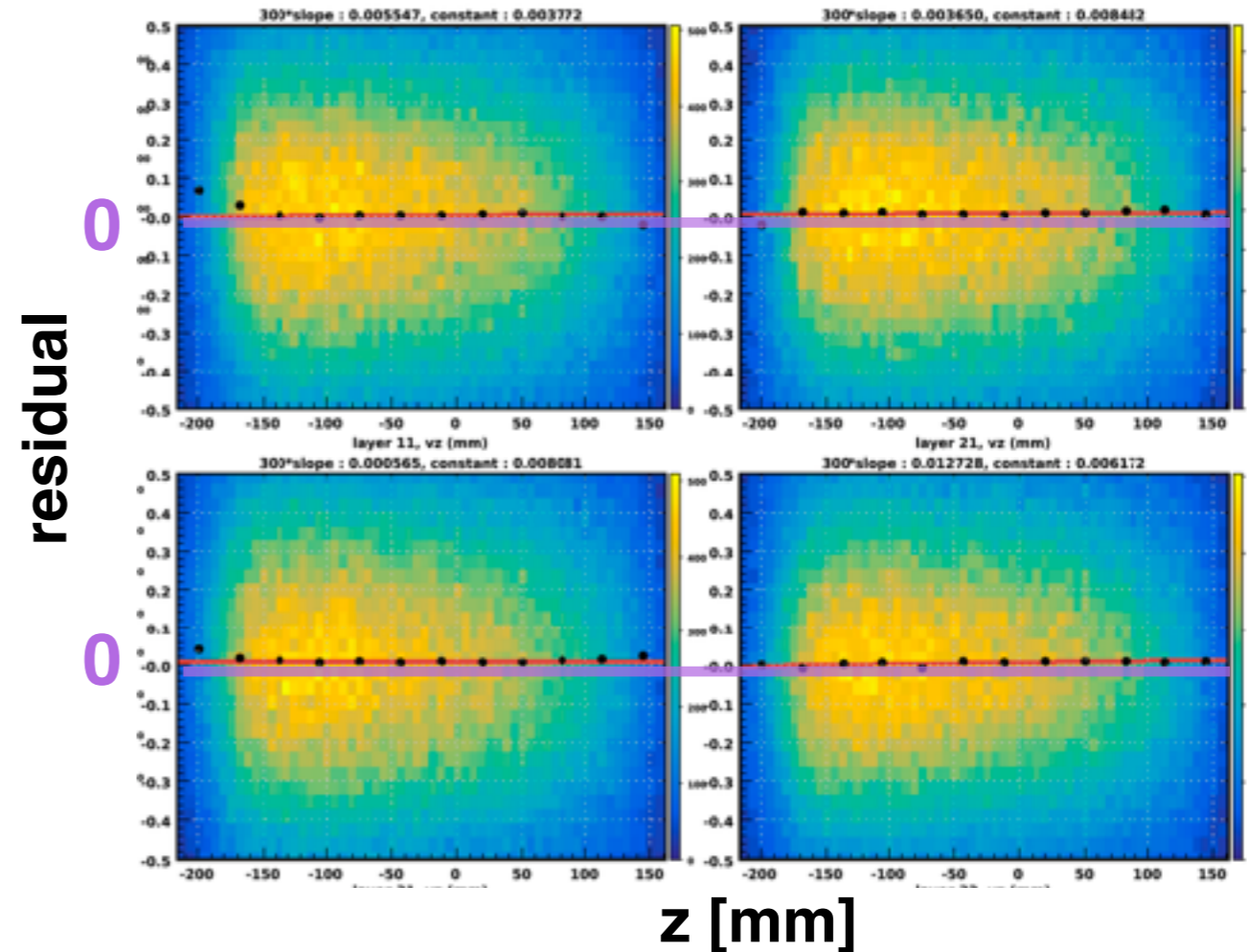
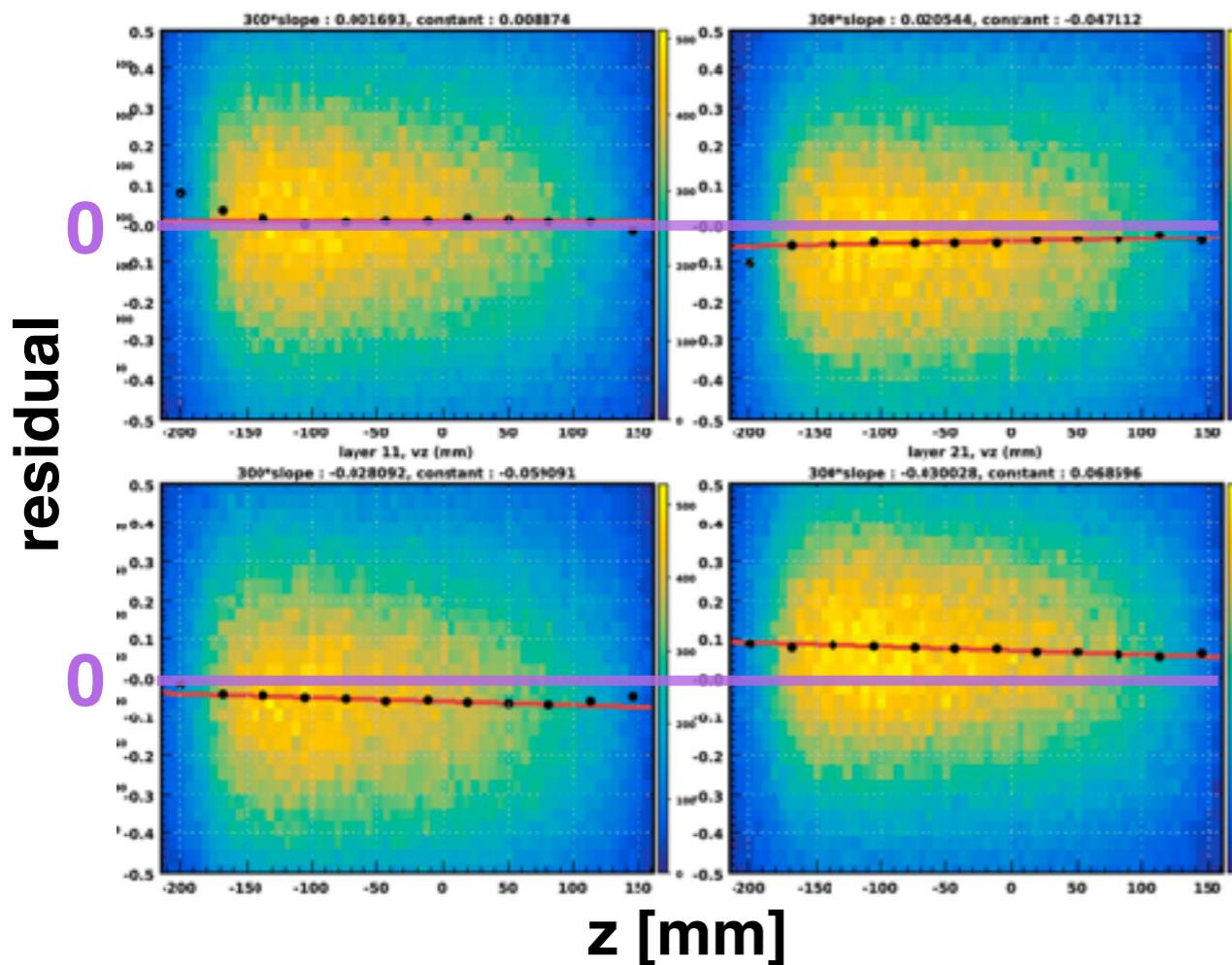
- Simulations with Plane-Wave-Impulse-Approximation
 - ^4He spectral function (N. Rocco and A. Lovato)
 - Two-body and three-body breakup
- Triton momentum acceptance $\sim 120 - 300$ MeV/c

Status of Analysis

- Significant development of software for particle tracking in ALERT
- Calibration of CLAS12 and ALERT on-going — expect completion in fall
- ALERT wire alignment improves track residuals

before alignment

after alignment

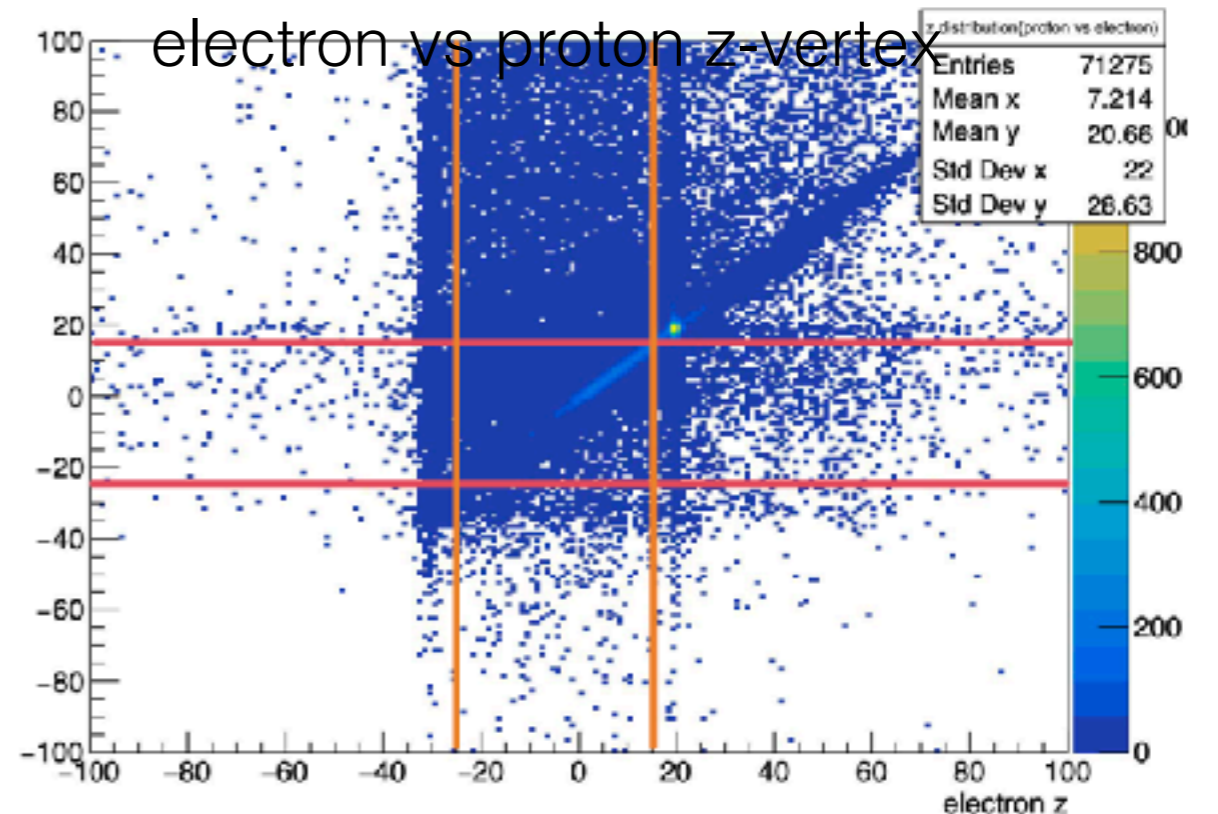
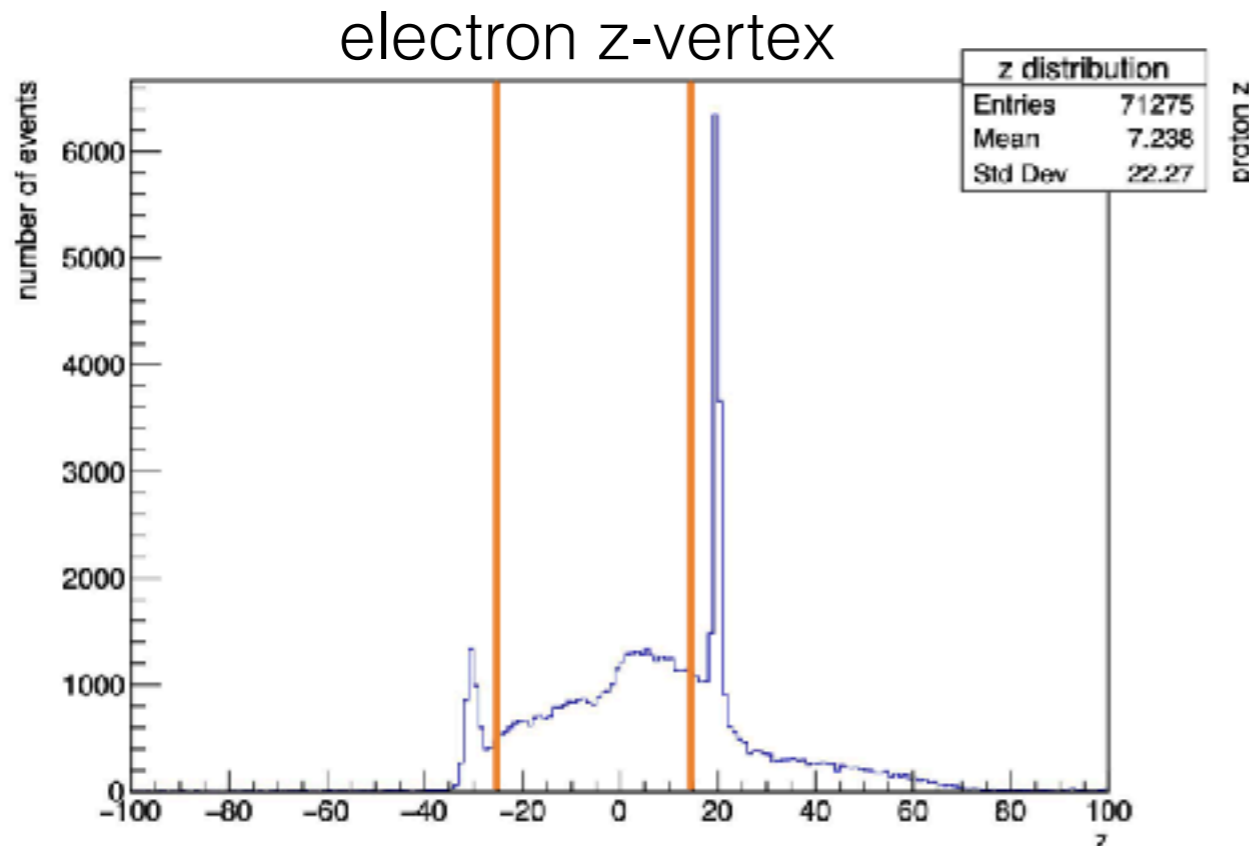
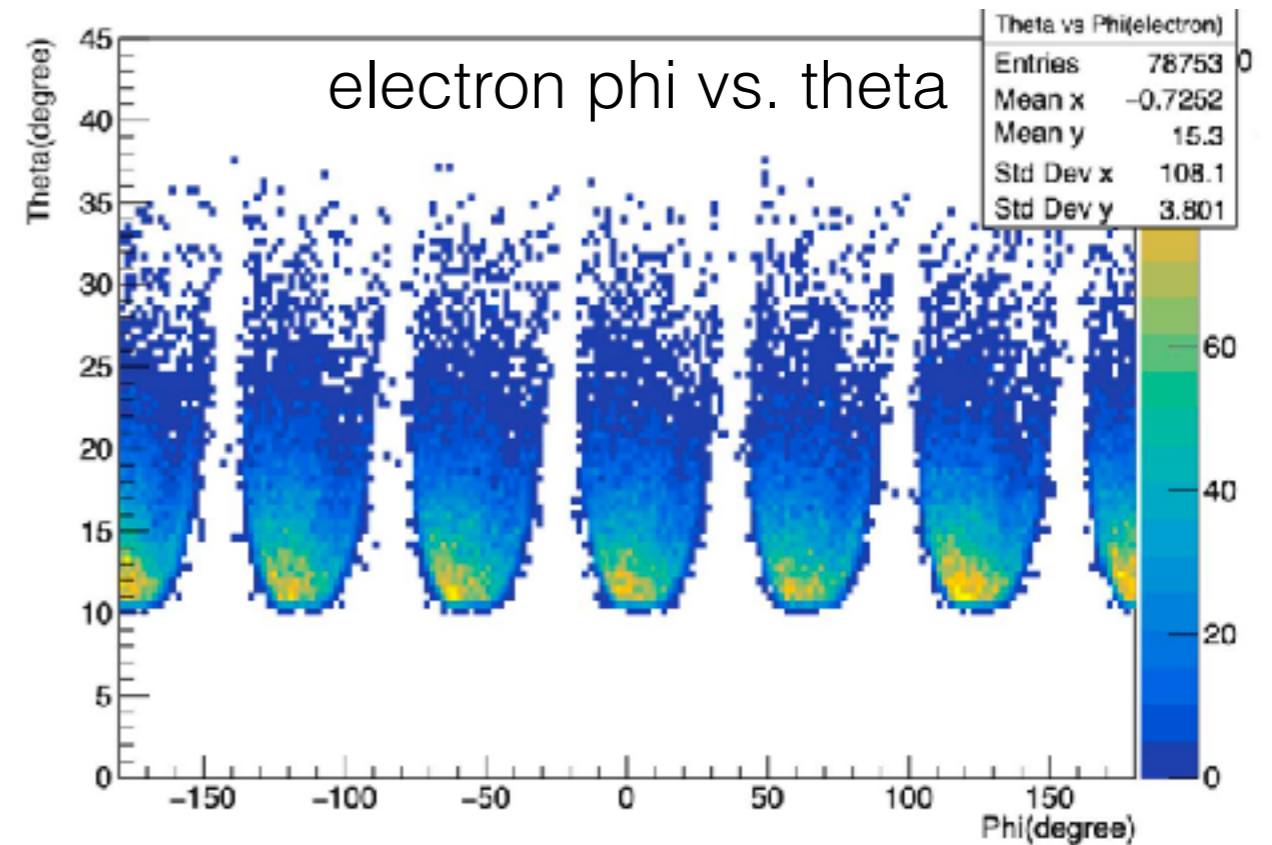


Courtesy of Felix Touchte-Codjo

- Cooking of full data by the end of the year

SRC “Online” Analysis - He(e,e'p)

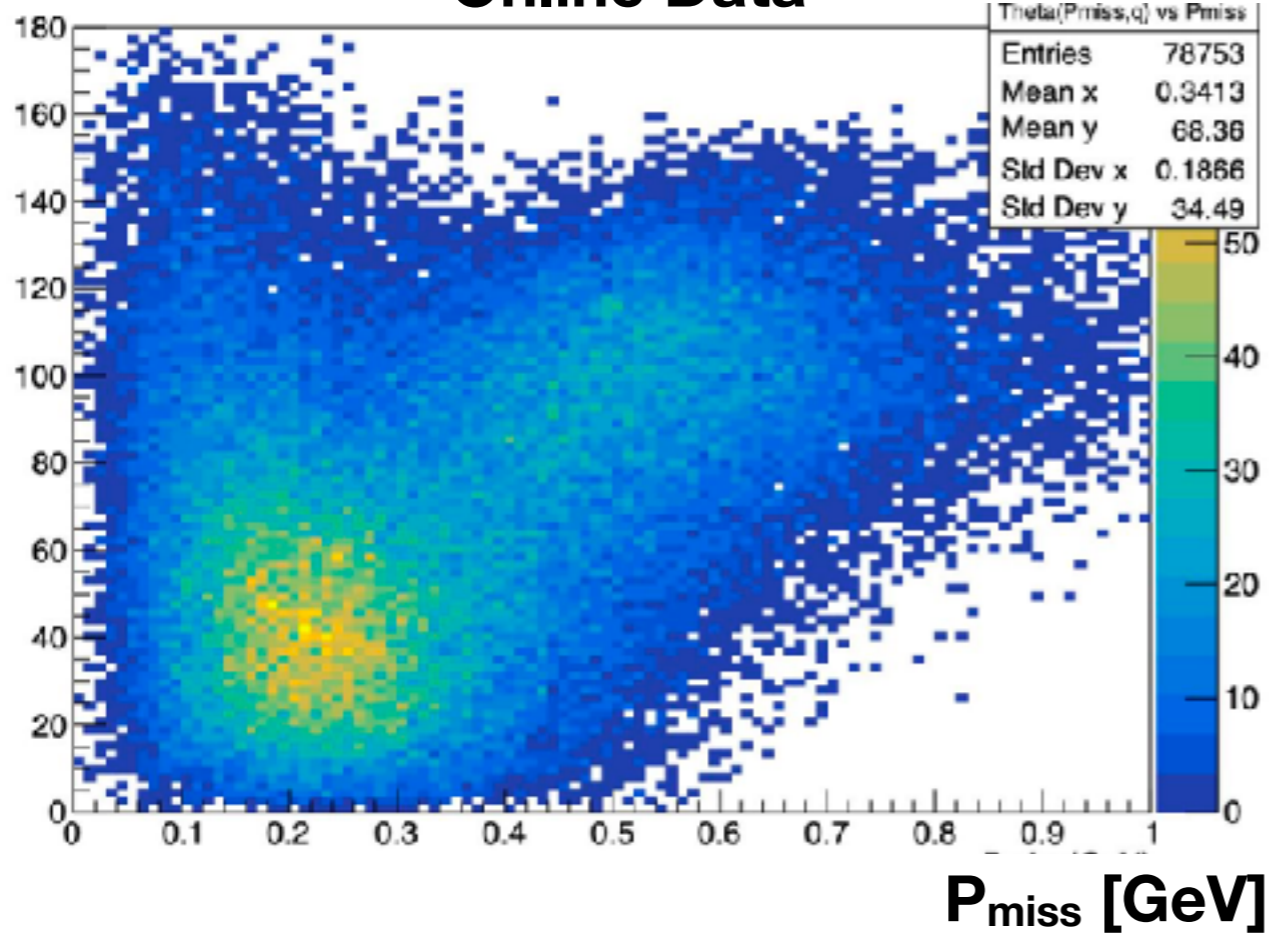
- Based on ~675M events (~5% of data)
- Non-optimized detector calibrations
- Event selection:
 - 1 electron and 1 proton in CLAS12
 - $Q^2 > 1.2 \text{ GeV}/c^2$
 - $X_B > 1.2$
 - $0.65 \text{ GeV} < M_{\text{miss}} < 1.1 \text{ GeV}$
 - $\theta_p < 37 \text{ deg}$
 - $P_p > 1 \text{ GeV}$
 - Vertex cut for e and p: [-25cm, 15cm]



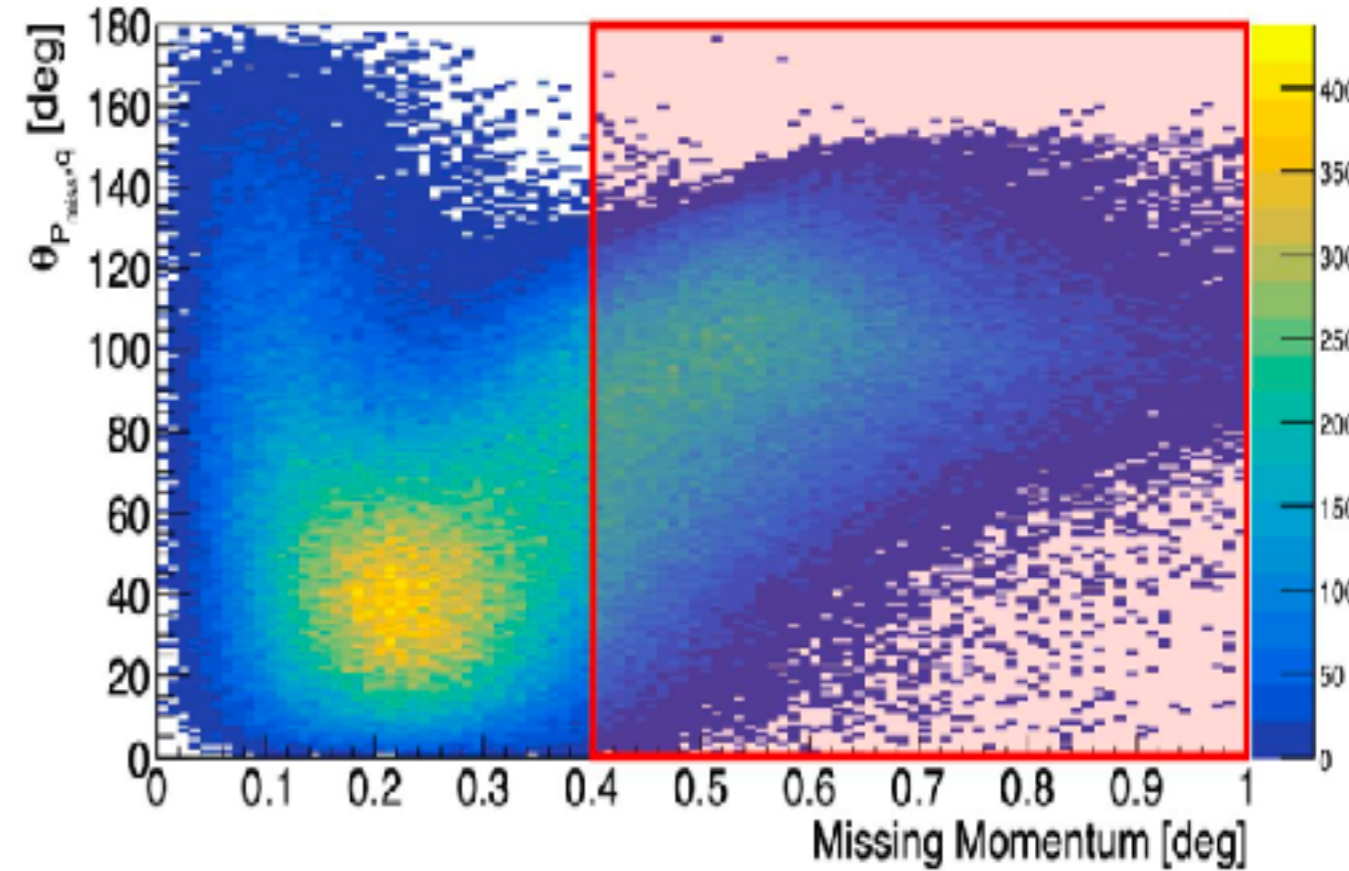
He(e,e'p) Comparison with previous CLAS12 data

$\theta(q, P_{\text{miss}})$ [deg]

Online Data



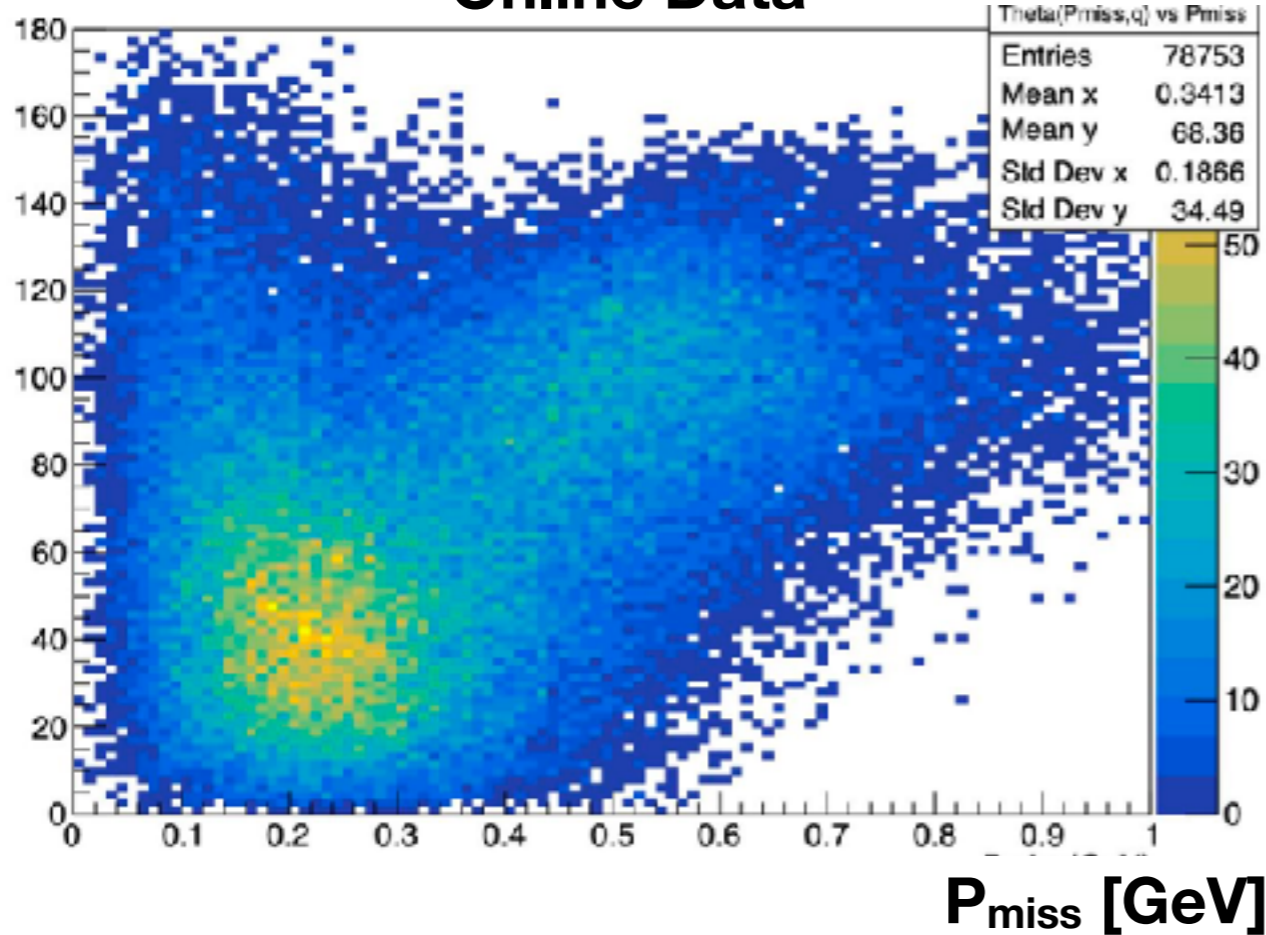
Previous data (RGM) SRC Region



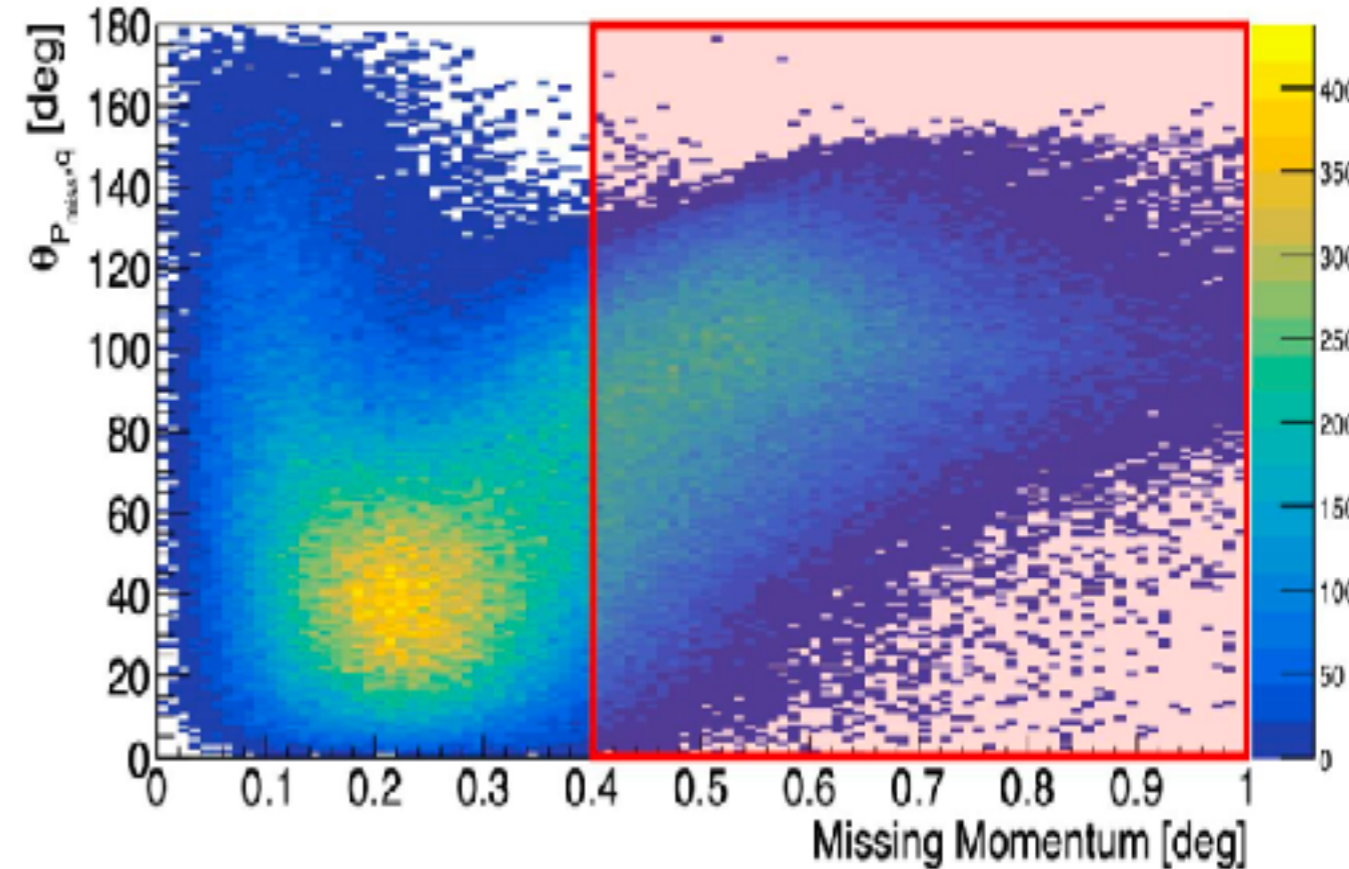
He(e,e'p) Comparison with previous CLAS12 data

$\theta(q, P_{\text{miss}})$ [deg]

Online Data



Previous data (RGM) SRC Region



- With additional P_{miss} cut: $0.4 \text{ GeV} < P_{\text{miss}} < 1 \text{ GeV}$:

Online Data

22448 events for $\sim 110 \text{ fb}^{-1}$
#ev/L $\sim 249 \text{ fb}$

Previous CLAS12 data (RGM)

14257 events for 57.24 fb^{-1}
#ev/L $\sim 202 \text{ fb}$

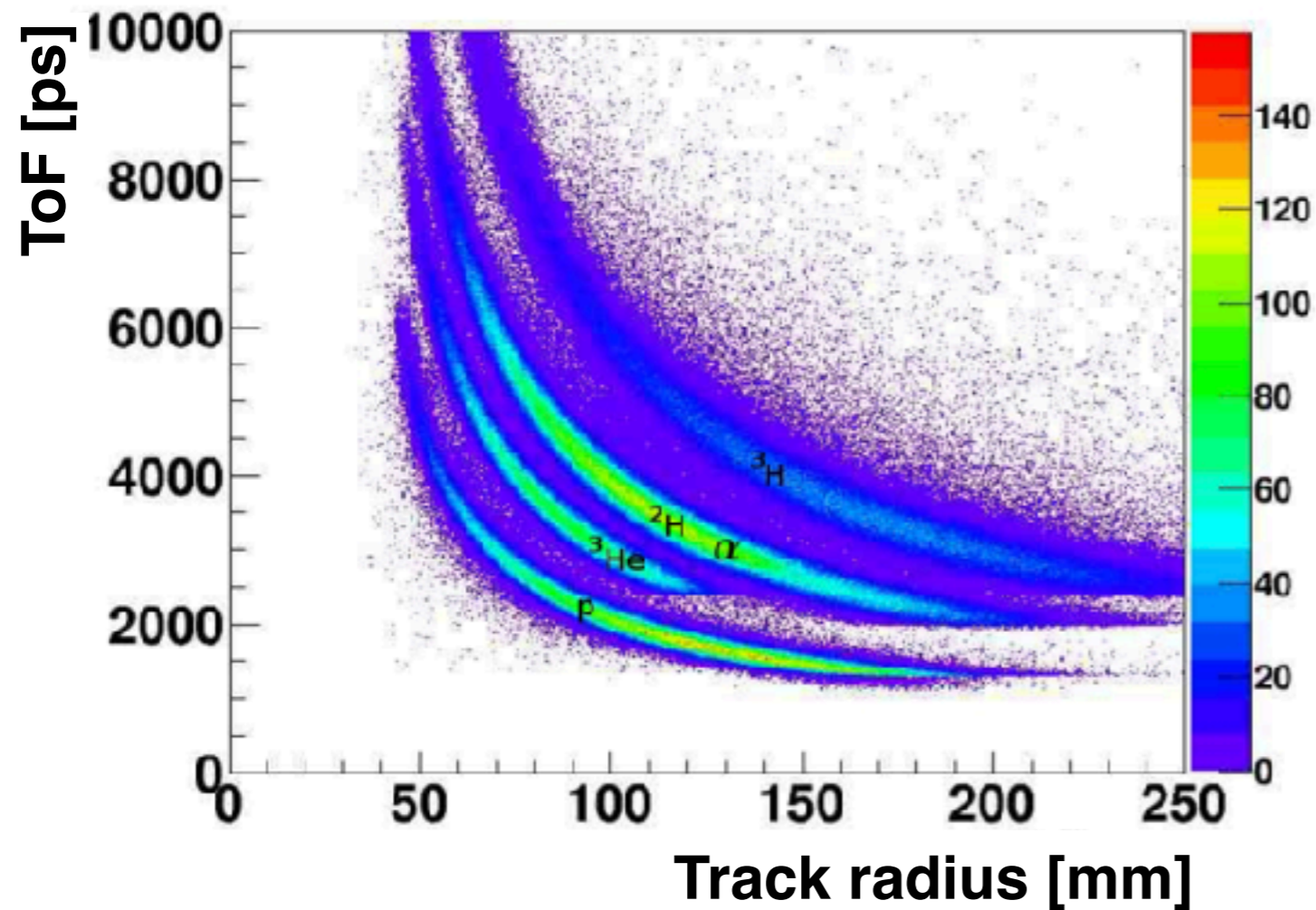
- “online” numbers consistent with previous data \rightarrow data quality is reasonable 22

Summary

- Measuring recoil nuclei is a great tool to study reactions
 - exclusive measurements
 - selection of initial states
 - suppression of backgrounds
- ALERT in CLAS12 detects p, d, ^3H , ^3He and ^4He recoils
- Expect interesting new physics from $\text{He}(e',X)$ with ALERT
 - Tagged DVCS and EMC
 - Transition region from mean-field to SRC regime with high statistics
- Data collected successfully in 2025
- Analysis status
 - Calibration underway \rightarrow cooking of full data at the end of the year
 - “Online” analysis showed reasonable data quality

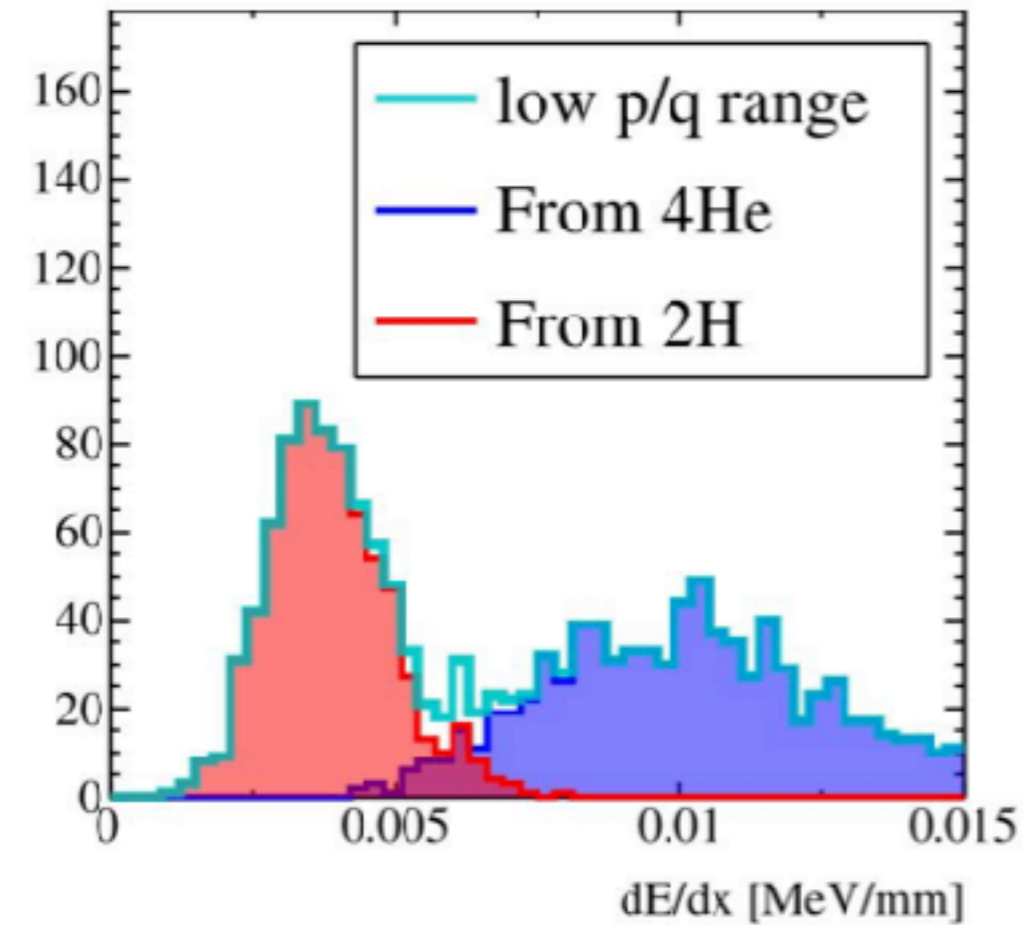
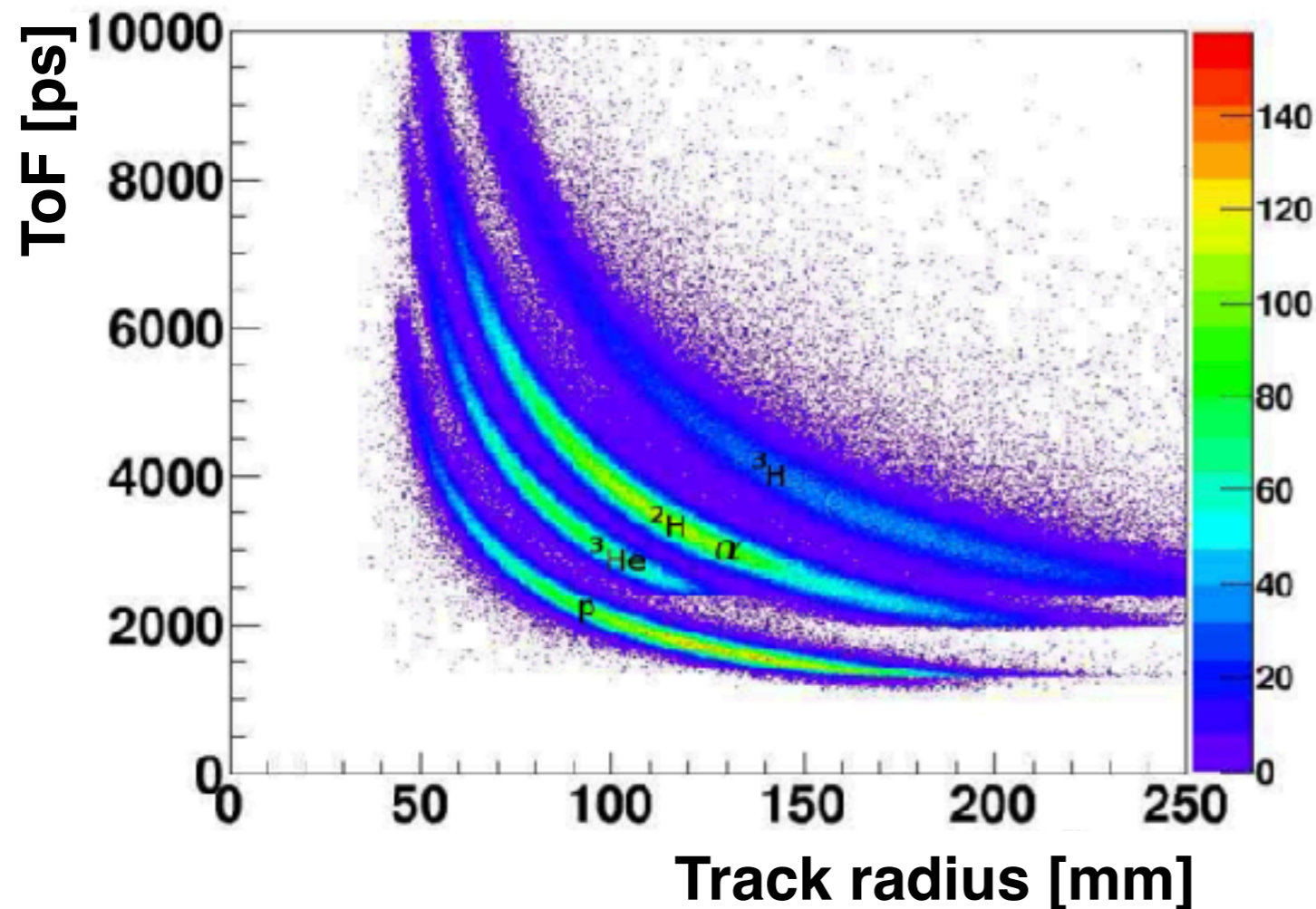
Backup

ALERT PID of Recoil Nuclei



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

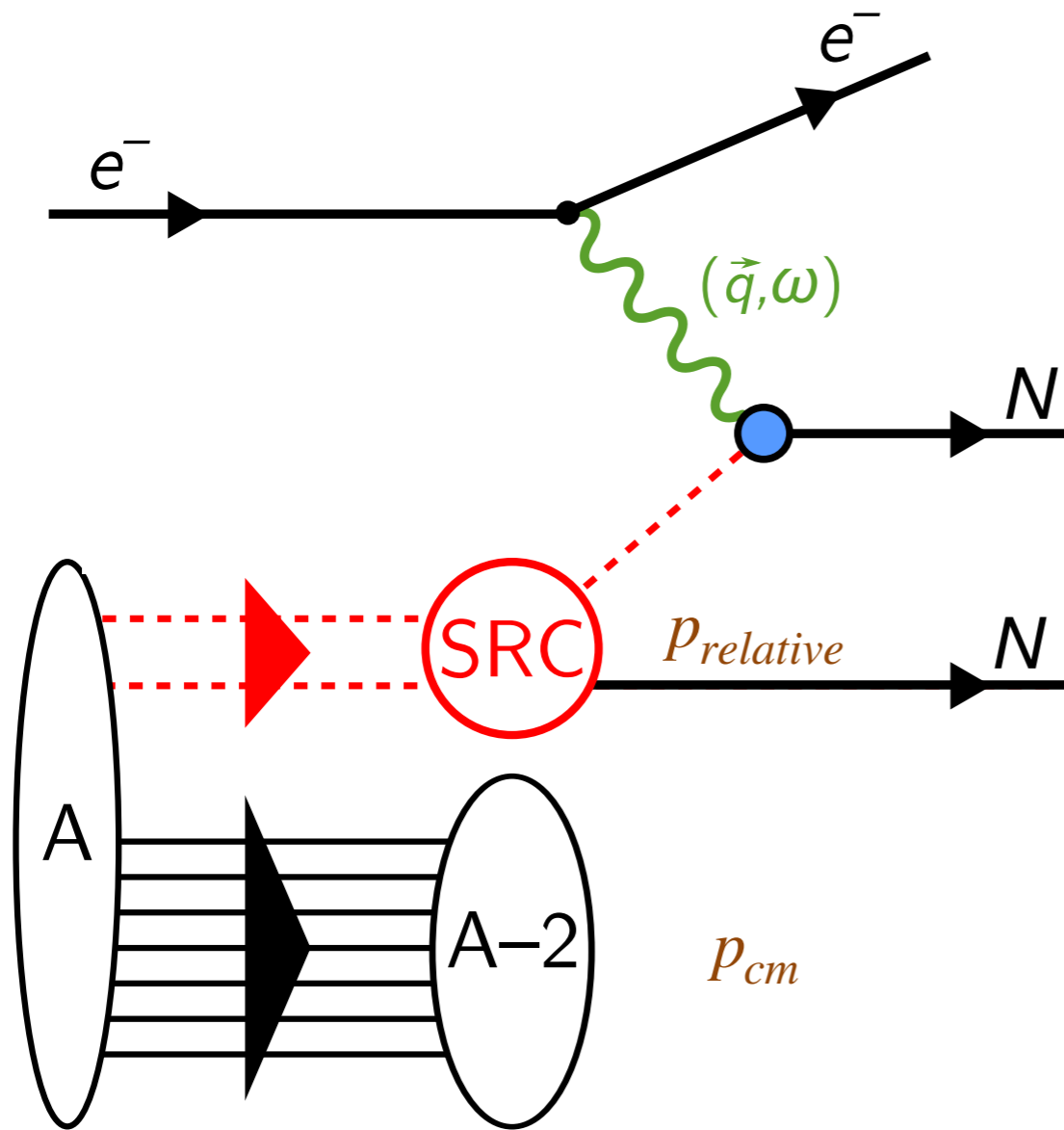
ALERT PID of Recoil Nuclei



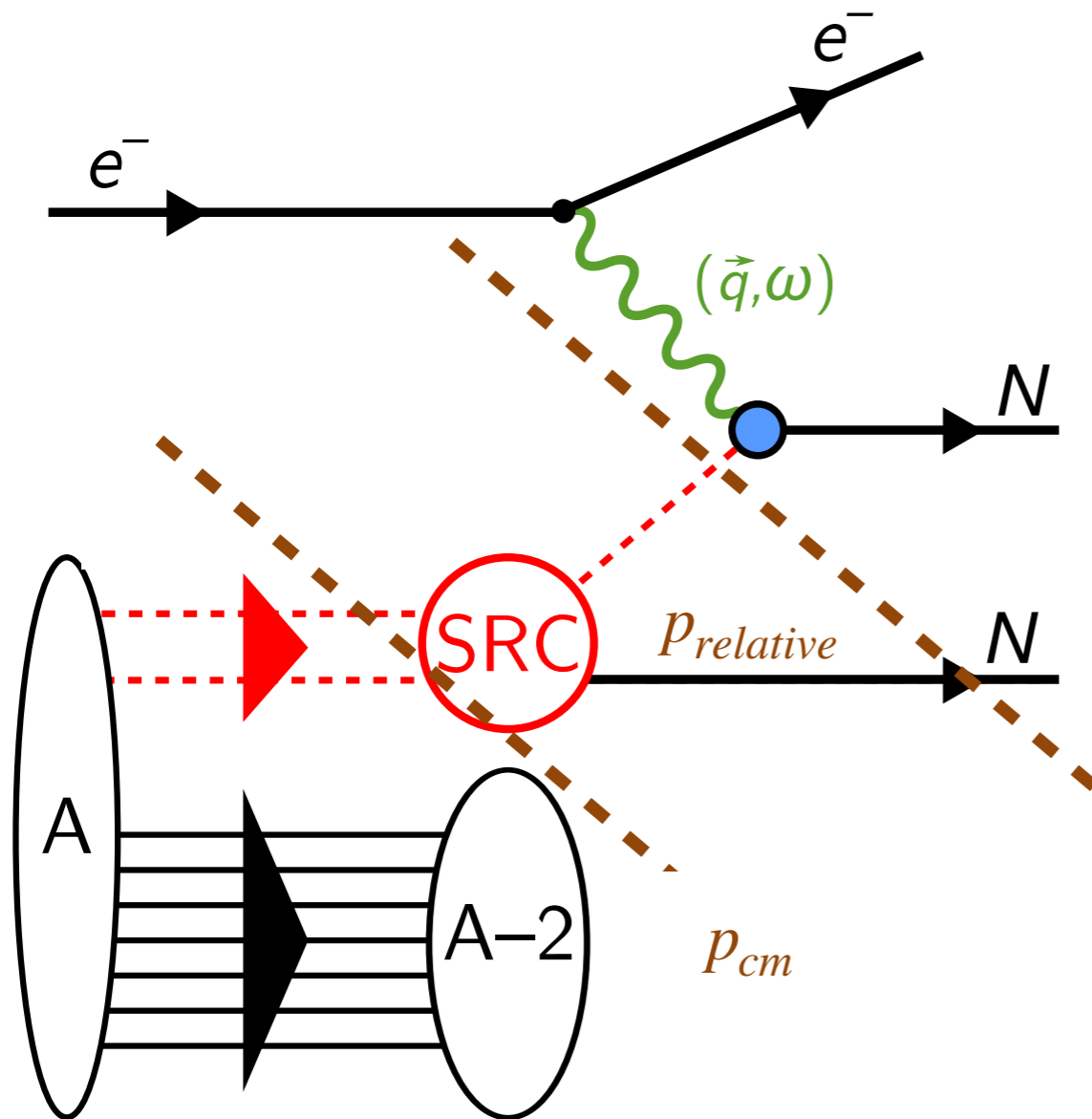
- well separated p, ^3He , d/ ^4He and ^3H bands

- d and 4He separation via dE/dx

SRC Theory: Generalized Contact Formalism



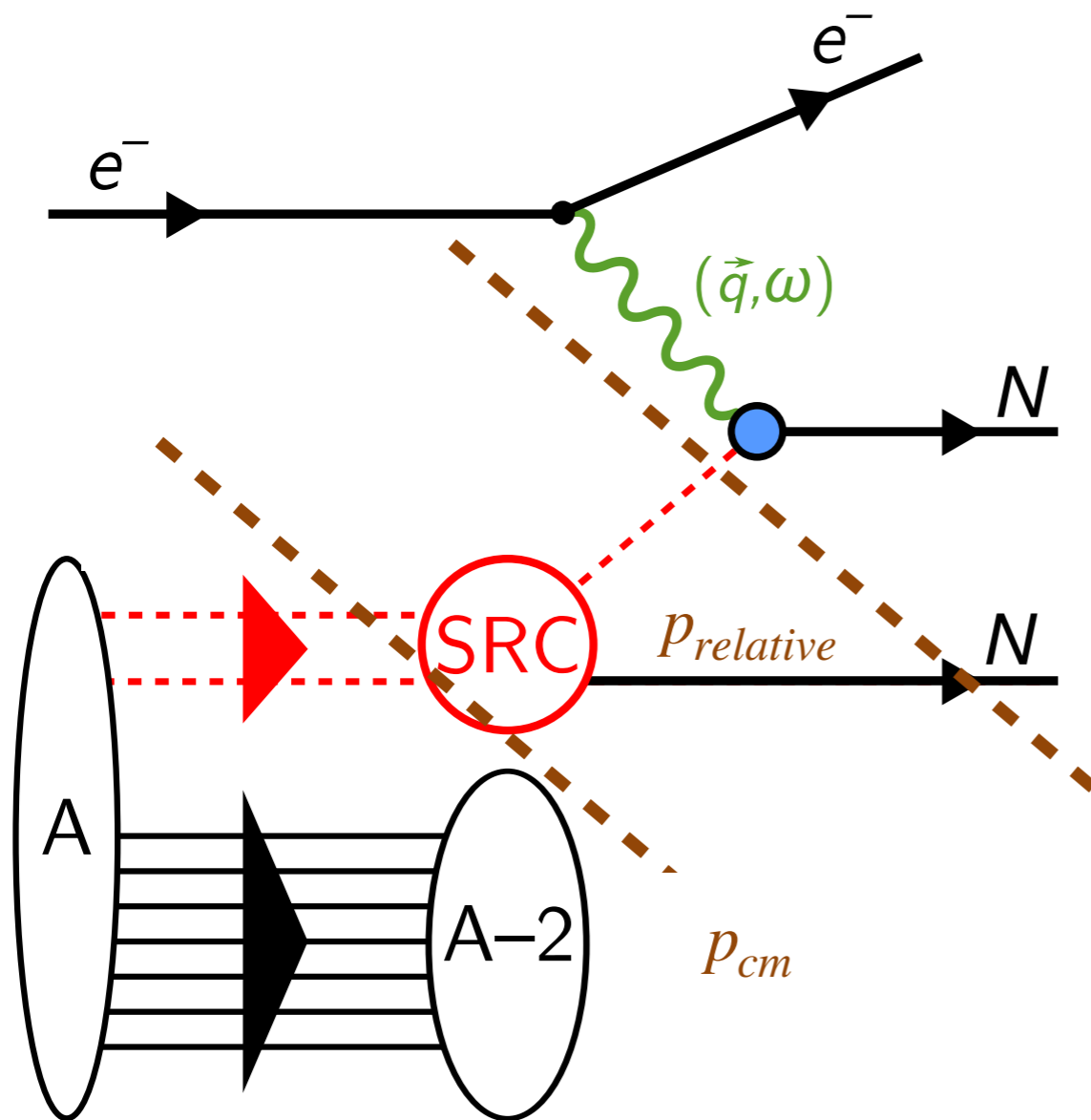
SRC Theory: Generalized Contact Formalism



Scale separation

$$q \gg p_{rel} \gg p_{cm}$$

SRC Theory: Generalized Contact Formalism



Scale separation

$$q \gg p_{rel} \gg p_{cm}$$



Factorization of many-body wave function



$$\sigma = \sigma_{e,N}(q) \sum_{\alpha} \phi(p_{relative})^2 C^{\alpha} n(p_{c.m.})$$

Rate Estimates

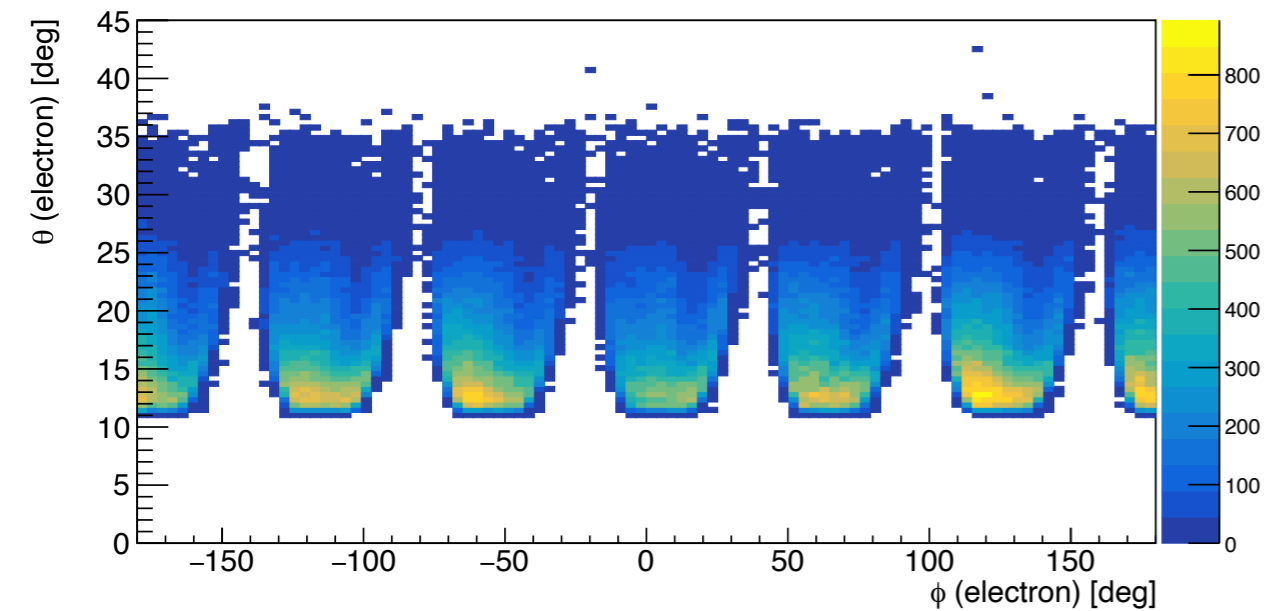
- Based on RGM ${}^4\text{He}(e,e'p)$ pass0 SRC data (high missing momentum)
 - assume all events have correlated neutron and isotropic spectator deuteron
 - add corrections for
 - deuteron p - θ acceptance (f_{acc})
 - deuteron survival probability (f_{surv})
 - pp pairs and ϕ acceptance ($f_{pp/\phi acc}$)
 - pn rescattering (f_{FSI})

$$N_{He(e,e'pd_s)n} = N_{He(e,e'p)^{RGM-SRC}} f_{acc} f_{surv} f_{pp/\phi acc} f_{FSI}$$

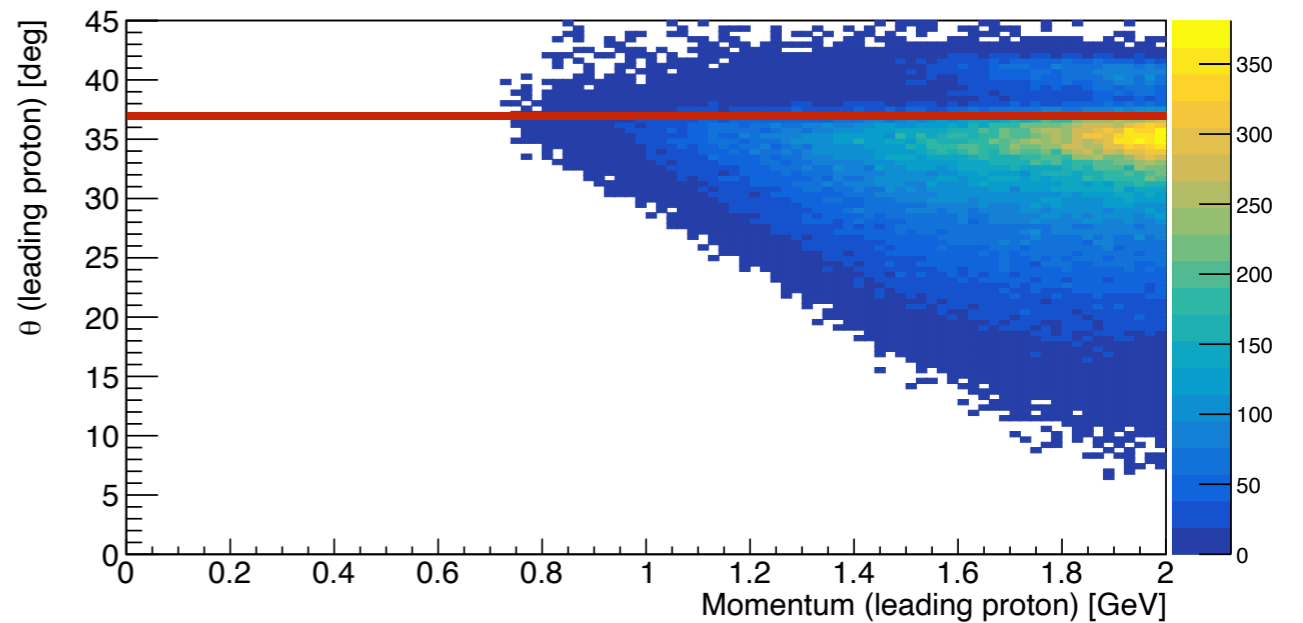
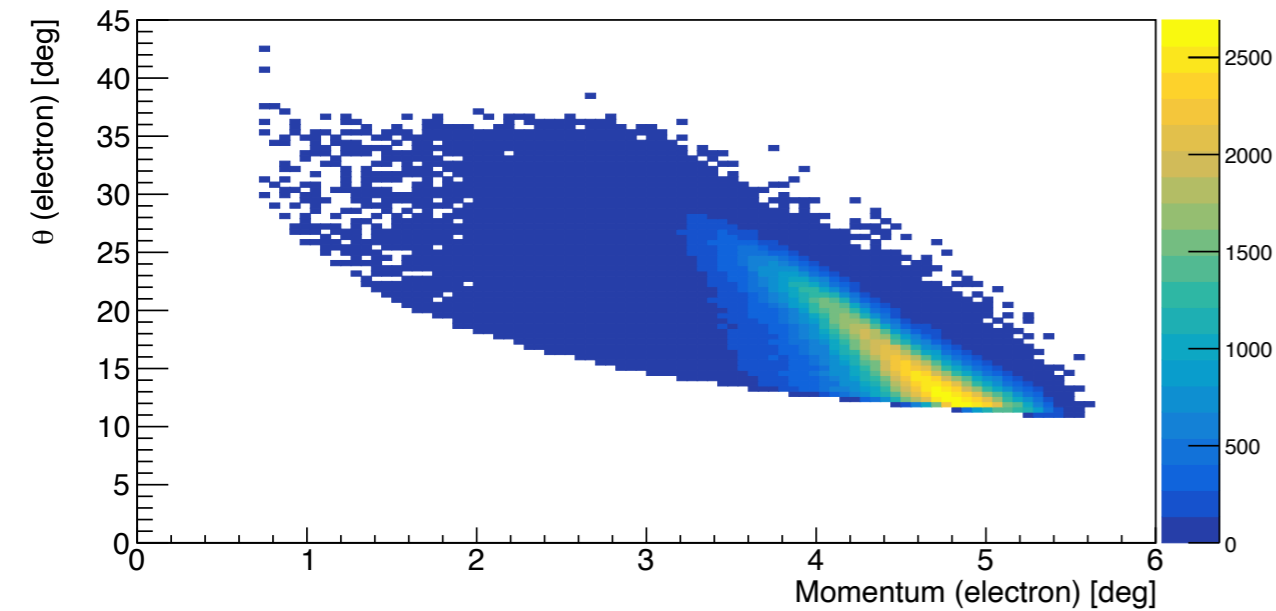
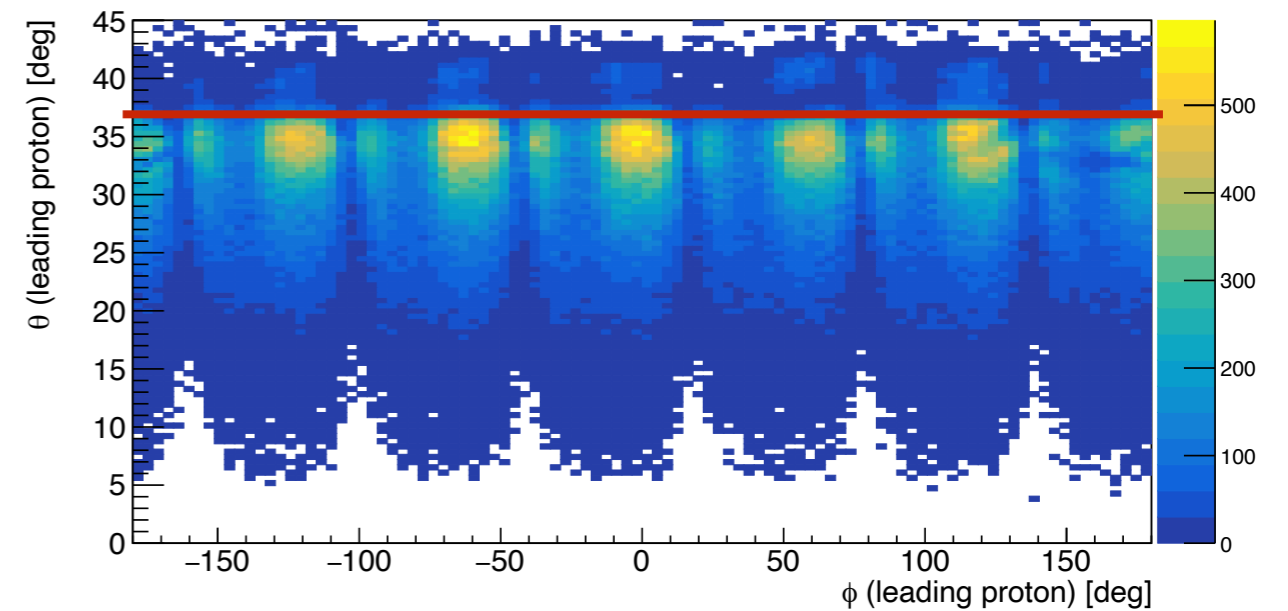
- Normalize rate from RGM to ALERT luminosity

Electron and Proton Distributions

Electrons

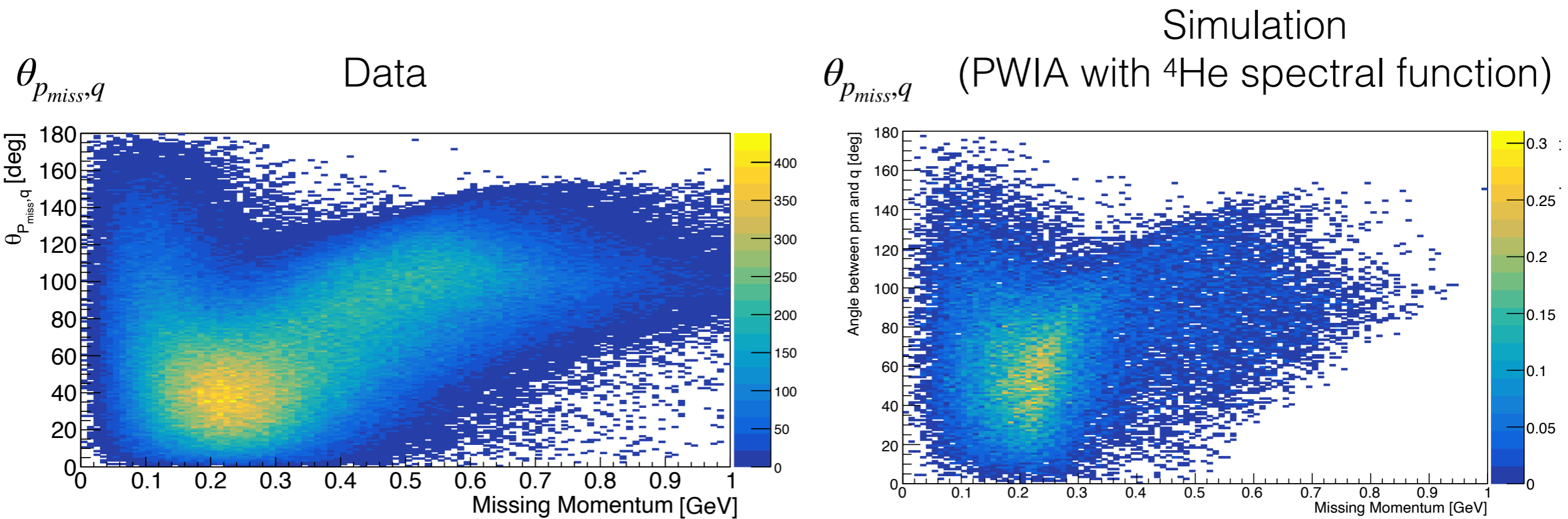


Protons



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

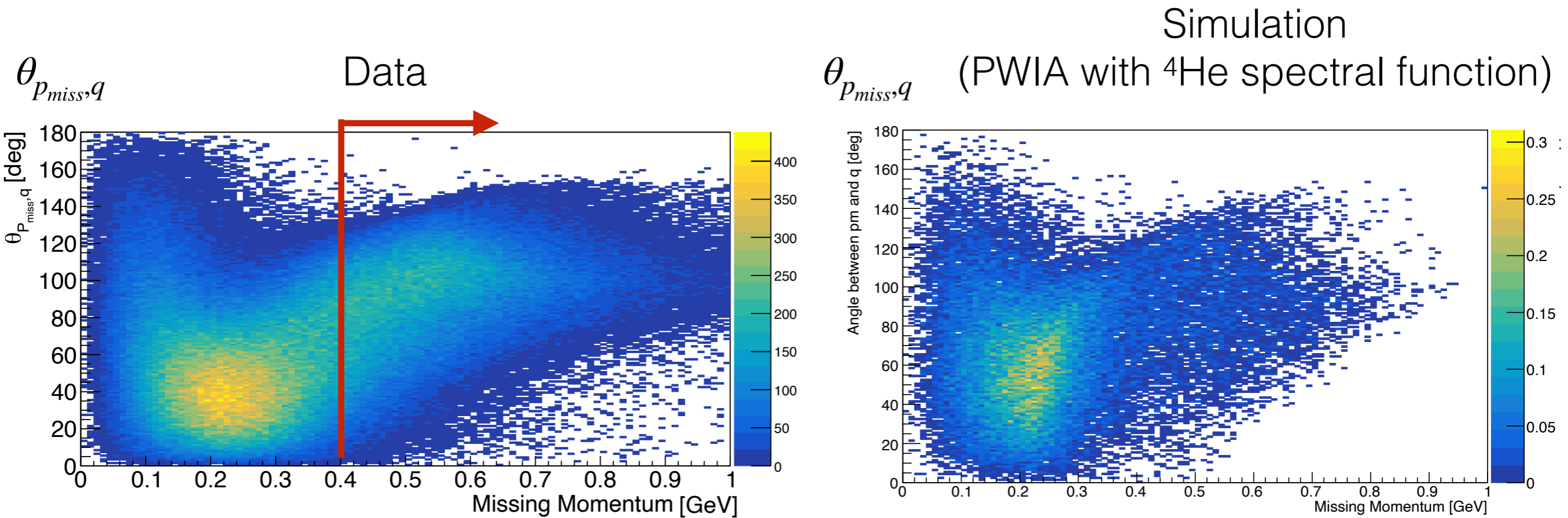
RGM SRC Events



$$\vec{p}_{miss} = \vec{p}_p - \vec{q}$$

- Data and simulation in qualitative agreement
- Rescattering effects (FSI) in data
 - can be suppressed with cut on θ_{pn} (not possible in RGM pass0 data)
 - reduction of expected number of events \rightarrow conservative factor 0.1 in rate estimate

RGM SRC Events

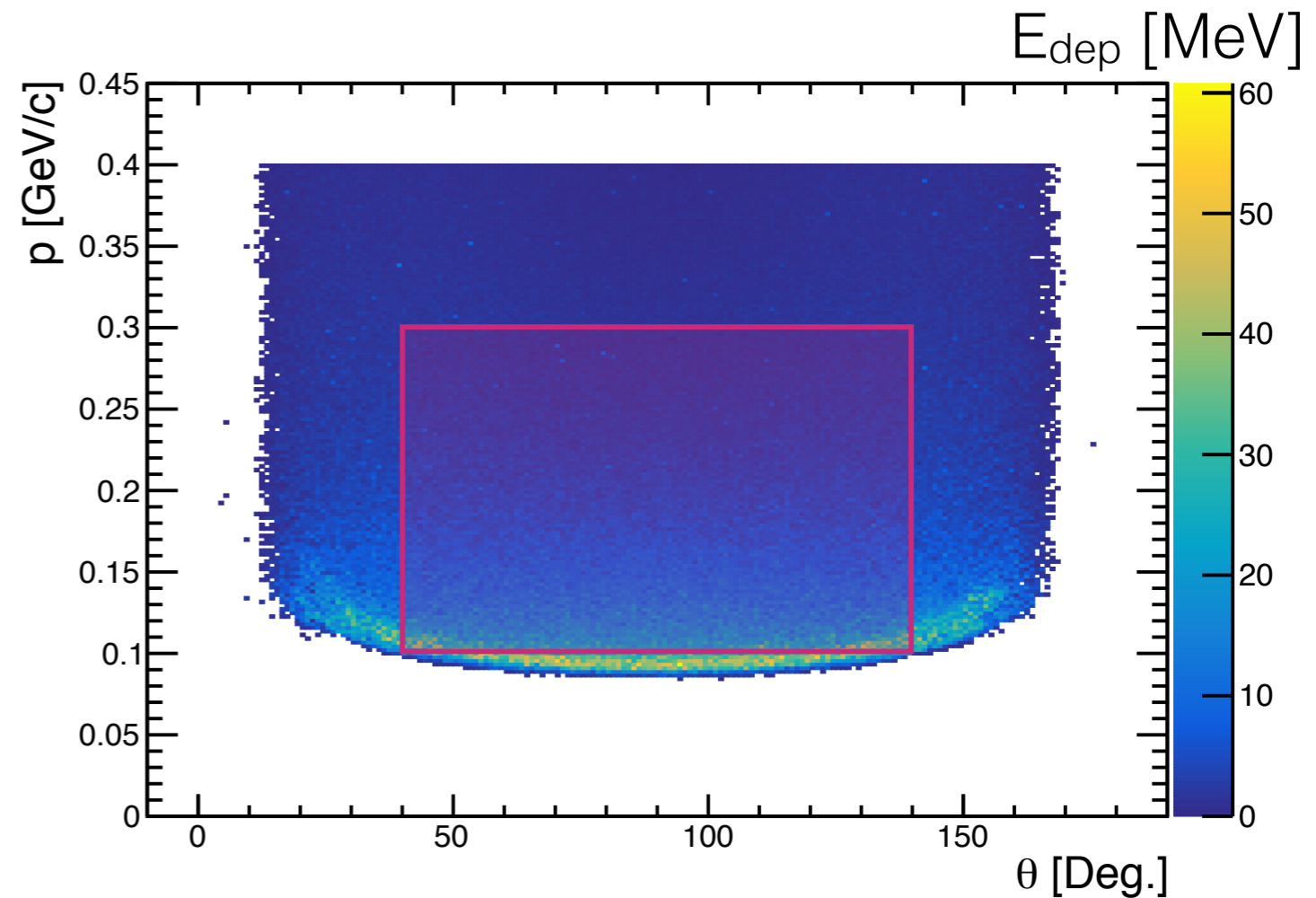


$$\vec{p}_{miss} = \vec{p}_p - \vec{q}$$

- Data and simulation in qualitative agreement
- Rescattering effects (FSI) in data
 - can be suppressed with cut on θ_{pn} (not possible in RGM pass0 data)
 - reduction of expected number of events \rightarrow conservative factor 0.1 in rate estimate
- SRC events ($p_{miss} > 400$ MeV/c): **3.8×10^5**

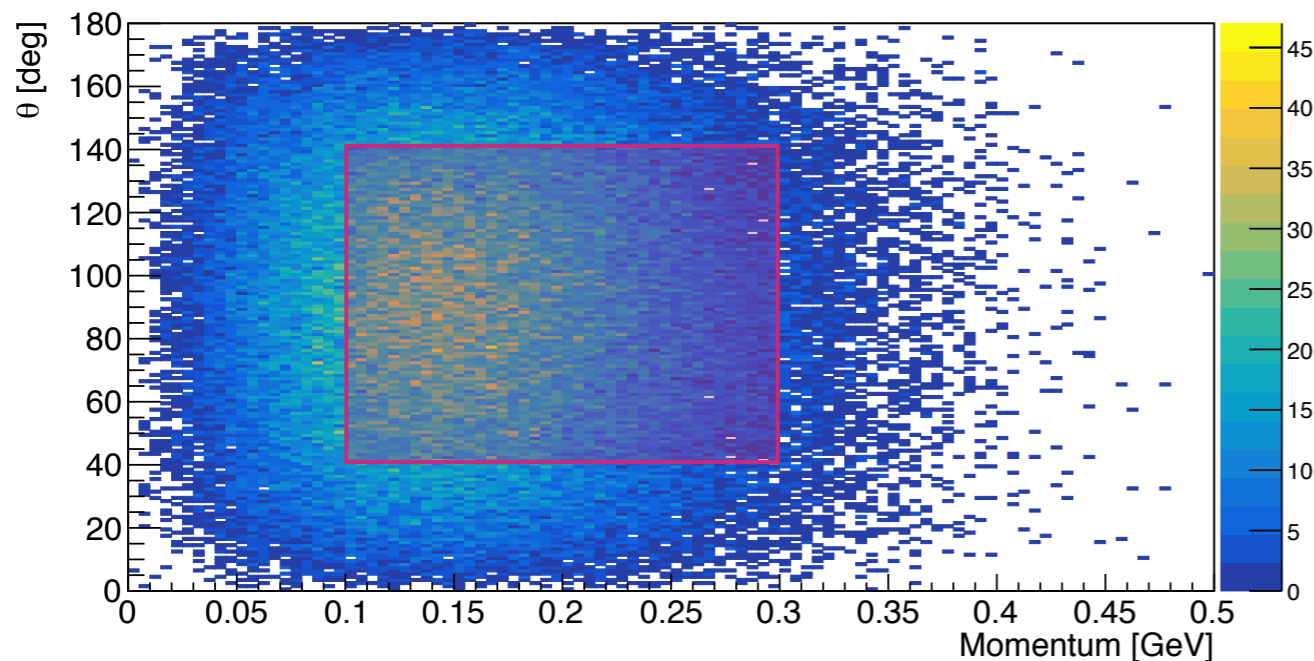
Deuteron Acceptance (1)

- 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°

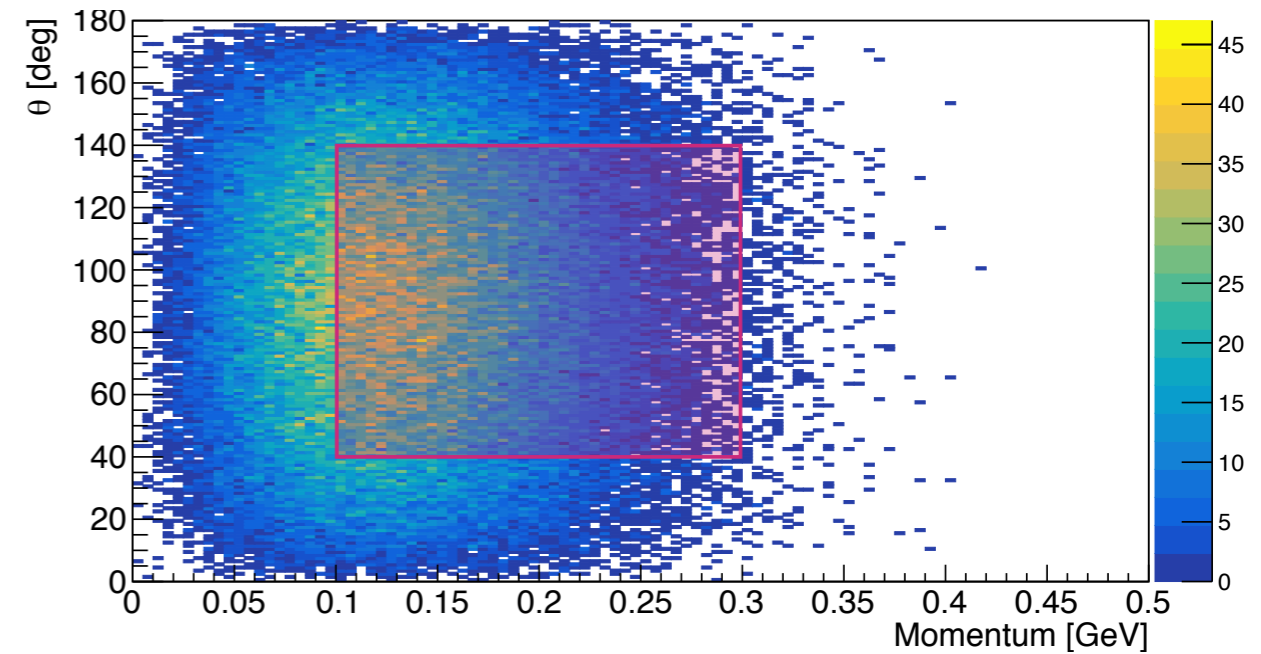


Deuteron Acceptance (2)

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



$\sigma = 100$ MeV/c



$\sigma = 84$ MeV/c

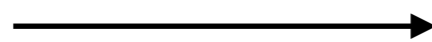
- More spread in momentum for larger σ (expected)
- 59% (100 MeV/c) or 53% (84 MeV/c) events in (conservative) ALERT acceptance box
- For rate estimate: conservative **deuteron acceptance factor = 0.5**

Rate Estimate and Beam Time

$$N_{He(e,e'pd_S)n} = N_{He(e,e'p)^{RGM-SRC}} f_{acc} f_{surv} f_{pp/\phi acc} f_{FSI}$$
$$= 3.8 \cdot 10^5 \times 0.5 \times 0.1 \times 0.8 \times 0.1 = 1.6 \cdot 10^3$$

- RGM ^4He data

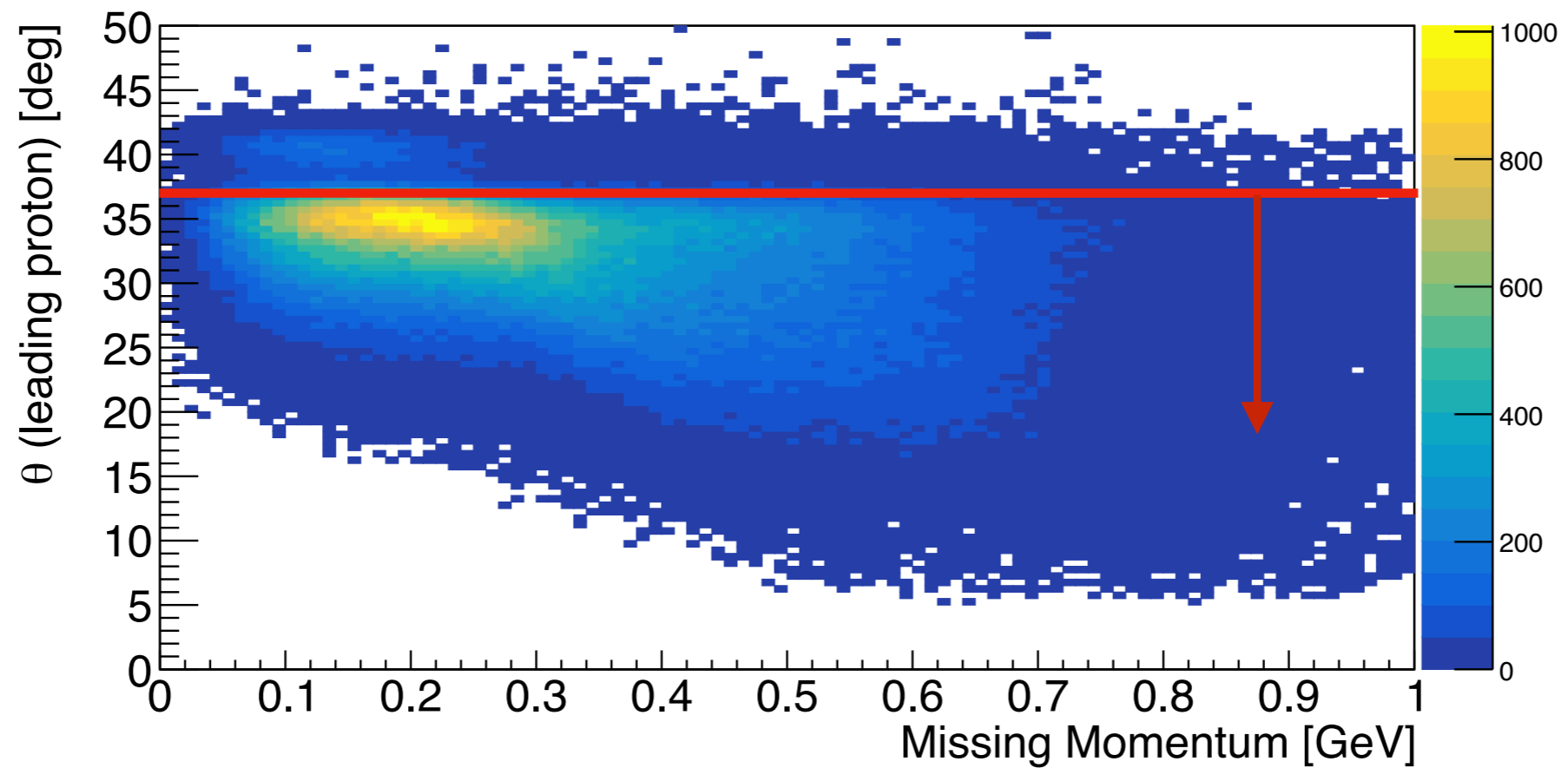
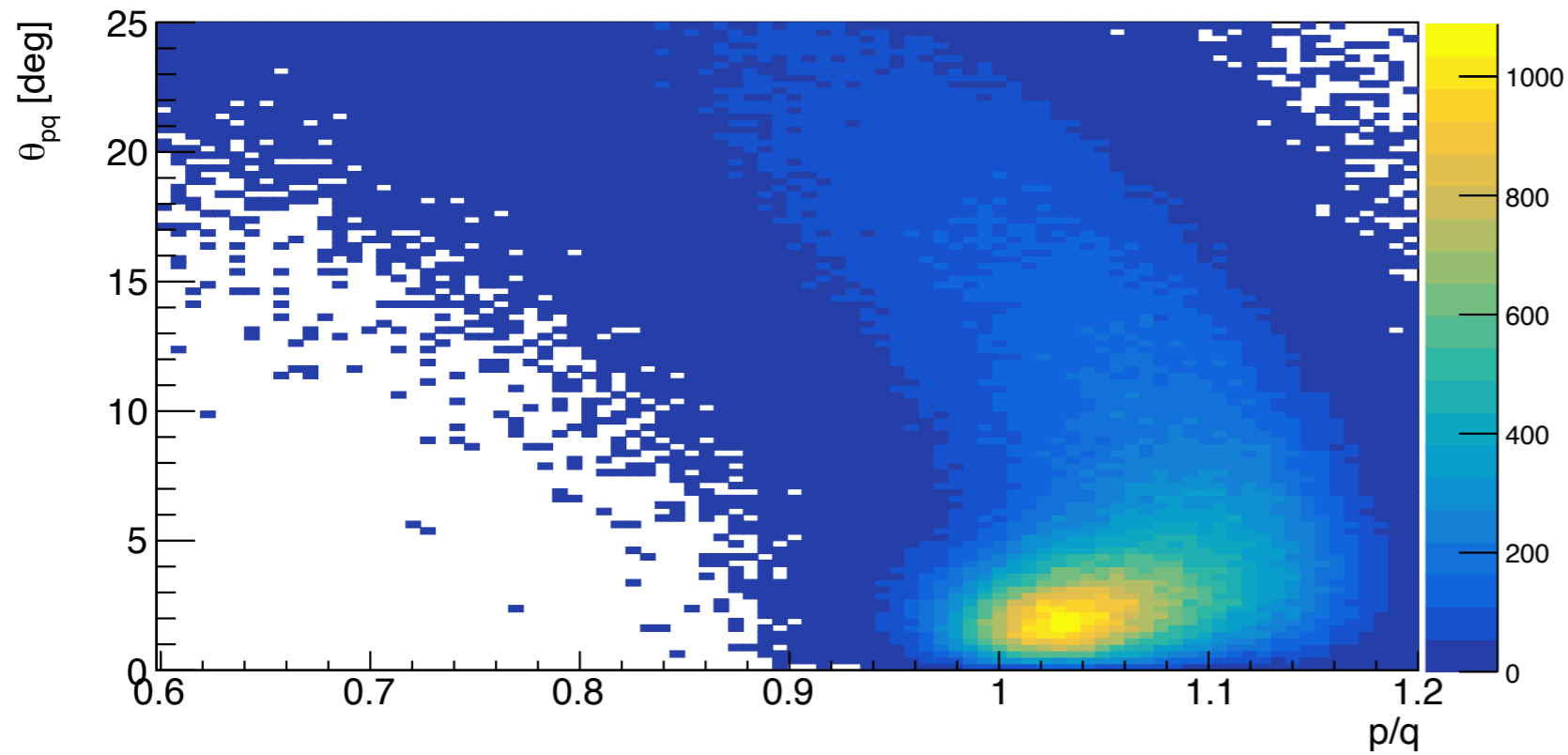
- 1.2×10^{35} luminosity
- 4 PAC days



- This proposal

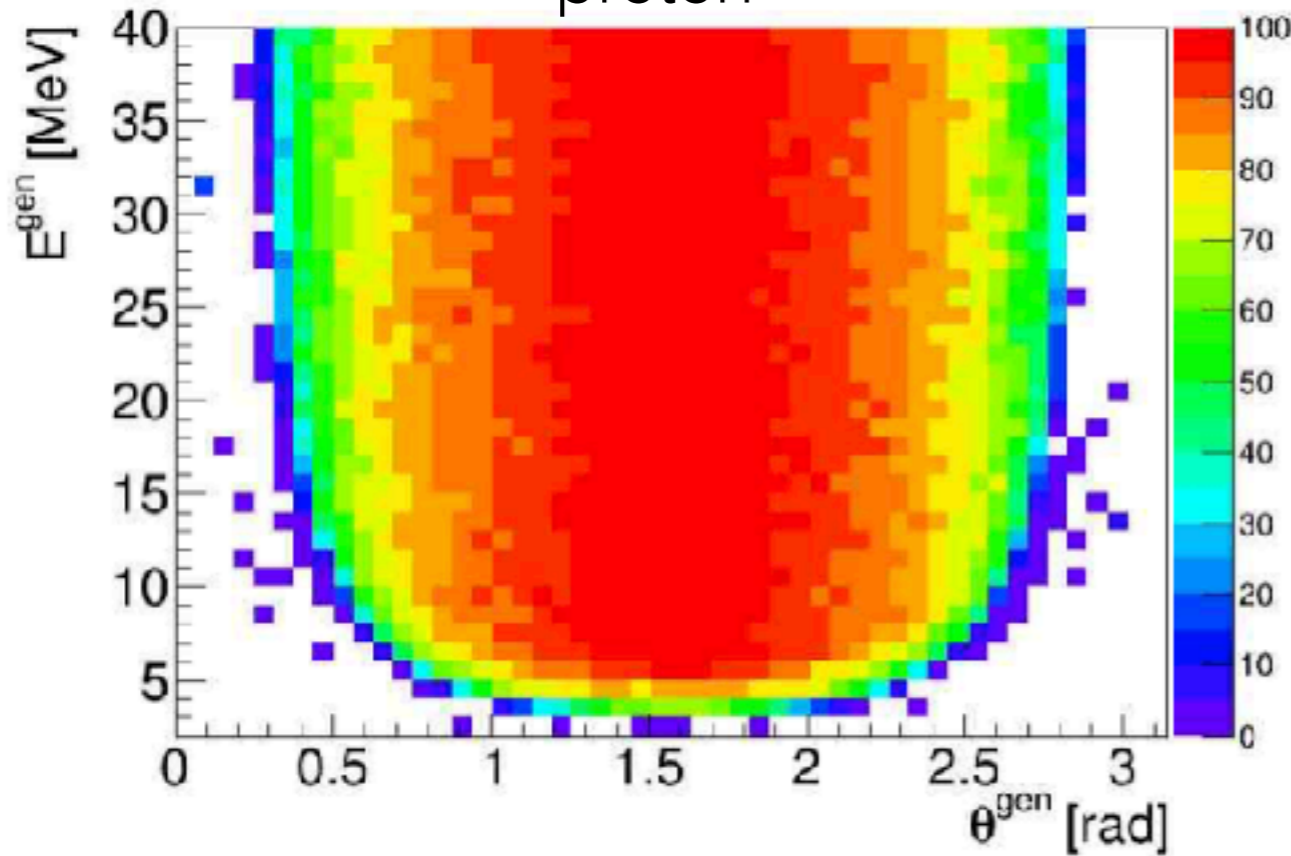
- 0.3×10^{35} luminosity
- **16 PAC days**
- 1.6×10^3 SRC events
- similar or more Mean-field events

Other Kinematic Distributions

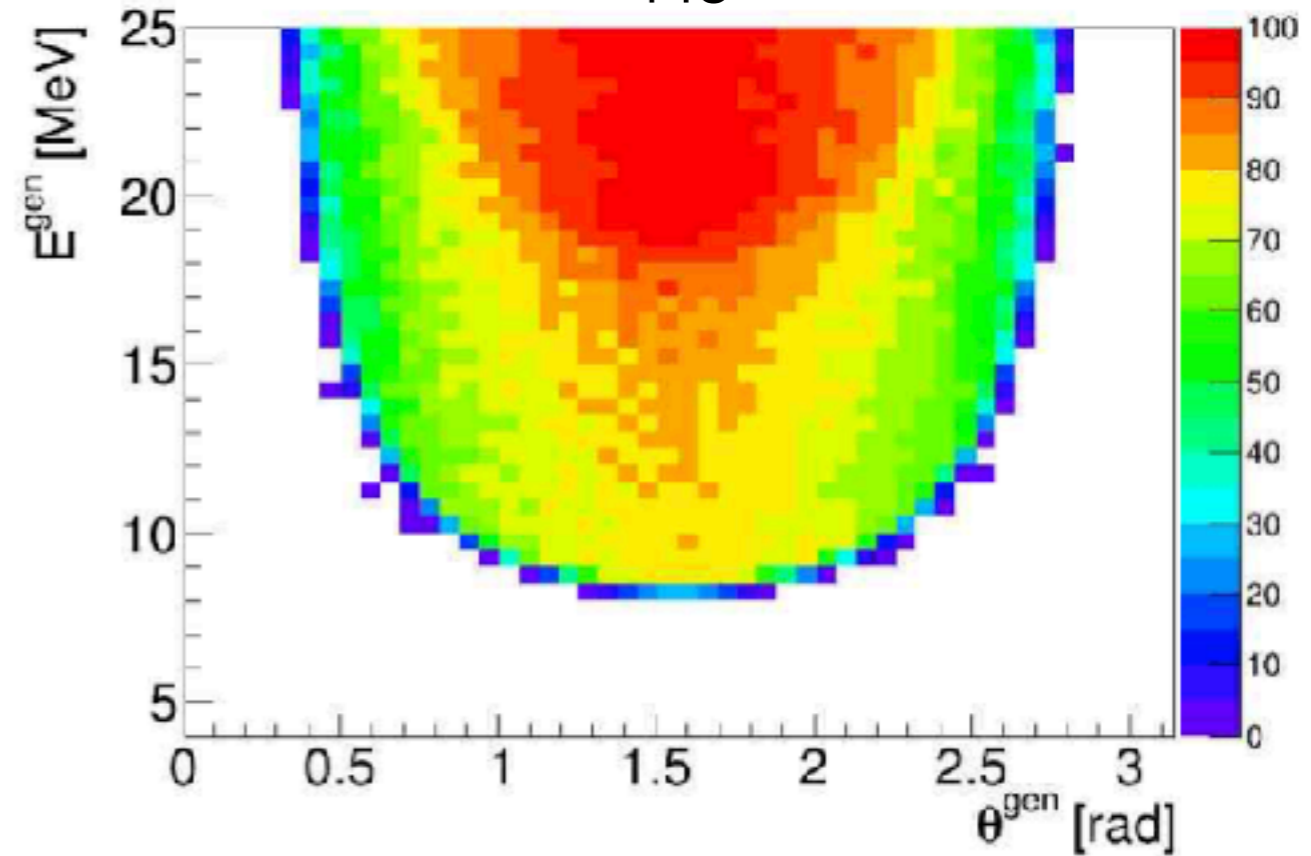


Comparison Acceptances

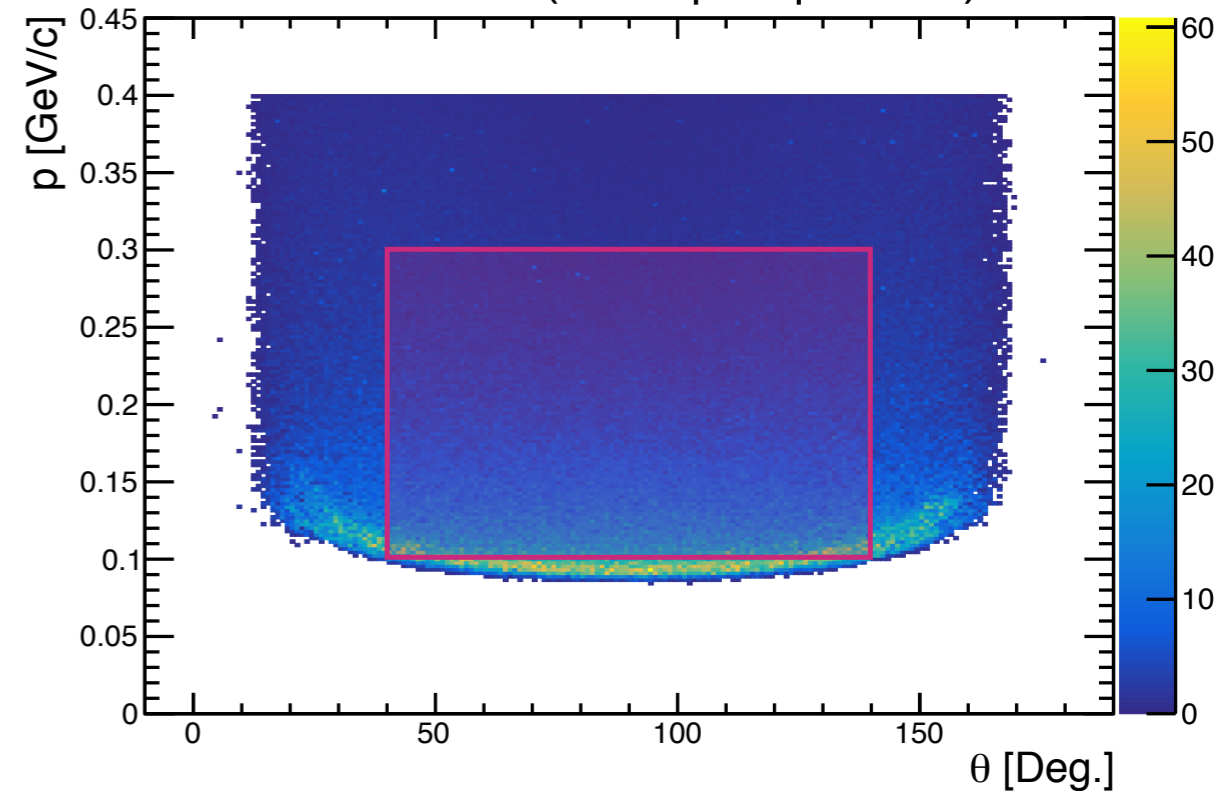
proton



^4He

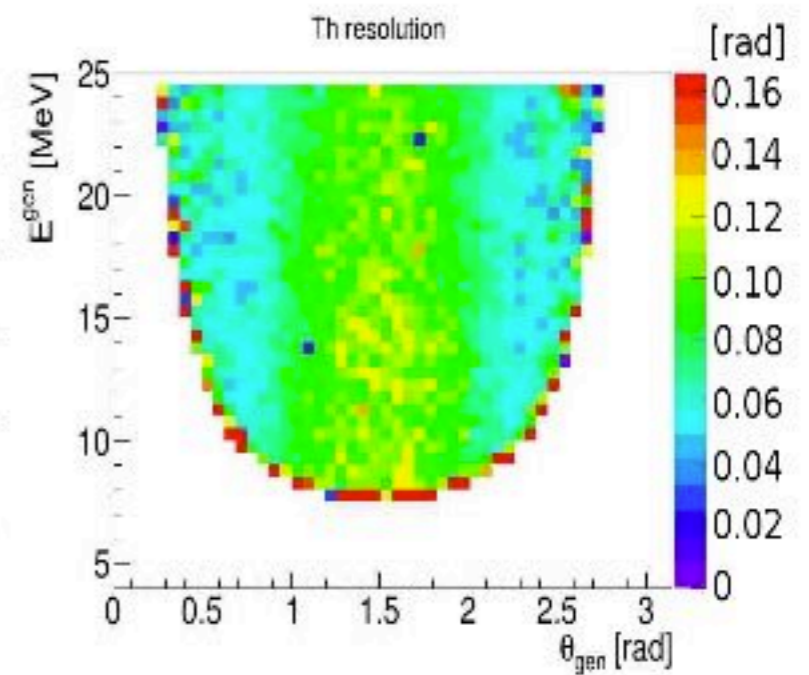
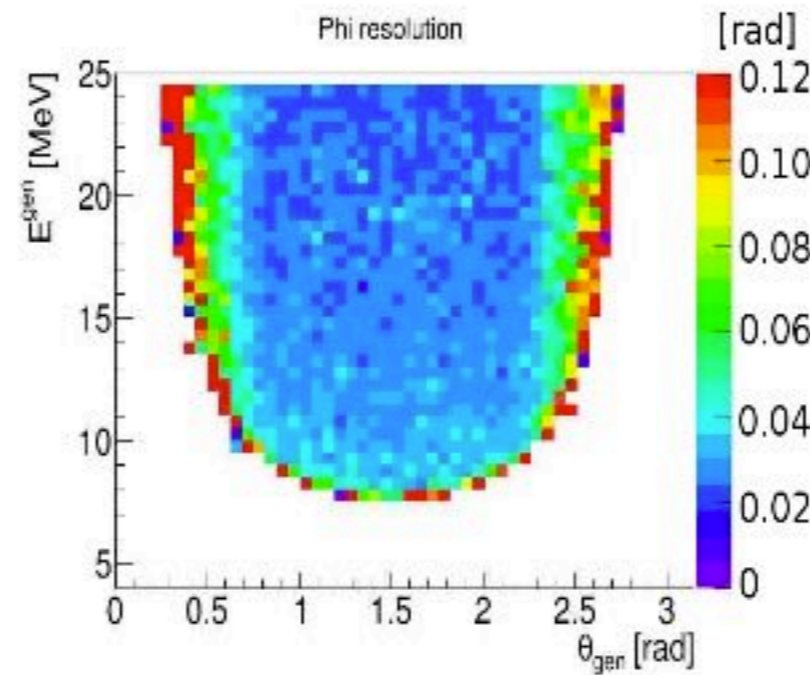
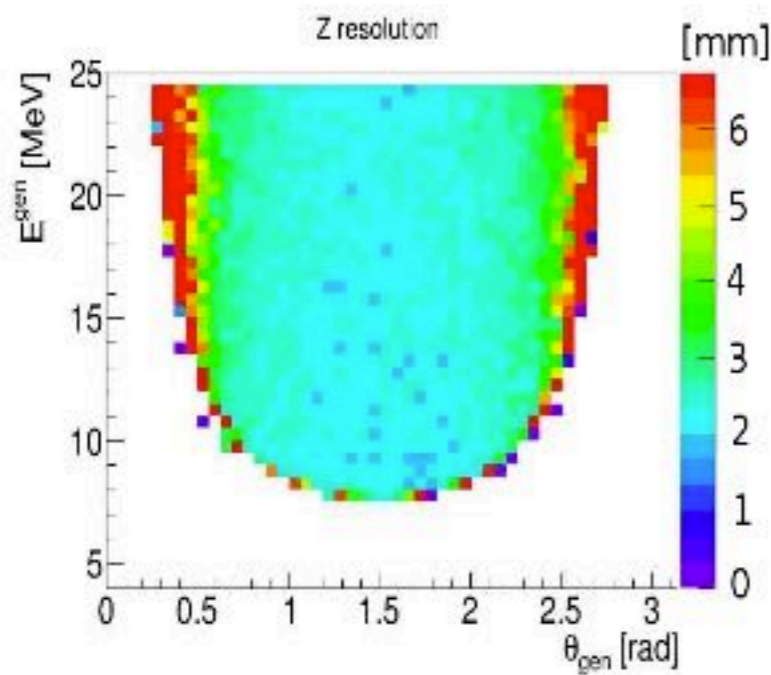
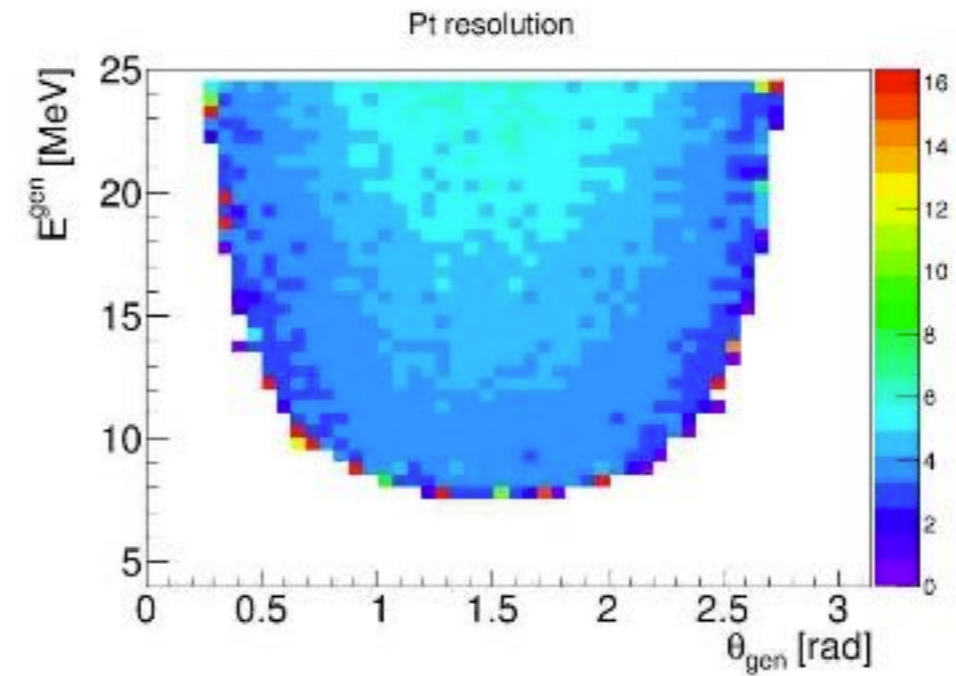
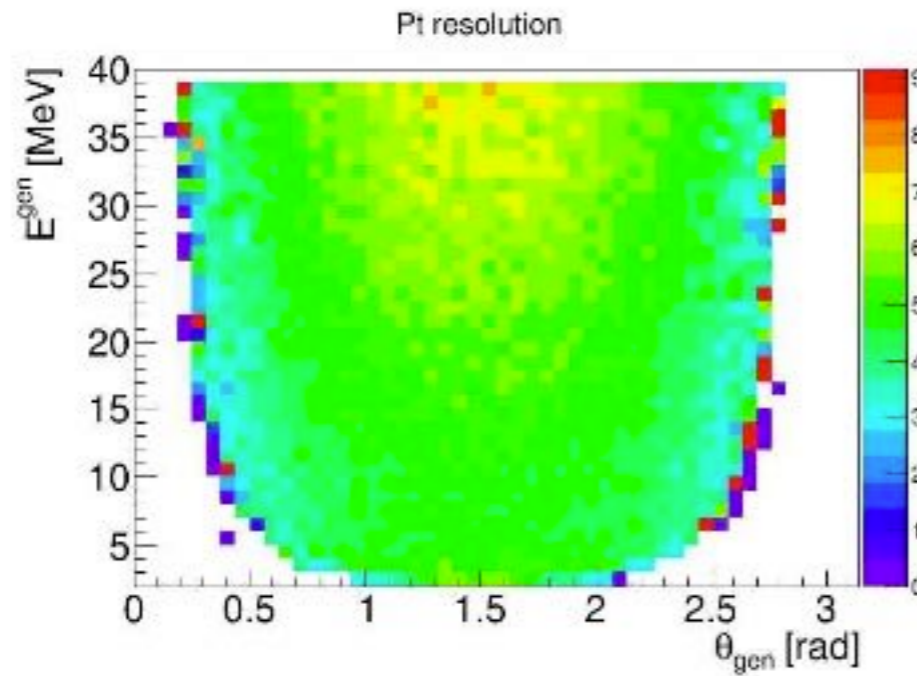


Deuteron (this proposal)



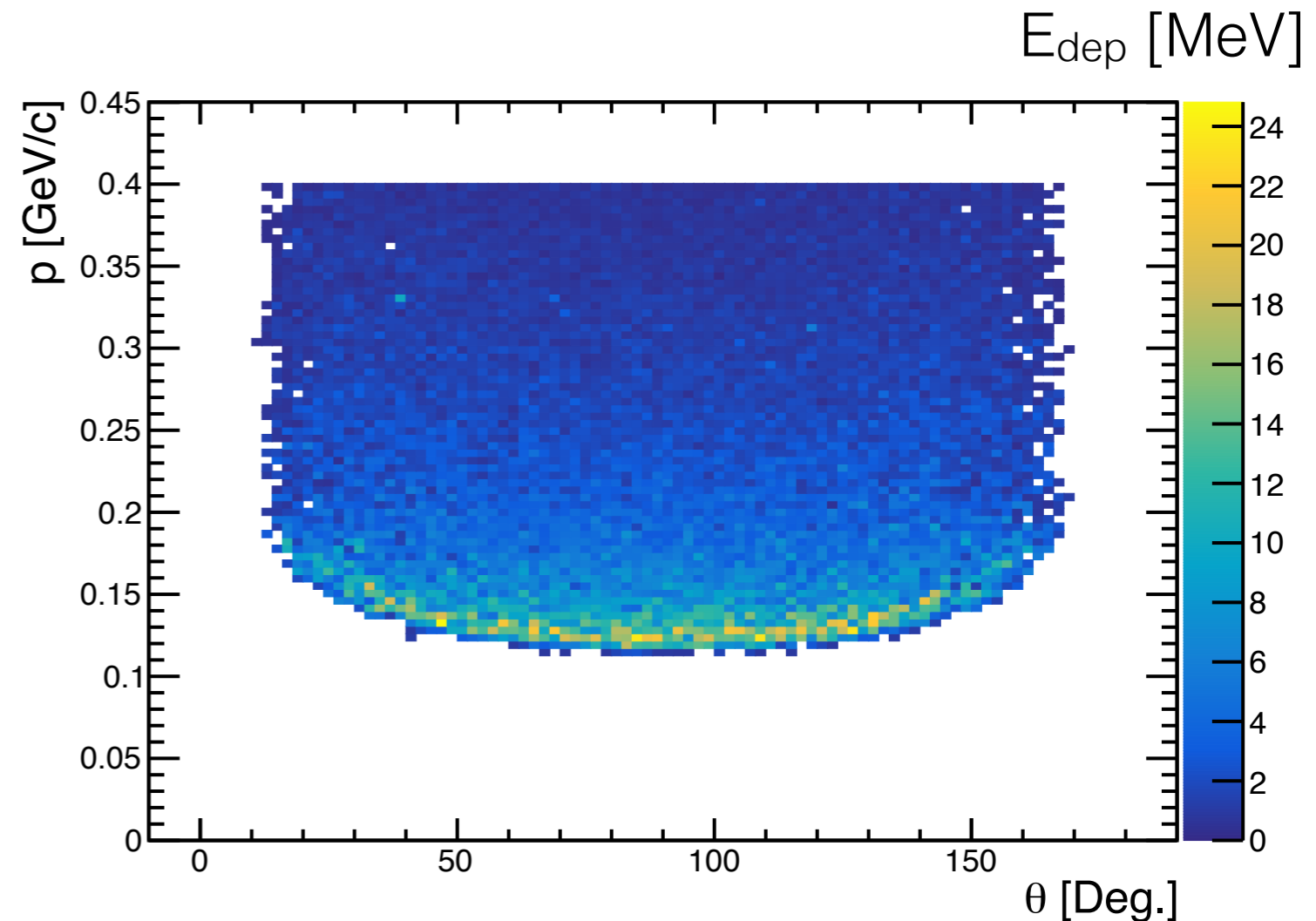
- Acceptances consistent with previous simulations from approved ALERT proposal E12-17-012 (<https://misportal.jlab.org/pacProposals/proposals/1338/attachments/98370/Proposal.pdf>)

Acceptance and Resolutions from ALERT Proposal



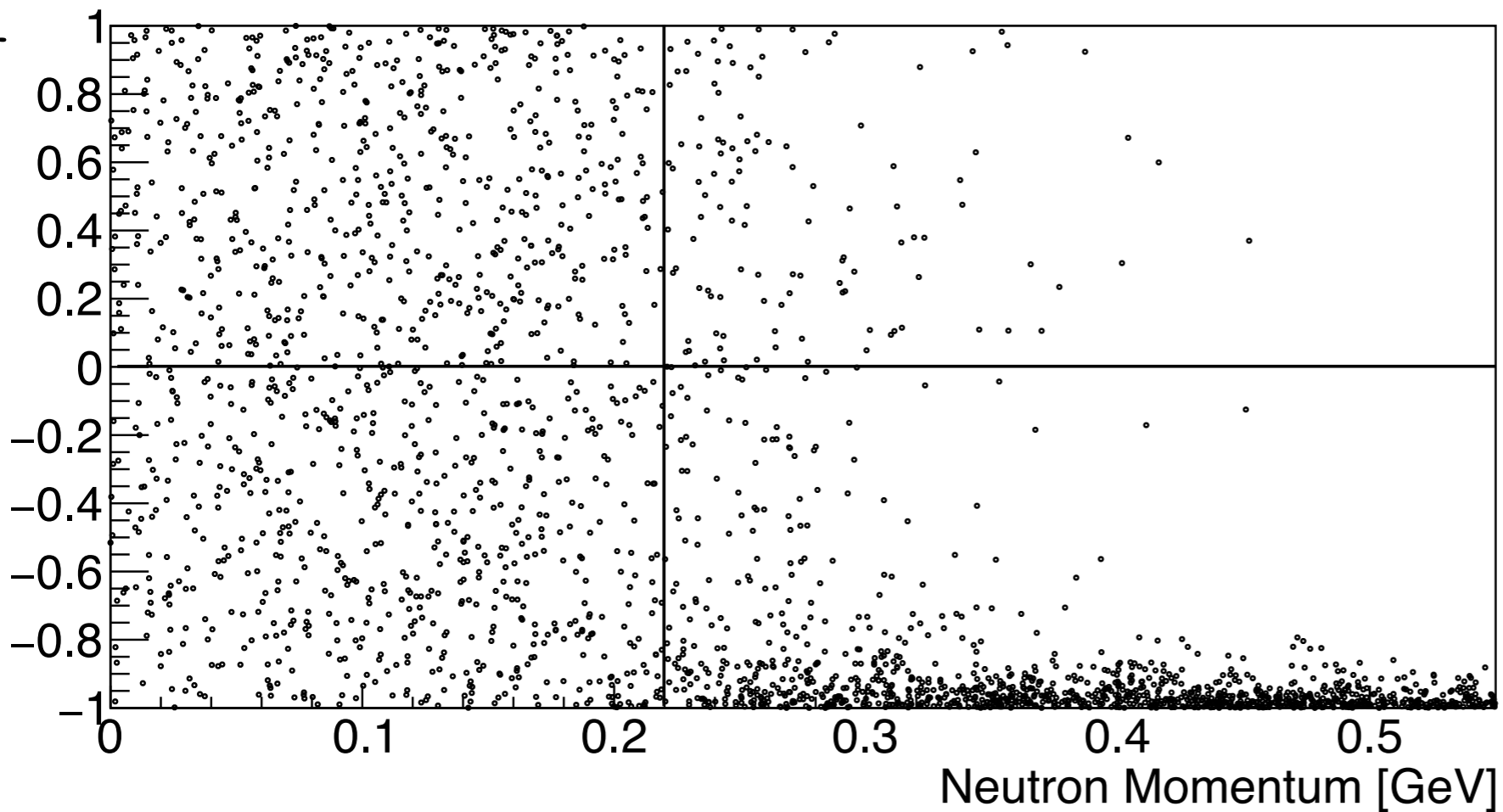
Triton ALERT Acceptance

- 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

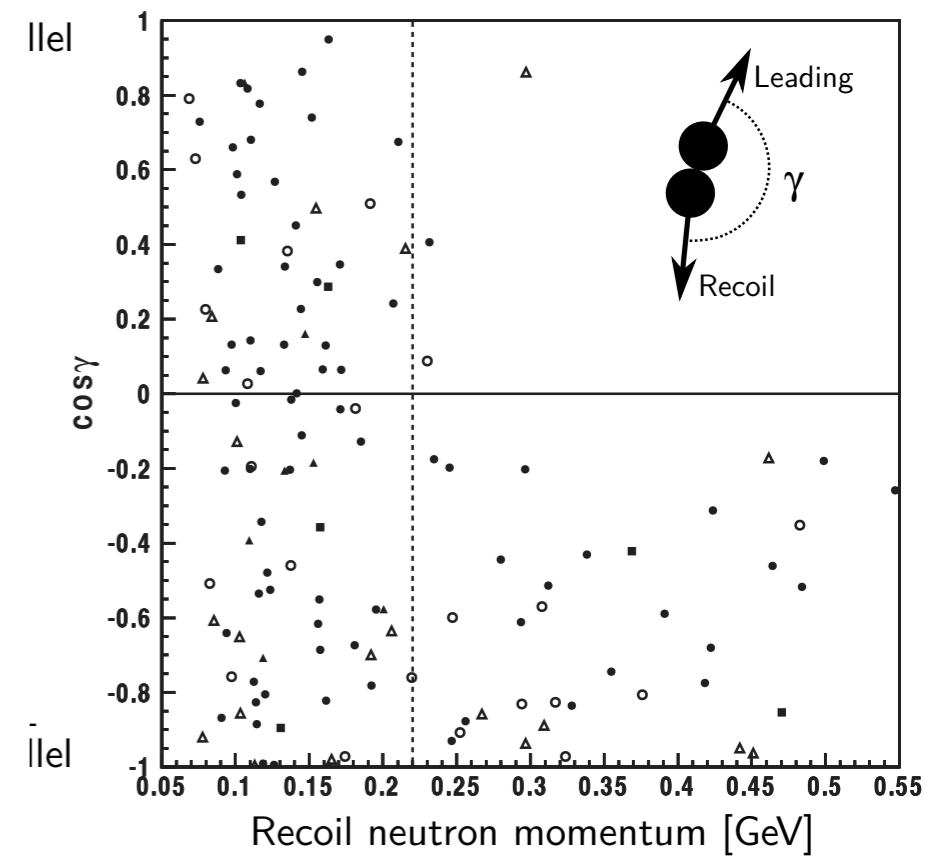


Projected Results: Transition

This proposal



Previous experiment



Projected Result: Test of Factorization

This proposal

