The ALERT-SRC Experiment

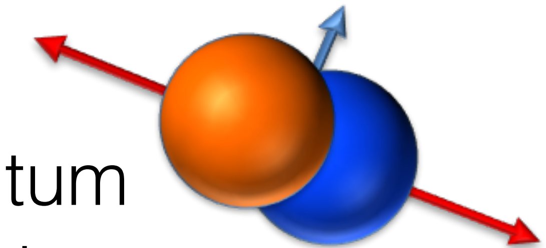
Florian Hauenstein

CLAS Collaboration Meeting

07/10/25

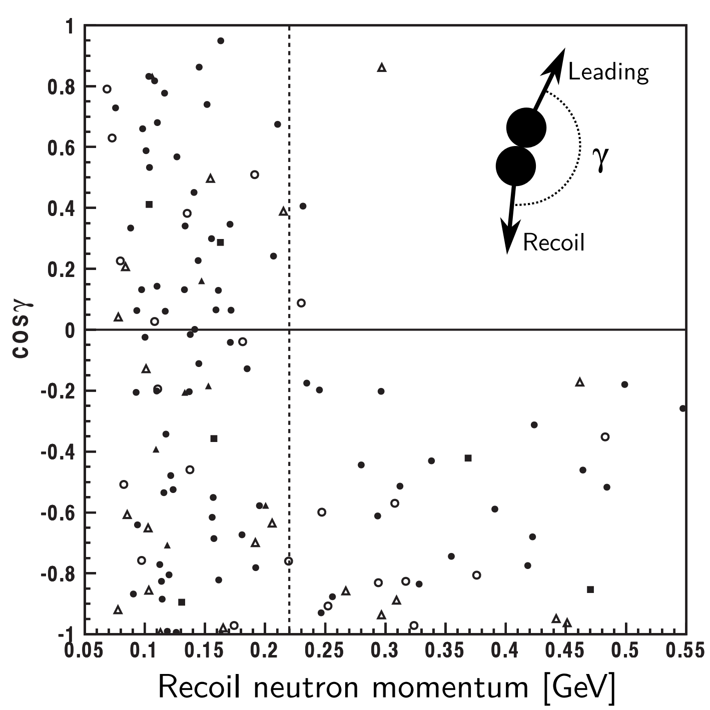
What we know about SRCs

- NN pair with
  - high relative momentum above Fermi momentum
  - lower c.m momentum



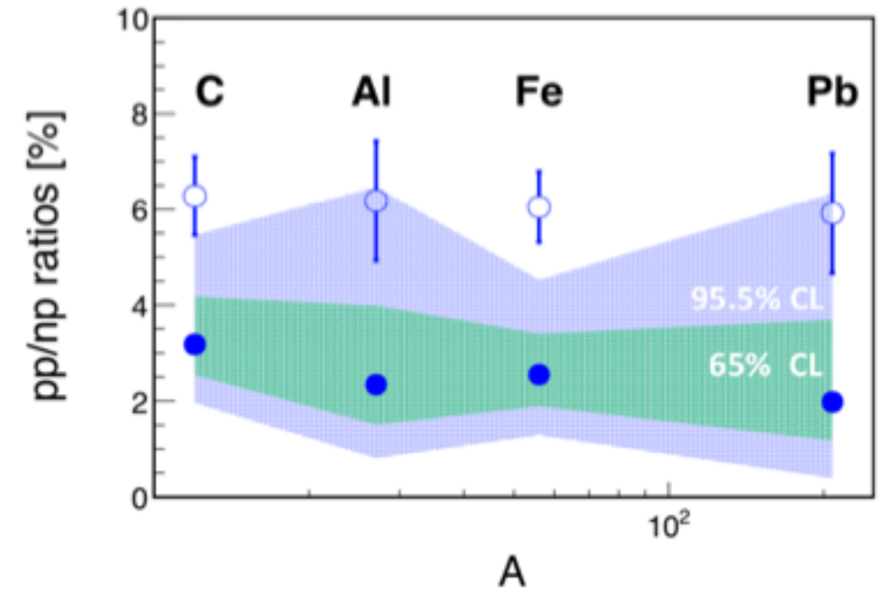
- Knockout of SRC nucleon --> always correlated partner

parallel

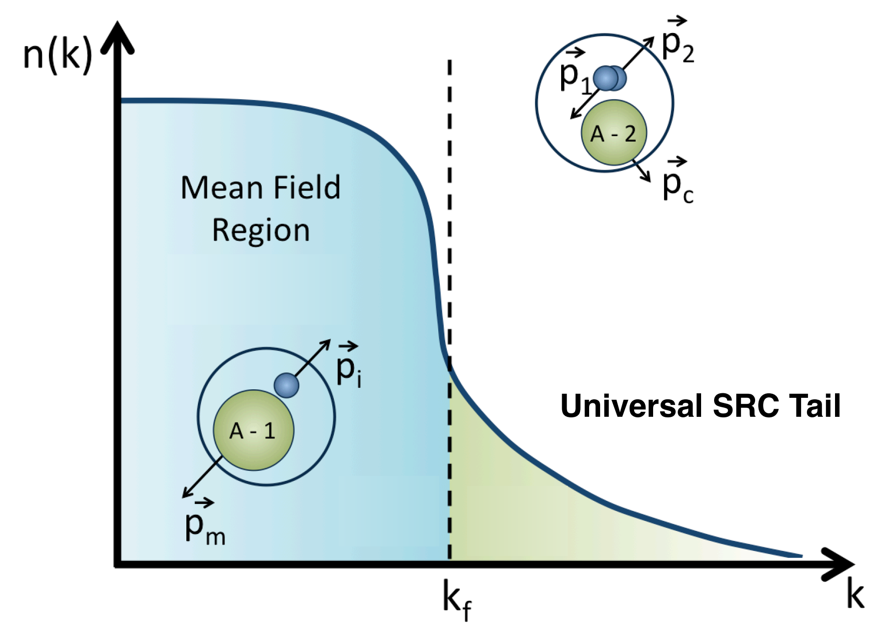


anti-parallel

- np dominance

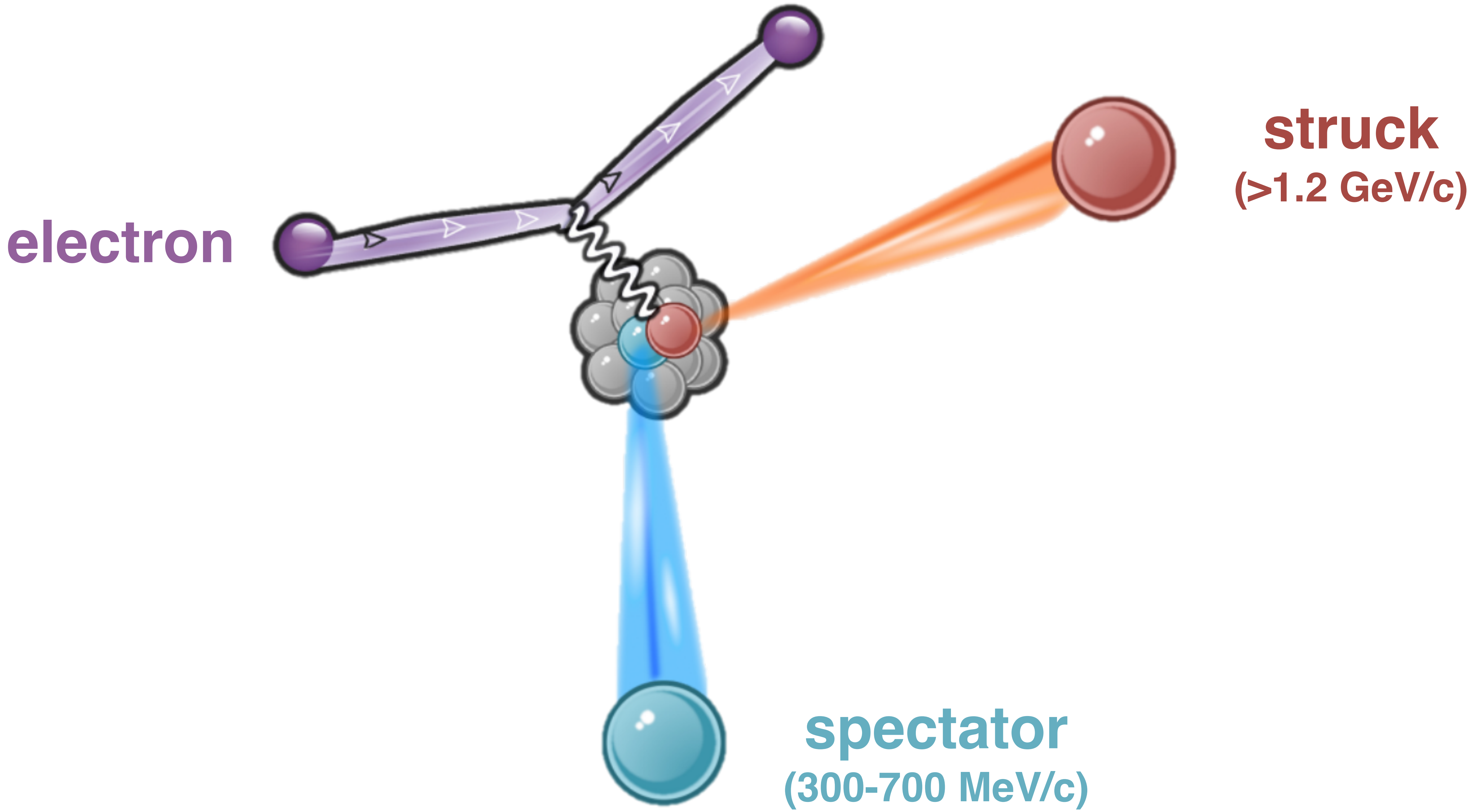


- Universality



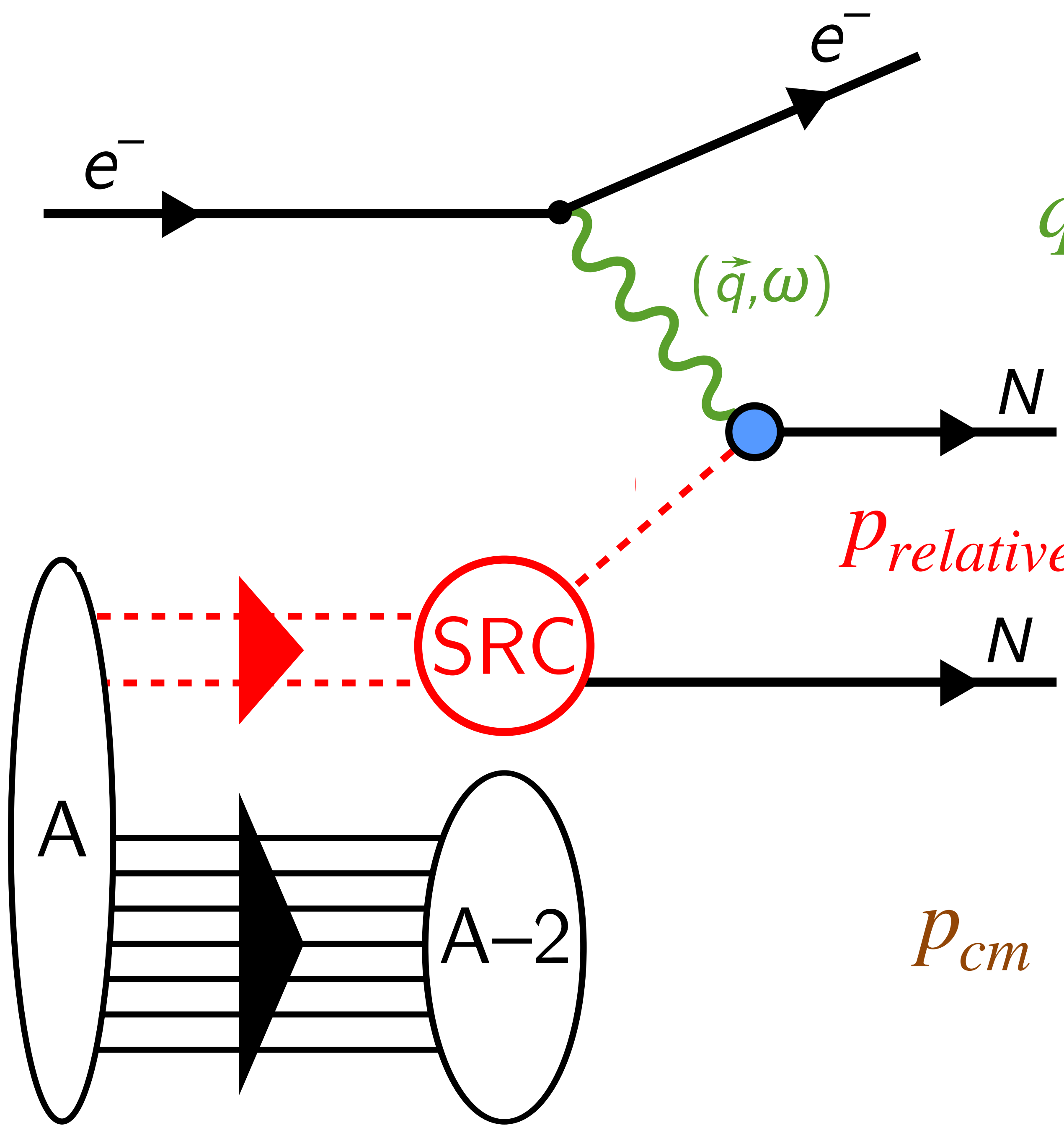
Piasetzky, PRL (2006), Shneor, PRL (2007), Subedi, Science (2008), Korover, PRL (2014), Hen, Science (2014), Duer, Nature (2018), Duer, PRL (2019), Schmidt, Nature (2020), Korover, PLB (2021), Korover, PRC (2023), <u>Review:</u> Hen RMP (2017)

SRC Measurements



PRL (2006), PRL (2007), Science (2008), PRL (2014), Science (2014),
Nature (2018), PRL (2019), Nature (2020), PLB (2021), PRC (2023), Review: RMP (2017)

Scale Separation: $q \gg p_{relative} \gg p_{cm}$



$q > 1.5$ GeV/c

$p_{relative} \sim 300\text{-}700$ MeV/c

$p_{cm} \sim 100\text{-}150$ MeV/c

PRC 92 (2015), PLB 780 (2018), PLB 791 (2019), PLB 792 (2019), JPG 47 (2020), Nature Physics 17 (2021), PRC 104 (2021), PRC 53 (1996), PRL 119 (2017)

Scale Separation

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

$\downarrow$

Factorization of many-body wave function

PRC 92 (2015), PLB 780 (2018), PLB 791 (2019), PLB 792 (2019), JPG 47 (2020), Nature Physics 17 (2021), PRC 104 (2021), PRC 53 (1996), PRL 119 (2017)

Scale Separation

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

$\downarrow$

Factorization of many-body wave function

$\downarrow$

Elementary eN cross section	Nuclear Contacts	Two-body wave function	Center of mass motion

$$\sigma = \sigma_{eN}(q) \cdot \sum_{NN} \cdot C_A^{NN} \cdot |\phi(p_{relative})|^2 \cdot n(p_{cm})$$

PRC 92 (2015), PLB 780 (2018), PLB 791 (2019), PLB 792 (2019), JPG 47 (2020), Nature Physics 17 (2021), PRC 104 (2021), PRC 53 (1996), PRL 119 (2017)

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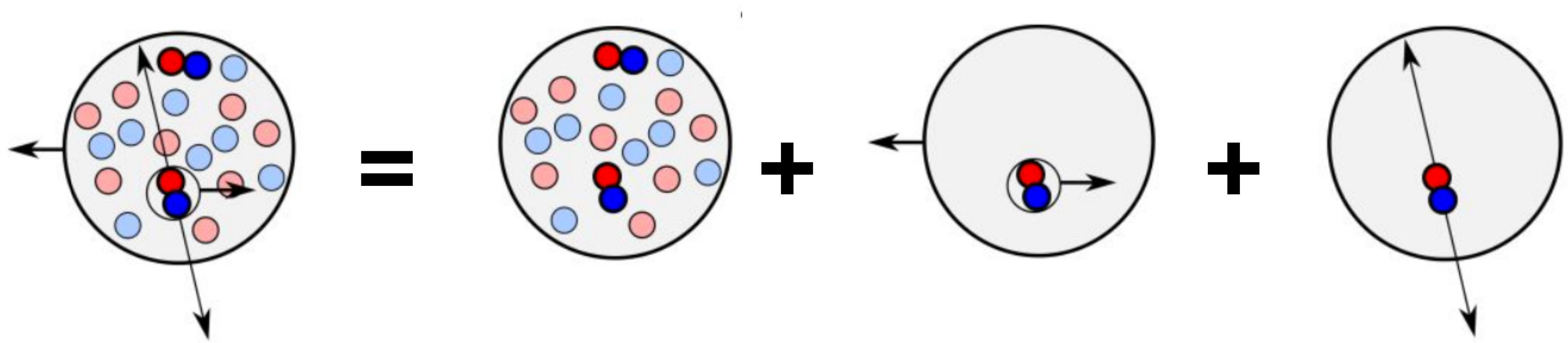
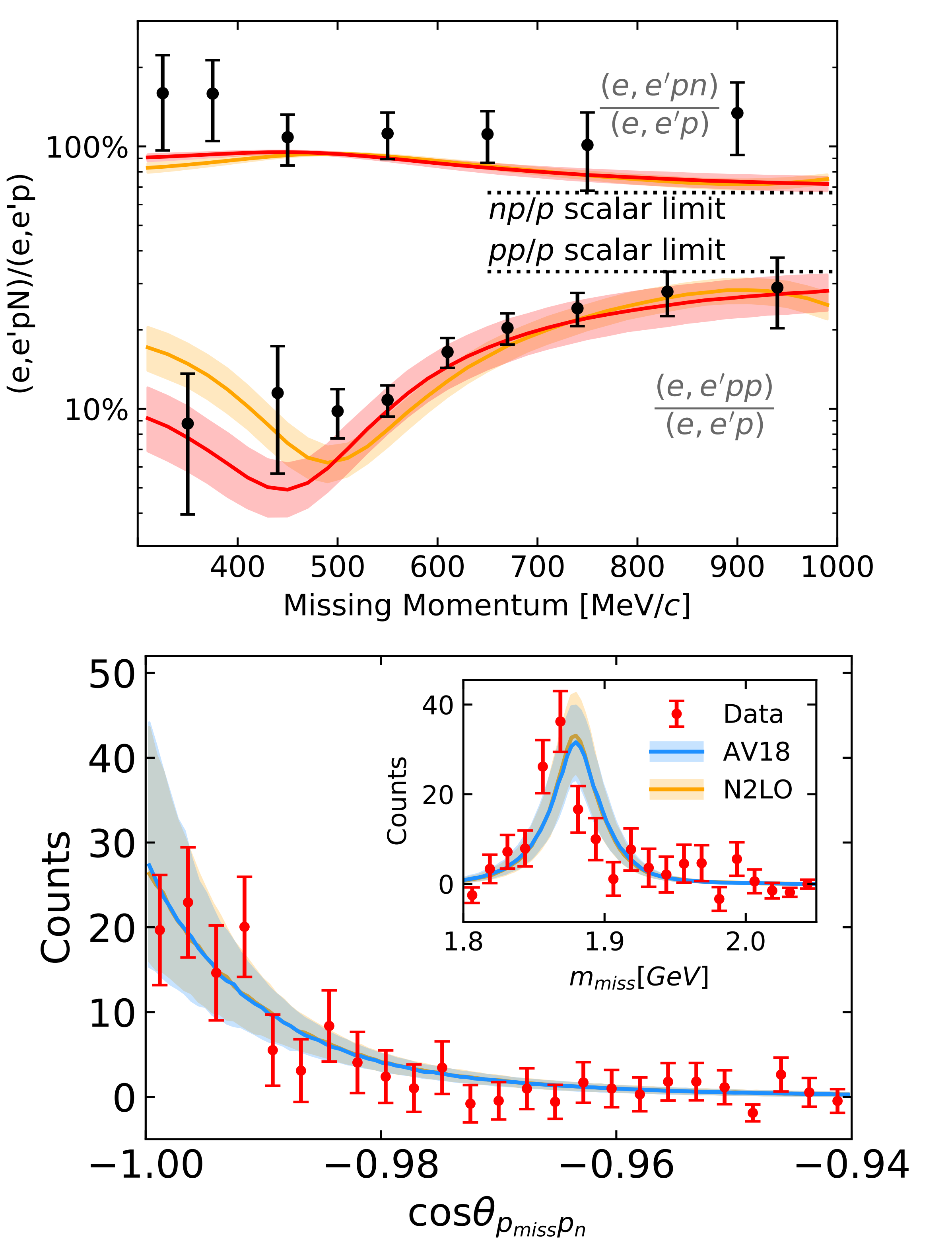


PRC 92 (2015), PLB 780 (2018), PLB 791 (2019), PLB 792 (2019), JPG 47 (2020), Nature Physics 17 (2021), PRC 104 (2021), PRC 53 (1996), PRL 119 (2017)

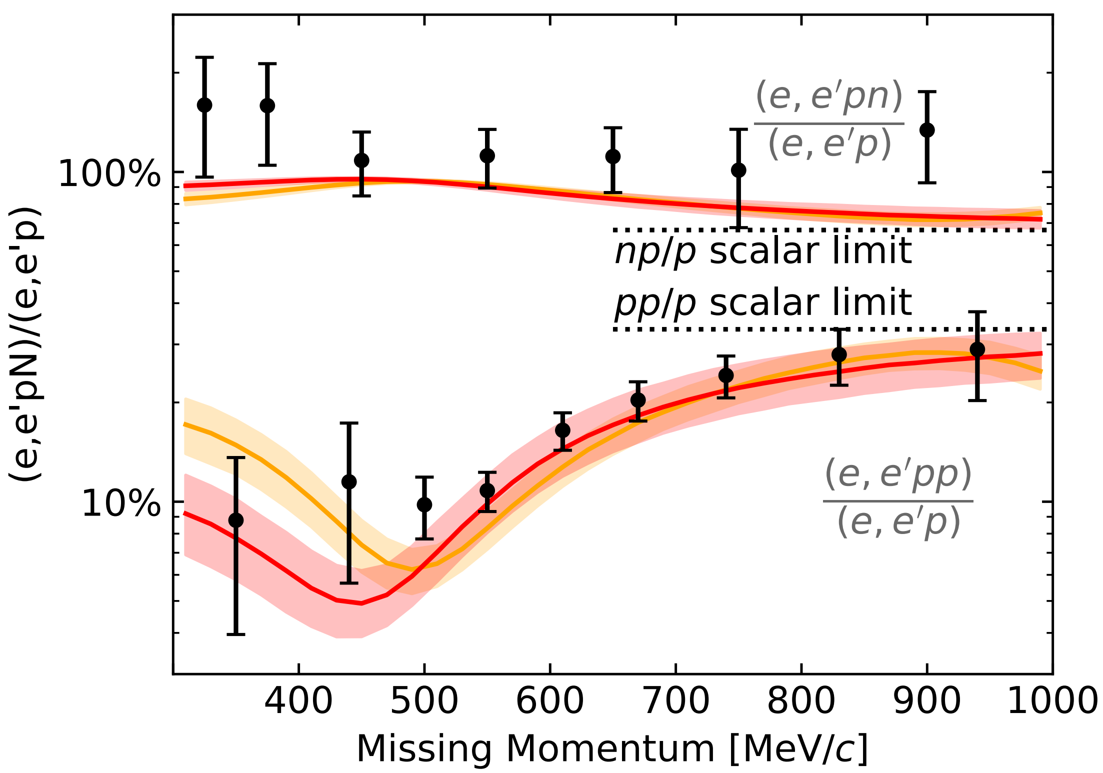
Formalism works very well!

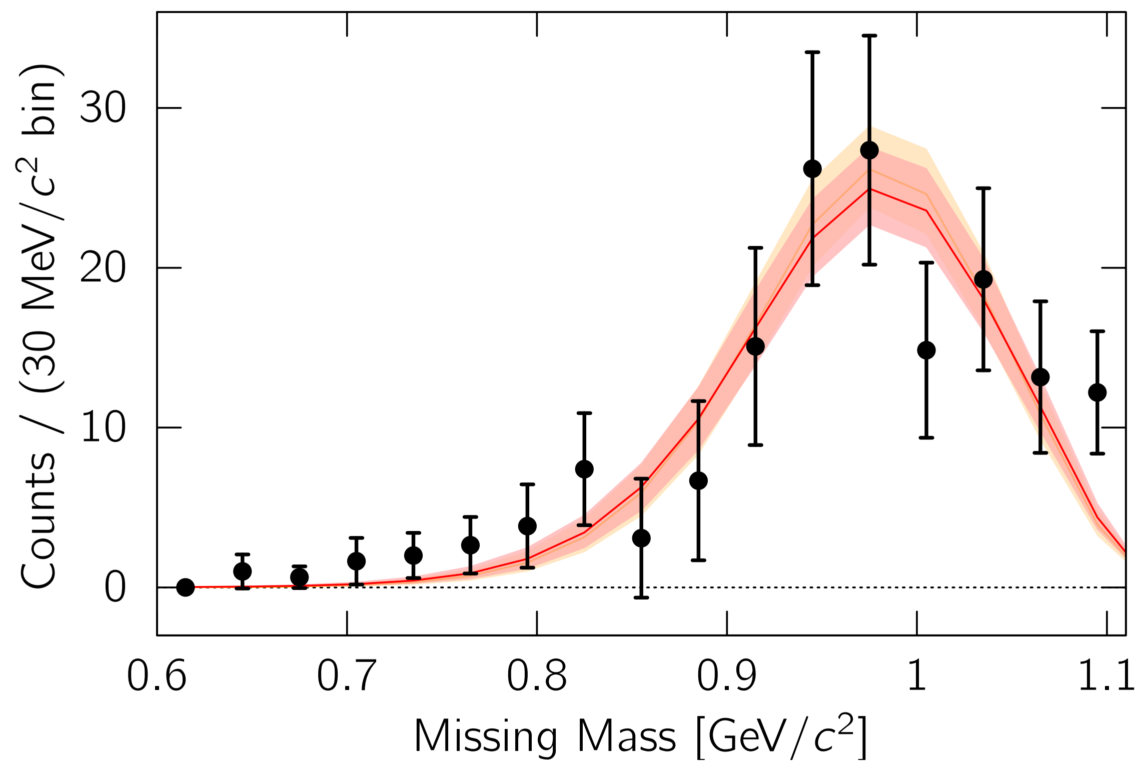
PRL 122 (2019), Nature 578 (2020), PLB 805 (2020), PLB 820 (2021), PRC 103 (2021), PRC 107 (2023)

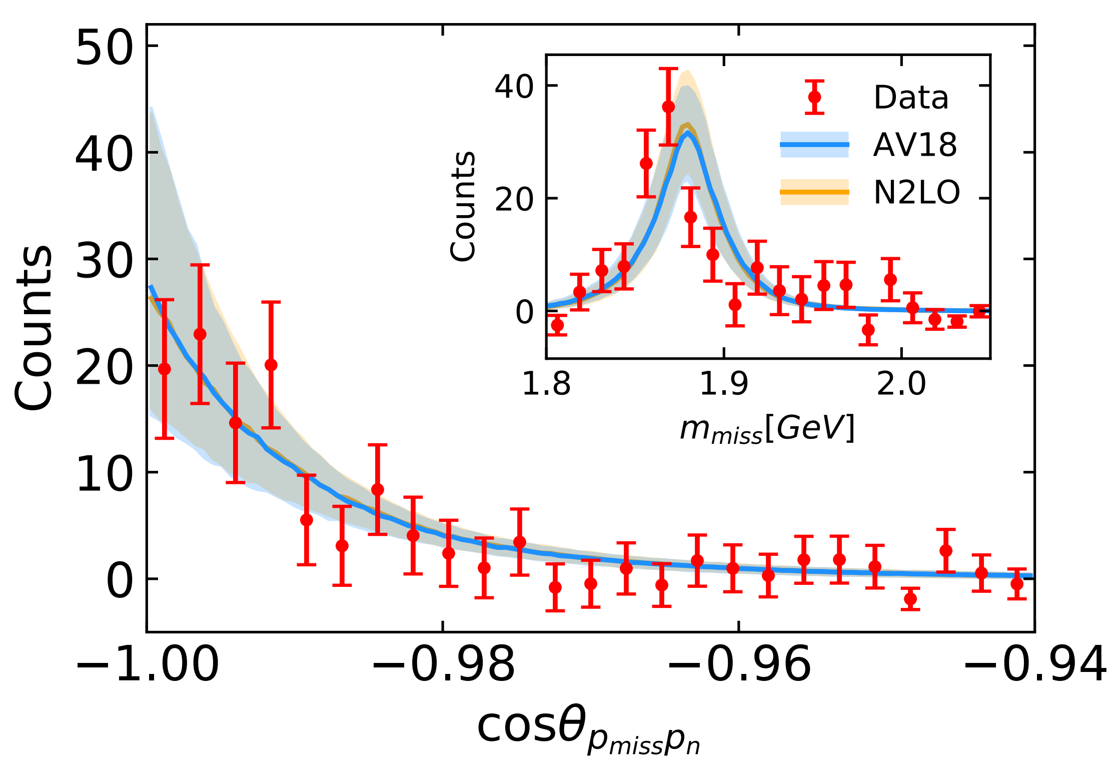


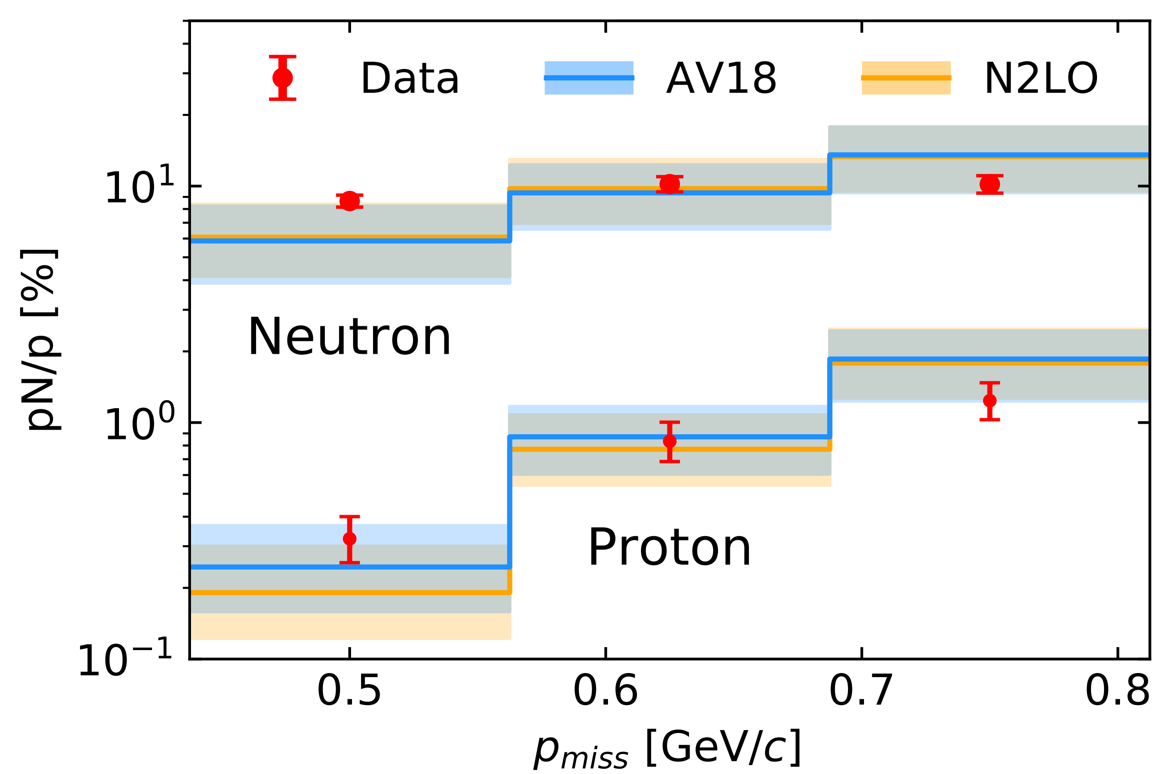
Formalism works very well … <u>where tested</u>

PRL 122 (2019), Nature 578 (2020), PLB 805 (2020), PLB 820 (2021), PRC 103 (2021), PRC 107 (2023)









Question 1: SRC pair Factorization

Elementary eN cross section	Nuclear Contacts	Two-body wave function	Center of mass motion

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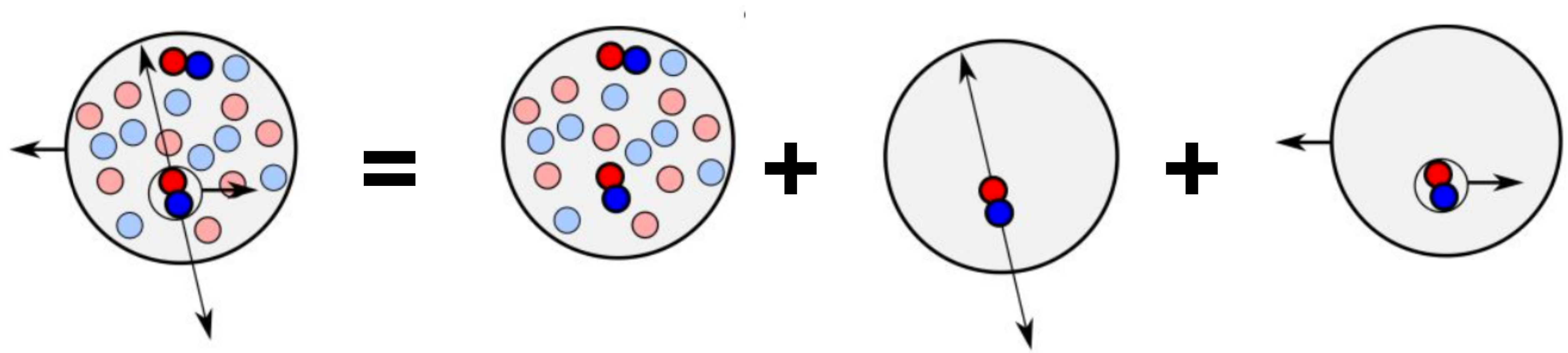

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Question 1: SRC pair Factorization

Elementary eN cross section	Nuclear Contacts	Two-body wave function	Center of mass motion

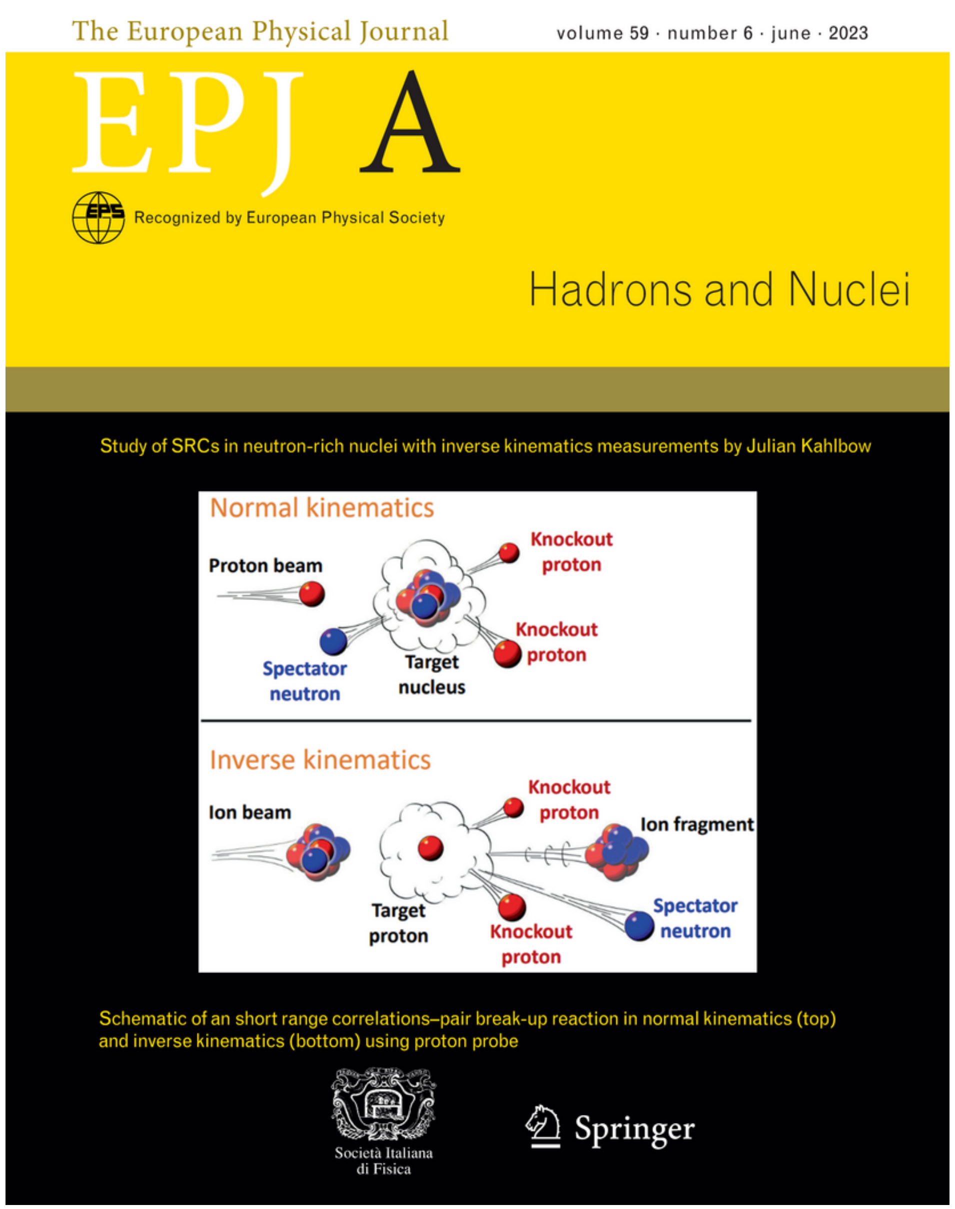
$$\sigma = \sigma_{eN}(q) \cdot \sum_{NN} \cdot C_A^{NN} \cdot \, |\phi(p_{relative})|^2 \cdot \, n(p_{cm})$$

Factorization test: uncorrelated relative and c.m. motions

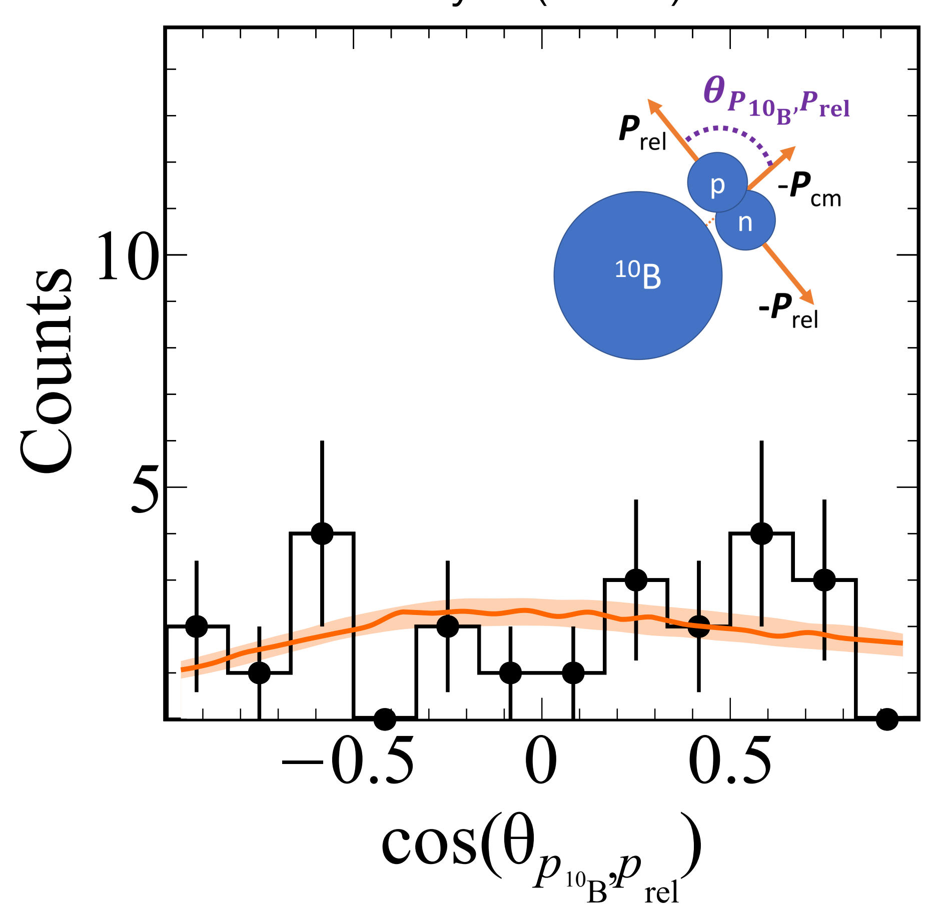
PRC 92 (2015), PLB 780 (2018), PLB 791 (2019), PLB 792 (2019), JPG 47 (2020), Nature Physics 17 (2021), PRC 104 (2021), PRC 53 (1996), PRL 119 (2017)

Goal 1: Precision Test of Factorization

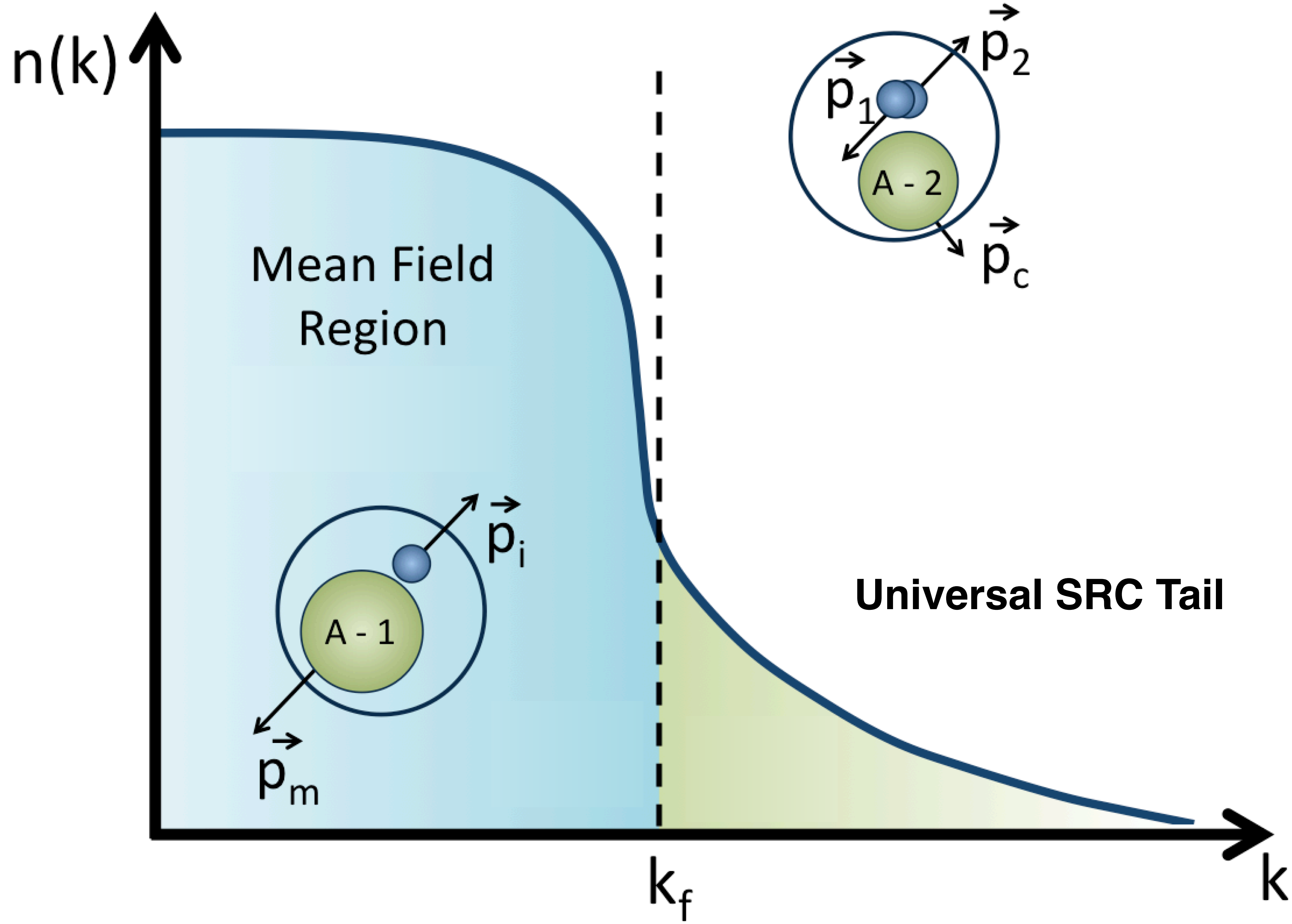
- 23(!) inverse kinematics $^{12}C(p,2p)^{10}B$ events
- Consistent with factorization but… limited statistics
- Need better data with spectator nucleus tagging



Nature Phys. (2021)

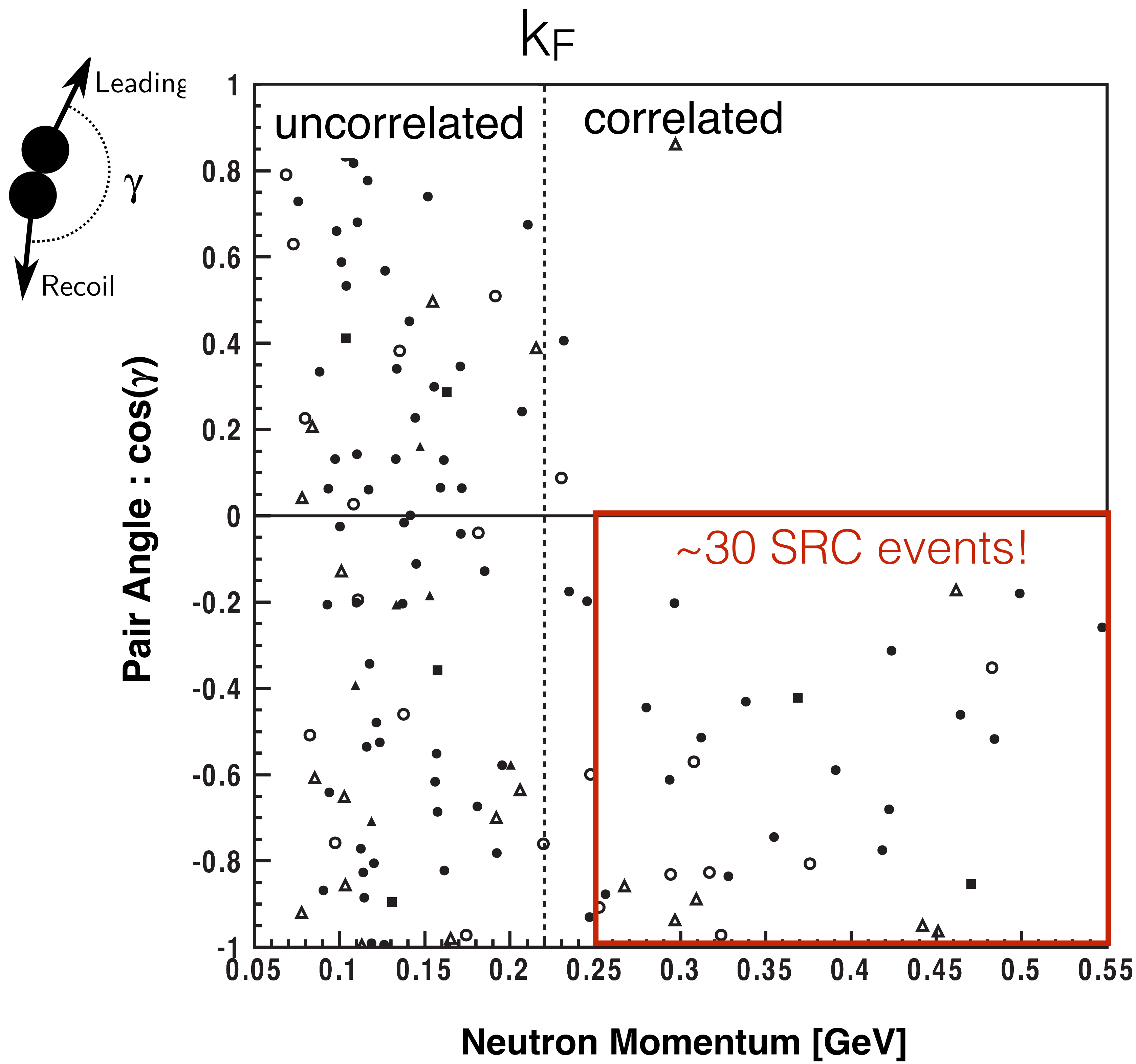


Question 2: Mean-field to SRC Transition



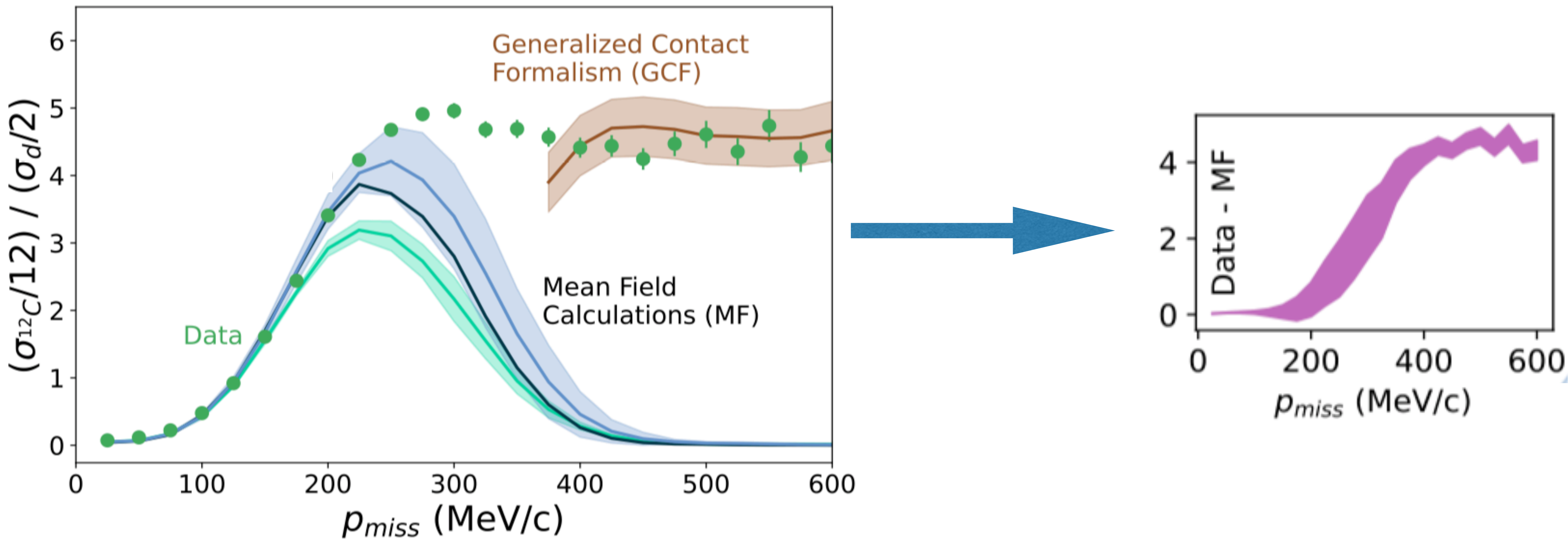
Goal 2: High-statistics, Exclusive Mapping of Transition Region

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



Goal 2: High-statistics, Exclusive Mapping of Transition Region

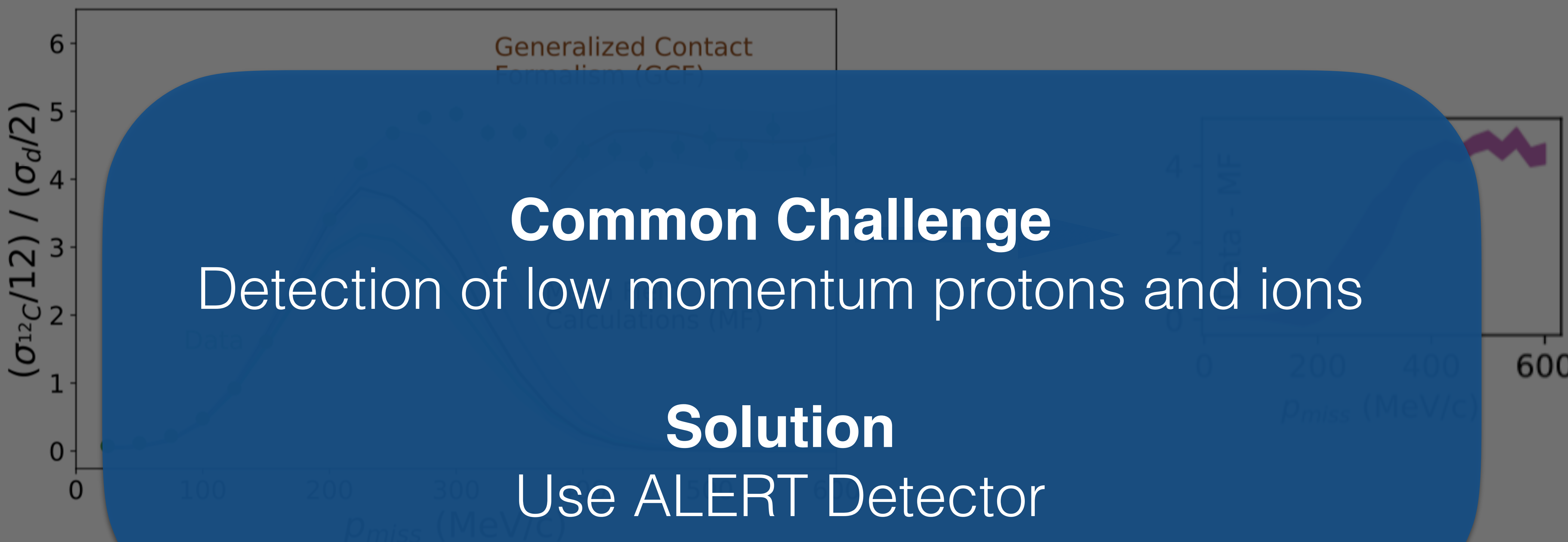
Korover et al., PRC 107, L061301 (2023)



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

Goal 2: High-statistics, Exclusive Mapping of Transition Region

PRC 107, L061301 (2023)



Common Challenge

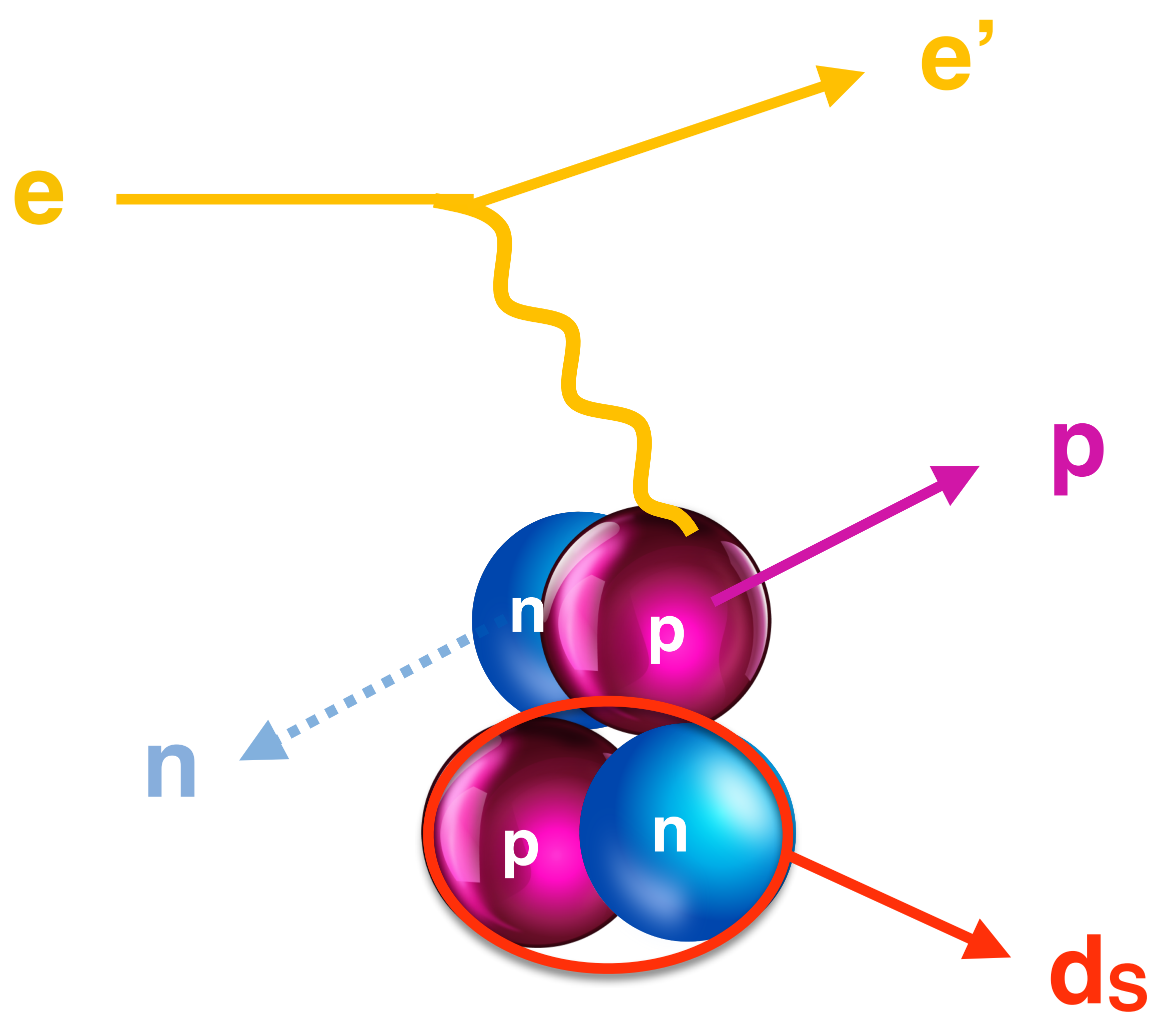
Detection of low momentum protons and ions

Solution

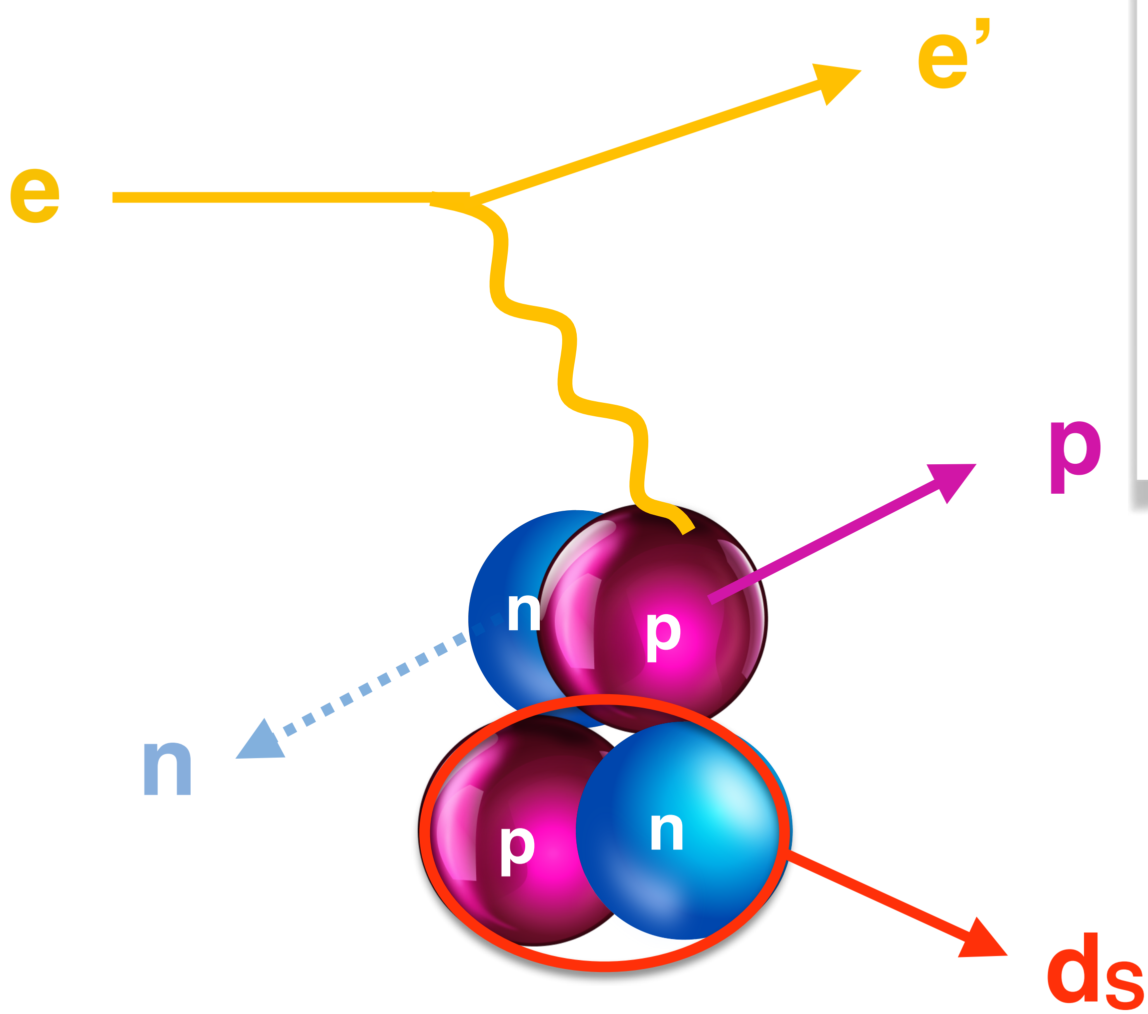
Use ALERT Detector

- 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

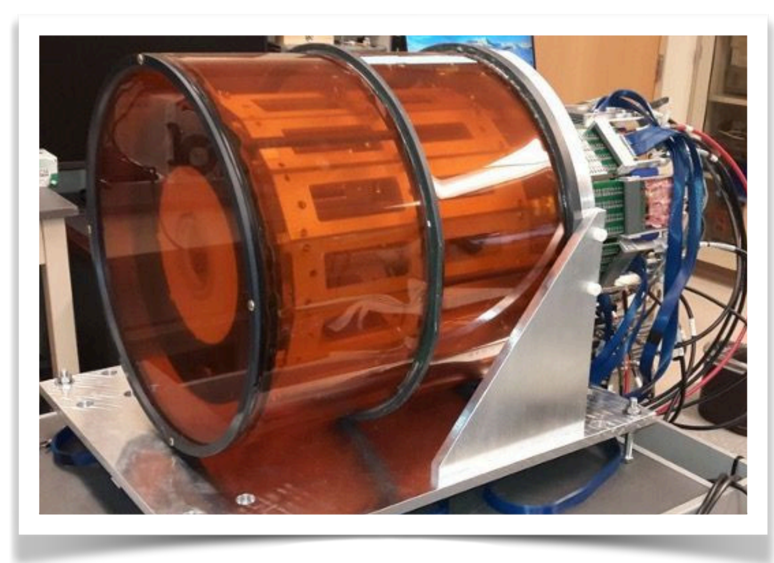


Main Channel $^{4}He(e,e'pd_S)n$



CLAS12

ALERT



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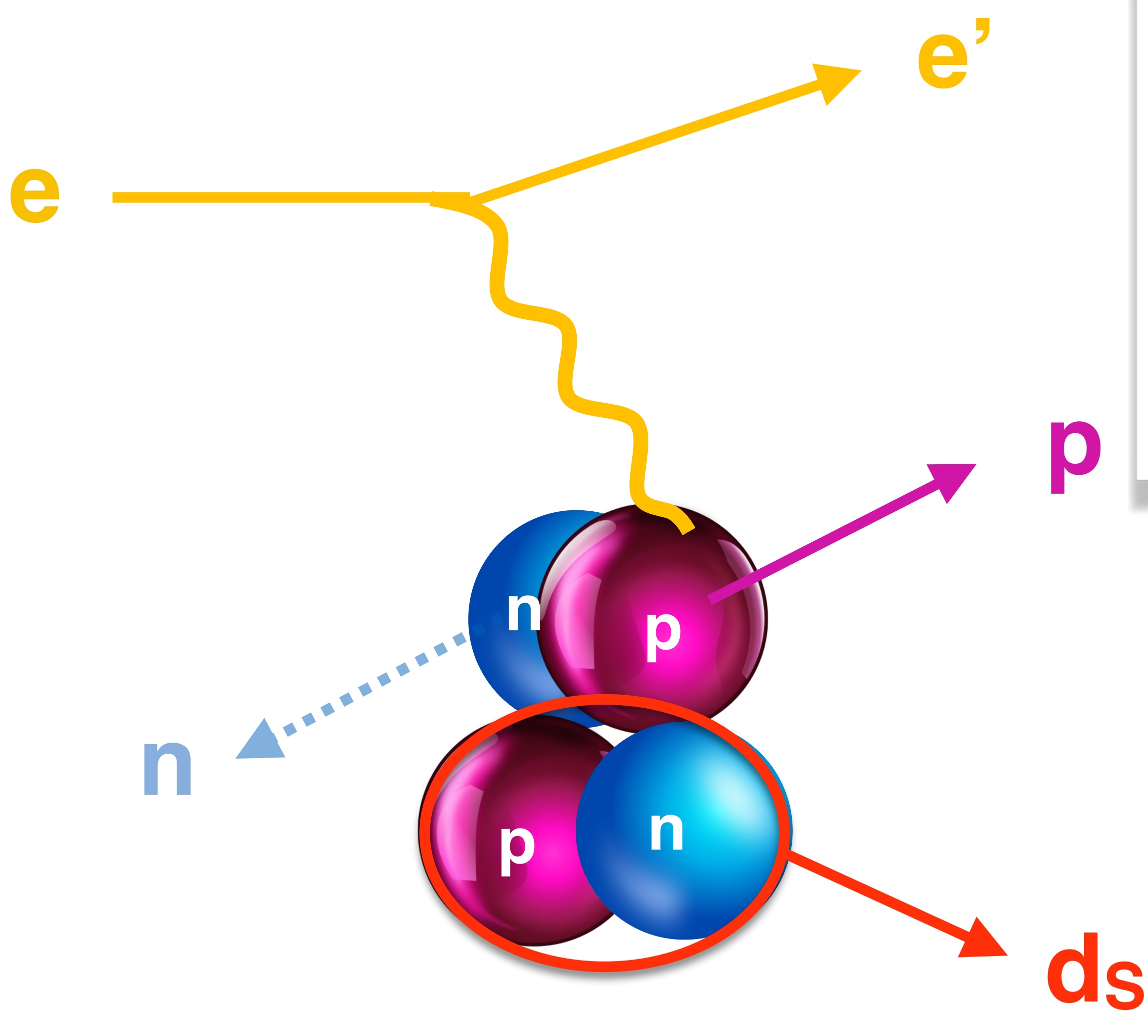
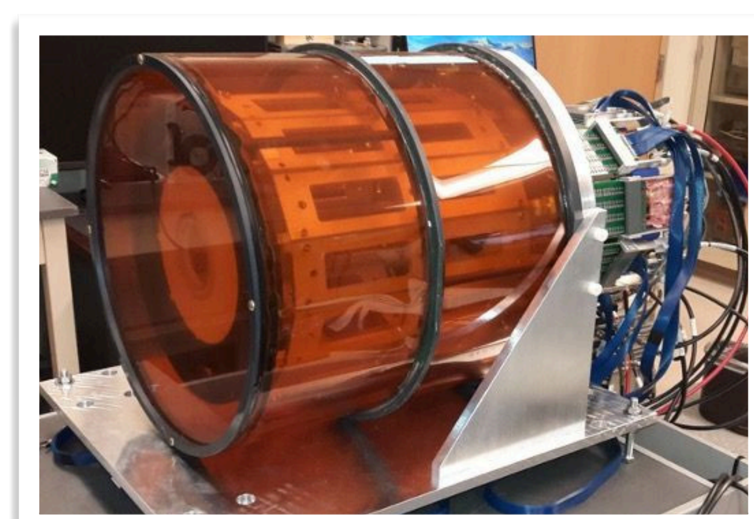


CLAS12

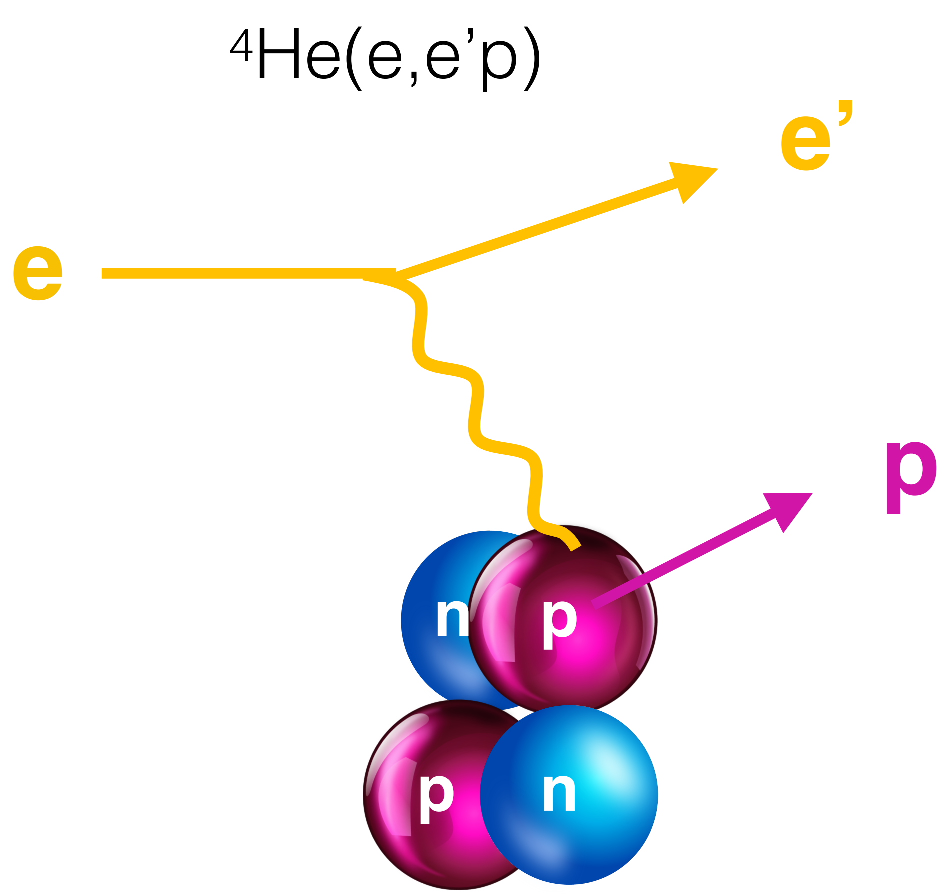
ALERT

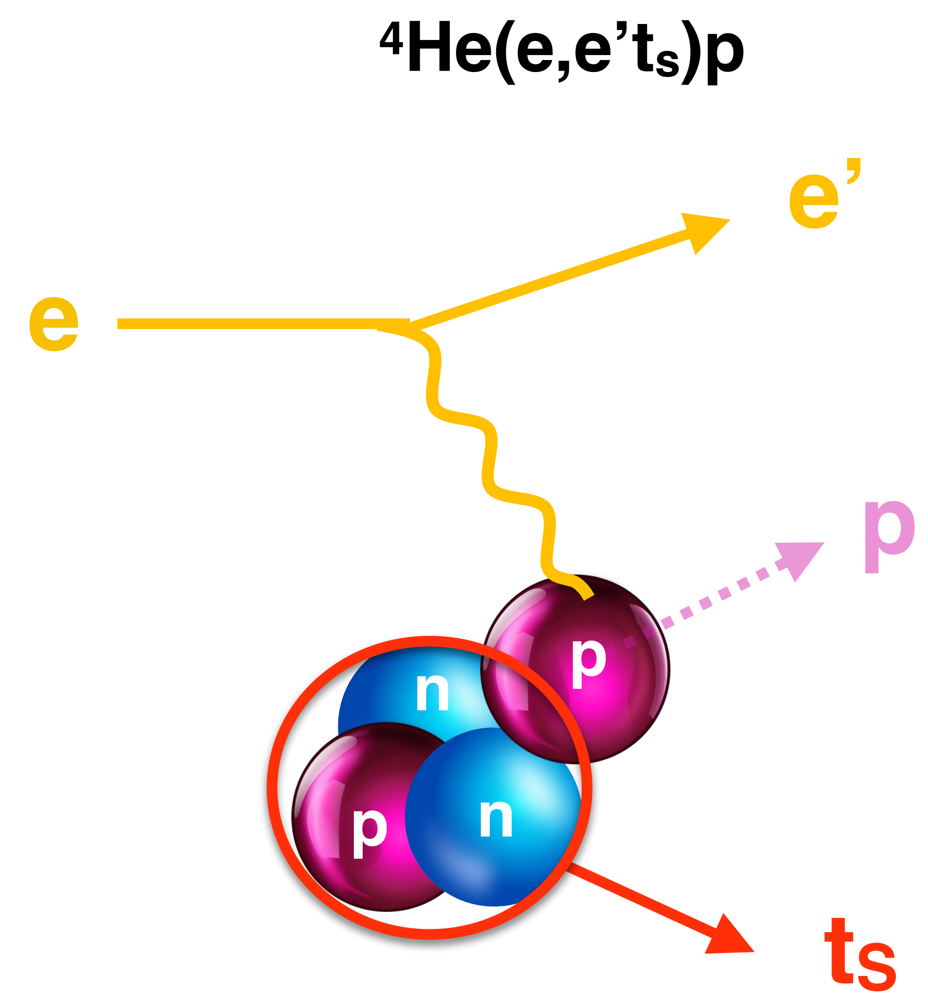


Summary

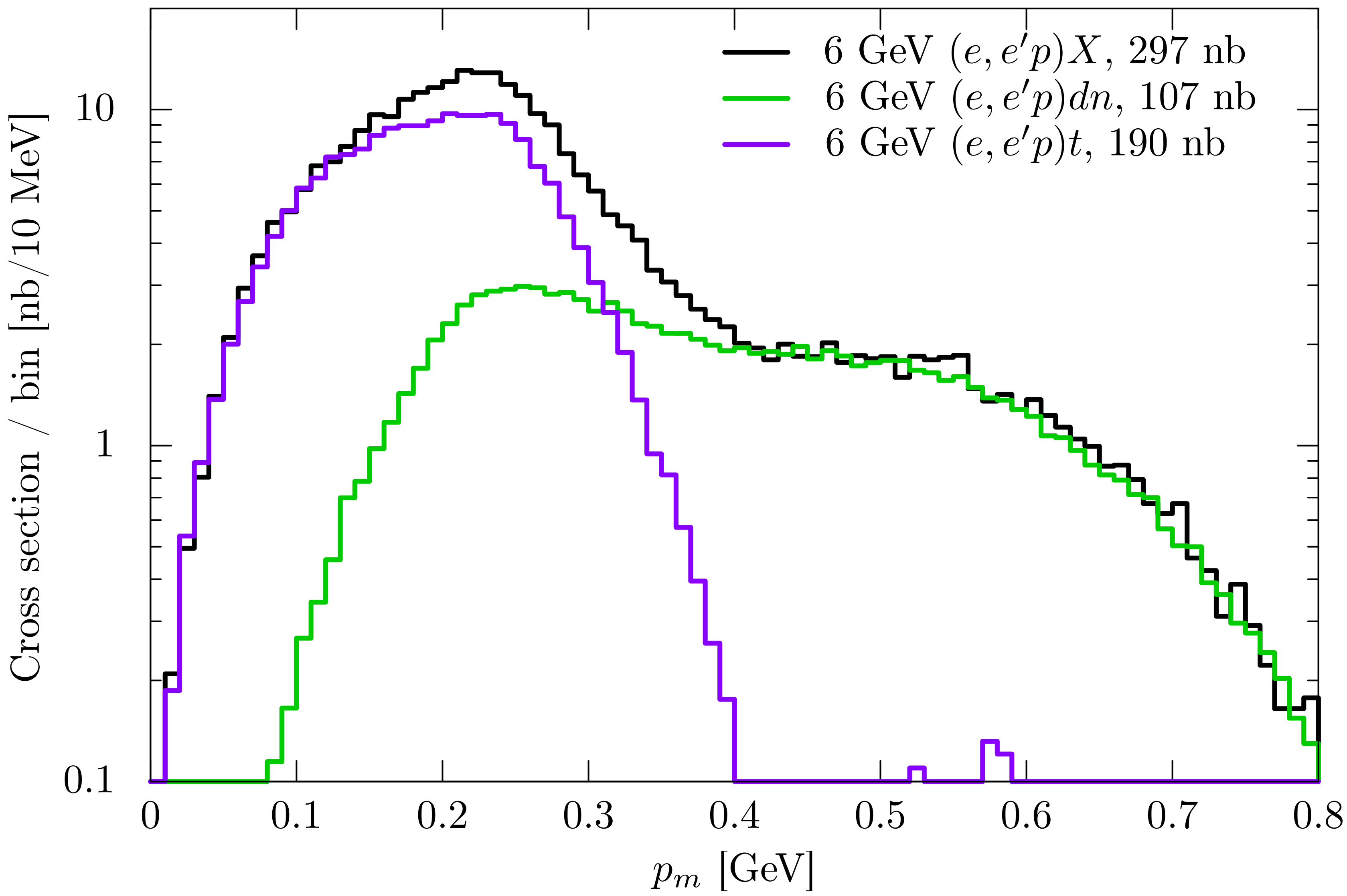
- 17 PAC days
- CLAS12+ALERT
- 6.4 GeV, Lumi 3×10^{34} $cm^{-2}s^{-1}$
- Standard ALERT He-4 target

Other Channels





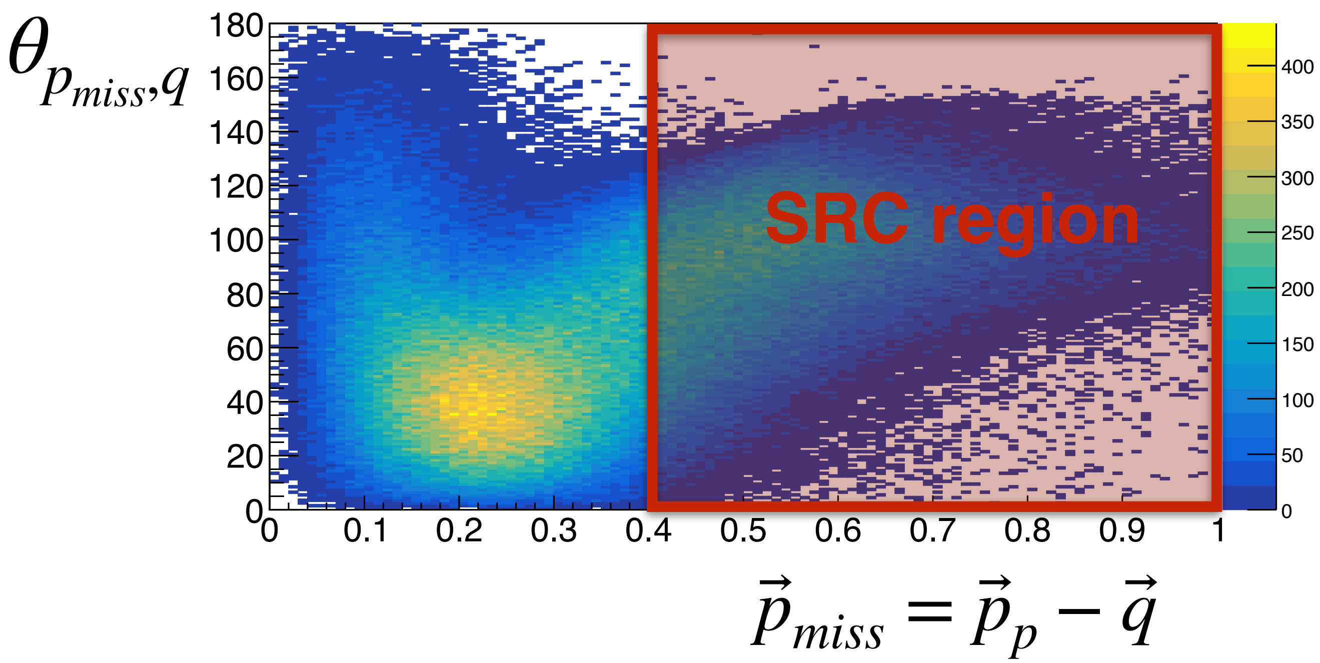
Bonus Goal: Validation of ^{4}He Model



- 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

Rate Estimates from Proposal

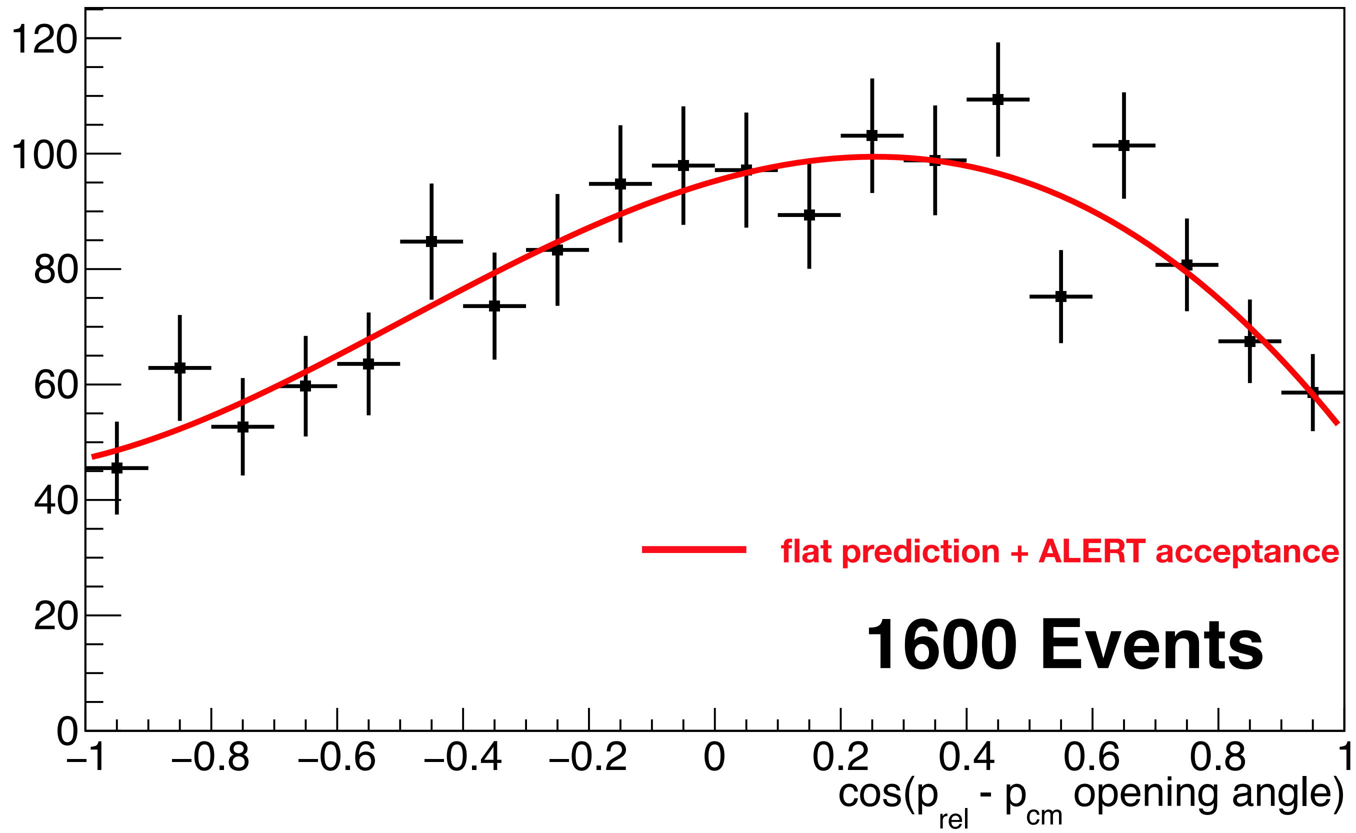
- Measured CLAS12 rates (RGM ^{4}He(e,e'p) data), scaled to ALERT luminosity
- Standard CLAS12 SRC events selection cuts
- Account for recoil ion tagging using ab-initio spectral function event generator and a ALERT simulation



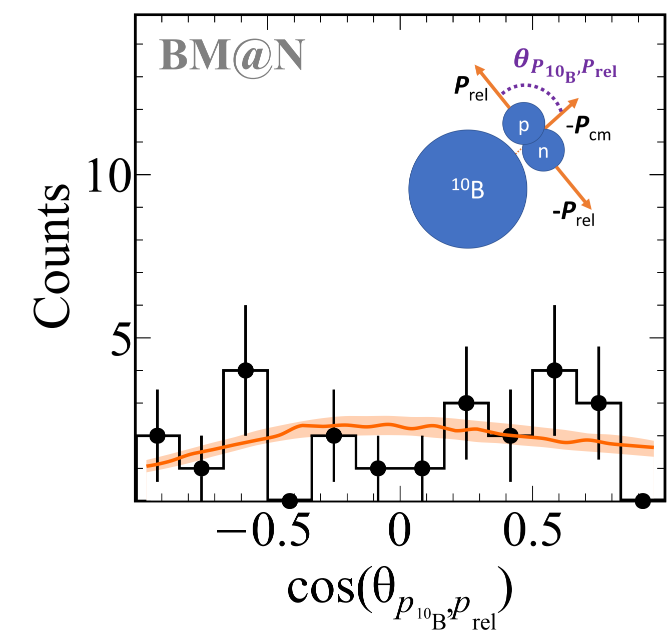
- 3 x 10^{34} luminosity
- **17 PAC days**
- 1600 SRC events with deuteron tagging

Projected Results: $^4He(e,e'd_sp)n$

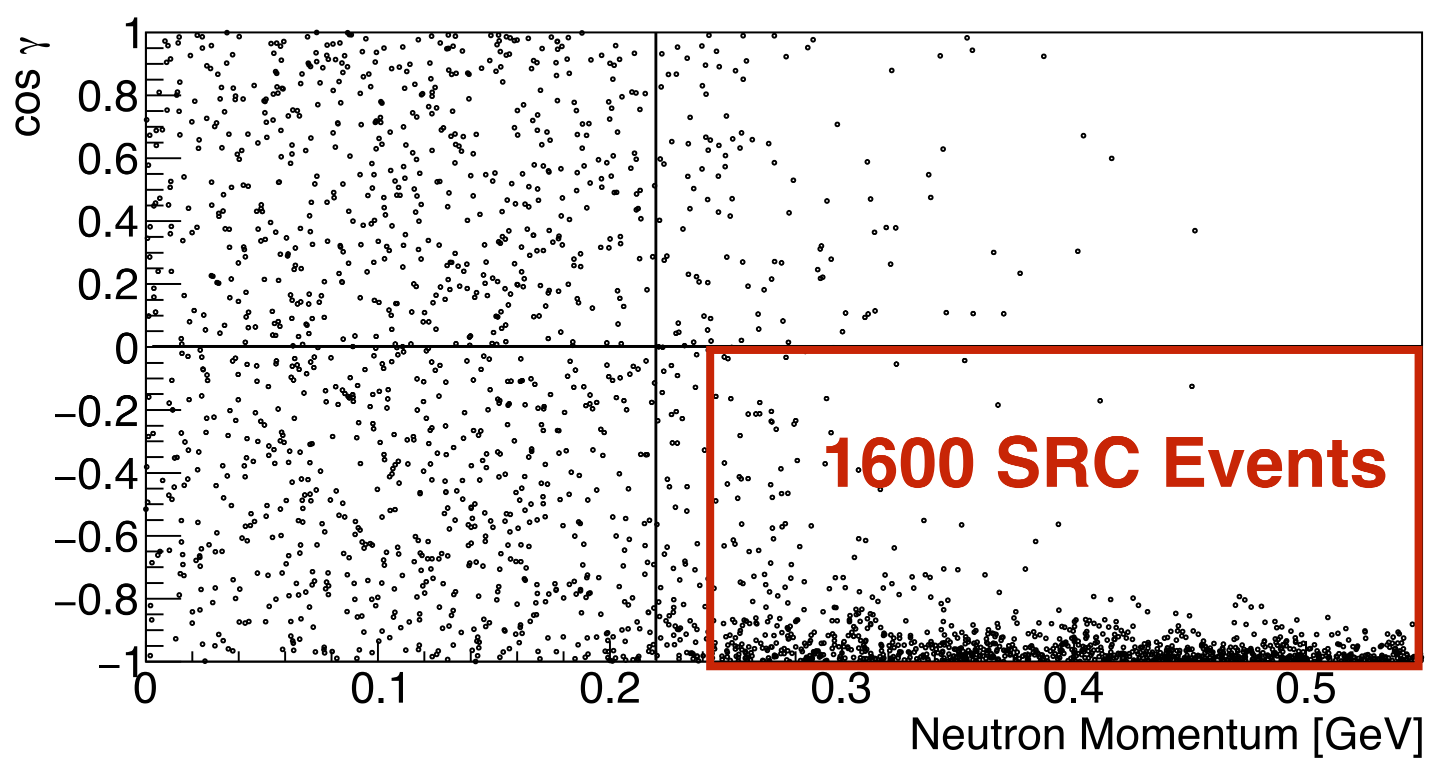
This Proposal

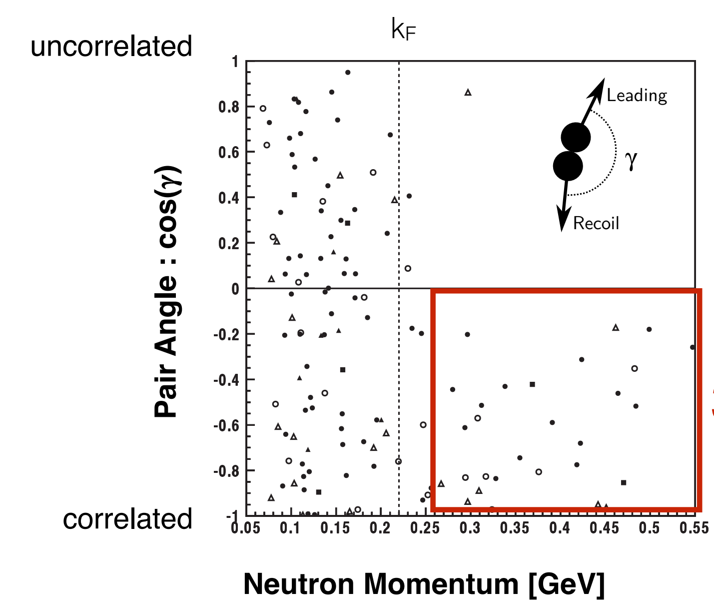


Previous Experiments



23 events





30 Events

Run Plan (rather simple)

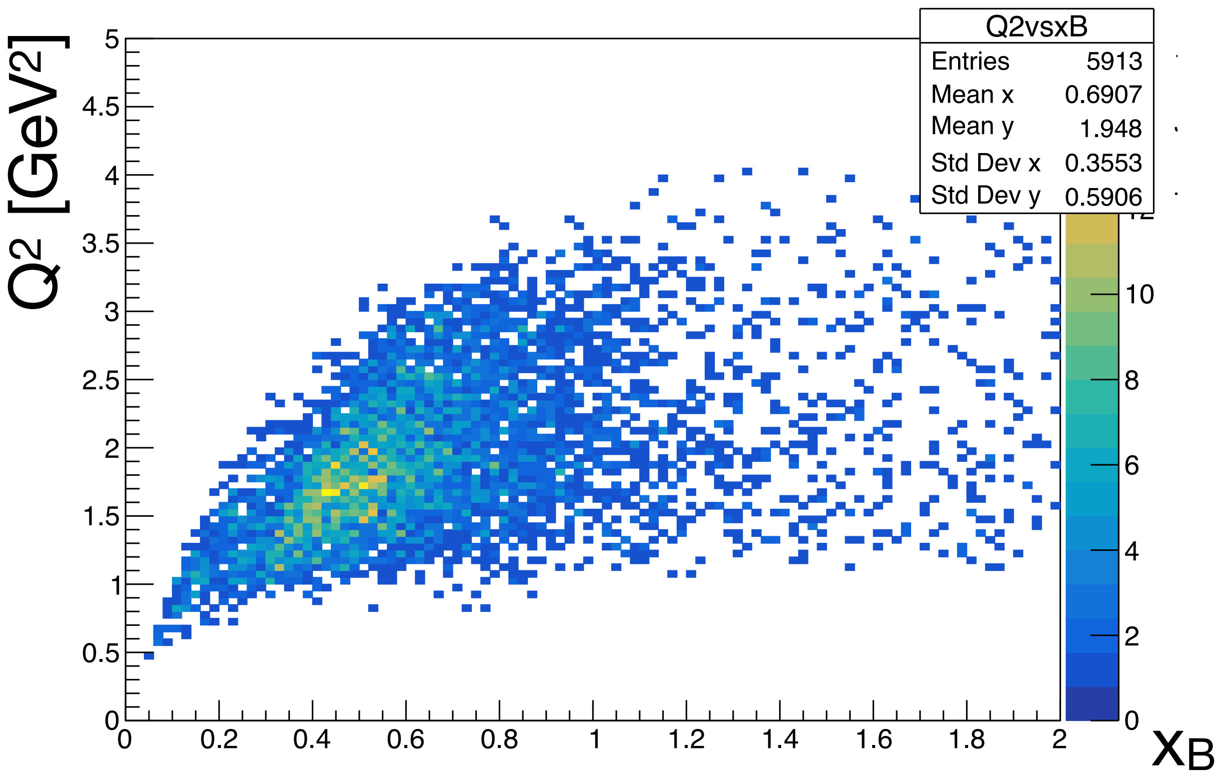
- Switch to 3rd pass ~ 6.4 GeV between July 28 to August 4
- Trigger will be just electrons (same roads as for 11 GeV)
- 2 days run with hydrogen and deuterium
  - Check AHDC rates
  - Optimize AHDC HV
  - Calibration data with elastic and QE protons
- Move to He
  - Luminosity scan and establish optimal beam current to run (325nA?)
  - Run 32 days (16 PAC days)

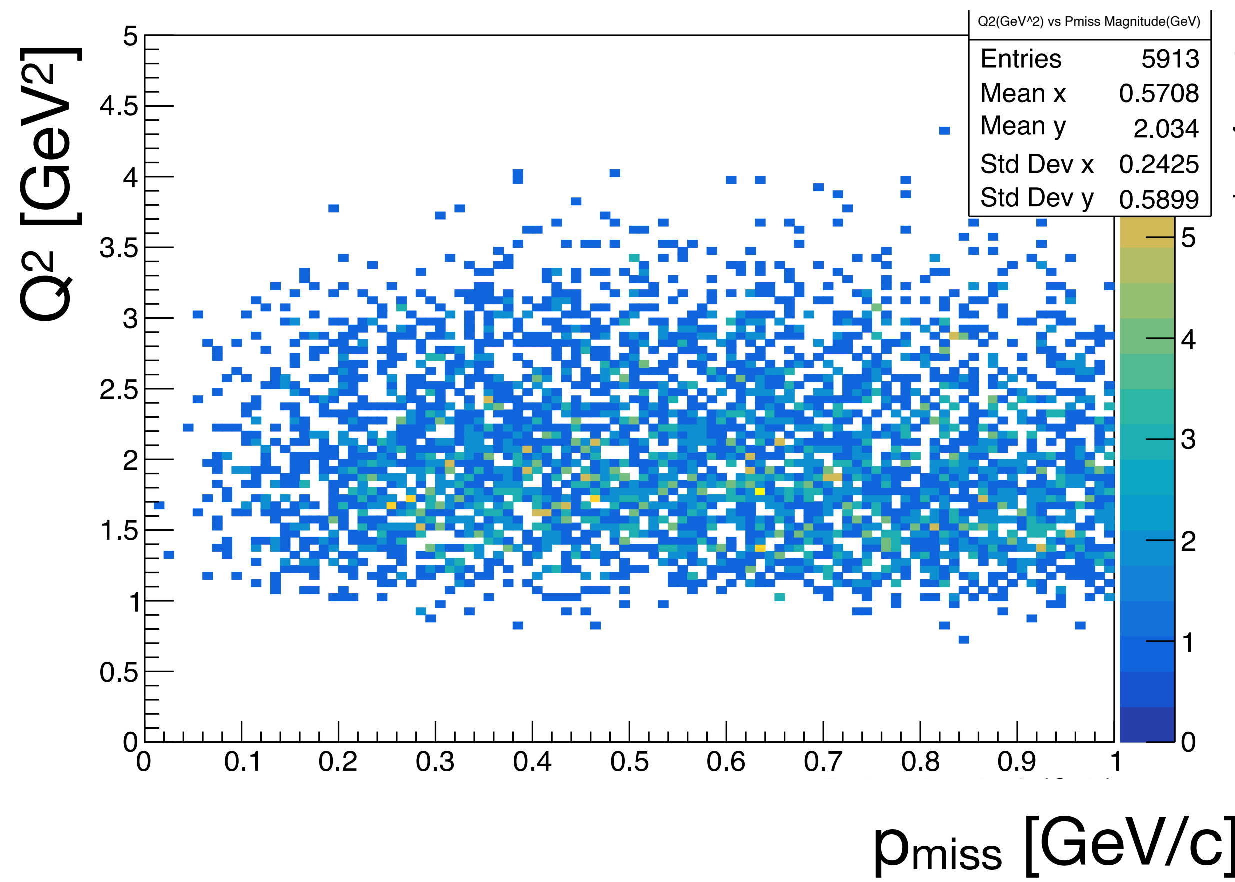
Should: Find deuteron tagged events within the first 2 weeks of running - depends on updated ALERT calibrations

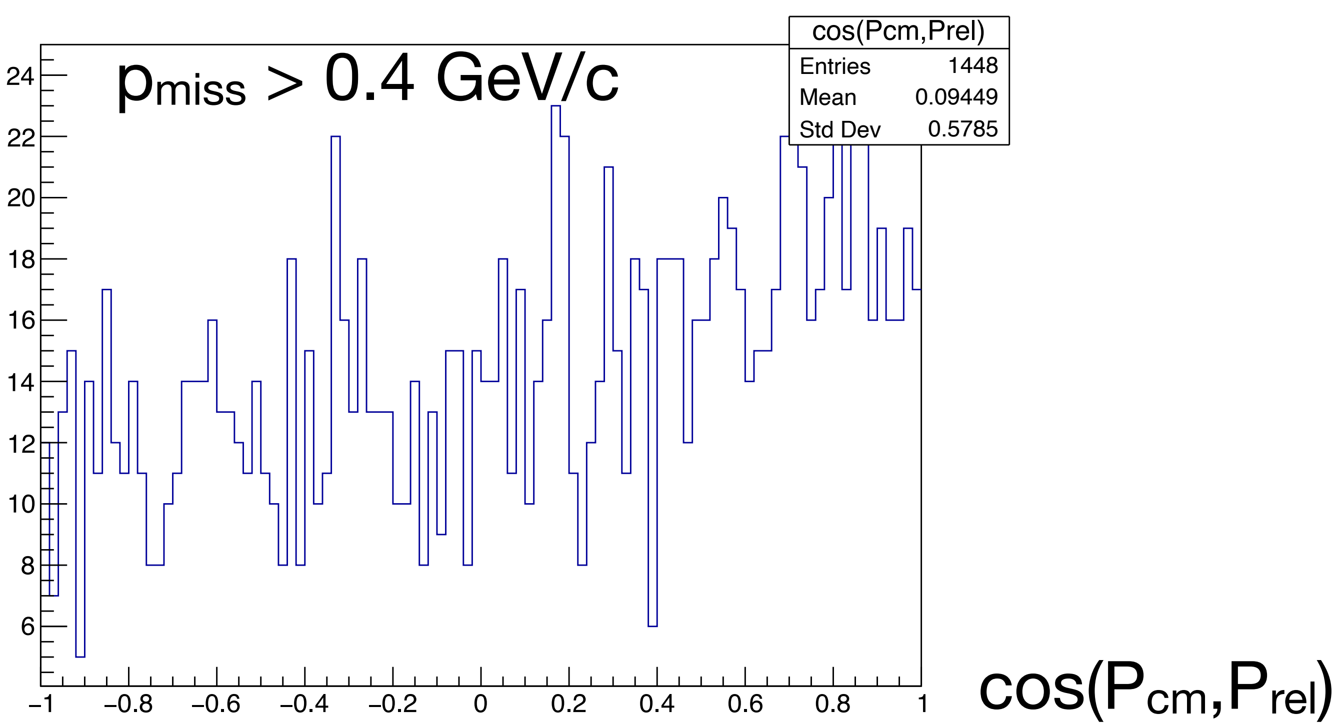
Simulation Update

Work by Zeyu Zhang from Tsinghua University

- Updated event generator (done by Axel)
- Updated ALERT implementation in GEMC and new coatjava version



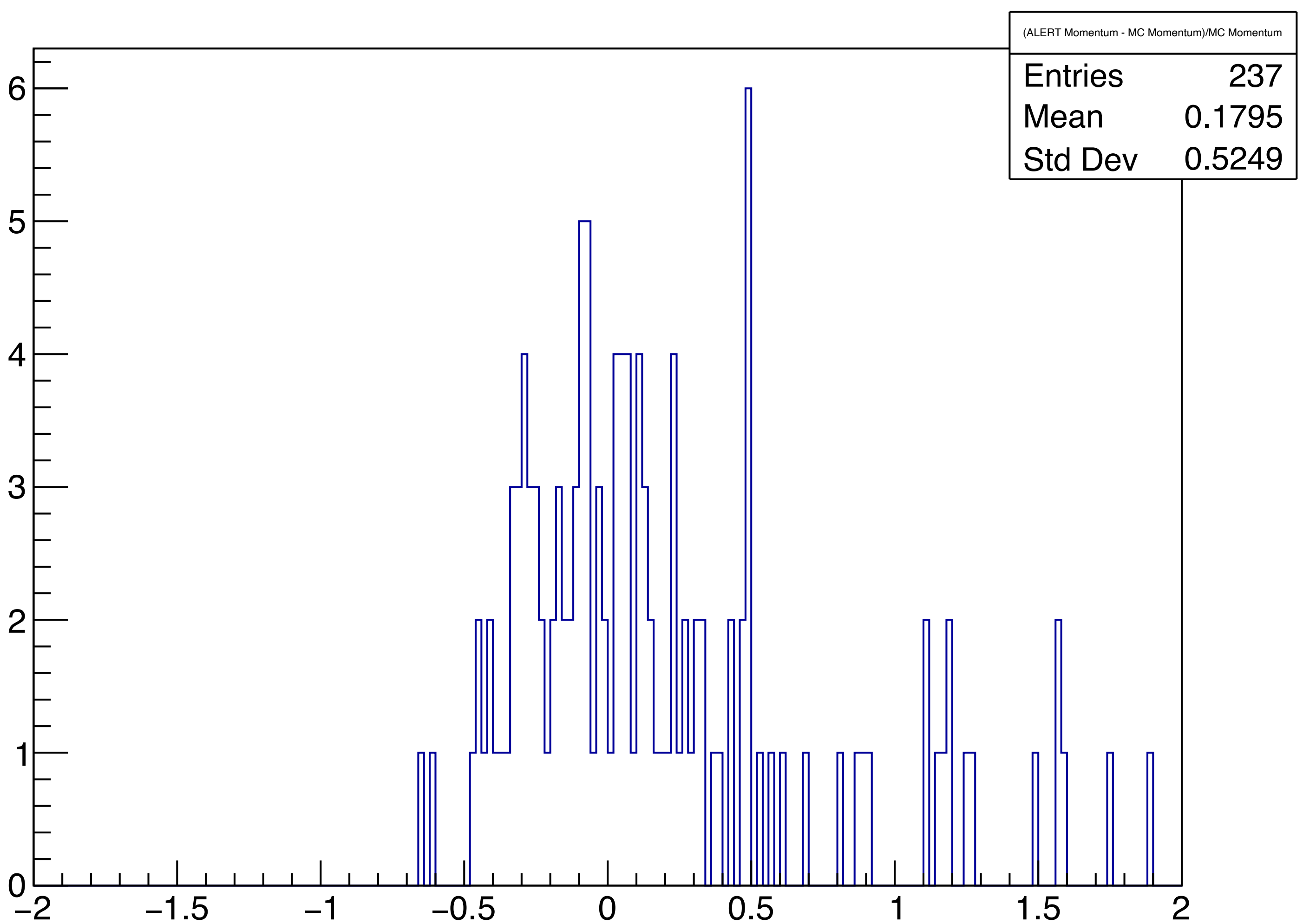




- All events with reconstructed electron and proton in FD
- Deuteron track in AHDC but using generated momentum

Simulation Update 2

Work by Zeyu Zhang from Tsinghua University

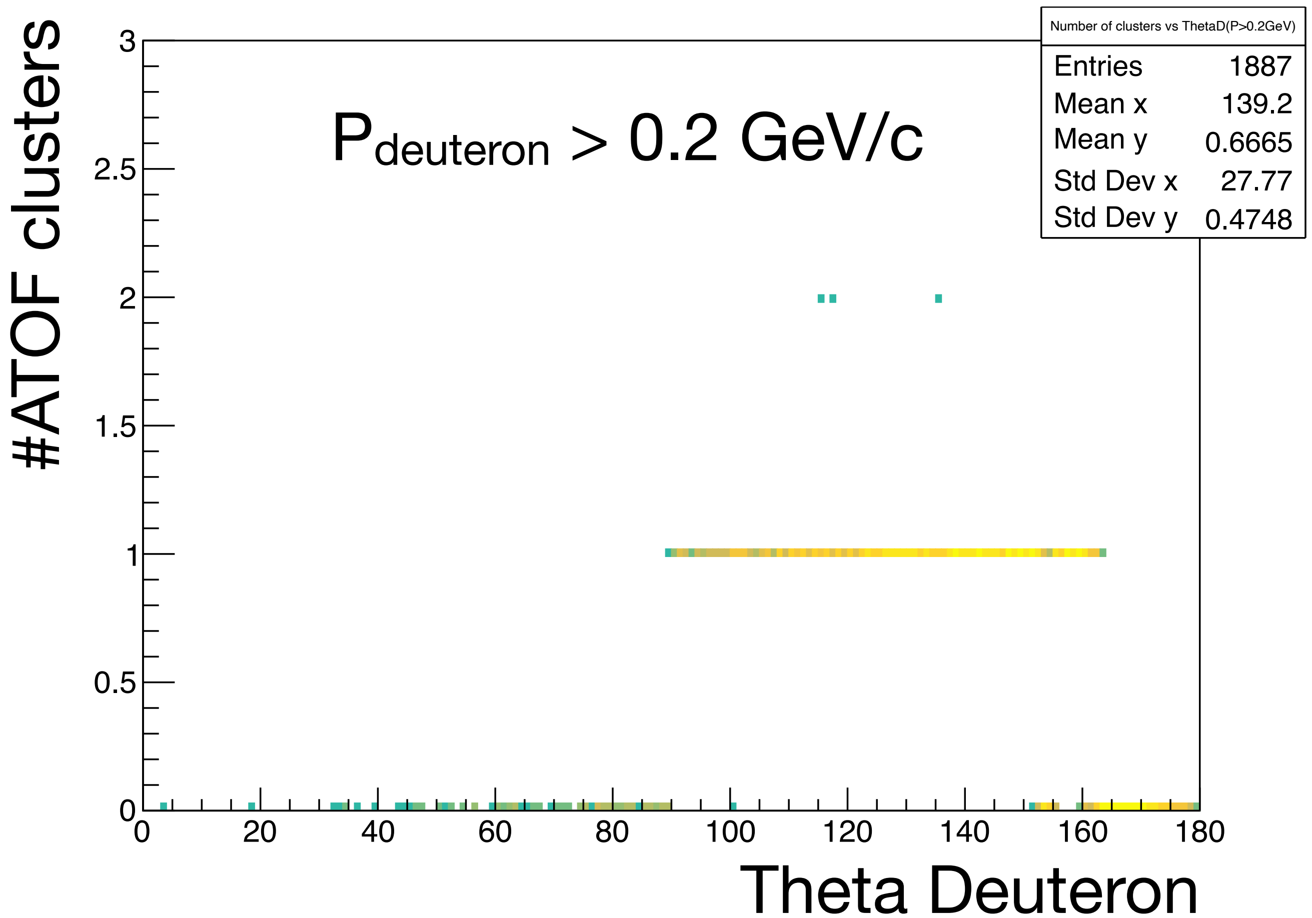


D mom: (Reco-MC) / MC

- ALERT tracking without AI or KF
- More studies in progress for momentum resolution

Simulation Update - Recent Issue with ATOF geometry

Work by Zeyu Zhang from Tsinghua University



- No hits for particles below 90 deg
- Wrong z-position of ATOF in GEMC after recent update —> fixed now

Simulation Update - Recent Issue with ATOF geometry

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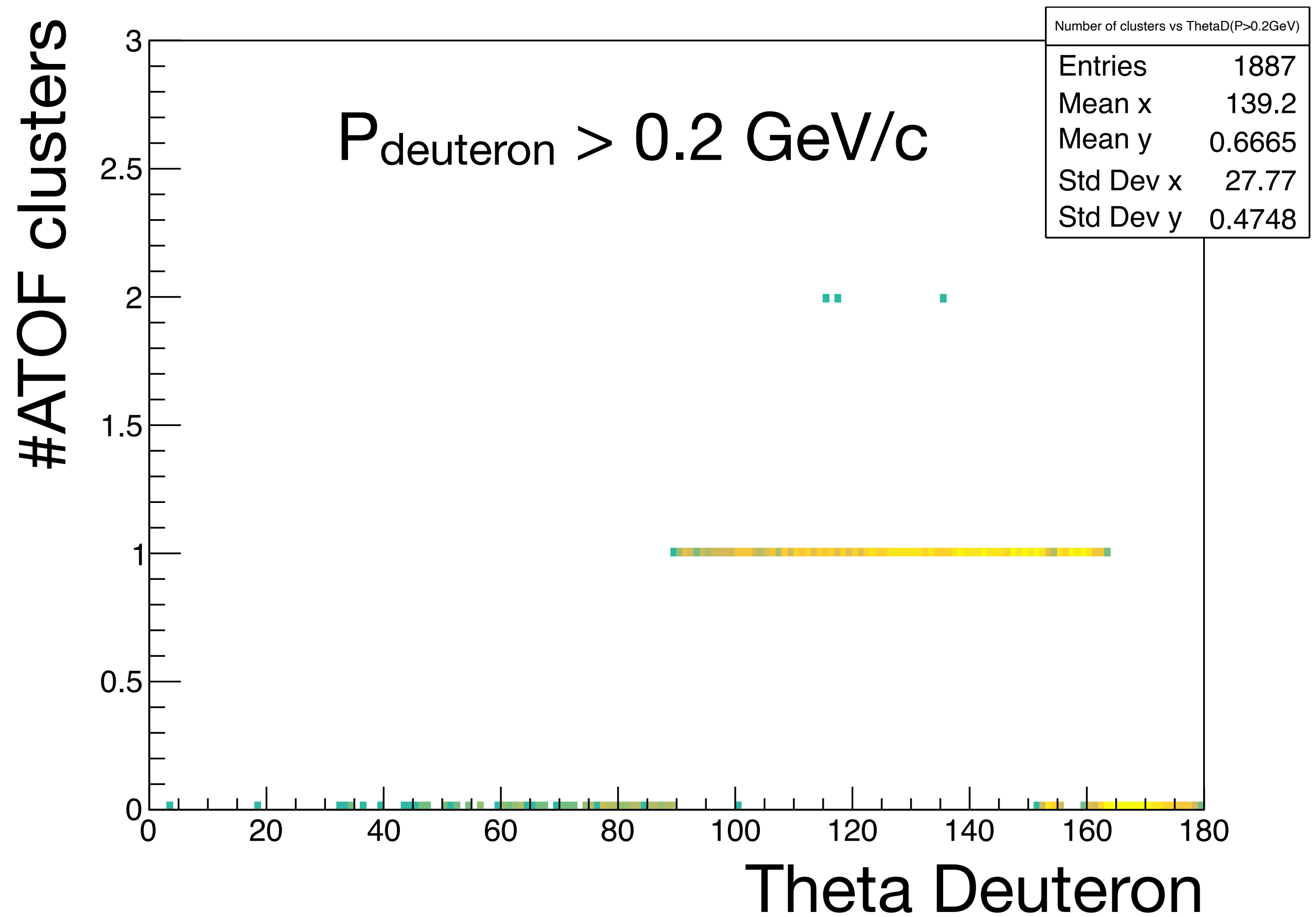
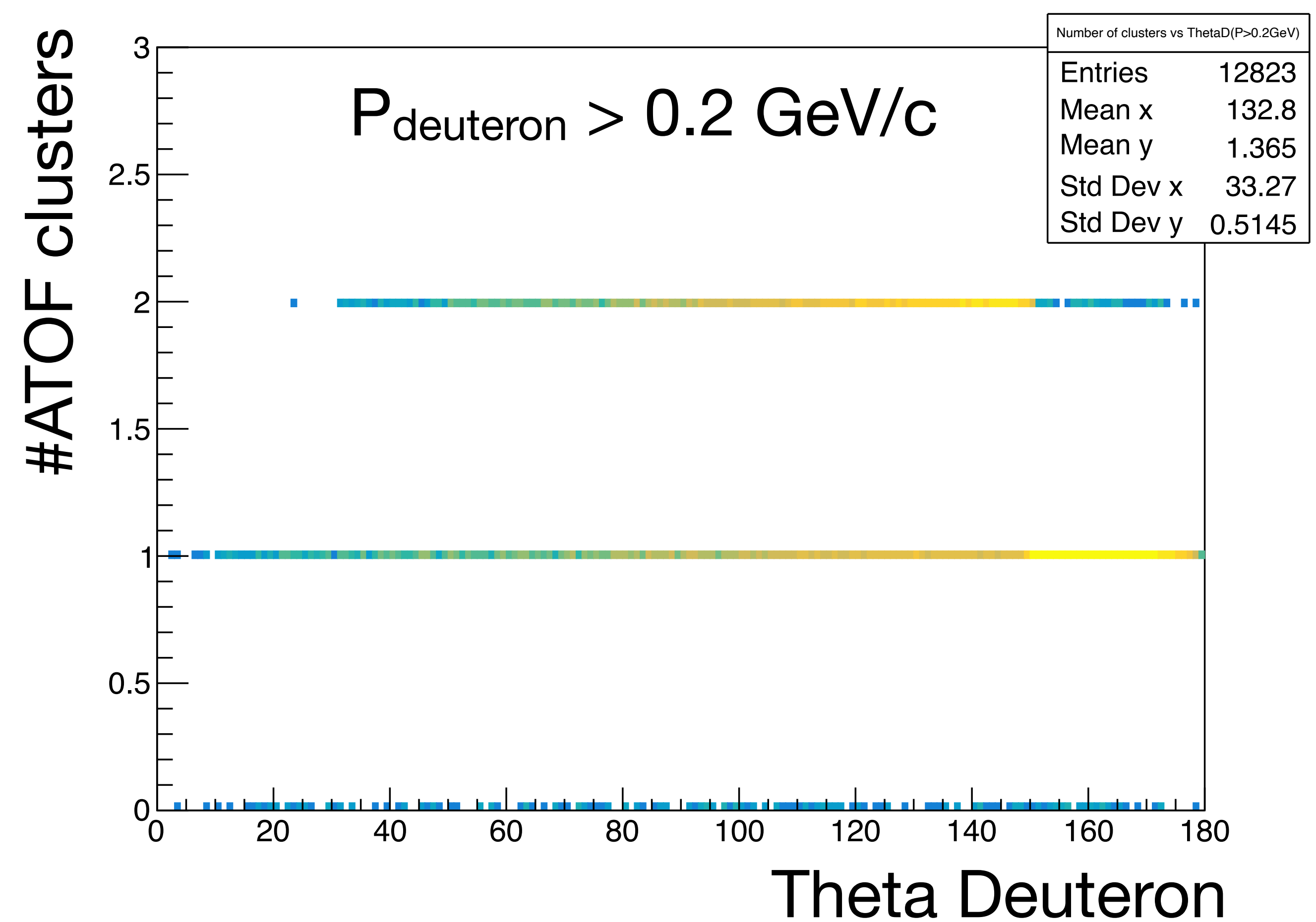


- No hits for particles below 90 deg
- Wrong z-position of ATOF in GEMC after recent update —> fixed now

- but still some weirdness - more studies to follow



Summary

- Unique opportunity with CLAS12 + ALERT to obtain high-statistics data (two orders of magnitude improvement) to address open issues in short-raged correlation physics
  - Test of factorization of SRC pair and remnant nucleus
  - Measurement of transition from mean-field to SRCs

- Getting ready for beam time
  - Draft run plan
  - Prepare scripts to look at data
  - Looked into some of the 2 GeV and 11 GeV data but need improved ALERT calibrations

- Recent updates to simulations
  - Event generator improved
  - Issues with GEMC seen

Backup slides

Beam Time Request

Configuration	Target	Luminosity $cm^{-2}s^{-1}$	Beam current nA	Beam energy GeV	Beam time request days
Measurement Days	^4He	$3 \cdot 10^{34}$	500	6.4	16
Commissioning	^4He	various	various	6.4	1
Total					**17**

Rate Estimates from Proposal

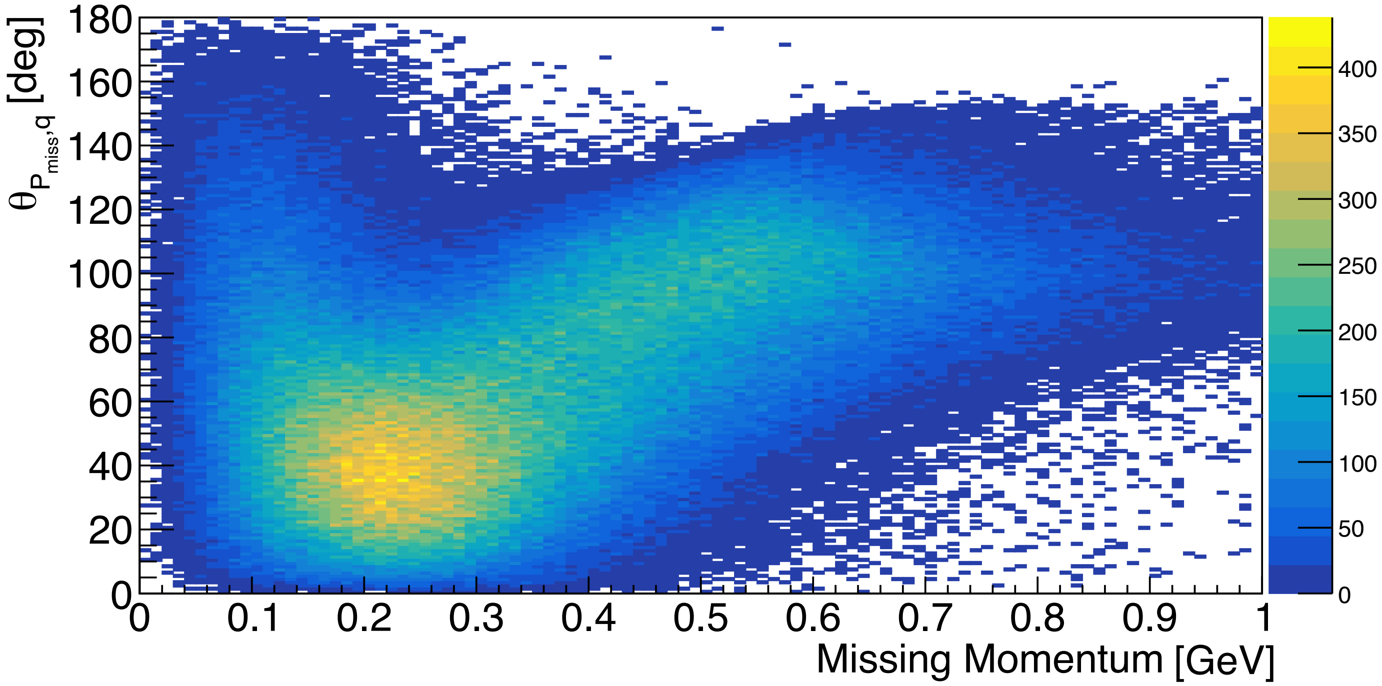
- Based on RGM ^{4}He(e,e'p) pass0 SRC data (high missing momentum)
  - assume all events have correlated neutron and isotropic spectator deuteron
  - add corrections for
    - deuteron p-θ acceptance (f_{acc})
    - deuteron survival probability (f_{surv})
    - pp pairs and ϕ acceptance ($f_{pp/\phi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

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

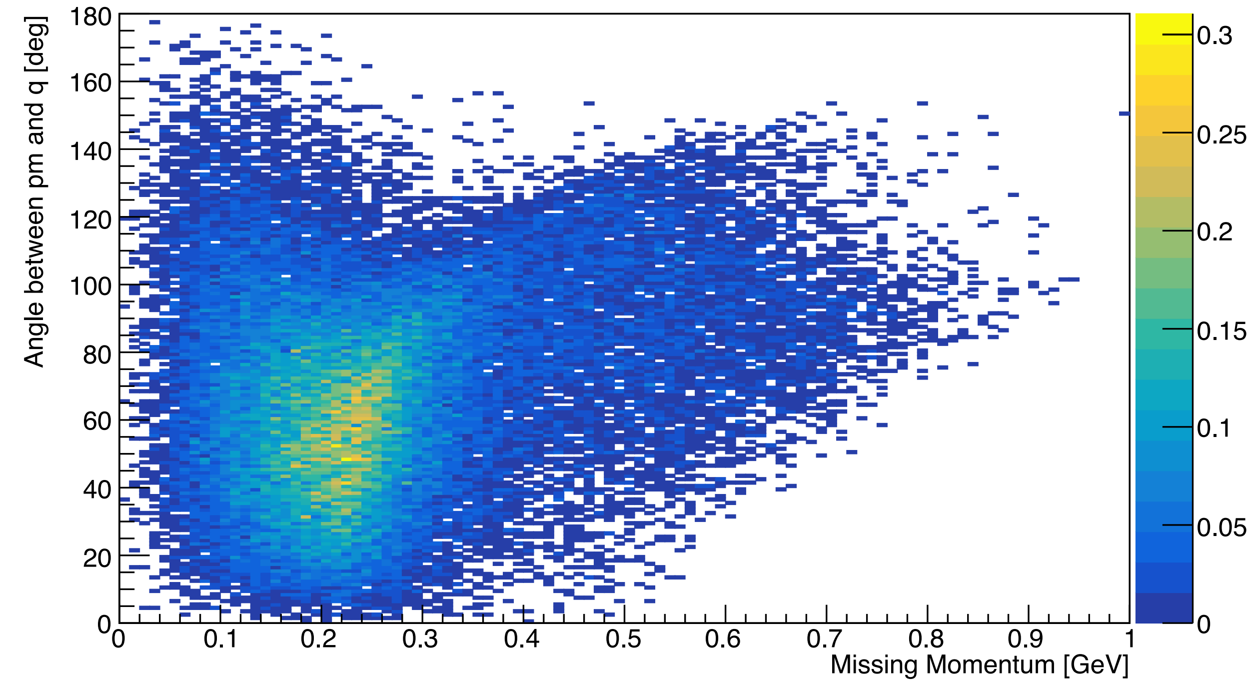
- Normalize rate from RGM to ALERT luminosity

RGM SRC Events

$\theta_{p_{miss},q}$ Data



Simulation
$\theta_{p_{miss},q}$ (PWIA with ^{4}He spectral function)



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

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

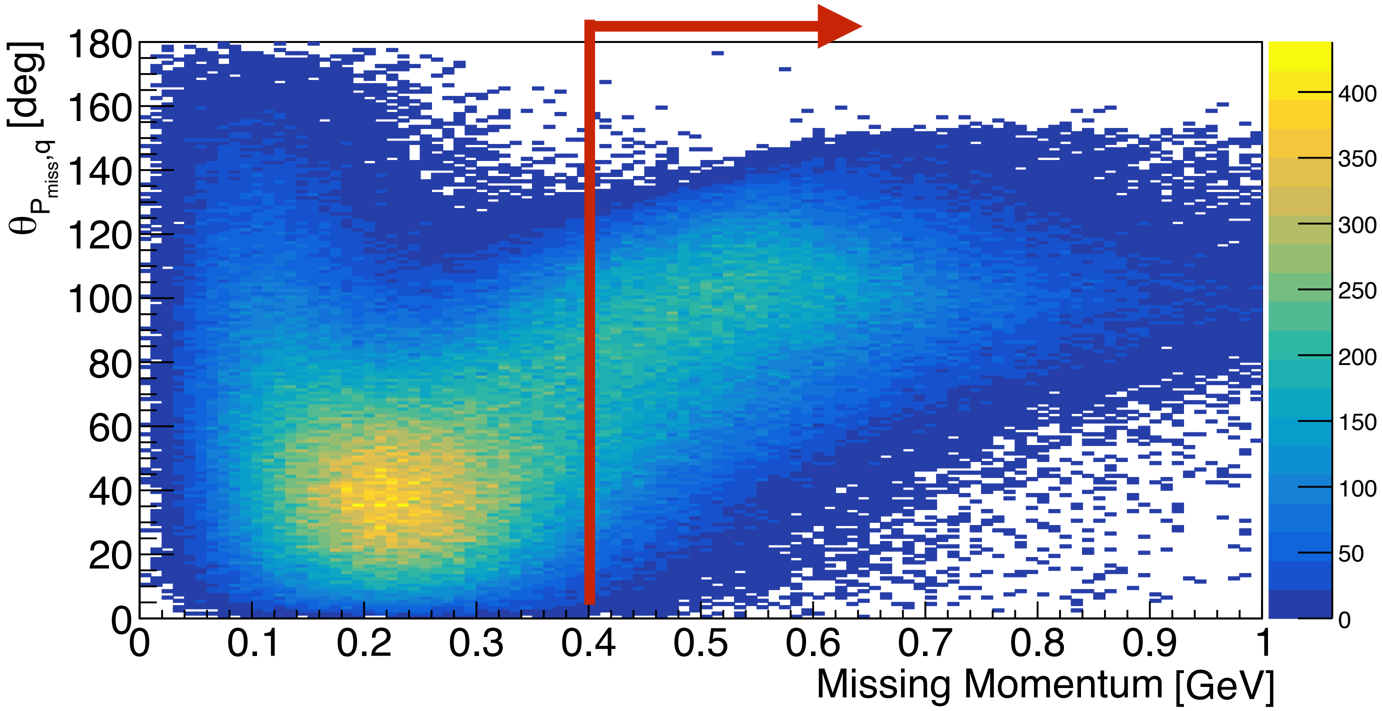
RGM SRC Events

Simulation

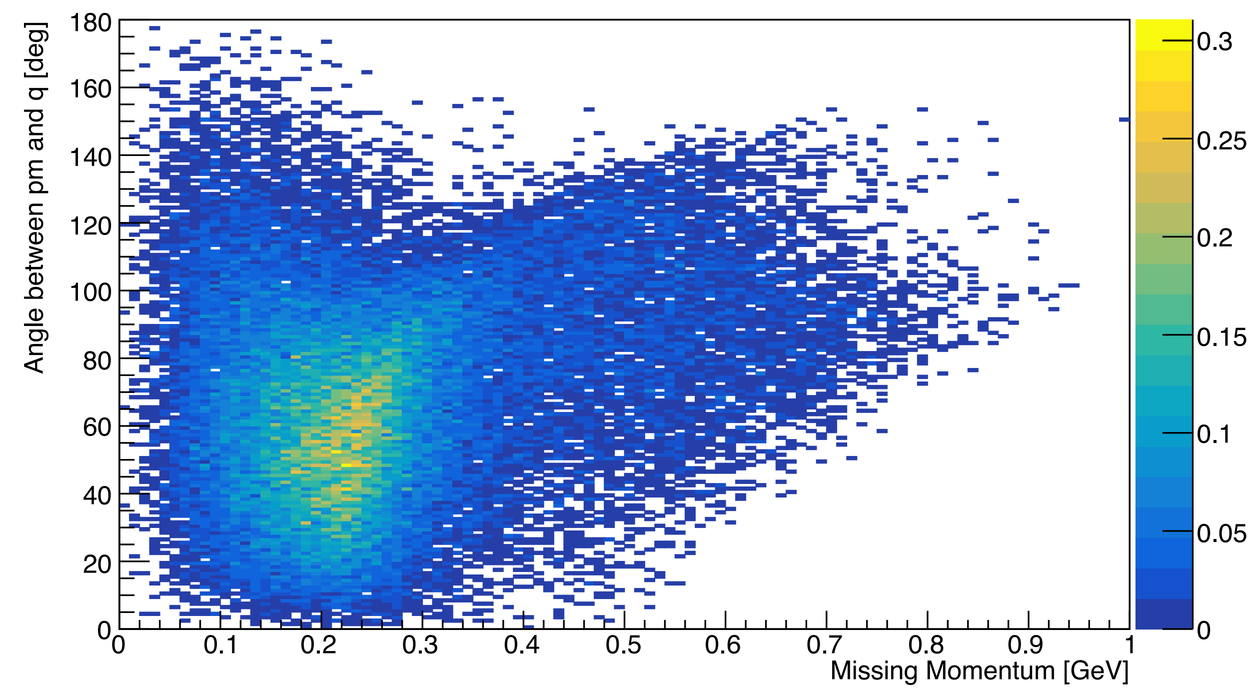
(PWIA with ^{4}He spectral function)

Data

$\theta_{p_{miss},q}$



$\theta_{p_{miss},q}$



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- 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 —> conservative factor 0.1 in rate estimate
- SRC events (p_{miss} > 400 MeV/c): **3.8 x 10^5**

Rate Estimate and Beam Time

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

$$= 3.8 \cdot 10^5 \times 0.5 \times 0.1 \times 0.8 \times 0.1 = \boxed{1.6 \cdot 10^3}$$

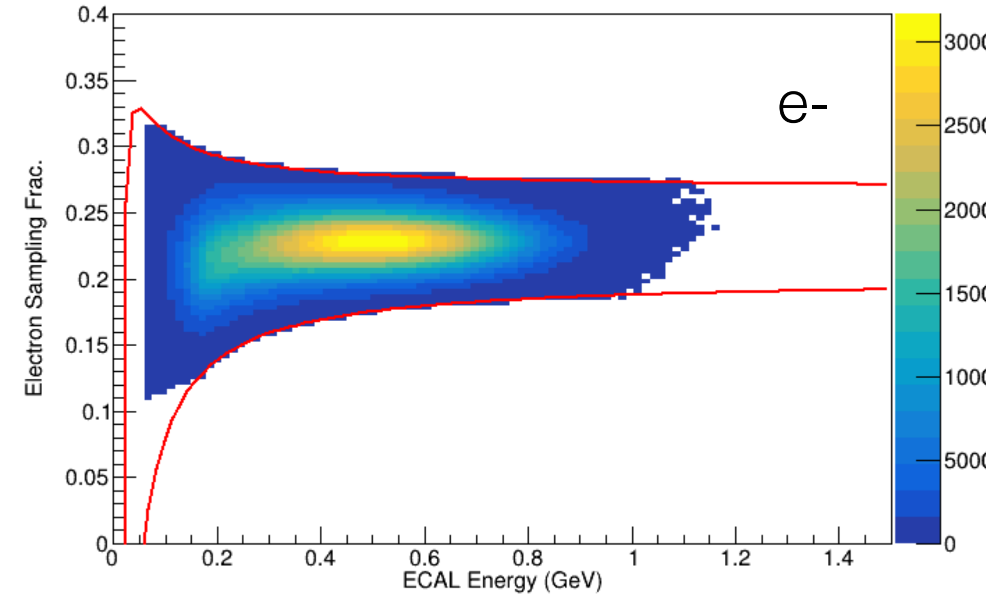
- RGM ^{4}He data
  - 1.2 x 10^{35} luminosity
  - 4 PAC days

→

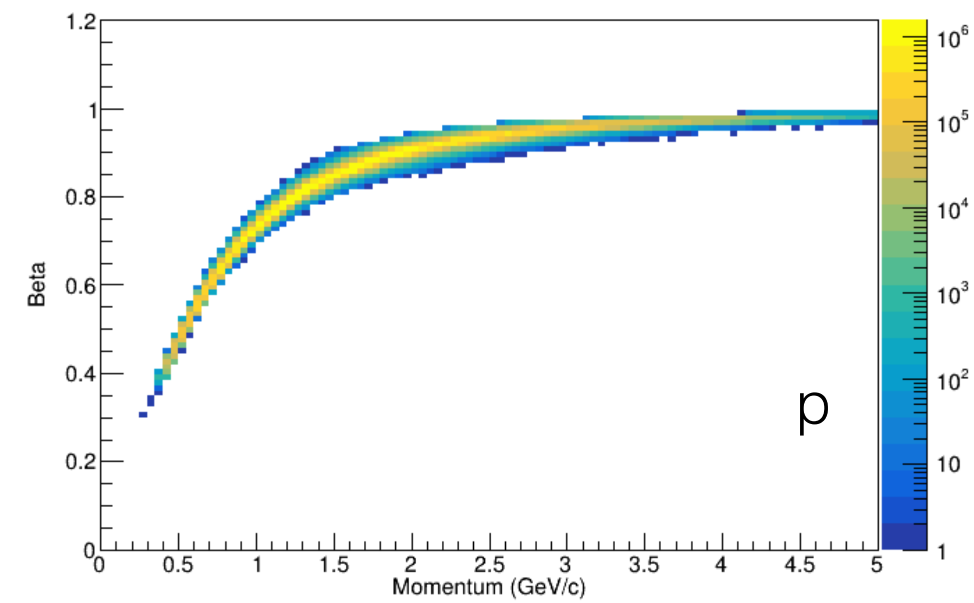
- This proposal
  - 0.3 x 10^{35} luminosity
  - **16 PAC days**
  - 1.6 x 10^3 SRC events
  - similar or more Mean-field events

RGM (e,e’p) Event Selection

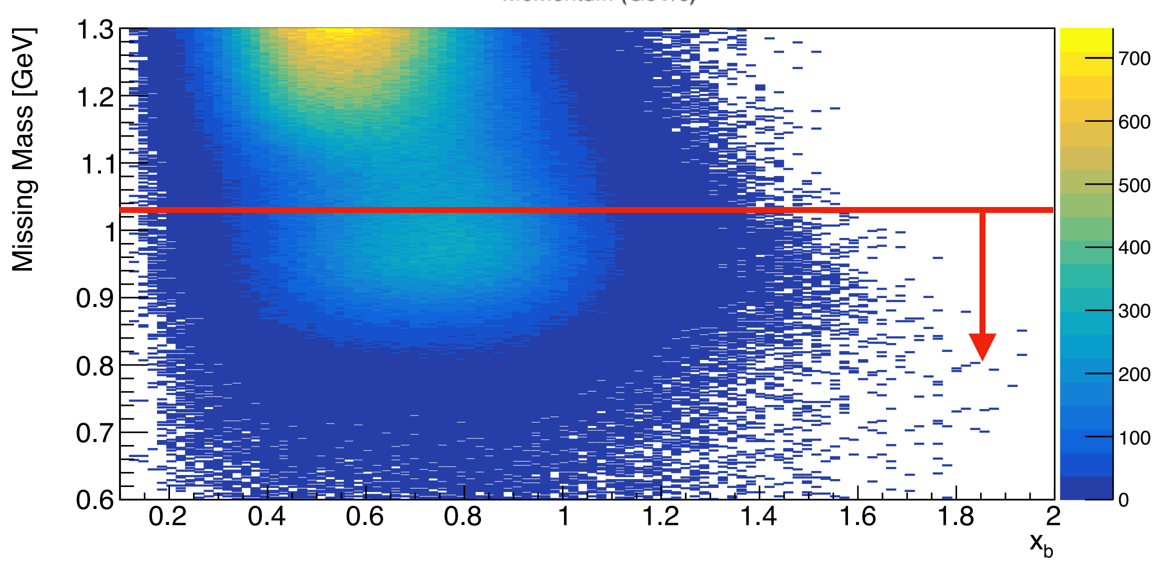
- Electron in Forward Detector
  - Calorimeter sampling fraction cut
  - PCAL fiducials



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

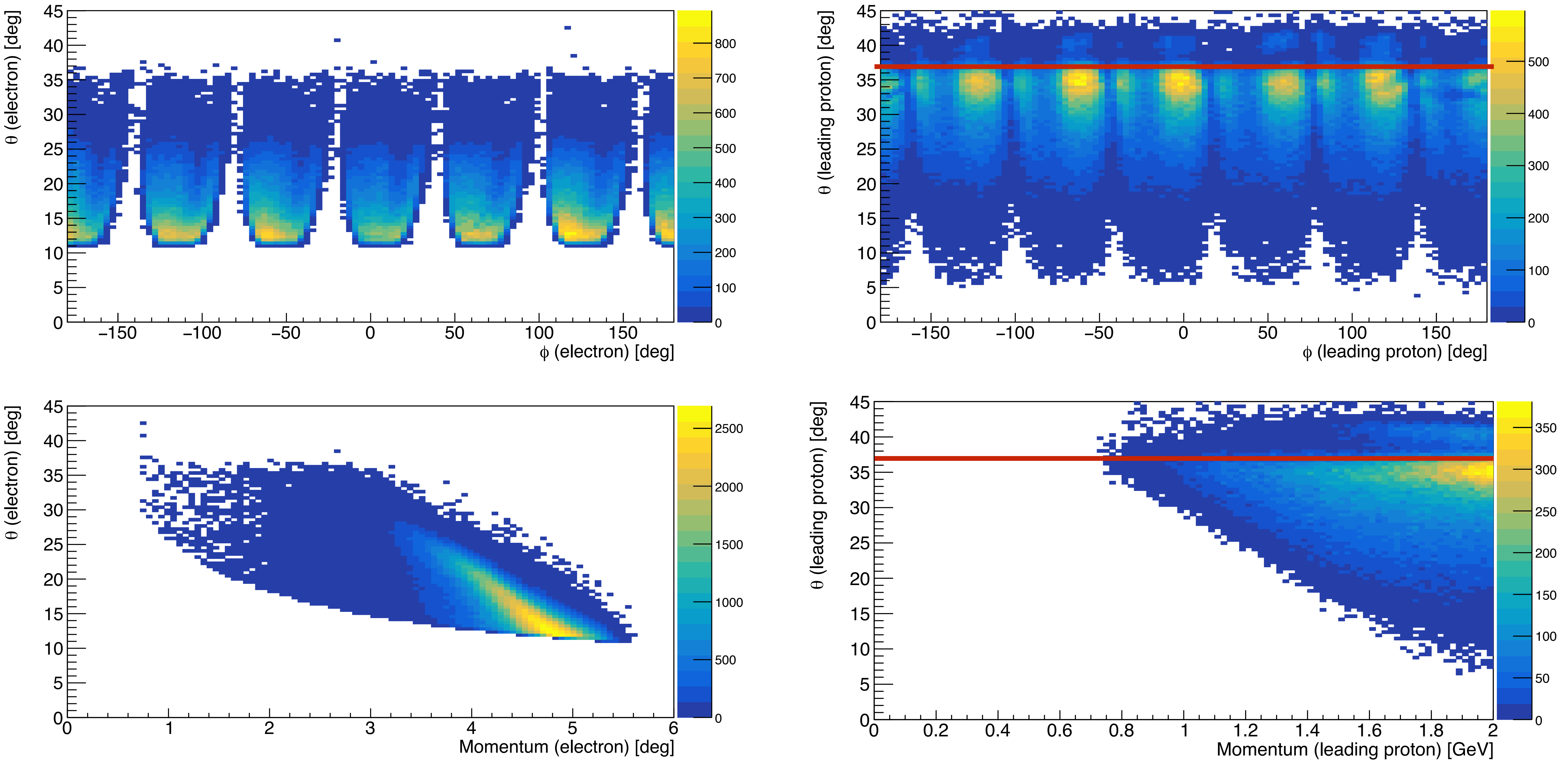


- Kinematic Cuts for Quasi-elastic selection
  - $Q^2 > 1.2$ GeV^2
  - $\theta_{pq} < 25°$
  - $|p|/|q| > 0.6$
  - $M_{miss} < 1.03$ GeV (assuming stationary pair with deuteron mass)



Electron and Proton Distributions

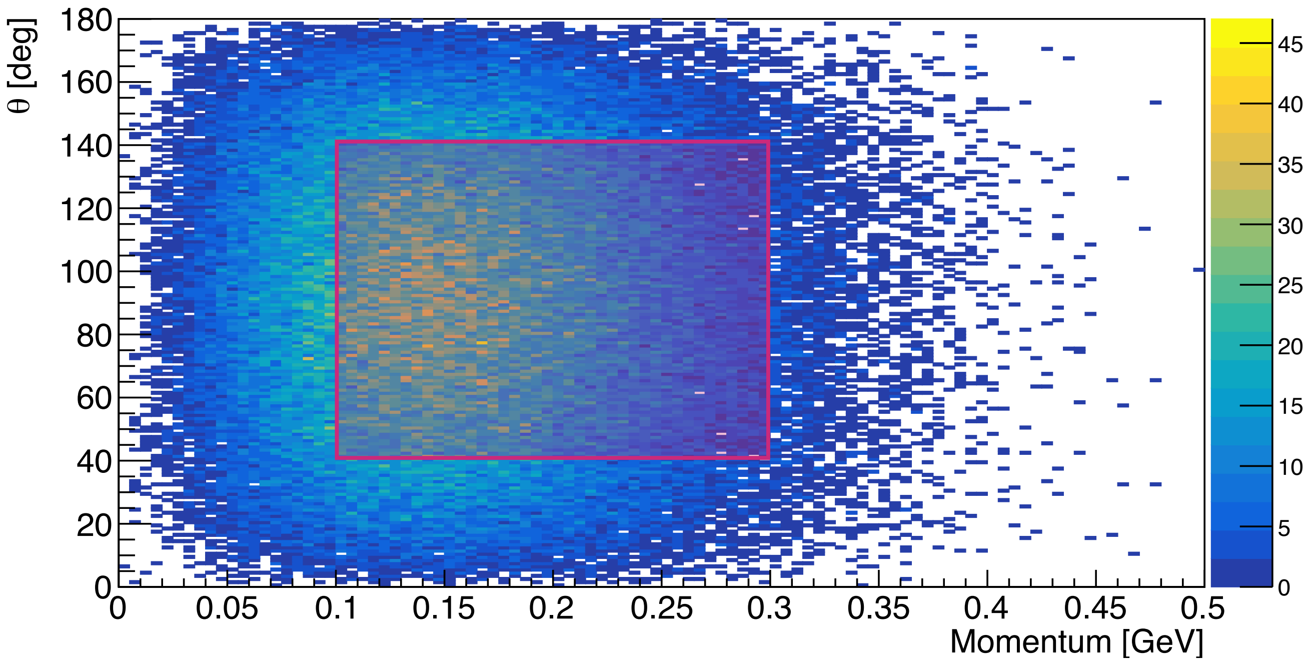
Electrons | Protons



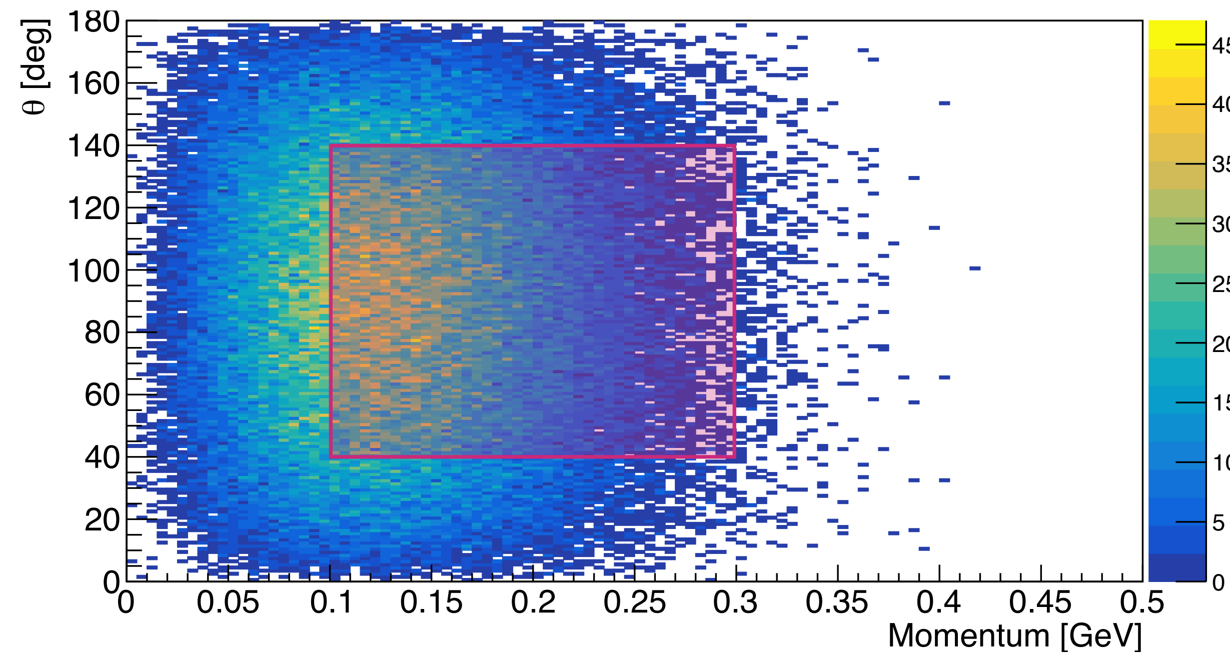
- Standard 6-fold sector structure of CLAS12
- Additional proton scattering angle cut $\theta_p < 37°$ to ensure proton only in forward detector

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 [Korover, PRL 113 (2014)] and σ = 84 MeV/c [Wiringa, PRC 89 (2014)]



σ = 100 MeV/c

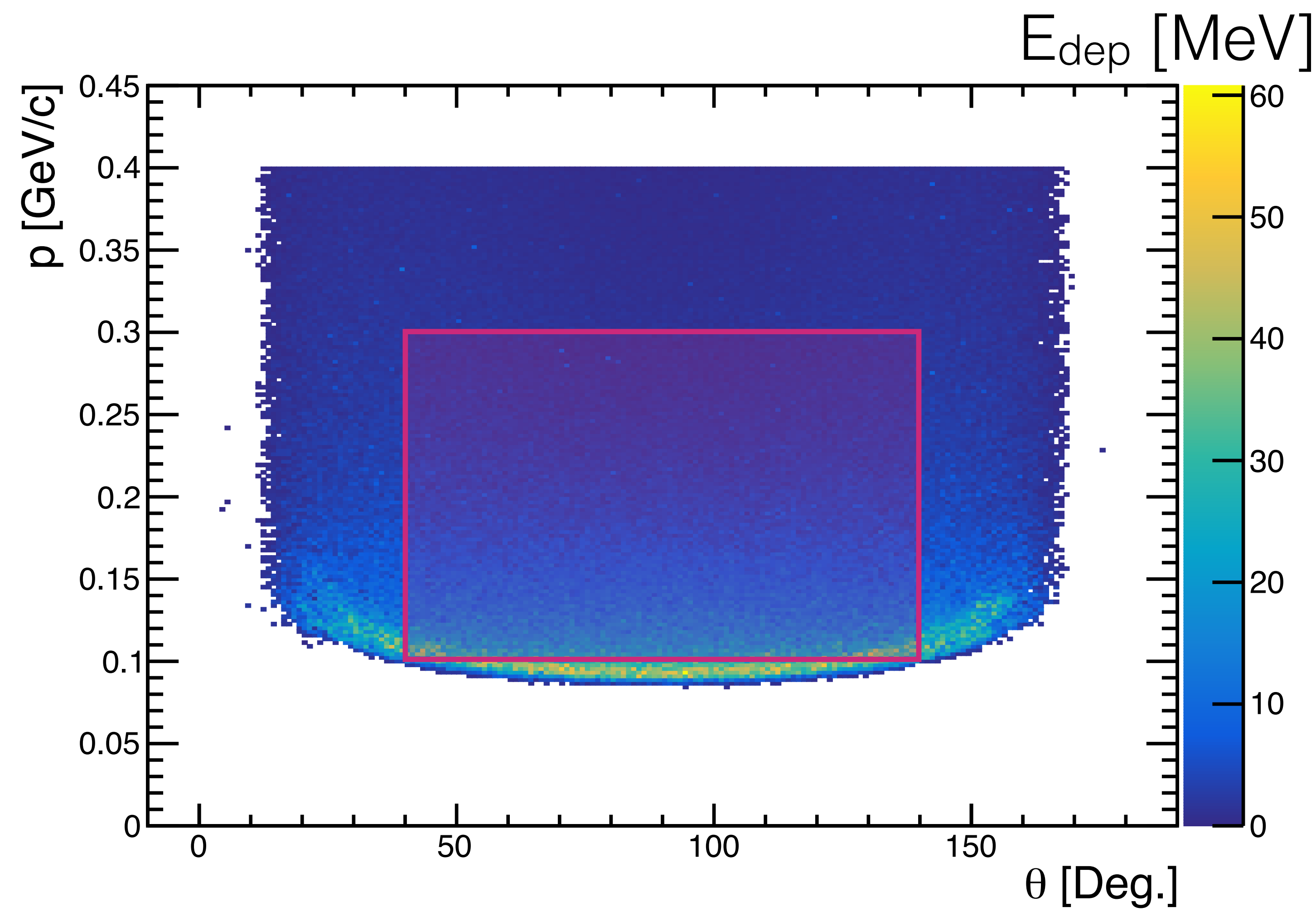


σ = 84 MeV/c

- 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**

Deuteron Acceptance (1)

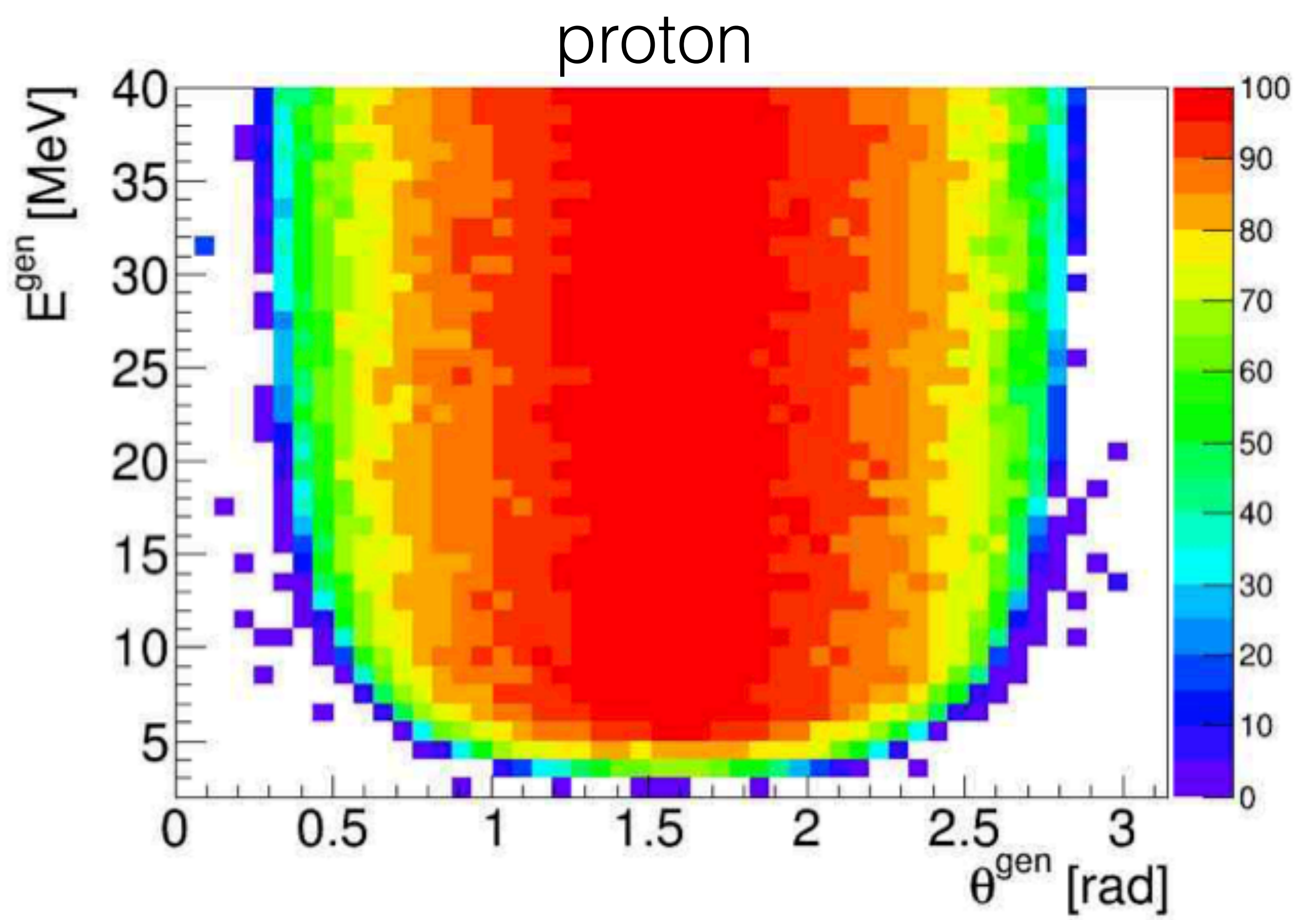


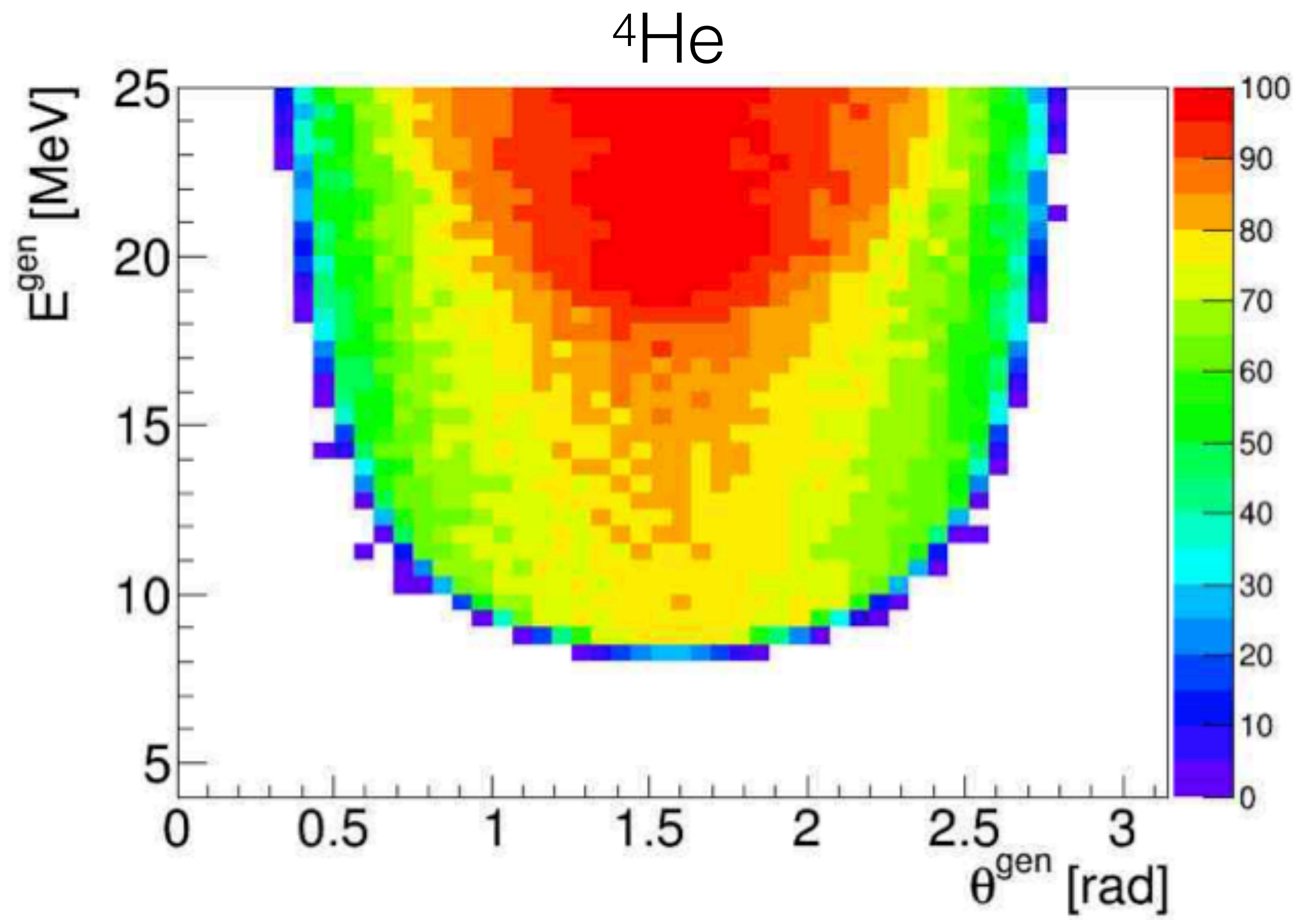
- Uniformly generated deuterons
  - 0-400 MeV/c momenta
  - 0-180° polar angle
  - 0-360° azimuthal angle

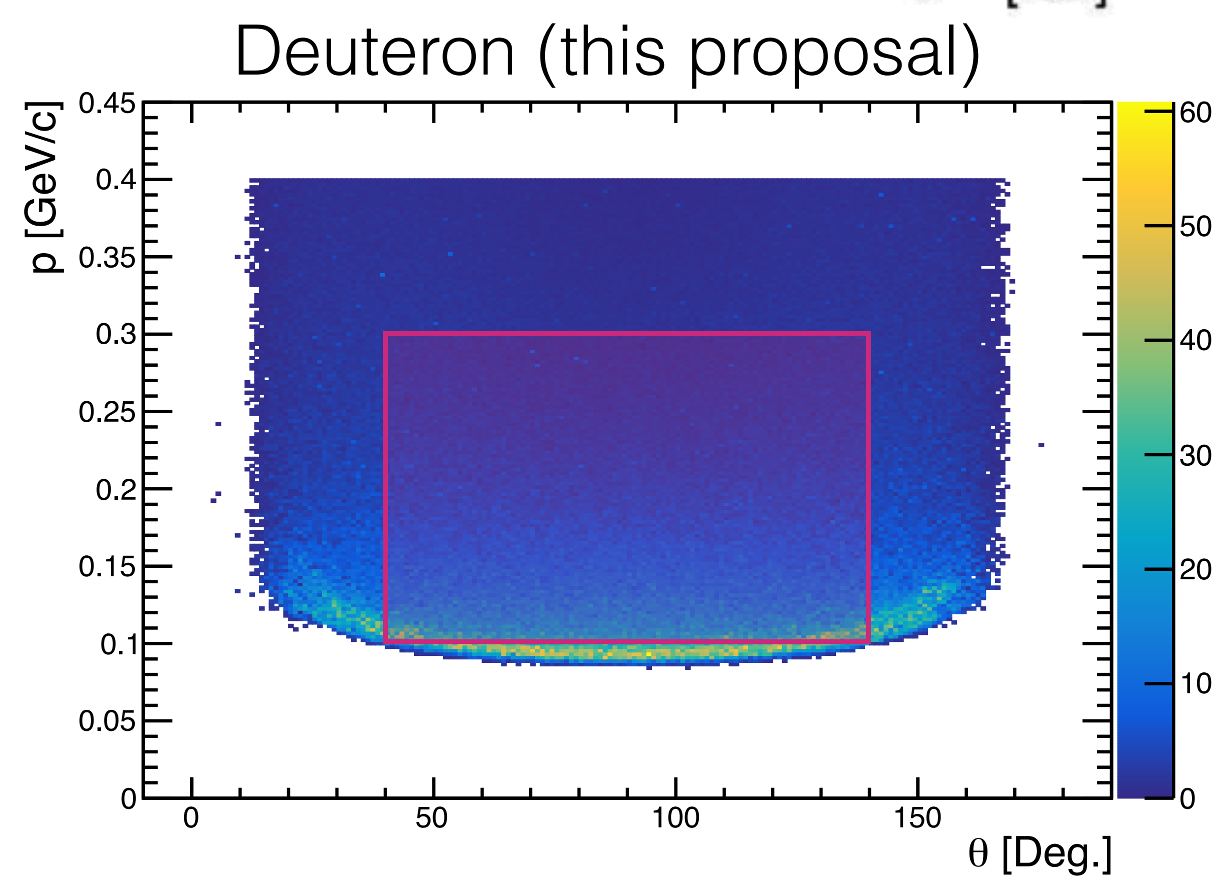
- Events through GEMC (ALERT only)
  - Accept event if hit in all DC layers
  - No explicit track reconstruction

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

Comparison Acceptances

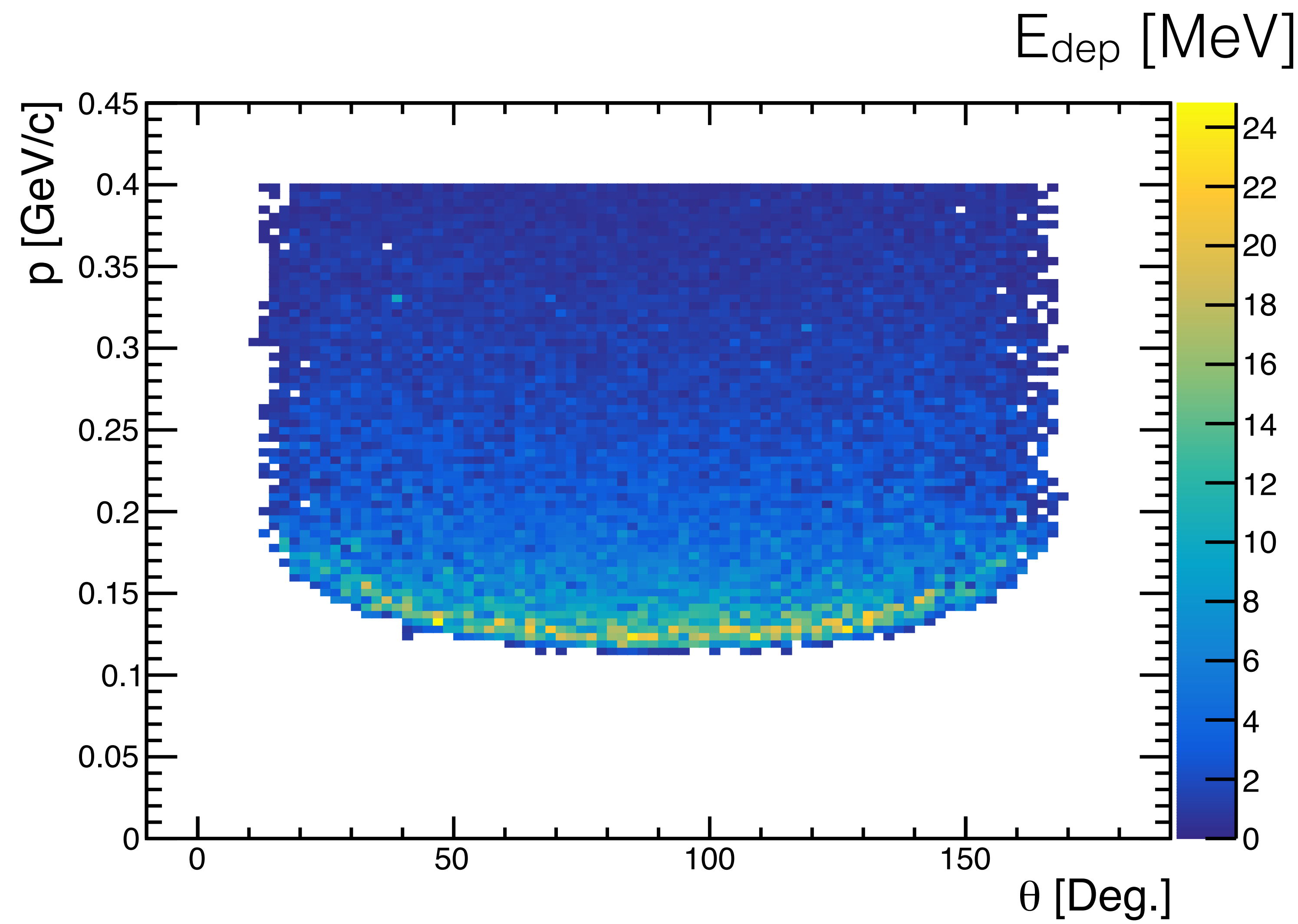






- Acceptances consistent with previous simulations from approved ALERT proposal E12-17-012 (https://misportal.jlab.org/pacProposals/proposals/1338/attachments/98370/Proposal.pdf)

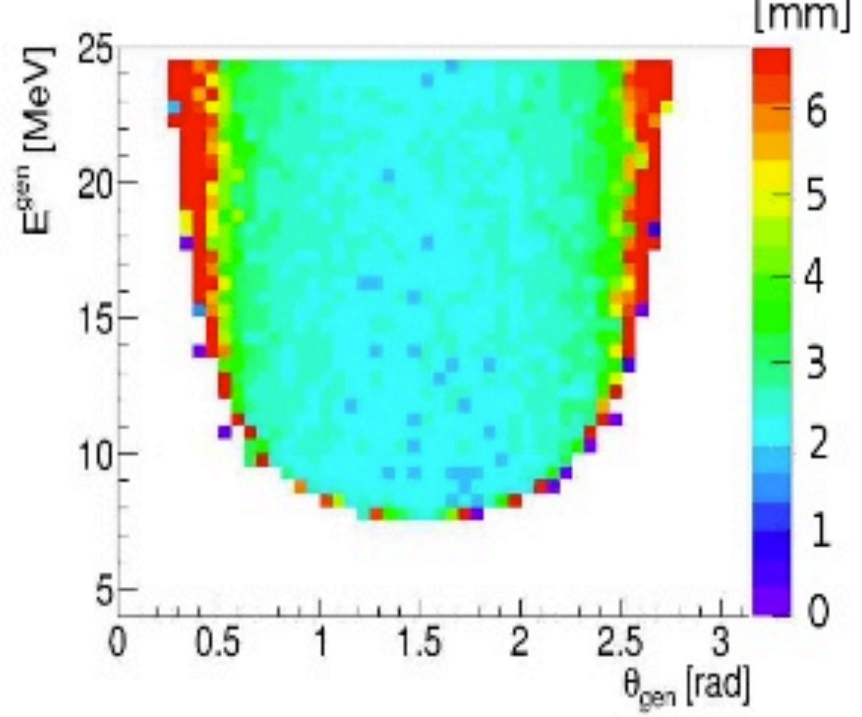
Triton ALERT Acceptance



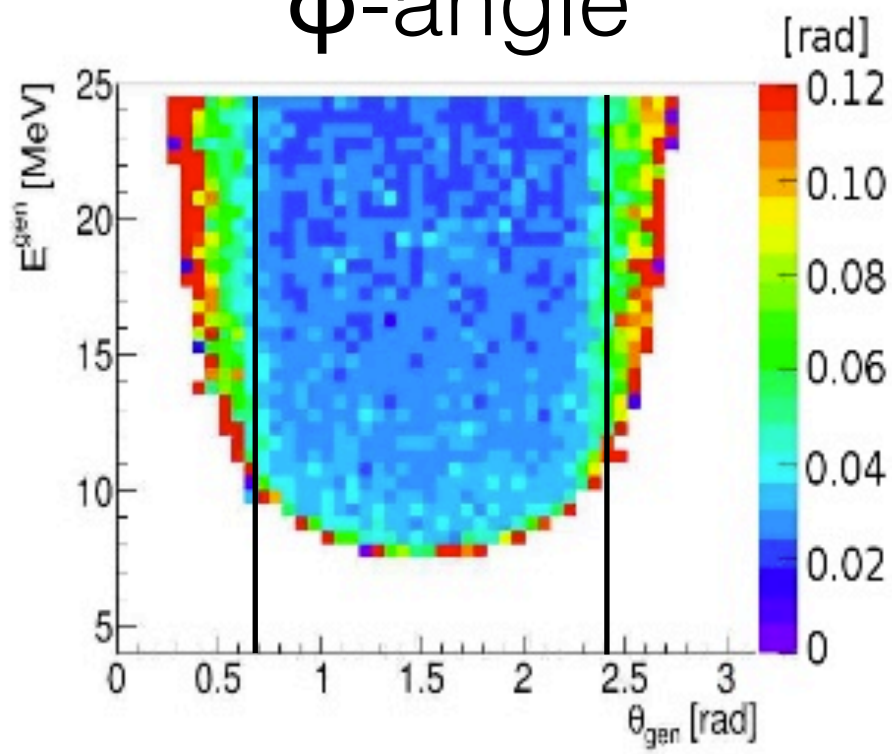
- Uniformly generated tritons
  - 0-400 MeV/c momenta
  - 0-180° polar angle
  - 0-360° azimuthal angle
- Events through GEMC (ALERT only)
  - Accept event if hit in all DC layers
  - No explicit track reconstruction
- Similar acceptance range than deuterons —> can detect tritons from 120-300 MeV/c

Expected ALERT Resolutions ^{4}He

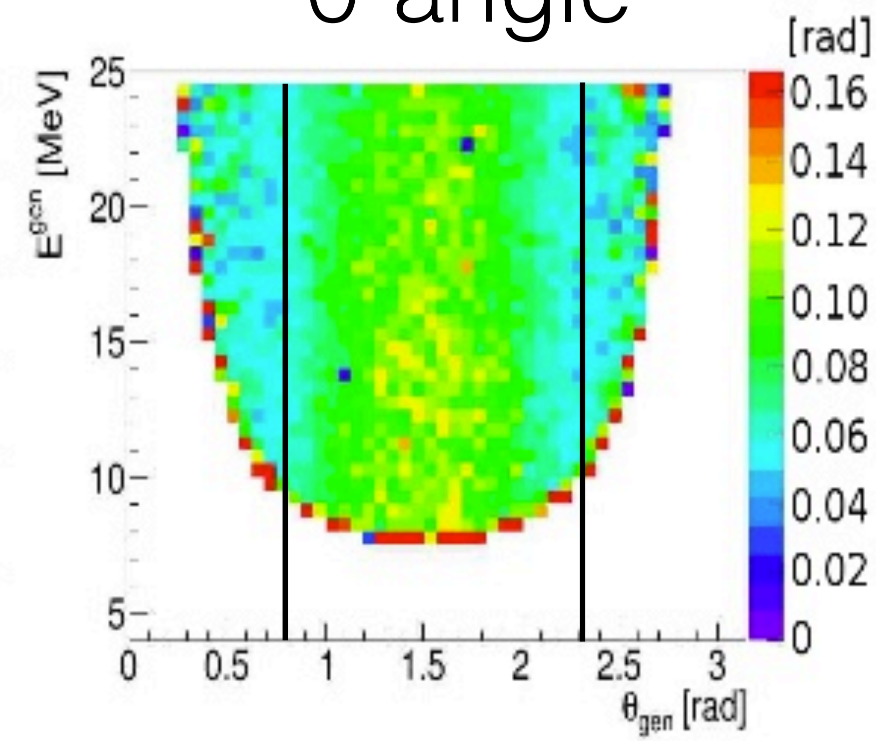
z-vertex



ϕ-angle



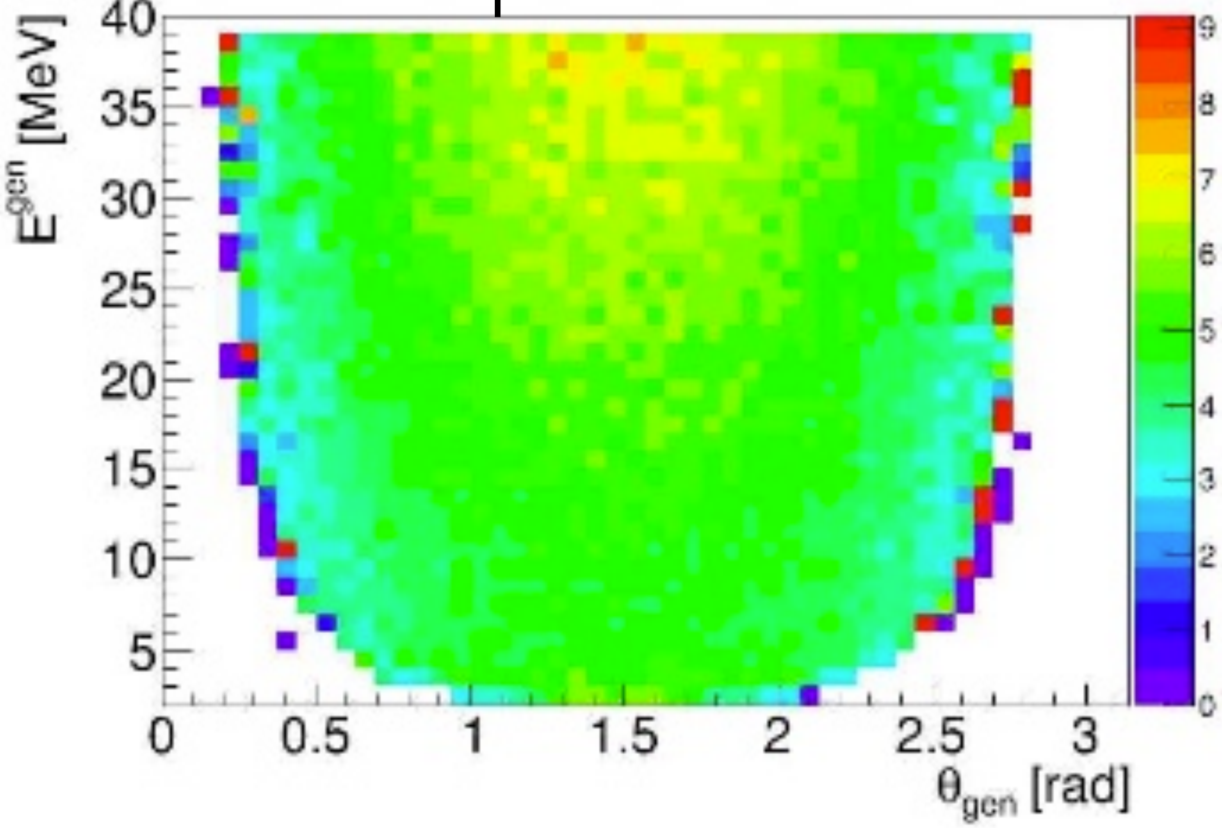
θ-angle



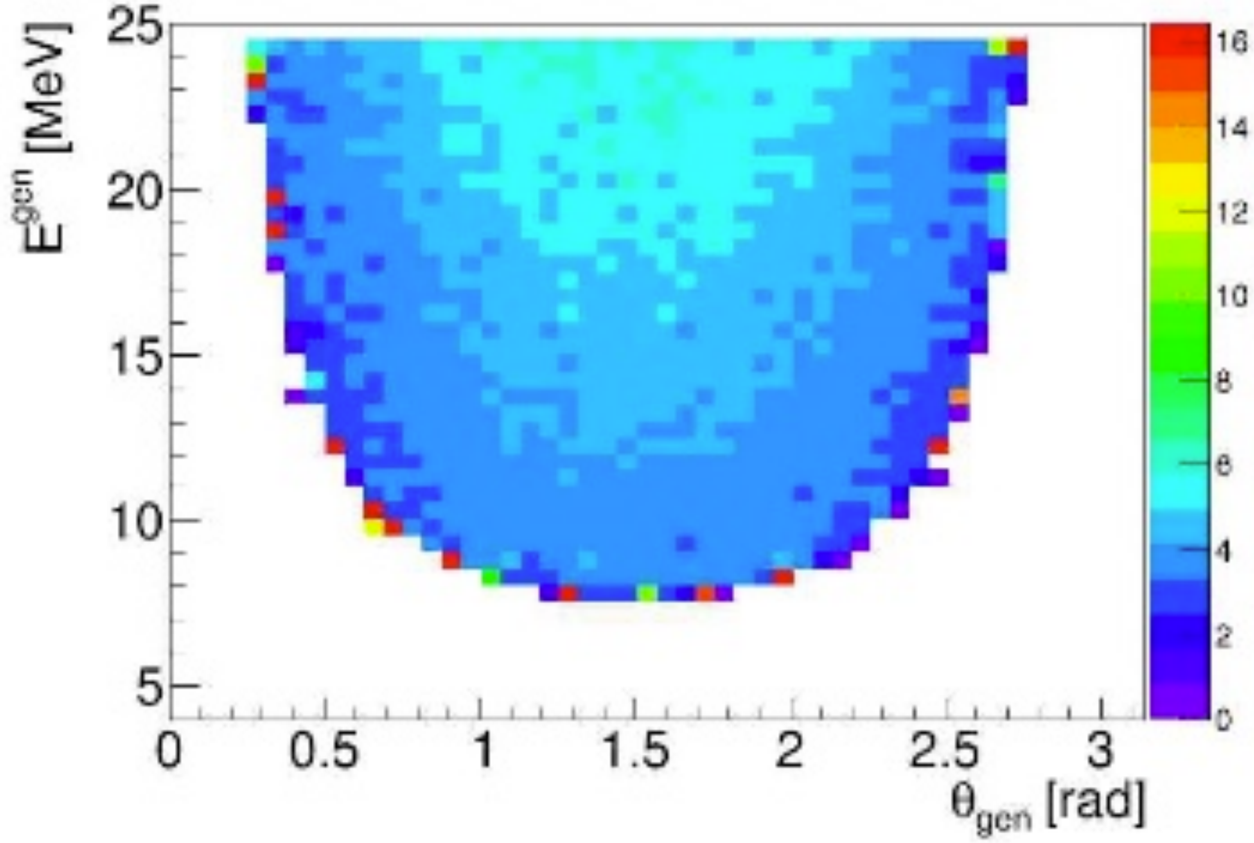
- Resolutions from approved ALERT proposal E12-17-012 (https://misportal.jlab.org/pacProposals/proposals/1338/attachments/98370/Proposal.pdf)
- Assumed resolutions for deuterons/tritons within acceptance
  - ϕ = 0.1 rad
  - θ = 0.1 rad

ALERT Momentum Resolutions

proton

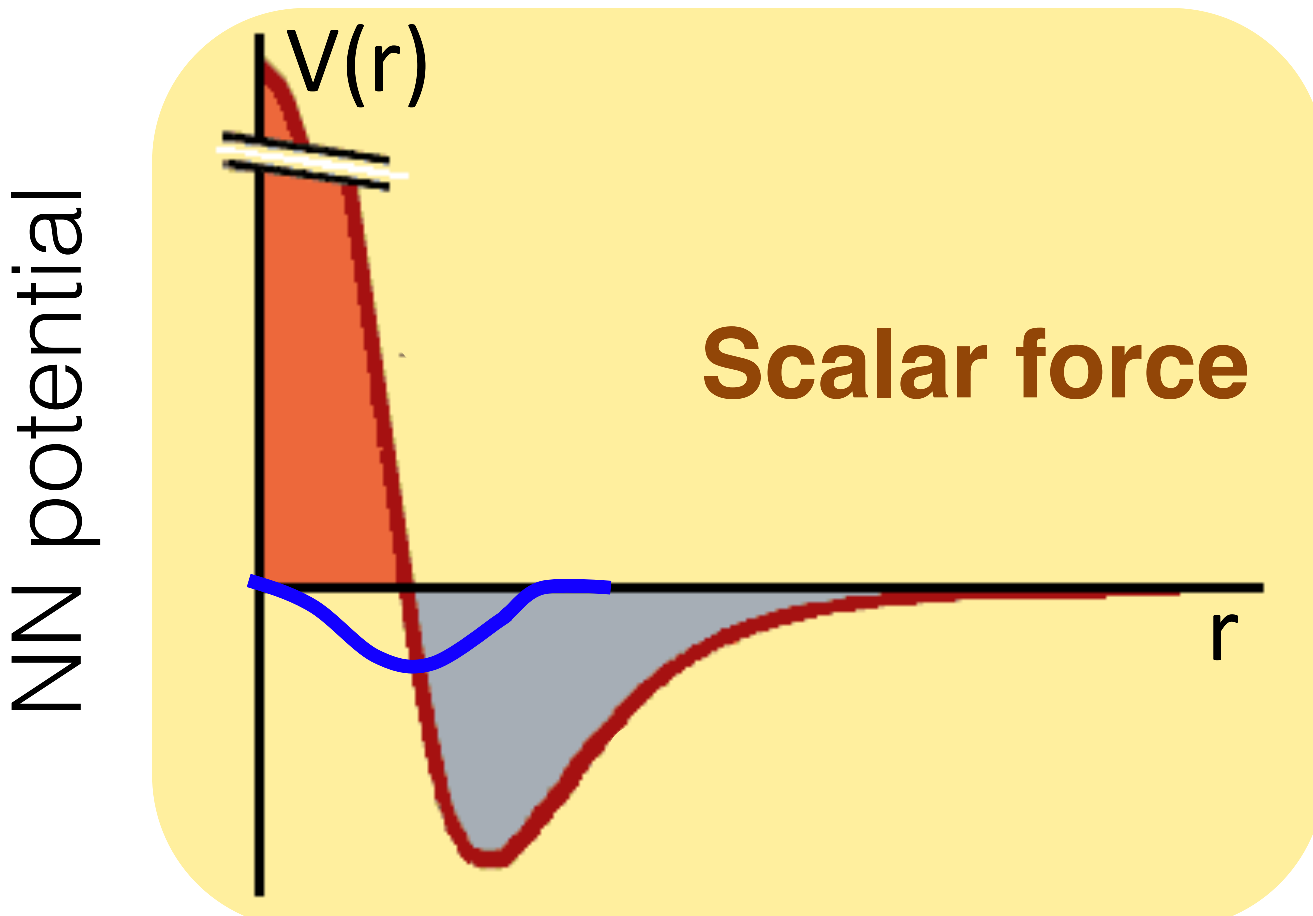


^{4}He



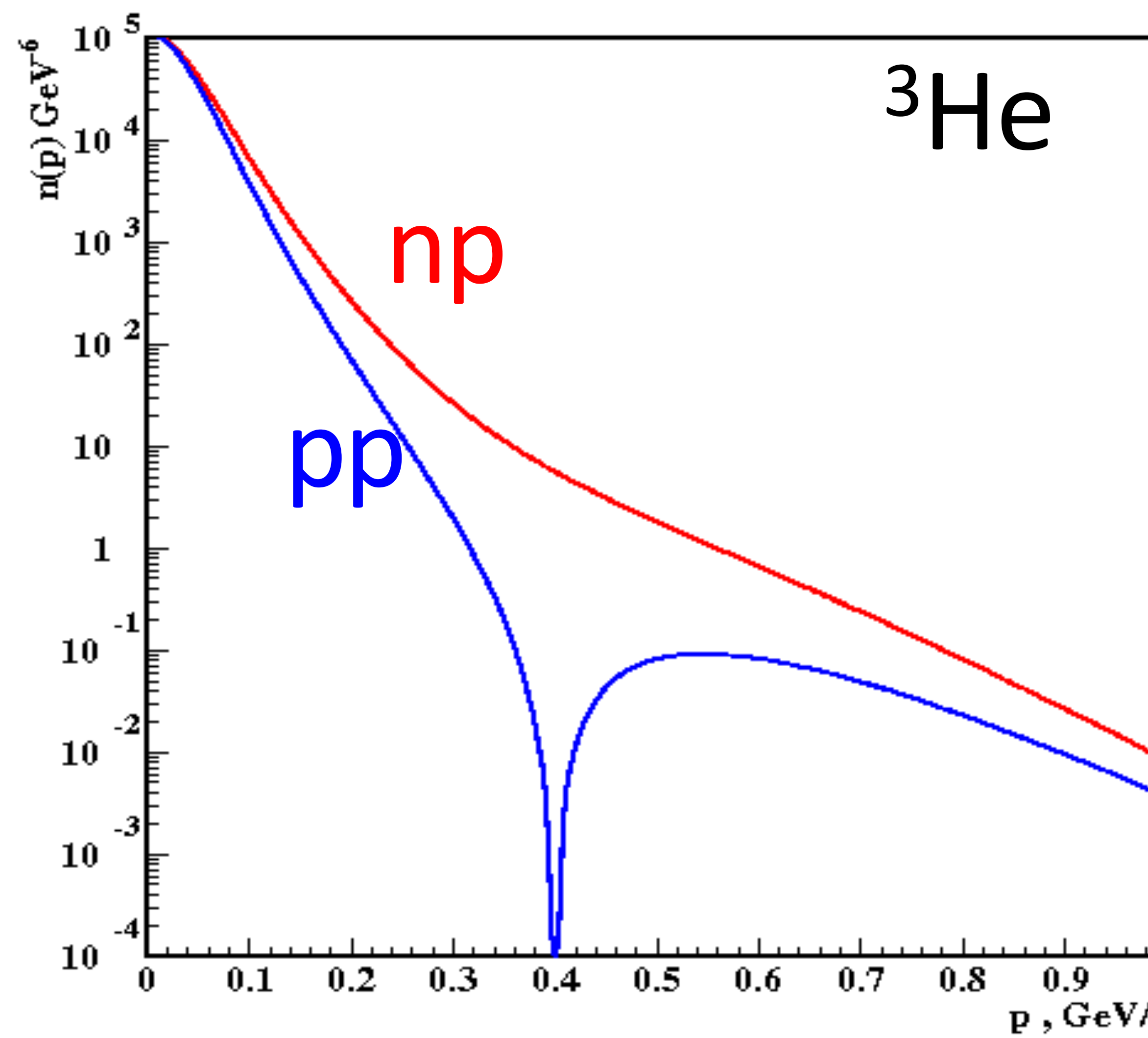
- Resolutions from approved ALERT proposal E12-17-012 (https://misportal.jlab.org/pacProposals/proposals/1338/attachments/98370/Proposal.pdf)
- Assumed resolution for deuterons/tritons will be between protons and 4He —> ~4%

np-Dominance from Tensor Force

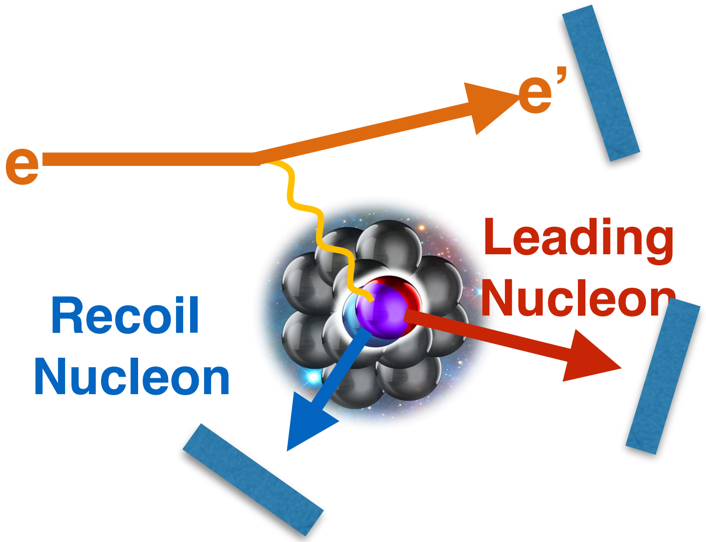


Tensor force
Short-Range attraction

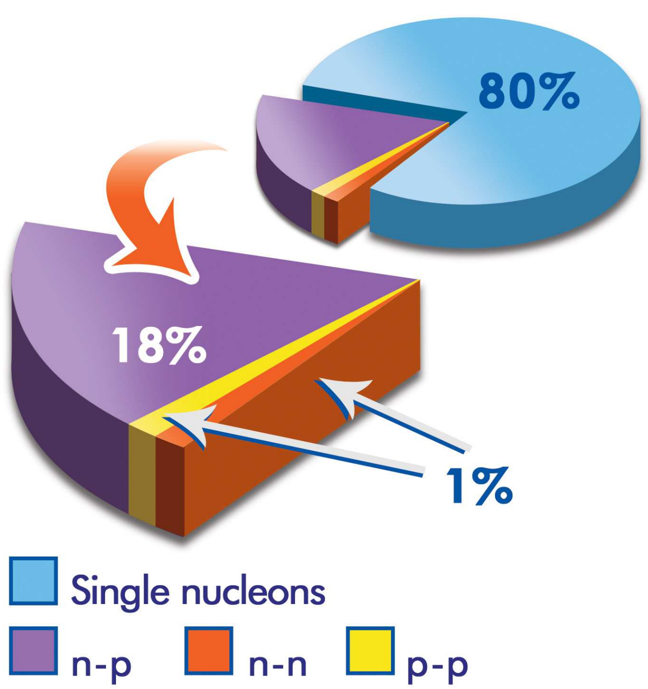
Sargsian et al., PRC (2005)

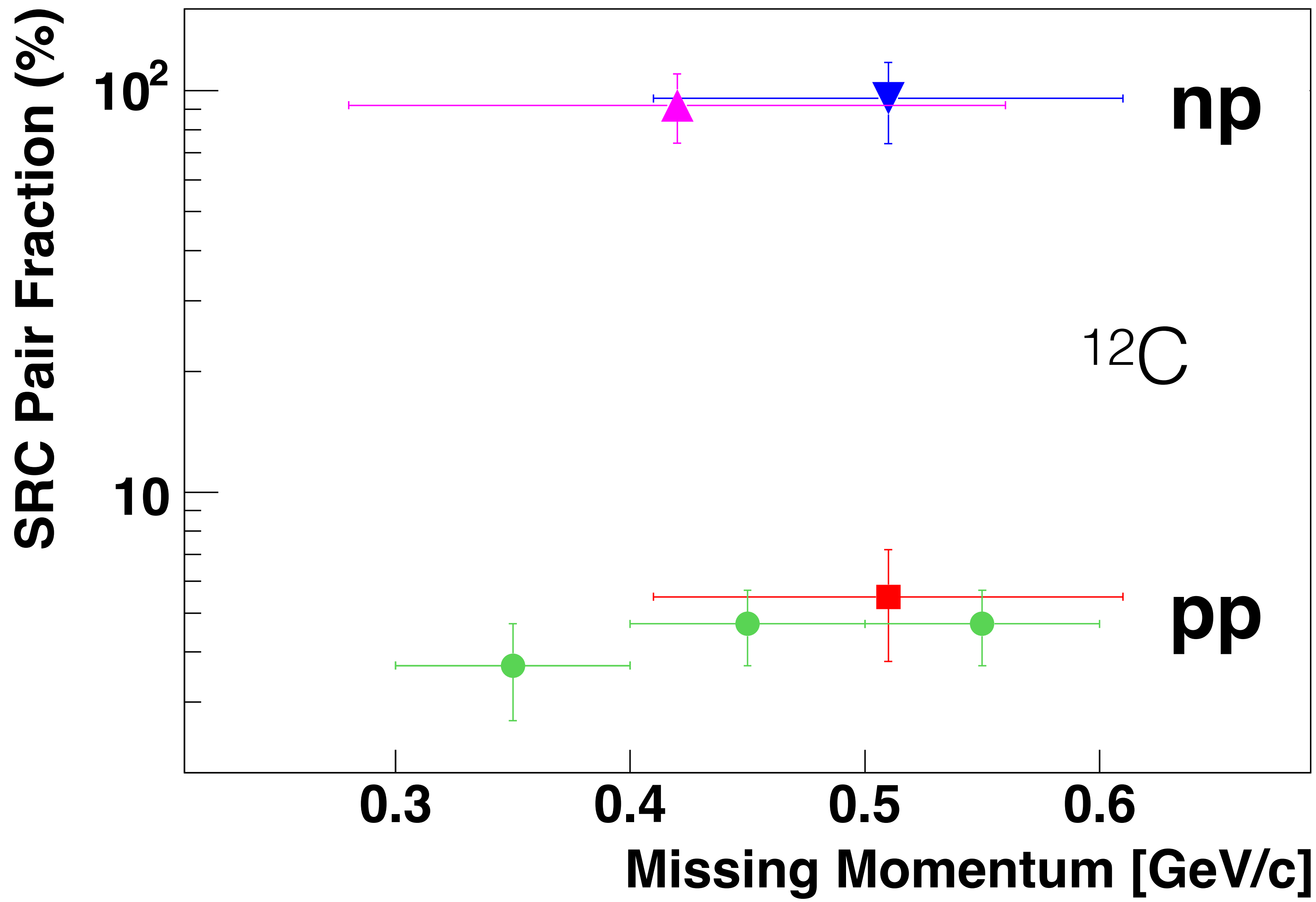


np-Dominance



- 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)