Measurements and Simulations of *(e,e'n)/(e,e'p)* in ^{3}He for High and Low Momentum Nucleons

Erin Marshall Seroka, Holly Szumila-Vance, Axel Schmidt

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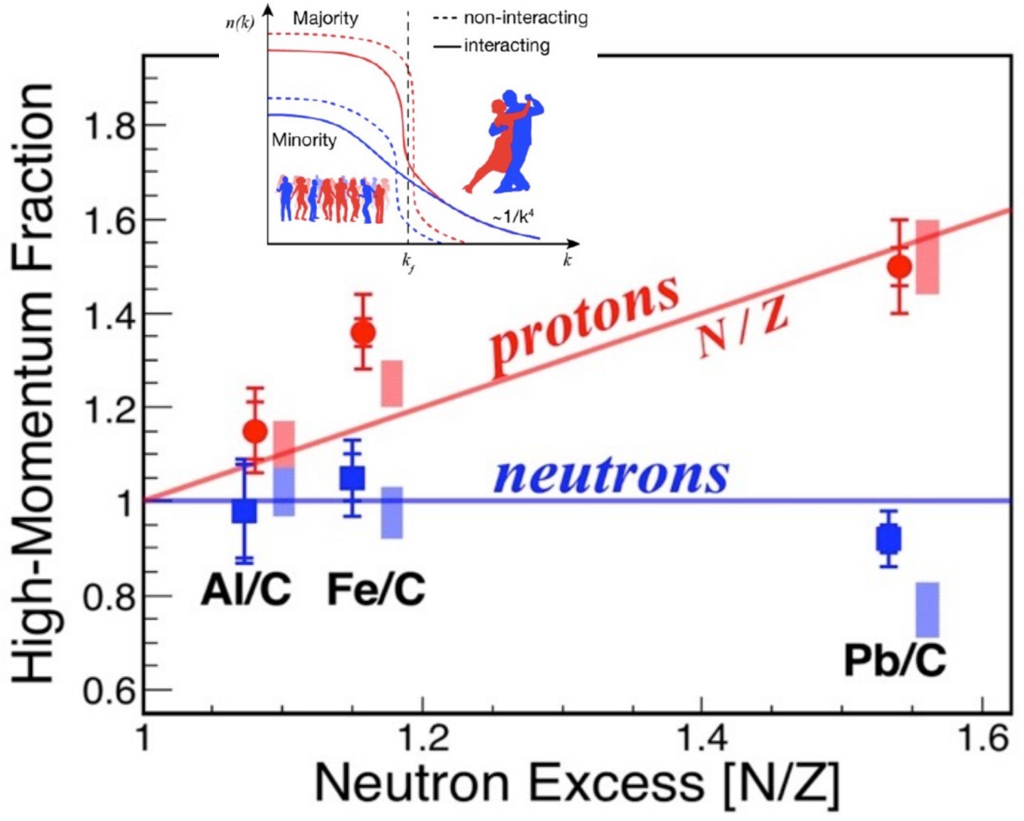
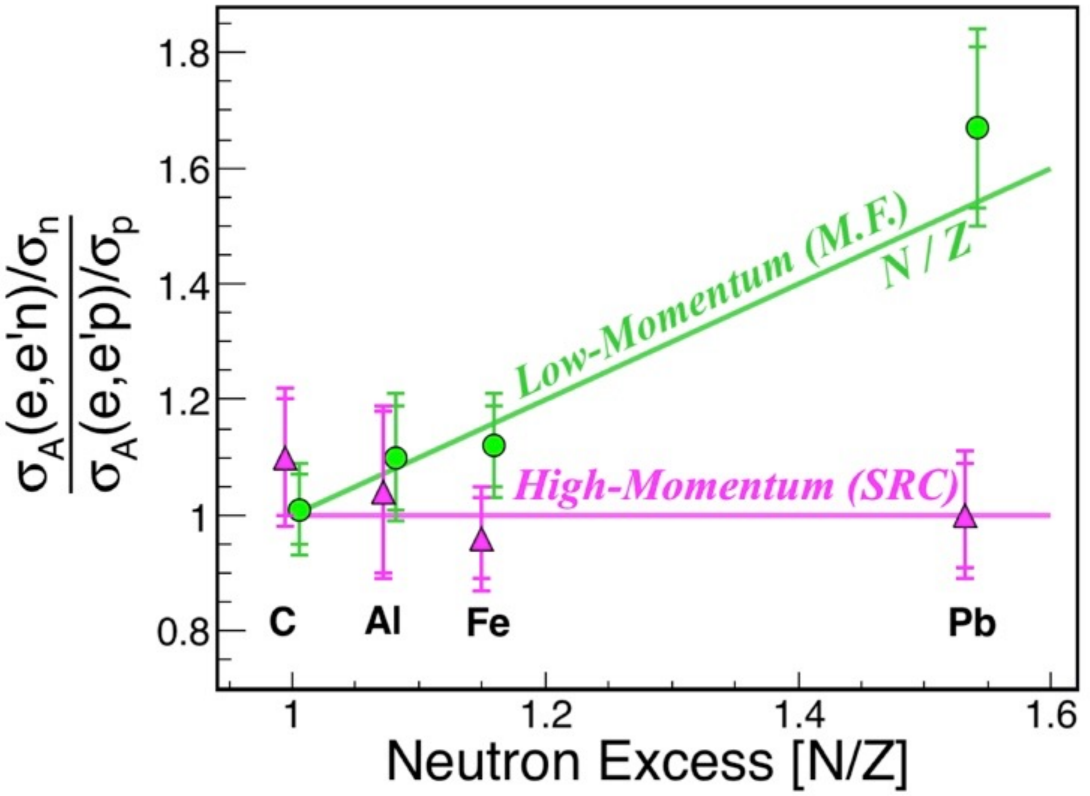
Protons "speed up" in neutron-rich nuclei

- Minority (p) moves faster than majority (n) in neutron-rich nuclei

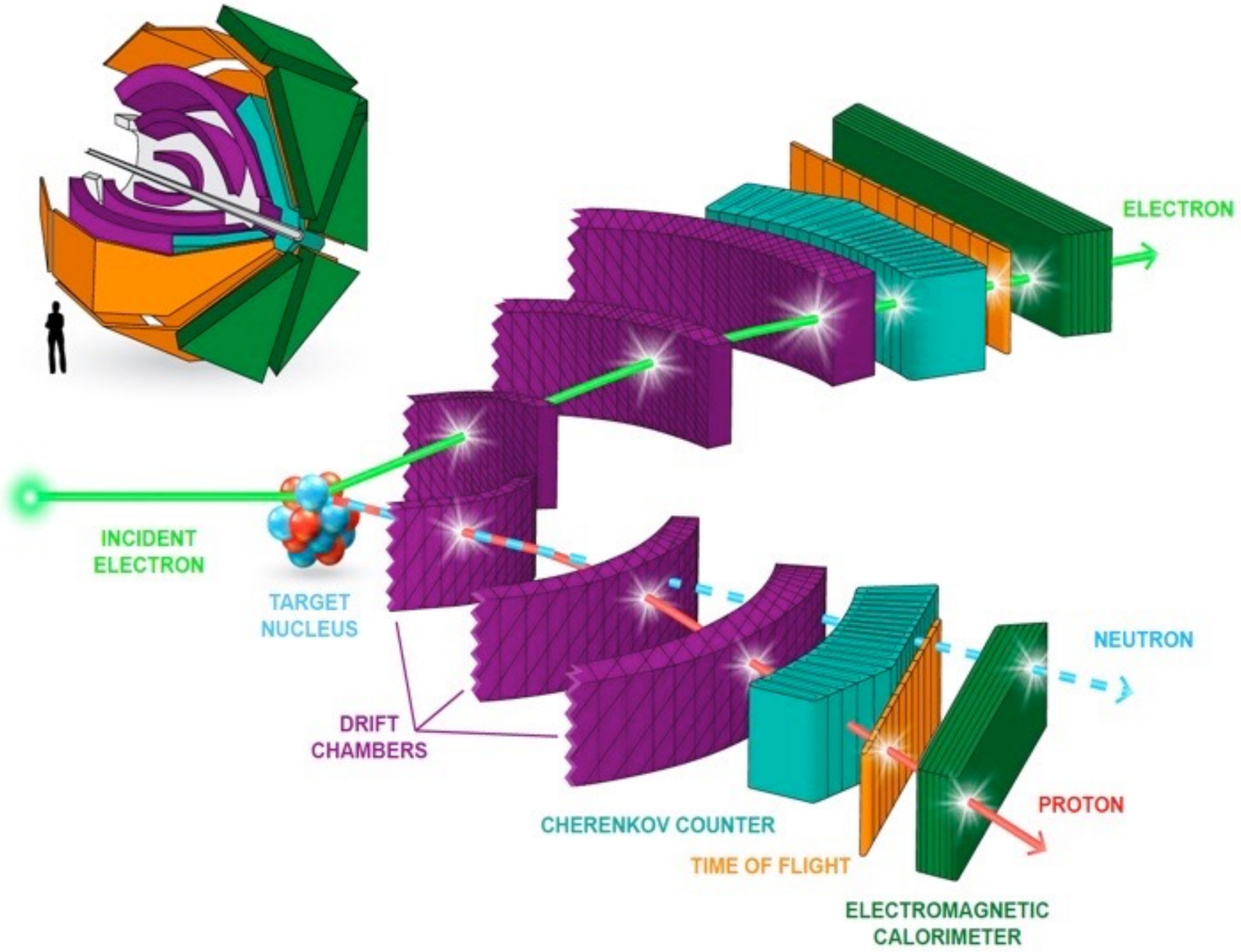




Duer et al. (CLAS Collaboration), Nature 560, 617 (2018)

Neutron Detection in CLAS6

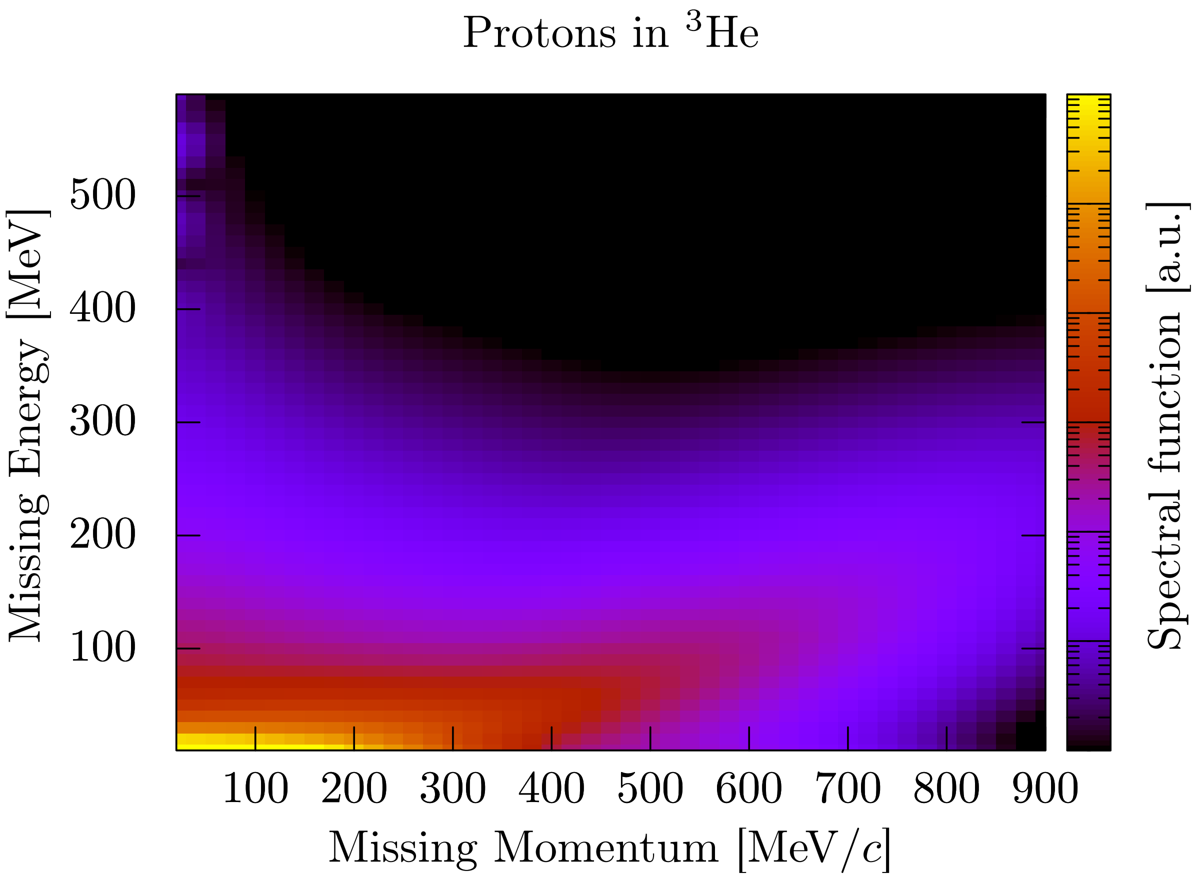
- Experiment e2a (April-May 1999)
- 4.4 GeV e^- beam on ^3He, ^4He, ^{12}C targets
- Measure $^3He(e,e'n)/^3He(e,e'p)$
- Neutron knocks out proton in the EC
- Unlike proton, no DC track or TOF hit



Source: Meytal Duer thesis (2018)

Fast Monte Carlo Simulations

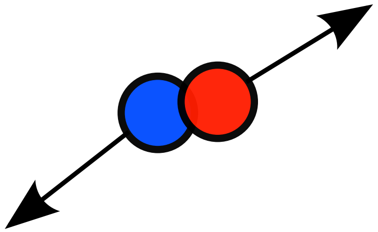
- Used 3-body spectral functions based on Fadeev equations from Ciofi degli Atti and Kaptari
- Unweighted quasielastic generator under PWIA
- No neutron momentum correction/inefficiency



$$\frac{d^6\sigma}{d\Omega_e dE_e d\Omega_N dE_N} = |\vec{p}_N| E_N \sigma_{eN} S_N(E_m, \vec{p}_m)$$

Ciofi delgi Atti and Kaptari, Phys. Rev. C 71:024005, 2005.

Event Selection Criteria for Protons



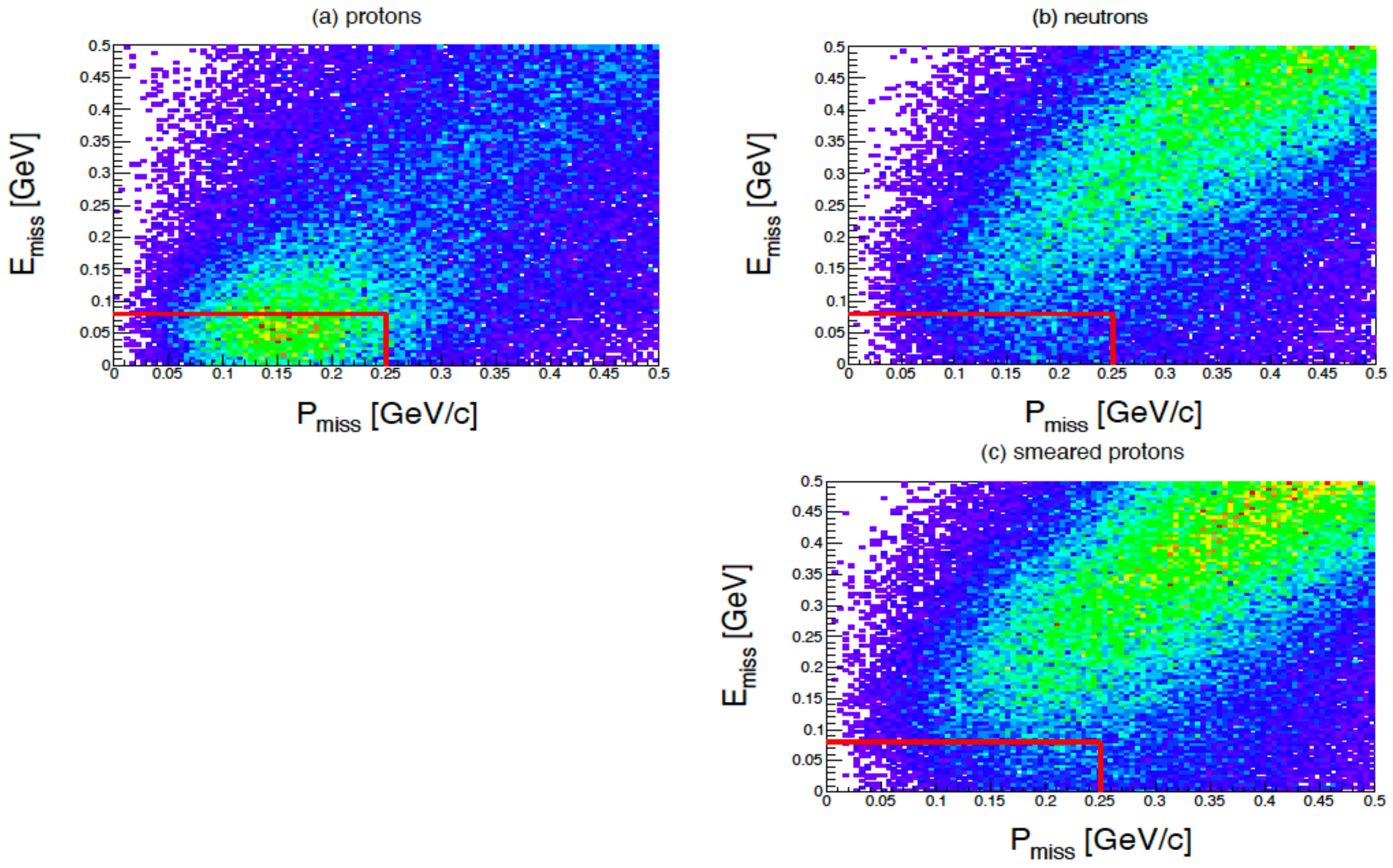
Low Momentum (MF)
$-0.05 < y < 0.2$
$0.9 < \nu < 1.6\ GeV$
$\theta_{pq} < 7\ deg$
$\boldsymbol{E_{miss} < 0.08\ GeV}$
$\boldsymbol{p_{miss} < 0.22\ GeV/c}$

High Momentum (SRC)
$x_B > 1.2$
$0.62 < \frac{\lvert p \rvert}{\lvert q \rvert} < 1.1$
$\theta_{pq} < 25\ deg$
$\boldsymbol{M_{miss} < 1.1\ GeV/c^2}$
$\boldsymbol{0.3 < p_{miss} < 1\ GeV/c}$

The p-dependent cuts developed for protons don’t work for neutrons!

Smearing the Proton Momentum

- Neutron have worse momentum resolution than protons
- Need to apply same cuts to both p and n
- **Solution**: smear proton momentum and find modified cuts!

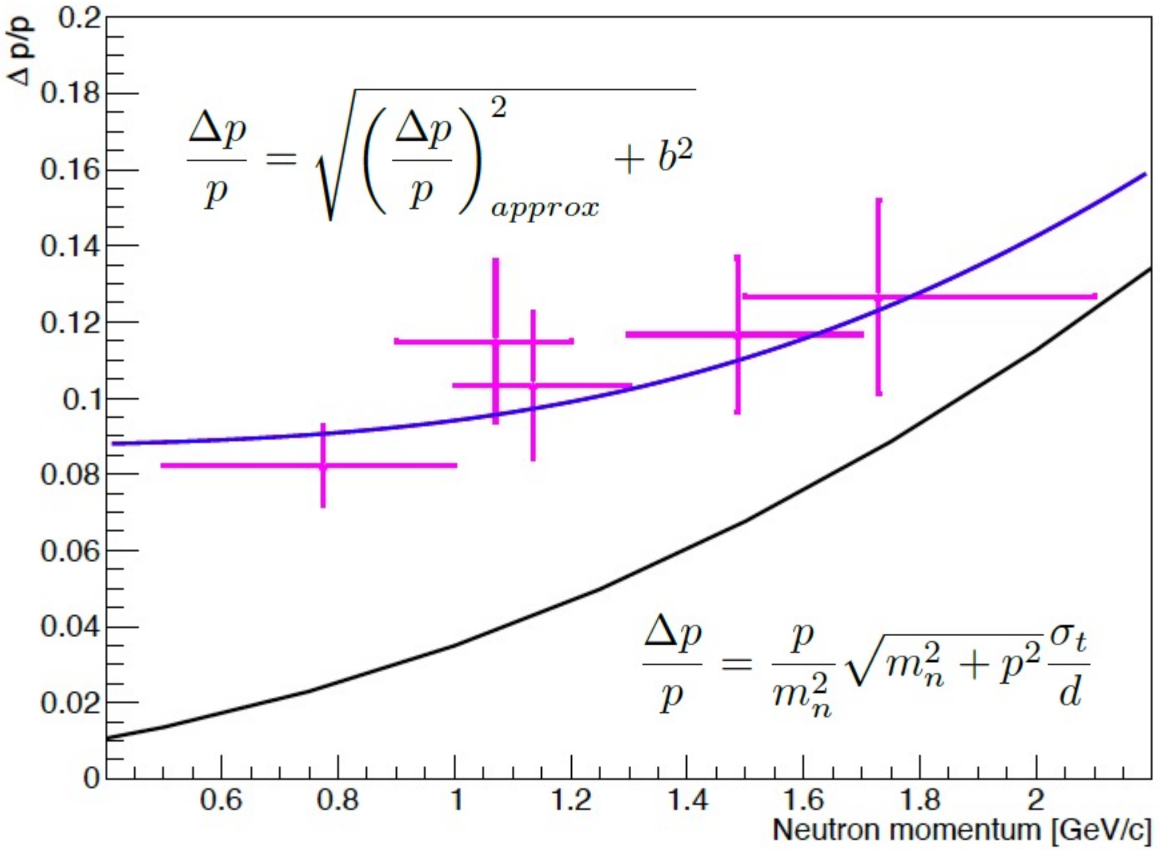


Source: Meytal Duer thesis (2018)

Smearing Methodology

- First correct neutron momentum based on mean of $\Delta p/p$
- Find neutron momentum error $\Delta p/p$ vs momentum
- Scale proton momentum by smearing factor drawn from Gaussian with $\sigma = \Delta p$
- Same smearing used in Fast MC

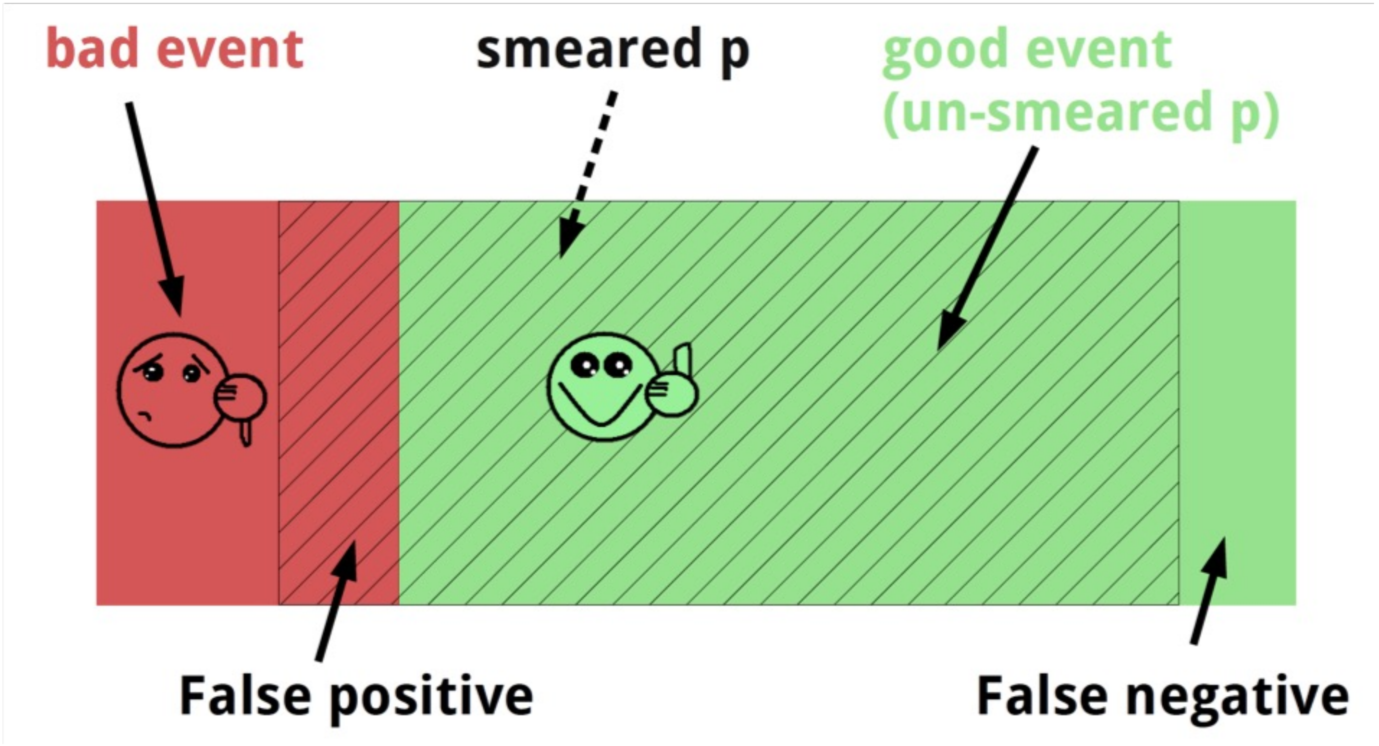
$$\frac{\Delta p}{p} = \frac{p_{miss} - p_{measured}}{p_{measured}}$$



Finding Modified Cuts for Neutrons

Low Momentum (modified)
$E_{miss} < ?$
$p_{miss} < ?$

High Momentum (modified)
$M_{miss} < ?$
$p_{miss} > ?$



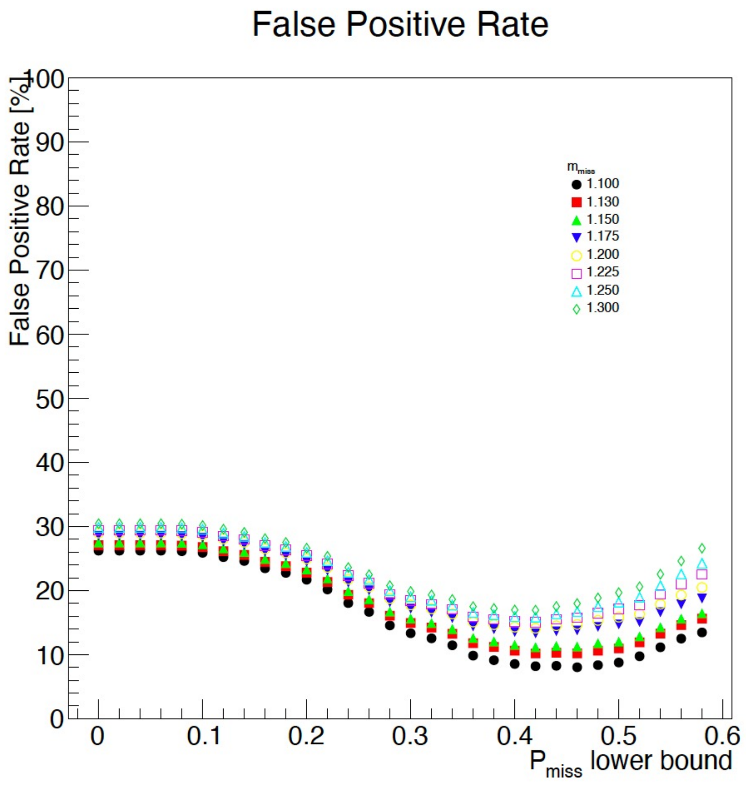
Goal: # of smeared protons passing modified cuts = # of unsmeared protons passing original cuts

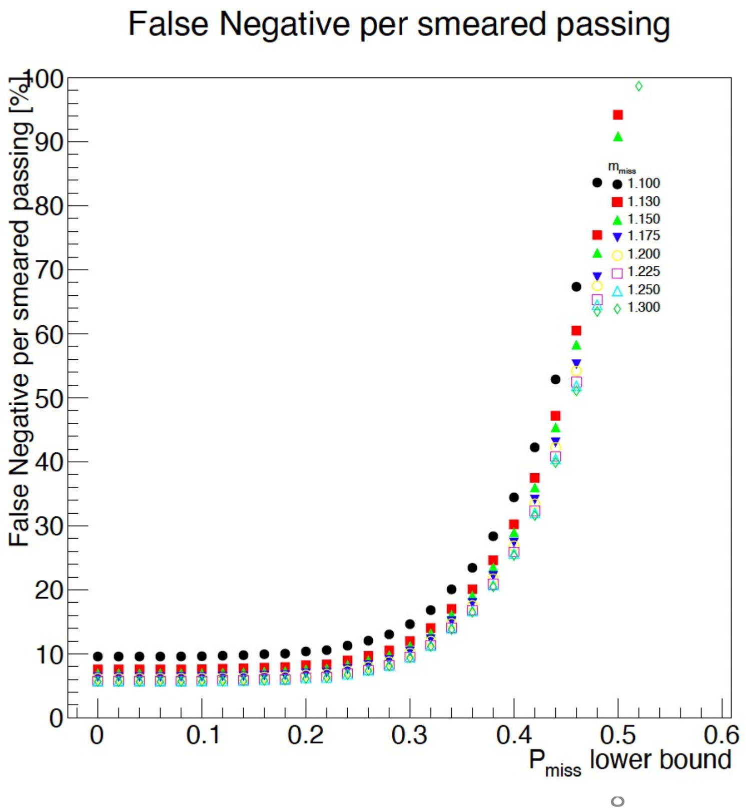
Cut Optimization

- Minimize difference between false negatives and false positives
- Same cuts for all targets

Low Momentum (modified)
$E_{miss} < 0.265\ GeV$
$p_{miss} < 0.265\ GeV/c$

High Momentum (modified)
$M_{miss} < 1.13\ GeV/c^2$
$0.32 < p_{miss} < 1\ GeV/c$





Cut Optimization

- Minimize difference between false negatives and false positives
- Same cuts in simulation as data

Low Momentum (modified)
$E_{miss} < 0.265\ GeV$
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High Momentum (modified)
$M_{miss} < 1.13\ GeV/c^2$
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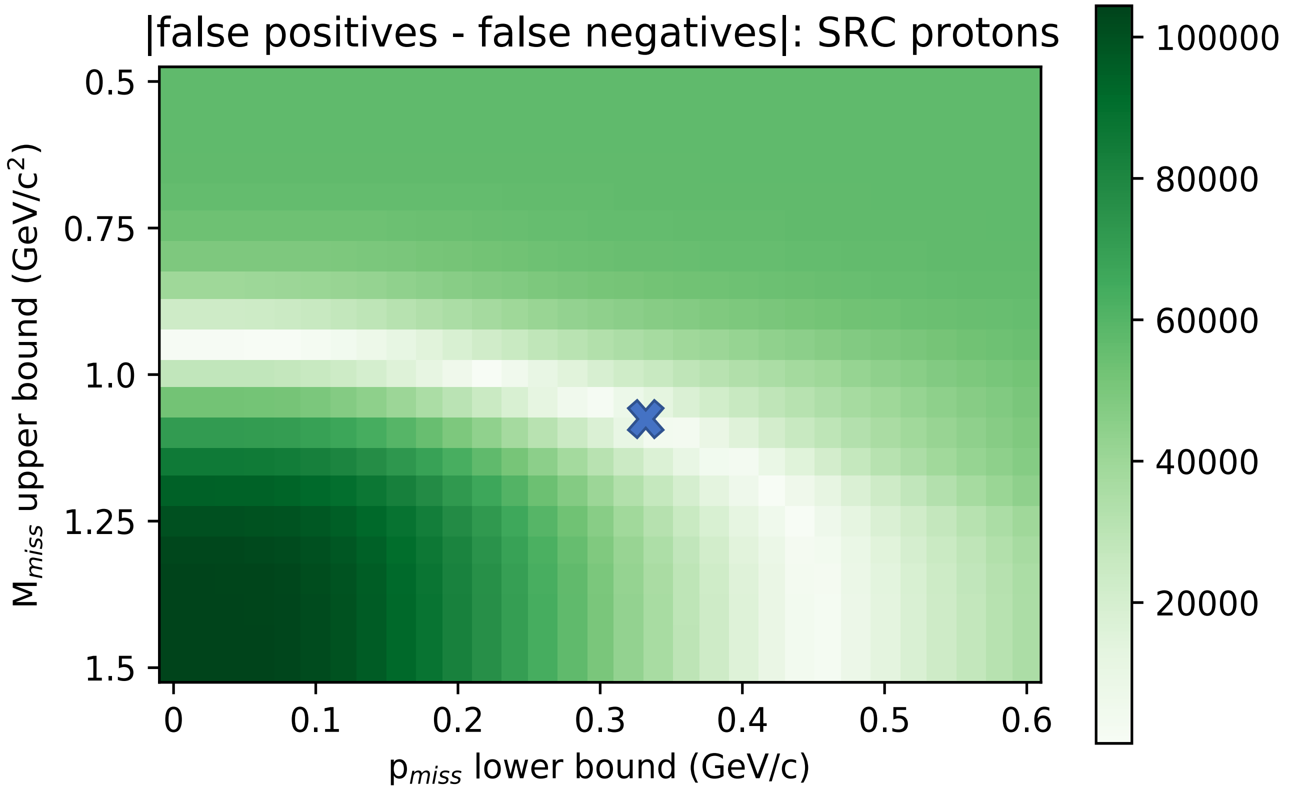
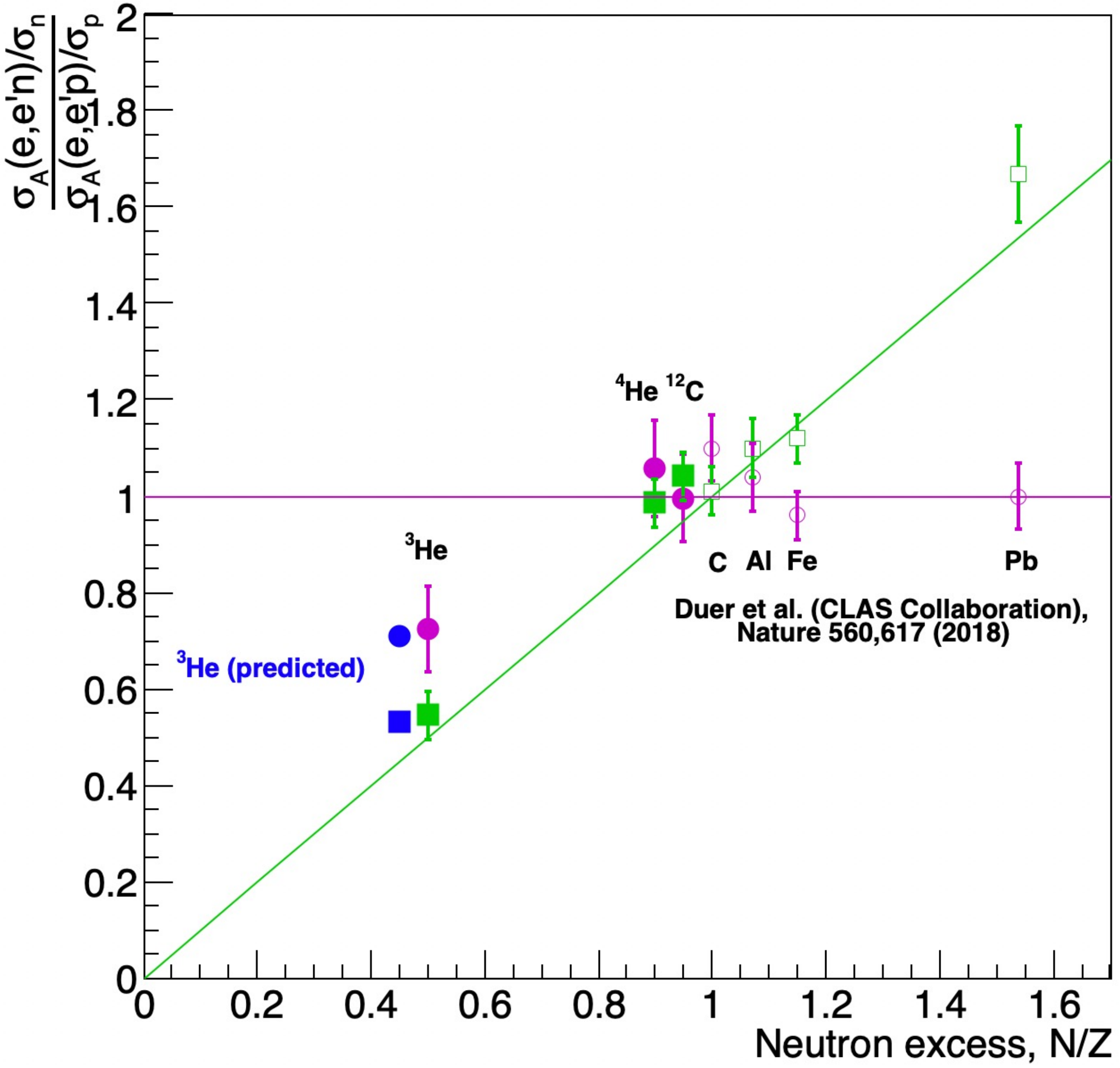


Results

- Low momentum nucleons behave as expected
- Neutrons speed up in proton-rich nuclei
- Spectral functions good at replicating $^3He(e,e'n)/^3He(e,e'p)$ ratios



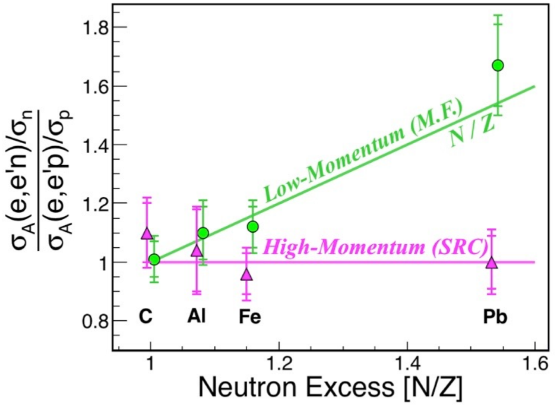
Updates

- Results submitted for CLAS review (July 2021)
- Comments received (August 2021)
- Set aside to focus on Hall B and D experiments
- Going through full GEANT simulation with CLAS reconstruction (rather than fast MC)
- Working on systematics

Our analysis has two observables

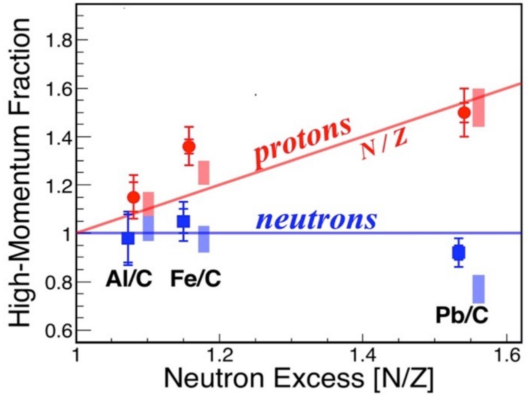
- n/p ratios:

$$\frac{\sigma^A_{SRC,n}/\sigma_n}{\sigma^A_{SRC,p}/\sigma_p}, \qquad \frac{\sigma^A_{MF,n}/\sigma_n}{\sigma^A_{MF,p}/\sigma_p}$$



- SRC/MF double ratios

$$\left[\frac{\sigma^A_{SRC,n}}{\sigma^A_{MF,n}}\right] \Big/ \left[\frac{\sigma^{A_0}_{SRC,n}}{\sigma^{A_0}_{MF,n}}\right], \qquad \left[\frac{\sigma^A_{SRC,p}}{\sigma^A_{MF,p}}\right] \Big/ \left[\frac{\sigma^{A_0}_{SRC,p}}{\sigma^{A_0}_{MF,p}}\right]$$



Observable and systematics

n/p ratios:

$$\frac{\sigma^A_{SRC,n}/\sigma_n}{\sigma^A_{SRC,p}/\sigma_p}$$

$$\frac{\sigma^A_{MF,n}/\sigma_n}{\sigma^A_{MF,p}/\sigma_p}$$

Fundamental cross section

$$\frac{\sigma^A_n/\sigma_n}{\sigma^A_p/\sigma_p} = \frac{\sum_i \frac{1}{\epsilon_{n,i}\sigma_{n,i}}}{\sum_i \frac{1}{\epsilon_{p,i}\sigma_{p,i}}} \cdot F$$

Correction factor for false pos./neg. in case smearing is different p/n (Assume = 1)

Ratio of "corrected yields" (event selection)

Efficiency correction

Correcting each individual event is equivalent to correcting the yields.

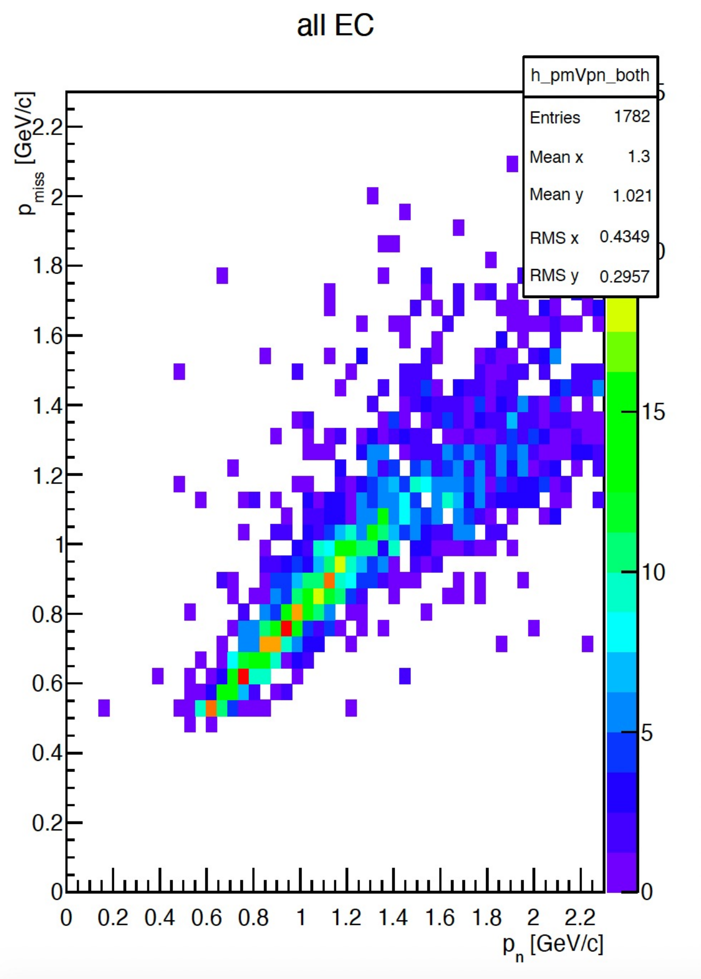
Sources of Systematic Uncertainty

	Typical Size for Meytal	Size for e2a (preliminary)
• Neutron efficiency • Estimate by comparing change in yields with different ϵ_n models.	0.03 – 0.07	0.04
• Proton efficiency • Compare acceptance maps to GSIM efficiency	0.01 – 0.03	0.01
• Event selection • Estimate by varying cuts	0.04 – 0.05	0.03 – 0.04
• Fundamental electron-nucleon cross sections • Compare yields using Ye et al., to Kelly et al.	Not quoted (Kelly 2004)	Not quoted (Ye 2018) (small?)
• False pos./neg. correction • Calculate change in yields using data-driven Gaussian smearing vs. GSIM-driven Landau smearing model.	Not quoted	Small?

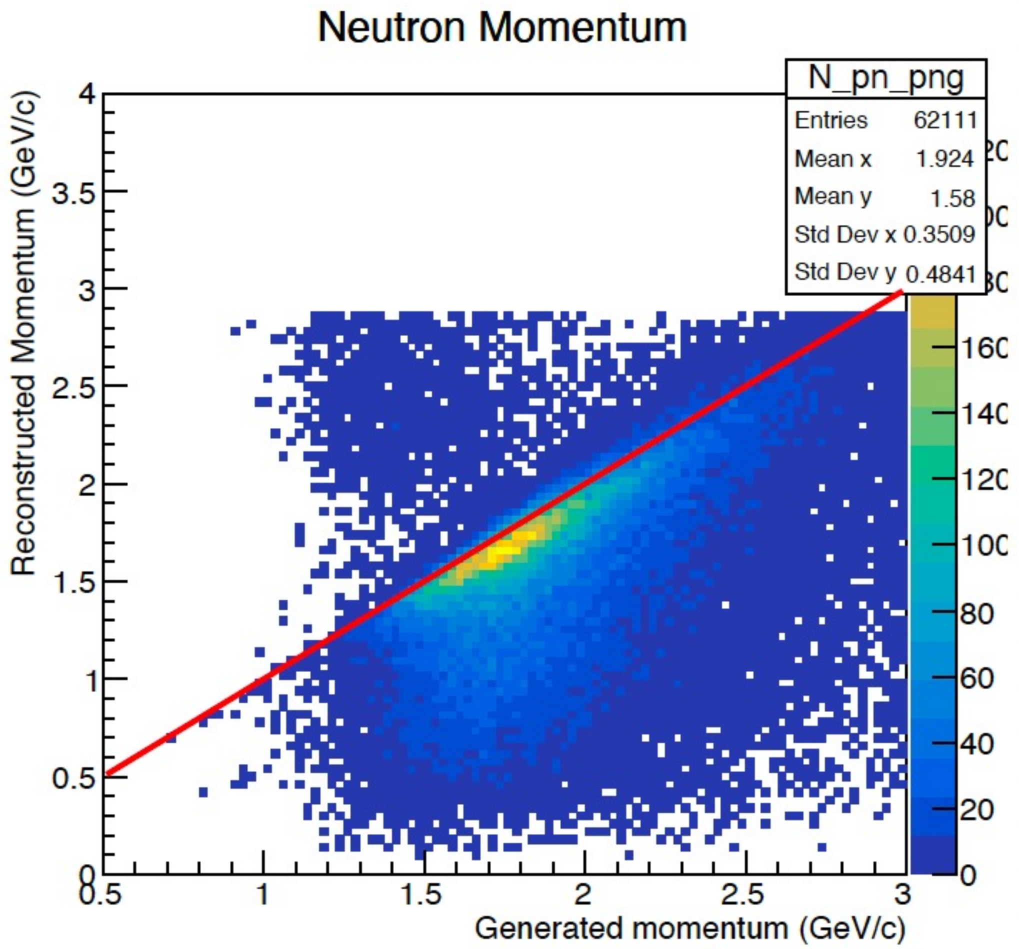
Neutron Momentum Reconstruction Accuracy

Comparing measured neutron momentum to missing momentum

e2a



GEANT Simulation



Comparing generated to reconstructed momentum

Fitting to Landau

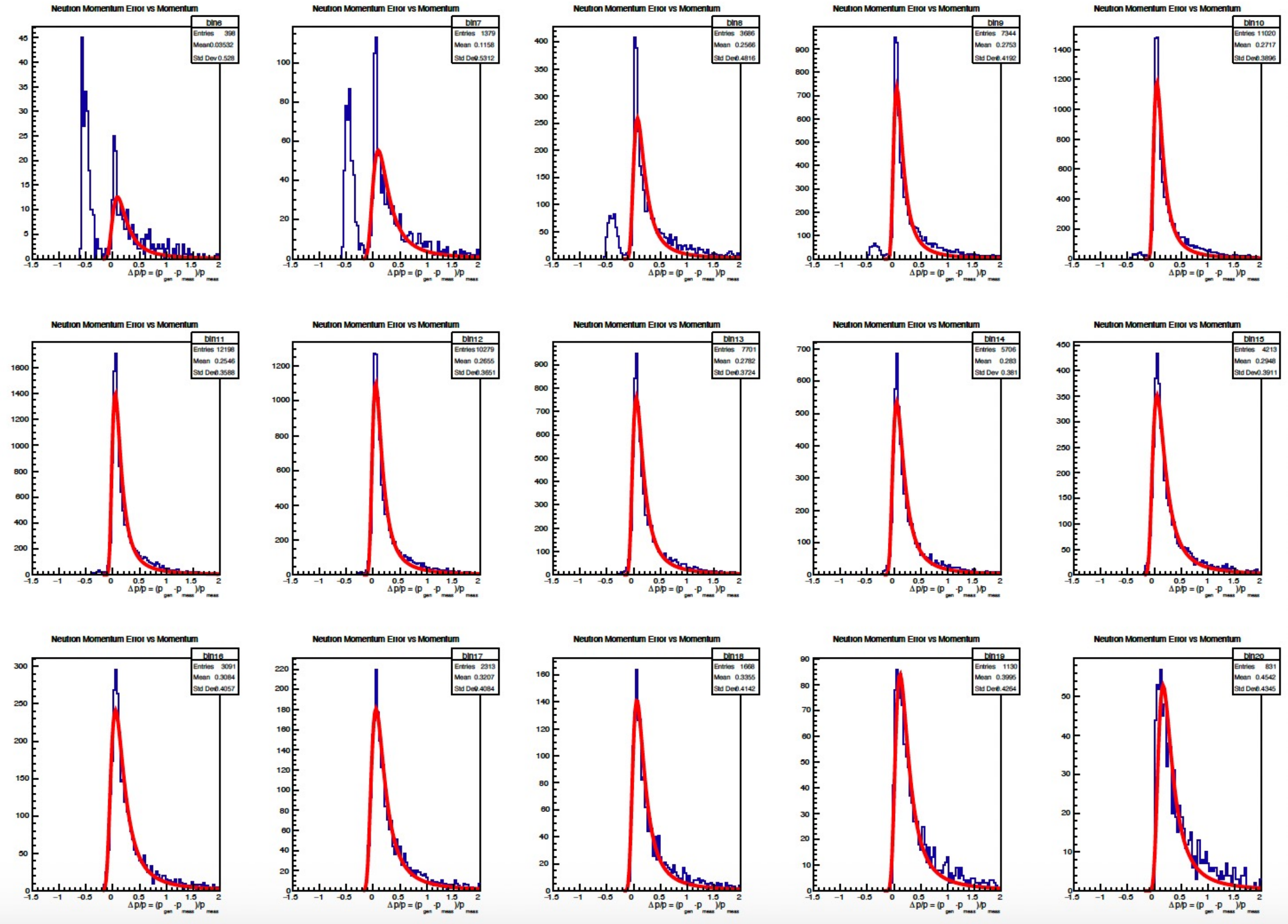
<u>eg2 and e2a</u>

- Gaussian fits used for momentum error

<u>Simulation</u>

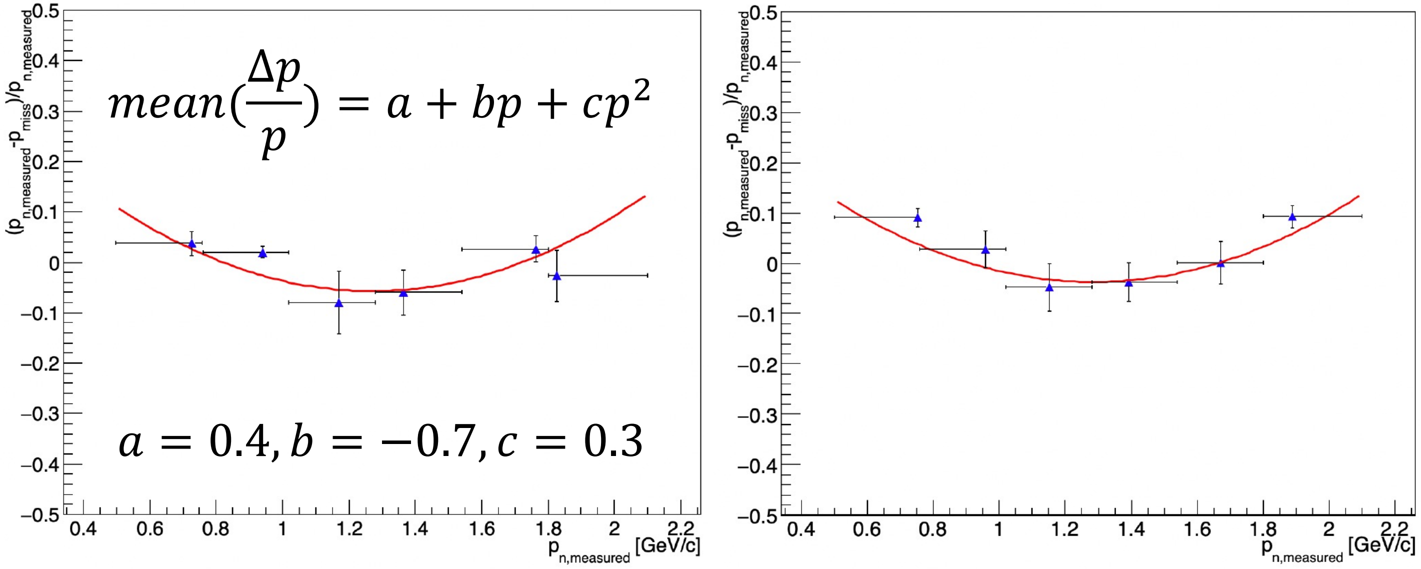
- Gaussian fits used for FMC
- GSIM indicates Landau error

$\frac{\Delta p}{p}$ for momentum intervals from 1.25 – 3 GeV/c

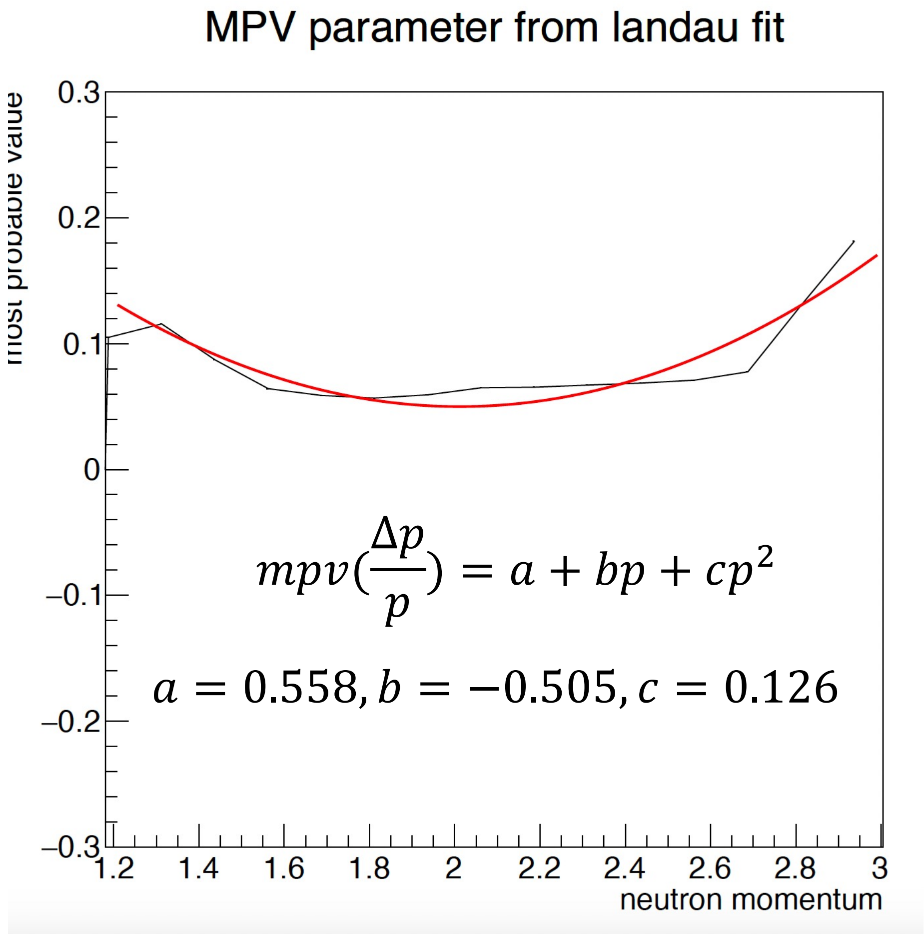


Neutron Momentum Correction (MPV)

- e2a correction up to 10%

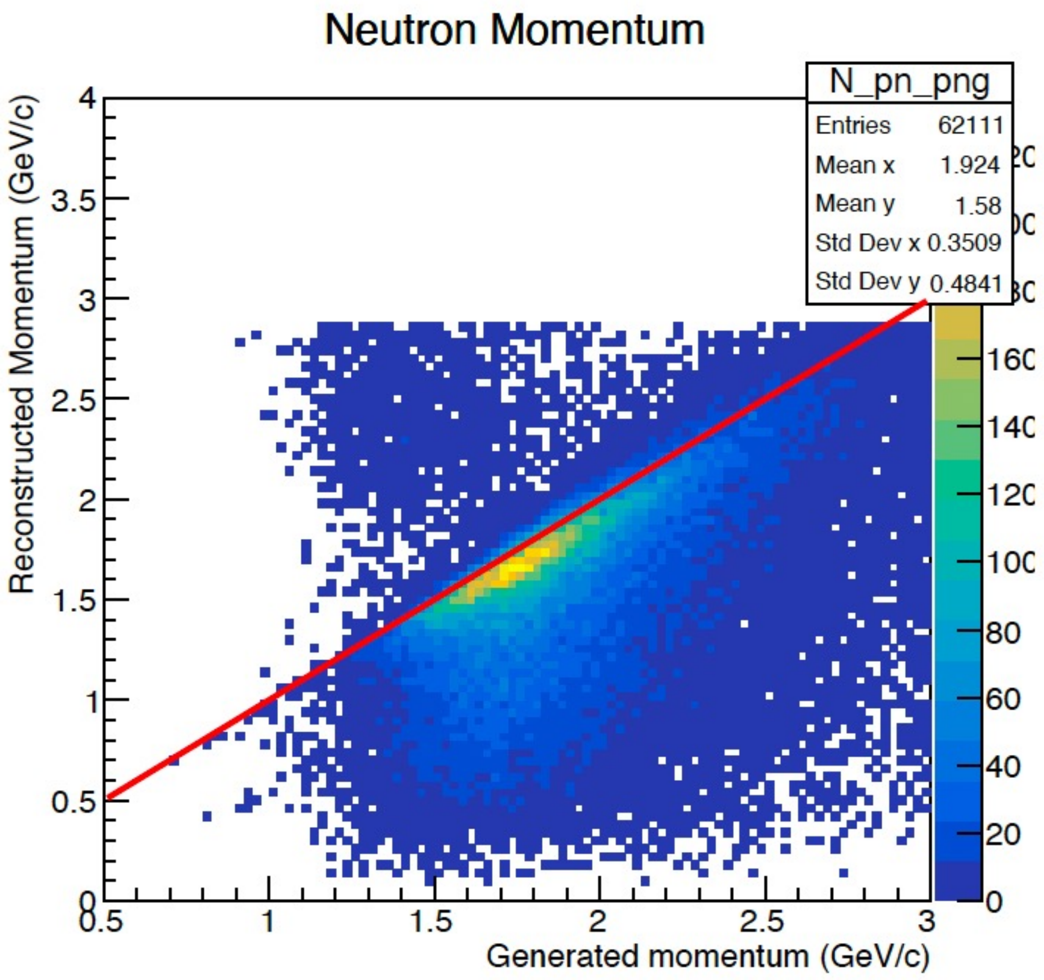


- Sim correction of 5-15%

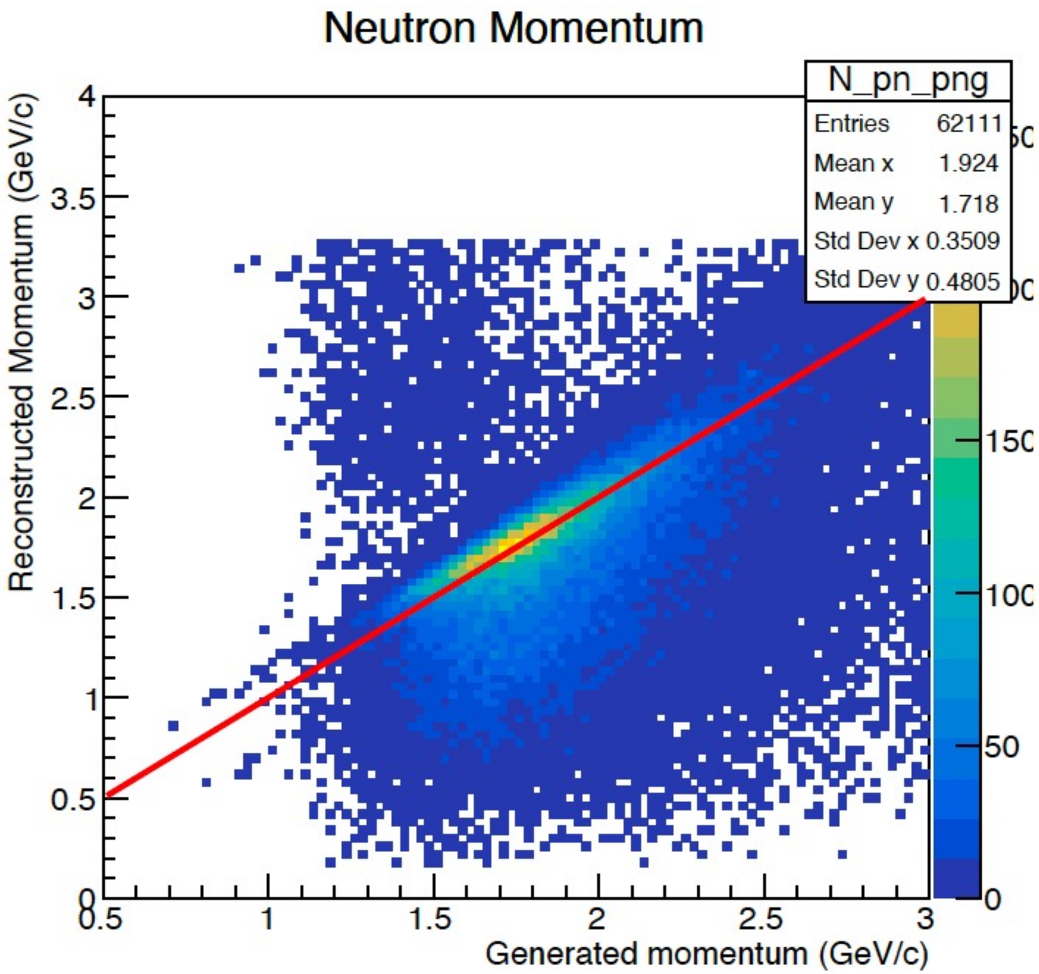


Neutron Momentum Correction

Before

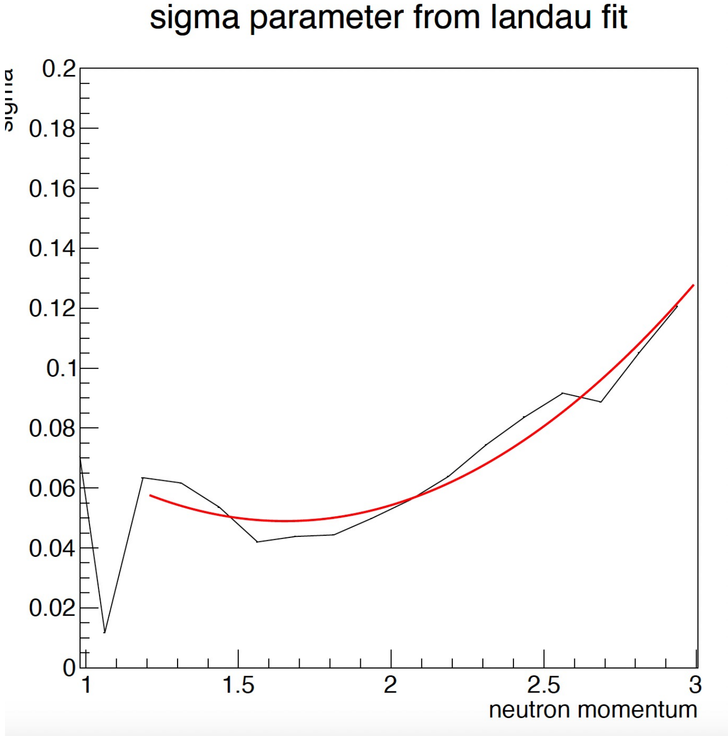


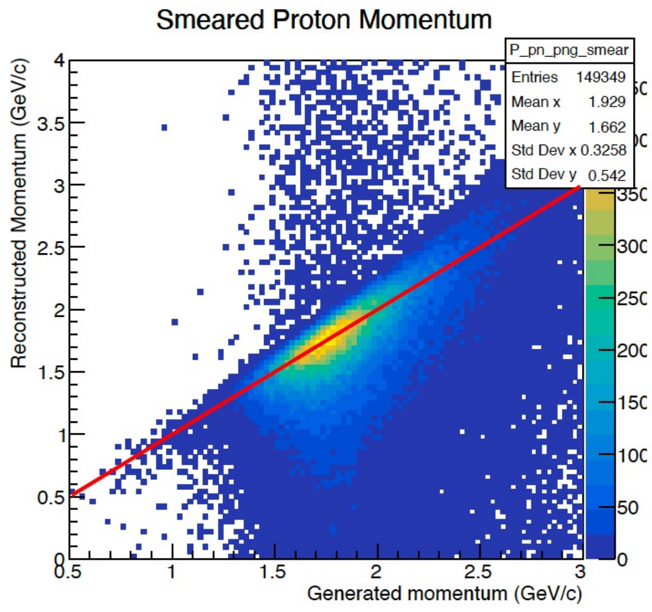
After

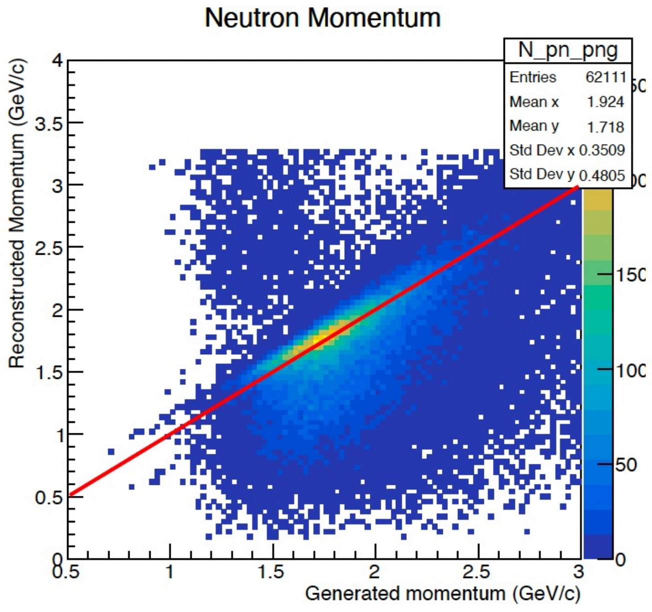


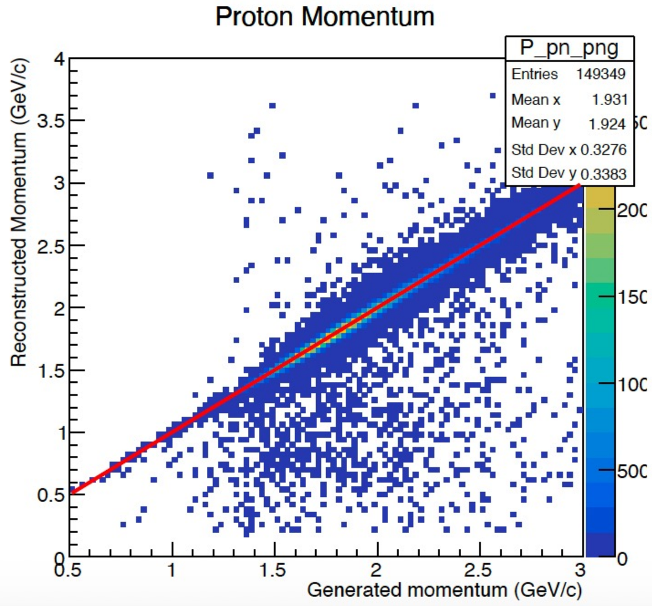
Landau Smearing

- Smearing factor drawn from Landau distribution with $\sigma = \Delta p$







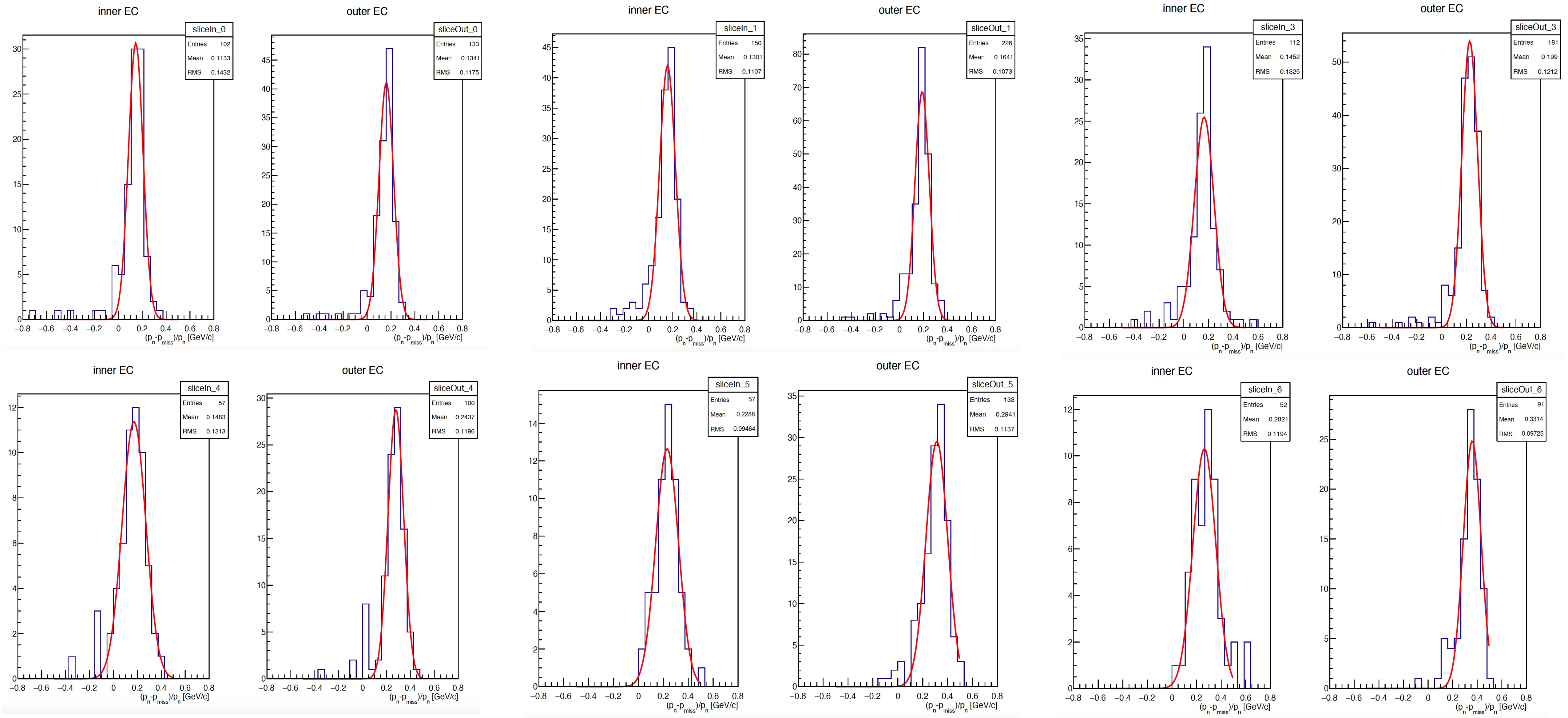


$$\sigma\left(\frac{\Delta p}{p}\right) = a + bp + cp^2$$

$$a = 0.169, b = -0.145, c = 0.044$$

Landau Smearing in Data?

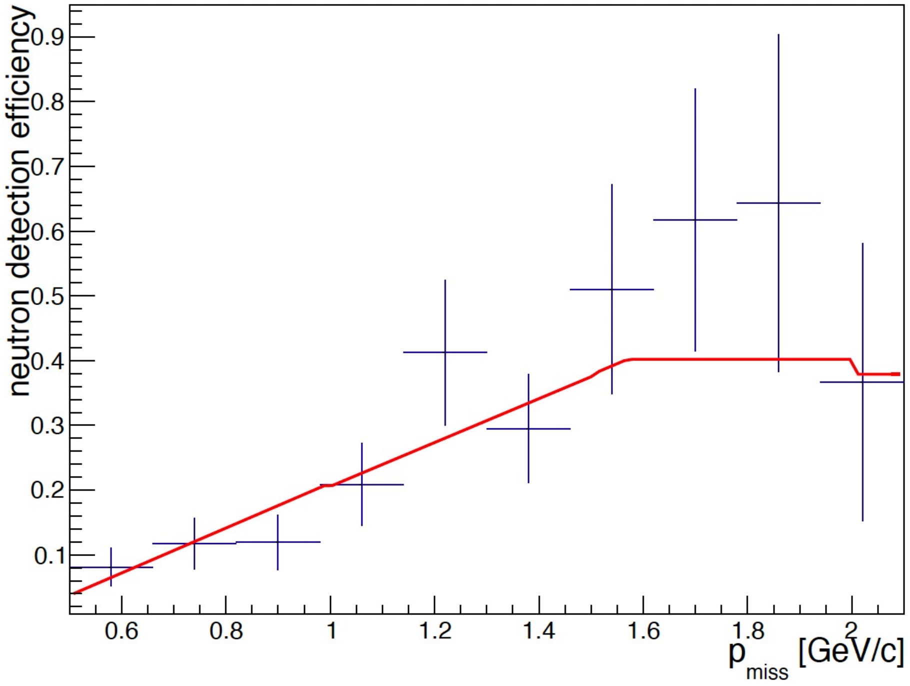
$\frac{\Delta p}{p}$ for momentum intervals from 0.5 – 1.9 GeV/c



Neutron Detection Efficiency

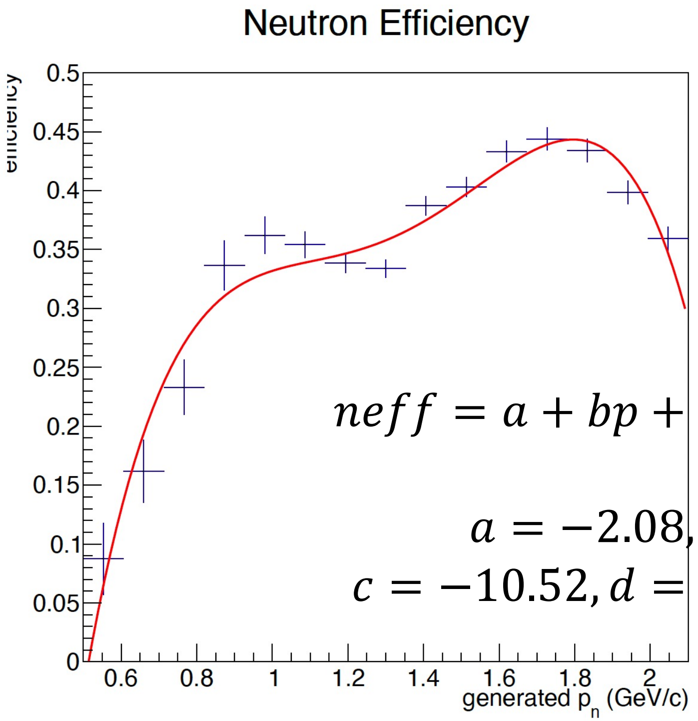
e2a

- *^{3}He(e,e'ppn)*
- Consistent with Meytal's measurements



GEANT Simulation

- Comparing generated to reconstructed neutrons
- Higher than expected



$$neff = a + bp + cp^2 + dp^3 + ep^4$$

$$a = -2.08, b = 8.26,$$
$$c = -10.52, d = 5.77, e = -1.13$$

Still to do

- Finalize contribution of neutron and proton efficiency/acceptance
- Find contribution of fundamental cross section uncertainty
- Find systematic uncertainty due to smearing function (using Fast MC and/or GEANT simulation)

Thank You!

Questions?