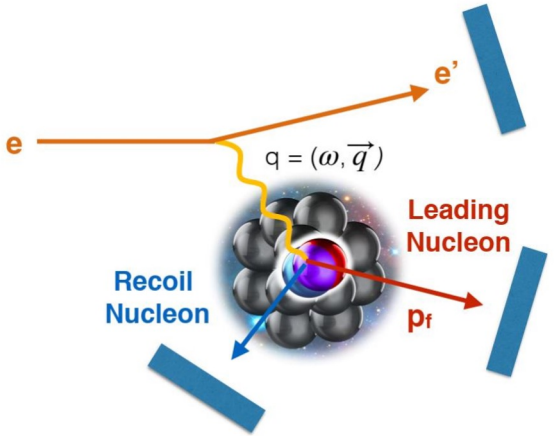
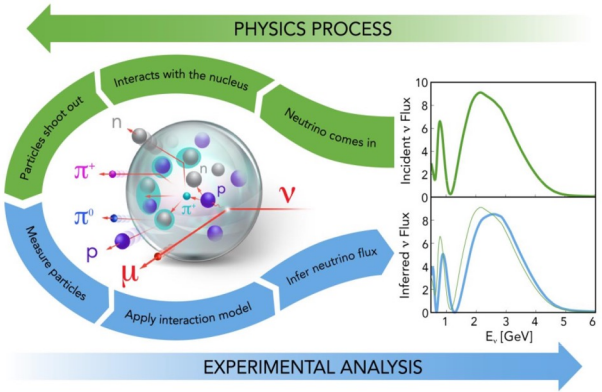
RG-M Analysis Update

Andrew Denniston

Overview

- 1st Analysis Note
- SRC Analyses
  - CND Neutrons He(e,e'pn)
  - CND ML Algorithm
  - BAND Neutrons
  - Calcium Analysis
- e4v Analyses
  - LAr target
  - Inclusive Analysis
  - Kaon Analysis





RG-M Experiment at CLAS12

- November 2021 – February 2022
- 2, 4, and 6 Gev Beam Energies
- H, D, He, C, 40Ca, 48Ca, Ar, and Sn
- Fully cooked pass 1 production runs
- Future cooking after CVT improvements

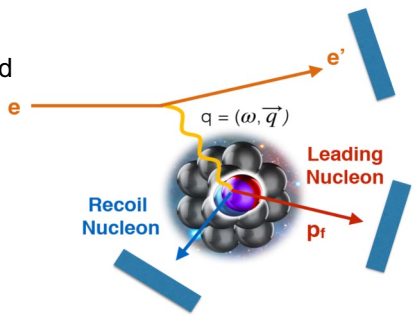
Analysis Note

RG-M Analysis Note: 6 GeV electron proton selection and Particle ID

Andrew Denniston[1], Justin Estee[1], Julian Kahlbow[1], and Erin Marshall Seroka[2]

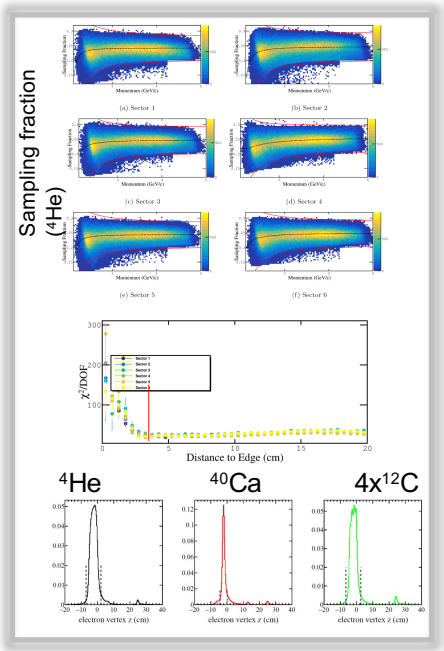
[1]Department of Physics, Massachusetts Institute of Technology
[2]Department of Physics, The George Washington University

→ “General“ Analysis Note has been resubmitted

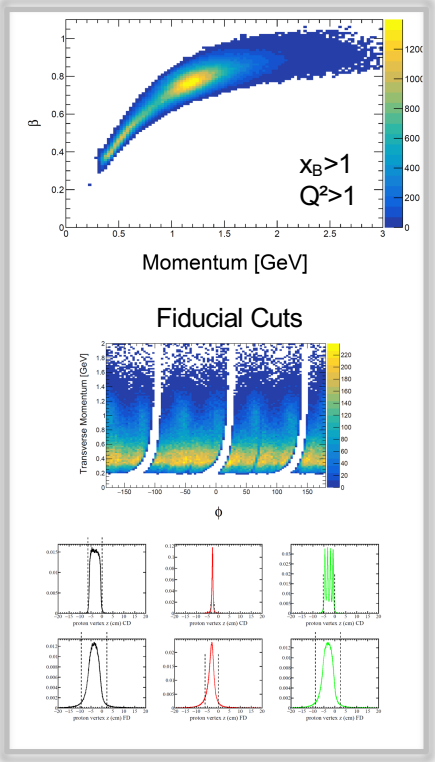


Cuts and Corrections for Electrons and Protons

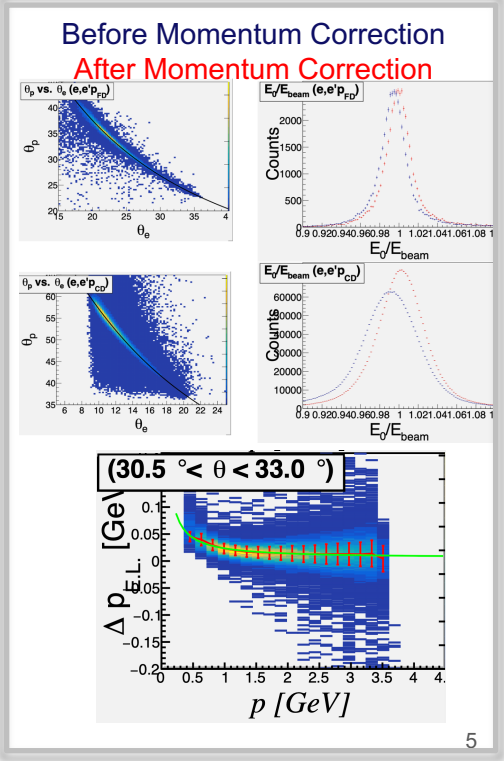
Electron Cuts



Proton Cuts



Corrections



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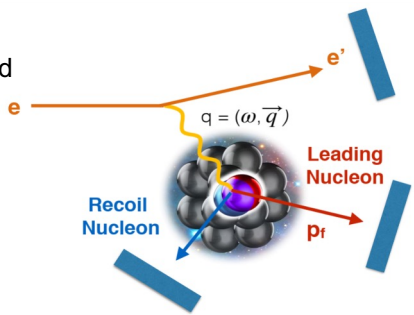
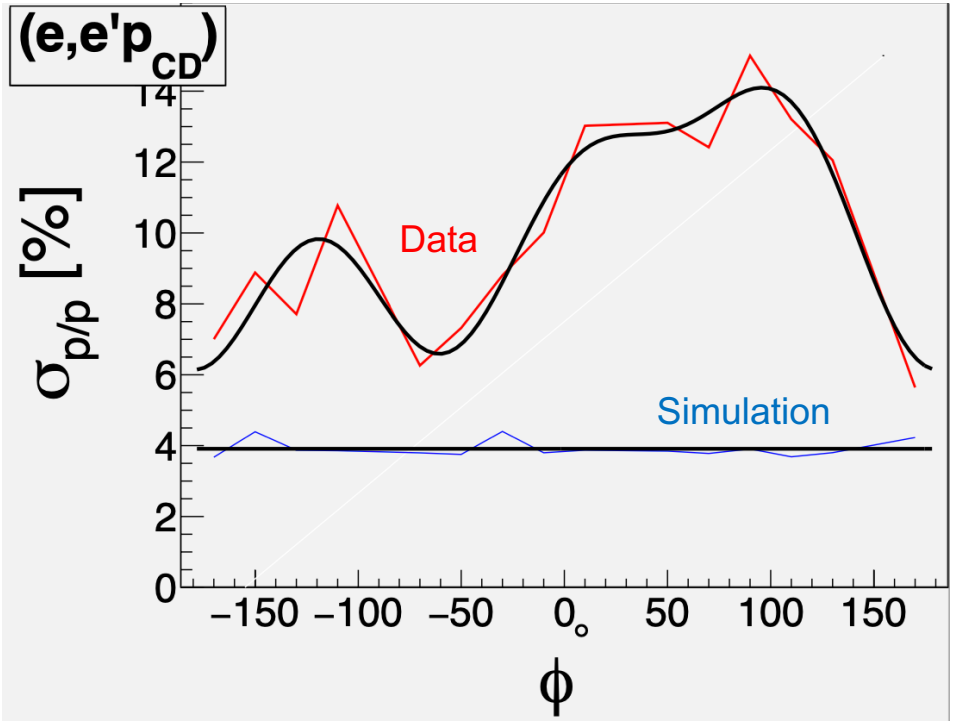


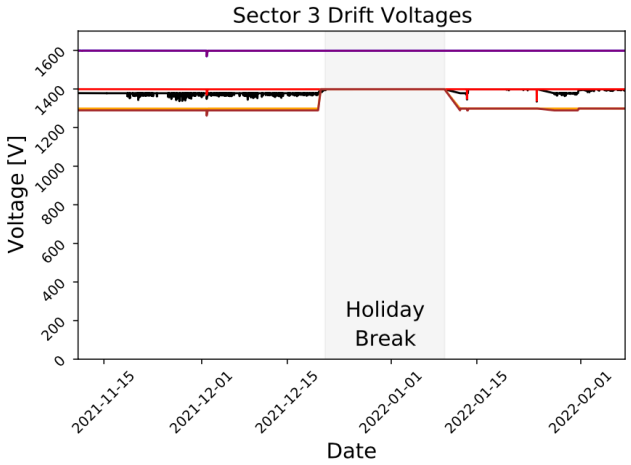
Central Detector Momentum Resolution

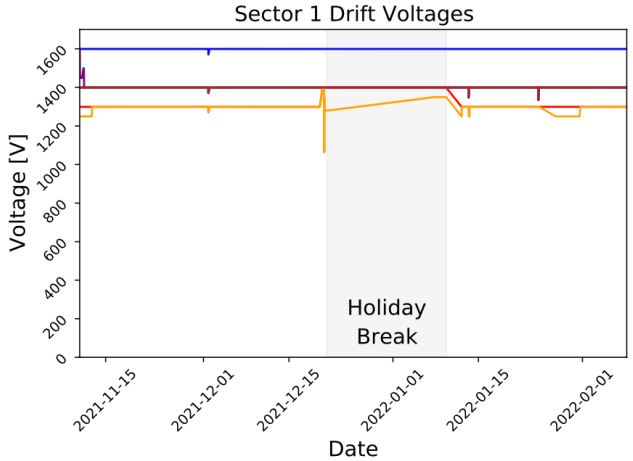
Andrew Denniston

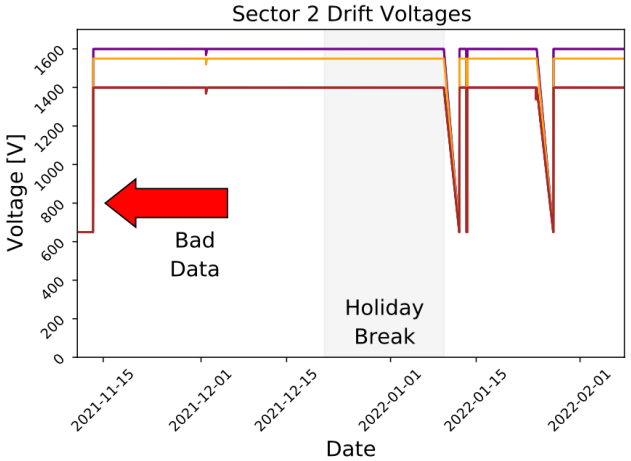


Strip Chart Archive

- Look over the RGM run in 15-minute intervals.
- Cut out events with livetime<90%.
- Look at Drift Voltage of BMT Sectors and Layers.







Comparing to Proton Resolution from LD2 Target

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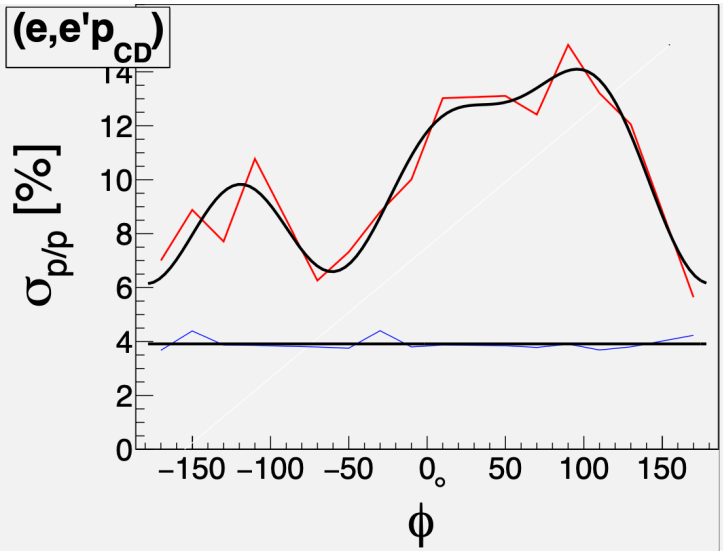
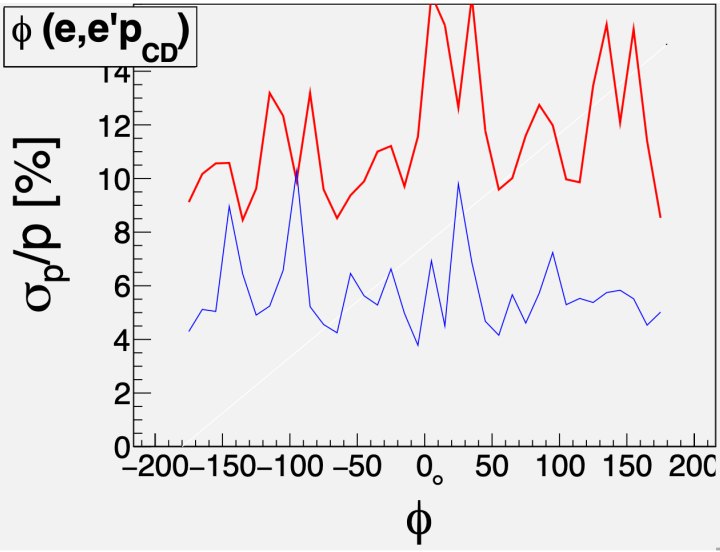
Hydrogen Target



Resolution calculated from electron angles

Deuterium Target



Resolution calculated from neutron missing mass

Our 6 GeV Hydrogen Data is Used for

Andrew Denniston

- NOT important for physics results (SRC/e4v)
- Angular Corrections
- Momentum Corrections and Resolution

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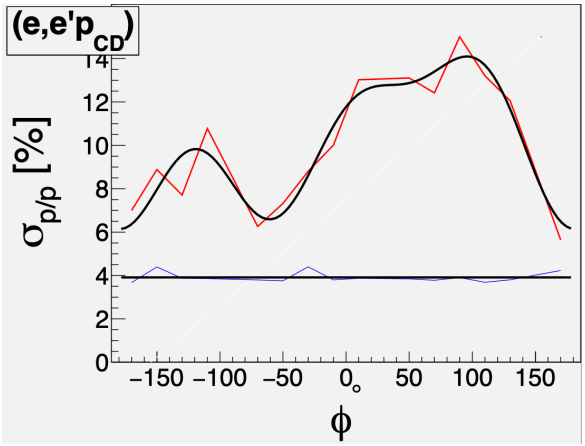

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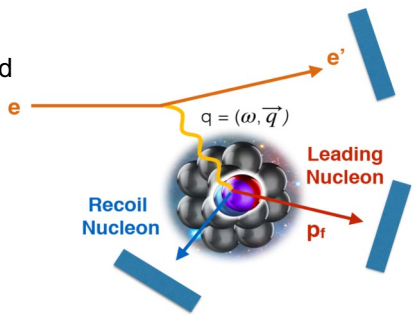

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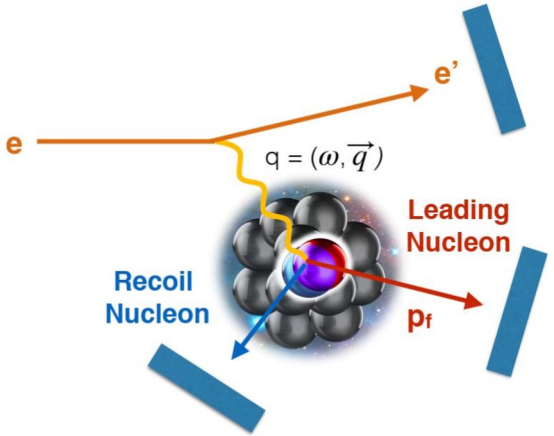
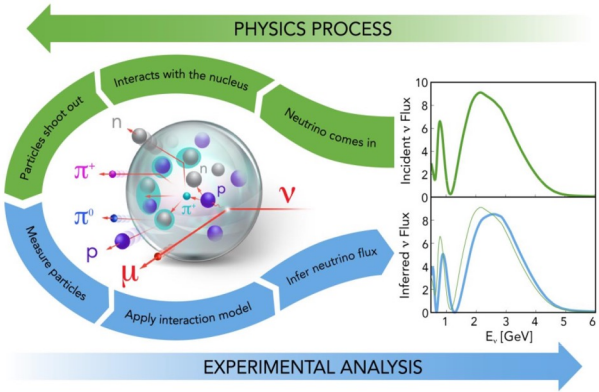
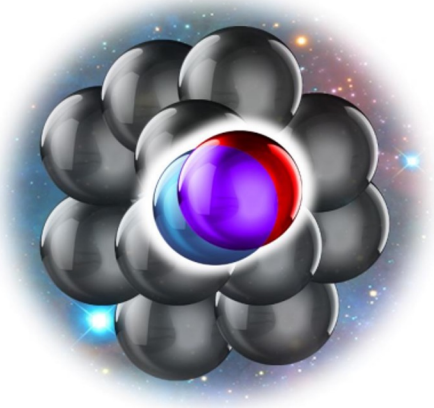




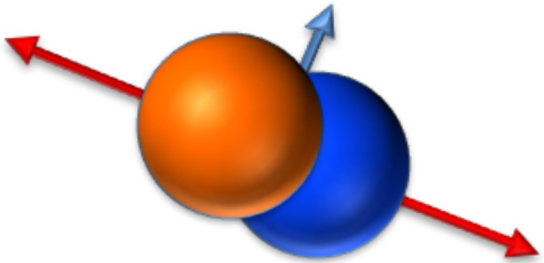
Short range, short lived,
highly correlated pairs



r-space

High relative momentum

Lower center of mass momentum



k-space

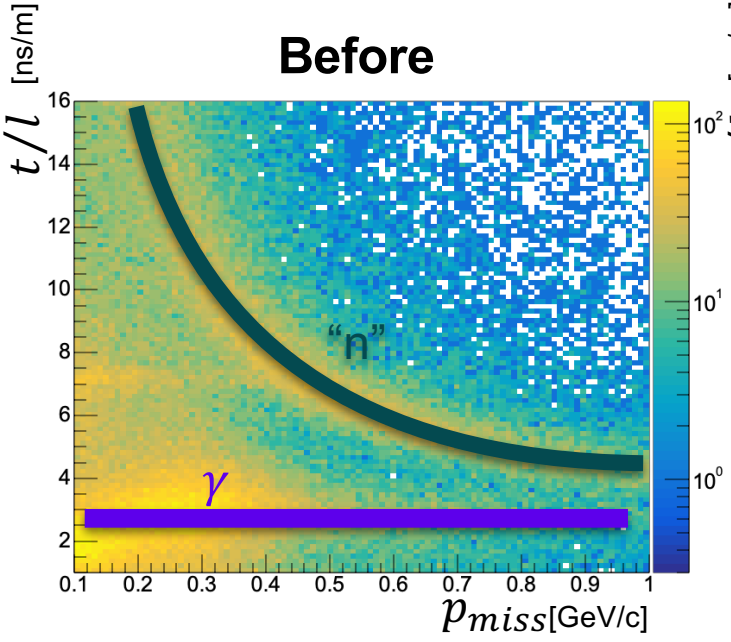
Neutrons

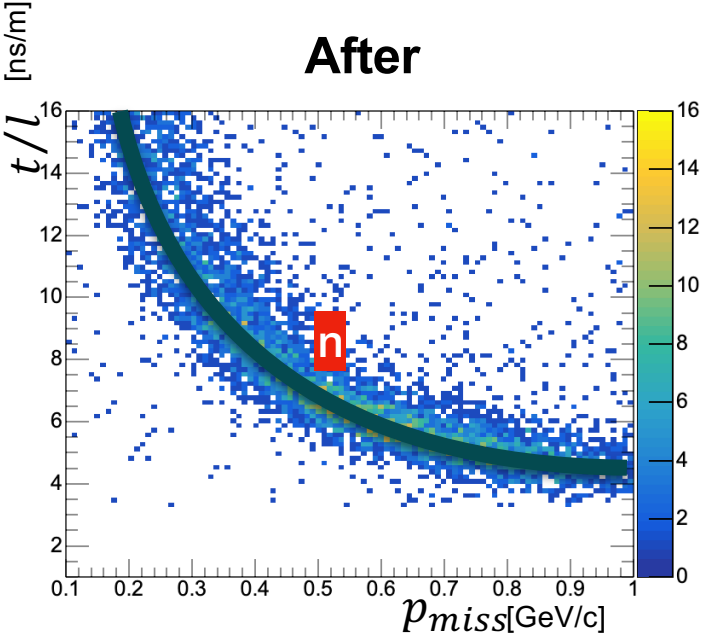
- ECAL Neutrons
- CND Neutrons
- BAND Neutrons

Igor Parshkin

Neutron Algorithm

Time per meter vs Missing momentum

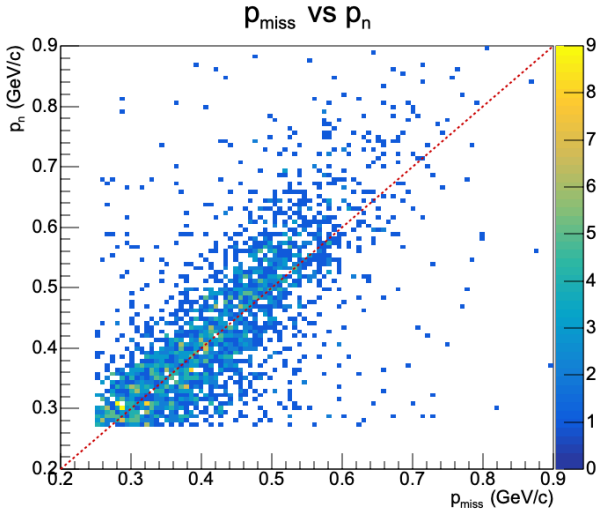




Algorithm Results

Igor Parshkin

Missing vs Neutron momentum

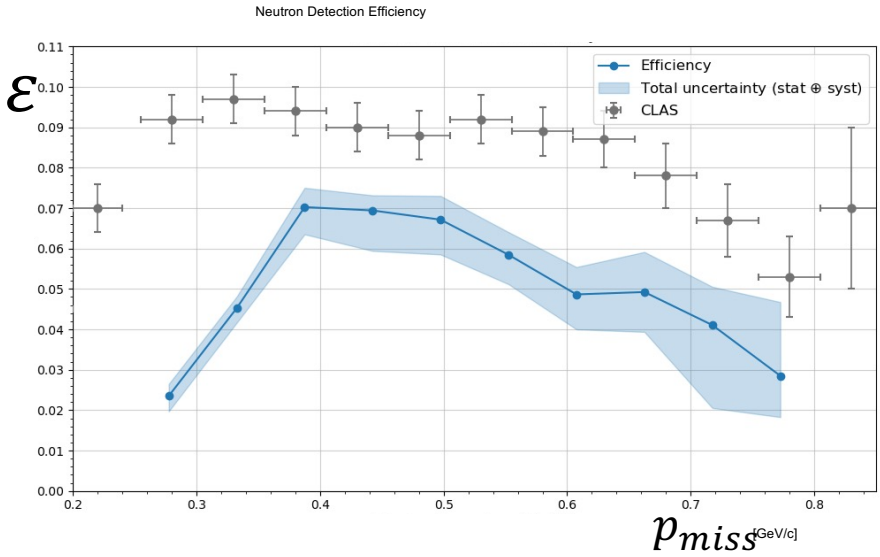


Algorithm Results

Igor Parshkin

Efficiency

$$\varepsilon = \frac{N_{\text{det}}}{N_{\text{prod}}} = \frac{N_{e'pn}}{N_{e'p}}$$



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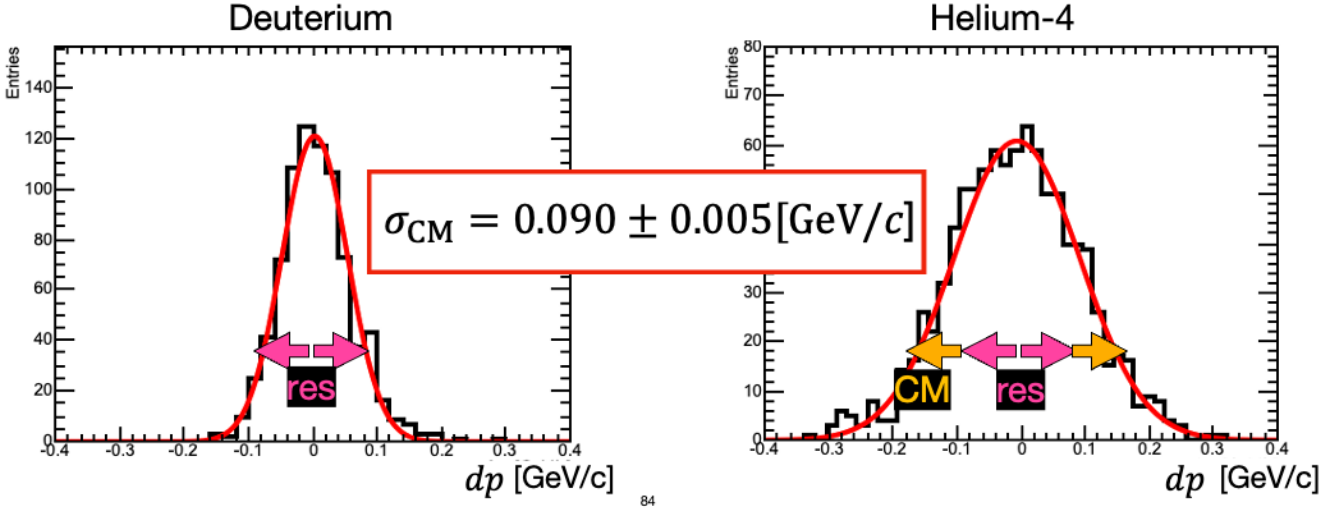
Helium-4 Center of Mass Motion

$$\sigma_{CM}^2 = \sigma_{\mathrm{He}}^2 - \sigma_{\mathrm{D}}^2$$



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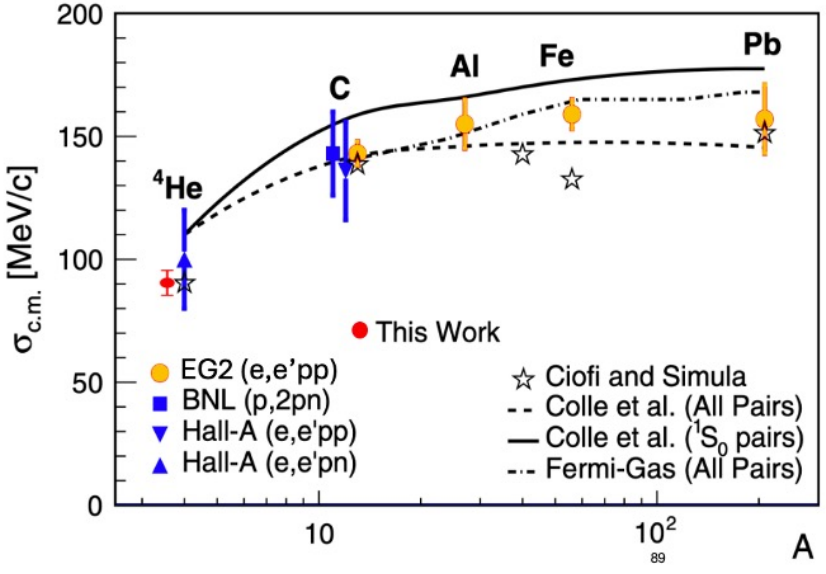
Helium-4 Center of Mass Motion

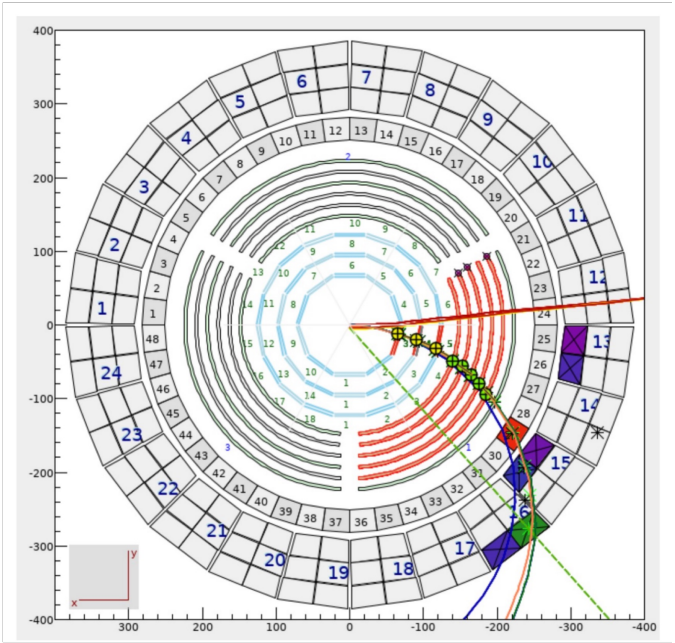


$$\sigma_{\mathrm{CM}} = 0.100 \pm 0.020 \mathrm{GeV}/c$$

$$\sigma_{\mathrm{CM}} = 0.090 \pm 0.005 \mathrm{GeV}/c$$

E.O. Cohen, O. Hen, E. Piasetzky, et al. "Center-of-Mass Motion of Short-Range Correlated Nucleon Pairs studied via the A(e, e ′ pp) Reaction". In: Physical Review Letters 121.9 (2018), p. 092501.

Improving CND Neutron Algorithm with ML



Natalie Wright

Data-driven train/test samples

Samples span a range of beam energies and interaction processes:

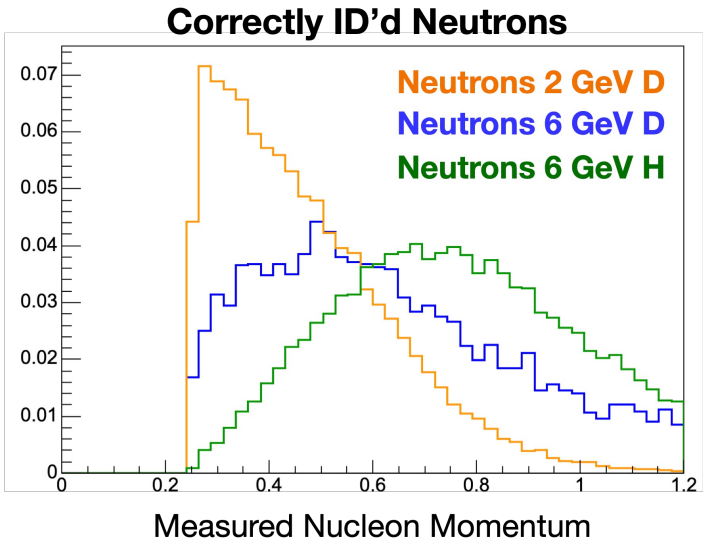
Signal: Correctly ID'd neutrons

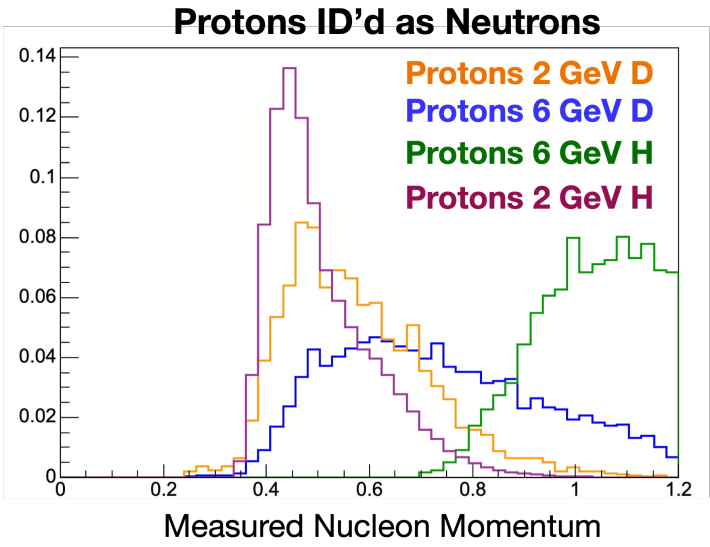
$D(e, e'pn)$	2 GeV
$D(e, e'pn)$	6 GeV
$H(e, e'\pi^+ n)$	6 GeV

Background: Protons ID'd as neutrons

$D(e, e'p\pi^- n)$	2 GeV
$D(e, e'p\pi^- n)$	6 GeV
$H(e, e'n)$	2 GeV
$H(e, e'n)$	6 GeV

Each sample has different kinematics





LD2 6 GeV:

Similar p, n kinematics

Momenta most similar to SRC recoil

→ Use for training, validate with other reactions

Natalie Wright

General variables to construct features:

Primary hit energies E_{CND}, E_{CTOF}

Within N steps:

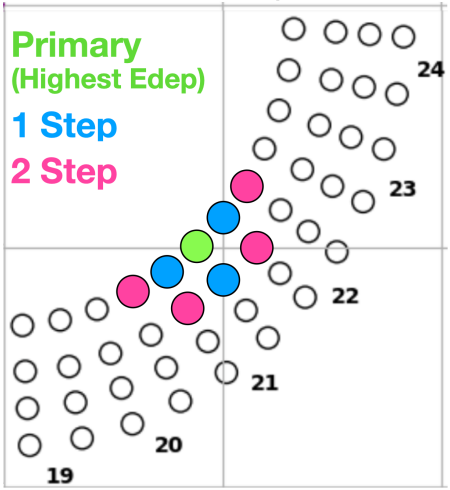
$\sum$ Hit energy

Hit multiplicity

$< |\vec{r} - \vec{r}_{prim.}| >$

$<$ Hit energy / layer $>$

Scintillator Components



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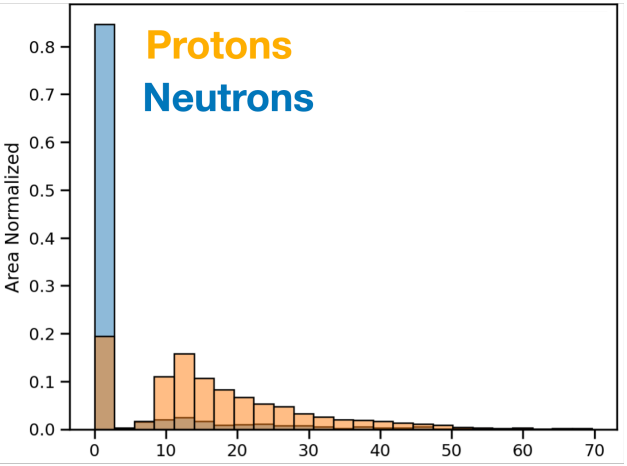
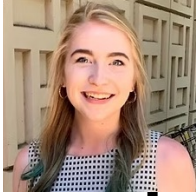
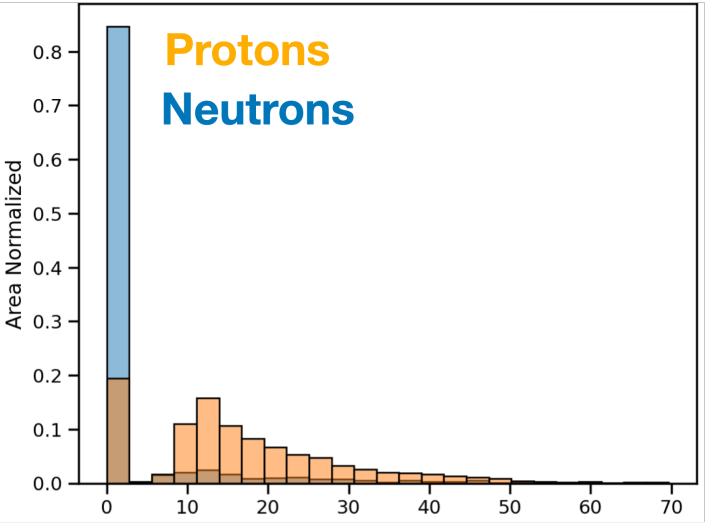
CTOF Veto is ~80% Successful



Total CTOF Edep in 3 Steps



But additional features help with edge cases!



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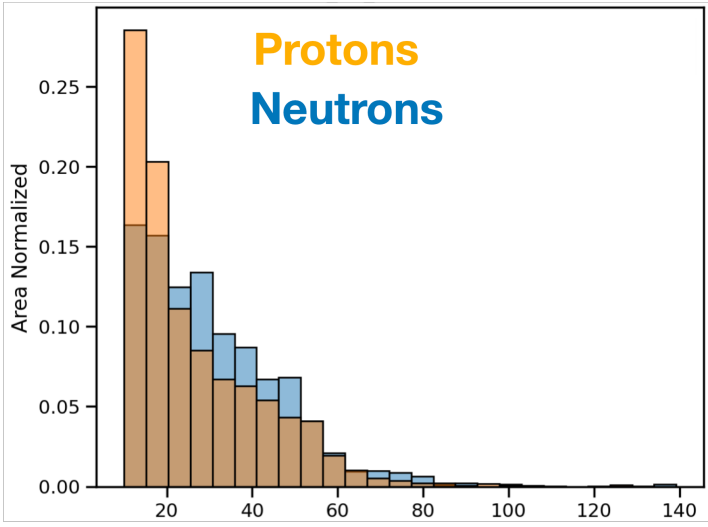

Primary CND Hit Energy

Model Performance on Exclusive Samples

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Exclusive Channel	Neutron Recall
6 GeV $D(e,e'pn)$*	0.872
2 GeV $D(e,e'pn)$	0.826
6 GeV $H(e,e'\pi^+n)$	0.926

Exclusive Channel	Proton Recall
6 GeV $D(e,e'p\pi^-n)$*	0.897
2 GeV $D(e,e'p\pi^-n)$	0.923
6 GeV $H(e,e'n)$	0.895
2 GeV $H(e,e'n)$	0.926

**held out from training sample*

Natalie Wright

Validation with New Helium-4 Data

SRC Analysis:

$x_B > 1.2$

$Q^2 > 1.5$ GeV^2/c^2

$p_{Lead} > 1.$ GeV/c

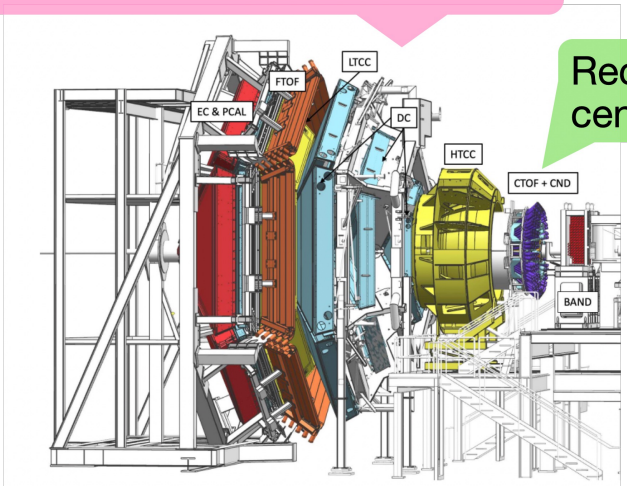
$.65 < m_{Miss} < 1.1$

$.3 < k_{Miss} < 1.$

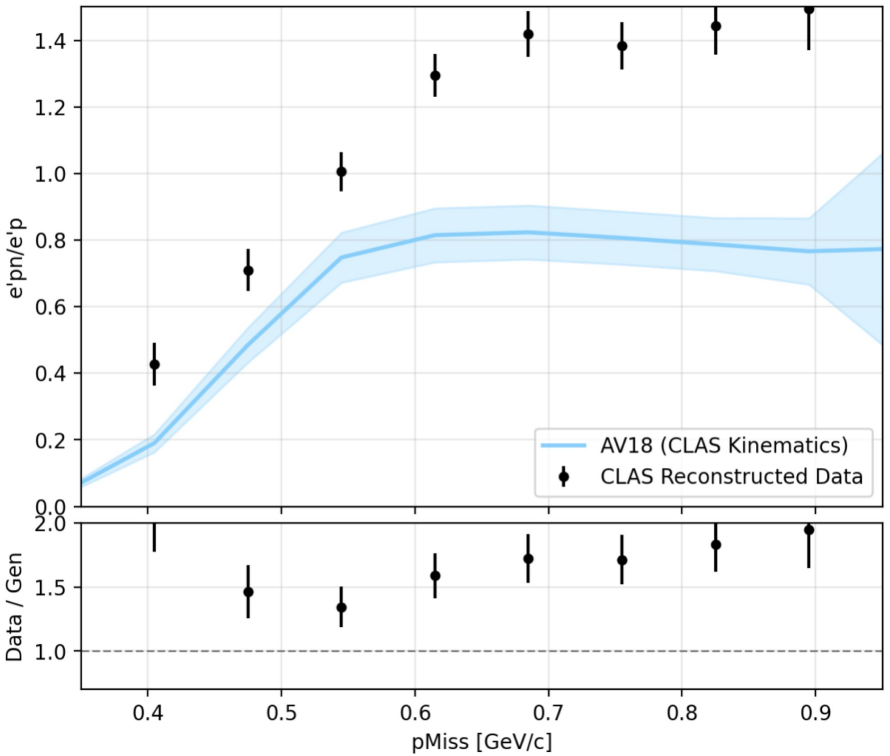
$$k^2_{miss} \equiv m^2_N \left(\frac{p^2_{miss,\perp} + m^2_N}{p^-_{miss}(2m_N - p^-_{miss})} \right) - m^2_N$$

Lead proton in forward detector

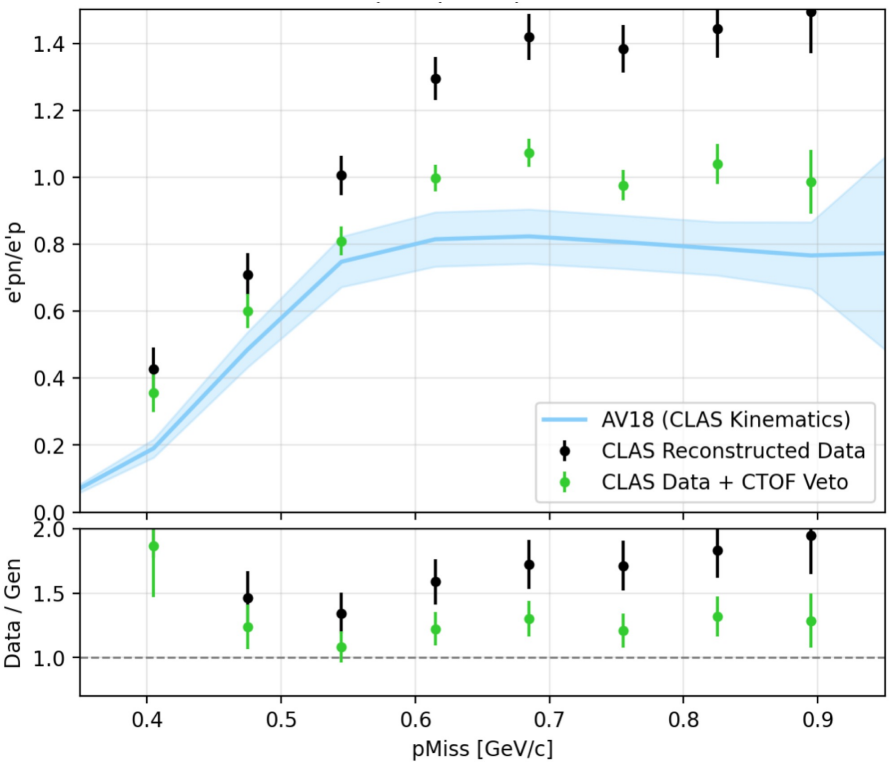
Recoil neutron in central detector



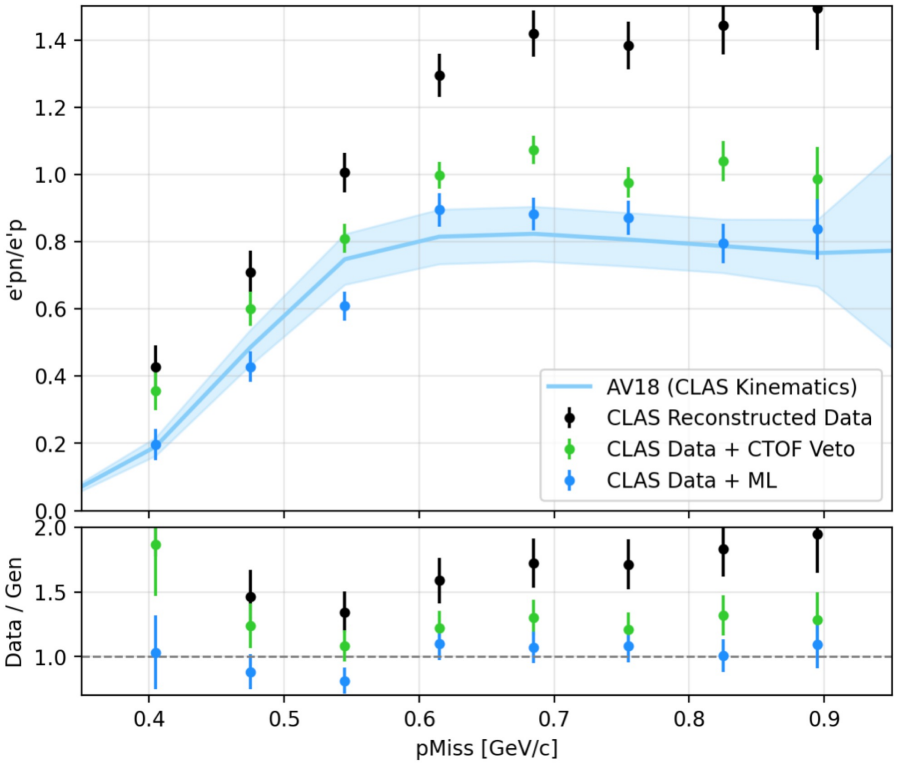
Out of the box PID overpredicts neutrons



Using CTOF veto helps



ML agrees with theory/previous measurements



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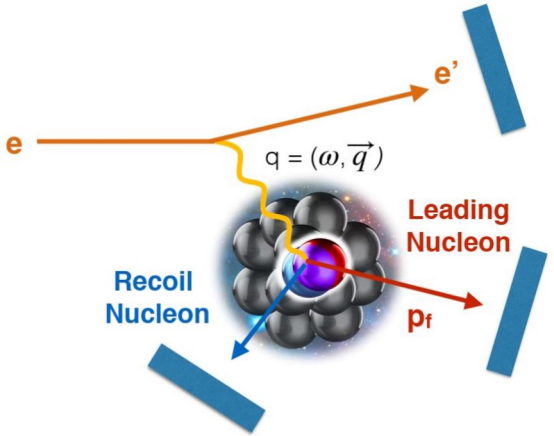
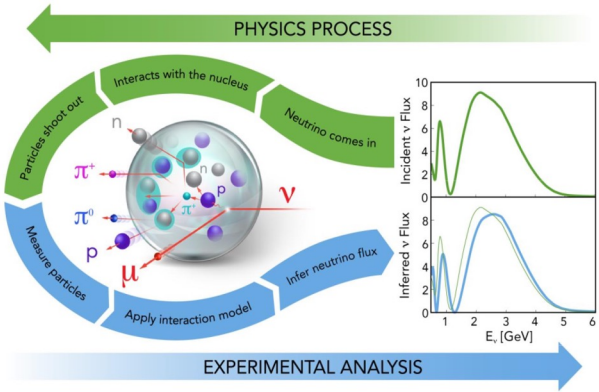
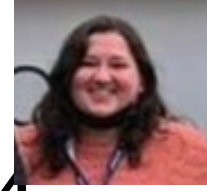


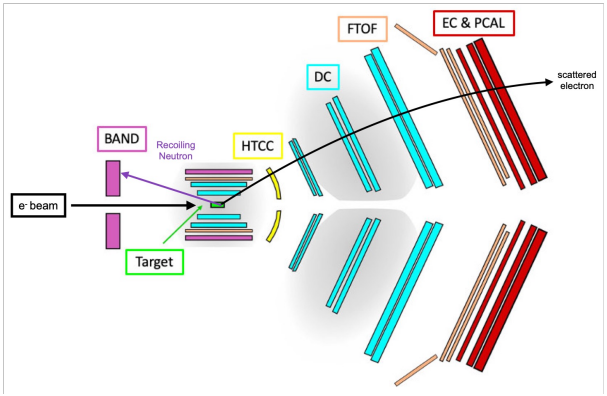


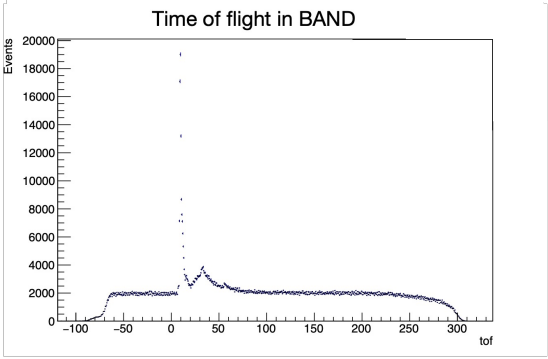


Recoil-Tagged DIS in He-4

Sara Ratliff

- 6 GeV He-4 data from RGM
- Neutrons in BAND
- Detect recoiling neutron to determine correlation status between struck and detected nucleons





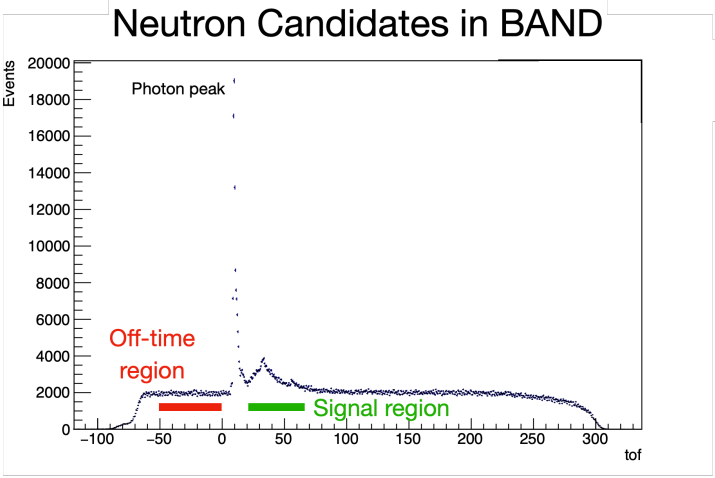
Recoil-Tagged DIS in He-4

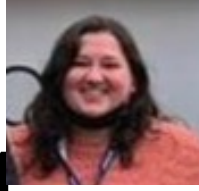
Sara Ratliff

Random-Coincidence Background Subtraction

“Event-mixed background”:

Using off-time neutrons shifted into the signal region to create artificial random-coincidence background



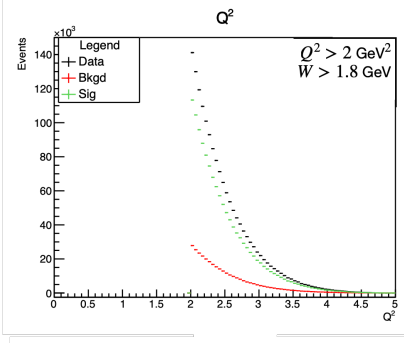


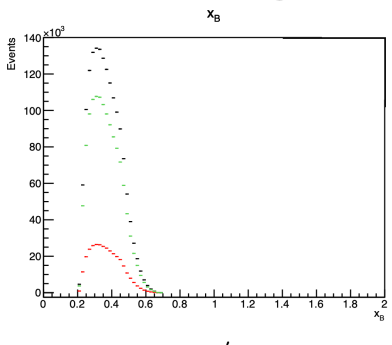
Recoil-Tagged DIS in He-4

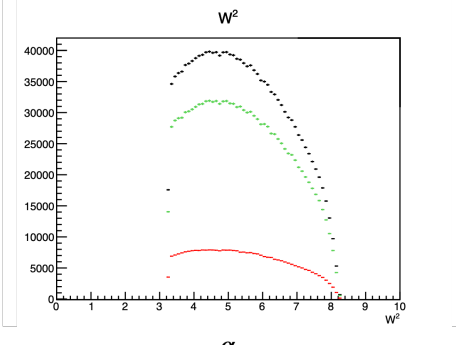
Sara Ratliff

Random-Coincidence Background Subtraction

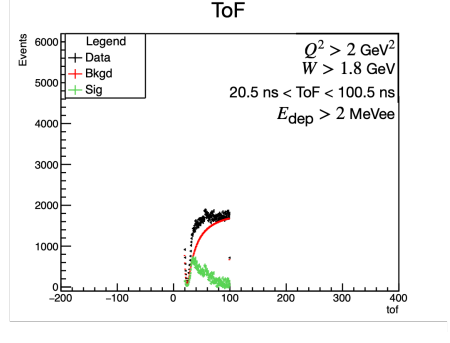
$He^4(e, e')$

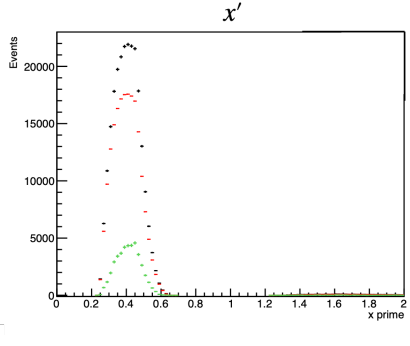


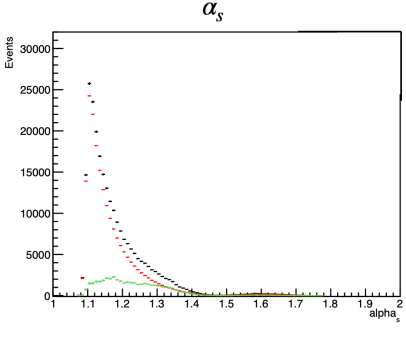




$He^4(e, e'n_{BAND})$





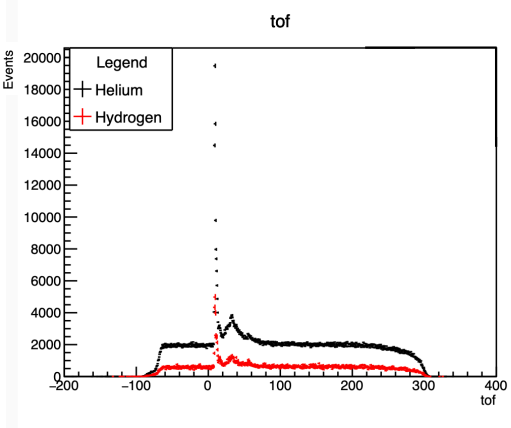


Sara Ratliff

Recoil-Tagged DIS in He-4

On-Time Background Subtraction

- On-time background discovered in BAND in Hydrogen data
  - Unexpected “neutron” peak in H data
- Scaled hydrogen 6 GeV data to helium-4 by accumulated charge and proton density
- This scaling accounts for scattering from protons
  - Need additional scaling to account for background for scattering from a neutrons

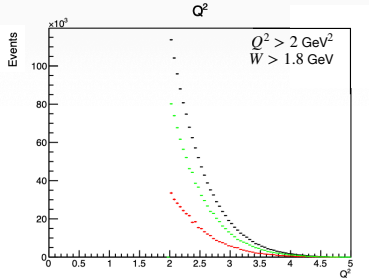


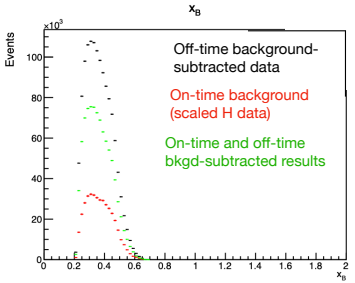
Sara Ratliff

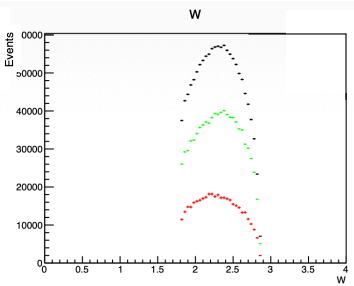
Recoil-Tagged DIS in He-4

On-Time Background Subtraction

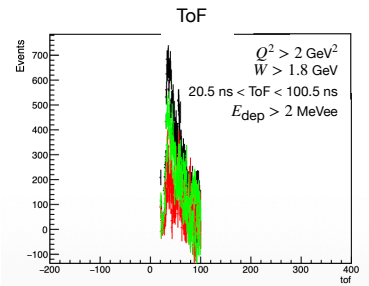
$He^4(e,e')$

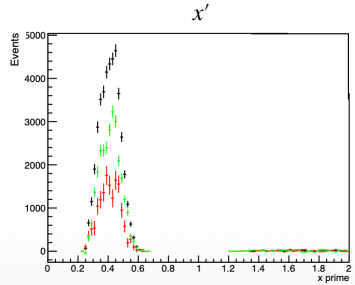


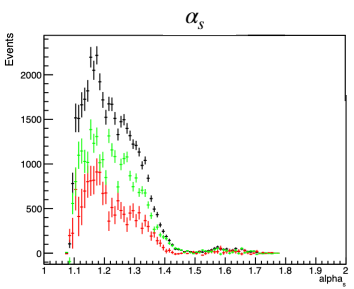




$He^4(e,e'n_{BAND})$







Recoil-Tagged DIS in He-4

Sara Ratliff

- On-time background likely from a secondary interaction with detector support structure
- Can account for additional background for scattering from a neutron using F_2^A / F_2^p
- With this additional on-time background, this channel within this data set is limited statistically

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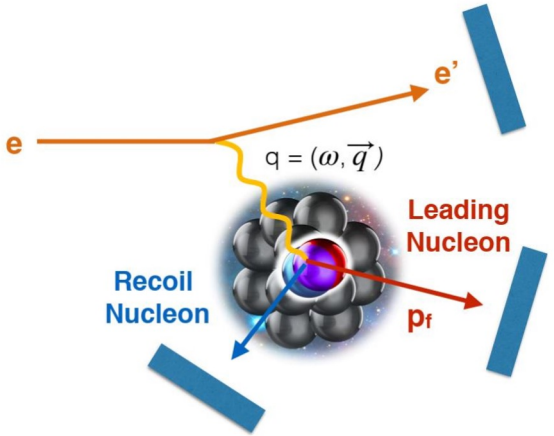
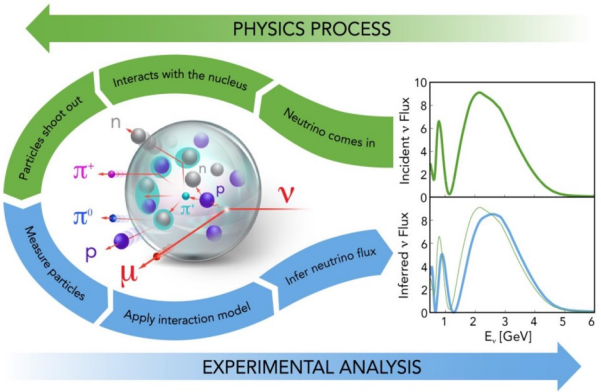
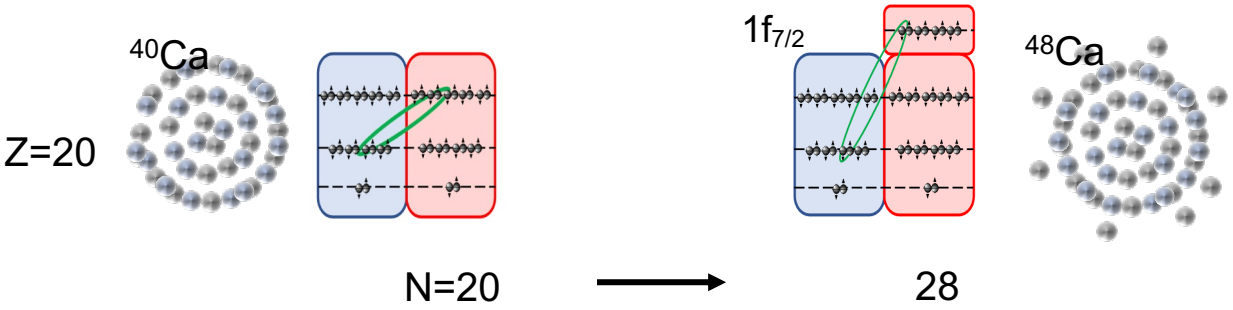
  - Inclusive Analysis
  - Kaon Analysis





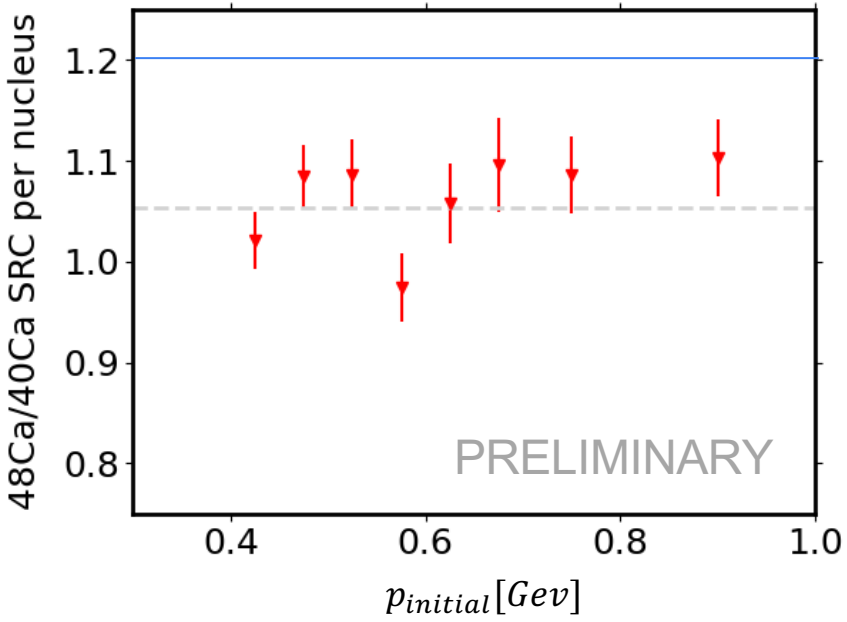
SRCs in Asymmetric Nuclei

Julian Kahlbow



SRCs in Asymmetric Nuclei

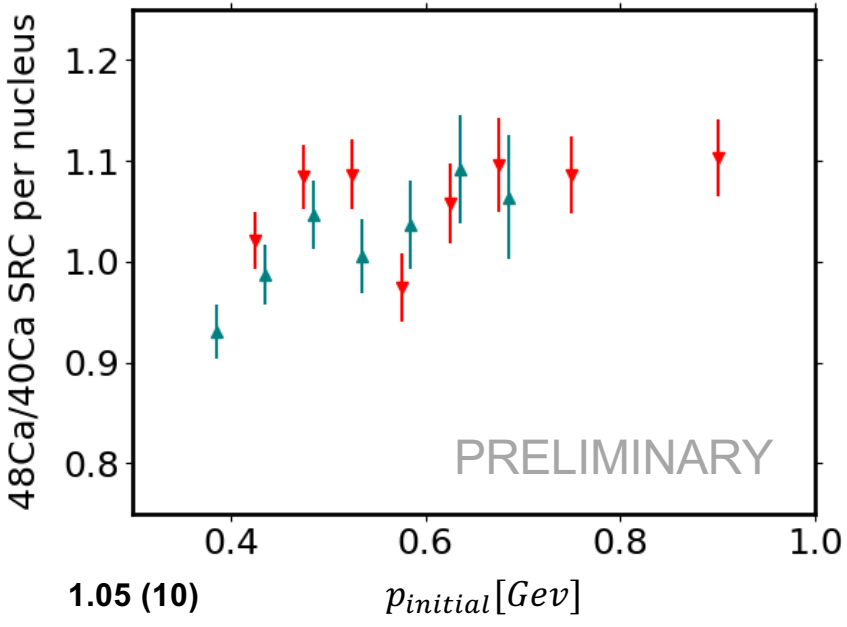
Julian Kahlbow



≠ ~1.2

SRCs in Asymmetric Nuclei

Julian Kahlbow



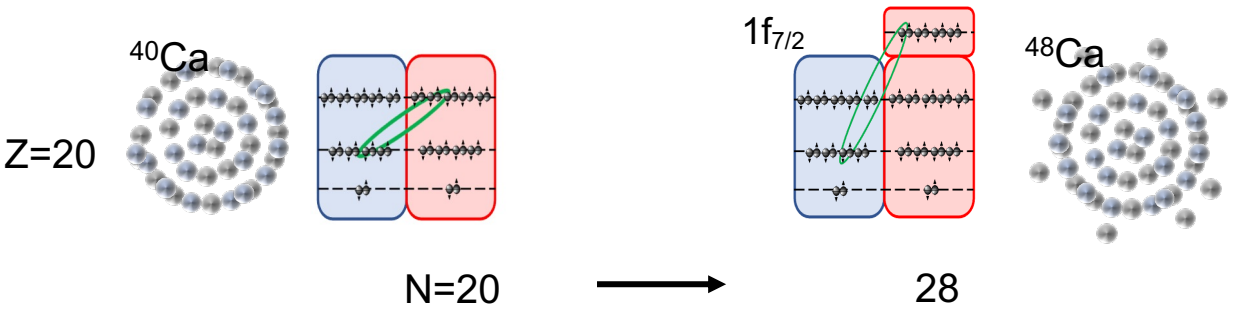
RG-M (Hall B) **1.05 (10)**

CaFe (Hall C) **1.02 (1)**

[Carlos Yero (ODU), Dien Nguyen (JLAB) et al.]

SRCs in Asymmetric Nuclei

Julian Kahlbow



48Ca/40Ca(e,e'p) = 1.05

Reduction in short-range pairing across shells! Long-range nuclear structure to impact SRC

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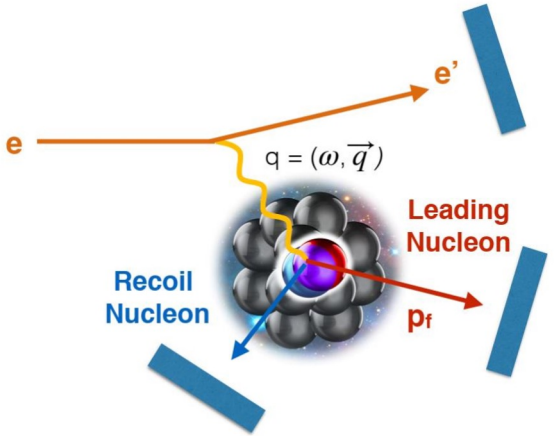
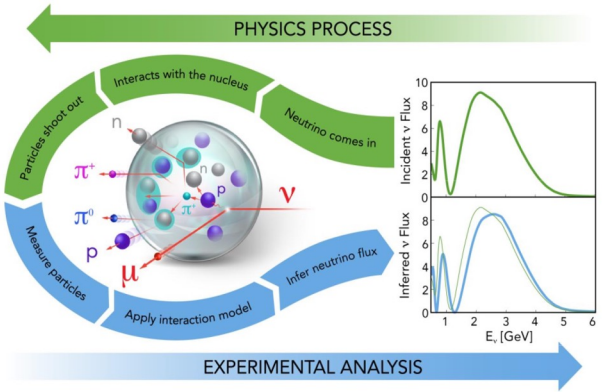
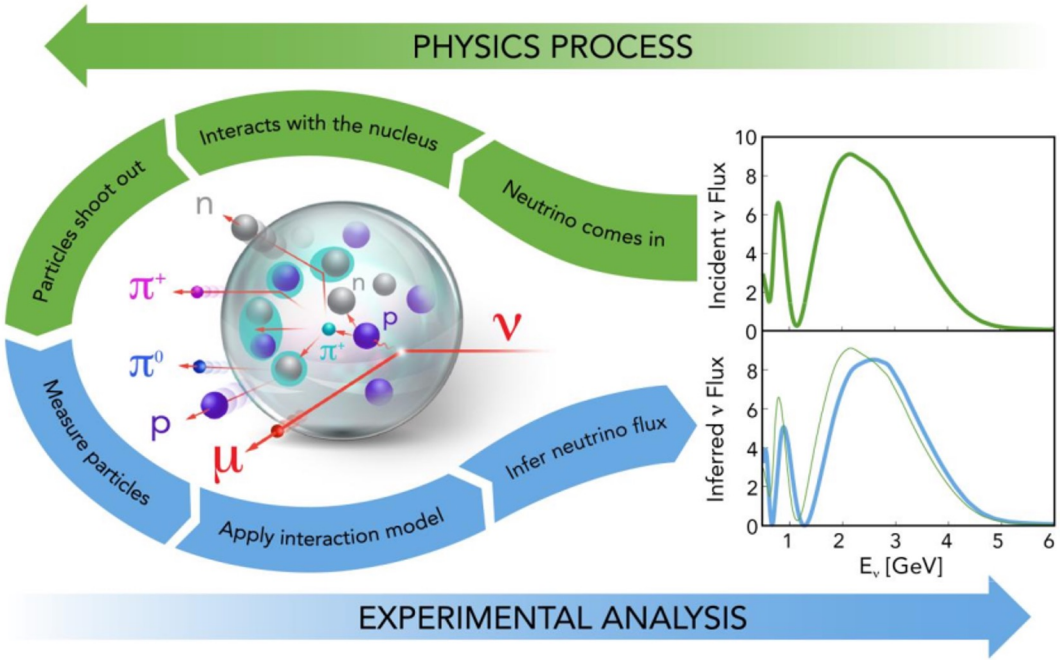
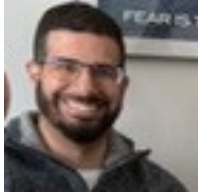




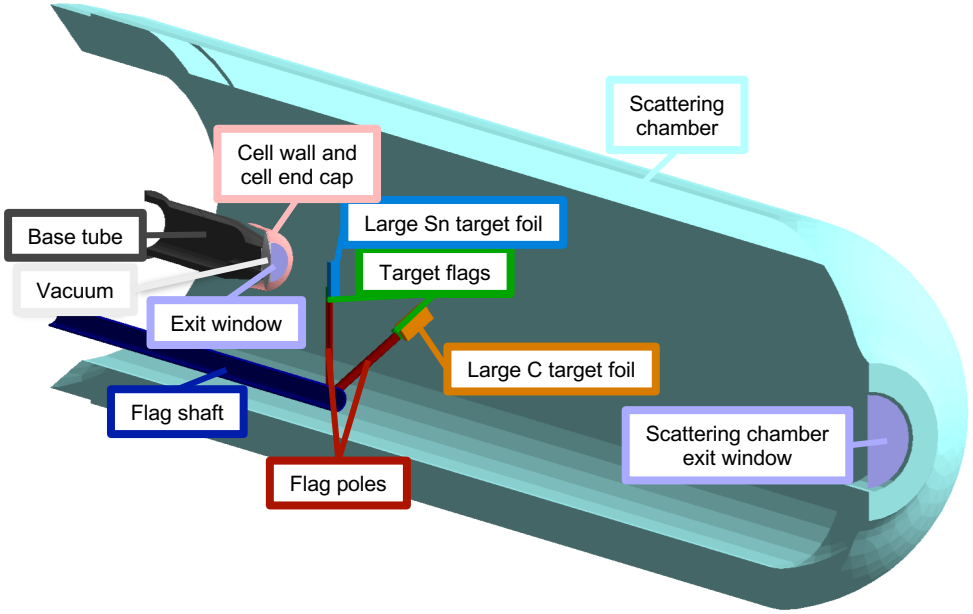
Electrons for Neutrinos



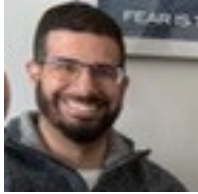
The rgm_fall2021_Sn_L variation



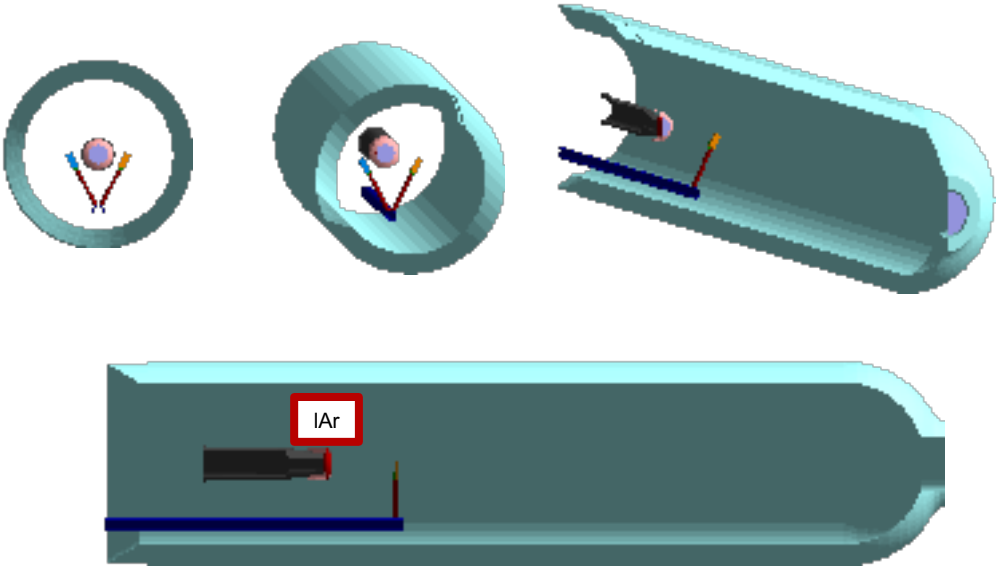
Alon Sportes



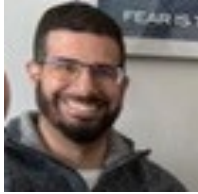
The rgm_fall2021_Ar variation



Alon
Sportes

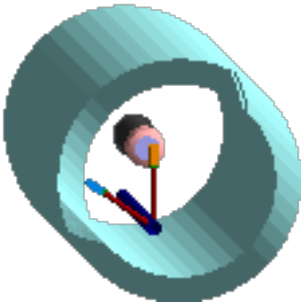


The new RGM variations



Alon
Sportes

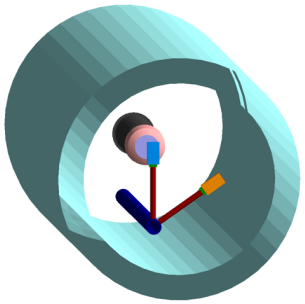
`rgm_fall2021_C_S`



`rgm_fall2021_C_L`

`rgm_fall2021_Ar`

`rgm_fall2021_Sn_L`



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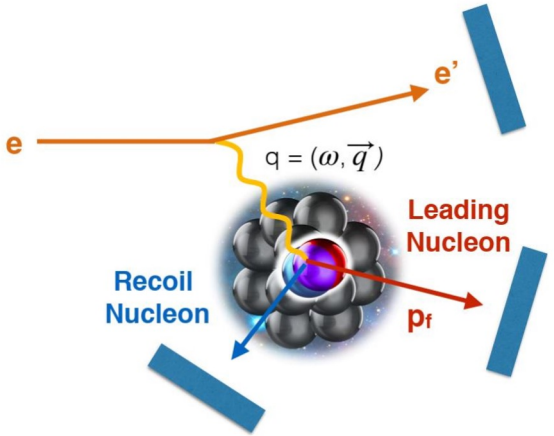
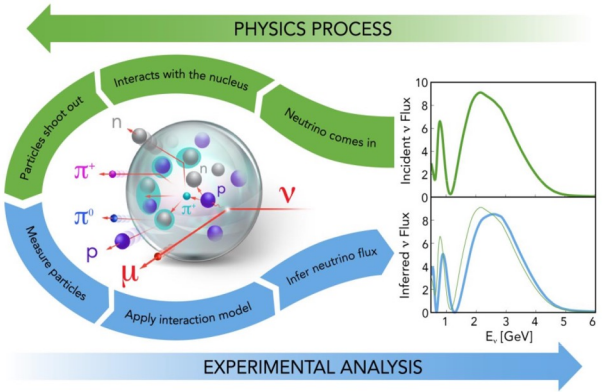




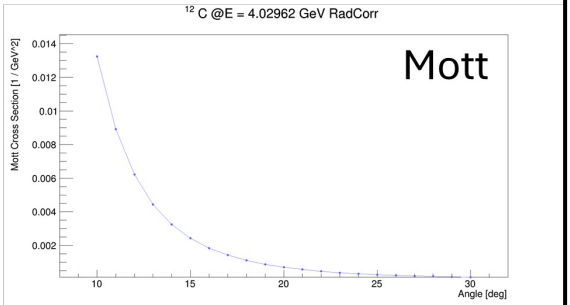
Matan
Goldenberg

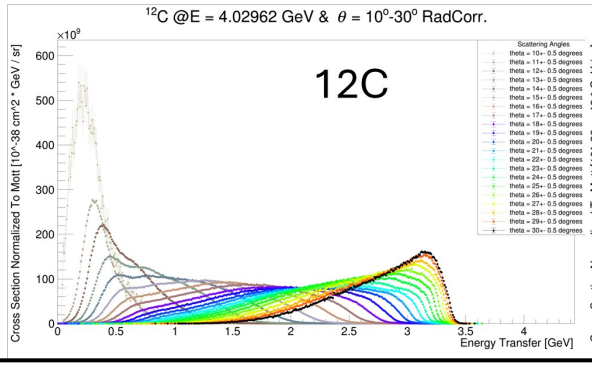
Inclusive Cross Sections

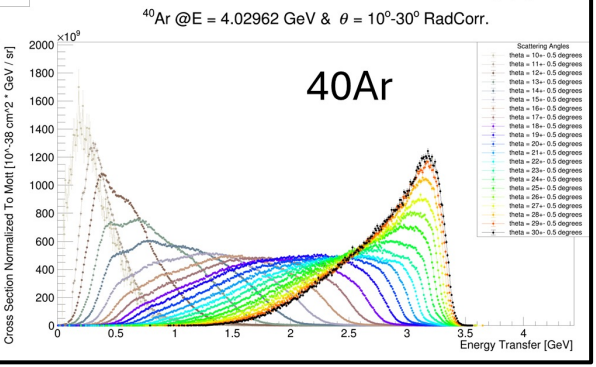
- electron-12C & electron-40Ar.
- For 2, 4 & 6 GeV beam energies
- At 10-30 degrees integer angles.

Resulting 4 GeV Preliminary Cross Sections

(Normalized to Mott [GeV^{-2}])







Normalization to Cross-Section – Current Status:

- Normalization to physical units (What is in an Unnormalized bin?)
- Performing momentum correction for the 2 GeV distributions (using Hydrogen data)
- Radiative corrections (on a bin-by-bin basis)
- Tracking Efficiency
- Accounting to the detector's acceptance (while avoiding Outlier Sectors)
- Backgrounds

Done in the past
Current work
To be done

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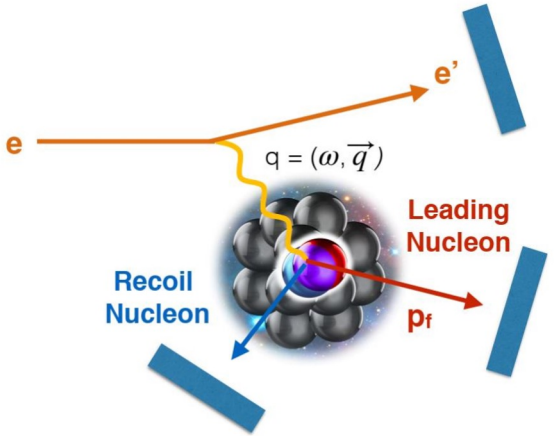
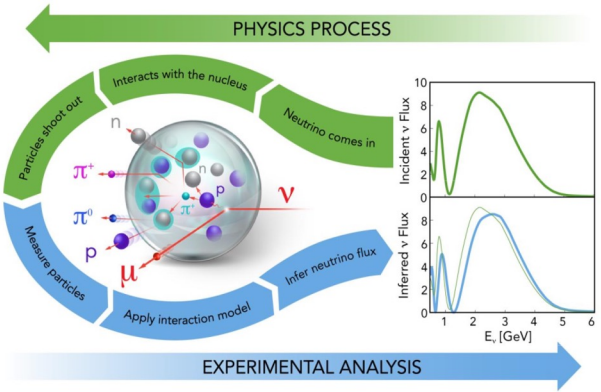
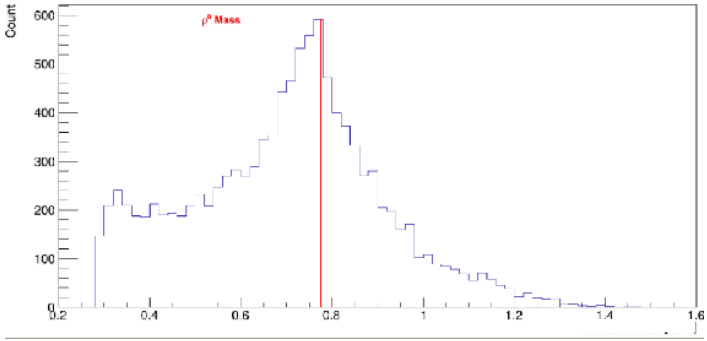


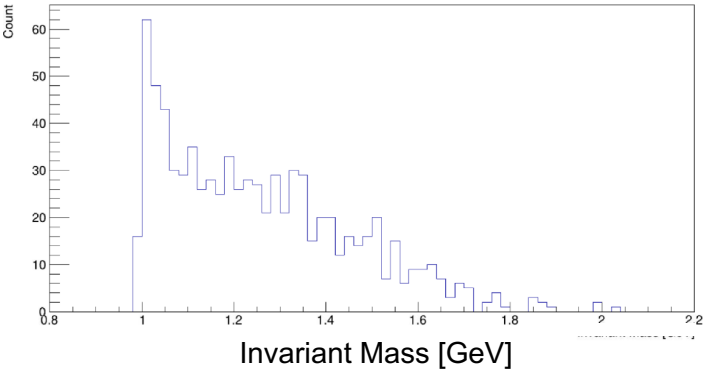


Jhanzeb Ahmed And Stuart Fegan

Pion and Kaon Analysis

- Mainly contributing to e4nu analysis via two main channels: $A(e, e'p\pi^+\pi^-)$ and $A(e, e'pK^+K^-)$.
- Complicated final states for e4nu, but very insightful for upcoming neutrino experiments such as DUNE.
- Focus on Argon and Carbon targets.
- Exploring other applications of these event samples, including meson-nuclear scattering length on ρ and ϕ.





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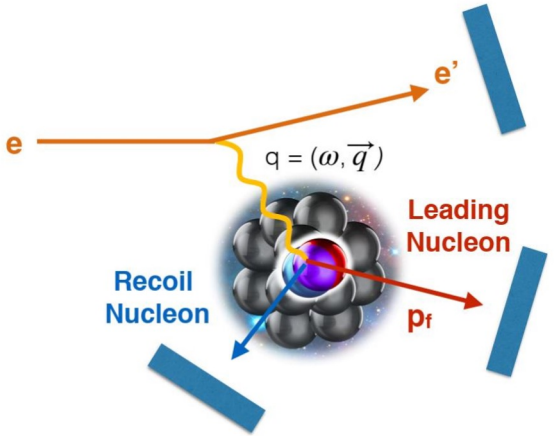
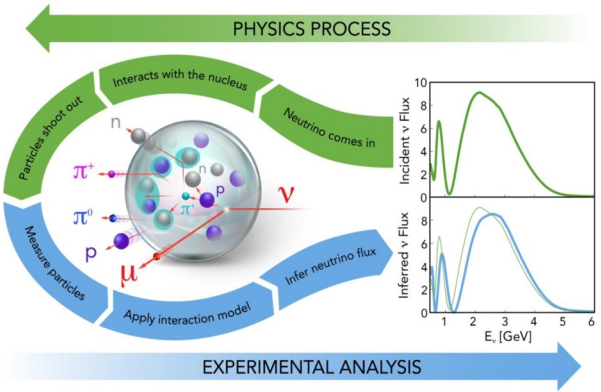
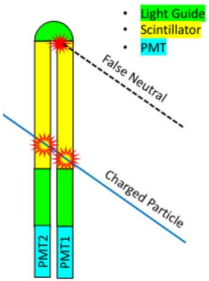


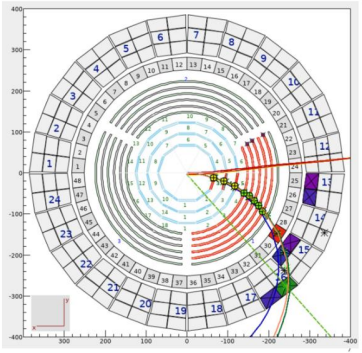


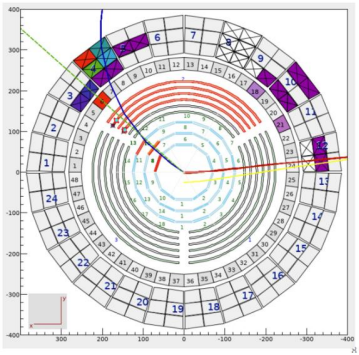
End

Particle ID for Neutrons in 6 GeV data

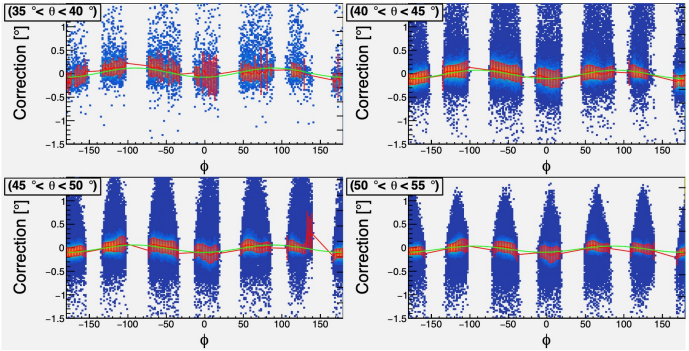
- Developed a general neutron veto for CND with Machine Learning.
- Define “features” to train model on training sample
- Evaluate performance using testing sample

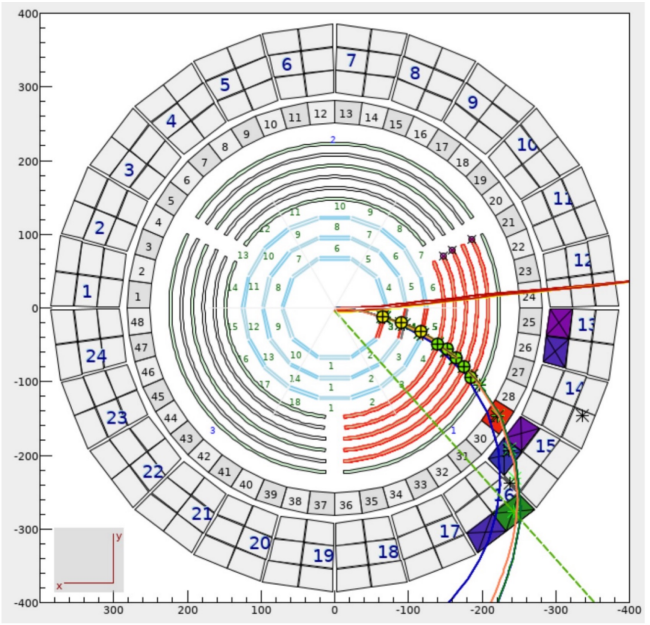




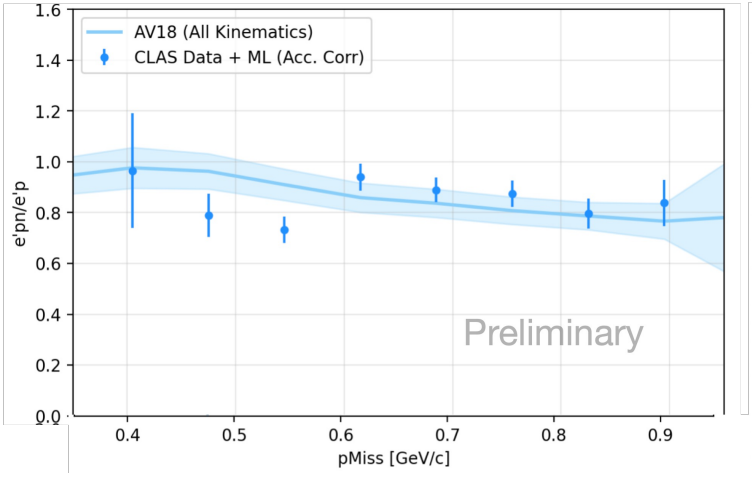


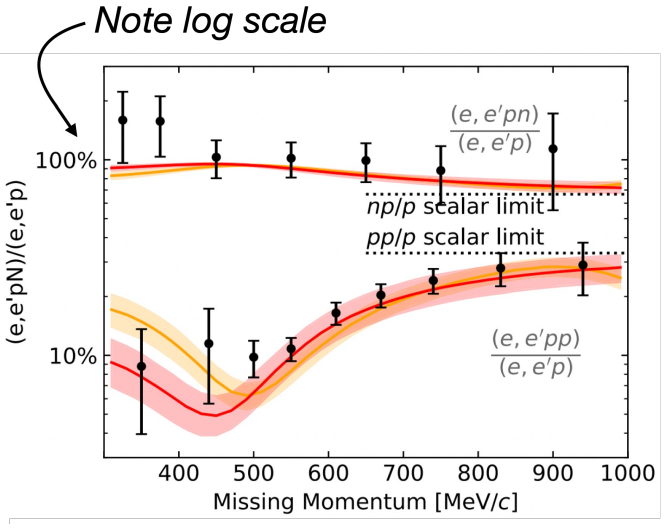
SVT dominates the θ resolution





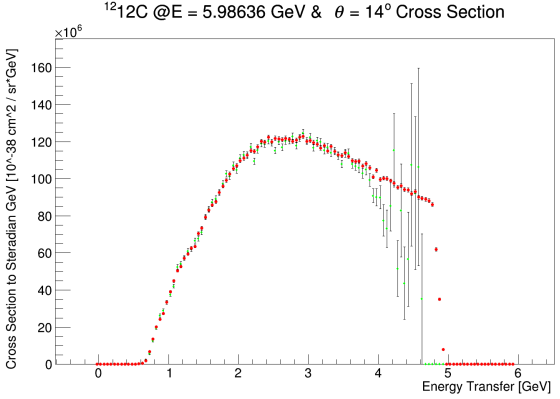
ML agrees with theory/previous measurements





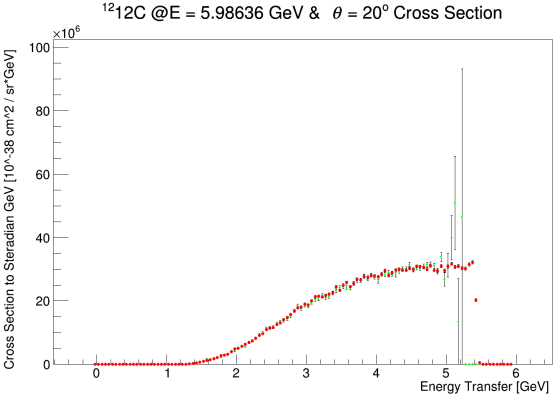
Accounting to the detector's acceptance

- Currently working on testing the correction methods.
- The tests are done using a uniform sample and a GENIE sample – they do not involve data.
- Results are good; however, some disagreements are seen at the inclusive distribution's edges. This disagreements are still under examination.



Green – The test result

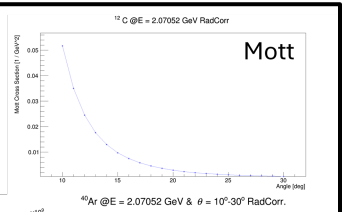
Red – True GENIE cross section

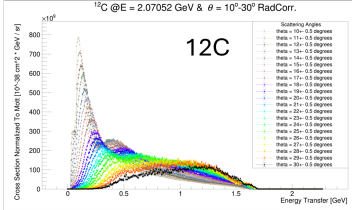


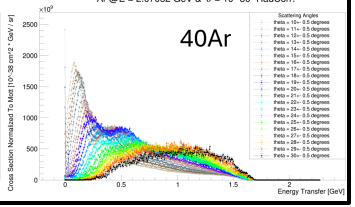
Inclusive Cross Sections

- electron-12C & electron-40Ar.
- For 2, 4 & 6 GeV beam energies
- At 10-30 degrees integer angles.

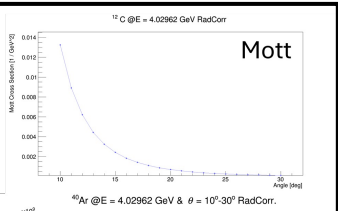
Resulting 2 GeV
Preliminary
Cross Sections
(Normalized to Mott [GeV^{-2}])

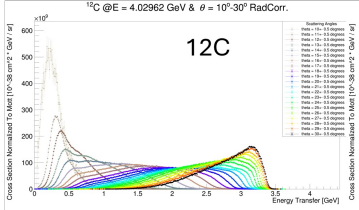


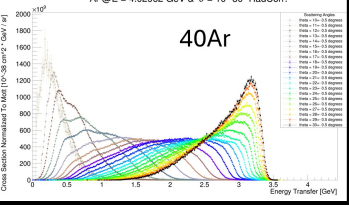




Resulting 4 GeV
Preliminary
Cross Sections
(Normalized to Mott [GeV^{-2}])







Data-driven train/test samples

Meas. Neutron Momentum

Predicted Momentum

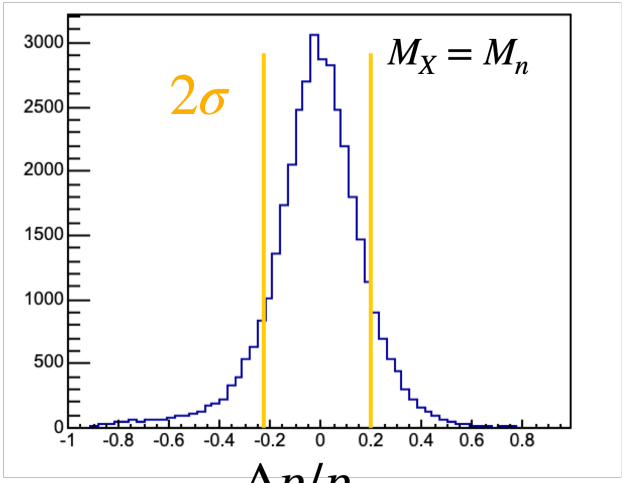
Nucleons selected from exclusive topologies

Ex: $D + e \rightarrow e' + p + X$

$$\vec{p}_X = \vec{q} - \vec{p}_p$$

$$E_X = M_D + \omega - E_p$$

1. Require $M_X = M_n$
2. Select neutrons with $\vec{p}_X = \vec{p}_n$



x

Ingredients for Veto Algorithm:

1. Training and test samples

How to isolate examples of neutrons vs untracked charged particles?

2. Feature Engineering

What information should we give to the algorithm?

3. Model structure

What hyperparameters and network size serve our problem best?

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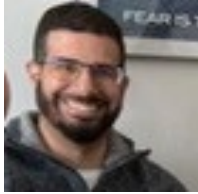
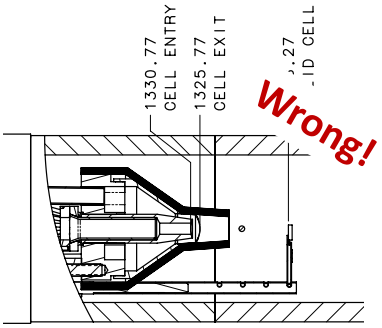
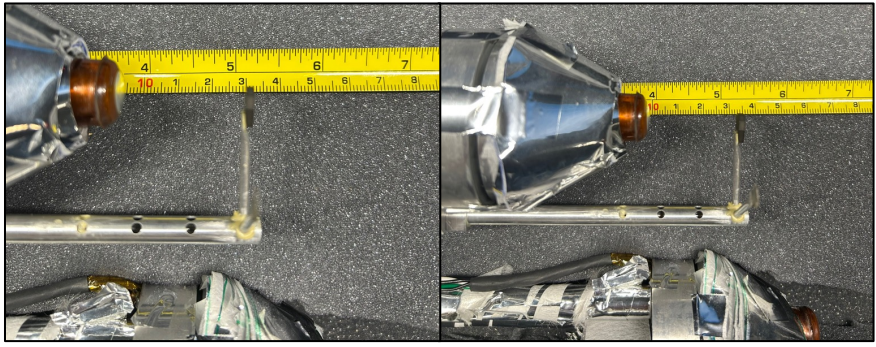
New target measurements



Alon
Sportes





Source: Bob Miller