# CND NEUTRON DETECTION

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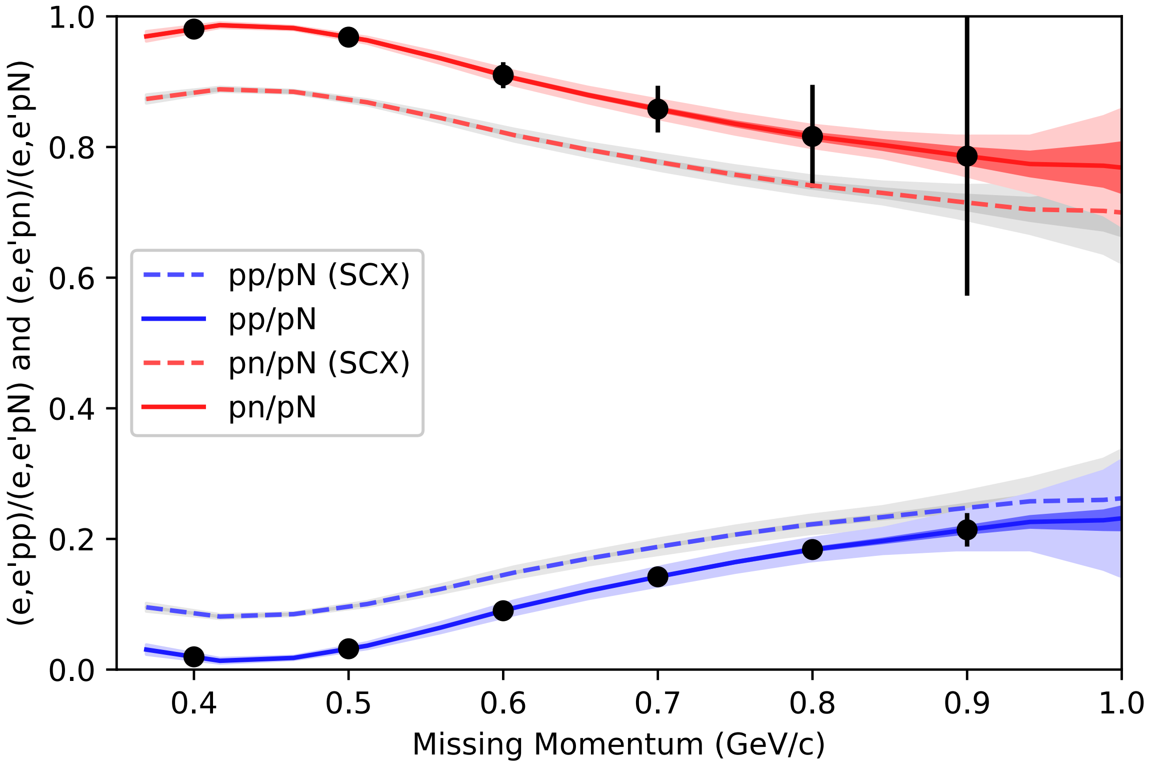
# MOTIVATION FOR NEUTRON DETECTION

## Short-Range Correlation studies in RG-M

- Nuclear targets: H, D, $^{4}$He, C, Ar, Sn, $^{40}$Ca, $^{48}$Ca
- With increasing relative momentum, pn pairs expected to decrease relative to pp pairs
- Important to distinguish neutrons from protons
- Dominant systematic uncertainty: neutron efficiency

## Goal

- Measure of neutron efficiency
- Algorithm for vetoing non-neutrons (especially protons) that are mis-reconstructed with neutron PID
- Applicable to non-exclusive channels with multi-particle final states in various targets



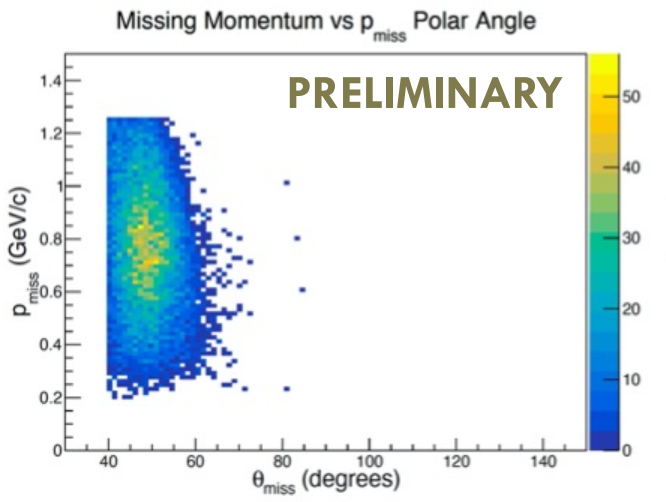

Under review in EPJA

# DETECTION EFFICIENCY: EARLY WORK

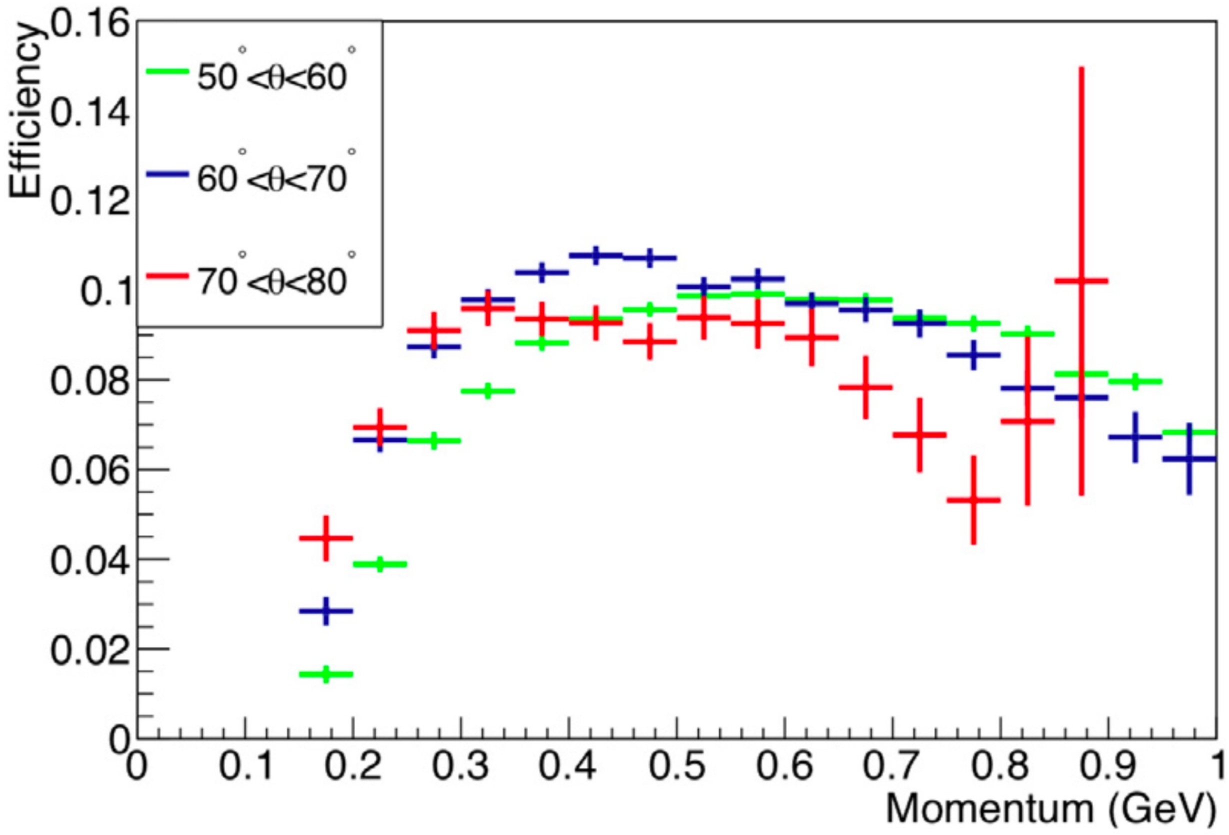
RG-K data, 7.5 GeV

Momentum conservation used to predict neutron momentum

- $h(e, e'\pi^+ n)$




$H(e, e'\pi^+ n)$



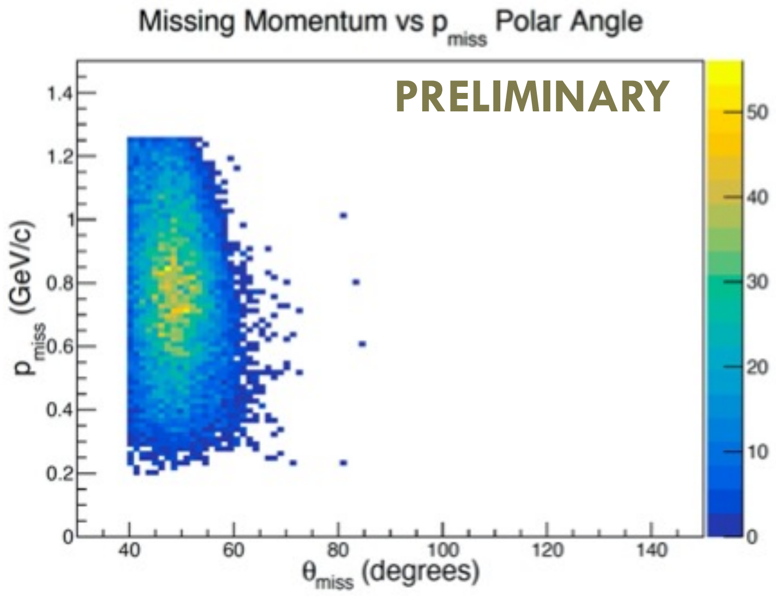

Chatagnon thesis, CLAS12 NIM paper

# DETECTION EFFICIENCY: APPROACH

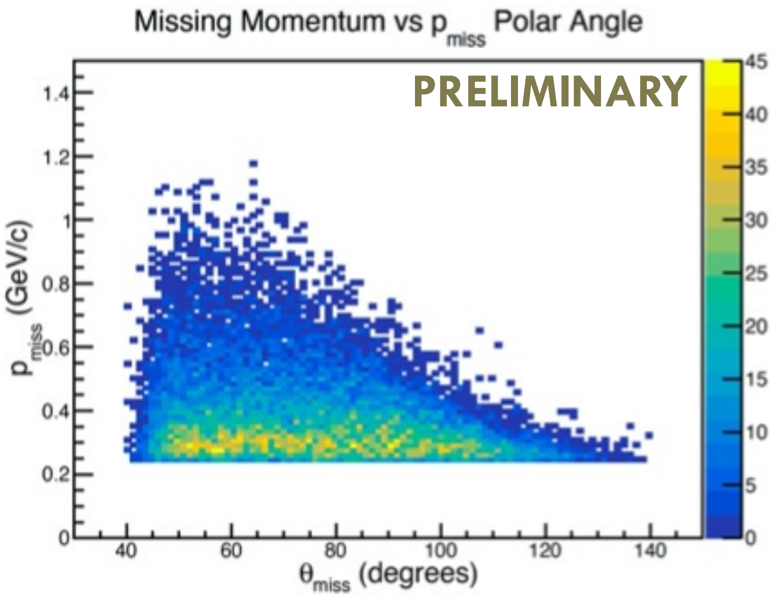
Multiple channels to extend phase space: $h(e,e'\pi^{+}n)$, $d(e,e'p_{CD}n)$, $d(e,e'p_{FD}n)$

Background subtraction in bins of momentum or polar angle

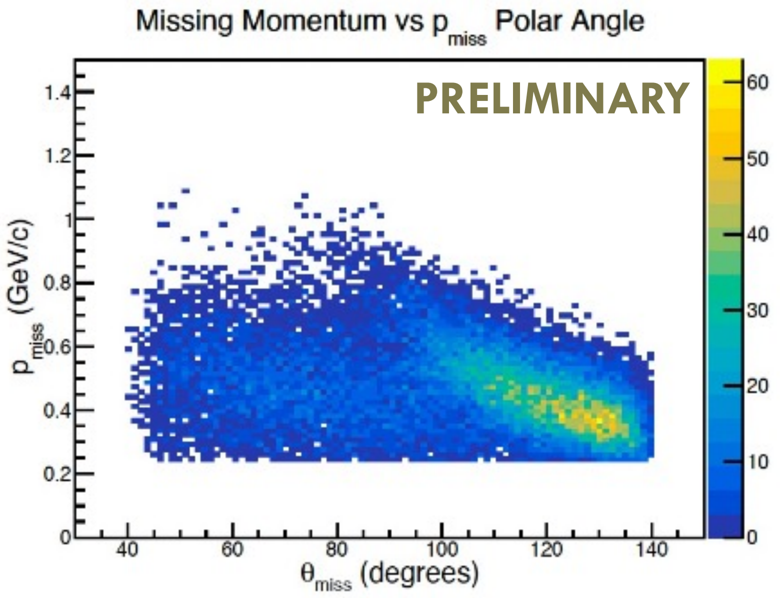
Data sets: RG-K (H at 7.5 GeV), RG-B (D at 4.5 GeV), RG-M




$H(e,e'\pi^{+}n)$

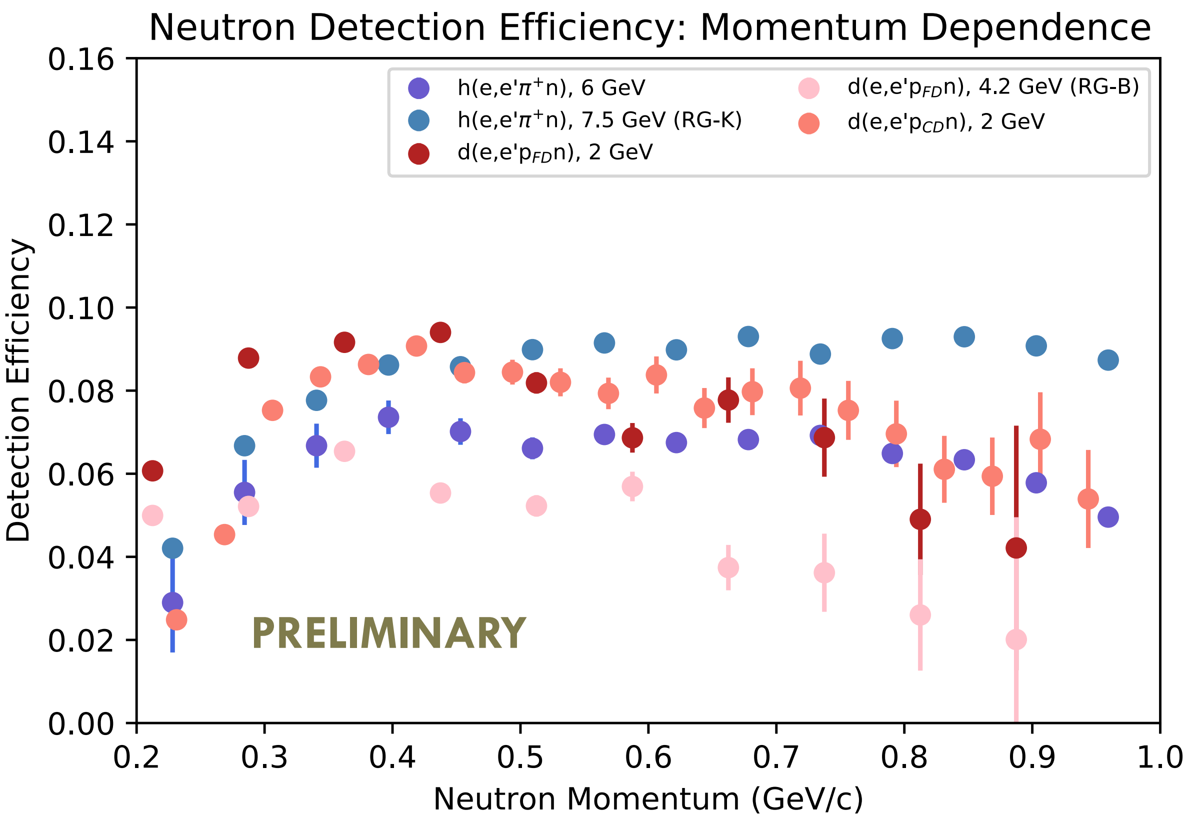


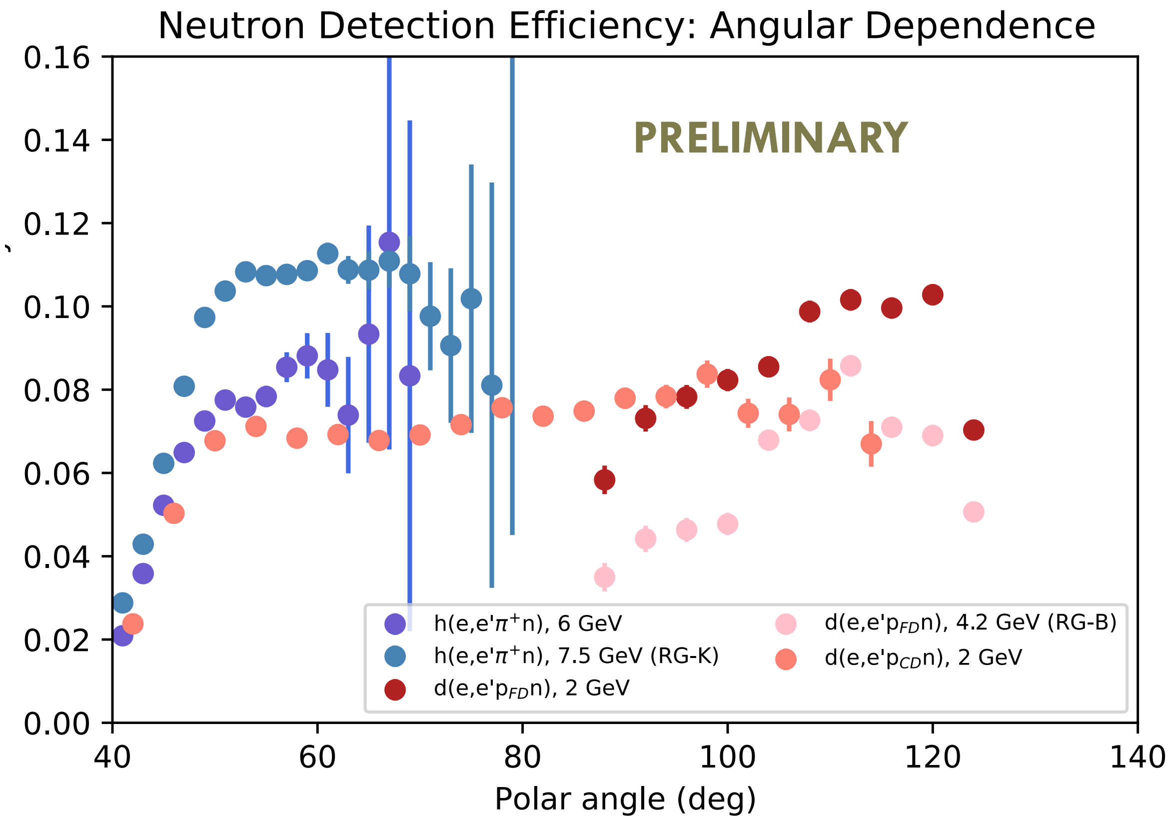

$D(e,e'p_{CD}n)$




$D(e,e'p_{FD}n)$

# DETECTION EFFICIENCY: RESULTS



# NEUTRON VETO

## CND neutron reconstruction

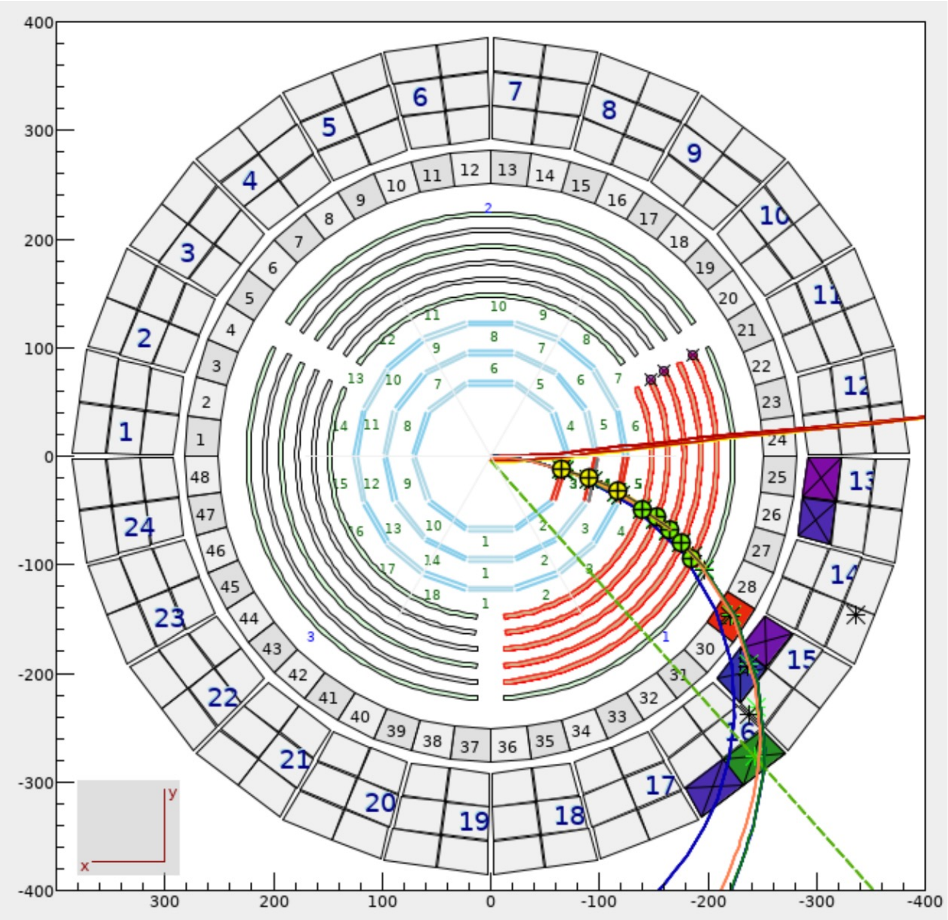
- Clusters form neutral seed if unassociated with a CVT track
- Neutrals considered to be only photons or neutrons
- Velocity cut: $\beta < 0.8$ for neutron, $\beta > 0.8$ for photon

## Background sources

- Double hits
- Neutron and proton reconstructed in same place (cut on $\theta_{np}$)
- Random co-incidence (off-time, etc.)
- Big problem: imperfect CVT efficiency means charged particle contamination

## Past work

- Andrew Denniston: preliminary CND veto work
- Adam Hobart: Machine learning for DVCS



# NEUTRON VETO: DEVELOPMENT IN SIMULATION

Approach using Machine Learning: Boosted Decision Trees

- Identify features that are best at distinguishing between real neutrons and "fake" neutrons (non-neutrons with neutron PID)
- Features: local, detector-level information, avoid kinematics

Sample generation

- Uniform e'*n* and e'*p* generators with nucleon momentum up to 1 GeV/c
- Run through GEMC, added CLAS12 RG-A background, reconstructed with coatjava
- Generated momentum "truth" preserved

Good neutron sample (signal): agreement with generated momentum in e'*n*+bknd

Fake neutron sample (background): all neutron PID in e'*p*+bknd

# NEUTRON VETO: SIMULATION FEATURE LIST

Number of hits in 5 CND sectors closest to neutron

Energy deposition in 5 CND sectors closest to neutron

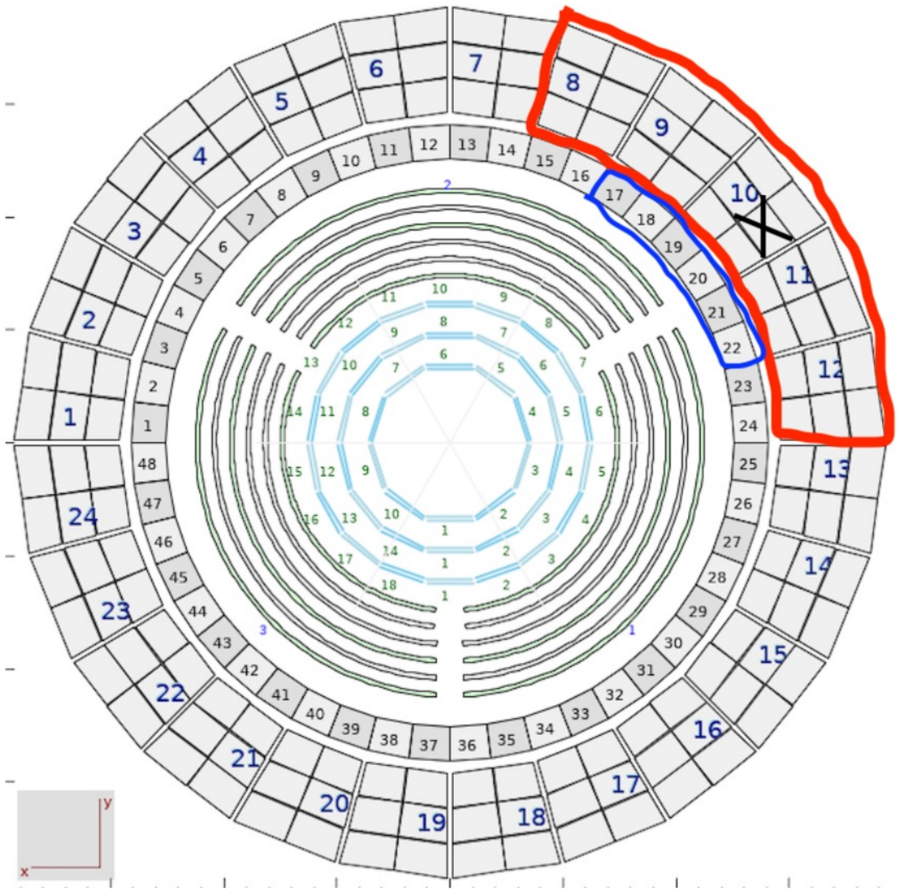
Number of hits in 6 CTOF components closest to neutron

Energy deposition in 6 CTOF components closest to neutron

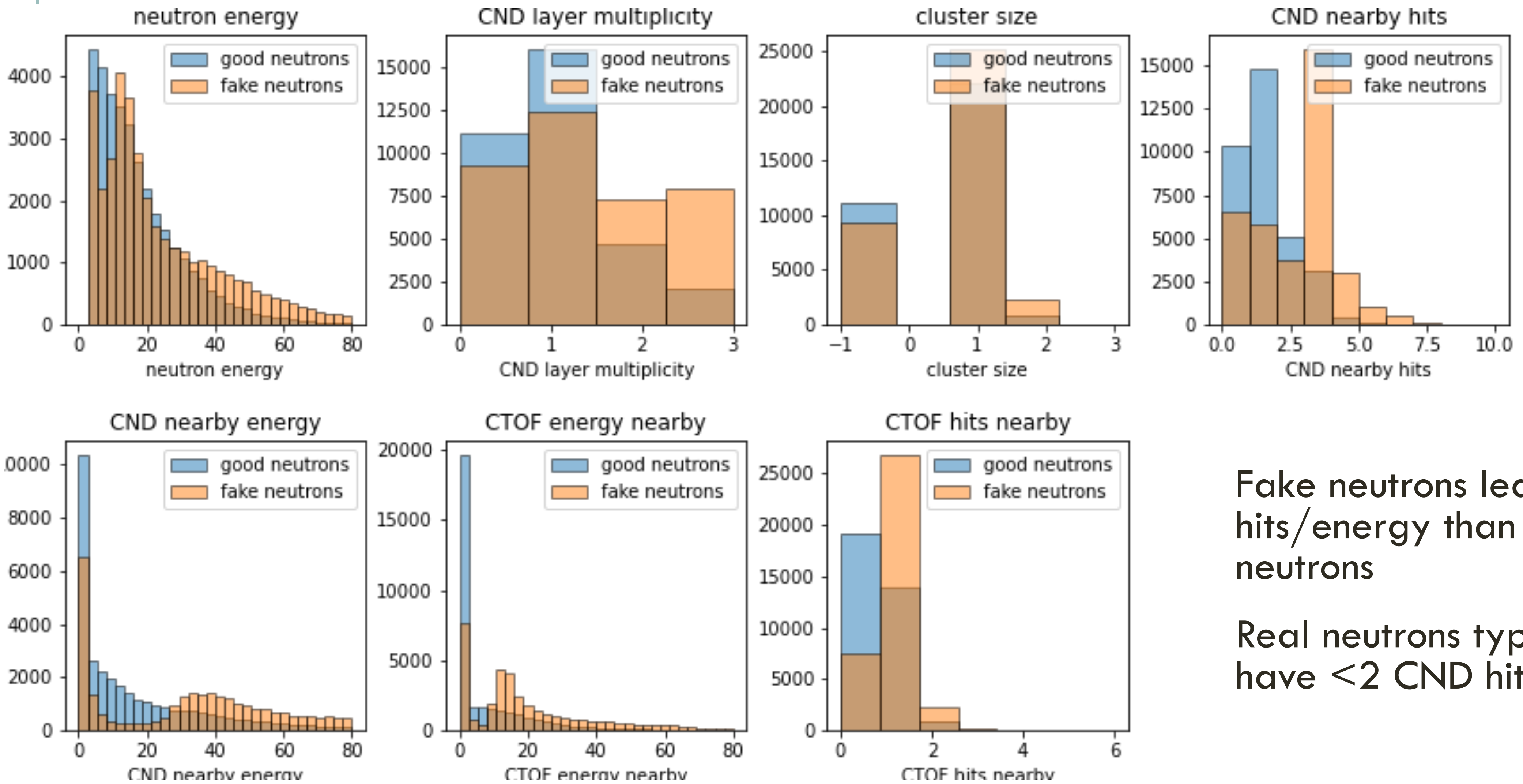
Number of hits in CND cluster

Neutron energy

CND layer multiplicity (0 if CTOF only)



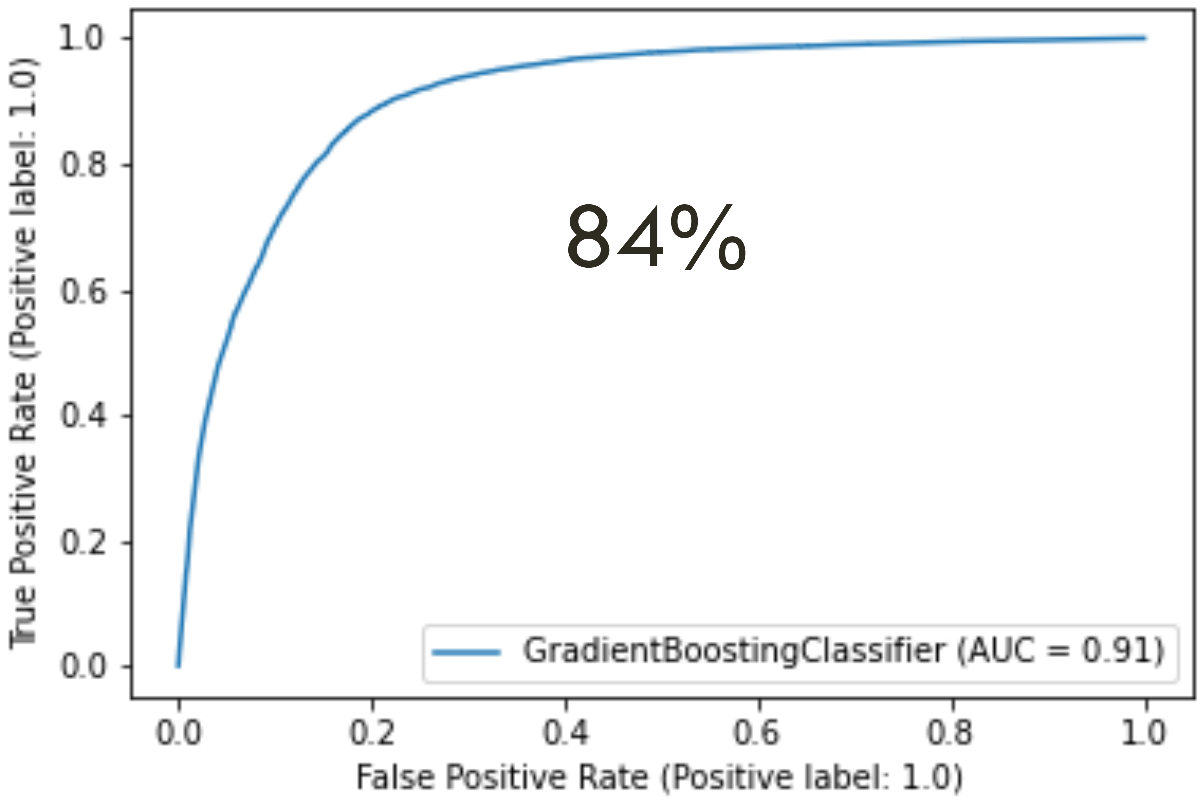
# NEUTRON VETO: SIM FEATURE LIST




Fake neutrons leave more hits/energy than real neutrons

Real neutrons typically have <2 CND hits

# NEUTRON VETO: SIMULATION RESULTS




| | feature | importance |
|---|---|---|
| 3 | CND nearby hits | 0.390608 |
| 5 | CTOF energy nearby | 0.382342 |
| 4 | CND nearby energy | 0.090312 |
| 0 | neutron energy | 0.064781 |
| 1 | CND layer multiplicity | 0.058599 |
| 6 | CTOF hits nearby | 0.006953 |
| 2 | cluster size | 0.006405 |

# NEUTRON VETO: DATA APPROACH

Available exclusive channels

- $h(e, e'\pi^+ n)$
- $d(e, e' p_{CD} n)$ (2 GeV, 6 GeV)
- $d(e, e' p_{FD} n)$ (2 GeV, 6 GeV)
- $d(e, e' p p \pi^-)$

Select good and false neutrons

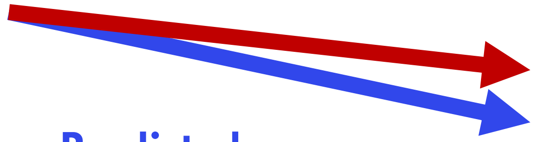
- Train on data when possible
- Start with $d(e, e' p_{CD} n)$ QE channel (higher stats)
- Using data from RG-M: LD2, 2 GeV
- Calculate expected neutron momentum with momentum conservation
- Train ML to separate neutrons vs bad neutrons

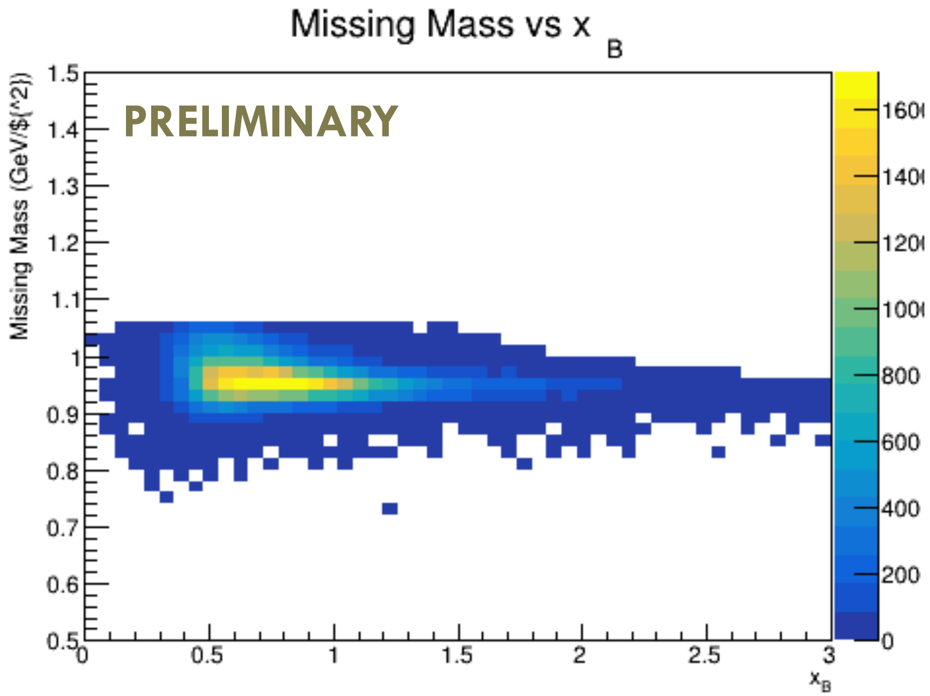
# NEUTRON VETO: GOOD NEUTRONS (SIGNAL)

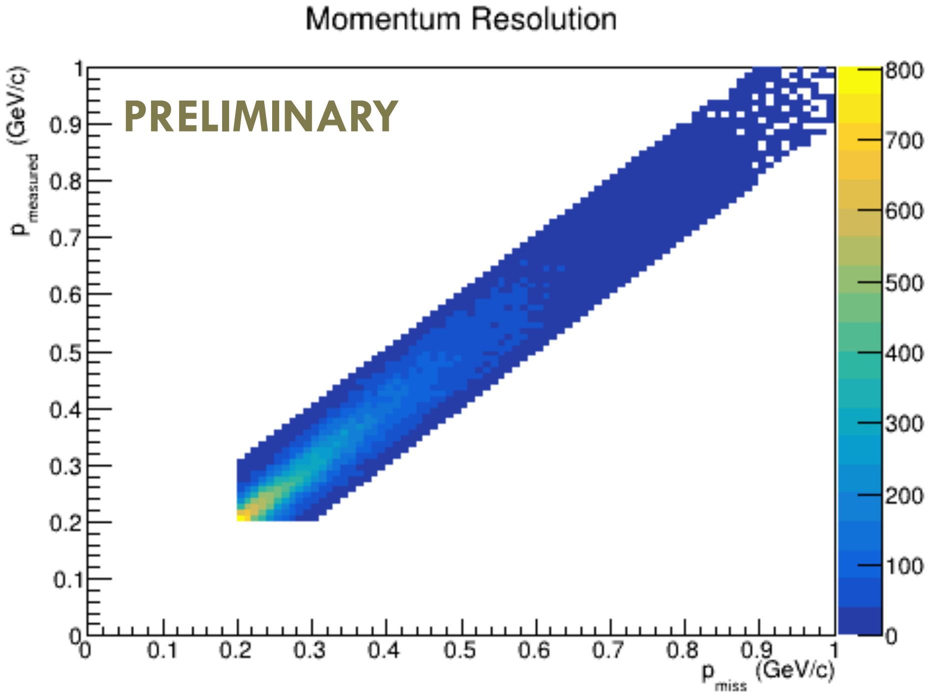
$\cos\theta_{neut,pred} > 0.9$

$|\, p_{pred} - p_{neut} \,| < 0.1$ GeV/c

$M_{miss} < 1.05$ GeV/c



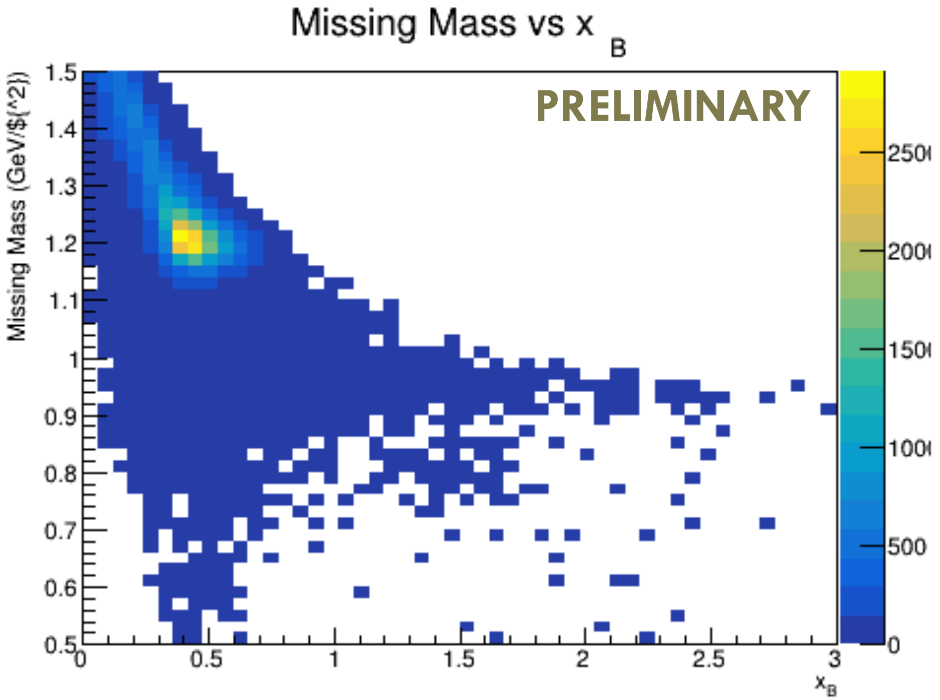



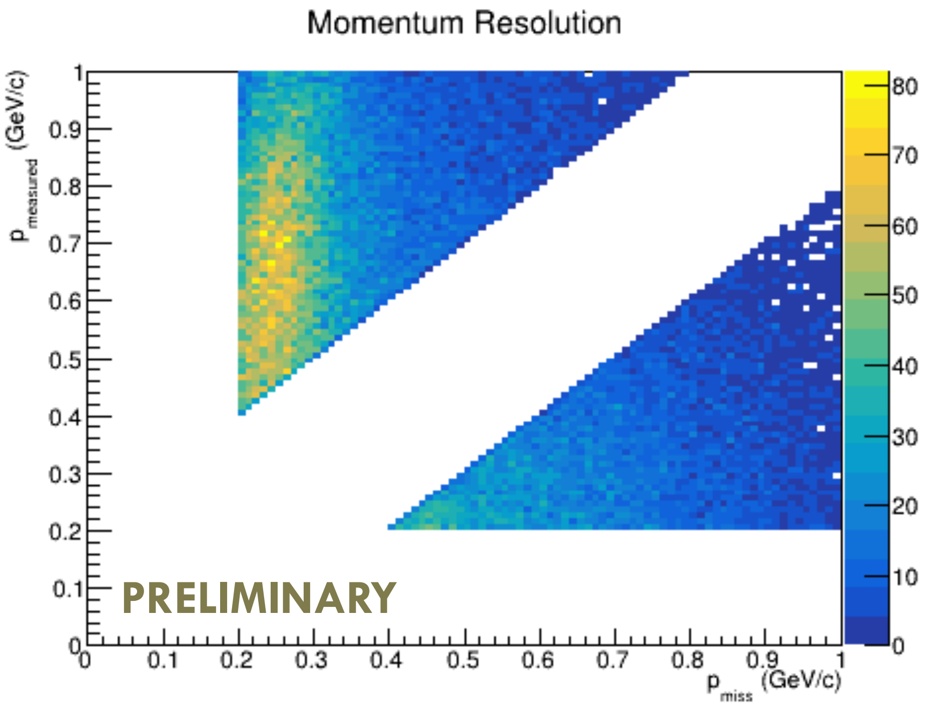



# NEUTRON VETO: NON-NEUTRONS (BACKGROUND)

$\cos \theta_{neut,pred} < 0.8$

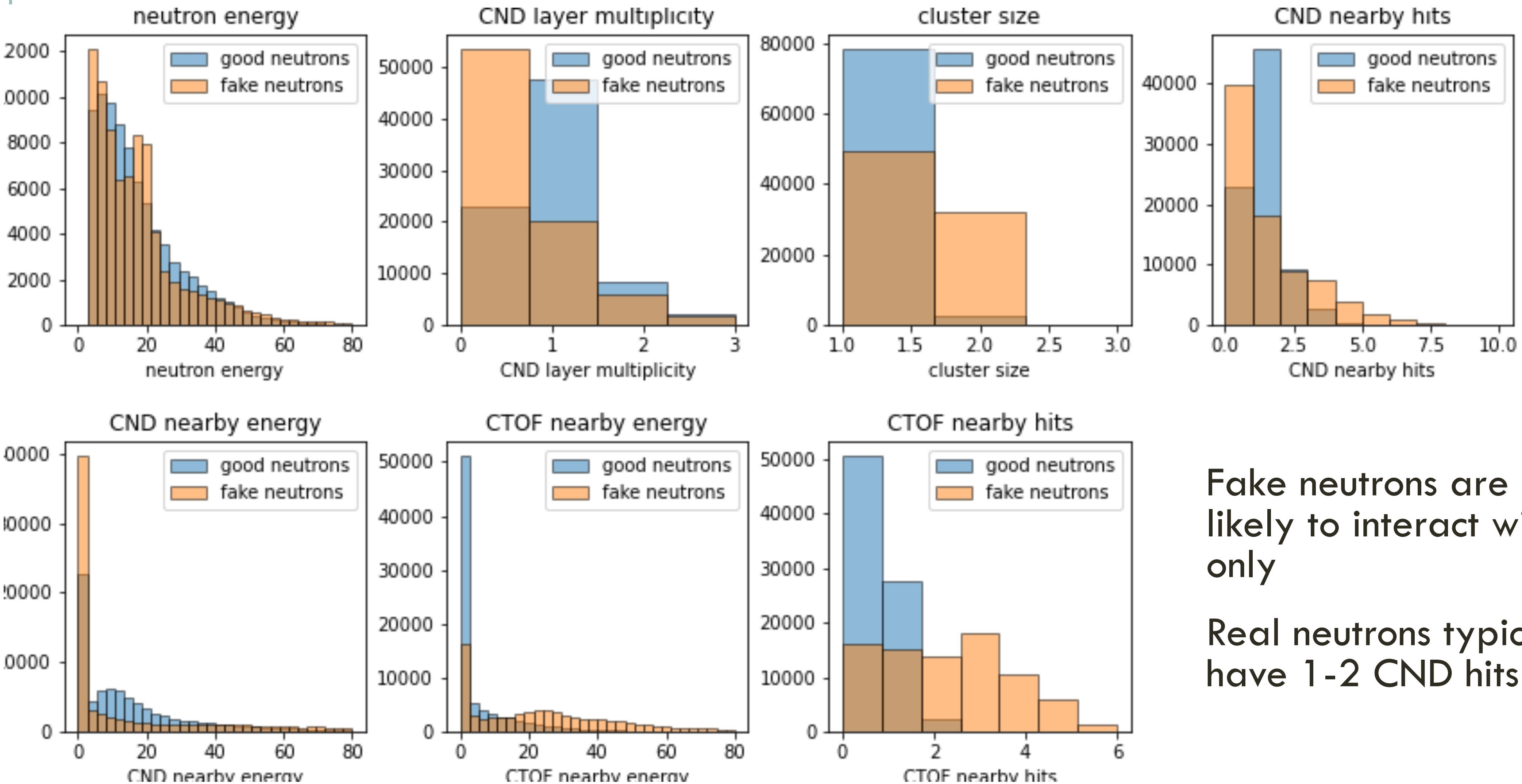
$| p_{pred} - p_{neut} | > 0.2$ GeV/c

# NEUTRON VETO: D FEATURE LIST

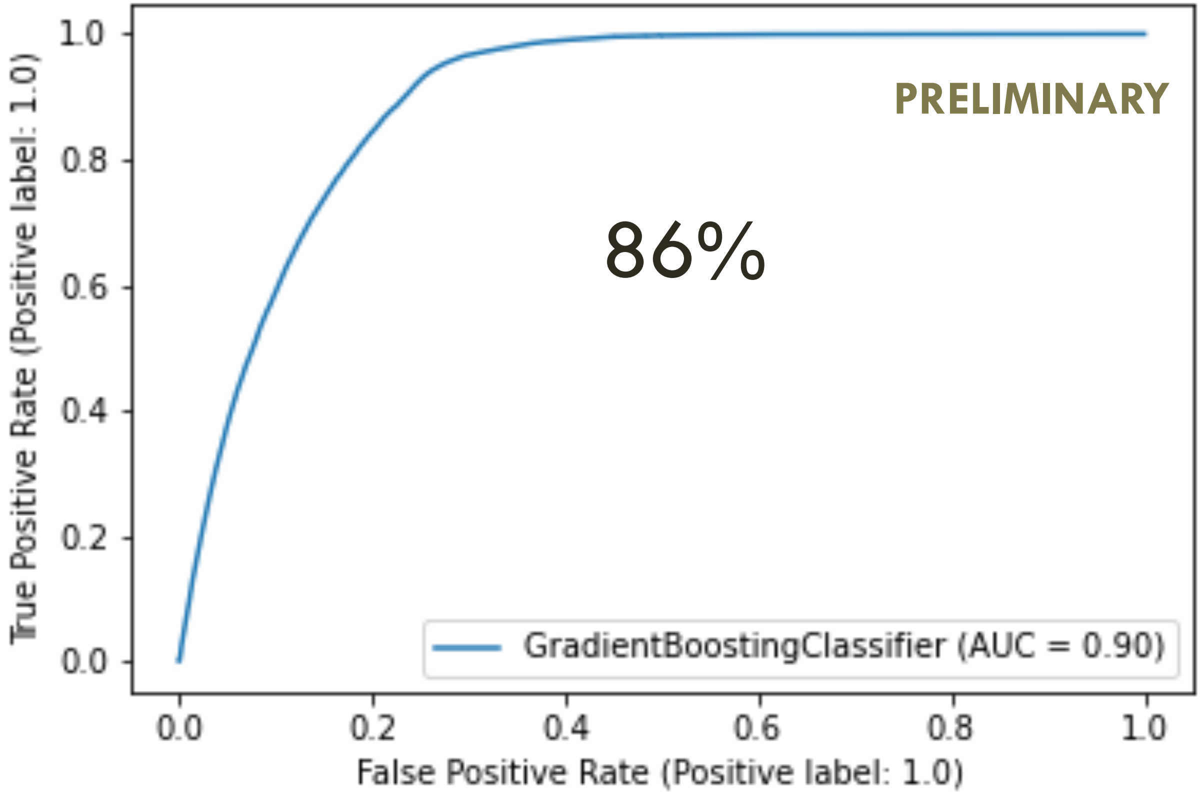
**PRELIMINARY**




Fake neutrons are more likely to interact with CTOF only

Real neutrons typically have 1-2 CND hits

# NEUTRON VETO: D RESULTS




| | feature | importance |
|---|---|---|
| 6 | CTOF nearby hits | 0.708382 |
| 3 | CND nearby hits | 0.130615 |
| 1 | CND layer multiplicity | 0.049967 |
| 0 | neutron energy | 0.045472 |
| 5 | CTOF nearby energy | 0.036551 |
| 4 | CND nearby energy | 0.023944 |
| 2 | cluster size | 0.005070 |

# NEXT STEPS

## Detection Efficiency

- Re-run with pass2 reconstruction
- Apply neutron veto algorithm
- CLAS analysis note

## Neutron Veto ML Algorithm

- Channel to focus on protons mis-reconstructed as neutrons (e.g. $d(e, e'pp\pi^-)$)
- Continue search for good features (e.g. number of nearby hits in CVT)
- Cross-tests on different data sets (end goal: apply to Carbon)

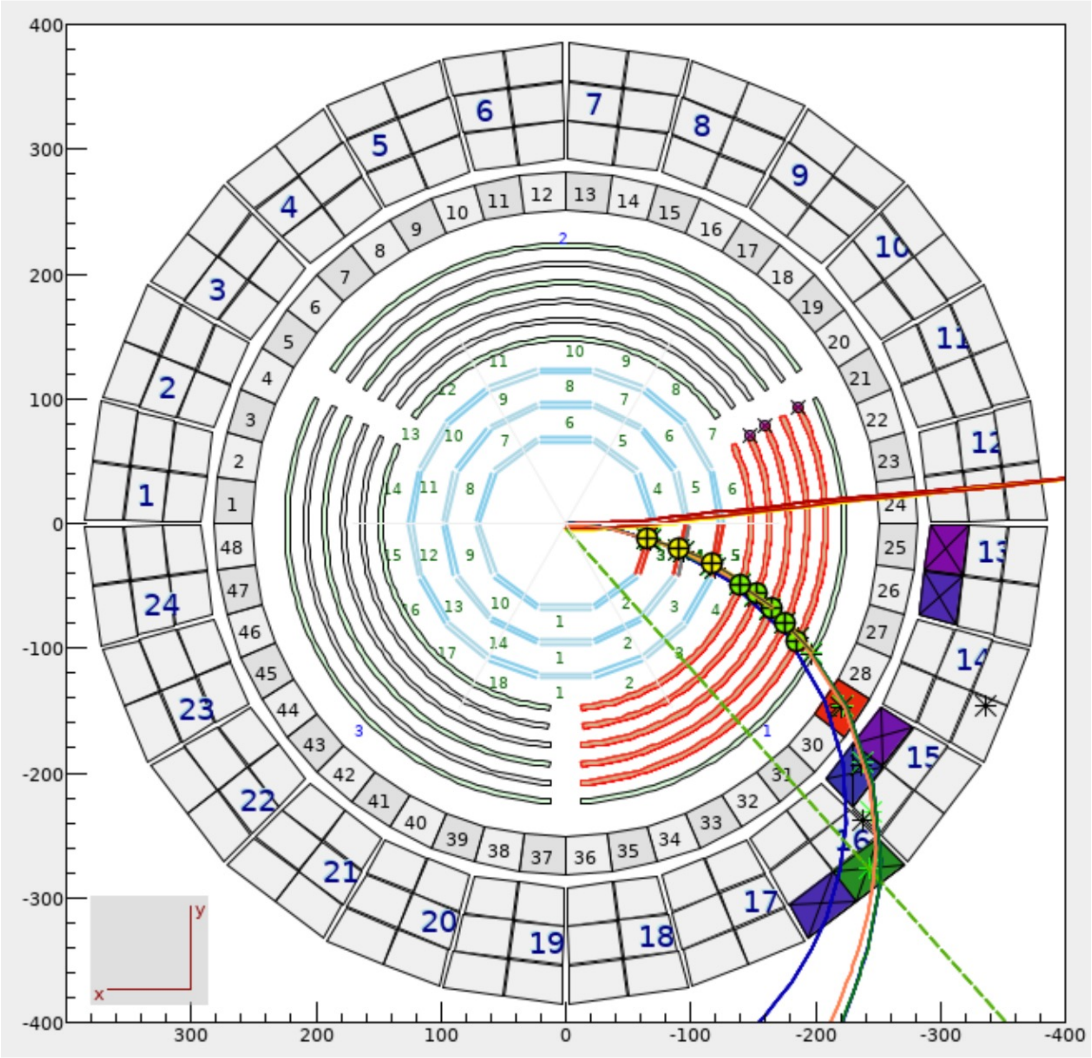
# THANK YOU!

# BACKGROUND: CND HIT NOT ASSOCIATED W/ TRACK

CND hits not associated with CVT track

Proton associated with one CND cluster but not another

Can cut on angle between neutron and proton

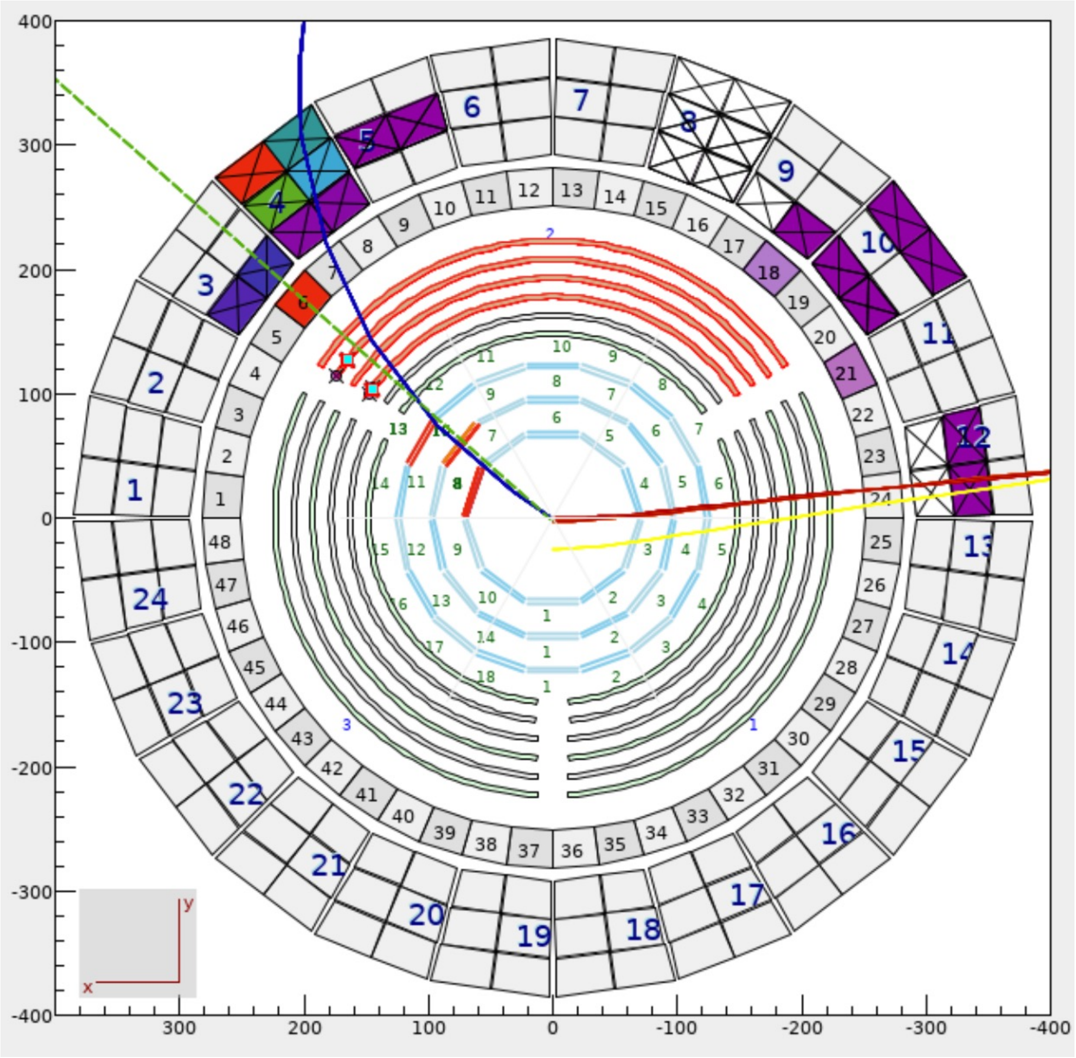


# BACKGROUND: PROTONS MISIDENTIFIED AS NEUTRONS

Imperfect CVT tracking efficiency

Some protons mis-reconstructed as neutrons

This is the main background source we seek to eliminate with ML

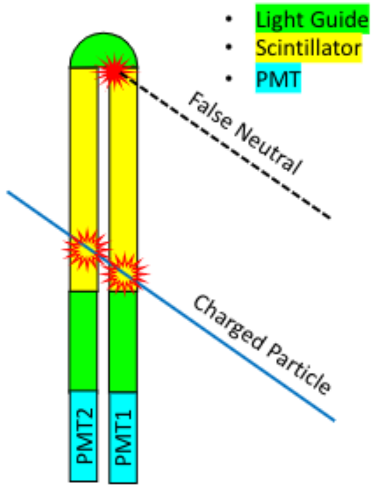


# BACKGROUND: DOUBLE HITS

Charged particles may leave two hits with two sets of PMT signals

Two PMT signals arrive at same time -> reconstructed near $40°$

Easily eliminated using z cut




Hit Time = $t_{PMT1} + t_{PMT2} + c_t$
Hit Z = $t_{PMT1} - t_{PMT2} + c_z$