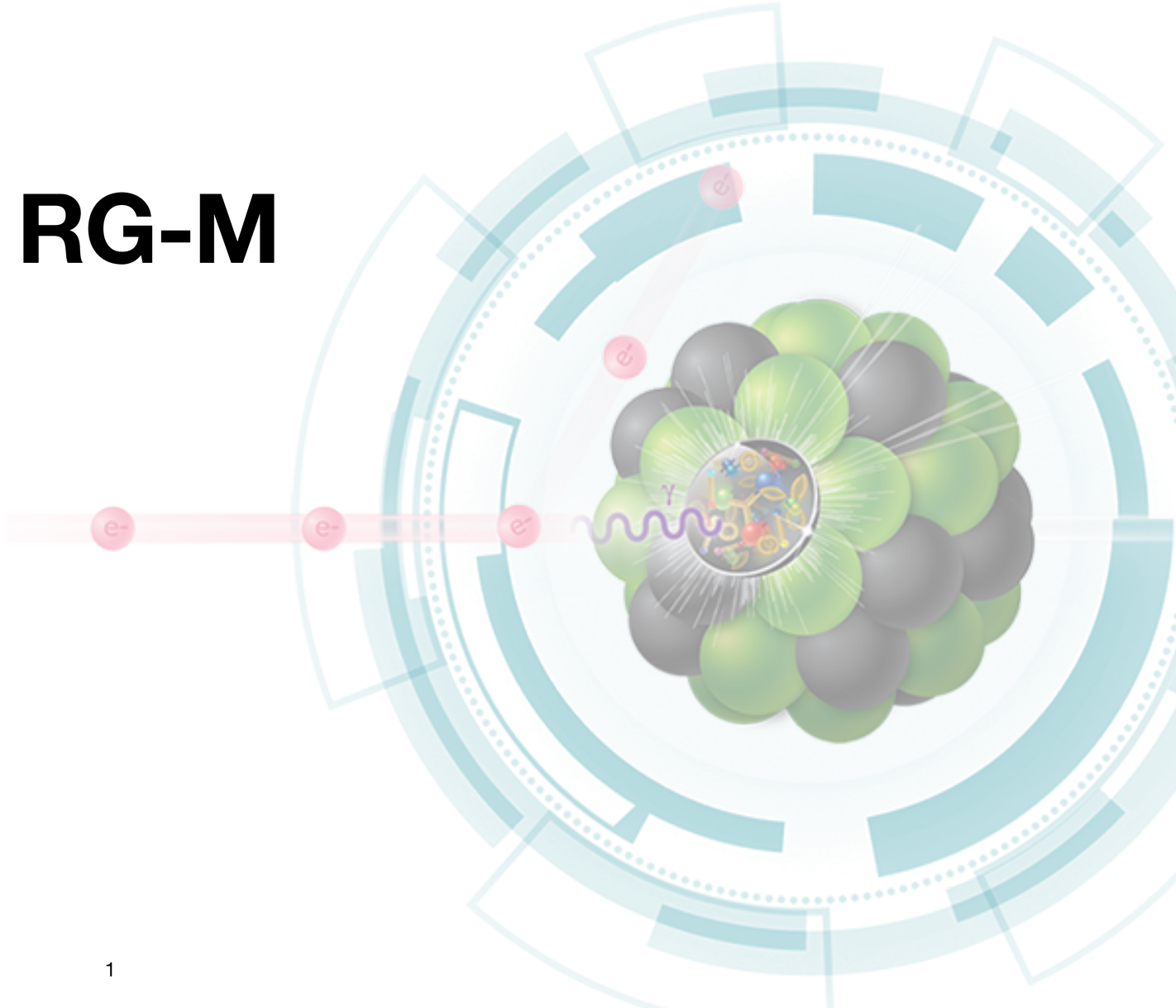
Recent Results from RG-M

Natalie Wright



Overview

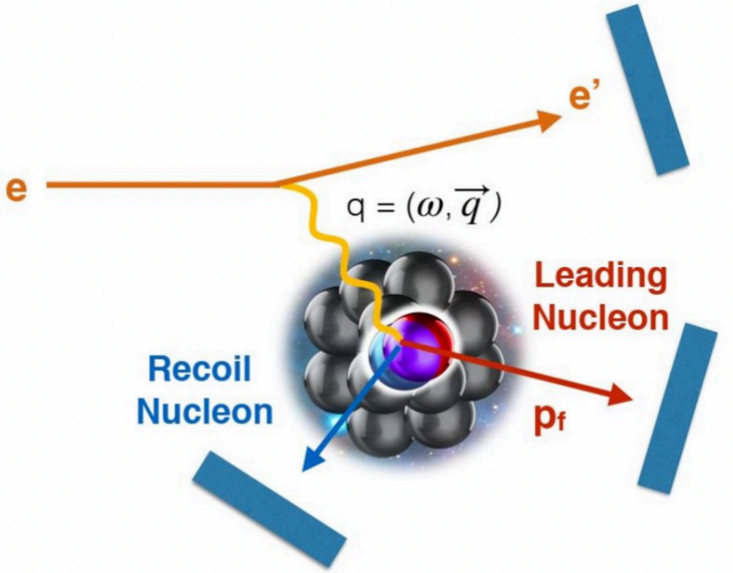
SRC Analyses

48,40Ca pair ratios: $e'p(p)_{FD}$, $e'n_{FD}$

Center-of-mass motion: $e'pn_{CD}$

Scale dependence: $e'p(p)$

3N correlations: $e'pd$

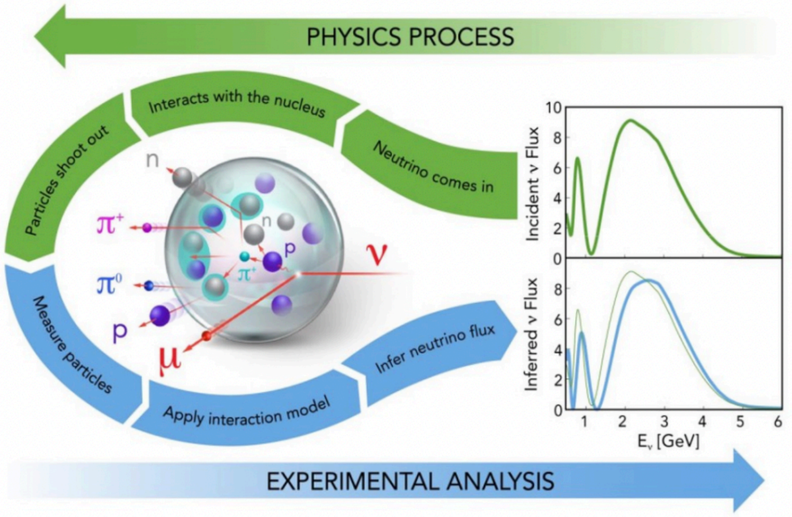


e4ν Analyses

$1p0\pi$

Inclusive cross section

Two nucleon topologies



Overview

SRC Analyses

48,40Ca pair ratios: $e'p(p)_{FD}$, $e'n_{FD}$

Center-of-mass motion: $e'pn_{CD}$

Scale dependence: $e'p(p)$

3N correlations: $e'pd$

e4ν Analyses

$1p0\pi$

Inclusive cross section

Two nucleon topologies $(2p, 1p1n)$

9:50 AM **RGM results on Calcium**
Speaker: Mr Igor Becker

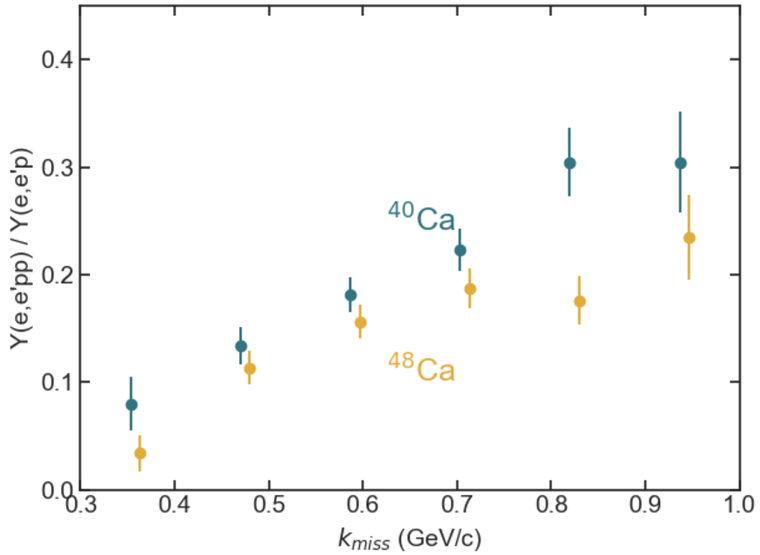
10:10 AM **Inclusive electron scattering for neutrinos with CLAS12**
Speaker: Matan Goldenberg

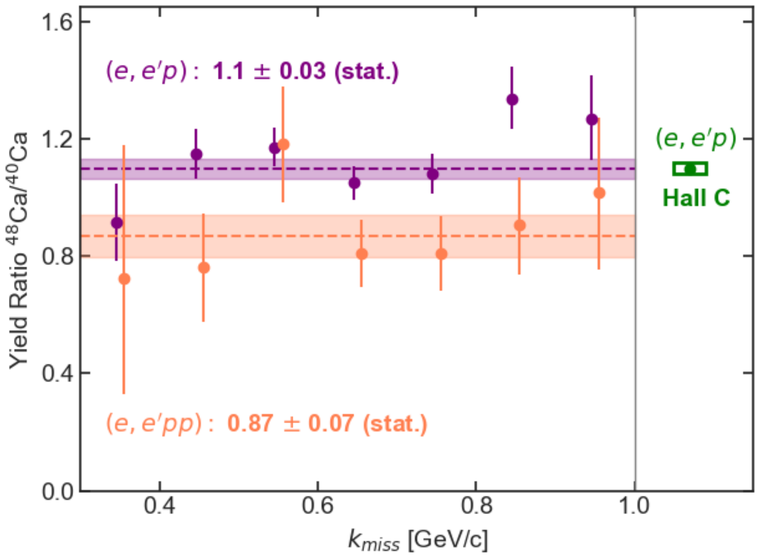
11:00 AM **CLAS12 e4nu 1p analysis**
Speaker: Pablo Barham

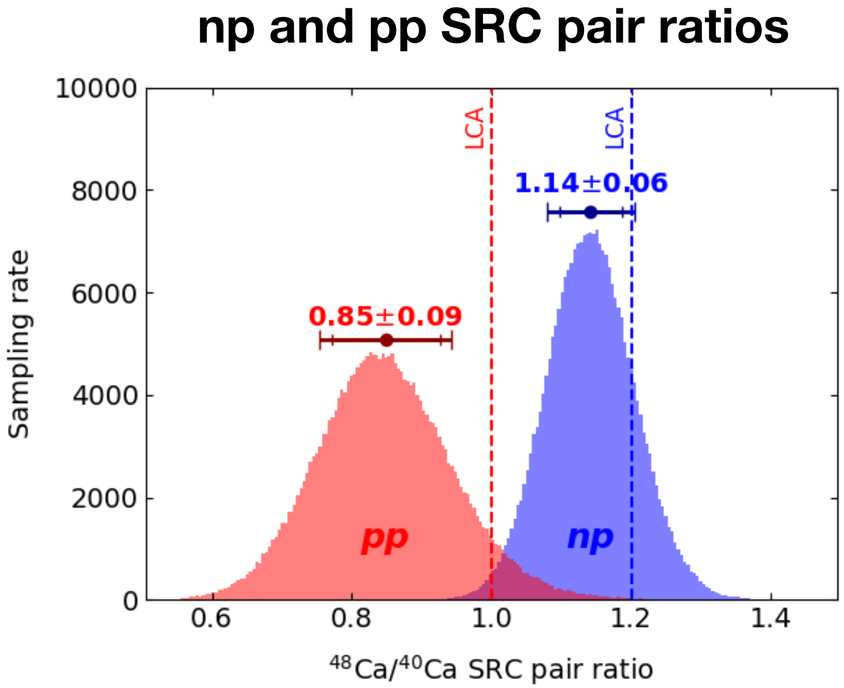
11:20 AM **(e,e'n) SRC analysis on Calcium in the RGM experiment**
Speaker: Ron Wagner (Tel Aviv University)

Calcium 40, 48 e’p(p) SRC pair ratios

Approved!









Julian Kahlbow

- Small increase in np pairs despite +40% neutrons
- Suppression of pp pairs from Ca40 -> Ca48

→ Complex SRC pair formation mechanism beyond N/Z scaling and shell-model structure?

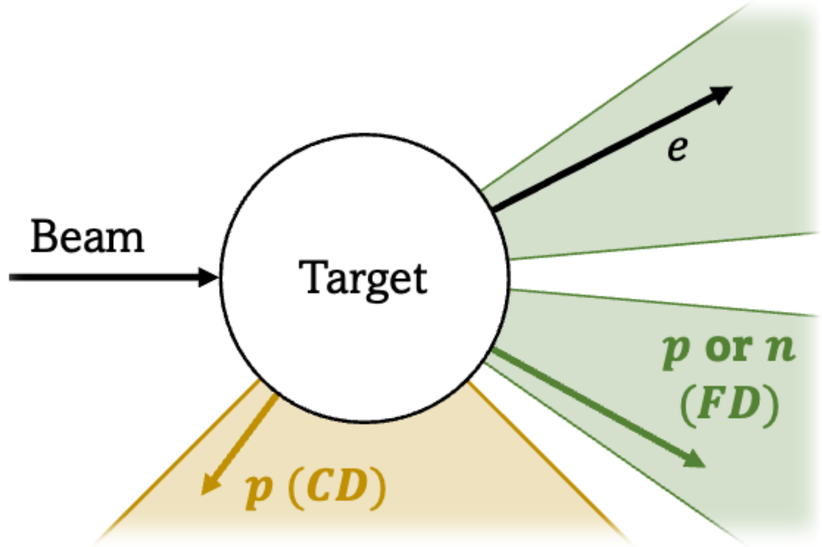
e4ν 2-Nucleon Topologies


Alon Sportes

Goal: Study MEC contributions in $e'pp$, $e'pn$ reactions to inform nuclear modeling in neutrino experiments

Signal selection – based on detector constraints!

- **2p:** one p in the FD (≡ $\boldsymbol{pFD}$) and one p in the CD (≡ $\boldsymbol{pCD}$)
- **1n1p:** *leading* n in the FD (≡ $\boldsymbol{nFD}$) and one p in the CD (≡ $\boldsymbol{pCD}$)



e4ν 2-Nucleon Topologies

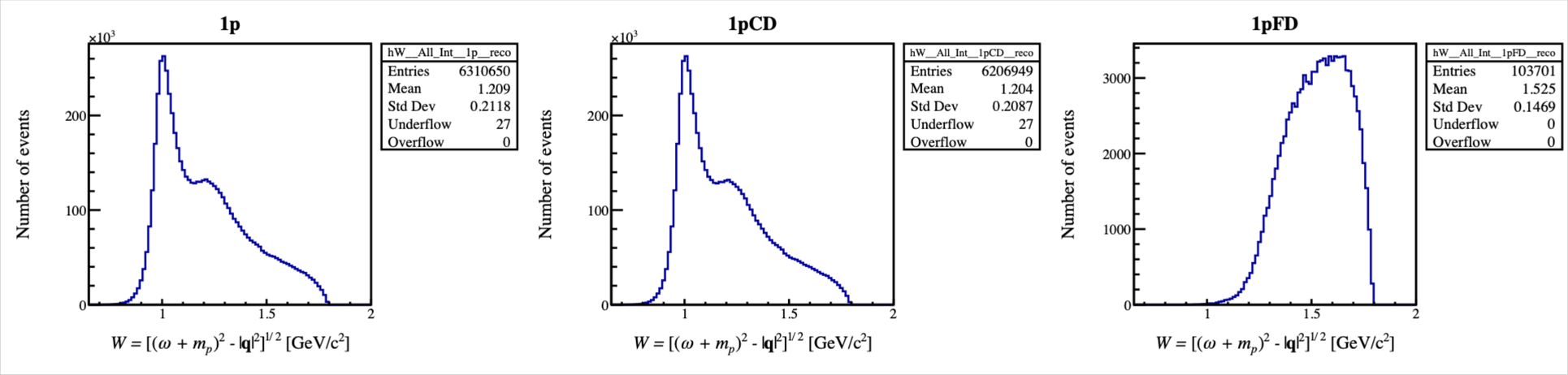


Alon Sportes

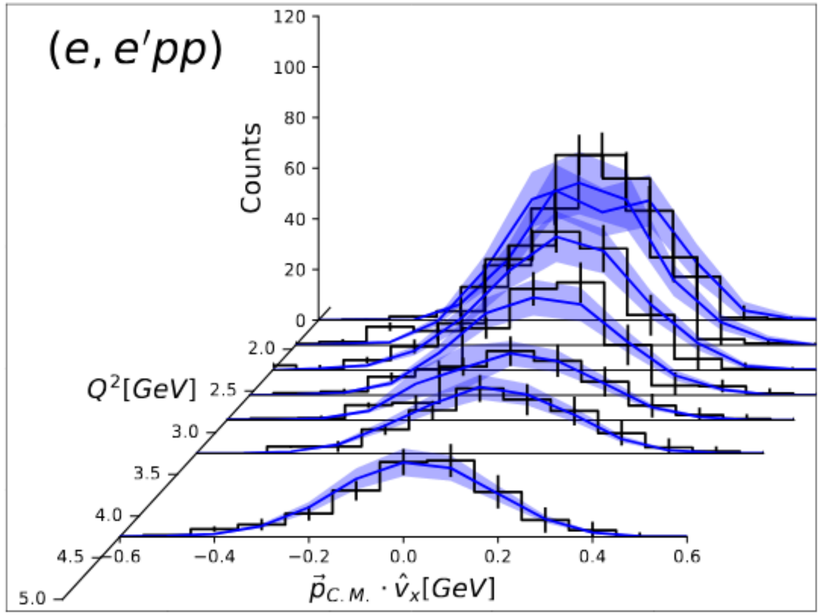
Goal: Study MEC contributions in $e'pp$, $e'pn$ reactions to inform nuclear modeling in neutrino experiments

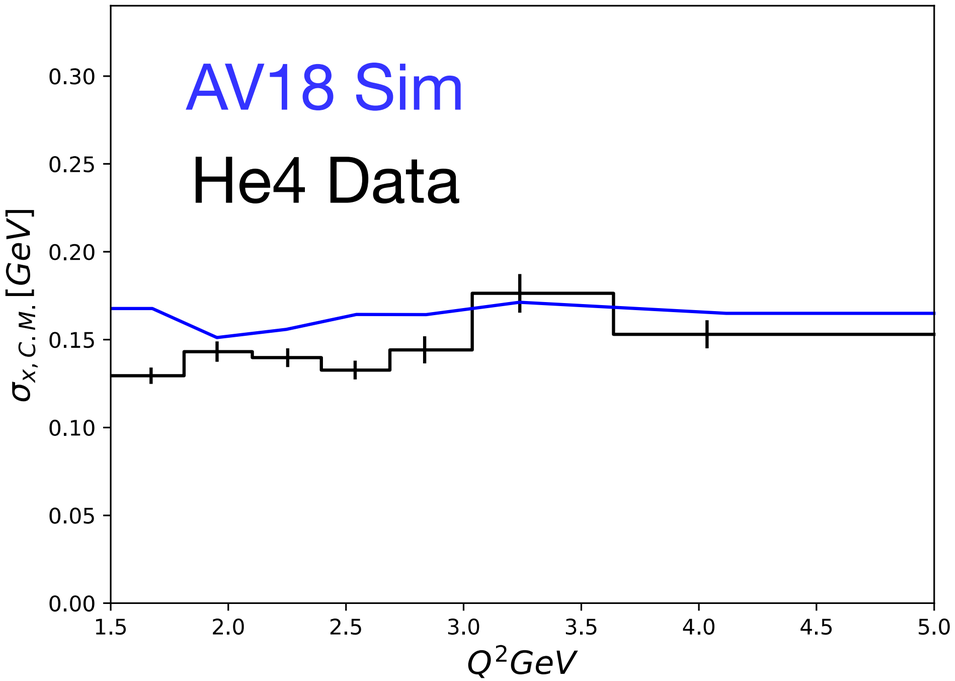
Status: Characterizing dominant reaction mechanisms at different kinematics

Results are for: C^{12} data 2 GeV (run 015658)



SRC Scale (In)Dependence





PWIA: $\sigma_{QE} \propto \sigma_{eN} \times S_A^N(p, E)$

- If SRC properties describe nuclear ground state, should be Q2 independent

SRC Scale (In)Dependence

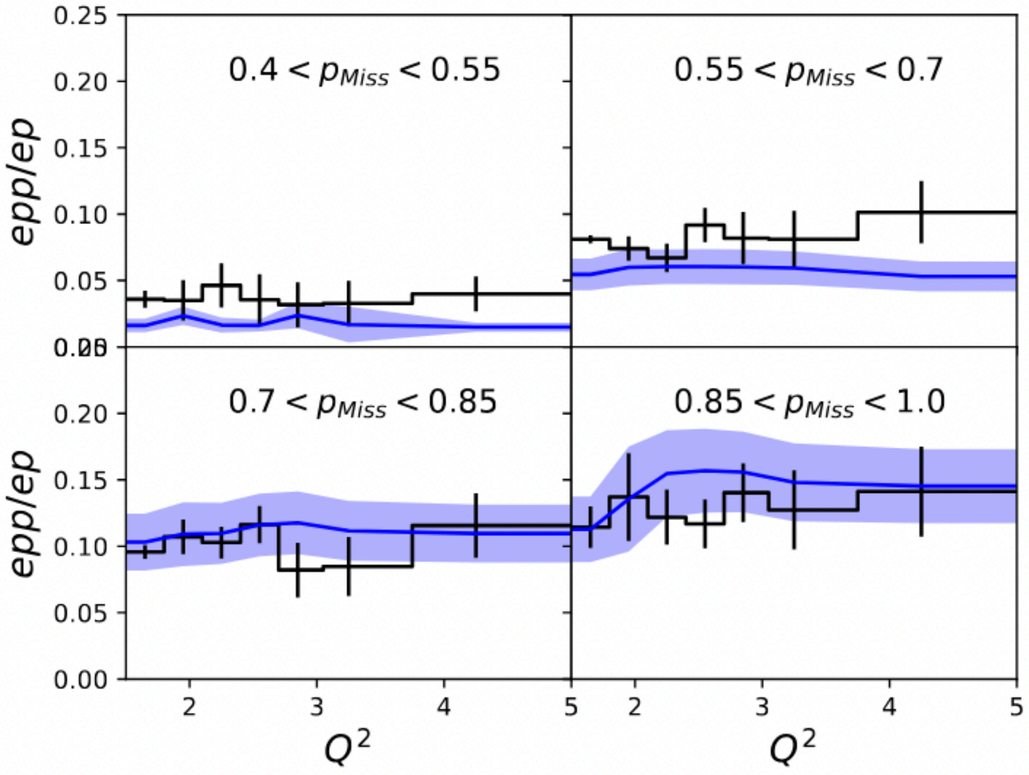
- Data-driven, sim used to compare trivial Q2 dependence from phase space, FF

Status:

- With common note calibrations + approved physics note selection, FD analysis complete

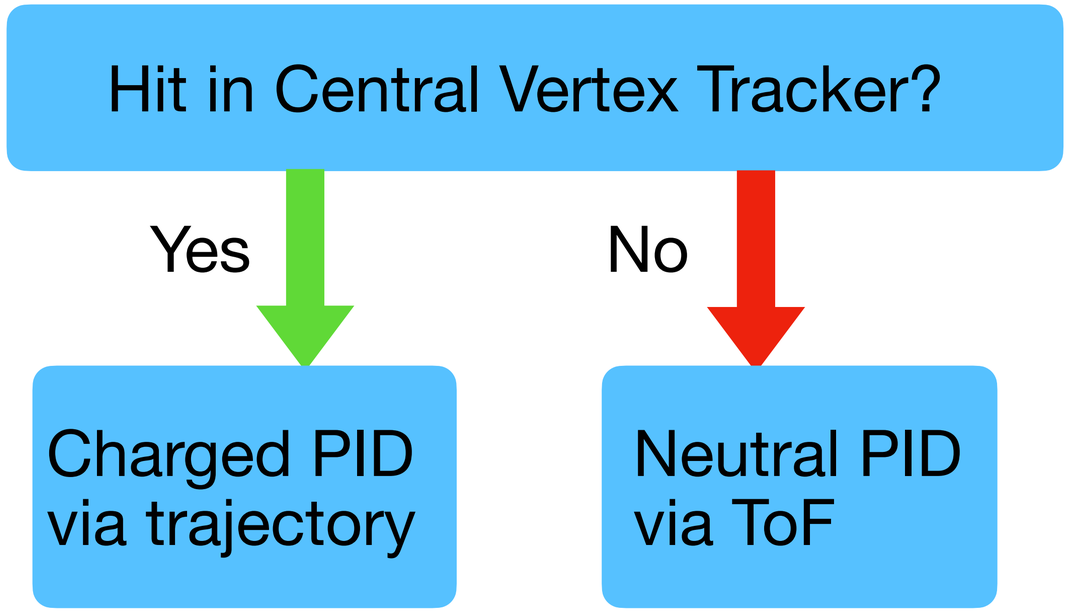
- Validating selection of CD protons for factor of ~8 stats increase

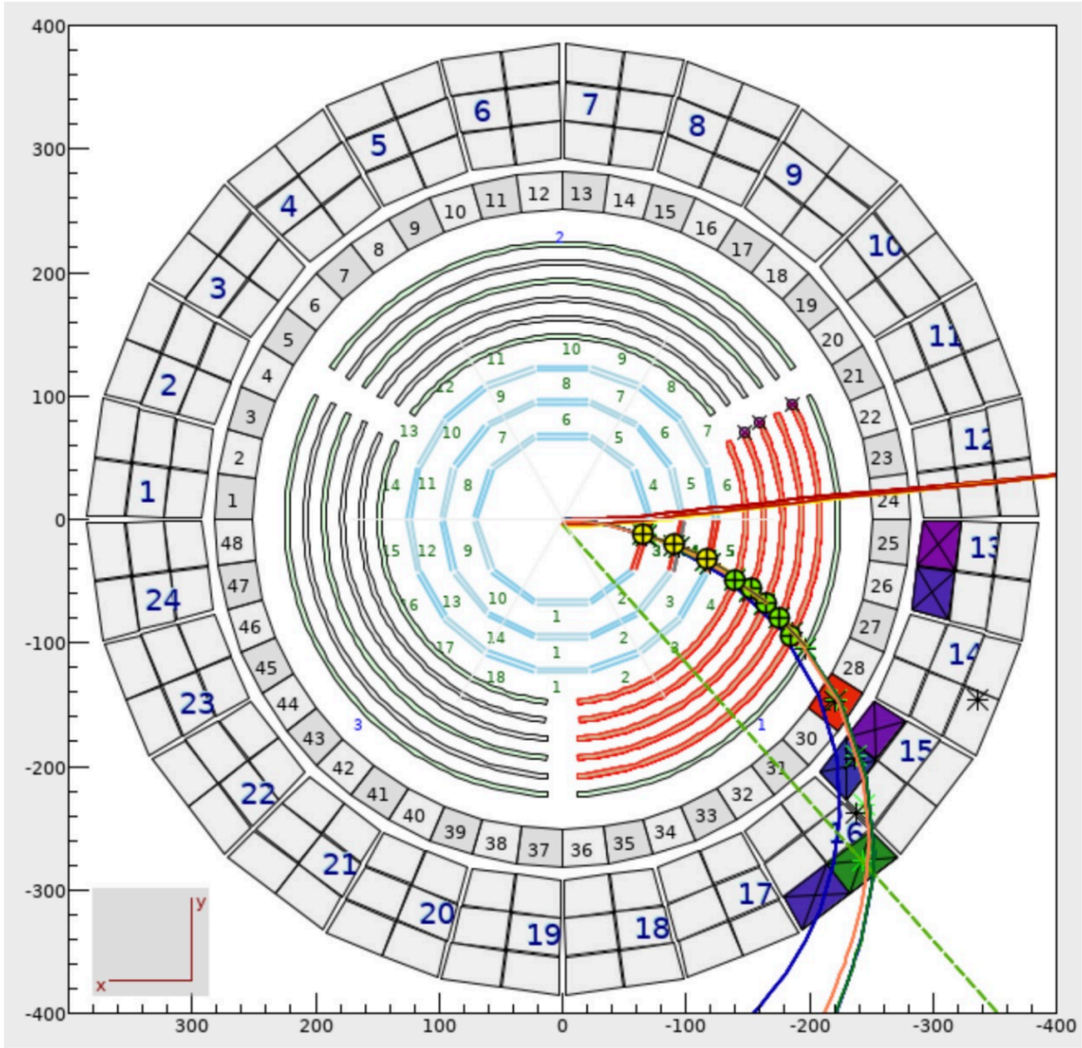
- Extending from 4He to heavier nuclei



CND Neutrons: Addressing from all sides

How CD particles are ID’d:





CND Neutrons: Addressing from all sides

Many efforts already to ID CD neutrons, particularly for RGB

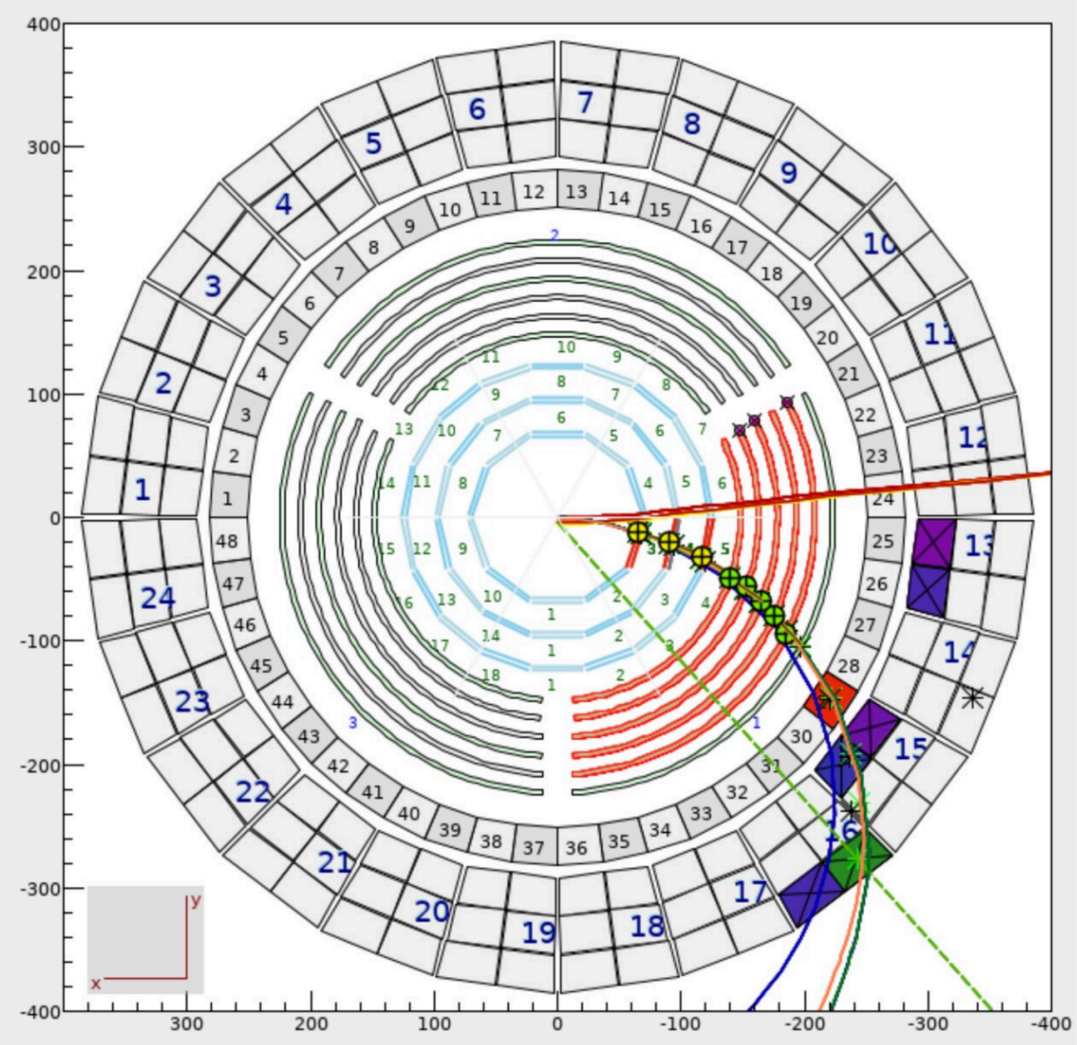
In our case:

- Lower beam energies

- No exclusivity variable, as in DVCS

- Background removal prioritized over signal retention

- Ideally, extrapolate to heavier nuclei



CND Neutrons: Addressing from all sides

Many efforts already to ID CD neutrons, particularly for RGB

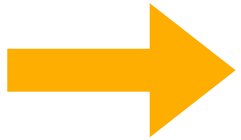
In our case:

- Lower beam energies

- No exclusivity variable, as in DVCS

- Background removal prioritized over signal retention

- Ideally, extrapolate to heavier nuclei



Two approaches for RGM:

1. Manual algorithm
2. Neural network

Cross-check on same events

CND Neutrons: Addressing from all sides

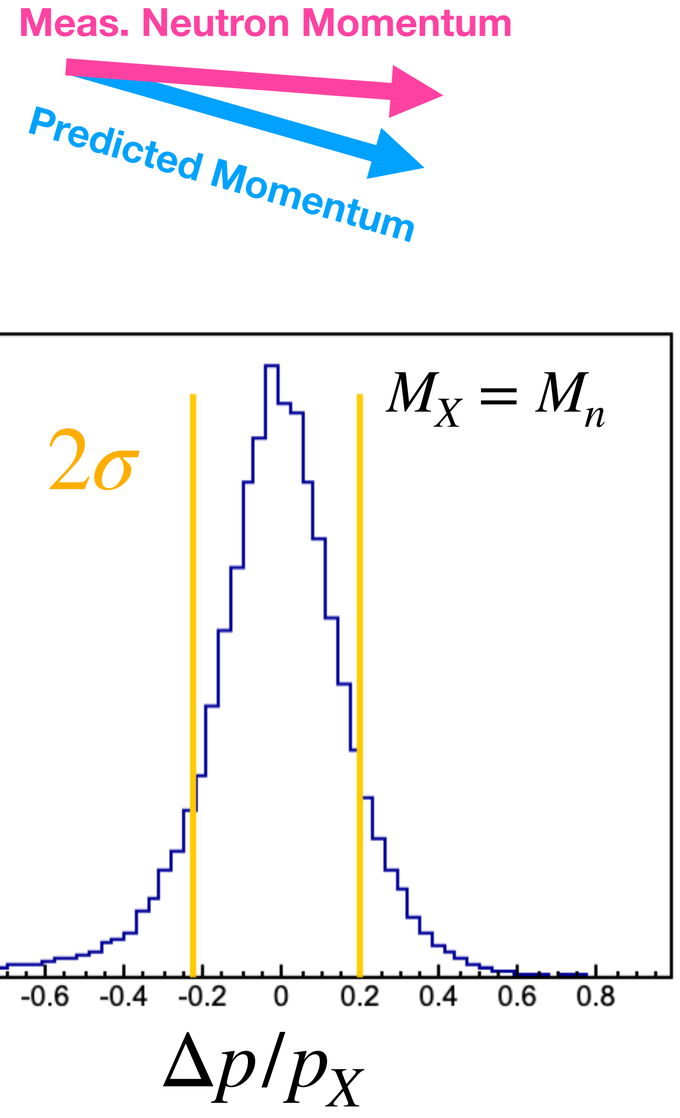
Nucleons selected from exclusive topologies in RGM **data**

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

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

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

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



CND Neutrons: Addressing from all sides

“Manual” algorithm



Igor Becker

Define “matched” hits: $\Delta t < 10$ ns and $\Delta \text{Sector}_{CND} \leq 1$

1. CTOF veto
2. Hit matched in both other CND layers → entire combination removed
3. Hit matched with charged particle’s CND hit → Removed
4. If Hit A matches Hit B and Hit B matches Hit C, Hits ABC are clustered

$$\sum_{Cluster} E_{dep} > 3 \text{ MeVee}$$

CND Neutrons: Addressing from all sides

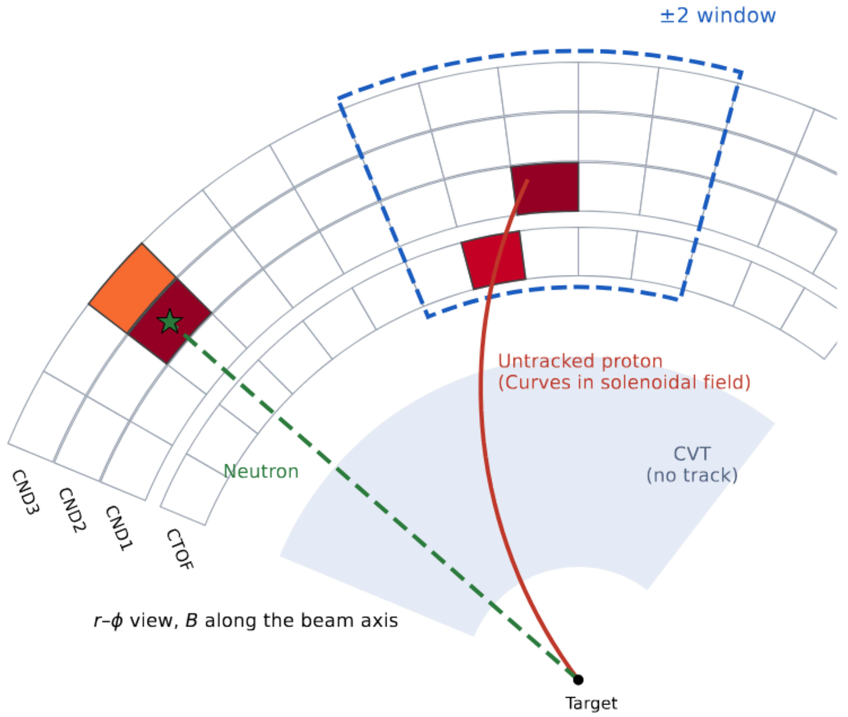
Neural network algorithm

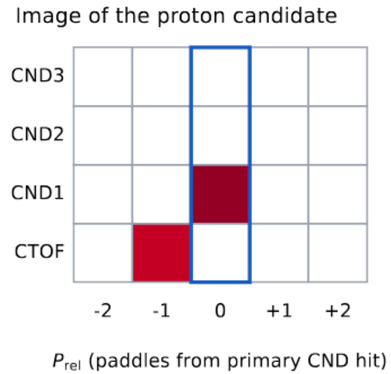
Hits placed on a grid to represent CND+CTOF

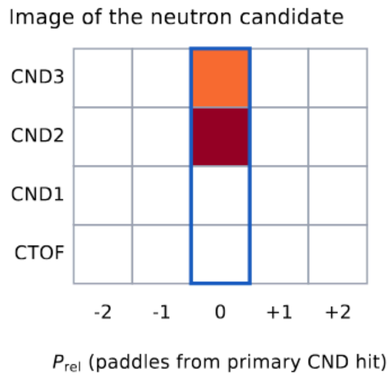
- “Primary” CND hit = most energetic attributed to reconstructed particle

- Primary CND hit defines center of grid

- After primary defined, all hits in grid area are added

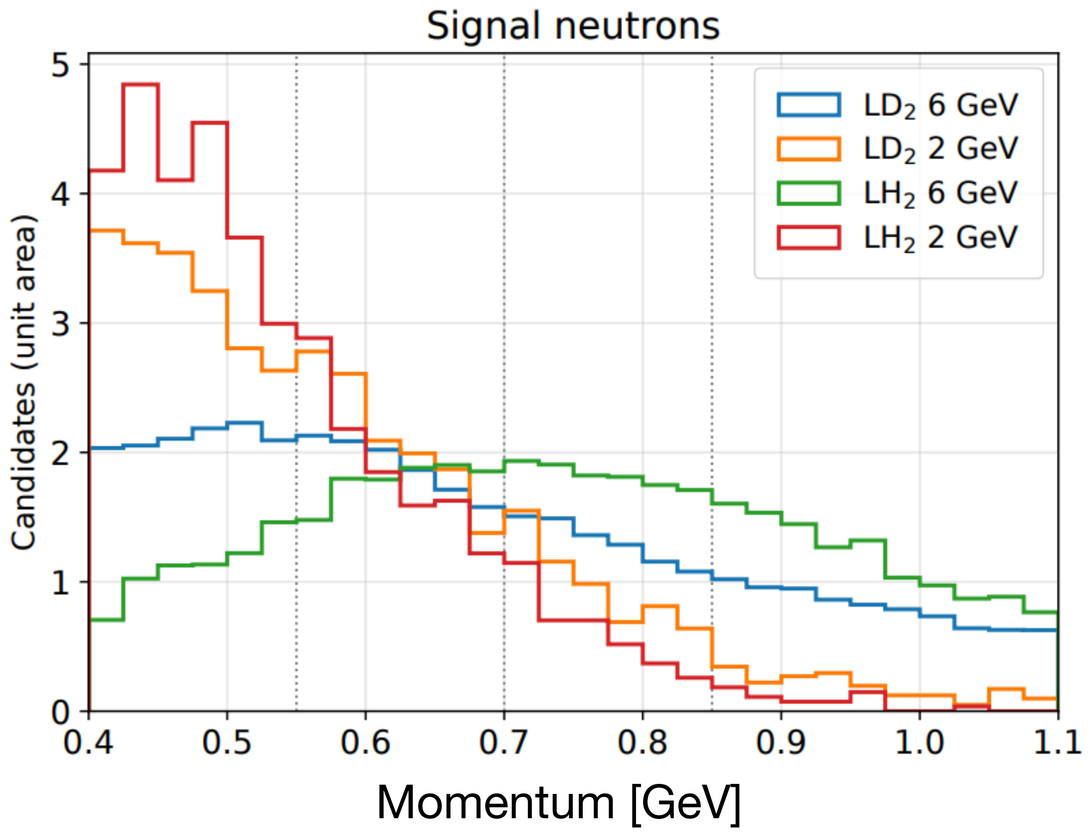


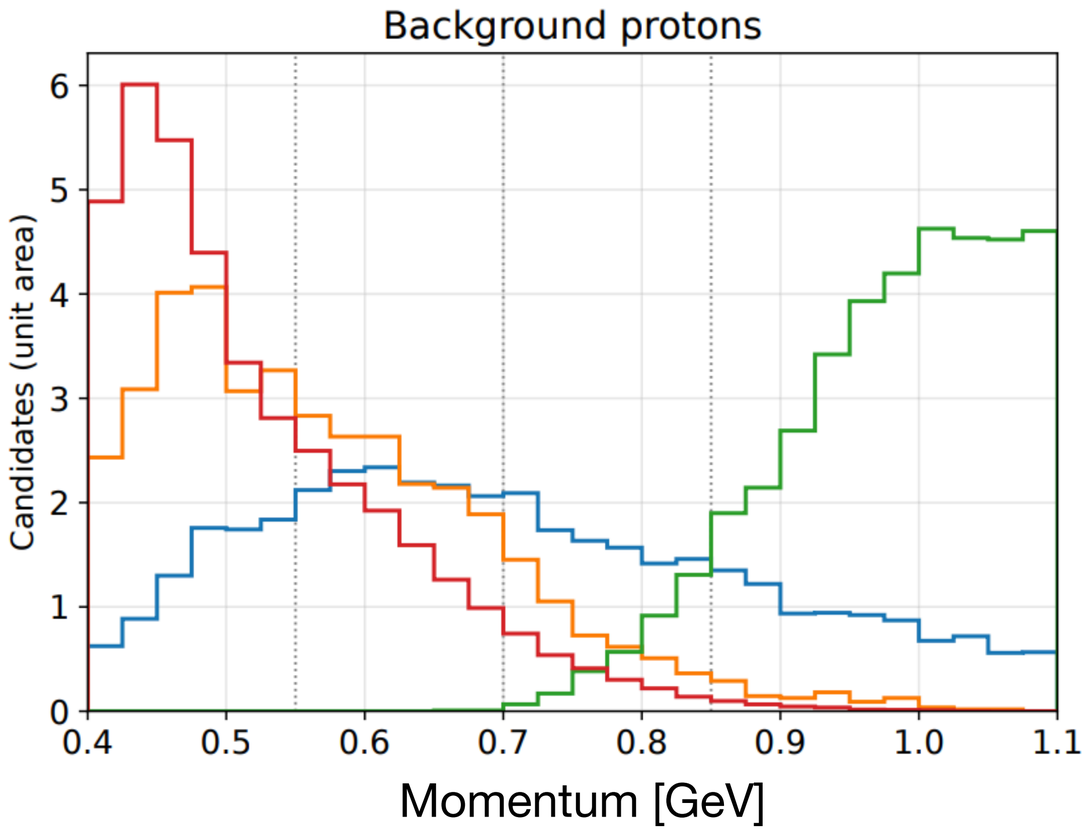




CND Neutrons: Addressing from all sides

Neural network algorithm





LD2 6 GeV:

Similar p, n kinematics

Momenta most similar to SRC recoil

→ Use for training, validate with other reactions

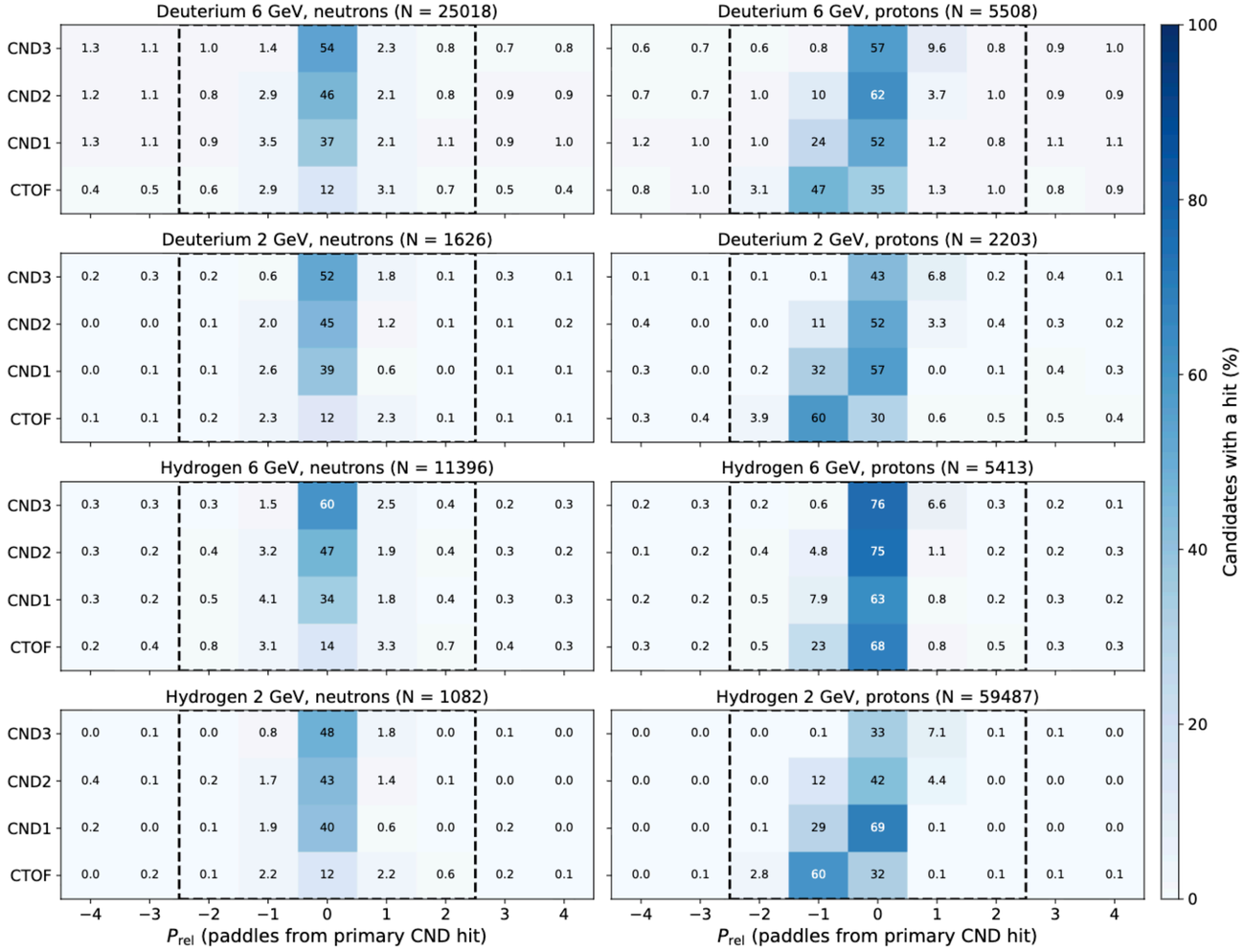
CND Neutrons: Addressing from all sides

Neural network algorithm

Hits placed on a grid to represent CND+CTOF

- Grid channels: Cluster time and energy

- Representation captures differing detector responses



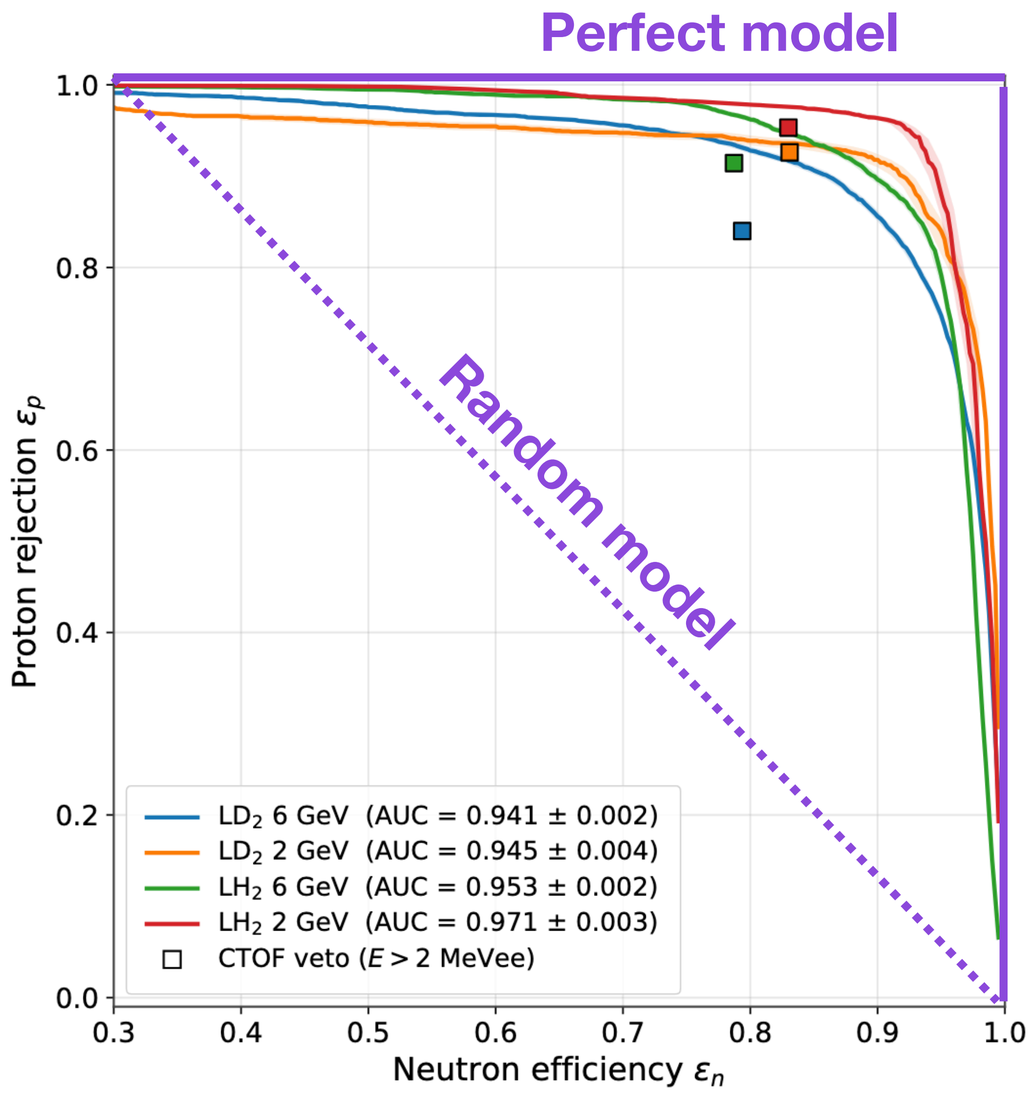
CND Neutrons: Addressing from all sides

Neural network algorithm

Area under ROC curve > .94 in all domains

Uncertainties shown:

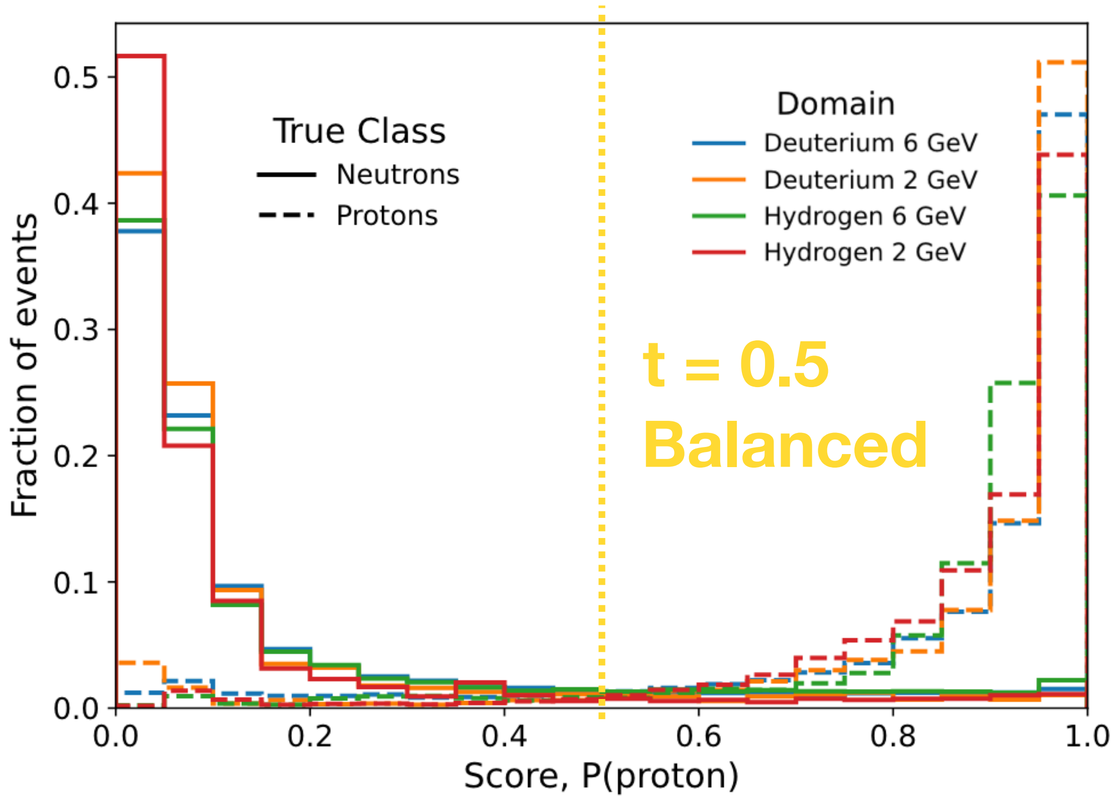
- Bootstrapping 68% CI
- Std. dev. from repeated training over different data slices



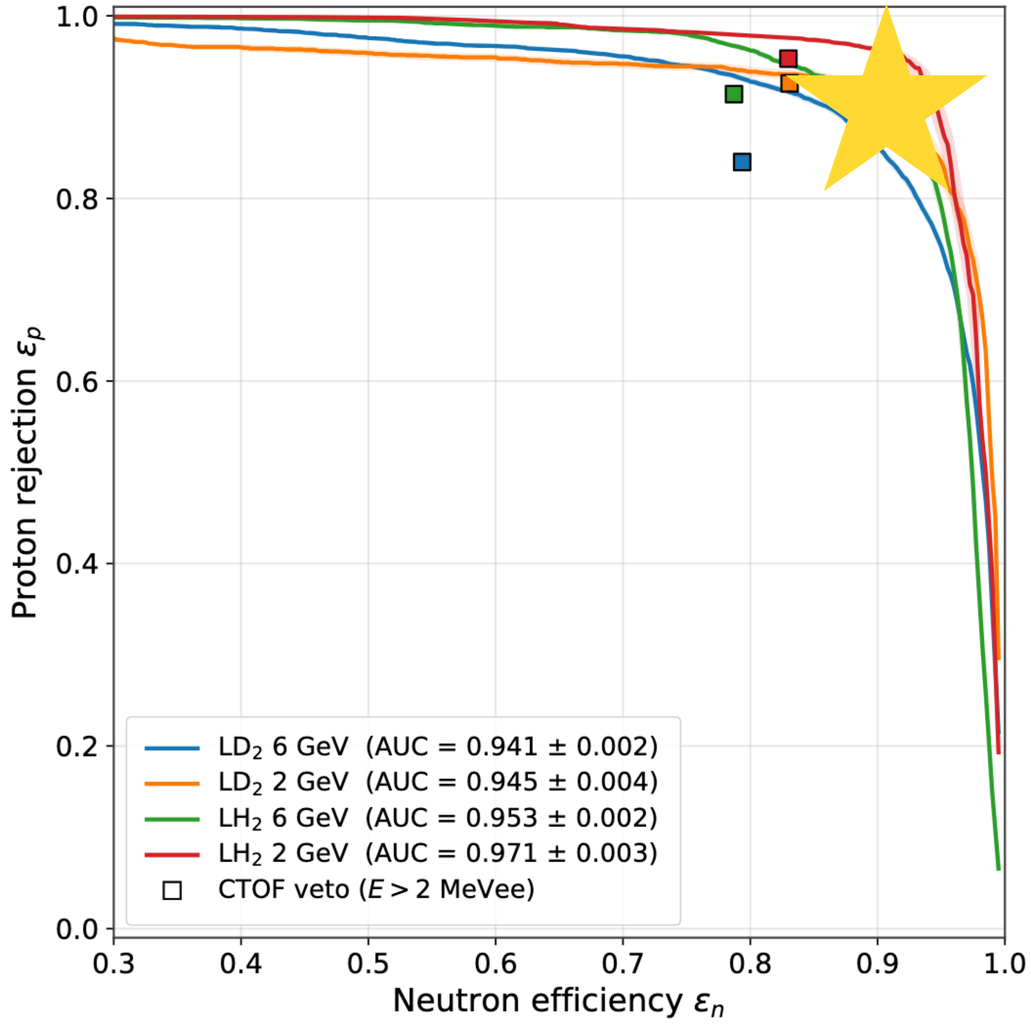
CND Neutrons: Addressing from all sides

Neural network algorithm

Advantage of NN: Continuity of operating points, can tailor to analysis



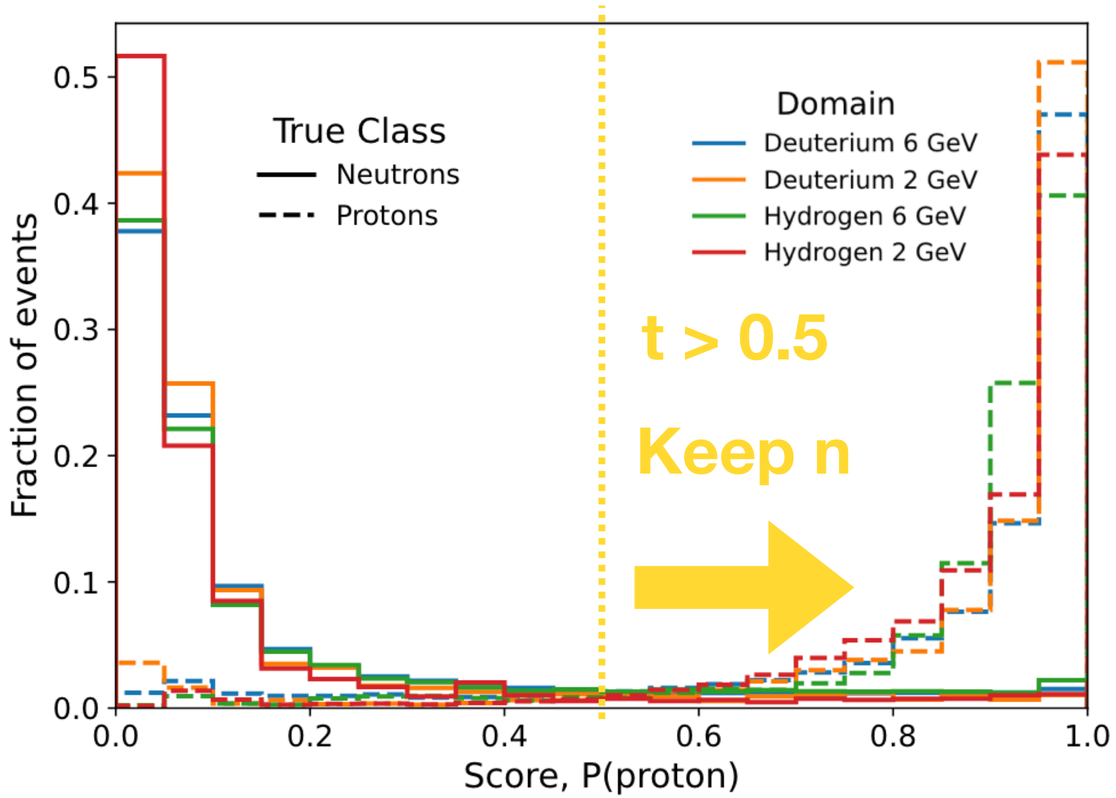
Balanced

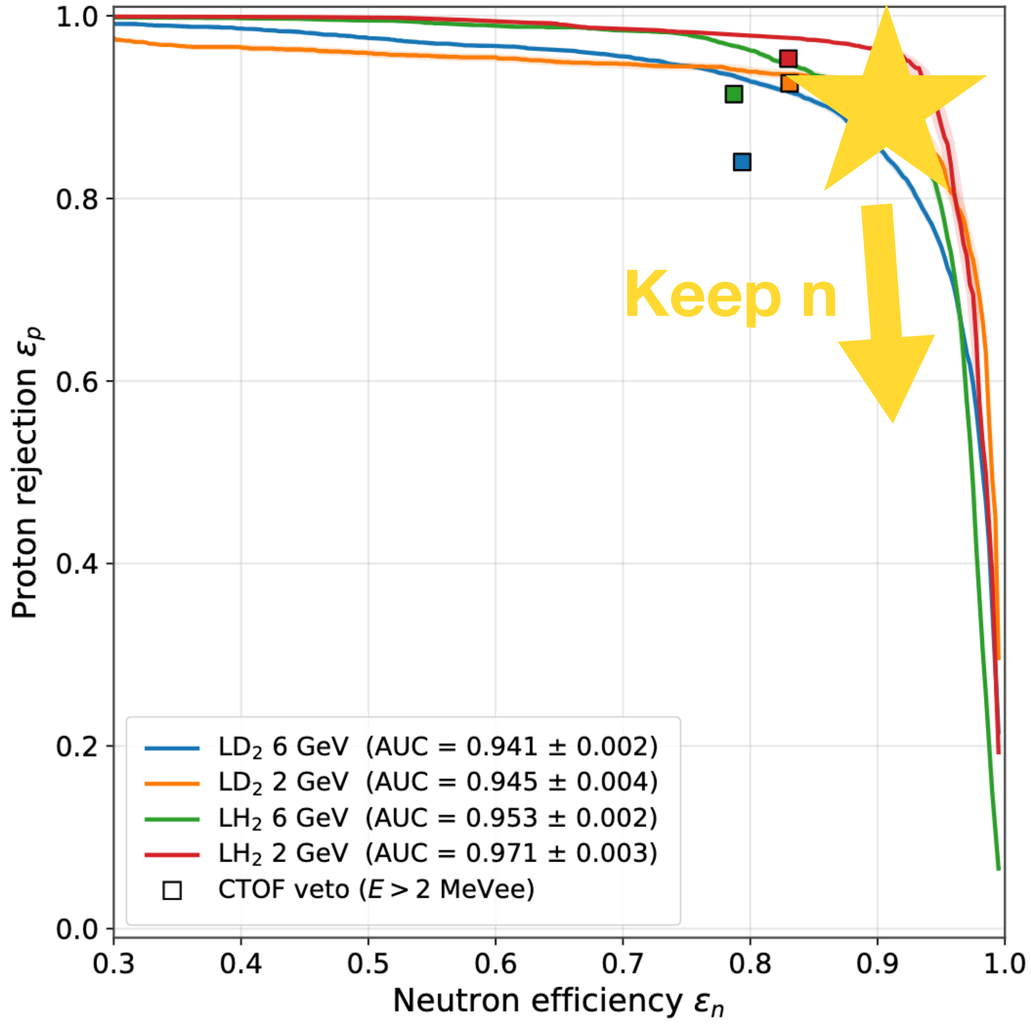


CND Neutrons: Addressing from all sides

Neural network algorithm

Advantage of NN: Continuity of operating points, can tailor to analysis

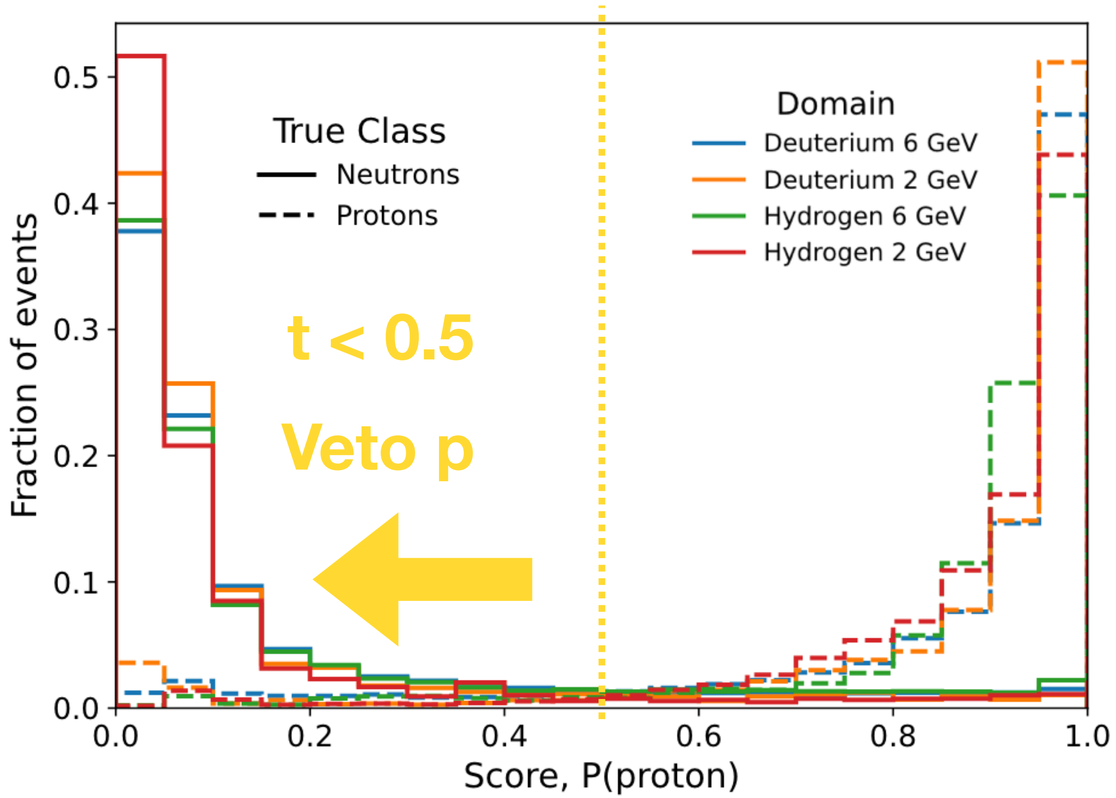


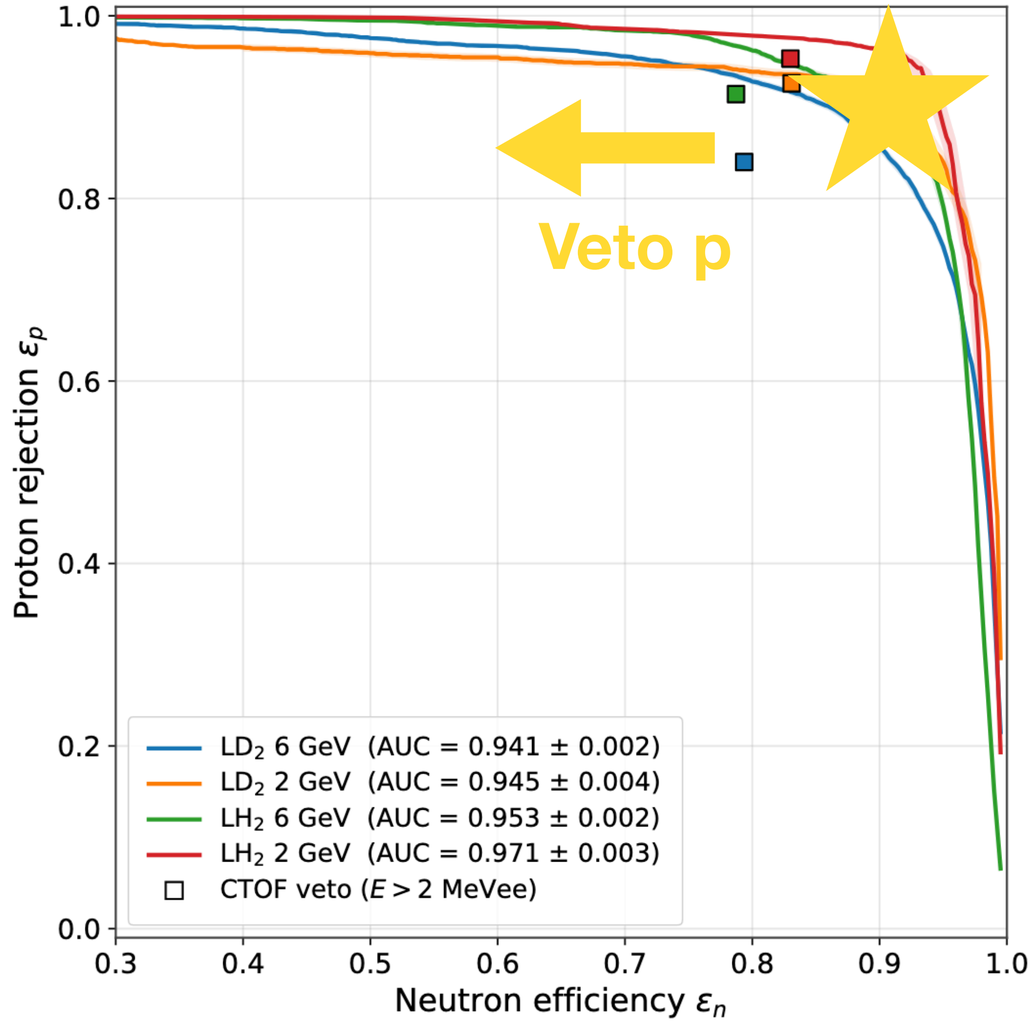


CND Neutrons: Addressing from all sides

Neural network algorithm

Advantage of NN: Continuity of operating points, can tailor to analysis





CND Neutrons: Addressing from all sides

Neural network algorithm

Illustrative point: Threshold where $\varepsilon_p^{ML} = 0.95$ in D2 6 GeV validation

- Keep > 70% of neutrons in all domains

- Consistent or better veto power across domains

Domain	Neutrons Kept	Protons Vetoed
D, 6 GeV	73.0 ± 0.3	95.0 *
D, 2 GeV	79.3 ± 1.1	94.1 ± 0.5
H, 6 GeV	71.2 ± 0.5	98.3 ± 0.2
H, 2 GeV	82.3 ± 1.2	97.3 ± 0.1

*by construction

CND Neutrons: Addressing from all sides

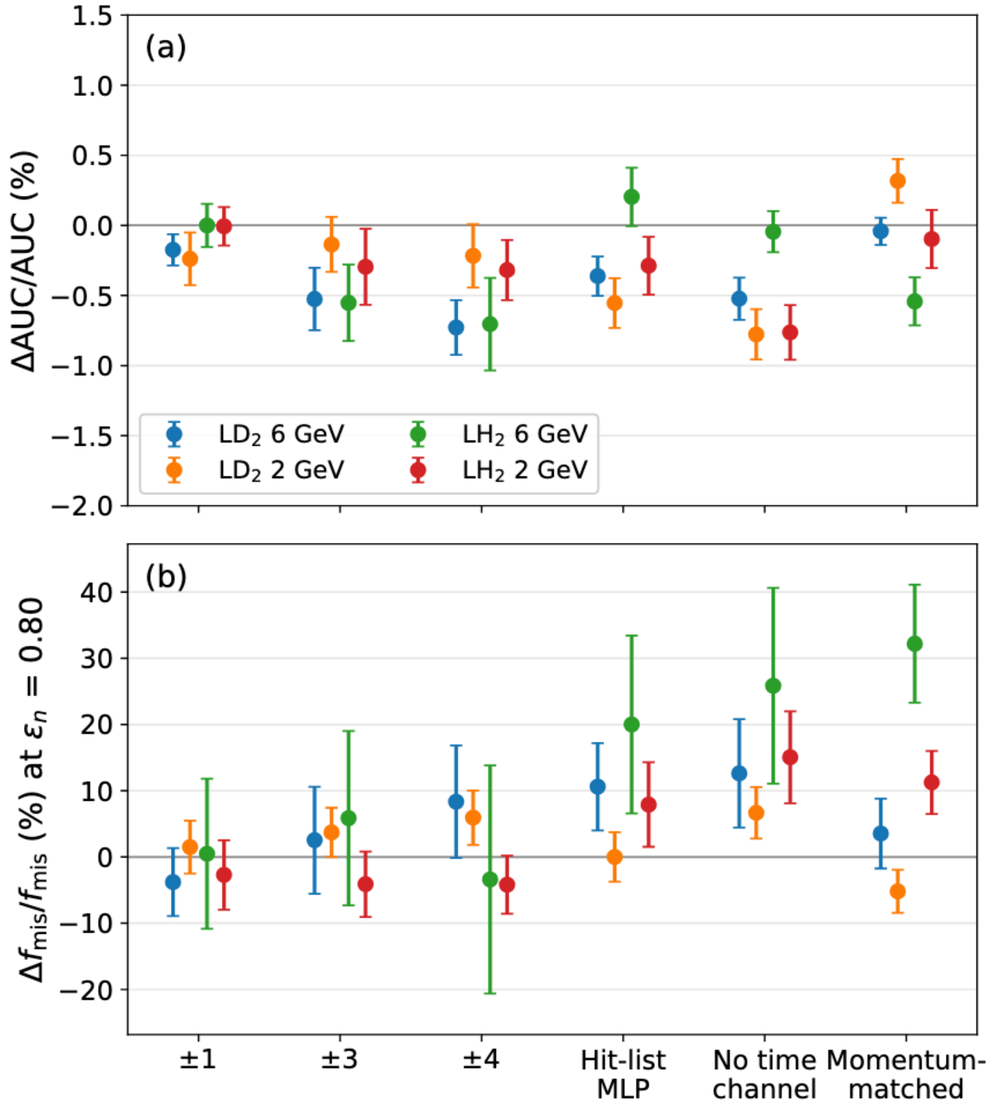
Neural network algorithm

Robustness checks:

1. Grid azimuth window size
2. Different NN architecture
3. Remove time channel
4. Match training momentum spectra

Overall discrimination

Proton rejection at fixed neutron retention

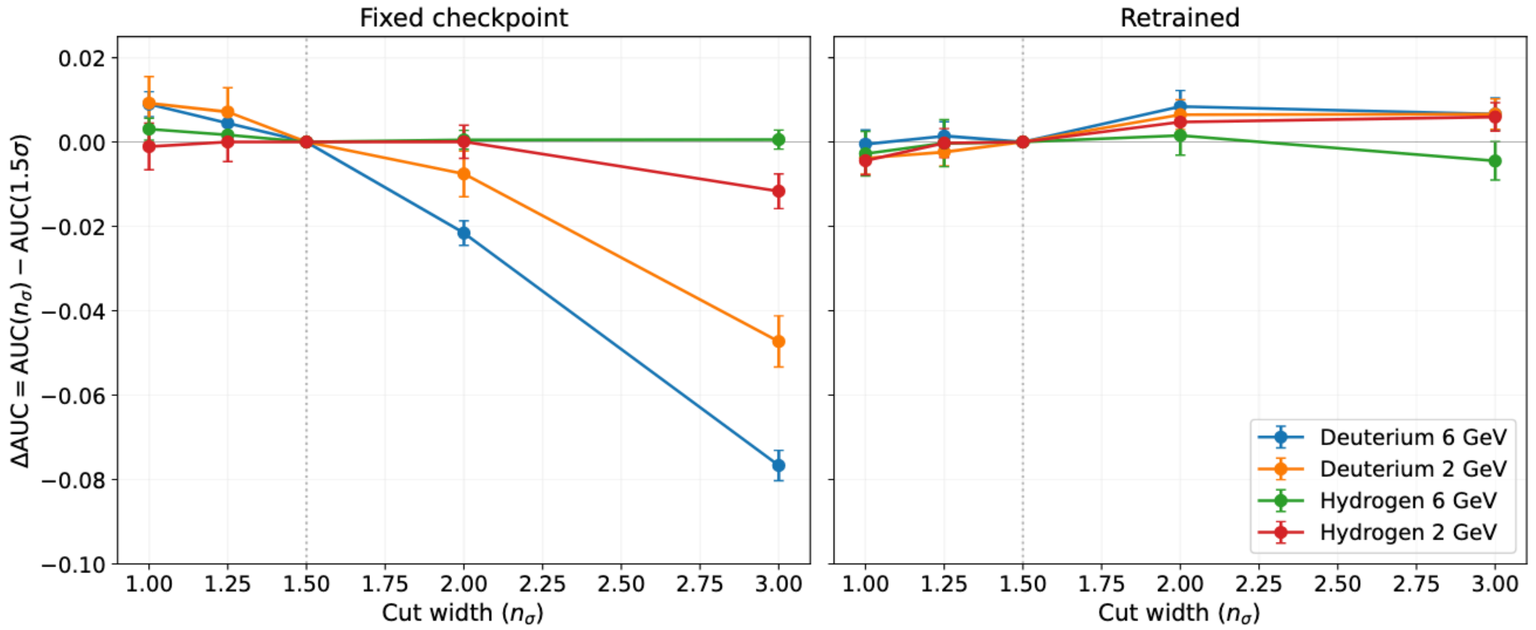


CND Neutrons: Addressing from all sides

Neural network algorithm

Robustness checks:

1. Grid azimuth window size
2. Different NN architecture
3. Remove time channel
4. Match training momentum spectra
5. Exclusive sample cut width sensitivity



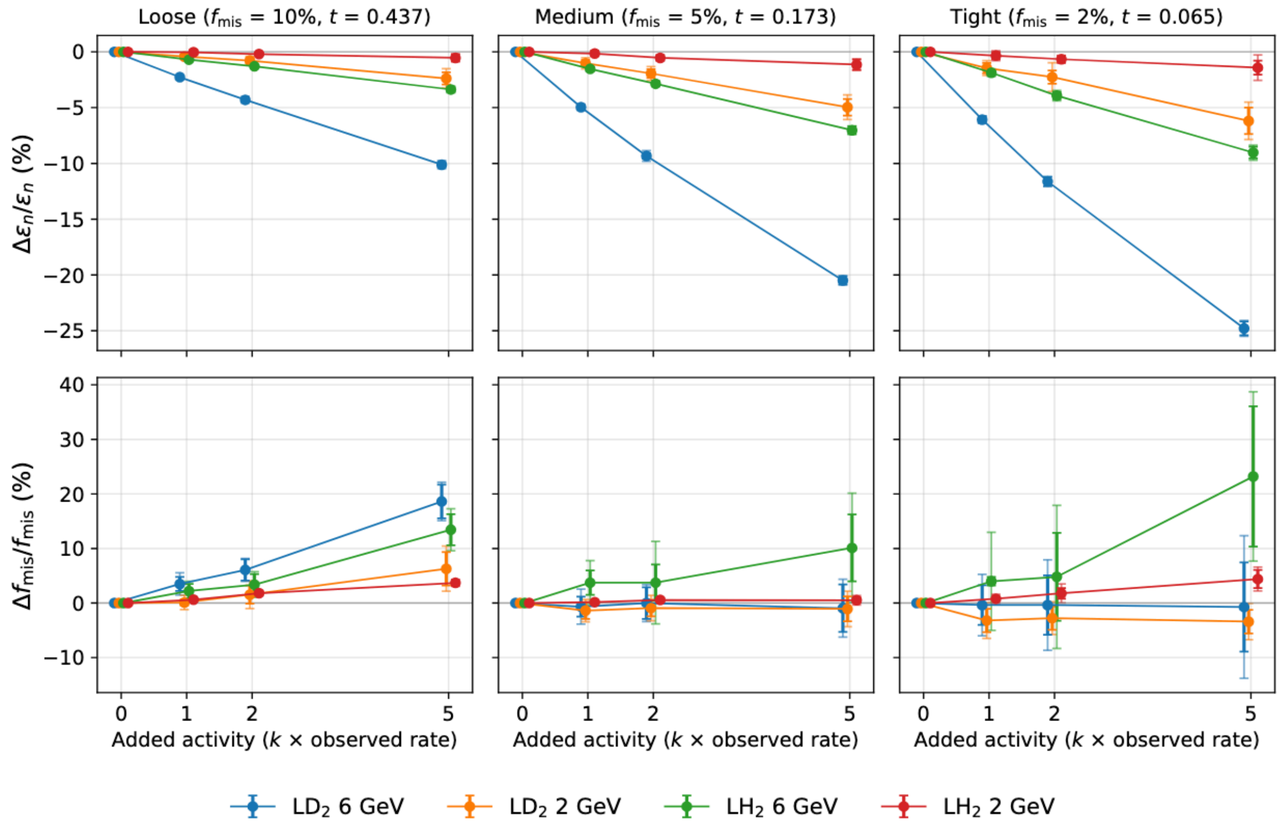
Model sensitive to impure evaluation samples but robust against less pure training

CND Neutrons: Addressing from all sides

Neural network algorithm

Robustness checks:

1. Grid azimuth window size
2. Different NN architecture
3. Remove time channel
4. Match training momentum spectra
5. Exclusive sample cut width sensitivity
6. Addition of random hits



Neutron retention decreases with added randoms, proton veto power relatively consistent

CND Neutrons: Addressing from all sides

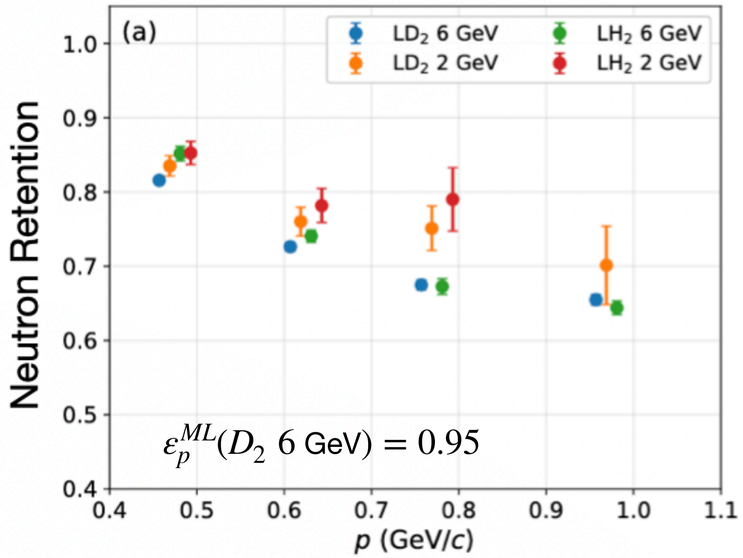
Neural network algorithm

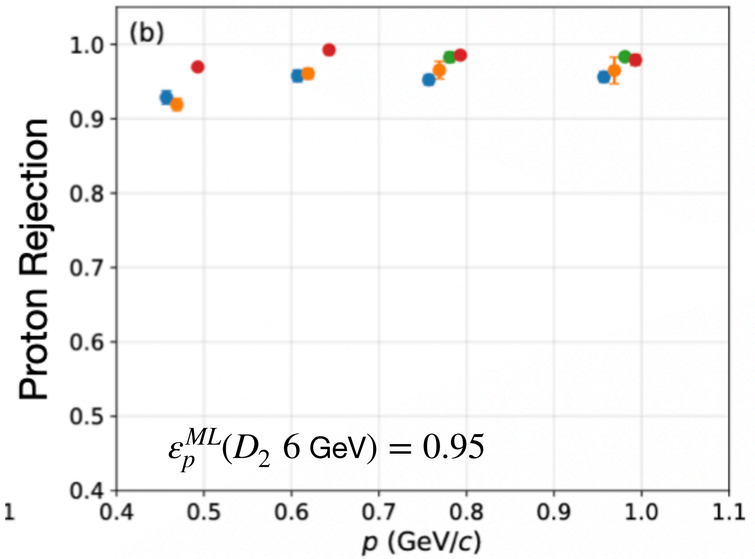
<u>Intended use: SRC recoils and similar</u>

- Validated on light nuclei
- $0.4 \leq p \leq 1.1$
- Must account for threshold-dept retention/veto changes

<u>Status:</u>

- Manuscript prepared for NIM-A
- Tool to be released: Recall rates for all domains at any threshold
- Implement in Iguana?





CND Neutrons: Addressing from all sides

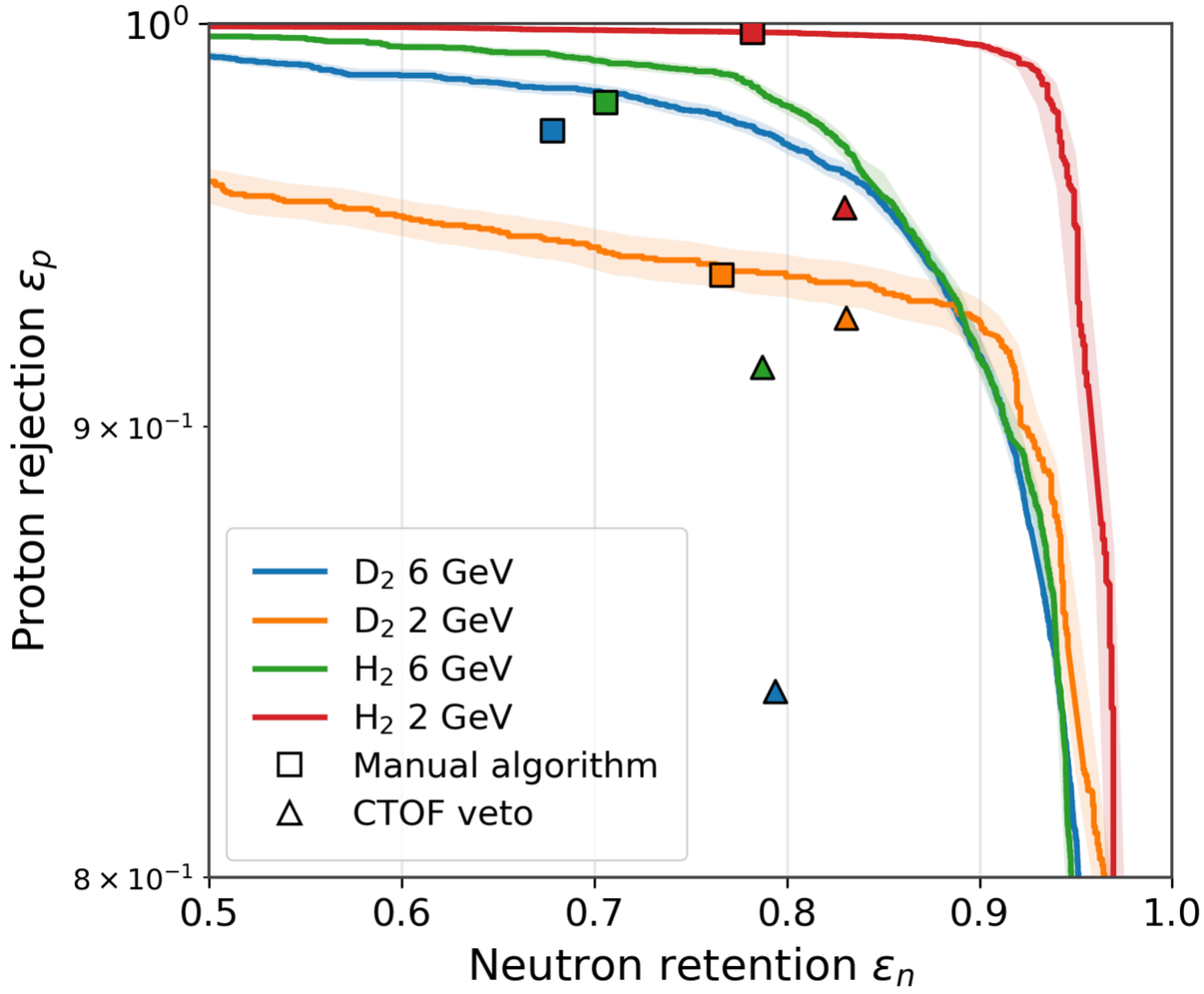
Algorithm comparison

- 2 GeV data: Manual algorithm nearly equivalent to CNN at matched neutron retention

- 6 GeV data: CNN outperforms manual algorithm, likely due to increased noise

- Overall, both improve over CTOF veto

- More on manual algorithm in next talk



Summary

Approved:

RGM common analysis note (e^-, p at 6 GeV)

GEMC Argon target implementation, A. Sportes

e4ν $1p1\pi$, J. T. Vidal

Calcium SRC pair ratios $e'p_{FD}$, J. Kahlbow

Analysis note in preparation:

$A(e,e'p(p))$ Q^2 dependence, N. Wright

CNN for CD neutron PID, N. Wright

$^4He(e,e'pn_{CD})$ σ_{CM}, I. Becker

Calcium SRC pair ratios $e'n_{FD}$, R. Wagner

Under analysis:

MEC contributions $e'pp$, $e'pn$, A. Sportes

Inclusive cross sections, M. Goldenberg

e4ν $1p0\pi$, P. Barham

Summary

Thank you and stay tuned!

9:50 AM	**RGM results on Calcium** **Speaker**: Mr Igor Becker
10:10 AM	**Inclusive electron scattering for neutrinos with CLAS12** **Speaker**: Matan Goldenberg

11:00 AM	**CLAS12 e4nu 1p analysis** **Speaker**: Pablo Barham
11:20 AM	**(e,e'n) SRC analysis on Calcium in the RGM experiment** **Speaker**: Ron Wagner (Tel Aviv University)

Backup

CND Neutrons: Addressing from all sides

Neural network algorithm

Samples span a range of beam energies and interaction processes:

Signal: Correctly ID'd neutrons

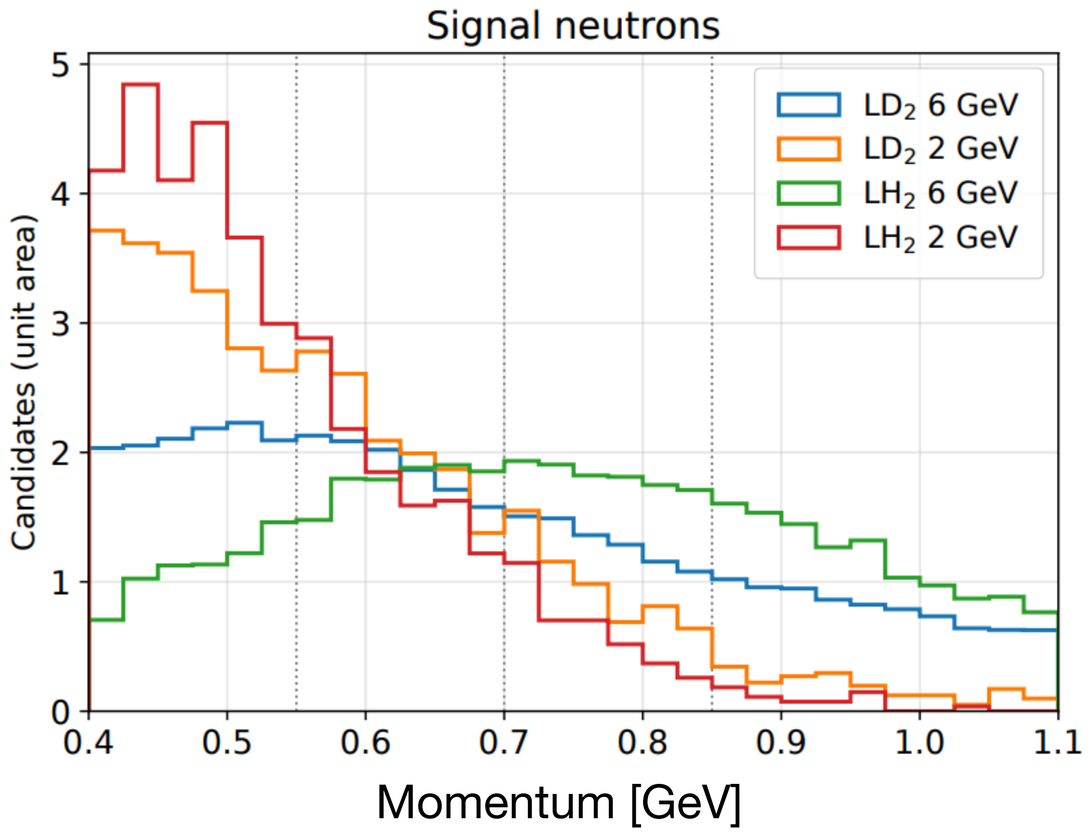
$D(e, e'pn)$	2 GeV
$D(e, e'pn)$	6 GeV
$H(e, e'\pi^+ n)$	6 GeV
$H(e, e'\pi^+ n)$	2 GeV

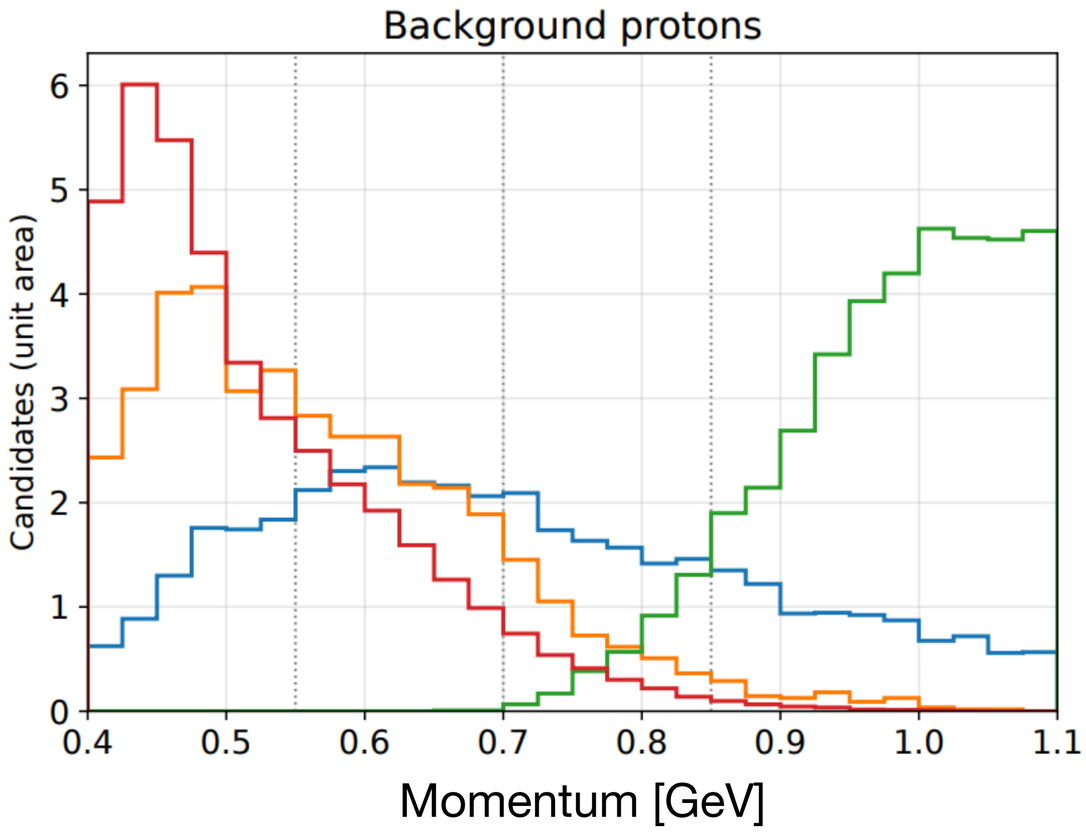
Background: Protons ID'd as neutrons

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

CND Neutrons: Addressing from all sides

Neural network algorithm



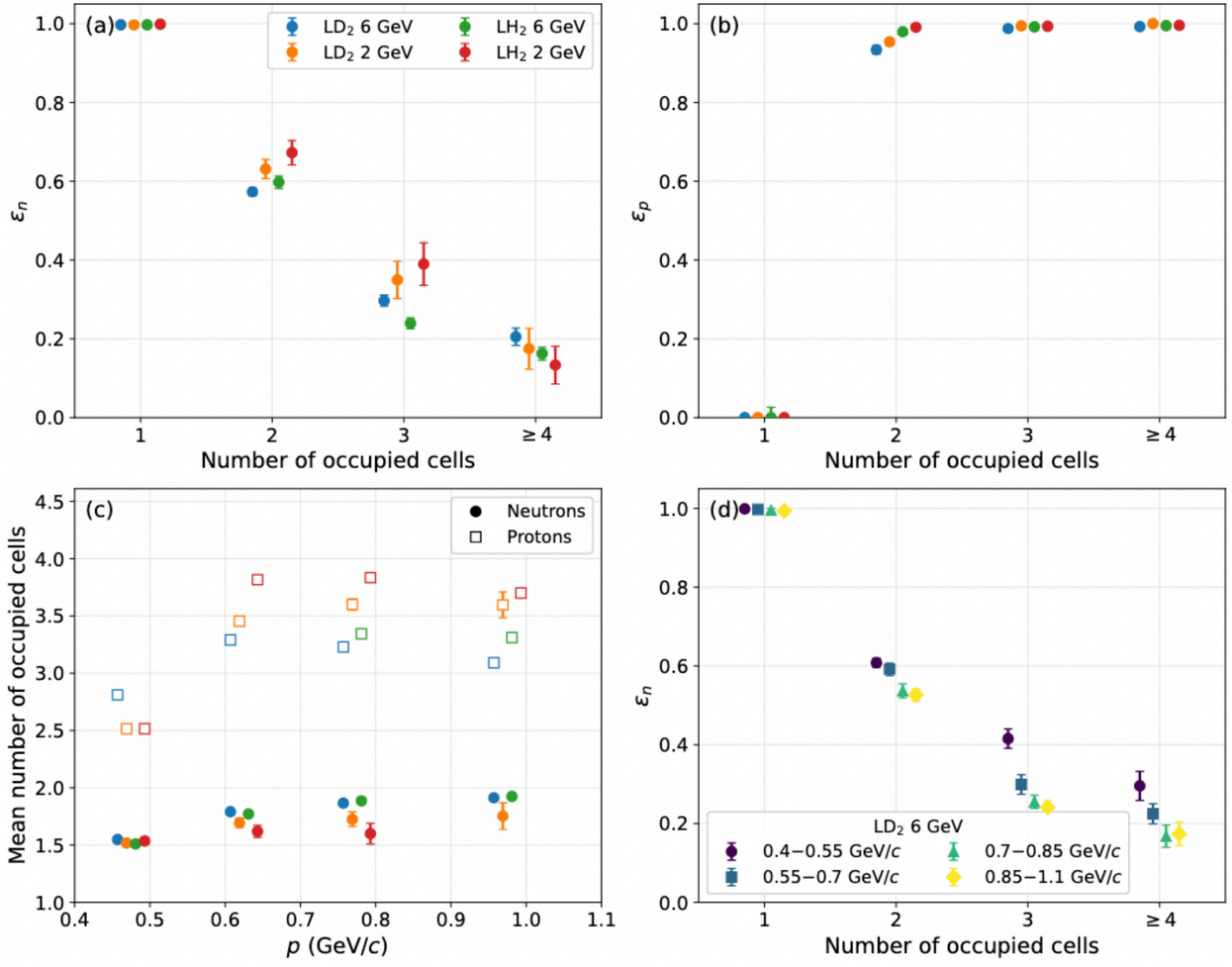


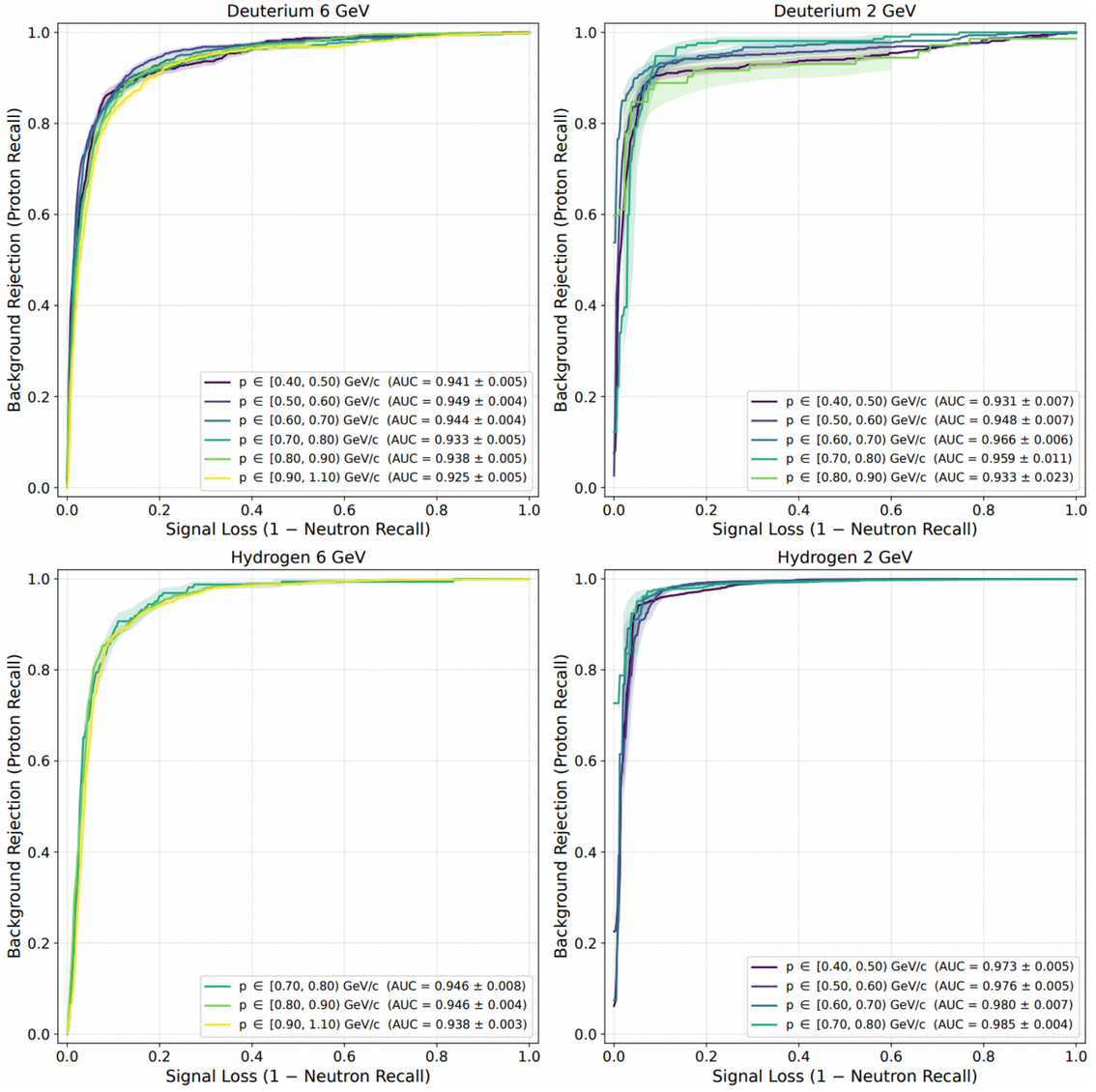
LD2 6 GeV:

Similar p, n kinematics

Momenta most similar to SRC recoil

→ Use for training, validate with other reactions


(a)
LD$_2$ 6 GeV
LD$_2$ 2 GeV
LH$_2$ 6 GeV
LH$_2$ 2 GeV
ε_n
Number of occupied cells
(b)
ε_p
Number of occupied cells
(c)
Neutrons
Protons
Mean number of occupied cells
p (GeV/c)
(d)
ε_n
LD$_2$ 6 GeV
0.4−0.55 GeV/c
0.55−0.7 GeV/c
0.7−0.85 GeV/c
0.85−1.1 GeV/c
Number of occupied cells

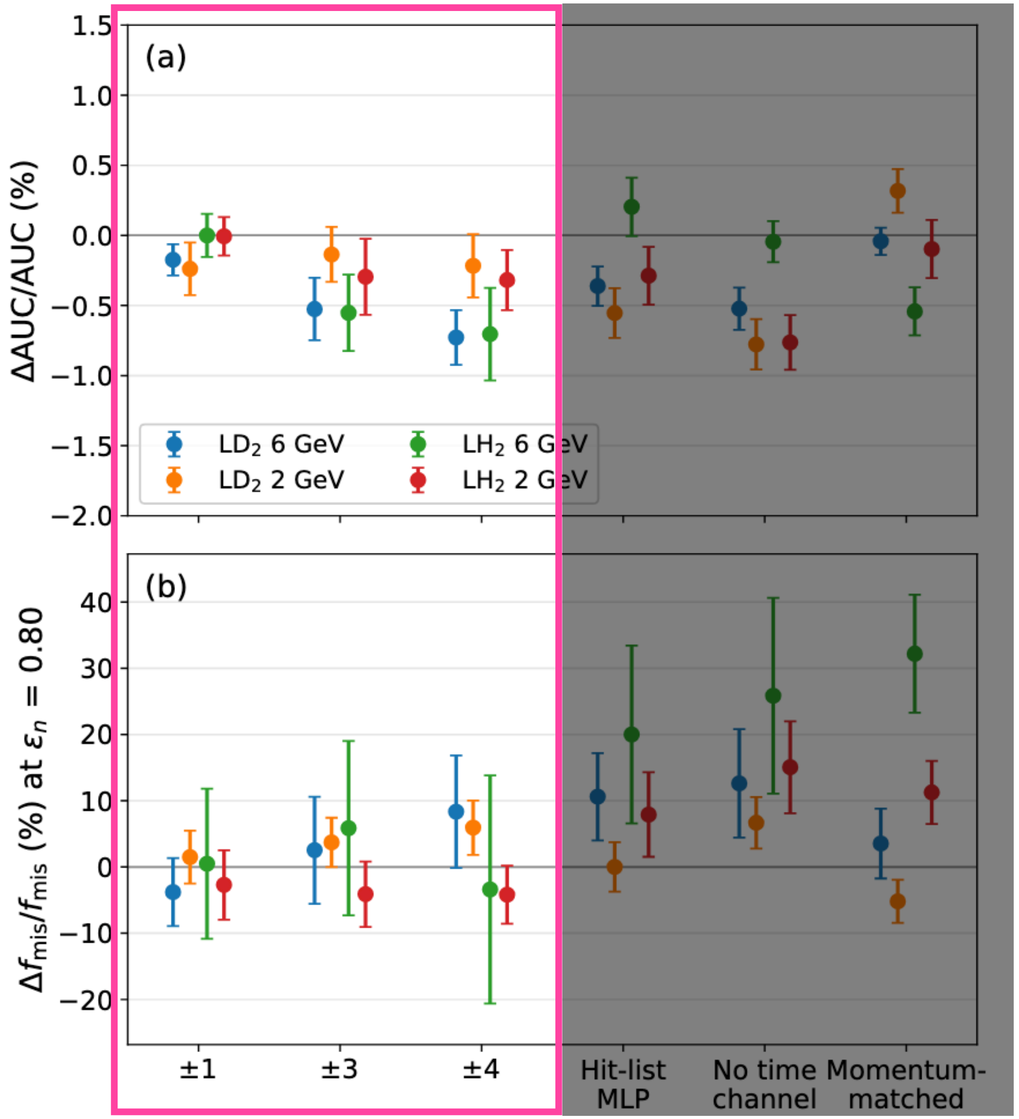

Deuterium 6 GeV
p ∈ [0.40, 0.50) GeV/c (AUC = 0.941 ± 0.005)
p ∈ [0.50, 0.60) GeV/c (AUC = 0.949 ± 0.004)
p ∈ [0.60, 0.70) GeV/c (AUC = 0.944 ± 0.004)
p ∈ [0.70, 0.80) GeV/c (AUC = 0.933 ± 0.005)
p ∈ [0.80, 0.90) GeV/c (AUC = 0.938 ± 0.005)
p ∈ [0.90, 1.10) GeV/c (AUC = 0.925 ± 0.005)
Deuterium 2 GeV
p ∈ [0.40, 0.50) GeV/c (AUC = 0.931 ± 0.007)
p ∈ [0.50, 0.60) GeV/c (AUC = 0.948 ± 0.007)
p ∈ [0.60, 0.70) GeV/c (AUC = 0.966 ± 0.006)
p ∈ [0.70, 0.80) GeV/c (AUC = 0.959 ± 0.011)
p ∈ [0.80, 0.90) GeV/c (AUC = 0.933 ± 0.023)
Hydrogen 6 GeV
p ∈ [0.70, 0.80) GeV/c (AUC = 0.946 ± 0.008)
p ∈ [0.80, 0.90) GeV/c (AUC = 0.946 ± 0.004)
p ∈ [0.90, 1.10) GeV/c (AUC = 0.938 ± 0.003)
Hydrogen 2 GeV
p ∈ [0.40, 0.50) GeV/c (AUC = 0.973 ± 0.005)
p ∈ [0.50, 0.60) GeV/c (AUC = 0.976 ± 0.005)
p ∈ [0.60, 0.70) GeV/c (AUC = 0.980 ± 0.007)
p ∈ [0.70, 0.80) GeV/c (AUC = 0.985 ± 0.004)
Background Rejection (Proton Recall)
Signal Loss (1 − Neutron Recall)

CND Neutrons: Addressing from all sides

Neural network algorithm

Robustness checks:

1. Grid azimuth window size



CND Neutrons: Addressing from all sides

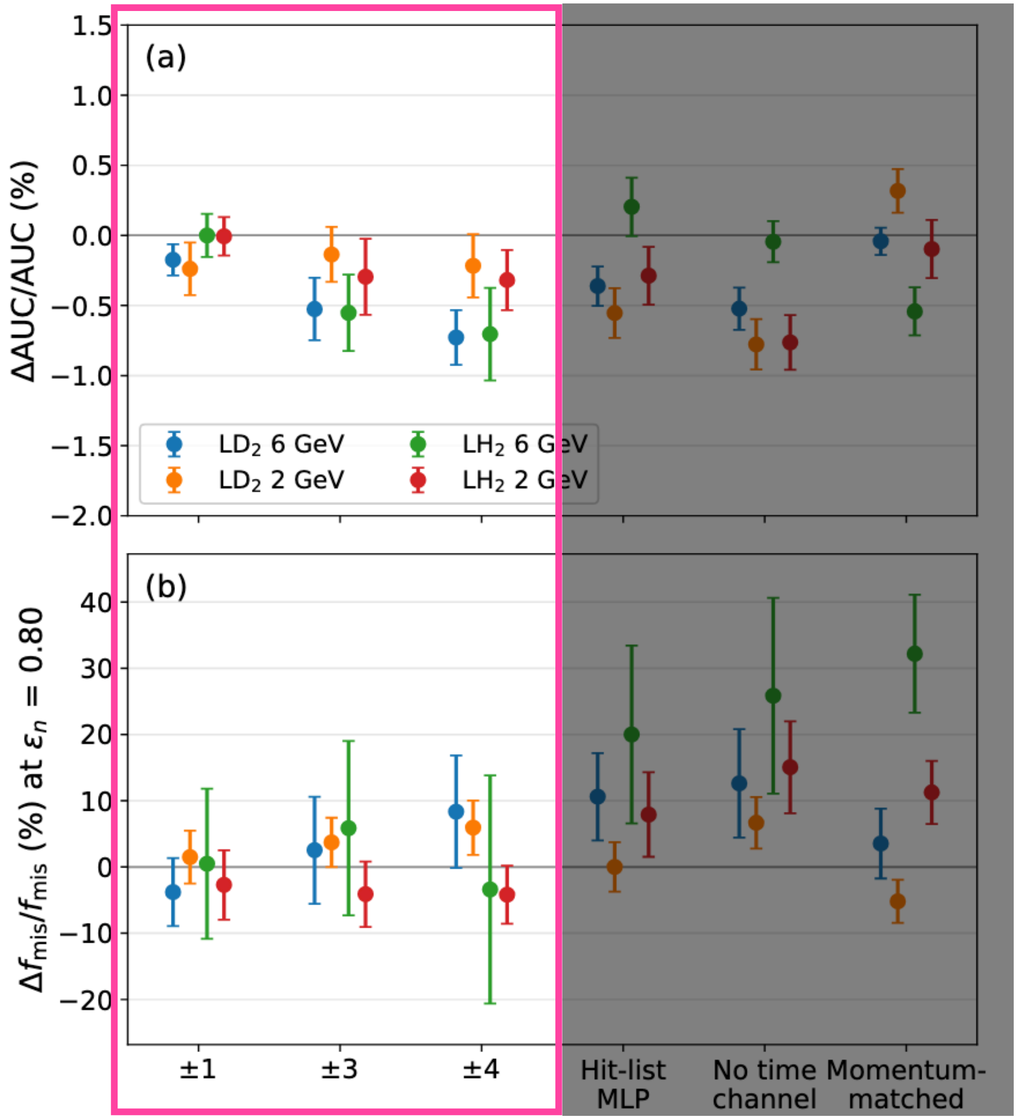
Neural network algorithm

Robustness checks:

1. Grid azimuth window size

Overall discrimination

Proton rejection at fixed neutron retention

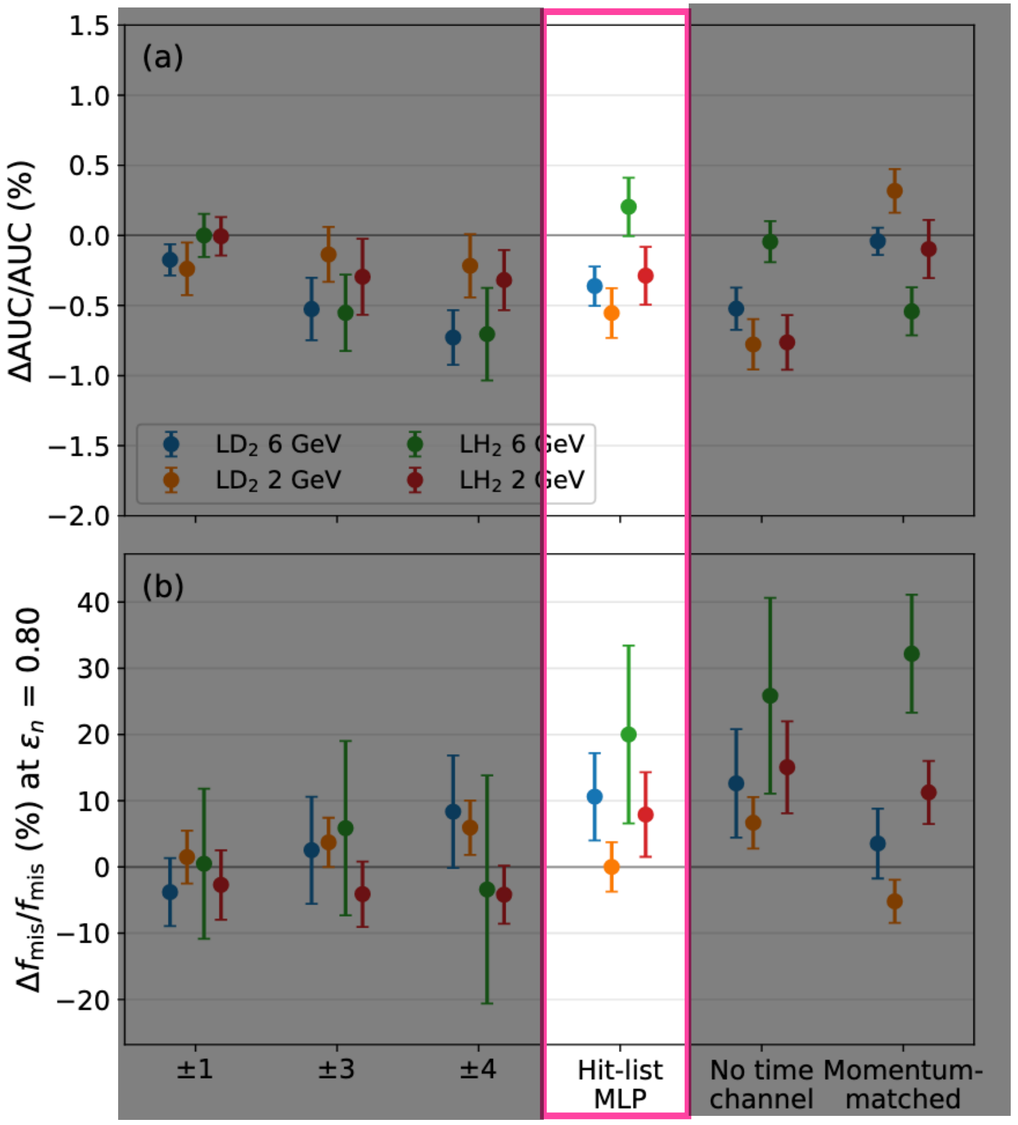


CND Neutrons: Addressing from all sides

Neural network algorithm

Robustness checks:

1. Grid azimuth window size
2. Different NN architecture



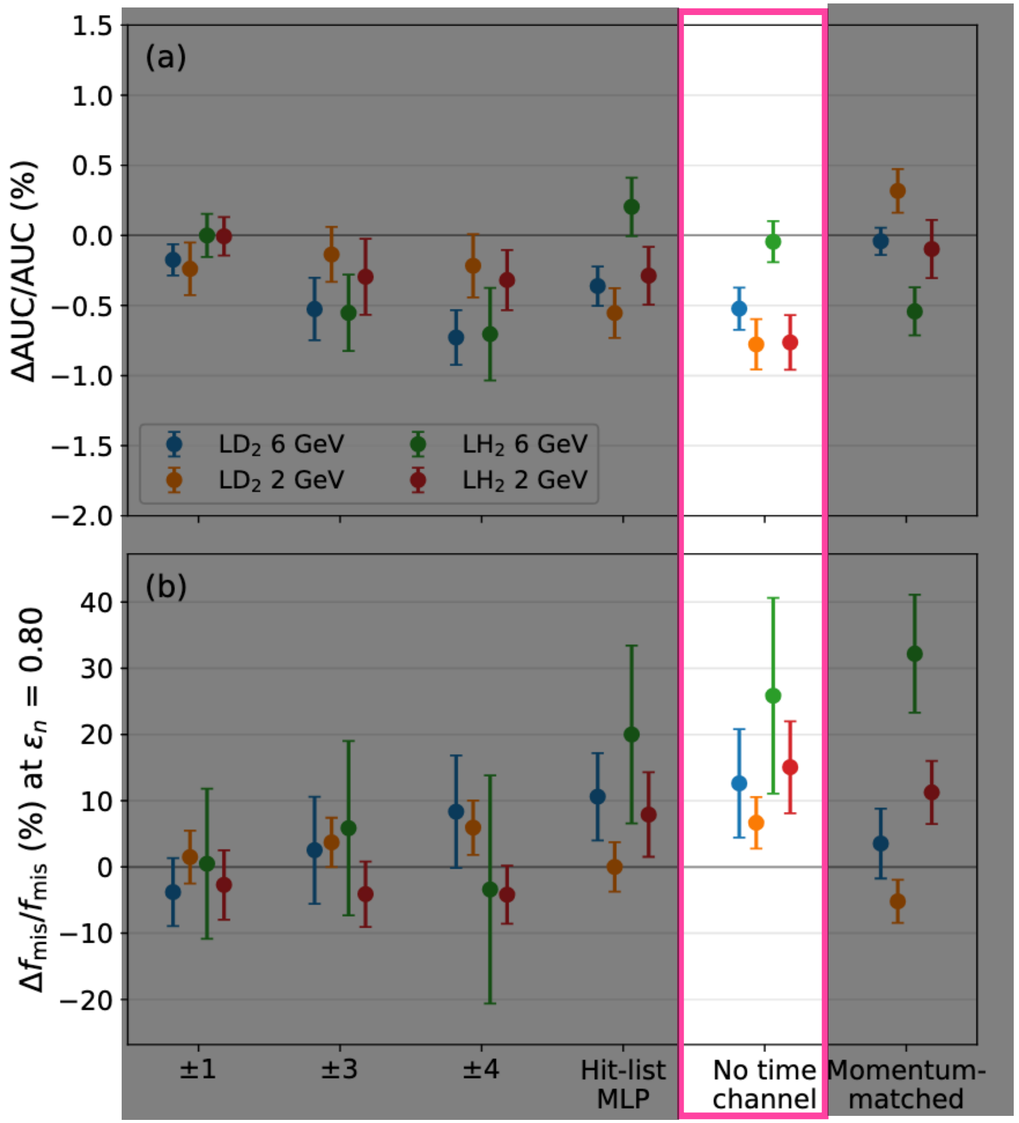
CND Neutrons: Addressing from all sides

Neural network algorithm

Robustness checks:

1. Grid azimuth window size
2. Different NN architecture
3. Remove time channel

   Momentum encoded?



CND Neutrons: Addressing from all sides

Neural network algorithm

Robustness checks:

1. Grid azimuth window size
2. Different NN architecture
3. Remove time channel
4. Match training momentum spectra

