UNIVERSITY OF CAMBRIDGE

DEEP UNDERGROUND NEUTRINO EXPERIMENT

Transverse Kinematic Imbalance Study in ProtoDUNE-SP for the interaction proton-argon

Joint APP/HEPP Meeting 2022
6th April, 2022

Stefano Vergani for the DUNE Collaboration

OVERVIEW

- Transverse Kinematic Imbalance Analysis
- DUNE and ProtoDUNE Single Phase
- Primary Particle Selection
- Interaction Selection
- Observables in the pion study

Transverse Kinematic Imbalance: Scope

Transverse Kinematic Imbalance (TKI) is a technique used to measure intranuclear dynamics in particle – nucleus interaction.

These dynamics are poorly understood -> important to create better models.

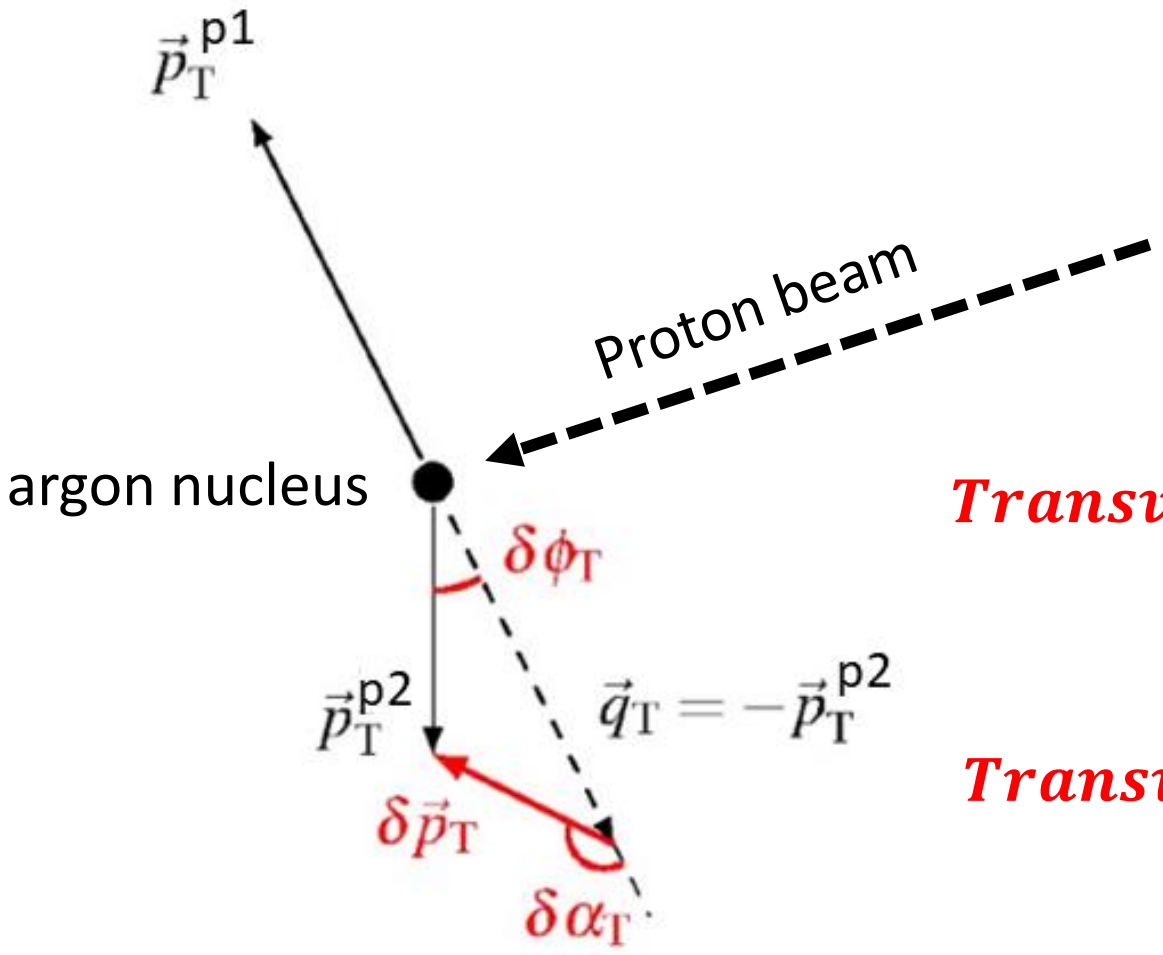
Better models will turn into better simulations -> more precise measurements in particle physics.

Transverse Kinematic Imbalance in Neutrino Physics

TKI analysis is applied to a variety of neutrino physics experiments studying different interactions.

- T2K Off-Axis Near Detector: $\nu_\mu + p \rightarrow \mu^- + \pi^+ + p$ (https://arxiv.org/abs/2102.03346)
- MINERvA: $\nu_\mu + n \rightarrow \mu^- + p$ (Phys.Rev.D 101, 092001, 2020)
- ProtoDUNE Single Phase (SP):
  1. $\pi^+ + p\left({}^{40}Ar\right) \rightarrow \pi^+ + p$
  2. $\pi^+ + n\left({}^{40}Ar\right) \rightarrow \pi^0 + p$
  3. $p + {}^{40}Ar \rightarrow p + p$

TKI Observables for $p + {}^{40}Ar \rightarrow p + p$



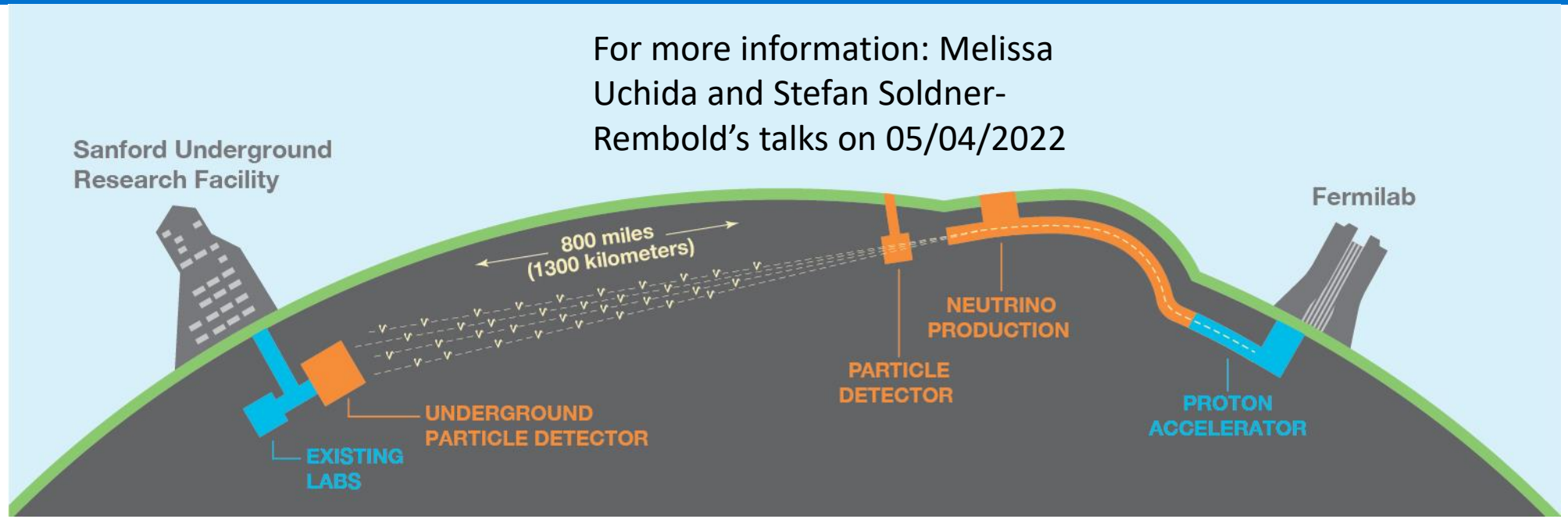
[Lu. *et al.* Phys. Rev. D92, 051302 (2015), Lu. *et al.* Phys. Rev. C94, 015503 (2016)]

Transverse Momentum Imbalance $\delta\overrightarrow{p_T} \equiv \overrightarrow{p_T^{p1}} + \overrightarrow{p_T^{p2}}$

Transverse Boosting Angle $\delta\alpha_T \equiv \arccos \dfrac{-\overrightarrow{p_T^{p1}}\,\delta\overrightarrow{p_T}}{\overrightarrow{p_T^{p1}}\,\delta\overrightarrow{p_T}}$

Deep Underground Neutrino Experiment

For more information: Melissa Uchida and Stefan Soldner-Rembold's talks on 05/04/2022

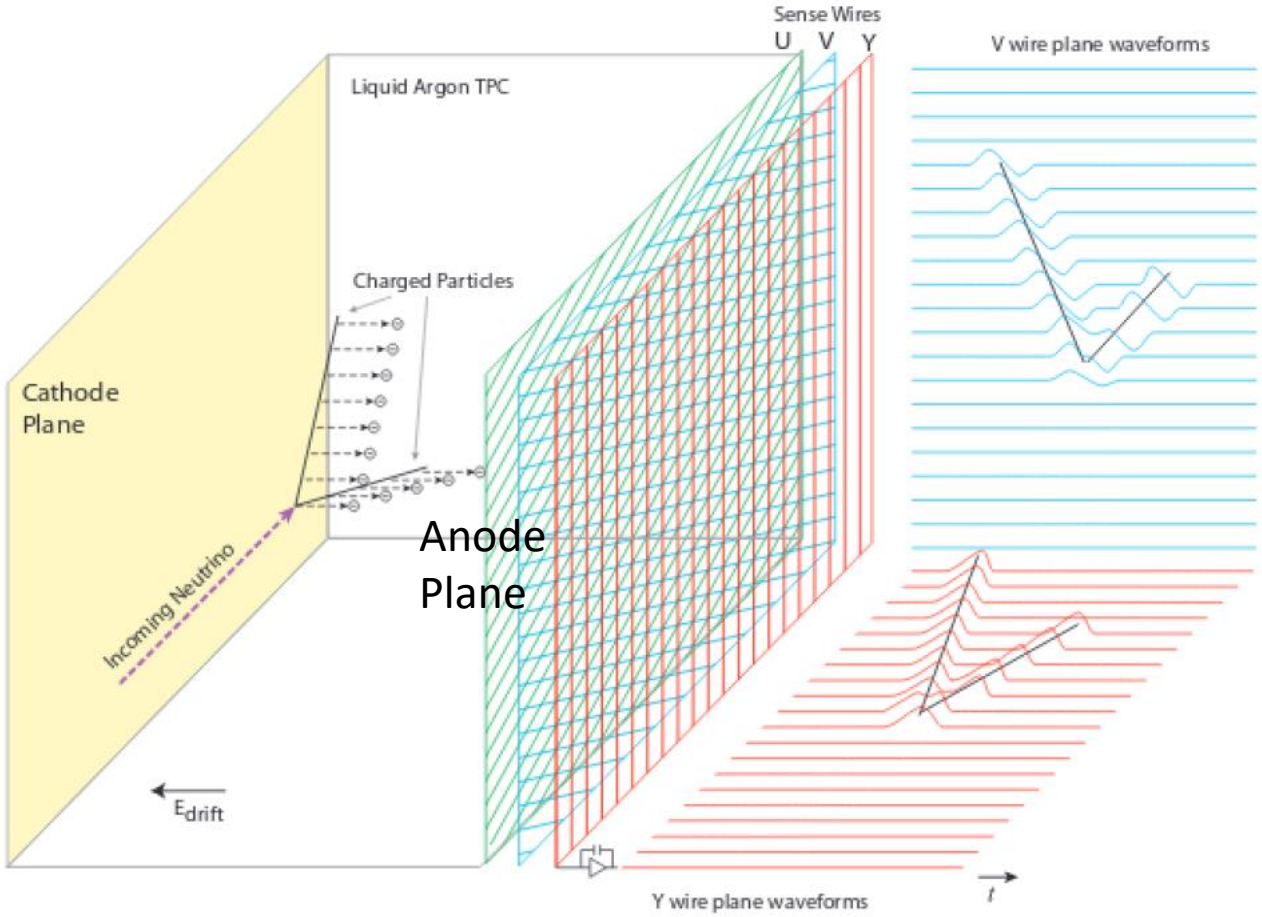


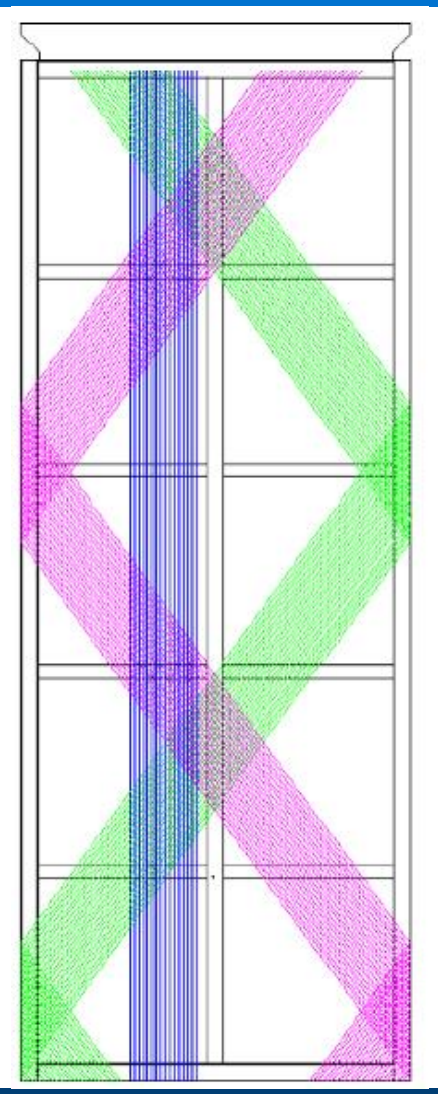
ORIGIN OF MATTER

UNIFICATION OF FORCES

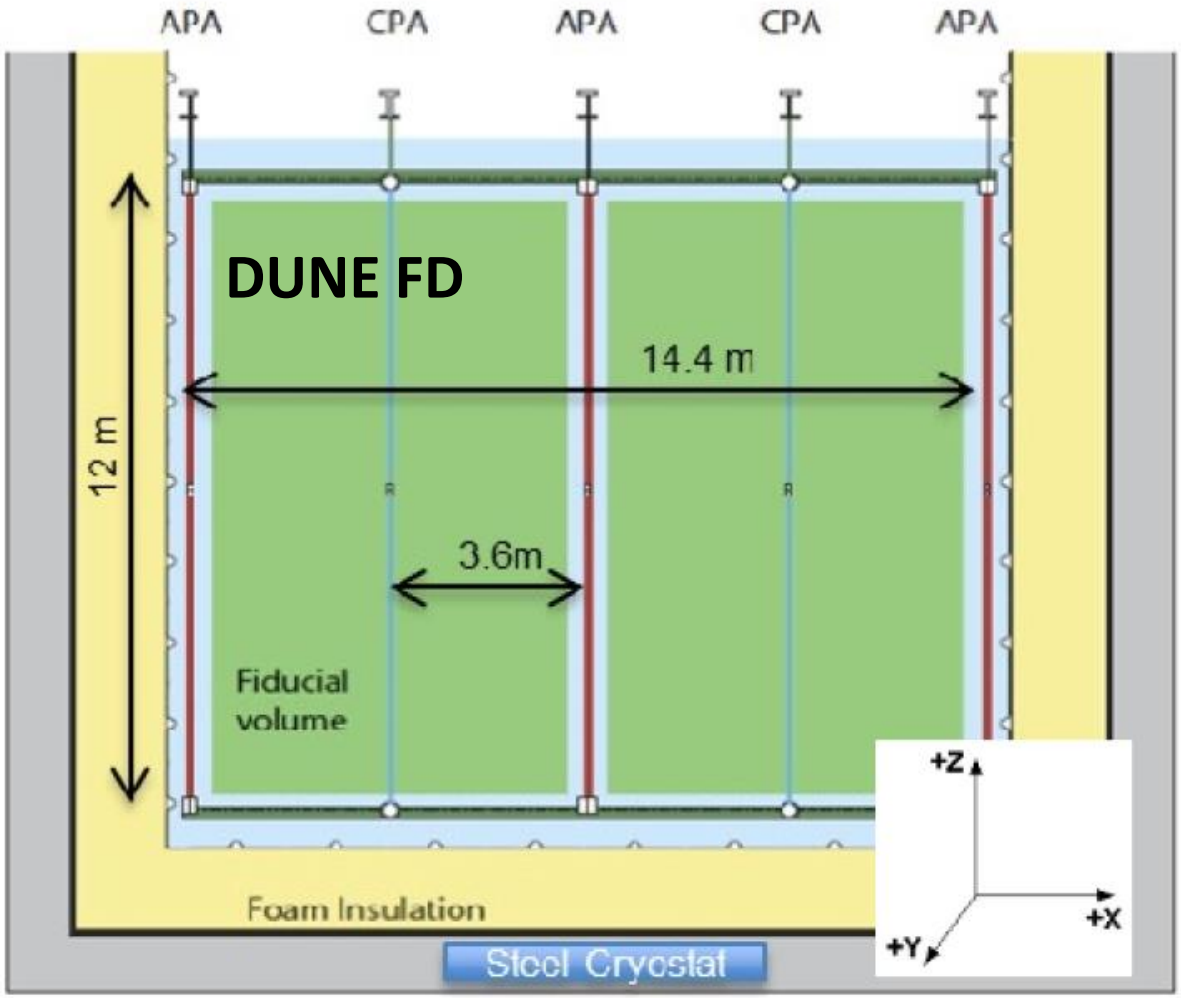
BLACK HOLE FORMATION

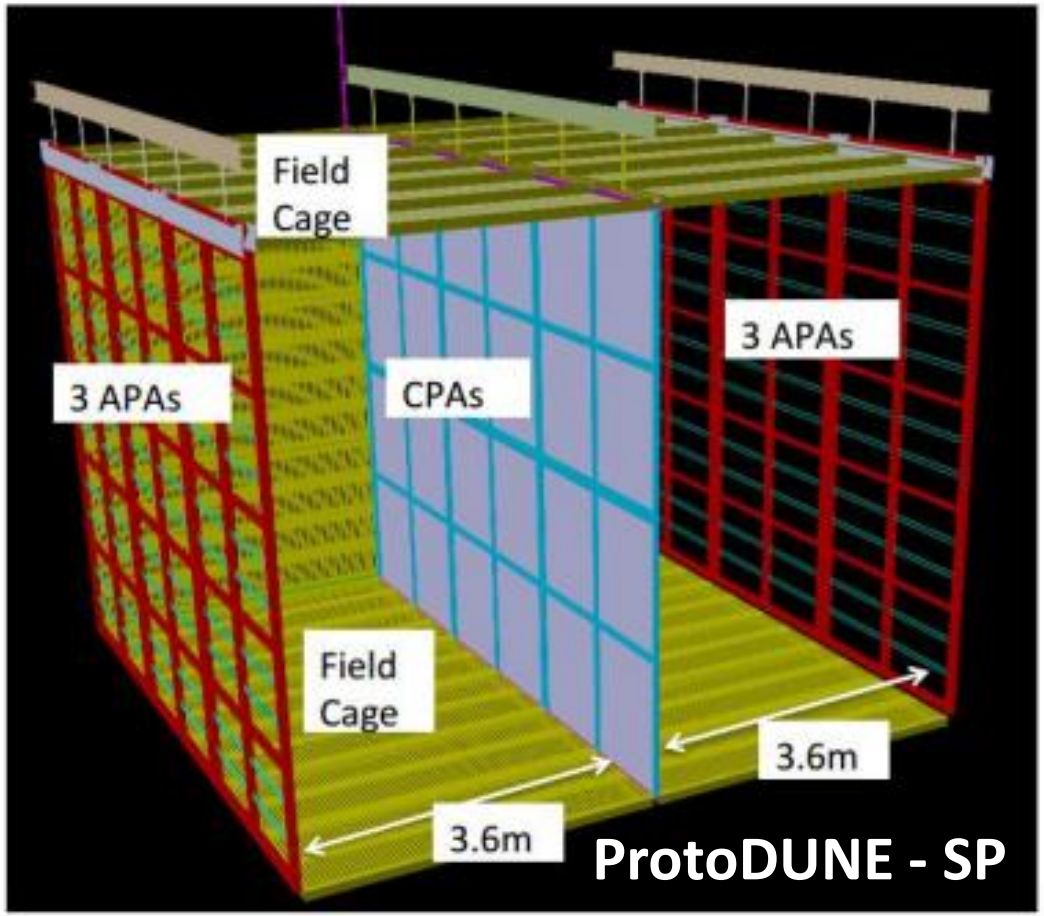
Liquid Argon Time-Projection Chamber



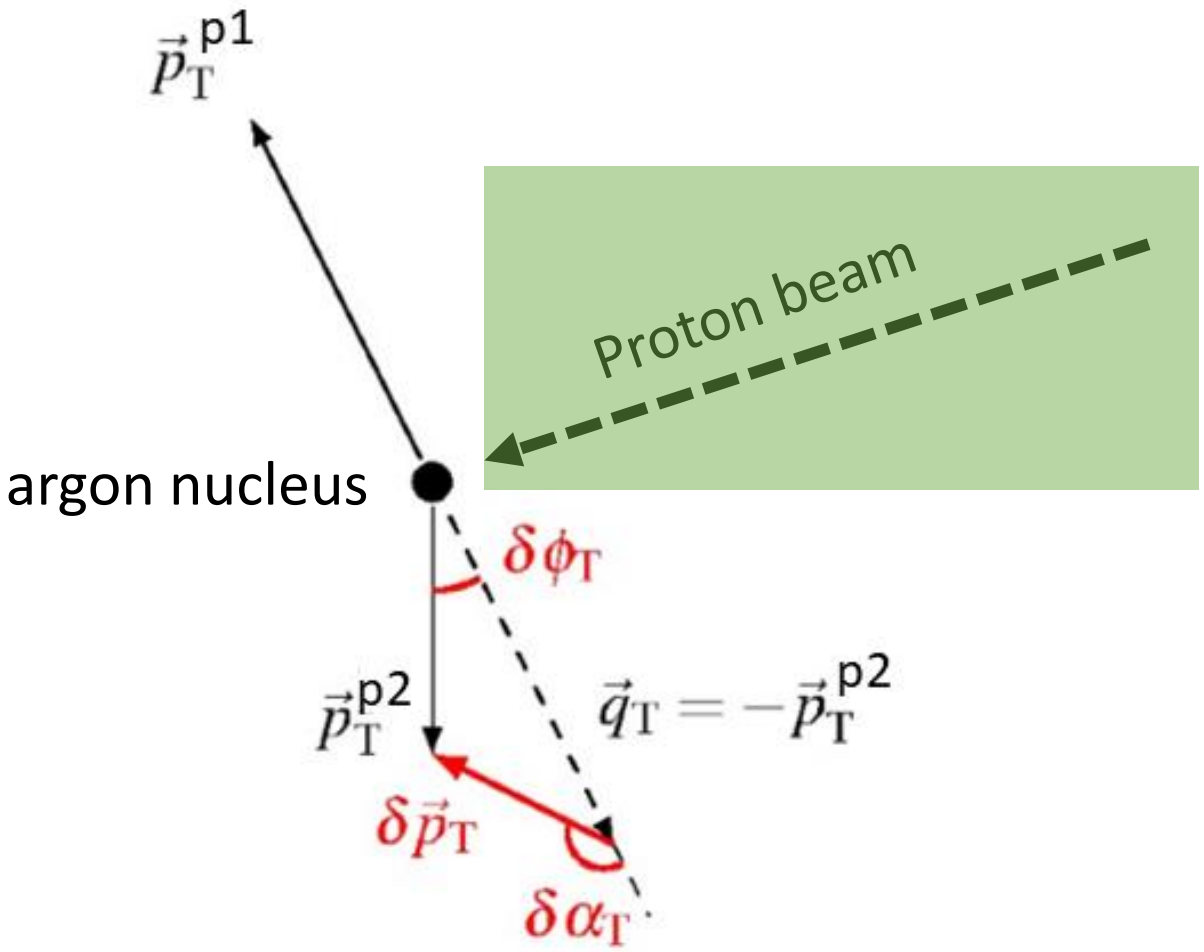


DUNE Far Detector and ProtoDUNE Single Phase





Primary Particle Selection



Primary Particle Selection

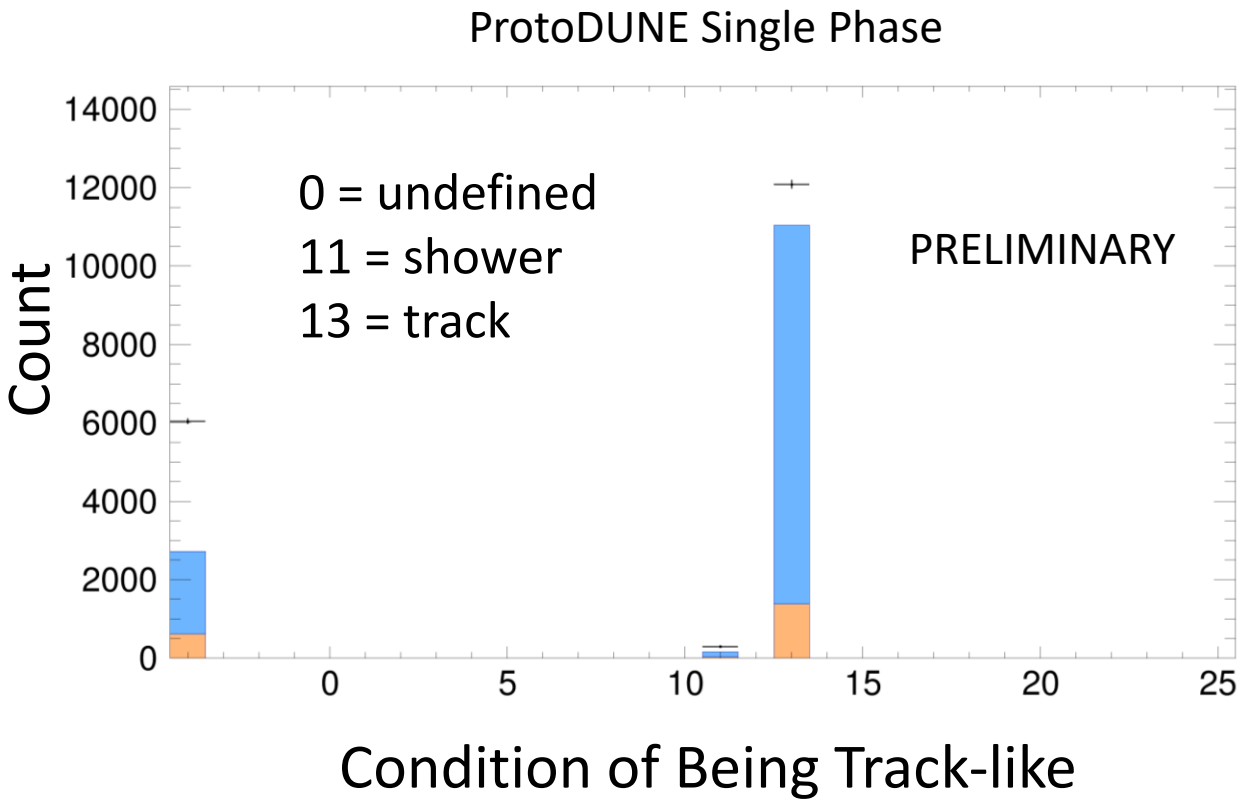
1) Primary particle identified as proton from beam instrumentation

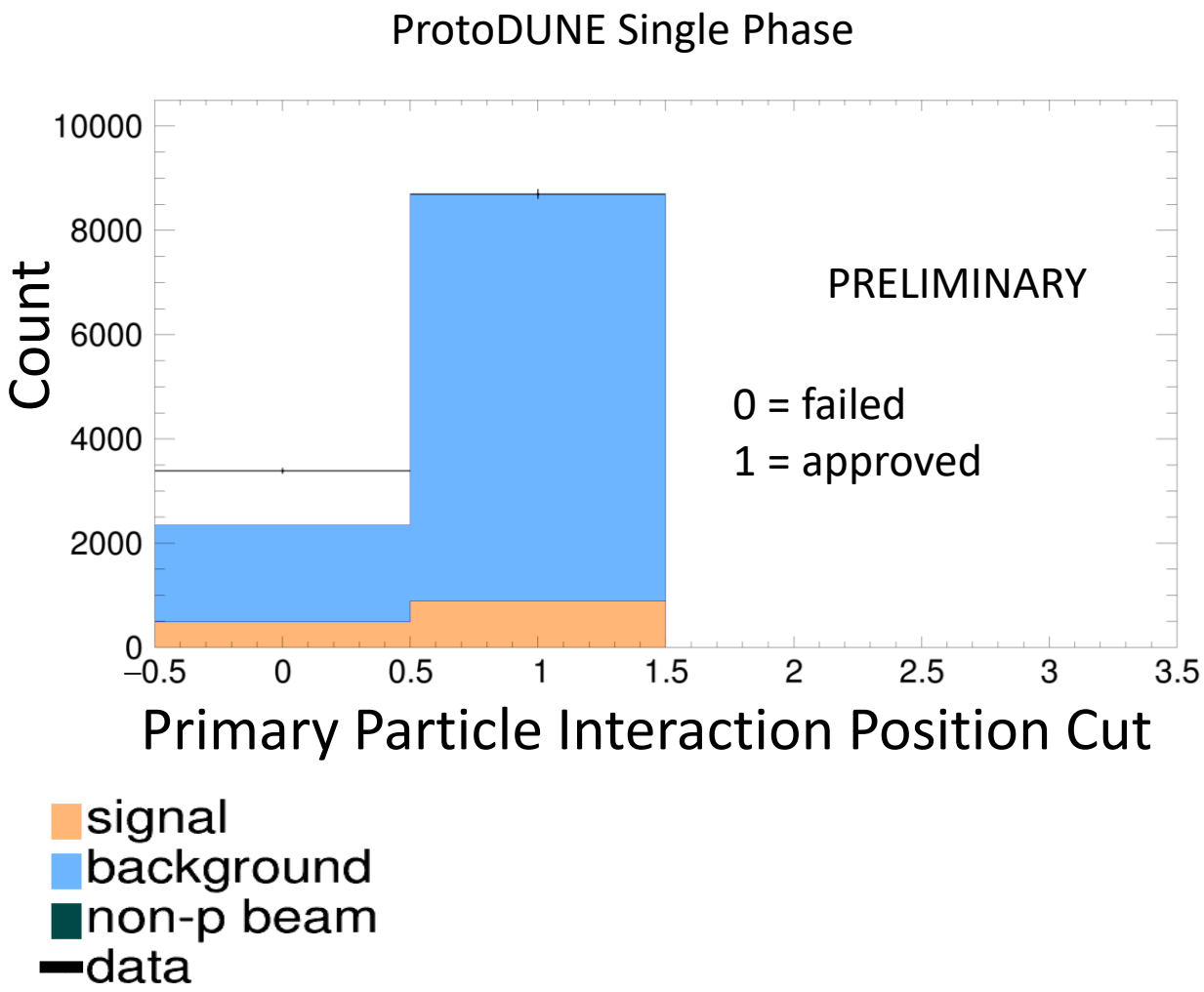
2) Primary particle identified as track inside the detector

3) Primary particle's interaction must satisfy requirements

4) Interaction inside fiducial volume

Primary Particle Cuts

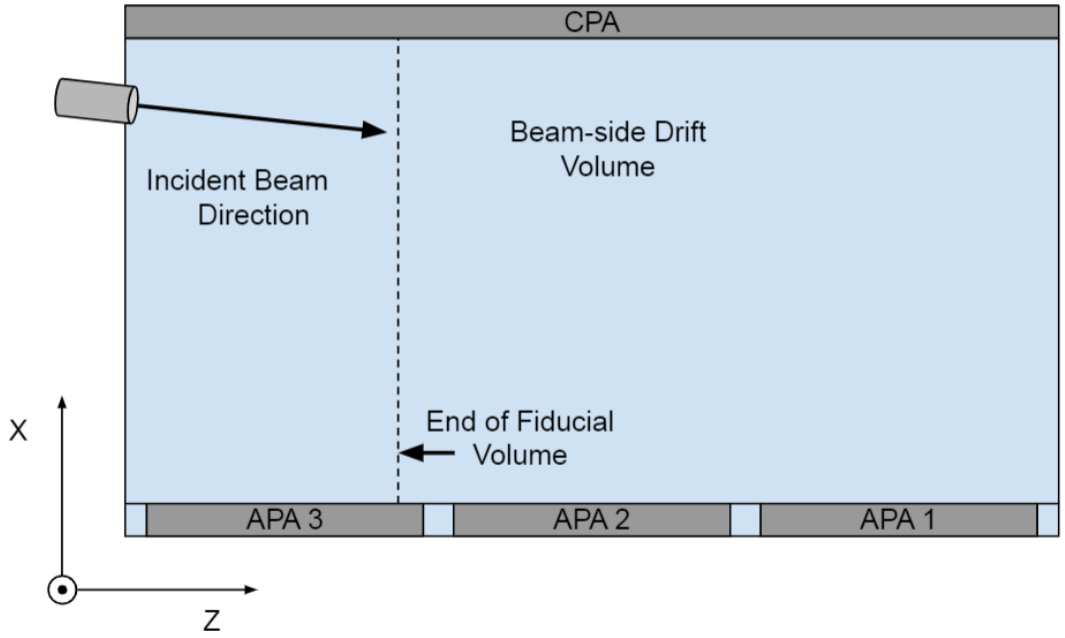


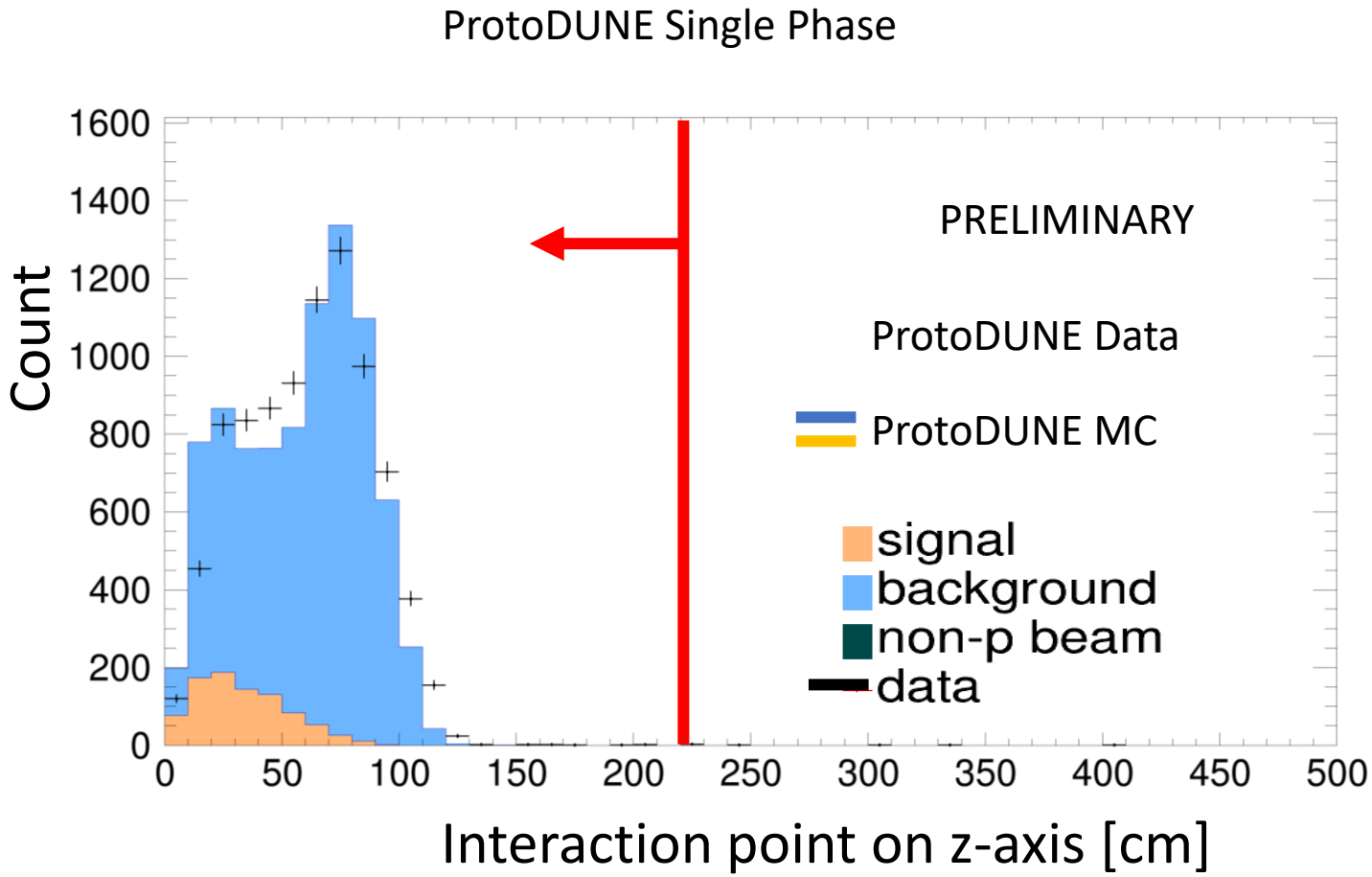


Signal = p-> p+p event

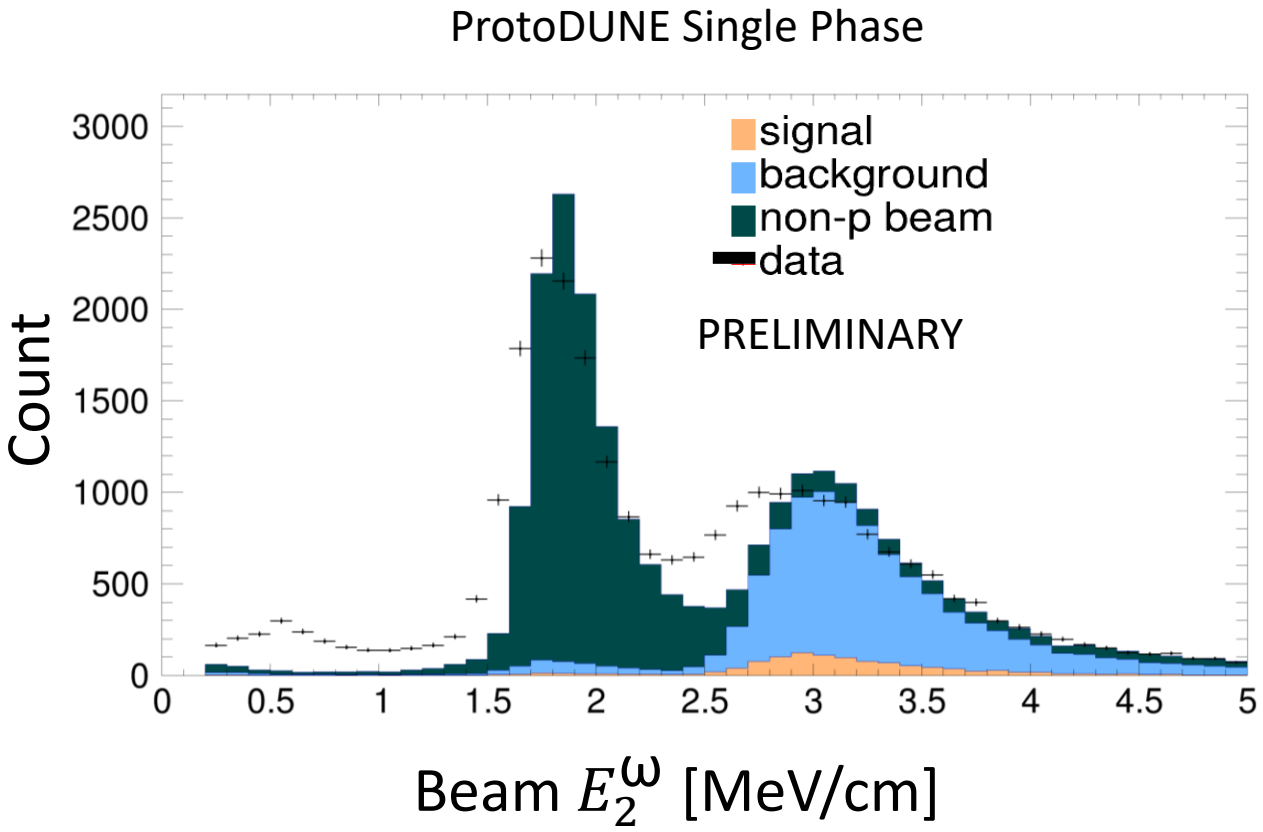
Background = any other proton beam event

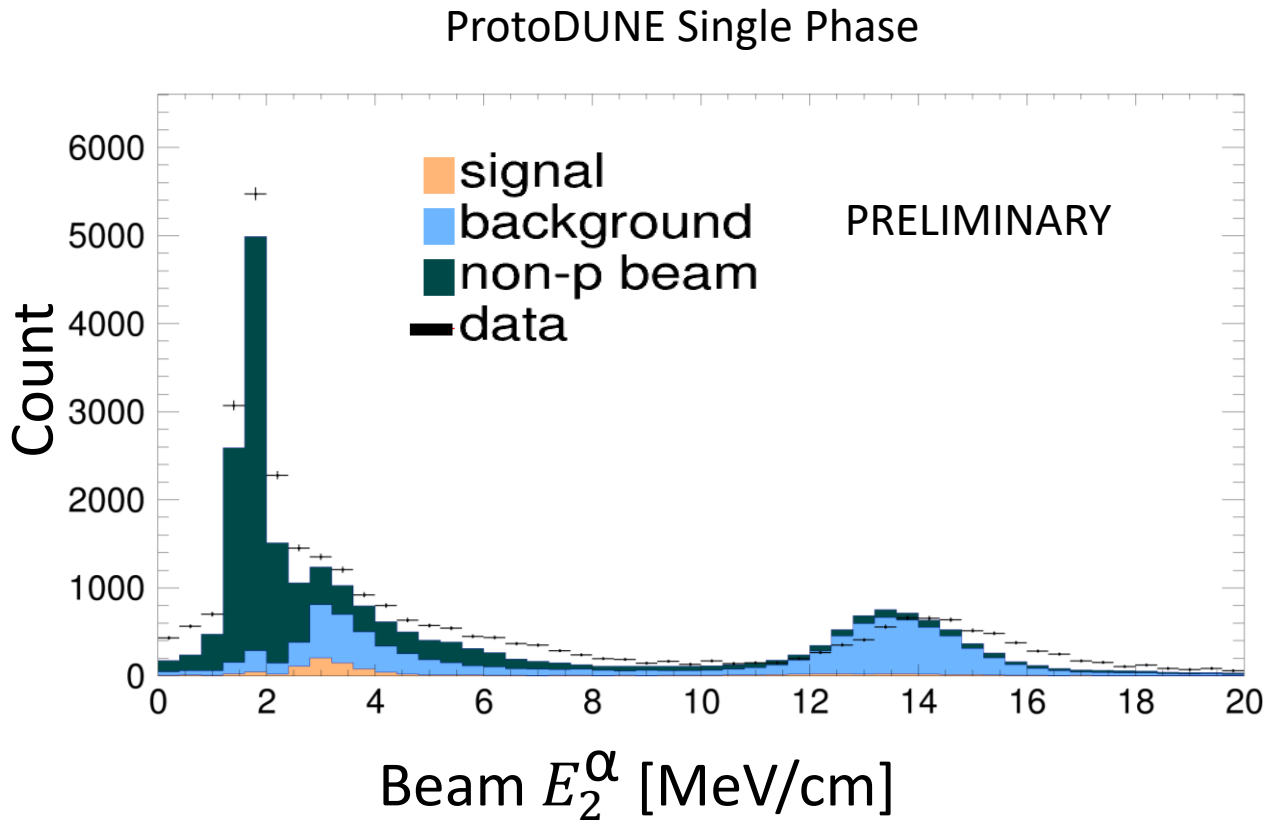
Beam Cuts


CPA
Beam-side Drift Volume
Incident Beam Direction
End of Fiducial Volume
APA 3
APA 2
APA 1
X
Z


ProtoDUNE Single Phase
PRELIMINARY
ProtoDUNE Data
ProtoDUNE MC
signal
background
non-p beam
data
Count
Interaction point on z-axis [cm]
0
200
400
600
800
1000
1200
1400
1600
0
50
100
150
200
250
300
350
400
450
500

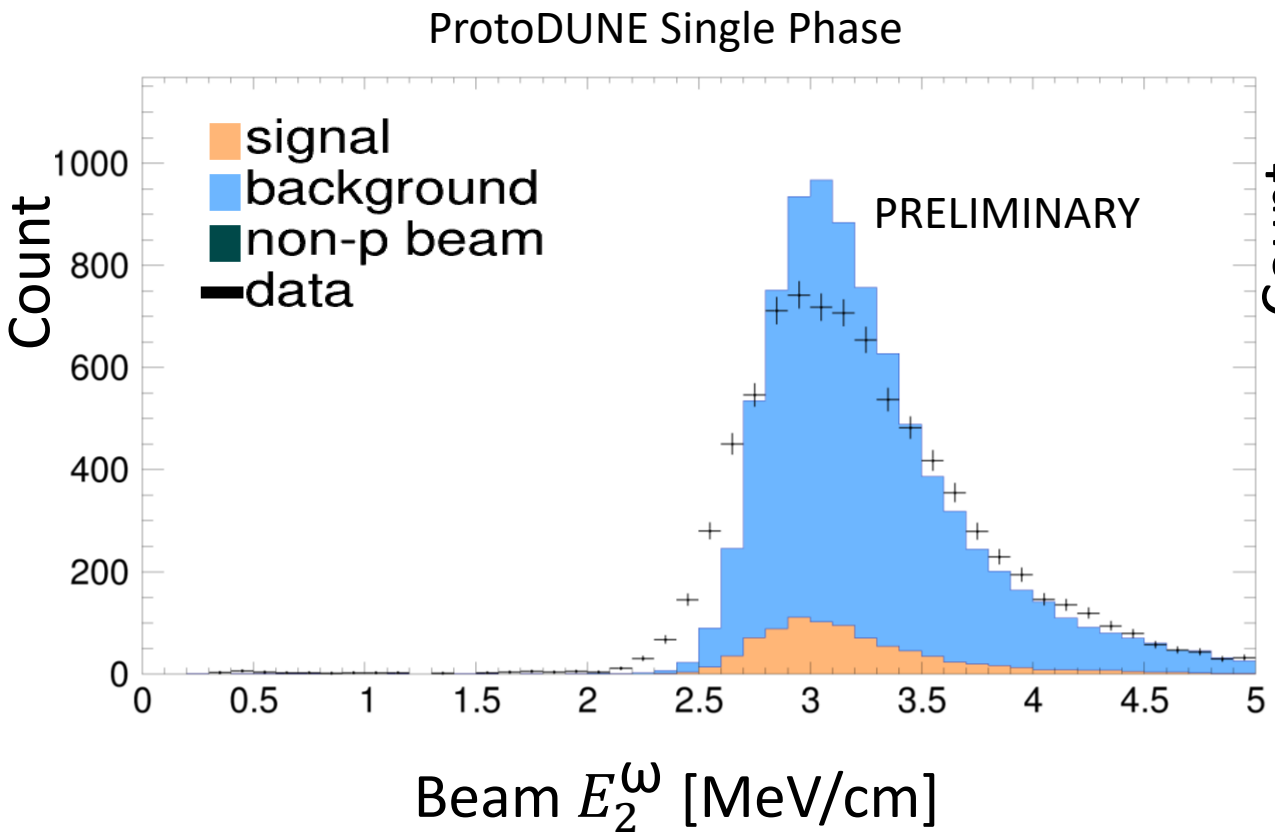
Before Primary Particle Cuts

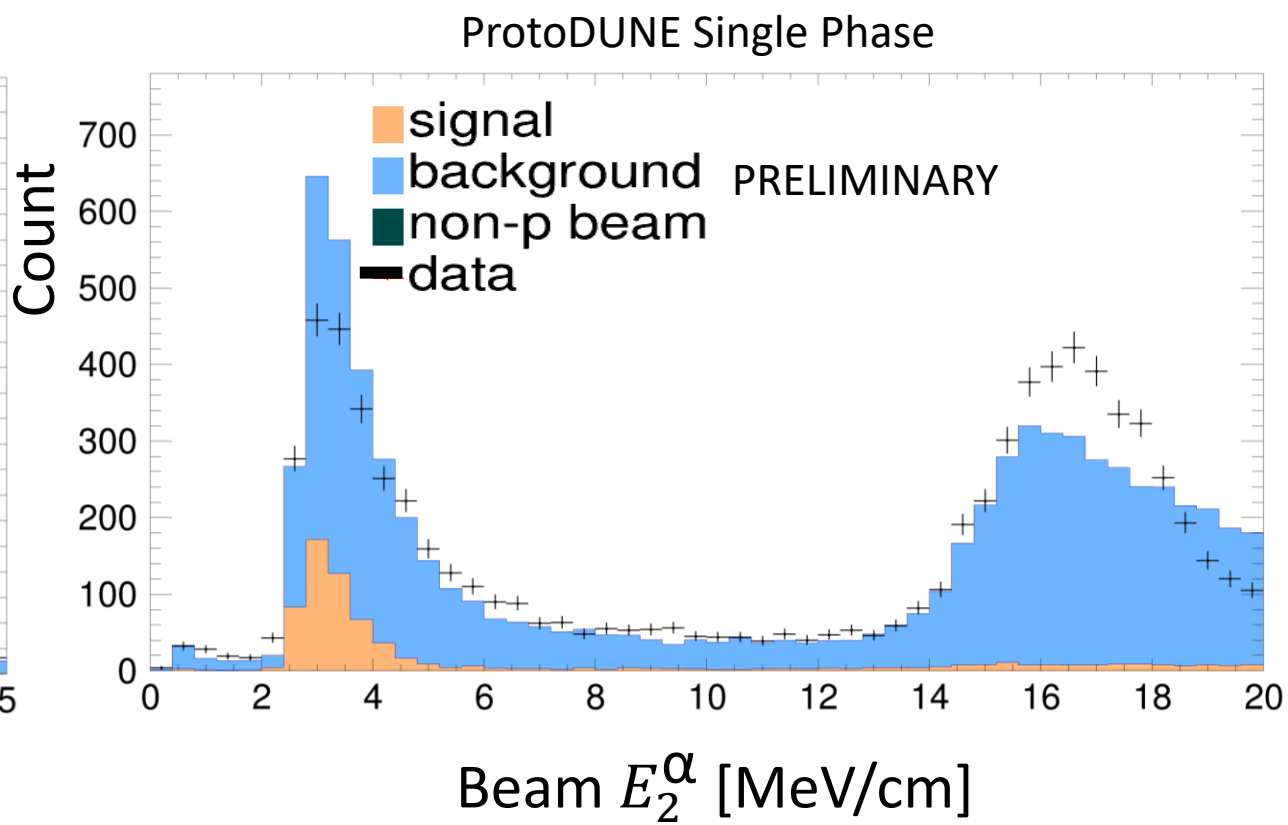




E_2^{ω} is the dE/dx at the vertex far end, the beam entrance
E_2^{α} is the dE/dx at the vertex near end, the beam interaction point. This is the Bragg peak region

After Primary Particle Cuts

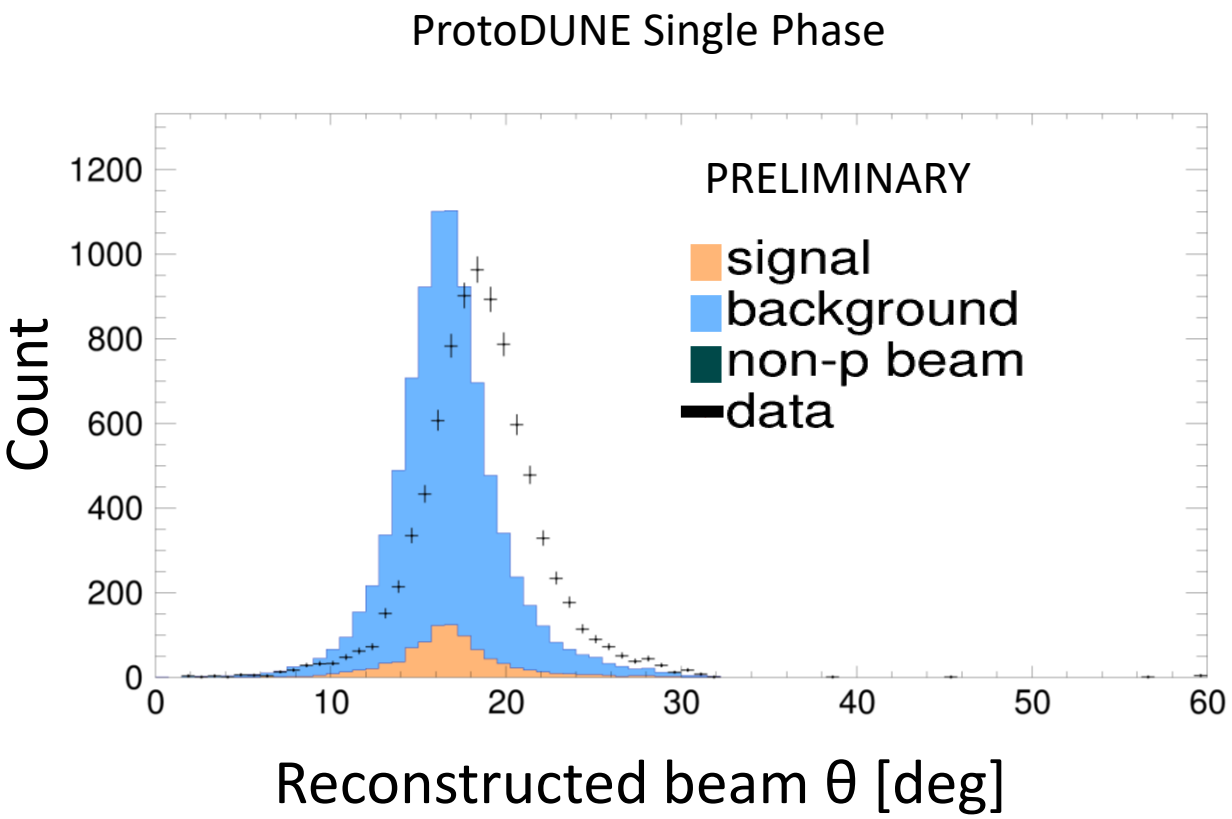


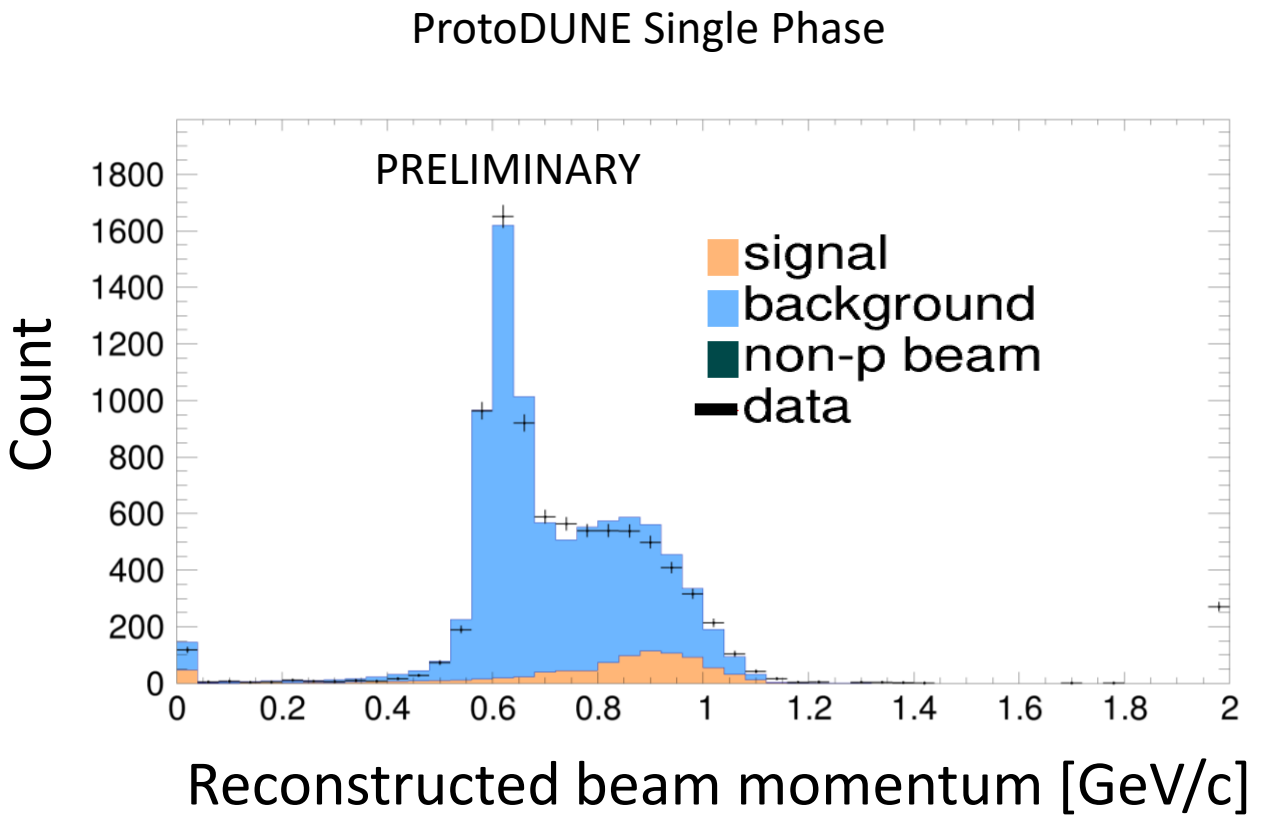


Beam Cuts

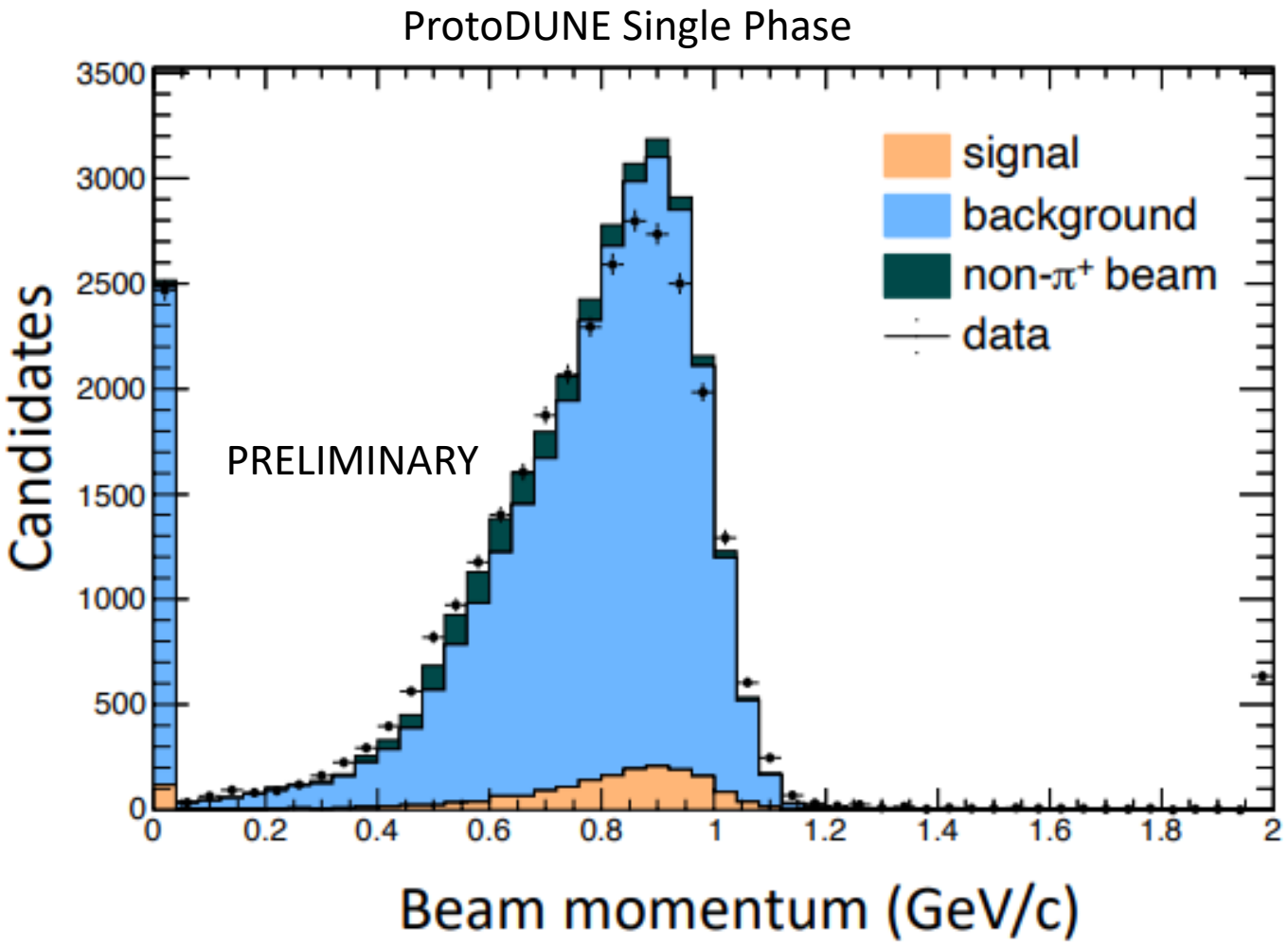
CUT	MC BEFORE CUT	MC AFTER CUT	% MC AFTER CUT	DATA BEFORE CUT	DATA AFTER CUT	% DATA AFTER CUT
PID	129365	55216	42.7	120602	18412	15.3
TRACK-LIKE	55216	43780	79.3	18412	12082	65.6
BEAM POS	43780	34463	82.6	12082	8696	71.9
END POS	34463	34463	100	8696	8691	99.9

Reconstructed Primary Particles After Cut

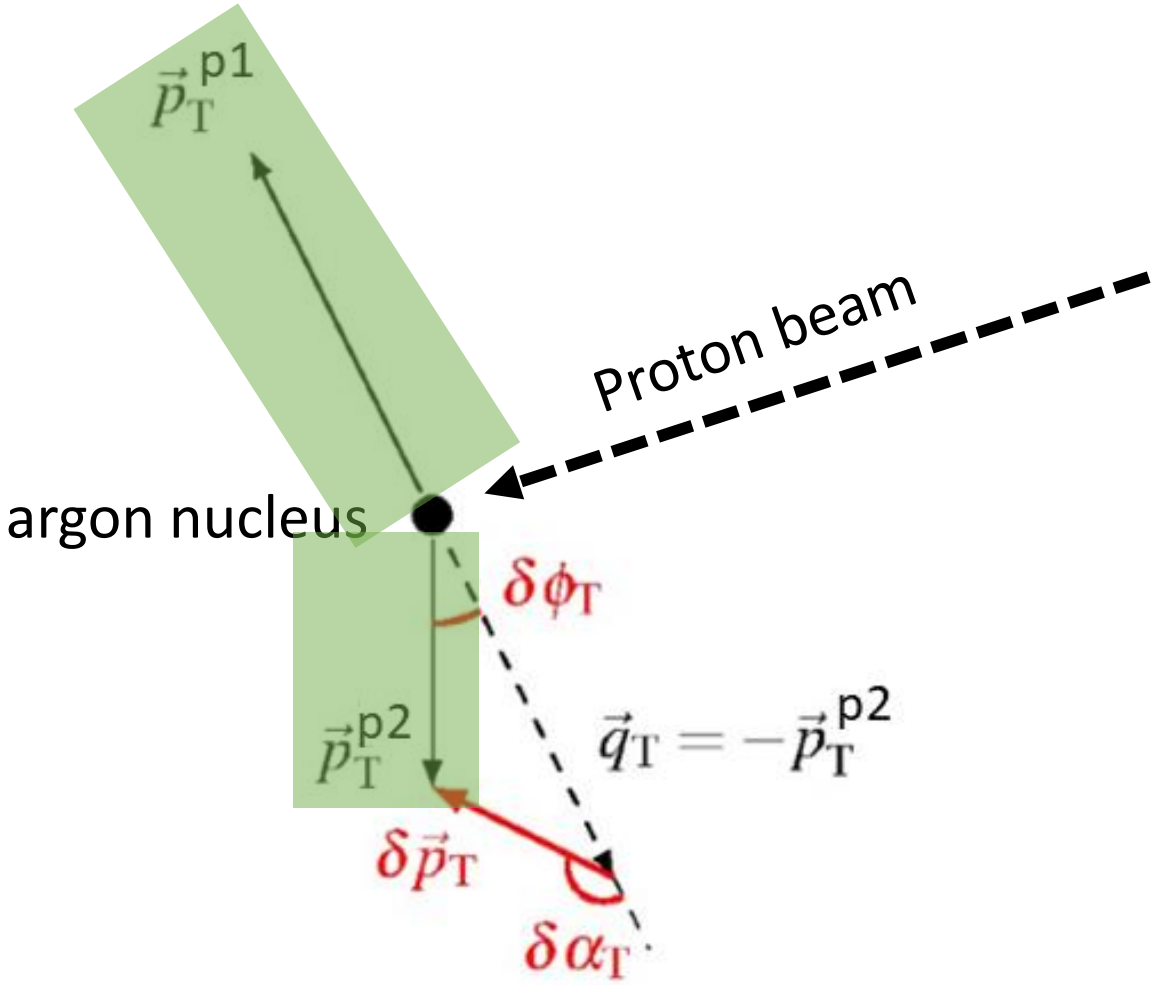




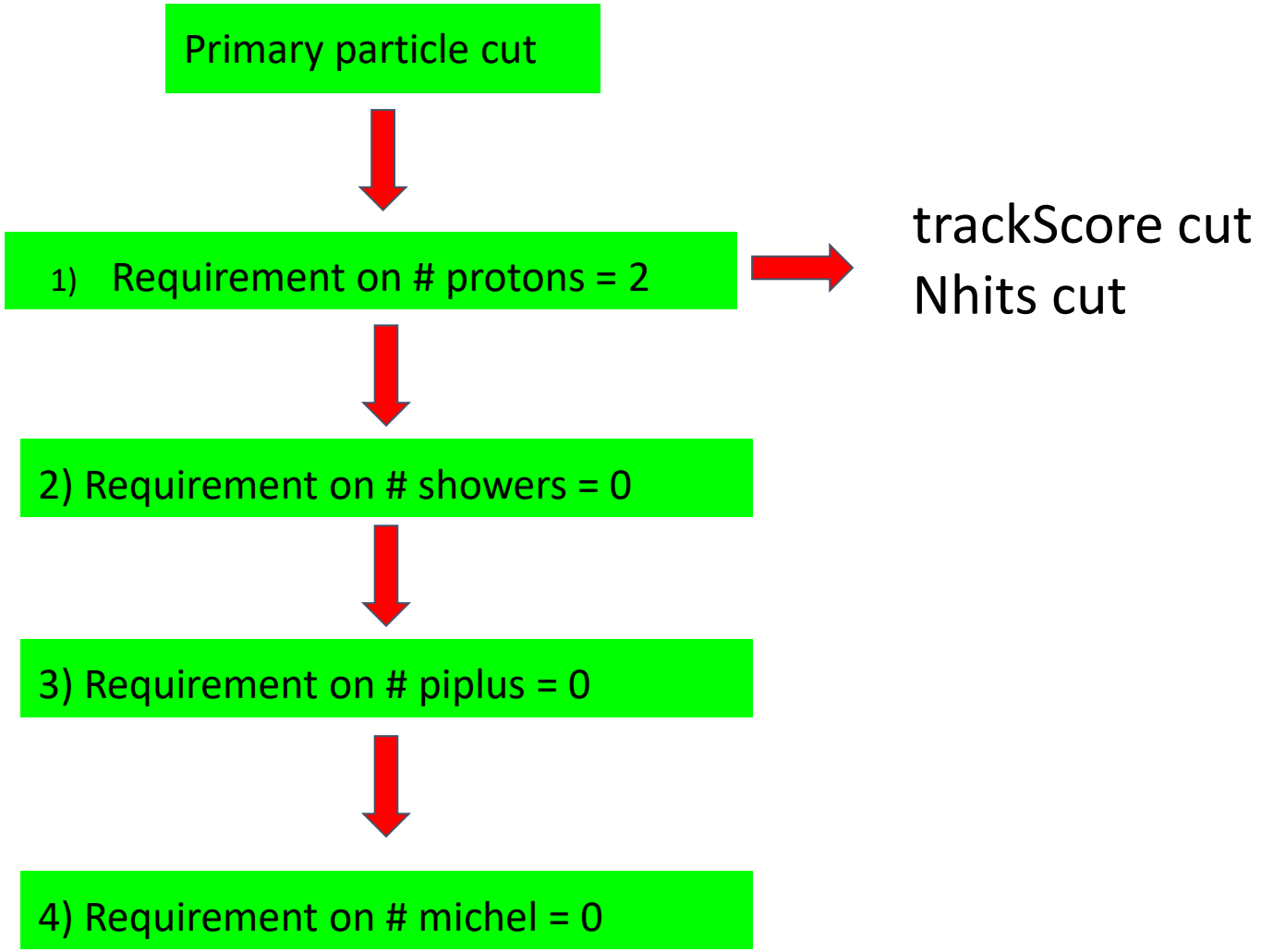
Reconstructed Primary Particles for $\pi^+ + p(^{40}Ar) \rightarrow \pi^+ + p$



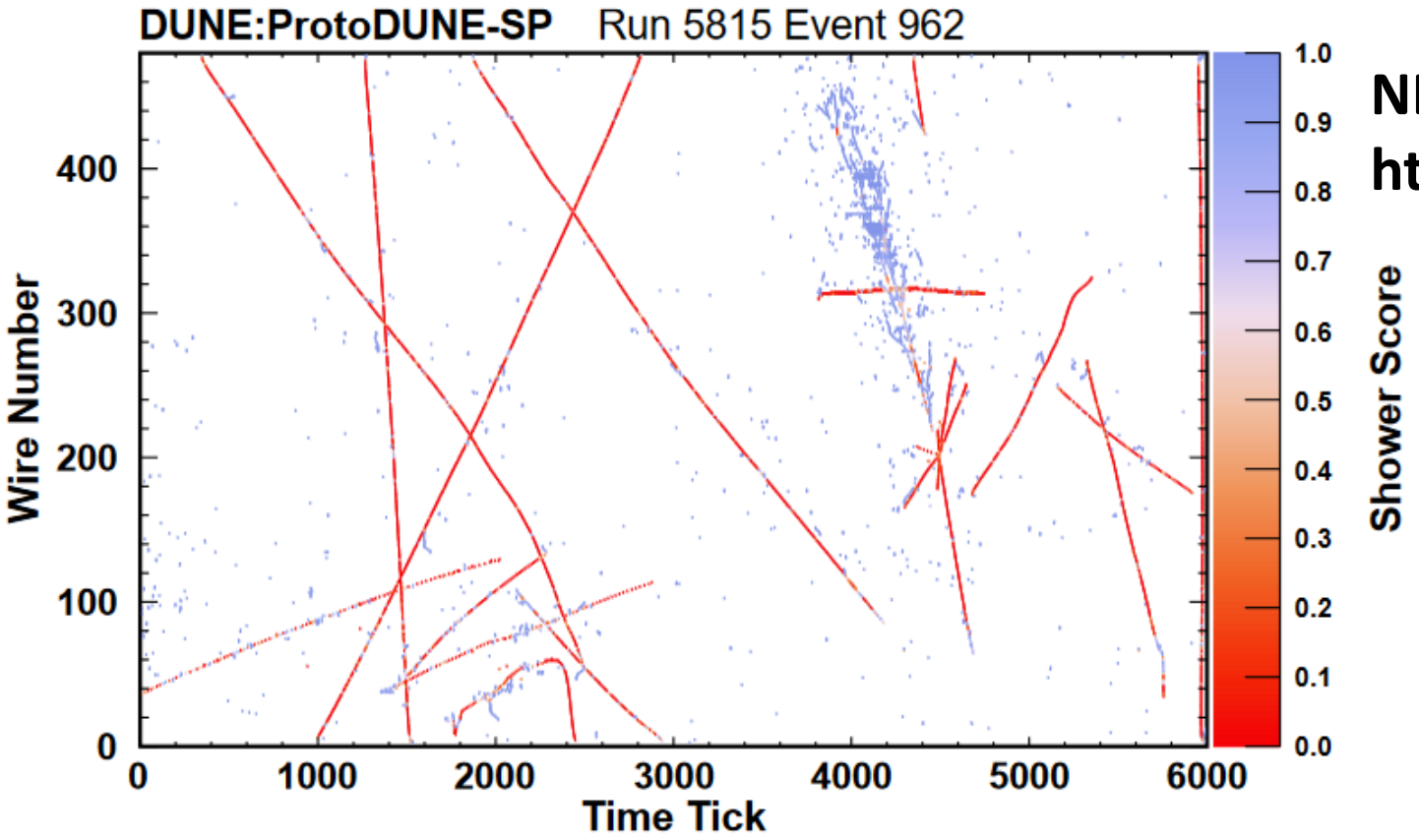
Interaction Selection



Interaction Selection

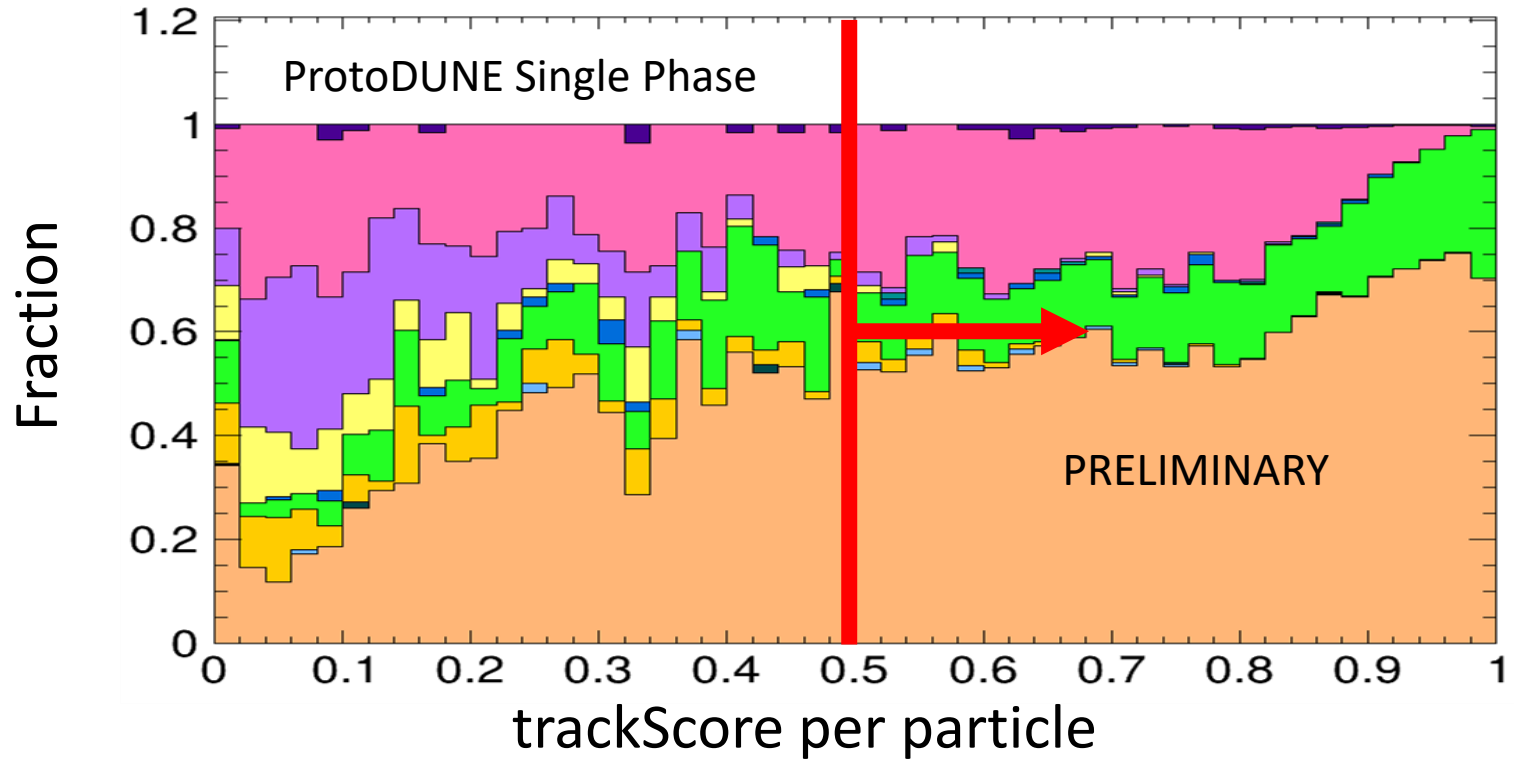


Convolutional Neural Network and TrackScore



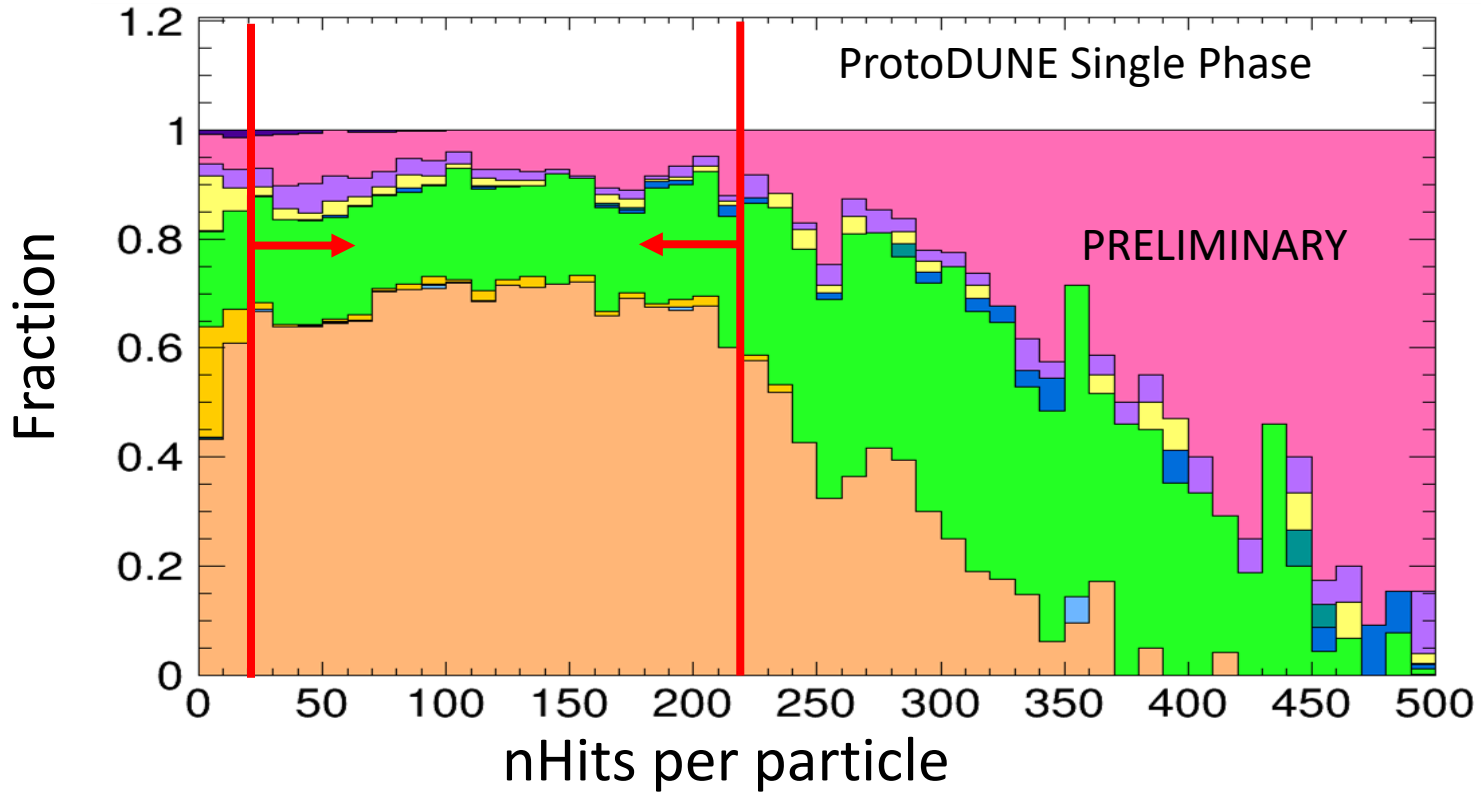
NEW PAPER FROM DUNE COLLABORATION
https://arxiv.org/abs/2203.17053

TrackScore



Trackscore appears to be flat after 0.5 for protons, therefore we keep 0.5 as threshold for protons.

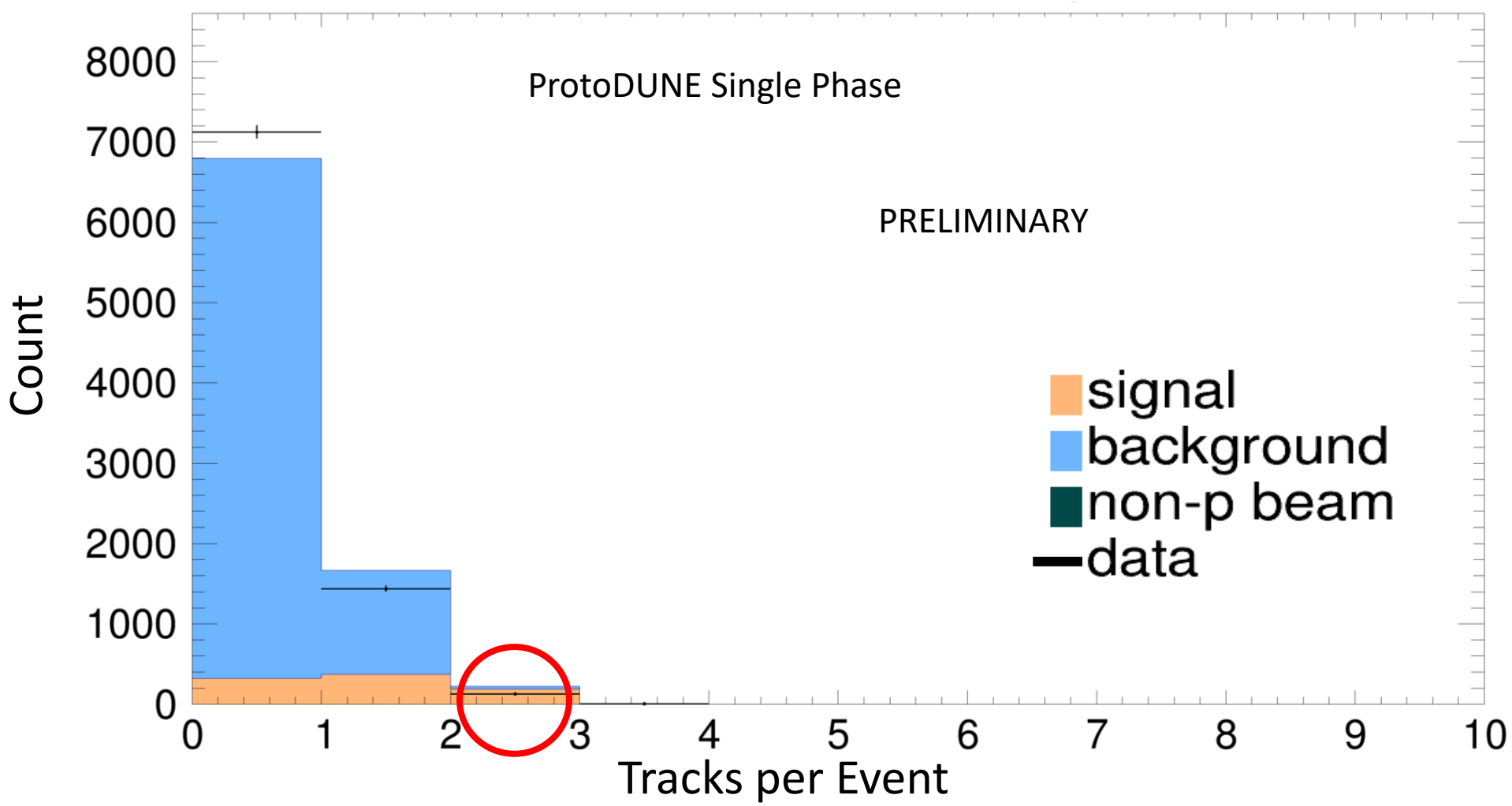
Number of Hits



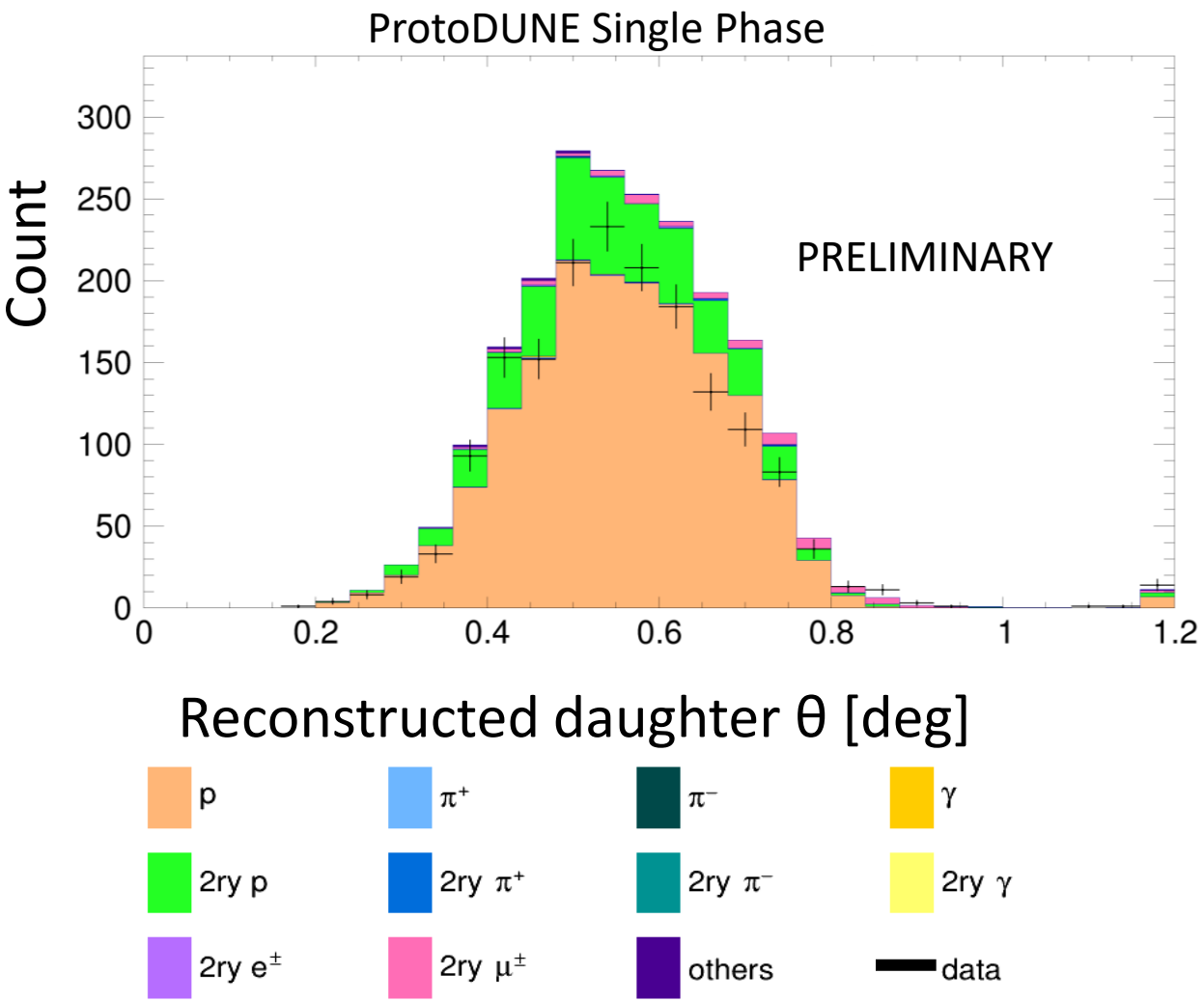
p
π^+
π^-
γ
2ry p
2ry π^+
2ry π^-
2ry γ
2ry $e^\pm$
2ry $\mu^\pm$
others
data

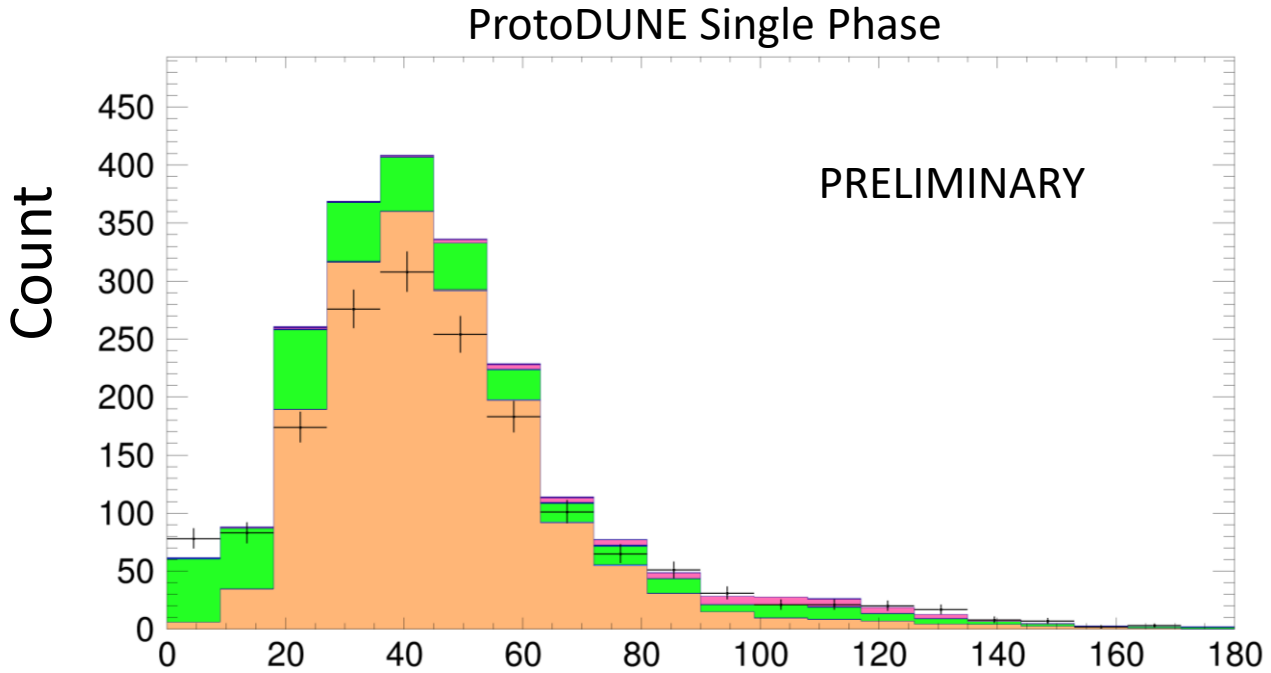
We take deposits with 20<nhits<220.

Interaction Cut on Topology



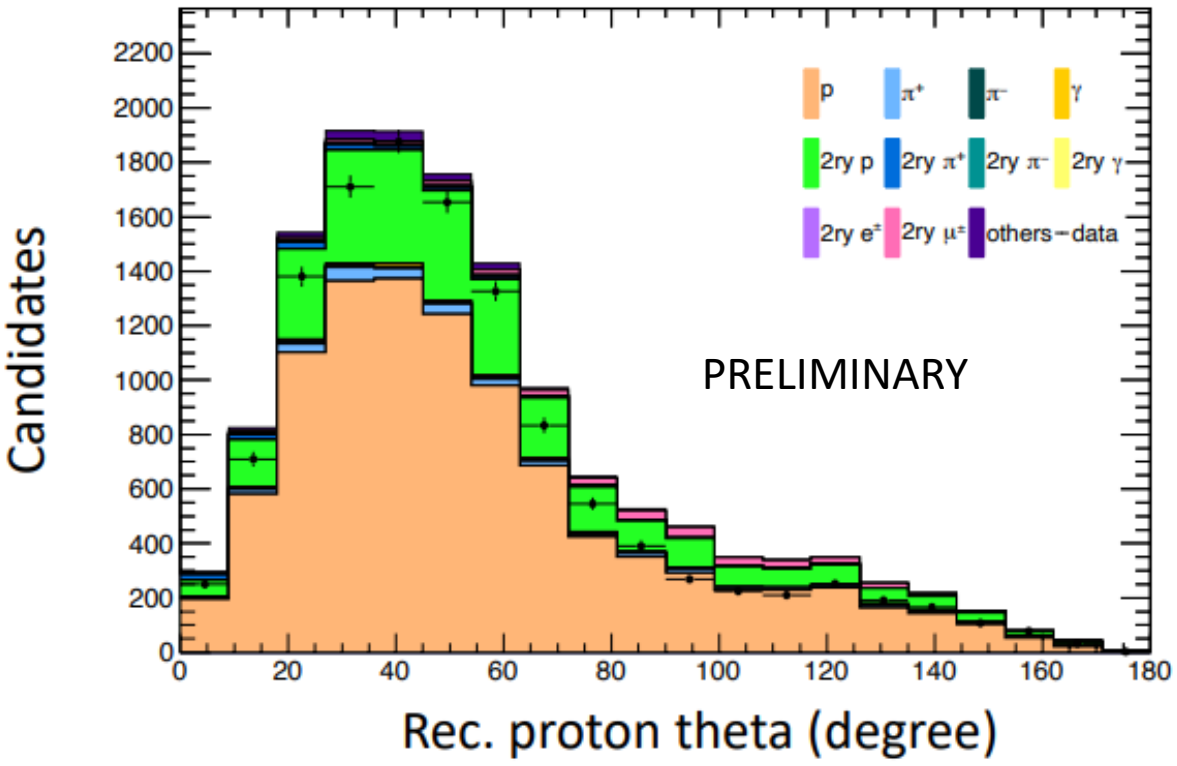
Reconstructed Daughters



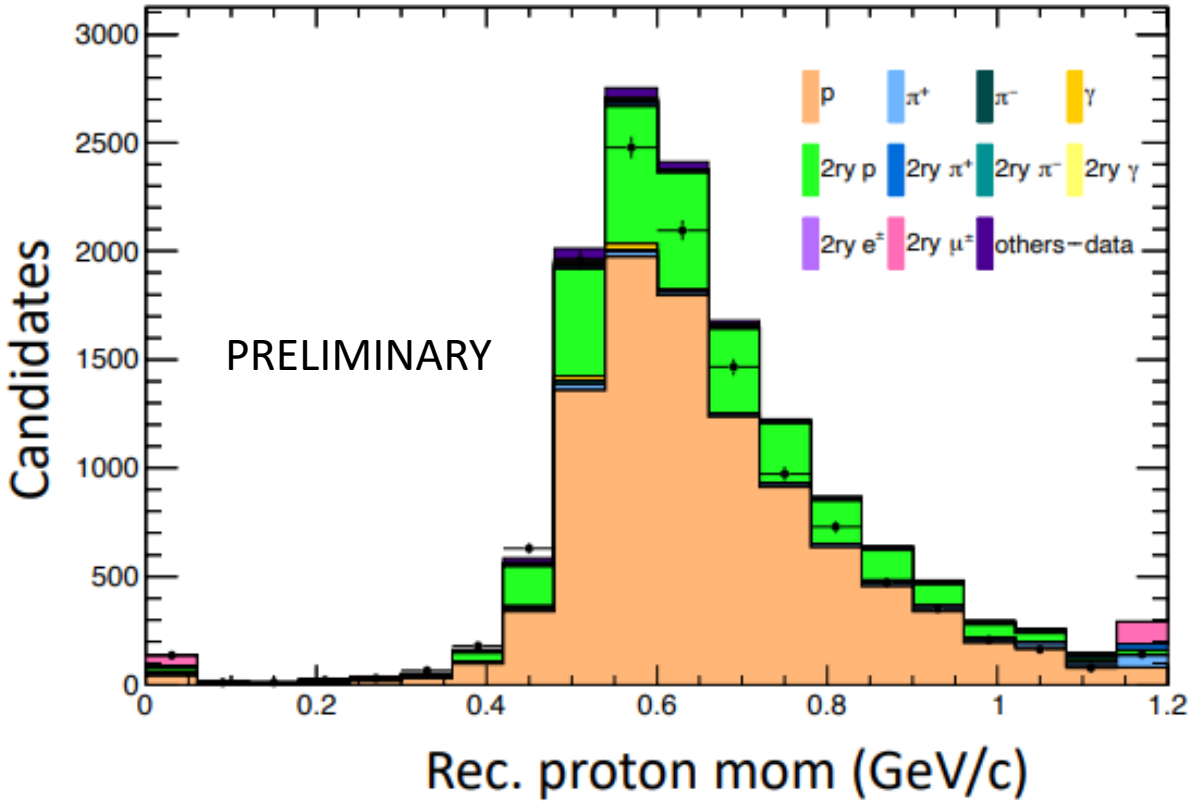


Reconstructed Daughters for $\pi^+ + p(^{40}Ar) \rightarrow \pi^+ + p$

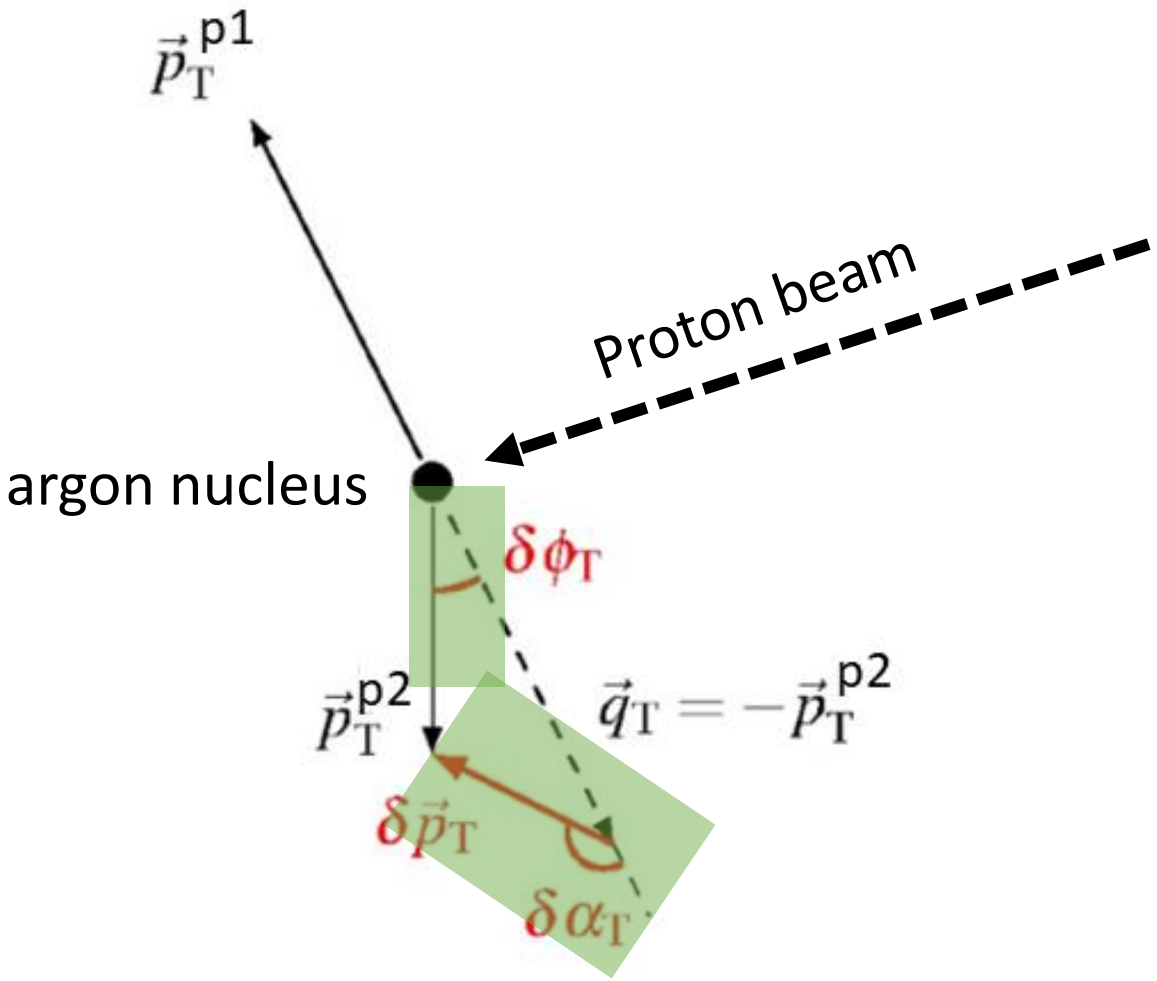
ProtoDUNE Single Phase



ProtoDUNE Single Phase

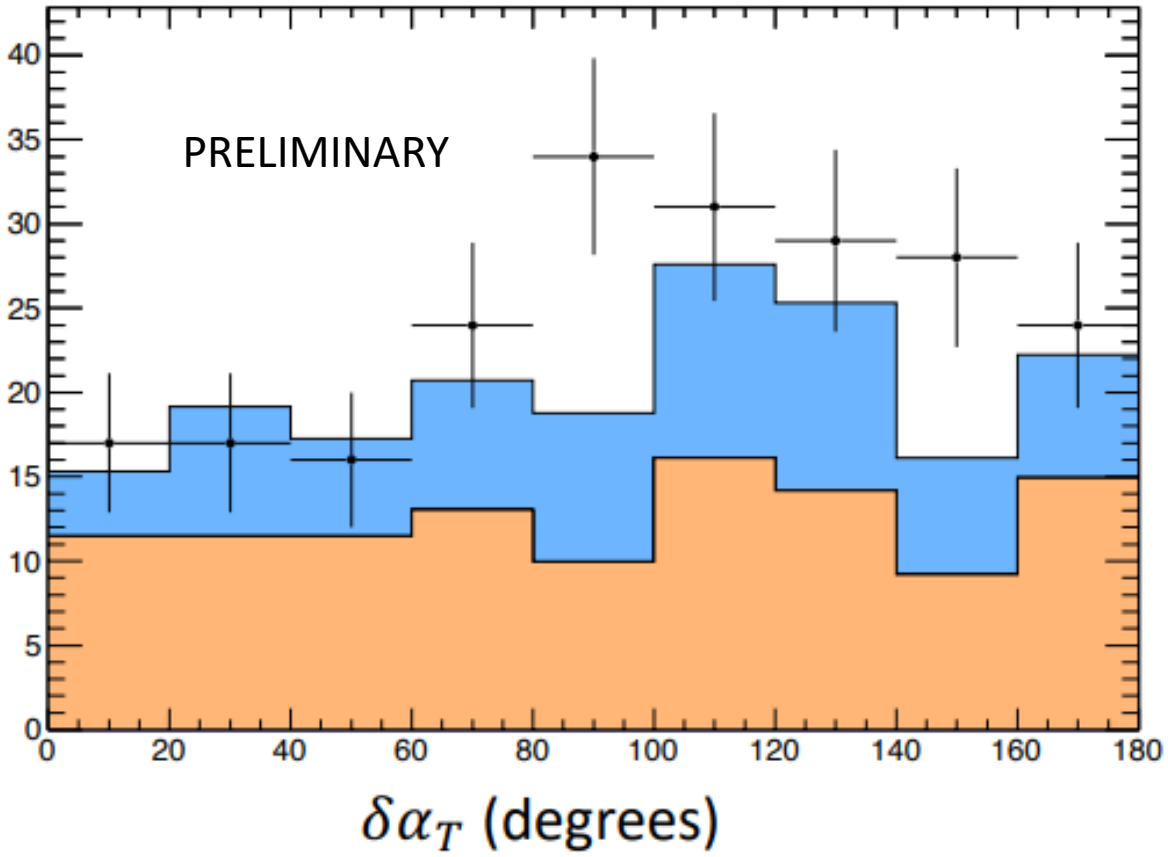


Observable Reconstruction

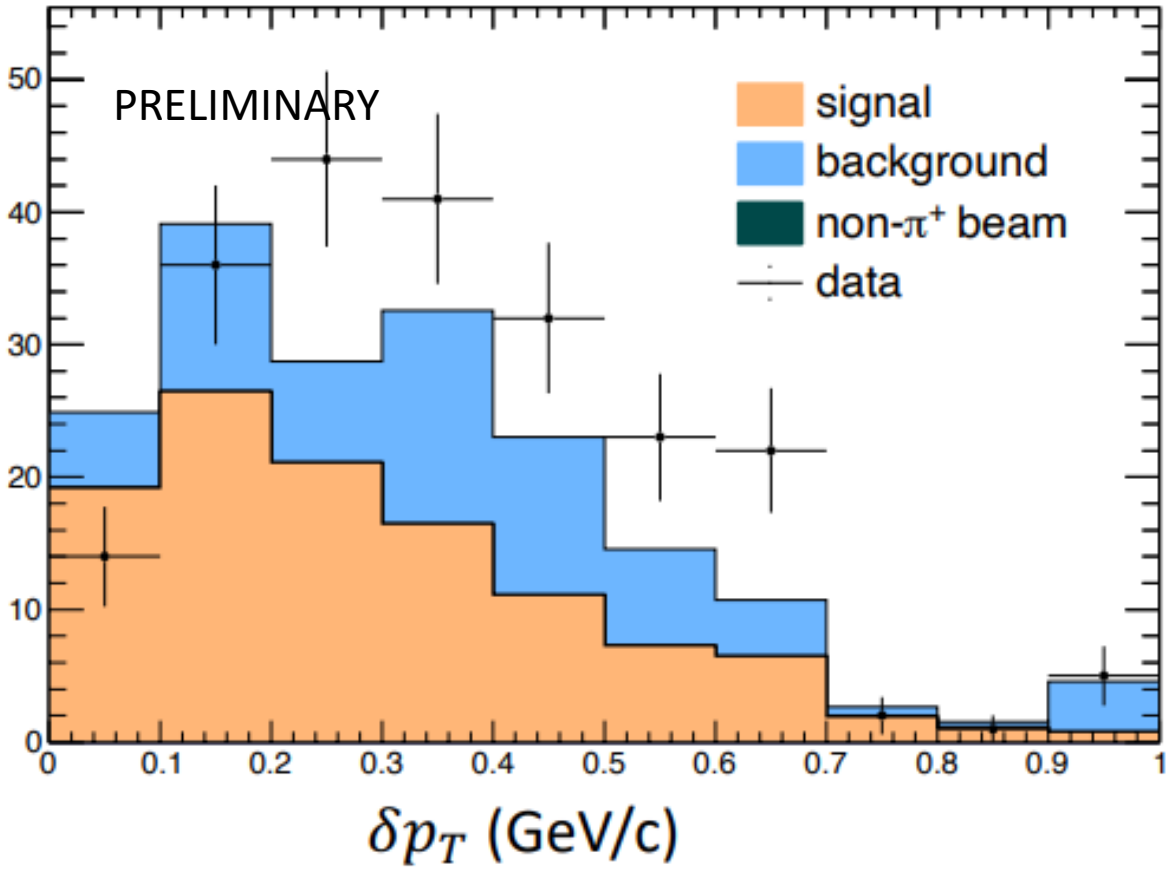


Reconstructed Observables for $\pi^+ + p(^{40}Ar) \rightarrow \pi^+ + p$

ProtoDUNE Single Phase



ProtoDUNE Single Phase



THANK YOU FOR YOUR ATTENTION!

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Back-Up Slides: Quick Review of the Beam Cuts

- Beam Particle Identification: identified a protons via PDG candidates
- Beam Track-like: selected only events with a track-score value above a certain threshold
- APA3: a cut on the end z-plane position
- Beam Position: a collection of subcuts
  1. 3 sets of $|\Delta(x/y/z)/\sigma_{(x/y/z)}| \leq 3$, where the sigmas are hardcoded values and delta is the difference between the beam start and the mean beam start
  2. Oval cut $\sqrt{((\Delta x/\sigma_x)^2 + (\Delta_y/\sigma_y)^2)} < 3$
  3. Angular cut