Nuclear Effect Study Based on Pion Absorption Reactions Study with ProtoDUNE

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Outline

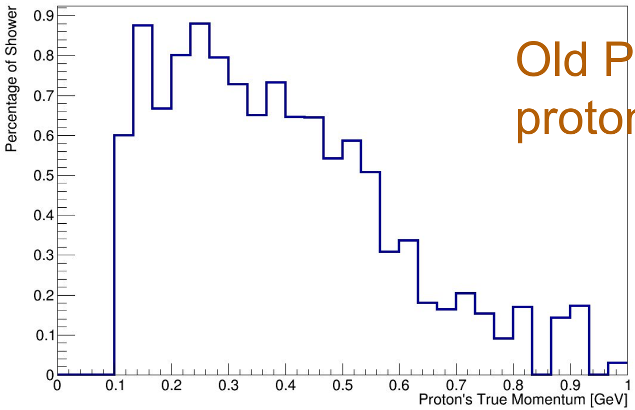
- Motivations
- Modifications of the module file
  - Currently using Jake Calcutt’s module file
  - A new module file is in preparation
- Particle Identifications
  - Protons,
  - Charged Pions
  - Neutral Pions
- GEANT4: Simulation of Pion Reactions
- Validation of the Particle Identifications using 1 GeV Pion-Ar MC samples
- Kinematic Distributions of Pion Absorption Reactions with particle identification
- Summary and Conclusion

Motivations

- Gain insight into the origins of multi-nucleon absorption
  - The primary process for pion absorption on heavy nuclei (A>0) is thought to be the absorption on two nucleons (I=0 pn pair)
  - several past experiments have shown that the 2NA cross-section does not exhaust the total absorption cross-section [1–3]
- Study the strength of the final states with multiple energetic particles (3p, 4p, 5p ..)
- Final state interaction study through pion absorption process

Modifications to reconstruction and module file

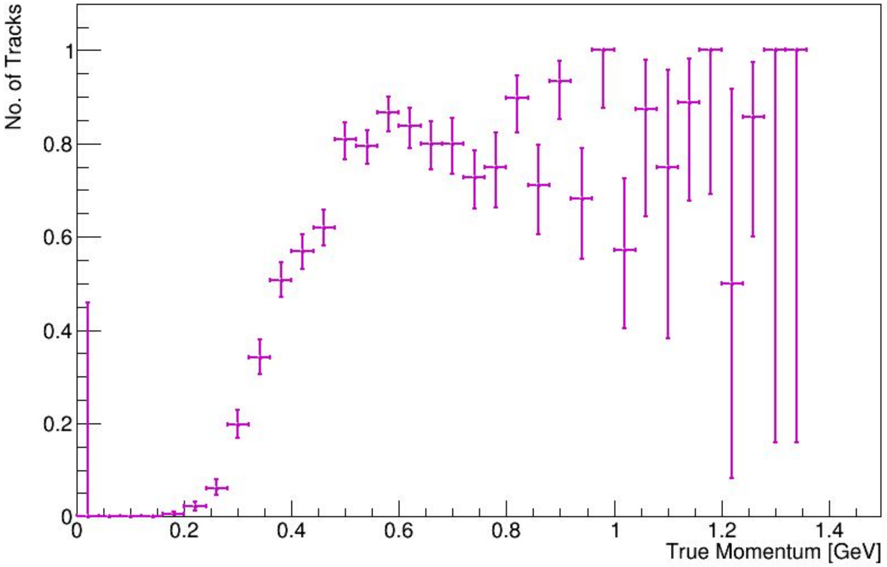
- Added the many new more variables:
  - the final state particles' momentum (calculated from track range considering protons and muons)
  - Did not find the function to calculate momentum for the pions, but the effect on pion absorption study should be small
- Reprocess samples treating all showers as tracks
  - Get the chi2, start end point posibles … for showers
  - Save some protons identified as showers in the past



Old Plot showing that "the lower the momentum, the more protons reconstructed as showers by Pandora!"

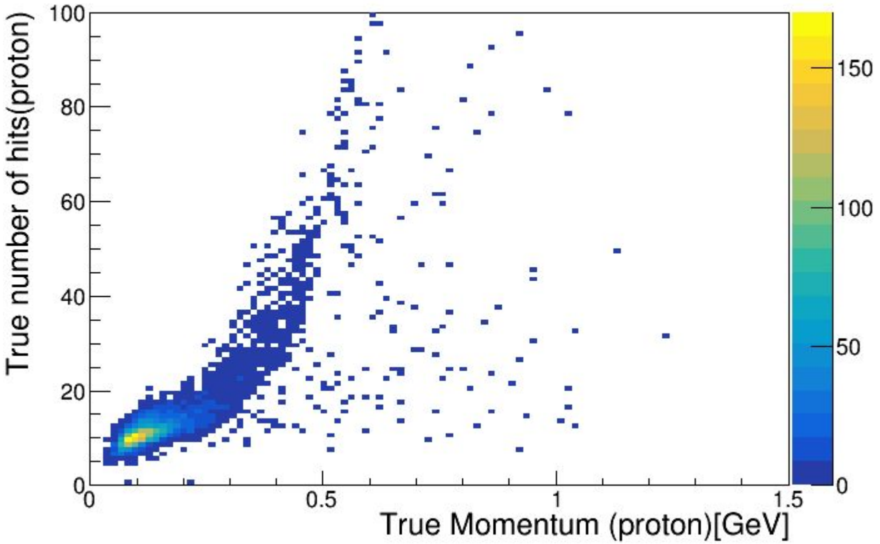
Protons Reconstruction Efficiency without any cuts

- Beam Information:
  - **Particle** : Pion+
  - **Beam Energy**: 1 GeV



- Left figure shows the distribution of protons (primary protons, from beam interactions) reconstruction efficiency without cuts
  - Did not consider grand daughter tracks/showers
- Large amount of low momentum protons not reconstructed (need to interface with reconstruction group and understand this)

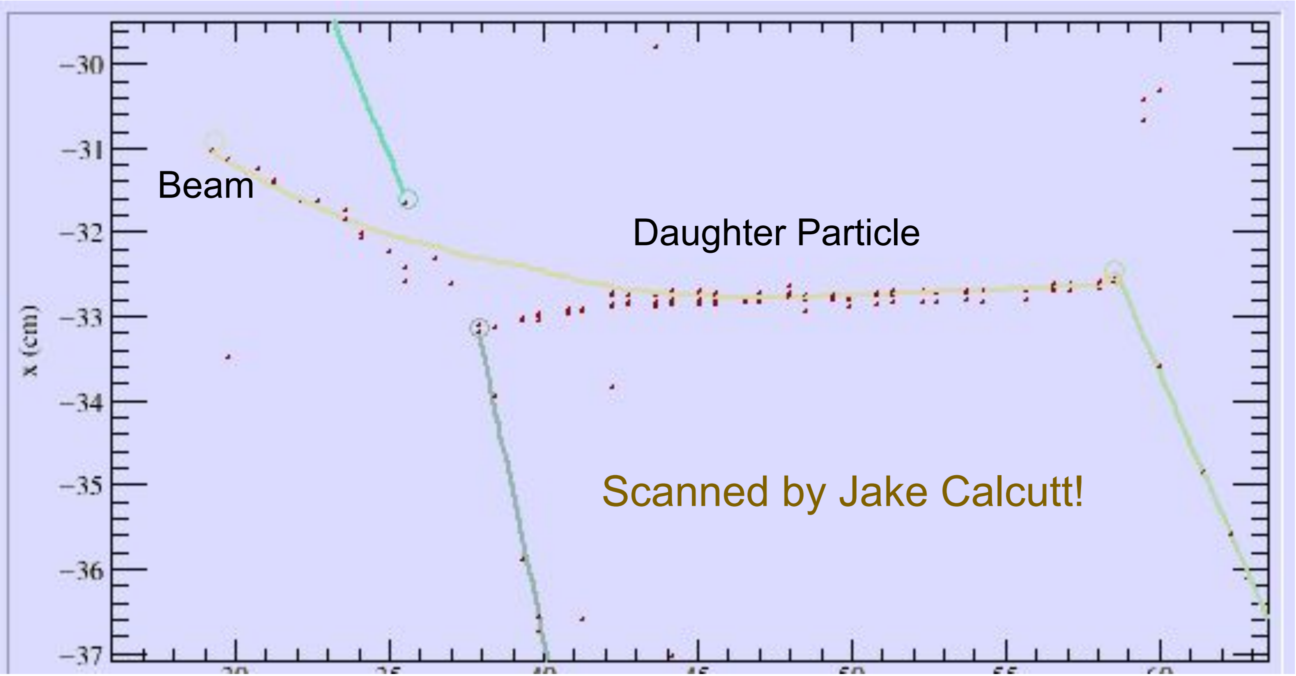
Protons Identification - Non reconstructed protons



- Most non reconstructed protons with low energy (~0.1 GeV)
- Number of hits ~ 5-10 of the non reconstructed protons
- Possible reasons caused the non-reconstruction
  - Low number of hits can not be reconstructed
  - Hits of protons are merged into other tracks (Example shown next page)

Protons Reconstruction Efficiency without any cuts

Example of non-reconstructed events:

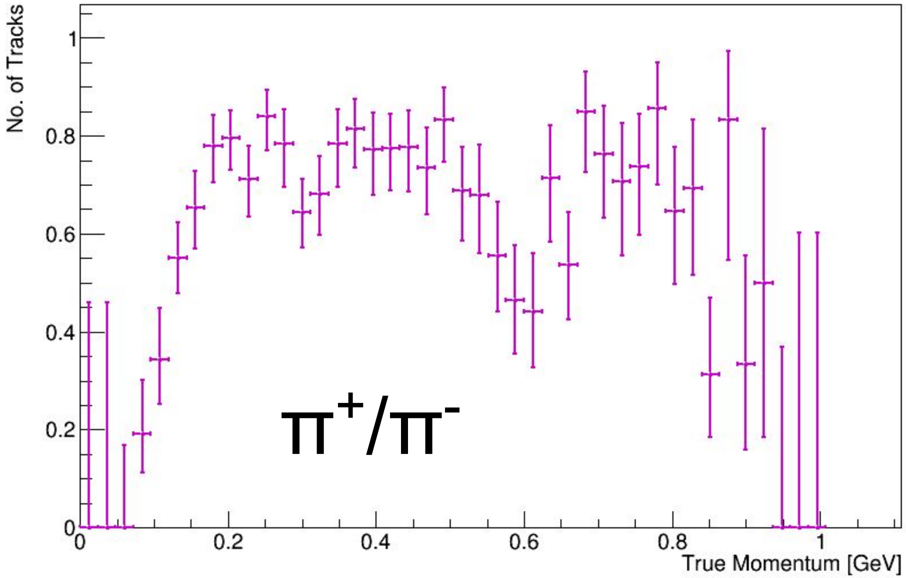


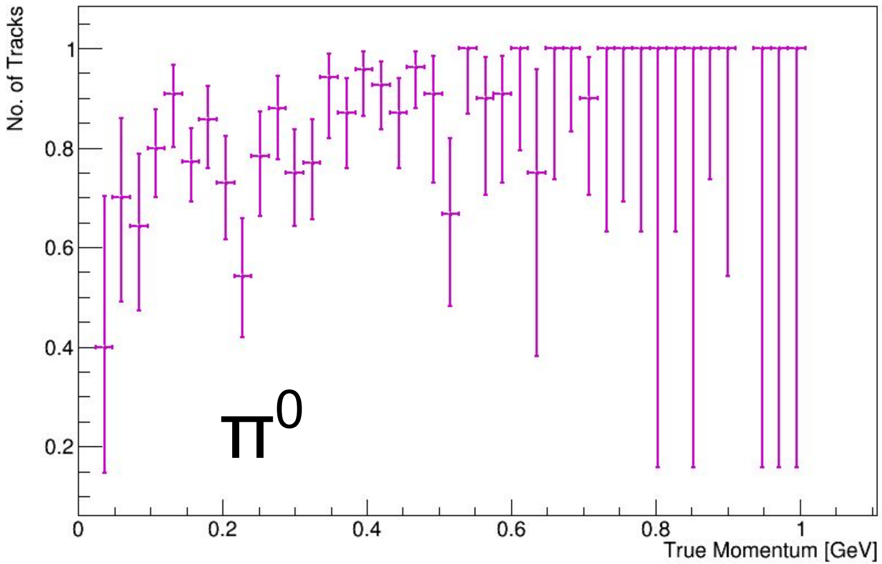
Possible non-reco reasons:

- Merged into other tracks because of small angle
- low number of hits

Trying to quantify the fraction of the non-reco protons for different reasons

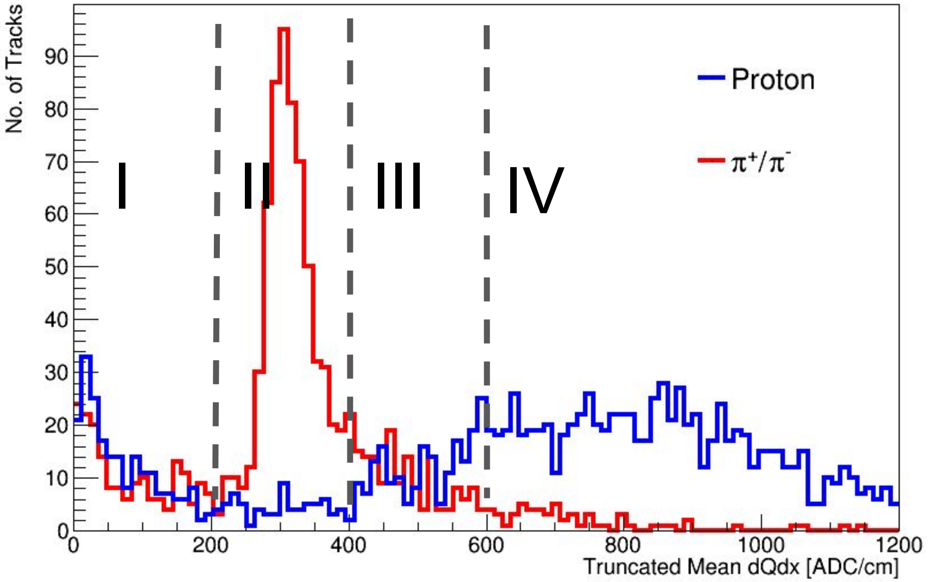
Pions Reconstruction Efficiency w/o cuts





- π^+ Can be identified with similar criteria as the proton
- π^0 Identification will be studied after adding more informations to the module file.
    - Over 90% of the showers are from neutral pions

Particle Identification for Protons-Truncated Mean dQdx

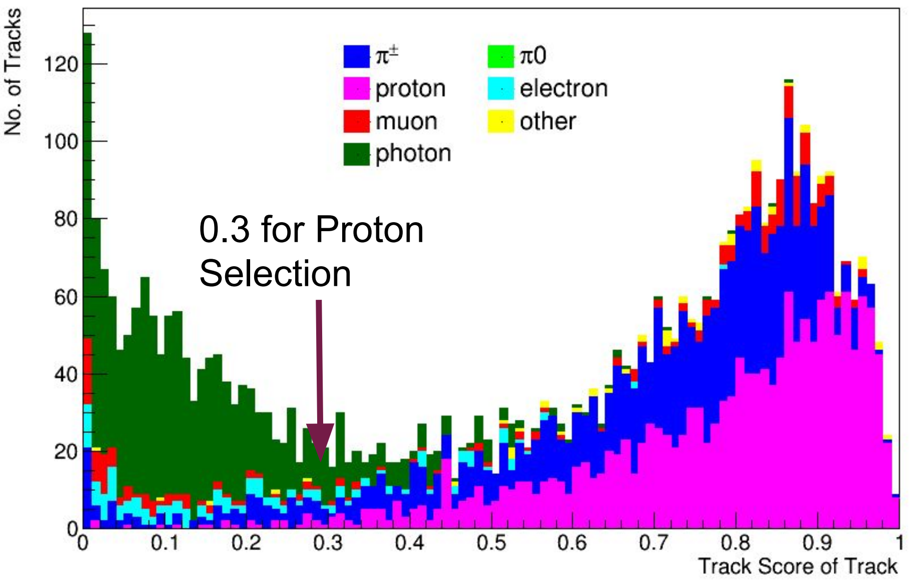


egion Selection:

- Proton Region : IV
- Pion Region: II
- Transition Region: I, III

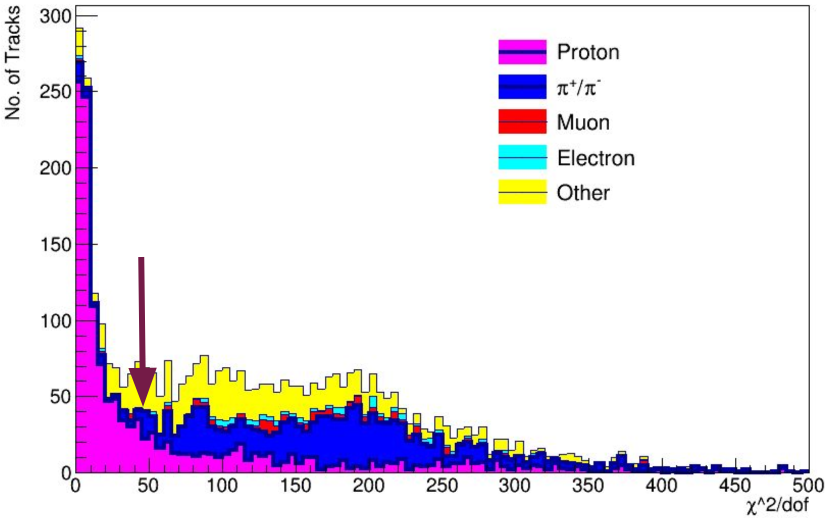
leed to further study the roton-identification in the Transition egions.

Particle Identification for Protons-TrackScore



- In the new MC samples, events are processed with Pandora treating all showers as track
  - Select the showers by track/shower score, not the shower-like/track-like provided by Pandora
- In the proton-identification and π^0 shower, the cut value is 0.3
- Most of the showers are identified as photons

Particle Identification for Protons - Chi2 of dEdx

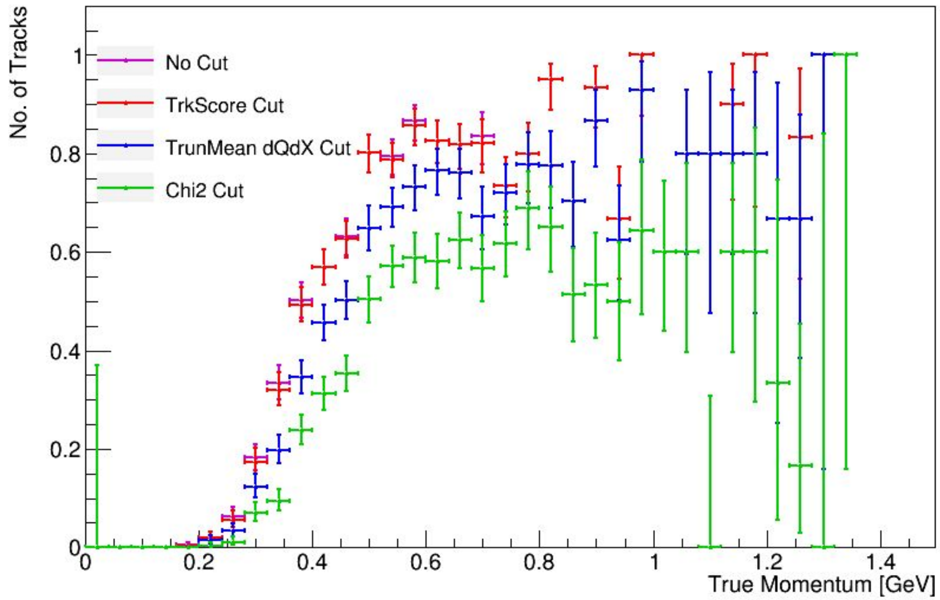


Note *: ndof*: Number of hits on collection plane

$$PID = \chi^2_{proton}/ndof = \sum_{hit}\left(\frac{(dE/dx_{measured} - dE/dx_{theory})}{\sigma_{dE/dx}}\right)^2/ndof$$

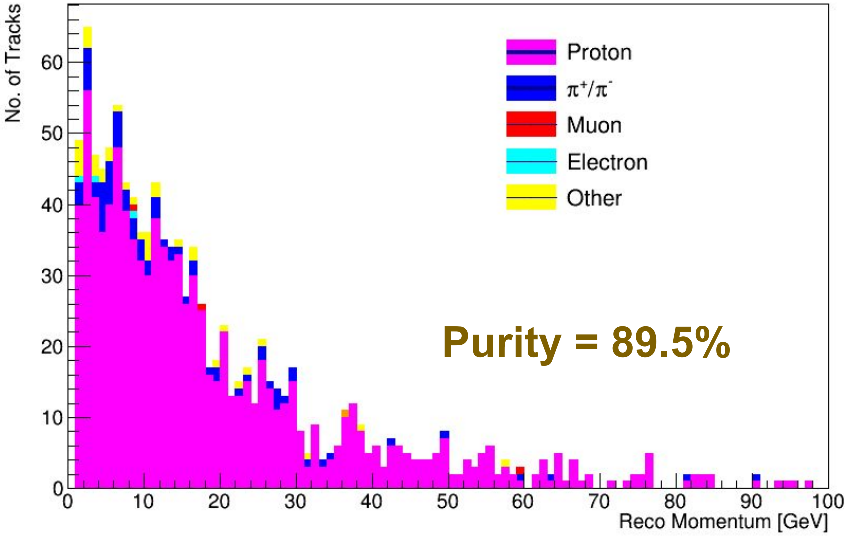
- chi2/ndof < 40 → Proton candidate
- chi2/ndof < 40 → Non-proton candidate

Particle Identification - Efficiency/Purity Study



- Track score cut only cut off a few protons - **great!**
- Truncated mean dQdx cut off a lot of charged pions, but small amount of protons - **Good**
- more tracks with the momentum > 1.0 GeV were cut off by Chi2 cut
  - For 1 GeV sample, few number of protons with momentum > 1GeV -- **Acceptable**

Particle Identification - Efficiency/Purity Study



	Purity
Before Selection	35.8%
After Selection	89.5%

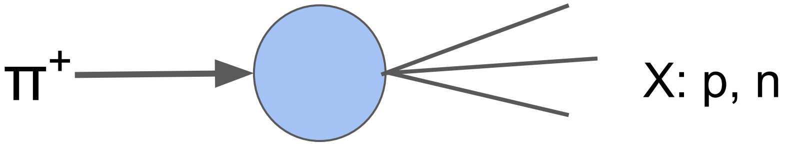
Simulation of Pion Inelastic interaction

- All the inelastic channels are handled using the cascade model
  - Bertini Intranuclear cascade model
- Cross Sections and Kinematics
  - Path length sampled according to the local density and the free NN cross section
  - **Angles after the collision sampled by experimental cross sections**
- For pions the intra-nuclear cross sections are provided to treat elastic collisions and the following inelastic channels:
  - $\pi^- p \to \pi^0 n$, $\pi^0 p \to \pi^+ n$, $\pi^0 n \to \pi^- p$ and $\pi^+ n \to \pi^0 p$
- The pion absorption channels are
  - $\pi^+ nn \to pn$, $\pi^+ pn \to pp$,
  - $\pi^0 nn \to nn$, $\pi^0 pn \to pn$, $\pi^0 pp \to pp$
  - $\pi^- pn \to nn$, $\pi^- pp \to pn$

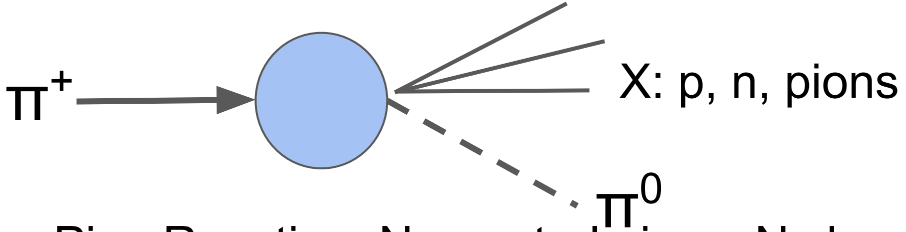
Selection of Pion Absorptions from Pion Beam Data

Pion Absorptions Selection based on the event topology from GEANT 4

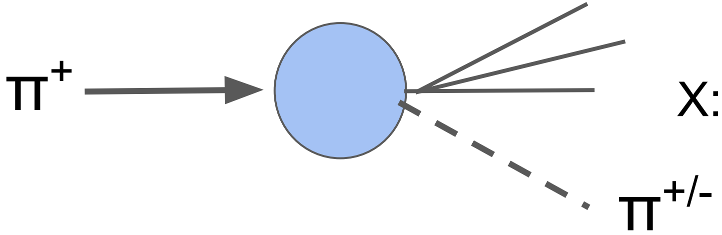
- Pion Absorption: No charged/neutral pions in the final State



- Pion Charge Exchange: At least one neutral pions in the final state

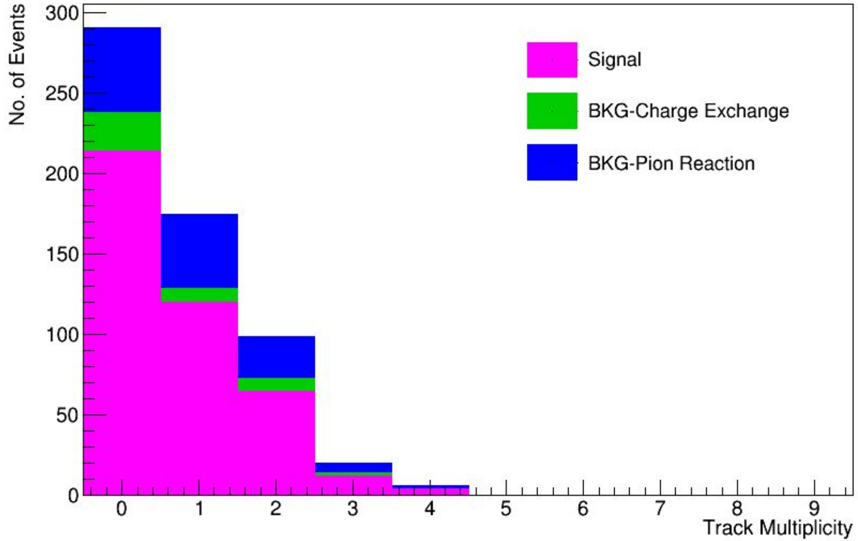


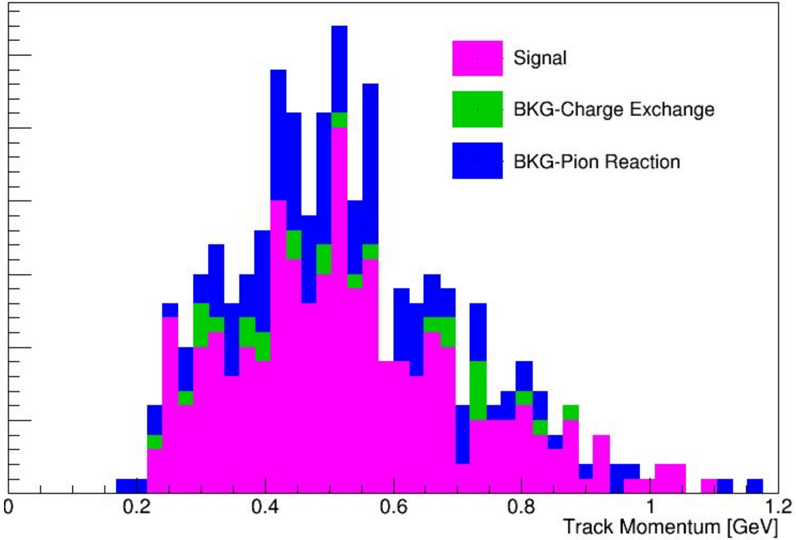
- Pion Reaction: No neutral pions, N charged pions in the final state(N>=1)



Selection of Pion Absorptions from Pion Beam Sample

	N(Pion Absorption)	N(Charge Exchange)	N(Pion Reaction)
Before Selection	722	550	928
After Selection	415	43	133





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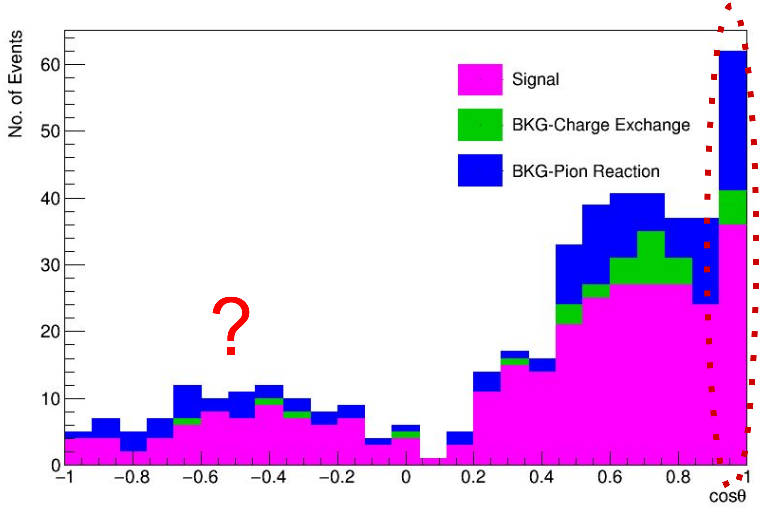
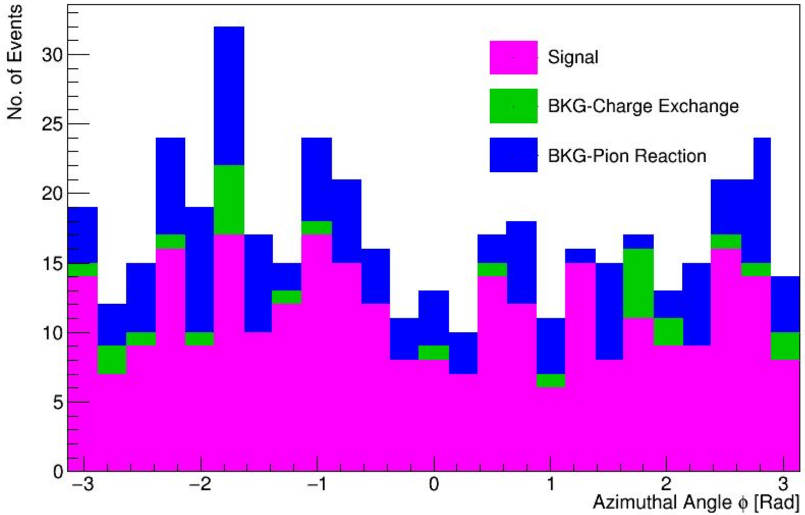
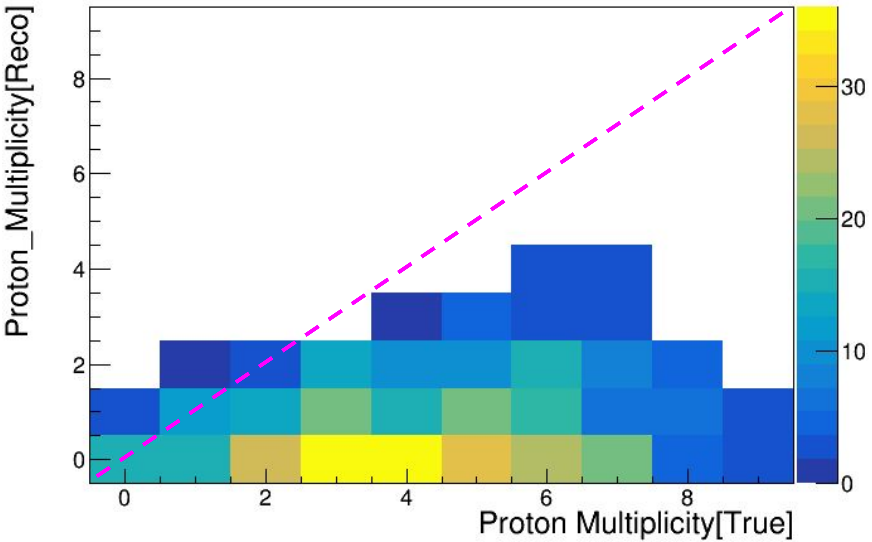


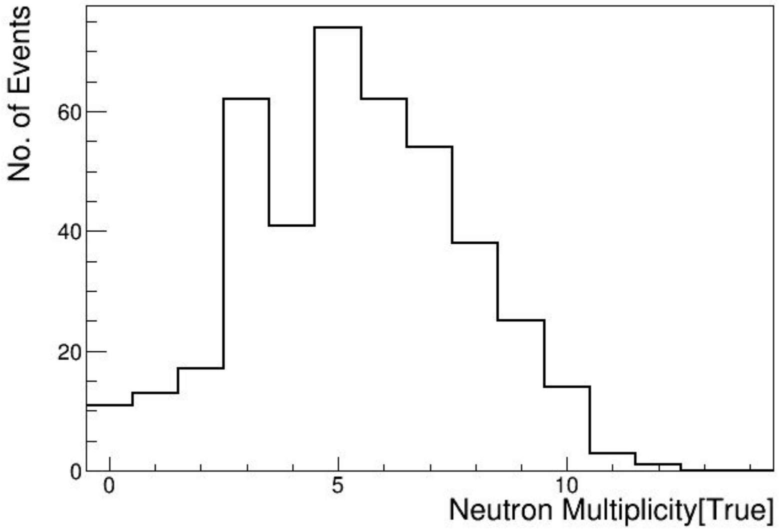


Selection of Pion Absorptions from Pion Beam Sample

Proton multiplicity (reco vs true) of the pion absorption:

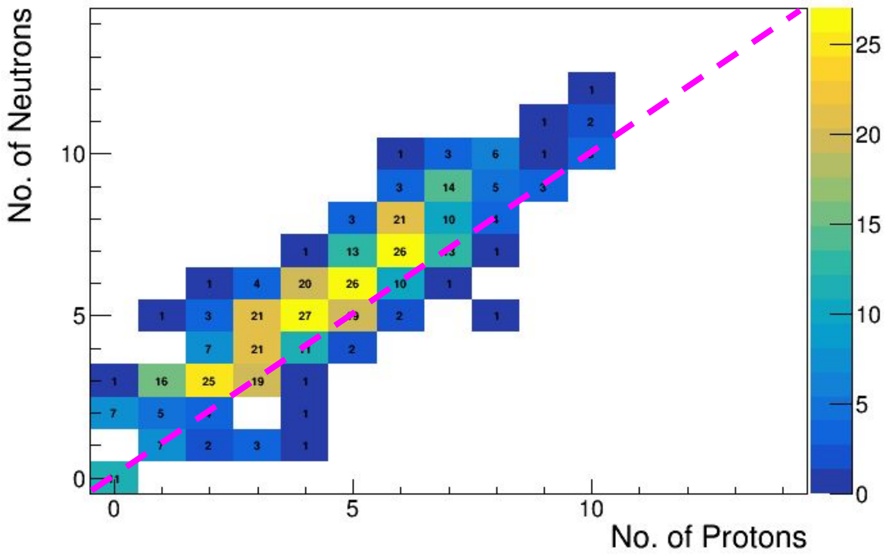


Neutron multiplicity of the pion absorption:



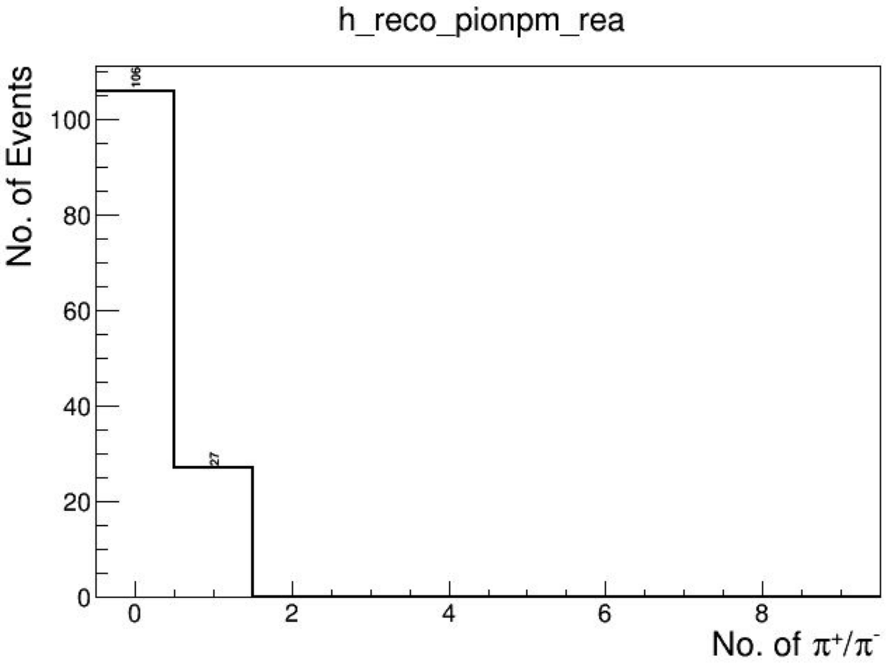
- True proton multiplicity is the proton multiplicity of the daughter protons
- Reco proton multiplicity is the number of tracks after reconstruction, some granddaughter particles are also included. There are only 8 protons of all the 415 selected pion absorption reactions; Results are still reliable.

Missing Energy & Missing Momentum



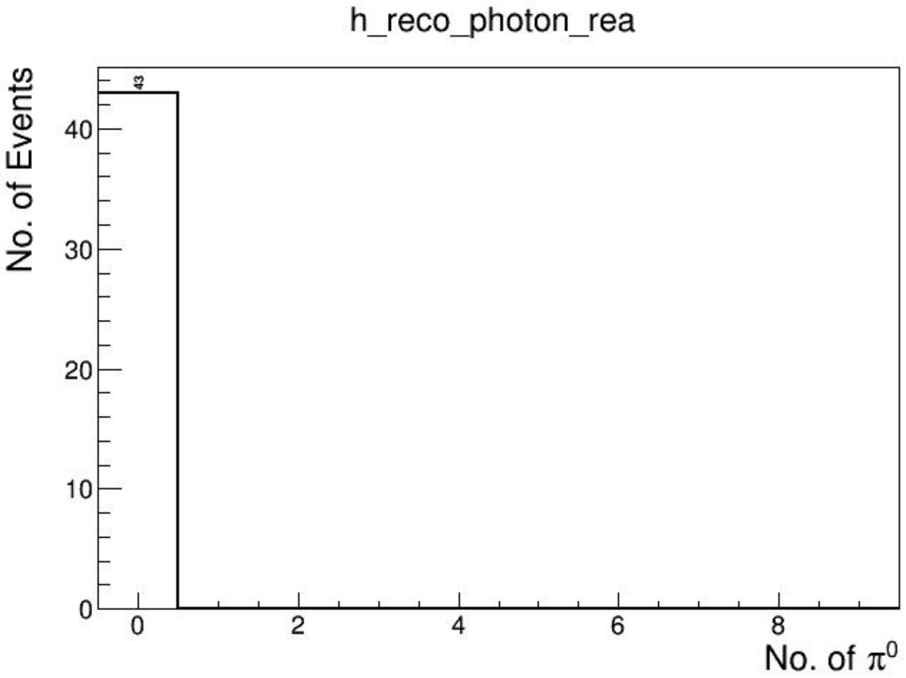
This study can only be done after add more variables to the module file

Background from Pion Reaction



- 80% of Pion reaction (charged pion produced the in the final state) past selection because there are no pions reconstructed
- 20% of the pion reaction with pion reconstructed
  - Of all the reconstructed pions, some of them have 0 hits on collection plane

Background from Charge Exchange



- In the background from charged pion exchange, all of them have no photon reconstructed - no π^0
- Can not be removed through final state in the events

Compare to previous experimental result

- *Table 1* on the right shows the LADS experimental result; the beam energy of LADS is 239 MeV[4]
- The table at the bottom shows the result of protoDUNE with the beam energy equal to 1GeV
  - More nucleons involved in the interaction due to the high beam energy

Table 1. Contributions (in mb) from several Monte Carlo event generators to the observed Ar(π^+,3p) channel at 239 MeV pion energy. Their sum is equal to the observed 3p cross-section.

MC event generators							
4p	4pn	3p	3pn	3p2n	3pdn	Other	Sum
1.7	1.5	9.2	5.9	0.3	0.4	0.9	19.9

ProtoDUNE MC (1GeV) pion energy					
4p5n	5p5n	5p7n	6p7n	6p8n	other
1	3	2	1	1	2

Summary & Conclusion

- A scheme for proton identification based on track score, truncated mean dqdx and chi2 has been tested and seems to work reasonably well.
- We studied final state kinematic variables using proton identification to select pion absorption processes.
  - Most of the backgrounds from charge exchange and reaction survived because the non-reconstructed charged pions and neutral pions
- More studies on nuclear effect based on pion absorption process are coming soon
  - Need to complete the module file and add more variables for nuclear effect study
  - Add comparison between data and MC

References

1.A.Altman et al., Phys. Rev. C34, 1757 (1986)

2.W.J.Burger et al. Phys. Rev. C 41,2215(1990)

3.D.J. Mack et al., Phys. Rev. C 45, 1767 (1992

4.B.Kotlinski et al. Eur. Phys. J. A 9, 537-552(2000)