Pion Absorption and Charge Exchange Cross Section Analysis

Jacob Calcutt & Francesca Stocker

Jan. 26, 2020

Outline

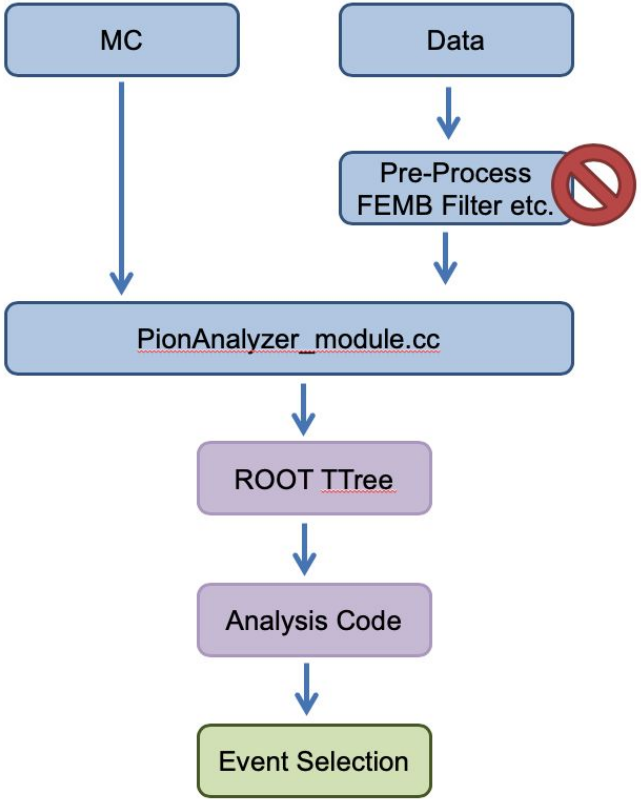
- Motivation For Cross Section ⟶ Libo Jiang's Talk
- Thin Slice Method
- Signal Definition & Background
- Event Selection
- Results so far
- Outlook
- Some Event Displays

Technical Specifications

Code sits in `protoduneana` (repo):
`protoduneana/singlephase/Pion/PionAnalyzer_module.cc`

Analysis Code on GitHub

- Using PyRoot or ROOT RDataFrame for the event selection
- More in-depth studies
- Plotting

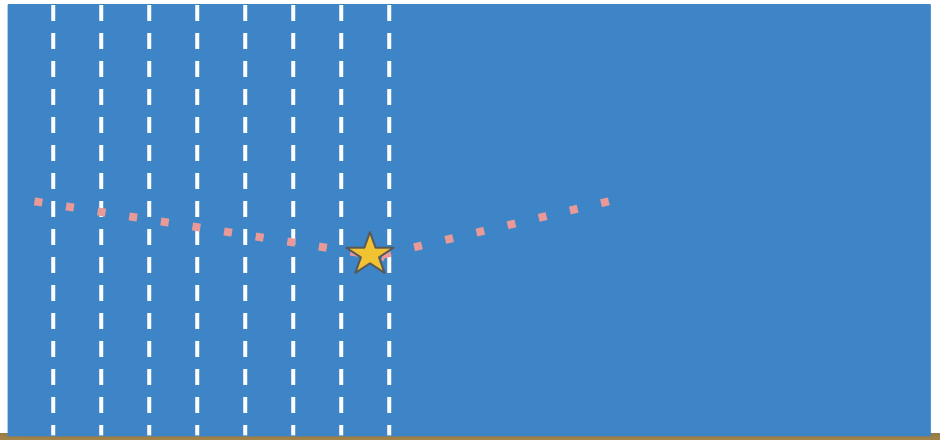


★ For the data shown in this talk we did not run the FEMB filters etc.

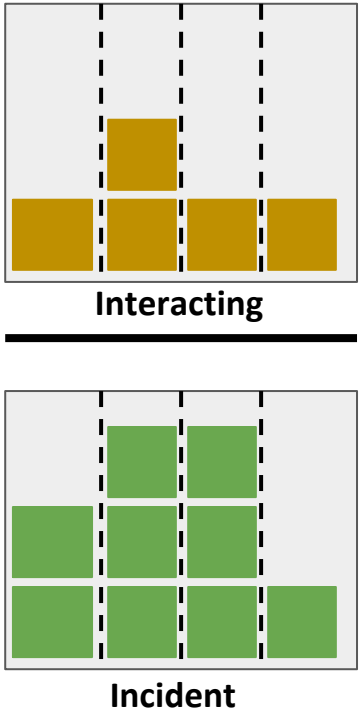
★ **For now: only looking at 1GeV, Run 5387**

Thin Slice Method

- Estimate the energy at each slice (using calorimetry info from collection plane)
  - Fill the **Incident** histogram (bottom) for each slice's energy
- Determine interaction point
  - Passes signal selection?
    - Fill **Interacting** histogram (top)

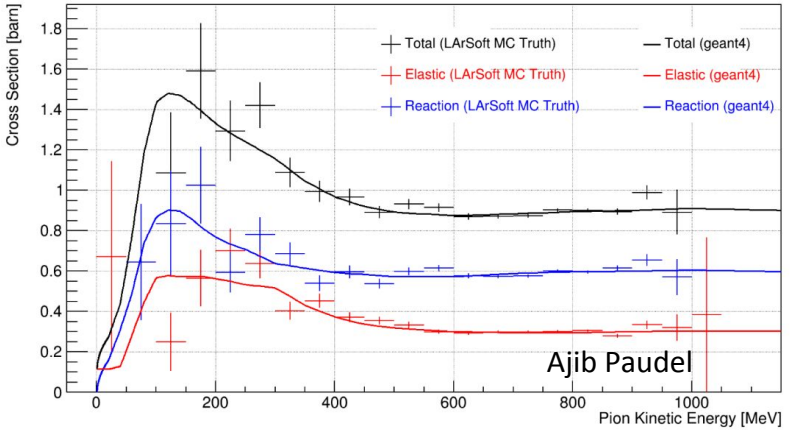


$\sigma \sim$

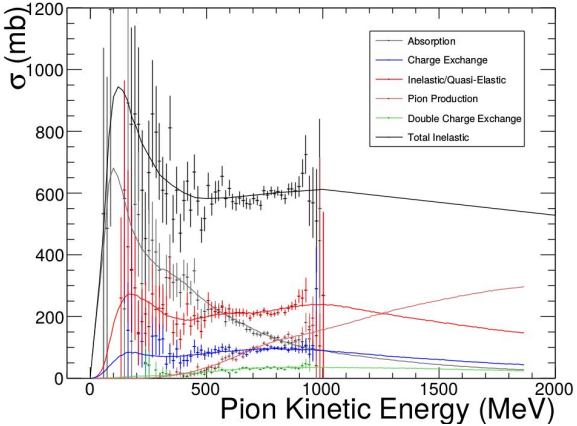


Thin Slice Method -- MC Truth

Ajib & Heng-Ye showed the performance of the thin slice using the true ionization deposits from beam pions, compared to true Geant4 cross sections

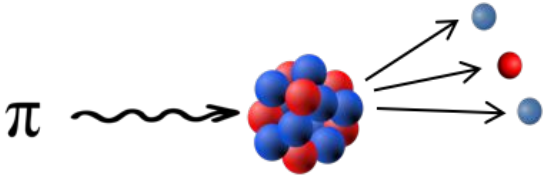


Technique also valid when separating by inelastic subtype/final state content

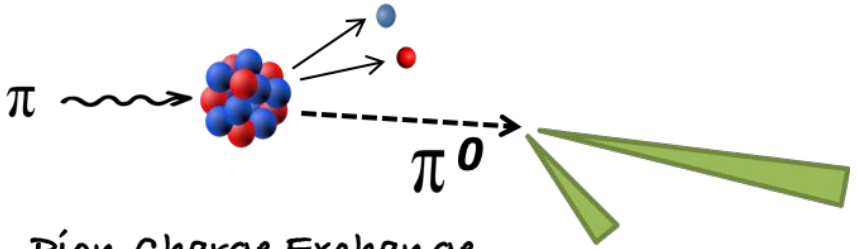


Signal & Background Definition

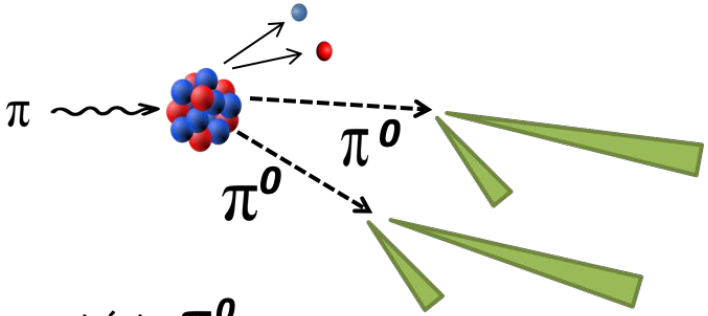
Combined Signal Definition



Pion Absorption



Pion Charge Exchange

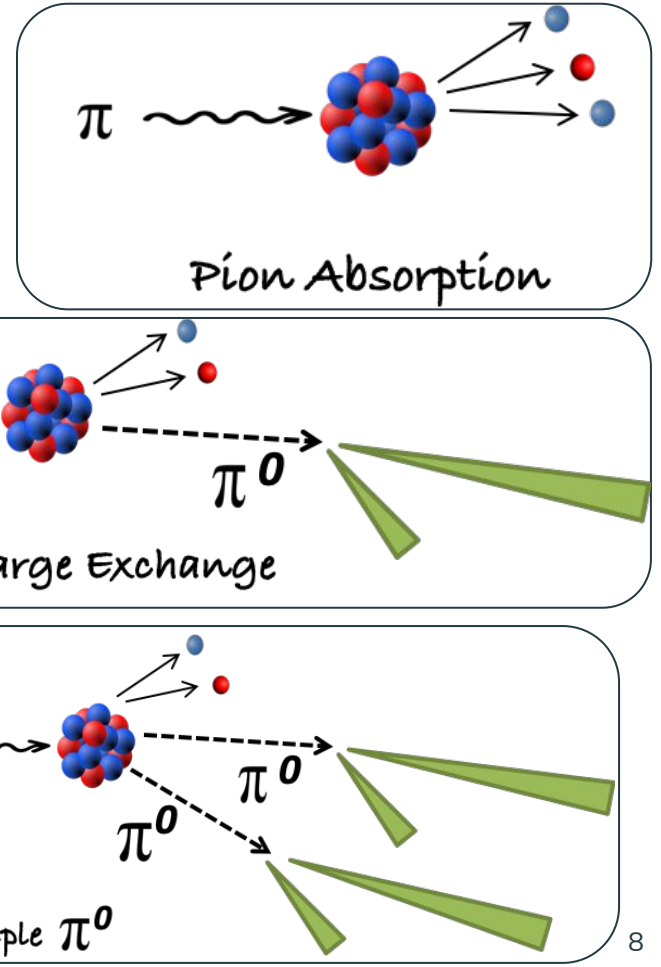


Multiple π^0

Signal Definition

Basic selection:

- Abs + Cex*: Pion interactions without charged pion in the final state
- Separate Abs & Cex*: Look for π^0-like showers

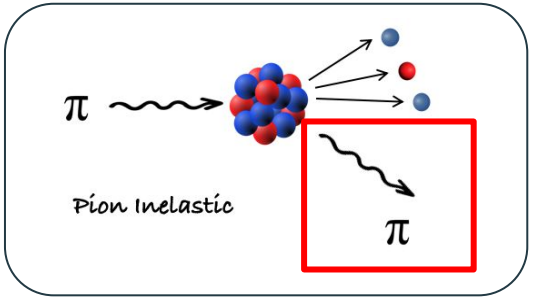


Cex*: Cex + Multiple π^0

Backgrounds

Absorption + Charge Exchange + $n\pi^0$

- The Reco could miss the outgoing Pion
  - Thresholds/reinteractions
- The outgoing Pion is not identified as a Pion
- Other primary beam particles misidentified as Pions
- Stopping/Decaying Pions



Absorption

- Missed π^0- showers

Charge Exchange

- Proton Daughter looks like a shower
- Multiple π^0 ??
  - Maybe later able to separate

Background -- Vertex

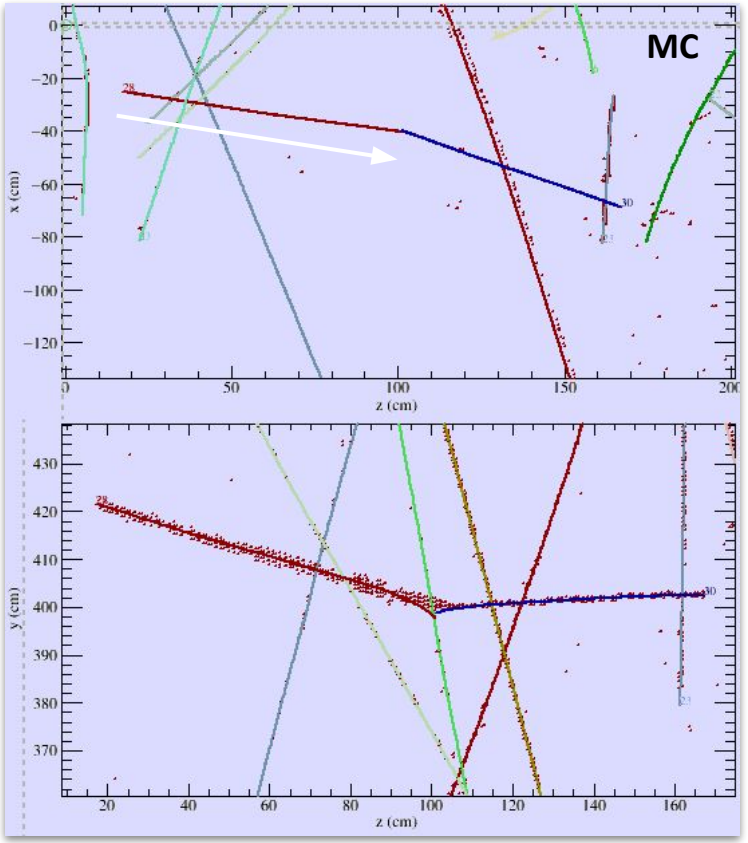
Right: A pion elastically scatters, then ends in an inelastic scatter. Pandora reconstructs the elastic

Do we call this signal or background?

Thin slice method: We only care what happens at the vertex of red

⟶ Need to define what happens here

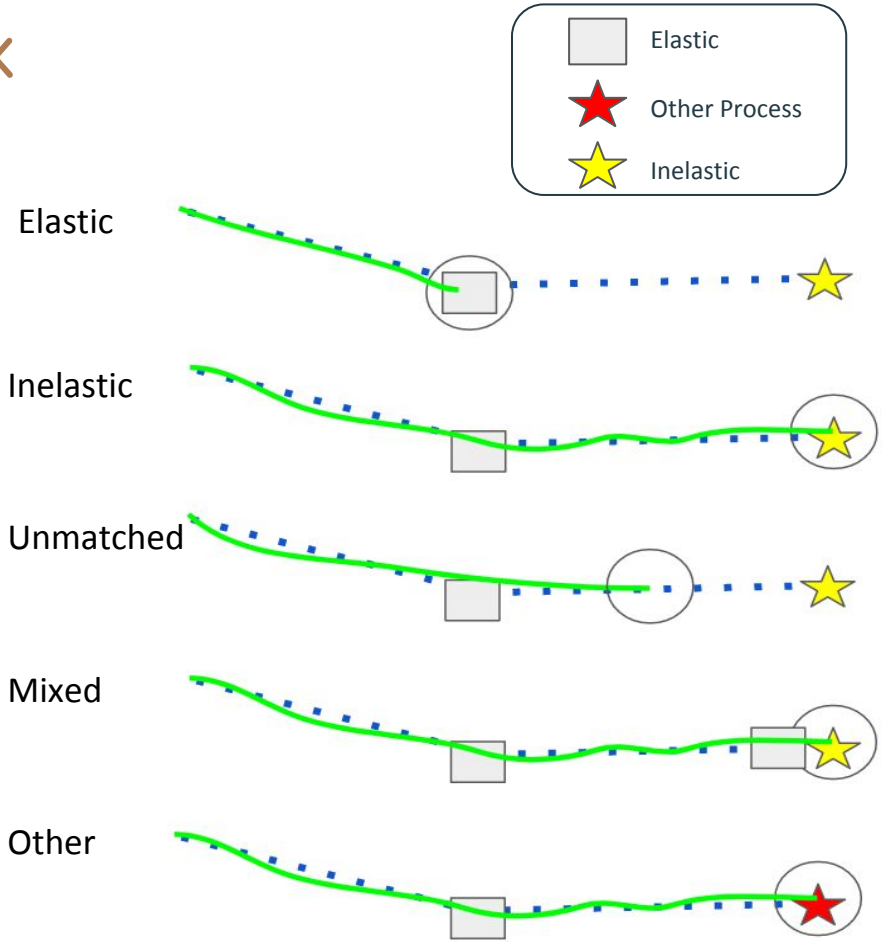
⟶ Cannot just use the Geant4 process name



Background -- Vertex

Categorize vertex by distance of simulated ionization deposits to true interaction points

Gives an estimate for backgrounds, needs more robust treatment for full cross section analysis/fits



For more info, see this talk from previous CM
(It's a google drive link because of indico weirdness)

Event Selection

Event Selection - a Flow Chart

BL Particle
- BL PID
- BL Momentum
- BL Tracks

Pandora Beam Particle
- Beam Cuts
- Ends in APA3

Abs + Cex + $n\pi^0$
- Daughter Tracks vs. Shower
- PID: Reject $\pi^{\pm}$ daughter tracks
- Ignore Far Tracks

Separate Abs and Cex
- Find π^0-showers
  - Hits
  - Distance to vtx

Pion Absorption

Final State Dynamics (Libo)

Pion Charge Exchange

$n\pi^0$

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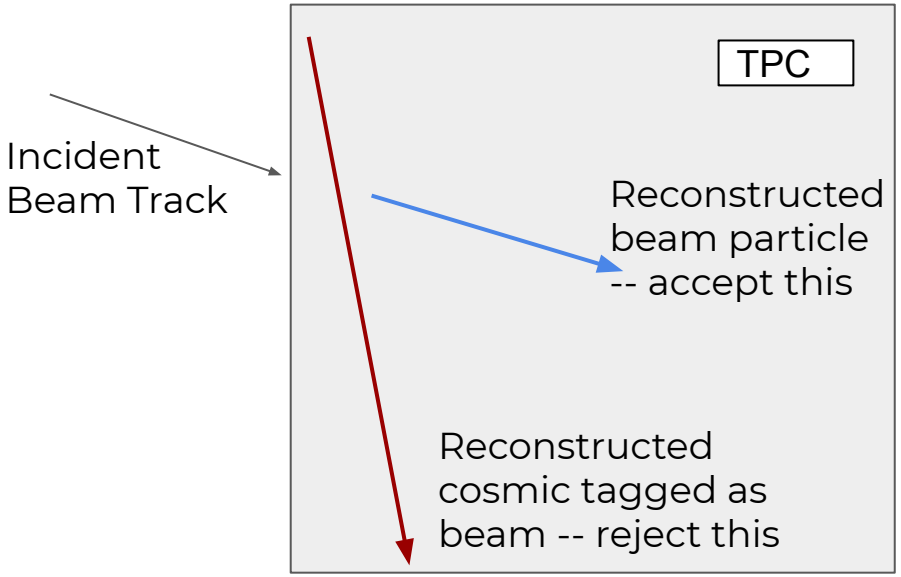
Beam Line Selection

The beam line gives us a momentum measurement (thin slice) + tracking (cut away backgrounds) + PID

For data quality:

- Require good reconstructed momentum
  - 1 active fiber in each monitor
- 1 reconstructed beam line track



See earlier talk on Beam Interface

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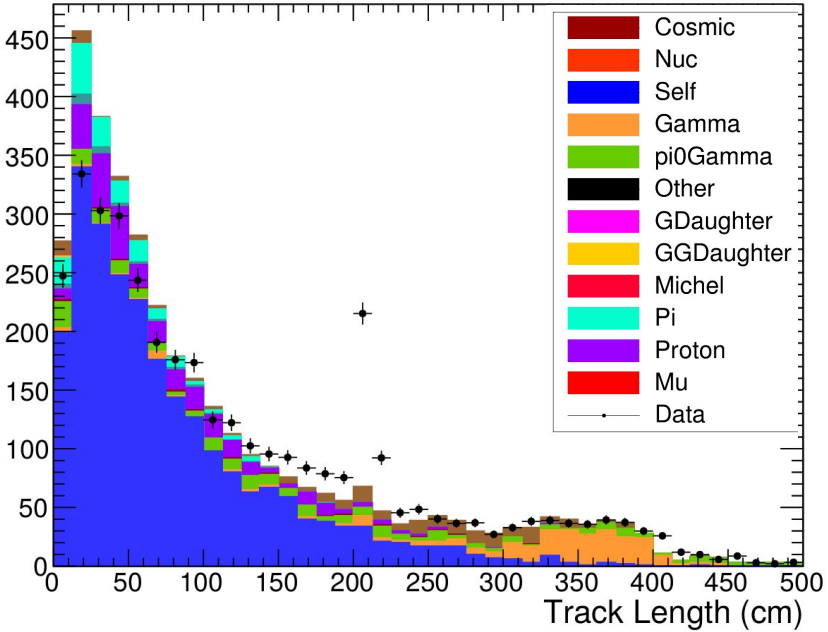
Incident Particles

Choose true π^+/μ^+ in MC or π^+/μ^+-like PID in data with track-like beam PFParticle

MC: True particle corresponding to reconstructed beam PFParticle

- Significant cosmic + interaction background

Data: Large spike at ~200cm track length from broken tracks at APA3⟶2 transition

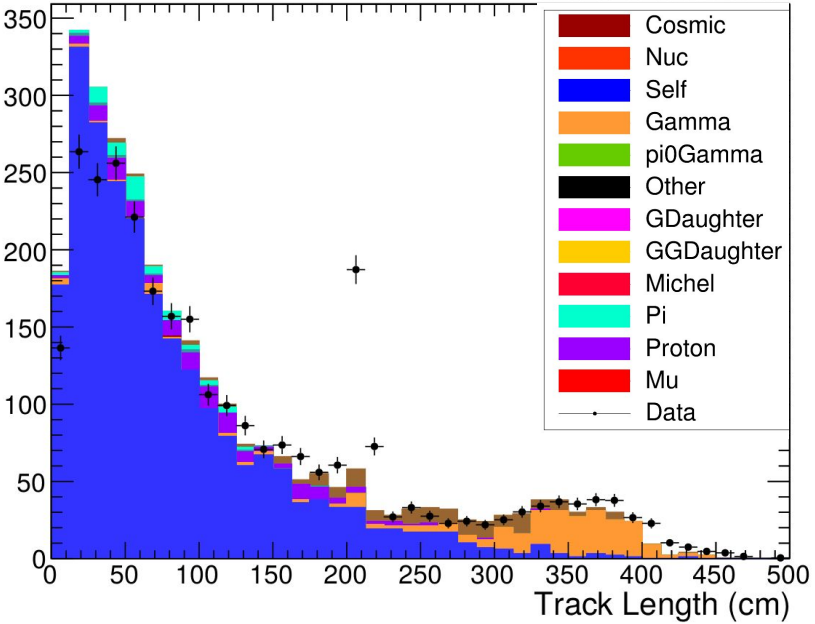


Beam Cuts

Use beam cuts to remove backgrounds from cosmics + upstream interactions

Cuts on difference in position/angle between incident beam track & TPC beam track

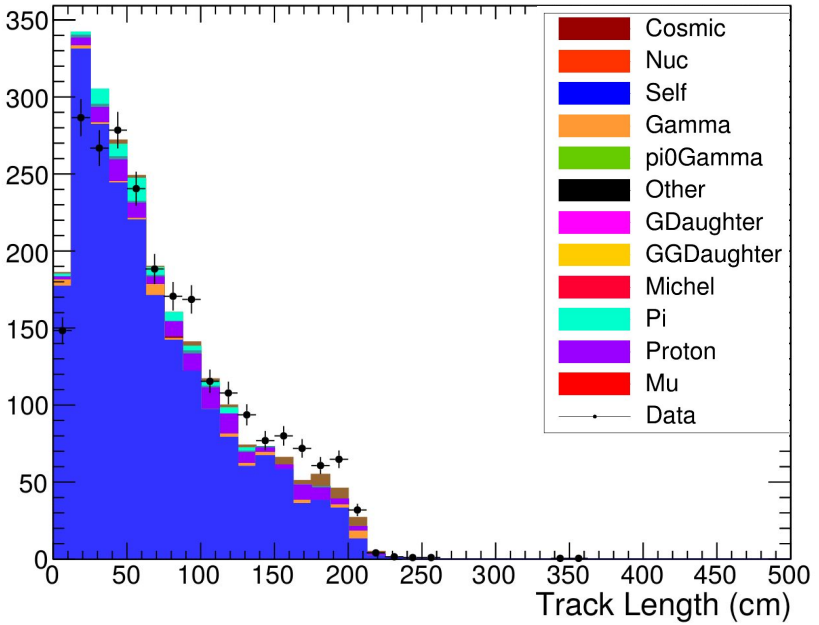
Using values from Owen's latest talk



End Position Cut

Cutting out tracks with end position > 226 cm into TPC

- Removes muon background
- Can later use these in a sideband analysis to constrain remaining muon background in APA 3
- ★ Changes for higher Beam Energy (to be studied)



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Pion Charge Exchange

$n\pi^0$

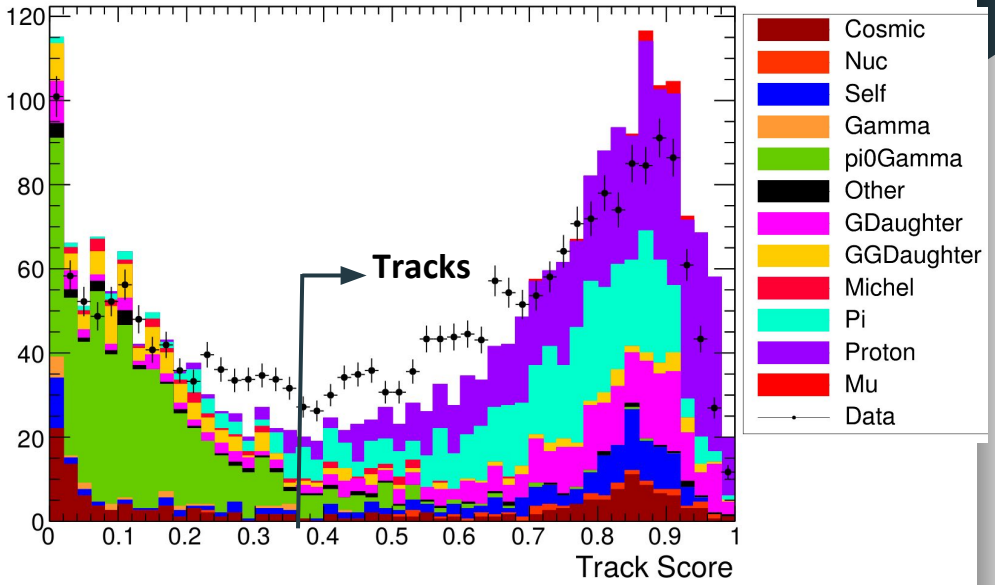
Track/Shower Discrimination

Use 2D CNN (Aidan) to separate PFParticle daughters into tracks and showers

- Use ‘forced’ reco Track and Shower objects accordingly
  - See previous talk (p. 9,10)

For this study:

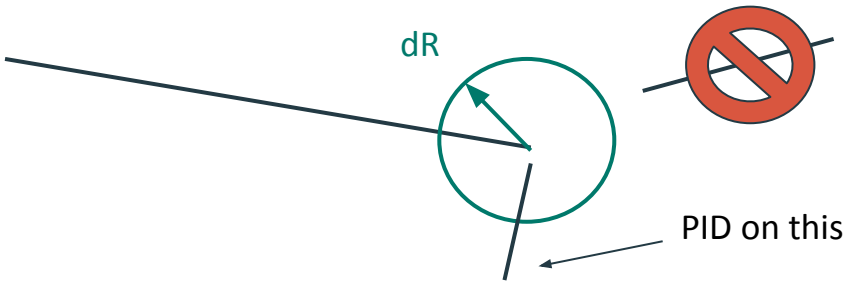
- >.35 ⟶ Track
- <.35 ⟶ Shower

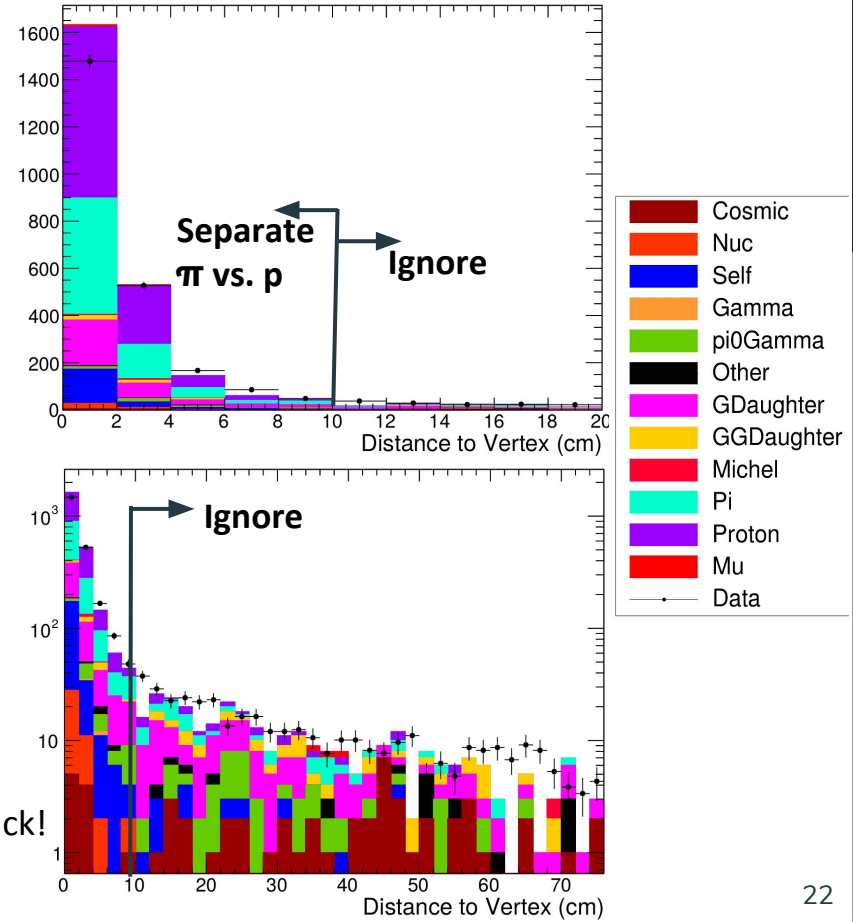


Distance to Vertex

Many track-like daughters at a far distance are from downstream interactions or cosmics → Ignore

For pion vs. proton discrimination only look at daughters within 10cm



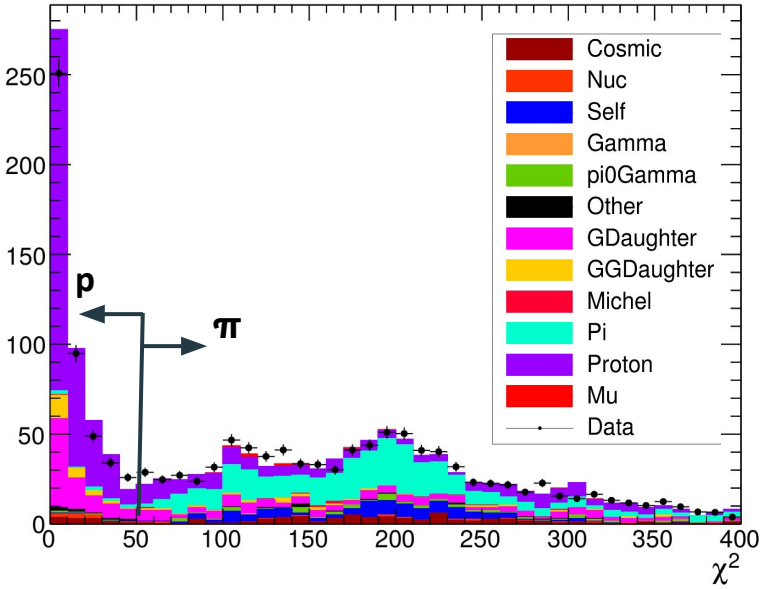


π -- p Separation

Fit dE/dX vs. Residual Range to proton expectation

Any track has χ^2/dof > 50
⟶ reject event

All tracks < 50
⟶ accept event



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Pion Absorption

Final State Dynamics (Libo)

Pion Charge Exchange

+

$n\pi^0$

Distance to Vertex -- Showers

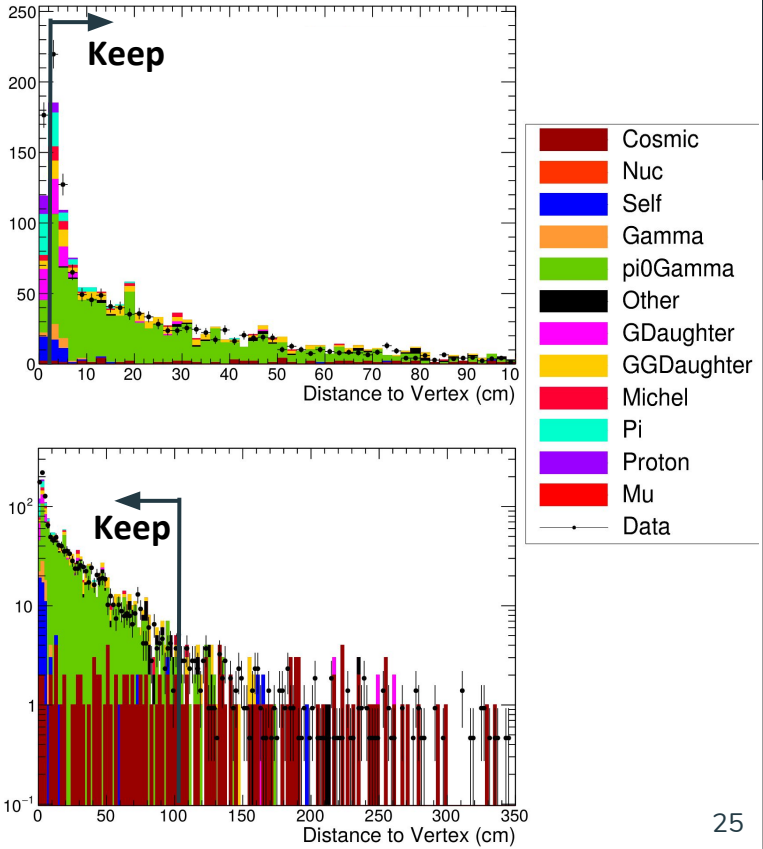
Too close to vertex:

- Shower-like daughters/grand daughters
- Missed vertex

Too far from vertex:

- Cosmics

Only consider showers within 2 cm and 100 cm



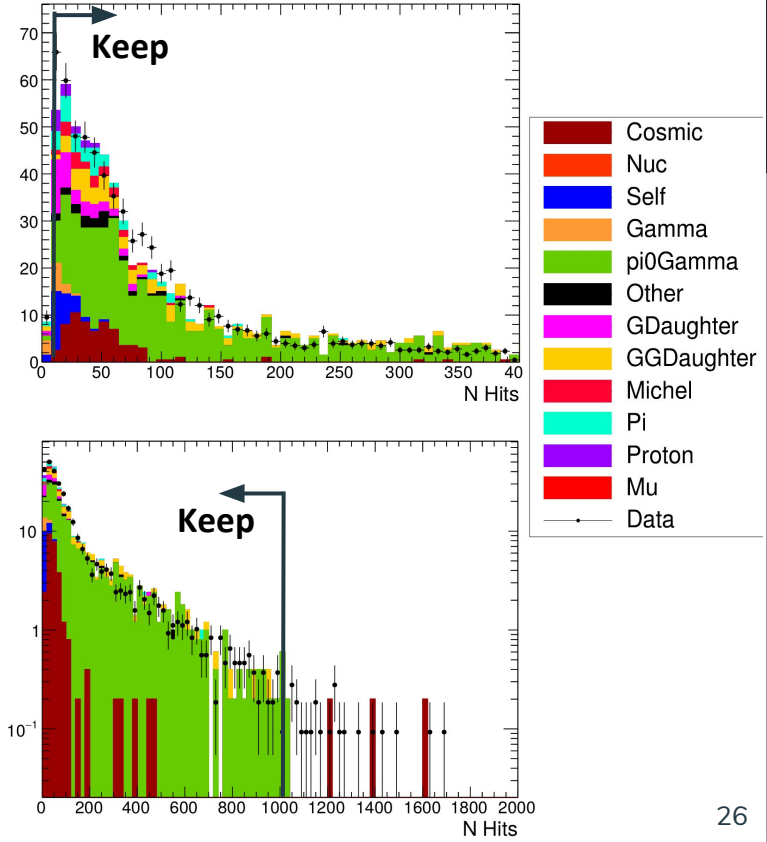
Number of Hits -- Showers

Similar to previous slide

High number of hits: Cosmics

Low number of hits: Backgrounds from interaction (i.e. (great-)grand-daughters)

Require shower candidates to have between 12 and 1000 hits



Event Selection - Performance

Event Selection Cut Flow MC & Data

Cuts:

→ Start with incident π^+/μ^+

→ Beam PFP is track

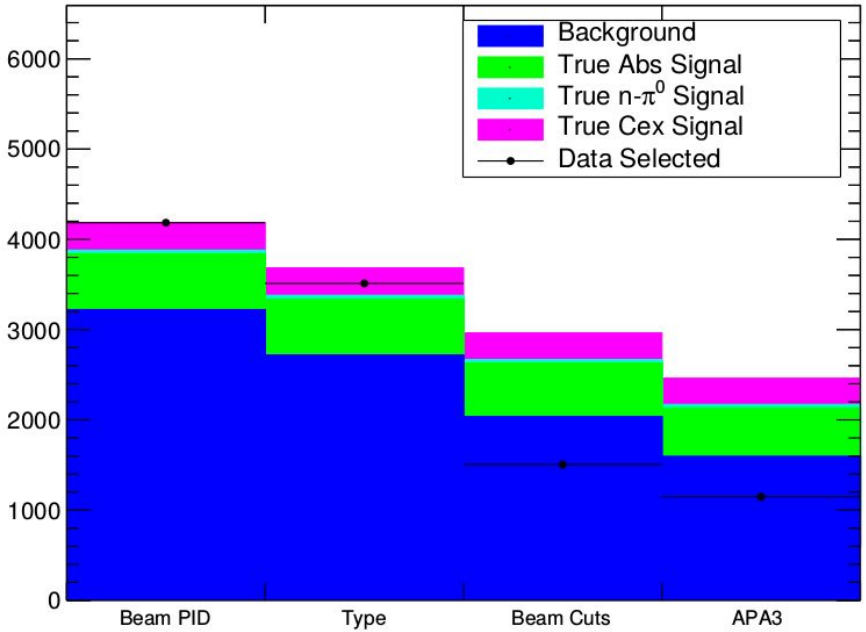
→ Beam position/angle cuts

→ Track ends in APA3

Background includes elastic, “other process”, and unmatched vertices

→ Unmatched can be from other particles

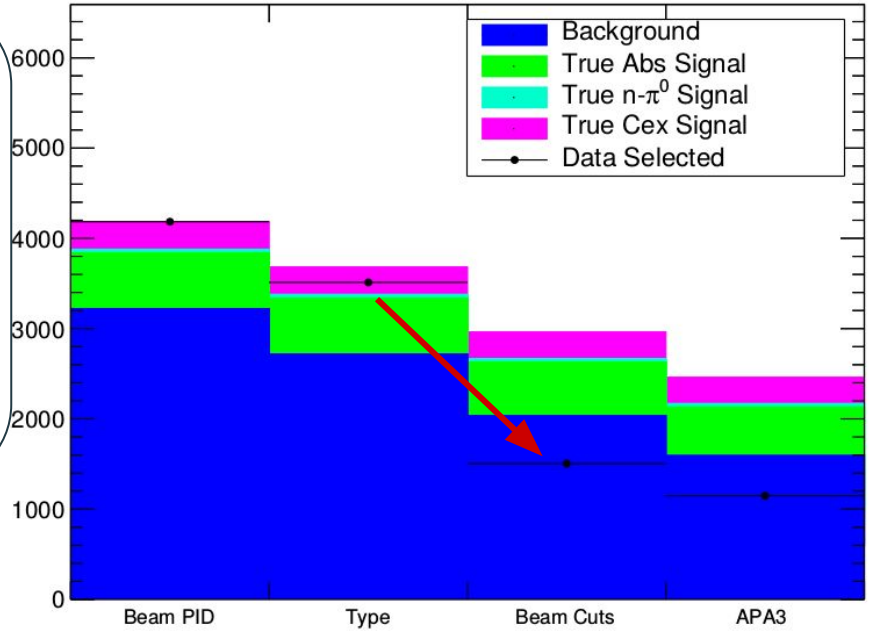
Signals are inelastic/mixed vertices



Event Selection Cut Flow MC & Data

The large drop is from requiring ‘good quality’ from beam
→ 1 momentum, 1 track
→ No analogy in MC

Extra events cut out due to fiber glitch
→ Will improve with next production

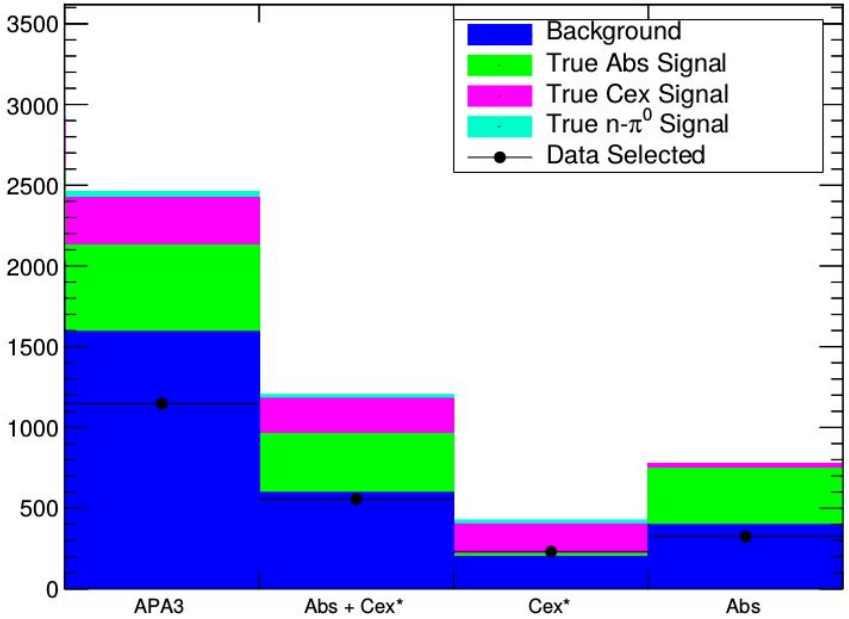


Event Selection Purity and Efficiency

Events surviving the APA3 cut are “available” for the thin slice analysis

➢ Efficiency relative to signal in APA3 bin

Selection	Efficiency	Purity
Abs + Cex*	70%	51%
Cex*	64%	49%
Abs	65%	45%



Separation between Abs & Cex* is promising

Next Steps

Reducing/Understanding Background

- Rate of selecting decaying/stopping Pion?
- Incident beam particle
  - Cherenkov inefficiencies unknown for now
- Try forced tracking reconstruction on primary beam particle
  - χ^2--based PID of primary beam particle?
- Looking for input

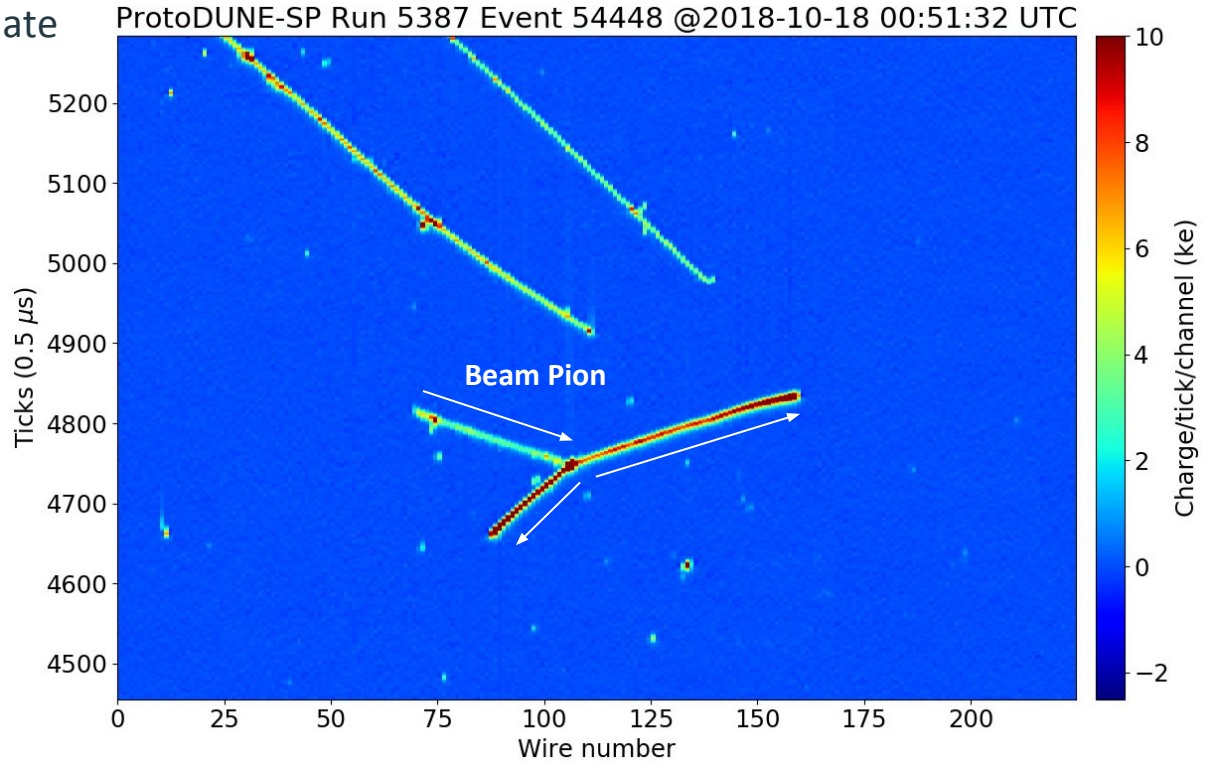
Other topics

- Crossing Cosmics
- Good Reconstruction (see this talk on reconstruction failures)
- Does daughter reconstruction depend on position in TPC?
  - Similar to APA 3 cut

Some Event Displays for Illustration

Data Fun!!

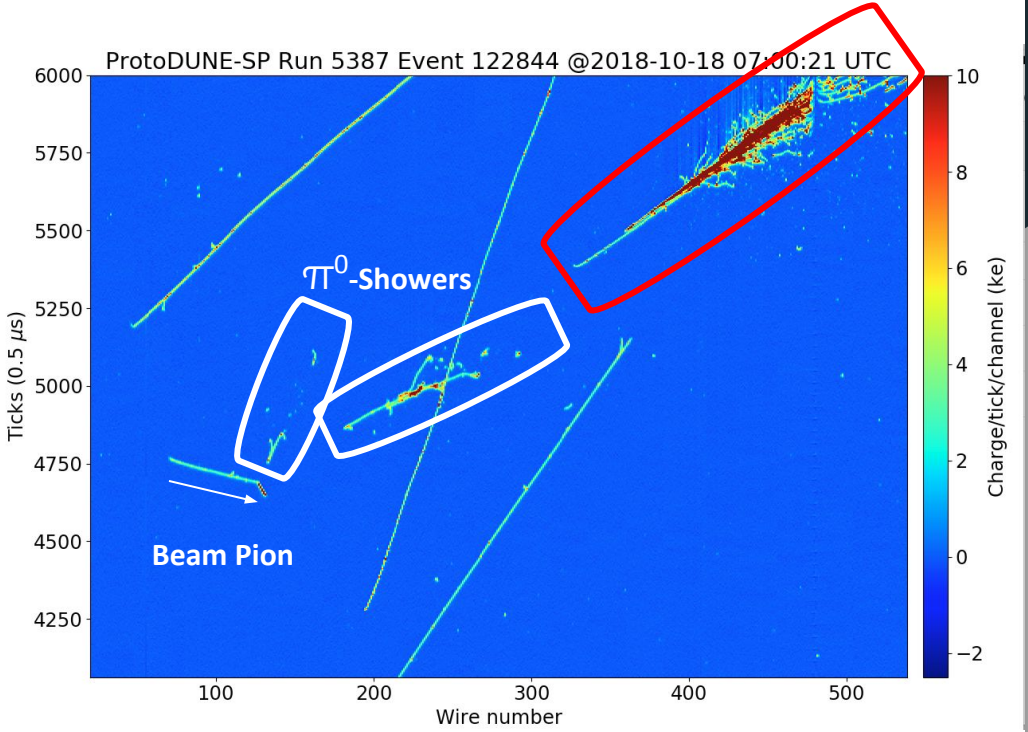
Selected Absorption Candidate



Data Fun!!

Selected Charge Exchange Event

- 2 - π^0 Event
  - One π^0 is heavily boosted
- Low Energy Showers are recognised as Daughters
- The big shower is not associated as a daughter of the Pion



Data Fun!!

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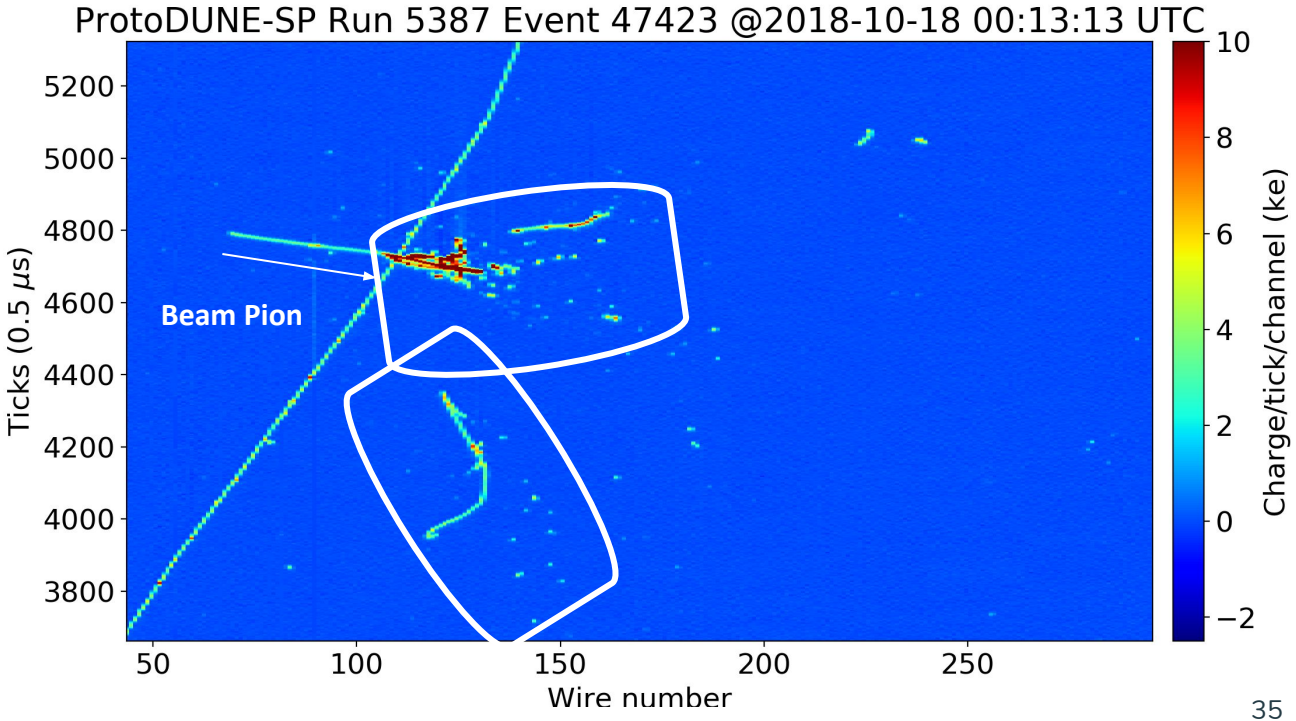
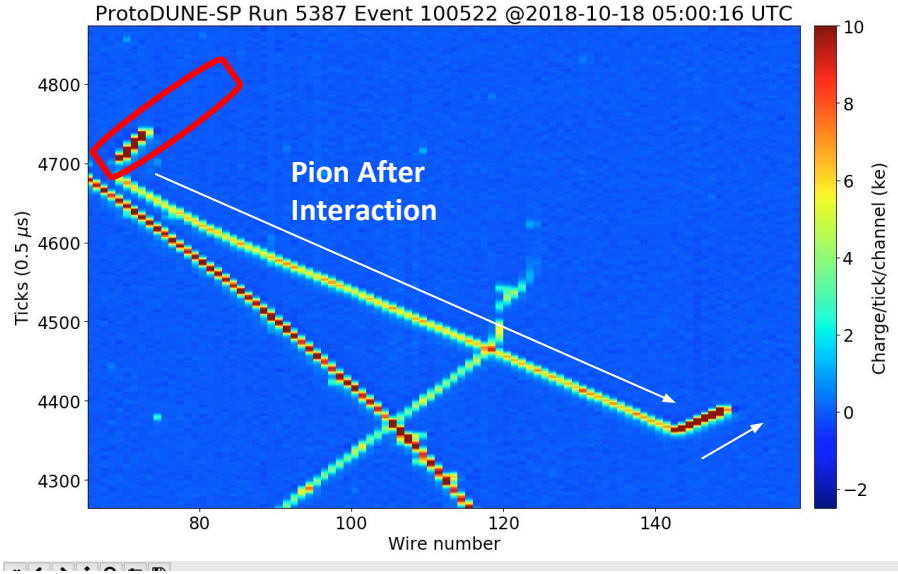


Data Fun!!

NOT Selected because of Beam Cut

- Otherwise a Pion Absorption Candidate
  - Has a proton from an upstream interaction
- Would not want to consider an event like that because of the upstream interaction ⟶ Energy estimation would be wrong

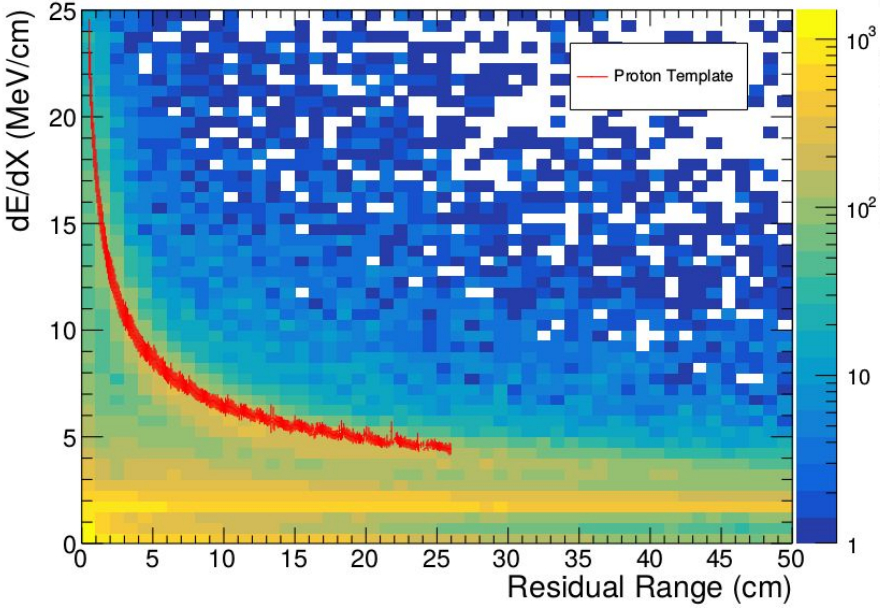


Thanks for listening!

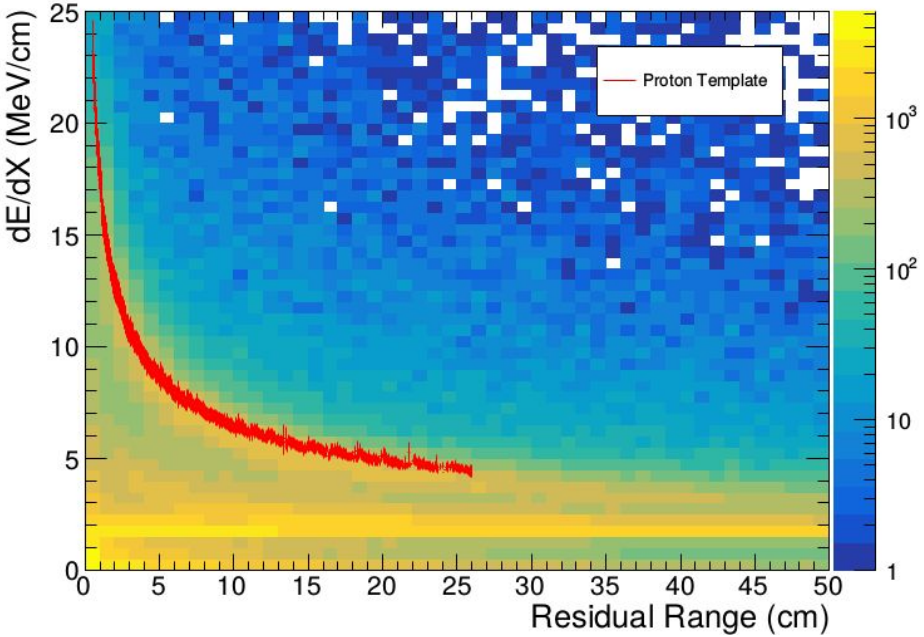
Backup Slides

Daughter Calorimetry

MC

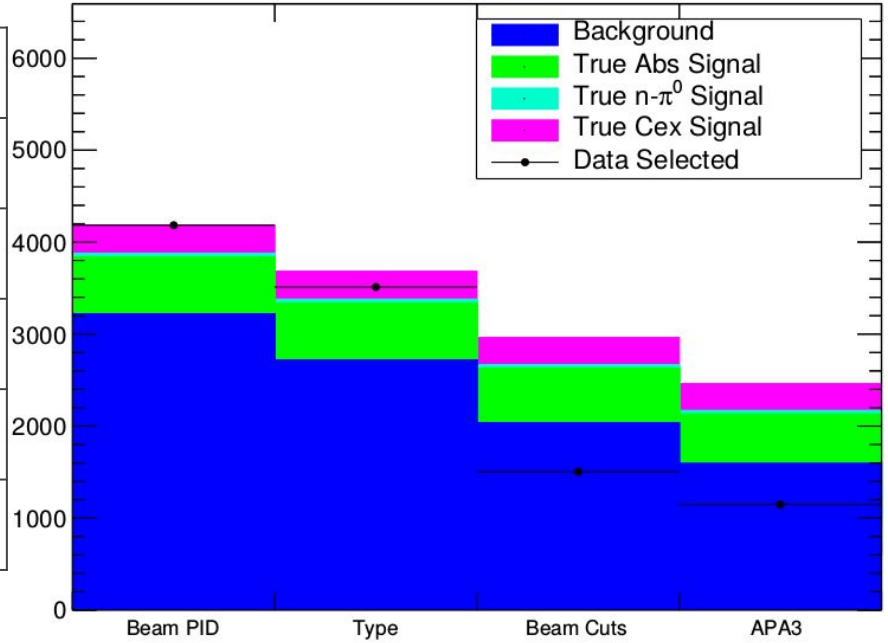


Run 5387

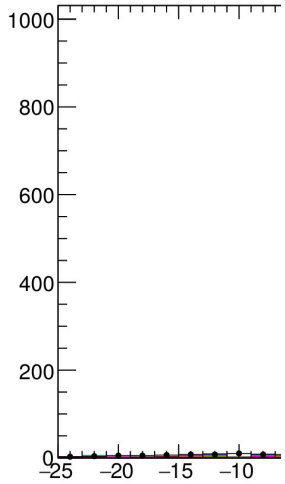


Event Selection Cut Flow MC & Data

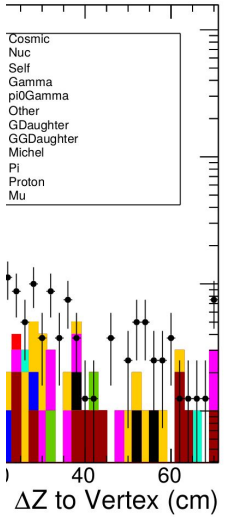
	Data	MC
Cut	**Surviving**	**Surviving**
PID	100%	100%
Type	84%	88%
Cuts	36%	71%
APA3	27%	59%



deltaZ



Cosmic
Nuc
Self
Gamma
pi0Gamma
Other
GDaughter
GGDaughter
Michel
Pi
Proton
Mu
Data



Shower deltaZ