Backward-Going Cosmics in T2K's ND280

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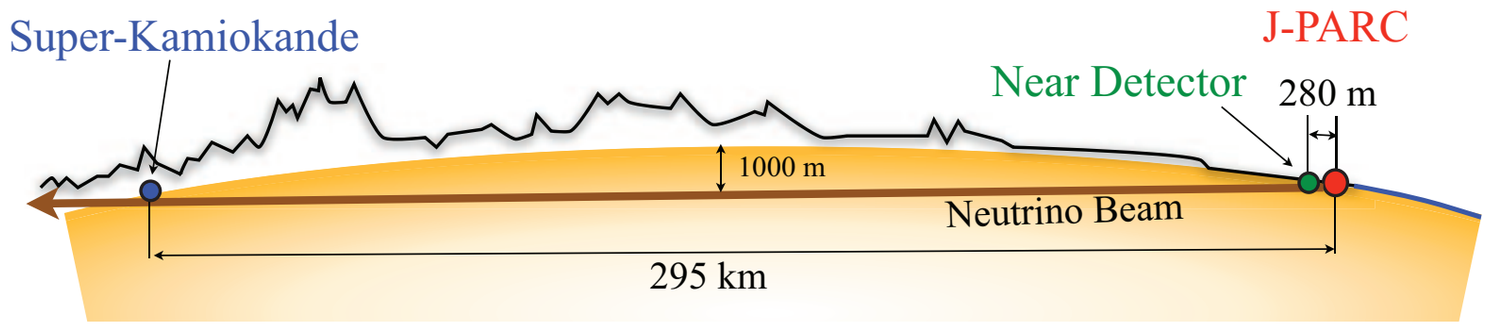
Outline

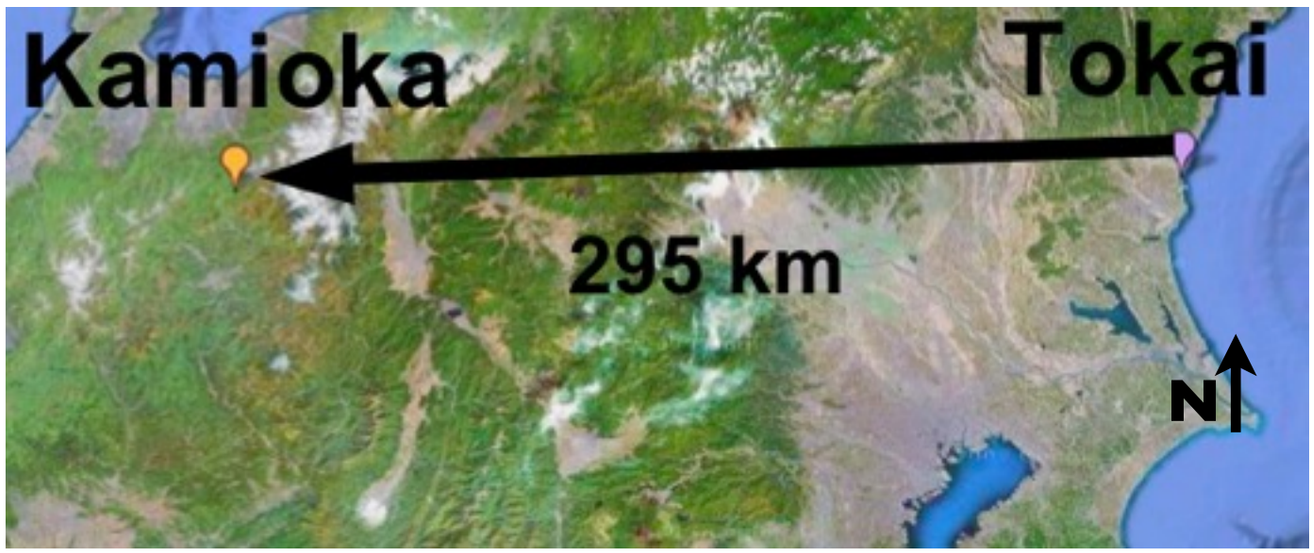
- A **brief** introduction to ND280 and the Pi-zero Detector (P0D)
- A different sort of cosmic ray analysis: Backward-going sample
  - Preliminary selection cuts
  - Track Length, Energy Loss, dE/dx
  - MIP Scales
  - Discussion of current status and future prospects
- Some other miscellaneous work and prospects
- Closing thoughts on this Summer's work

T2K: Tokai To Kamioka

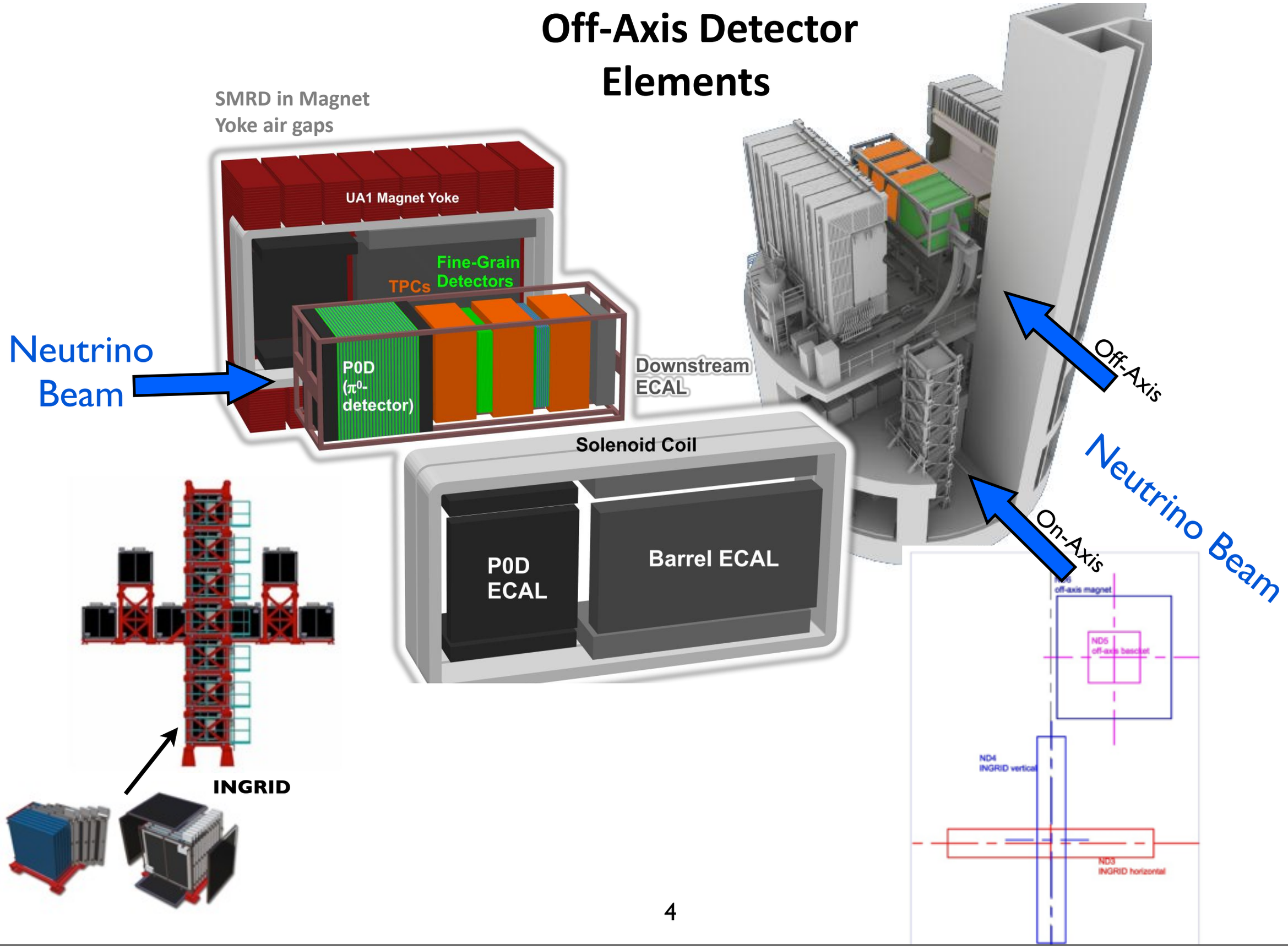
~500 members, 59 Institutes, 12 countries



J-PARC: Japan Proton Accelerator Research Complex



Off-Axis Detector Elements



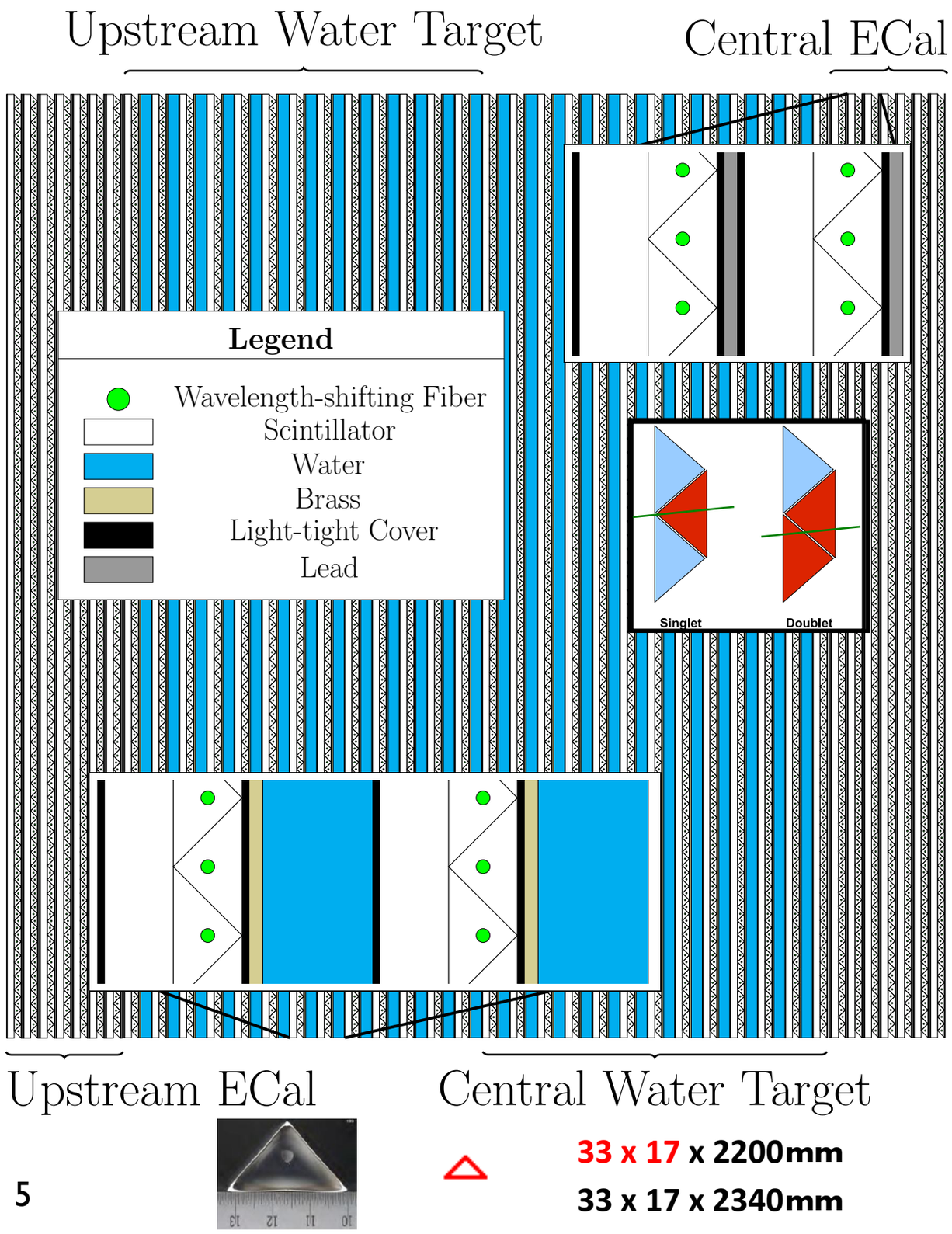
The Pi0 Detector (P0D)

40 X-Y layers of scintillator
10,400 Channels (MPPC)

5432kg Fiducial Mass (total)
1950kg Fiducial Mass (water)

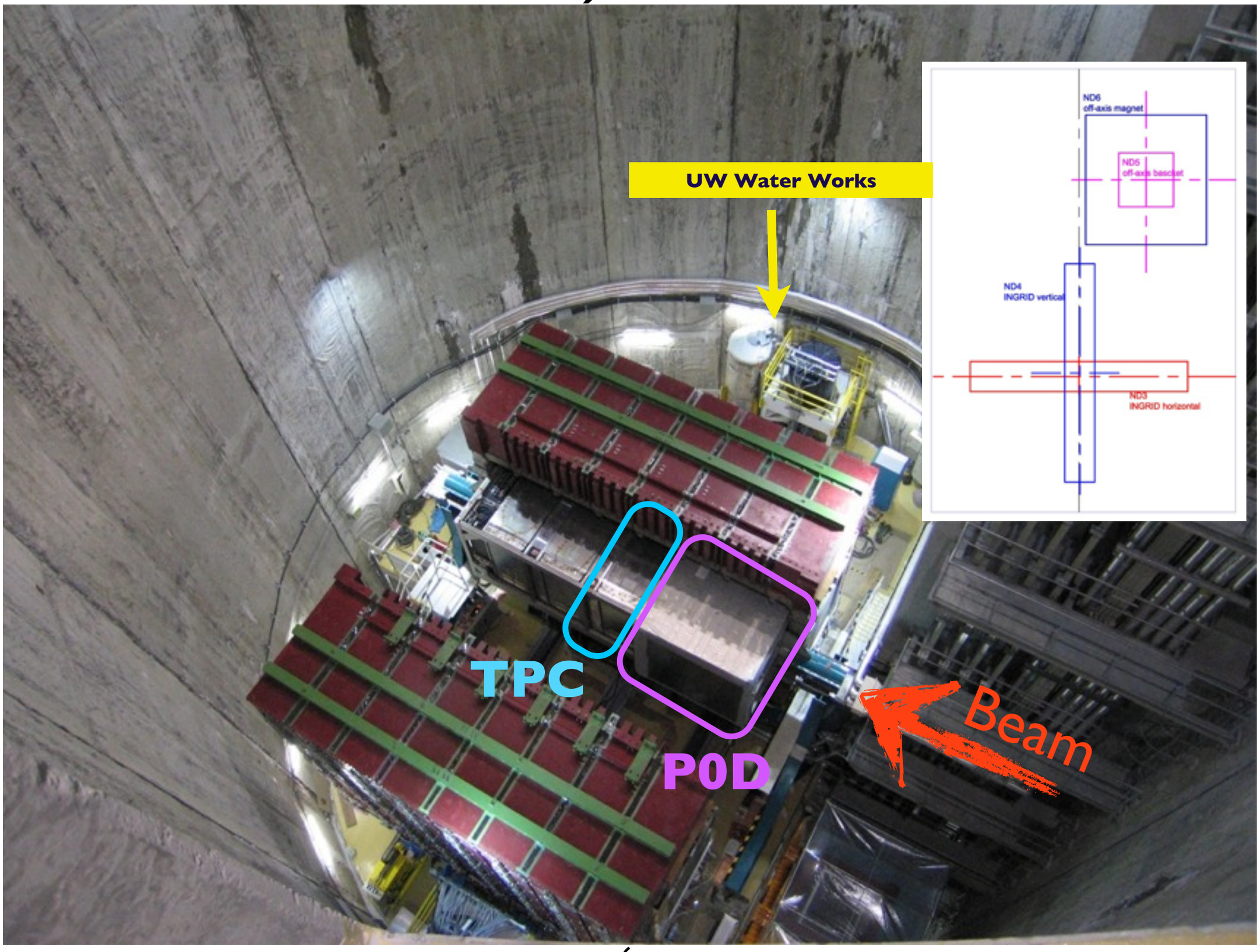
Super-PØDule	Mass (kg)	Dimensions (mm×mm×mm)	Depth in R.L.
Upstream ECal	2900	2298×2468×305	4.946
Upstream Water Target:		2298×2468×888	
Empty	3600		1.370
Filled	5100		2.379
Central Water Target:		2298×2468×854	
Empty	3500		1.356
Filled	4900		2.287
Central ECal	2900	2298×2468×304	4.946

UW Group: J.Wilkes, Hans Berns, Dave Forbush, Kev, Mike Dziomba, Scott Davis



33 x 17 x 2200mm
33 x 17 x 2340mm

ND280, for Real!



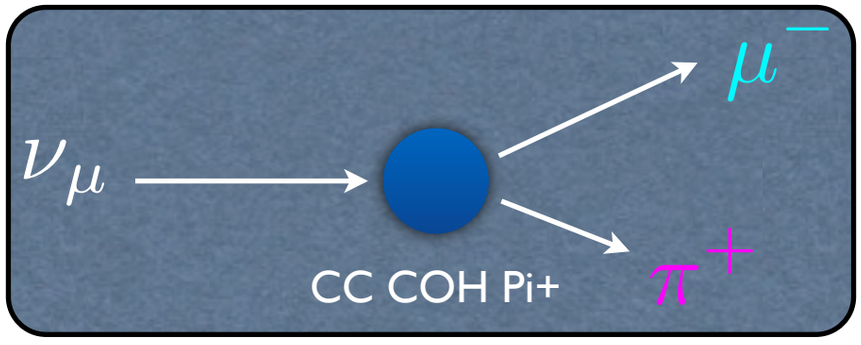
A Little Motivation?

- ~9 months ago I asked: "What sort of capability do we have for momentum reconstruction of P0D-contained tracks?"

- Answer: 笑う

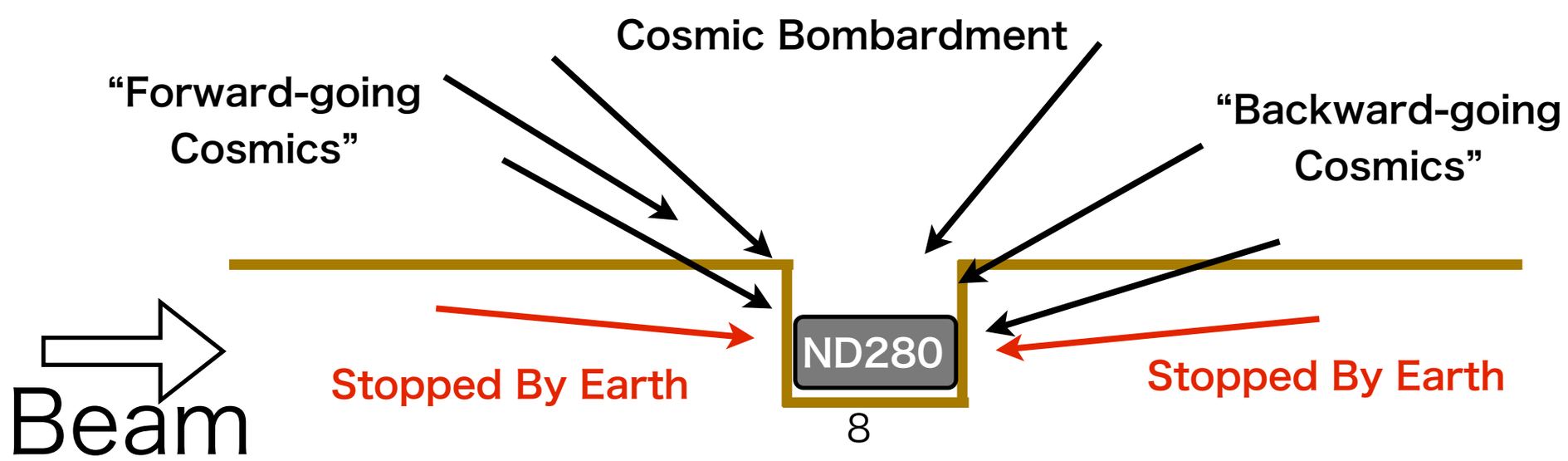
- Interest: Explore methods to reveal more information on track momentum, energy loss

- (Finally)Decided to start exploring these questions in August



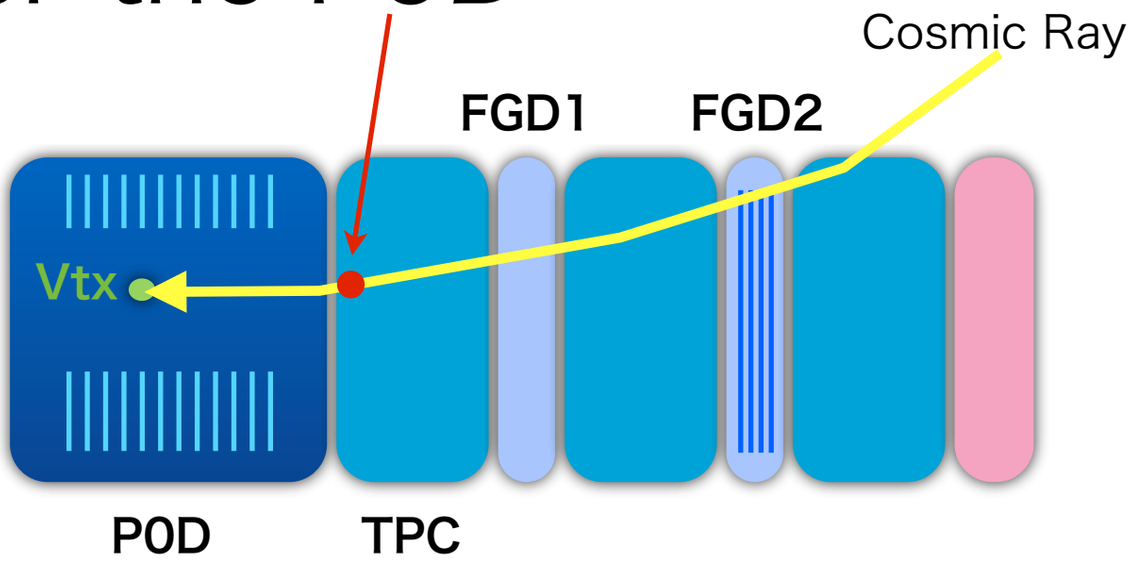
Concept

- Given the slight depth of ND280 cosmics have a natural angle cutoff
- Backward-going cosmics can be selected by angle or timing+recon info



The Benefit of Doing things Backwards

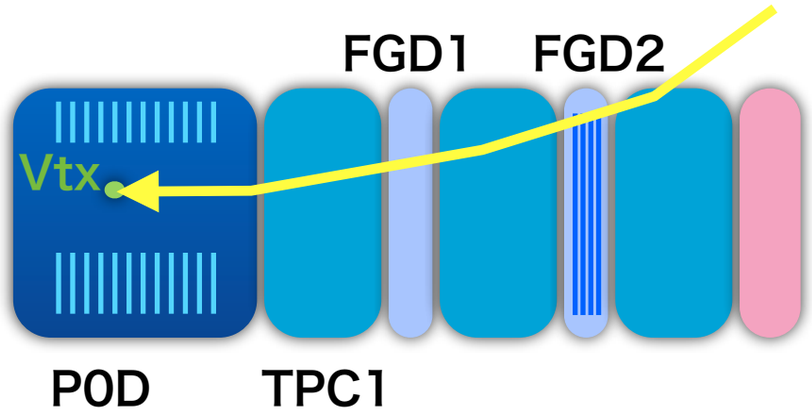
- With backward-going cosmic events take TPC momentum measure when cosmic is just about to enter the P0D



ND280 Cartoon Diagram

Event Selection Cuts

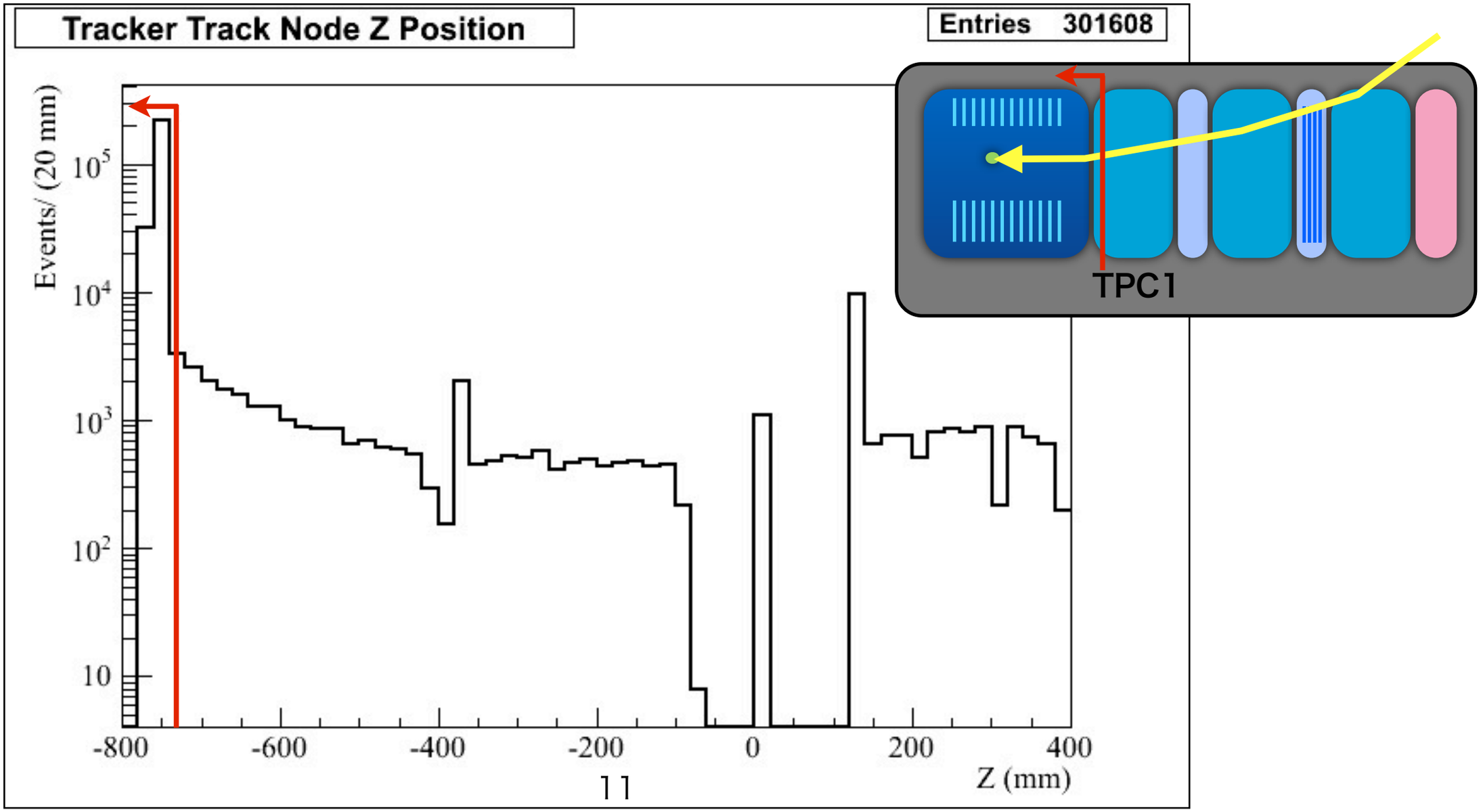
- FGD Cosmic Trigger
- Backward-going
- Single Track in TPC



- Single Track in P0D
- Track Matching Conditions Met
- Single 3D P0D Vertex Reconstructed
  - “Vertex” in this this case is the stopping location of the cosmic

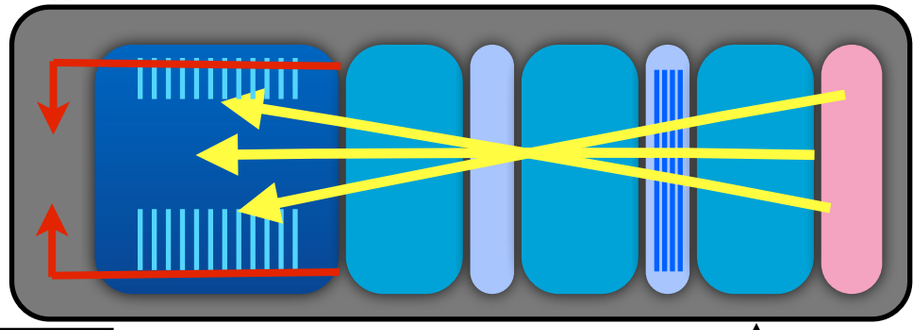
TPC1 Z Position

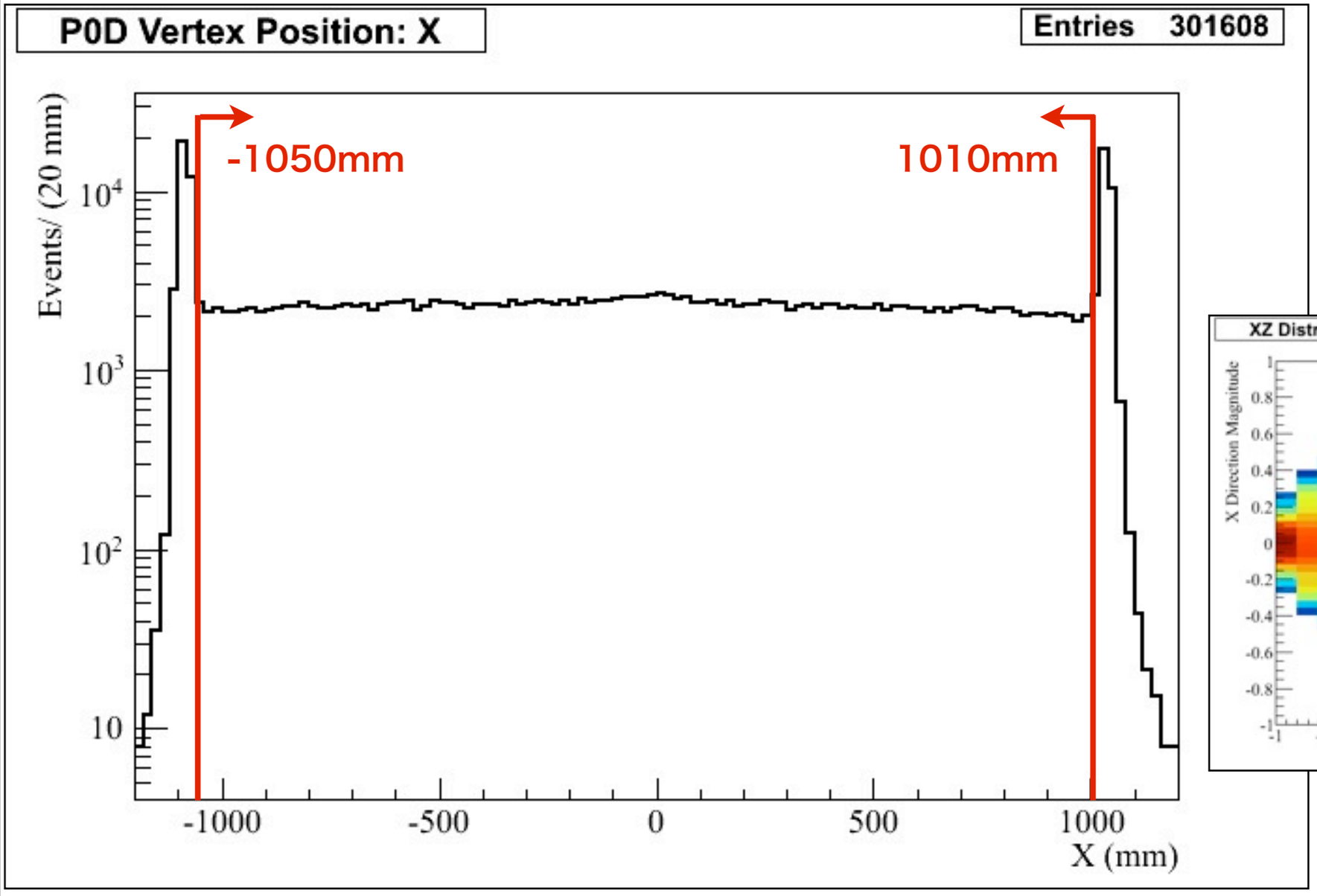
- TPC Reconstruction's track's first node position in Z: Require Z < -740mm



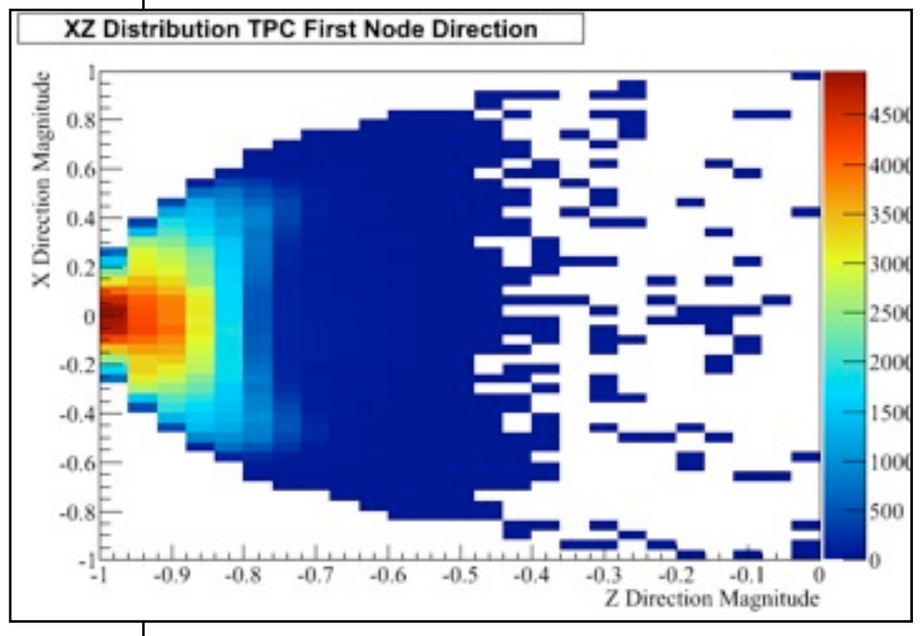
P0D Vertex

- X Position of P0D Vertex



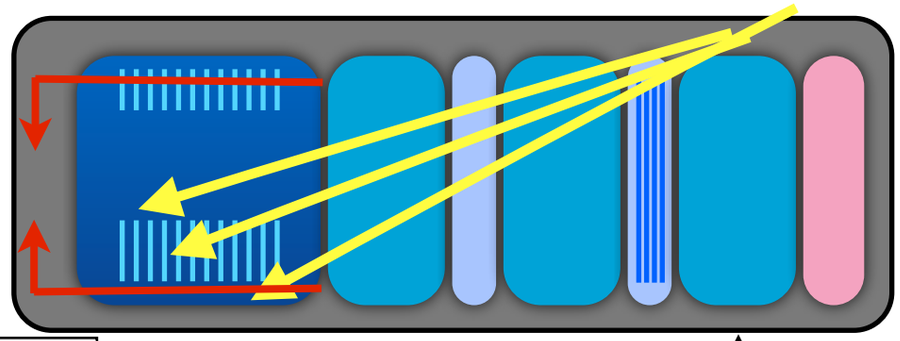


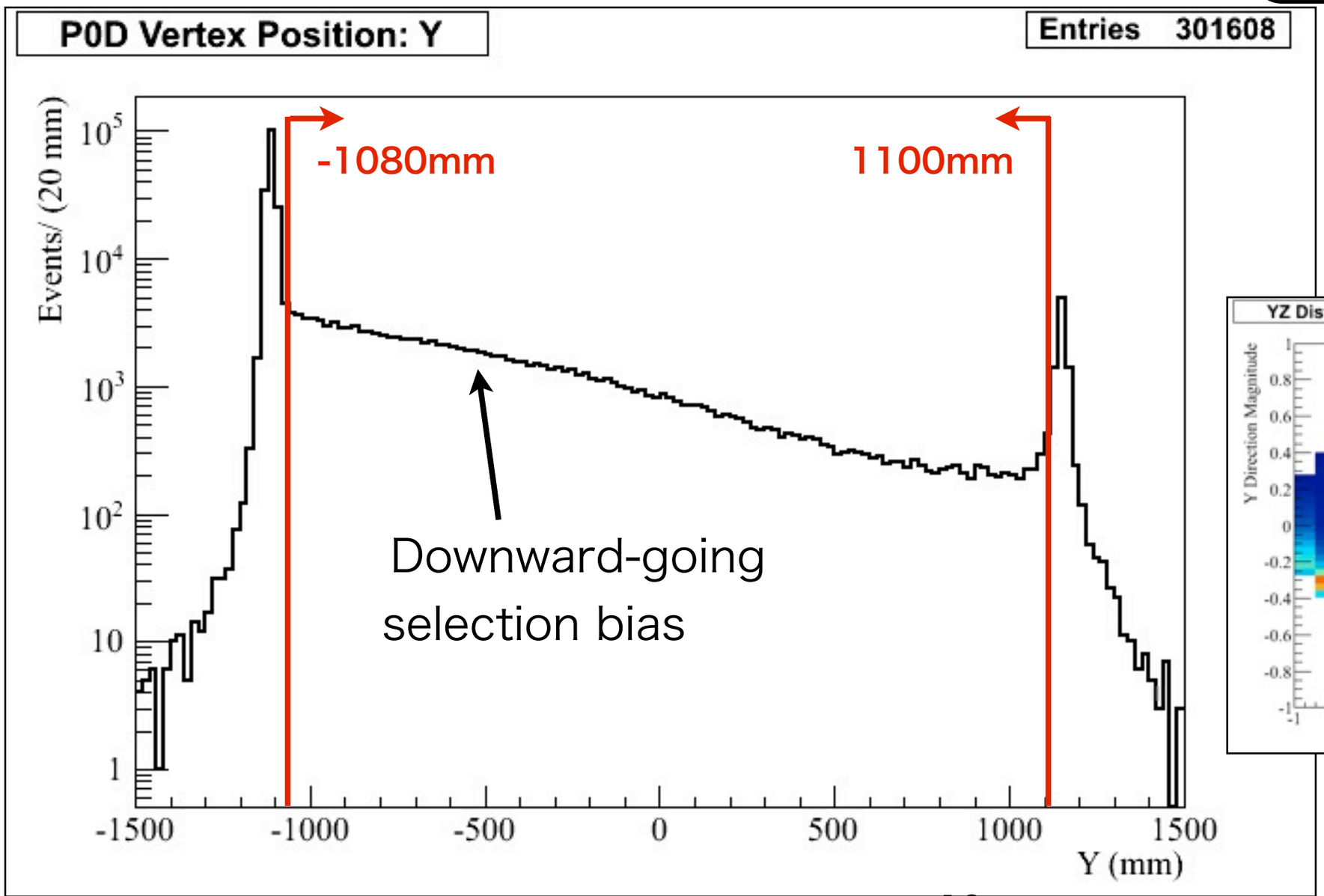
TPC X-Z Direction



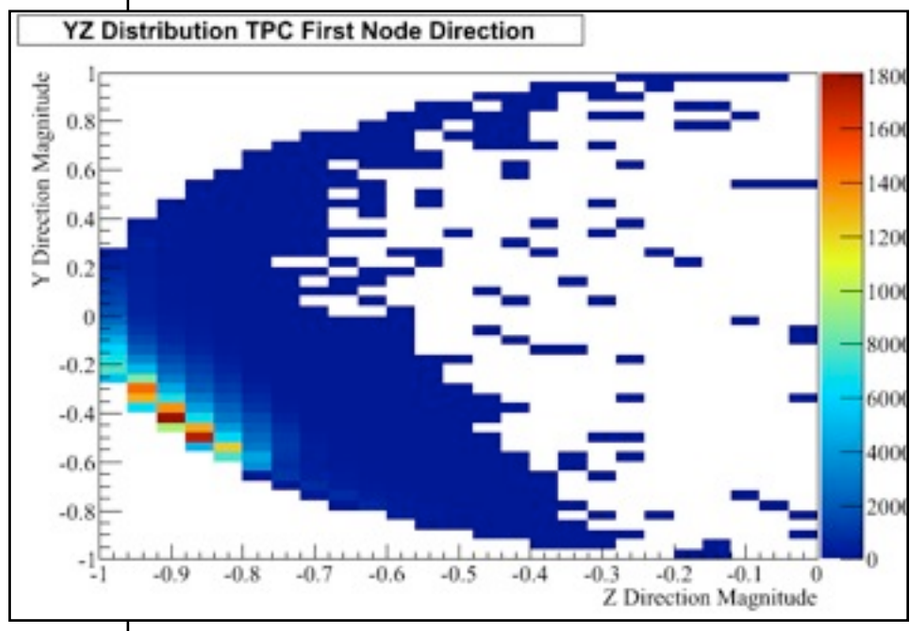
P0D Vertex

- Y Position of P0D Vertex





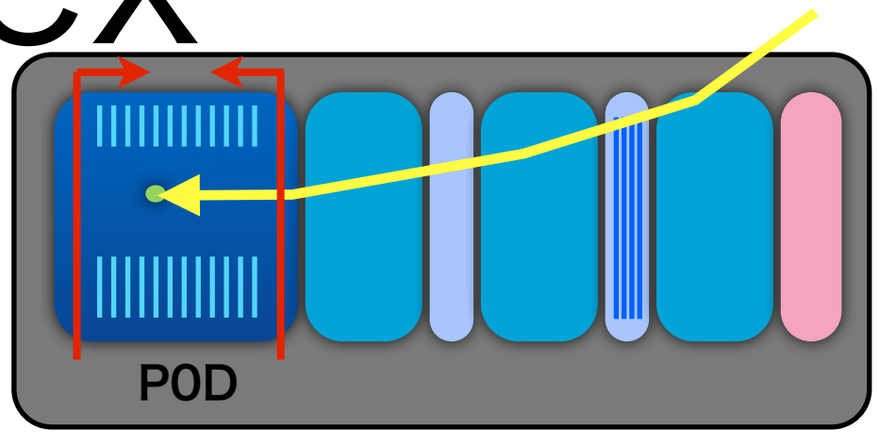
TPC Y-Z Direction

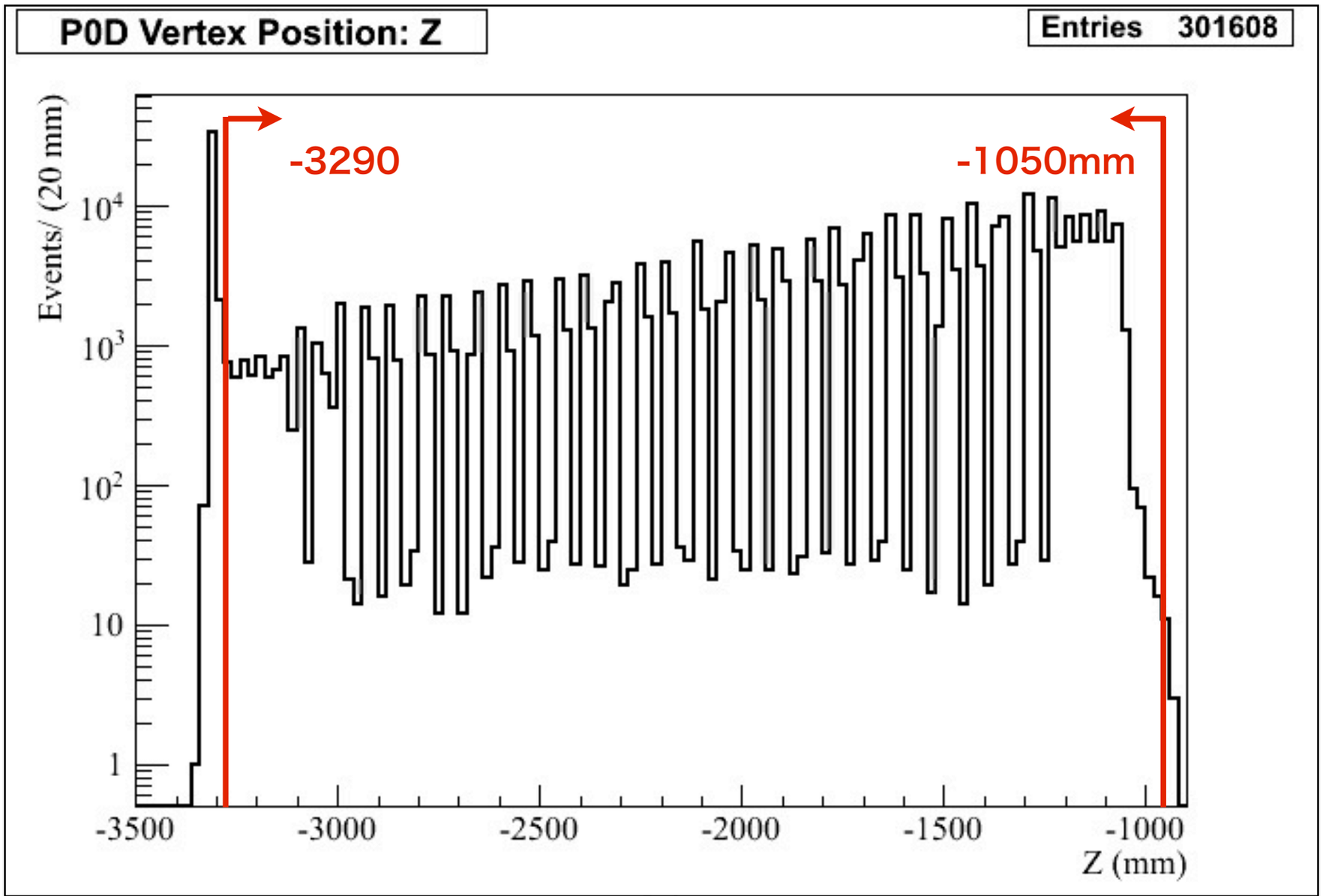


Downward-going selection bias

P0D Vertex

- Z Position of P0D Vertex



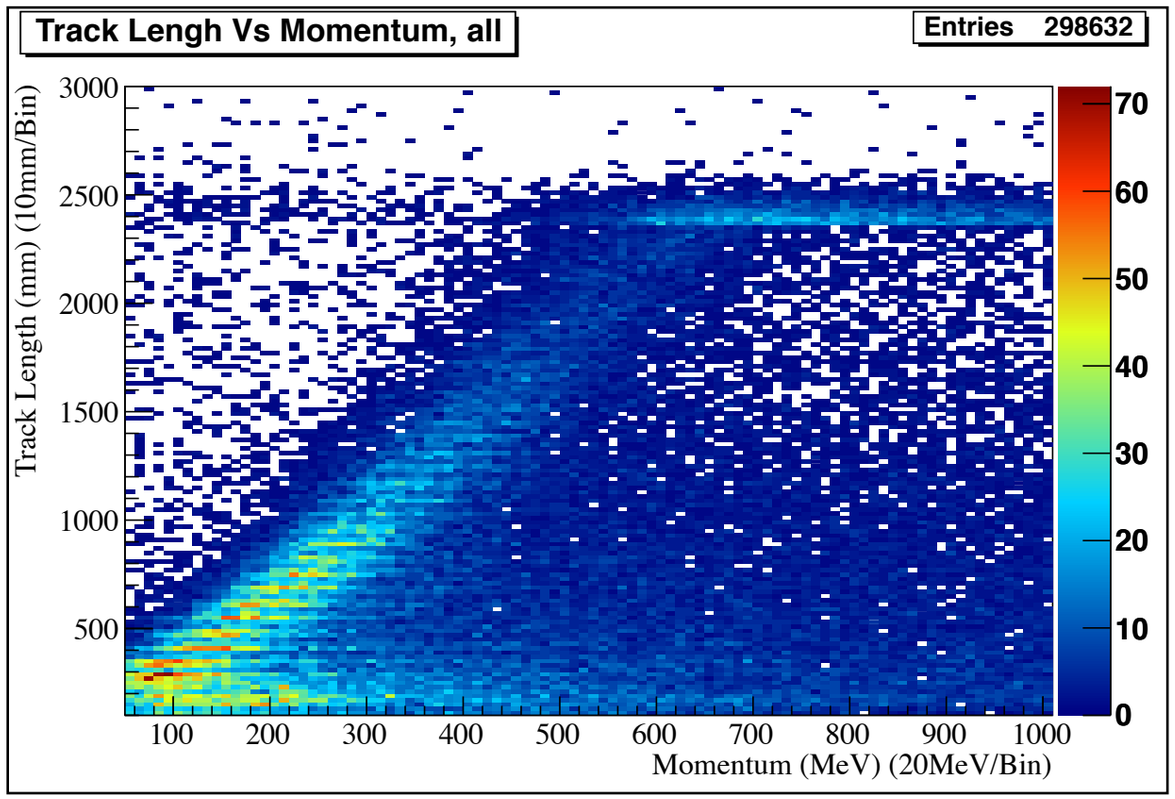


Actually...

- There are more cuts:
  - P0D Reconstruction quality checks (Some more on this later -- if there's time)
  - Position and direction matching between P0D,TPC
  - TPC Vertex "fiducial"-like cut (no events near edges)
  - Track angle CosTheta > 0.9
  - TPC momentum recon quality check
  - TPC PID (really should be removed)
- Analysis-specific cuts:
  - Water-in, water-out

Data Reduction

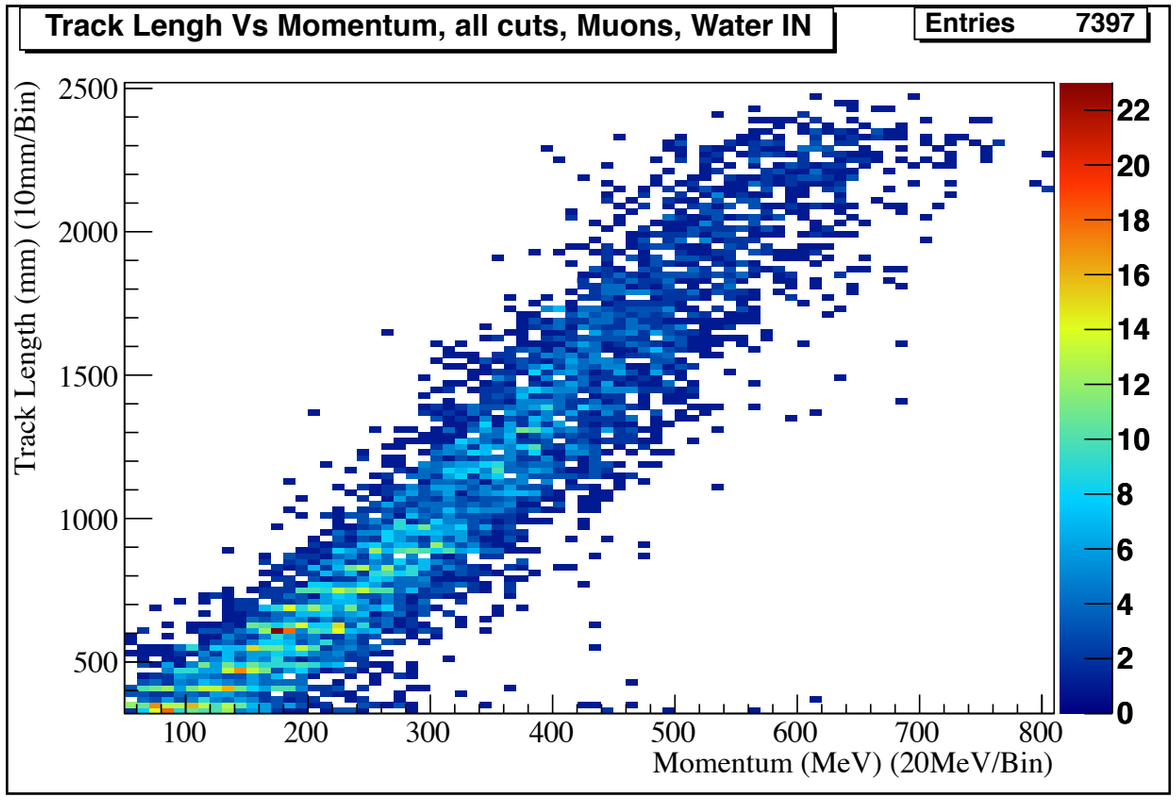
Candidate Events



All events that pass requirements

FGD Cosmic Trigger
Single 3D P0D Vertex
Single P0D Track
Single TPC Track
Backward-going
P0D-TPC Track Matching:
Timing, Position, Angle

Analyzed Events



All events that pass analysis selection cuts

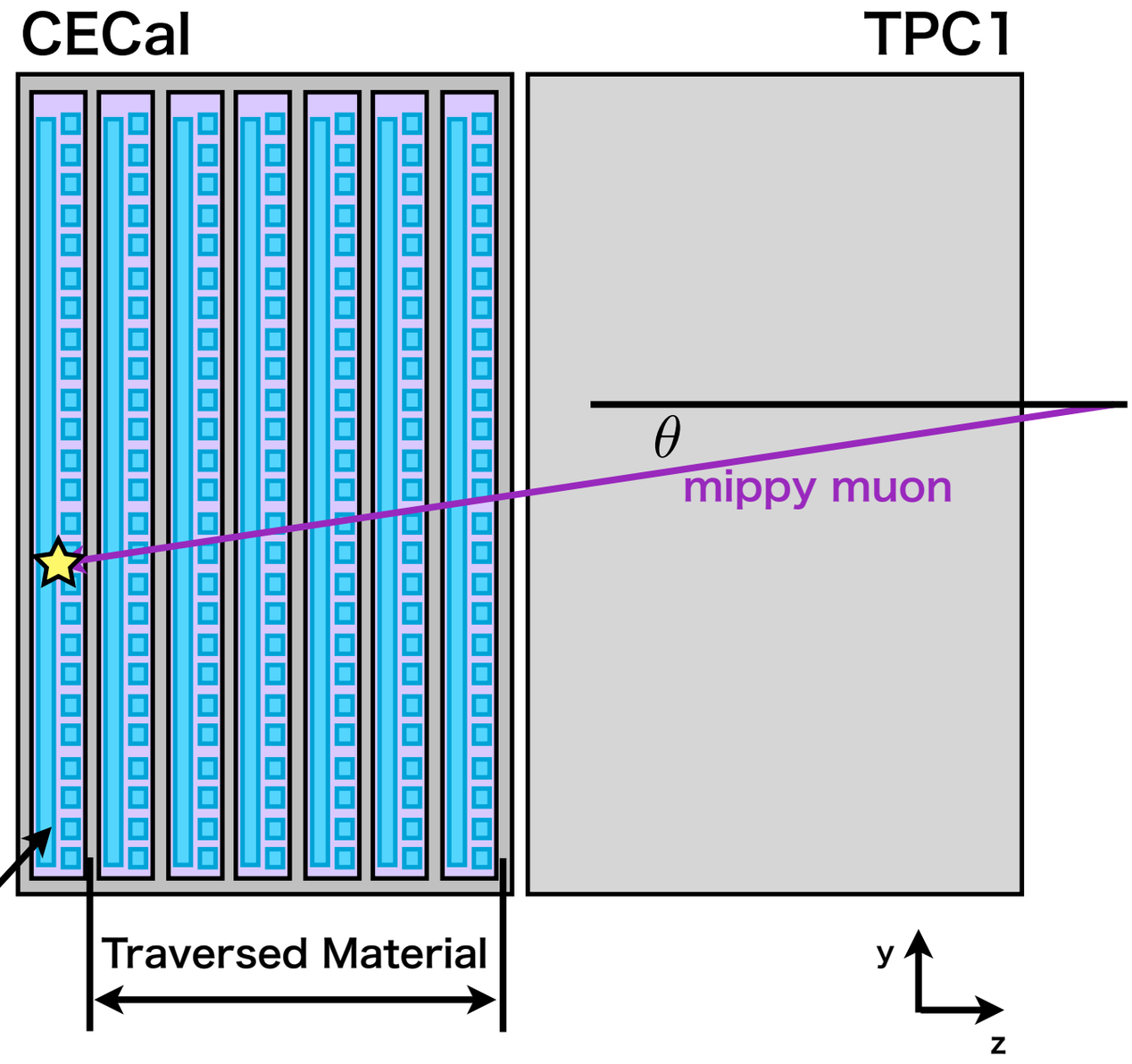
TPC Muon PID
P0D Vertex is Contained
Water-In
P0D Vertex, First Node Sep < 60mm
TPC node > 150mm from edge
TPC Node Angle , Cos > 0.9
Check TPC Node Momentum Ordering

Track Length, Energy Loss, g/cm^2

- Walter Toki (Colorado State University) recently tabulated and calculated the g/cm^2 of all P0D materials, along with estimated energy loss for each component of the P0D
- Implemented these values in analysis to generate the following plots
- Will give a brief outline of a calculation here, and discuss some important reference numbers

Calculation

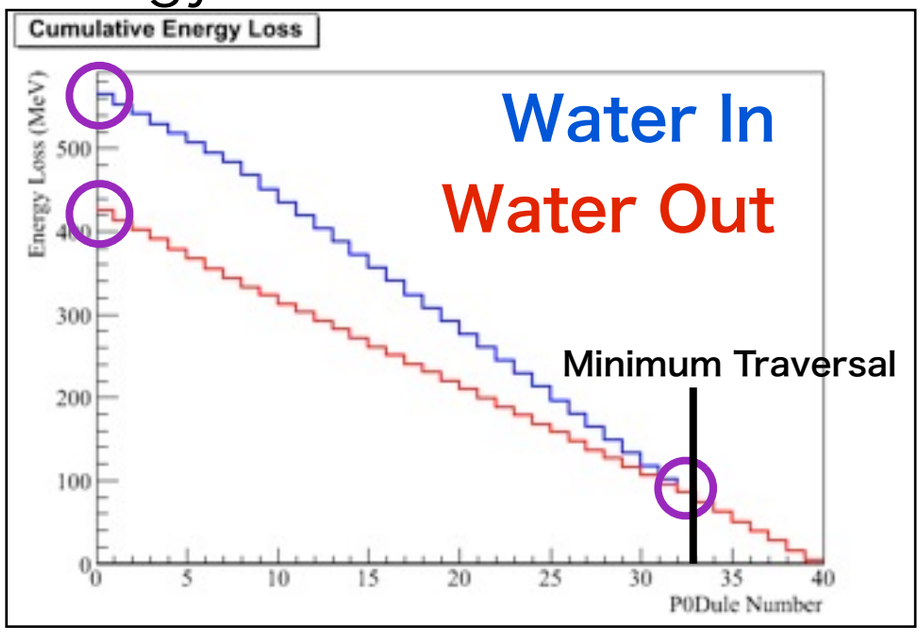
- Get the P0D Vertex Z position
- Calculate P0Dule number based on Z Position
- Assume coming from downstream, thus pass through a number of layers prior to stopping P0Dule:
  - Lead, Brass, Water, Water Bag(plastic), P0Dule
- Vertex placed in a P0Dule, so add additional 0.5*P0Dule length or E Loss (generic average)
- Correct for true path length with 1/Cos(theta) factor
- Not Accounted for: gap between TPC and P0D



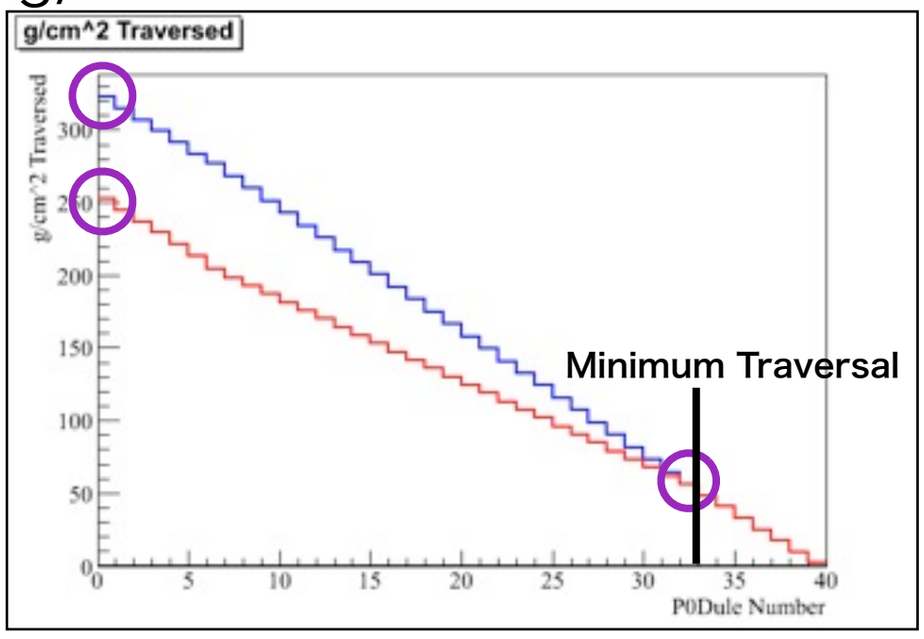
Reference Values

Normal Incidence Muon

Energy Loss vs. P0Dule



g/cm^2 traversed vs. P0Dule



Energy Loss

Complete P0D Traversal:

Water In ~568 MeV

Water Out ~429 MeV

Minimum Traversal:

~81 MeV

g/cm^2 Traversed

Complete P0D Traversal:

Water In ~325 g/cm^2

Water Out ~255 g/cm^2

Minimum Traversal:

~54 g/cm^2

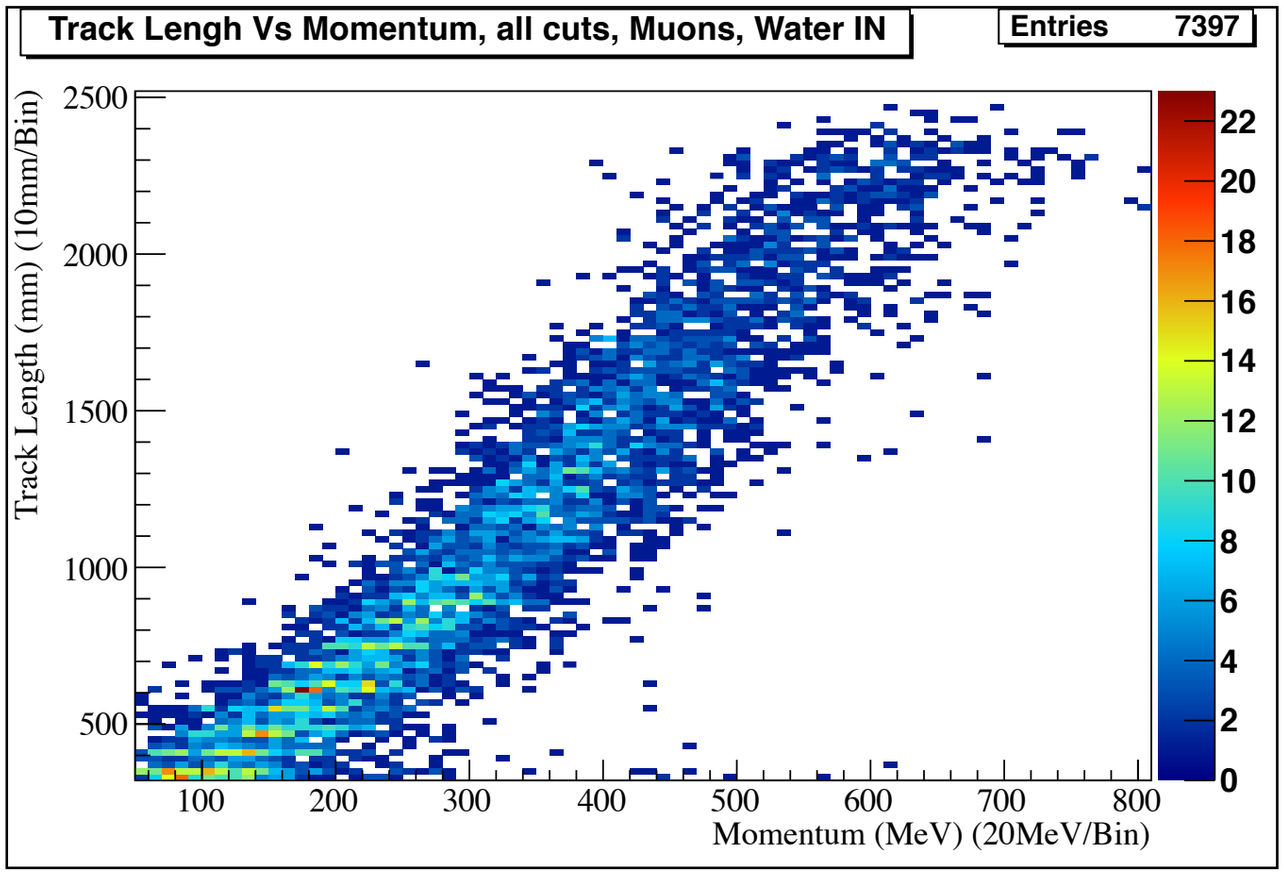
Minimum Traversal: used as min value for range of fits later on. Equal to passing CECal.

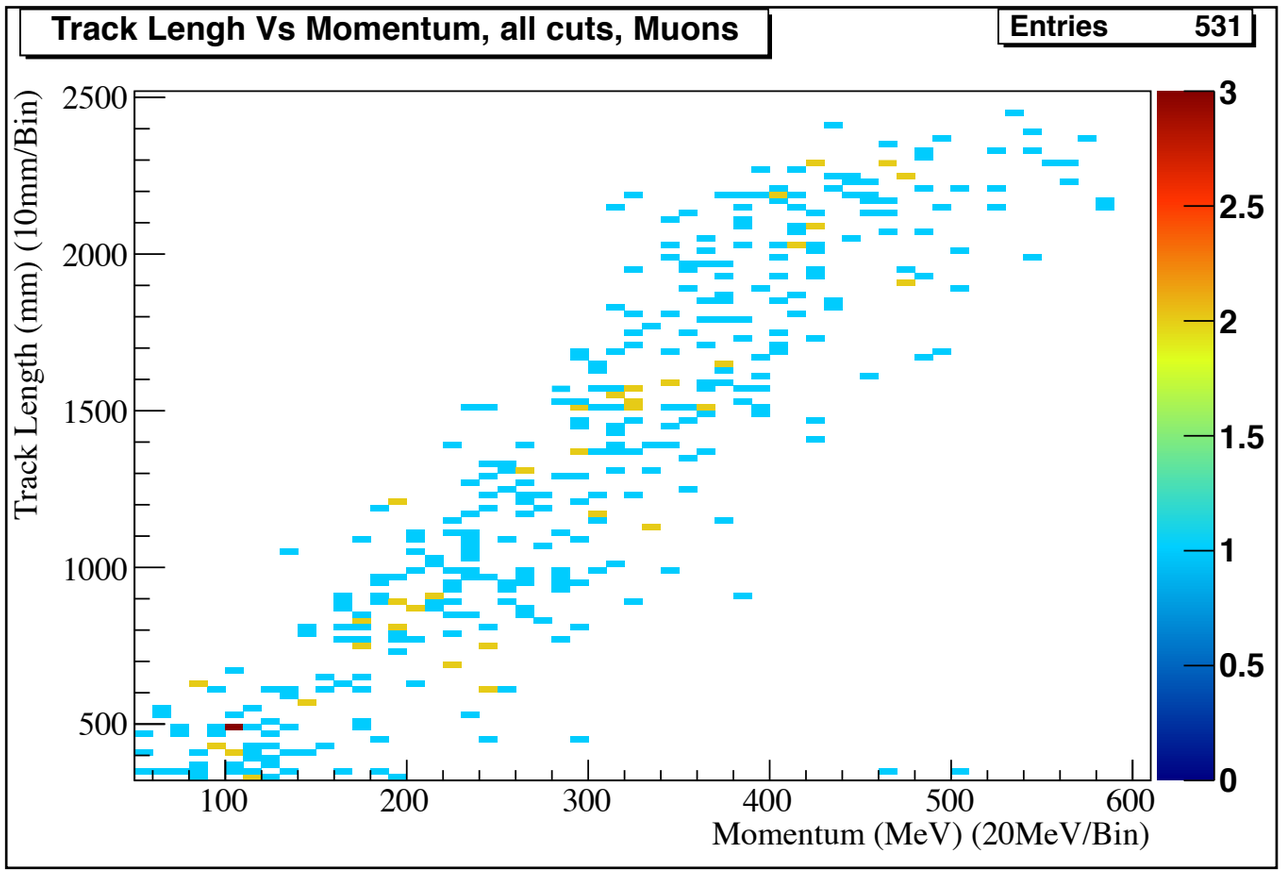
Regarding MC

- MC currently used is not yet the official sample
- Manually generated MC from data kinematics
- Only generated MC with water in P0D, so no water-out Data/MC comparisons here (yet).
- Am now discussing official cosmic MC generation for ND280 with manager (Mike Wilking, TRIUMF)

Track Length Vs. P

Track Length Vs P

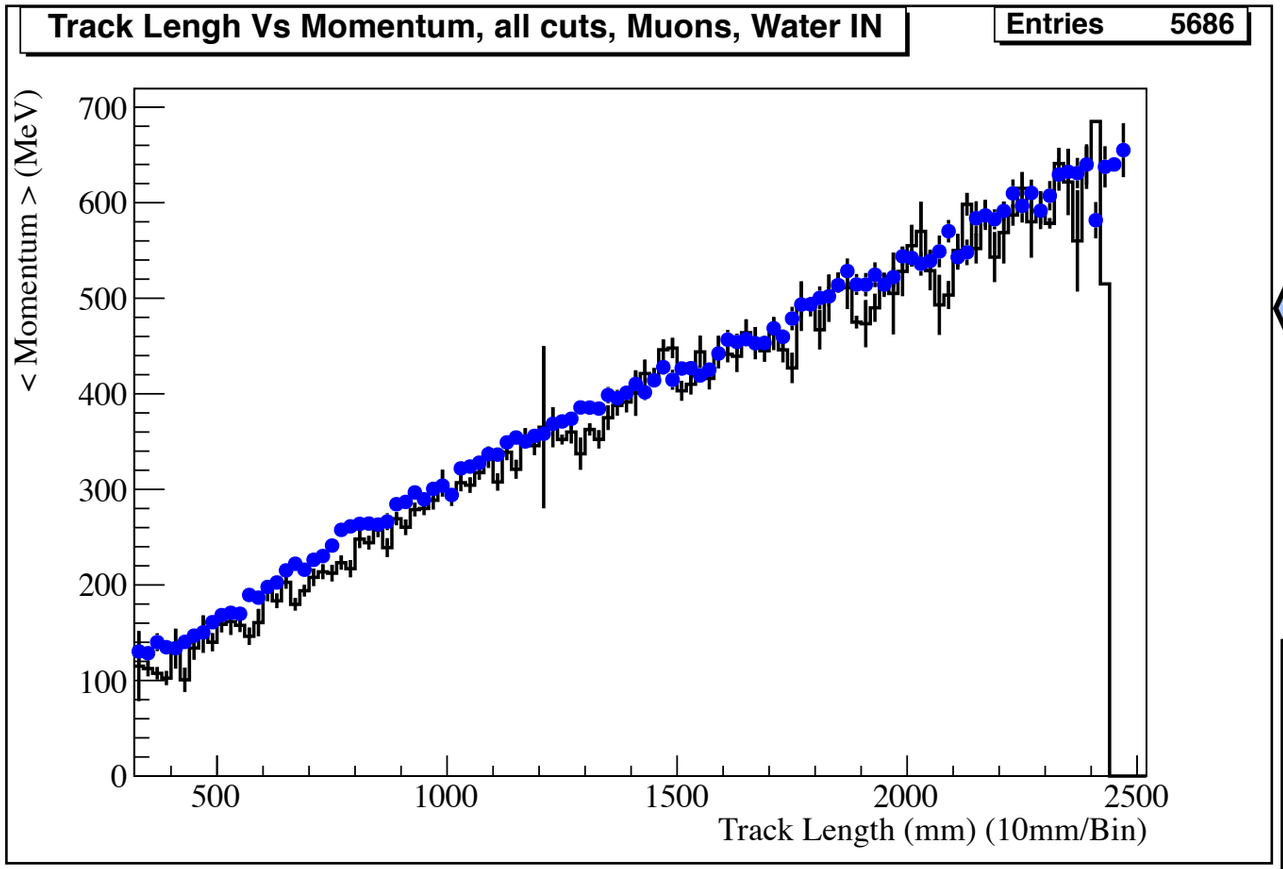




Water IN

Water OUT

Track Length Vs P

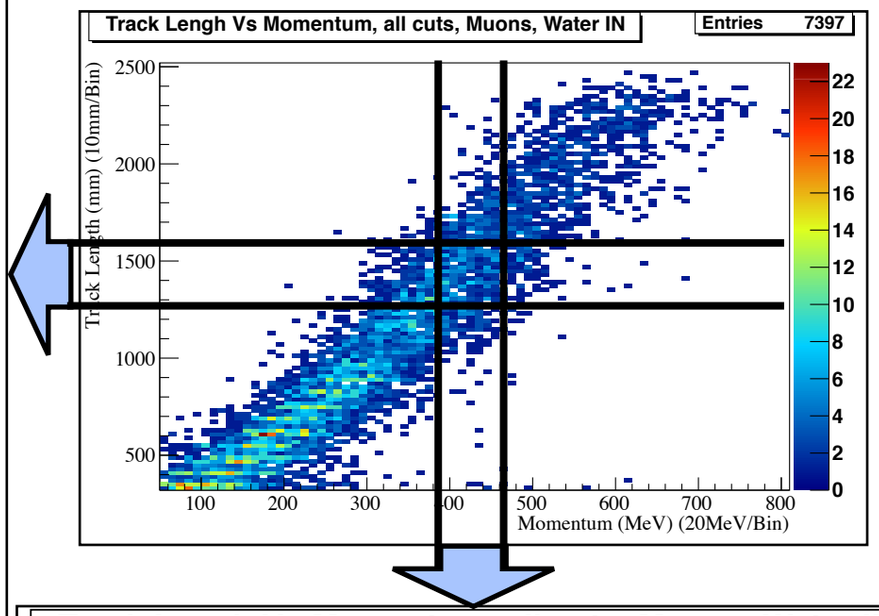


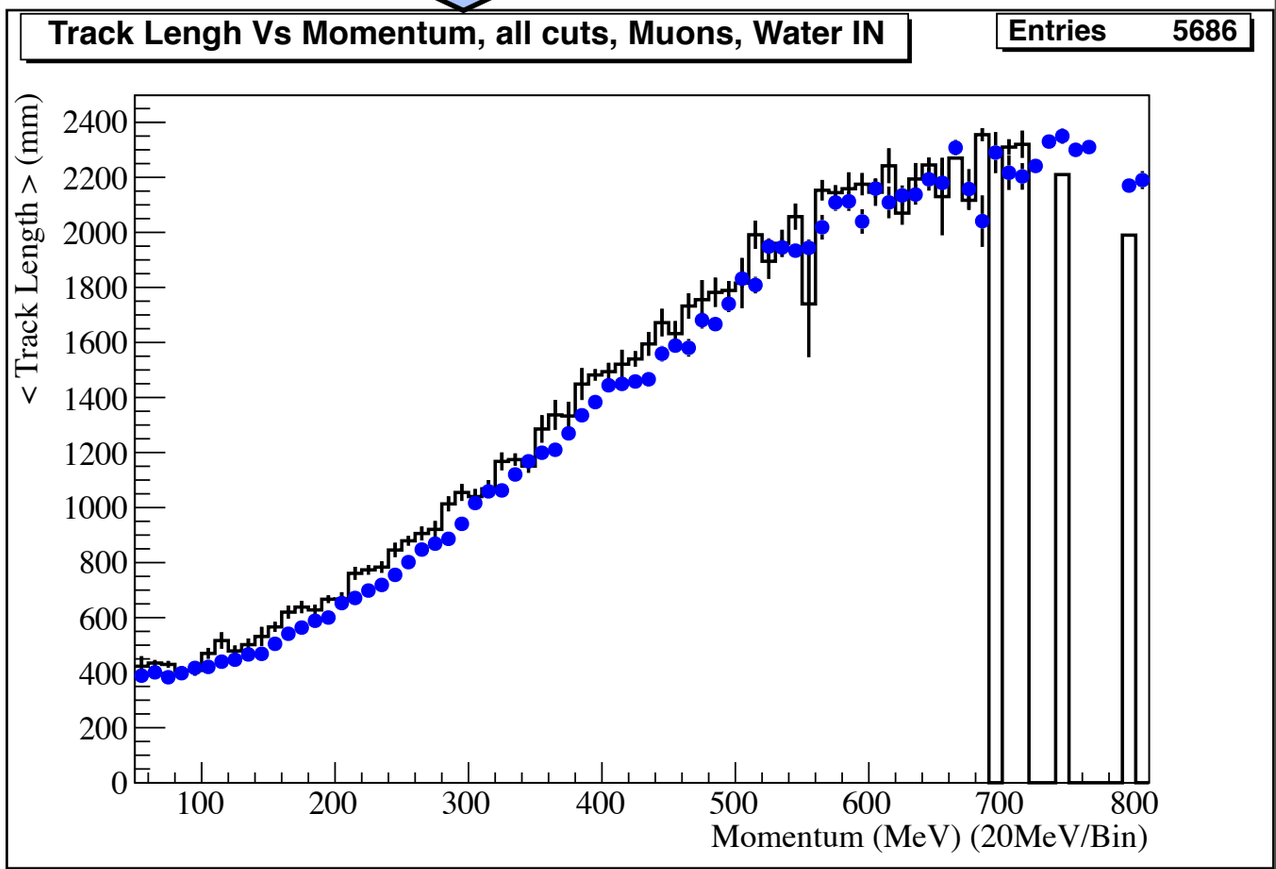
(sorry, overbinned!)

Water IN

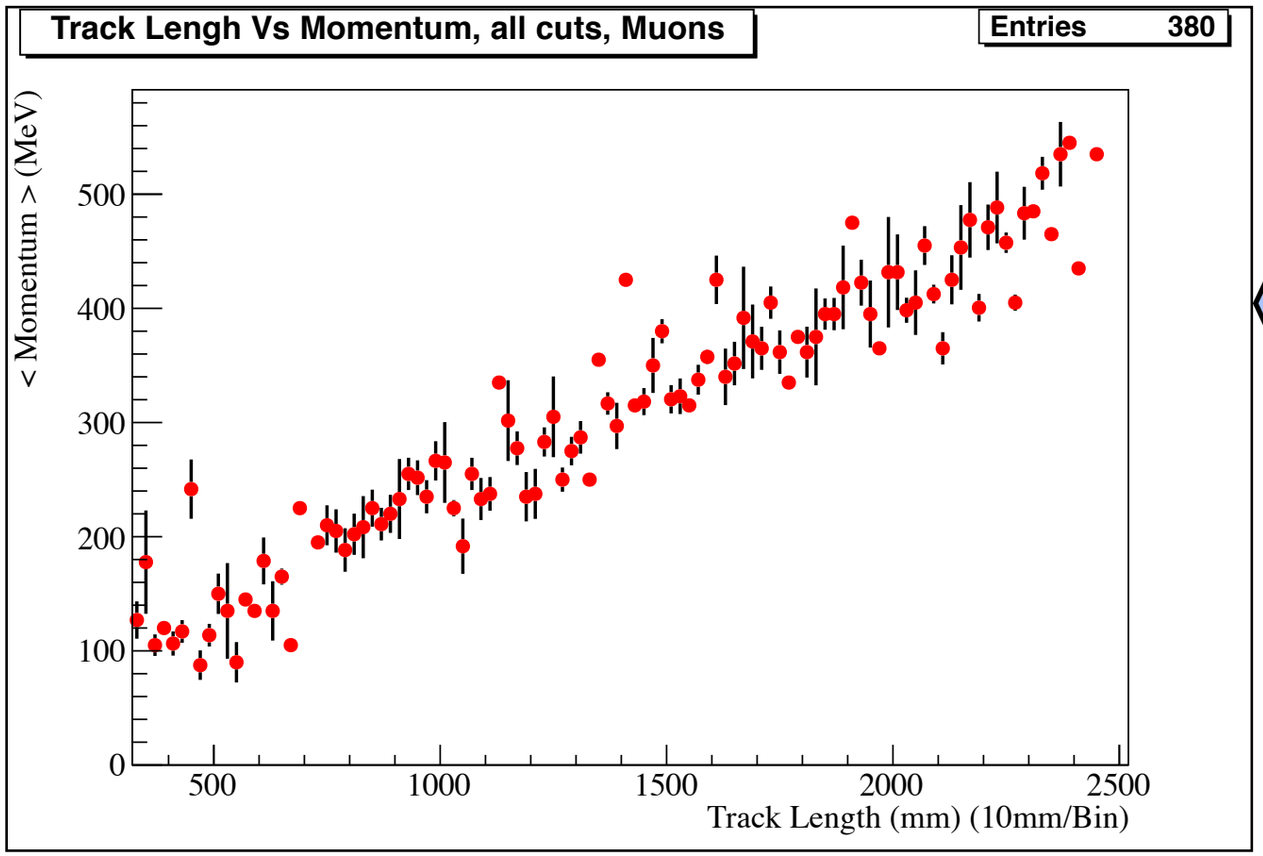
Profile Plots

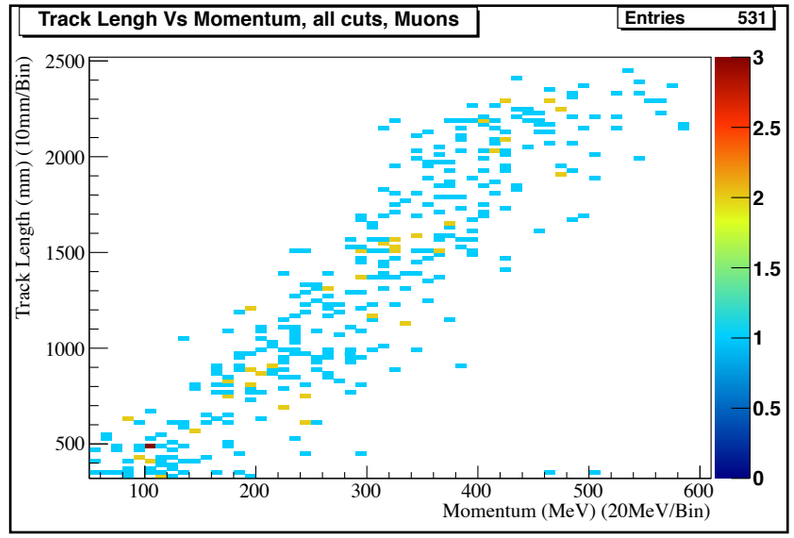
MC: Black Histograms

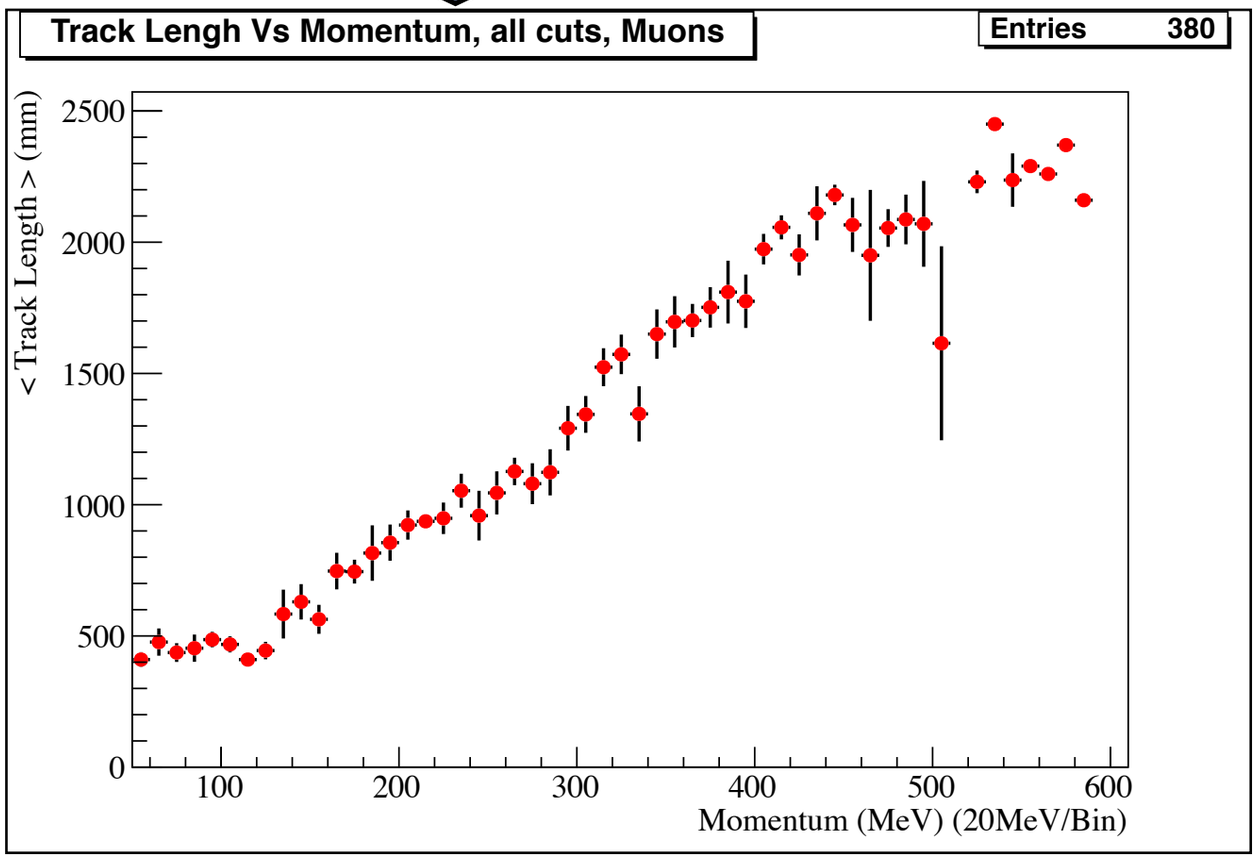




Track Length Vs P





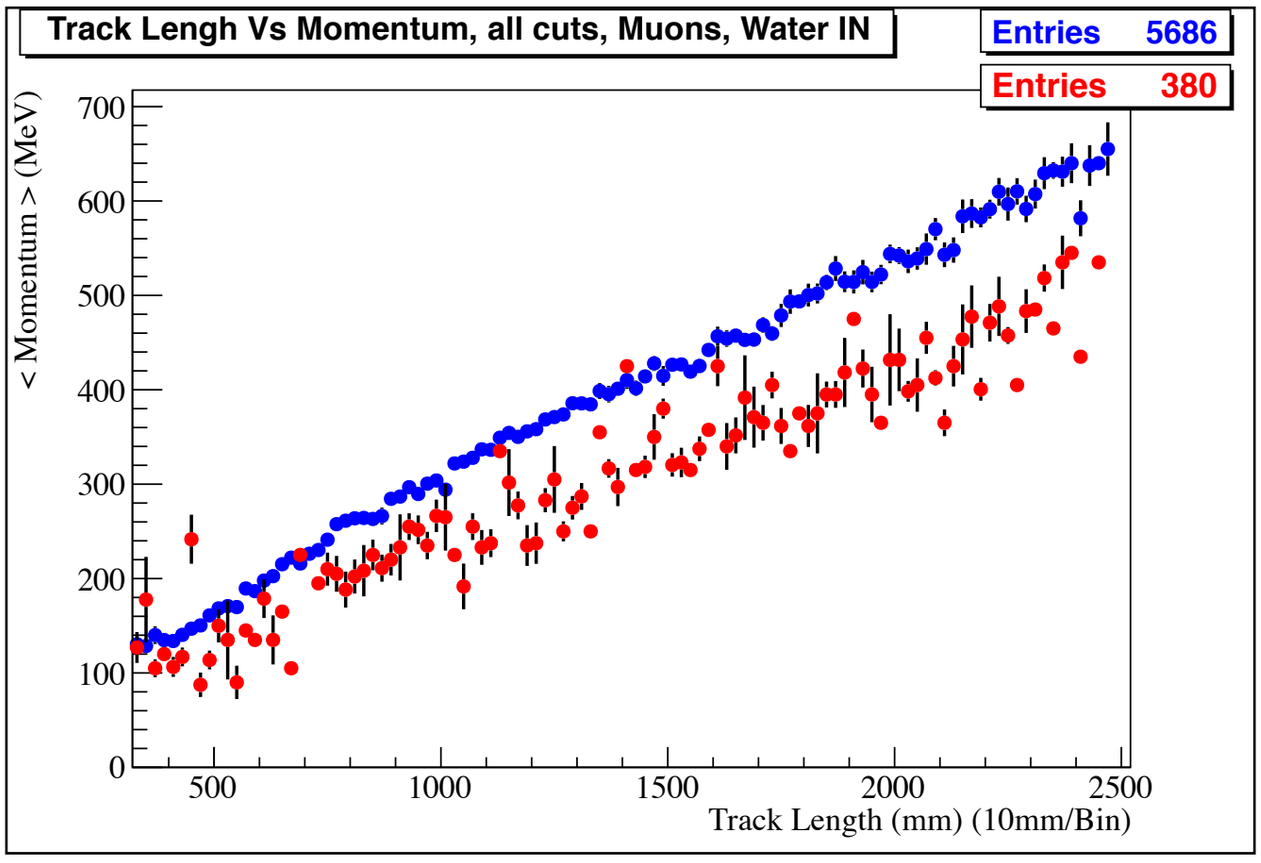


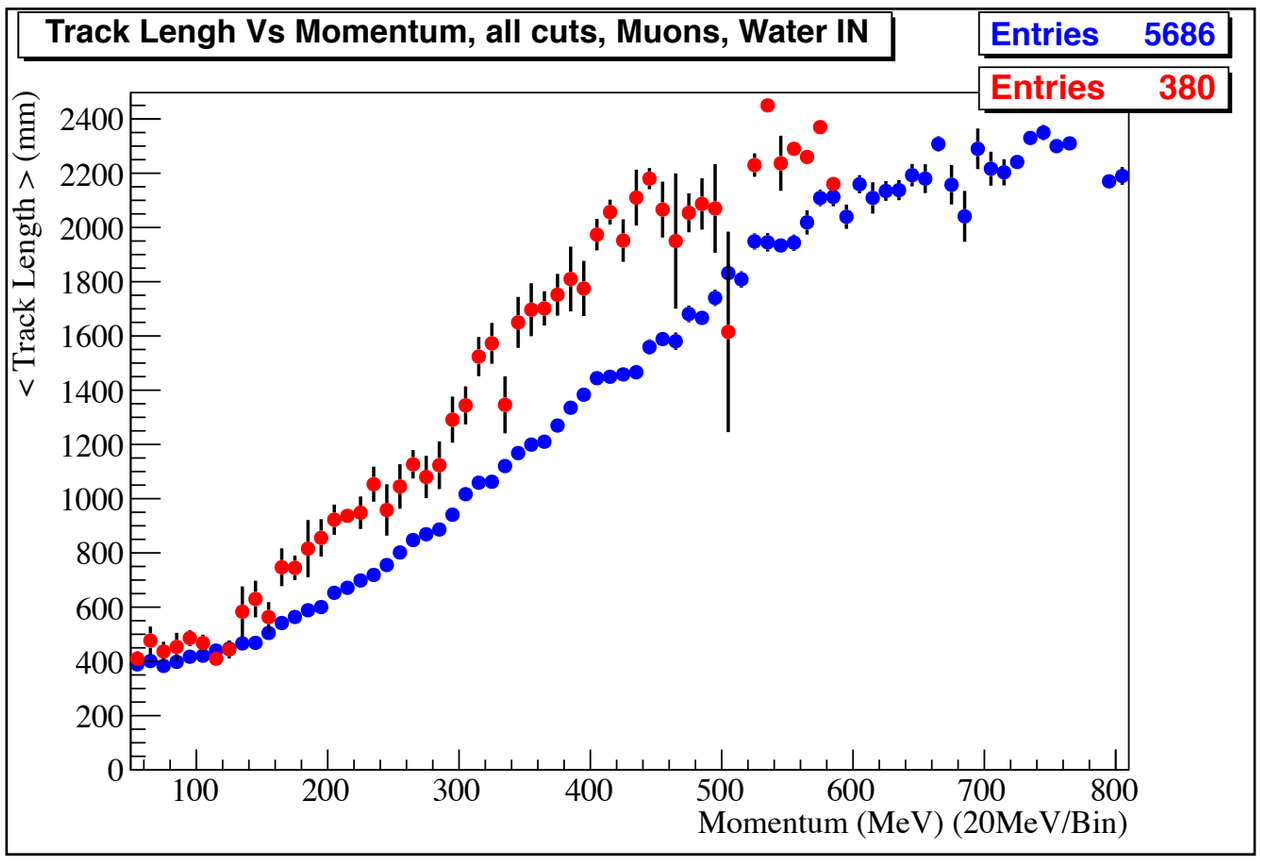
Water OUT

Profile Plots

Track Length Vs P

Water In
Water Out

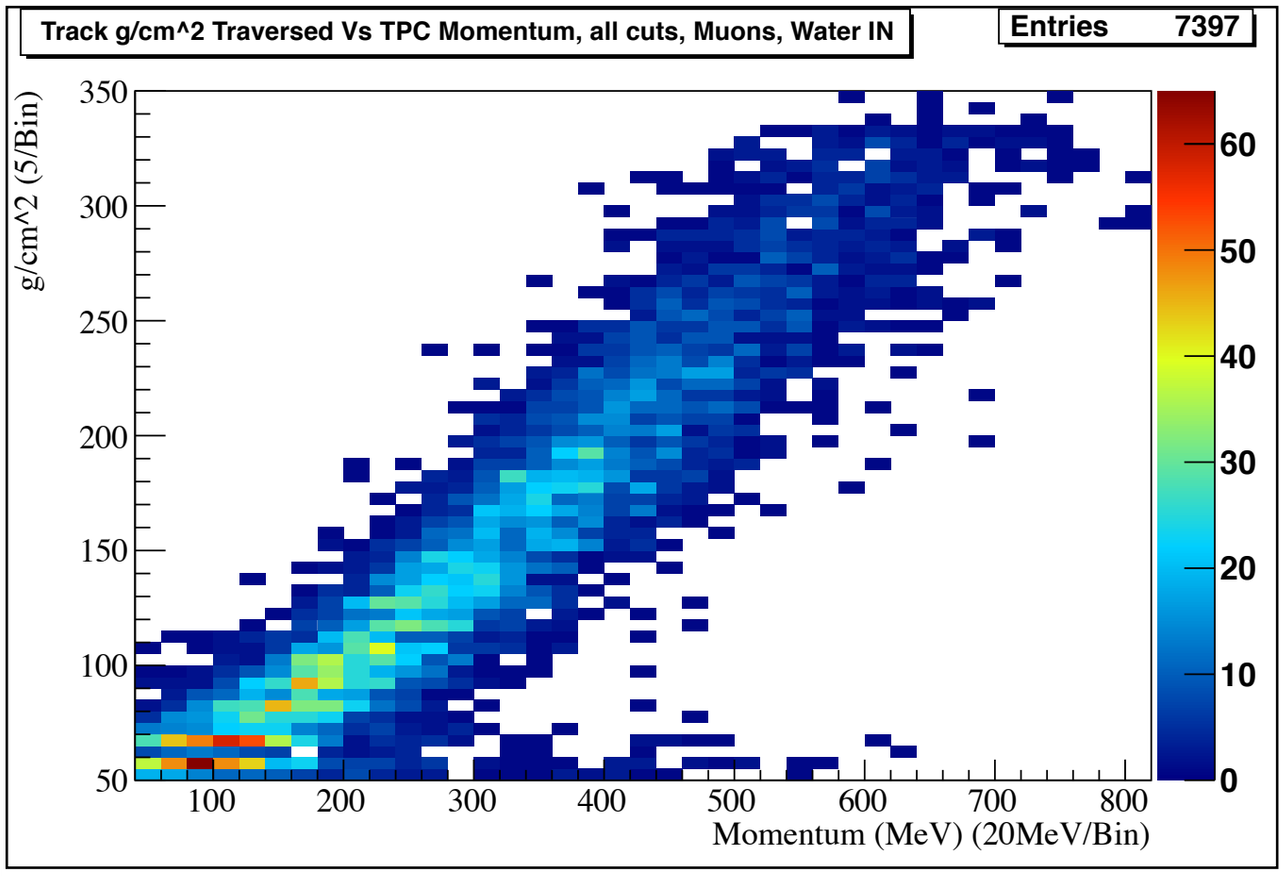




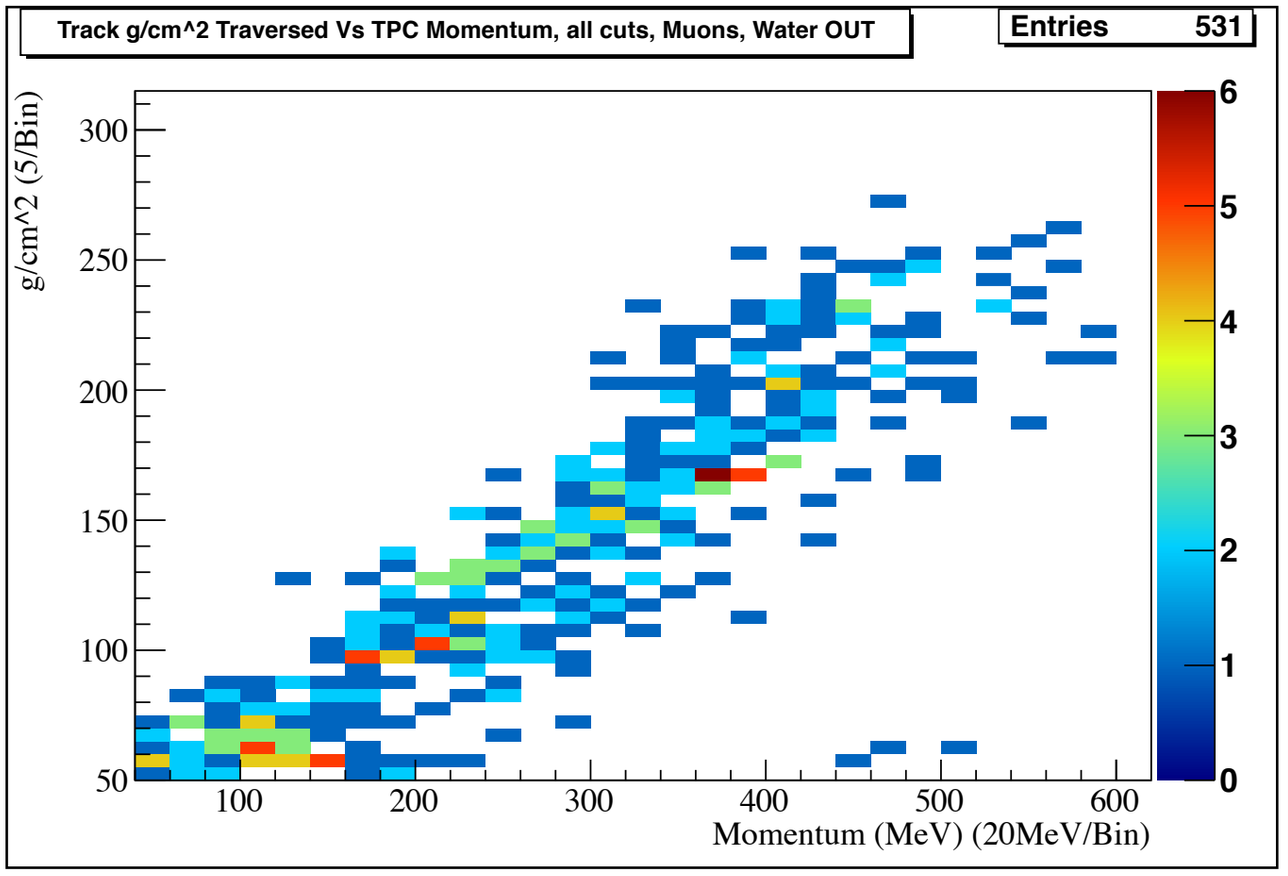
Water-out tracks have greater track length for given momentum

g/cm^2 Vs P

g/cm^2 Vs TPC P

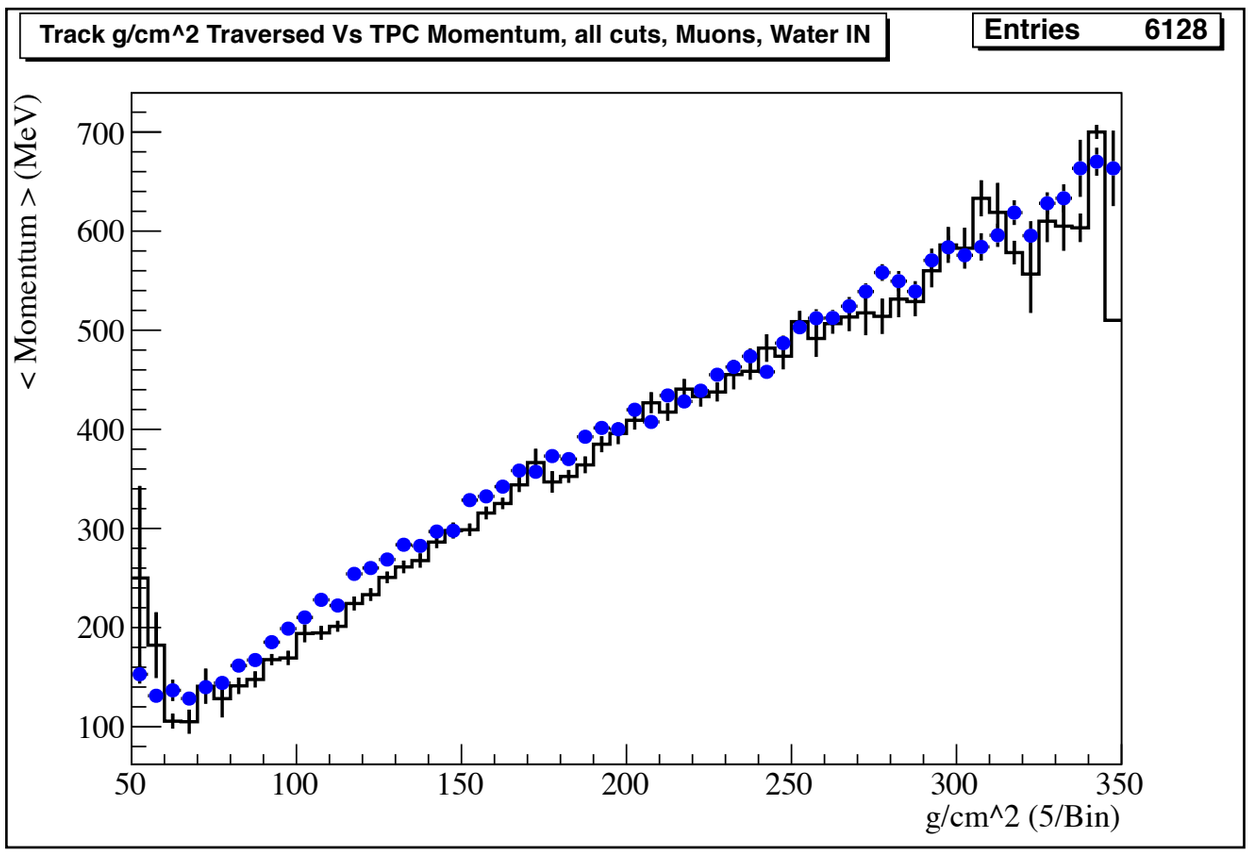


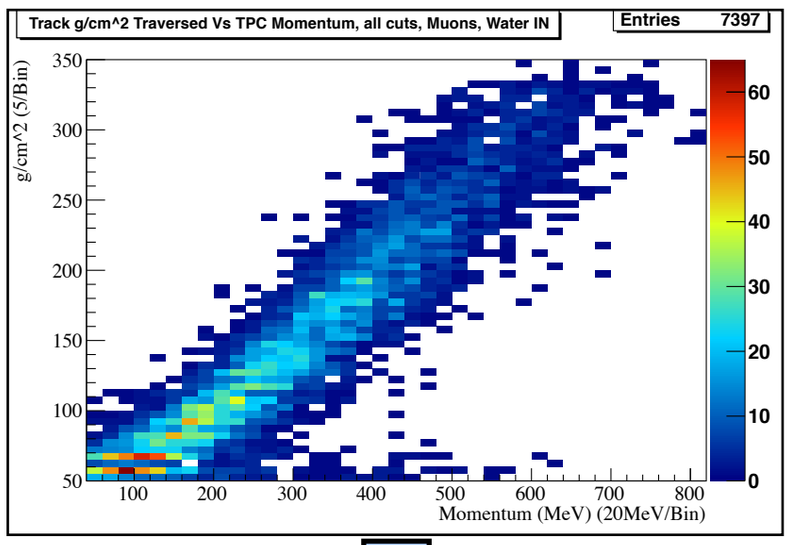
Water IN

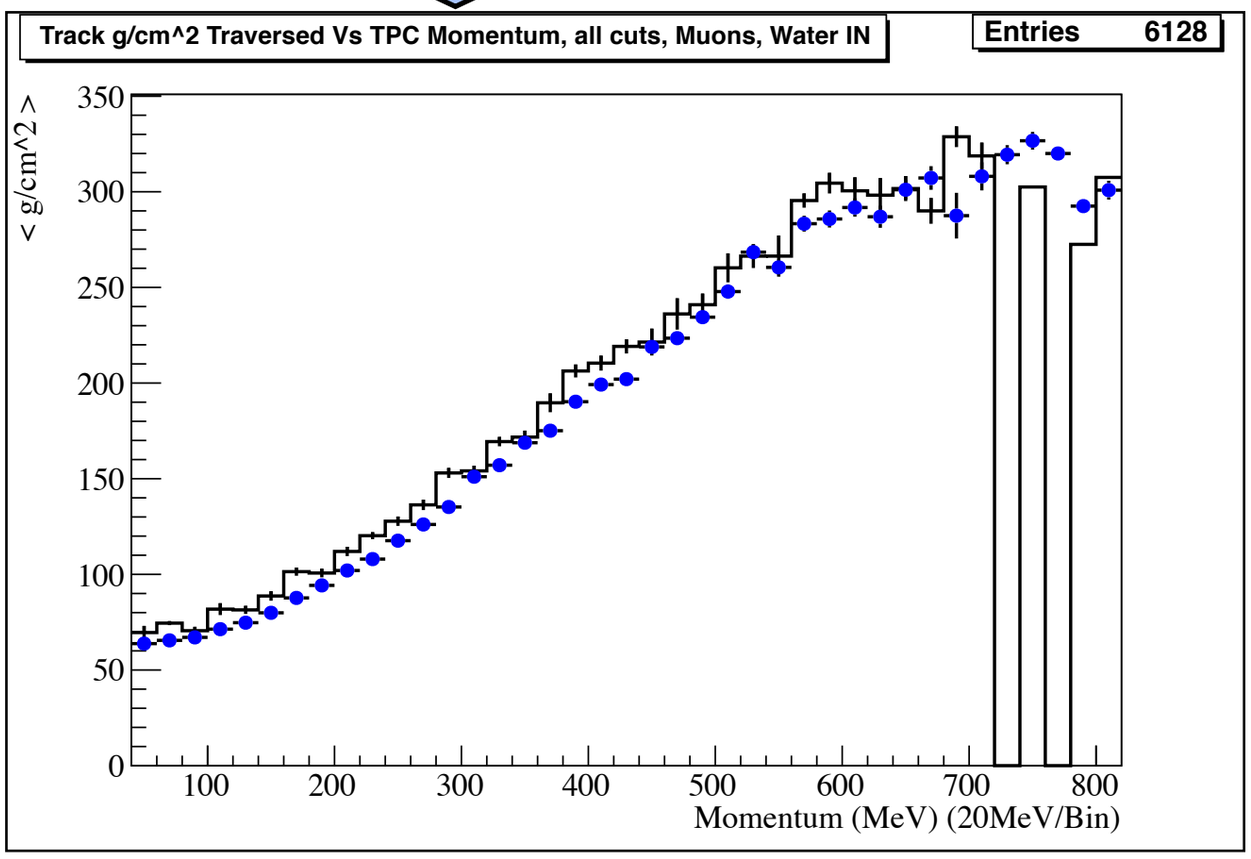


Water OUT

g/cm^2 Vs TPC P



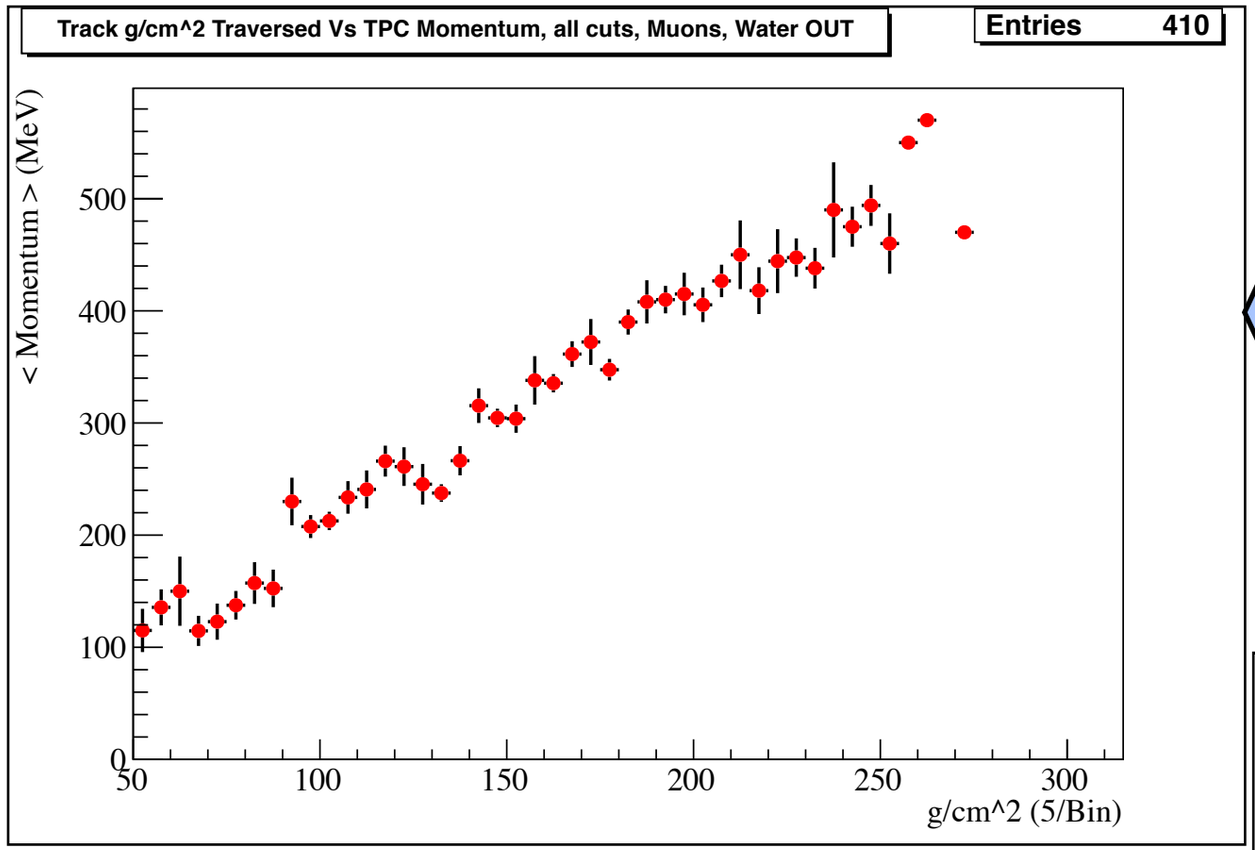


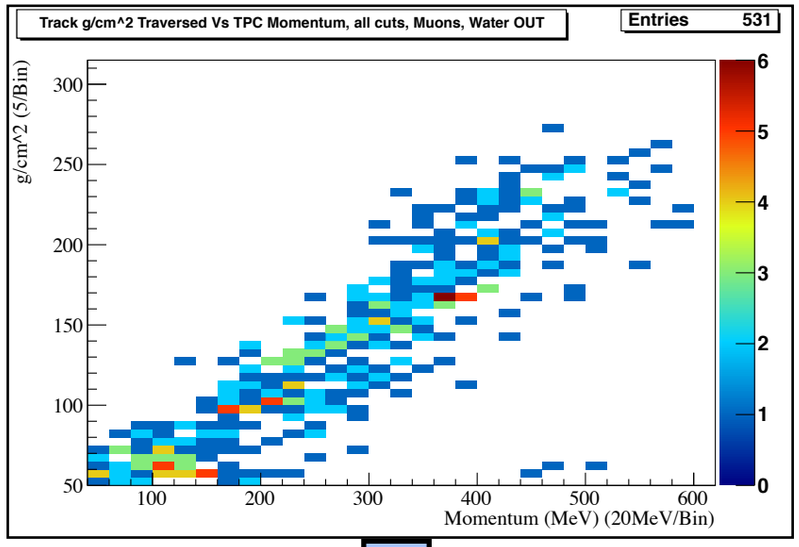


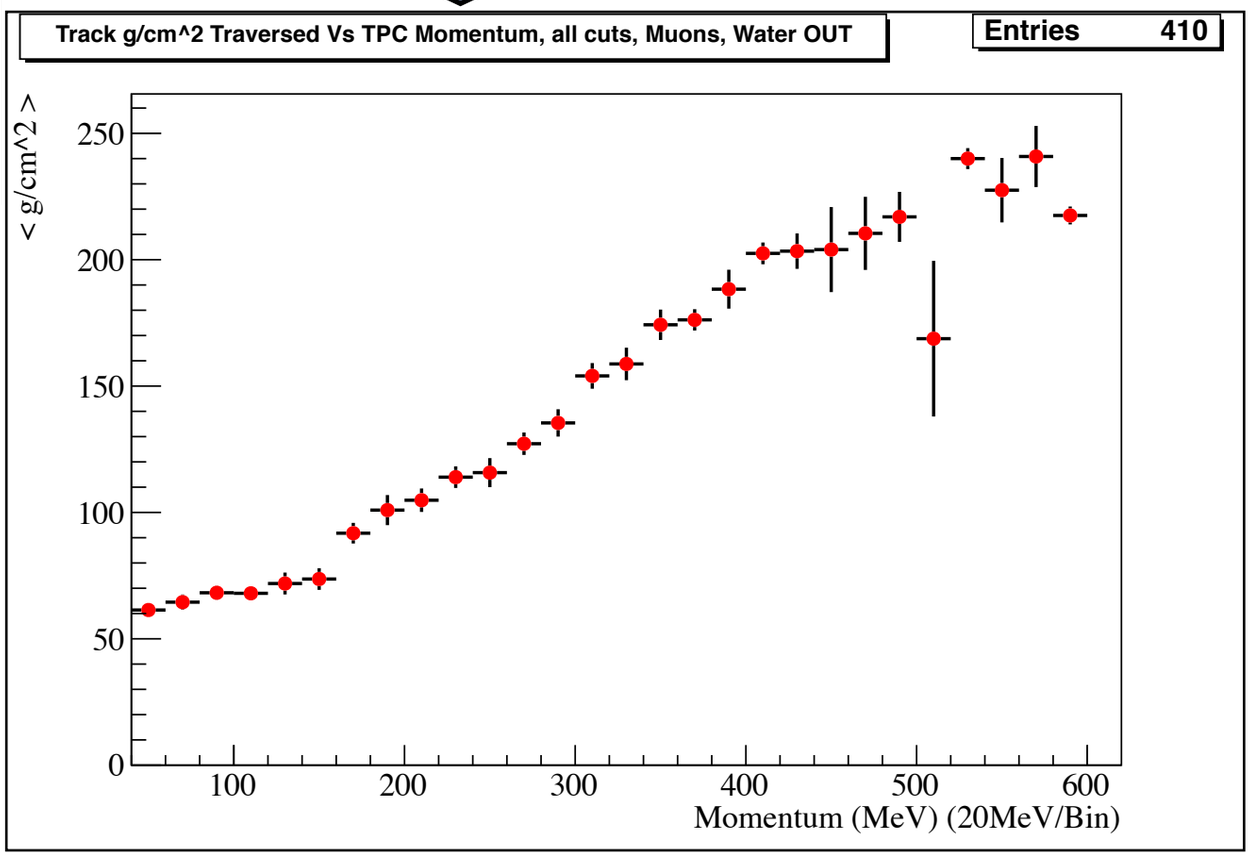
Water IN

Profile Plots

g/cm^2 Vs TPC P





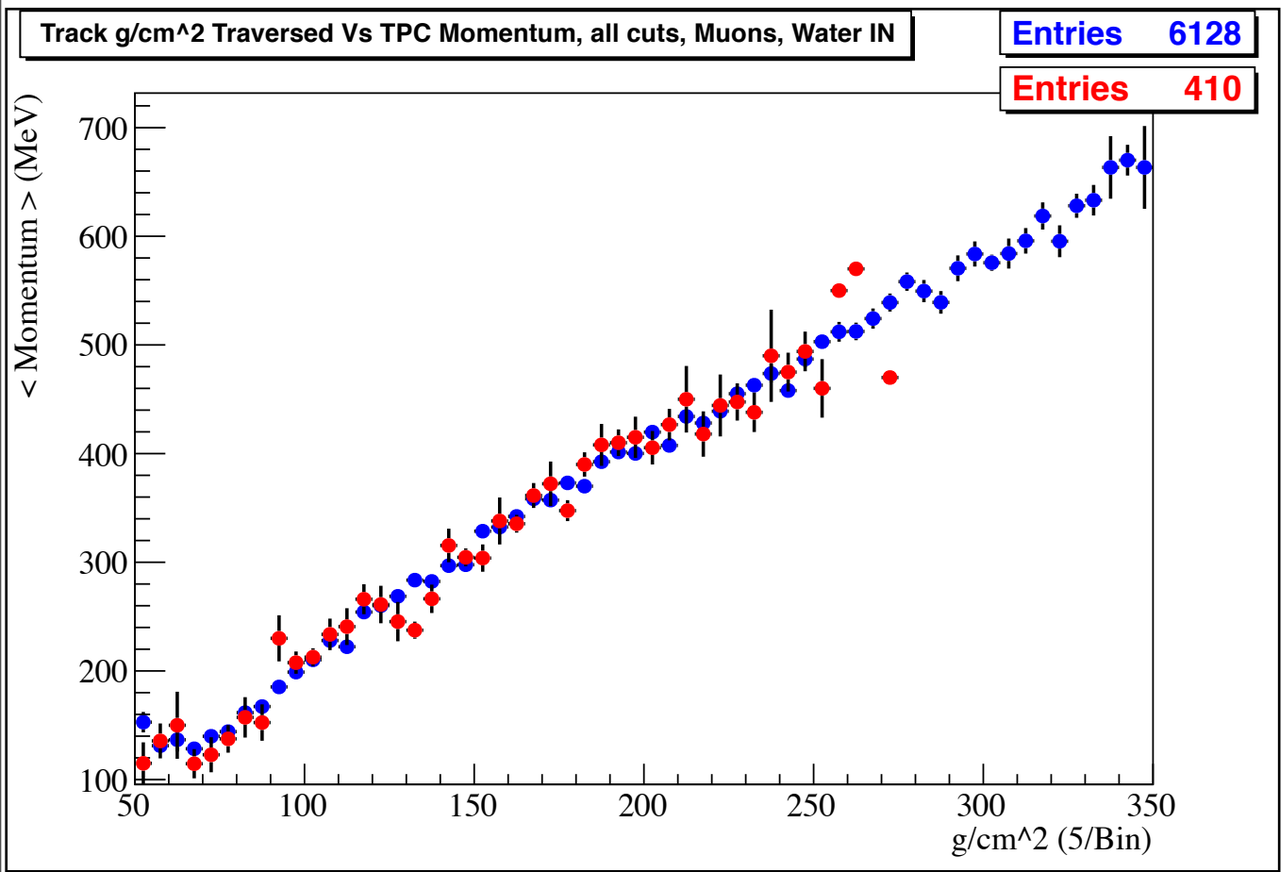


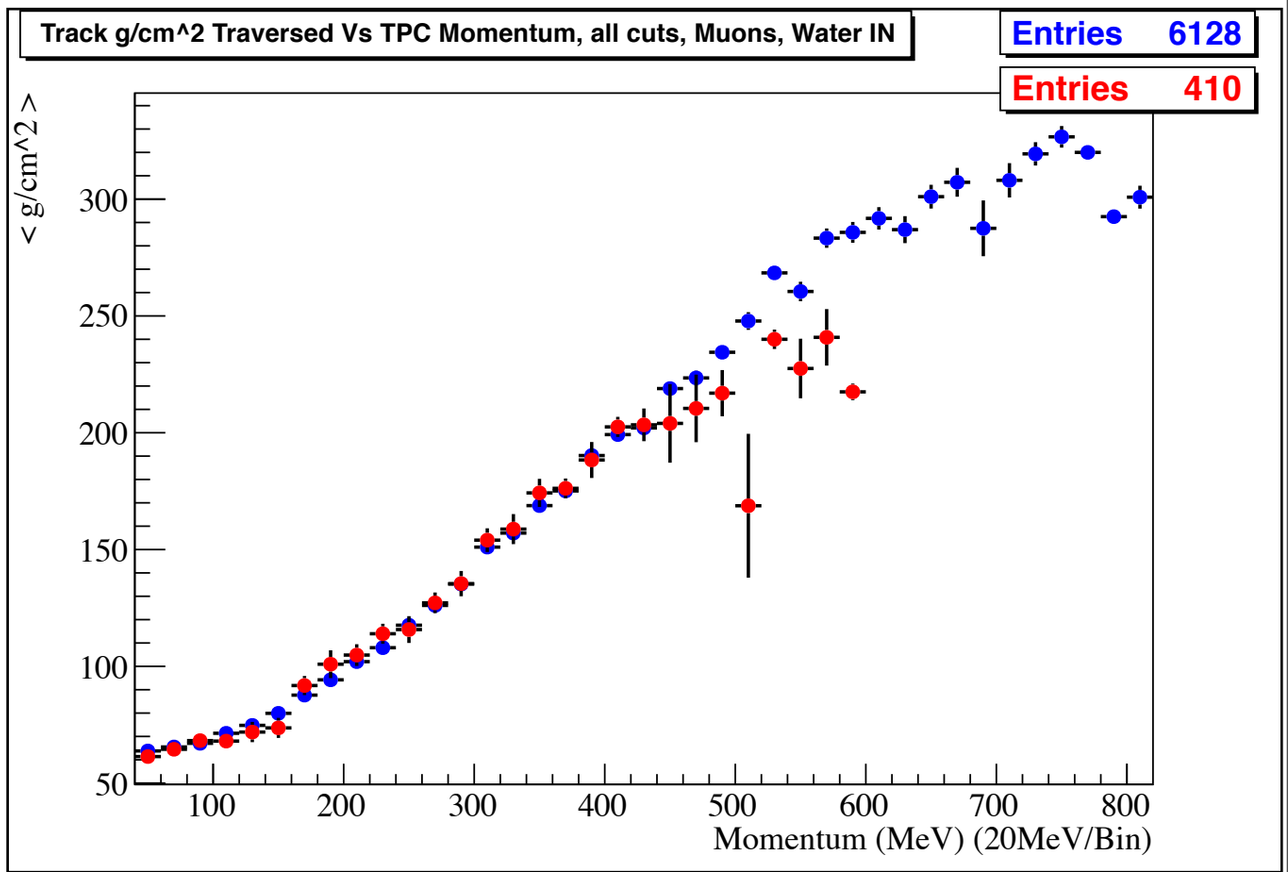
Water OUT

Profile Plots

g/cm^2 Vs TPC P

Water In
Water Out

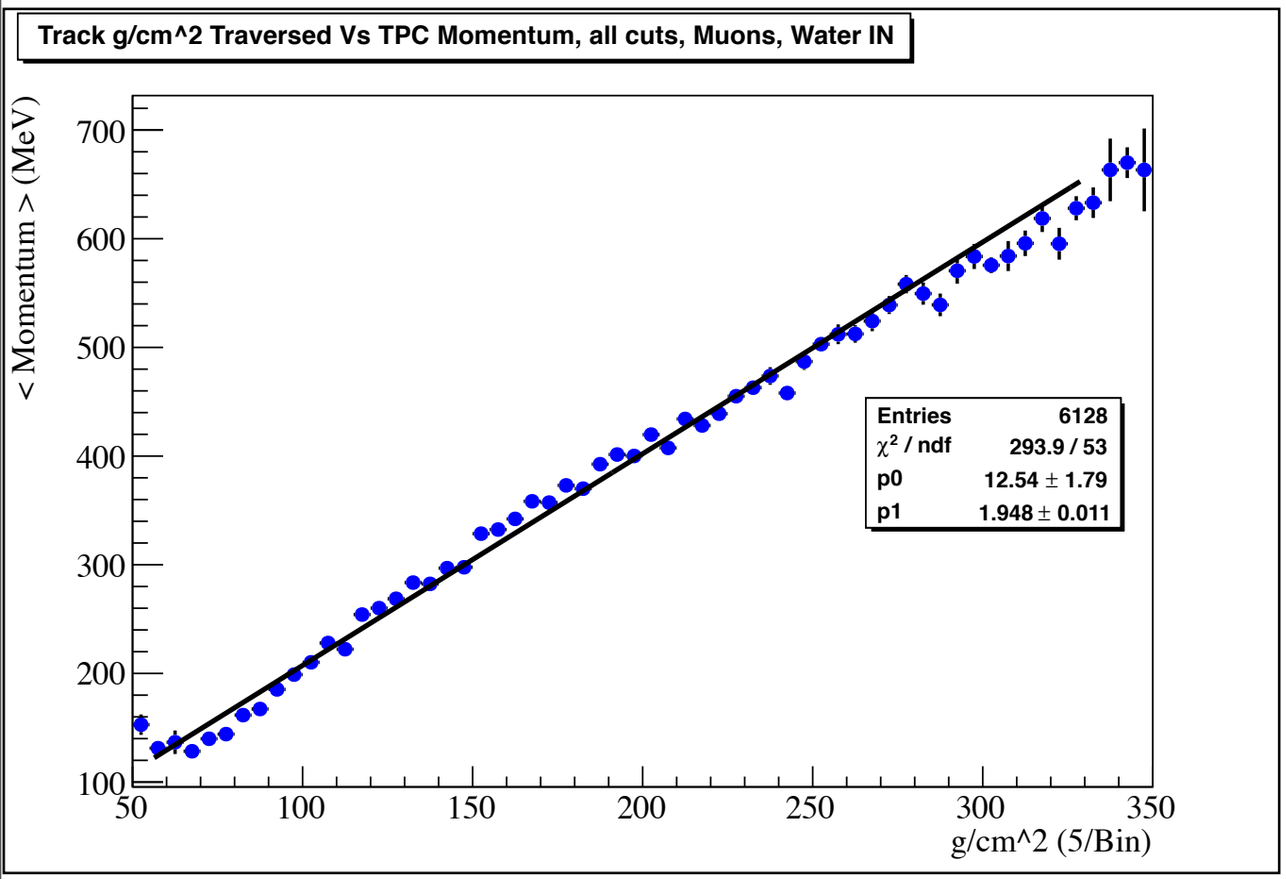


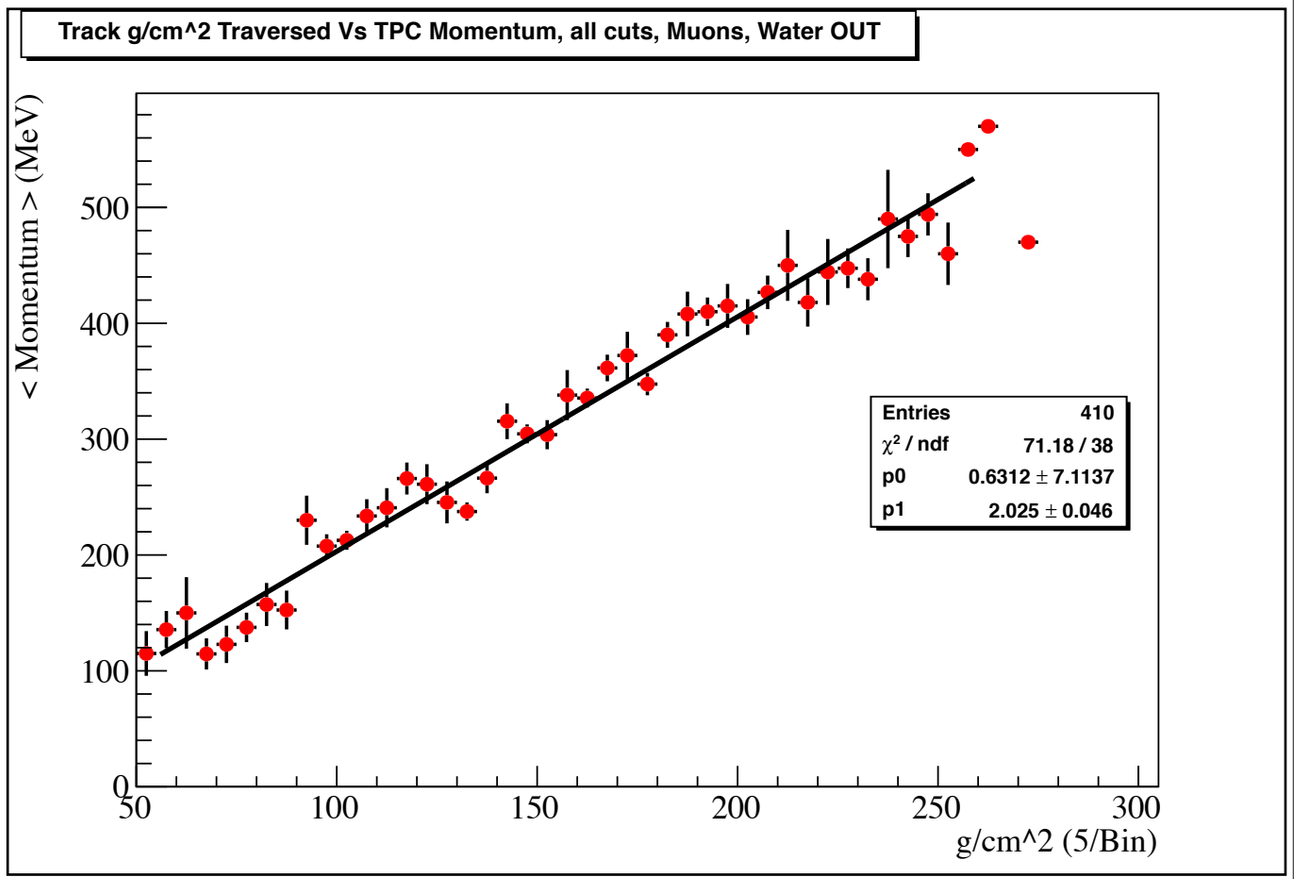


Length traversed expressed in g/cm^2 results in identical water-in, water-out results, as hoped for.

g/cm^2 Vs TPC P

Water In
Water Out





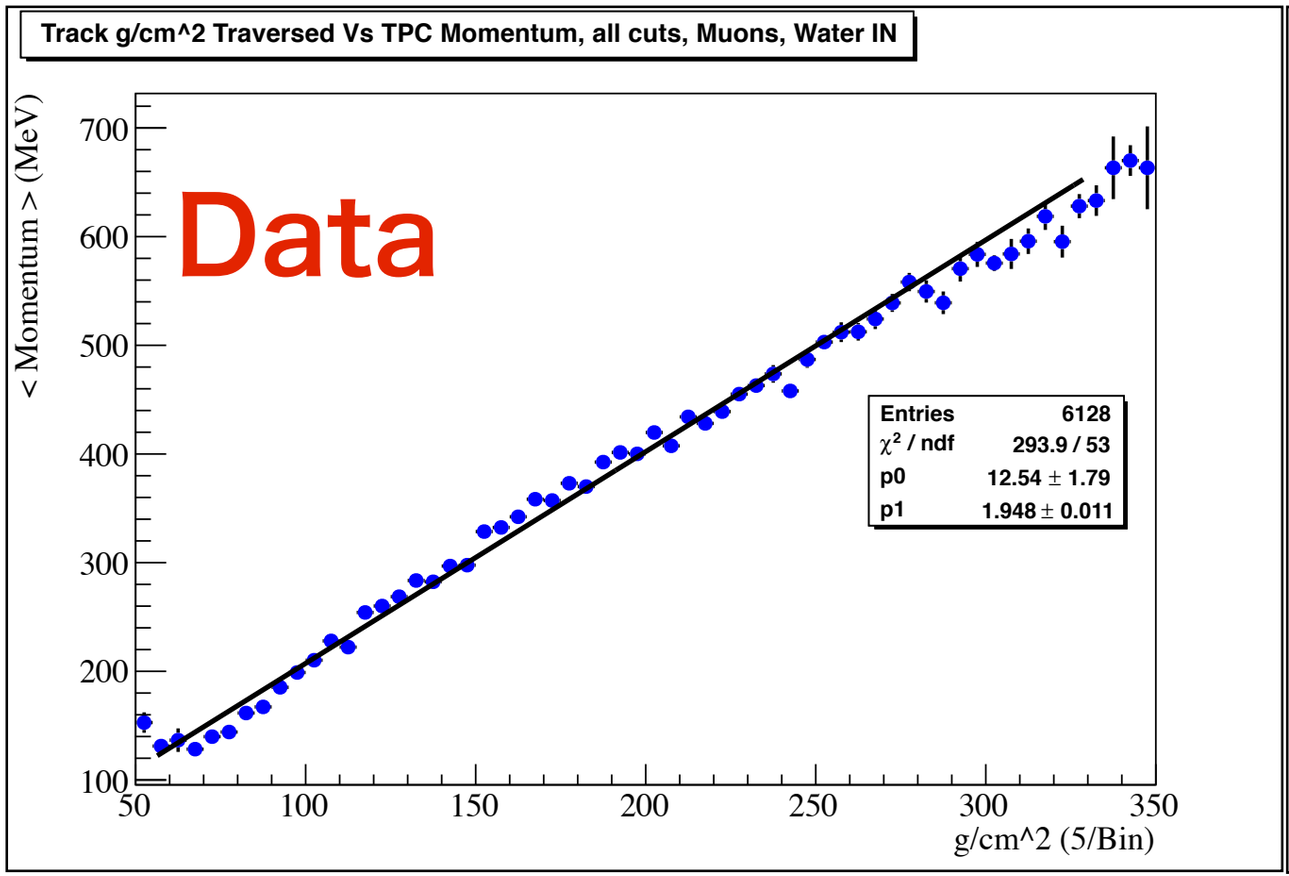
$$\text{Slope} = 1.948 \pm 0.011 \, \frac{\text{MeV}}{\text{g cm}^{-2}}$$

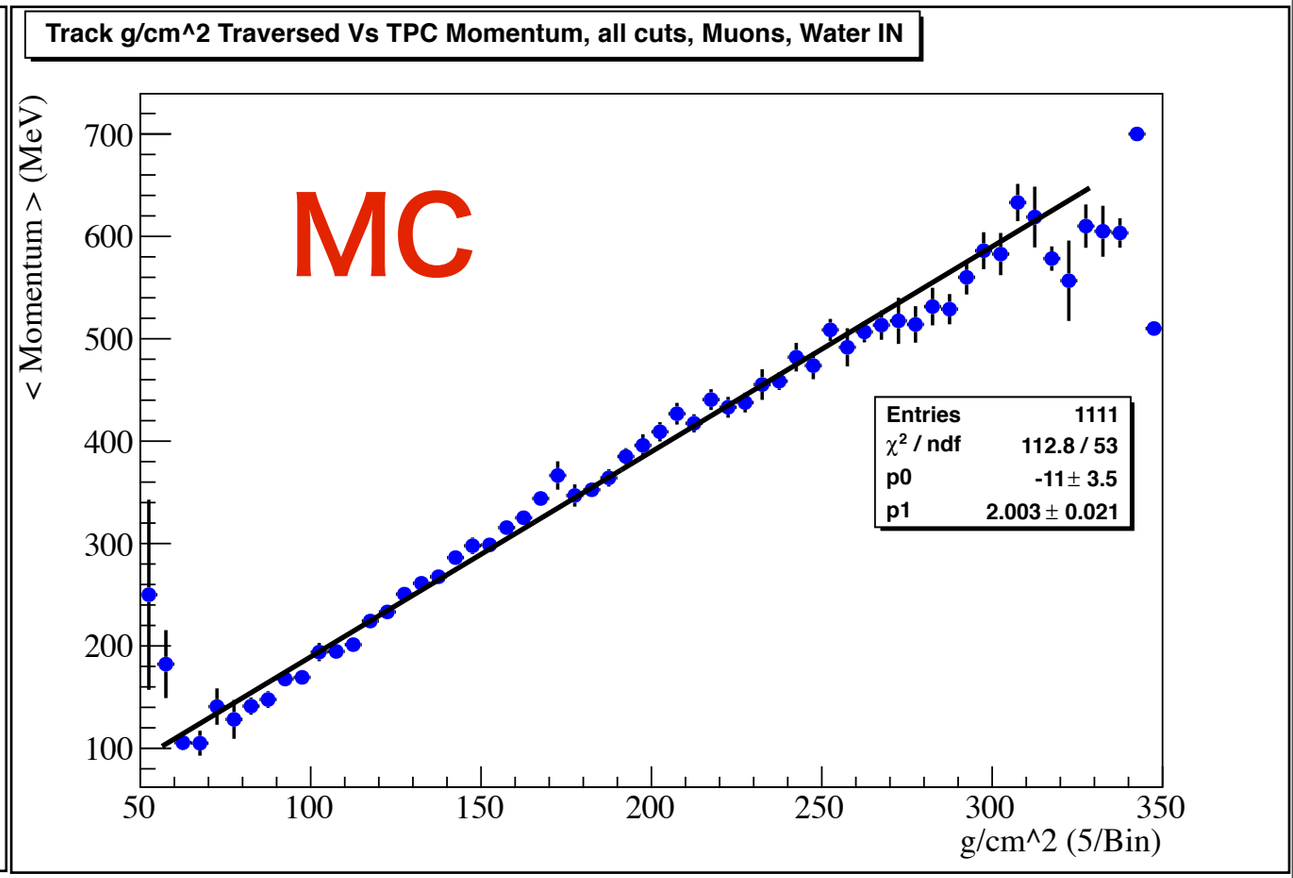
$$\text{Slope} = 2.025 \pm 0.046 \, \frac{\text{MeV}}{\text{g cm}^{-2}}$$

Intercept suggests P0D-TPC gap ~13 MeV

g/cm^2 Vs TPC P

Water In





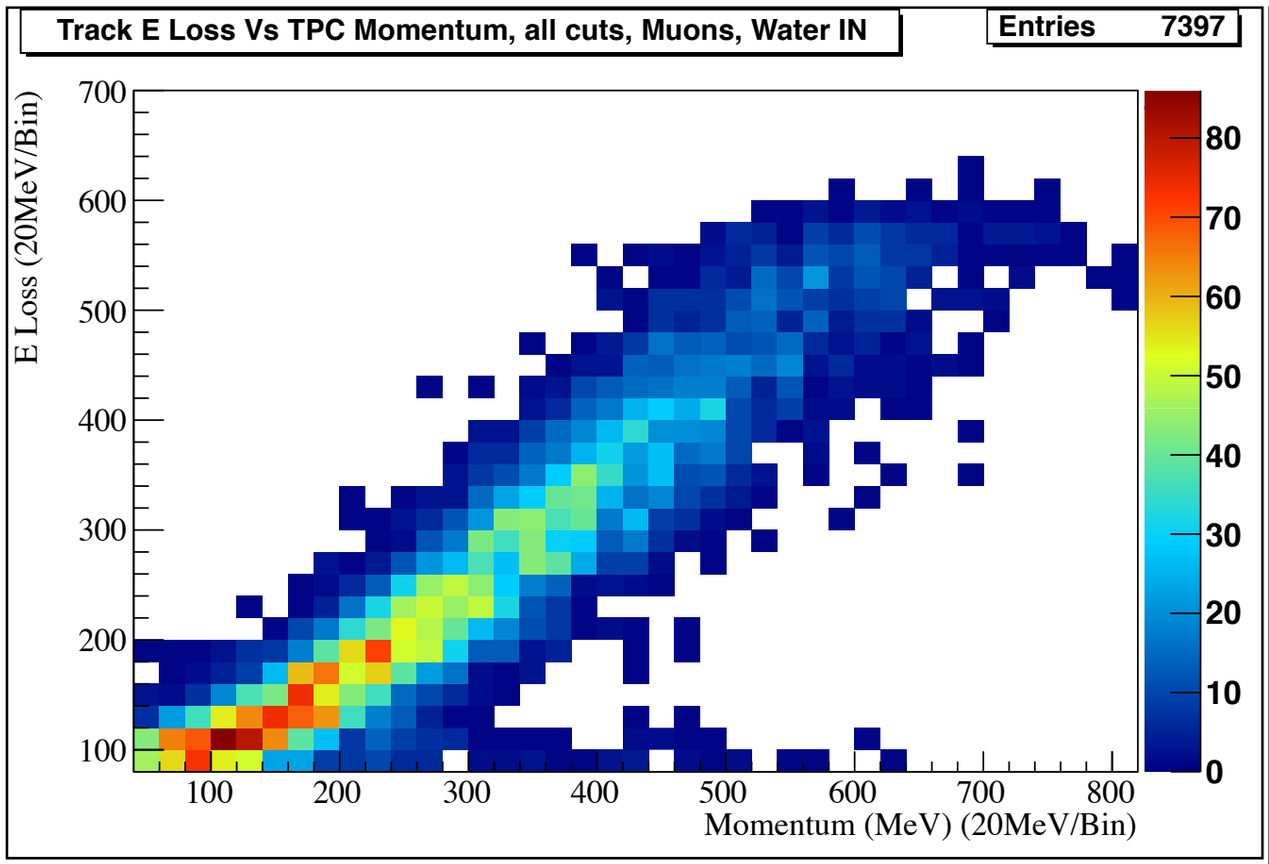
$$\text{Slope} = 1.948 \pm 0.011 \, \frac{\text{MeV}}{\text{g cm}^{-2}}$$

$$\text{Slope} = 2.003 \pm 0.021 \, \frac{\text{MeV}}{\text{g cm}^{-2}}$$

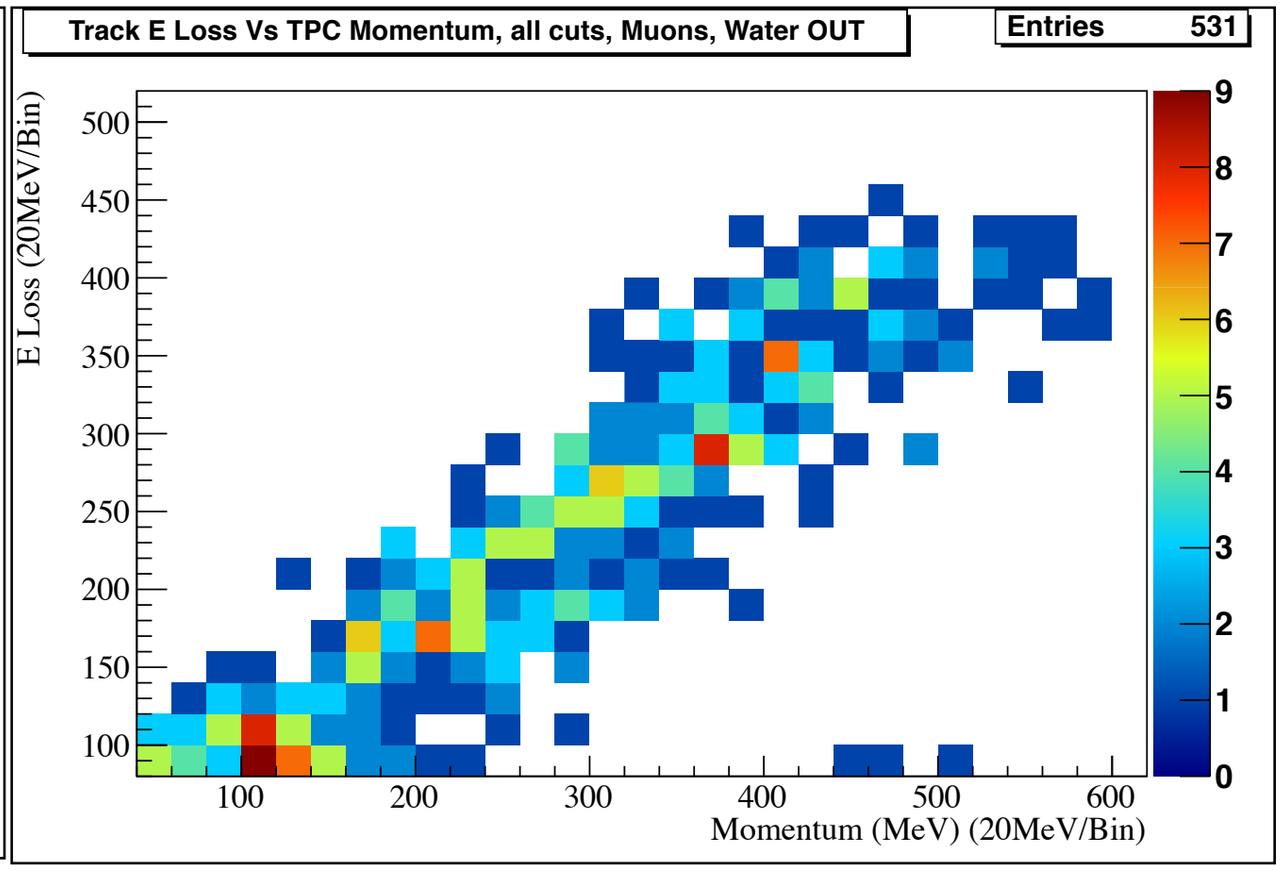
$$\text{Data/MC} = 0.97 \pm 0.01$$

Energy Loss Vs P

E Loss Vs TPC P

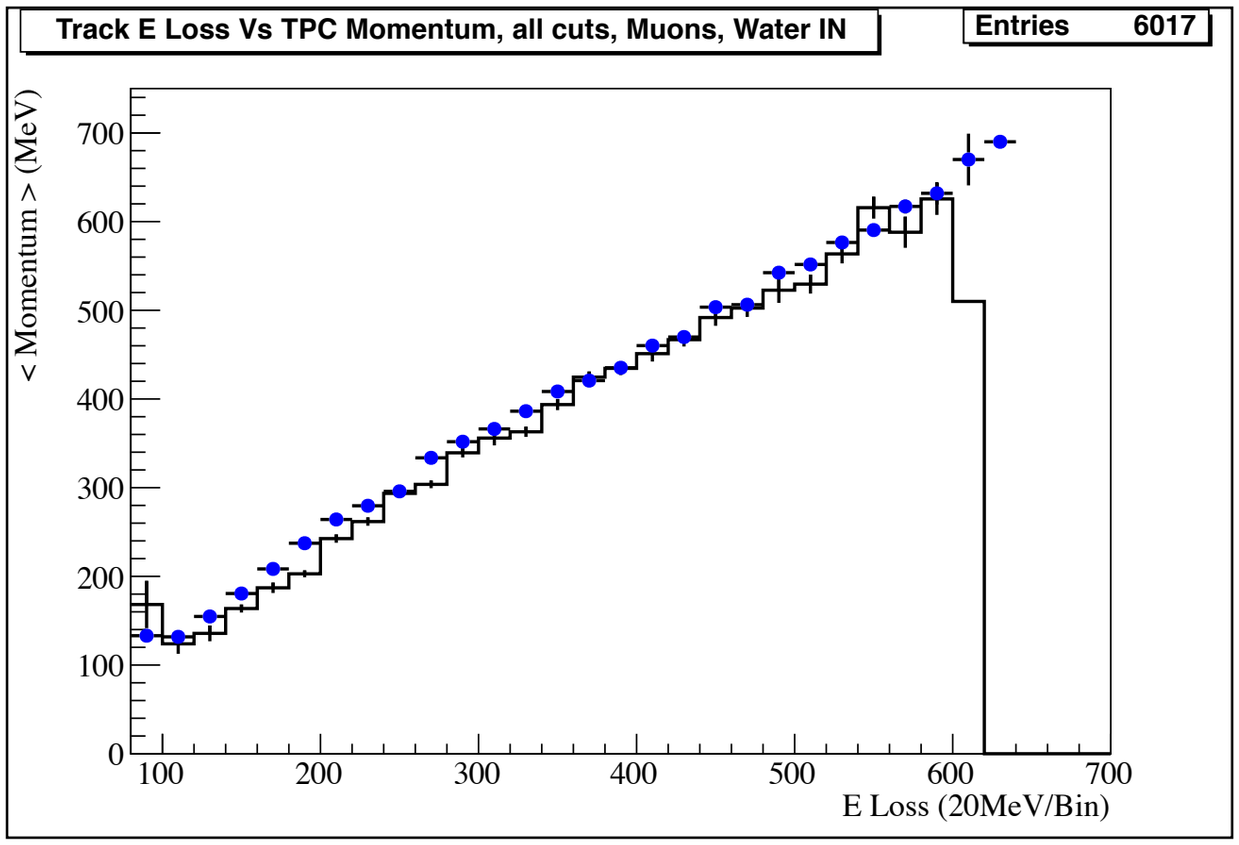


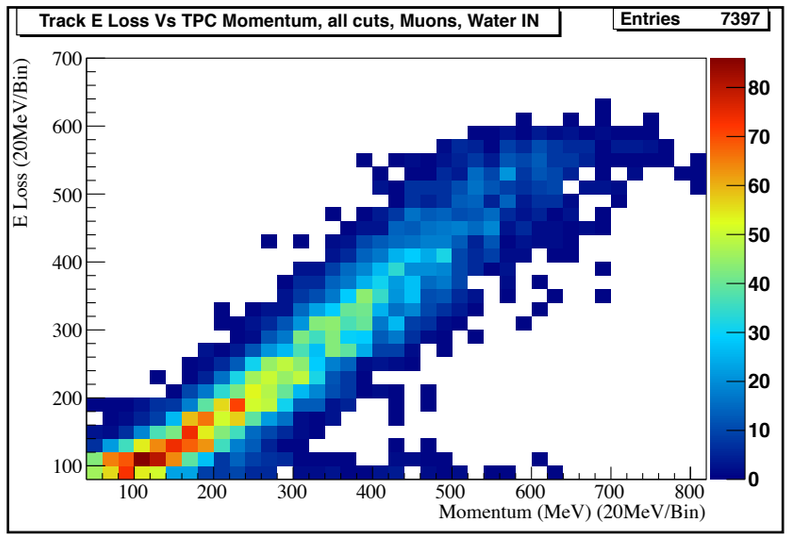
Water IN

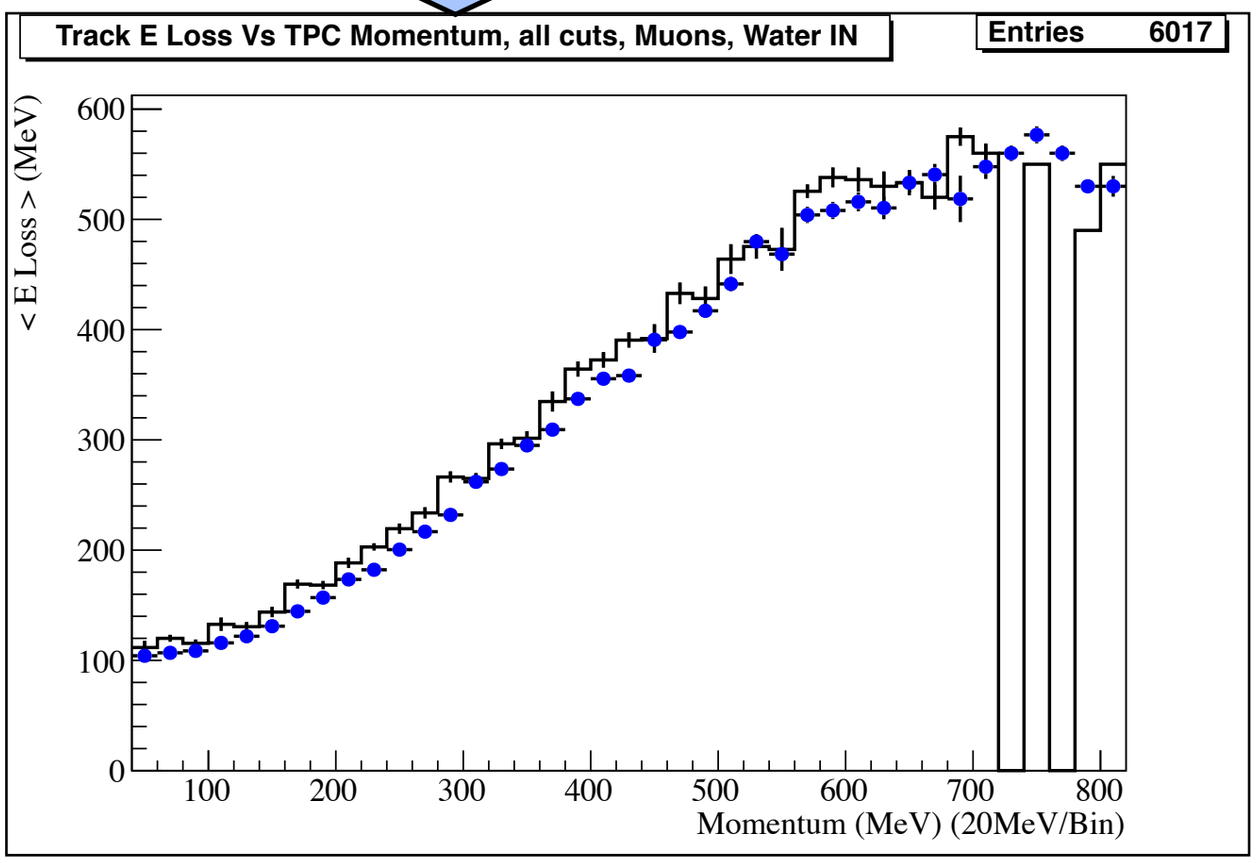


Water OUT

E Loss Vs TPC P



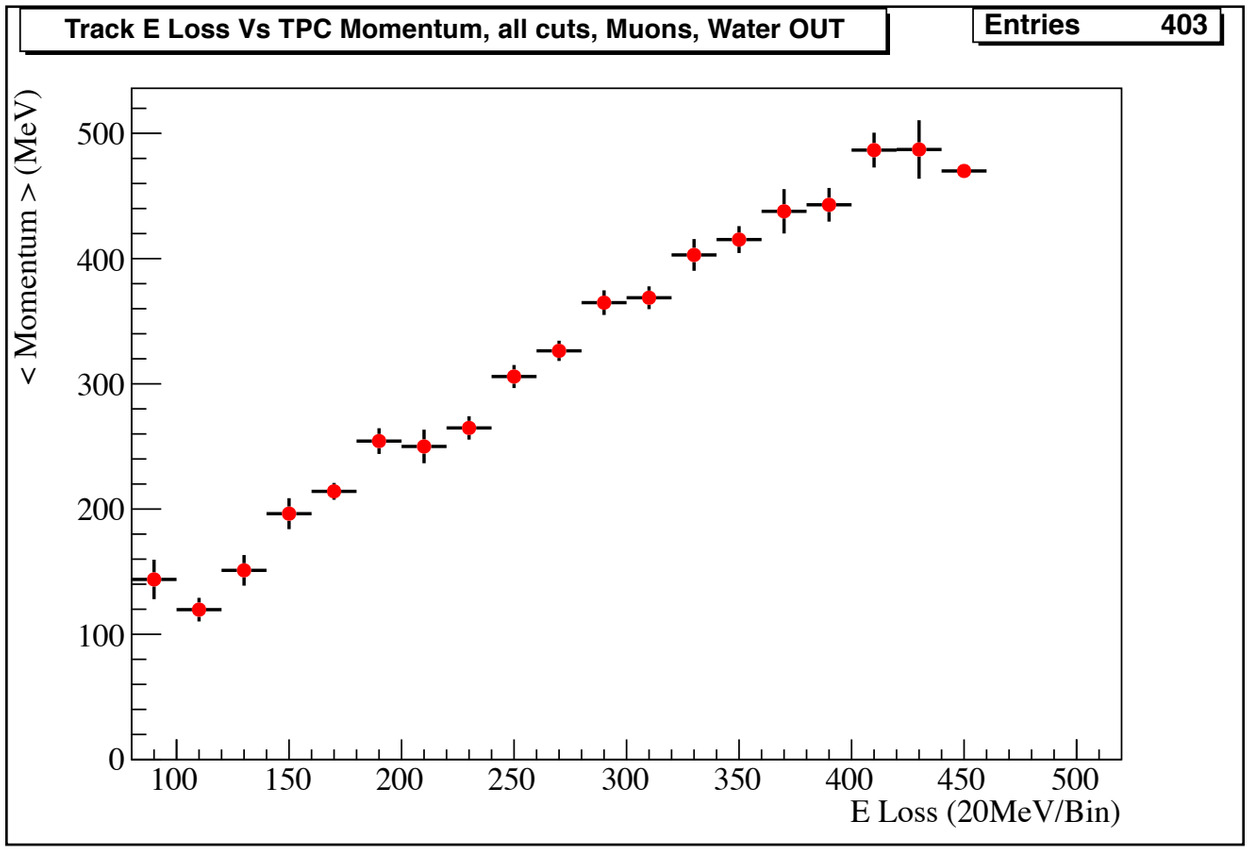


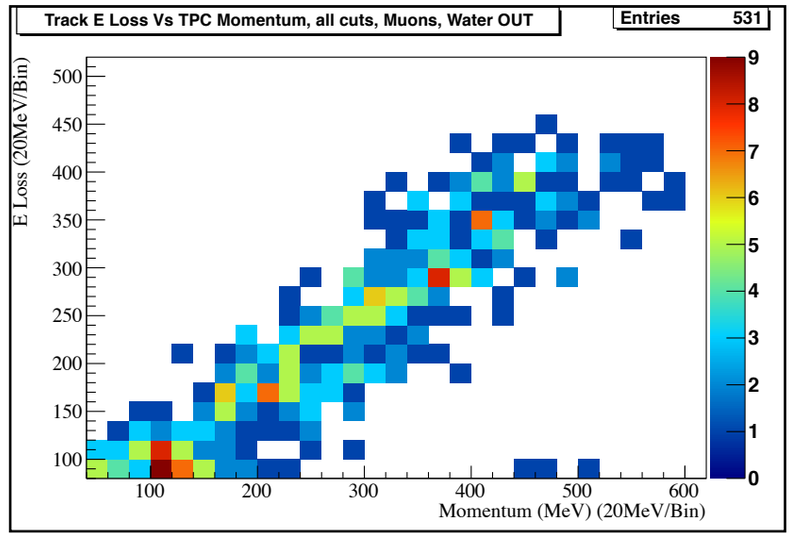


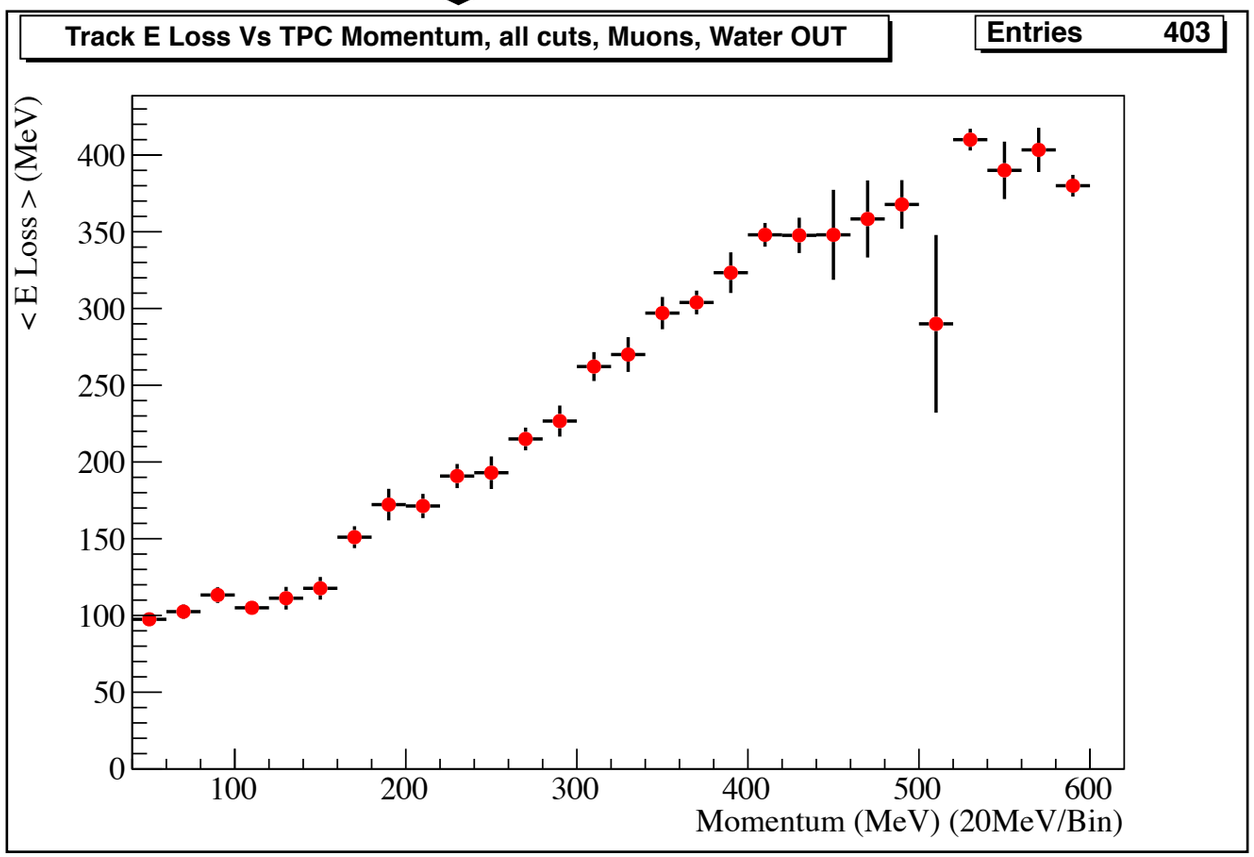
Water IN

Profile Plots

E Loss Vs TPC P





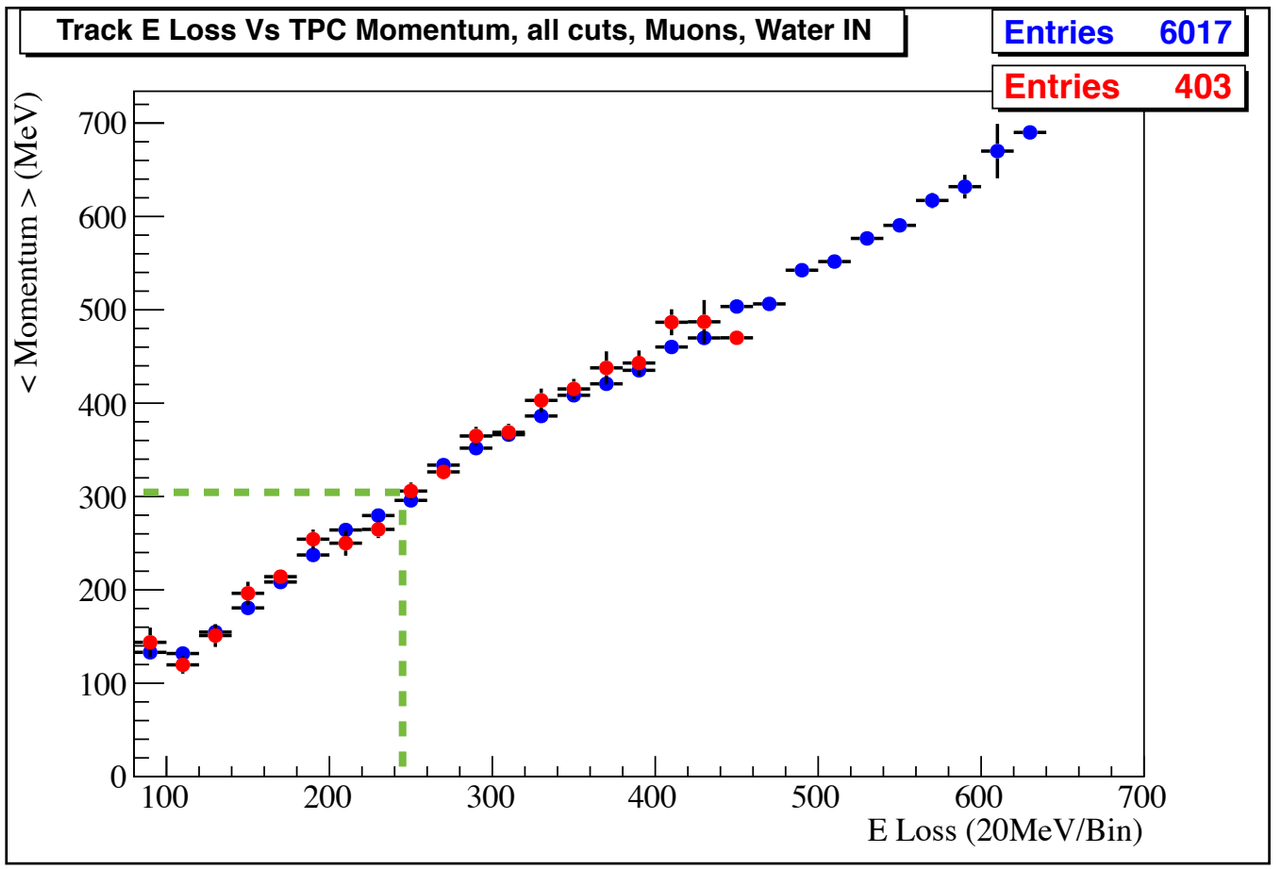


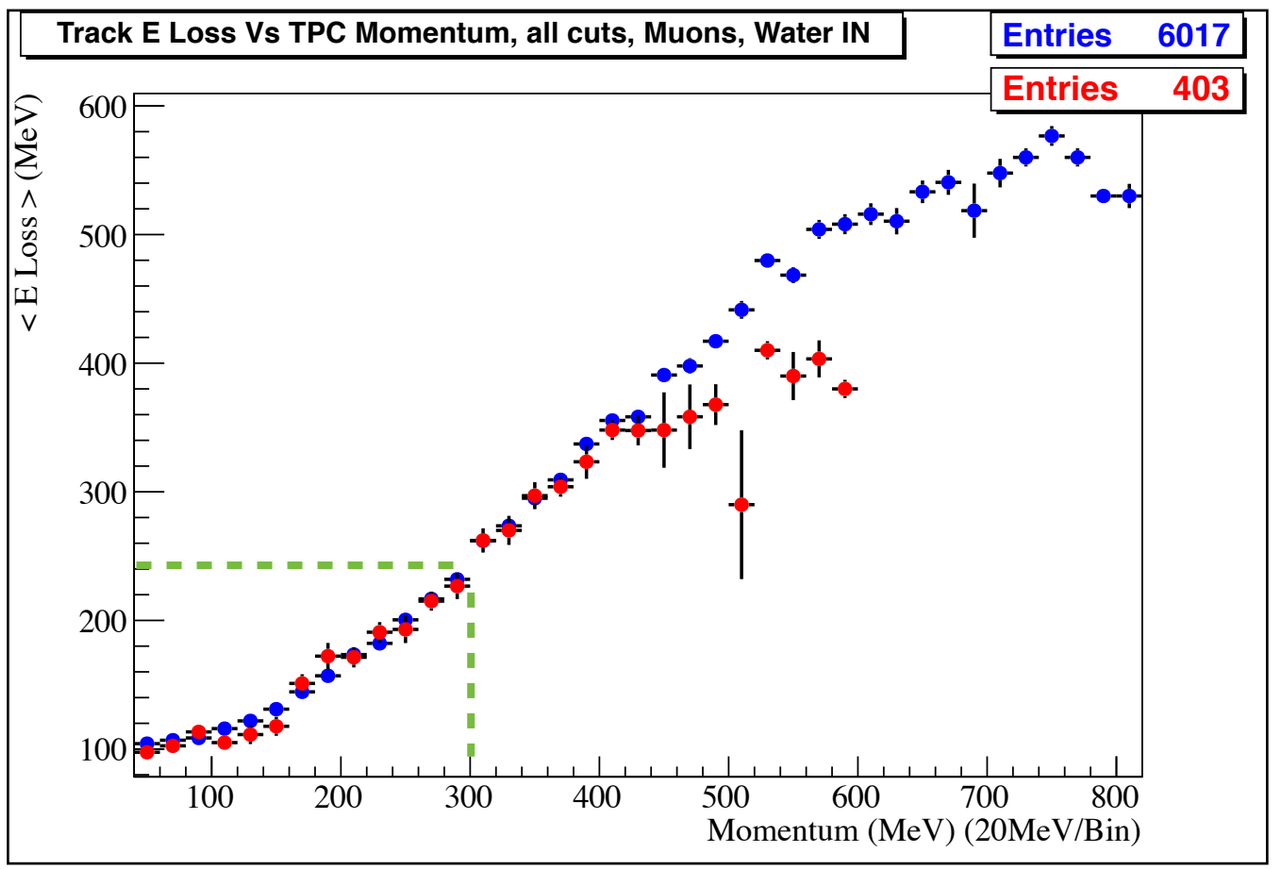
Water OUT

Profile Plots

E Loss Vs TPC P

Water In
Water Out





Energy loss within P0D consistent for water-in, water-out.

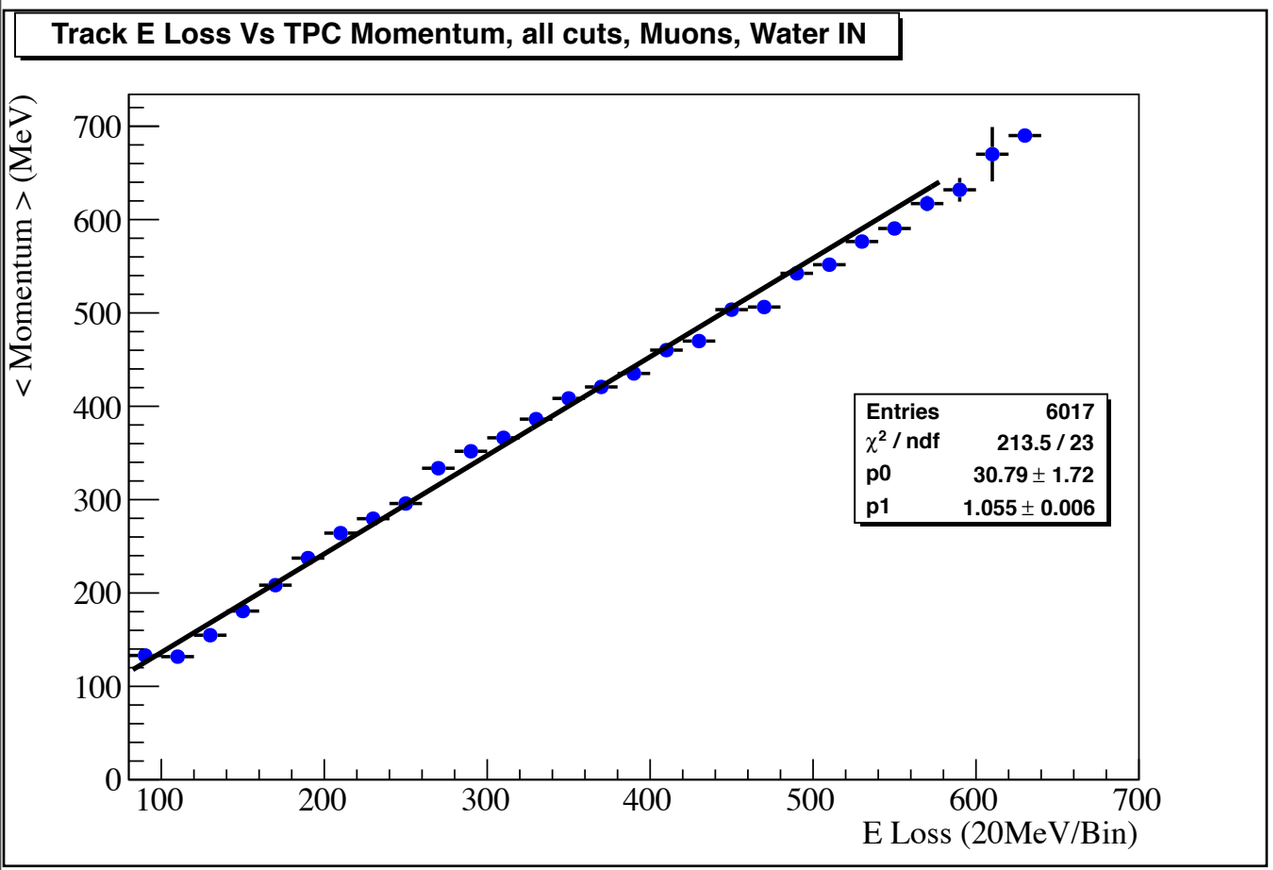
(For a mippy muon)

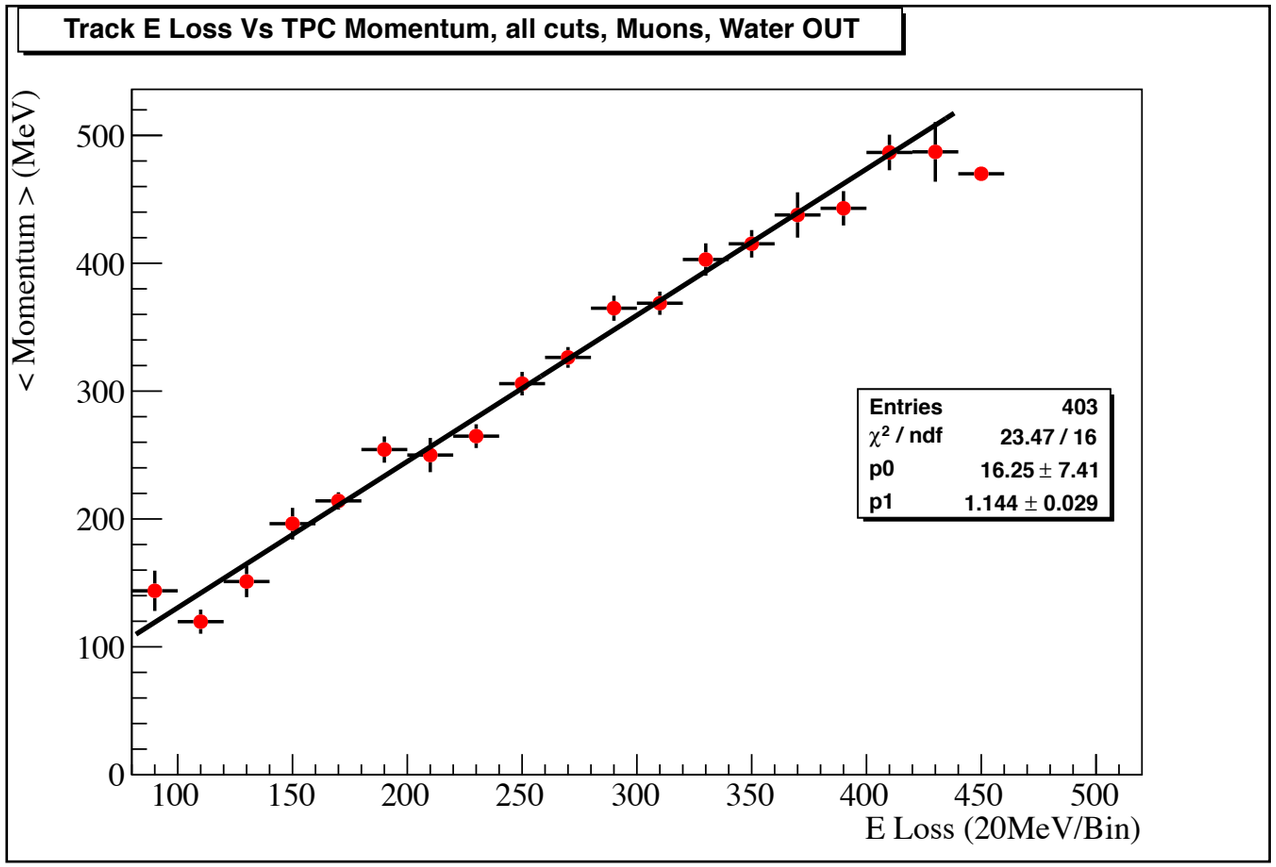
Expect energy loss ^ "range out" at 430MeV (water out), 570MeV (water in)

Pretty clear there is some sort of systematic offset here. Perhaps unaccounted energy loss between the P0D and TPC

E Loss Vs TPC P

Water In
Water Out





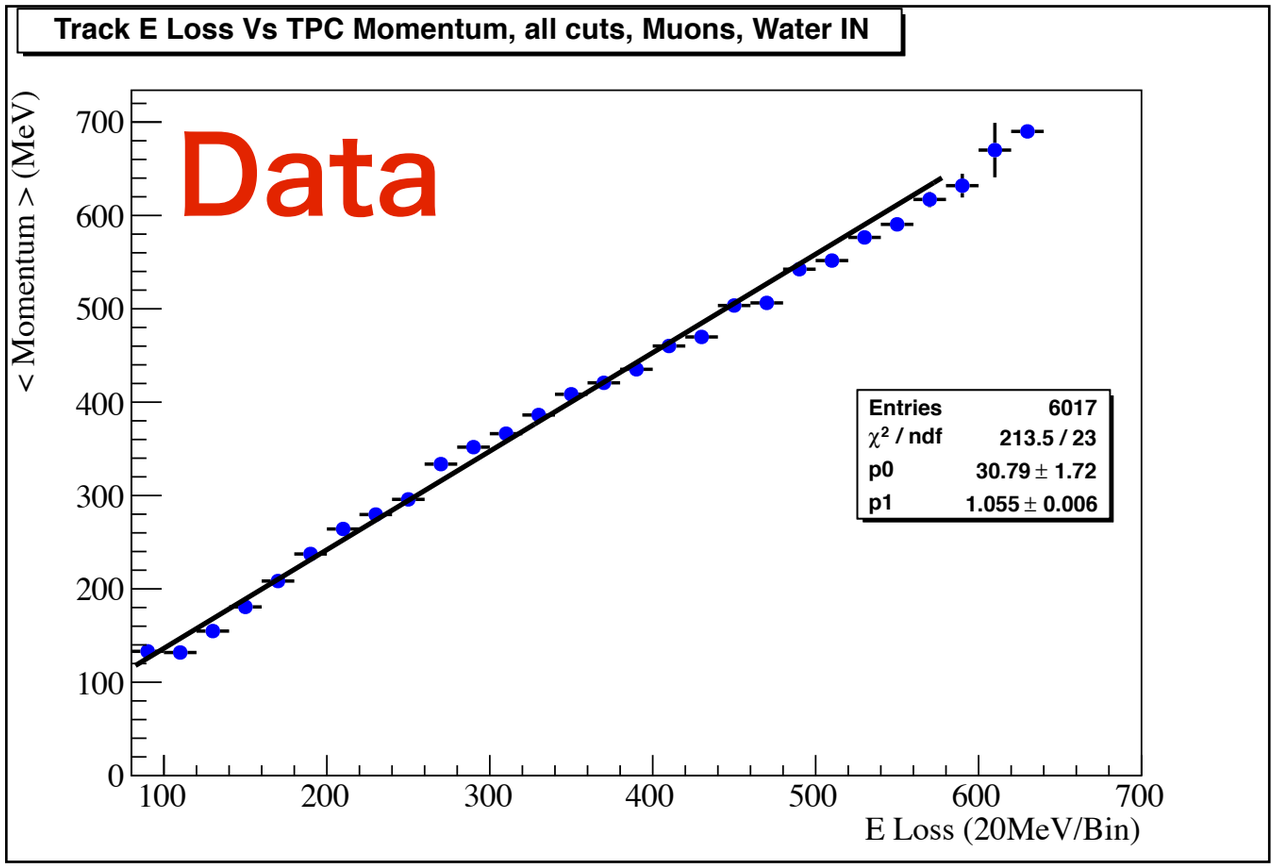
$$\text{Slope} = 1.055 \pm 0.006$$

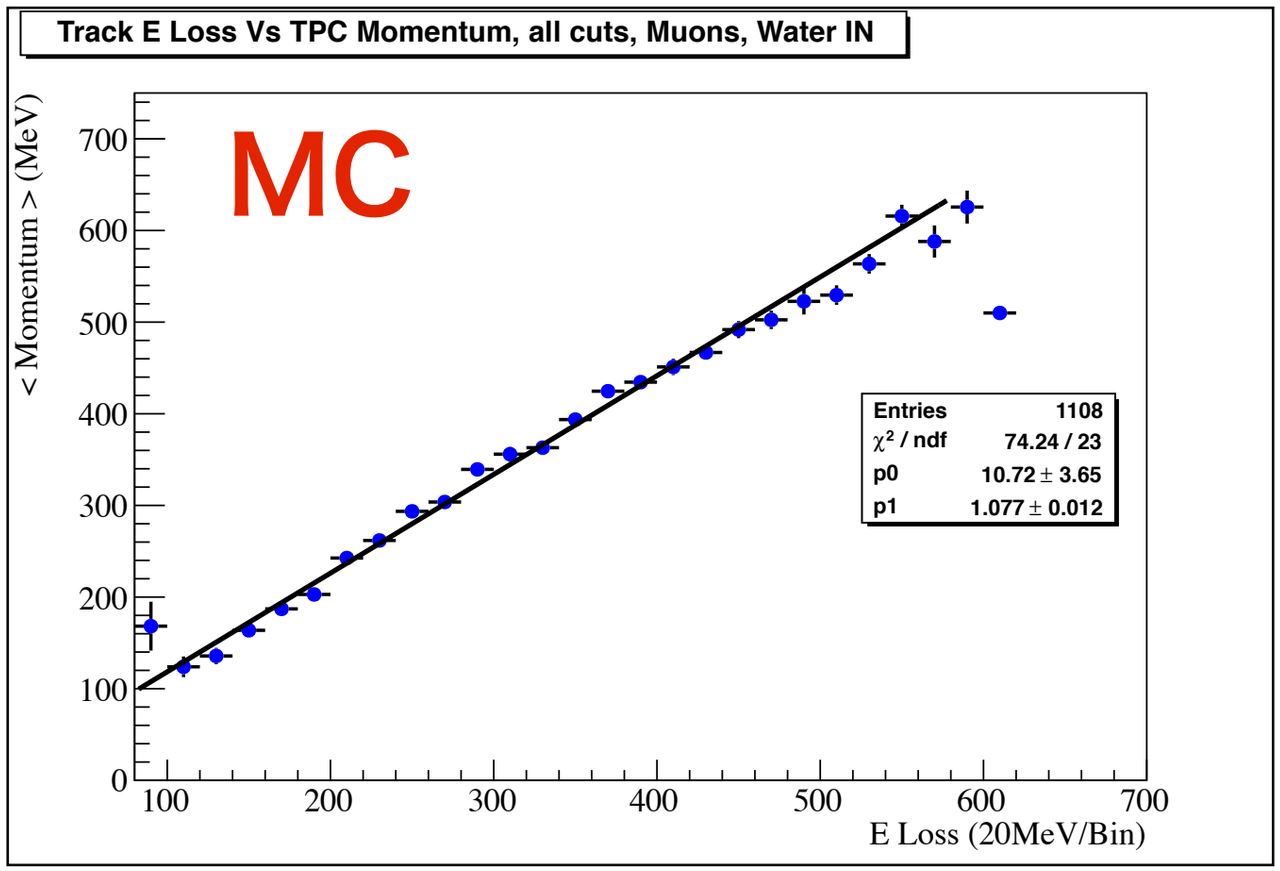
$$\text{Slope} = 1.144 \pm 0.029$$

Intercept suggests P0D-TPC gap ~30MeV

E Loss Vs TPC P

Water In





$$\text{Slope} = 1.055 \pm 0.006$$

$$\text{Slope} = 1.077 \pm 0.012$$

$$\text{Data/MC} = 0.980 \pm 0.012$$

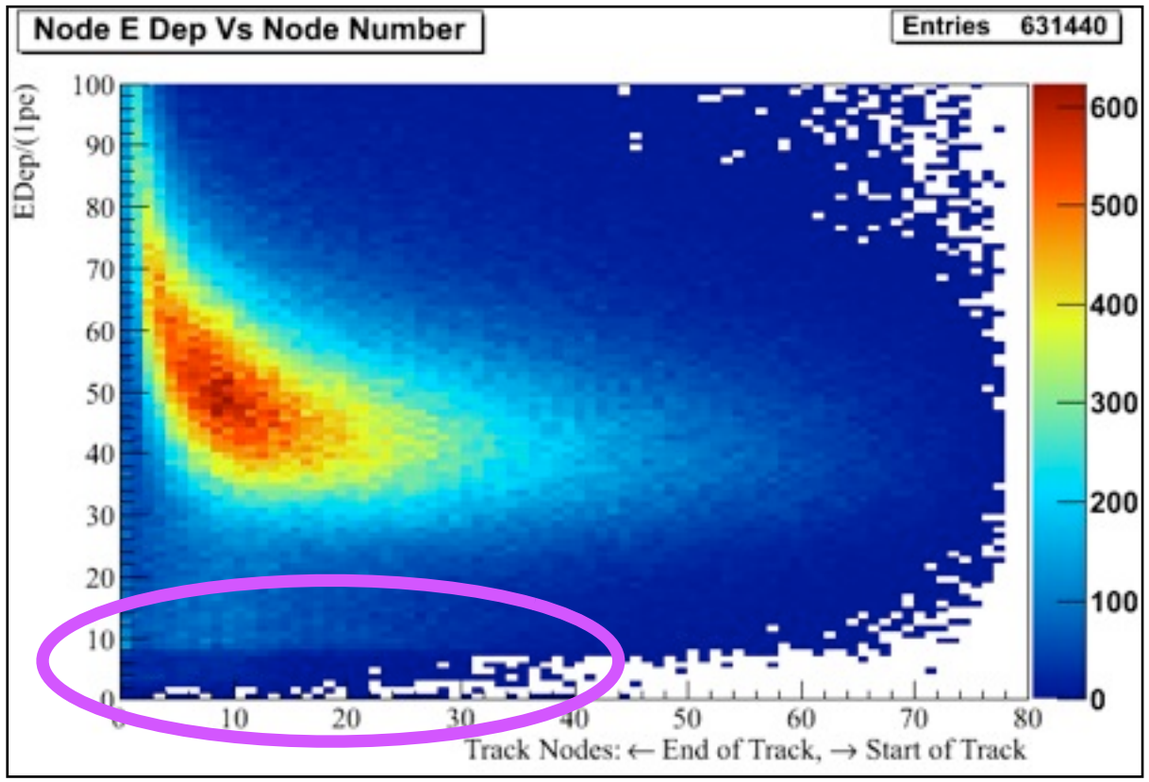
Misc + Conclusions

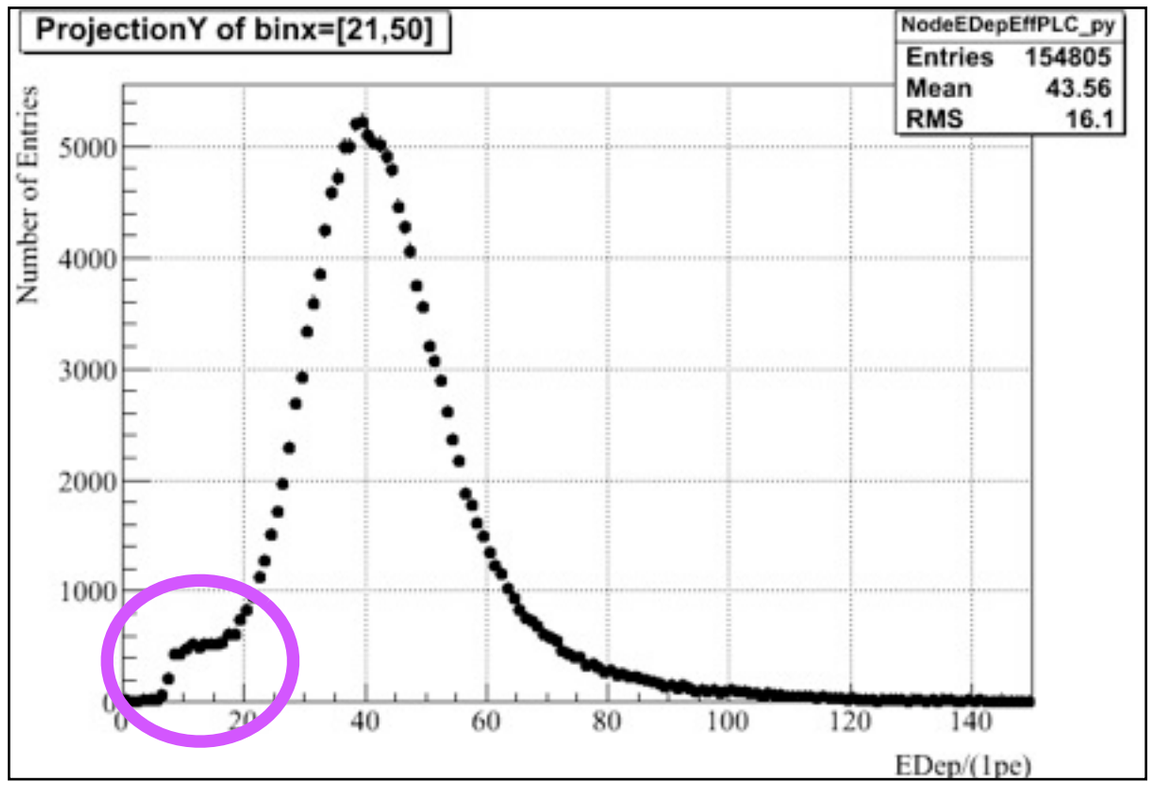
Some Comments

- Extracting MIP, Energy Scale
  - Can use dE/dx and ELoss to validate understanding of P0D materials, then calculate p.e.-to-MeV scale
- Cosmic Ray data shows that sample should really only be ~1% pions --> increase sample size by not cutting on TPC PID=muon (important for augmenting water-out)
- Byproduct of this work: Will re-visit current overall MIP calibration for P0D, switch from region-calibration to individual scint layer calibration
- Have finally settled down on primary cuts and plots, next step is to consider systematic uncertainties and cut optimization
- Will finalize this analysis into a one-click macro to be run on all cosmic data as it is taken and processed, produce validation plots

Low EDep Node Summary

From P0D Group Report



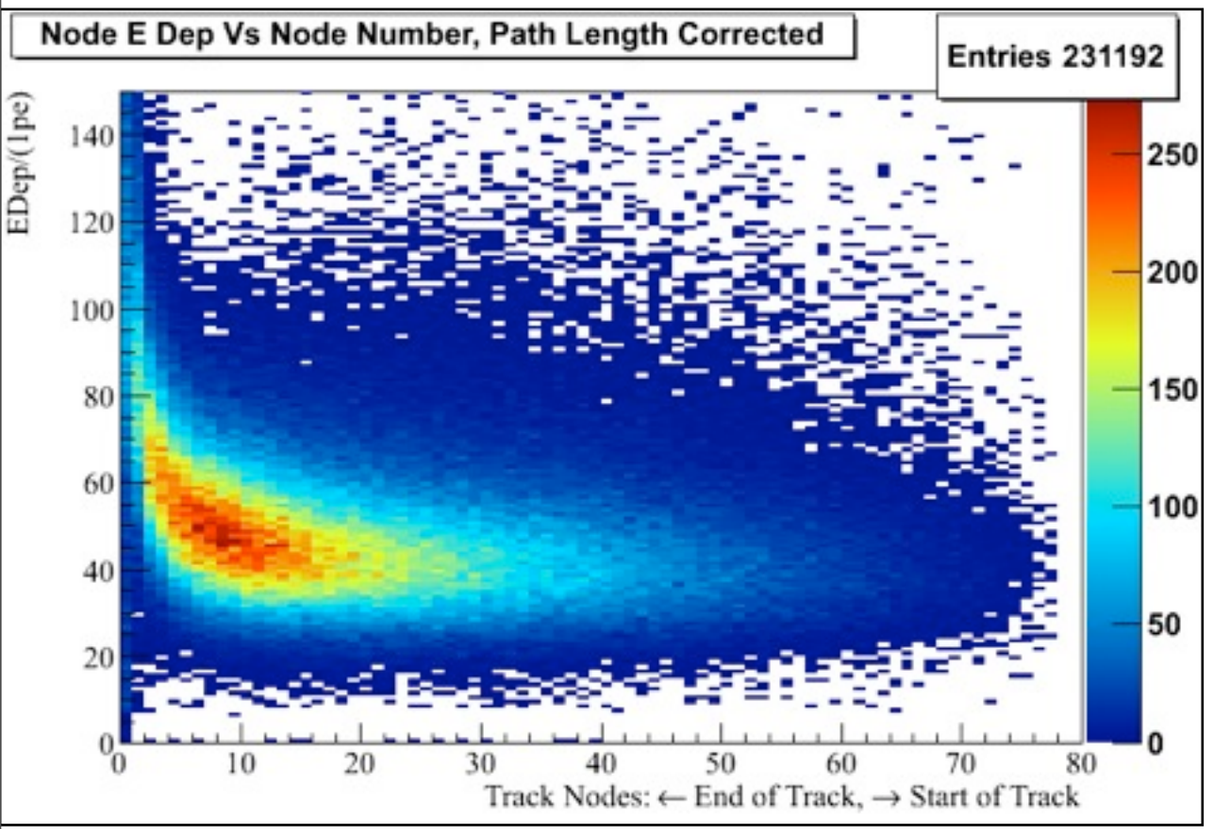


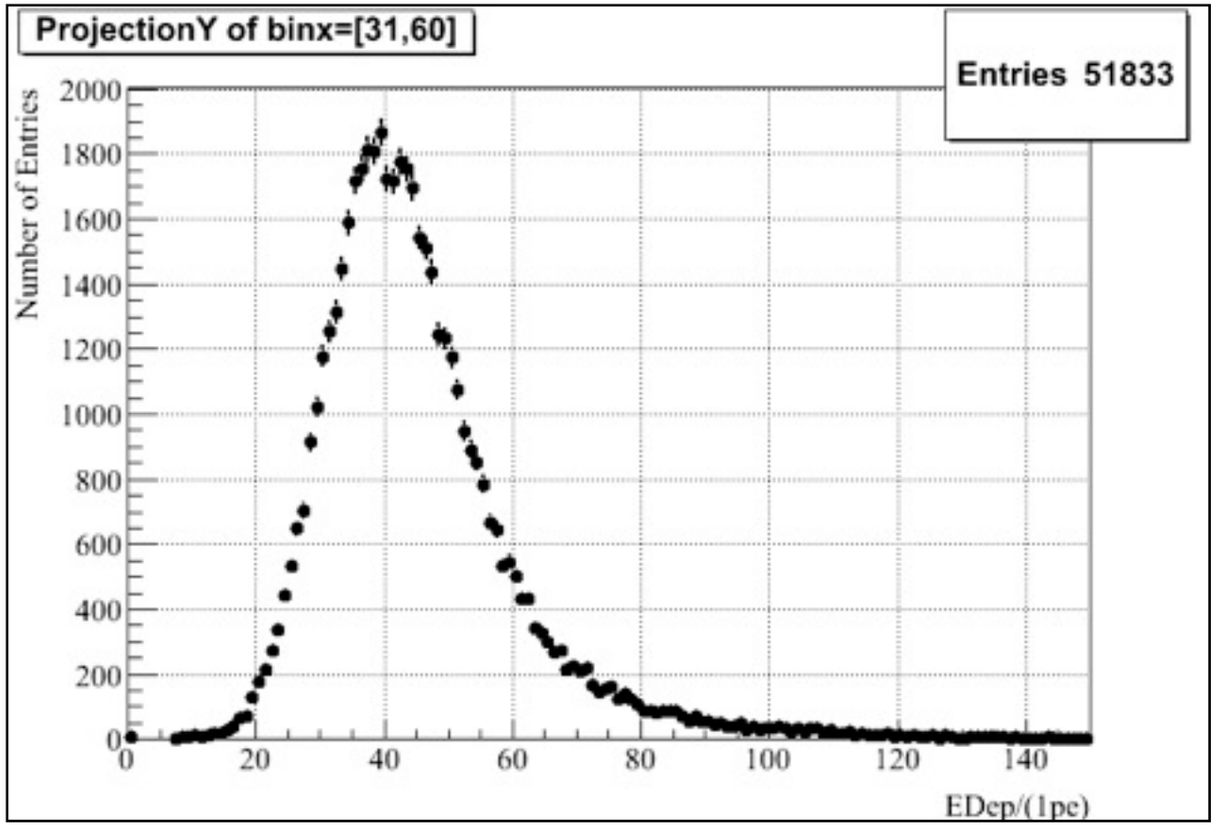
"The Shelf" EDep between 10p.e. and 20p.e.

Original Goal: make set of plots as above on the right, pursue a p.e.-to-MeV MIP calibration

From POD Group Report

Current Results:





No more Low EDep shelf. \(^o^)/

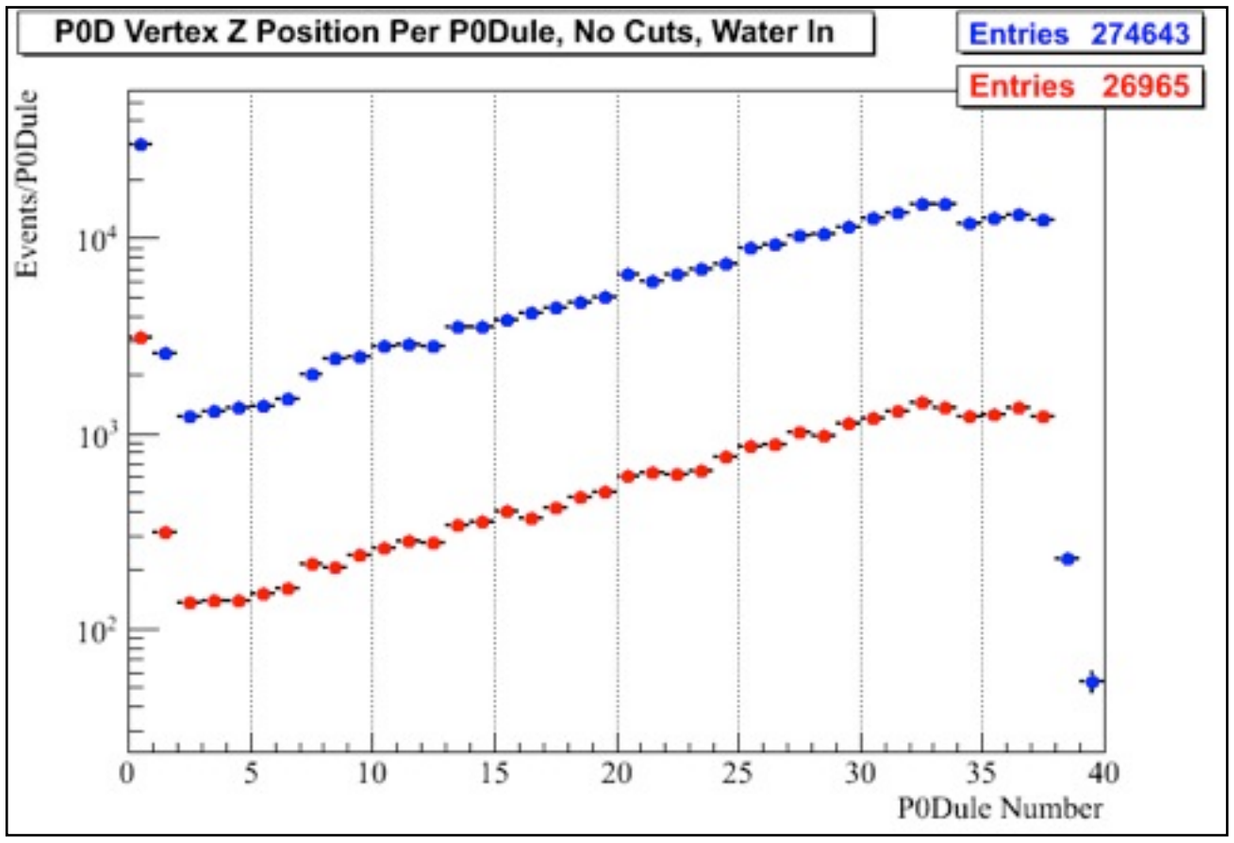
Problem traced to beam trigger difference from cosmic trigger,
still working on exact cause, but can now cut out bad events.

Conclusions

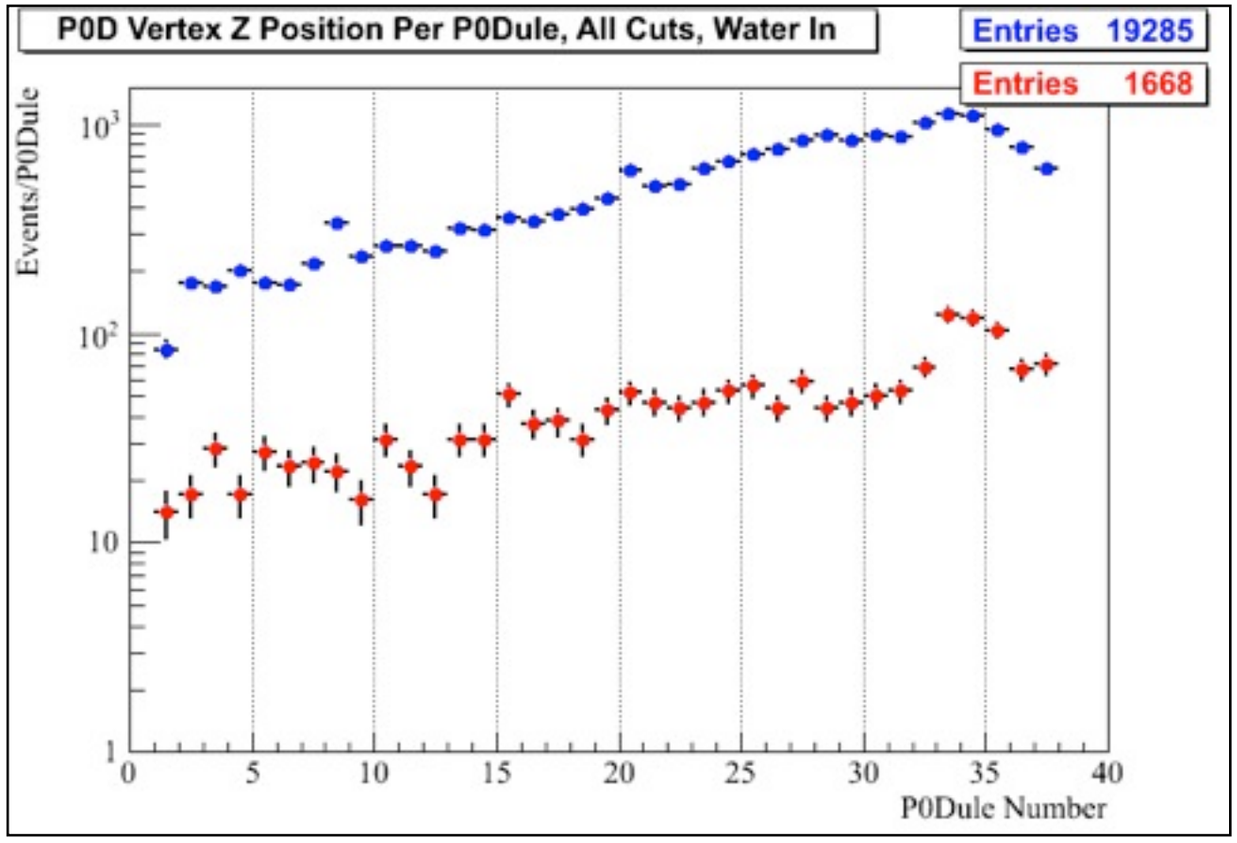
- Has been an incredibly productive and positive summer
- Have had the joy of being able to create and answer a lot of questions, with plenty more questions to explore
- Intended to work on Coherent Pion analysis this summer but got very distracted by this fun topic
    - However, track matching between P0D and TPC is essential for CC COHPi so that work will be directly applicable
- Submitted draft of P0D Fiducial Water Mass tech note
- Also managed to finish reading my first ライトノベル this summer, non-physics milestone reached \(^o^)/
- Thank you all for your time, and special thanks to Nakaya-san and Minamino-san for helping arrange to let me partake in the BIEP summer program!

Vertex Distributions

Vertex Distribution



All events that pass analysis selection cuts



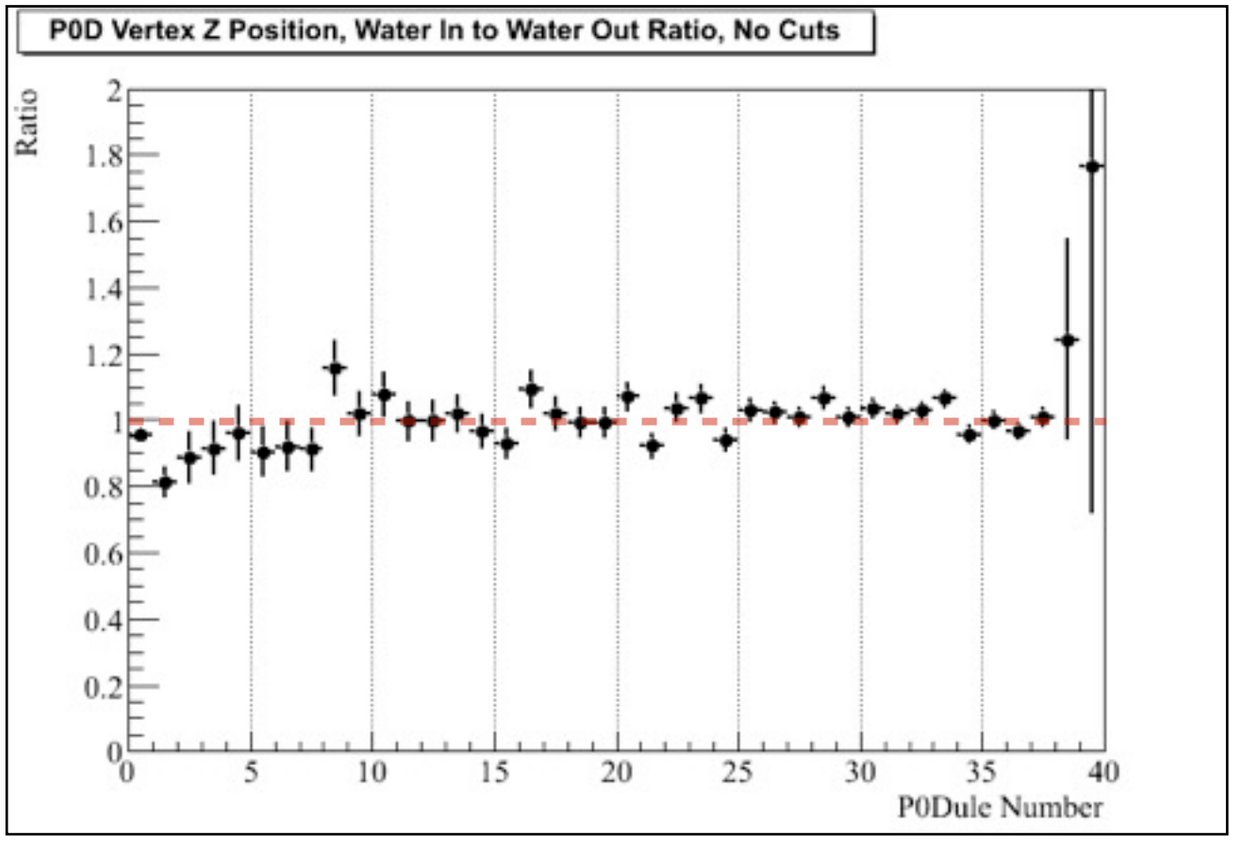
All selection and analysis cuts

Water-out sample size kind of small

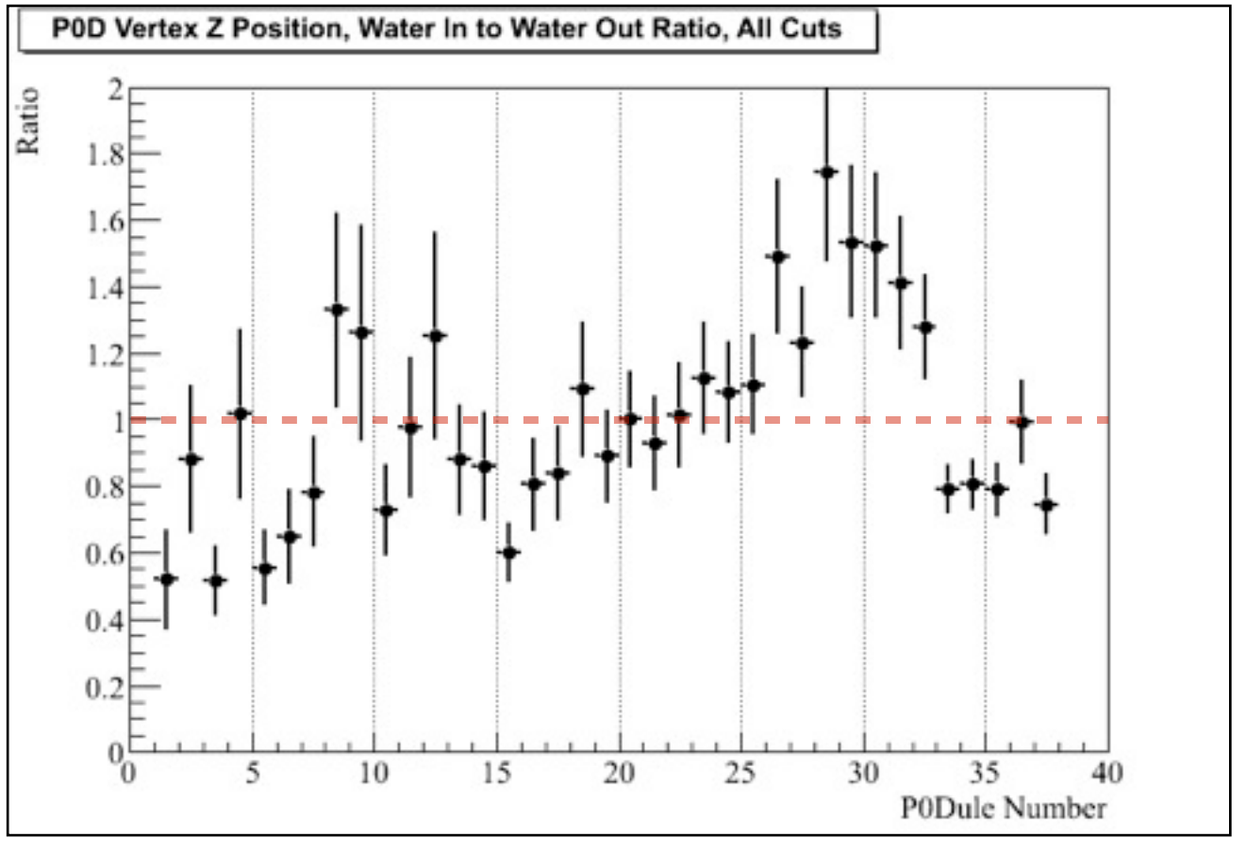
Water In
Water Out

Vertex Distribution

Water-In/Water-out Ratio



All events that pass analysis selection cuts



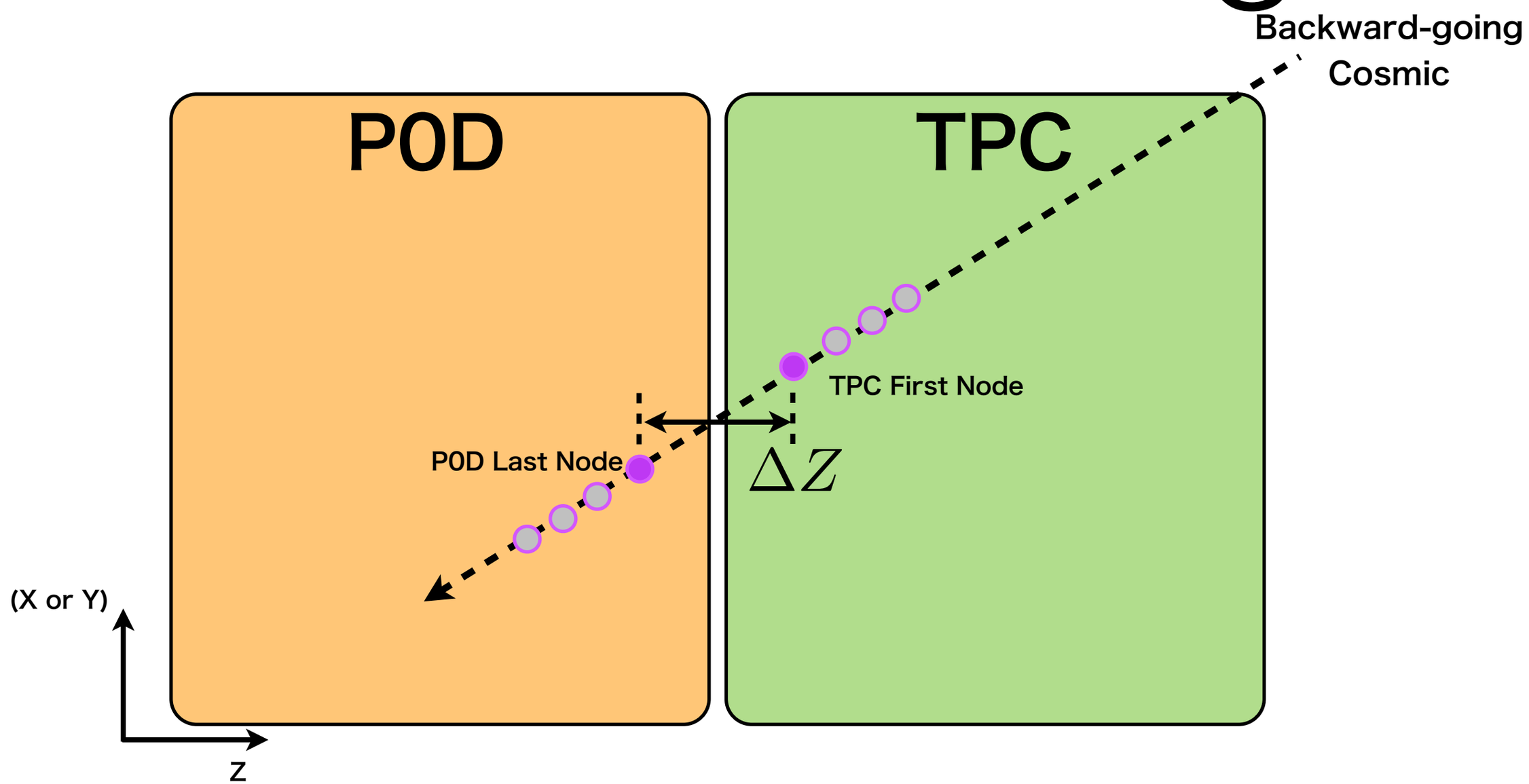
All selection and analysis cuts

Water-out sample size kind of small

Normalize each water-in, water-out vertex distribution histogram, take ratio

Track Match & Angle

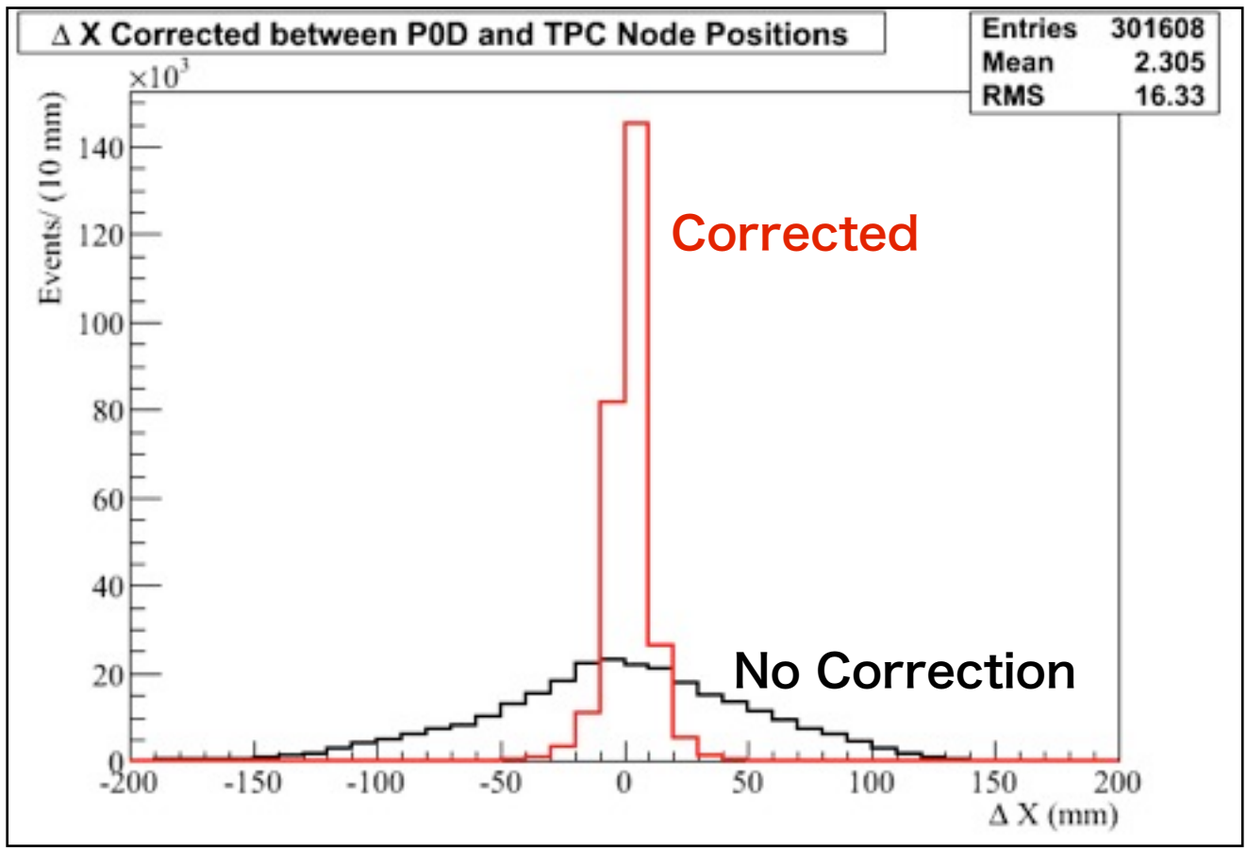
Position Matching



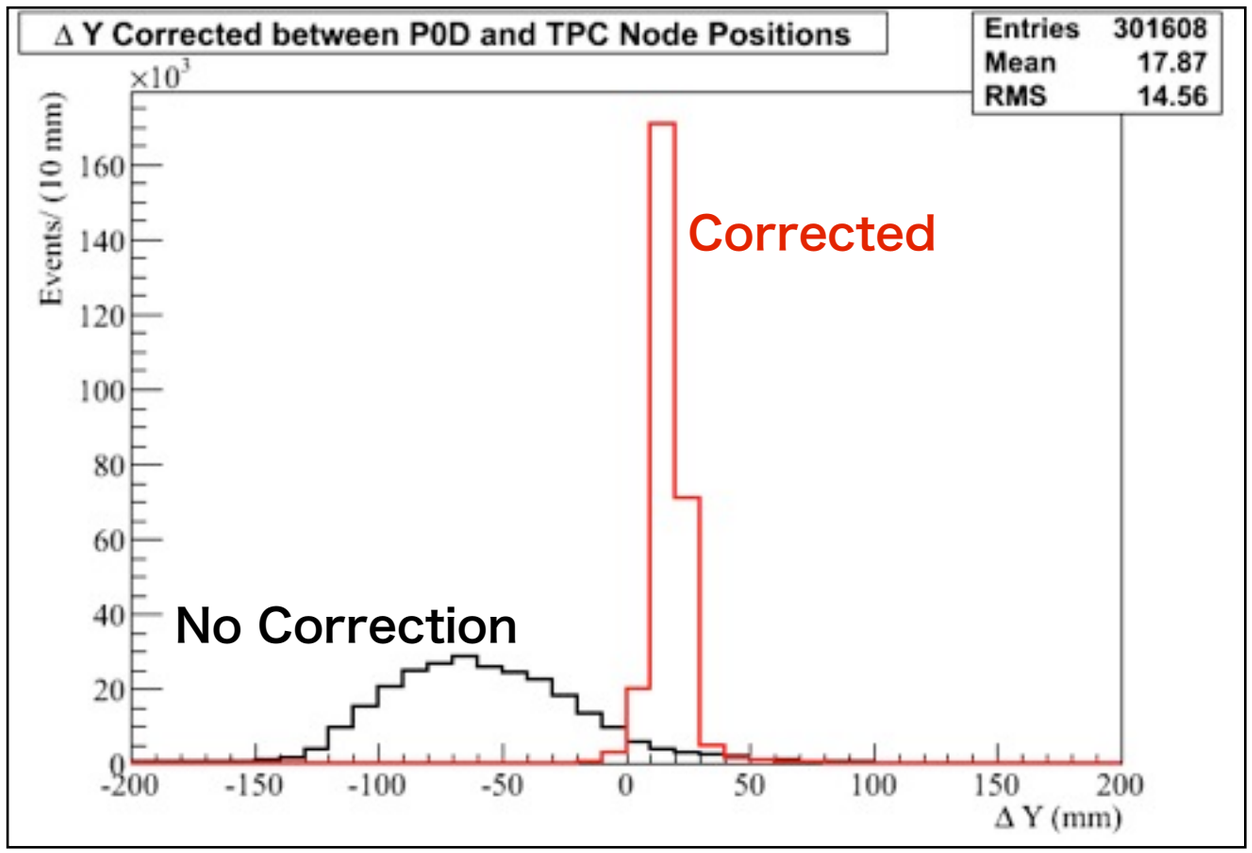
If ΔZ were zero, the two nodes would ideally match pretty well. If ΔZ is not zero, extrapolate from track angle and ΔZ where the matching node would be (do two fits, one for XZ, one for YZ).

Node Position Match

X



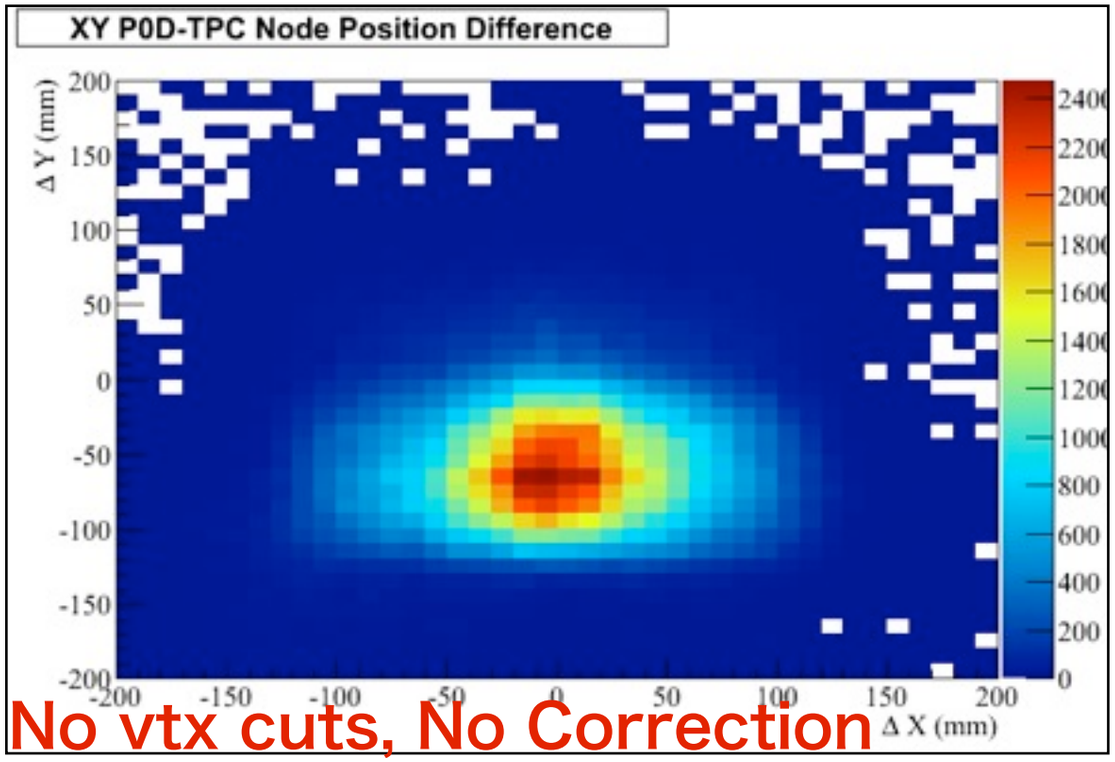
Y



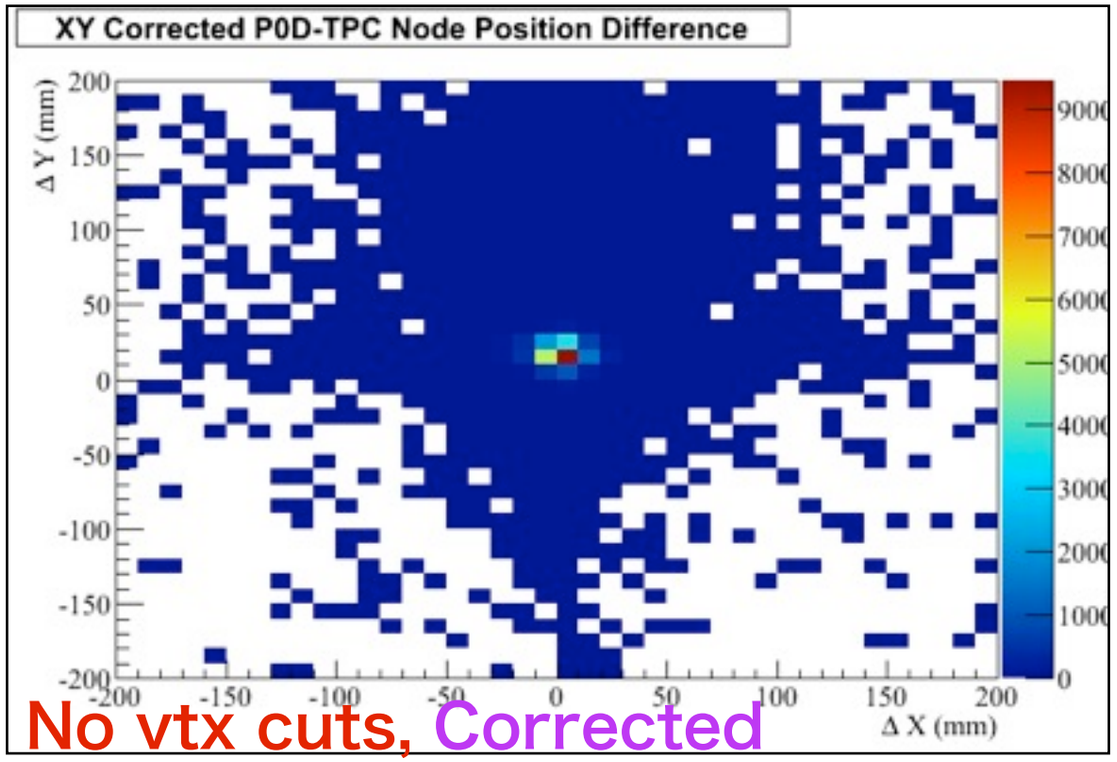
Require: $-50\text{mm} < \Delta X < 50\text{mm}$

$-35\text{mm} < \Delta Y < 65\text{mm}$

Node Position Match



No vtx cuts, No Correction

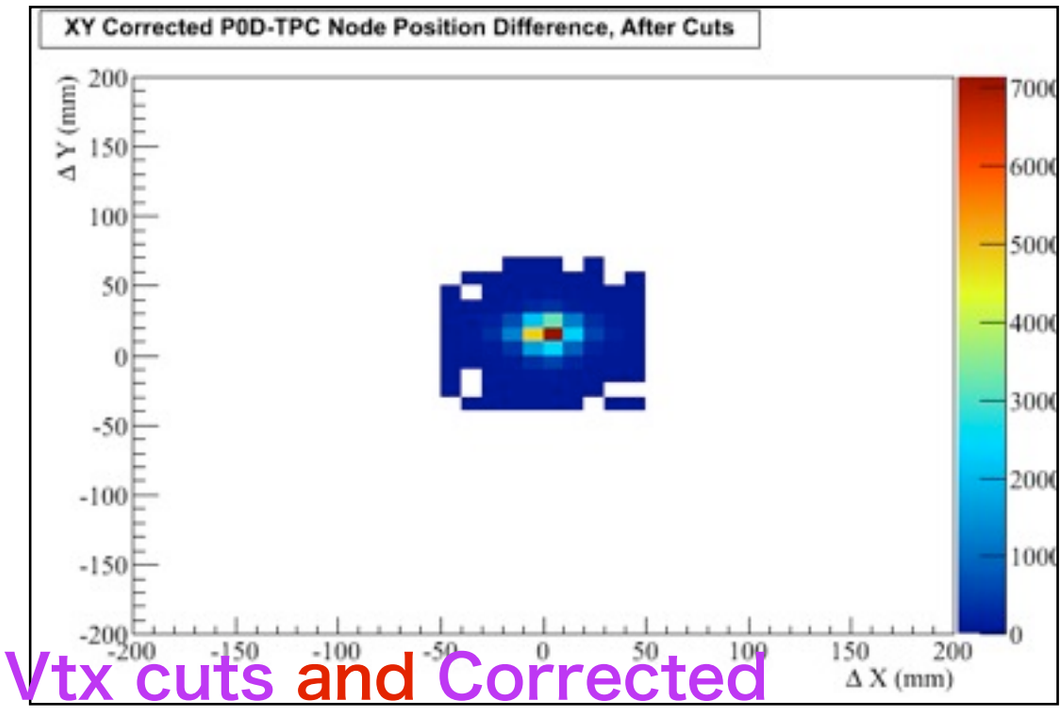


No vtx cuts, Corrected

Require:

$$-50\text{mm} < \Delta X < 50\text{mm}$$

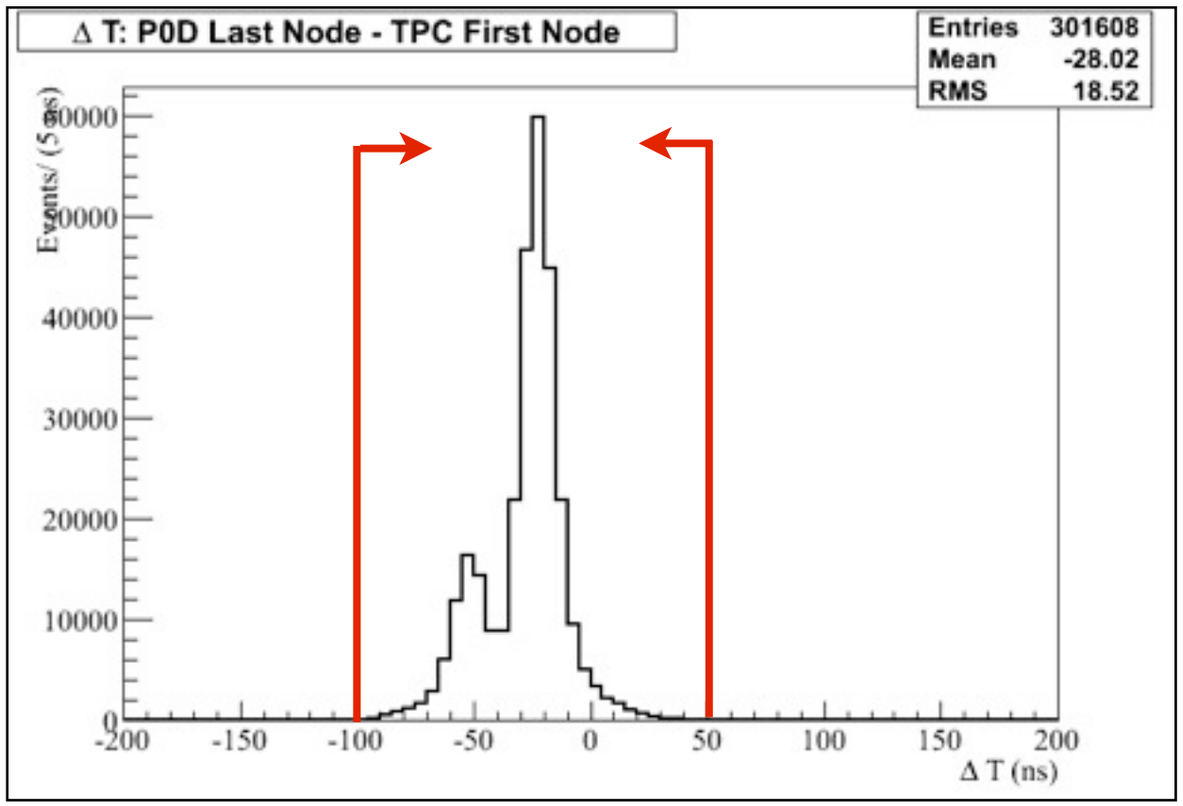
$$-35\text{mm} < \Delta Y < 65\text{mm}$$



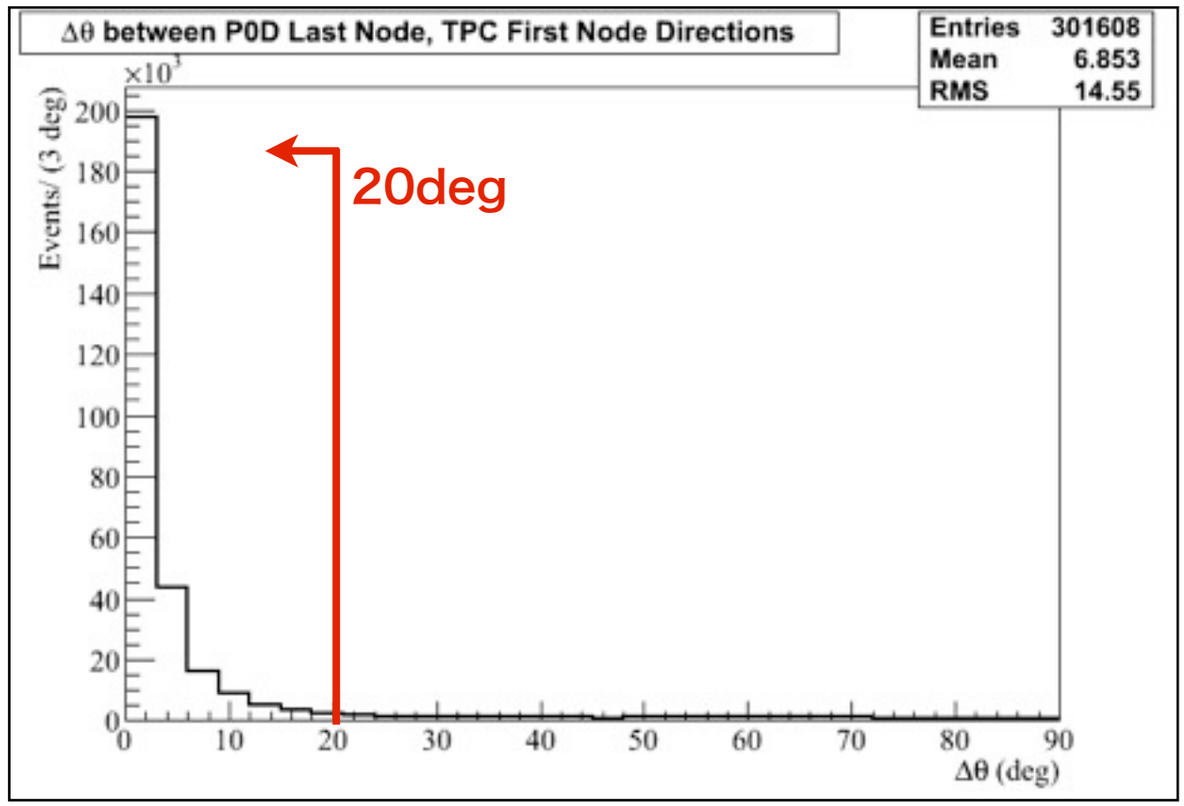
Vtx cuts and Corrected

Timing and Angle

- Timing Between TPC and P0D track



- Angle between direction of matched P0D, TPC nodes



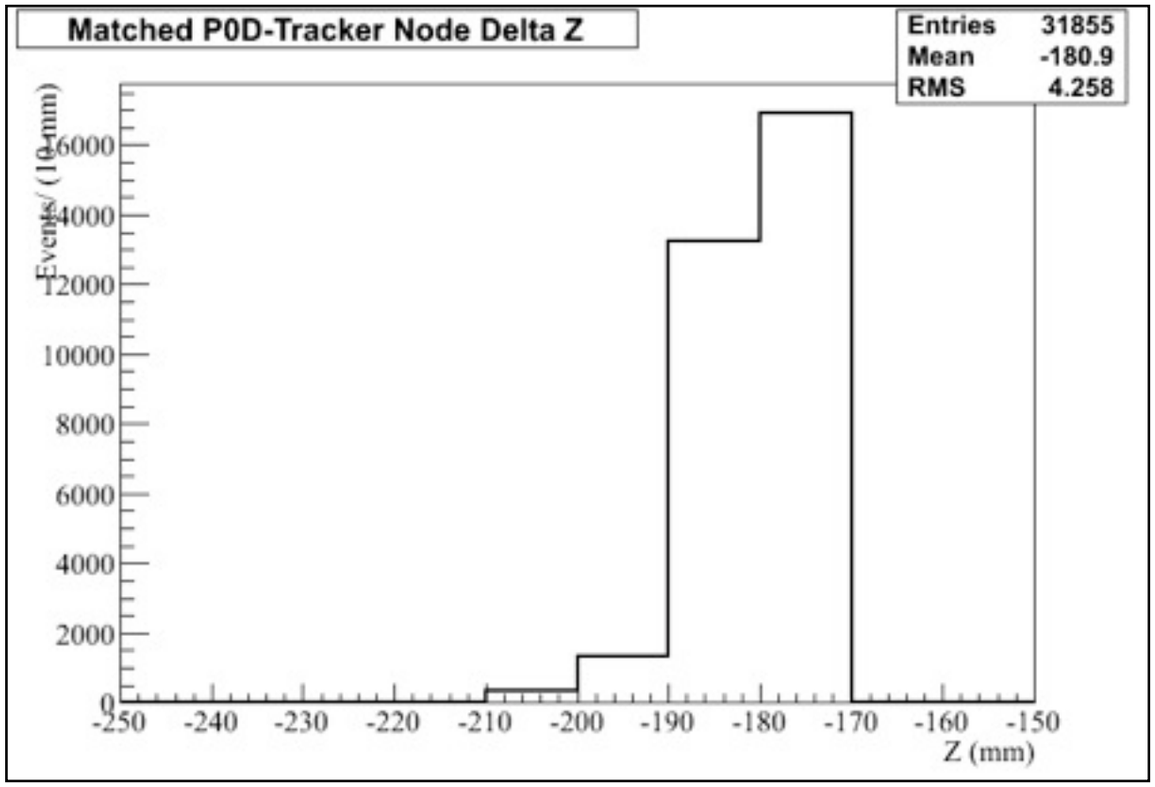
Require:

$-100\text{ns} < \Delta T < 50\text{ns}$

P0D TPC Gap

P0D-TPC Gap

- It seems there is a systematic offset in energy loss and g/cm^2 traversed (will see in a few slides)
- Reconstruction reveals sizable gap between P0D and TPC
- Closer look at geometry information reveals answer



18cm reconstruction, real gap

Cartoon Detector Schematic