Studies of Cosmic Events at ProtoDUNE with PandoraPFA

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Outline

- Updated results switching to the latest LarSoft version
- Preliminary results on analyzing cosmic Runs **[2018/12/14 - 2019/10/11]**
- Summary and on going work

Many thanks to **Tingjun** , who helped selecting and processing, for this study. one cosmic run per month (from **2018/12/14** to **2019/10/11**), with the release v08_27_01

Updated results and improvements with beam Run 5387 processed with LarSoft v08_27_01

See previous presentation with older reconstruction release (v07_08_00_03)

https://indico.fnal.gov/event/22149/

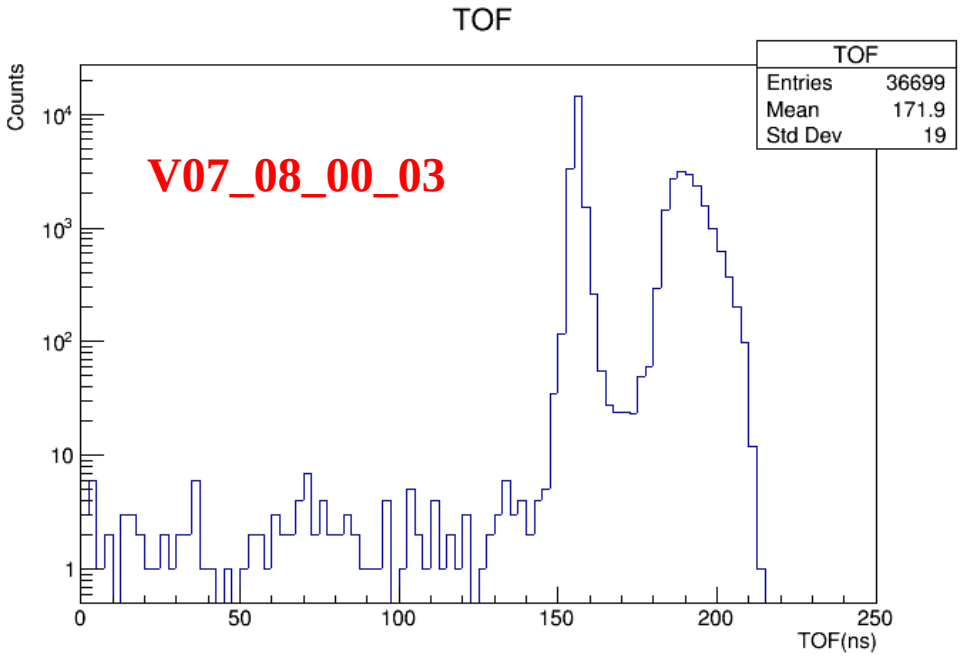
Summary of Event Information

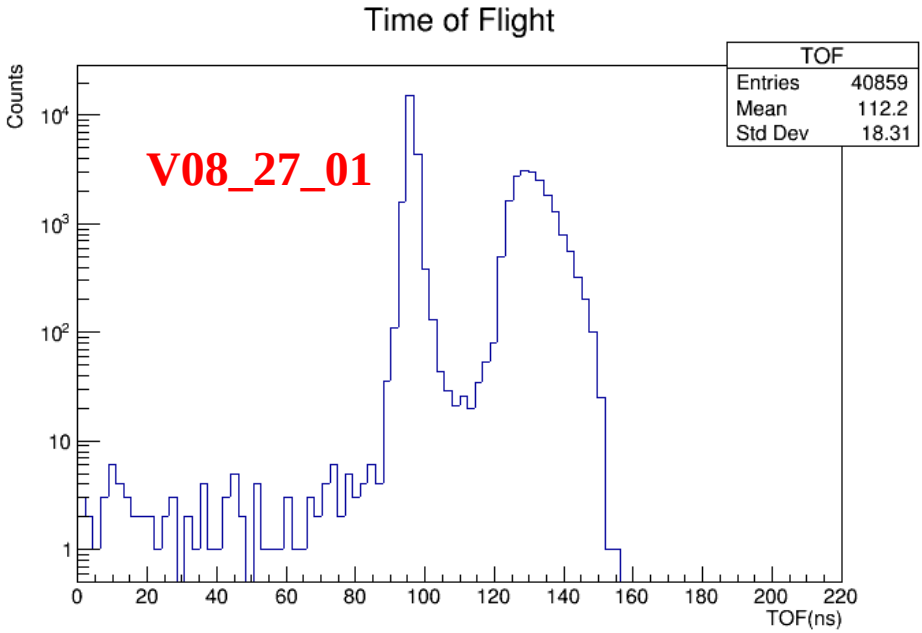
For the run 5387 which has 126.384 events

Processed 119.752 events, ie 97% (918 files) of the run

	OLD	NEW
ANALYZED EVENTS	123.377 events	*119.752 events*
Beam_Event & Matched	27.401 (22,21% ± 0,13%)	31.794 (26,55% ± 0,14%)
Beam_Event & ! Matched	9.030 (7,32% ± 0,08%)	5.554 (4,64% ± 0,06%)
! Beam_Event & Matched	12.056 (9,77% ± 0,09%)	12.125 (10,13% ± 0,09%)
! Beam_Event & ! Matched	74.890 (60,70% ± 0,22%)	70.279 (58,69% ± 0,22%)

TIME OF FLIGHT

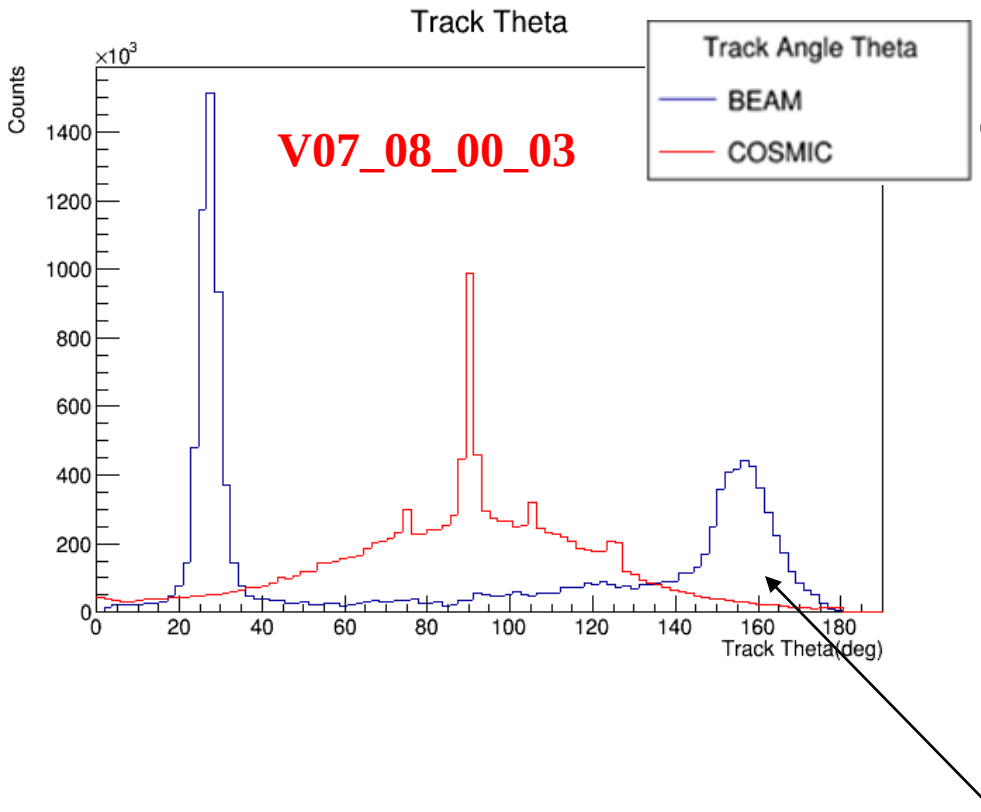


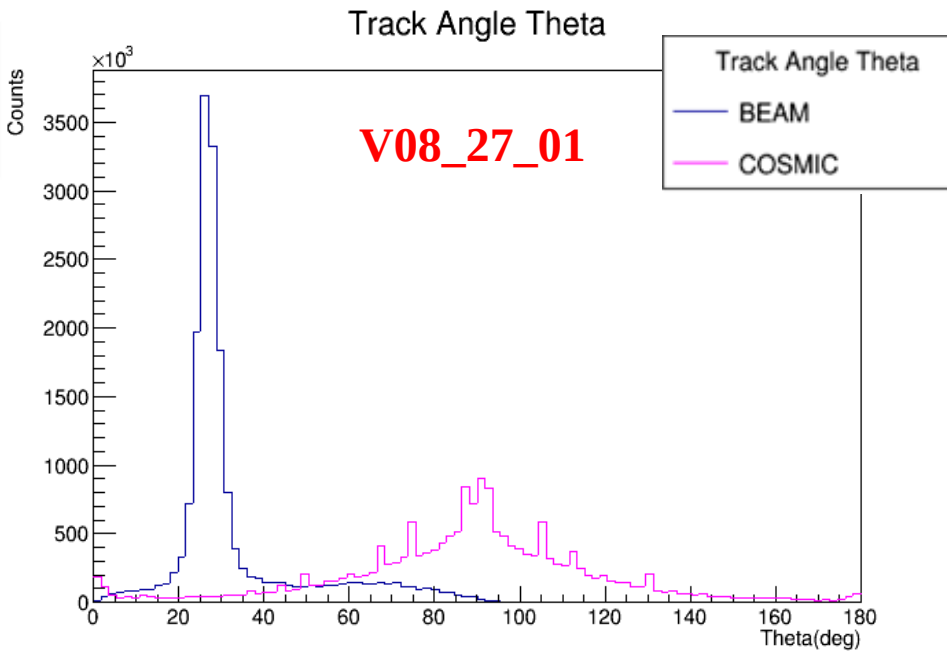


ftof	196.805
ftof_expElec	95.316
ftof_expMuon	95.9468
ftof_expPion	96.414
ftof_expKaon	108.255
ftof_expProt	136.38
ftof_expDeut	230.007

- With new reconstruction TOF values in agreement with expectations!

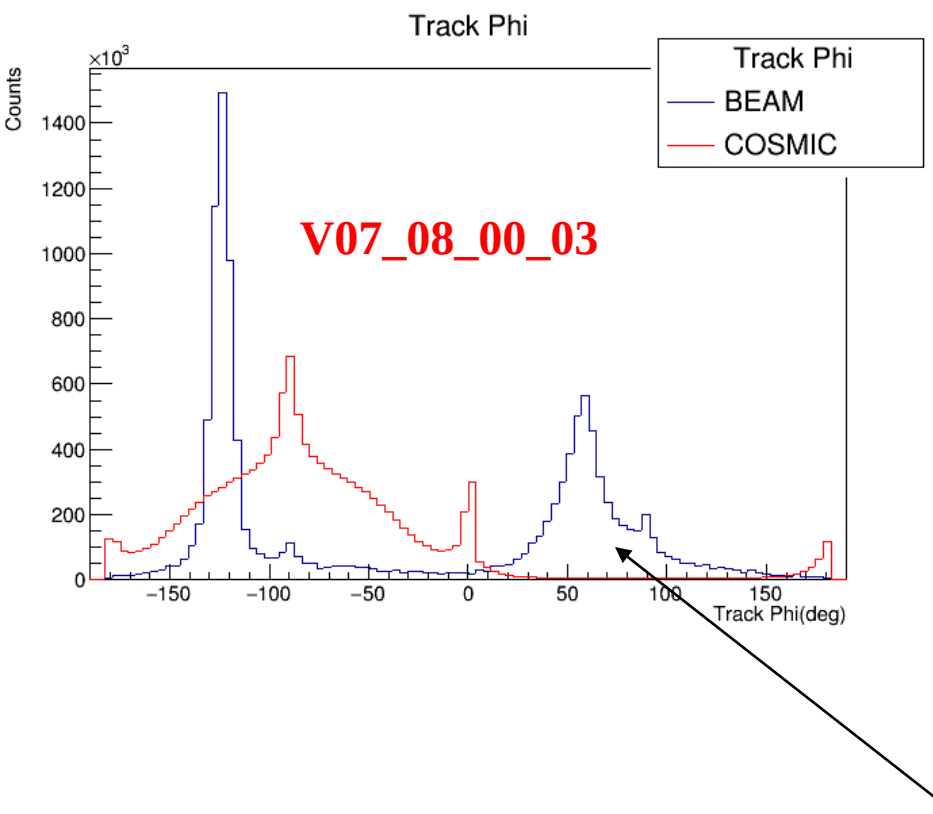
TRACK THETA

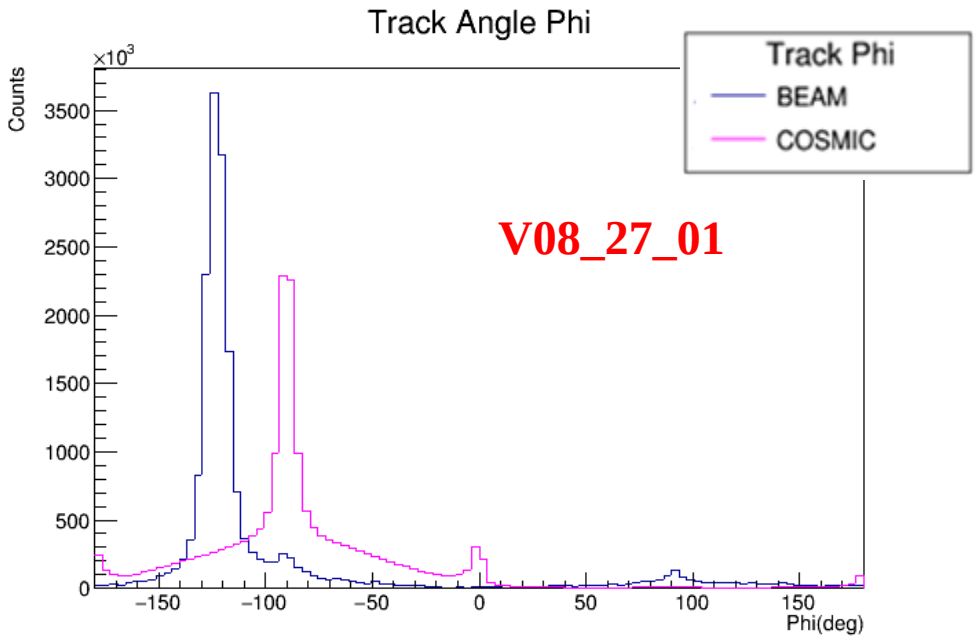




- With new reconstruction beam particles are not reconstructed “backwards” any more.

TRACK PHI





- With new reconstruction beam particles are not reconstructed “backwards” any more.

Analysis of Cosmic Data

Summary of event type vs time

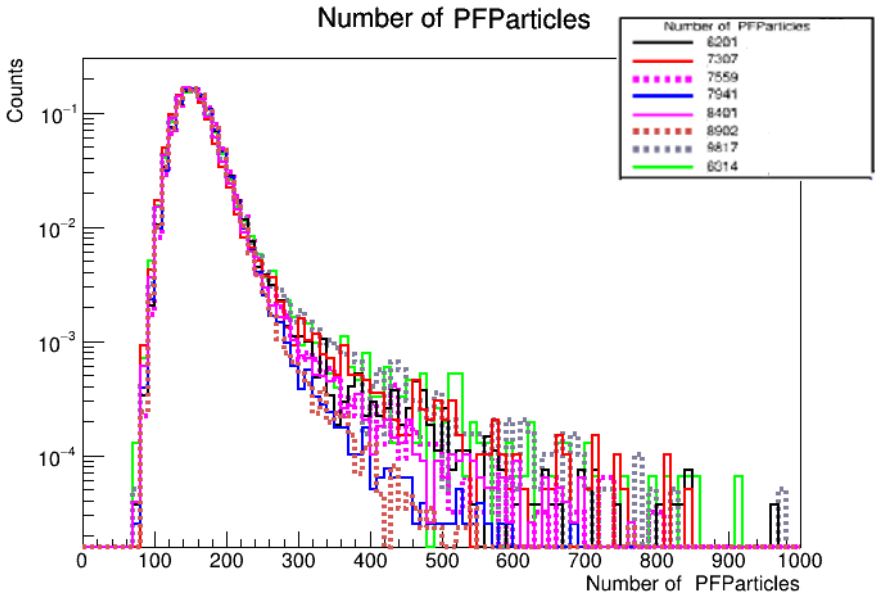
Run	6201	6314	7307	7559	7941	8401	8902	9817
Events	39.694	29.279	25.297	35.708	85.740	99.908	91.970	24.177
Analyzed Events	27.206 68,5% ± 0,4%	15.461 52,8% ± 0,4%	19.581 77,4% ± 0,6%	31.688 88,7% ±0,5%	79.532 92,8% ± 0,3%	78.025 78,10% ± 0,28%	87.141 94,7% ± 0,3%	19.811 81,9% ± 0,6%
Beam Event=0	**25.339 93,1% ± 0,6%**	**14.472 93,6% ± 0,4%**	**18.474 94,3% ± 0,7%**	**29.393 92,8% ± 0,5%**	**74.206 93,3% ± 0,3%**	**72.888 93,4% ± 0,3%**	**81.341 93,3% ± 0,3%**	**18.486 93,3% ± 0,7%**
Beam Event=1	**1.867 6,86% ± 0,16%**	**989 6,40% ± 0,20%**	**1.107 5,65% ± 0,17%**	**2.295 7,24% ± 0,15%**	**5.326 6,70% ± 0,09%**	**5.137 6,58% ± 0,09%**	**5.800 6,66% ± 0,08%**	**1.325 6,69% ± 0,18%**
Date	2018/12/14	2019/1/14	2019/3/25	2019/4/11	2019/5/21	2019/6/19	2019/7/17	2019/10/11

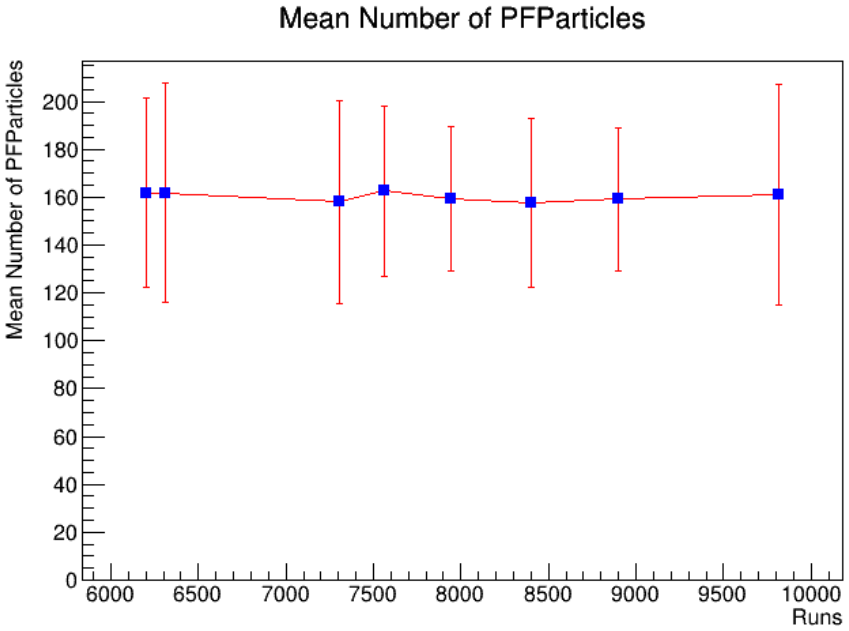
- Percentage of cosmic particle stable vs time
- Percentage of "wrongly" characterized beam particles is rather low (6%-7%) and also stable vs time.

Aug and Sept 2019 are missing because of low argon purity

****Events ,**which had reconstructed beam Pfparticles ,are characterized as **Beam_Event=1** (otherwise **Beam_Event=0**)

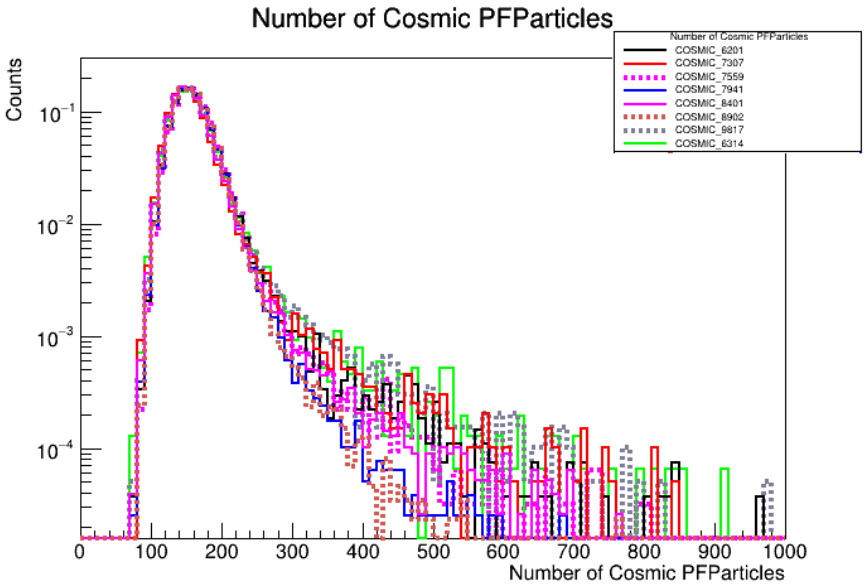
PFParticles per Event

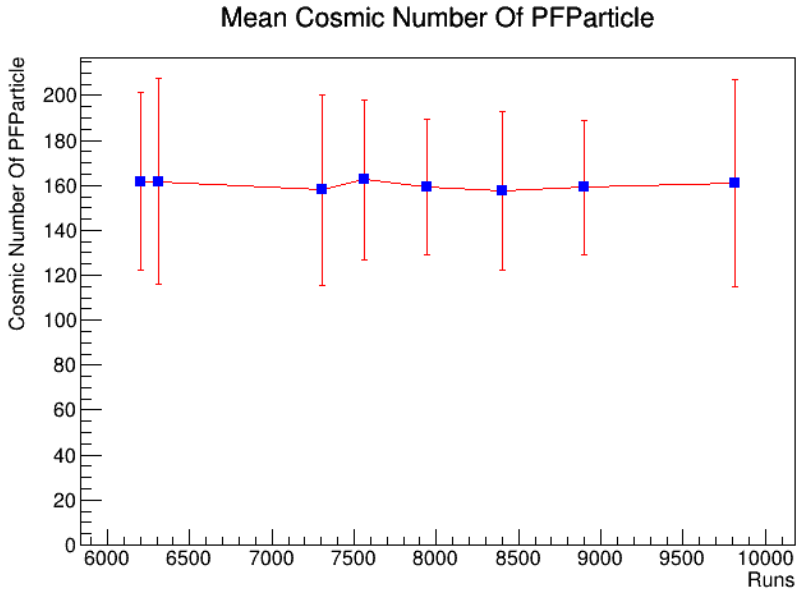




- Mean number of PFparticles per event is stable within its uncertainty.
- Will look into tails in more detail (introducing variable bin size histograms)

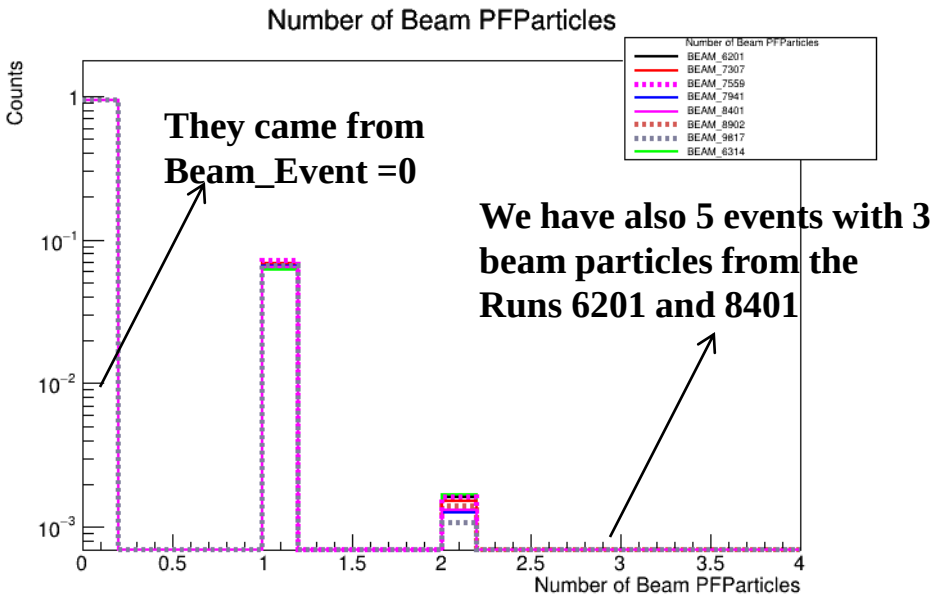
Cosmic PFParticles per Event

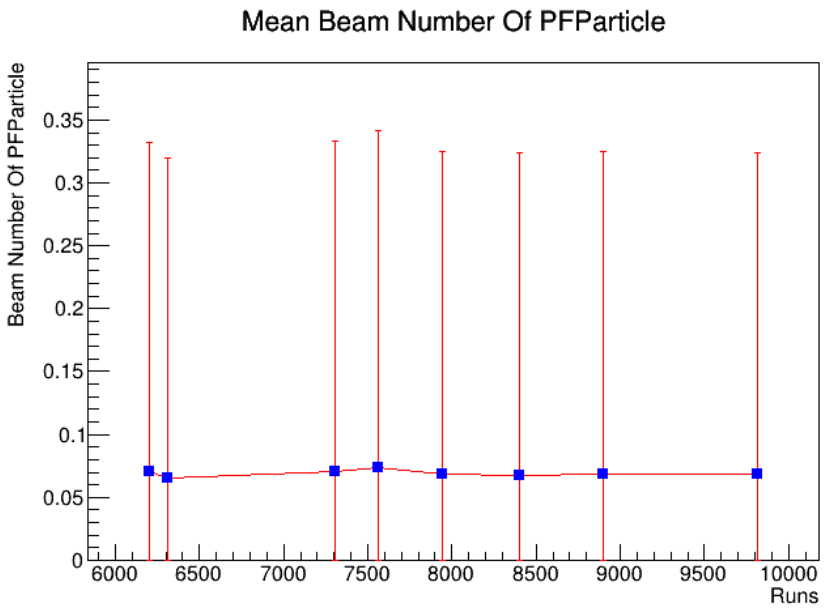




- Mean number of cosmic muons per event is stable within its uncertainty.
- Will look into tails in more detail (introducing variable bin size histograms)

“Beam” PFParticles per Event

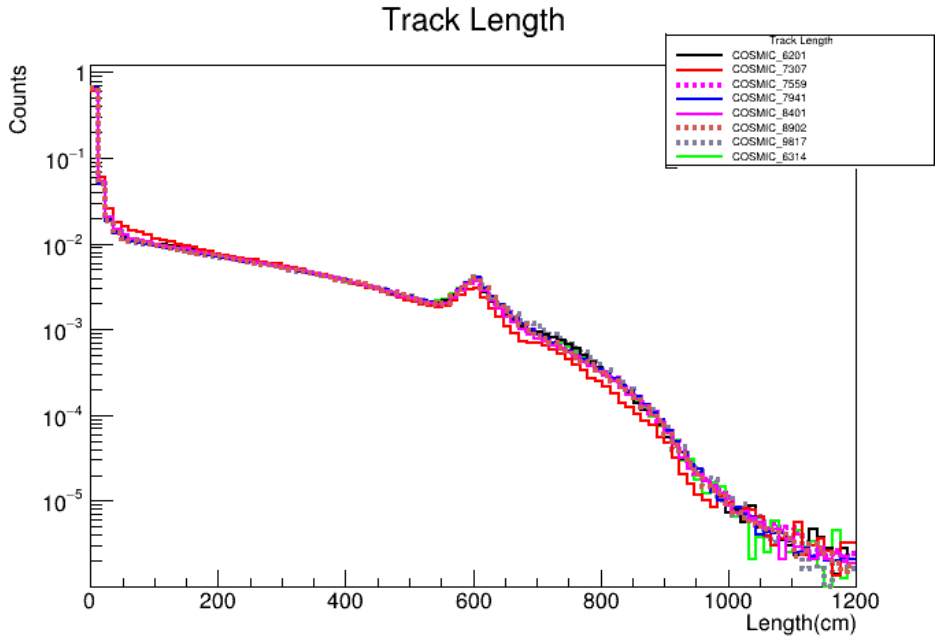


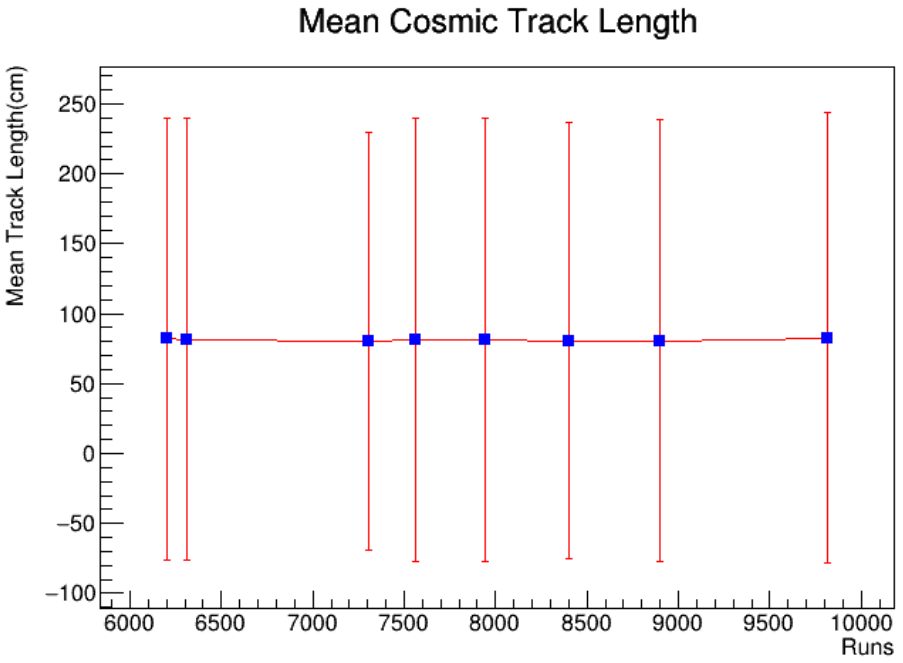


- Mean number of “beam” particles per event is stable and close to zero.

- Will investigate more what kinds of events those are, and why they are characterized as “beam” particles: Looking at the corresponding quantities for those, **shown in later slides**, it seems like more “horizontal” tracks and showers are characterized as beam related.

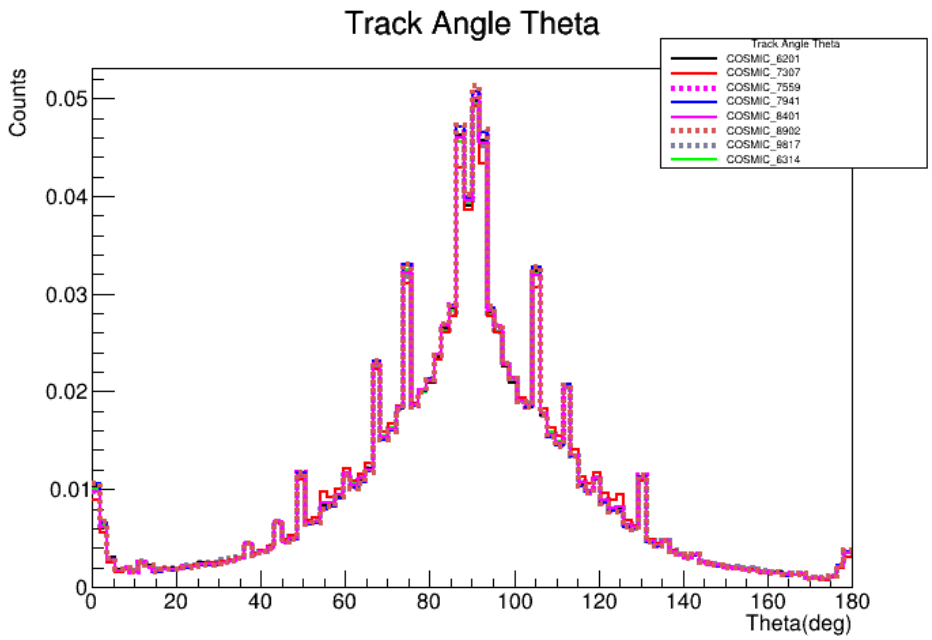
Cosmic Track Length

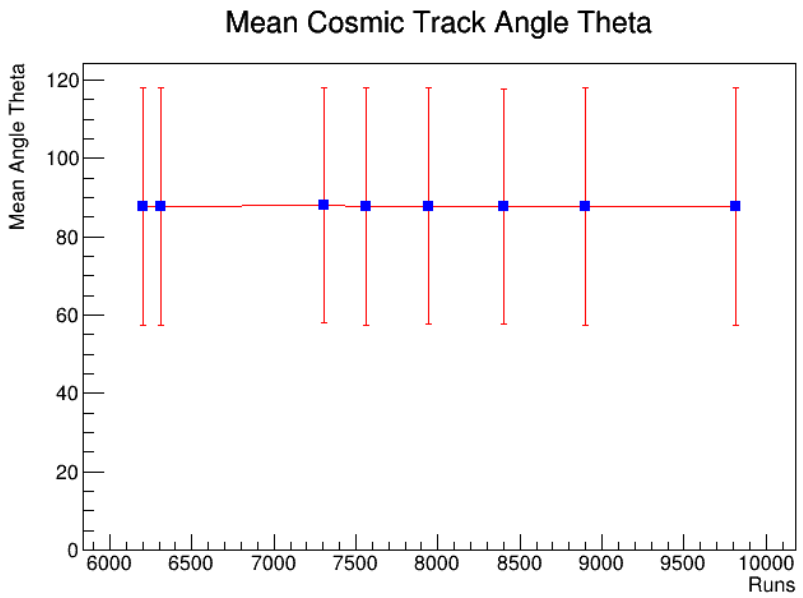




- Cosmic muons track length per event is stable as a function of time

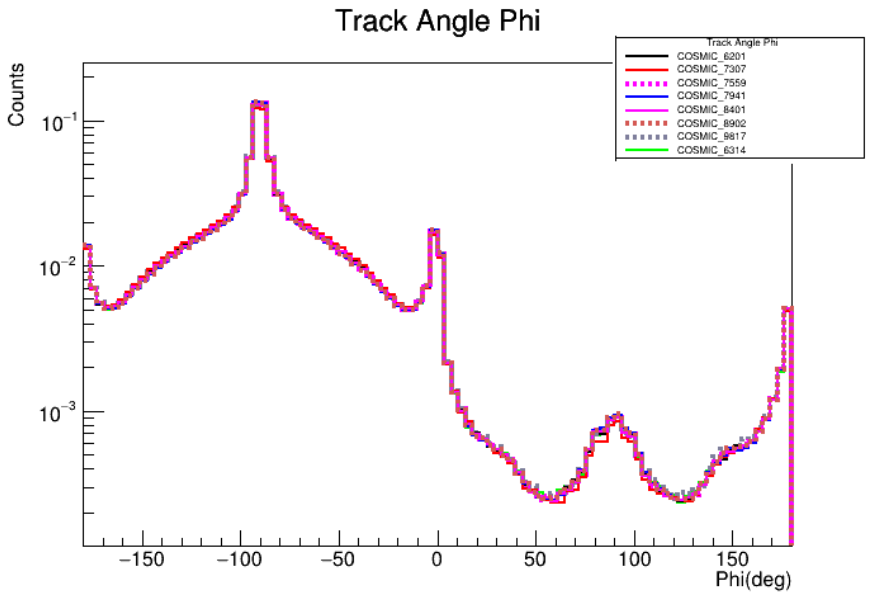
Cosmic Track Angle Theta

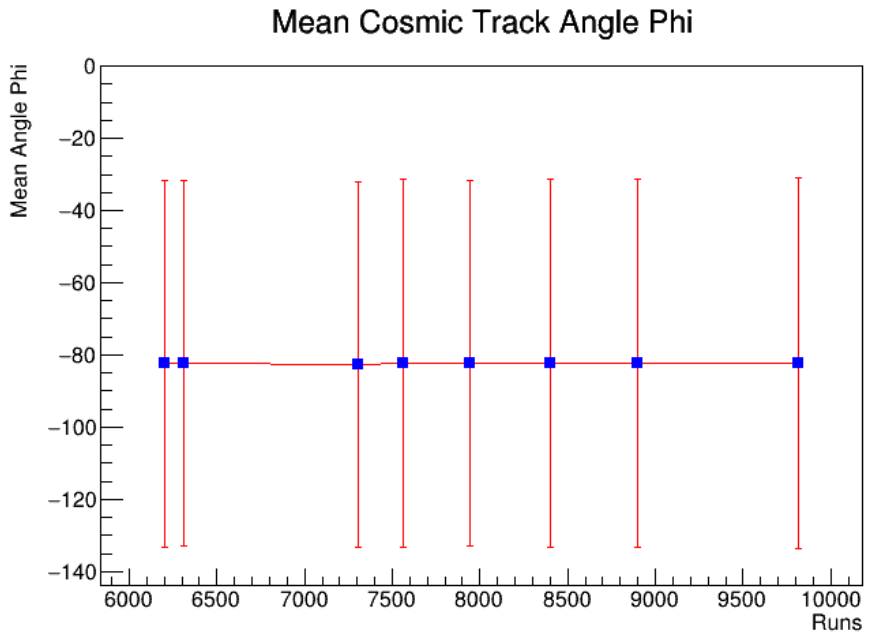


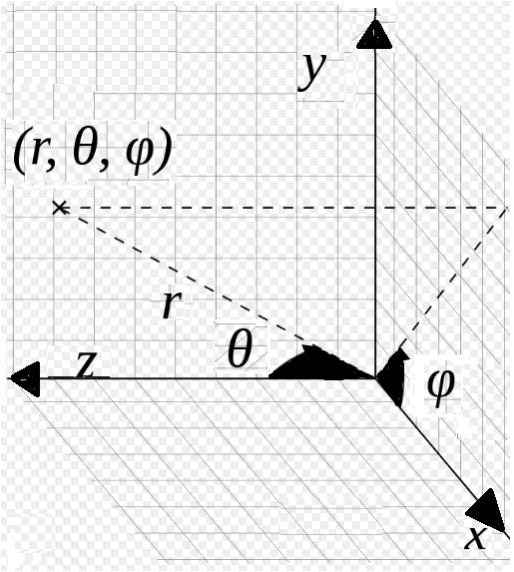


- Cosmic muons track theta is stable as a function of time

Cosmic Track Angle Phi

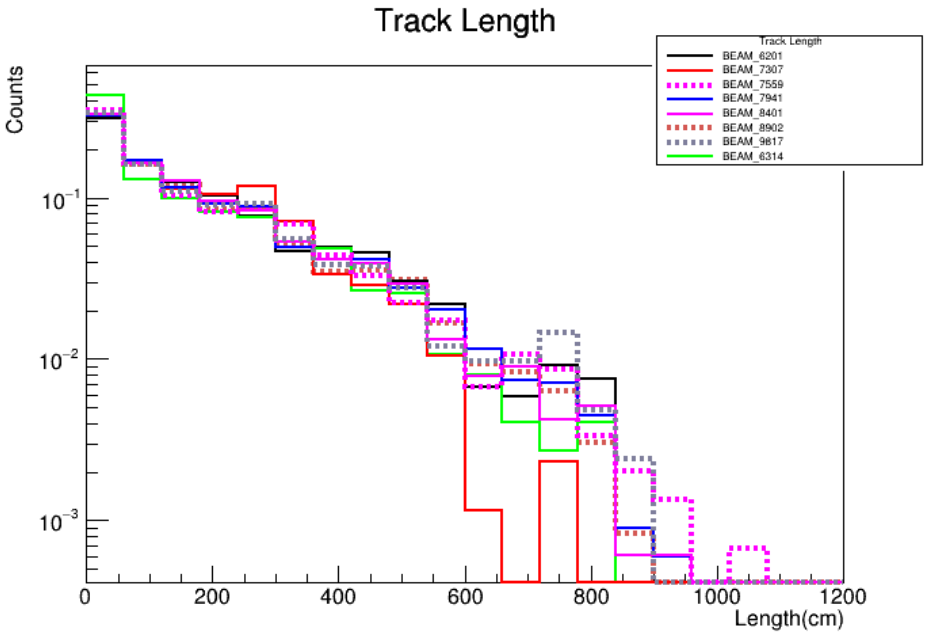


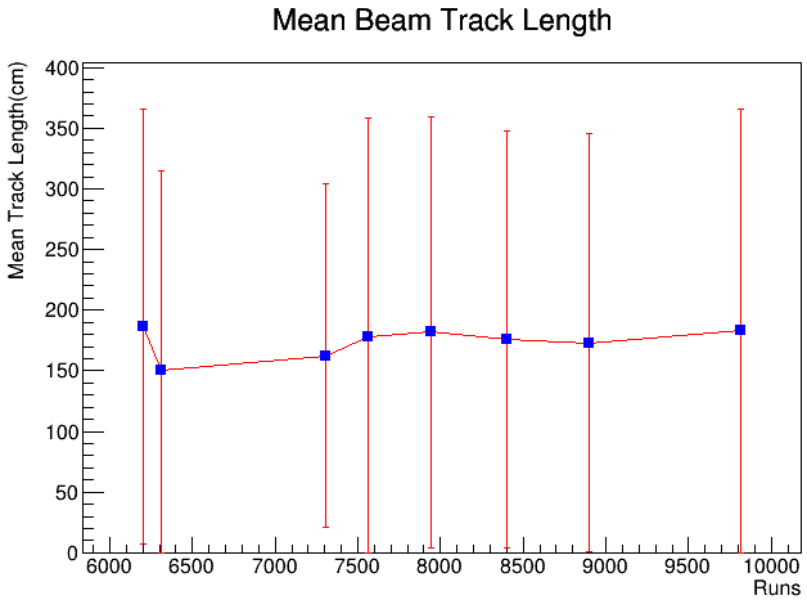




- Cosmic muons track phi is stable as a function of time.
- We do see “upward” going muons as well.

”Beam” Track Length

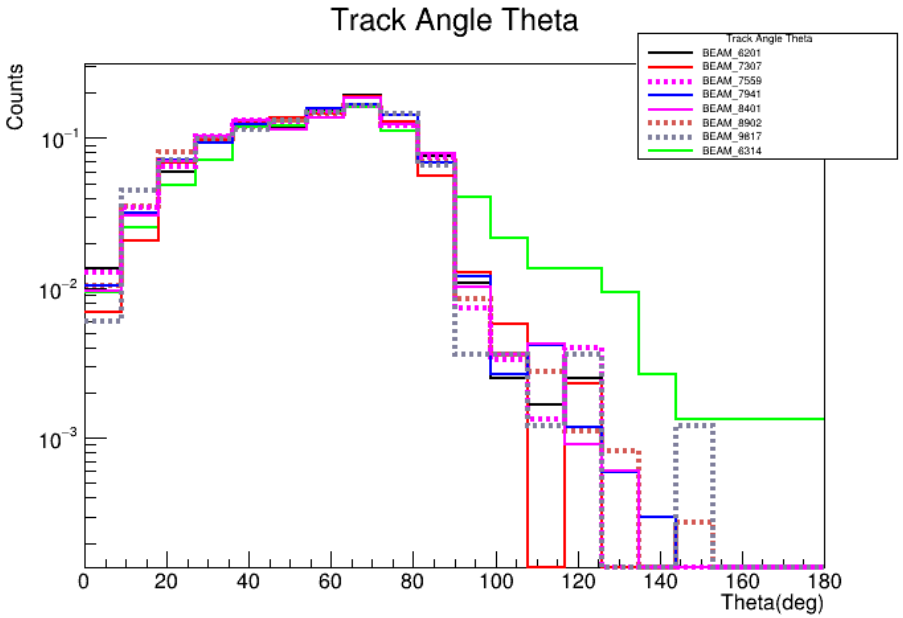


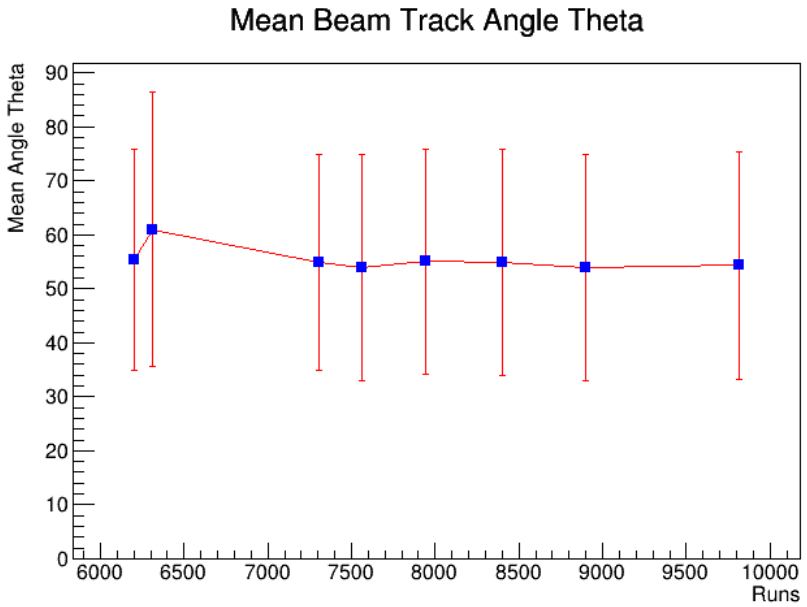


- Track length of “beam” particles is stable vs time and much larger than the cosmic one.

- Will investigate more what kind of events those are, but it seems like more “horizontal” and longer tracks are characterized as “beam induced”.

“Beam” Track Angle Theta

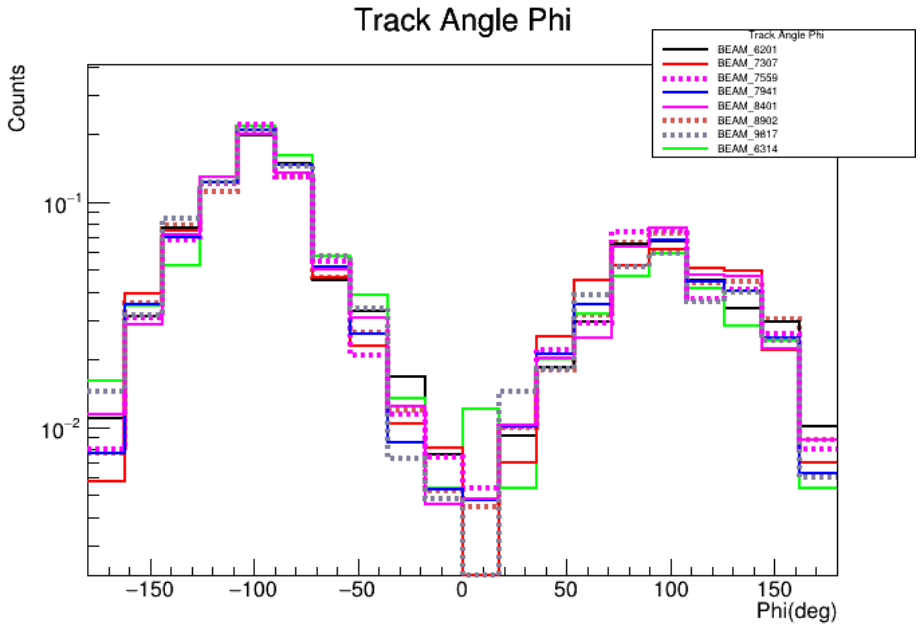


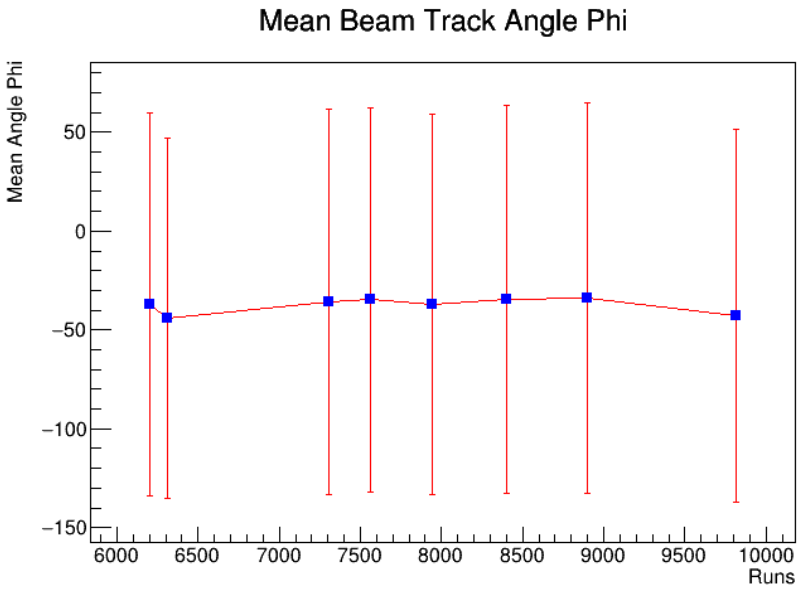


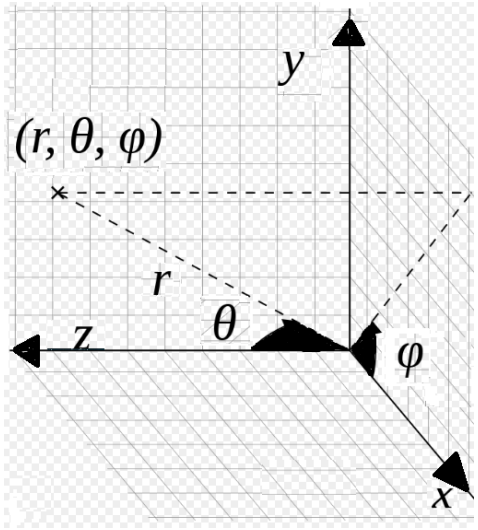
- Track angle theta of “beam” particles is stable vs time and smaller than the 90^{o} it is for cosmics.

- Run 6314 shows some longer tail compared to the others, and would like to understand why.

“Beam” Track Angle Phi

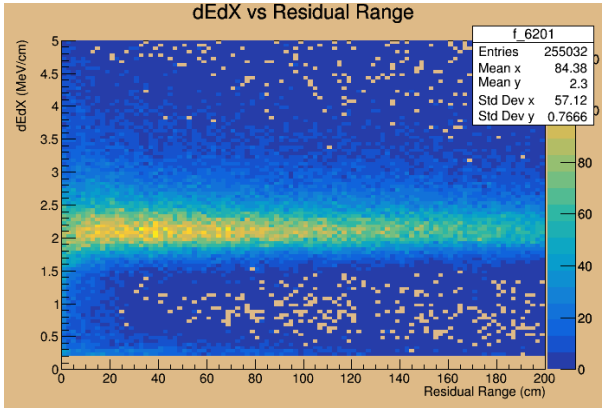


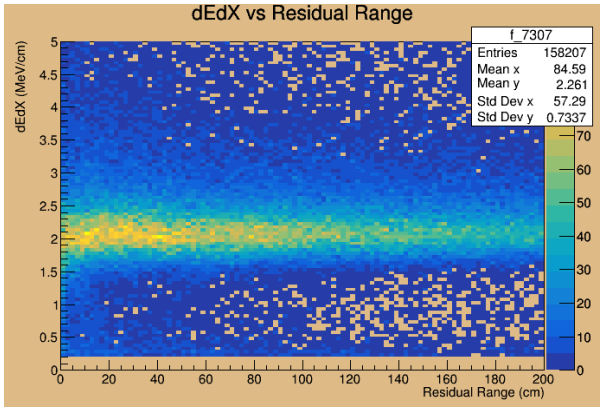


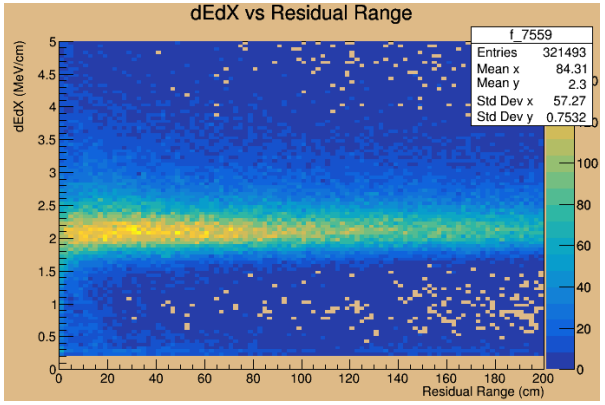


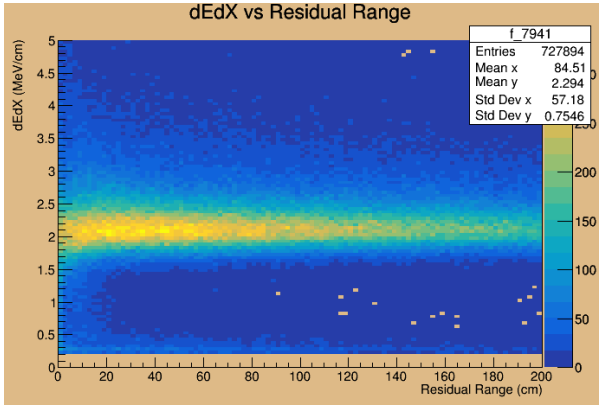
- Track angle phi of “beam” particles is stable vs time and almost positive-negative symmetric

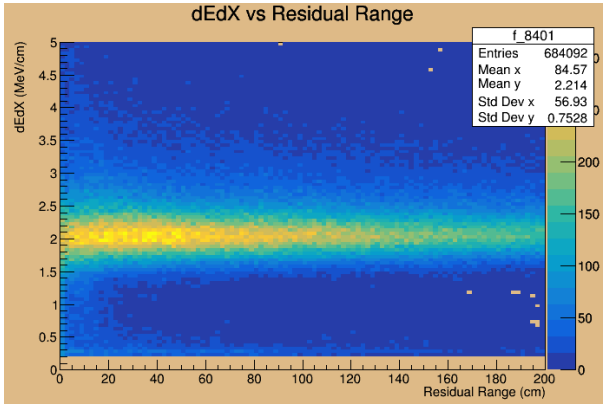
dE/dx vs Residual Range

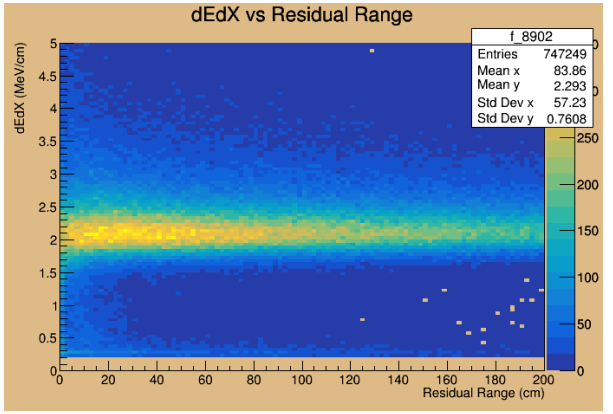


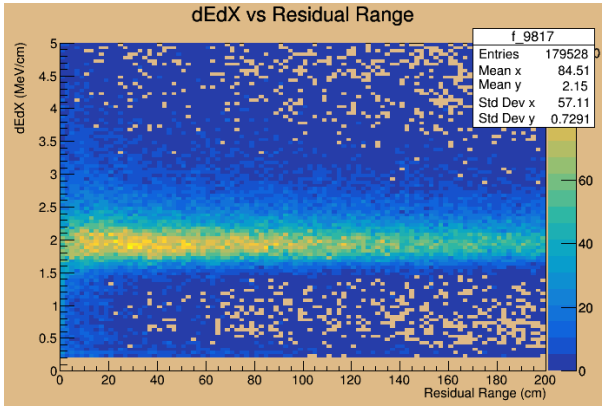


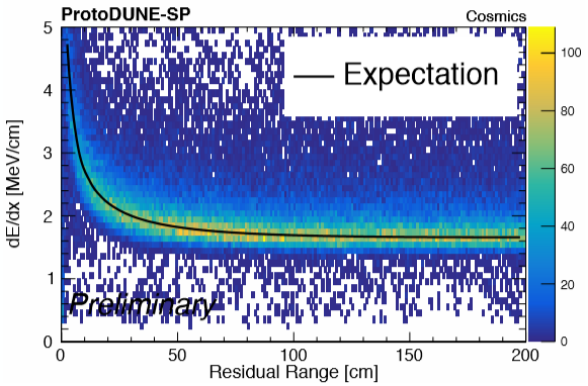








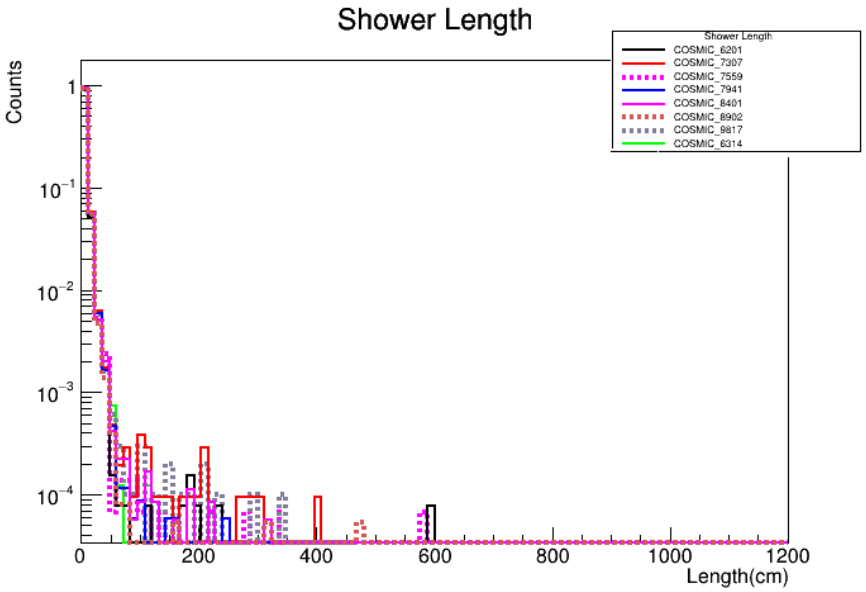


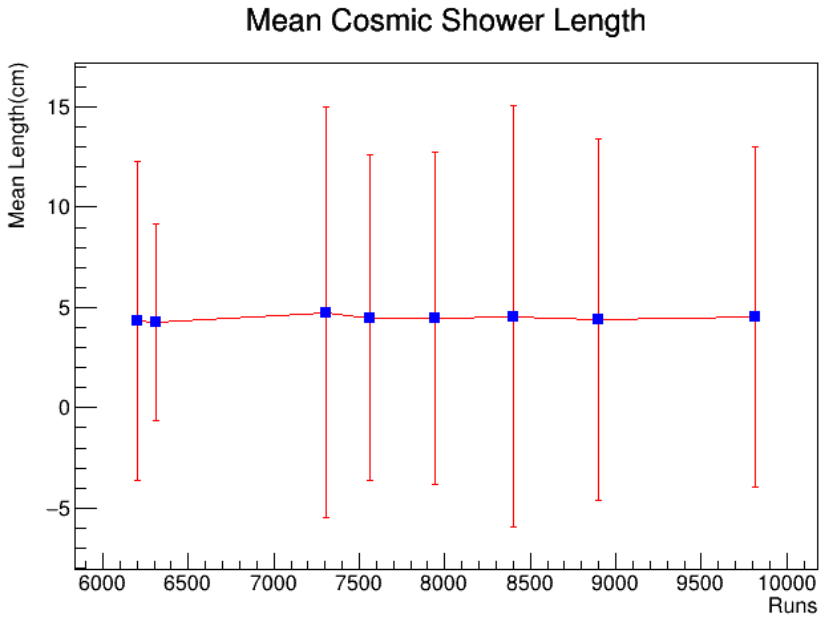


20th International Workshop on Next Generation Nucleon Decay and Neutrinos Detector

https://indico.cern.ch/event/835190/contributions/3576901/attachments/1942058/3220554/protodune_nnn19_higuera.pdf

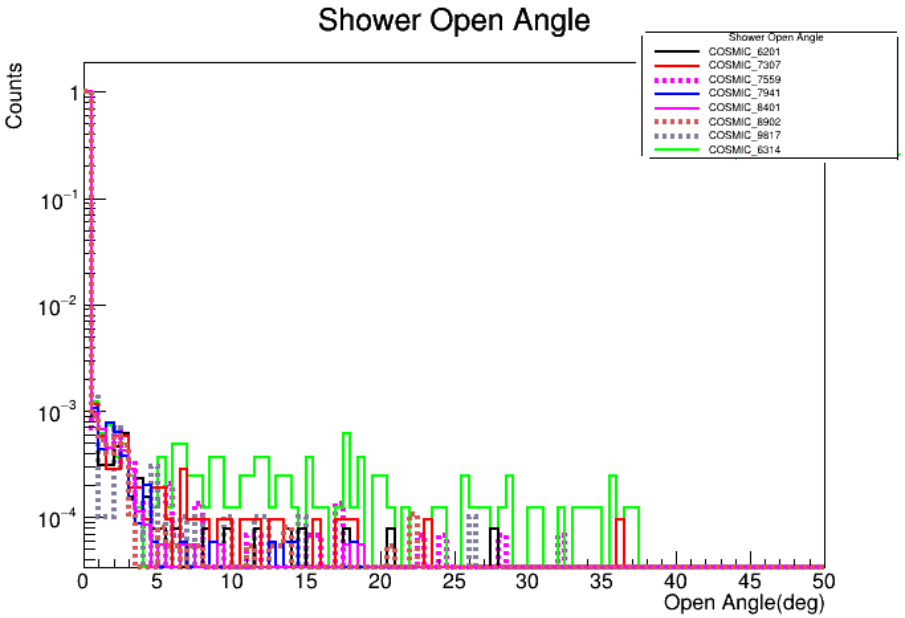
Cosmic Shower Length

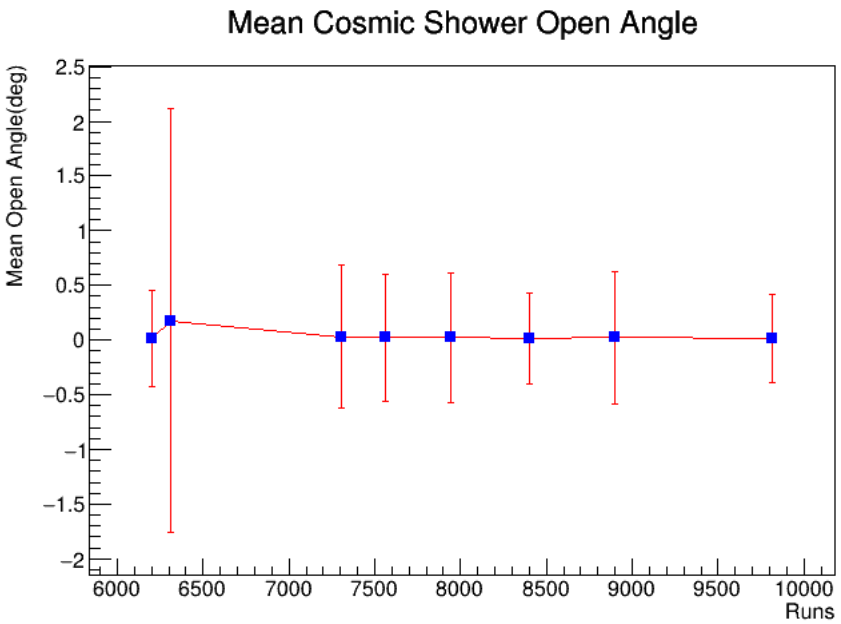




- Showers induced by cosmic muons have a length that is stable as a function of time

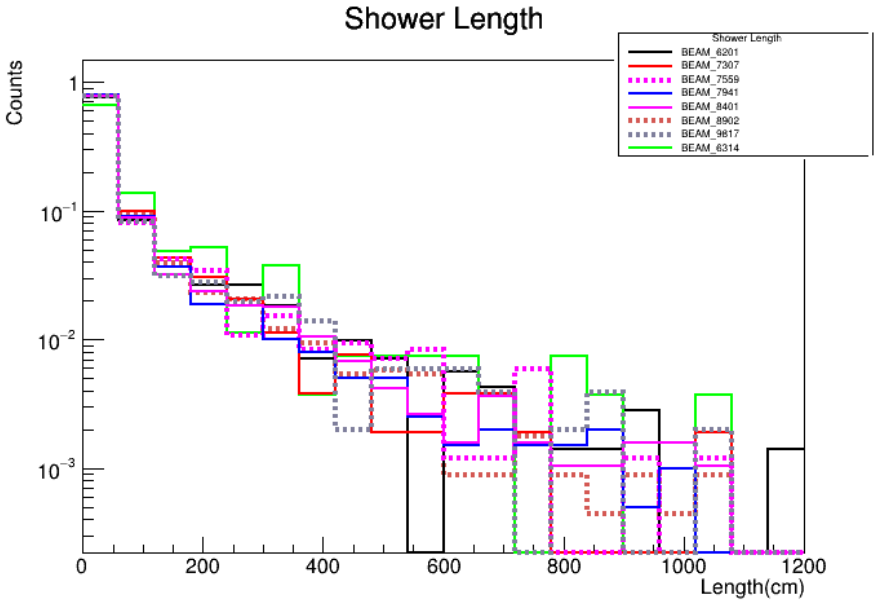
Cosmic Shower Open Angle

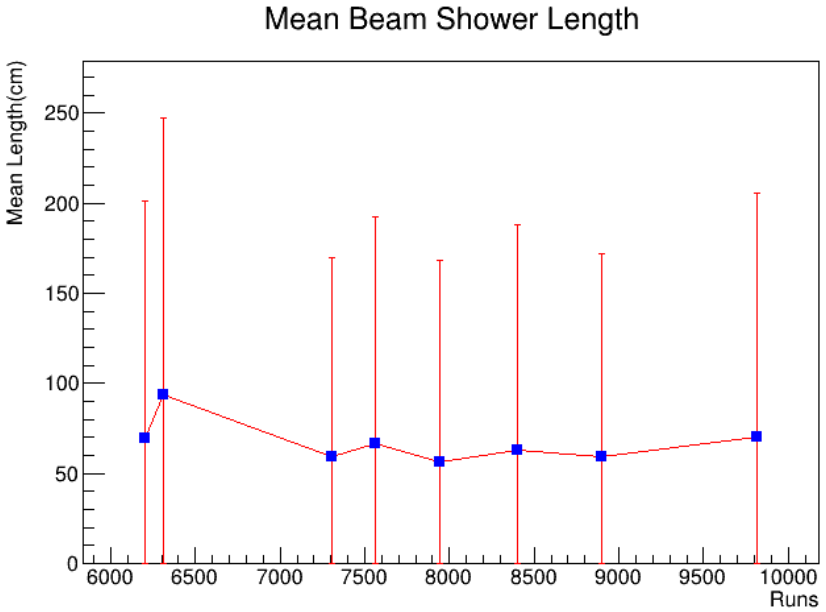




- Shower open angle also stable vs time
- Run 6314 shows some longer tail compared to the others, and would like to understand why (will investigate, ideas are welcome). This is also seen in the track theta angle.

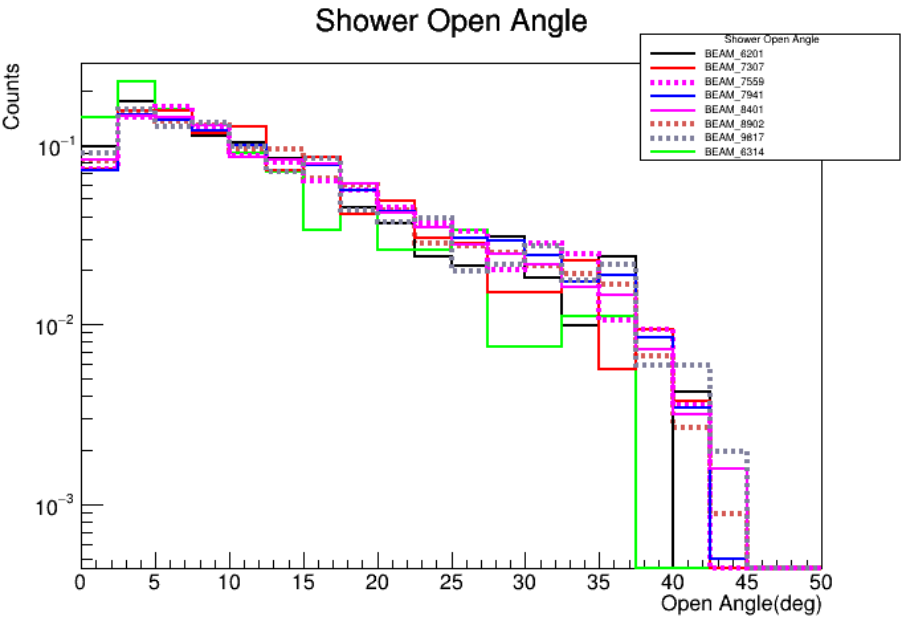
”Beam” Shower Length

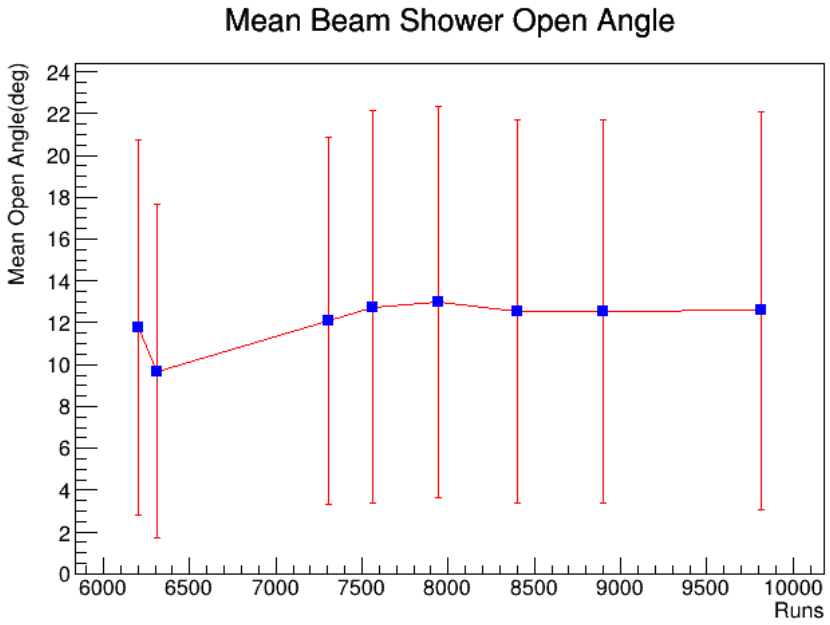




- Mean shower length stable within its uncertainty and much larger than the cosmic one.

“Beam” Shower Open Angle



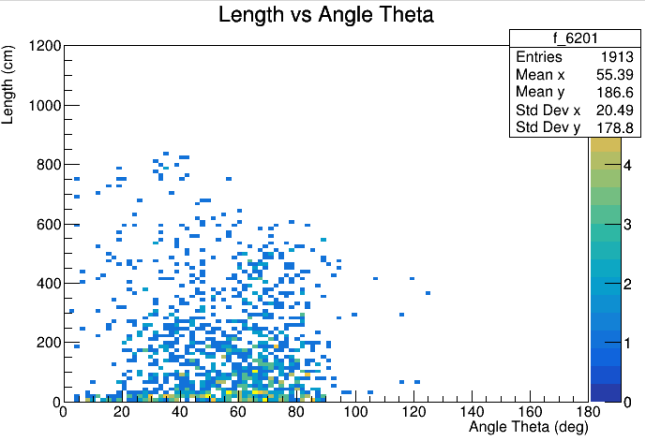


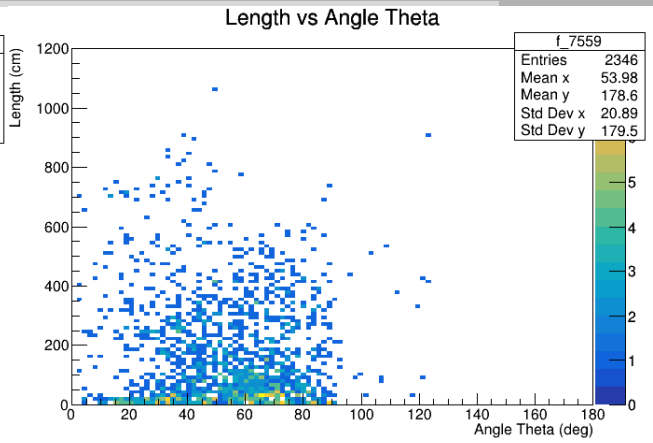
- Shower open angle of “beam” particles is stable vs time and much larger than the cosmic one.

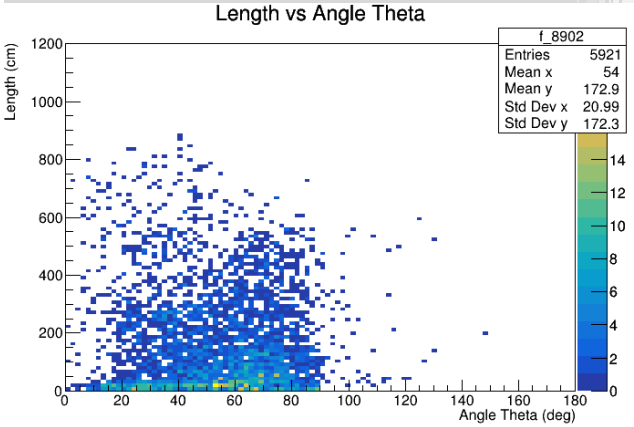
Summary

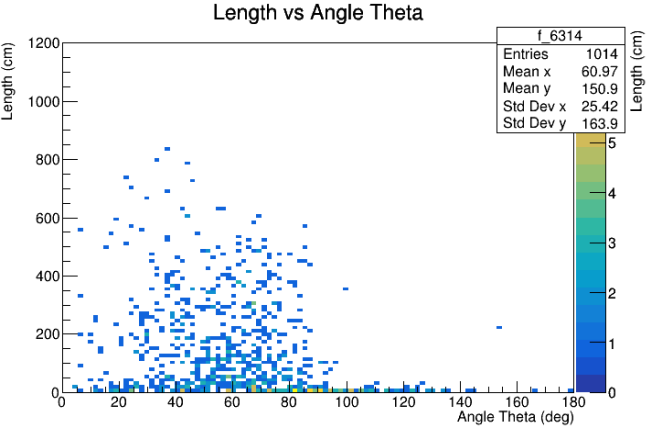
- Updated results studying beam events (Run 5387) with latest LarSoft released, show significant improvements.
- Preliminary studies of the characteristics of cosmic events as a function of time, indicate detector and reconstruction performance is stable.
- We will further investigate run 6314 and analyze/study more cosmic runs if they exist.
- Any suggestions, comments, corrections would be more than welcome !

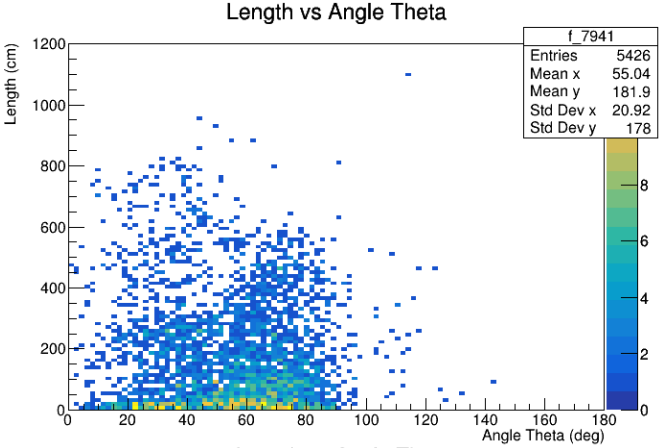
BACK UP

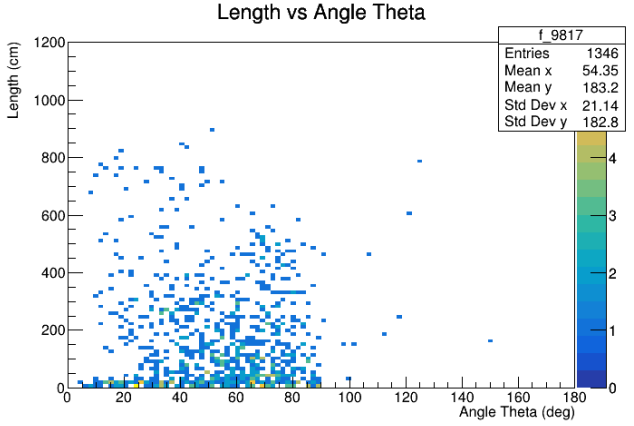

Length vs Angle Theta
f_6201
Entries 1913
Mean x 55.39
Mean y 186.6
Std Dev x 20.49
Std Dev y 178.8
Length (cm)
Angle Theta (deg)

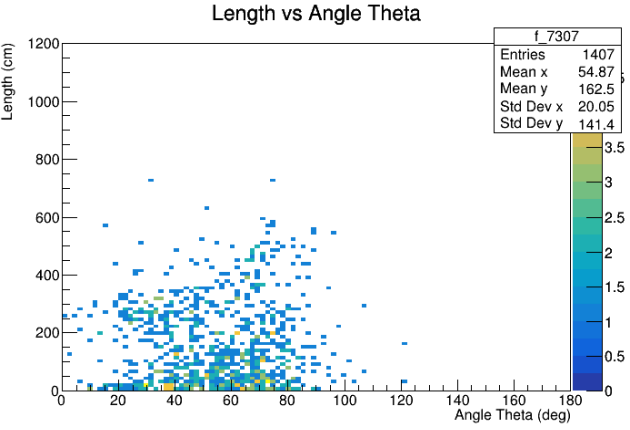

Length vs Angle Theta
f_7559
Entries 2346
Mean x 53.98
Mean y 178.6
Std Dev x 20.89
Std Dev y 179.5
Length (cm)
Angle Theta (deg)

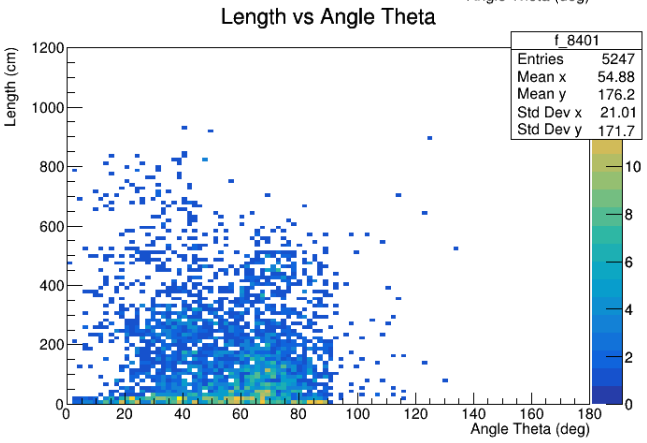

Length vs Angle Theta
f_8902
Entries 5921
Mean x 54
Mean y 172.9
Std Dev x 20.99
Std Dev y 172.3
Length (cm)
Angle Theta (deg)


Length vs Angle Theta
f_6314
Entries 1014
Mean x 60.97
Mean y 150.9
Std Dev x 25.42
Std Dev y 163.9
Length (cm)
Angle Theta (deg)


Length vs Angle Theta
f_7941
Entries 5426
Mean x 55.04
Mean y 181.9
Std Dev x 20.92
Std Dev y 178
Length (cm)
Angle Theta (deg)


Length vs Angle Theta
f_9817
Entries 1346
Mean x 54.35
Mean y 183.2
Std Dev x 21.14
Std Dev y 182.8
Length (cm)
Angle Theta (deg)


Length vs Angle Theta
f_7307
Entries 1407
Mean x 54.87
Mean y 162.5
Std Dev x 20.05
Std Dev y 141.4
Length (cm)
Angle Theta (deg)


Length vs Angle Theta
f_8401
Entries 5247
Mean x 54.88
Mean y 176.2
Std Dev x 21.01
Std Dev y 171.7
Length (cm)
Angle Theta (deg)

```
rtException:  PostEndJob 07-Nov-2019 08:09:24 CST ModuleEndJob
eption caught in art
erArt BEGIN
ventProcessorFailure BEGIN
tProcessor: an exception occurred during current event processing
 EventProcessorFailure BEGIN
dPathExecutor: an exception occurred during current event processing
-- ScheduleExecutionFailure BEGIN
Path: ProcessingStopped.
---- ProductNotFound BEGIN
  getByLabel: Found zero products matching all criteria
  Looking for type: std::vector<recob::PFParticle>
  Looking for module label: pandora
  Looking for productInstanceName:
  cet::exception going through module MyProtoDUNETestAnalyzer/myana run: 5387 subRun: 1 event: 121454
---- ProductNotFound END
Exception going through path end_path
-- ScheduleExecutionFailure END
 EventProcessorFailure END
ventProcessorFailure END
erArt END
```