ProtoDUNE DD Generator Test: First Result

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SOUTH DAKOTA MINES
An engineering, science and technology university

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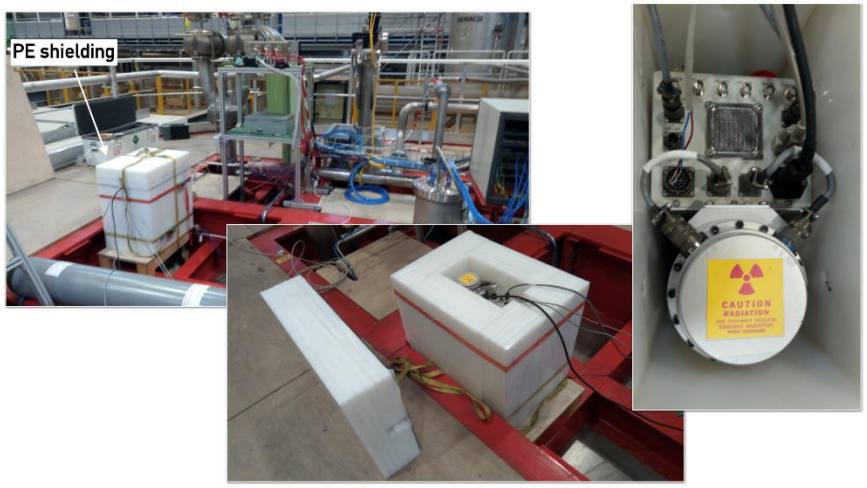
DDG Test at ProtoDUNE-SP

- DD generator test was done at ProtoDUNE-SP in July 2020
- Main goal:
  - Verify neutron transport model and help develop neutron capture analysis algorithms.
  - Gain experience on DD generator operation/shielding and data acquisition with liquid argon TPC.



PNS Grp: UCDavis, LANL + CERN

Limitations of the Test

- **Neutron generator:** the minimum pulsed rate of the LANL DD generator is 200 Hz, which is higher than that the DAQ can handle
- **Source location:** the source location (roof feedthrough) was practical but not ideal, which results in limited neutron capture yield (about a factor of 4 less than that of the beam plug location)
- **Shield:** there was no gamma shield due to technical reasons. The neutron capture signals may have contamination from 2.2 MeV gammas
- **Cosmic background:** the neutron capture signals may be overwhelmed by cosmic ray activities.

Data Taking

- Ten days of data taking with different trigger modes and neutron intensities

- Force trigger mode:
  - DDG ON, E=650 V/cm, 2 Hz random trigger
  - DDG OFF, E=650 V/cm, 2 Hz random trigger
  - DDG ON, E=350 V/cm, 5 Hz random trigger
  - DDG OFF, E=350 V/cm, 5 Hz random trigger

- Pulsed trigger mode:
  - DDG ON, E=350 V/cm, 5% duty cycle, ~175 μs pulse width, ~4 Hz
  - DDG ON, E=0 V/cm, 5% duty cycle, ~175 μs pulse width, ~4 Hz

Quick Hit-Rate Analysis

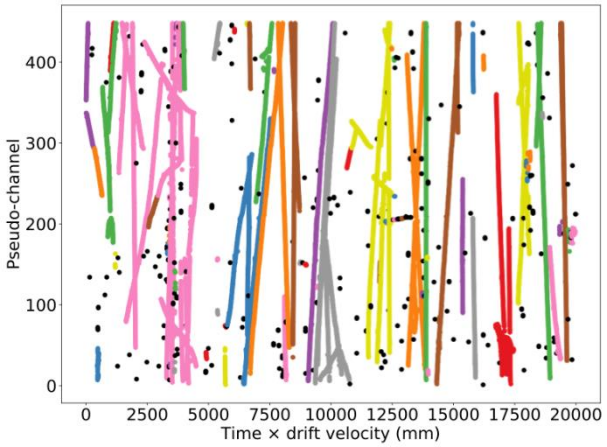
- DD generator was located on top of APA 5.
- Compare collection channel hits for DD generator on and off data
  - Use the clustering algorithm DBSCAN to find clustered hits forming tracks
  - Neutrons are expected to leave unclustered and isolated hits.
  - Identify hits on tracks and the rest could be neutrons (or 39-Ar, or EM spray from cosmics)
- Clear evidence of neutron-induced hits when the neutron source is on
- Overall hit rate APA 5 increases by ~7% when neutron source on

see P. Rodrigues' talk at the operation meeting

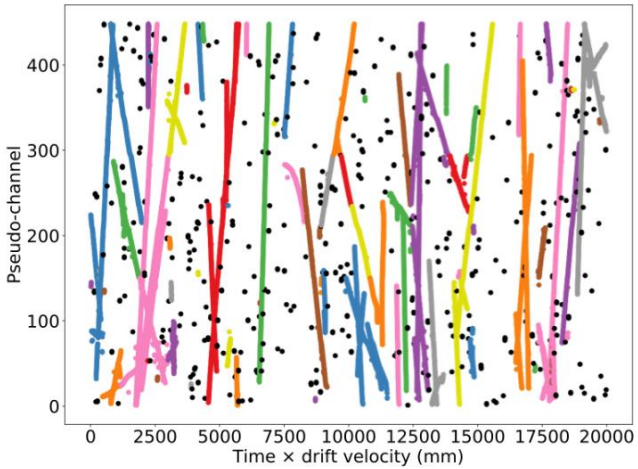
Philip Rodrigues: http://www-pnp.physics.ox.ac.uk/~rodrigues/protodune-neutron-source-2020-07-14.pdf

Quick Hit-Rate Analysis

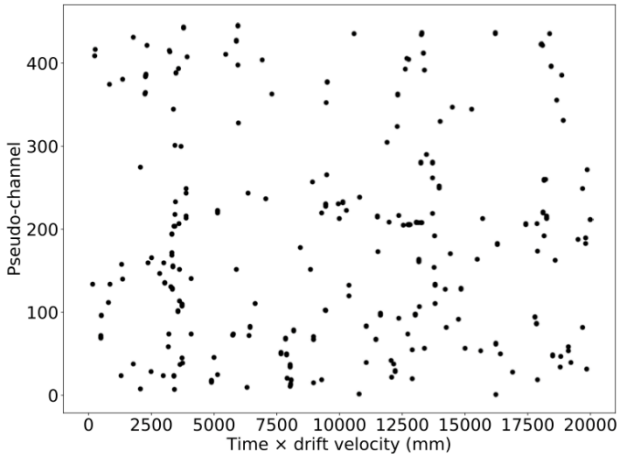
DBSCAN example. Neutron source off



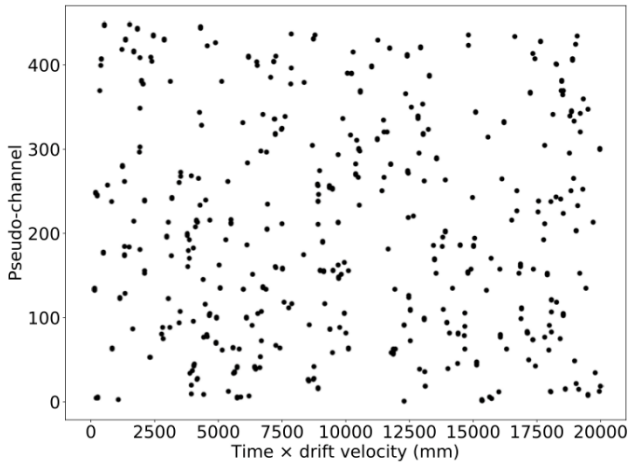
DBSCAN example 5. Neutron source on



DBSCAN example. Neutron source off



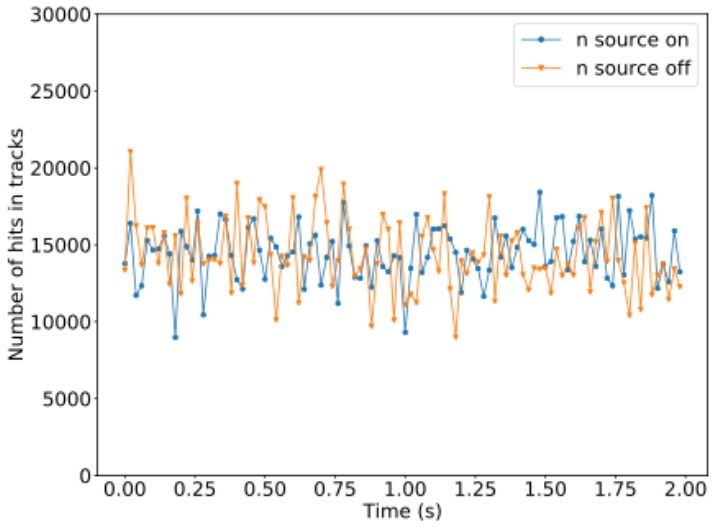
DBSCAN example 5. Neutron source on

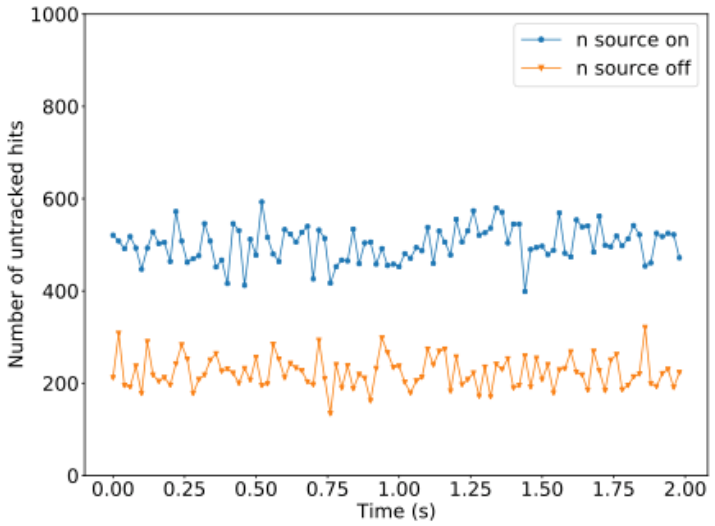


Philip Rodrigues: http://www-pnp.physics.ox.ac.uk/~rodrigues/protodune-neutron-source-2020-07-14.pdf

Quick Hit-Rate Analysis

Clustered and unclustered hit rates on APA 5



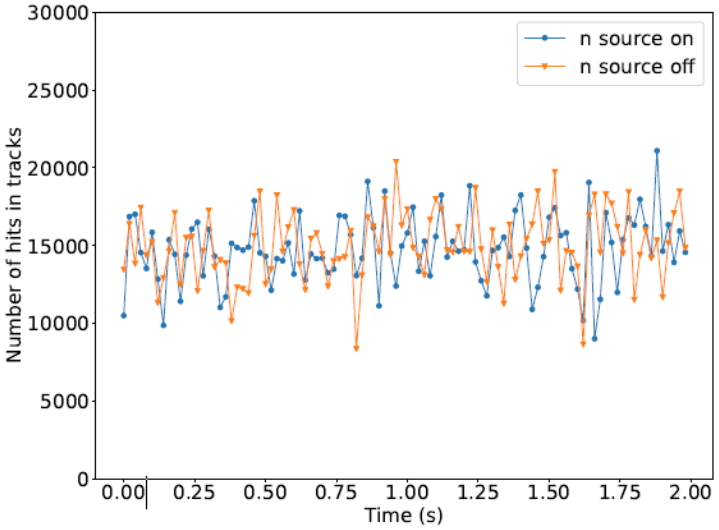


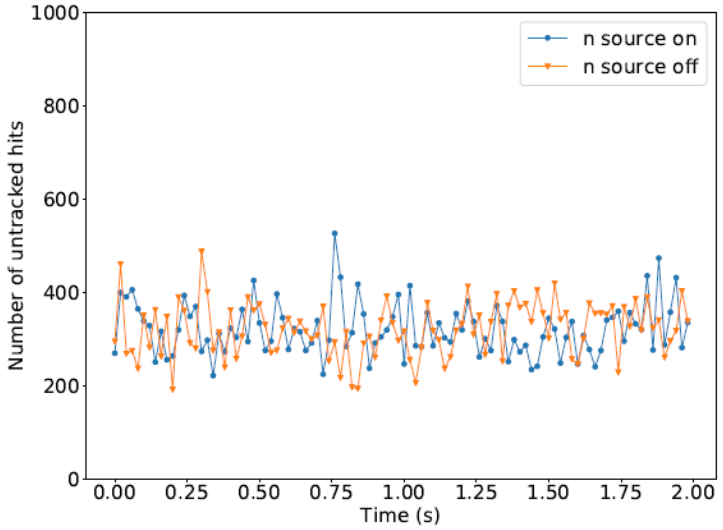
- Left: Number of hits clustered by DBSCAN (ie, tracked) in each 20ms window *vs* time
- Right: Number of unclustered hits (ie, neutron/EM candidates) in each 20ms window *vs* time
- (Just ran on 100 20ms windows to save time/memory)
- Tracked hits don't change with neutron source on. Untracked hits increase by about a factor of 2
- Clear evidence of neutron-like hits when source is on

Philip Rodrigues: http://www-pnp.physics.ox.ac.uk/~rodrigues/protodune-neutron-source-2020-07-14.pdf

Quick Hit-Rate Analysis

Clustered and unclustered hit rates on APA 1

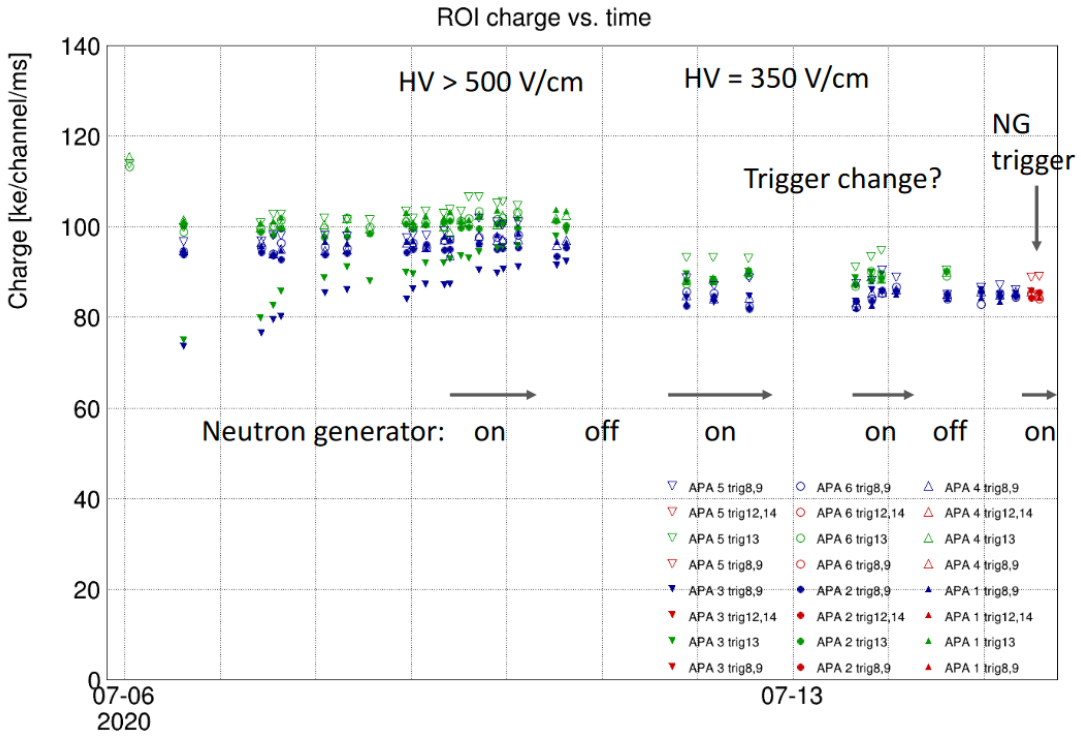




APA 1 is further from the neutron source. No statistically significant increase in hit rate

Philip Rodrigues: http://www-pnp.physics.ox.ac.uk/~rodrigues/protodune-neutron-source-2020-07-14.pdf

Signal Strength Analysis



[see D. Adams' talk at the operation meeting]

- Data shows an increase of ~2 ke/ms/channel in APA 5
  - ×(480 channels) = 1000 ke/ms in APA 5, which is 10X the prediction for 6.1 MeV neutron capture gammas.
- The energy excess is due to gammas from the neutron source or gammas from neutron captures on cryostat foam. This would contribute to near the top of detector.

Reconstruction & Analysis

- **Raw signal processing:**
  - Noise filtering, ROI finding
- **Cosmic veto:**
  - Remove track related hits

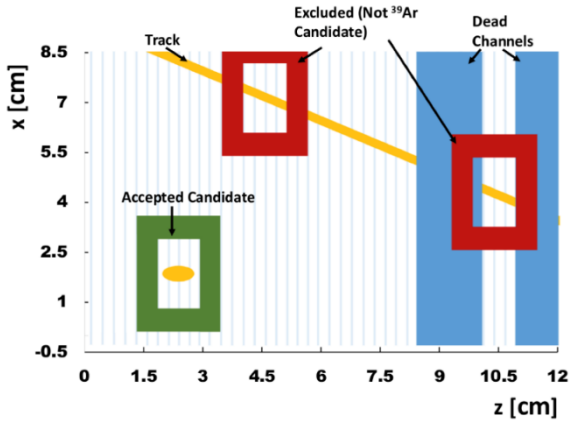
Near-done

- **3d position reconstruction:**
  - Spatial distribution of isolated space points for testing neutron transport model
- **Neutron capture clustering:**
  - Associate all gammas from a neutron capture (challenging due to the cosmic background)
- **Energy analysis:**
  - Low energy specific reconstruction: ADC to charge, electron lifetime correction, recombination correction.

Ongoing

Cosmic Track Veto (1)

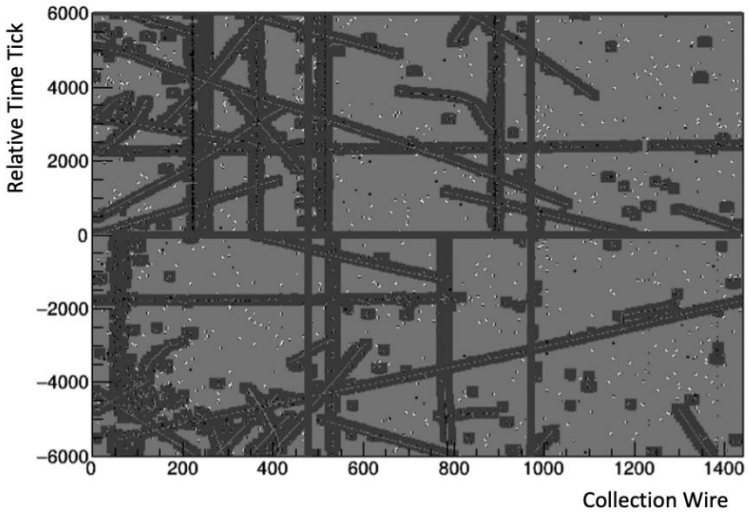
- Performed a track veto analysis for the ProtoDUNE-SP neutron data using similar method as MicroBooNE analysis
- Track identification and removal were done in separate framework. Will be ported to dunetpc soon.



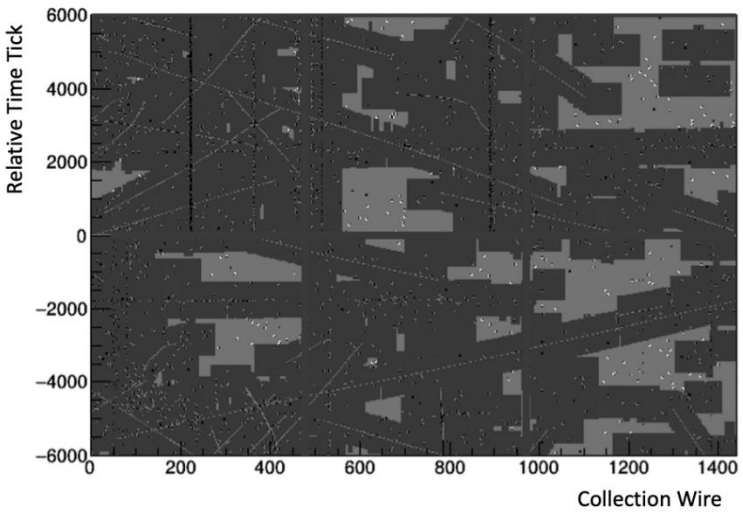
See MicroBooNE Public Note 1050

equivalent to the veto size used for MicroBooNE

24 Wires x 144 Time Ticks



80 Wires x 480 Time Ticks

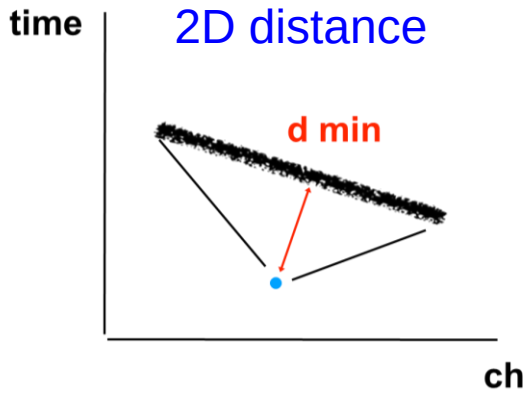


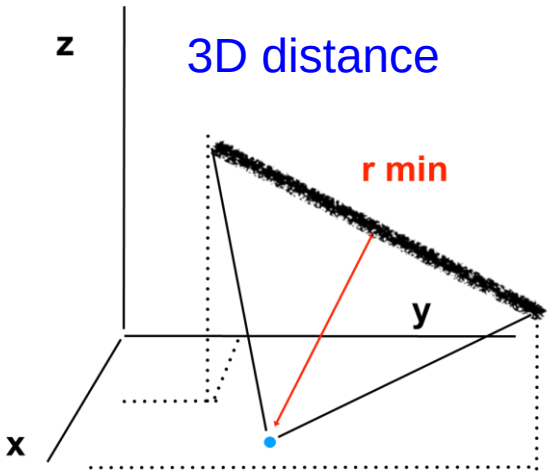
See Alex Flesher's presentation in the Calibration WG meeting

Cosmic Track Veto (2)

- A separate effort done by Yash Bezawada and Luca Pagani (UC Davis). The goal is to define a cut in space ((x,y,z) or (ch,time)) to remove cosmic activity nearby cosmic tracks.
- Reconstruction:
  - For tracks: use the default pandora-based track reconstruction
  - For space points: use the standard 3D space point solver
- Analysis:
  - Consider only APA#5 (since DDG location is nearby).
  - Consider collection plane hits not belonging to any reconstructed track.
  - Calculate 2D distance between a hit and its nearby track (in collection)
  - Calculate 3D distance between a space point and its nearby track

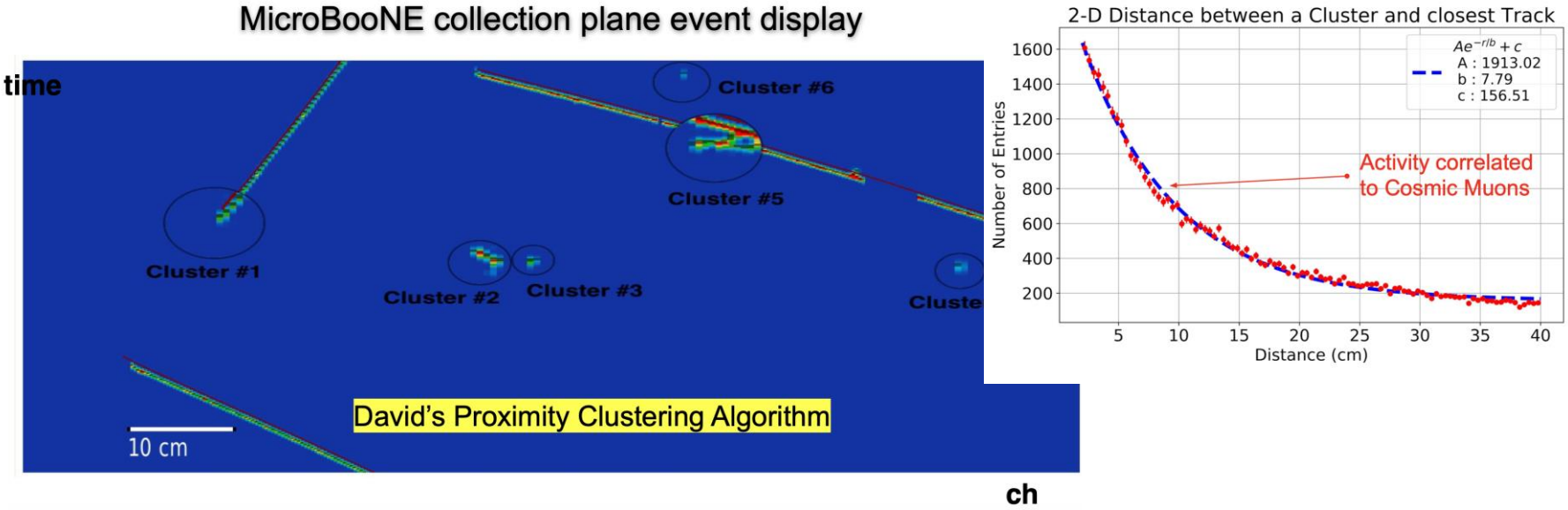
Distance from Hit/Space-point to Track





1) Each track has a start (t_0) and a stop (t_1) time
2) For each hit (w/o a track) correlated in time with a track (time of the hit between t_0 and t_1), the distance between the hit and each point of the track is calculated. The shortest distance is considered as the true distance between the hit and the track
3) Since each hit could have multiple space points, the procedure defined in 1) is repeated for each space point. Among all the calculated distances the shortest is considered as the true distance between the it and the track
4) 1) and 2) are calculated considering both the 3D (x,y,z) and 2D (ch,time) position of the hit
5) Channel and time are converted to length in centimeter

What to Expect: μBooNE Example

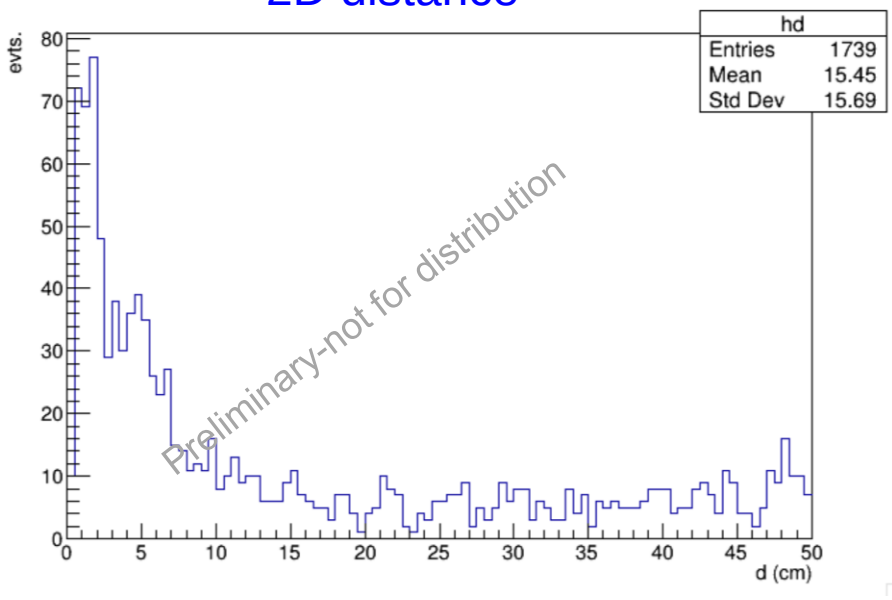


- uBooNE analysis done by A. Bhat: expected exponential decreasing number of hits moving away from the track. Fit with exponential function and define rejection distance by 2*b parameters appearing in the fit

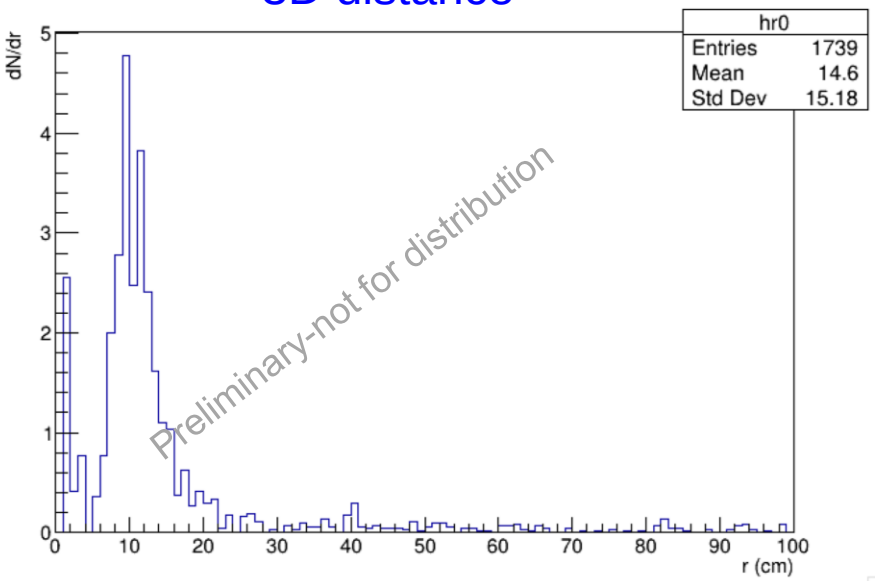
ProtoDUNE-SP Result

- Analysis was done for Run 11617 with DDG off
- 20 cm seems to be a reasonable cut distance to remove cosmic-related activities.

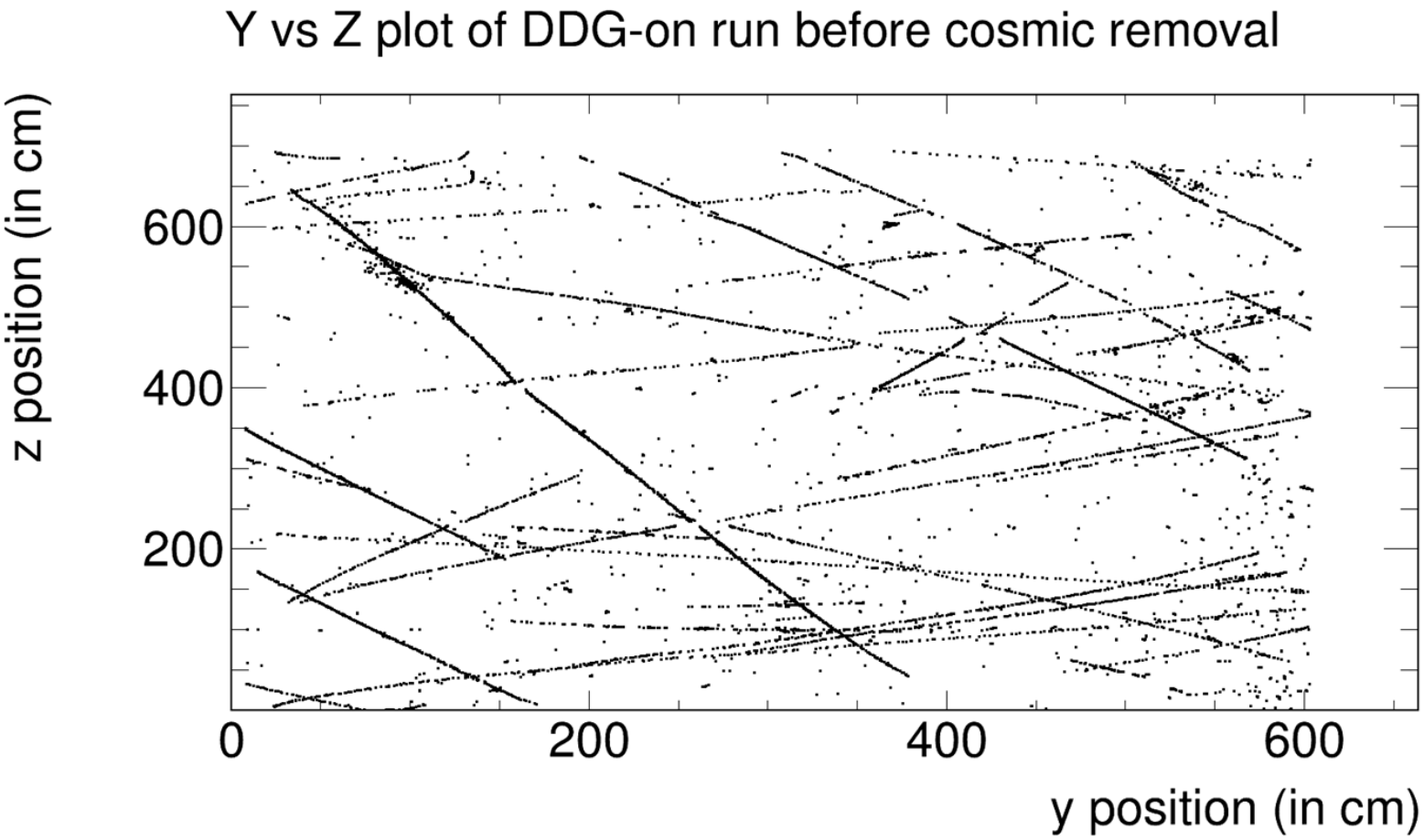
2D distance



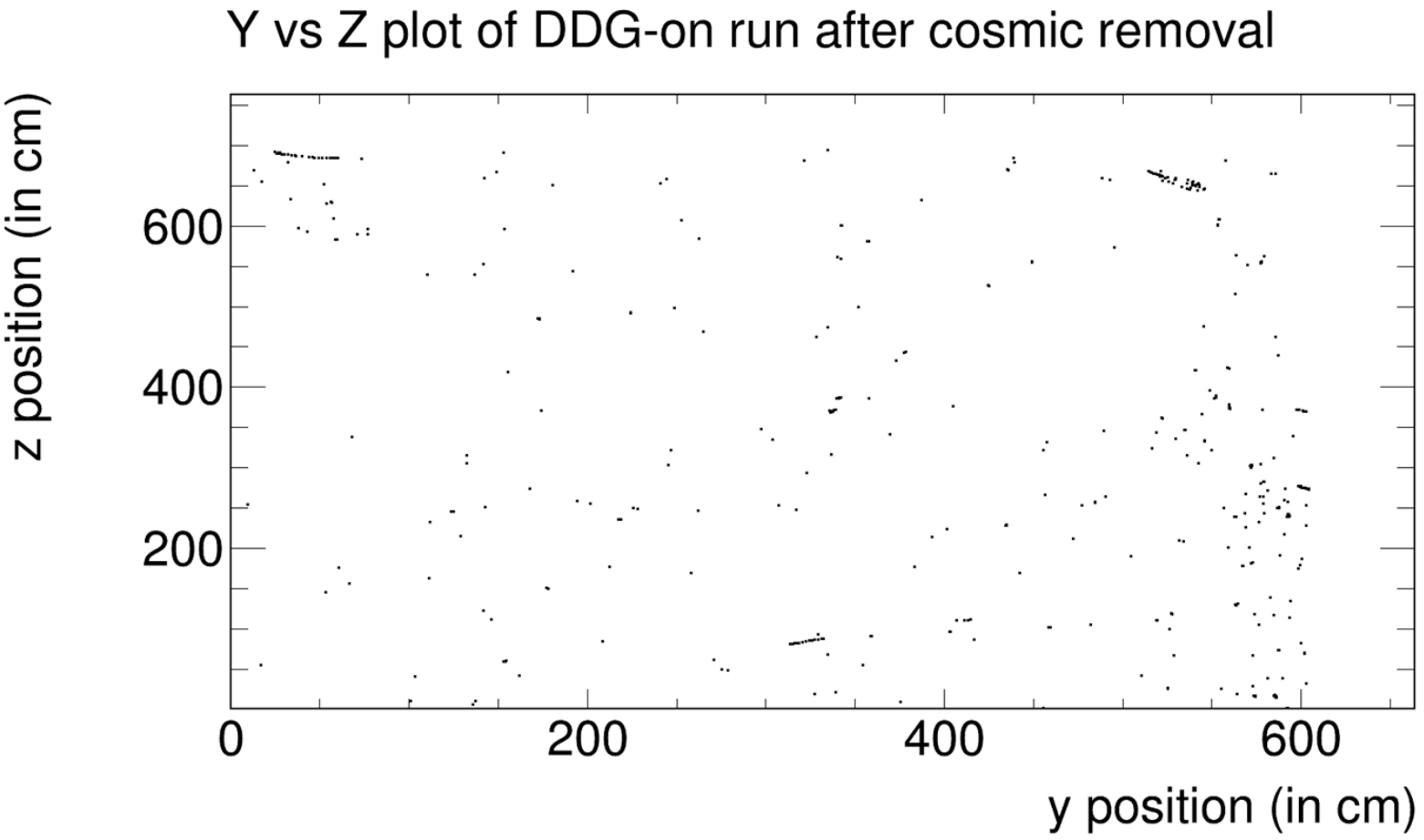
3D distance



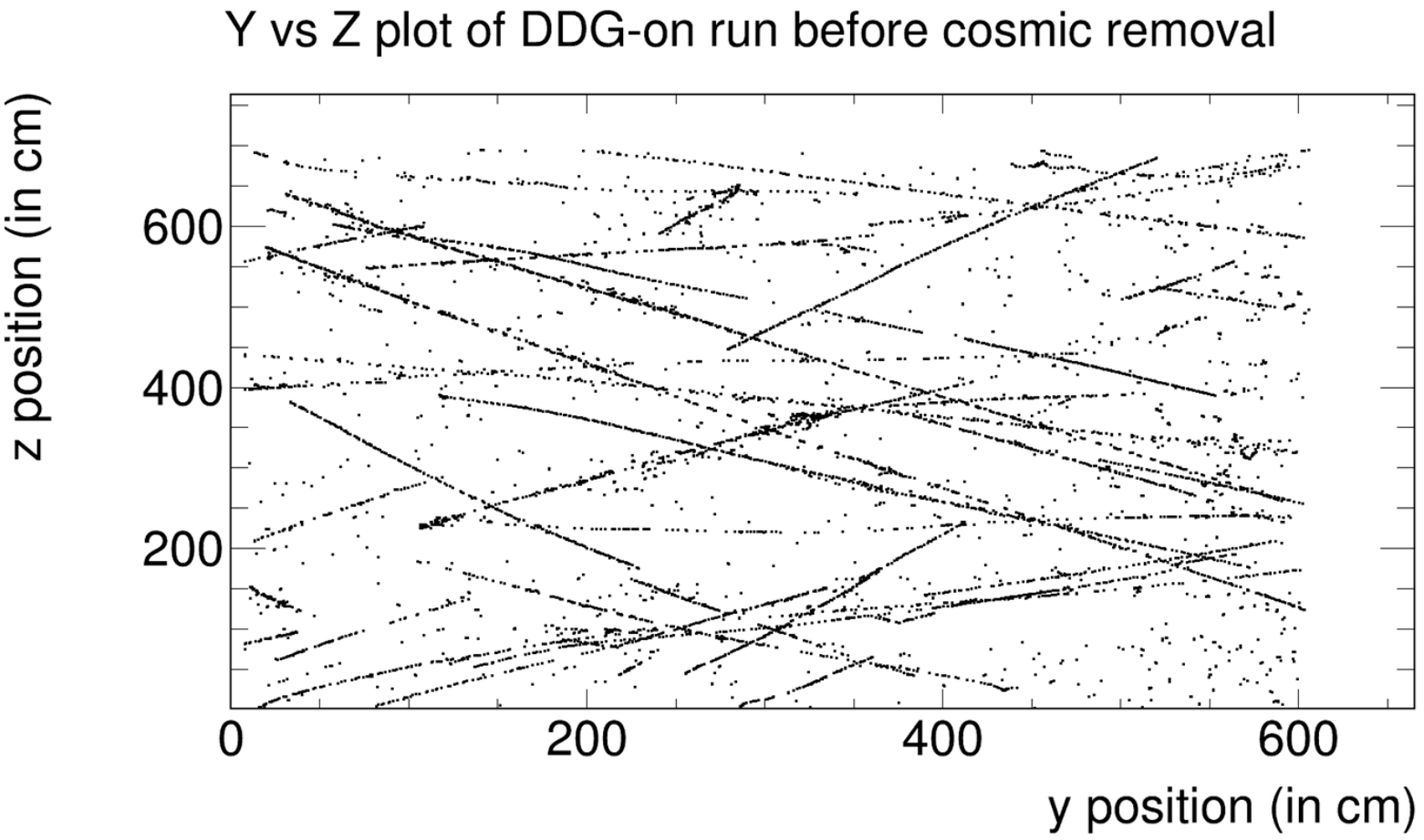
Cosmic Removal: Example#1



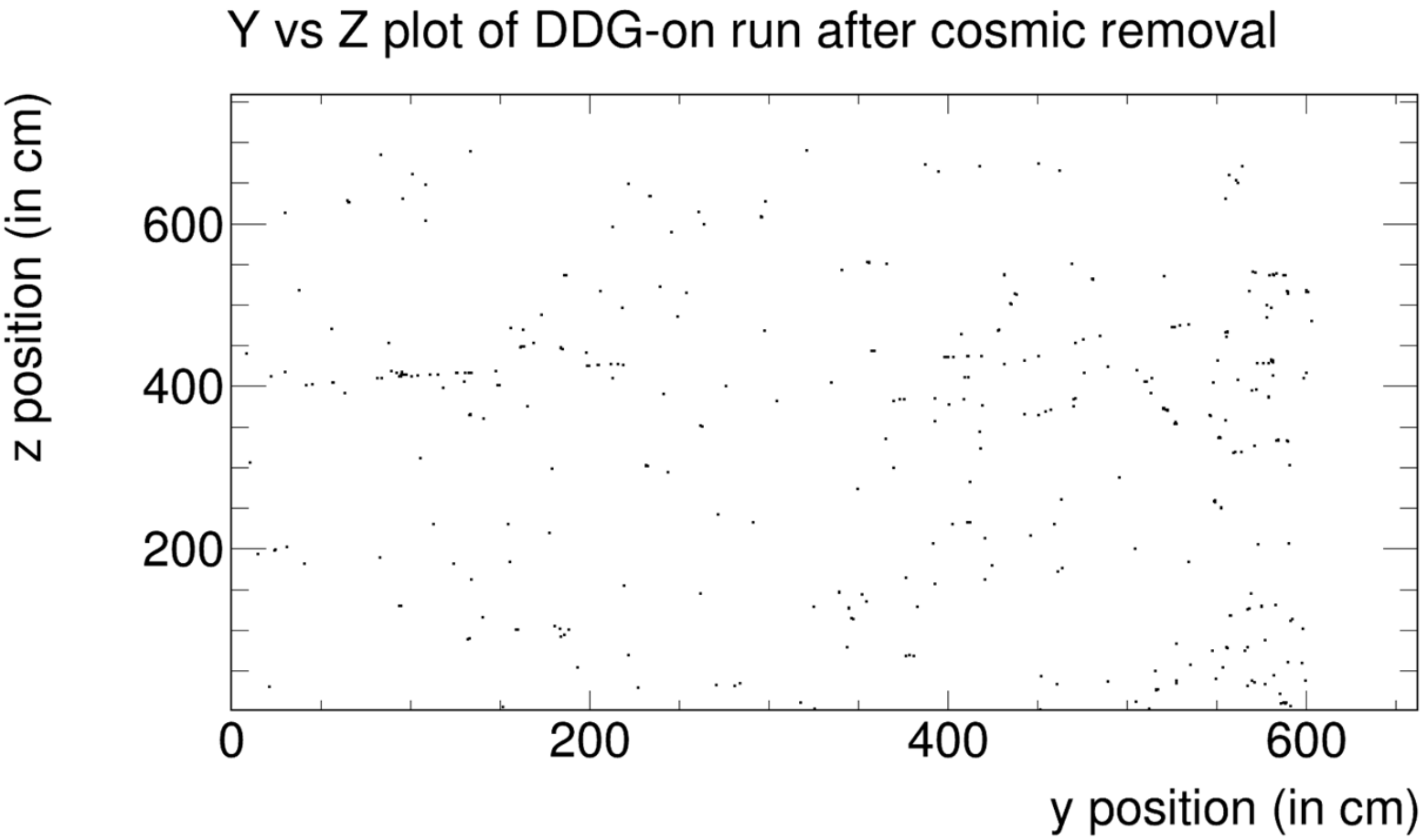
Cosmic Removal: Example#1



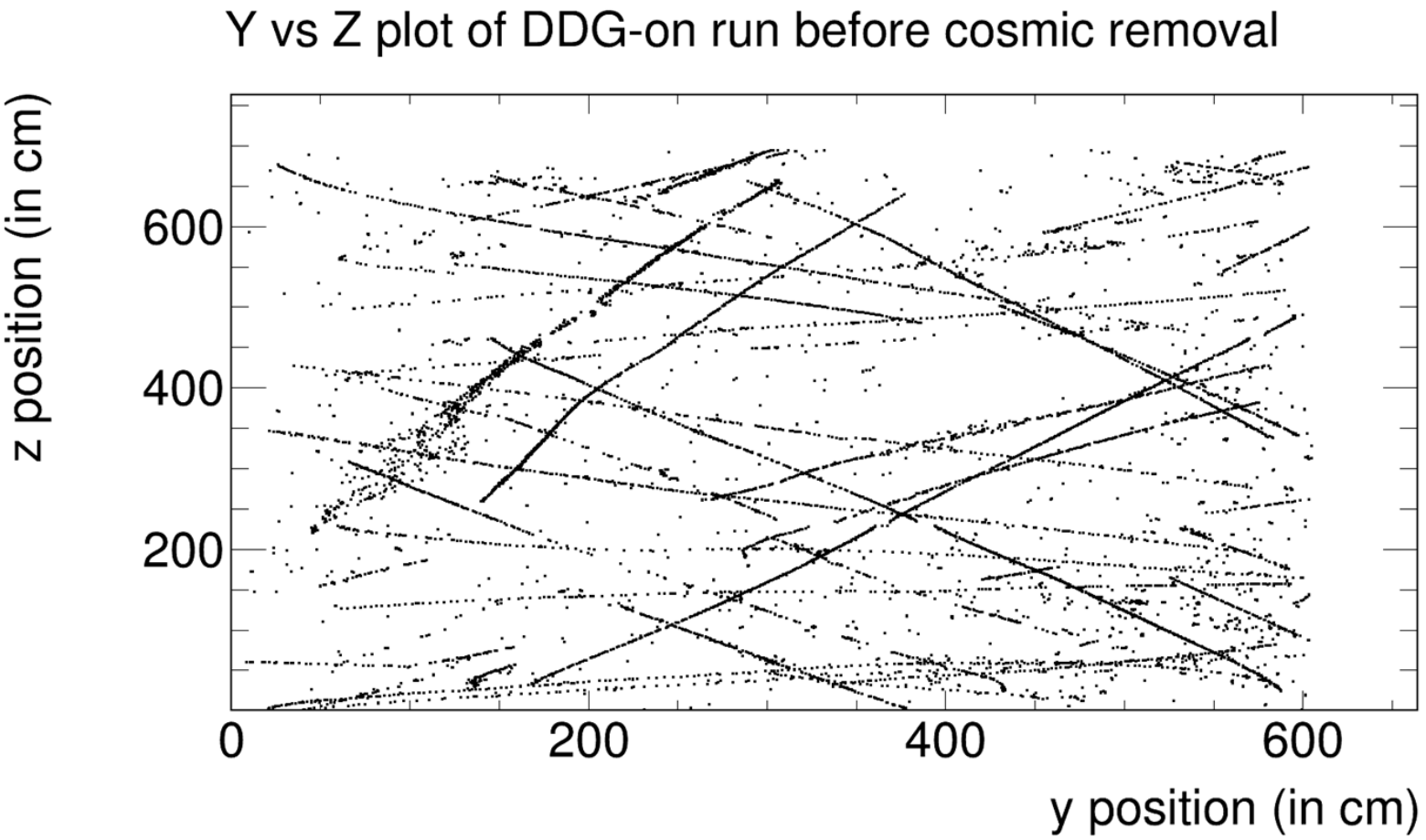
Cosmic Removal: Example#2



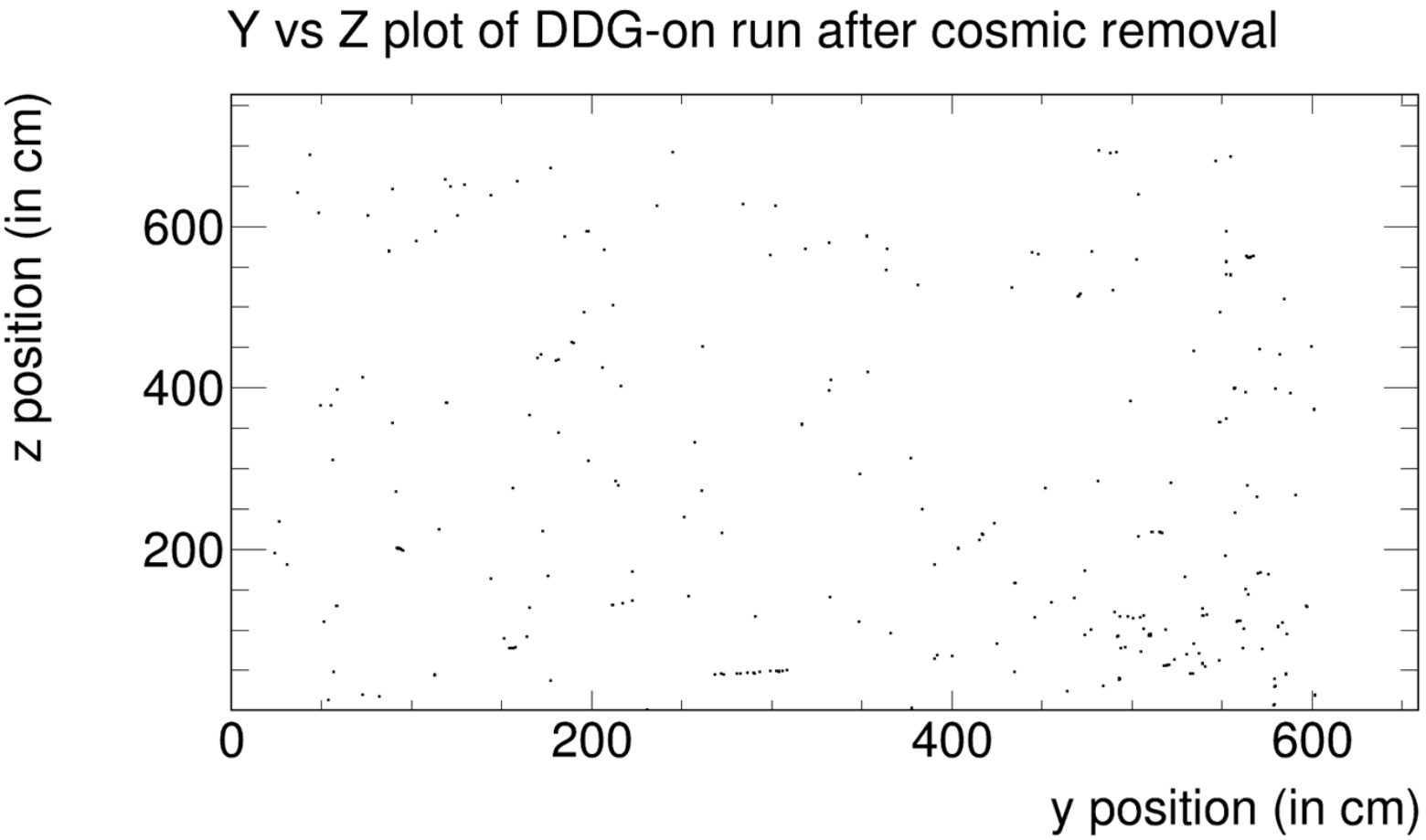
Cosmic Removal: Example#2



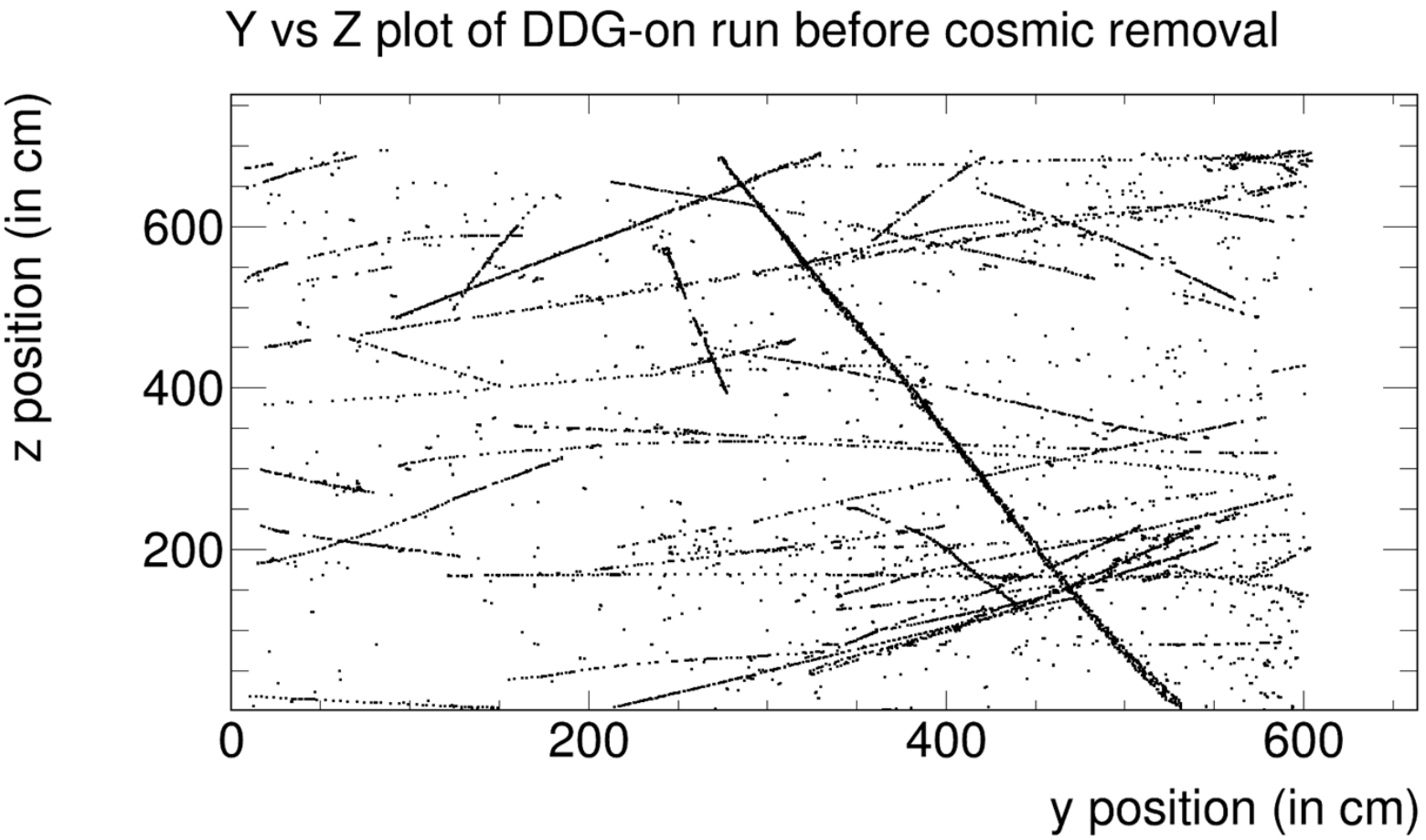
Cosmic Removal: Example#3



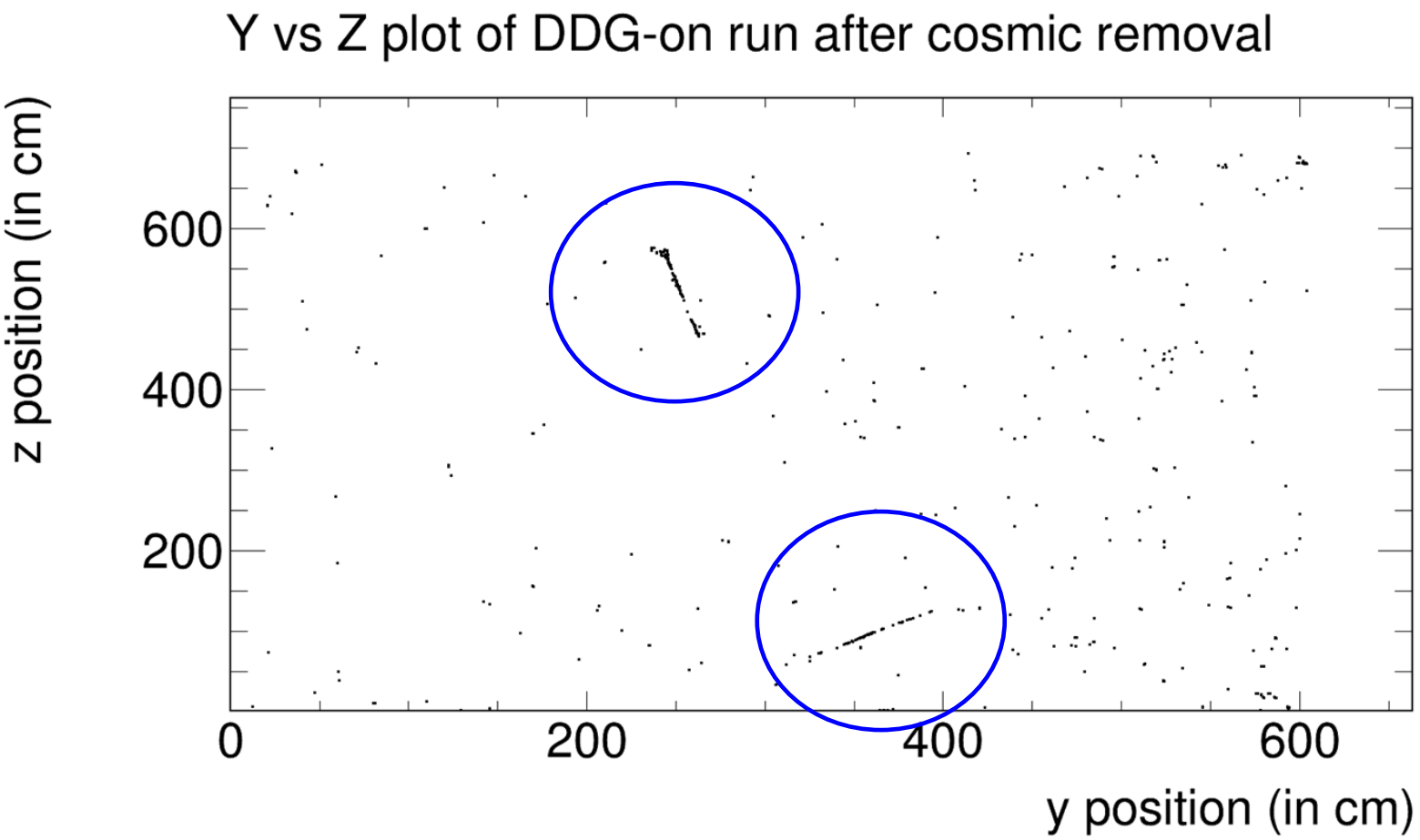
Cosmic Removal: Example#3



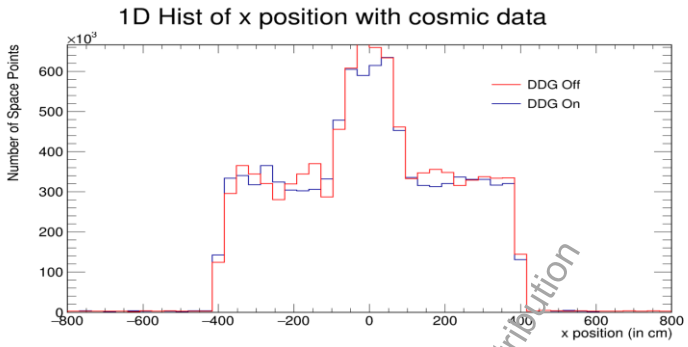
Cosmic Removal: Example#4

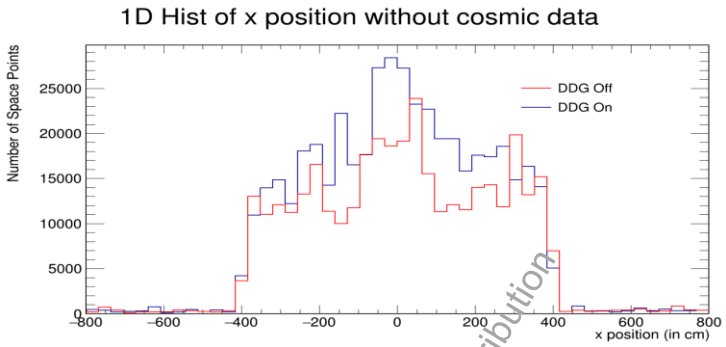


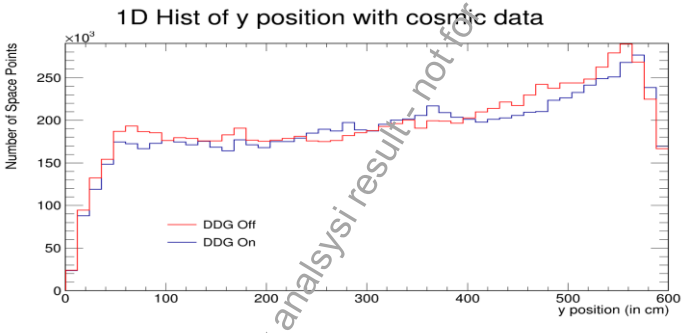
Cosmic Removal: Example#4

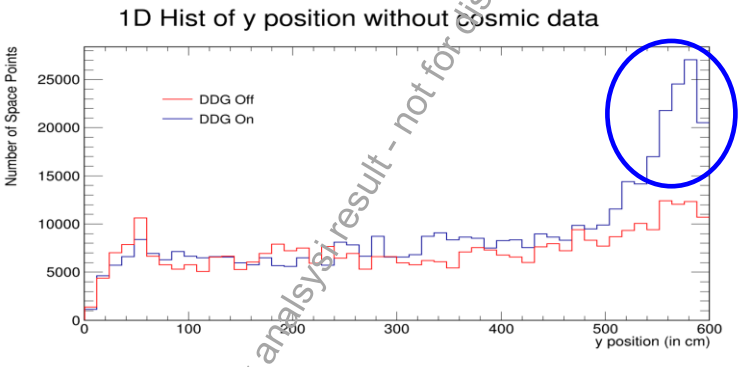


1D Space Point Distributions

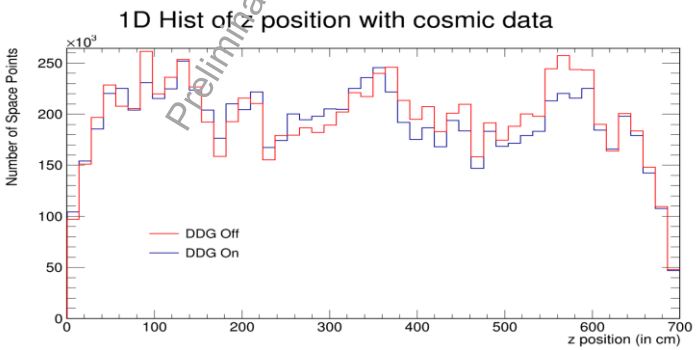


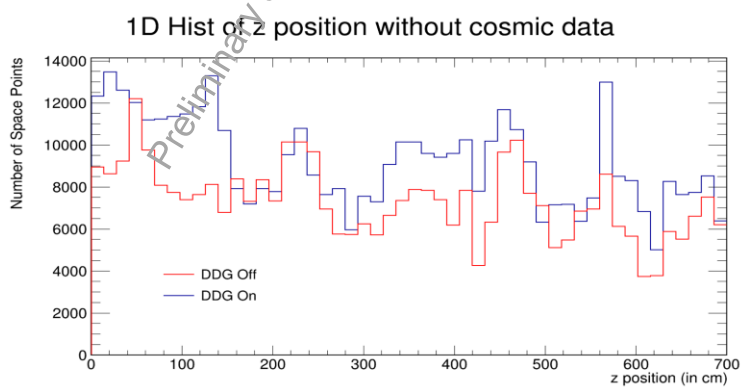






Gamma + neutron





Simulation is Needed to Understand Data

- **Compare neutron transport simulation with data**
  - Produce a distribution of energy deposition
- **Detector response to low-energy gammas**
  - Simulate 167 keV, 1.2 MeV and 4.7 MeV gammas
  - Test Noise modeling/filtering, study threshold effect
  - Study electron lifetime and recombination corrections
- **Background simulation**
  - 39-Ar and cosmic rays (chance of seeing 39-Ar decay within the neutron capture event is 18%)
- **Clustering**
  - What's the best clustering radius? How much background is clustered as neutrons?
  - 2D or 3D clustering? Which performs better?
- **Photodetector response to neutrons**
  - Precise t_0 determination. Is it possible?

Summary

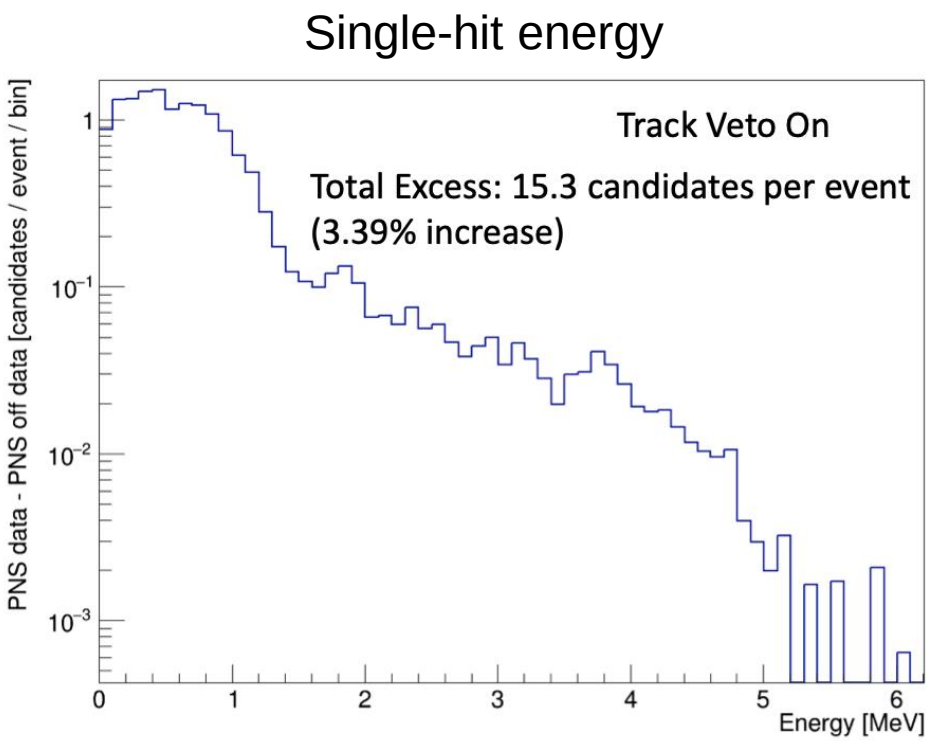
- The neutron DD generator was tested at ProtoDUNE-SP in July 2020.
- Quick hit analysis clearly shows that the DD generator is on.
- More sophisticated reconstruction and analysis are ongoing
  - Cosmic veto cut
  - 3D position distribution
- Next: run energy reconstruction and compare with simulation

Backup

Energy of point-like hits

PNS Studies:

- ^{39}Ar analysis took a small excursion into studying Neutron generator data
  - Finding out if Track Veto would help this effort
- 11632 is PNS on; 11639 is a nearby reference run with the PNS off
  - Only looking at the 4 APAs online in both runs
- Utilizes the same point-like reconstruction for ^{39}Ar, optimized for higher energy hits
  - Uses 5 wire x 61 time tick window instead of 3 wire x 41 ticks (for ^{39}Ar)



Alex Flesher, https://indico.fnal.gov/event/44544/contributions/192106/attachments/131894/161713/DUNE_CalibWG_Update_aflesher.pdf