First Results from the Neutron Generator Test at ProtoDUNE

ProtoDUNE DRA Meeting
6 October 2021

Yashwanth Bezawada (Yash)
Junying Huang
University of California, Davis

OUTLINE

- Pulsed Neutron System
- DDG Test at ProtoDUNE
- Clustering Using DBScan
- Removing Cosmic Backgrounds
- MC Simulations
- Comparing Data and Simulations
- Conclusions

Neutrons for Calibration

- Argon has a near transparency to neutrons of energy 57 keV due to anti-resonance section
- Can travel ~30 m in natural liquid argon
- Fractional energy loss of 4.8% per scatter for the neutrons above this dip
- But the only experiment performed did not see the anti-resonance

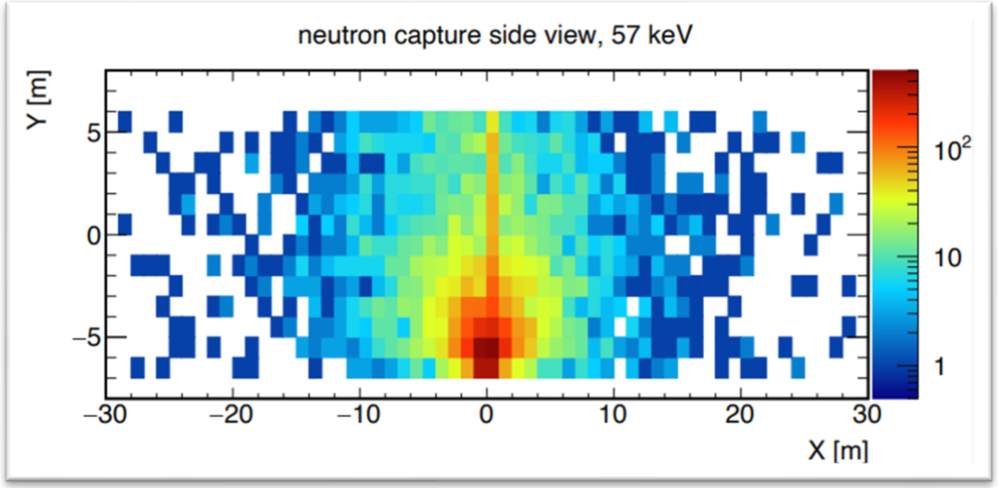


Fig. (left) Simulated spread of 57 keV neutrons in the DUNE-size module (work done by J. Wang)

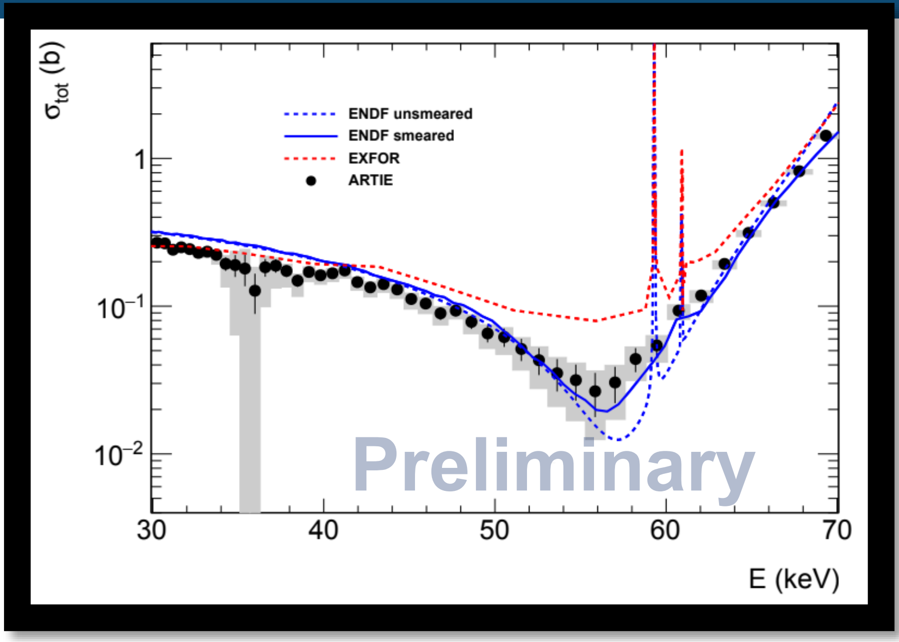


Fig. ARTIE Preliminary results for the neutron cross section in liquid argon at the anti-resonance dip

- Neutron captures in liquid argon (^{40}Ar - 99.6%) release distinct 6.1 MeV gamma ray cascade

$$n + {}^{40}Ar \rightarrow {}^{41}Ar + 6.1\ MeV$$

(Start)

How can we use Neutrons?

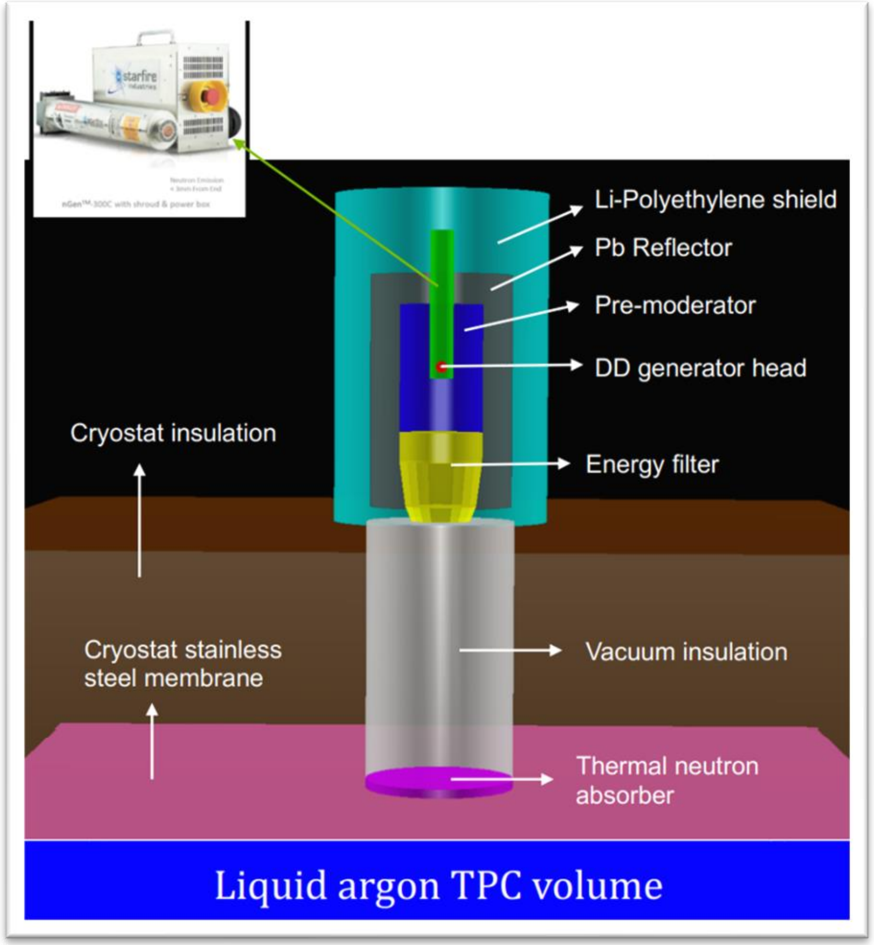


Fig. A schematic of the proposed PNS system (Investigating a simplified design)

Pulsed Neutron Source (PNS)

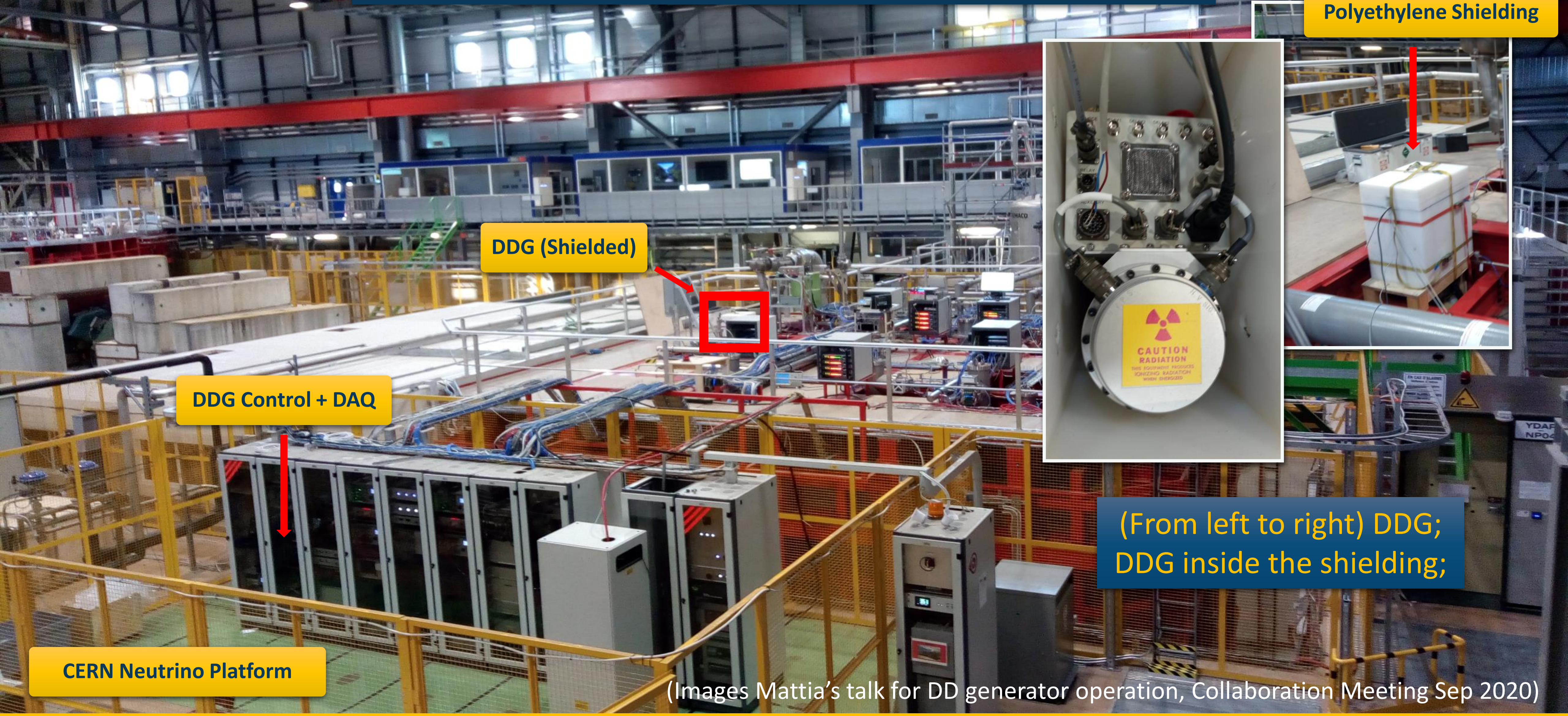
Deuterium-Deuterium neutron generator (DDG) produces 2.5 MeV neutrons

$$^{2}H + {}^{2}H \;\rightarrow\; {}^{3}He + n + Q(2.5\,MeV)$$

Advantages

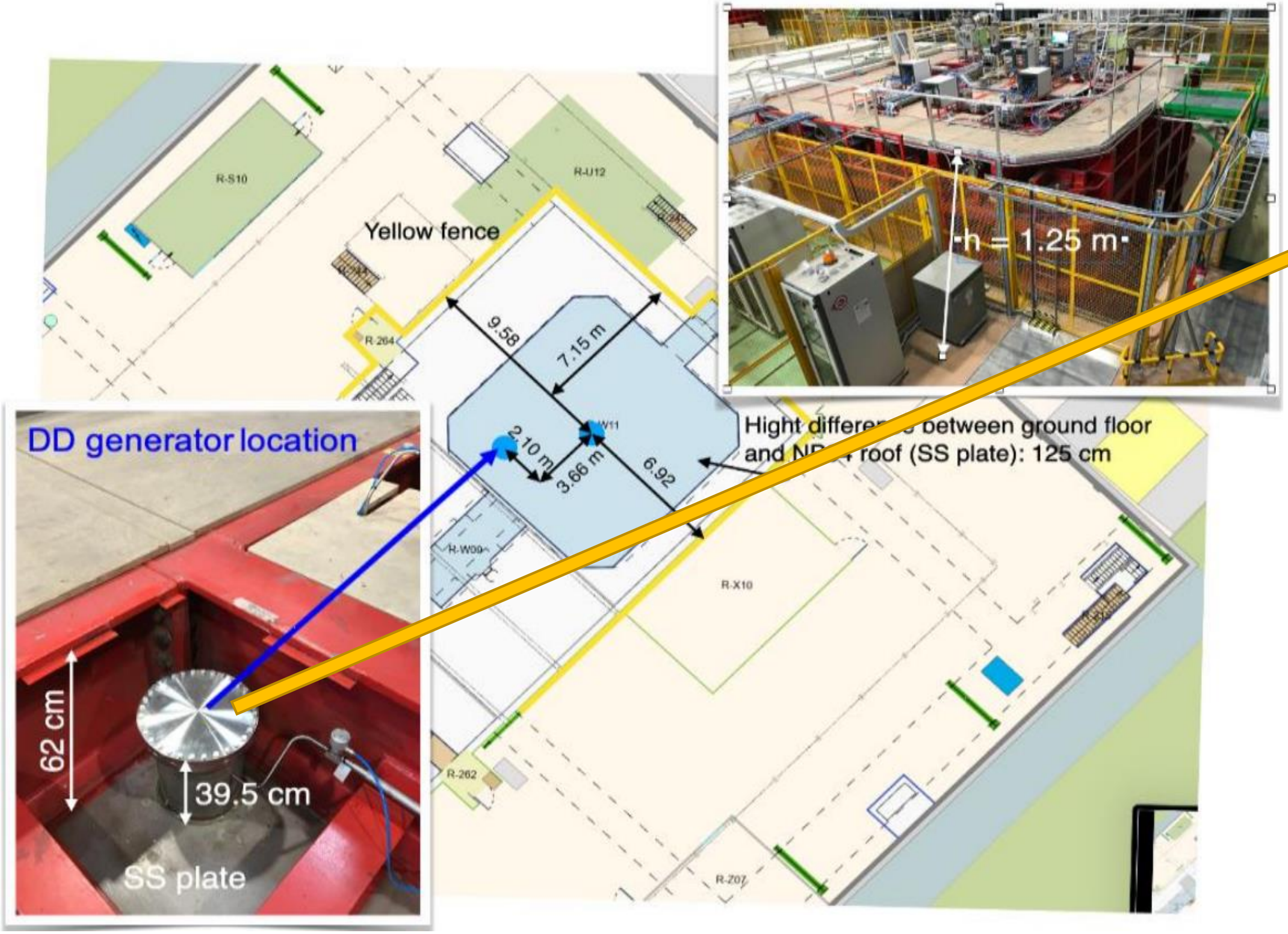
- External Deployment: No contamination to liquid Ar
- Adjustable neutron yield, pulse width and pulse rate
- Broad coverage: Neutrons travel long distances in liquid Ar
- Fixed energy deposition: 6.1 MeV gamma cascade can be used as "standard candle"
  - Signal also resembles Supernova Neutrino Burst (SNB) signal, thus acting as a "fake" SNB event trigger
- Frequent calibration runs can be conducted, due to the ease of deployment

DDG Test at ProtoDUNE-SP



(Images Mattia's talk for DD generator operation, Collaboration Meeting Sep 2020)

DDG Test - Setup



Location of the roof feedthrough

APA Numbering

5	6	4
3	2	1

DD Generator is deployed at a roof feedthrough near APA 5

DDG Test – Data Taking

- Data taking was done over 10 days with different trigger modes and neutron intensities
- Random Trigger Mode:
  - DDG Off: E = 650 V/cm; 2 Hz Trigger Frequency
  - DDG Off: E = 350 V/cm; 5 Hz Trigger Frequency
  - DDG On: E = 650 V/cm; 2 Hz Trigger Frequency
  - DDG On: E = 350 V/cm; 5 Hz Trigger Frequency
- Pulsed Trigger Mode (Only for DDG On):
  - E = 350 V/cm, 5% duty Cycle, ~175 μs pulse width, ~4 Hz
  - E = 0 V/cm, 5% duty Cycle, ~175 μs pulse width, ~4 Hz

(For more information refer to Mattia's talk on DD generator operation, Collaboration Meeting Sep 2020)

Motivation For DDG Analysis

- Understanding the neutron spread in ProtoDUNE-SP
- Remove cosmic events from the DDG run
- 3D space point reconstruction to test the neutron transport model
- Check the agreement between MC simulation and Data
- Energy reconstruction of the neutron capture events in the DDG run

Reconstructing Raw Data

- We are using "protoDUNE_SP_keepup_decoder_reco.fcl" to reconstruct the raw data
- We are using the following Modules:
  - "hitpdune" for extracting hits
  - "reco3d" for extracting spacepoints
  - "dbcluster3d" for clustering spacepoints

```
# Space point finder
reco3d:                 @local::protodunespdata_spacepointsolver
# Hit disambiguation
hitpdune:               @local::pdune_disambigfromsp
#3d dbscan
dbcluster:              @local::protodunespmc_dbcluster3d
```

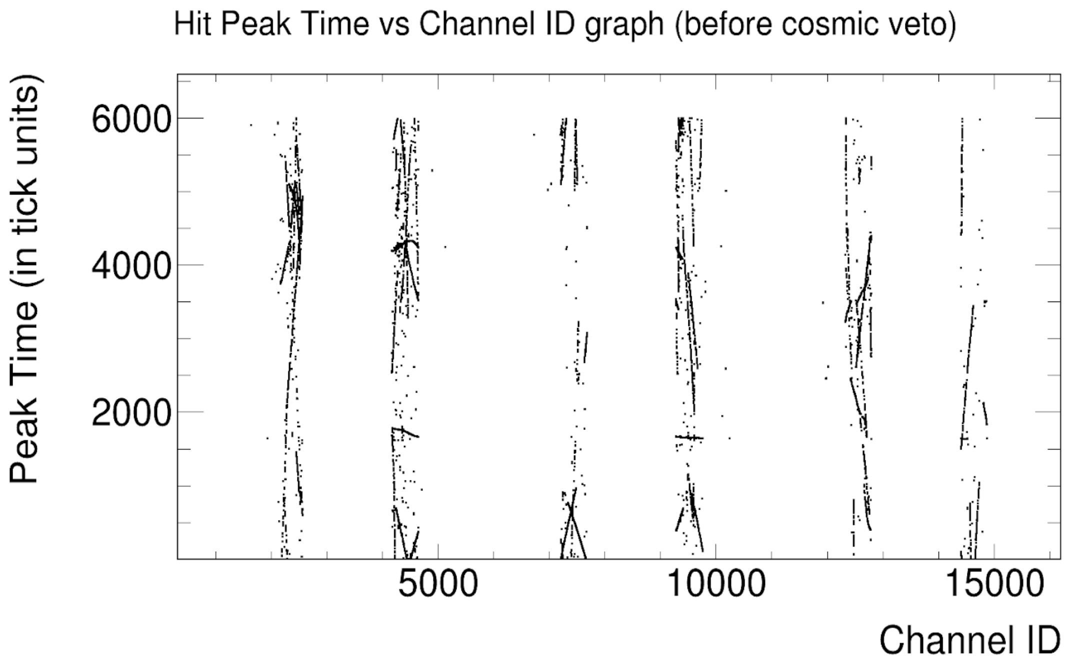


Fig. Hits from the collection plane for an event in the run 11668 (DDG-off). The empty spaces are induction planes.

APA-5 (14400-14900 Channel IDs) is the nearest to the DD Generator

Spacepoint Clustering Using DBScan 3D

Run Number: 11711 – Pulsed Trigger Run (E = 350 V/cm Field)

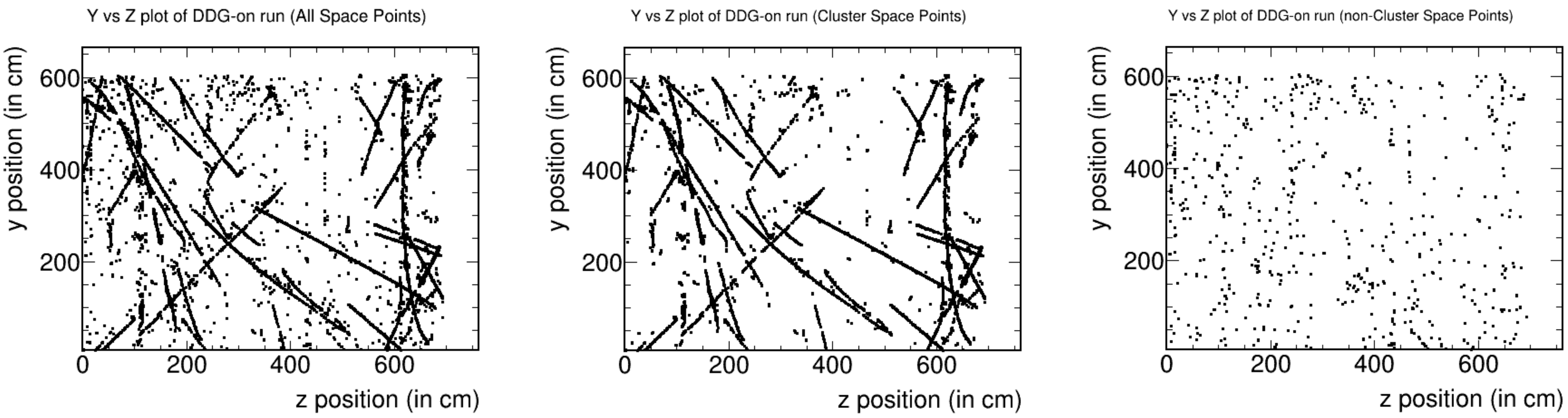
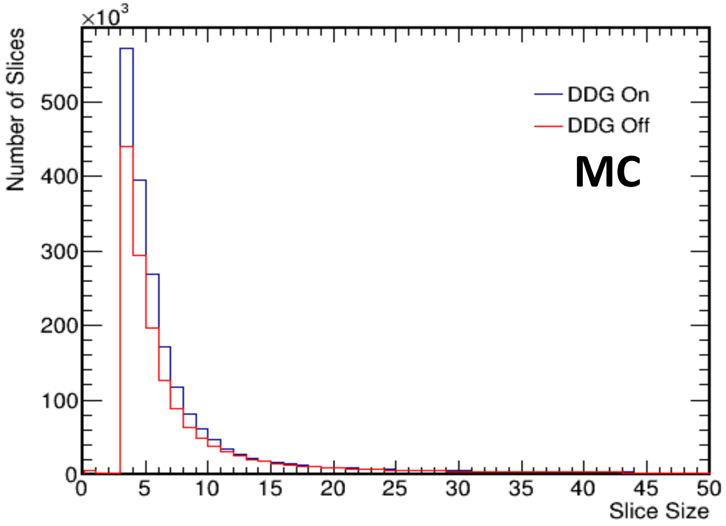
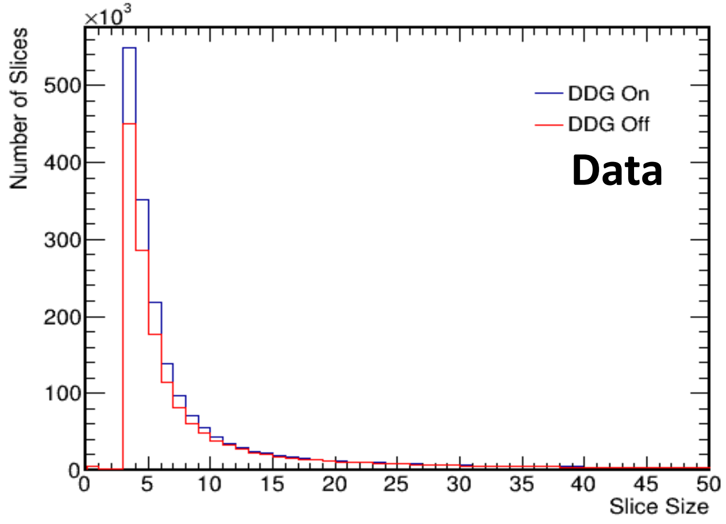


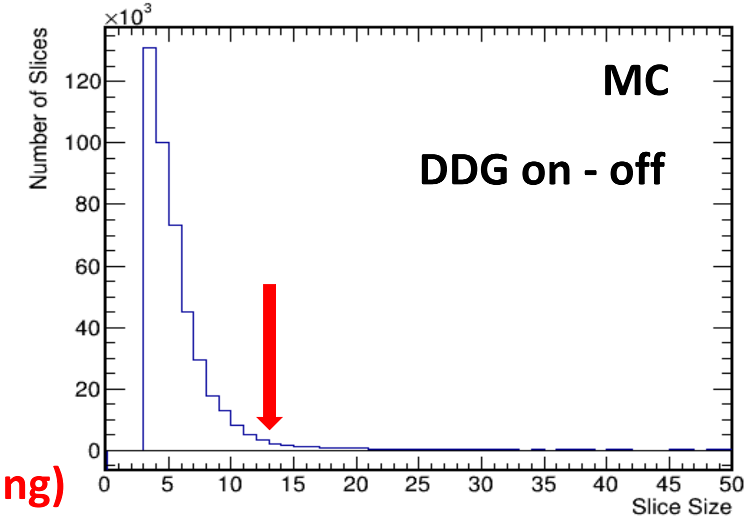
Fig. Y vs Z plot of spacepoints for one event. Clustering is performed on the reconstructed 3D spacepoints.

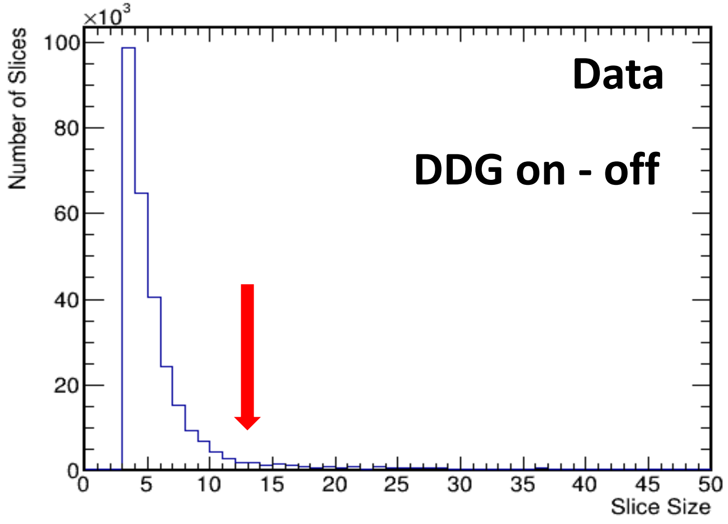
- Minimum points per slice is set to 3
- Epsilon (neighborhood radius) is set to 2cm
- Cosmic rays partially removed by a cut on slice size

Determining the Slice Size Cutoff









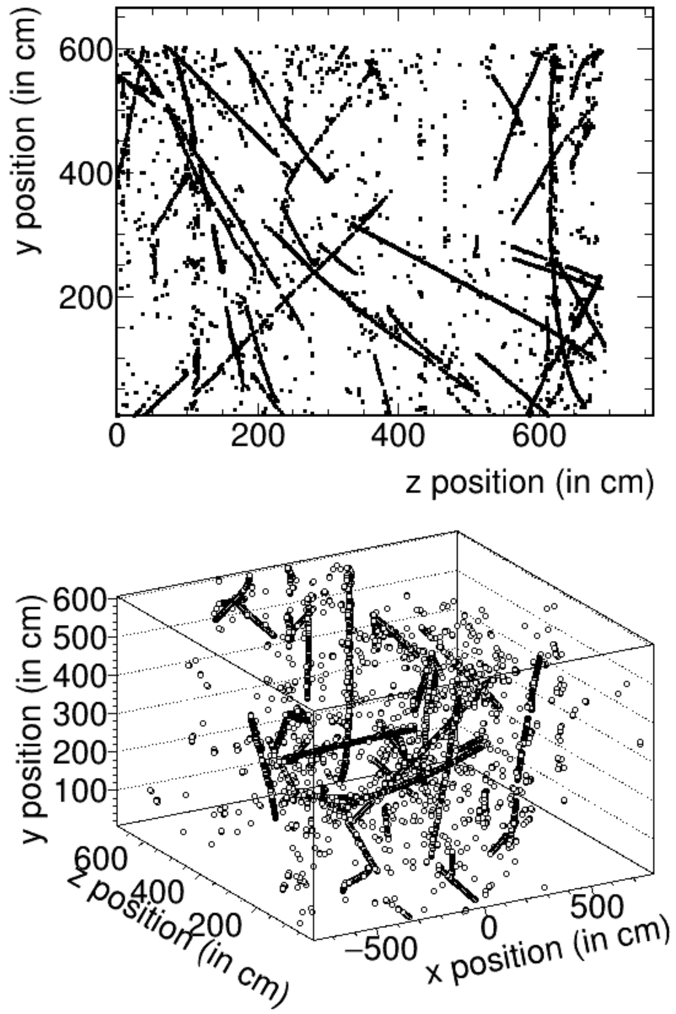
(Junying)

Fig. Slice Size vs Number of Slices Plots

- We use a slice size cutoff of <=13 to remove some cosmics.
- 5000 events included.

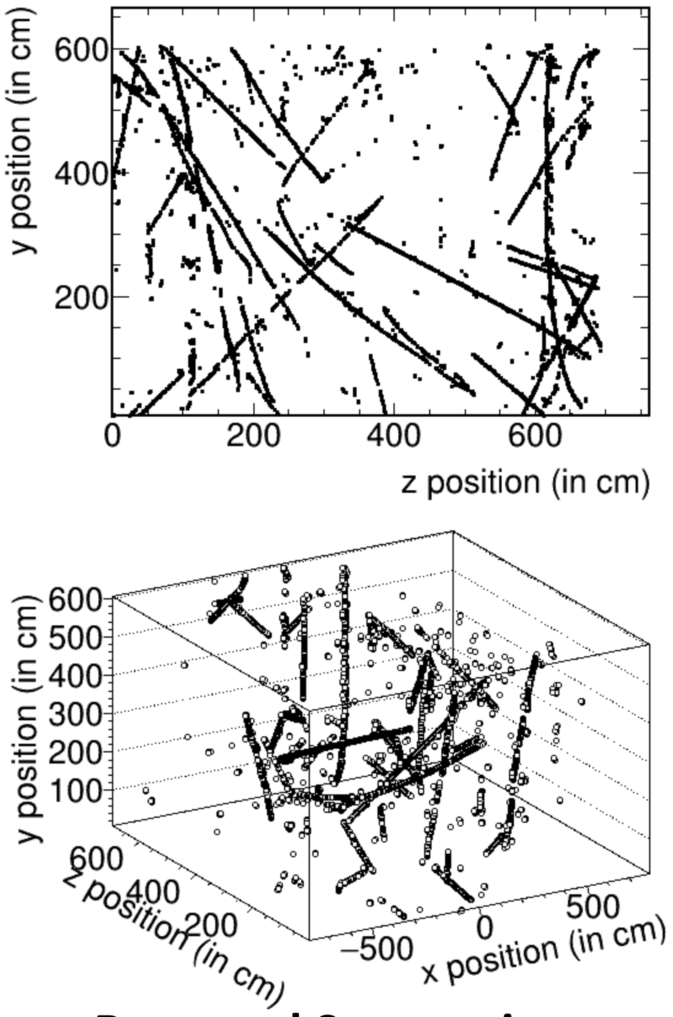
Note: We recently found a bug in the MC simulations. We have fixed it and waiting for the results

Removing Cosmic Backgrounds



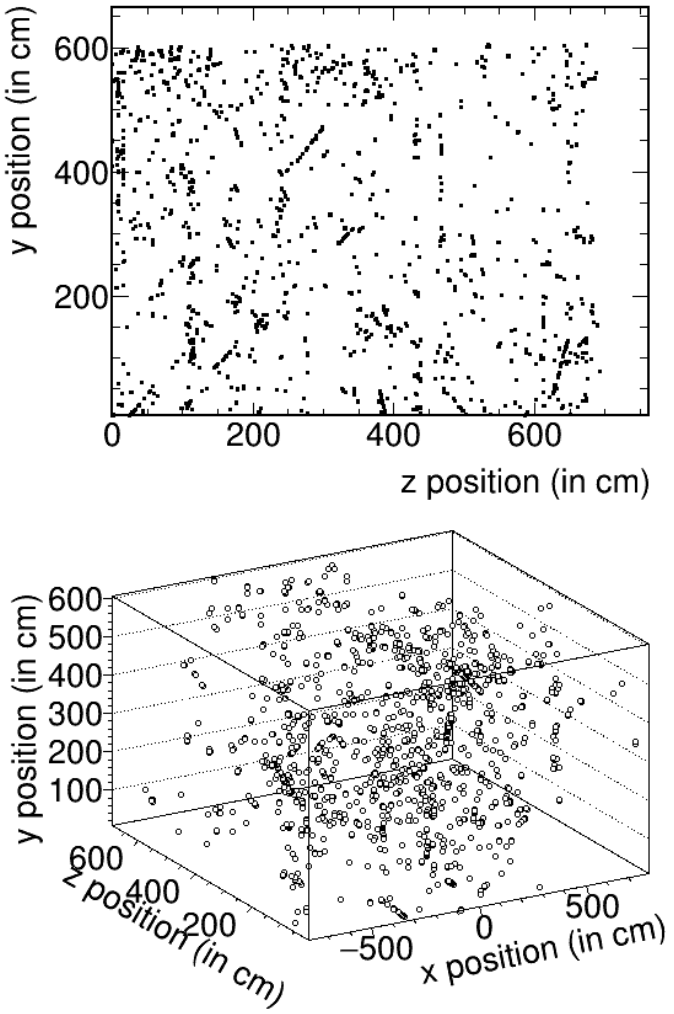
All Spacepoints

-



Removed Spacepoints (Slice Size > 13)

=



Remaining Spacepoints (Slice Size <= 13)

Simulations

- Updated the Geant4 physics list in LArSoft
- Modified the LArSoft geometry to include the polyethylene shield around the DDG
- Text file generator: 1500 neutrons with 2.5 MeV per event
- Using "protodune_corsika_cmc" for cosmic ray
- Using "protodunesp_39ar" for Ar39
- Same reconstruction chain as data

(Work by Junying Huang)

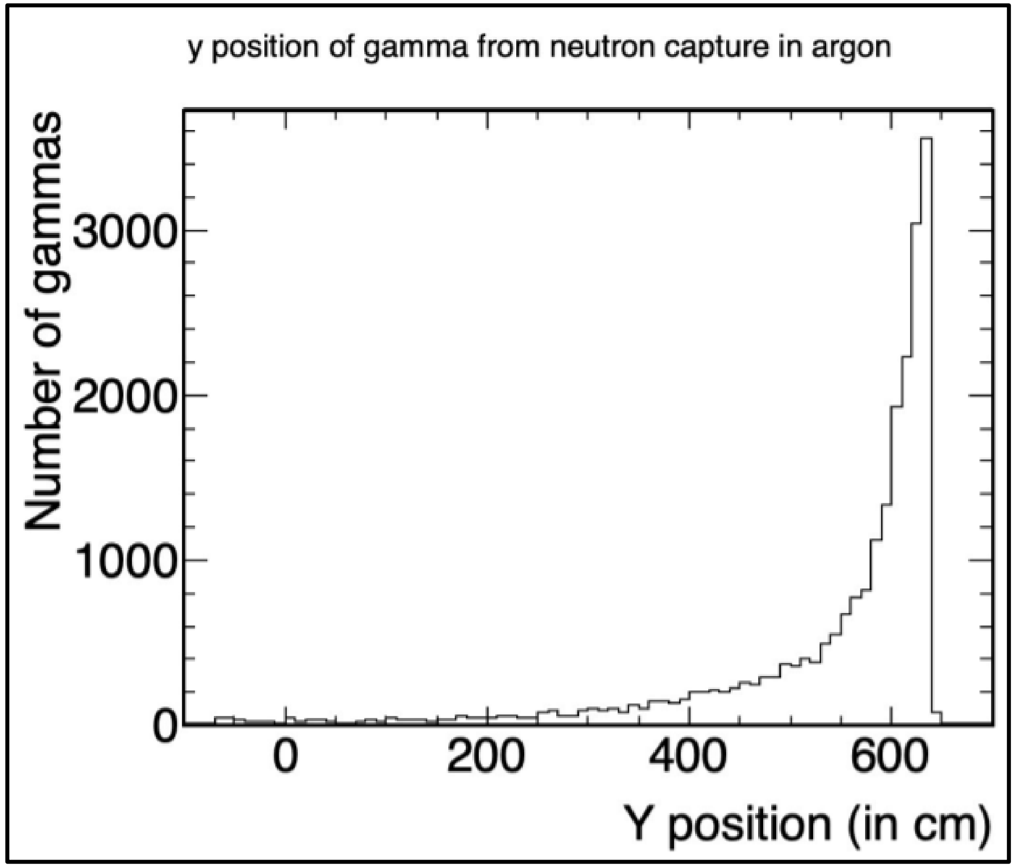


Fig. Simulation confirms that gammas from neutron capture are seen

Comparing Data and Simulations

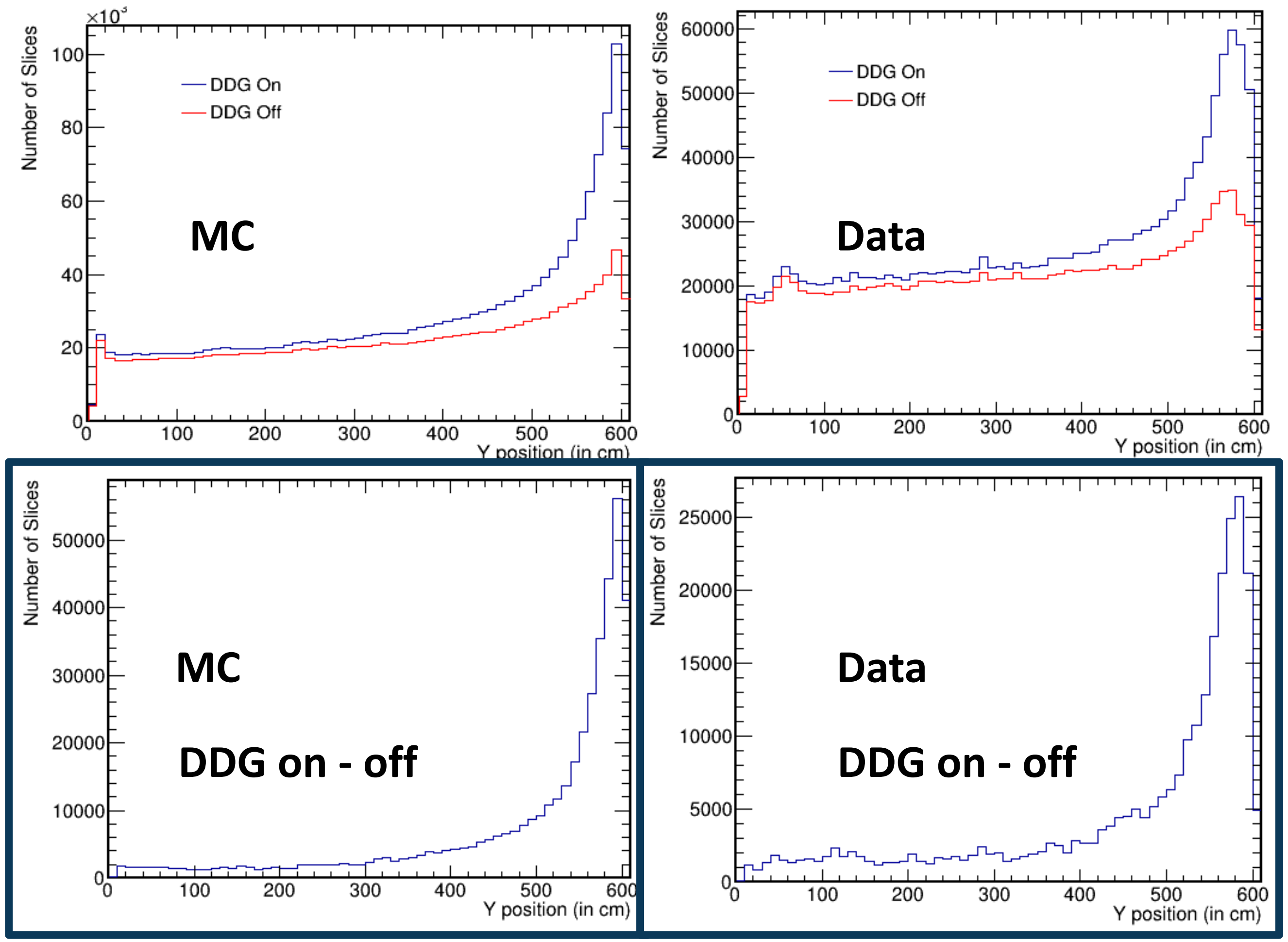


Fig. Number of Slices on Y-axis and vertical position on X-axis.

- DDG off data is subtracted from DDG on data
- The resulting slices (clusters) are the contribution from the DDG
- Chi-square minimization used to fit the data with MC simulations
- Excluded bins up to 50 cm and from 550 cm to ignore the edge effects

$$\chi^2 = \sum_{i=bins} \frac{\left[\left(D_{on,i} - D_{off,i}\right) - \beta\left(MC_{on,i} - MC_{off,i}\right)\right]^2}{D_{on,i} - D_{off,i}}$$

$D_{on,i}$: DDG on – Data　　$D_{off,i}$: DDG off – Data

$MC_{on,i}$: DDG on – MC　　$MC_{off,i}$: DDG off - MC

(Start)

What can we conclude from this?

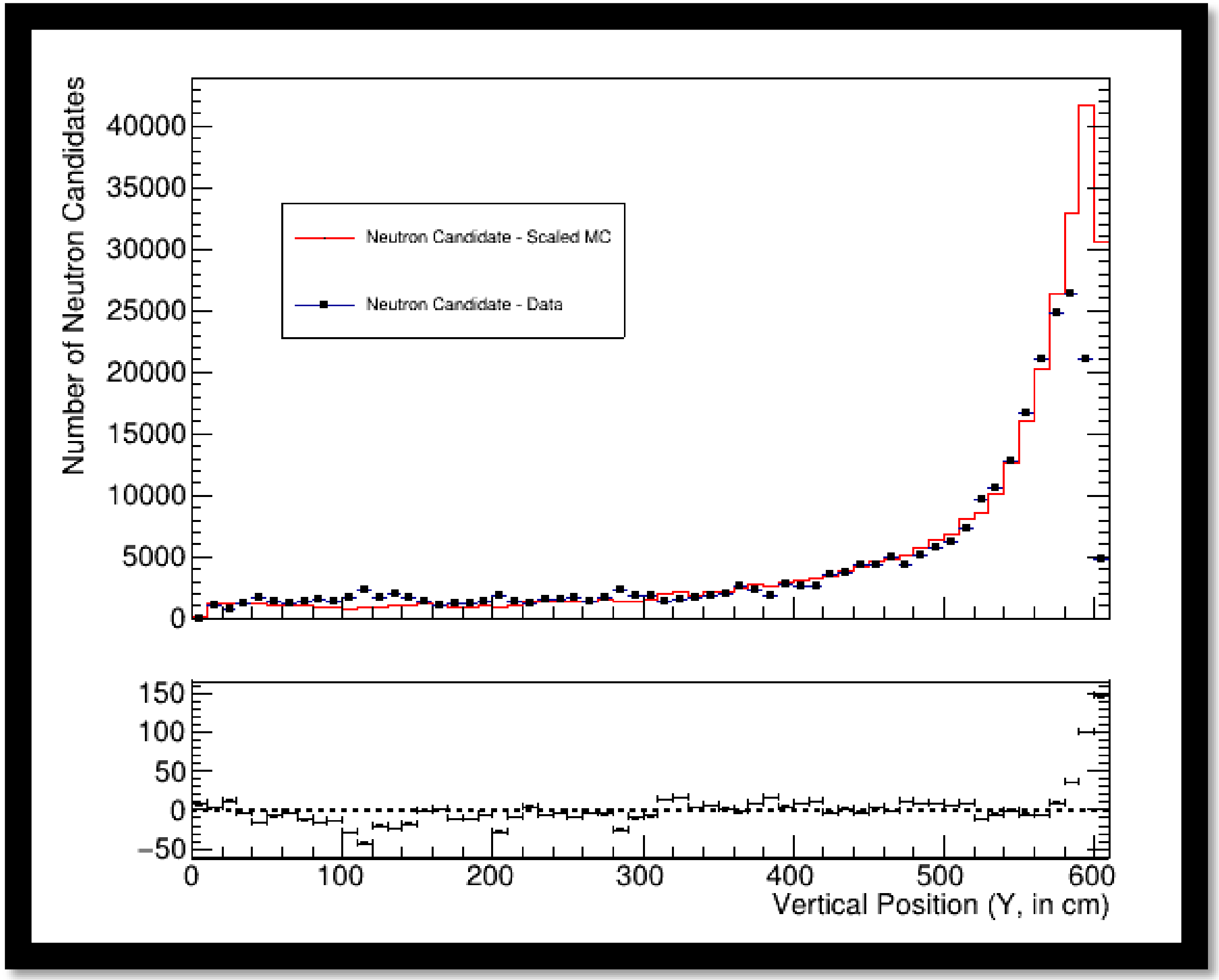


Fig. Plot with data and the fit. Number of neutron candidates on Y-axis and vertical position on X-axis.

- Expect to see more activity at the top
- Good agreement between data and MC, except at the edges
- Possible inefficiency at the top of the detector
- Excess neutron candidates at the bottom, in data

The fit parameter, β = 0.74

Note: Also see the machine-learning-based analysis result (done by L. Uboldi and P. Sala, CERN)

Conclusions

- Key features in Data are also seen in Monte Carlo simulations
- Used DBScan to remove cosmic backgrounds
- Used MC Simulations to fit Data
- Need to know why there is an inefficiency at the top of the detector

To Do List:

- Need to associate gammas to single neutron captures
  - Plan to use machine learning techniques to identify neutron captures
- Energy reconstruction of the single neutron captures

Back Up Slides

Cosmic Removal Using Pandora

Run Number: 11711 – Pulsed Trigger Run (E = 350 V/cm Field)

- Using Pandora to tag track hits and shower hits
  - Using "pandoraTrack" and "pandoraShower" modules

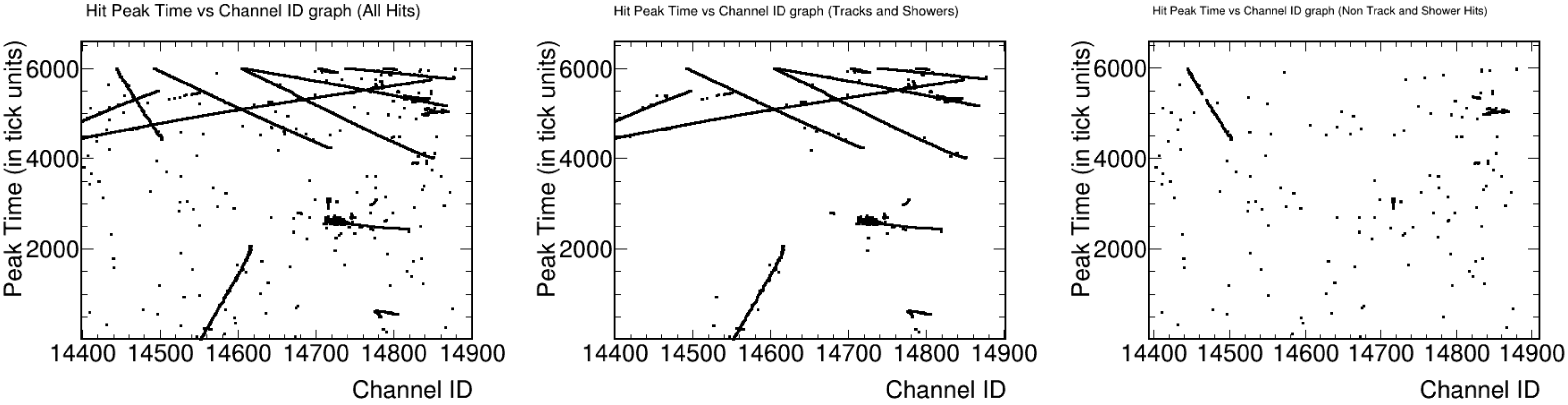


Fig. Peak Time vs Channel ID plot for one event. Hits tagged as Track or Shower are removed. It is not perfect, but it does a good job at removing cosmics.

Cosmic Removal – Hits near Tracks

- We want to remove/tag hits which are within 20cm from a track/shower hit
- Wire Pitch is 4.7mm; This turns into ± 42 Channel ID
- Electron Drift Velocity is 0.16 cm/µs and sampling rate is 2 MHz; This turns into ± 250 tick units in Peak Time

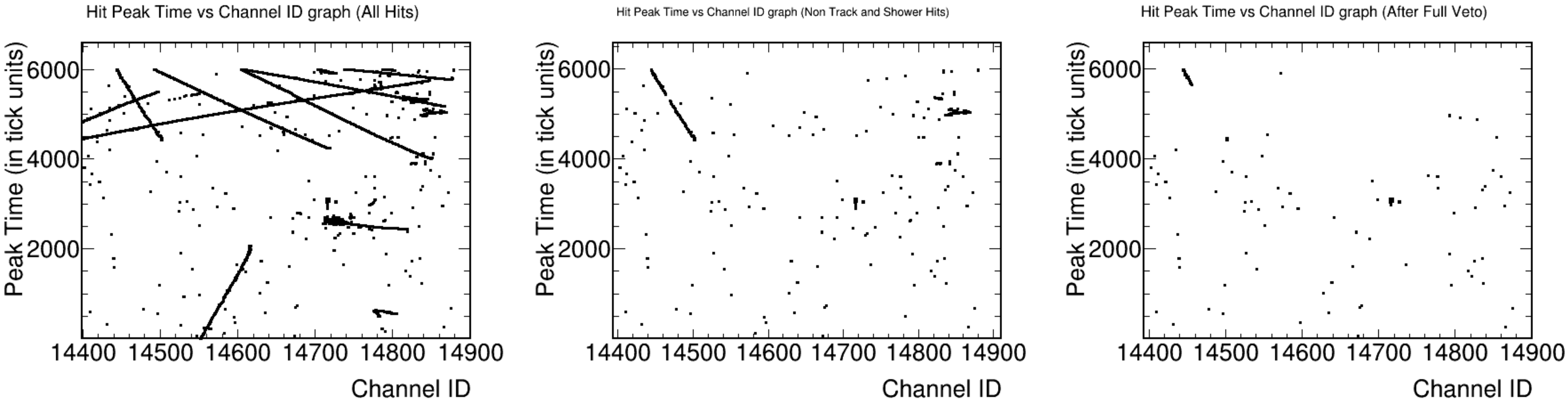


Fig. Peak Time vs Channel ID plot for one event. Hits tagged as Track or Shower are removed. Additionally, all hits within 20cm of a track/shower hit

Argon Resonant Transport Interaction Experiment (ARTIE)

- Experiment to measure the depth of the anti-resonance section at 57 keV in the neutron-argon total cross section

Neutrons →	LAr Target	Vacuum	Detector

- Cross section is calculated using:

$$\sigma(E) = -\frac{m_{Ar}}{\rho_{eff}\, d} \ln T(E)$$

m_{Ar} : Mass of an Ar atom

d : Target thickness

ρ_{eff} : Effective density of Ar

$T(E)$: Transmission Coefficient