Results from the Neutron Generator Test at ProtoDUNE

PNS & PDS Meeting
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Yashwanth Bezawada (Yash)
Junying Huang
University of California, Davis

OUTLINE

- Pulsed Neutron System
- DDG Test at ProtoDUNE
- Clustering Using DBScan
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- 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

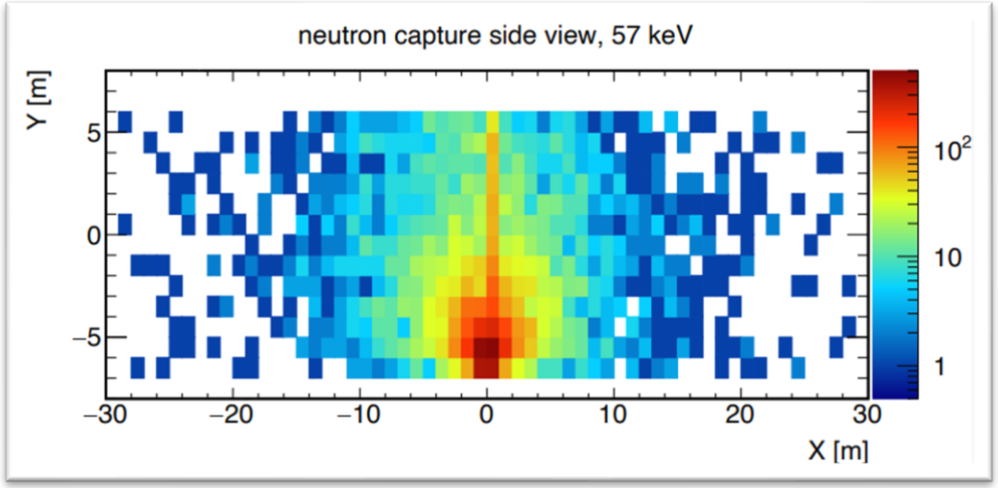


Fig. (left) Simulated spread of 57 keV neutrons in the DUNE-size module (work done by J. Wang)

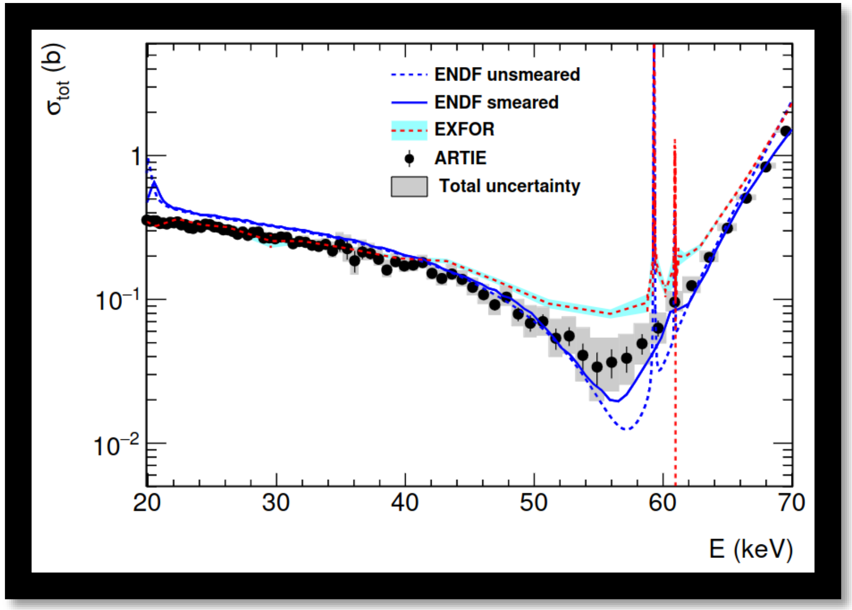


Fig. ARTIE results for the neutron cross section in liquid argon at the anti-resonance dip

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

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

How can we use Neutrons?

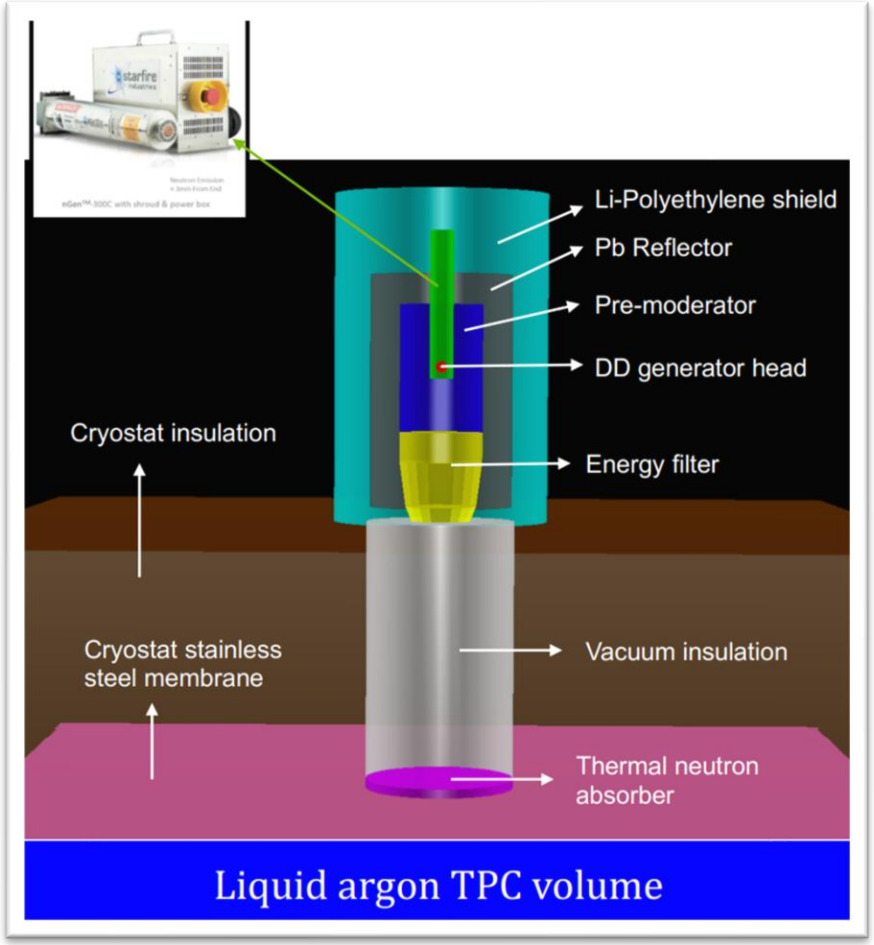


Fig. A schematic of the proposed PNS system
(Investigating a simplified design)

Pulsed Neutron Source (PNS)

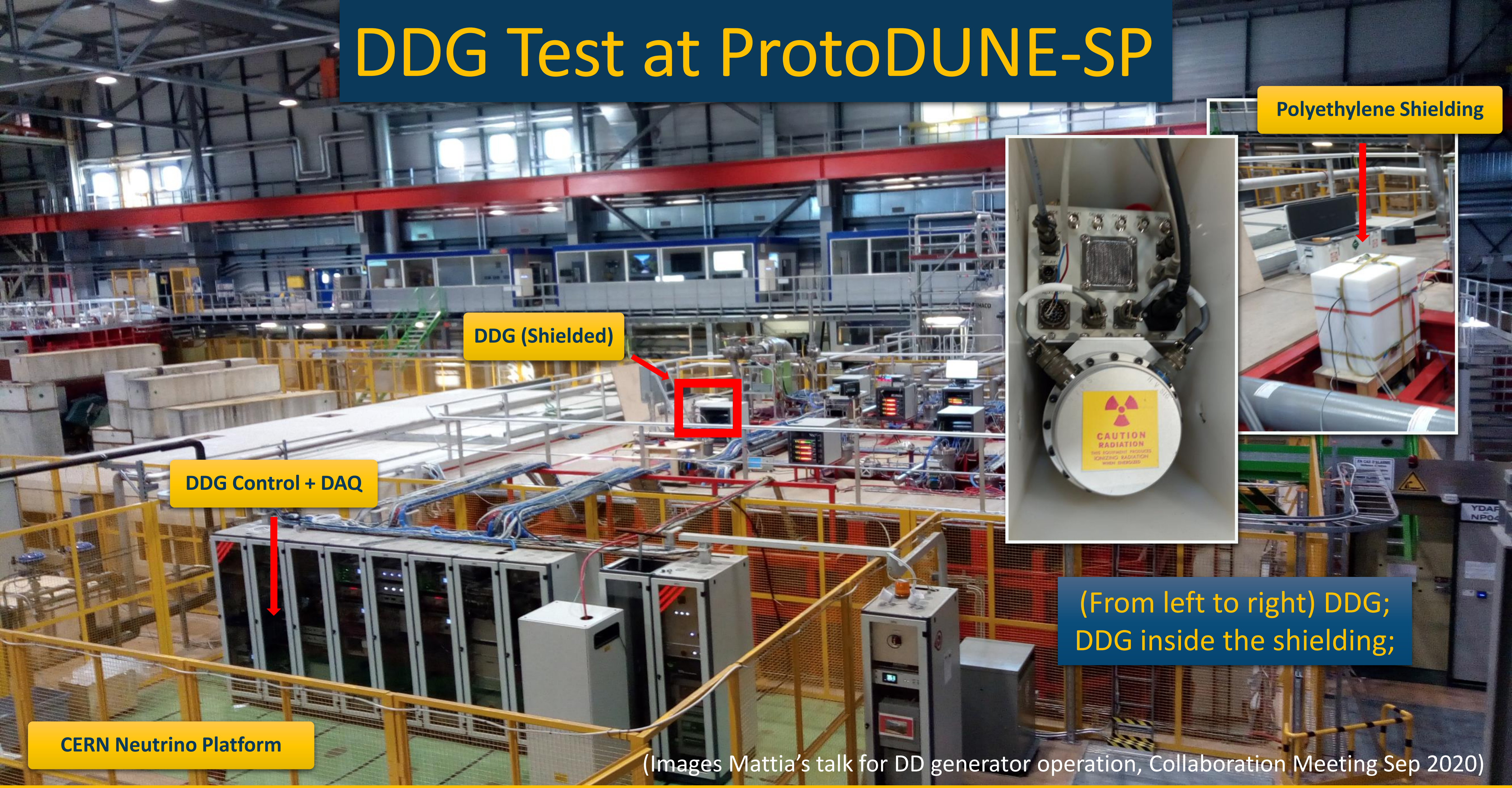
Deuterium-Deuterium neutron generator (DDG) produces 2.5 MeV neutrons

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

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

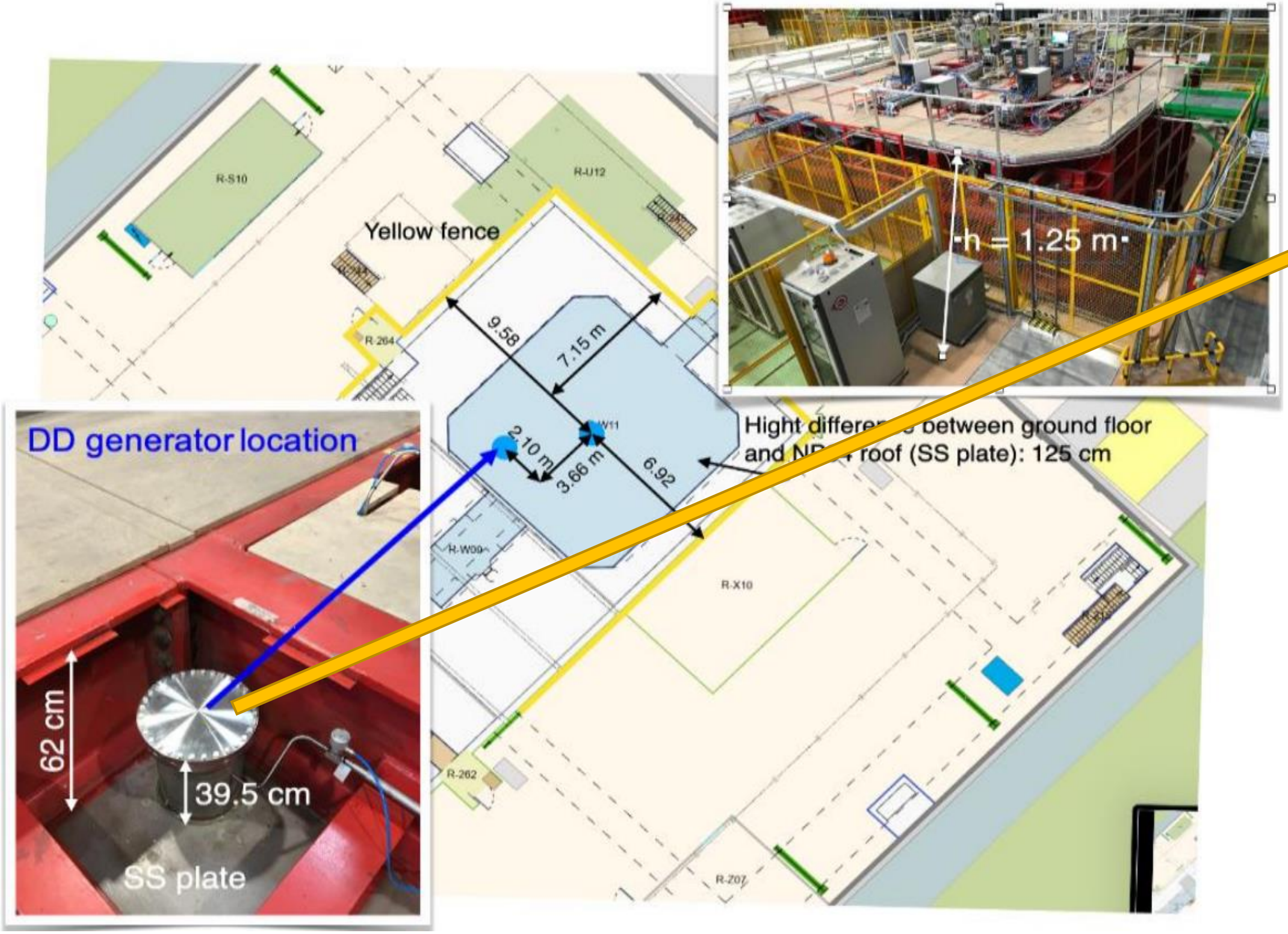
DDG Test at ProtoDUNE-SP



(From left to right) DDG; DDG inside the shielding;

(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 was deployed at a roof feedthrough port 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 **Run 11669**
  - 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): **Run 11711**
  - 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)

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
```

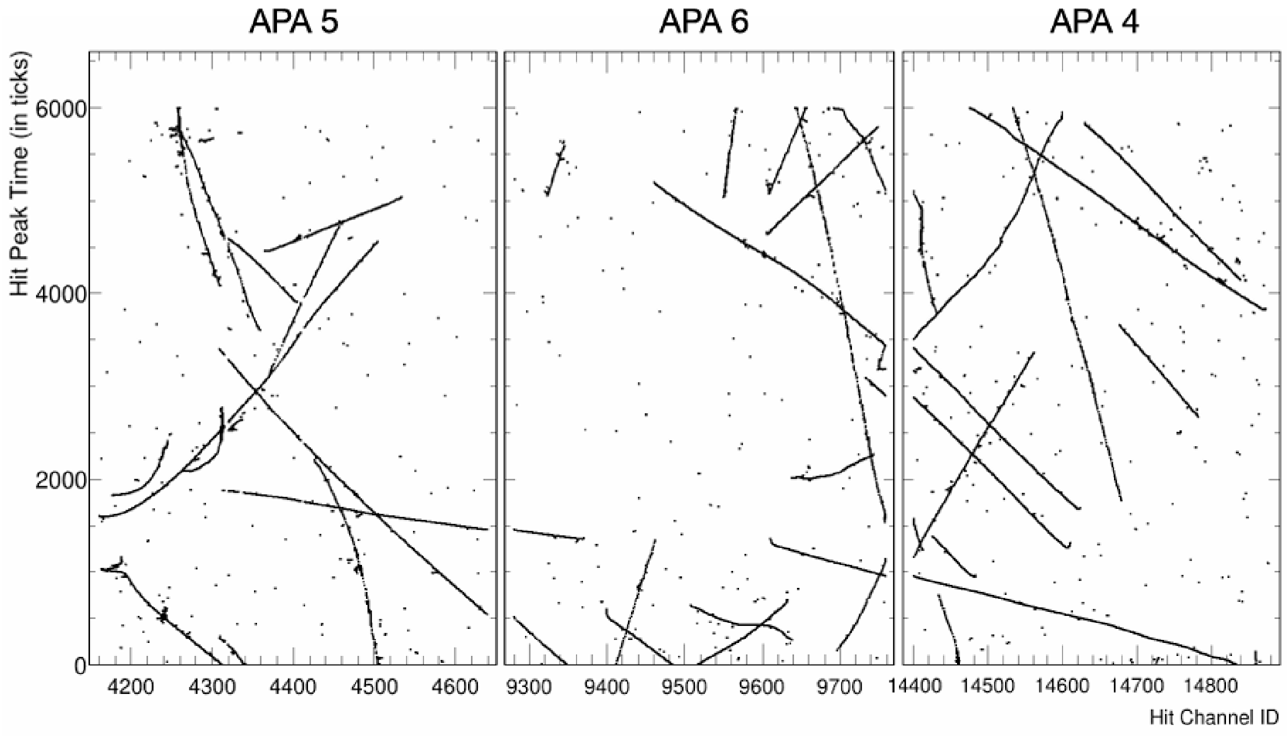


Fig. Hits from the collection planes (APAs 4, 5, and 6) for an event in the run 11669 (DDG-off).

APA-5 is the nearest to the DD Generator

Spacepoint Clustering Using DBScan 3D

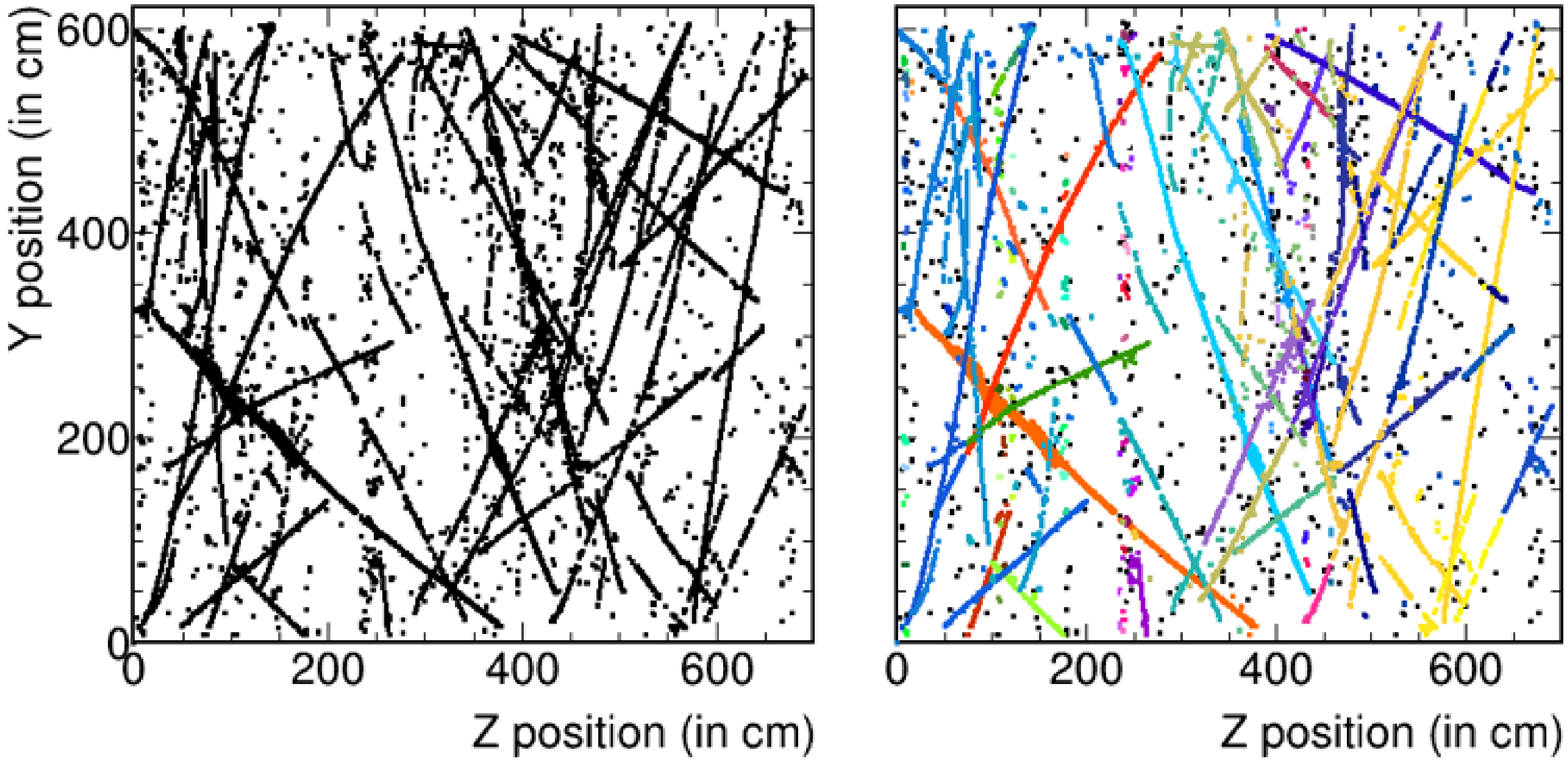
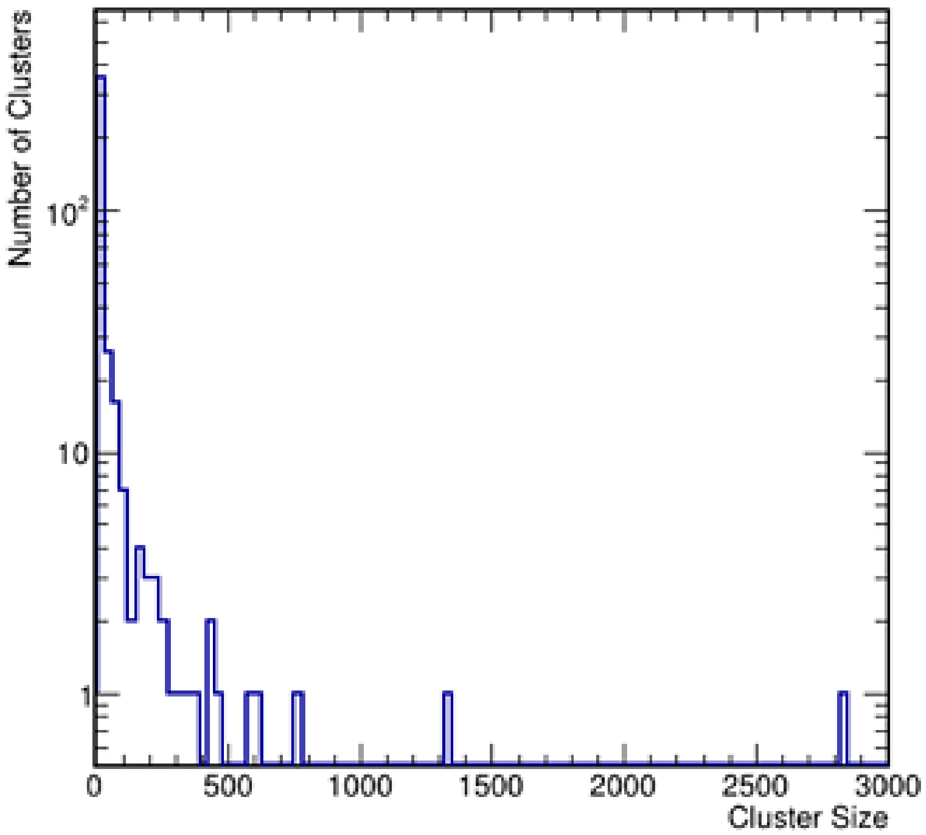


Fig. Y-position vs Z-position plots of the SpacePoints from one event.

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

Size Distribution of the Clusters



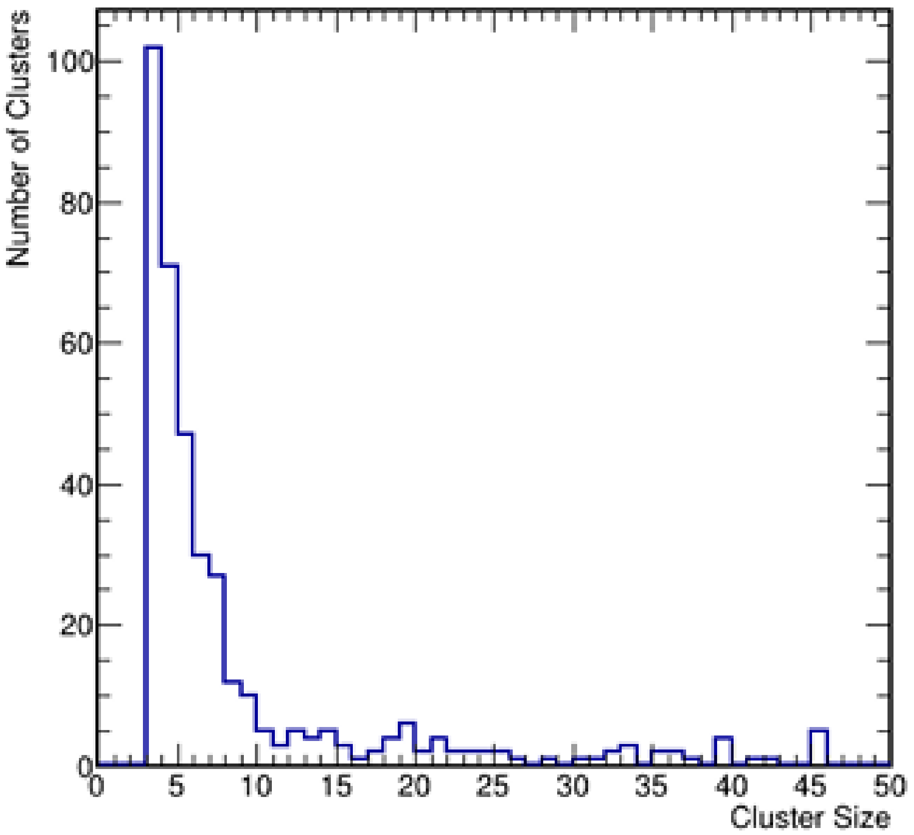
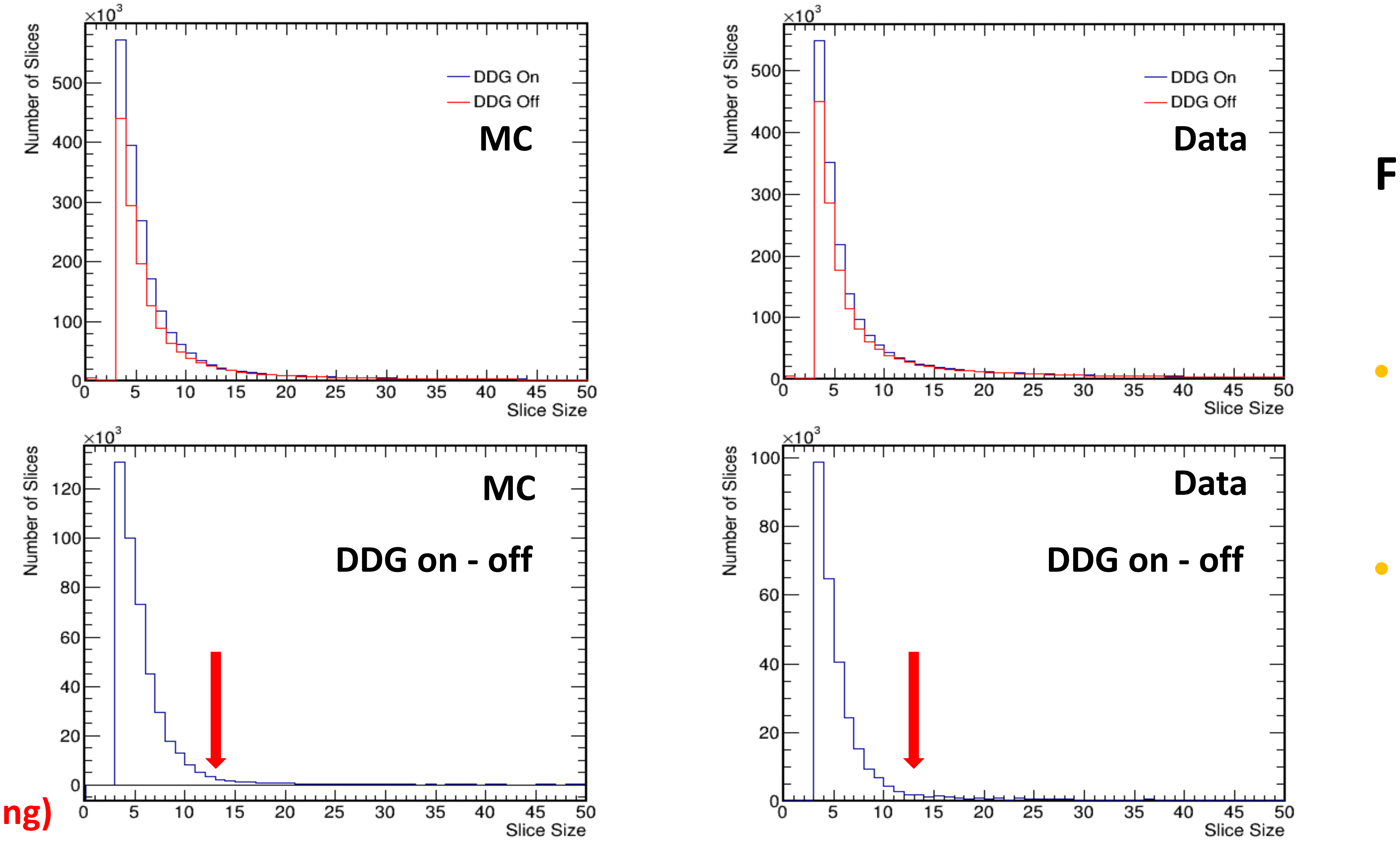


Fig. Above plots show the size distribution of size distribution of clusters in one event.

Determining the Slice Size Cutoff

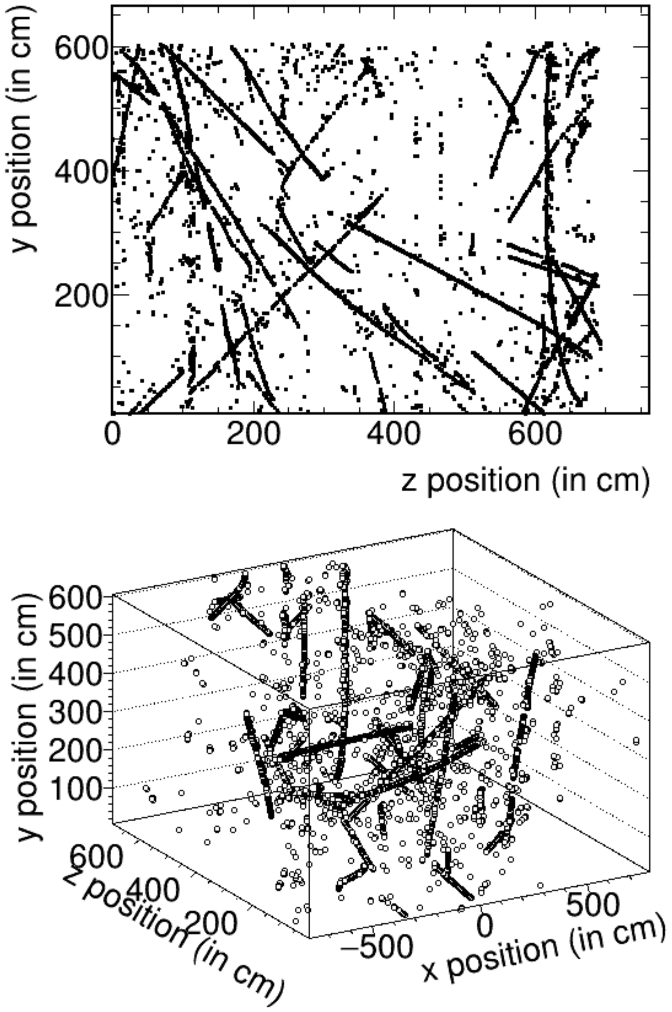


(Junying)

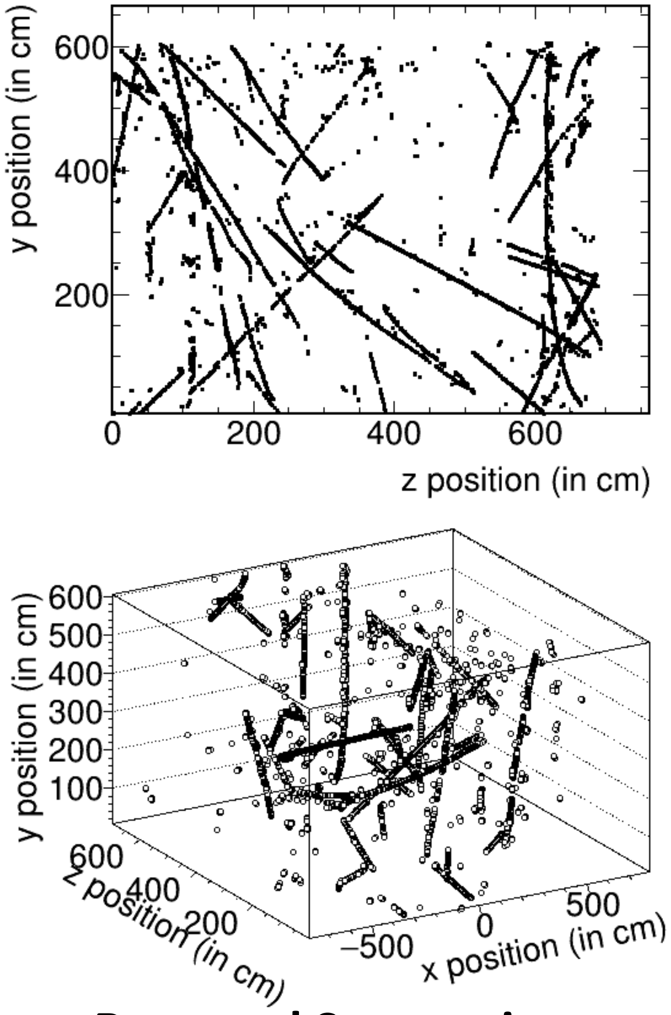
Fig. Slice Size vs Number of Slices Plots

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

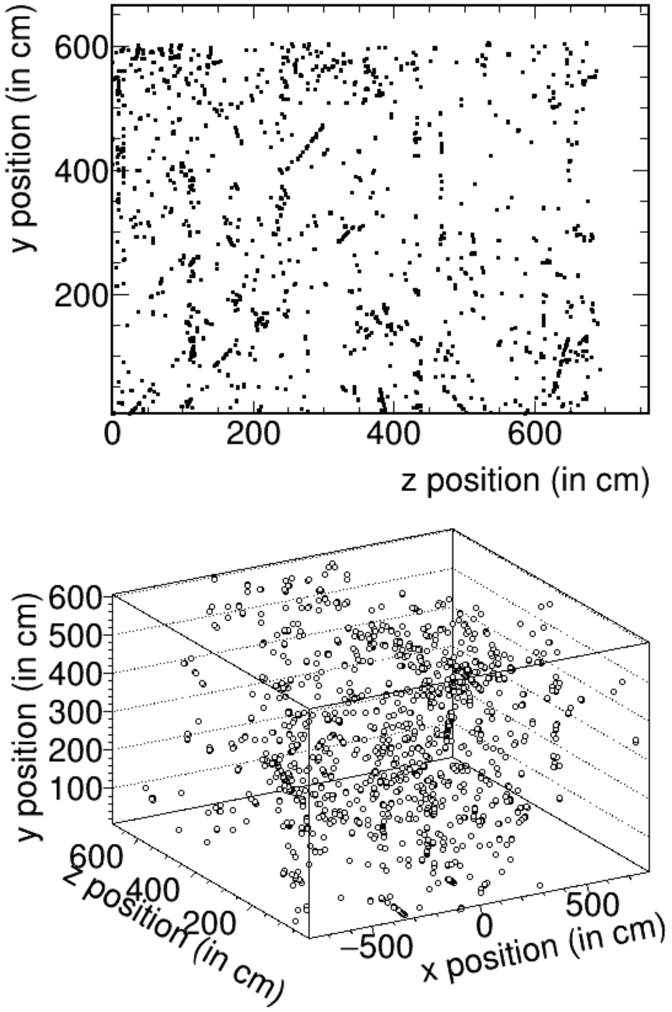
Removing Cosmic Backgrounds



All Spacepoints

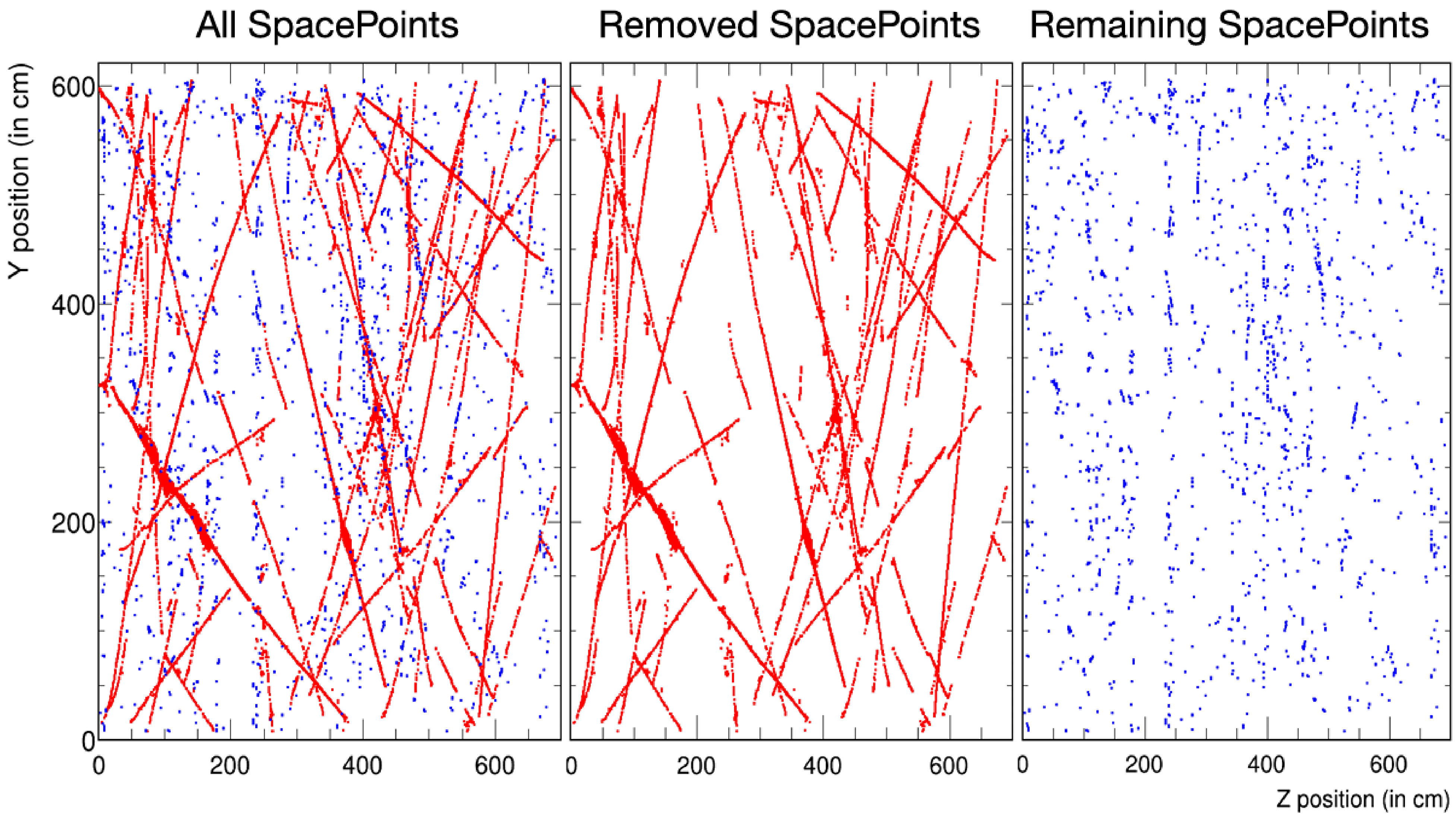


Removed Spacepoints (Slice Size > 13)



Remaining Spacepoints (Slice Size <= 13)

Removing Cosmic Backgrounds



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)

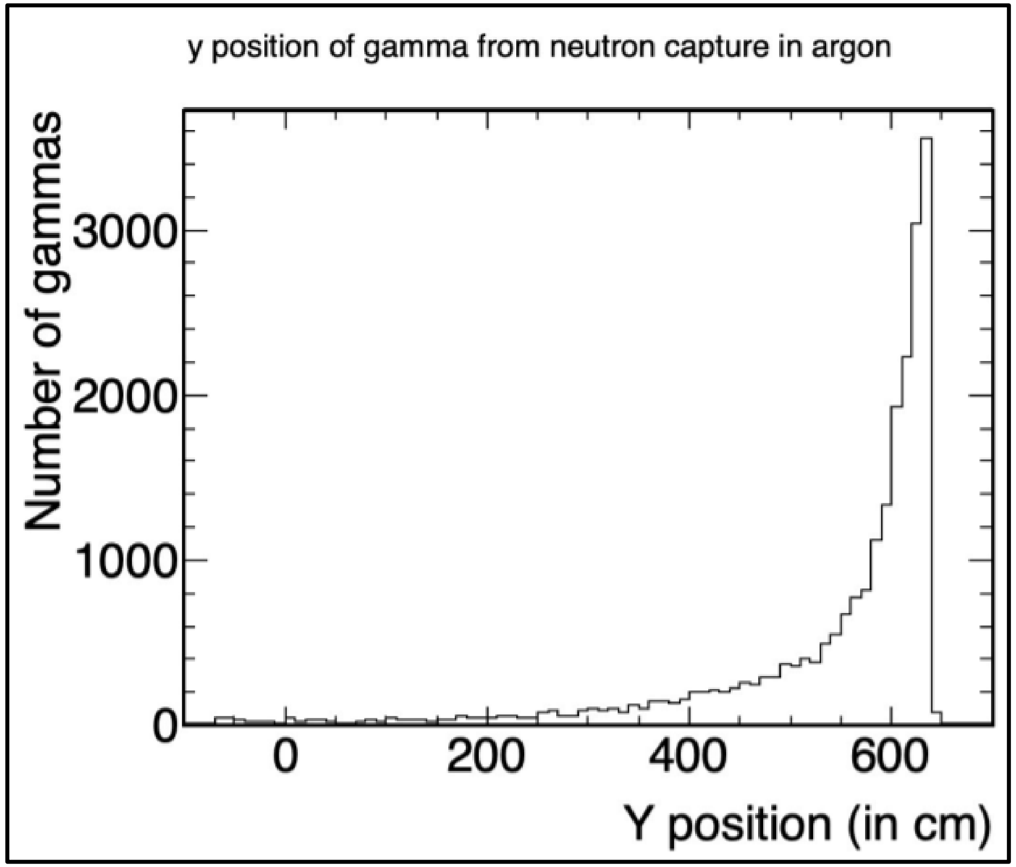


Fig. Simulation confirms that gammas from neutron capture are seen

Comparing Data and Simulations

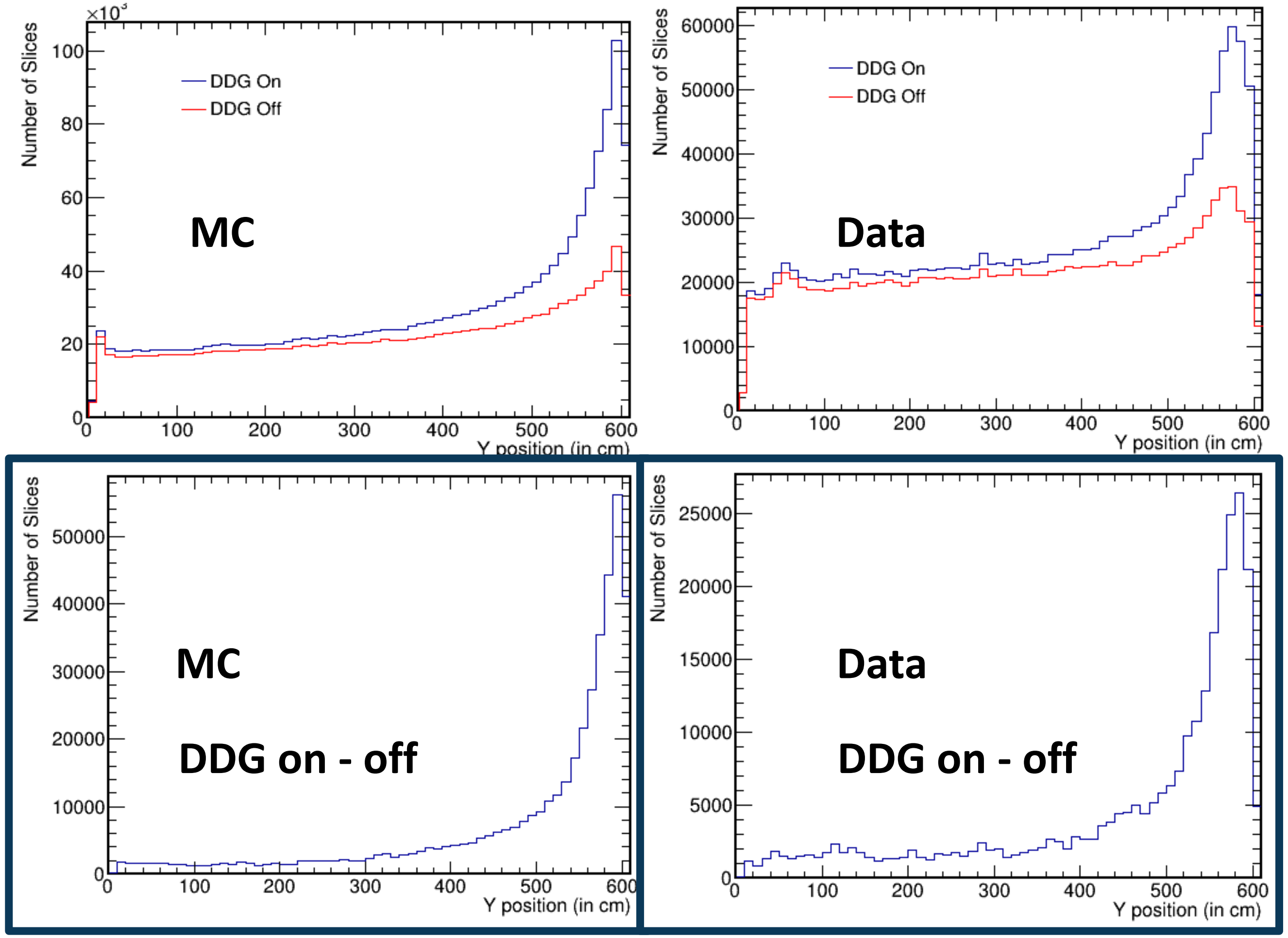


Fig. Number of Slices on Y-axis and vertical position on X-axis.

- 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?

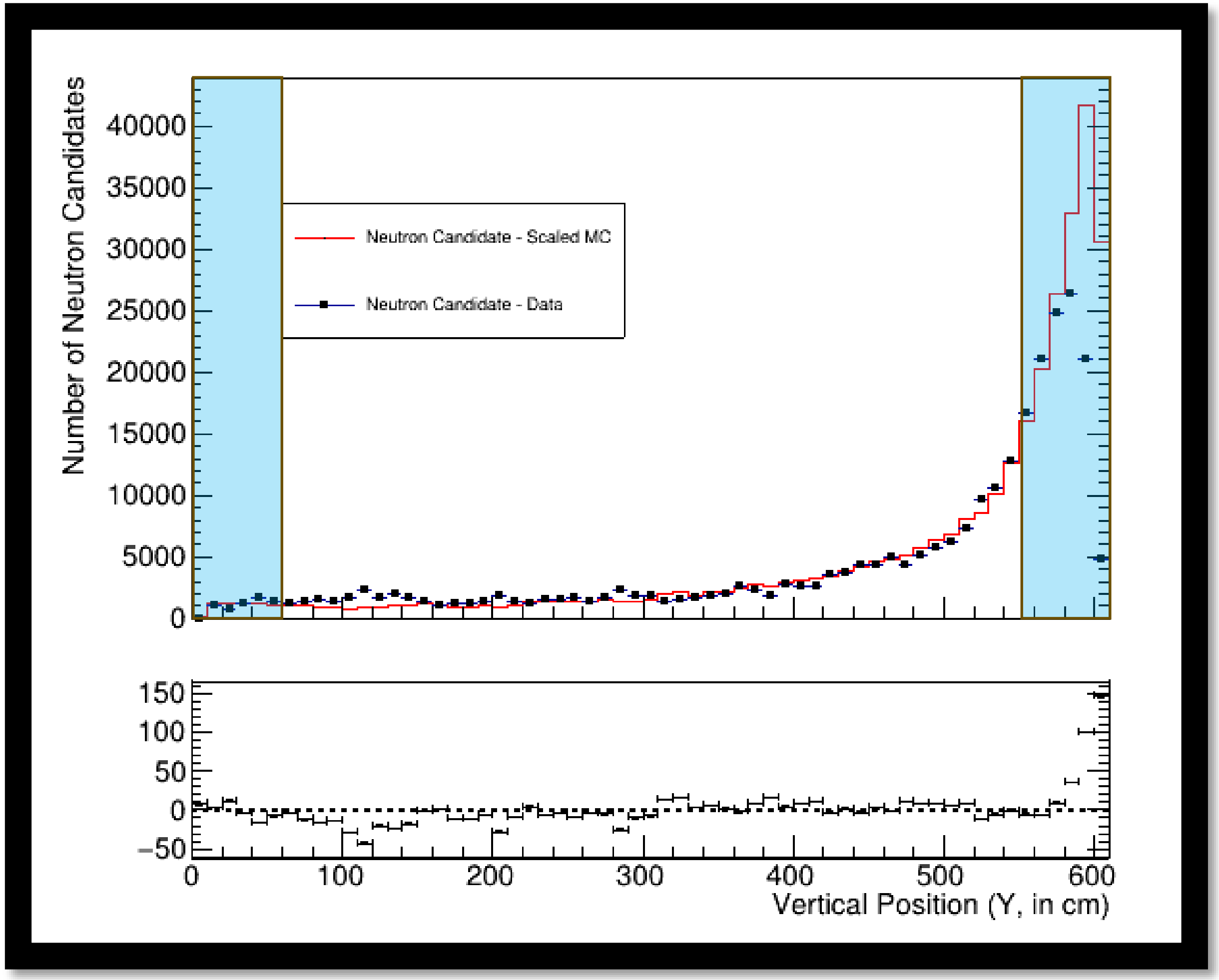


Fig. Plot with data and the fit. Number of neutron candidates on Y-axis and vertical position on X-axis.

- Fit parameter was β = 0.74
  - Simulations overestimate number of clusters in an event
- 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

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

Conclusions

- Used MC Simulations to fit Data
- Key features in Data are also seen in Monte Carlo simulations
  - Large number of clusters at the top
  - Long attenuation tail
  - Neutrons do reach the bottom of the protoDUNE detector
- Need to know why there is an inefficiency at the top of the detector
- Need to identify the full gamma cascade or individual gammas from a single neutron capture on Ar-40