Region of interest (ROI) filter optimization for the DUNE data acquisition system

Matthew Man,
On behalf of the DUNE Collaboration

matthew.man@utoronto.ca
May 28th, 2024

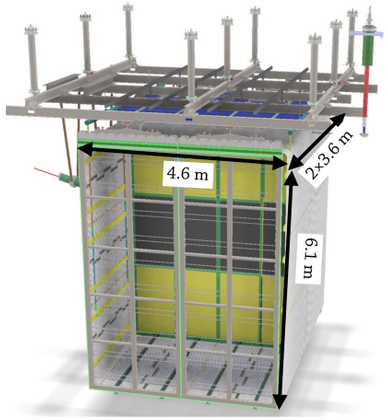
FPCP 2024

DUNE

Broad program of physics:

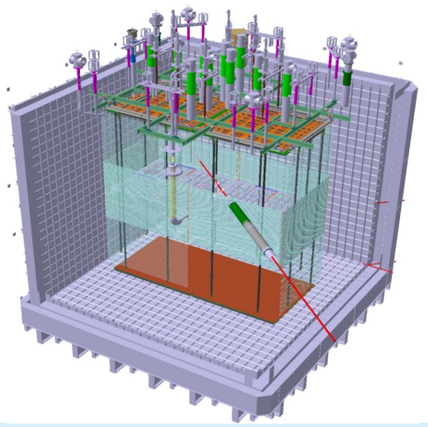
- precision neutrino oscillation measurements
- MeV-scale neutrino physics
- searches beyond the Standard Model

ProtoDUNE – prototypes of 2 far detector (FD) modules, at CERN



ProtoDUNE HD

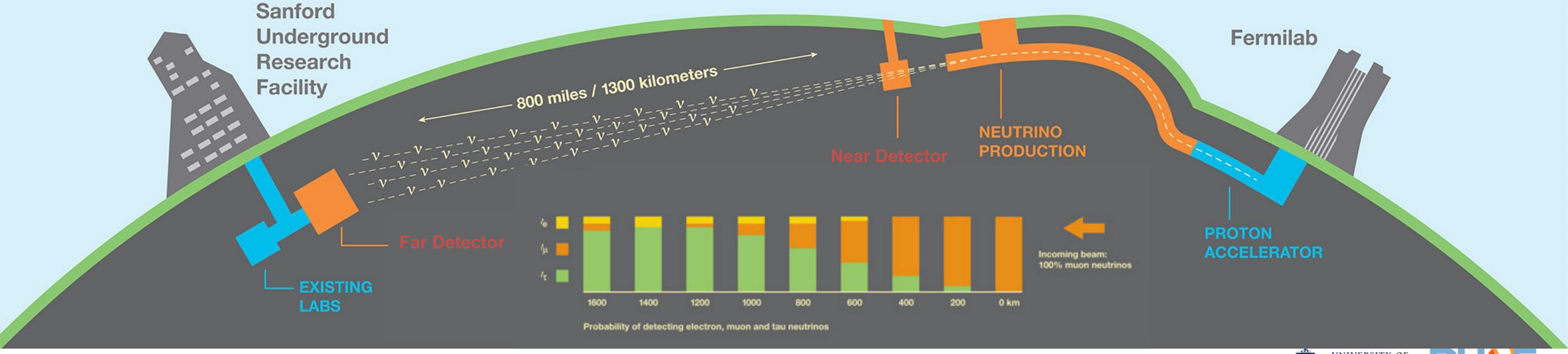
ProtoDUNE VD



Far Detector – Liquid Argon Time Projection Chamber (LArTPC) at SURF.

- Horizontal drift (HD) technology
- Vertical drift (VD) technology

High-intensity neutrino beam, and **near detector** complex at Fermilab.



UNIVERSITY OF TORONTO

Motivation – data selection constraints

Untriggered, the FD HD module has a data volume of ≈1.4 TB/s (FD VD ≈1.8 TB/s).

DUNE's storage limit is ≈30 PB/year for all FD modules.

So **DAQ is responsible for data reduction on the order 10^4**.

This is why we need the trigger.

Triggering on beam events in not a problem (through external beam window trigger).

The challenge is capturing a wide range of physics, including interesting low energy physics, without being swamped by backgrounds.

- Solar boron 8 neutrinos are important part of DUNE's low energy program, but argon-39 for example has a similar signature, and so acts as a background

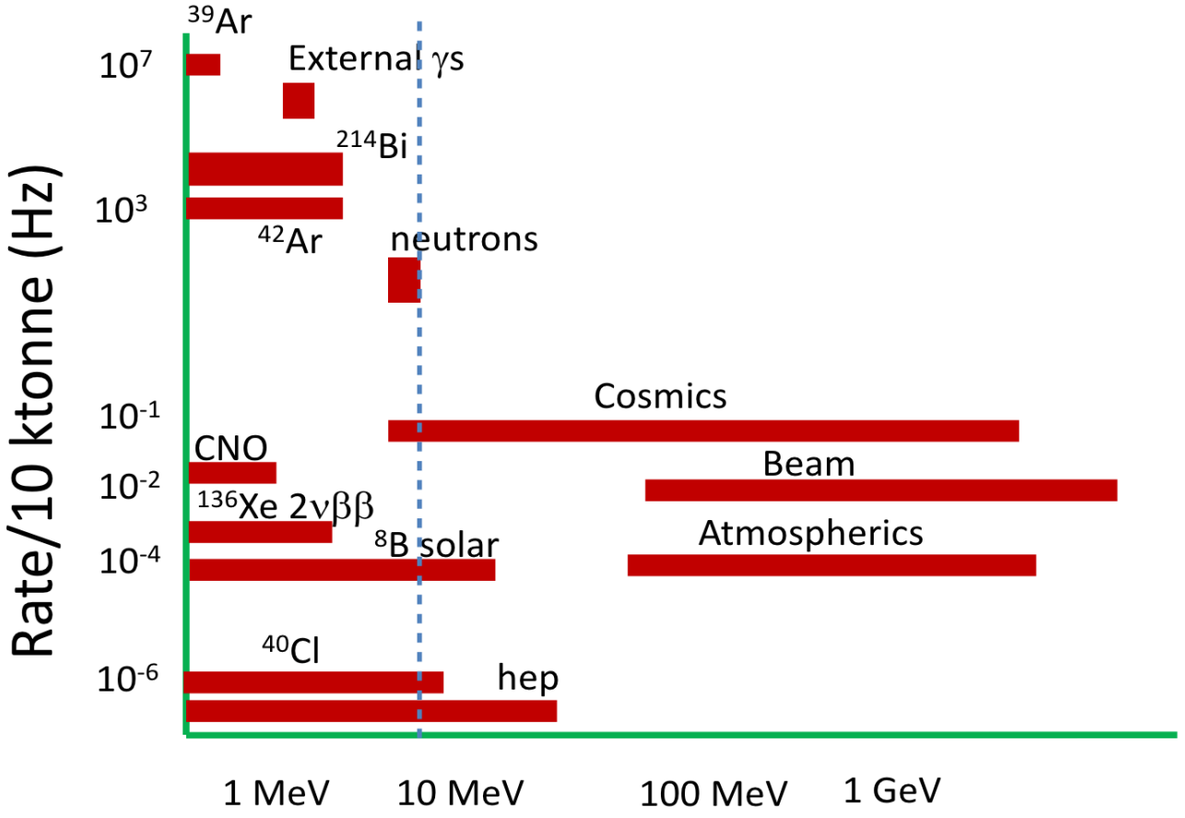
https://indico.fnal.gov/event/57752/contributions/260312/

Goal

- DUNE low energy physics program specifies threshold of 5 MeV
- DAQ specification for low energy trigger threshold >10 MeV
  - Lower is possible at reduced efficiency

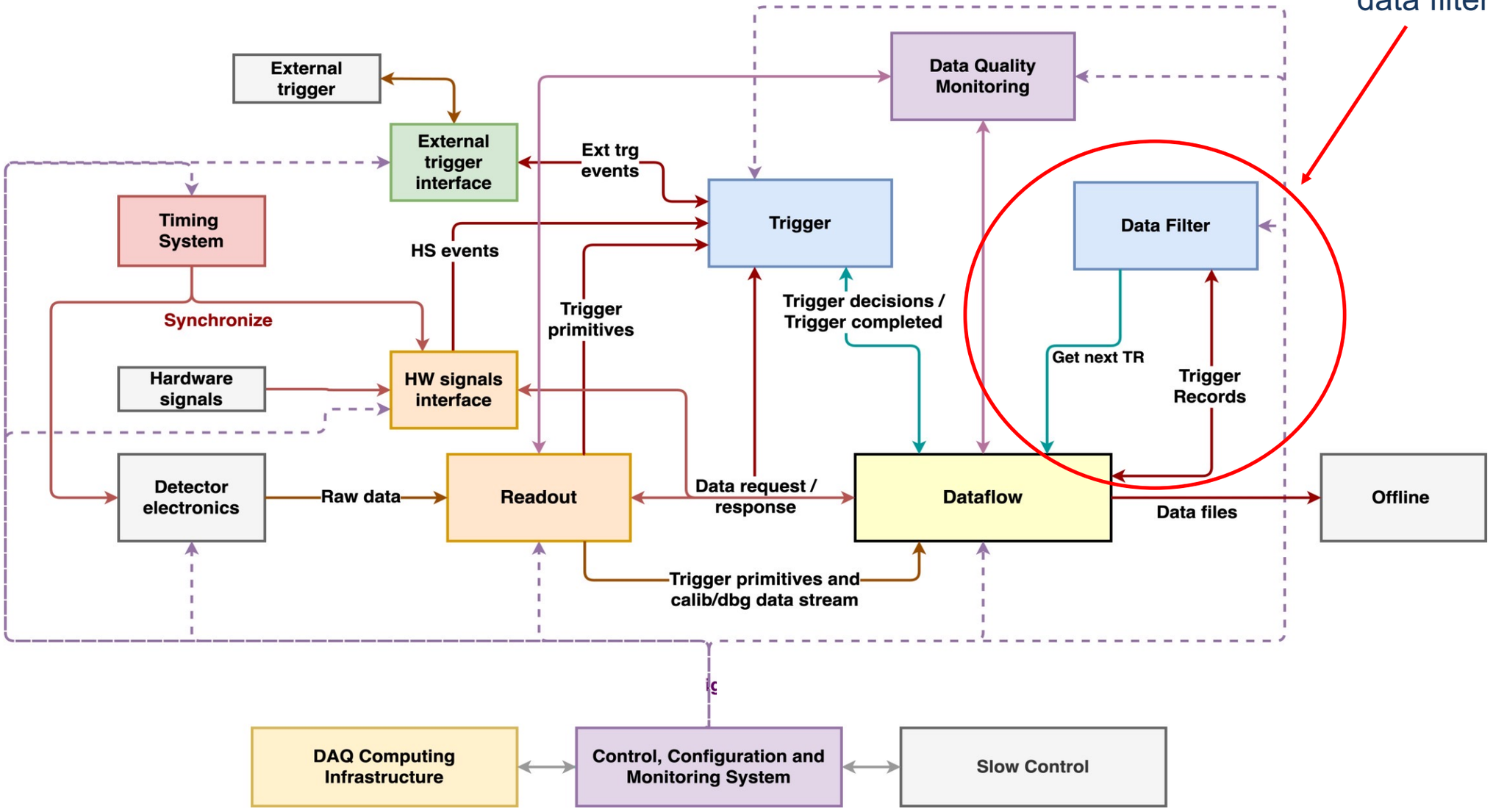
- Activity below ~10 MeV dominated by background, by orders of magnitude

- **Region-of-interest** readout
  - Applies on raw detector signal
  - This study considers **solar boron 8 neutrinos**
  - **ROI attempts to reduce data bandwidth to allow more low energy physics to be kept**



The data acquisition (DAQ) system

ROI will go in the data filter

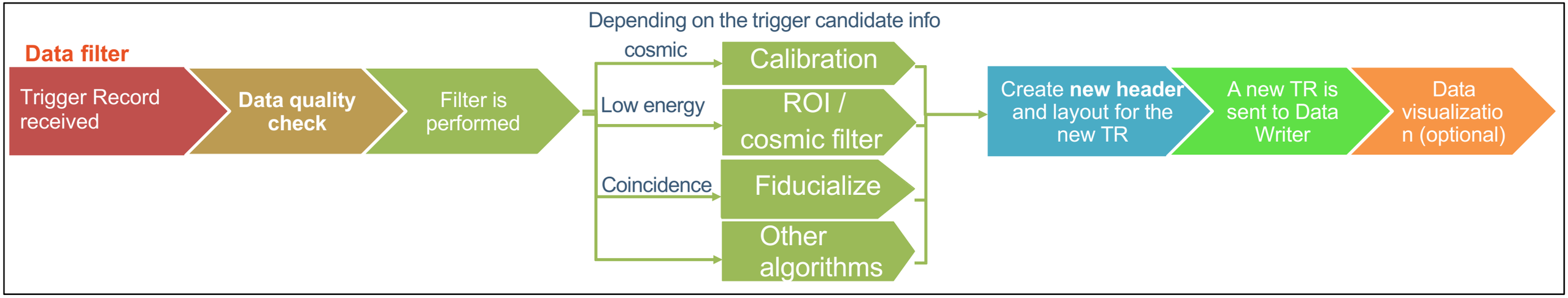


For more details see DAQ talk: https://indico.cern.ch/event/1291023/contributions/5866459/

Data Filter

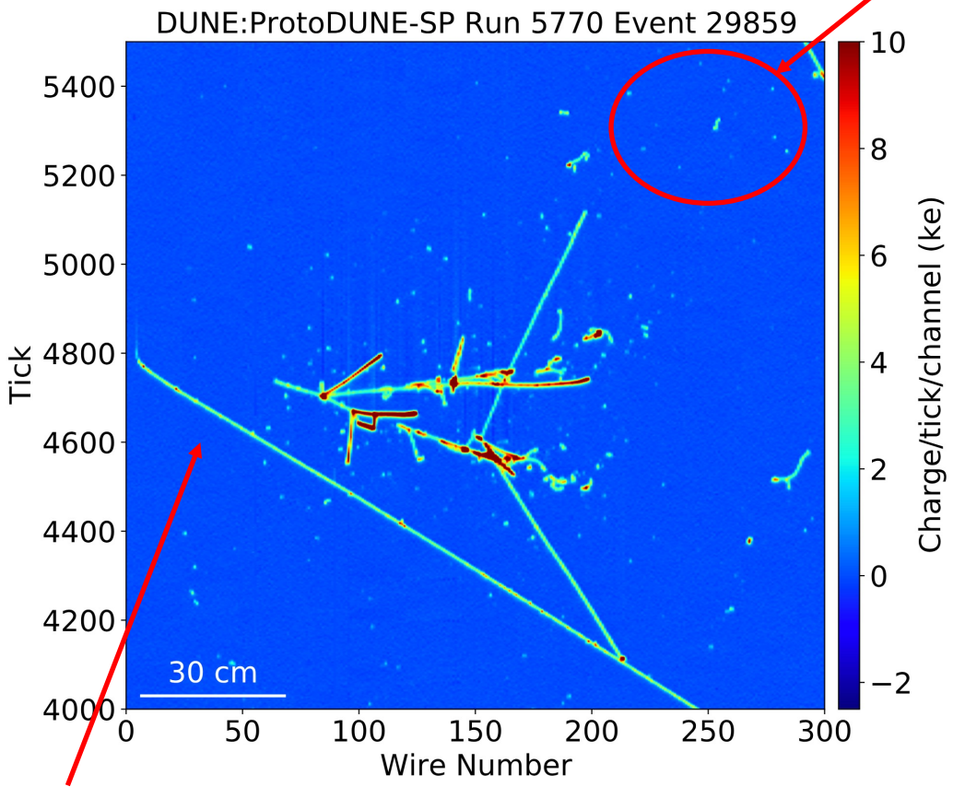
The Data Filter has several possible roles:

- Additional reduction (beyond Trigger) of data volume to disk to fit within DUNE's 30 PB/year storage allocation.
- Removal of instrumentally generated "garbage" events (eg. high-voltage 'streamers').
- ROI filtering to optimizing DAQ for low energy physics such as Supernova & Boron 8 neutrinos.
- Filtering of event classes used for calibration monitoring (e.g. 39 Ar events) after some processing is done.
- Other high-level processing tasks that can help filter the data.



LArTPC

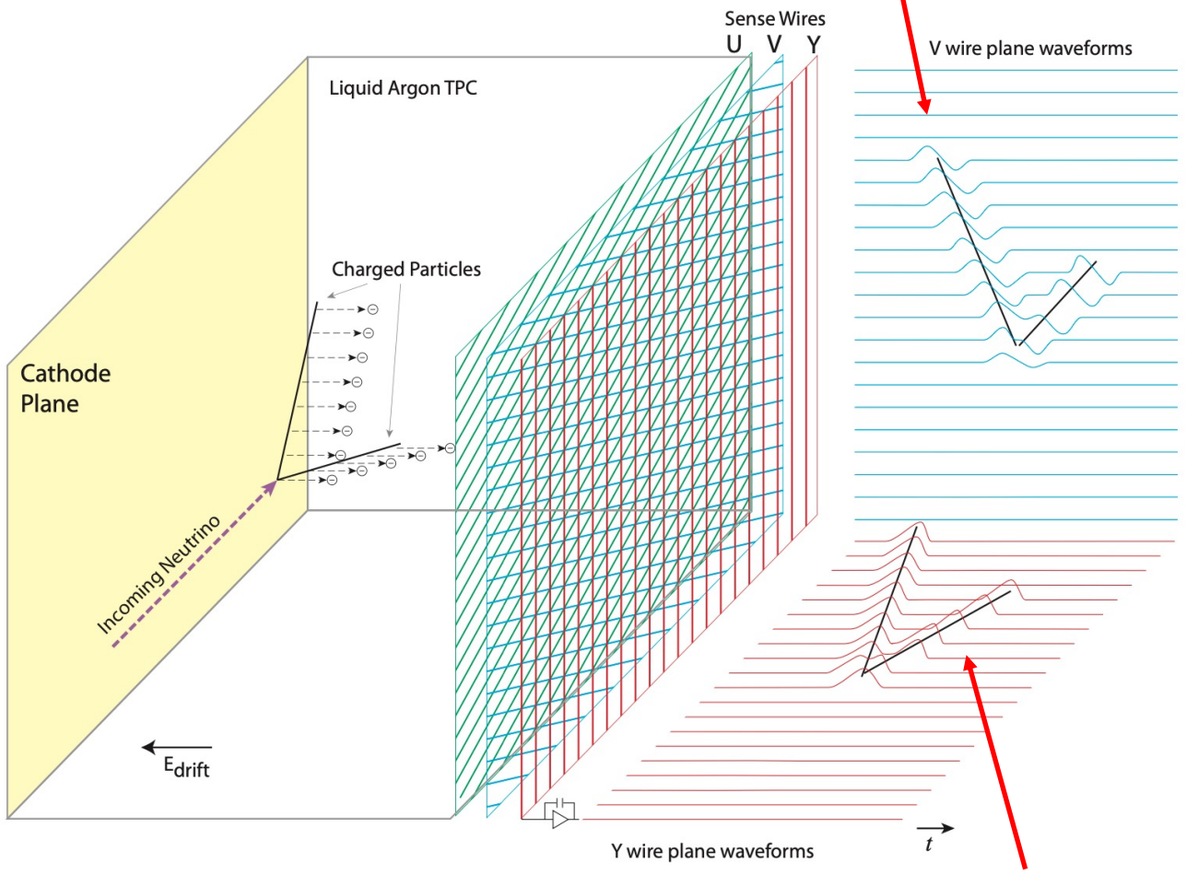
Low energy blip signature



High energy track signature

1 tick = 500 ns

Induction plane bipolar signal

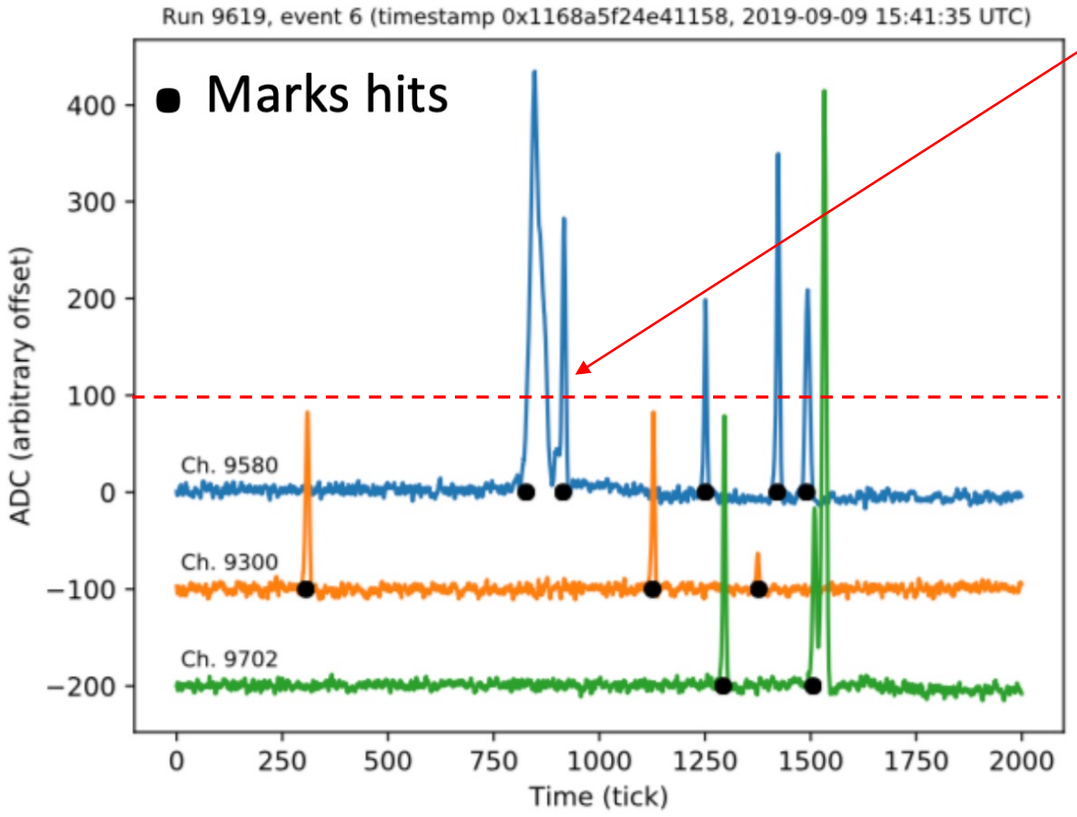


Collection plane unipolar signal

https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004

ROI details

Eg. blue waveform, threshold=100 ADC counts (above baseline), triggers ROI



Single channel level ADC waveform thresholding

The ROI algorithm is threshold based. When a channel goes above an ADC peak threshold, ROI is applied

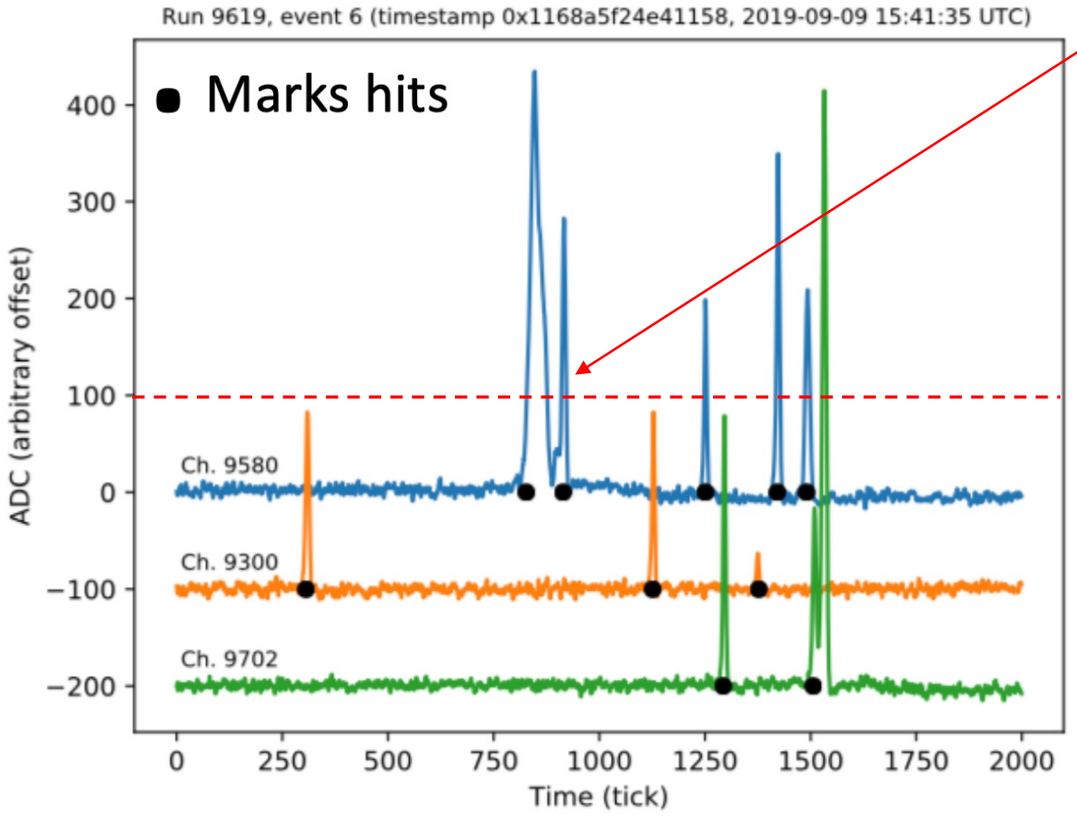
- Outside the ROI is zero suppressed

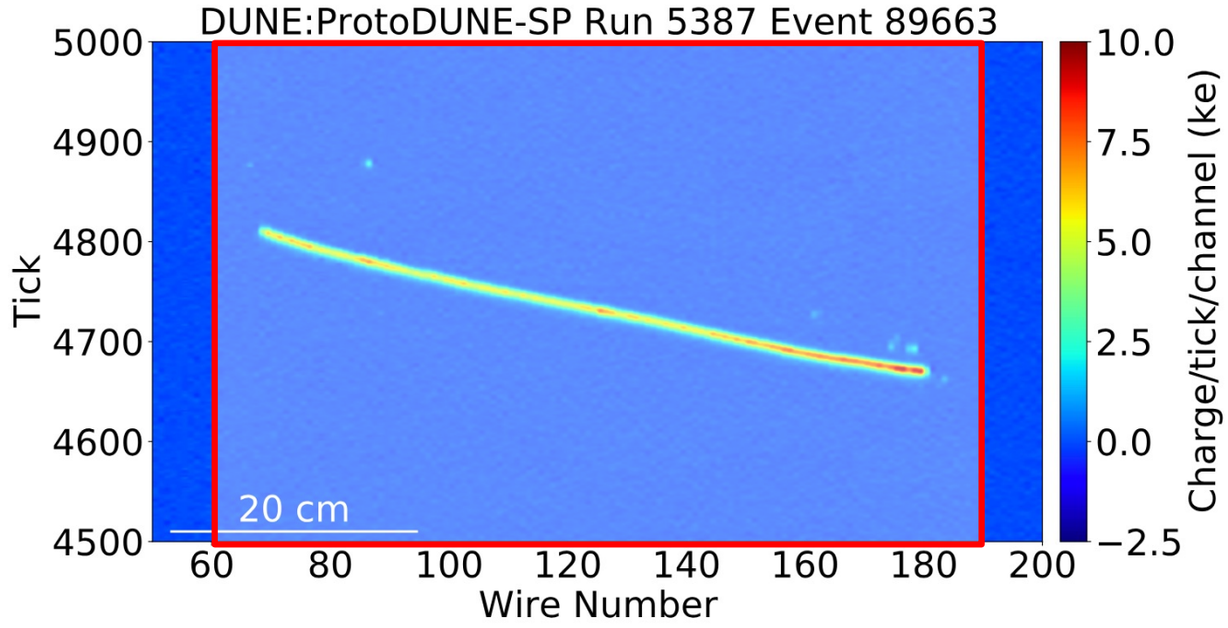
Tunable parameters are the **threshold**, and neighboring **channel width**

- Neighboring channels stored, width of 10 channels on each side
  - Effective induction range for a point charge
- ROI time window is **nominal drift length time ~3 ms**
  - Reducing time window any further affects reconstruction performance

ROI visualization

Eg. blue waveform, threshold=100 ADC counts (above baseline), triggers ROI





Single channel level ADC waveform thresholding

Event window level ROI
- zoomed in for emphasis
- zero suppress outside ROI

1 tick = 500 ns

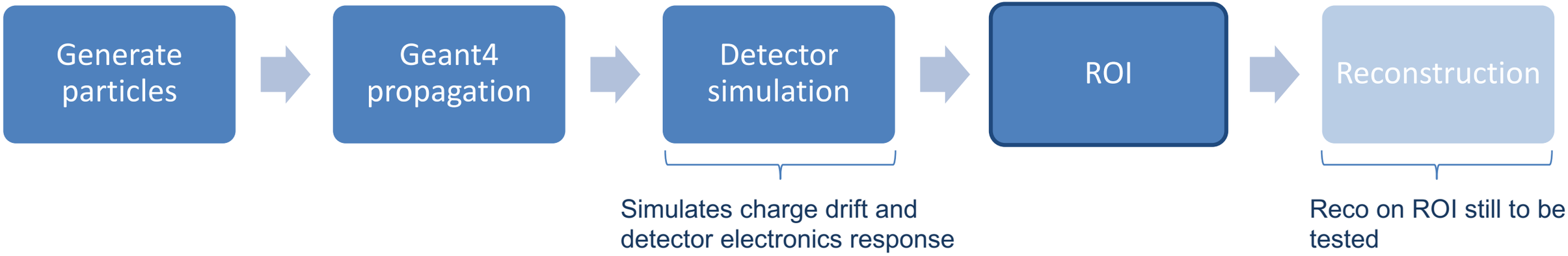
https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004

From theory to practice

Simulations

- The ROI is run in simulation to analyze performance
- 10,000 **boron 8** neutrino interactions + radiological backgrounds
  - Due to processing memory limitations, only ~1000 interactions are analyzed
  - See backup slide for list of backgrounds included

- Simulation workflow:
  - Geometry simulated is 12% of the FD HD module



ROI analysis

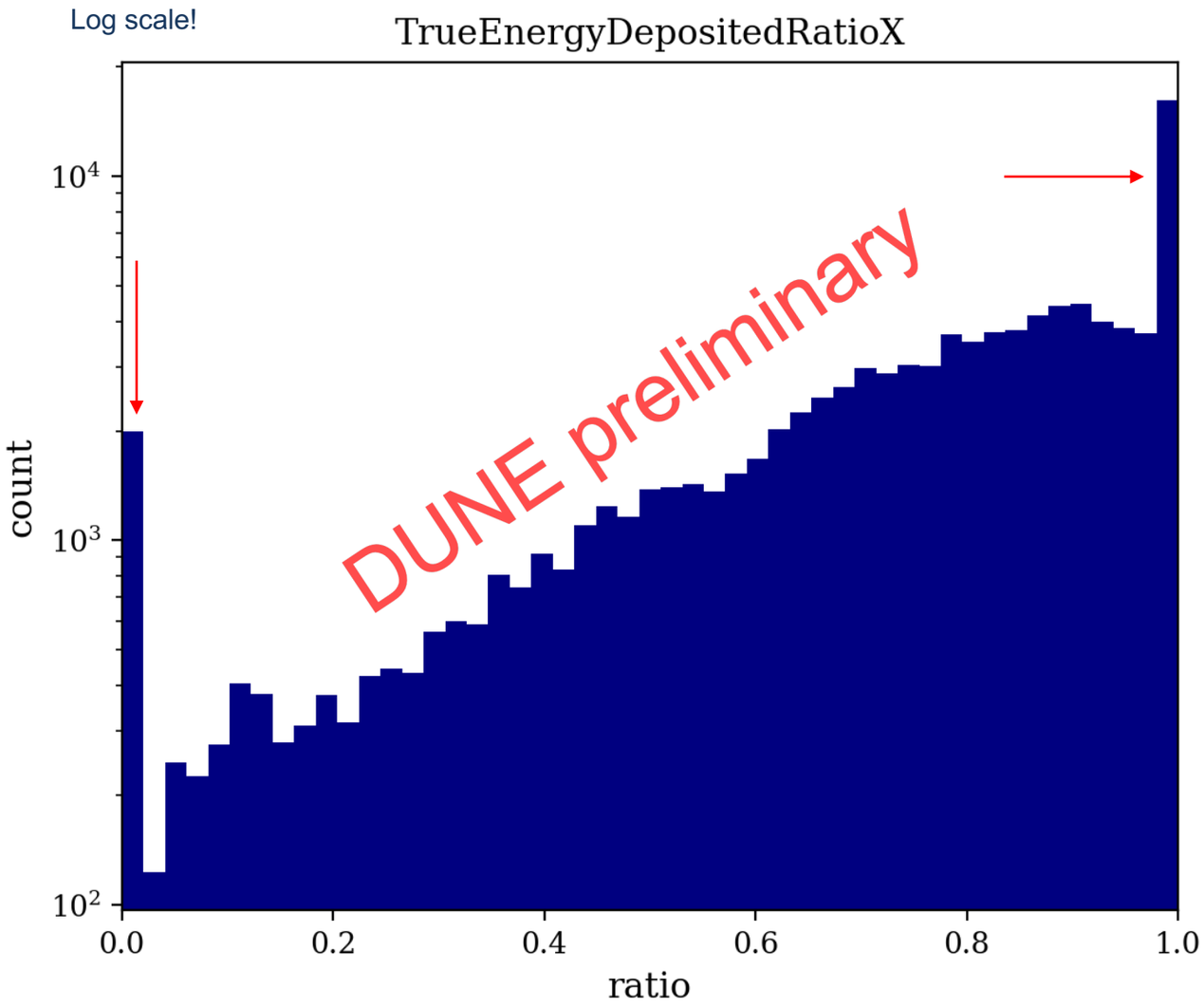
The ROI is applied in simulation to calculate various performance metrics:

- **Energy** fraction captured within ROI
- **Data reduction rate** estimate (as fraction of channels within ROI)
- **Sensitivity** to signal

Plot shows boron 8 signal on collection plane:

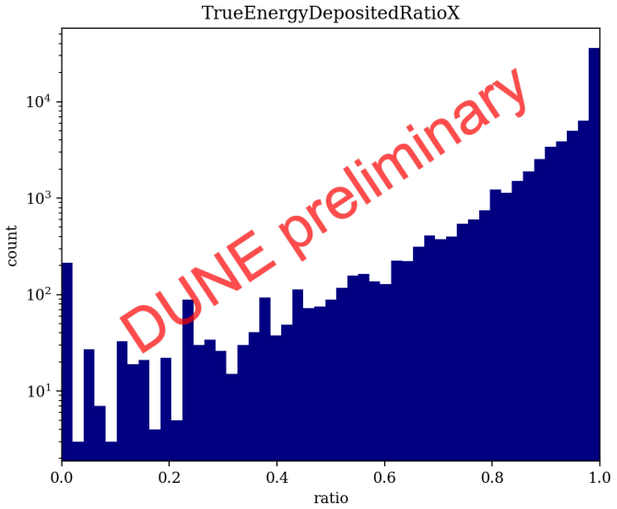
- Ratio=0 means the tracks are fully outside ROI
- Ratio=1 means the tracks are fully inside ROI

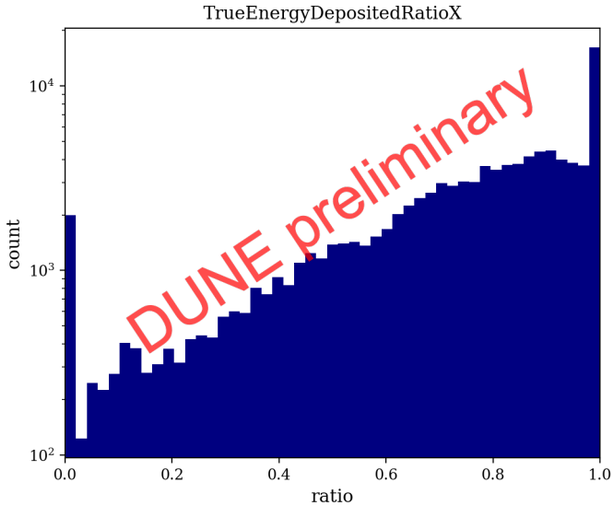
- This study is performed varying the peak threshold ADC values [50, 100, 150, 200]
  - **Threshold 100** corresponds to **1 MeV energy**

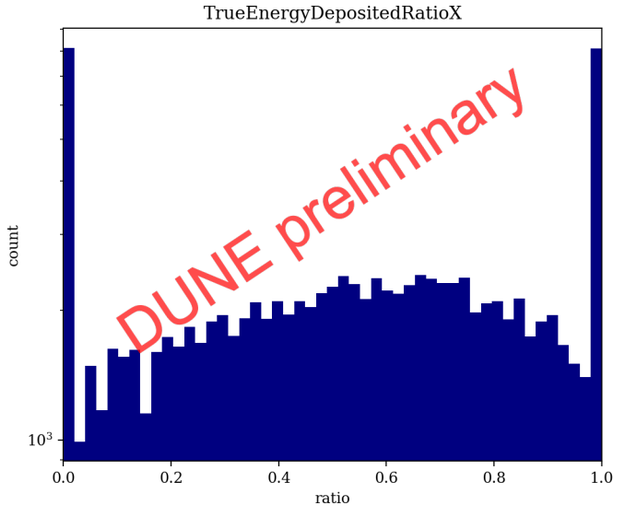


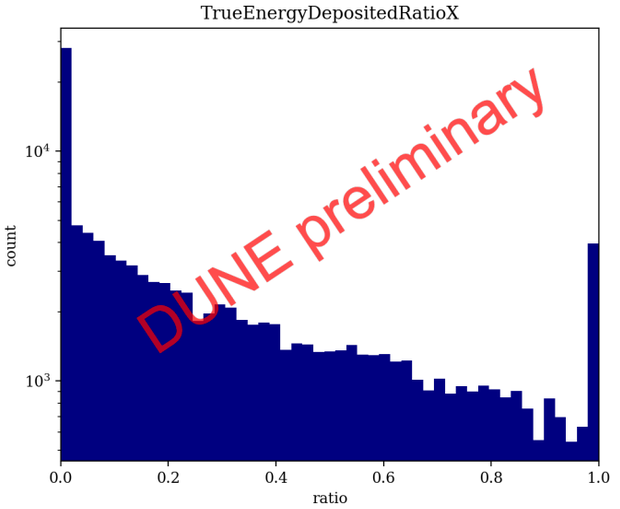
ROI performance

ROI inclusion ratio plots, varying threshold from left to right [50, 100, 150, 200]









Threshold	Data reduction rate
50	50%
100	80%
150	88%
200	95%

Future studies

The goal is to show the **energy distribution of B8 interactions and backgrounds** using the ROI.

If more background is removed than signal, then ROI can increase boron 8 sensitivity while reducing data rate.

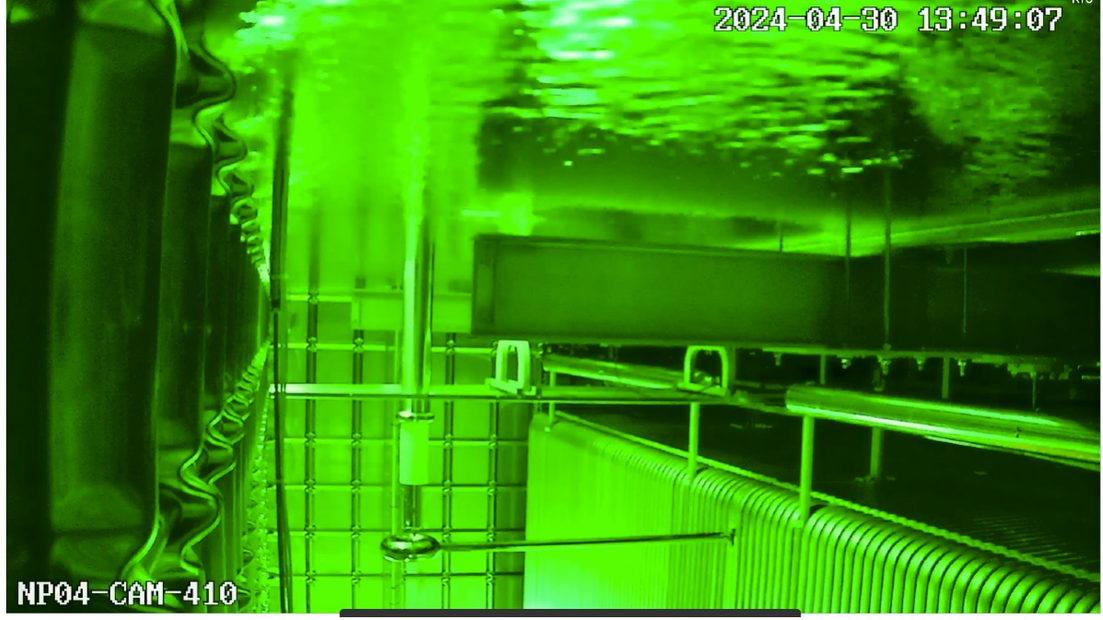
These plots are too recent and so have not been approved to be shown yet… sorry

Summary

- DUNE represents a significant scientific endeavor with the potential for groundbreaking discoveries.
- The TDAQ system is being optimized for low energy physics (~1-10 MeV) such as boron 8 neutrinos.
- Analysis ongoing to determine optimal solar boron 8 sensitivity, data reduction rate, and possible cuts that could improve performance.
- Using the ROI with a **100 ADC threshold** we can achieve an **80% data reduction rate.**

END

Thanks for your time!!!



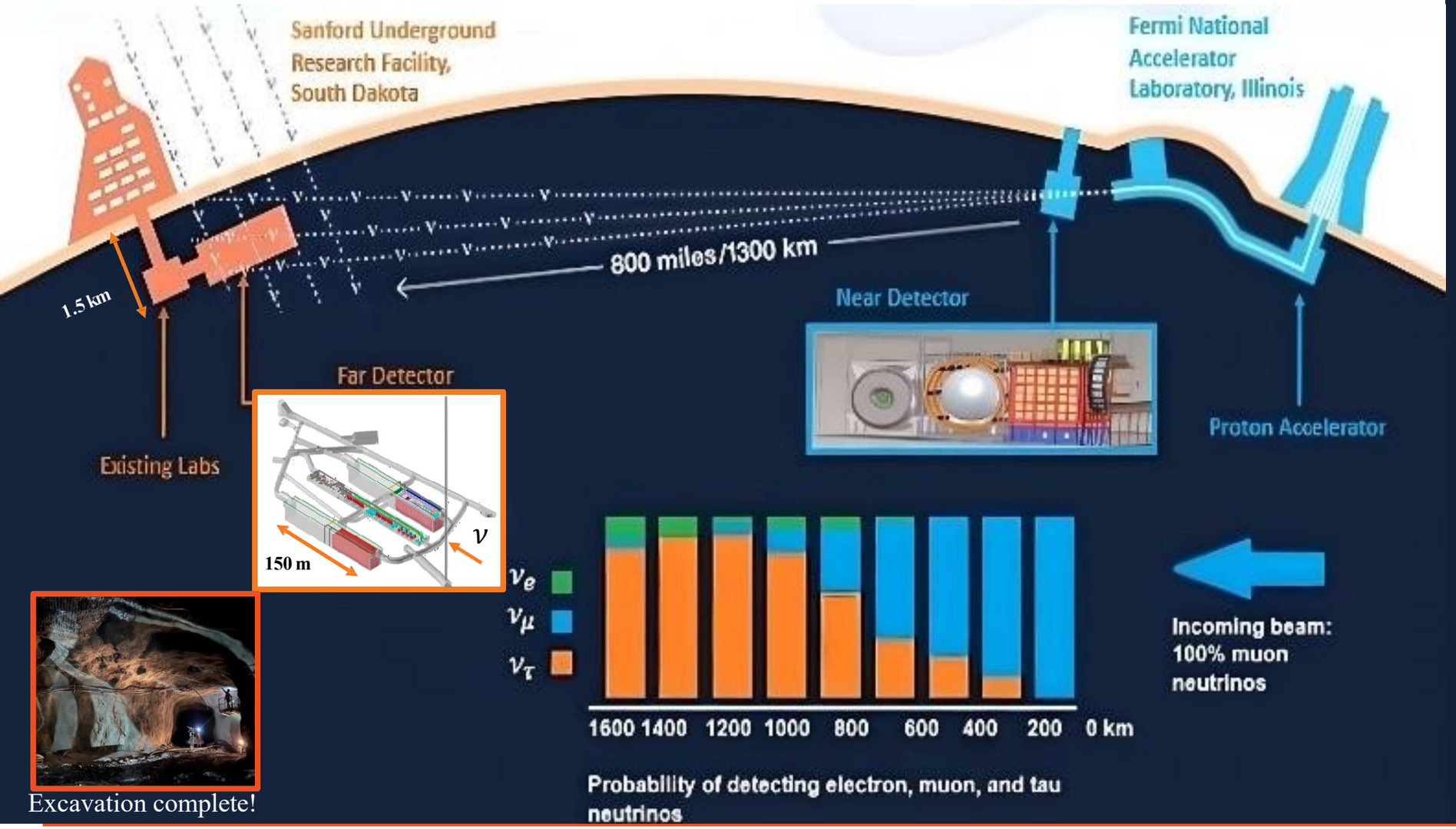
ProtoDUNE HD filled and being purified!

References

- FDR https://edms.cern.ch/ui/#!master/navigator/document?D:101190518:101190518:subDocs
- Trigger and Data AcQuisition Overview https://indico.fnal.gov/event/57752/contributions/260312/
- The readout system of the DUNE experiment: https://indico.phy.ornl.gov/event/112/contributions/561/
- The DAQ for the single-phase DUNE Prototype at CERN: https://indico.cern.ch/event/543031/contributions/2921456/
- Kubernetes for DUNE DAQ https://indico.jlab.org/event/459/contributions/11389/

Backup slides

DEEP UNDERGROUND NEUTRINO EXPERIMENT



Excavation complete!

- Next-generation neutrino experiment hosted in the United States.
- High-intensity neutrino beam, near detector complex at Fermilab.
- Underground Liquid Argon Time Projection Chamber (LArTPC) far detectors at SURF.
- Broad program of physics: precision neutrino oscillation measurements, MeV-scale neutrino physics, searches beyond the Standard Model.

ProtoDUNE

Prototypes of 2 DUNE far detector (FD) modules, located at CERN

Two LArTPC designs:

- Horizontal drift (HD) technology
- Vertical drift (VD) technology

- ProtoDUNE Horizontal drift is an 800t active mass TPC, making it the largest LArTPC constructed.
- ProtoDUNE successfully operated in 2018 and is preparing for its second run now

Figure: CERN Neutrino Platform.

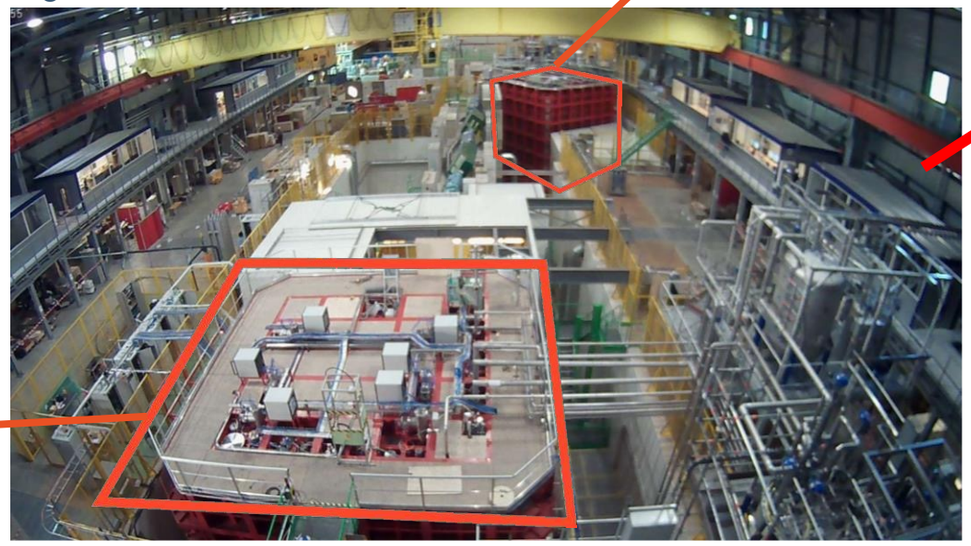
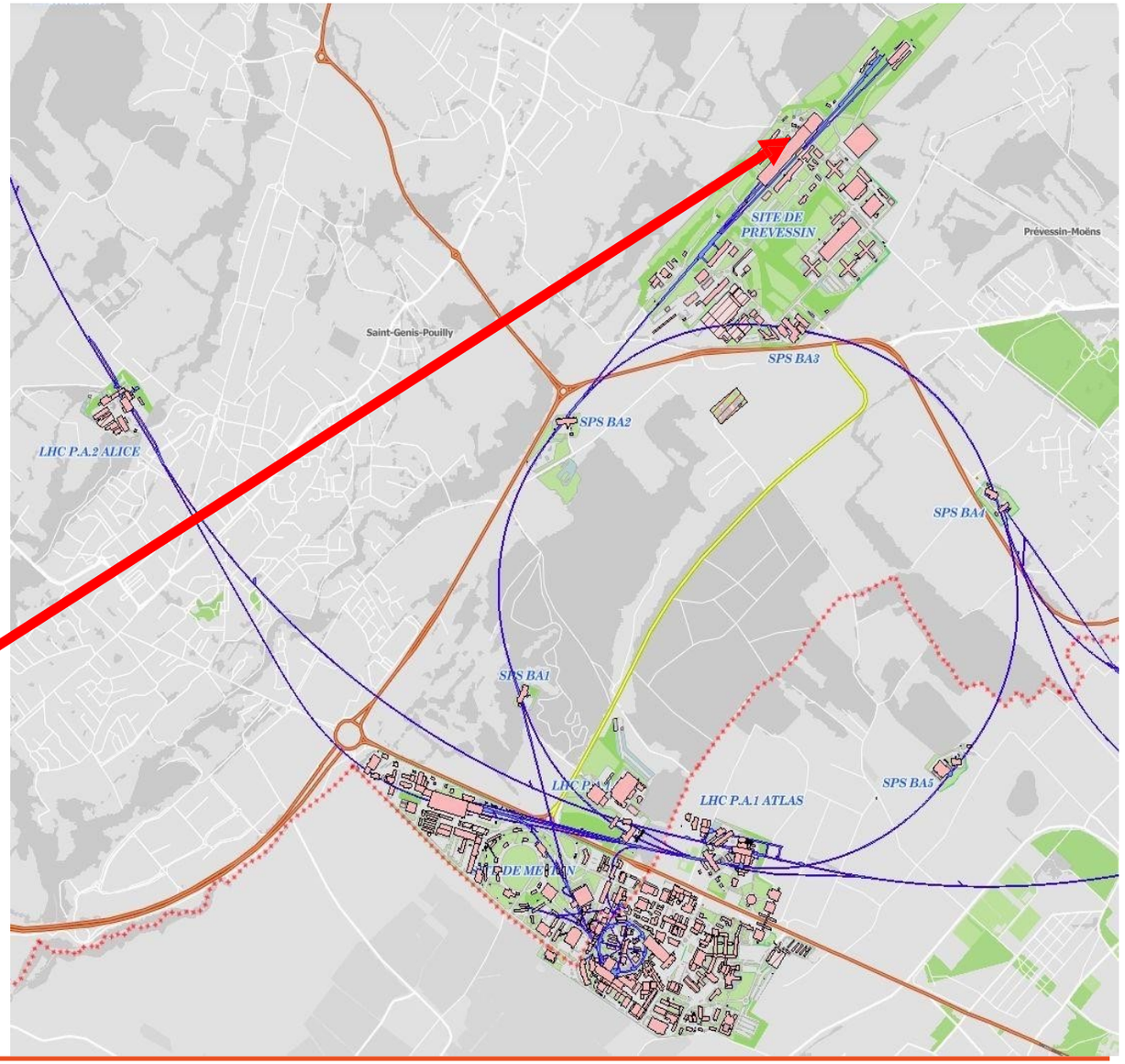
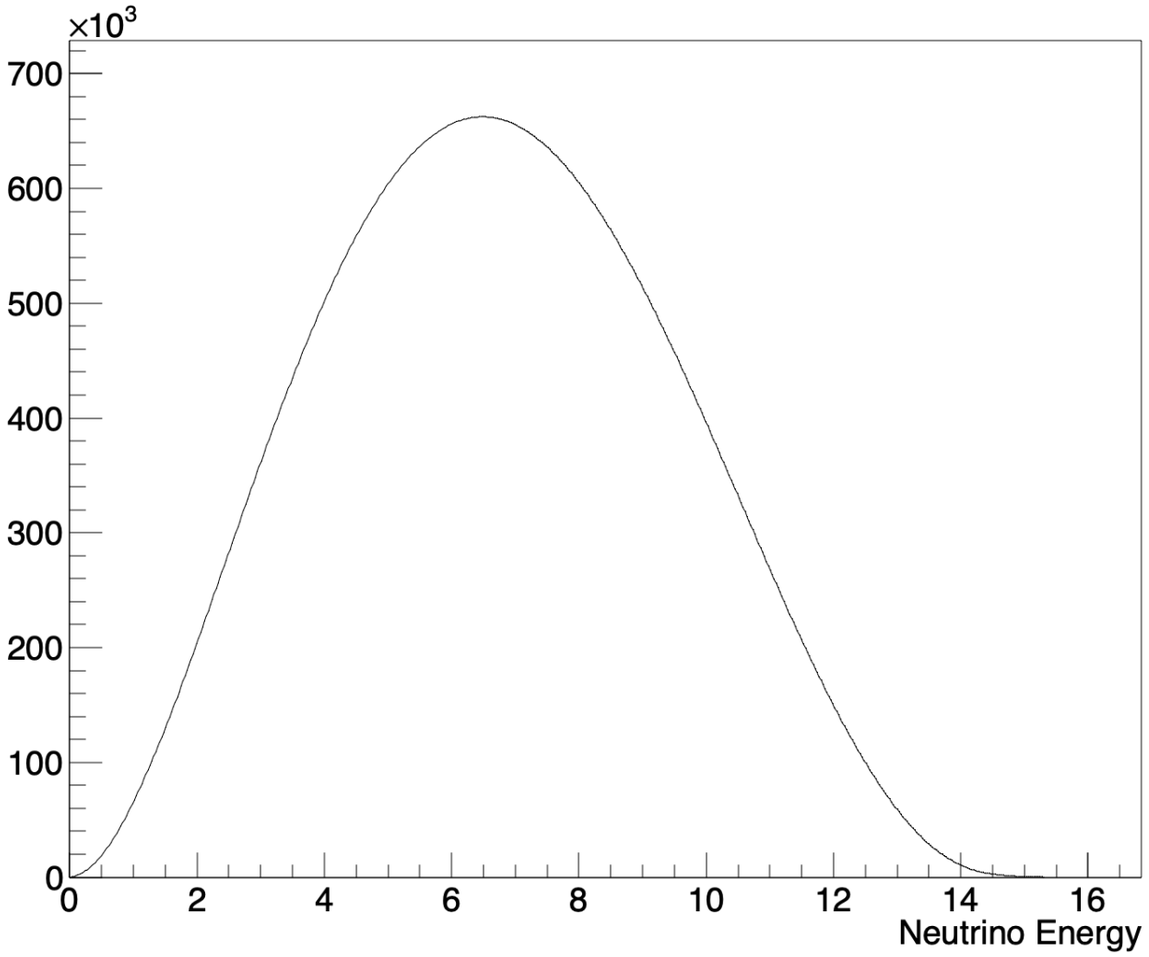


Figure: CERN.



UNIVERSITY OF TORONTO DUNE

Solar B8 spectrum



- We expect a solar neutrino event rate of ~100 per day in a 40kt LArTPC
- So our sample of 10000 events represents 100 days

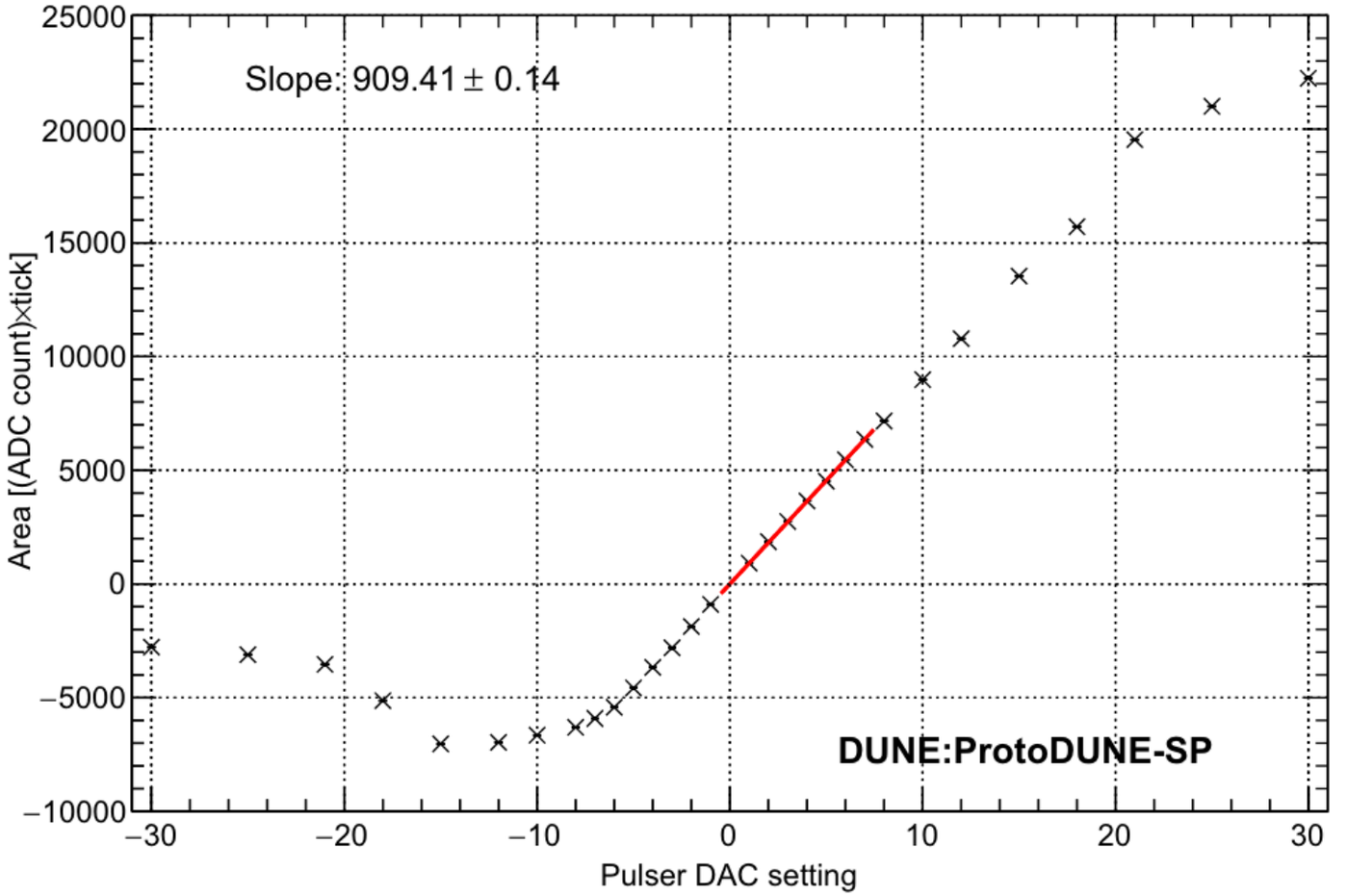
ADC charge calibration

A known charge is injected, controlled by a DAC, and the ADC response measured.

Gain is calculated from ADC integral vs. pulser DAC setting.

For a typical collection plane as shown, gain here is

g = (21.4 ke)/(909.4 (ADC count)xtick)
= 23.5 e/((ADC count)xtick)



https://iopscience.iop.org/article/10.1088/1748-0221/15/12/P12004

Radiological backgrounds

The radiological background sources considered for the FD HD module. Work is ongoing in developing the background model.

In liquid argon:
- Ar-39
- Ar-42
- Kr-85
- Rn-220 & Rn-222 chain
- K-42

External:
- External gammas
- External neutrons

From detector elements:
- Th-232 chain
- U-238 chain
- Rn-220 & Rn-222 chain
- K-40
- Co-60
- Pb-212

Simulations – detailed

- 2DROIAna package in duneana fork here:
  - https://github.com/matthew-man-457/duneana/tree/mman/2D_ROI

- Simulation workflow (dune10kt_1x2x6):
  - MARLEY gen using solar boron 8 flux + latest decay0 backgrounds
  - Standard G4
  - Detsim uses notpcsigproc (outputs rawdigits)
  - ROIAna

Uses:

- larsoft_v09_82_02d01
- dune10kt_v6_refactored_1x2x6.gdml
- dunefd_hd_backgrounds_1x2x6_v3_5