Region of interest filter in DUNE DAQ

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ABSTRACT

The Deep Underground Neutrino Experiment (DUNE) is the next generation neutrino experiment currently under construction. It consists of a broadband neutrino beam at Fermilab, a high precision near detector, and the largest liquid argon time projection chamber far detector ever designed at the Sanford Underground Research Facility (SURF).
The Region of Interest (ROI) filter is designed for DUNE's online Data Acquisition (DAQ) system to address data rate constraints and enable low energy physics in the <10 MeV range. The filter employs zero suppression on the detector signal, and by tuning the readout window and threshold the data rates can be reduced by >90%. Performance of the ROI is analyzed in LArsoft on MARLEY generated low energy MC events propagated through the detector simulation. Notably, the optimized ROI filter enables a lower trigger threshold for readout at ~5-10 MeV, allowing DUNE to explore low-energy physics, specifically focusing on solar boron 8 neutrinos which are relevant in this energy range. This advancement enhances DUNE's scientific capabilities, opening avenues for detailed analyses of previously inaccessible low-energy neutrino interactions.

1. DUNE

The Deep Underground Neutrino Experiment (DUNE) is a cutting-edge international research project aimed at advancing our understanding of neutrinos, the universe's most elusive particles. DUNE's goals include solving key mysteries about the behavior of neutrinos and their role in the cosmos.

- **Far Detector**: Liquid argon time-projection chambers (LArTPC) with 40 kilotons active mass across four modules, designed to capture detailed images of neutrino interactions. [1]
- **Near Detector**: Located at Fermilab, this detector characterizes the neutrino beam before it travels to the far detector, ensuring accurate measurements.

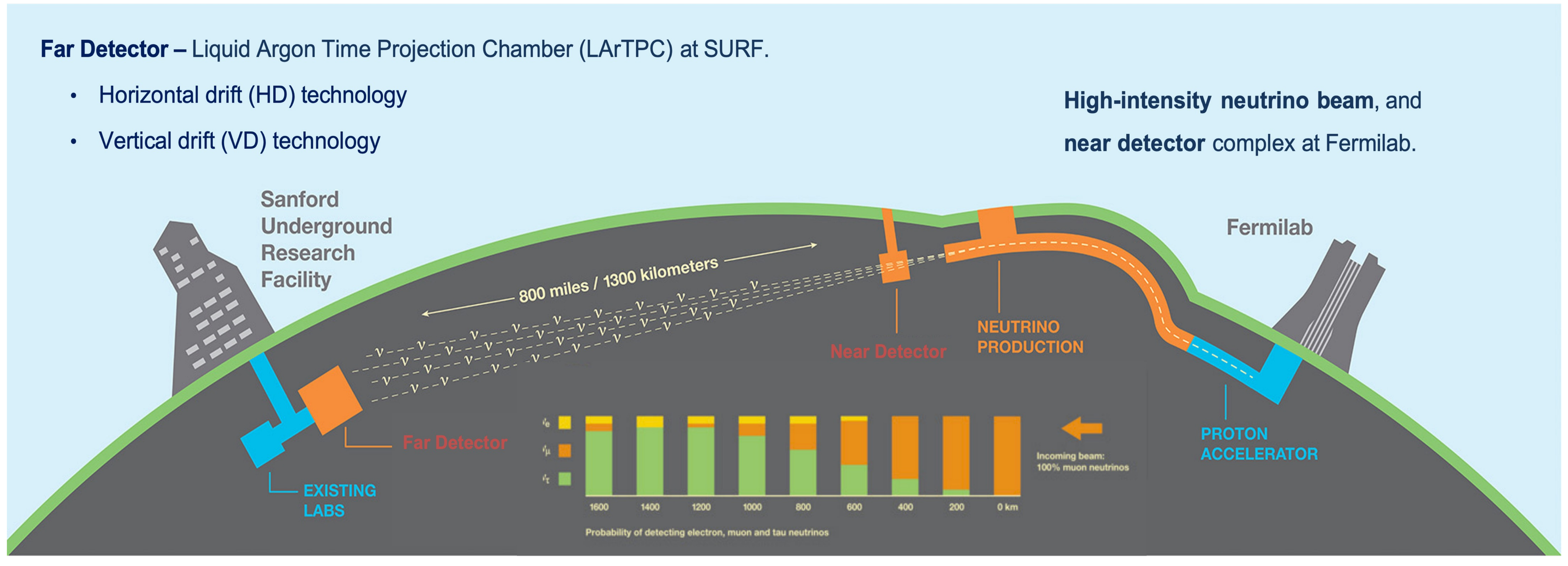

Figure 1: DUNE experiment

2. SOLAR NEUTRINOS IN DUNE

A key part of the DUNE low energy physics program is sensitivity to solar neutrinos. These neutrinos, produced by nuclear reactions in the sun's core, provide insights into solar processes through flux measurements. DUNE will also be sensitive to $\Delta m_{21}{}^2$ and $sin^2\theta_{12}$ from these measurements.

- DUNE will be sensitive to solar neutrinos in the energy range of 1.5 to 19 MeV, including those from ^8B and hep reactions.
- **Detection mode**: Solar neutrinos will primarily be detected through charged-current (CC) interactions with argon (Ar) nuclei, with a cross-section of approximately 10^{-42} cm².
- With four far detector (FD) modules, DUNE is expected to observe around 171,000 CC ν_e events per 40 kT per year of exposure.

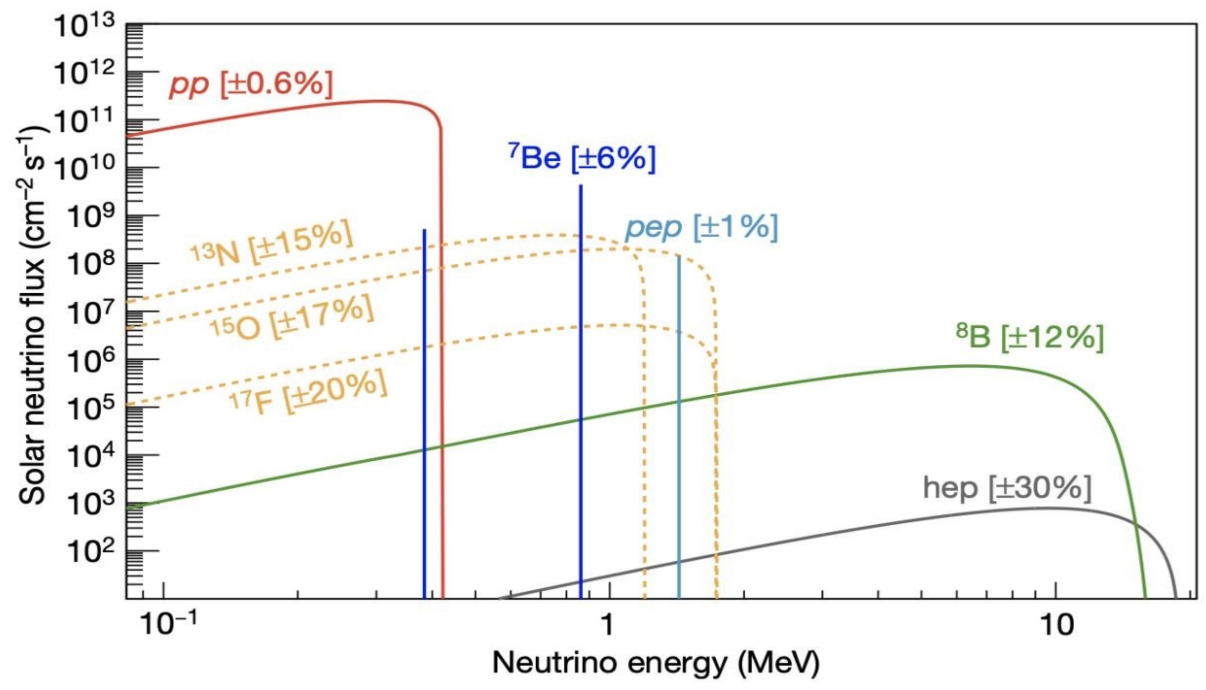

Figure 2: Solar Neutrino Spectrum [4]

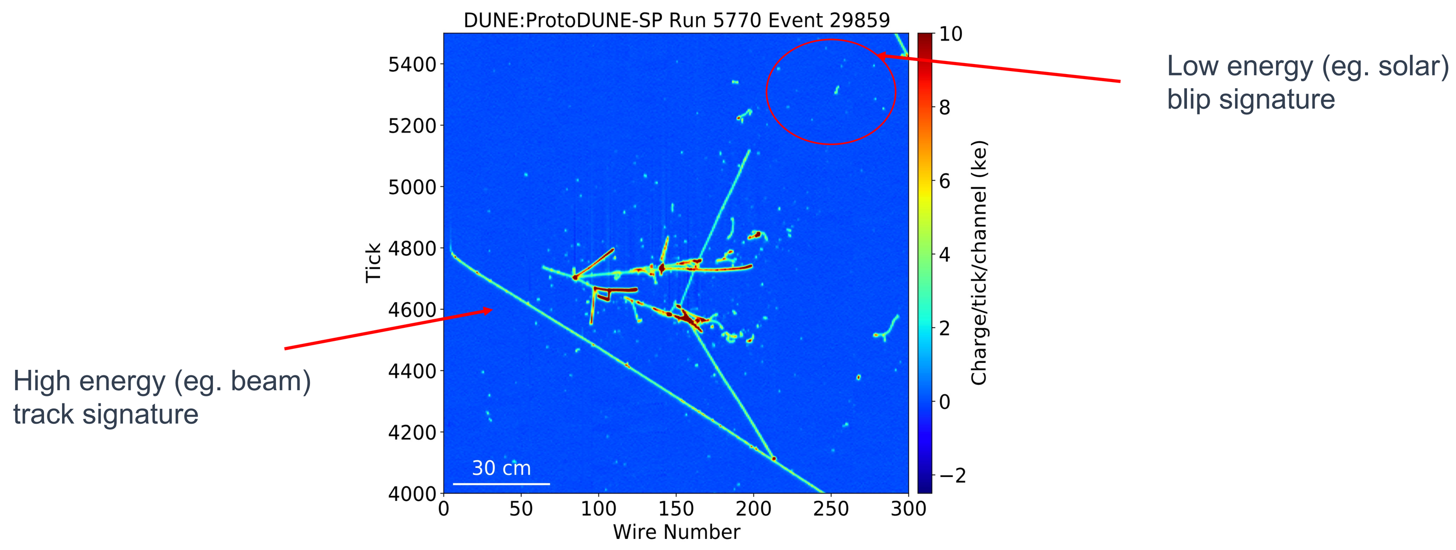

Figure 3: Event Display [2]

3. DAQ AND LOW ENERGY PHYSICS

The challenge that the DUNE data acquisition (DAQ) system faces is **data reduction on the order 10^4** to meet the storage limit of ≈30 PB/year for all FD modules. This is the role of the trigger and the data filter.

Triggering on beam neutrinos in not a problem, **the challenge is capturing the 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 acts as a background to the trigger

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

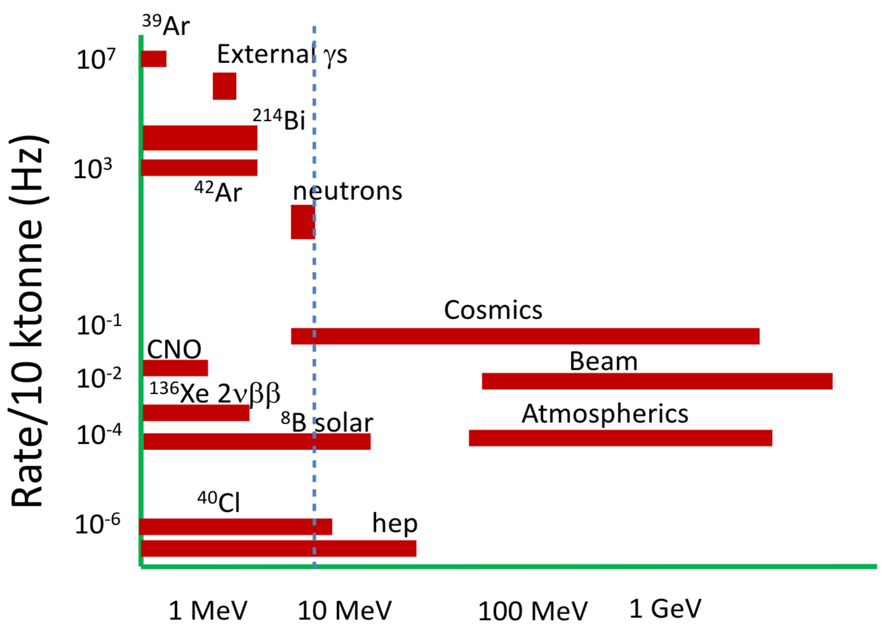

Figure 4: Backgrounds

4. REGION OF INTEREST FILTER

The goal of the region of interest (ROI) filter is to reduce the data bandwidth to allow storage of more low energy (solar neutrino) interactions.

- ROI applied in DAQ, right before data is sent offline
- Removes detector regions with no activity above threshold (ie. zero suppression)
- Attempts to remove low energy backgrounds

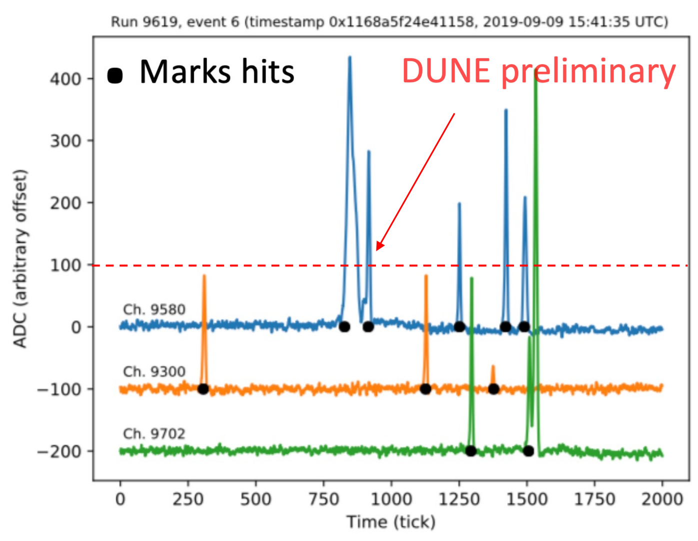

Figure 7: Single channel ADC waveform thresholding. Eg. blue waveform, threshold=100 ADC counts (above baseline), triggers ROI. 1 tick = 500 ns

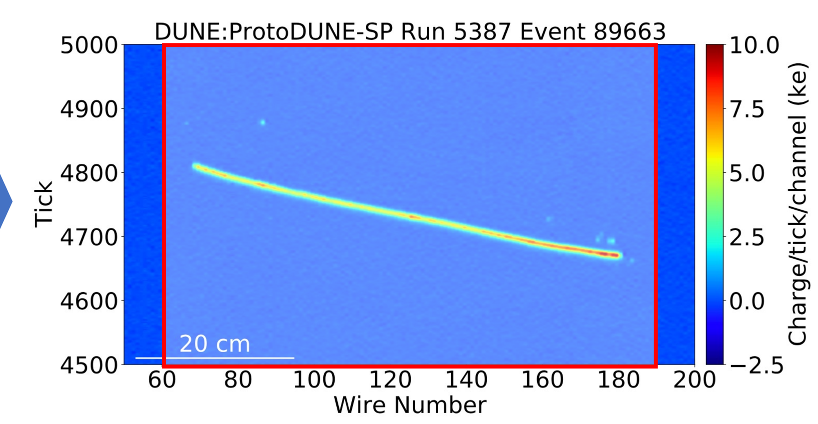

Figure 8: Event window level ROI with 1 tick = 500 ns

5. ROI PERFORMANCE

The ROI is applied in simulations of solar neutrinos + radiological backgrounds, to calculate various performance metrics:

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

Plots below shows energy deposits from boron 8 signal + background on collection plane:

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

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

Table 1: Data reduction rate

This study is performed varying the peak threshold ADC values [50, 100, 150, 200]

- **Threshold 100** corresponds to **1 MeV energy**

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

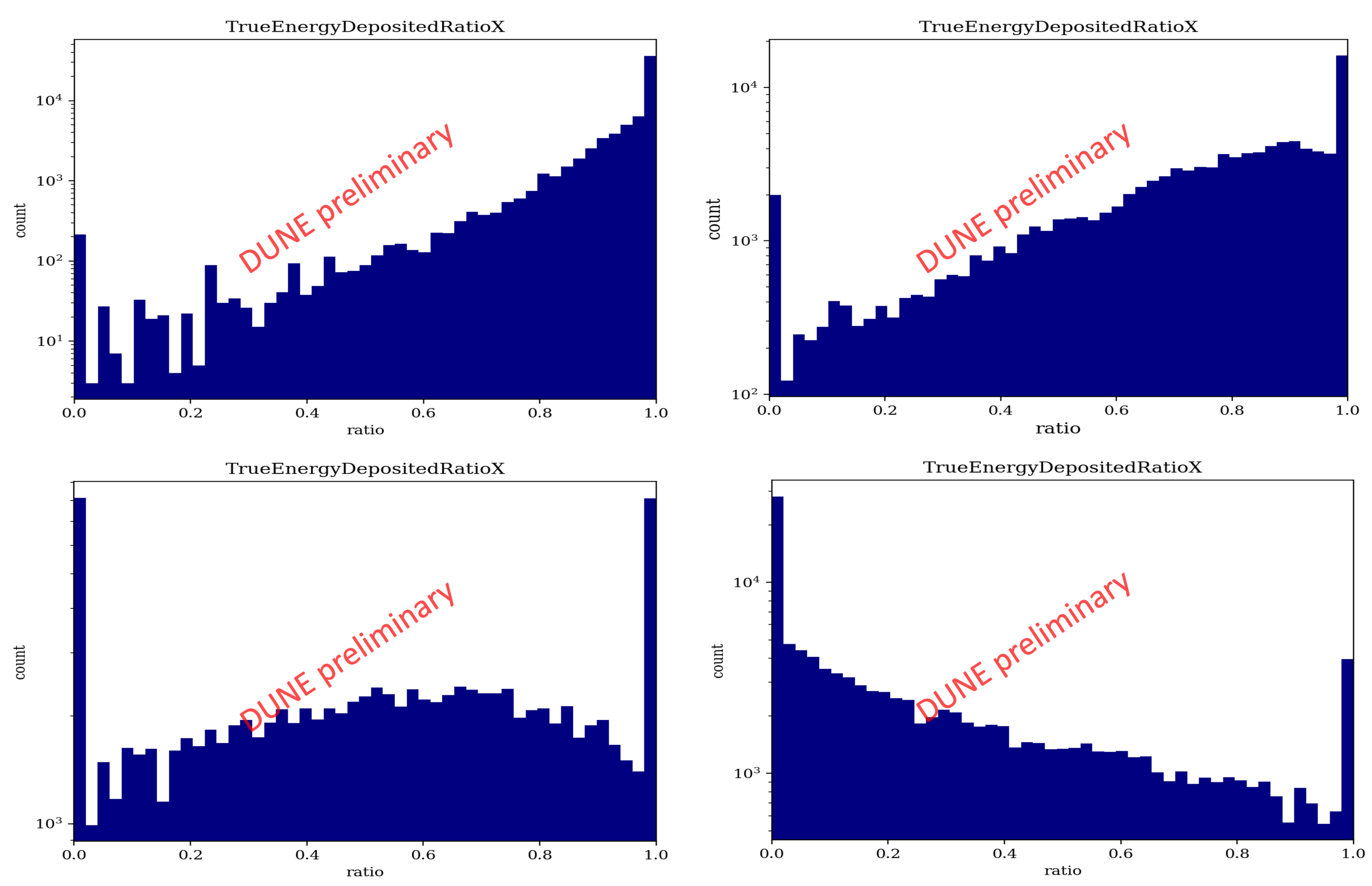

Figure 9: Collection plane

CONCLUSION

- The trigger and DAQ system is being optimized for low energy physics (~1-10 MeV).
- Analysis ongoing to determine optimal solar boron 8 sensitivity, signal/background separation, 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.
- This would allow more low energy interaction data to improve DUNE's low energy sensitivities

REFERENCES

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