Liquid Argon TPC Trigger Development with MicroBooNE

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on behalf of MicroBooNE collaboration

Columbia University

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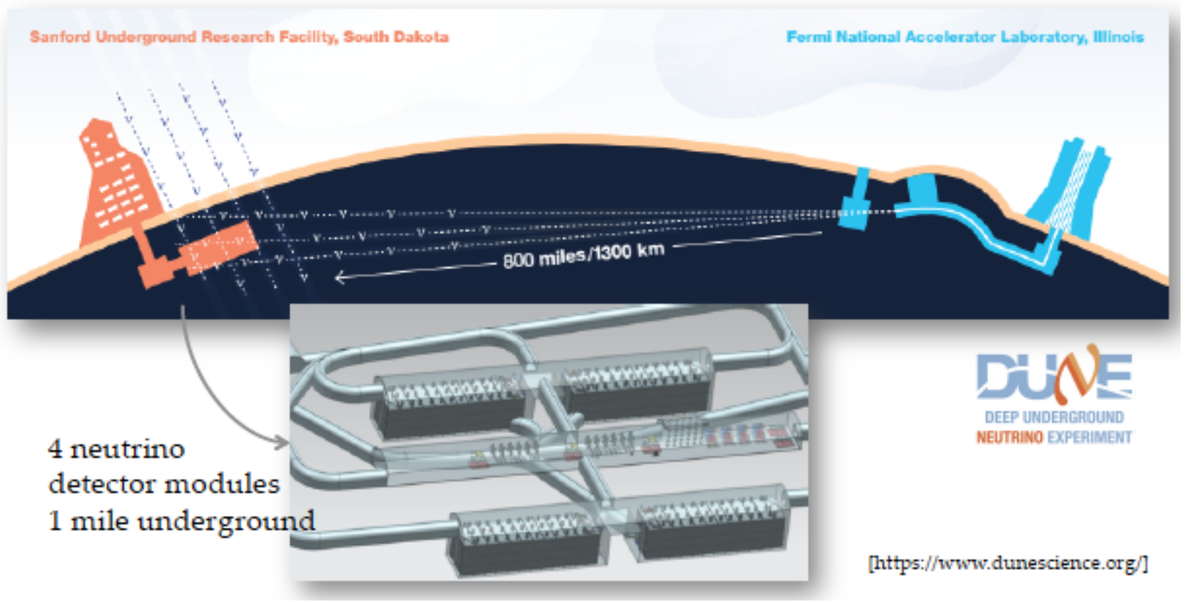
Motivation

- DUNE: World's largest LArTPC neutrino experiment (once constructed), will start taking data ~2027, with millions of readout channels.

- One of the DUNE physics goal is to search for rare (off-beam) events (< 1 interaction/ year)



[https://www.dunescience.org/]

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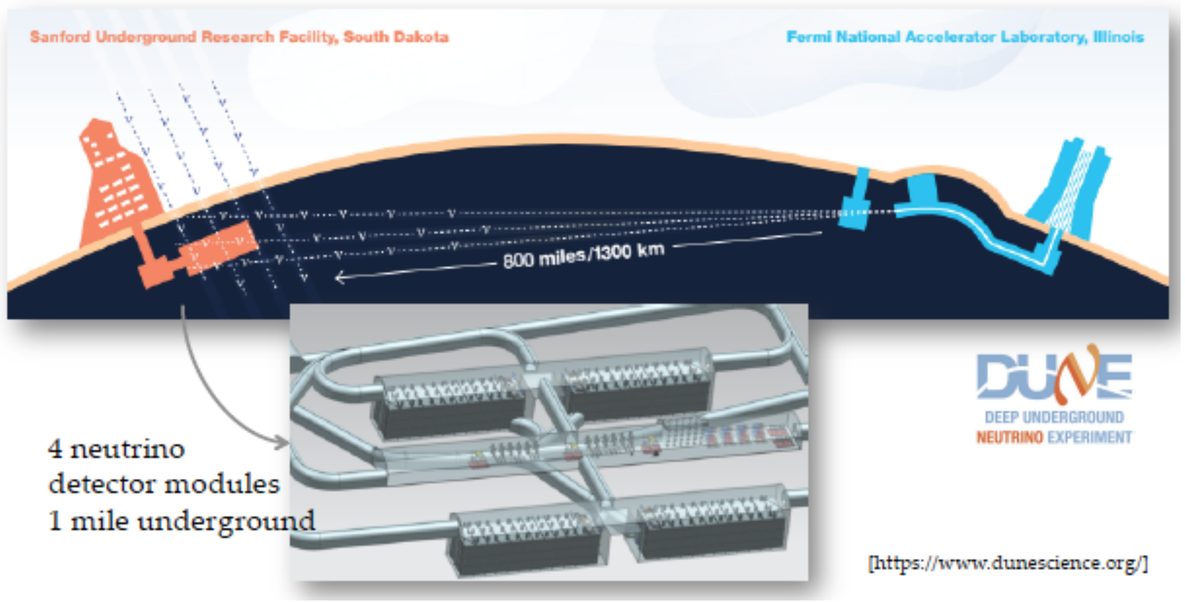
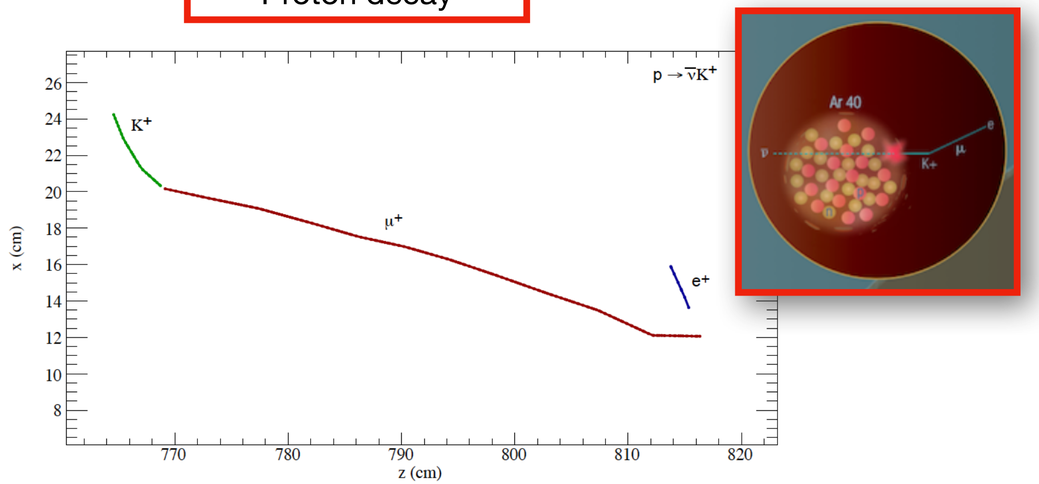
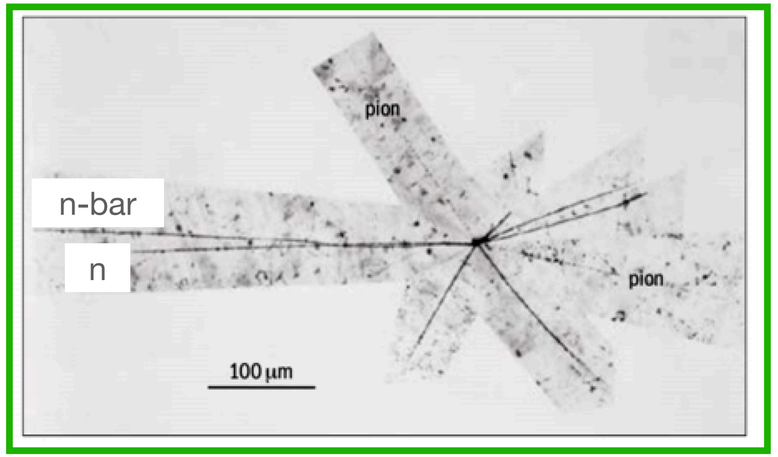


Neutrinos from Supernova burst

Proton decay



n-nbar oscillation



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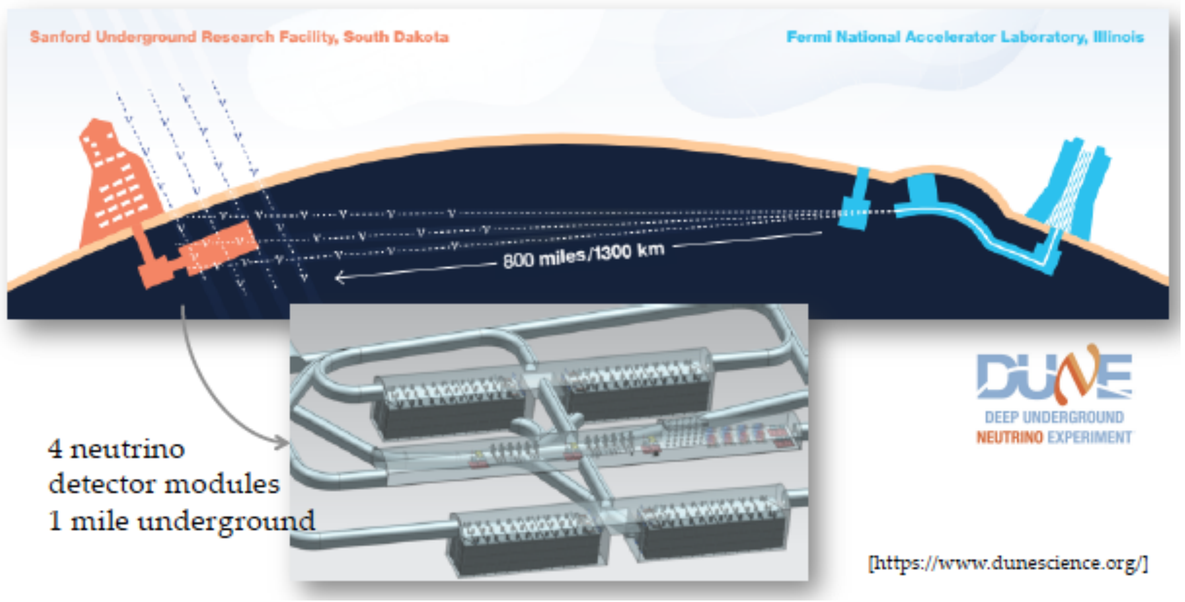

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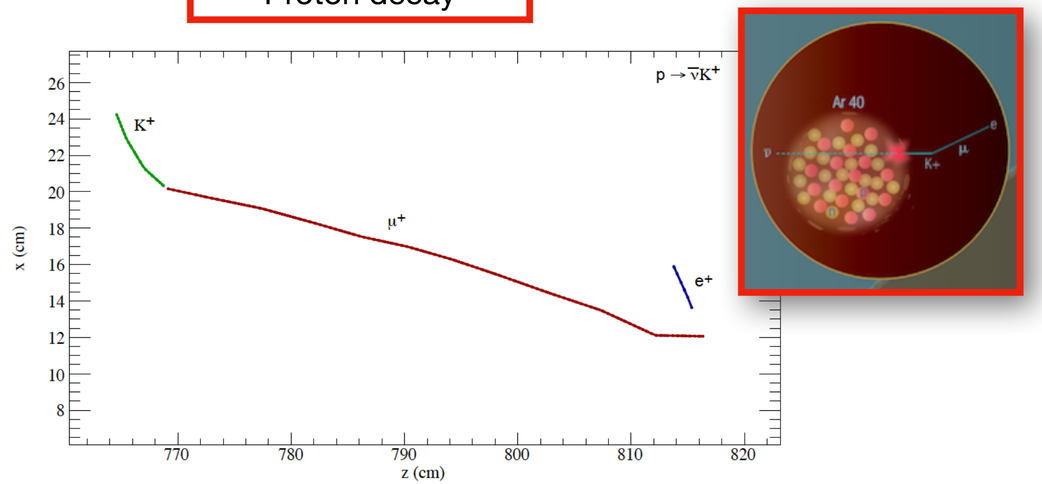

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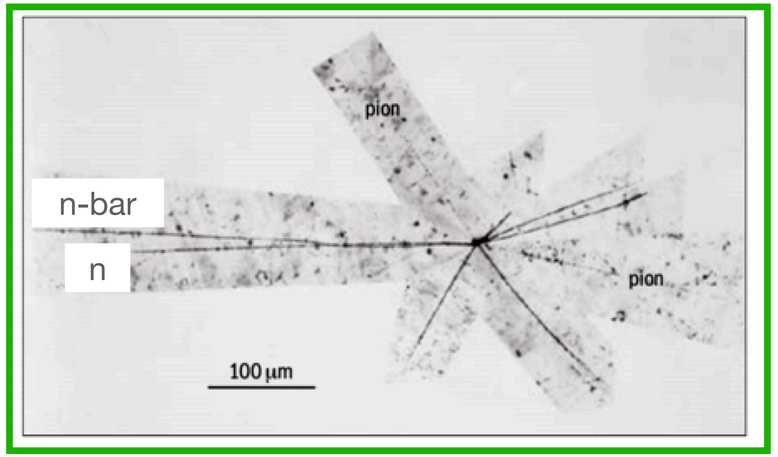

Requires continuous readout with ~100% live time and self-triggering.

MicroBooNE

- Current LArTPC detectors such as MicroBooNE can be exploited to demonstrate and develop TPC-based trigger: ***One of the first demonstrations with a real LArTPC for TPC self-triggering***

- MicroBooNE is currently in R&D measurement phase, so offers a unique opportunity to develop TPC self-triggering.

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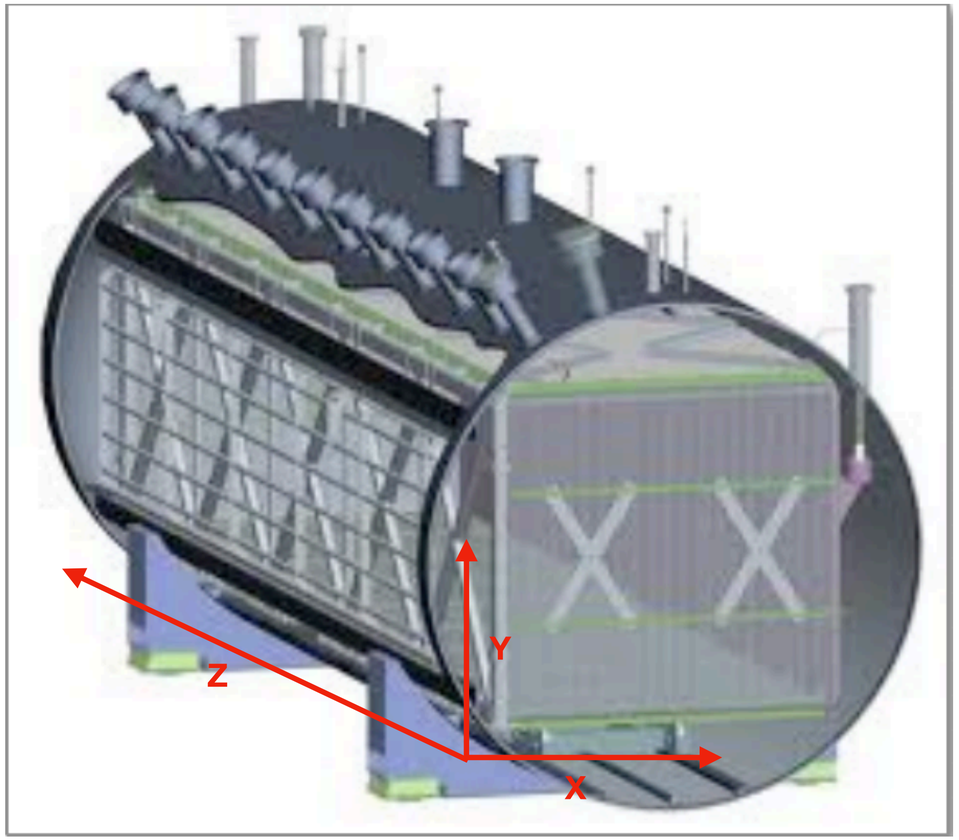
- MicroBooNE is currently in R&D measurement phase, so offers a unique opportunity to develop TPC self-triggering.

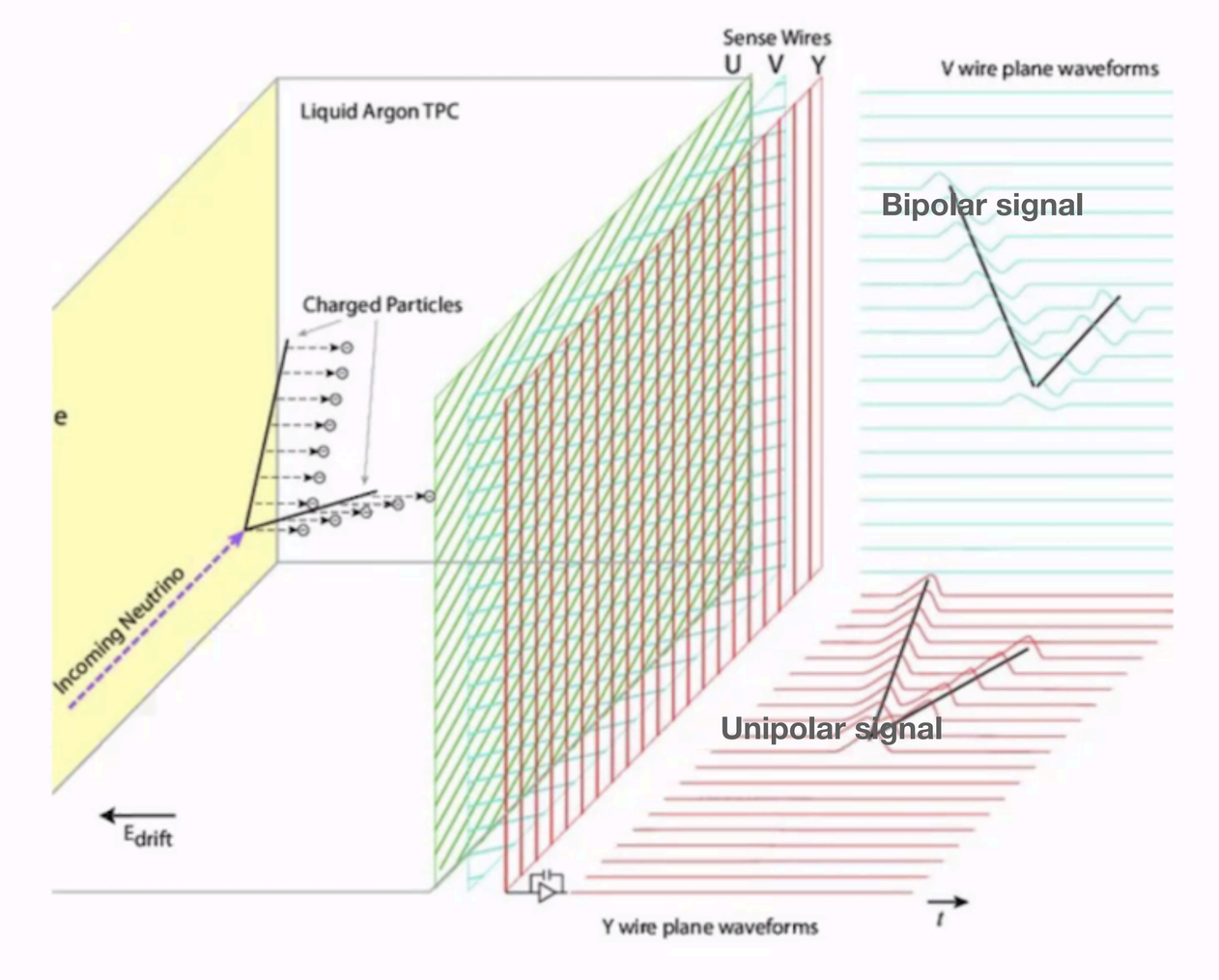
  - 89 tons active* LAr volume
  - 8256 TPC wires (2MHz)
  - 32 8” PMTs (64 MHz digitization)
  - **Data Rates: 33 GB/s**



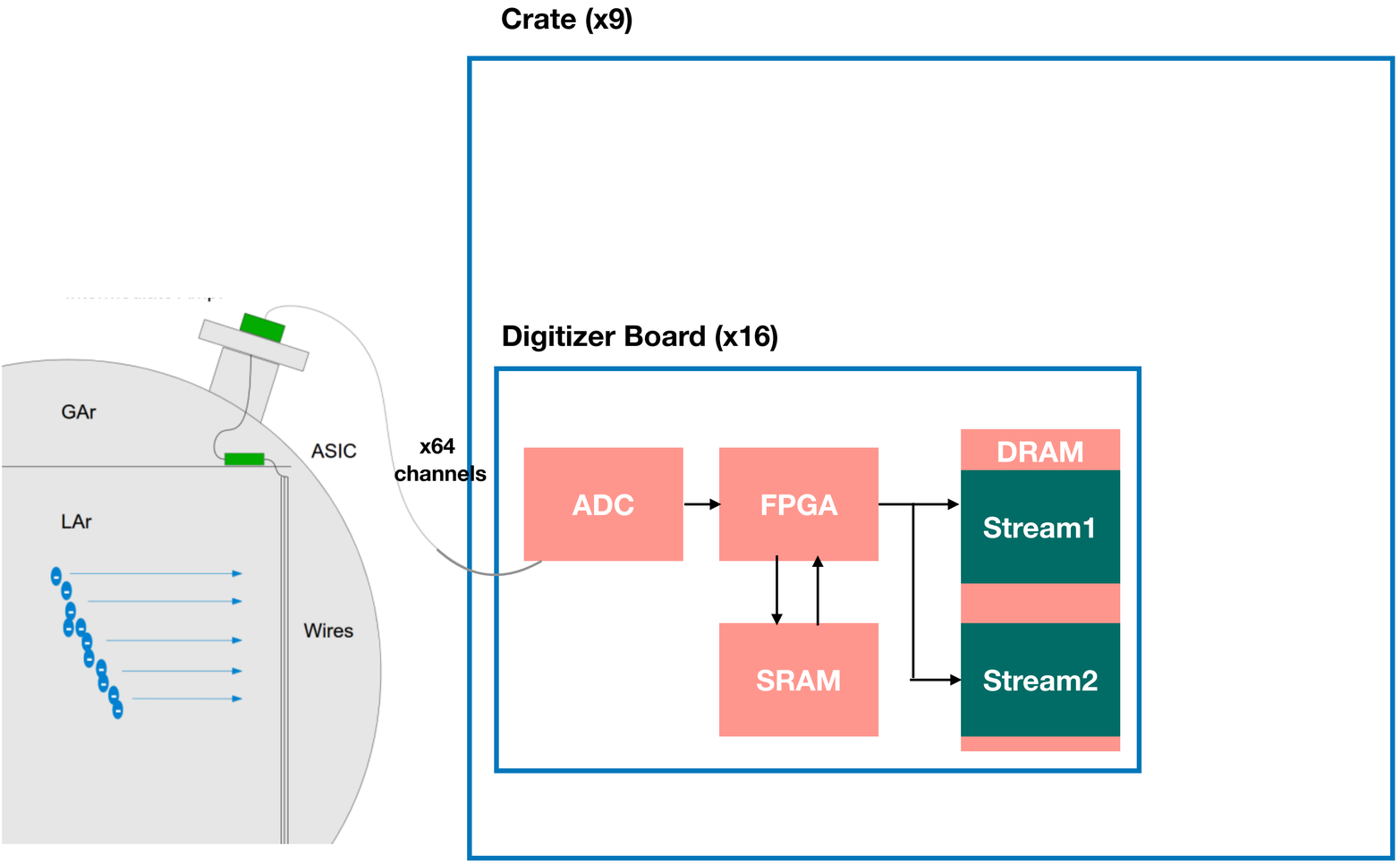
*Maximum volume that can be used for physics analysis.

Liquid Argon Time Projection Chamber (LArTPC)

- LArTPC works by producing fine-grained images of particle interactions.
- Light signal from PMTs complement the TPC information and help in achieving 3D reconstruction.

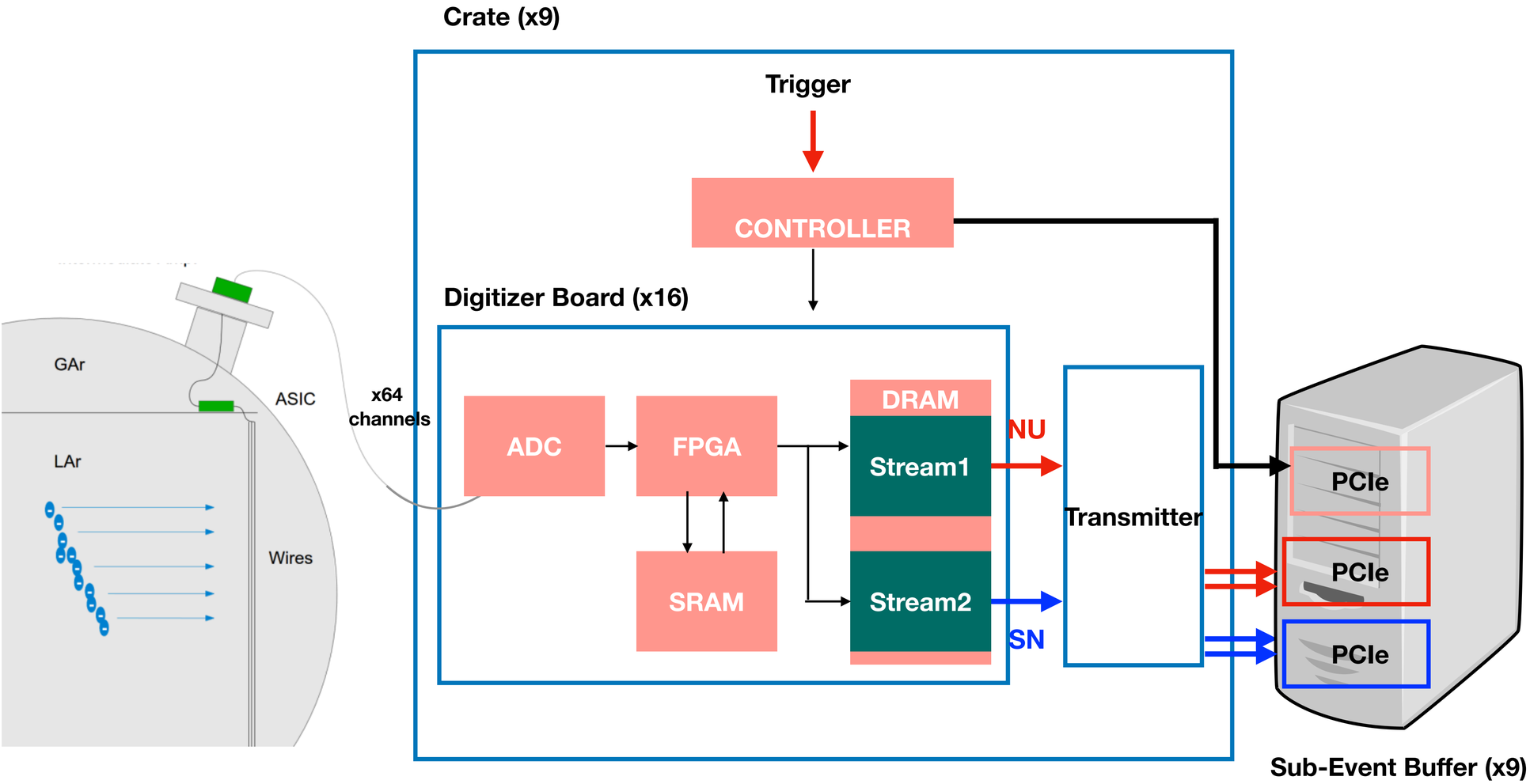


Readout Electronics



Readout Electronics

NU stream Losslessly compressed data associated with event triggers.
SN stream Continuous data stream compressed with some data loss.



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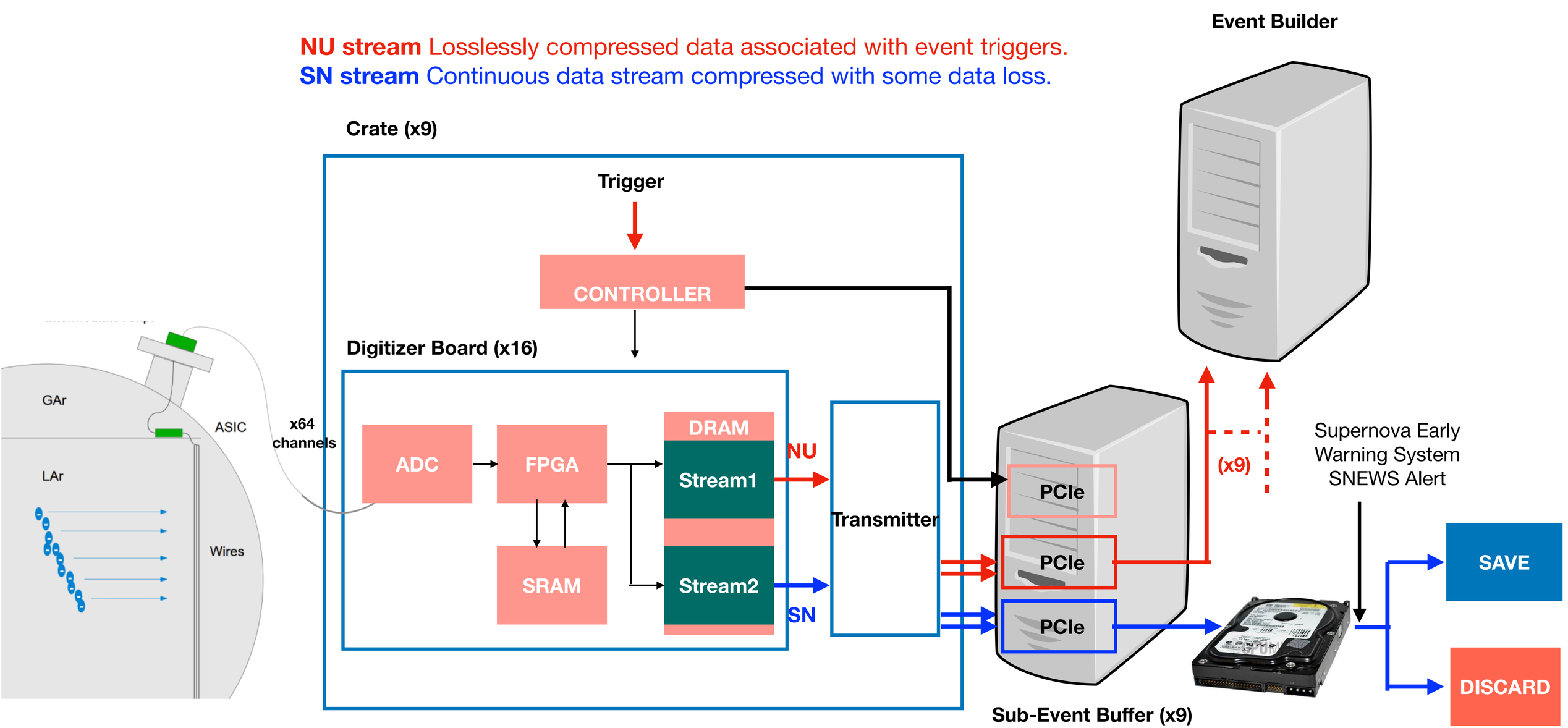
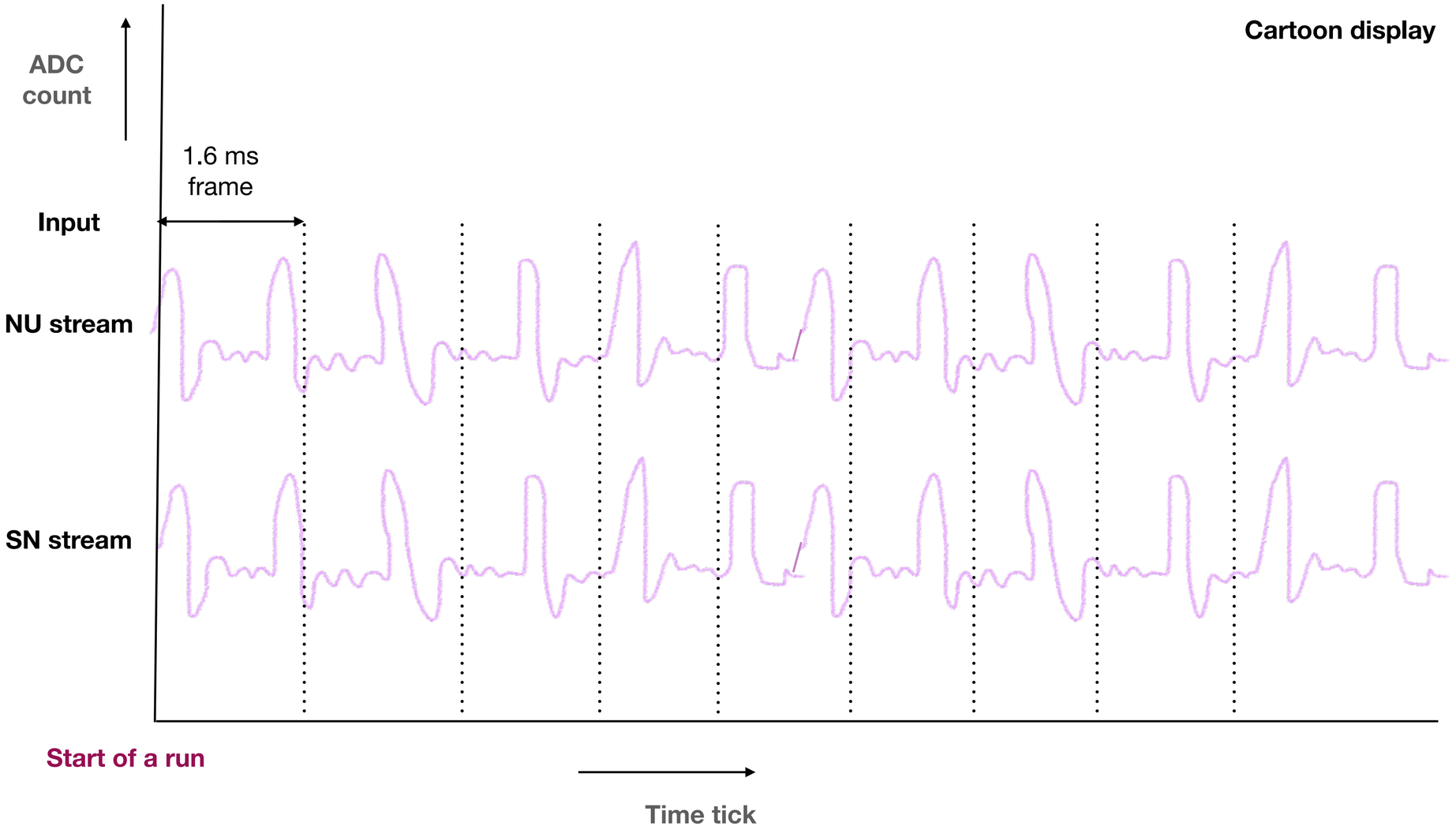


Data Streams (MicroBooNE)



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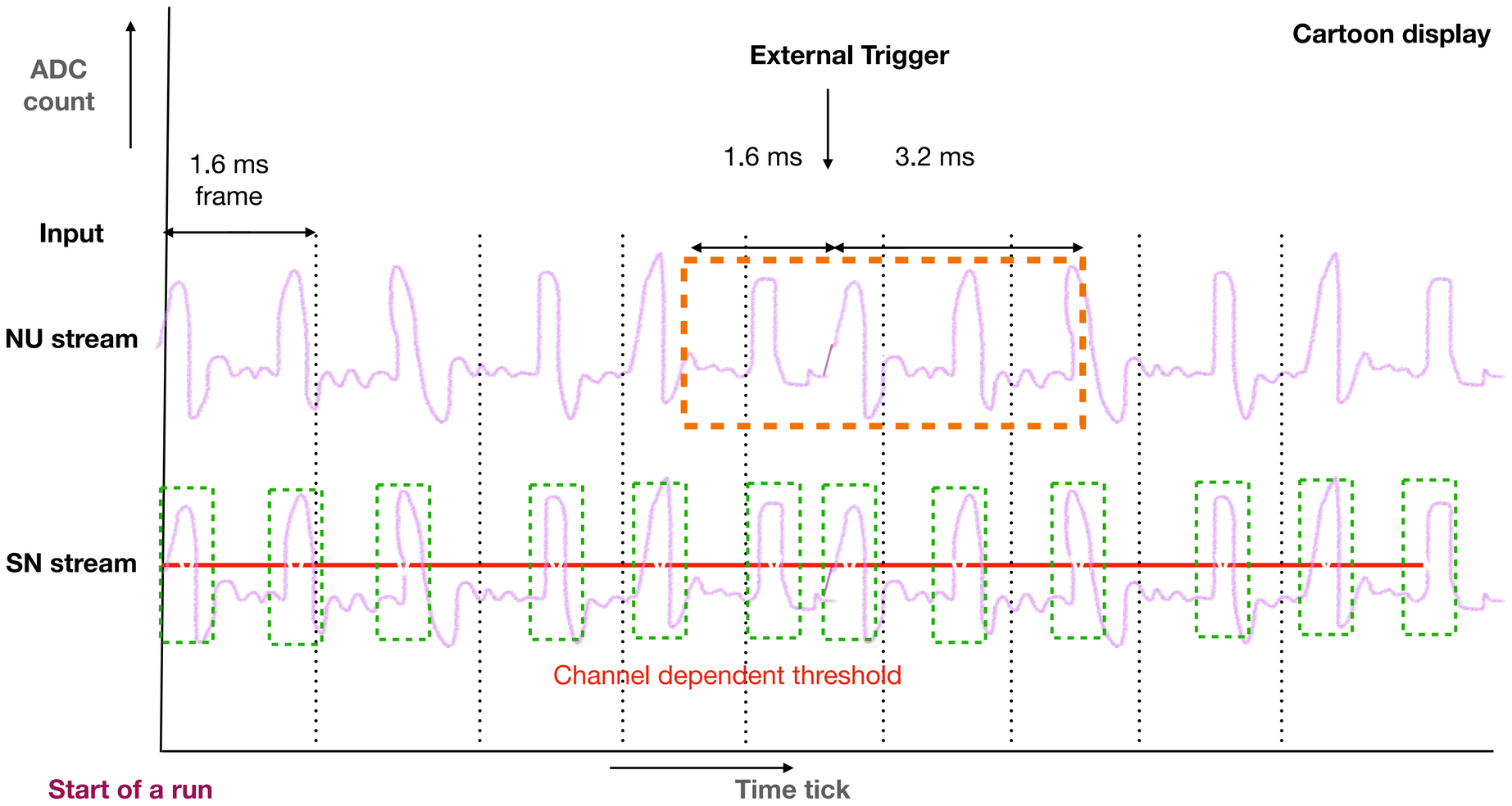

- NU stream: On receiving an external trigger, 4.8 ms of data is readout (useful for physics analysis).
- SN stream: Regions of interest (ROI) are extracted, whenever a waveform crosses a certain threshold.

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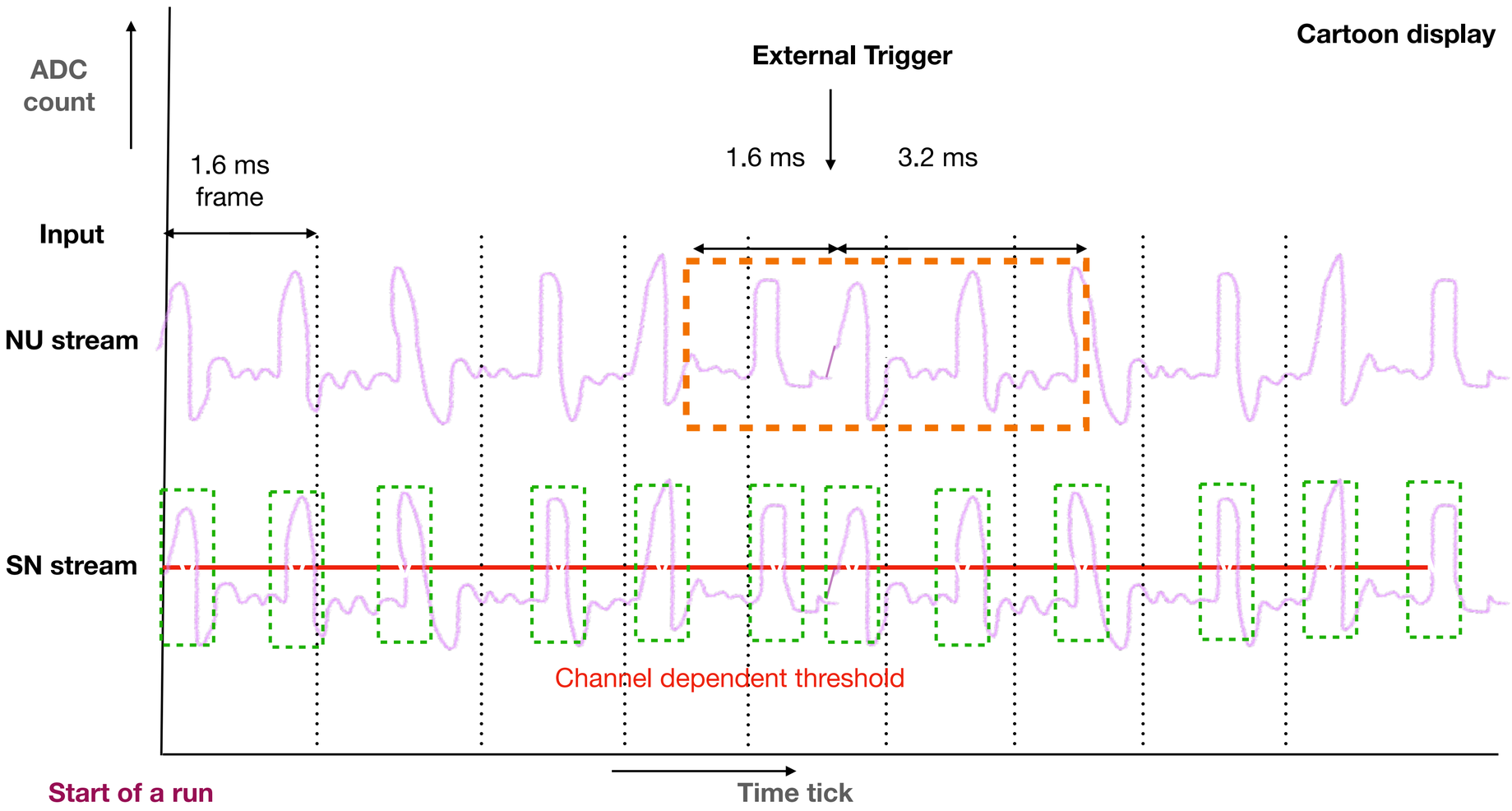
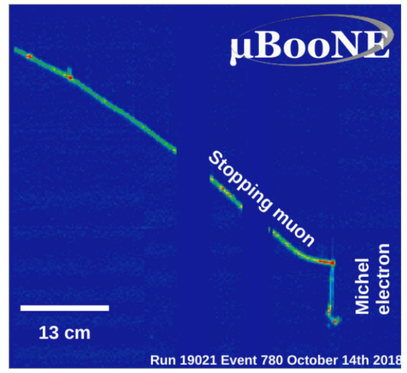
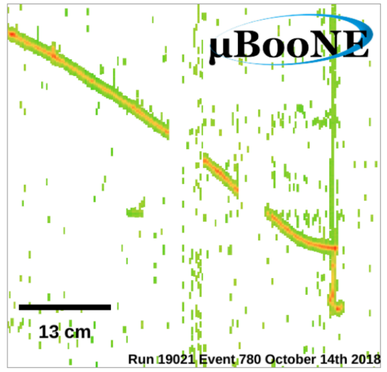


Cartoon display

NU Readout
Losslessly compressed data



SN Readout
Cropped around the ionization



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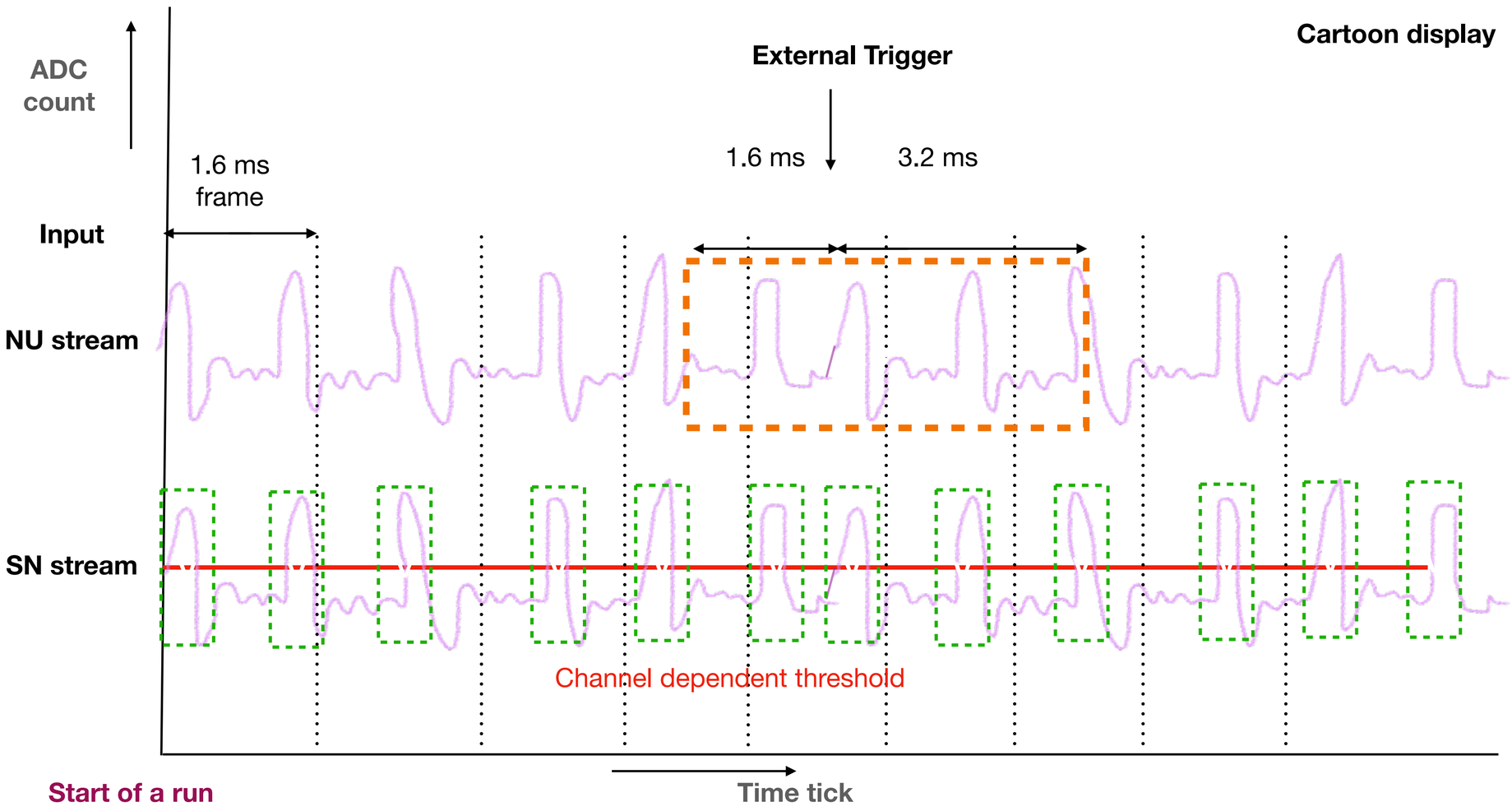

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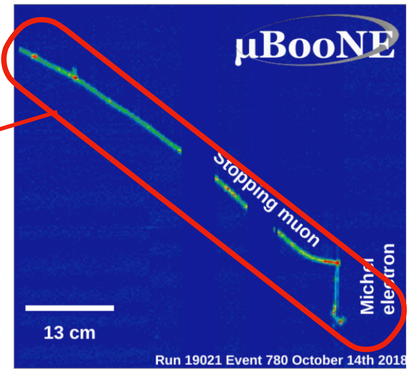

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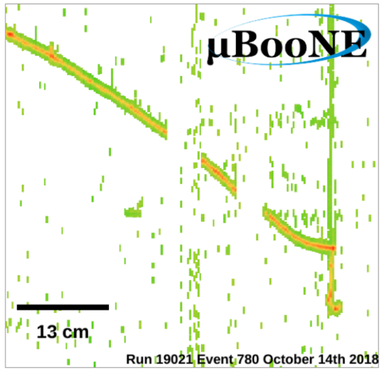

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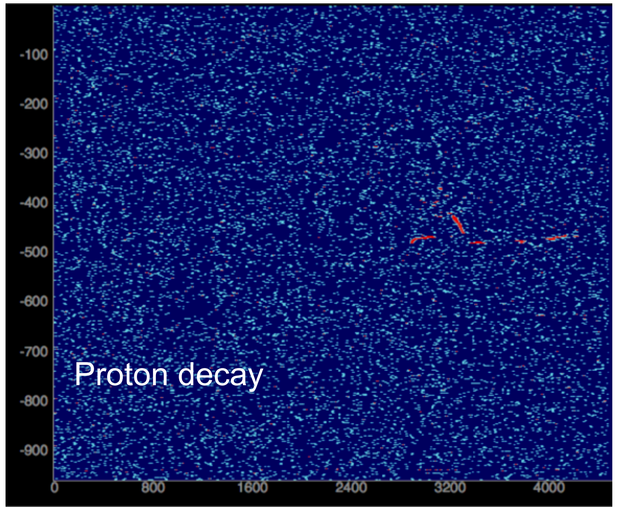
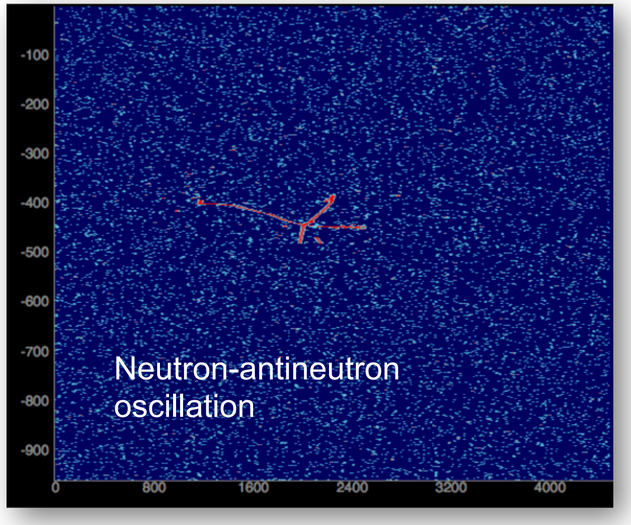
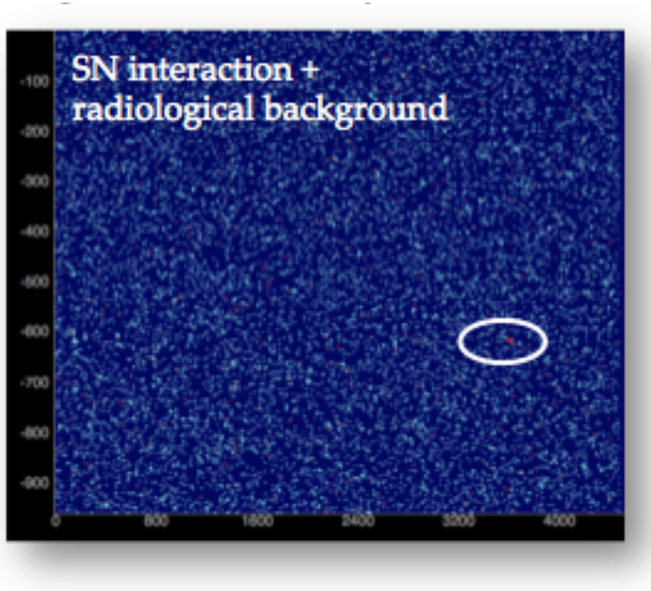
Which events to trigger on?

- DUNE will look for the off-beam events such as proton decay, n-nbar, neutrinos from SN burst.







DUNE Single Phase Simulated Event Displays

Which events to trigger on?

- MicroBooNE won’t have much sensitivity to proton decay, or n-nbar and won’t be able to trigger on SN events due to ambient background (cosmogenic activities) but we attempt to develop the techniques to look for these signatures as R&D towards DUNE.

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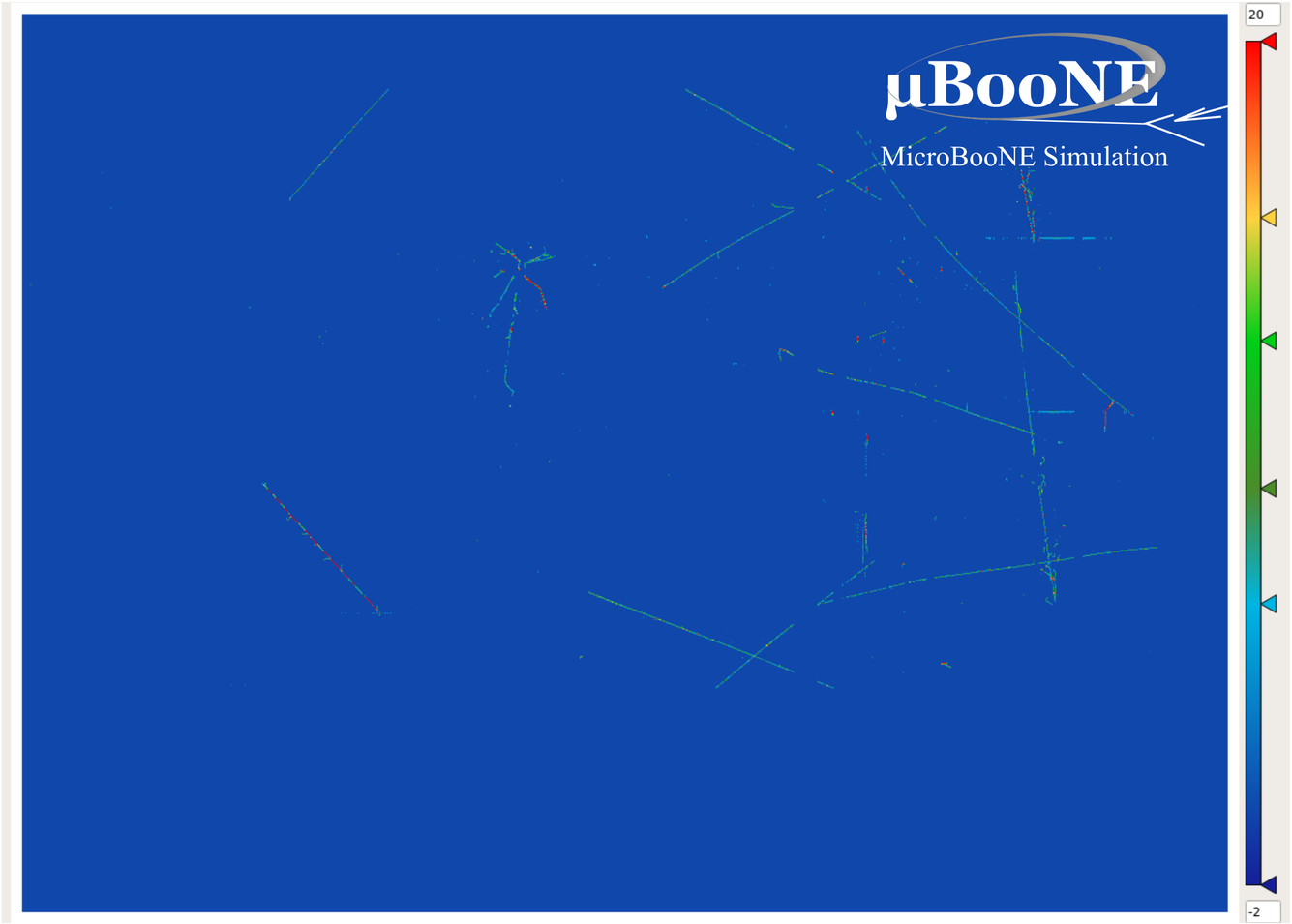

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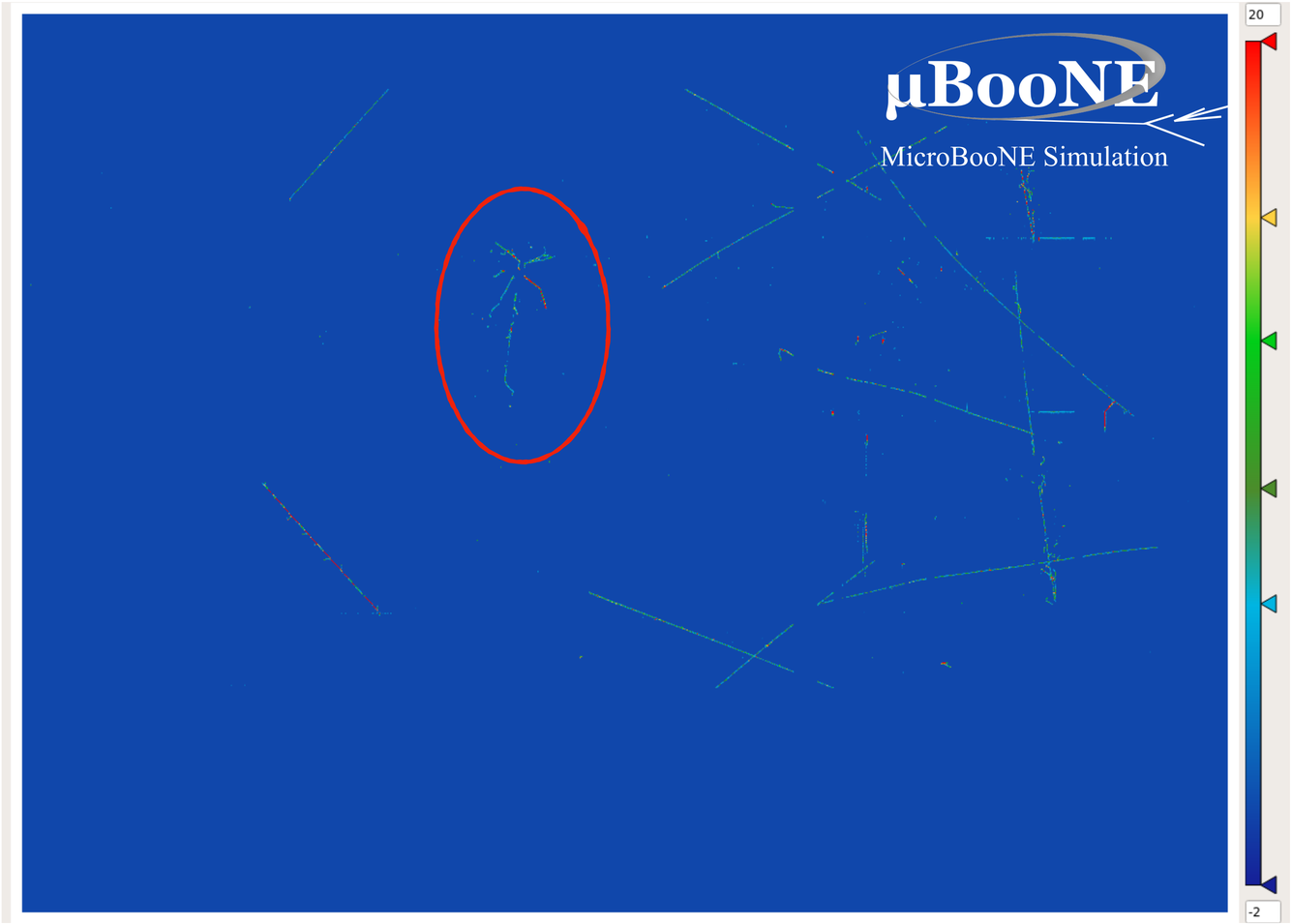
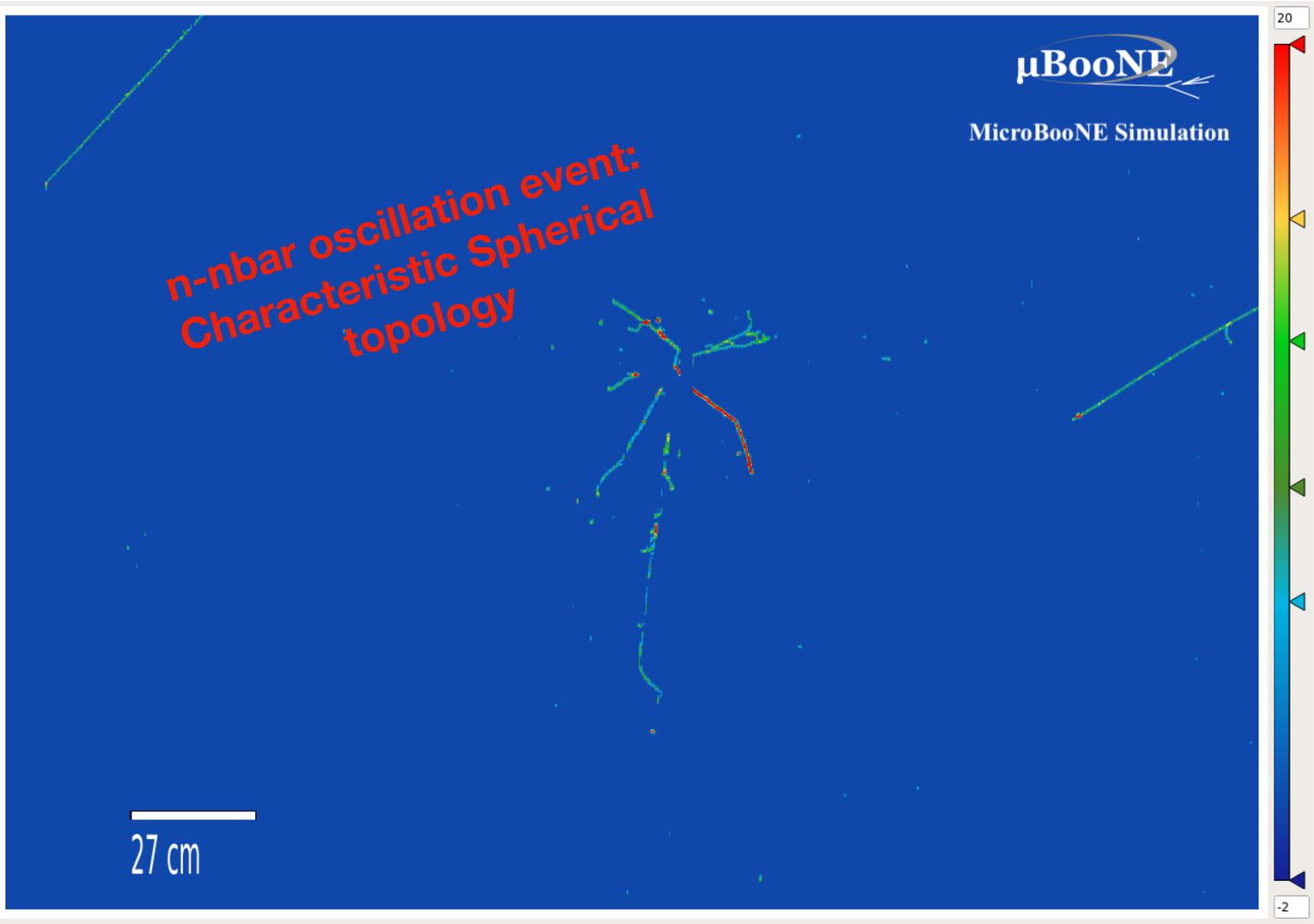


Interesting events to trigger



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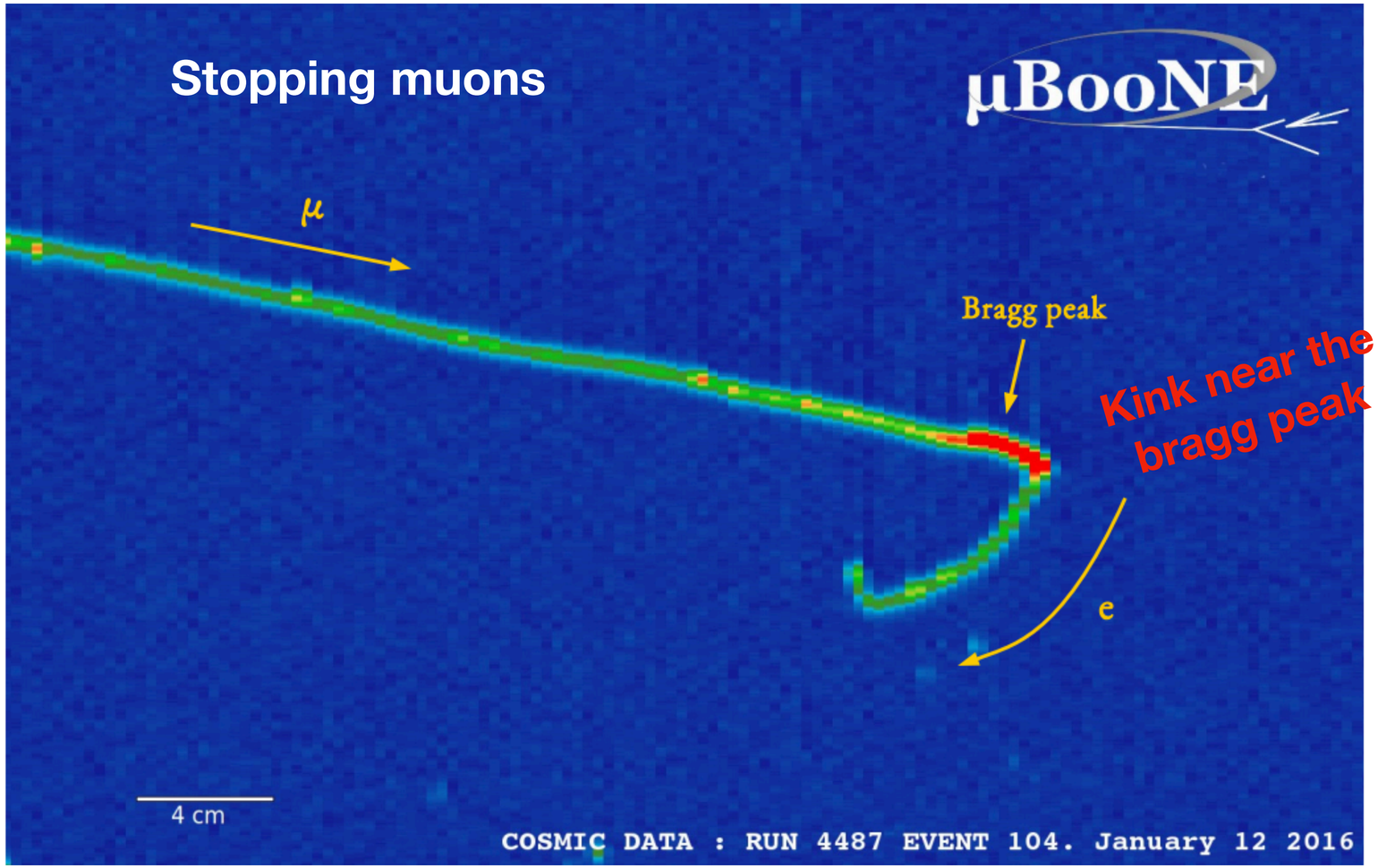

ProtoDUNE has demonstrated TPC self-triggering on cosmic muons (through-going muons), we aim to target topologically more complex signatures using MicroBooNE.

TPC Trigger Strategy

- Following DUNE trigger strategy, trigger primitives (TPs) can be constructed from **MicroBooNE's SN stream ROIs*.**

*P. Abratenko *et al* 2021 *JINST* **16** P02008

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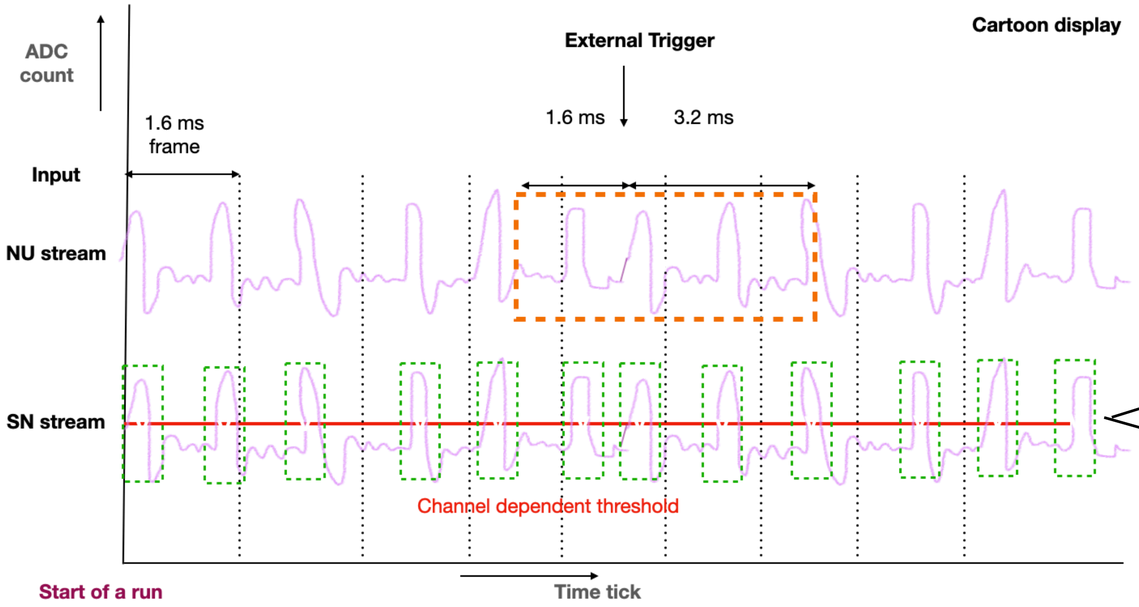
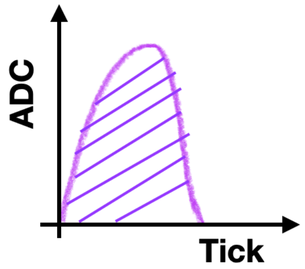
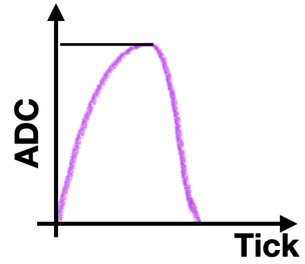


TPs are defined as a "summary" of an ROI:

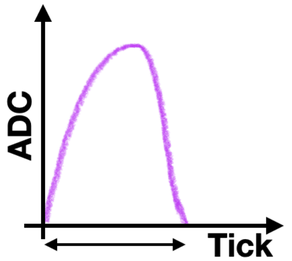
Baseline subtracted



Integral



Amplitude



Time over threshold

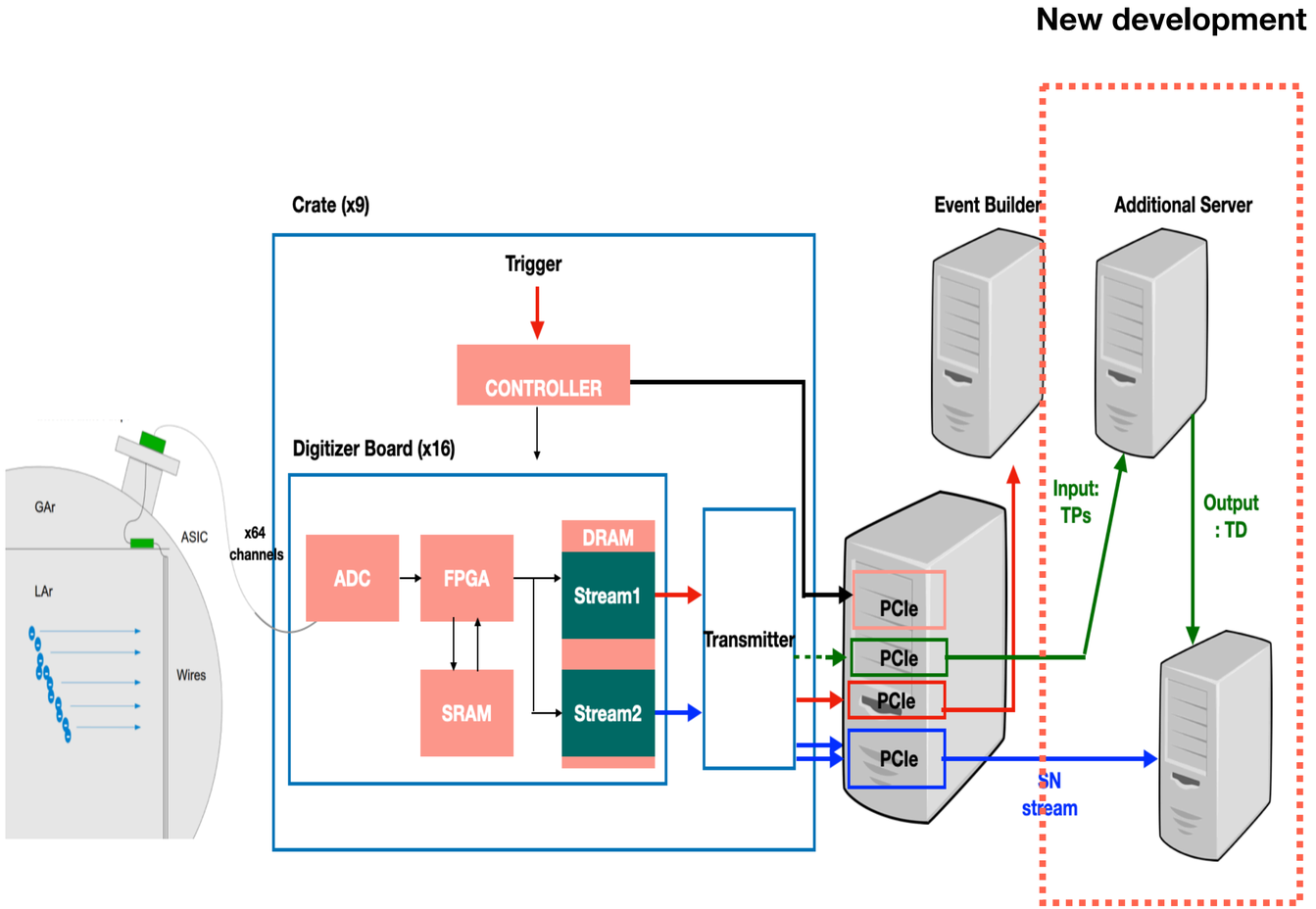
*P. Abratenko *et al* 2021 *JINST* **16** P02008

TPC Trigger Strategy

- Following DUNE trigger strategy, trigger primitives (TPs) can be constructed from **MicroBooNE's SN stream ROIs*.**

- TPs stream to DAQ servers for online processing with a goal of generating higher level TPC-triggered objects to construct a Trigger Decision (TD).

- TD can be used to select the corresponding buffered SN readout data for subsequent event building.



*P. Abratenko *et al* 2021 *JINST* **16** P02008

Current Status for Online Trigger Development

- TP generation has been implemented in FPGA for real-time implementation and testing in MicroBooNE.

```
FFFFFFFF F1E3FFFF F6A8F001 F007F000 F006F000 F000F000 F000F000 117F4792
C000C000 C000C000 C000C000 1180418A C010C1A8 C008C154 C006C822 F1E3FFFF
F6A8F001 F007F000 F006F000 F000F000 F000F000 118041A2 C010CE77 C007CEBE
C005C7F3 1180458A C010C1A8 C008C154 C006C822 F1E3FFFF F6A8F001 F007F000
F006F000 F000F000 F000F000 118045A2 C010CE77 C007CEBE C005C7F3 1180498A
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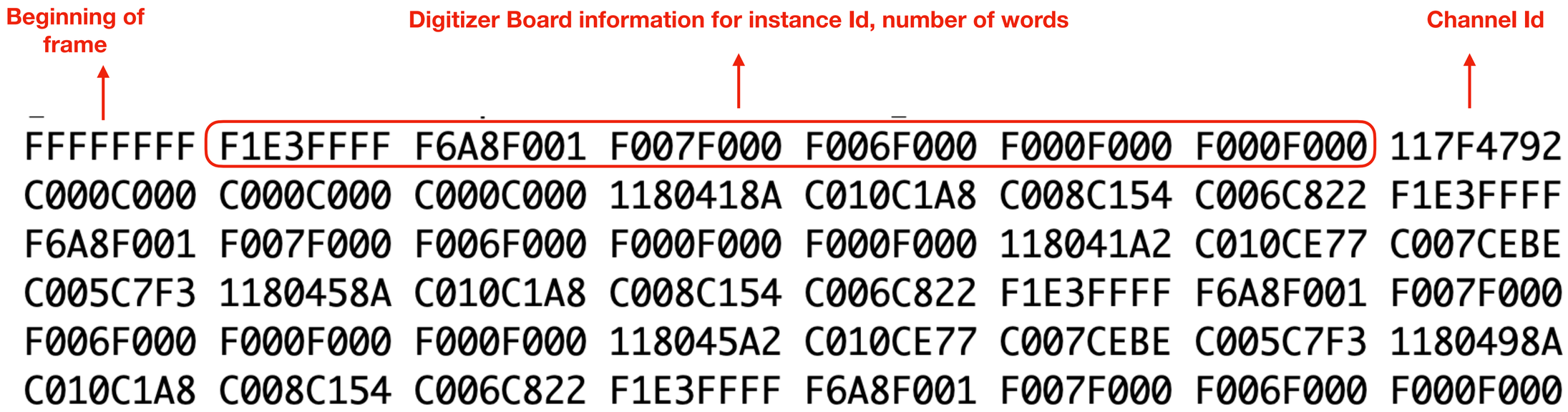

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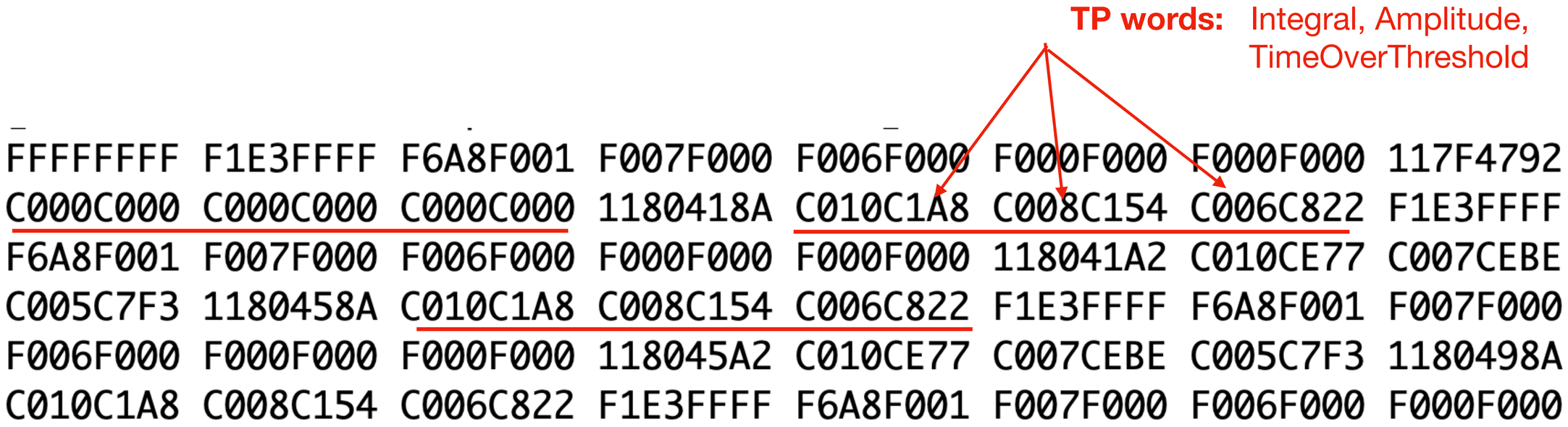
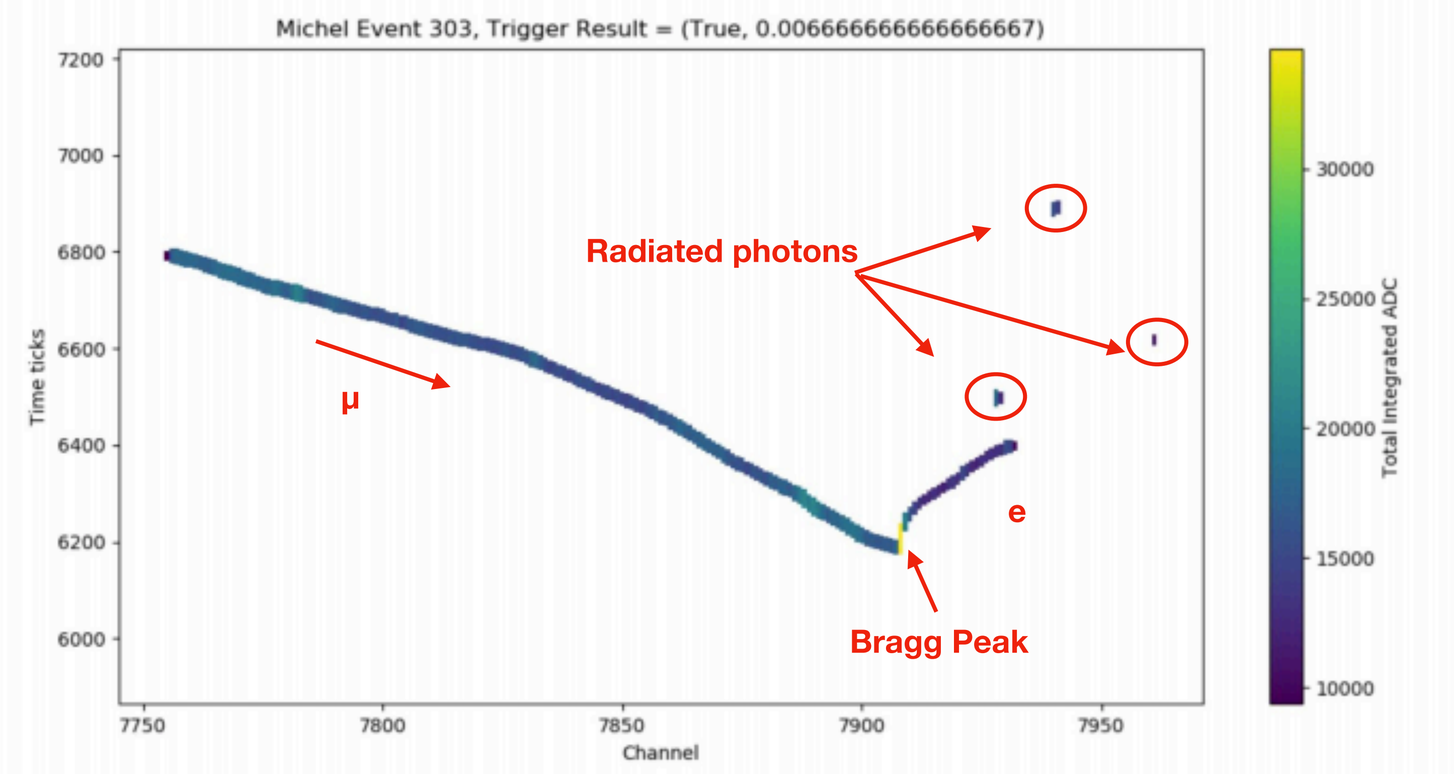


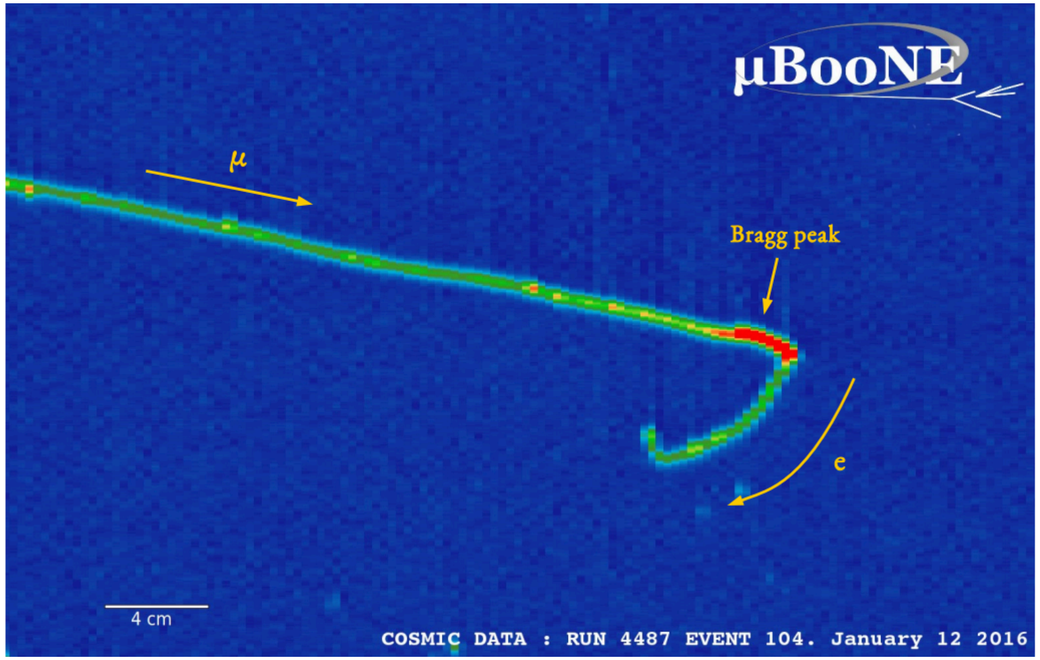
Current Status for Online Trigger Development

- Working towards developing trigger algorithms for online trigger generation.
- Example of stopping muon in MicroBooNE.



Trigger Approaches

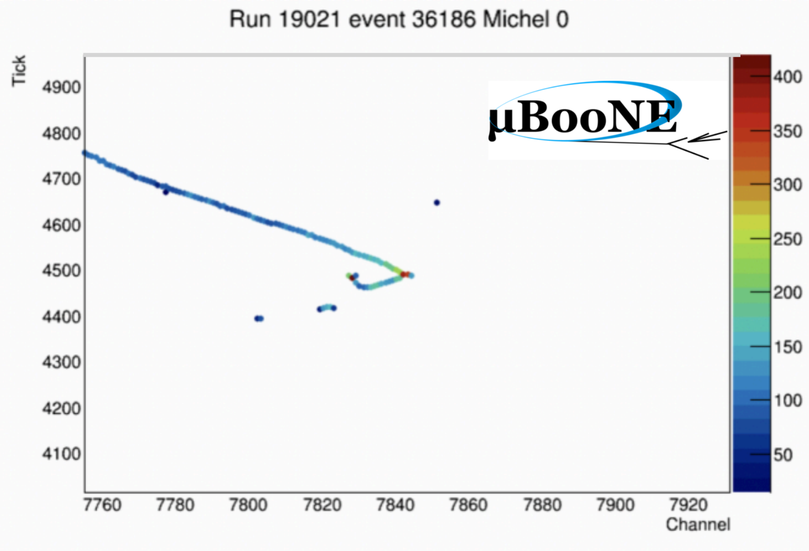
- One can look for stopping muons, *by looking at straight tracks making use of topological (existence of kink) and calorimetric (change in dE/dx at bragg peak) information to trigger on.
- There is also a possibility of exploring **image classification**, rather than having to cluster TPs to make a track to construct high lever trigger objects.

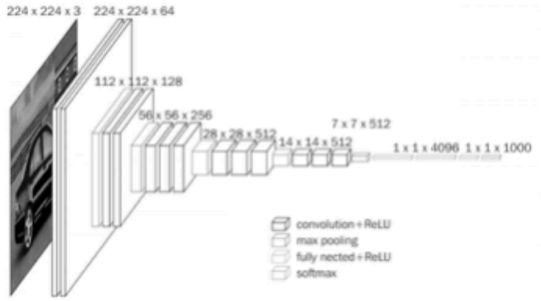


*Michel Electron Reconstruction Using Cosmic Ray Data from MicroBooNE LArTPC (MicroBooNE Collaboration), JINST 12 (2017) 09, P09014

Machine Learning (ML) based Trigger Approach

Image classification





Convolution Neural Network (CNN)
classification

Low energy activity

Stopping muon

High energy Annihilation

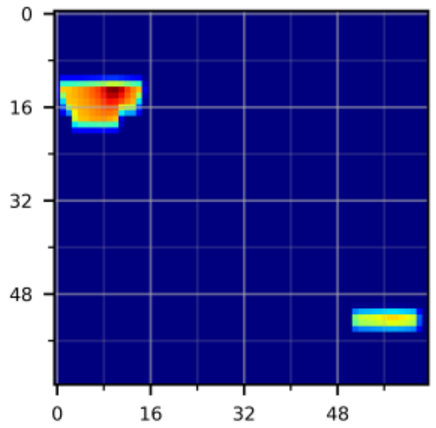
Classification will be done based on Activity

Low energy activity → Supernova neutrino events

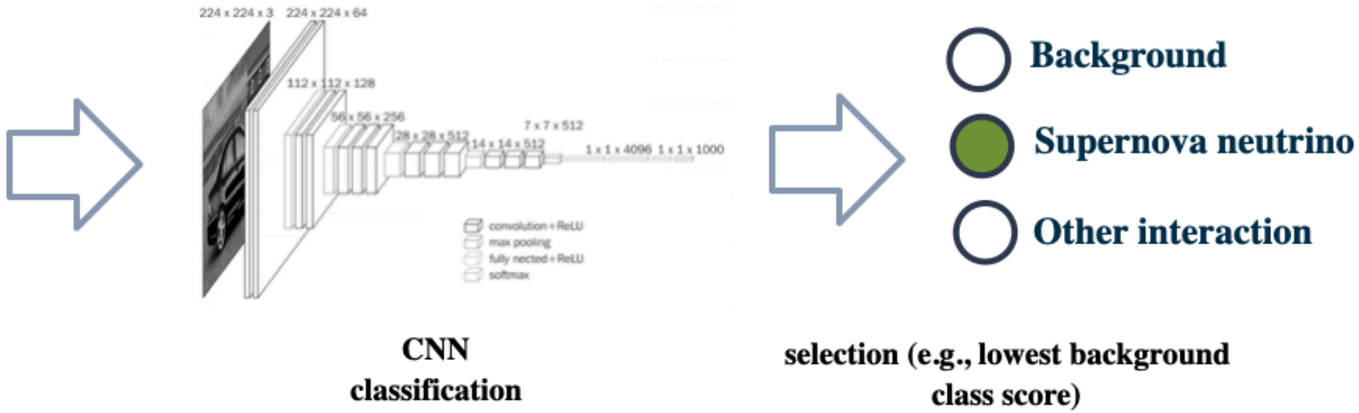
High energy activity → Stopping muon, n-nbar oscillation event

Future Possibility

- For future experiment such as DUNE, there is a possibility to use ML tools on specialized hardware like Field Programmable Gate Array (FPGA).
- Our group is also working on deploying CNN on FPGA as it is much more power efficient.
- Preliminary results on ROI downsized images.



Downsized 2D image of physics interaction
(Collection-plane only)



CNN classification

selection (e.g., lowest background class score)

Y. Jwa, G. Di Guglielmo, L. P. Carloni and G. Karagiorgi, "Accelerating Deep Neural Networks for Real-time Data Selection for High-resolution Imaging Particle Detectors," 2019 New York Scientific Data Summit (NYSDS), 2019, pp. 1-10, doi: 10.1109/NYSDS.2019.8909784.

Summary

With the currently operating LArTPC detector, we have an exciting opportunity to:

- Carry out dedicated demonstrations for DUNE TPC trigger design.
- Develop novel (ML based) LArTPC trigger techniques for online or real-time data processing.

Thank you