Liquid Argon TPC Trigger Development with MicroBooNE & SBND

Daisy Kalra
on behalf of MicroBooNE & SBND collaborations

Columbia University

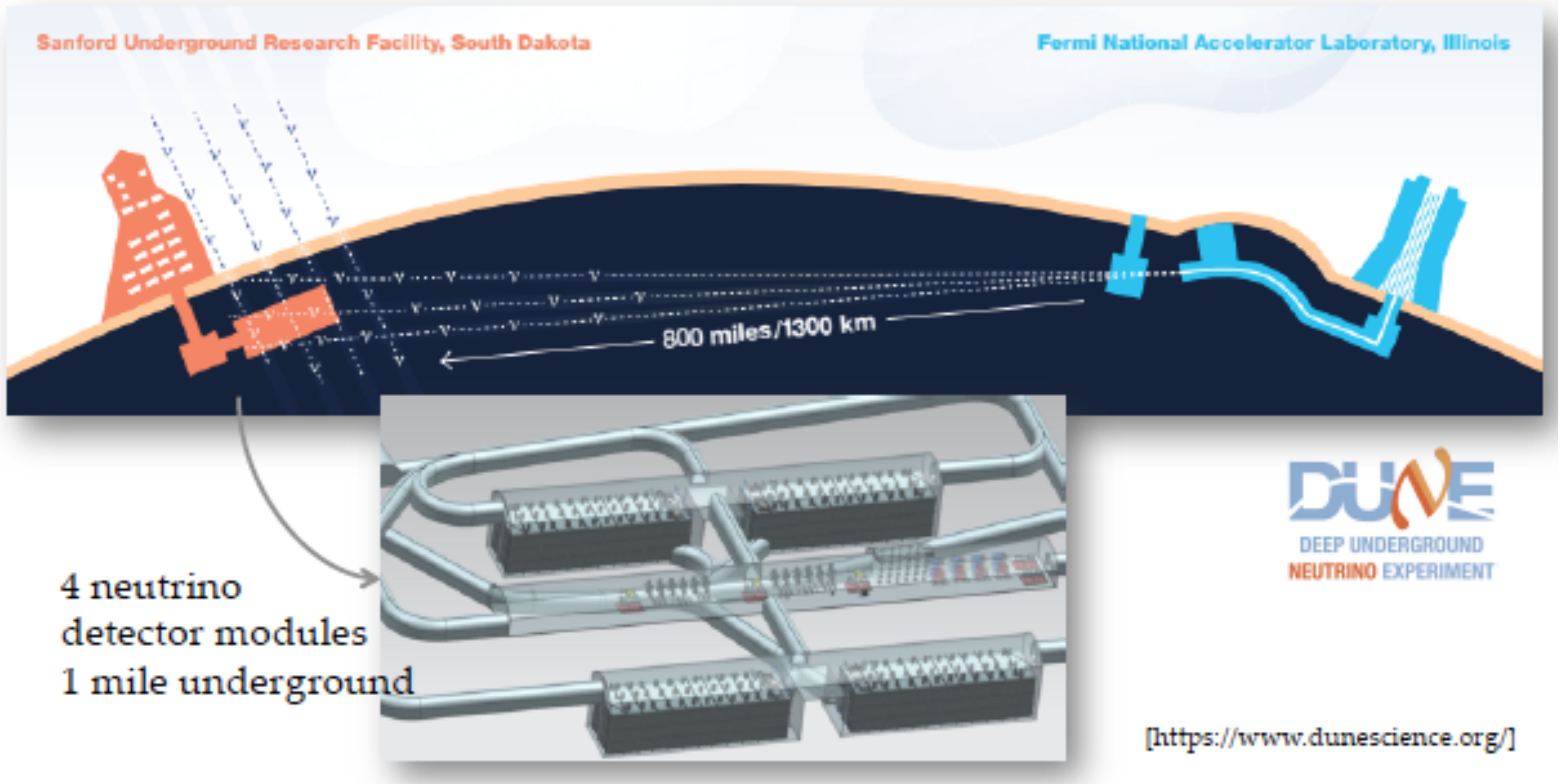
CPAD-2021
March 18, 2021

Contents

Motivation

DUNE: World's largest LArTPC neutrino experiment (once constructed), will start taking data ~2026.

Data rates in DUNE:
up to >1 million readout channels
2 MHz x 12 bit ADC digitization
>5 TB/s data rate!



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

- One of the DUNE physics goals is to search for non-beam events (rare events) such as neutrinos from Supernova burst, *(up to ~few thousand interactions over first 10 seconds, but ~once per century)*

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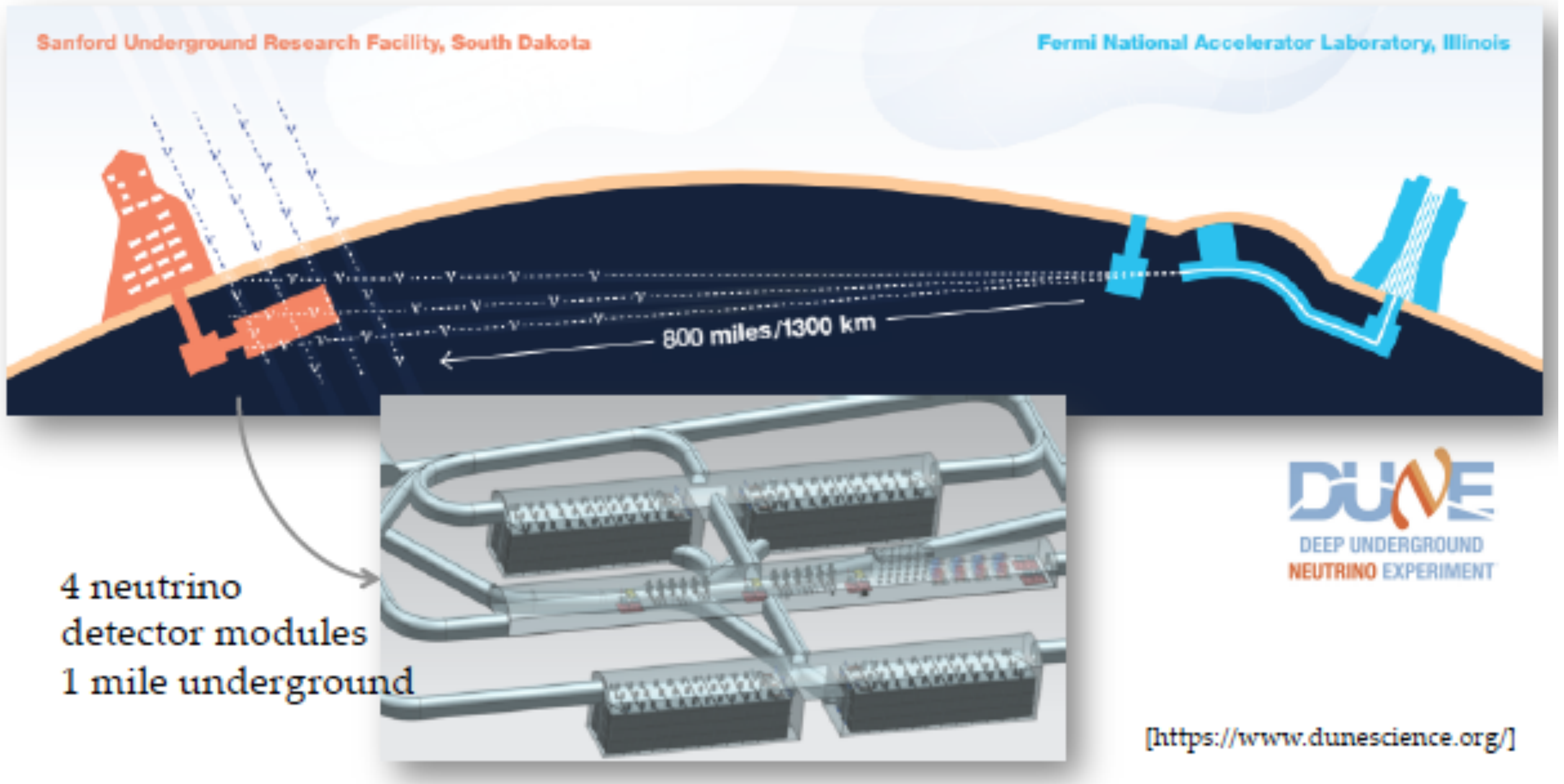

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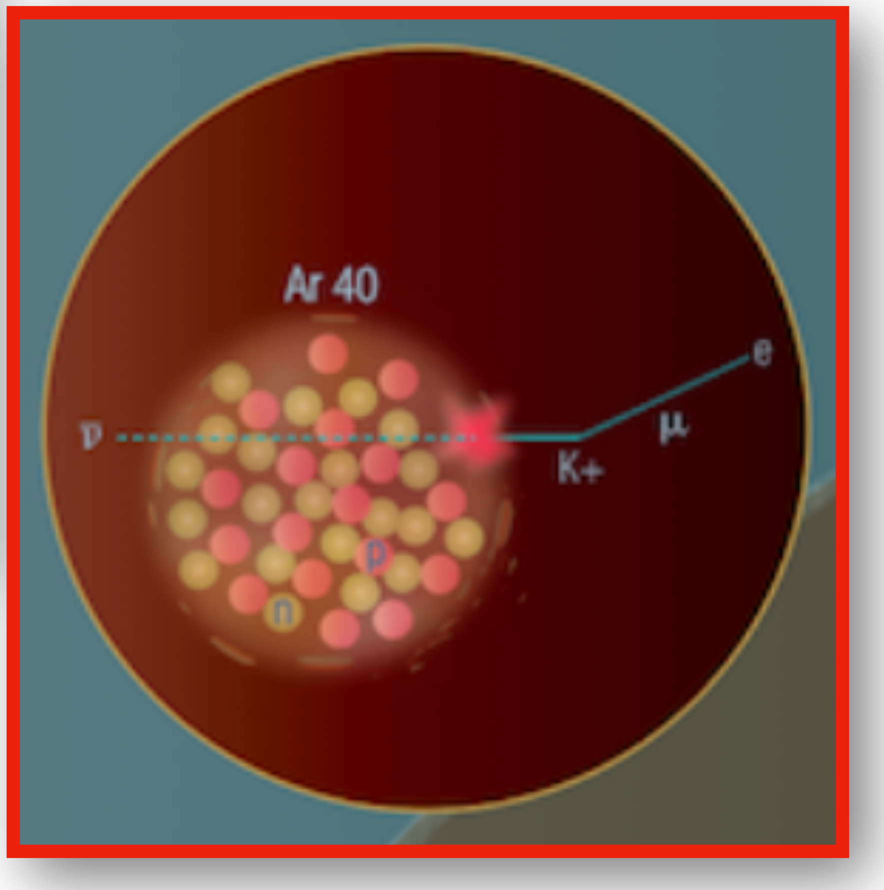

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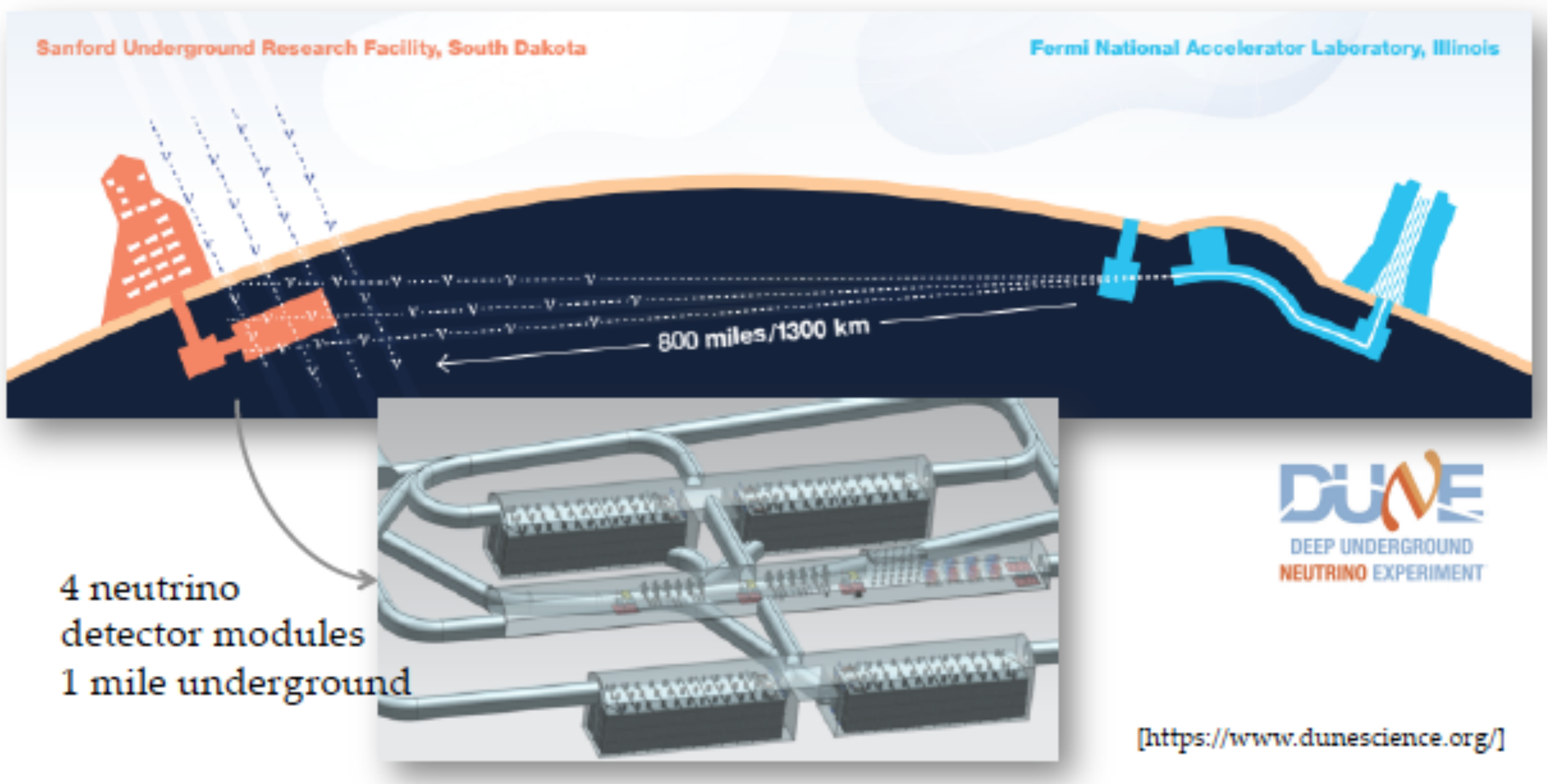

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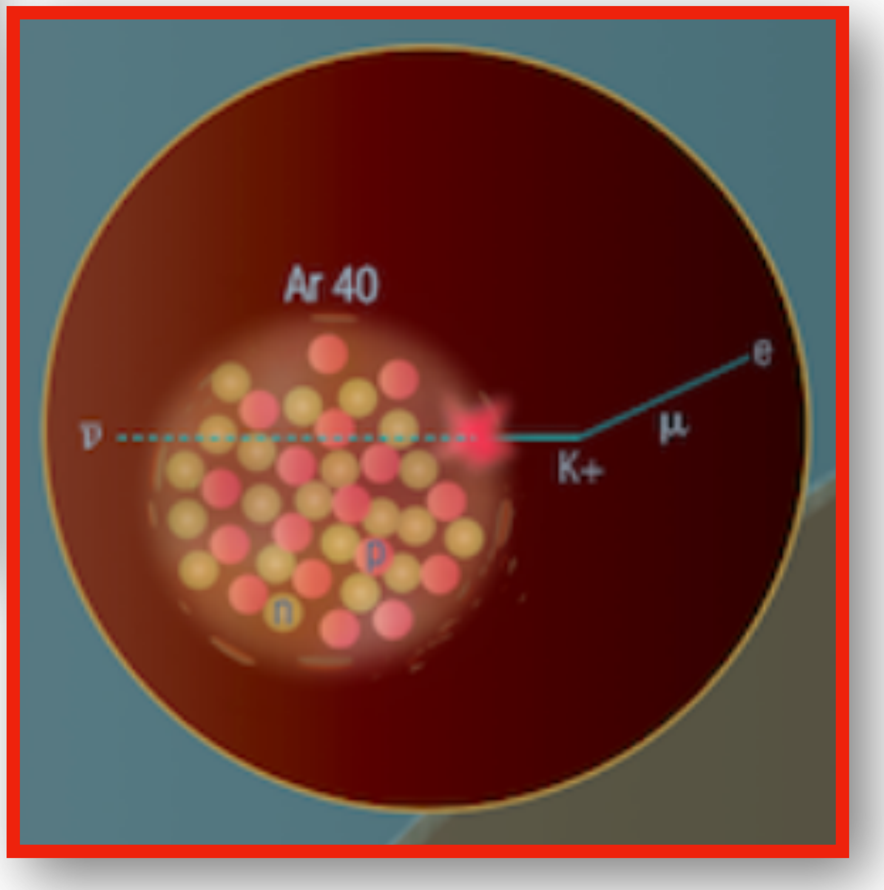
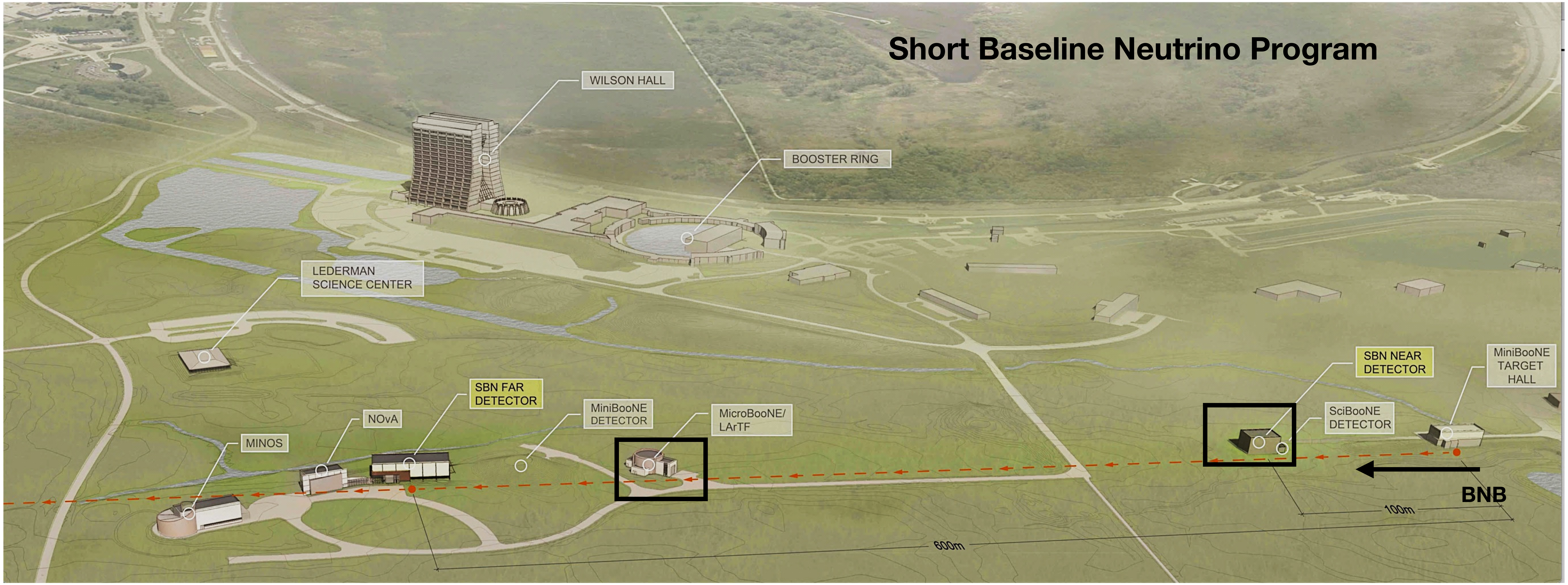


Requires continuous readout with ~100% live time and self-triggering.

Motivation

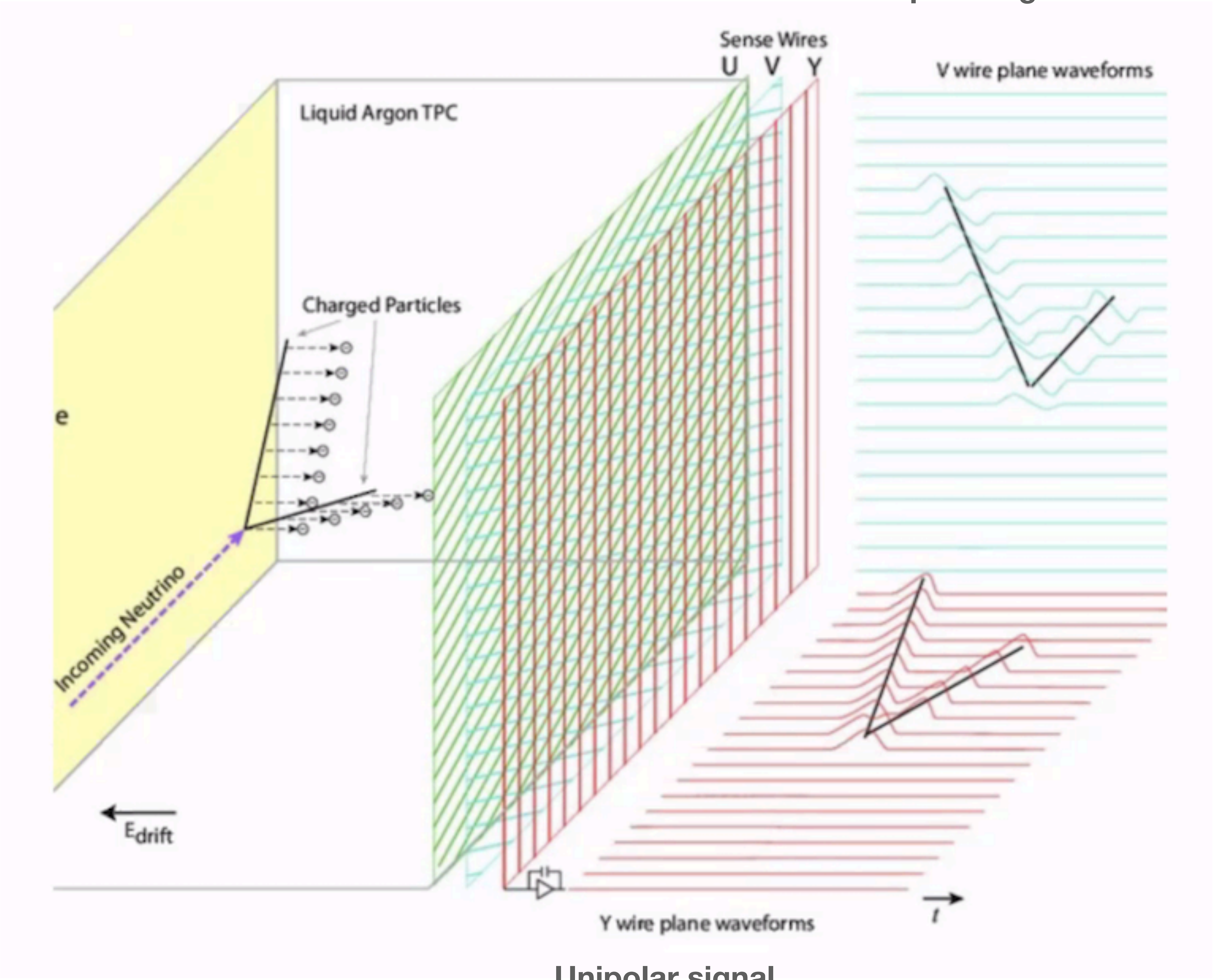
Current LArTPC detectors such as MicroBooNE and SBND, which share functionally identical back-end readout electronics, can be exploited to demonstrate and develop TPC-based trigger.



Liquid Argon Time Projection Chamber (LArTPC)

- Neutrino interactions with Ar nuclei leave a trail of ionization electrons, drift towards anode under uniform electric field.
- Two induction planes (U & V) wires: orientation: @ 60^o w.r.t vertical
  Collection plane (Y) wires: vertically oriented
  to enable 3D reconstruction of collected ionization tracks.
- PMTs located behind the anode planes capture prompt scintillation light and hence achieve 3D reconstruction along with the wire signal information.
- High spatial resolution and calorimetry for excellent particle identification.

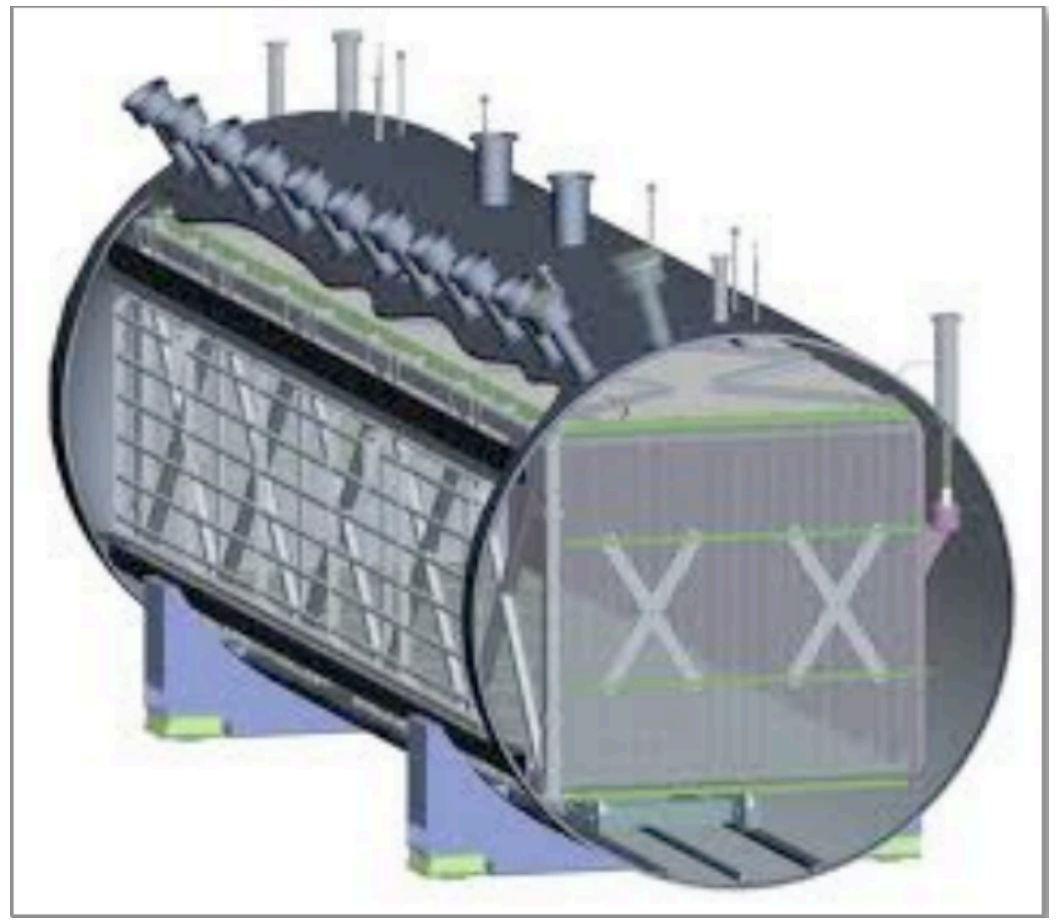
Bipolar signal



Unipolar signal

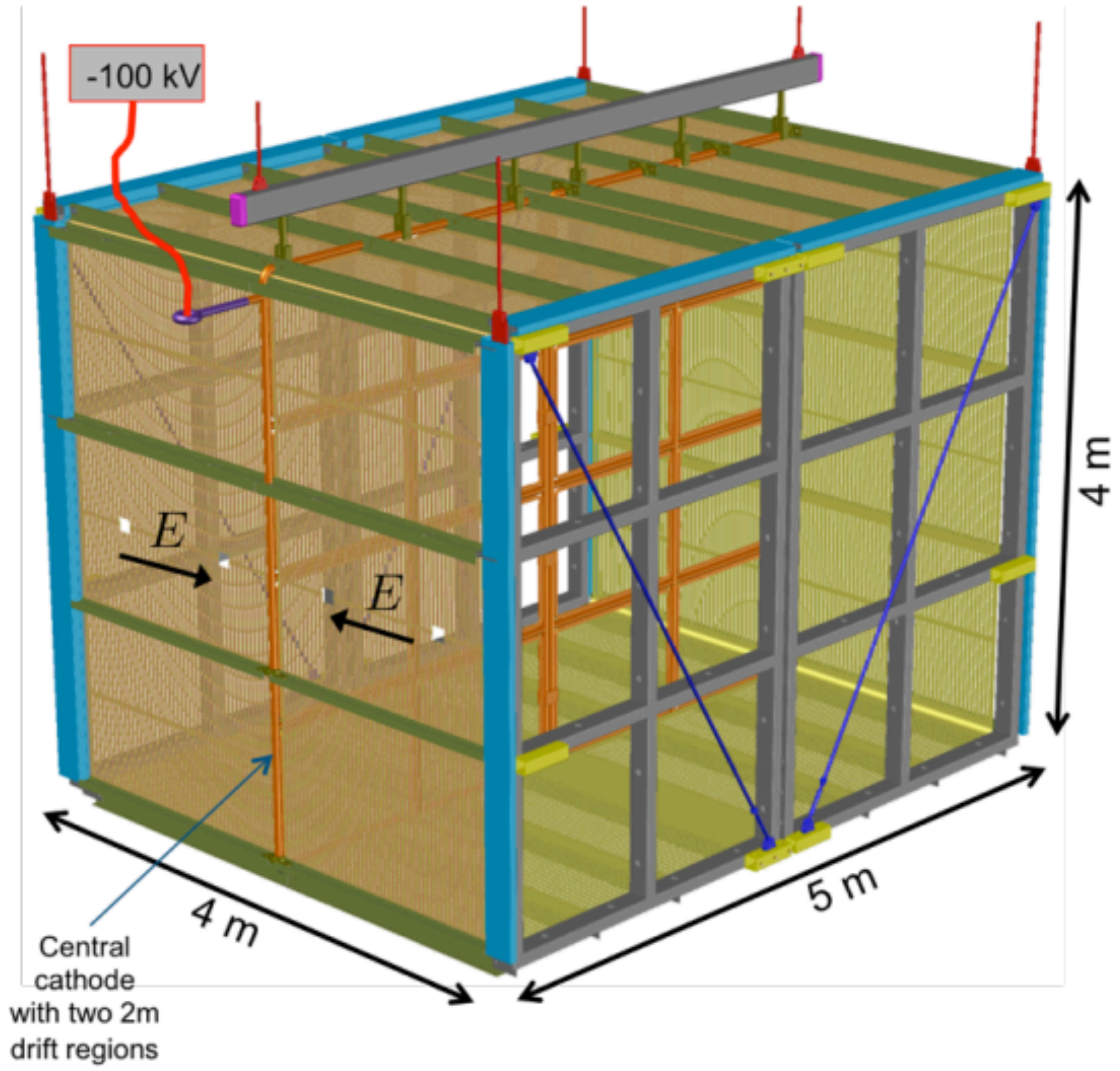
MicroBooNE and SBND

Part of Short Baseline Neutrino Program at Fermilab



MicroBooNE

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



- Functionally identical back-end readout electronics (digital processing electronics) in both experiments.

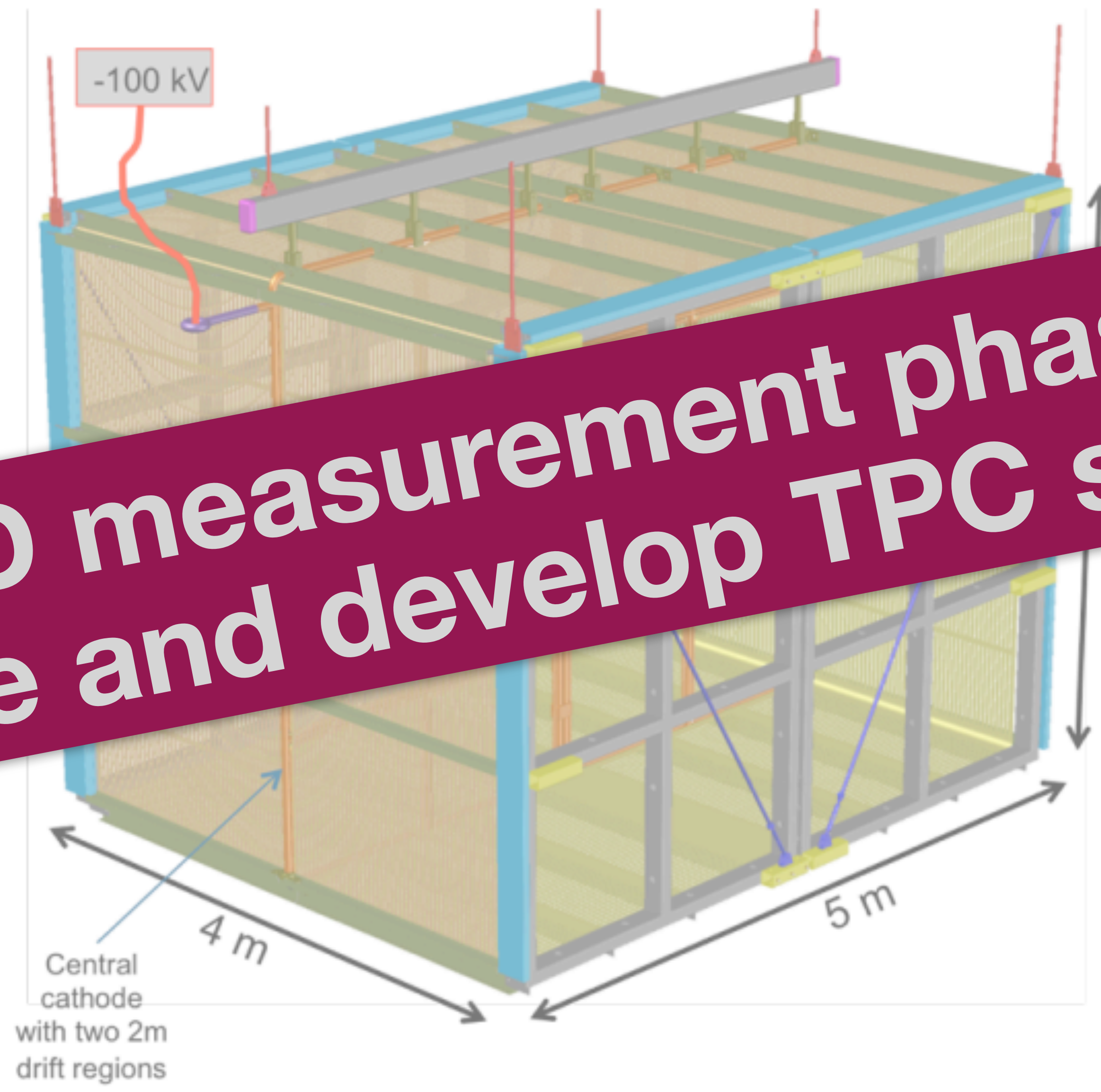
SBND

- 112 tons active* LAr volume
- 11264 TPC wires (2MHz)
- 120 8" PMTs (500 MHz digitization)
- **Data Rates: 45 GB/s**

**Maximum volume that can be used for physics analysis.*

MicroBooNE and SBND

Part of Short Baseline Neutrino Program at Fermilab



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

MicroB

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

- Functionally identical back-end readout electronics (digital processing electronics) in both experiments.

SBND

- 112 tons active* LAr volume
- 11264 TPC wires (2MHz)
- 144 8” PMTs (500 MHz digitization)
- **Data Rates: 45 GB/s**

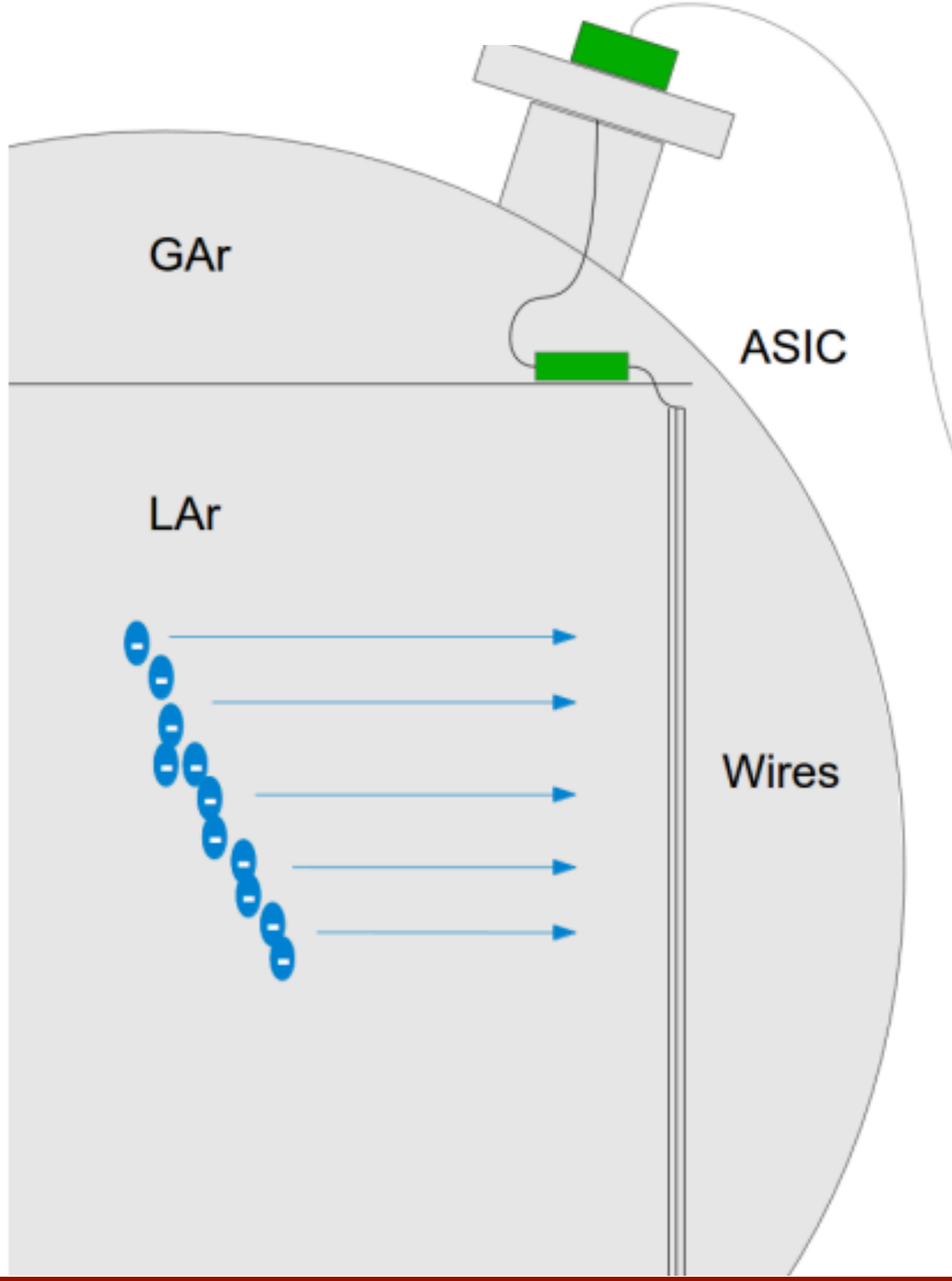
Maximum volume that can be used for physics analysis.

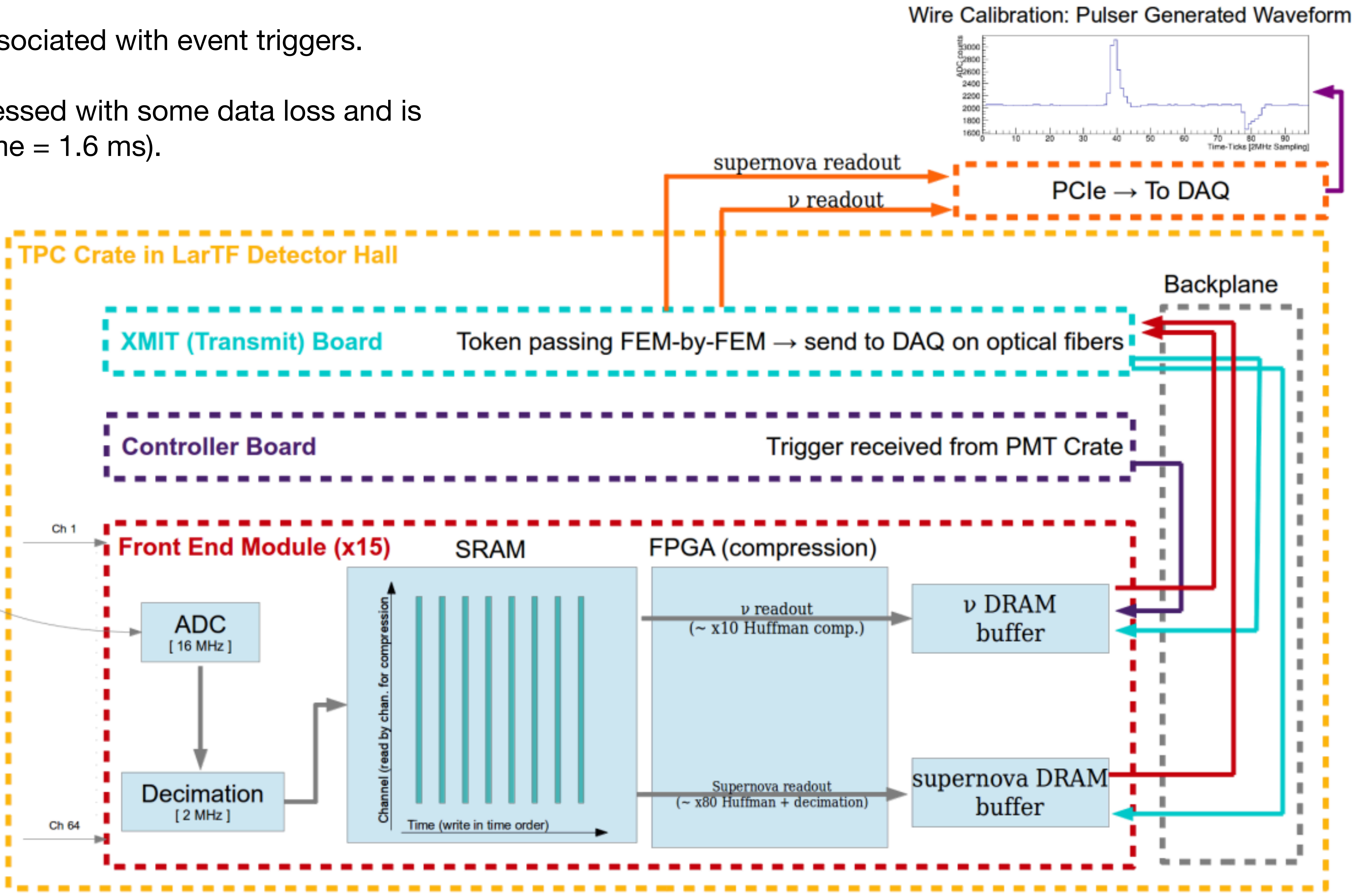
TPC Readout electronics (MicroBooNE)

The TPC readout electronics shapes, amplifies, digitizes and records the signal induced on anode wire planes and pass it to downstream data acquisition (DAQ) system.

NU stream Losslessly compressed data associated with event triggers.

SN stream Continuous data stream compressed with some data loss and is continuously readout frame by frame (1 frame = 1.6 ms).





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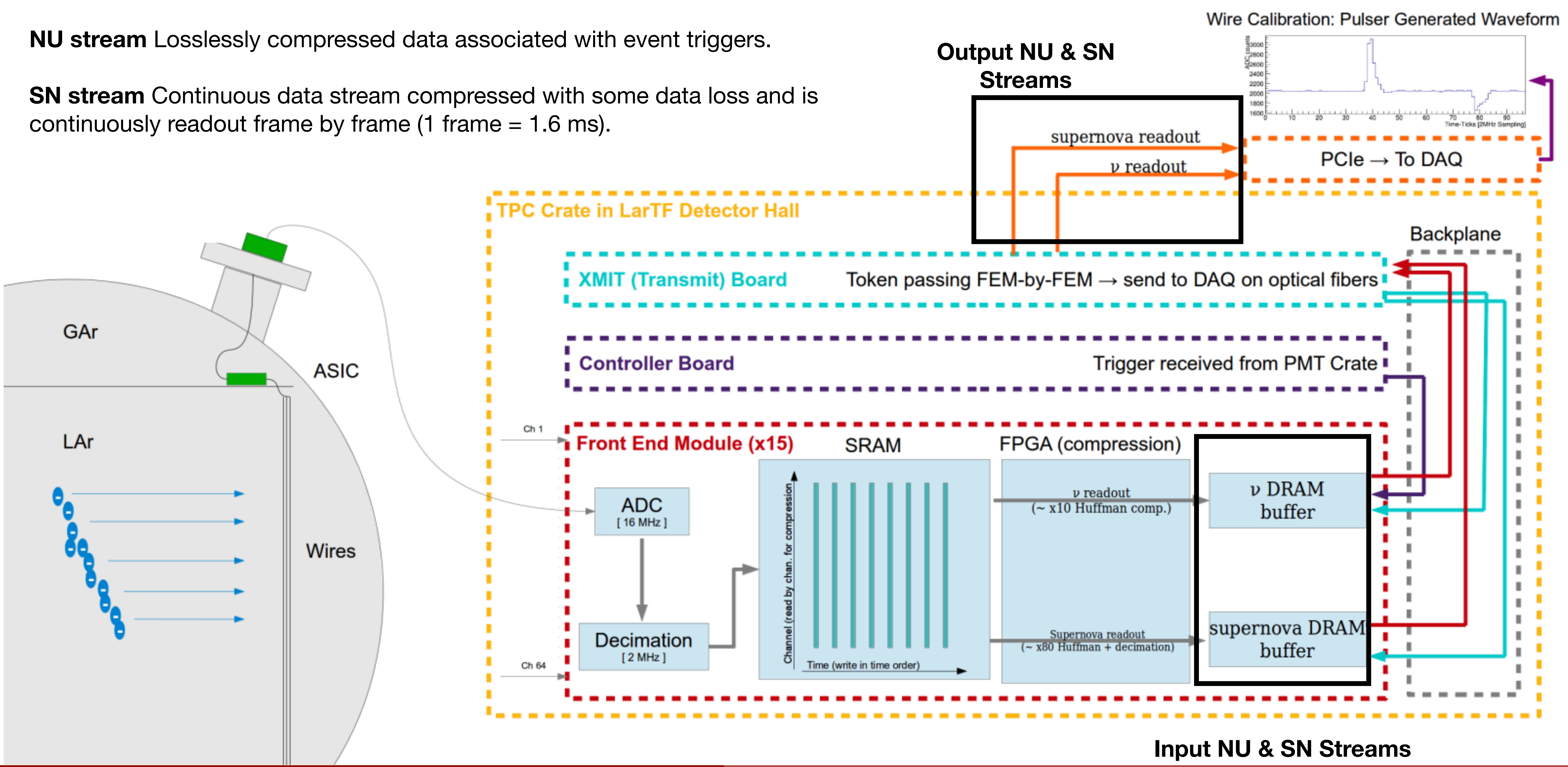
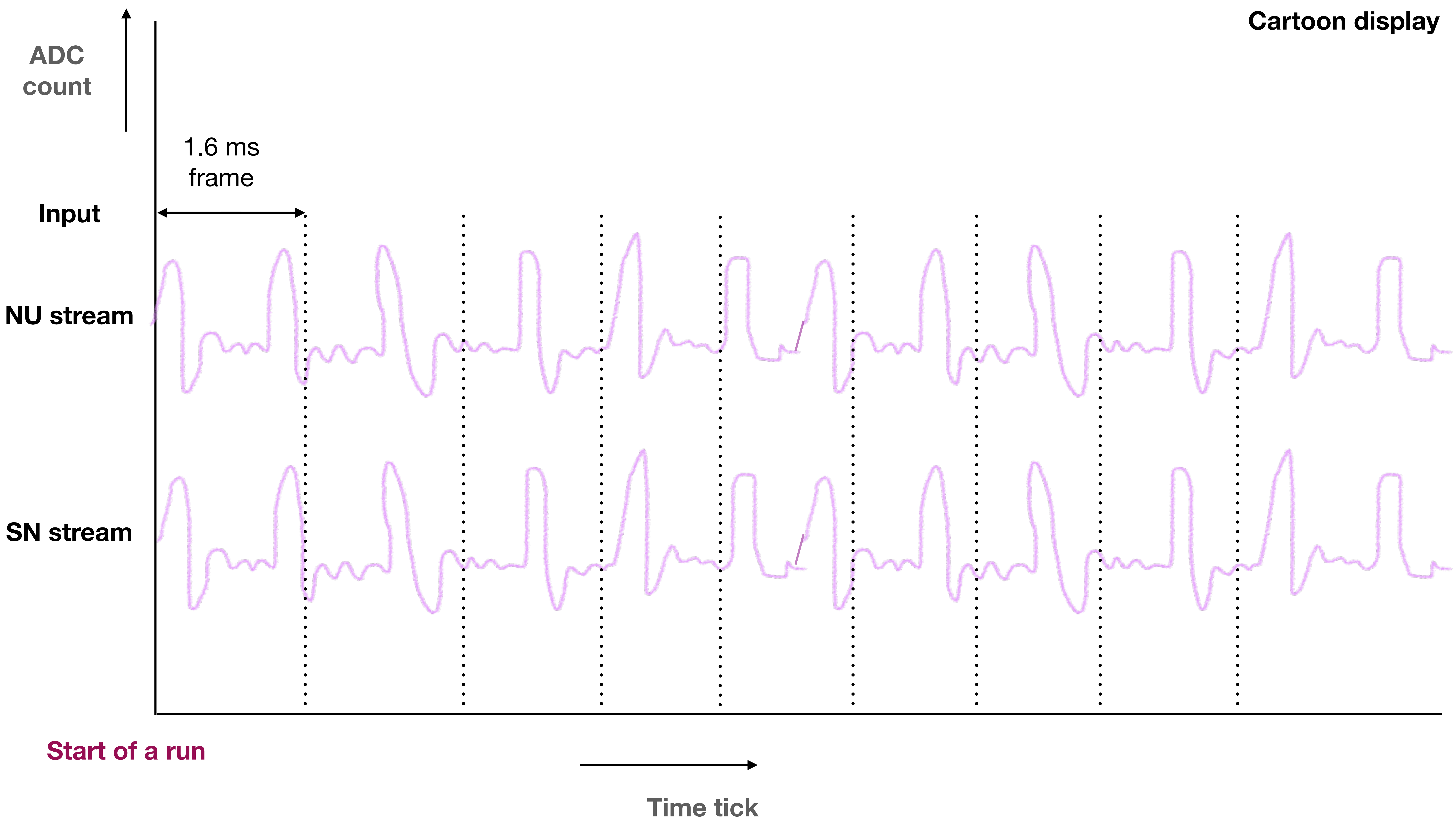


Data Streams (MicroBooNE)



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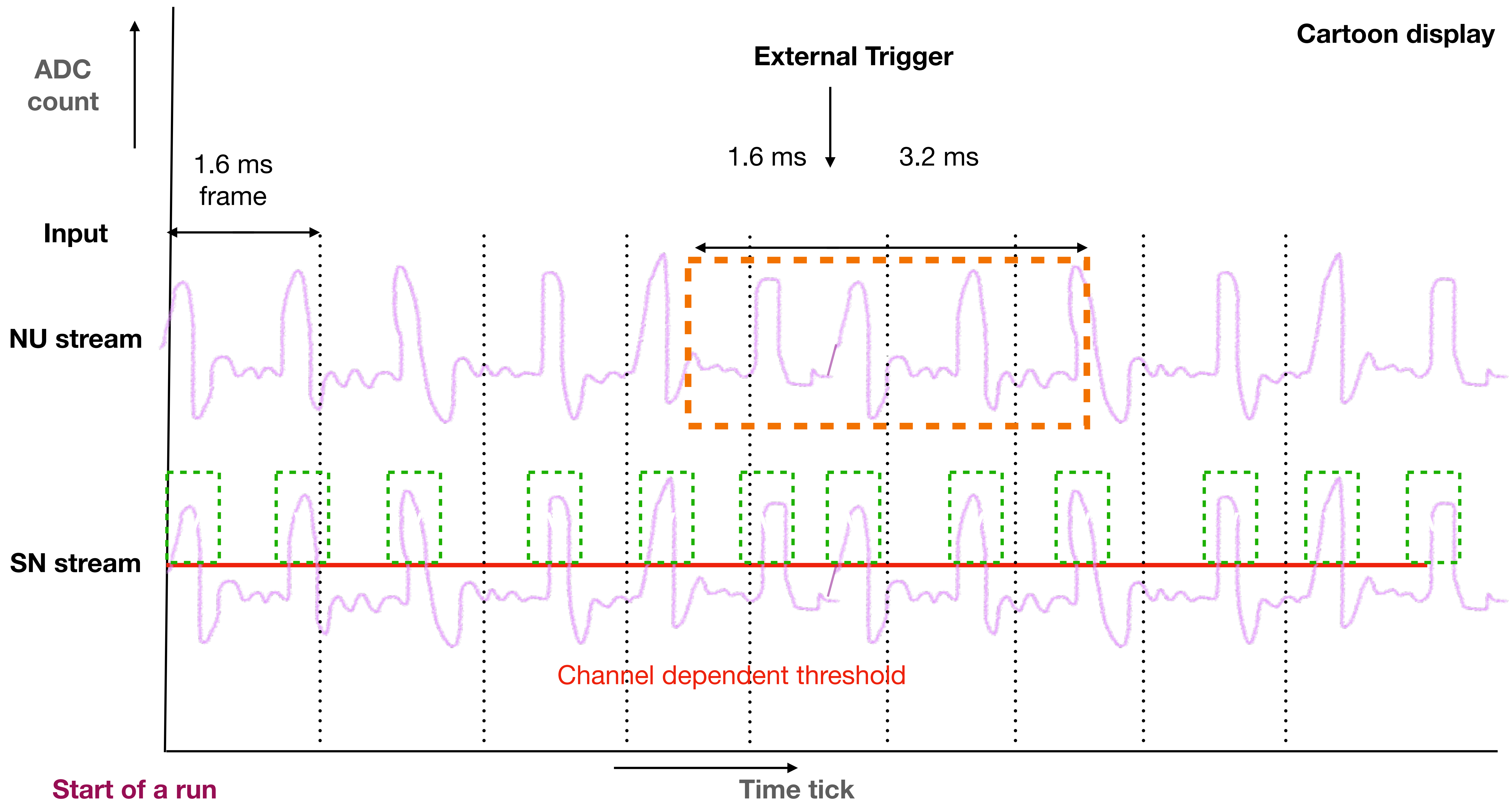

- NU stream: On receiving an external trigger, 4.8 ms of data is readout.
- SN stream: Regions of interest (ROI) are extracted, whenever a waveform crosses a certain threshold.

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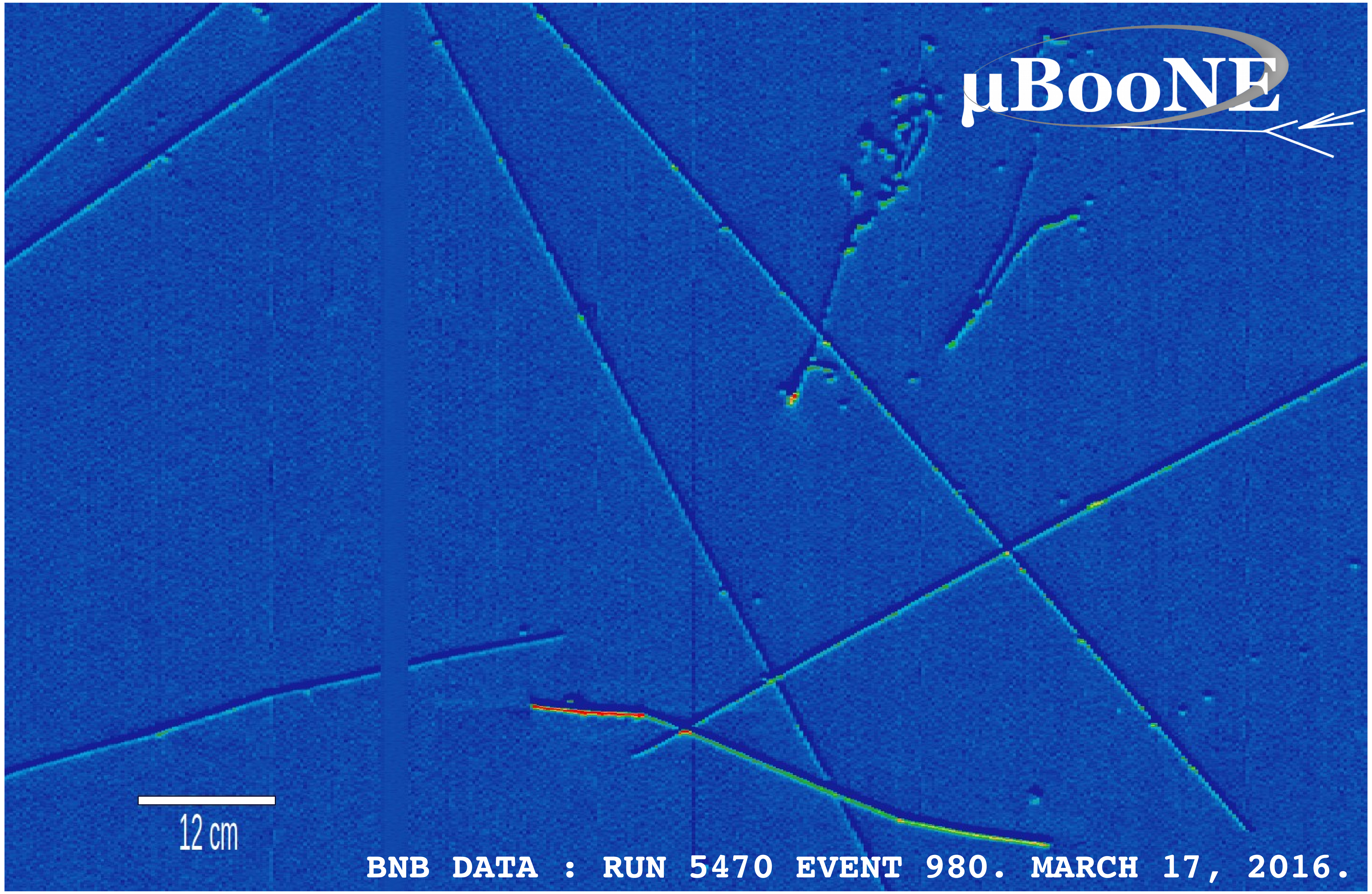
Data Streams (MicroBooNE)

- NU stream is saved every time there is a trigger and then is diverted to Sub Event Buffers (SEBs) and then to Event Builders to build events (Data used for beam physics measurements)

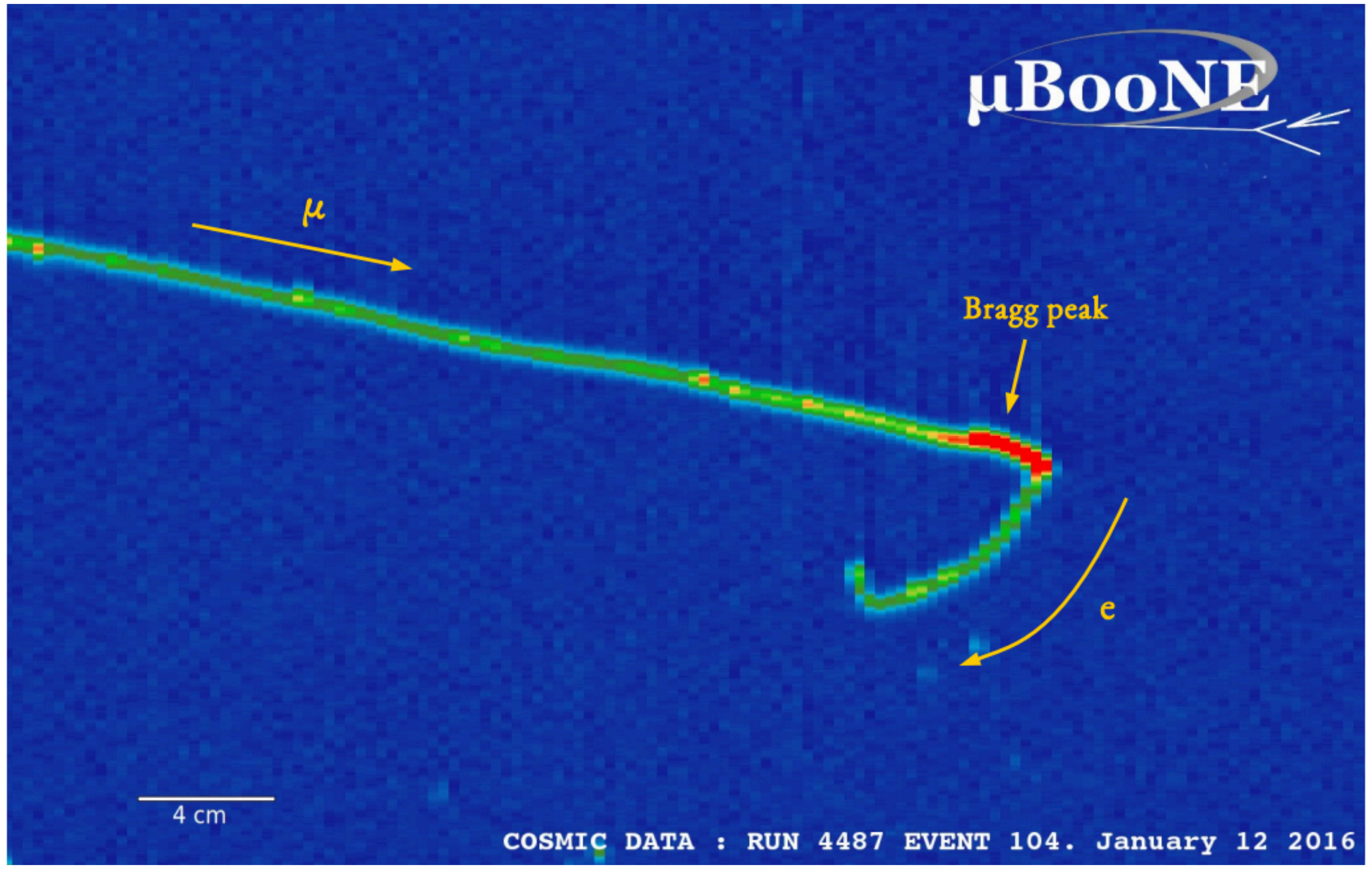
- SN stream is saved to drive and is written to disk on receiving a SuperNova Early Warning System (SNEWS) alert (Data to search for non-beam events).

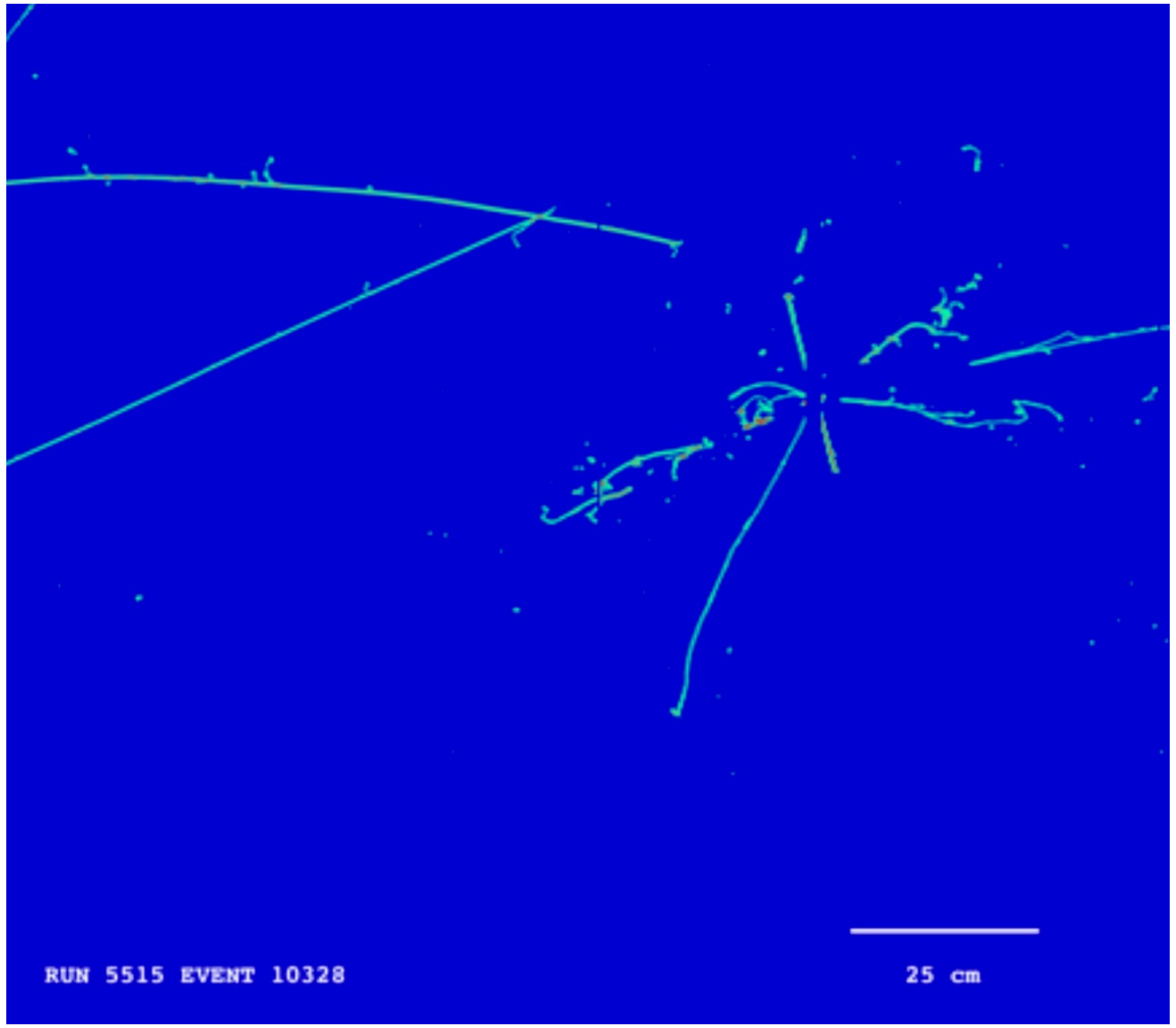
Which events to trigger on?



MicroBooNE, being situated on-surface, has a lots of cosmogenic activities.

Interesting events to trigger





- Some of the interesting interactions to trigger on include stopping muons, cosmogenic anti-proton or anti-neutron annihilation.

TPC Trigger Strategy

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

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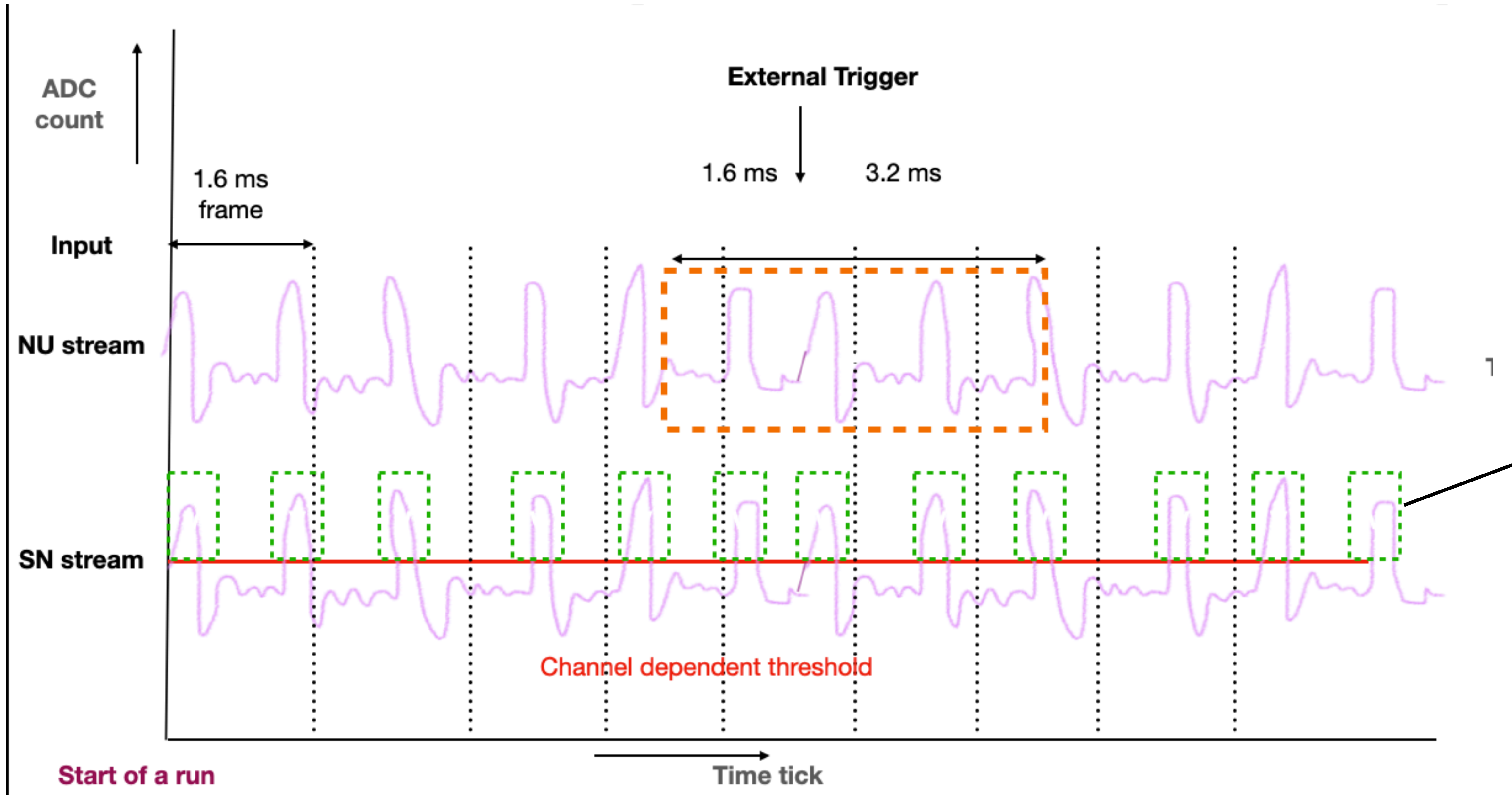
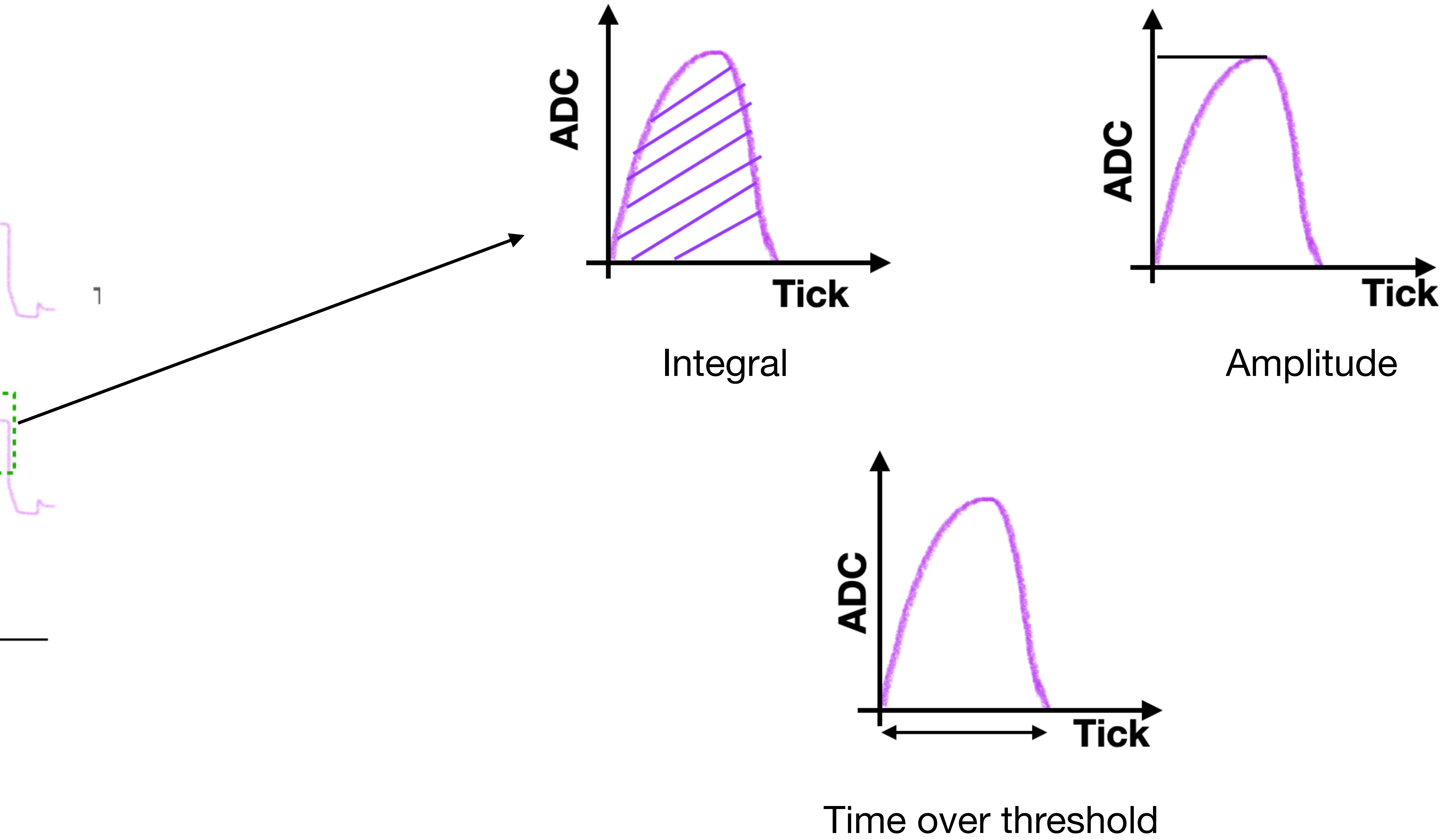
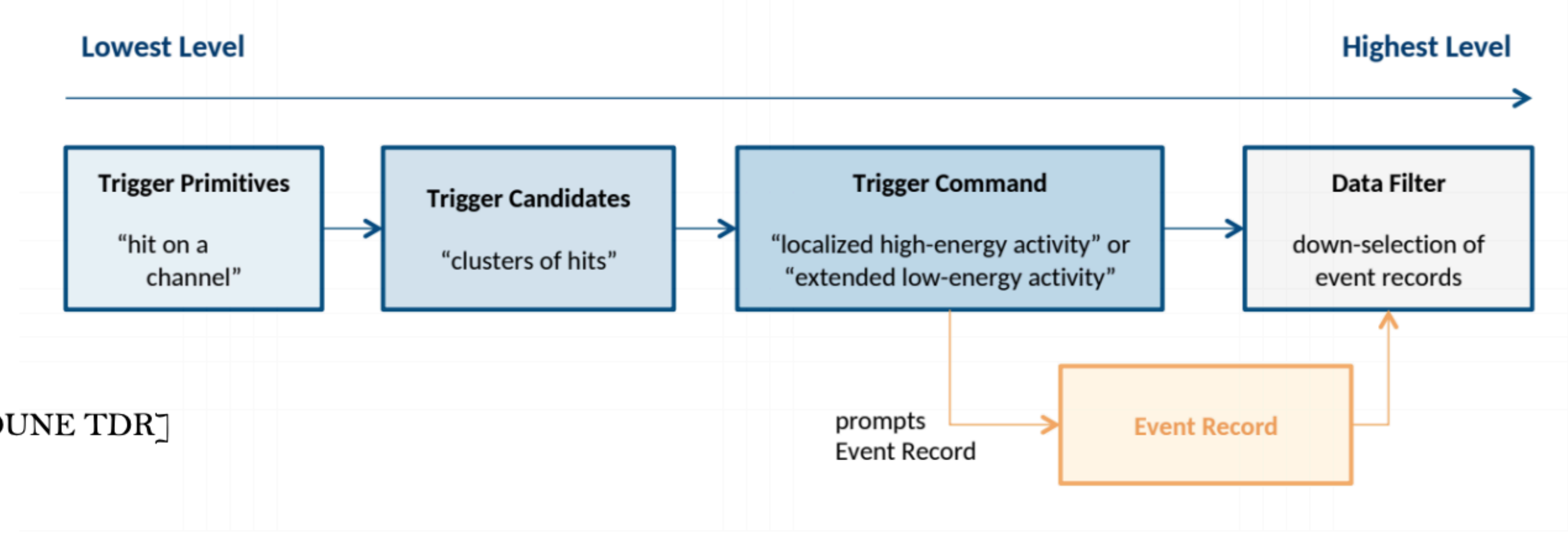


TPs are defined as a "summary" of an ROI:



TPC Trigger Strategy

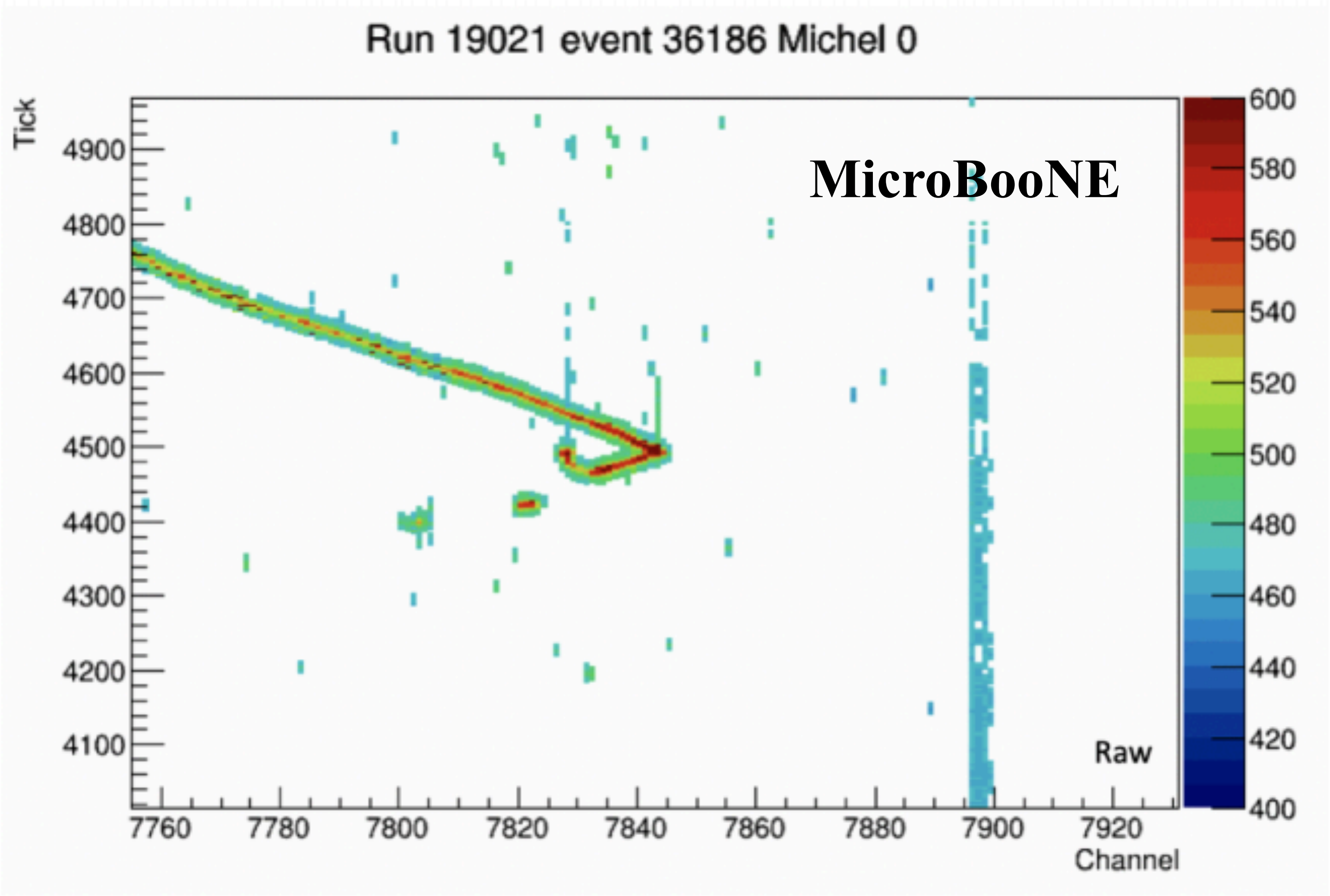
- Following DUNE trigger strategy, trigger primitives (TPs) can be constructed from MicroBooNE's SN stream ROIs.
- TPs can be used to make an online TPC trigger decision (TD) (in CPUs or GPUs) by constructing higher-level TPC triggered objects.



[DUNE TDR]

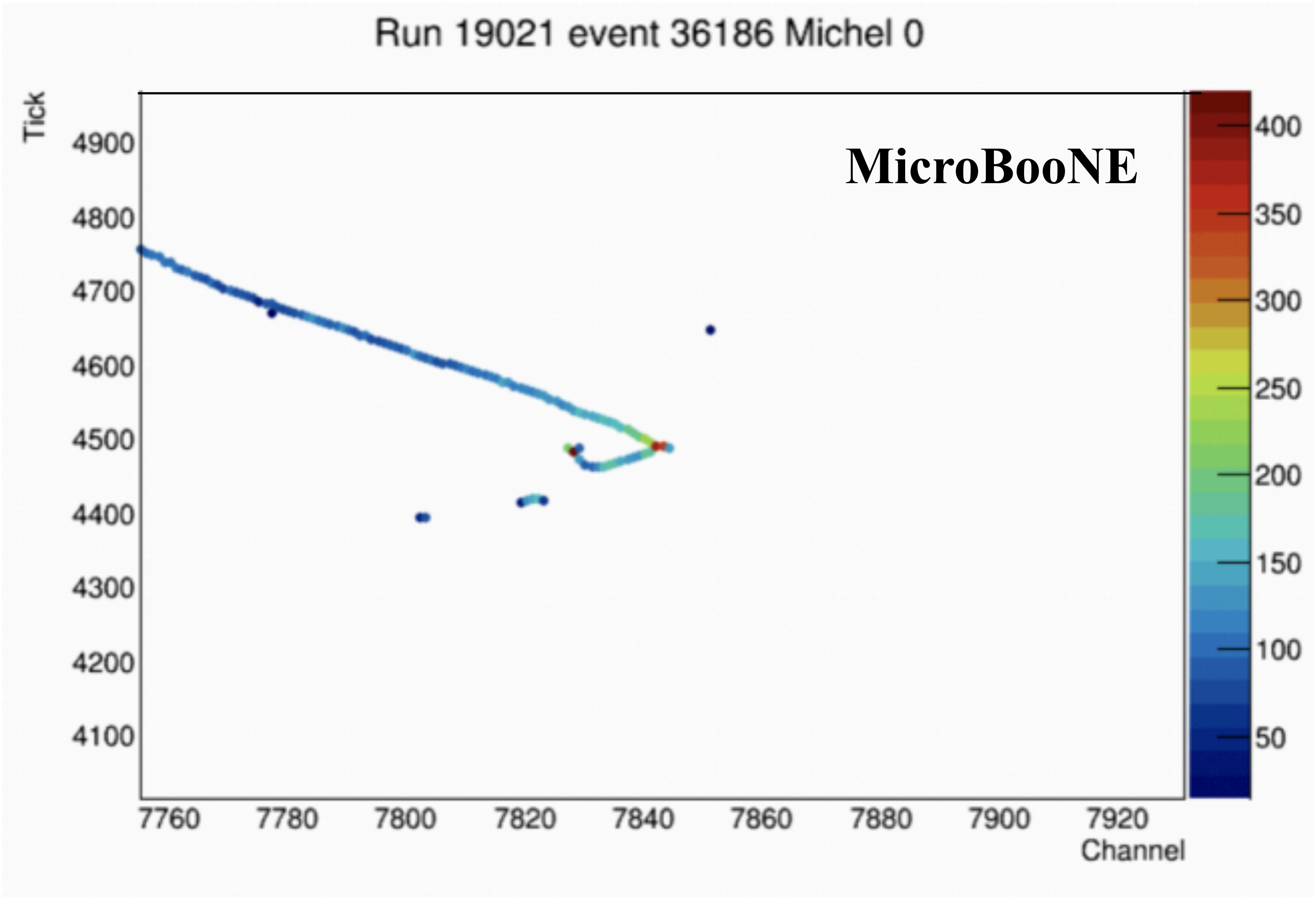
Trigger Approaches

Michel electron candidate event display (MicroBooNE's ROI)



Hits are found by offline Gaussian Hit Finder Module

An example of applying TP generation to ROIs. (ROI integral)



Current Status for Online Trigger Development

- TP generation has been implemented in FPGA for real-time implementation and testing in MicroBooNE (& SBND in near-future).
- Working towards TP processing software and algorithms for online trigger generation.

0xFFFFFFFF	Begin of crate read-out
0xE0000000	End of crate read-out

```
FFFFFFFF F1E3FFFF F6A8F001 F003F000 F002F000 F000F000 F000F000 107F4792
C000C000 C000C000 C000C000 E0000000 FFFFFFFF F1E3FFFF F6A8F001 F003F000
F002F000 F000F000 F000F000 108049A2 C060C05D C030C154 C006C822 E0000000
FFFFFFFF F1E3FFFF F6A8F001 F003F000 F002F000 F000F000 F000F000 10814993
C042C20E C008C7B8 C001C201 E0000000 FFFFFFFF F1E3FFFF F6A8F001 F003F000
F002F000 F000F000 F000F000 108249A1 C063C848 C031C141 C006C822 E0000000
FFFFFFFF F1E3FFFF F6A8F001 F003F000 F002F000 F000F000 F000F000 10834992
C045C7F0 C008C7AB C001C200 E0000000 FFFFFFFF F1E3FFFF F6A8F001 F003F000
F002F000 F000F000 F000F000 108449A1 C06CC060 C036C13C C006C821 E0000000
FFFFFFFF F1E3FFFF F6A8F001 F003F000 F002F000 F000F000 F000F000 10854991
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C000C000 C000C000 C000C000 E0000000 FFFFFFFF F1E3FFFF F6A8F001 F003F000
F002F000 F000F000 F000F000 108049A2 C060C05D C030C154 C006C822 E0000000
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F002F000 F000F000 F000F000 108249A1 C063C848 C031C141 C006C822 E0000000
                                    F002F000 F000F000 F000F000 10834992
                                       FFFFF F1E3FFFF F6A8F001 F003F000
                                      CC060 C036C13C C006C821 E0000000
                                      2F000 F000F000 F000F000 10854991
```

6 32-bit FEM header words

Header N	Left 16bit	Description	Right 16bit	Description
1	0xF...	contains FEM physical (slot) address in crate in the lowest 5 bits and FEM ID in the next 3 bits	0xFFFF	
2	0xF...	contains lower 12 bits of number of ADC words from FEM for this event	0xF...	contains upper 12 bits of number of ADC words from FEM for this event
3	0xF...	contains lower 12 bits of event number	0xF...	contains upper 12 bits of event number
4	0xF...	contains lower 12 bits of frame number	0xF...	contains upper 12 bits of frame number
5	0xF000		0xF000	
6	0xF000		0xF000	

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Channel header(0x1..),

TP header (0x[4..7]), unique Id)

TP Payload

```
FFFFFFFF F1E3FFFF F6A8F001 F003F000 F002F000 F000F000 F000F000 107F4792
C000C000 C000C000 C000C000 E0000000 FFFFFFFF F1E3FFFF F6A8F001 F003F000
F002F000 F000F000 F000F000 108049A2 C060C05D C030C154 C006C822 E0000000
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         00F000 F000F000 108449A1 C06CC060 C036C13C C006C821 E0000000
         E3FFFF F6A8F001 F003F000 F002F000 F000F000 F000F000 10854991
```
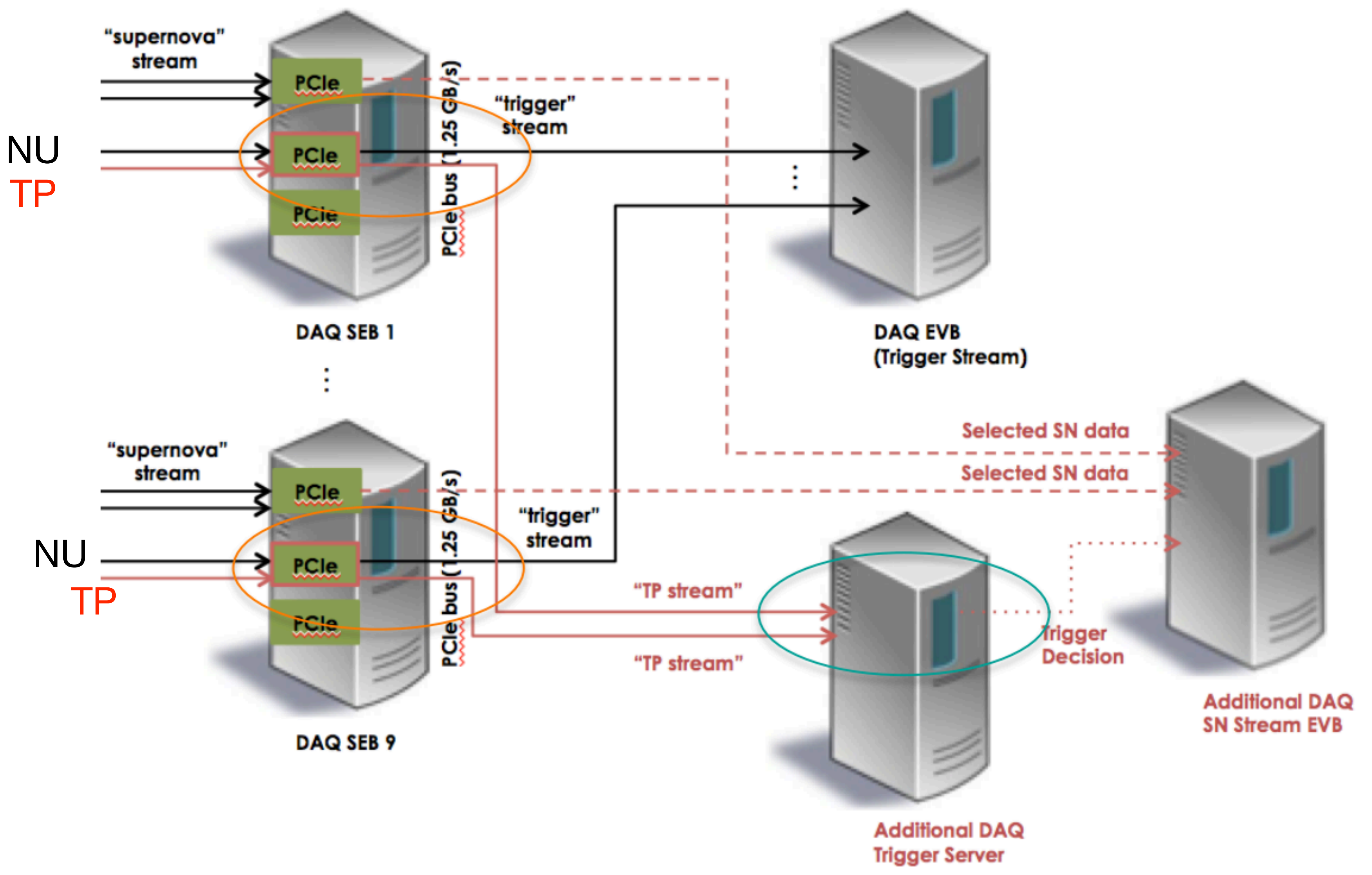

Word # / Bit #	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	Time over threshold (number of values)											MSB	0	0	1	1
2	Integral												0	0	1	1
3													0	0	1	1
4	Integral over 12 samples												0	0	1	1
5												MSB	0	0	1	1
6	Amplitude											MSB	0	0	1	1

Trigger Approaches

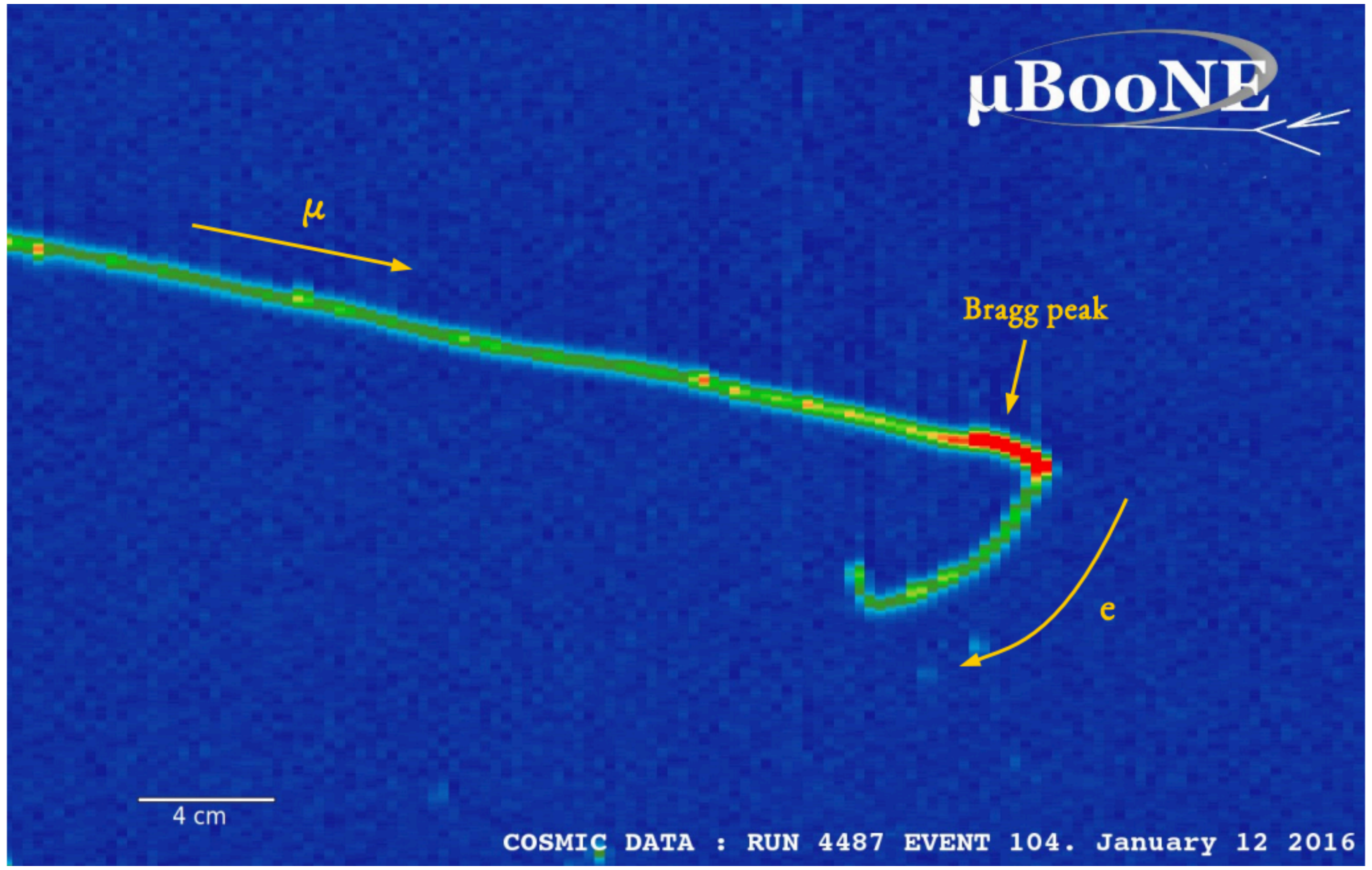
- TP generation has been implemented in FPGA for real-time implementation and testing in MicroBooNE (& SBND in near-future).
- Working towards TP processing software and algorithms for online trigger generation.

- TPs stream to DAQ servers for online processing with a goal of generating TD.
- TD can be used to select the buffered SN readout data for subsequent event building.



Trigger Approaches

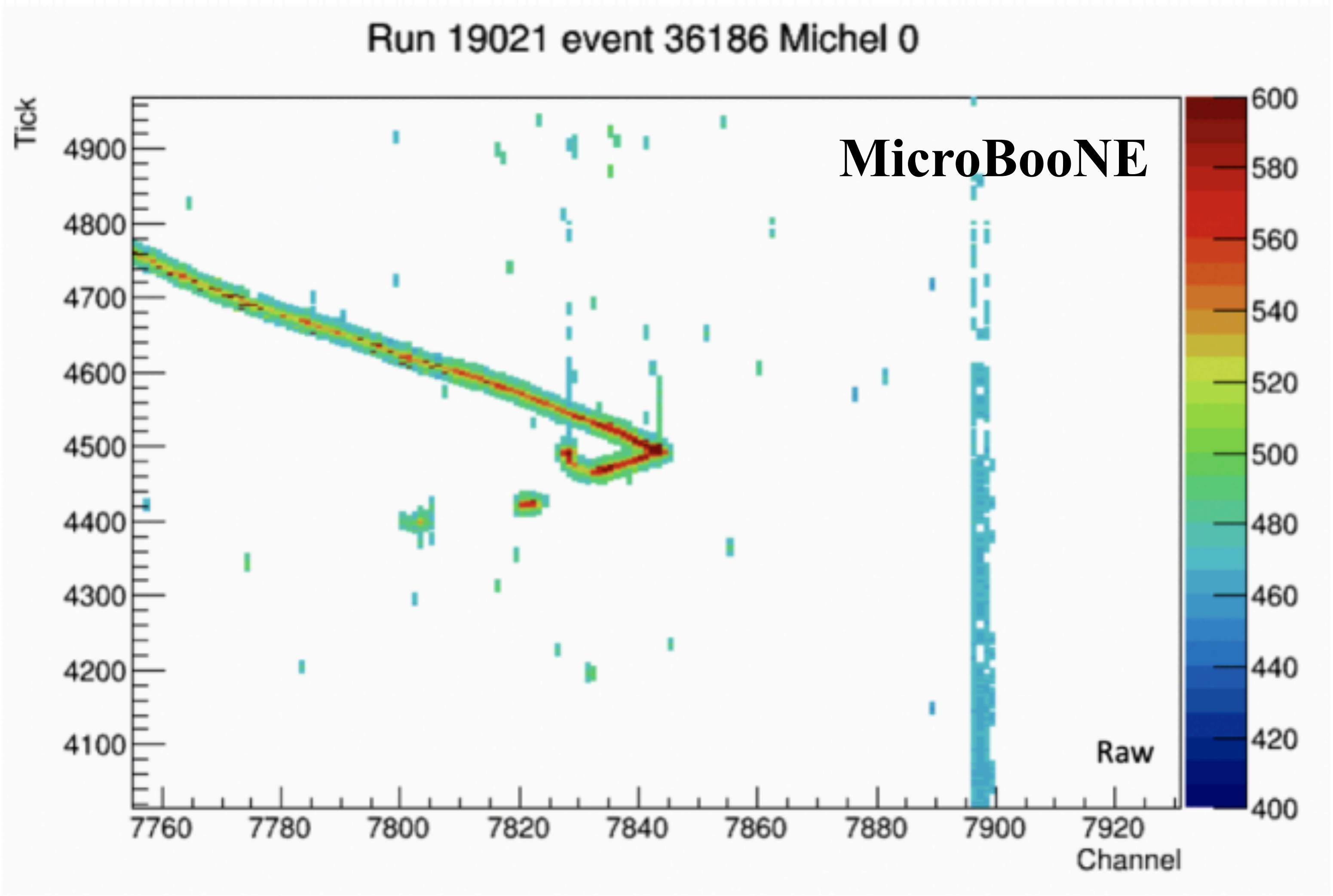
- One can look for stopping muons, *by looking at straight tracks making use of topological (existence of kink) and calorimetric (change in dE/dx at bragg peak) information to trigger on.
- There is also a possibility of exploring **image classification**, rather than having to cluster TPs to make a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

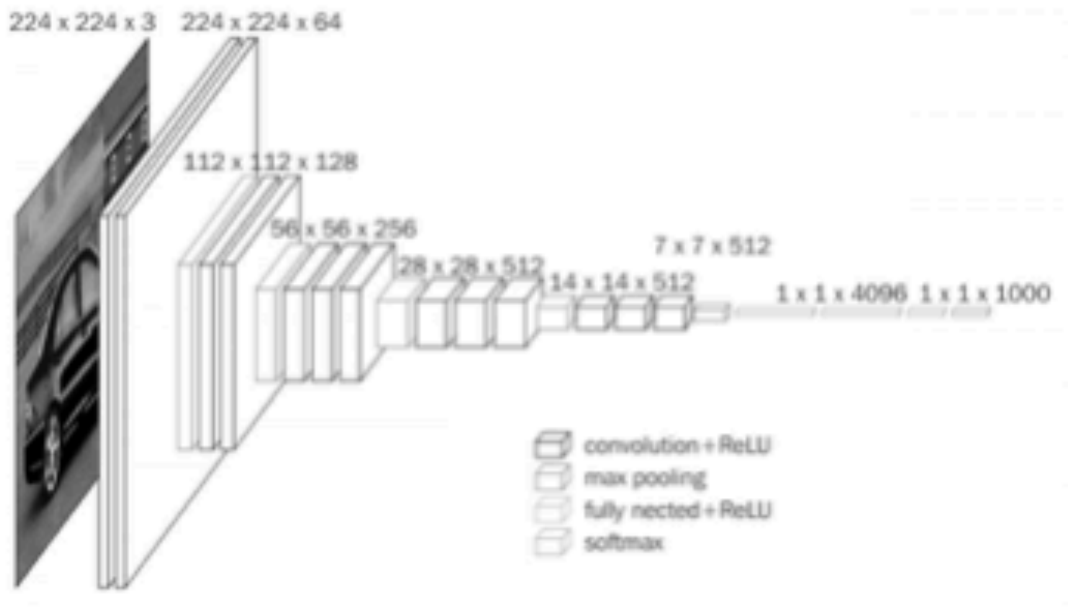


Michel Electron Reconstruction Using Cosmic Ray Data from MicroBooNE LArTPC (MicroBooNE Collaboration), JINST 12 (2017) 09, P09014

Machine Learning (ML) based Trigger Approach

Image classification





CNN classification

Low energy activity

High energy Michel

High energy Annihilation

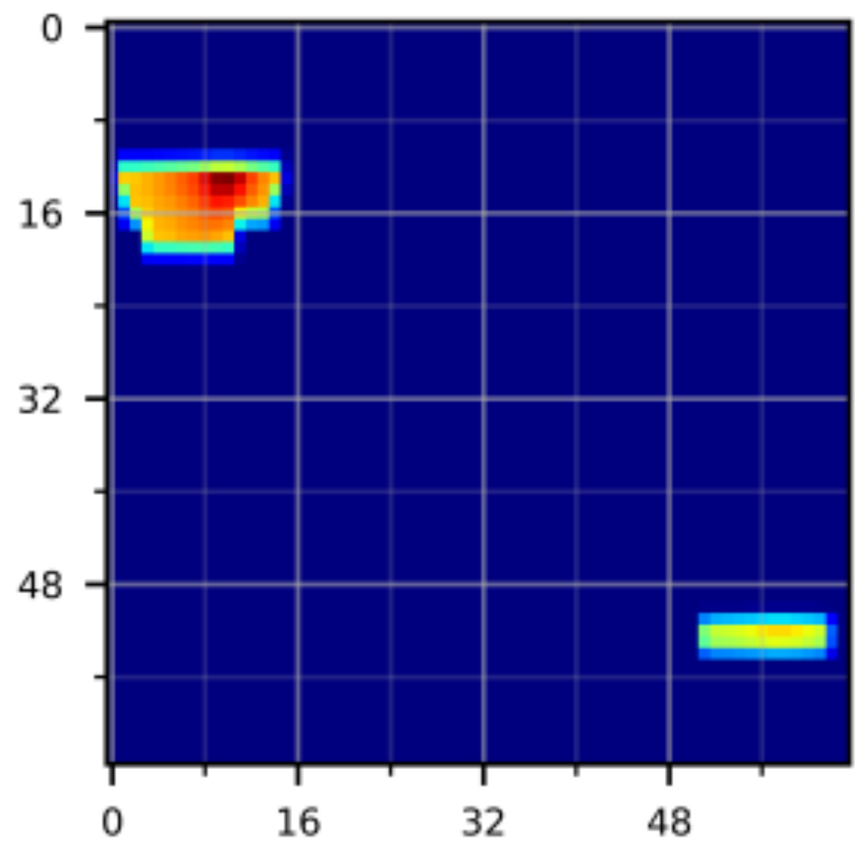
Classification will be done based on Activity

Low energy activity → Supernova neutrino events

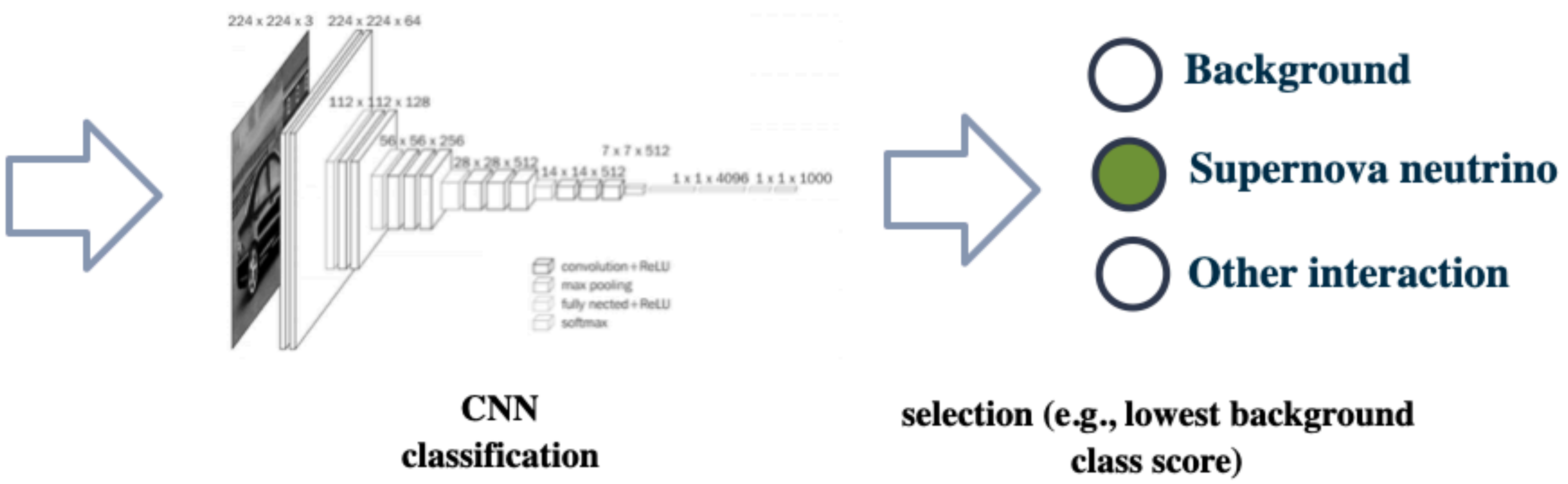
High energy activity → Michel electron, anti-neutron or anti-proton annihilation

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 (hardware stage of data selection, using HLS4ML tools*) as it is much more power efficient.
- Preliminary results on ROI downsized images.



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



*Please refer to the other talks in ***TDAQ Session*** of CPAD-2021 for more details

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Sample	Train Size	Test Size	Accuracy (%)			Inference Time (ms)
			ϵ_{NB}	ϵ_{LE}	ϵ_{HE}	
NB	12,023	4,027	99.53	0.47	0.12	
LE	12,050	3,970	4.01	94.48	1.51	1.6$\pm$0.1
HE	10,137	3,417	3.63	6.15	90.22	

NB: Noise & Background
LE: Low Energy
HE: High Energy

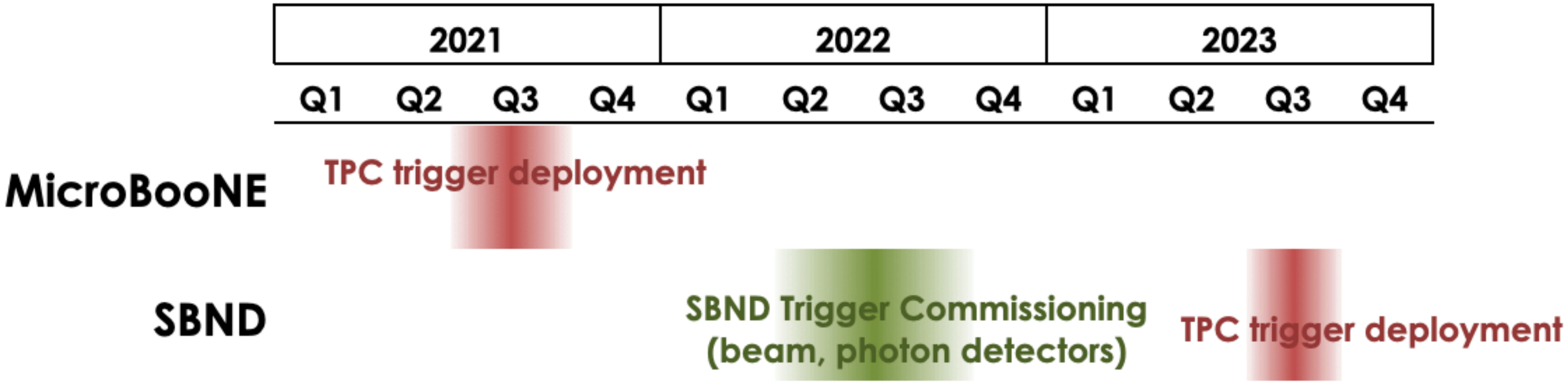
**Accelerating Deep Neural Networks for Real-time Data Selection for High Resolution Imaging Particle Detectors*
https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8909784&tag=1

Summary

With the currently & soon to be operating MicroBooNE & SBND LArTPCs, 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.
- Enhance future SBND and DUNE physics program.

Timeline:



Thank you