Liquid Argon TPC Trigger Development with SBND

Georgia Karagiorgi, Columbia University
on behalf of SBND Collaboration

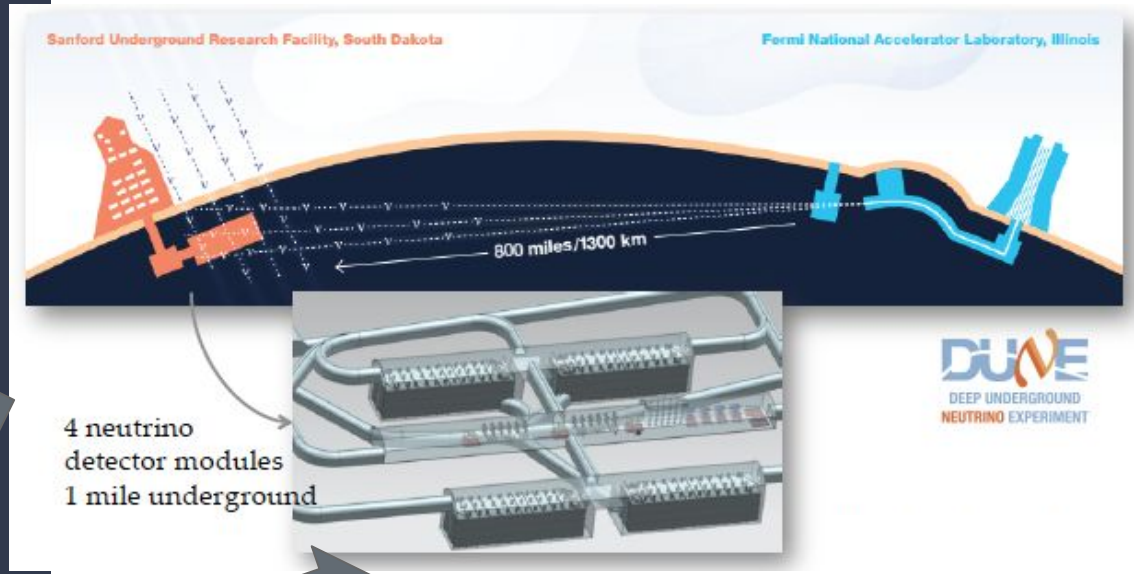
DPF 2019, Northeastern University
July 29 - August 2, 2019

Particle Detectors Session
Wednesday, July 31, 2019

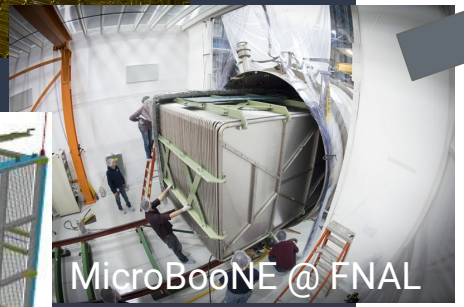
COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

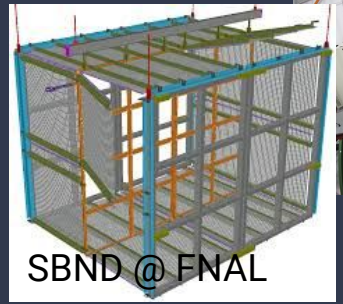
LArTPC Landscape and Motivation

~100x



~500x





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

LArTPC Landscape and Motivation

For rare event searches, future LArTPCs will require ***efficient data processing systems*** *to parse increasingly large amounts of data through data-informed data selection!*

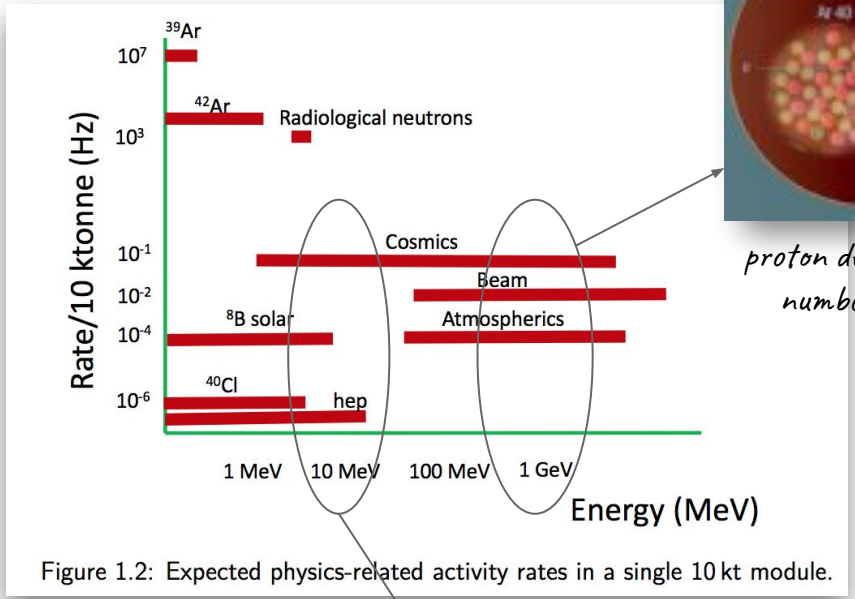
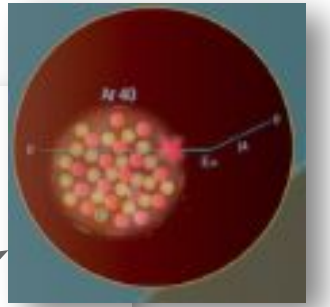


Figure 1.2: Expected physics-related activity rates in a single 10 kt module.

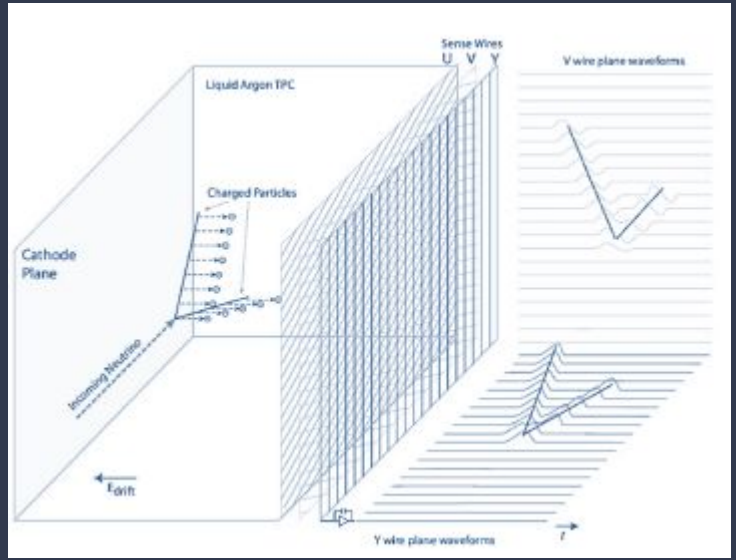
[DUNE TDR]



proton decay, baryon number violation

neutrinos from nearby supernova bursts

LArTPC Self-triggering Challenges



Imaging of interactions done by drifting ionization toward sensor arrays over relatively **long drift distances/ timescales** (of order milliseconds).

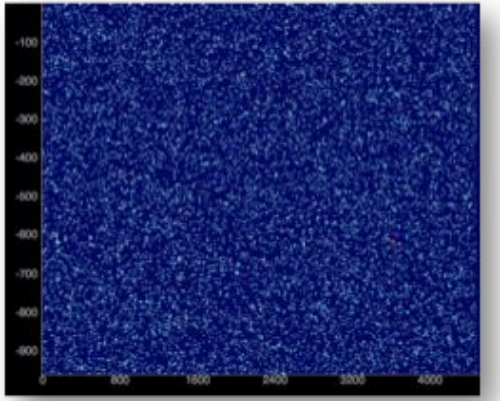
Have to wait for all the data to arrive, and then make a decision about the interaction.

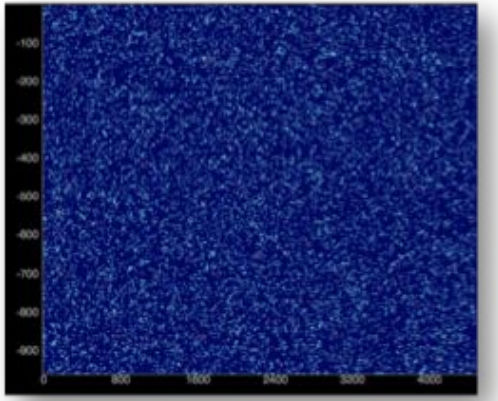
Requires:

- **Large buffering** to hold data while decision is being made (a full drift for DUNE SP is 2.6 GB)
- **Fast data processing** for trigger decision (2.25 ms)
- Orders of magnitude more buffering and processing for a **supernova burst trigger**, which looks for correlated signatures in O(10) seconds

Spot the supernova neutrino!

- Special challenge: **neutrinos from supernova core collapse**
- Very low energy and small (in extent) topology, similar to radiological background activity in the detector





[DUNE SP simulation of a drift window, for 1/200th of far detector module volume.]

- Need O(10^4) background suppression, while maintaining high efficiency to a frame containing a supernova neutrino interaction

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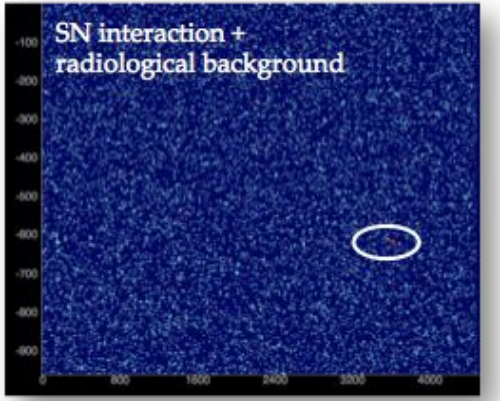

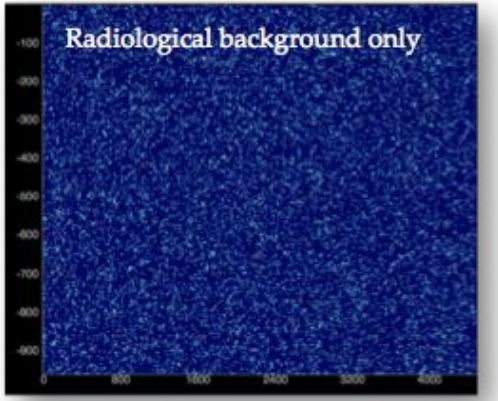

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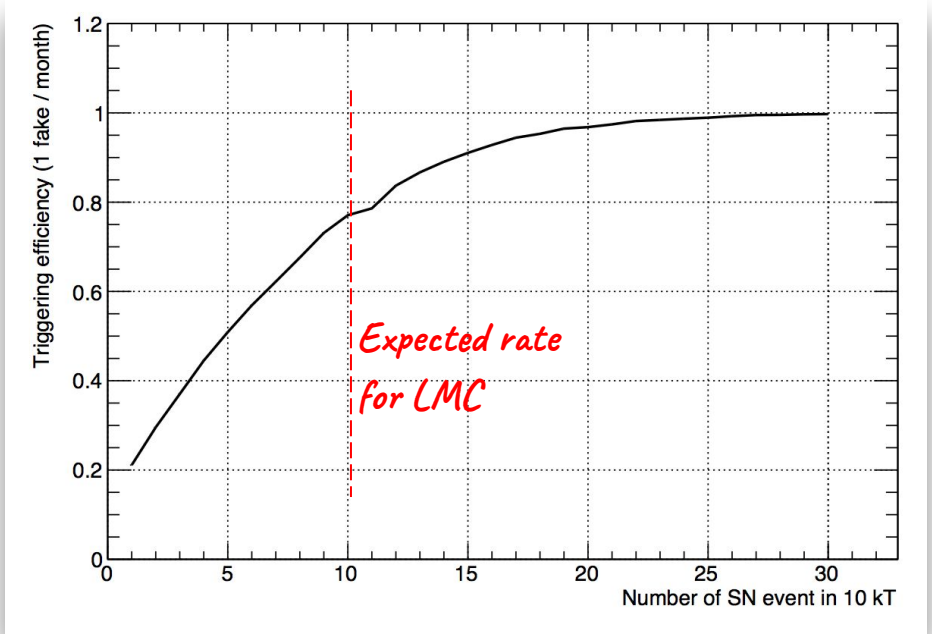
- Need O(10^4) background suppression, while maintaining high efficiency to a frame containing a supernova neutrino interaction

Not impossible!



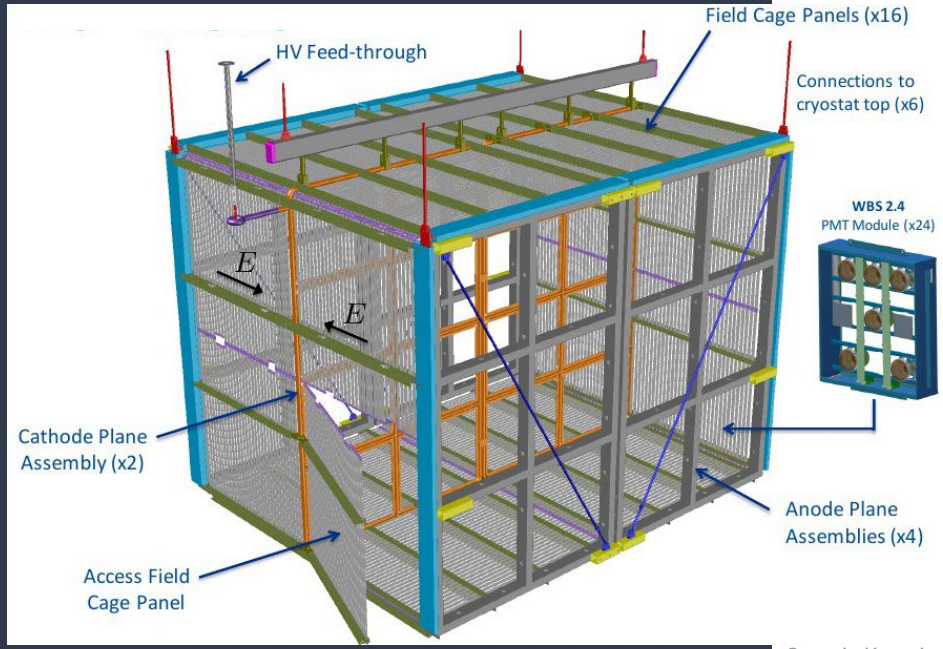
DUNE [Technical Design Report]

DUNE supernova burst trigger efficiency utilizing supernova neutrino interaction coincidence count (over ~10 seconds) and deposited energy information.

A supernova burst at the Large Magellanic Cloud would produce ~10 neutrino interactions in 10kton module

→ ~80% efficiency!

SBND Detector Parameters



- 112 tonnes of liquid argon (active).

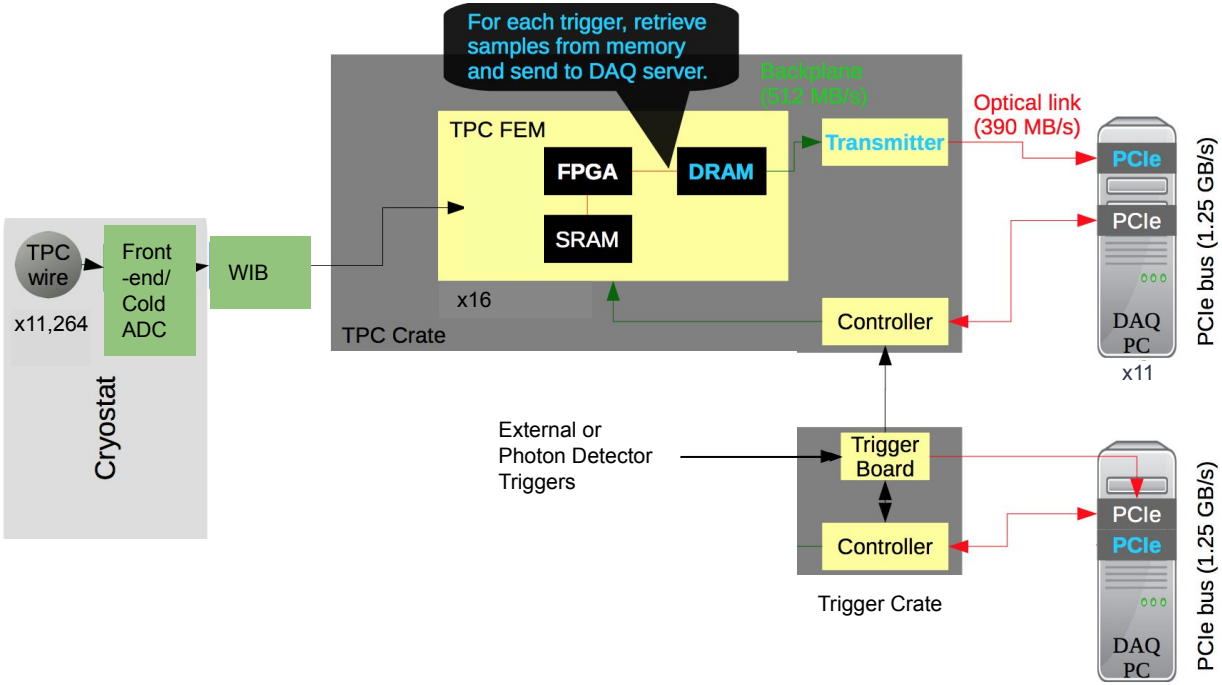
- Cathode Plane Assembly in the middle of the TPC at -100 kV. Edrift = 500 V/cm.
- 2 drift volumes.
- Maximum drift length: 2 m. Maximum drift time: 1.28 ms.
- 3 wire planes. 3 mm wire pitch. 11264 channels.

- Cold TPC front-end electronics by BNL
- 2 MHz digitization. Cold ADC.
- Custom TPC back-end electronics by Columbia University Nevis Laboratories.

- 160 8” Hamamatsu R5912 Cryogenic PMTs mounted behind the wire planes. (≥ 24 not TPB-coated to detect Cherenkov light).
- CAEN flash-ADC (500 MHz) PMT readout electronics.
- Additional photon detection systems: light guide bars and photon traps.

Expect 10-50 events for the case of a galactic SN!

The SBND TPC Readout System (1/2)



Custom TPC back-end electronics by Columbia Nevis Labs

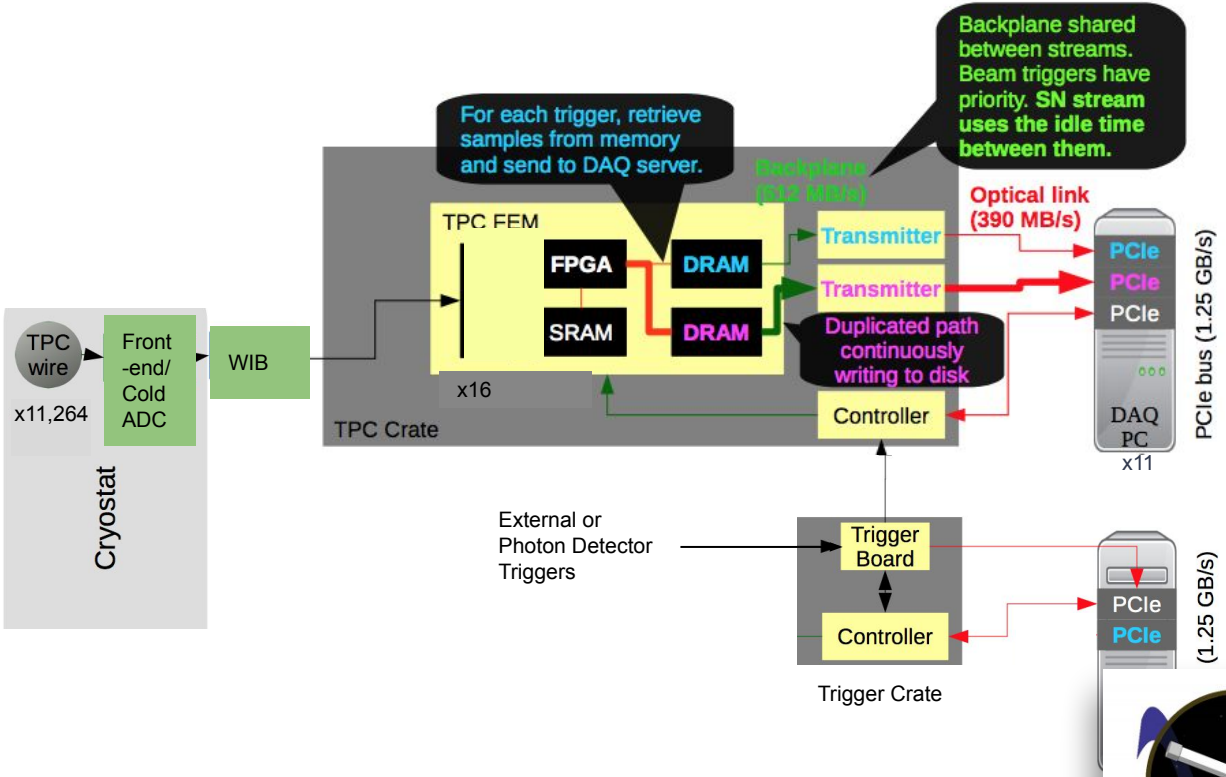
Based on the MicroBooNE readout system.

Readout of O(11,000) TPC wires, 2MHz, 12-bit ADC.

Two readout streams:

1. **Externally triggered, lossless compression**
   → *Guarantees data for beam physics!*

The SBND TPC Readout System (2/2)



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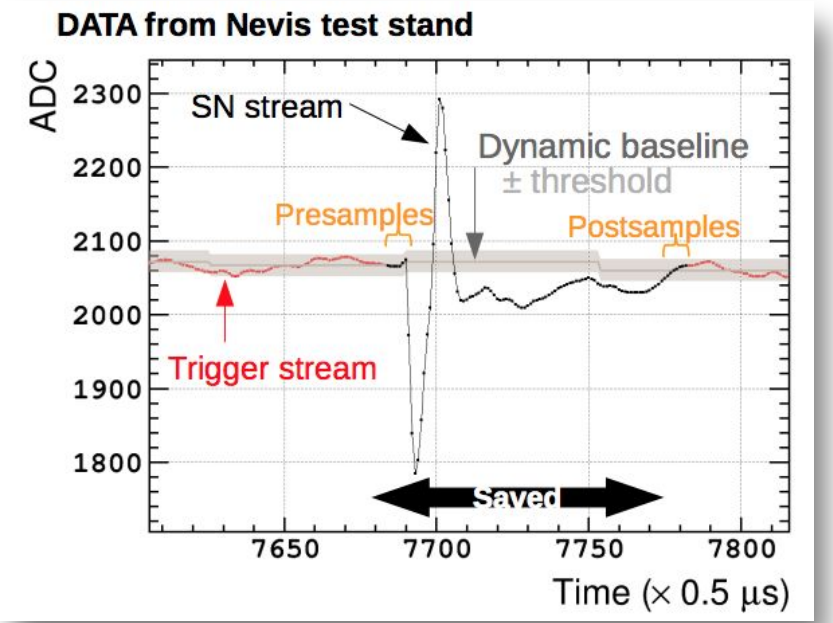
Two readout streams:

1. Externally triggered, lossless compression
2. Continuous (triggerless) stream, with lossy zero-suppression

→ *Guarantees supernova-coincident data upon receipt of external SNEWS alert!*

SBND continuous "supernova" stream

For SBND (on-surface detector),
supernova triggering is **challenging**, at best!



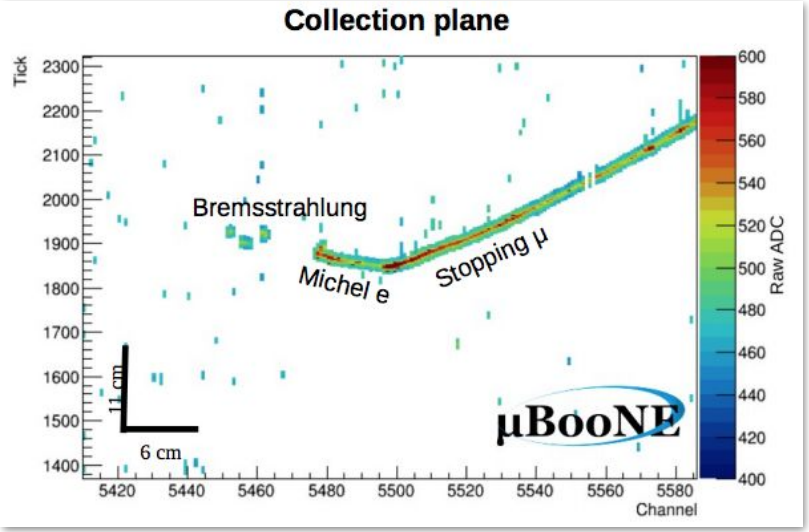
However, **Regions-Of-Interest (ROIs)** are saved semi-permanently in offline disk (up to 2 days),
and can be **analyzed offline** (upon external SNEWS "trigger").

Can also study performance on low-energy signals!

2. **Continuous (triggerless) stream, with lossy zero-suppression**

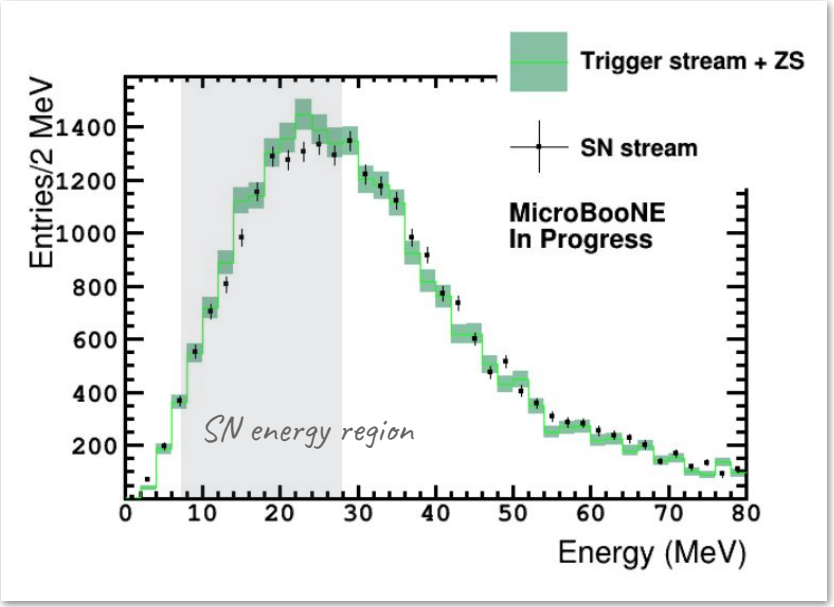
→ Guarantees supernova-coincident data upon receipt of external SNEWS alert!

SBND continuous "supernova" stream



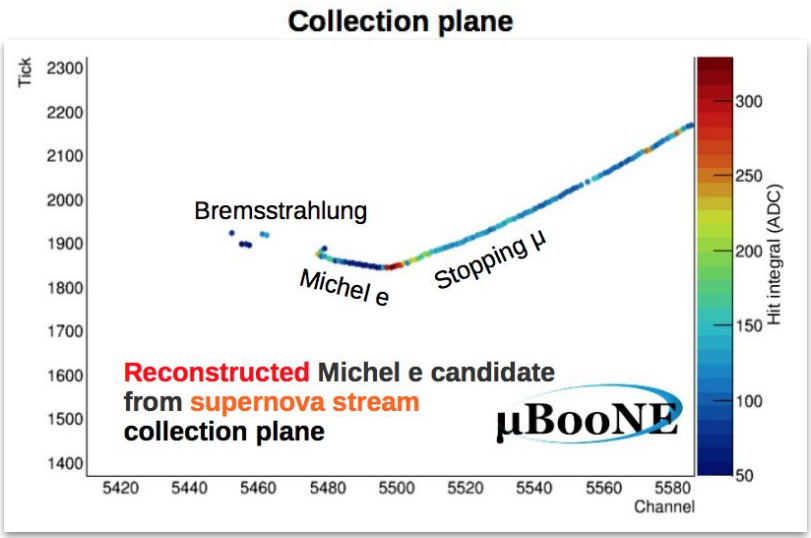
[J. Crespo Anadon, for the MicroBooNE Collaboration, SNEWS 2.0
See also JINST 12 P09014 (2017)]

Benchmarking performance on low-energy activity with MicroBooNE with Michel electrons:



Data from the supernova stream yields expected performance at low energy!

SBND continuous "supernova" stream



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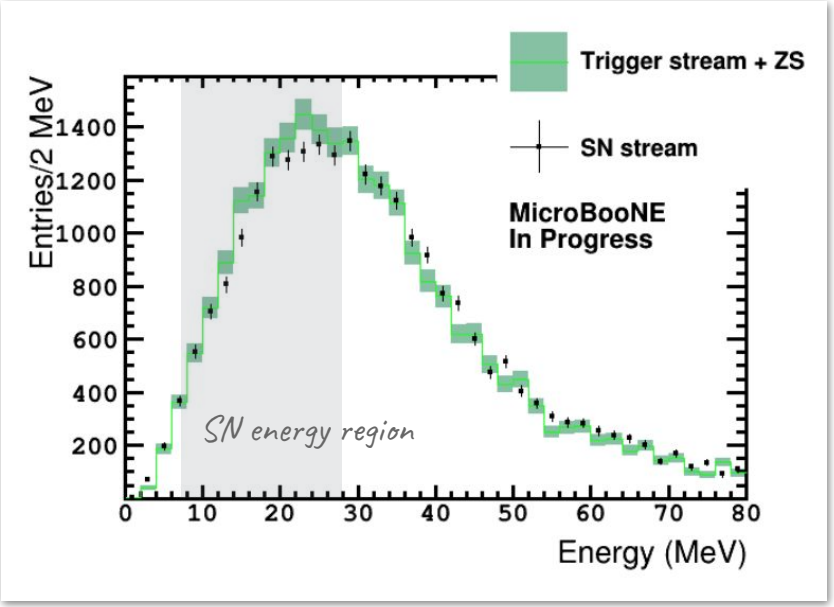

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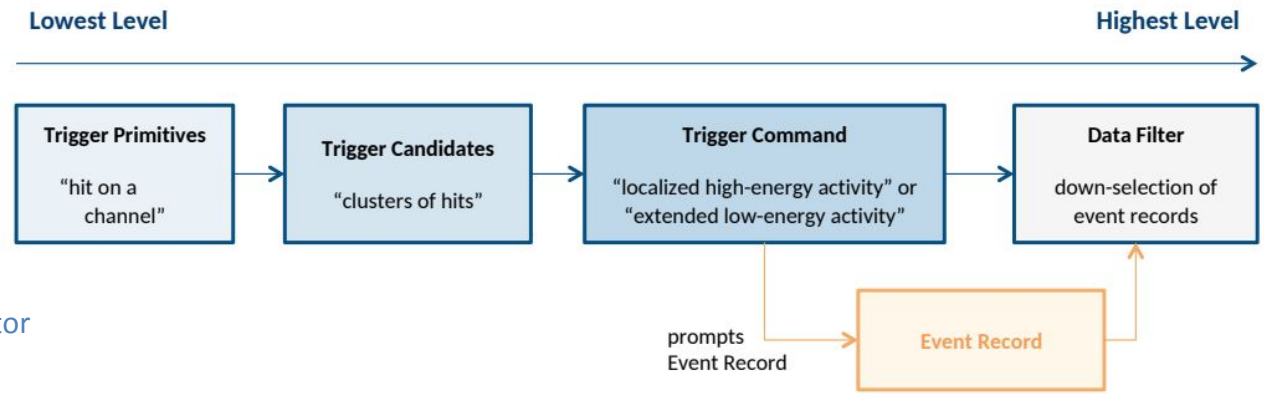
SBND Trigger Development: Toward DUNE

DUNE [Technical Design Report]



Hit finding on collection plane
→ "Trigger Primitives" (TPs)

Aggregation of TPs within detector sub-component (e.g. APA)
→ "Trigger Candidates" (TCs)

Aggregation of TCs within detector module
→ "Trigger Decision" (Trigger)

Trigger prompts module-wide readout with lossless compression.

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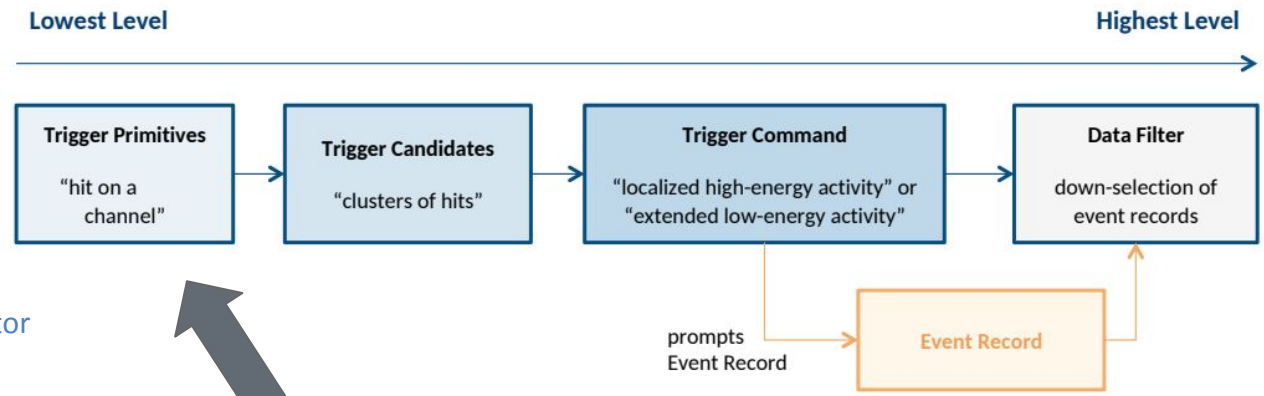

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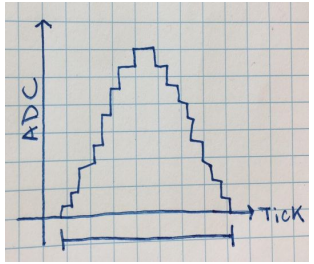
Trigger prompts module-wide readout with lossless compression.

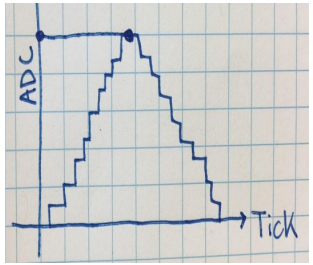
SBND: ROI finading (on all planes)
→ **Can construct TPs**
→ Can exercise subsequent full data selection chain:
1. In software
2. In hardware (transmitter firmware)

SBND Trigger Development: Toward DUNE

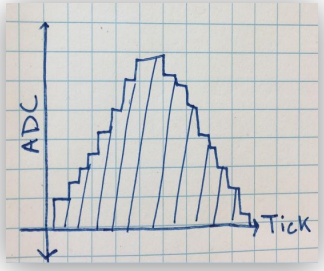
A Trigger Primitive is generated as a “summary” of an ROI, including:



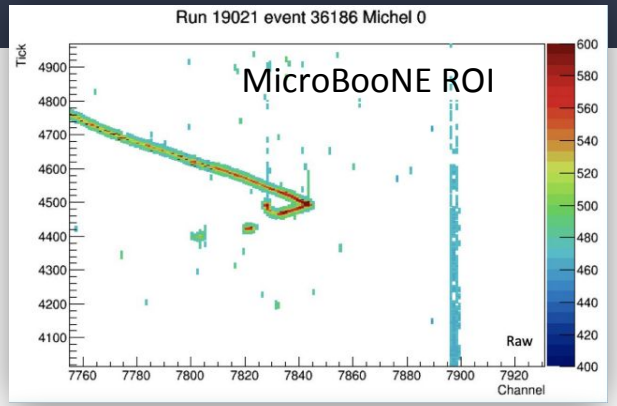
time over threshold

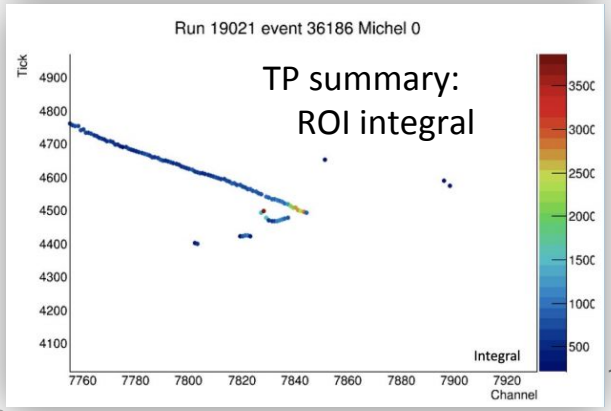


amplitude



integral





[Offline software processing: C. Hinrichs, Columbia NSF REU Student, 2019]

SBND Trigger Development: Toward DUNE

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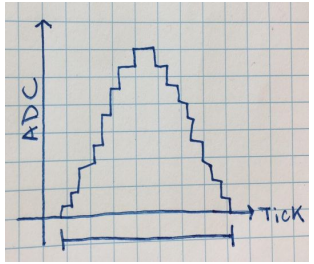

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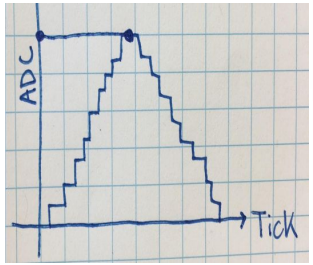

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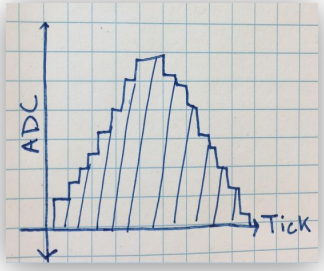

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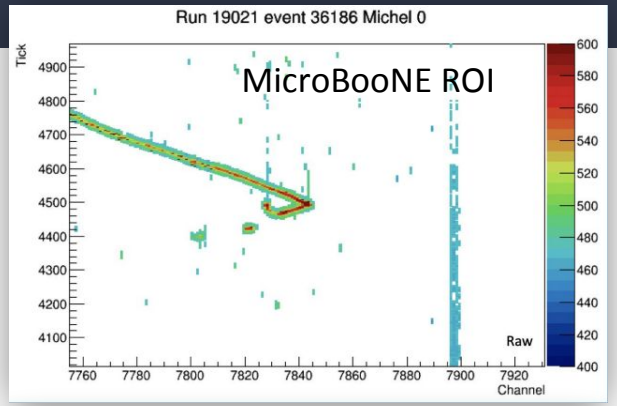
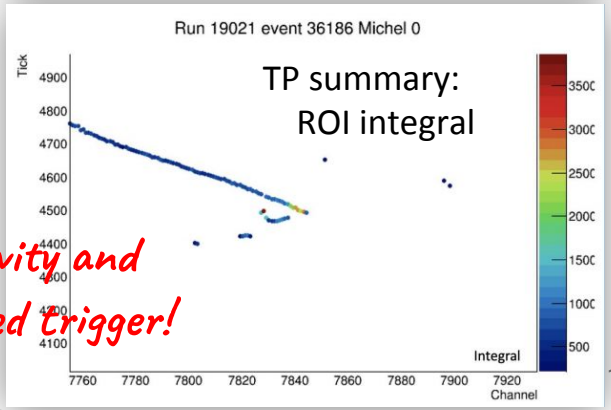
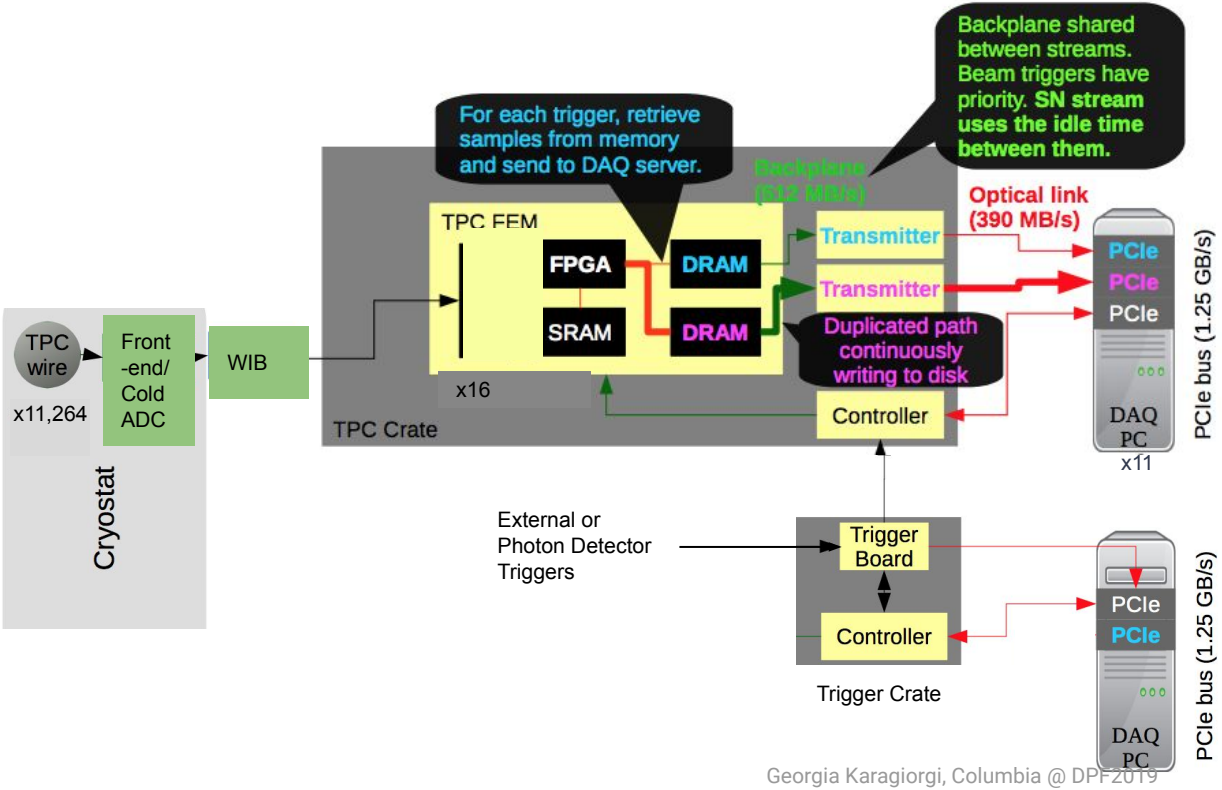




Promising for activity and topology-based trigger!

SBND Trigger Development: Toward DUNE



Same algorithm (TP summary) and subsequent TC generation algorithms can be **implemented in FPGA in transmitter module for real-time implementation and testing in SBND**

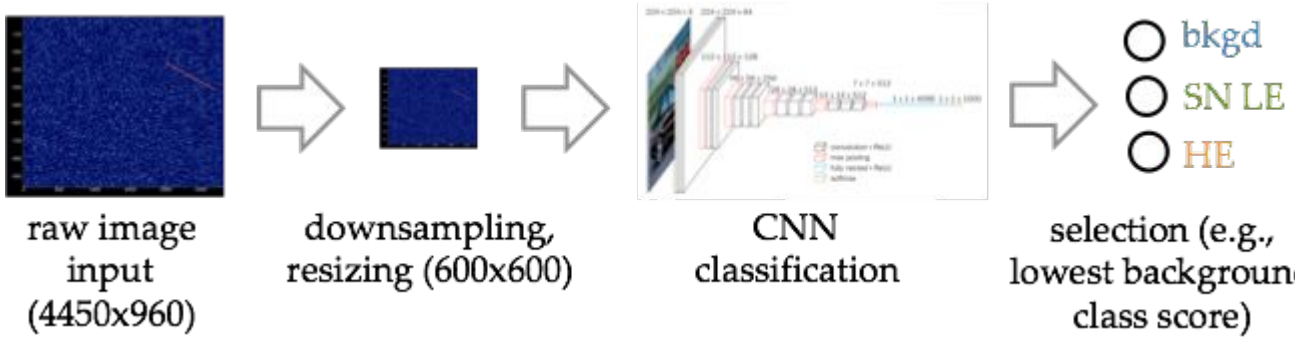
And new ideas!

Raw LArTPC data format ideally suited for image analysis!

E.g., **Convolutional Neural Networks (CNNs)** could be applied for real-time image classification, using hardware acceleration (FPGA) [alternatively, online in GPU or CPU]:

- Can work with only one projection (2D), preferably collection plane
- Down-sample and resize image
- Classify via CNN

  E.g., in DUNE, as one of three cases: **background**/**supernova-like low energy activity**/**high-energy activity**



Status

Real-time trigger development efforts, following DUNE prescription: ramping up, targeting **deployment during first accelerator summer shutdown period for SBND**

SBND status:

Detector is under construction!

- Most major components already delivered to FNAL
- Completion of SBND TPC construction fall 2019
- Cryostat fabrication progressing well at CERN and installation at FNAL starts fall 2019
- ND building cryogenics installation has started
- Readout electronics delivery end of summer

Commissioning in 2020 and first neutrino data in 2021

Summary

SBND will employ a dual TPC readout stream which guarantees lossless readout of beam events for its physics program, externally triggered, and compressed data readout for offline search for supernova neutrinos via external SNEWS alert.

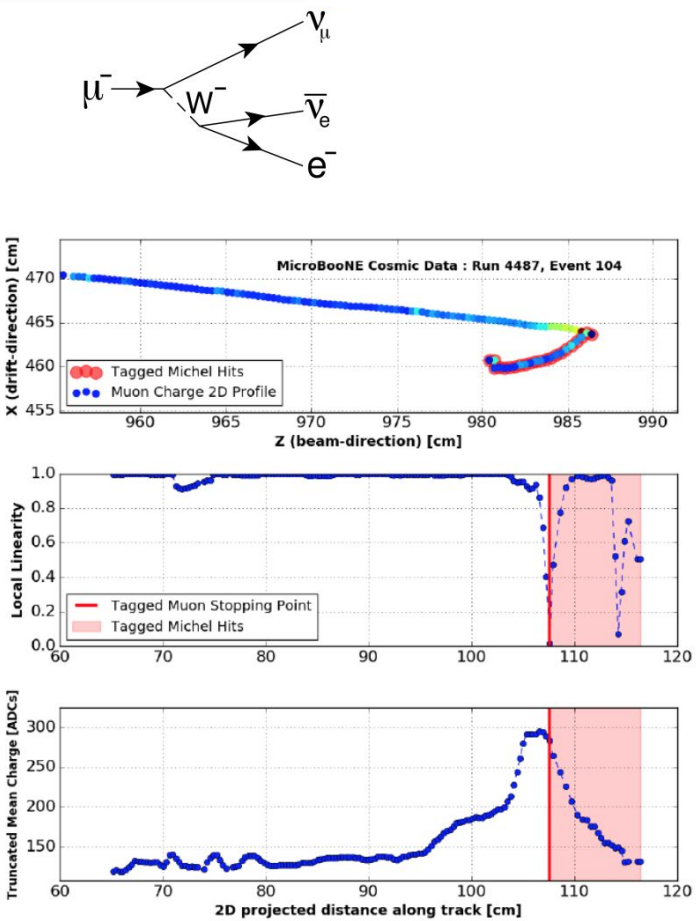
Multiple readout design aspects are common between SBND and DUNE, and allow for expansion!

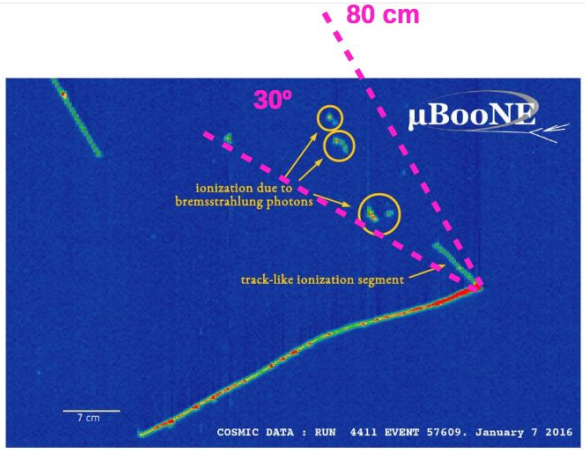
→ **SBND serves as platform for LArTPC trigger R&D toward DUNE**

Ongoing efforts to implement real-time triggering in SBND readout, for deployment and testing in situ at SBND starting summer 2021!

Thank you!

MicroBooNE Michel e reconstruction





JINST 12 P09014 (2017)

First fully automated electron reconstruction.

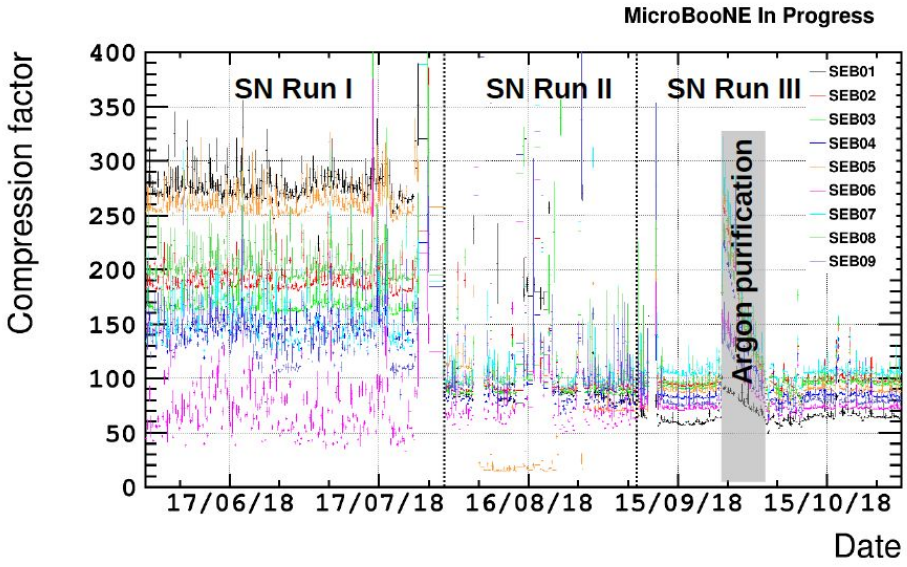
- Input from Pandora pattern recognition..

  Eur.Phys.J. C78 (2018) no.1, 82

- Uses muon Bragg peak and decay kink to select events.

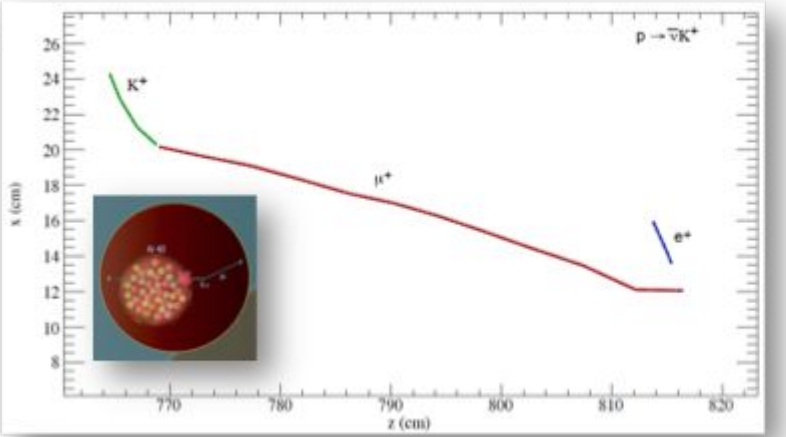
MicroBooNE compression factors for continuous readout stream

$$\text{Compression factor} = \frac{\text{Expected rate w/o compression}}{\text{Measured rate}}$$



- **First SN Run** used single threshold for all channels within one TPC plane.
  - Noisy channels affected dynamic baseline estimation, producing large variations.
- **Second SN Run** used individualized (lower) channel threshold → Increased sensitivity to low-energy physics.
  - Still noisy channels affected dynamic baseline calculation.
- **Third SN Run** uses individualized (lower) channel threshold and static baselines.
  - Target compression factor achieved!
  - Lesson: MicroBooNE TPC channel baselines are stable for discrimination.

Baryon number violation in DUNE

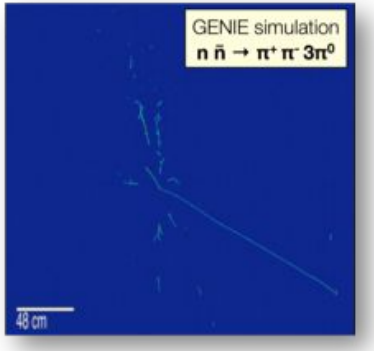


Simulated $p \rightarrow K^+\nu$ event in a LArTPC

Golden proton decay mode: Assuming >90% signal efficiency,

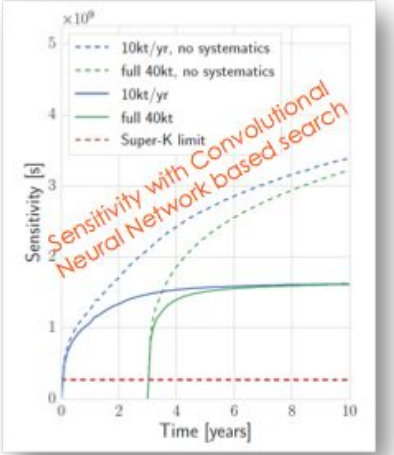
$\tau/BR > 3.8\times10^{34}$ years [DUNE CDR]

Simulated neutron-antineutron oscillation event in a LArTPC: "star event" topology



Baryon-number violating ($\Delta\mathcal{B}$=2) process.

Nucleus-bound neutron oscillation, followed by annihilation with neighboring nucleon (p or n) inside the parent nucleus.



[J. Hewes, PhD Thesis]