The MicroBooNE Continuous Readout Stream for the Detection of Supernova Neutrinos

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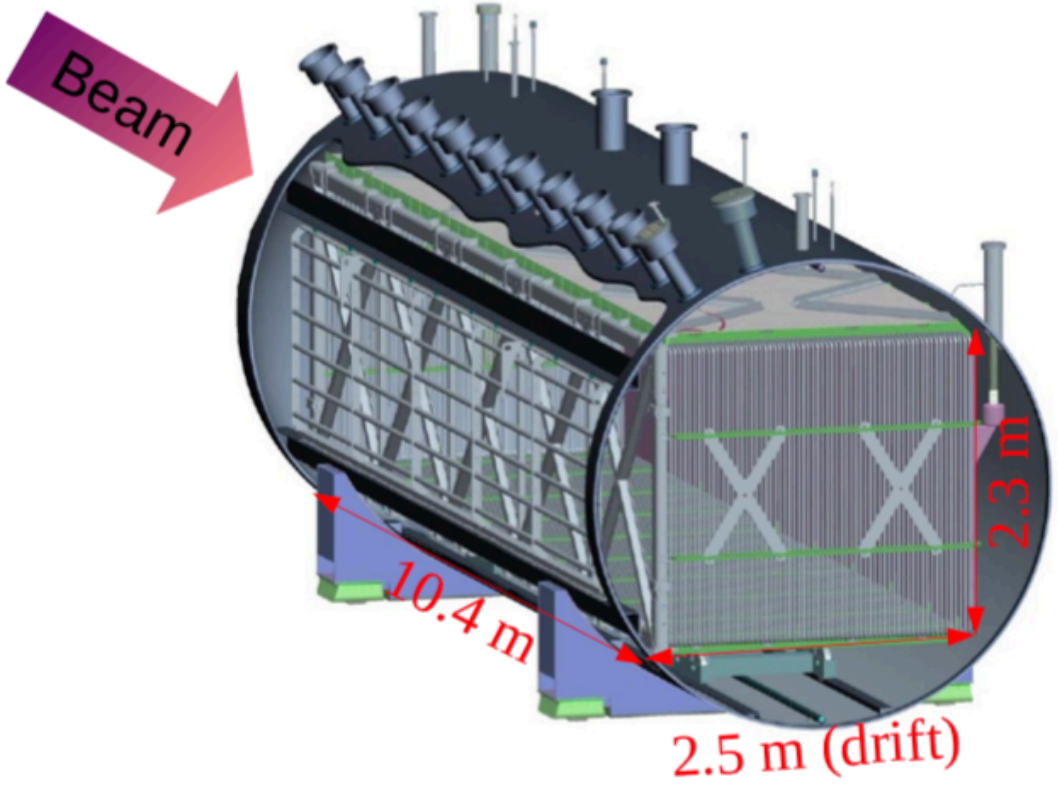
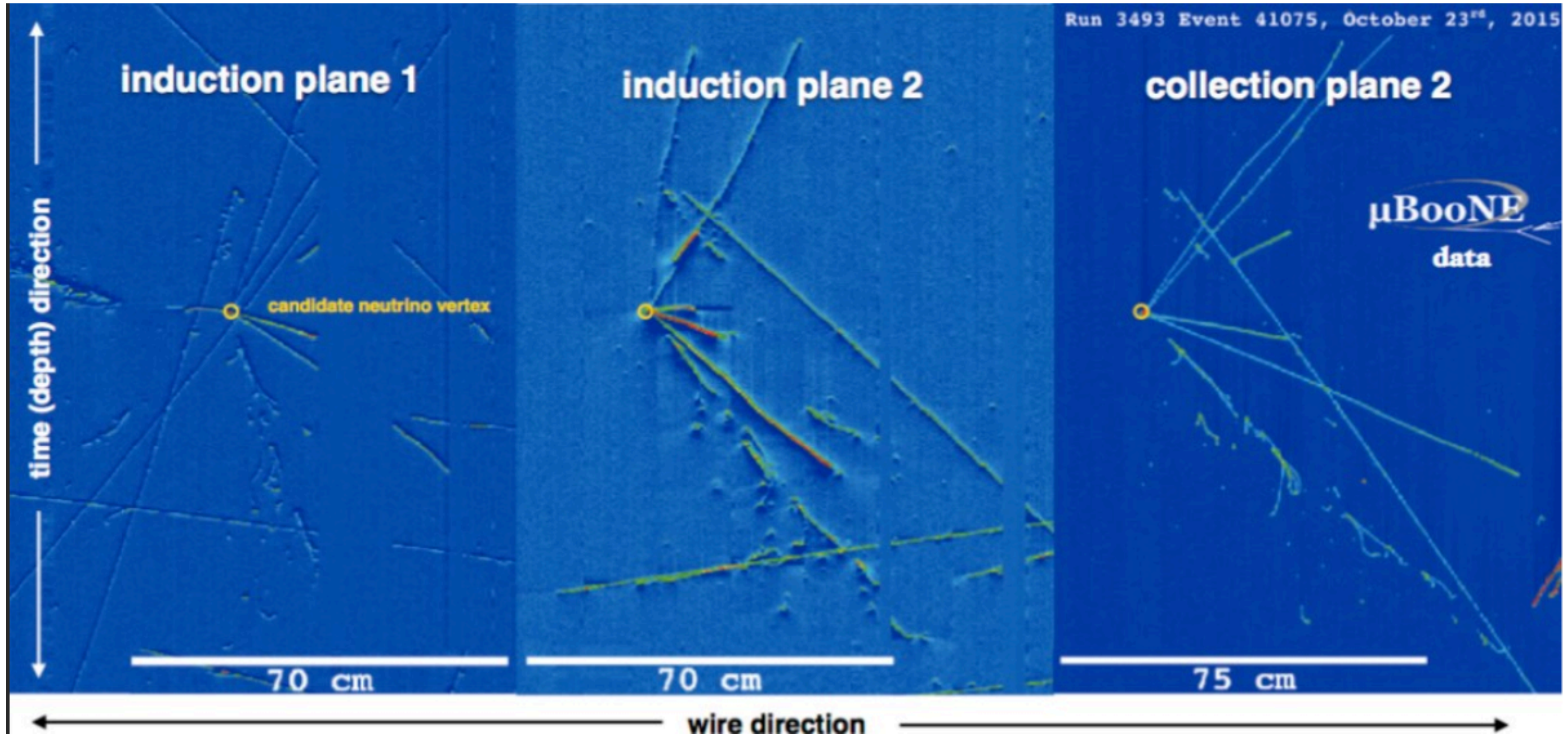
On Behalf of the MicroBooNE Collaboration

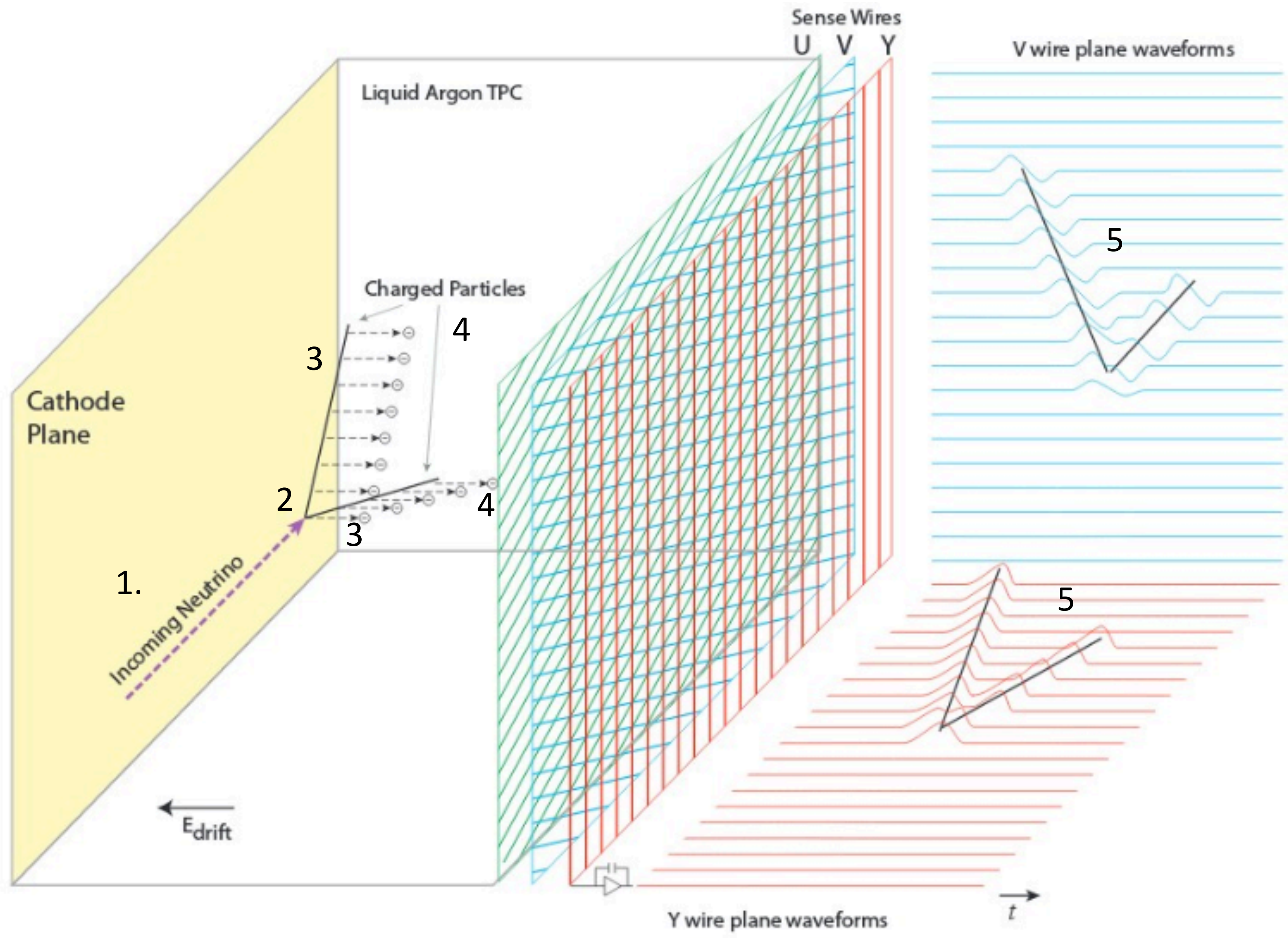
What is MicroBooNE?

- MicroBooNE is an 89 active ton liquid-argon time projection chamber (LArTPC)
- Along the Booster Neutrino Beamline (BNB) located at Fermilab
- Collecting data since 2015





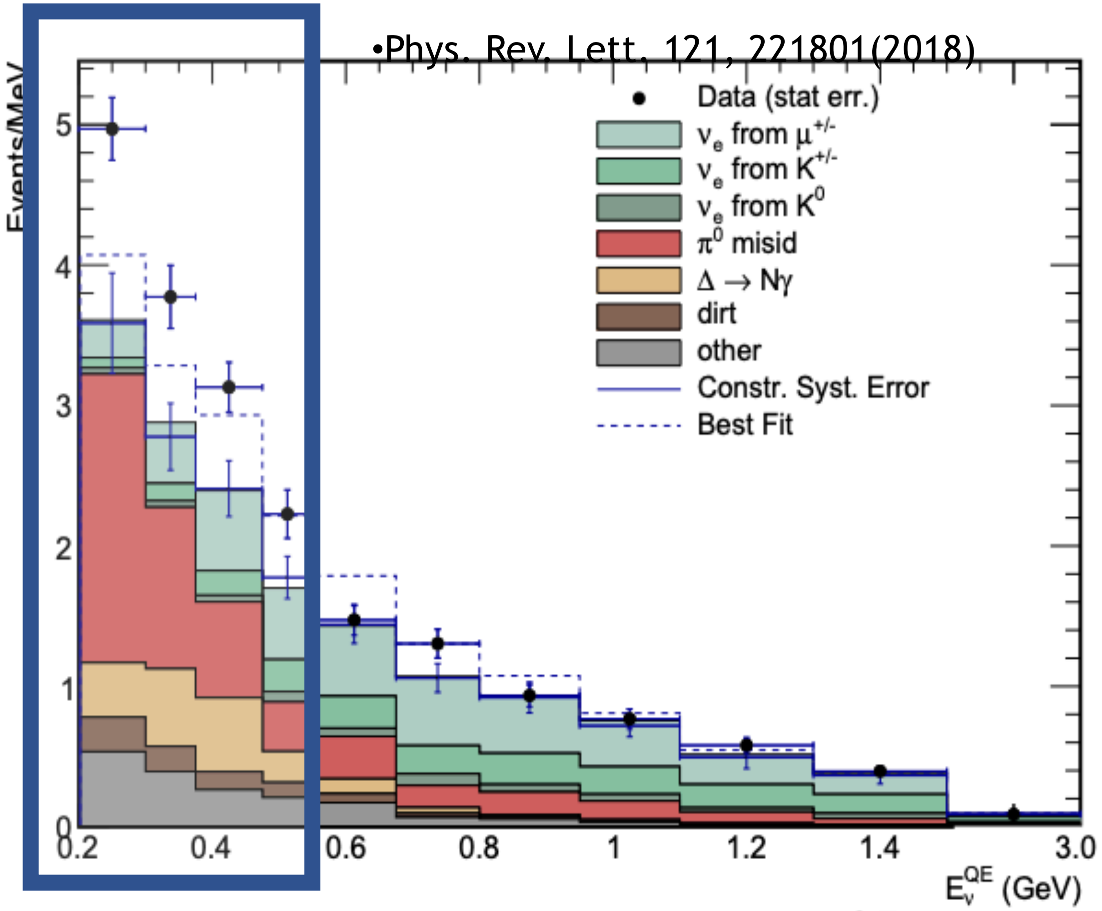
LArTPC Technology

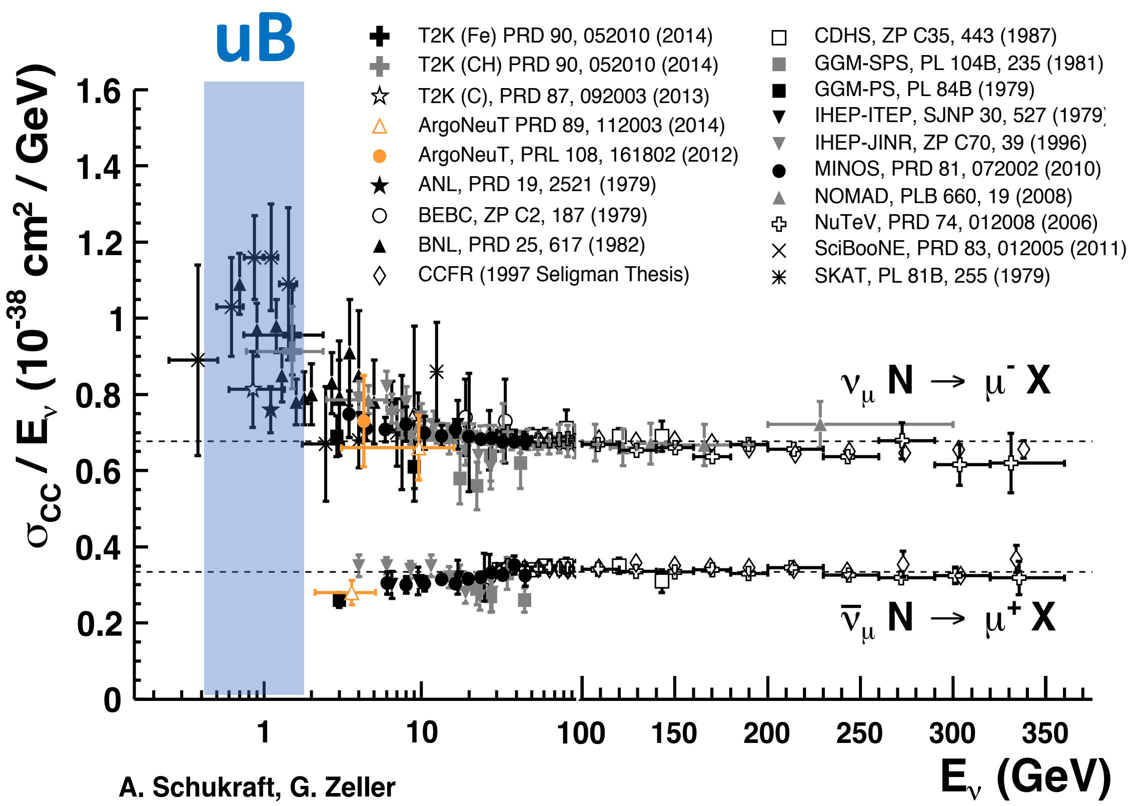


1. Neutrinos enter the TPC
2. Neutrino interacts with an Argon nucleus and creates charge particles
3. The particles created ionize the argon and release ionization electrons
4. The electric field inside the TPC drifts the electrons toward the wire planes
5. The electrons are recorded as signals in the wires

MicroBooNE Research Goals

- Investigate the Low Energy Excess (electron-like events) seen in MiniBooNE
- Measurement of neutrino-Argon cross-sections

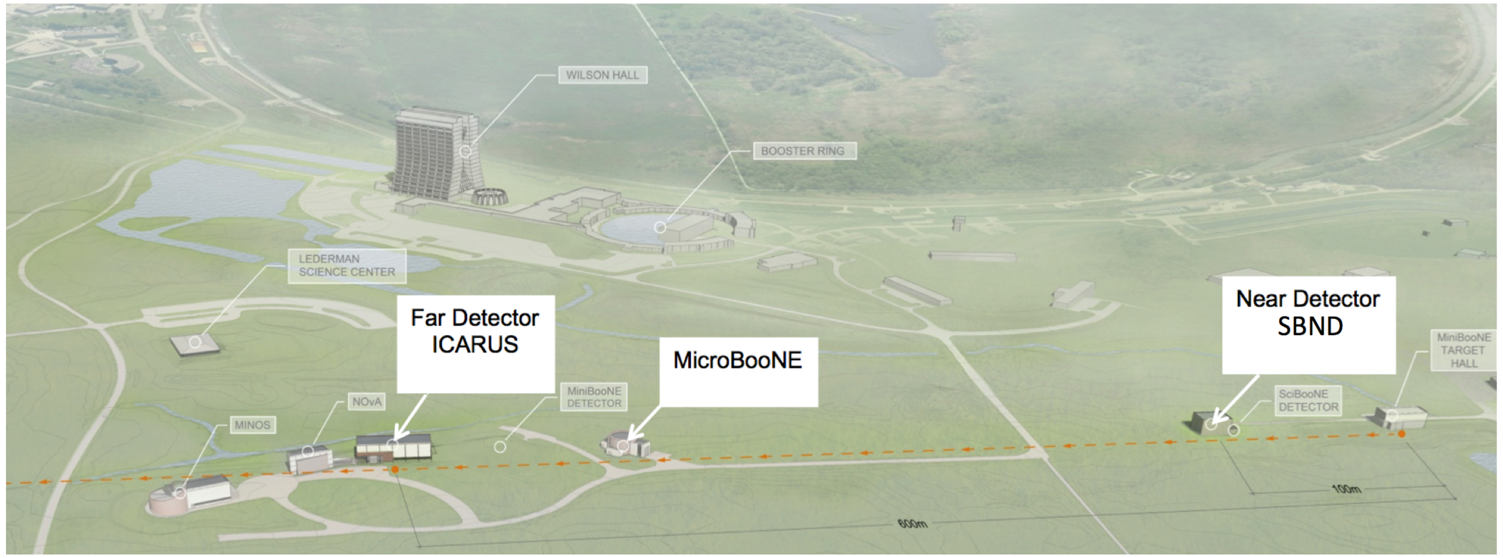




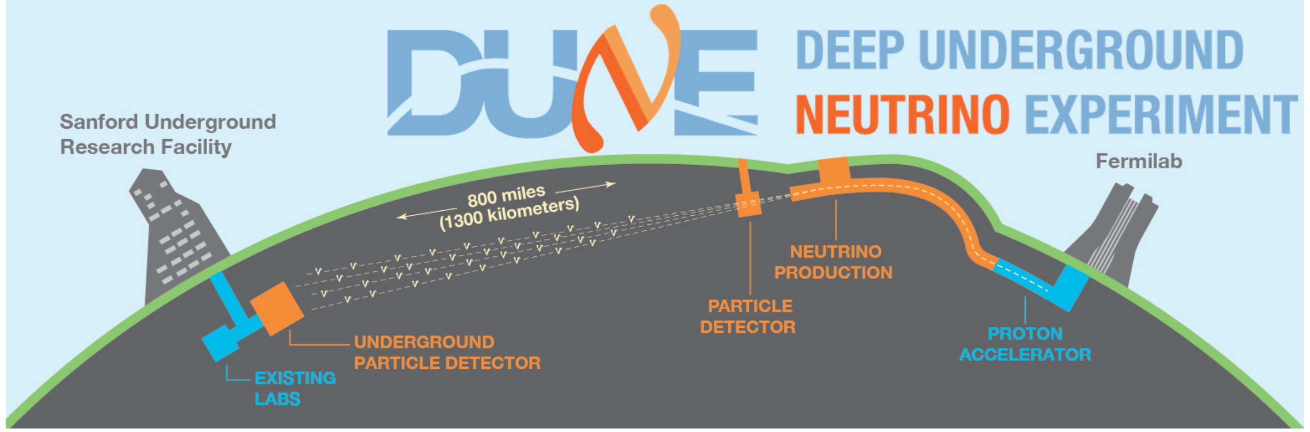
MicroBooNE Research Goals

- R&D opportunities for current and future LArTPC experiments
  - Longest operating LArTPC
- Searches for astroparticle and exotic physics
  - Galactic supernova bursts neutrinos

ESA/Hubble & NASA



Begins operation in 2021



Begins operation in 2026

Supernova Neutrinos

- Supernova (SN) core-collapse radiates neutrinos
  - Short timescale ~ 10 seconds
  - Low Energy ~ 10 MeV
- MicroBooNE could detect ~O(10) events for SN at 10 kpc.

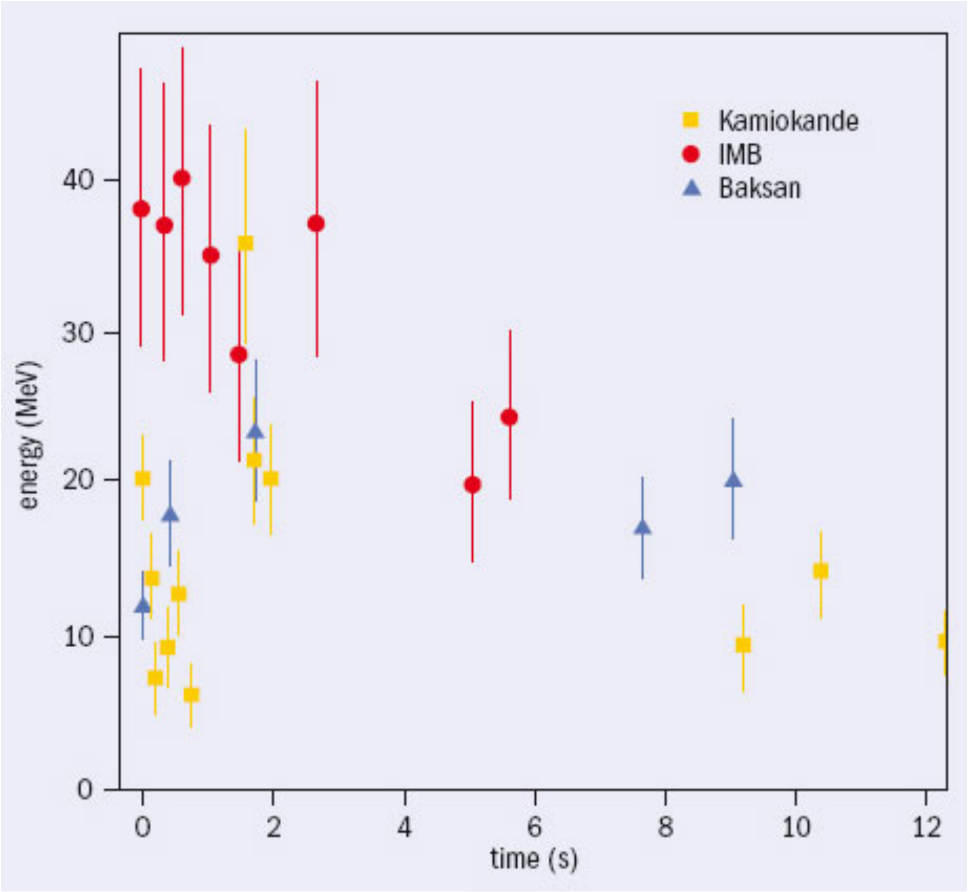
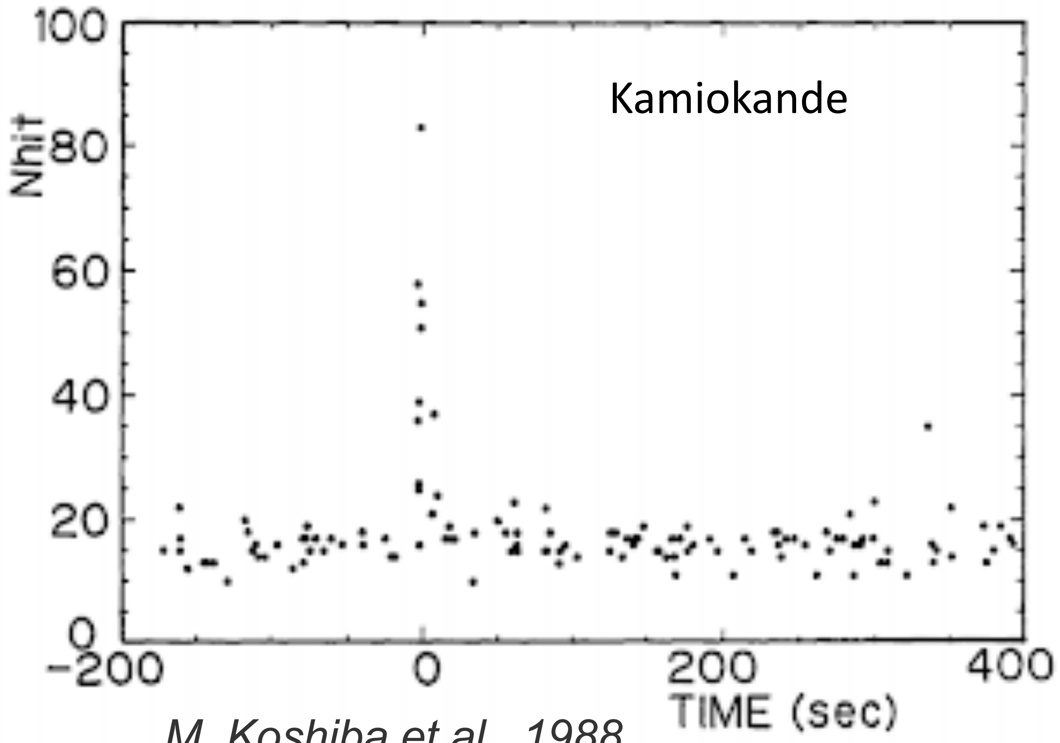


Image: CERN Courier, M. Nakahata SN1987A



M. Koshiba et al., 1988

Supernova Neutrinos

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  - Short timescale ~ 10 seconds
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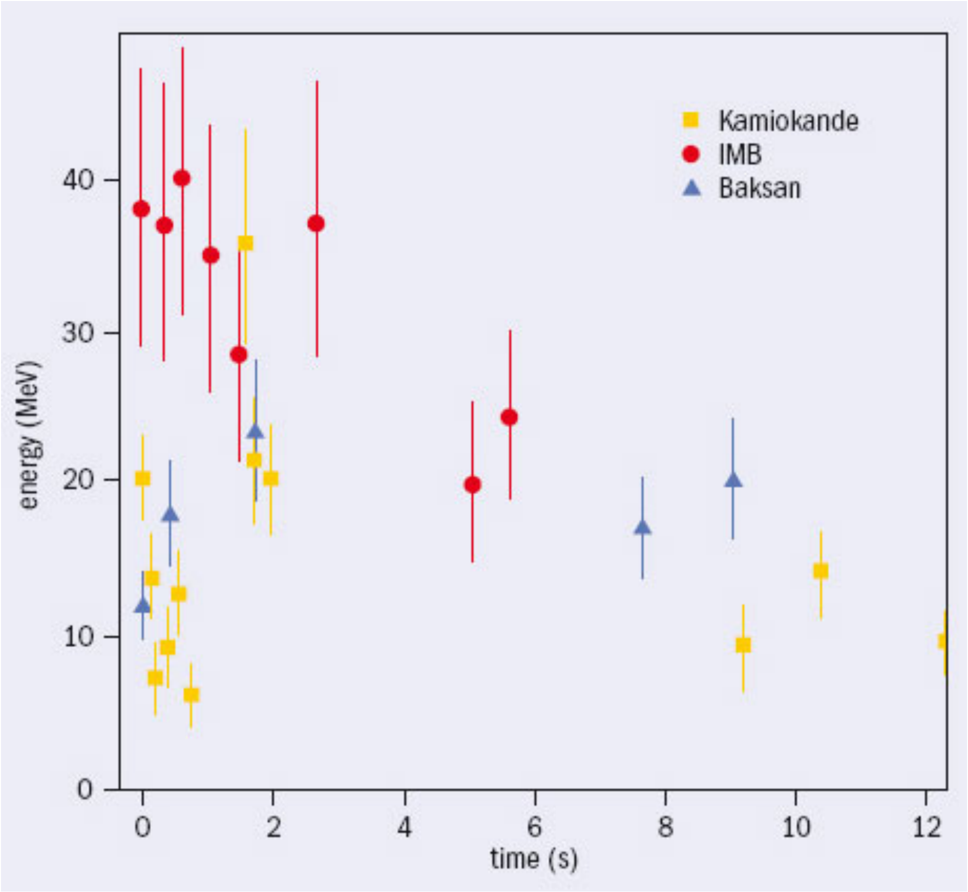
- MicroBooNE could detect ~O(10) events for SN at 10 kpc.
- Complication -> MicroBooNE as a surface detector cannot self-trigger
  - An alternative approach is needed
  - A second data stream which records data continuously in parallel to the trigger (neutrino beam) stream



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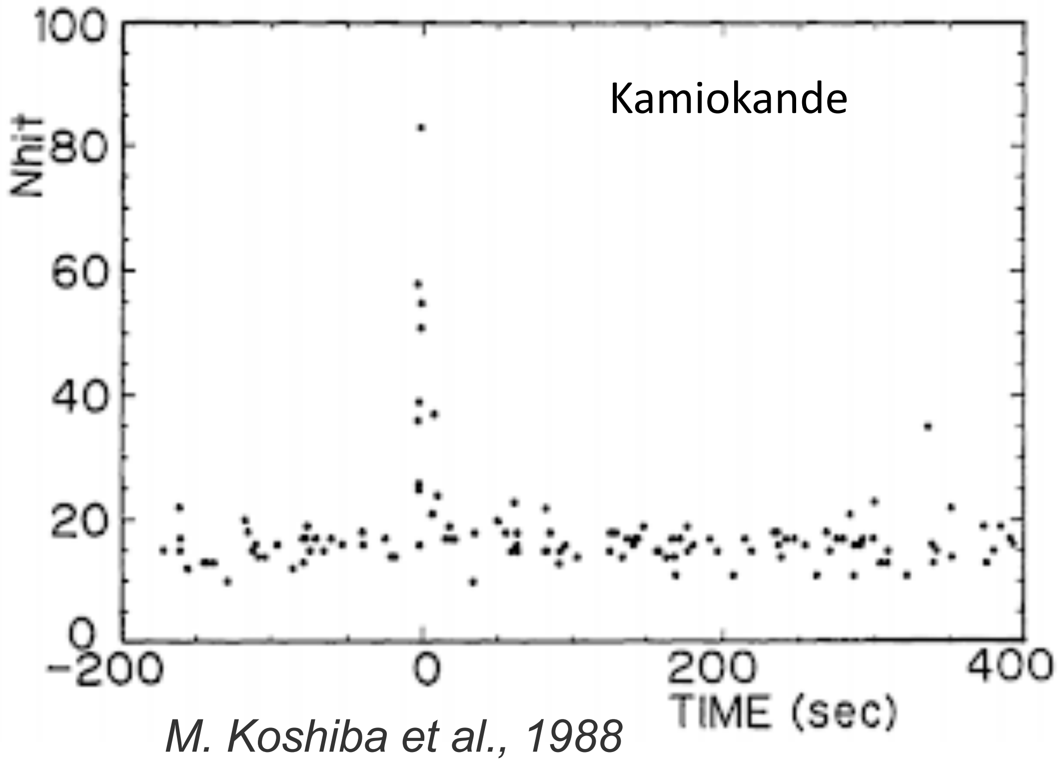

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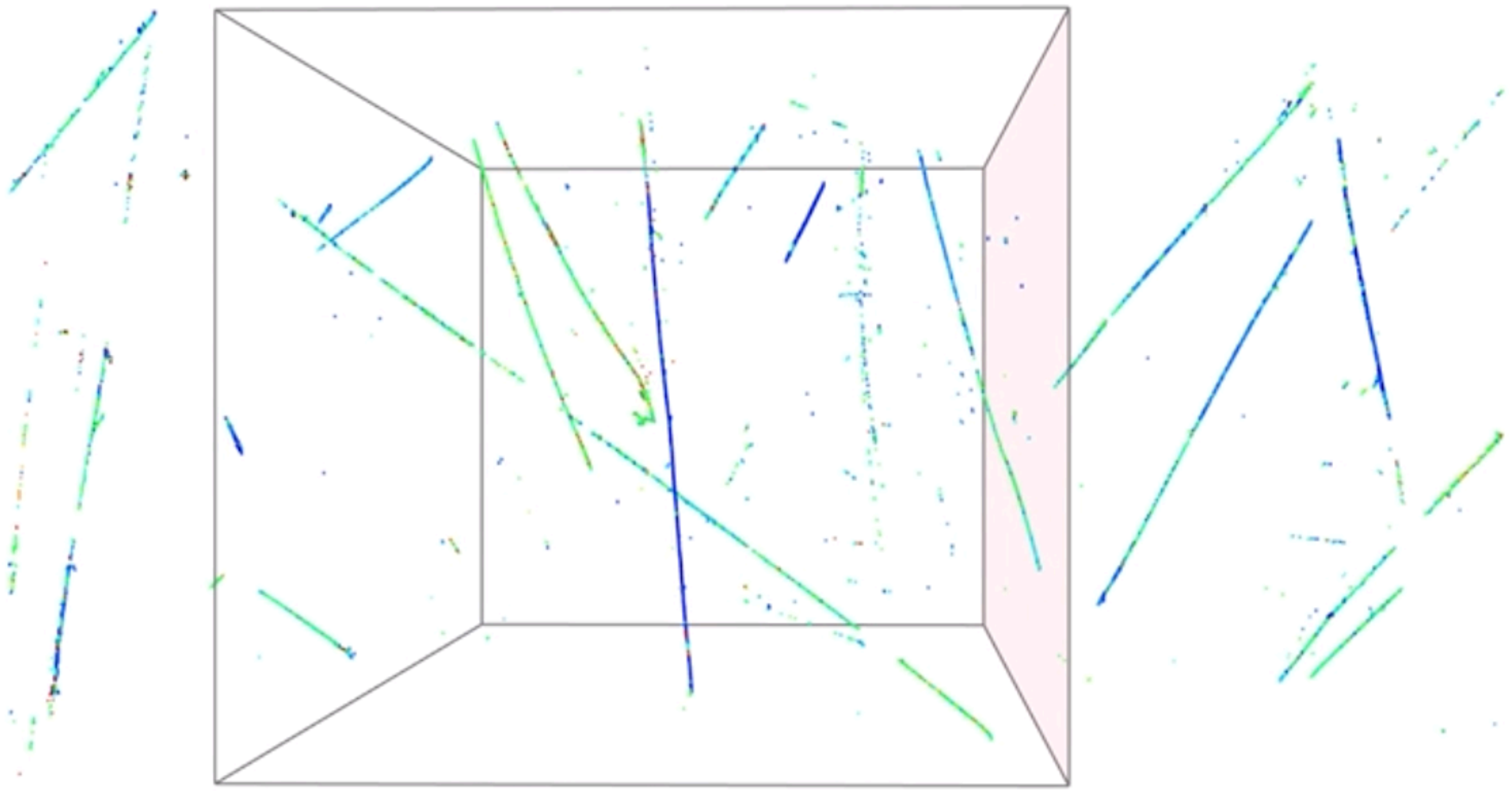
Example of the cosmic background in MicroBooNE



Finding a supernova interaction from all the cosmic activity will be non trivial

Two Main Challenges for MicroBooNE

- Is it possible to maintain the data rates needed for a continuous readout?

- If we use a lossy compression algorithm, are we sensitive to such low energy events?

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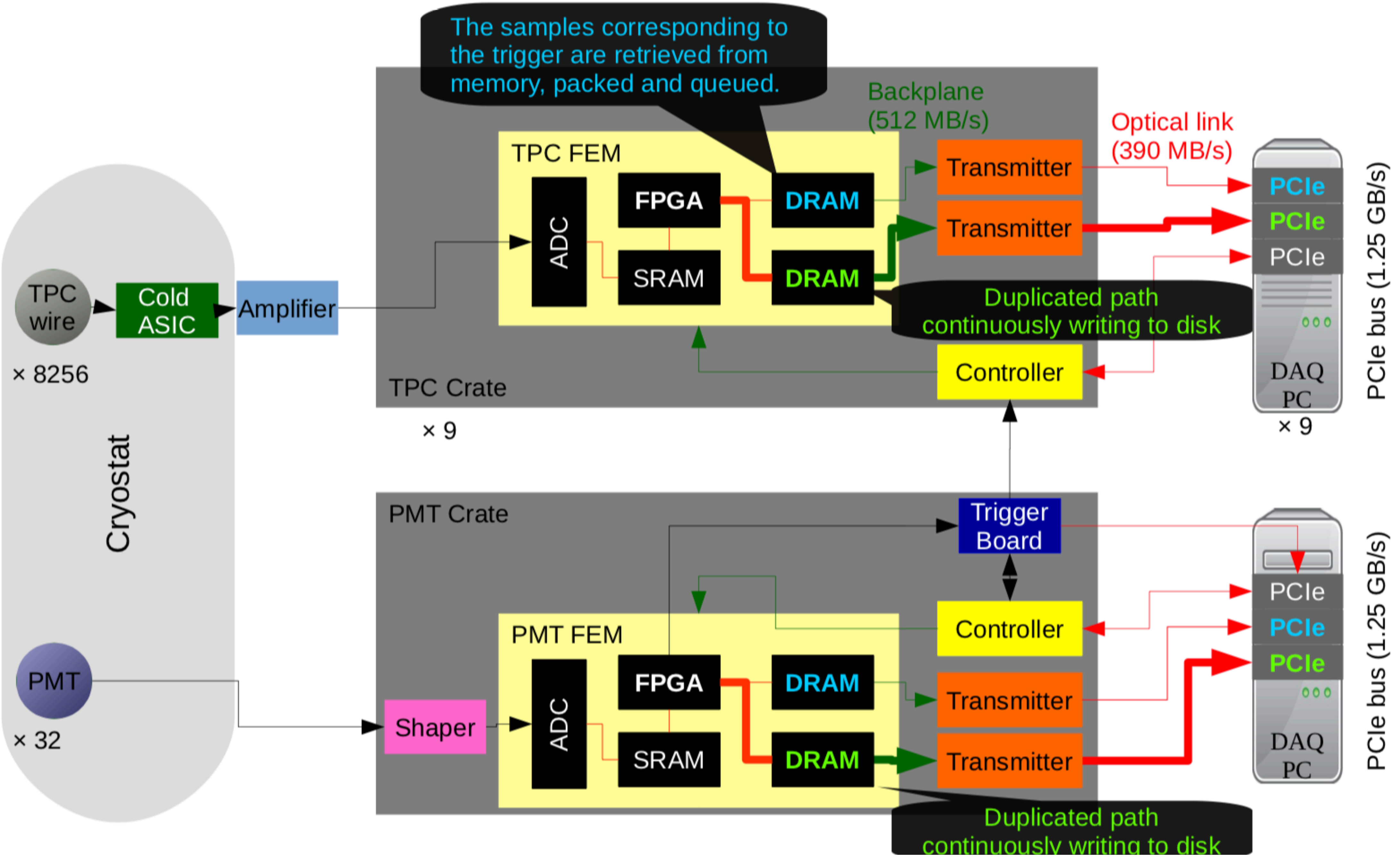
MicroBooNE has shown we can!

SN and Trigger Data Scheme



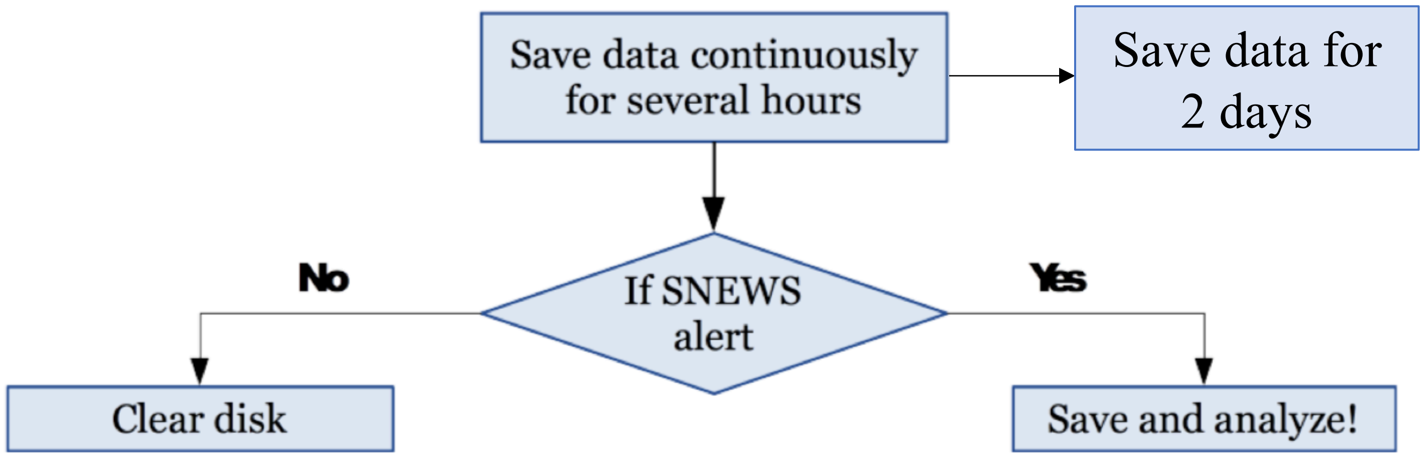
MicroBooNE’s Continuous (Supernova) Readout Stream

- The supernova stream reads out the data continuously
  - Relies on delayed external trigger –Supernova Early Warning System (SNEWS)
- Saving data continuously is non trivial
  - Without compression:

2 Msamples/s * 2 B/sample * 8256 channels = **33 GB/s**

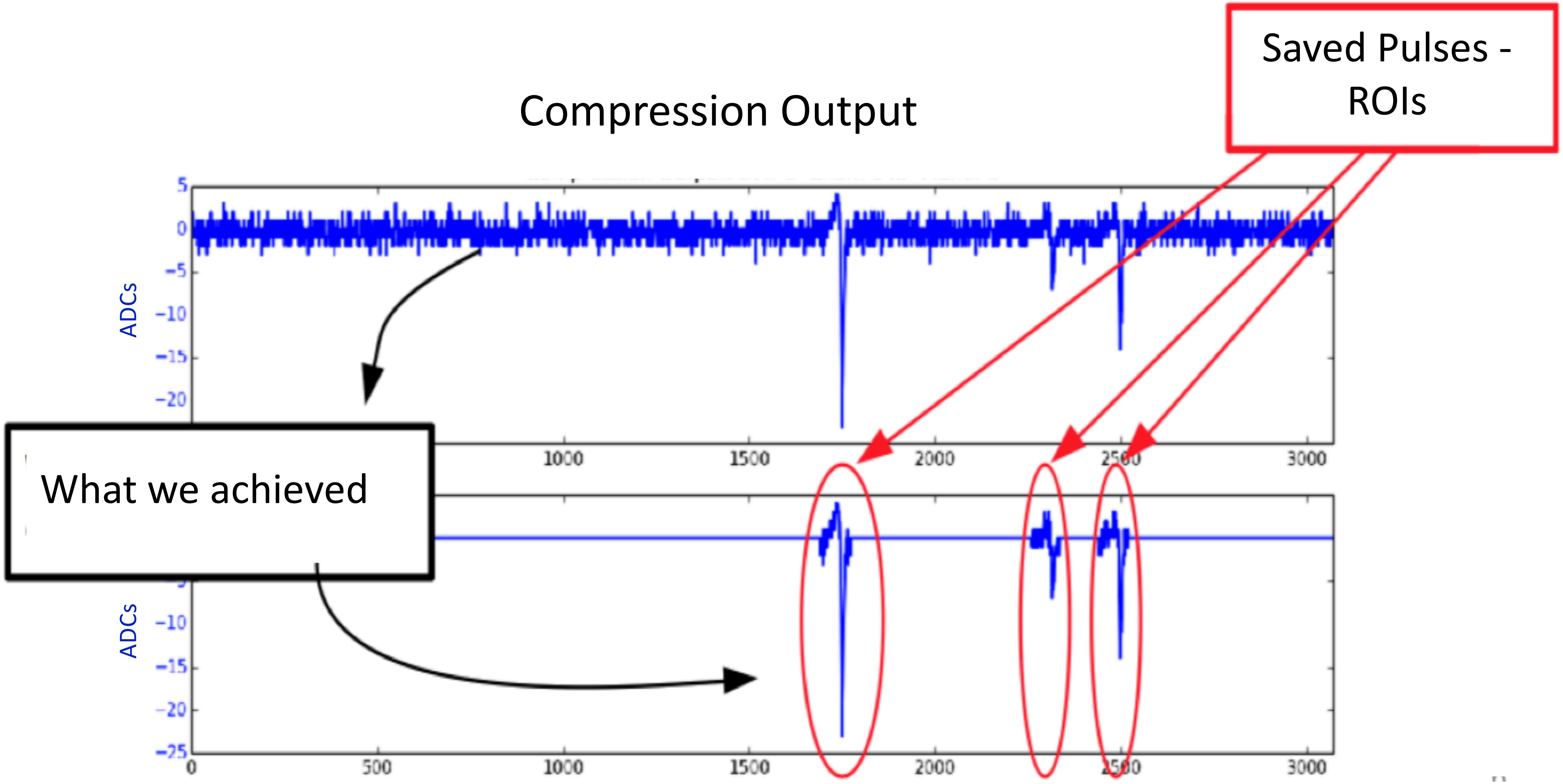
3.7GB/s per DAQ server

  - Set the target writing speed of ~**50 MB/s** for servers
  - Apply lossy compression to reduce data by a factor of 80



Zero Suppression Algorithm

- Implemented in the Front End Module FPGA (developed at Columbia University)
- Save regions which are above a threshold relative to the channel baseline.



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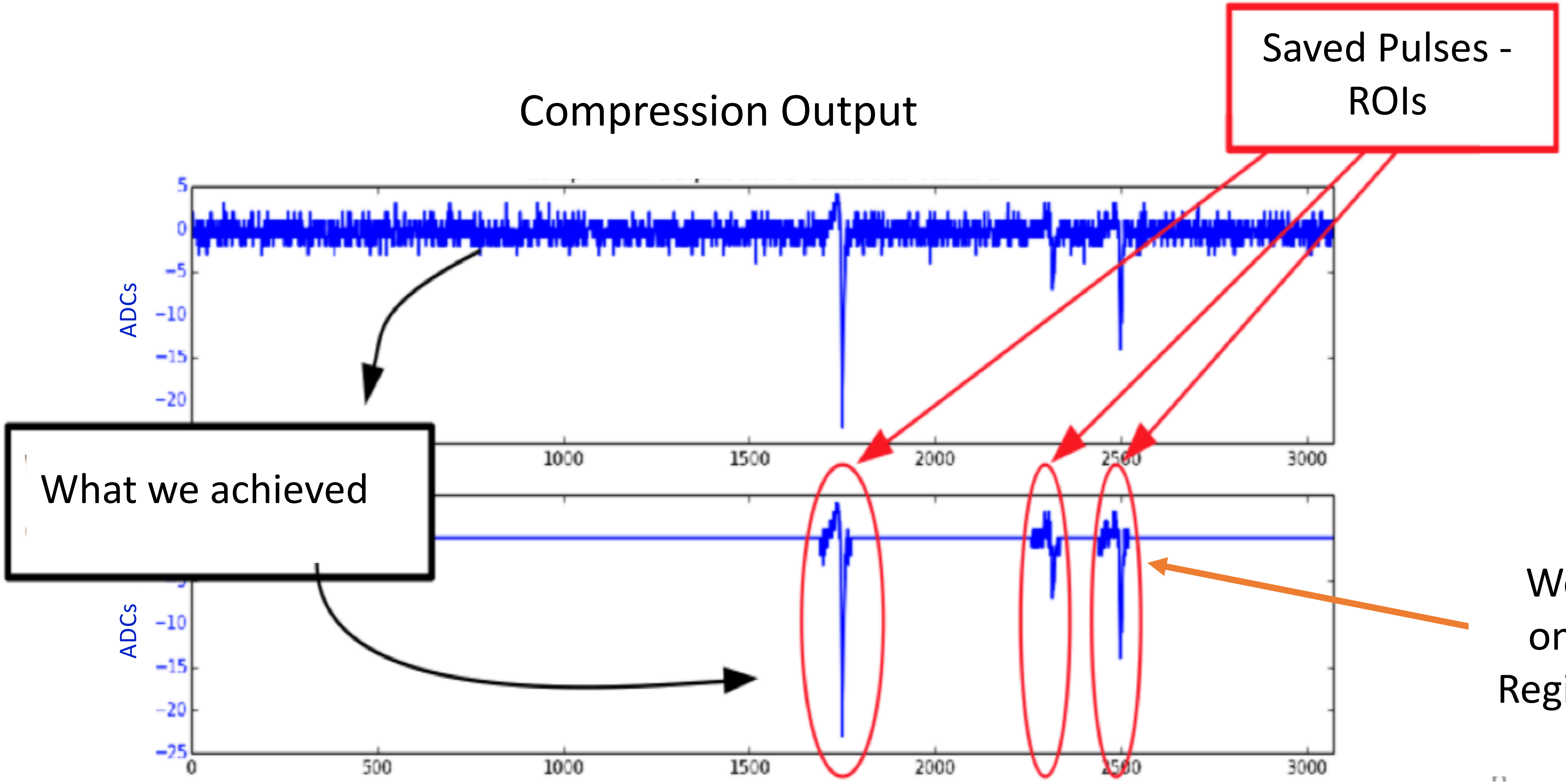

We can zoom in onto one of the Regions-of-Interest

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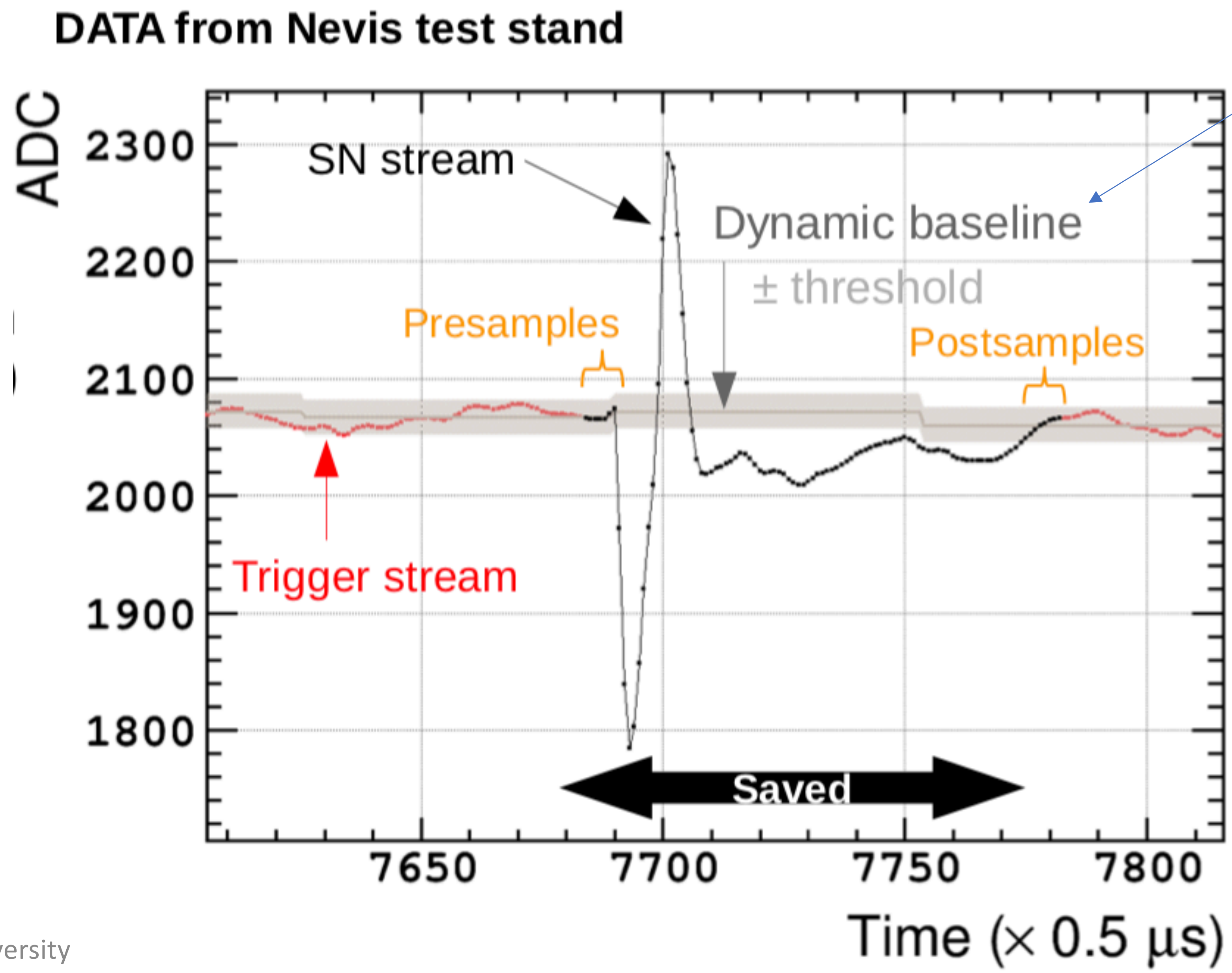

Dynamic baseline: calculated by FPGA
Or
Static baseline: loaded on the FGPA at beginning of the run

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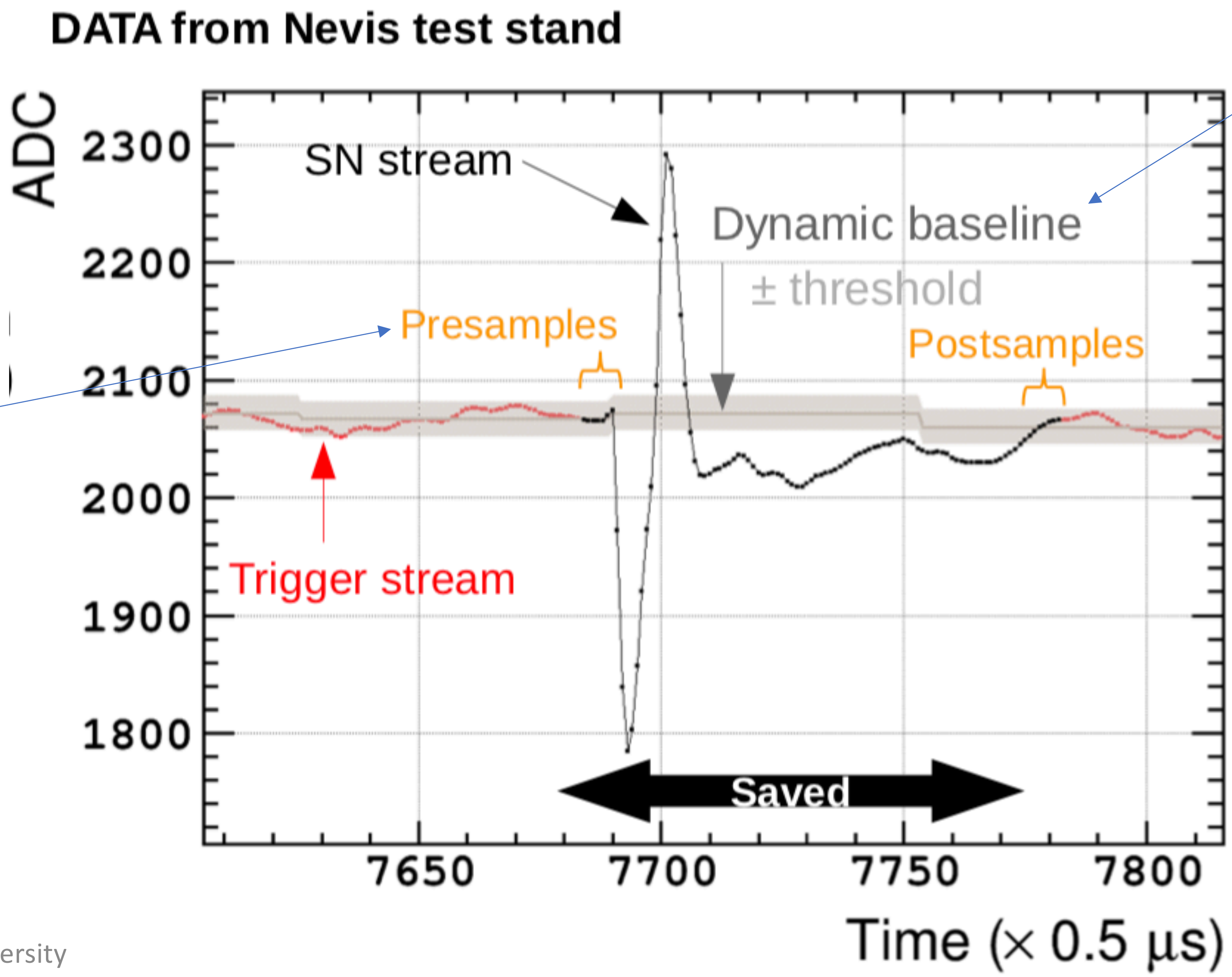
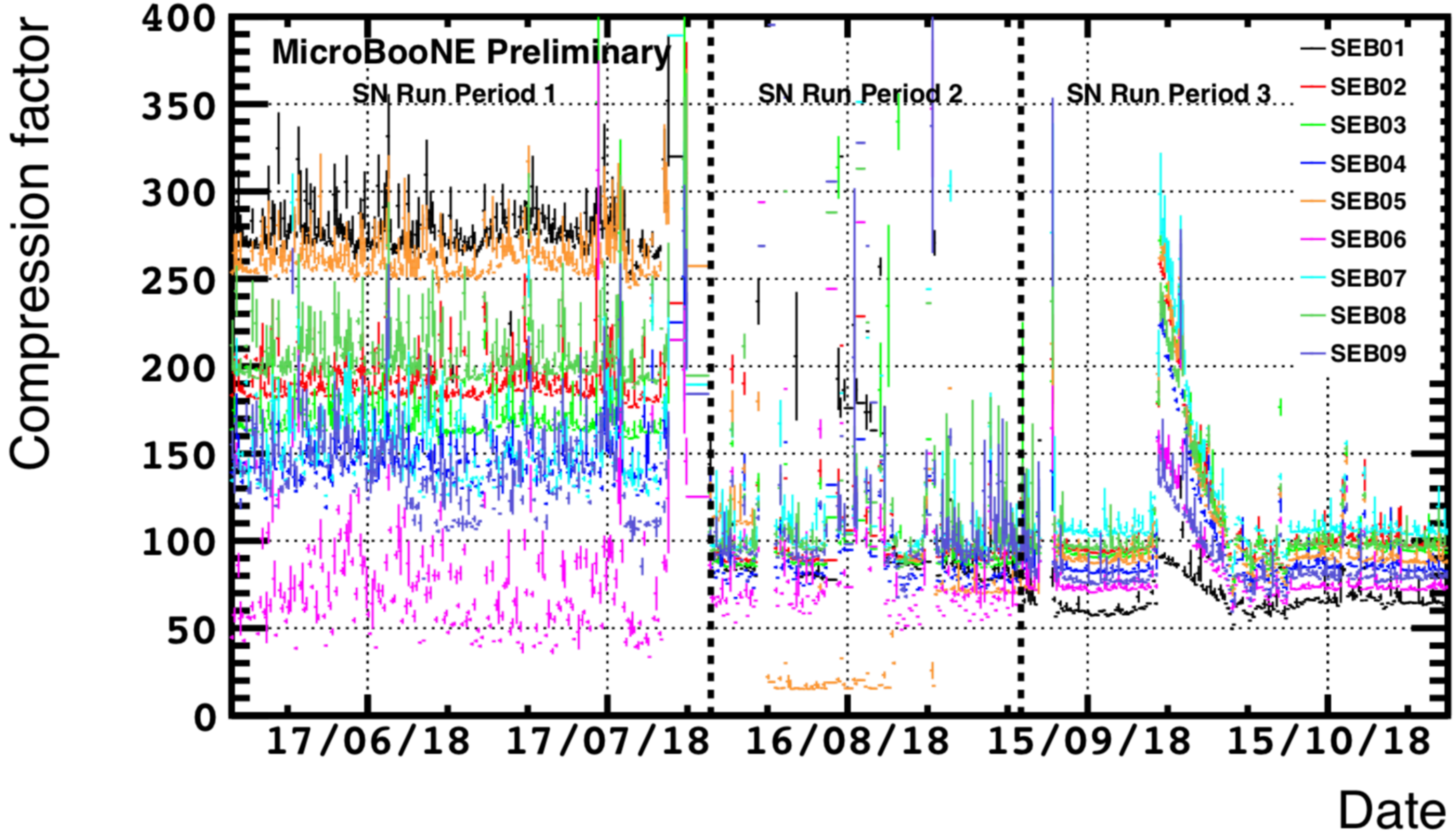


Pre and post samples are needed for reconstruction

Our Current Data Rates after Compression

Supernova Stream Run III uses **static baseline** and **low** thresholds



Supernova TPC DAQ Servers (Crate) compression factor

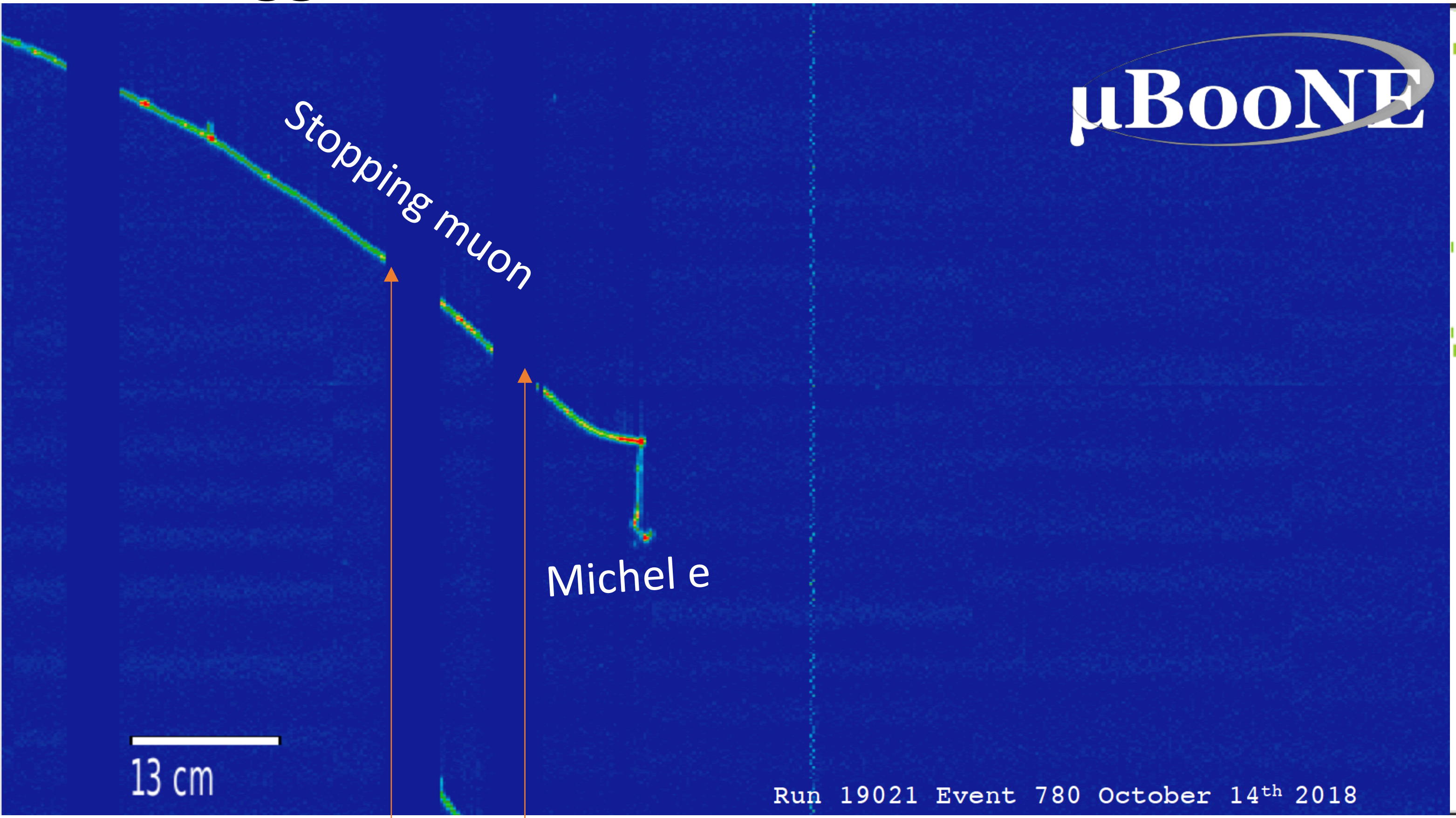
With Run III, the rates are stable ~50 Mb/s

The Supernova Continuous Readout

- Supernova Stream finalized commissioning on October 2017
- To test the performance of the readout we created a software emulation which can recreate the existing data reduction algorithms implemented in LArSoft
- We can make compressed data sets from the non-compressed stream (trigger stream) and simulation (Monte Carlo)
  - We can simulate the response of the electronics

Michel Electron Candidates in Collection Plane

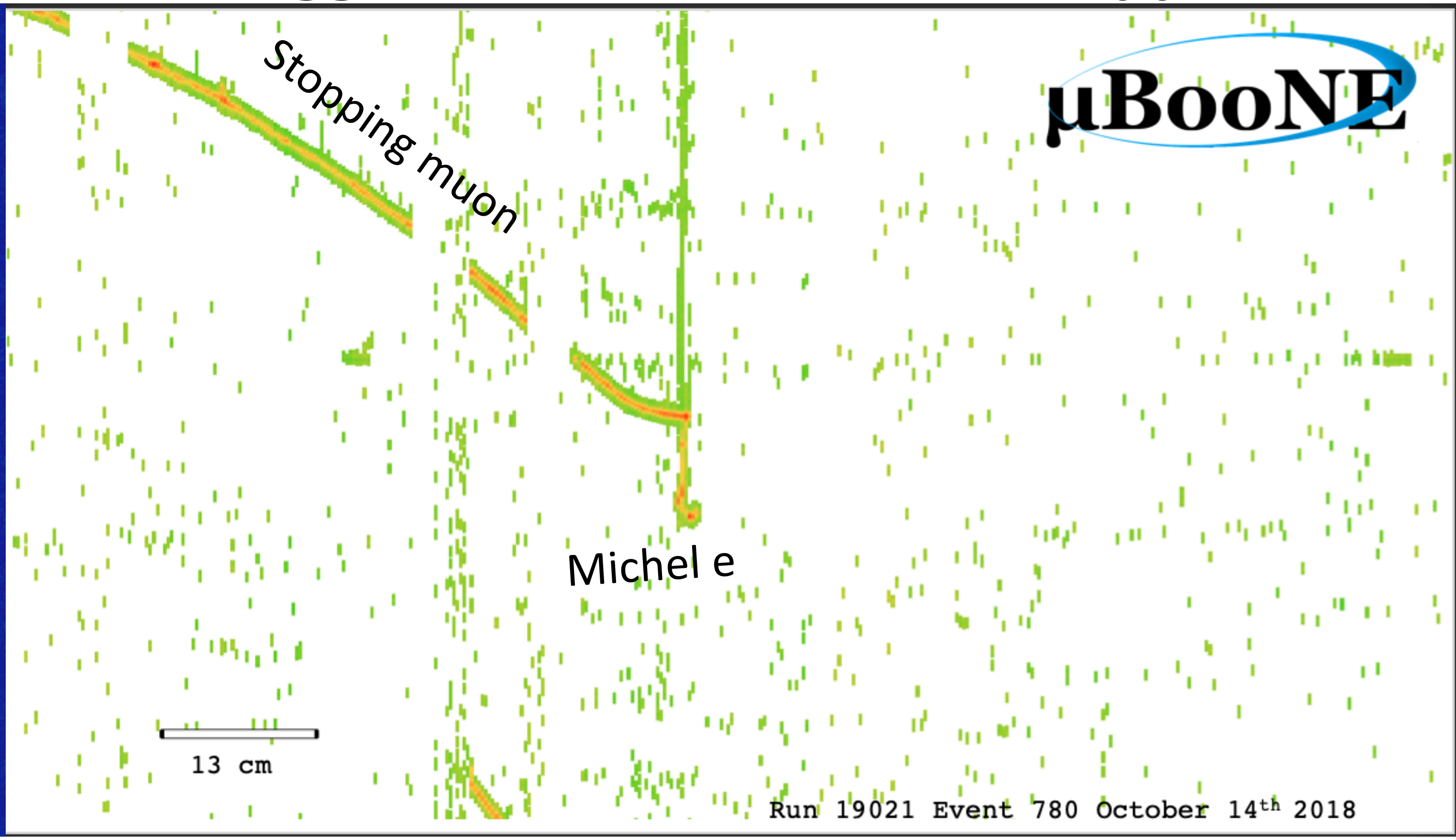
Trigger Stream Data



Blue Background = Data at Baseline values

Dead Wires

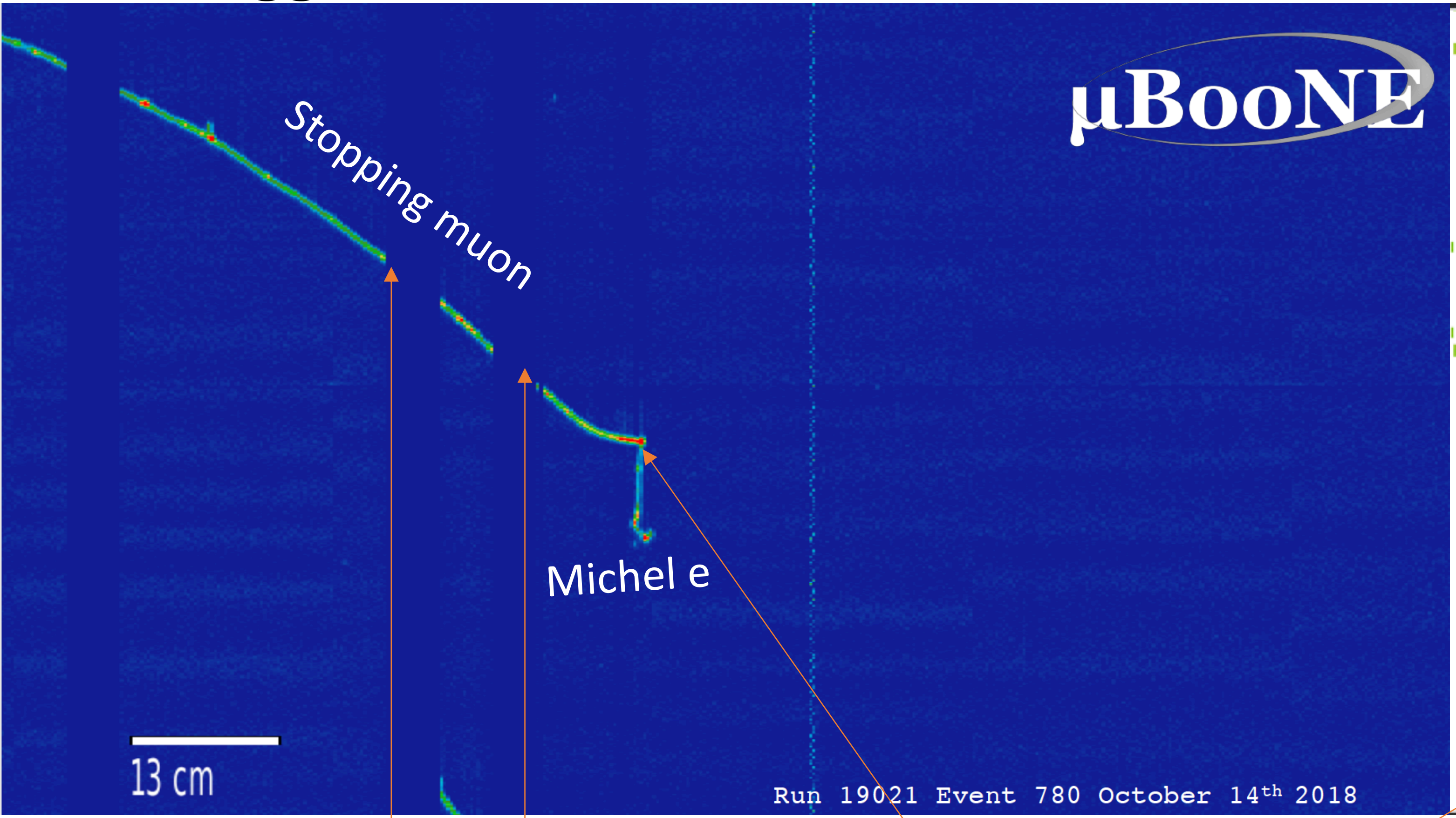
Same Trigger Stream Data + Zero Suppression



White Background = No Data

Michel Electron Candidates in Collection Plane

Trigger Stream Data



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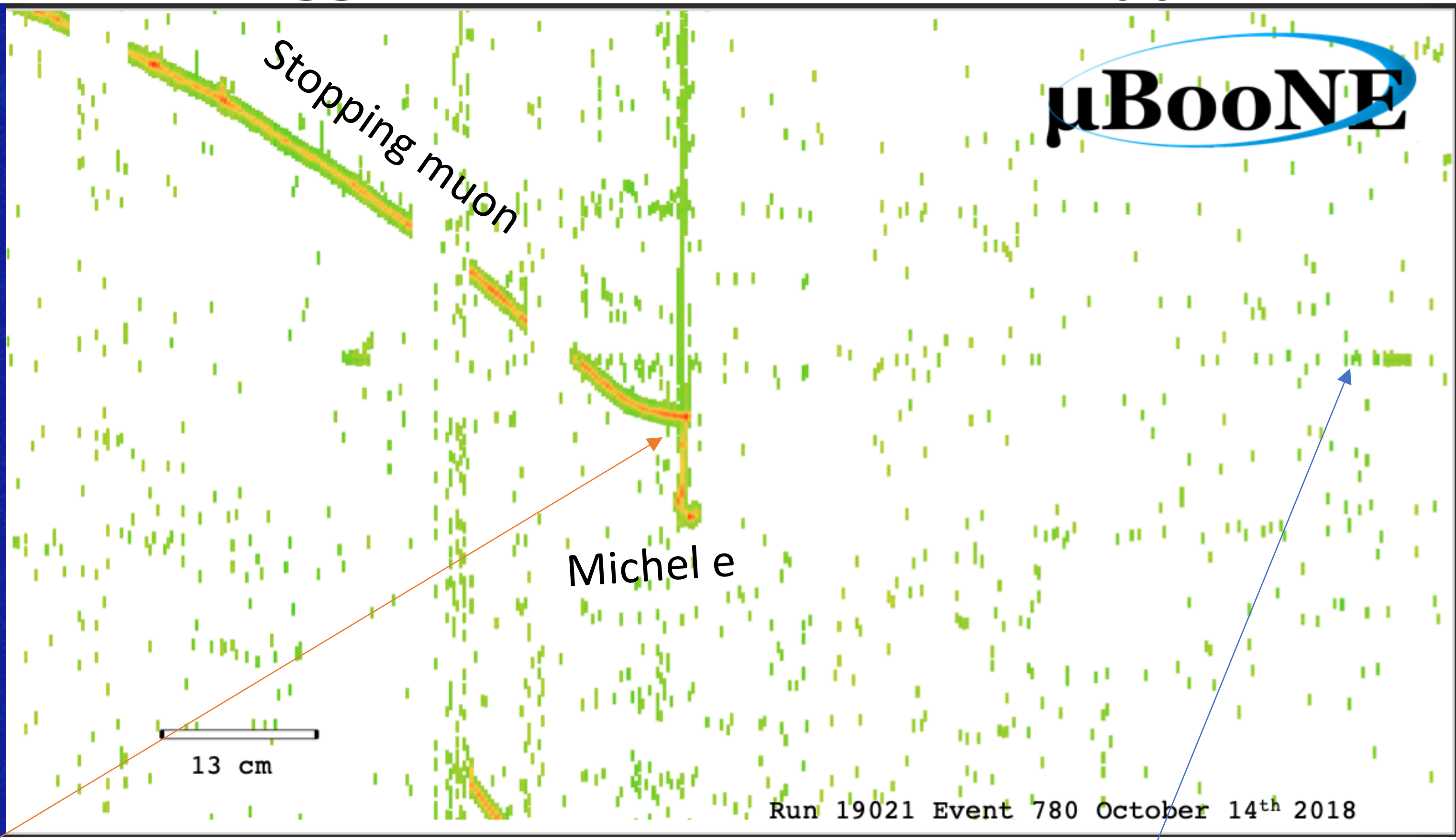


Dead Wires

Blue Background = Data at Baseline values

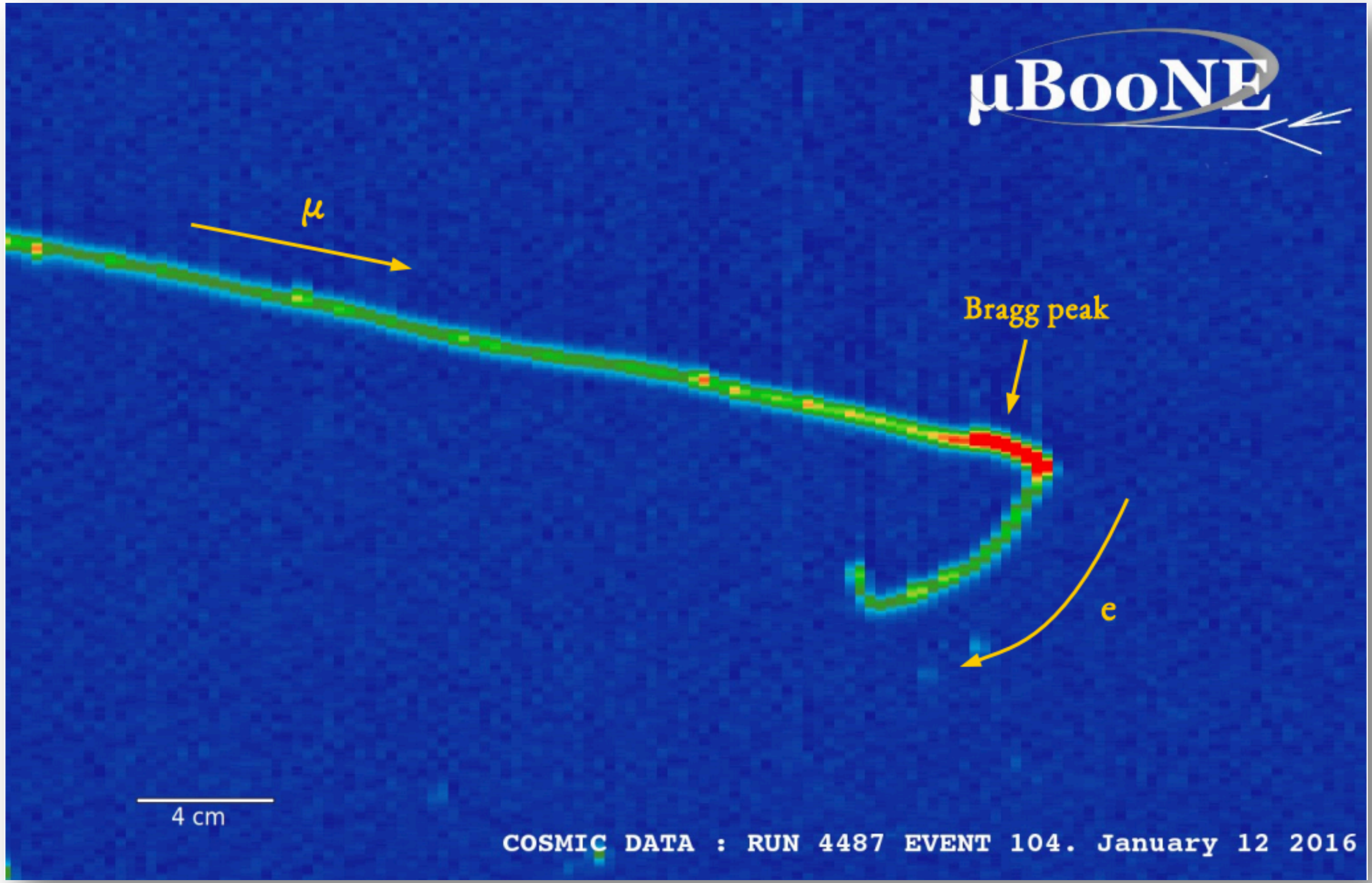
White Background = No Data

We keep the important features while discarding most of the background signals

Noise passing zero suppression -> Set thresholds to keep as much information as possible

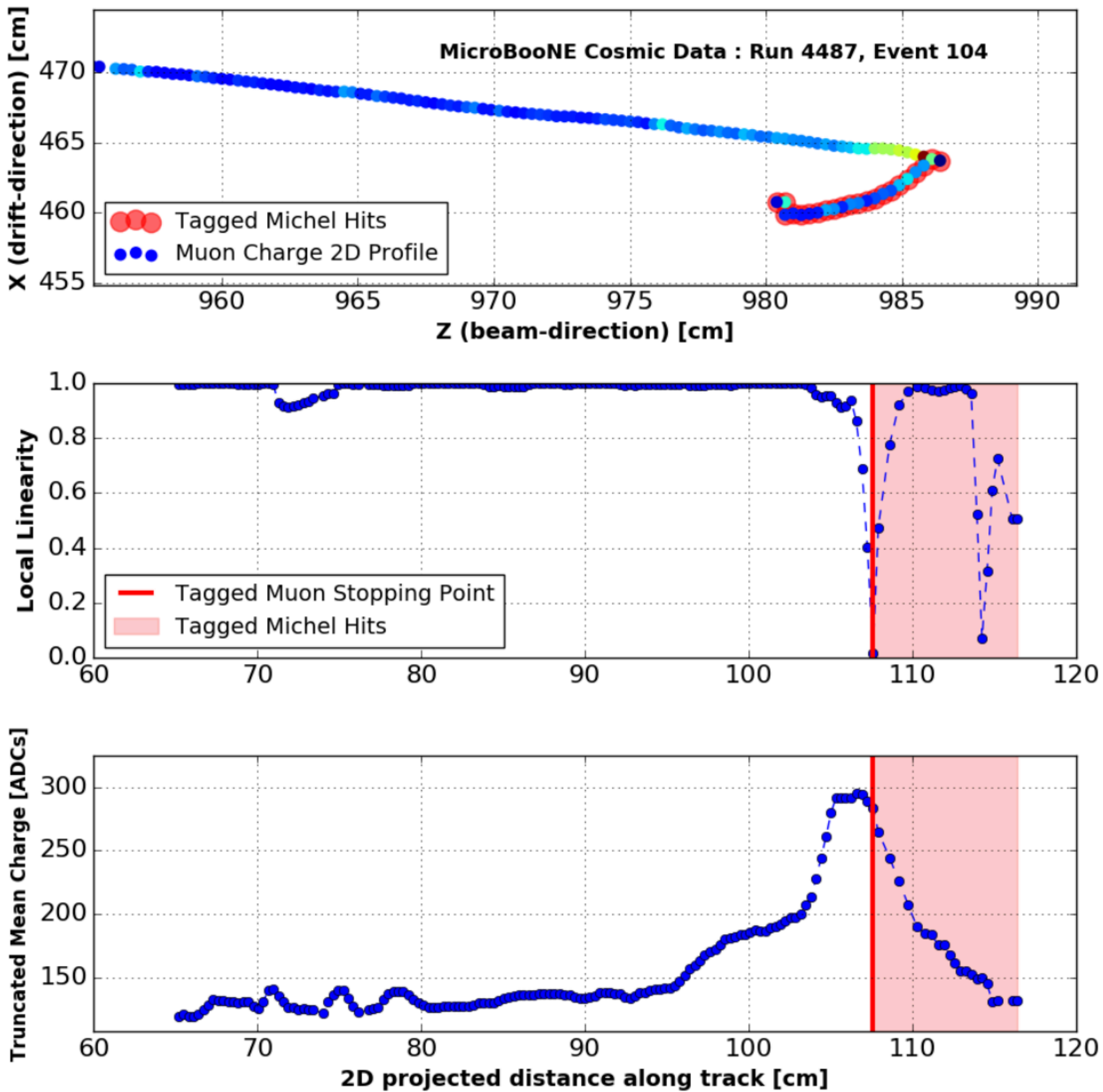
Testing the performance of the Readout

- Use Michel electrons from a decaying cosmic muon to probe the SN readout sensitivity to low energy EM activity.



Testing the performance of the Readout

- Use the reconstruction and selection algorithms used follow MicroBooNE's previous publication.



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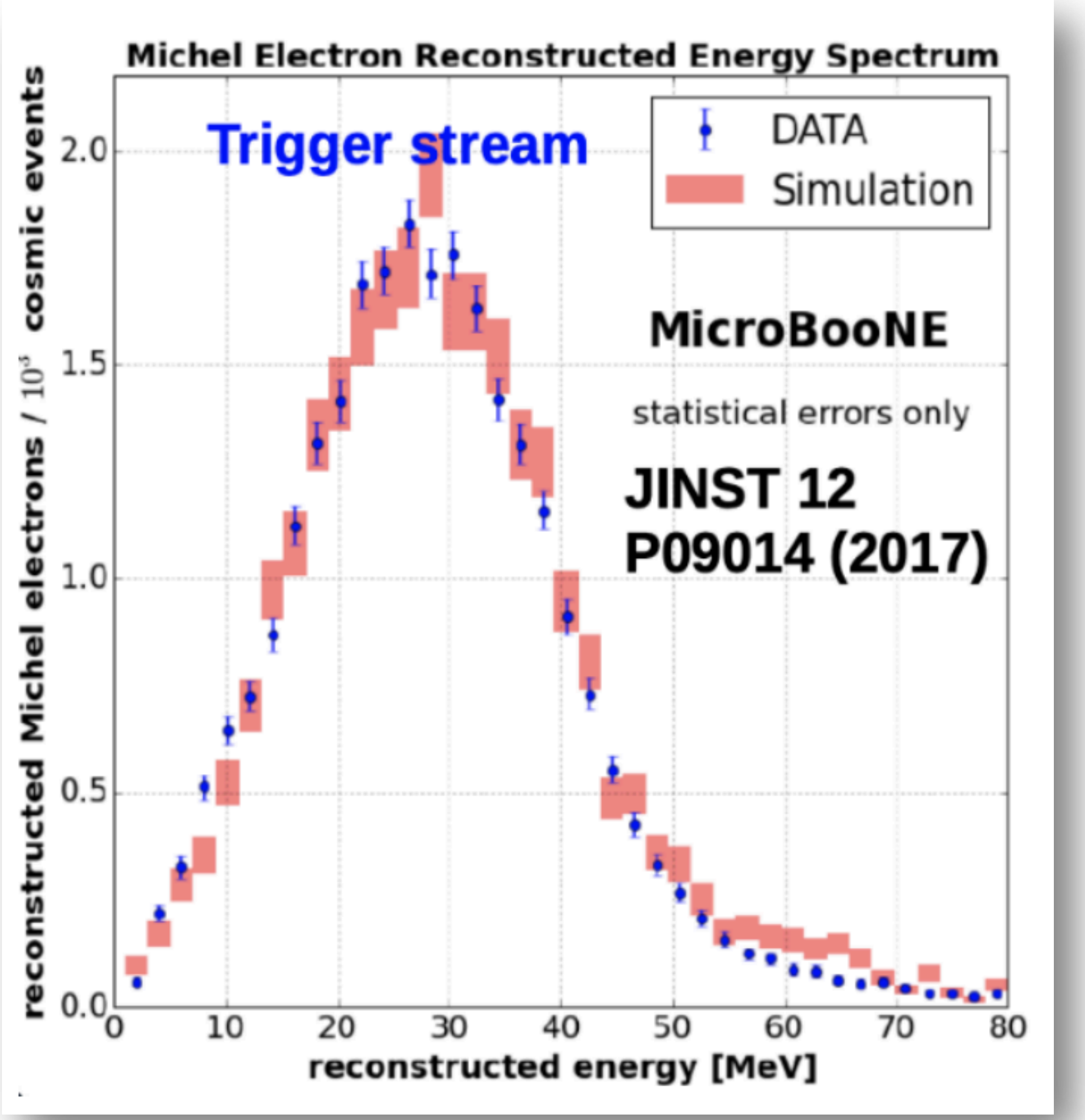
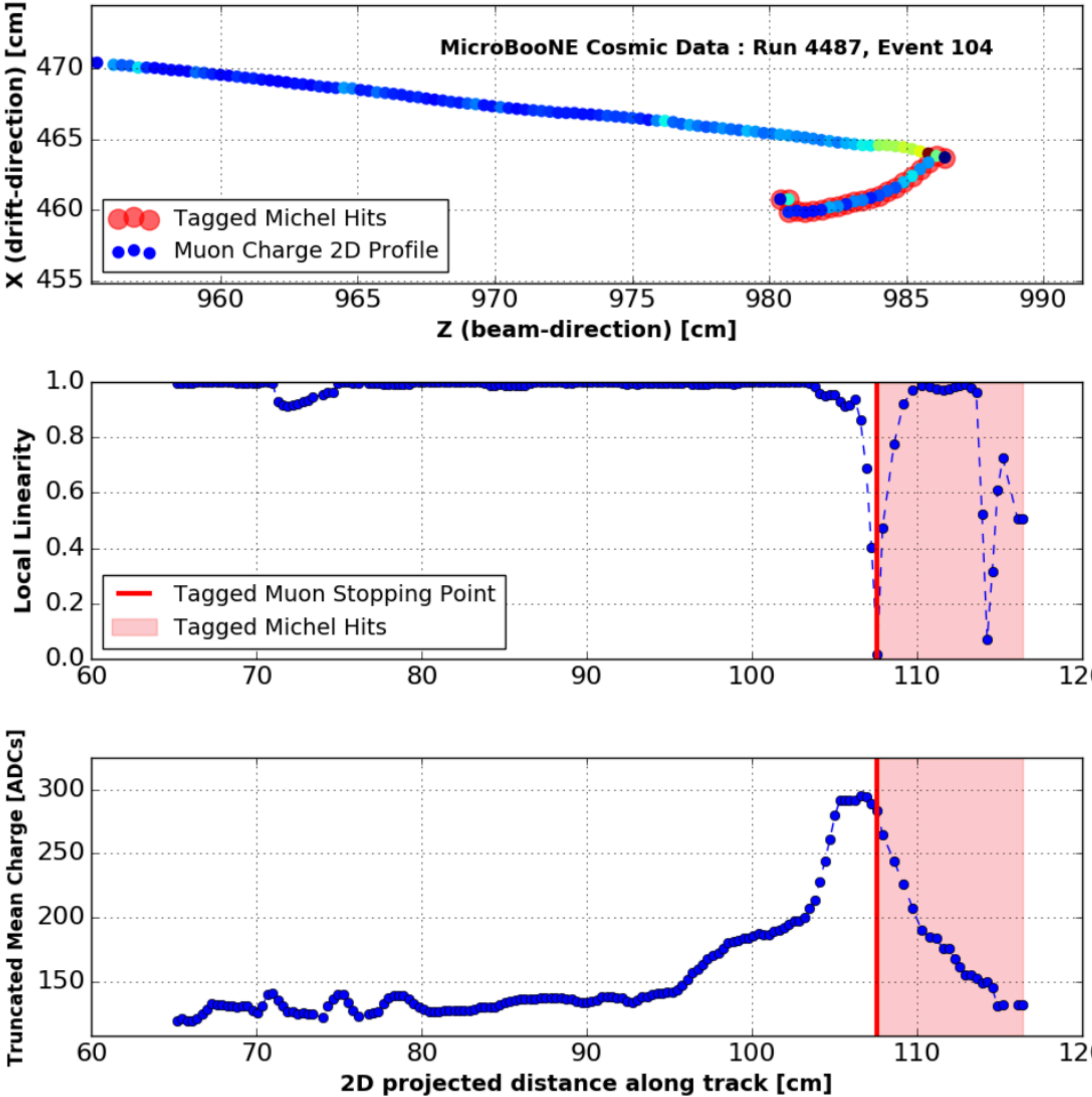
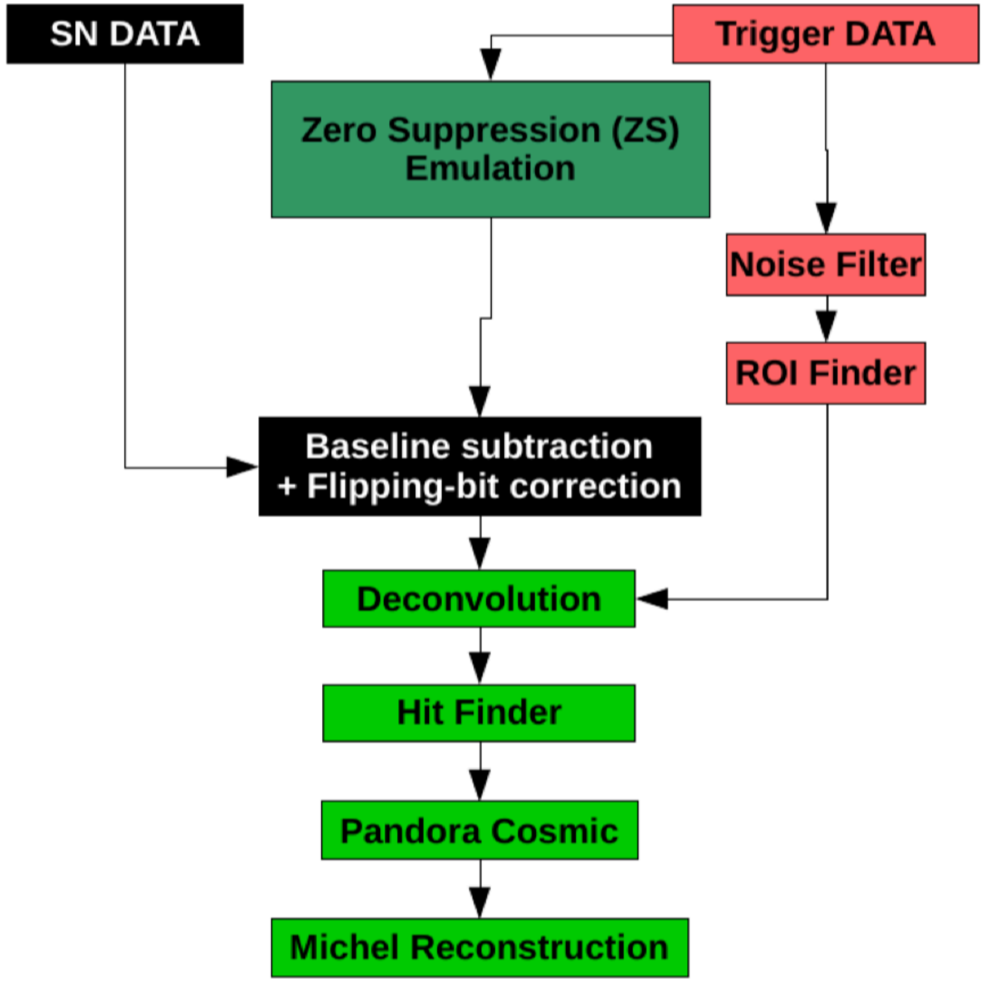


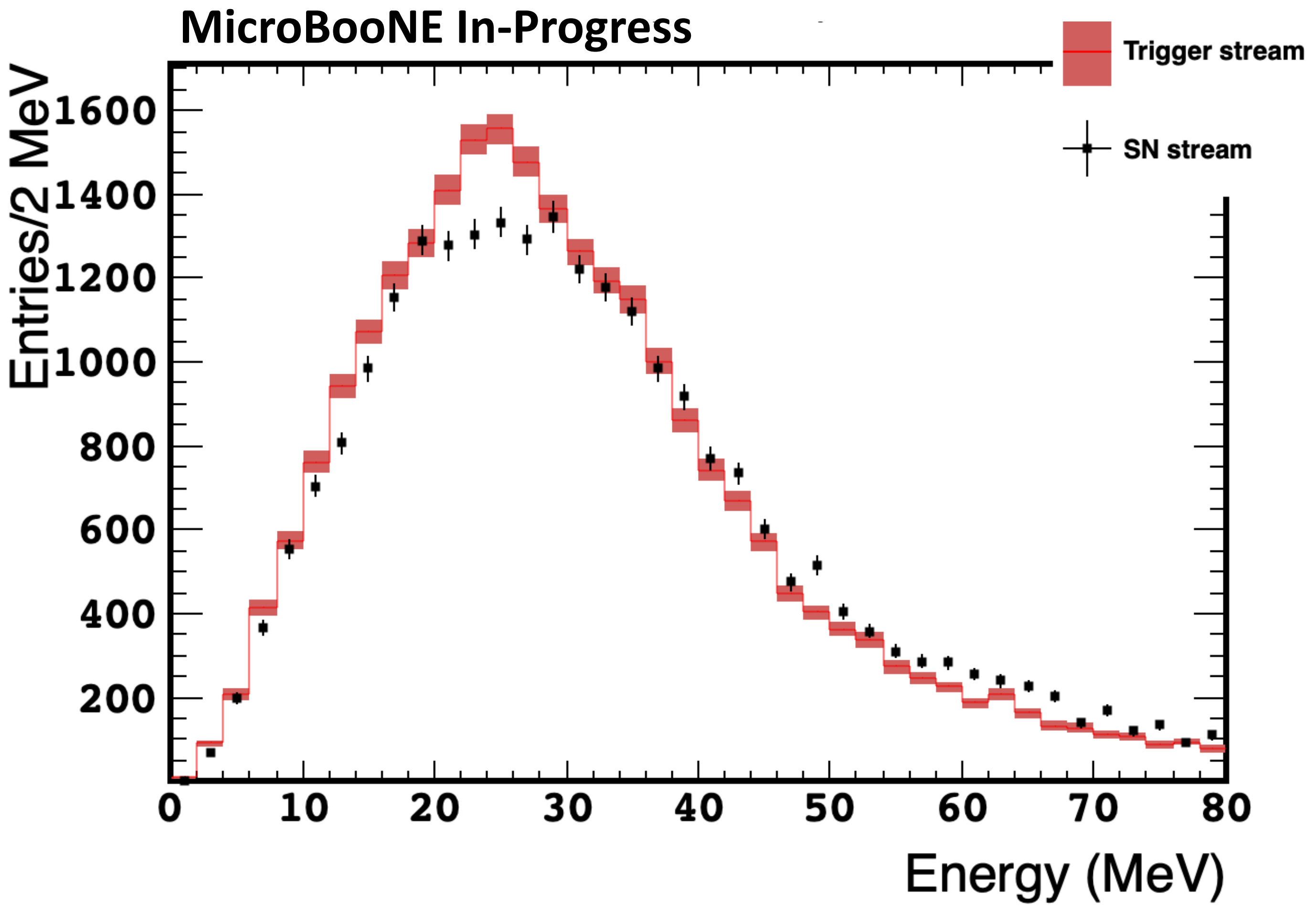


Reconstructing the Michel Energy Spectrum

- Continuous Stream data: 53.31 minutes taken on September 21st, 2018
- Trigger Stream: 58.85 minutes taken between December 1st, 2017 and July 7th, 2018
  - Data set without offline zero suppression
  - Data with offline zero suppression

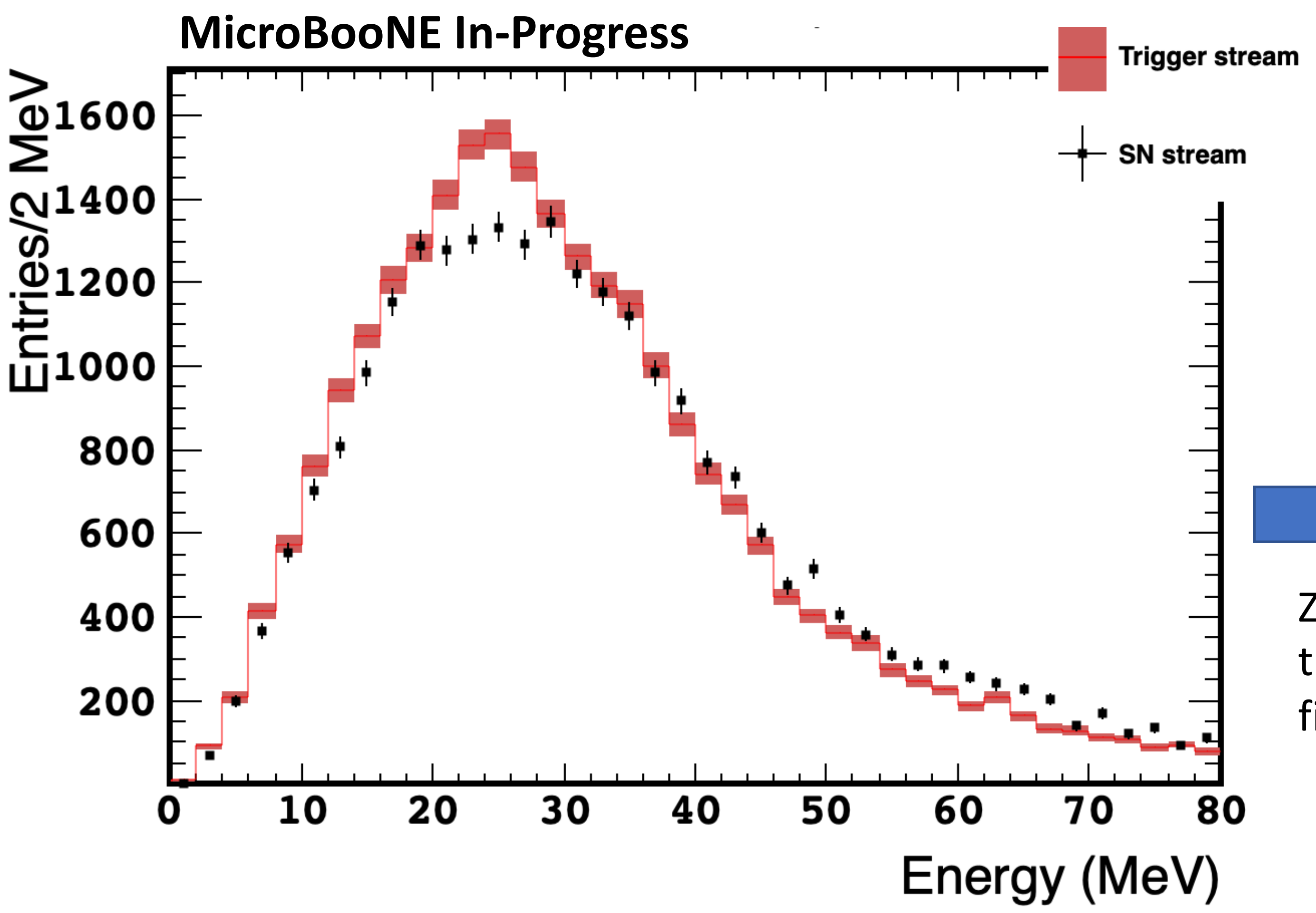


The Michel Energy Spectrum

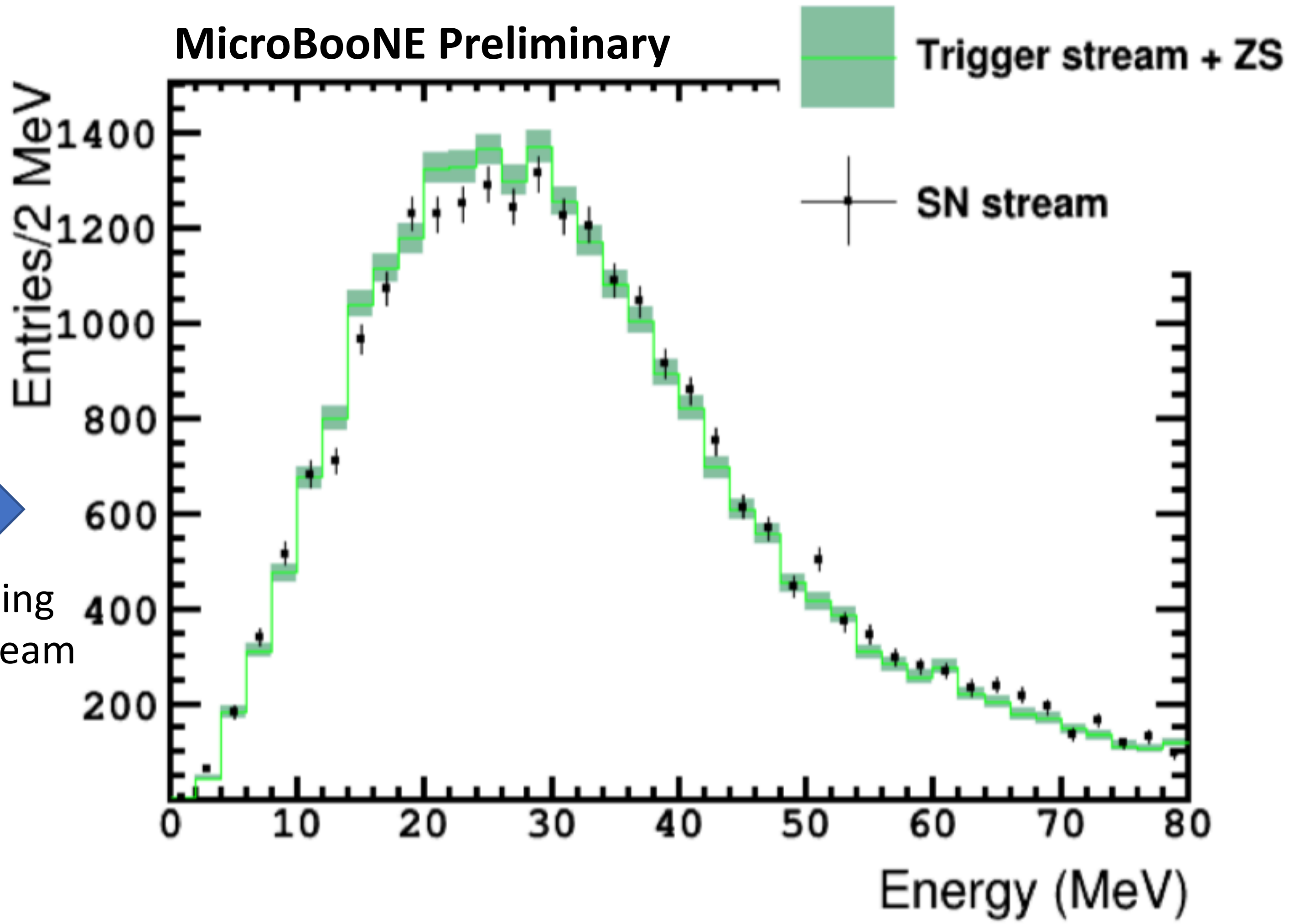


- Both spectra were generated using the reconstruction detailed before
- The spectra are relatively normalized
- Discrepancies between the Trigger Stream and SN stream are caused by the zero suppression

The Michel Energy Spectrum

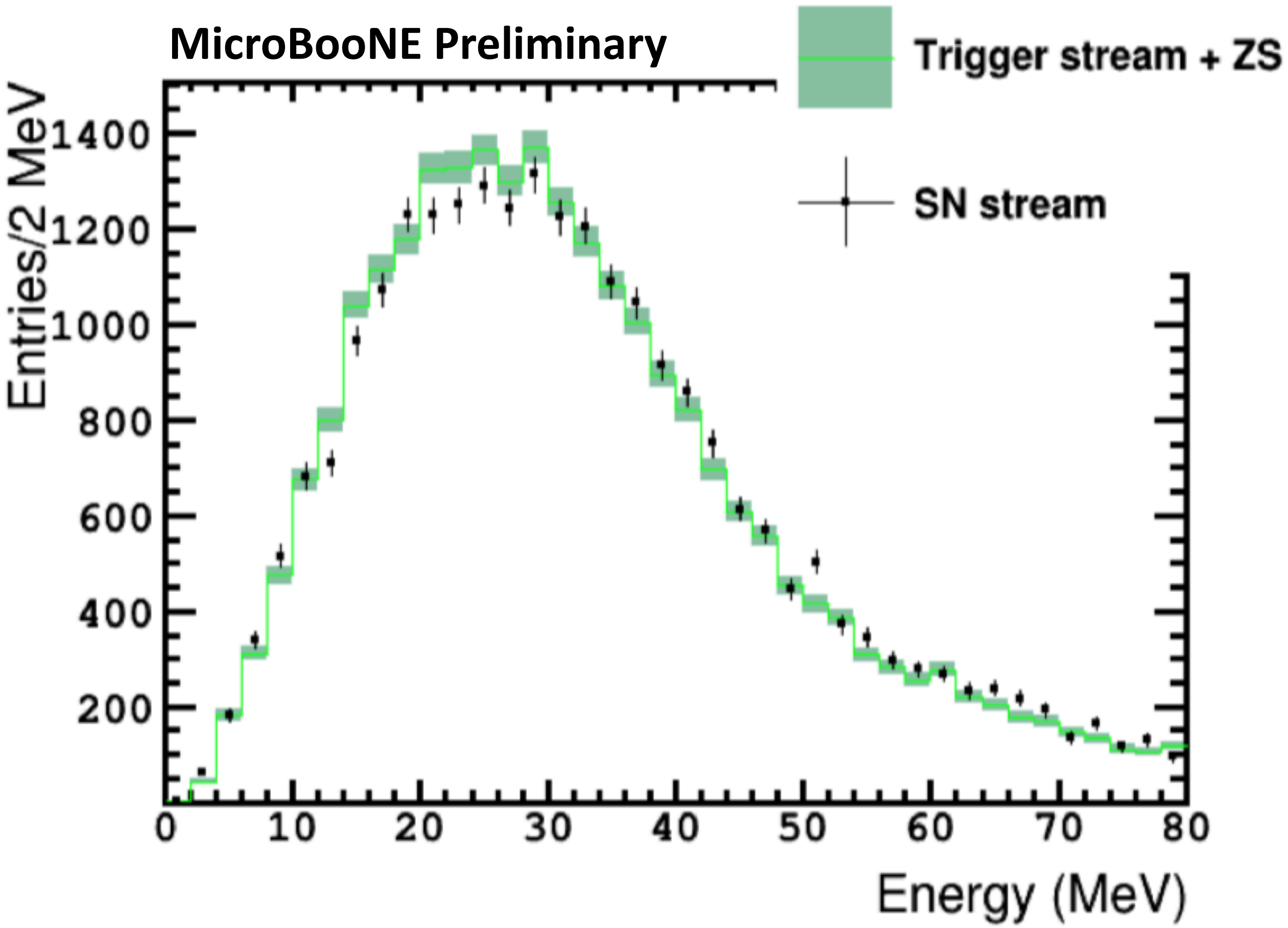


Zero suppressing the trigger stream files offline



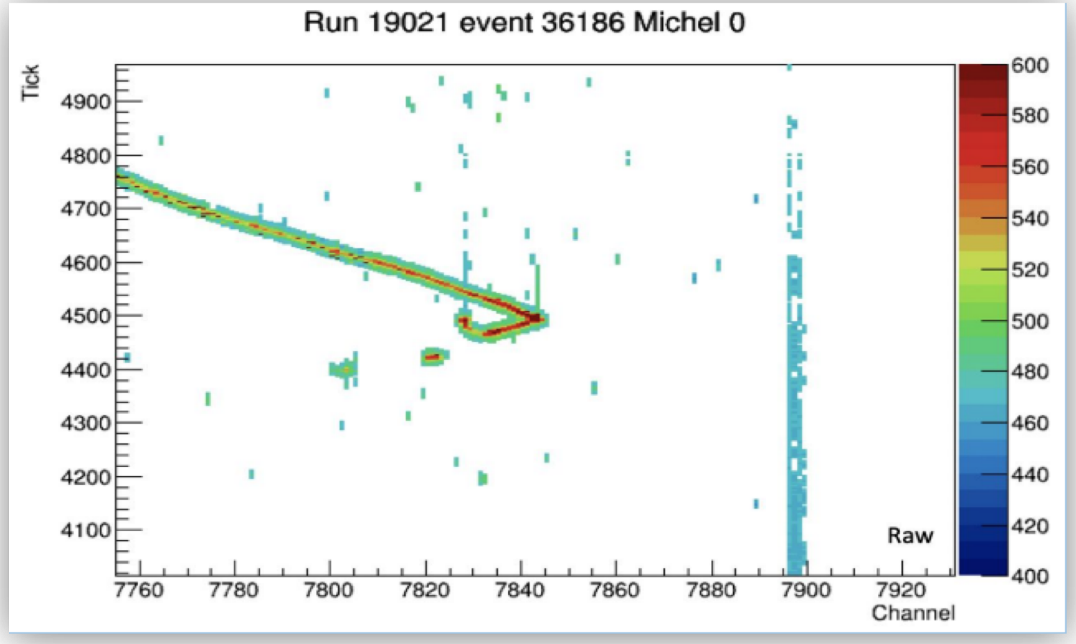
The Michel Energy Spectrum

- Both spectra are relative normalized
- The shapes of the spectra match very well!

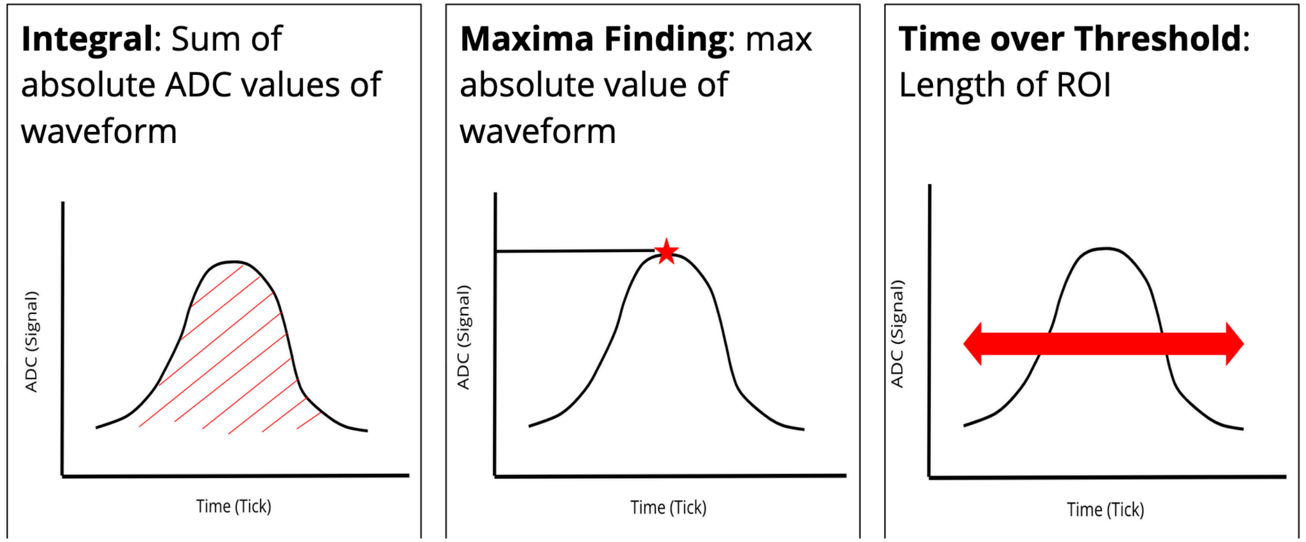


Next Steps

Start with MicroBooNE's suppressed data "ROIs"



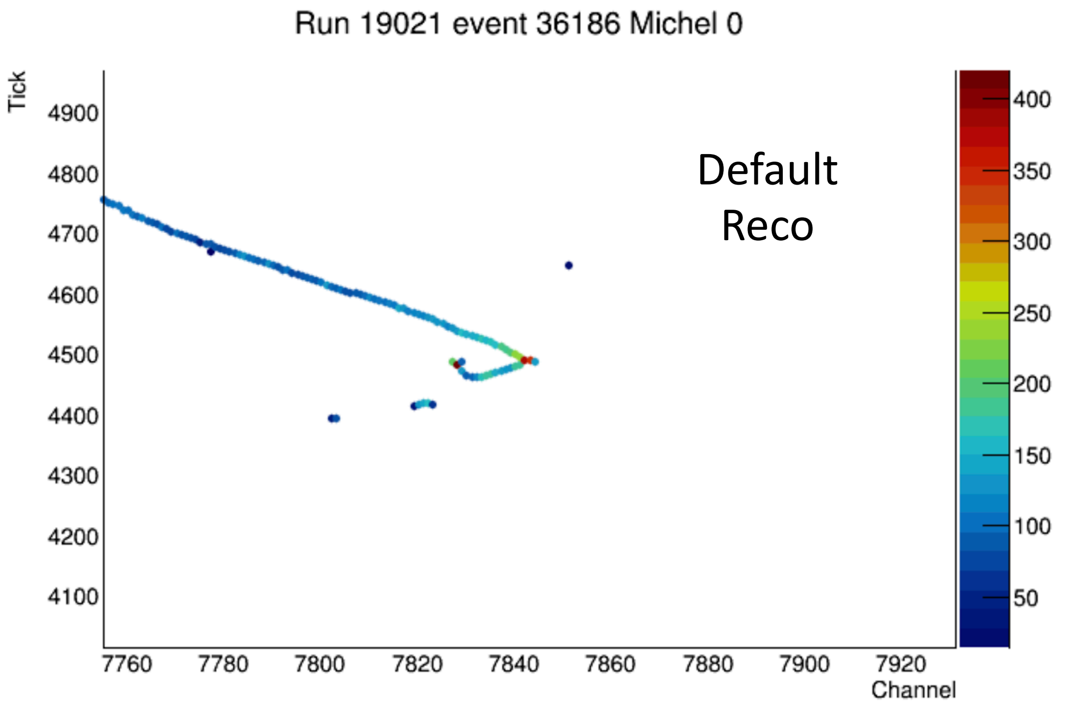
Create Trigger Primitives (will be used in DUNE) and remove hit noise



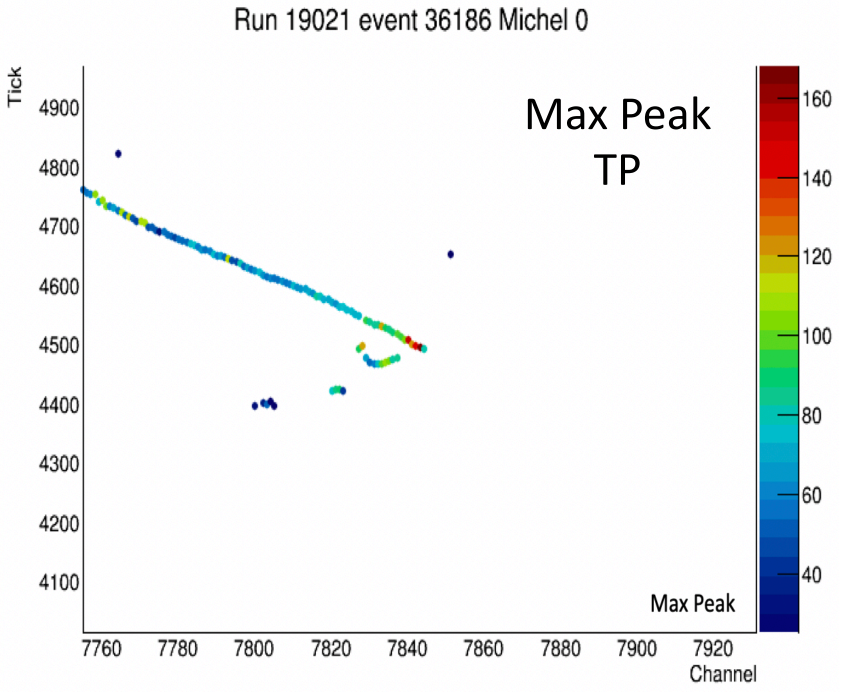
https://www.nevis.columbia.edu/reu/2019/reports/Hinrichs_report.pdf

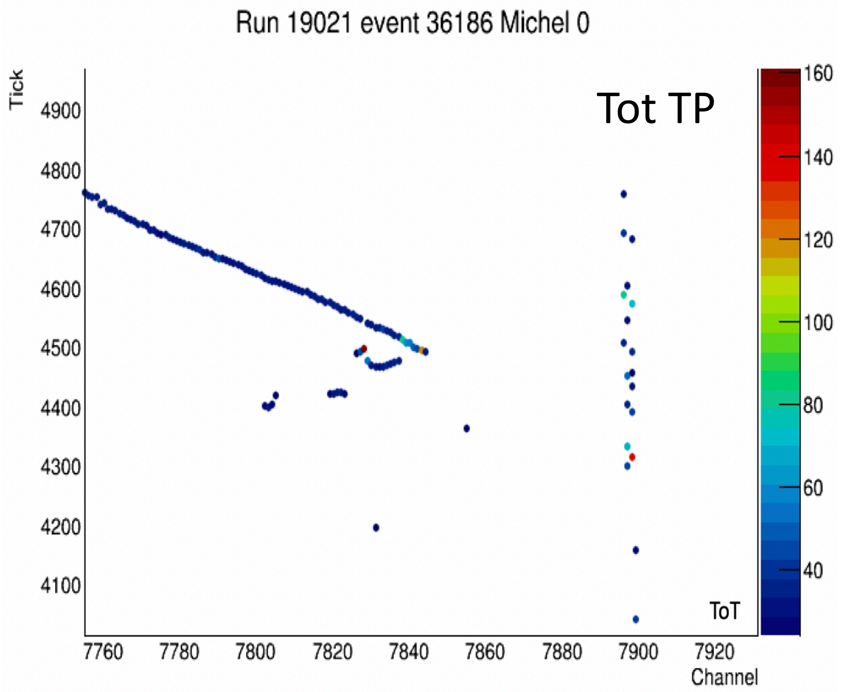
Next Steps

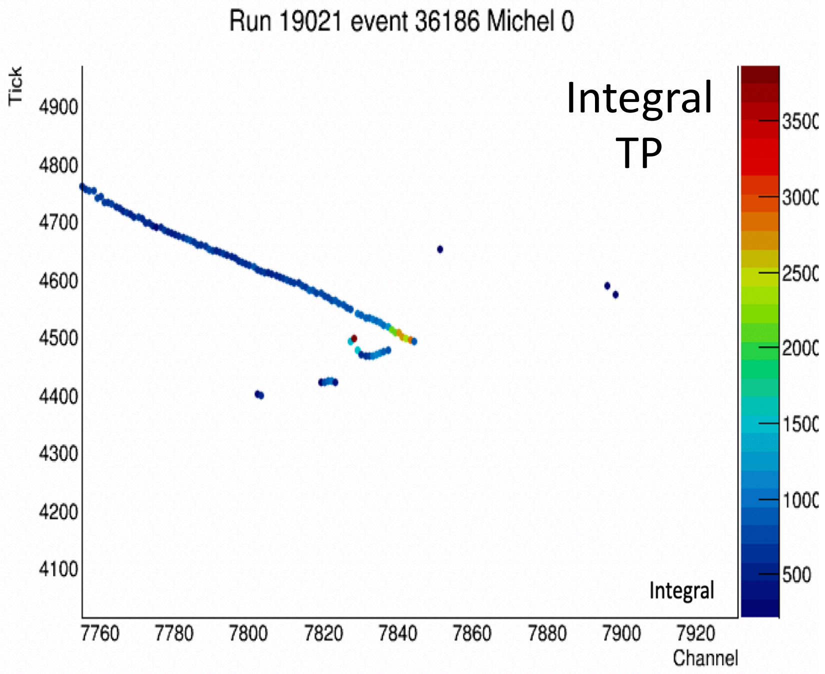
MicroBooNE's default reconstruction



Resulting TPs







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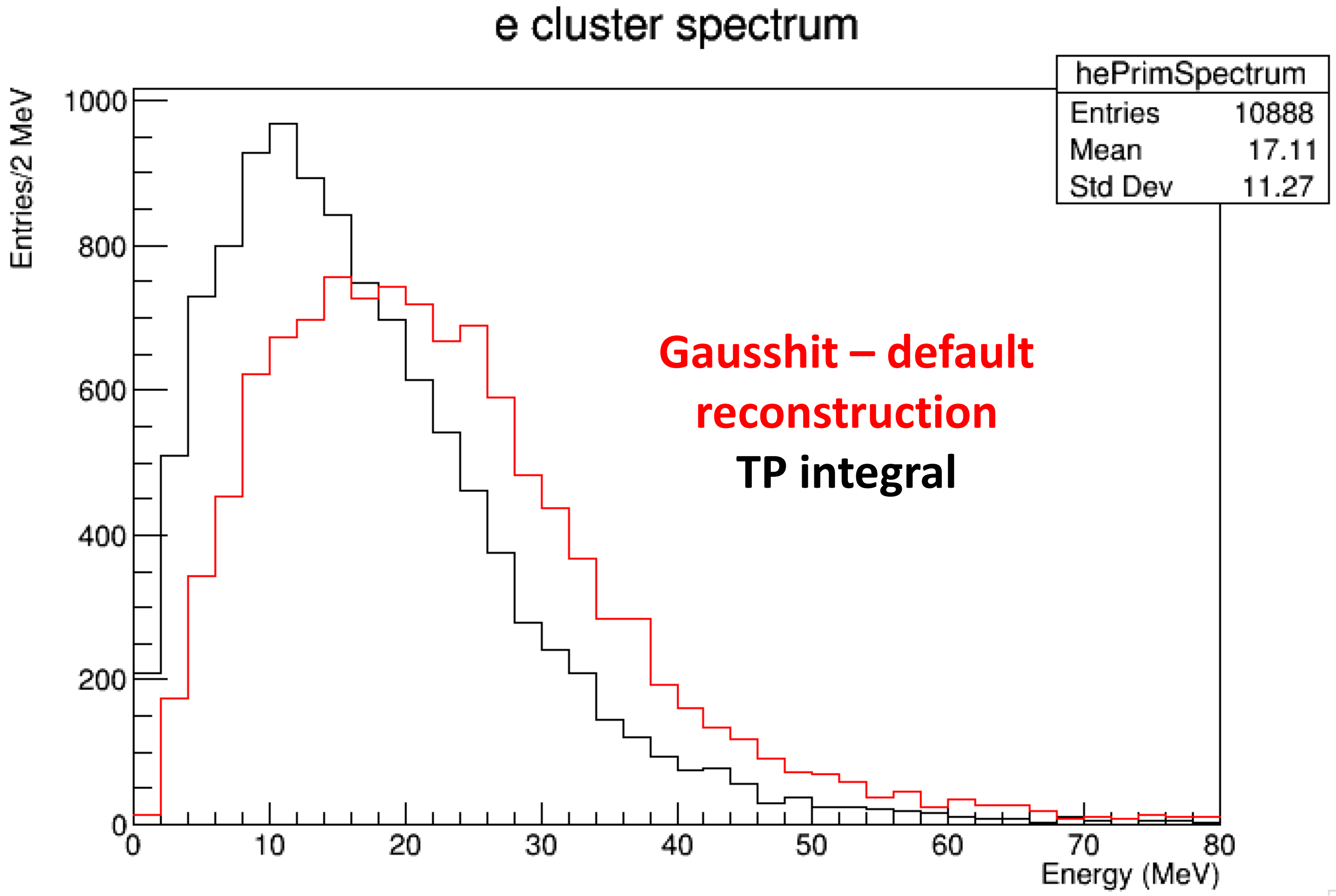
Michel Energy Reconstruction using TPs

- Both spectra were ran using MicroBooNE's Michel reconstruction module.
- The TPs recreate the tracking and calorimetry information.
- The TPs can reconstruct the michel energy spectrum reasonably.



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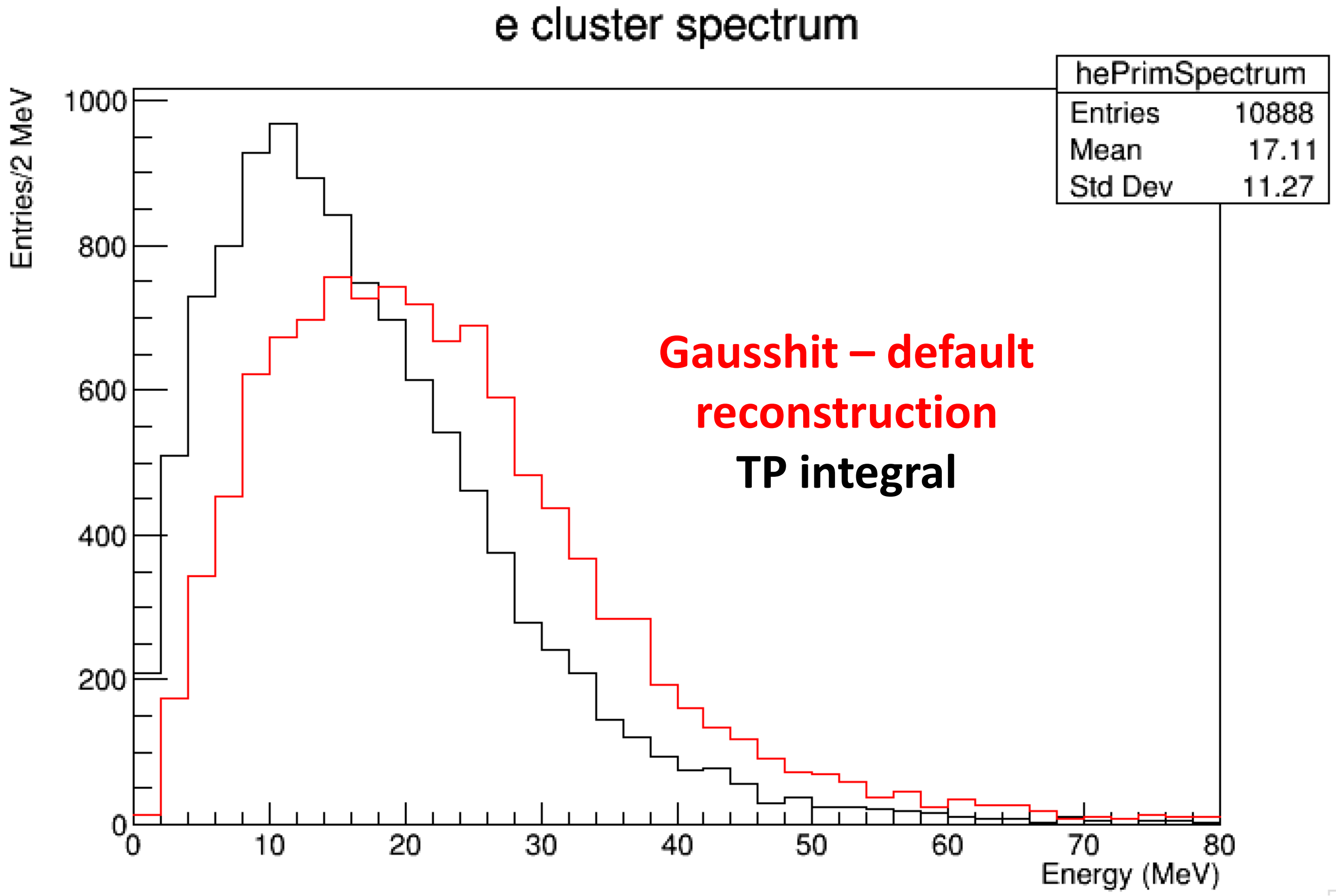


This is can be developed further to have online clustering for a trigger for MicroBooNE or SBND

https://www.nevis.columbia.edu/reu/2019/reports/Hinrichs_report.pdf

Conclusions

- MicroBooNE has commissioned **the only** LArTPC readout to detect neutrinos from a supernova core-collapse
- We have accomplished a stable compression rates ~80
- We validated the performance of the Continuous Readout with Michel Electrons
- Future Goals : Work on evaluating MicroBooNE's sensitivity to Supernova neutrinos with simulations

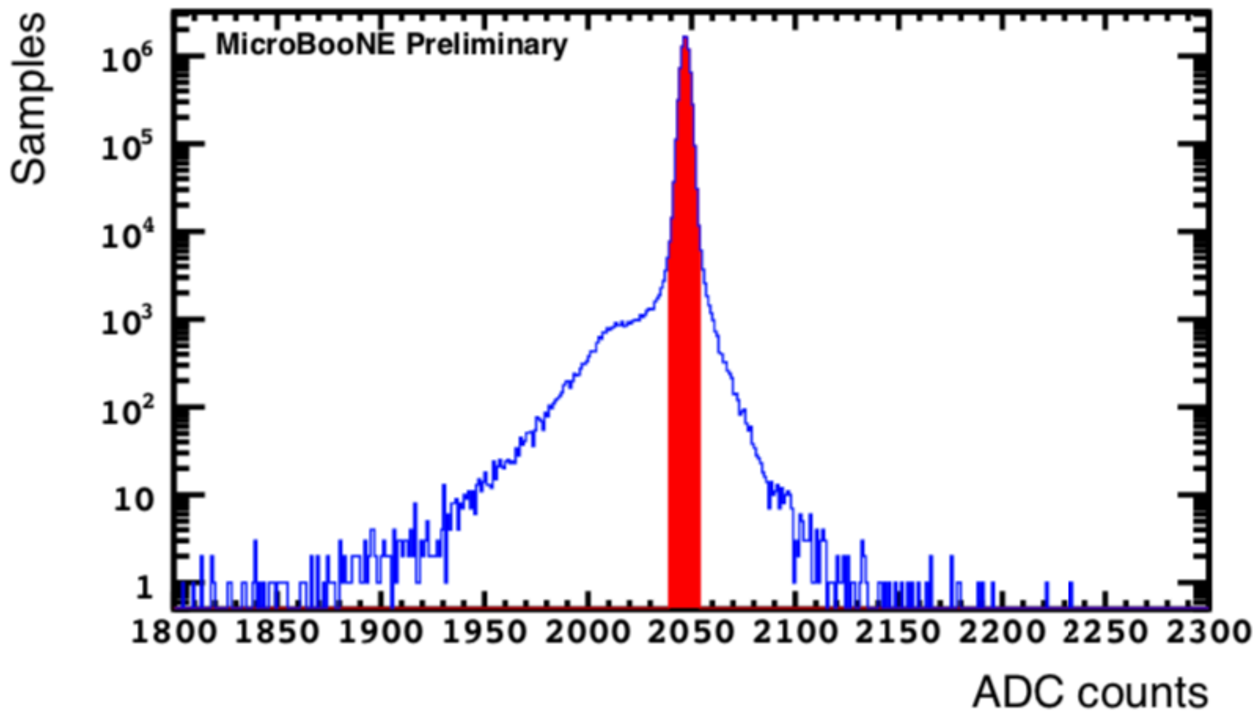
Observe a galactic supernova burst!

Thank you!

Back-Up Slides

Calculating Channel Thresholds

- The goal with is to keep as much data as possible
  - We want to get rid of noise but maintaining the physics intact.
- Channel thresholds allow us to optimize the compression algorithm and keep a steady data rate



The limits of the red region are the thresholds

Red shaded regions are the samples which will be zero-suppressed. This corresponds to 98.5% of the integrated distribution symmetric to the baseline value