Data acquisition systems to detect accelerator and supernova neutrinos with MicroBooNE and SBND

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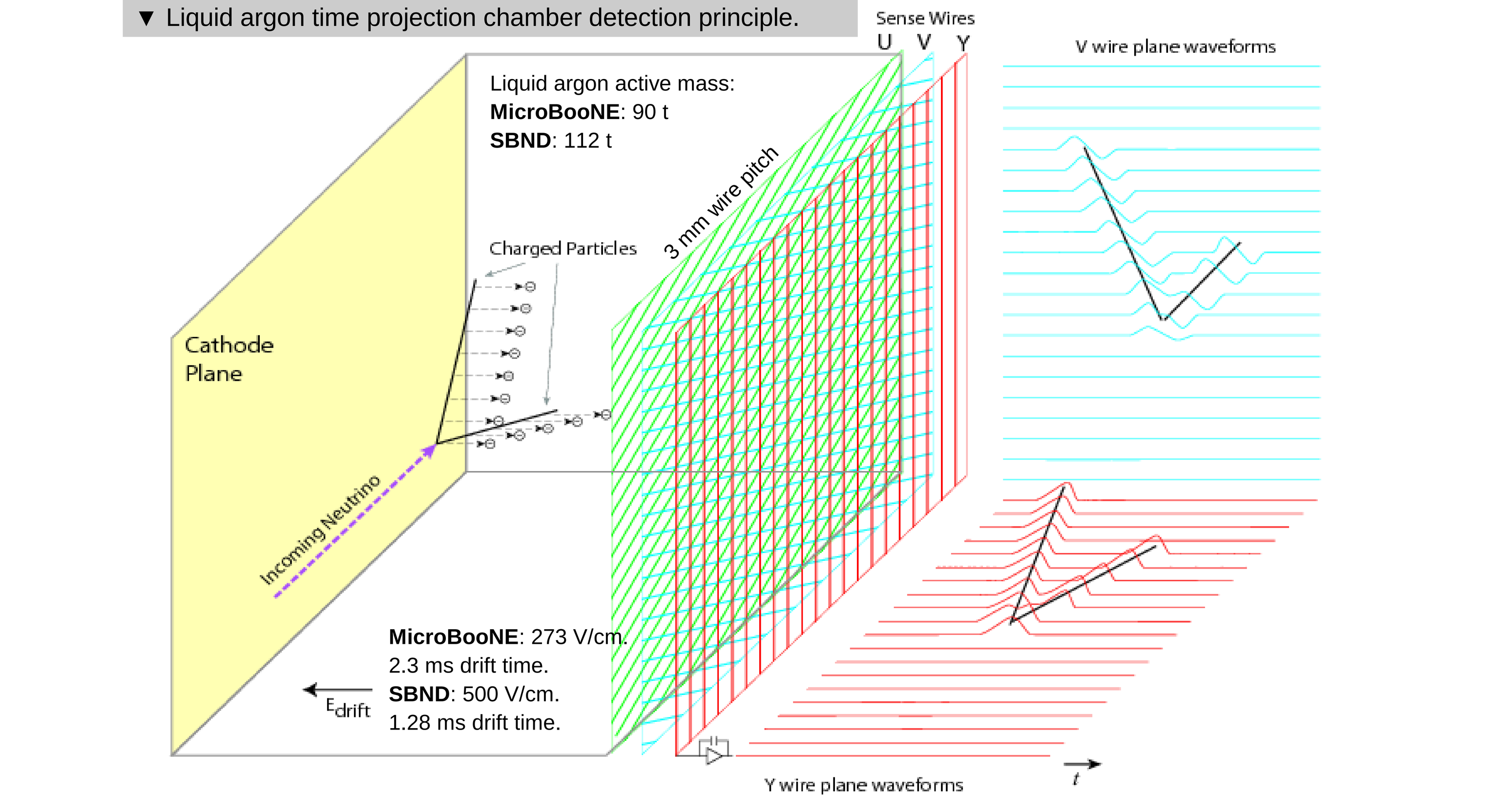
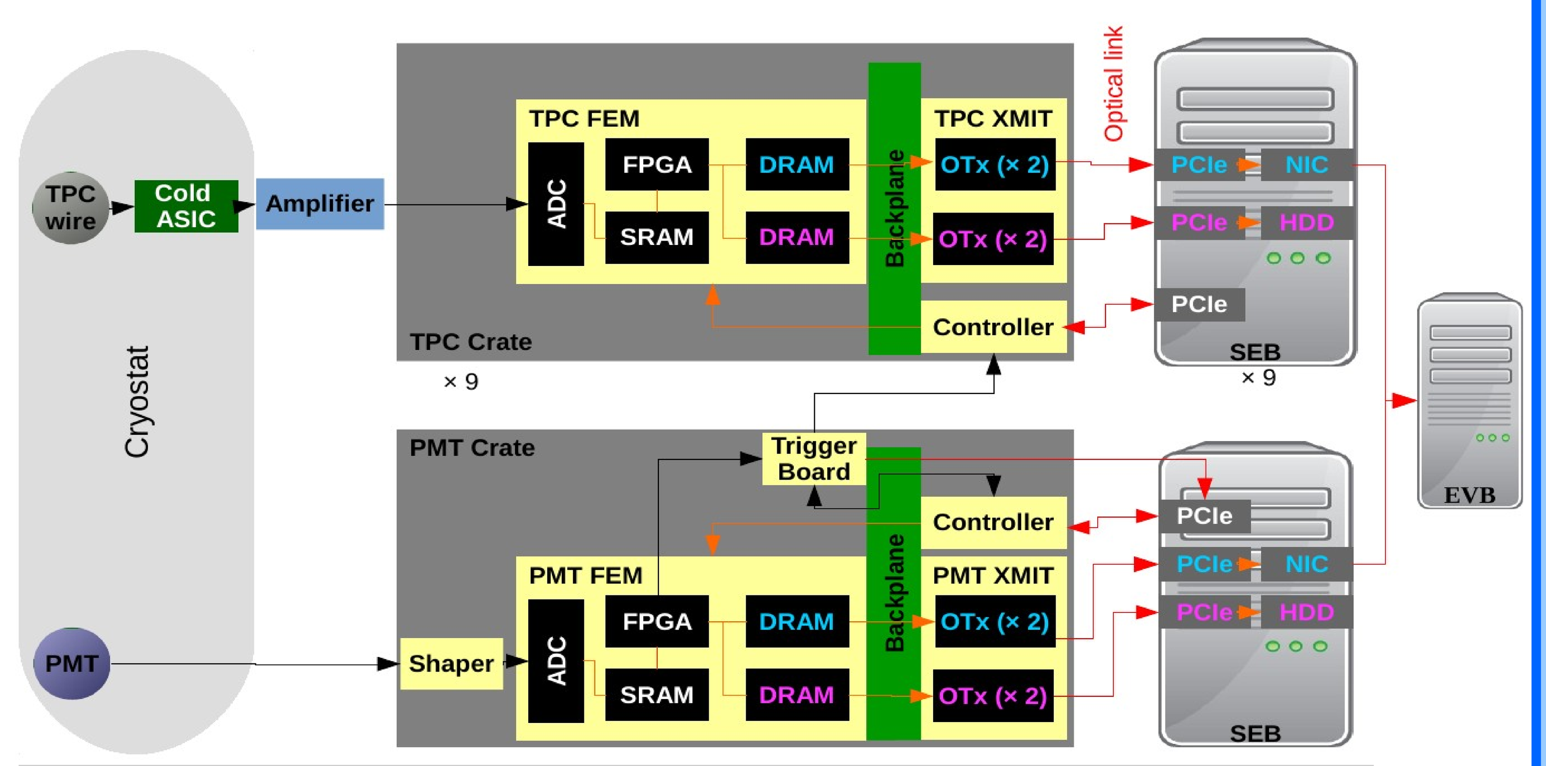
Liquid argon time projection chamber readout

▼ Liquid argon time projection chamber detection principle.



- Two subdetectors: TPC (charge image) and Photon Detection System (scintillation light). Similar readout architectures.
- **TPC** digitized at 2 MS/s.

  PMTs digitized at 64 MS/s (**MicroBooNE**) or 500 MS/s (**SBND**).
- Same TPC back-end electronics in **MicroBooNE** and **SBND**.
- **Parallel TPC readout**: FPGA splits the data in two streams.
  - Trigger stream for accelerator neutrinos: read out detector upon decision from light detection (PMTs) & accelerator gates.
  - Continuous stream for supernova (SN) neutrinos: **no trigger.**
- Shared backplane (512 MB/s bandwidth). **Trigger stream prioritized** over continuous stream.
- Dedicated optical link pair (3.125 Gbps) for each stream. PCIe card interfaces with DAQ server.



▲ Diagram of the **MicroBooNE** detector readout. Blue text highlights trigger stream components. Magenta text highlights continuous stream components. **SBND** will have a similar design, but with the ADCs for the TPC inside the cryostat to reduce noise and the number of cryostat feedthroughs.

SN stream: "CCTV for supernova neutrinos"

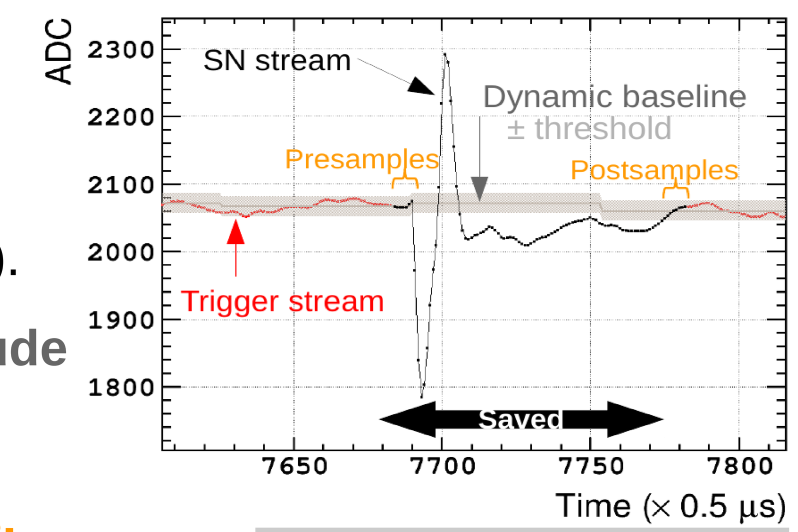
- **MicroBooNE** data is stored temporarily on a 13 TB HDD at each DAQ server, awaiting a **Supernova Early Warning System (SNEWS) alert** to be transferred to permanent storage.
- **Bottleneck: disk writing speed** (50 – 200 MB/s safely).
- 8256 TPC wires → 26.4 MPixels/frame.
- Continuous readout → 33 GB/s.

  → Distributed between 9 servers: ~ 3.7 GB/s/server.

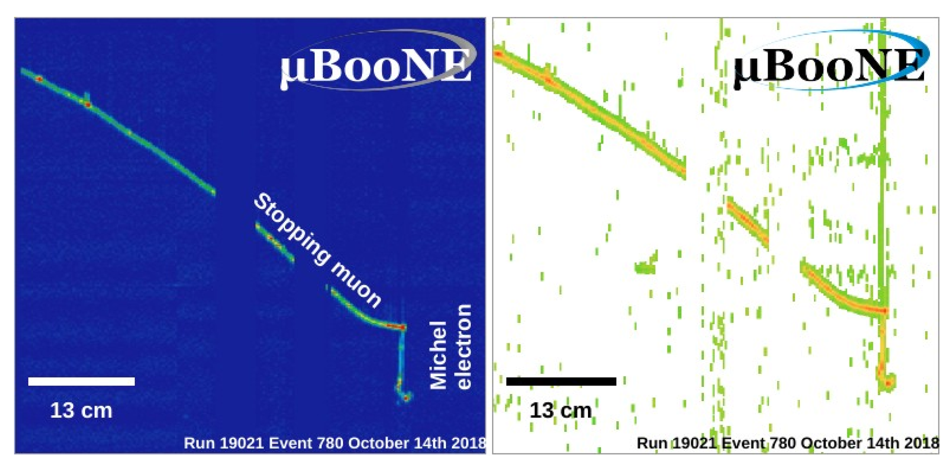
  Need a compression factor ~ 20 – 80.
- Writing at 50 MB/s → window of > 48 h before data is deleted.

FPGA-based real-time compression

- Lossless compression (Huffman) gives factor ~ 5: not enough.
- Additional lossy compression: **zero suppression (ZS).**
- Implemented in the Front End Module FPGA (Altera Stratix III).
- **Waveform** passing the **amplitude threshold** with respect to the channel baseline is saved + **presamples** and **postsamples.**

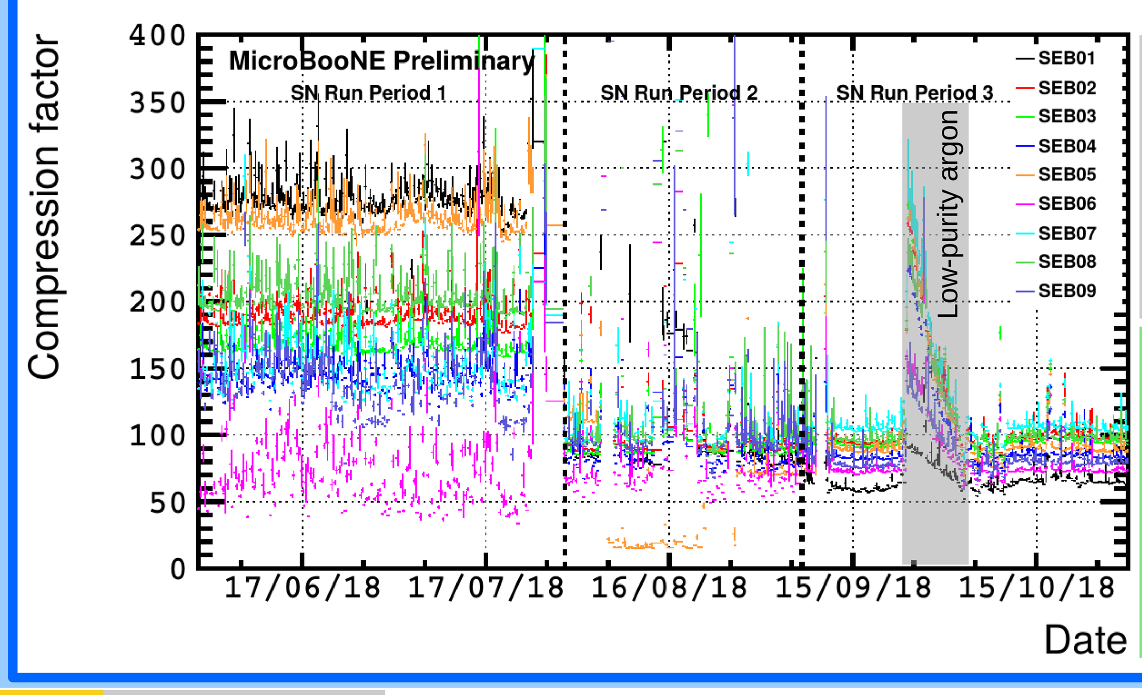


▲ Data from Nevis Laboratories test stand showing the same frame and channel in the trigger stream (red) and the continuous (SN) stream (black).



◄ Stopping cosmic muon decaying into a Michel electron.
Left: original event from the trigger stream.
Right: same event processed with zero-suppression software emulation.

- Two baseline options tested:
  - **Dynamic baseline**: estimated using preceding samples.
  - **Static baseline**: set at the beginning of the run.



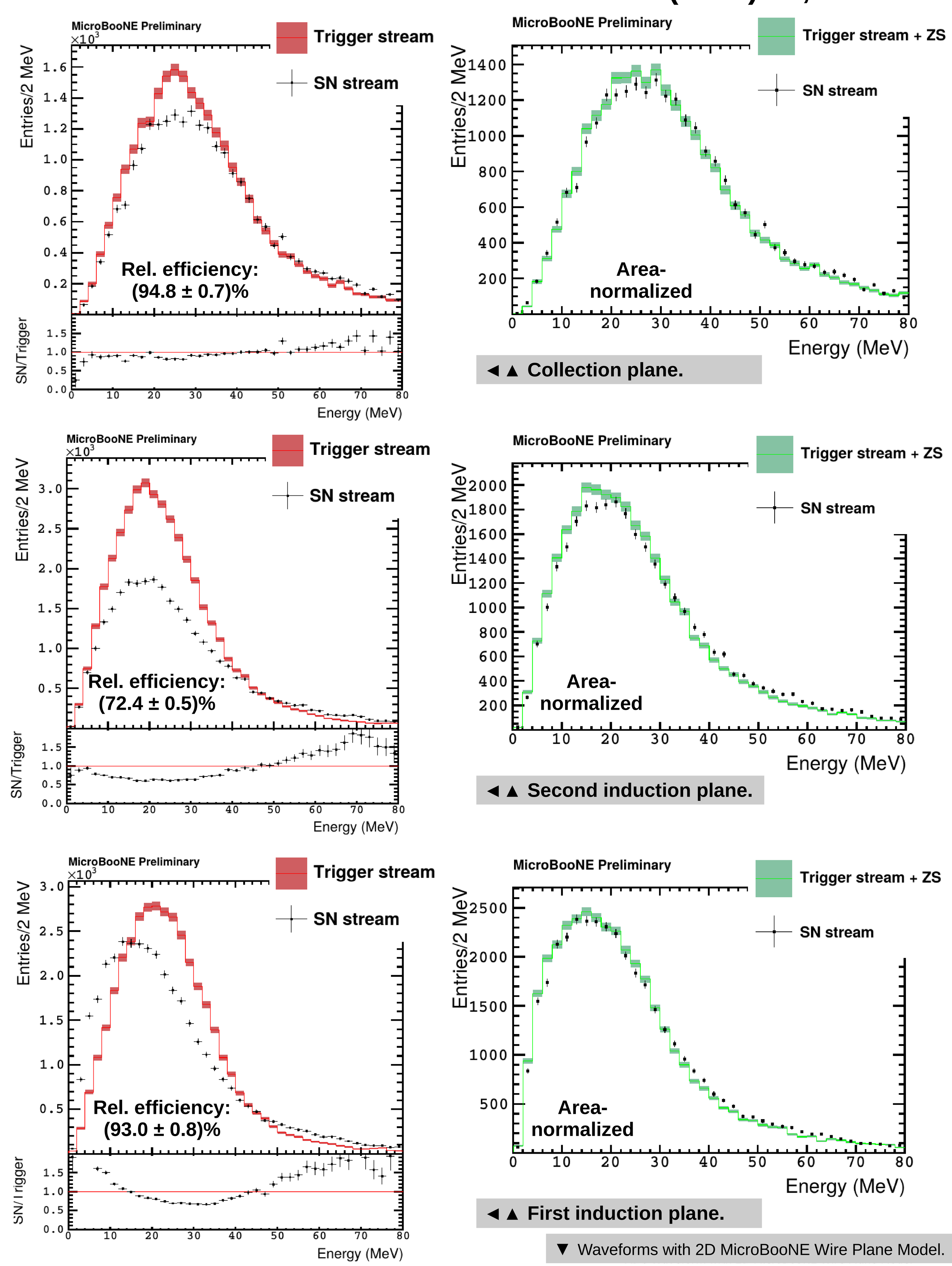
◄ Compression factor in the continuous readout stream (6h average).
SN Run 1: plane-wide thresholds + dynamic baselines.
SN Run 2: channel-wise thresholds + dynamic baselines.
SN Run 3: channel-wise thresholds + static baselines.

Compression factor target achieved using static baselines & channel-wise thresholds.

Michel electron analysis

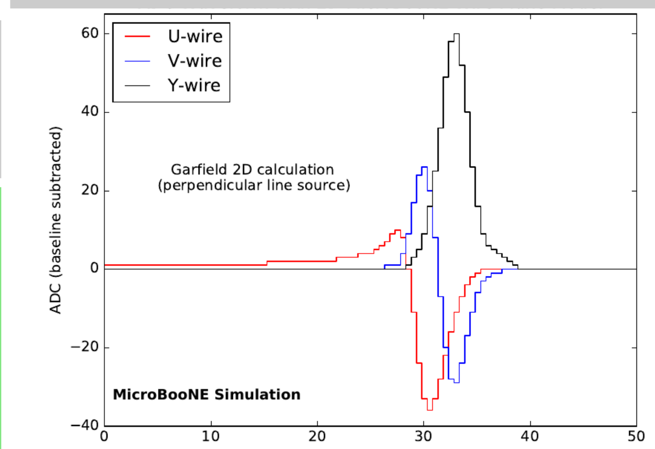
Using Michel electrons (similar energy to the electrons from supernova ν_e CC interactions) to evaluate the detection efficiency and energy reconstruction of the SN stream.

Michel electron reconstruction as in **JINST 12 (2017) 09, P09014**



▲ Michel electron energy spectra from the continuous (SN) stream (black), and from the trigger stream using standard reconstruction (red histograms, normalized to the the SN stream exposure) and with zero-suppression (ZS) software emulation (green histograms, area normalized). Error bars/bands show statistical uncertainty.

▼ Waveforms with 2D MicroBooNE Wire Plane Model.



Zero suppression impacts the reconstruction of low-energy electrons (well reproduced by simulation). Slight shift to lower energies on collection plane, and large shift on 1st induction plane. Large inefficiency on 2nd induction plane due to the smaller signals.

For more information:

- https://microboone.fnal.gov/wp-content/uploads/MICROBOONE-NOTE-1030-PUB.pdf
- J.Phys.Conf.Ser. 1312 (2019) 1, 012006
- arXiv:1909.03038 [physics.ins-det]
- JINST 12 (2017) 02, P02017

NEUTRINO 2020 XXIX International Conference on Neutrino Physics
June 22 – July 2, 2020