The Astroparticle and Exotic Physics program of MicroBooNE

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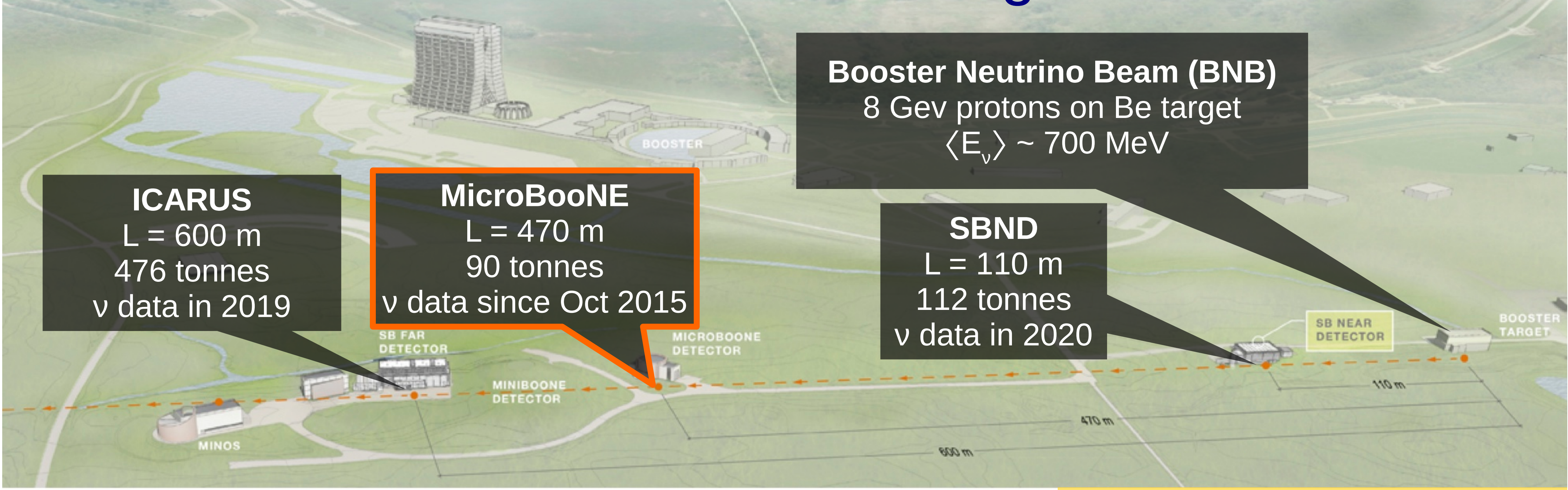
11/02/2018 19th International Workshop on Next generation Nucleon Decay and Neutrino Detectors (NNN18)

The Short-Baseline Neutrino Program at Fermilab



See talk by B. Russell, Nov 3 10:05

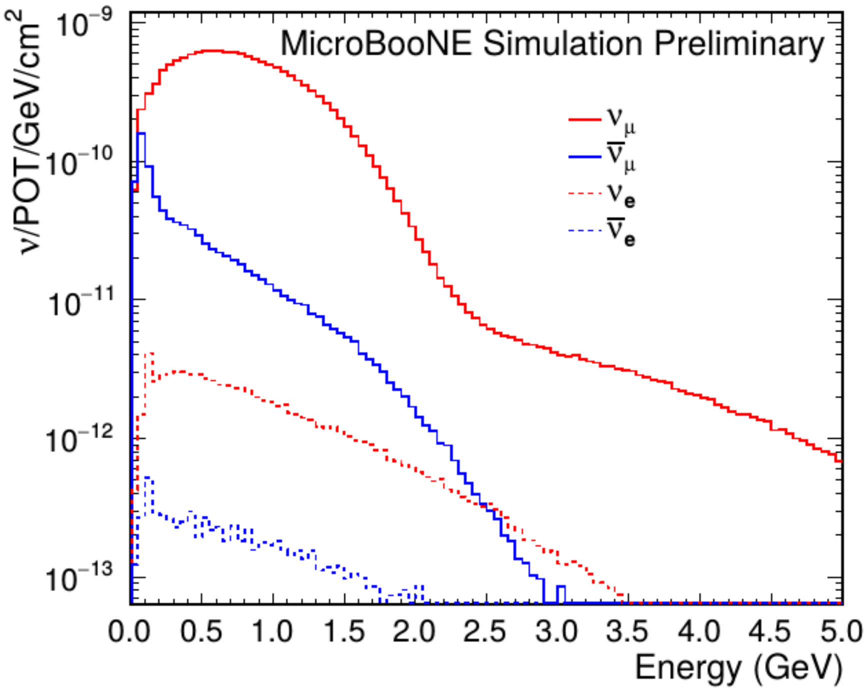
- **Booster neutrino beam** from pion decay-in-flight mostly (plus kaon and muon decays).
  - Single horn for focusing charged mesons.
  - Well-known beam, same as MiniBooNE (**PRD 79, 072002**).
  - Also, **NuMI beam off-axis**.
- 3 Liquid Argon Time Projection Chamber (LArTPC) detectors.
  - **Same detector technology and target** to reduce systematic uncertainties.

MicroBooNE Physics Goals

See talk by D. Porzio, Nov 3 15:20
See talk by T. Wongjirad, Nov 1 15:10

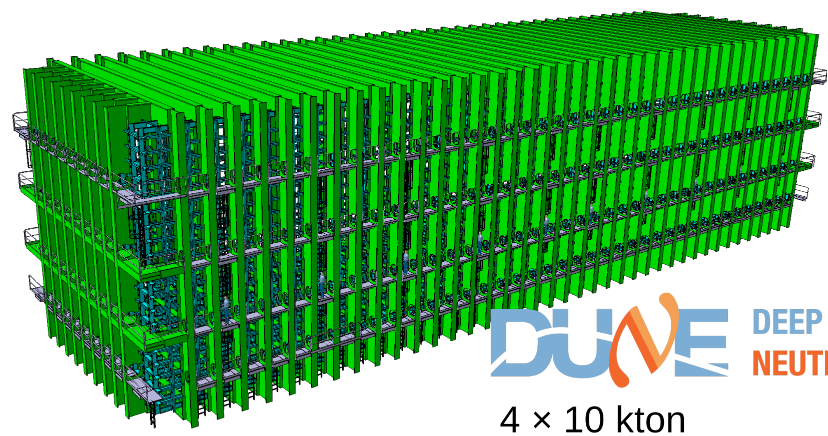
1) **Investigate the excess of electron-like events observed in MiniBooNE.**
2) **Perform high-precision measurements of cross-sections of ν_μ and ν_e on Ar.**
3) **Develop further the LArTPC detector technology.**
4) **Perform searches for astroparticles and exotic physics exploiting the LArTPC capabilities**

BNB flux @ MicroBooNE
http://microboone.fnal.gov/wp-content/uploads/MICROBOONE-NOTE-1031-PUB.pdf



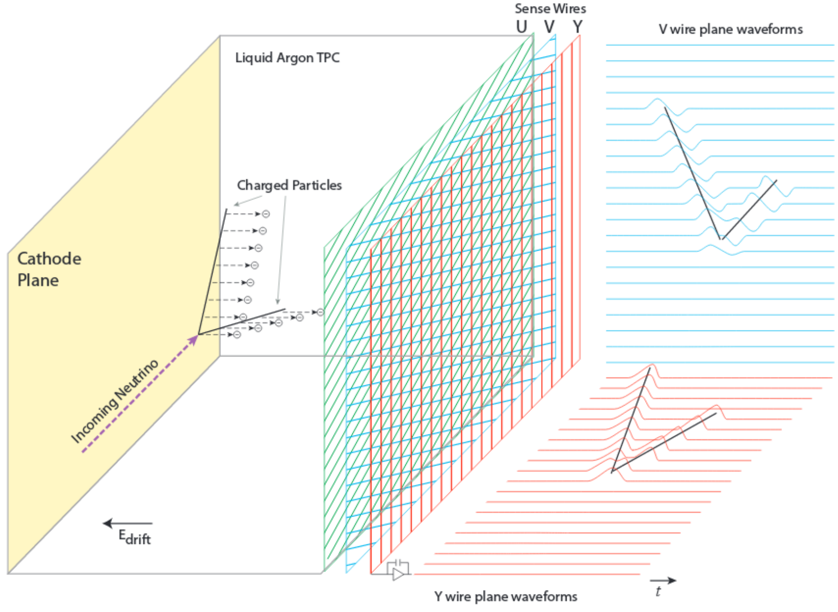
µBooNE

90 tonnes
Near surface



DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

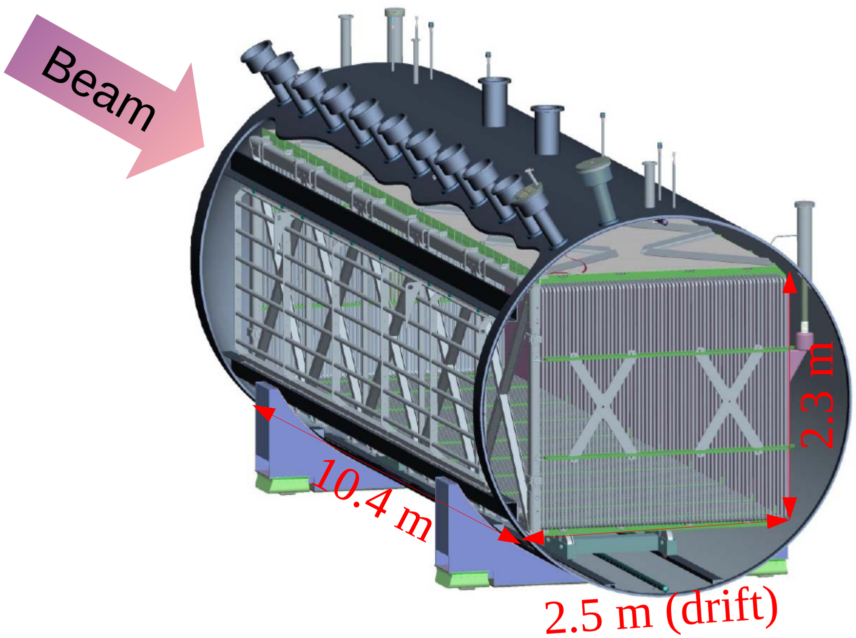
4 × 10 kton
1475 m underground

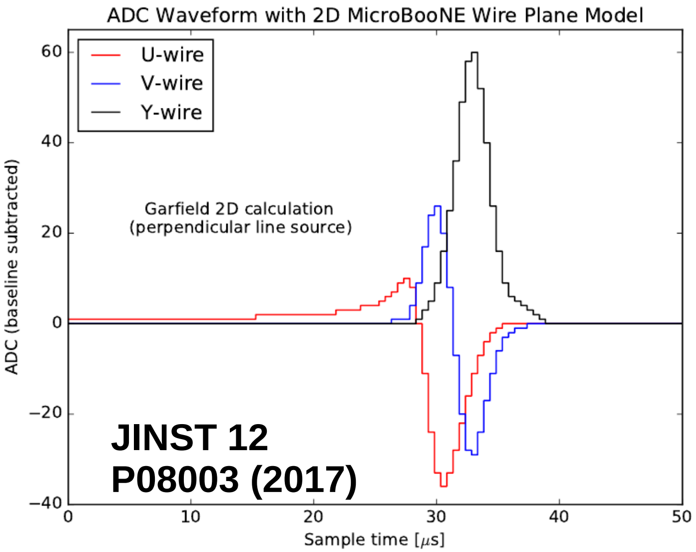


JINST 12 P02017 (2017)

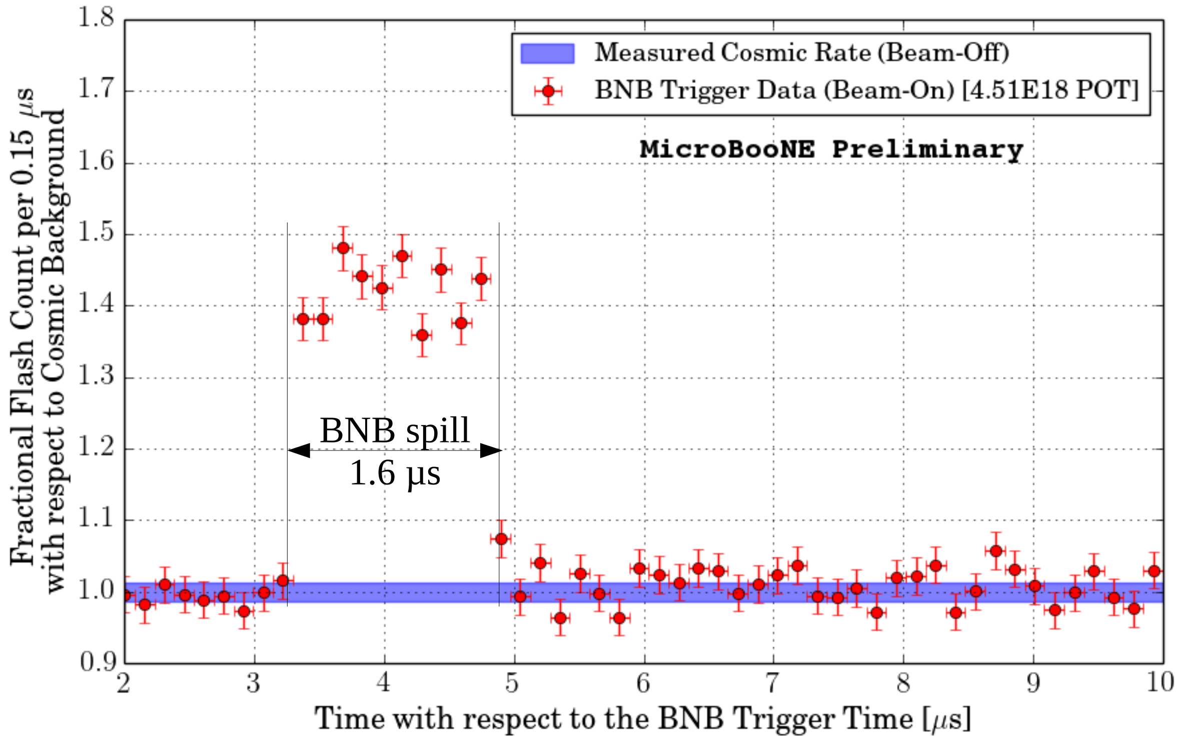
MicroBooNE TPC

- 170 tonnes of liquid argon (**90 tonnes active**).
- Cathode at -70 kV. E_{drift} ~ 273 V/cm.
- **Maximum drift length: 2.5 m.** Drift time: 2.3 ms.
- Three wire planes to reconstruct 3D interaction. 3 mm wire pitch. **8256 channels.**
- Two induction planes with 2400 wires each at ± 60º from vertical. One collection plane with 3456 vertical wires.
- Cold front-end electronics.
- 2 MHz digitization with warm electronics.





MicroBooNE PMT & trigger systems



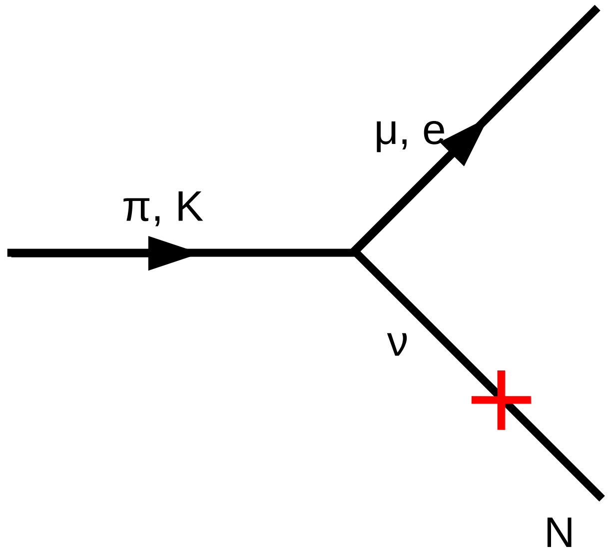
32 8” Hamamatsu R5912 Cryogenic **PMTs** mounted behind the wire planes with TPB-coated acrylic plates.

Custom (**64 MHz**) readout electronics.

- **Level-1 trigger** using accelerator gates (BNB and NuMI) and external triggers (for cosmics).
- **Level-2 trigger** in software using PMT information in the beam window.

Exotic physics with beam neutrinos:
Heavy Sterile Neutrinos @ MicroBooNE

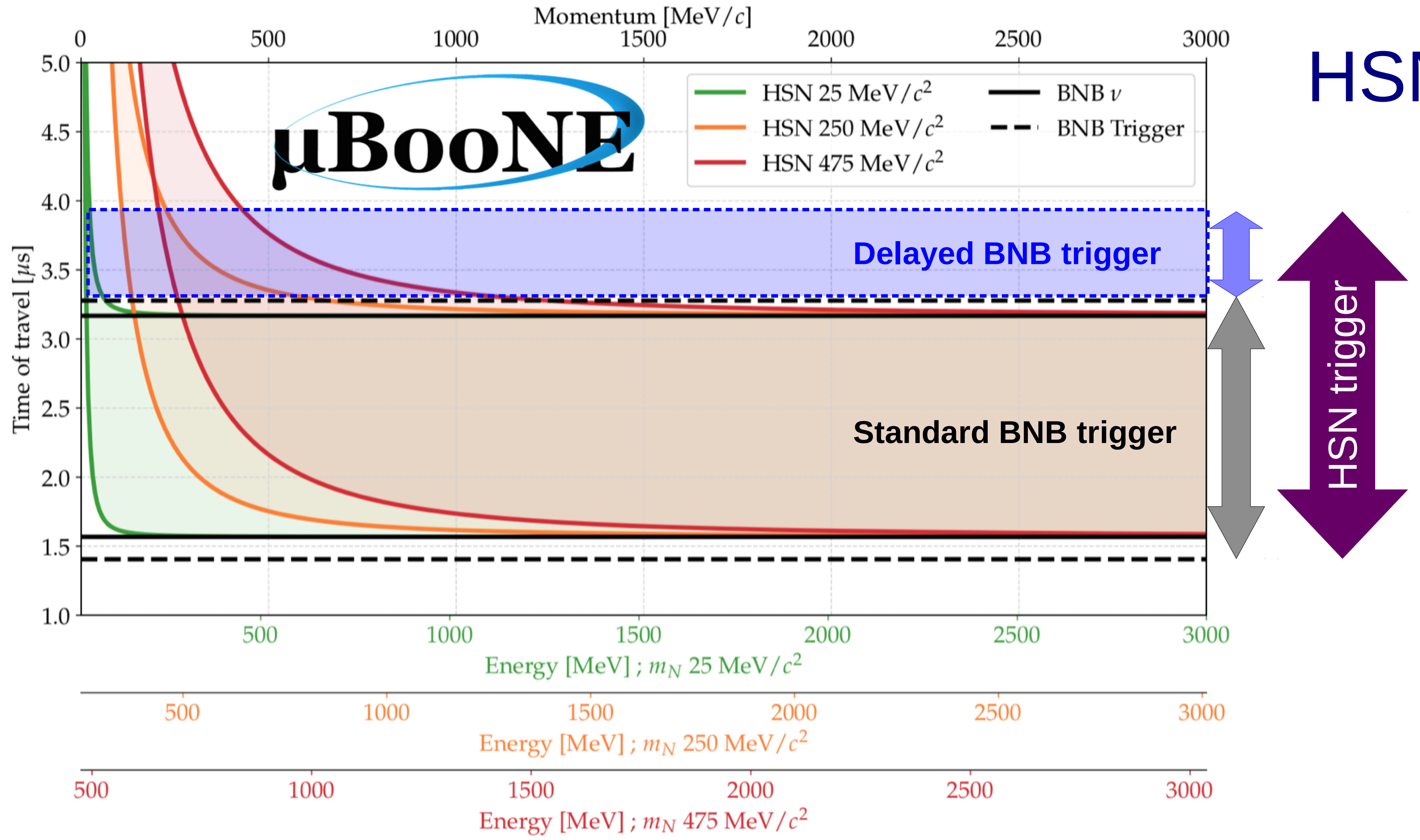
Heavy Sterile Neutrinos (HSN)



- HSN **produced in BNB/NuMI** secondary **meson decays** through mixing with Standard Model neutrinos.
  - **Mixing matrix elements: U_{e4}, $U_{\mu4}$.**
- **Mass between ~ 1 – 493 MeV**

  (K threshold).
- **No oscillation** due to large mass – loss of coherence.
- Large mass: **no helicity suppression**.
- HSN **decays in flight**. Look for HSN decays within the detector.

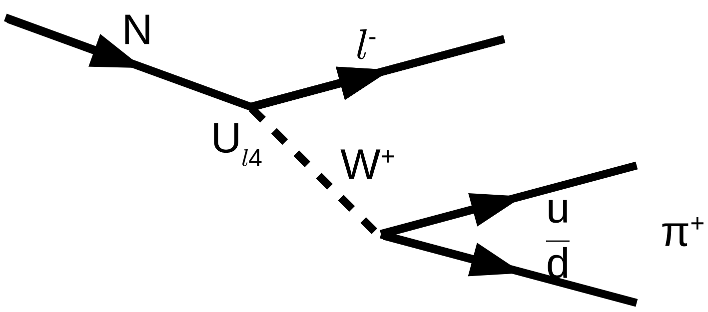
HSN trigger



- HSN travel slower than SM neutrinos.
- Opportunity: extend trigger window to **capture HSN delayed events.**
  - BNB trigger window extended by 33% (extra 624 ns).
  - After end-of-spill: (background) **SM neutrino-free window.**
- **HSN trigger commissioned in June 2017.**

HSN decay channels

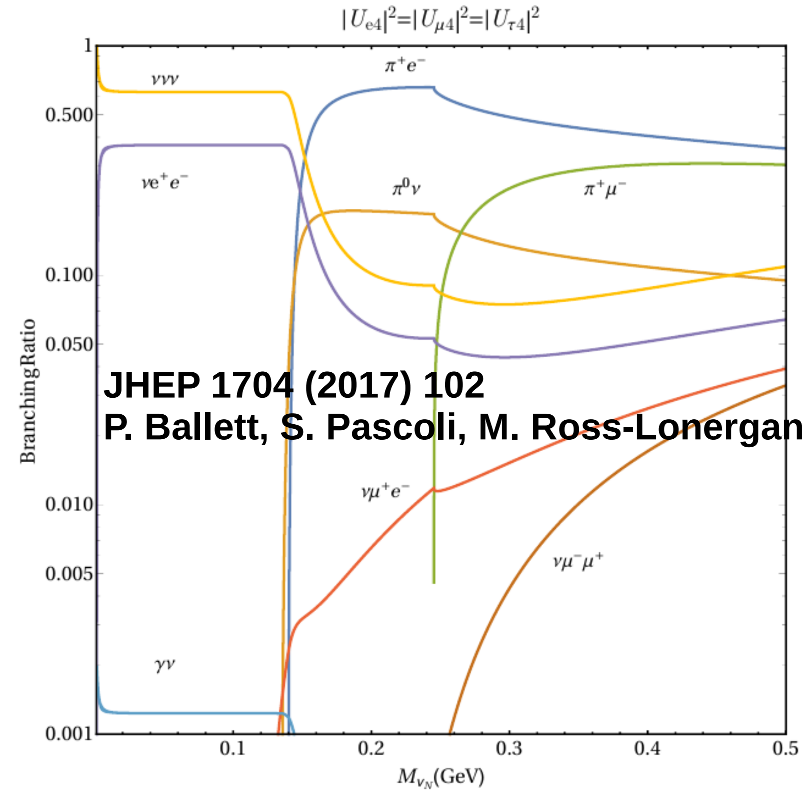
- CC + NC: N → 3ν, νπ⁰, e⁻e⁺ν, μ⁻μ⁺ν
- CC: N → γν, μeν, **eπ**, **μπ**

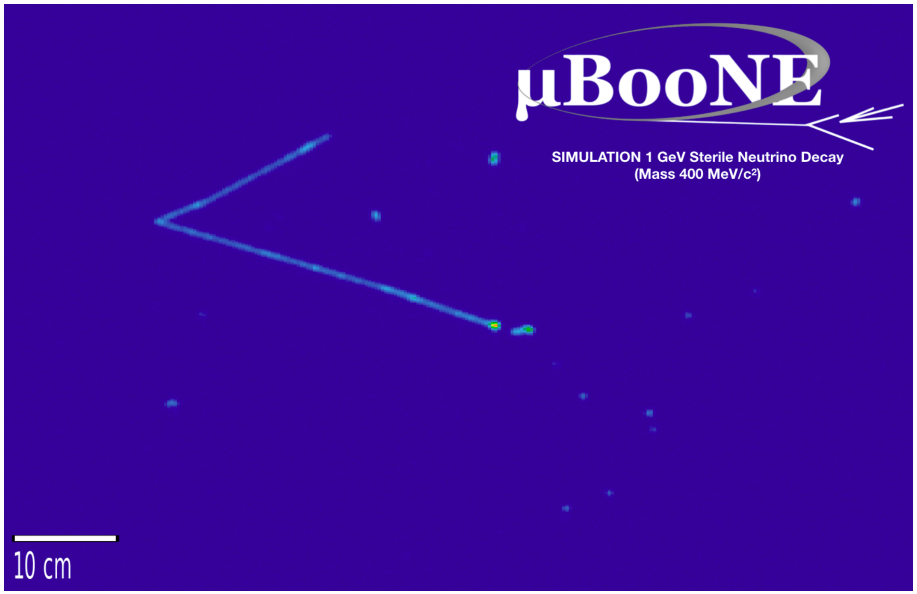


- Focus first on $U_{\mu 4}$-mediated **N → μπ in delayed BNB window**
- **On-site background measurement using an off-time trigger** with same thresholds as the HSN trigger.

For on-time searches:

- HSN decays within the LArTPC: **clean vertex.**
- Relatively **forward-going.**
- **Reconstruct invariant mass.**



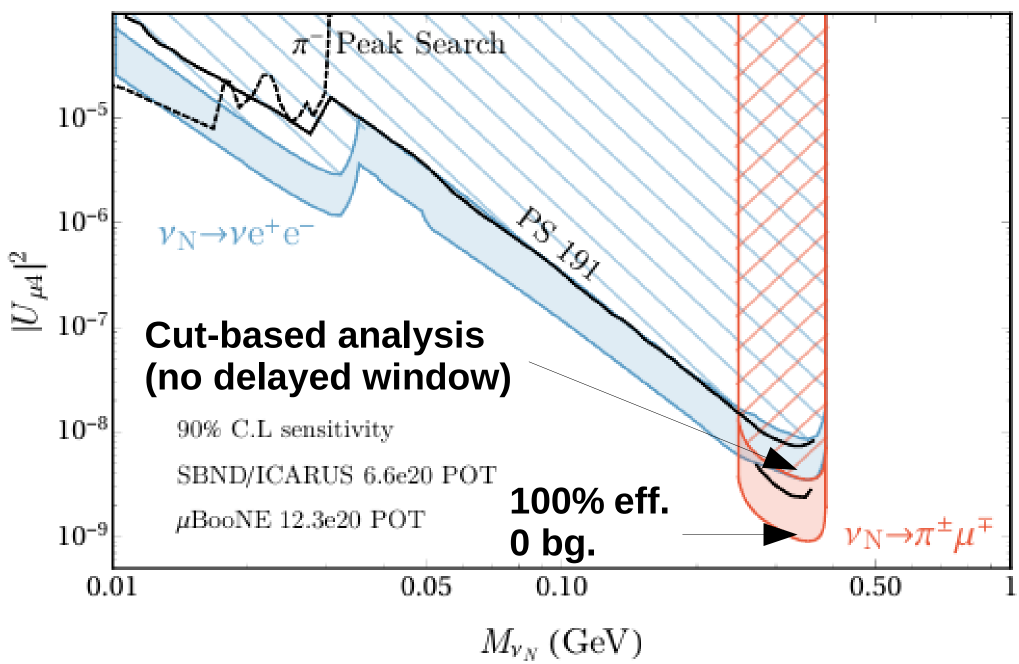


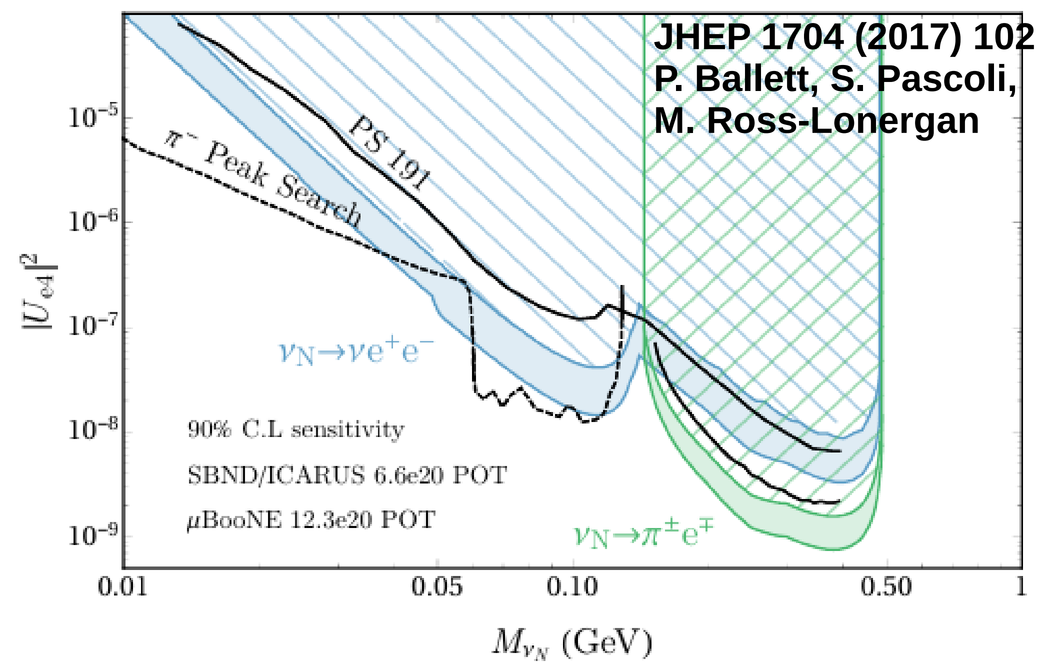
Prospects

- **MicroBooNE paving the way for the SBN measurement.**
  - **Analysis using only delayed-window events (~ 2E20 POT) in progress.**

    Focus on **N → μπ channel.**

    Mass range 246 – 388 MeV.
  - **First search in a LArTPC.**
  - Exploring the possibility to use the **NuMI beam** too (off-axis).
- SBN expectations:

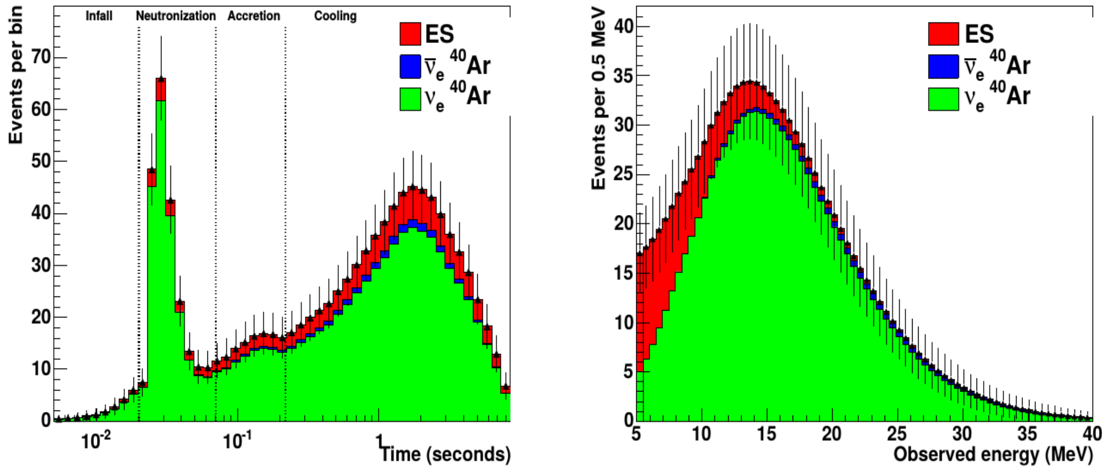




Astroparticles:
Supernova Neutrinos @ MicroBooNE

Supernova neutrinos

Prediction for DUNE (40 kt) [arXiv:1512.06148]



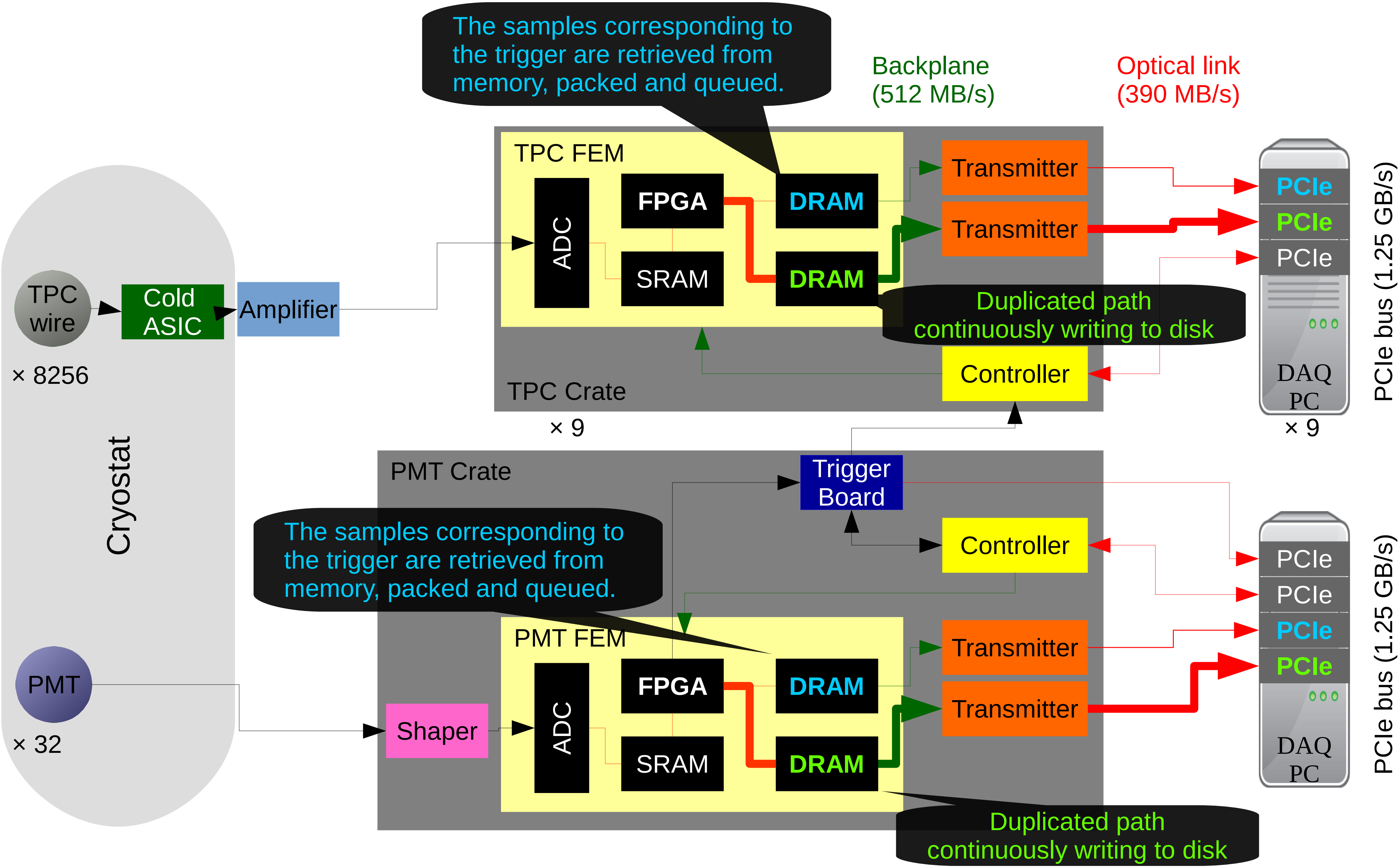
- Neutrinos emitted by a core-collapse SN.
  - Short burst: **~ 10 s**.
  - Low energy: **tens of MeV**.
- Expectation at MicroBooNE:
  - **~ O(10) events** for a SN at 10 kpc.
  - CC: ν_e + ^{40}Ar → e^- + ^{40}K* (E_{th} ~ 5 MeV)

    Unique sensitivity to ν_e flux.

    Complementary to $\bar{\nu}_e$ sensitivity of water Cherenkov and liquid scintillator detectors.
  - Surface detector. **Cannot self-trigger**.

    Instead, **read out data continuously and rely on a delayed external trigger from Supernova Early Warning System** (Super-K + LVD + IceCube + KamLAND + Borexino + Daya Bay + HALO).
- Continuous readout of the detector also enables:
  - **R+D for beyond-Standard Model physics at DUNE (p decay, n-nbar oscillation...)**
    - Study backgrounds, prototype analyses...
  - **Continuous monitoring** of the detector for diagnosing.

Trigger + “supernova” readout streams



Zero suppression (TPC)

- **Data stored temporarily** on a 13 TB disk at each DAQ server, awaiting an **SNEWS alert** to be transferred to permanent storage.
- The **bottleneck** of the stream is the **disk writing speed** at the DAQ servers (assumed conservatively to be 50 MB/s).
- Neglecting header sizes:

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

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

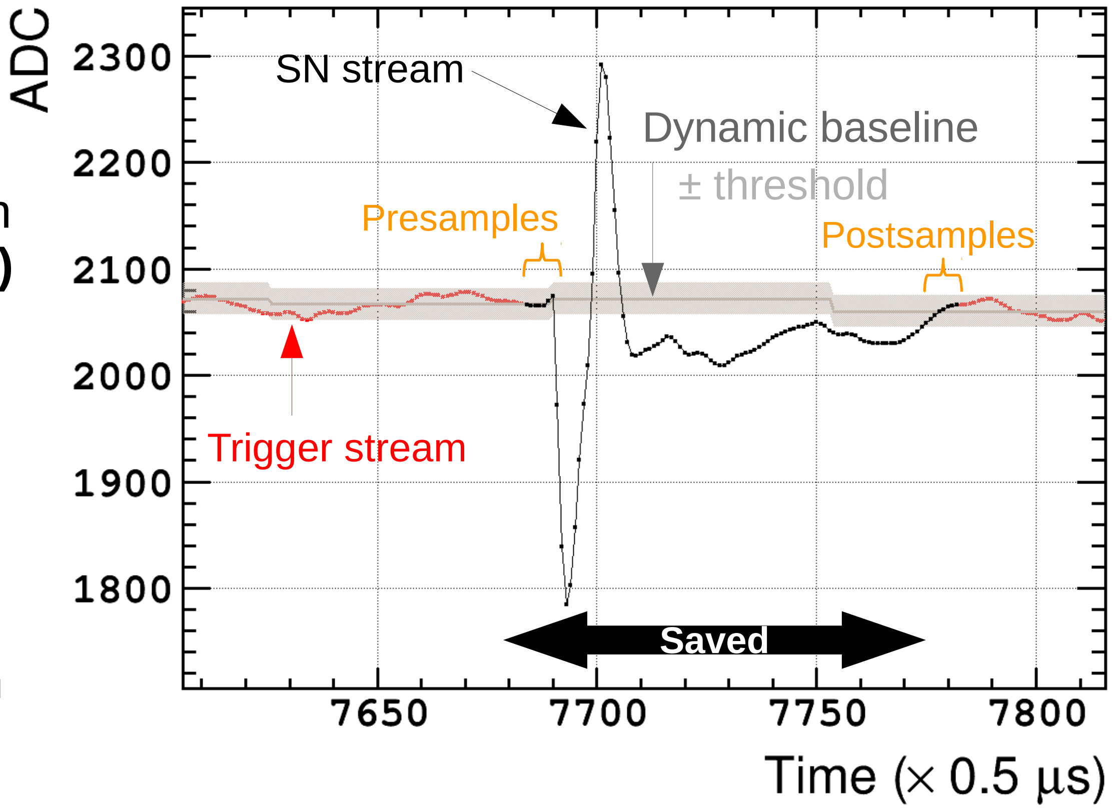
  (cf. One DUNE module – 384000 channels – 1.15 TB/s).

  Need a **compression factor ~ 80**.
- Lossless compression (Huffman) gives factor ~ 5: not enough.
- Requires **lossy compression**.
- Writing at 50 MB/s gives us a window of **> 48 h before data is deleted**.

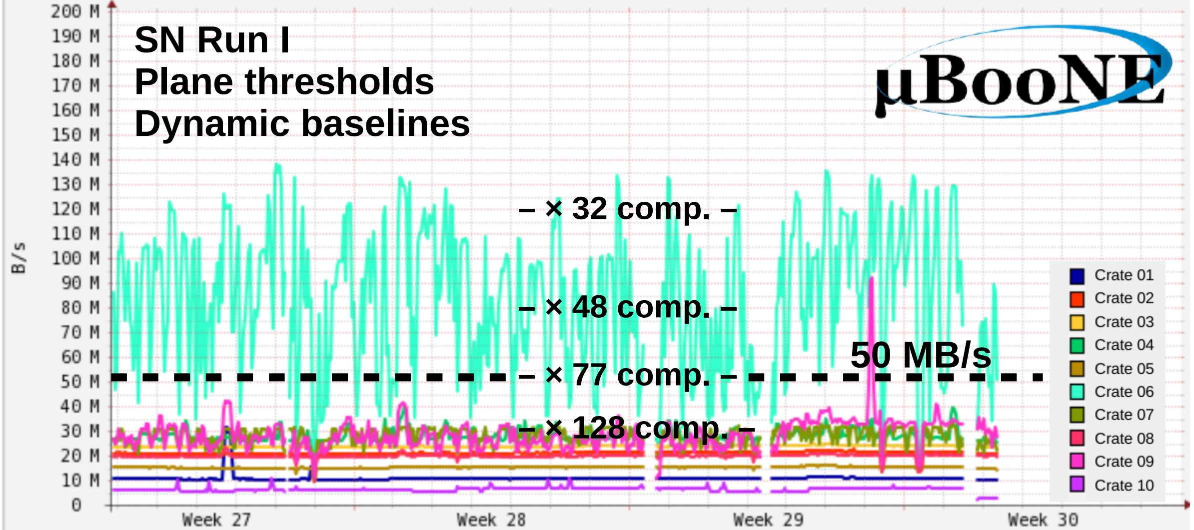
Zero suppression (TPC)

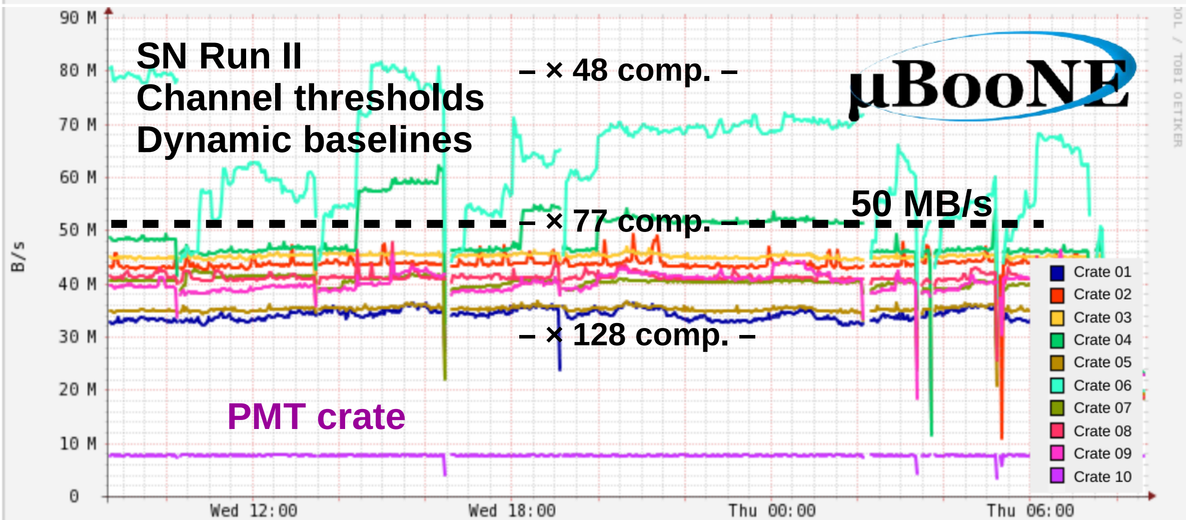
- **Implemented in the Front End Module FPGA.**
- Only the **waveform** passing a certain **amplitude threshold (configurable)** with respect to the channel **baseline** is saved, plus **presamples** and **postsamples (configurable)**.
- The **baseline can be dynamically computed** using preceding samples **or** use a **static value** loaded at the beginning of the run (both have been commissioned and tested).

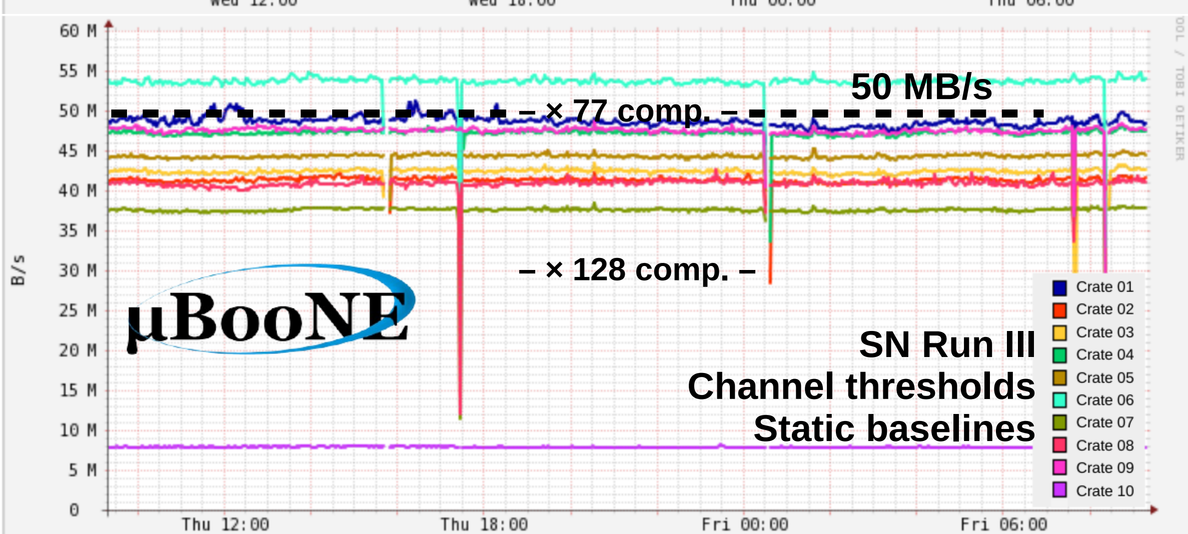
DATA from Nevis test stand



Data rates after compression







First SN Run used **common thresholds** 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.

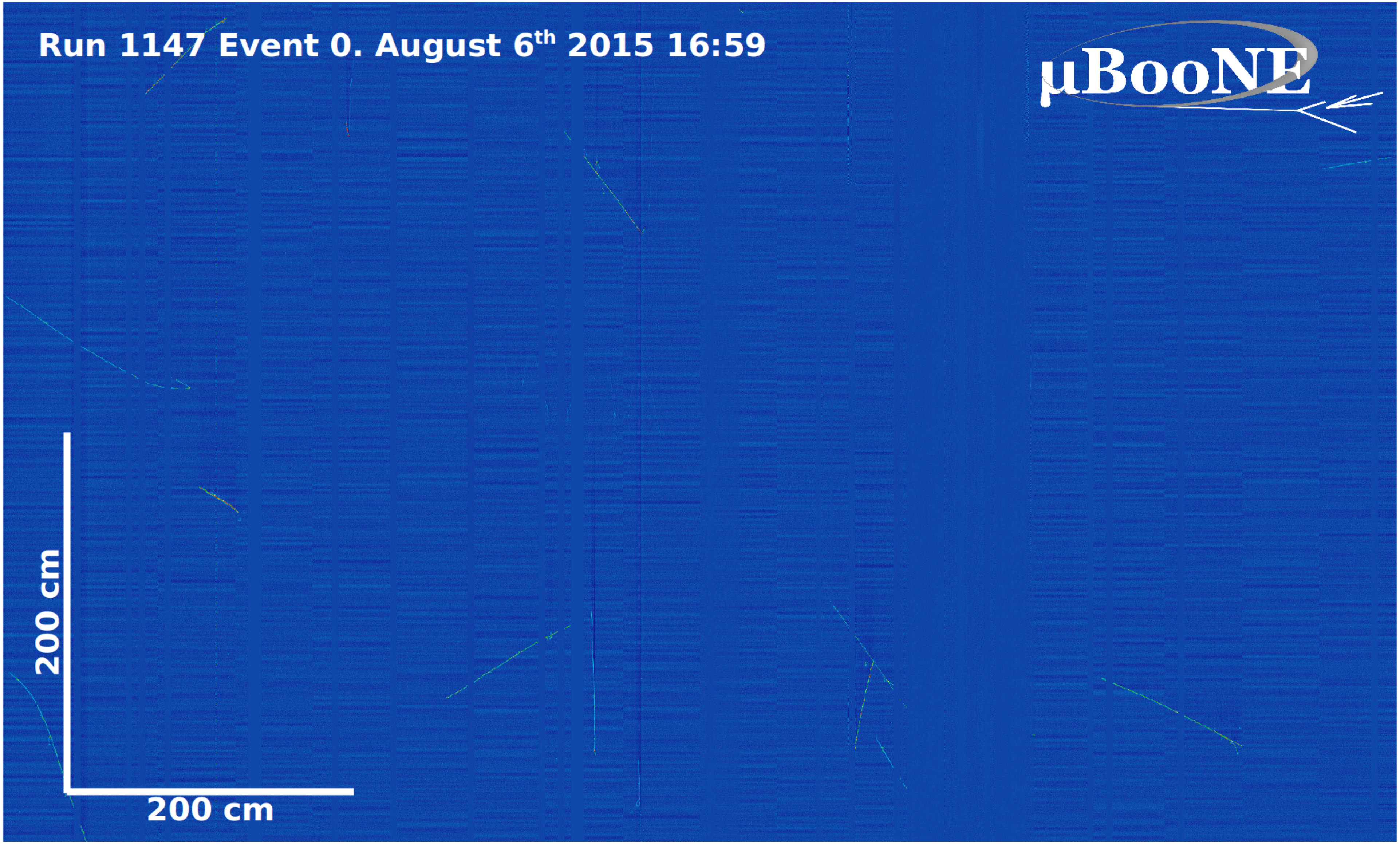
Still noisy channels affected dynamic baseline calculation.

Third SN Run uses **individualized (lower) channel threshold** and **static baselines**.

Rates stable at ~ 50 MB/s.
Target compression factor achieved!

Comparison: trigger readout

No lossy compression



MicroBooNE's first cosmic event

Comparison: continuous readout

SN Run II
Channel thresholds
Dynamic baselines

5 fps gif → 125 times slower than actual readout

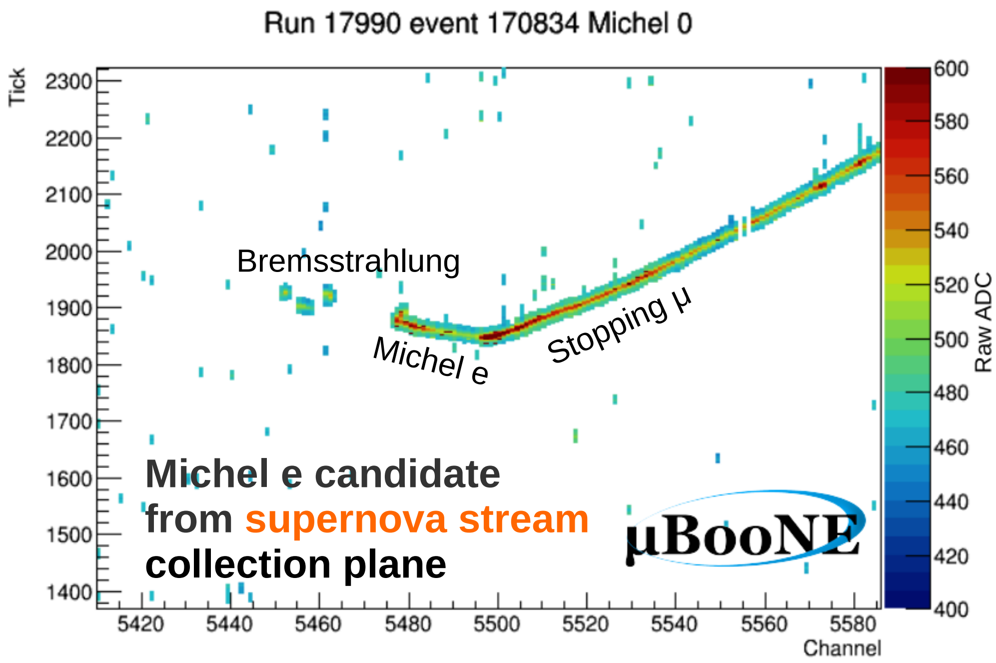
½ Frame N + 1

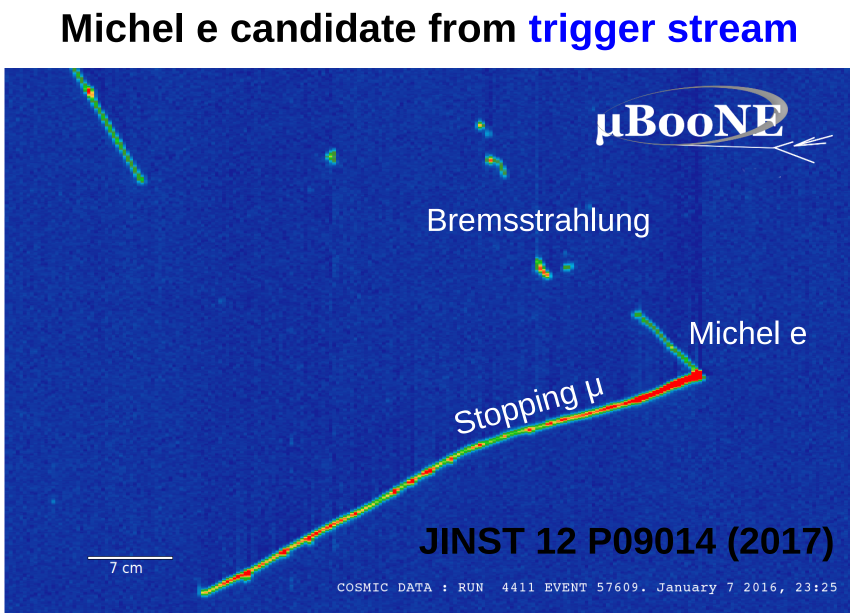
Frame N

½ Frame N - 1

Raw ADC (12-bit)

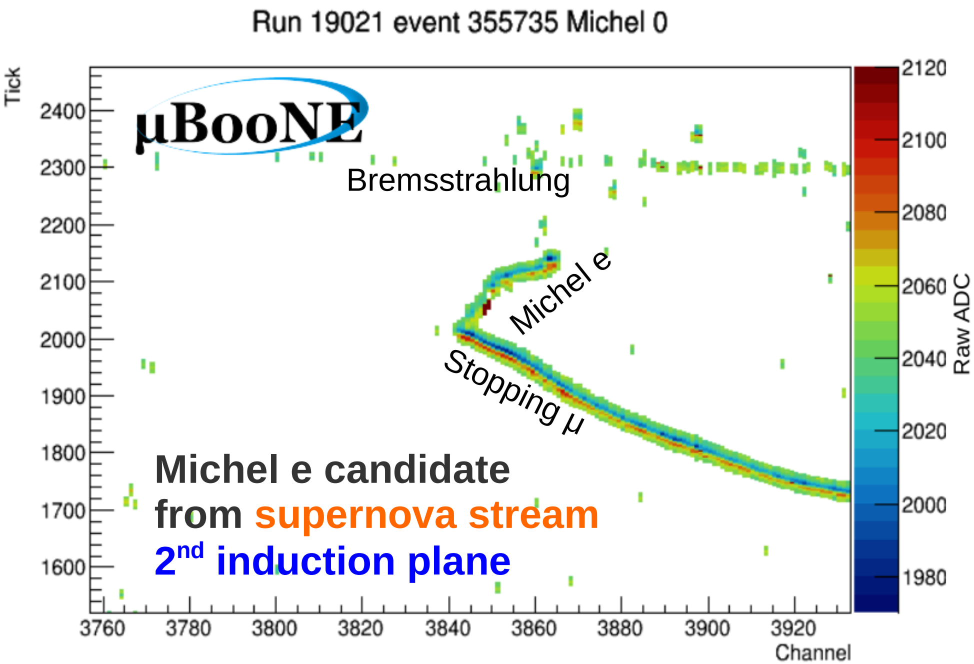
SN-like physics with continuous stream

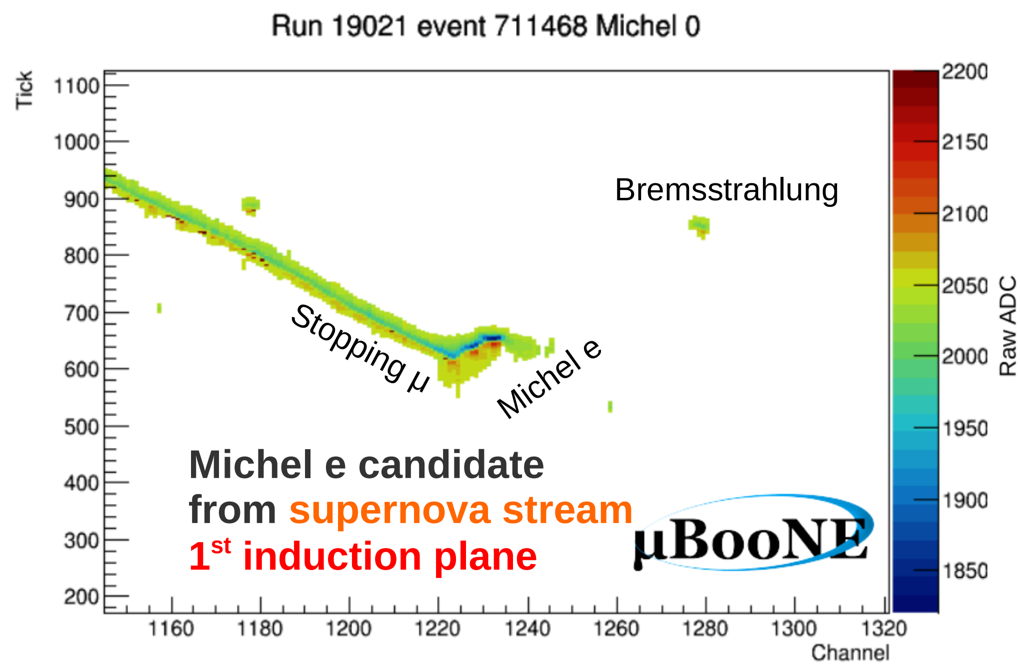


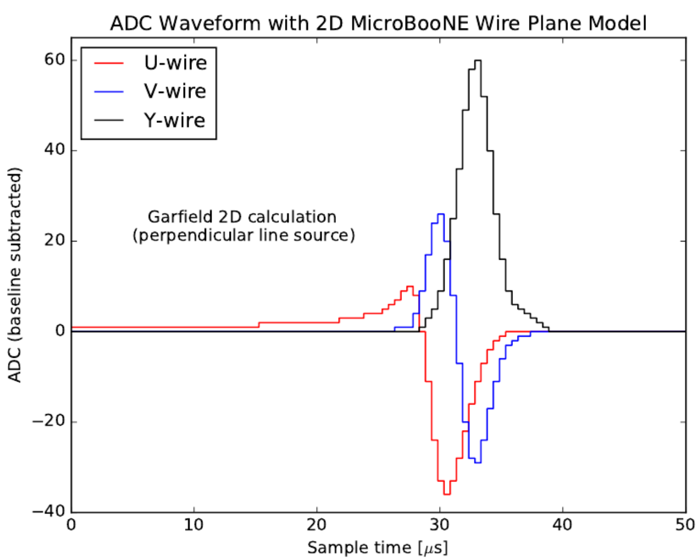


- Tuning of the zero-suppression is **critical**: reject the **noise** but keep the **physics**!
- Goal: set **threshold as low as possible** to detect the low energy e^- and the de-excitation γ from $^{40}K^*$.
- Michel electrons are a nice sample to use: similar energies.

SN-like physics with continuous stream







Induction planes are **especially challenging** due to the different waveforms.

Conclusion

- MicroBooNE has potential for a broad exotics program.
- MicroBooNE is spearheading a **search for heavy sterile neutrinos in the BNB**.
  - Dedicated **trigger exploiting delayed signature**.
  - Focus on **N →μπ** channel. Publication in 2019.
- Commissioned a **continuous readout stream for detection of supernova neutrinos**.
  - First Michel electrons observed in three planes → **Demonstration of low-energy (SN-like) capabilities.**
  - **Publication in preparation.**
  - Zero-suppressed TPC waveforms can be used to **develop TPC-trigger algorithms** of interest for DUNE.


Thank you for your attention!

MicroBooNE Collaboration

October 2018

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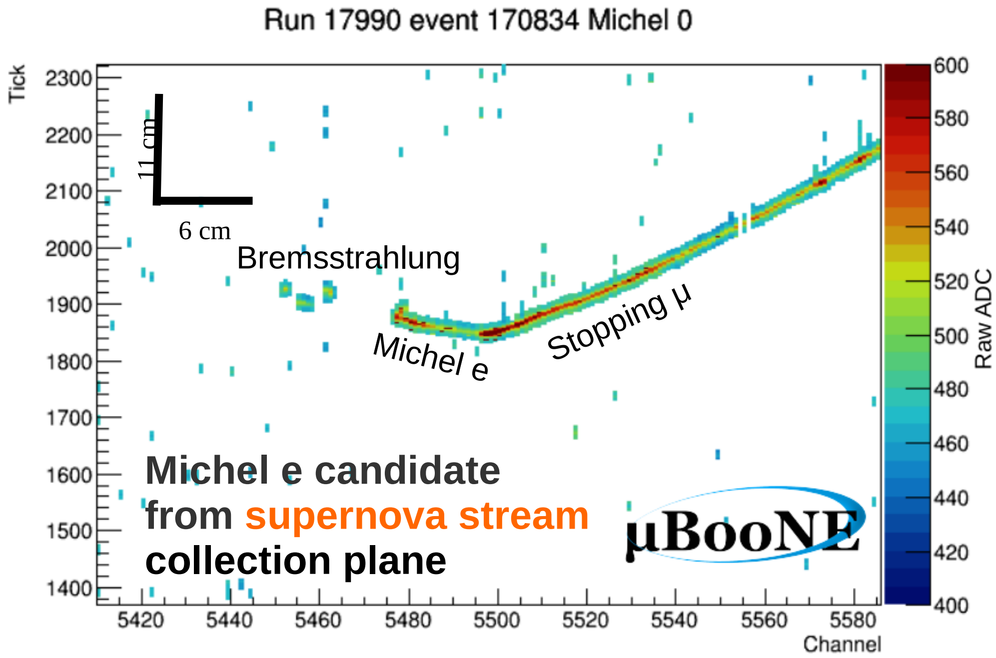
174 collaborators
34 institutions (7 non-U.S.)
44 postdocs
52 grad students

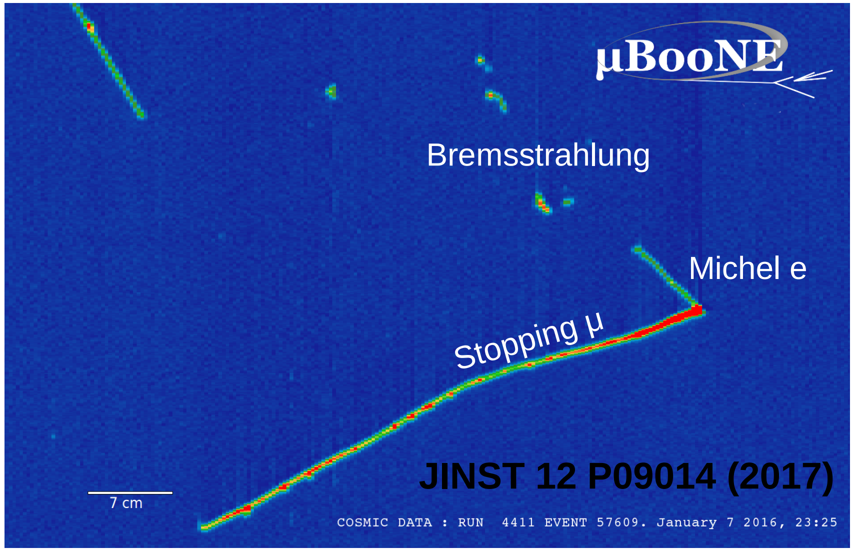
*spokespeople

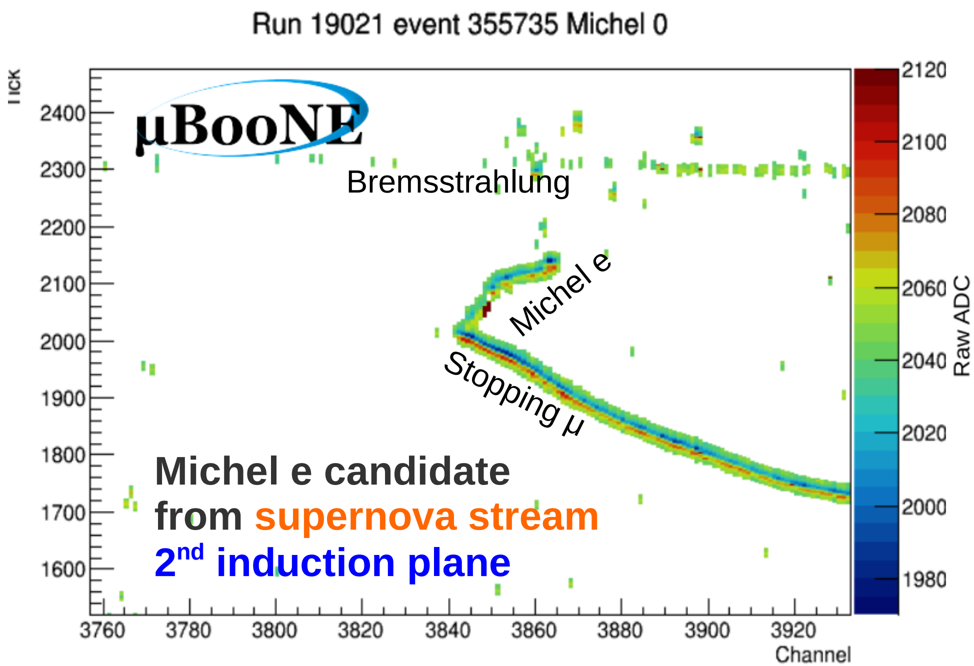
Backup

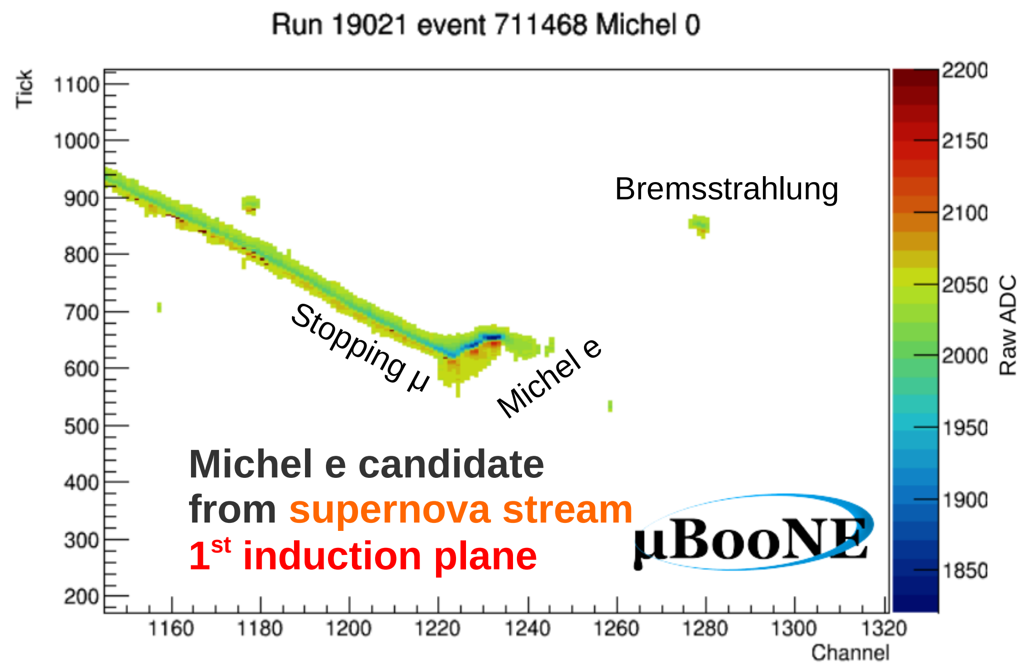
SN-like physics with continuous stream



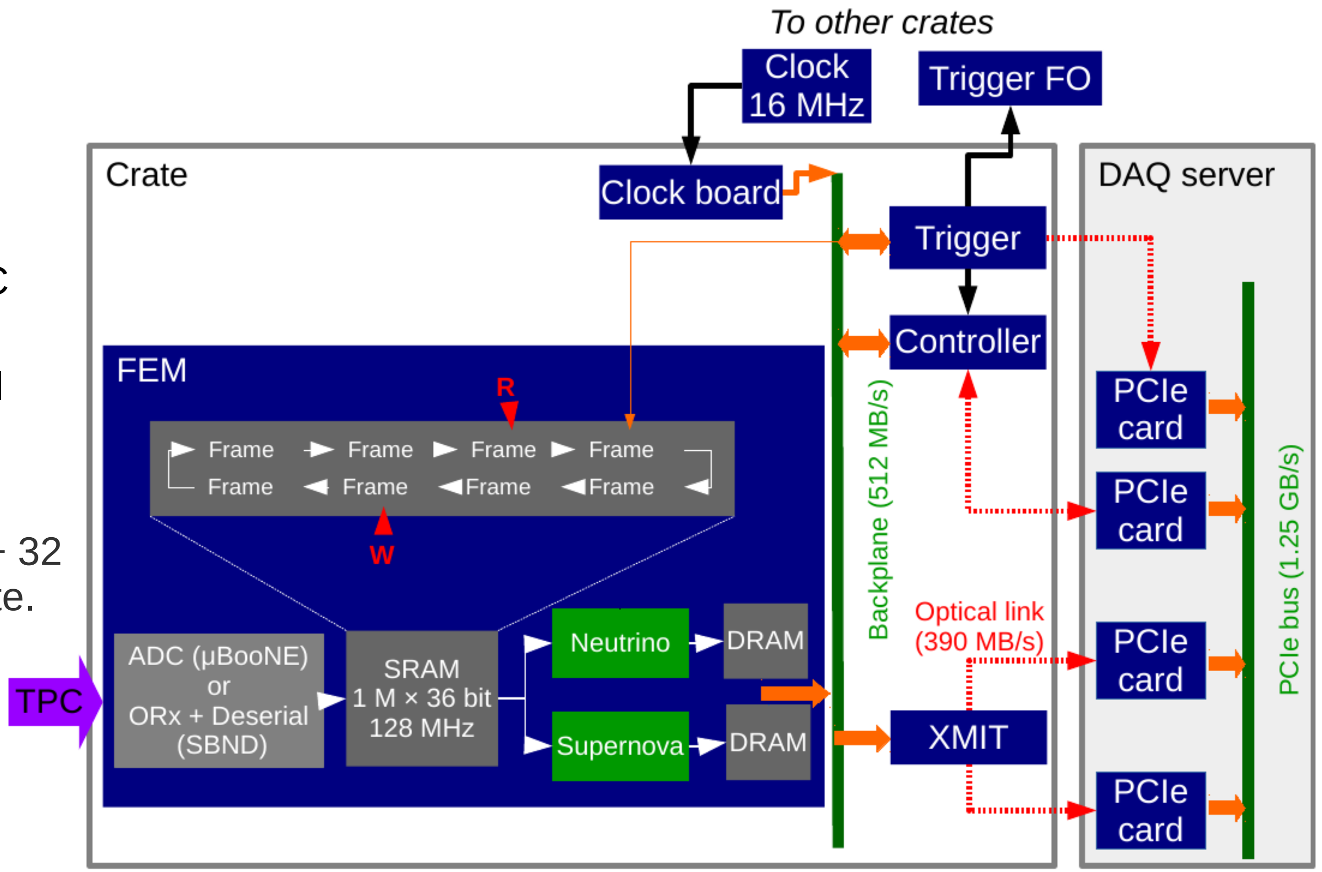
Michel e candidate from trigger stream







MicroBooNE & SBND



Very similar designs.

MicroBooNE: analog data sent to ADC attached to back-end electronics.

SBND: digital data sent through optical link to back-end electronics.

Front End Module (FEM).

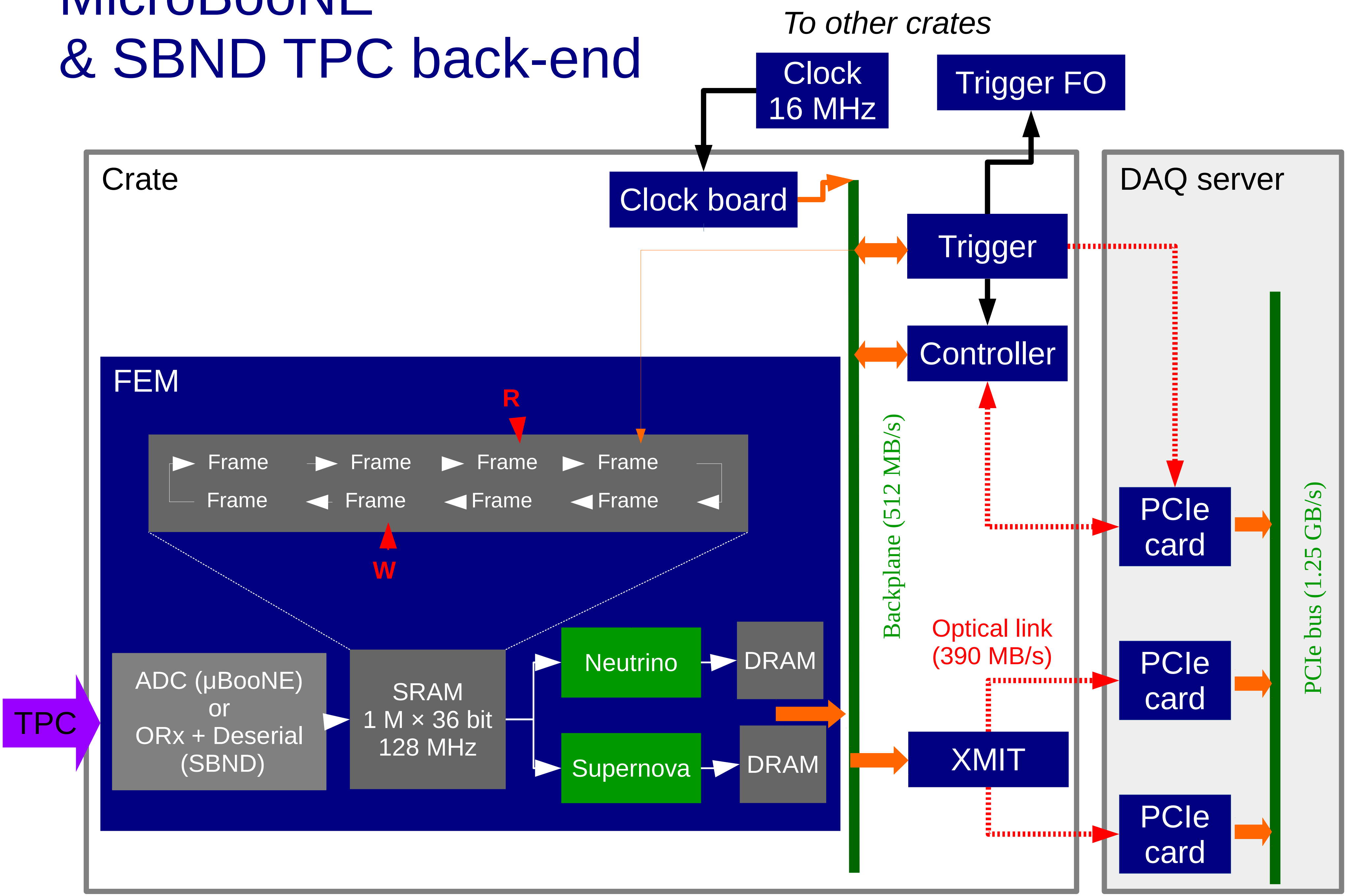
64 ch/board (typically 32 induction ch + 32 collection ch). Up to 16 boards per crate.

- Data processing by FPGA (Altera Stratix III).
- 1 M × 36 bit 128 MHz SRAM as ring buffer. 8 frames in buffer (1.6 ms/frame × 8 frames = 12.8 ms).
- 64 MHz for writing in time-order. 64 MHz for reading by channel. **No deadtime.**
- Two data streams. **1) Triggered stream**: read out 1 frame before + 2 frames after trigger. 3 × 1.6 ms window/ch × 2 MS/s × 2B/S = 19.2 kB/ch. But ~ × 5 lossless (Huffman) compression. **2) “Supernova”** stream: continuous readout.

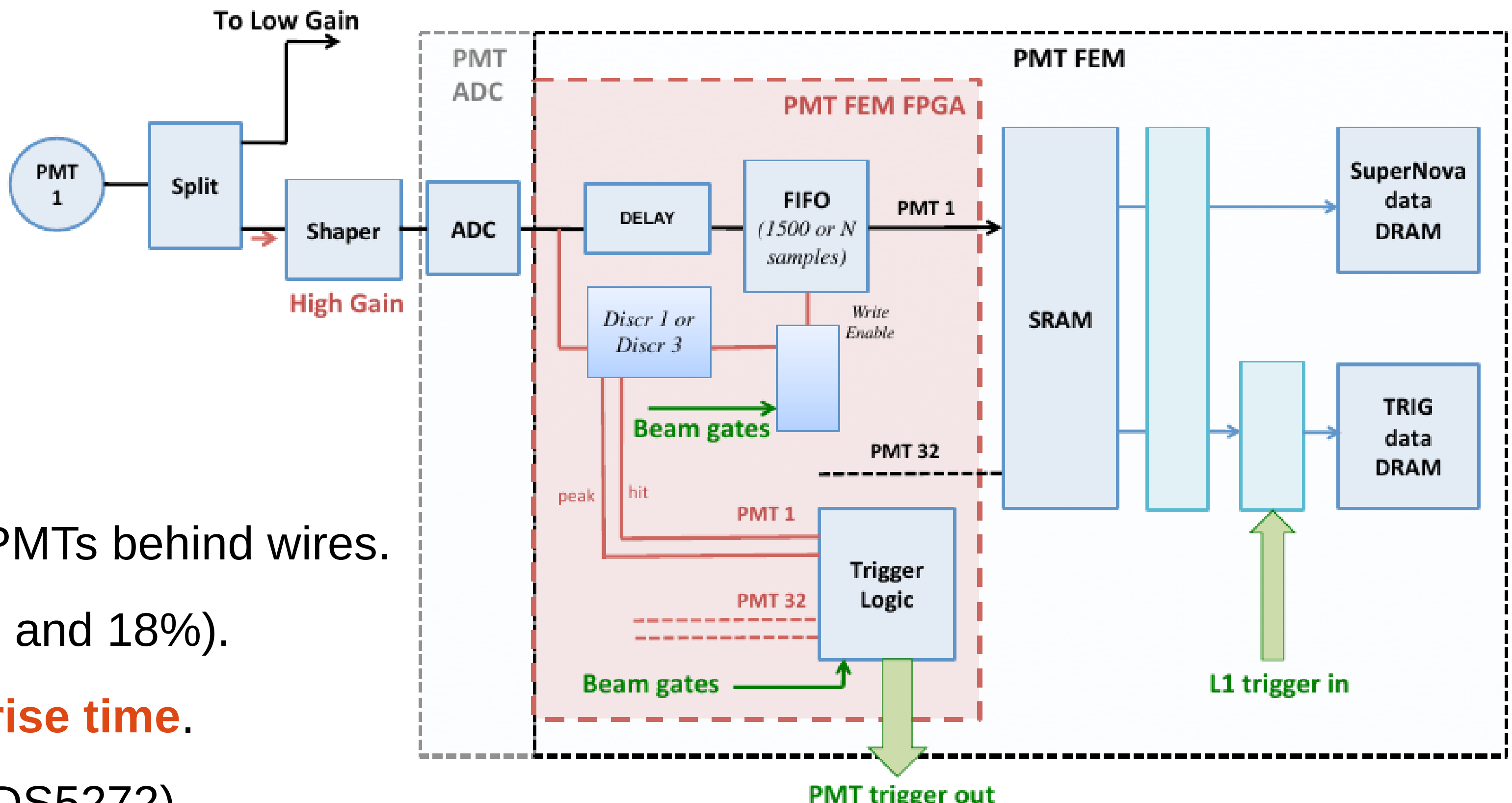
Transmitter (XMIT) board. 1 board/crate reads up to 16 FEMs.

- Fetching data through backplane (512 MB/s). Data sent to PCIe card on DAQ server via optical links (390 MB/s).

MicroBooNE
& SBND TPC back-end



MicroBooNE PMT readout



- 32 TPB-coated PMTs behind wires.
- Two gains (1.8% and 18%).
- Shaping: **60 ns rise time**.
- **64 MHz ADC** (ADS5272).
  - Accurate determination of event t_0.
- Read 23.44 μs around beam (1500 samples).
- 0.31 μs (20 samples) for cosmics passing amplitude threshold.
- Back-end electronics similar to TPC design.

Zero suppression (PMT)

- The **bottleneck** of the stream is the **disk writing speed** at the DAQ PCs (assumed conservatively to be 50 MB/s).
- Neglecting header sizes:

  64 Msamples/s * 2 B/sample * 32 PMTs * 2 gains / 1 DAQ server = **8.2 GB/s/server**
- **Cannot write all data. Front End Module FPGA decides on the fly.**

Single-PMT ADC data

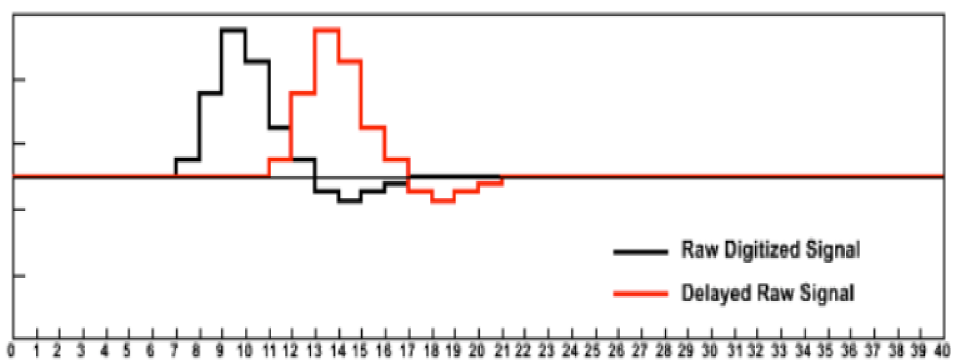
Same data delayed by 4 samples

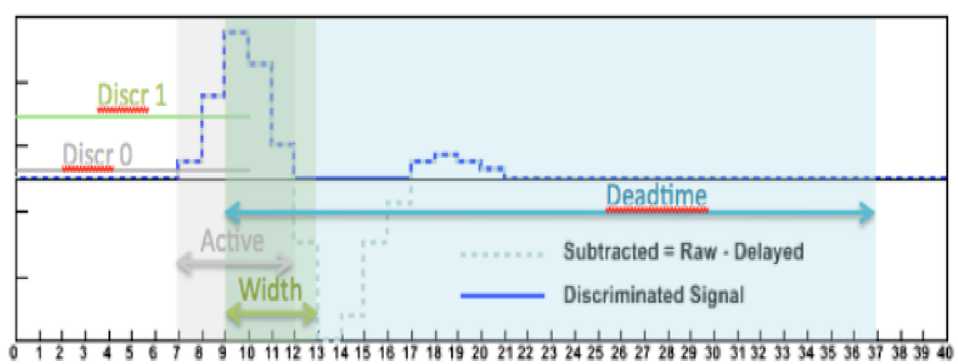
Subtracted pulse: original waveform – delayed one

Difference: only retain positive values from the subtracted pulse.

Apply two discriminators:

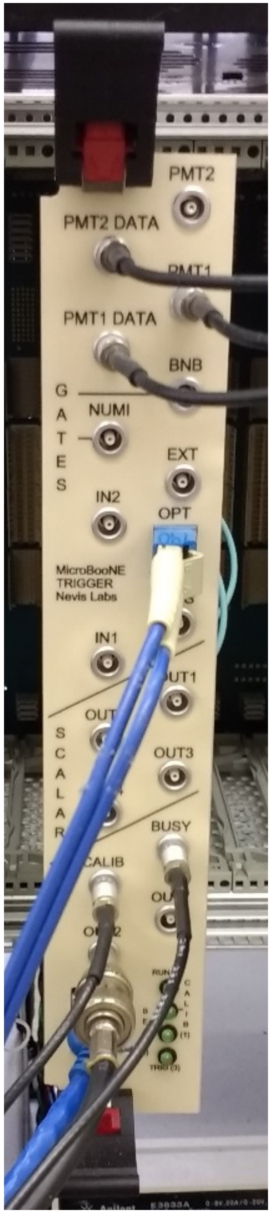
- Discr0 to open an active window.
- Discr1 to cut on amplitude.



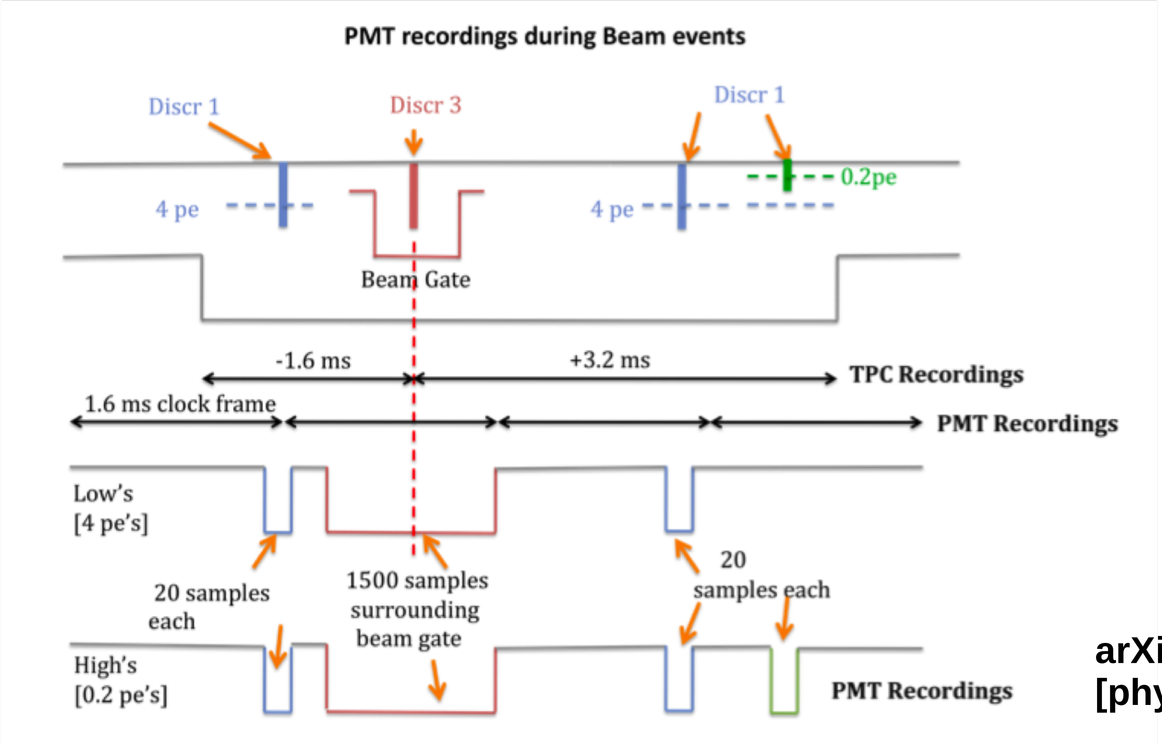


Instead, if **difference** passes threshold, **20 samples (312.5 ns)** are recorded (enough for prompt scintillation, τ ~ 6 ns)

MicroBooNE trigger



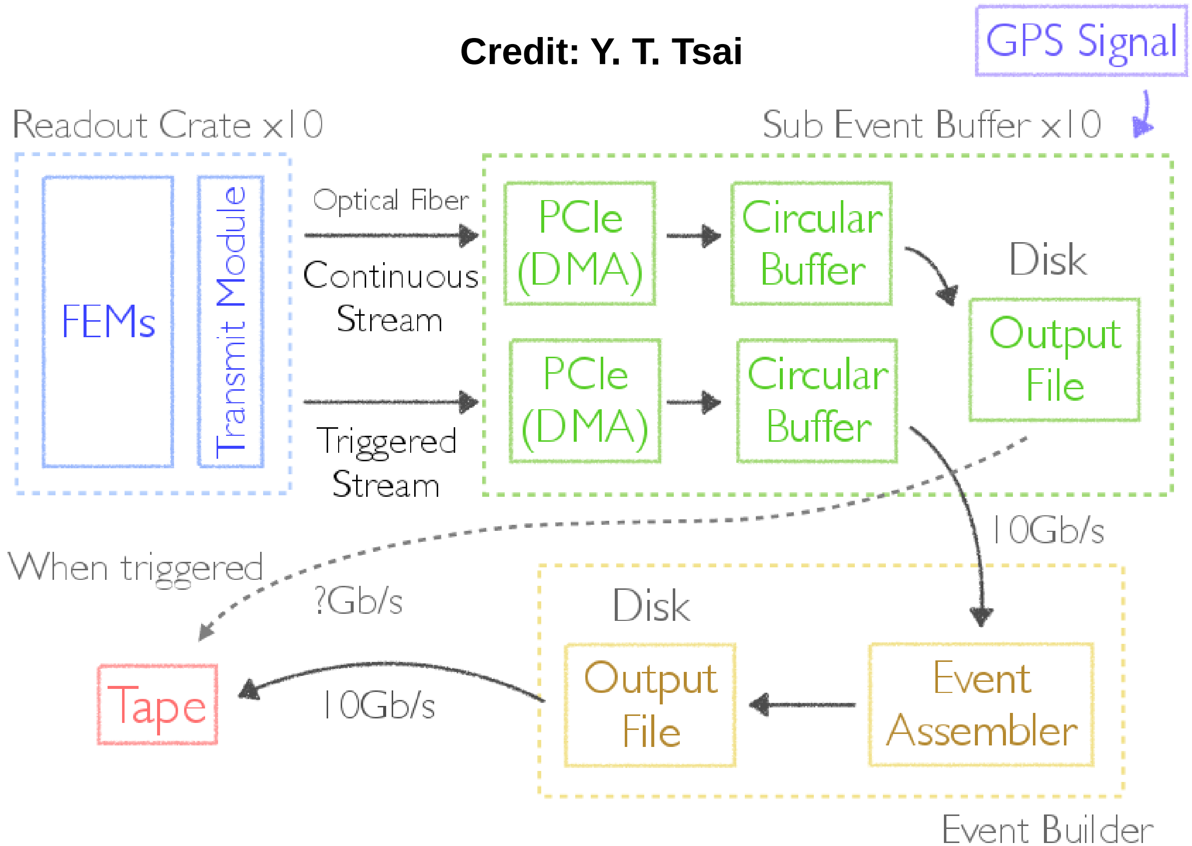
- Inputs for **PMT primitives**, **accelerator signals** (BNB and NuMI beam), **external trigger** and **calibration subsystems** (UV laser calibration, cosmic-ray tracker).
  - Configurable logic and prescaling.
- PMT trigger based on both multiplicity and pulse height provided by an FPGA. Currently disabled. Instead, **level-1 trigger on accelerator gates** and **software (level-2) trigger running an emulation of the FPGA** algorithm at the Event Builder stage.



arXiv:1308.3446 [physics.ins-det]

MicroBooNE DAQ

Credit: Y. T. Tsai



- Jungo Windriver to interface with PCIe card.
- TPC data distributed between 9 servers (Sub-event buffers).

  PMT + GPS data in 1 server.
- Triggered stream data sent over 10 Gbps network to Event Assembler.
- Continuous readout stream written locally on each server waiting for an SNEWS alert. After a few hours, it is deleted.
- Ganglia monitoring for DAQ servers. Slow Monitoring using EPICS.

Supernova neutrinos

[arXiv:1512.06148]