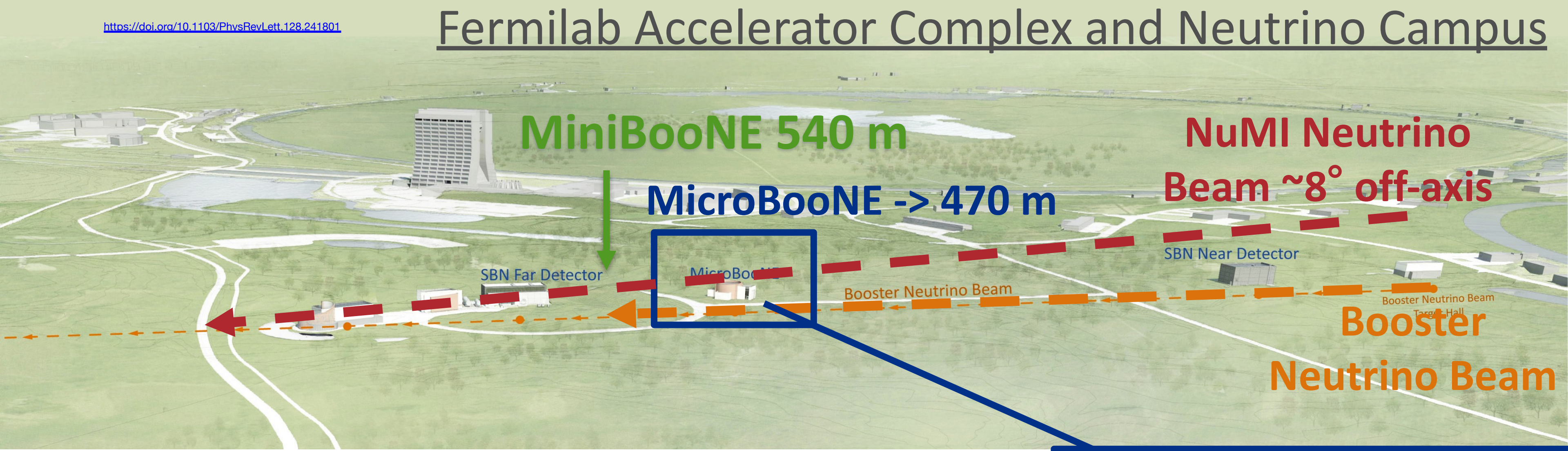
MicroBooNE Detector Physics Measurement and Calibrations

Vincent Basque For the MicroBooNE Collaboration

ICHEP 2024 in Prague, CZ

19/07/2024

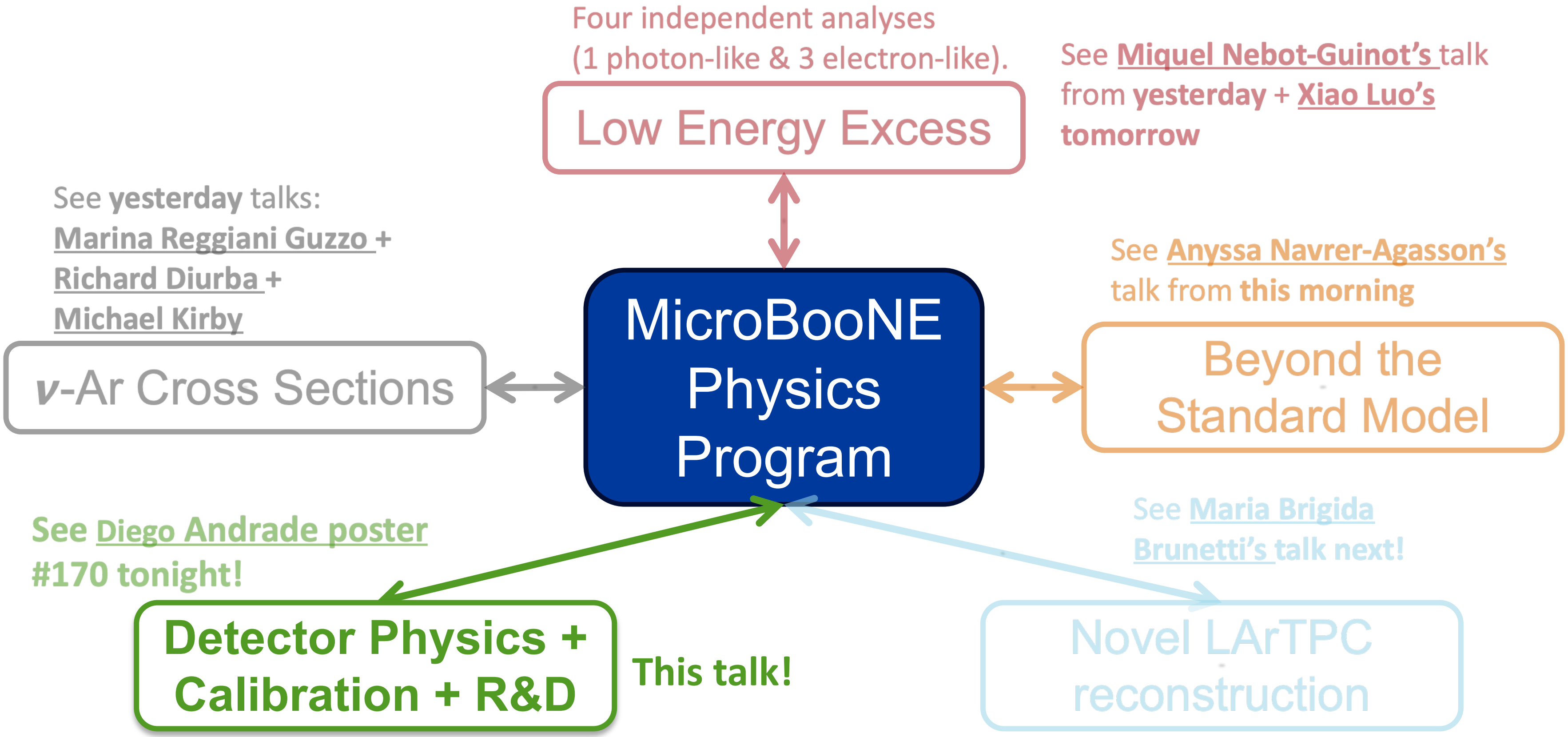
MicroBooNE at Fermilab



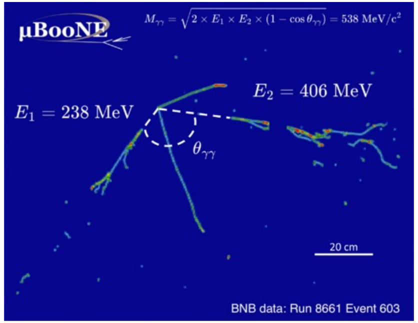
- **MicroBooNE** is a **LArTPC at Fermilab**.
- **Main physics goal**: **investigate MiniBooNE low energy excess** at the **GeV-scale neutrino** energy.
- Ran from **2015 to 2021** (neutrino beams + R&D campaigns).

MicroBooNE's Physics Program – Main Outputs

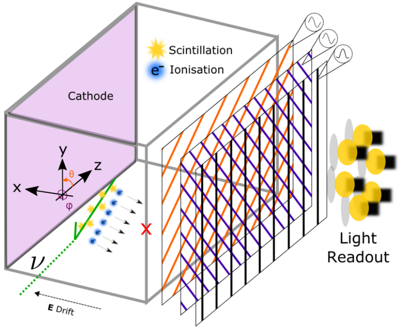
μBooNE



Detector Physics, Calibration, R&D Program - Outline



Detector Physics + Calibration + R&D



Scintillation Light

- Light yield calibration
- Nanosecond timing resolution

R&D

- LAr impurities
- HV runs

Ionization Charge

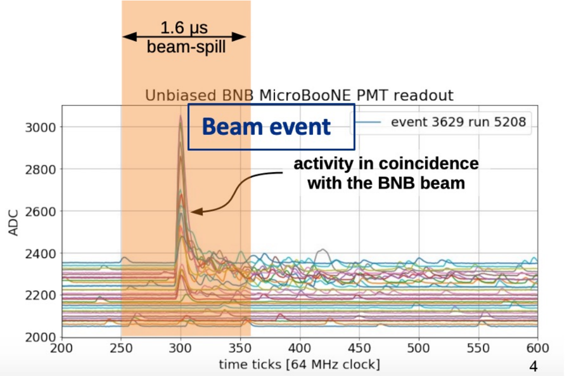
- Radon search
- Blips search

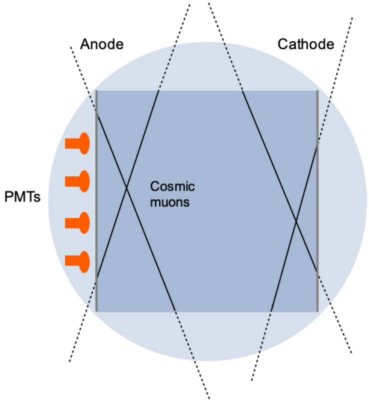
} **MicroBooNE's MeV-Scale program**

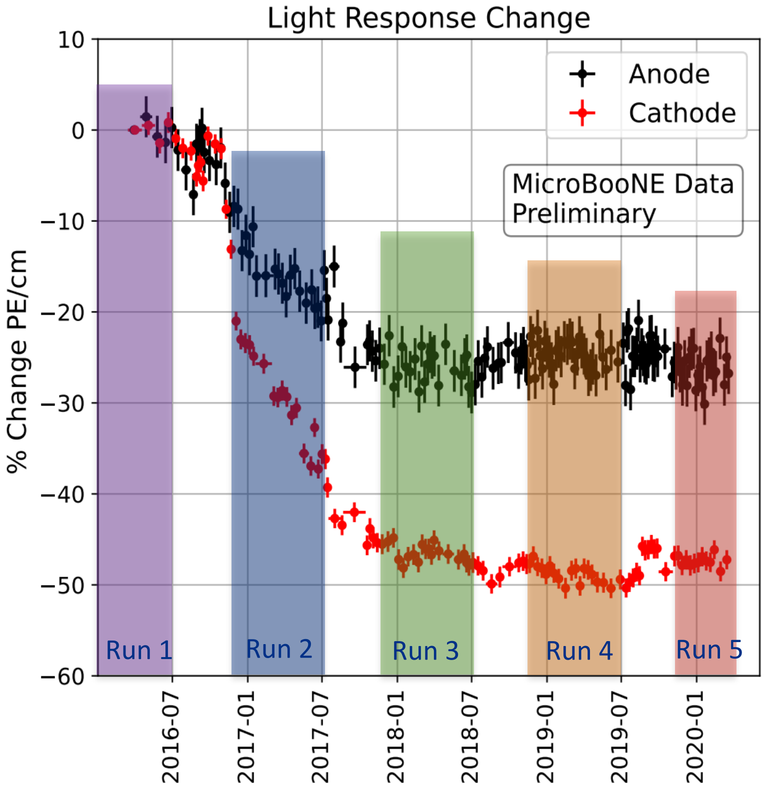
Already published

- **Signal processing** → JINST 13 P07006 (2018) & JINST 13 P07007 (2018)
- **Energy calibration** → JINST 15 P03022 (2020)
- **Longitudinal diffusion measurement** → JINST 16 P09025 (2021)
- **Detector uncertainties** → Eur. Phys. J. C 82, 454 (2022)

Time-Based Light Yield Stability Measurement



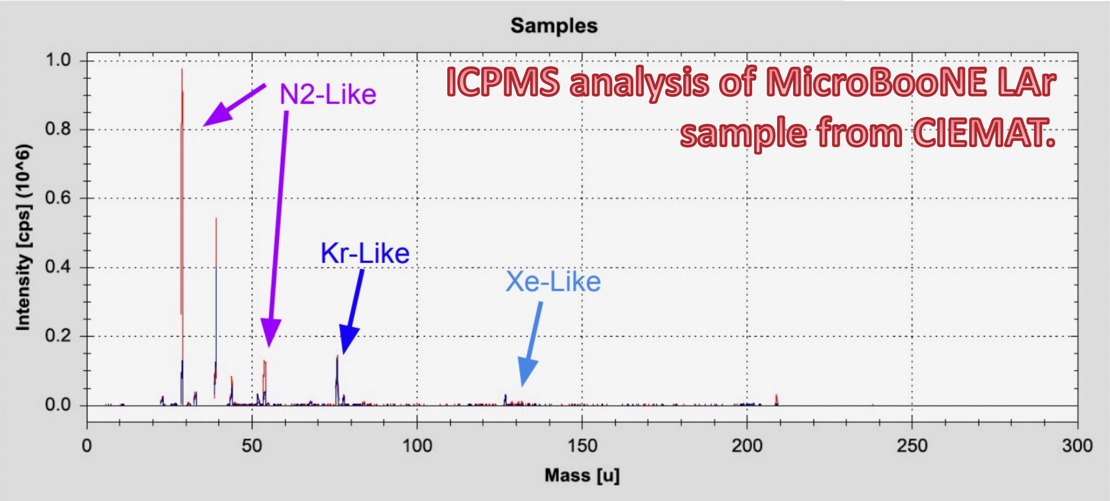


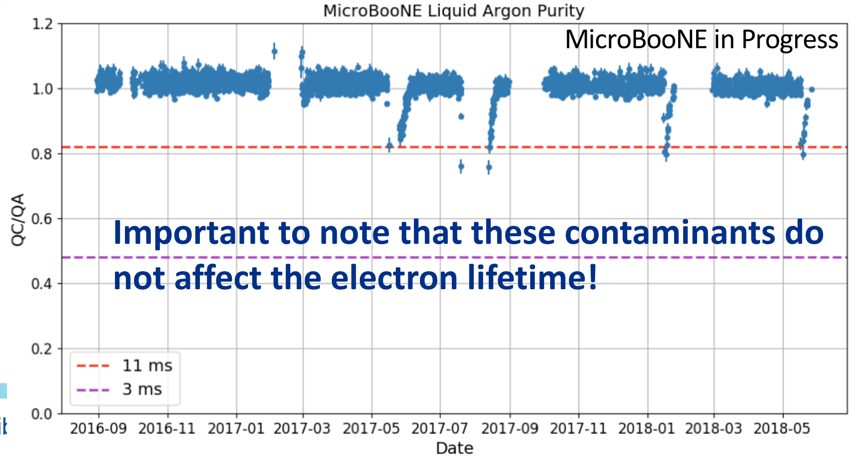


- We use light to trigger on *beam neutrino* events.
- **Light yield ➔** cathode or anode piercing muons.
- Truncated median populates the light response change by comparing to the first-time bin.
- **Important feature**: the amplitude of the decline is different at the **anode** vs **cathode**.
- Cause still unknown but under-investigation.

LAr Impurities in MicroBooNE

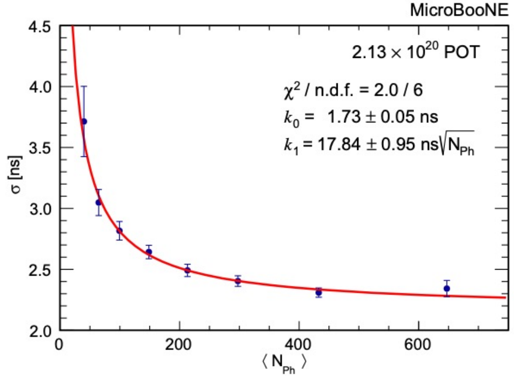
- We took a sample of argon from the detector to be analyzed
- We have found *more* nitrogen, krypton and even xenon compared to commercial high purity argon.
- These can quench (late light) and/or absorb the light.
- 2 more argon samples being analyzed for comparisons.
- Light impurities different than charge impurities
  - High electron lifetime throughout



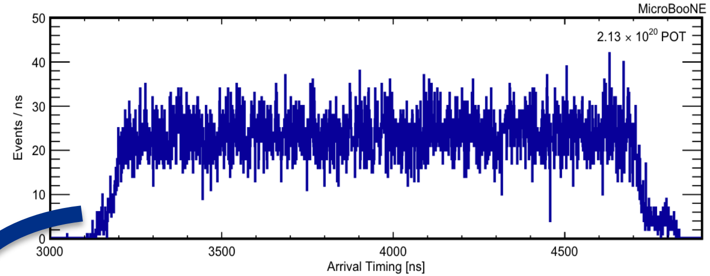


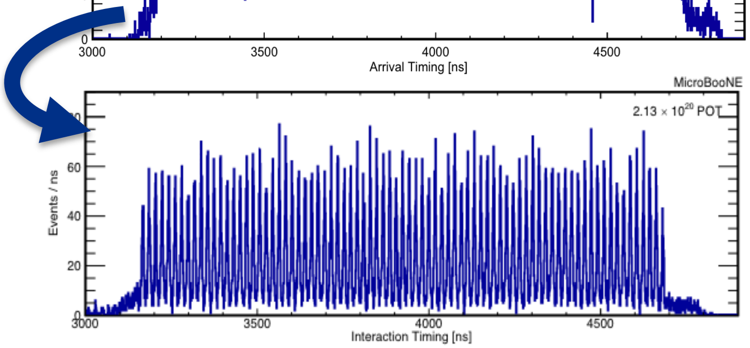
Nanosecond-scale Timing Resolution

- Achieved the time **reconstruction of neutrino interaction with a O(1 ns) resolution**:
  - Used prompt scintillation signal, corrected for the light propagation + electronics response
  - Obtained **intrinsic resolution of 1.73±0.05 ns**



- **Neutrinos** arrive at MicroBooNE with a **beam structure**. This structure can be resolved:
  - Each **beam spill length ➜ 1.6 μs.**
  - Each **spill** -> **81 proton bunches of ~2 ns width.**

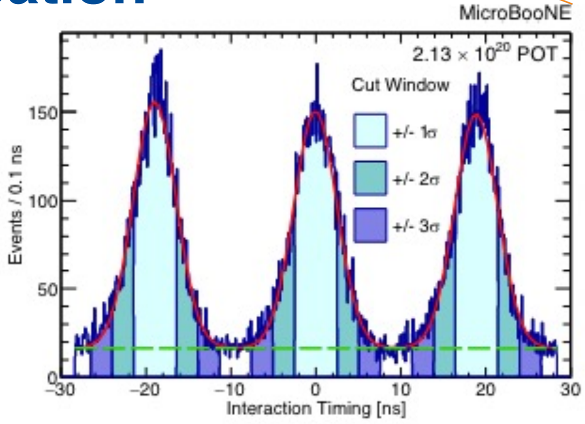


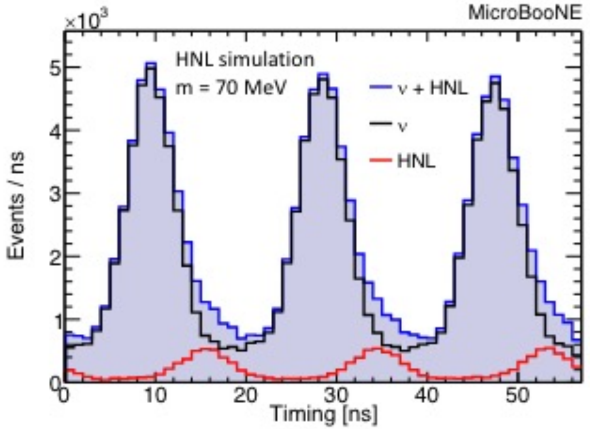


- For more details: Phys. Rev. D 108, 052010

Nanosecond-scale Timing Resolution - Application

- MicroBooNE has **significant background from cosmic rays** due to being on the surface.
- **Beam structure** can be used to **mitigate backgrounds**
  - Reject events outside of the beam window with more precision.
  - Example: $\pm 2\sigma$ cut applied on the ν_μ CC selection:
    - 95.5% signal efficiency & rejects 46.6% of cosmic background
- **Search for BSM particles** in the beam:
  - Example: HNL will travel slower and reach the detector later.
  - Can **look between bunches** where the neutrinos from the beam background is reduced.

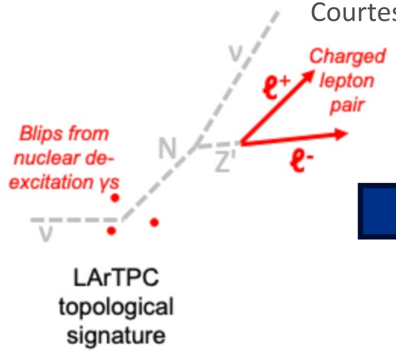


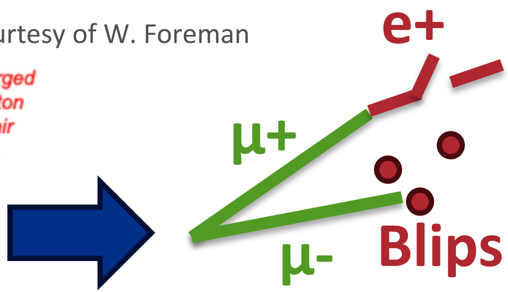


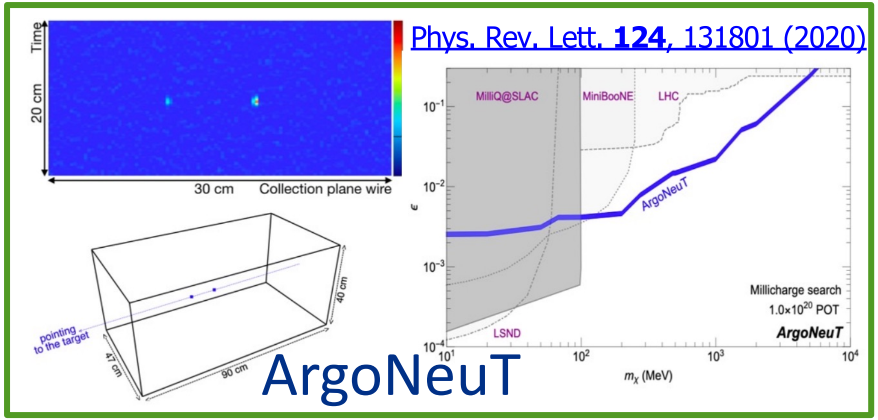
MeV-Scale Physics – What can it be used for?

- LArTPCs mainly look at **~GeV-scale** events.
- ArgoNeuT pioneered looking at **~MeV-scale blips:** ν_μ CC induced gammas & millicharged particle interactions in the TPC.
- Identifying specific particle topological features and improve background rejection could improve sensitivity to some BSM signatures
  - Potential in charge-sign discrimination for μ+/- & π+/-
- MicroBooNE has implemented a comprehensive MeV-scale physics program:
  - Expanded "MeV-blips" reconstruction.

Courtesy of W. Foreman

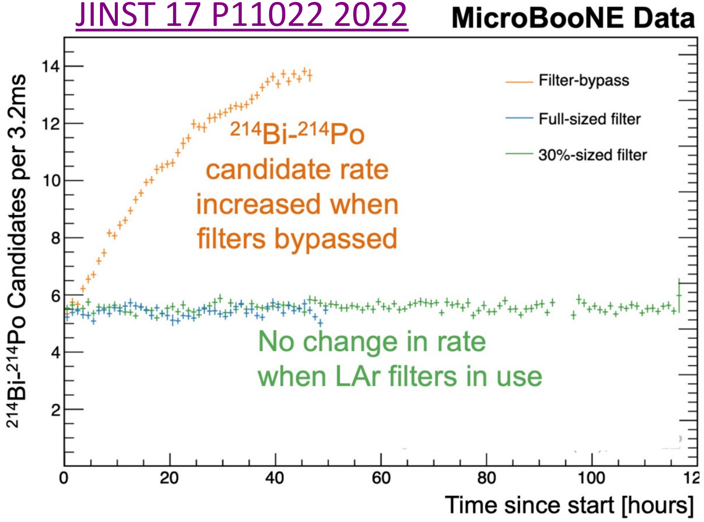




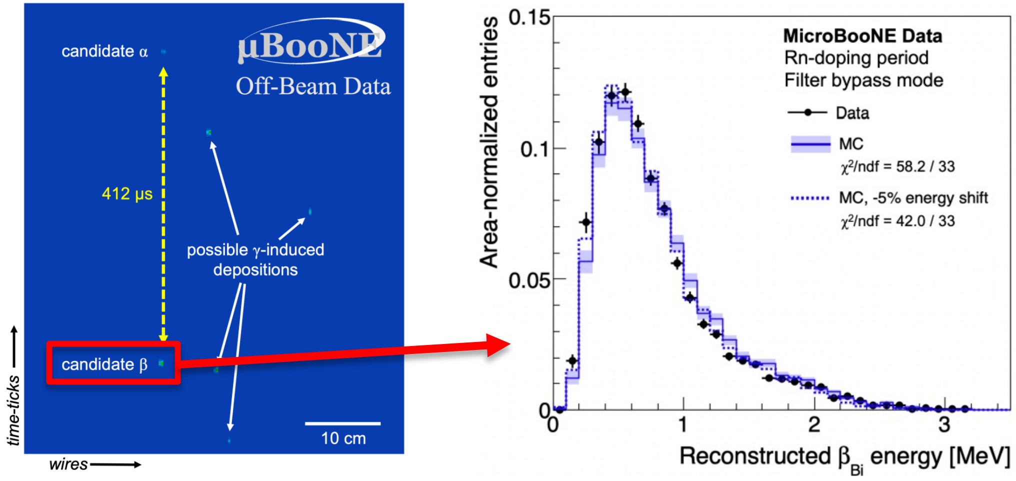


MeV-Scale Physics with MicroBooNE – Radon Search

JINST 17 P11022 2022



Phys. Rev. D 109, 052007



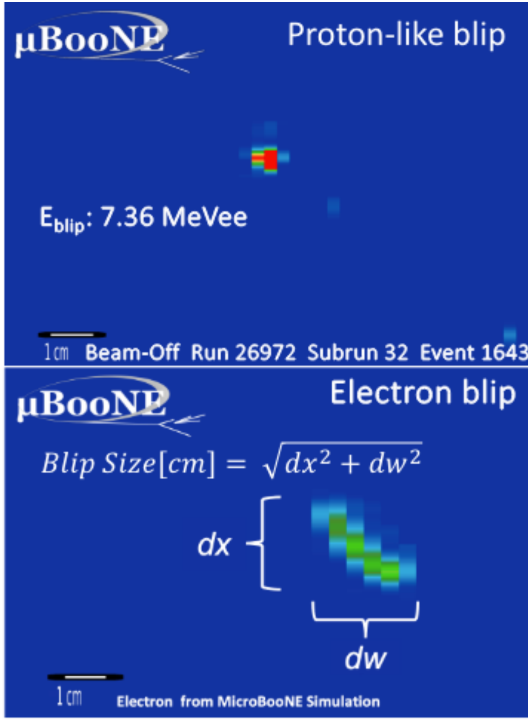
- Proof of concept: **injected Rn** during the R&D campaign to look for **Bi(β) - Po (α). signatures**.
- **Unexpected result:** had to bypass our extremely good filters!

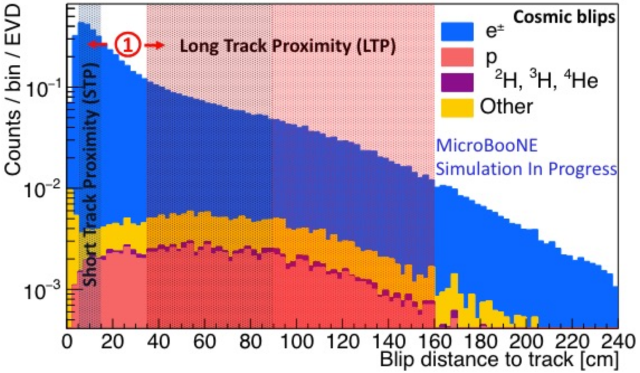
- Measured: ambient radon through Bi(β)-Po (α).
  - Good β-spectrum reconstruction - These are **very low energy events** for LArTPCs!
- Measured: **Bi-214 rate < 0.35 mBQ/kg** at a 95% C.L. outside of the Rn-doping period.
- Estimated Rn-222 rate < 1 mBQ/kg for DUNE.

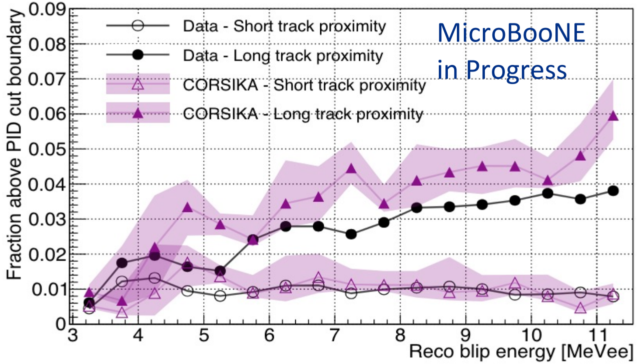
MeV-Scale Physics with MicroBooNE – Blip Searches

See Diego Andrade poster #170 tonight!

- **Goal:** distinguish proton and electron blips
- **MeV-Scale calibration** using **ambient radiogenic blips (E < 3 MeVee).**
- **Data-driven PID** method to select **proton-like blips using cosmogenic nature blips (> 3 MeVee).**
- Stay tuned for final results!

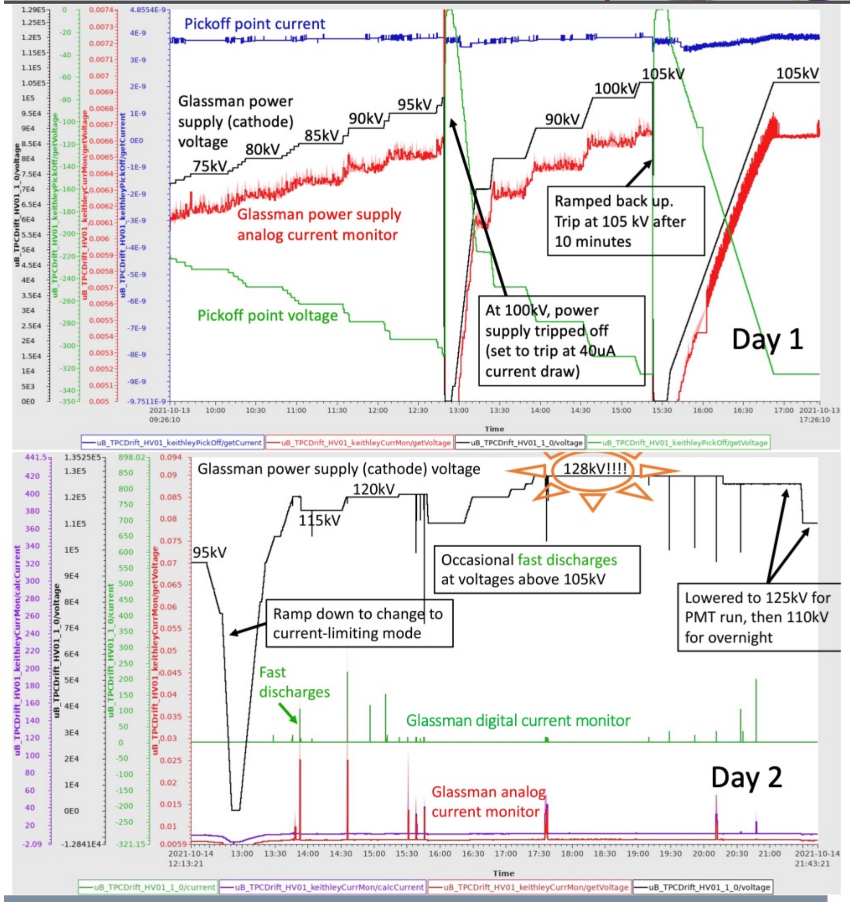






MicroBooNE's R&D Campaign

- **Operational Electrical field**
  - Due to HV instabilities during commissioning, never operated at nominal electrical field of 500 V/cm (128kV).
  - Operated at 273.9 V/cm (70kV).
    - Discharges seen above 70kV decided to stay safe.
- **Electrical field ramp up to nominal**
  - Post data-runs, ramped up to 128kV in steps. Instabilities seen but stable operation at 128kV was achieved.
- **Data recorded at different HV**
  - Recombination, diffusion, SPE rate, etc.
  - Also ran light-only in reverse HV polarity.



Summary

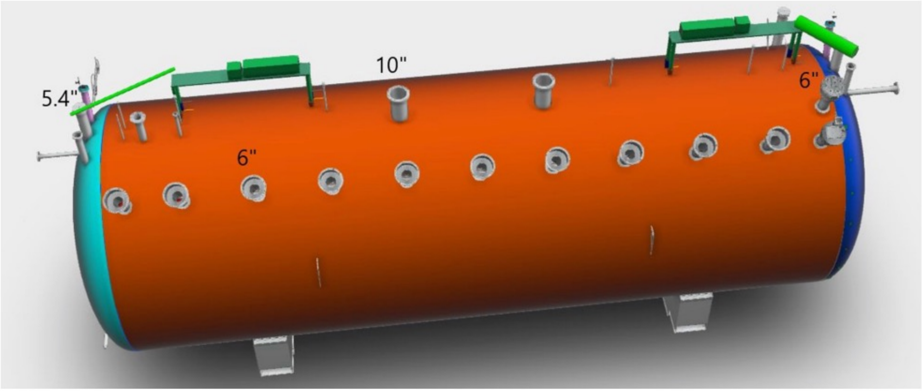
- MicroBooNE completed **7 years of data running** in 2021.
  - Record for the **longest running LArTPC in a neutrino beam** to date!
  - **Detector is in a decommissioning phase** to understand certain features observed during operation & look at the longevity of LArTPCs after 7 years.
    - *Rare* and exciting opportunity to inform the greater community!
- Our detector physics, calibration and R&D program is crucial for the success of all our analyses + provide guidance to the next LArTPCs.
- **New detector physics measurements + R&D studies already being published many more on the way:**
  - Looking at light yield with isolated protons + Michel electrons ➜ point-like events.
  - Exploring explanation of high SPE rate observed.
  - Recombination at different E-field.
  - Light yield decline explanation.
  - Cherenkov light studies.

Questions?

Backup

MicroBooNE Decommissioning Effort

- Earlier this year, the MicroBooNE detector entered a decommissioning phase.
  - This will allow us to characterize the detector after 7 years of operation.
  - Potential to understand some of the unresolved mysteries.
- Before venting the cryostat, we took some argon samples that are currently being analyzed through different characterization techniques (e.g. GC/MS).
- The cryostat is now back at ambient temperature, and we are planning to open ports to have a look at the TPC.
- Plans are still brewing, but we want to look at the wire planes and our light detection system:
  - Trying to determine what 7 years in LAr has done to them.



Detector Physics, Calibration, R&D Program - Outline

Detector Physics + Calibration + R&D

Scintillation Light

- Light yield calibration
- Light impurities contamination
- Nanosecond timing resolution

Ionization Charge

- Radon search
- Blips search
- R&D campaign

(Radon search and Blips search: MicroBooNE's MeV-Scale program)

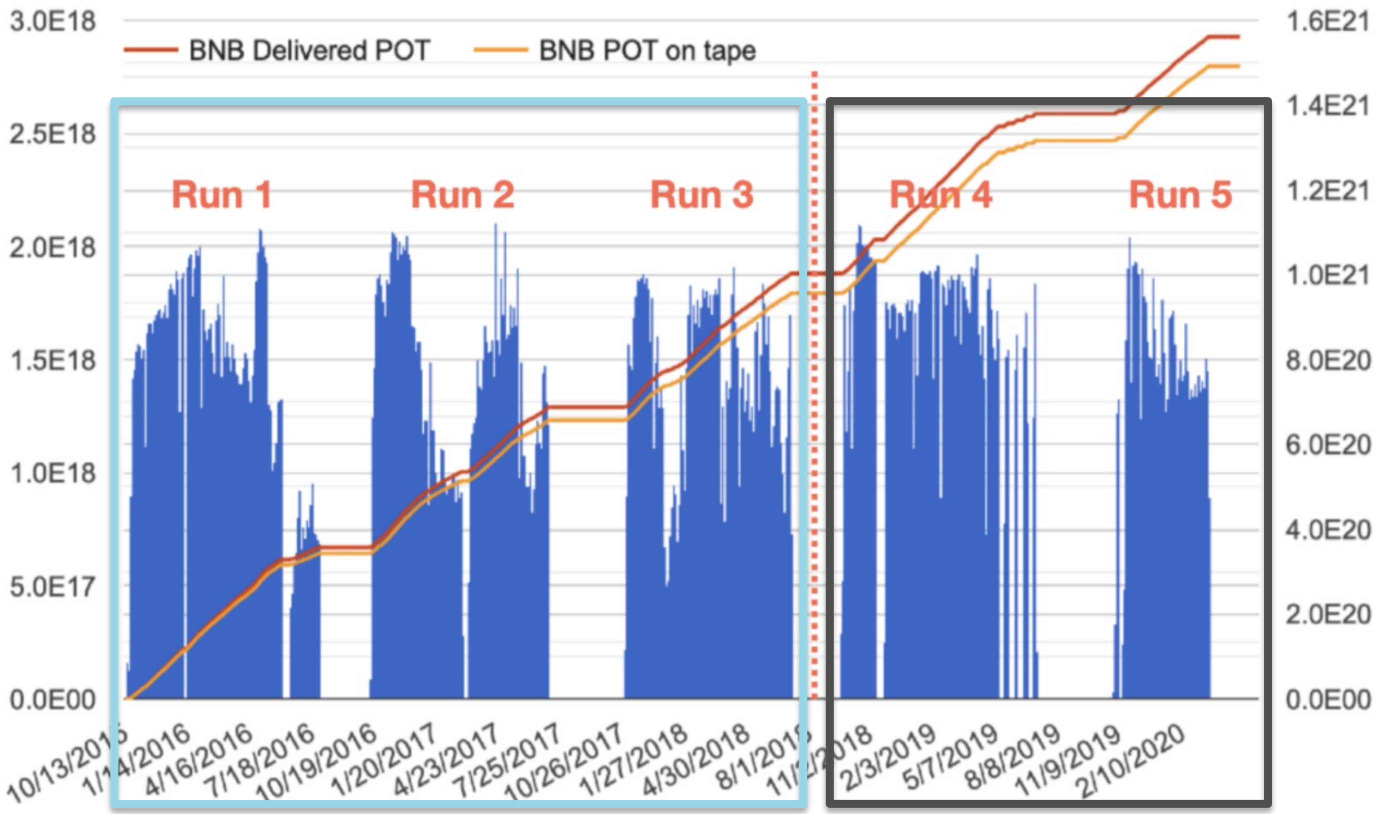
Won't have time to cover today:

- **Signal processing** → JINST 13 P07006 (2018) & JINST 13 P07007 (2018)
- **Energy calibration** → JINST 15 P03022 (2020)
- **Longitudinal diffusion measurement** → JINST 16 P09025 (2021)
- **Detector uncertainties** → Eur. Phys. J. C 82, 454 (2022)

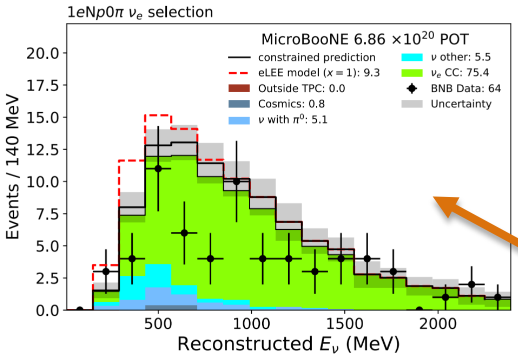
Running over 5 years of Beam Data!

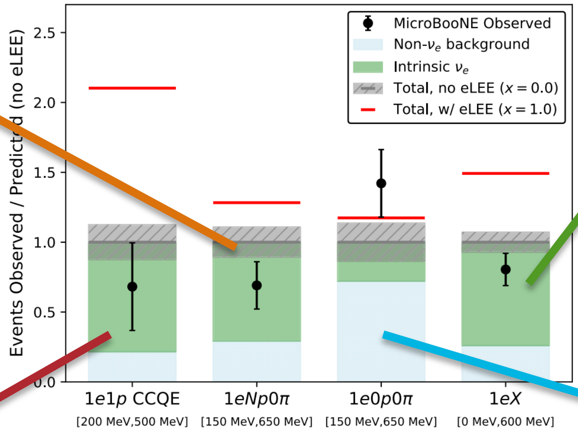
- All analyses published so far only use ~1/2 of the full dataset.

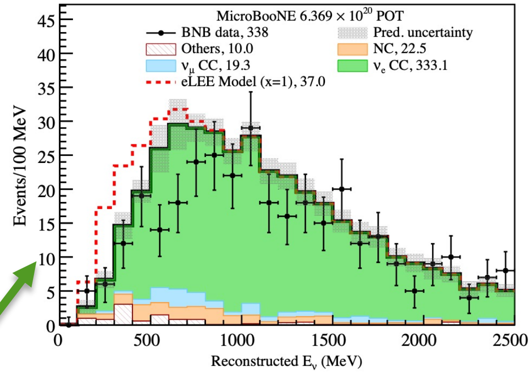
- Expect to have full dataset analyses start to come out in 2024!

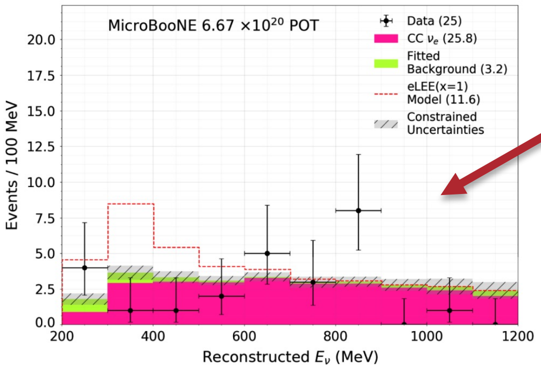


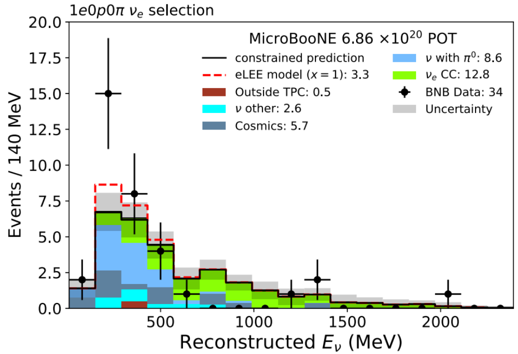
Low Energy Excess Searches Through Electrons











MicroBooNE Timeline

Low energy excess anomalies

2007

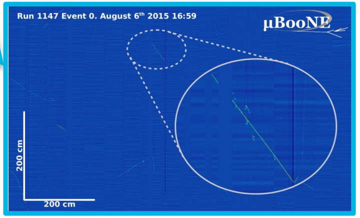
A Proposal for a New Experiment
Using the Booster and NuMI Neutrino Beamlines: MicroBooNE

[Link to proposal]

Construction + Installation

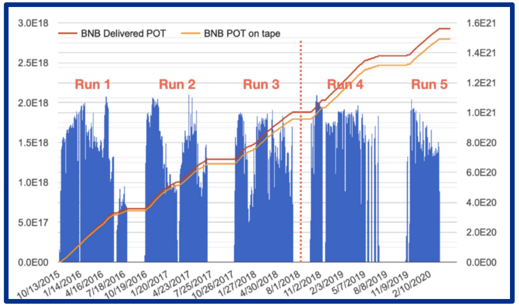
Mid 2015

Late 2015



Filling + Commissioning

Operations



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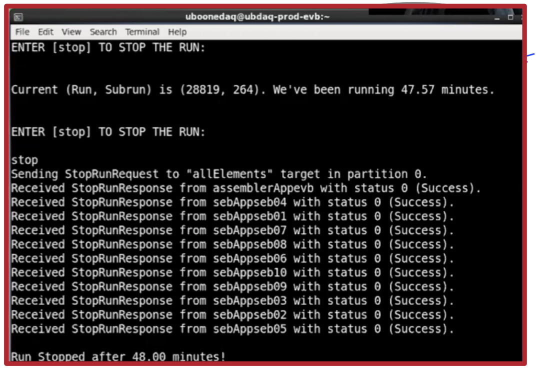
2020

2021

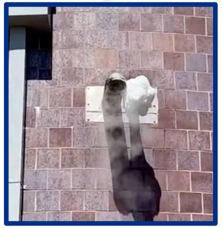
R&D Period

Late 2021



2023

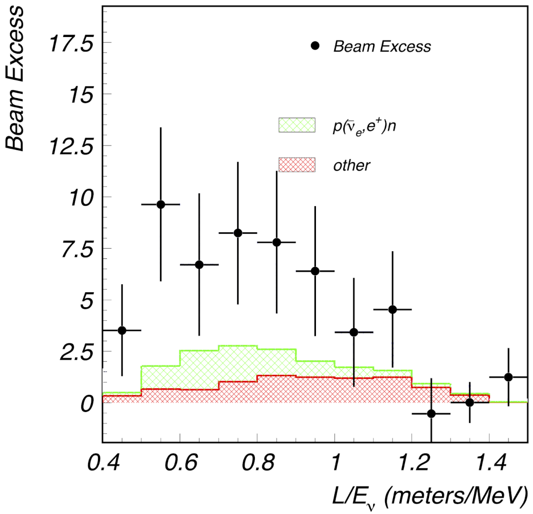
Decommissioning



Argon Venting

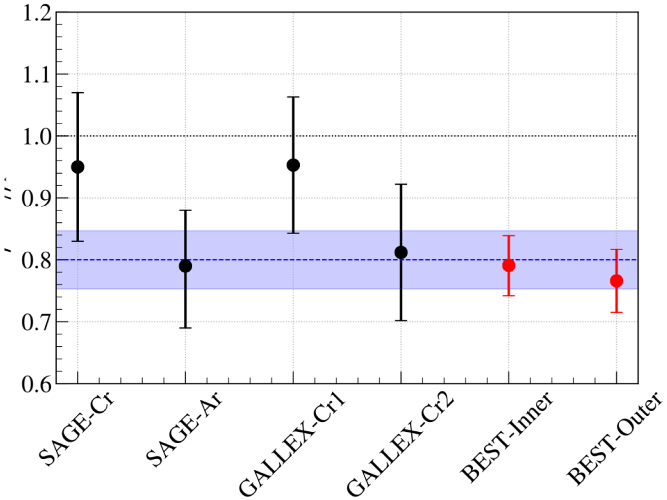
Low Energy Excess (LEE) and You – Anomalies

Phys. Rev. D **64**, 112007 (2001)



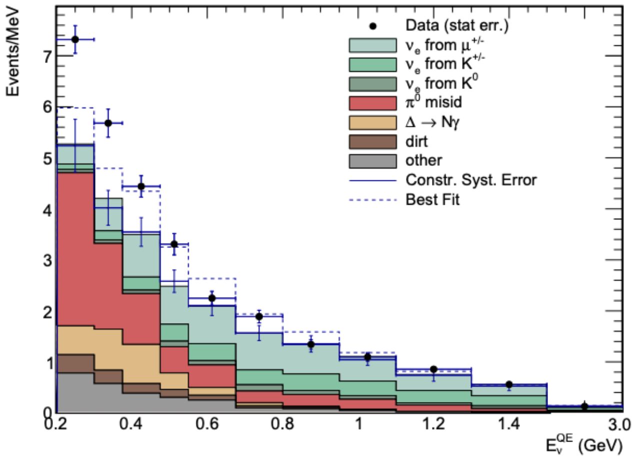
LSND -> stopped pion source. Observed **excess** of $\bar{\nu}_e$ in a $\bar{\nu}_\mu$ beam.

Phys. Rev. C 105 6, 065502 (2022)



Gallium detectors -> calibration sources in detectors. Observed **deficit** of ν_e.

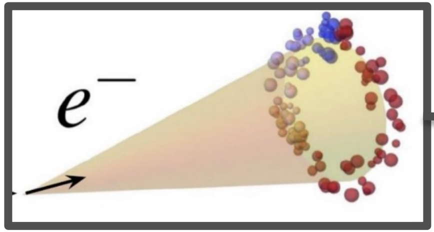
Phys. Rev. D 103, 052002 (2021)



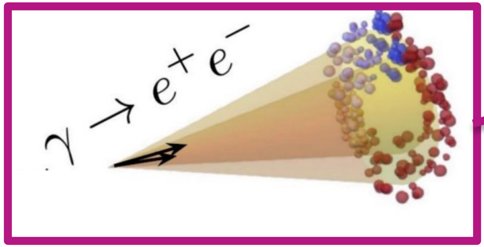
MiniBooNE -> neutrino beam. Observed **excess** of $\nu_e(\bar{\nu}_e)$ in a $\nu_\mu(\bar{\nu}_\mu)$beam.

Low Energy Excess (LEE) and You – MiniBooNE

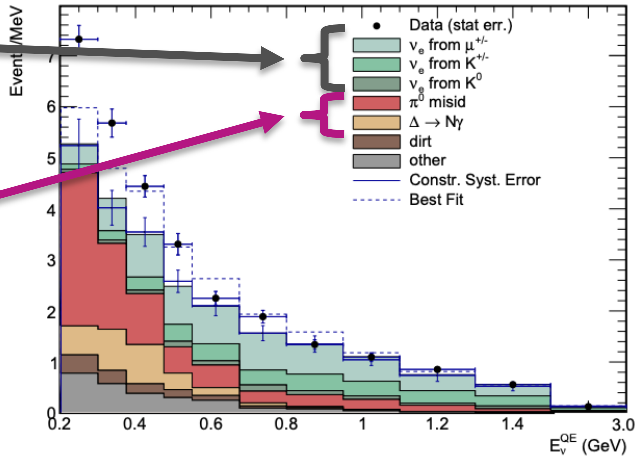
Signal



Background



Phys. Rev. D 103, 052002 (2021)

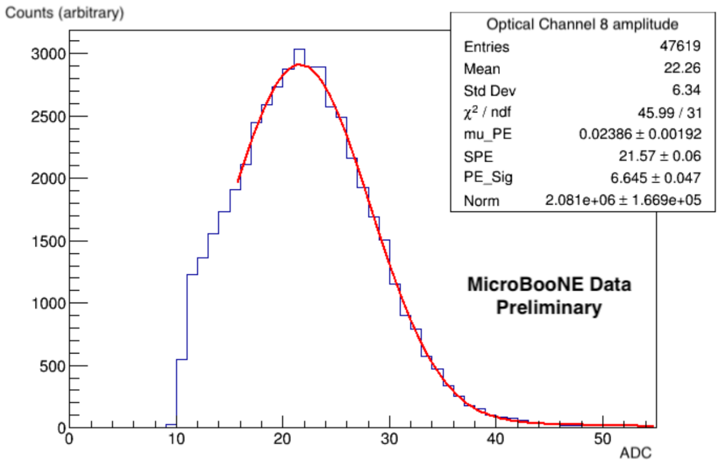


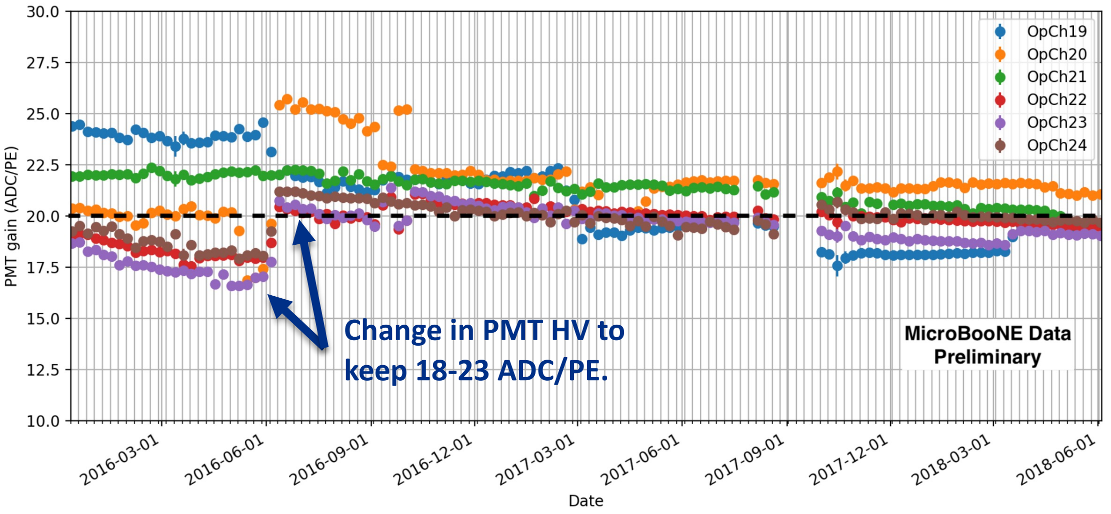
MiniBooNE is a Cherenkov detector. **Hard to differentiate between electron and photons**. Could we use a *new* detector technology instead?

MiniBooNE -> neutrino beam. Observed **excess** of $\nu_e(\bar{\nu}_e)$ in a $\nu_\mu(\bar{\nu}_\mu)$beam.

PMT Gain calibration

- PMT gain calibration algorithm has been implemented by:
  - Fitting the response to the Single Photo-Electron (SPE) noise (~200 kHz SPE noise rate).
- The fluctuations over time are caused by a combination of a change of the temperature, HV, intensity/frequency of incident light.

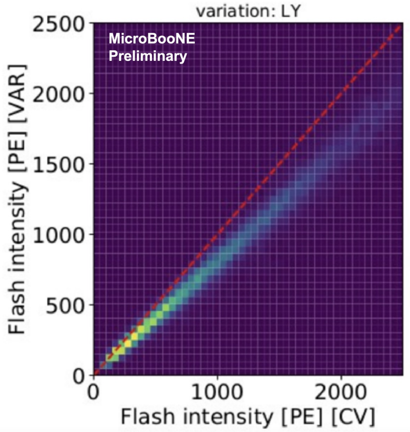


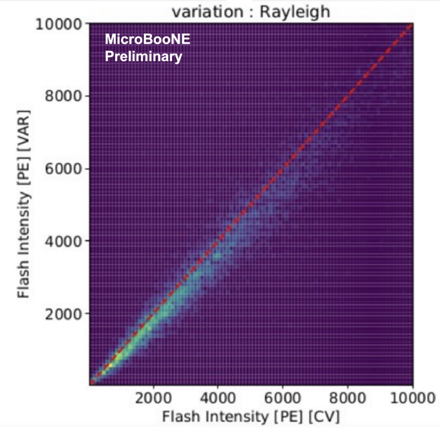


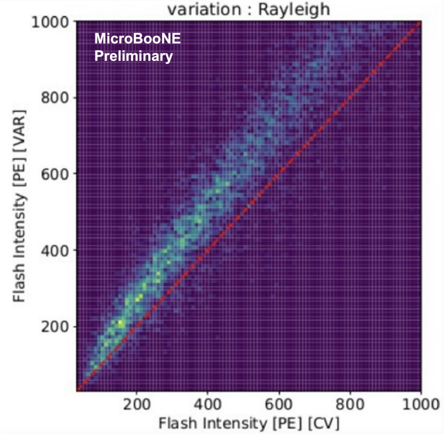
Light Yield Modelling & Decline as Systematic Uncertainty

μBooNE

- MicroBooNE uses 3 light detector variation samples to account for systematic uncertainties on light modelling and the light yield decline.
  - **Light yield down**: 25% reduction of MC to match with data.
  - **Modified Rayleigh scattering length**: 120 cm scattering value to compare with nominal 60 cm*.
  - **Modified attenuation**: 20% - 40% quenching and 8 m - 13 m absorption length for lowest and longest drift distances, respectively.







*MicroBooNE has not yet moved to the ~100 cm RSL value

[Phys. Rev. D **108**, 052010 (2022)]

First demonstration of $\mathcal{O}(1\text{ ns})$ timing resolution in the MicroBooNE liquid argon time projection chamber

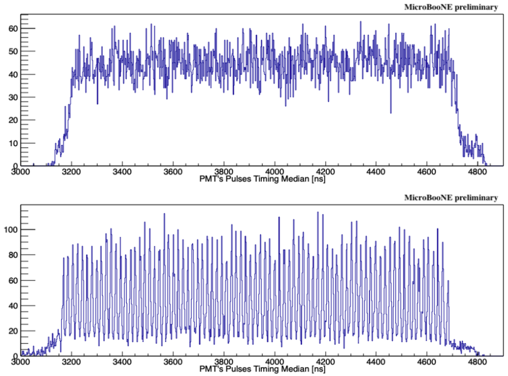
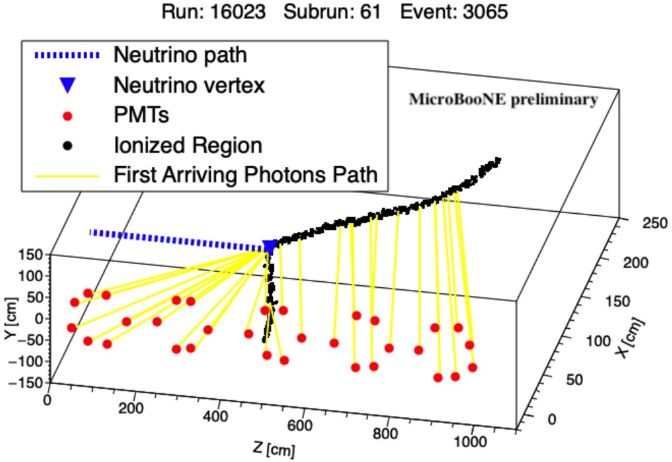


Figure 7: Top: neutrino interaction timing distribution before the reconstruction. Bottom: neutrino interaction timing distribution after the reconstruction. The 81 bunches composing the ∼1.6 μs beam pulse sub-structure are well visible after the reconstruction.



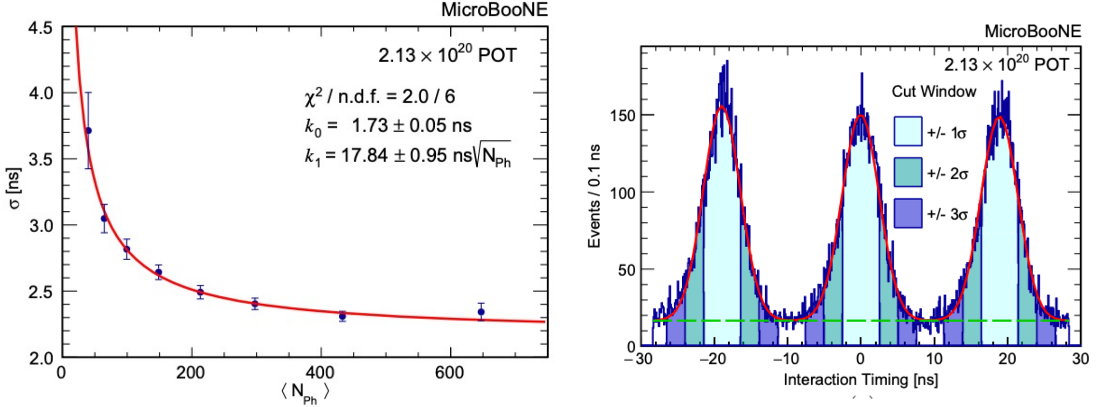


FIG. 12. Interaction timing resolution as a function of the total number of photons detected.