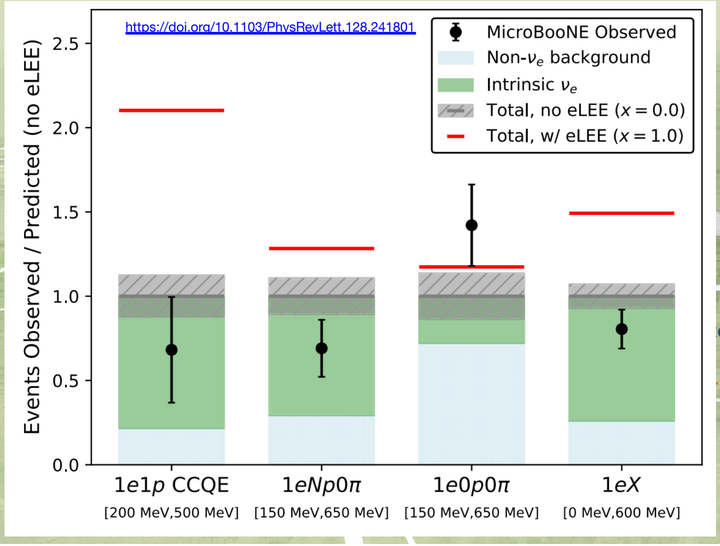
Light Yield Calibration and Stability Throughout MicroBooNE's 5 Years of Data Taking

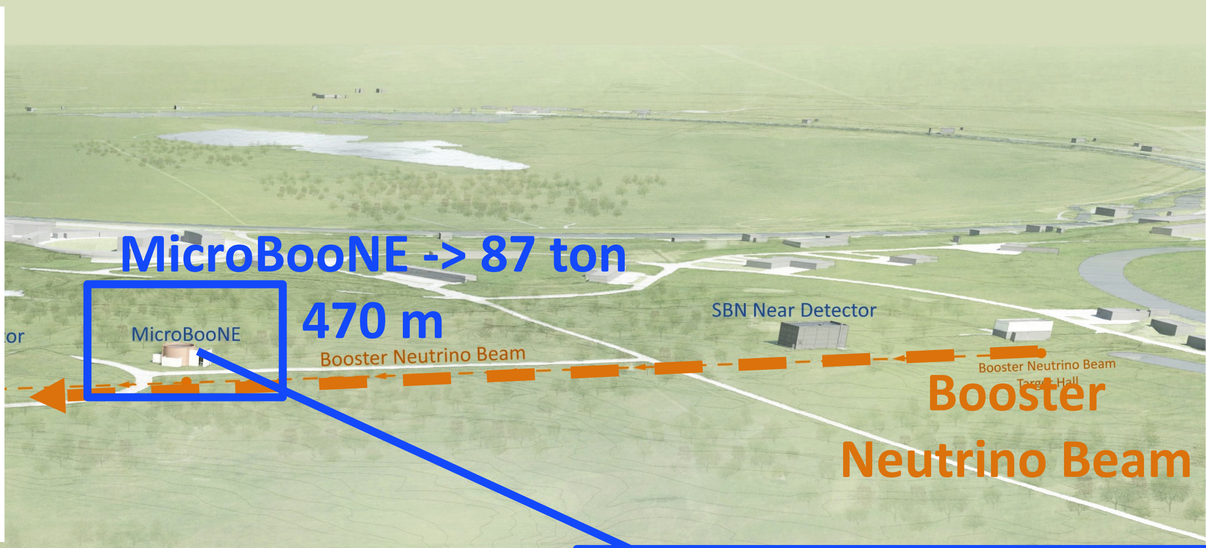
Vincent Basque For the MicroBooNE Collaboration

LiDINE 2022

21/09/2022

Short-Baseline Program & MicroBooNE

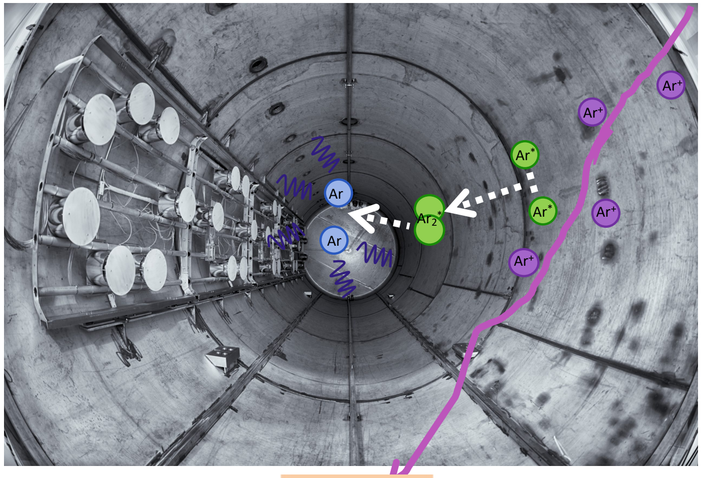


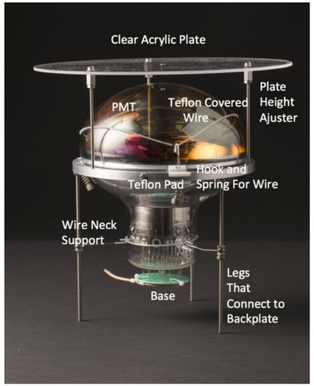


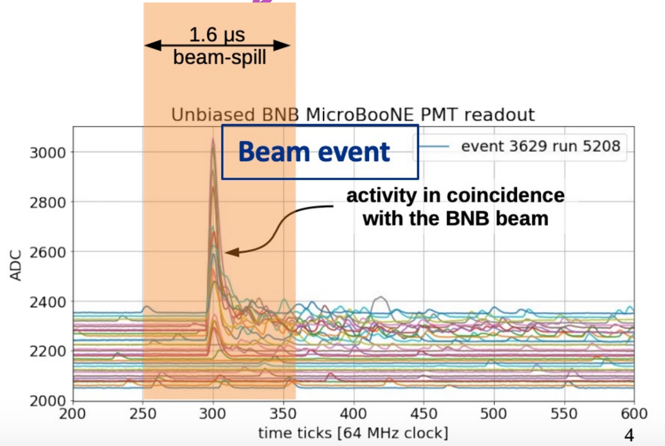
- MicroBooNE is a 2.56 m by 2.33 m by 10.36 m LArTPC.
- It ran from 2015 to 2021 (main physics + R&D campaigns).
- Its main physics goal is to determine whether the observed MiniBooNE excess is electron-like or photon-like.
- It will also perform cross section measurements of neutrino-argon, BSM, and LArTPC R&D.

Scintillation Light in MicroBooNE

- MicroBooNE detects the VUV light using 32 8” Hamamatsu R5912-02 MOD PMTs placed behind acrylic plates painted with TPB + polystyrene.
- Main usage: Identifying in-time TPC events by matching with light flashes (t_0 for x position, rejection of cosmic).
- When a beam neutrino interacts, the PMTs will see an increase in the amount of light in the expected beam-spill time window.







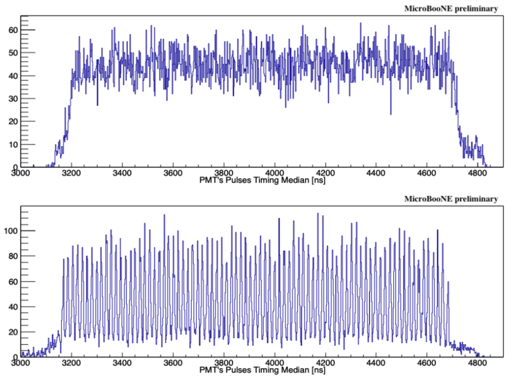
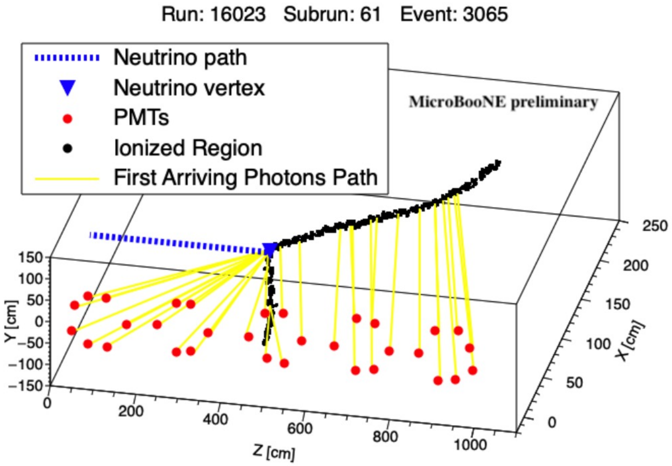


Figure 7: Top: neutrino interaction timing distribution before the reconstruction. Bottom: neutrino interaction timing distribution after the reconstruction. The 81 bunches composing the $\sim$1.6 μs beam pulse sub-structure are well visible after the reconstruction.



MICROBOONE-NOTE-1115-PUB

Demonstration of <2 ns timing resolution for neutrino interaction in the MicroBooNE detector

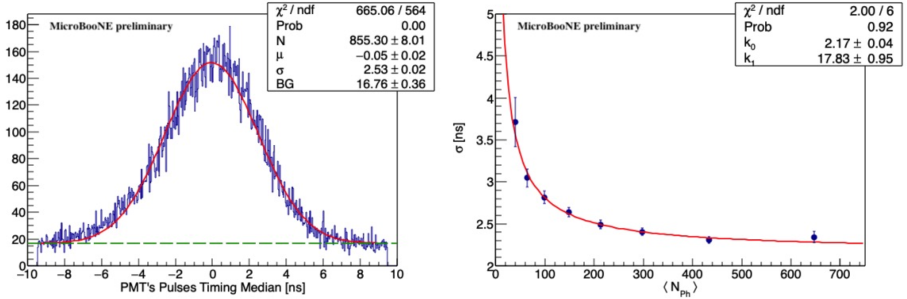
8.1 Detector intrinsic timing resolution

A characterization of the timing resolution versus the total number of detected photons is made. The parameter σ versus the total number of detected photons, shown in Figure 12 right, is fitted using the function:

$$\sigma\left(\langle N_{Ph}\rangle\right) = \sqrt{k_0^2 + \left(\frac{k_1}{\sqrt{\langle N_{Ph}\rangle}}\right)^2} \tag{3}$$

The k_1 parameter is associated to the statistical uncertainty ($\propto \sqrt{N_{Ph}}$). The constant term k_0, independent of the number of photons detected, is associated with the intrinsic resolution. As for R_{Tot}, the beam bunch width is subtracted from k_0 obtaining the final value for the intrinsic detector timing resolution (R_{Int}) for ν_μCC candidate events:

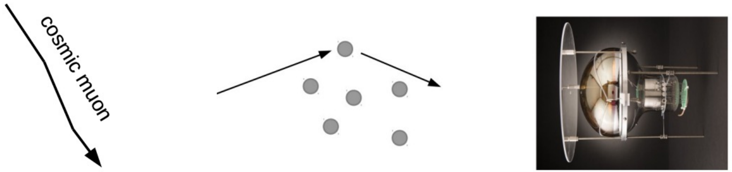
$$R_{Int} = \sqrt{k_0^2 - \sigma_B^2} = \sqrt{2.17^2 - 1.31^2} = 1.73 \pm 0.04\,ns \tag{4}$$



Light Detection System Calibration

- MicroBooNE has developed a continuous calibration of its light response throughout its lifetime to:
  - Ensure a proper understanding of the behaviour and stability of the light detection system over time.
  - Be able to use calibrated physical quantities (photo-electron) in data analyses.

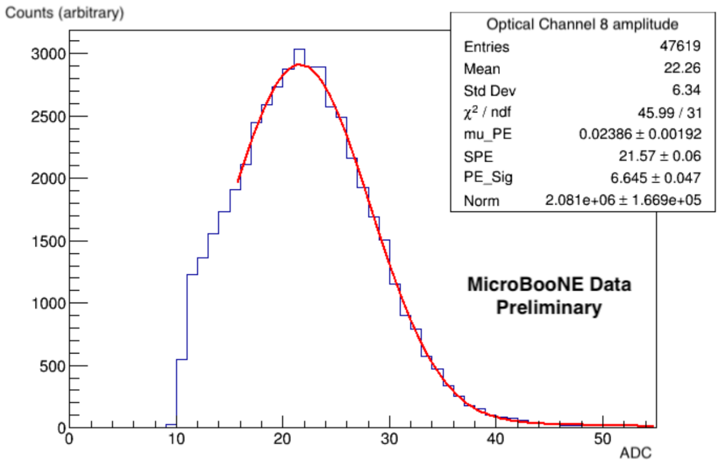
- Calibration consists of:
  - Calibrate continuously the **PMT gains** while the detector is running.
  - Use a data-driven calibration of the **light response variations** over time in terms of light yield in PE/MeV.

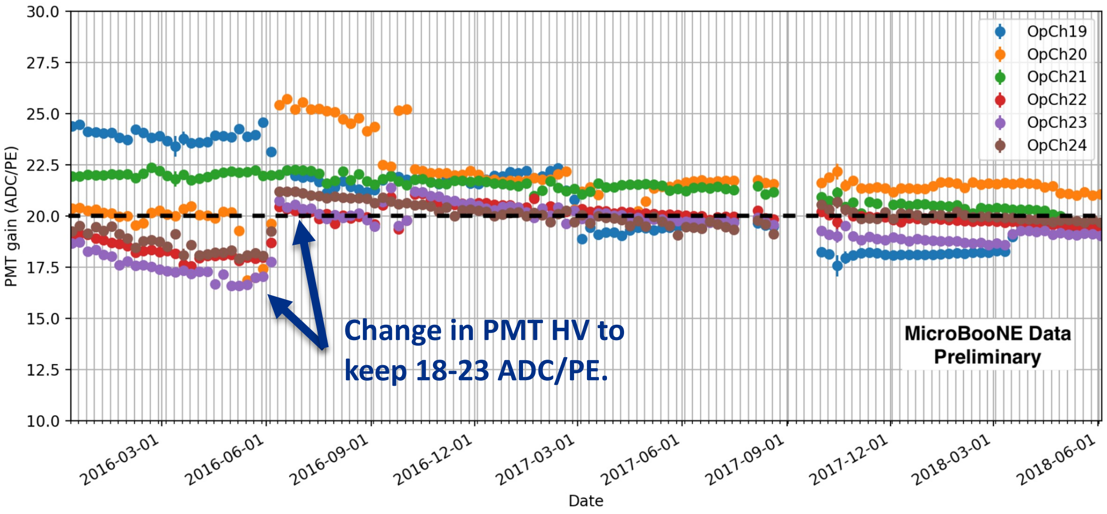


(1) MeV → ɣ (2) photon transport (3) ɣ → PE

PMT Gain calibration

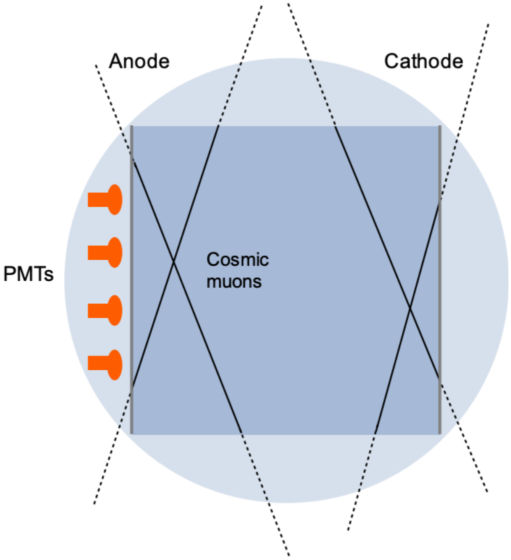
- PMT gain calibration algorithm has been implemented by:
  - Fitting the response to the Single Photo-Electron (SPE) noise (~200 kHz SPE noise rate).
- The fluctuations over time are caused by a combination of a change of the temperature, HV, intensity/frequency of incident light.

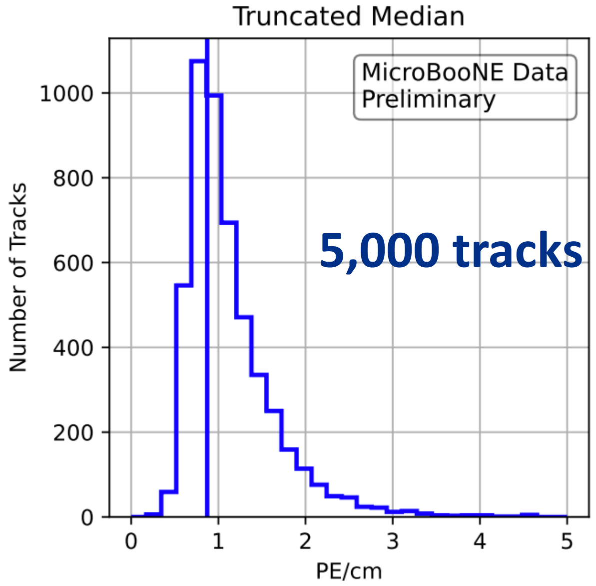




Time-Based Light Yield Stability Measurement – Method

- We look at tracks that pierce the anode or the cathode and look at the amount of light they produce (e.g. lowest and largest drift distance).
- These tracks can be selected without light information.
- Metric for light yield response:
  - Tracks sorted into time bins with equal statistics (varying bin width).
  - PE/cm evaluated using truncated median of distribution in each bin (disregards the tail and avoids a potentially bias fitting).

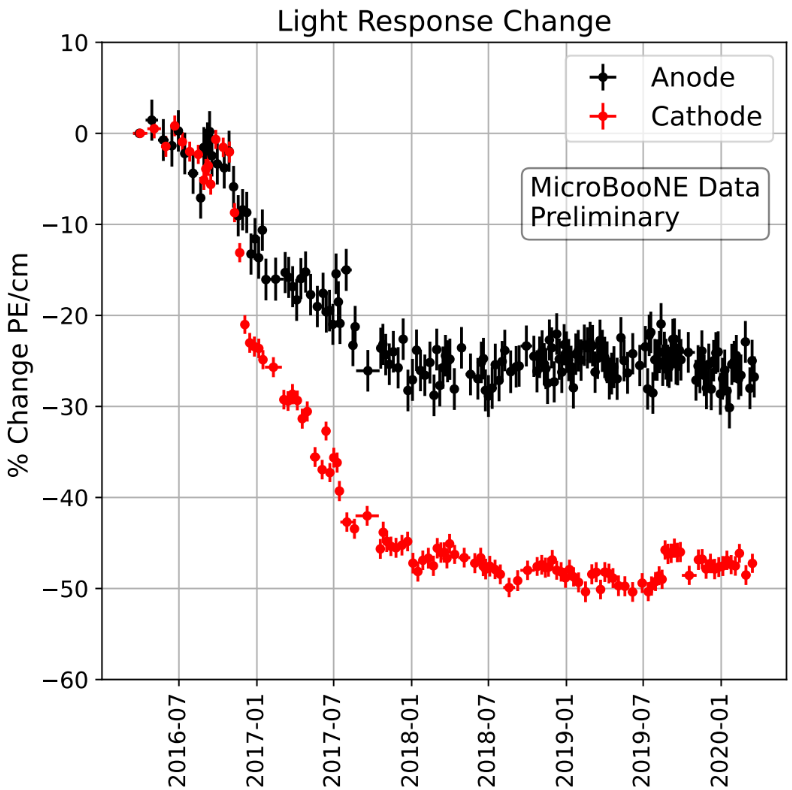




Time-Based Light Yield Stability Measurement – Results

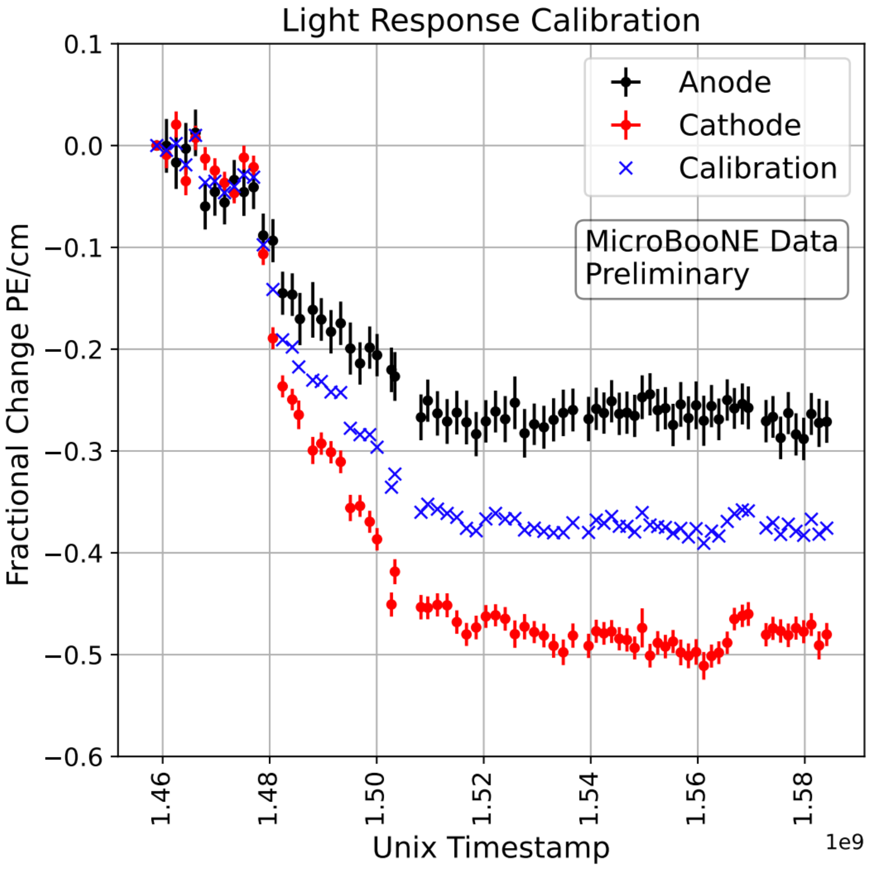
µBooNE

- The truncated median is used to populate the light response change by comparing to the first time bin.
- Here we show the relative change for tracks at the **anode (black)** and **cathode (red)**.
- By mid 2018, the light yield at the cathode is nearly ½ of what it was initially but then stabilizes.
- **Important feature**: the amplitude of the decline is different at the anode compared at the cathode.

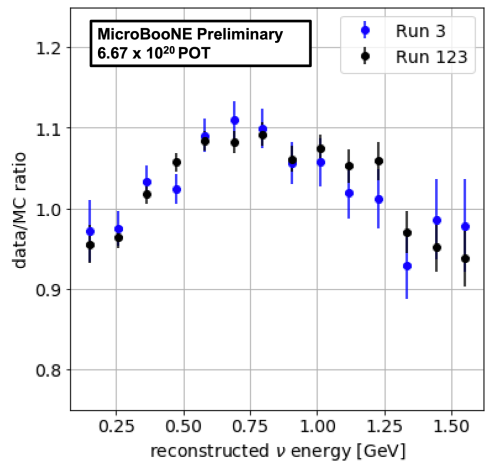


Light Yield Calibration

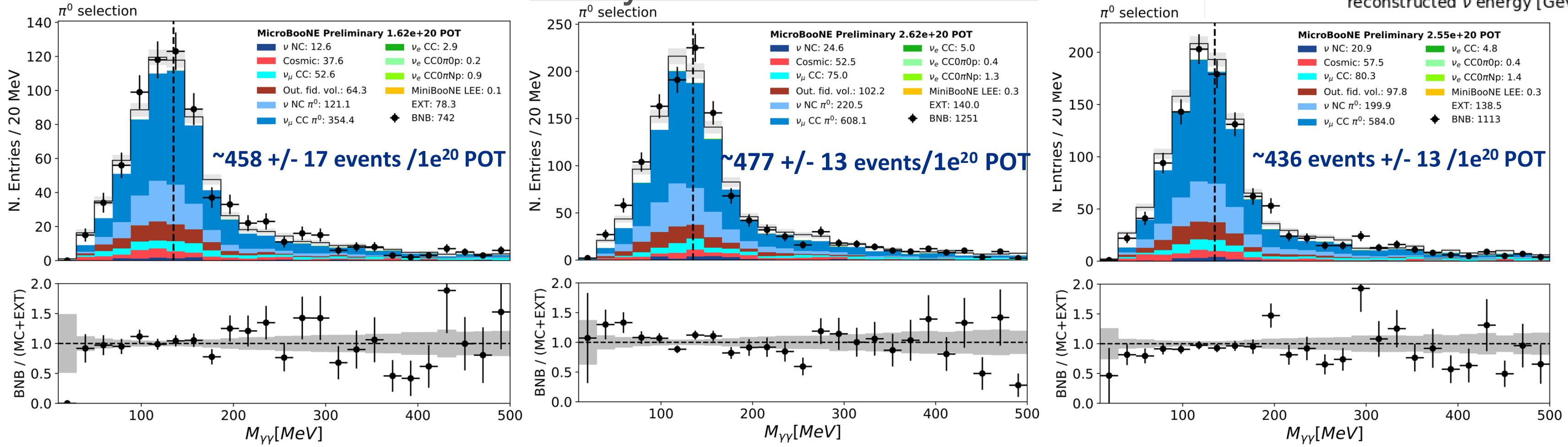
- The calibration values, in blue, are simply the average between the anode and cathode tracks.
- Uncertainty in nature of position-dependence motivates choice of average as calibration. Difference accounted for through systematic uncertainties.
- The calibration is model independent (assumes no absorption).



Effects of the Light Yield Decline on Analyses



- We account for the light decline with systematic samples.
- We need to verify that our physics analyses are still valid are not impacted by the decline.
- We do this by looking at the data/MC ratio of the selected $\boldsymbol{\nu}_{\mu}$ is stable between runs and similarly with the π^0 mass selection.



(a) Run1 π^0 mass (b) Run2 π^0 mass (c) Run3 π^0 mass

Potential Sources of Decline

- *What could cause the light decline?*

Potential Sources of Decline

- *What could cause the light decline?*

Is it the argon?

Is it the PMTs?

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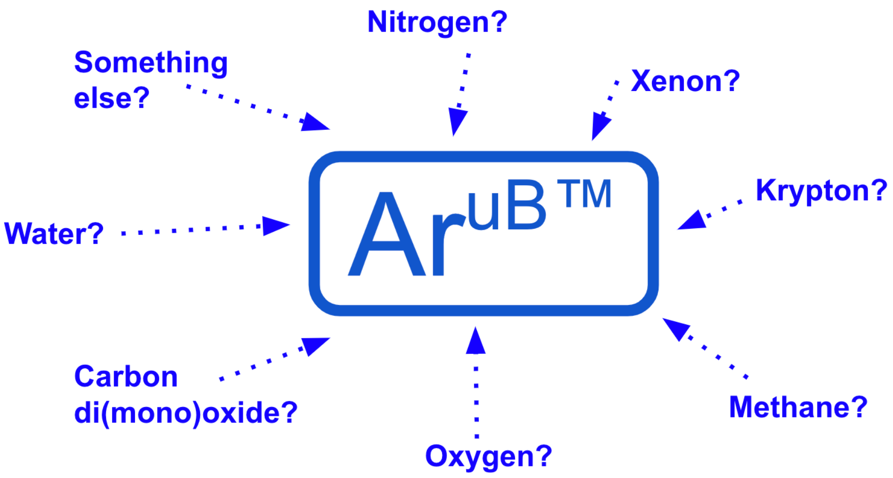


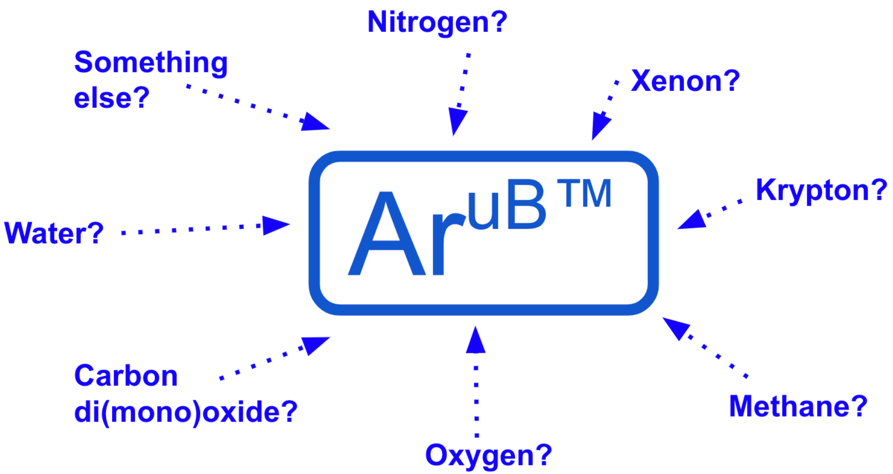
Light transport? Quenching? Absorption? Scattering?

Is it the PMTs?

Potential Sources of Decline

- *What could cause the light decline?*

Is it the argon?



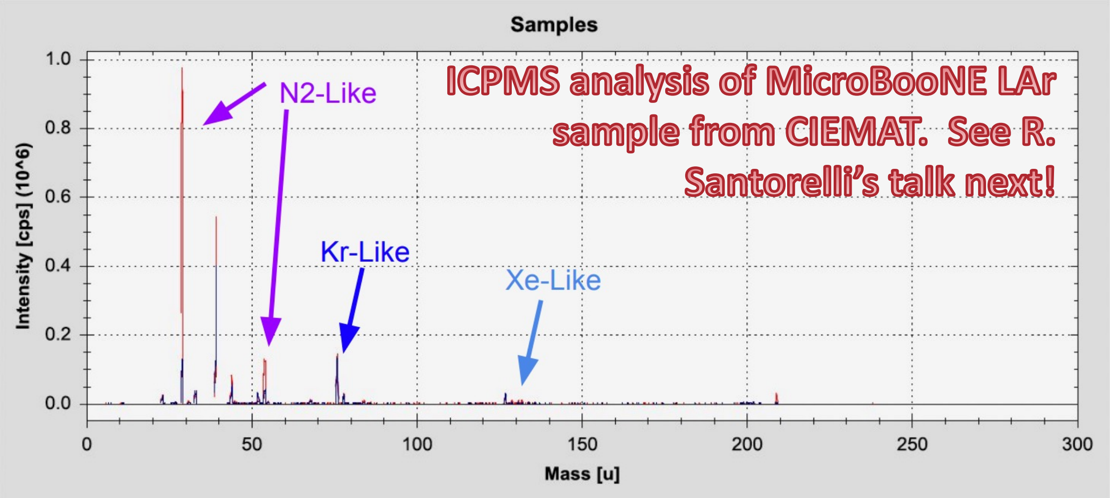
Light transport? Quenching? Absorption? Scattering?

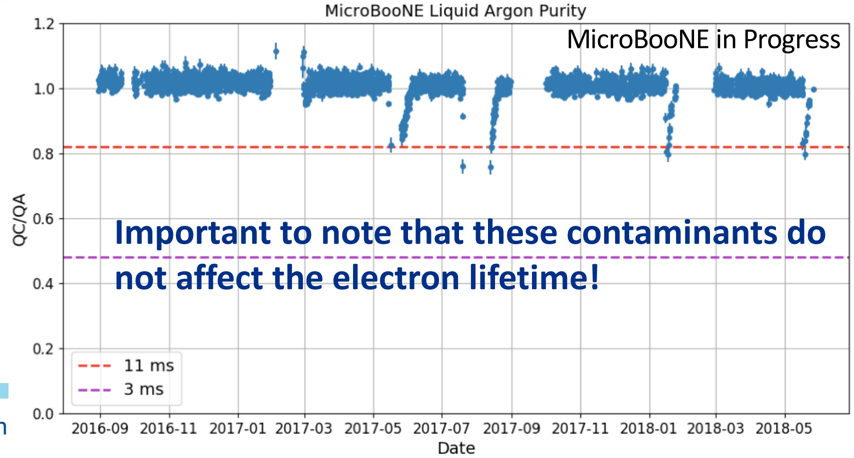
Is it the PMTs?

TPB degradation? PMT QE? Digitization? Gain?

Impurities in MicroBooNE

- The CIEMAT DM group has kindly analyzed a sample of our argon after a discussion at a previous LiDINE. Thank you Roberto Santorelli!
- They have found that we have *more* nitrogen, krypton and even xenon compared to commercial high purity argon.
- These can quench (late light) and/or absorb the light.
- We do not currently have an absolute value of the concentration but good guesses.



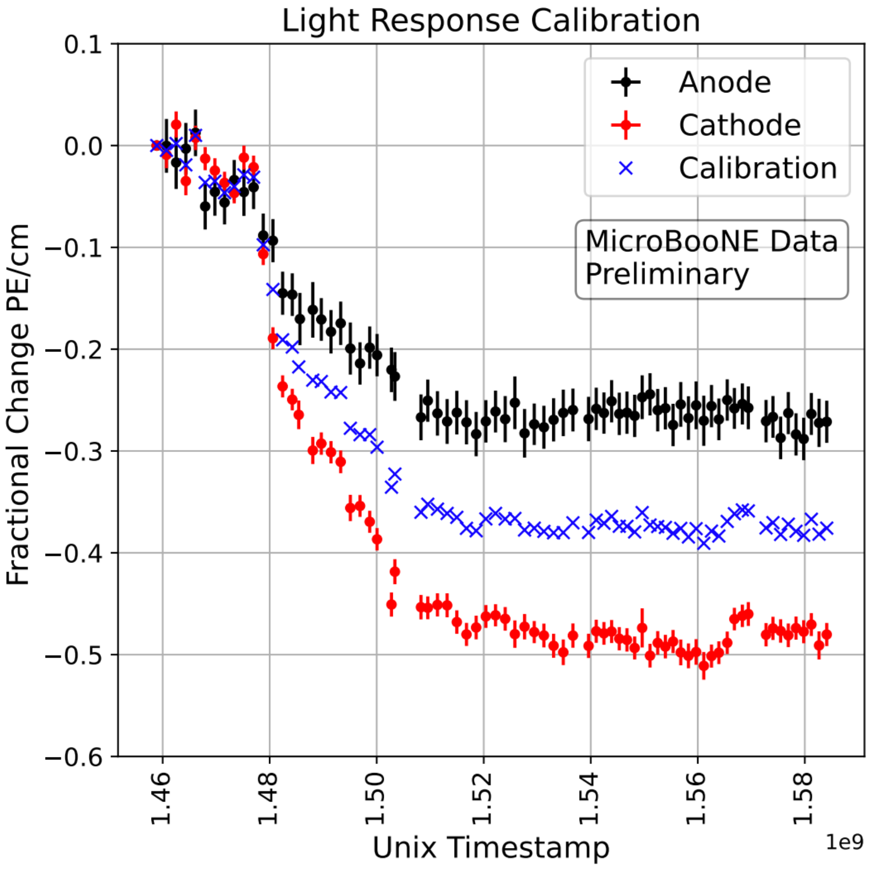


On-going Investigation Related to the Light Decline

- Cosmic muons could potentially bias the light yield spread (anode vs cathode) with:
  - Cherenkov light.
  - Saturate the PMTs with their long tracks.
- We currently have other analyses on going to study the light decline using other samples:
  - Protons from cosmic neutron producing shorter non-MIP particles tracks (**see Li Jiaoyang's talk on Friday!**)
  - Michel electrons from stopping cosmic muons to give point source-like particles tracks.
- Since MicroBooNE is turned off, we have opportunities for further studies during decommissioning (e.g. TPB ageing, impurities).
- All of this will be important knowledge for the long-term operation of SBN (SBND + ICARUS) and DUNE.

Summary

- MicroBooNE is the longest running surface LArTPC and has a lot to share with the community.
- Light yield calibration has been performed from run 1 all the way to run 5! This is an important step for MicroBooNE's physics results to release the second half of our dataset.
- Full cause of the decline is still unknown but there are various investigations in progress.
- A public note on this work can be found MICROBOONE-NOTE-1120-TECH.
- A paper is in the pipeline as well.

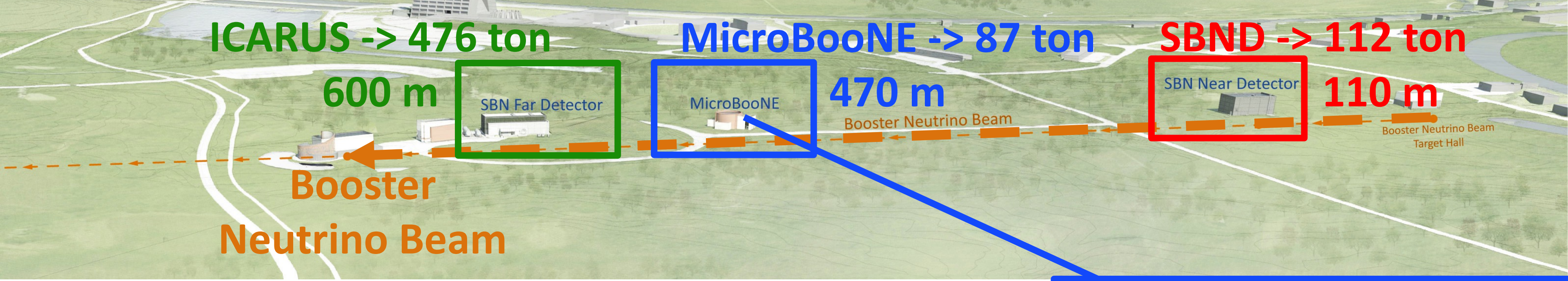


Thank you!

Short-Baseline Program & MicroBooNE

µBooNE

Short-Baseline Neutrino (SBN) program at Fermilab consists of 3 LArTPCs at different baselines to probe the MiniBooNE electron-like excess and oscillations with $\Delta m^2 \sim 1eV^2$.



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MicroBooNE Physics Results

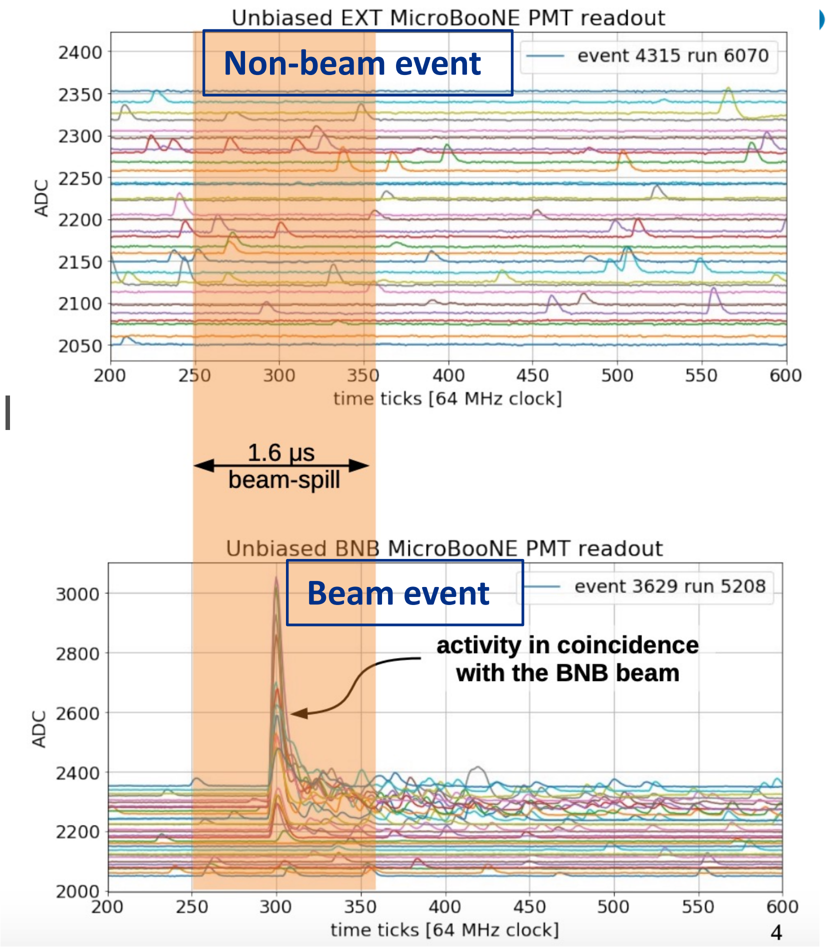
µBooNE

- MicroBooNE has entered a new era since the end of data taking.
- We have released the first round of our flagship analysis: testing the MiniBooNE LEE model using ½ of our dataset
- We have published many many other detector physics, cross section measurements and BSM physics analyses + many more to come!

5+ papers draft on light in MicroBooNE coming up!

Scintillation Light in MicroBooNE (2)

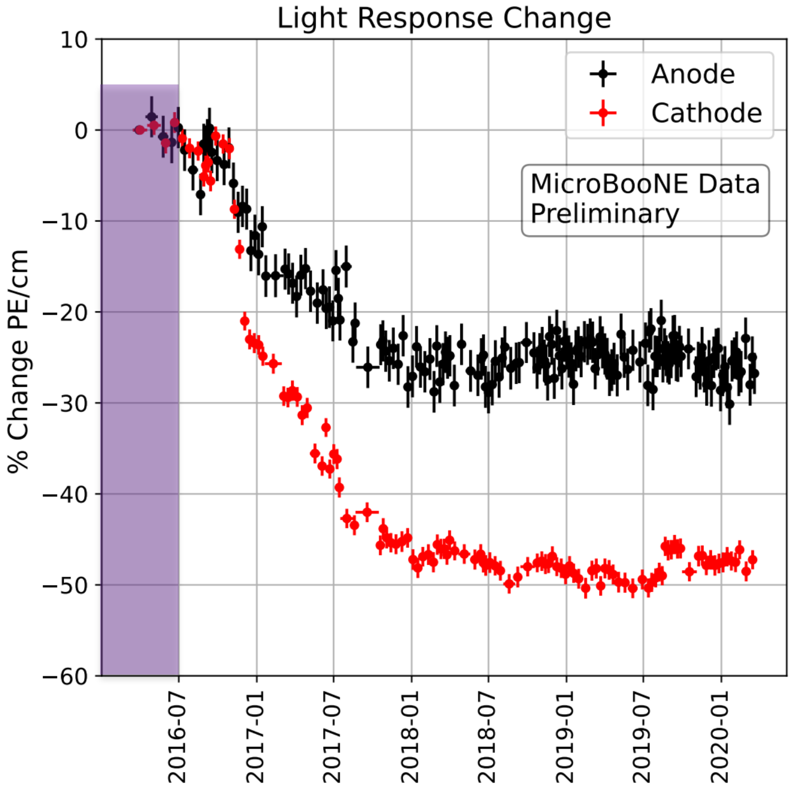
- MicroBooNE sitting on the surface see's a high rate of cosmic background.
- It is important to be able to distinguish those with neutrino beam events.
- When a beam neutrino interacts, the PMTs will see an increase in the amount of light in the expected beam-spill time window.
- Triggering Threshold > 5 PE for 1 PMT.
- Prompt light O(ns) is collected to provide the trigger and timing complimentary to the TPC information.



Fermilab

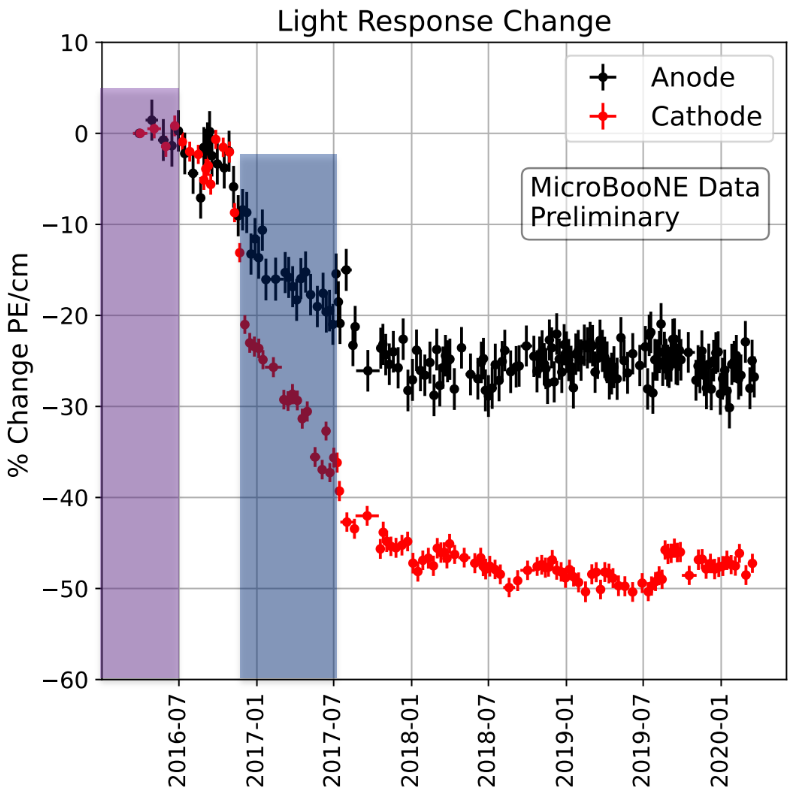
Time-Based Light Yield Stability Measurement – Results

- It shows that our light yield has been declining after the end of **run 1**



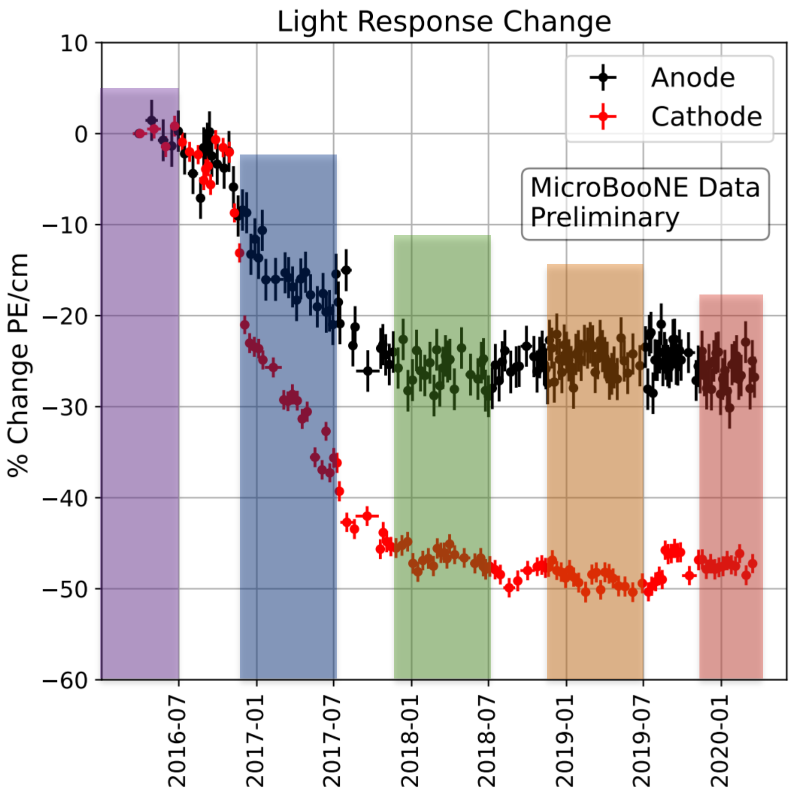
Time-Based Light Yield Stability Measurement – Results

- It shows that our light yield has been declining after the end of **run 1** with a sharper decline during **run 2**.



Time-Based Light Yield Stability Measurement – Results

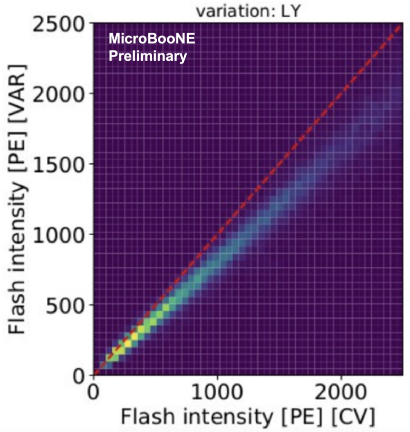
- It shows that our light yield has been declining after the end of **run 1** with a sharper decline during **run 2**. Some *stability* has been obtained throughout **run 3** and **run 4** until the end of **run 5** where the light yield has nearly ½ at the cathode.
- The *gaps* between each run represent the annual beamline shutdown.

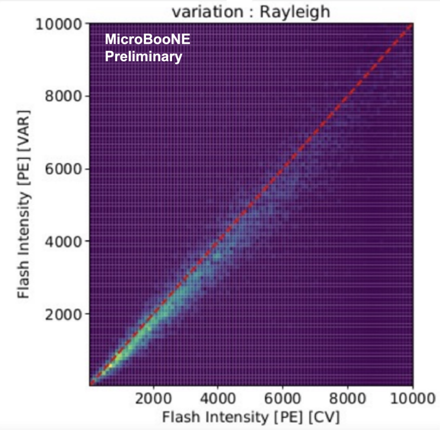


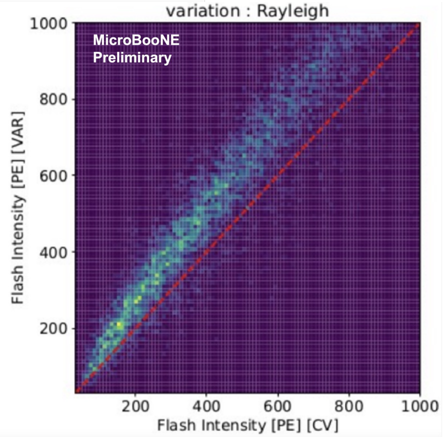
Light Yield Modelling & Decline as Systematic Uncertainty

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.





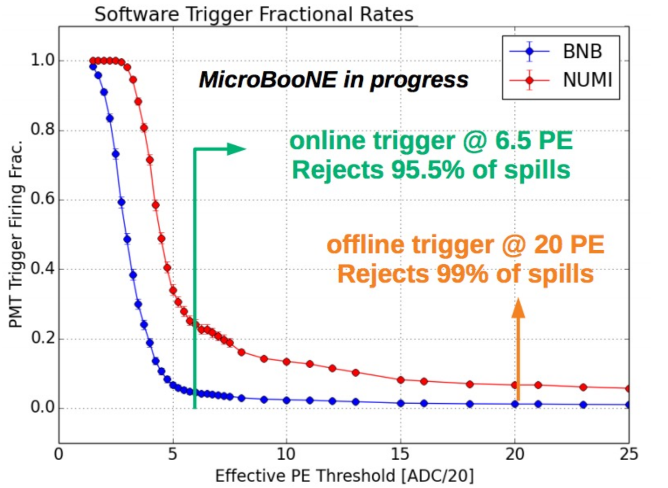


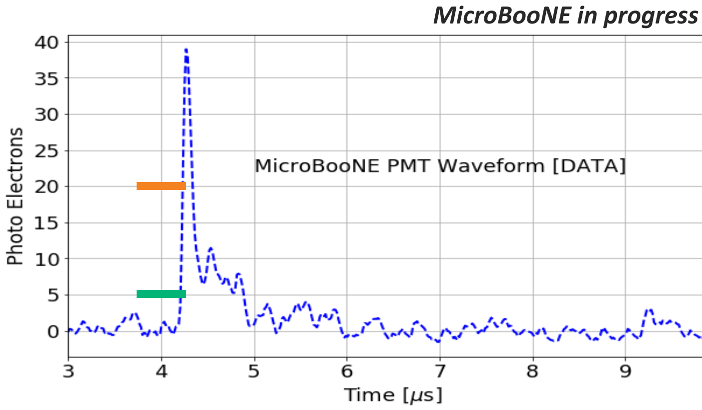
*MicroBooNE has not yet moved to the ~100 cm RSL value

Light Triggering in MicroBooNE

- MicroBooNE collects a lot of data but not all of it can be saved and processed.
- Two software triggers exist in MicroBooNE based on amount of Photo-Electrons (PE) measured by the PMTs from prompt light in beam-window:
    1. Online -> >~5 PE to not be rejected for BNB.
    2. Offline -> >20 PE to be processed and used in current analyses to further reduce computing load.

- **What is the 20 PE triggering efficiency?**
- Measurement is compared with MC to test of light propagation models for MicroBooNE (e.g. Rayleigh scattering length, light decline).



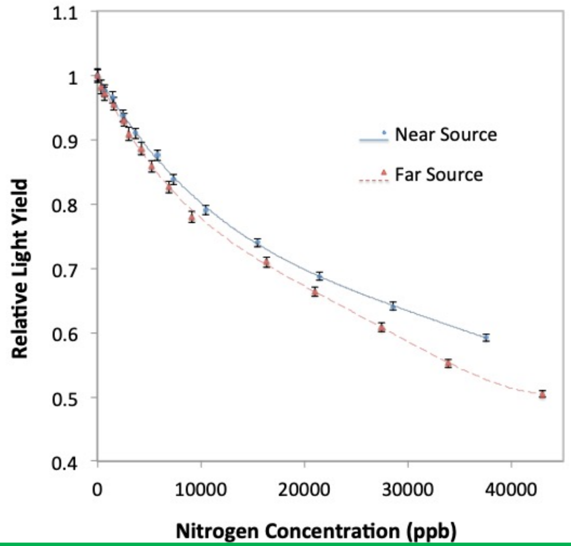


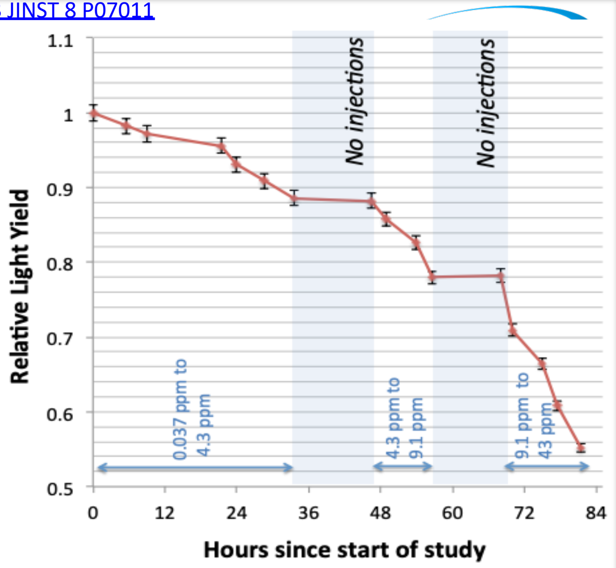
Fermilab

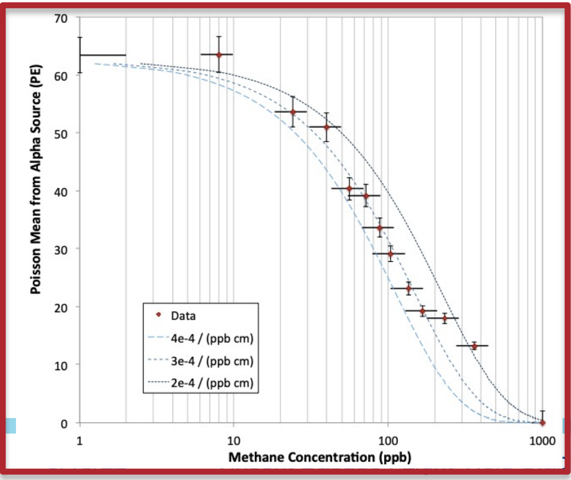
Light Contaminants

- There has been multiple studies on the effect of various contaminants on the light yield.
- The contaminants shown here are Nitrogen, oxygen, methane.

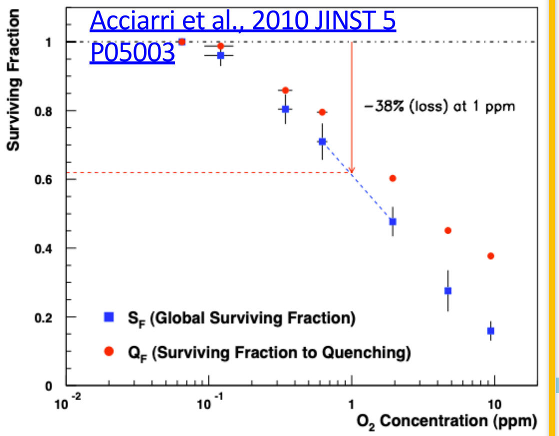
Jones et al., 2013 JINST 8 P07011



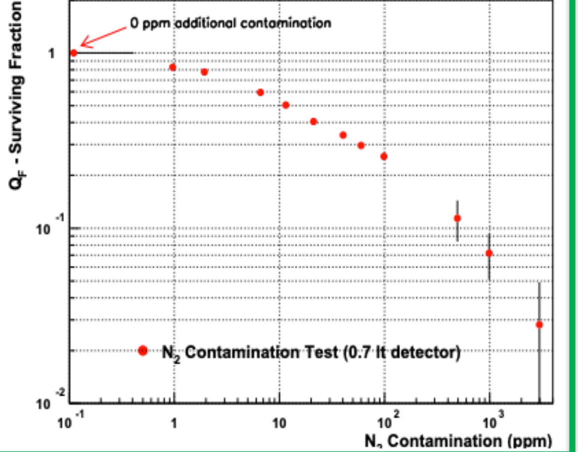




Acciarri et al., 2010 JINST 5 P05003

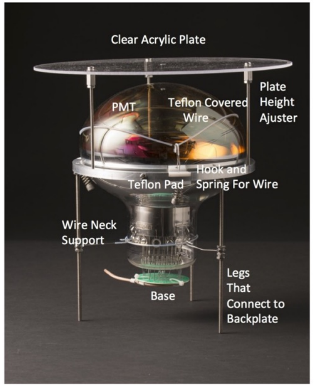


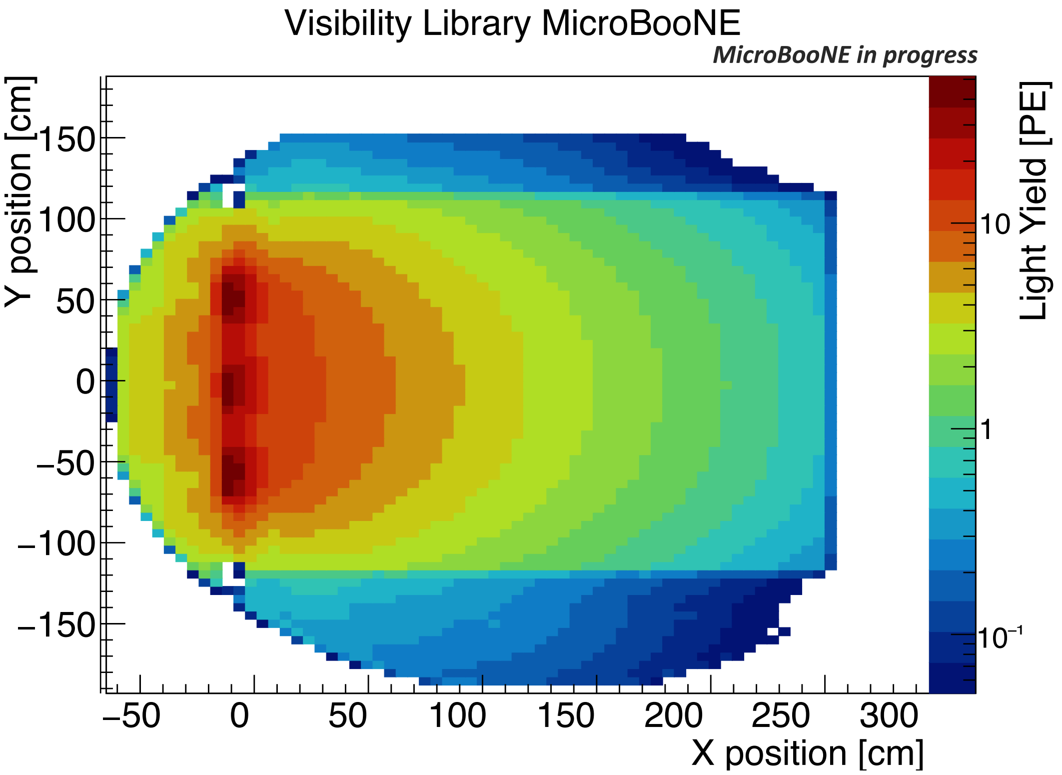
Acciarri et al., 2010 JINST 5 P06003



Light Yield in MicroBooNE

Semi-transparent anode and field cage



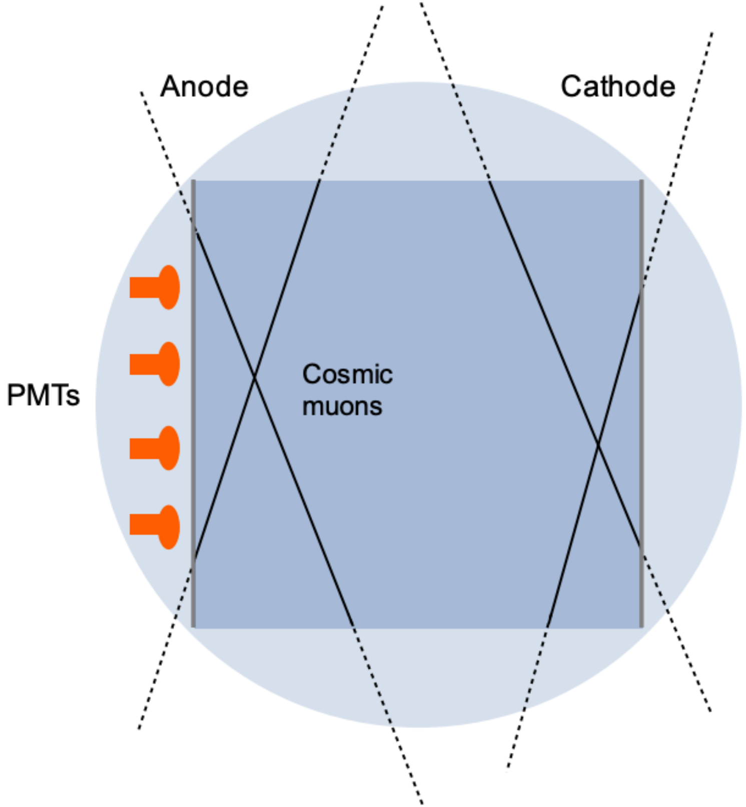


Opaque cathode

- Mapping of the light yield is calculated using a convolution of the Electrical Field map, geometrical acceptance of the PMTs and light propagation from Geant4.

Time-Based Light Yield Stability Measurement – Sample

- MicroBooNE uses Anode-Cathode-Piercing-cosmic muons to calibrate the light yield (reconstruction minimally dependent on light).
- We look at both tracks at the anode and at the cathode and look at the amount of light they produce (e.g. lowest and largest drift distance).
- Tracks are removed that have:
  - Length: L < 40 cm or L > 400 cm;
  - Total number of photons: PE > 10000 for Anode-piercing or PE > 1000 for Cathode-piercing tracks;
  - Start or end within 50 cm of the cathode for Anode-piercing or anode for Cathode-piercing tracks.



Time-Based Light Yield Stability Measurement – Sample

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