Detector physics at the MicroBooNE experiment

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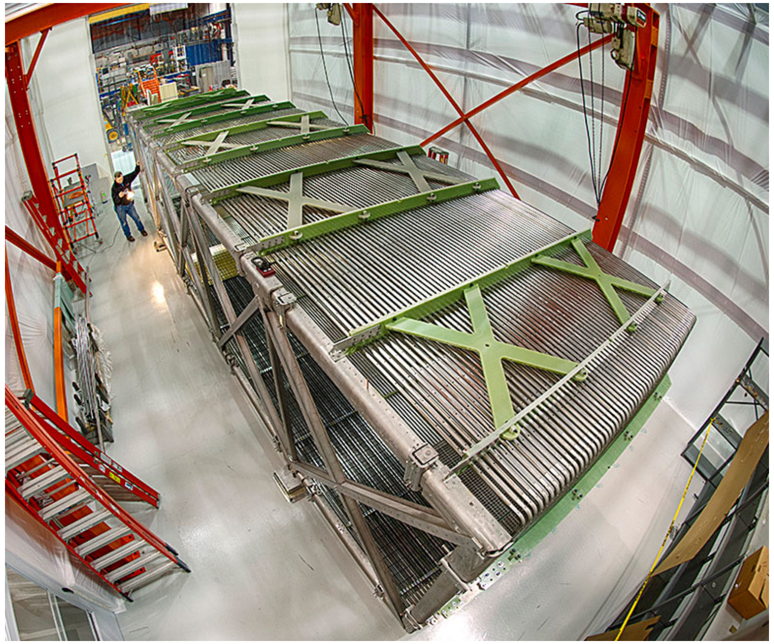
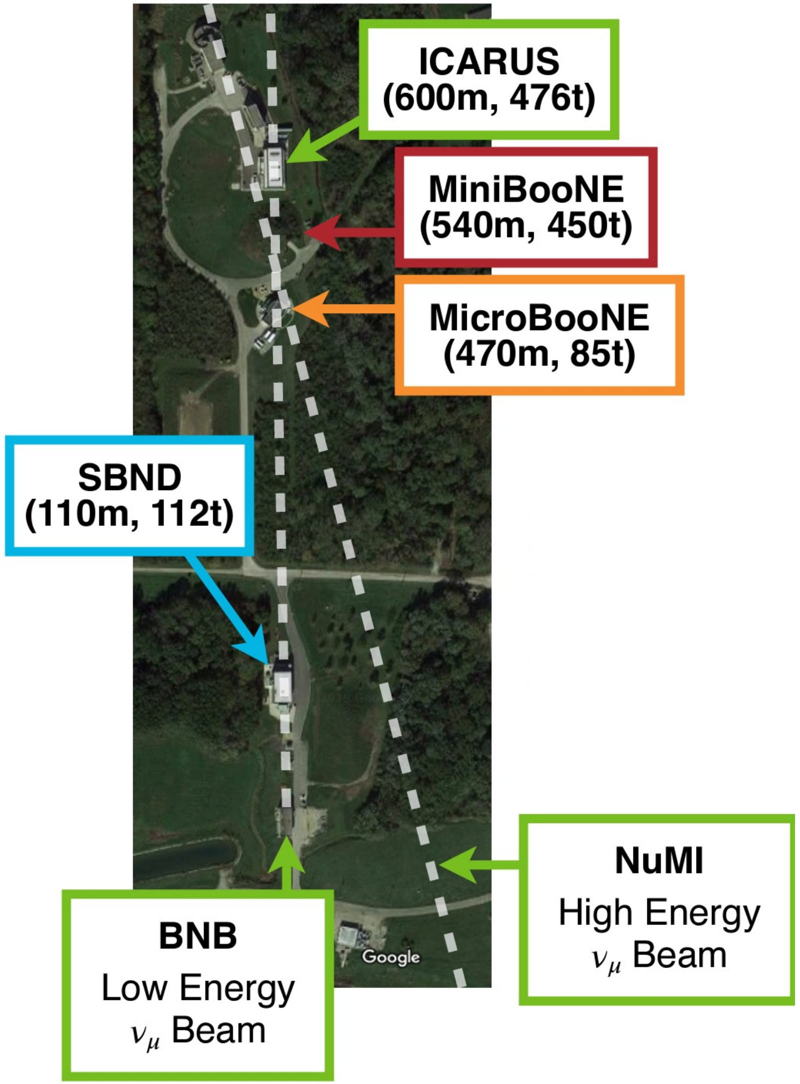
MicroBooNE experiment

MicroBooNE is an 85-tonne active mass LArTPC at Fermilab, US:

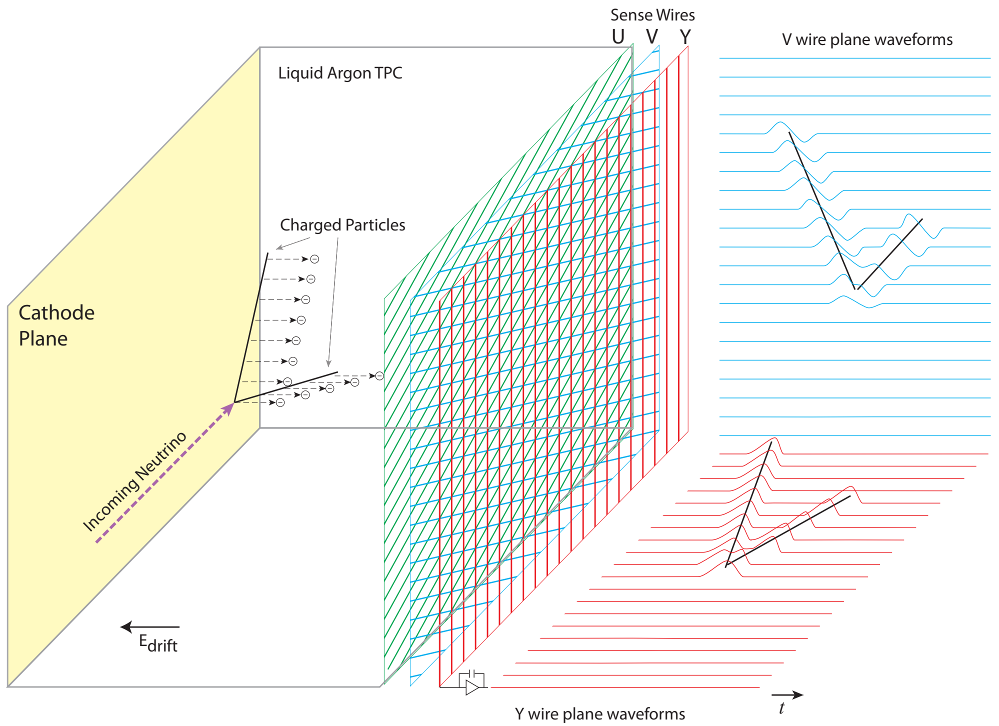
- two neutrino beams: BNB (8 GeV, on-axis), NuMI (120 GeV, off-axis)
- 5 years of beam data: world's largest dataset of neutrino interactions on Argon
- several post data-taking R&D runs, currently in decommissioning phase



Fermilab Neutrino Campus



MicroBooNE LArTPC



Fully active tracking calorimeter

3 planes of wires, collecting ionization charge

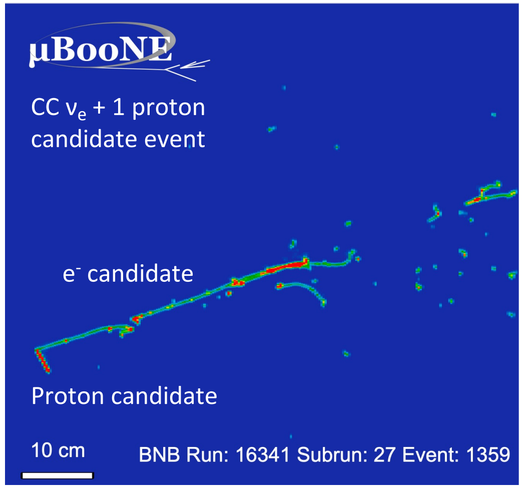
- vertical, +60° and -60° with 3mm wire spacing
- 2.6m drift length, E_{drift} = 273 V/cm

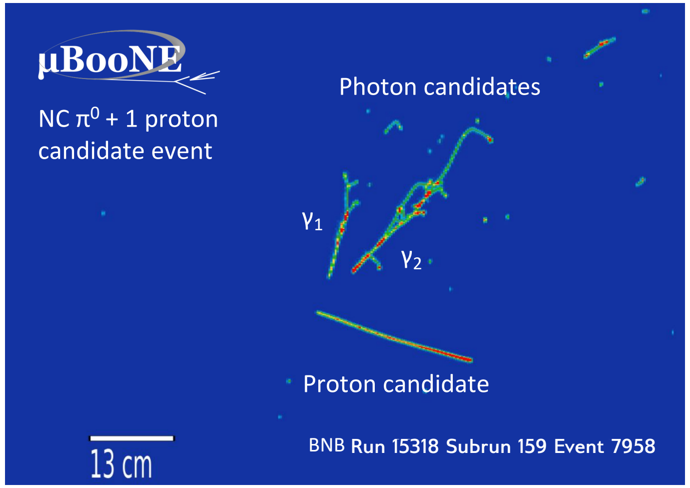
32 PMTs, collecting scintillation light

- located behind the wire planes at the anode

Precision neutrino measurements at scale:

- mm-level resolution, low thresholds
- excellent particle identification

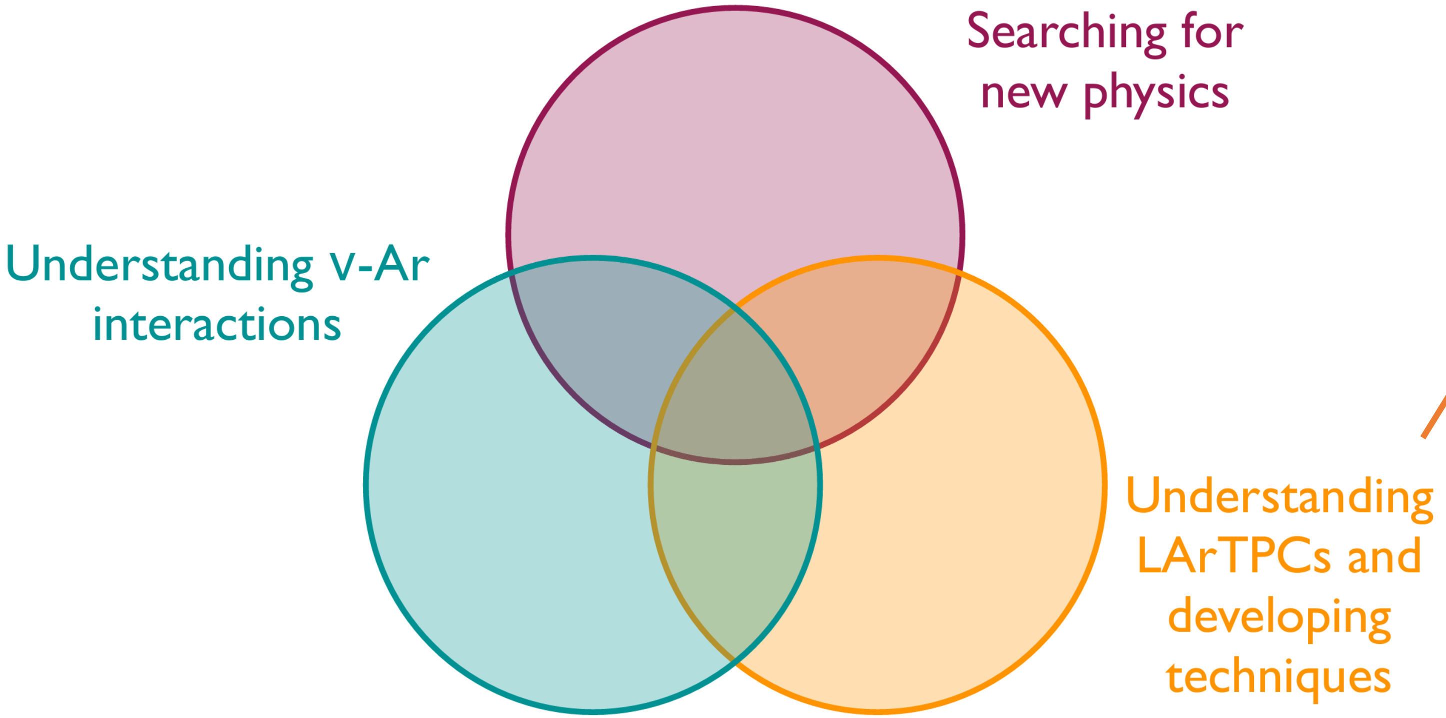




MicroBooNE physics

Broad physics program covering ν-Ar interactions, searches for new physics and detector physics:

- currently processing runs 4 and 5 – full data-set analyses coming soon!



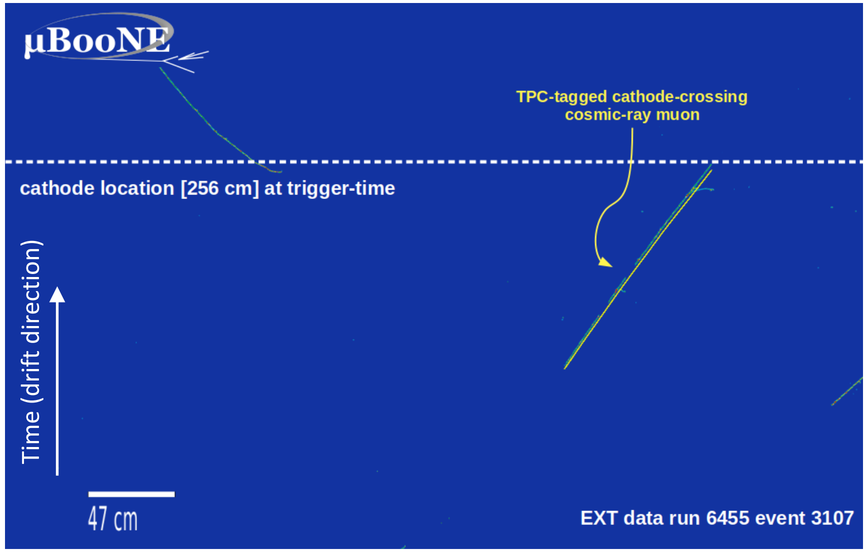
This talk:

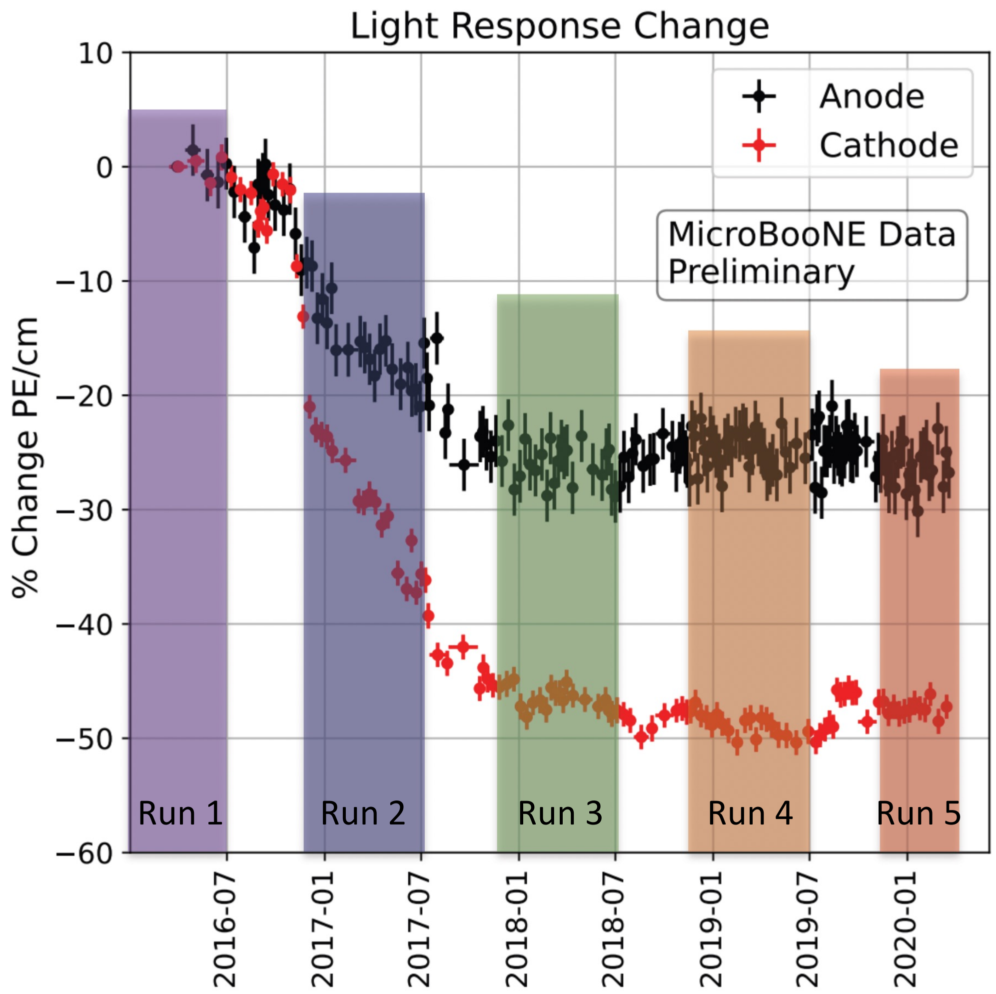
- light yield measurements
- ns-scale timing
- MeV-scale reconstruction
- R&D runs and decommissioning

Light yield stability over time

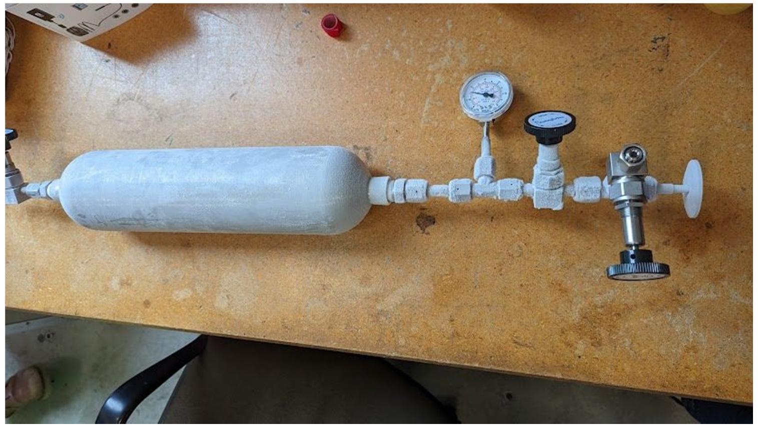
Light yield stability over time measured using anode/cathode piercing cosmic-ray muons: [MICROBOONE-NOTE-1120-TECH]

- significant decline observed between run 1 and run 3, ~25% at anode and ~45-50% at cathode
- cause unknown – investigations on-going





Argon gas sample measurement



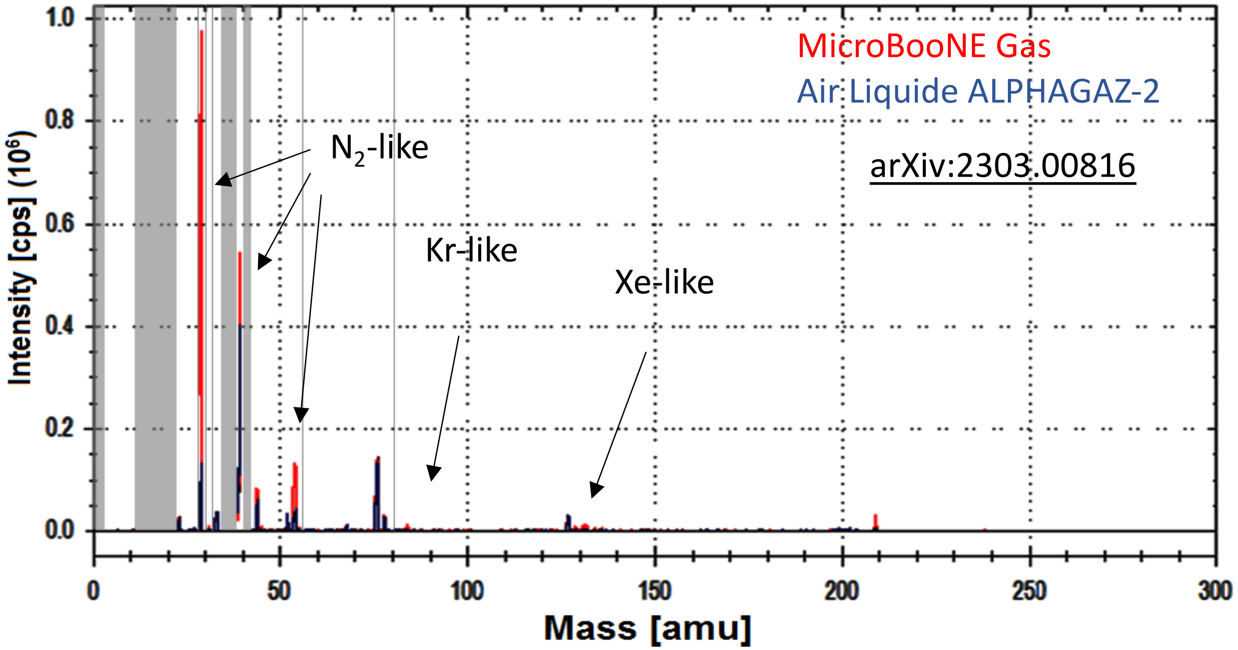
Possible cause of light yield decline: introduction of a contaminant that absorbs and/or quenches the scintillation light

Sample of argon gas extracted from detector and analyzed for contaminants:

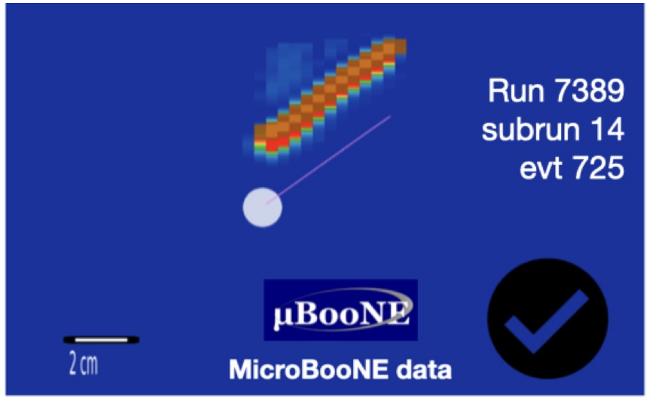
- ICP-MS measurement performed @ CIEMAT DM group [for details see arXiv:2303.00816]
- found Nitrogen-like polyatomic ions, Krypton and Xenon at higher level than commercial argon
- but, insufficient levels to explain decline

Technique used not sensitive to lower mass contaminants (grey bands):

- second argon sample extracted during de-commissioning – measurement(s) targeting these regions planned



Light yield with isolated protons



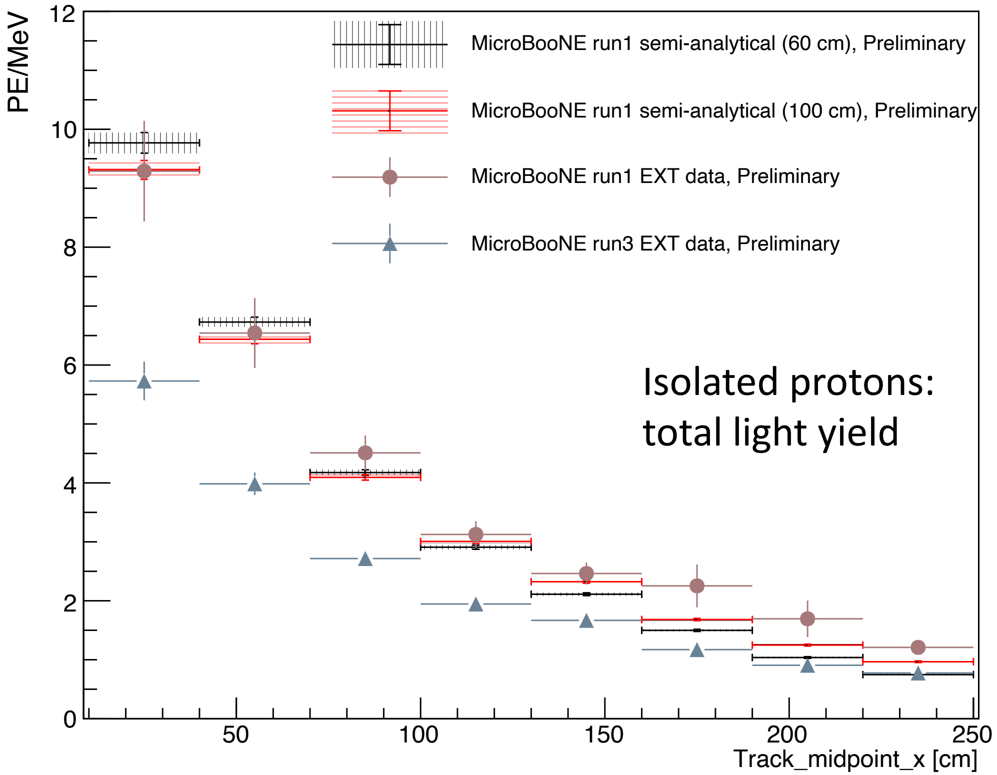
Cosmic-ray induced isolated protons:

- approximately point-like relative detector size – allows position dependent measurement
- but limited stats relative to muons – fine-grained time-dependence not possible

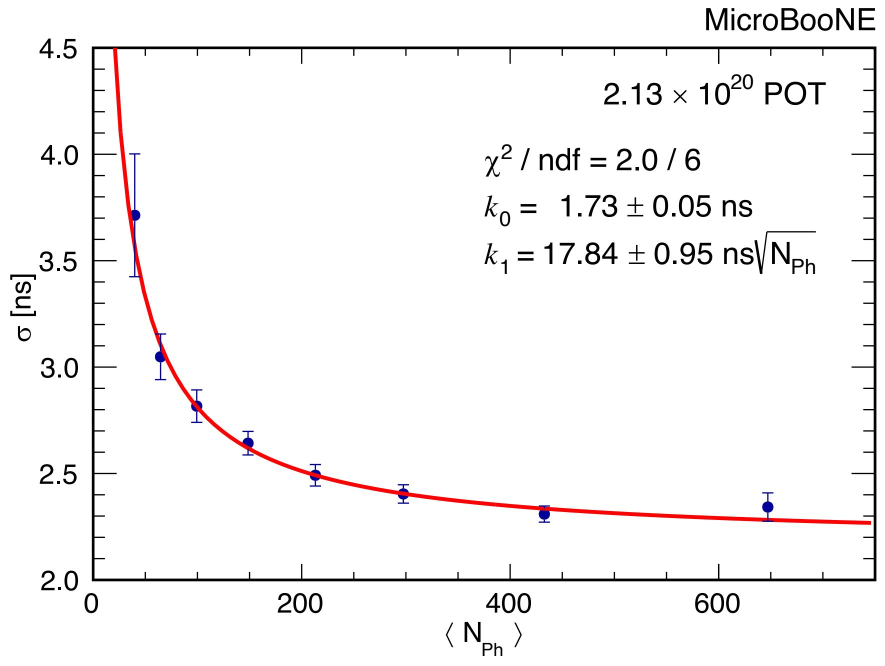
Total light yield and PMT-by-PMT light yield measured:

- observed expected dependence with distance from PMTs
- good agreement with simulation using semi-analytical model [Eur. Phys. J. C 81 (2021) 4, 349]
- see ~40% decline in light yield between runs 1 and 3
- for details see: MICROBOONE-NOTE-1119-PUB

Complimentary measurement on-going using Michel electrons



Nanosecond scale timing

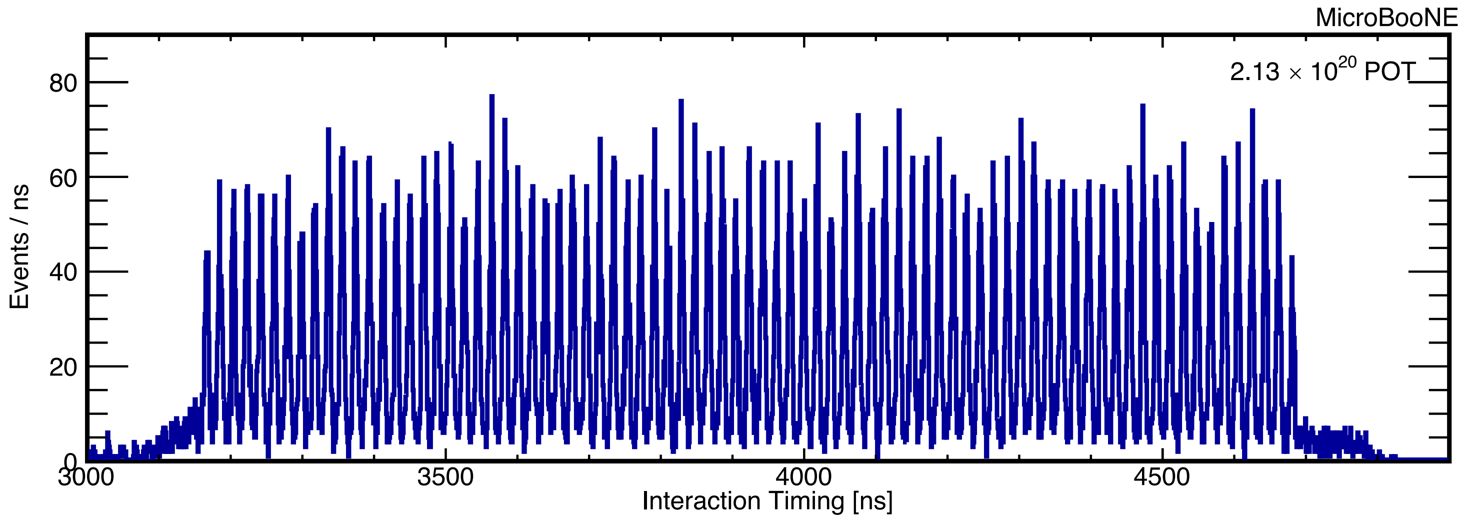


Neutrino interaction time reconstruction with O(1 ns) resolution achieved in MicroBooNE:

- prompt scintillation light signal, correcting for propagation and electronics response
- intrinsic resolution of **1.73 ± 0.05 ns**
- significantly improvement on previously reported resolution of O(100 ns)

Can resolve BNB beam structure:

- beam spill 1.6 μs
- 81 proton bunches per spill (~2 ns width)



For details see: arXiv:2304.02076 (accepted by PRD)

Applications of O(1 ns) timing

BNB beam structure can be used to mitigate backgrounds

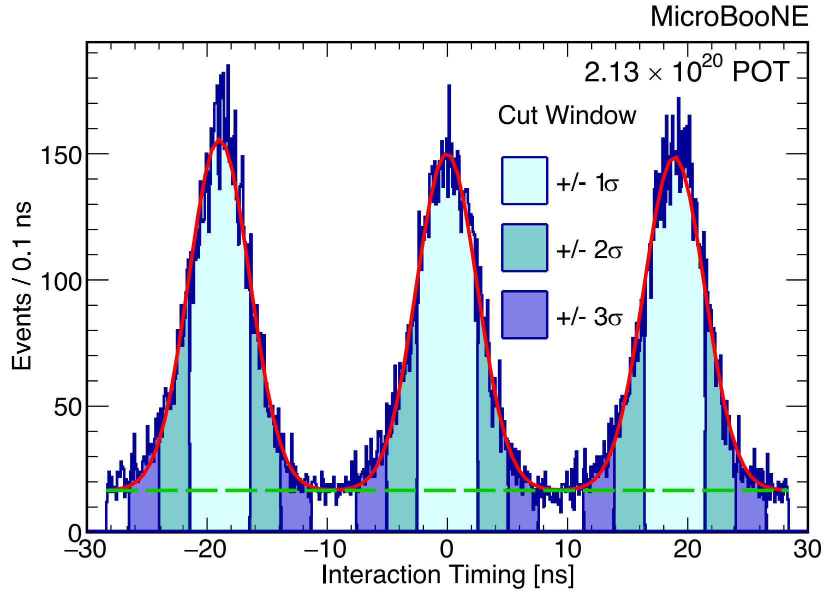
Neutrino selection / cosmic-ray rejection:

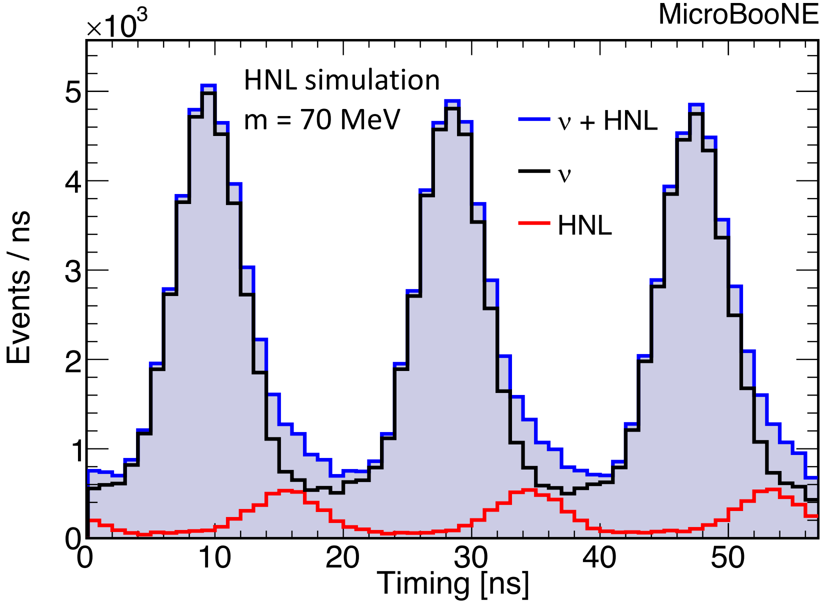
- surface detector – significant background from cosmic-rays
- can mitigate by cutting around each bunch
- example ±2σ cut applied to ν_μ CC selection:
    - 95.5% signal efficiency, rejects 46.6% of cosmic-rays

Searches for BSM particles:

- arrival of BSM particles (e.g. HNLs) at detector delayed relative to neutrinos due to their mass
- reduce neutrino background by searching between bunches

For details see arXiv:2304.02076 (accepted by PRD)

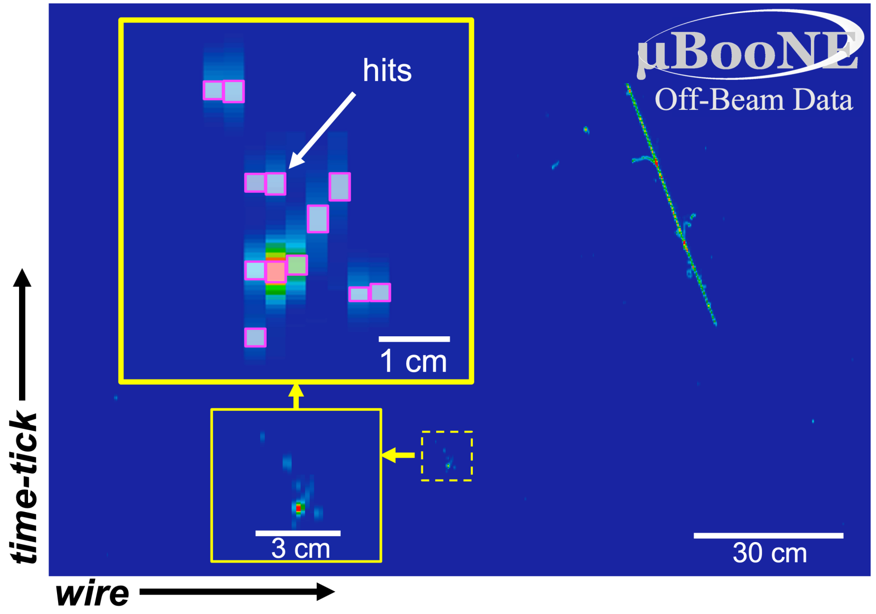


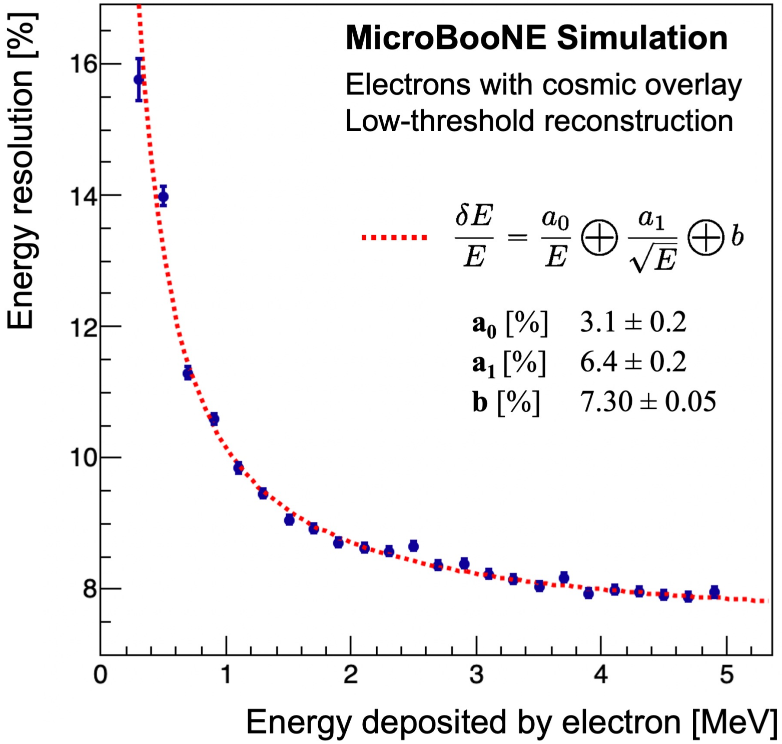


MeV-scale reconstruction

LArTPC neutrino detectors capable of reconstructing low-energy signals:

- pioneered by ArgoNeuT, threshold 300 keV
- Phys. Rev. D 99 012002 (2019))





Further developed by MicroBooNE:

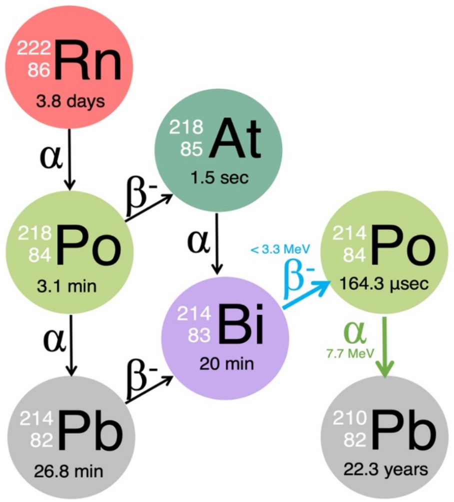
- "blip" reconstruction, threshold 75-100 keV
- energy resolution 10% @ 1 MeV
- JINST 17 P11022 2022, arXiv:2307.03102

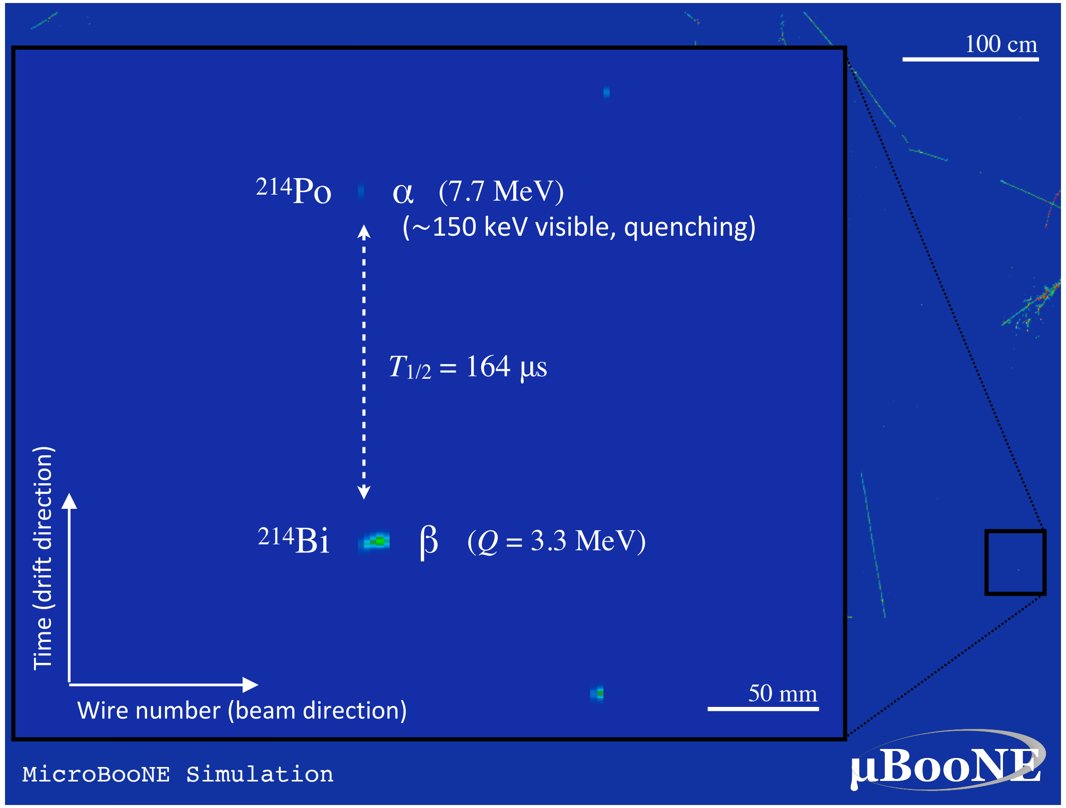
MeV-scale reconstruction: radon identification

Example application of MeV-scale reconstruction in MicroBooNE:

- measuring ^{222}Rn activity by tagging Bi-Po decays

^{222}Rn forms background to low-energy searches, e.g. astrophysical neutrino in DUNE





R&D run: radon mitigation in LAr filtration system

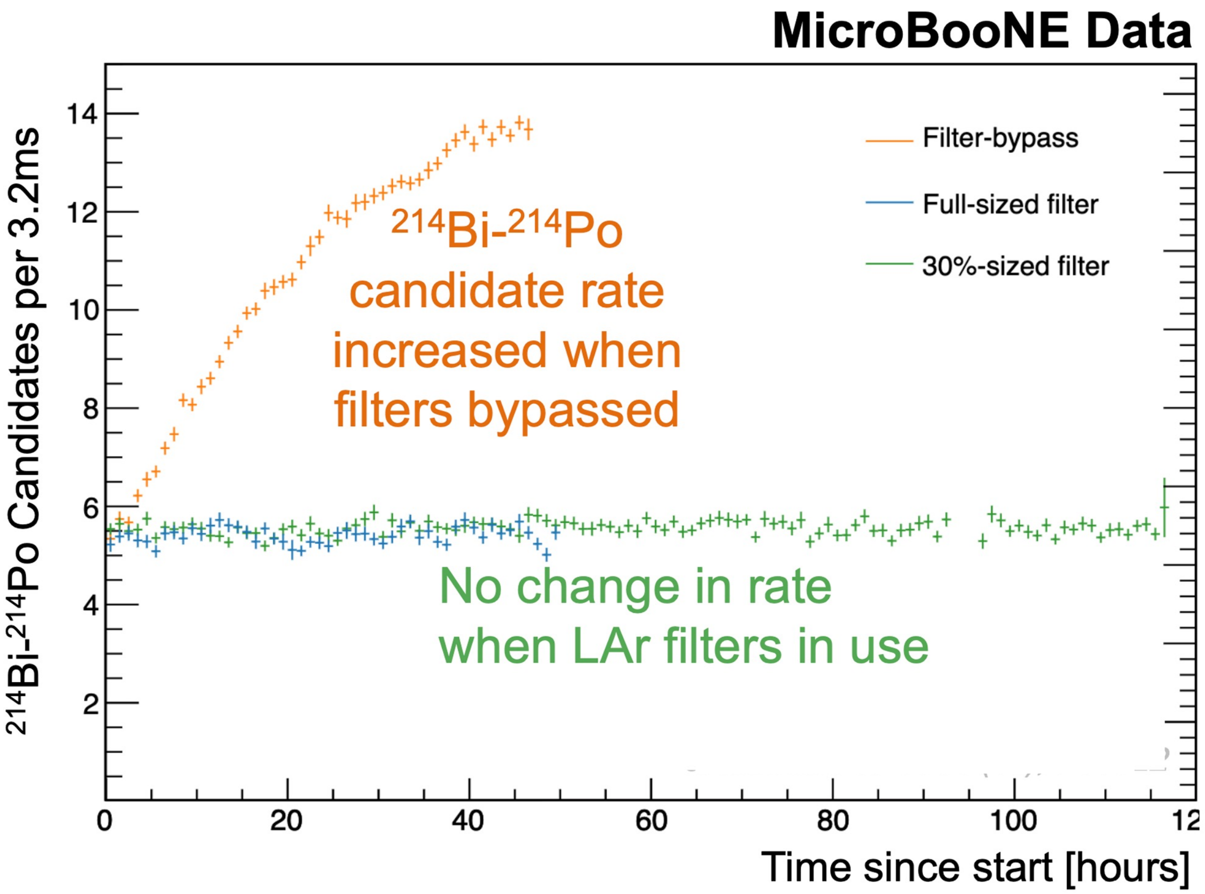
Radon added to the detector using a 500 kBq source at input argon gas line [R&D run]:

- expected 100s of events per readout
- instead, only observed increase in Bi-Po candidate rate when filters bypassed

Increase in radioactivity of copper filter (Cu-0226 S) observed above background rates

- copper LAr filtration system appears to be highly efficient at mitigating radon

For details see: JINST 17 P11022 2022



Ambient radon activity

MeV-scale "blip" reconstruction tools:

- achieve good data/MC agreement for β_{Bi} reconstructed energy and α_{Po} identification
- lowest energy particle identification and calorimetry demonstrated so far in single-phase neutrino LArTPC

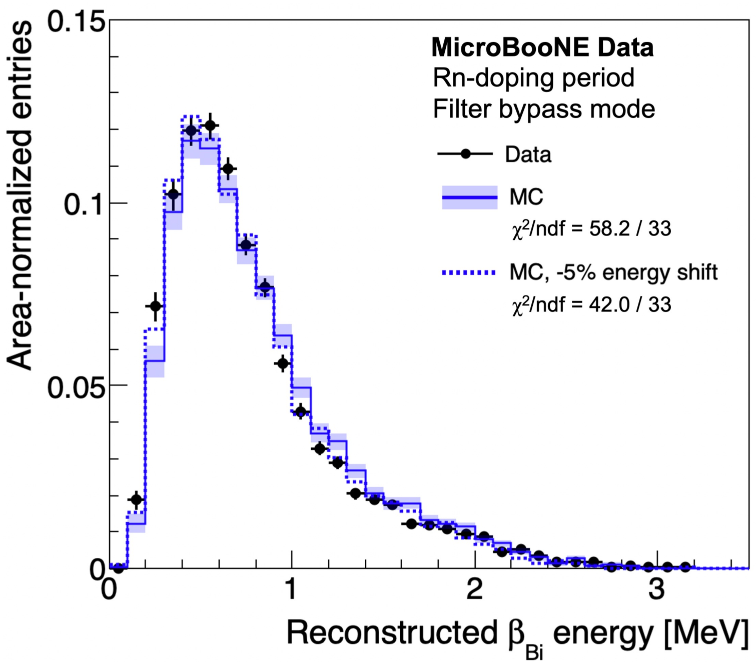
Ambient radon activity measured:

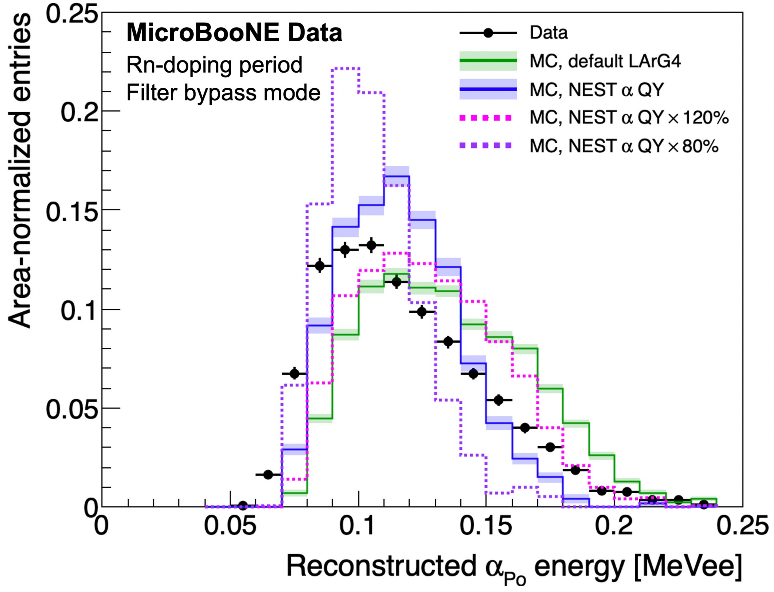
- beam-off data from normal running
- 95% CL upper limit of **0.38 mBQ/kg**

Below requirements for DUNE's low-energy physics program:

- less than 1 mBQ/kg
- similar filtration system – may expect similar radon levels

For details see: arXiv:2307.03102 (submitted to PRD)





R&D run: high voltage

MicroBooNE drift electric field:

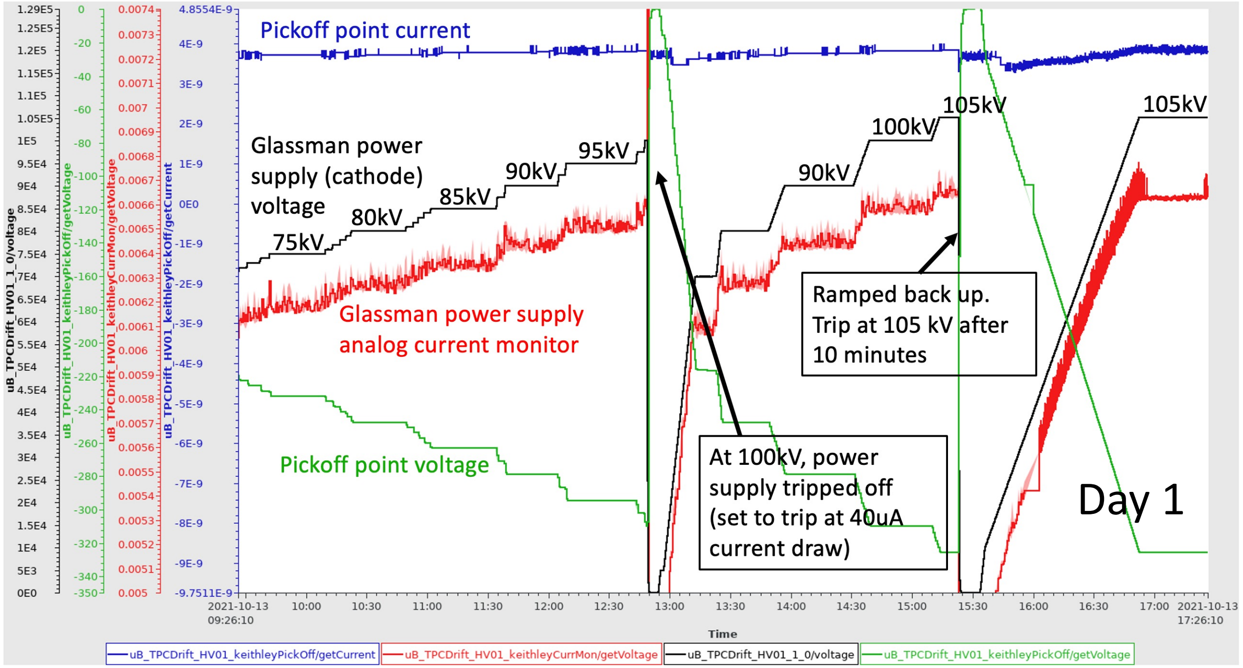
- design electric field of 500 V/cm (128kV)
- but, saw instability/discharges during commissioning when above 70kV
- operated at electric field of 273.9 V/cm (70kV)

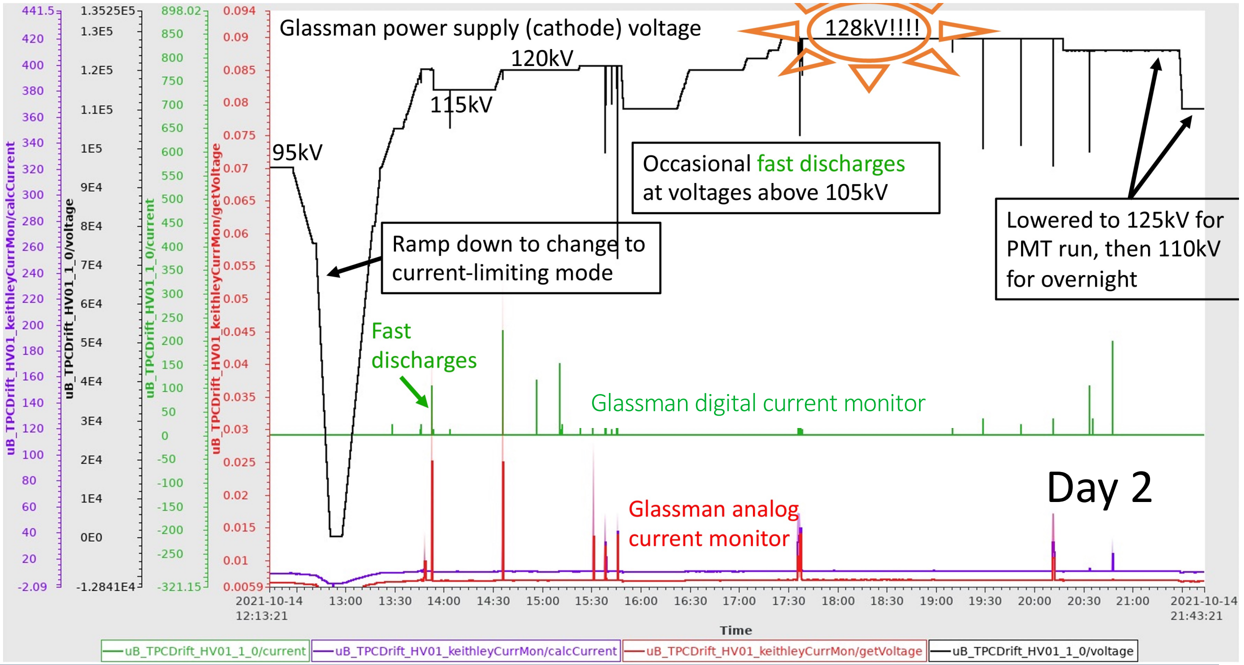
R&D run: high voltage increased (post data-taking)

- discharges above 70 kV as before, but able to achieve design voltage of 128 kV for first time
- after short period of discharges, stable operation achieved at 128 kV

R&D data taken at multiple voltages:

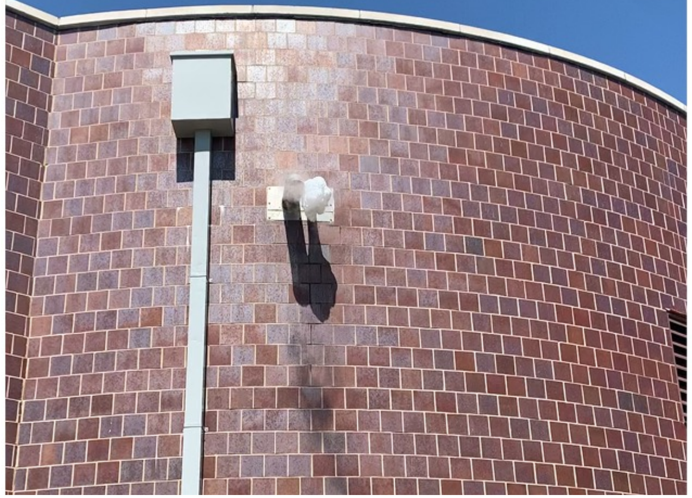
- ongoing studies: recombination, single PE rate, etc.
- + special light-only run with reverse polarity





Decommissioning

Venting of argon on-going:
3-month process, nearing completion



MicroBooNE is currently being decommissioned:

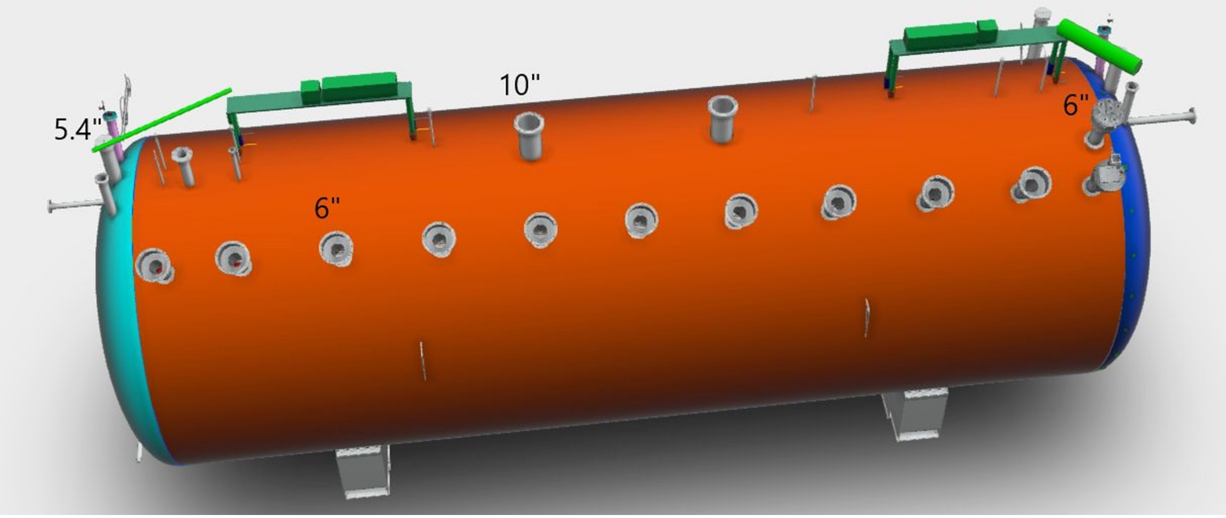
- unique opportunity to characterize a LArTPC after 7 years of operations and explore several long-standing mysteries

Opening cryostat difficult (expensive), but have variety of access points:

- current plans focused on inspections using cameras, etc. through these

Planned studies include:

- unresponsive wires: resistance measurement during venting + visual inspection
- light yield decline: argon sample taken + inspection of wavelength-shifter (TPB)



Conclusions

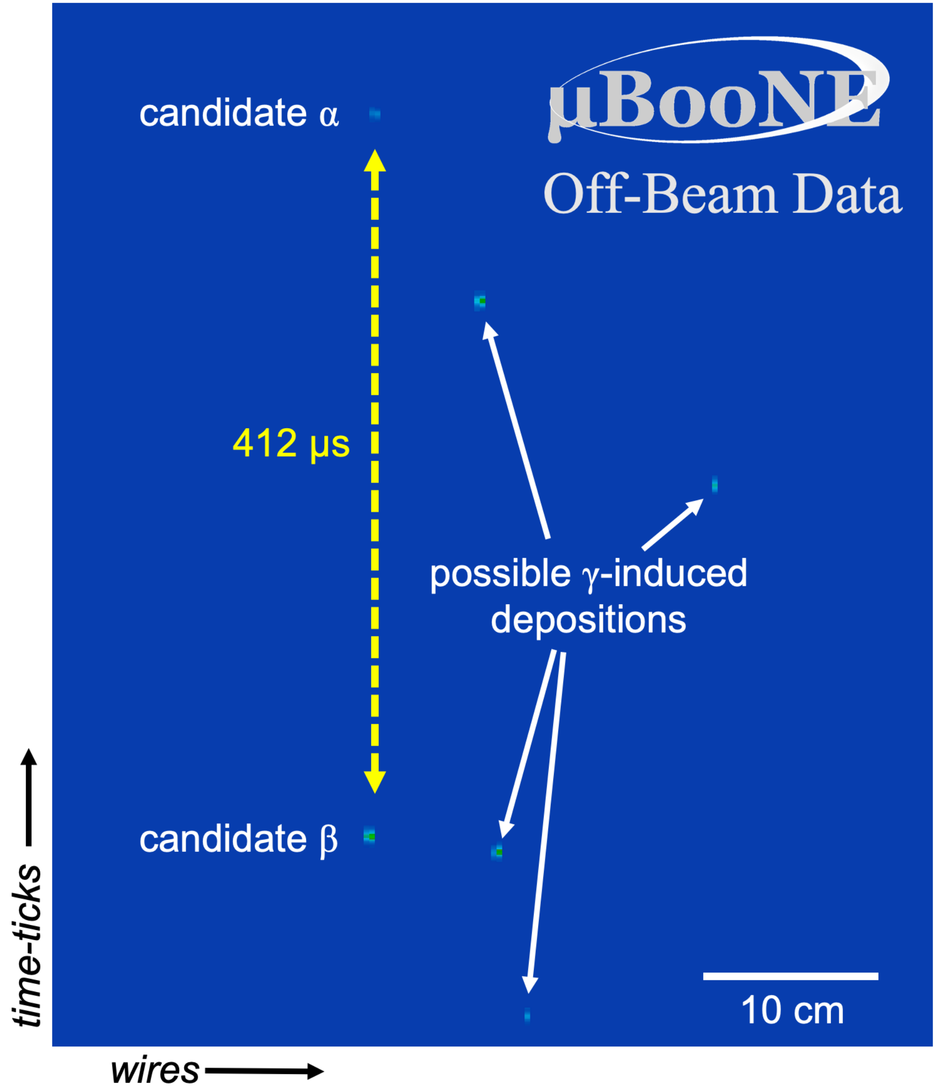
MicroBooNE has the world's largest dataset of neutrino interactions on Argon:

- processing runs 4-5 data – full dataset analyses coming soon

Continuing to push the capabilities LArTPC neutrino detectors and pioneering new and improved reconstruction techniques

Dedicated R&D run data currently being analyzed

Entering decommissioning phase – unique opportunity to characterize long-running LArTPC neutrino detector: 7 years total operations, 5 years of beam physics data



Backups

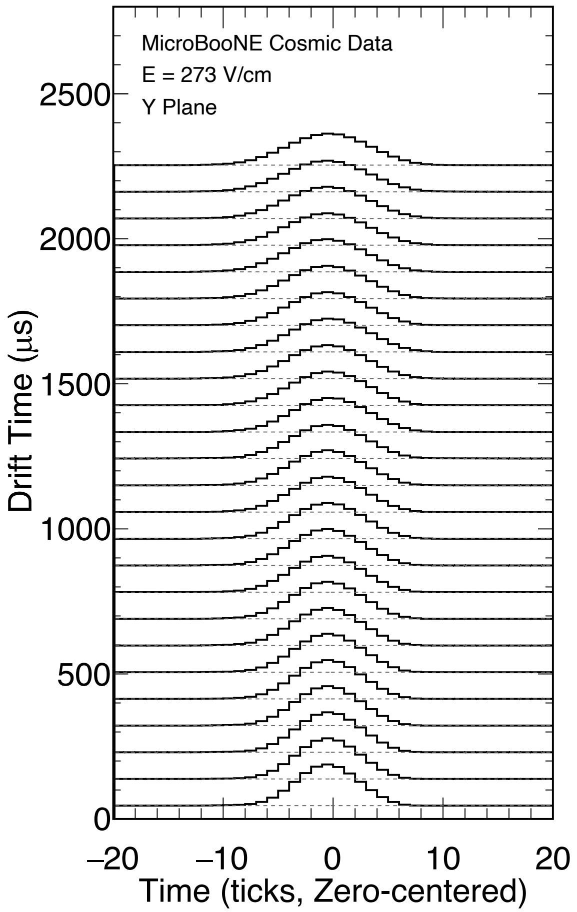
Longitudinal electron diffusion measurement

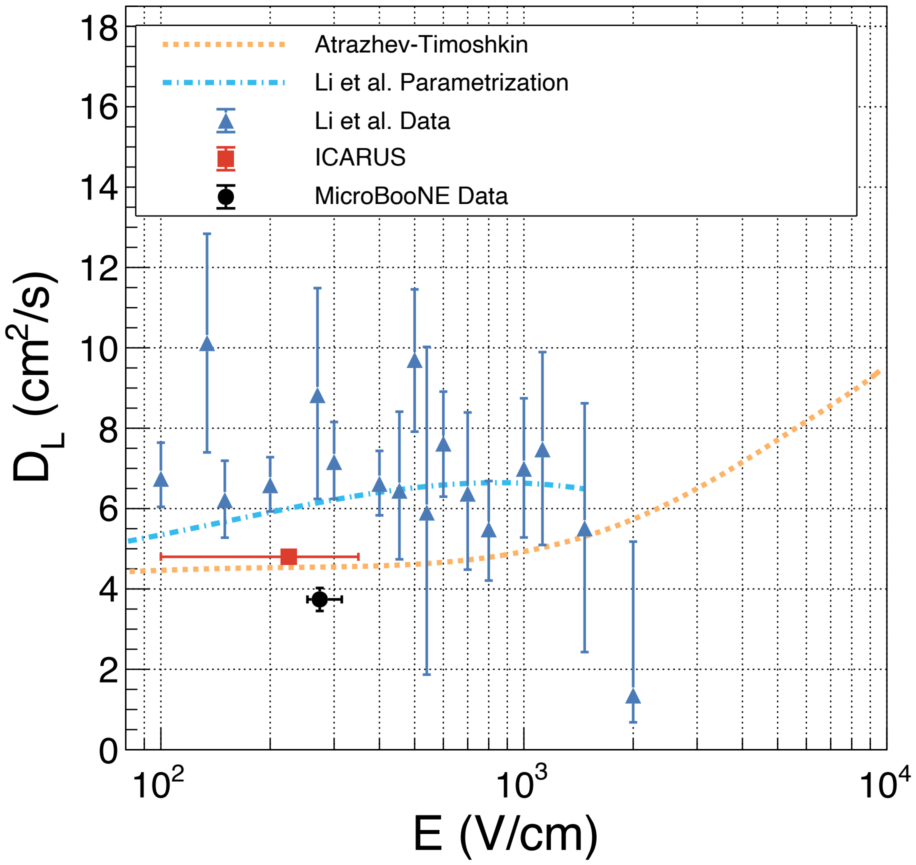
Longitudinal diffusion of ionization electrons measured using large sample of cosmic-ray muons

$$D_L = 3.74^{+0.28}_{-0.29} \text{ cm}^2/\text{s}$$

at E_{drift} = 273 V/cm

For details see:
JINST 16 (2021) 09, P09025





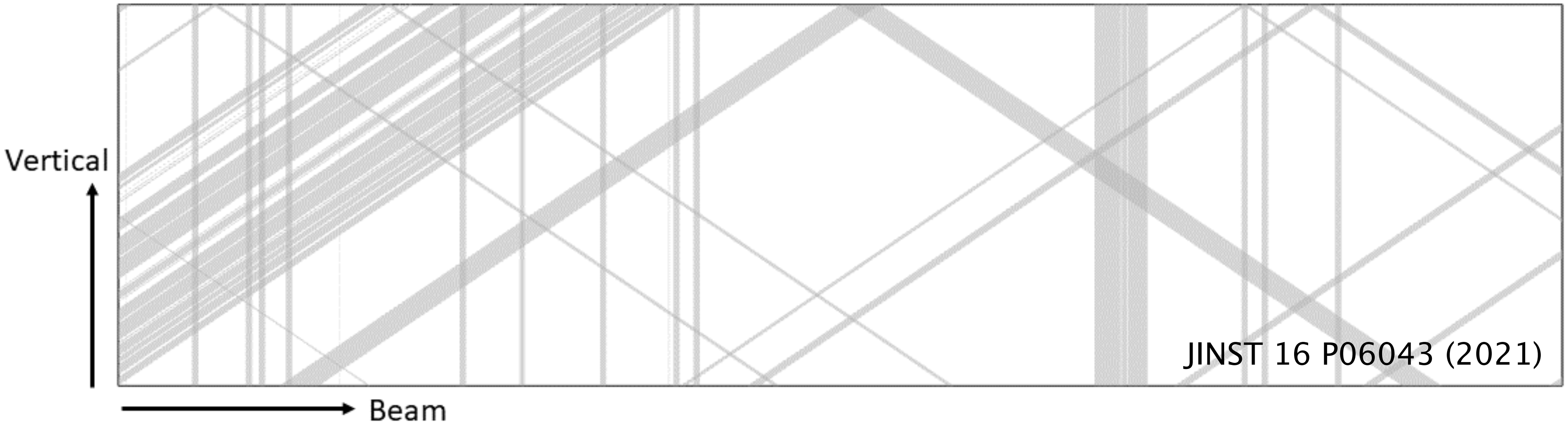
Decommissioning studies: unresponsive wires

MicroBooNE has significant number of unresponsive wires:

- potentially caused by shorting between wires that occurred as detector cooled

Measuring resistance of shorted wires as detector is vented / warms up + plan visual inspection with camera

MicroBooNE unresponsive channels



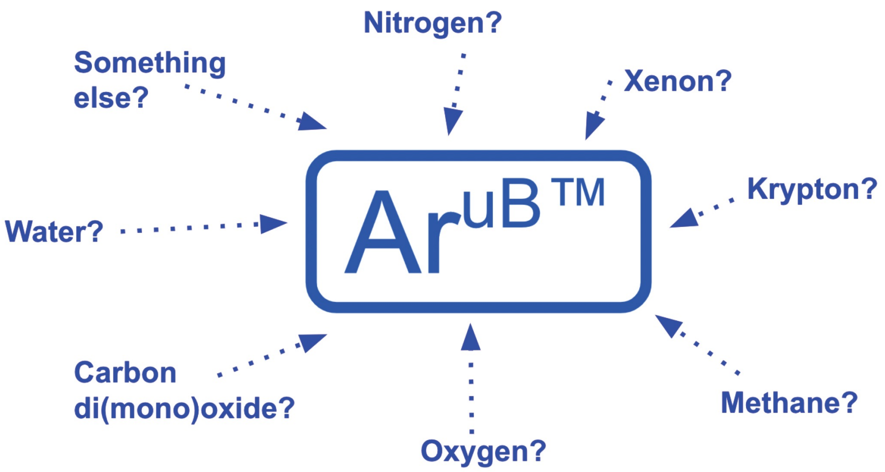
Decommissioning studies: cause of light yield decline

MicroBooNE experienced ~40-50% decline in light yield, remains unexplained

- important to understand – long term light response stability essential for DUNE

Potential cause 1 – introduction of a contaminant:

- argon sample taken before venting
- vendor identified to analyze for contaminants



Potential cause 2 – TPB WLS degradation/flaking:

- inspection of PMT plates / detector using camera
- inspection of filters

R&D run: high voltage day 3

Stable operation achieved at design voltage of 128 kV for extended periods