THE UNIVERSITY *of* EDINBURGH

μBooNE

Measurement of the Light Yield in MicroBooNE with Isolated Protons

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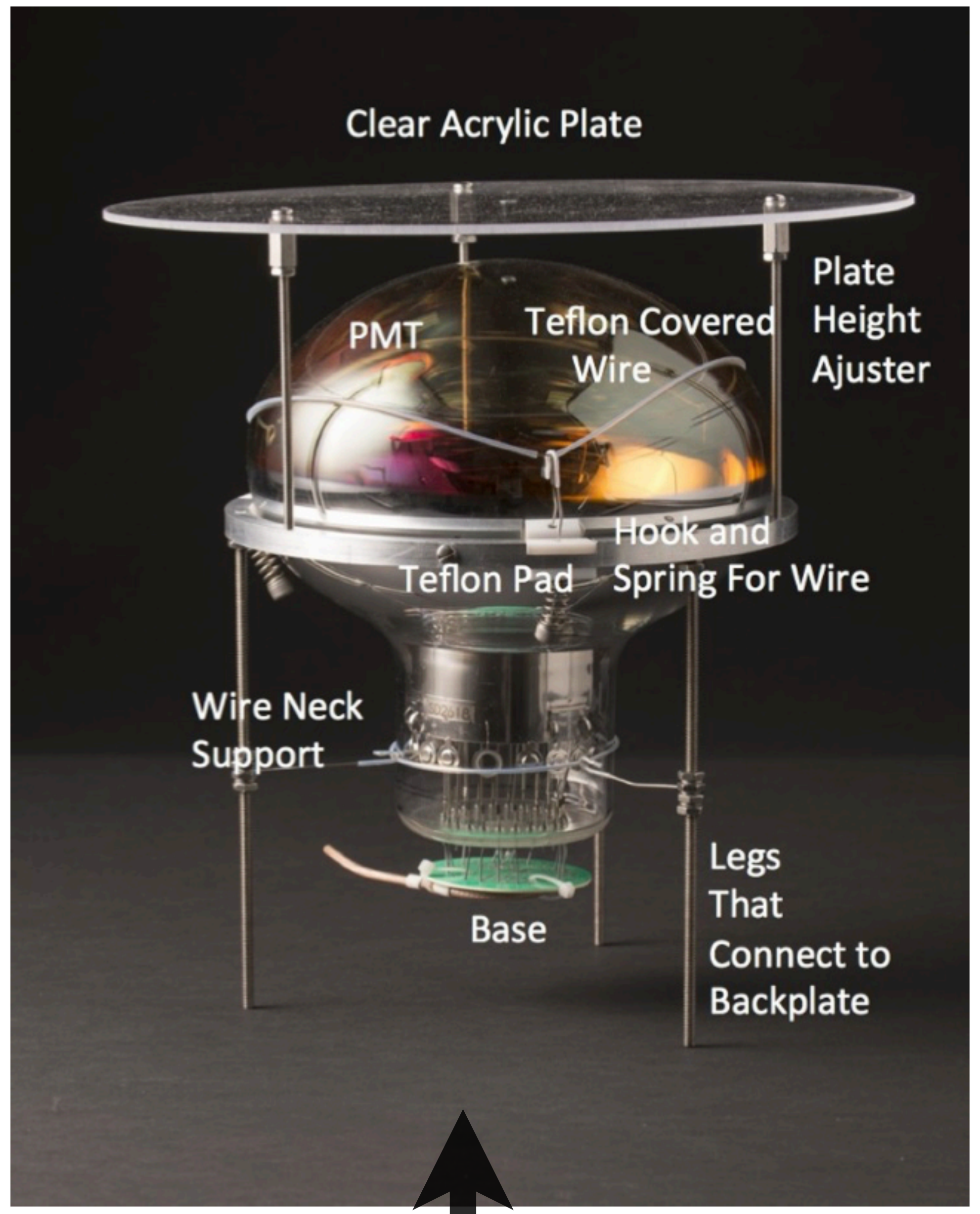
MicroBooNE Collaboration

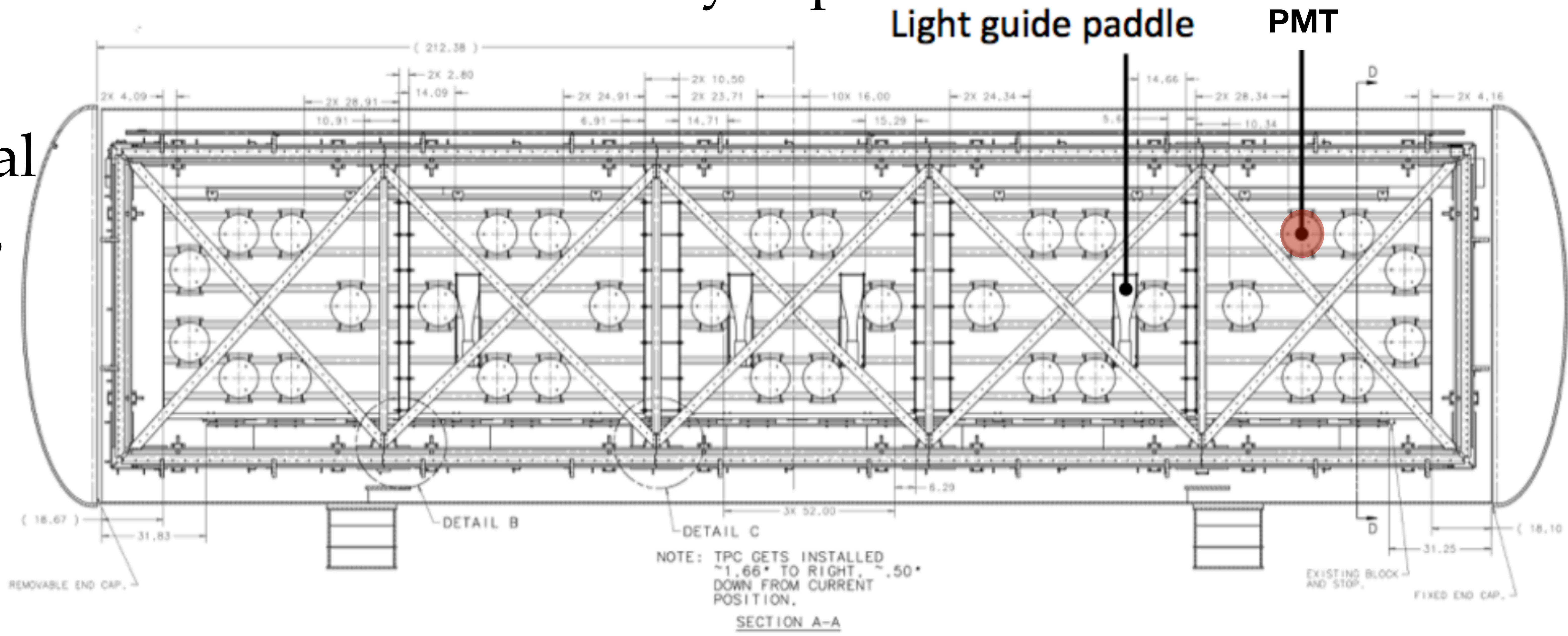
LIDINE 2022

The MicroBooNE detector

Design and Construction of the MicroBooNE Detector, JINST 12 (2017) no.02, P02017



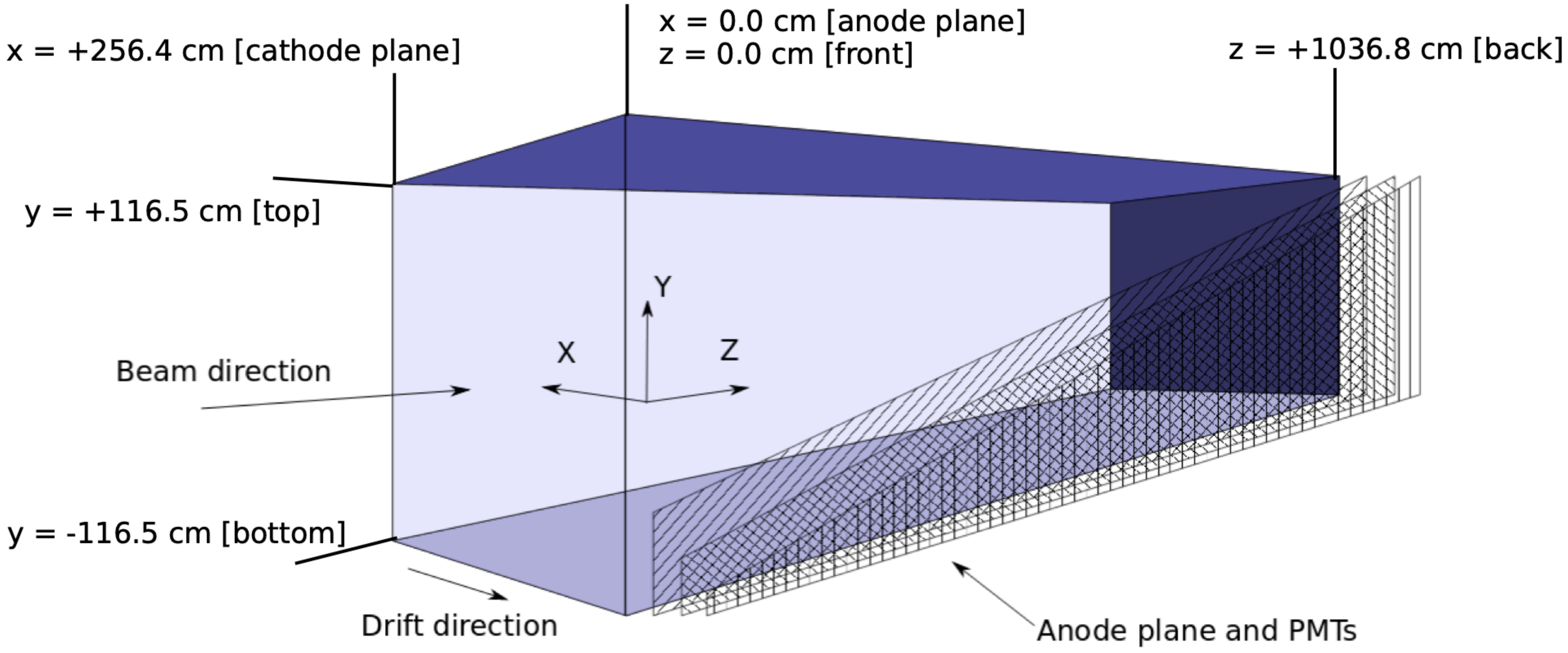
- MicroBooNE is a large 170-ton Liquid Argon Time Projection Chamber (LArTPC), more details can be found in Vincent Basque's talk on Wednesday!
- **Photon detection system:**
  - Primary light detection system consists of 32 8" diameter Hamamatsu R5912-02 MOD PMTs behind TPB-coated acrylic plates
  - Two PMTs with an electronics response different from nominal are excluded from this analysis



MicroBooNE coordinate system

- MicroBooNE uses a right-handed Cartesian coordinate system in which x, y and z denote the drift, vertical and beam-aligned direction

- The origin is defined to be located:
  - centred in the vertical direction
  - on the first induction plane near the anode
  - on the upstream face of the LArTPC



MICROBOONE-NOTE-1028-PUB

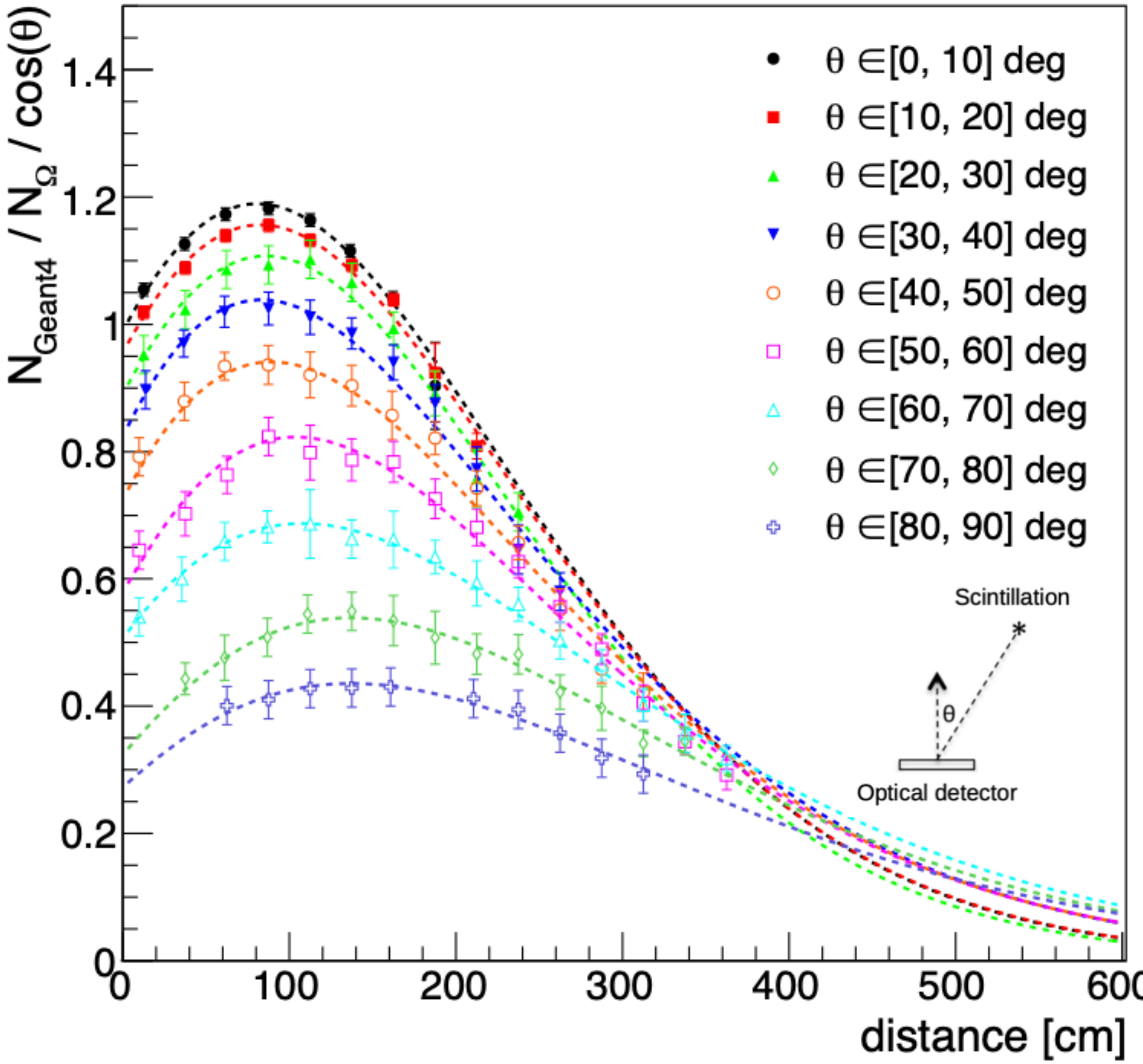
Scintillation light in MicroBooNE

- In MicroBooNE, the scintillation light is produced abundantly, propagates through the detector volume in nanoseconds and is used to
  - provide timing information for triggering
  - reject out-of-time cosmic ray activity to discern the in-time neutrino interaction
- The light calibration has been done with cosmic muons, see the MicroBooNE tech note

- For many applications, we need a better understanding of the light propagation and detection efficiency
  - The light propagation can be influenced by absorption, reflections and Rayleigh scattering
  - Need to compare "point-like" sources to enable a precise mapping of the light detection capability in the detector
    - **Protons** as potential sources were chosen for this analysis

Simulation: semi-analytic model

- The **semi-analytical model** [1] is a simulation using
  - **geometric predictions** + **corrective factors**
- Geometric prediction uses solid angles to calculate number of incident photons
- Corrective factors are calculated numerically to account for angle and position-dependent impact of Rayleigh scattering, absorption and reflections
- Has a good agreement with full optical simulation (but is much faster)

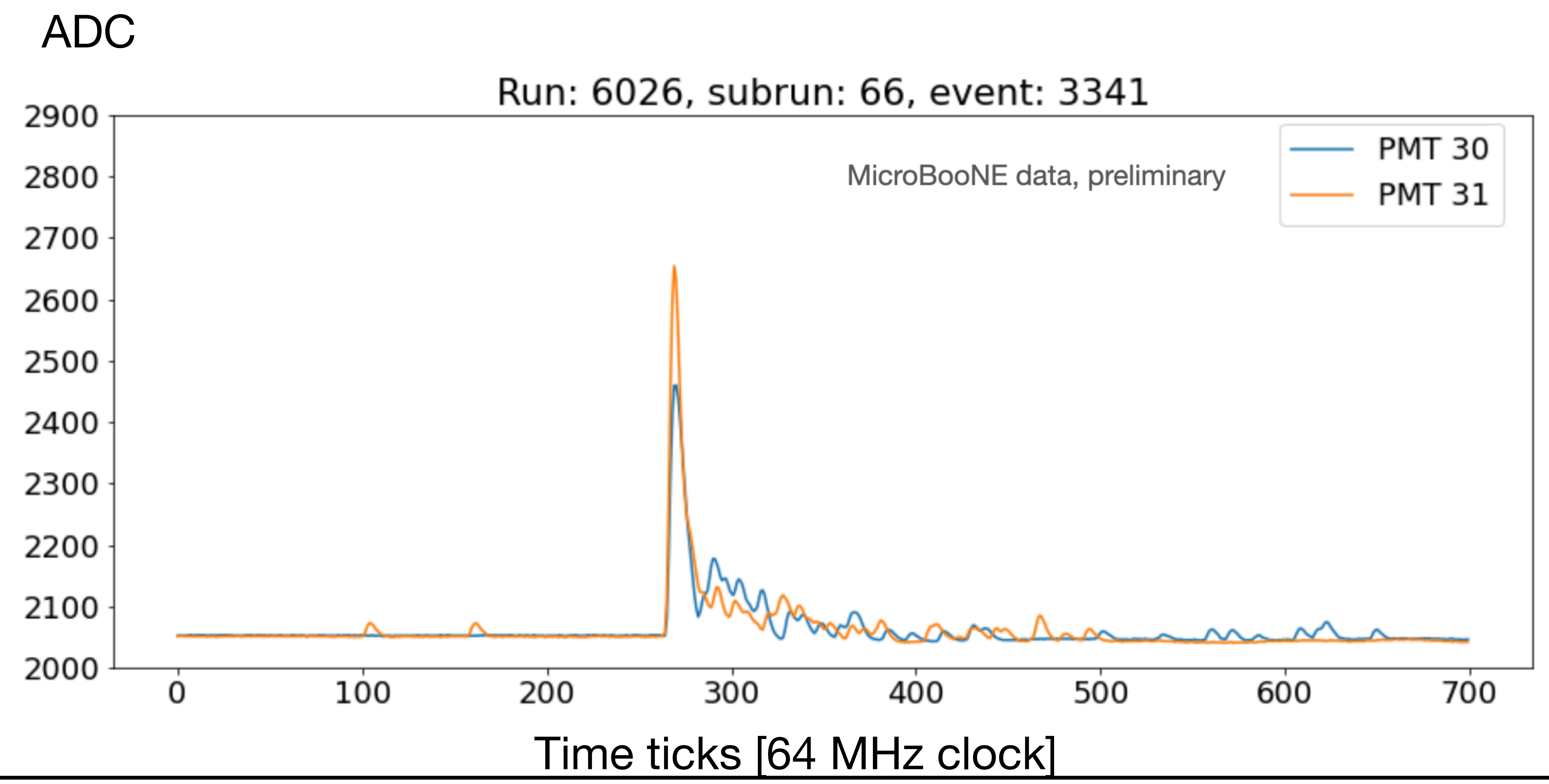


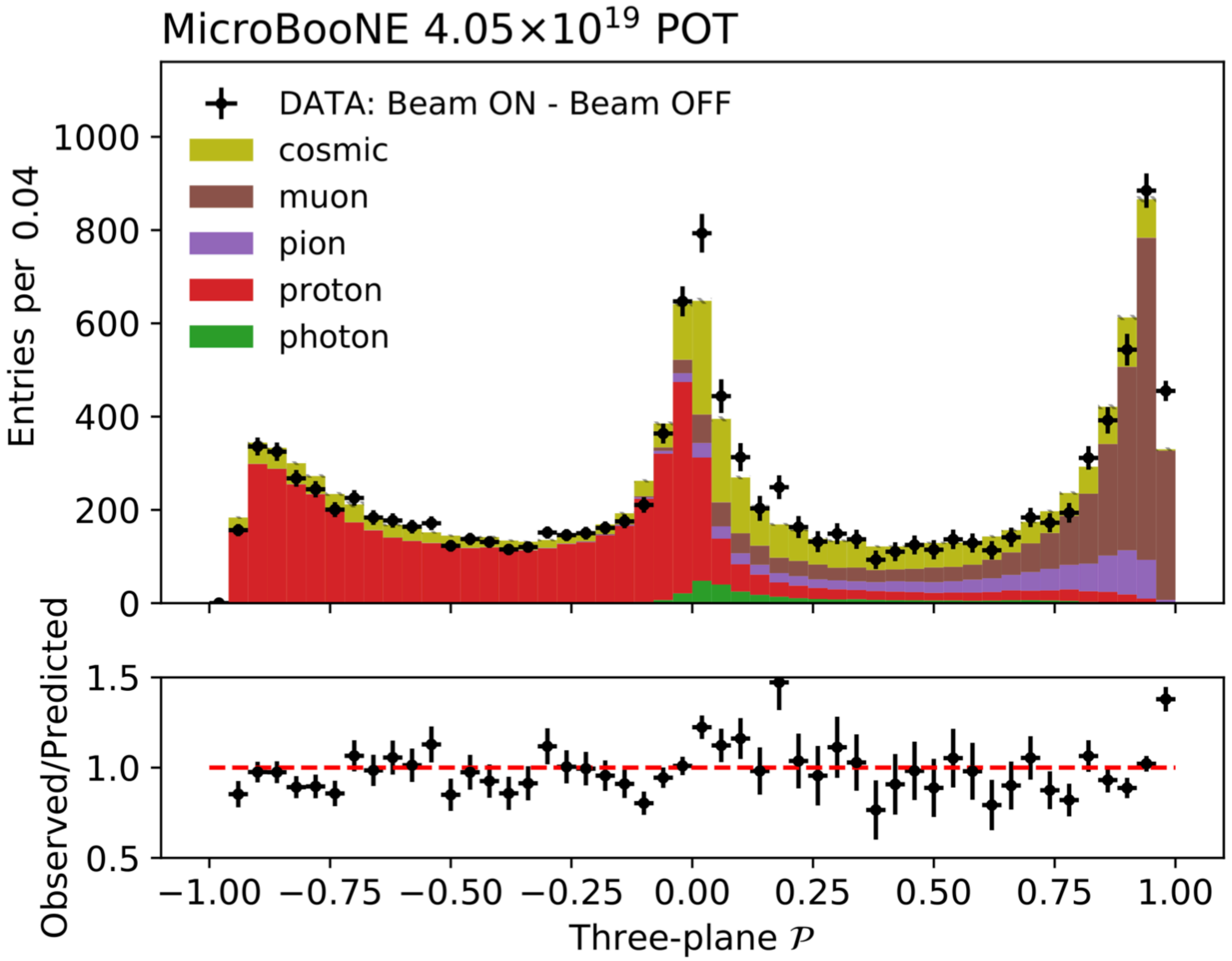
[1] Garcia-Gamez, D., Green, P. & Szelc, A.M. Predicting transport effects of scintillation light signals in large-scale liquid argon detectors. *Eur. Phys. J. C* **81,** 349 (2021). https://doi.org/10.1140/epjc/s10052-021-09119-3

Data sample

- **Cosmic ray neutrons** can induce isolated proton events, which travel short distances in the LAr O(10 cm) at low energies.
- The distribution of particle ID (PID) score for events with track-like particles for MicroBooNE's on and off-beam datasets shows that we should be able to obtain a high-purity sample for this analysis

Calorimetric classification of track-like signatures in Liquid Argon TPCs using MicroBooNE data.
Journal of High Energy Physics, 2021, 12 2021

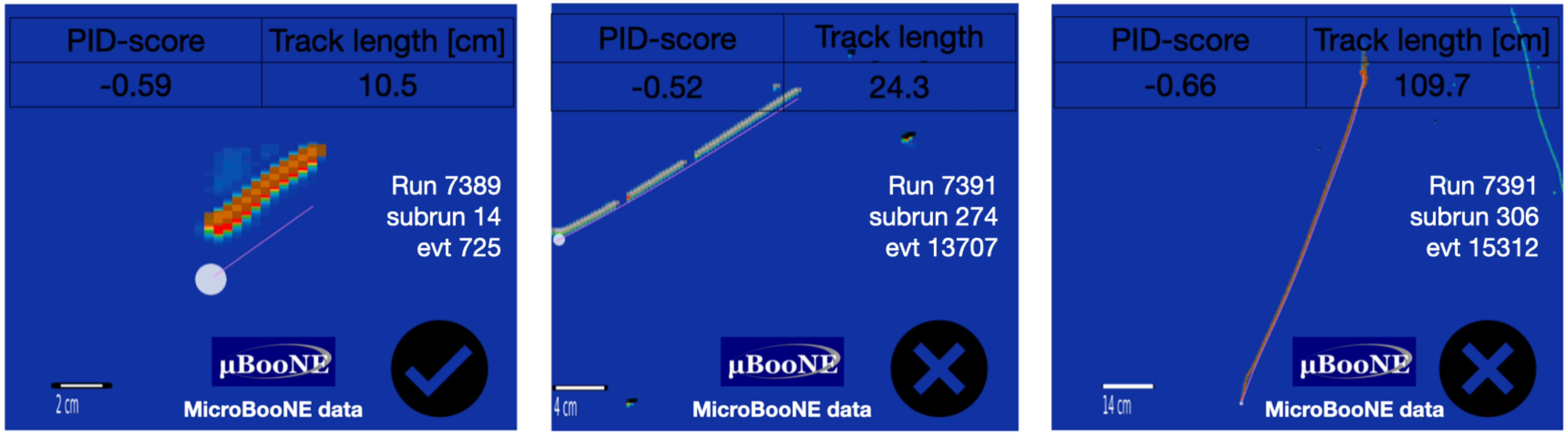




Event selection

More details can be found in MICROBOONE-NOTE-1119-PUB

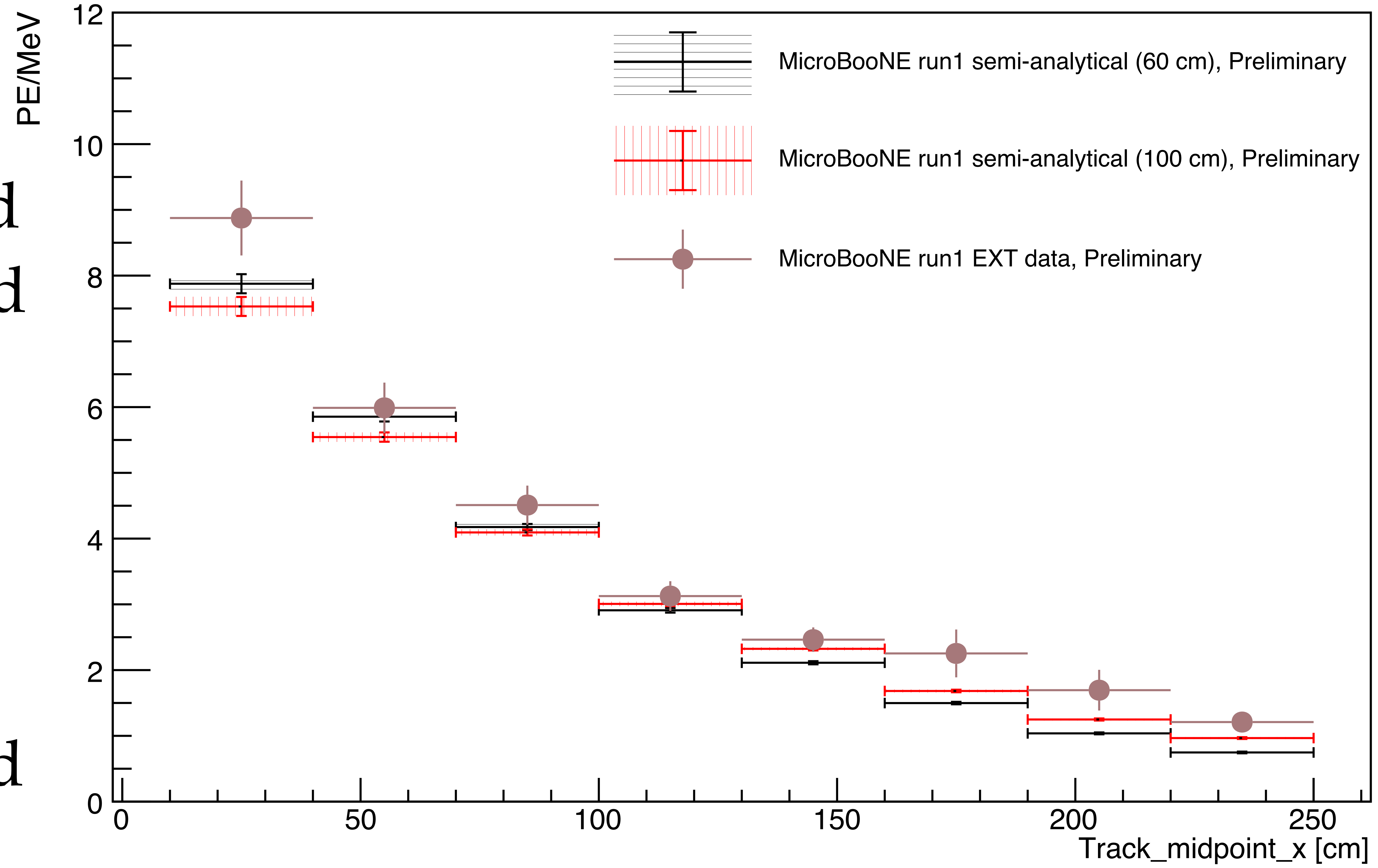
- Identifying isolated protons
- Track is within fiducial volume
- Track-length < 30 cm ("point-like")
- Length difference in x < 10 cm (minimise effect of light yield gradient in x)
- Light reconstruction quality cuts
- As a result, 595 proton candidates in Run 1, 1856 events in Run 3



- In this analysis, the light yield is defined to be the amount of light detected per unit of deposited energy
- Error on the mean is used in data and simulation for the uncertainties

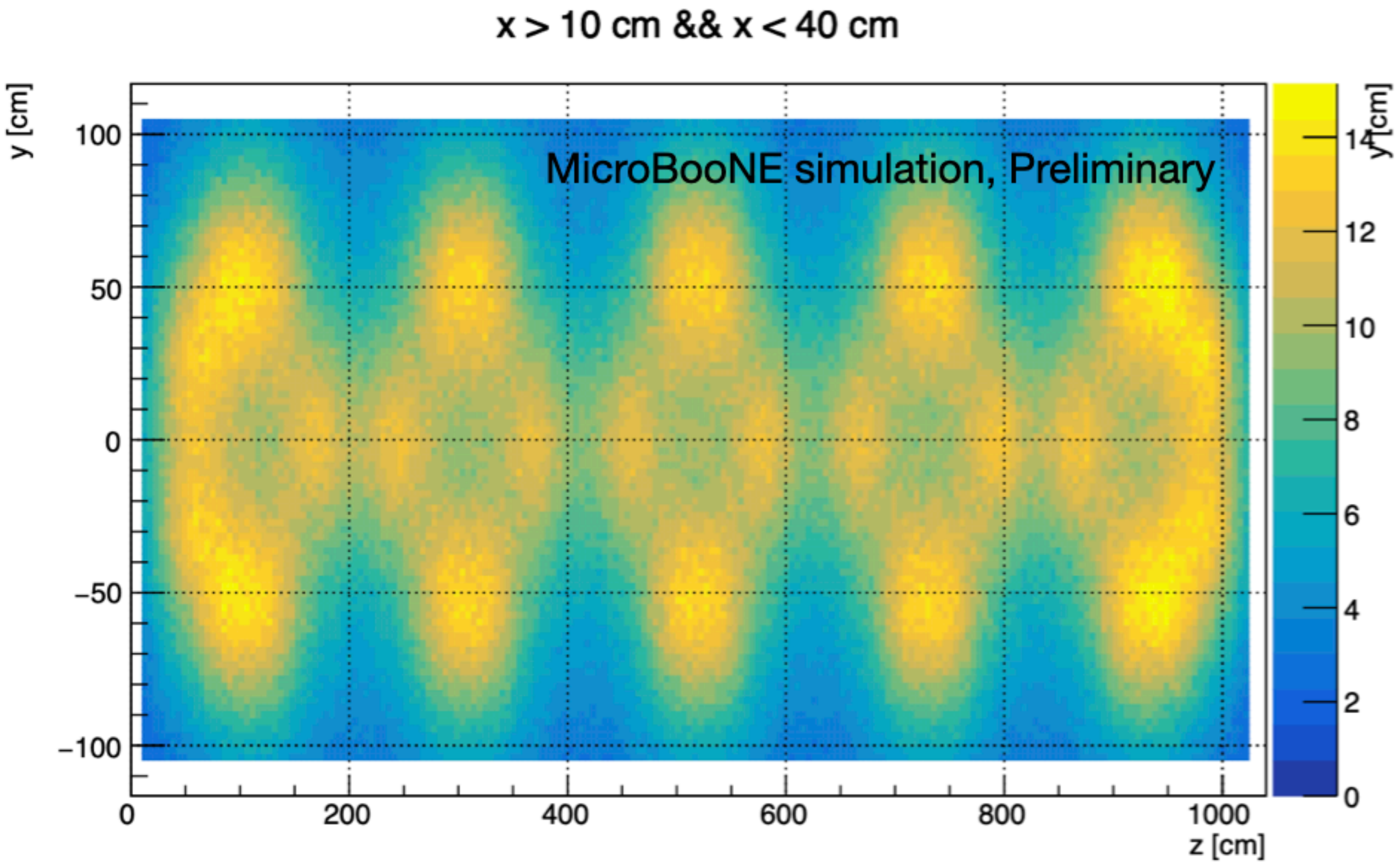
Total light yield along the drift direction

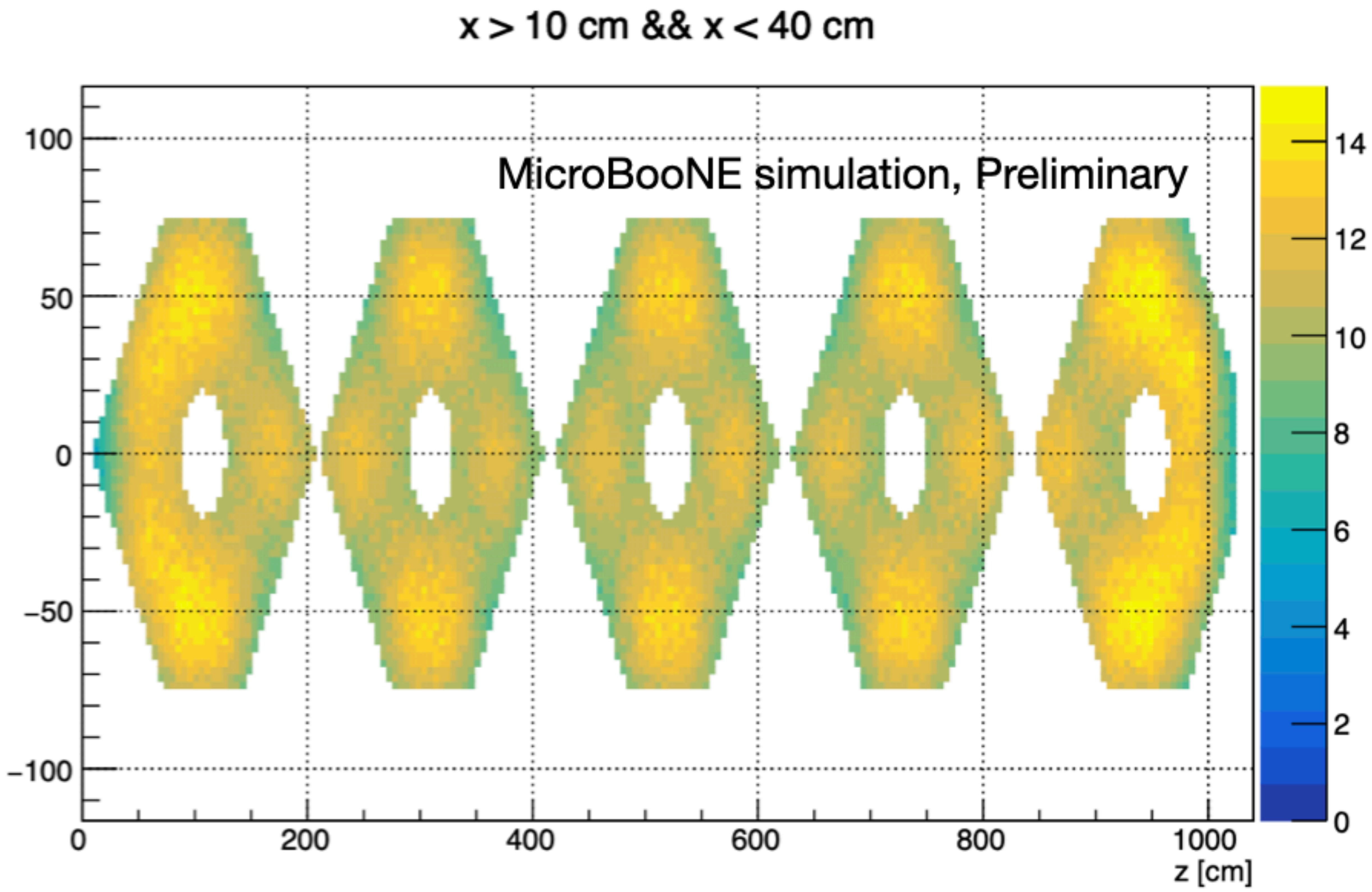
- The LY is not uniform along the drift direction, it decreases significantly with increasing drift distance
- Simulations show that the expected light yield would not vary significantly for the two tested Rayleigh scattering lengths
- A slight excess over simulations in the lowest x-bin
  - challenge of simulating light response for large angles between the photon source and detectors
- Run 1 data, before decline described in Vincent B.'s talk on Wednesday



The hexagonal cut

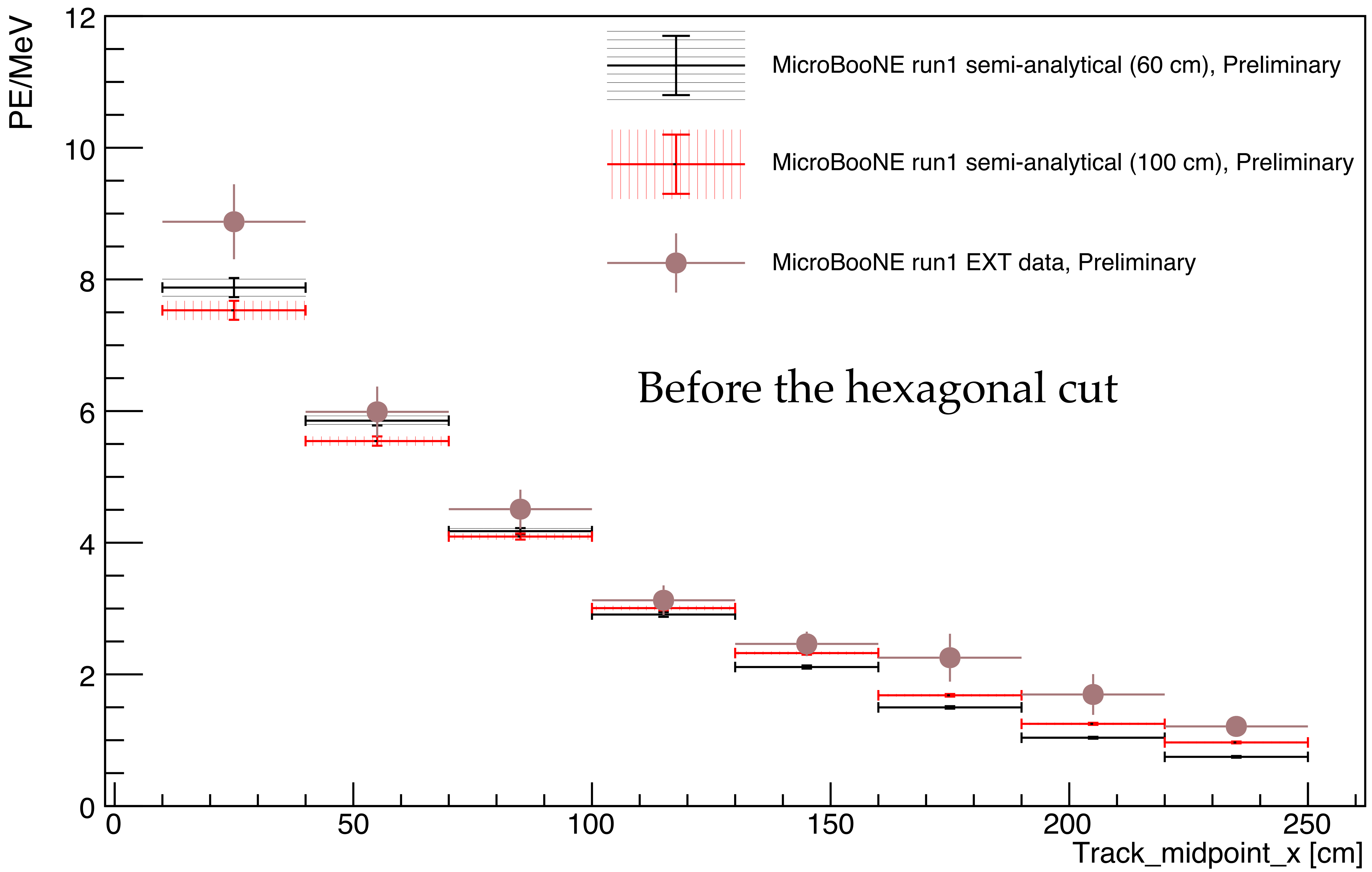
- The light yield changes drastically across the y – z plane close to the PMT array (low x)
- We apply an additional hexagonal cut to select events in line with PMTs

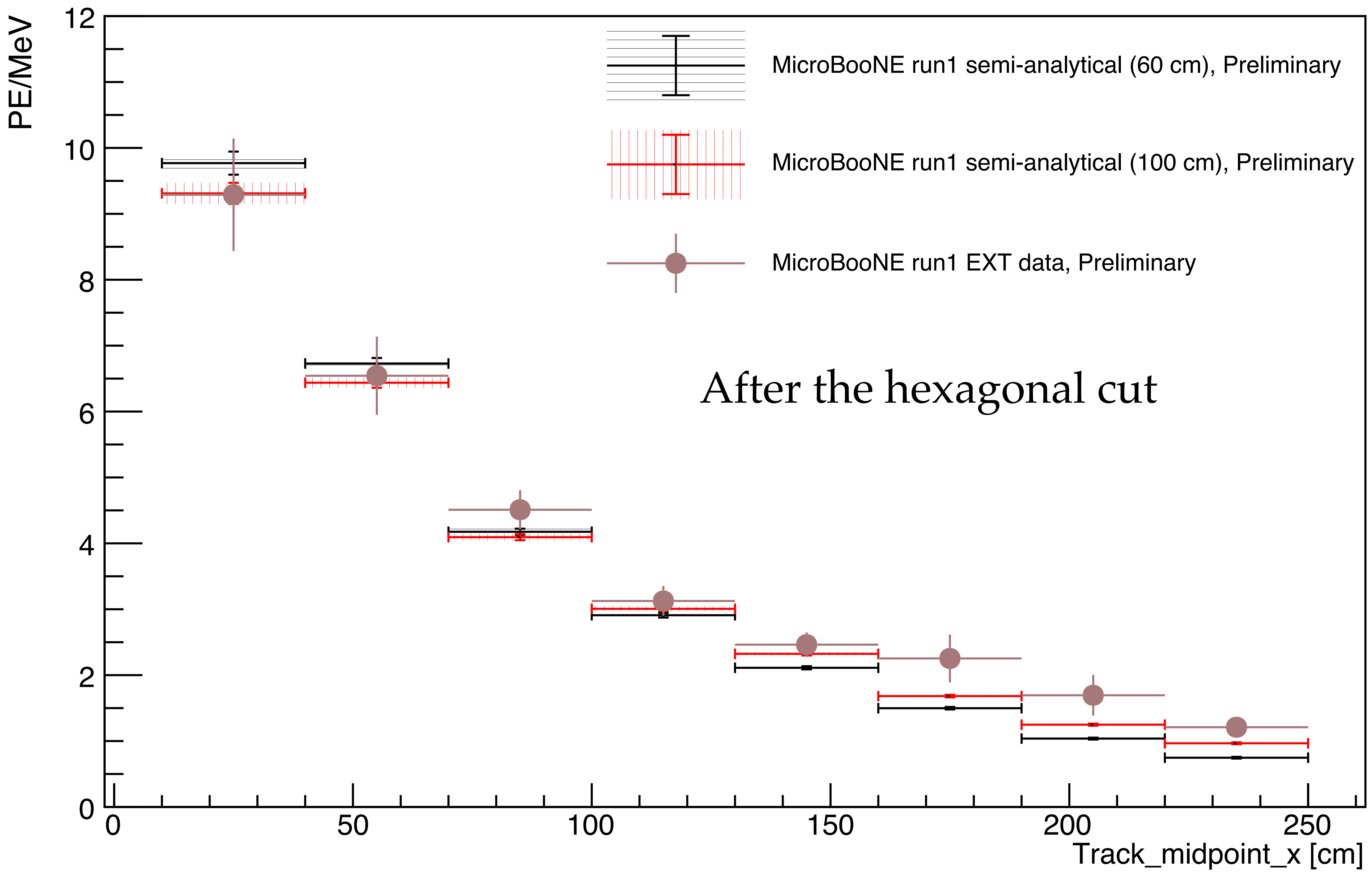




Total light yield with hexagonal cut

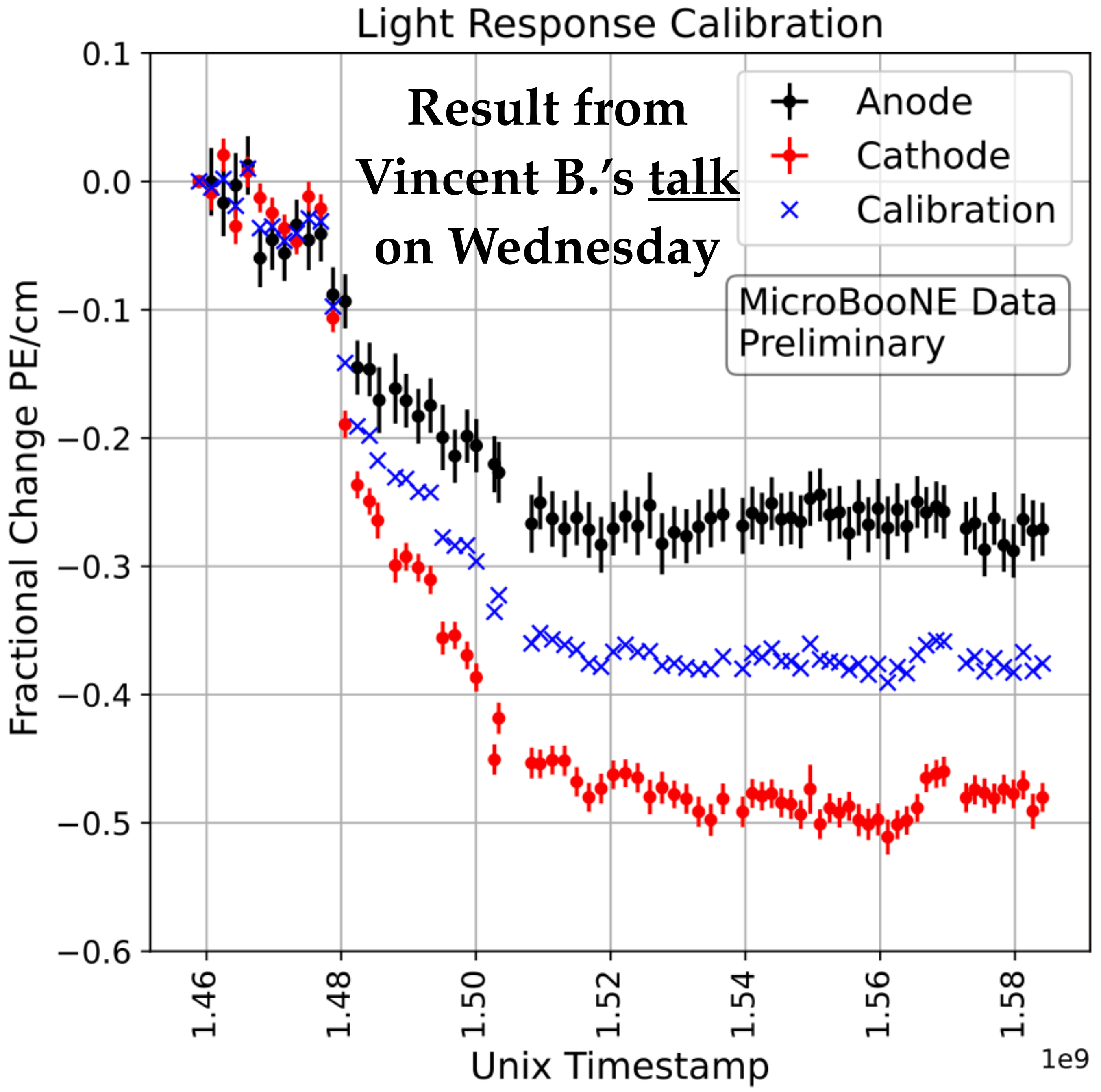
- With this extra selection, simulations and data are seeing more light as expected, and simulations show a better agreement with data

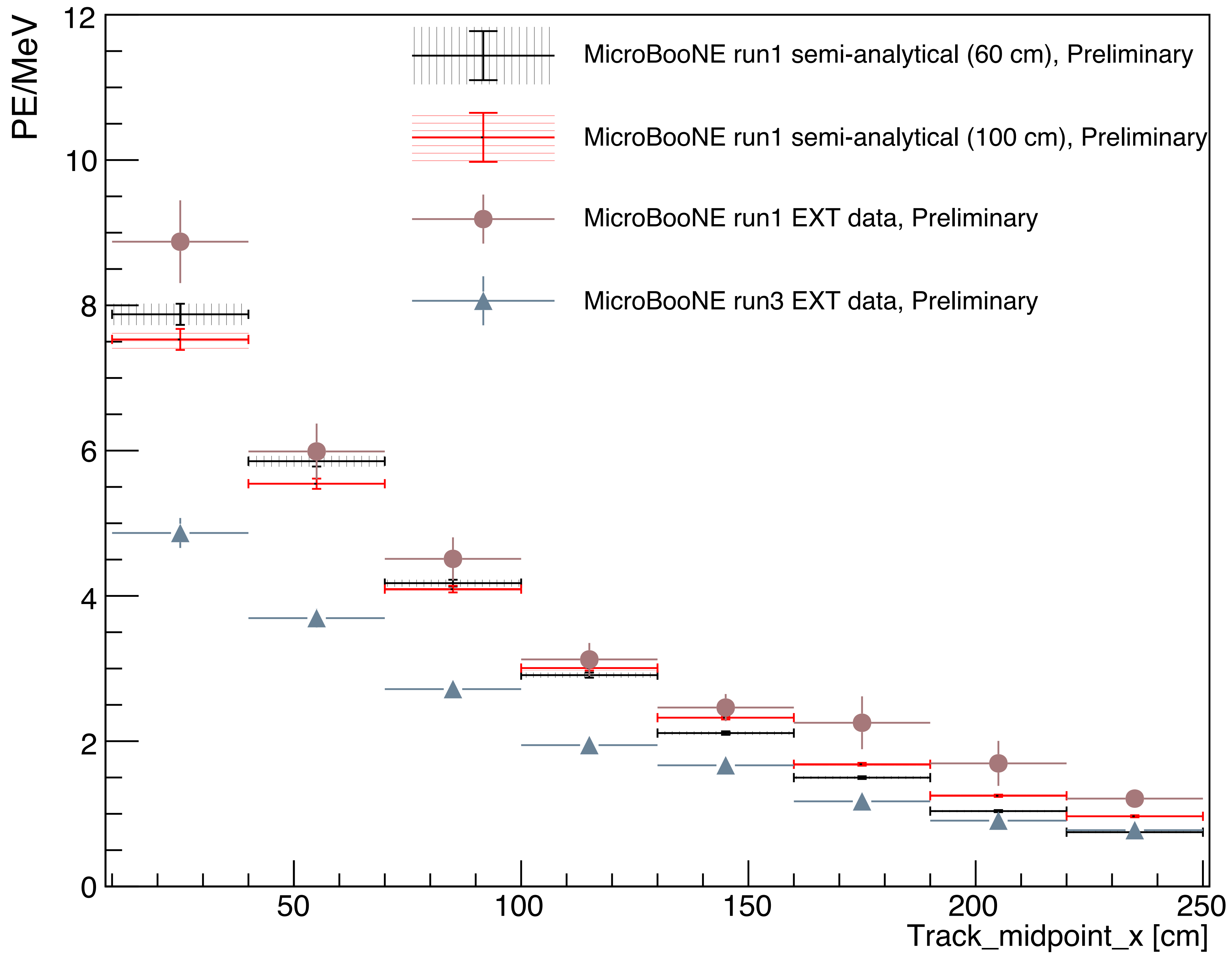


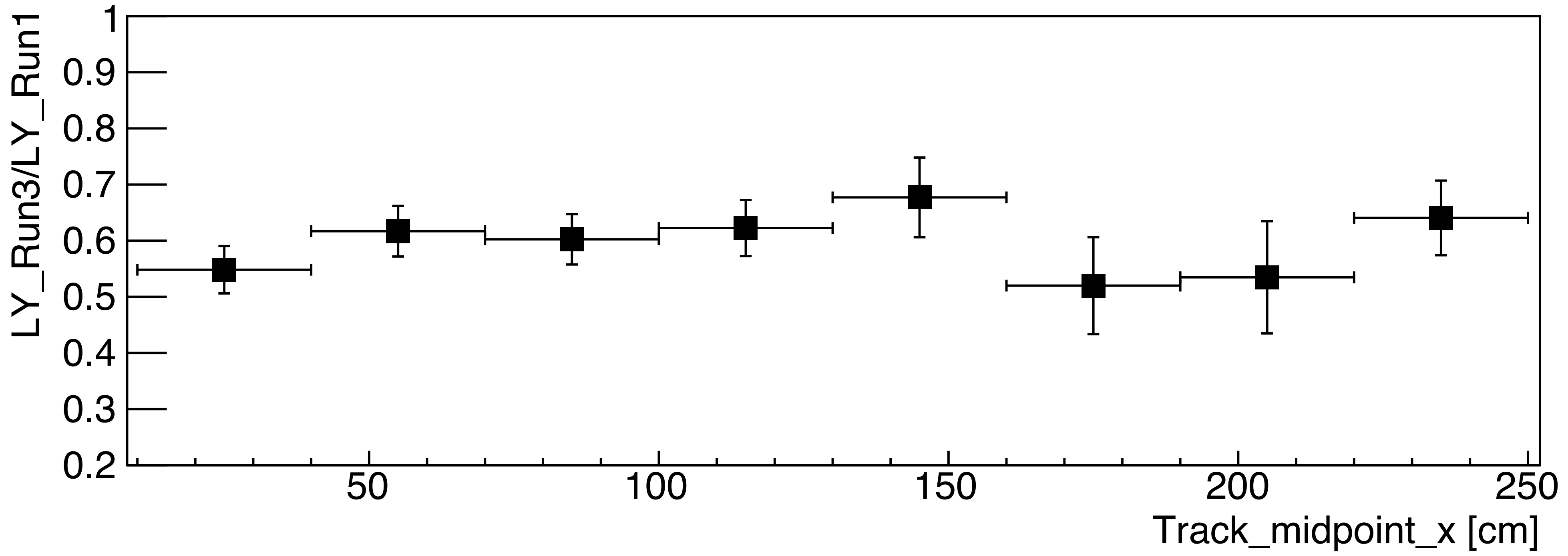


Total light yield along the drift direction

- Examining Run 3 data confirms previously observed light yield decline
- The ratio between the total light yields in Run 3 and Run 1 is mostly flat around 0.6 with some fluctuations
  - Consistent with calibrations applied in MicroBooNE
  - No position dependence for the decline in this analysis, unlike what was found in previous calibration with cosmic ray muons

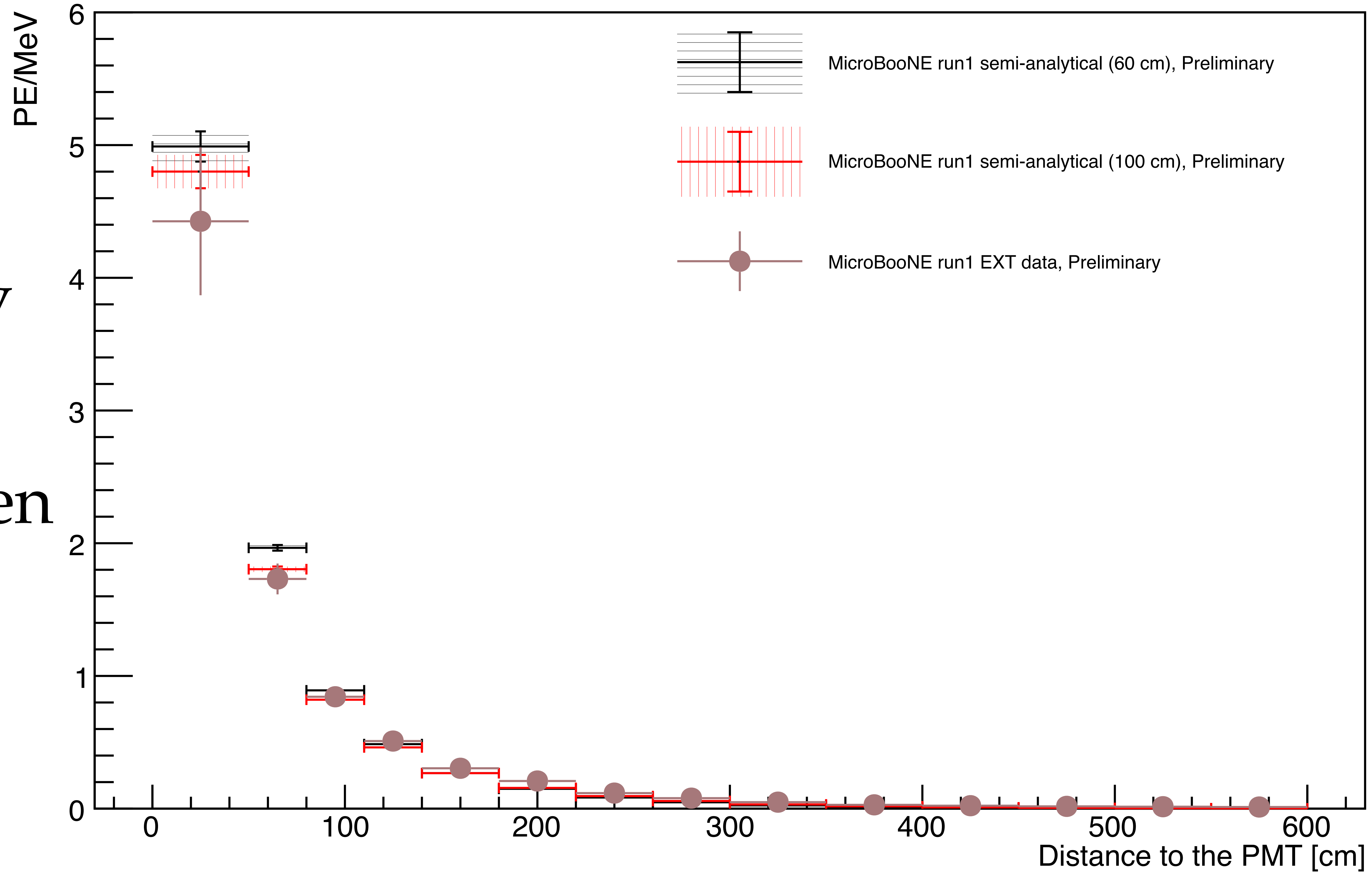






The PMT-by-PMT measurement

- Total light yield study shows that it is challenging to work with the 1d distance
- To study the distance dependency more accurately:
  - separate the number of detected photons by each PMT
  - introduce a 3d distance: the distance between a scintillation point and each PMT
- No angle-selection applied here
- Light yield with increasing distance also decreases significantly



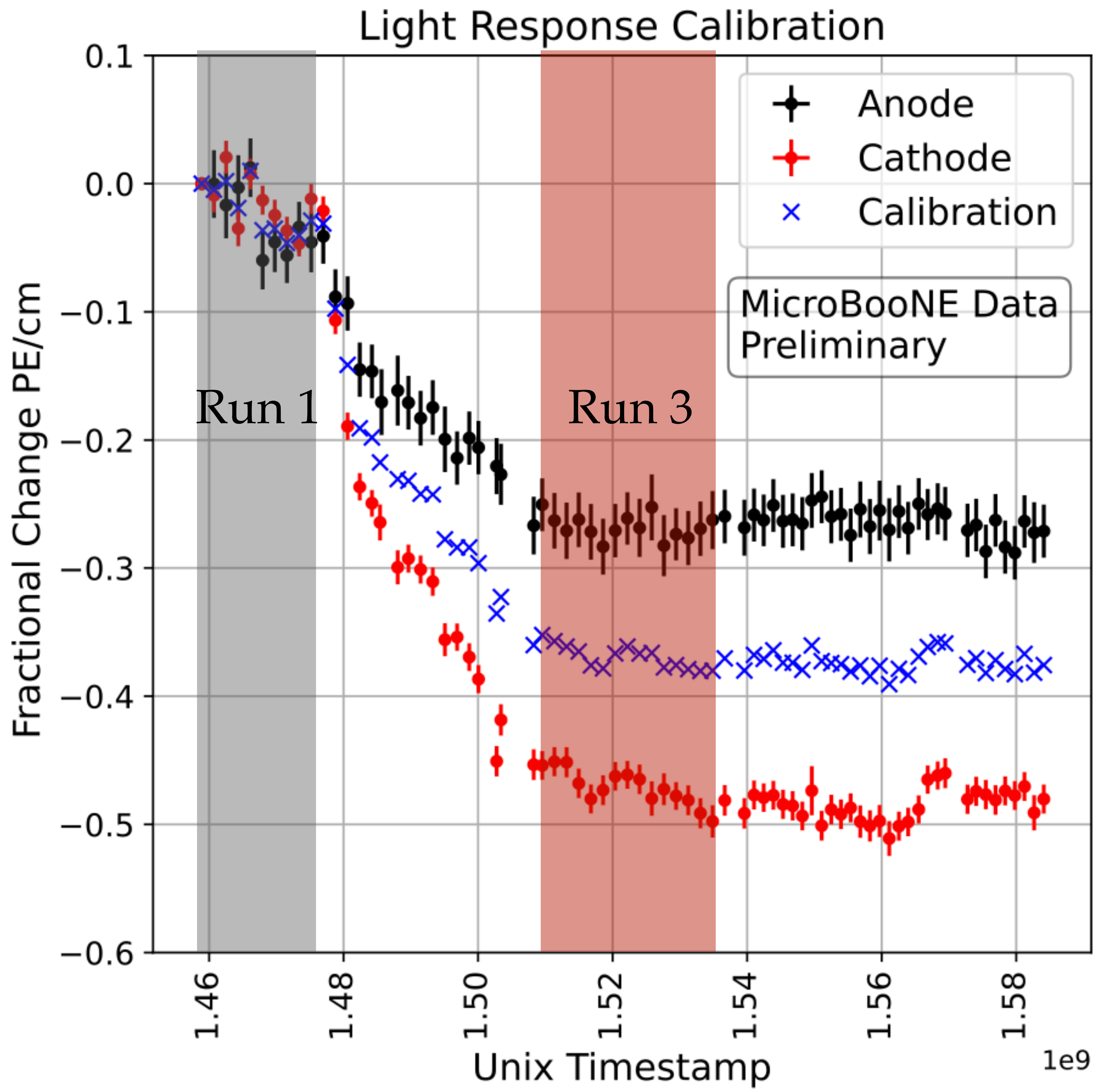
Conclusion

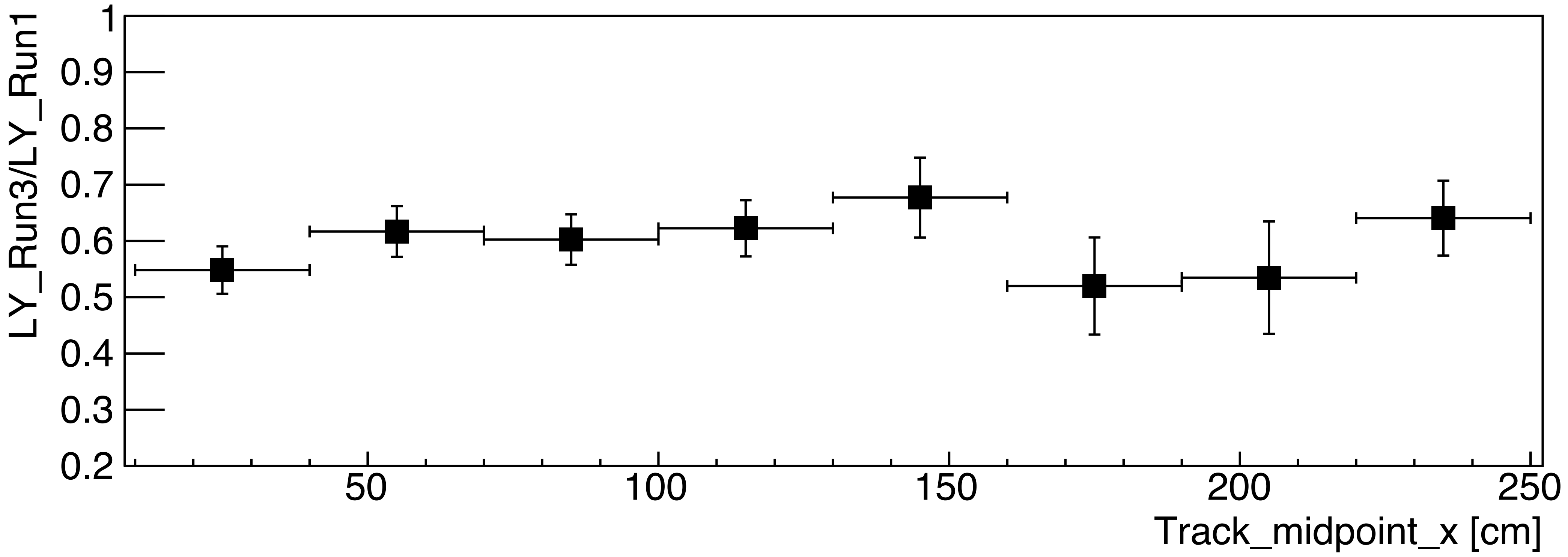
- A new method of measuring the light yield using isolated proton events from cosmic rays, enables a position-dependent light yield measurement to map the response of the detector across its volume
- Total light yield:
  - decreases significantly as a function of drift-distance
- PMT-by-PMT measurement (for individual PMT):
  - light yield decreases significantly with increasing distance

- The details of this work can be found in the **MicroBooNE public note**

Conclusion

- We confirm a light yield decline from run 1 to run 3
- The ratio of light yield between run 1 and run 3 is around 0.6
    - consistent with the calibration applied in MicroBooNE simulation and reconstruction
- For protons, there is no difference between anode and cathode, unlike what was found in previous calibration with cosmic ray muons.

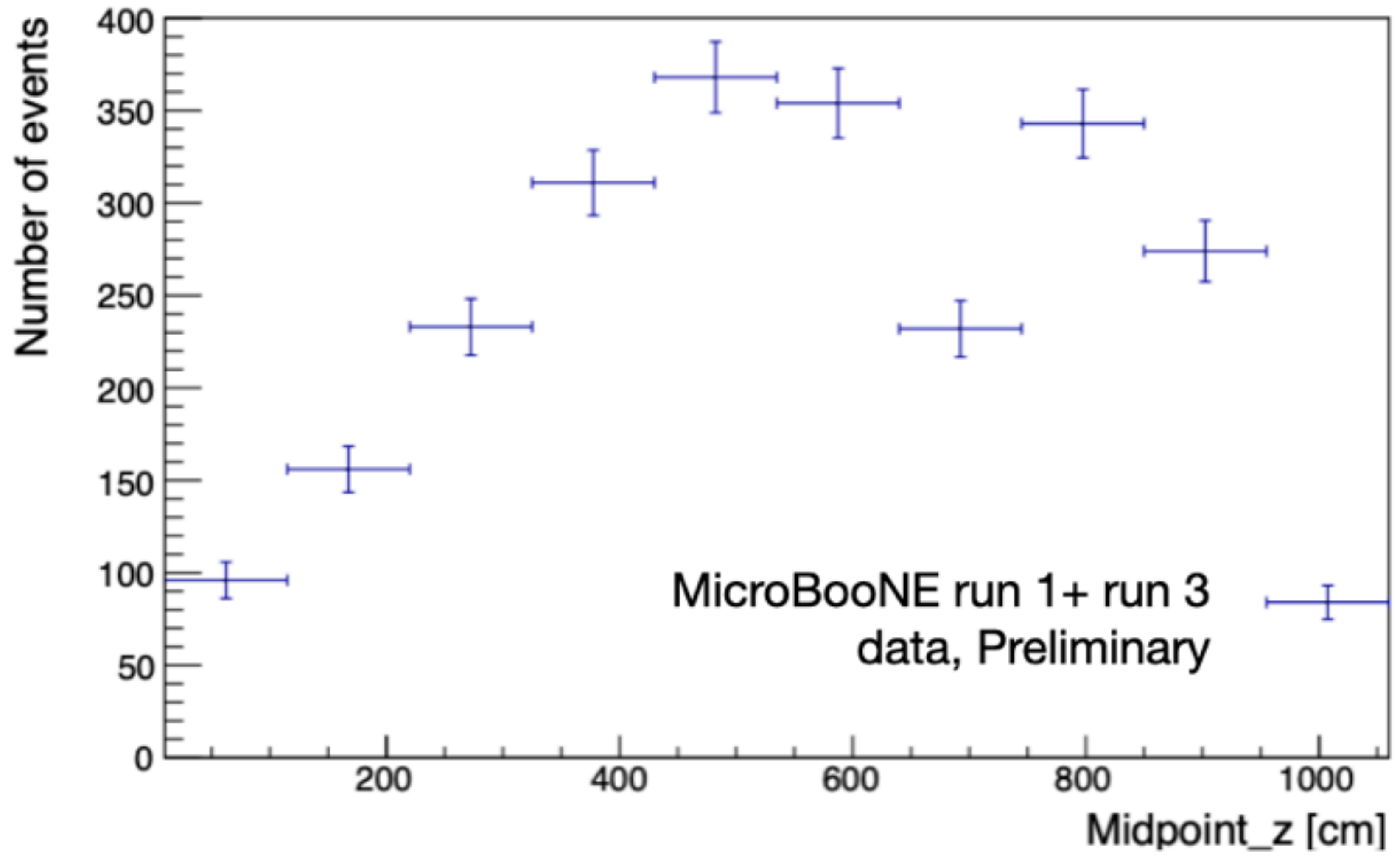


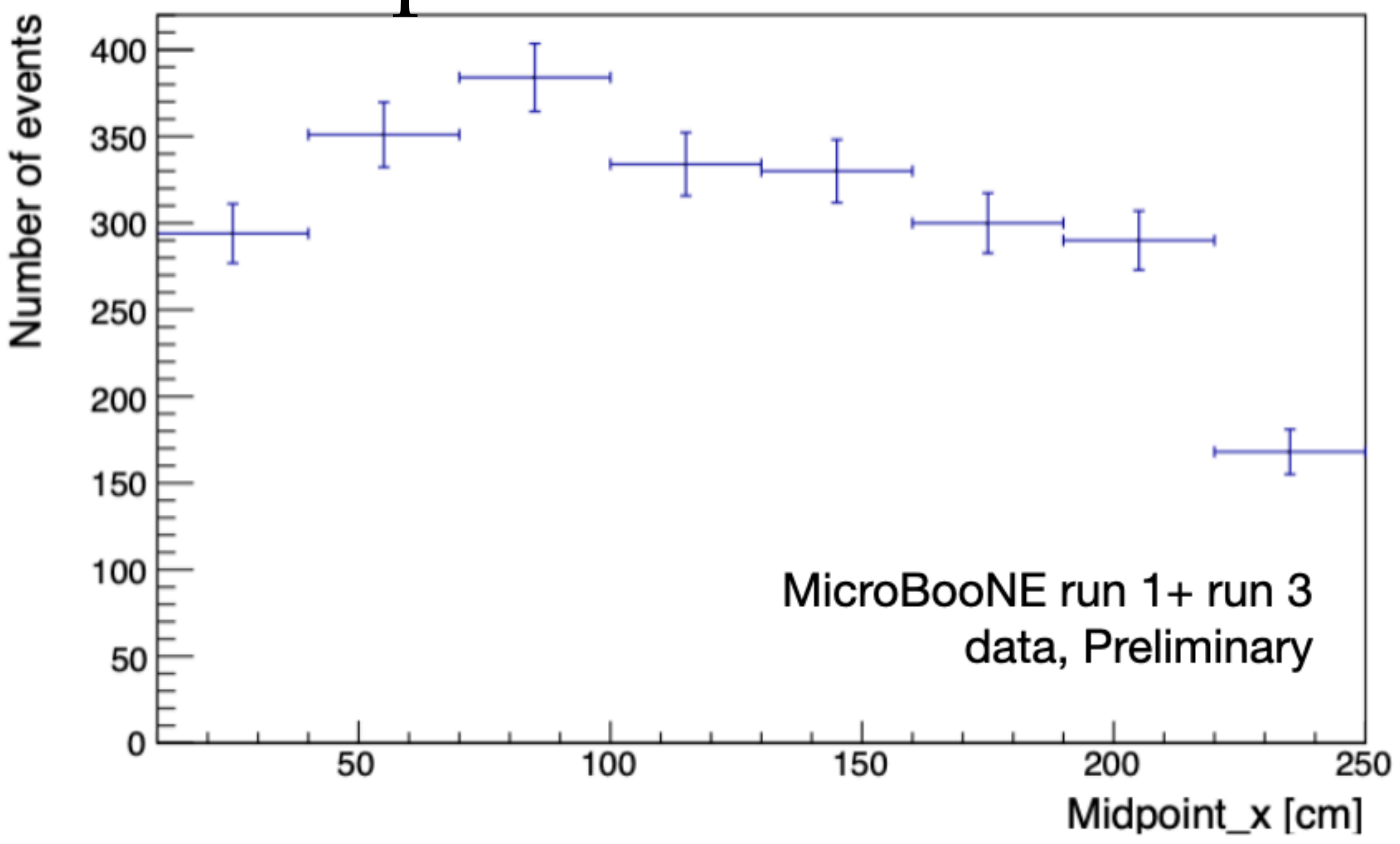


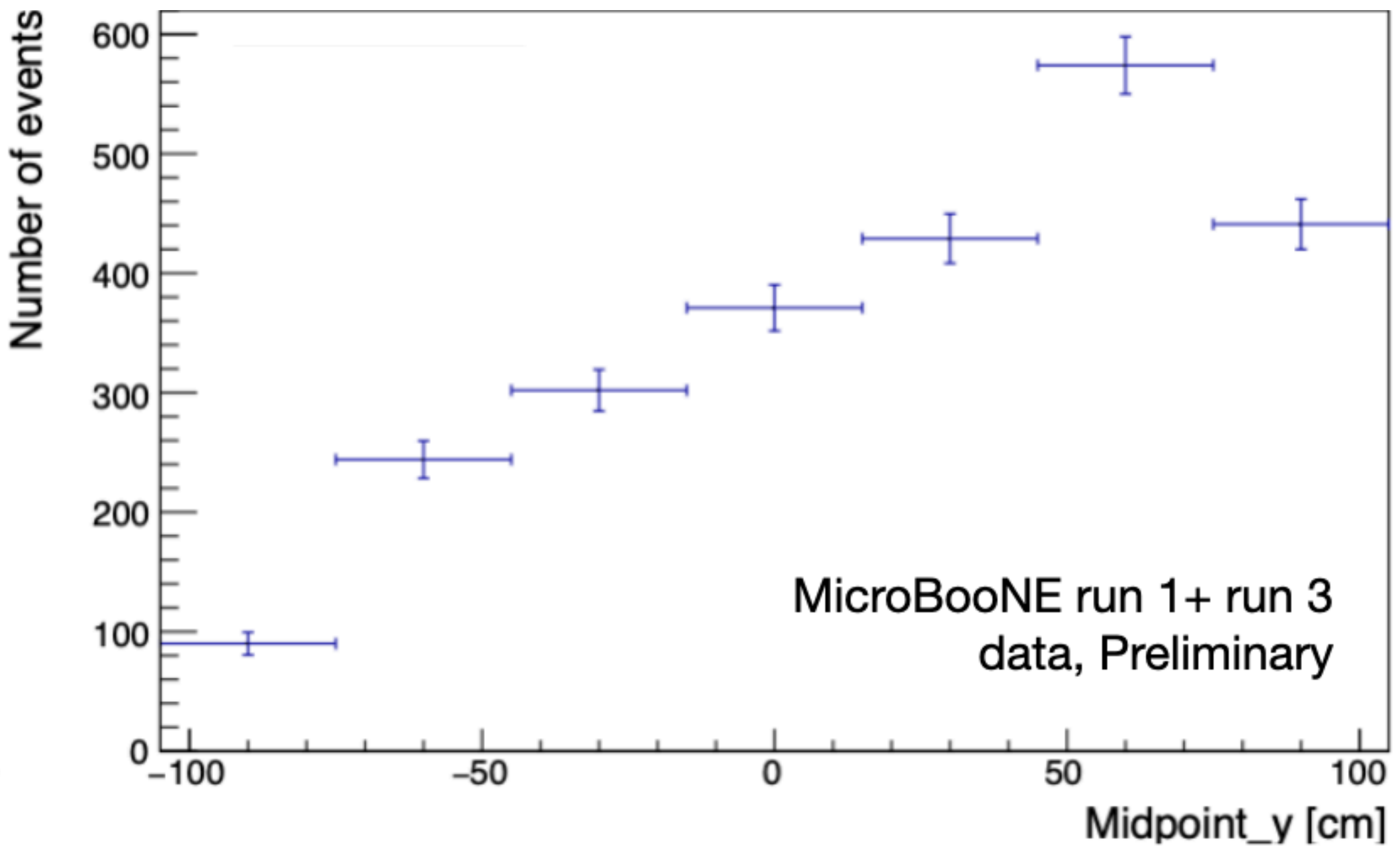
Backup

Position distributions

- The proton candidates:
  - distribute all over drift direction (x)
  - a higher distribution is observed with higher y because our sample comes from cosmic rays
  - the dips in small z and around 700 cm are due to the difficulty to reconstruct "point-like" tracks in a region of the collection-plane with unresponsive wires







Total light yield in the vertical/beam direction

- The light-yield is higher in the middle part of the detector compared to the light-yield at the top and bottom.
  - This is due to the border effect which refers to the absorption from the wall of the detector
- Both predicted and detected light-yields are almost uniform along the beam direction
  - The dip in small z is due to is due to the exclusion of the two PMTs