Demonstrating Calorimetry and Particle Discrimination at MeV Energy Scales with Ambient Backgrounds in the MicroBooNE LArTPC

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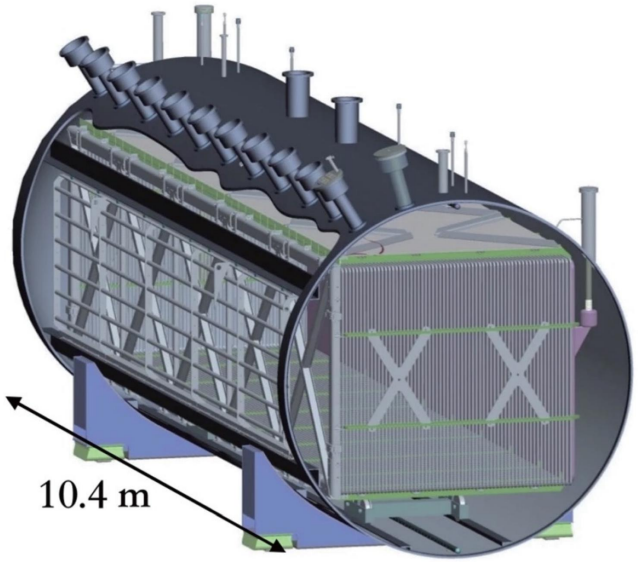
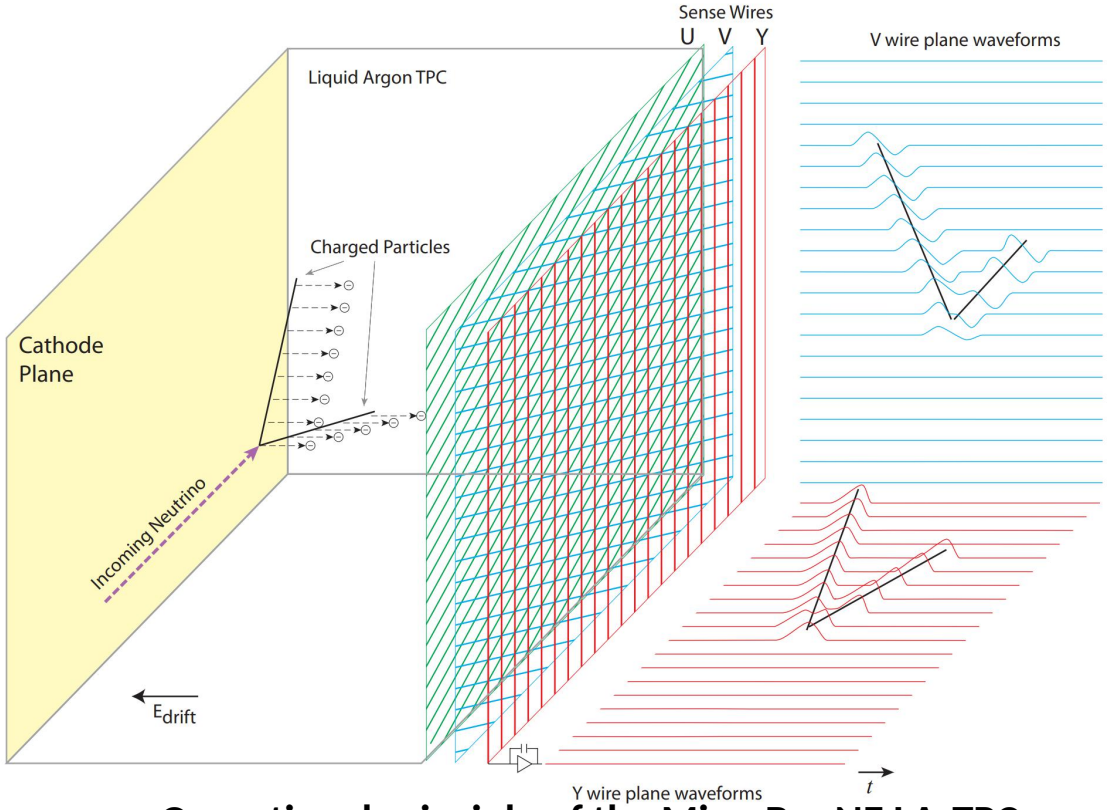
DOE Report Number:
FERMILAB-SLIDES-23-104-ND

MicroBooNE Detector

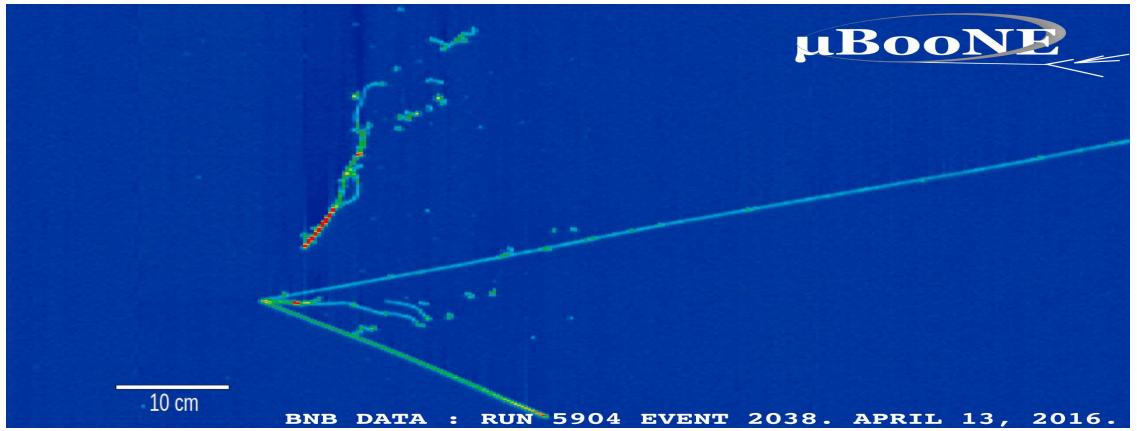
- 85 tonne LArTPC
- Exposed to NuMI and BNB
- Collected data: 2015-2021
- 3 wire planes (Charge) & PMT's (Light)





Operational principle of the MicroBooNE LArTPC

PMT's



Event display

Motivation

- Explore the MeV regime in MicroBooNE

MeV-scale energy depositions are visible in LArTPC as small, topologically isolated **blips** of ionization roughly mm- or cm-scale in size.

- Tell apart ***p***-blips from ***e***-blips

MeV regime : Entire final state comprised by blips
- Supernovae neutrinos
- Solar neutrinos

GeV regime : Identify blip content in final states
- Signatures in accelerator neutrino interactions
- BSM searches

MeV scale - PID capability can be broadly useful:
- **Displaced proton tagging (Neutrons)**
- **Low hadronic energy final state identification (Coherent Interactions)**
- **Low-momentum-transfer NC interactions**

What if this blip was sitting right next to a neutrino interaction vertex? Is it a proton or electron?

Particle - ID

- *If Tracks -> dE/dX*
- *If energy is deposited over a small number of hits we can not use dE/dX*

Ambient backgrounds in MicroBooNE

Radiogenic blips

- **MicroBooNE's lower-energy blips (E_{blip} < 3 MeVee)**

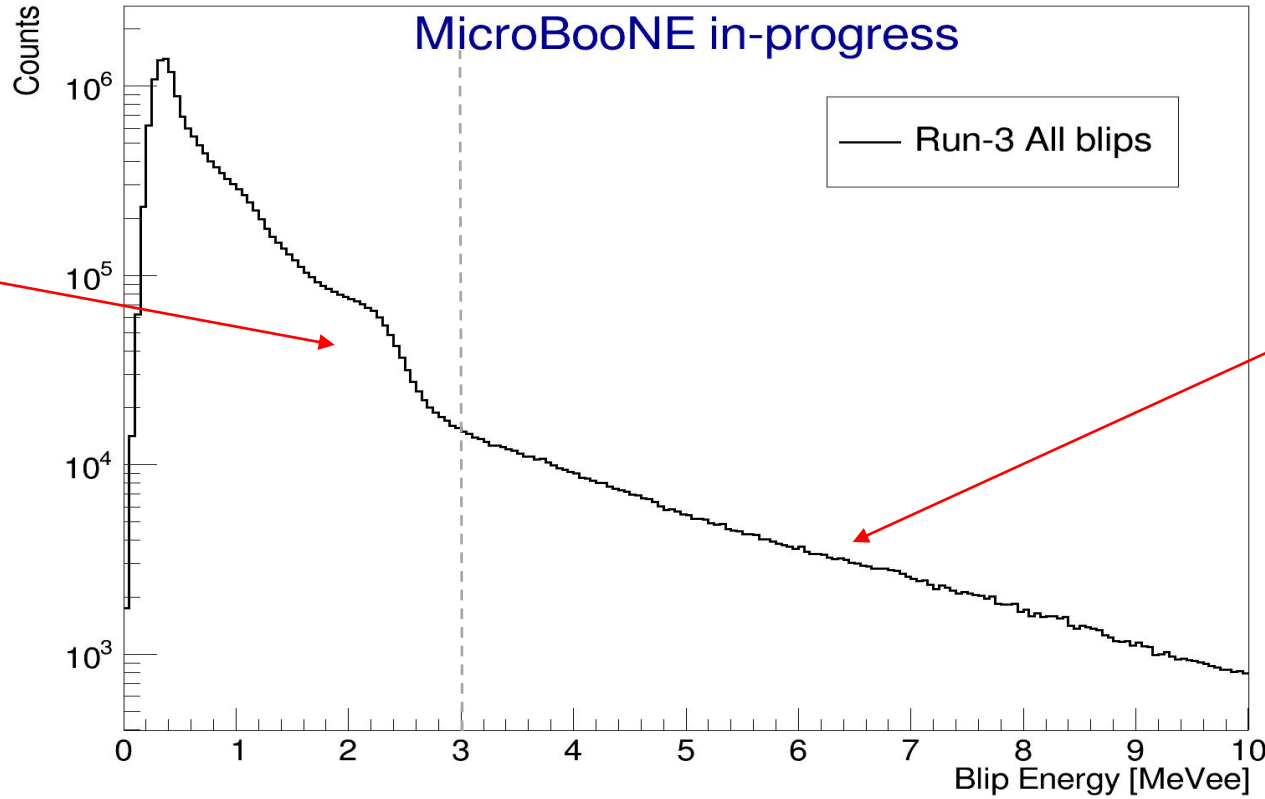
  - Calibrate the energy scale and energy resolution of MeV-scale reconstruction.

Cosmic blips

MicroBooNE's higher-energy blips (3 MeVee < E_{blip} <8 MeVee)

- Cosmogenically-produced *e*-blips and *p*-blips useful to assess MeV-scale particle discrimination metrics

Radiogenic contamination features



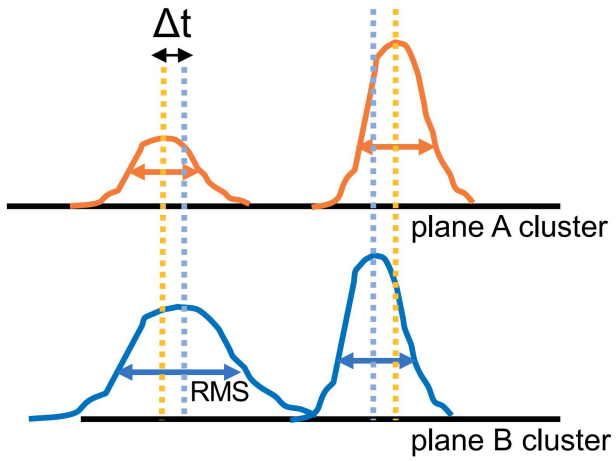
Cosmics

Blip Reco

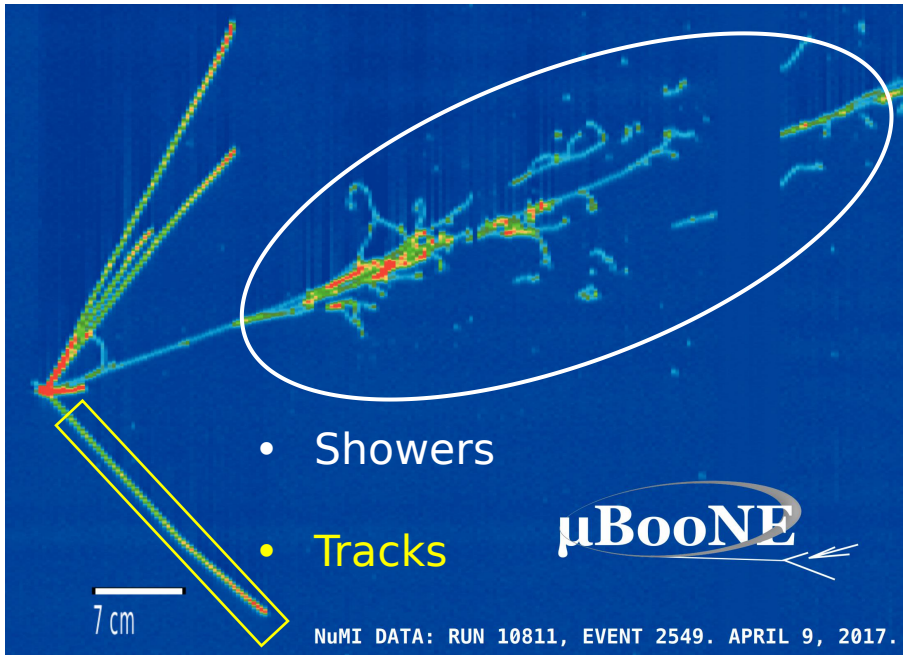
- Algorithm class (BlipReco) under development (Will Foreman)

Basic procedure

1. Veto hits in or near tracks
2. Cluster hits
3. For each collection plane cluster, calculate a match-score for clusters on other planes
4. Best-matched clusters grouped into 3D "blips" using wire intersections to get Y/Z coordinates



$$\text{Match score} \sim \Sigma\,(1 - \Delta t_i / \text{RMS}_i)$$

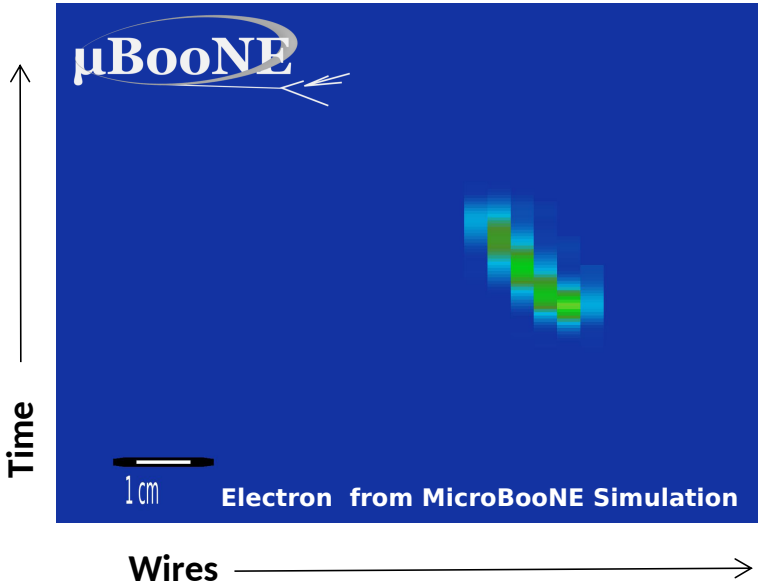


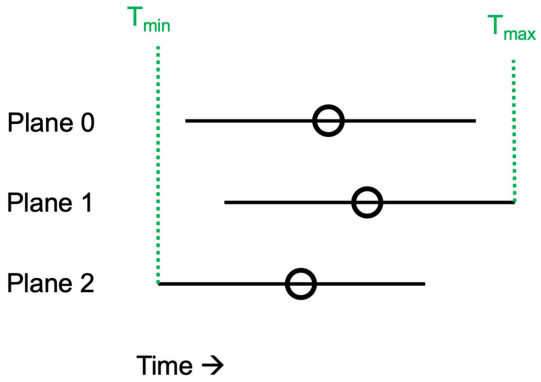
- We take the hits that are not in **tracks/showers** to make another objet: **blip**

MeV-Scale Particle ID metric

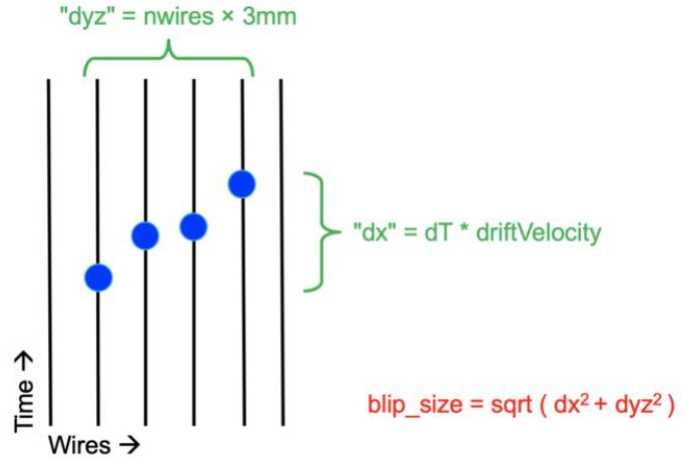
blip_charge [e] / blip_size [cm] → **Collection plane charge**

- `blip_size = sqrt((dx)² + (dyz)²)`
  - `dx` → **Length of the blip along the drift axis** (time-span * drift Velocity)
  - `dyz` → **Length of the blip projected onto the YZ plane** (wires span * 0.3 cm)



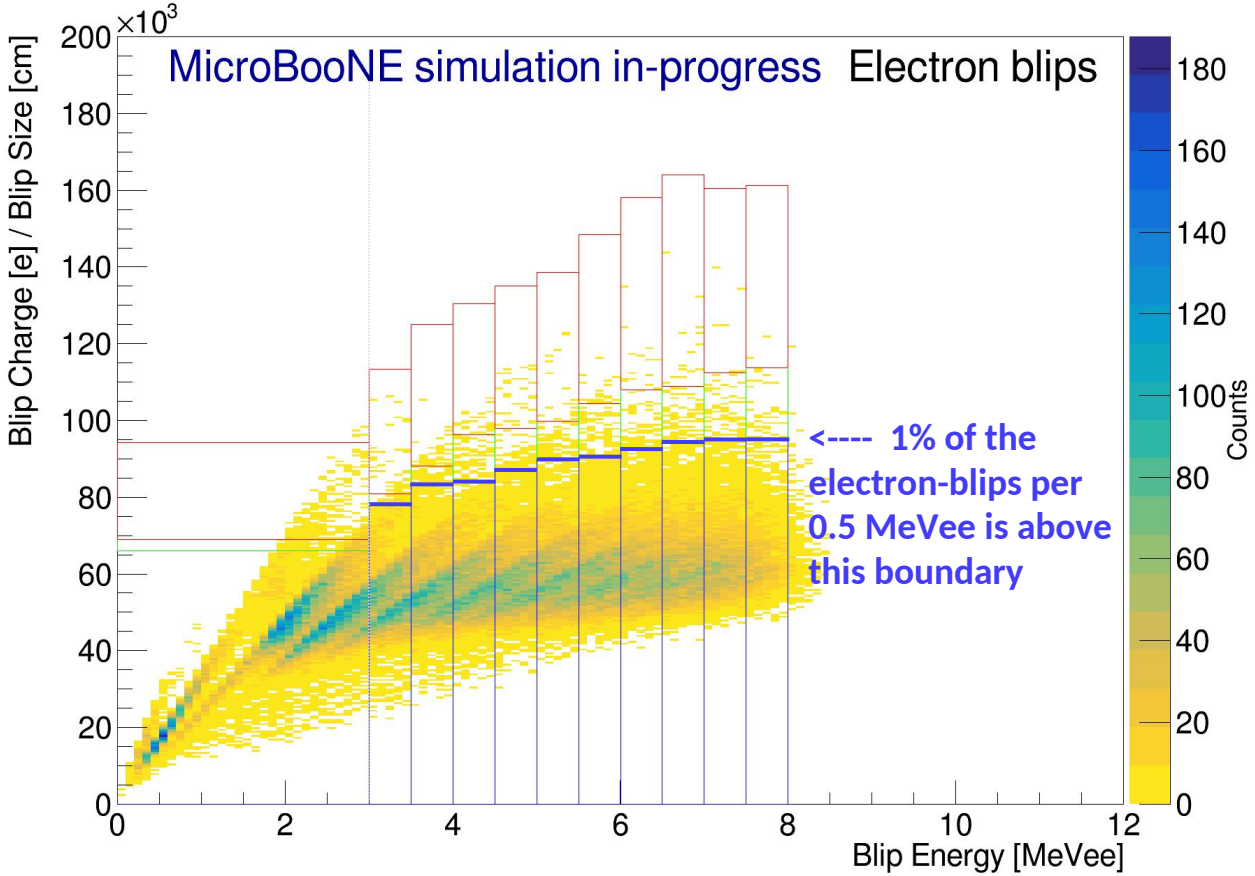


$dx = (T_{max}-T_{min}) \times (driftVelocity)$

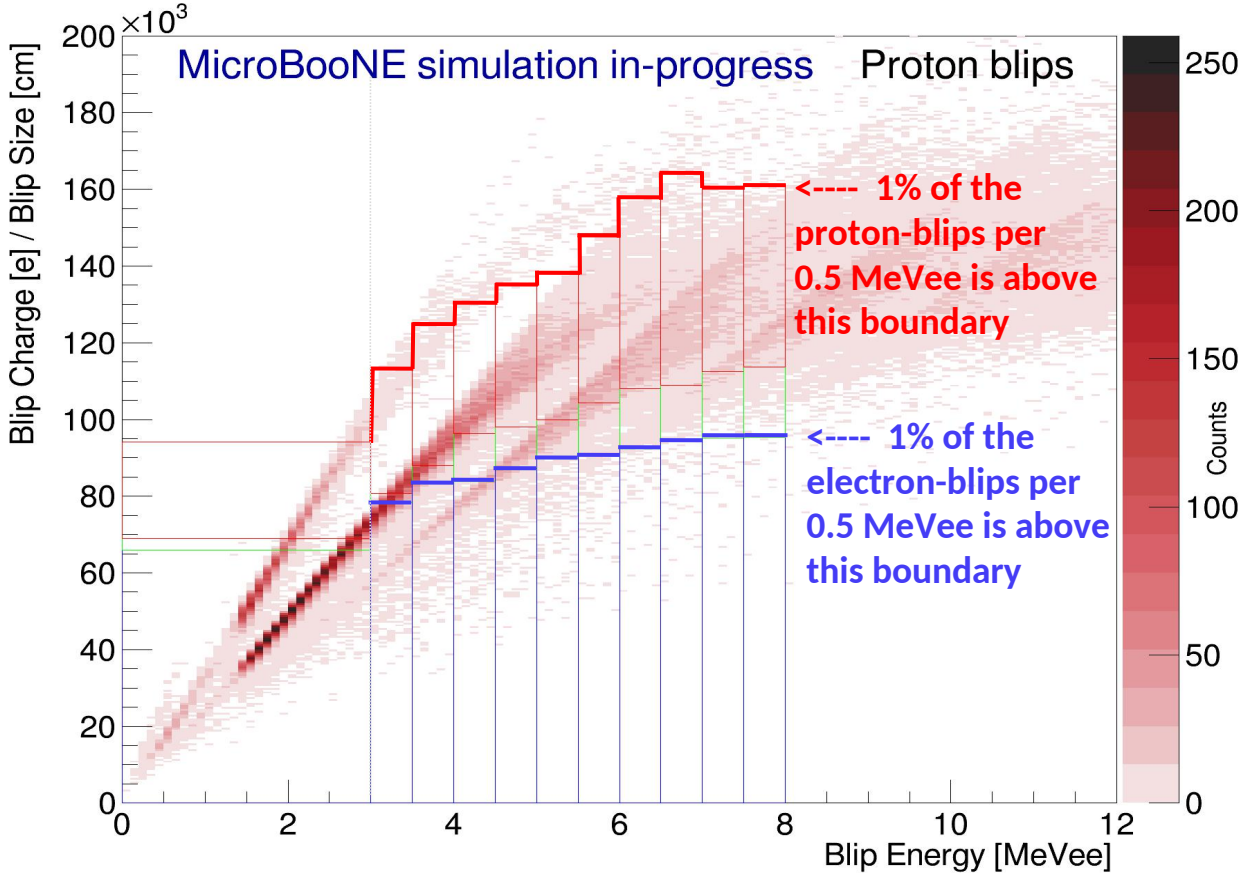


*Diagrams by Will Foreman

Simulated Electrons 2-8 MeV

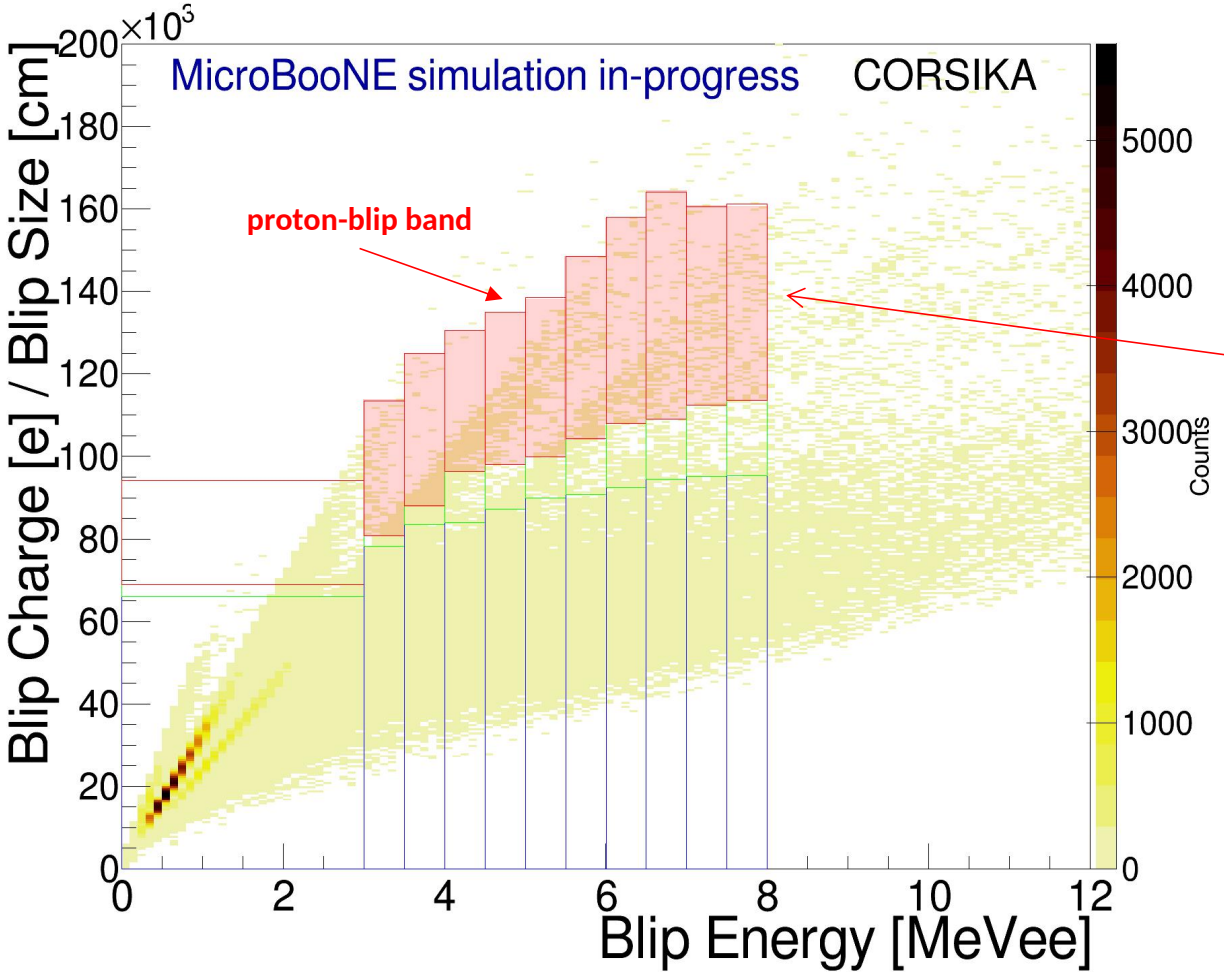


Simulated Protons 10-40 MeV



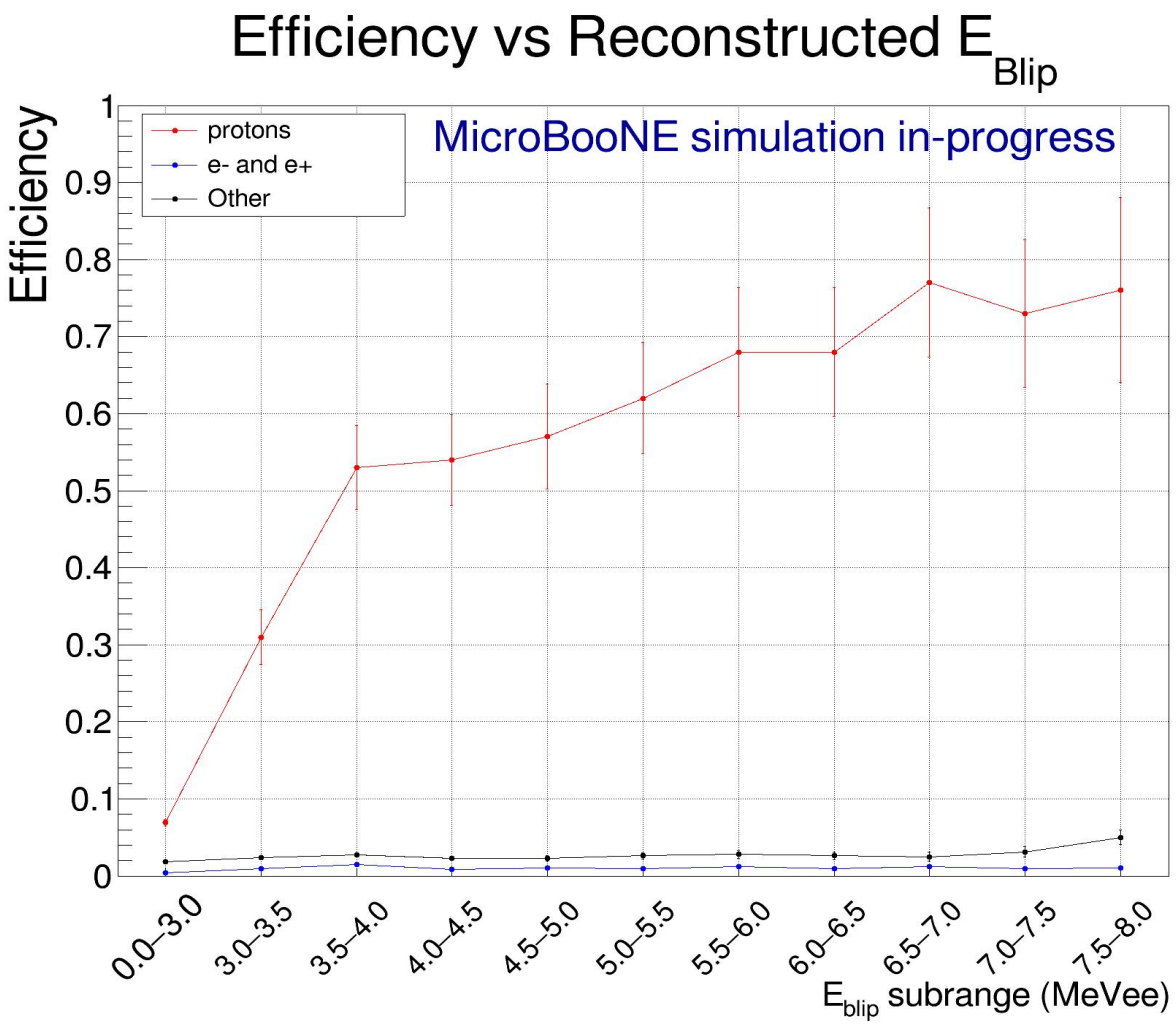
- Samples processed with lower threshold settings. Showing 3-plane matched blips only.
- 1% of the entries in a 0.5 MeVee bin, fall above the indicated limits for a given particle type.
- The proton-blip band is “contaminated” with less than 1% of electron-blips between 3-8 [MeVee].

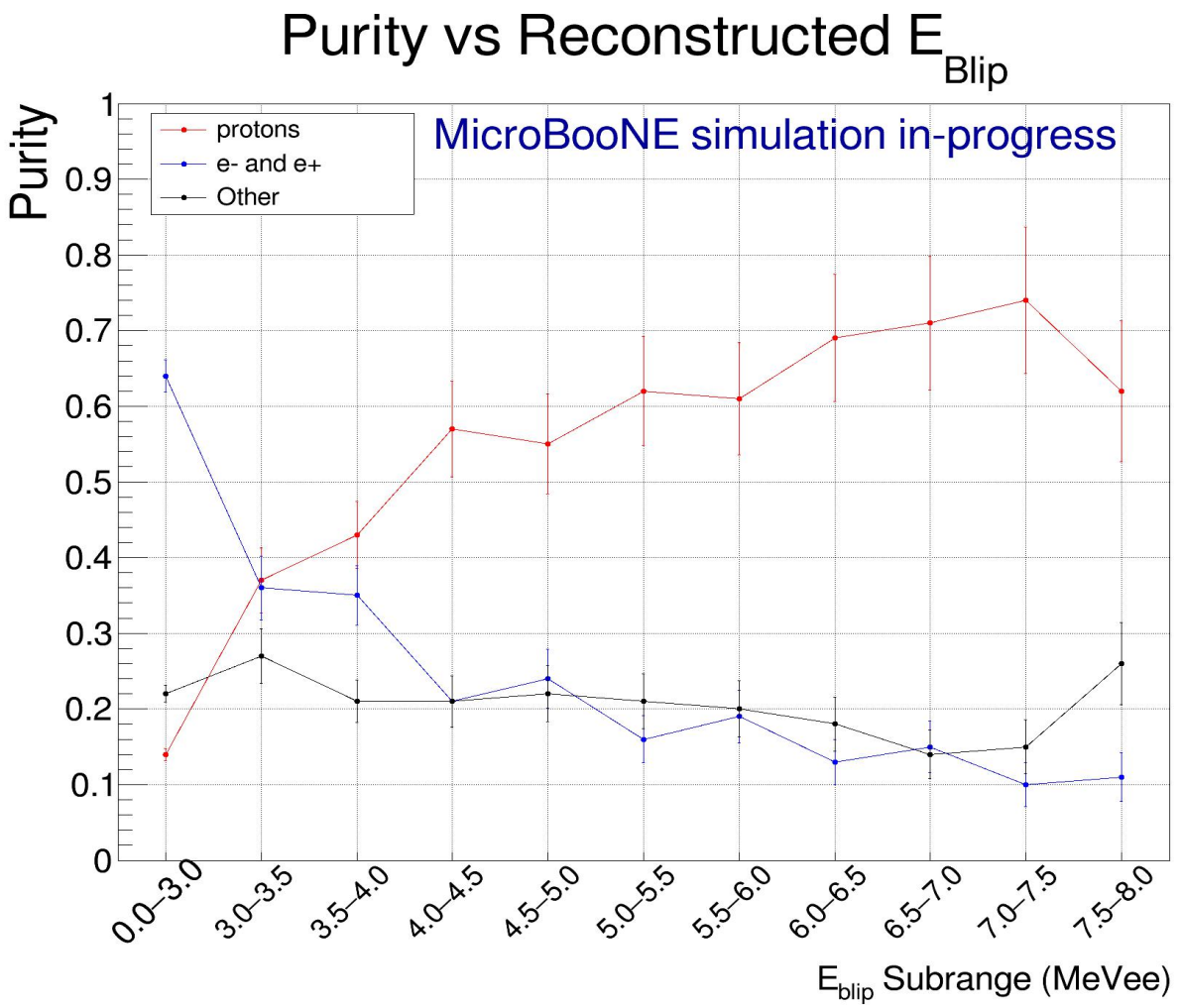
CORSIKA - Cosmic Mass Composition simulation



- Assess the efficiency and purity for the proton-blip band
- CORSIKA -CMC simulation
- We get blips from cosmics within the proton-blip band.
- MC ---> *proton-blip* if most of deposited charge in it is due to a proton.

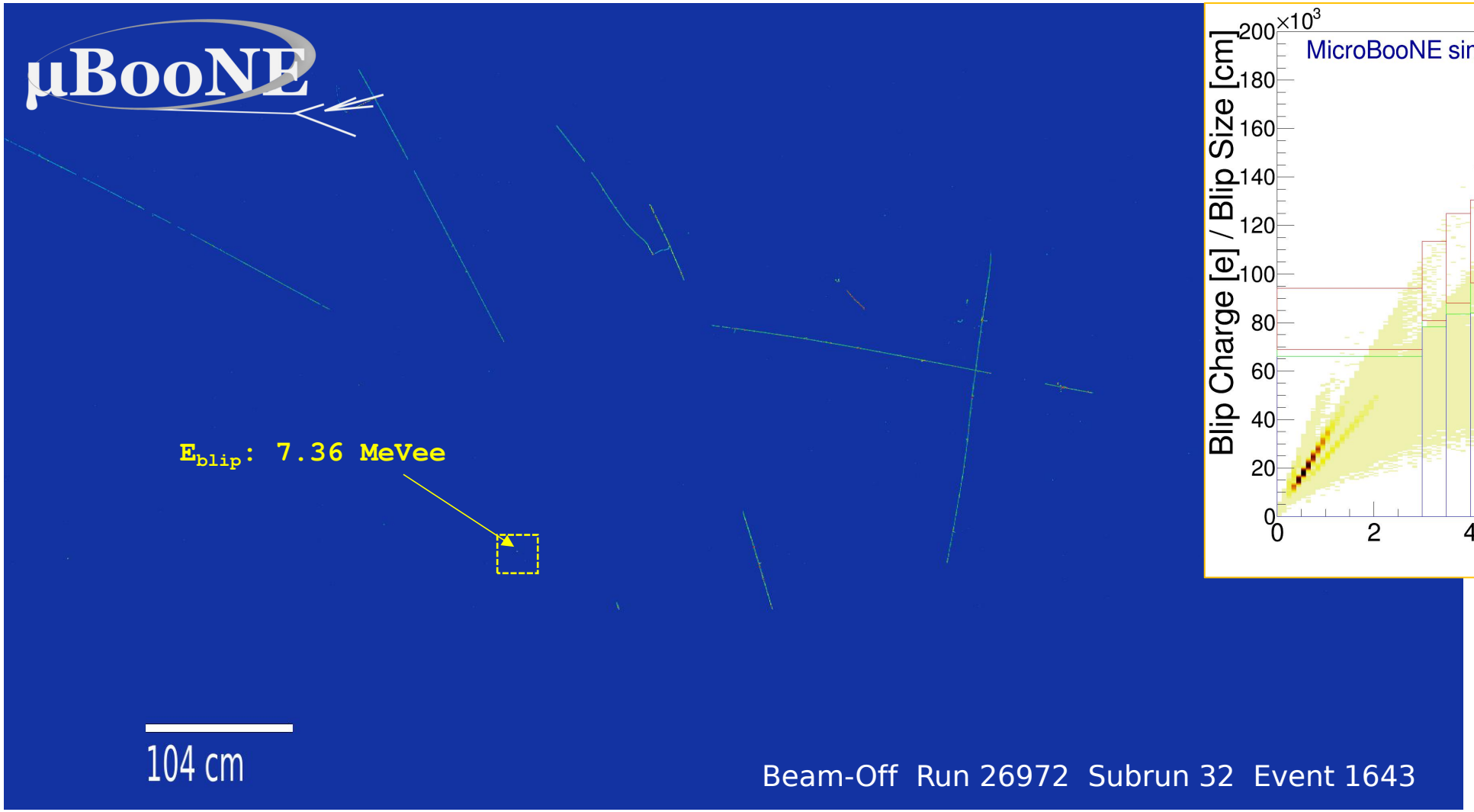
- CORSIKA CMC - Proton-blip efficiency and purity for the proton-blip band

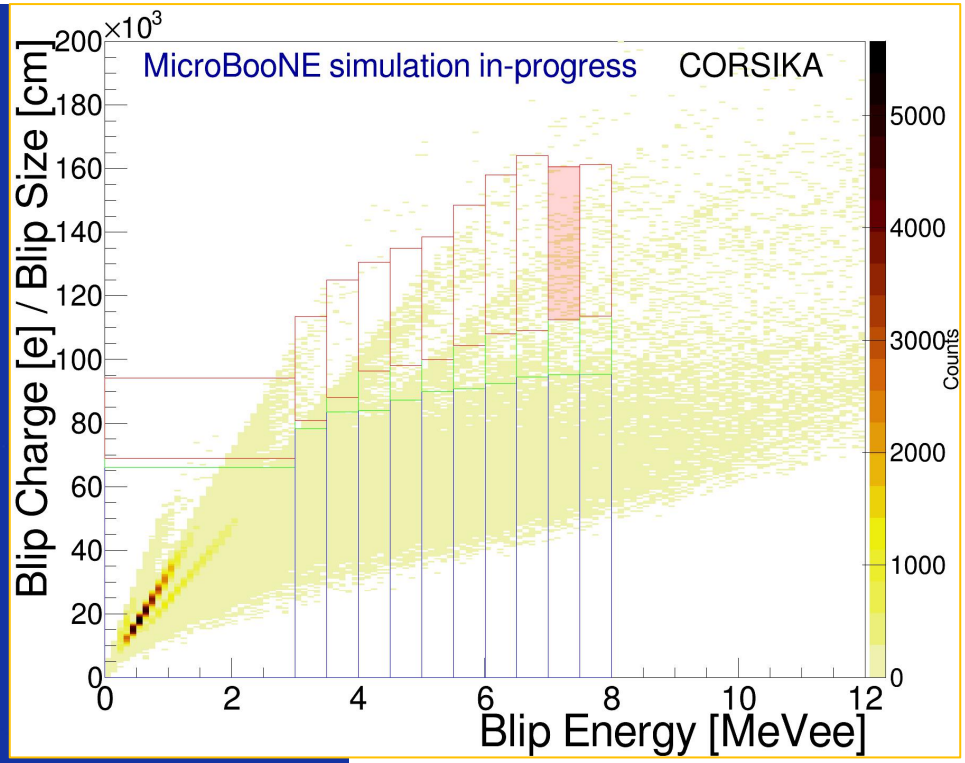




- Efficiency and purity by blip energy intervals.
- Substantial electron-proton separation above roughly 3 MeVee

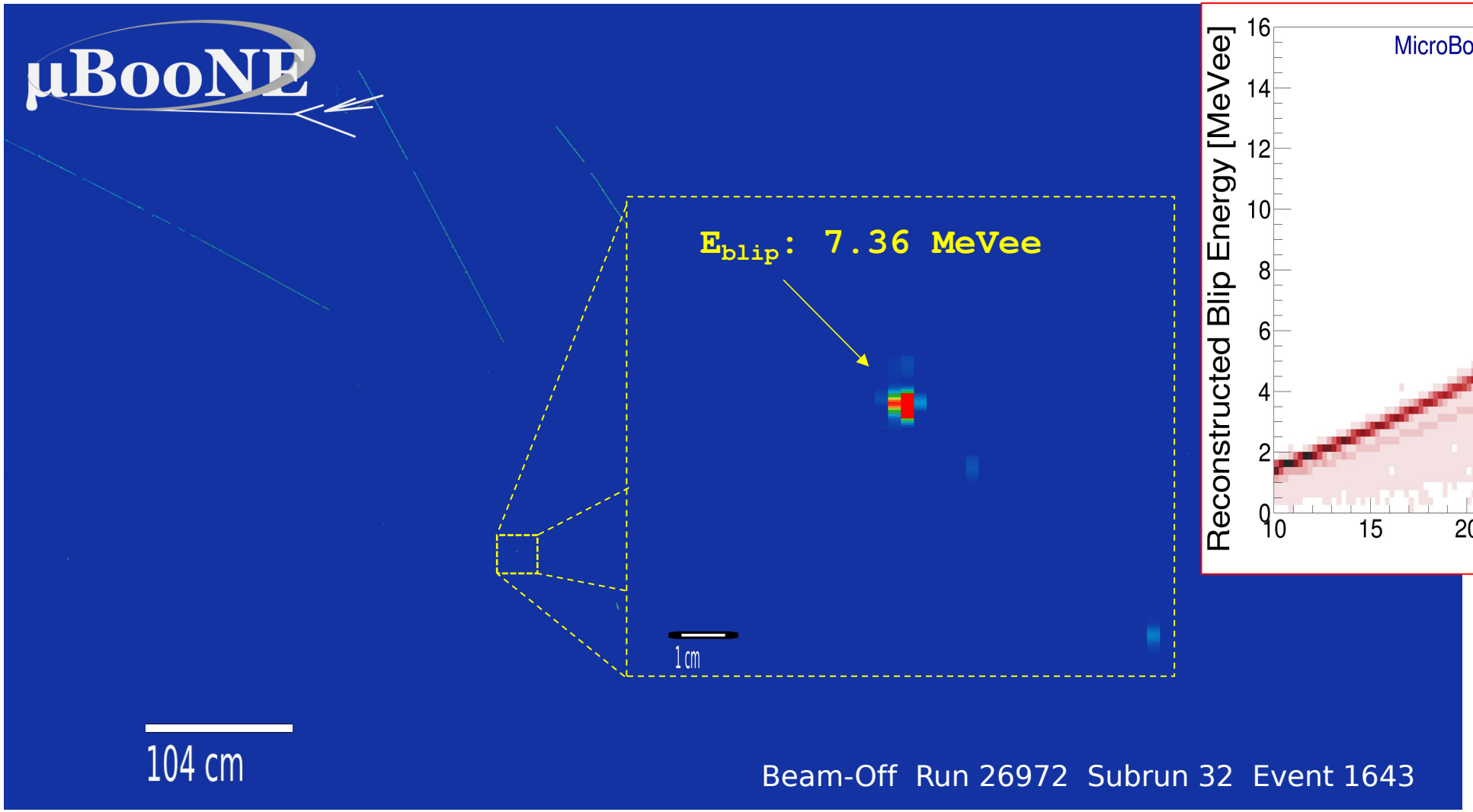
Data blips in blip-proton band

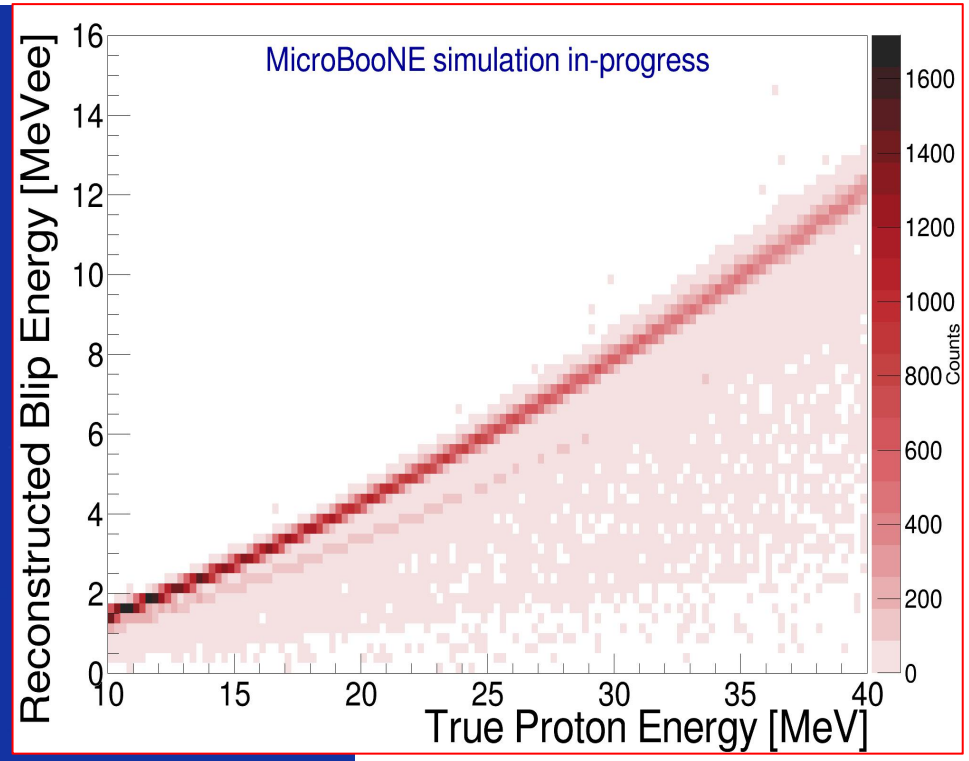




- Searching for p-blips on Data based on MC

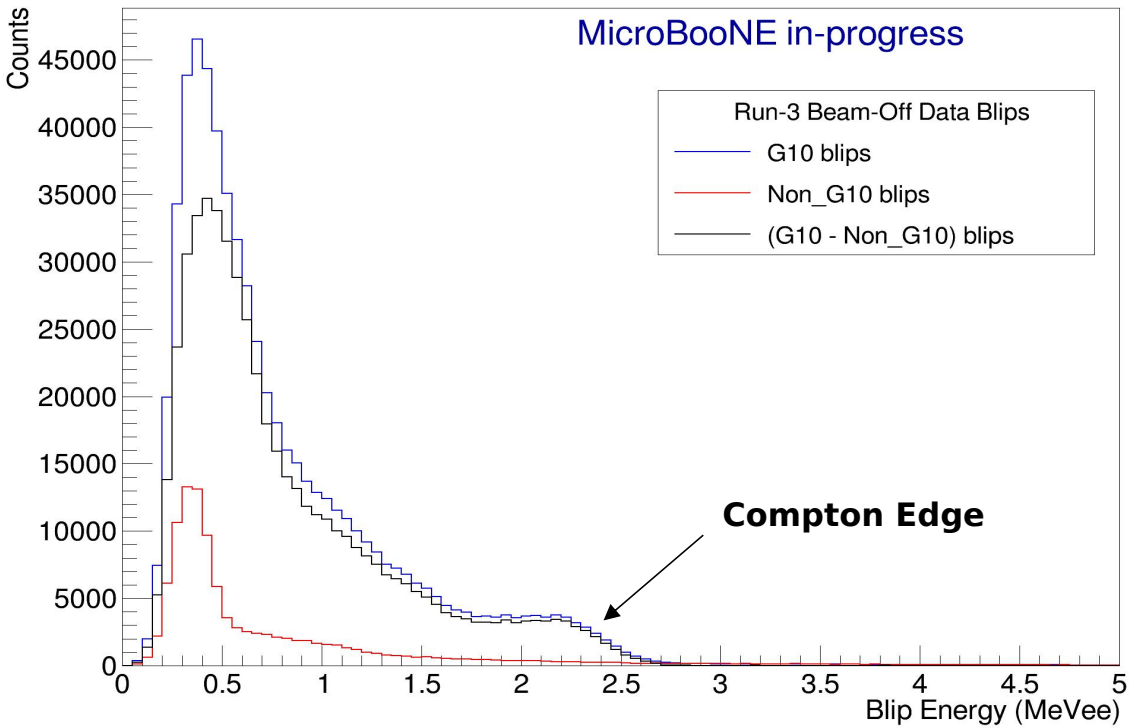
Data blips in blip-proton band

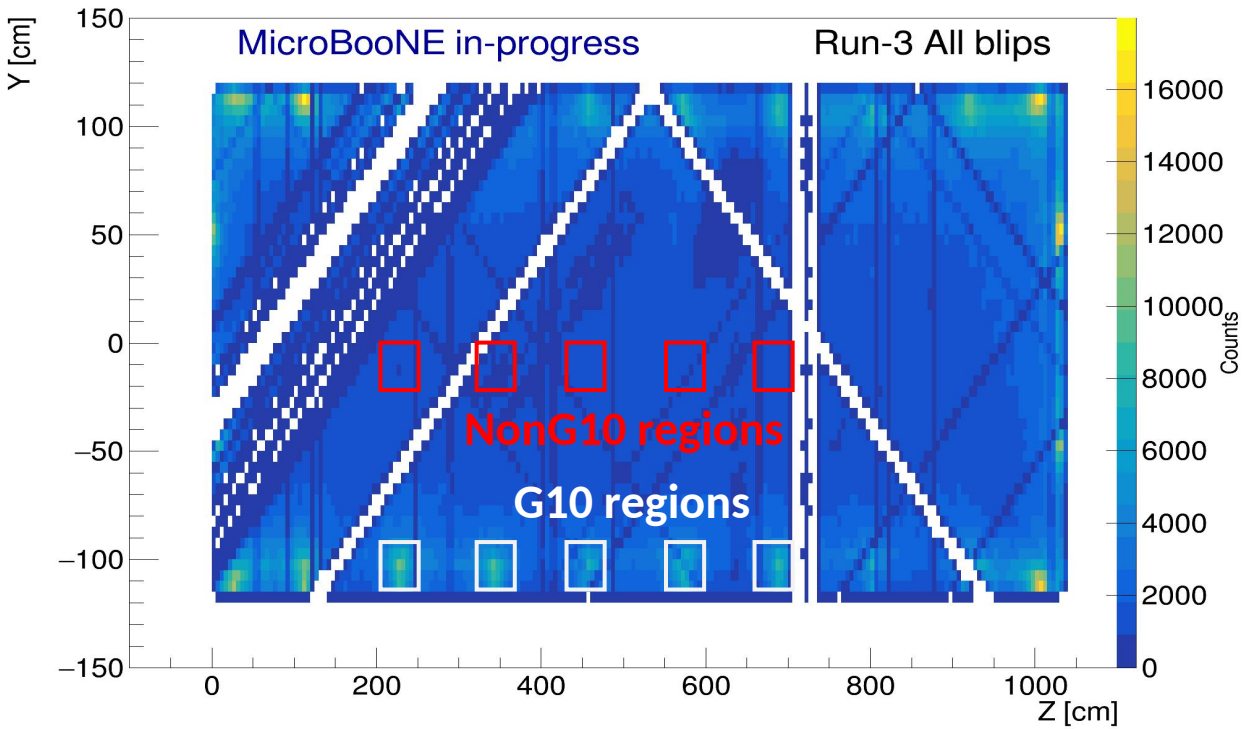


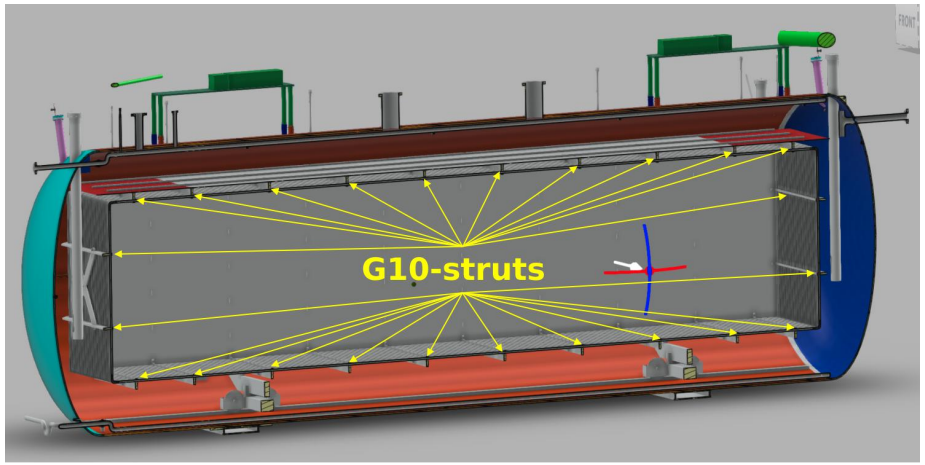


- Lower the threshold for detecting protons

MeV-scale Calibration



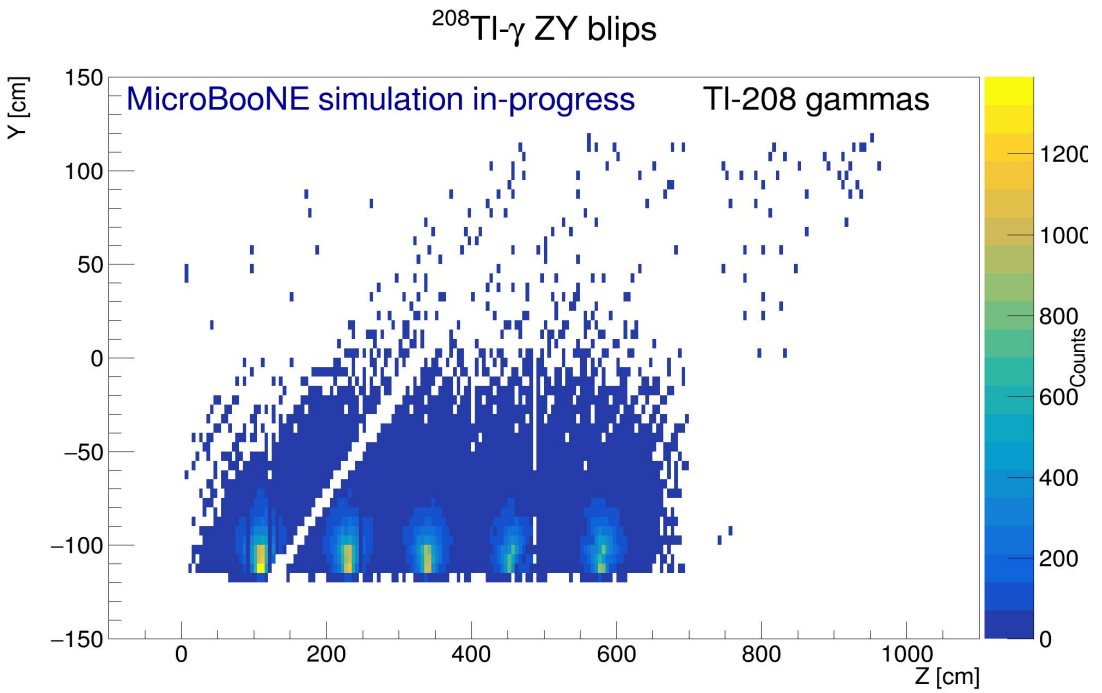


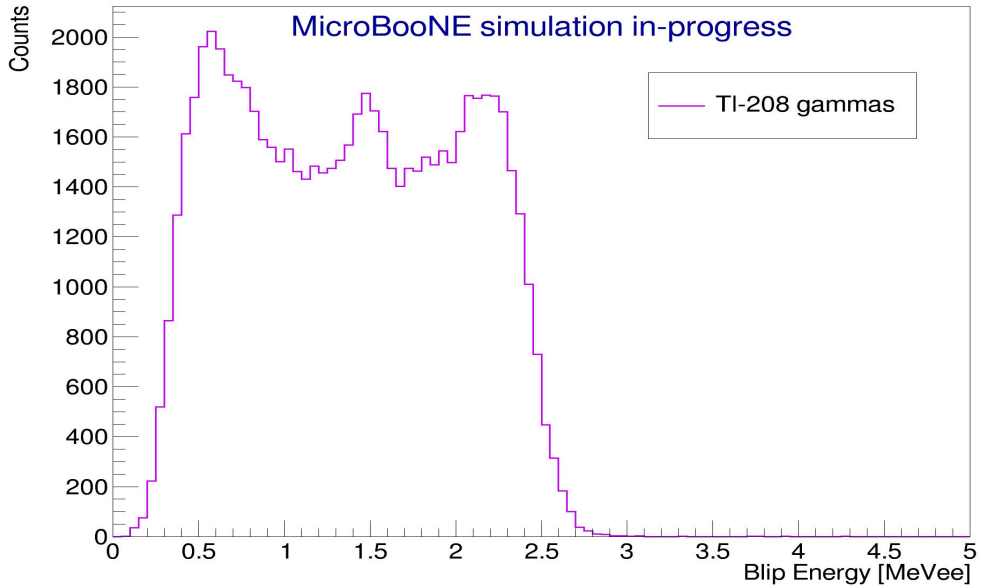


- MicroBooNE's **lower-energy ambient blips** contain specific radiogenic spectral features that can be used to calibrate the energy scale and energy resolution of MicroBooNE's MeV-scale reconstruction.

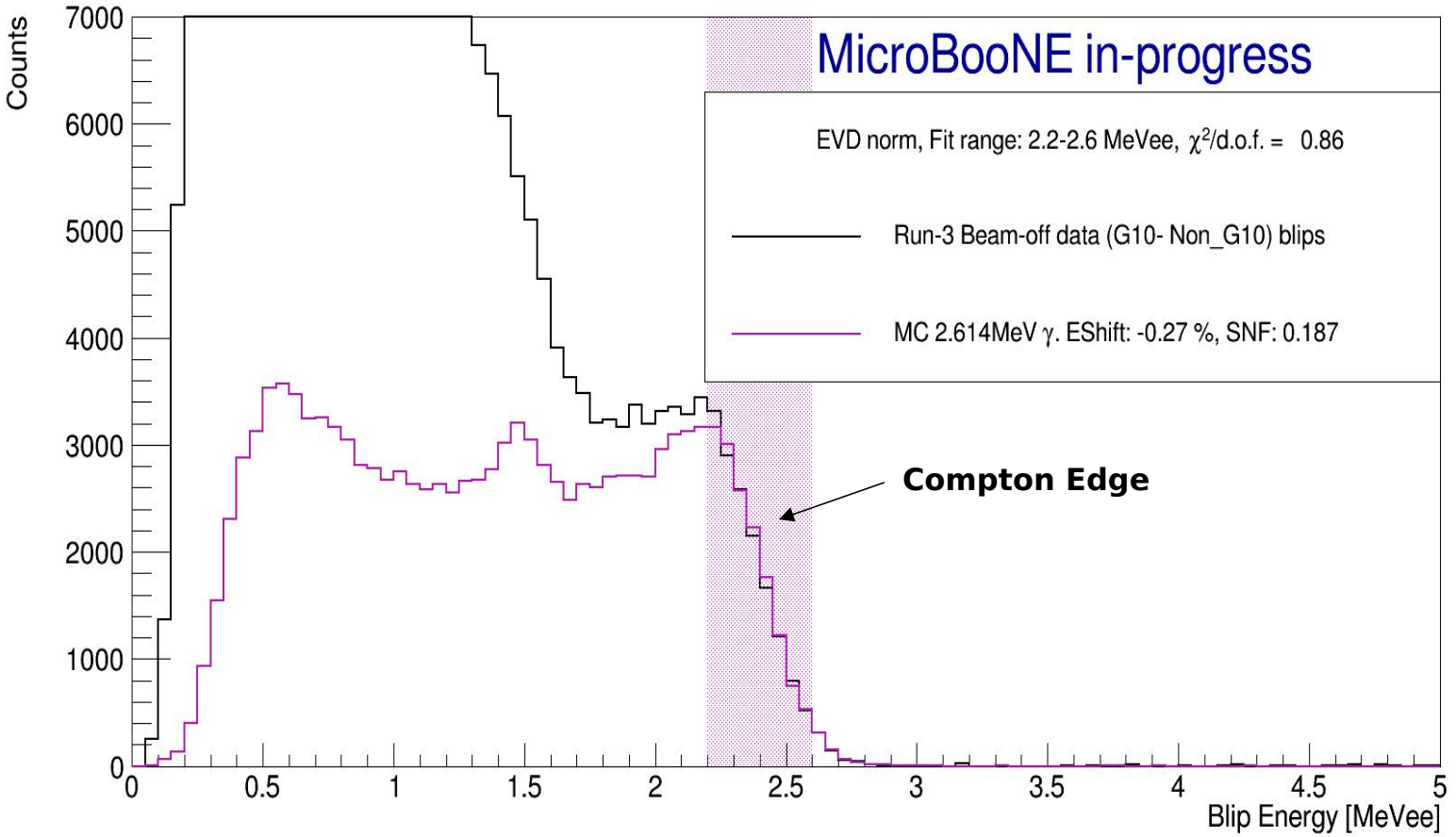
G10 - struts

- Simulated 2.614 MeV gammas (^{208}Tl - γ).
- Three gammas/per strut, within the G10-struts volume.
- Get an **energy calibration offset** by matching the Tl-208 gammas spectrum to the G10-blips spectrum Compton edge.





- **Compton Edge - G10 blips and Tl-208 gammas energy spectra**



- Resulting Tl-208 gamma spectrum for the best fit within 2.2 -2.6 MeVee range.

- Systematic variations:
  - No Background subtraction
  - Diffusion up
  - Diffusion down

- **Energy Calibration Offset: -0.27 ± 0.45 (stat) ± 0.35 (syst) [%]**
- **Estimated Specific Activity of ^{208}Tl- gammas : 11.37 ± 0.81 (stat) ± 1.21 (syst) [Bq/kg]**

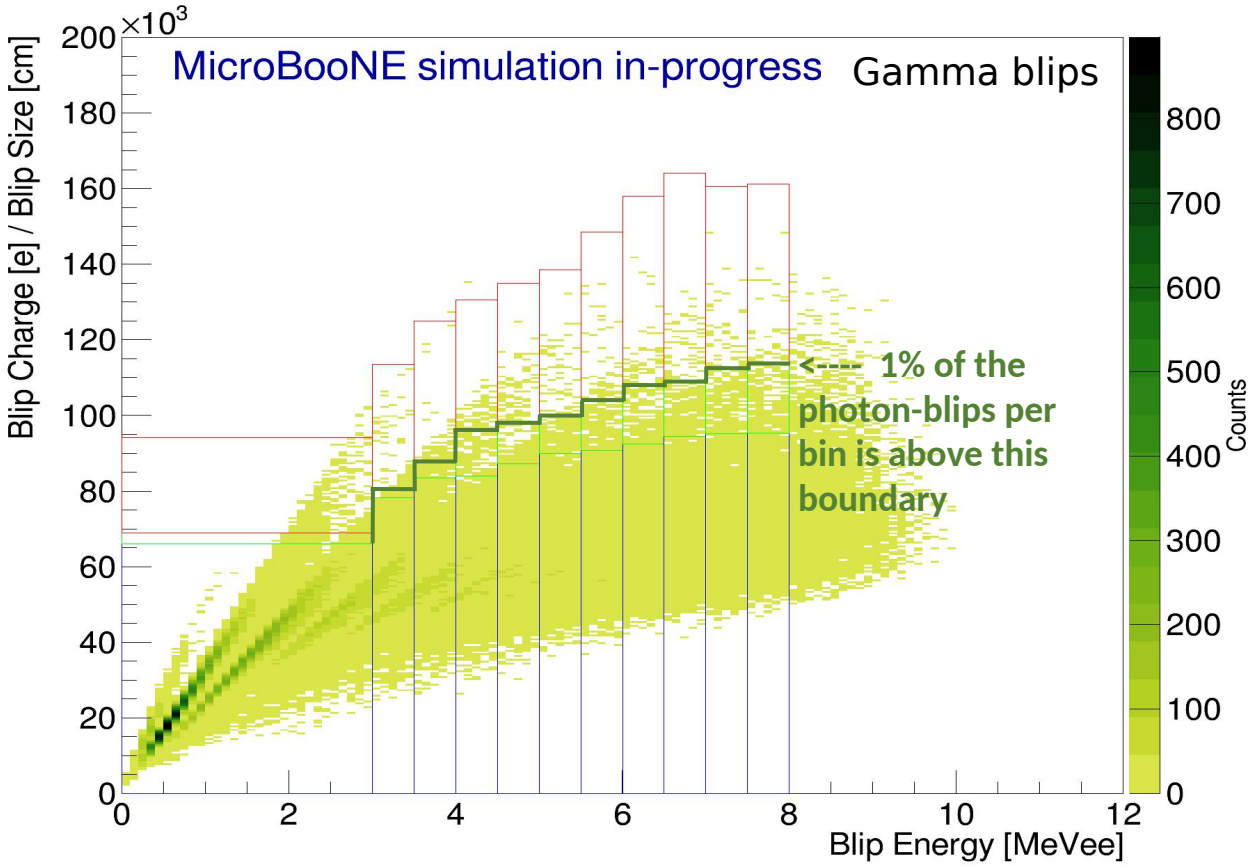
Summary

- Particle-ID should be possible in a neutrino LArTPC even at MeV energy scales.
- MicroBooNE MC blips appear to be properly calibrated to data within 1%.
- The G10-struts seem to be the most radioactive component in the vicinity of the LArTPC active volume, they must contain Th-232.
- In the future we will use properly calibrated blips to study MeV scale-PID at detail.

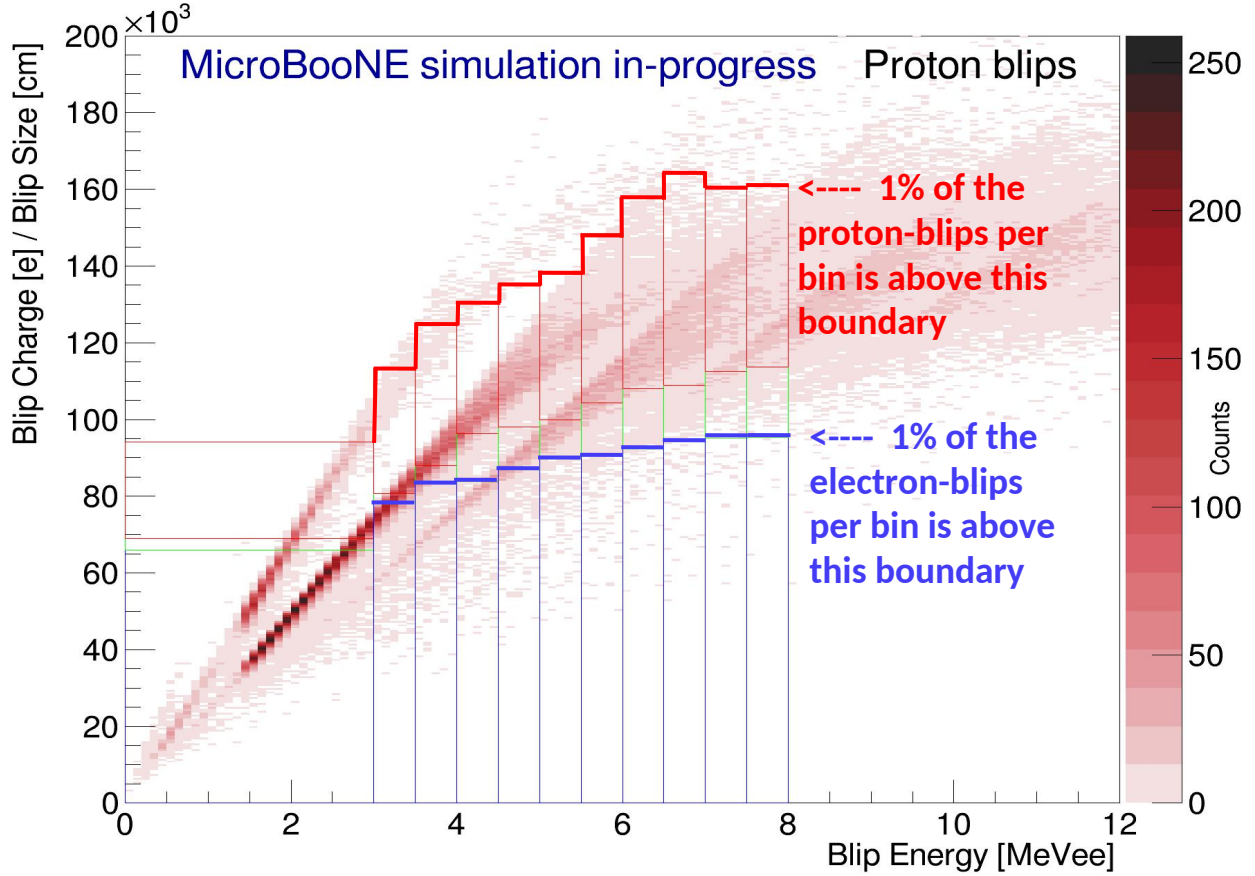
Thank you!

Backup Slides

Simulated Photons 2-10 MeV



Simulated Protons 10-40 MeV



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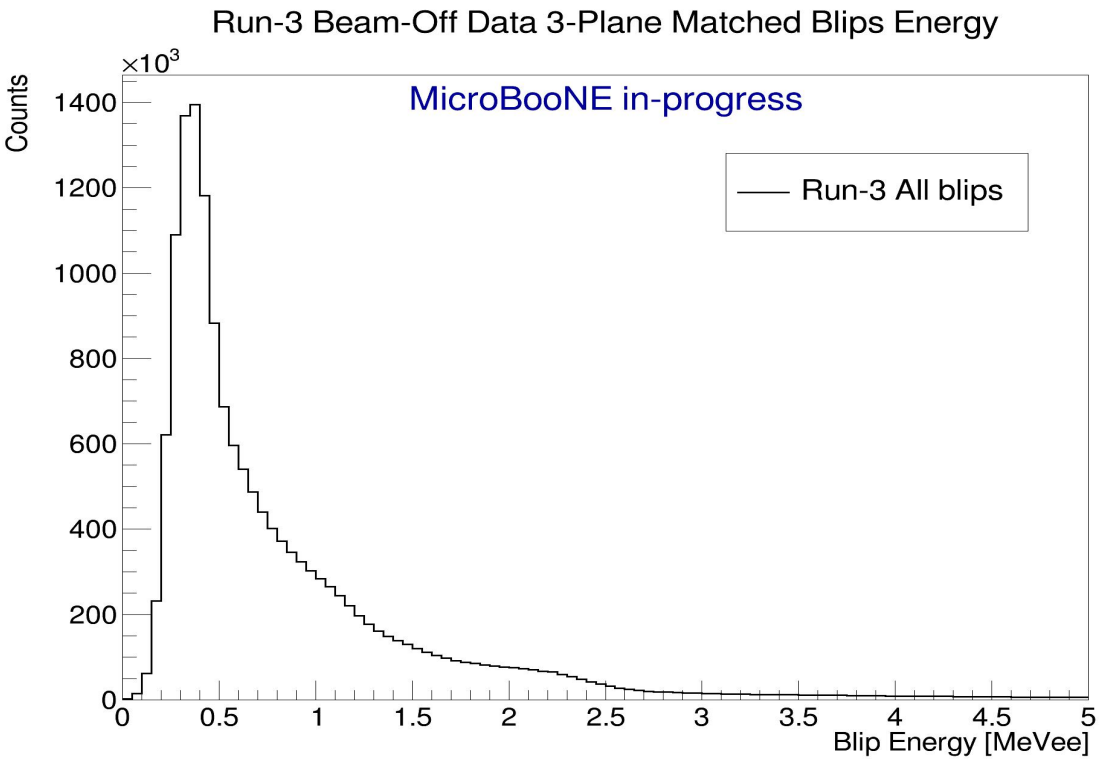
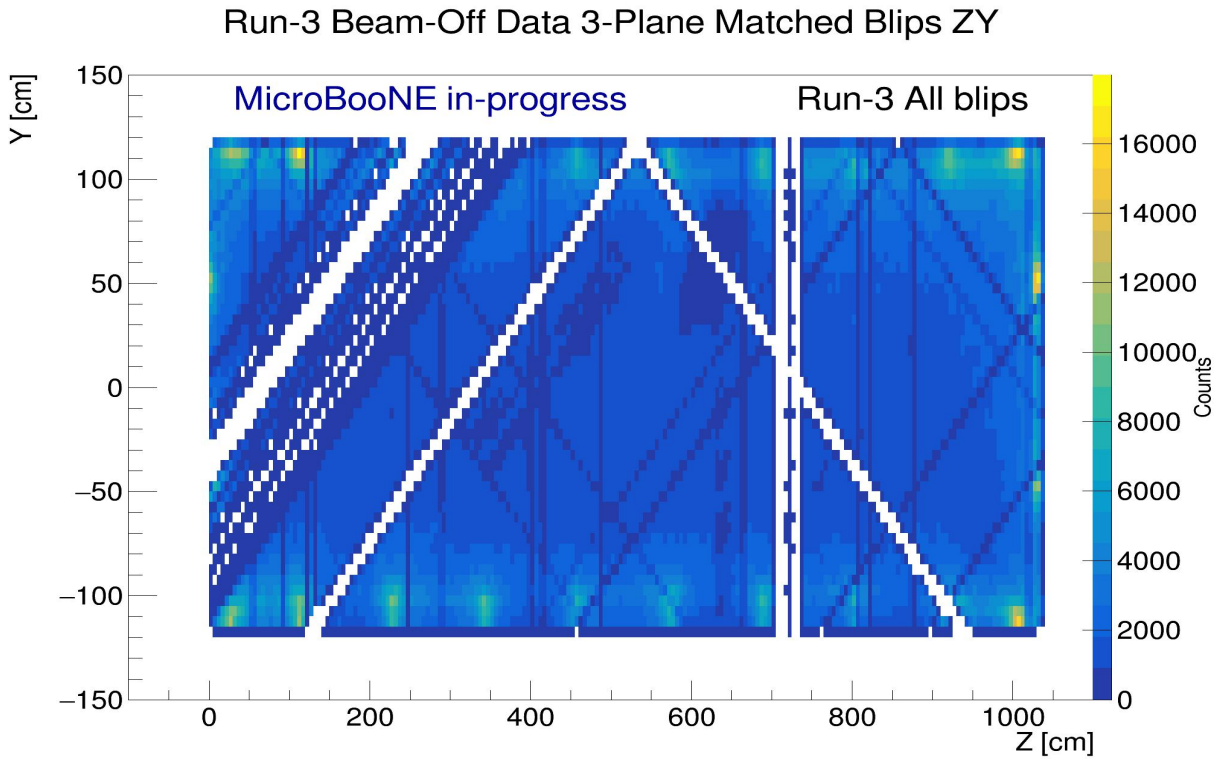
- The proton-band is “contaminated” with less than 1% of electron-blips per bin between 3-8 [MeVee].

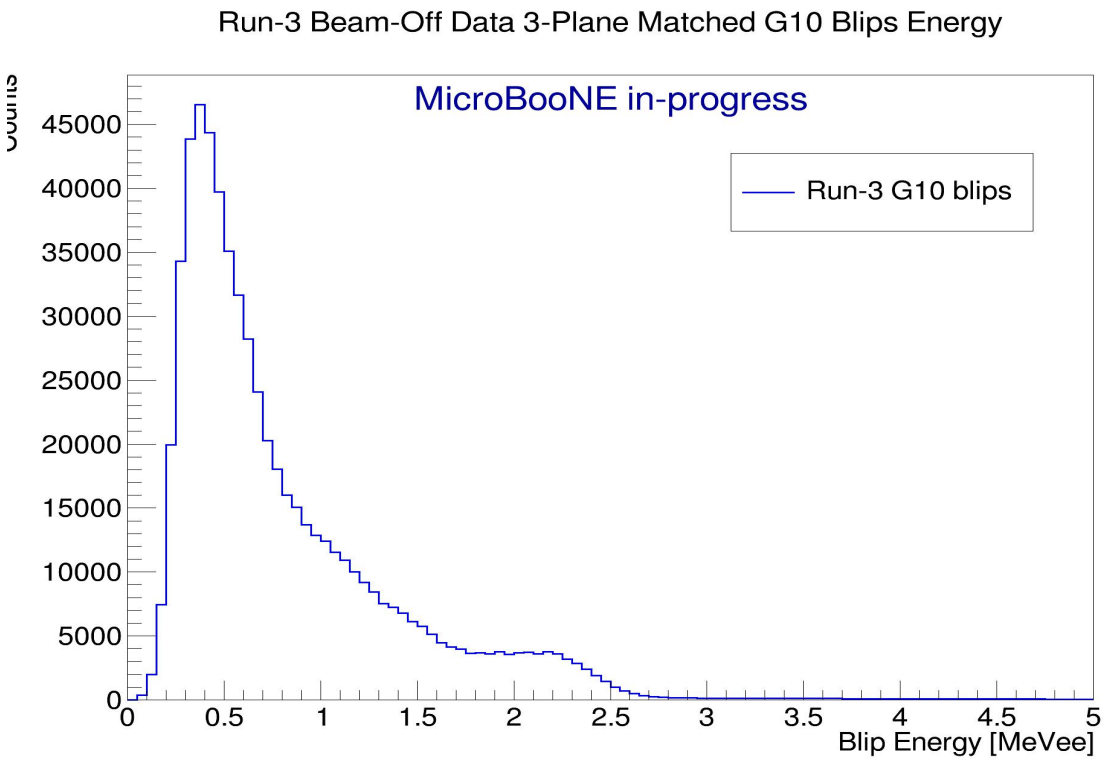
Run 3 Data - Beam Off
Blip Energy spectrum and YZ distribution

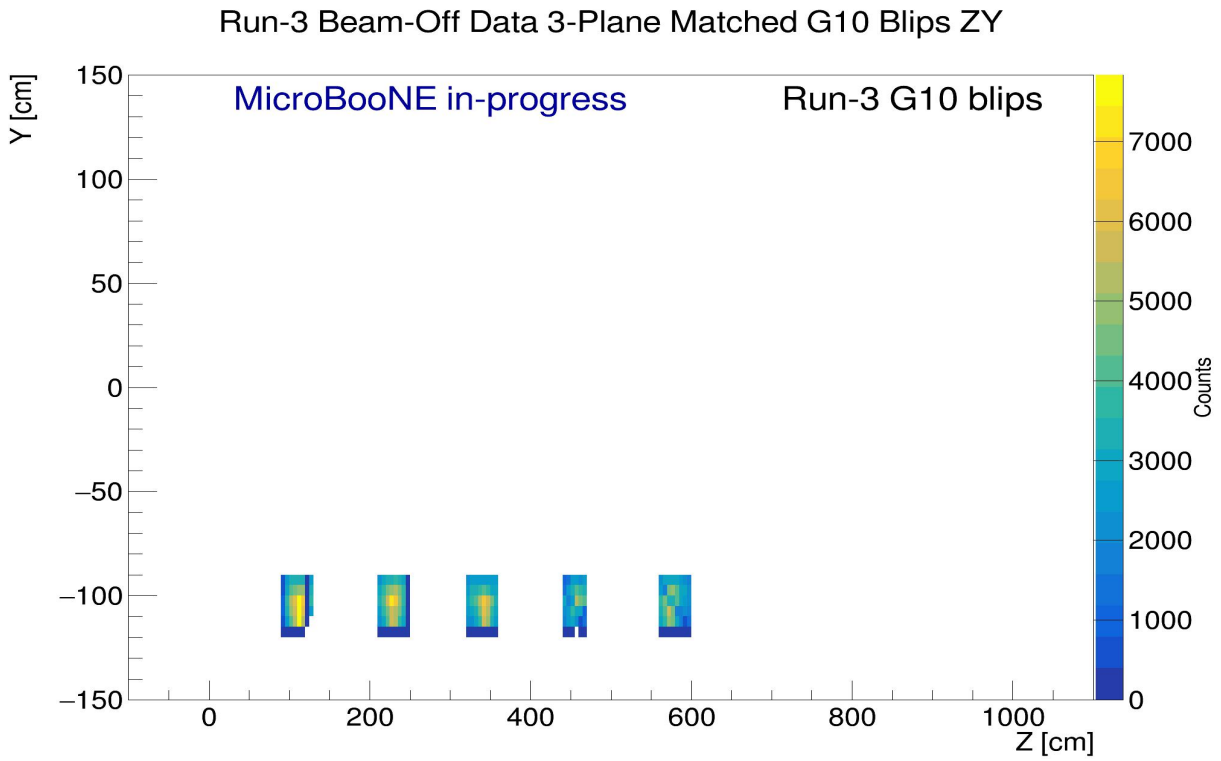




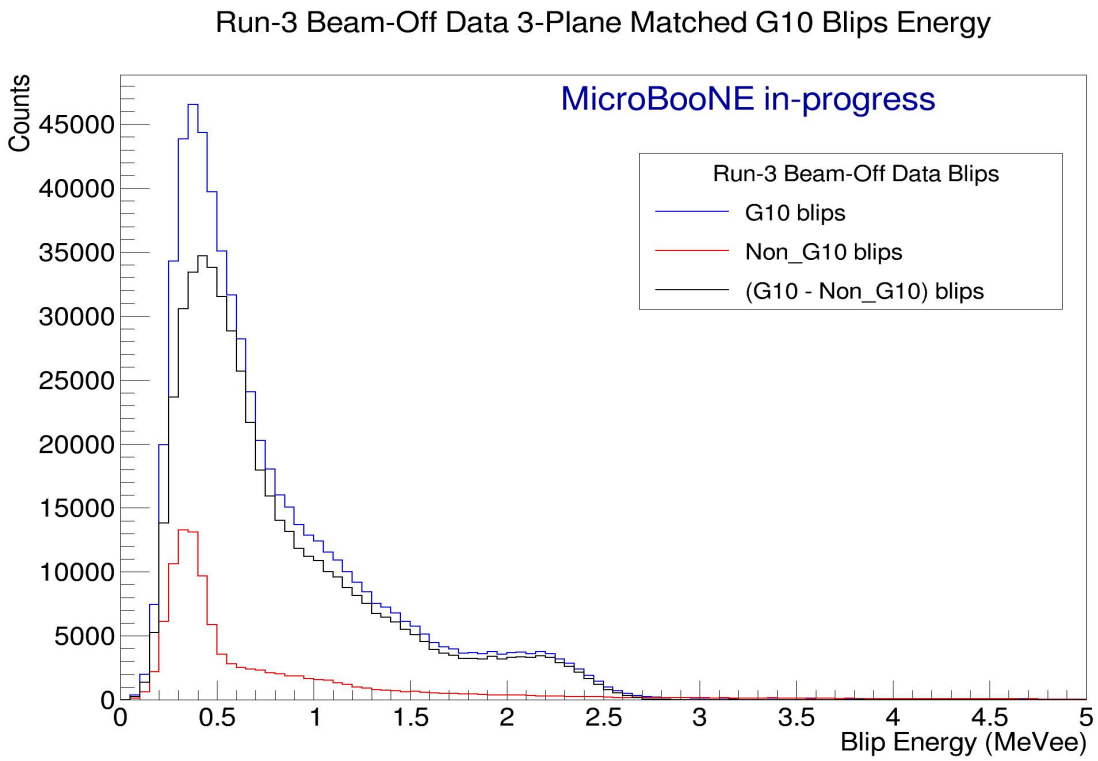
- Energy spectrum and YZ distribution of the three-plane matched blips from Run3 Beam-off data. We can see the hot spots in MicroBooNE detector by looking at the YZ distributions of blips. The above energy spectrum is shown up to 5 MeV but it extends beyond. The lower region of the spectrum is related to the radiological backrgounds in the detector,whereas the higher one is mainly related to cosmic rays.

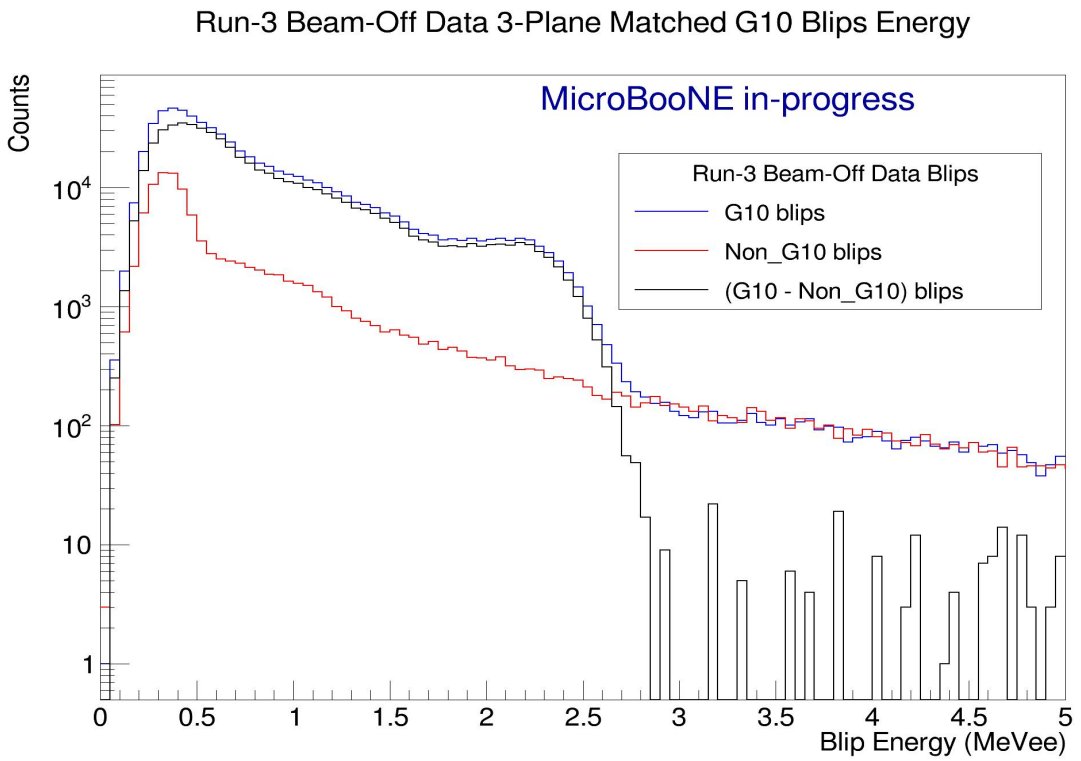
Run 3 Data - Beam Off
G10 struts- Blip Energy spectrum and YZ distribution





Run 3 Data - Beam Off
Subtracted Blip Energy spectrum G10 - NonG10





- These plots show (Linear and Log versions) the blip energy spectrum of the G10 region(blue), the one from the NonG10 (red), similar volume as G10 but in the center of the detector, and the resulting one (black) after subtracting them.