# Shower Reconstruction

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ICARUS Collaboration Meeting

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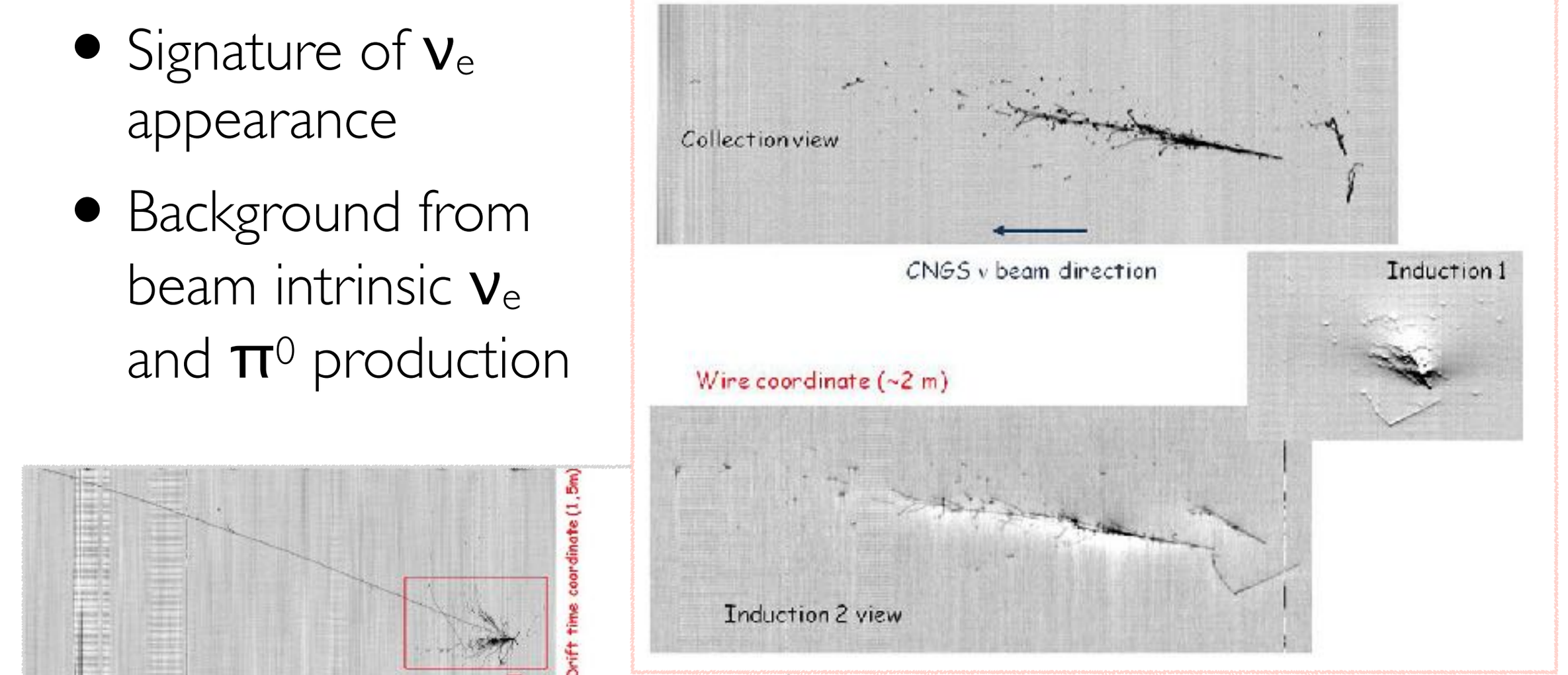
# Electromagnetic Showers

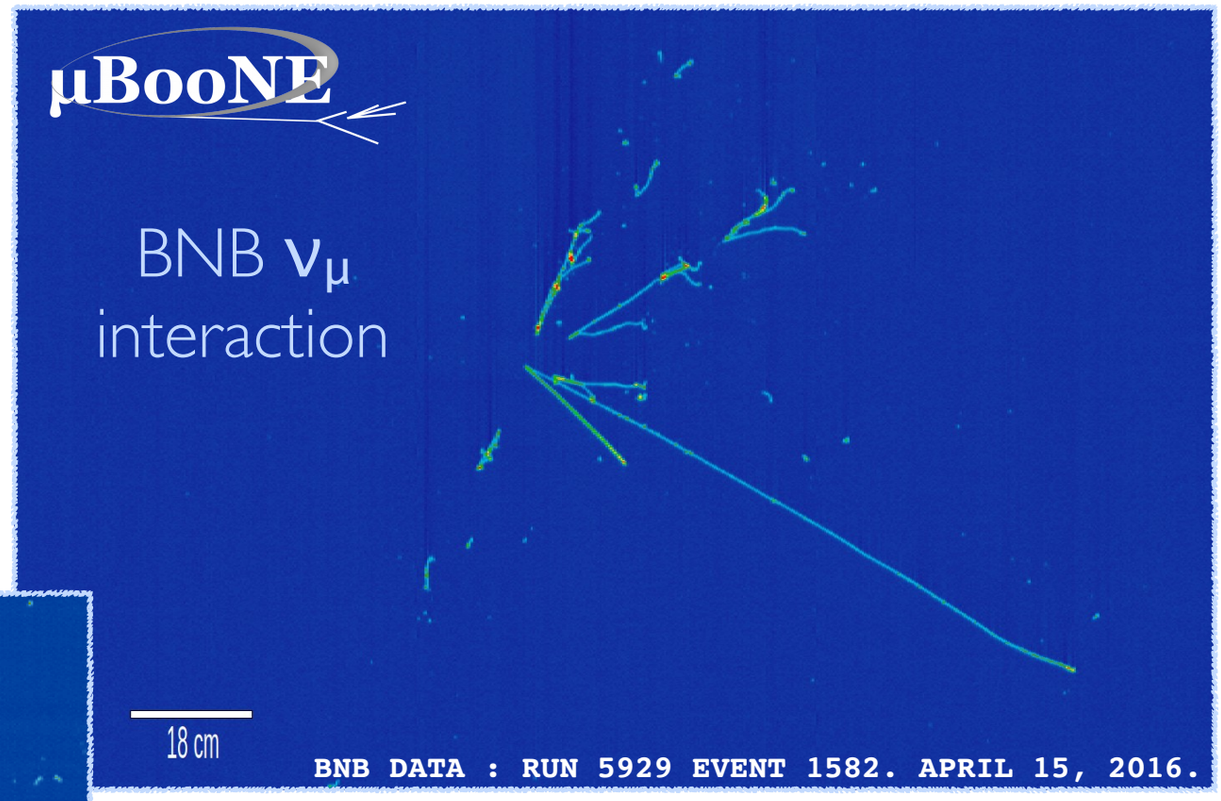
- Signature of $\nu_e$ appearance
- Background from beam intrinsic $\nu_e$ and $\pi^0$ production

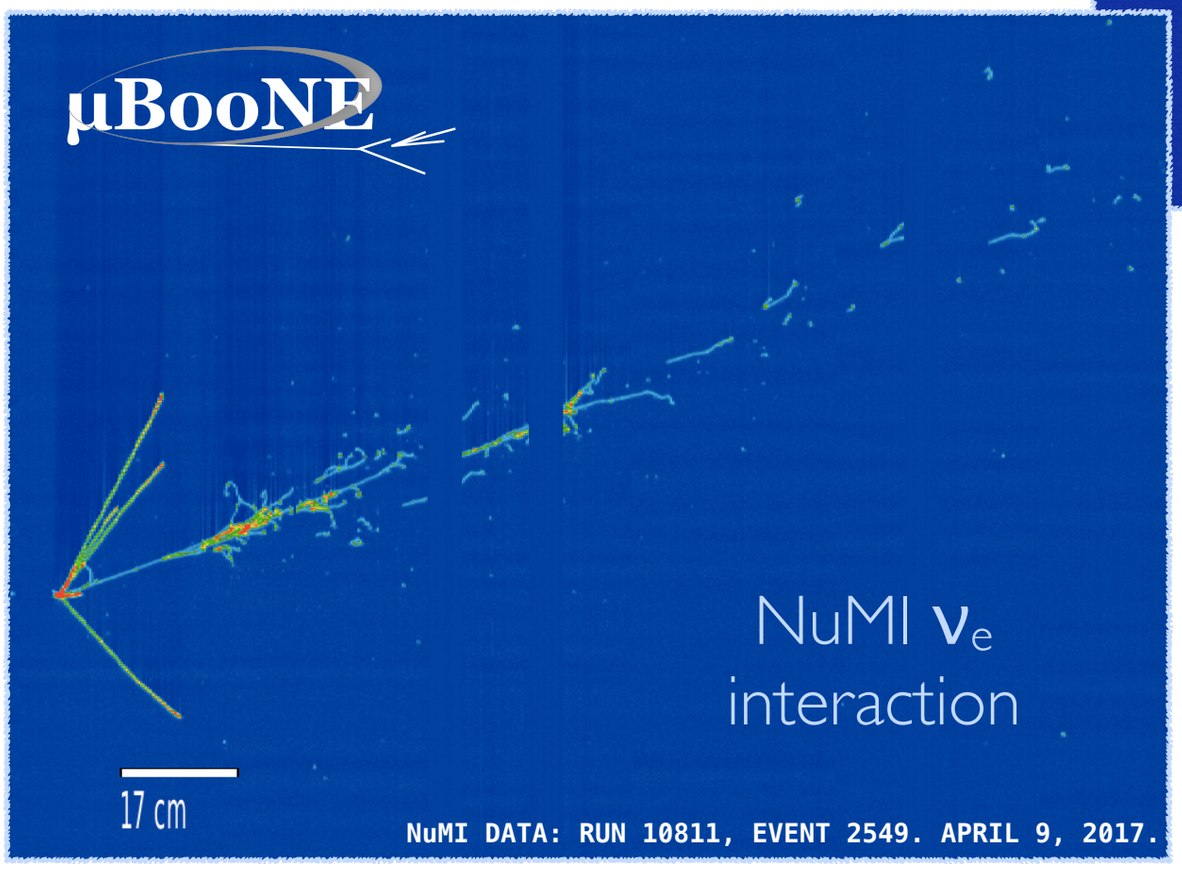



Important to reconstruct and characterize EM showers

# EM Showers at SBN

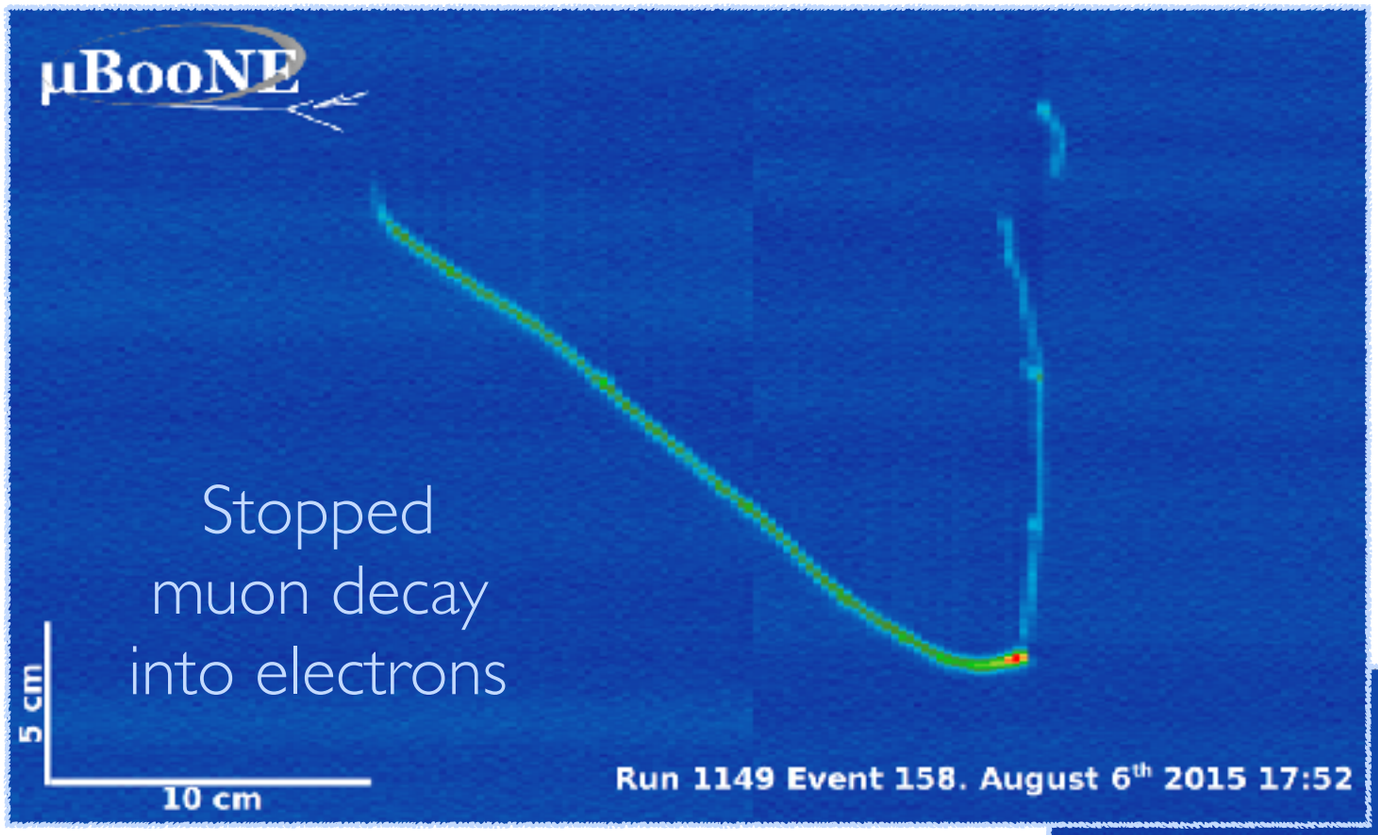
- BNB $\nu_\mu$ beam: neutrino energy peak around 800 MeV



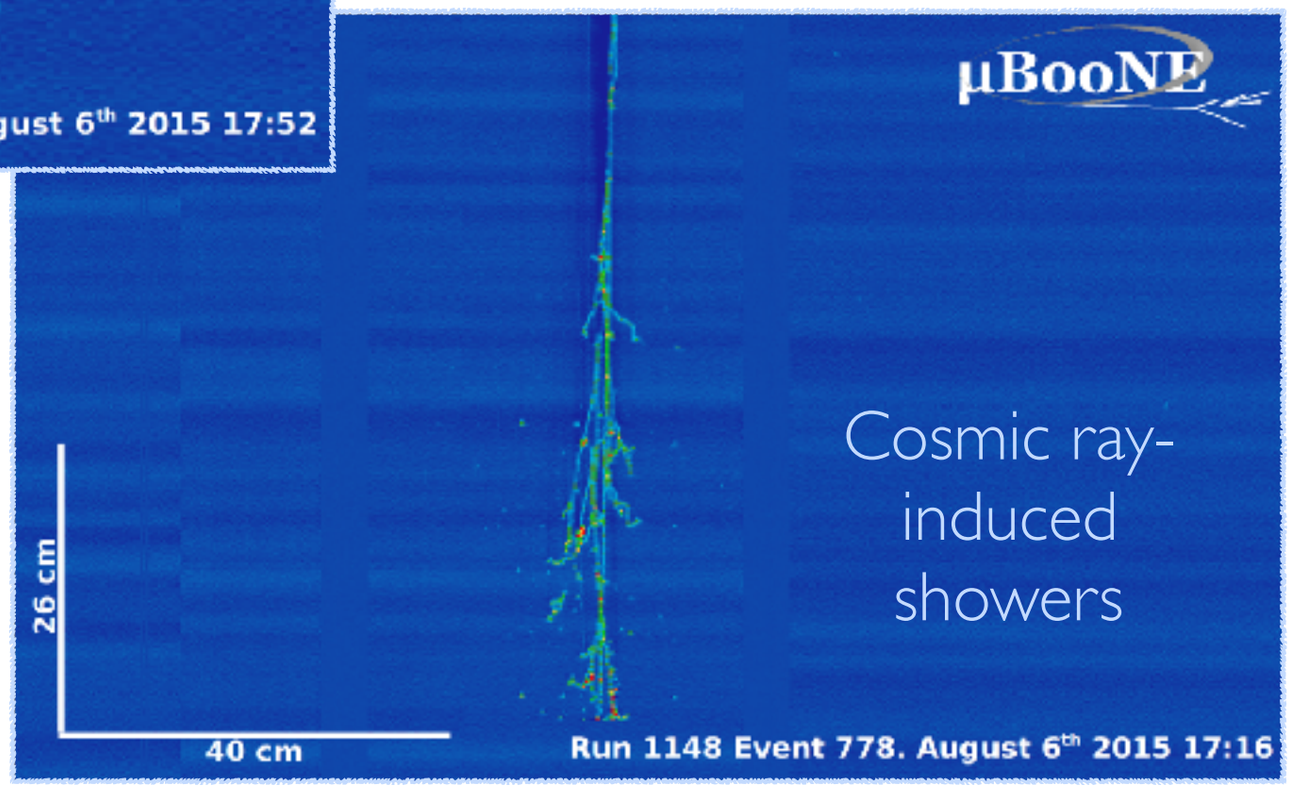




- NuMI $\nu_\mu$ beam: neutrino energy peak around 8 GeV (on-axis); different energy spectrum for ICARUS (off-axis)

# EM Showers at SBN



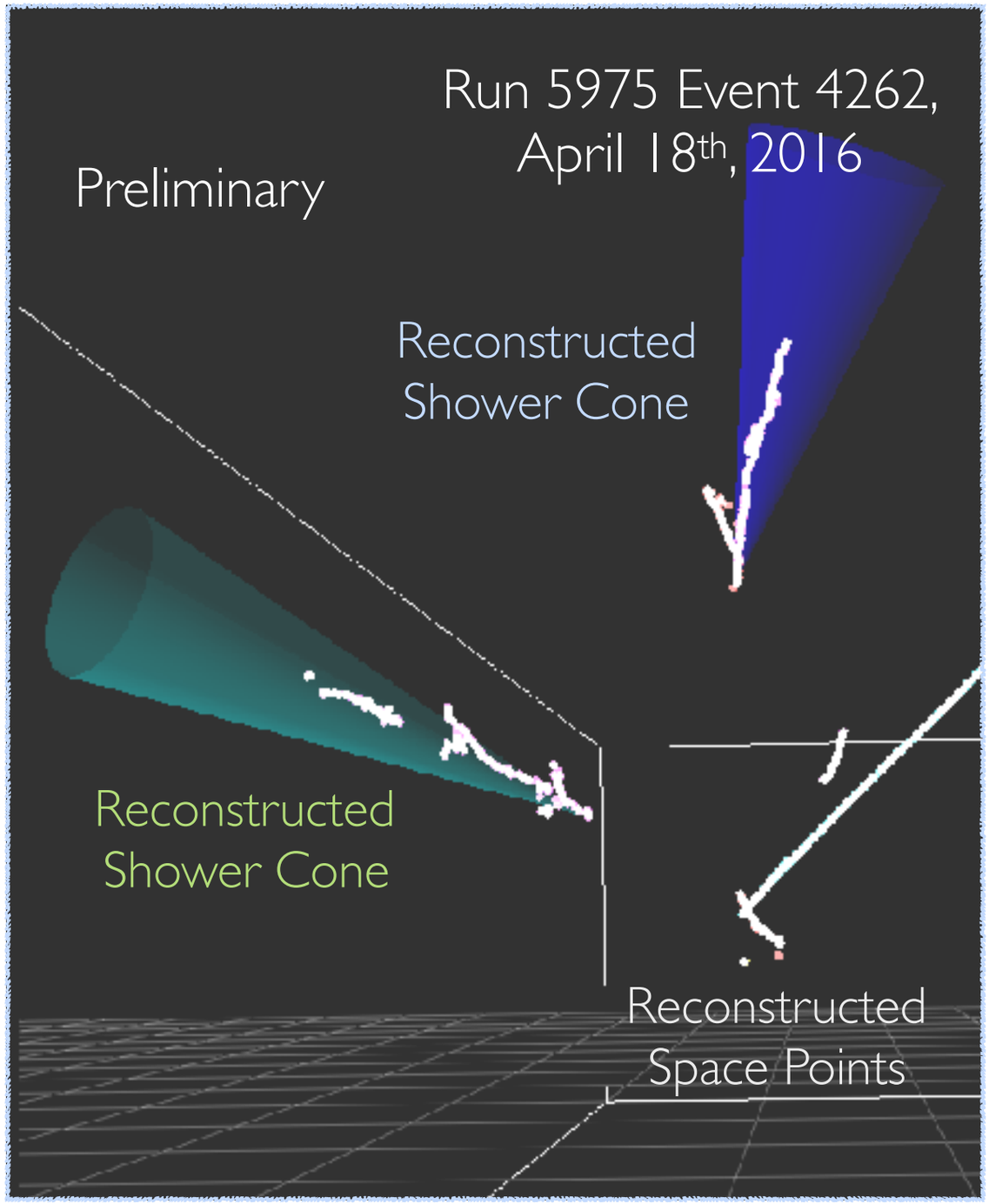

Detectors at surface:
a lot of cosmic rays




- Cosmic muons decaying into Michel electrons (<53MeV)
- Cosmic ray-induced showers

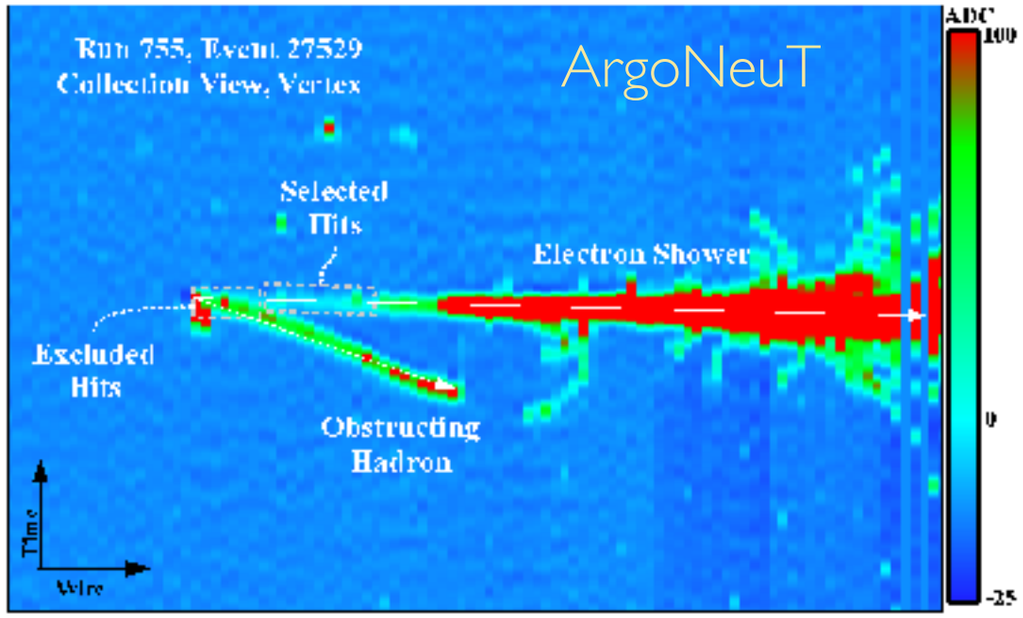
# Shower Characteristics

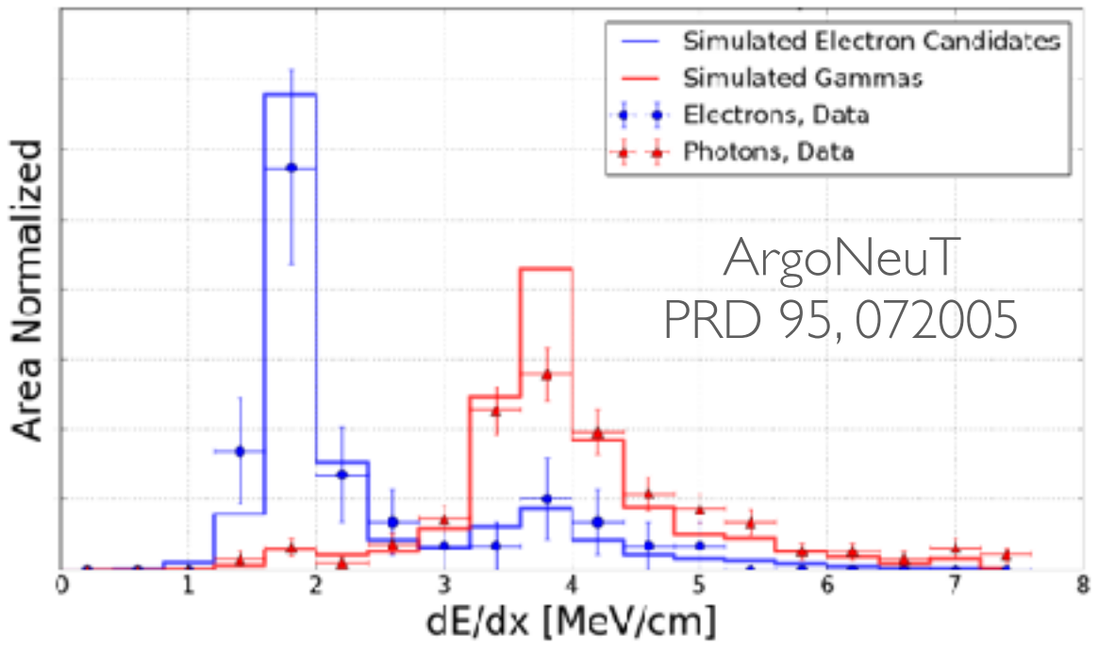
- Geometric parameters
  - Starting point
  - Direction
  - Opening angle, length
- Calorimetric parameters
  - Energy
- Combined
  - dE/dx; particle identification
- Systematic uncertainty

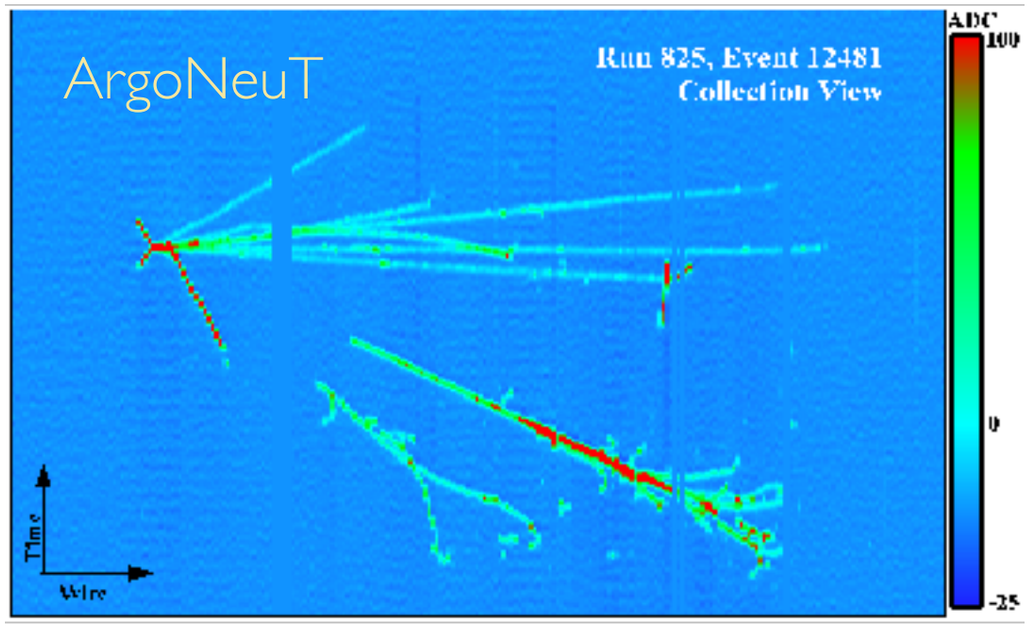


# Impact on Particle ID

- Electron-Photon separation: impacts from shower starting points, directions, calorimetry
- Track-Shower separation: impacts from opening angles, calorimetry, etc.



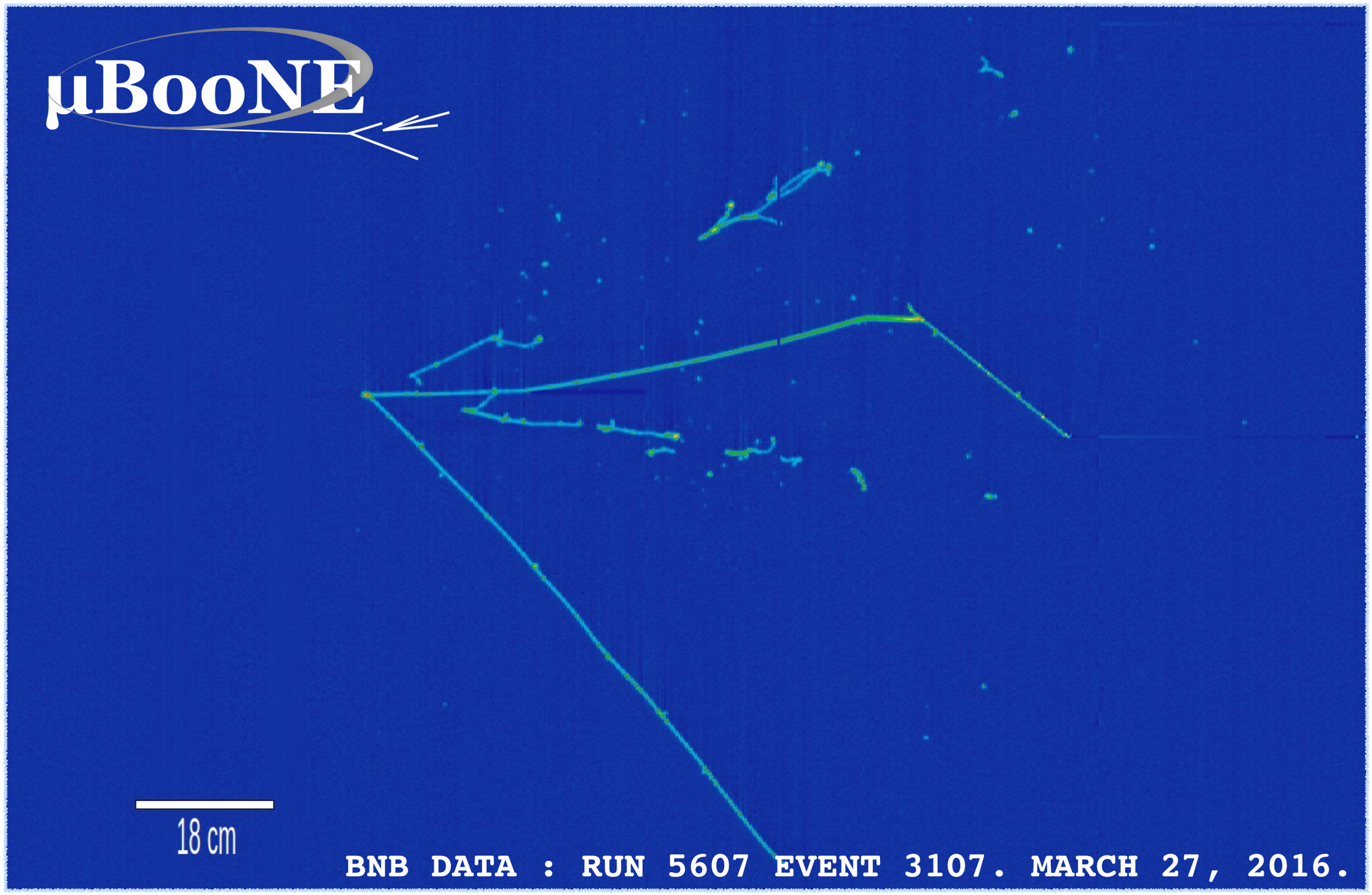



# Main Issues on Shower Reco

- Currently, the most significant issue is the energy reconstruction of EM showers.
  - Hit finding
    - Identify hits from complicated topologies
    - Identify hits from low energy deposits
  - Pattern recognition/clustering
    - Determine hits originating from a EM shower
    - Impacts from bad wires, Bremsstrahlung, etc.
  - Energy correction
    - Electron-ion recombination effect
    - Containment

# To Merge or Not To Merge



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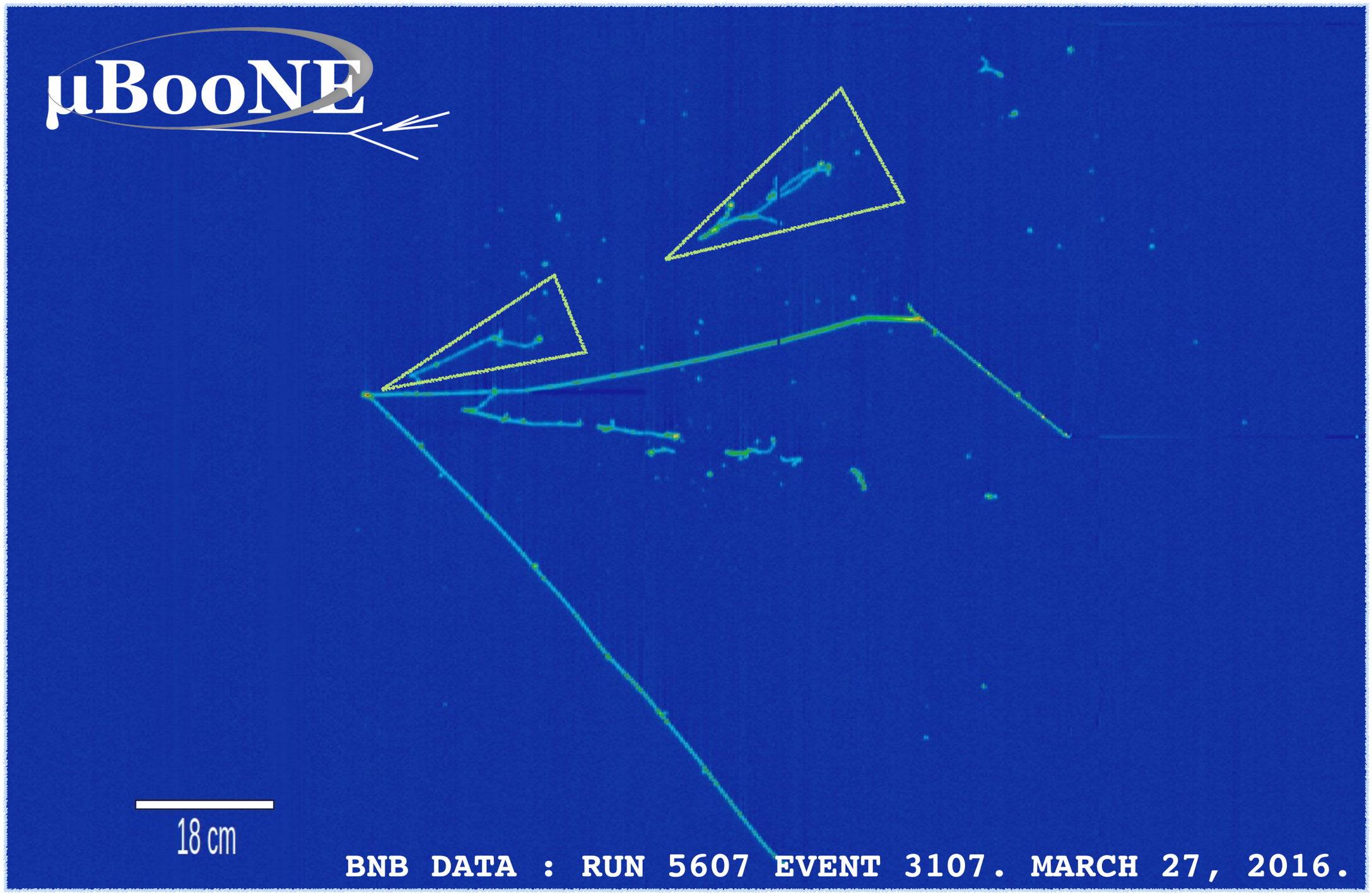

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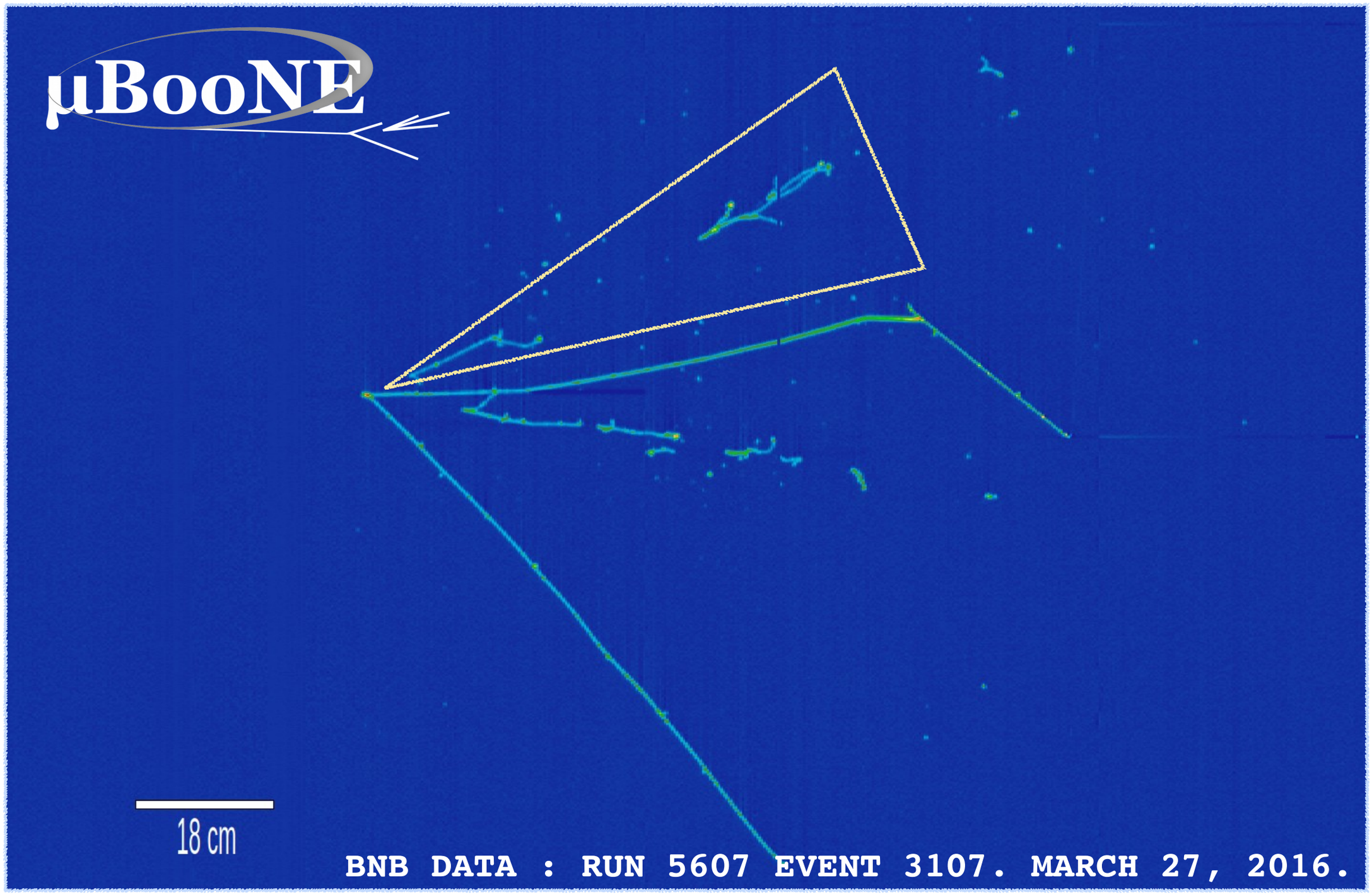
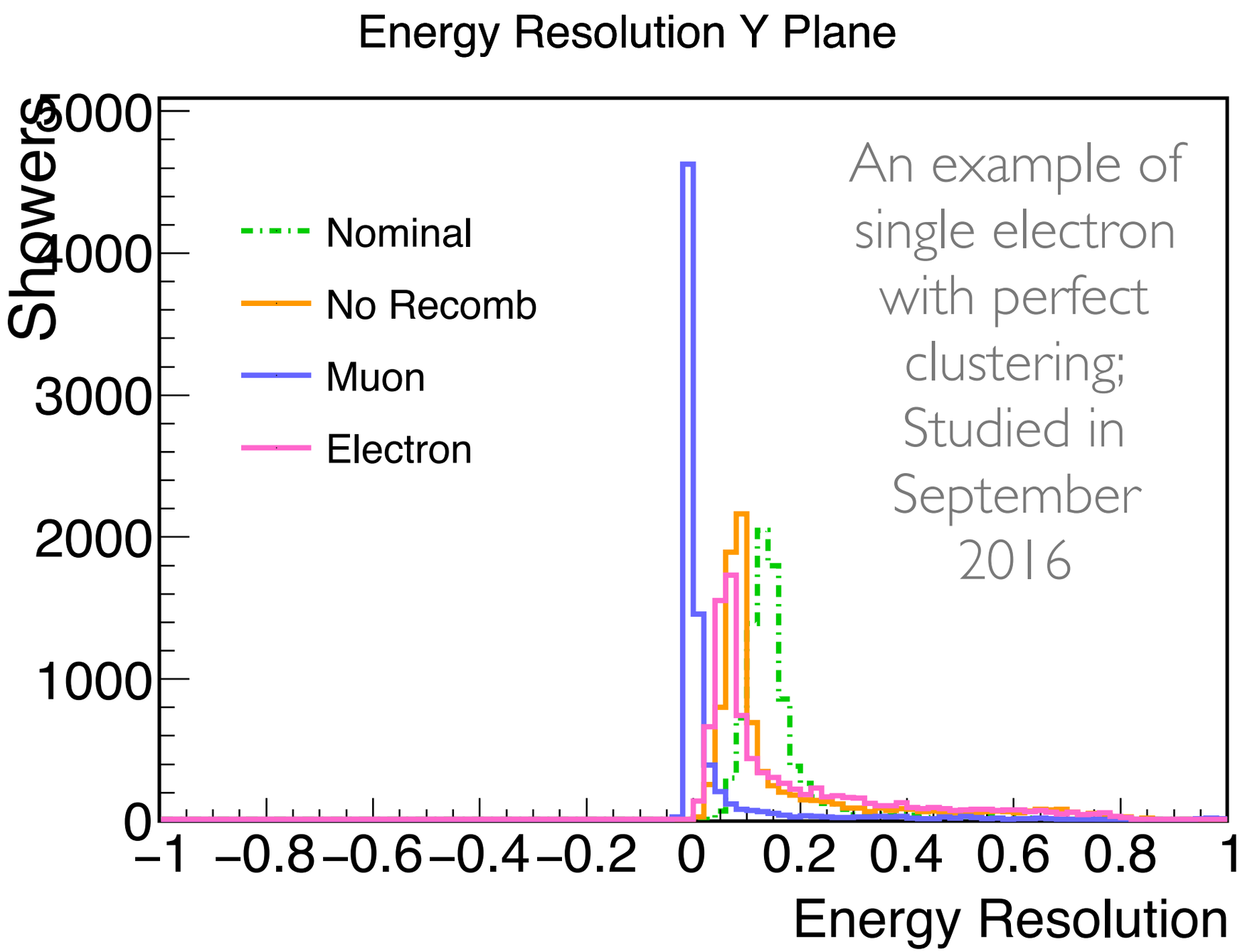


# Energy Resolution

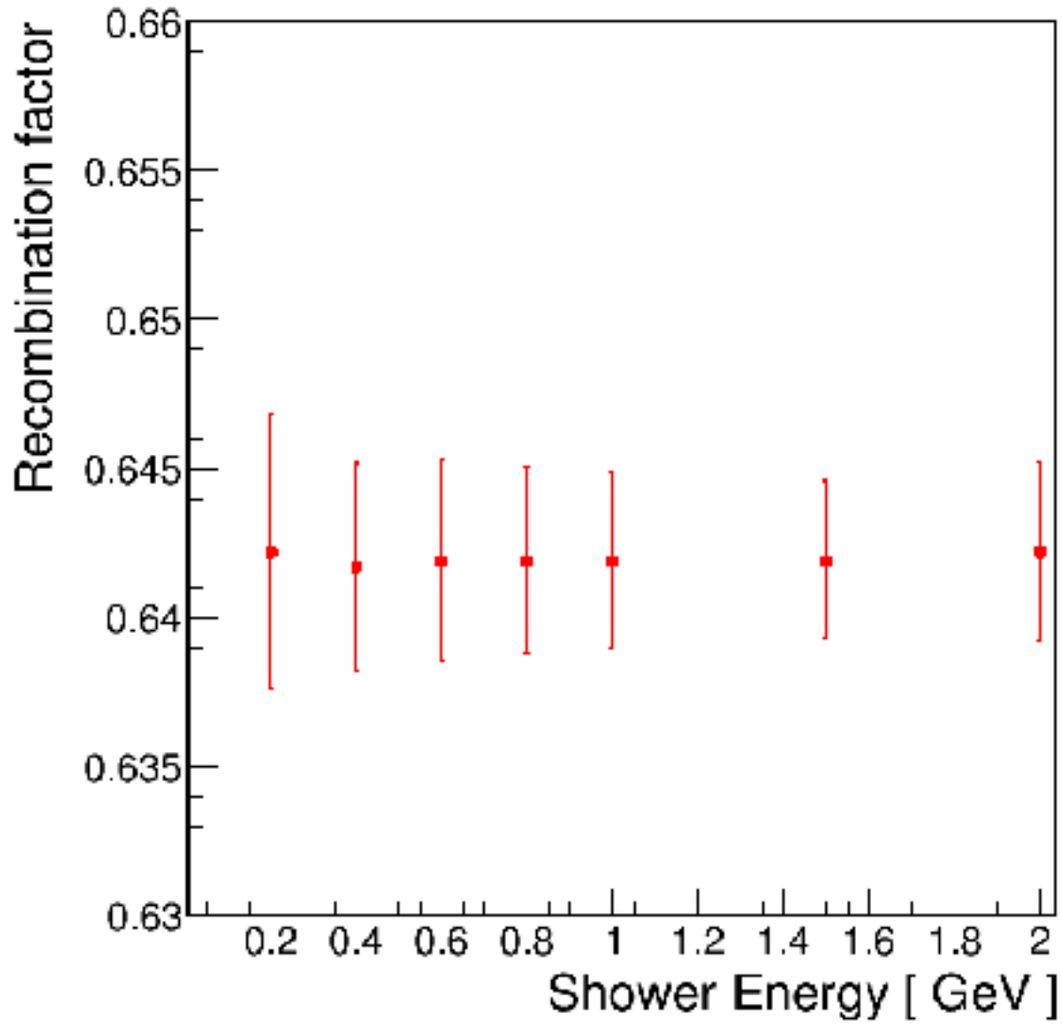
(Deposited E - Reconstructed E) / (Deposited E)



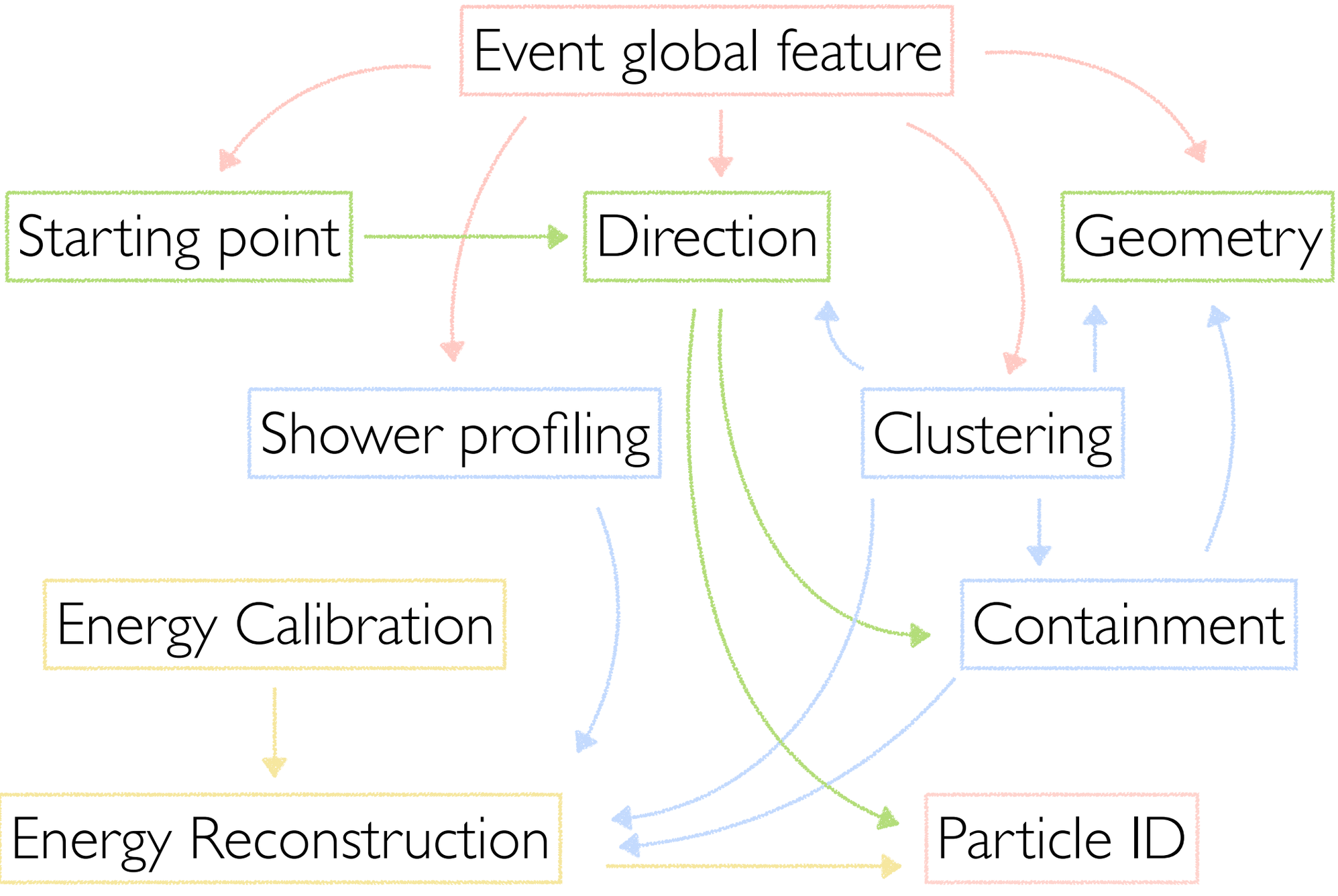
# Study on Recombination

- Quantify the recombination effect on shower energy reconstruction
- For electron showers with different energy, 200MeV to 2GeV, compare charges collected with the recombination effect to those without
- Conclude that a constant correction factor for the recombination effect is good

Plot courtesy of Christian Farnese
Studies at Padova SBN workshop, March 2018



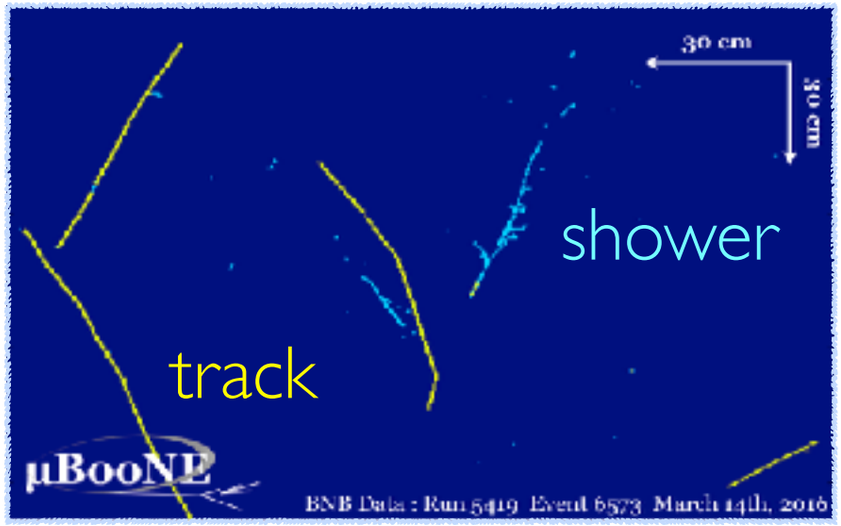
# Systematic Uncertainty

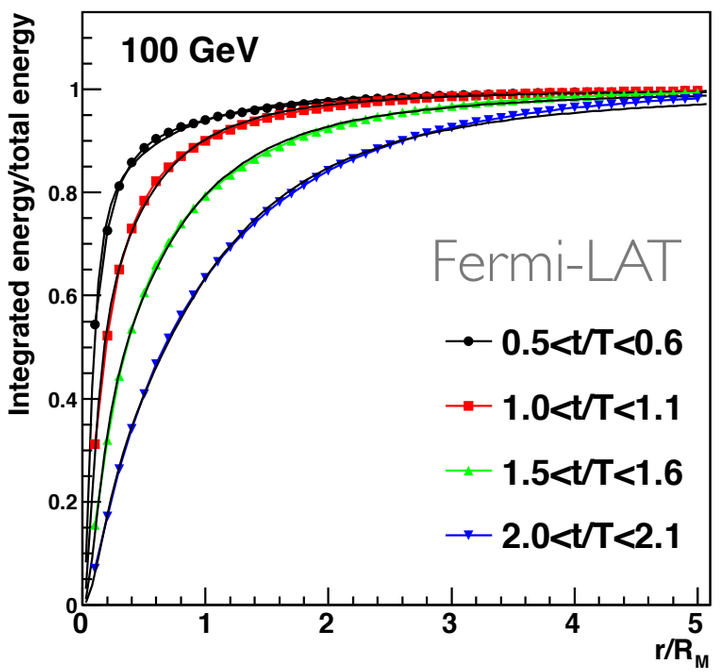


# Outlook

- Deep learning technique to categorize each pixel into tracks or showers and thereby recover charges
- Understand charge distribution of each type of EM particles and correct for
  - residual hit finding and clustering inefficiency
  - partial contained showers: direction, energy, etc.

Categorizing each pixel into tracks vs showers



# Summary

- Reconstructing EM showers is relevant to $\nu_e$ appearance measurements.
- Shower characteristics include geometric, calorimetric, and combined parameters.
  - Impacts on particle identification.
- Current main issues focus on shower energy reconstruction.
  - Studies and improvements underway.
- "Informal" meetings across SBN on 10:30am CDT Wednesdays, sharing the previous ICARUS (Christian) and MicroBooNE (Yun-Tse) experience. Welcome to join!