Shower Reconstruction

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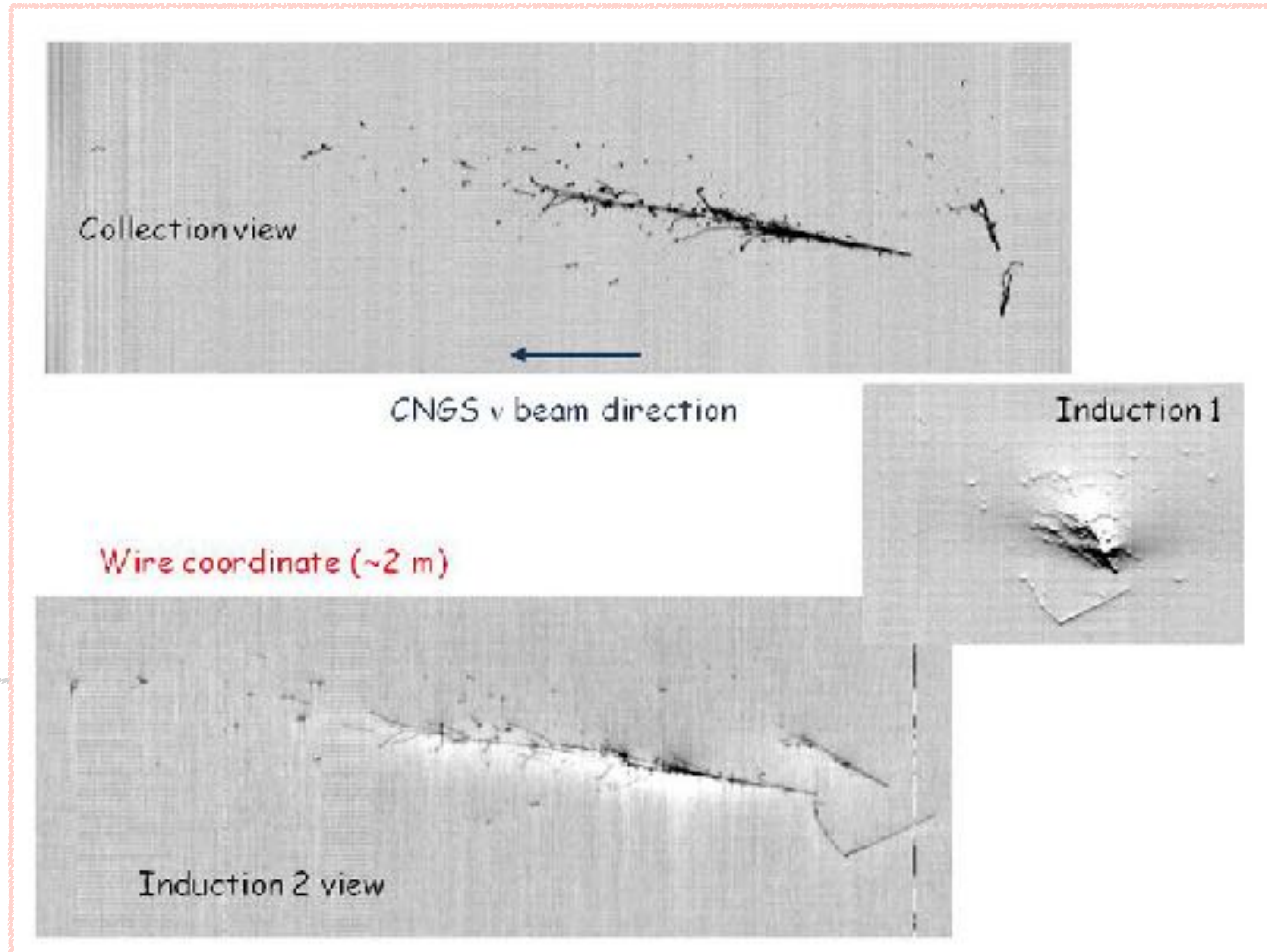
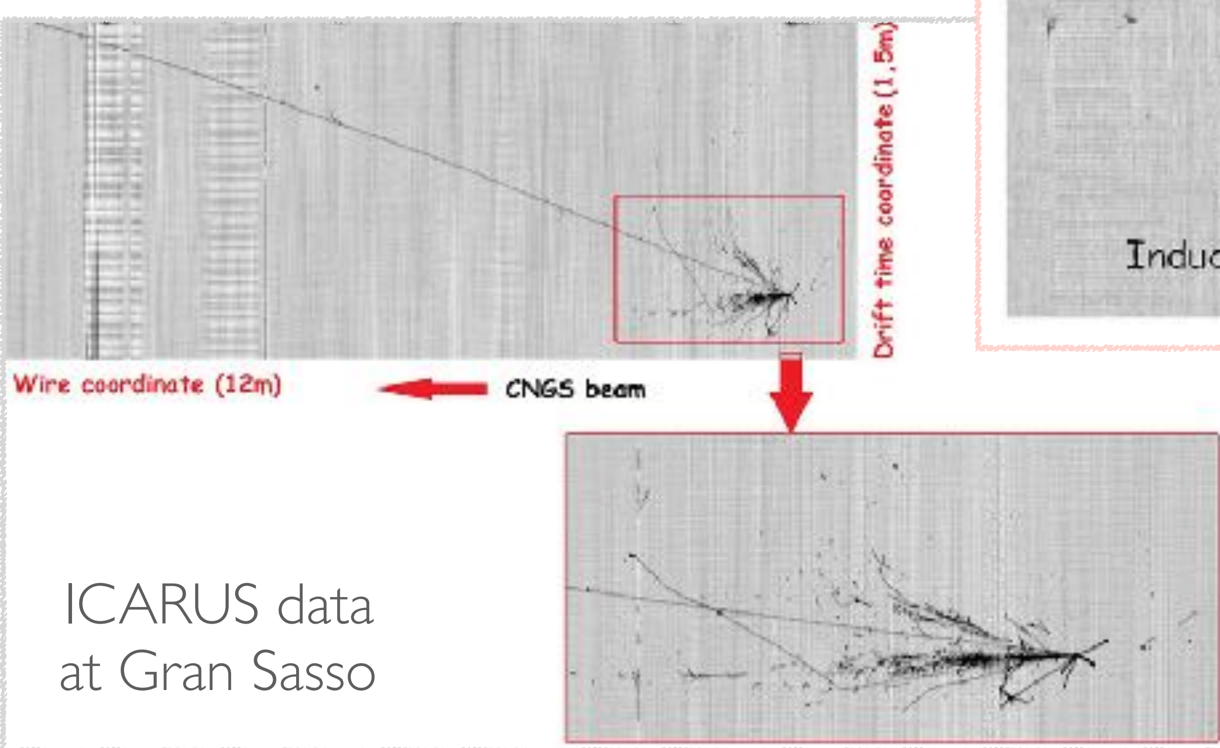
ICARUS Collaboration Meeting
September 12th, 2019

Electromagnetic Showers

- Signature of ν_e appearance
- Background from beam intrinsic ν_e and π^0 production

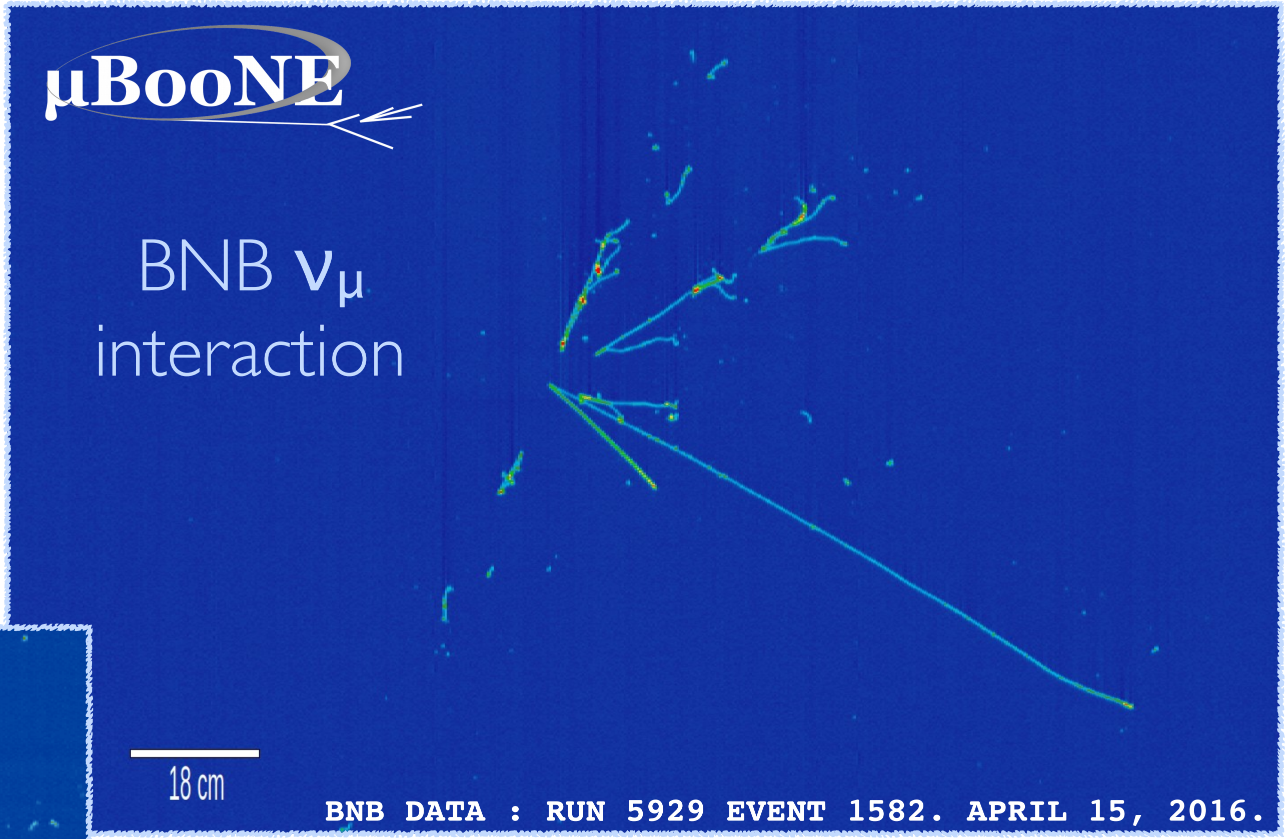


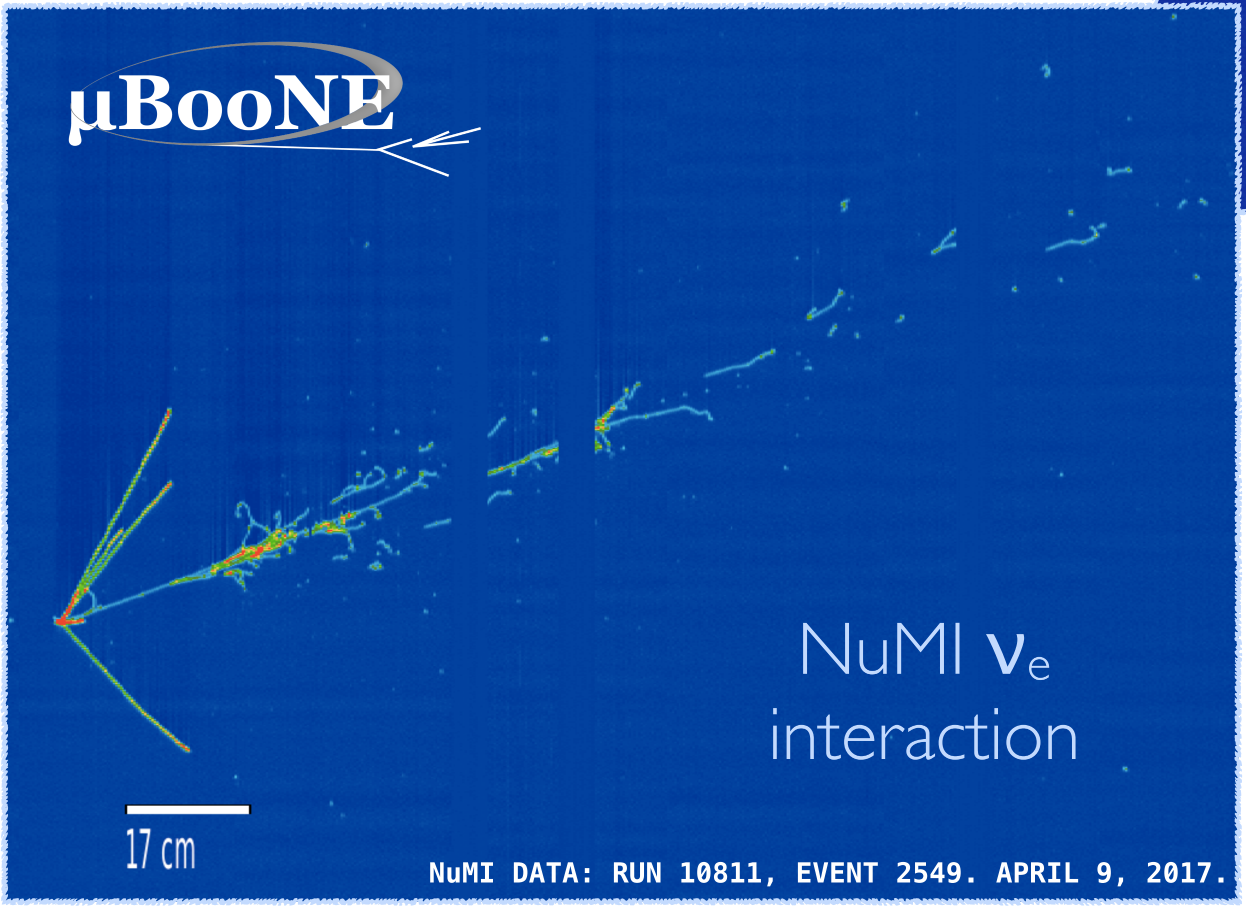


Important to reconstruct and characterize EM showers

EM Showers at SBN

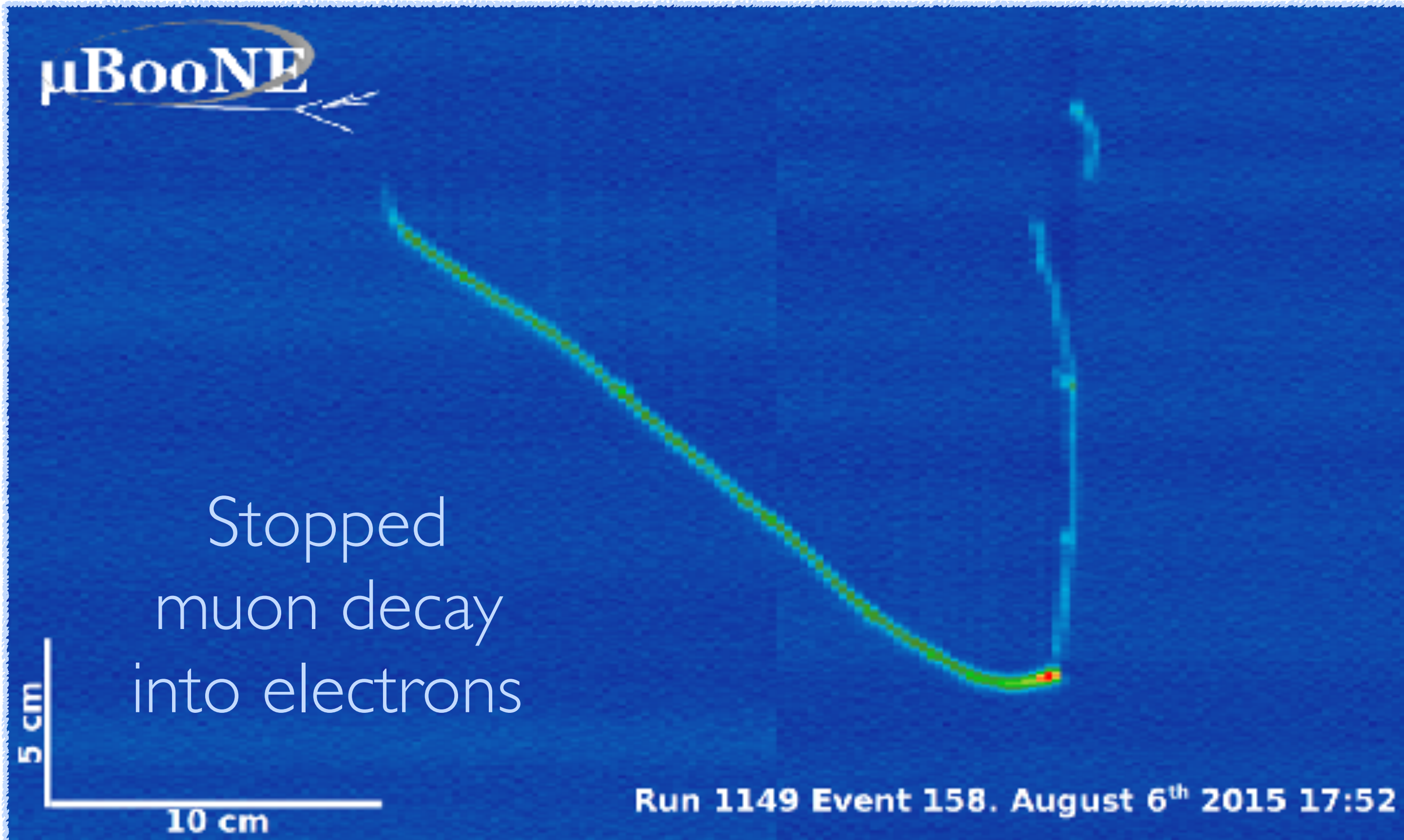
- BNB ν_μ beam: neutrino energy peak around 800 MeV





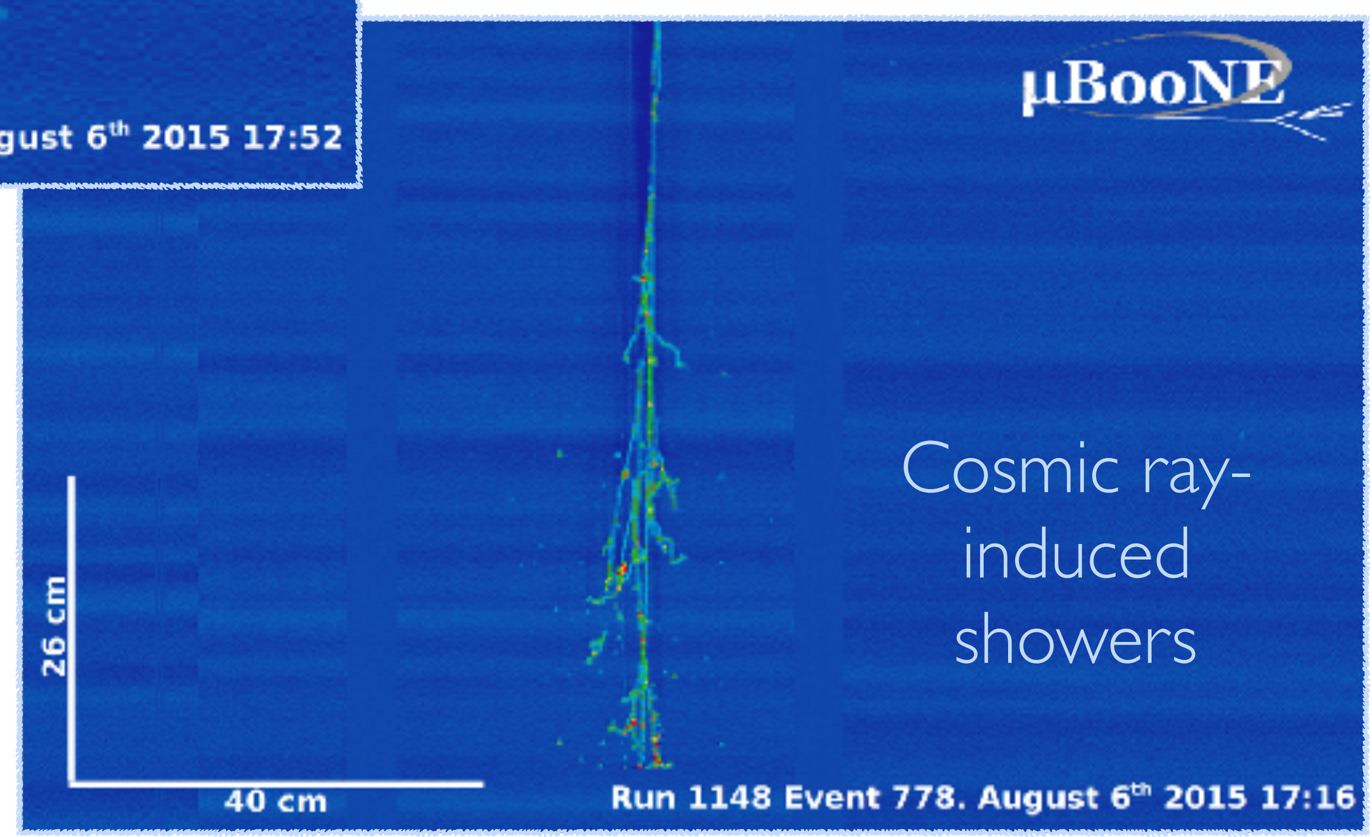
- NuMI ν_μ beam: neutrino energy peak around 8 GeV (on-axis); different energy spectrum for ICARUS (off-axis)

EM Showers at SBN



Detectors at surface:
a lot of cosmic rays

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

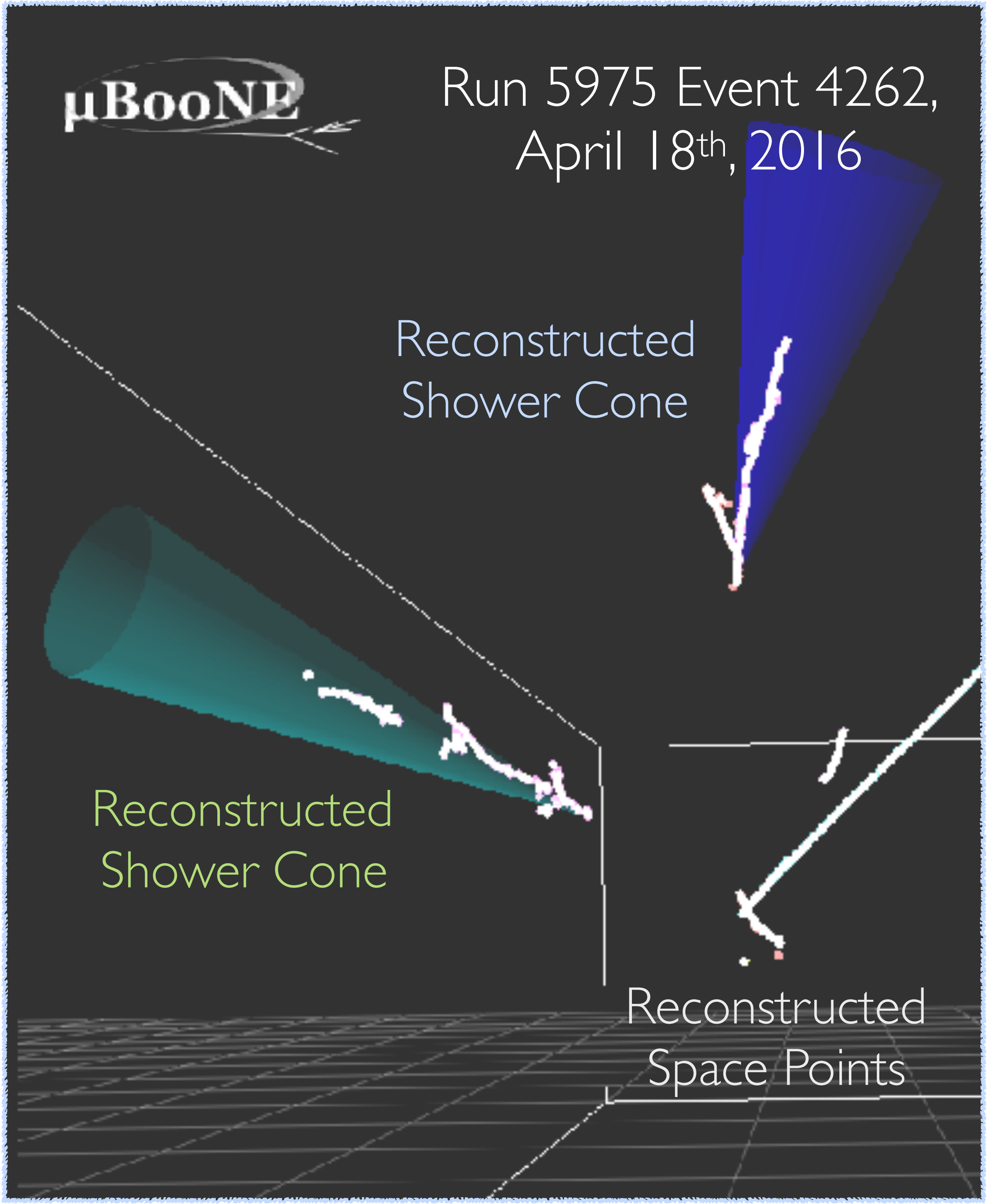


Shower Reconstruction

- Pandora pattern recognition based approach
  - 2D to 3D reconstruction
  - Shower characterization based on the particles recognized by pandora (this talk)
  - Currently the common reconstruction path with SBND for the oscillation measurement
- Machine learning based approach
  - 3D reconstruction
  - See Francois Drielsma and Laura Domine's talk

Shower Characteristics

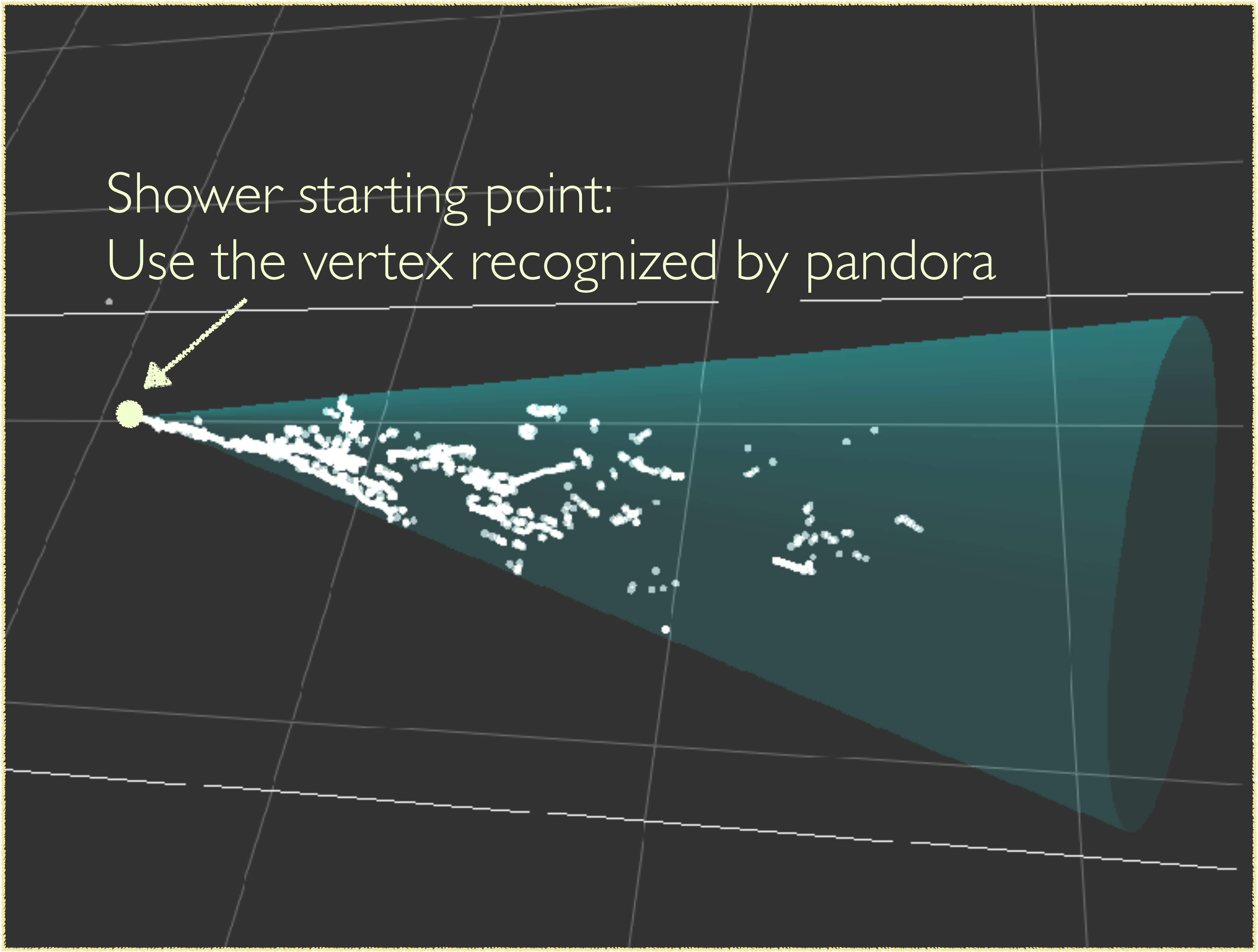
- Geometric parameters
  - Starting point
  - Direction
  - Opening angle, length
- Calorimetric parameters
  - Energy
- Combined
  - dE/dx; particle identification
- Systematic uncertainty



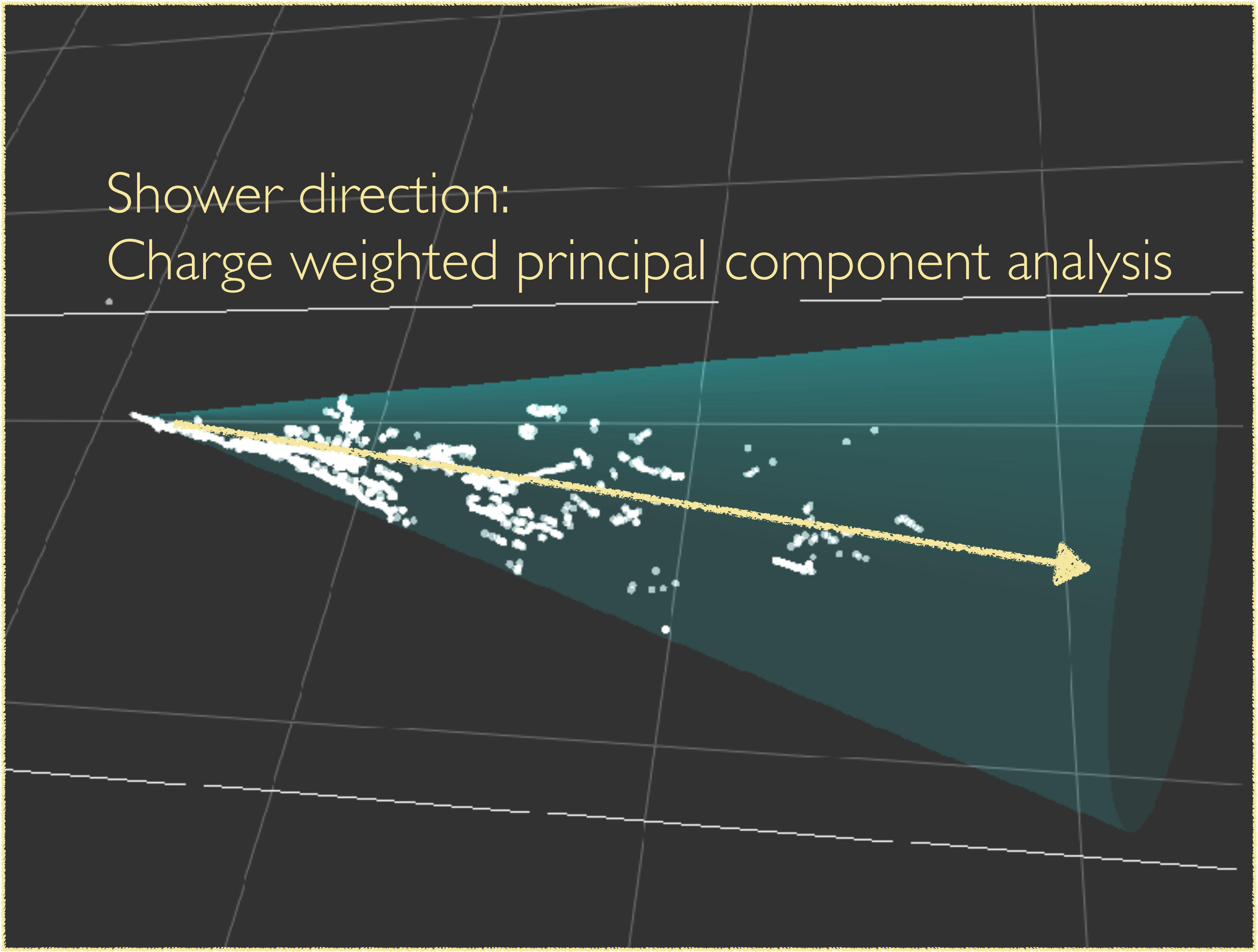
SBN Shower Module

- A Tool based Reconstruction Algorithm for Characterizing Showers (TRACS)
- An interface with configurable algorithms for different shower characteristics
    - Flexible; also allow iterative approaches
- 3D clustered objects (PFParticles) as the input
- Baseline tools in place; more development underway
- Included in official LArSoft releases (larreco)
- Successfully tested in SBND, ICARUS (this talk)
- Initiated by the SBN shower group; a lot of work done by SBND folks (D. Barker, E. Tyley, D. Brailsford)

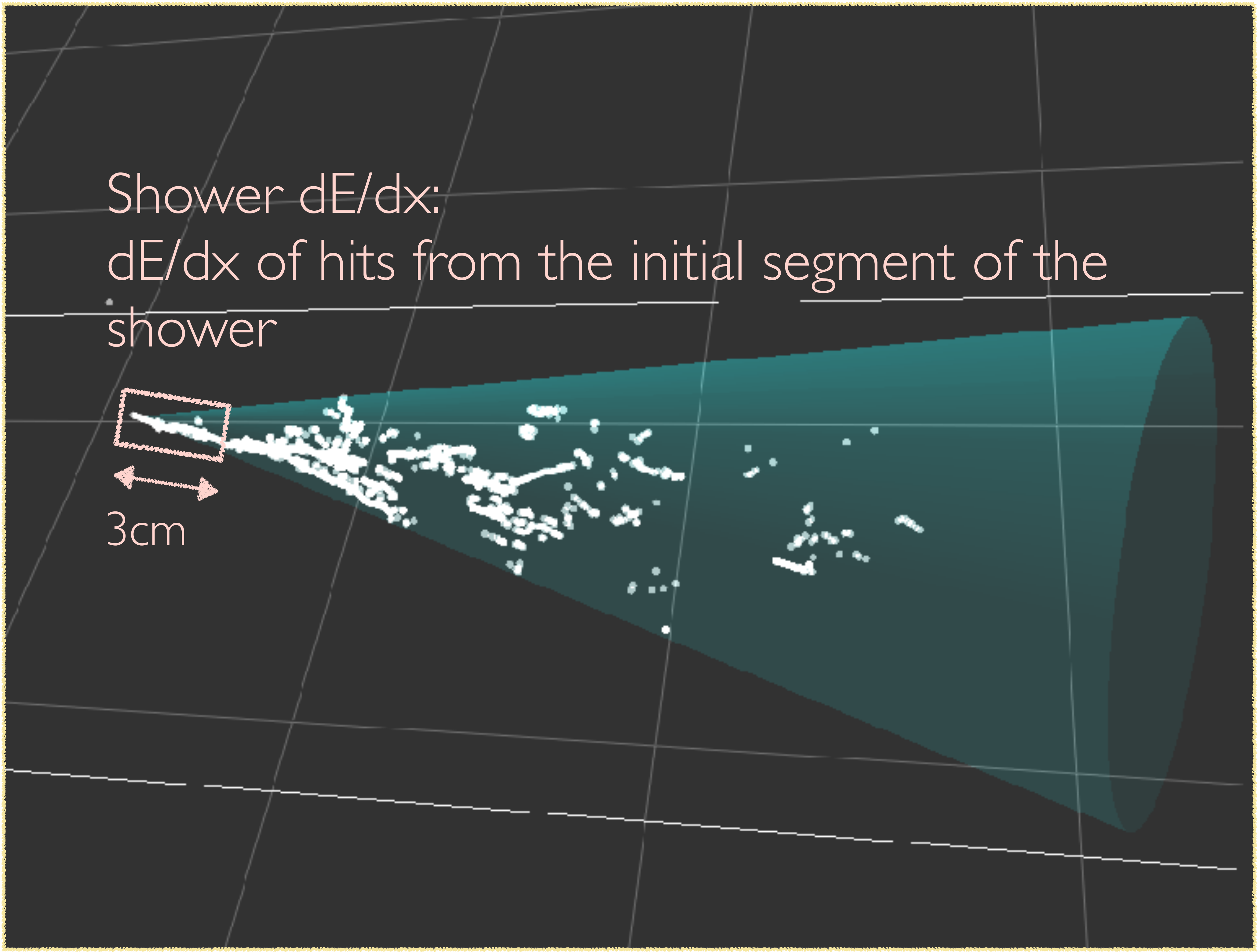
Baseline Algorithms



Baseline Algorithms



Baseline Algorithms

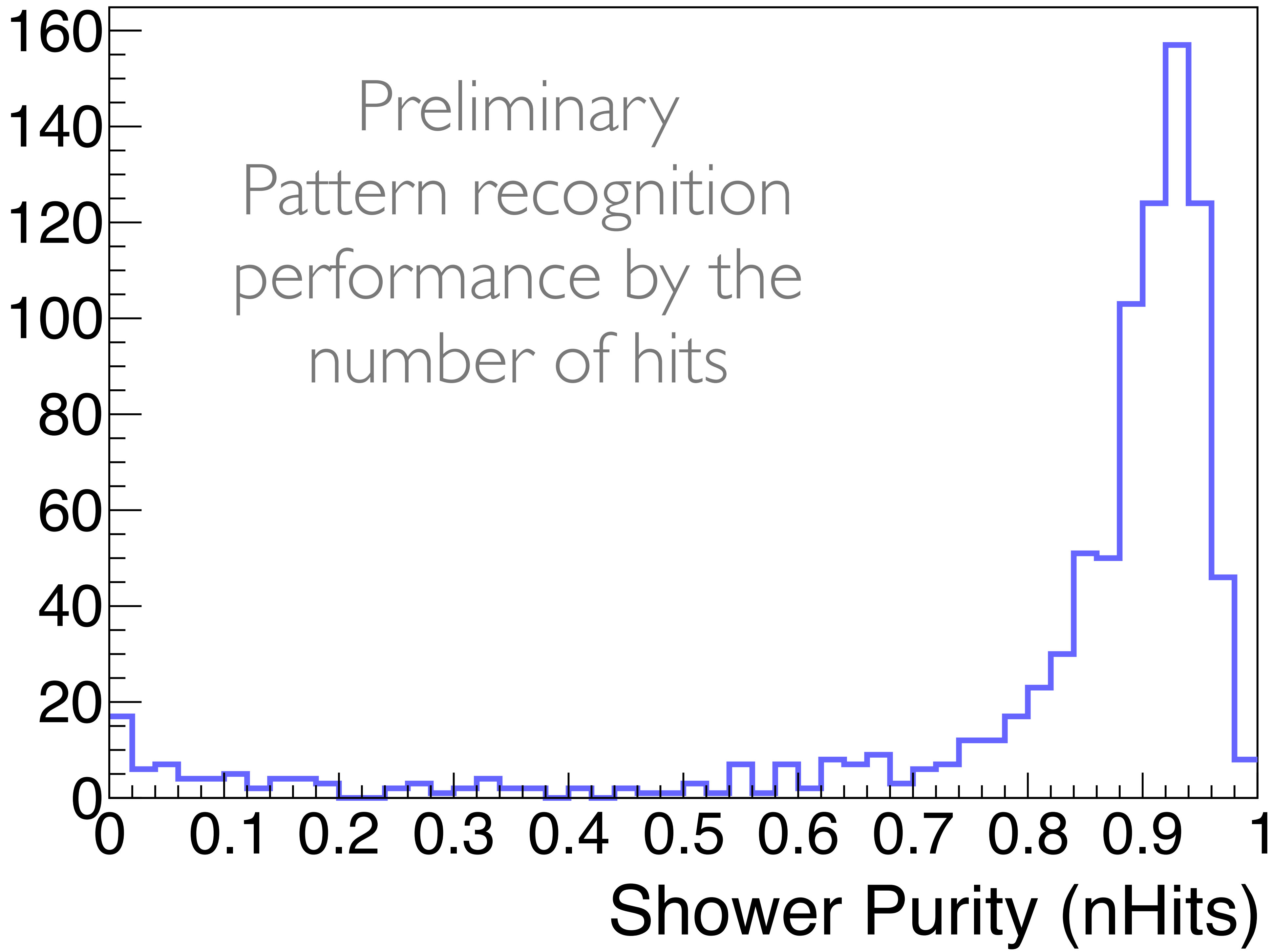


Monte Carlo Sample

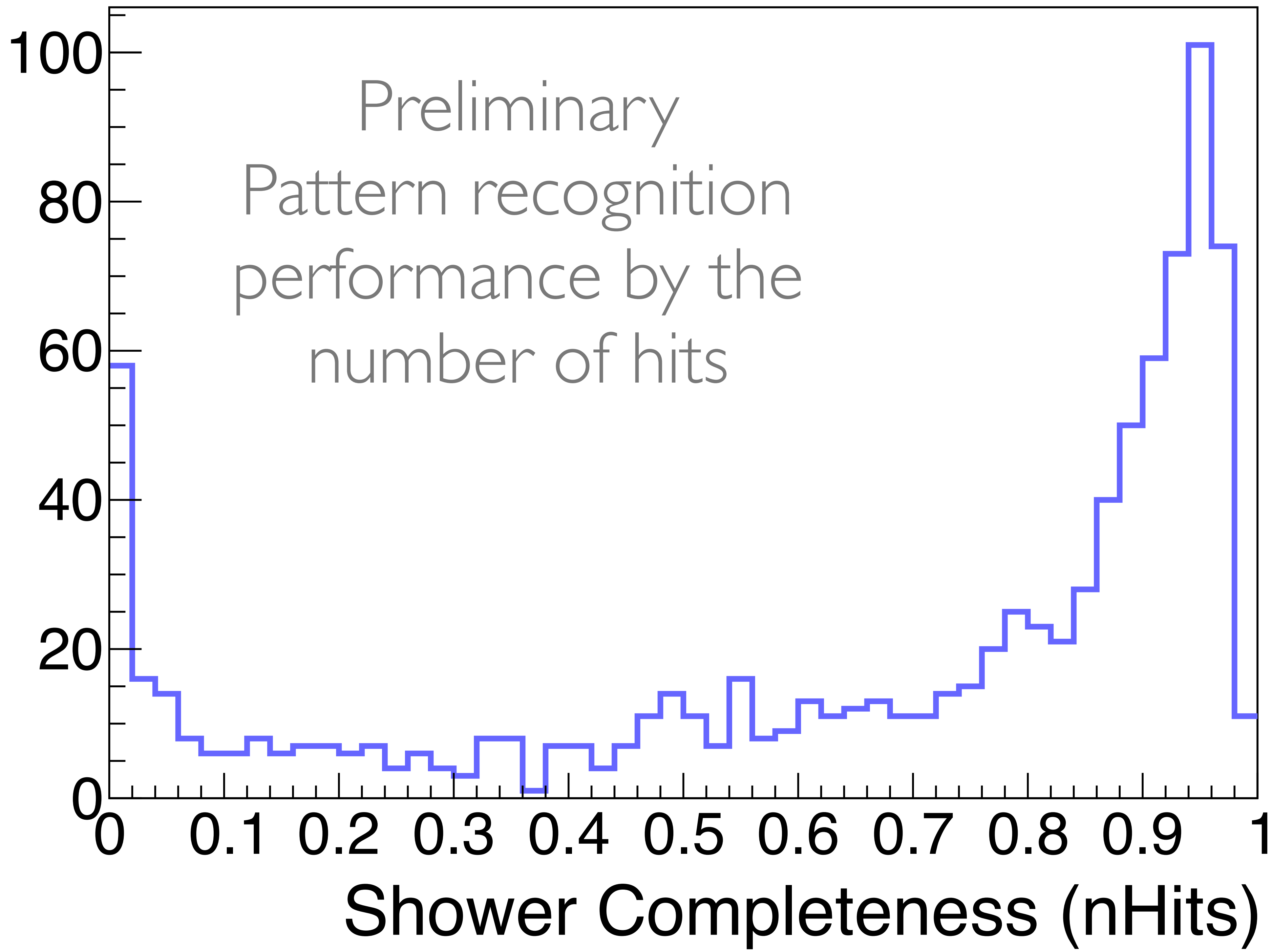
- Dual-particle sample: $e+\pi^+$, 1000 events
  - Test the shower reconstruction performance
  - Has a vertex to mimic a neutrino interaction for pattern recognition
- Both the particles have momentum 0-1.5 GeV, peak at 0.3 GeV
- Both the particles mostly along the BNB beamline
- Latest reconstruction algorithms with deconvoluted TPC waveforms and baseline shower algorithms
- Match to the true particles and validate the reconstruction performance

Out of the Box Performance

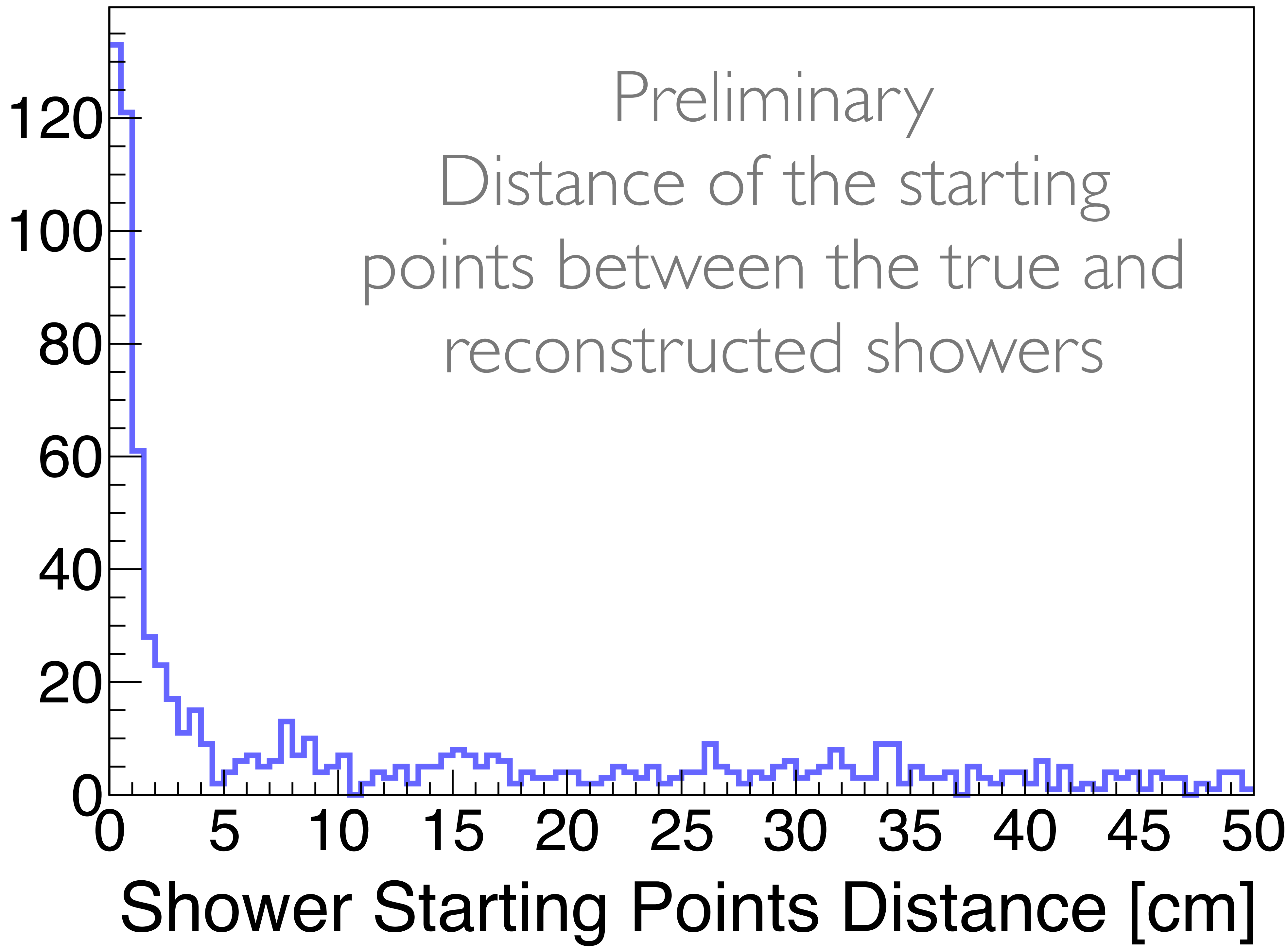
Shower Purity



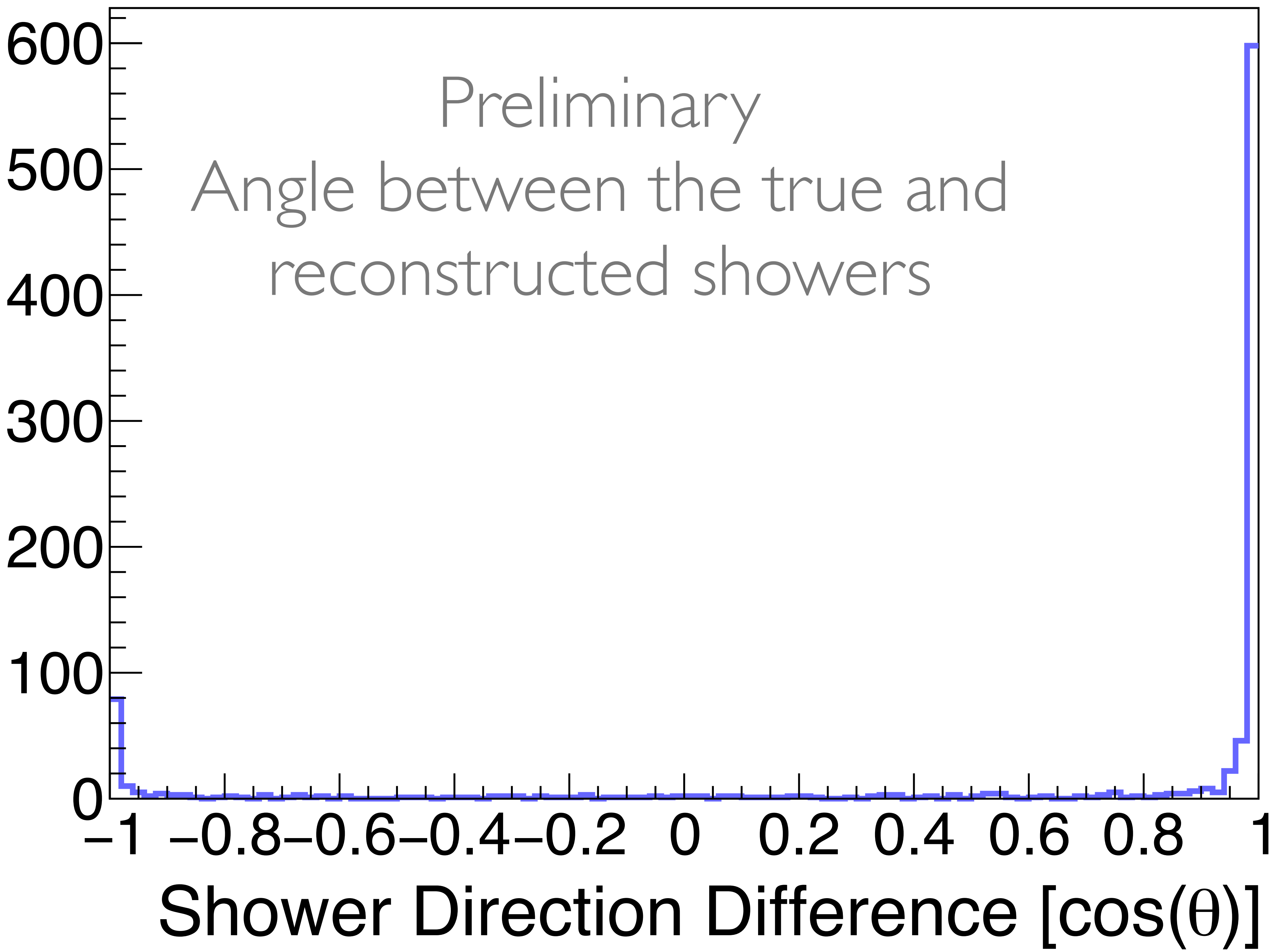
Shower Completeness



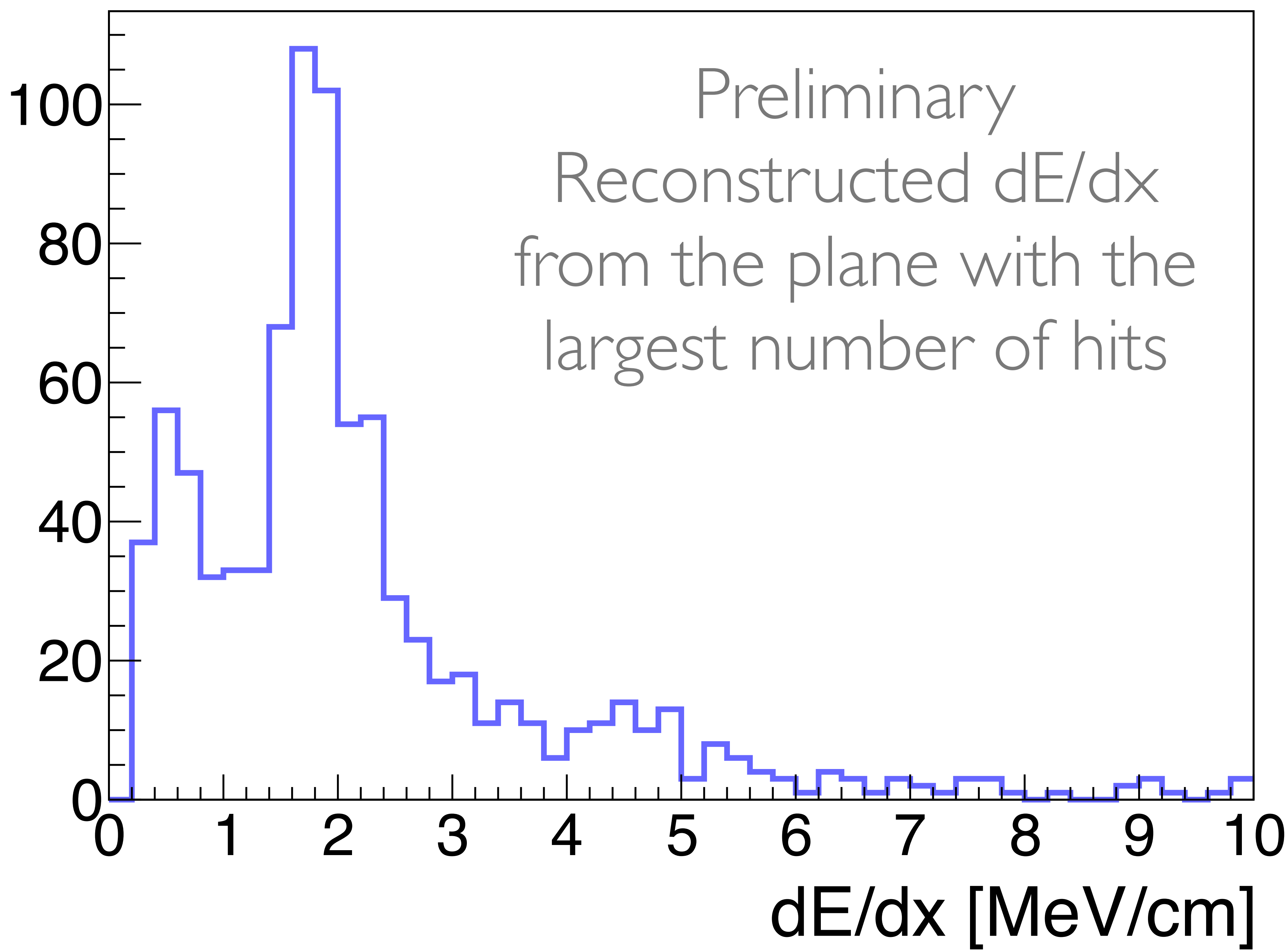
Shower Starting Point



Shower Direction



dE/dx



Preliminary
Reconstructed dE/dx
from the plane with the
largest number of hits
0
20
40
60
80
100
0
1
2
3
4
5
6
7
8
9
10
dE/dx [MeV/cm]

Main Challenges

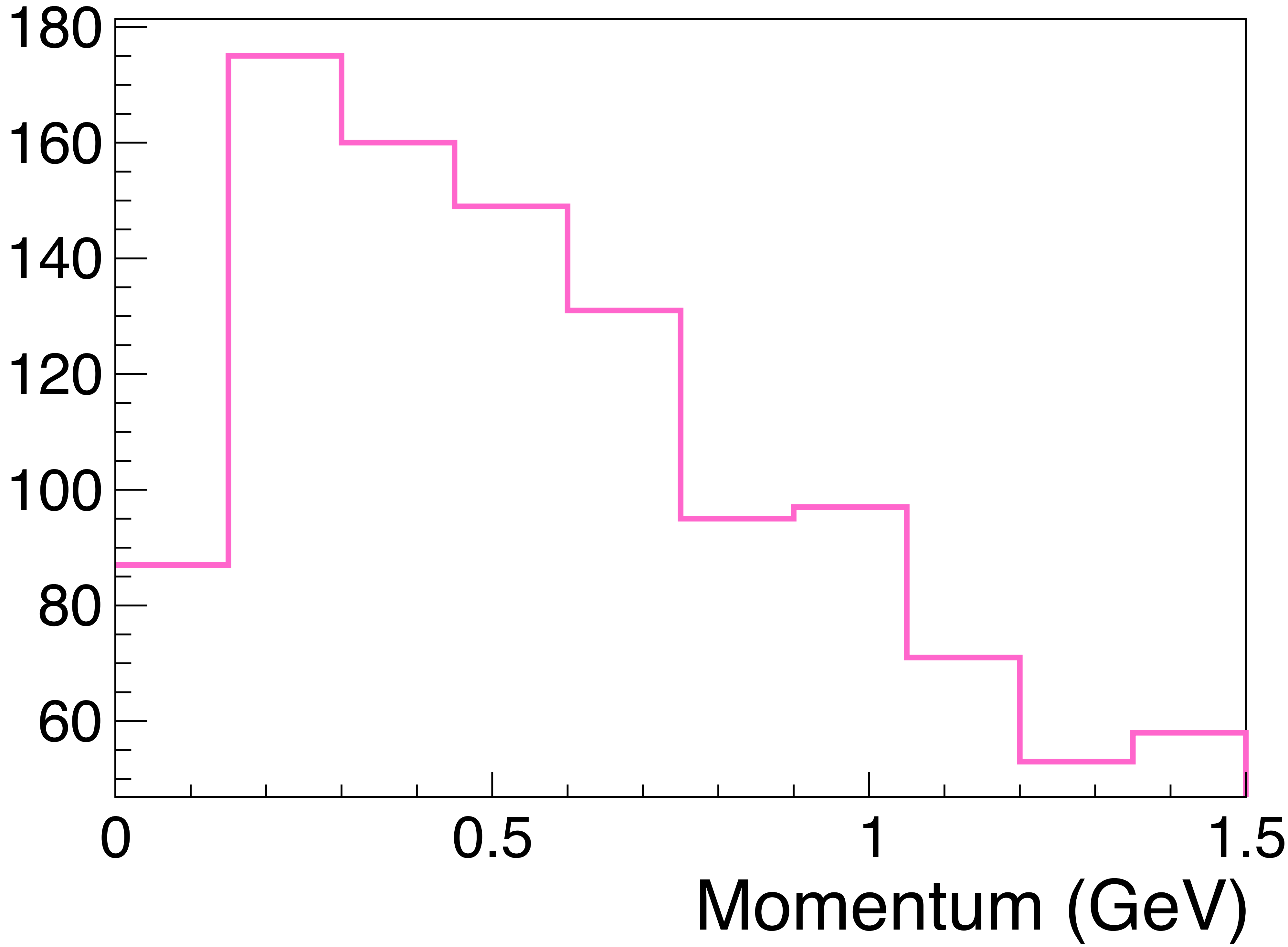
- Pattern recognition
  - Identify the interaction vertex
  - Determine a particle to be a track or a shower
  - Cluster hits and form a shower candidate accordingly
  - Deal with Bremsstrahlung, etc.
- Hit finding from
  - complicated topologies
  - low energy deposits
- Energy reconstruction

Summary

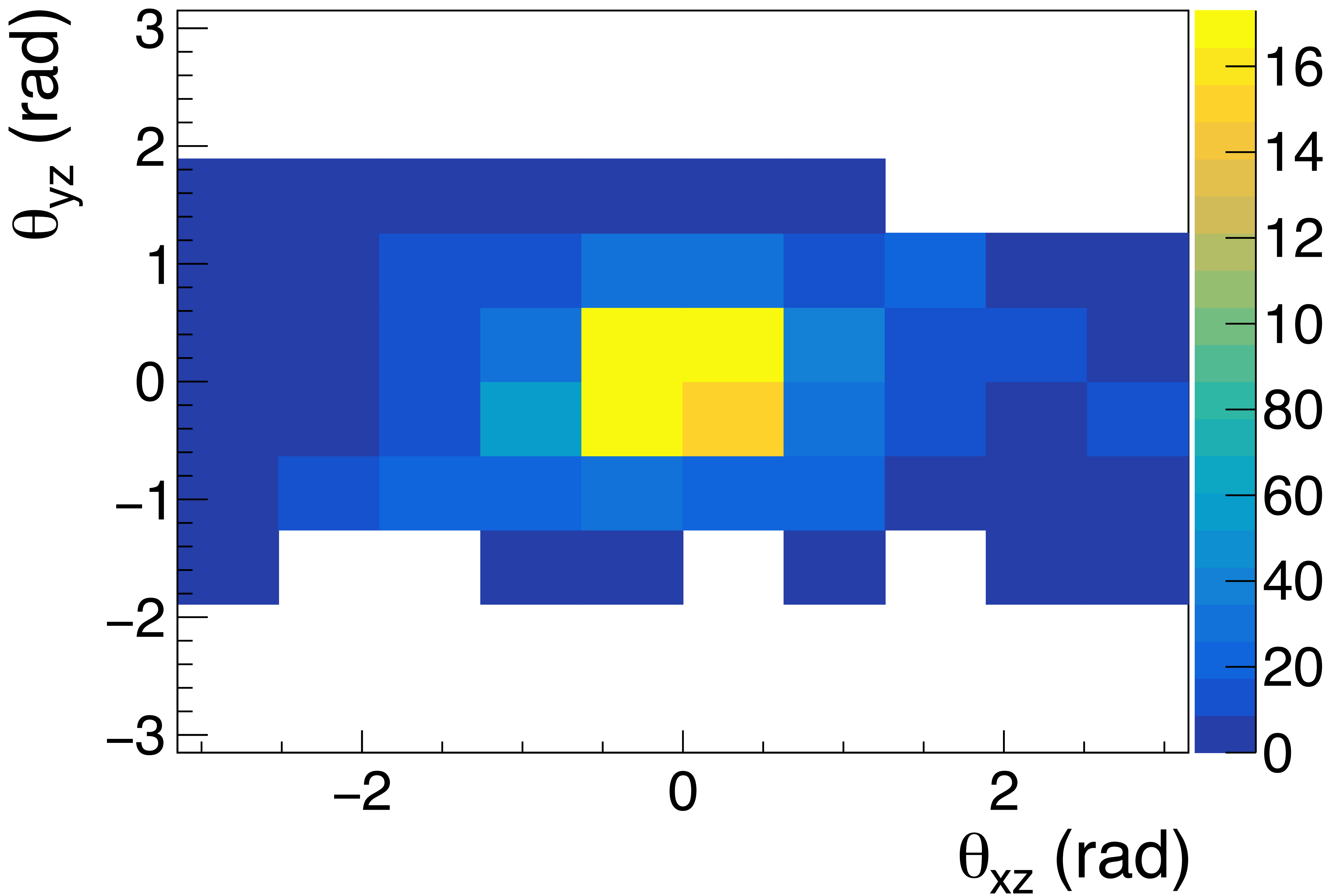
- Shower reconstruction: An essential step towards $\nu_\mu \rightarrow \nu_e$ oscillation measurement
- A lot of progress on Pandora-based approach shared/coordinated with SBND
  - Good out-of-the-box performance with the ICARUS dual-particle MC sample
- SBN shower meeting: 10:30am CDT on Wednesdays fortnightly
  - Subscribe sbn-shower@fnal.gov
- We need your contributions!

Backup

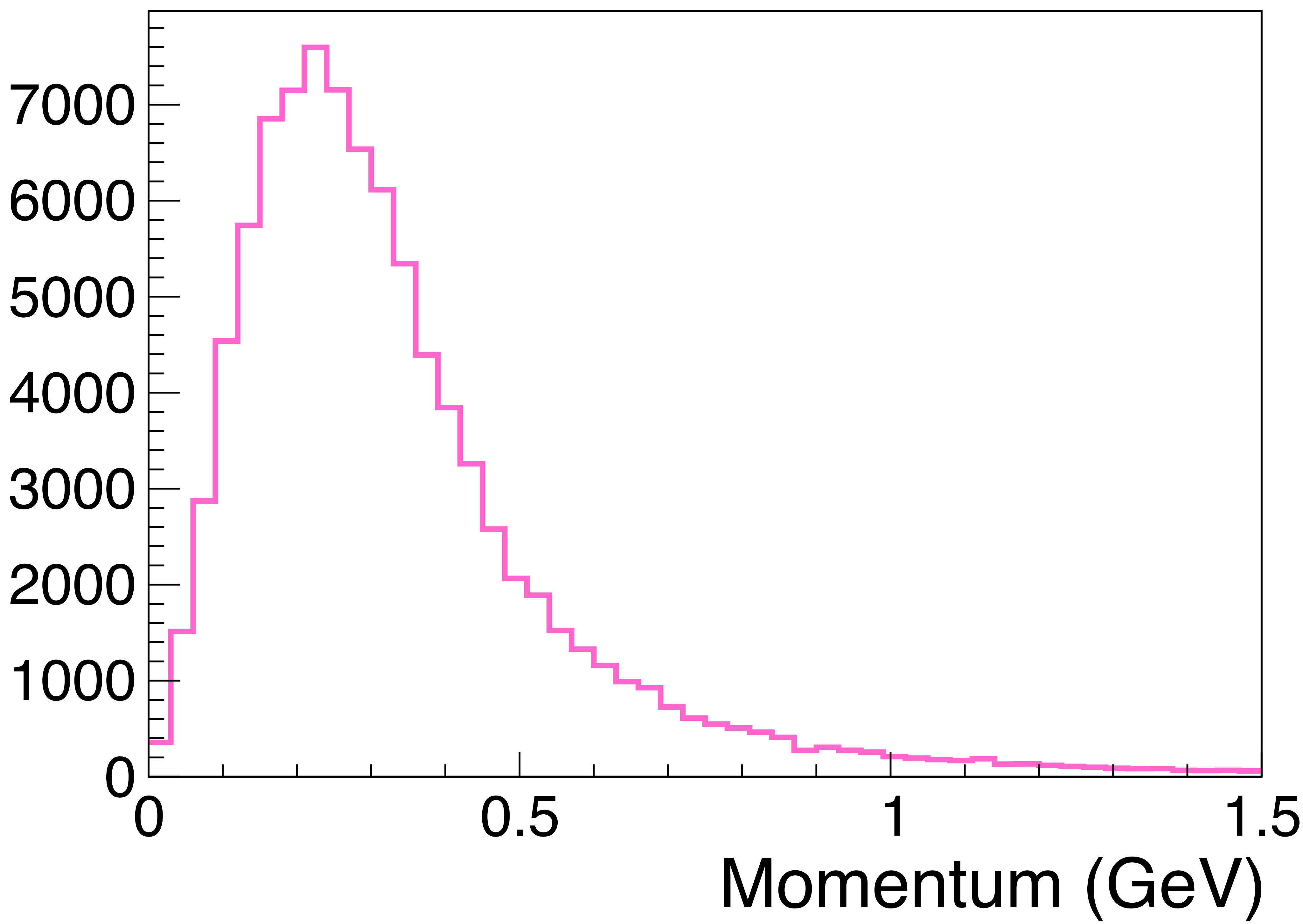
Electron Momentum



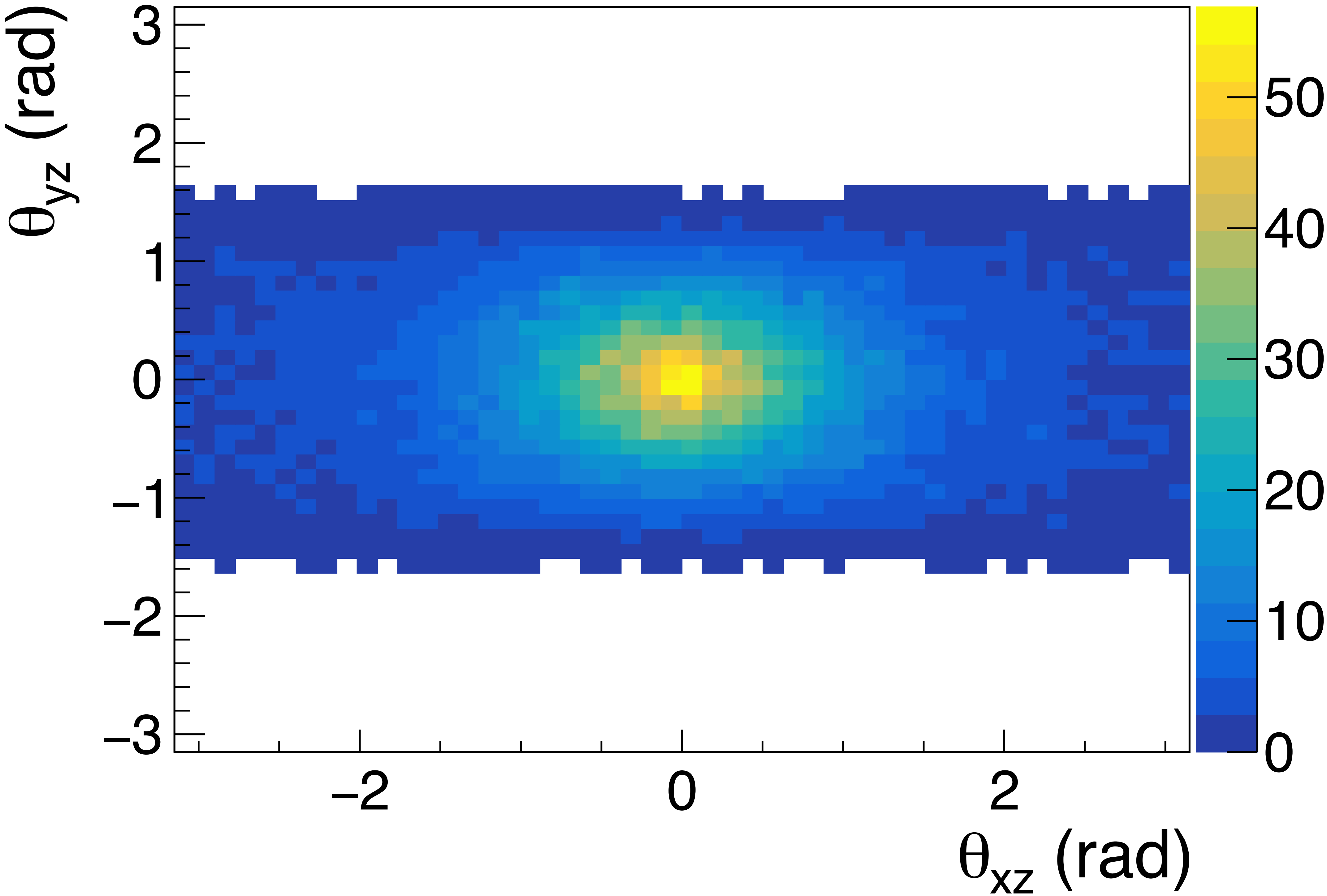
Electron Direction



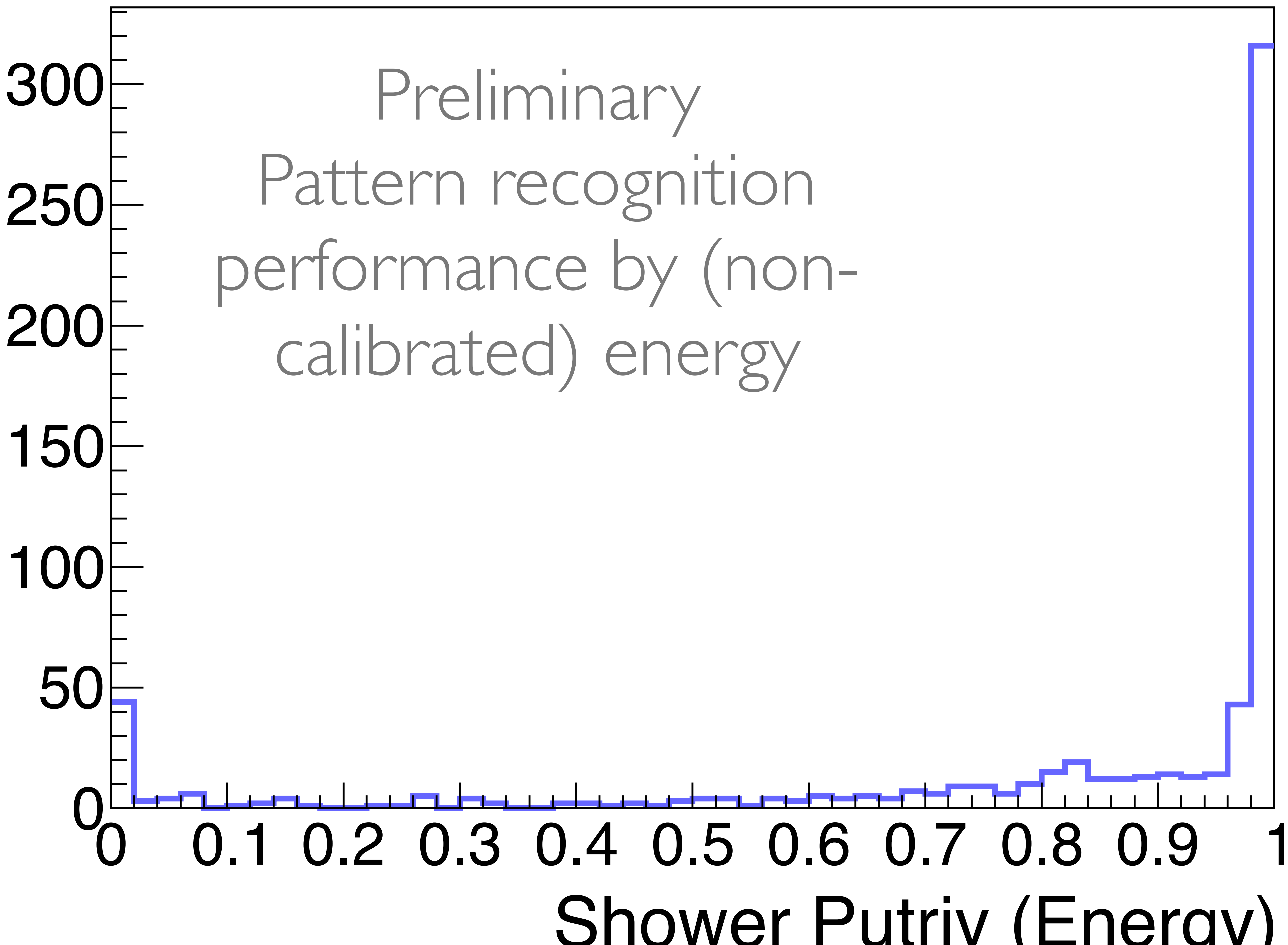
Pion Momentum



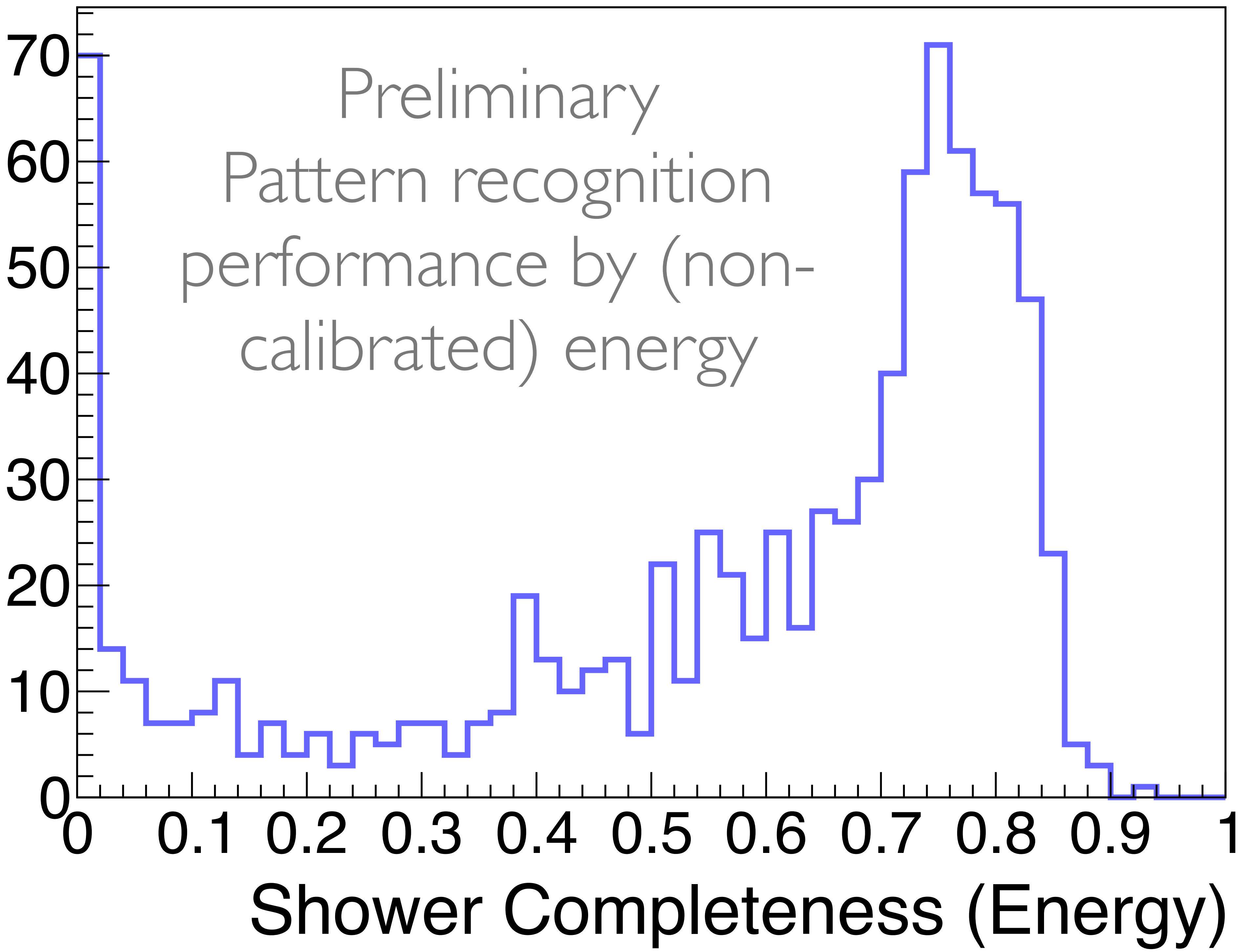
Pion Direction



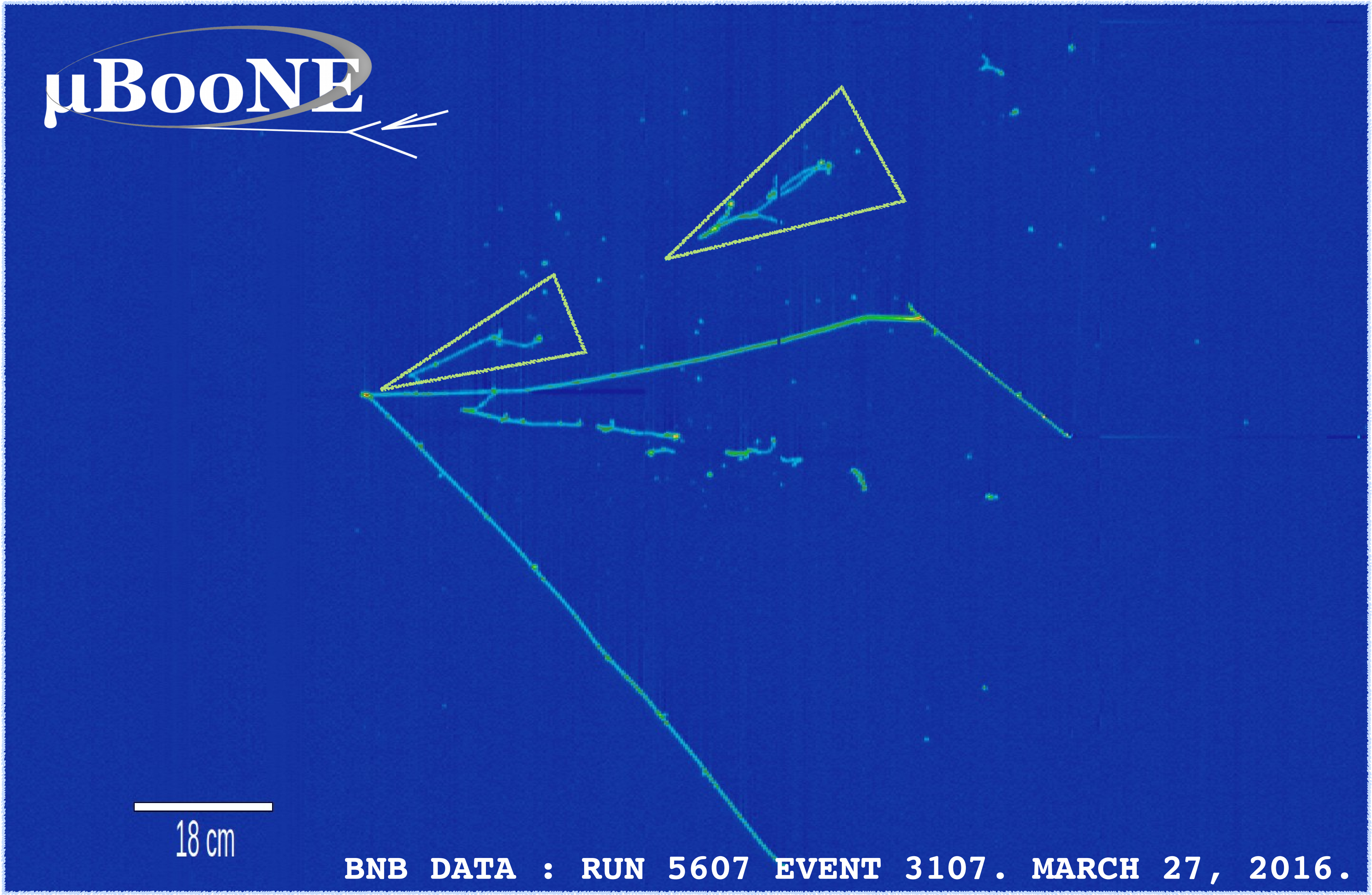
Shower Purity



Shower Completeness



To Merge or Not To Merge



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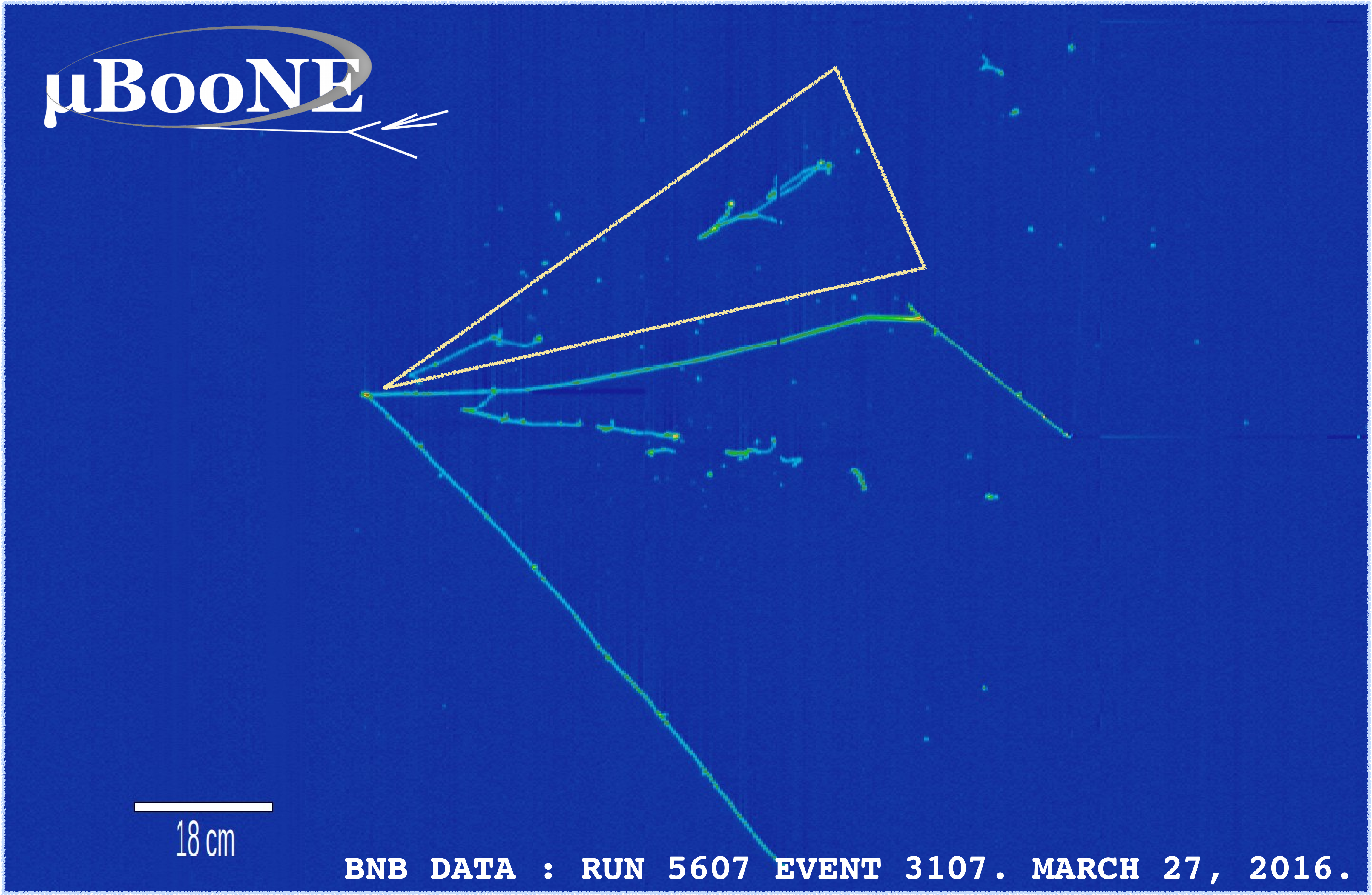
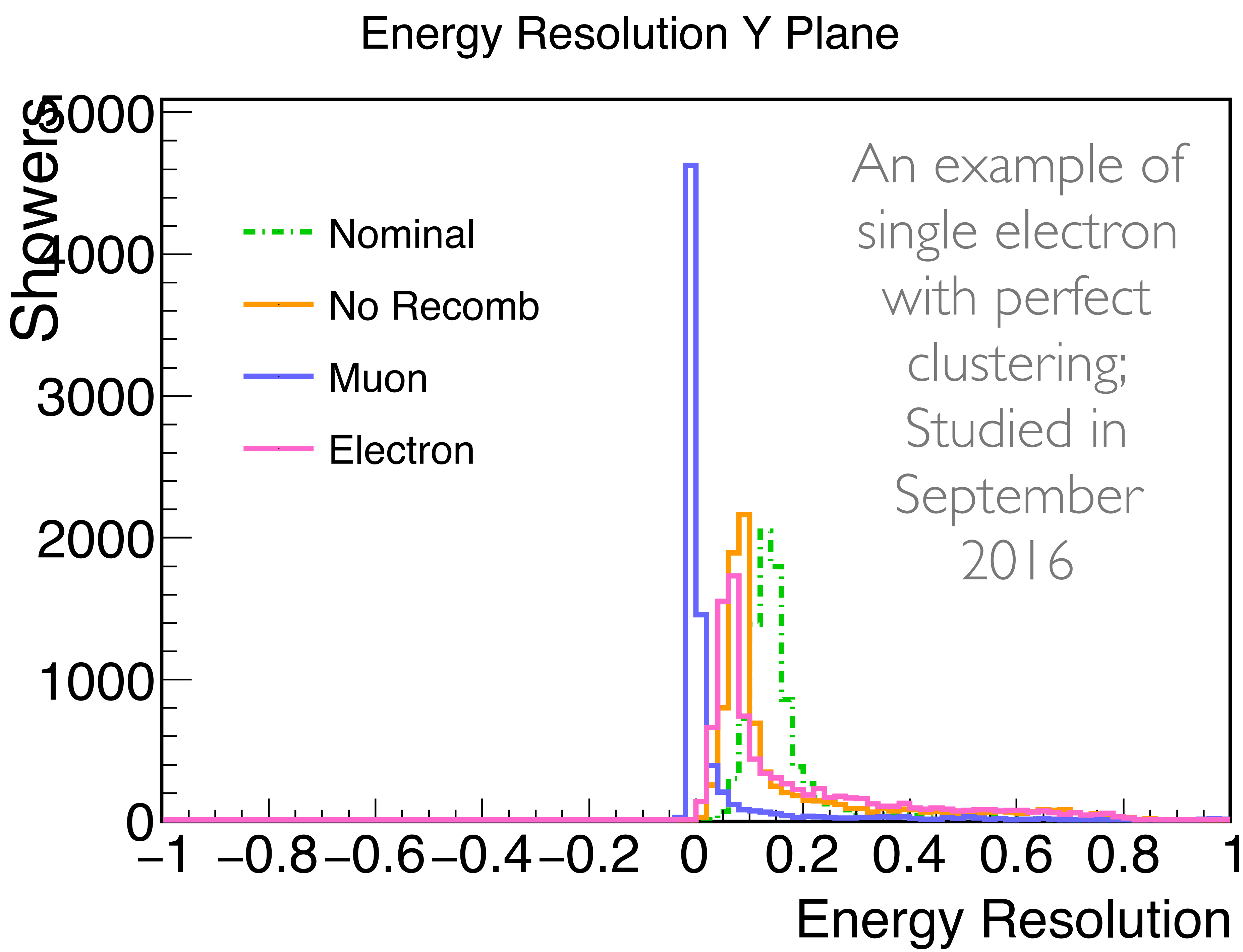


Energy Resolution

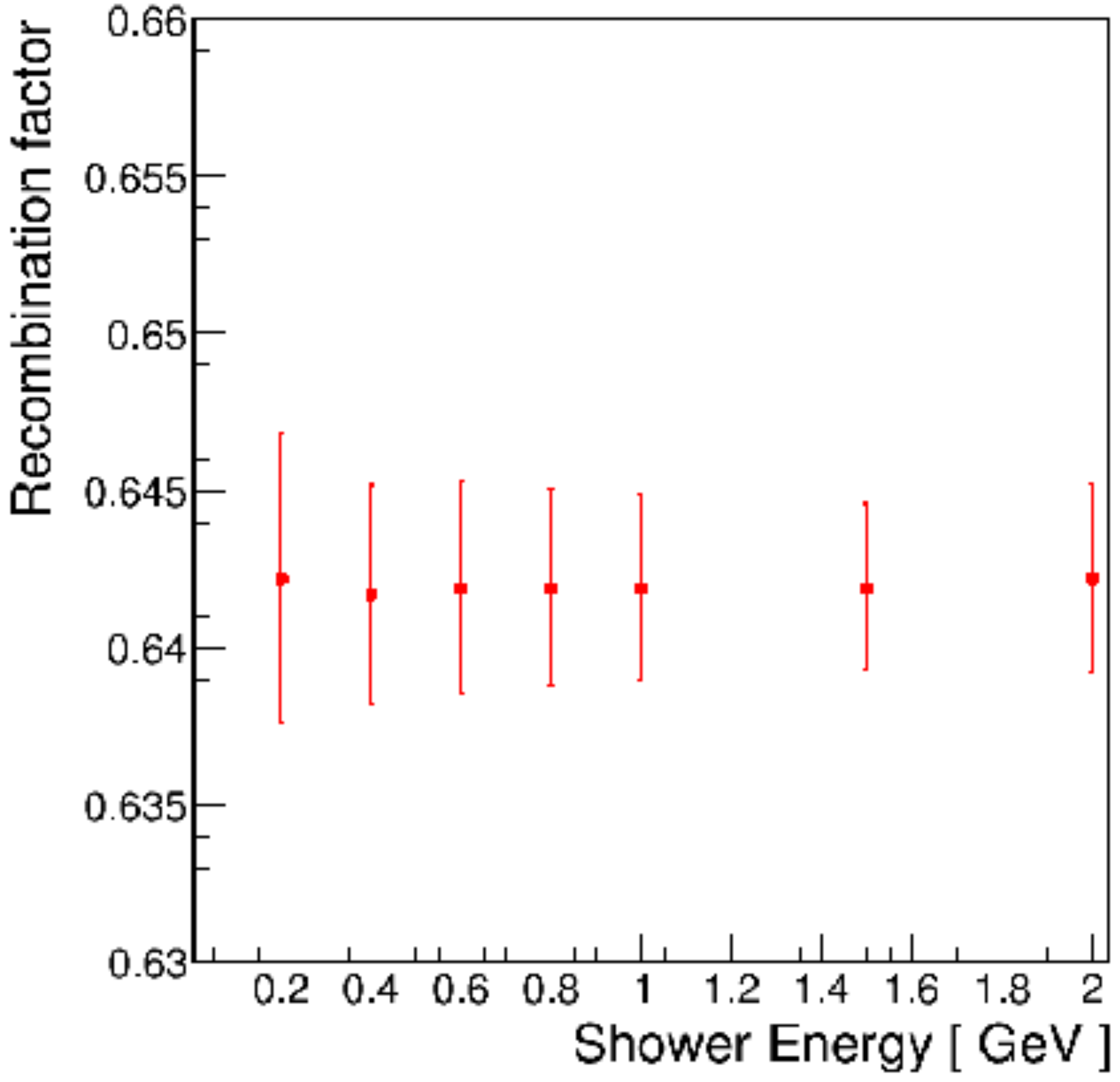
(Deposited E - Reconstructed E) / (Deposited E)



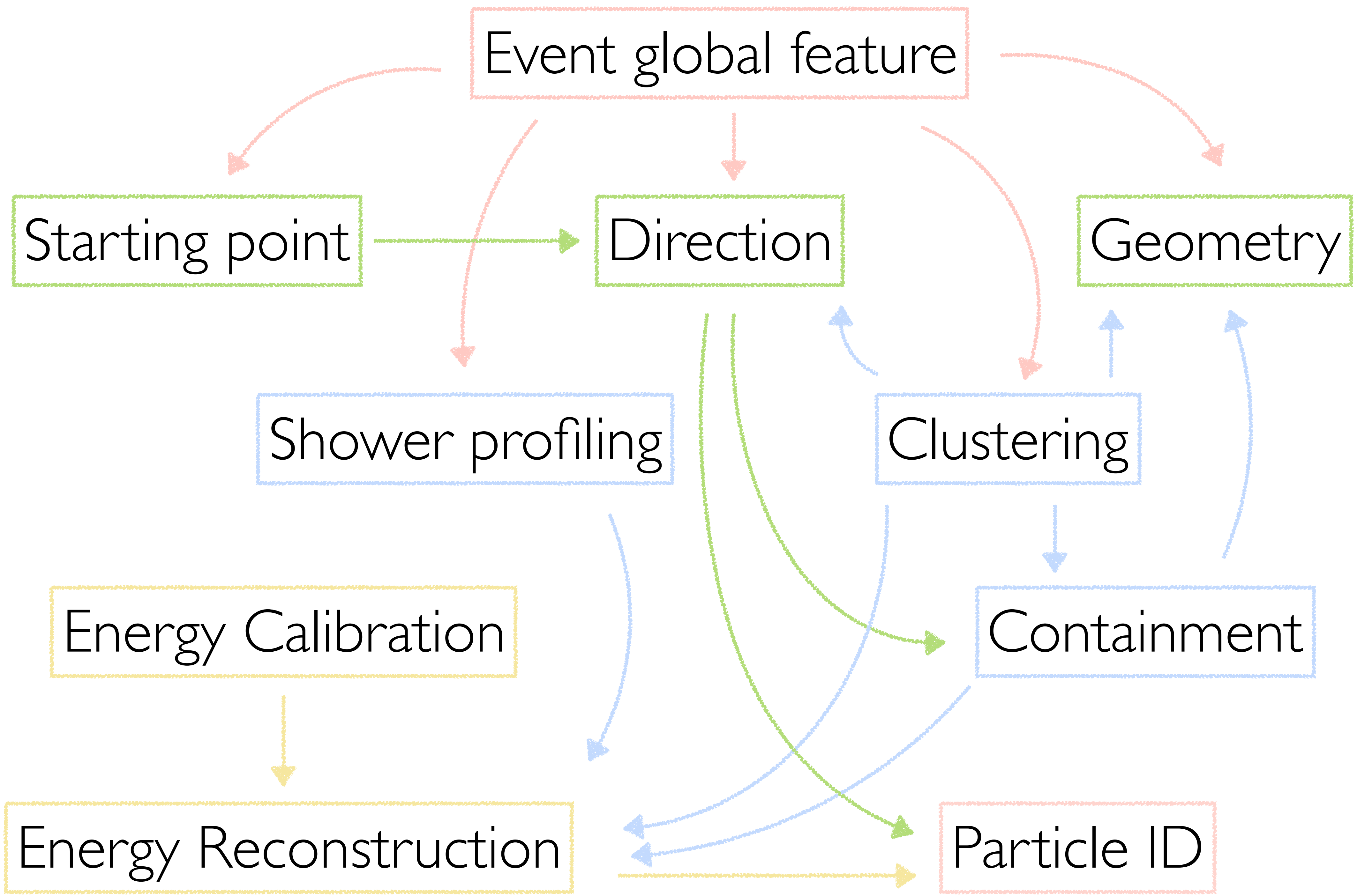
Study on Recombination

- 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