Pioneer
Simulation & Proto-Analysis

Overview, Status and Opportunities for Improvement

Patrick Schwendimann on behalf of the Framework Developers* - 21. June 2024

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What do we want from the Simulation?

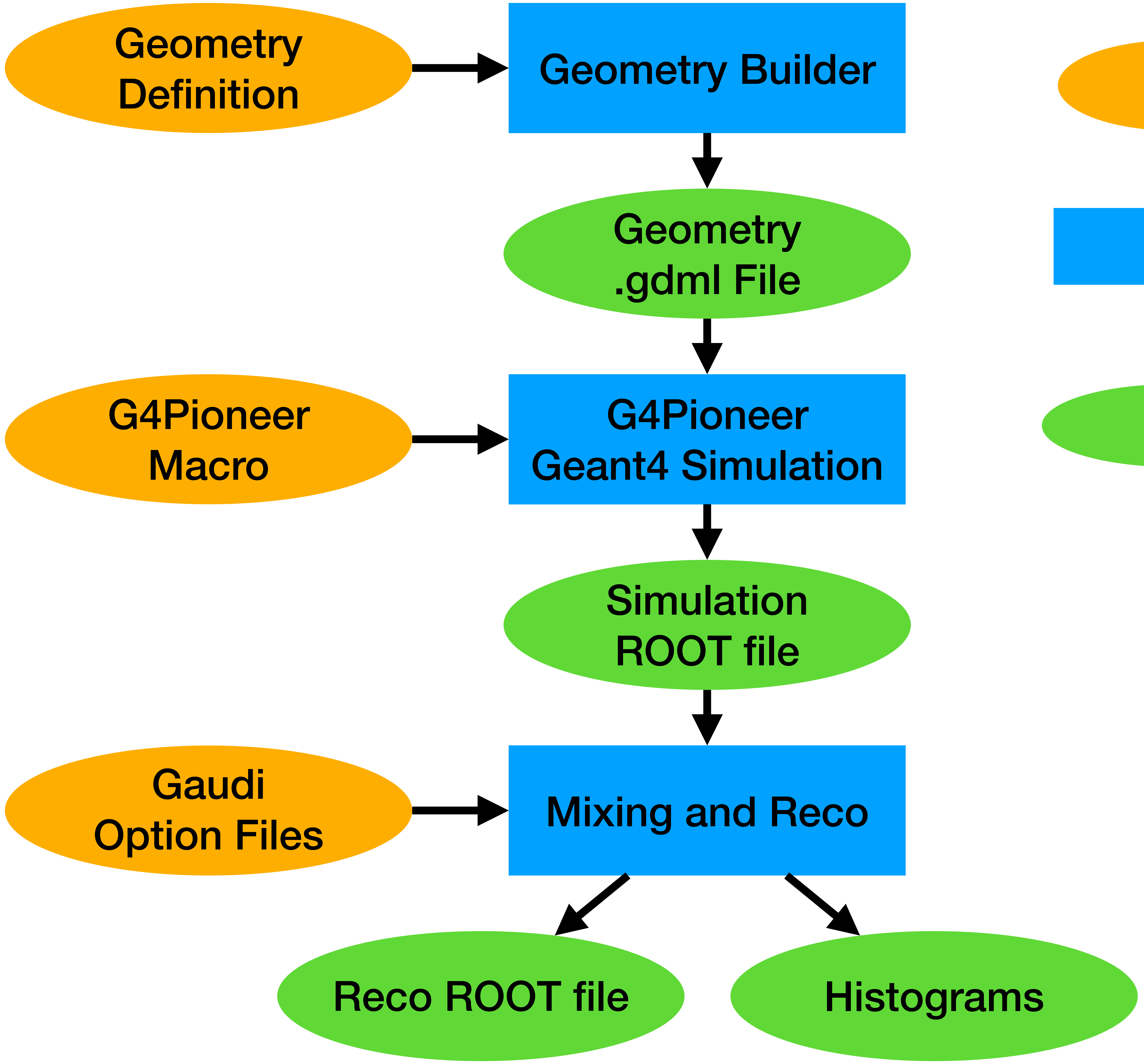
- **Guidance on the detector design**
  Which parts are crucial? At which point does dead material ruin the Calo resolution? Where do we have to spend the money and where can we save?

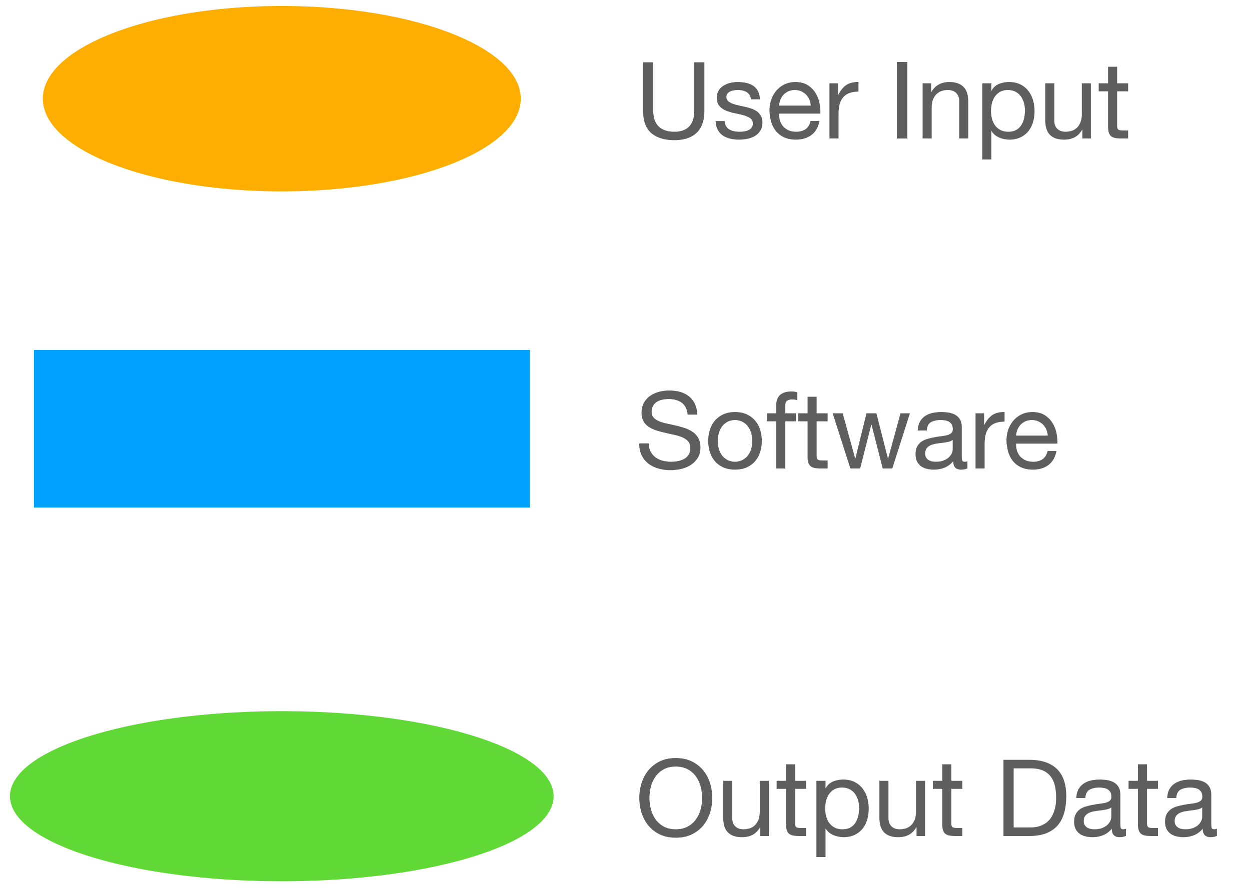
- **Understand (rare) event topologies**
  We know that there will be a $\pi \rightarrow e\nu$ tail, but what fraction will go there?
  Which mechanism? What other events can mimic $\pi \rightarrow e\nu$ events?

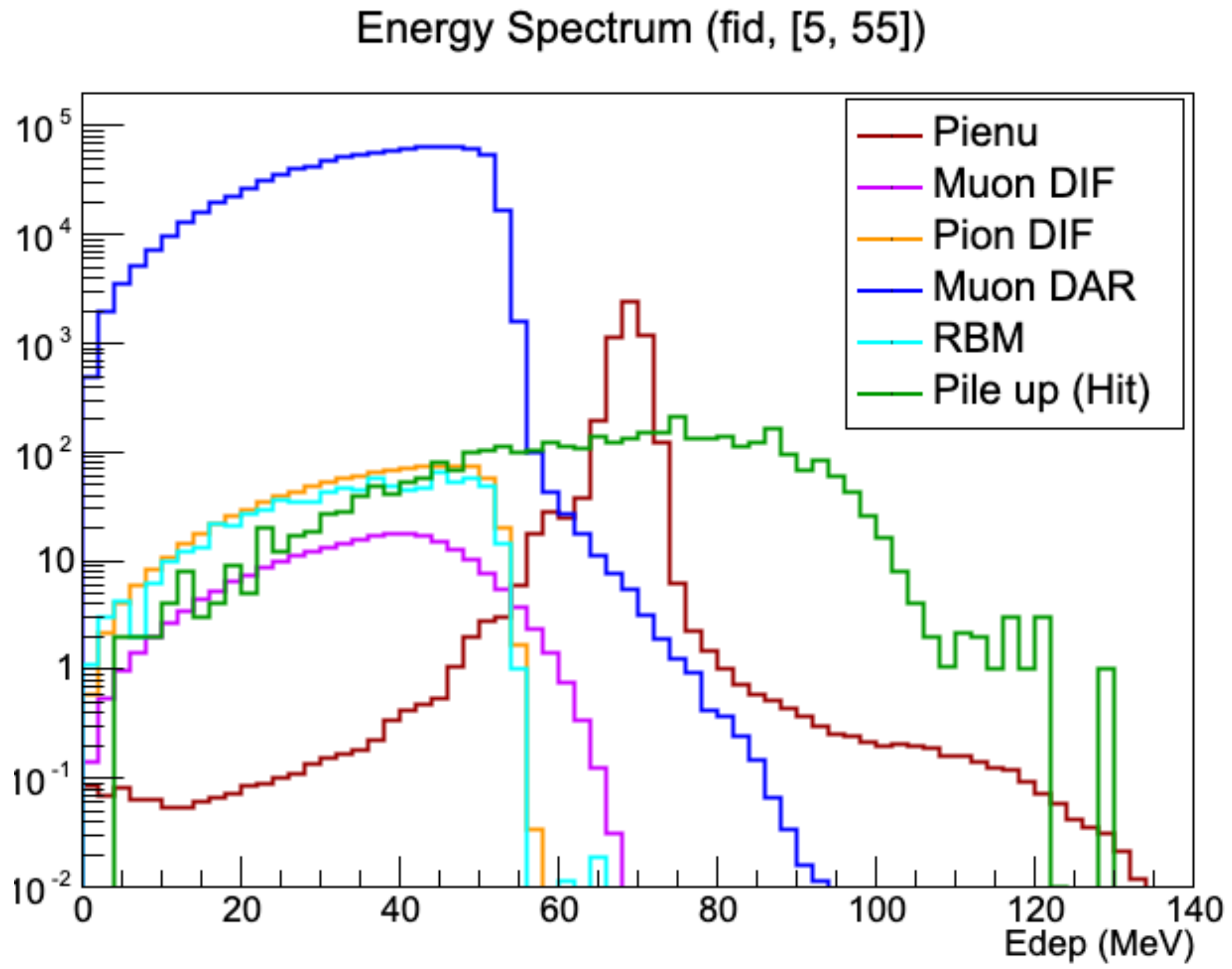
- **Develop the Reconstruction and Analysis**
  How do we process the data? What selections can we make without biasing? What are promising algorithms to get the numbers out we need?

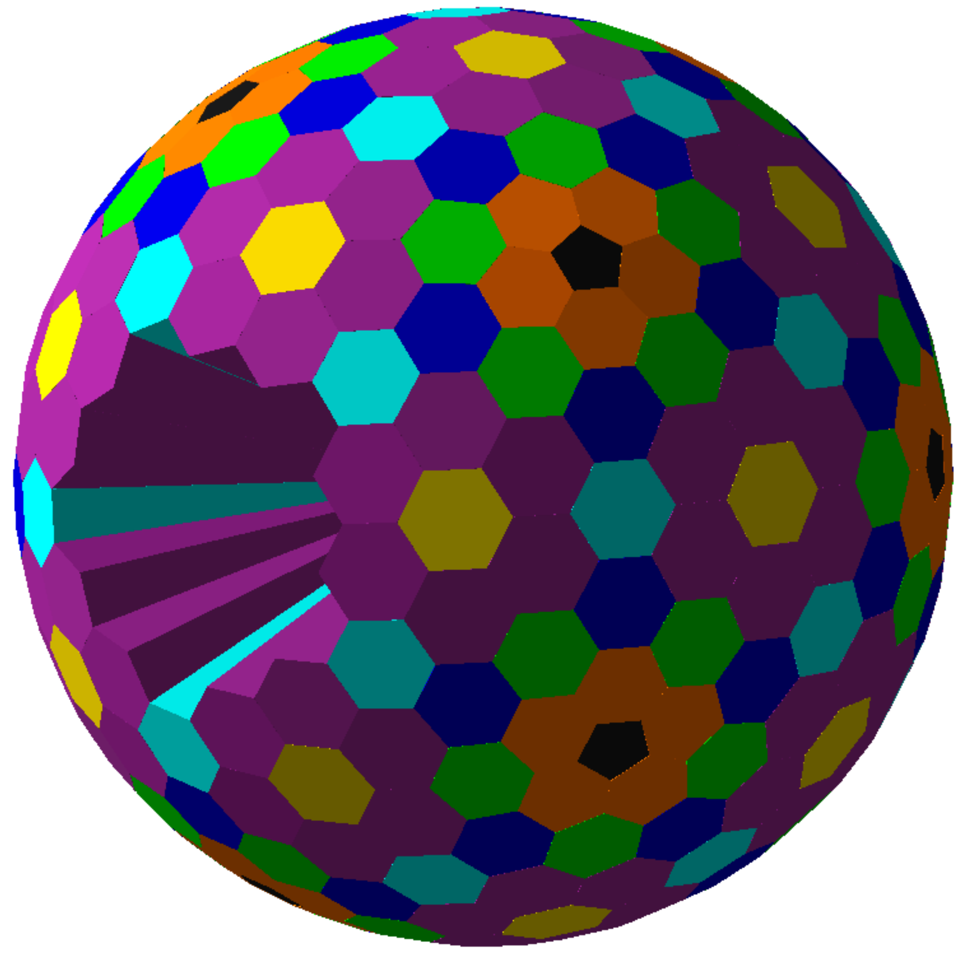
We want to prove PIONEER works with a conceptual detector without spending all the money.

What the Framework provides

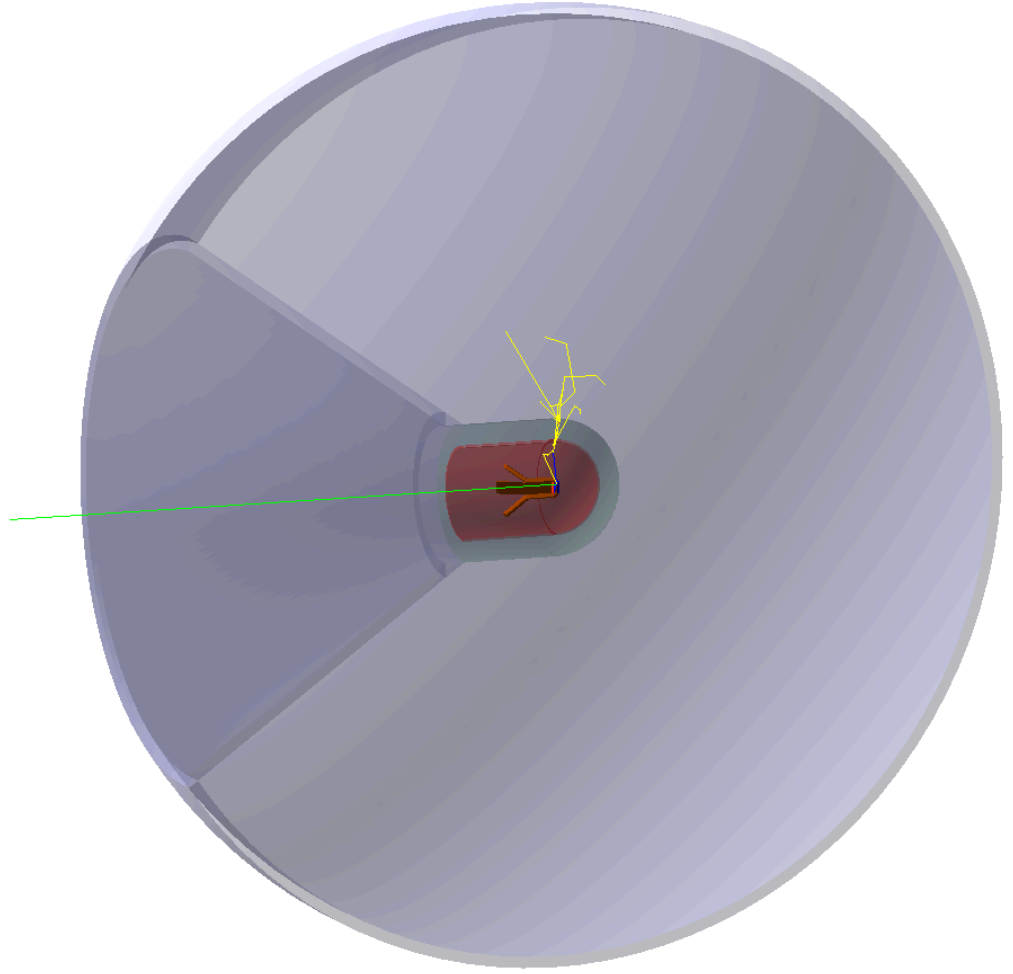








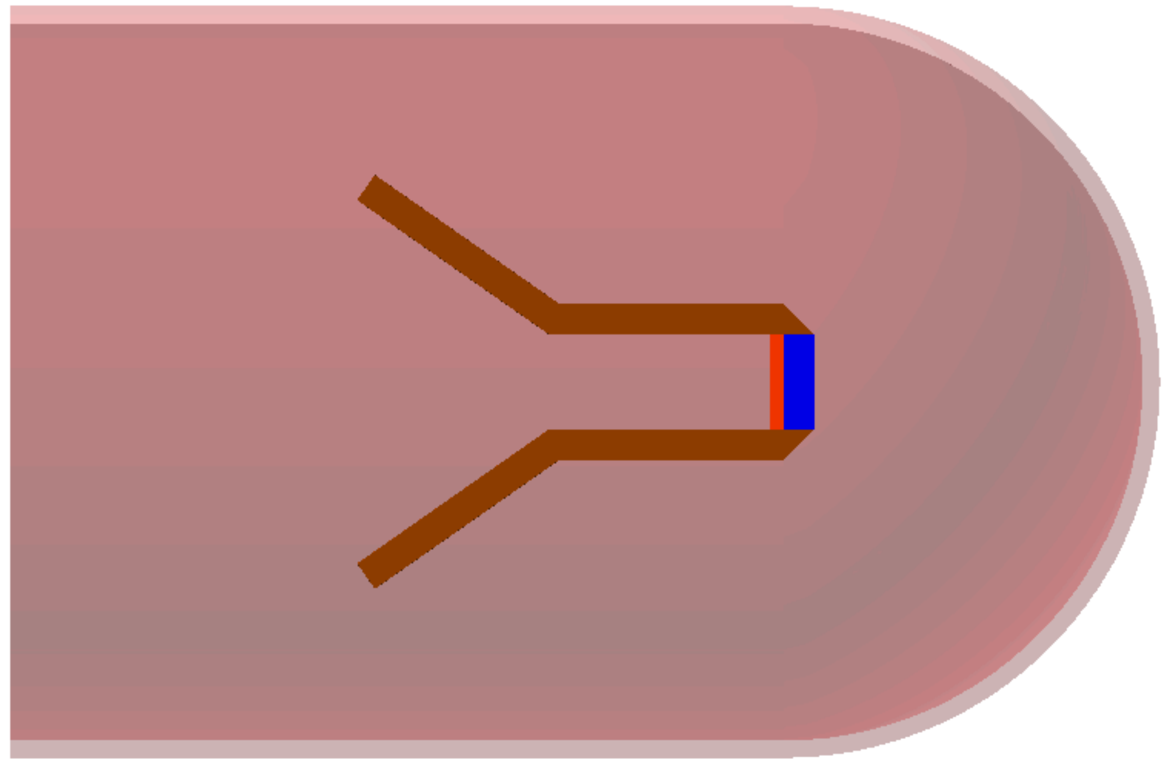
LYSO Crystal Calo Concept



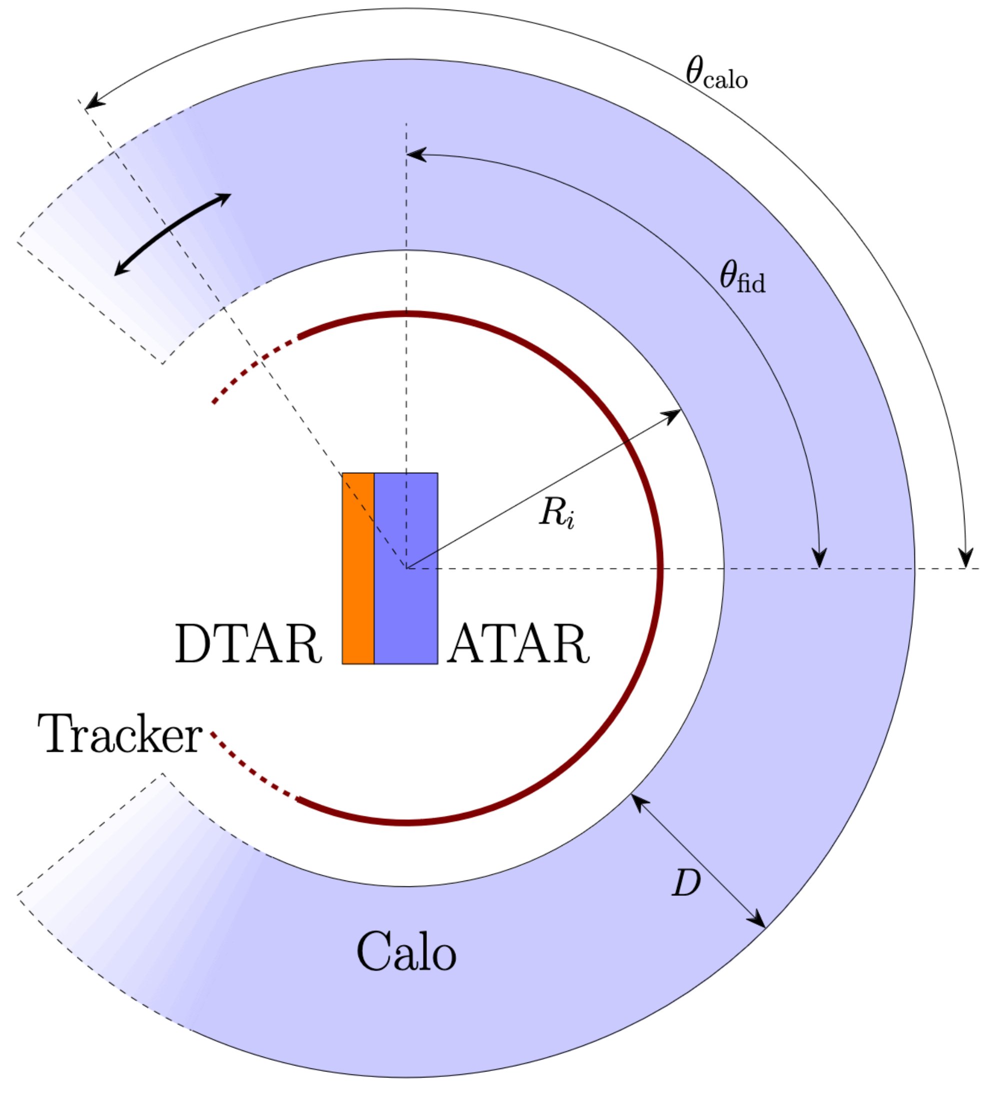
Pion Decay Simulation in LXe Calo

Geometry Building

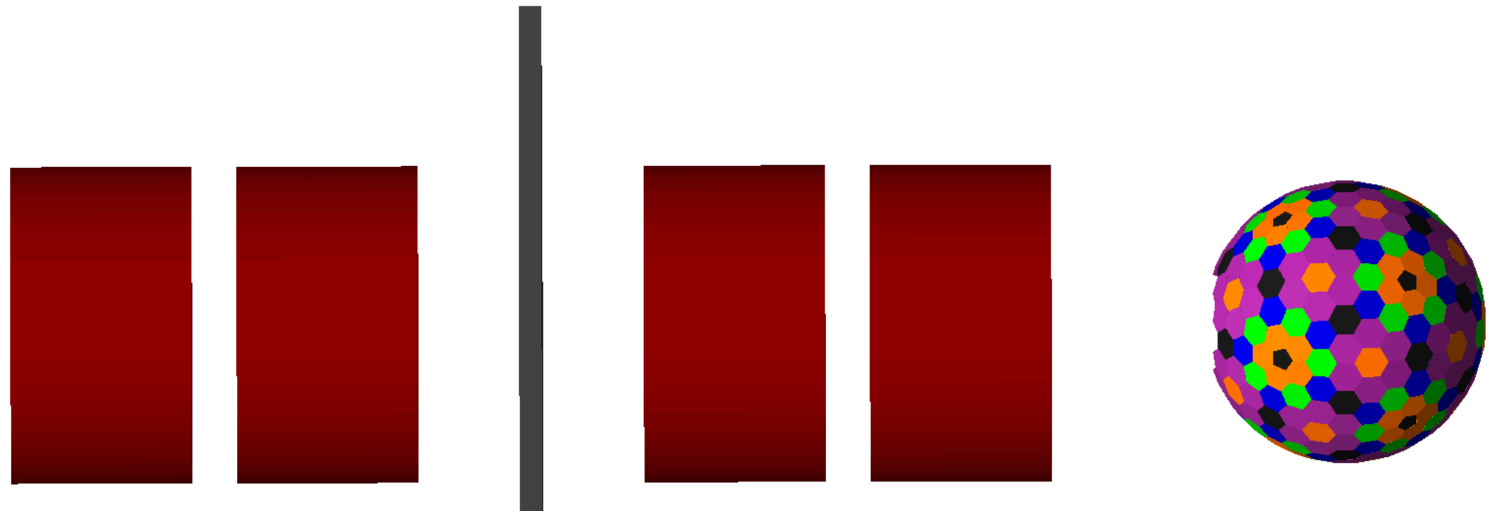
- Use an existing, configurable geometry.
- Sophisticated ATAR model based on strips
- Mockup DTAR and Cables
- Best guess of 2022 on Tracker
- LXE or LYSO calorimeter
- Optional beamline elements



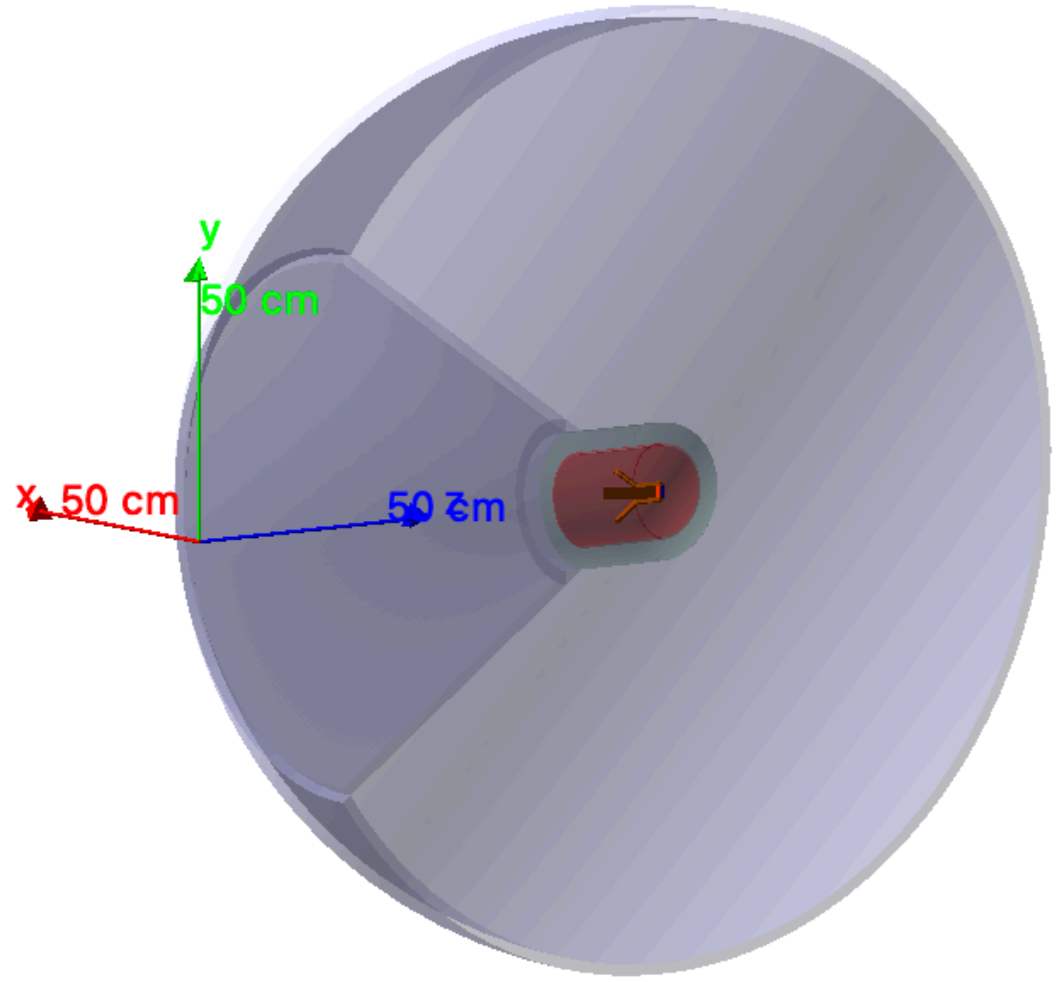
Inner region in Simulation



Conceptual Design



LYSO Calo with Beamline



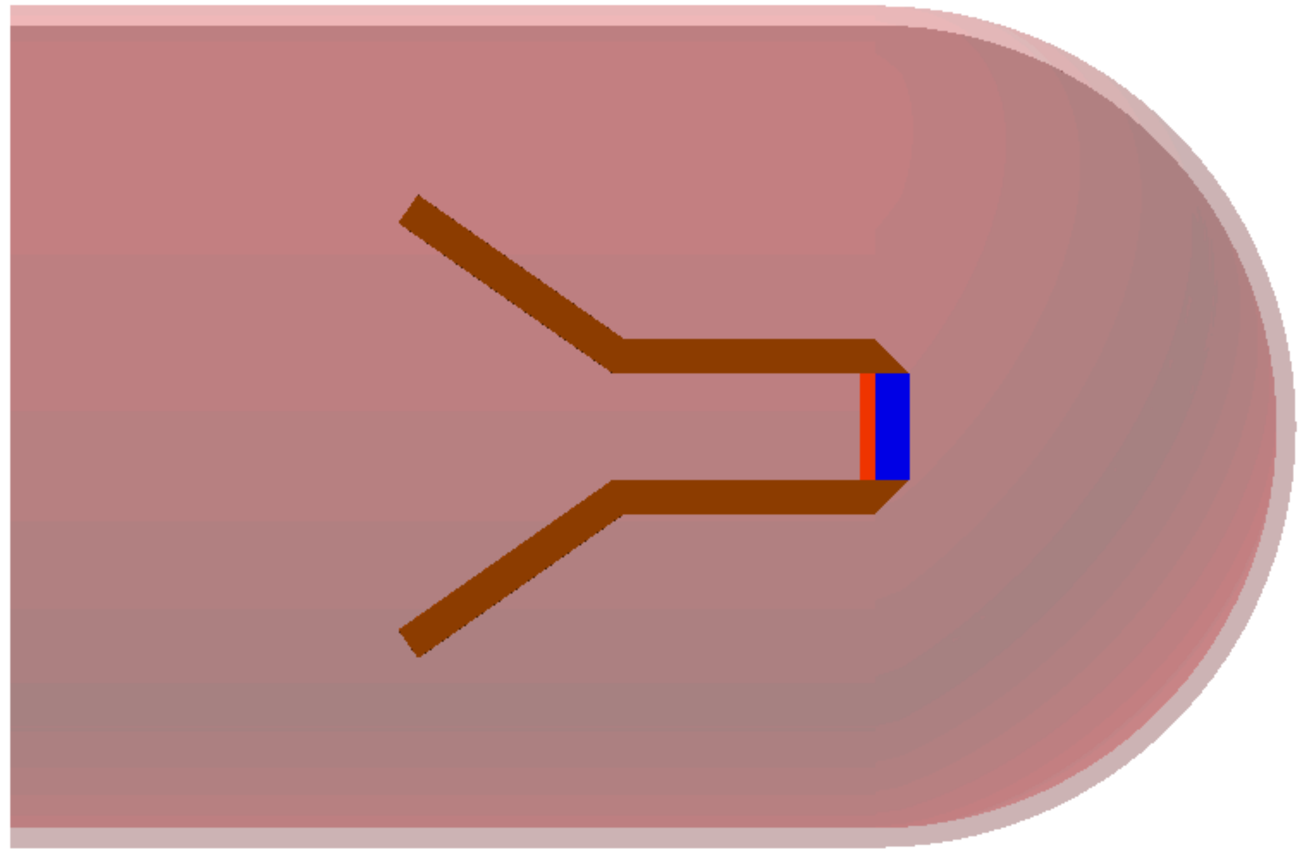
LXe calo cross-section

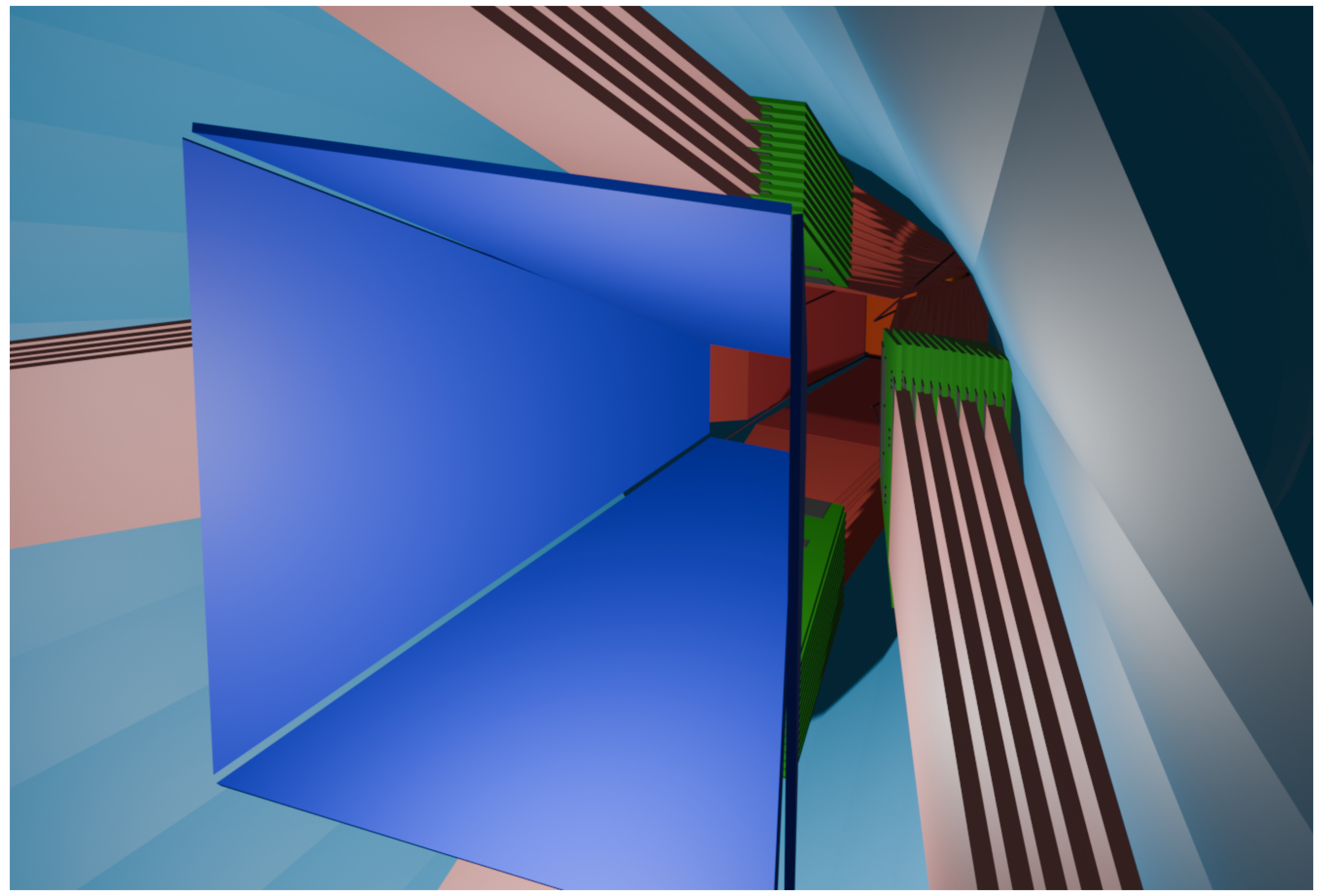
Many elements are already well modelled and their impact can be studied

The Inner Region (ATAR, DTAR, Tracker)

- ATAR stable with 48 Layers, 100 strips per layer, 20 x 20 x 6 mm in size.
- Tracker implementation goes back to Josh taking some numbers from Jaydeep
- DTAR is a single block of silicon
- Cable routing requires an update that should include boards
- Halo Monitors?

SPA Goal 1: Converge on a setup that can be implemented for the central region.


Inner region in simulation

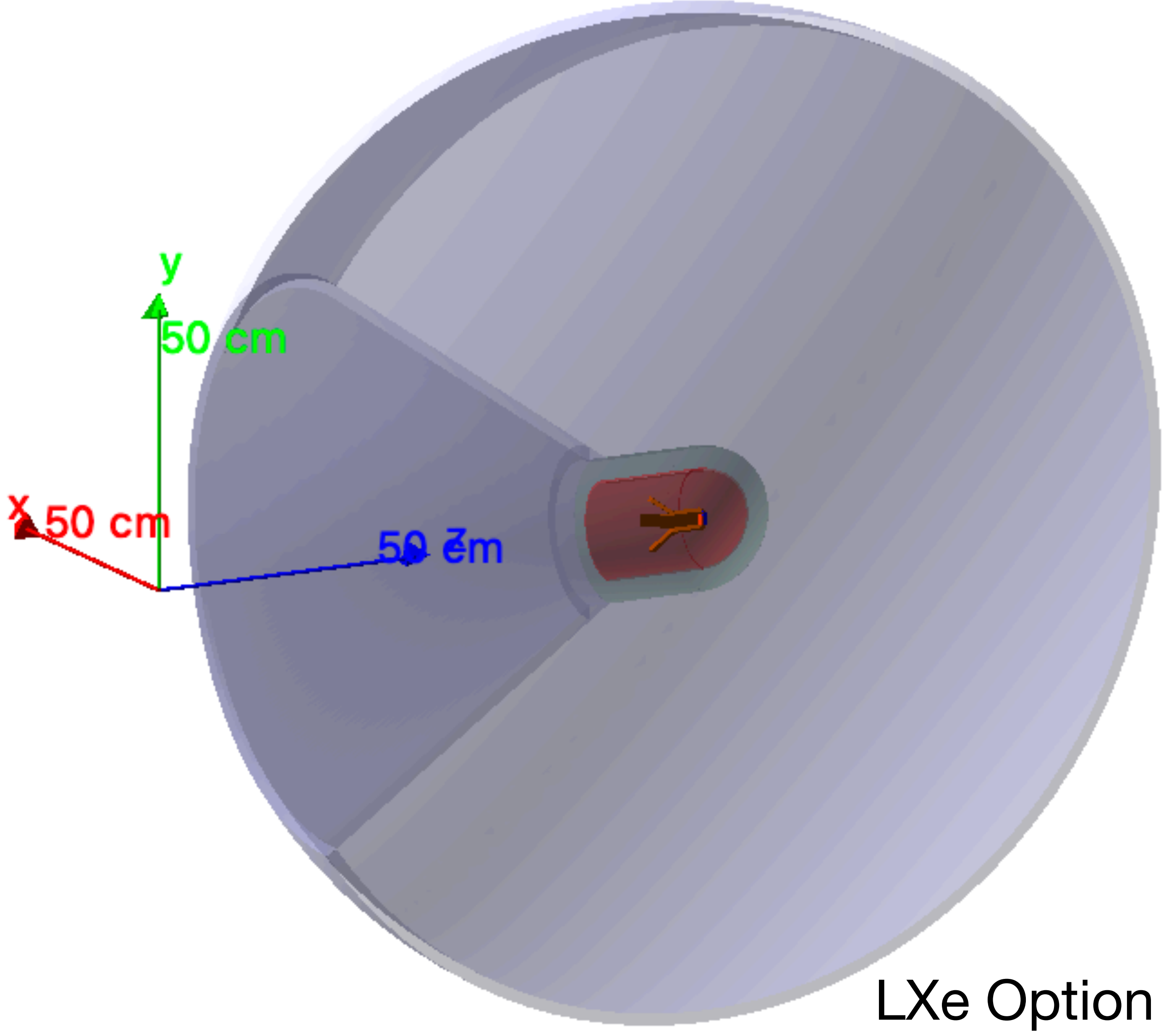

Inner region in Simone's drawing

The two Calorimeter Options

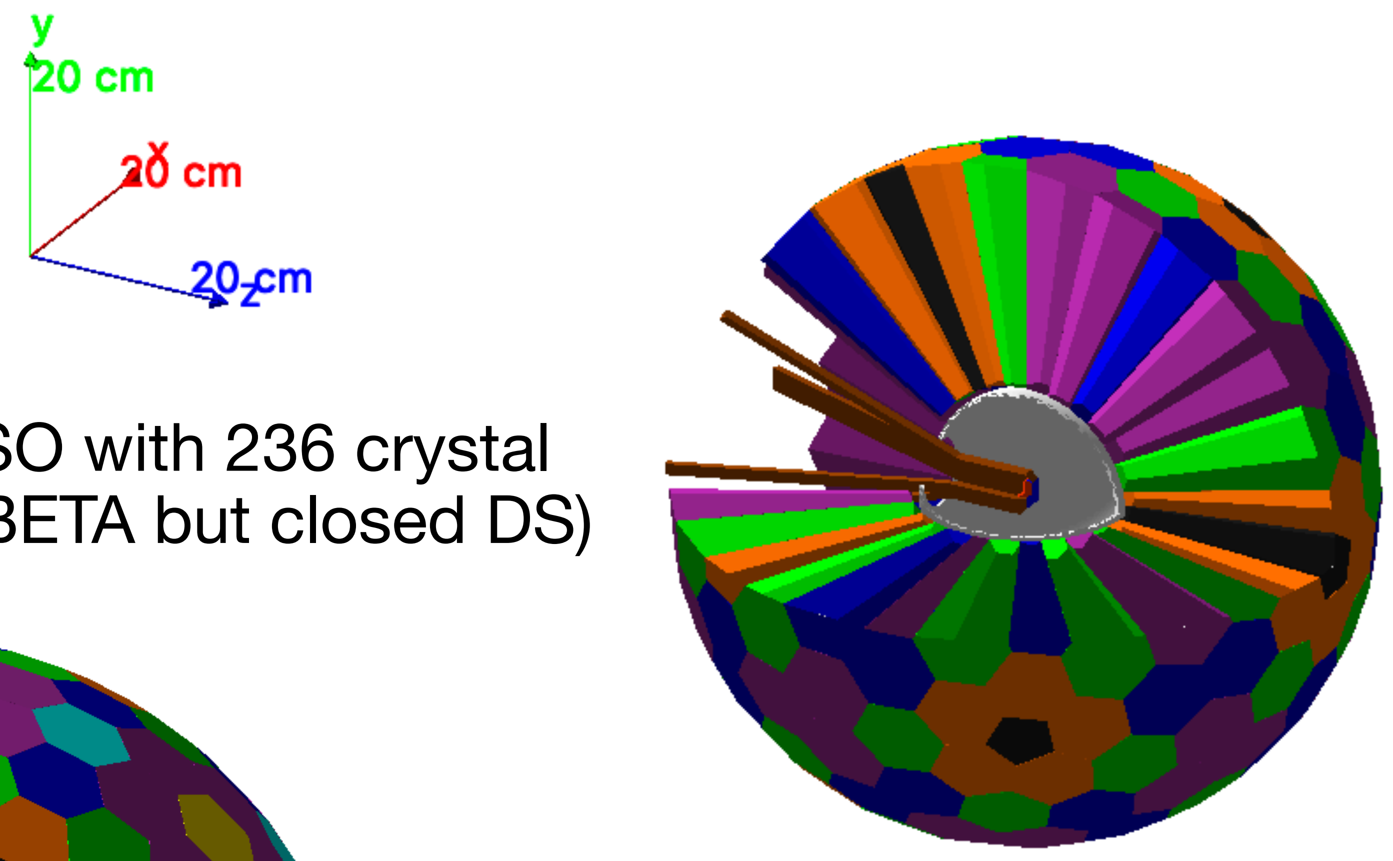
- LXe option:
  - Double walled cryostat with insulation volume
  - Two individually configurable windows in the inner region
  - Pseudo-Uniform distributed PMTs on the outer surface

- LYSO Option:
  - Configuration file based number of crystals. (e.g. 236 or 346)
  - Option to wrap/coat crystals or attach PMTs

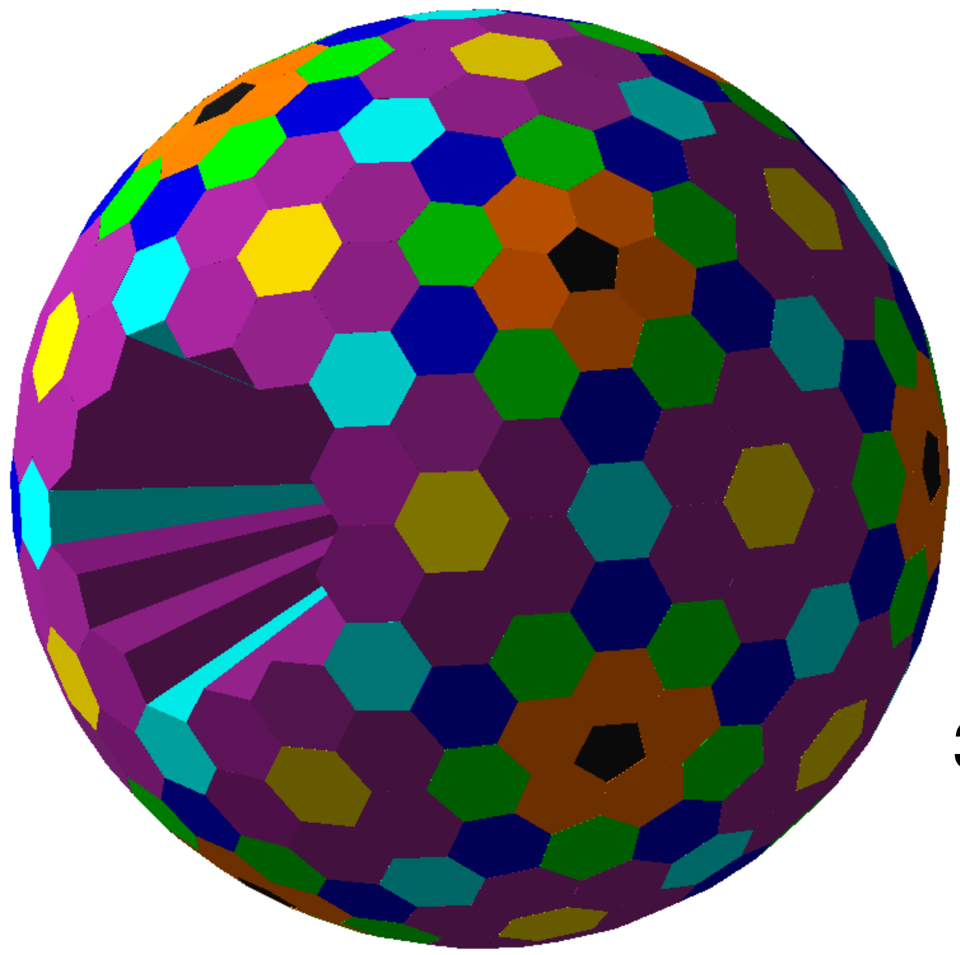
Very sophisticated Calo geometries are available and ready to be used



LXe Option



LYSO with 236 crystal
(PiBETA but closed DS)



346 crystal concept

The Geant4 based Simulation G4Pioneer

Combine geometry, initial particle and physics selection

Initial Particle Generators:

- **Beam Generator** fires initial particles (π^+, μ^+, e^+) towards the target from upstream. Momentum, size and emittance are configurable.
- **Signal Generator** will create positrons of selected momentum within ATAR and fire them in a configurable solid angle (e.g. fiducial volume only)
- Geant4 **GPS**: Most configurable but also most complex to use. See G4 Manual

Physics Selection:

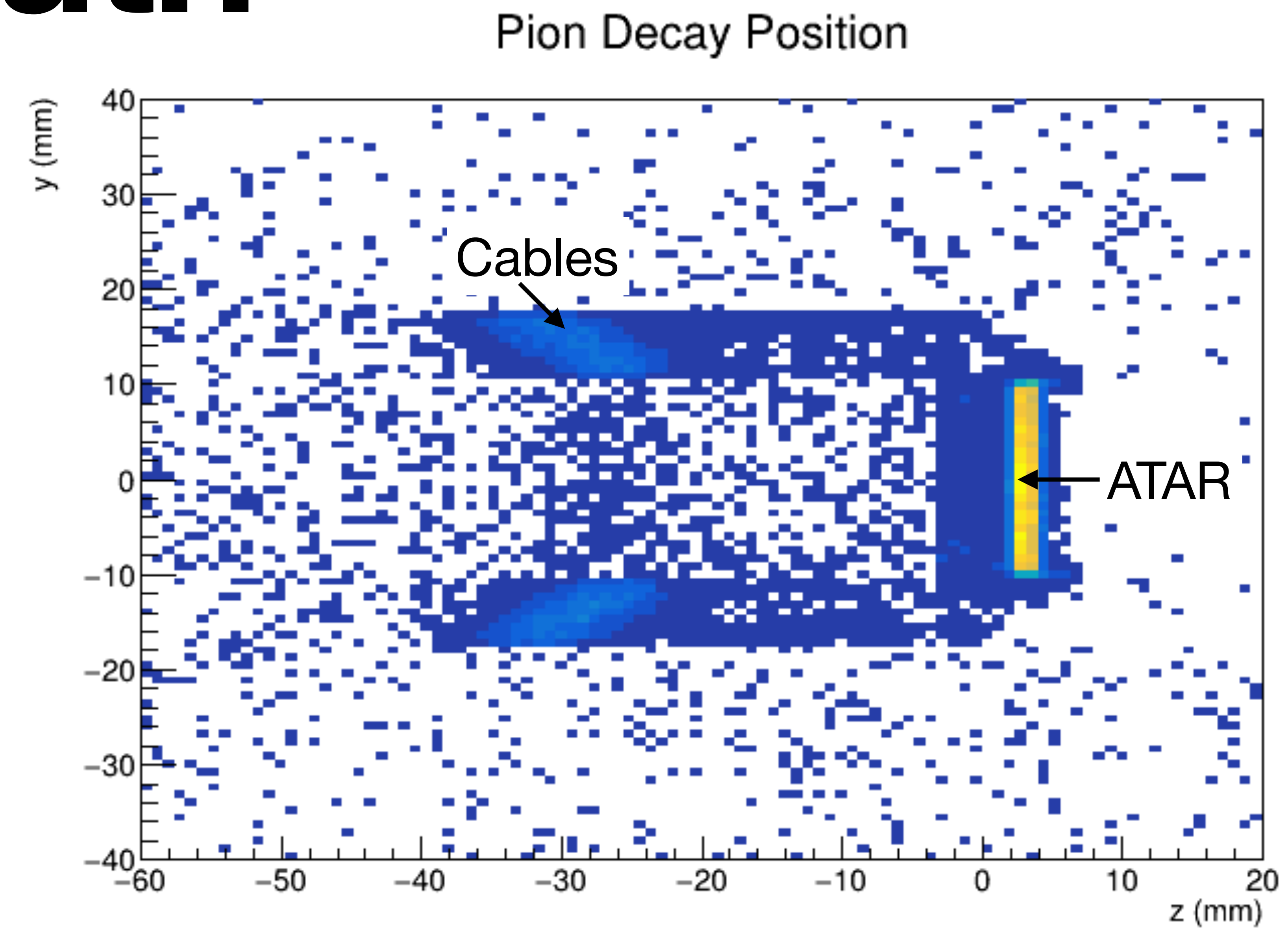
- Select a Geant4 Physics list as basis and add rare event selection if desired (e.g. $\pi \rightarrow e\nu$, $\pi \rightarrow \mu\nu\gamma$, $\pi^+ \rightarrow \pi^0 \nu e$ decay channel, decay in flights biasing etc.)

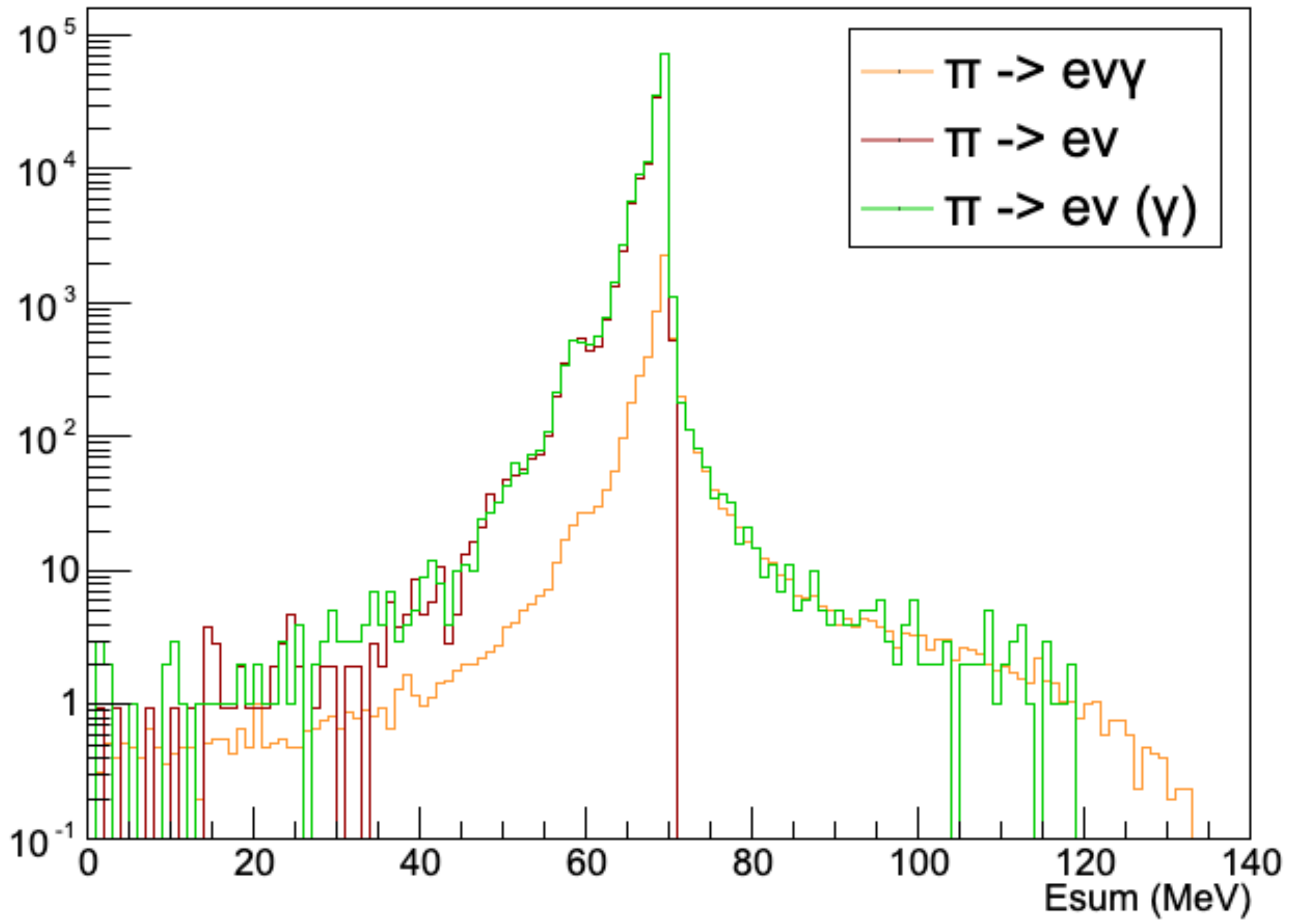
SPA Goal 2: What is a realistic beam to use for the simulation?

The G4Pioneer Output: MC Truth

- More detailed than the measurement can ever be.
- Useful for :
  - quick crosschecks
    e.g. decay position, diff. decay rates
  - dead material studies
    e.g. energy losses
  - reference
    e.g. weird events

Fairly mature status. Keep improving based on feedback and need

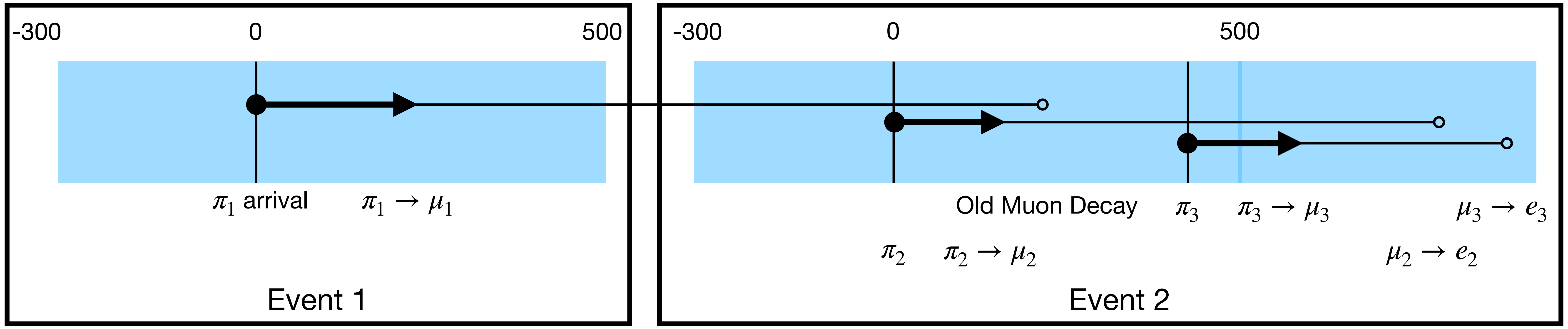




Event Mixing

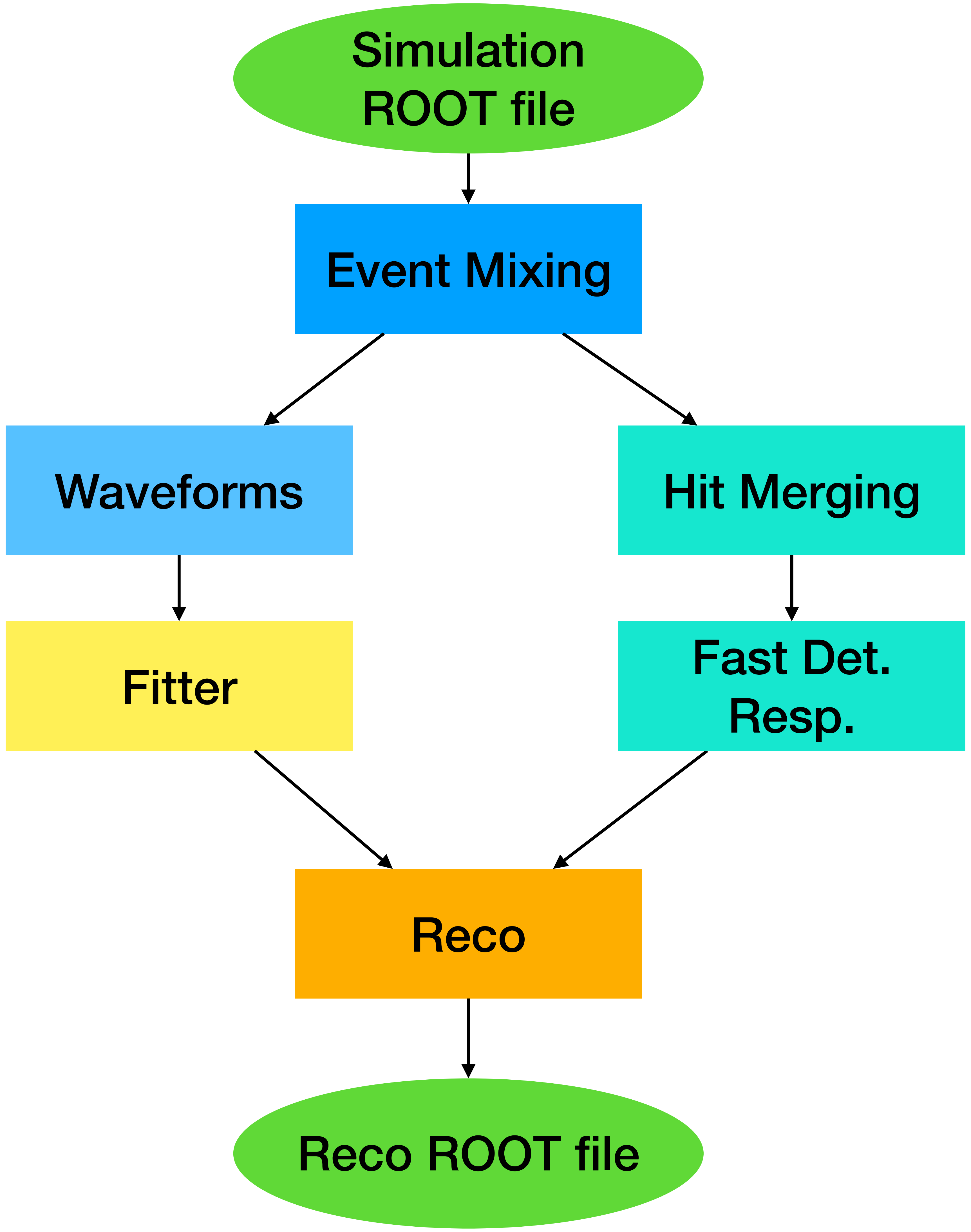
- The anticipated beam rate is 0.3 MHz, i.e. a pion every 3 μs on average. The mean muon lifetime is 2 μs. Some muons will decay after the next pion arrived (Old Muons).

- Mimic Data Acquisition: Use Pion/Muon in DTAR as trigger. Only consider hits between 300 ns prior to 500 ns after trigger. Extend as needed.



SPA Goal 3: What is a realistic Trigger and DAQ behaviour to implement?

Detector Response and Reconstruction Flow

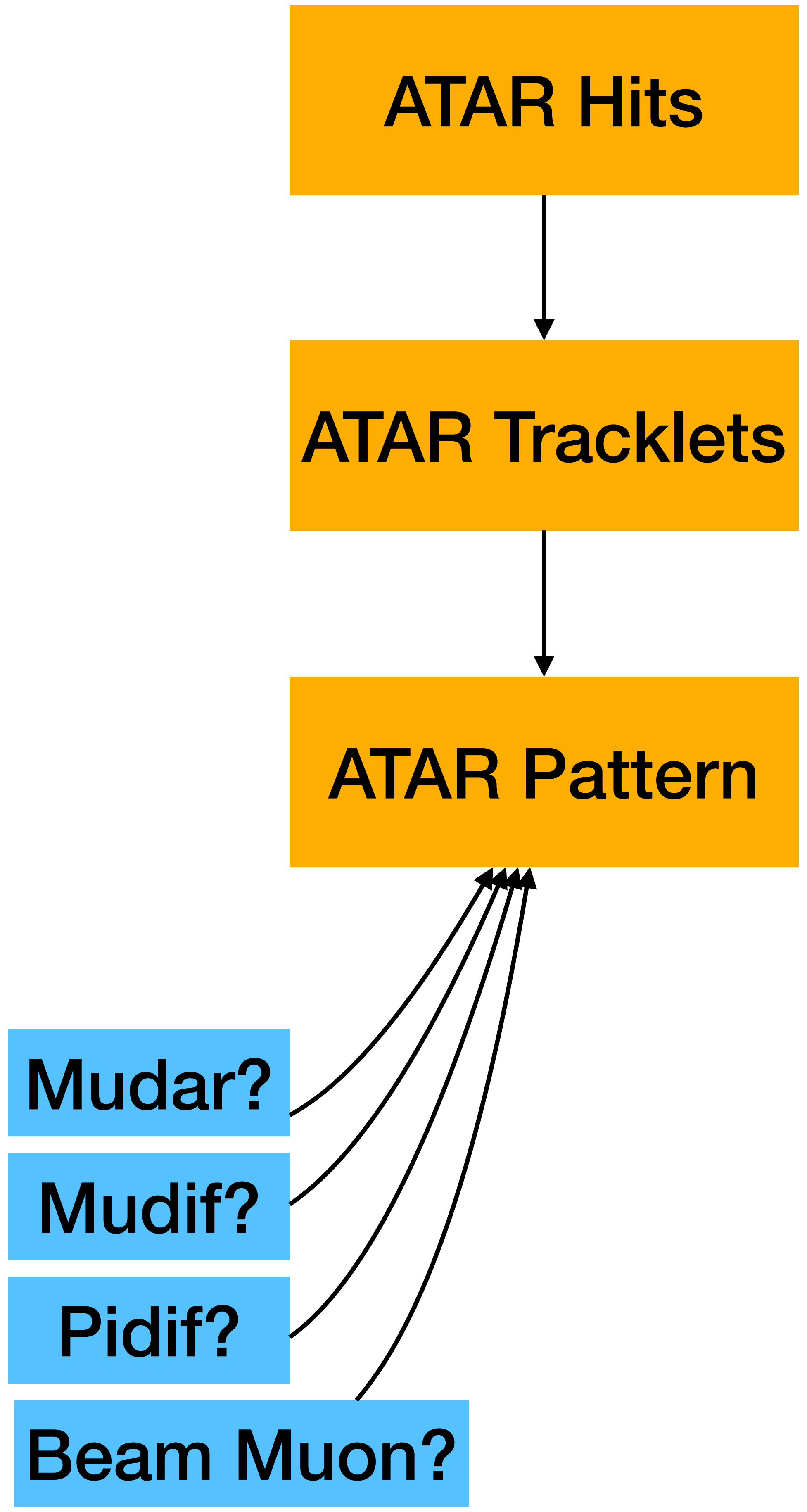


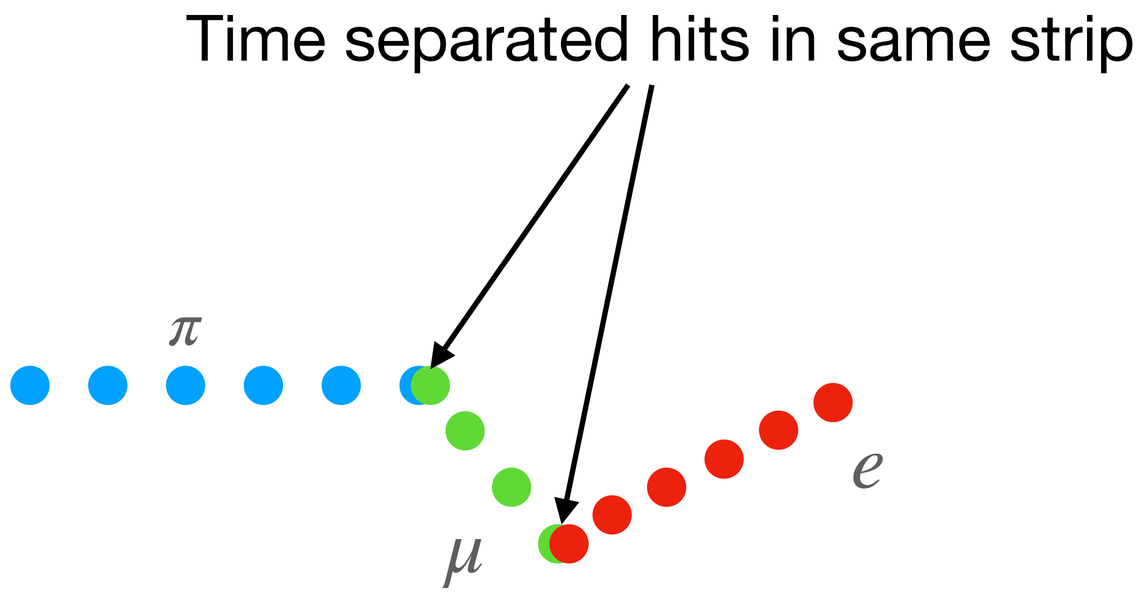
- Mixed events get processed to obtain data that mimics reality to the best of our knowledge/resources
- Possible to send some detectors through waveform simulation while others are processed by fast response.
- Lab data and waveform studies required to get reasonable fast response.

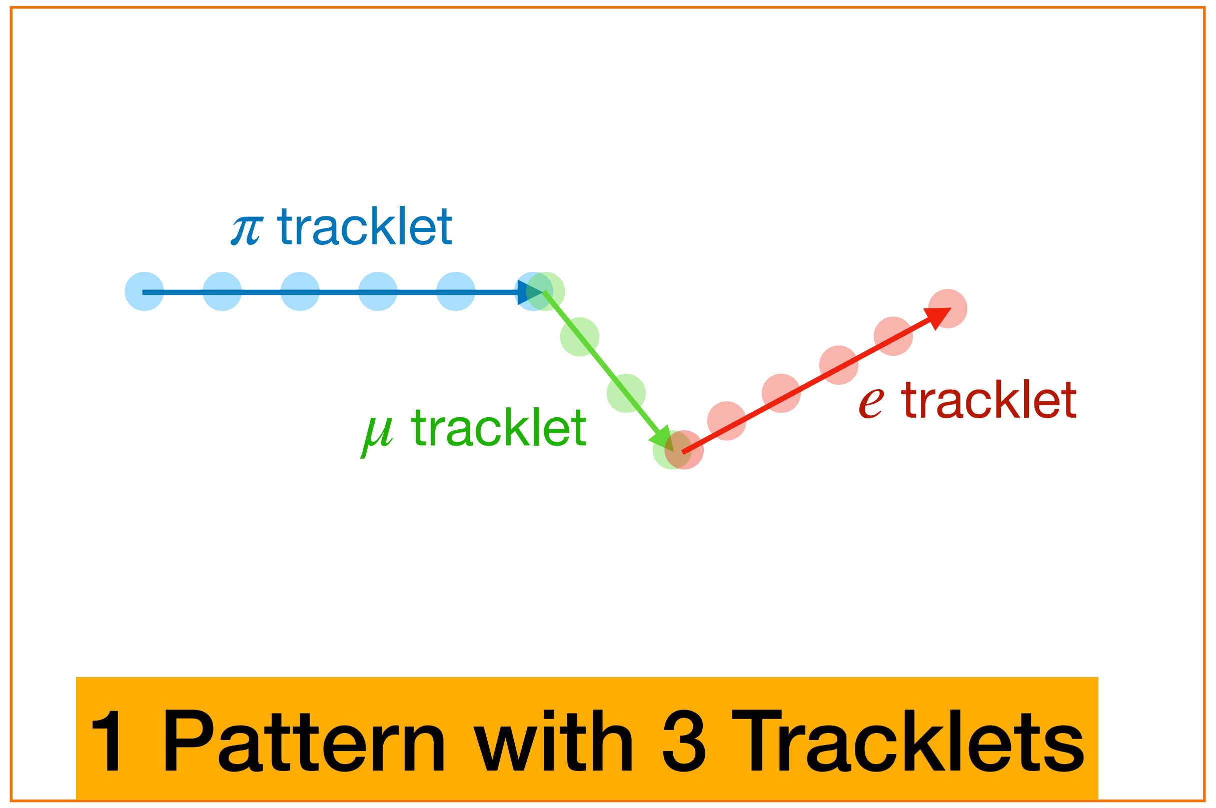
Input from detector groups required for:

- Implications on software structure
- Lab data and waveform studies

The Reconstruction Elements so far

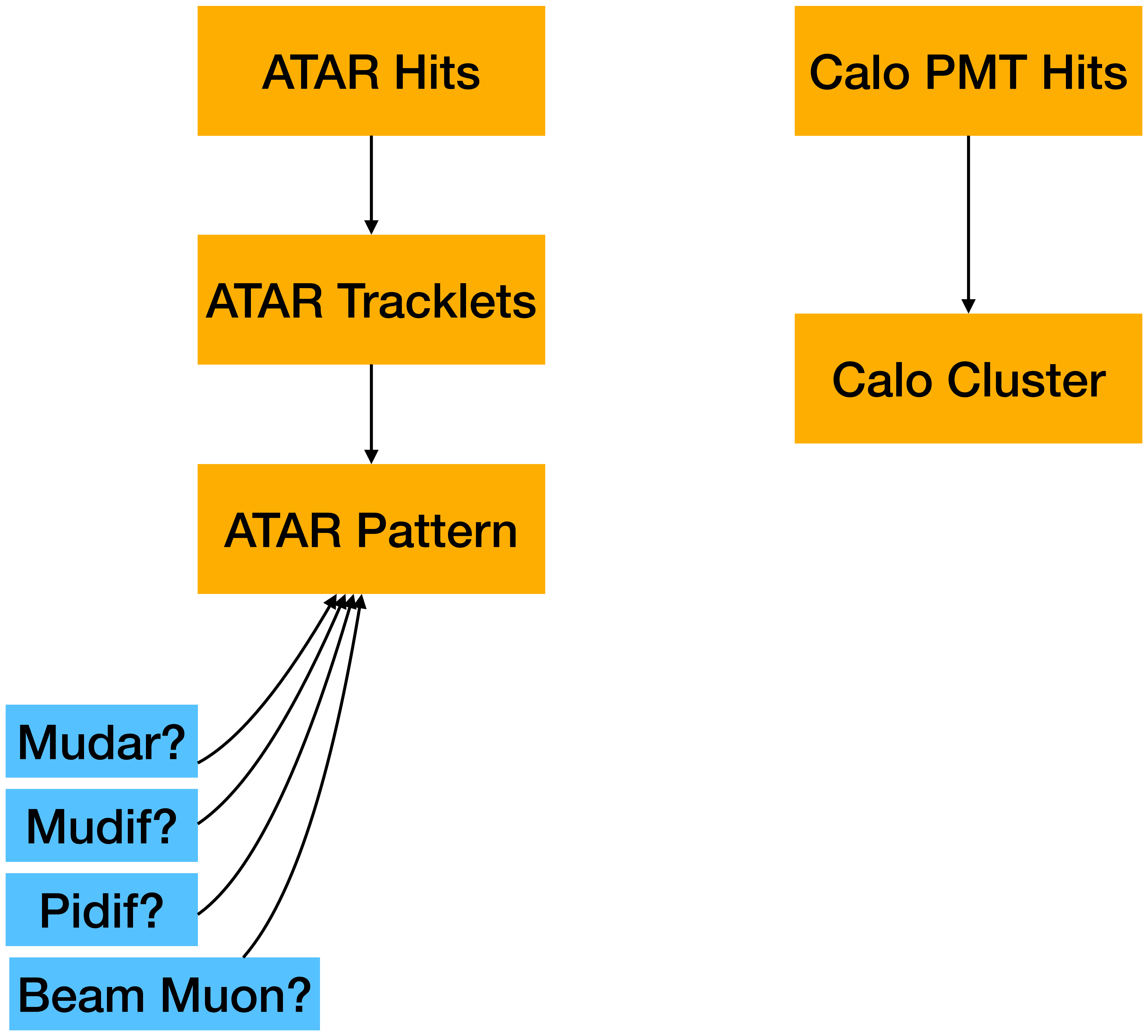




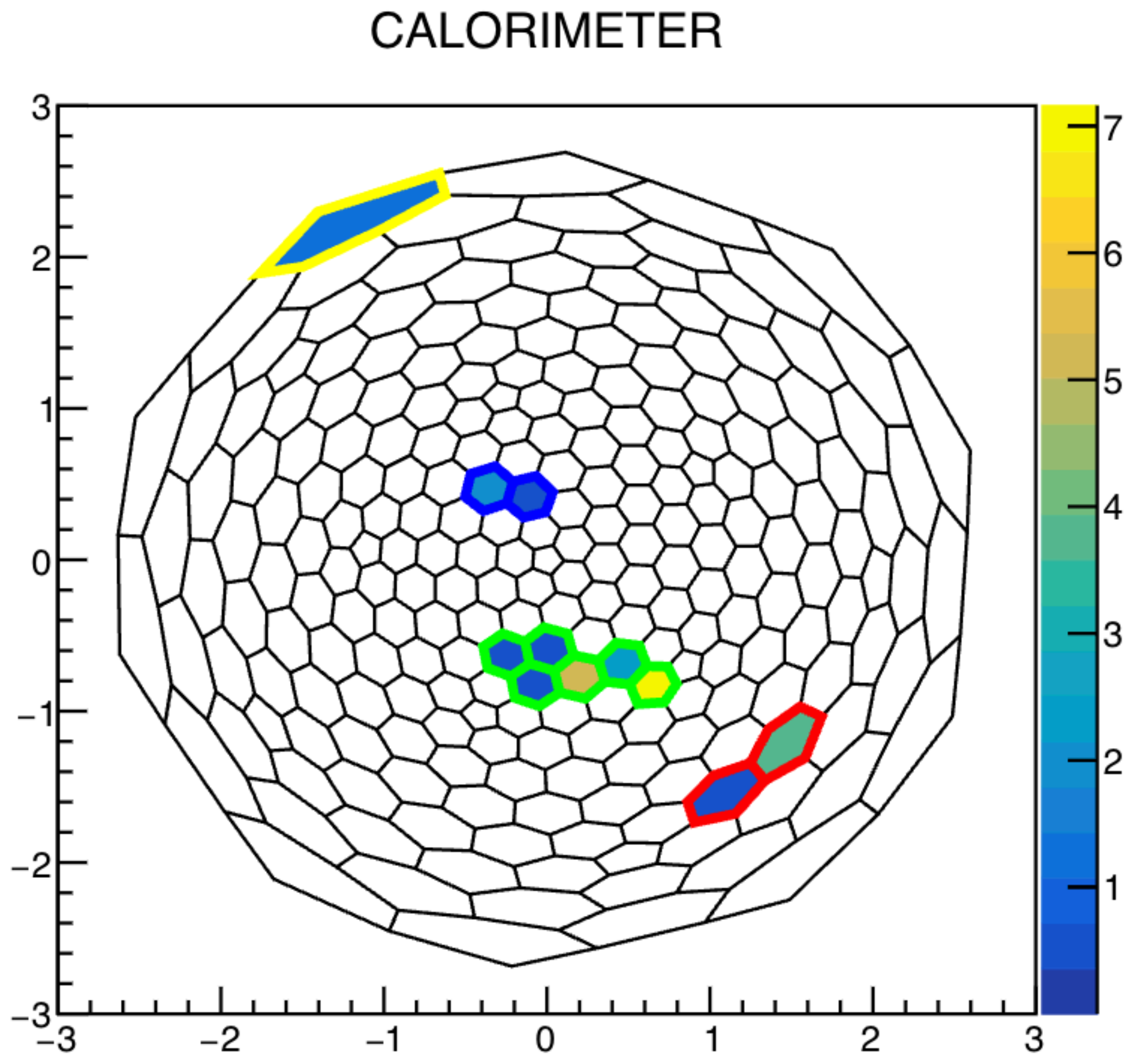


- Combine hits by the same particle.
  → ATAR Tracklet
- Combine tracklets by the same event.
  → ATAR Pattern
- Compute discriminating variables for each pattern
  - Improvements on PIDIF variables will be shared by Adam

The Reconstruction Elements so far

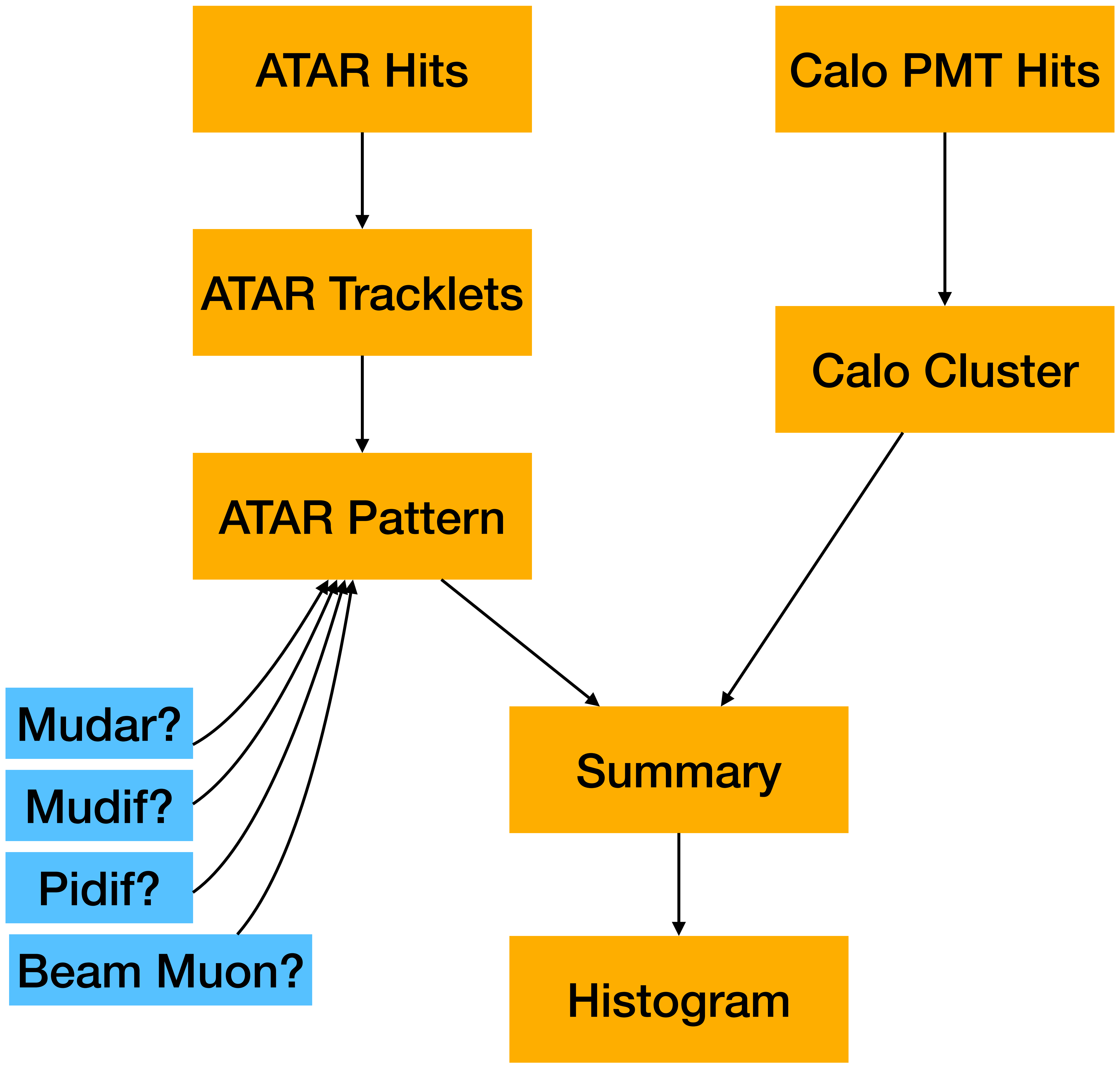


Calo Hits get combined to calo clusters for LYSO crystals. LXe logic would be based on PMT hits instead



Algorithm details are shared in Omar's Talk

The Reconstruction Elements so far

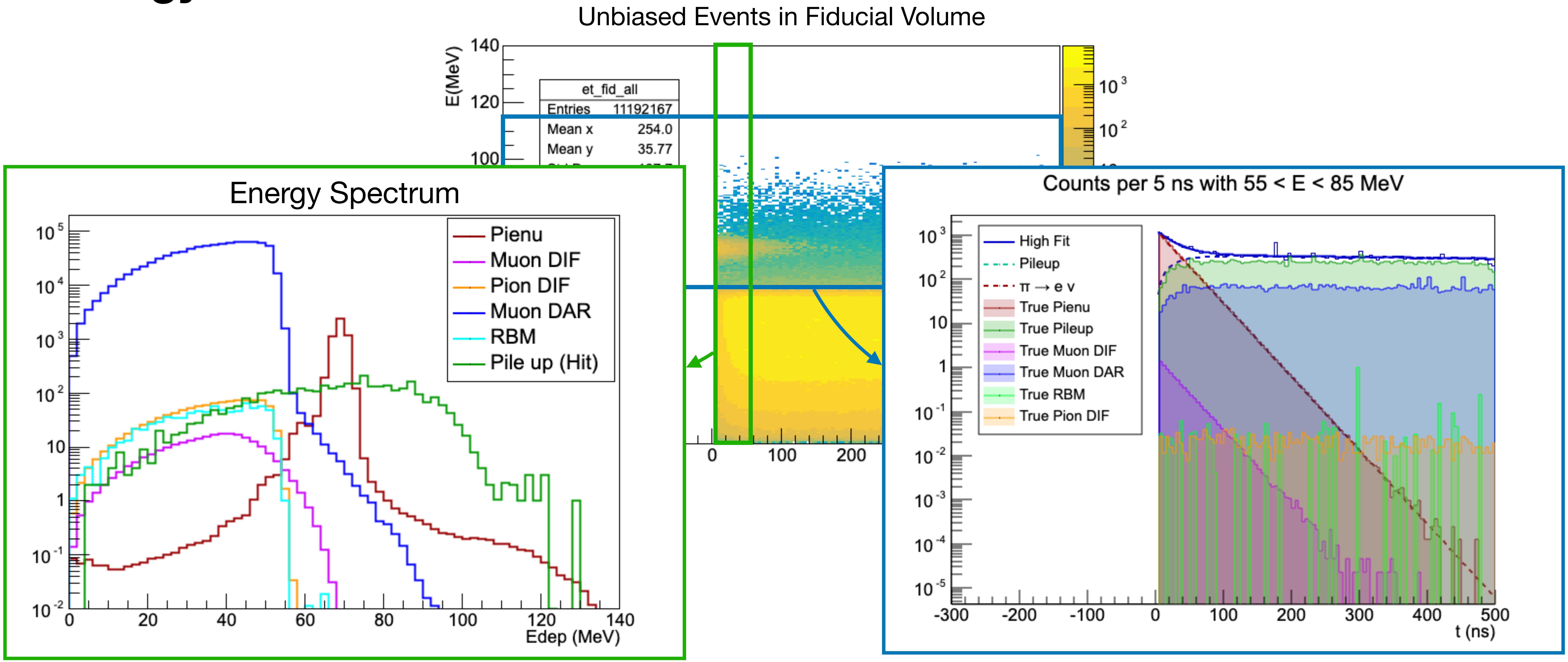


- Combine ATAR Patterns to Calo Clusters based on time.
- The formed summaries have all relevant information available.
  - All discriminating variables
  - References to MC truth
- Use configurable cut flow to fill Histograms

Automated histograms are convenient tools for analysis or simple validation crosschecks

Framework Histogram Examples

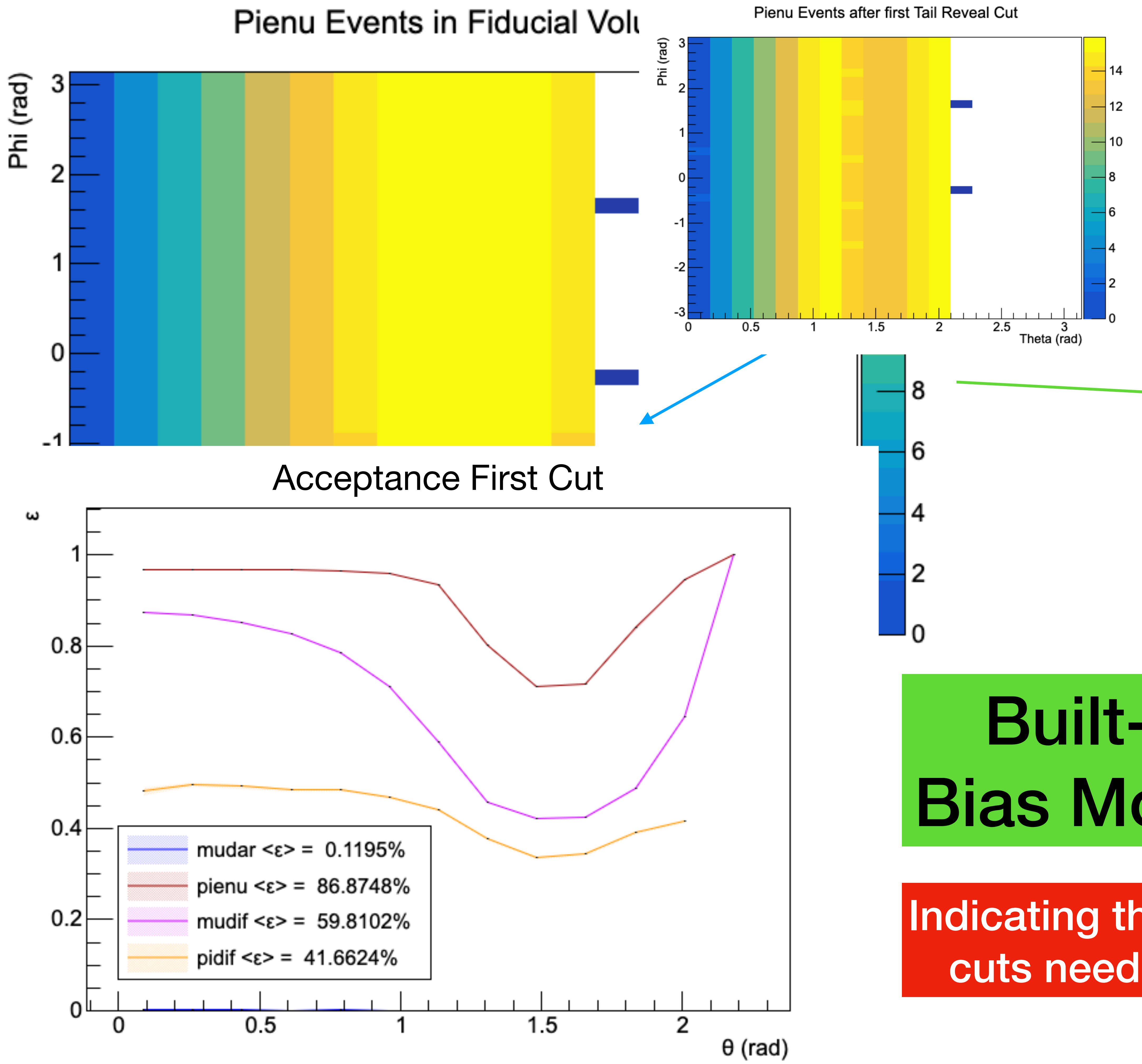
Energy vs. Time

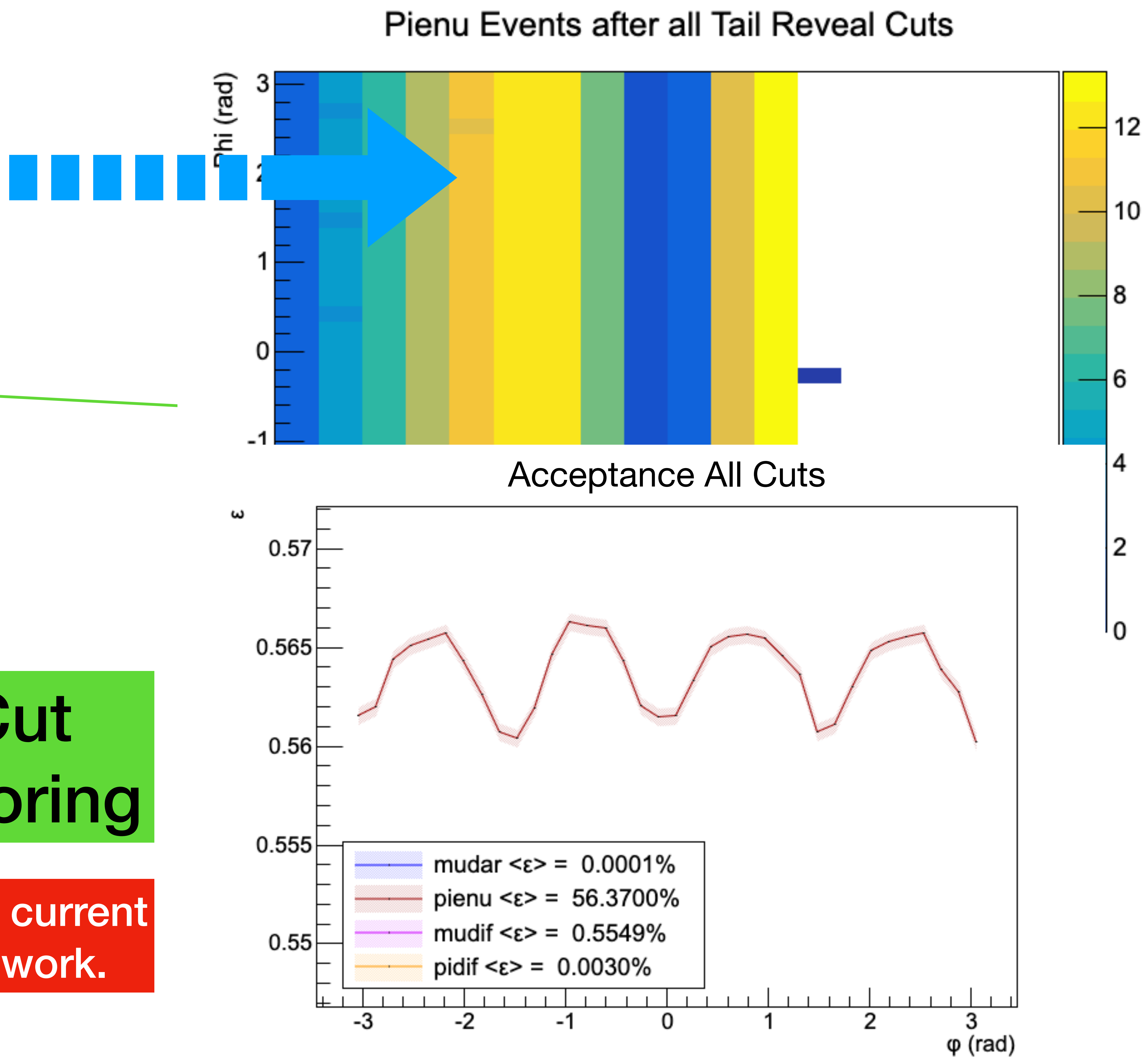


Framework Histogram Examples

True Positron Momentum (R, Theta, Phi)

Details on cuts for tail reveal are shared in Quentin's Analysis Talk



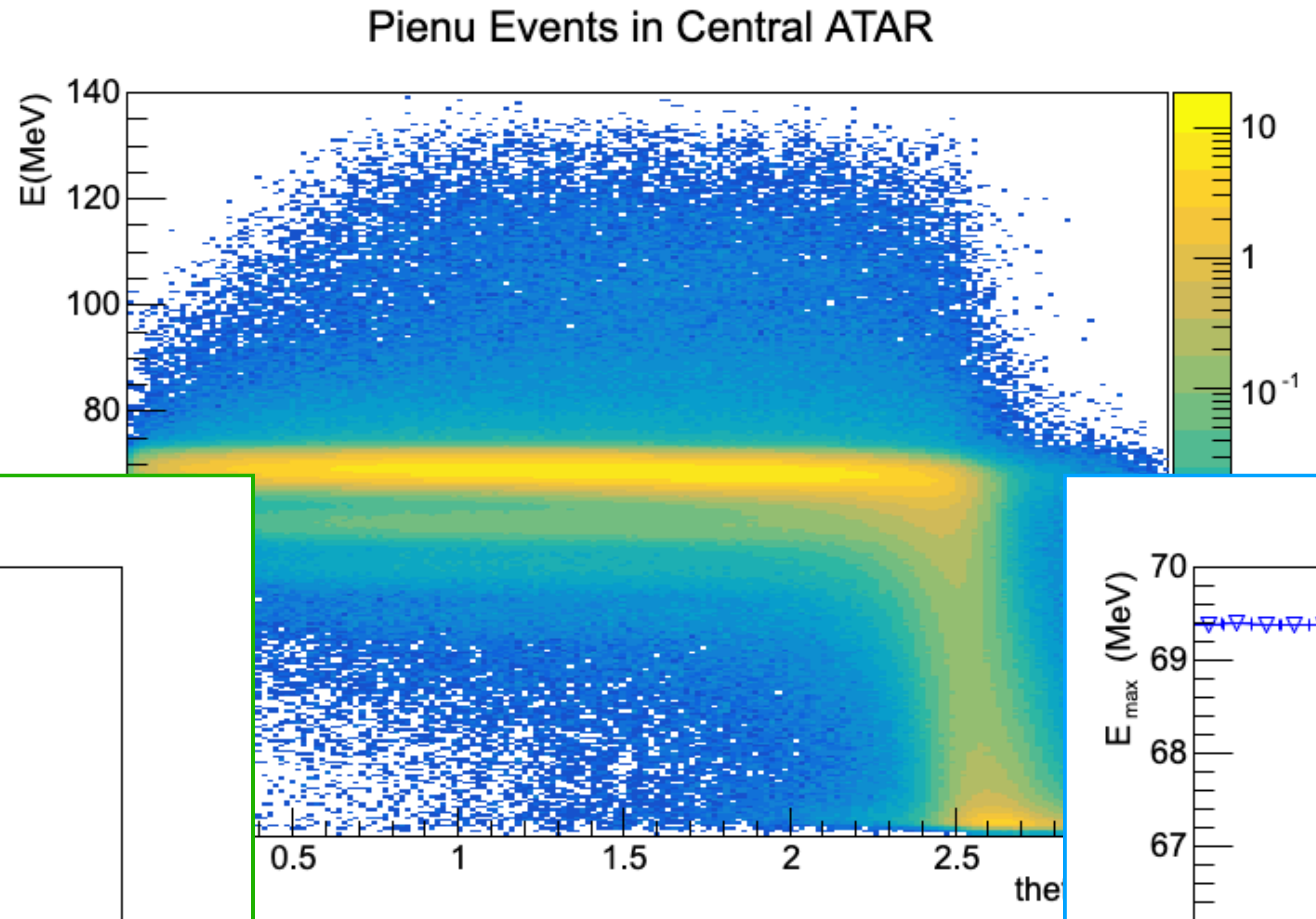


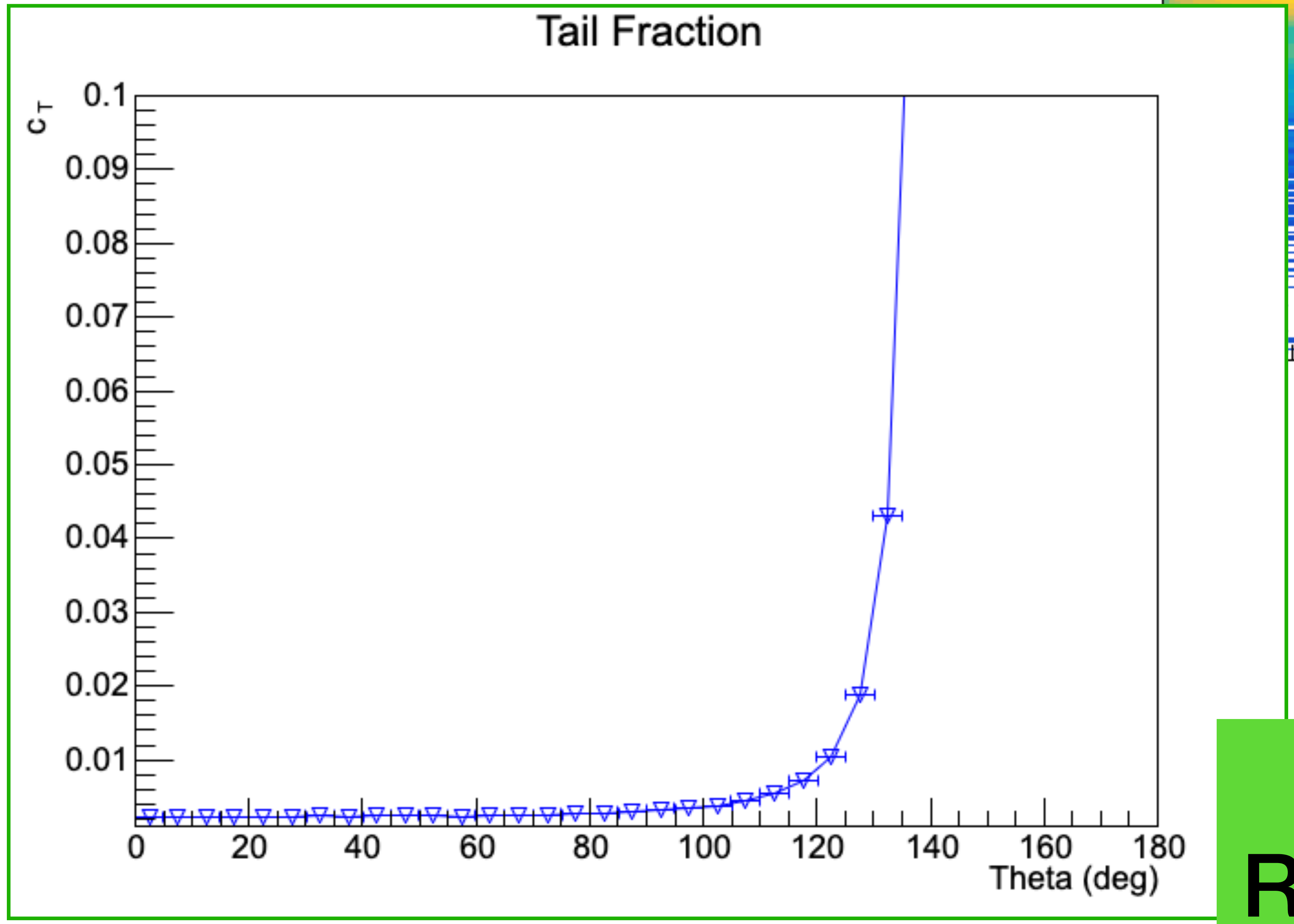
Built-in Cut Bias Monitoring

Indicating that the current cuts need more work.

Framework Histogram Examples

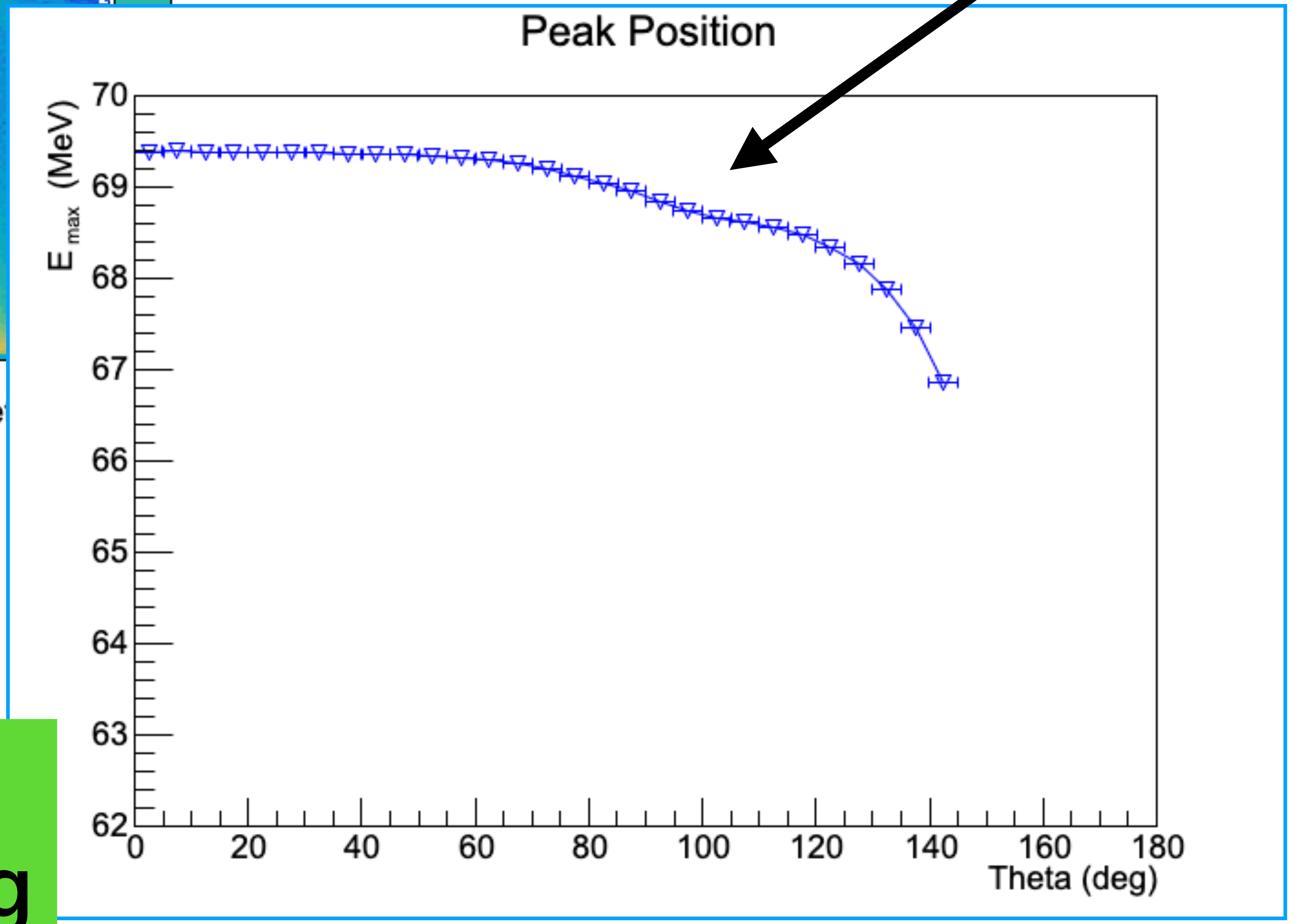
Energy vs. Theta





Built-in Detector Response Monitoring

Energy loss due to dead material →Jessie's Talk



The Simulation Framework is mostly built …

… but good output requires good input

In the discussions, we hope to …

- … converge on a setup that can be implemented for the central region.
- … identify a realistic beam we can use for the simulation.
- … get a feeling for trigger and data acquisition behaviour.
- … offer guidance about possible studies