Millipede –
the ShangriLa of reconstructions?

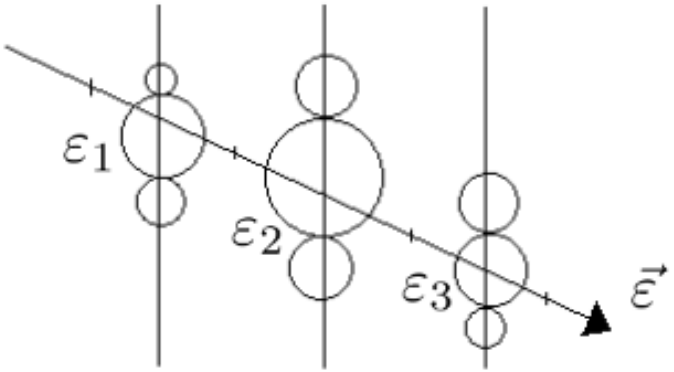
Millipede – what is it good for?

- Can reconstruct events while considering differential energy losses.
  - In theory gives you everything you want to know about an event.
- If seeded with MC truth best reco
- If not – not so much..
- Most famous for taking ages.

Millipede – How does it work?

Millipede

Reconstructing the detailed light pattern in the modules to an energy loss pattern for the muon track $\vec{\varepsilon}$



Sally Robertson, Muon Session

Data → $\vec{k} = \Lambda\vec{\varepsilon} + \vec{\eta}$ ← Noise

Transmission Matrix

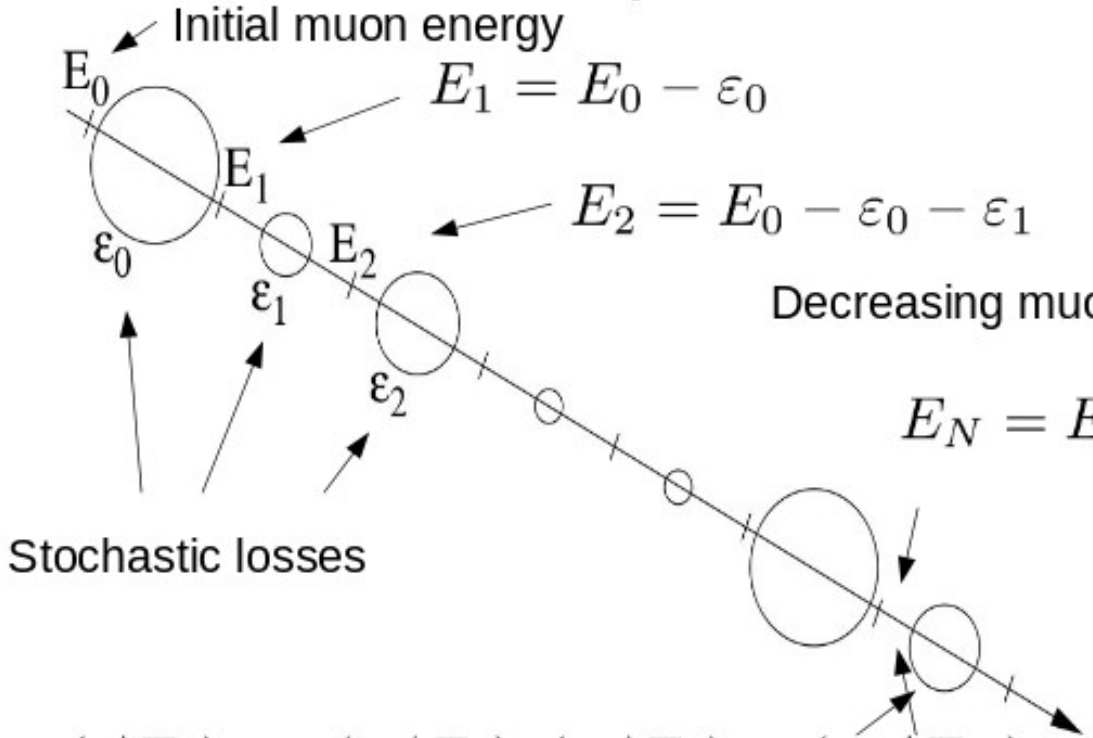
E-loss vector

A Maximum likelihood fit is performed to reconstruct to the best $\vec{\varepsilon}$ for data observed.

[2]

Edepillim

Millipede → Edepillim



$$E_1 = E_0 - \varepsilon_0$$

$$E_2 = E_0 - \varepsilon_0 - \varepsilon_1$$

Decreasing muon energy along track

$$E_N = E_0 - \sum_{i=0}^{N-1} \varepsilon_i$$

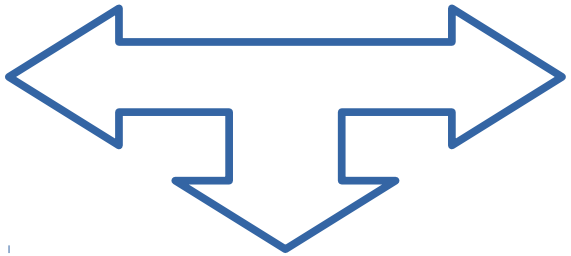
$$p(\varepsilon|E_0) = p(\varepsilon_0|E_0)p(\varepsilon_1|E_1)...p(\varepsilon_N|E_N)$$

$$p(\varepsilon|E_0) = p(\varepsilon_0|E_0) \prod_{j=1}^{N} p(\varepsilon_j|E_0 - \sum_{i=0}^{j-1} \varepsilon_i)$$

3

Millipede: One Code – Three strategies

Angular reco (standard)
Is not (much) better than seed!



Energy reco
Works!

Angular reco (scan)
Works but slow

Energy reco

- Provides energy losses along a predefined trajectory.
- Not too expensive computational wise.
- Very nice for starting analysis

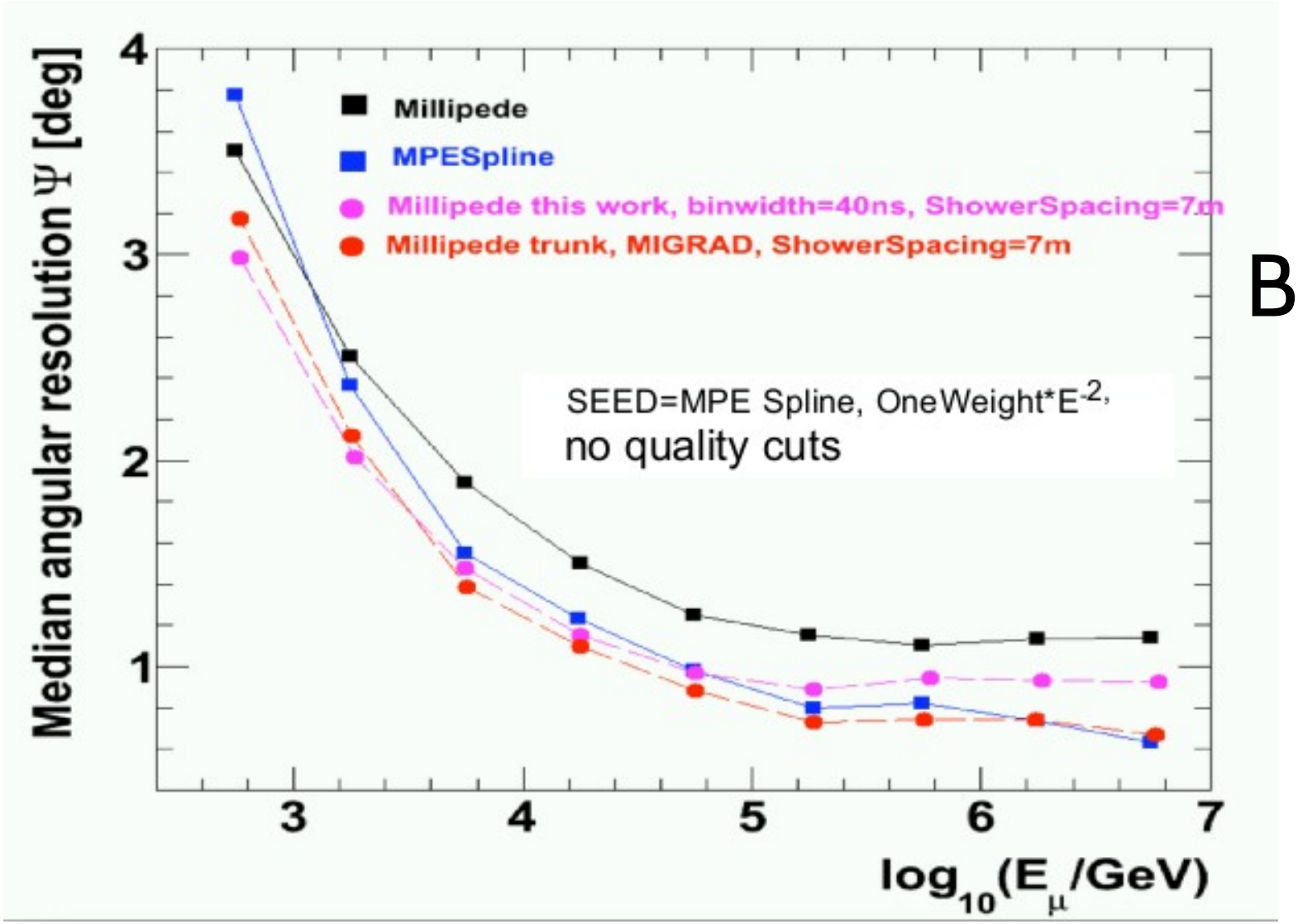
Angular reco (general issues)

- Success of reconstruction is extremely dependent on seed position.
- Not so much on direction.
- Connected to Millipedes preference for unphysical early hits?

Angular reco (standard)

- For normal tracks usually not much better than seed.
- Takes long (few minutes per event/ several GB RAM)
- **Might** perform slightly better for starting events (because "normal recos" usually are not so good with those)
- At the moment not worth to use- considering the required resources.
- Standard minimizer part of the problem?

Angular resolution



Banff 2014

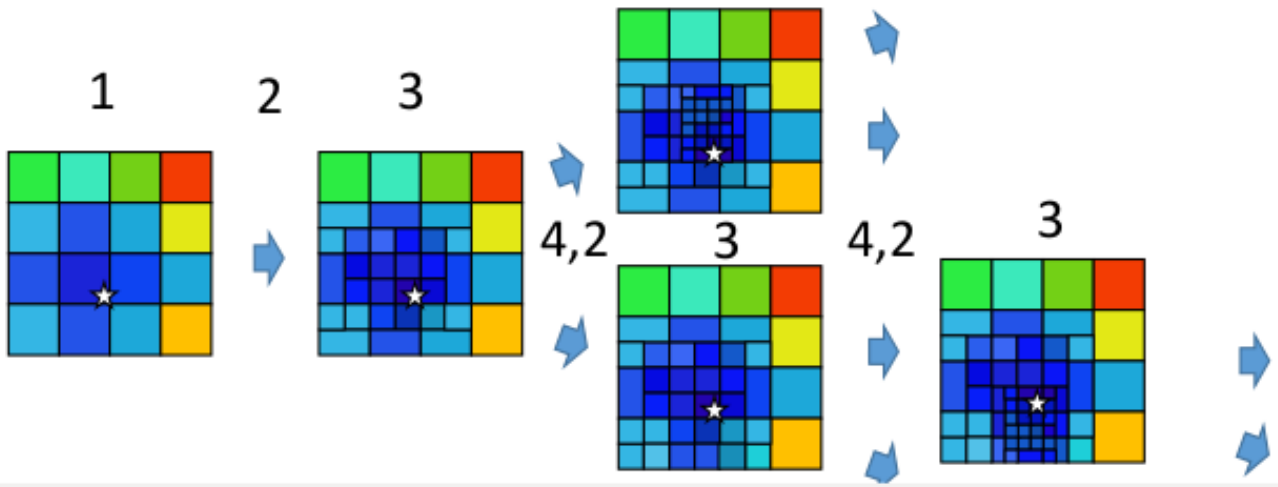
Angular reco (scan)

- Best available reconstruction in IceCube.
- Even if optimized still takes VERY long times (days to weeks!) for one event.
- Feasible for HESE but not much more.

State of the art grid scan (K. Jero)

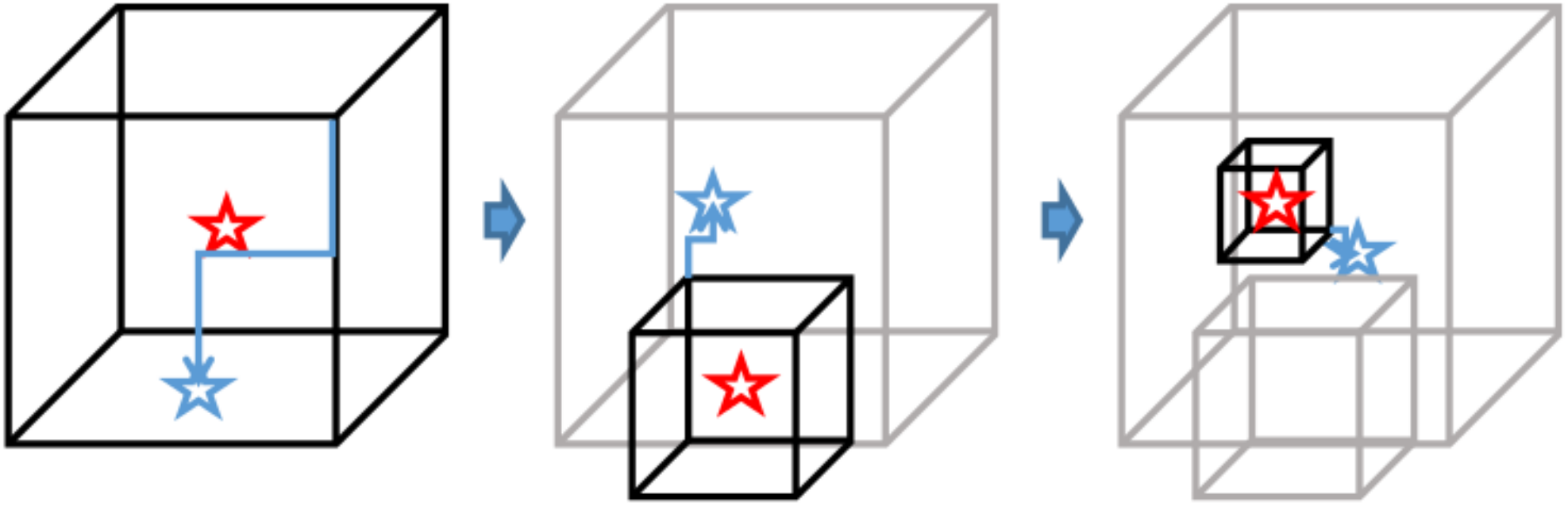
Directional Grid Scanning

- A metropolis like algorithm is implemented
  - Goal is to resolve areas proportional to how interesting they are
- To effectively use the template the following steps are taken
  1. Make a coarse set of evaluations seeded with an existing reconstruction
  2. Probabilistically choose a location to scan finer
  3. Scan grid around this location
  4. Choose whether to repeat from 2 with a location from those just scanned or from a coarser grid
- When preforming step 2 the probability for each location is selected from a Gaussian distribution with the width determined by the lowest two likelihood values and an annealing factor

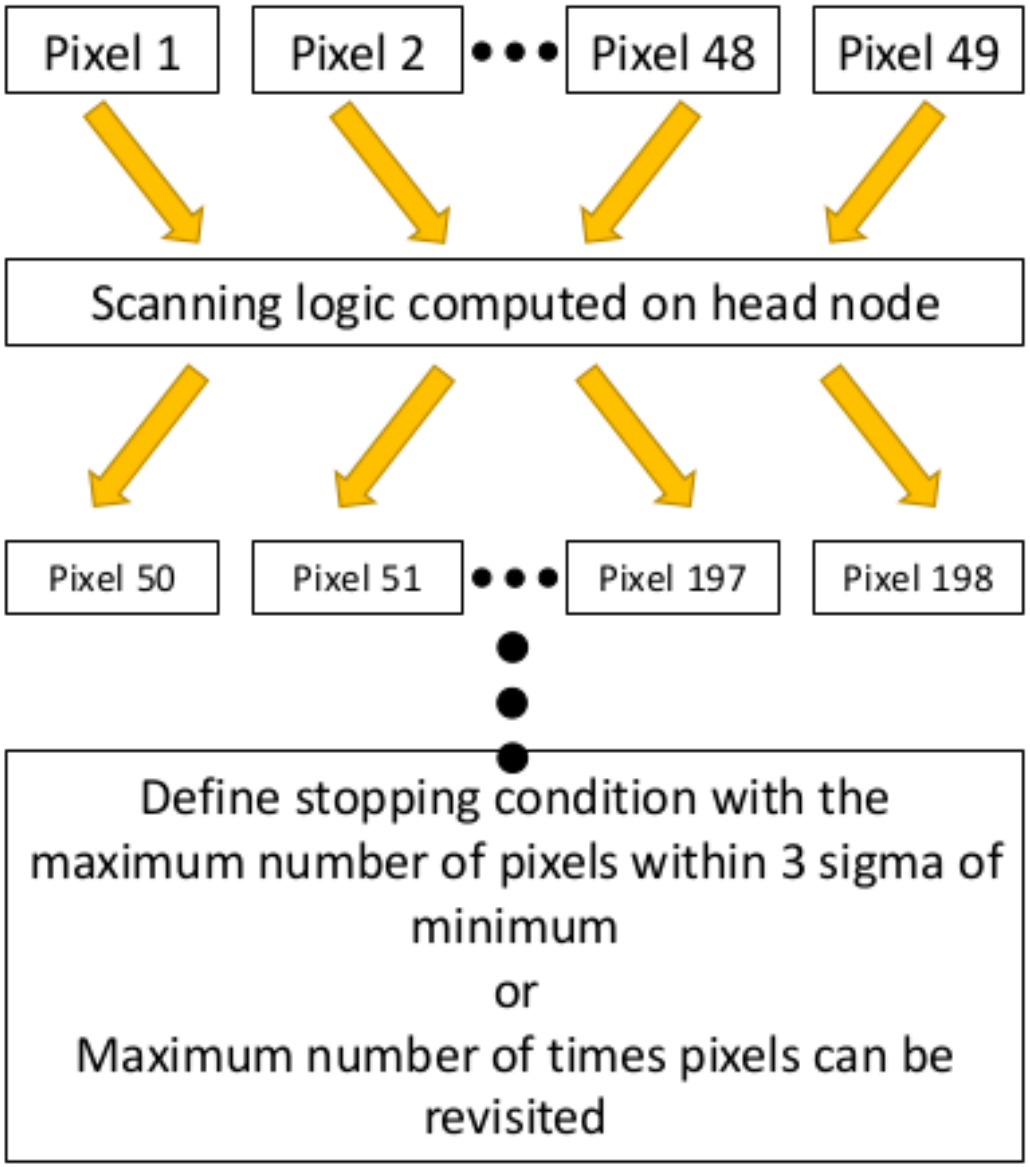


Position Grid Scanning

- Begin with a seed track's position and test the corners of a cube centered around this point in x, y, and z
- Preform up to three iterations of this using the most likely track's location from the previous iteration as the new seed, decrease the box size each time
- The best logl value found in search is taken as the pixel's logl value

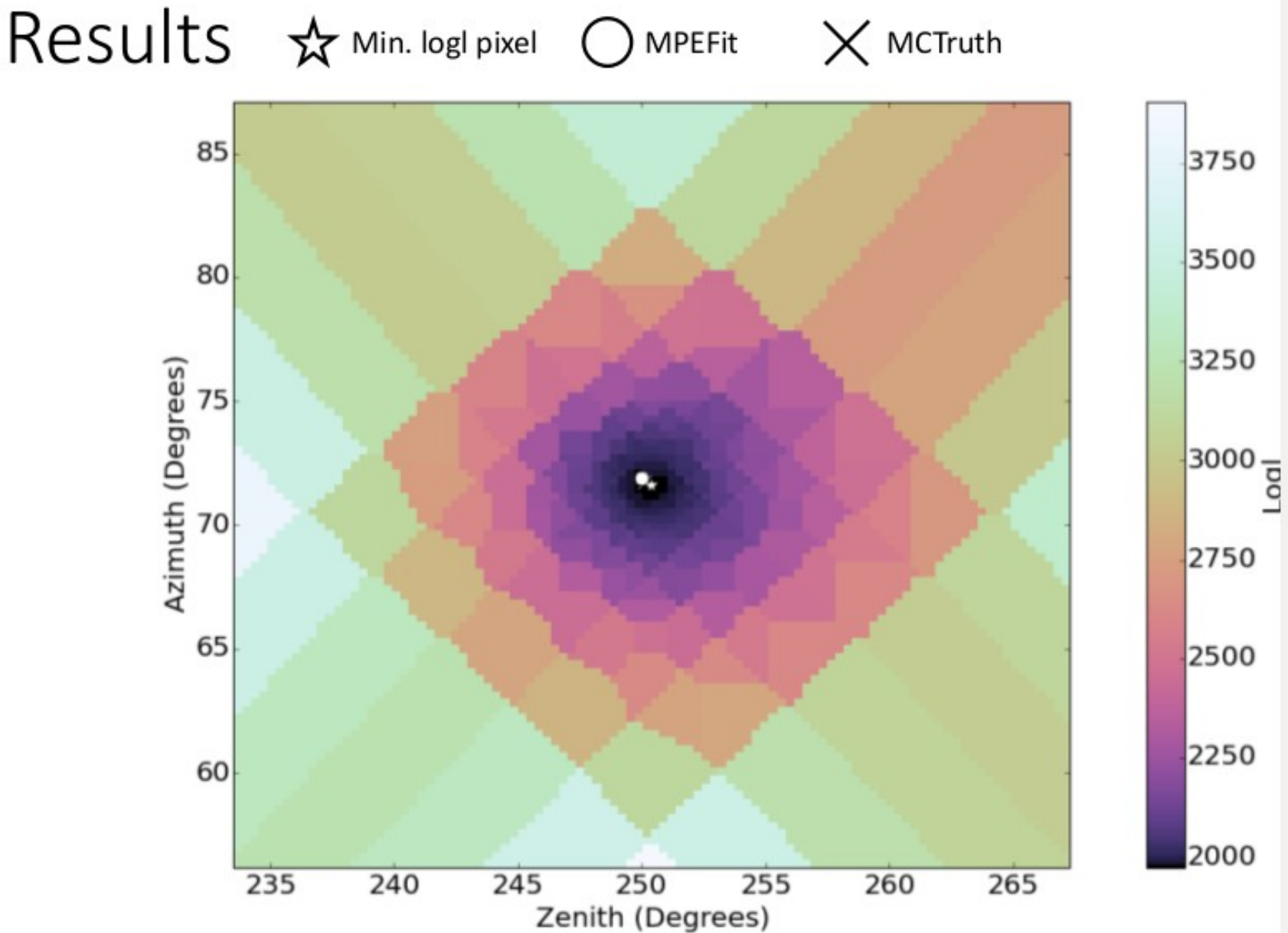


Improvements to Scanning Algorithm

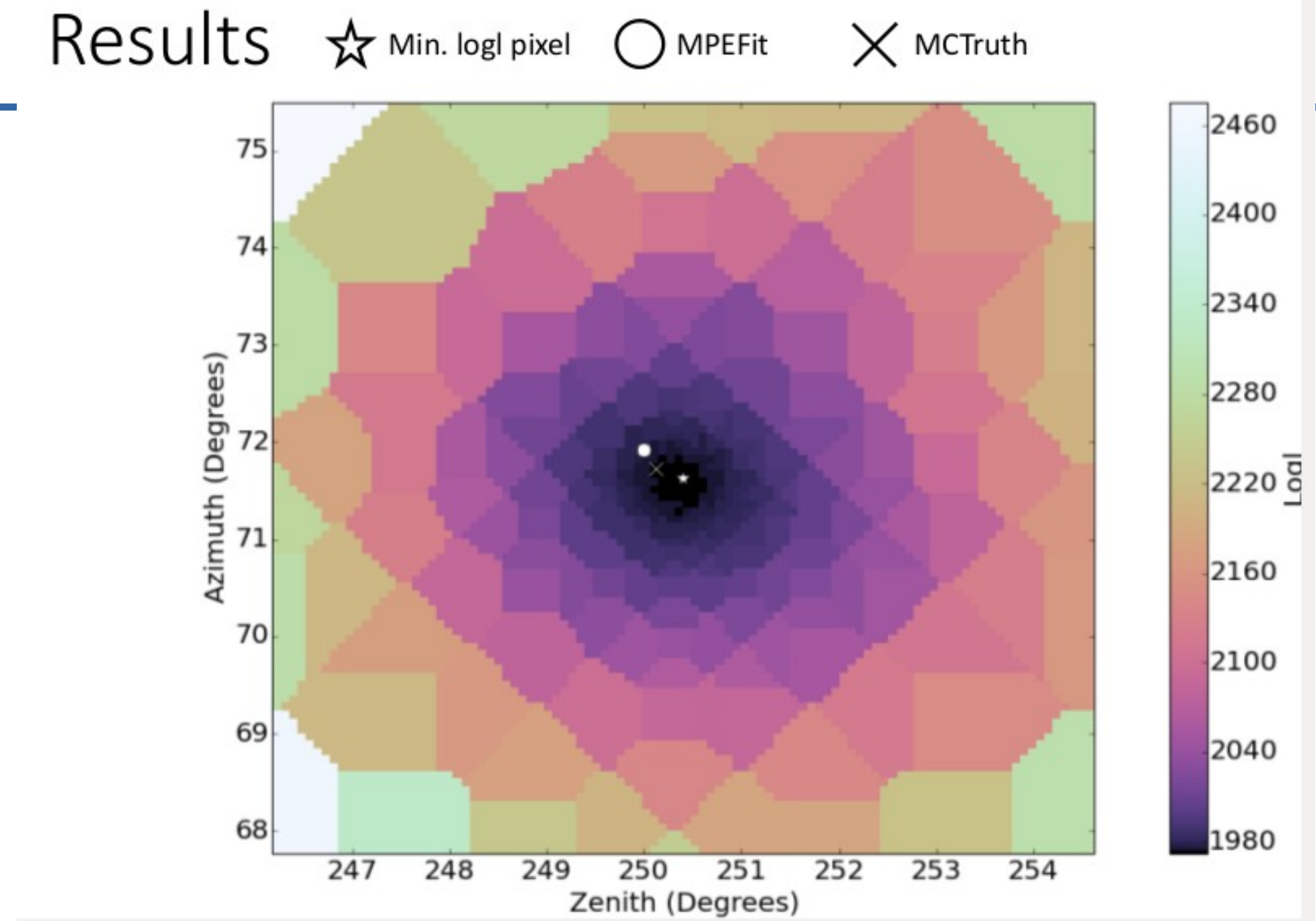


- Written as a simple state machine
  - Easier to understand and use
- Parallel computation on the Open Science Grid
  - Average of 1000 cores obtained
- Takes computation from weeks to days
- Number of pixels scanned in parallel can be scaled up or down

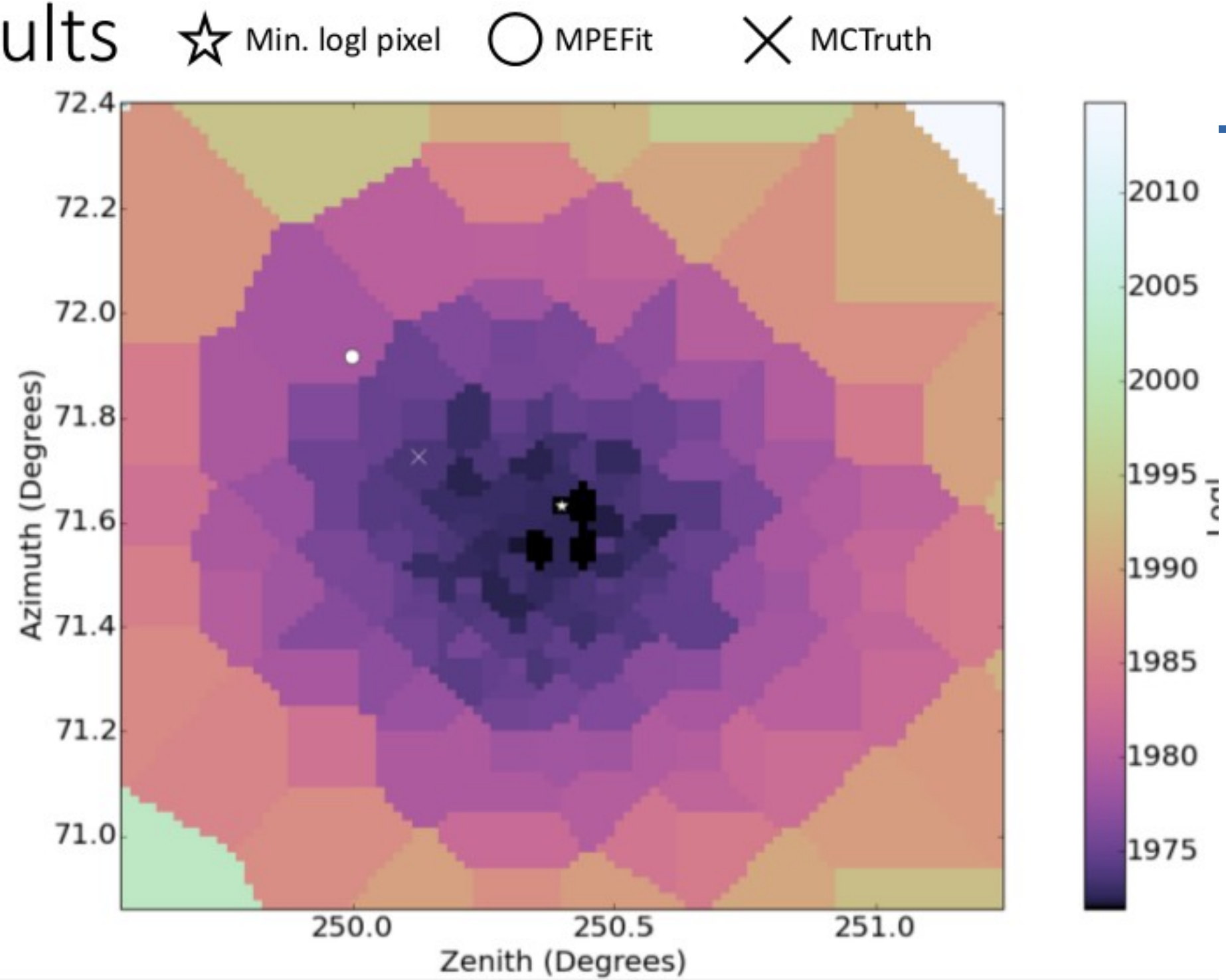
Kyle Jeros Likelihood scan



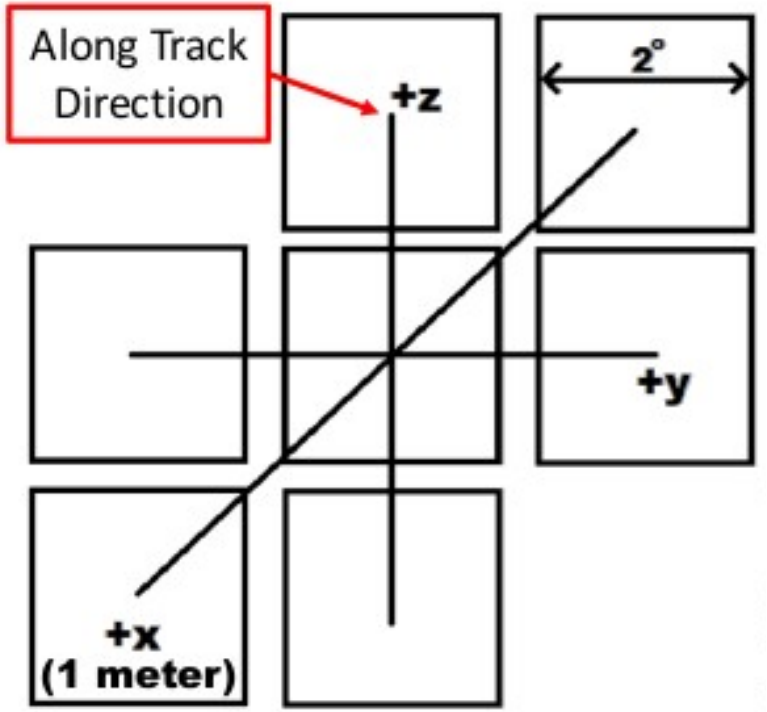
Results


Min. logl pixel
MPEFit
MCTruth
Azimuth (Degrees)
75
74
73
72
71
70
69
68
247
248
249
250
251
252
253
254
Zenith (Degrees)
2460
2400
2340
2280
2220
2160
2100
2040
1980
Logl

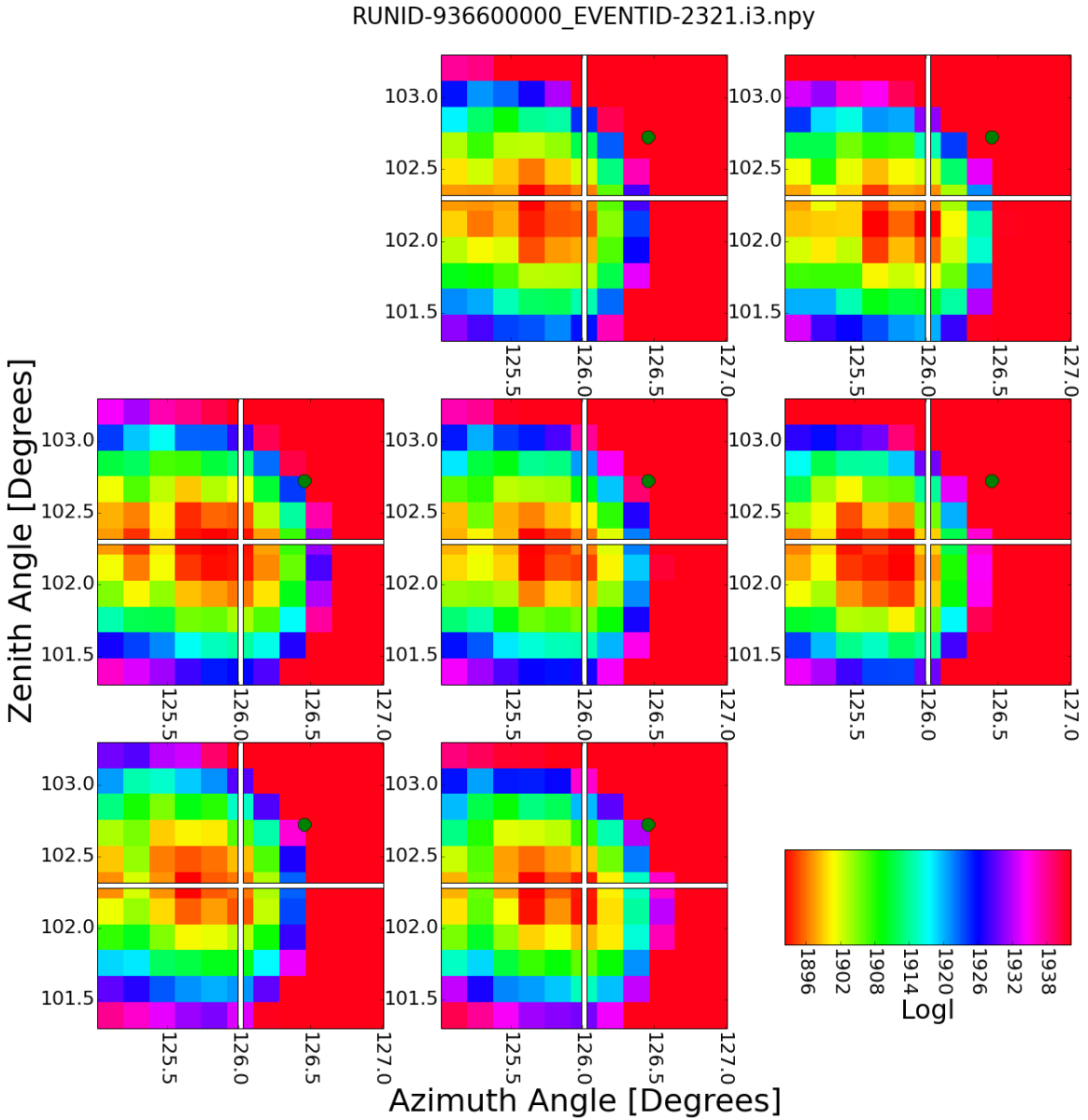
Results


Min. logl pixel
MPEFit
MCTruth
72.4
72.2
72.0
71.8
71.6
71.4
71.2
71.0
Azimuth (Degrees)
250.0
250.5
251.0
Zenith (Degrees)
2010
2005
2000
1995
1990
1985
1980
1975

Where does the bumpiness come from?



- Slight changes in position lead to large changes in likelihood



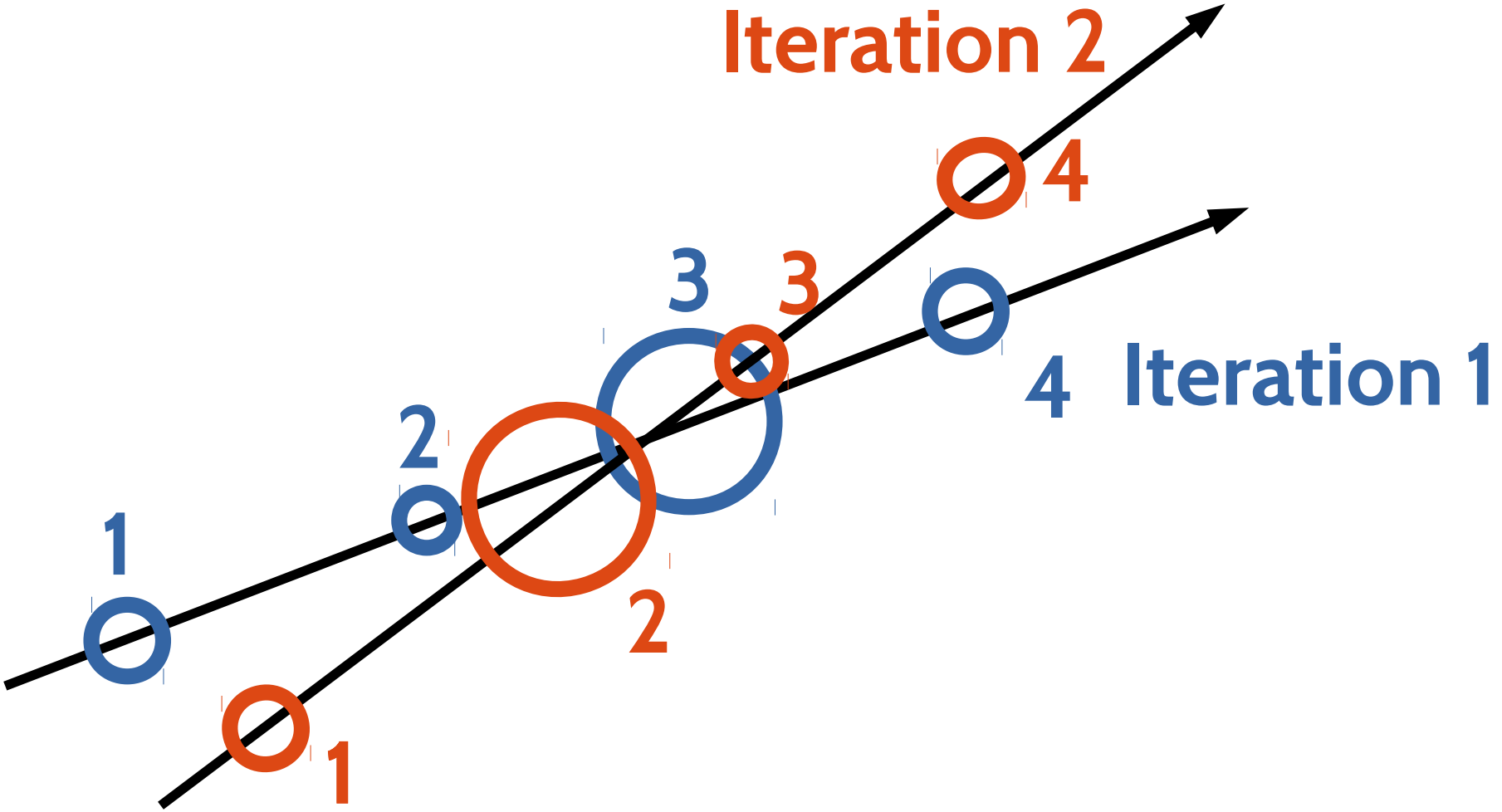
Combine Edepillim and Millipede

- Idea: Consider how likely a certain energy loss is at a certain point of the track.

  → HE losses are more likely to occur at the beginning of the track.

  → Work in progress

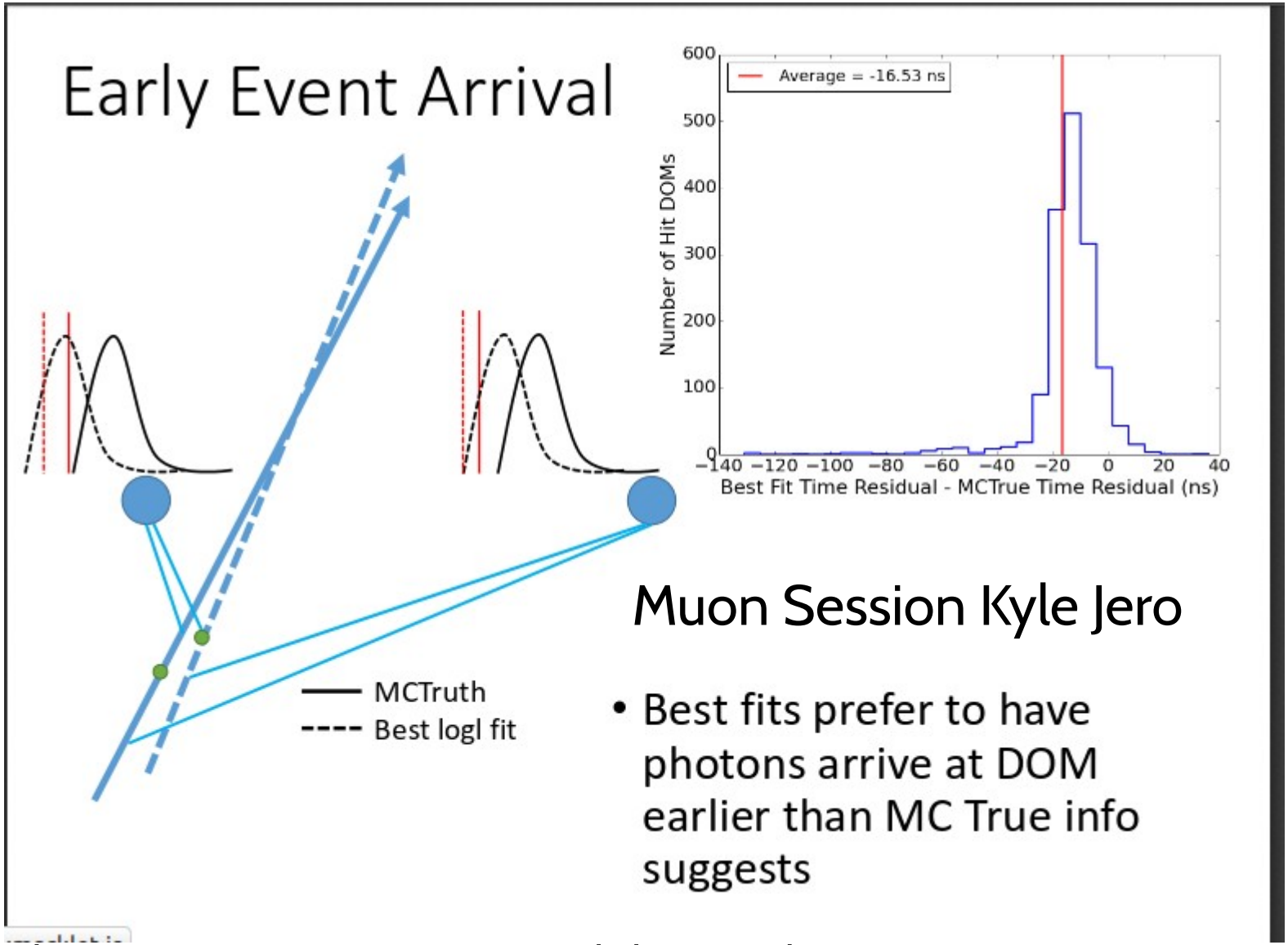
Binning issues?



Numerical precision

- Single vs double
- Work in progress
- JVS just added double precision here:
  http://code.icecube.wisc.edu/projects/icecube/browser/IceCube/projects/photospline/branches/double-precision

A possible explanation for the issues?



Millipede speed issues

- For every iteration look ups in the photon tables have to be done.
- This takes a very long time especially for bright events when most events are within default 400m range.
- Omitting DOMs that are far away from DOMs that have seen light can give some speed up (not the holy grail).
- Implemented!

Conclusion

- Millipede is potentially our most powerful reconstruction method.
- In development – not dead!
- At the moment it is not usable in high statistics analysis (for angular reconstructions).

- Open mic now!