

Cascade Reconstruction

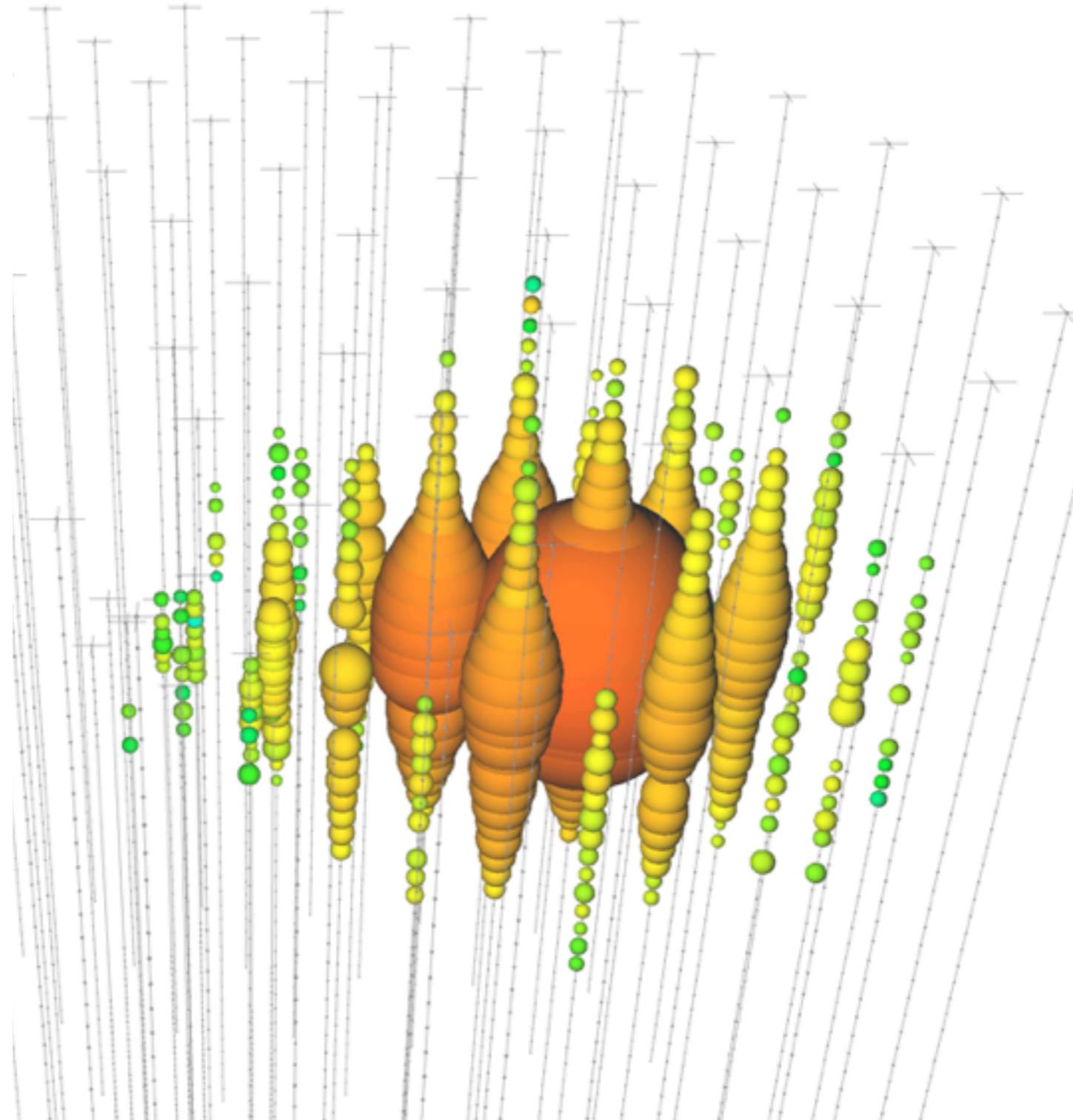
In IceCube



Claudio Kopper - MANTS 2013 - Garching

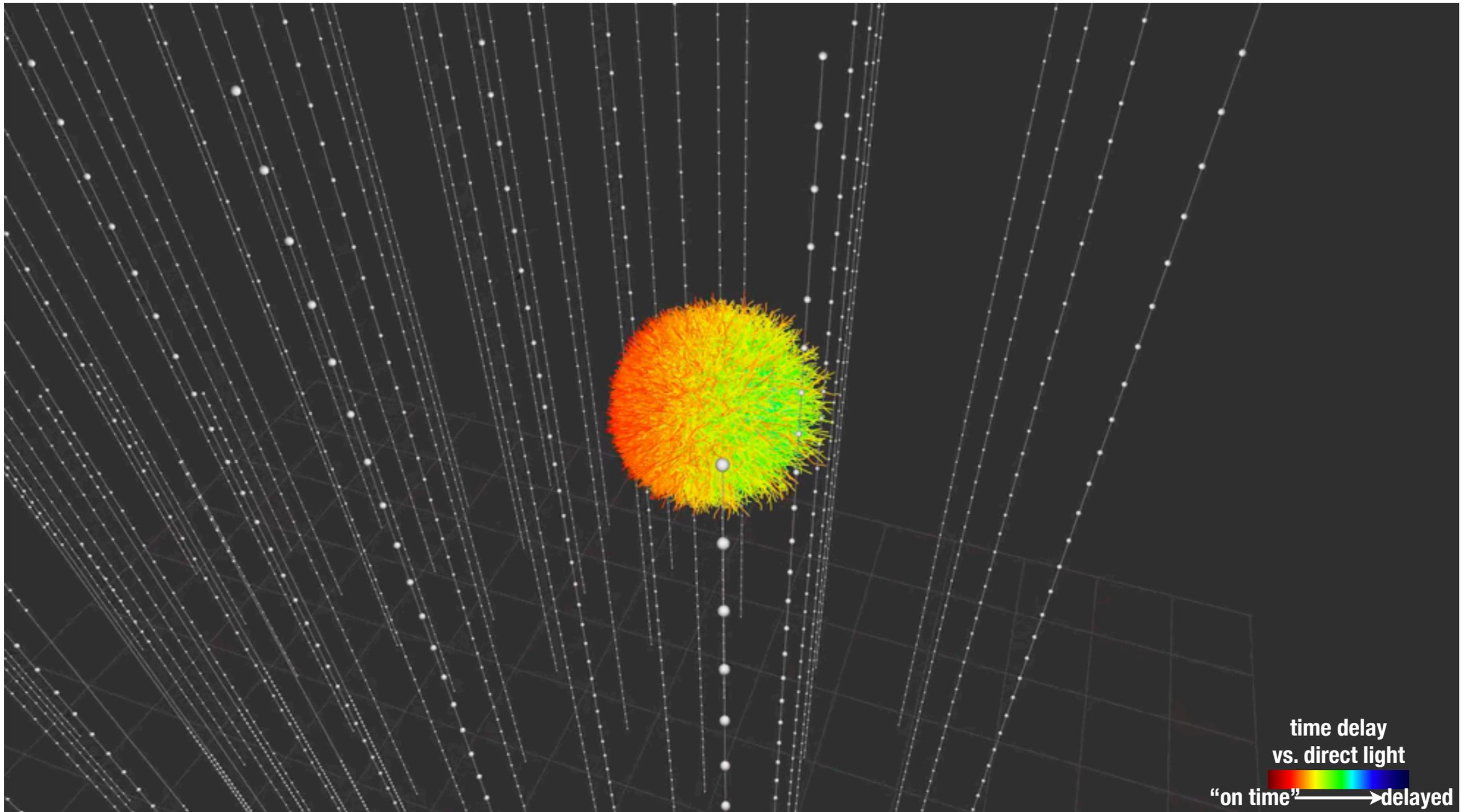
The Problem

Where do they point and what is their energy?



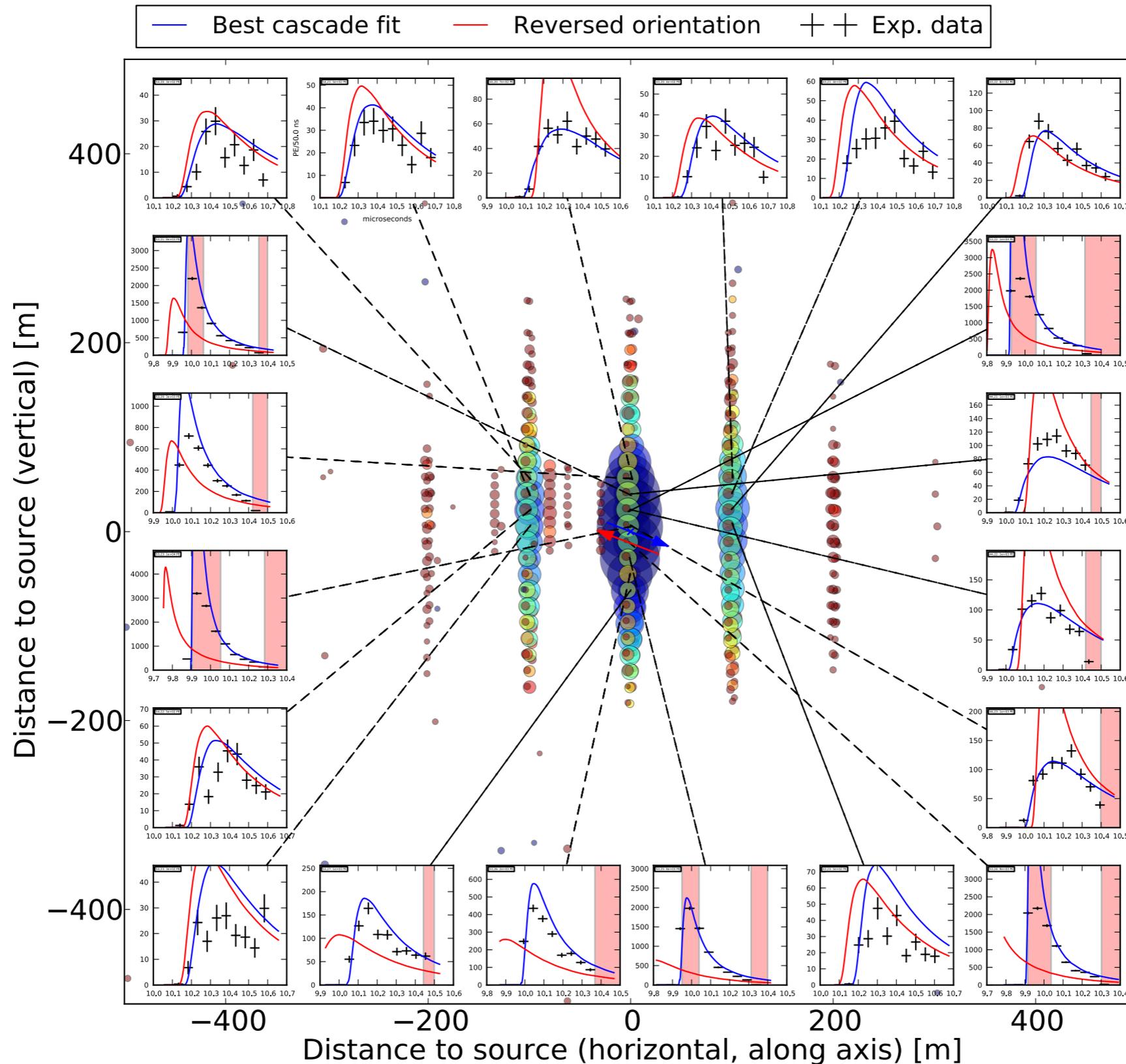
The Problem

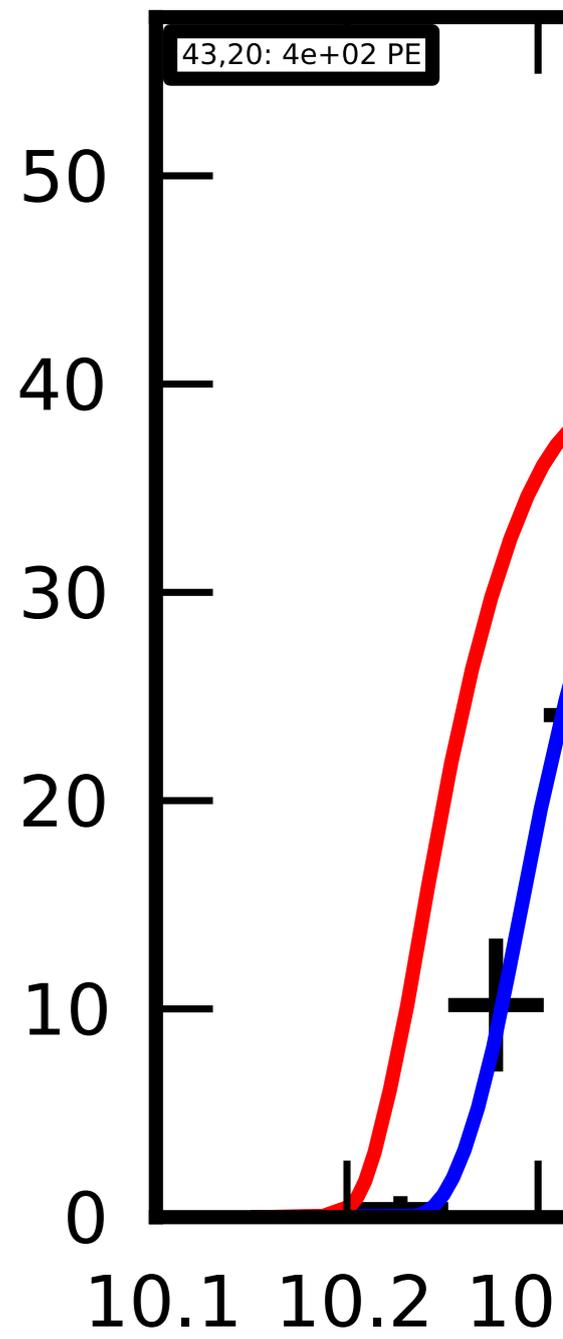
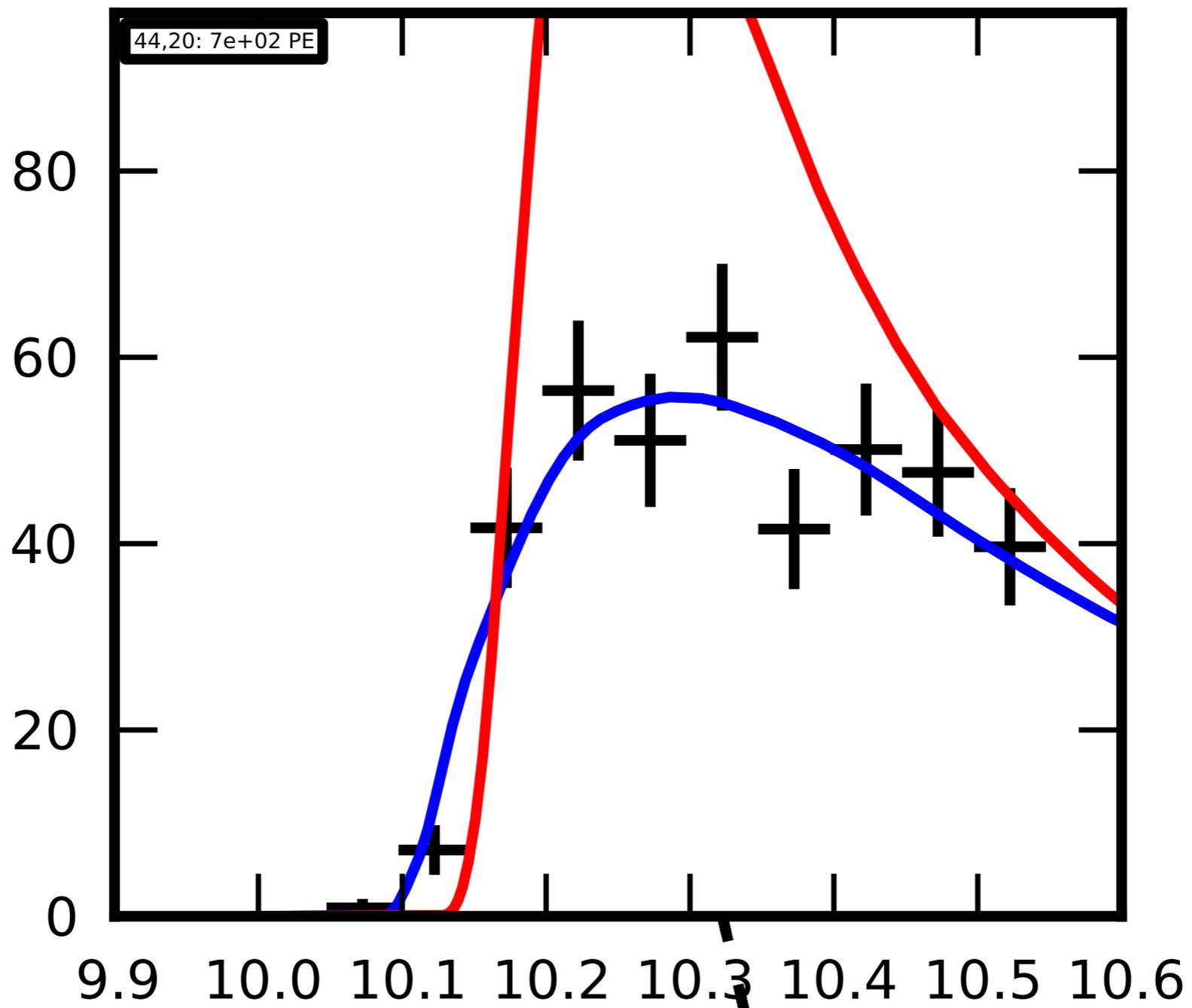
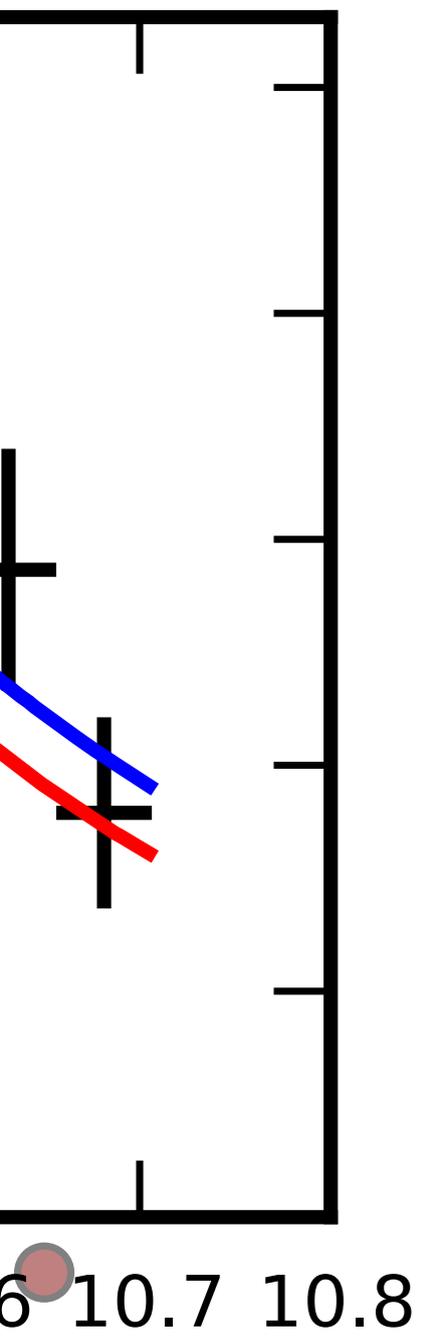
Showers directions are visible in timing profile!



Event Reconstruction

Compare data to MC predictions in bins in time and space





Some Notes

- ▶ **IceCube reads out waveforms**

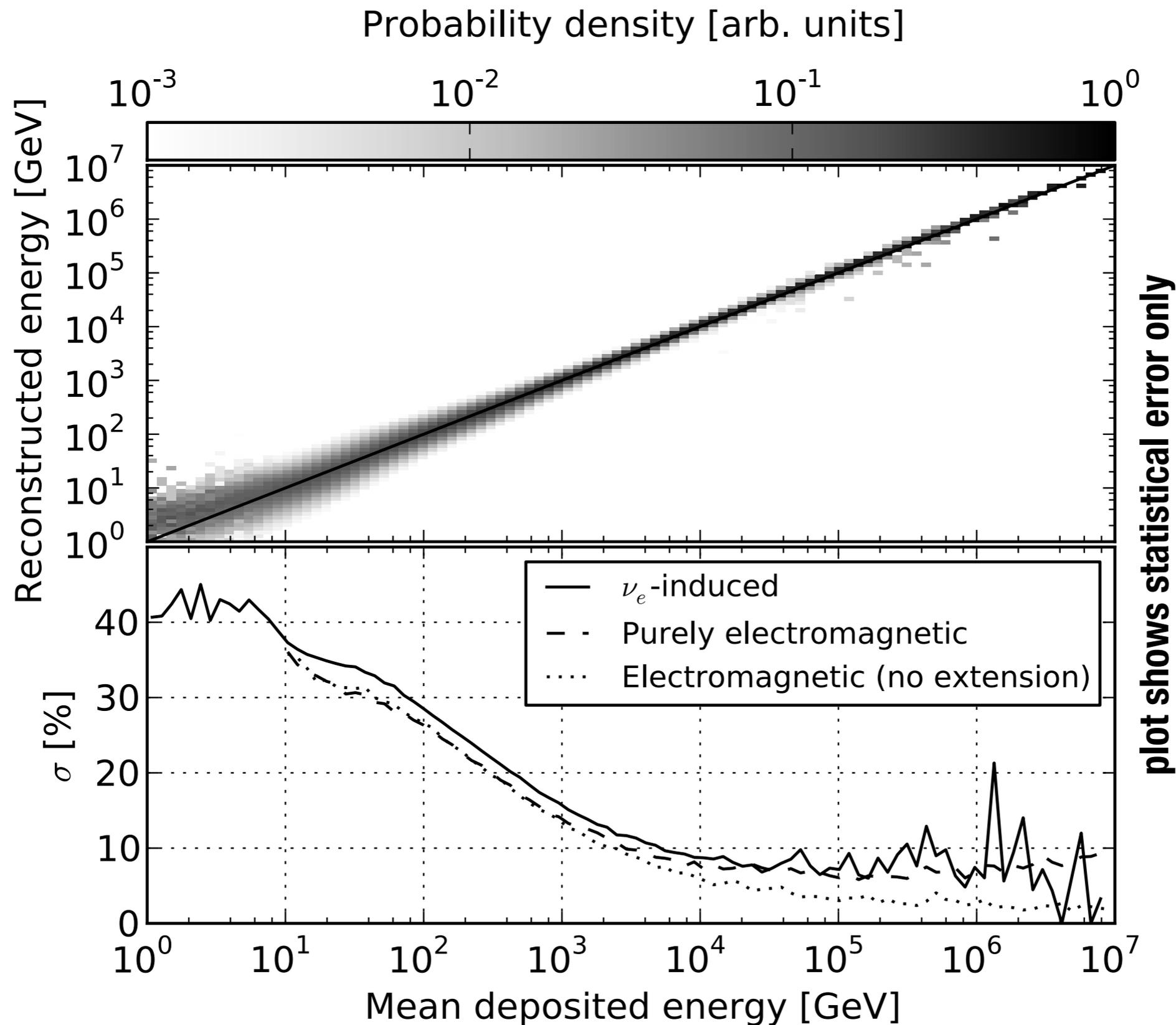
- they help in cascade directional reconstruction given the scattering in ice

- ▶ **Use full depth-dependent ice model**

- based on fits to LED flasher data
- fully spline-interpolated data

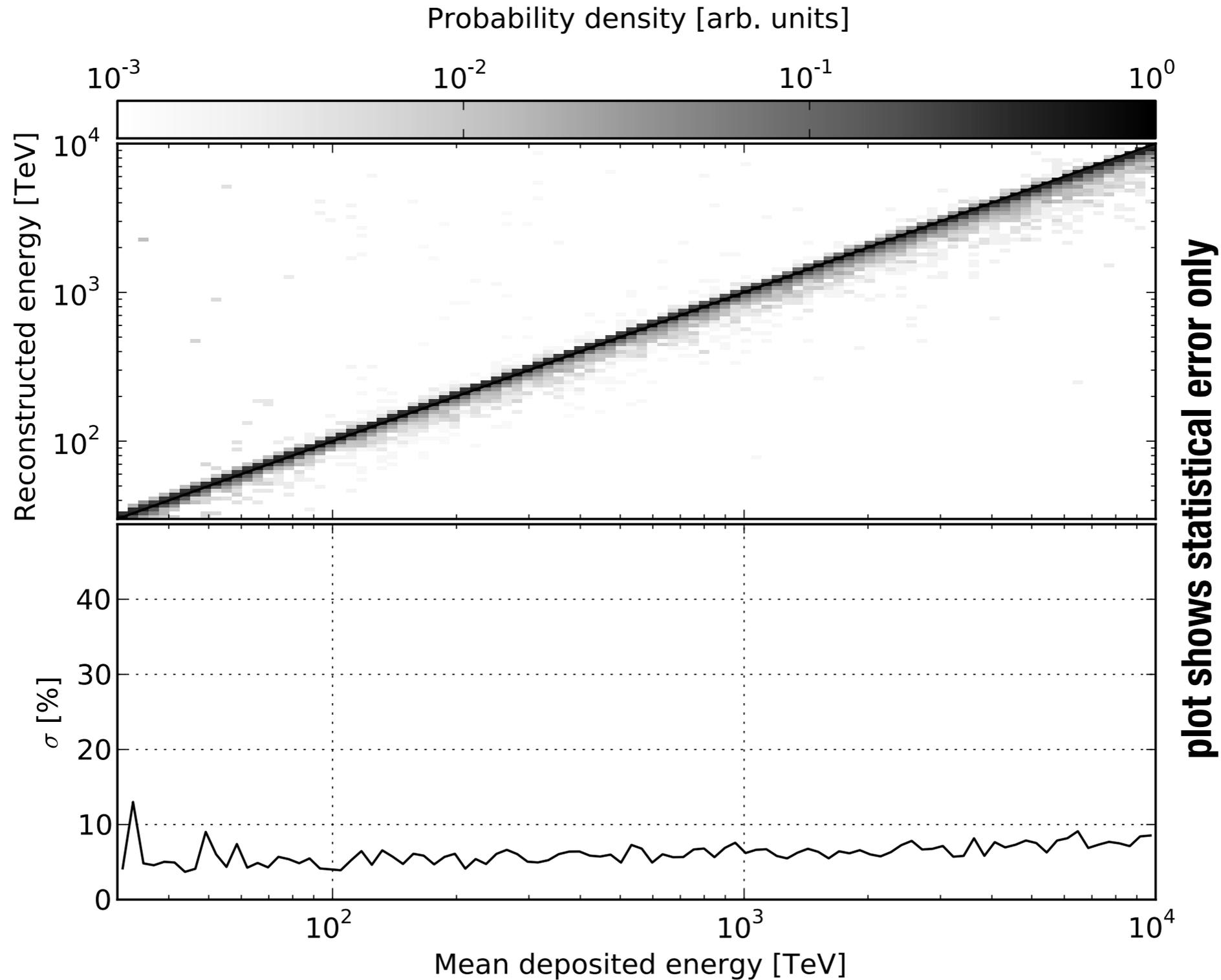
Shower Energy Resolution

For MC true vertex and direction and no event selection



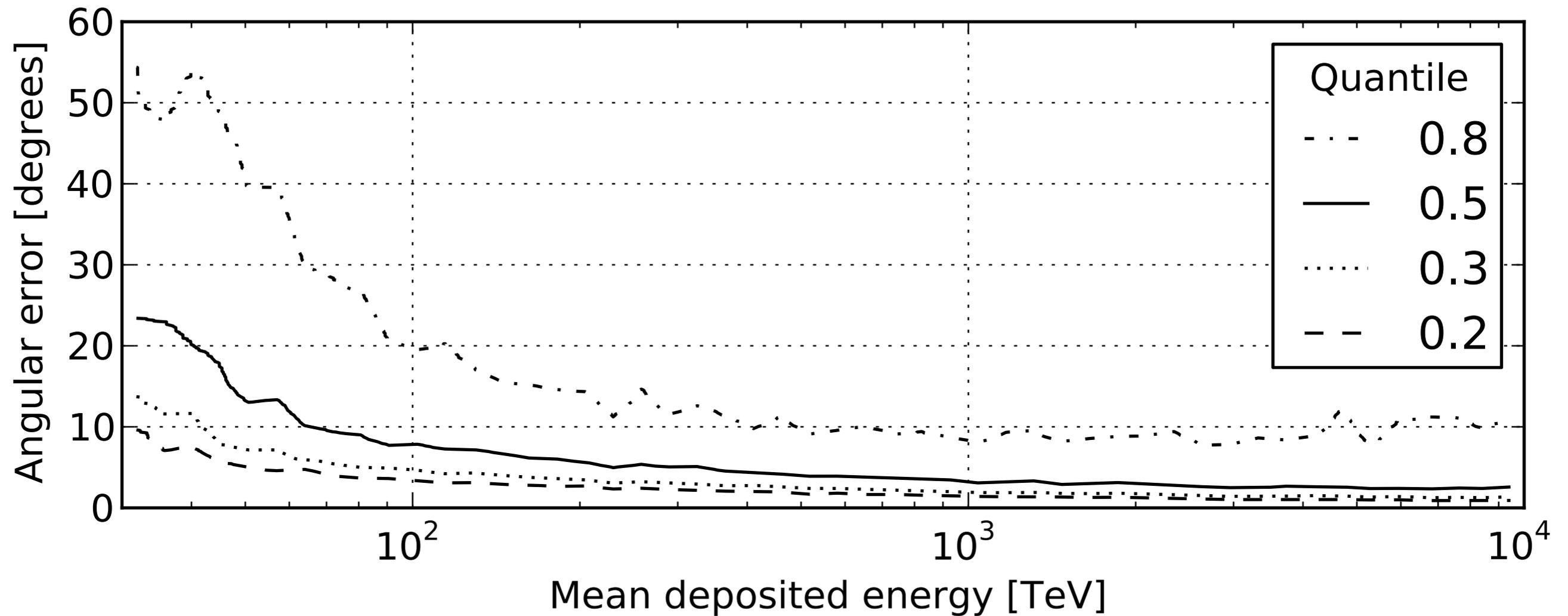
Shower Energy Resolution

For HESE analysis cuts with reconstructed vertices and directions



Shower Angular Resolution

For HESE analysis cuts with reconstructed vertices and directions

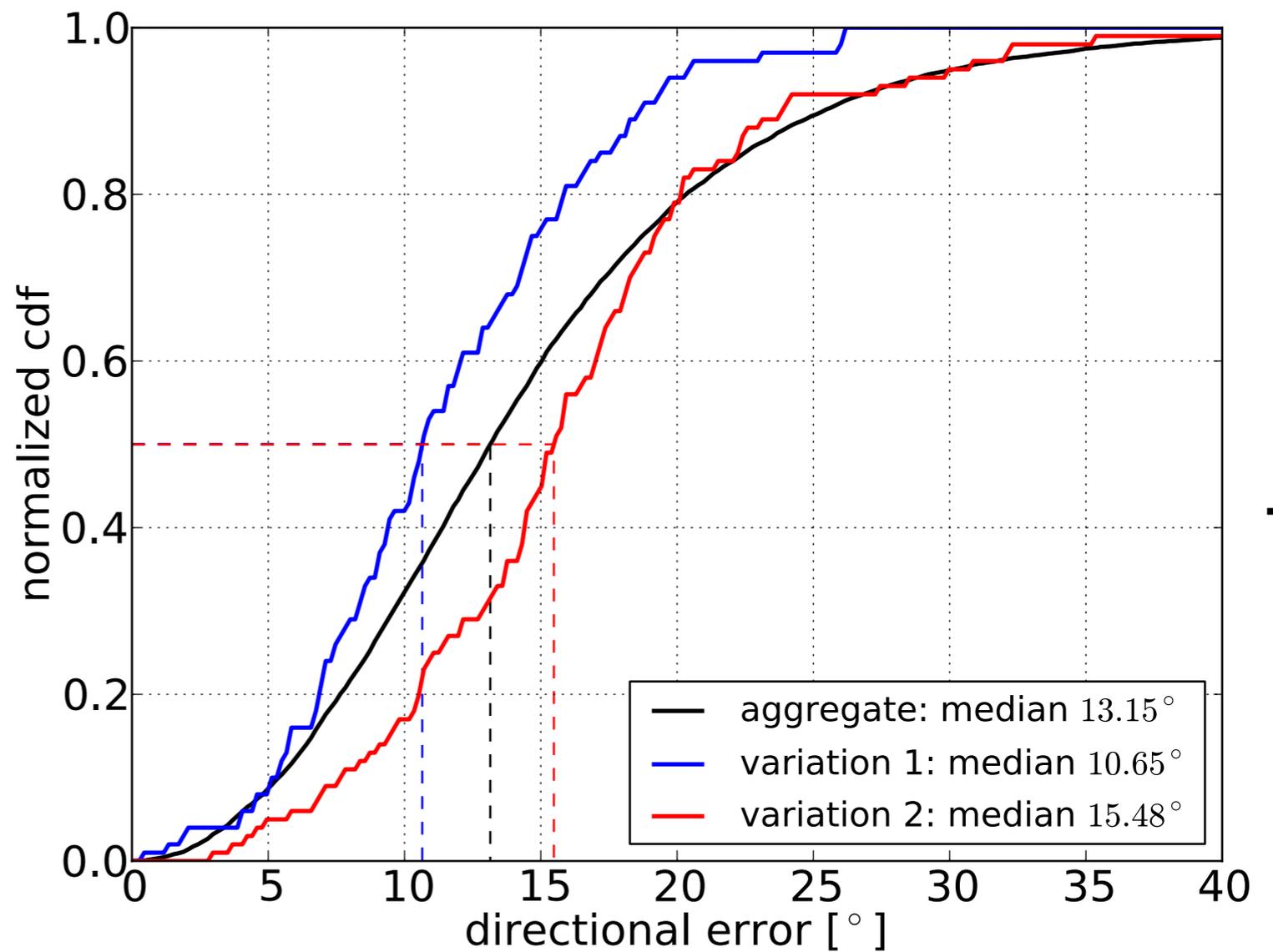


Reconstruction Systematics

Statistical uncertainties in angular reconstruction for showers is small. Dominated by ice systematics!

► **Angular error distributions on the order of 10° - 15° depending on the ice model assumption**

- two ice examples are shown
- aggregate resolution in black

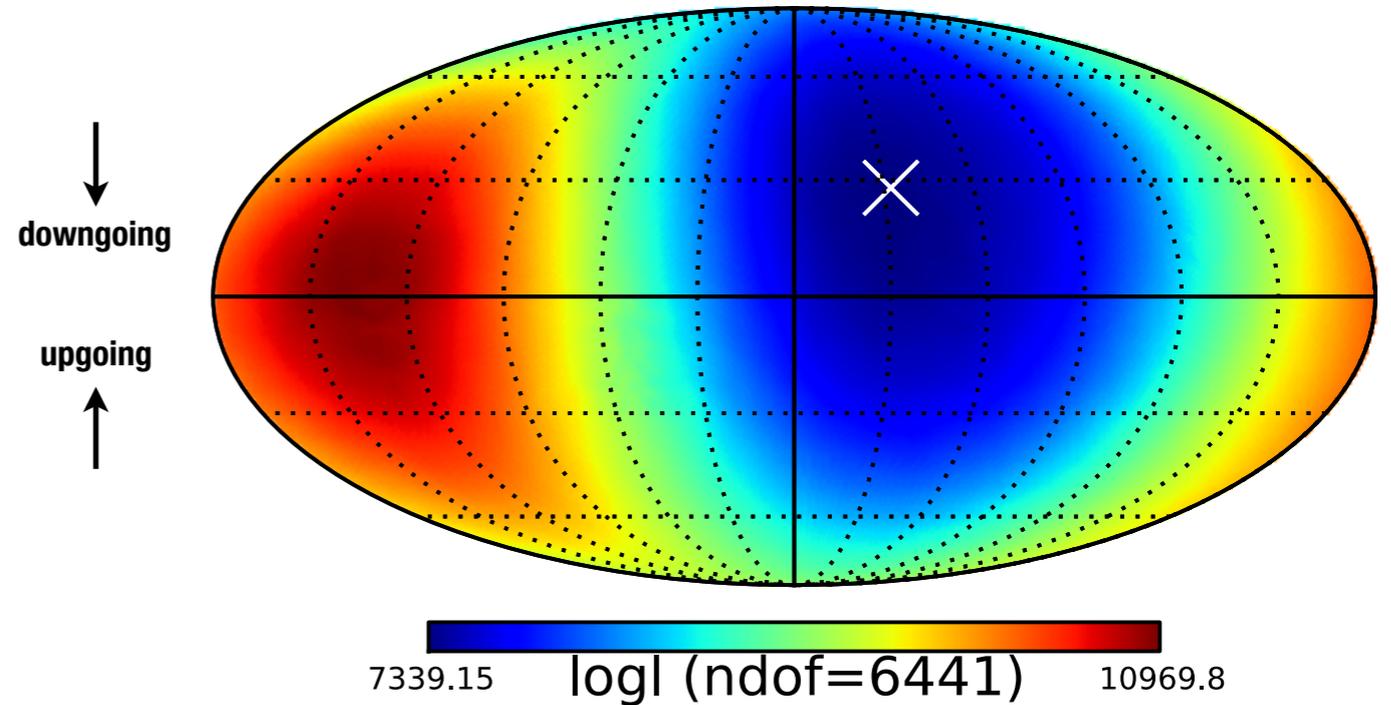
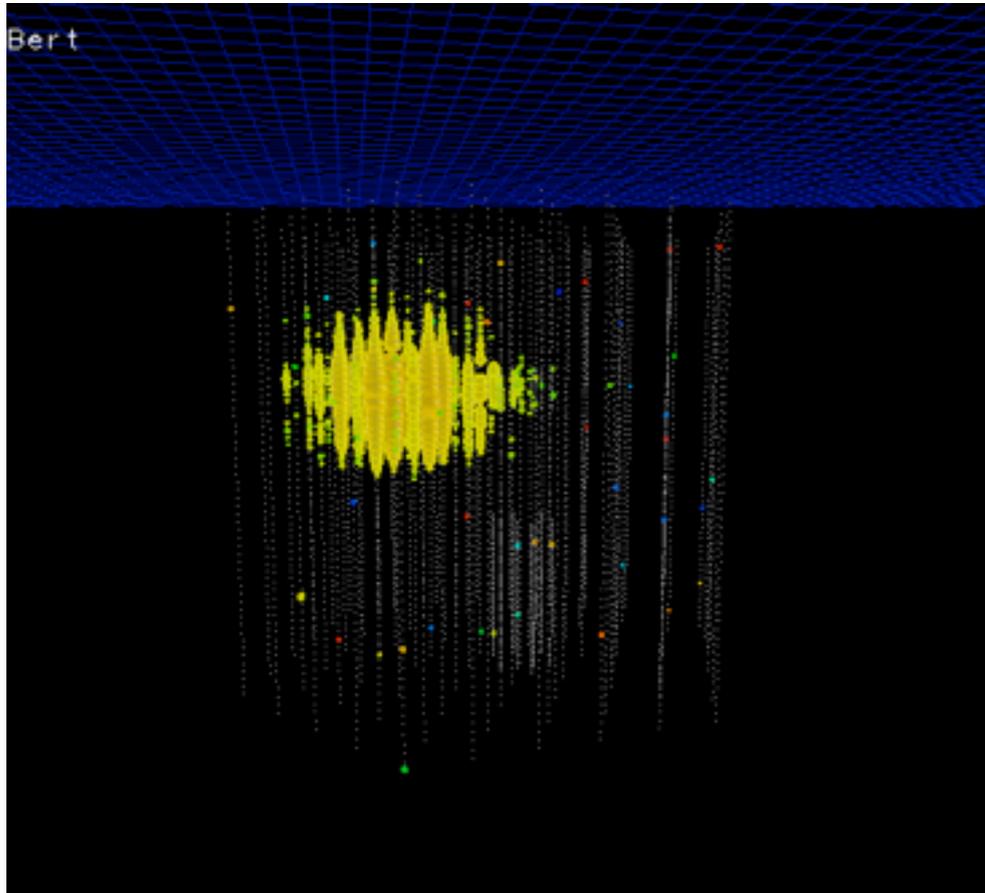


resolution for an individual example event from re-simulation

Systematics Example: Bert



Scan the likelihood space in direction to make sure we find the correct minimum and to get (statistical) uncertainty



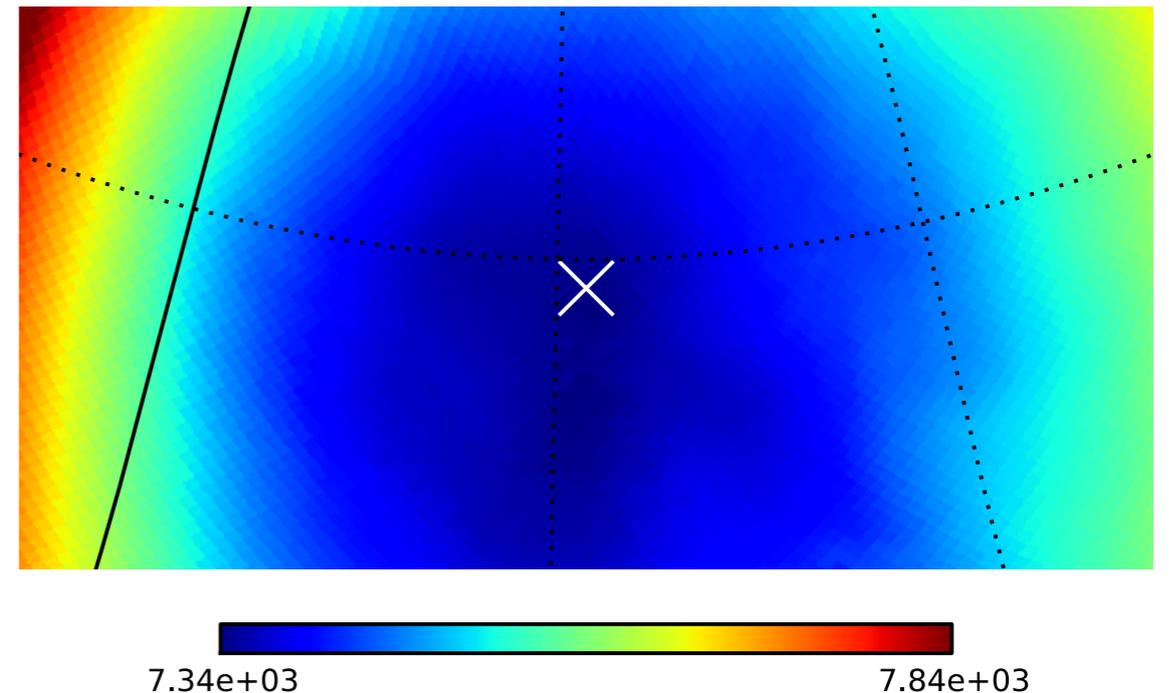
Charge (pe)

72907.6

reduced logl 1.14

Energy (TeV) 1069.6

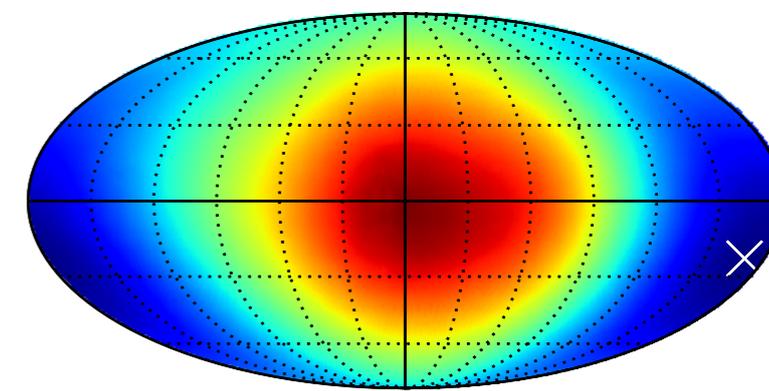
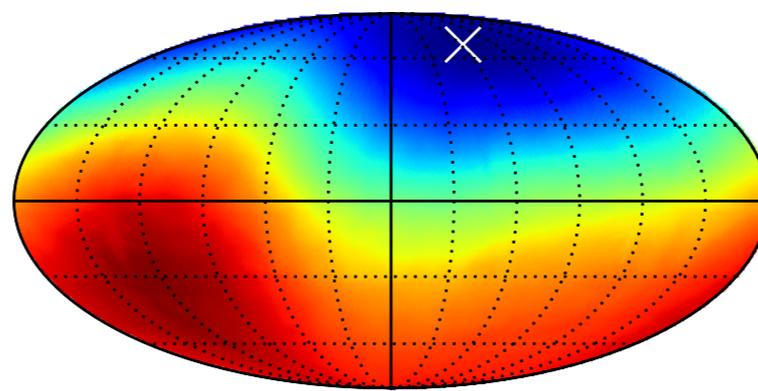
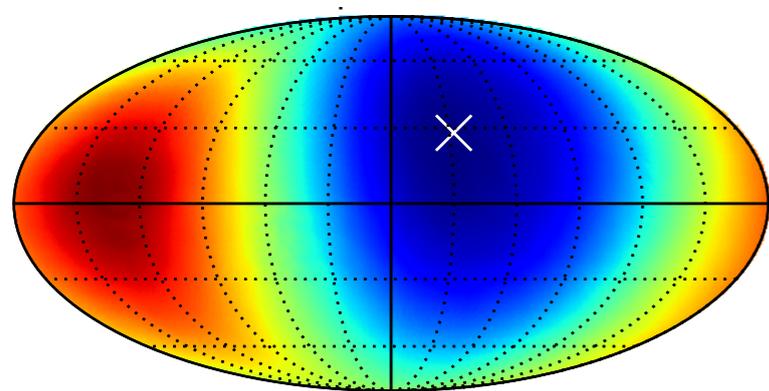
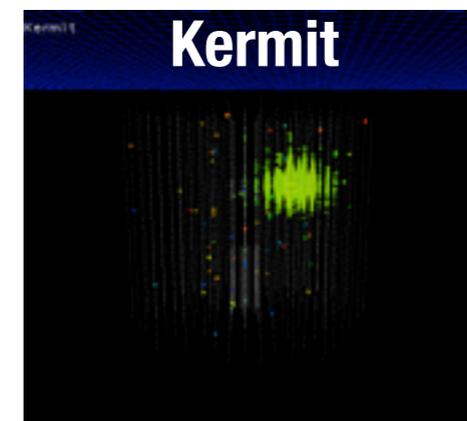
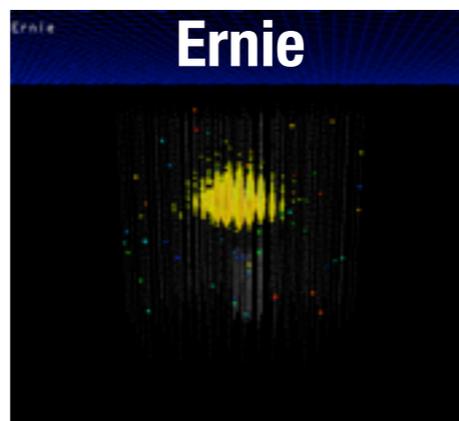
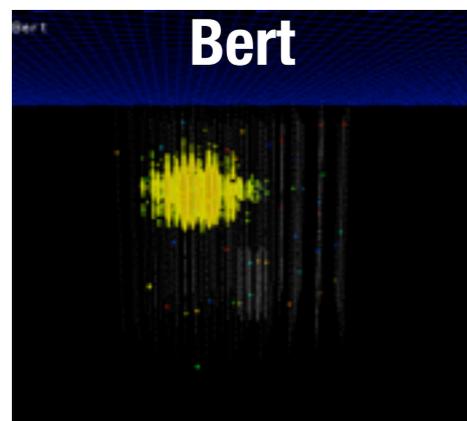
Zenith (deg) 62.0



Re-Simulation

How to determine systematics given the uncertainties in the ice model fit

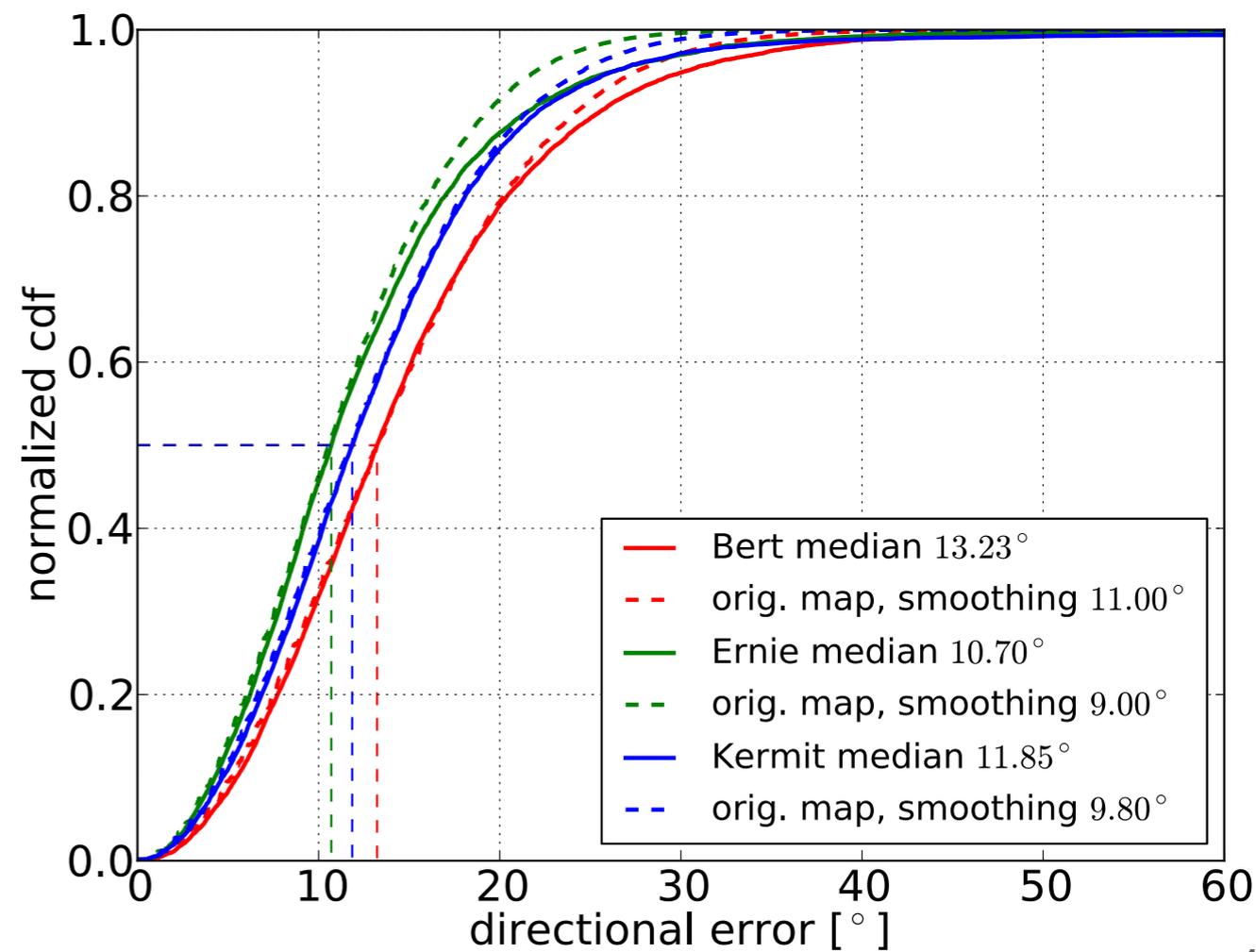
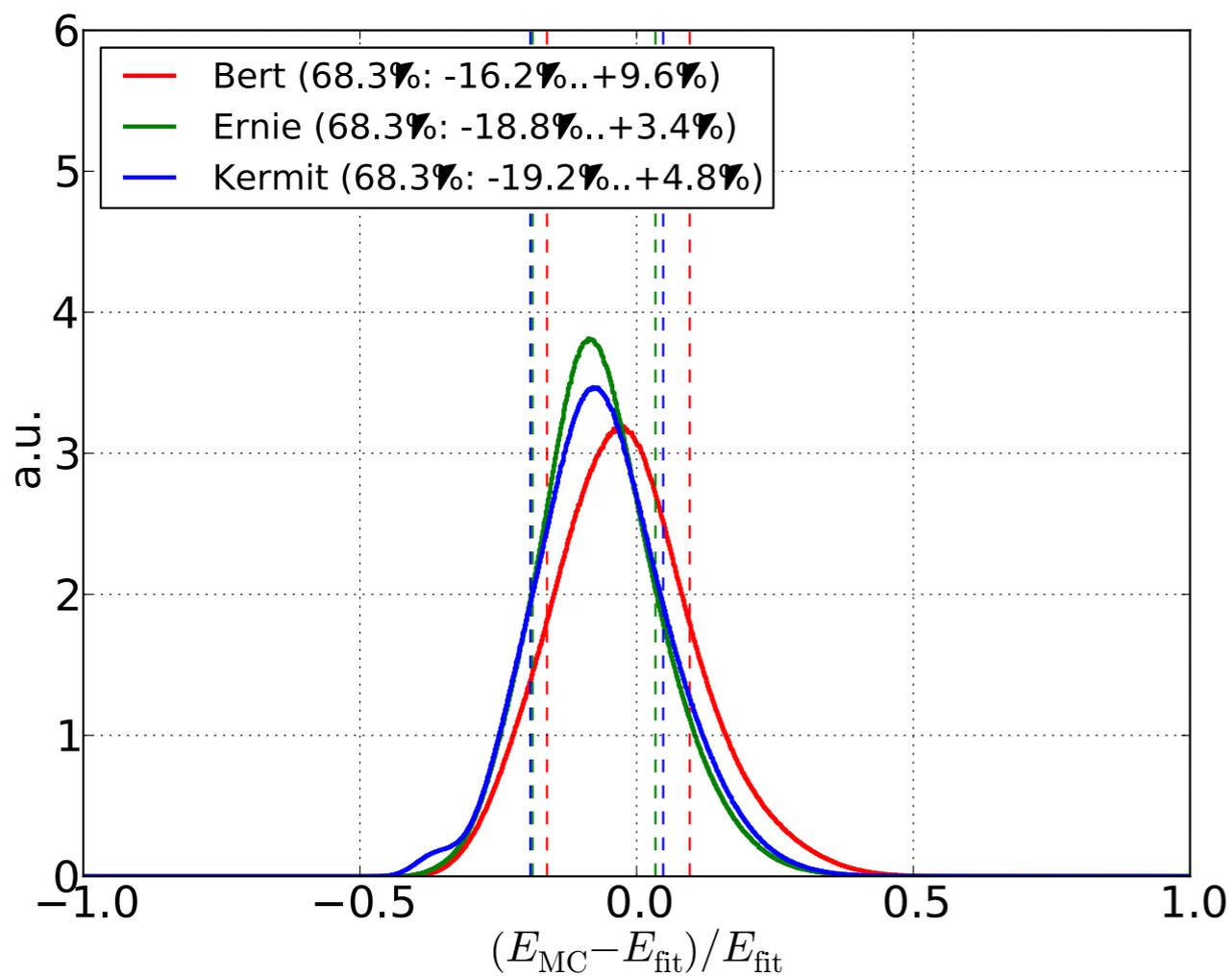
- ▶ **Re-simulation scheme:**
 - Sample from reconstruction skymap and energy
 - Sample from “ice-model space” (uncertainties including layer-to-layer uncertainties, tilt and anisotropy)
 - Simulate each event using full propagationReconstruct
 - Compare to MC truth for each event and plot differences



7339.15 $\log l$ (ndof=6441) 10969.8

10845.8 $\log l$ (ndof=6559) 15786.1

2595.66 $\log l$ (ndof=5600) 3273.33



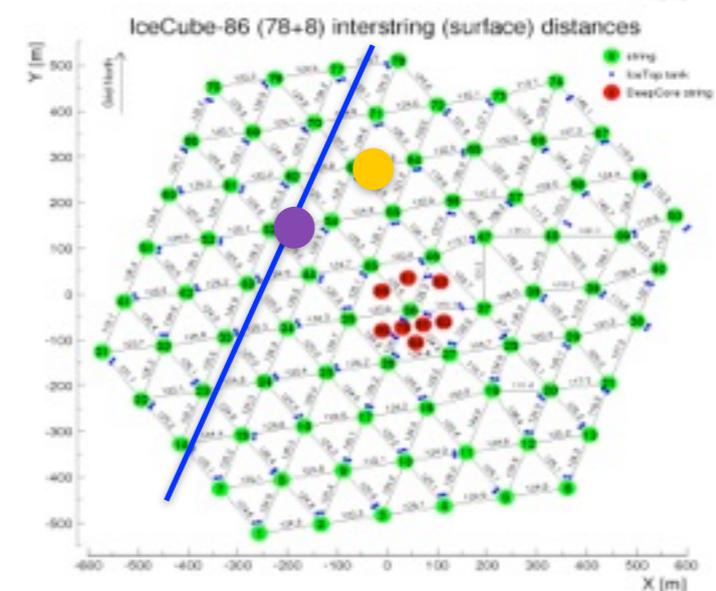
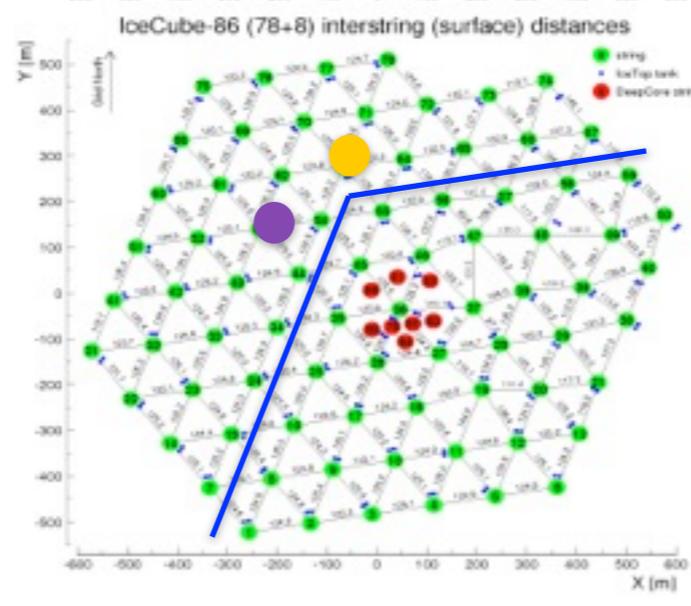
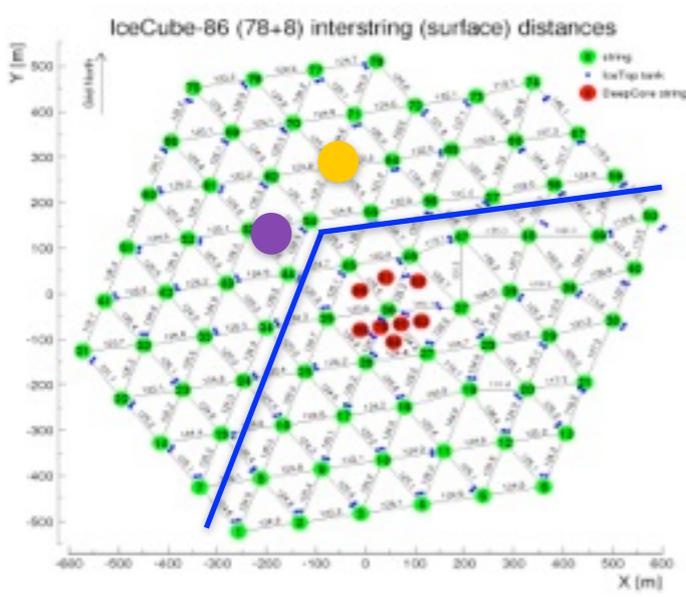
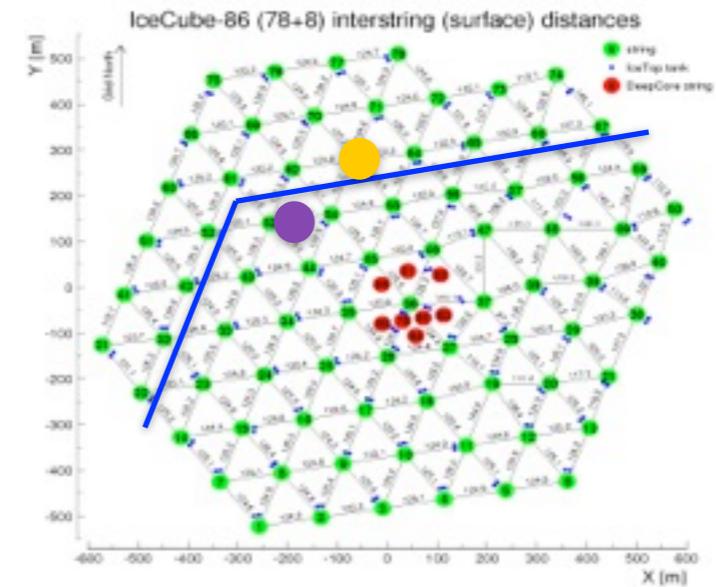
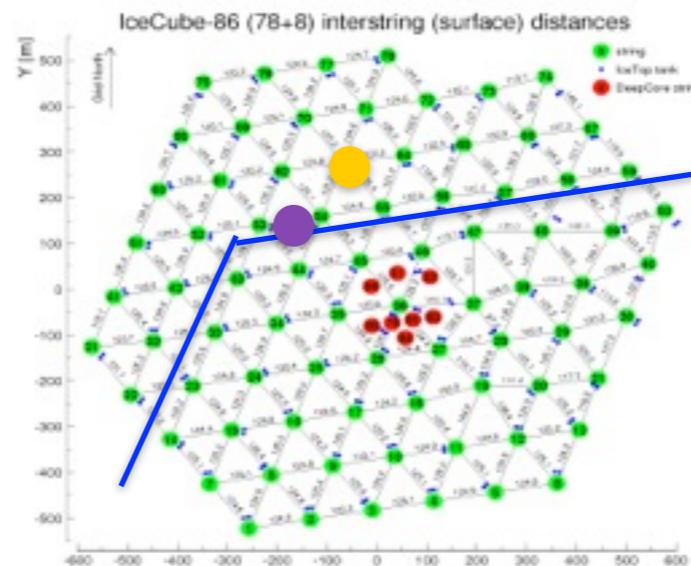
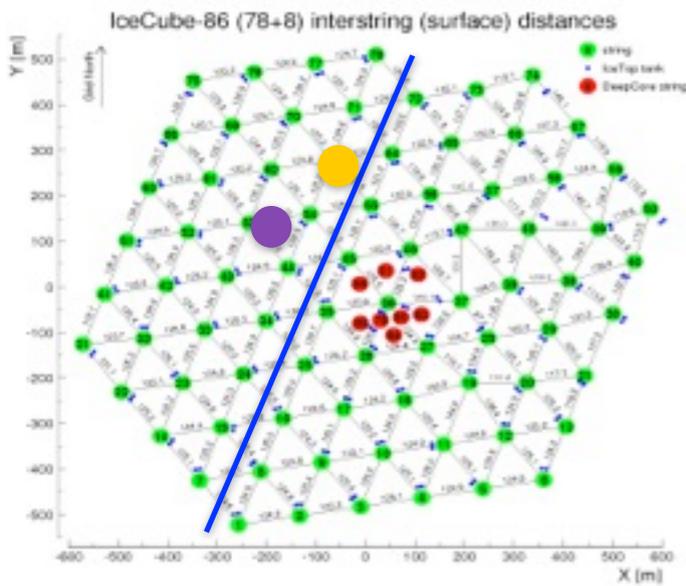
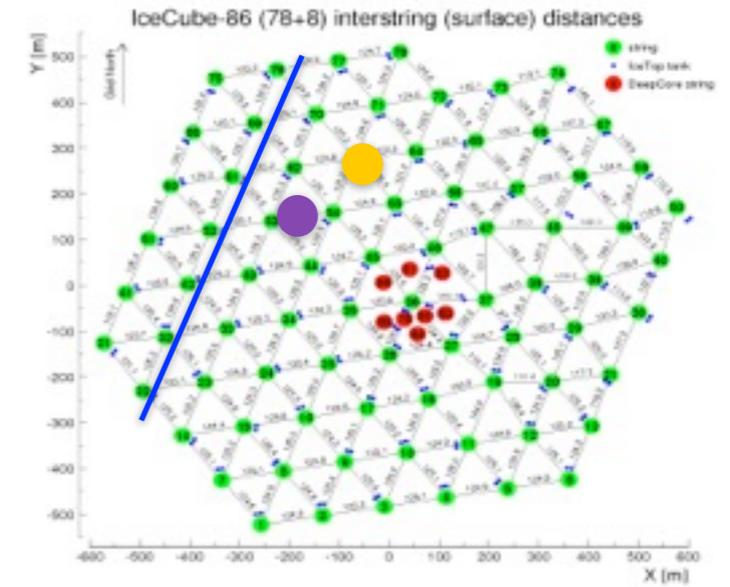
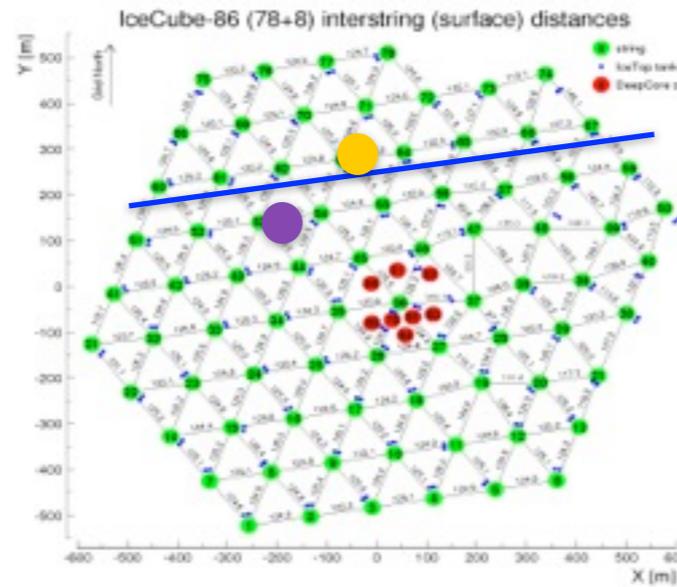
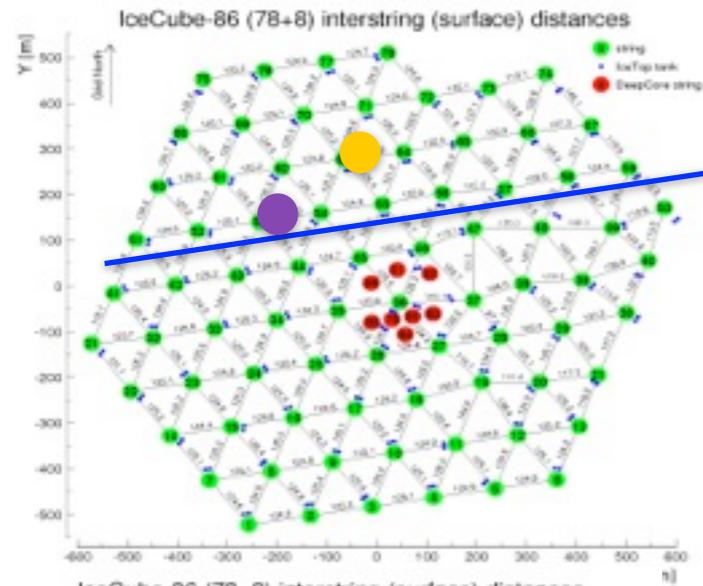
Partially Contained Showers

What if the shower is not fully contained?

- ▶ **Can be studied on data:**
 - remove DOMs from the detector and compare original reconstruction to reconstruction with reduced set of DOMs
- ▶ **When does the reconstruction break down?**
 - studied at by a student in Madison

The Exclusions

- Bert Event
- Ernie Event



3rd

1st

2nd

4th

5th

6th

7th

8th

9th

The Bert Event

Exclusion #	Charge Included	Charge Excluded	# of DOMs included	Vertex Error (m)	Energy Error	Angular Error (deg)
Total Event	N/A	N/A	464	N/A	N/A	N/A
1 st	0.1592	0.8408	246	2.9192	-0.0204	12.8
2 nd	0.9659	0.0341	339	4.0670	-0.1031	16.3
3 rd	0.9605	0.0395	339	1.3333	-0.1095	10.1
4 th	0.0093	0.9907	144	37.5556	-0.6325	57.4
5 th	0.1680	0.8420	225	6.3629	-0.0613	22.8
6 th	0.9454	0.0546	285	2.6350	-0.1380	19.3
7 th	0.0089	0.9912	129	35.5652	-0.6202	70.4
8 th	0.0093	0.9907	141	39.5324	-0.5719	45.4
9 th	0.1422	0.8578	237	1.9788	-0.0534	18.7

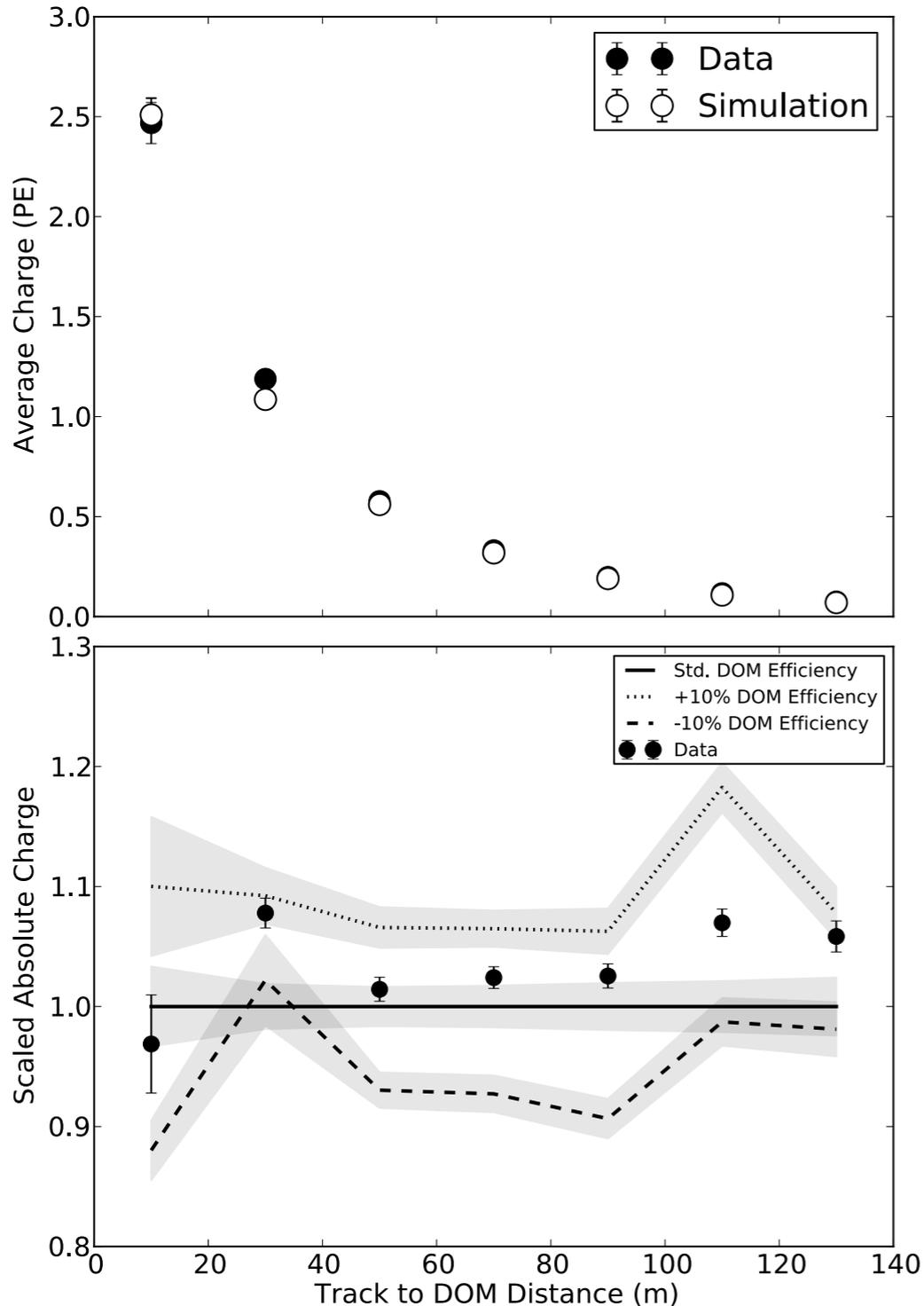
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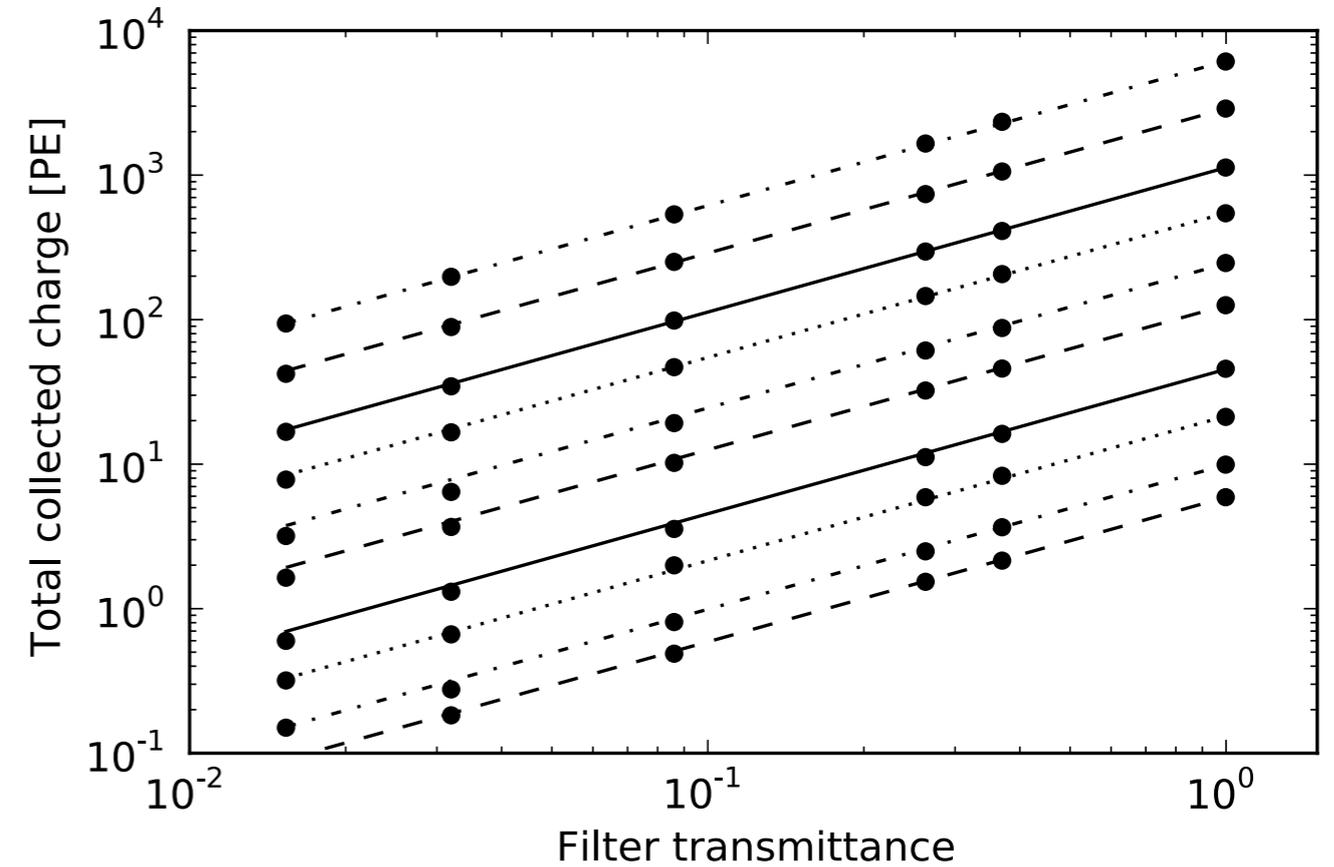
- ▶ **Even after excluding about 85% of the total charge, the event is still reconstructable!**
 - this in general depends on which parts of the event are excluded and how much charge is left

Absolute Energy Scale

Select minimum ionizing muons to test to a known process



Then use calibration laser with different ND filter settings to check DOM linearity:



Summary

- ▶ **Shower reconstruction in IceCube works great!**
- ▶ **We achieve about 15deg angular resolution and 10-15% energy resolution at the “HESE” energies**
 - dominated by ice systematics (especially in directional resolution!)