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Refining the IceCube detector geometry

using muon and LED calibration data

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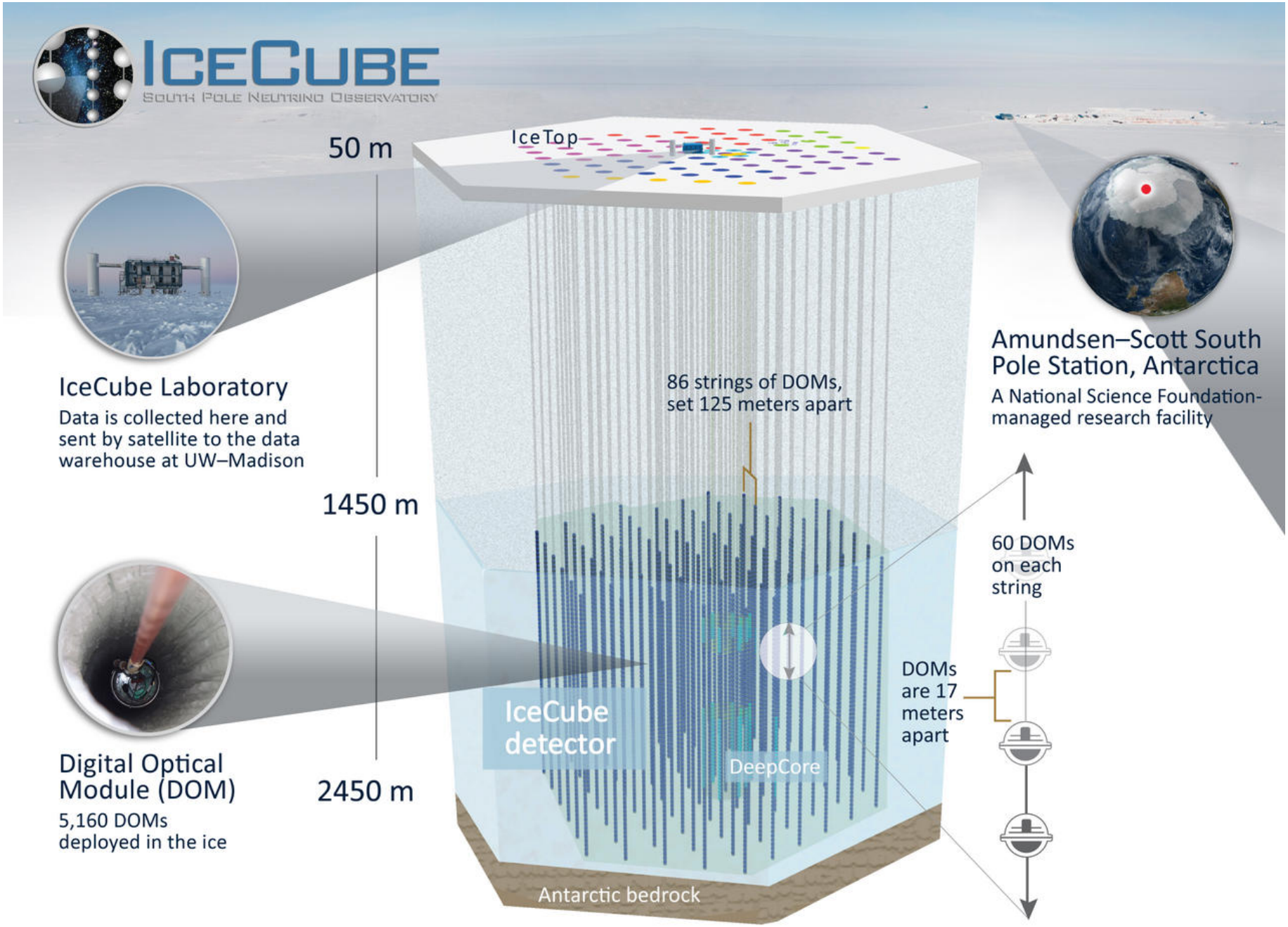
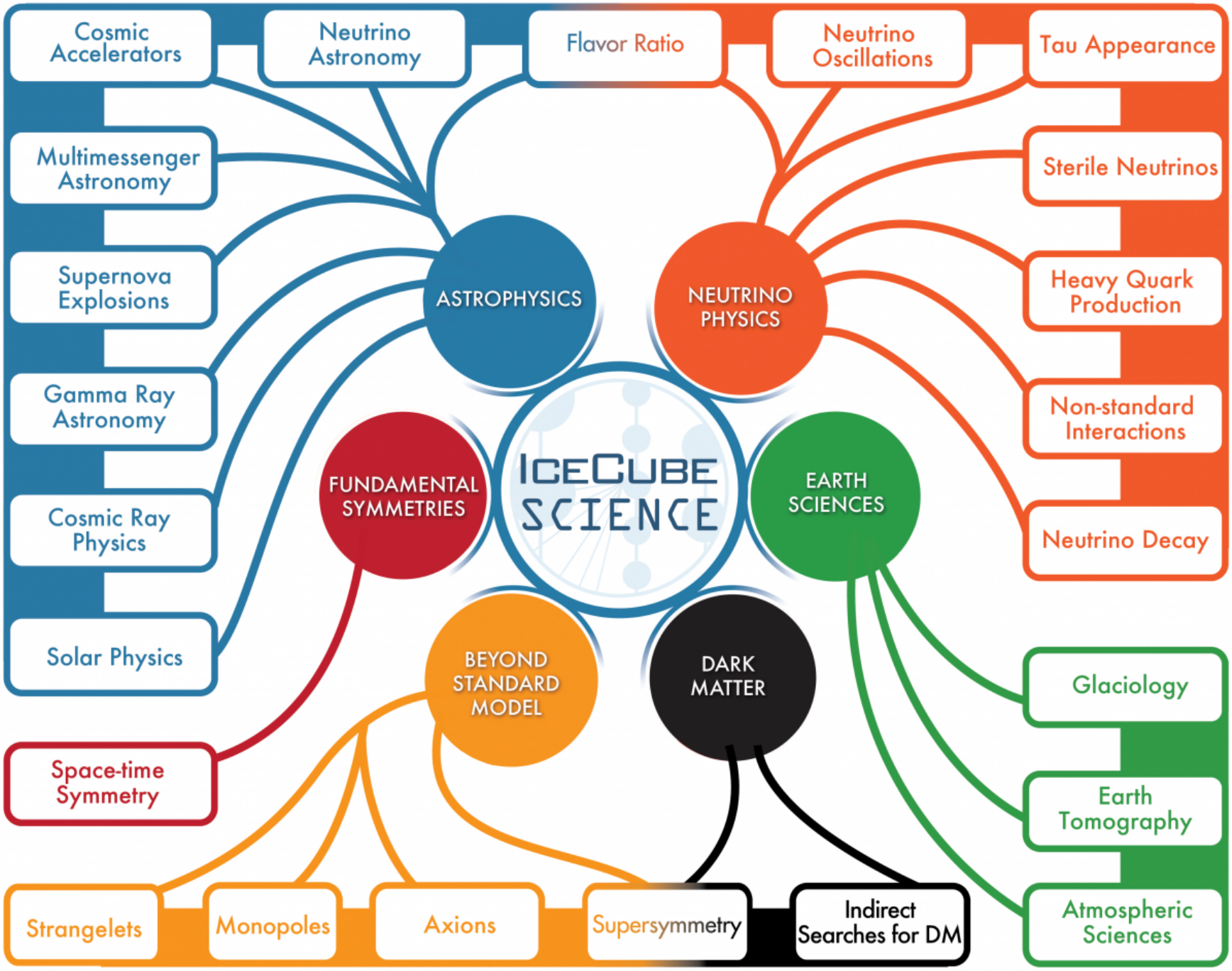
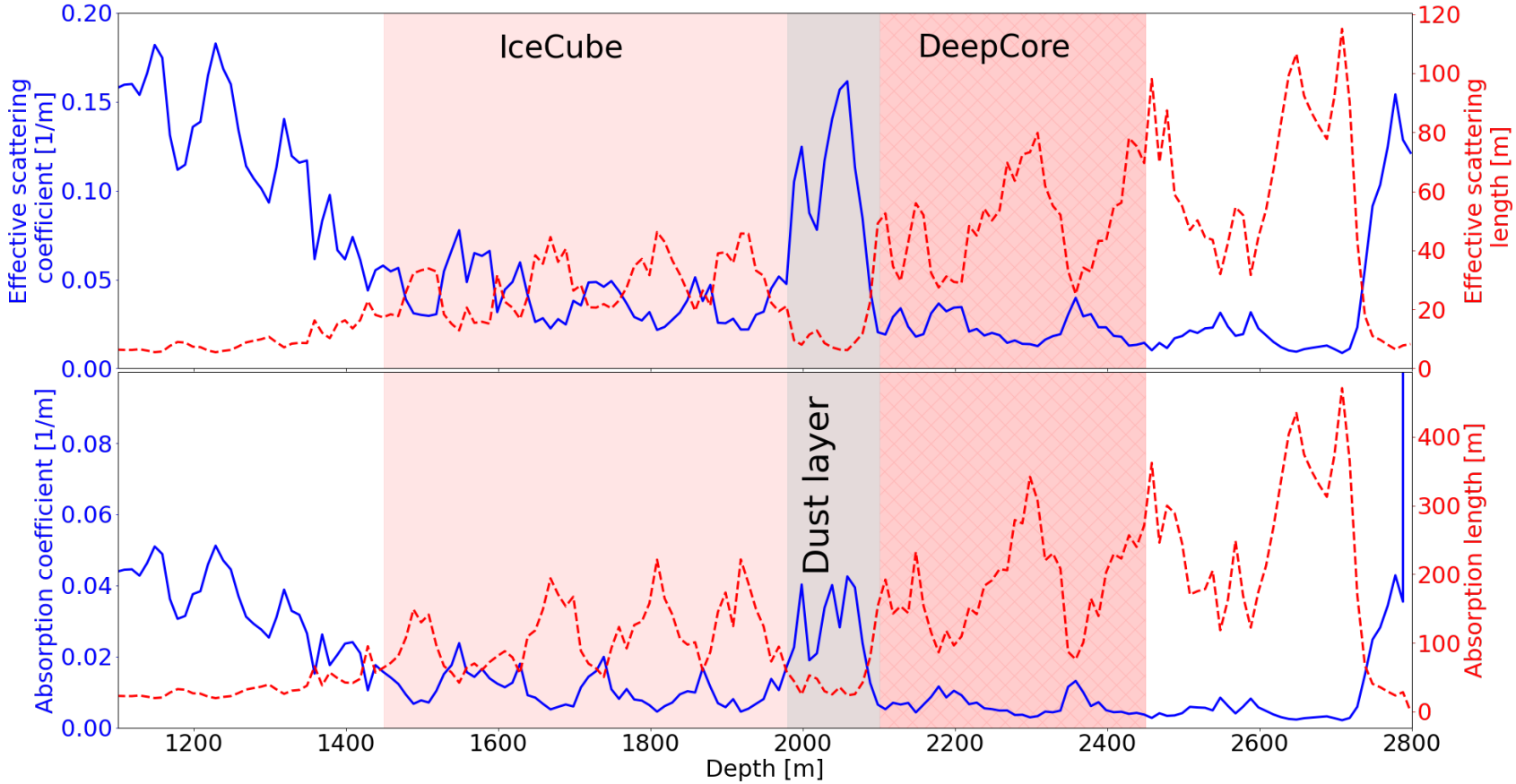

IceCube
South Pole Neutrino Observatory
50 m
IceTop
IceCube Laboratory
Data is collected here and sent by satellite to the data warehouse at UW–Madison
1450 m
86 strings of DOMs, set 125 meters apart
Amundsen–Scott South Pole Station, Antarctica
A National Science Foundation-managed research facility
60 DOMs on each string
DOMs are 17 meters apart
IceCube detector
DeepCore
Digital Optical Module (DOM)
5,160 DOMs deployed in the ice
2450 m
Antarctic bedrock


ICECUBE SCIENCE
ASTROPHYSICS
NEUTRINO PHYSICS
FUNDAMENTAL SYMMETRIES
EARTH SCIENCES
BEYOND STANDARD MODEL
DARK MATTER
Cosmic Accelerators
Neutrino Astronomy
Multimessenger Astronomy
Supernova Explosions
Gamma Ray Astronomy
Cosmic Ray Physics
Solar Physics
Flavor Ratio
Neutrino Oscillations
Tau Appearance
Sterile Neutrinos
Heavy Quark Production
Non-standard Interactions
Neutrino Decay
Space-time Symmetry
Glaciology
Earth Tomography
Atmospheric Sciences
Strangelets
Monopoles
Axions
Supersymmetry
Indirect Searches for DM

Systematics in IceCube



Other systematics

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- PMT response
- Photon Timings
- Quantum Efficiency
- Geometry

Flasher data for z calibration

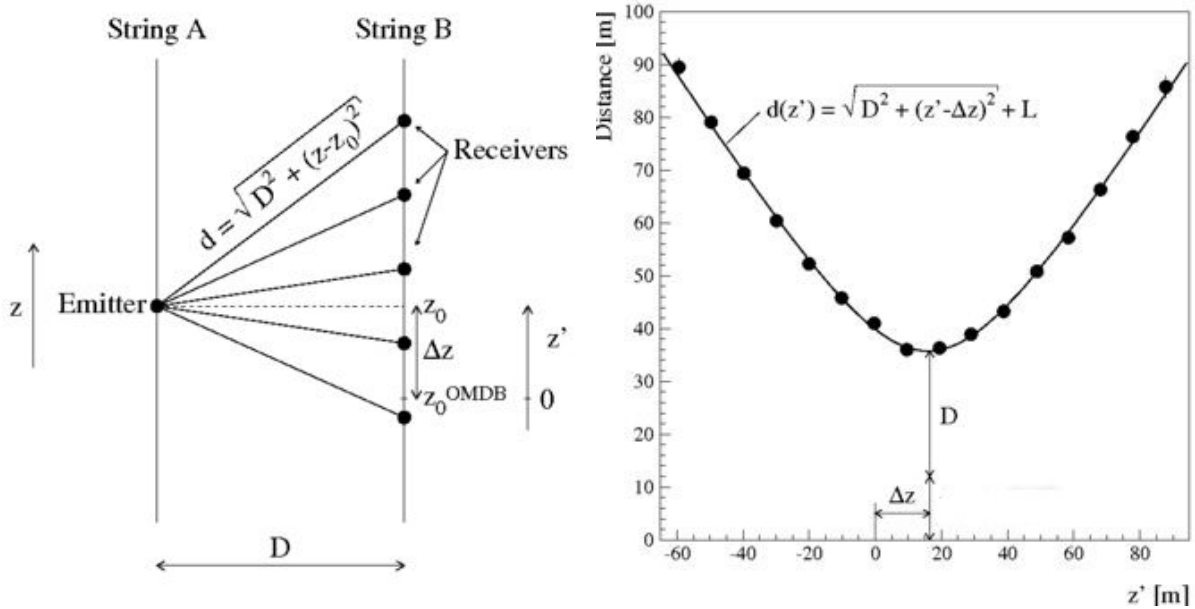

Figure: The method for extracting relative depth from flasher data. The timing of light from LEDs on other strings will form a hyperbola as a function of the nominal offset z'. Byt finding the minima of this function we get a correction to the offset between two strings Δz.

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- We have millions of muon tracks in the detector every day lighting up the detector.
- Our reconstruction gives us the origin of that light.
- Given the PMT timings and tracks we can estimate the location of our DOMs.

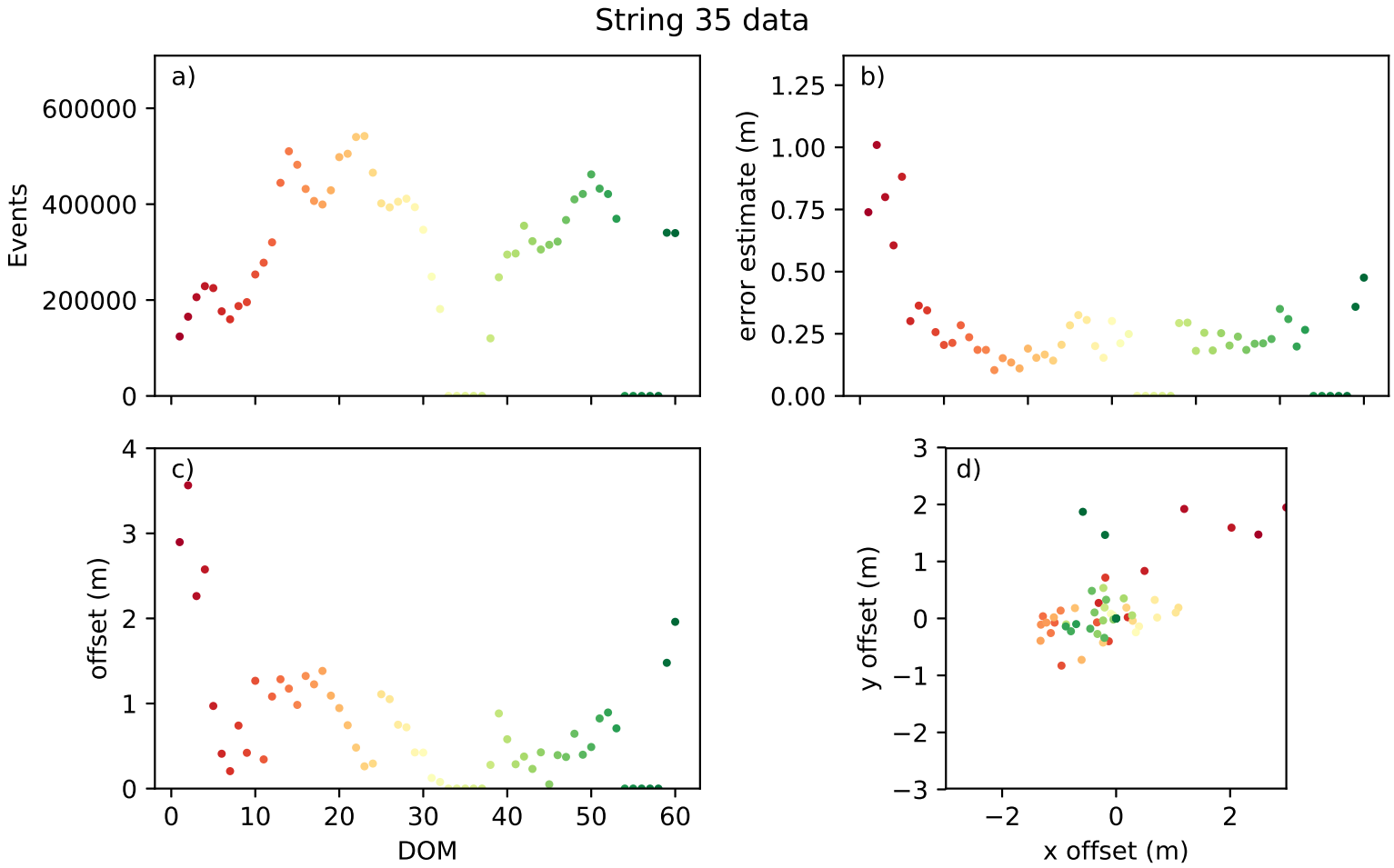
Method

- For a large number of tracks:
  - Remove hits on the string being calibrated.
  - Require at least 30 hits left.
  - Reconstruct the track.
- For track i, corresponding photon times $t_{i0}...t_{in_i}$ and noise level b find DOM position $(\hat{x}, \hat{y}, \hat{z})$ that maximizes

$$L(x, y, z) = Log\Big(\prod_{i}\prod_{t=t_{i0}}^{t_{in_i}}\big(p(t|i, x, y, z) + b\big)\Big)$$

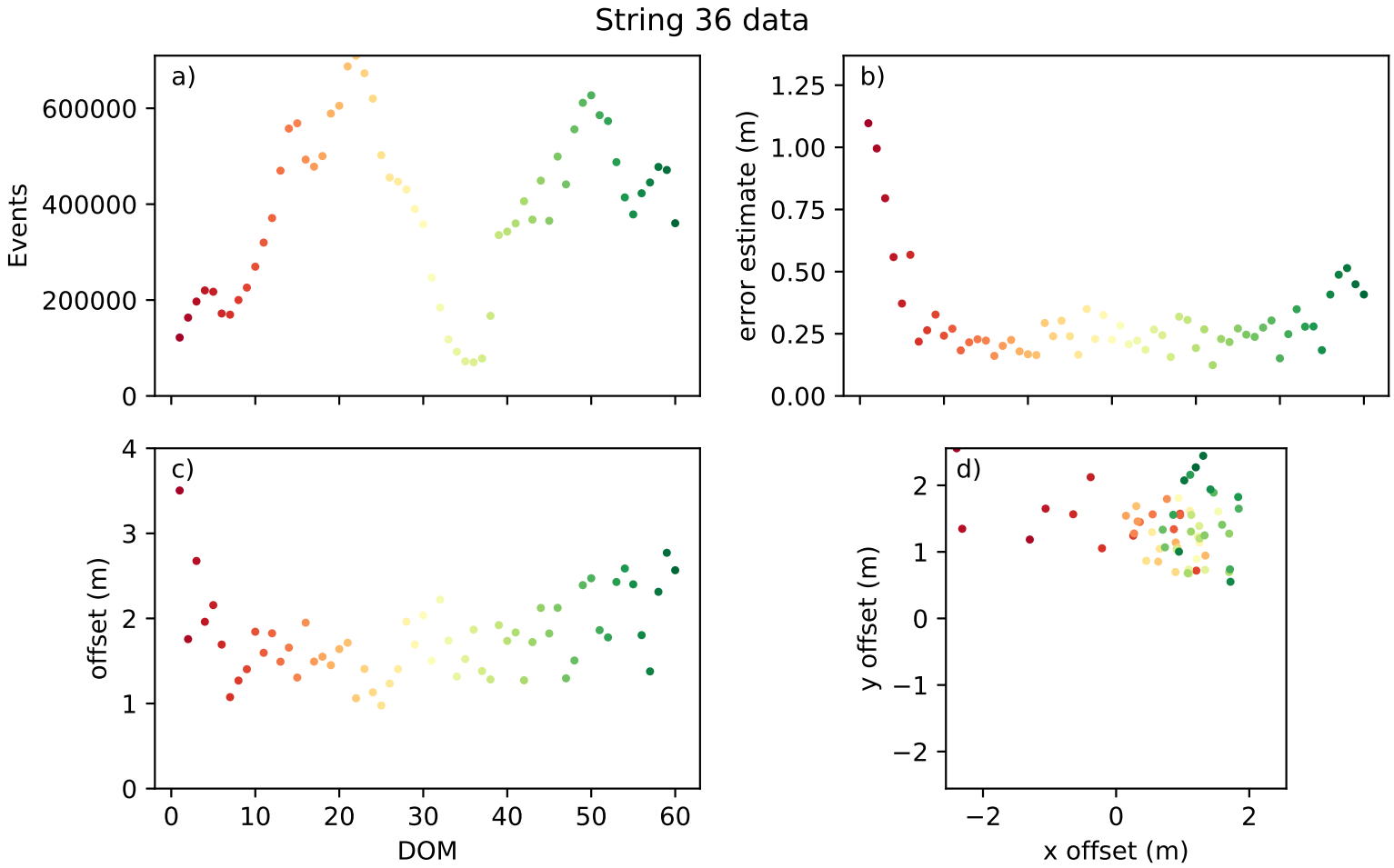
, where p is the photon time pdf.

String 35 results



a) number of events per DOM. b) error estimate given by bootstrap.
c) offset from nominal positions. d) best fit positions for each DOM.

String 36 results



a) number of events per DOM. b) error estimate given by bootstrap.
c) offset from nominal positions. d) best fit positions for each DOM.

Confirmation with flashers

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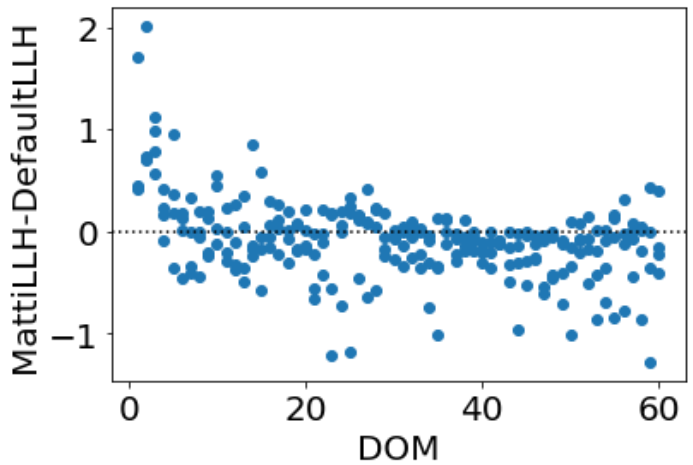
Recent improvements in modeling of light propagation in the ice (in particular birefringence) has shown flasher data to be consistent with my results.

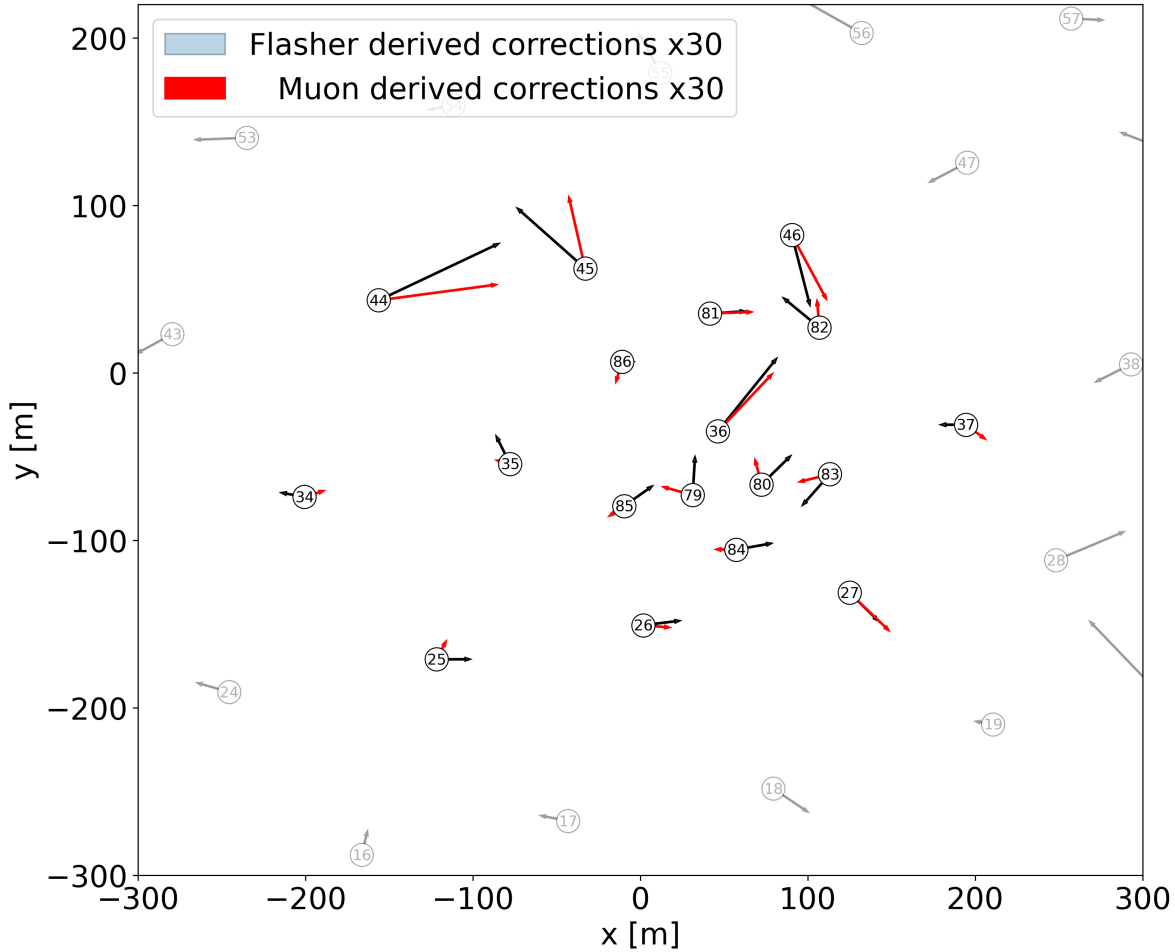


Worse

Better

Using the new geometry for the central strings we find that for strings where the DOM positions are clustered around nominal there is no change in likelihood but for string 36 which has moved over a meter the new position is a significantly better fit to the flasher data.

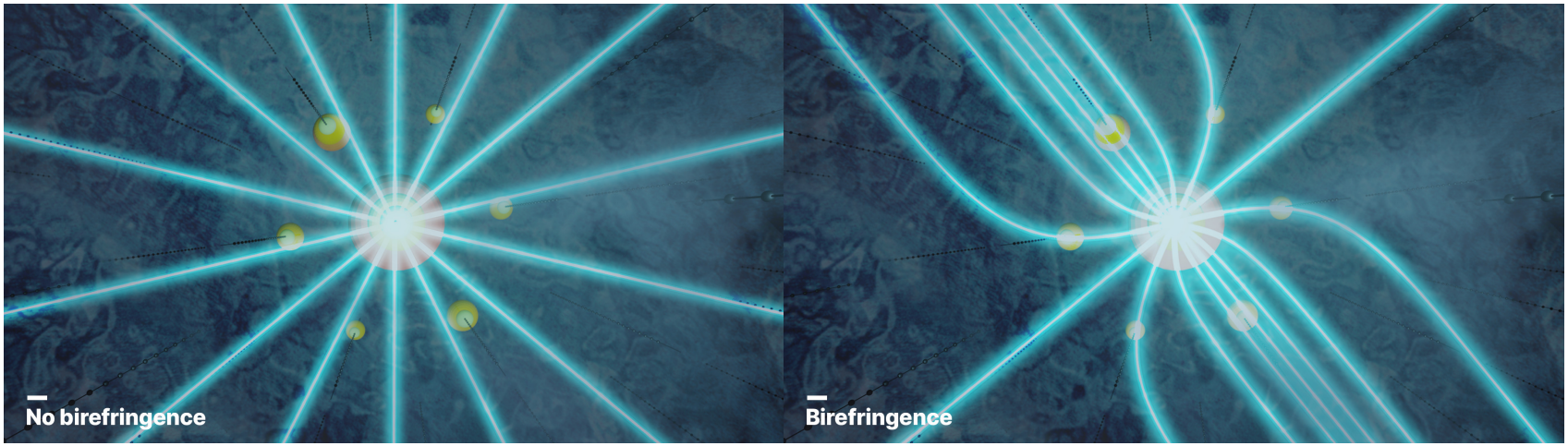
Corrections to central strings



But did I not say flasher did not work?

- Previous studies with flasher had not produced consistant results.
- But it seems that with the latest ice model, it gives a result.
- The result agrees with my results.

Birefringence



Latest ice model models the anisotropy as birefringence which is an effect of the ice grain sizes and the direction of the ice flow.
As can be seen in the artist rendering, after multiple scatters light gets bent and is more likely to travel in the flow direction.

Ice Model in Muon Reconstruction

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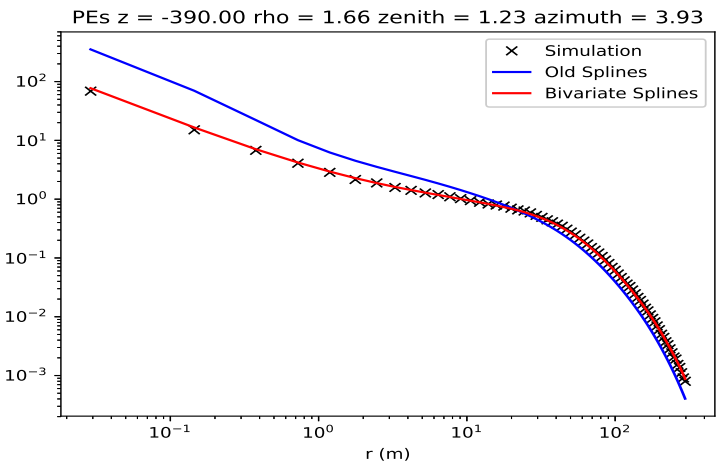
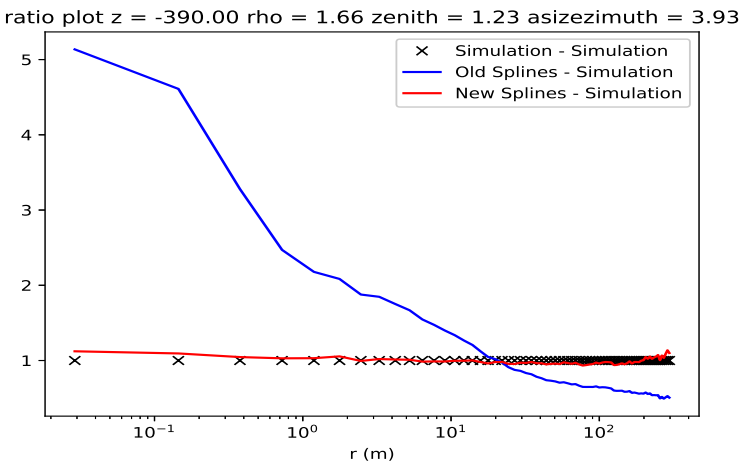
- IceCube track events are reconstructed using tables that describe photon propagation in the ice
- Last set of tables generated in 2015, did not include anisotropy/birefringence effect
- Working on implementation of new tables allowing for azimuthal asymmetry to incorporate this

Light yields tables





Left plot is number of absorbed photons and right plot is a ratio plot. Next step: update the tables used for reconstructing muon tracks, see how much it can improve e.g. direction and energy reconstruction.

Thank you for your attention!