Light Propagation in the South Pole Ice

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VLVNT 2013
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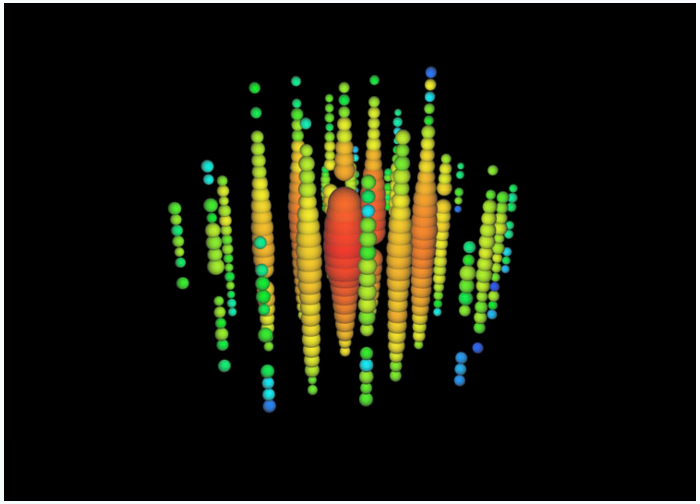
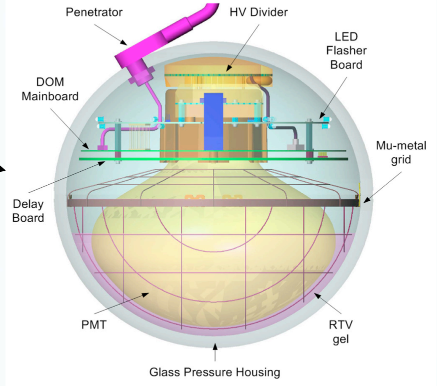
From neutrino to DOM

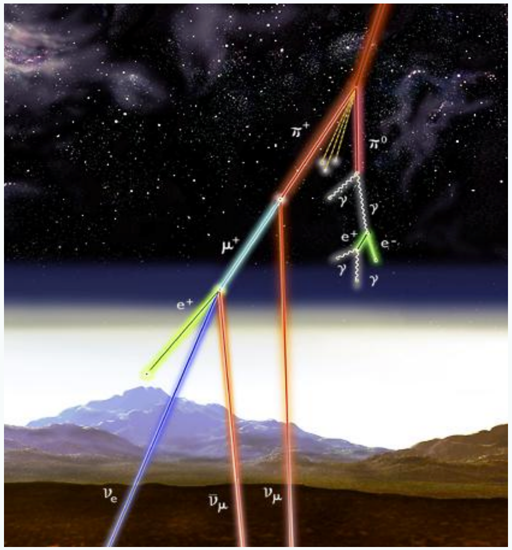




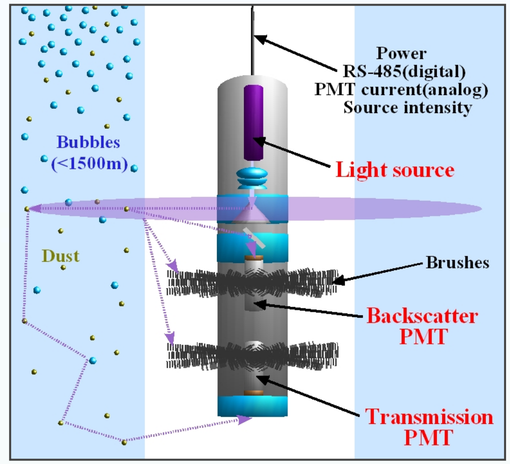
Photons undergo scattering and absorption in ice

Modeling the light propagation in ice is critical to reconstructing the properties of IceCube events

IceCube Calibration Devices

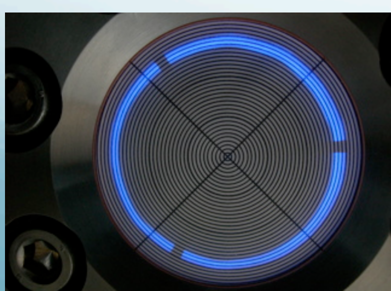


Muons from cosmic ray-induced air showers

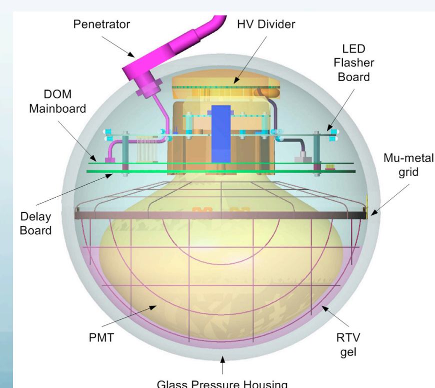


Dust logger (8 locations)

One camera located at the bottom of a string near the center of IceCube (see talk by Per Olof Hulth, this session)

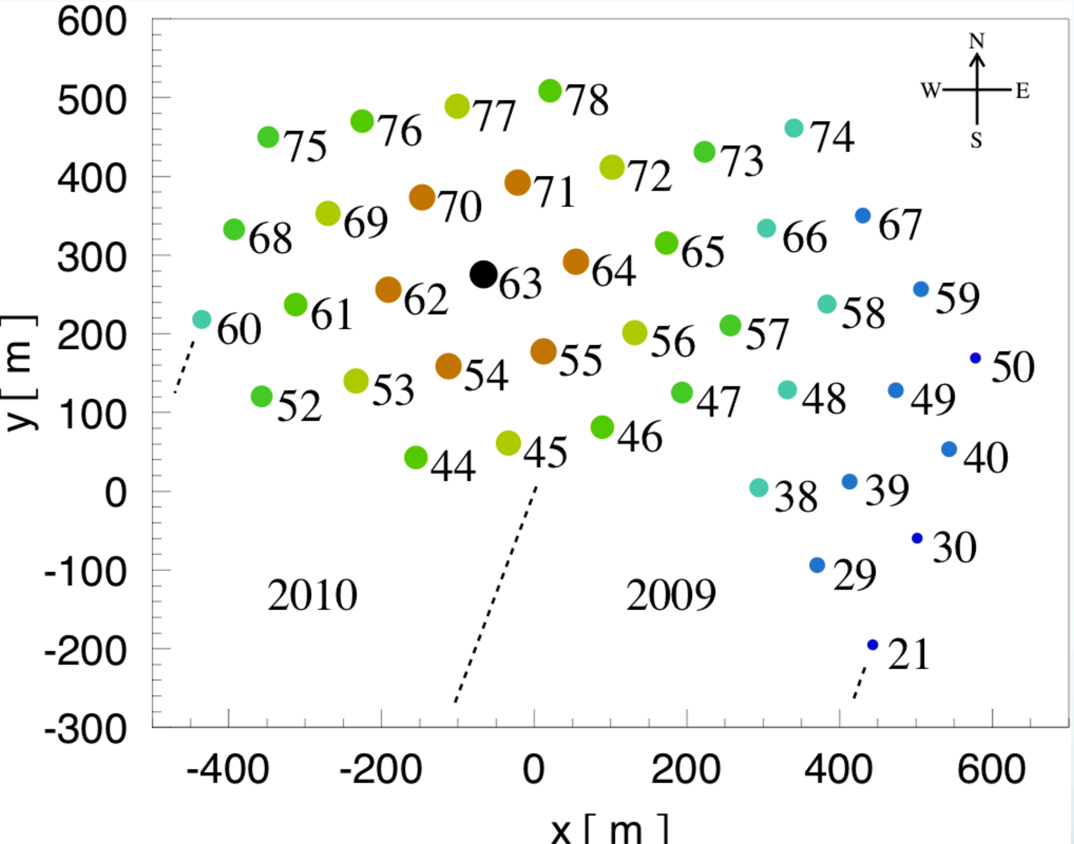


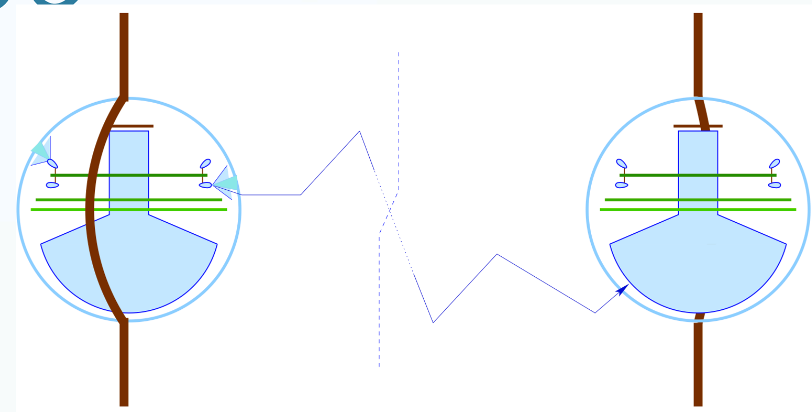
2 nitrogen laser "standard candles"

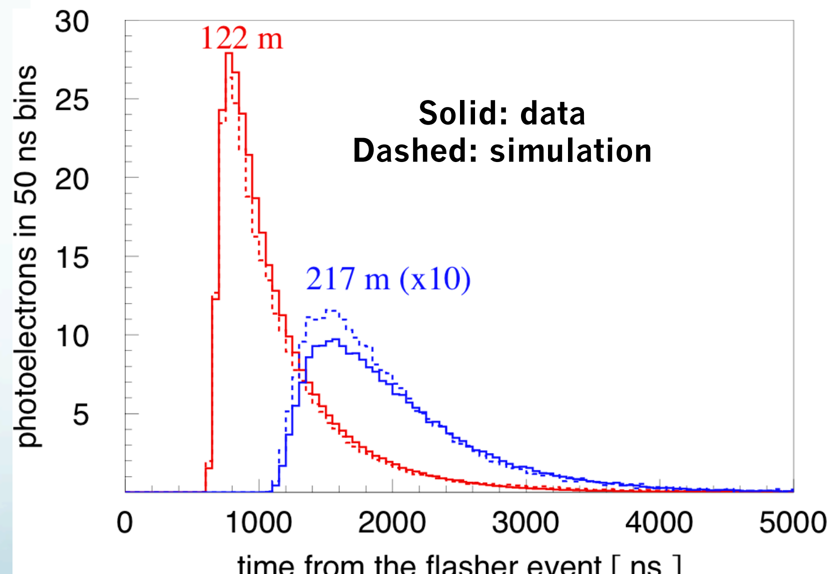


12 LED flashers aboard each DOM

Flasher Measurements in IceCube



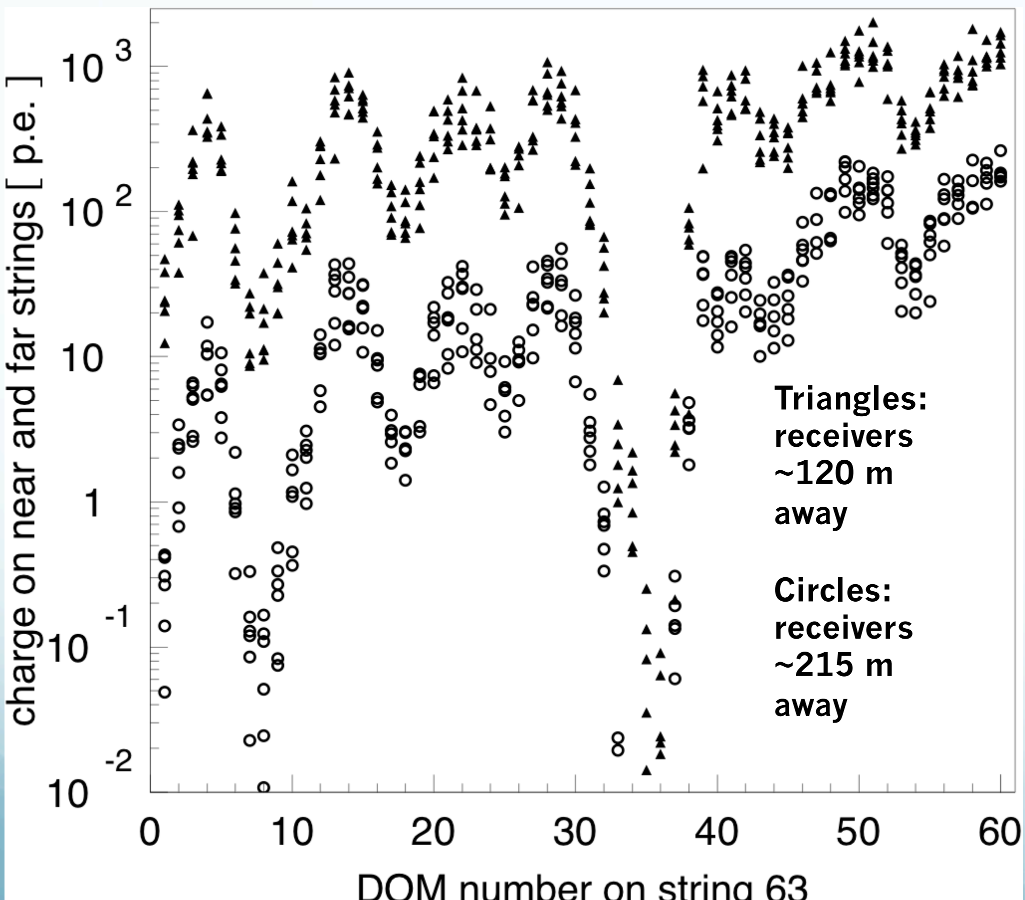




Flasher data collected in 2008 during IceCube construction
40 strings active

Received charge vs. time from flashing DOMs, collected by neighboring DOMs

Received charge vs. depth



Depth increases with DOM number from 1450 m (DOM 1) to 2450 m (DOM 60)

Received charge is plotted for flasher at the same depth as the receiver

Strong depth-dependent variations => depth-dependent scattering and absorption due to layers of dust in the ice

Simulation

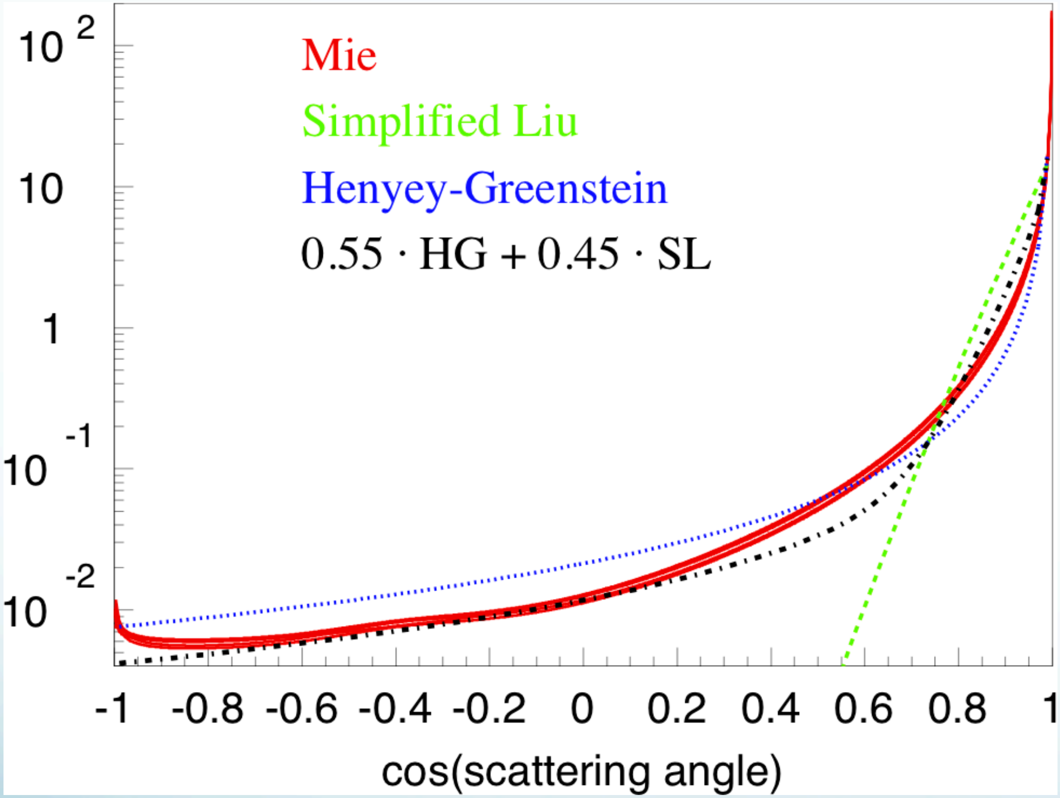
- Direct photon propagation with Photon Propagation Code (PPC)
- Geometric scattering coefficient b : distance between successive scatters is 1/b
- Effective scattering coefficient b_e

$$b_e = b \cdot \left(1 - \langle \cos\theta \rangle\right)$$

θ is the angle between scatters

- Absorption coefficient a : distance travelled by photon before absorption is 1/a
- Divide detector into 100 10-m layers in depth, fit to a and b_e in all layers (200 parameters)
- Simulate many values of a and b_e, find best fit to data using likelihood method

Scattering Function



Use linear combination of simplified Liu and Henyey-Greenstein models to approximate Mie Scattering

$g = \langle \cos\theta \rangle = 0.9$

Simplified Liu:

$$p(\cos\theta) \sim (1+\cos\theta)^{\alpha}, \quad \text{with} \quad \alpha = \frac{2g}{1-g}$$

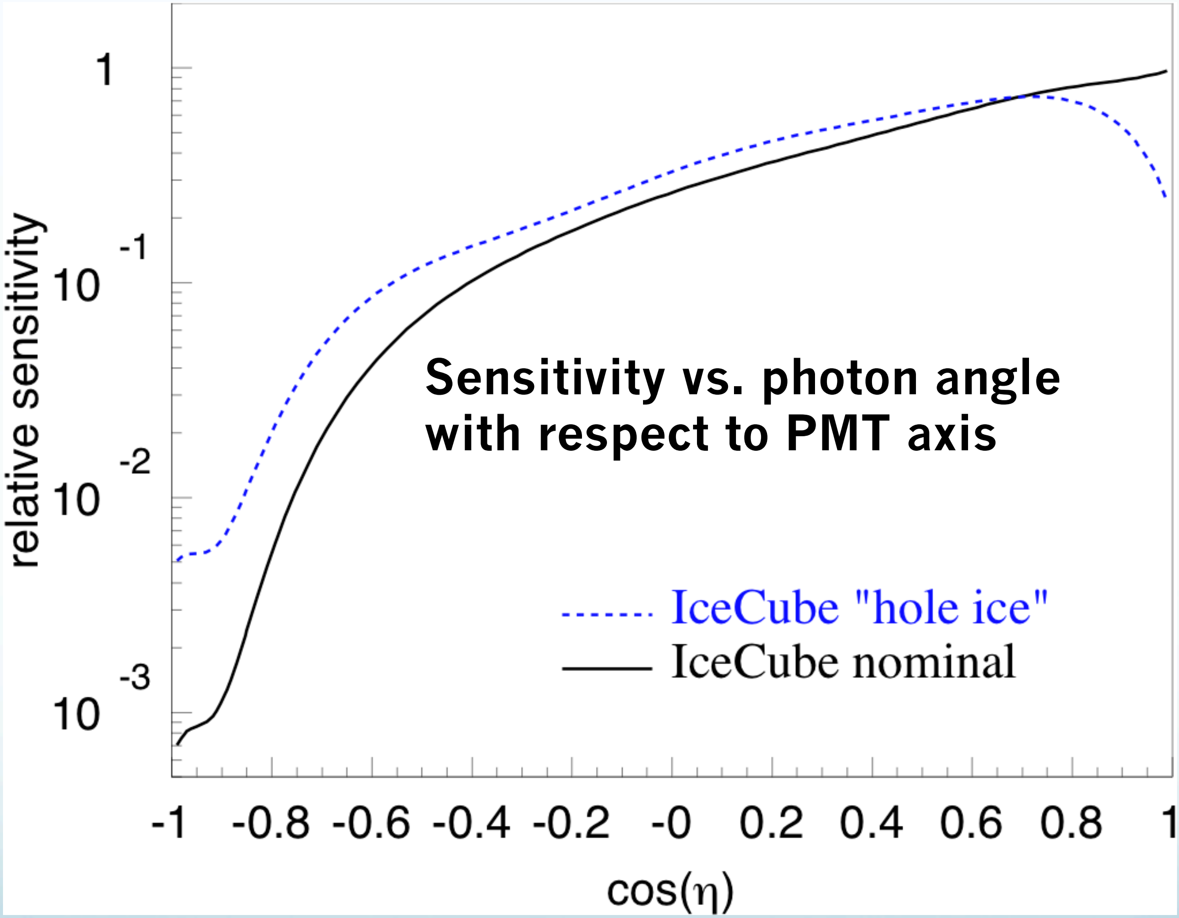
Henyey-Greenstein:

$$p(\cos\theta) = \frac{1}{2}\frac{1-g^2}{[1+g^2-2g\cdot\cos\theta]^{3/2}}$$

Mie:

Describes scattering on acid, mineral, salt, and soot with concentrations and radii at South Pole

Hole Ice Model

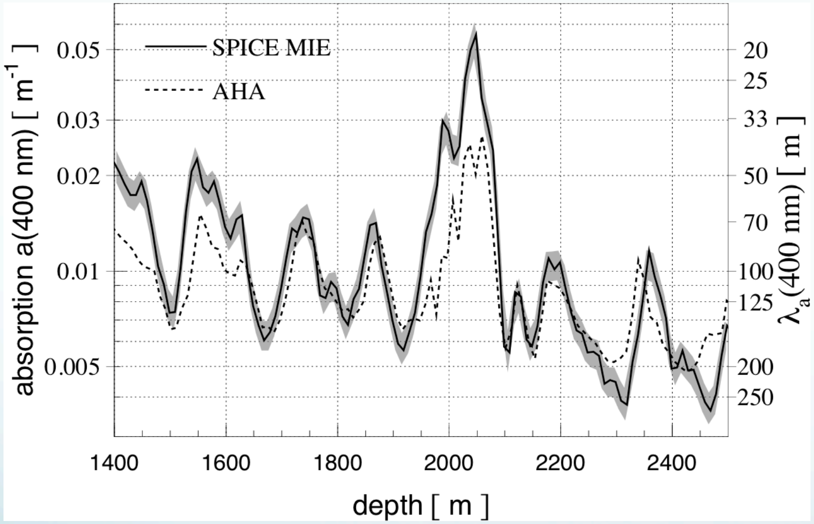


Melted and re-frozen "hole ice" introduces additional scattering
Effective scattering length of 50cm in the hole (under study)
modeled as a change in the effective angular sensitivity of the DOM

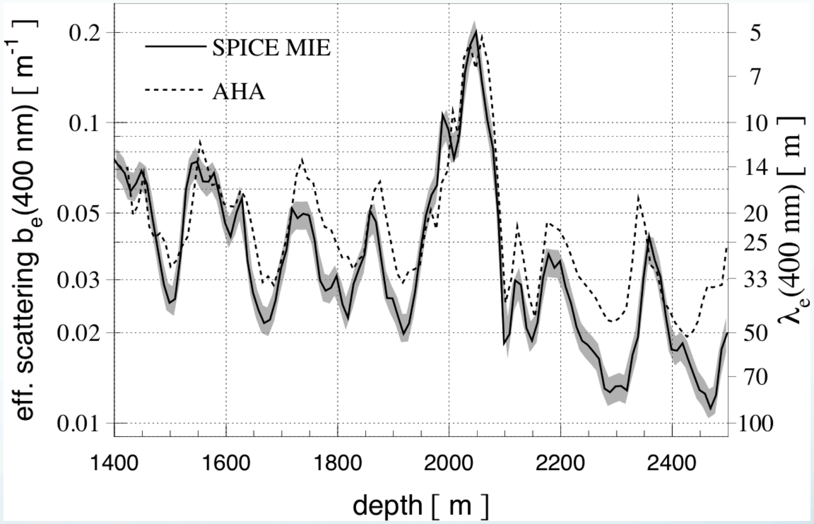
Results: SPICE Mie

SPICE = South Pole Ice model

Absorption



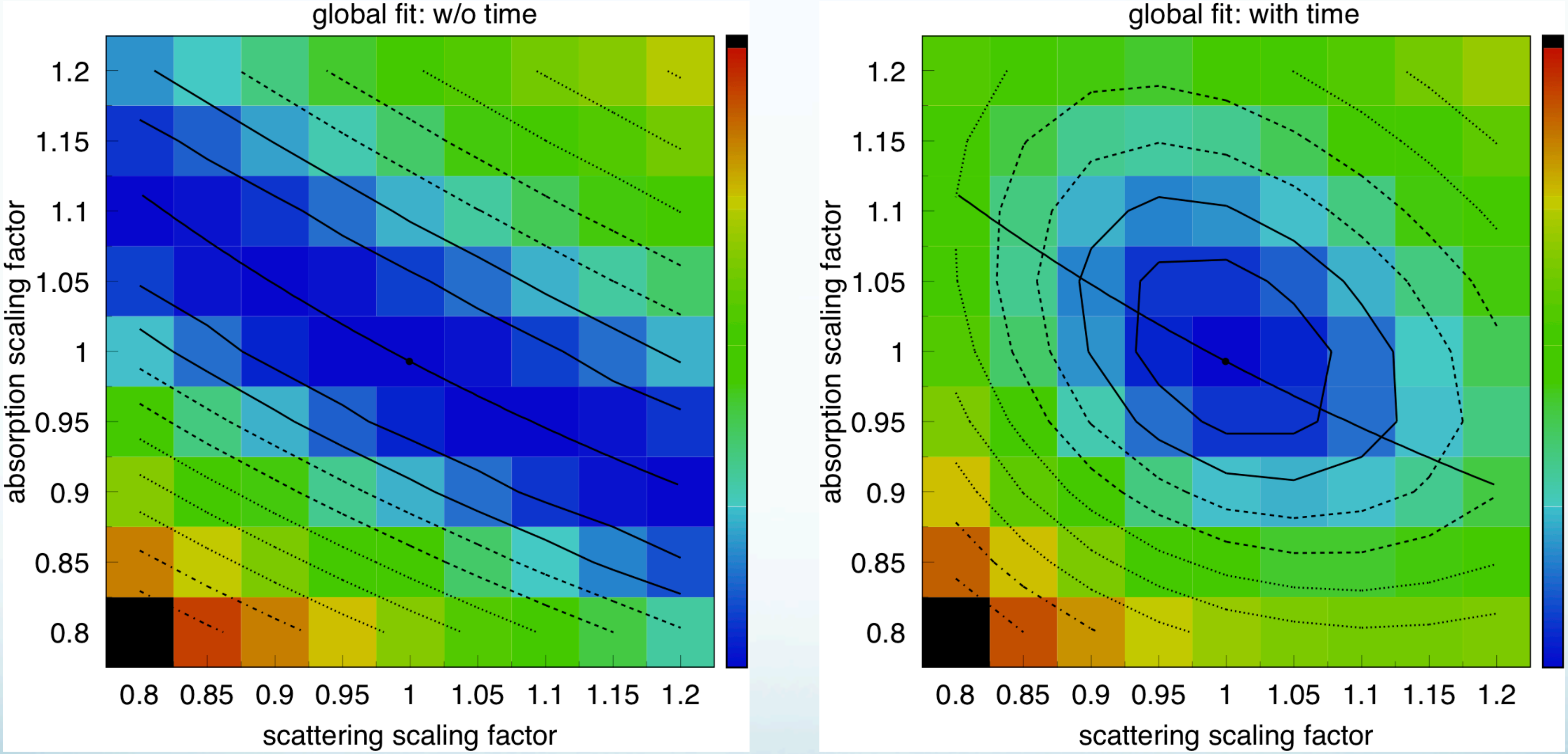
Scattering



Gray band: range allowed by uncertainties: ±10%

Aartsen et al., Nucl.Instrum.Meth. A711 (2013) 73-89

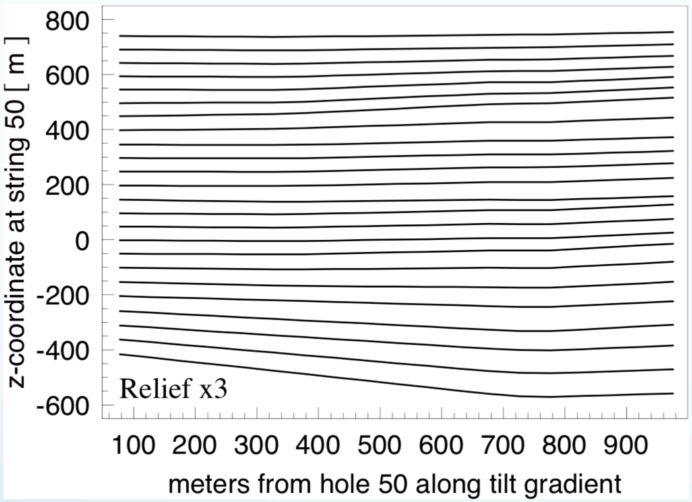
Likelihood

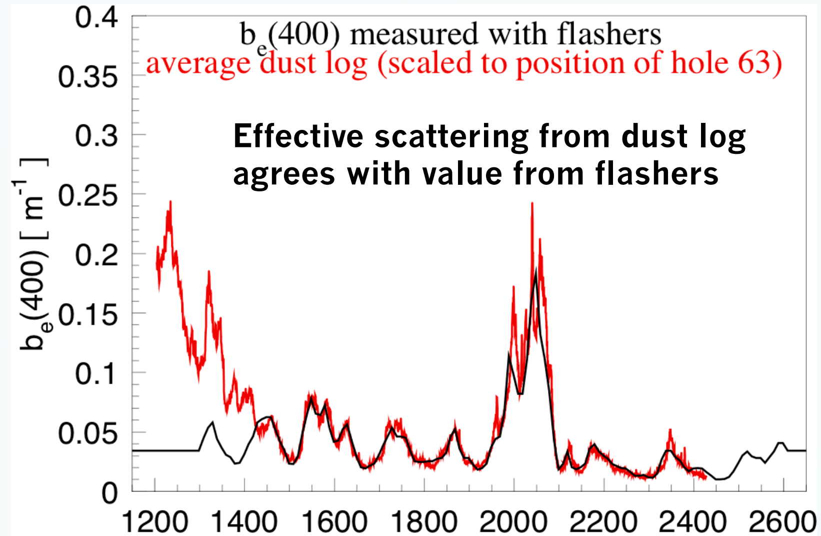


Likelihood functions using charge information only (left) and both charge and time information (right)

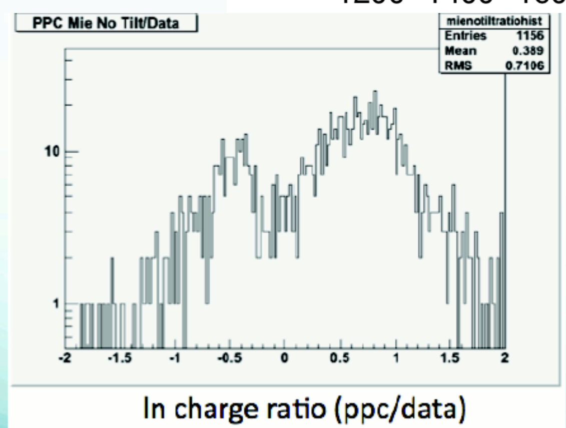
Comparison with Dust Log Data, Tilt

Dust log data shows that dust layers in ice are tilted

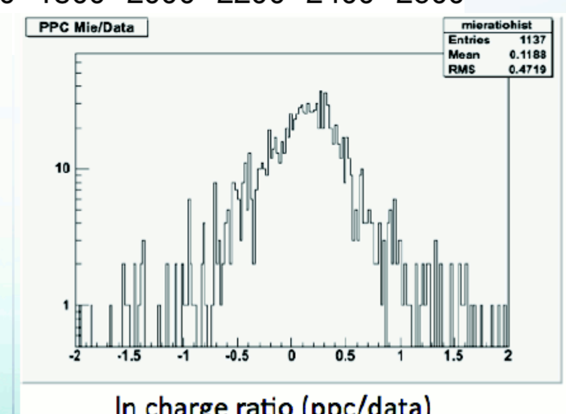




Comparison of simulation to 2012 flasher data over 200 m from string 63, shows strong effect from dust layer tilt

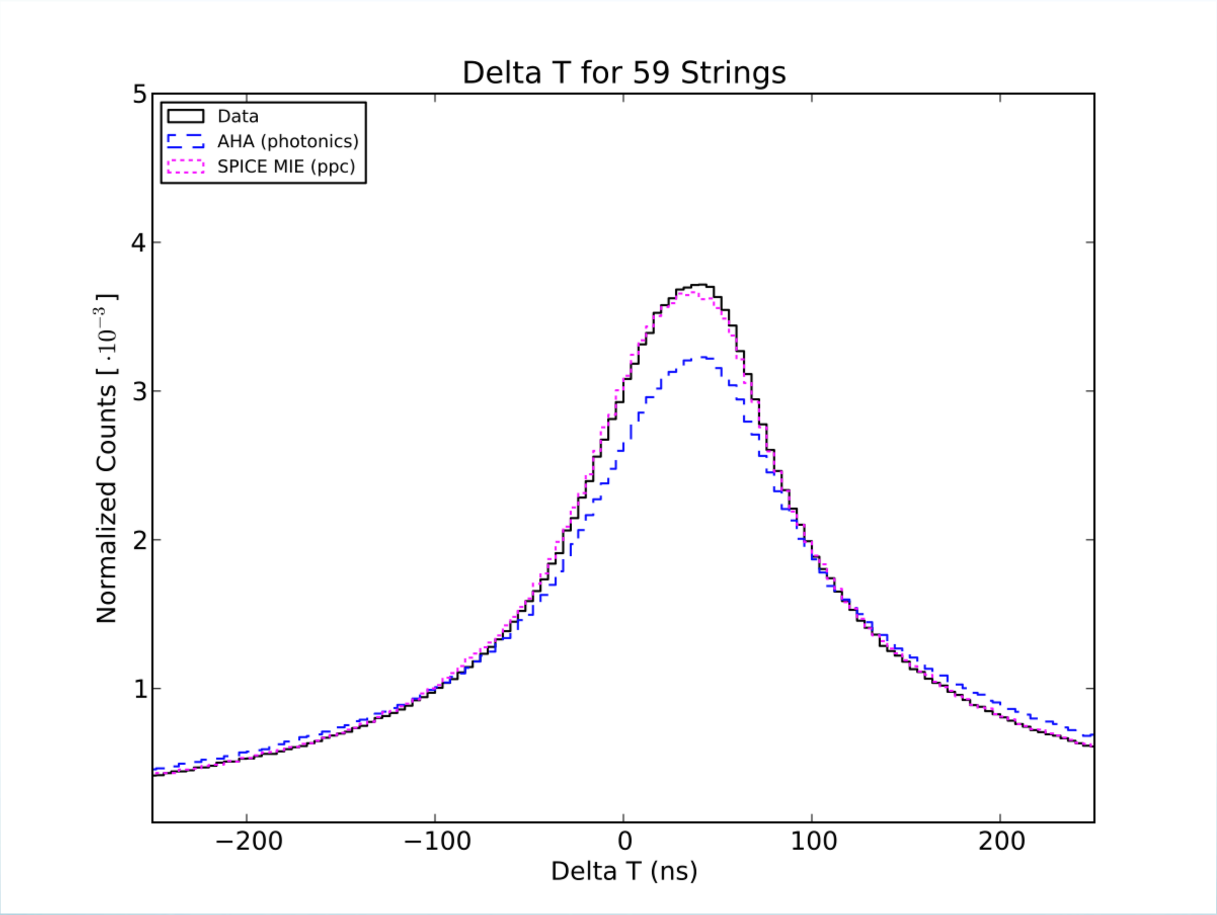


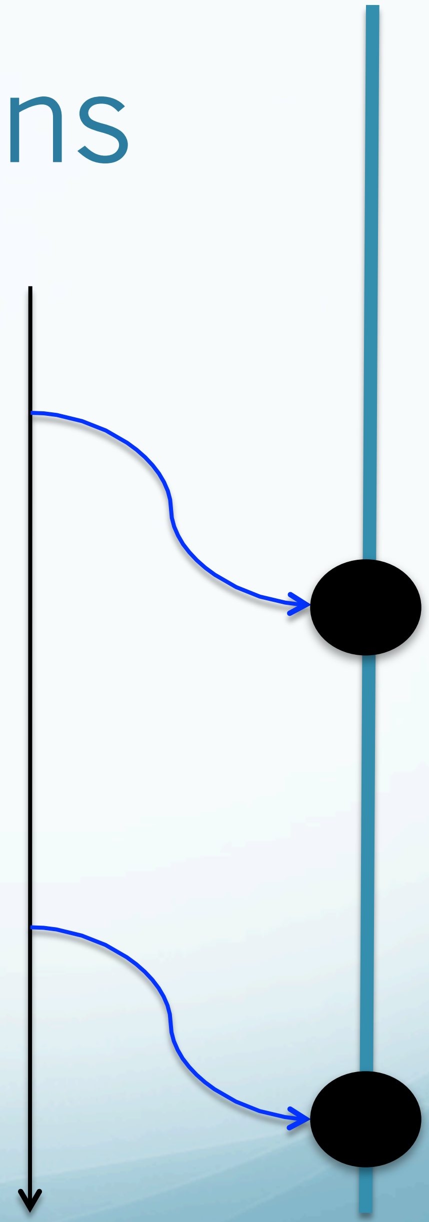
Comparison of LED flasher simulation to data without tilt



Comparison of LED flasher simulation to data with tilt

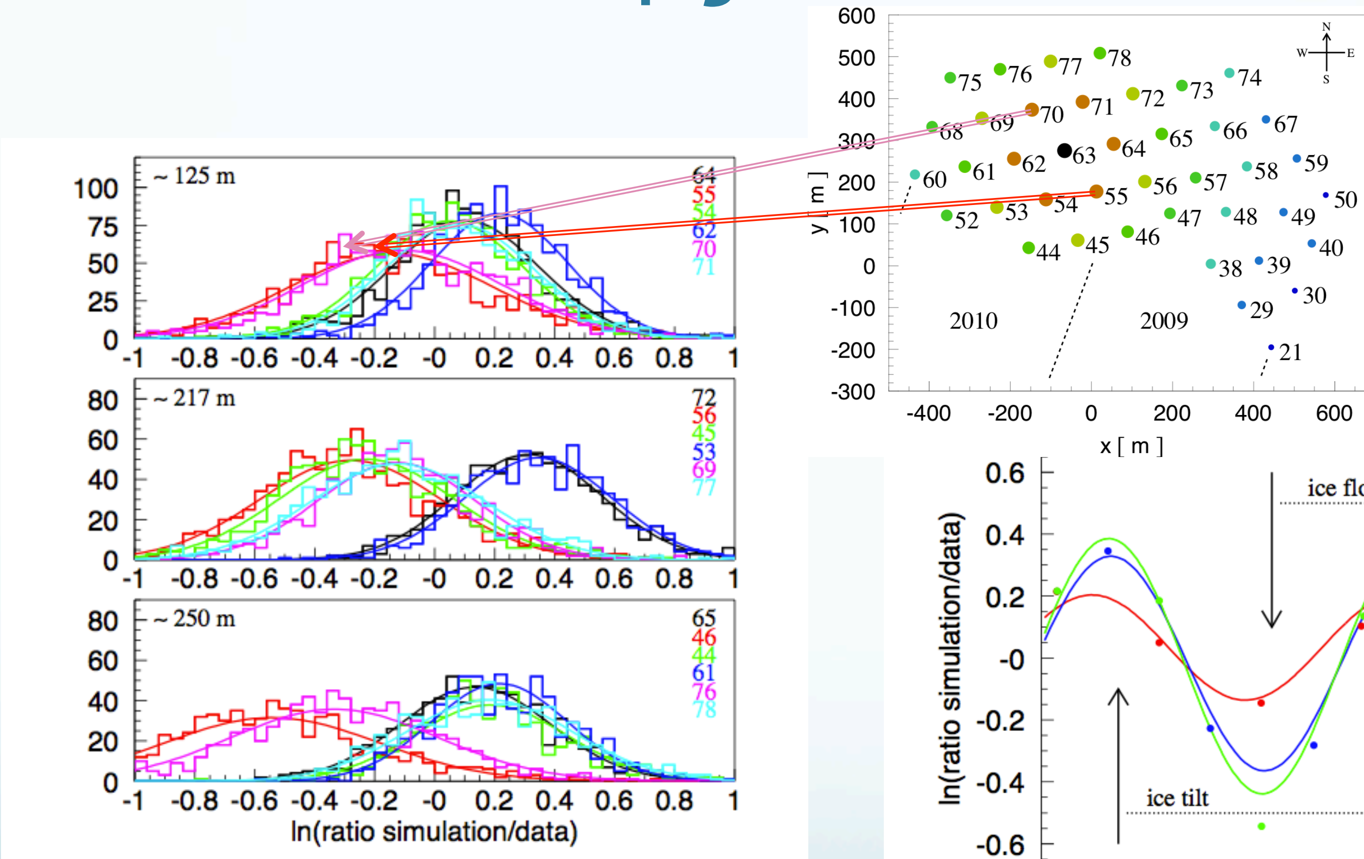
Delta T from Muons



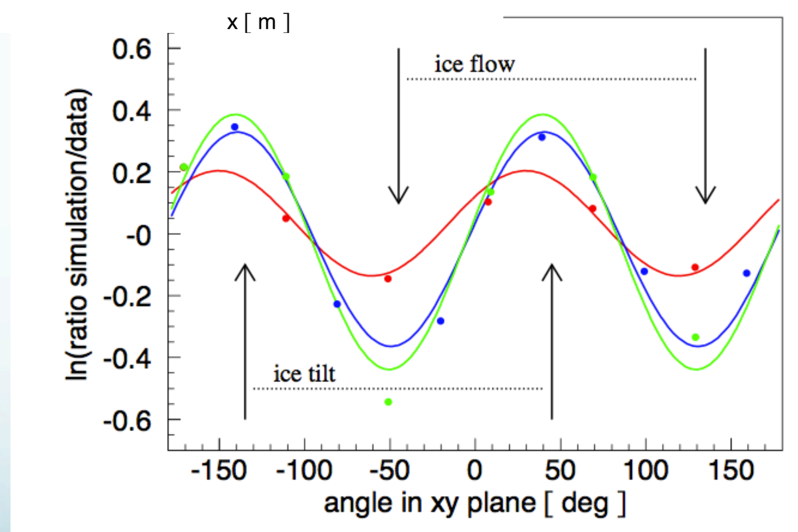


Comparison of difference in arrival times at neighboring DOMs on a string

Anisotropy in Scattering

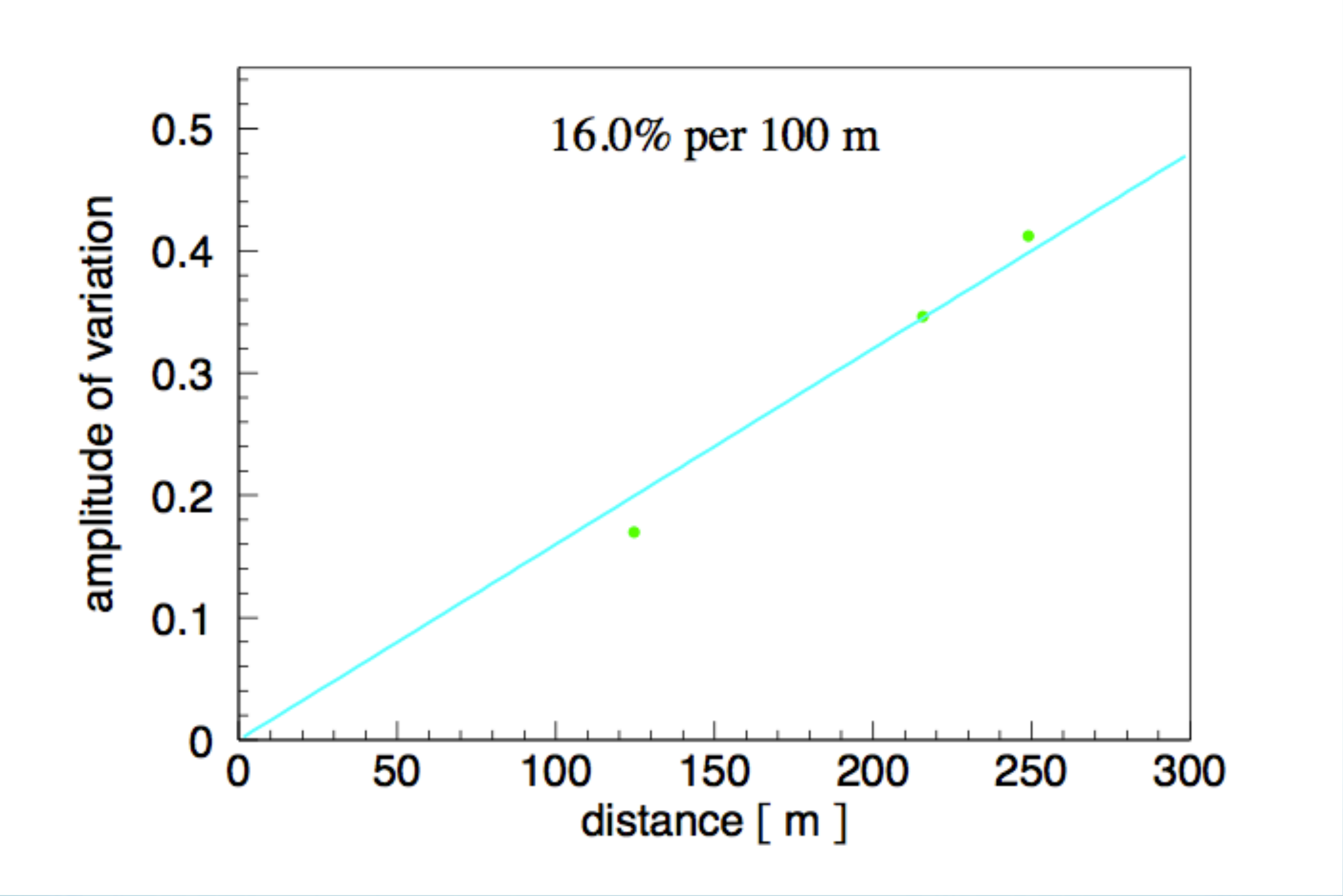


Ratio of simulated (SPICE Mie) charge to data on strings surrounding the flashing string



Maxima of ratio histograms vs. azimuth

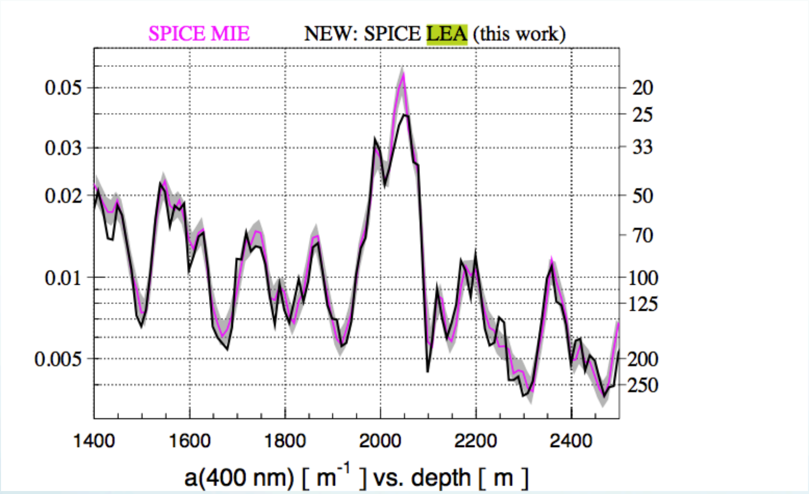
Anisotropy



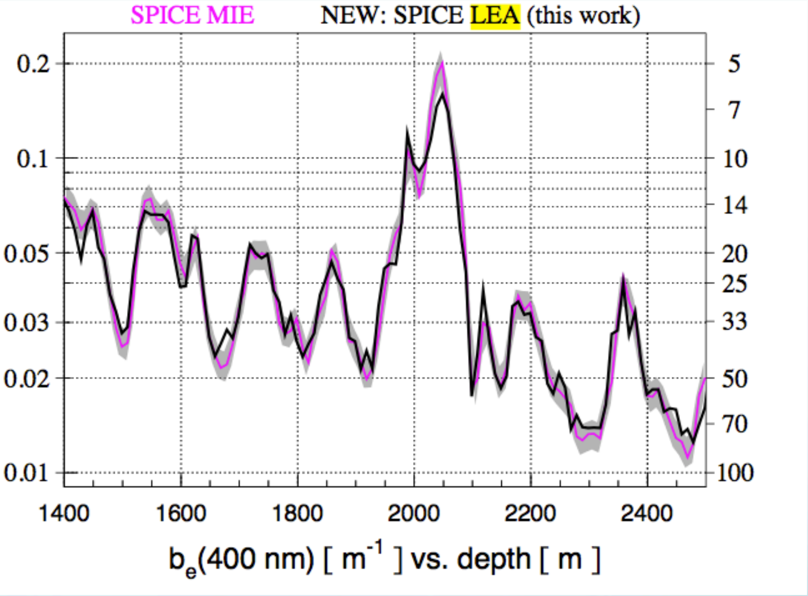
16.0% per 100 m
amplitude of variation
0.5
0.4
0.3
0.2
0.1
0
0
50
100
150
200
250
300
distance [m]

Ice Model with Anisotropy: SPICE Lea

Absorption

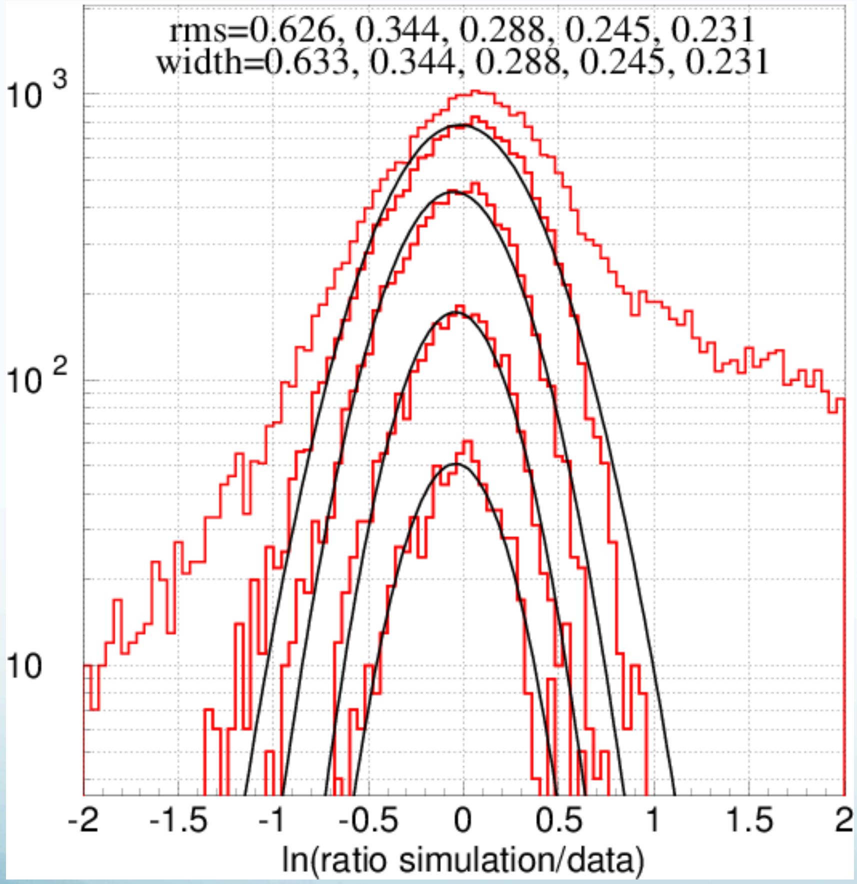


Scattering

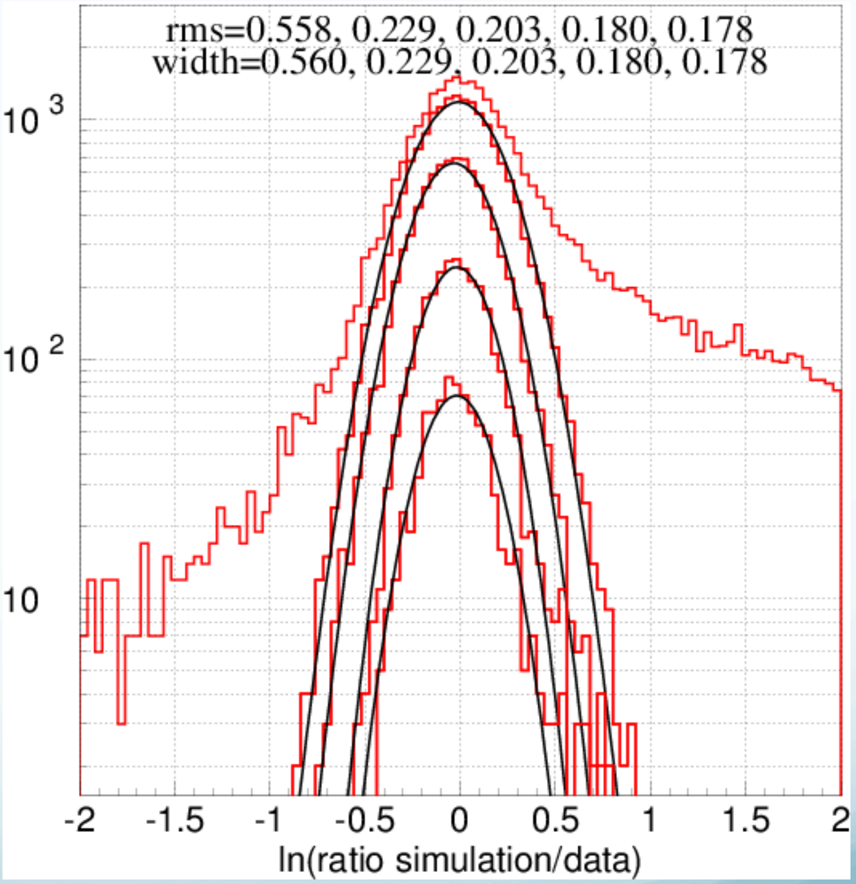


D. Chirkin, ICRC 2013

Model error improvement

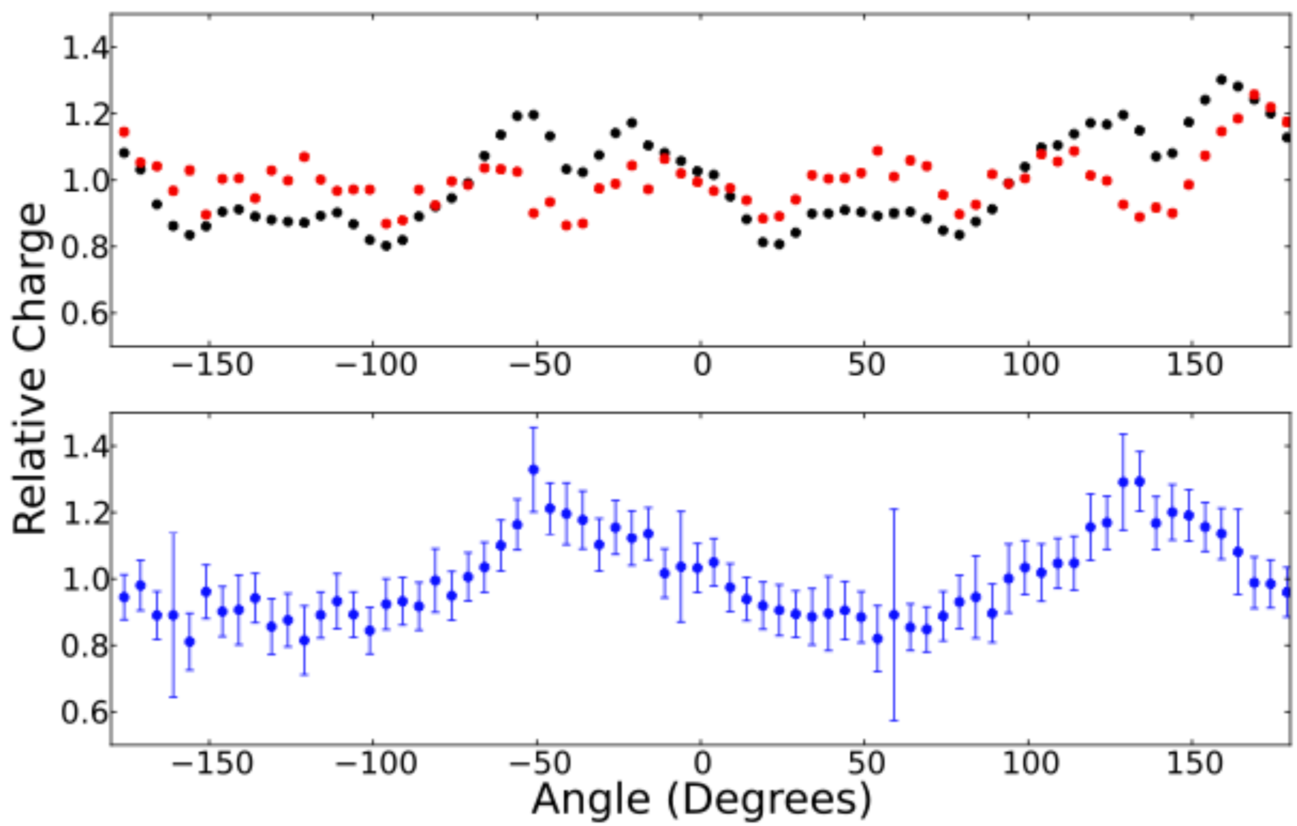


SPICE Mie flasher data/ simulation comparison



SPICE Lea comparison

Comparison with Muon Data



Data
SPICE Mie simulation

Ratio of data to simulation

Direction of maximum charge agrees with data from flashers

Summary

- Ice at the South Pole has complex depth- and x-y-dependent variations
- Model fit to flasher data using direct photon propagation shows good agreement with data
- Many more studies are ongoing
  - Using flasher data at multiple locations in the detector
  - Using multi-wavelength flasher data
  - Direct simulation of the hole ice