Detector Systematics in IceCube
A Calibration Coordinator's View

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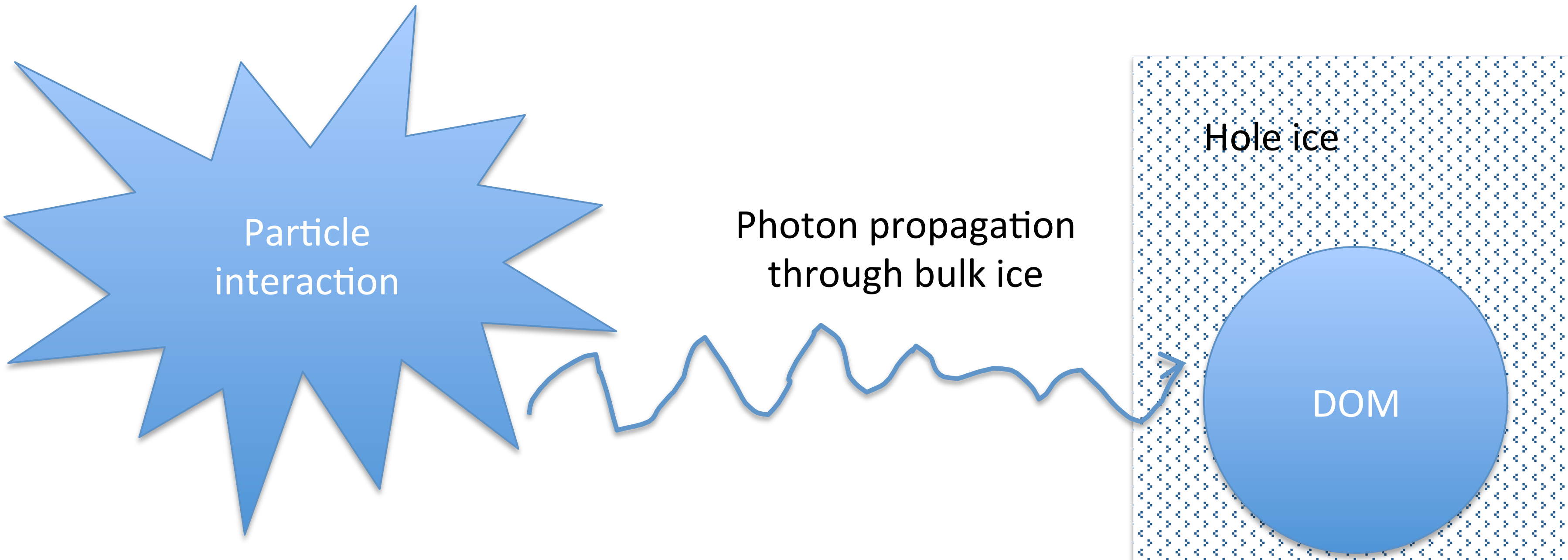
Workshop on Muon Analyses in IceCube

May 3, 2015

What this talk covers

- Bulk ice properties
- Hole ice
- DOM sensitivity
- Notes on the vocabulary and what it means in terms of implementation
- The current status of measurements in the calibration group and what it means for analyzers – not everyone has the same opinion!
- Thanks to Dima for preparing a beautiful ice talk for Peo's memorial plenary and saving me a lot of time!

From particle to DOM



The calibration group does not handle systematics of particle interactions, flux, etc.

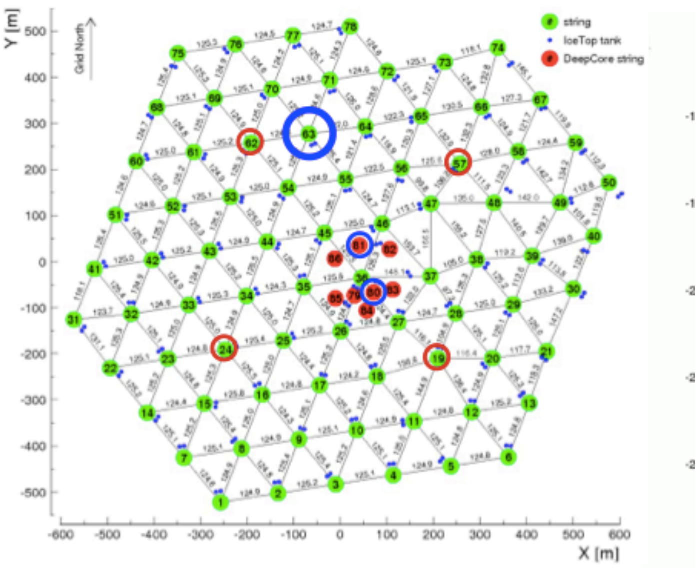
We communicate with IceTop (usually Serap) about IceTop detector issues, but primarily we deal with in-ice issues.

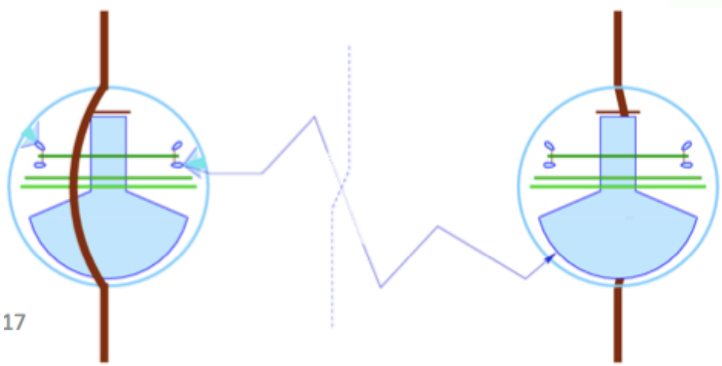
For the purposes of this talk, systematics are **in ice detector systematics**, and the detector consists of ice and DOMs.

Bulk ice

- Bulk ice is ice which was not melted during deployment: ice between strings and outside the instrumented volume
- In the IceCube volume, the principle effect on the optical properties of the bulk ice is from dust and impurities (not bubbles)
- Ice properties are generally measured using flashers and other calibration devices, and verified with muons where possible

Fitting ice model to flasher data





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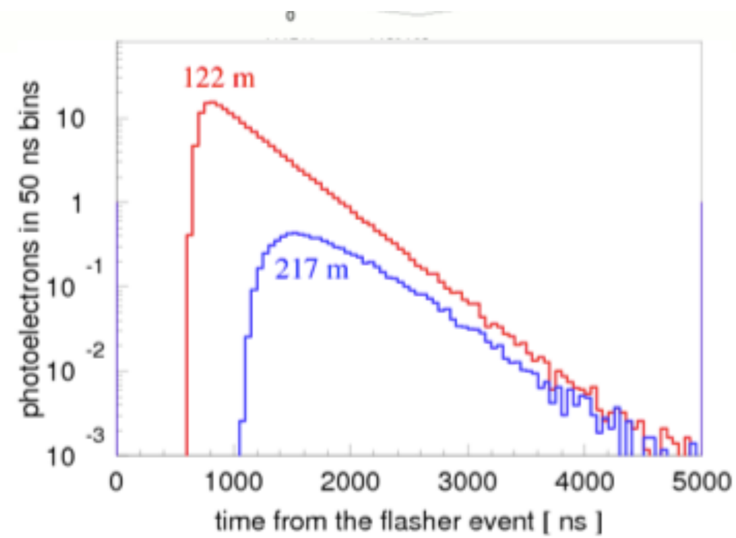
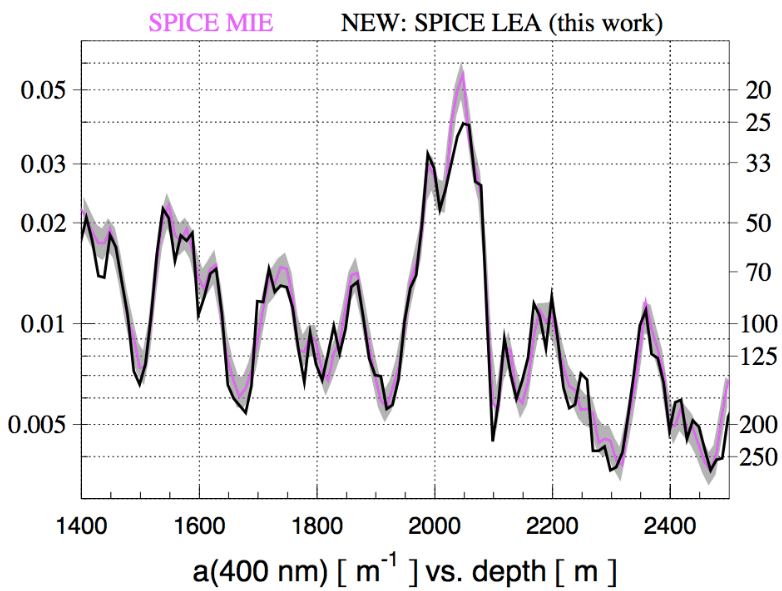


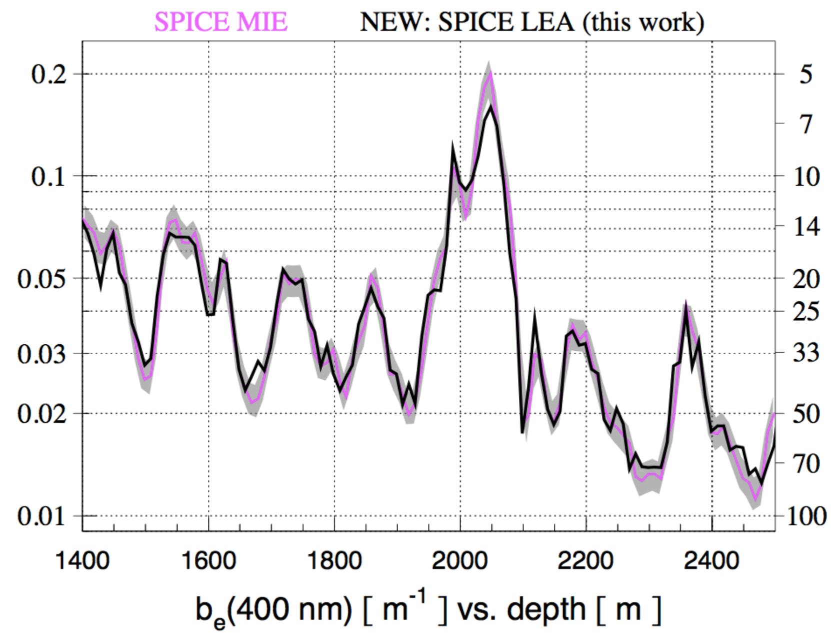
Both absolute flasher light output and angular distribution have uncertainties!

Bulk Ice Properties

absorption

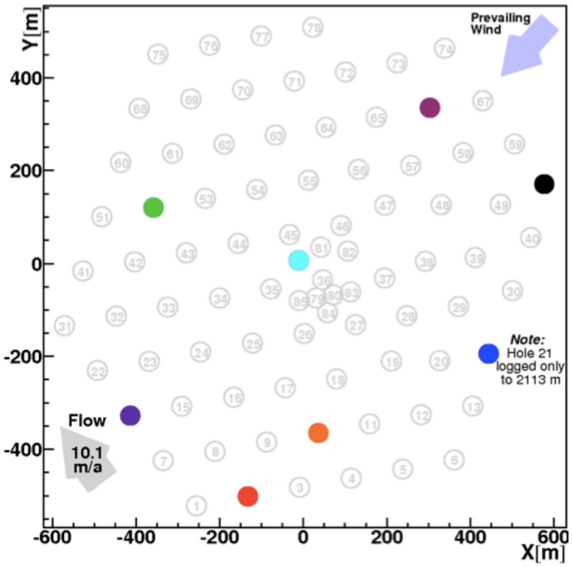


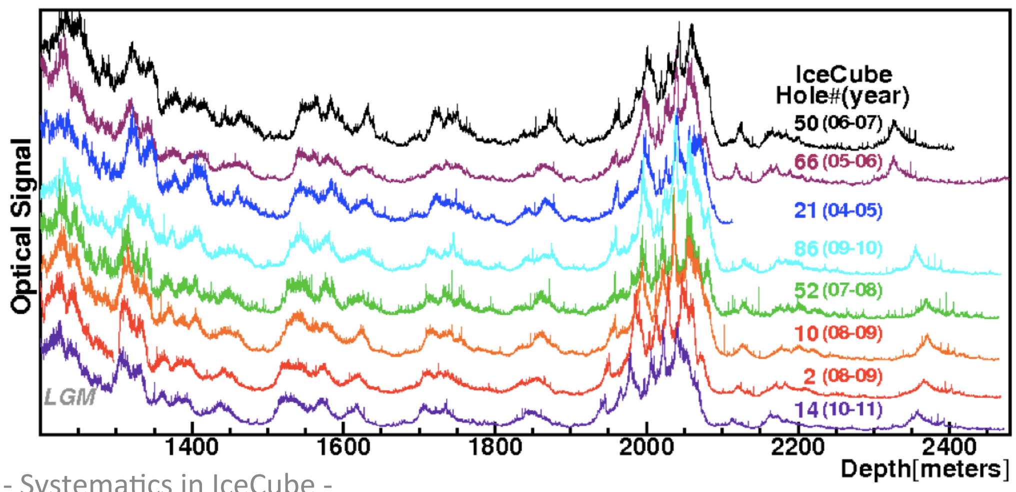
scattering



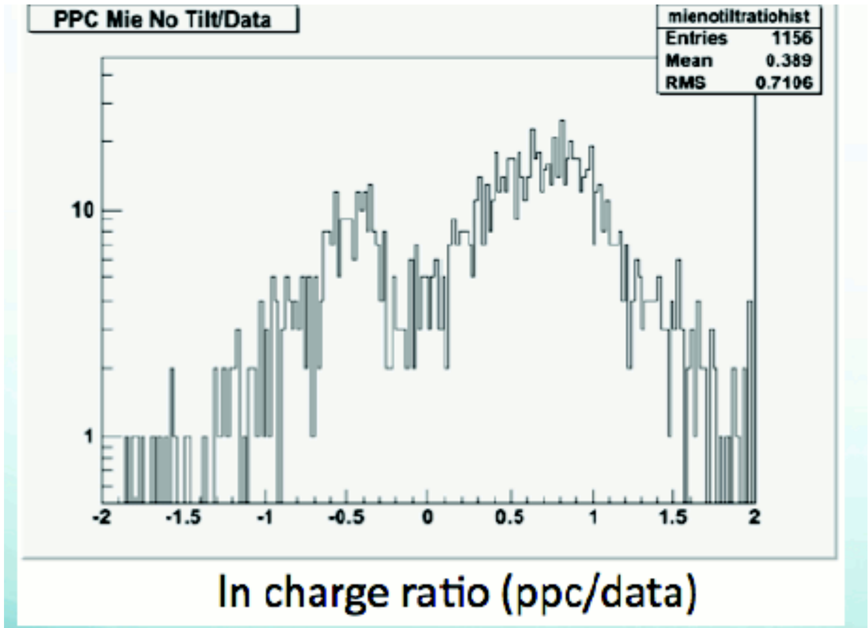
Dust layers, not layer

- The dust layers have been measured by loggers in multiple IceCube holes during deployment, and supplemented by ice core data
- The layers are tilted with respect to the detector geometry

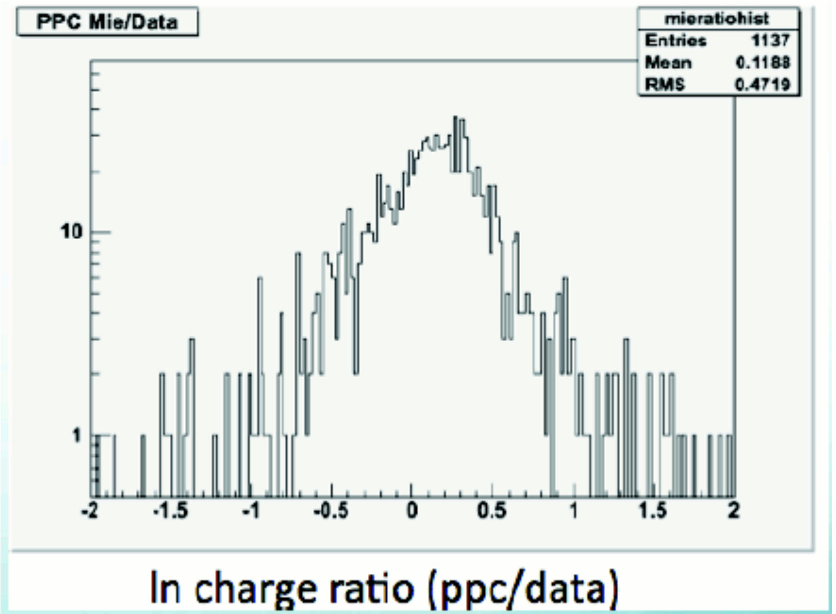




Effect of getting tilt wrong



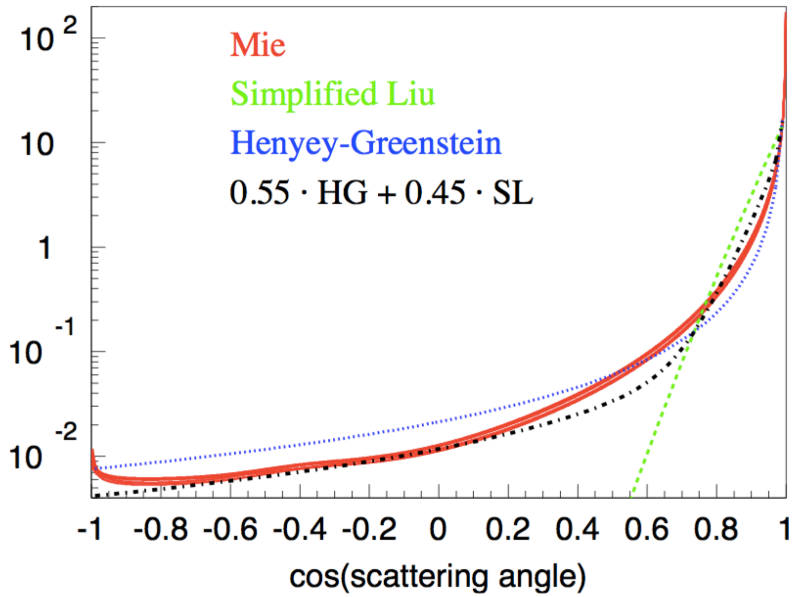
Comparison of LED flasher simulation to data without tilt



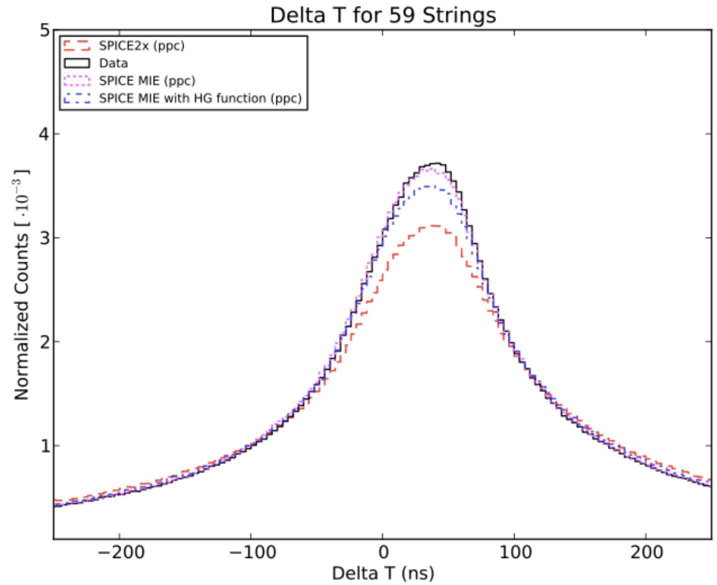
Comparison of LED flasher simulation to data with tilt

Scattering on dust: Mie scattering

Mie scattering: linear combination of SL and HG models

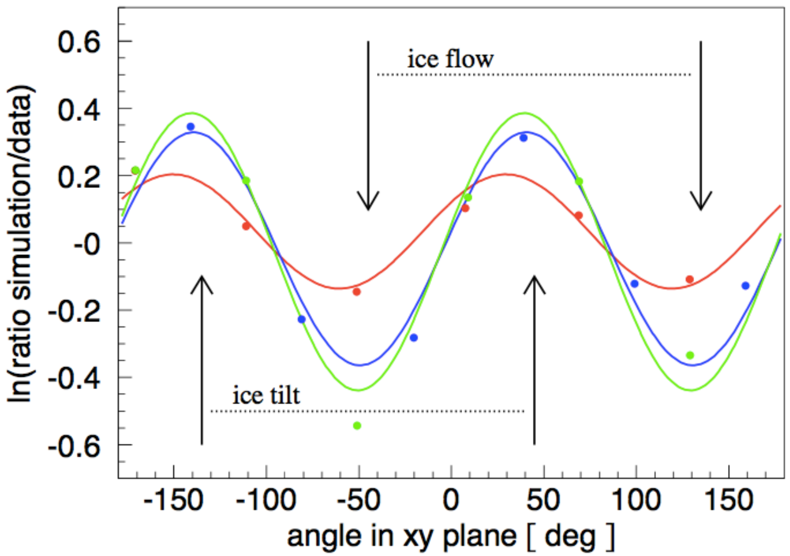


Effect of Mie model on muon delta-T distribution

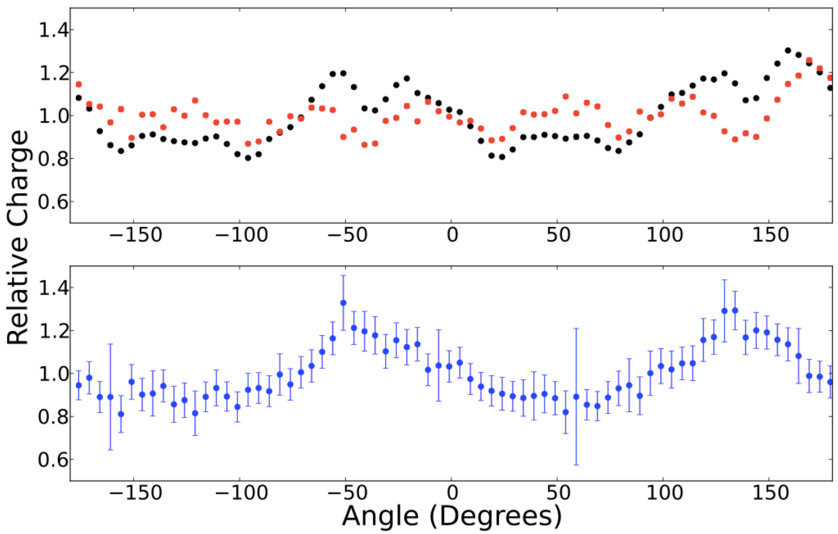


Scattering on dust: anisotropy

Anisotropy with flashers



Anisotropy with muons



Implementation of Bulk ice in simulation

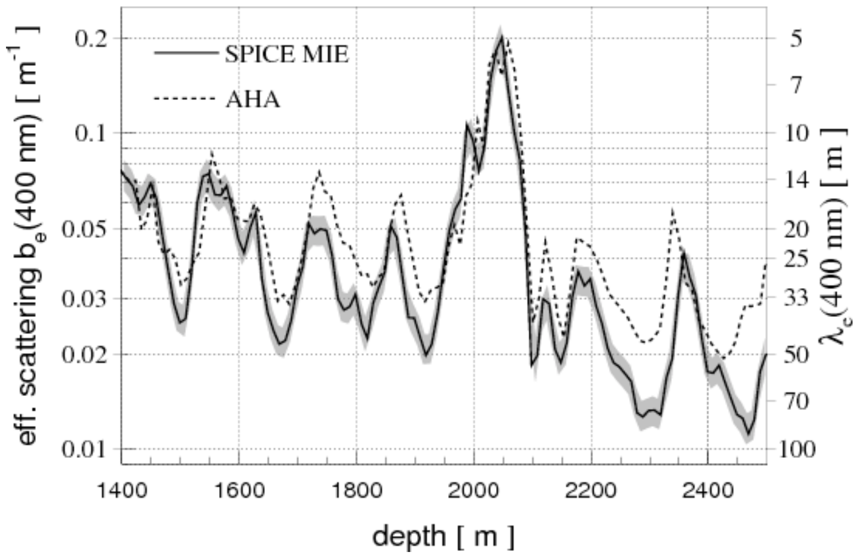
- Scattering as a function of depth
- Absorption as a function of depth
- Tilt
- Direction and magnitude of anisotropy
- Average cos(scattering angle)
- Relative fraction of SL and HG models
- Wavelength dependence of parameters
  - Quick note, this has been verified with cDOMs

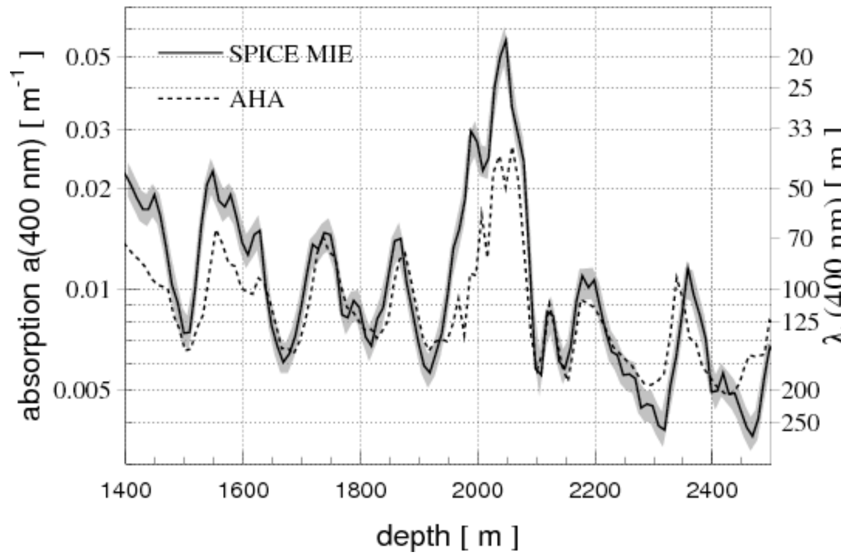
What do we mean by uncertainties? Error vs. model error

- "The resulting situation compels us to report both the parameter uncertainties (~10%), and the average model error (~30%)"

--Measurement of South Pole ice transparency with the IceCube LED calibration system, **Nucl.Instrum.Meth. A711 (2013) 73-89** (aka the Spice Mie paper)

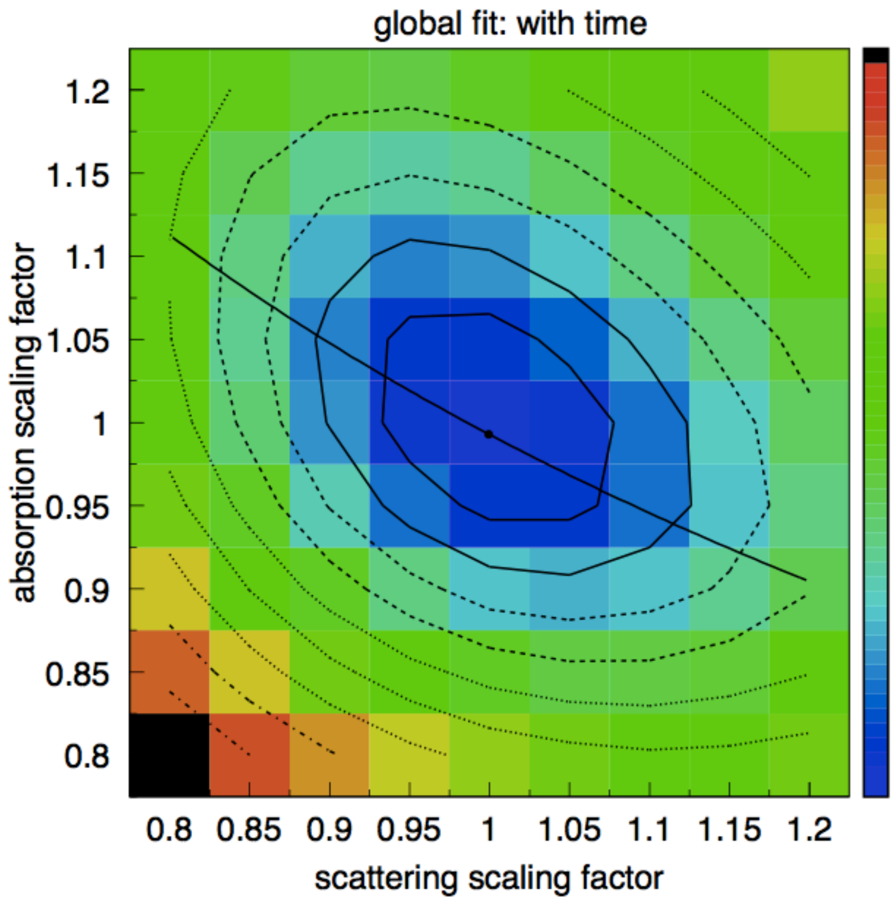
Parameter uncertainties



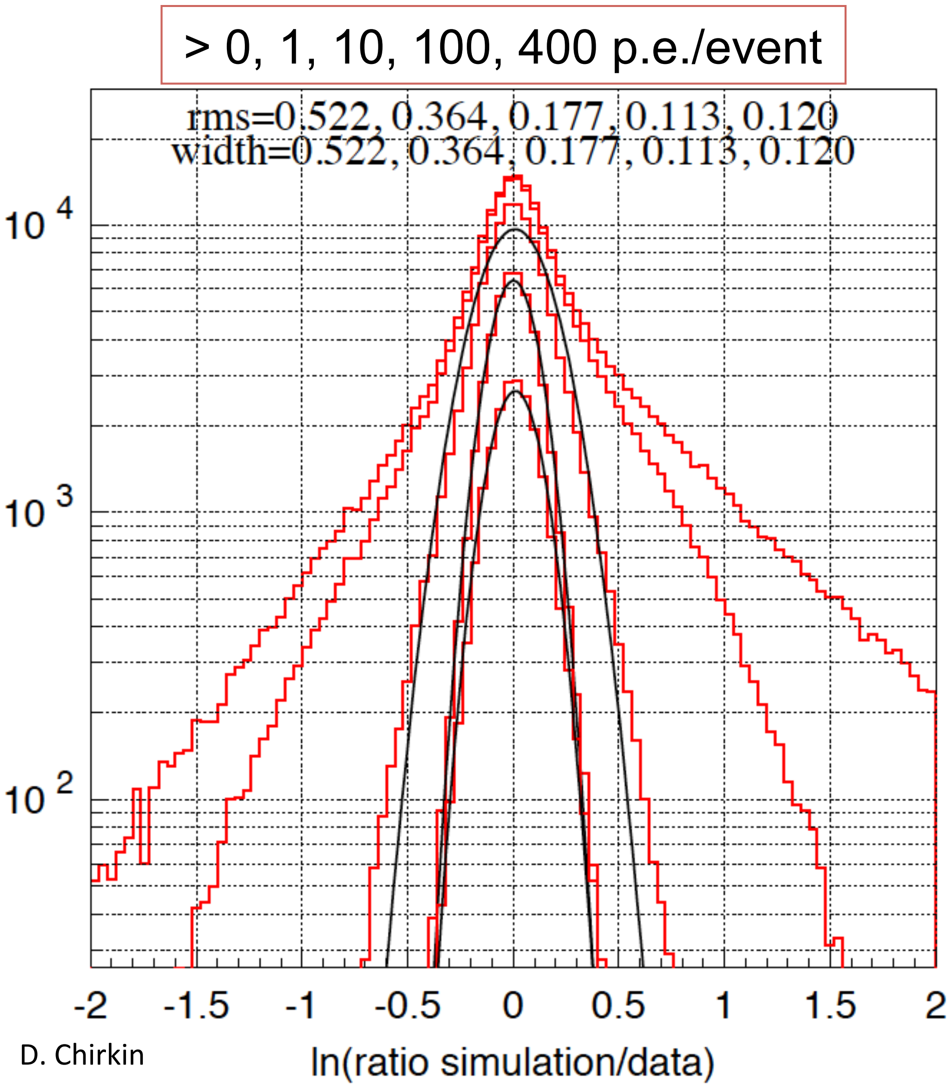


This is the statistical uncertainty on the scattering and absorption length, due to uncertainty in the flasher time profile, statistical fluctuations in the model fitting and calibration/feature extraction uncertainties.

The uncertainty ellipse



Model Error



D. Chirkin

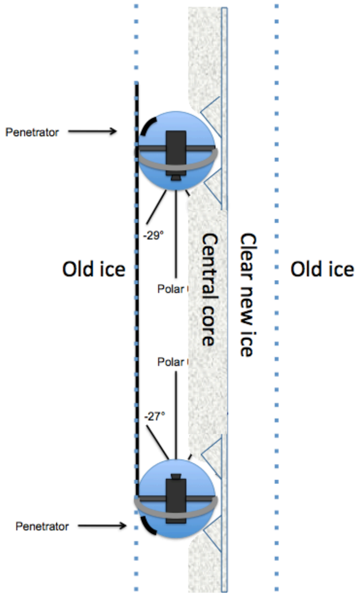
- Model error is the difference between the received charge per DOM in simulation and data
- Model error is in part due to unsimulated effects beyond the uncertainty in the bulk scattering/absorption

Beyond SPICE Lea

AMANDA ice models:			model error
bulk, f125, mam, mamint, stdkurt, sudkurt, kgm, …			
millennium (published 2006) → AHA (2007)			55%
IceCube ice models:			
WHAM	(2011)		42%
SPICE 1	(2009)		29%
SPICE 2, 2+, 2x, 2y	(2010)	added ice layer tilt	
SPICE Mie	(2010)	fit to scattering function	29%
SPICE Lea	(2012)	fit to scattering anisotropy	20%
SPICE (Munich)	(2013)	7-string, LED unfolding	17%
SPICE^3 (CUBE)	(2014)	llh fixes, DOM sensitivity fits	11%
SPICE^3 (CUBE)	(2015)	improved DOM, ang. sens. fits	10%

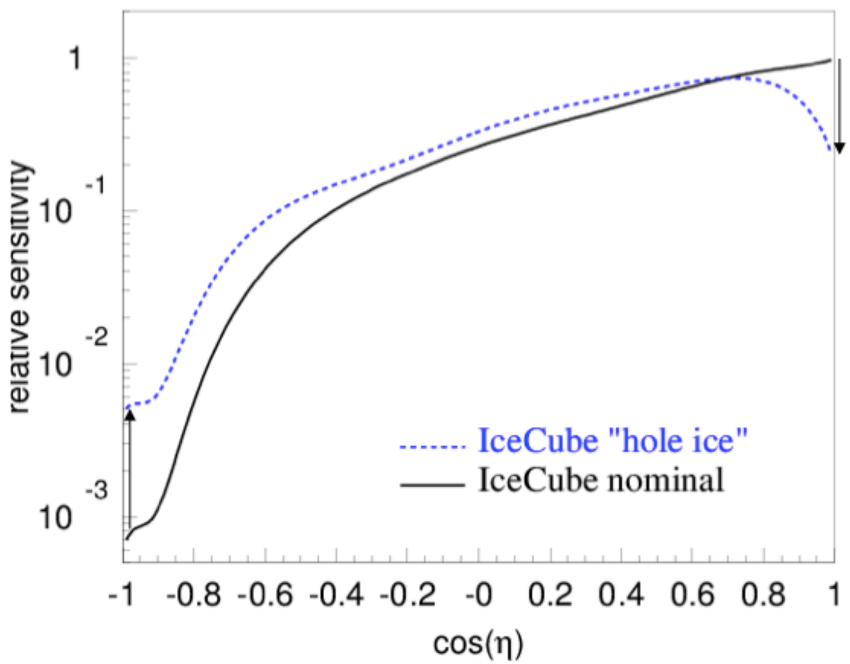
Hole ice

- Hole ice is ice which is melted and refrozen during deployment
- Hole ice can vary from hole to hole due to deployment conditions
- We have one location where hole ice can be photographed: we see a clear ice with a narrow column of bubbles in the center

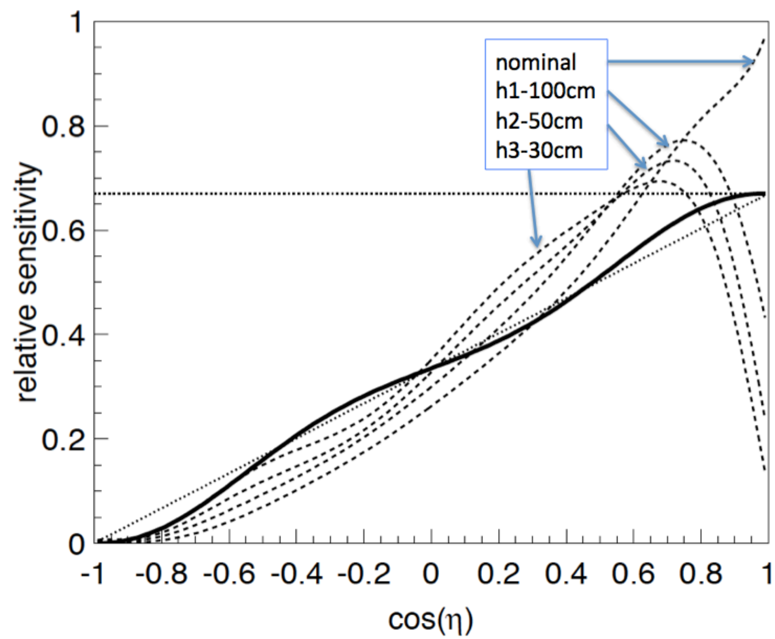


Implementation of hole ice

Current nominal implementation



New fit to flasher data



We do NOT directly simulate the bubble column: hole ice is implemented as a modification of the angular dependence of the DOM sensitivity!

Hole ice: what's the right answer?

- A lot of nuisance parameters in the flasher fit
- Attempts to find the hole ice in the flasher data with single LEDs have so far been dominated by the bulk anisotropy
- Martin Rongen reminds us that there is *inherent* azimuthal anisotropy in DOM response due to the dynode configuration
- Attempts to measure hole ice with muon timing residuals were dropped after the Mie model was adopted; Kevin Ghorbani is looking into updating this analysis

DOM sensitivity/acceptance/efficiency/response

- Unfortunately this term causes a lot of confusion
- In IceCube we use this term to cover a multitude of sins
  - PMT quantum efficiency
  - PMT collection efficiency
  - Cable shadowing
  - Discriminator threshold losses
  - Whatever local effects in the ice impact the DOM's sensitivity

You keep using that word. I do not think it means what you think it means. – Inigo Montoya, "The Princess Bride"

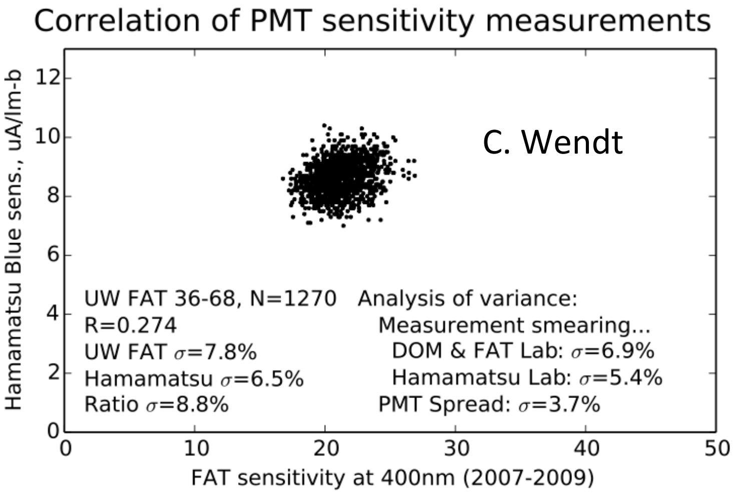
Measuring mean DOM efficiency in the ice

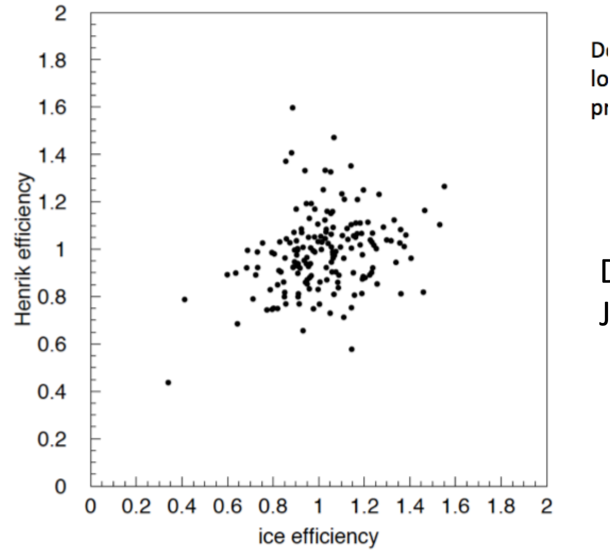
- Low energy muons with zenith angles between 40 and 70 degrees
- Compare simulated to expected charge
- Result was to raise average "efficiency" in simulation by about 10%, the quoted error on this measurement was ±3%
  - "Efficiency" in this context covers all effects except angular dependence
  - This is equivalent to taking out the cable shadow
- Caveats
  - 10% increase in efficiency does not lead to 10% increase in received charge
    - Alberta analysis points to reconstruction error as the reason for this
    - DANGER – reconstruction does not use anisotropic ice!!! Any reconstruction with tables is suspect in a Spice Lea simulation – Marcel Usner is working on this
  - This method cannot recover the relative efficiency of HQE DOMs
  - This analysis was done for SPICE Mie with old simulation (pre-V4), and most of it was done with photonics, with a scaling factor for PPC
- The relative efficiency of standard and HQE DOMs (1.35:1 HQE:STD) was determined with a double ratio occupancy analysis of muon simulation
  - https://wiki.icecube.wisc.edu/index.php/DeepCore_Relative_HQE_Setting
- ±10% is a more conservative error bar but not well motivated

Updating the muon mean efficiency analysis

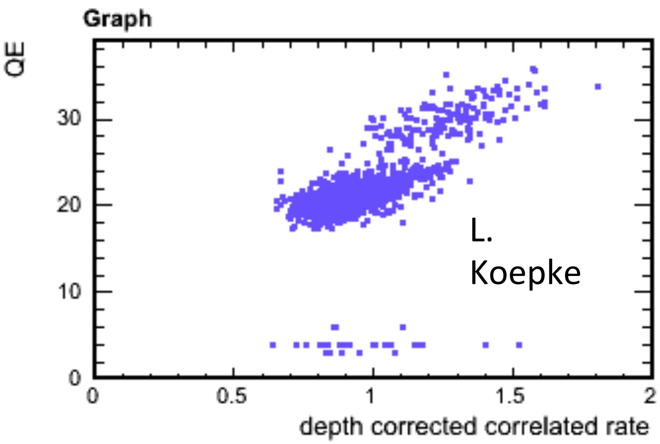
- Updated study with muons in V4/IC86/Spice Lea simulation going on at Alberta (see Tania's talk)
- The first attempt at the update was stalled by the DOMLauncher bug
- Getting simulation has been a bottleneck
  - Need to quickly produce muon simulation with a lot of different knobs to turn
  - But we also want direct photon propagation, non-oversized DOMs… hard to do that quickly!
- Direct simulation of cable shadow has been tried to actually determine what effect that should have on the efficiency – analysis was not completed
- Can we do anything with the DM ice muons? Low statistics, but we know where they are…

What does Relative DOM Efficiency Mean?





D. Chirkin, H. Johanssen



Various individual measures of DOM efficiency are weakly or not at all correlated – more studies in progress, i.e. muon relative efficiency with DOMs vs. FAT data

More plots at https://wiki.icecube.wisc.edu/index.php/Hamamatsu_PMT_Data

Relative DOM efficiency

- Morten Medici at NBI is trying to measure the relative DOM efficiency with muons in IC86
- The flasher RDE numbers improve the model error but do not correlate with any other measurement we have so far
- I think Spice 3 needs further study and in particular we need independent verification of the individual relative DOM efficiencies
  - DOM efficiencies are used in some reconstructions

Summary

- Tilt is measured with multiple methods
- The Mie scattering model fits flasher data and has an independent check from muons
- Anisotropy is seen in both flashers and muons
  - But not correctly accounted for in reconstruction except in direct reconstruction – it's real but we don't have the tools to use it properly yet
- Hole ice definitely has an effect, but we have yet to match simulation to what we see in the Swedish camera photograph, and implementation of individual hole ice would be computationally expensive – we have a new angular sensitivity curve from the flasher data but it has not yet been extensively tested, and has little effect on the model error (as expected) – needs more dedicated study
- Muon measurements of mean absolute "efficiency" have been hampered by the difficulty of getting simulation, and various bugs
- Relative DOM efficiency improves the model error in Spice 3, but has yet to be confirmed by any other method of measuring efficiency

Backup

Shifted DOM and hole ice column

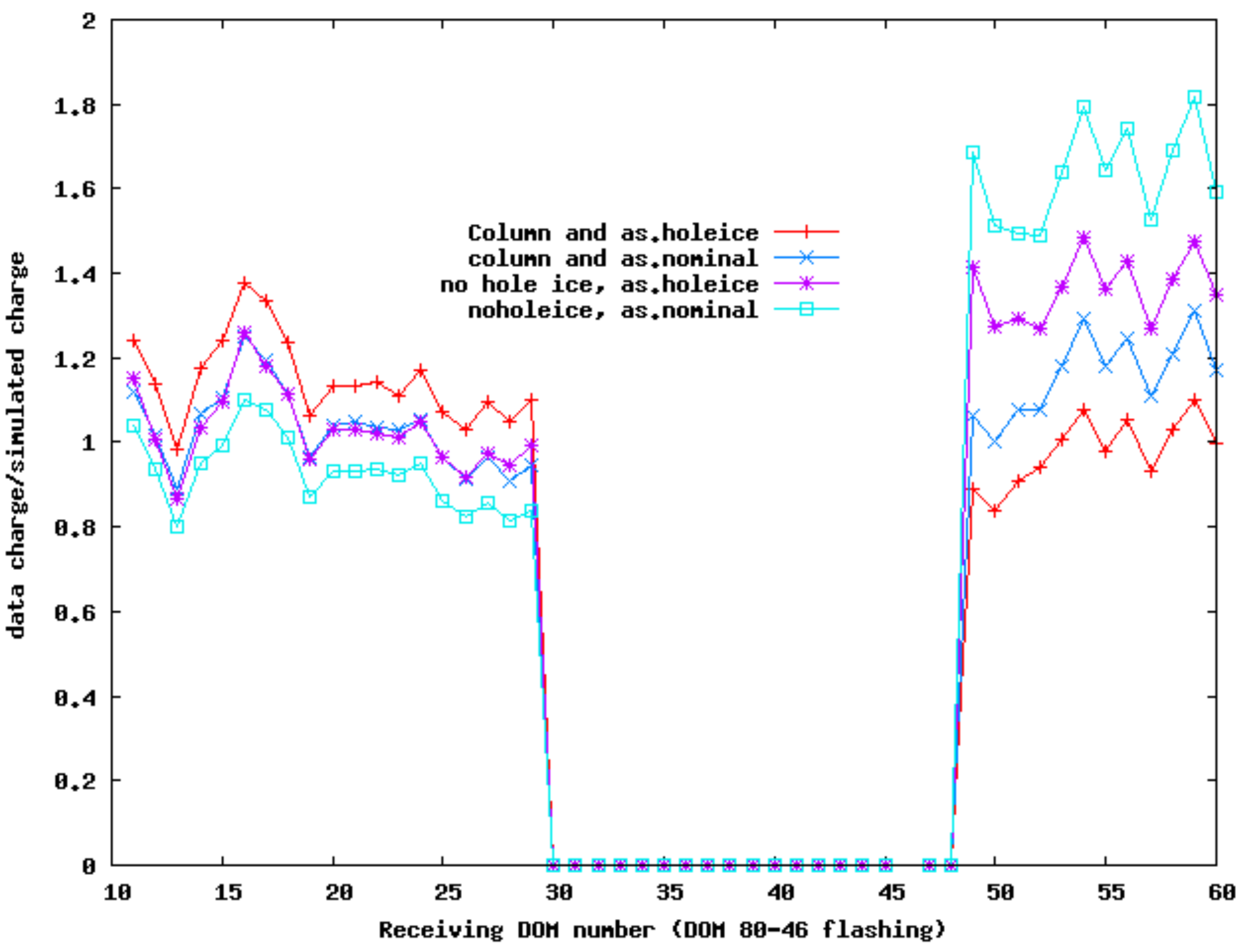
Parameters:

Hole ice column is 0.5 DOM width (about 17 cm)
20 m absorption
5 mm scattering

Flashing DOM is shifted 8 cm in x

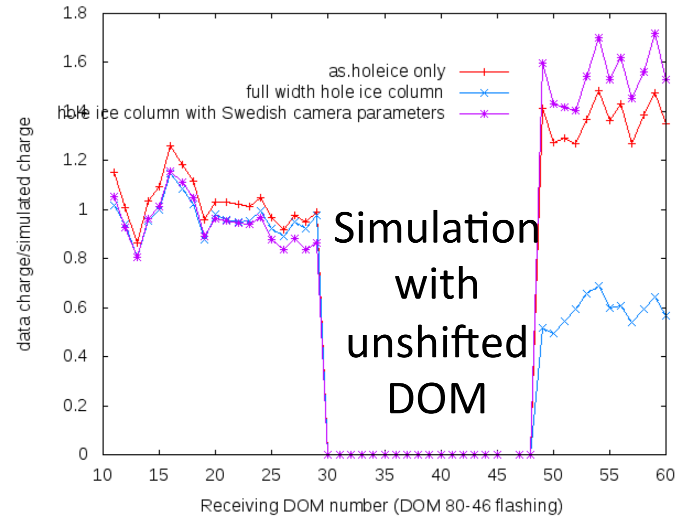
Receiver DOMs are at nominal positions, 5x oversize

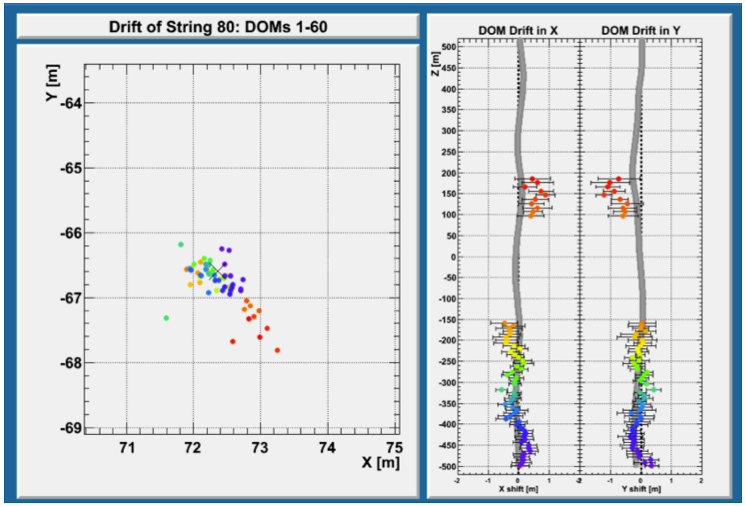
All tilted LEDs, maximum width and brightness



What are the positions of the DOMs?

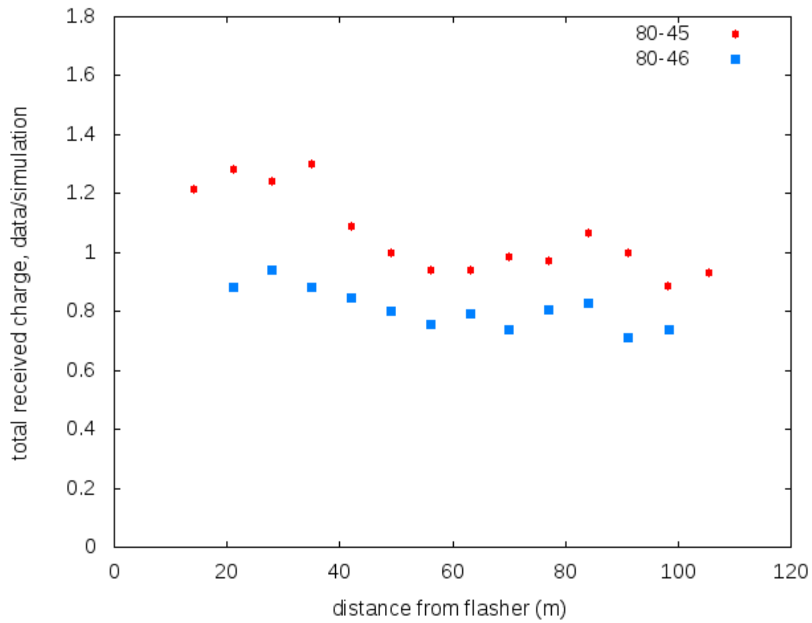
- The shift of the DOM with respect to the column makes a big difference
- Try simulating with the geometry coordinates on string 80 all shifted to match Chris Sheremata's results

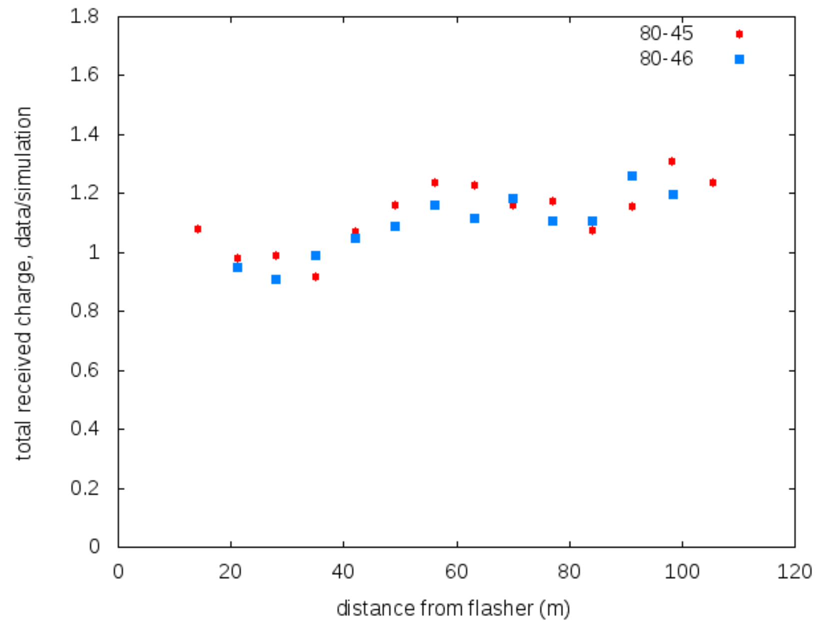




All tilted LEDs, looking below the flasher, comparing 2 adjacent flashers

Hole ice column with 5mm scattering and 20 m absorption





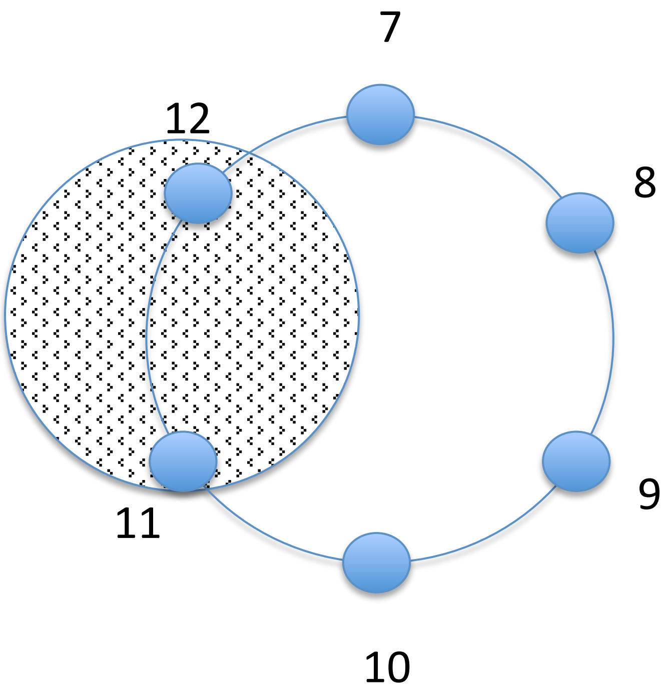
DOMs 45 and 46 shifted in x only
Large systematic difference between the received charge below as a function of distance

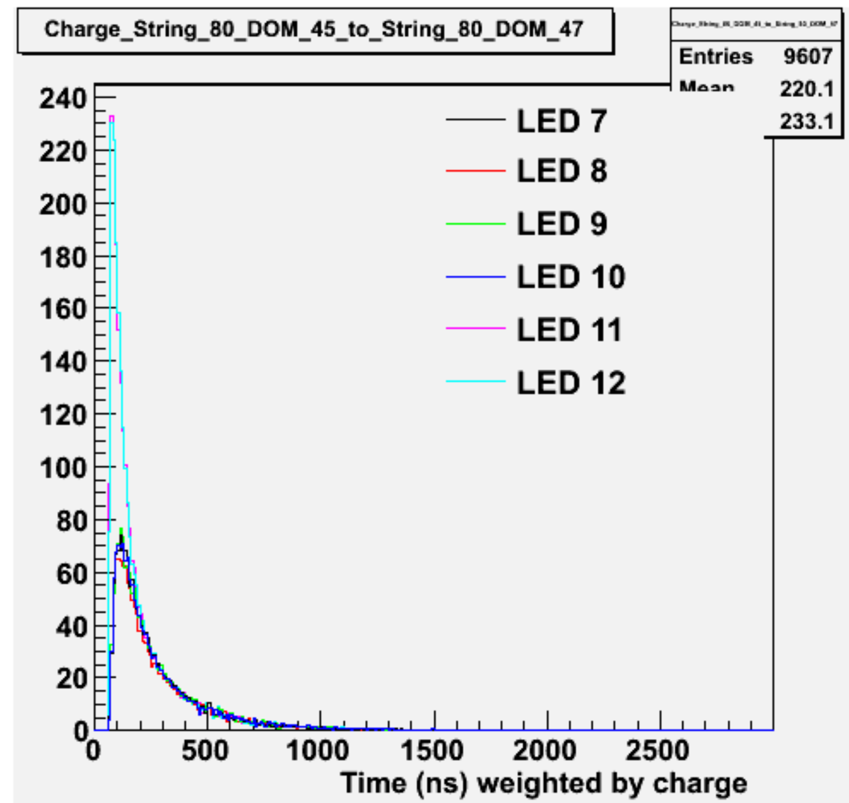
All DOMs on string 80 given x-y coordinates from Chris' analysis

(note, receiver doms have 5x oversize factor)

Hole ice (direct simulation of bubble column)

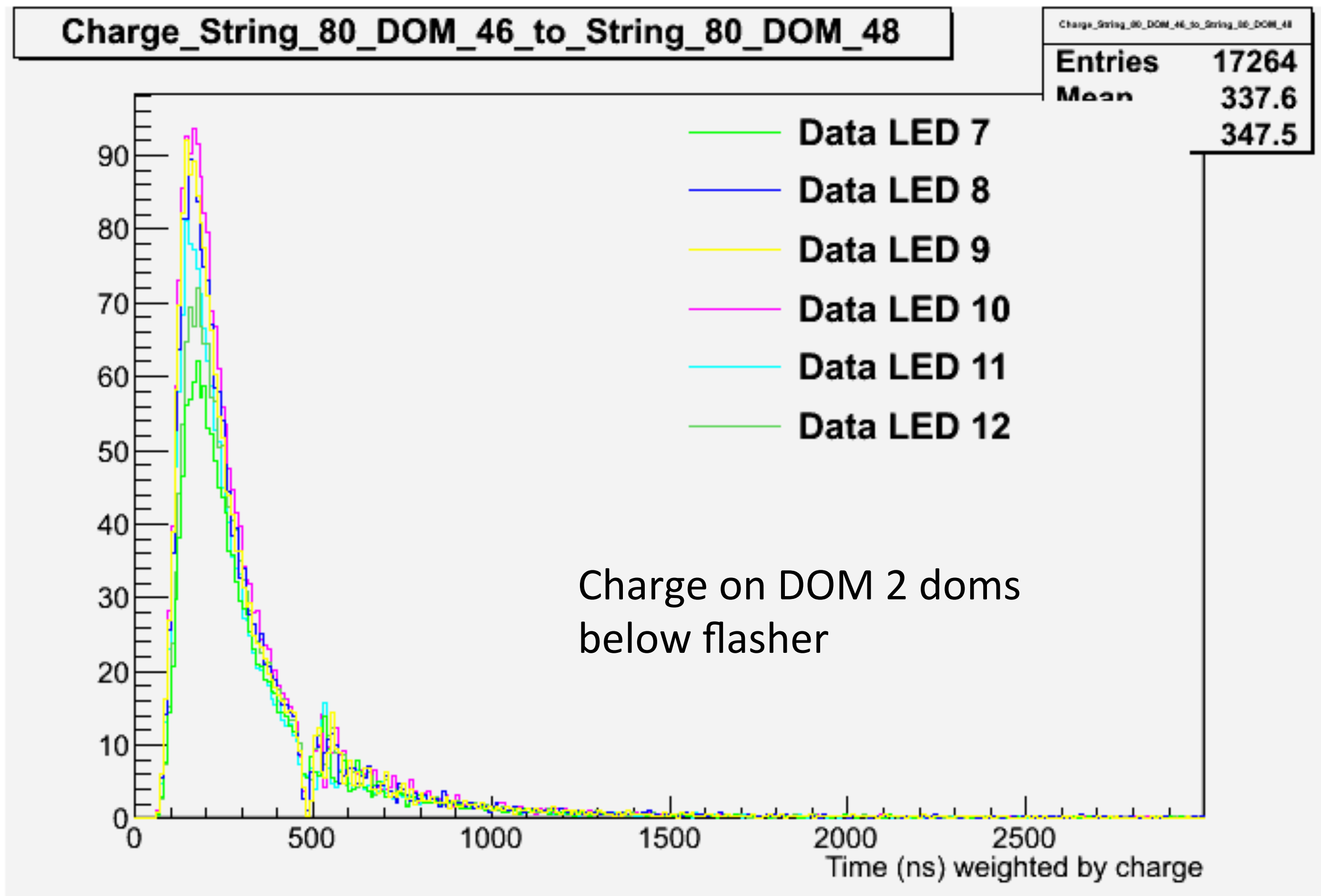
Hole ice: 5 mm scattering, 20 m absorption, half width of DOM
DOM shifted +12 cm in x





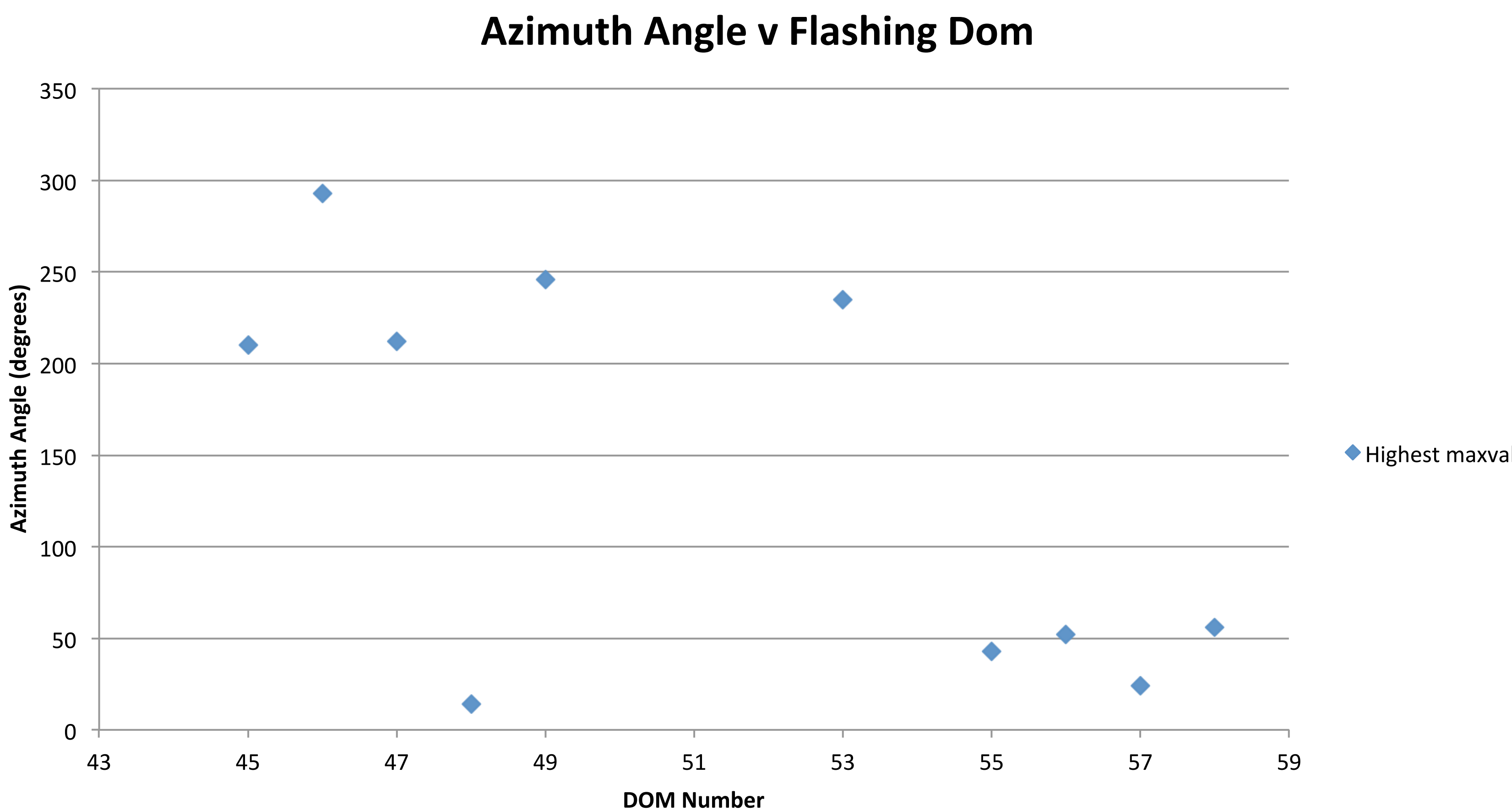
LEDs shining into hole column produce significantly more light in the DOMs below than LEDs not shining into the column

What the data looks like



Looked at all 6 individual horizontal LEDS on DOMs 45-60 on string 80: no one LED looks significantly brighter on the DOMs below

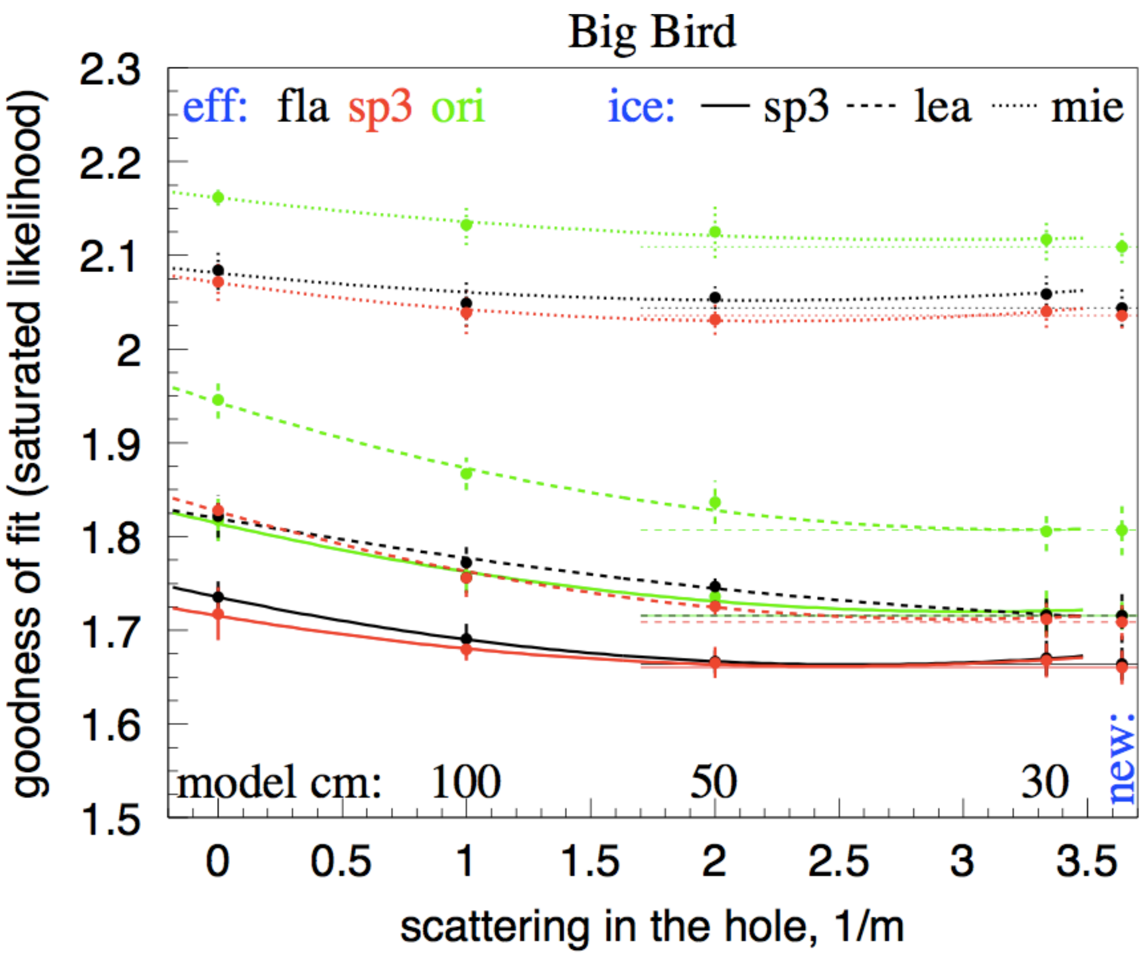
Azimuth of LED with highest peak value 2 DOMs below (data)



Using azimuths from Danica's analysis

Average azimuth position clusters around 239 and 37 degrees ... Looks more like anisotropy than hole ice

Big Bird Goodness of Fit



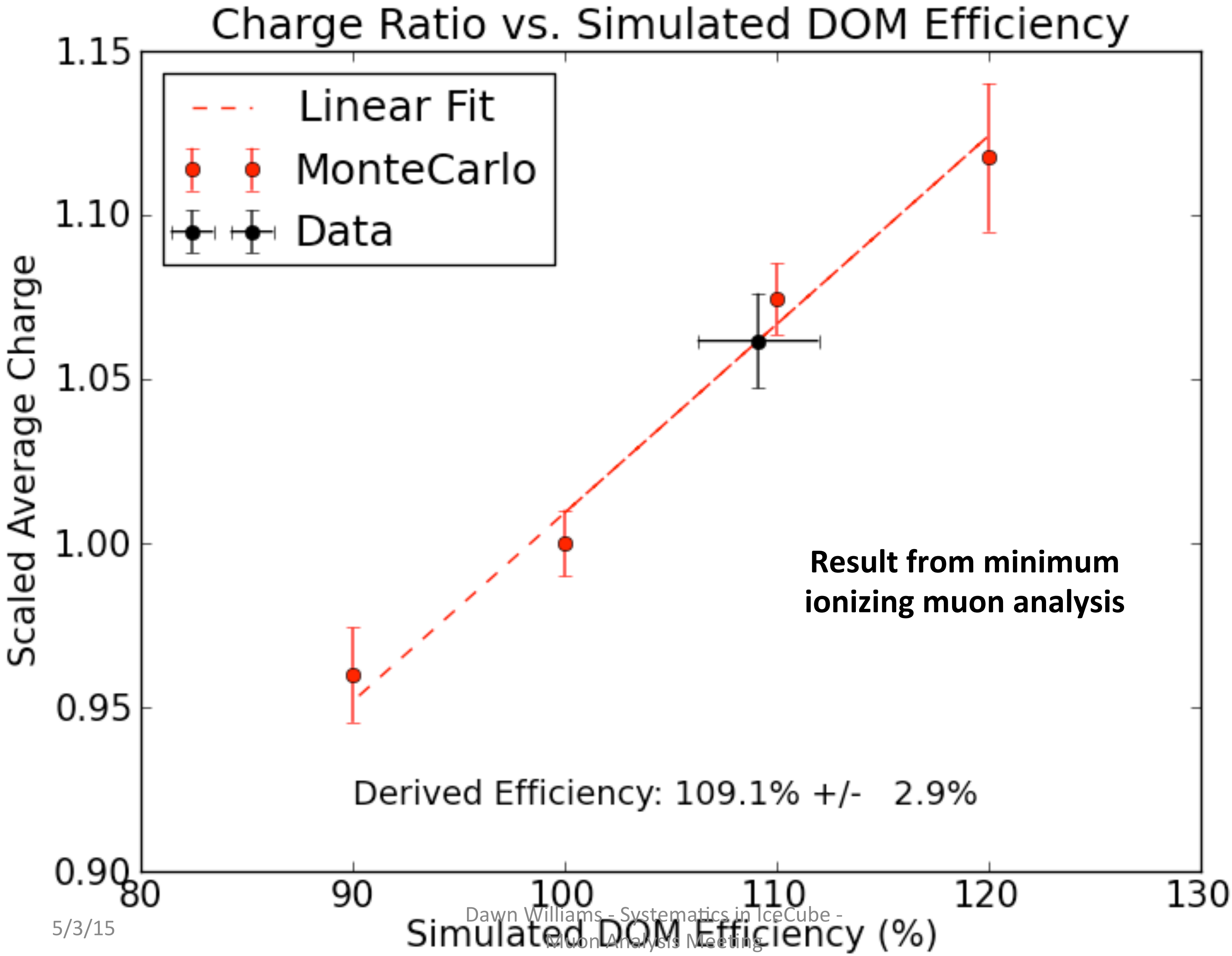
Update to simulated DOM efficiency

- At the fall 2012 IceCube collaboration meeting, multiple analyses indicated that the simulated DOM efficiency was too low
- Results were generally consistent with raising the DOM efficiency to 110% of the nominal value at that time
- Systematic uncertainty on DOM efficiency was conservatively chosen to be ±10% based on spread in the analyses; this requires further study
- This result is ice-model dependent and applies to SPICE Mie, the current default ice model
- Relative DOM efficiency of HQE/standard DOMS remains unchanged at 135%; analyses are consistent with this value

Results from Dedicated DOM Efficiency Analyses

Analysis	propagator	Ice model	efficiency	error
Minimum ionizing muons	photonics	SPICE Mie	109.1%	±2.9% (stat+sys)
Bright downgoing muons	PPC	SPICE Mie	120% ** Decreases to 110% at large inclination angles	±4% (sys) ±2% (stat)

Note that in the minimum ionizing muon analysis, muons were chosen with large inclination angles so that their light shines as directly as possible into the PMTs



Result from minimum ionizing muon analysis

Results from Nuisance Parameters/ Systematics Studies in IceCube Analyses

Analysis	propagator	Ice model	efficiency	error
Low energy atmospheric muon neutrinos	PPC	SPICE Mie	109%	not given
Upgoing neutrinos (diffuse)	photonics	SPICE Mie	99.6% ** PPC/photonics correction is 117.5%	±1.3%
Upgoing neutrinos (point source)	PPC	SPICE Mie	110%	not given