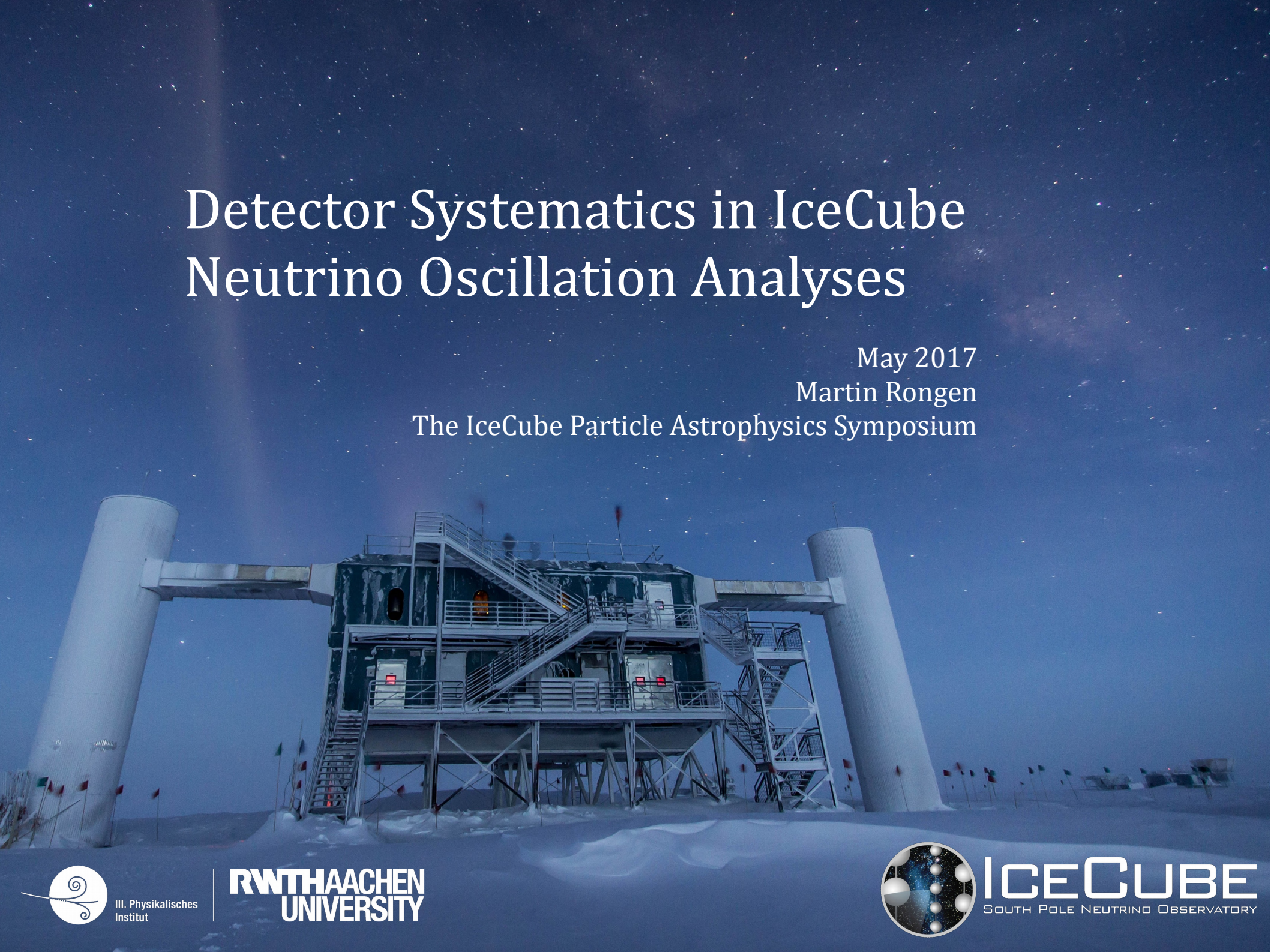
Detector Systematics in IceCube Neutrino Oscillation Analyses

May 2017

Martin Rongen

The IceCube Particle Astrophysics Symposium



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IceCube
South Pole Neutrino Observatory

IceCube is simple

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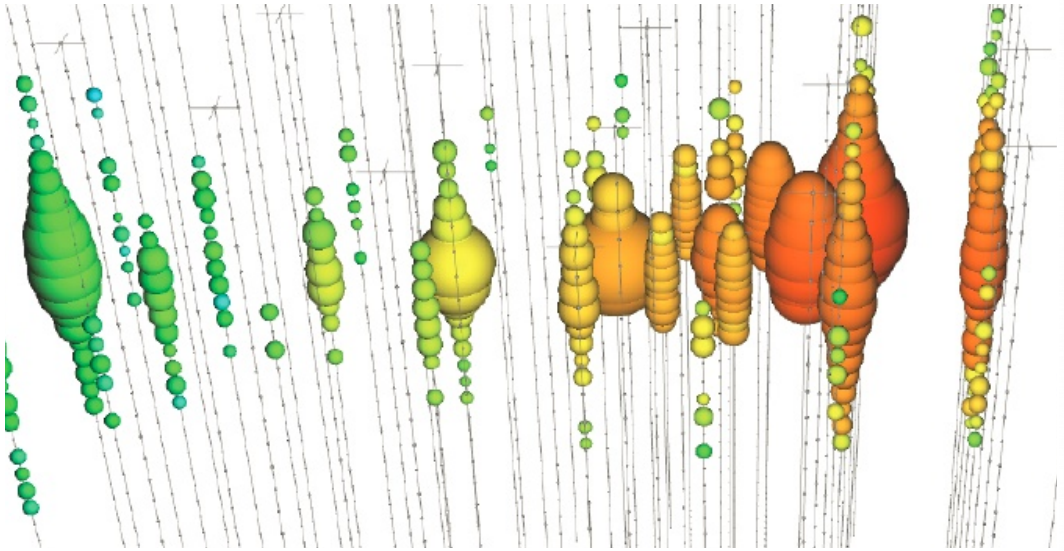
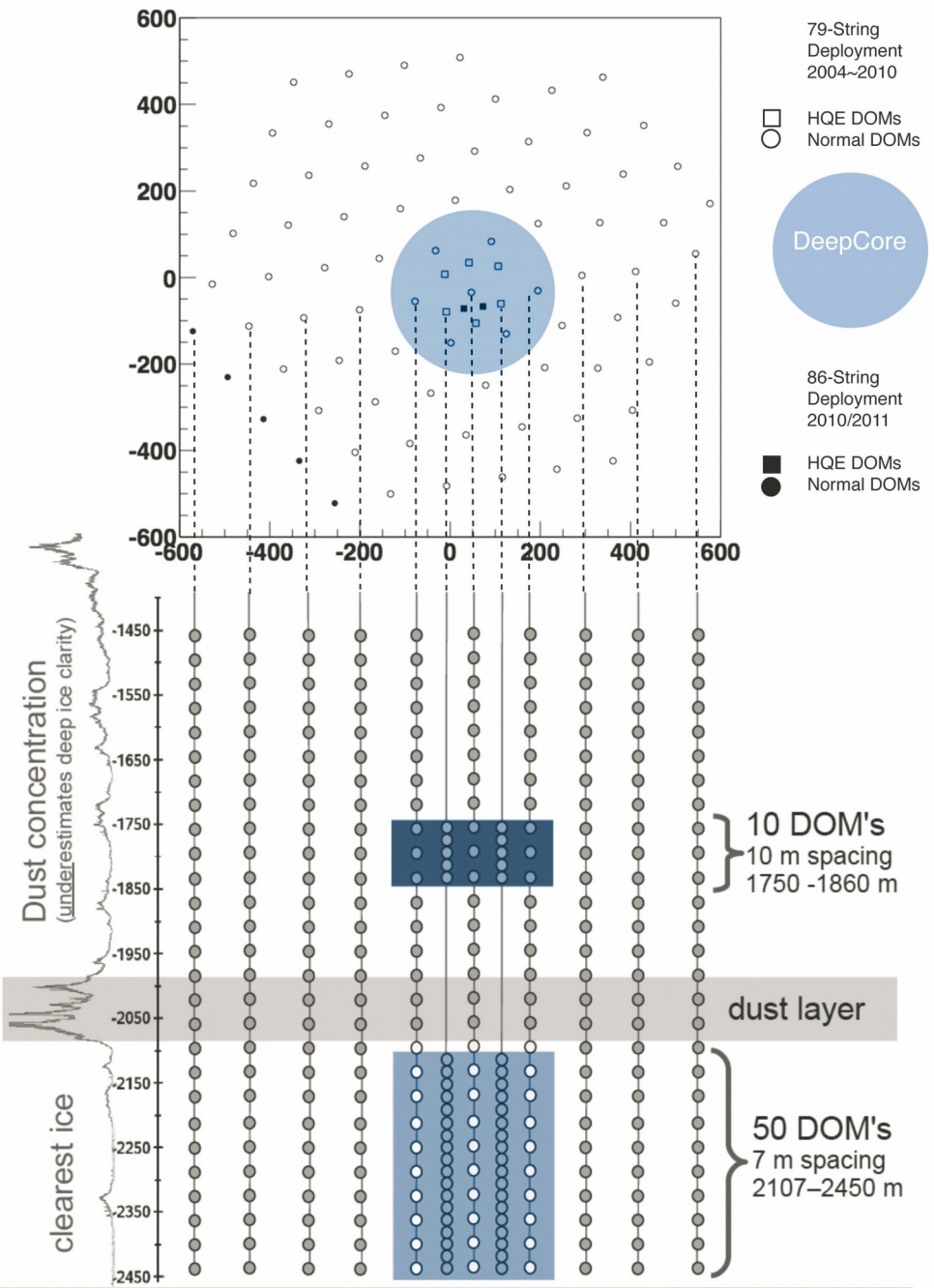
- An array of PMTs in clear glacial ice
- Count the number of photons
  → energy deposit
- Put a ruler to the photon pattern
  & timing information
  → arrival direction





The low-energy challenge

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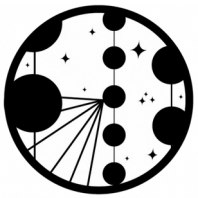
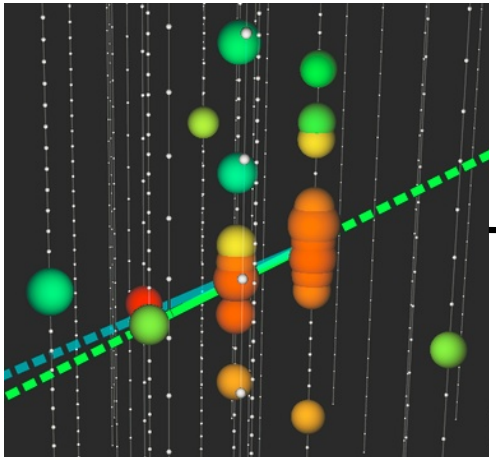
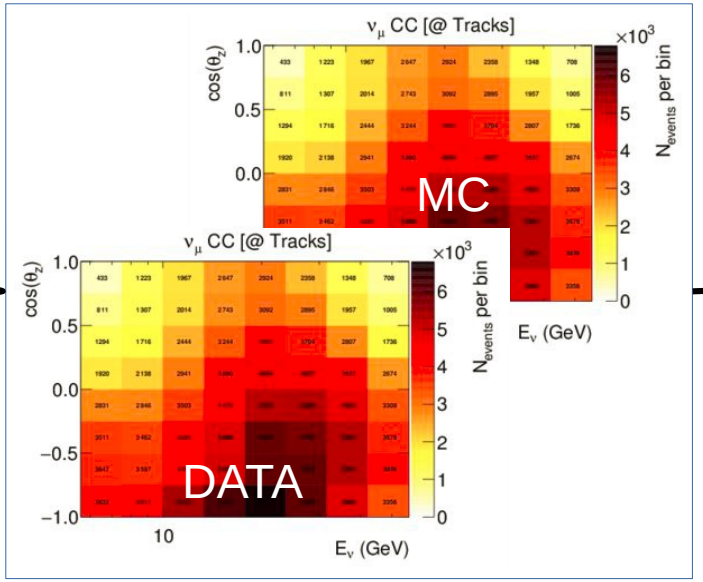


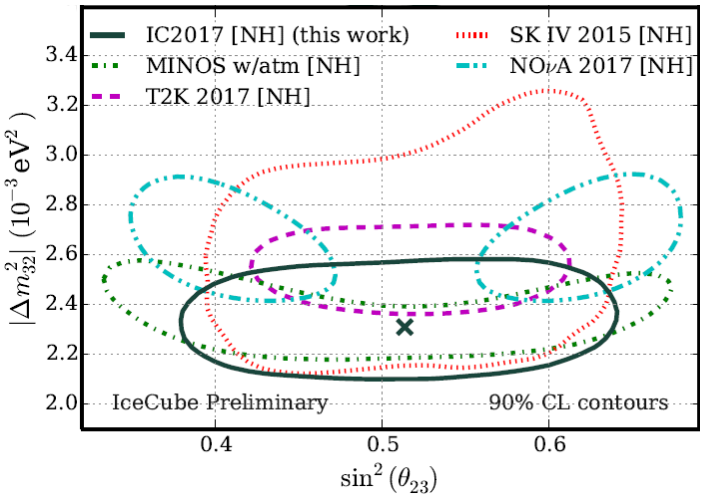
- At low energies this simple picture does not hold
  → we rely on the information from every individual DOM to be correct

- We have no off-source region, test beam, near detector
  → the analysis is a **forward folding** comparing data to simulation containing different oscillation and systematics assumptions

    → a **correct and precise** description in the MC is critical to obtain an unbiased and competitive oscillation result







Contribution to the contours

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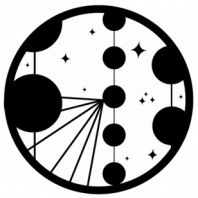

Contribution of systematics on $|\Delta m^2_{32}|$ mass splitting uncertainty

Parameters	Sample A High event statistics	Sample B Low statistics, high quality events
Detector parameters		
DOM efficiency	20.3%	6.9%
Hole ice modelling	2.2%	$\sim$ 9%
Bulk ice modelling	-	-
Flux and cross section parameters		
Spectral index	0.1%	3.1%
ν_e normalization	0.3%	<0.1%
Relative NC normalization	0.1%	<0.1%
flux $\nu/\bar{\nu}$ ratio	3.0%	0.1%
flux up/horizontal ratio	0.6%	6.8%
Nucleon cross sections	1.2%	$\sim$ 1.4%
Other		
Atmospheric muon contamination	0.8%	1.5%

→ **let's talk about detector systematics**

DOM detection efficiency

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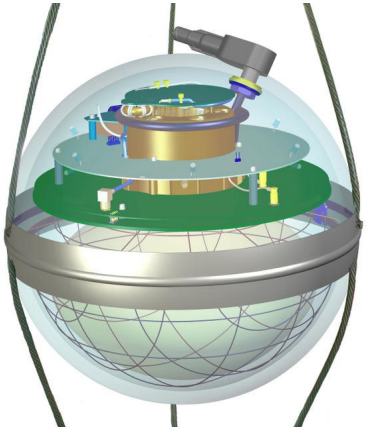
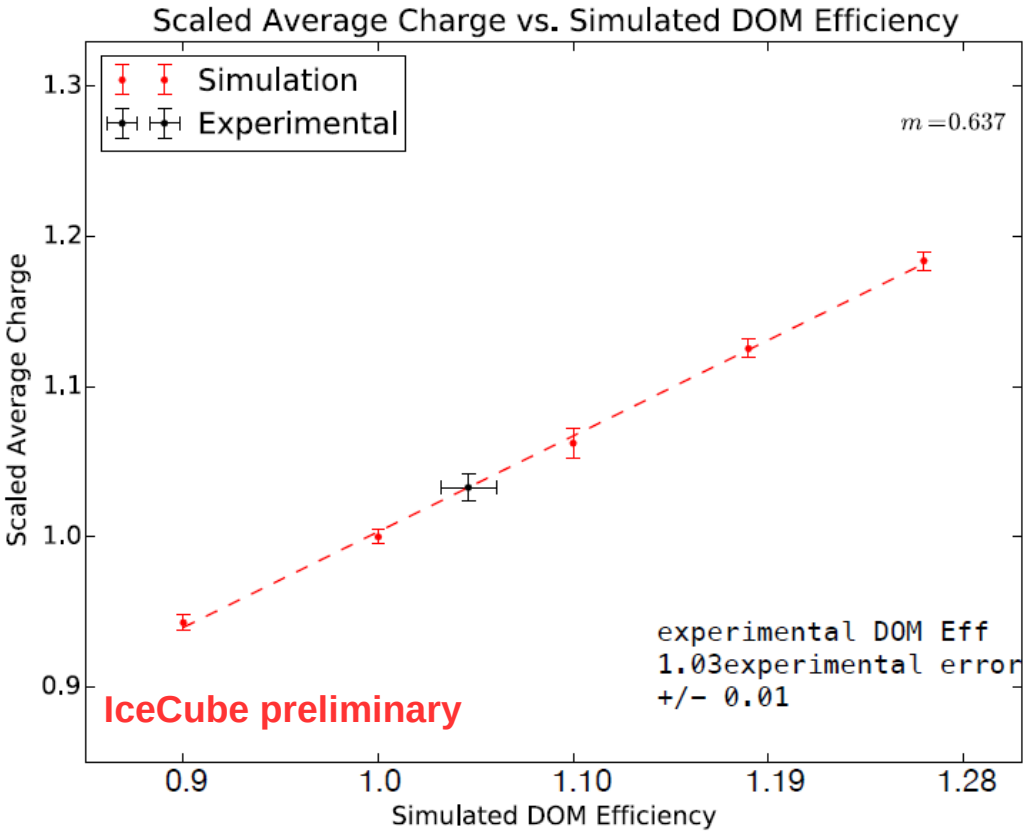
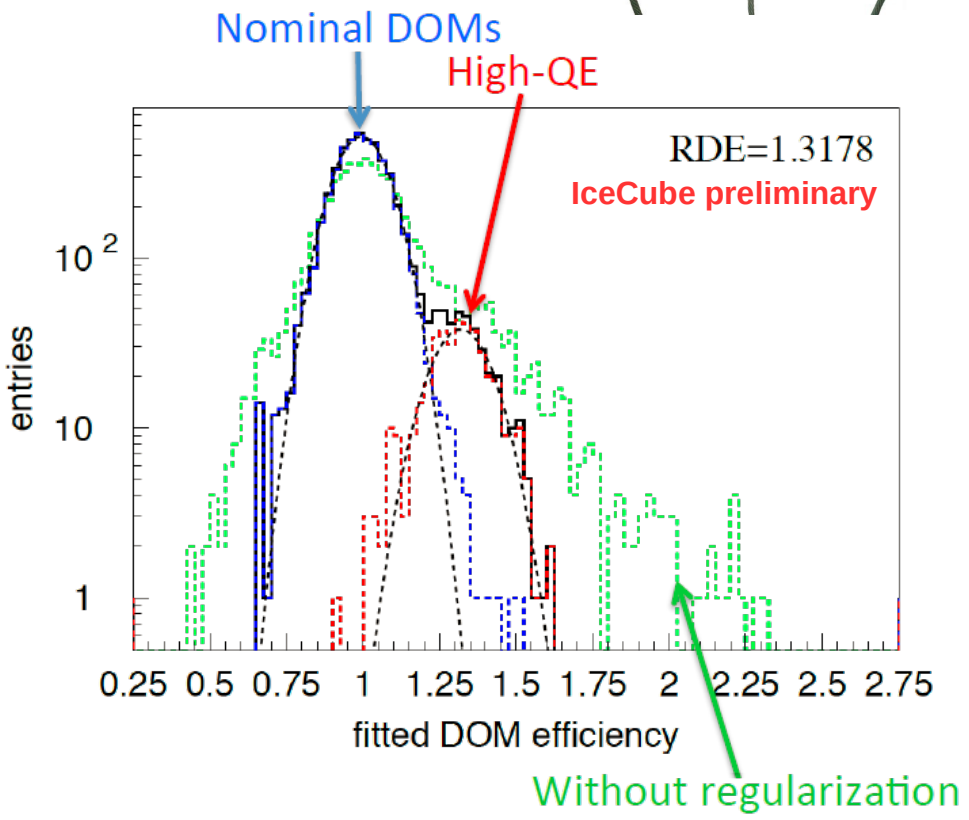
- Global optical efficiency measured with minimum ionizing muons (well know energy deposition)
- Relative parameter in MC compared to lab expectation

- DOM-to-DOM variations fit in LED data







The Antarctic glacier

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- Compacted snow up to 100'000 years old, absorption close to perfect water

- Above ~1500m air bubbles dominate scattering
- Below ~1500m air bubbles get incorporated into crystal structure (craigite), scattering dominated by dust and volcanic ash correlated to absorption

- Absorption sets viewing distance, scattering scrambles data

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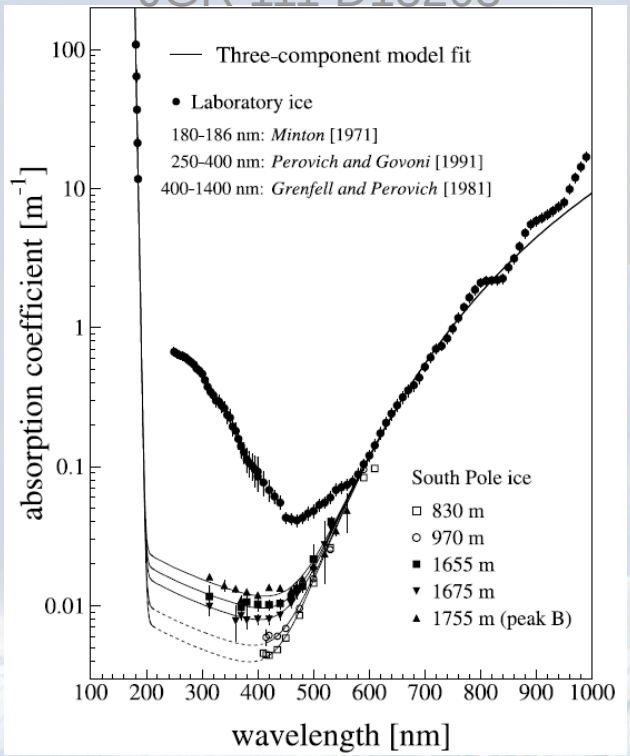
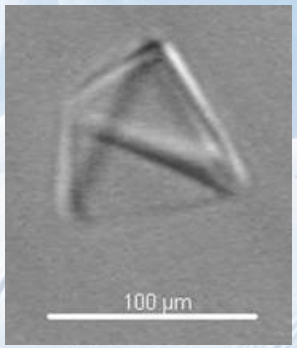
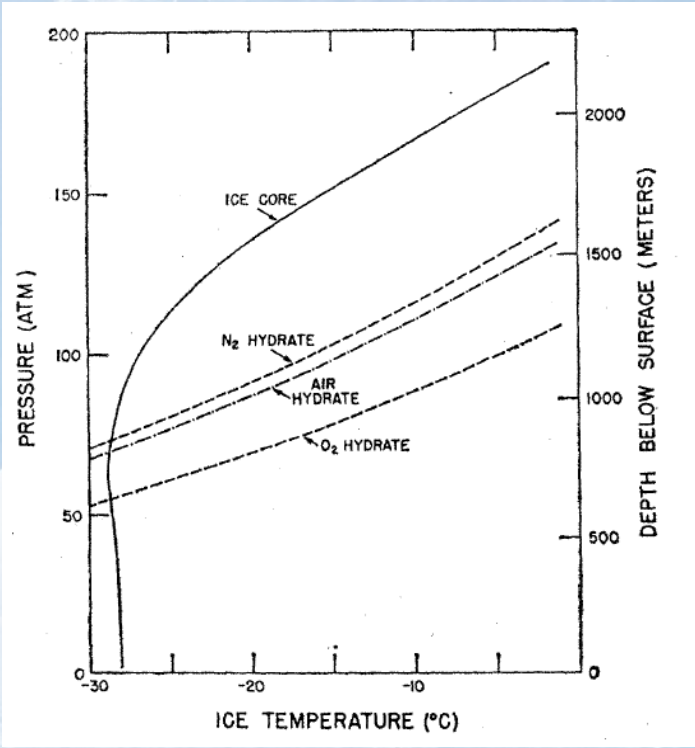




Nature 298, 548 - 550



Measurement tools

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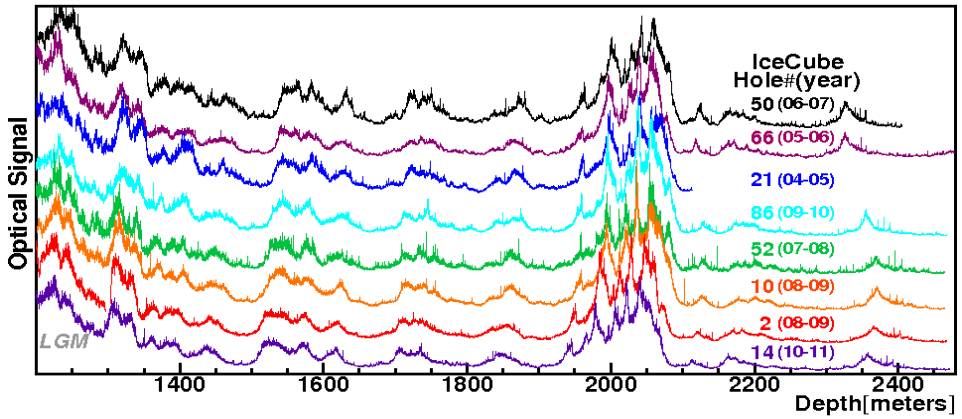
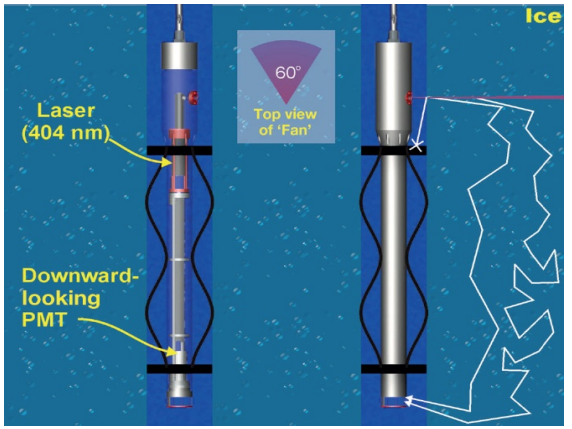
Dust logger:

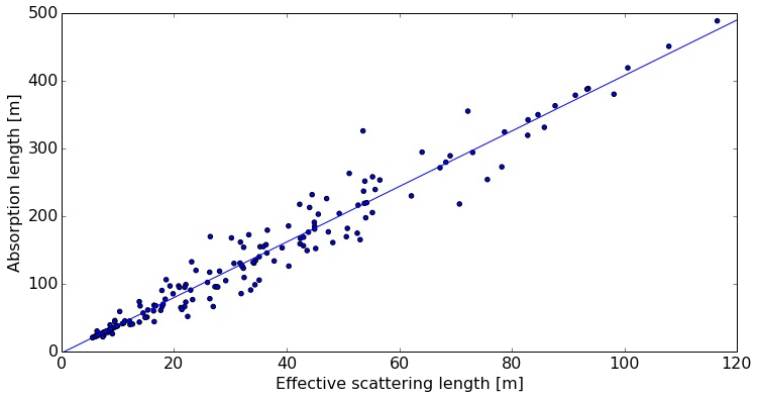
- Horizontal fan of light emitted into ice
- Scattering centers can deflect light into PMT shielded from direct light
  → DC current proportional to density of scattering centers

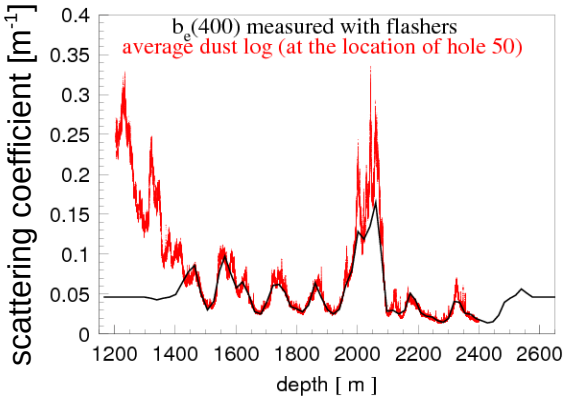


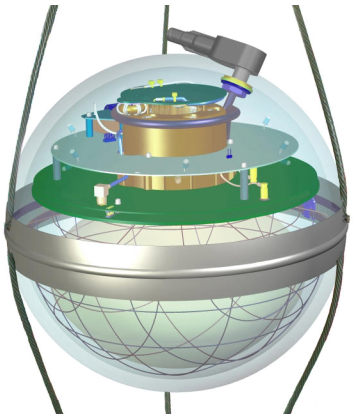


DOM LED data:

- Fitting photon propagation simulation to LED data, yields absolute scale
- 5-50m effective scattering length, 50-200m absorption length
- + more subtle effects such as tilt and optical anisotropy







Ice quality in drill holes

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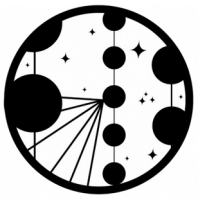
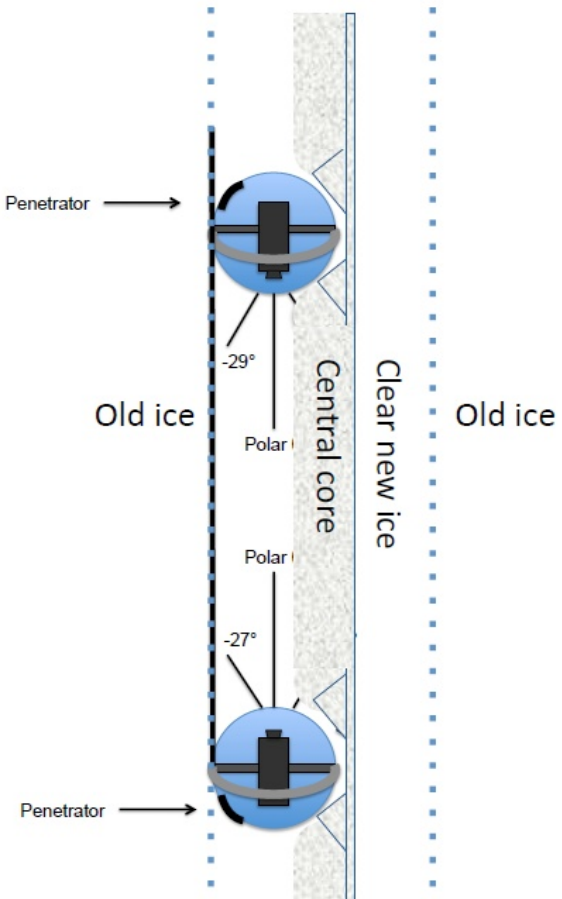
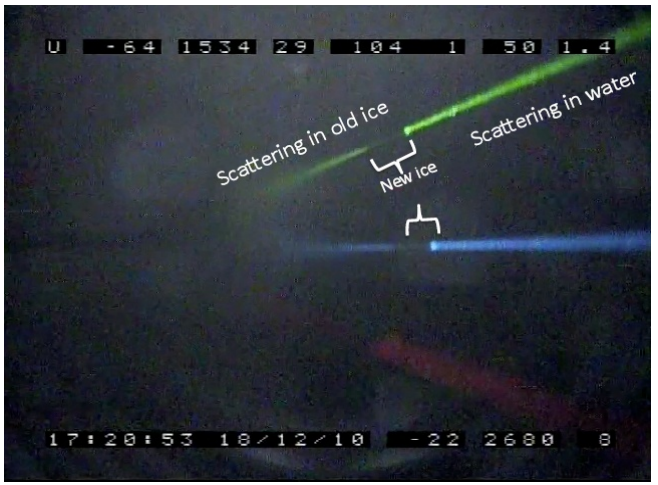


- Two freely rotatable cameras have been deployed at the bottom of a string
- Each equipped with strong LEDs and multi-color lasers
- 6 m separation between the cameras





The outer region of the refrozen drill holes (“hole ice”) is of good quality.

The hole ice contains a central bubble column. (Tightly confined region of strong scattering.)

Angular acceptance

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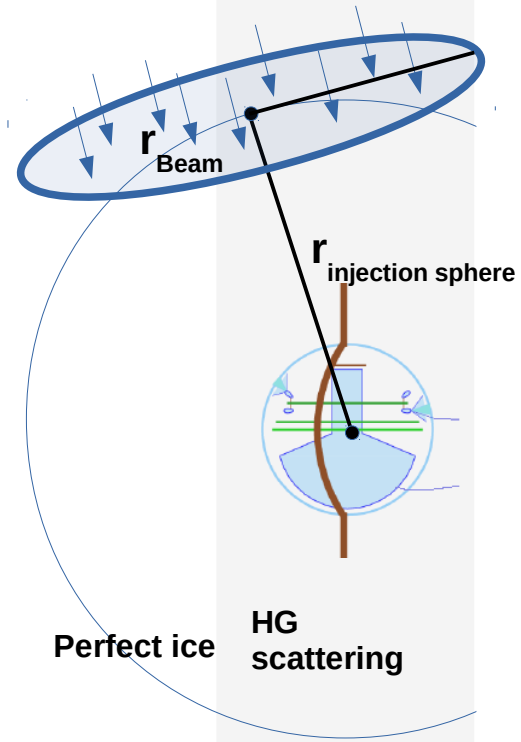
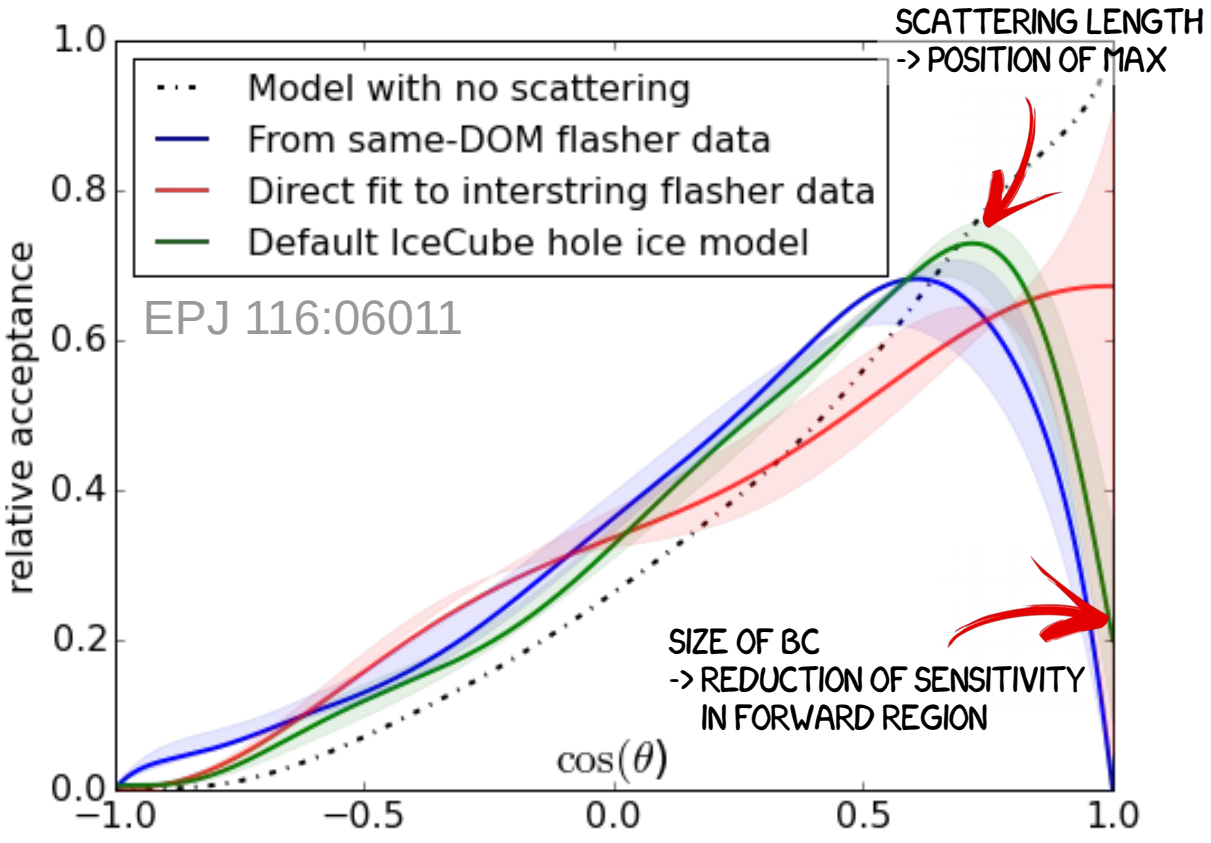


- Currently modeled as a modification to the DOM angular acceptance curve (up-going photons shaded off)
- Curve is obtained by rotating a test light source around DOM within a simulation of assumed/measured hole ice properties
- Competing models mostly differ in assumptions
- Analyses interpolate between models



Hole Ice fitting

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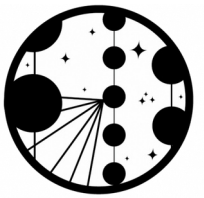
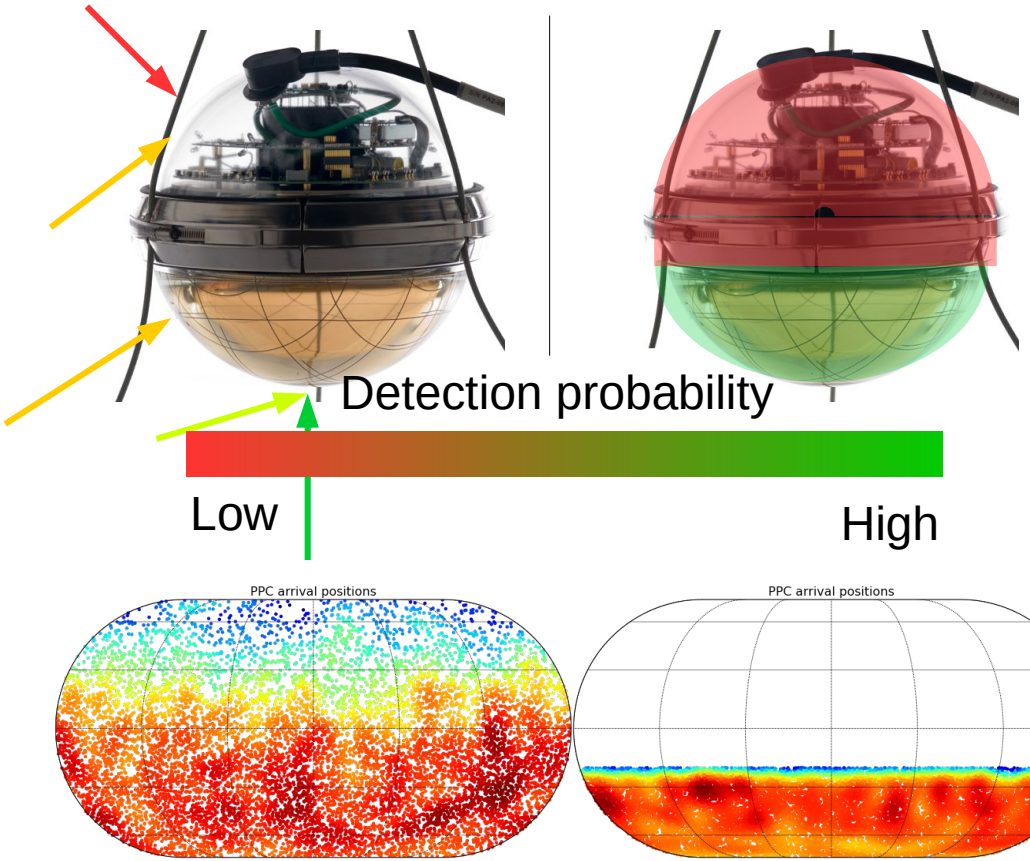
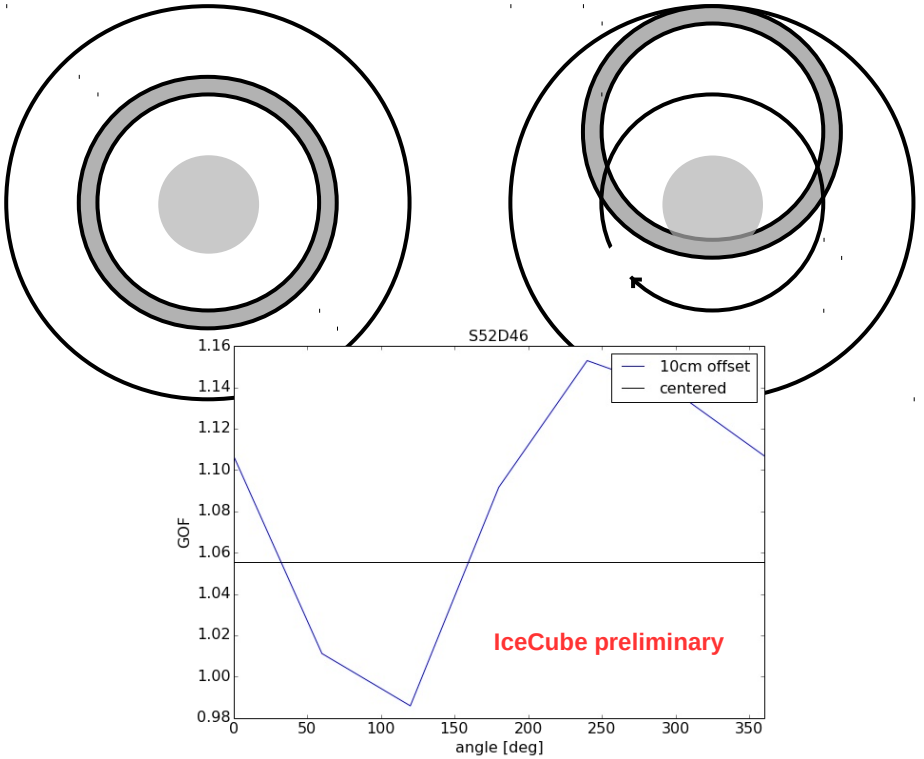


- Maybe modeling the DOM by an angular acceptance function is wrong

- Describe the hit probability as a function of the impact point
  → fit the hole ice properties (radius, scattering, offset from each DOM)
  by comparing simulation to flasher data (as with the bulk ice)





Hole Ice fitting

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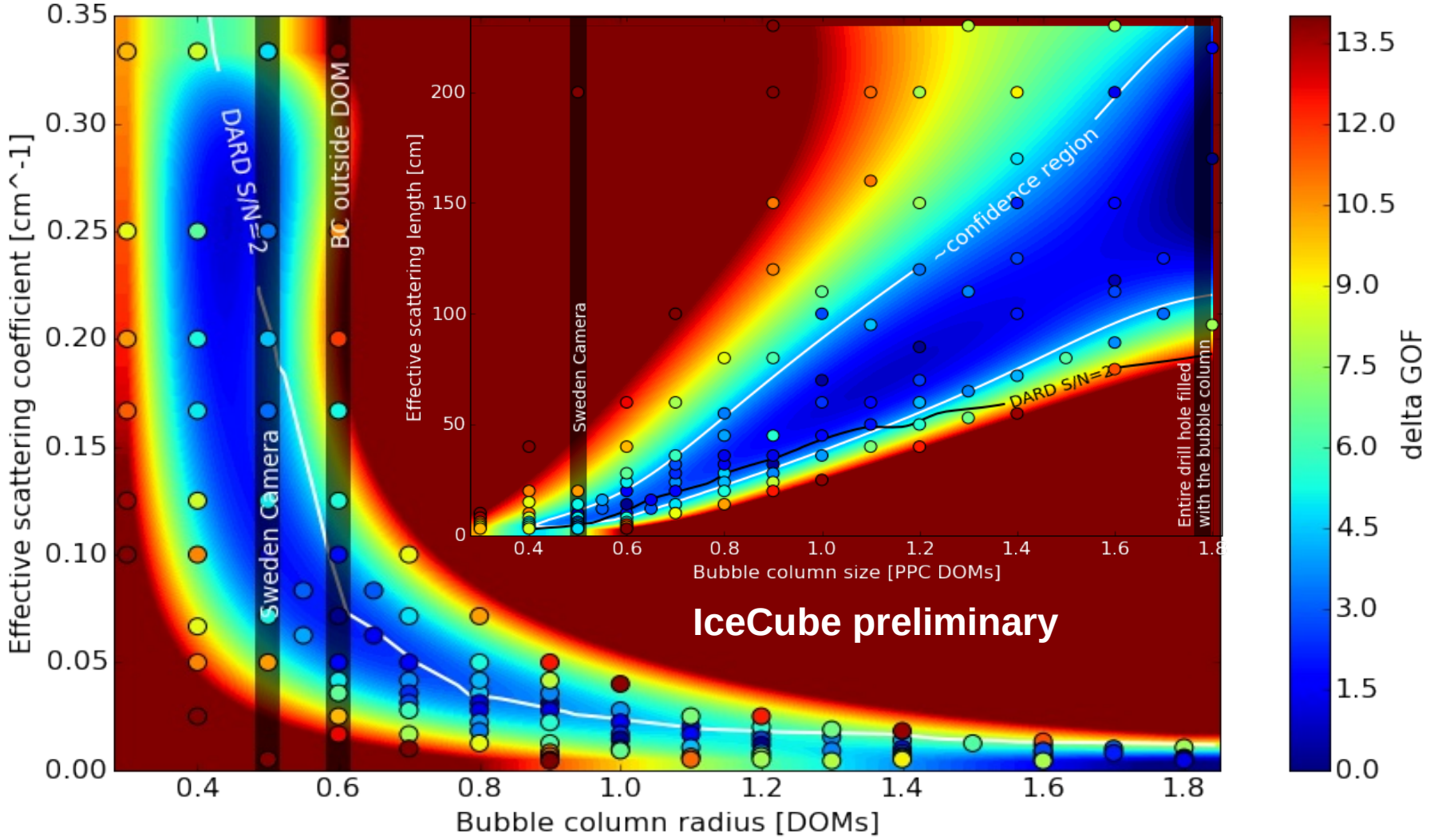

- New hole ice modeling method and derived parameters still being finalized
- Impact on oscillation analyses currently under investigation

Upcoming improvements

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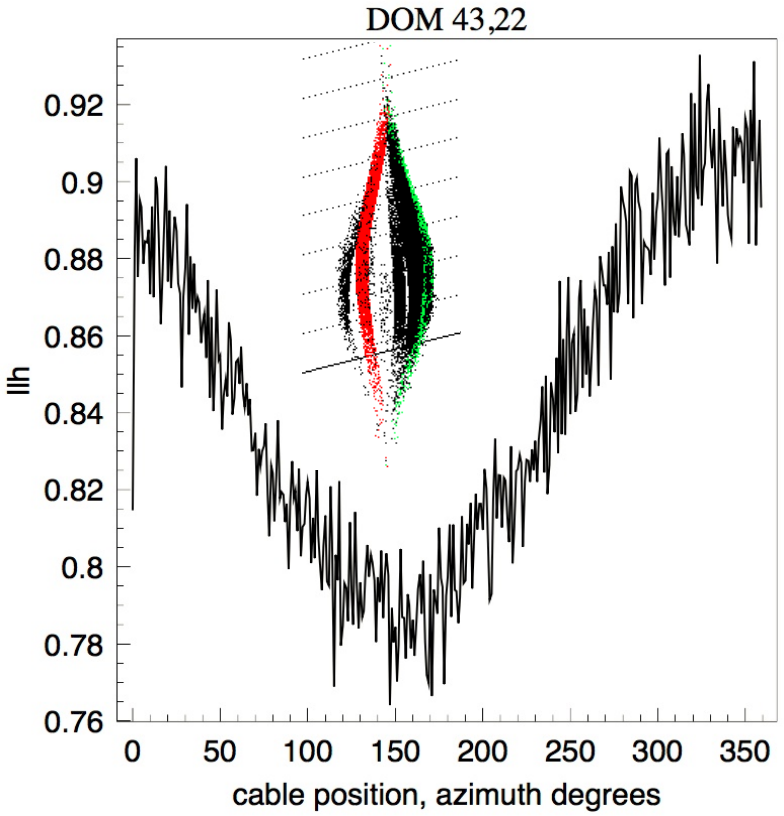
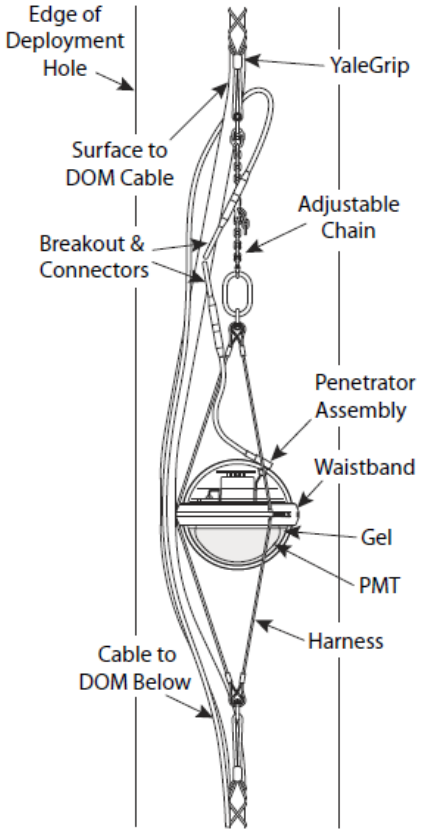
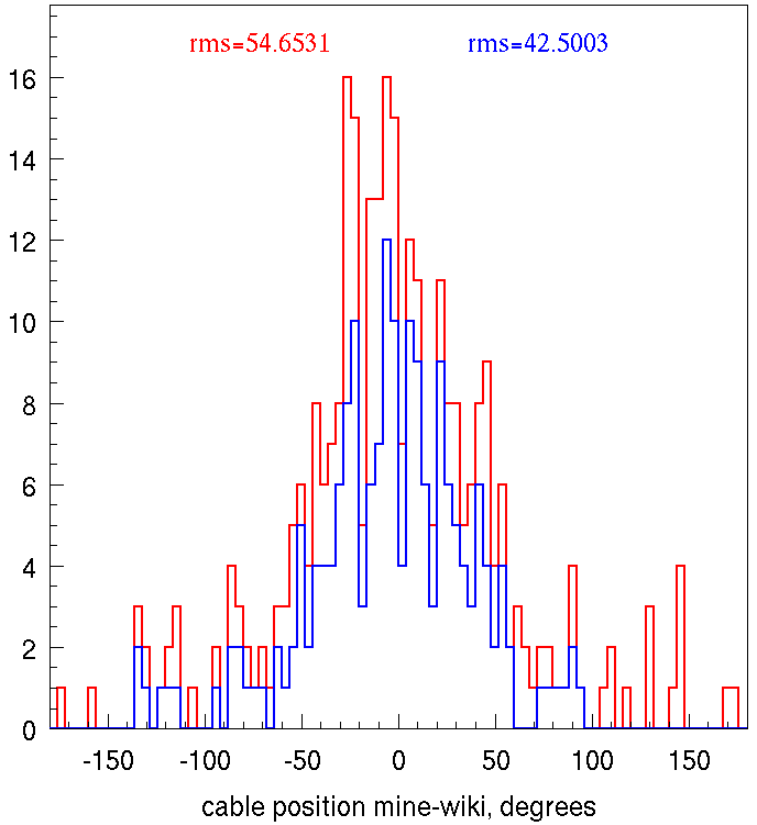


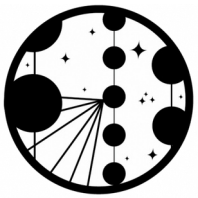




- Local DOM surroundings remain a fields of active research

- Most recent successes:
  - Fitting the DOM orientation and position of the cable on each DOM
  - Fitting slight tilts of the DOM/PMT axis

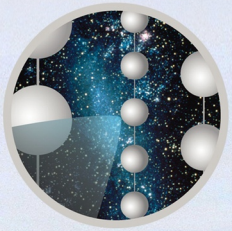
Conclusion



- IceCube is a simple detector
- BUT low-energy oscillation analyses critically depend on a detailed simulation correctly modeling hard-to-quantify in-situ effects
- The overall detection efficiency and the optical properties of the old glacial ice are well understood, with only very incremental improvements
- Effects in the local ice surrounding the DOMs are hard to measure and model correctly and remain a field of active research

Thank you for your attention!

Questions welcome



The IceCube Collaboration

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Clark Atlanta University
Drexel University
Georgia Institute of Technology
Lawrence Berkeley National Laboratory
Marquette University
Massachusetts Institute of Technology
Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines & Technology
Southern University and A&M College
Stony Brook University
University of Alabama
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