Direct reconstruction - a new event reconstruction algorithm for the IceCube Neutrino Observatory

Sarah Nowicki

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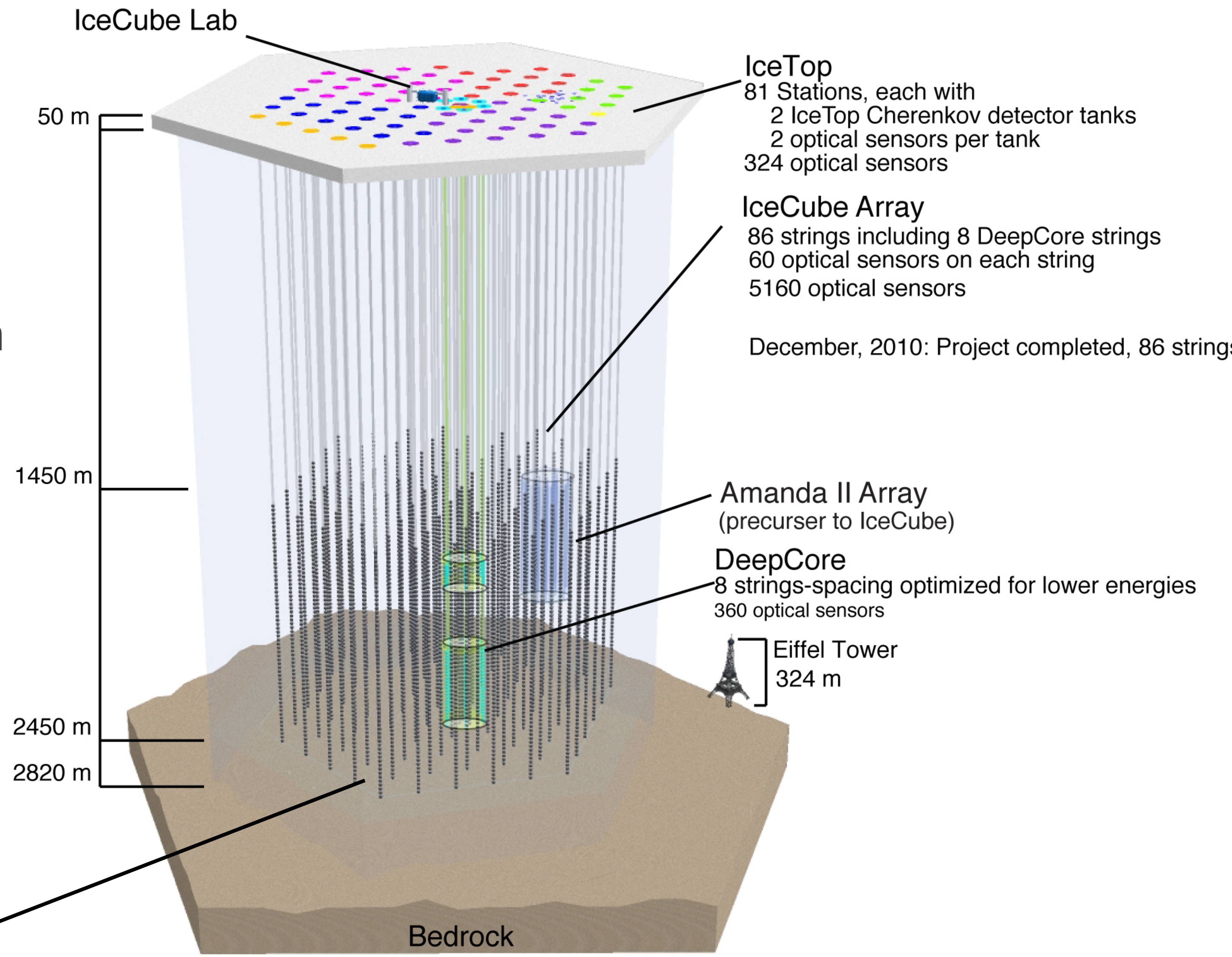
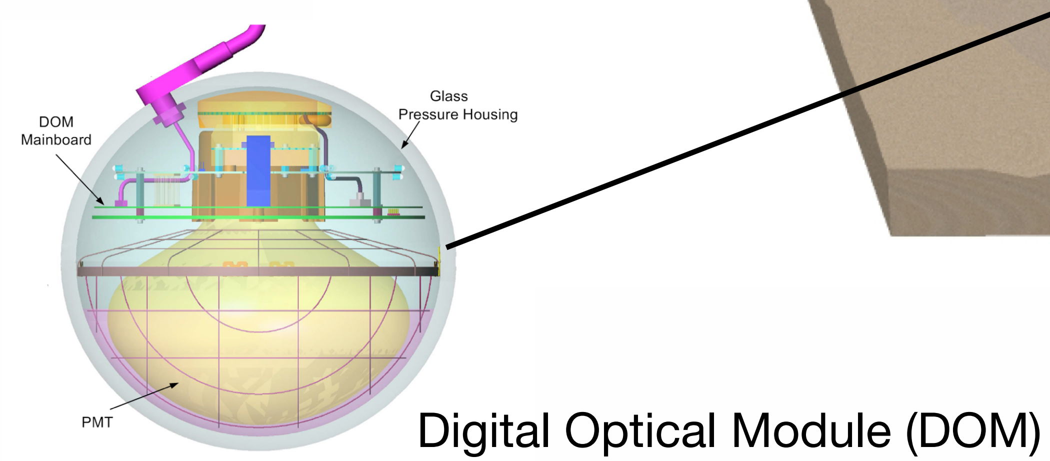
Everyone's favourite IceCube diagram

IceCube instruments more than a cubic-kilometre of the deep Antarctic glacier with optical sensors at South Pole Station

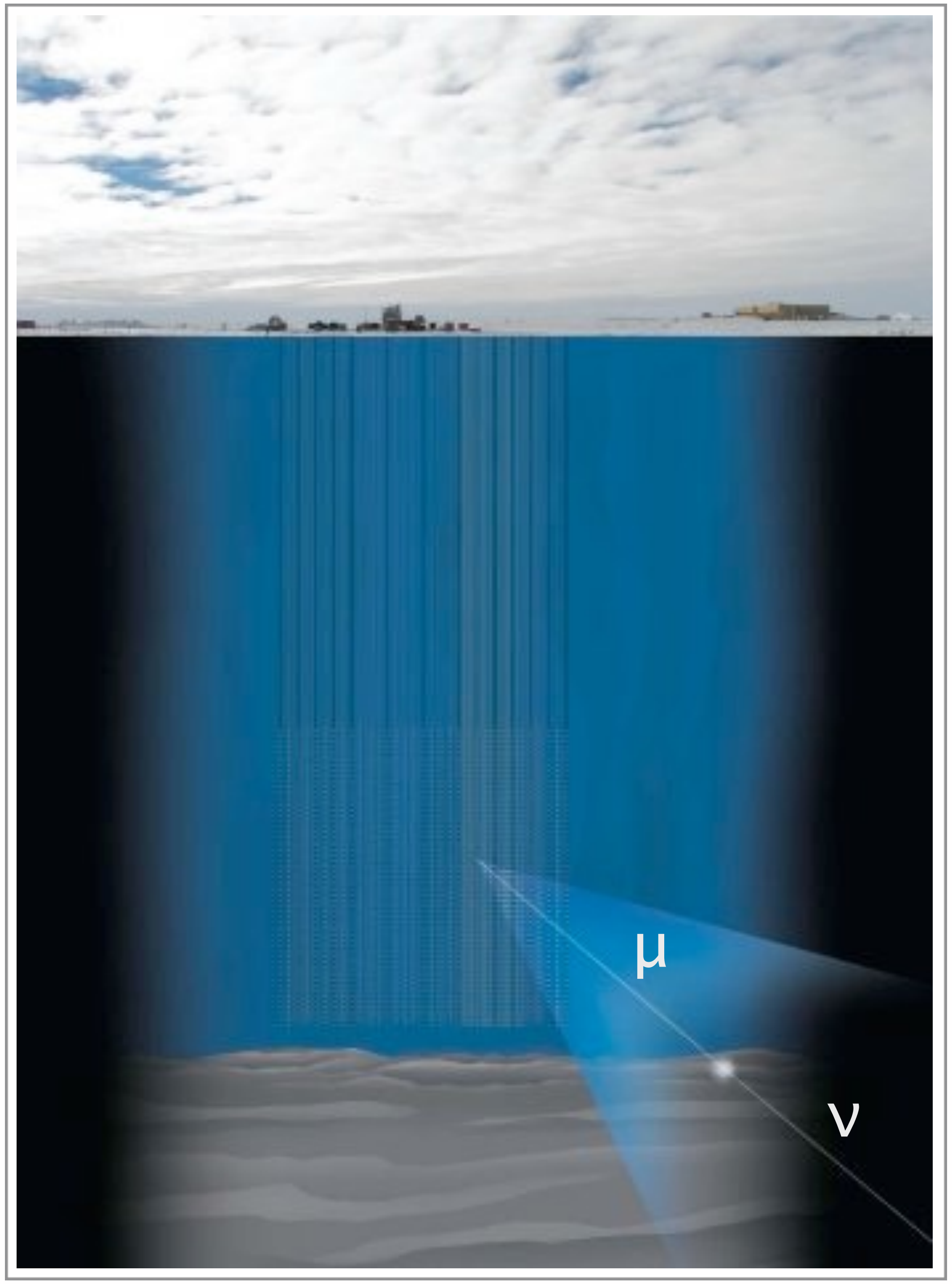
Designed to detect astrophysical neutrinos on the TeV to PeV scale

A more densely instrumented DeepCore region was included to study particles at much lower energies, ~10 - 100 GeV





IceCube - principles of neutrino telescope operation

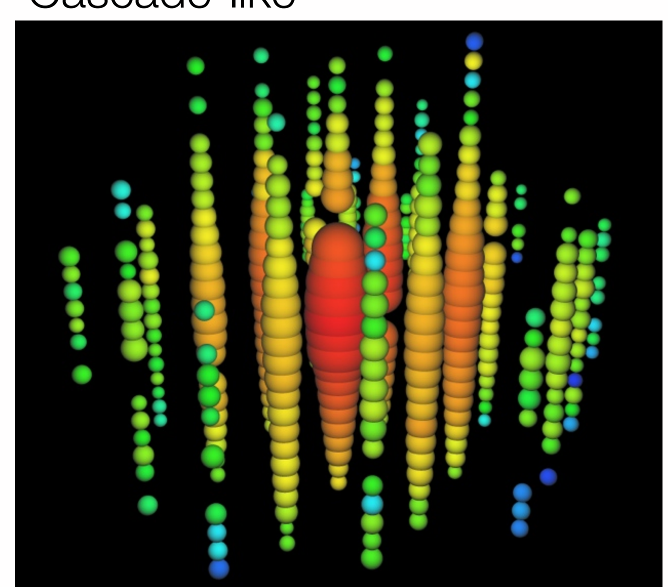


IceCube detects Cherenkov radiation emitted from charged particles produced by neutrino interactions in or near the detector volume

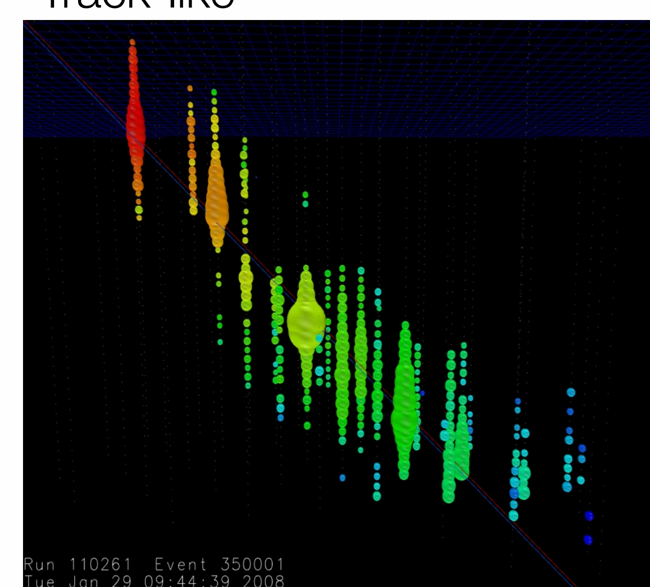
The shape and timing distributions of the emitted photons tells us the crucial information about the parent neutrino event.

It is therefore critical to accurately model the light propagation in the deep ice.

Cascade-like

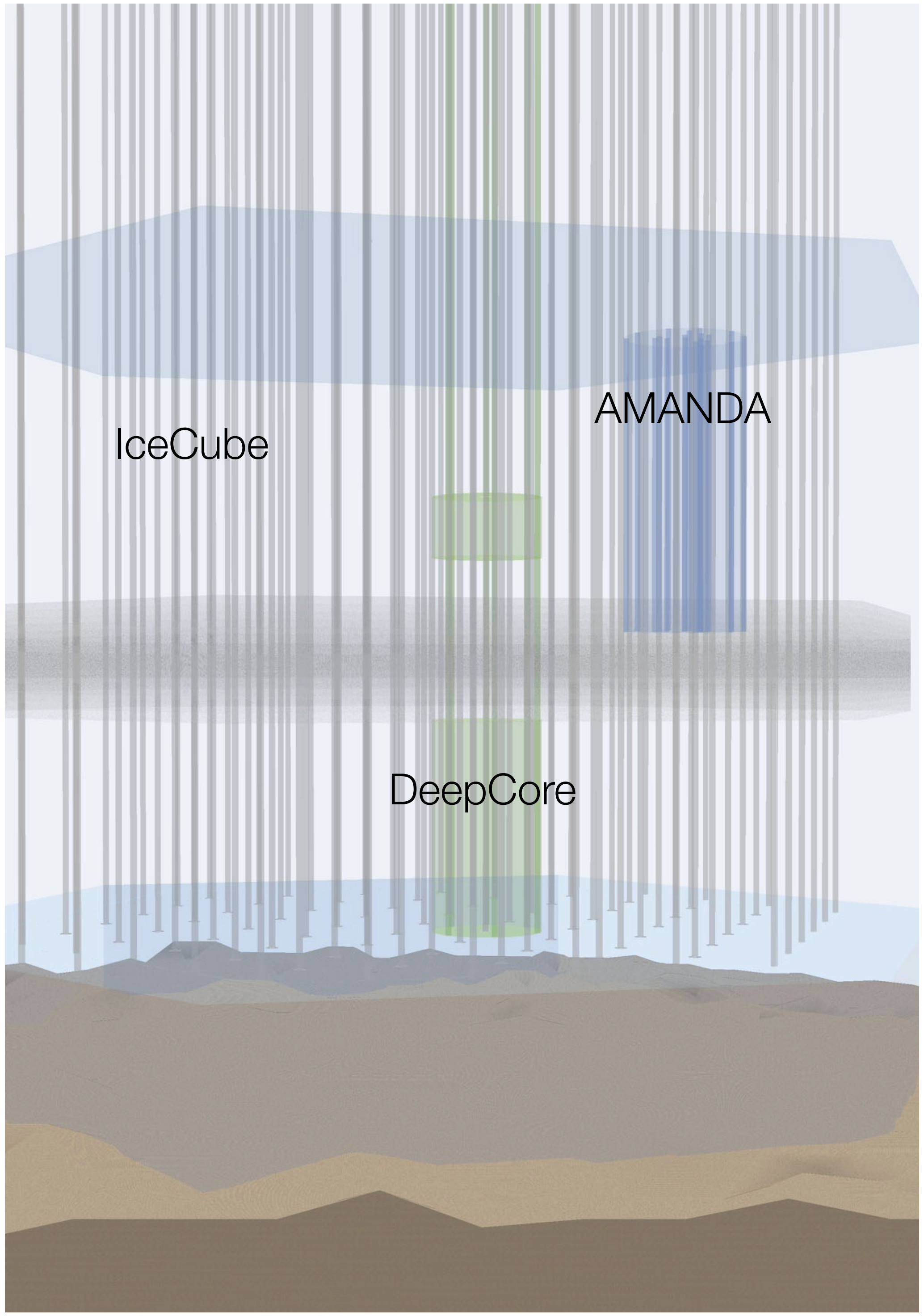


Track-like



However, glaciers are complex beasts…

Understanding light propagation in the glacier is a non-trivial task. This natural medium has formed over the past few hundred thousand years and many unexpected features have been uncovered.



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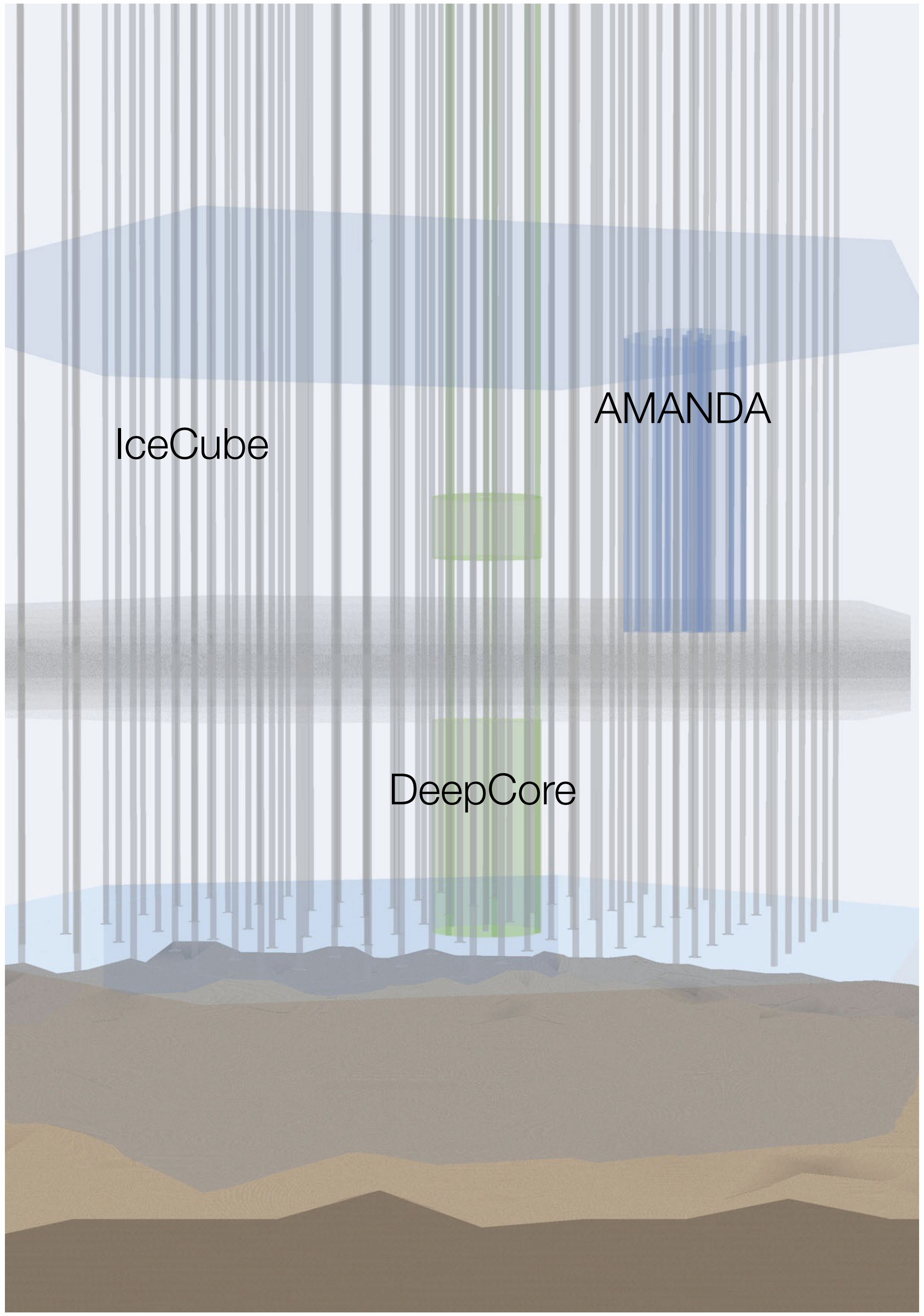

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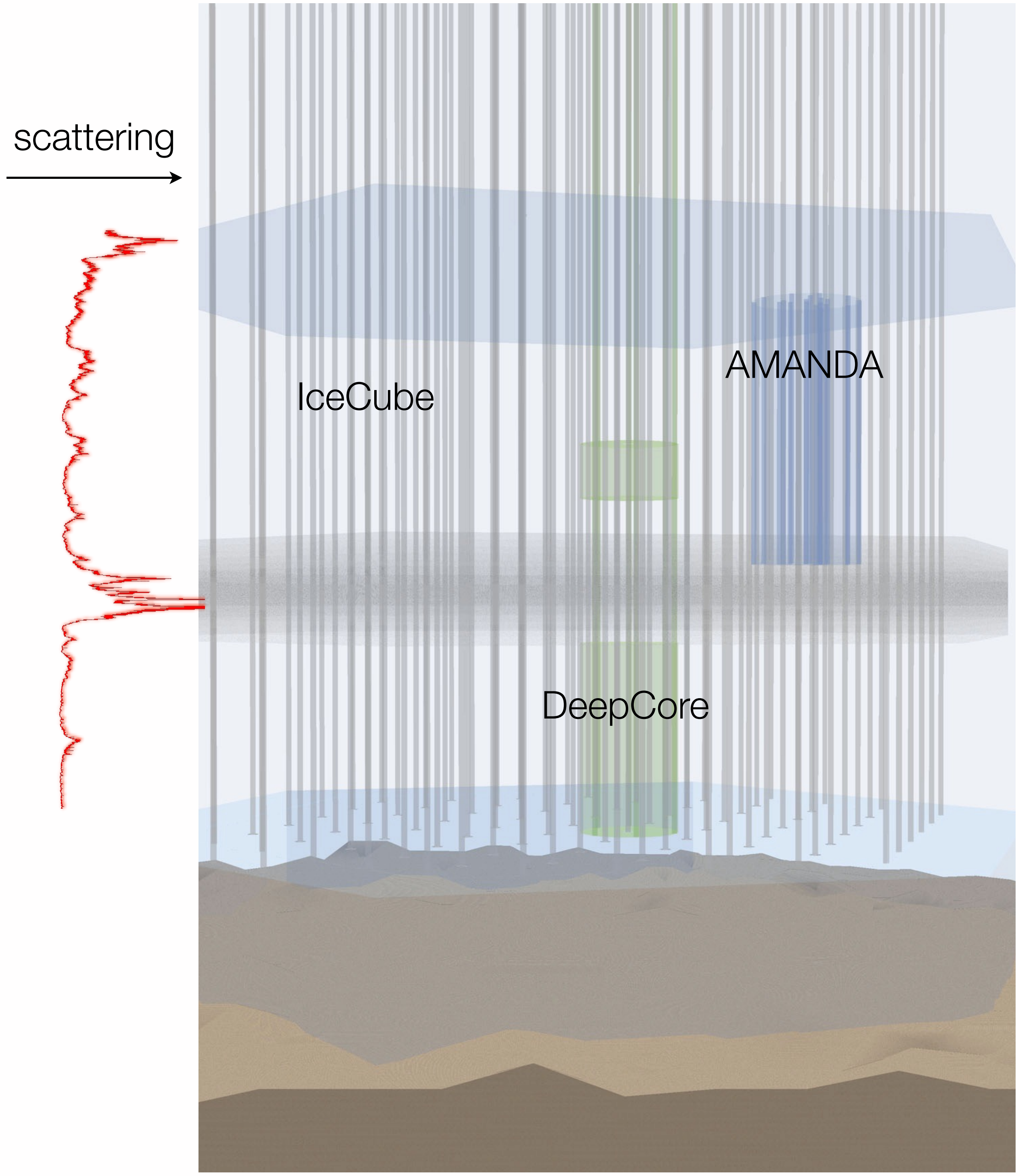

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Measurements with a dust-logger uncovered a series of discrete horizontal layers, each with its own scattering and absorption parameters

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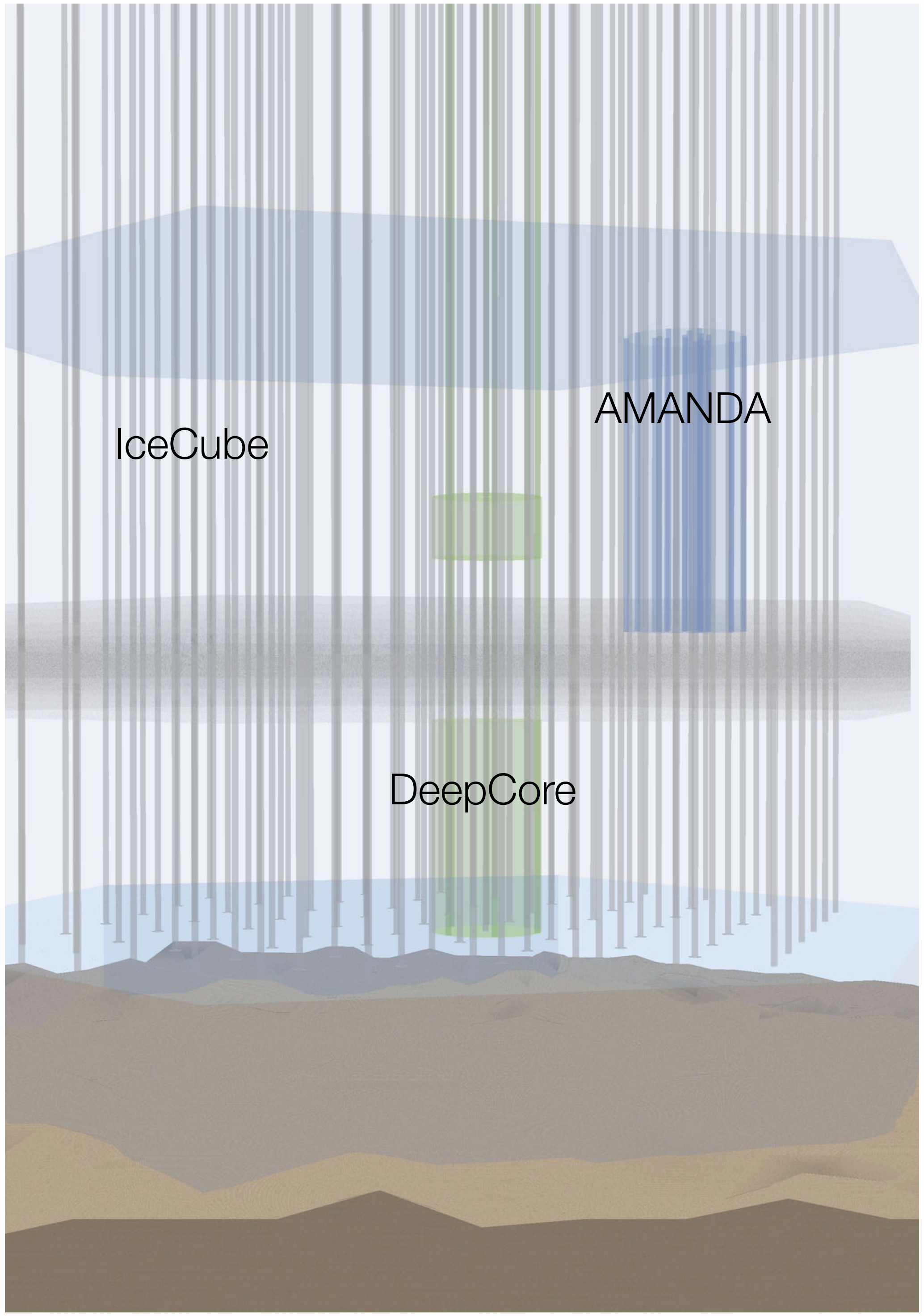

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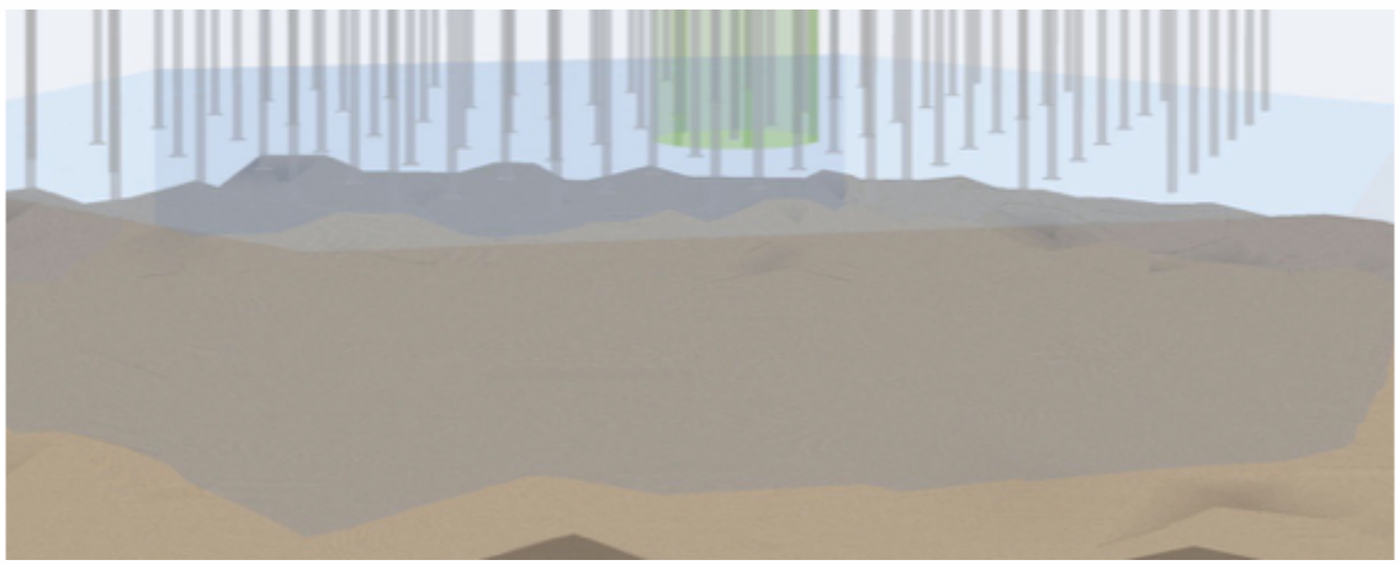

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when the glacier forms, it builds upon the continental bedrock, introducing a tilt to the dust layers depend on the local region of formation.

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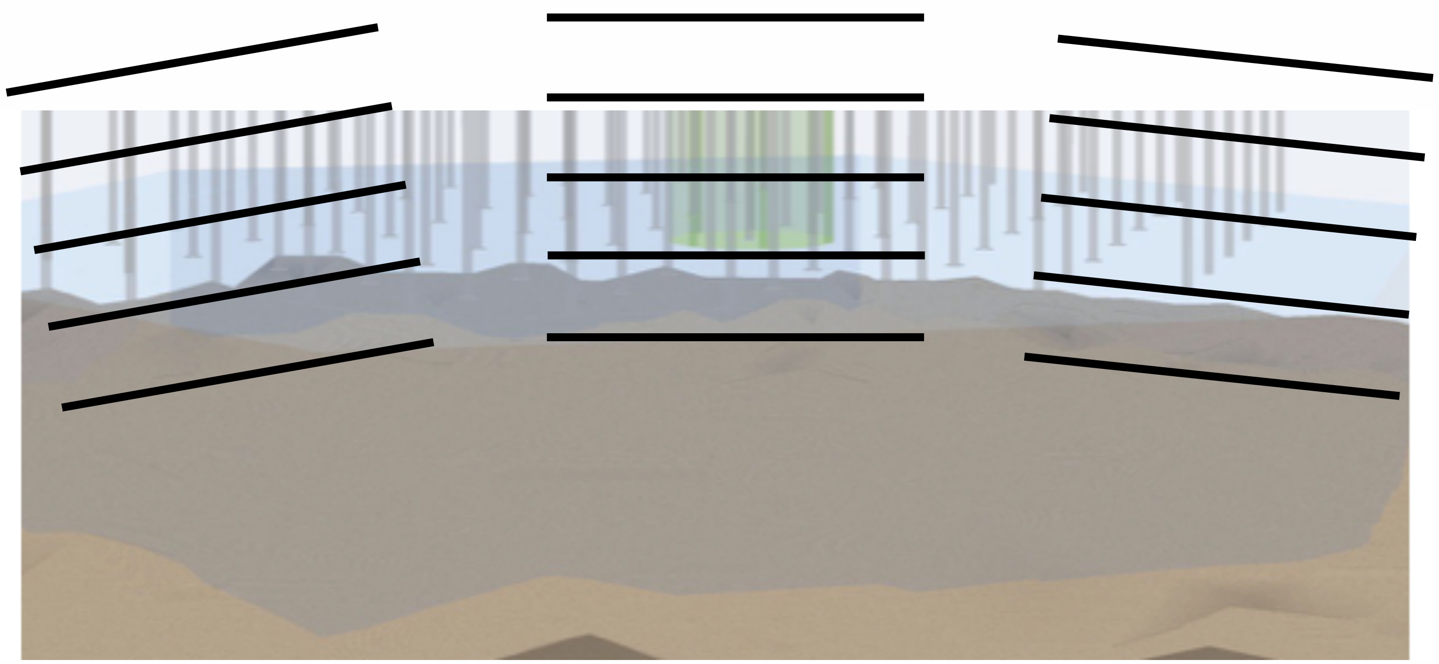

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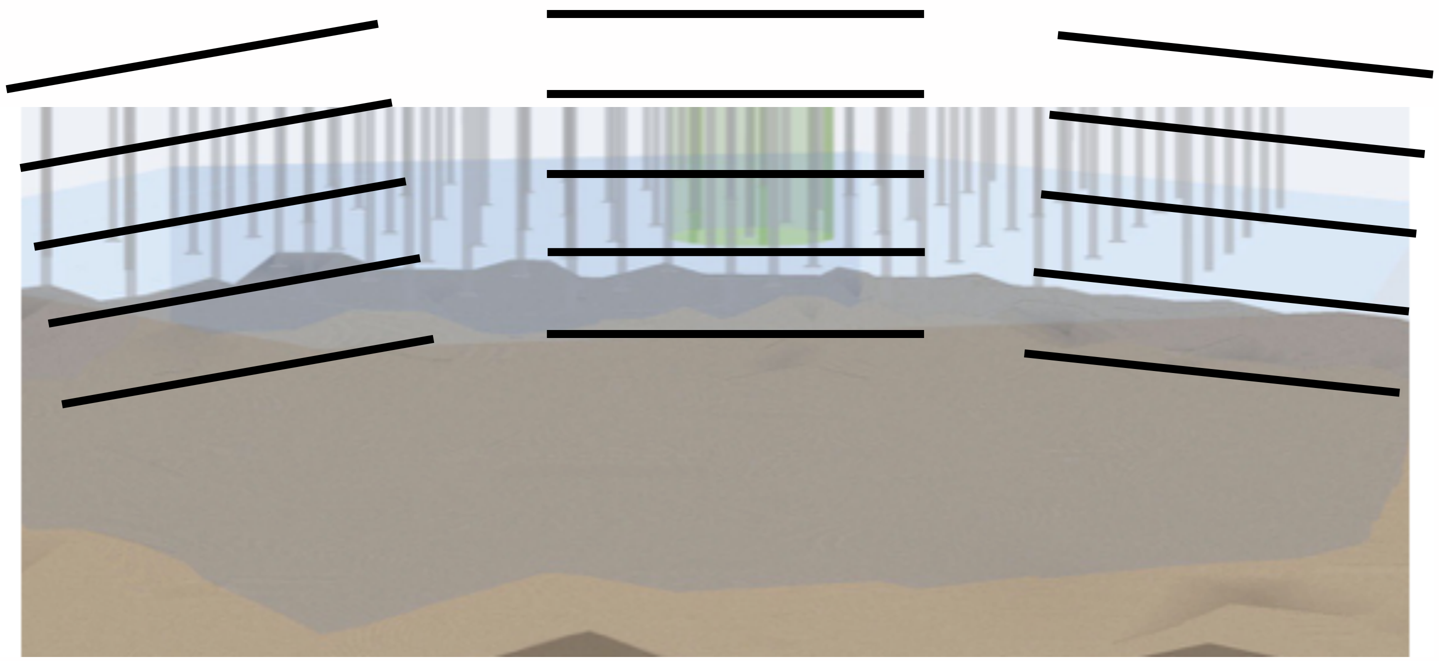

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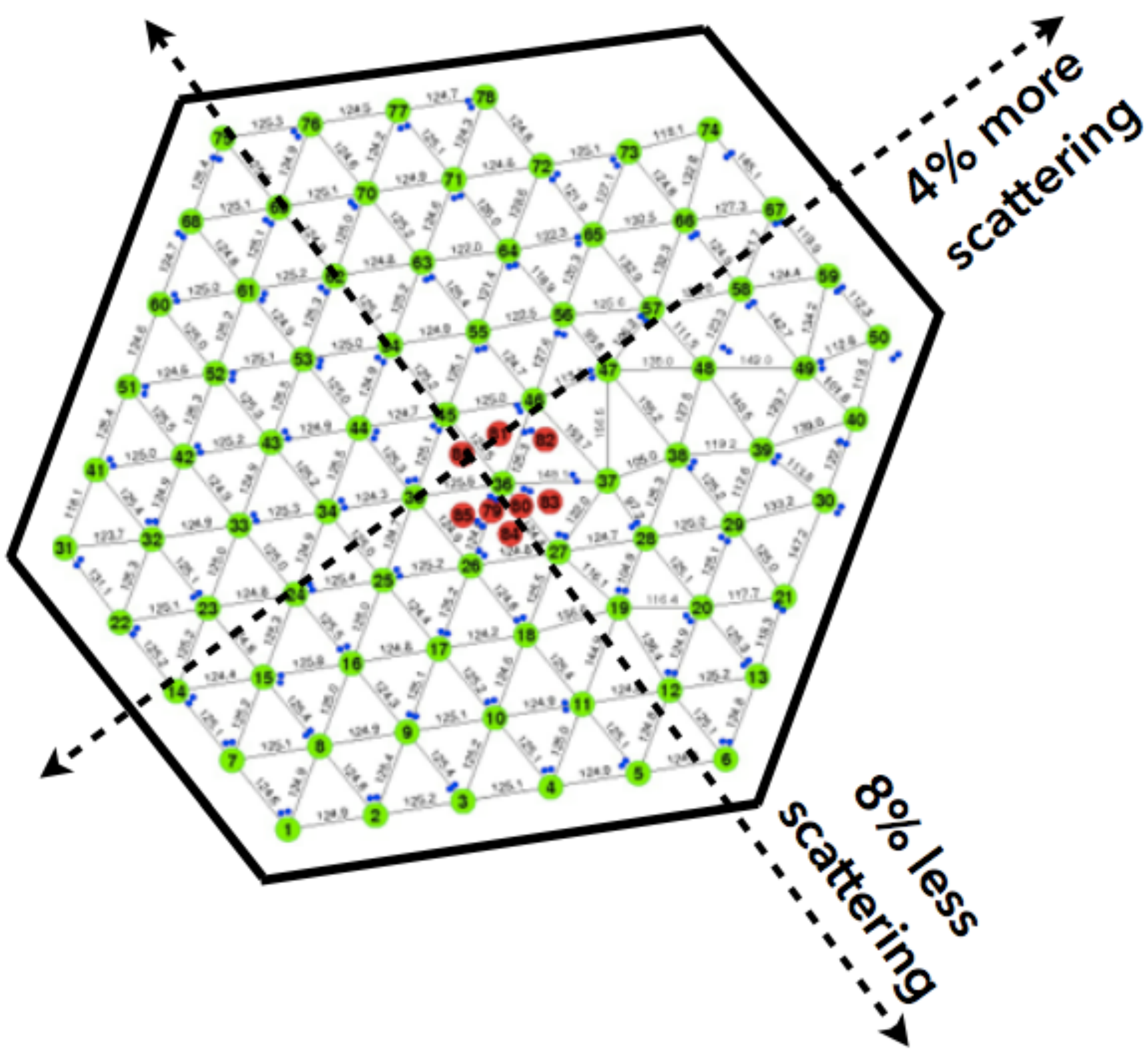
IceCube Top View



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the ice is not isotropic. The amount of scattering experienced by a photon is affected by its direction through the ice.

The cause of this remains unknown, although it may be due extreme pressures of the deep glacier changing the ice crystalline structure.

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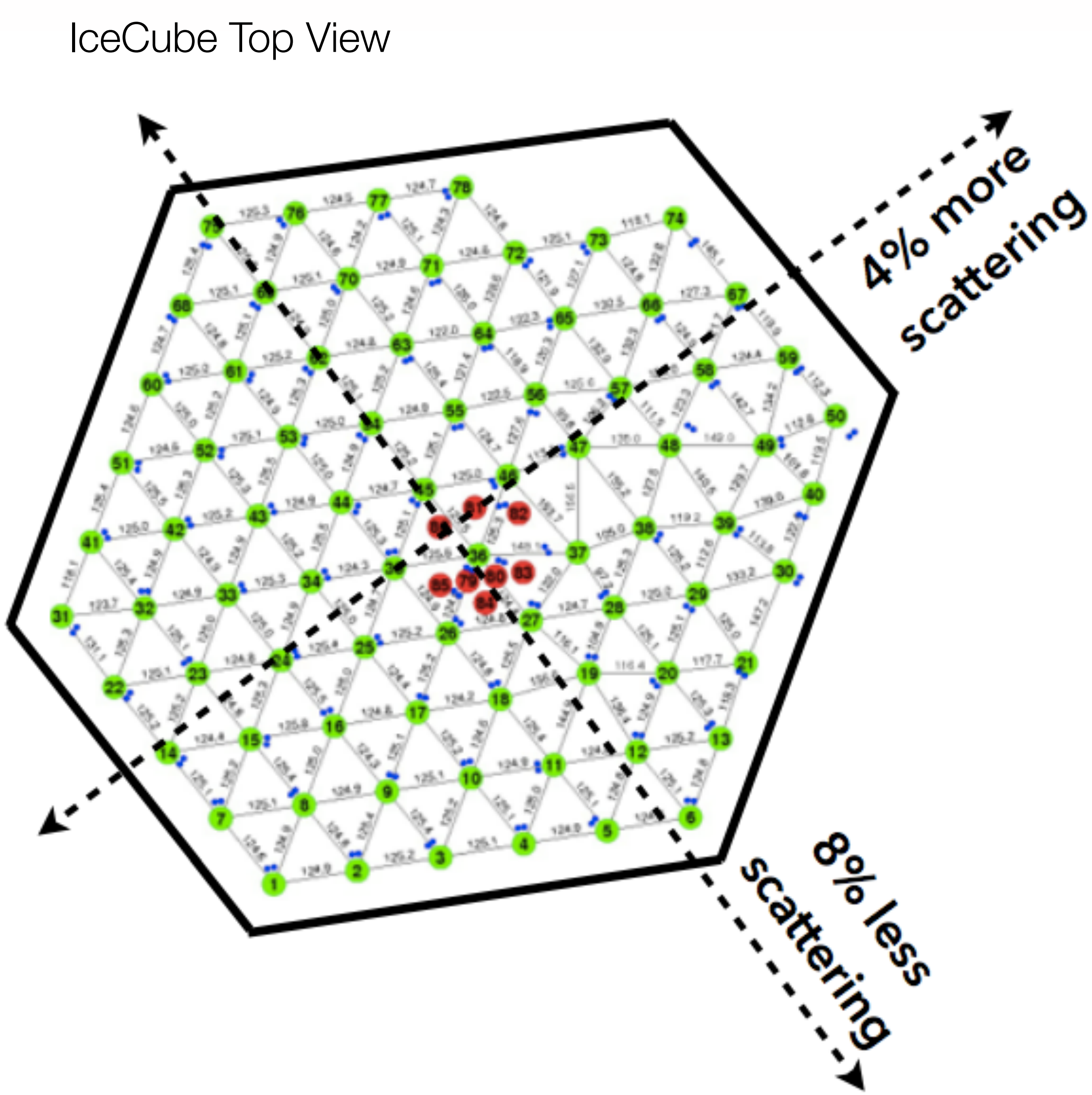

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All of these elements affect the ability to fully model the ice optical properties, impacting the systematic uncertainties of event reconstruction

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We are faced with quite a challenge…

Taming the glacial effects in reconstructions…

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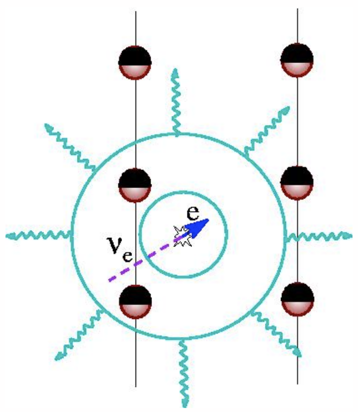
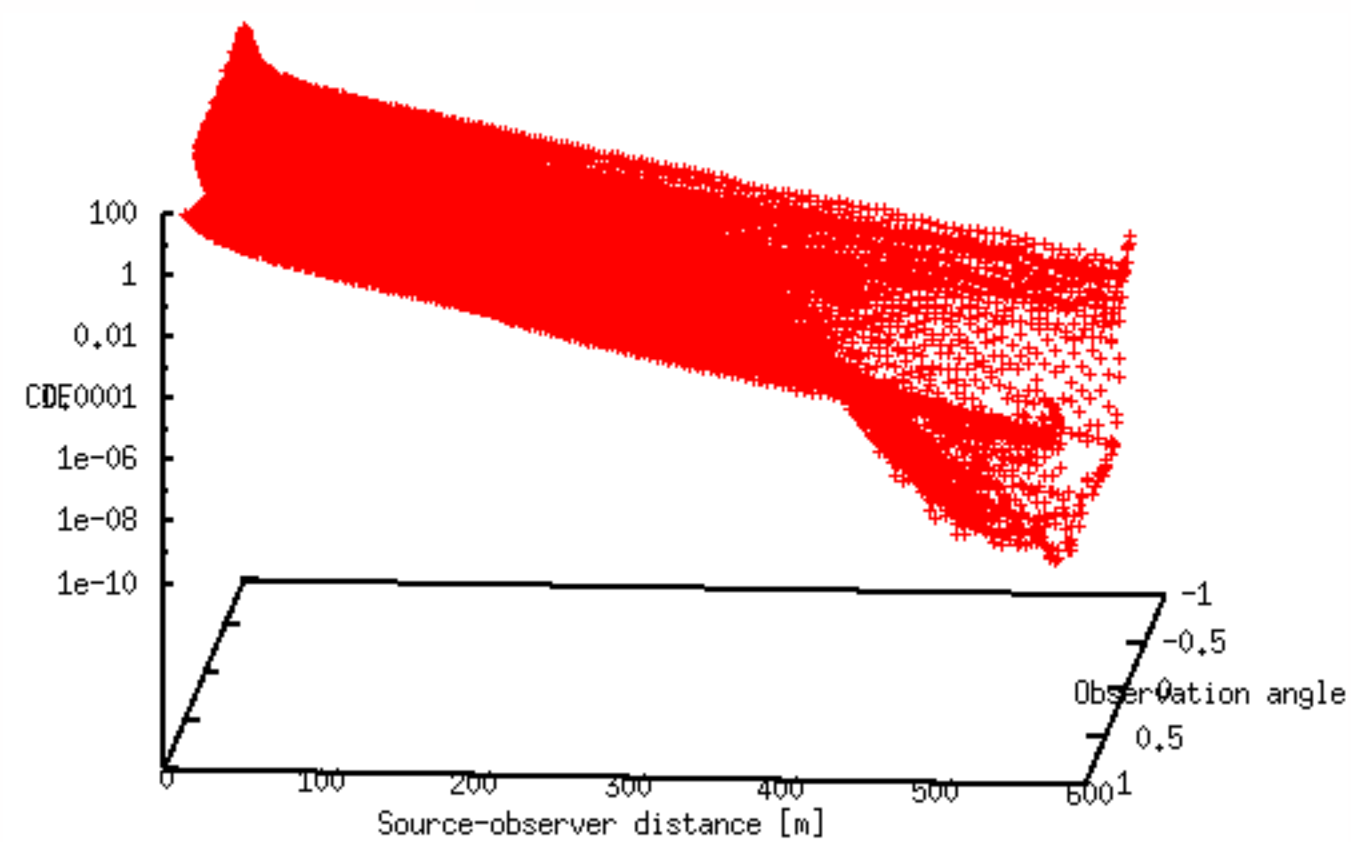
IceCube's event reconstructions, to date, rely on 'photon lookup tables'

These tables are tabulated values of the probability to detect the photon throughout the instrumented volume of the ice (shown below)





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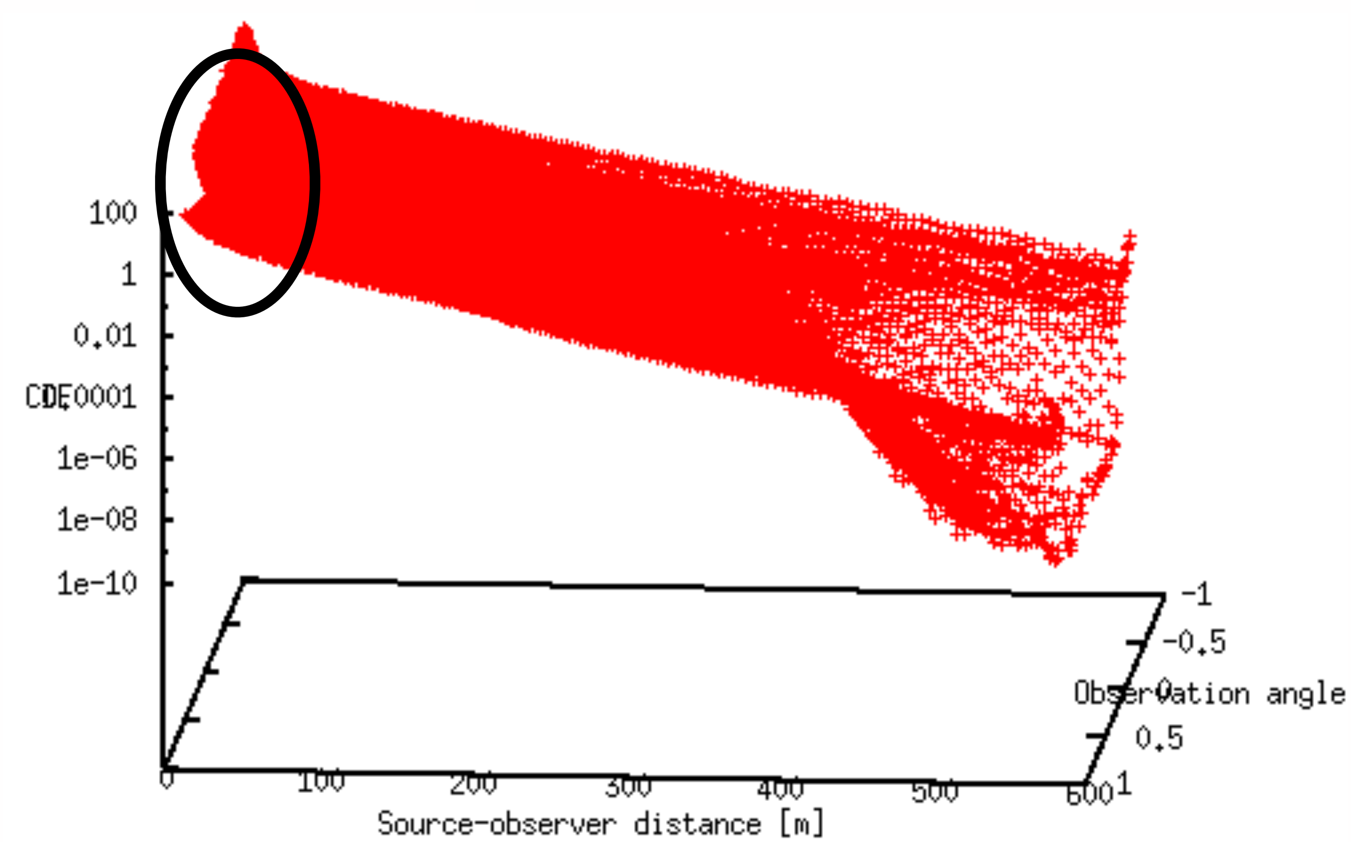

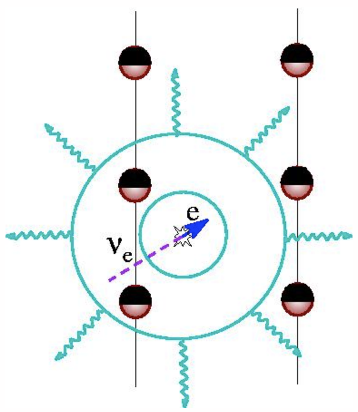

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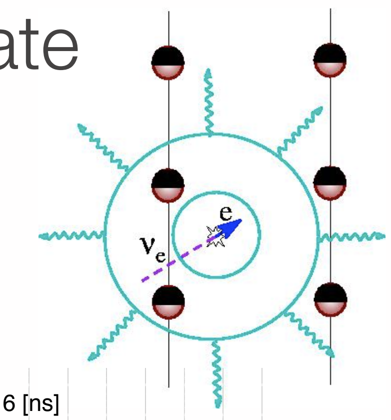
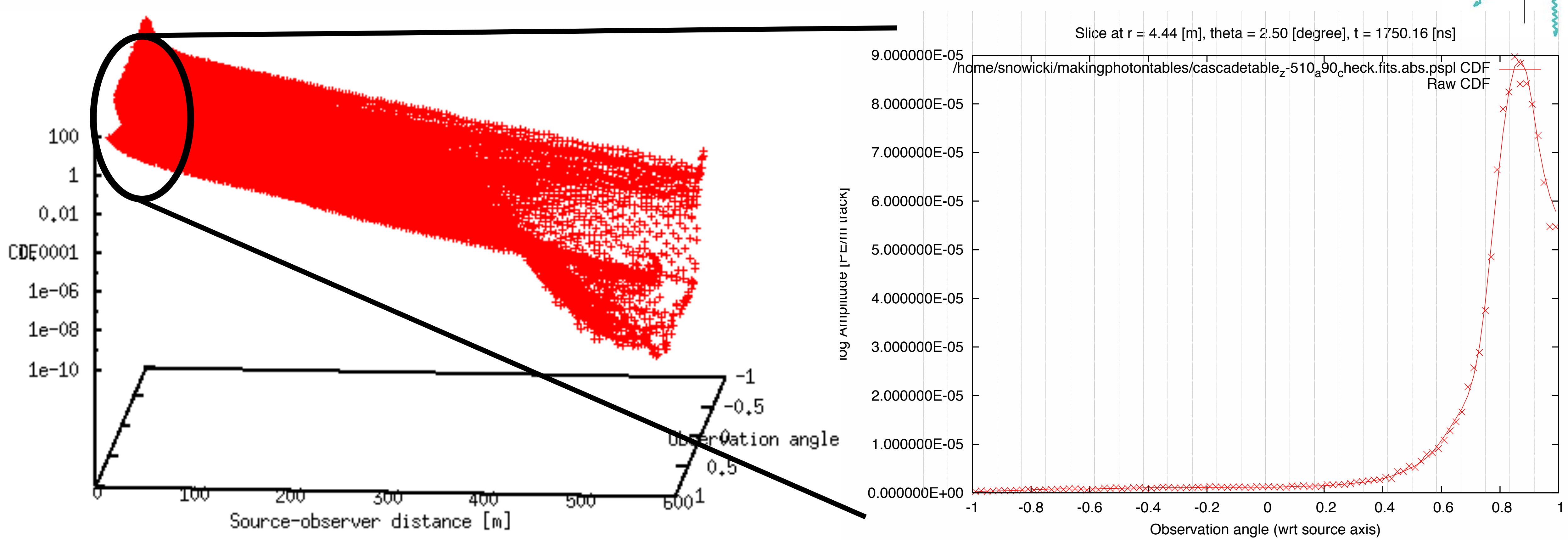
In this method, the tables parametrize the light emission using measured ice properties (from calibrations). They can then be used to generate event hypotheses, from which likelihoods may be calculated and minimized

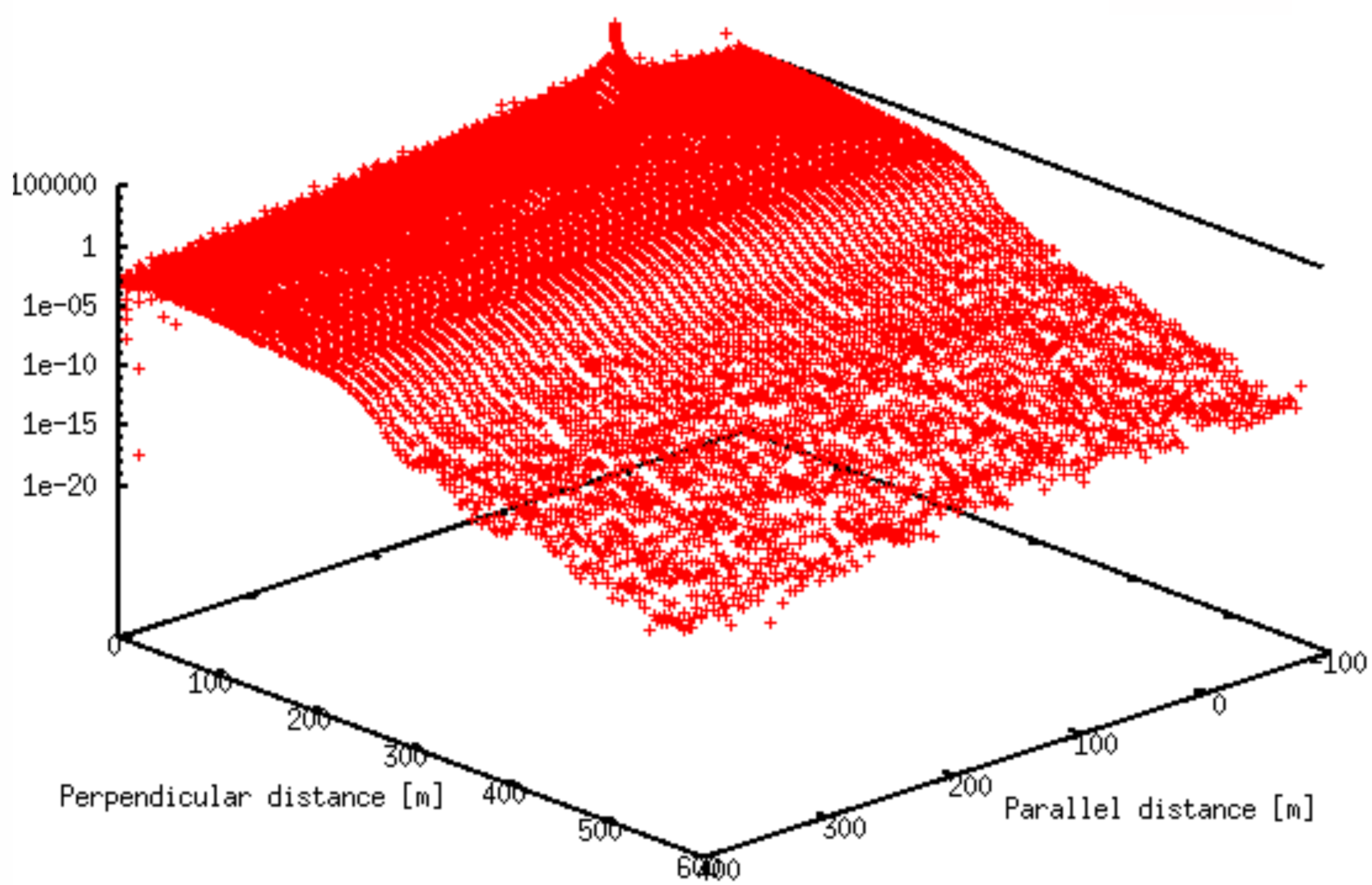


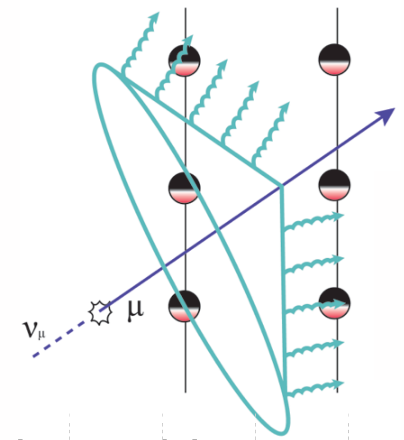


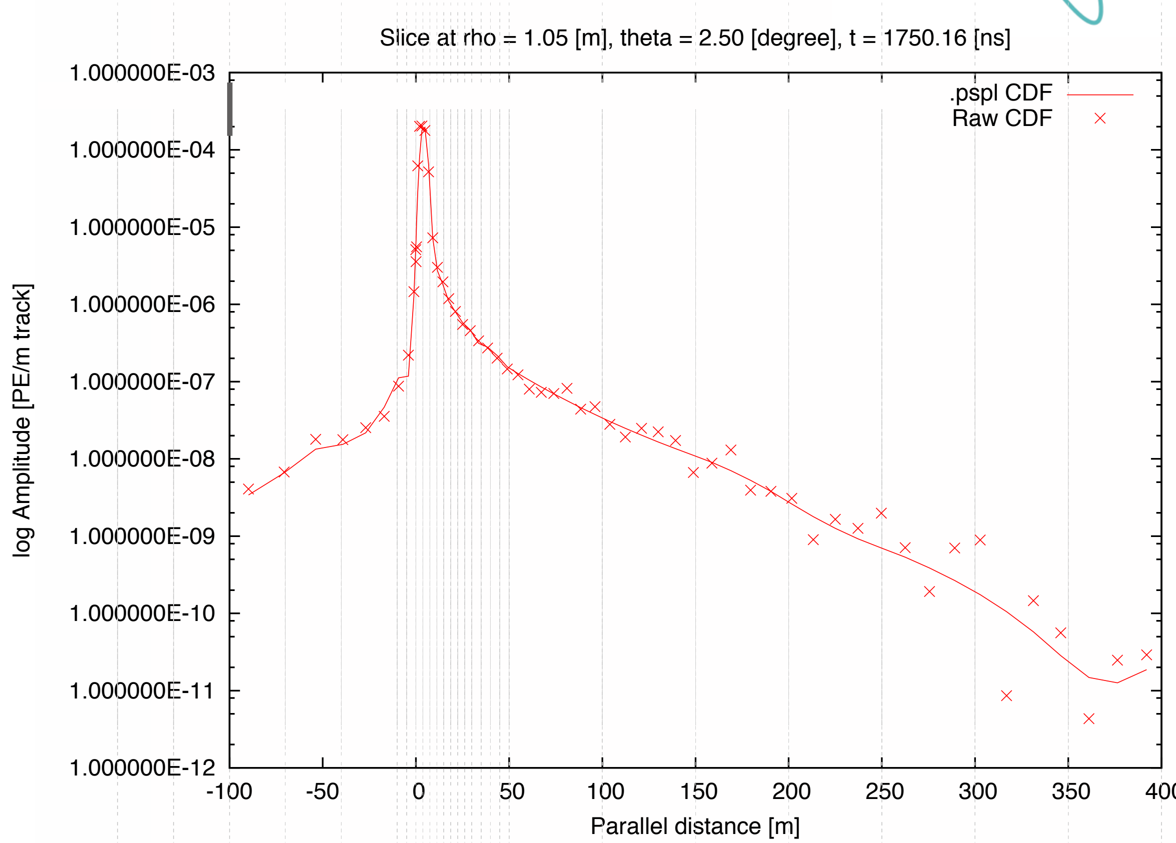
Improving the photon lookup tables

Regenerating the photon lookup tables with direct propagation and tracking of particles has increased their physical accuracy

Changing the table geometry for muons to mirror the intrinsic symmetries better represents the light distribution







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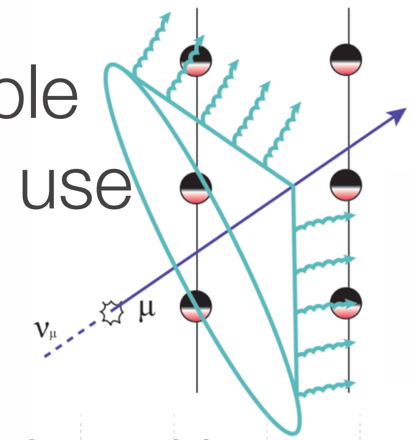
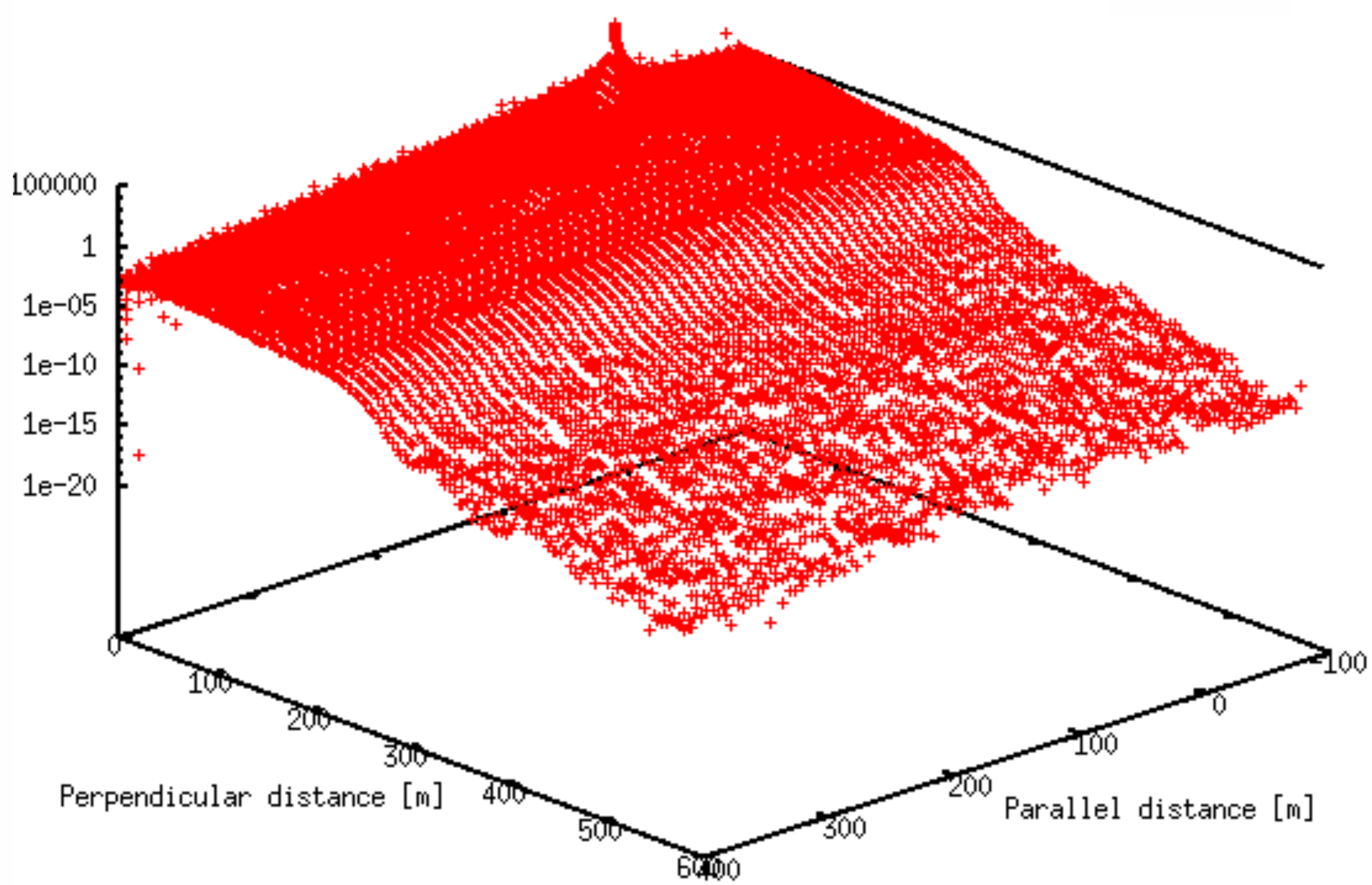
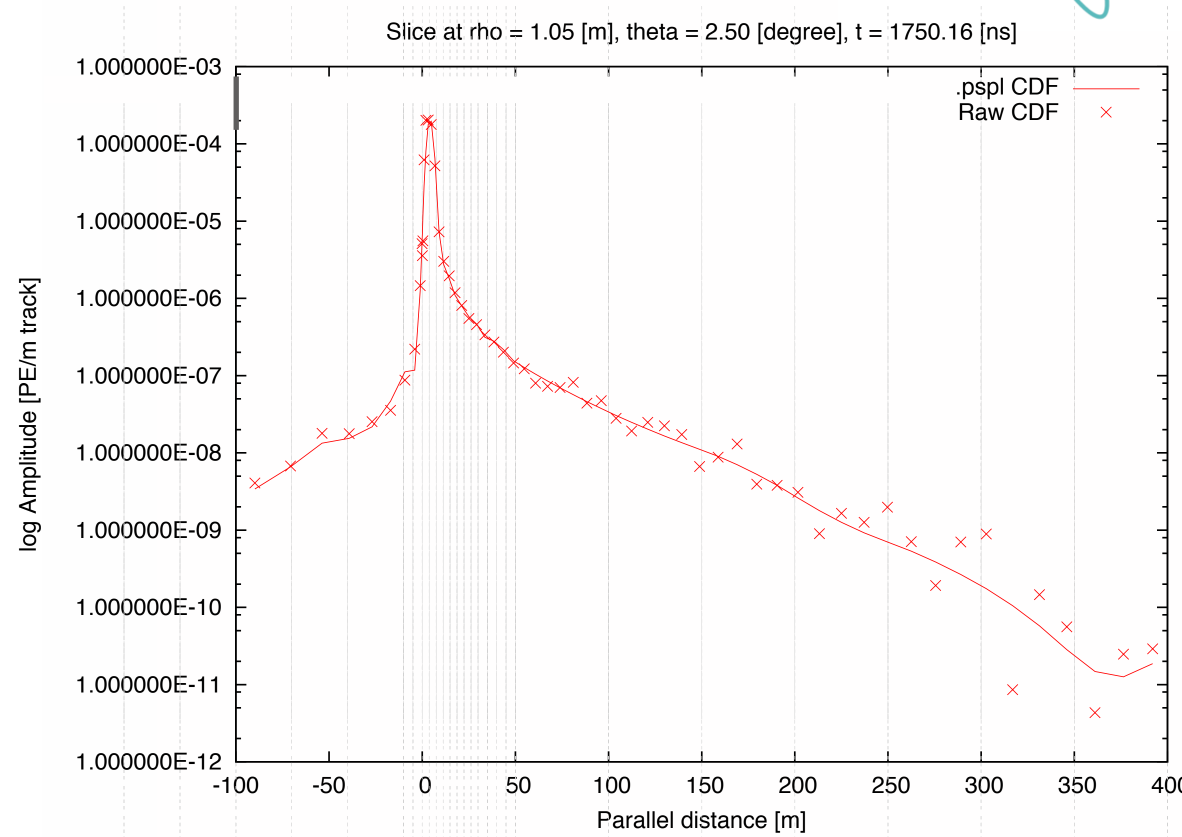
However, incorporating the ice anisotropy would require unattainable amounts of computational resources to generate, store or load for use







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A new method of reconstruction

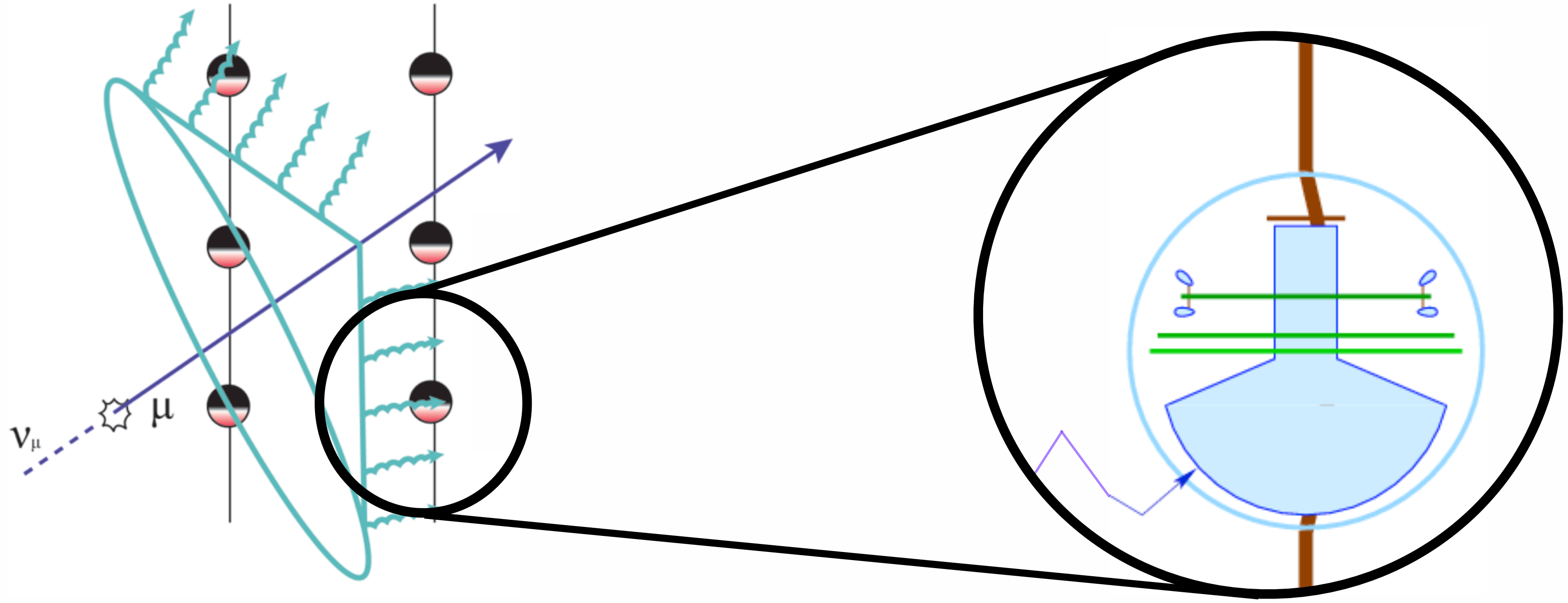
GPU computing has made it possible to achieve factors of 100x in speed-ups for the simulation of events in the deep ice

- particles and their interactions are simulated fully via GEANT4 (not the bottle neck; CPUs are OK here)

- photon emission and propagation consumes the majority of the computation time (due to the scatter probability look-ups, which are relatively common in the deep ice

- an advanced GPU algorithm parallelizes the photon propagation, making it possible to simulate the (even very high energy) events in real-time

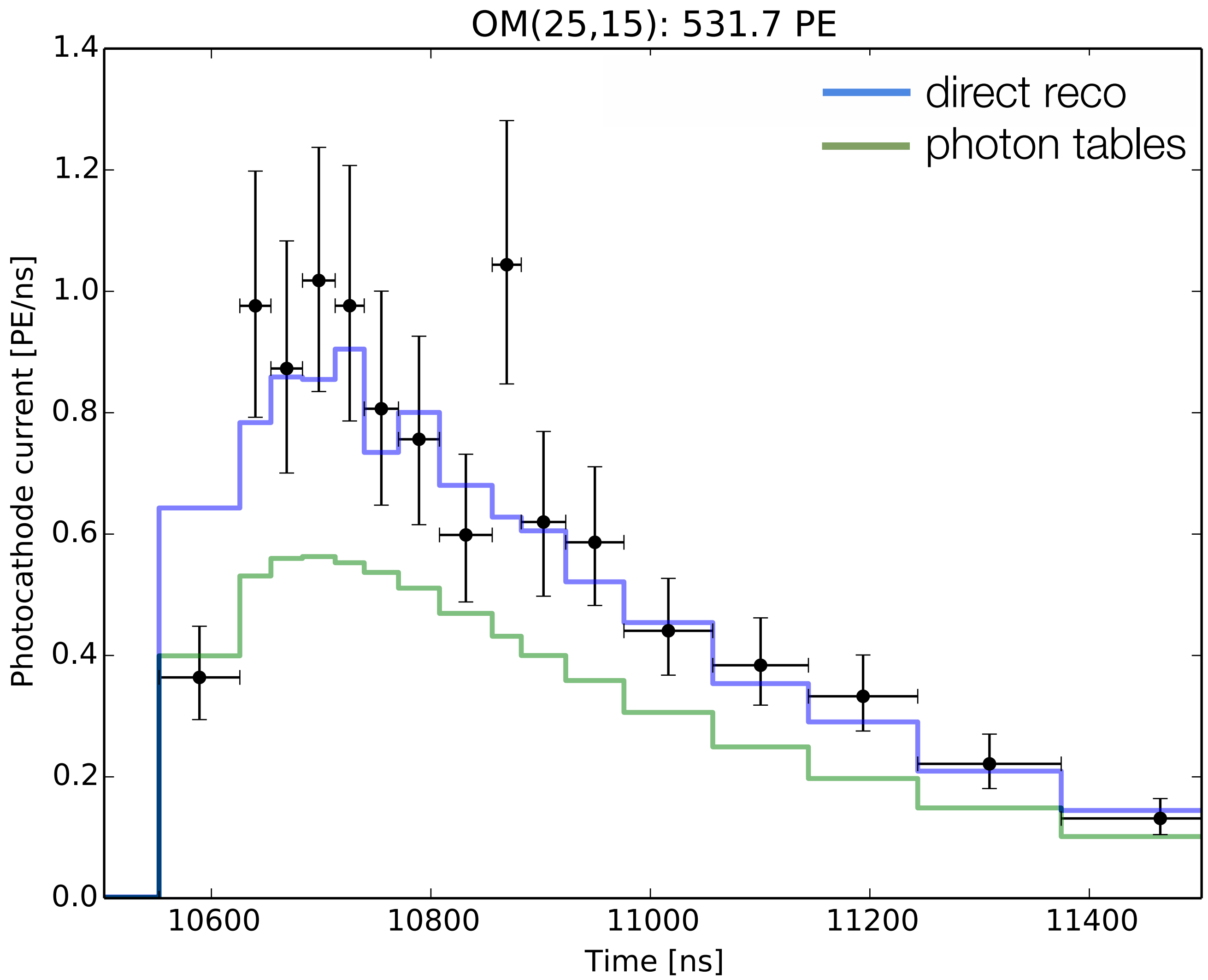
Using this technique to generate event hypotheses allows use of the complete ice model description



Status of direct reconstruction

Though the concept is fairly simple, the process must be implemented into the full IceCube analysis framework

The first steps are to check the method is providing reasonable representation of the light expectation in individual optical modules.



Comparison of the simulated waveforms to optical module data in an IceCube event shows the hypothesis is well-behaved (this is promising! current work in progress)

The resultant simulated waveforms of each module may then be combined in a full likelihood and minimized to provide the final reconstructed event information

Summary and outlook

IceCube has broken new ground for neutrino physics with first discovery of a high-energy astrophysical neutrino flux and precision atmospheric oscillation measurements in a new energy regime

The optical properties of the deep glacier have been discovered to hold unexpected characteristics (perhaps not surprising when using a natural medium)

IceCube's current methods of event reconstruction are incapable of incorporating all the details of the ice model, and these elements are now emerging in the analyses as leading systematic uncertainties

An advanced event reconstruction is under development (even lions can be tamed), and this 'direct reconstruction' is designed to provide the best representation of the ice model while avoiding other limitations of previous methods

First steps towards verification are underway! Stay tuned