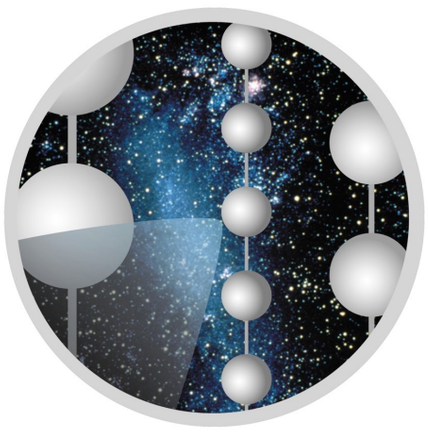


IceCube

Direct reconstruction - an advanced event reconstruction algorithm for IceCube-DeepCore

Sarah Nowicki

CAP 2017
Kingston, ON, Canada
May 31st, 2017

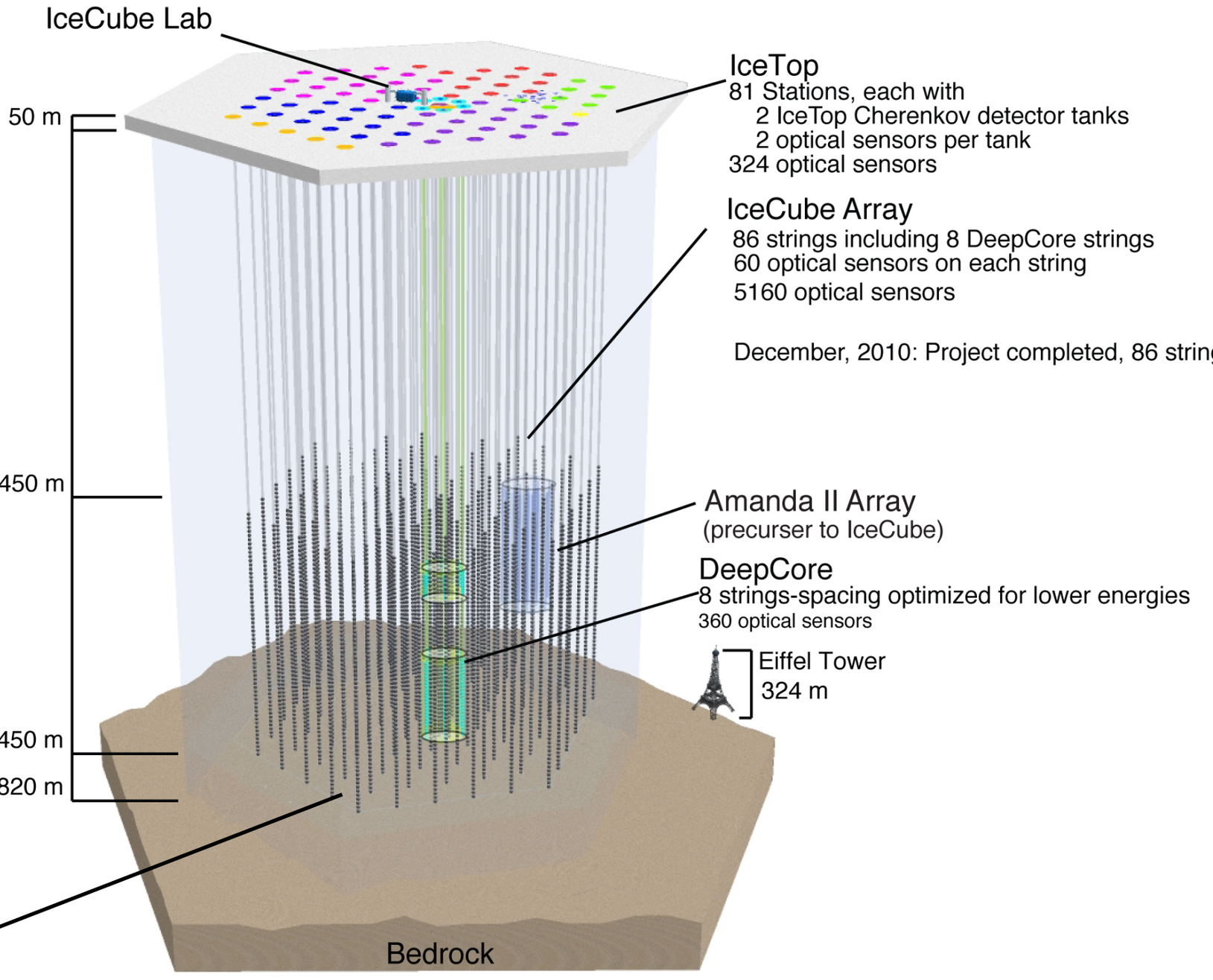
UNIVERSITY OF ALBERTA

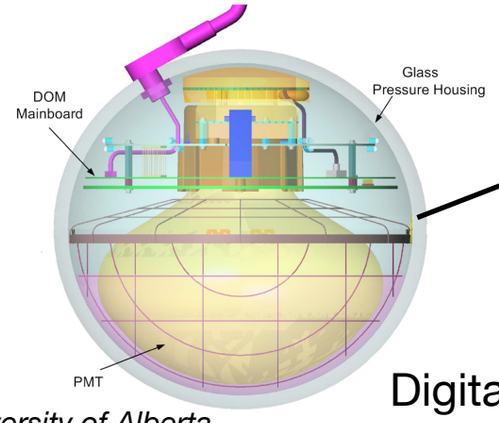
IceCube-DeepCore detector array

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

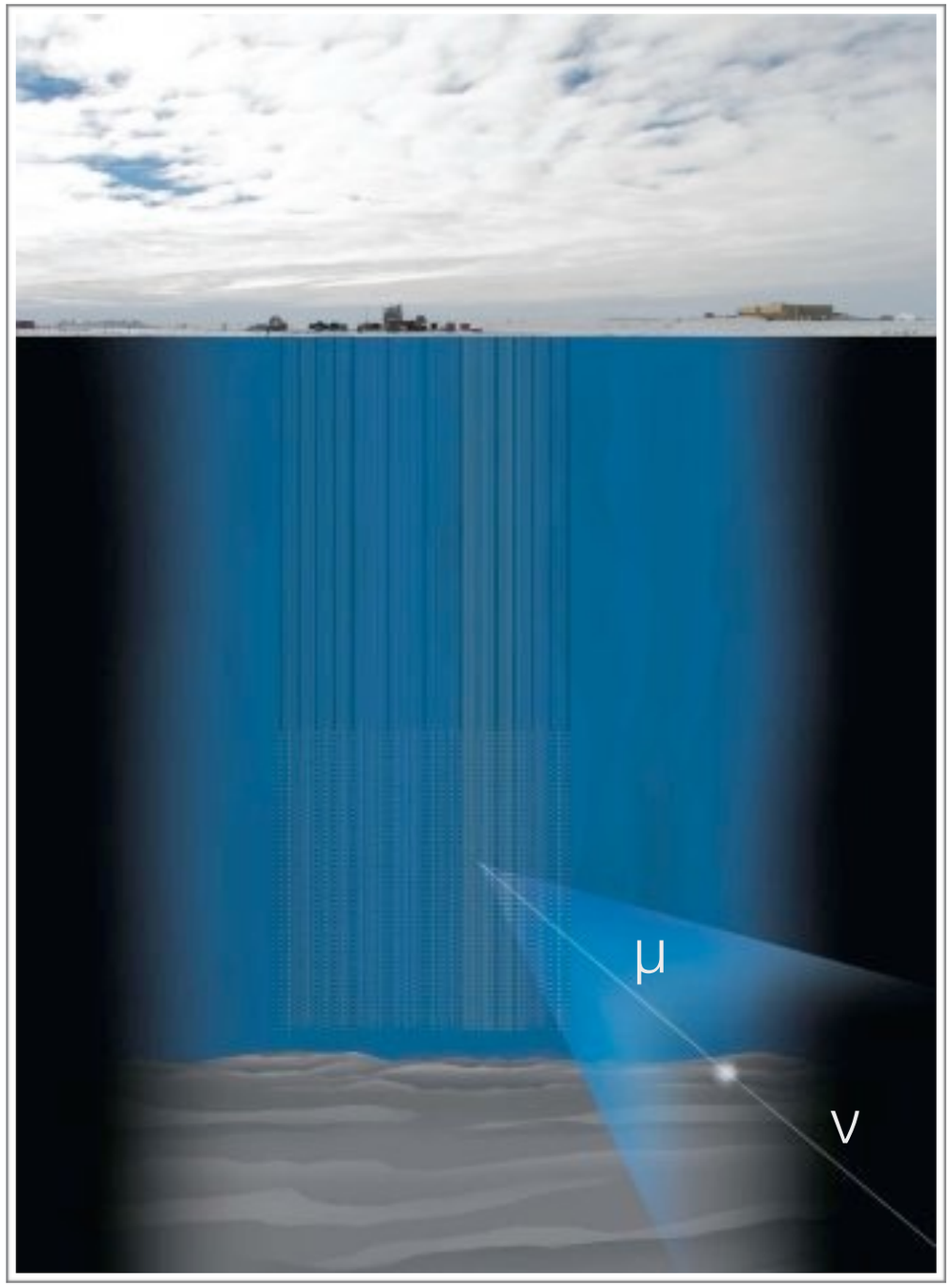
A more densely instrumented DeepCore region was included to study particles at much lower energies, ~10 - 100 GeV





Digital Optical Module (DOM)

Principles of neutrino telescope operation

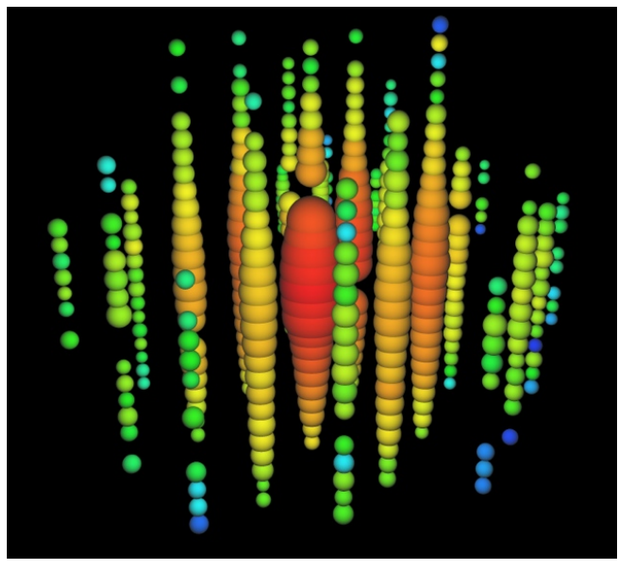


IceCube detects Cherenkov radiation emitted from charged particles produced by neutrino interactions in or near the detector volume

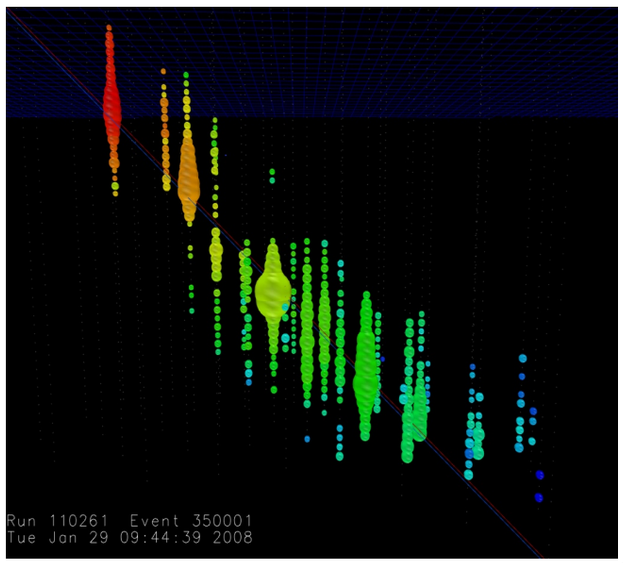
The shape and timing distributions of the emitted photons tells us the crucial information about the parent neutrino event.

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

Cascade-like

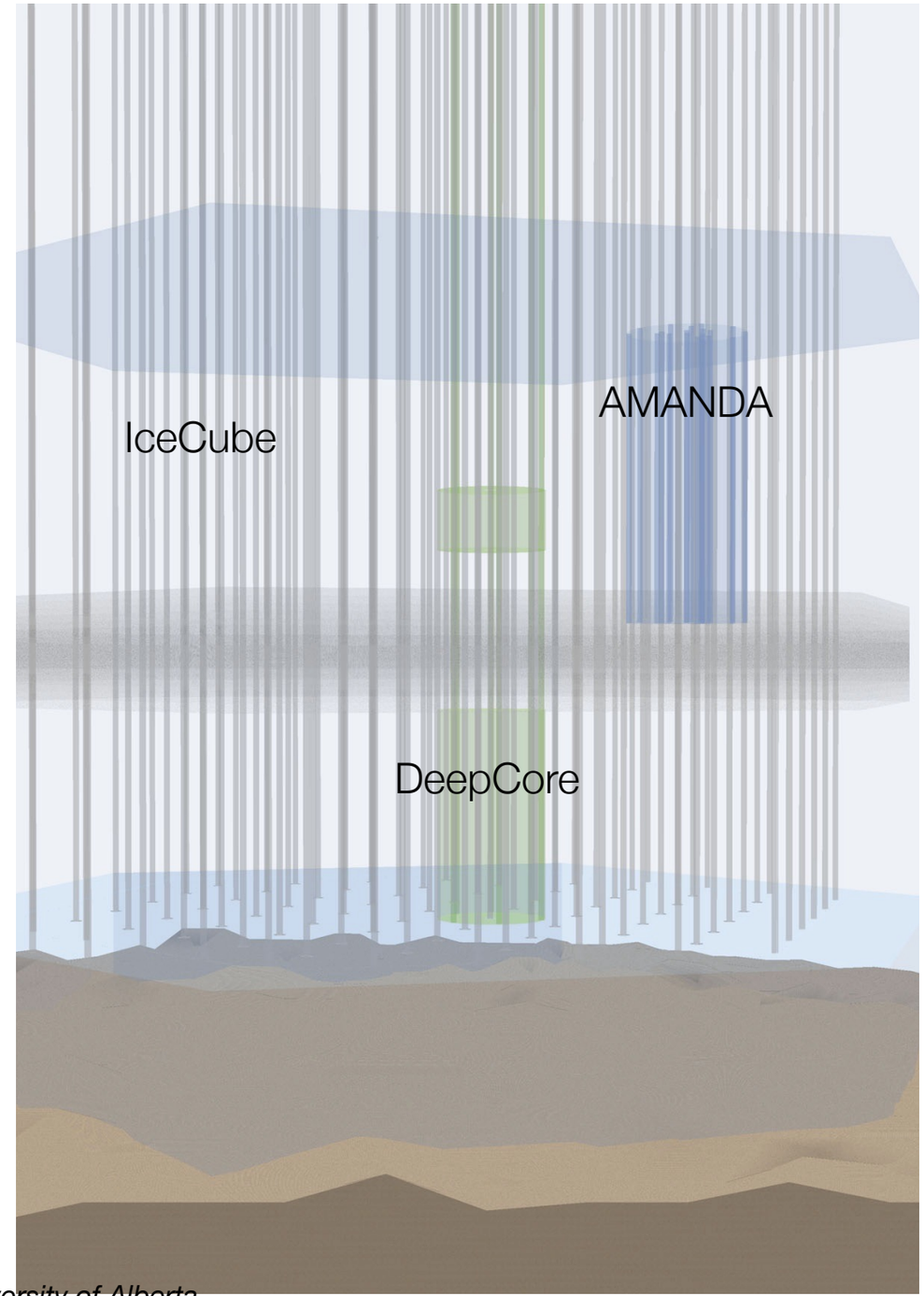


Track-like



Challenges of using a natural detector medium

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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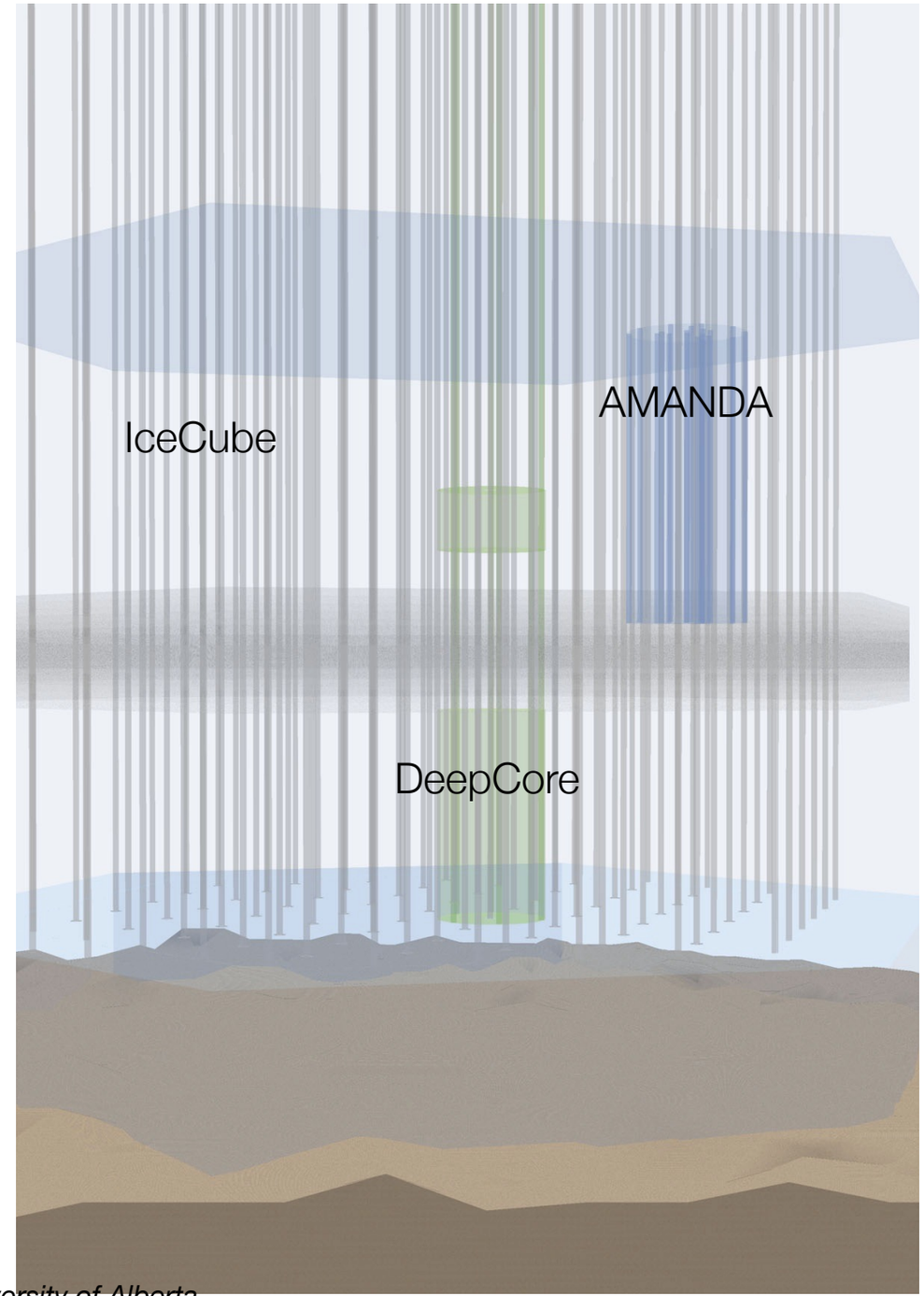

First deployed IceCube strings showed a loss of light in the middle of the detector

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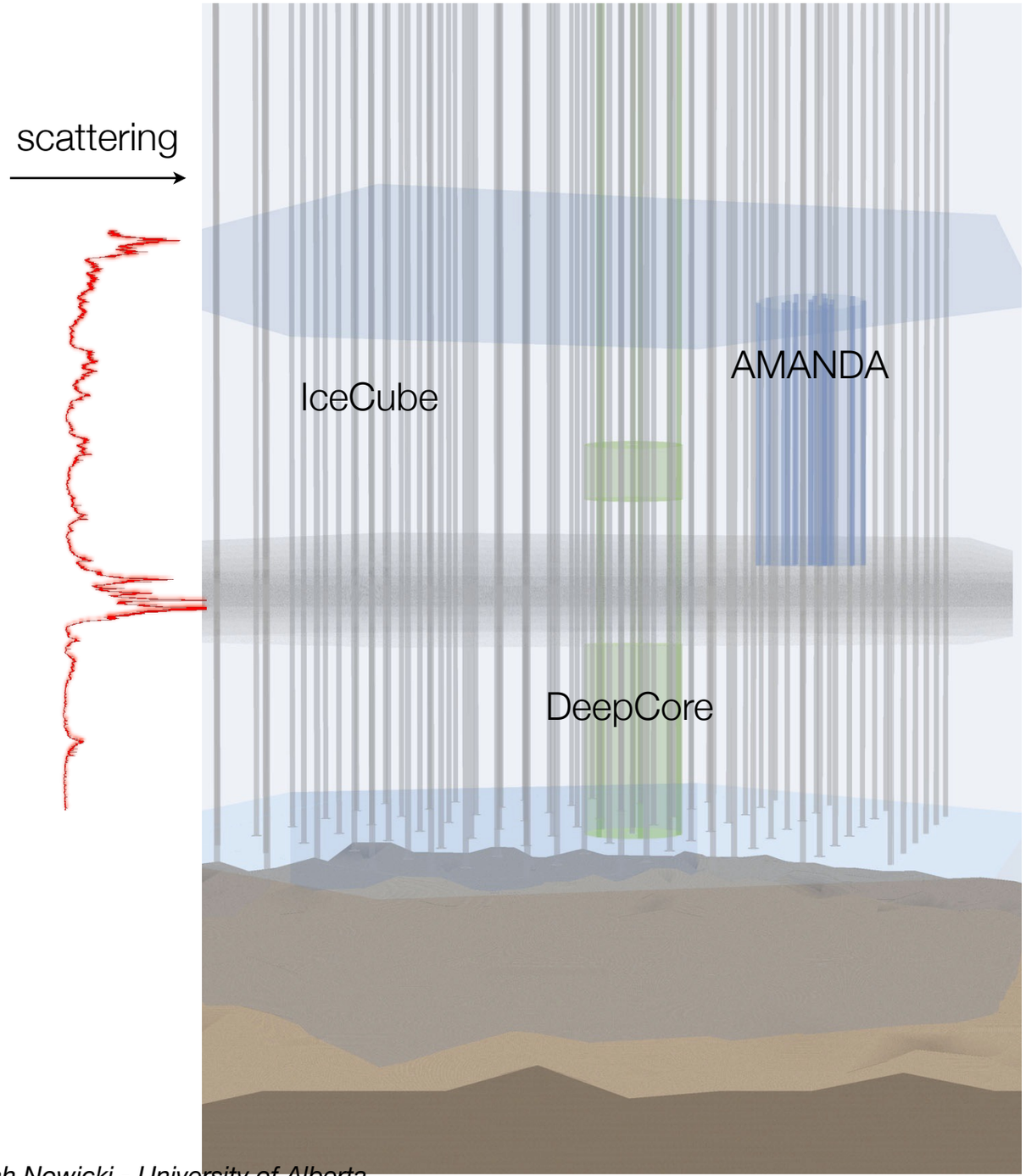

First deployed IceCube strings showed a loss of light in the middle of the detector

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

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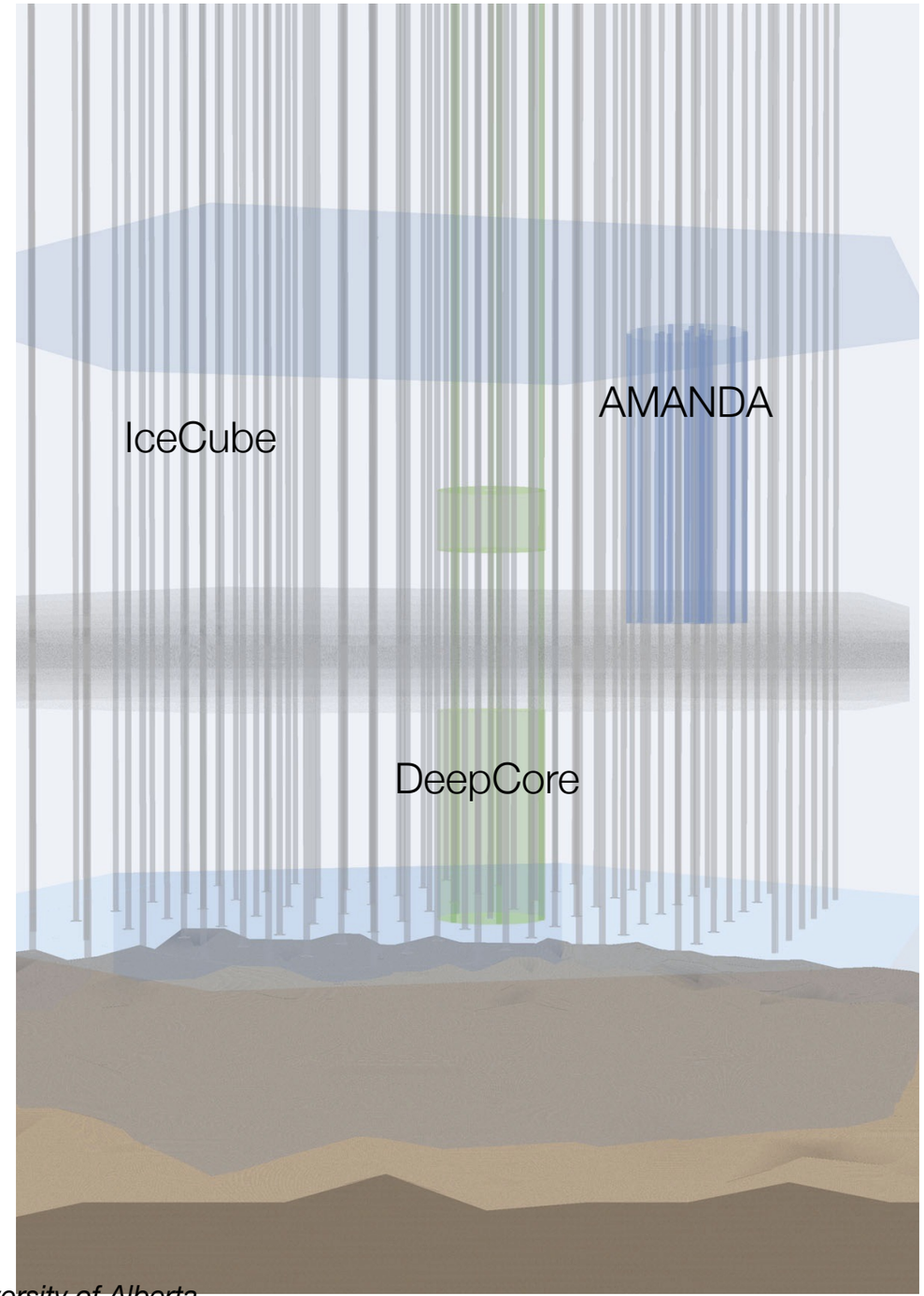

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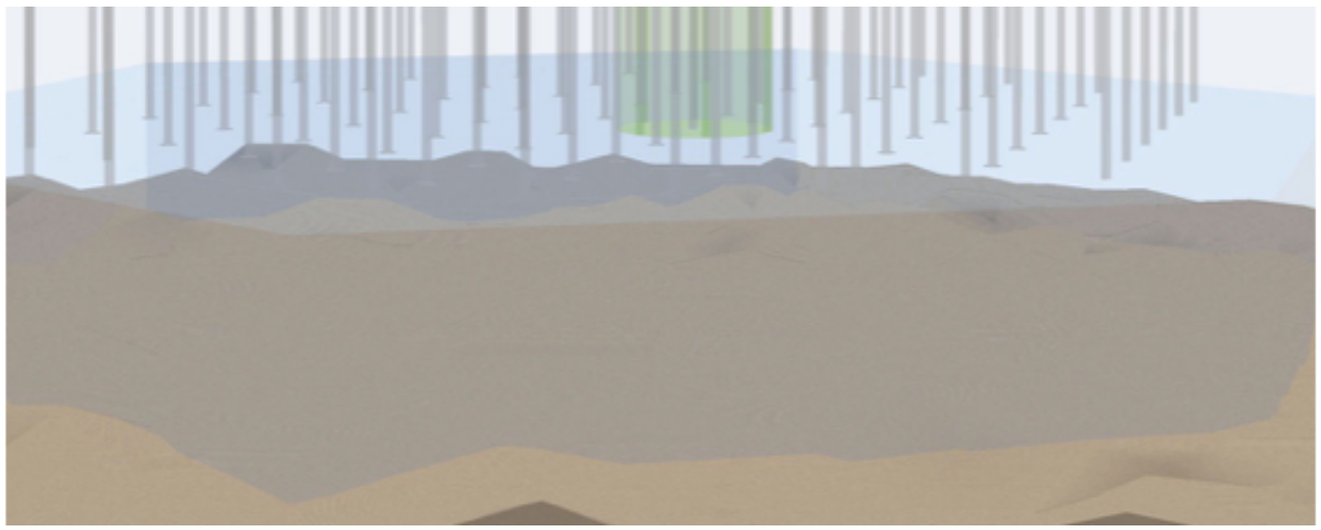

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when the glacier forms, it builds upon the continental bedrock, introducing a tilt to the dust layers depend on the local region of formation.

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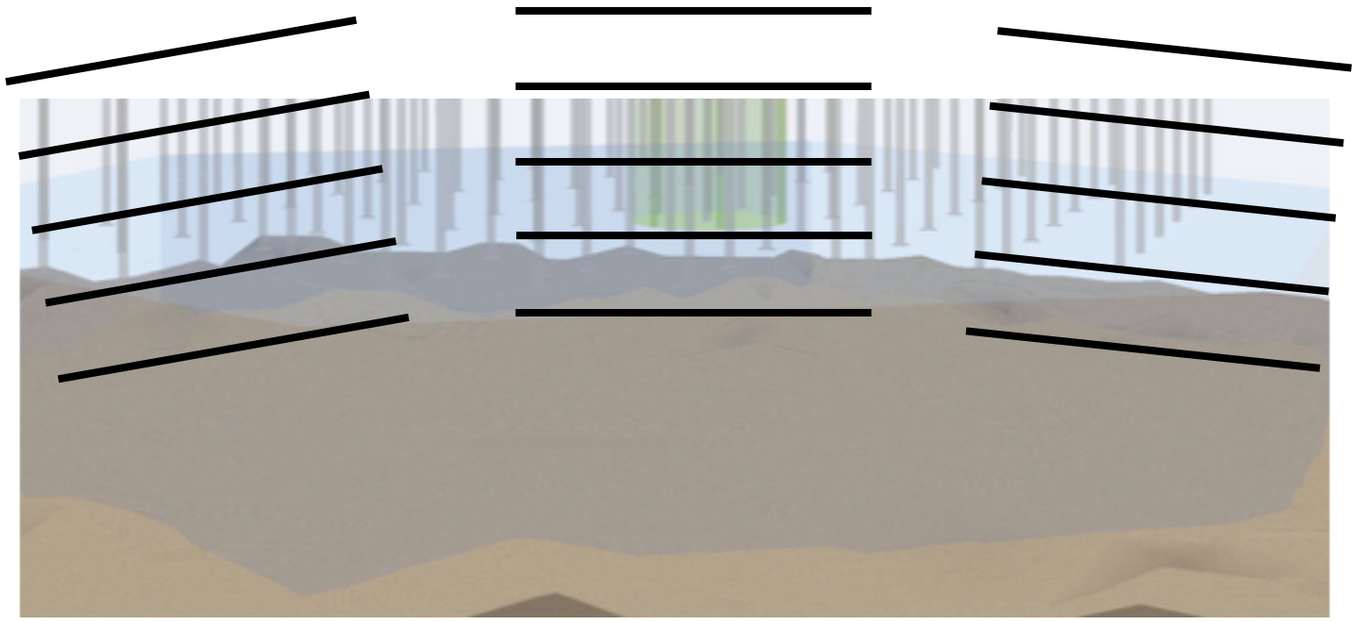

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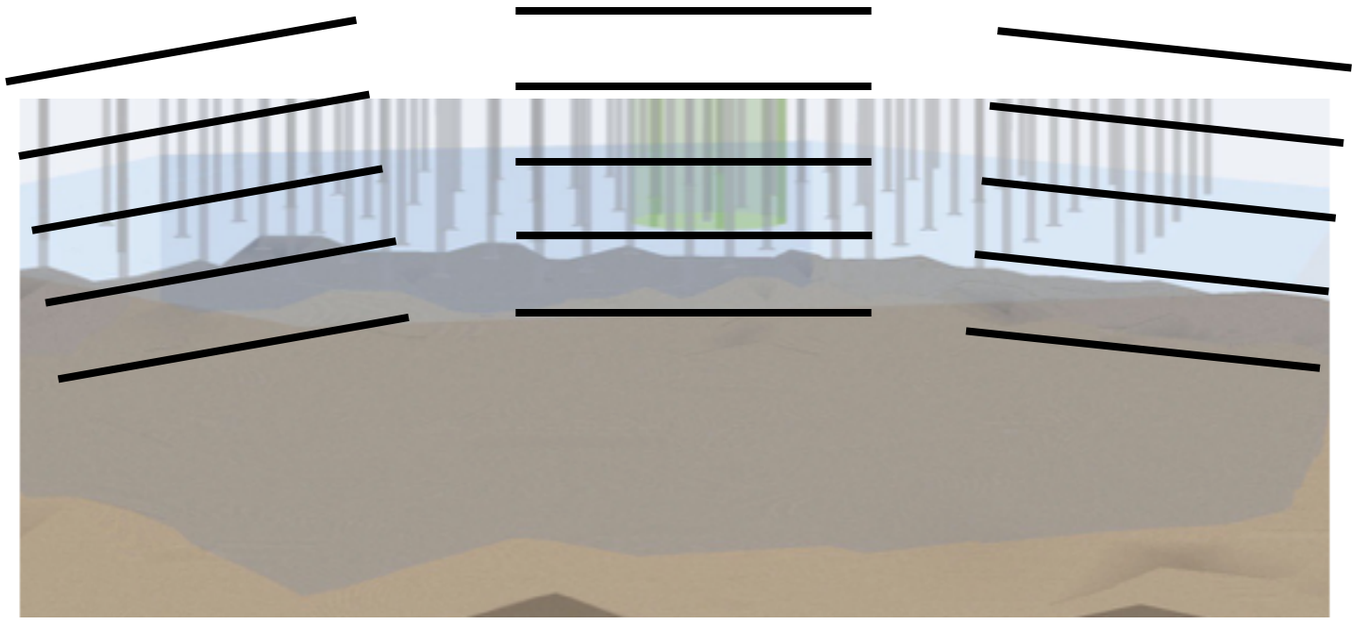

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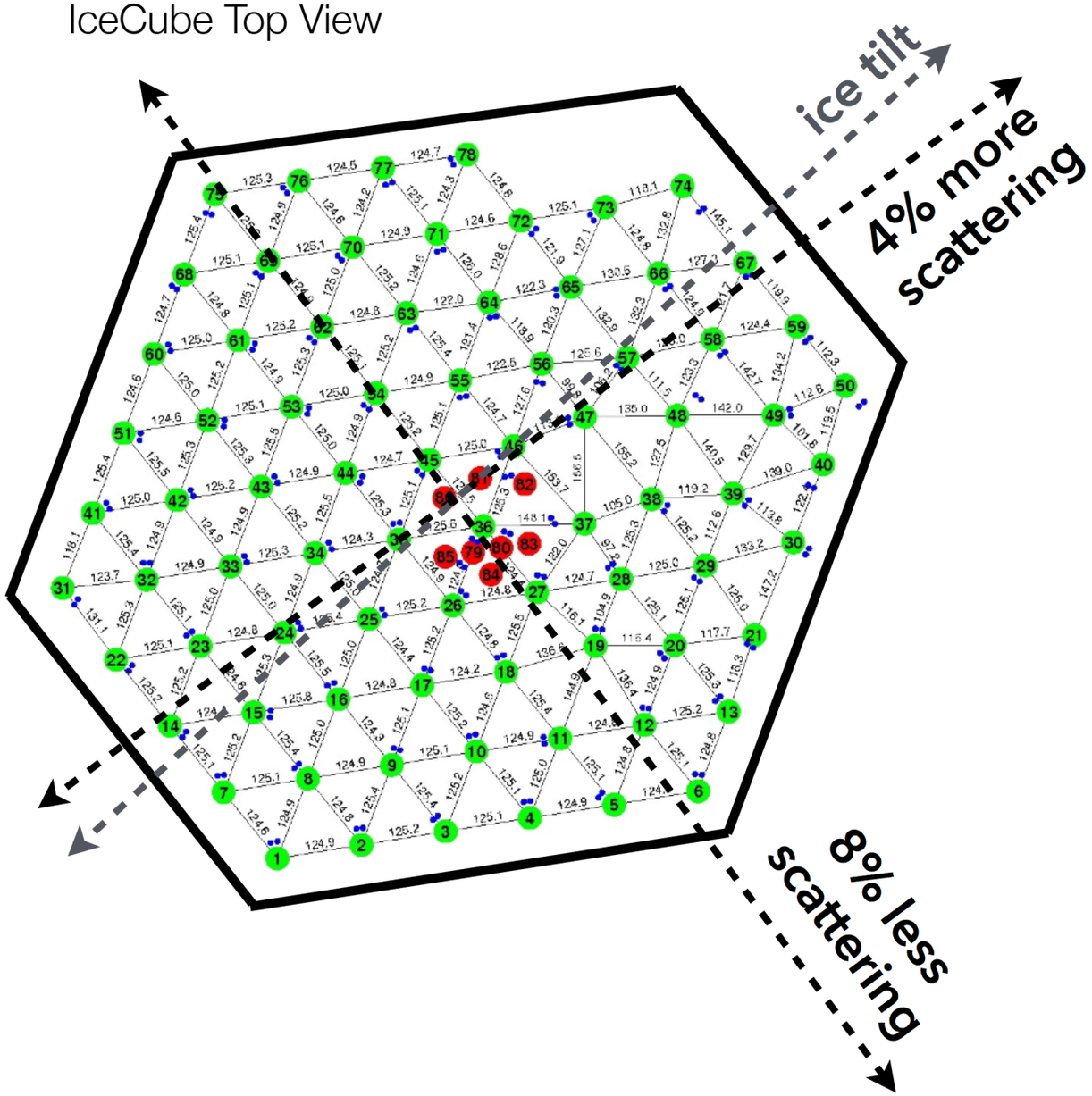
IceCube Top View



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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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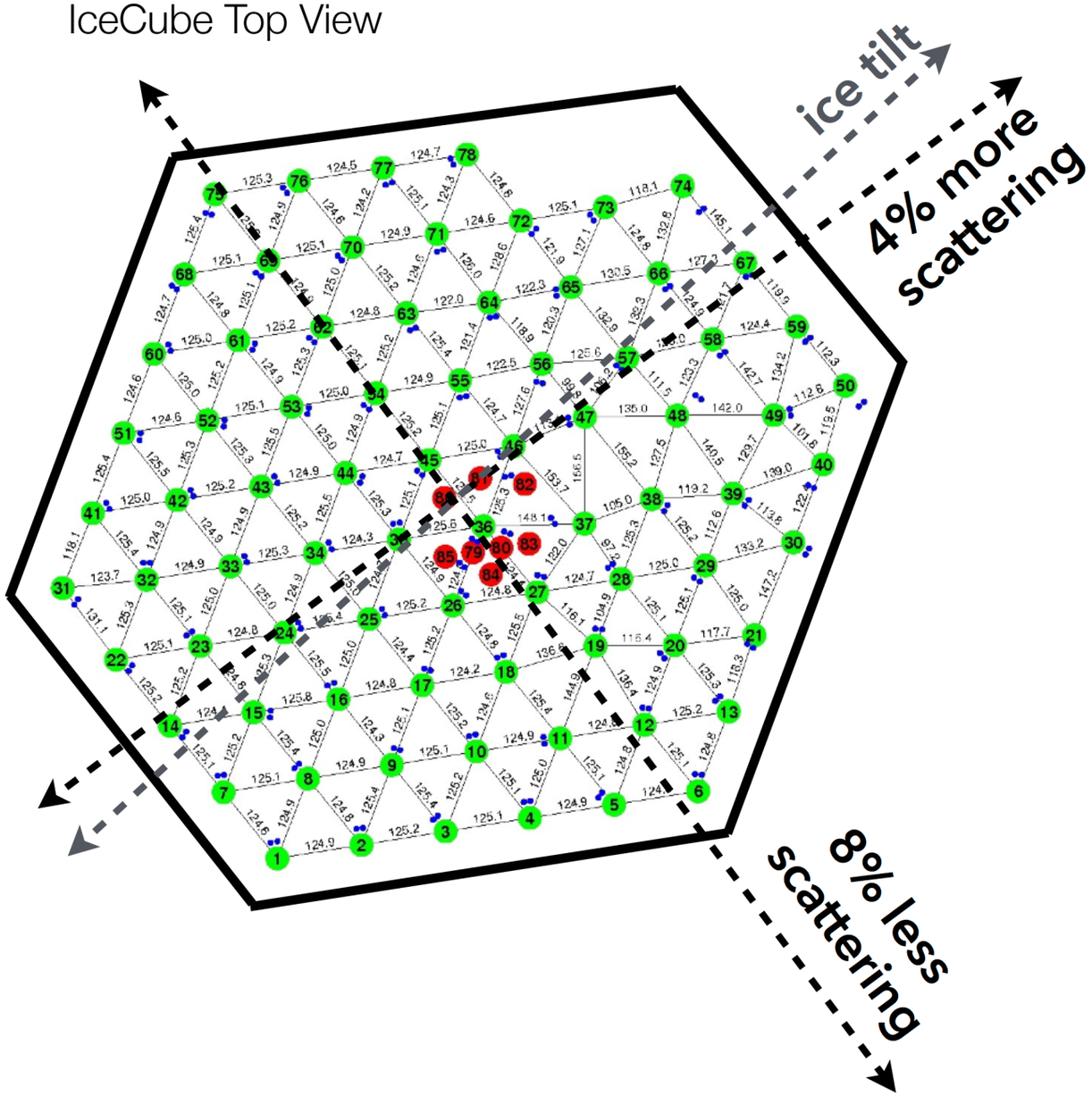

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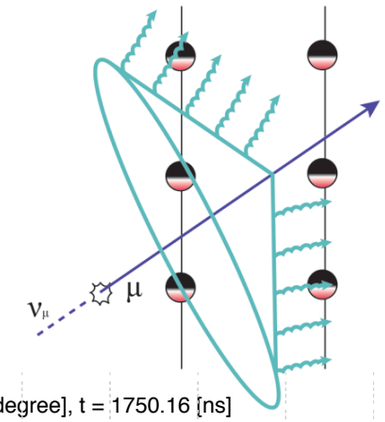
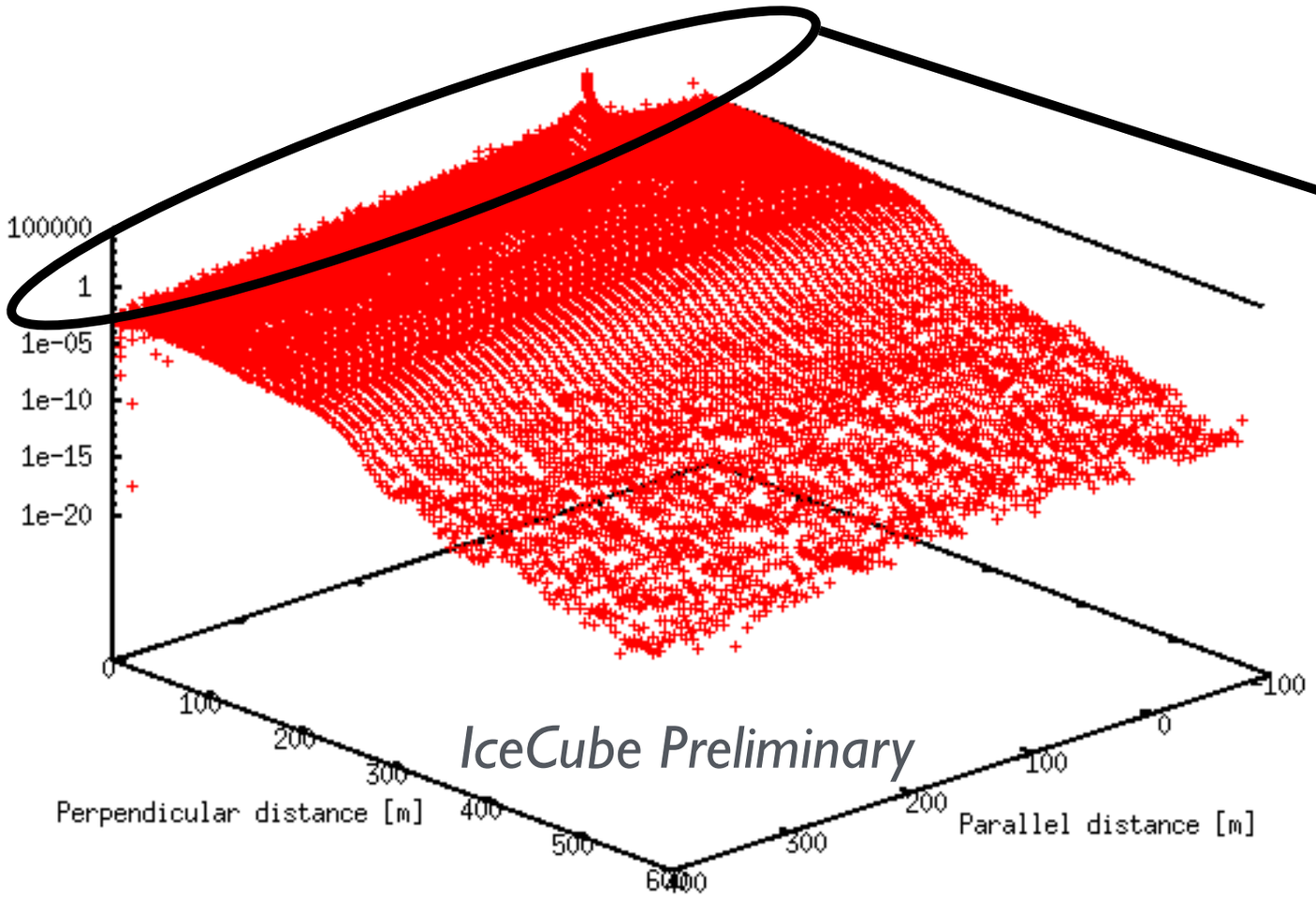
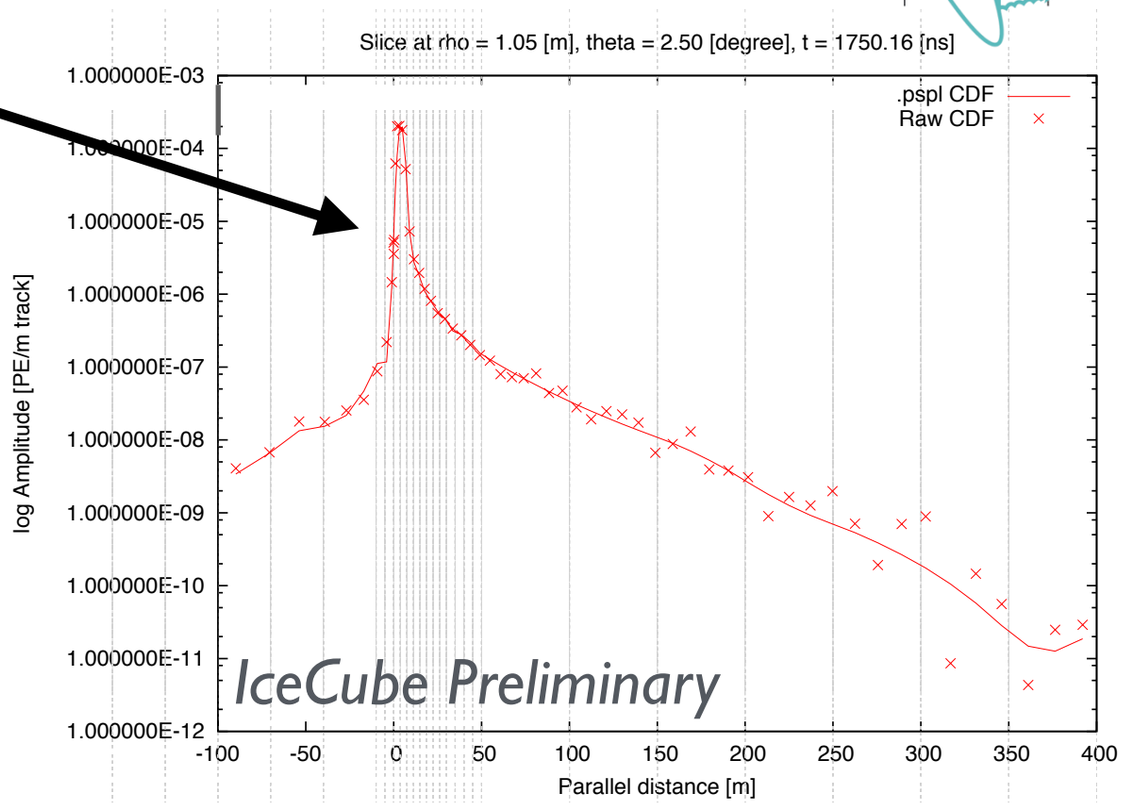
All of these elements affect the ability to fully model the ice optical properties, impacting the systematic uncertainties of event reconstruction

Describing the ice in reconstruction

IceCube's event reconstructions, to date, rely on 'photon lookup tables' - tabulated values of the probability to detect the photon throughout the instrumented volume of the ice (shown below)







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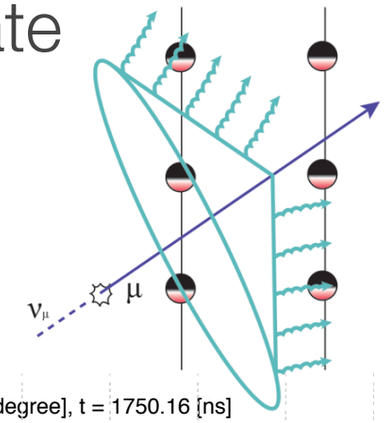
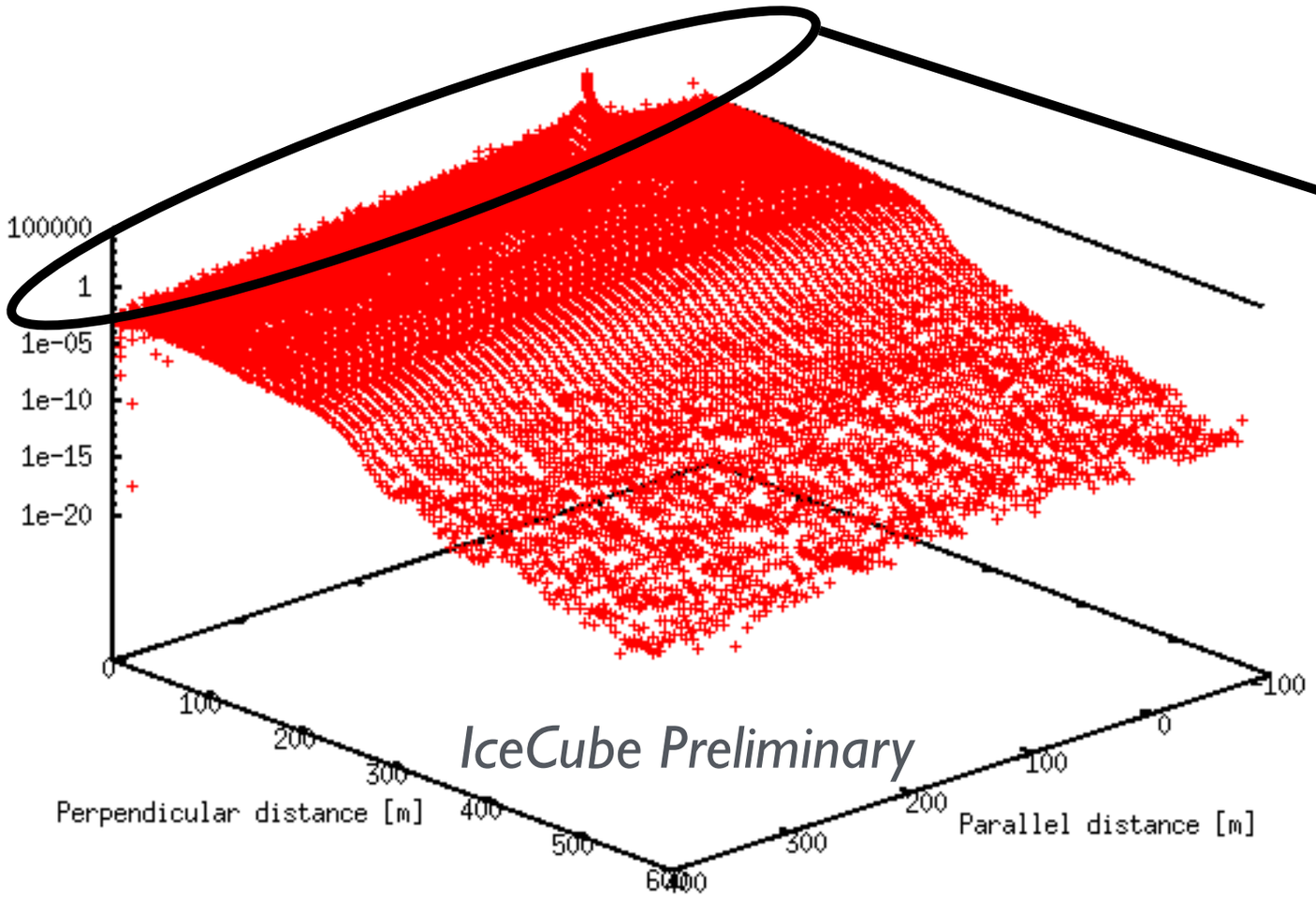
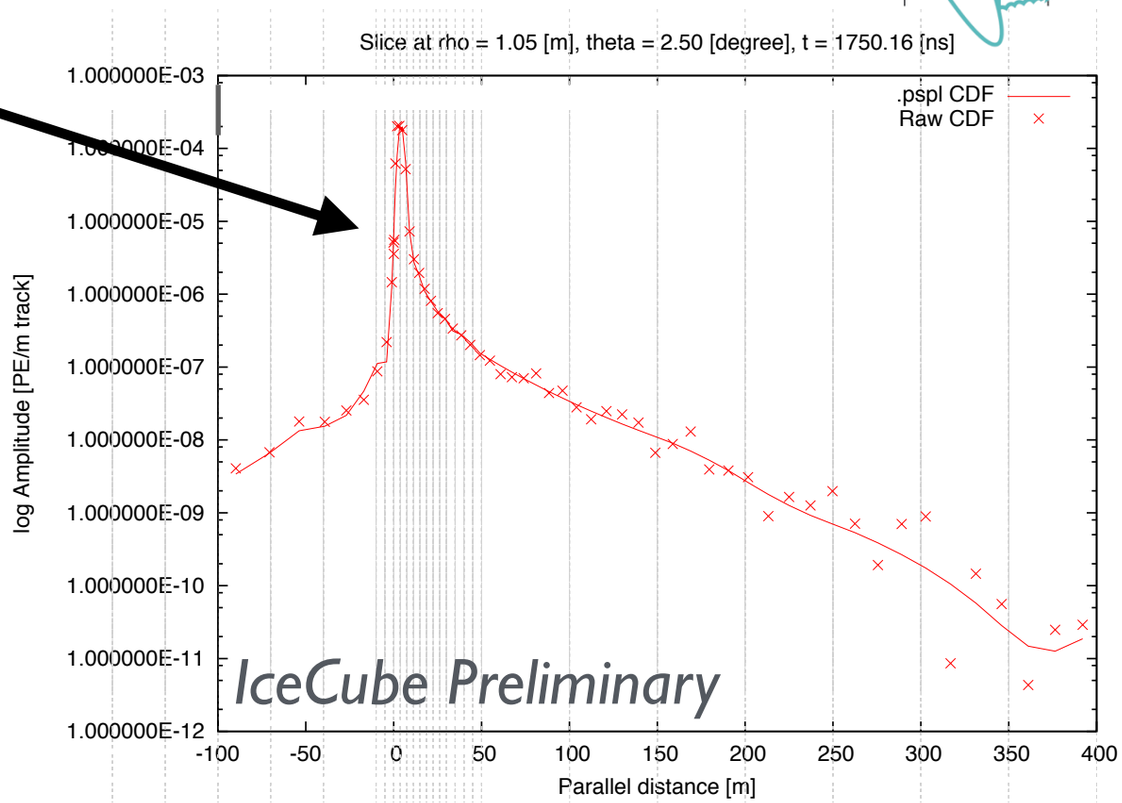
In this method, the tables parametrize the light emission using measured ice properties (from calibrations). They can then be used to generate event hypotheses, from which likelihoods may be calculated and minimized

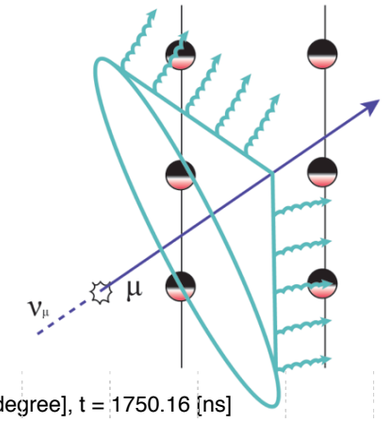


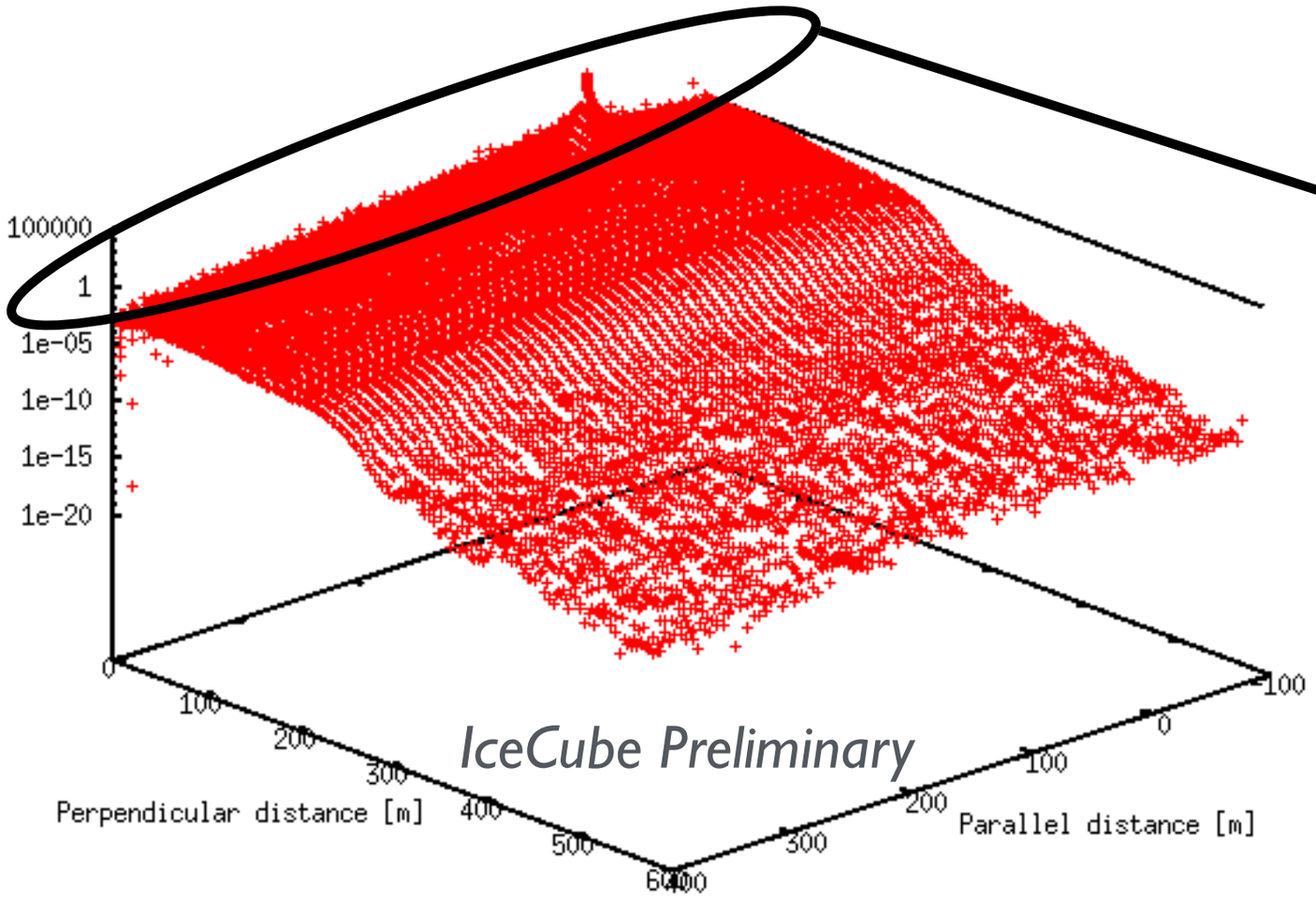


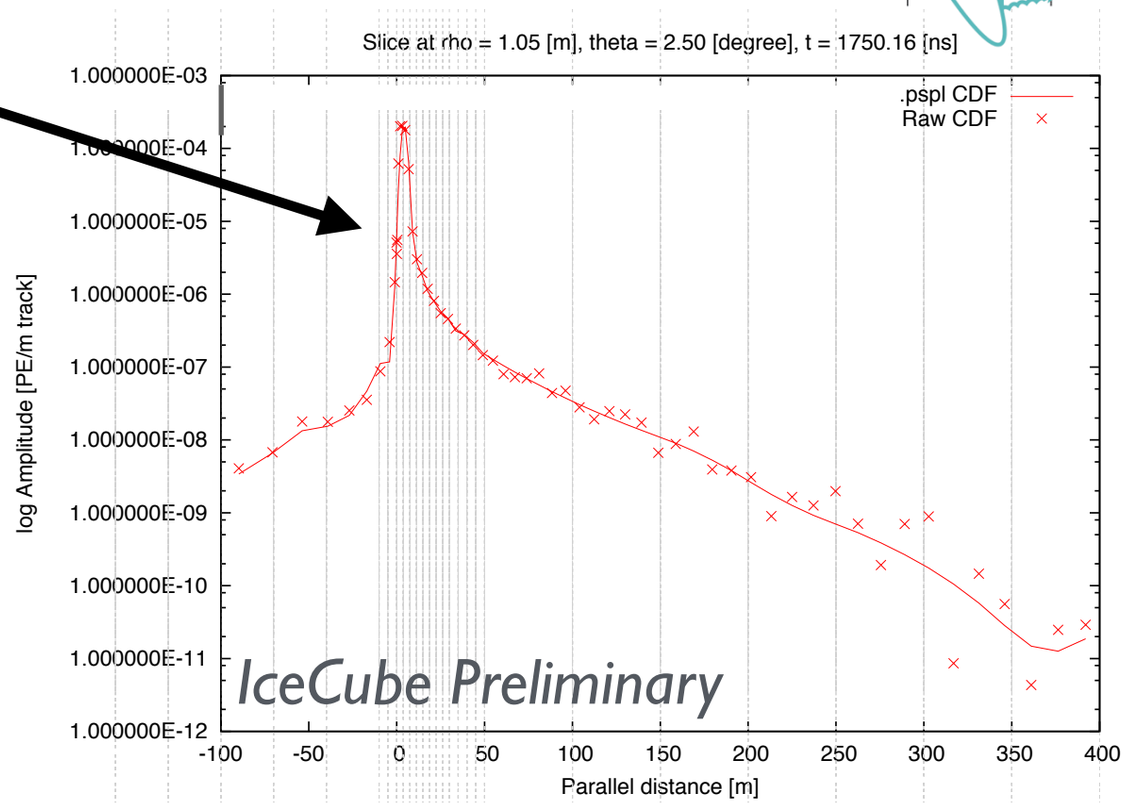


Describing the ice in reconstruction

Regenerating the photon lookup tables with direct propagation and tracking of particles has increased their physical accuracy - at the cost of large amounts of computational and human time



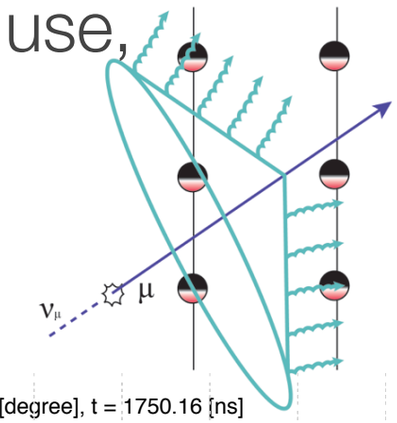


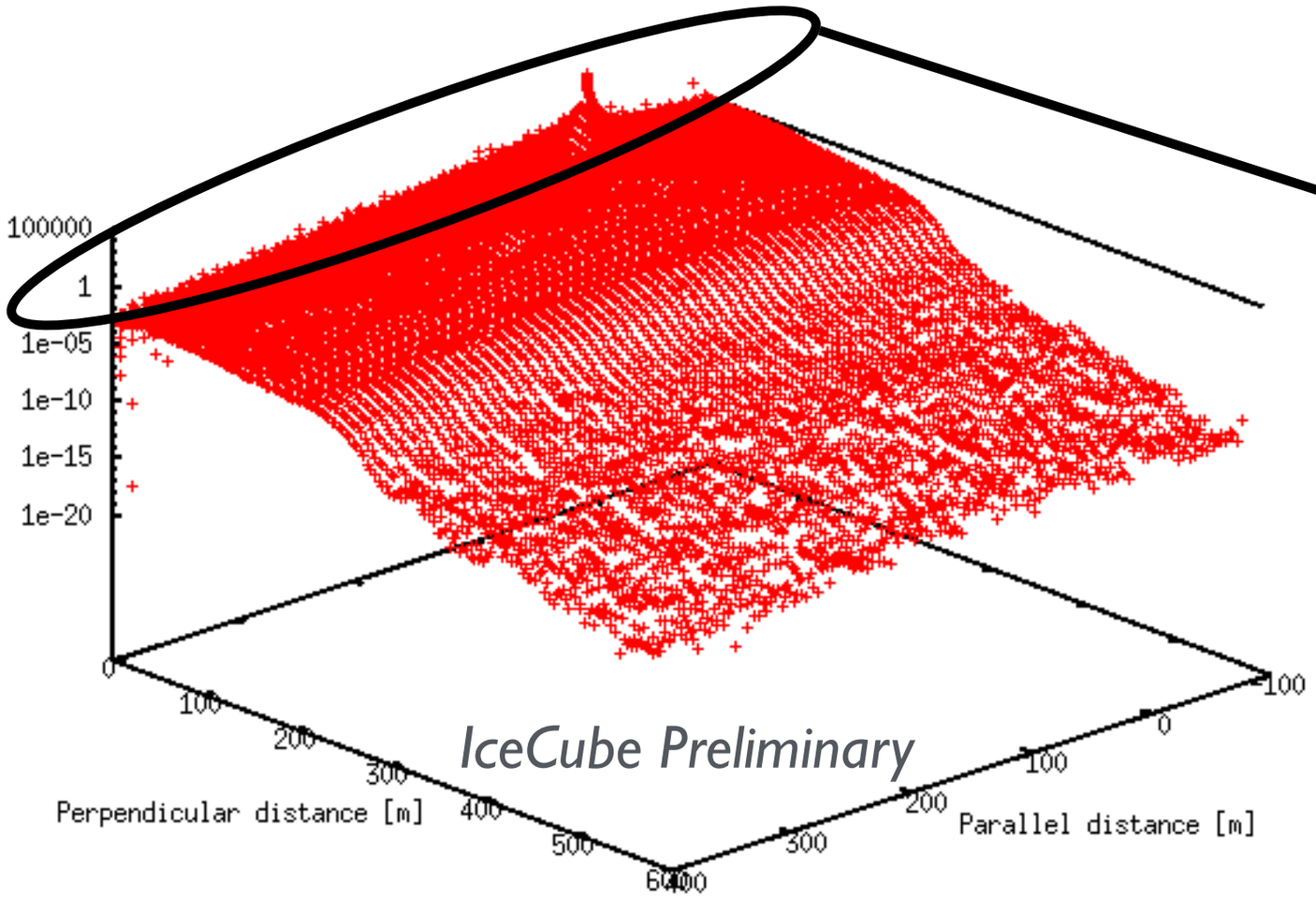


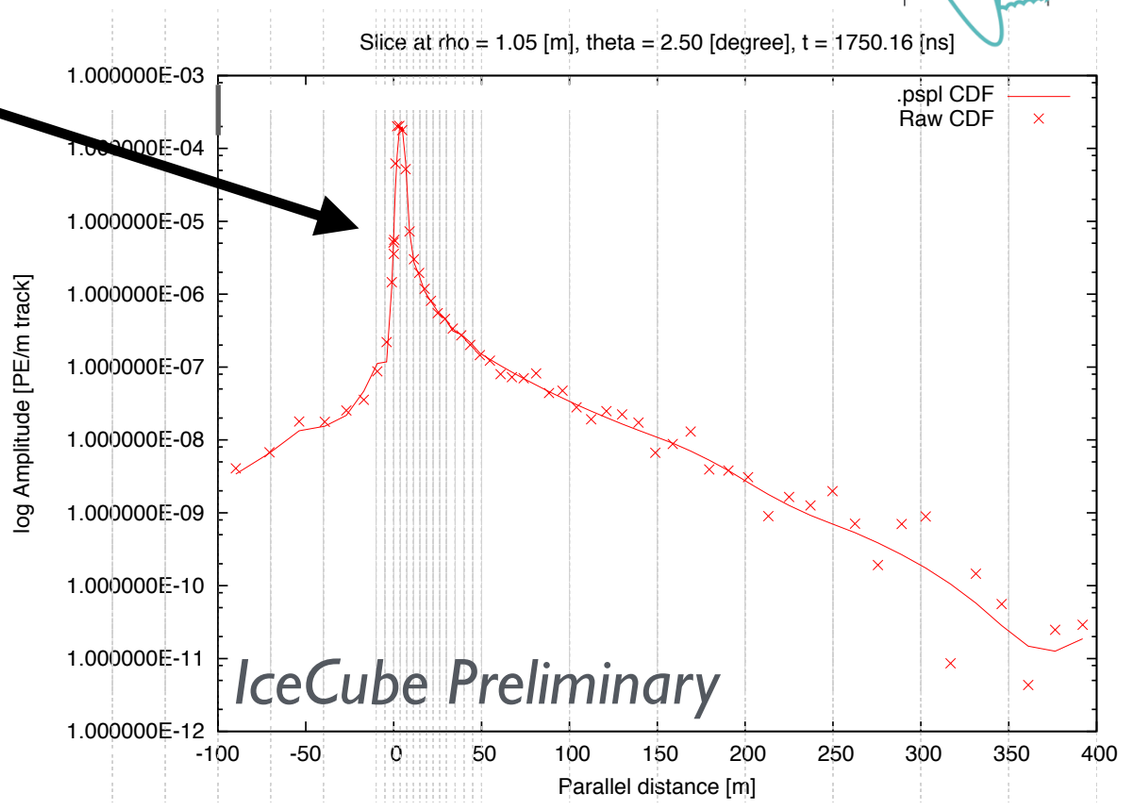
Describing the ice in reconstruction

Regenerating the photon lookup tables with direct propagation and tracking of particles has increased their physical accuracy - at the cost of large amounts of computational and human time

However, incorporating the ice anisotropy would require unattainable amounts of computational resources to generate, store or load for use, let alone a more complex model

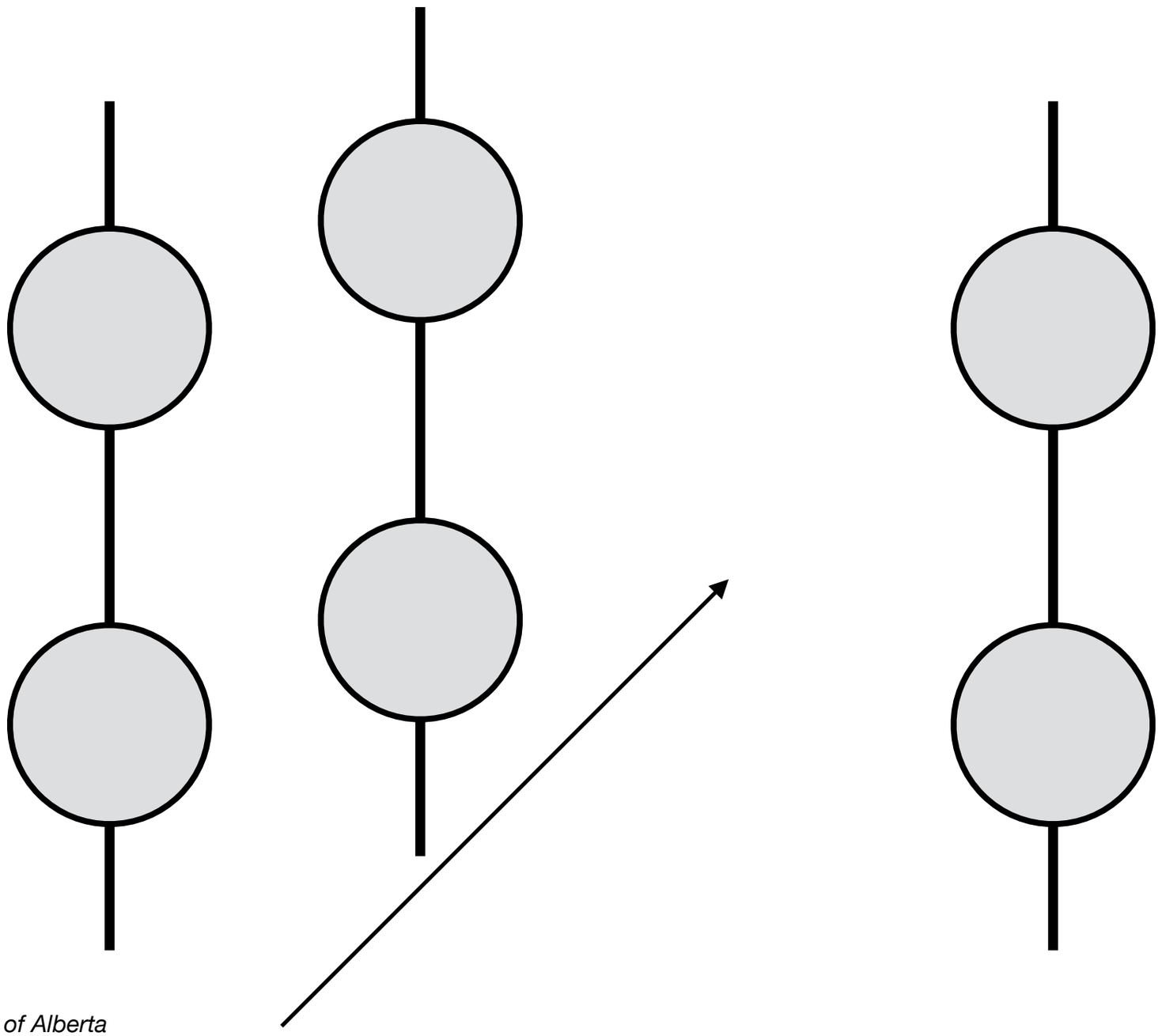






Replacing the photon tables - direct reconstruction

Instead of lookup tables, use GPUs to directly propagate photons for a given event hypothesis to get the expected light at each photosensor, allowing use of the complete ice model description



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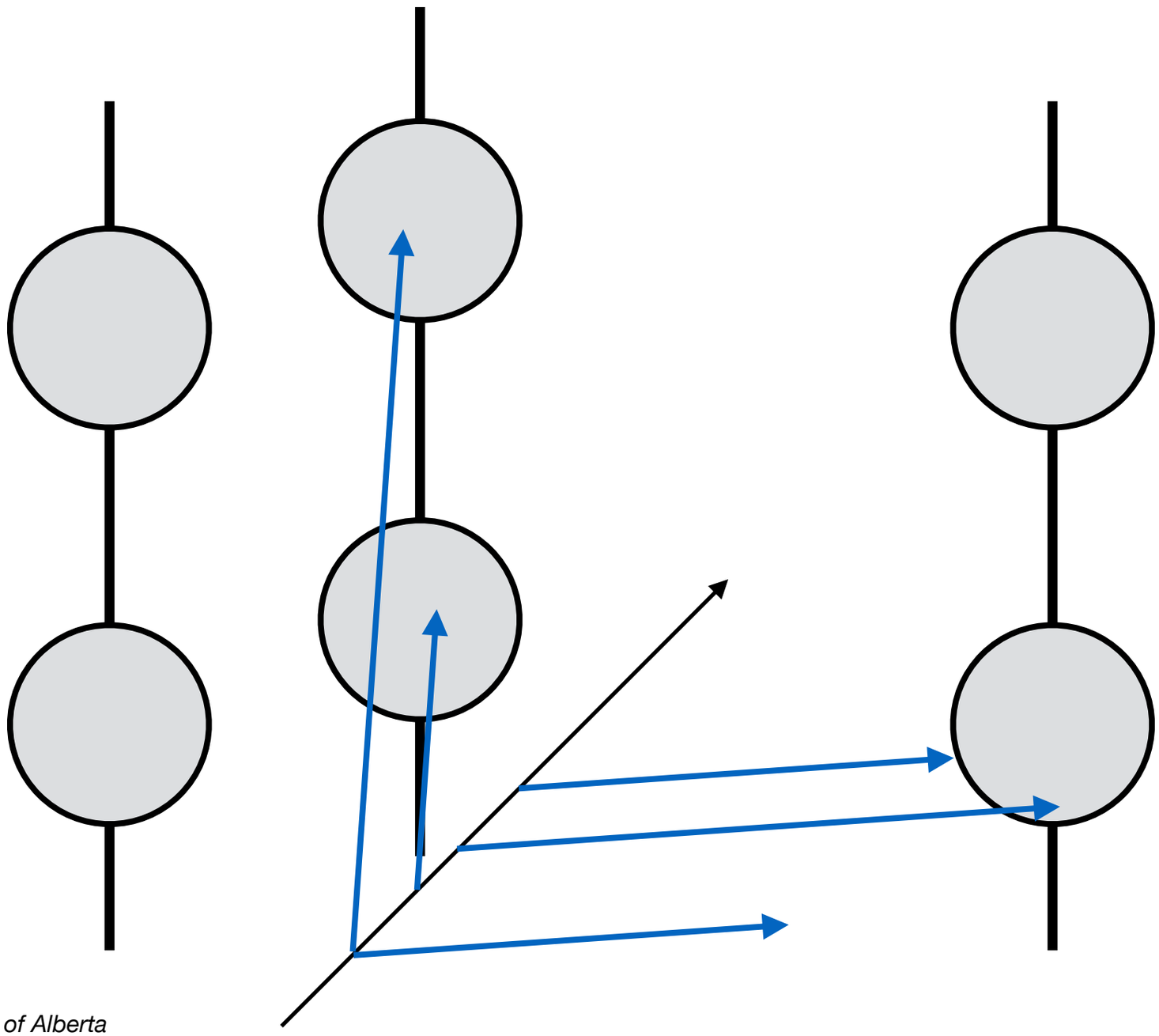

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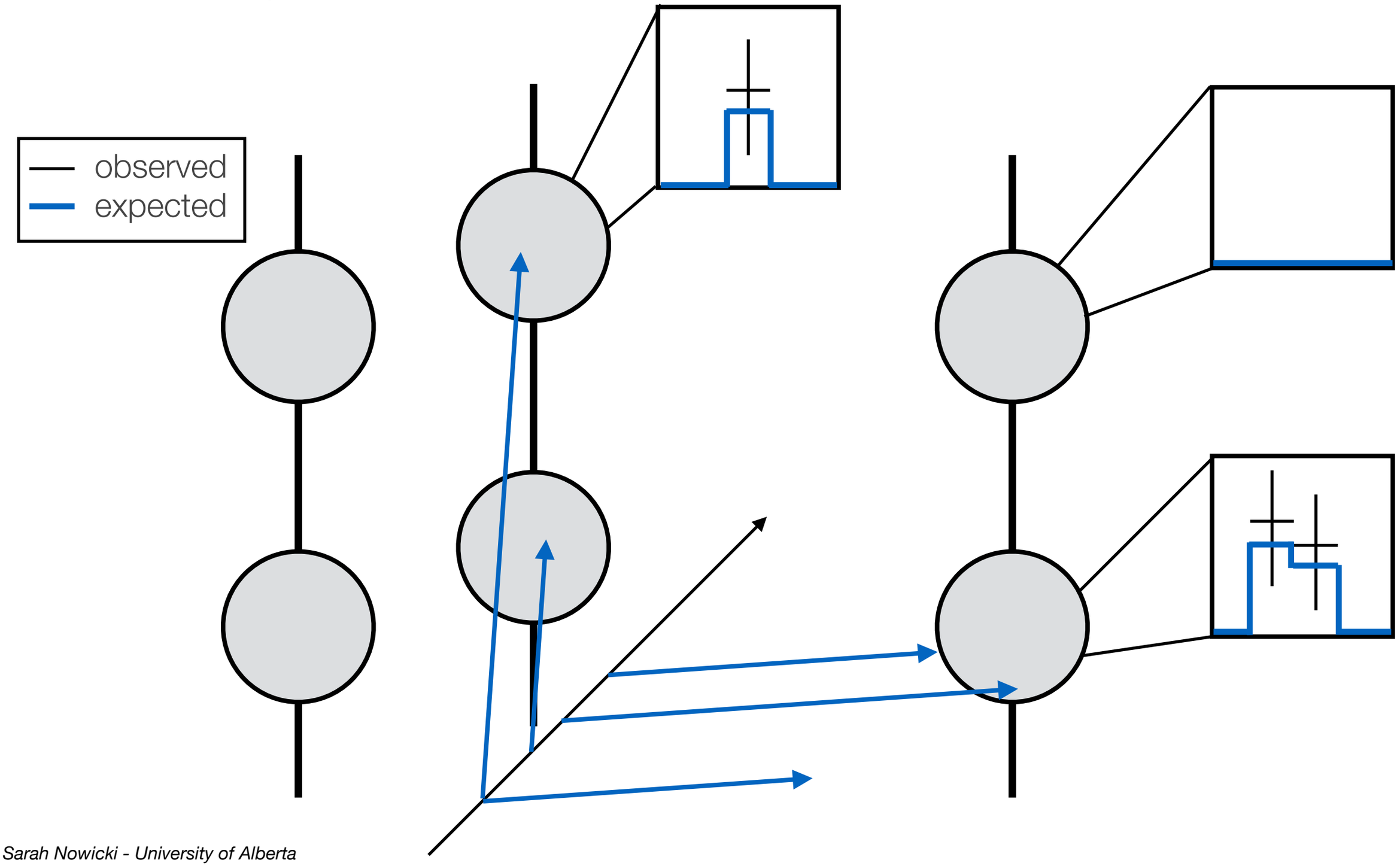
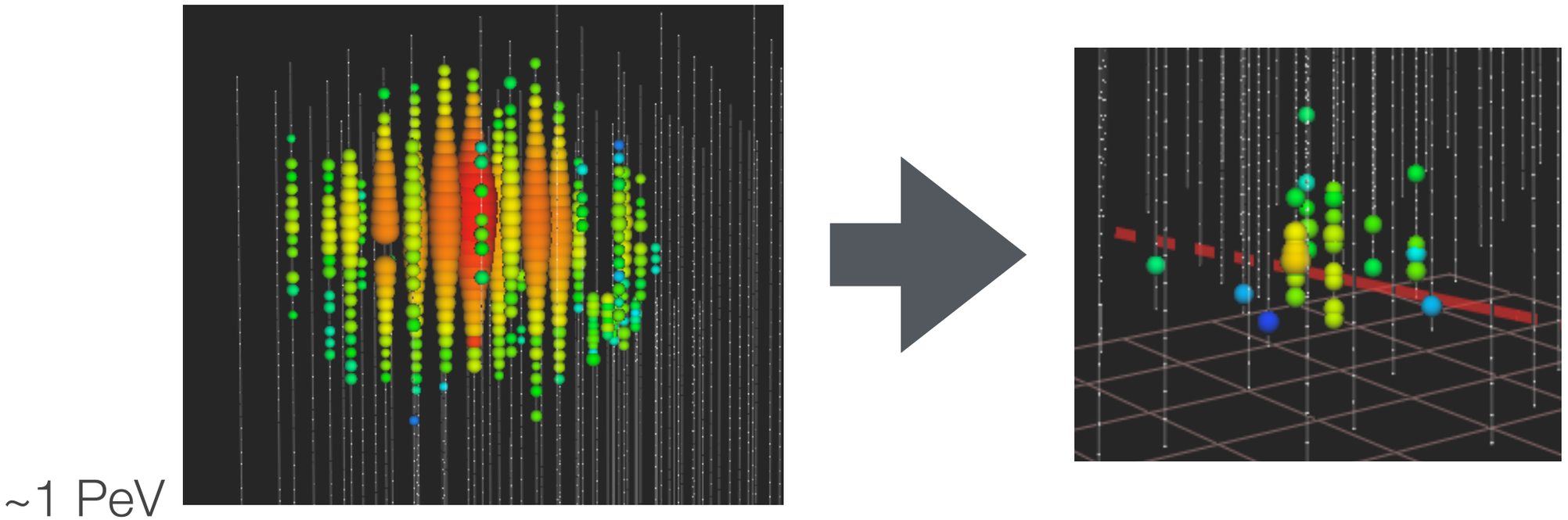


Reminder: IceCube detects a large range of energies



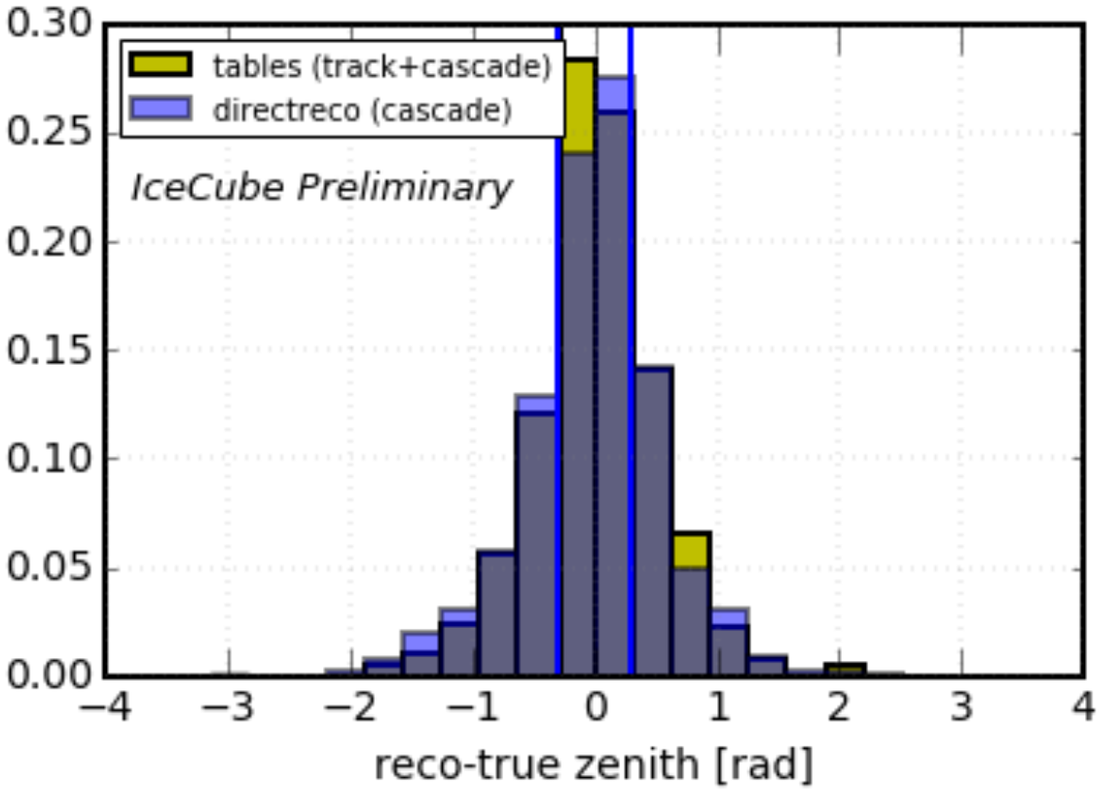
~1 PeV

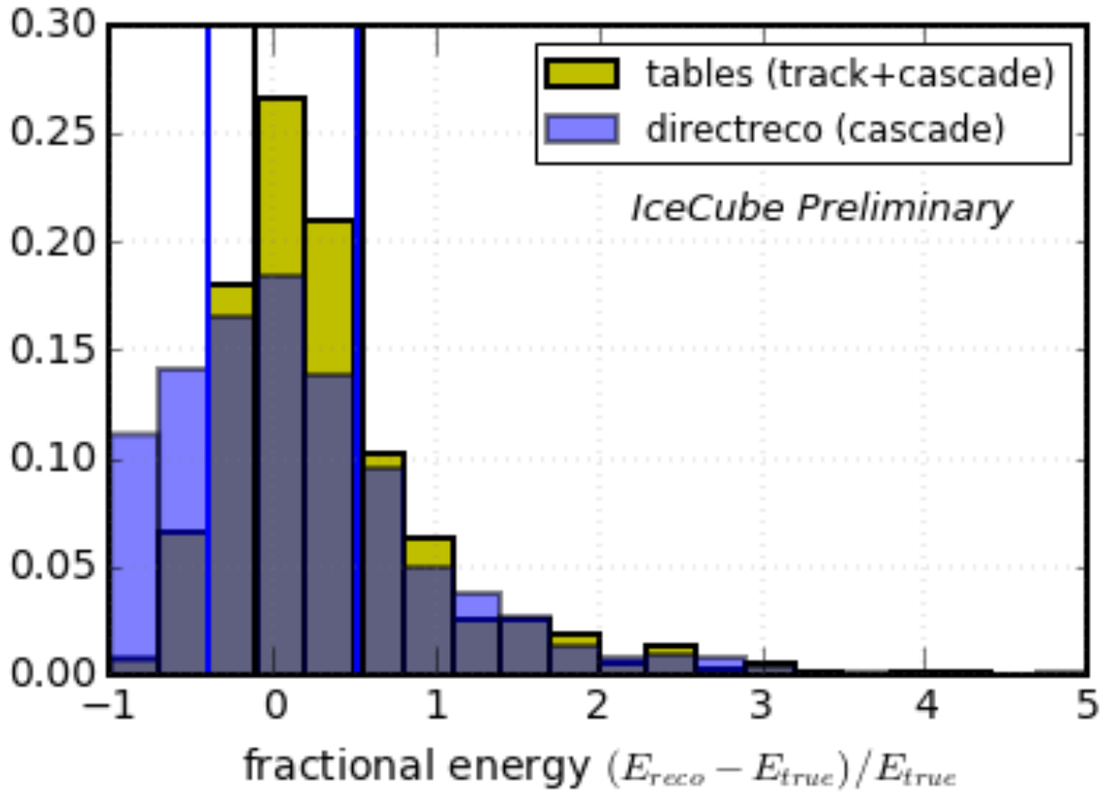
~30 GeV

Getting the photon distributions as correct as possible is critically important for event reconstruction in general, but this is especially true for DeepCore's low energy events, where every single photon counts

Neutrino oscillation results, for example, depend on reconstructed energy and zenith angle (tells path length) as fundamental observable parameters

Directreco preliminary fit results





Compare directreco (blue, quantiles in blue) to a table-based event reconstruction (yellow, quantiles in black) for a sample of **ν_e events** from a final-level event selection from a neutrino oscillation analysis

Without any fine-tuning (e.g. non-optimal minimizer), the results are comparable to our current best, highly optimized, low energy event reconstruction

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, and this 'direct reconstruction' is designed to provide the best representation of the ice model while avoiding other limitations of previous methods

First results are extremely promising - resolutions already comparable to our current best in the challenging low energy regime

Look out for updates!

IceCube Collaboration Meeting Fall 2016

Thanks for listening!

Backup slides

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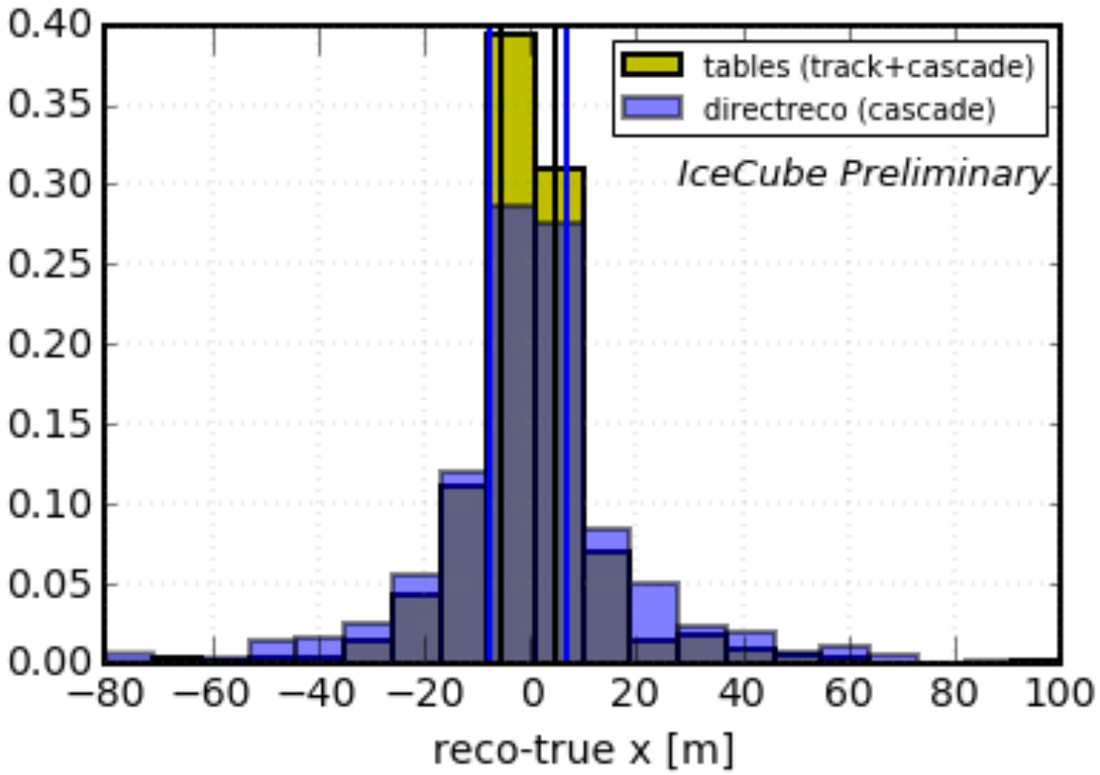

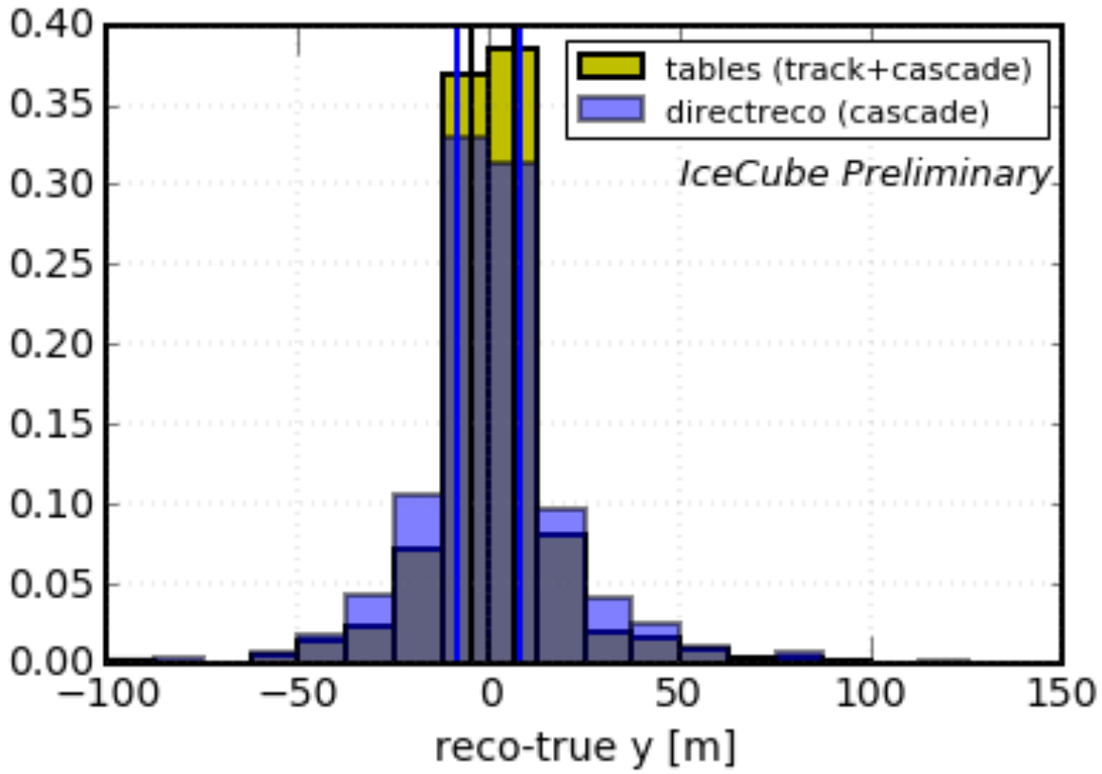

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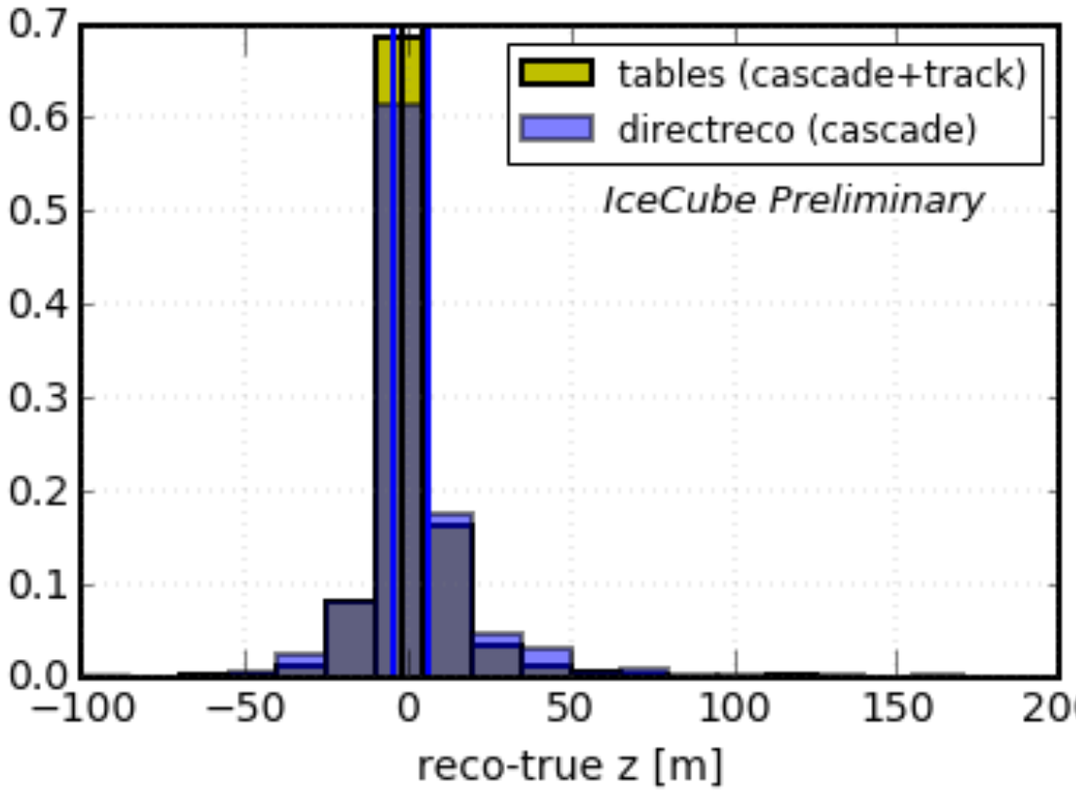

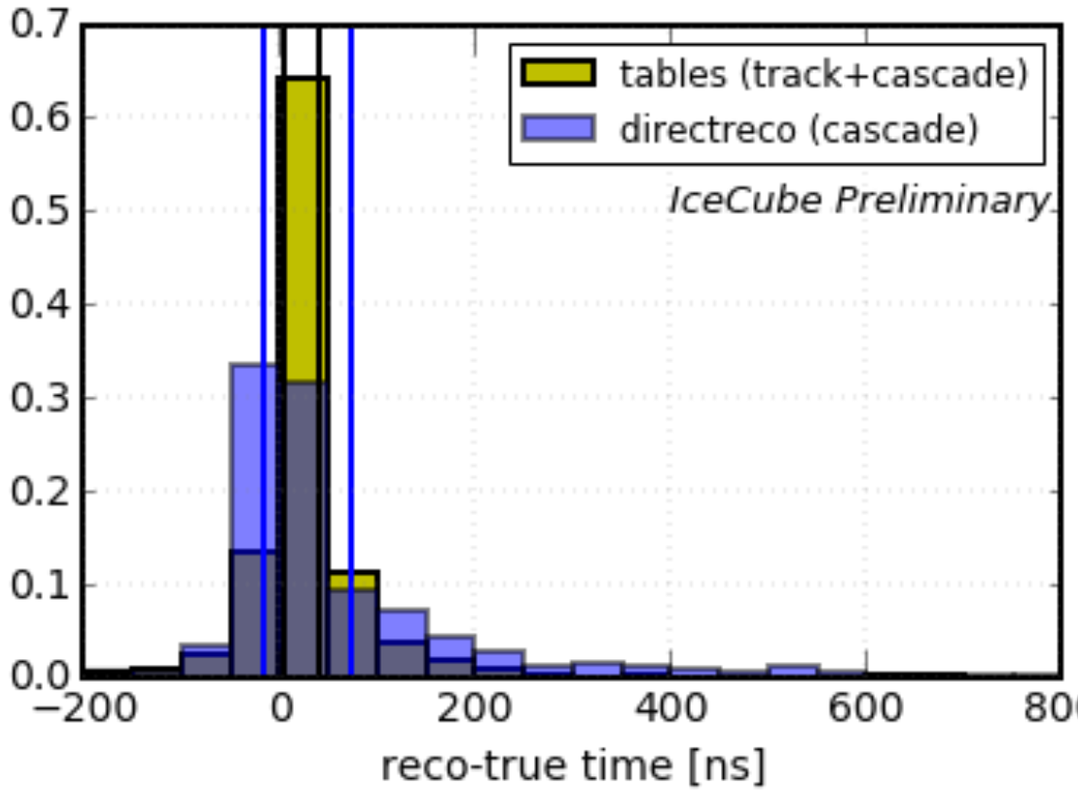

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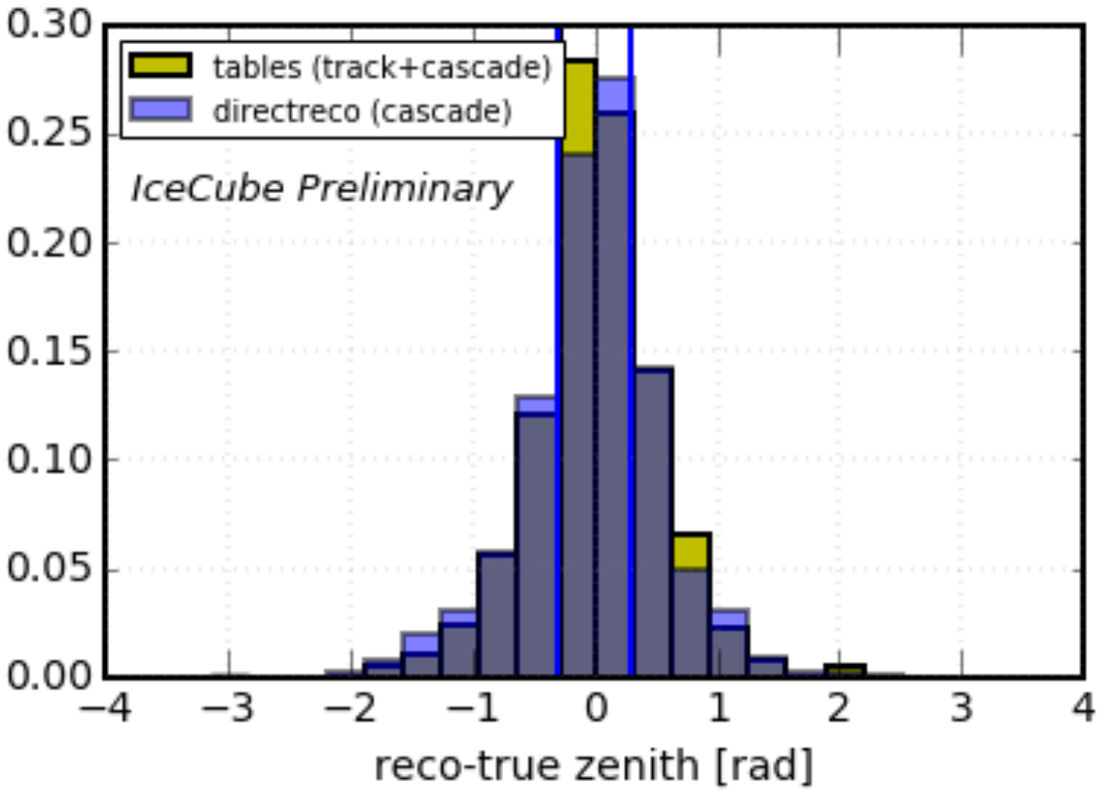

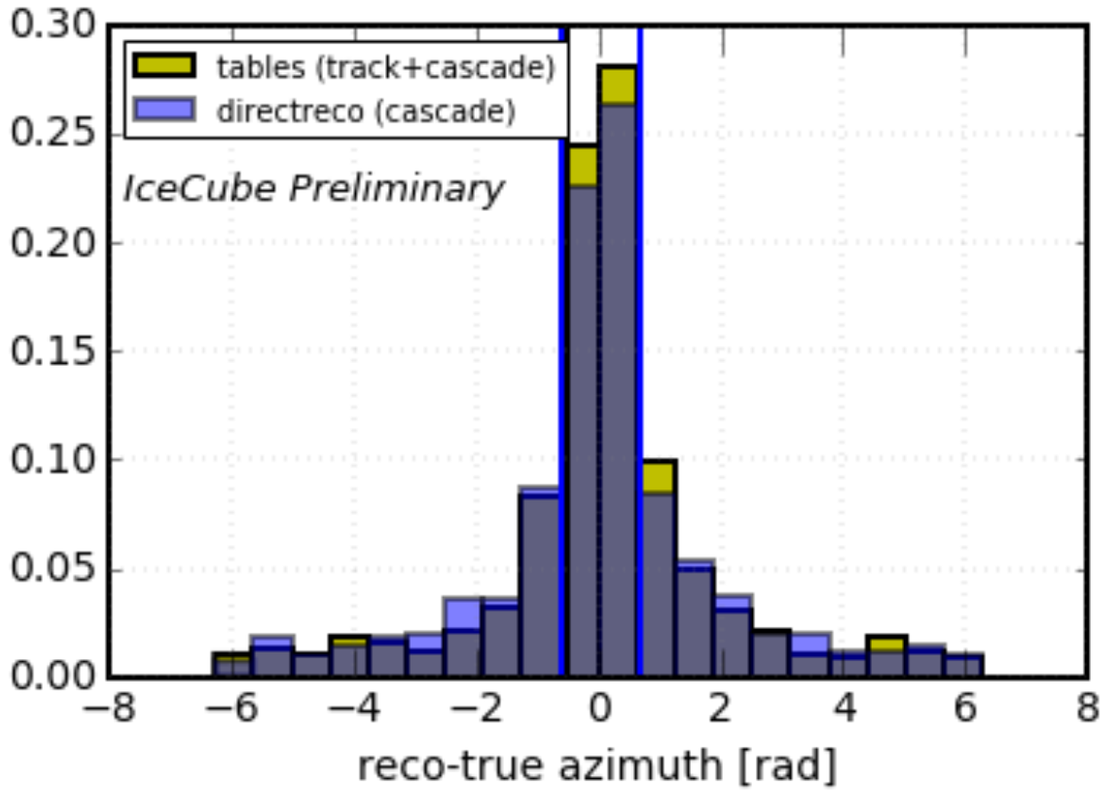

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