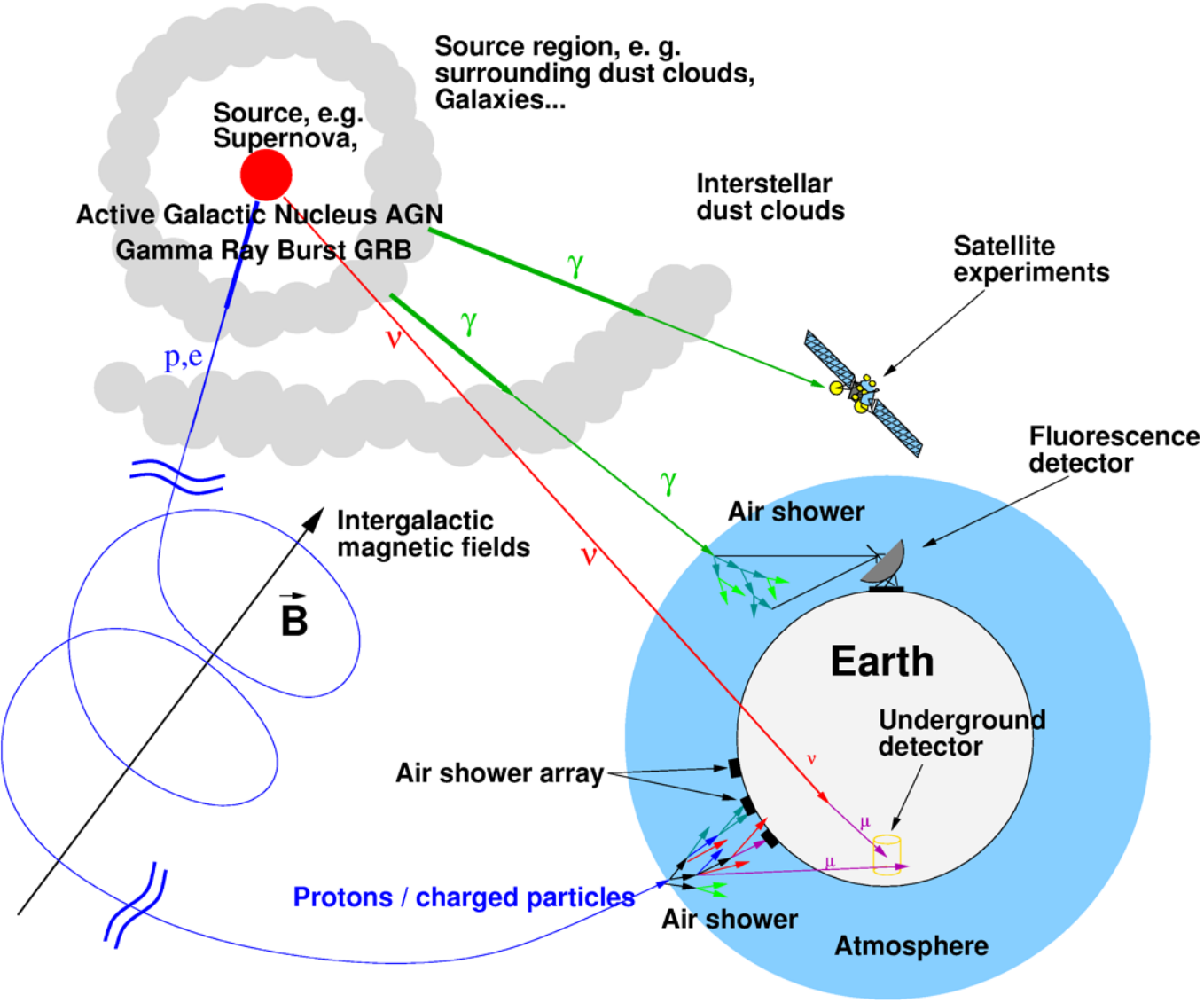
Glaciology for astronomy and vice versa

Albrecht Karle

Polar science workshop

Berlin, September 2017

Neutrinos as Cosmic Messengers

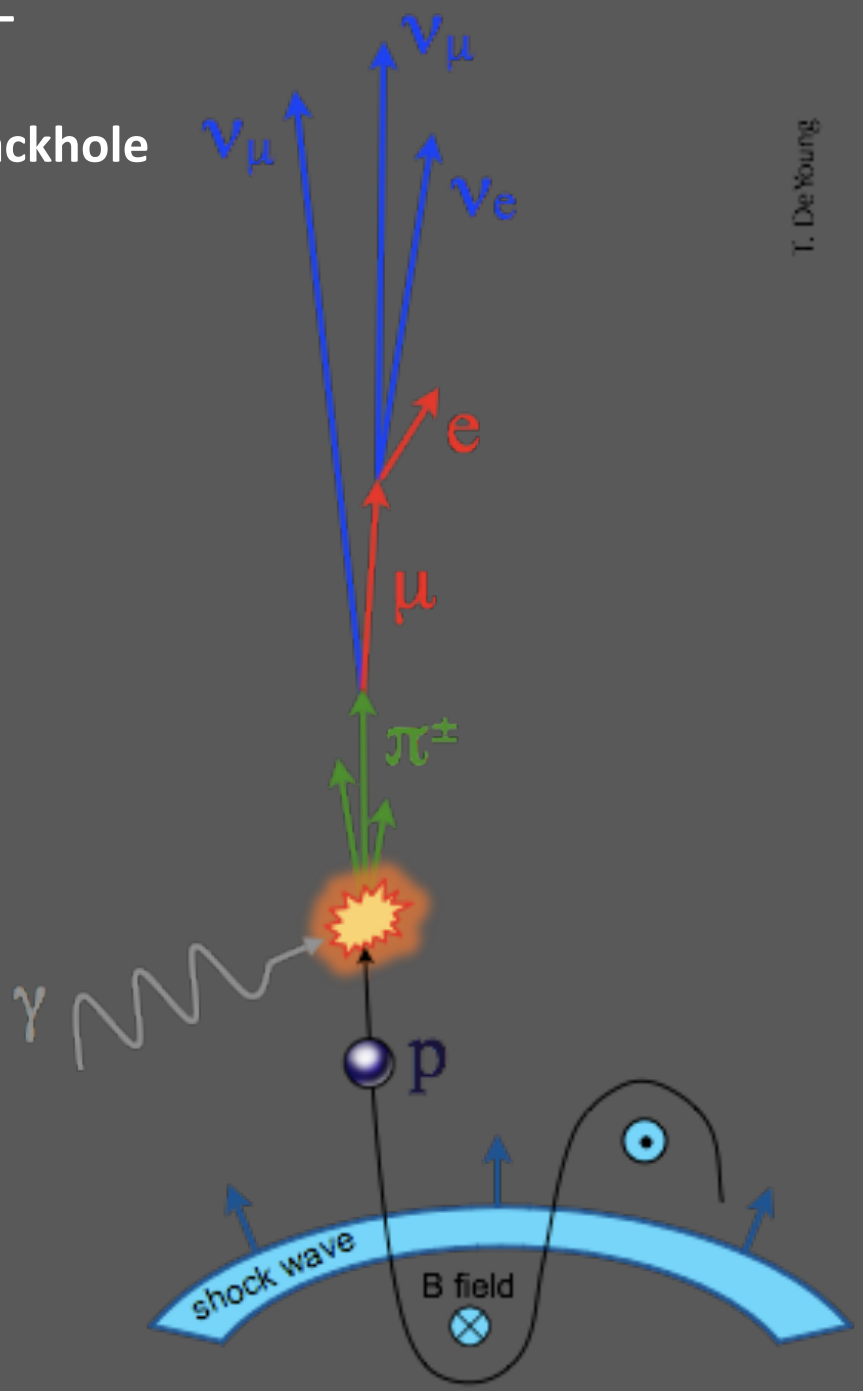


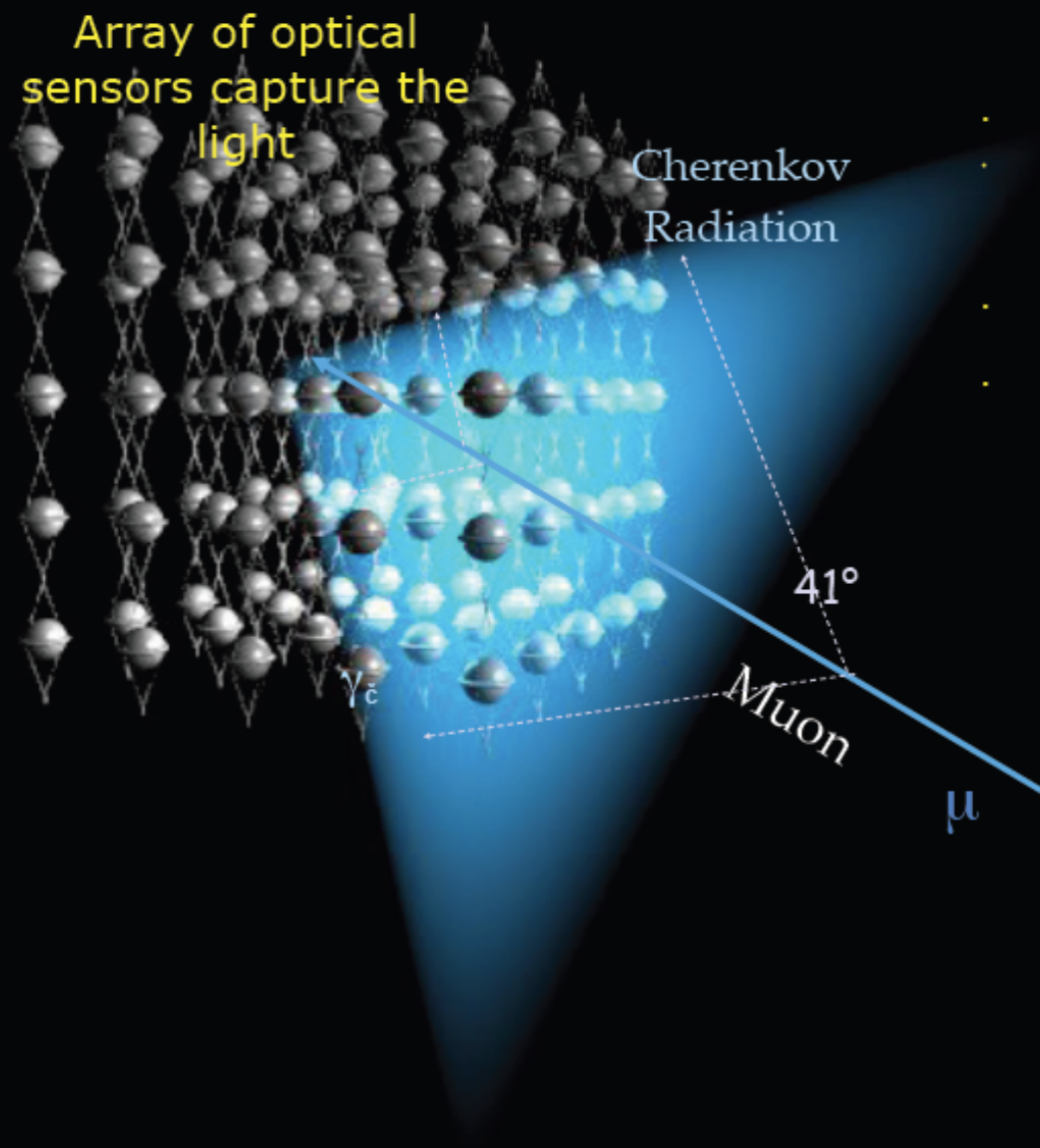
p ***Protons:*** **deflected by magnetic fields.**

Photons: **easily absorbed by CMB and IR backgrounds. EM/ Hadronic discrimination difficult**

ν ***Neutrinos:*** **not deflected by magnetic fields. Low interaction cross-section.**

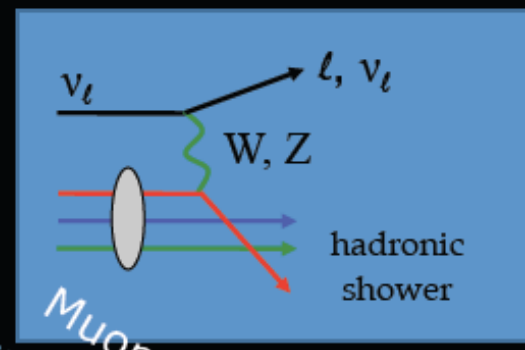
Possible source of cosmic neutrinos (example) –
Active galaxies:
Jet from accretion disk onto a supermassive blackhole





Neutrinos interact in or near the detector
Depending on the interaction a lepton (CC) or a shower (NC) is produced

- (km) muons from ν_μ
- (10m) cascades from ν_e, ν_τ, NC



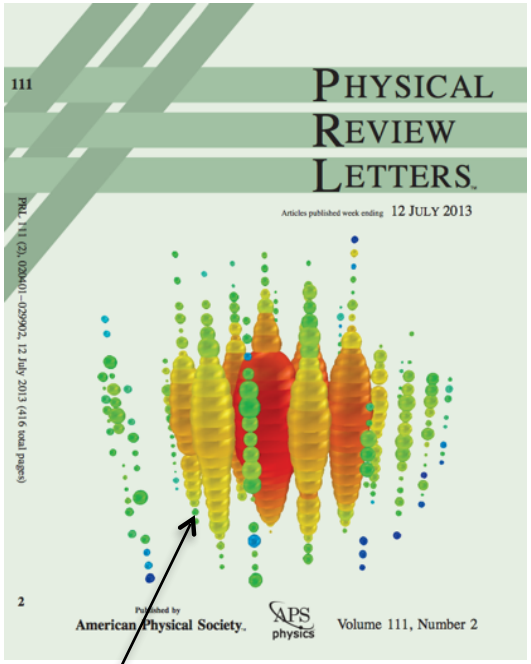
interaction

Muon Neutrino

ν

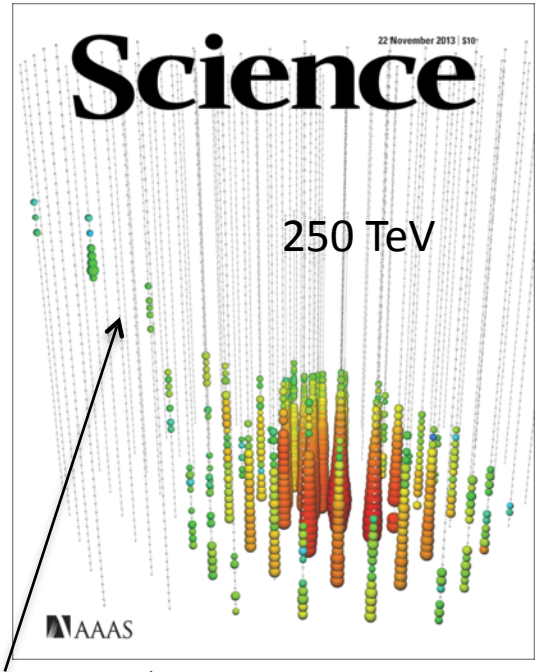
Discovery of high energy cosmic neutrinos

July 2013:
2 events: E > 1 PeV



1.1 PeV
"Bert"

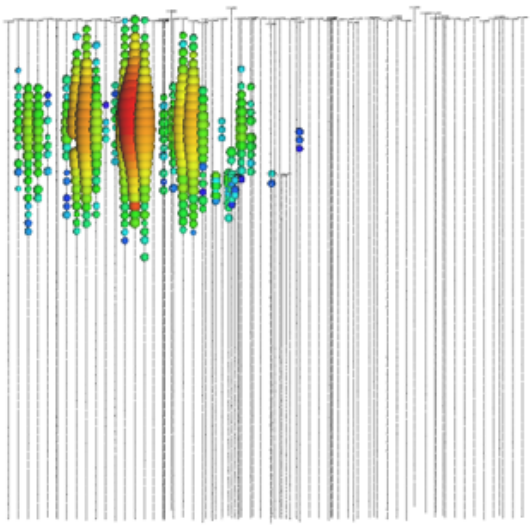
Nov 2013:
2 years of data:
28 events
~ 4 sigma above BG



Outgoing track

Phys.Rev.Lett. 113 (2014)

Excess of events compared to background at very high energies
37 events, one event at 2 PeV
5.7 sigma

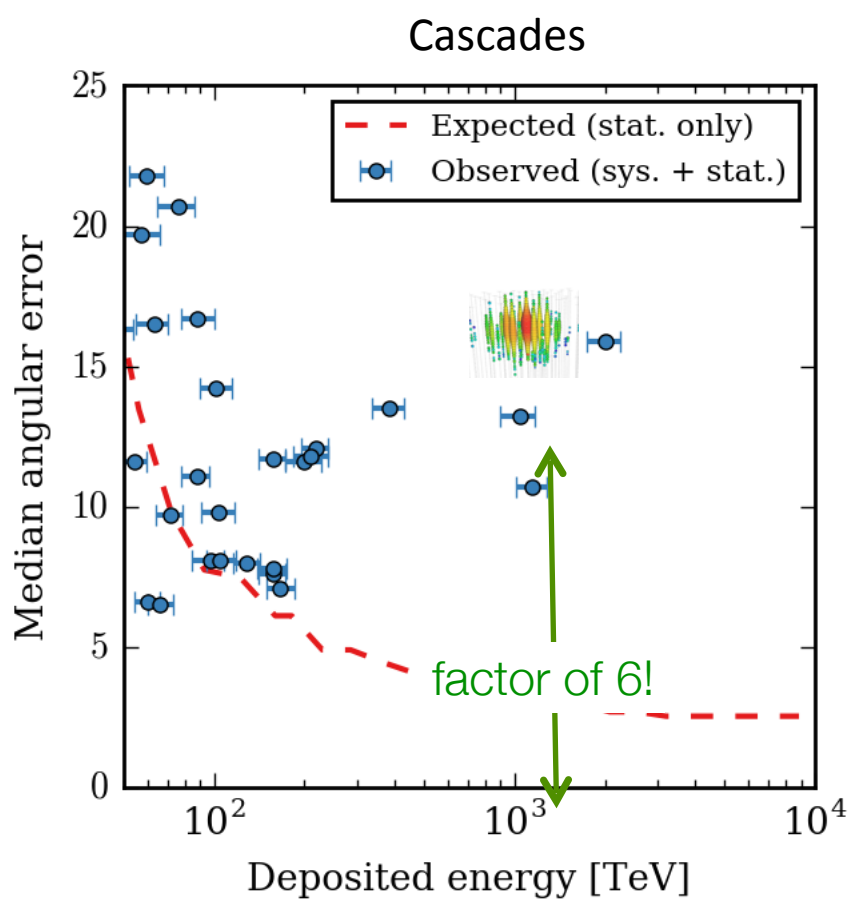


2 PeV

"Big Bird"

Angular resolution at high energies limited by understanding of ice optics.

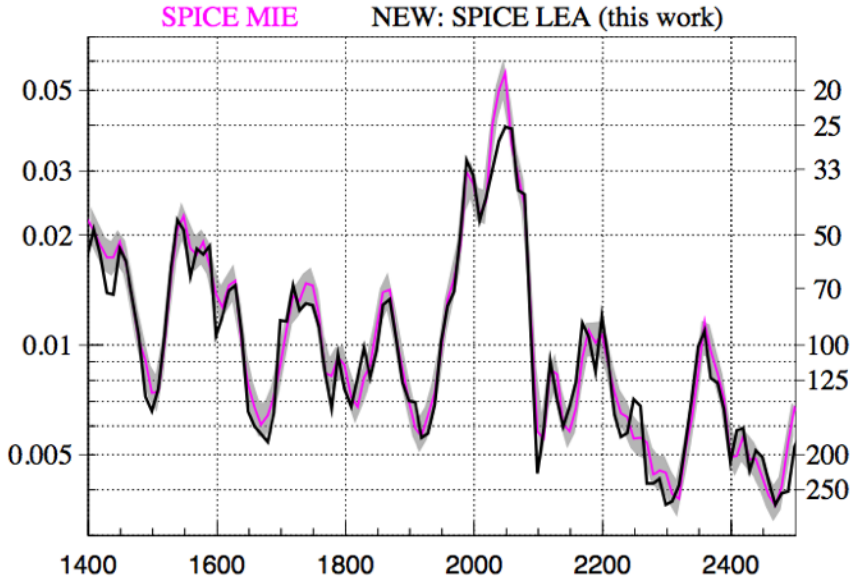
High energy events, eg 1 PeV have 100,000 photoelectrons.



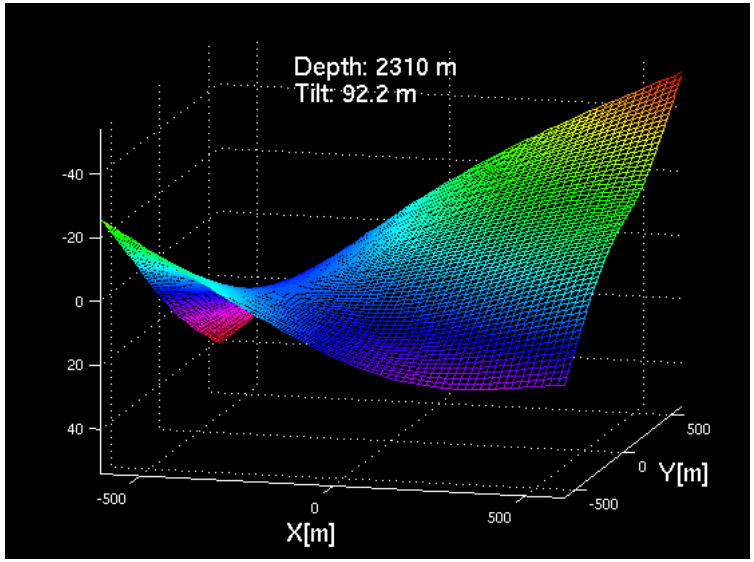
Two type of events
Muons: 0.5°
Cascade like events: ~15°

Global Ice model (bulk ice) used in IceCube

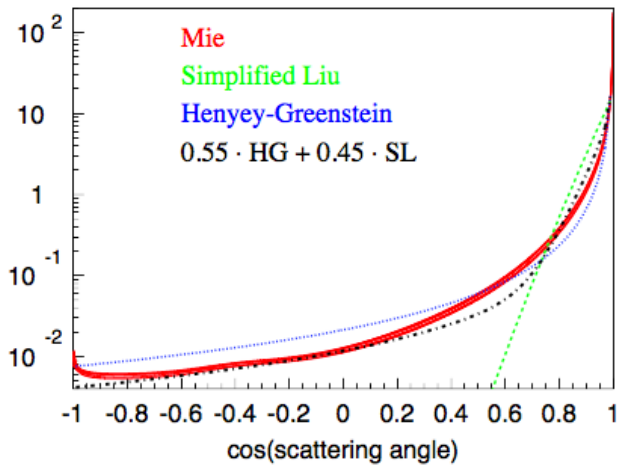
Depth dependence of absorption (and scattering)



Ice layers are tilted – not planar



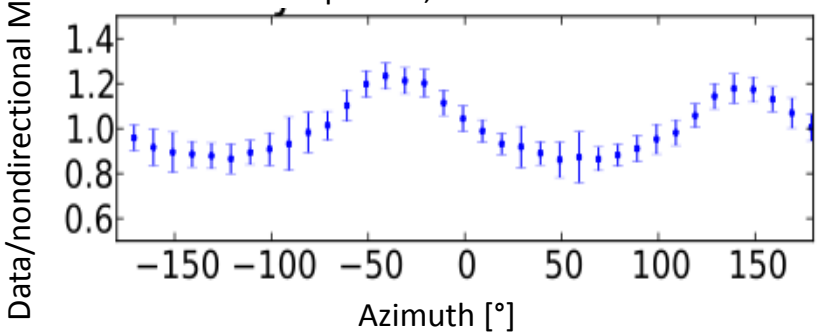
Scattering function



Directional anisotropy of scattering

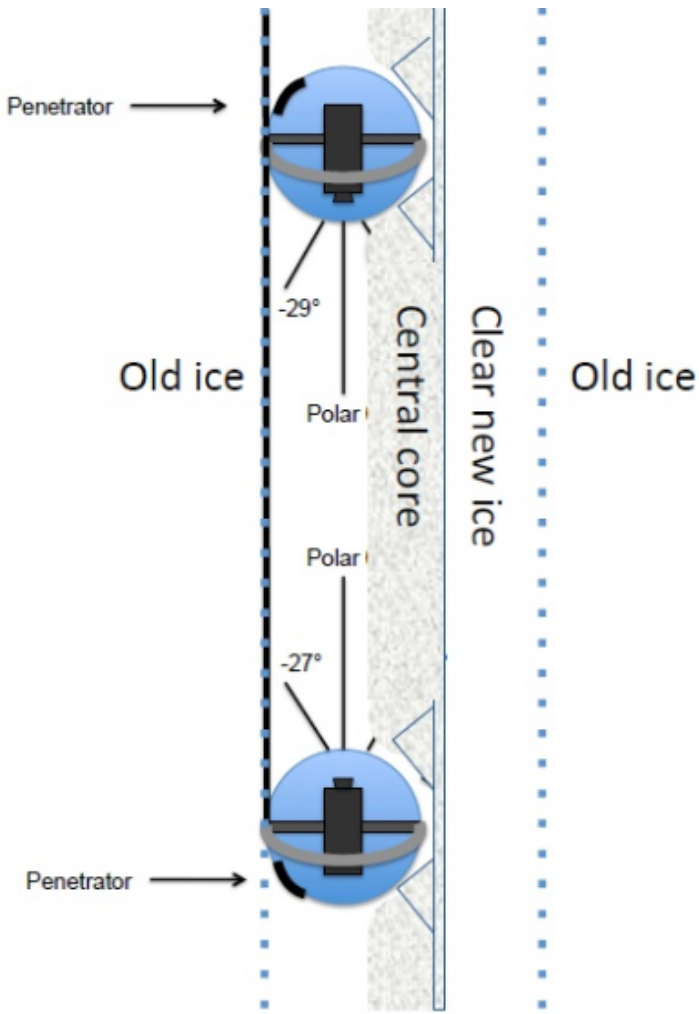
Less scattering in direction of ice flow:
→ up to ~10% /100m variation in amplitude

Relative amplitude, 125m from muons

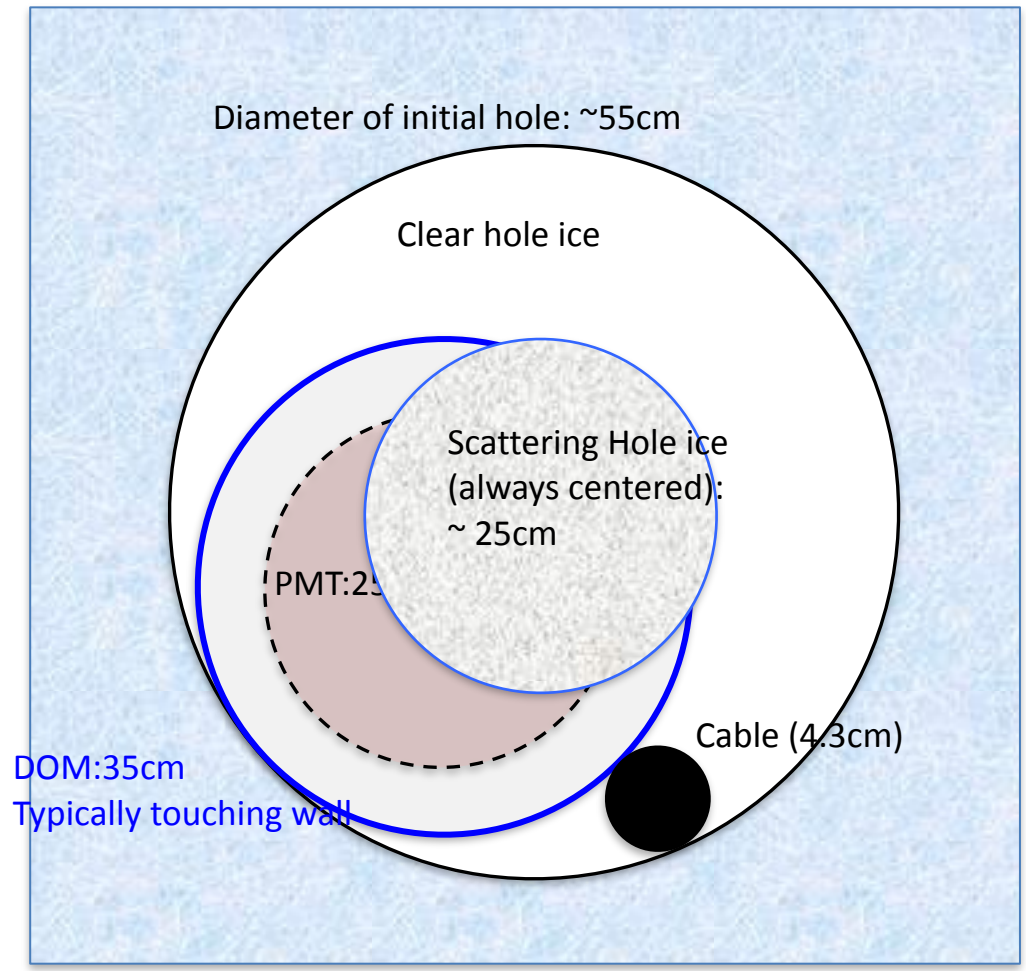


DOM sensor response and local ice

Current picture of hole ice



Some DOMs are less equal than others because of local effects in the hole ice.



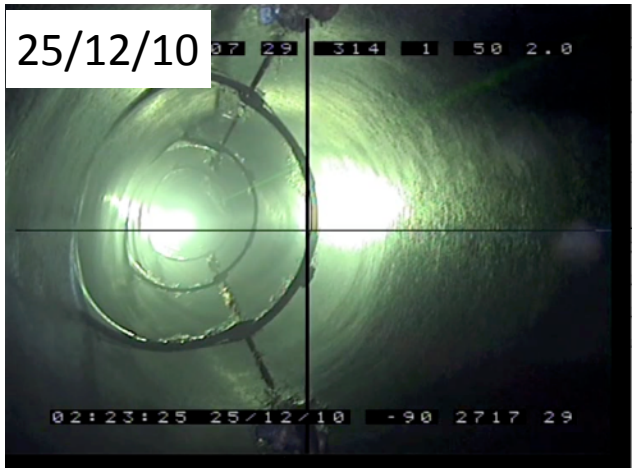

20/12/10
14:18:33 20/12/10 3 2695 9


21/12/10
10:11:43 21/12/10 3 2694 9

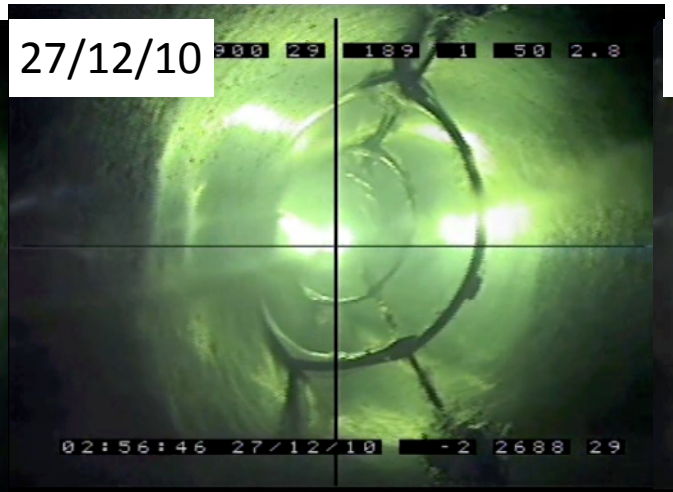

22/12/10
15:59:19 22/12/10 -1 2767 9


23/12/10
07:09:46 23/12/10 40 2646 29

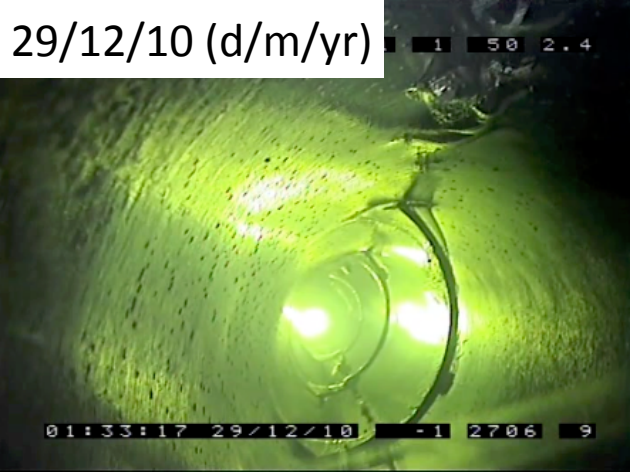

24/12/10
02:06:25 24/12/10 44 2659 29


25/12/10
02:23:25 25/12/10 -90 2717 29

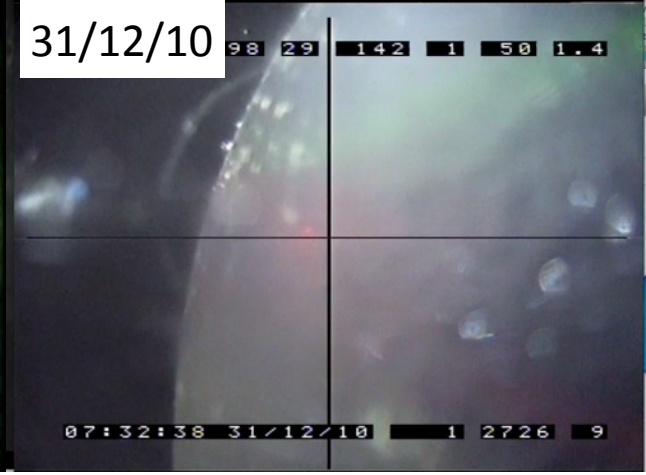

26/12/10
02:00:09 26/12/10 3 2702 29

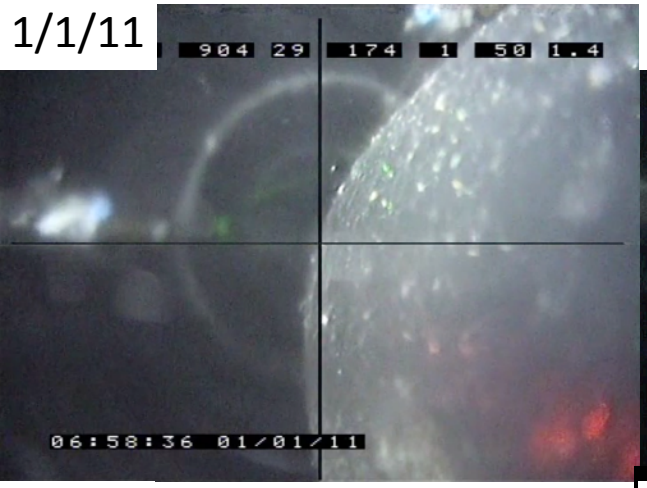

27/12/10
02:56:46 27/12/10 -2 2688 29


28/12/10
02:13:16 28/12/10 -2 2701 9


29/12/10 (d/m/yr)
01:33:17 29/12/10 -1 2706 9


30/12/10
03:08:05 30/12/10 -2 2702 9


31/12/10
07:32:38 31/12/10 1 2726 9


1/1/11
06:58:36 01/01/11


2/1/11
06:40:20 02/01/11 3 2701 9


10/2/11
02:44:40 18/02/11 -2 829 29

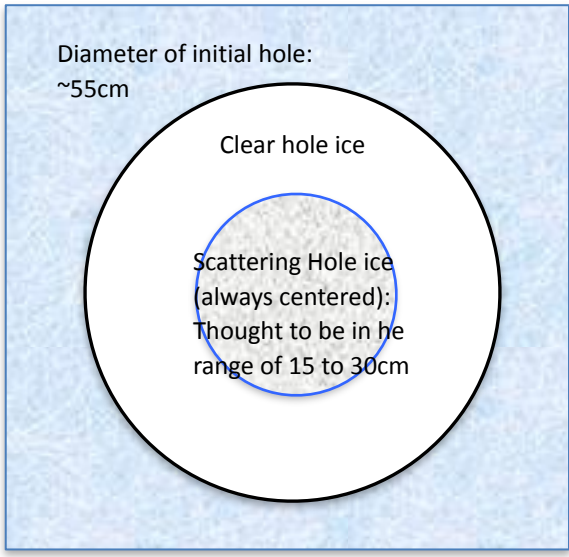

4/3/11
01:07:22 04/03/11 234 2094 9


8/4/11
02:30:48 08/04/11 -163 3398 9


9/11/11
03:27:19 09/11/11 338 2039 9

Why is there a substantial optical scattering in the refrozen local ice? Some thoughts.

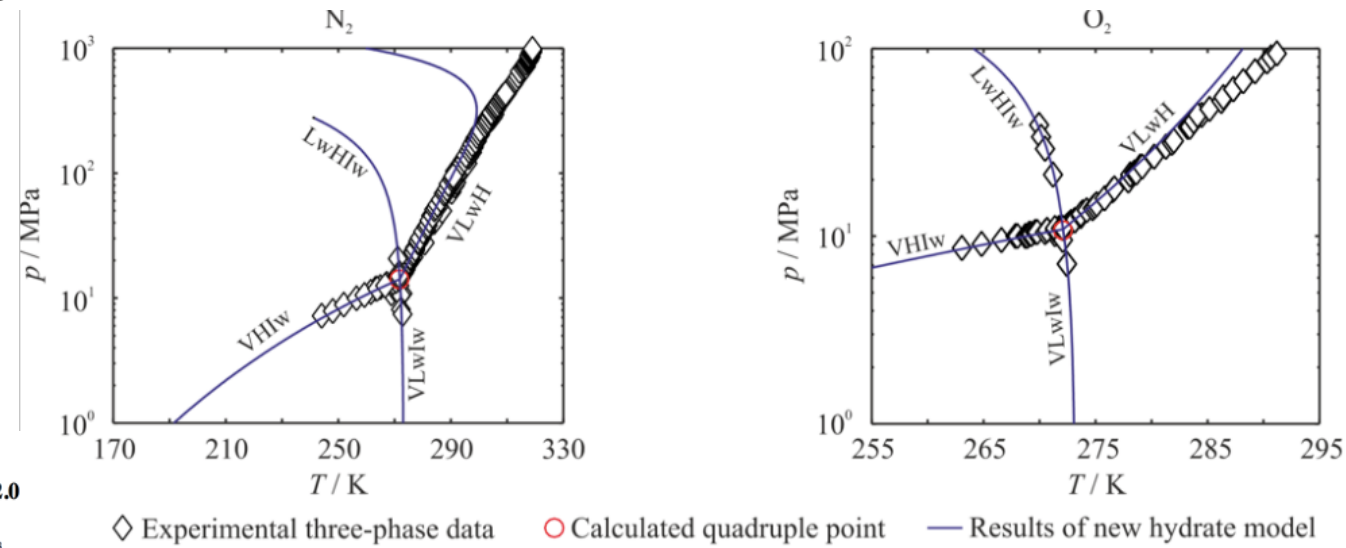
Recap of some things we know:
Initial refrozen ice seems very clear, more so than the surrounding bulk ice. Evidence suggest central column with stronger scattering:
Optical scattering corresponds to geometric scattering length of ~0.5m of assumed air bubbles in 0.5m diameter hole, or correspondingly 0.25 / 0.25.



Drilling:
The hot water drill melts ice on the way down and up .
The water left behind in the borehole consists to ~1/3 of newly melted ice and 2/3 of drill water from the surface.

The polar ice contains air in form of clathrate at the level of about ~10^-4.
The air content of the drill water is likely less than that but may be more than water at equilibrium at surface.
Solubility of that amount of air in water is no problem at 200 bar. Initially at least will form clear ice, no clathrate or bubble.

As the hole diameter shrinks, the concentration increases ~1/d^2.
Expect at some diameter formation of air bubbles or clathrates.



Model for gas hydrates applied to CCS systems
Part III. Results and implementation in TREND 2.0

Andreas Jäger[1,2,*], Václav Vinš[3], Roland Span[1], Jan Hrubý[3]

DOM and local ice

Images taken with camera (“Swedish Camera”) during refreeze process:

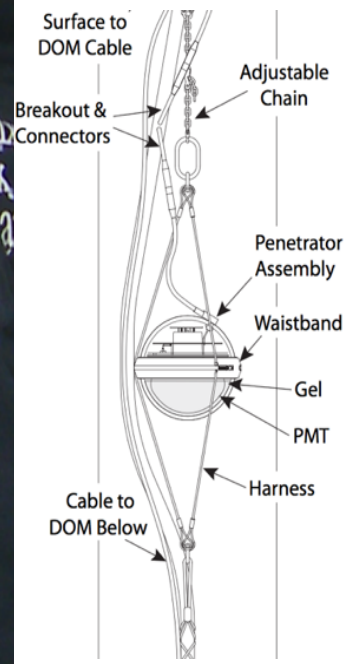
Hole ice visible on the right.
Need to determine the exact impact for every single DOM.

Cable shadow

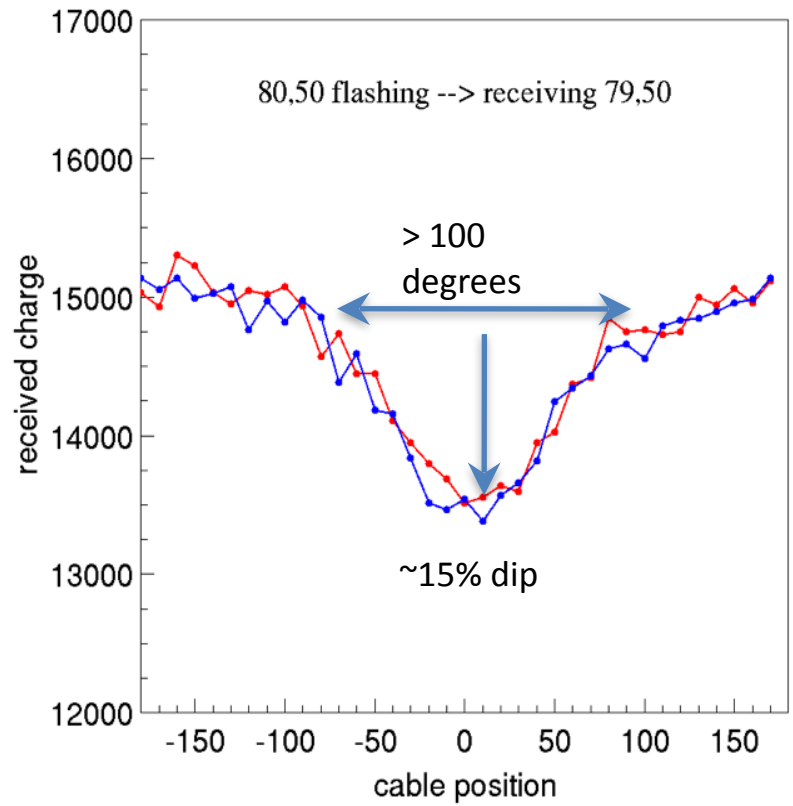
Cable diameter: 4.5cm

DOM sphere:32.5

PMT cathode diameter: 22 cm

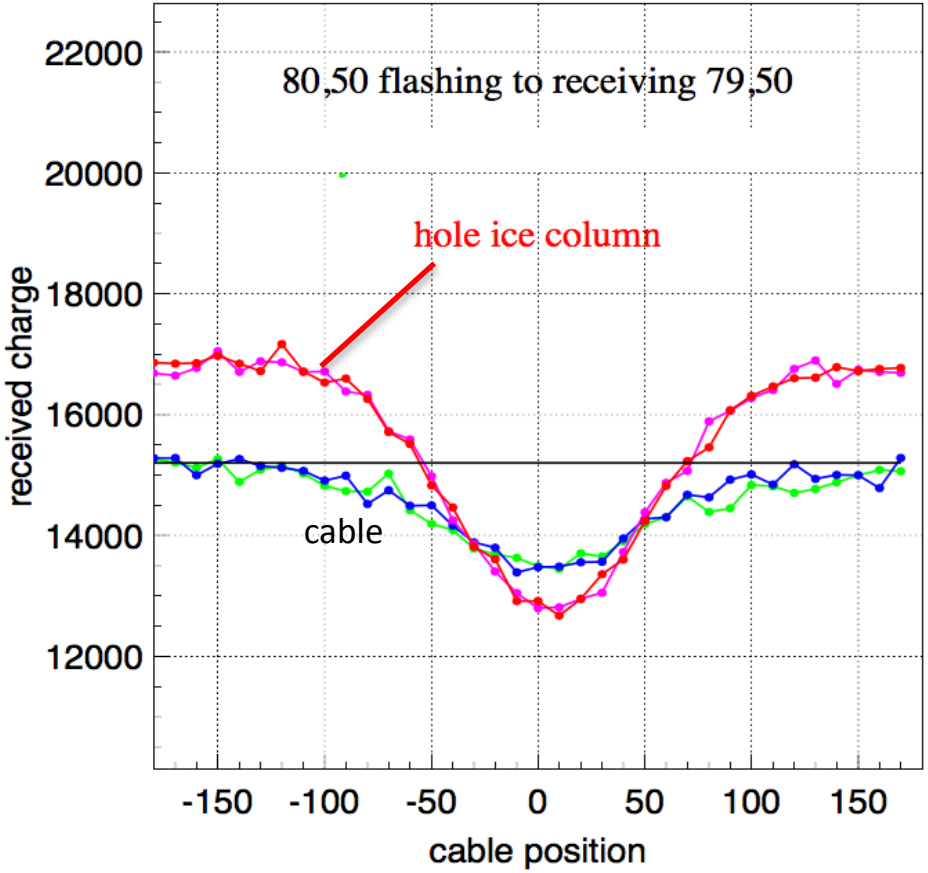


Azimuthal DOM response: Simulated effect on receiving DOM from flashers at close distance.



Simulation: Cable shadow and hole ice

Simulated effect with flasher data, Deep Core distance (~50m)



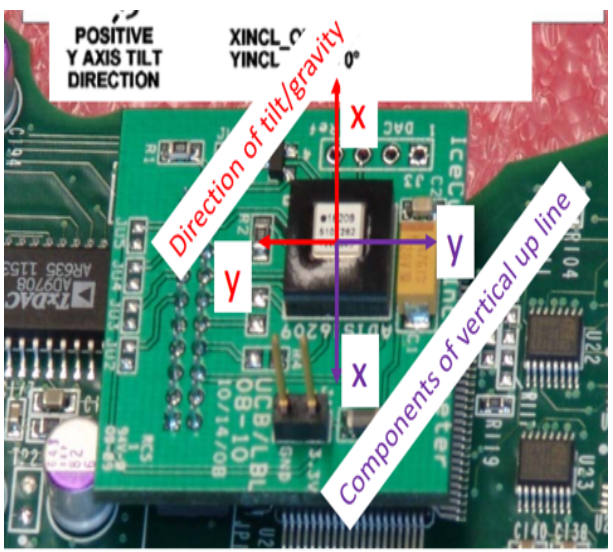
Cable shadow ~15%.
Hole ice modulation: ~ +12/-20%
Photons are blocked similar to cable, but reflected back when the column is behind the DOM

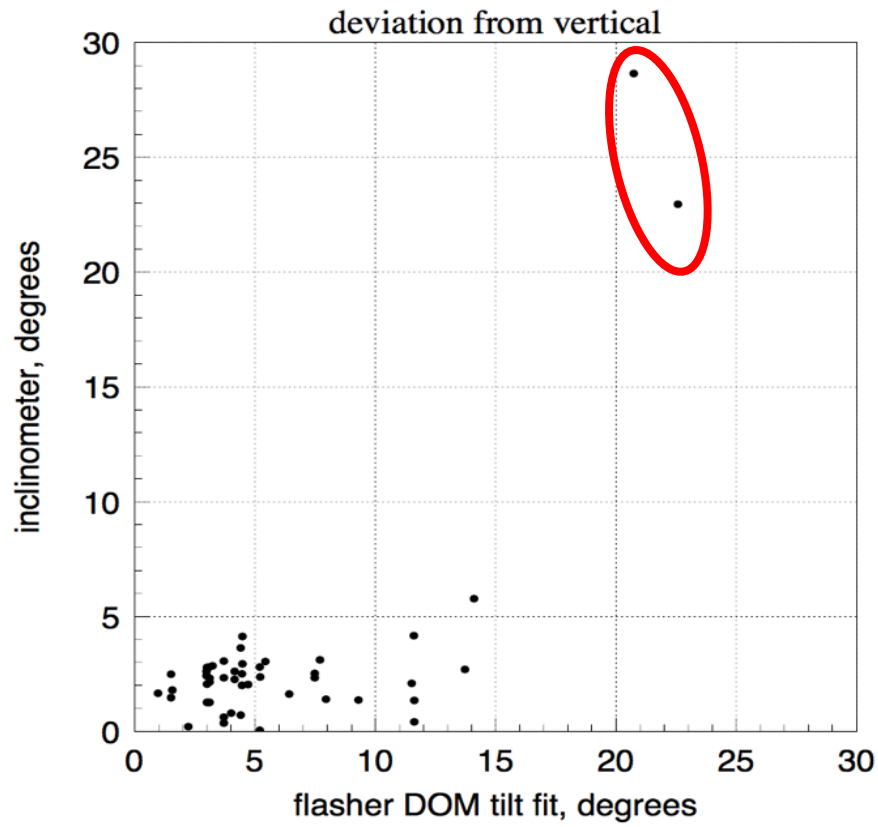
Built-in inclinometers vs DOM tilt fit

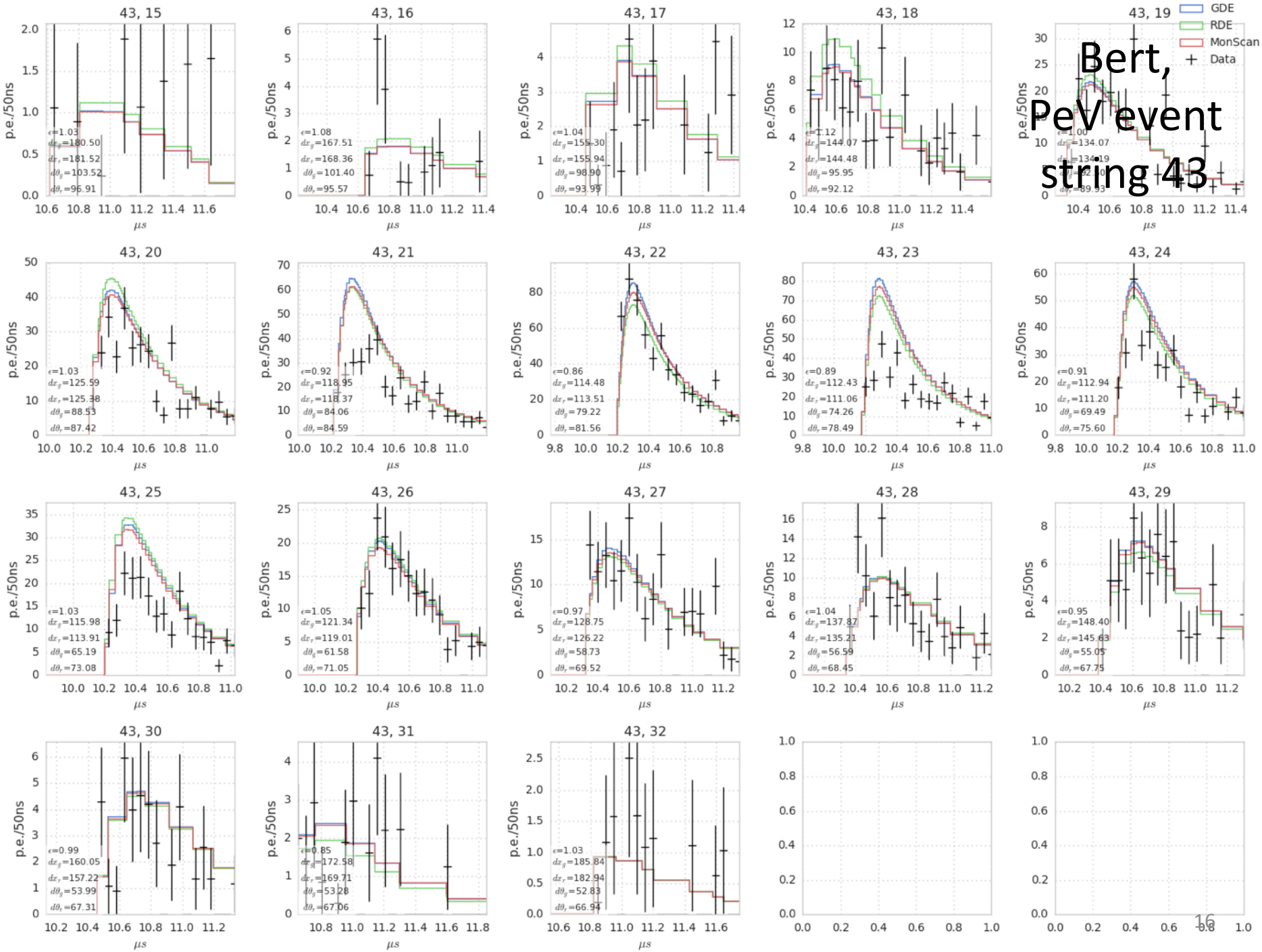
Evidence that in some cases DOMs are tilted by some amount, during freeze-in.

Indication of real tilt for 2 DOMs (out of 48)!

4 dozen DOMs have a built-in inclinometer, mounted on the mainboard, most of them have measured very small tilts, while 2 have tilts in excess of 20 degrees.







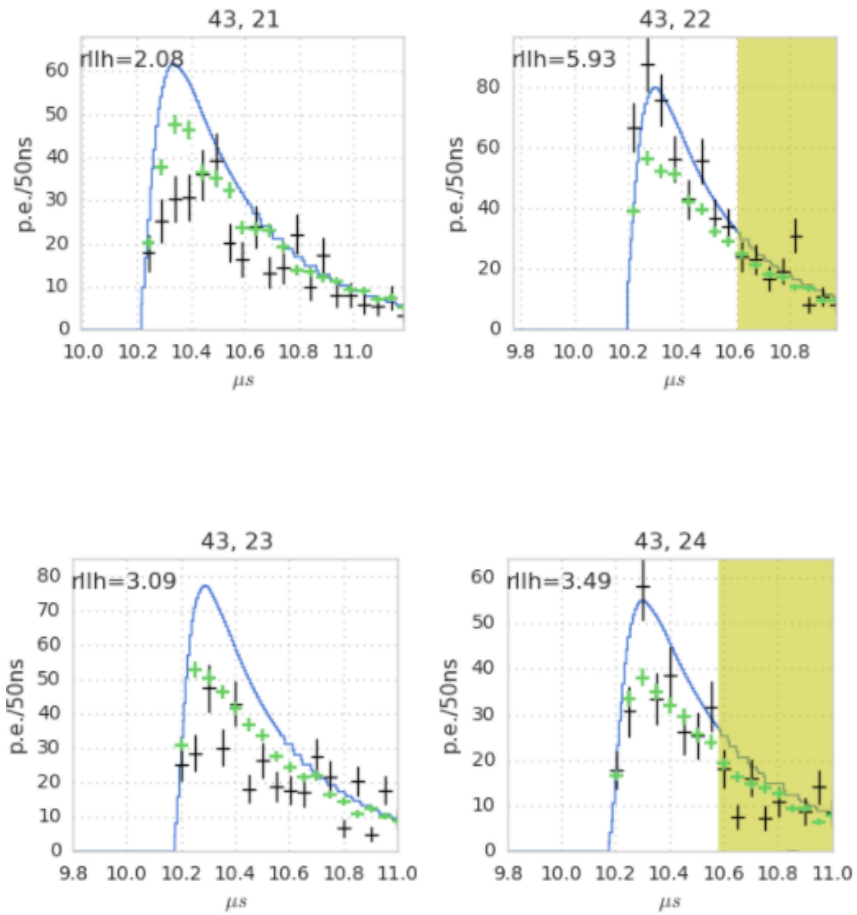
Bert, PeV event string 43

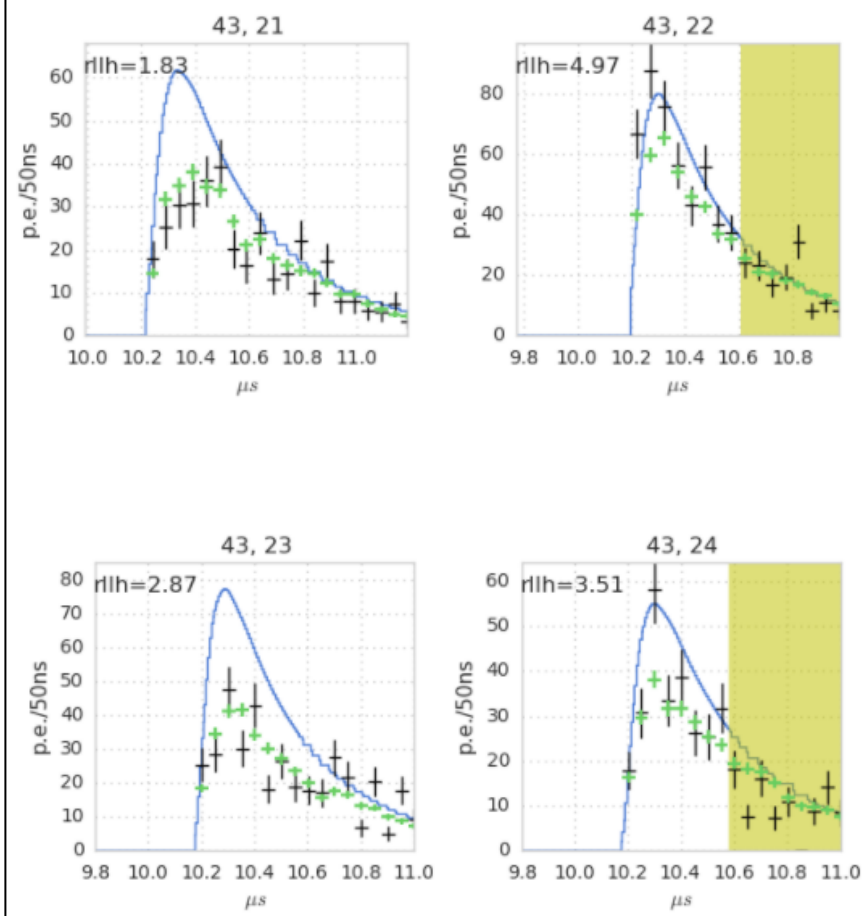
Local effects: DOM orientation and cable position

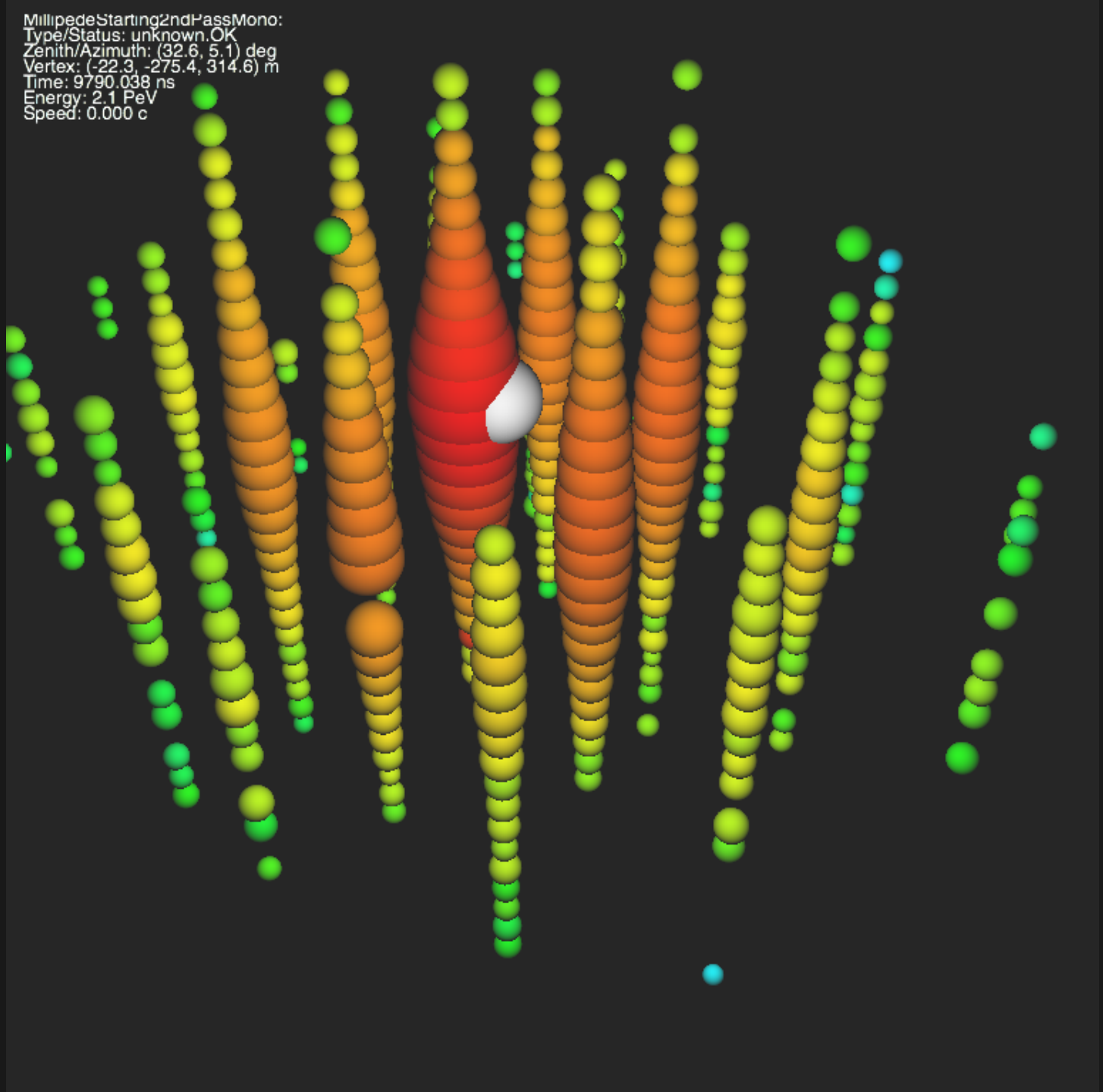
Without local effects

With local effects

Bert data
Direct photon MC
Effective photon MC

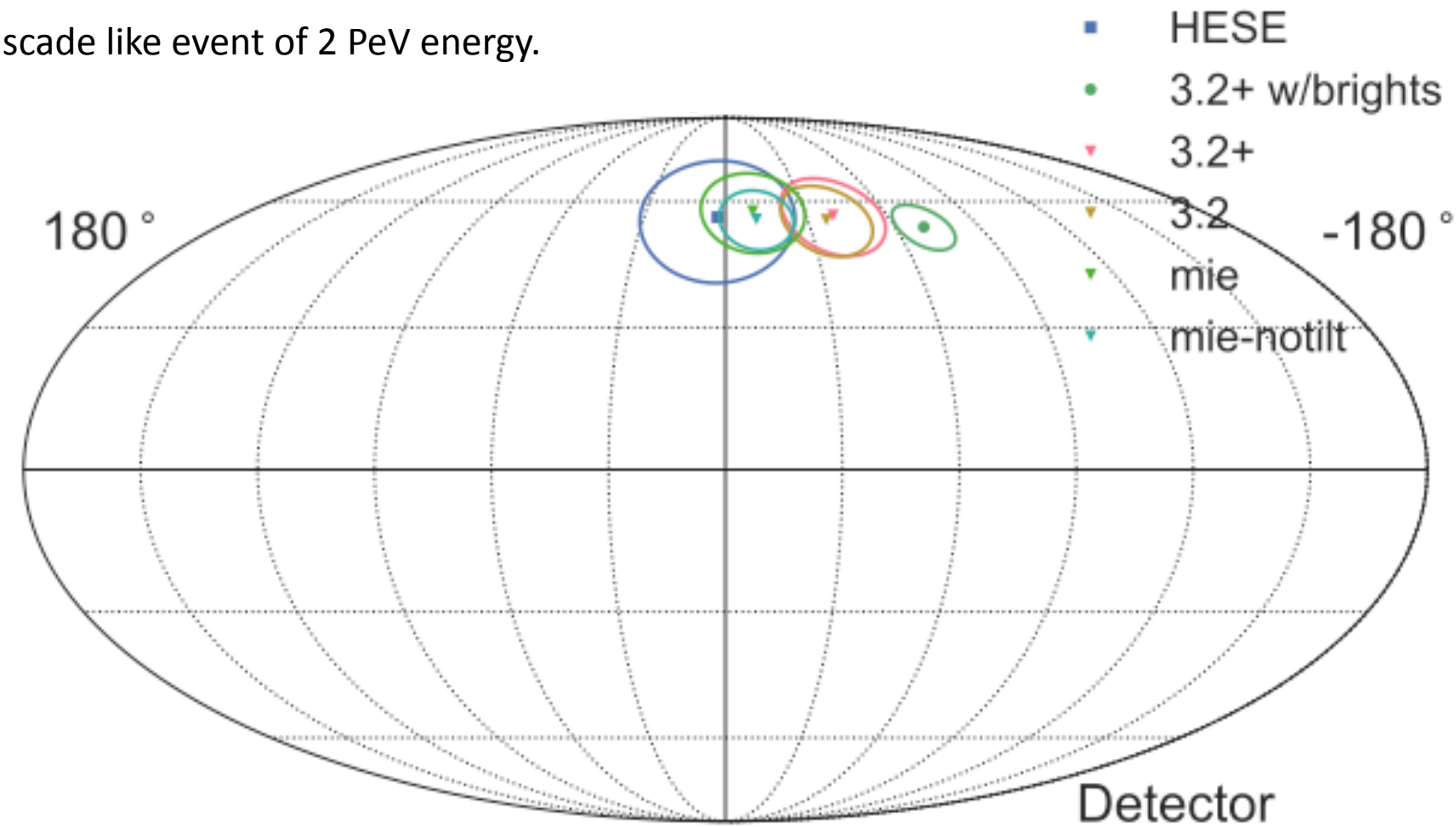





MillipedeStarting2ndPassMono:
Type/Status: unknown.OK
Zenith/Azimuth: (32.6, 5.1) deg
Vertex: (-22.3, -275.4, 314.6) m
Time: 9790.038 ns
Energy: 2.1 PeV
Speed: 0.000 c

Directional reconstruction of an extremely high energy neutrino

Cascade like event of 2 PeV energy.



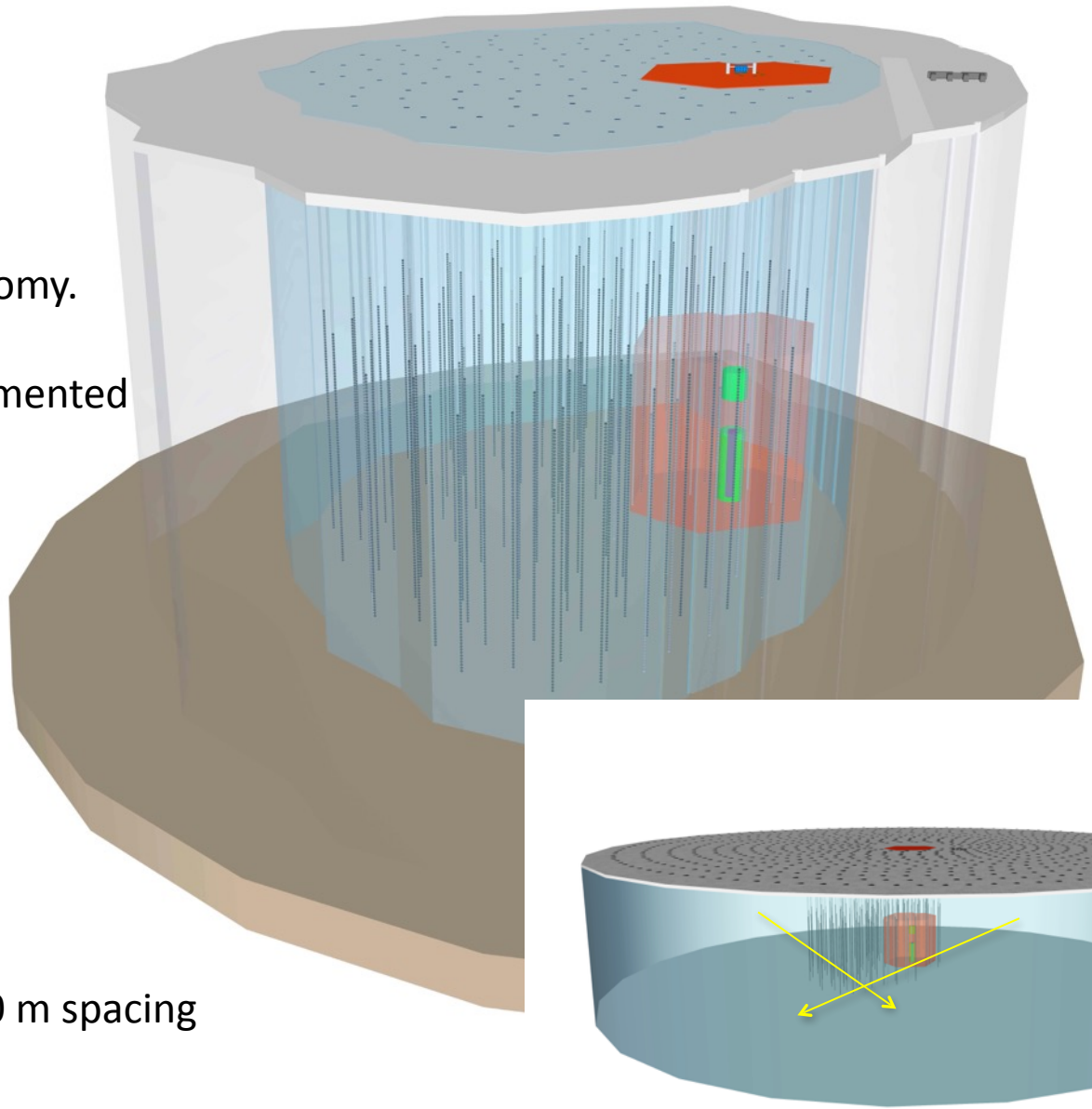
Understanding ice is critical to the science!

IceCube-Gen2
The next Generation IceCube

From discovery to astronomy.

Factor of 10 larger instrumented volume.

For about the same cost.



Artist conception
Here: 120 strings at 300 m spacing

Aim for significant improvement compared to IceCube design and construction

- in all areas

- **Drilling** → more efficient (faster, 40% less fuel)
- **Logistics** → less impact than IceCube
- **Sensor design** → higher sensitivity, more information
- **Analysis** → improve event reconstruction at high energies (why is reconstruction at 1 PeV not as much better than at 100 TeV as one might expect from additional photons?)

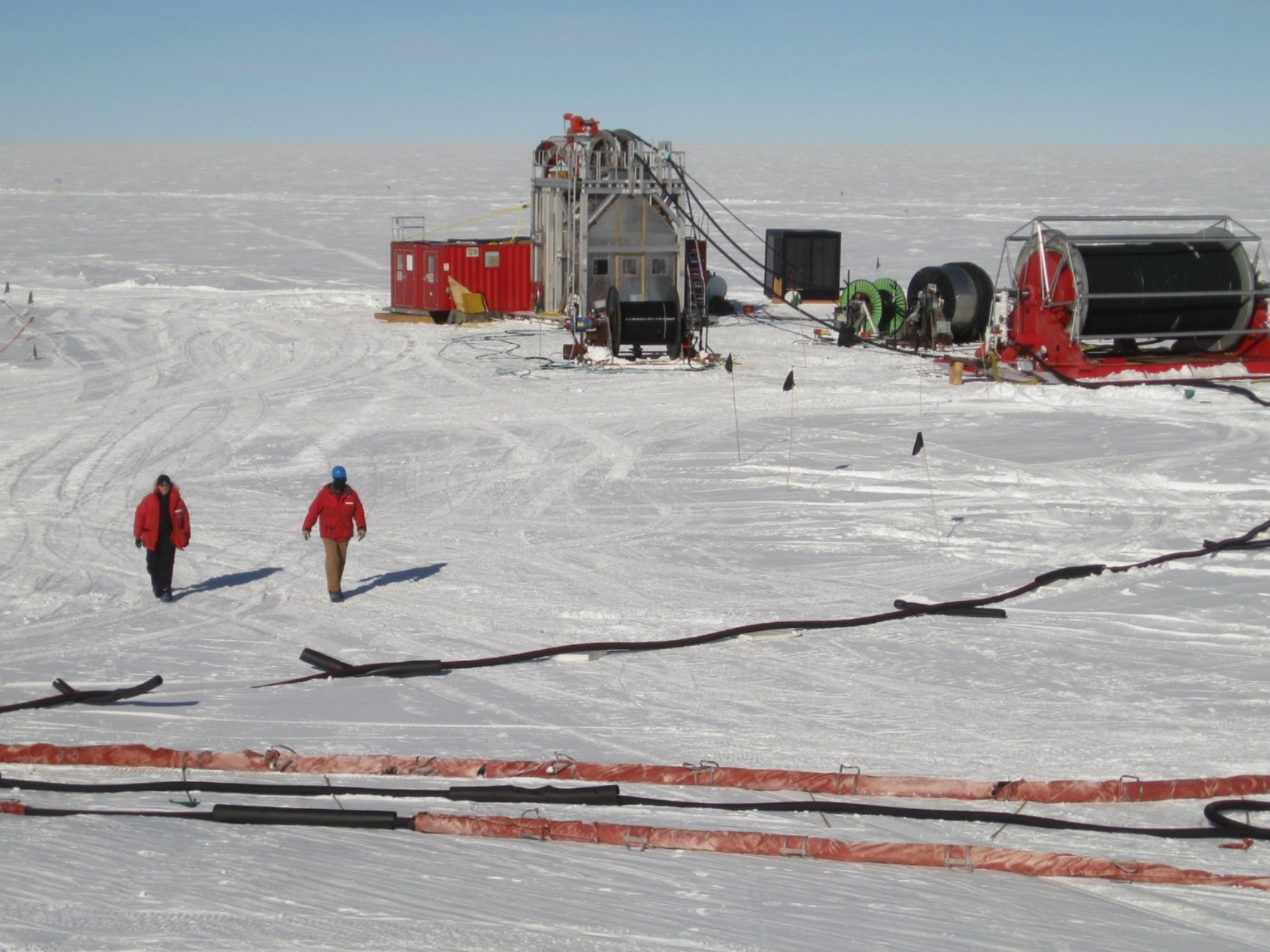
- All areas are related to ice, glaciology, Drilling and logistics in some way

Logistics challenges

IceCube:

- Cargo: more than 400 tons (fuel and equipment), 300 LC-130 flights. (in future thinking primarily of overland transportation)
- Housing: 50 people on ice, three shift operation for 3 summer months
- Drilling: hotwater drill, 5 MW, deliver 60 cm diameter hole to 2500m in 30 hours

  18 holes/ season



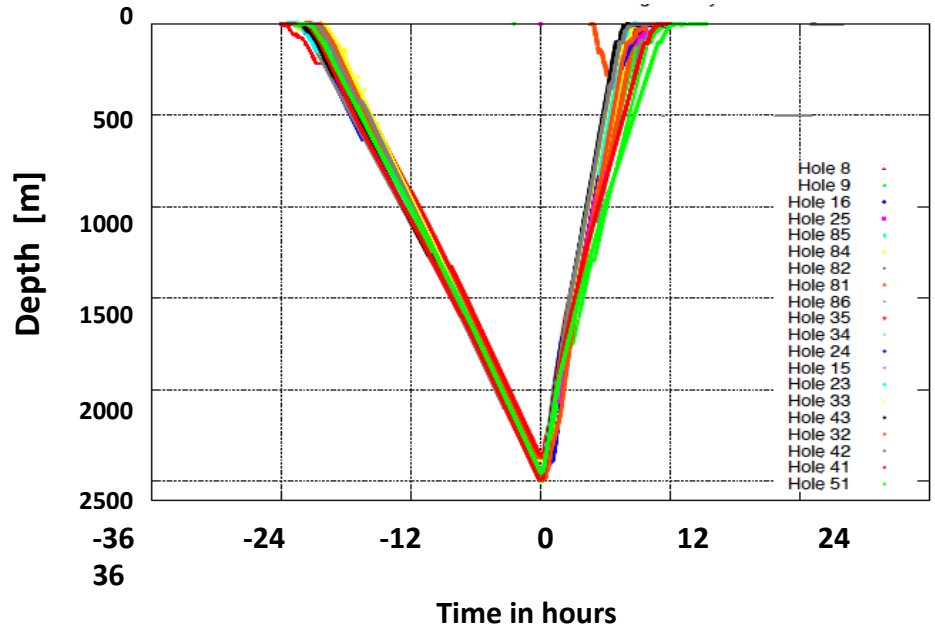
How much can drill speed be improved?

- Time required to drill hole in IceCube:
  - Drilling: 22h → 18
  - Reaming: 9 h → 7 h with low power (~25%)

Total: 31 hours

- Fuel Savings: 35 to 40%
- Smaller diameter instruments will allow for faster drilling

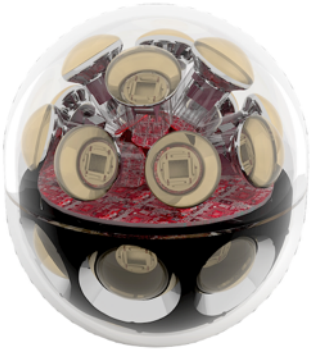
Depth versus time profiles
Overlay of 20 IceCube holes drilled in < 2 months



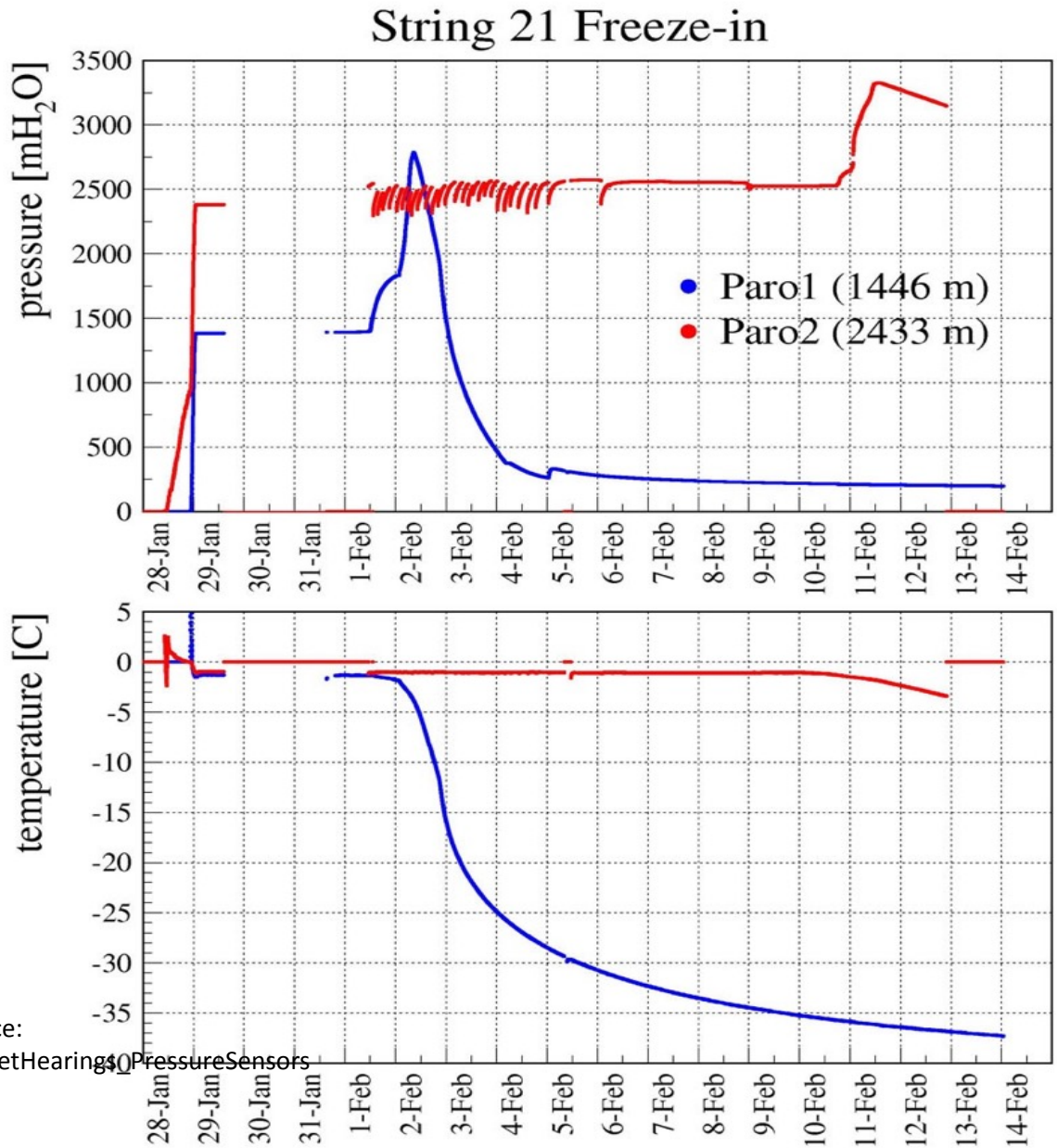
Optical sensors

- P-DOM
- M-DOM
- D-EGG
- WOM
- Brusselsprout OM
- Other (WLS fibers)

Drill hole diamater ~ square of
Drill time and fuel usage
(for large DOM level diameters)



Sidestep: A quiz for the ice experts – what are the wiggles from



Source:
GadgetHearings$0PressureSensors

Very similar pattern
On other strings.

My guess:
Hole freezes first at the top (we now that) pressure builds up until it reaches a point where the surrounding ice cracks and pressure goes back to equilibrium.

Have no theory. Perhaps someone finds that interesting.

→ For the coffee break

Ice

Neutrinos

Drilling

Particle Physics

dust

Glaciology

Astronomy

optical

radio

Logistics

Goal of workshop: IceCube-Gen2: bring different communities together to exchange information, discuss, learn, and explore options of future collaboration.