Friedrich-Alexander-Universität
Erlangen-Nürnberg

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FAU

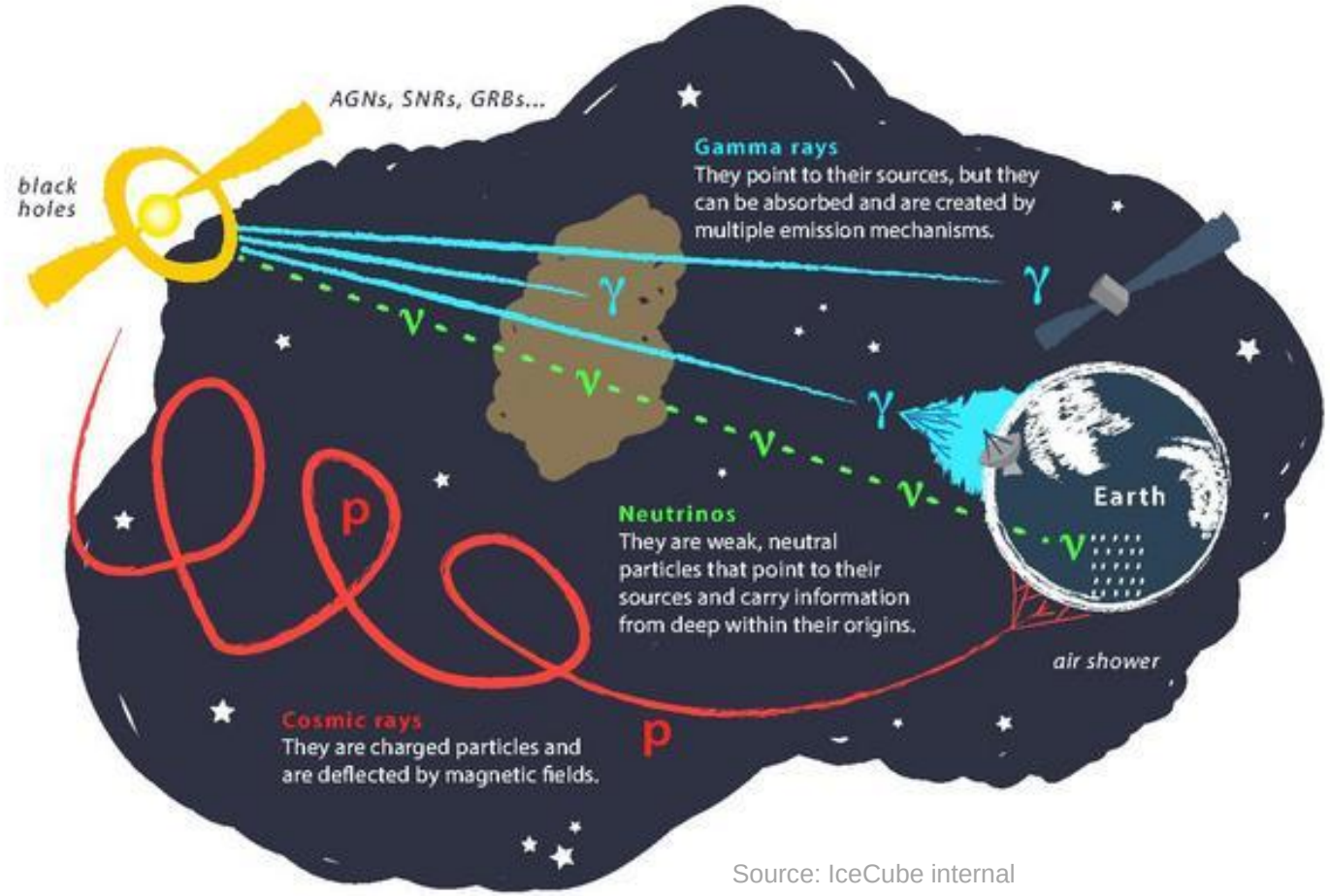
Design and operation of a co-deployed dust-logging instrument for the IceCube Upgrade and IceCube-Gen2

Anna, Eimer
Erlangen, 10.09.23

Neutrino Astronomy

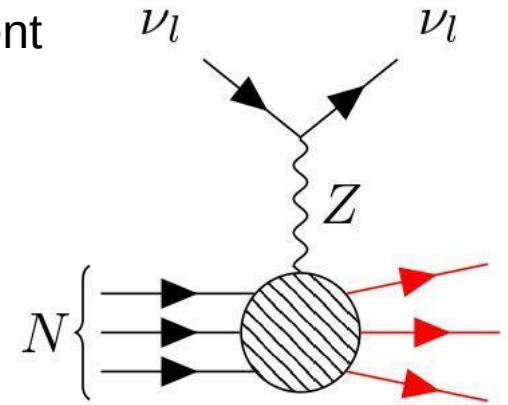
Sources and detection

Astronomy uses electromagnetic radiation or particles to get information about astronomical objects.

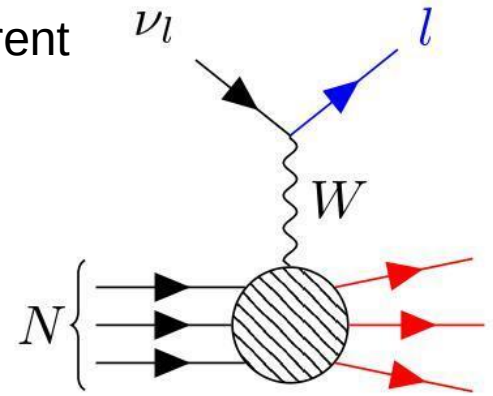


Source: IceCube internal

Neutral current interaction



Charged current interaction

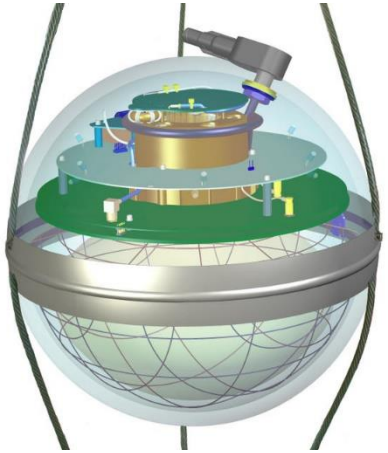


Cherenkov Telescope

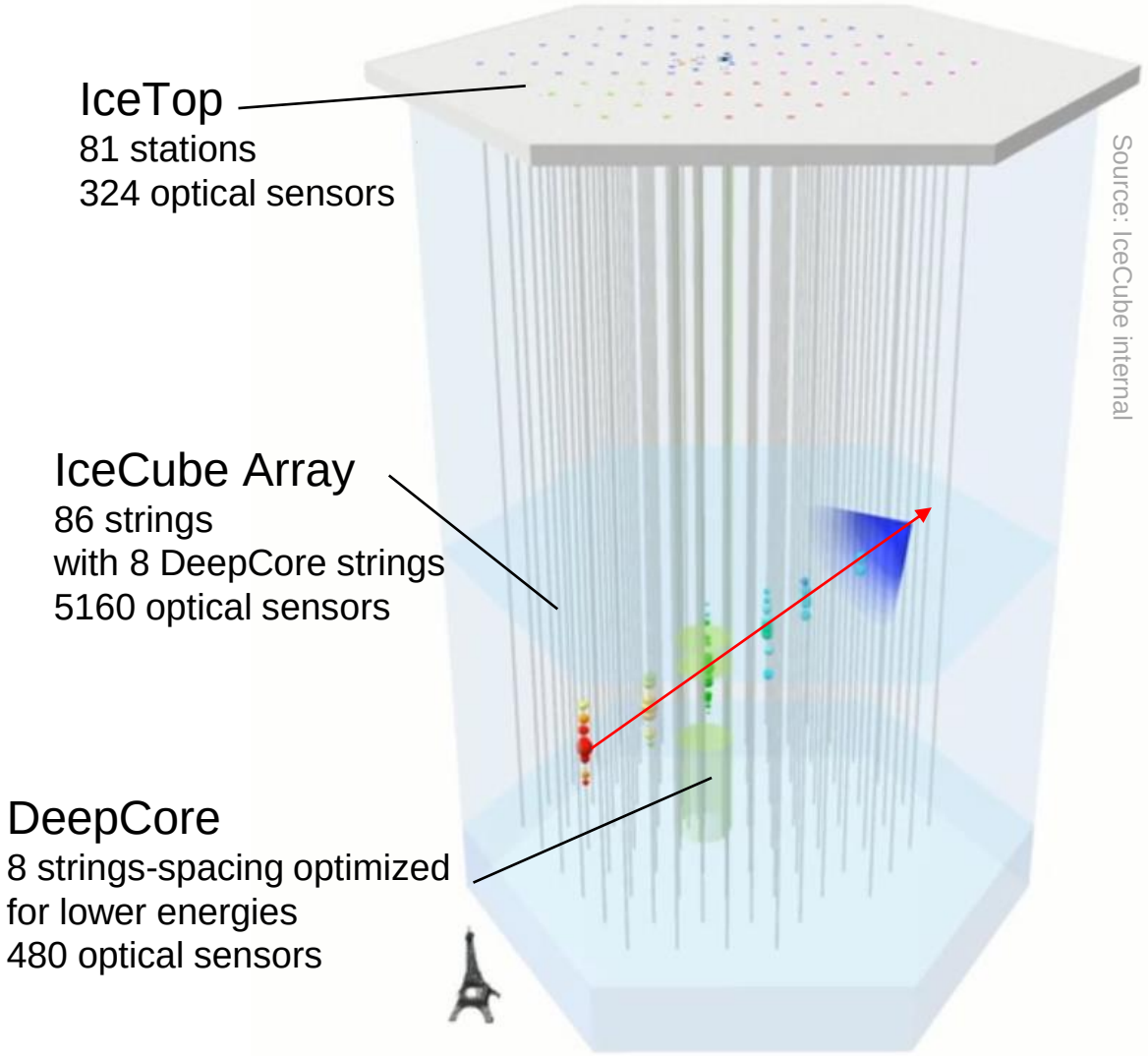
IceCube Neutrino Observatory

- km^3-scale high-energy neutrino observatory built at South Pole
- Charged particles produced in neutrino interaction travel faster than the phase velocity of light in ice and therefore emit Cherenkov photons
- Neutrino detection via photomultiplier tubes (PMT) organized in strings which are lowered into holes

Digital Optical Module (DOM):



Source: IceCube internal

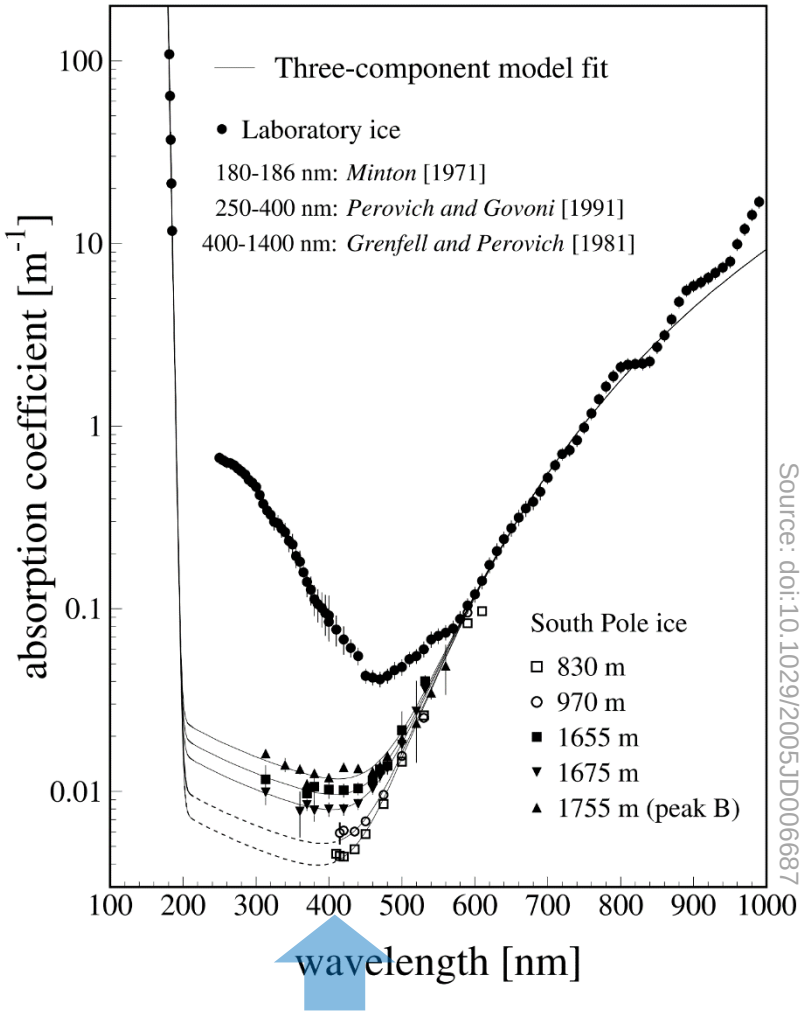


Glacial ice

Optical properties

- Light propagation in **ideal ice** can be described by:
  Complex refractive index
  - real part = 1.3
  - Ice absorption coefficient given by complex part
    → Ice is transparent for Cherenkov light

- Additional parameters for **real ice**:
  - Impurities:
    dust, marine salt crystals, acid droplets
    and vulcanic ash
  - Enclosed gases:
    air enclosed by snow
  - Stress acting on the ice:
    weight of new ice and snow, and glacial river

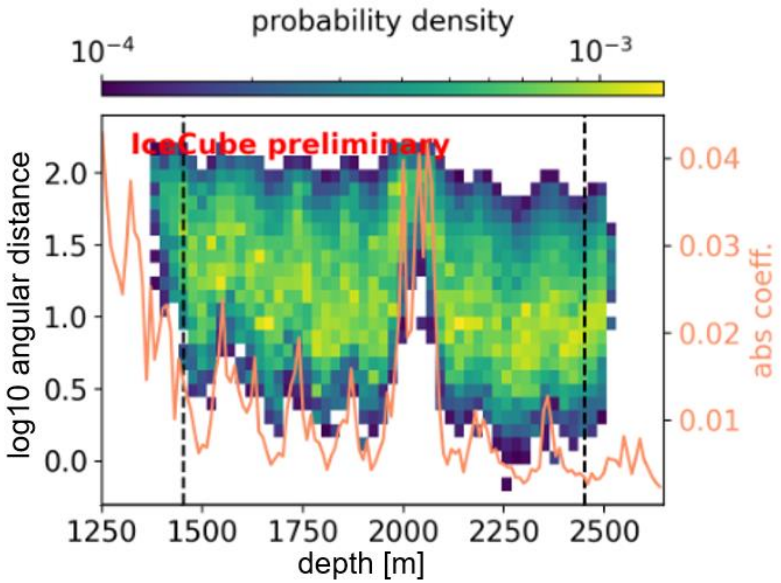


Visible Cherenkov radiation

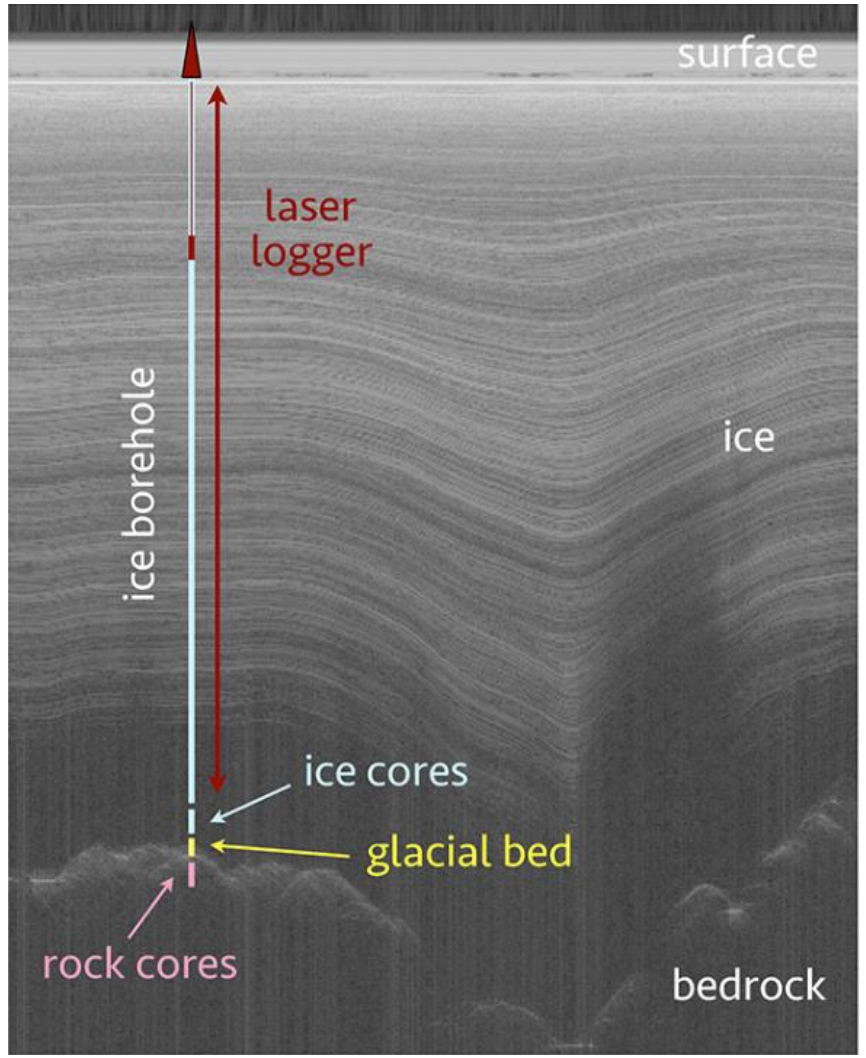
Ice calibration

Stratigraphy

- The additional parameters for real ice lead to a ice layer profile (stratigraphy) with different optical properties
- Additionally the bedrock shapes these layers which leads to undulation in the profile
- These properties need to be known to understand received detector signals



Source: PoS(ICRC2023)1003



Source: doi:10.18154/RWTH-2019-09941

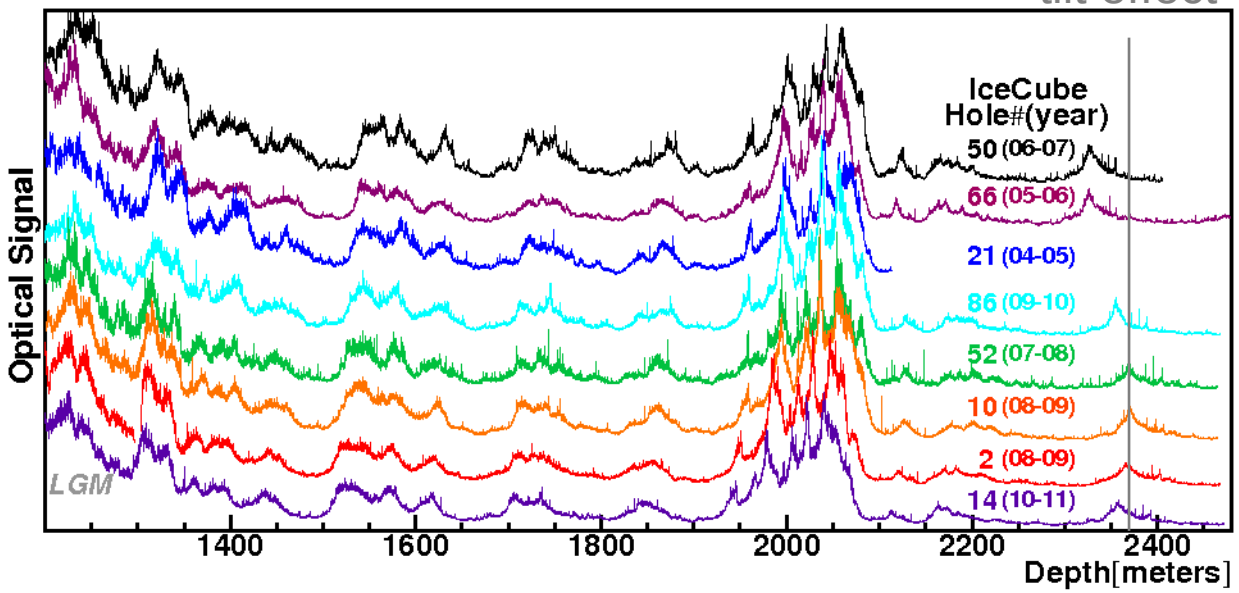
Ice calibration

Dust logger (used in IceCube)

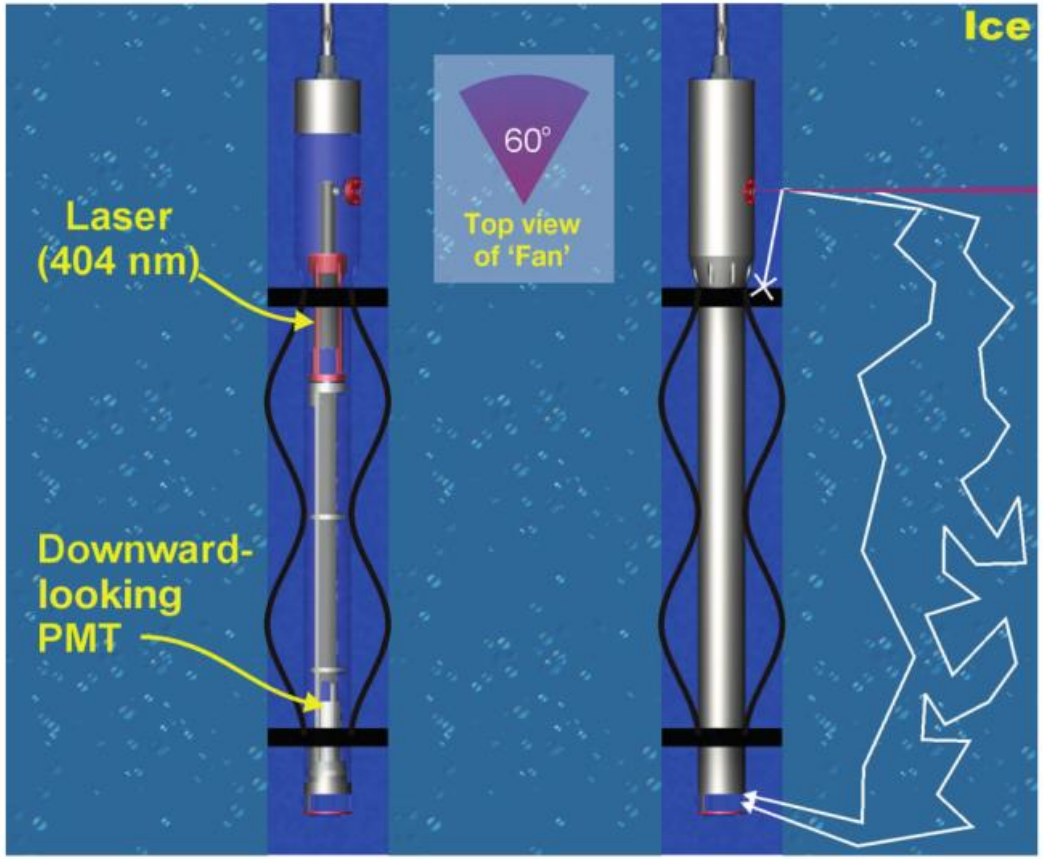
Working principle of the dust logger:

- Horizontal fan of light emitted into ice
- Scattering centers can deflect light into PMT (signal proportional to density of scattering centers)

tilt effect



Source: doi:10.3189/2013JoG13J068



Source: doi:10.3189/2013JoG13J068

Ice calibration

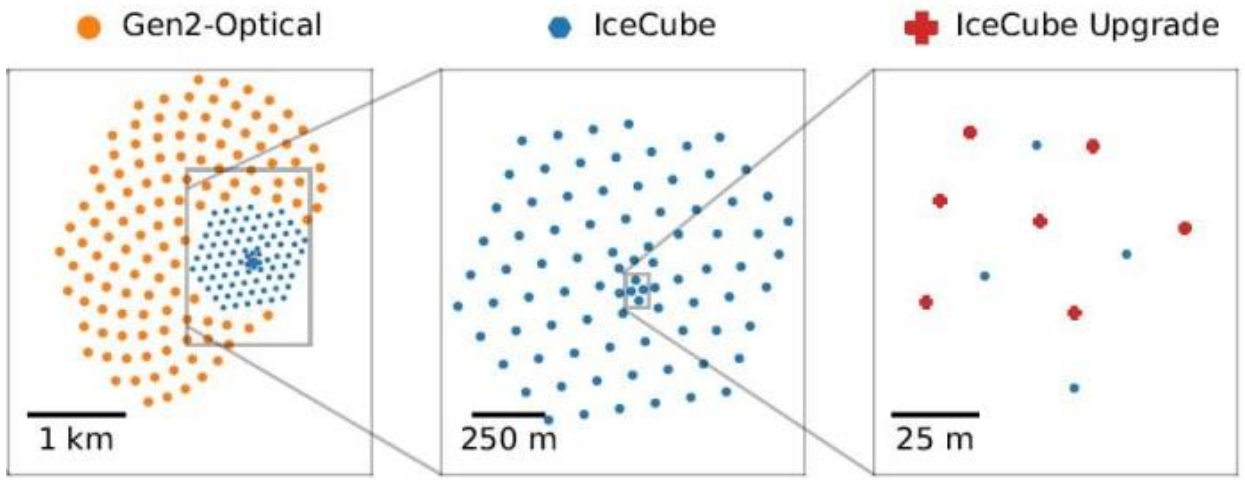
Dust logging in the future

IceCube wants to built a large extension called IceCube-Gen2 for detecting neutrinos with higher energies and higher sensitivity.

Envisioned IceCube-Gen2 footprint and spacing requires logging of each hole for layer undulation

→ deployment of standalone dustloggers too expensive, can we log with instrumentation on string?

For the Upgrade (testing new hardware for IceCube-Gen2) a low cost version of the dust logger should be tested: the POCAMlogger



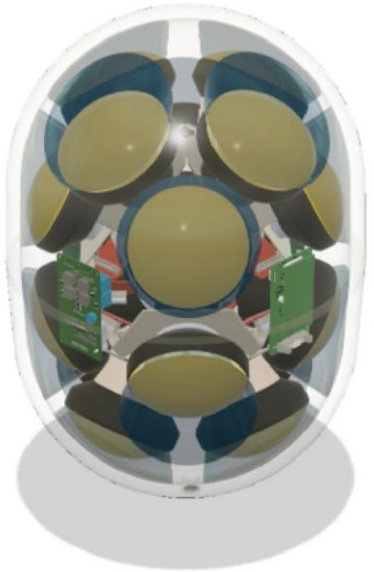
Source: IceCube internal

POCAMlogging

My project (suggestion for IceCube Upgrade)

POCAM works as isotropic light emitter (designed for calibration of the DOMs), but for the dust logger a fan of light is needed → my work

LOM



Source: arXiv:2308.02771v1

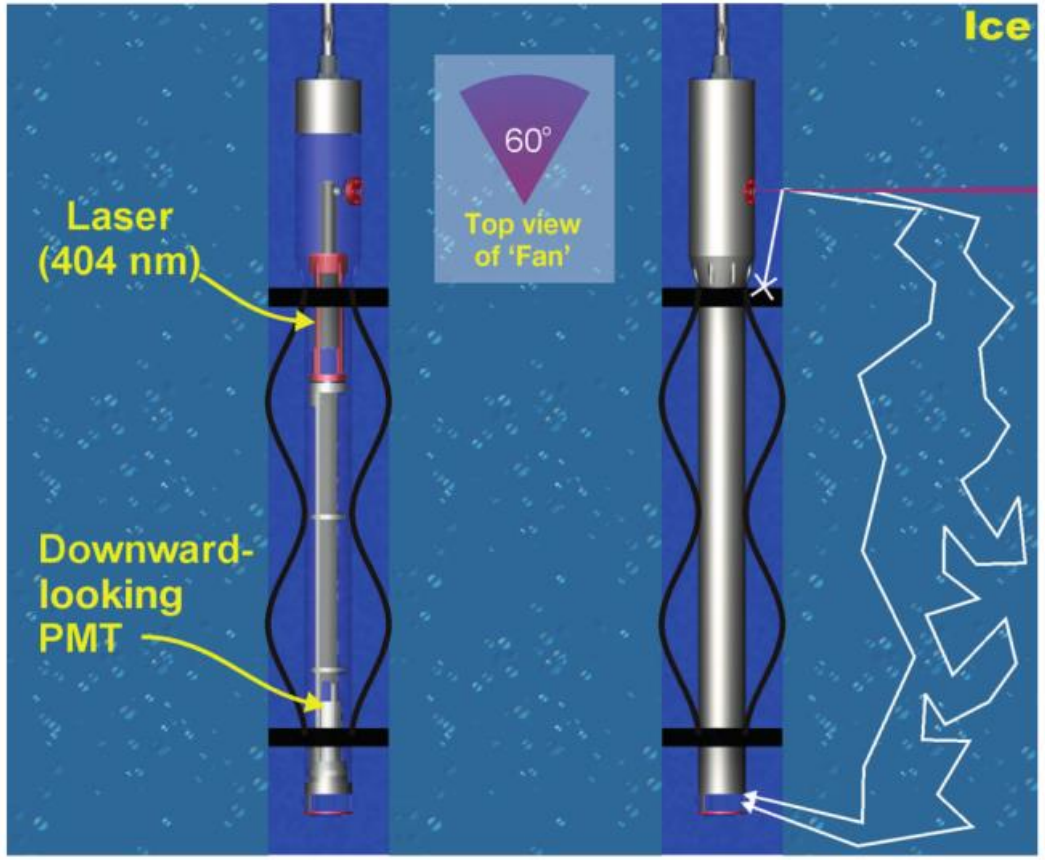
+

POCAM

Source: IceCube internal

=

Dust logger



Source: doi:10.3189/2013JoG13J068

DOI 10.1088/1748-0221/15/07/P07031

POCAMlogging

Planned optics system

Optical system should produce horizontal fan of light, for probing one layer of ice at a time, but get more statistics.

optics system

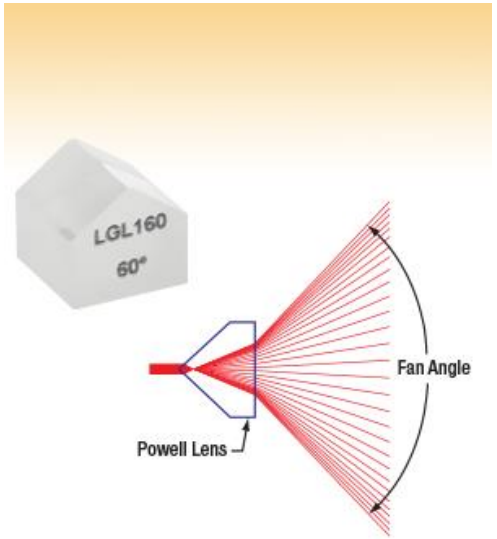
laser diode

Source: Roithner

collimator

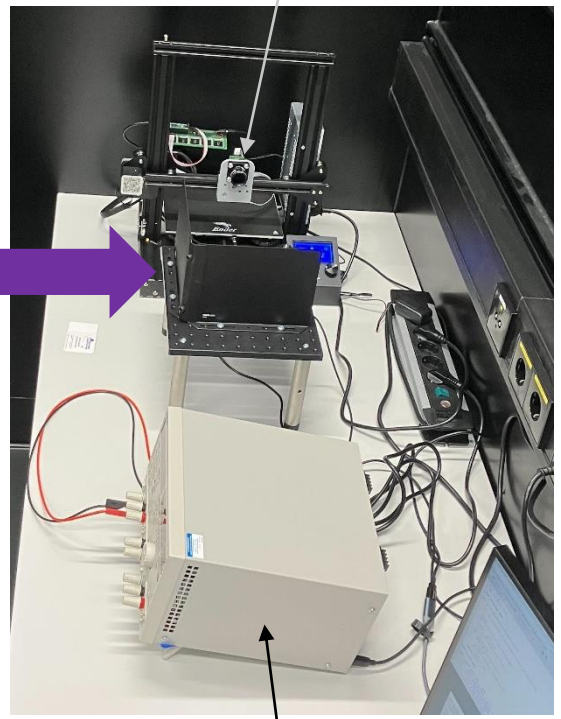
Source: Thorlabs

Powell lens



Source: Thorlabs

readout via photodiode

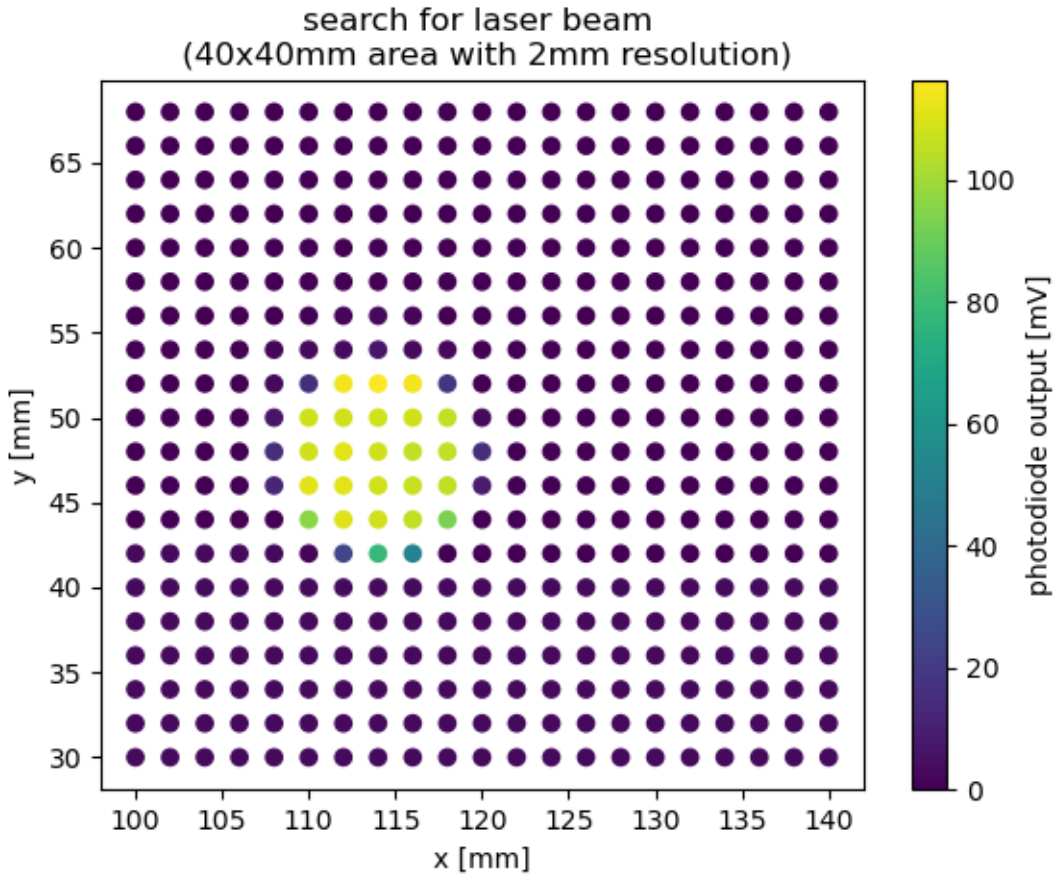


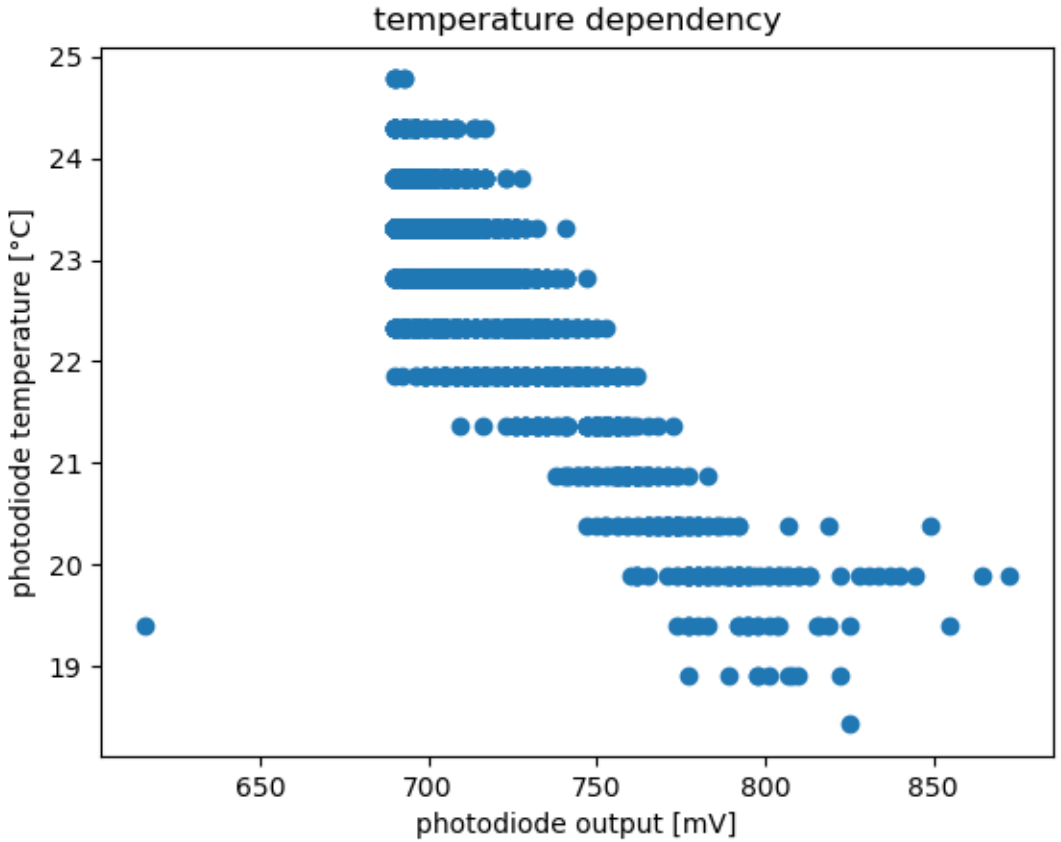
power supply for the laser

POCAMlogging

First measurements

First measurements testing the setup and understanding the system:





Summary

General:

- Neutrinos point back to their source, but are only detectable indirectly
- Cherenkov Telescopes such as IceCube are detecting neutrinos using large amounts of ice
- Ideal ice is very transparent to the measured Cherenkov light, but impurities in different ice layers absorb light which leads to different behavior of the detector in different depths
- In order to understand the ice behavior/purity IceCube uses calibration devices such as the dust logger

My work:

- For future IceCube extentions with larger footprints the behavior of the ice needs also to be known
- To achieve this, existing hardware (POCAM and first LOM on a string going into the ice) should be modified to work as a dust logger
- The laser system of the POCAM needs to be turned from a isotropic light source into a horizontal fan
- So far the xy-scan is tested and works
- A temperature dependency of the laser could be found

Back up

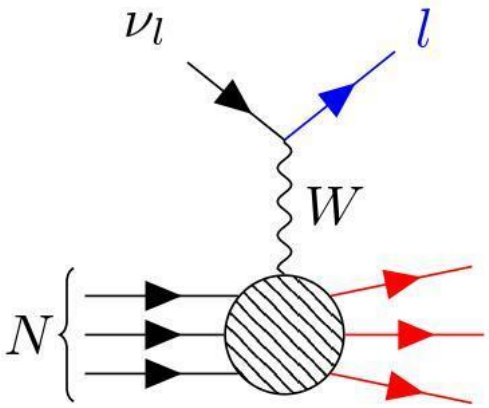
IceCube Neutrino Observatory

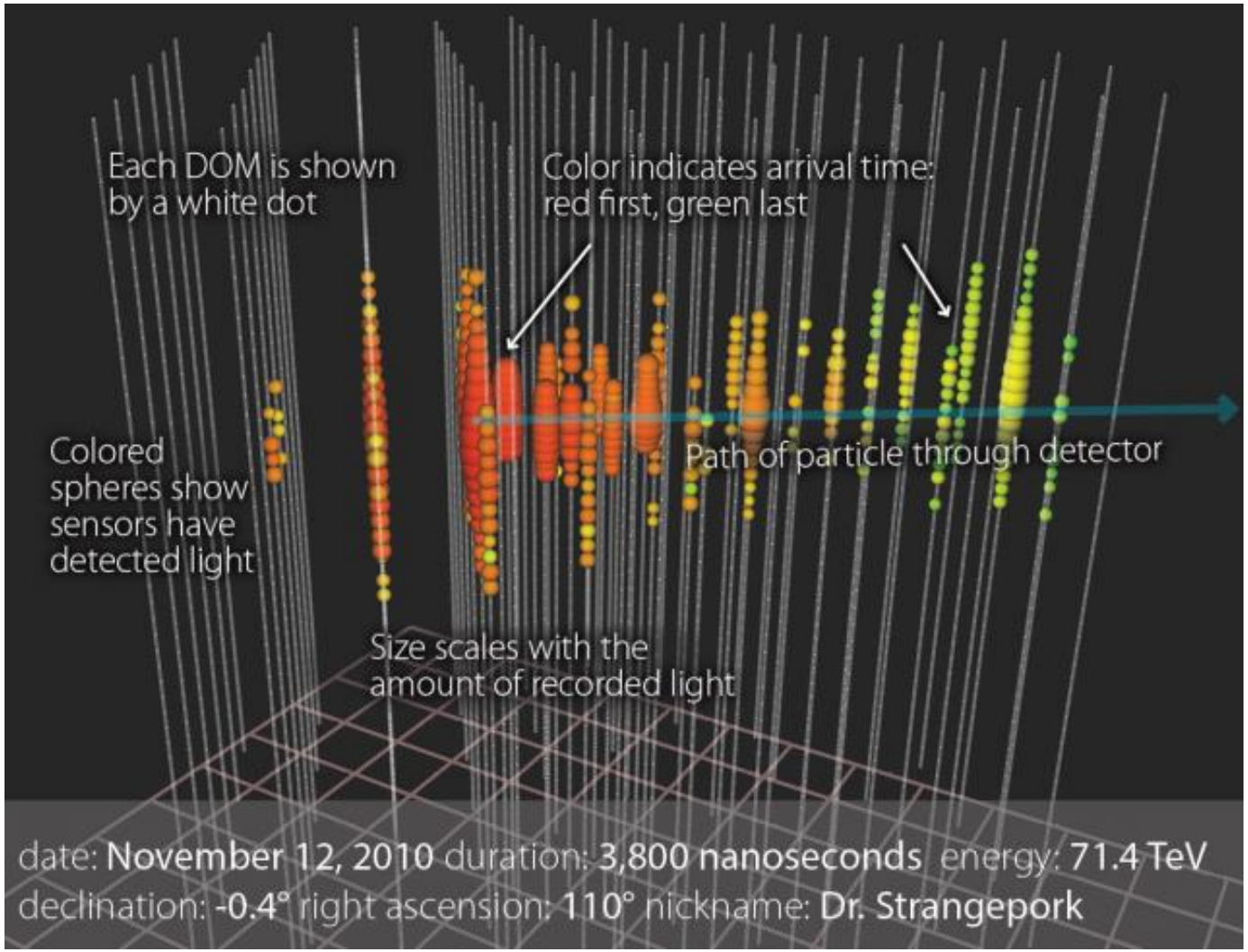
Event measurement

Charged particles produced in neutrino interaction travel through ice faster than the phase velocity of light in ice and therefore emit Cherenkov photons

Picture shows a muon track:

Charged current interaction



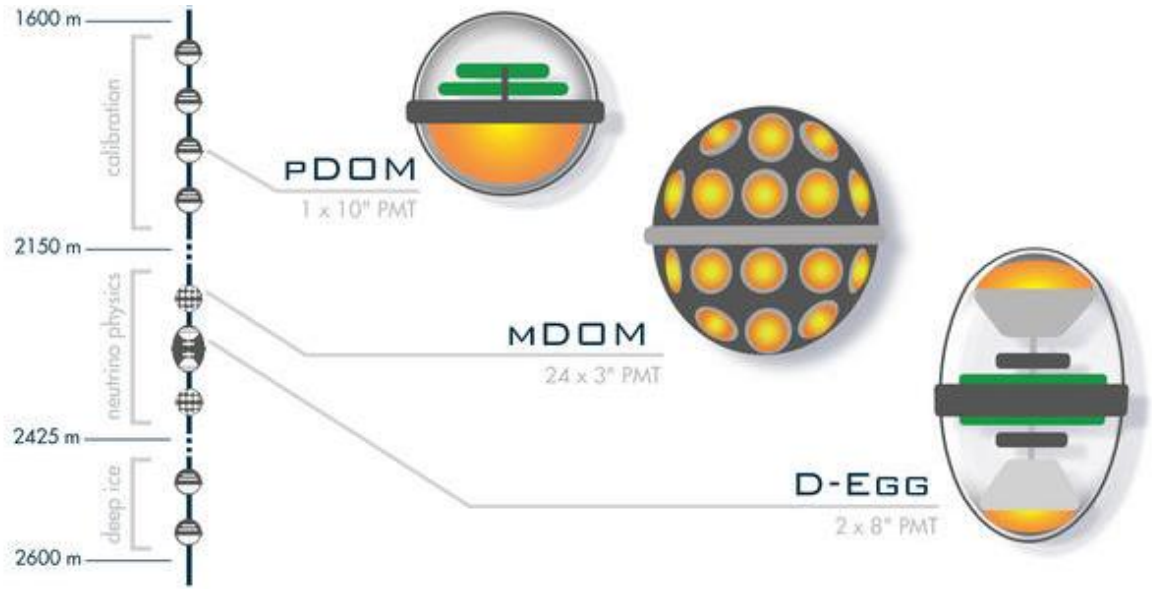


Source: IceCube internal

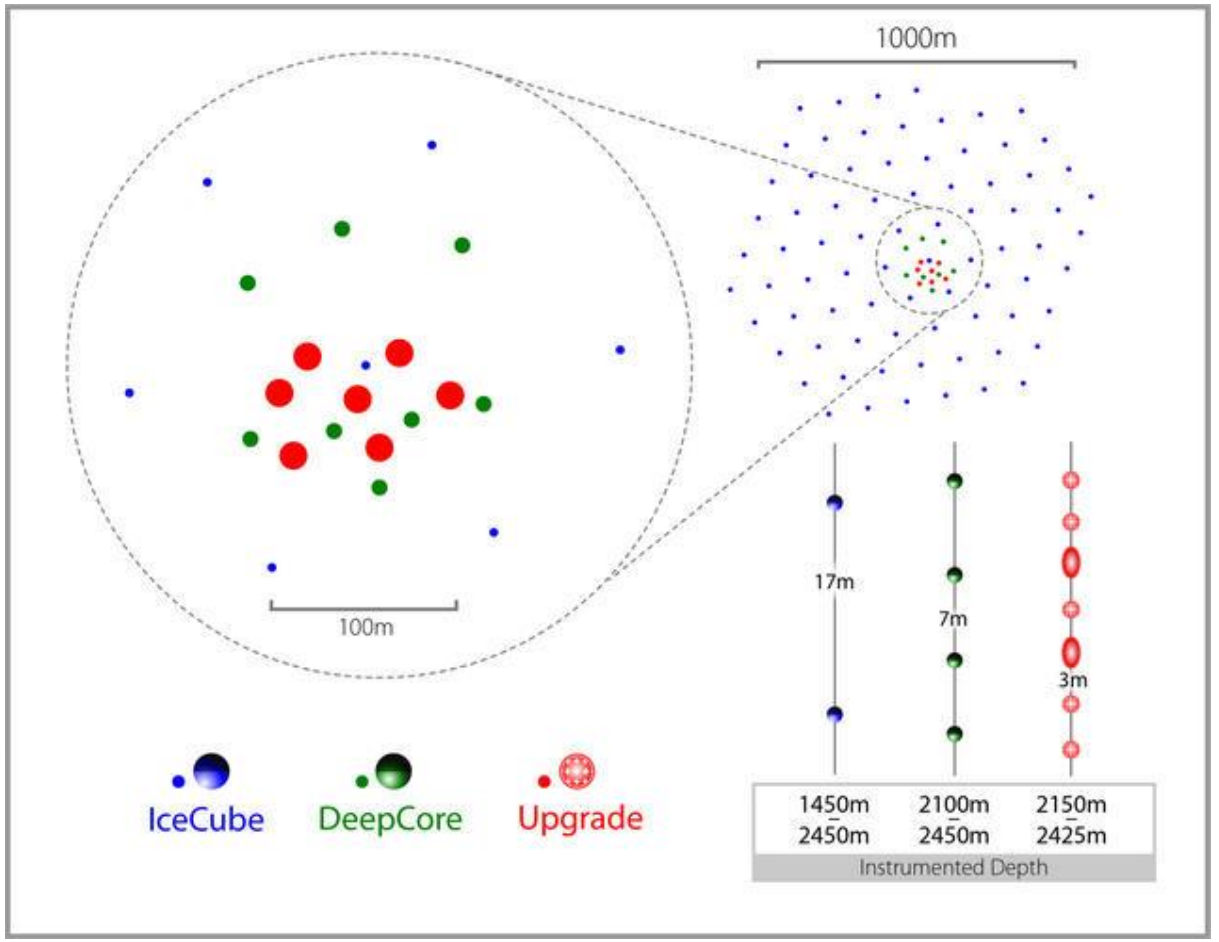
IceCube Upgrade

Detector

- New DOMs for improved photon detection efficiency and calibration capability
- New calibration devices for recalibration of the existing detector
- Research & Developement for IceCube-Gen2



Source: IceCube internal



Source: IceCube internal

Ice calibration

Importance of the ice regarding reconstruction