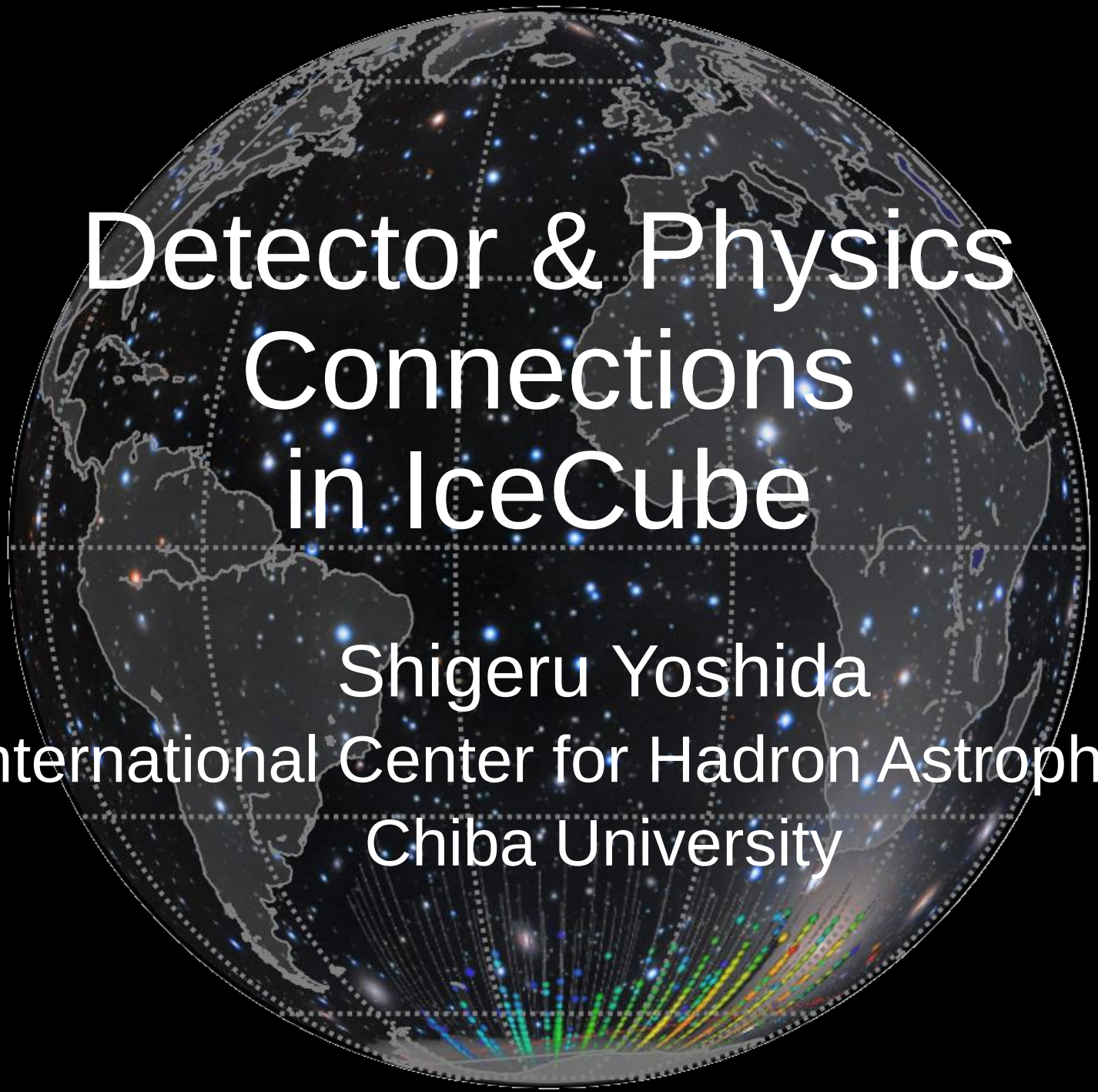

Detector & Physics Connections in IceCube

Shigeru Yoshida
International Center for Hadron Astrophysics
Chiba University

Radiations from Universe

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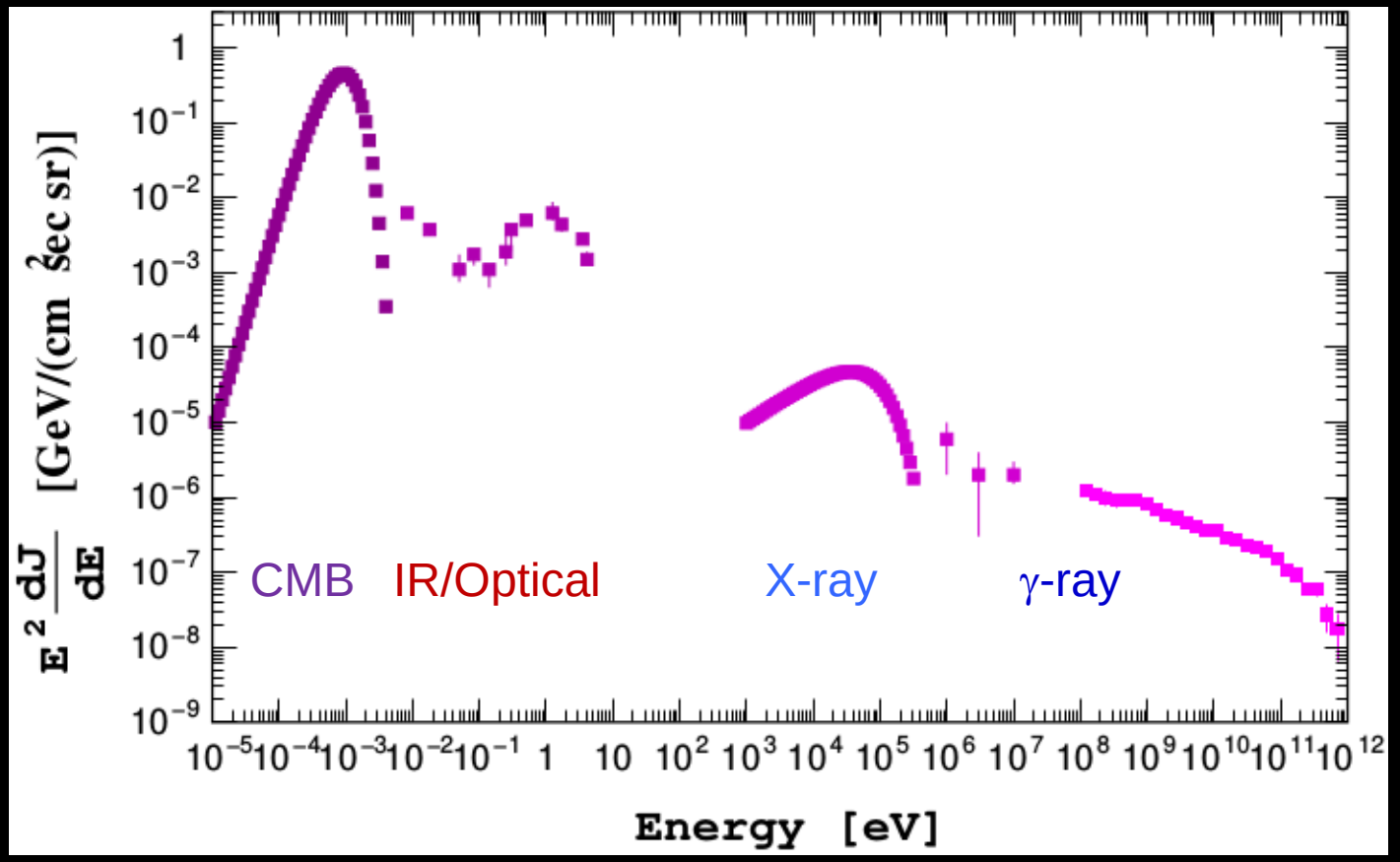
Luminosity



Radiations from Universe

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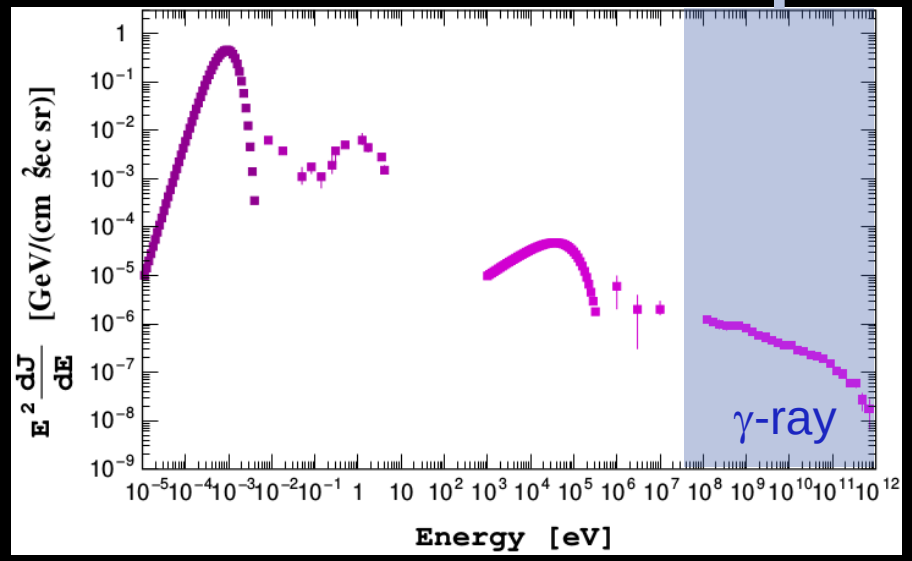
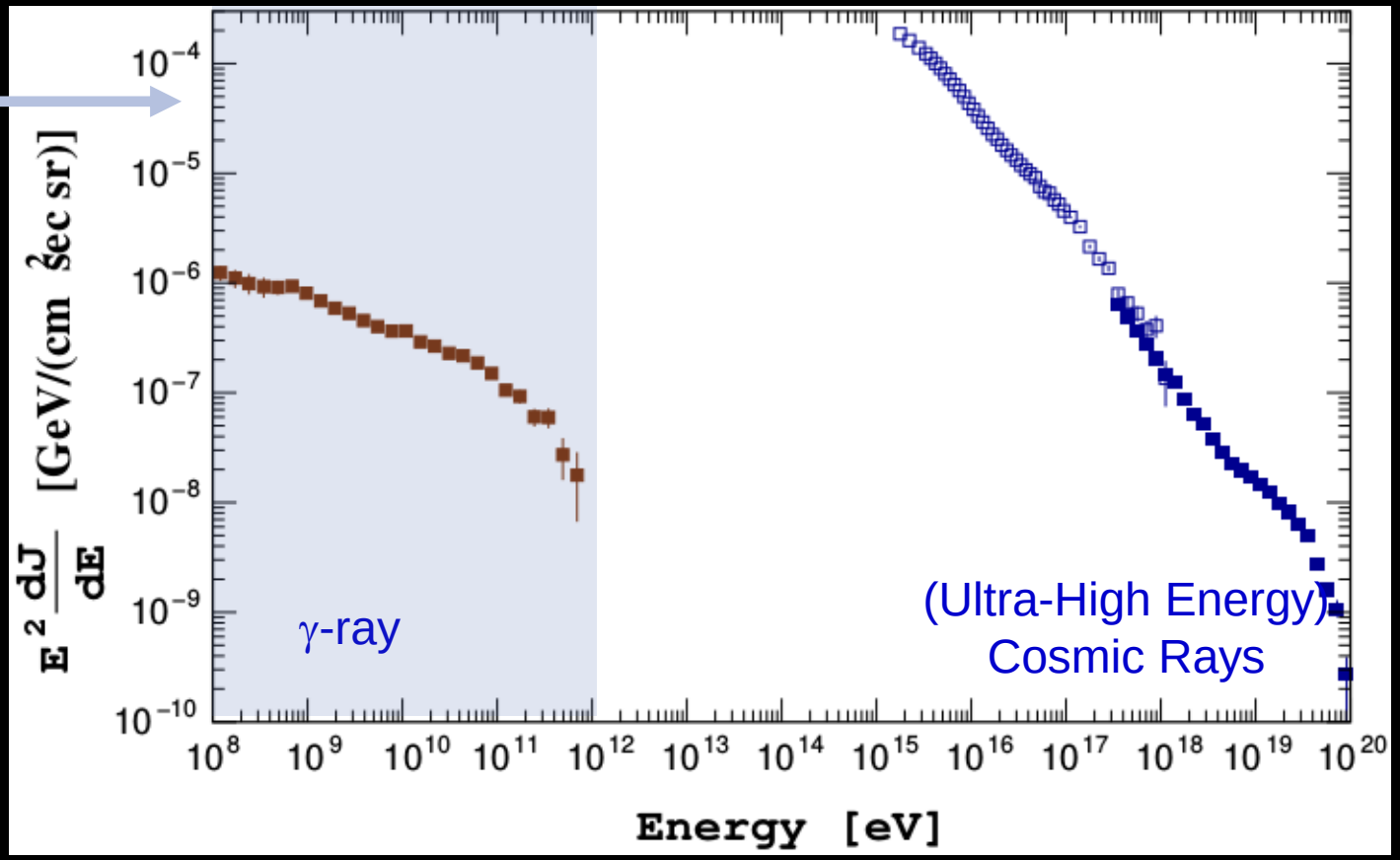


Luminosity



Multi-Messenger framework

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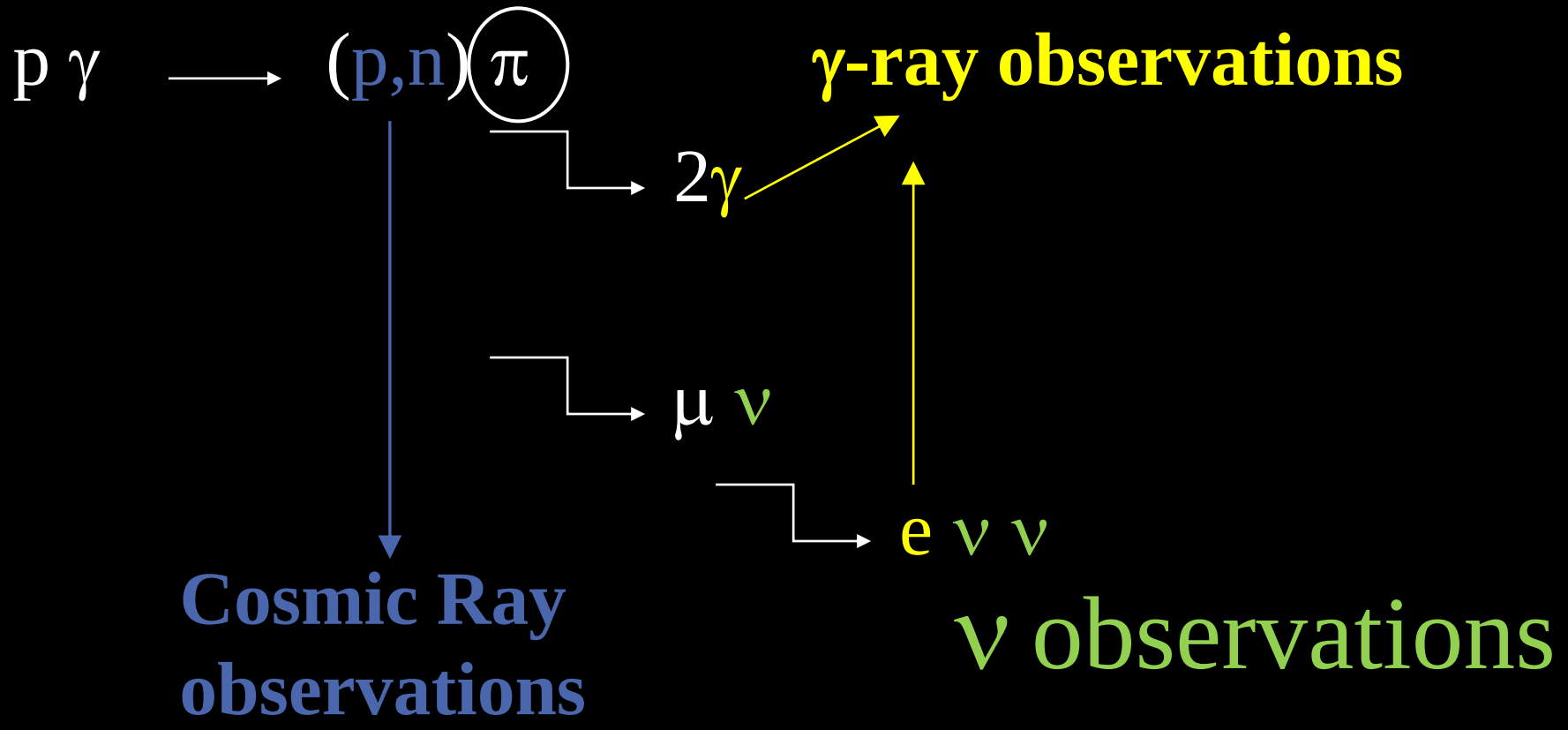
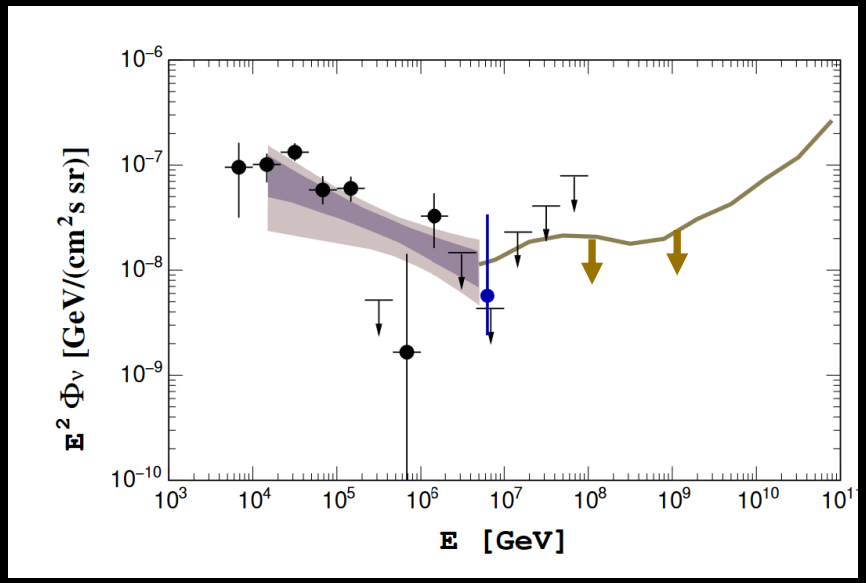


TeV PeV EeV

What we know about TeV-PeV ν sky



- Mostly coming from extragalactic space

  Their arrival directions are (nearly) isotropic

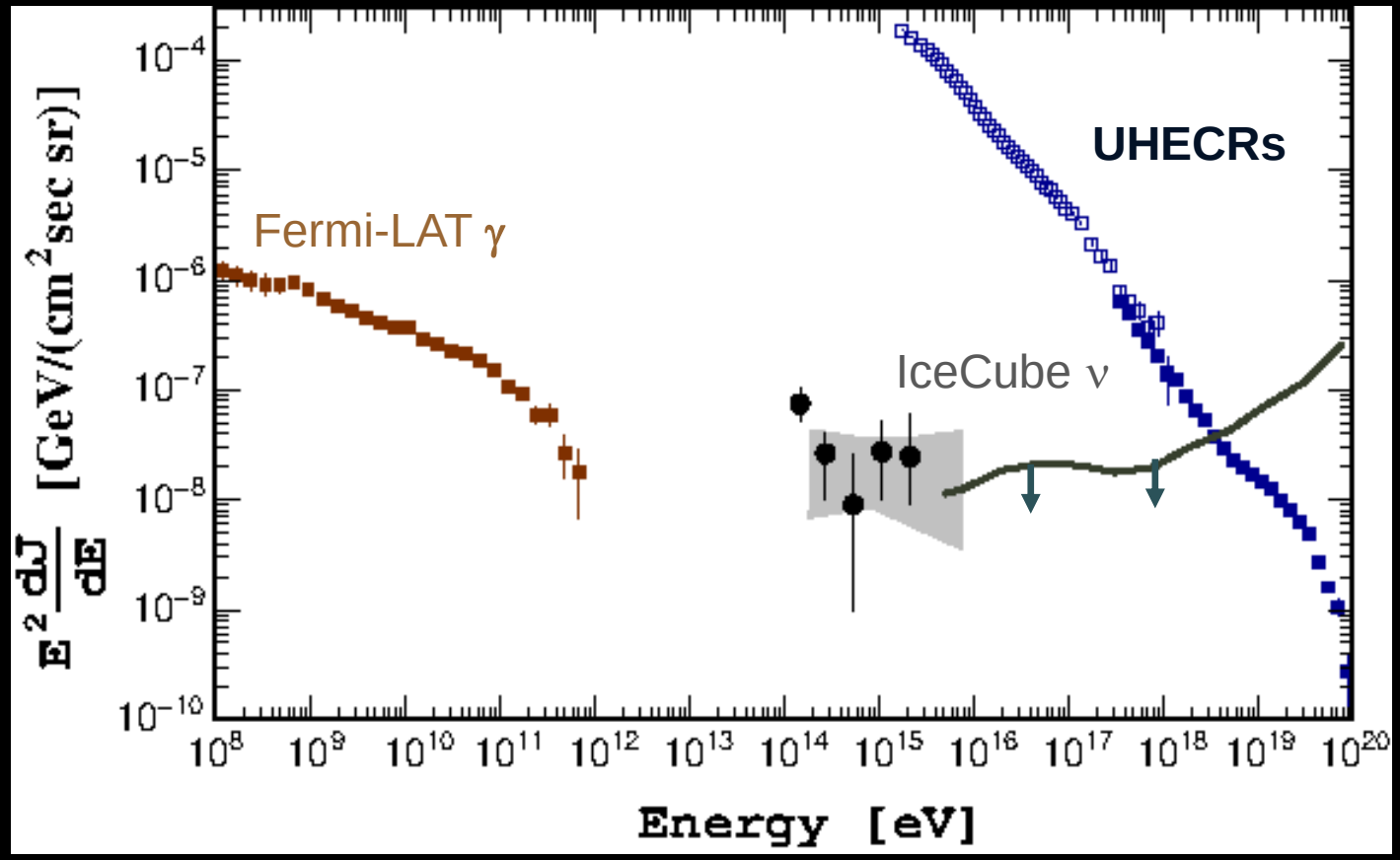
- $E^2\Phi_{\nu\ \text{all flavor sum}}$ $\sim 10^7$ GeV/cm^2 s sr in TeV

  $\sim 10^8$ GeV/cm^2 s sr in 100 TeV-PeV

- Still statistically allows a single $E^{-\alpha}$ spectrum but a weak tension exists

The big picture

The TeV-PeV ν energy flux is comparacble to UHECR flux



Is this just a coincidence?

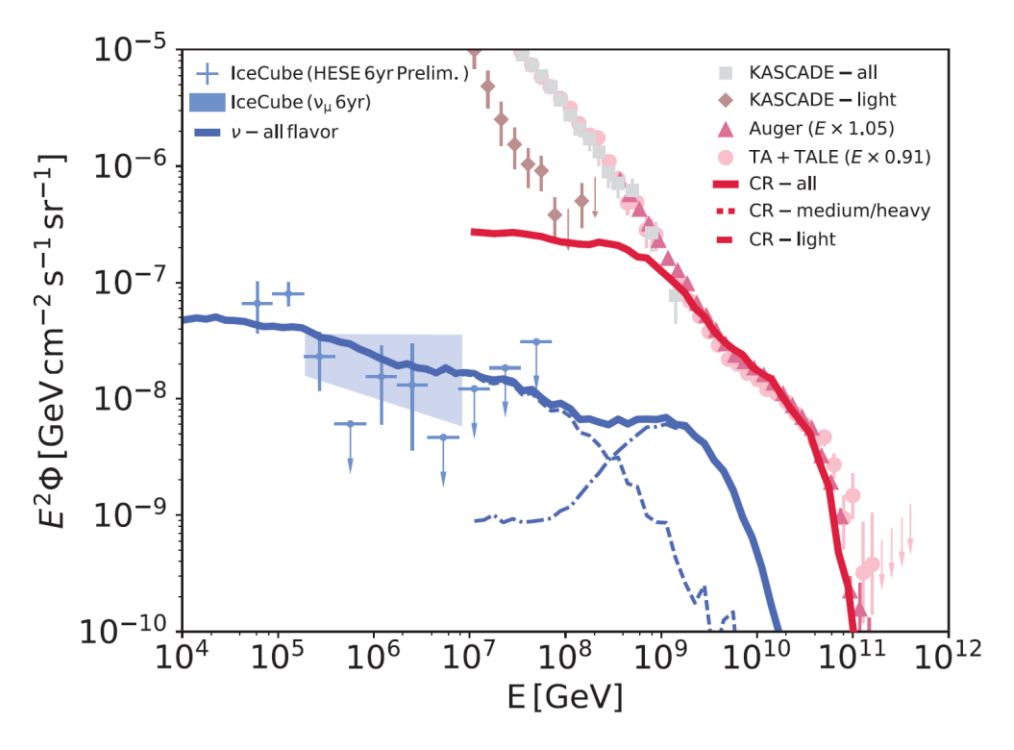
Maybe but maybe not

The Grand Unified Theory?

UHECRs ←→ TeV-PeV ν all shares the same origin?

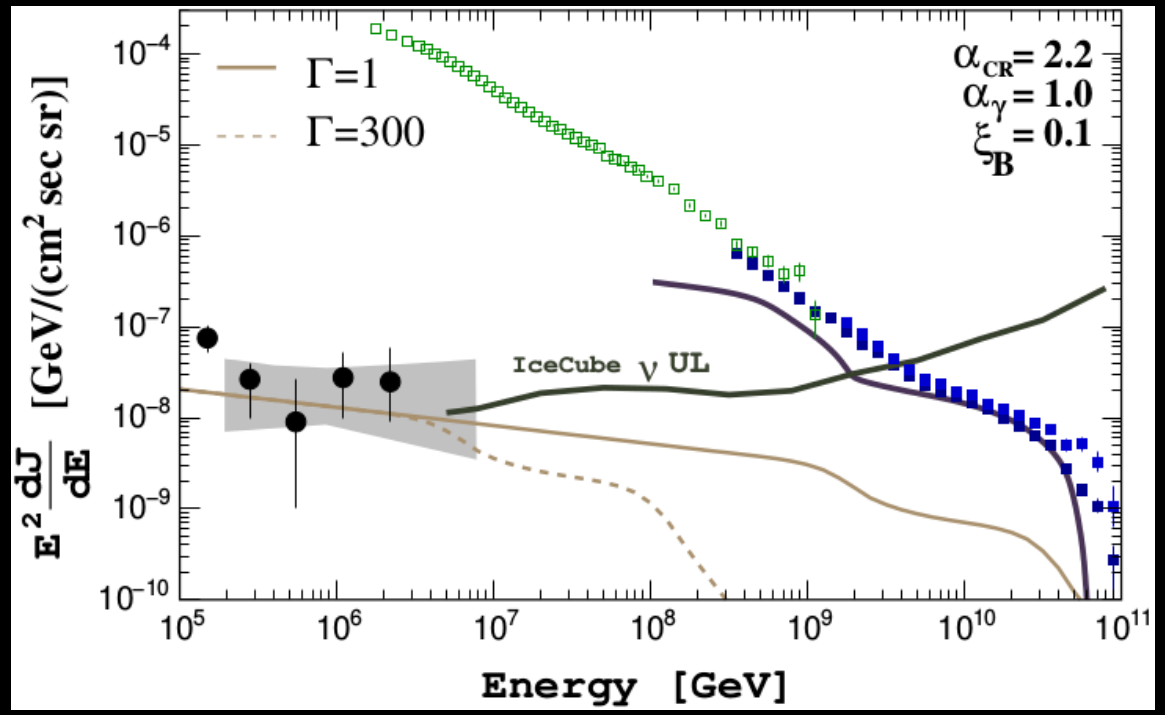
pp framework – jetted AGN in clusters of galaxies

Fang & Murase
Nature Physics **14** 196-198 (2018)



pγ framework – a generic model applicable to GRB/TDE/Blazar

Yoshida & Murase
PRD **102** 083023 (2020)



This scenario was more or less predicted.

Waxman – Bahcall bound

Waxman & Bahcall PRD (1999)

1st order estimate of the possible ultra-high energy ν flux induced by the cosmic ray energetics

$$I_{\max} \approx 0.25 \xi_Z t_H \frac{c}{4\pi} E_{CR}^2 \frac{d\dot{N}_{CR}}{dE_{CR}} \approx 1.5 \times 10^{-8} \xi_Z \mathrm{GeV\,cm^{-2} s^{-1} sr^{-1}}$$

UHE Cosmic Ray Energy Density ~ 10^{44} erg Mpc^{-3} yr^{-1}

Cosmic Evolution ~ from 3 to 8 : Cosmic Ray Emissions may be more active in the distant universe

a muon neutrino carries ¼ of pion energies

This scenario was more or less predicted.

Waxman – Bahcall bound

IceCube Preliminary Design Report (2001)

A standard technique to search for high energy neutrinos of astrophysical origin is to look for upgoing muons induced by ν_μ that have penetrated the Earth. The signal is given by the convolution

$$\text{Signal} \sim \text{Area} \otimes R_\mu N_A \otimes \sigma_\nu \otimes \phi_\nu, \quad (1)$$

where R_μ is the muon range in g/cm^2 and N_A is Avogadro's number. The range and cross

$$\text{a neutrino event rate of } f \times 30 \text{ events/km}^2\text{/yr}$$

(also by T.K. Gaisser astro-ph/9707283)

f = 0.3 → the case of the Waxman-Bacall 1st order estimate

This scenario was more or less predicted.

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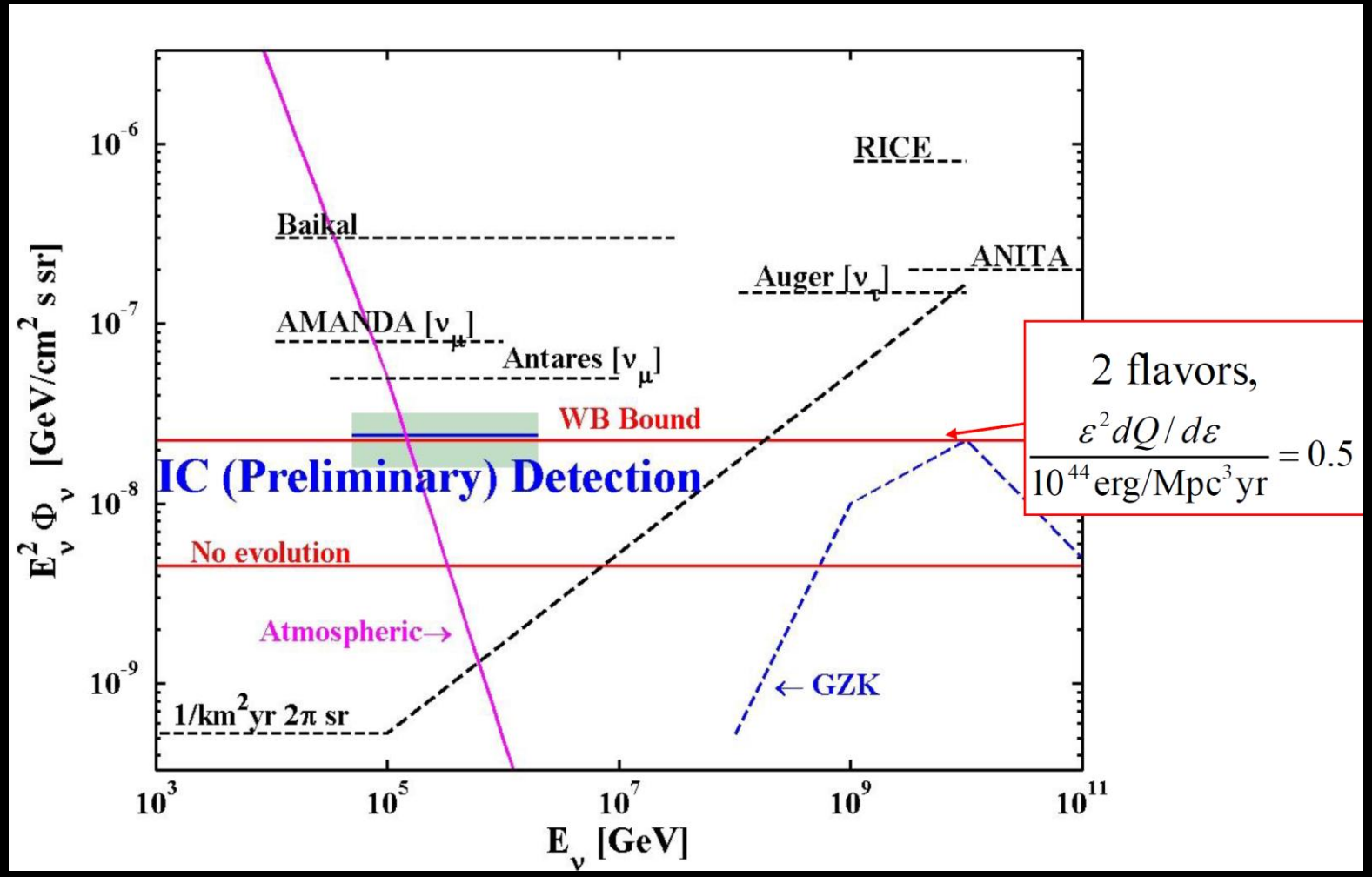
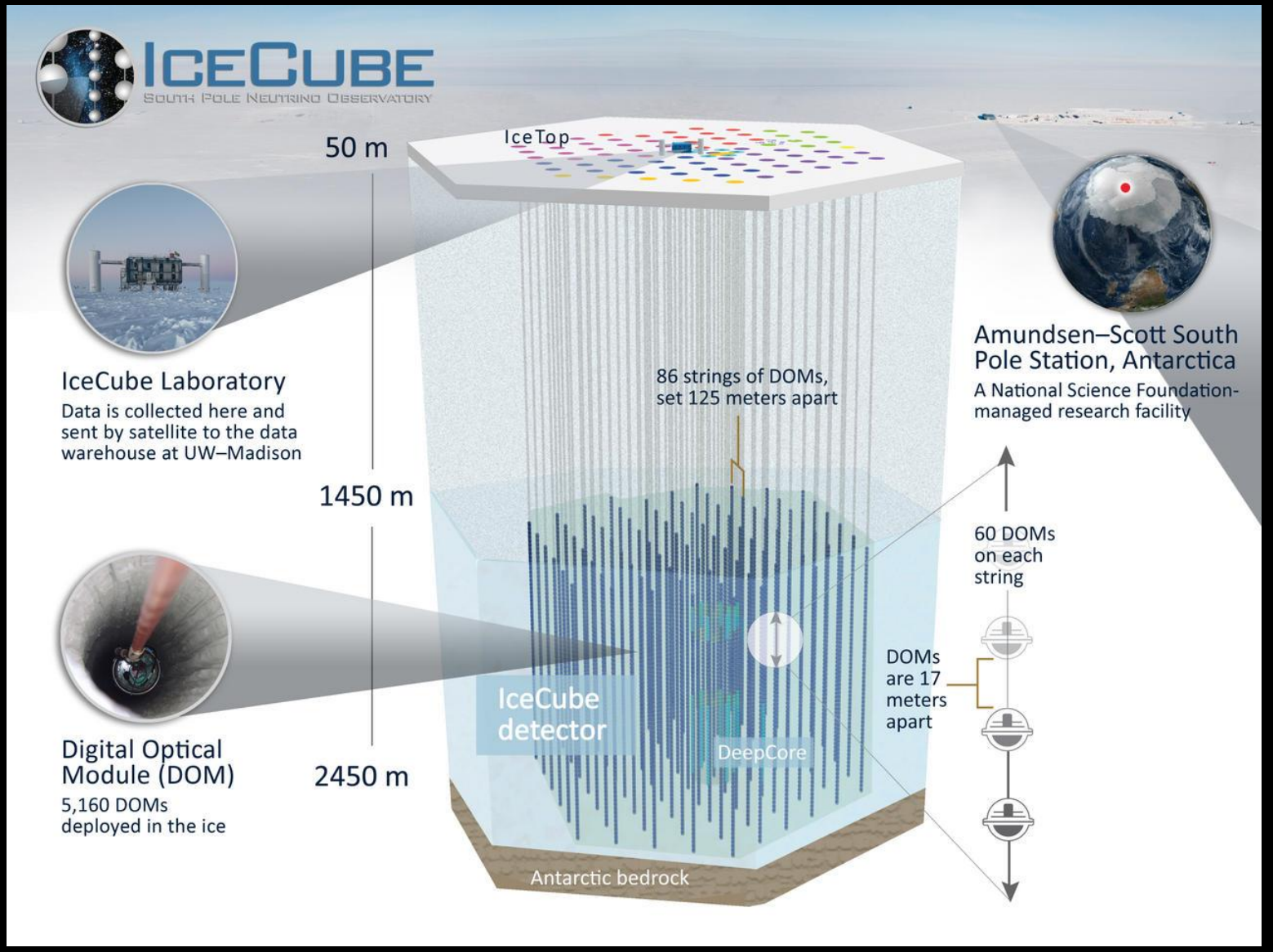
slide @ 2003!



IceCube Neutrino Observatory



FUNDING AGENCIES

Fonds de la Recherche Scientifique (FRS-FNRS)
Fonds Wetenschappelijk Onderzoek-Vlaanderen (FWO-Vlaanderen)
Federal Ministry of Education and Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)
Japan Society for the Promotion of Science (JSPS)
Knut and Alice Wallenberg Foundation
Swedish Polar Research Secretariat
The Swedish Research Council (VR)
University of Wisconsin Alumni Research Foundation (WARF)
US National Science Foundation (NSF)

Constructions2005-2011

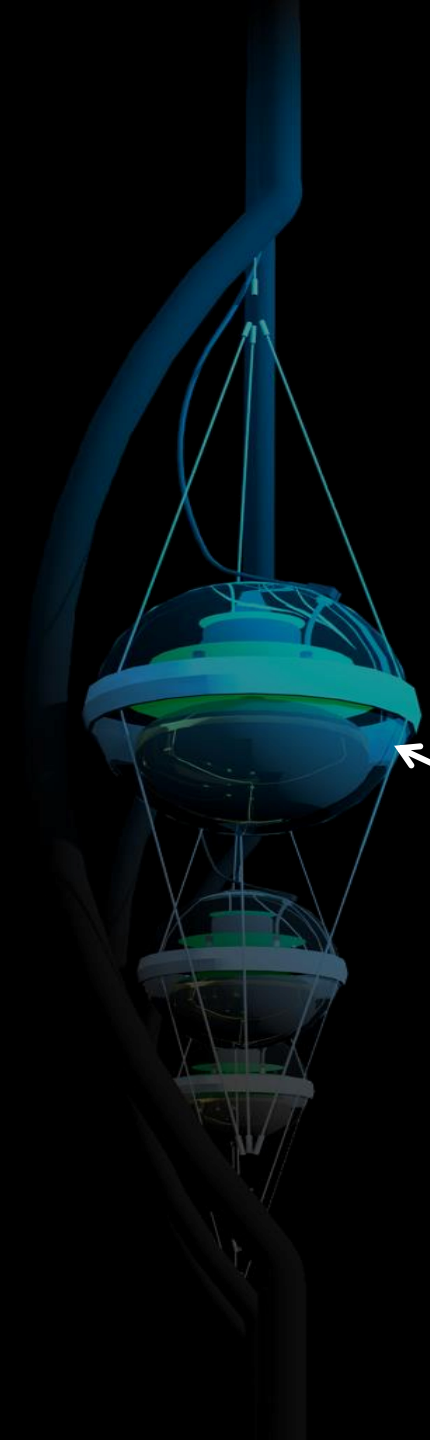
Detectors shipped from Japan

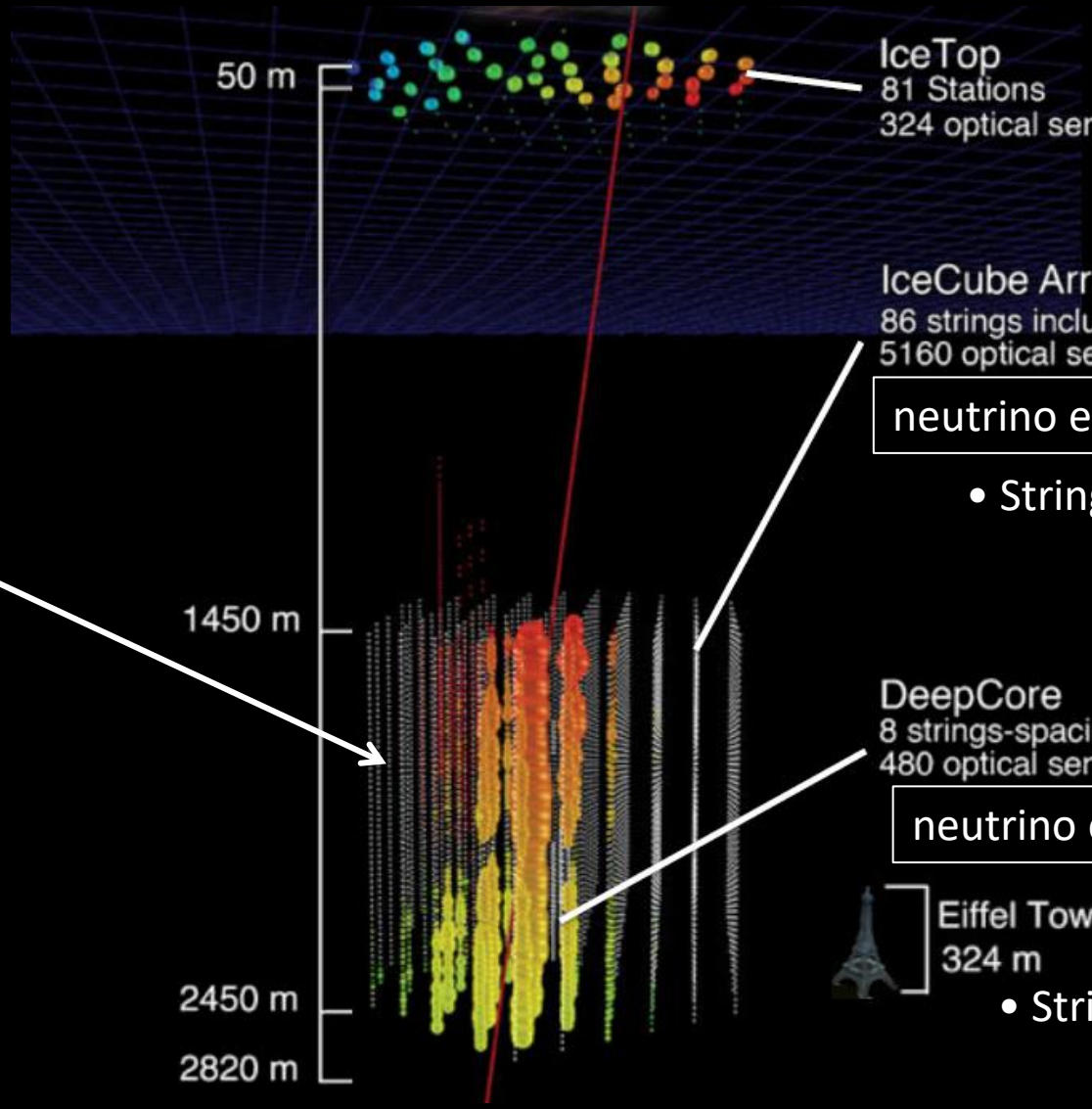
Drill House

The IceCube Lab 「Beer Can」

Researchers working on deployment

The IceCube Detector





IceTop
81 Stations
324 optical sensors

IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors

neutrino energy: 1TeV-100EeV

- String spacing 125 m, DOM spacing of 17 m

DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors

neutrino energy: 5GeV-100GeV

Eiffel Tower
324 m

- String spacing ~70 m, DOM spacing of 7 m

Optical Detector Module for IceCube

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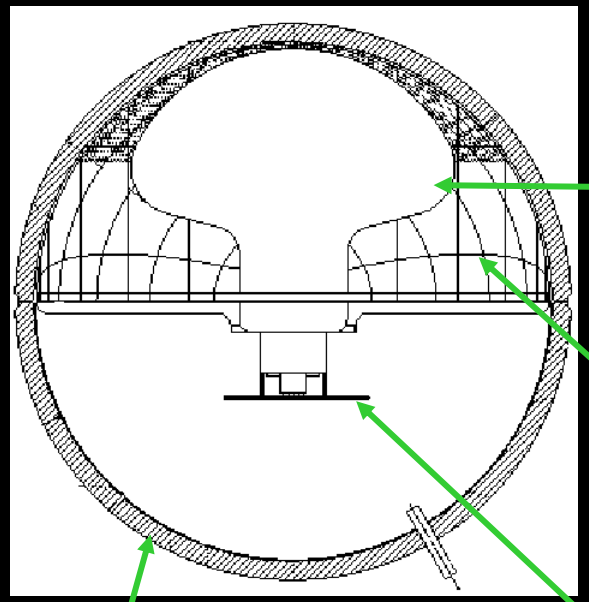
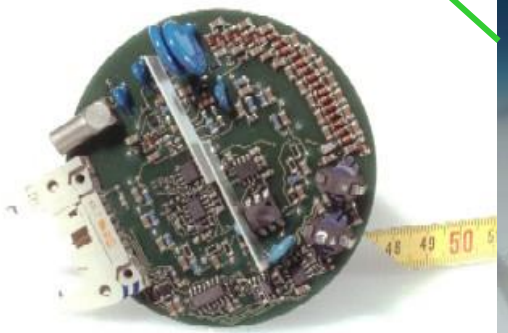
DOM breakdown



Photomultiplier: 10 inch Hamamatsu

Active PMT base

Glass sphere: Nautillus



Mu metal magnetic shield

Characterization of DOM

in Japan for 2004-2009

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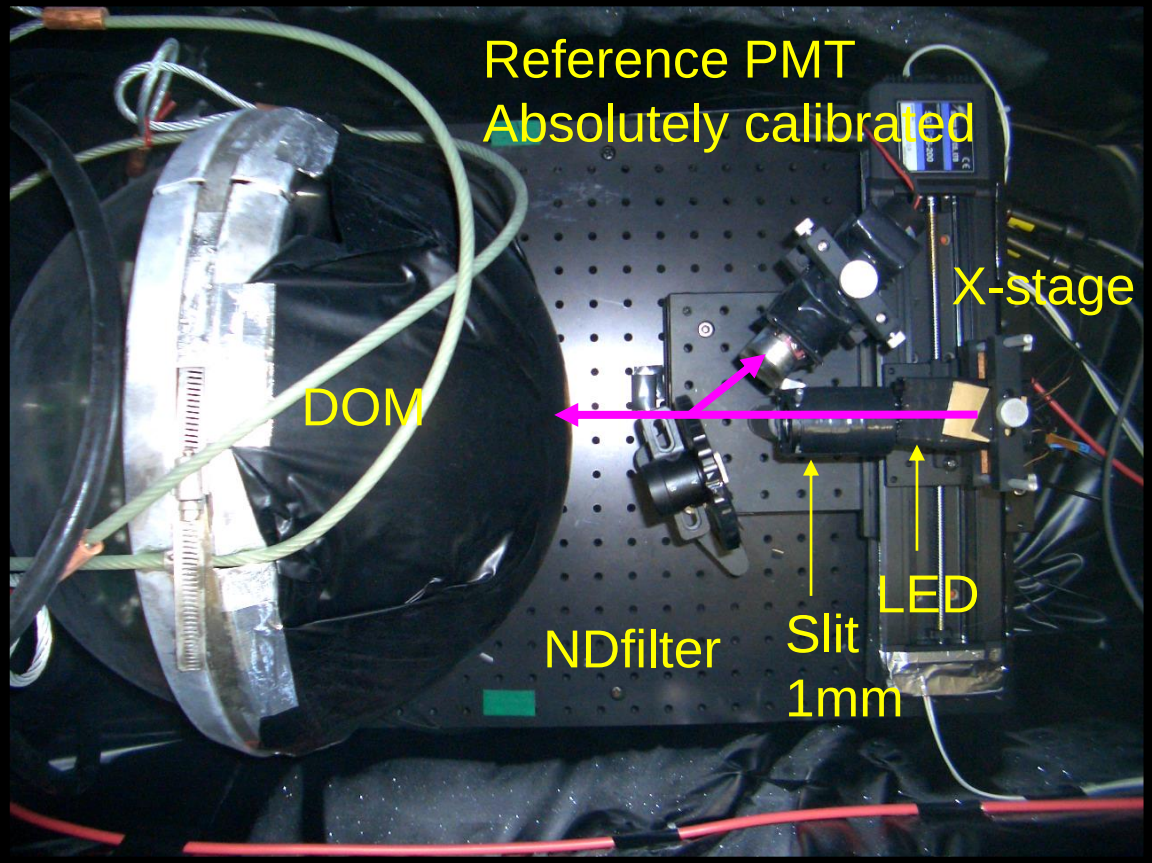
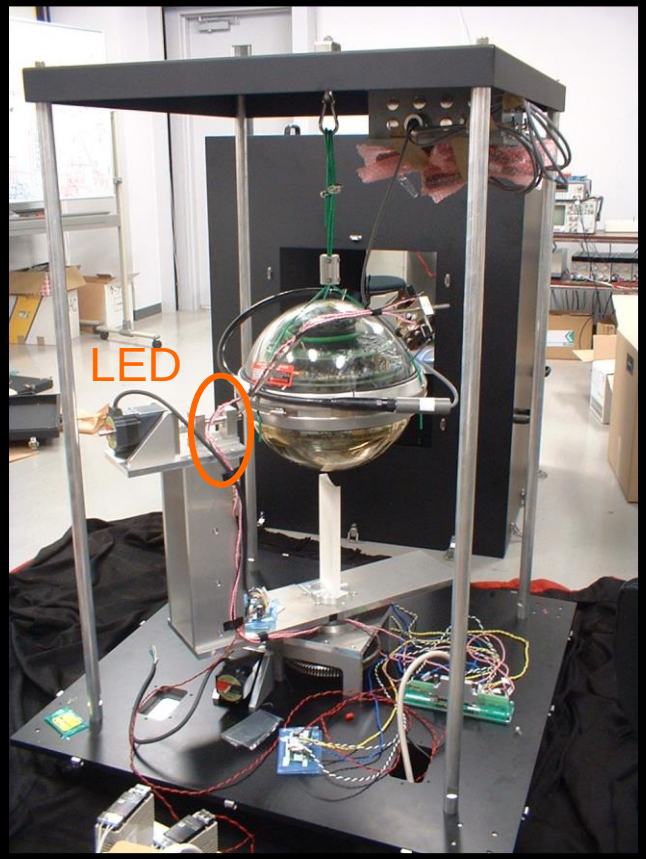
QE × CE Absolute calibration



4πCE scanning



Mapping photon detection efficiencies

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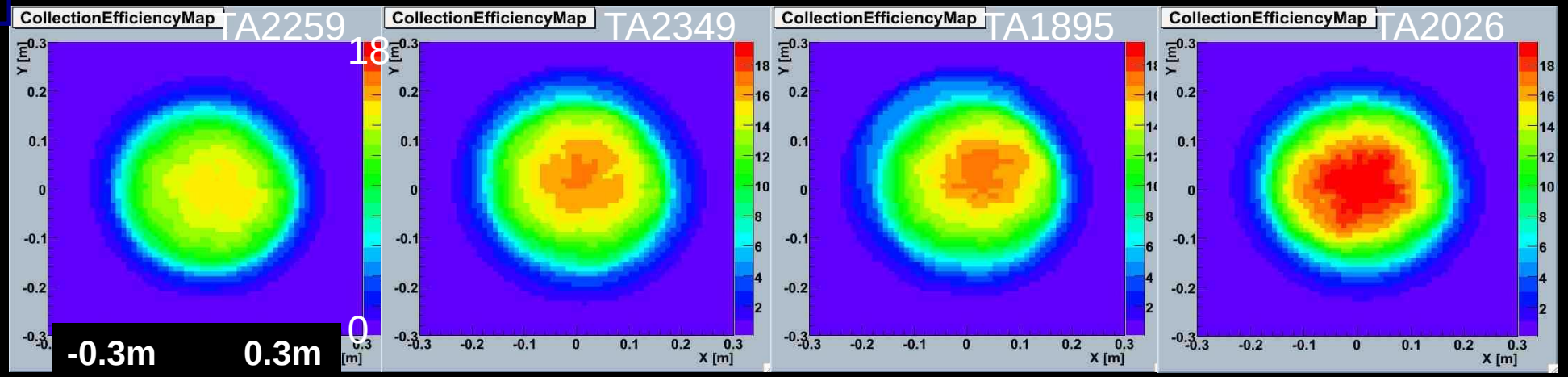
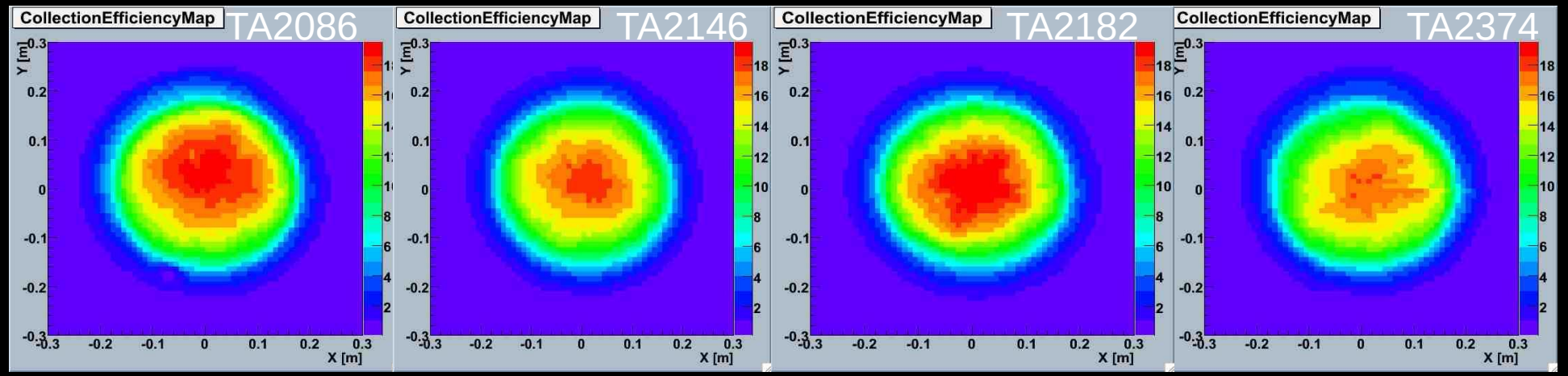
@365nm



14.0% 15.3% 15.4% 16.3%



17.5% 16.6% 18.0% 16.0%

IceCube Upgrade

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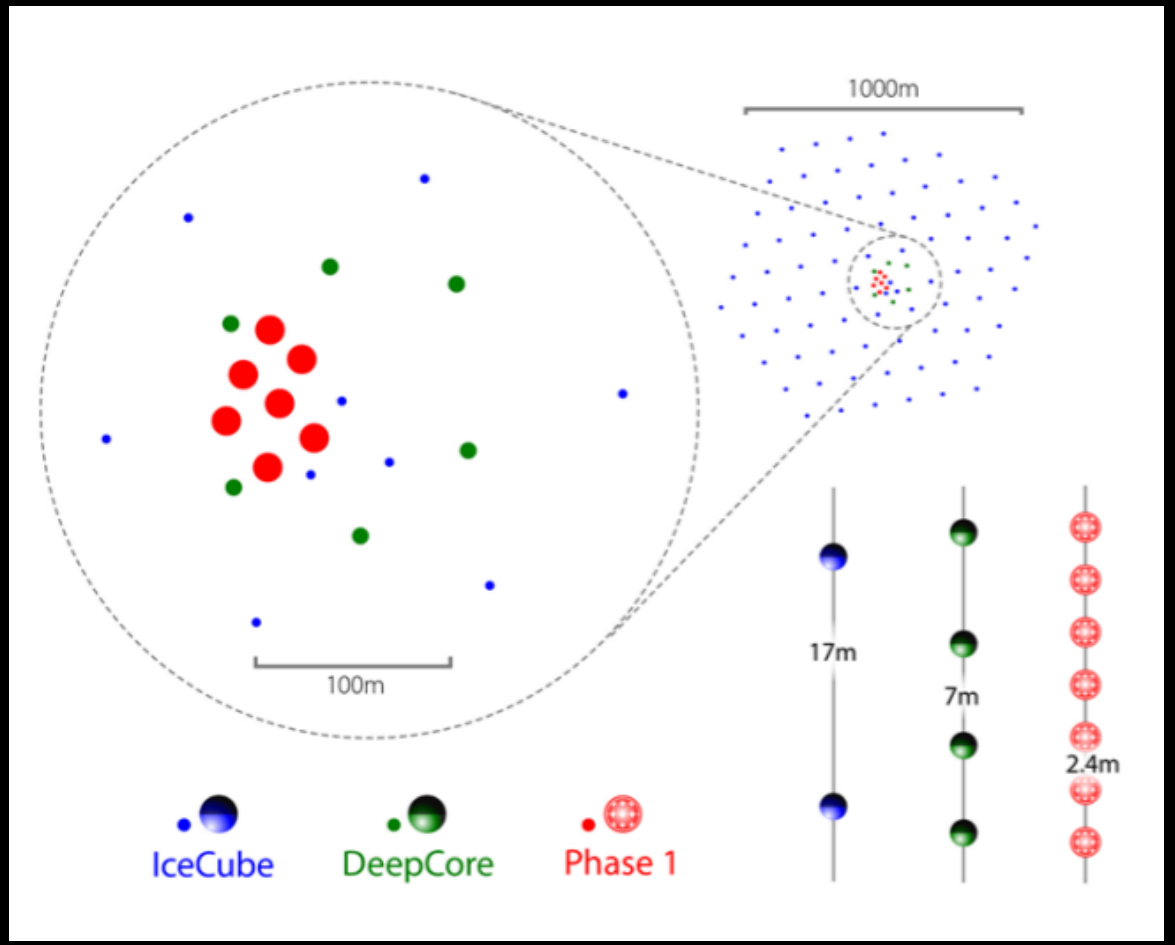

The next generation Cherenkov detector modules

D-Egg

developed and fabricated in Japan

278 pcs will be deployed in 2024/25

The DOM for the present IceCube

D-Egg

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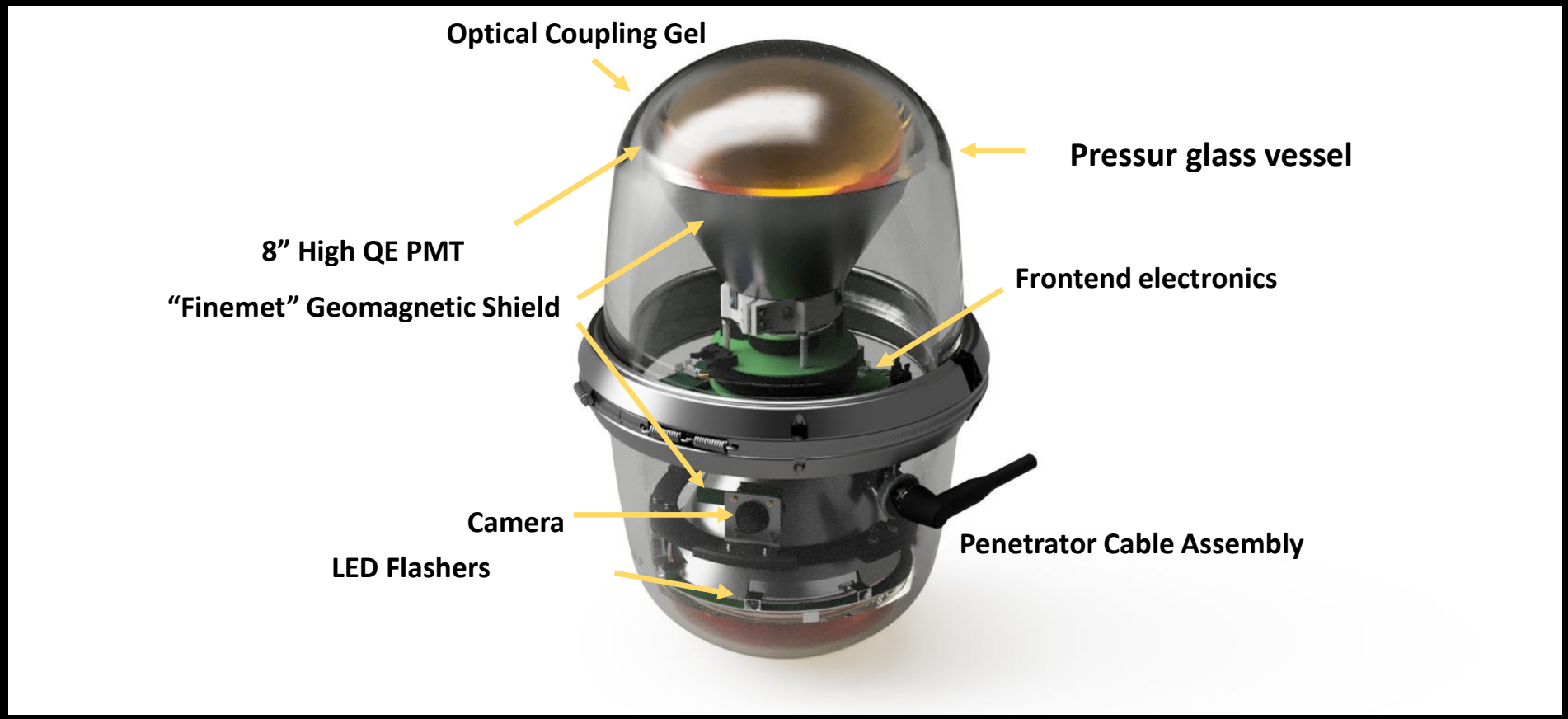

Summary

IceCube Neutrino Observatory had been designed to have enough volume to discover TeV-PeV energy cosmic neutrinos