



CHIBA
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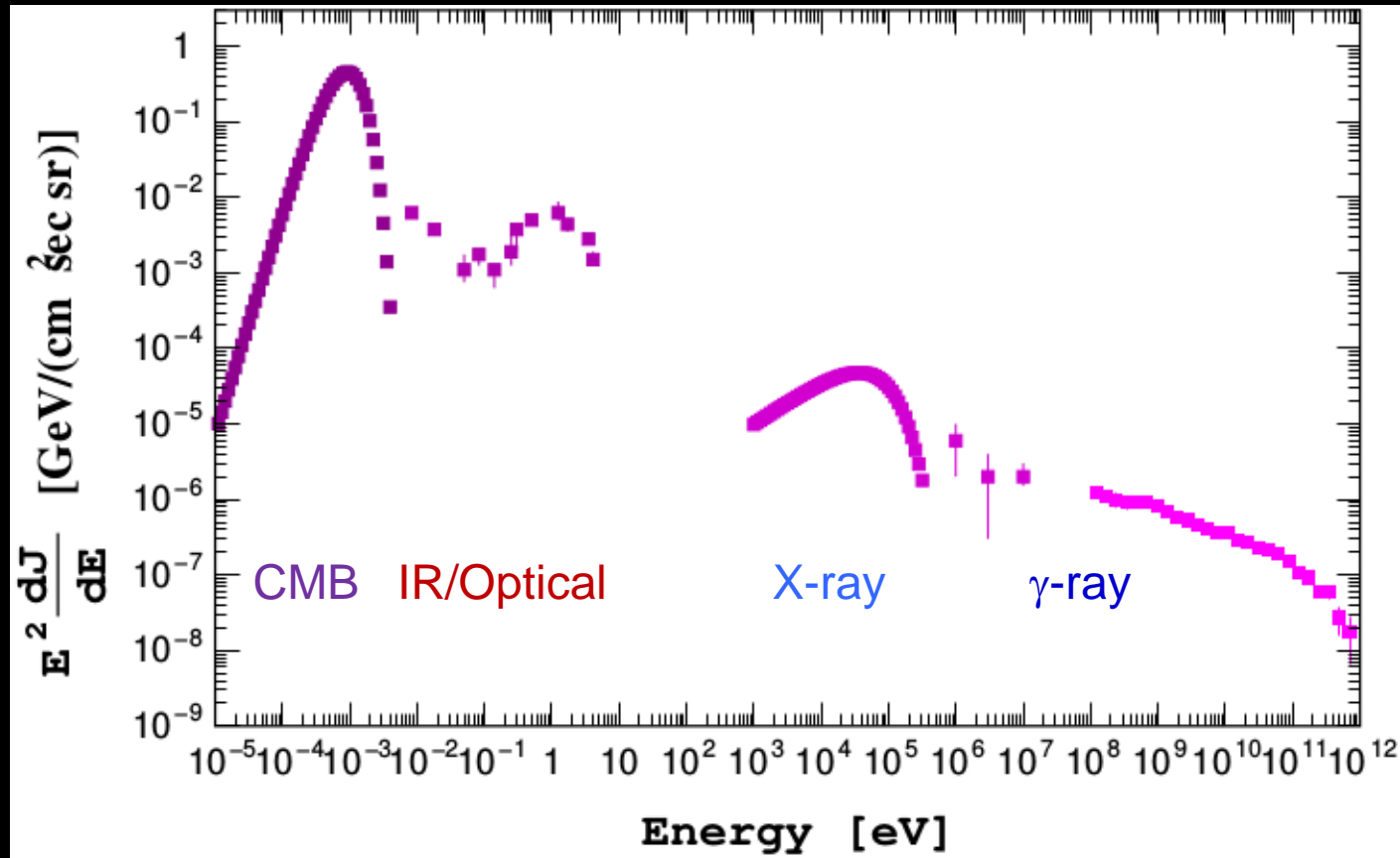


Detector & Physics Connections in IceCube

Shigeru Yoshida
International Center for Hadron Astrophysics
Chiba University

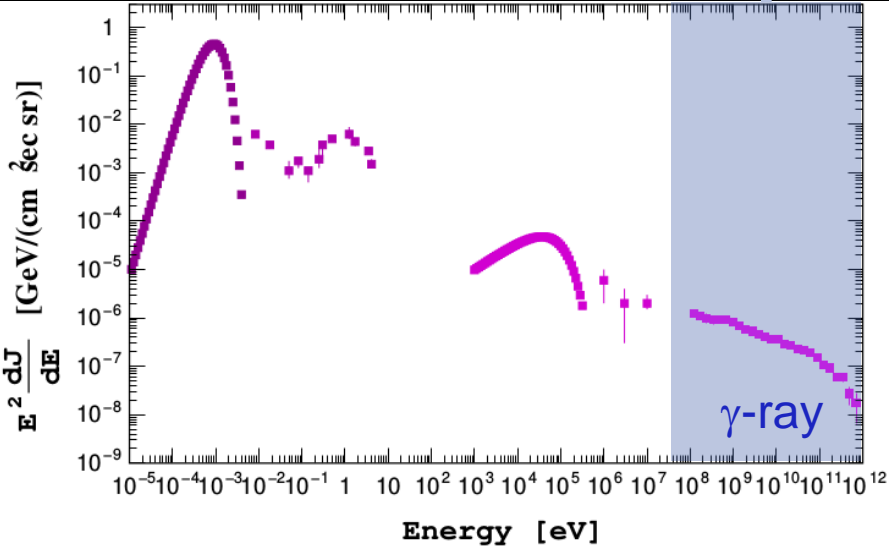
Radiations from Universe

Luminosity

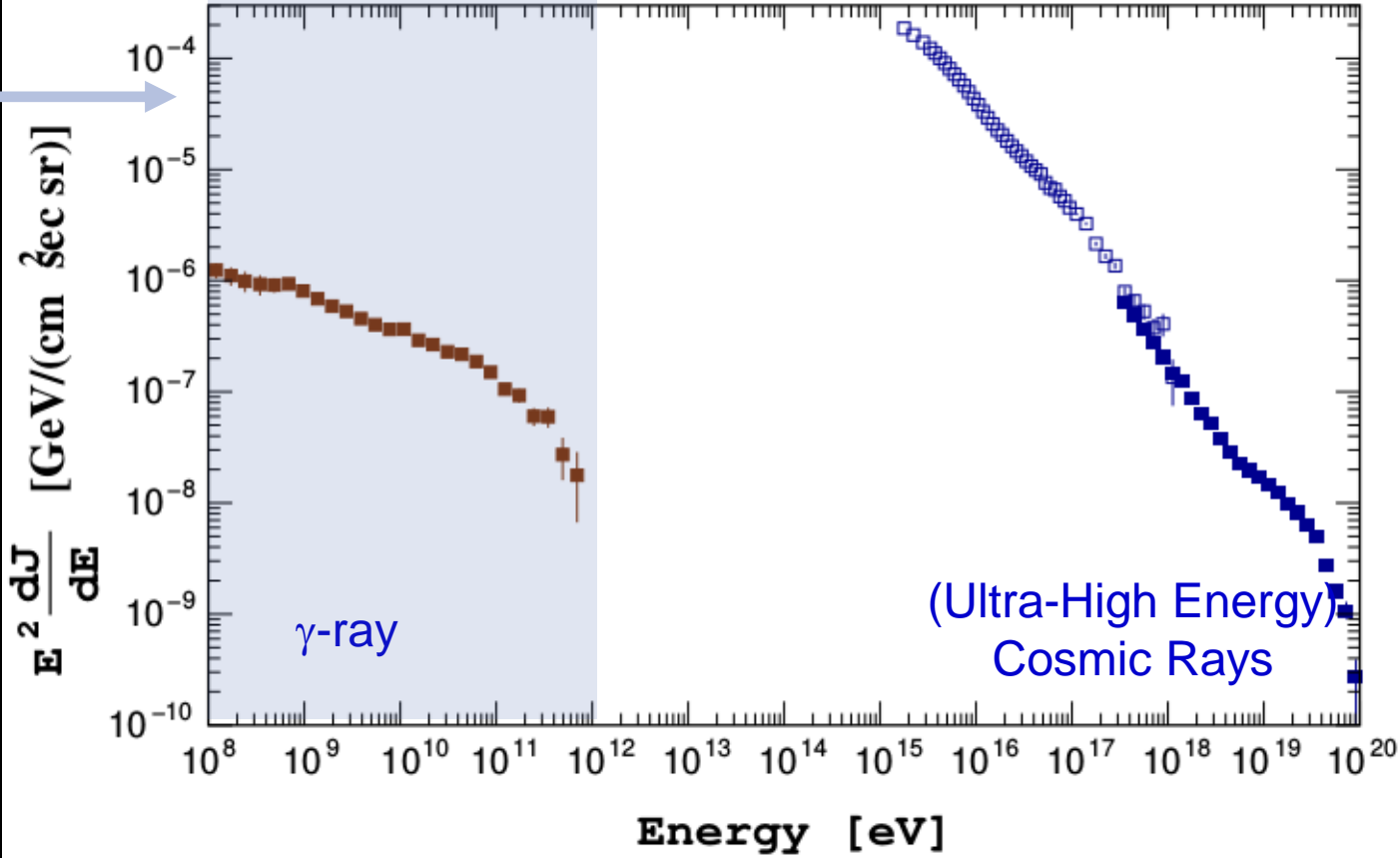




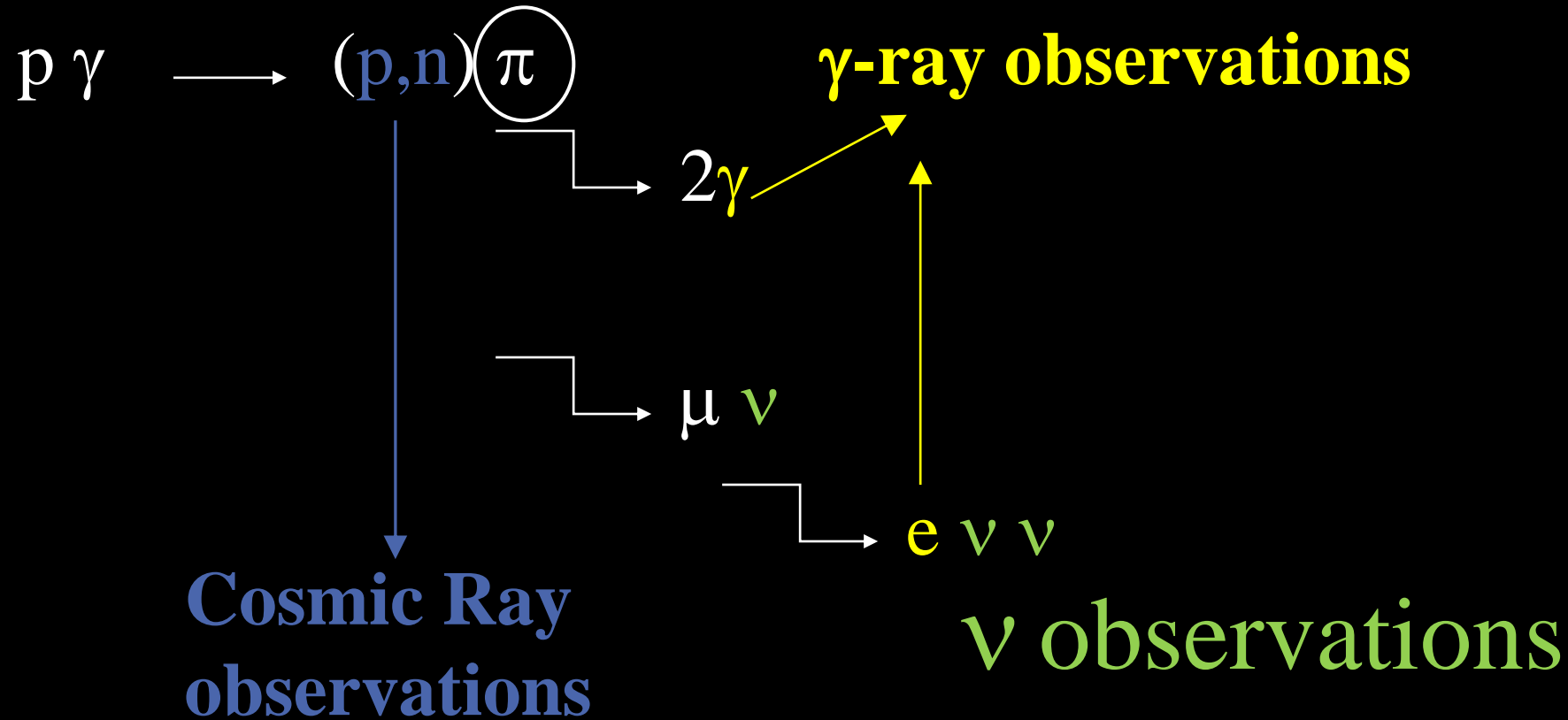
Radiations from Universe



Luminosity



Multi-Messenger framework





TeV

PeV

EeV



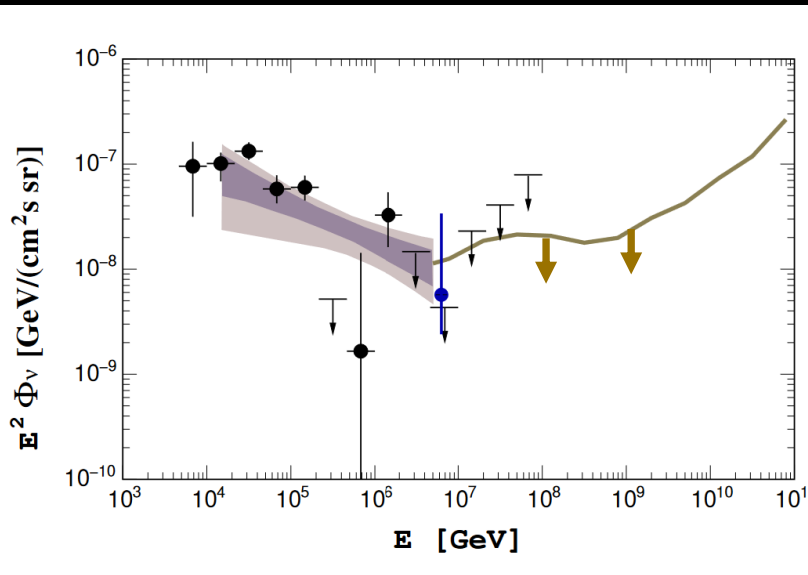
What we know about TeV-PeV ν sky

- Mostly coming from extragalactic space

Their arrival directions are (nearly) isotropic

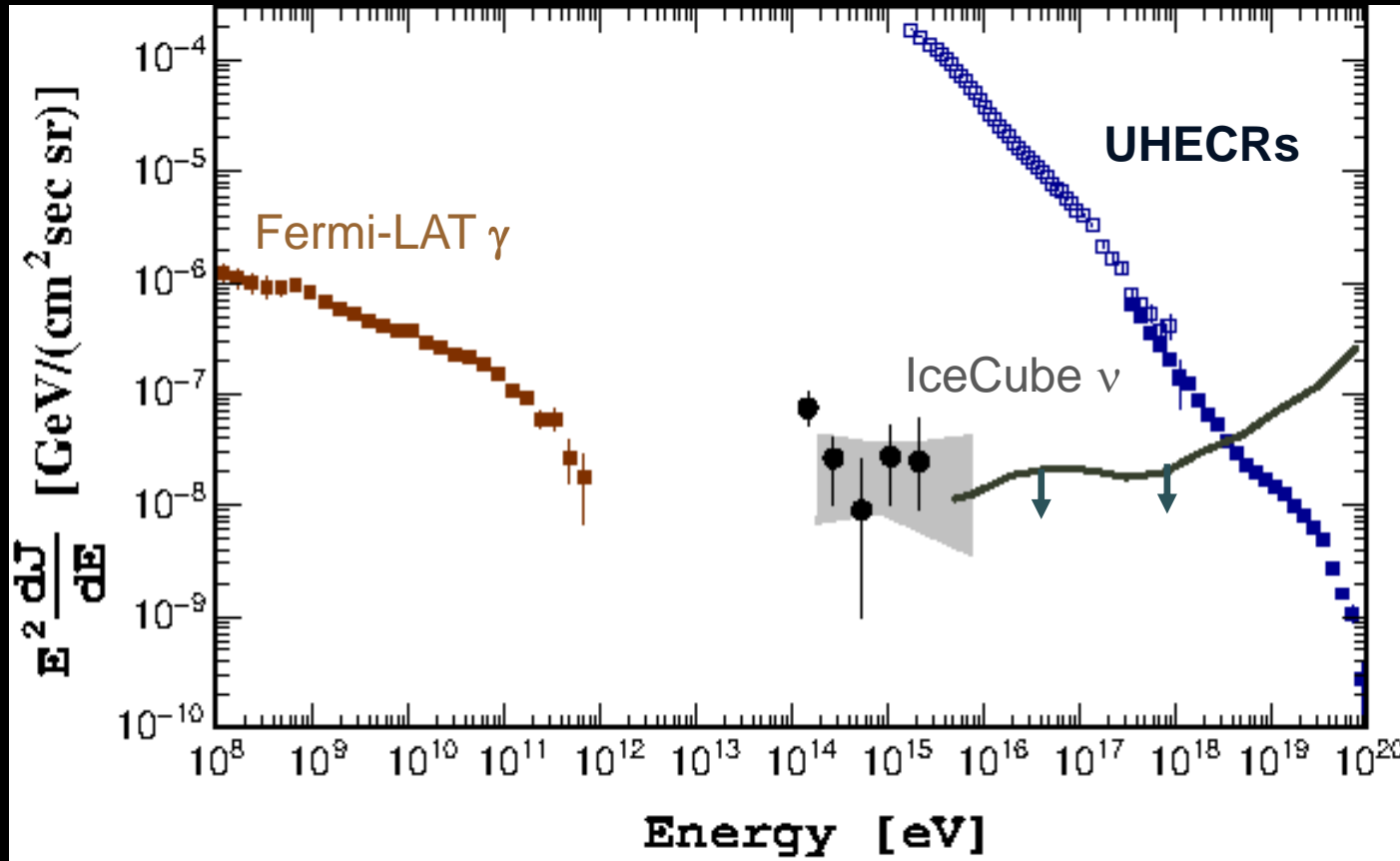
- $E^2 \Phi_\nu$ all flavor sum $\sim 10^7$ GeV/cm² s sr in TeV
 $\sim 10^8$ GeV/cm² s sr in 100 TeV-PeV

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



The big picture

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



Is this just a coincidence?

Maybe but maybe not

The Grand Unified Theory?

UHECRs \leftrightarrow TeV-PeV ν all shares the same origin?

pp framework – jetted AGN in clusters of galaxies

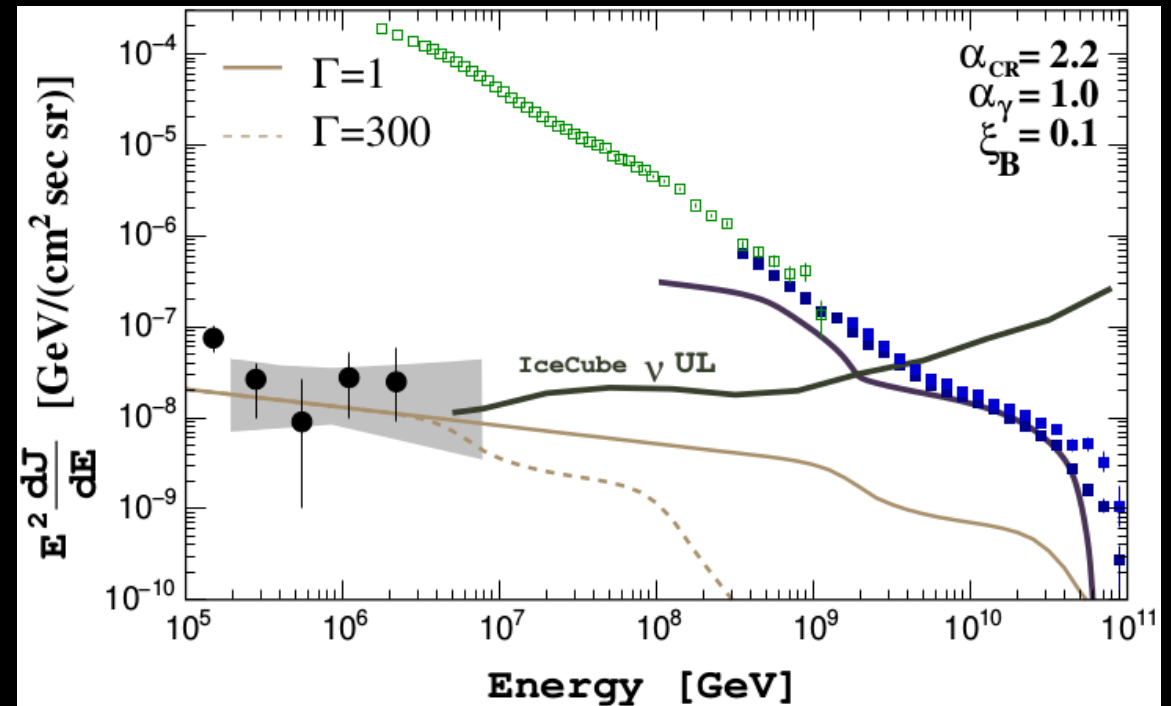
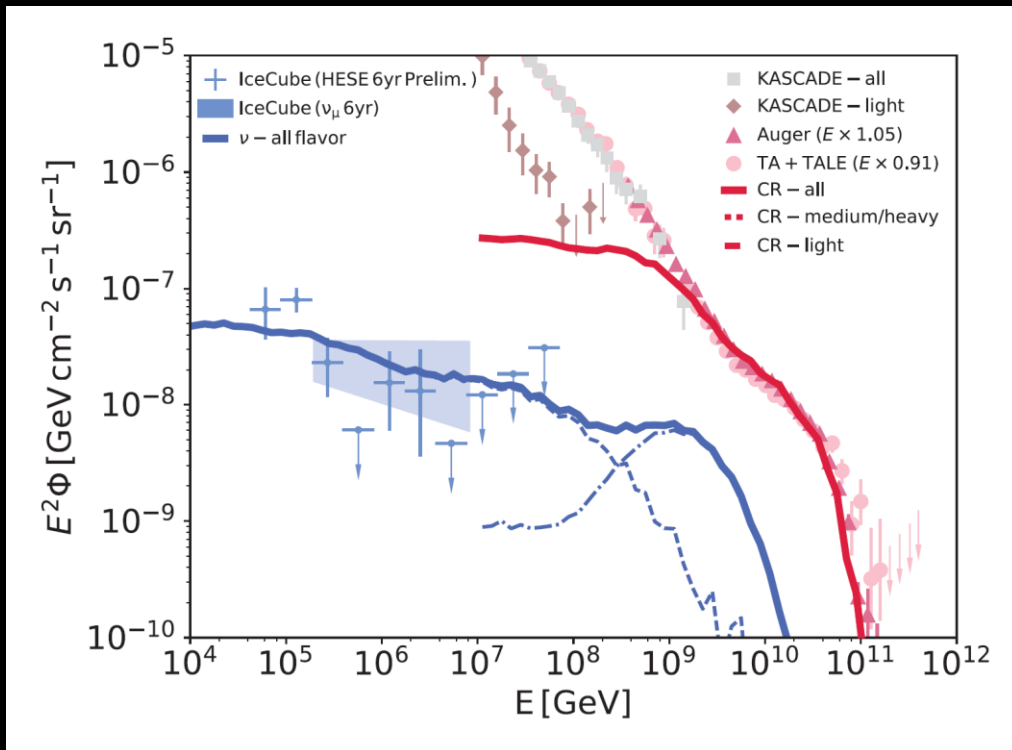
$p\gamma$ framework – a generic model applicable to GRB/TDE/Blazar

Fang & Murase

[Nature Physics 14 196-198 \(2018\)](#)

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

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

UHE Cosmic Ray Energy Density $\sim 10^{44} \text{ erg Mpc}^{-3} \text{ yr}^{-1}$

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

a muon neutrino carries $\frac{1}{4}$ 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

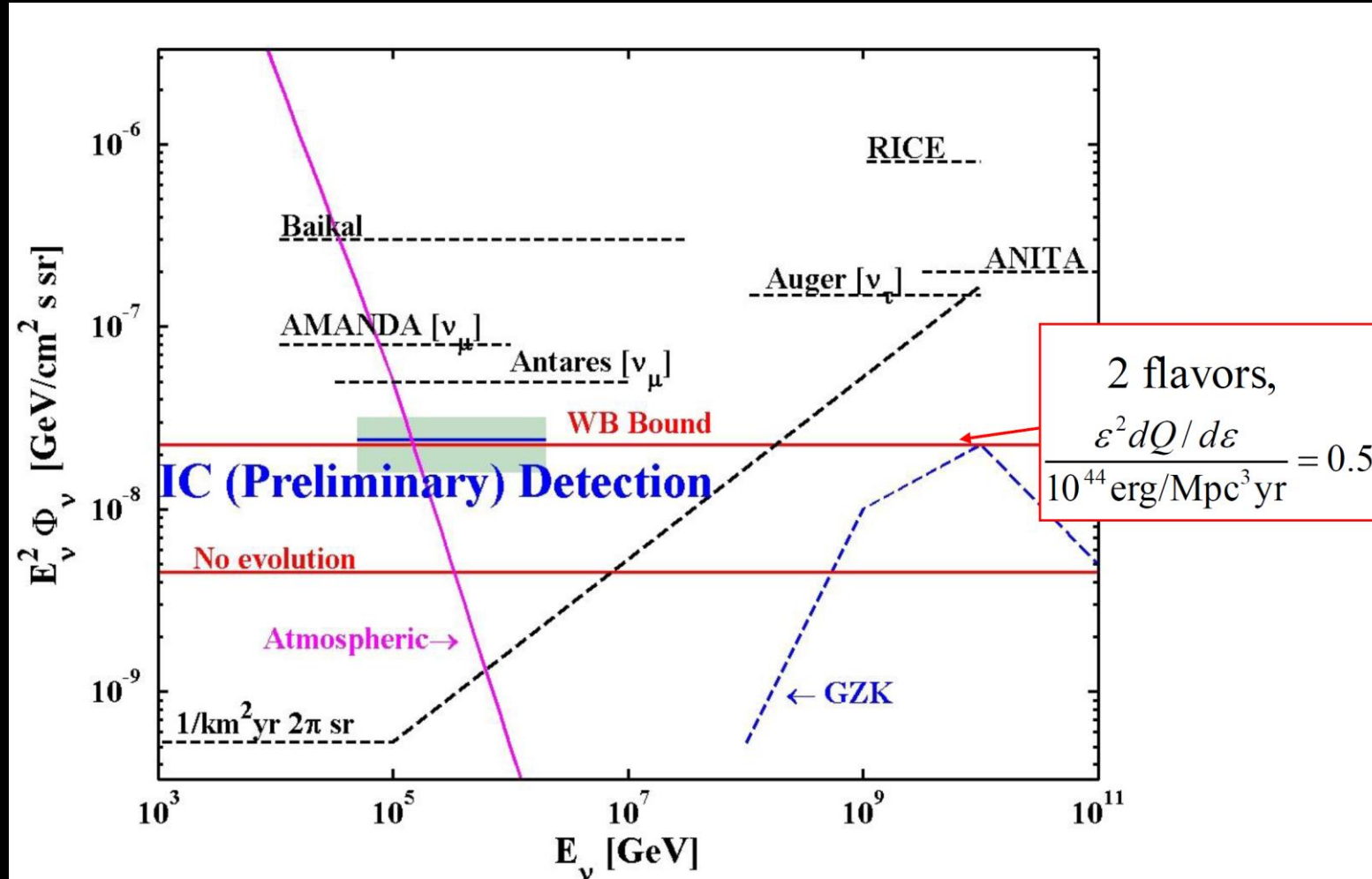
a neutrino event rate of $f \times 30 \text{ events}/\text{km}^2/\text{yr}$

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

$f = 0.3 \rightarrow$ the case of the Waxman-Bacall 1st order estimate

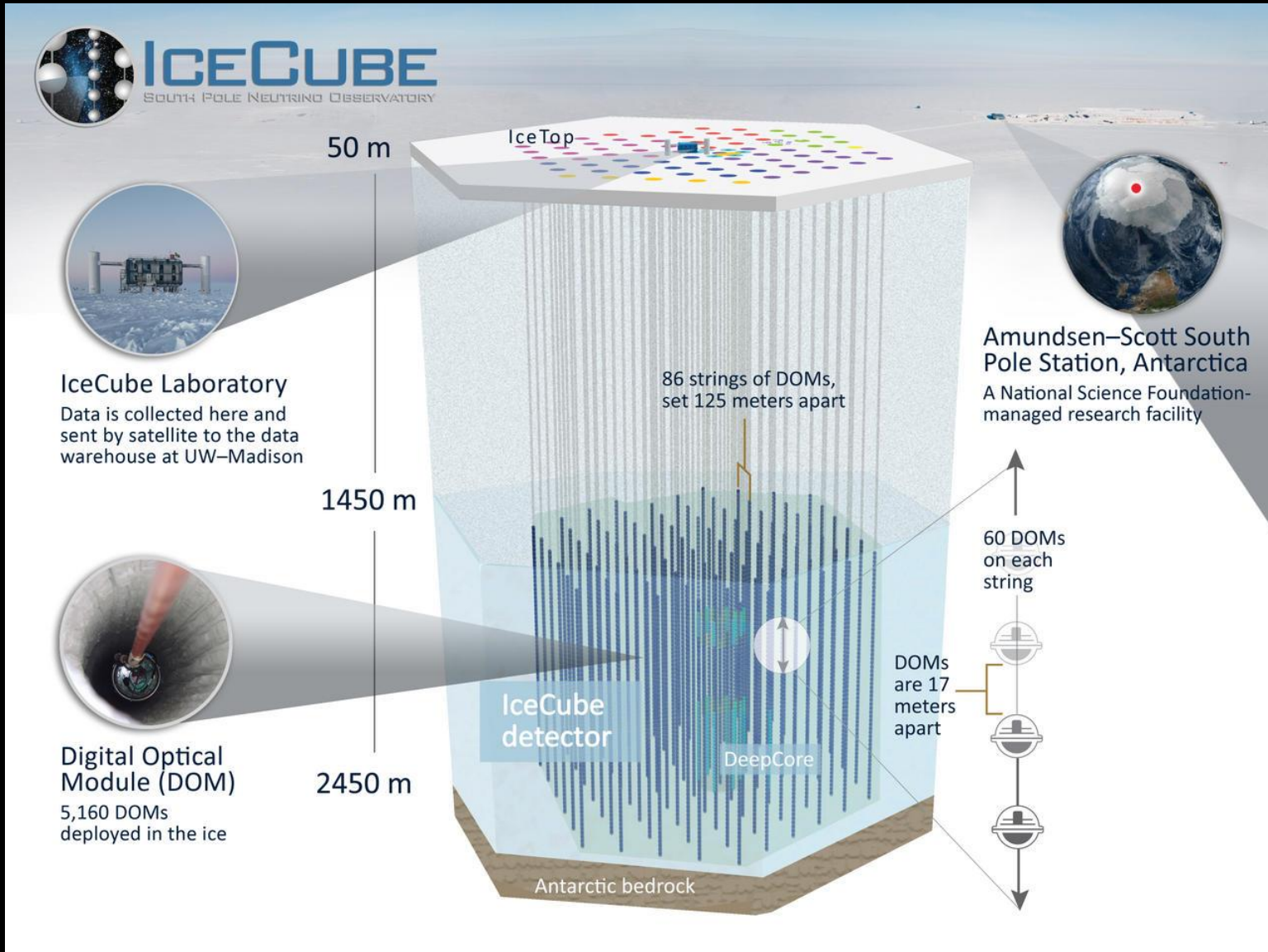
This scenario was more or less predicted.

slide @ 2003!





IceCube Neutrino Observatory



THE ICECUBE COLLABORATION

AUSTRALIA

University of Adelaide

BELGIUM

Université libre de Bruxelles
Universiteit Gent
Vrije Universiteit Brussel

CANADA

SNOLAB
University of Alberta–Edmonton

DENMARK

University of Copenhagen

GERMANY

Deutsches Elektronen-Synchrotron
ECAP, Universität Erlangen-Nürnberg
Humboldt-Universität zu Berlin
Ruhr-Universität Bochum
RWTH Aachen University
Technische Universität Dortmund
Technische Universität München
Universität Mainz
Universität Wuppertal
Westfälische Wilhelms-Universität
Münster

JAPAN

Chiba University

NEW ZEALAND

University of Canterbury

REPUBLIC OF KOREA

Sungkyunkwan University

SWEDEN

Stockholms Universitet
Uppsala Universitet

SWITZERLAND

Université de Genève

UNITED KINGDOM

University of Oxford

UNITED STATES

Clark Atlanta University
Drexel University
Georgia Institute of Technology
Lawrence Berkeley National Lab
Marquette University
Massachusetts Institute of Technology
Michigan State University
Ohio State University
Pennsylvania State University
South Dakota School of Mines and
Technology

Southern University
and A&M College
Stony Brook University
University of Alabama
University of Alaska Anchorage
University of California, Berkeley
University of California, Irvine
University of Delaware
University of Kansas
University of Maryland
University of Rochester
University of Texas at Arlington

University of Wisconsin–Madison
University of Wisconsin–River Falls
Yale University

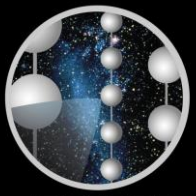
FUNDING AGENCIES

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Fonds Wetenschappelijk Onderzoek-Vlaanderen
(FWO-Vlaanderen)

Federal Ministry of Education and Research (BMBF)
German Research Foundation (DFG)
Deutsches Elektronen-Synchrotron (DESY)

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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)



ICECUBE

Constructions2005-2011

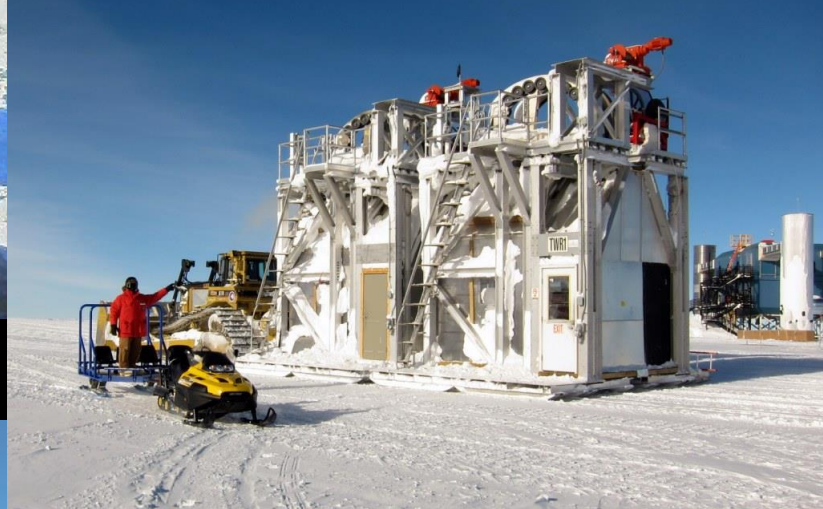


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Detectors shipped from Japan



Drill House



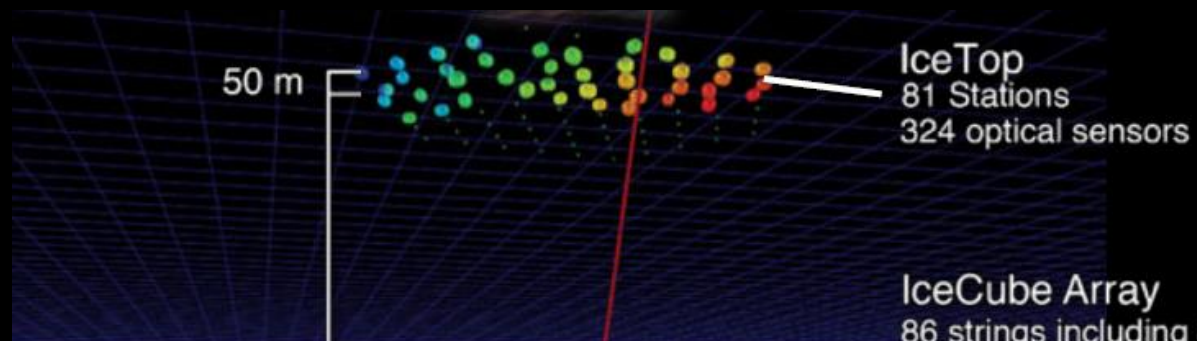
Researchers working on deployment



The IceCube Lab 「Beer Can」



The IceCube Detector

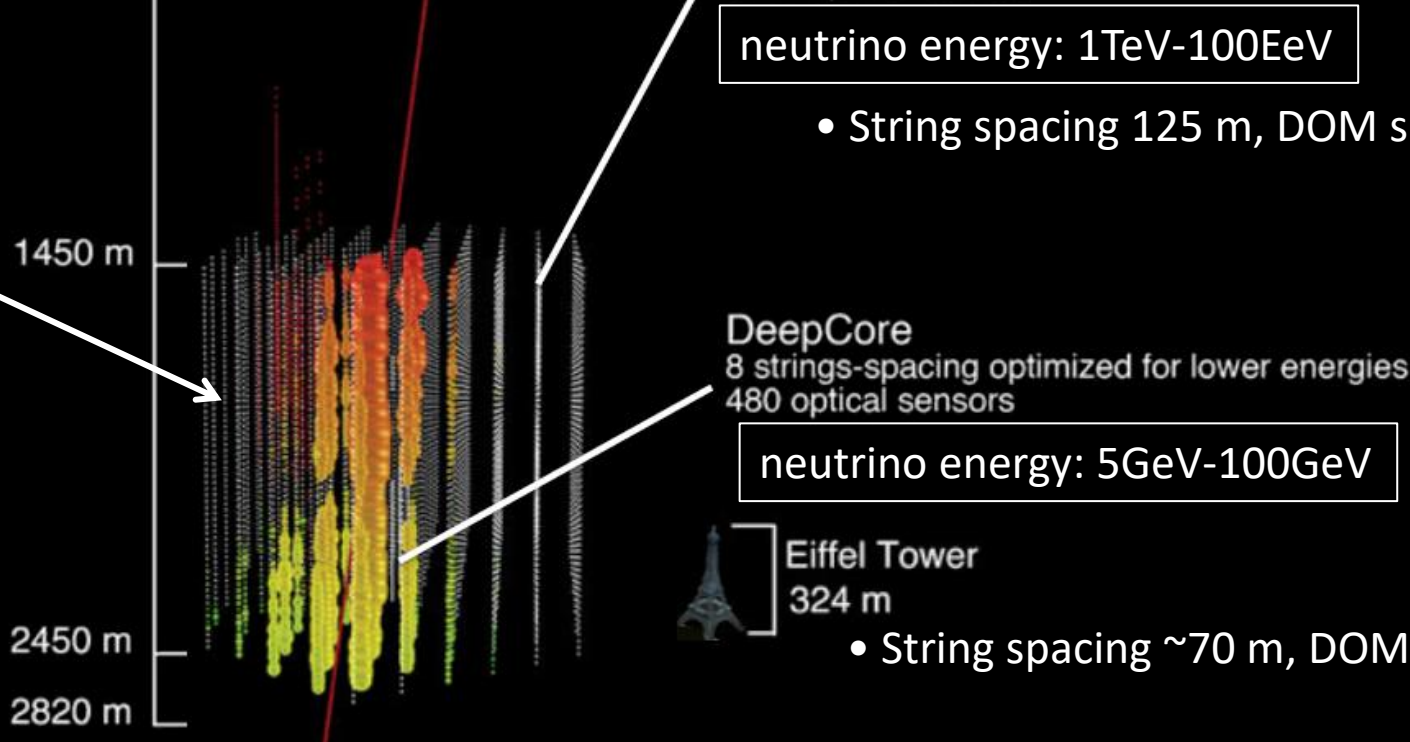


IceTop
81 Stations
324 optical sensors

IceCube Array
86 strings including 8 DeepCore strings
5160 optical sensors

neutrino energy: 1TeV-100EeV

- String spacing 125 m, DOM spacing of 17 m

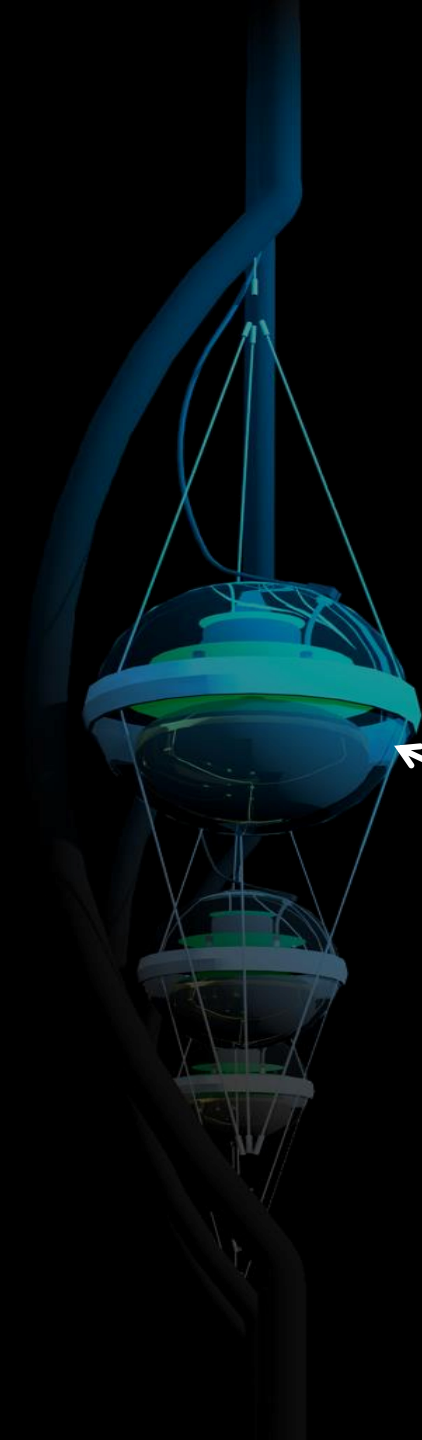


DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors

neutrino energy: 5GeV-100GeV

Eiffel Tower
324 m

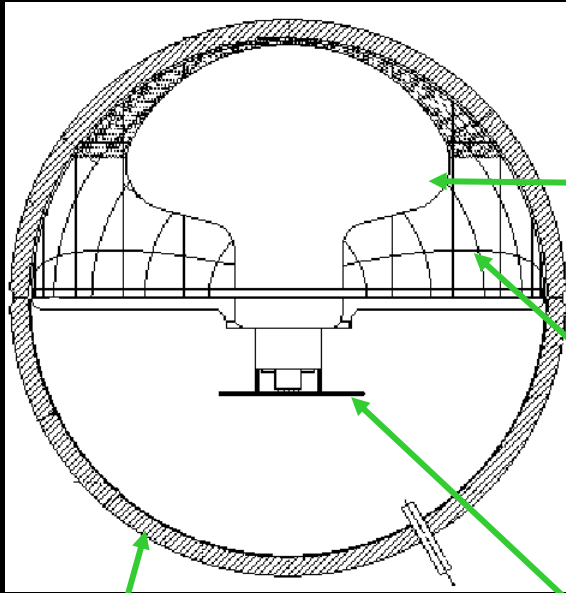
- String spacing ~70 m, DOM spacing of 7 m



Optical Detector Module for IceCube



DOM breakdown

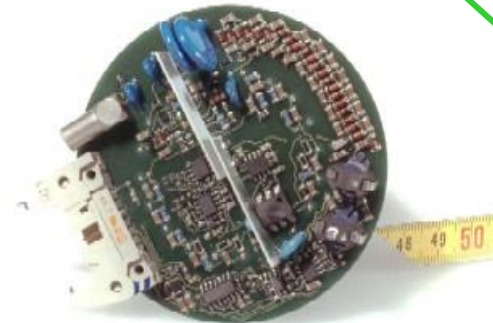


Photomultiplier: 10 inch Hamamatsu



Glass sphere: Nautilus

Active PMT base

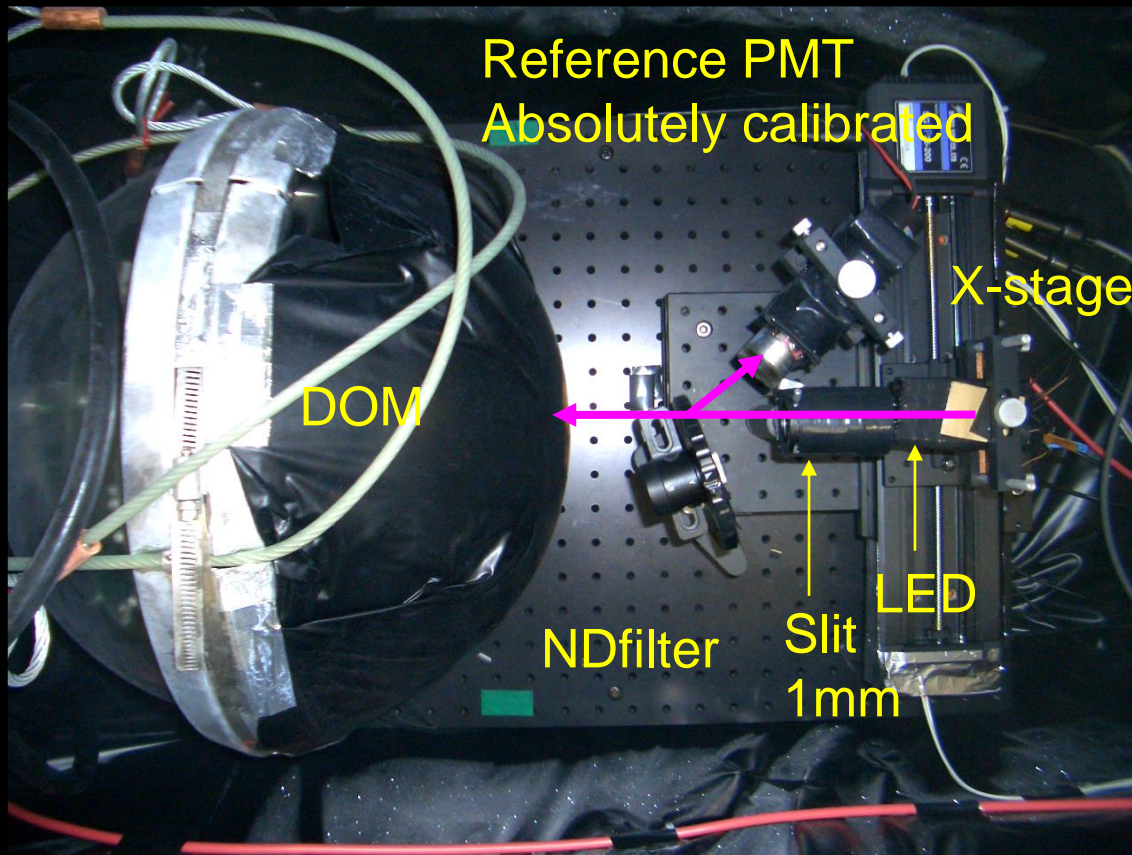


Mu metal magnetic shield

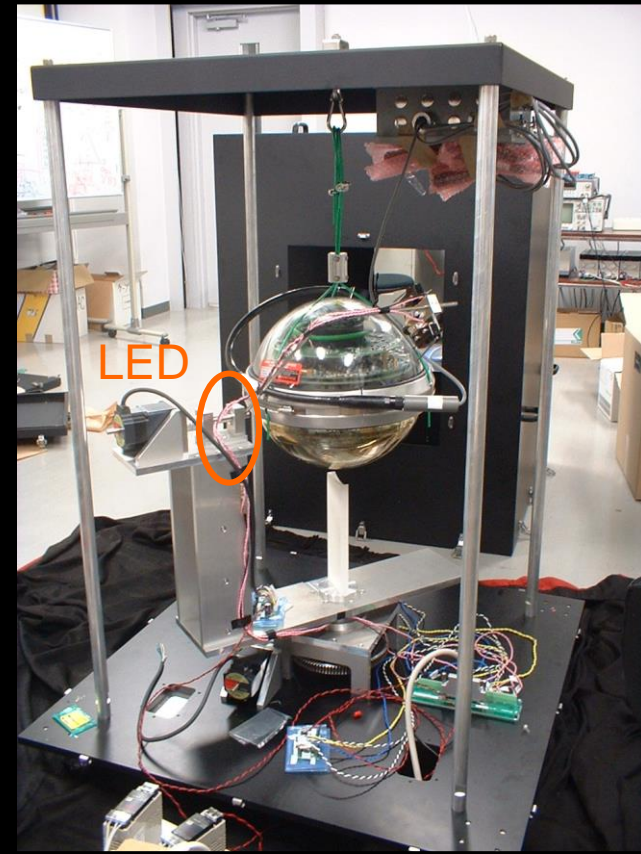
Characterization of DOM

in Japan for 2004-2009

QE × CE Absolute calibration

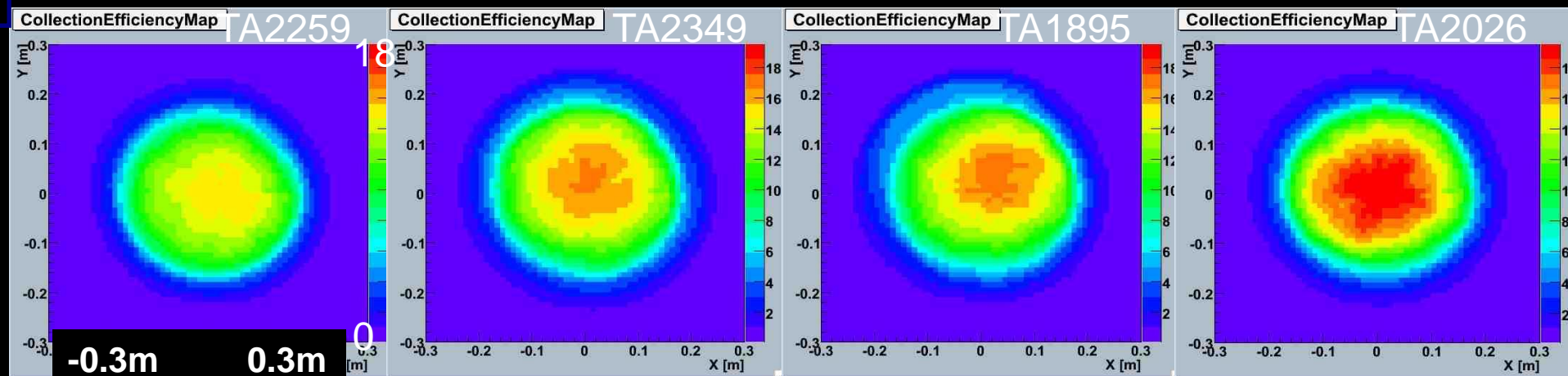


4πCE scanning



Mapping photon detection efficiencies

@365nm



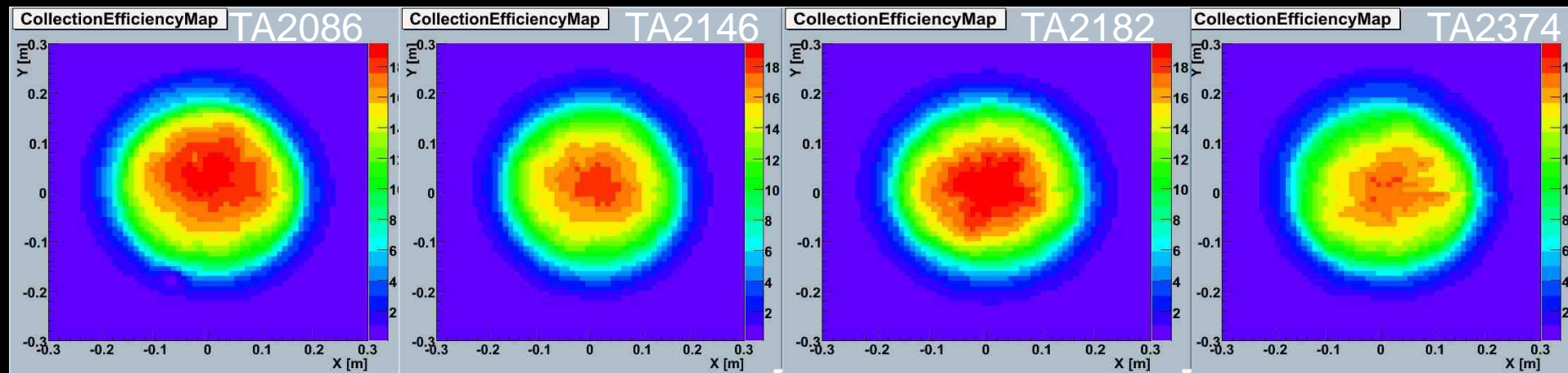
-0.3m 0.3m

14.0%

15.3%

15.4%

16.3%



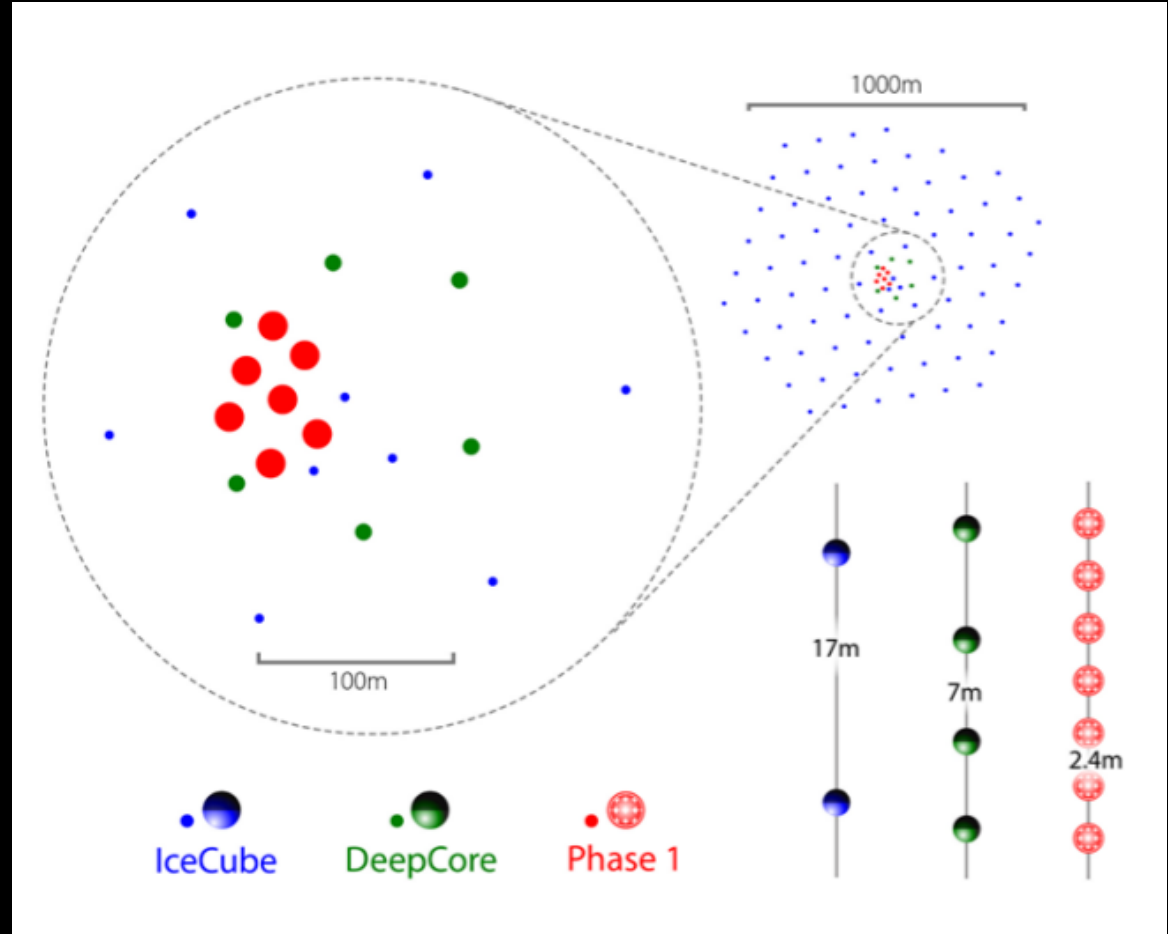
17.5%

16.6%

18.0%

16.0%

IceCube Upgrade





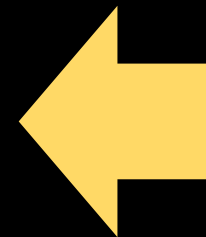
The next generation Cherenkov detector modules

D-Egg

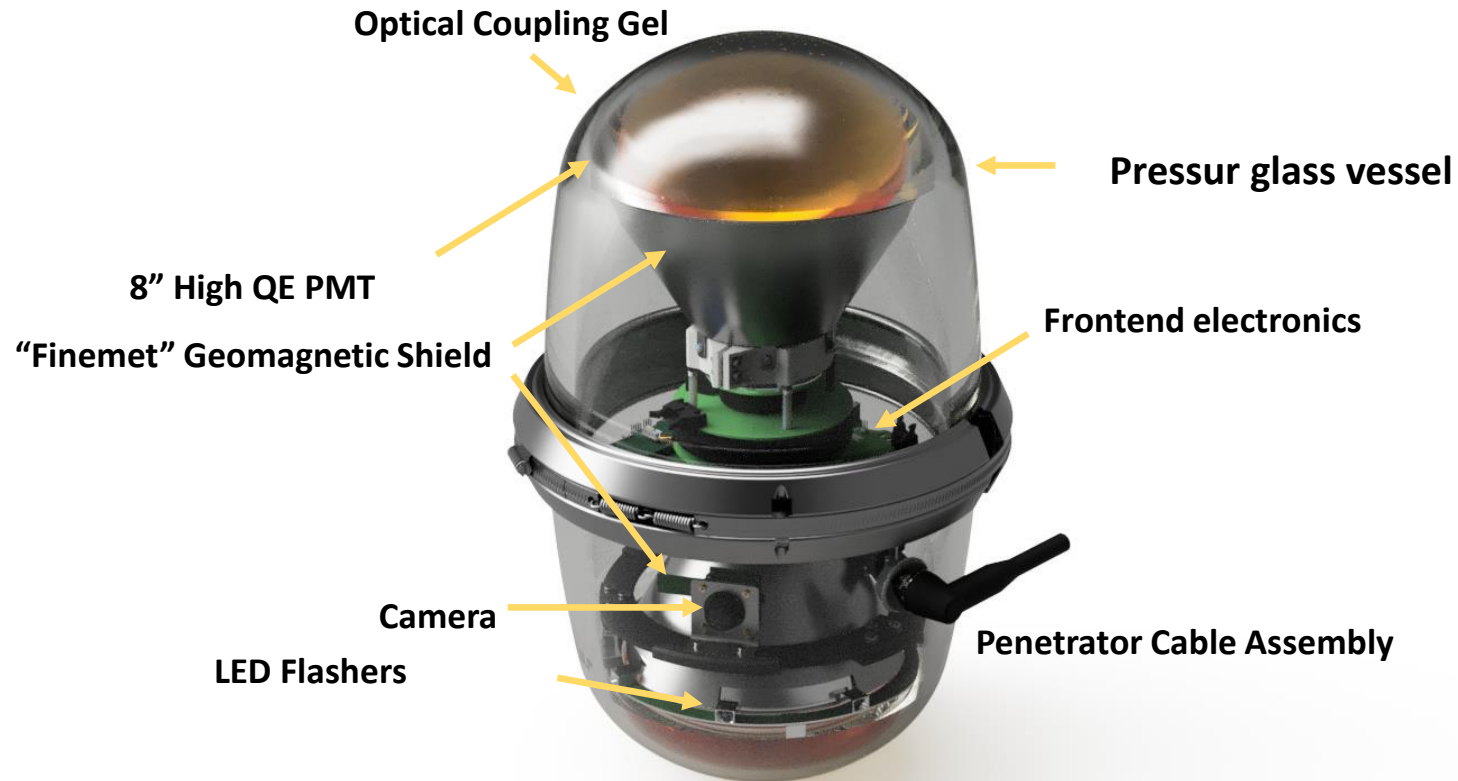
developed and fabricated in Japan

278 pcs will be deployed in 2024/25

The DOM for the present IceCube



D-Egg



Summary

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