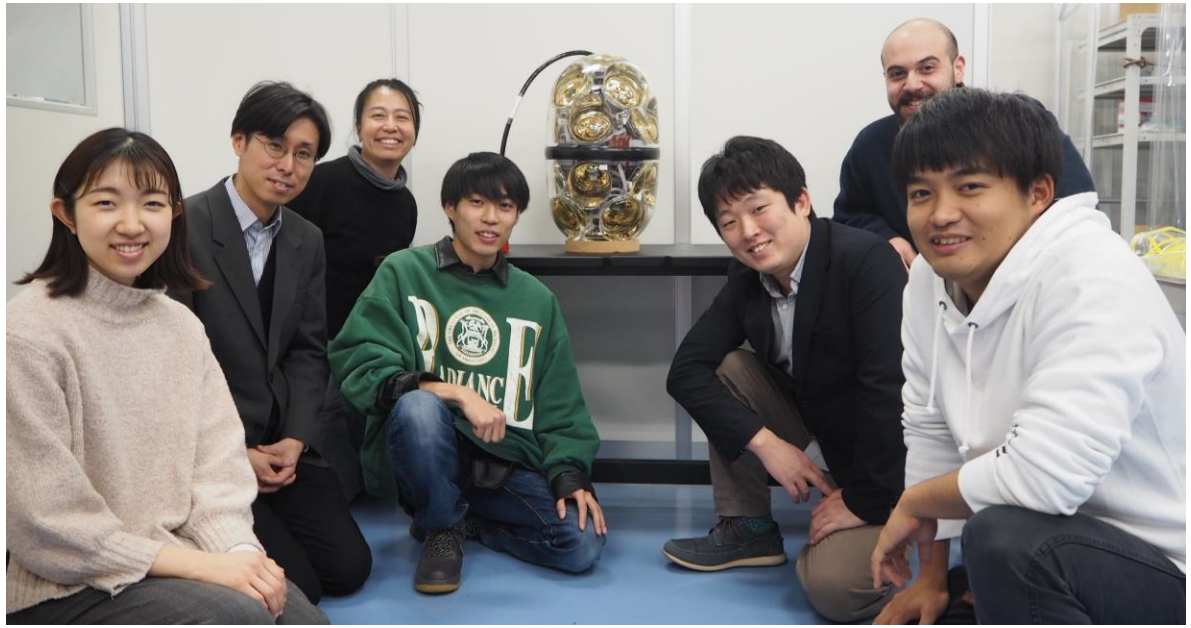


Development of the Optical Detector Module For IceCube-Gen2

The second annual conference of
Transformative Research Areas (A),
“Multimessenger Astrophysics”

20/11/2024 (Wed)

Tomoyuki Tsuji / Yujiro Kasai

IceCube Future Extension

IceCube-Upgrade

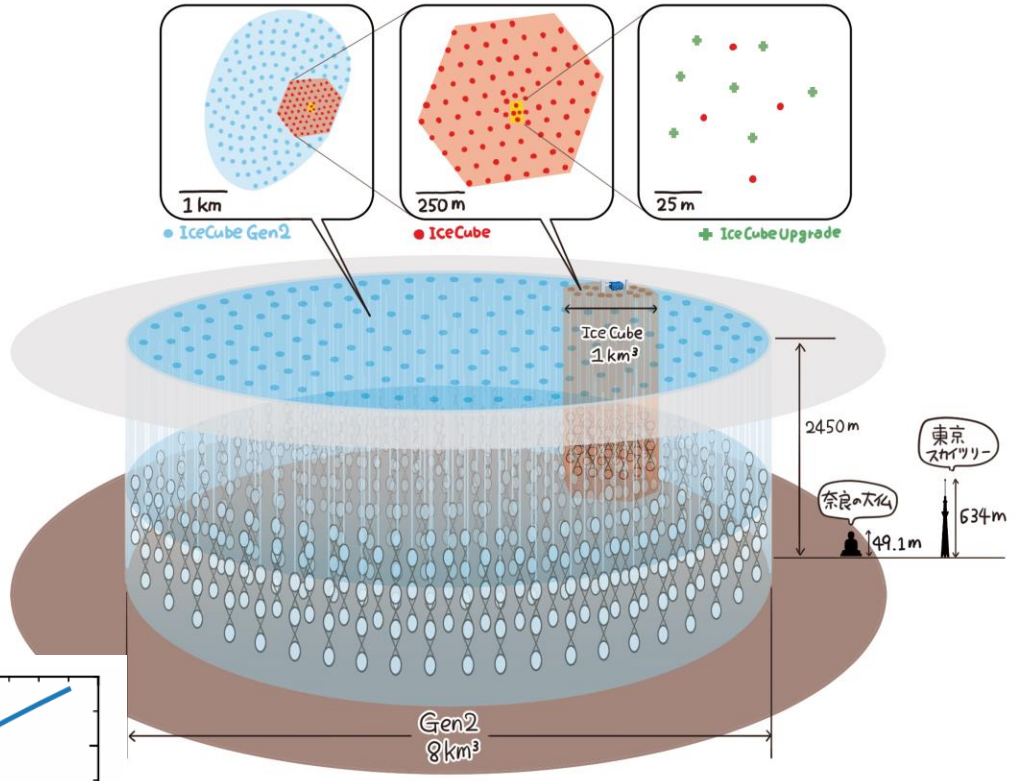
- Target : low energy Neutrinos (～GeV)
- Deployment begins in 2025

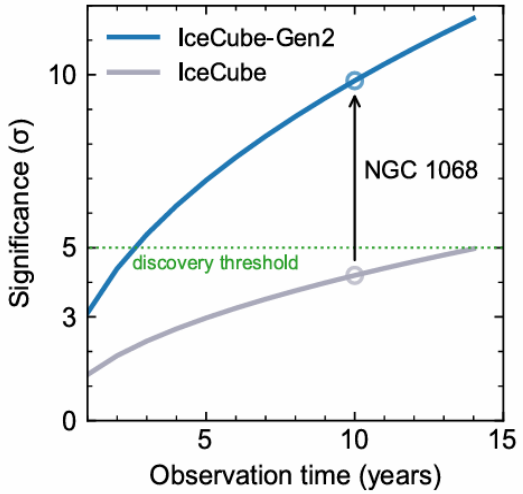
IceCube-Gen2

- Target : **High Energy Neutrinos** (>TeV)
- 8 km³ Volume (**8 times** Gen1)
- New **10000 Detector** will be deployed

Improvement

➢ Higher sensitivity
- Angular resolution
- Higher statistics



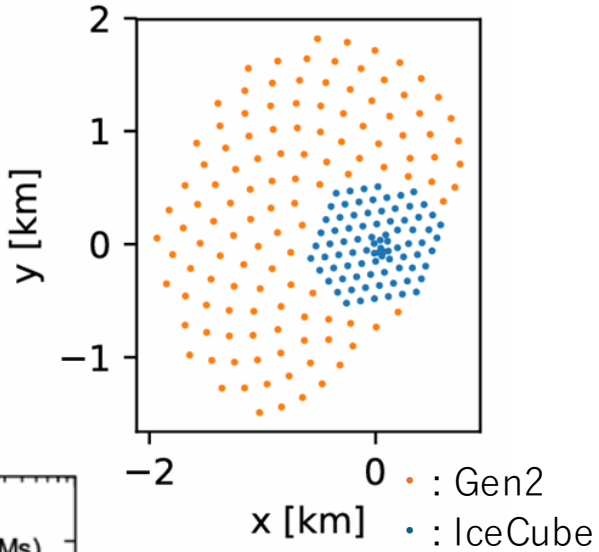


Why do we need new detectors?

In Gen2, the horizontal spacing between detectors will be increased.

- Gen1 : 125m
- Gen2 : 250m

→ **Twice as large as Gen1**

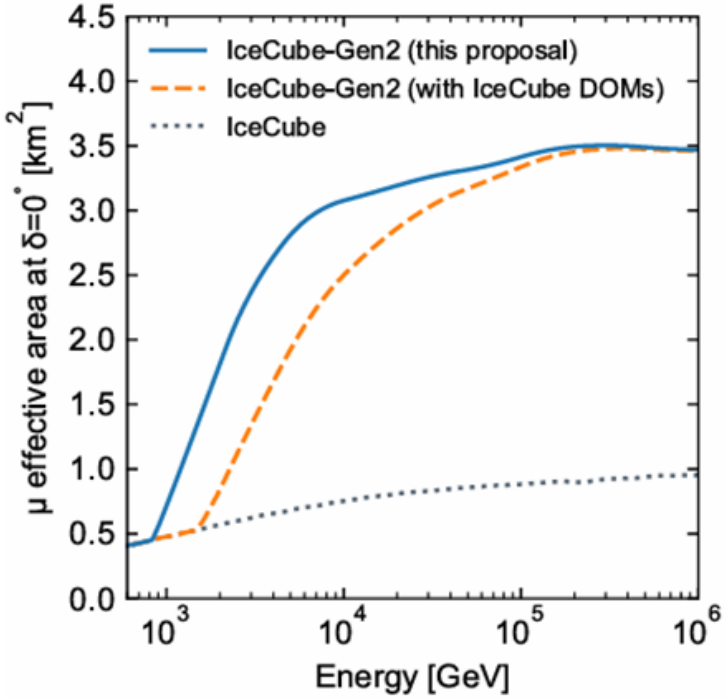


Problem

If we continue to use Gen1-DOMs for Gen2,

Sensitivity in the TeV region degrades

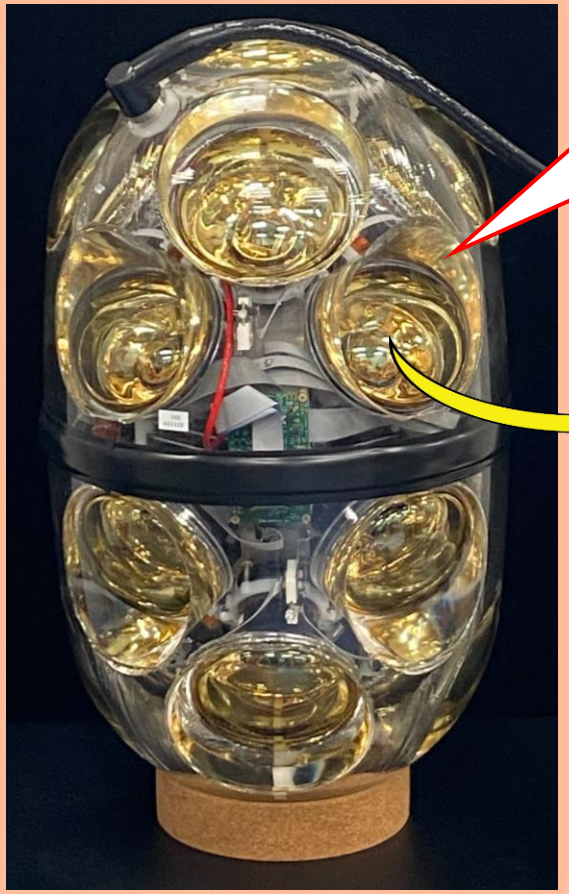
A more sensitive detector is needed.



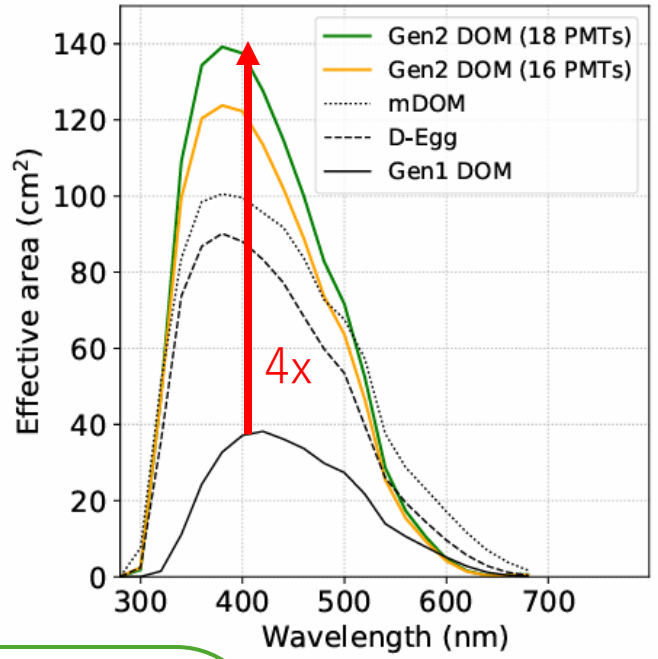
Gen2-prototype

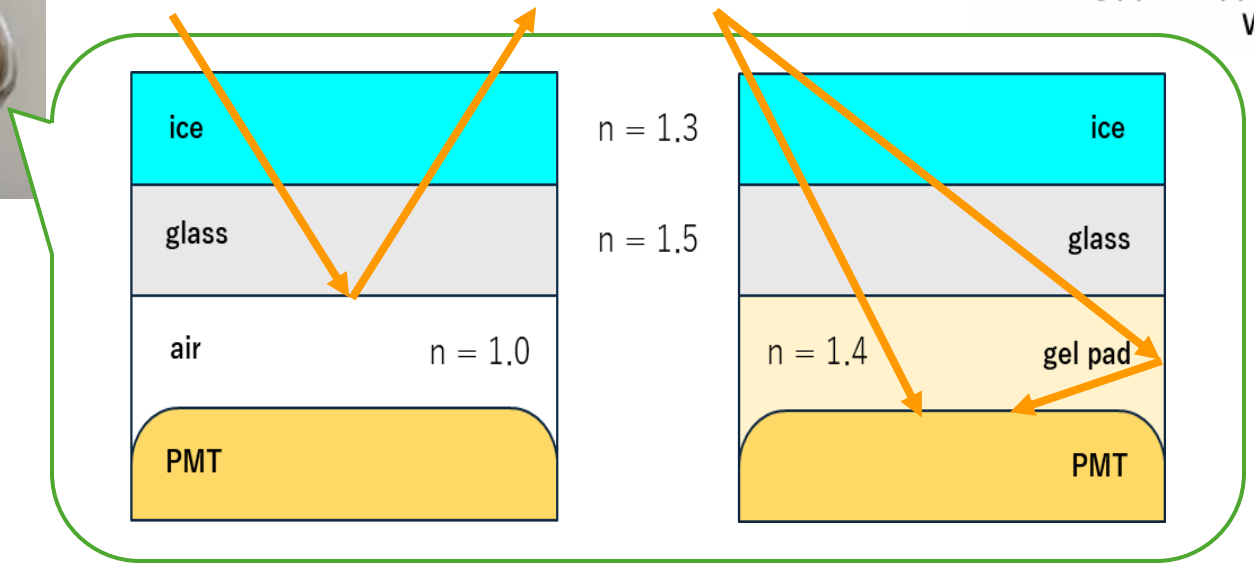
Gen2-prototype

Concept : More sensitive detector for Gen2



Feature ① : 18×4inch PMTs
→ Expand light collecting area
Feature ② : Gel Pad
→ improve sensitivity





Improvement of dynamic range

Need to measure 1 ~ 10000 photo electrons

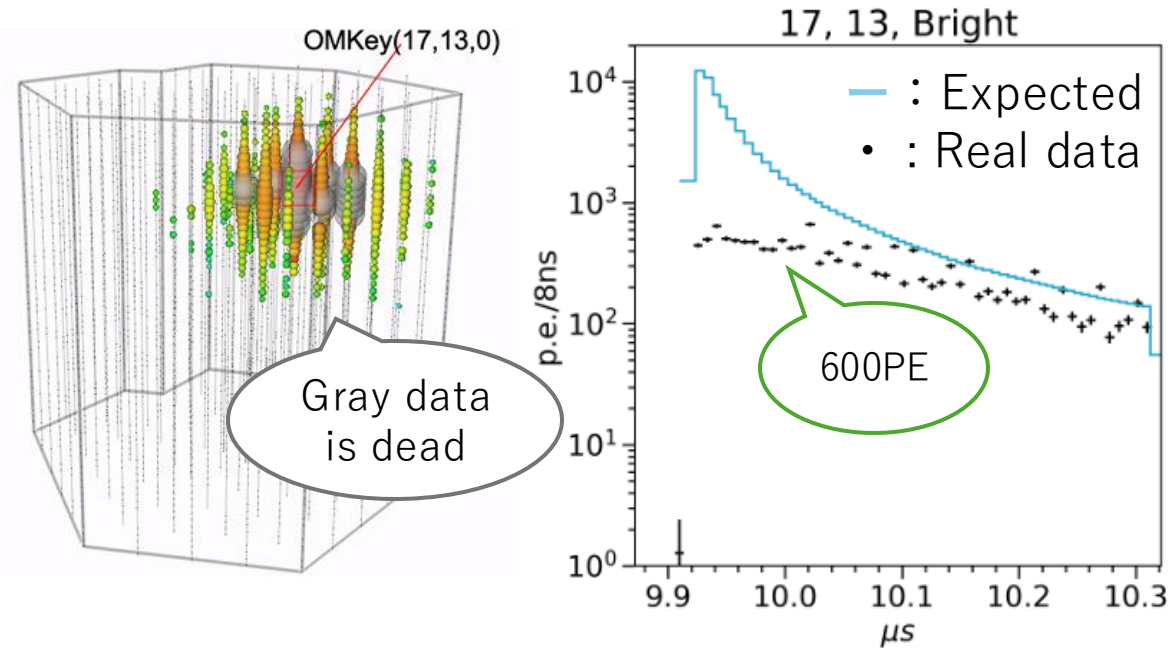
Gen1

- Too **bright** light saturates PMTs

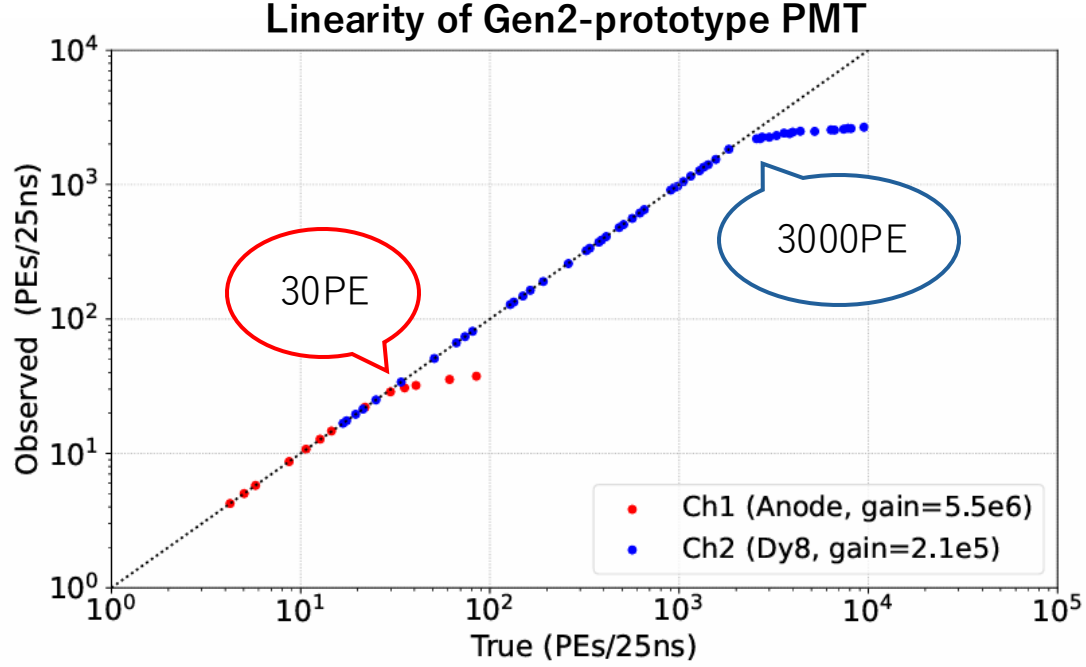
Dynamic range must be **Improved** !

Solution : Ch1 (low gain) & Ch2 (high gain)

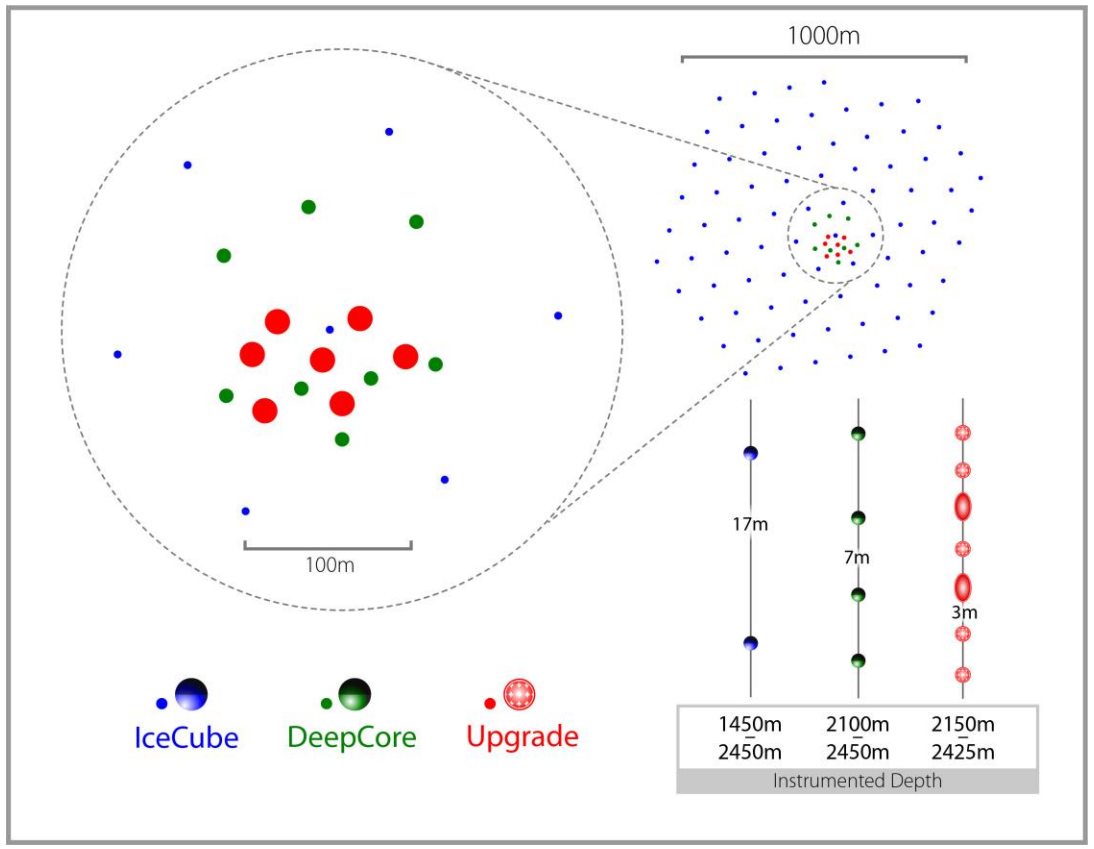
Gen 1



Gen 2



IceCube-Upgrade as Gen2-Phase1



Main detector

D-Egg

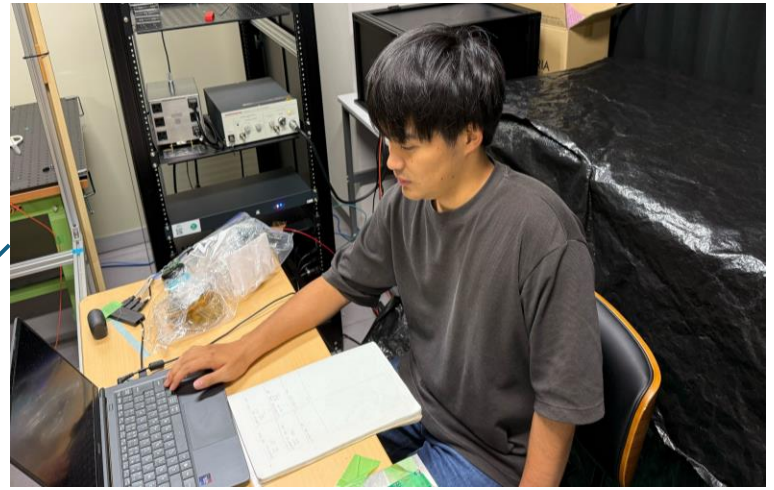
mDOM

12 Gen2-prototypes will be deployed to check their performances

Gen2-prototype Production Flow

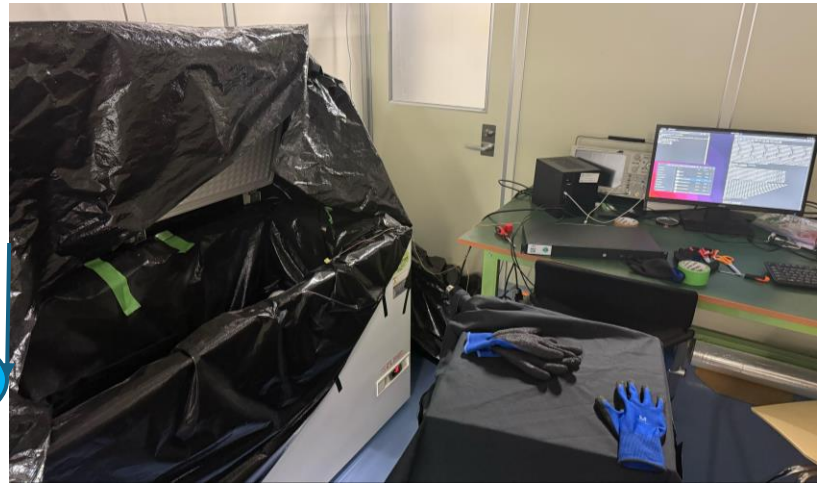
Gel pad production

Pre-inspection of PMT



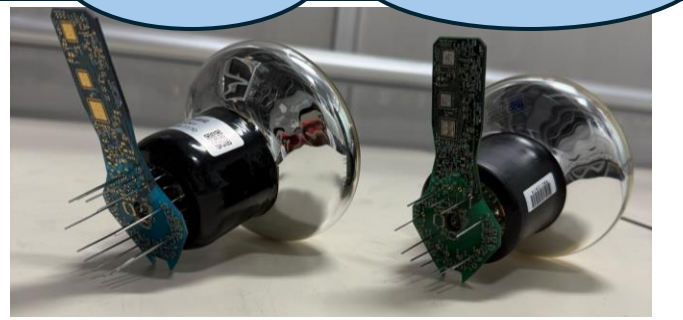
Assembly of Gen2-prototype

Inspection of Gen2-prototype



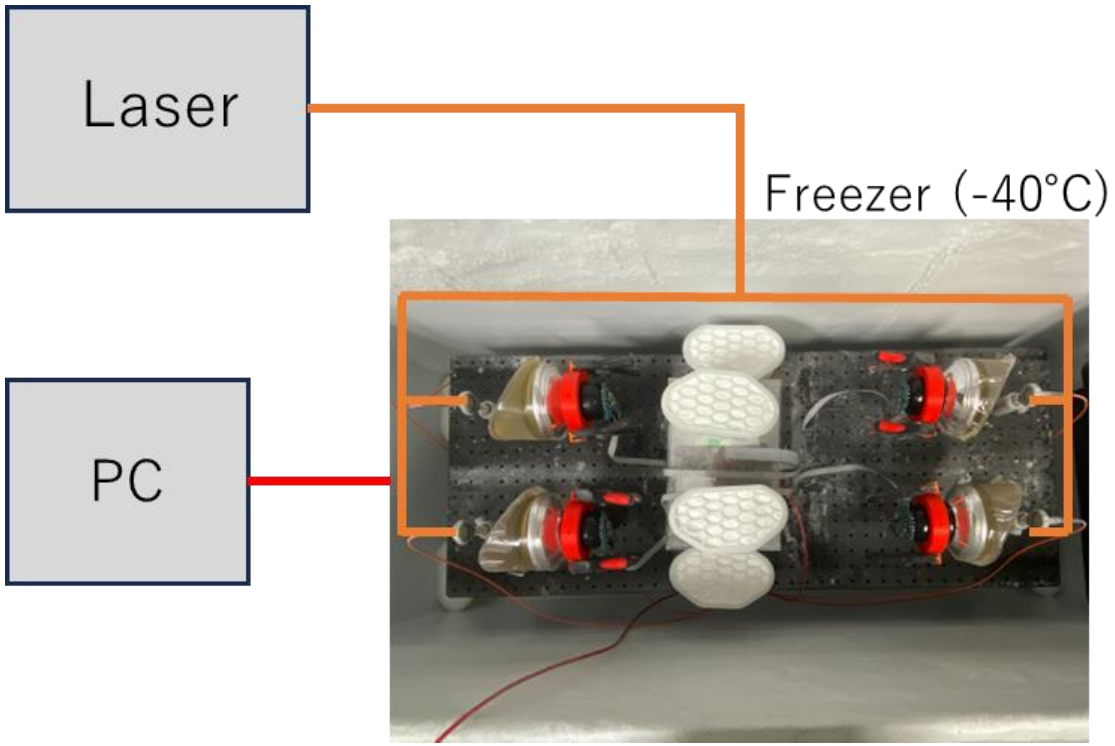
Pre-inspection Test

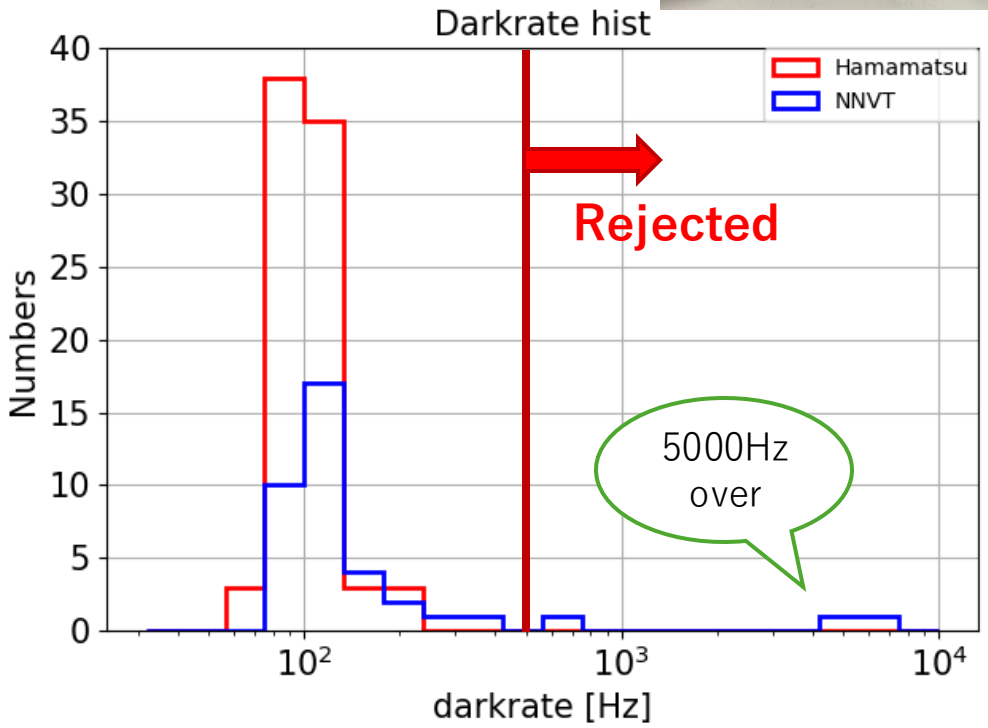
NNVT　Hamamatsu



Purpose

Assurance of the PMTs before their installation

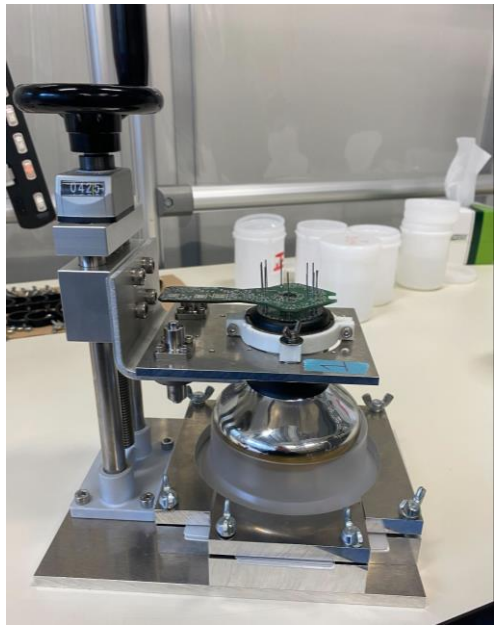


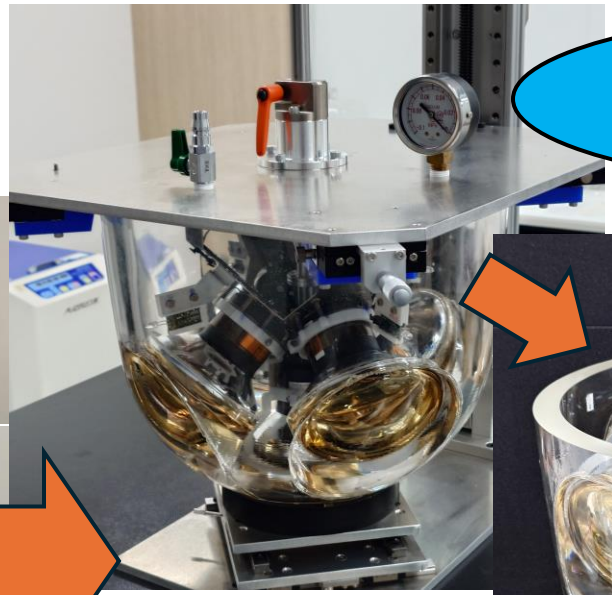


Pre-inspection Test can prevent the introduction of PMTs with bad performance

Assembly of Gen2-prototype

Gel pad production



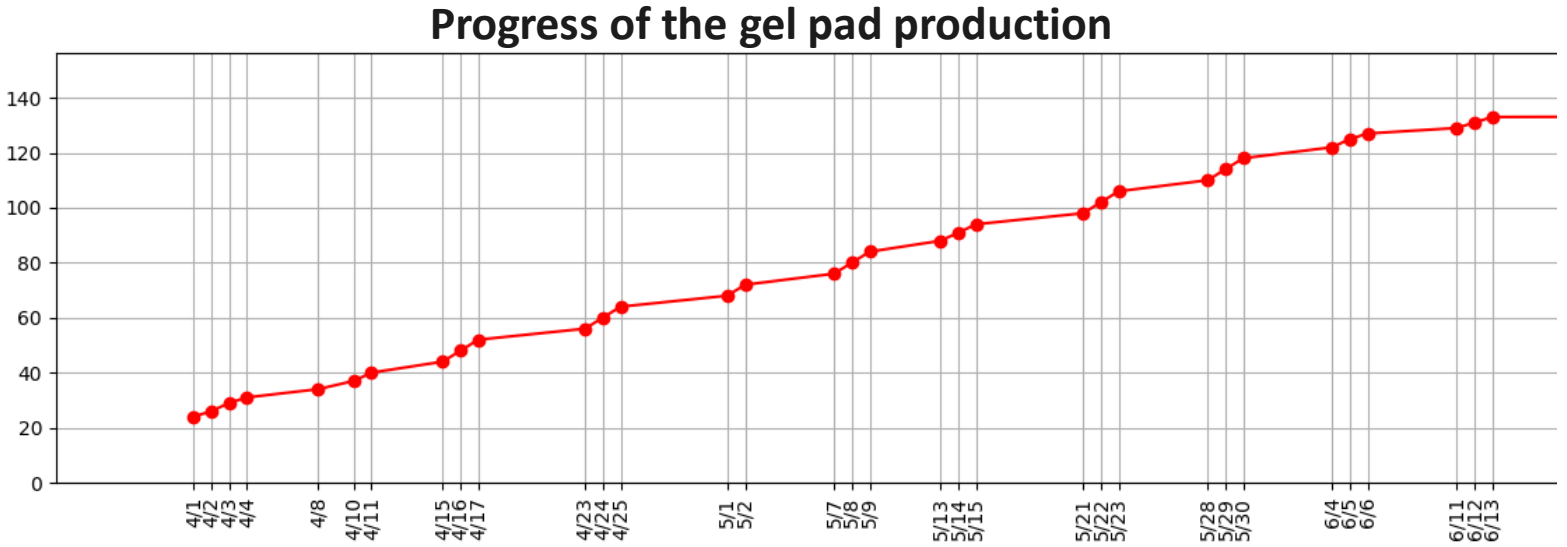


Gen2-prototype aseembly

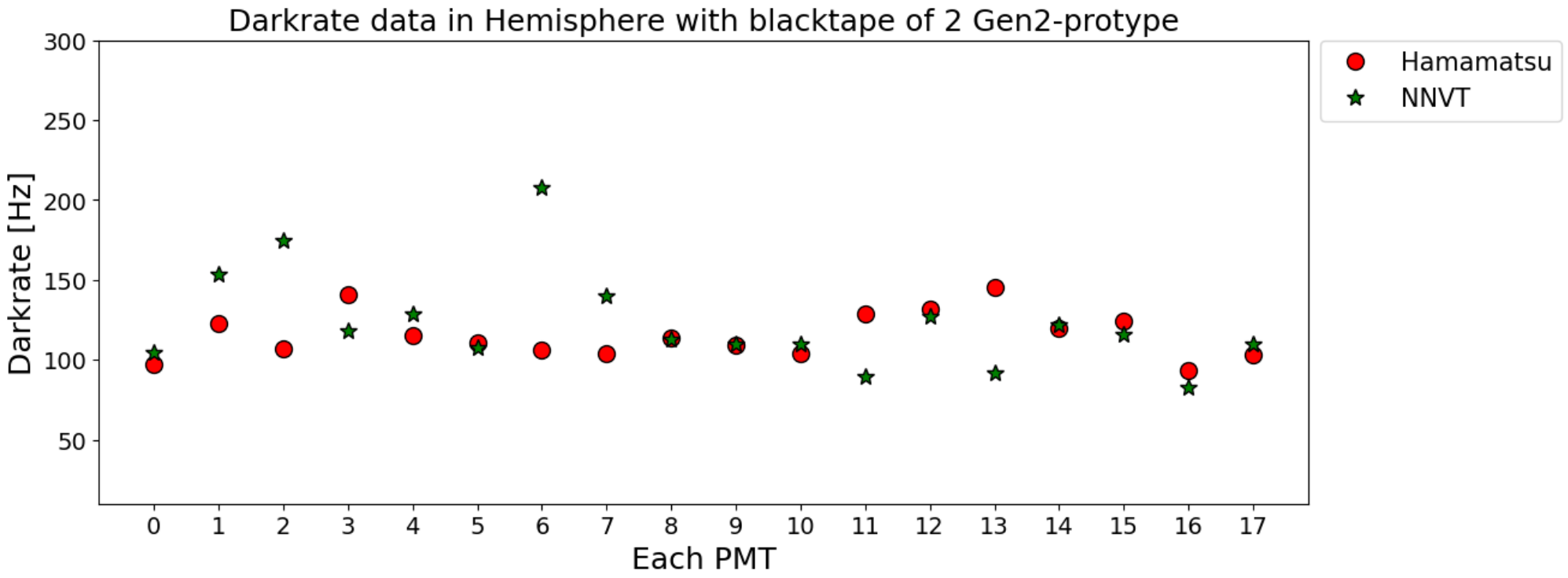
① Produce gel pads in three different shapes using a specific jig

② Assemble hemispheres using gel pad PMT
③ Upper and lower hemispheres are combined to complete the Gen2-prototype

10 Gen2-prototypes are completed!



Darkrate measurement of Gen2-prototype modules



About	Japanese manufacturer(Hamamatsu)	Chinese manufacturer(NNVT)
Average of 1PMT's Darkrate	115 Hz	122 Hz

Dark rate : About 120 Hz/PMT
For both vendors

Comparison of the darkrates

DOM

10 inch PMT×1

Gen2-prototype

4 inch PMT×18

	DOM	Gen2-prototype
Darkrate/detector	~1500 Hz	2241 Hz
Effective area (400nm)	~35 cm^2	~135 cm^2
Arbitrary darkrate / effective area	1	~0.4

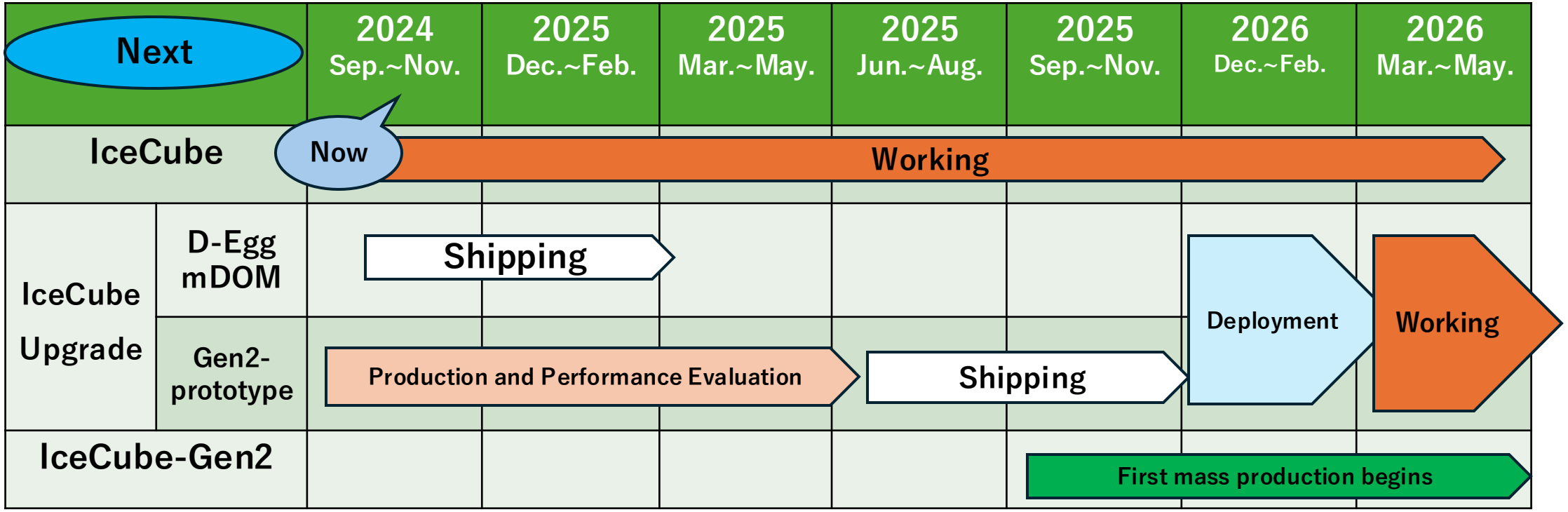
The effective darkrates per module improve by 60%!!

Contribute to the physics analysis of low-energy neutrino events like supernova

Summary and Next

Summary

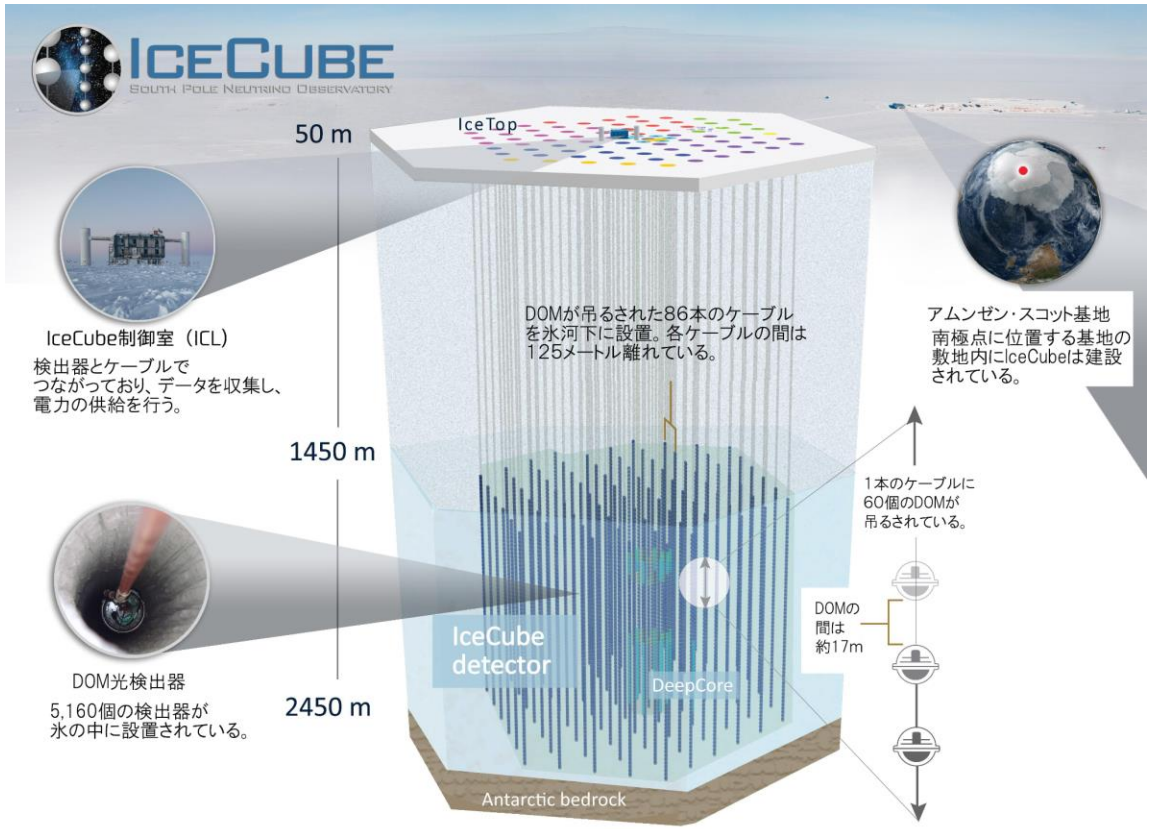
- Chiba University has developed the Gen2-prototype, one of the candidate detectors for IceCube-Gen2
- We have been able to guarantee the performance for the Gen2 project

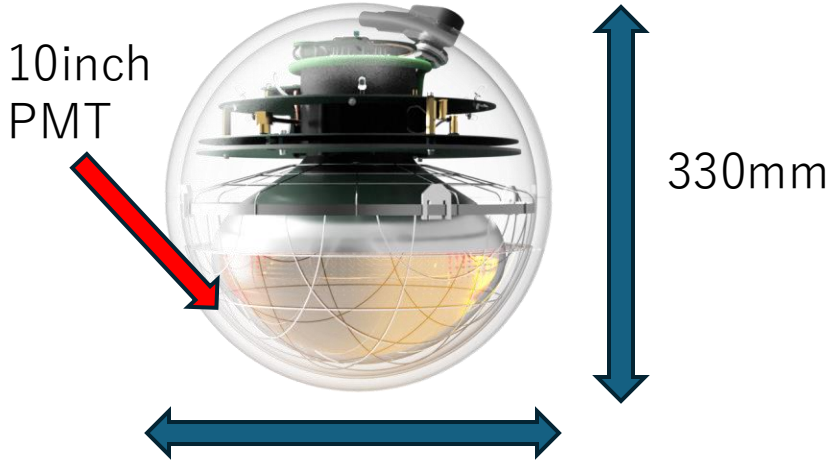


Back up

IceCube

Observation of high-energy neutrinos flying from space in the ice just below the South Pole





- 5160 “**DOM**”photodetectors buried within 1km^3 of the ice
- Observation of Cherenkov light from the reaction between neutrinos and nucleons in ice

IceCube Future Extension

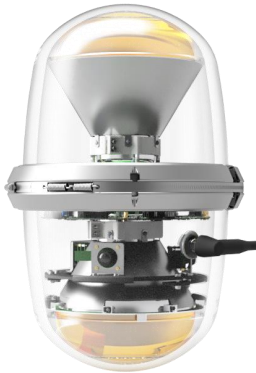
2011 2025～

IceCube → IceCube-Upgrade → IceCube-Gen2

Now

DOM

- Neutrino Observation Experiment in Antarctica.
- Detection area is 1 km^3
- Using the 5160 DOMs.



D-Egg

mDOM

Gen2-prototype

- Deployment begins in 2025
  - 300 D-Eggs (main)
  - 400 mDOM (main)
  - 12 Gen2-prototype (For testing for Gen2)
- To observe low energy neutrino.
- D-Egg is already ready to be shipped.

Undecided

- Upgrade to observe high energy neutrinos (1PeV)
- Detection area is 8 km^3
- 10000 new detector will be installed

Why do we need a new detector?

Gen2's Purpose : To observe high energy neutrinos **above 1PeV**

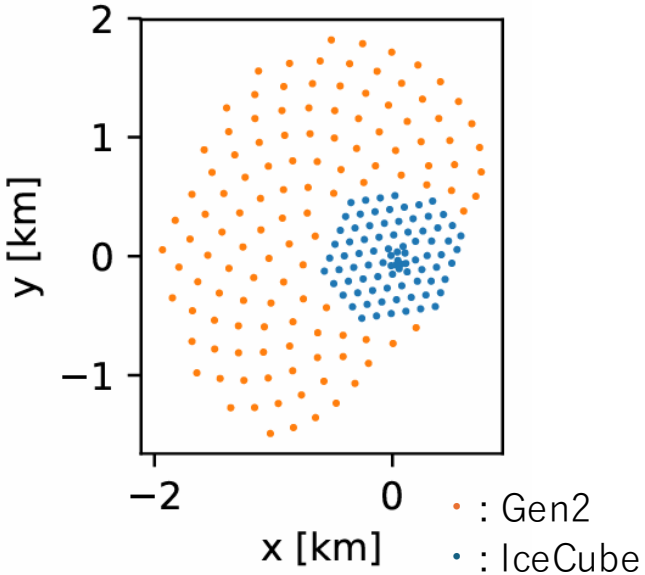
Need : Detection volume needs to be larger.

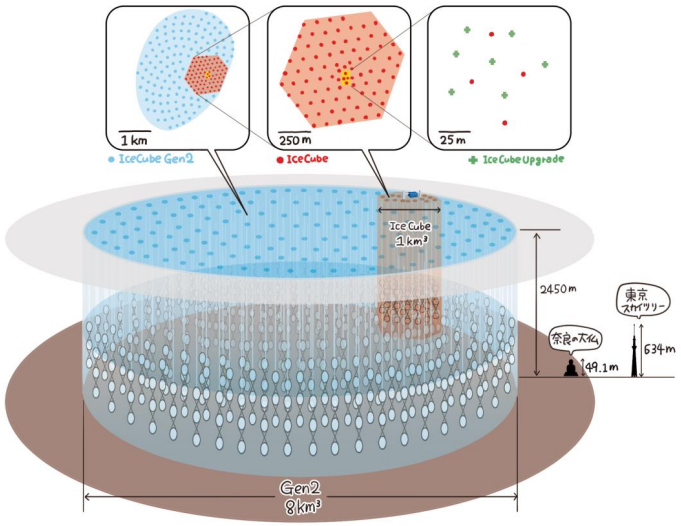
- Double-Bang events
- Charged-current interaction

Considerations

- Calibration by flasher
- Directional resolution
- Volume

Gen2 : Detector spacing set at **240m** (IceCube : 125m)





- **Improve neutrino detection frequency**
- **Improve Directional resolution**

⇨ **More sensitive detectors are now needed**

Detail of Gel

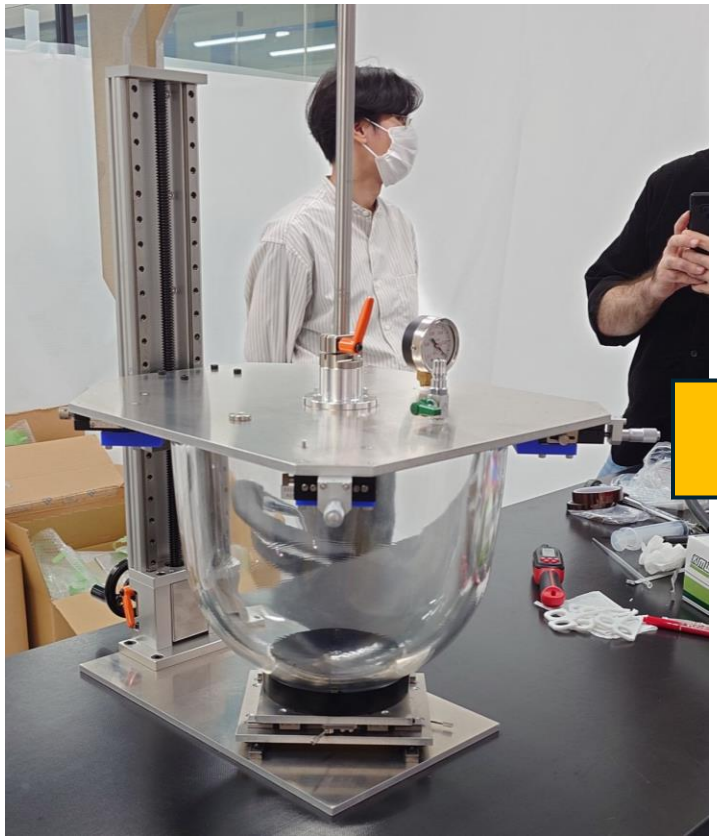
Prototyping Stages and Conclusions

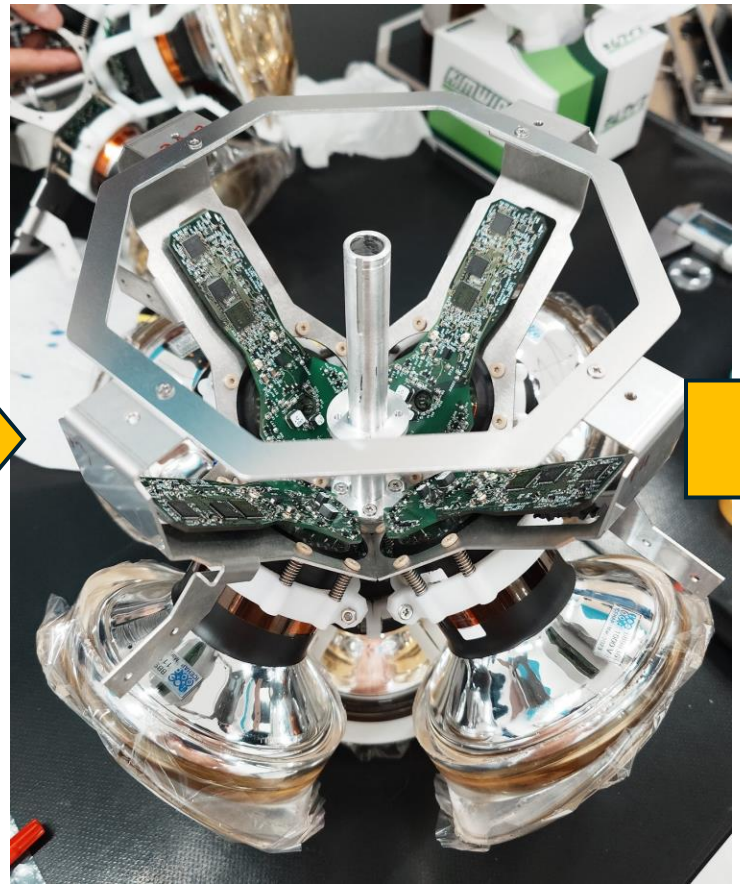
Brief descriptions of proof-of-concept and further prototype stages - Update as design evolves - Link to wikis or files in "shared documents" - add duplicate slides as necessary

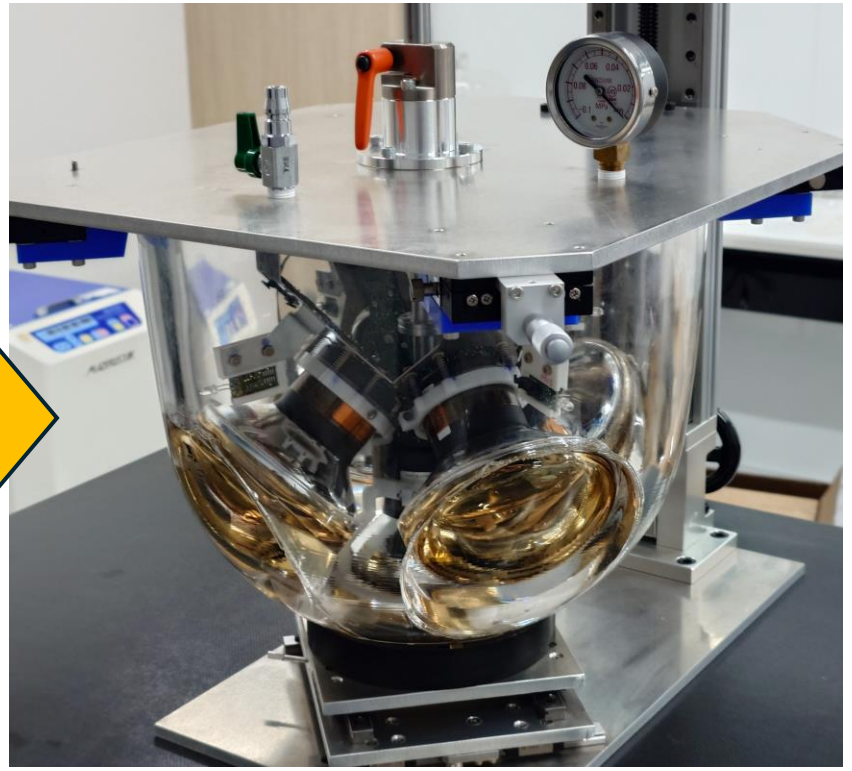
- Temperature dependence of gel properties
  - No noticeable change down to -50°C

		OSN-3547-A/B Lot.907102	X-32-3643-A/B Lot.908005	X-32-3547-2-A/B Lot.907001	X-32-3547-2-A/B Lot.909002
硬化前特性					
外観(色調)目視		無色透明	無色透明	無色透明	無色透明
粘度(23℃) A/B	Pa・s	4.4/3.7	4.4/3.7	4.4/3.5	4.7/3.6
屈折率(液状) A/B	nD25	1.431/1.430	1.431/1.430	1.431/1.430	1.432/1.430
液密度 A/B	g/cm3	1.01/1.00	1.00/1.00	1.00/1.00	1.01/1.00
硬化後特性					
硬さ	Shore00	45	27	37	18
切断時伸び	%	350	370	410	610
密度	g/cm3	1.00	1.00	1.00	1.00
光透過率 (350nm)(10mm 厚)	%	86	84	87	89
凝集破壊率(ガラス)※	%	100	100	100	100

Production of Gen2-prototype





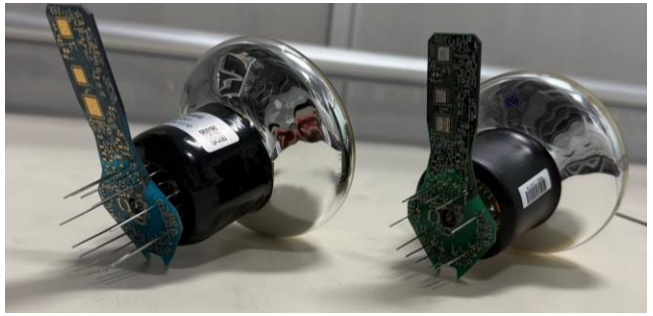


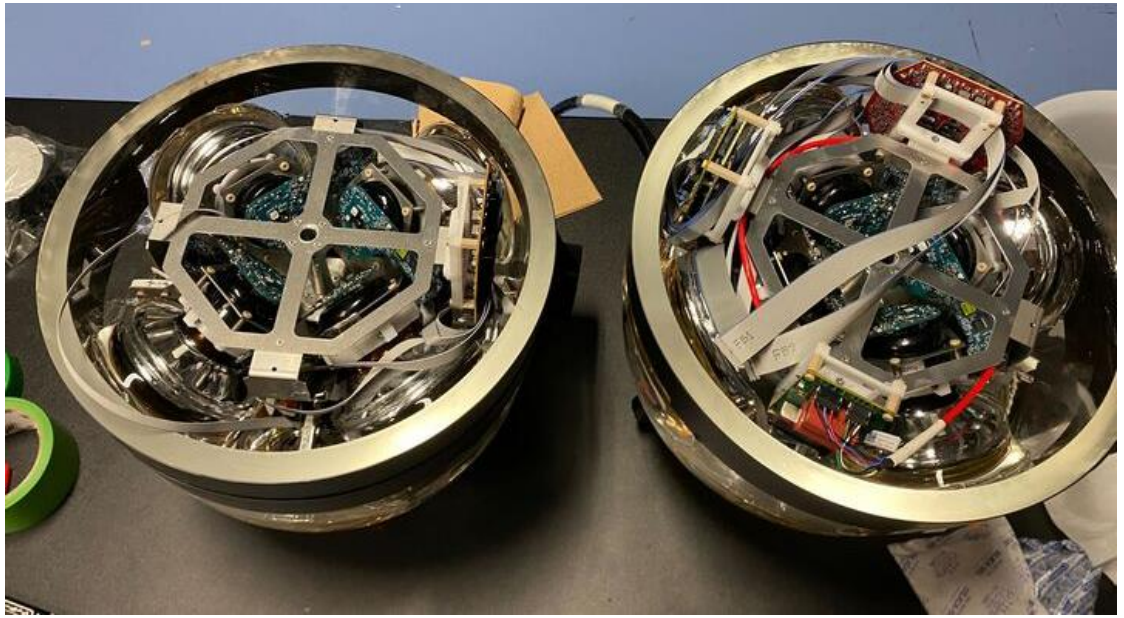
Adjust glass center

Fix PMT to frame

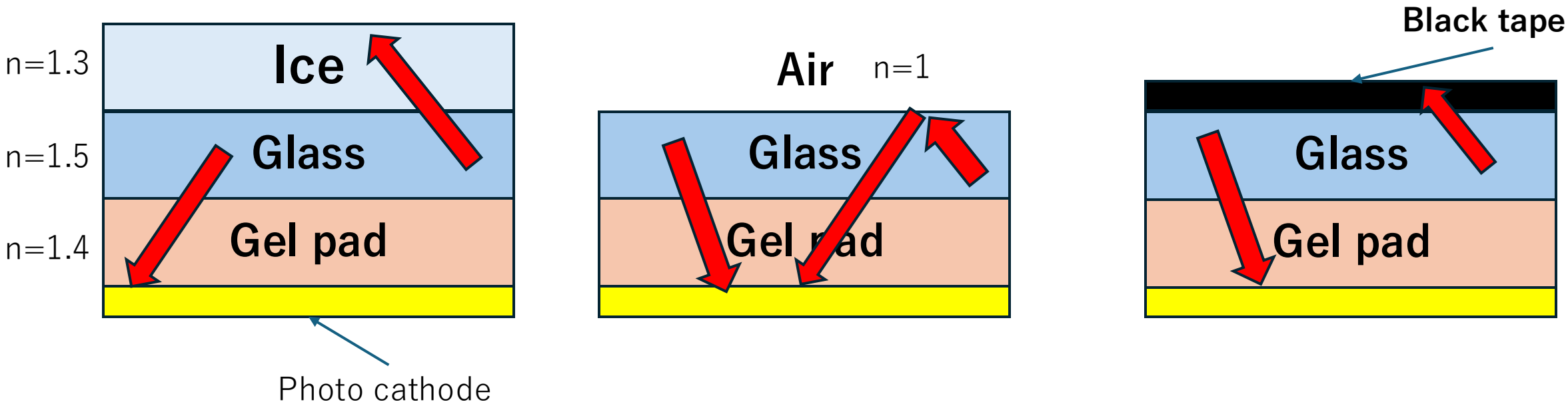
PMT inserted and attached to glass

PMT and Gen2-prototype





Why wrap black tape around glass?

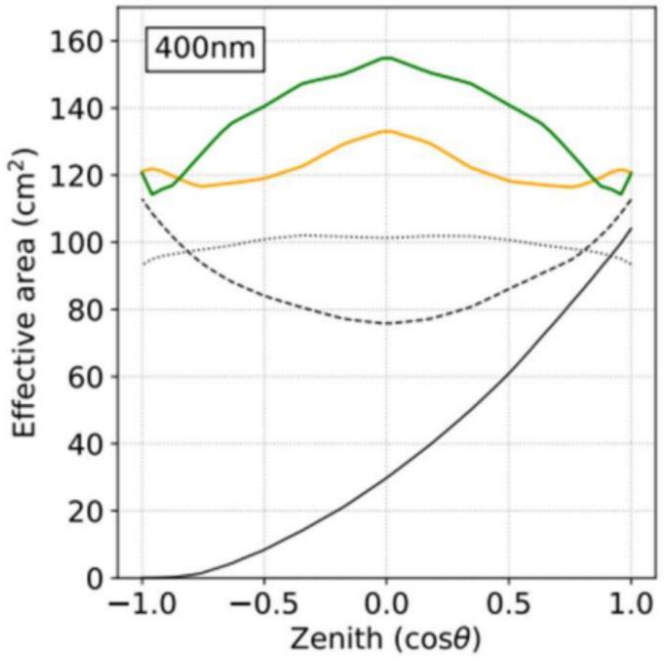


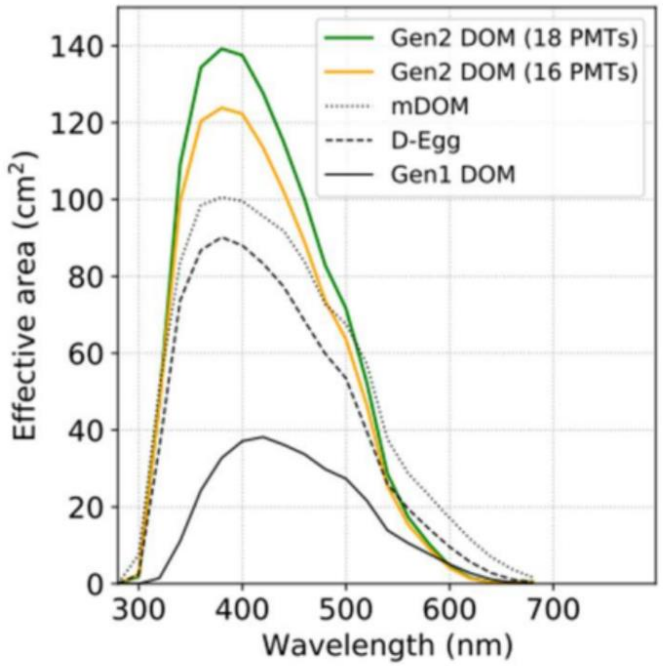
Antarctica

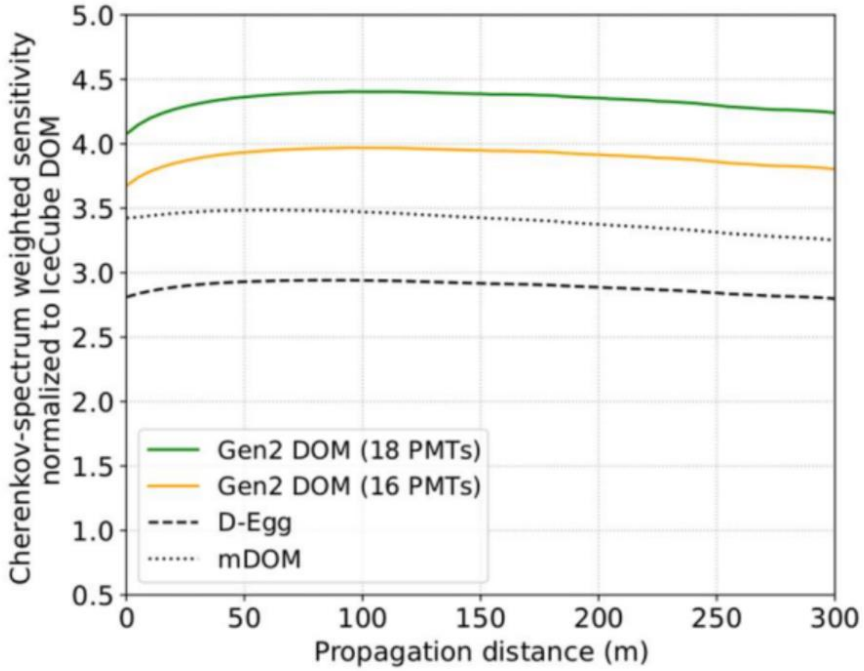
Only glass

Glass with black tape

Comparison of Effective area







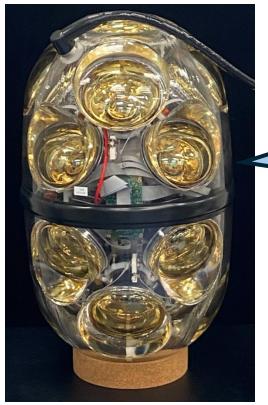
R. Abbasi et al, 2023

Comparison of darkrate with D-Egg

D-Egg

Gen2-prototype

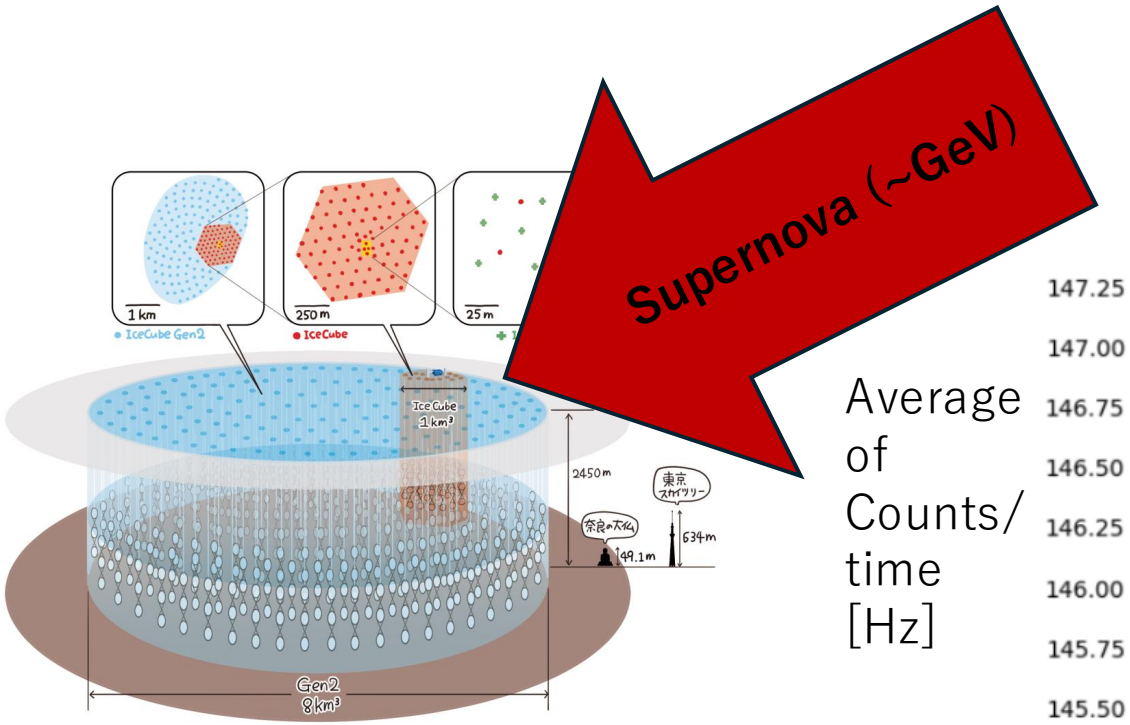
8 inch PMT × 2



4 inch PMT × 18

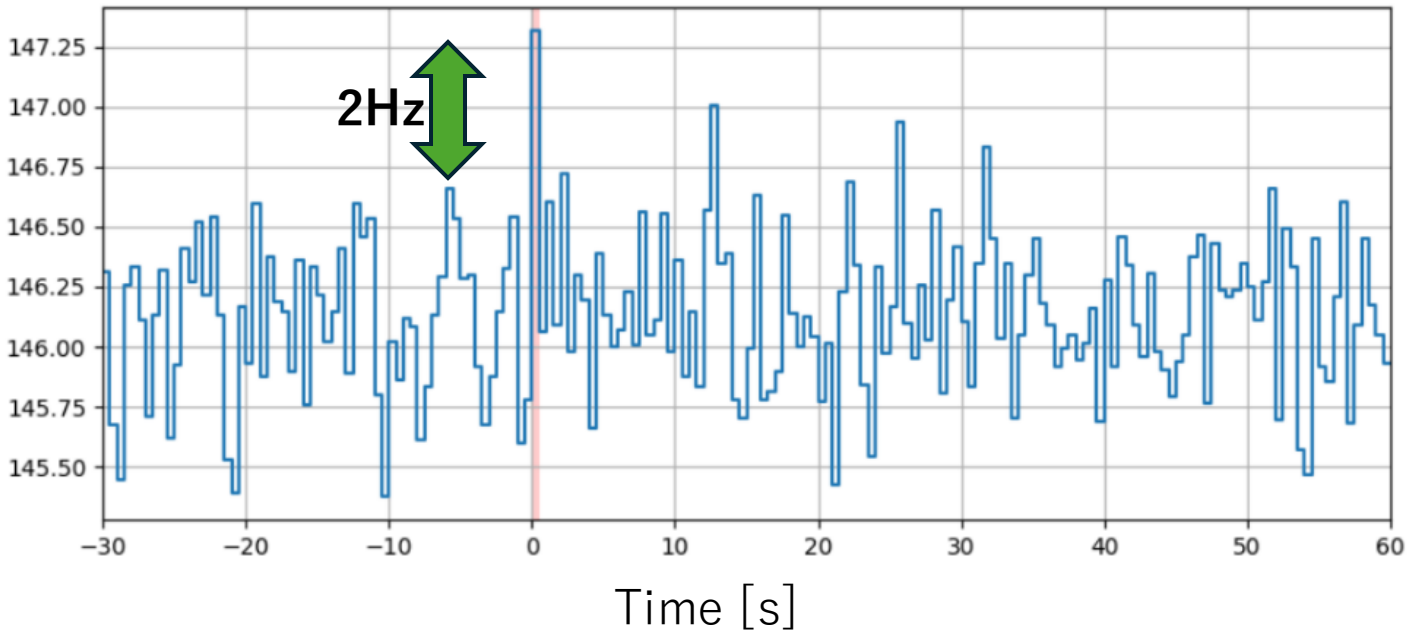
About	D-Egg	Gen2-prototype
Effective area (400nm)	About 90 cm^2	About 135 cm^2
Darkrate/detector	About 2000Hz	2241 Hz
Darkrate / Effective area	About 22 $\frac{Hz}{cm^2}$	About 17 $\frac{Hz}{cm^2}$

Supernova



Supernova(~GeV) produces a weak and short-lived optical signal

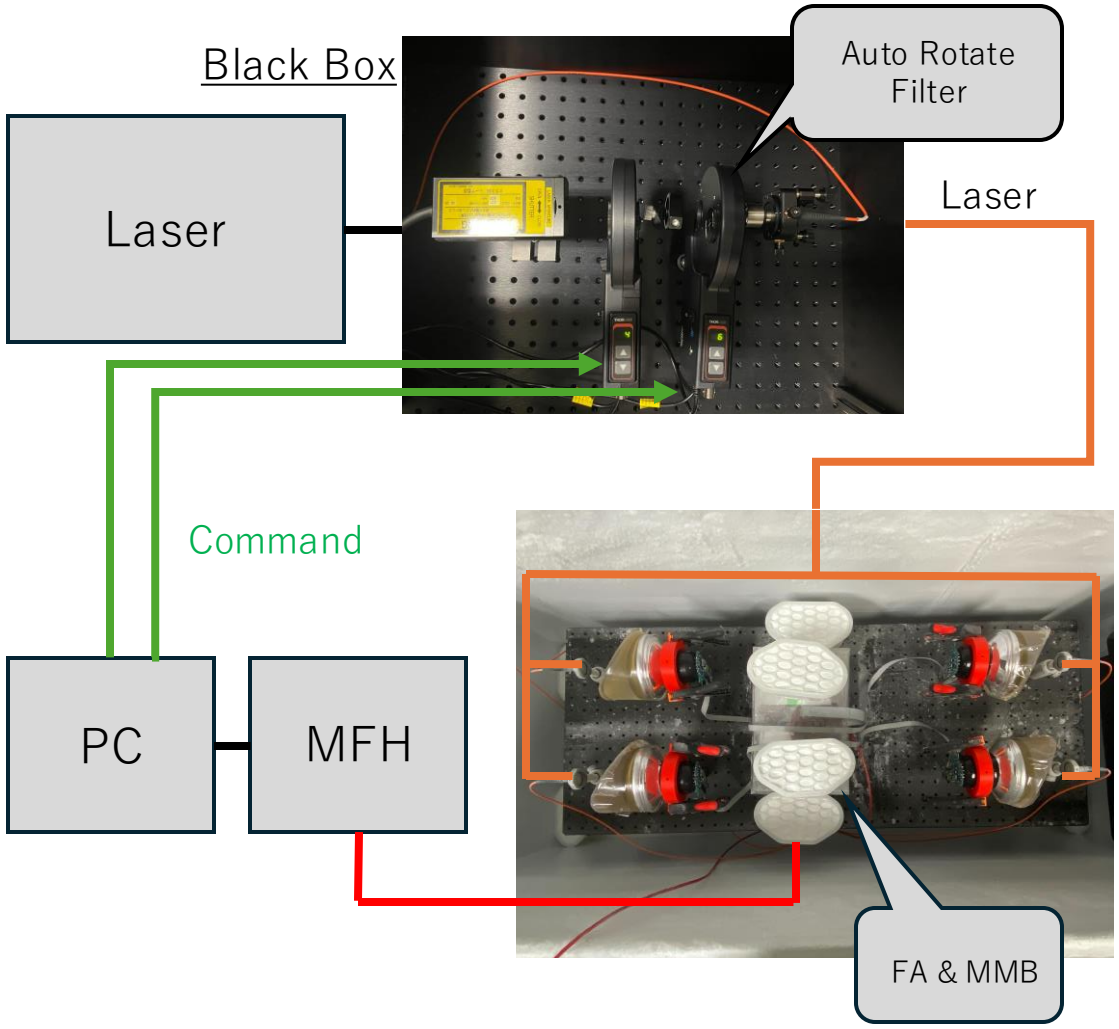
where the IceCube detected the supernova signal



Analysis of Supernovas near GeV need number of detector and low background of detector and so on

Gen2-prototype can contribute to its analysis!

Detailed Pre-inspection Test setup



➢ Topics of the test

① Gain
Measure the proper voltage for each PMT

② Dark rate
Signal frequency when light is blocked

③ Linearity
Response to intense light

About	Hamamatsu	NNVT	Remarks
Measured Number	85	40	
Gain issue	0	2	Charge Distribution couldn't be fitted
Dark rate issue	0	2	5000Hz over
Linearity issue	0	0	