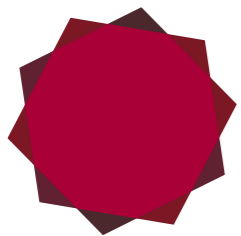


New Optical Module D-Egg for IceCube-Gen2

Yuya Makino

Chiba University

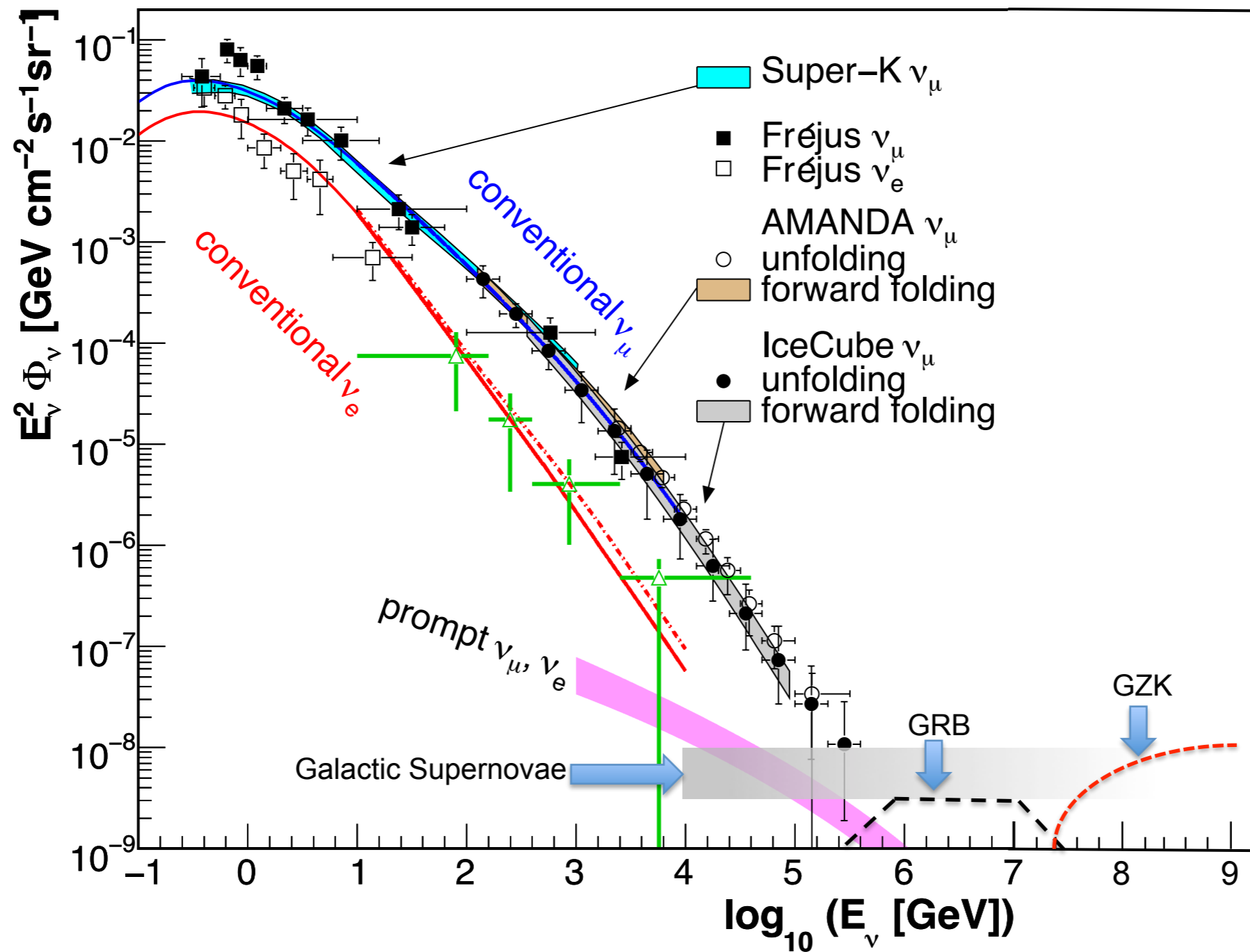
24th ICEPP symposium



CHIBA
UNIVERSITY



IceCube & Neutrino Astronomy



The Next Gen. Neutrino Telescope

IceCube

86 strings

5,000 modules

1 km³

IceCube-Gen2

+120 strings

+ 10,000 new
modules

5-10 km³



ICECUBE
GEN2

- High energy extension of IceCube
 - ▶ Point source search / Study on spectral index of astro. ν
 - ▶ Discoveries (GZK ν , PeV ν_τ , and etc.)
- **Started to develop new detectors to expand the detection power for high-energy neutrino hunting**

Requirement for Detectors in The Deep Glacier?

- **No access after deployment**
- **> 10 years without any maintenance**
- **Cable length max. 3.3 km**
- **A/D conversion inside the module**
- **Operation under -40 ~ -20 deg.**
- **High pressure (max. @ re-freezing while deployment)**
- **Limited power consumption**

IceCube DOMs...

Room for Further Improvement?



- IceCube DOMs work very well over a decade
 - ▶ Under high pressure & low temperature
 - ▶ Waveform measurement (max. 300 MHz)
 - ▶ Hamamatsu 10" PMT
- Large contribution of R&D from Chiba IceCube Group

- **Only one PMT seeing downward**
 - ▶ Useful for vetoing & reconstruction if segmented sensors
- **UV-opaque glass is not suitable Cherenkov photon detection**
 - ▶ Modest UV-transparency (10% @ 320 nm) of the glass vessel

Develop improved Optical Module for IceCube-Gen2 based on the proven technology with IceCube DOMs

D-Egg for IceCube-Gen2

*Dual optical sensor
in a Ellipsoid Glass for Gen2*

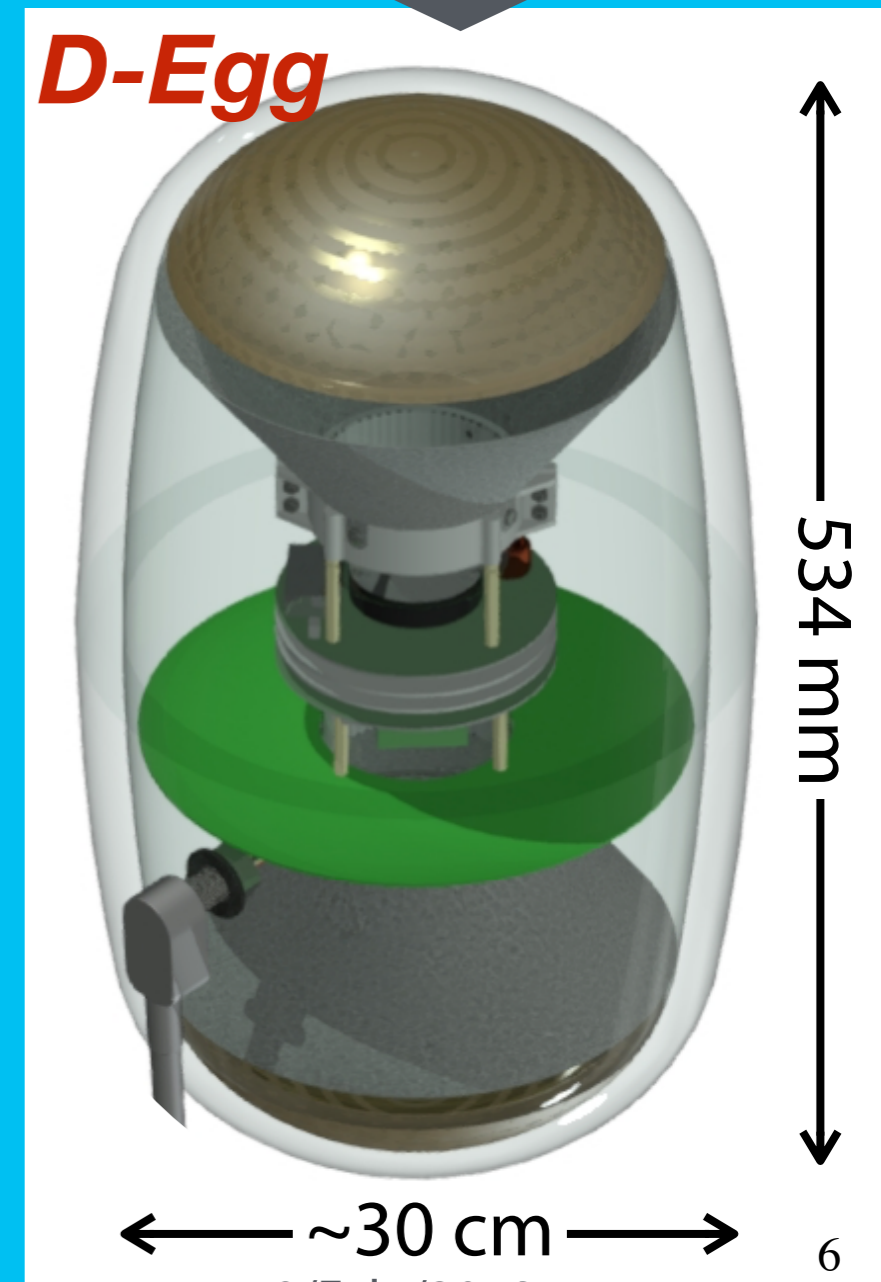
- **Inherit the basic concept from DOM**
- **Two 8" PMTs**
 - ▶ Hamamatsu R5912-100
- **Improved glass vessel**
 - ▶ High photon detection eff. expected by highly UV-transparent glass
 - ▶ 'Slim' design to reduce drilling cost (~20%)
- **Single ADC for each PMT**
 - ▶ 250 MHz sampling
 - ▶ Continuous data taking

**-> D-Egg has been developed
in IceCube Chiba Group**

DOM

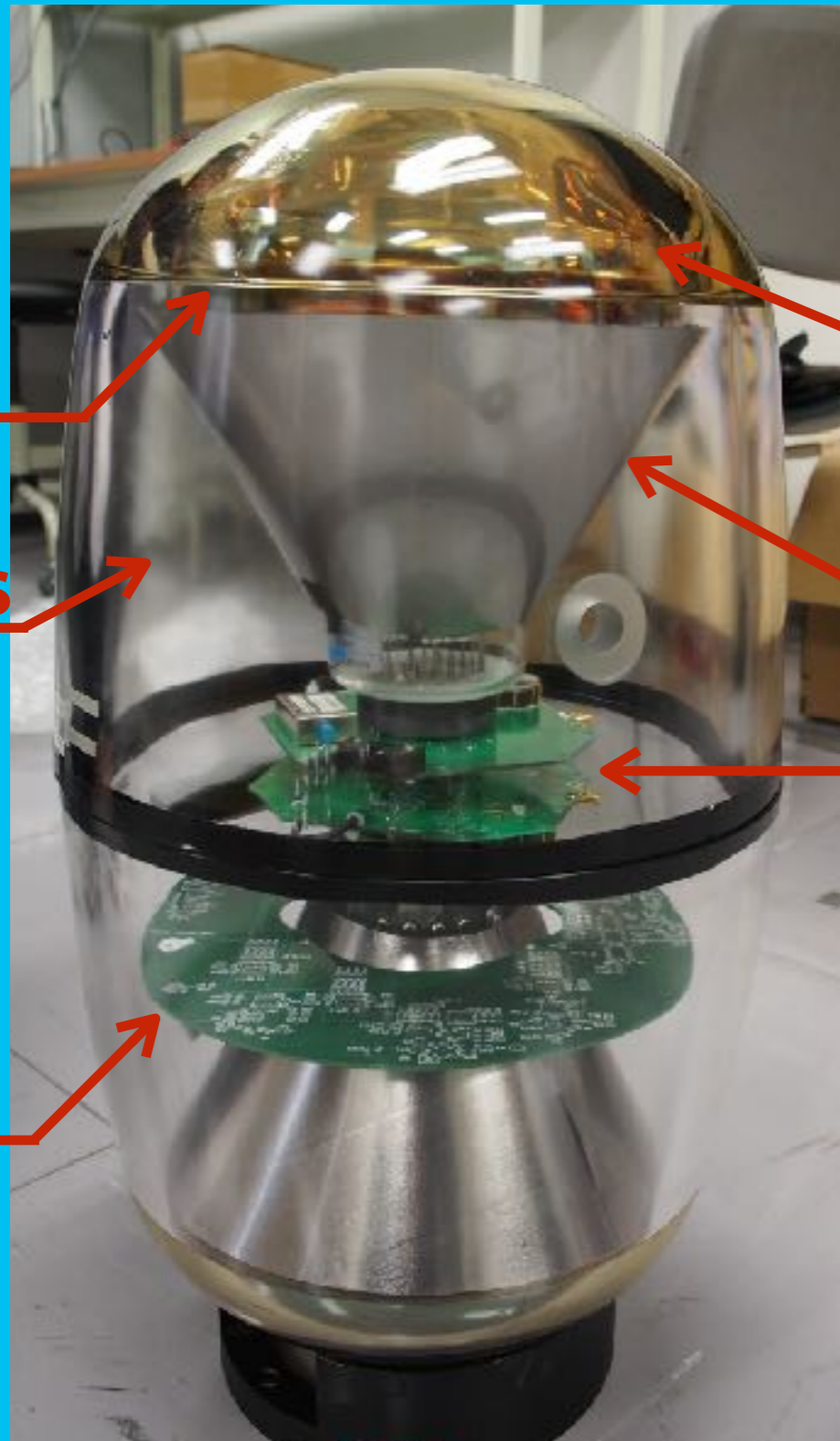


D-Egg



D-Egg R&D / Current Status

- **Current : Revision 2**
- **Next revision : 7 D-Eggs until April**



Gel

8" PMT

Glass

Magnetic shield

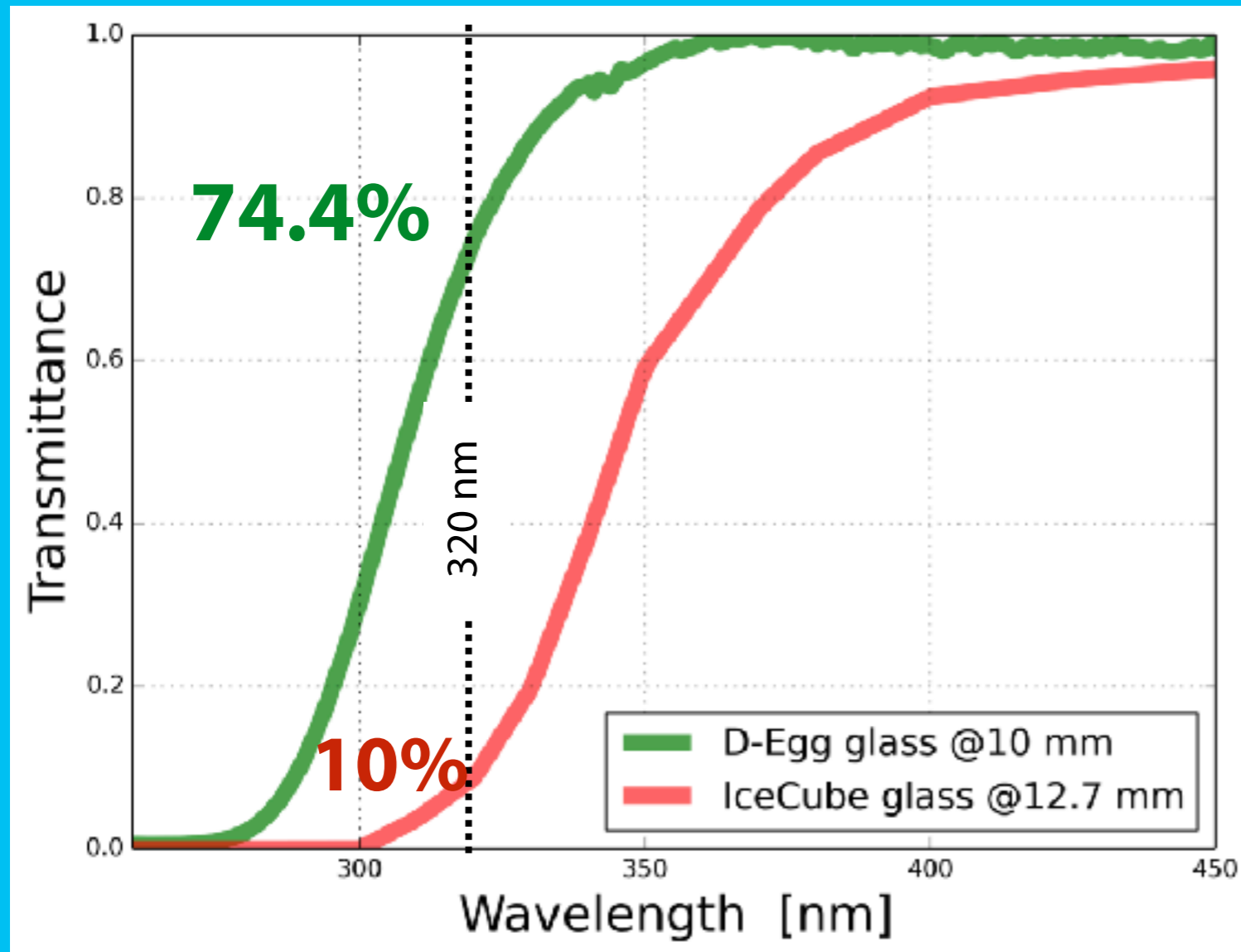
HV divider circuits

Main Board

- **This talk : Performance studies with Prototype D-Egg**
 - ▶ Detection efficiency
 - ▶ Dark rate
 - ▶ Uniformity

Better Glass For More Photons

Developed highly UV-transparent glass not to miss 300-400 nm photons
(Cherenkov spectrum $\sim \lambda^2$)



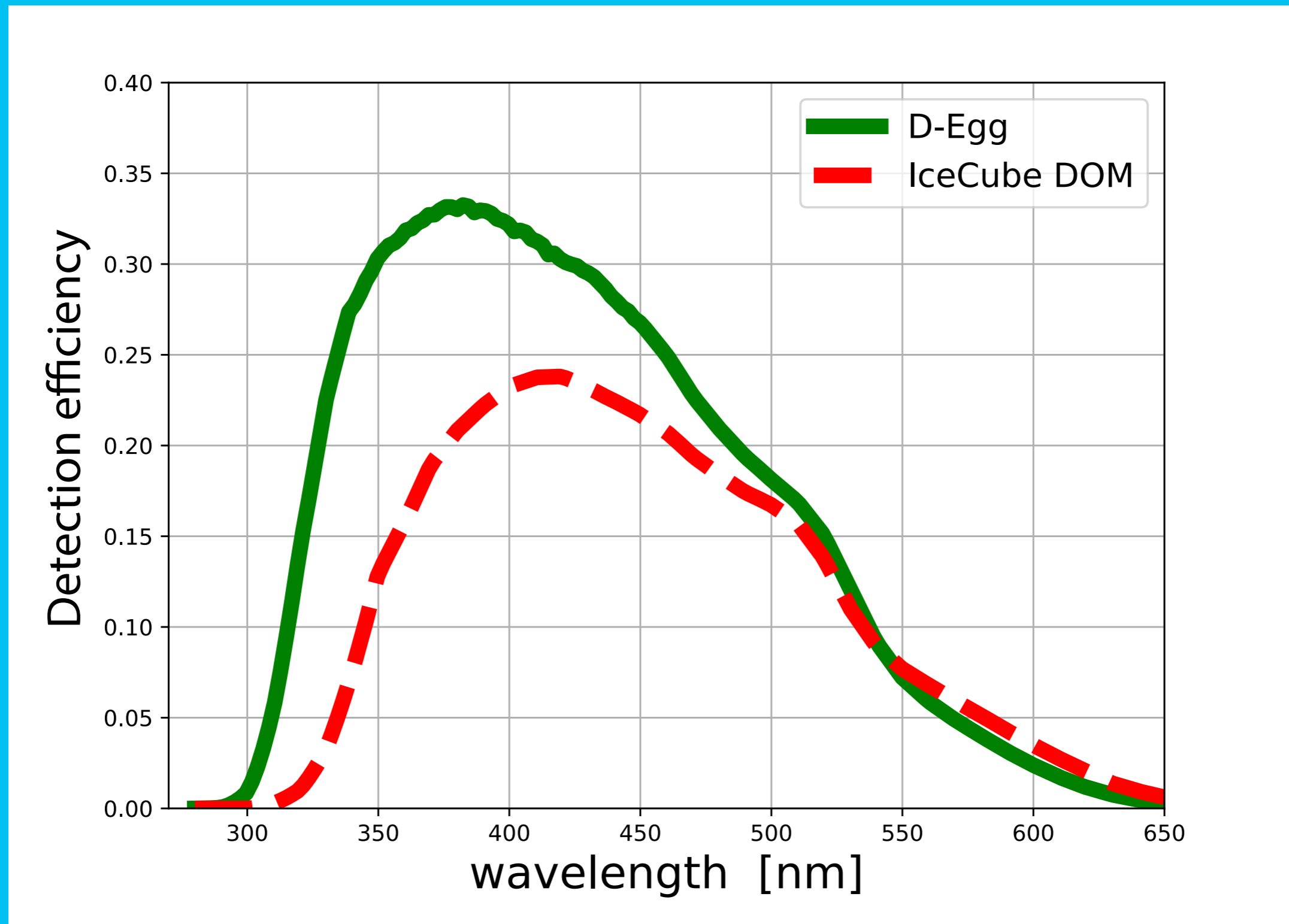
Glass
10 mm @ bottom



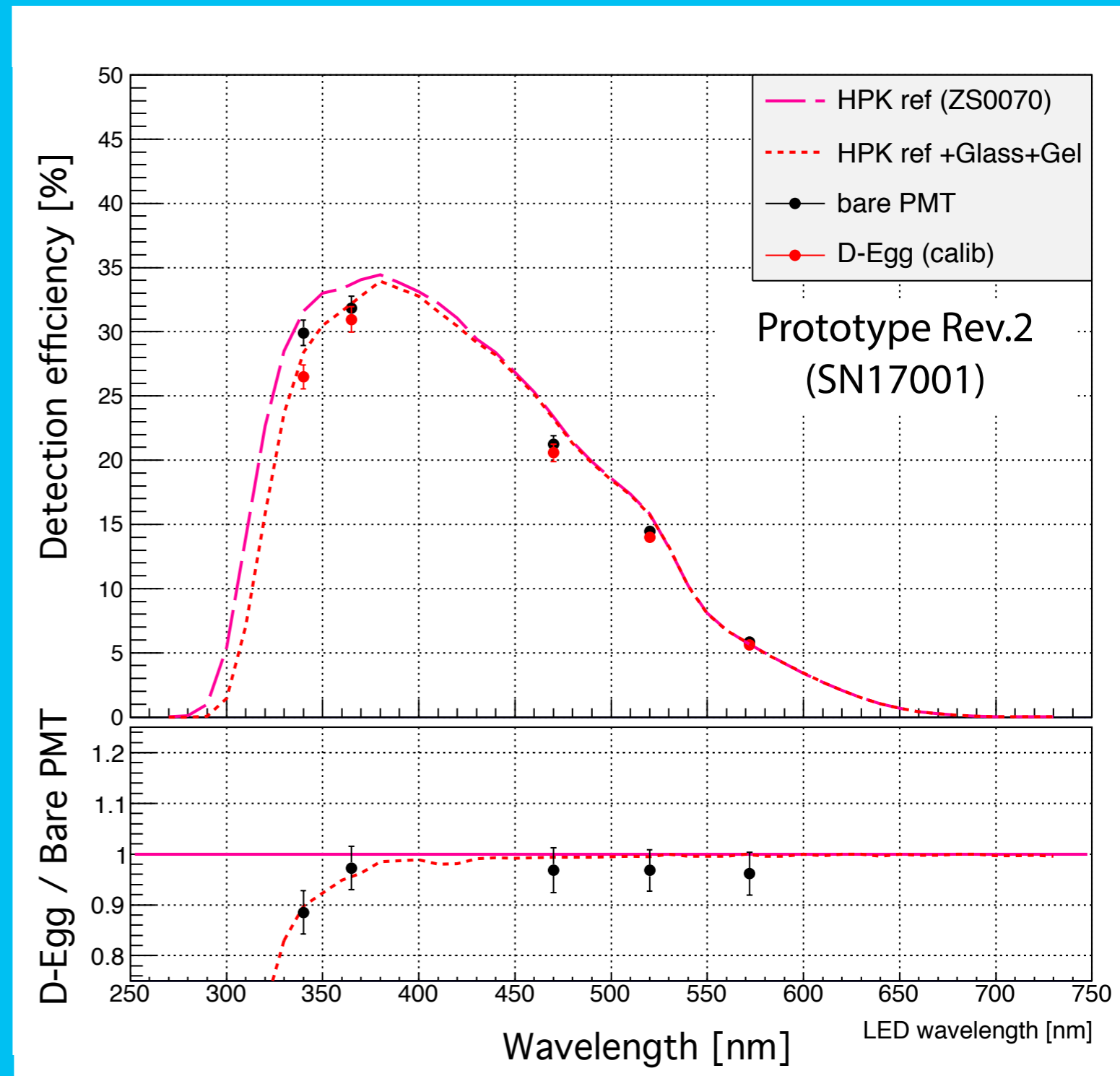
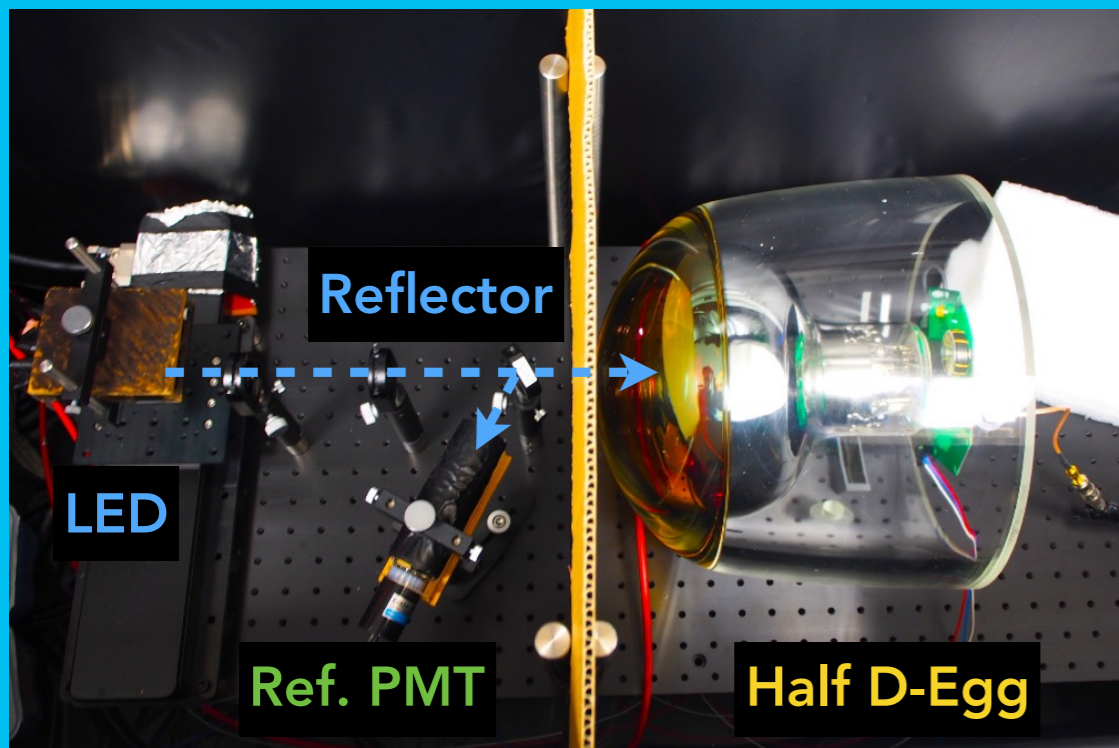
Glass & PMT are
coupled with gel

- **New glass shows significantly improved transmittance in particular at short wavelength (75% for D-Egg glass, 10% for DOM glass @ 320 nm)**

Expected D-Egg Detection Eff.



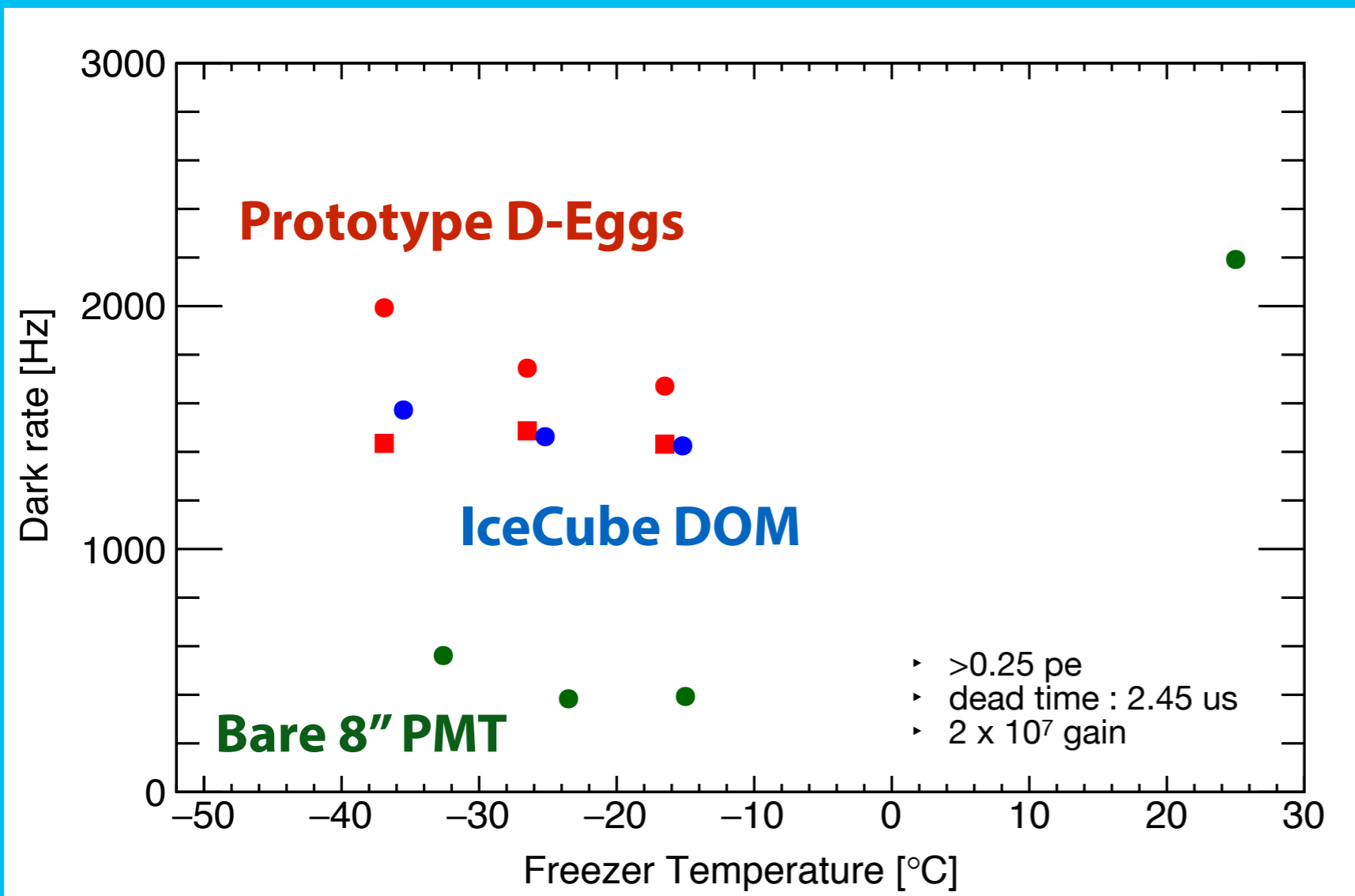
D-Egg Detection Efficiency



- **Obtained detection efficiency is 31% @ 365 nm**
- **New Glass and Gel reduce the efficiency by only level of 10%**

Dark Rate @ Low Temperature

Expected to be -40 ~ -20 deg. after the deployment



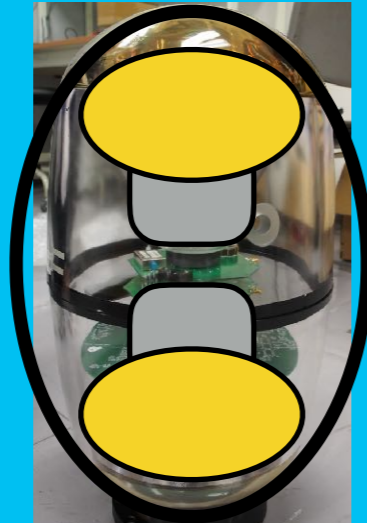
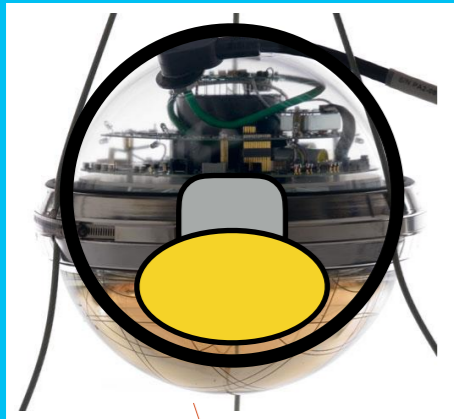
(⁴⁰K-reduced) Glass



- Current revision of **D-Egg modules show comparable dark rates with IceCube DOM**
- (Absolute values depend on the lab environment)

Noise Modeling

Current IceCube Noise Model



DOM and D-Egg are very similar design,
thus it's fair to expect that the current noise model is still valid

-> Can be confirmed by time interval distribution of the observed noises

Thermal noise
[Poisson process]

Time scale
(~ms)

+

Radioactive decay in glass
[Poisson process]

↓

Energy deposit in glass

↓

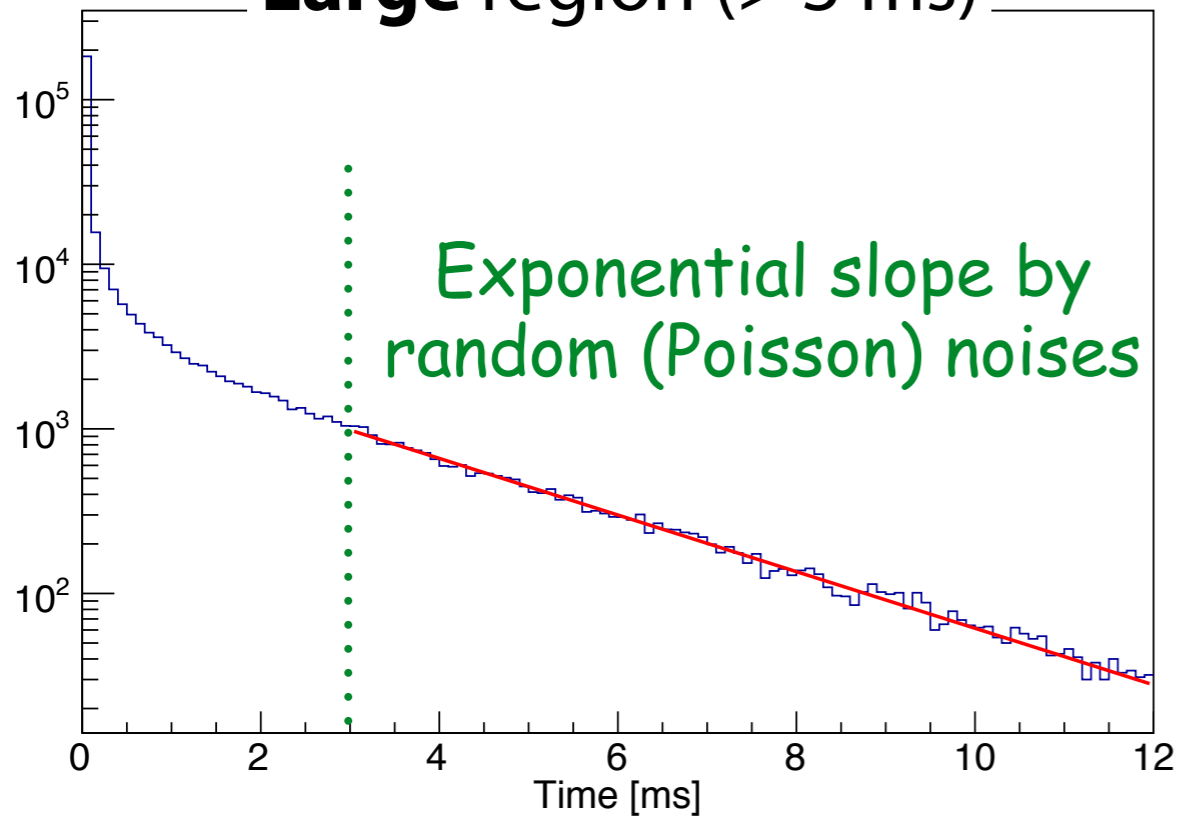
Glass scintillates/fluoresces
over long time scale
[Log-normal]

Time scale
(~ms)

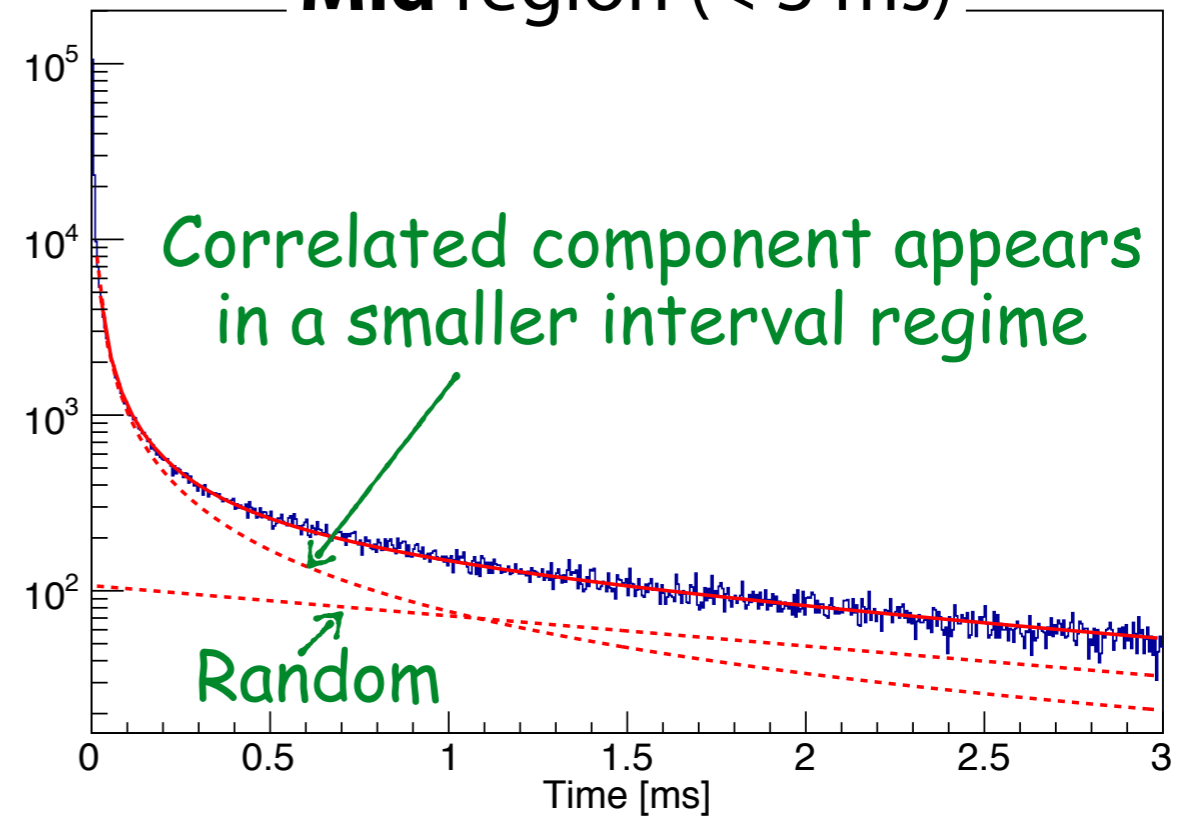
"Correlated noise"
Time scale
(< ms)

Noise Time Interval Distributions

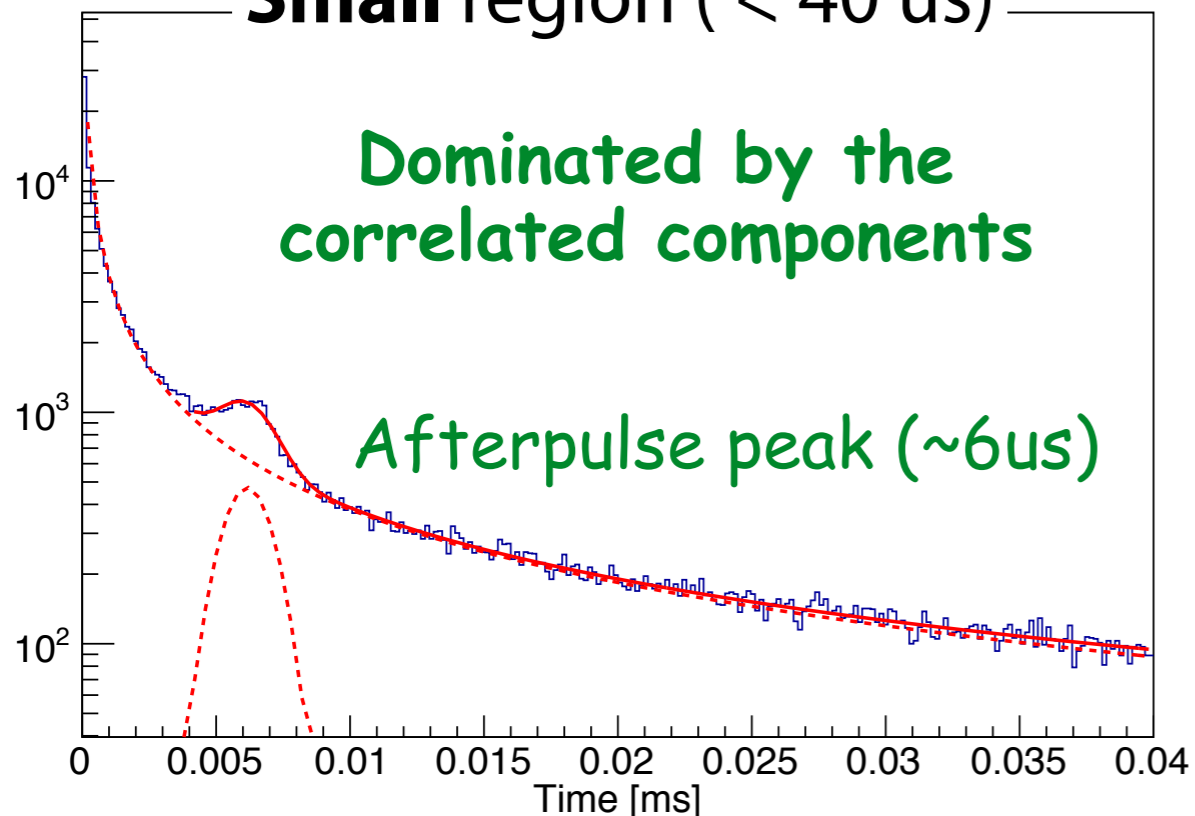
Large region (> 3 ms)



Mid region (< 3 ms)

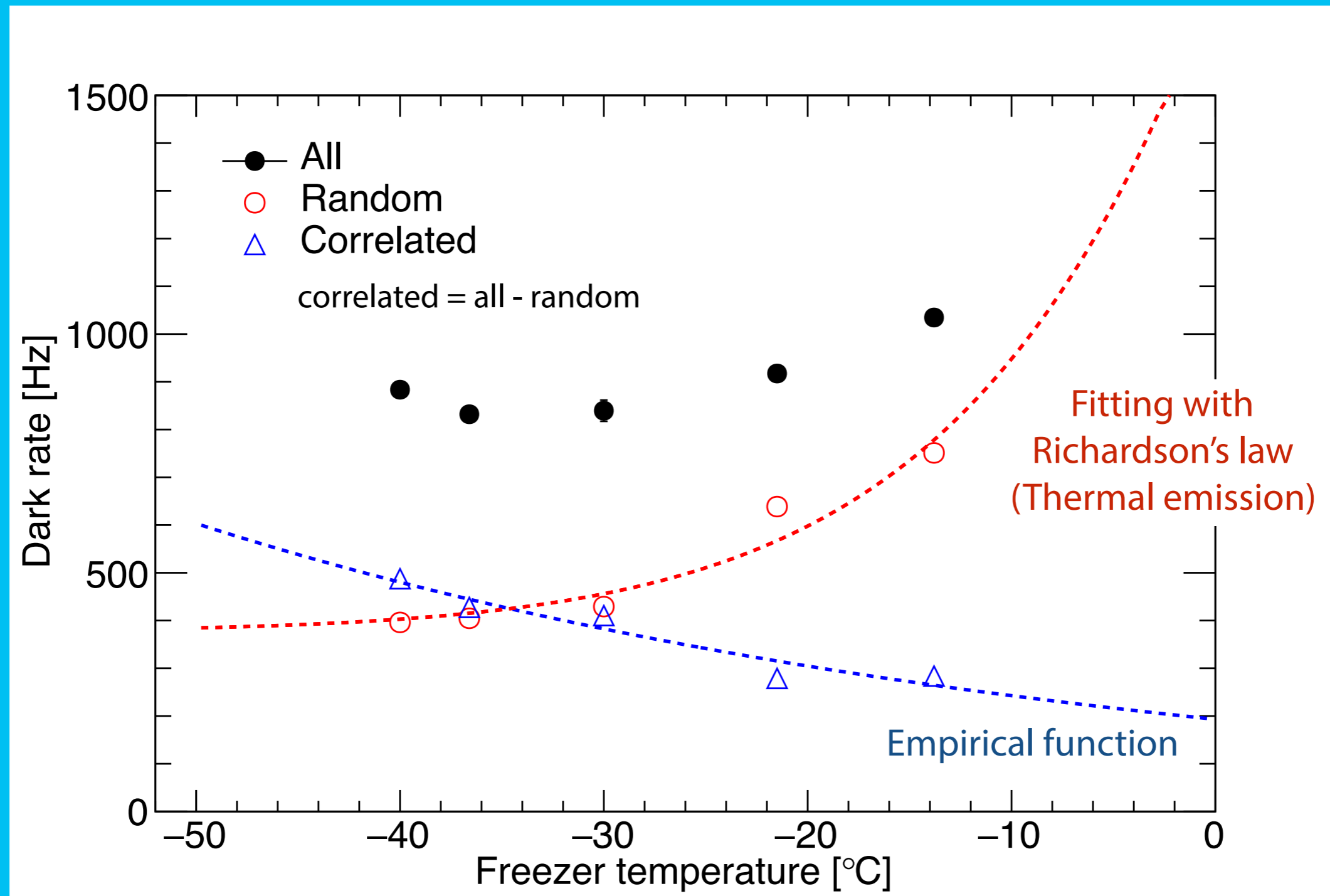


Small region (< 40 μ s)



Noise property of D-Egg is described very well with the current model (Exp + Log-normal + Gauss).

Dark Rate @ Low Temperature



More detailed property of the correlated component is under investigation

Magnetic Shielding & Uniformity

FINEMET for D-Egg instead of conventional Mu-Metal shielding

- **Mu-metal shielding**

- ▶ Performance proved by IceCube DOM
- ▶ Expensive
- ▶ Problem under low temp with D-Egg Gel

- **FINEMET shielding**

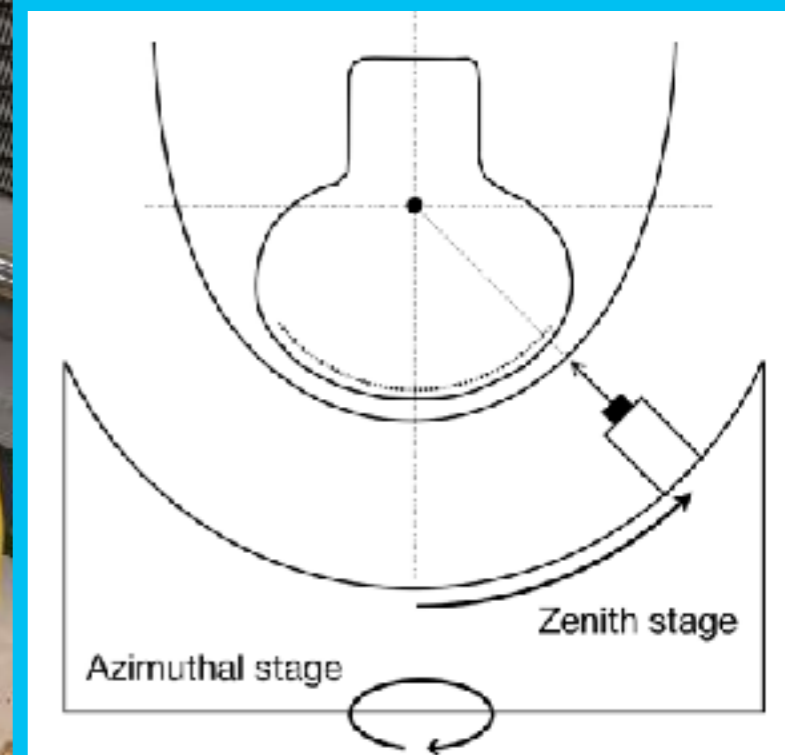
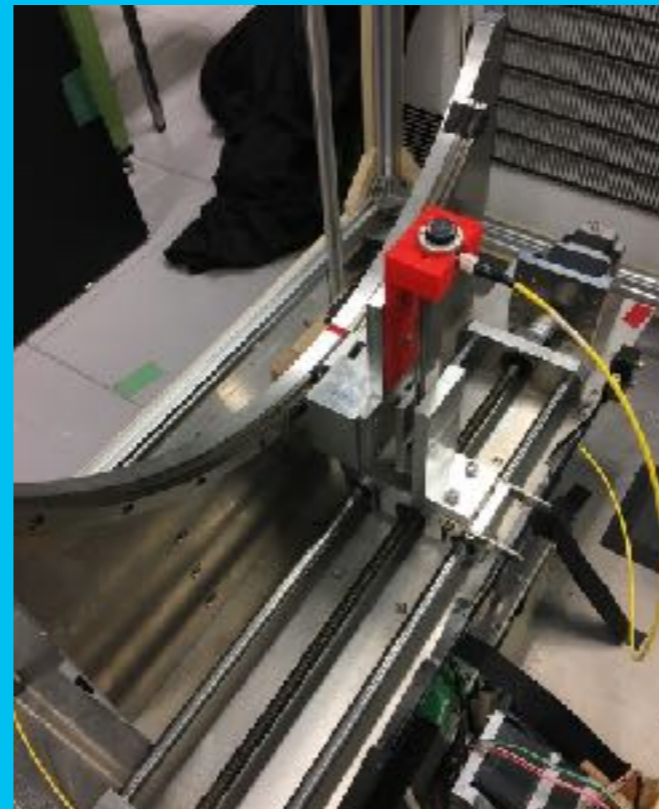
- ▶ Low-cost & Easy to mount
- ▶ Used in DayaBay (P. DeVore et. al., NIM A (2014))



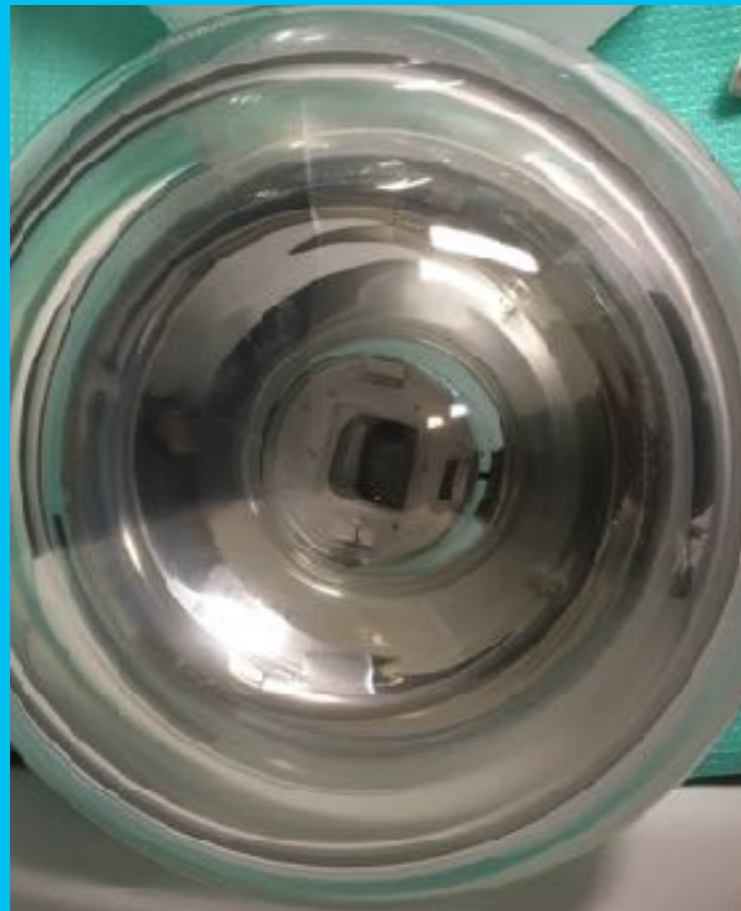
Check FINEMET
performance experimentally

2D Scan System in Chiba Univ.

- Fast laser (400 nm, $\phi=2\text{mm}$)
- Ability of absolute measurement
- 1 night for a full scan
 - ▶ 72 (azimuthal) x 63 (zenith) step

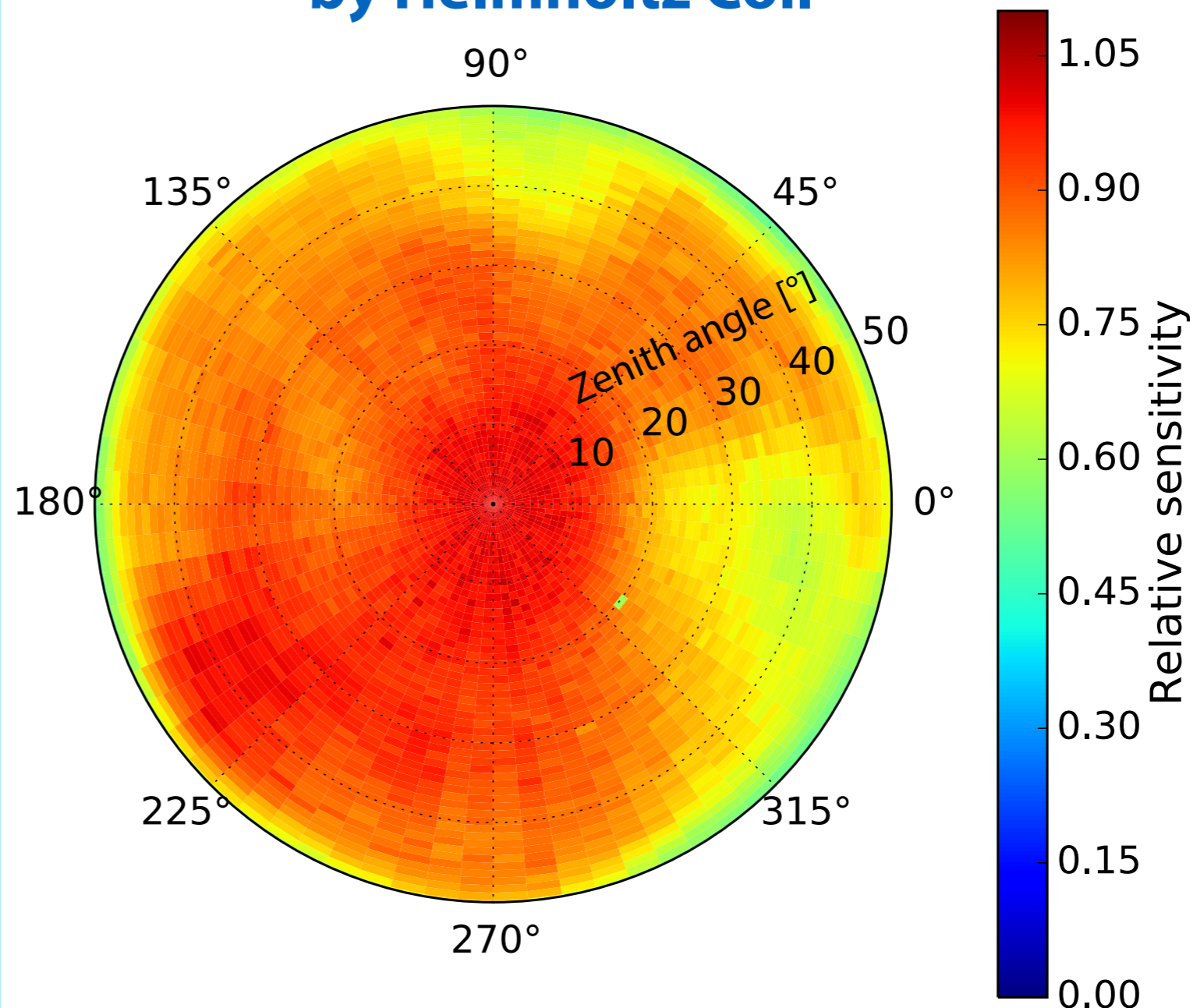


D-Egg Uniformity / If No Geomagnetic Field...



R5912-100
Box&Line type

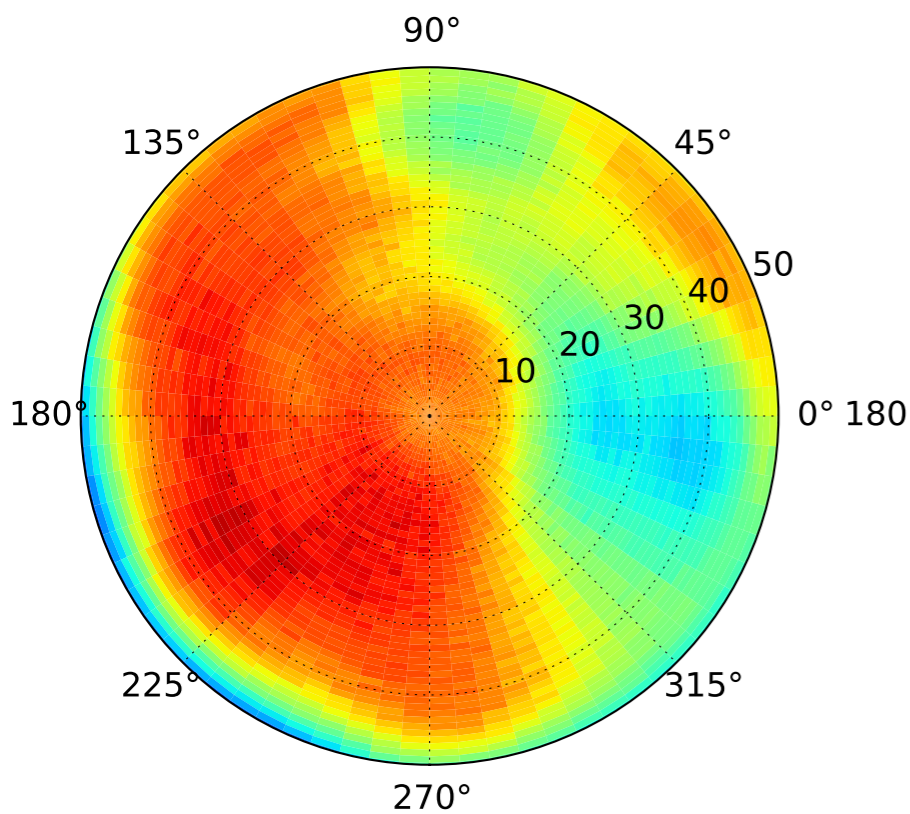
Active geomagnetic field cancellation by Helmholtz Coil



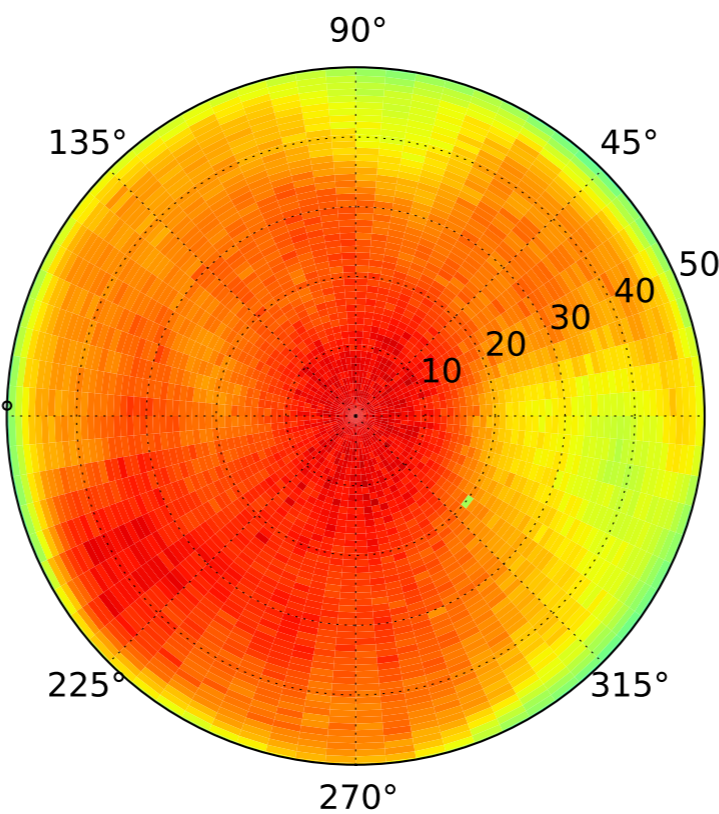
- **Mostly uniform, but local minimum due to the 1st dynode structure**

FINEMET Shielding & Others

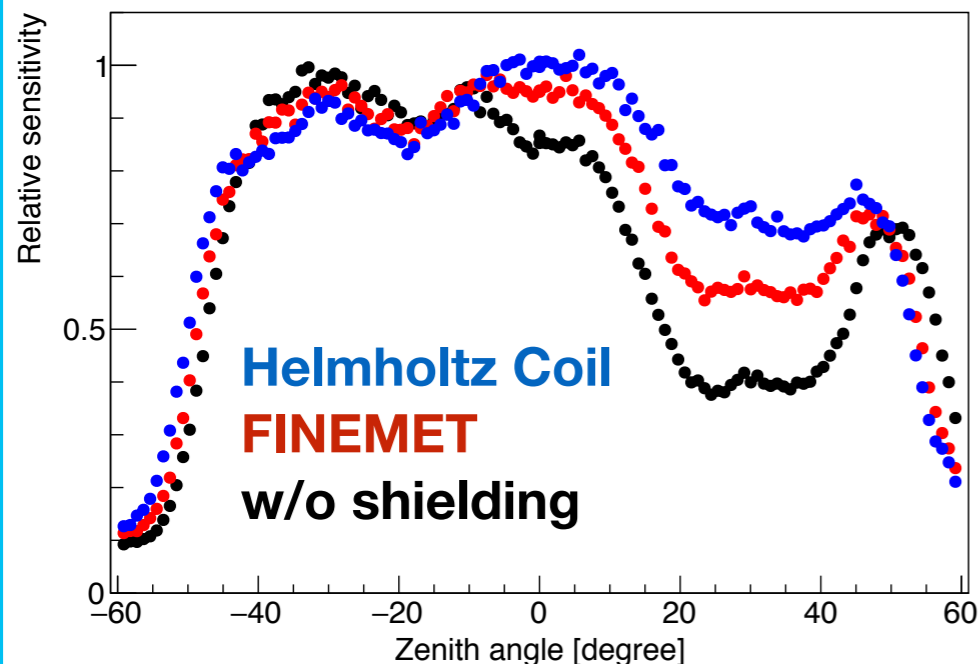
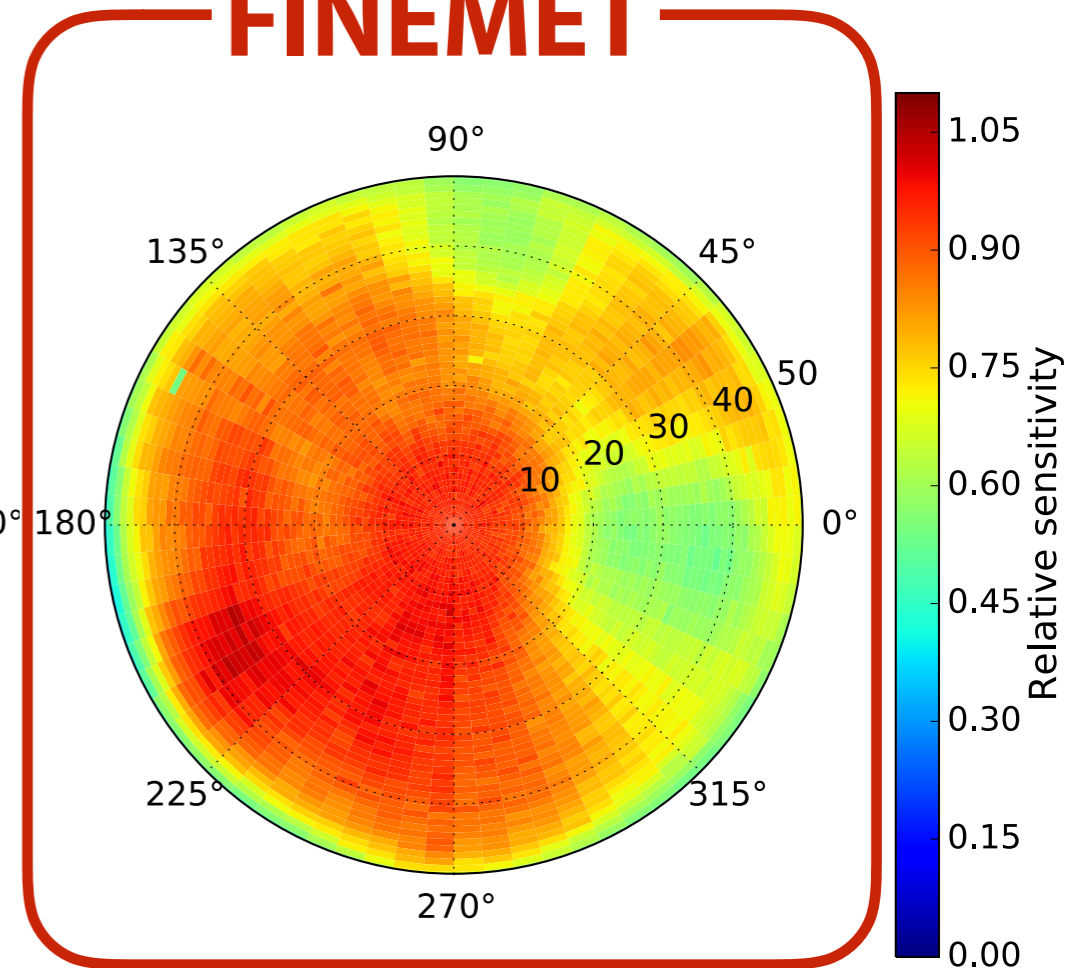
w/o shielding



Helmholtz Coil

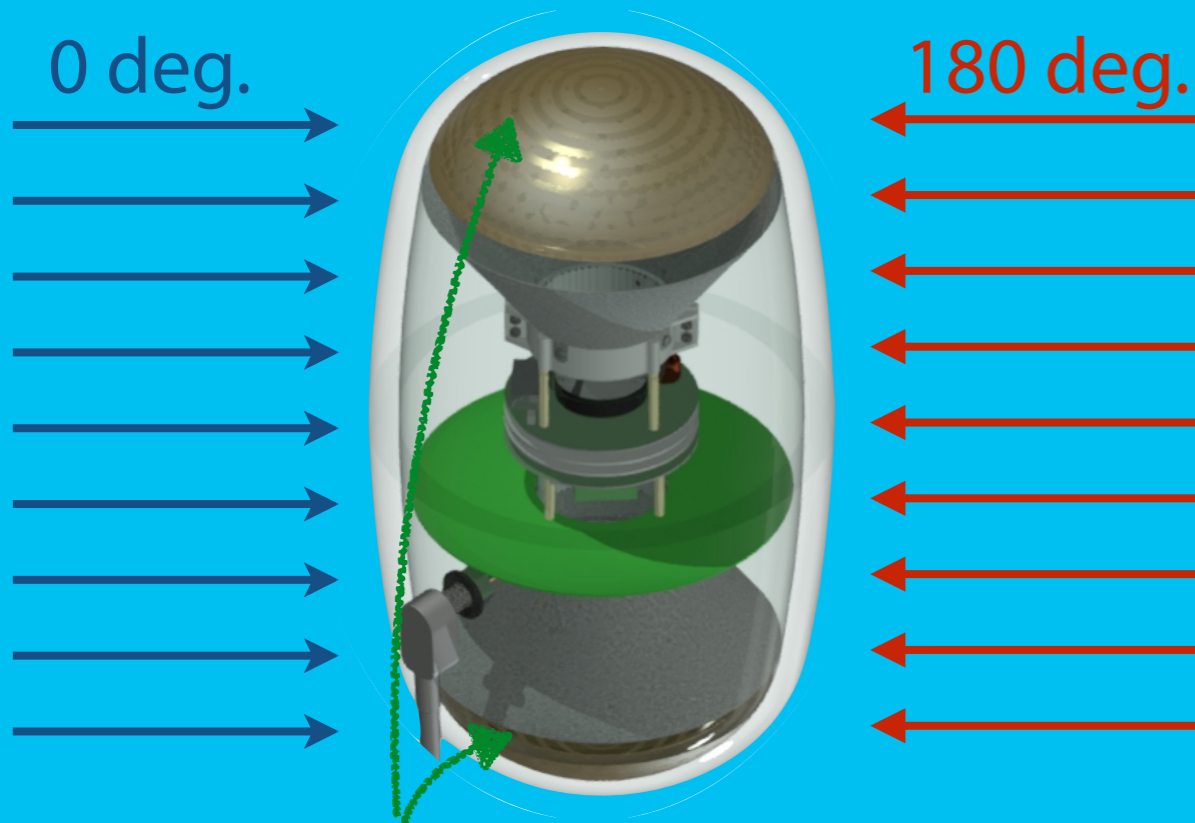


FINEMET



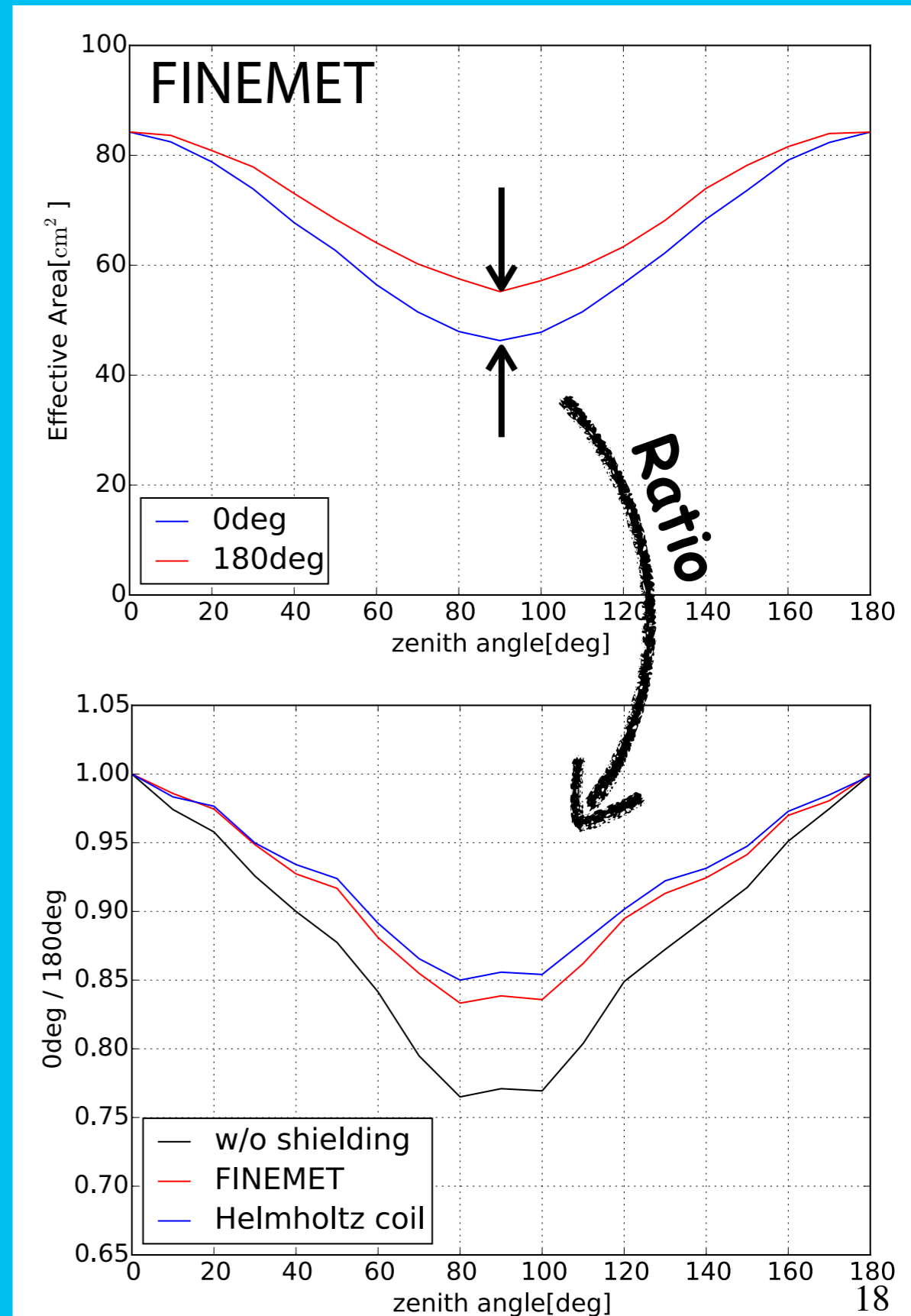
**<= Slicing along the
dynode direction**

Effective Area Azimuthal Dep.



Assuming the local minimum locates one side

- Effective area estimation
 - Simulation (geometry+photon propagation) + Measured PMT response
- 15 % asymmetric due to the intrinsic feature of the PMT
- FINEMET works as well as Helmholtz Coil, thus **FINEMET shielding is good**



Calibration Device(s) & More



- Still **plenty of room for optional device(s)**
- Ideas under studying
 - ▶ **Collimated LEDs** (standard option)
 - Calibration light source for better understanding of the ice-property
 - ▶ Tilt meter
 - ▶ Geomagnetic field sensor
 - ▶ Camera system
 - ▶ **Additional light sensor(s)**
 - Use of WLSF-belt under investigation
 - e.g.) Low-gain channel for the saturation correction

Summary

- **Need new Optical Module for IceCube-Gen2, “D-Egg” has been developed in IceCube Chiba Group**
 - ▶ More photons with two 8” PMTs in a highly-UV transparent glass
 - ▶ Full waveform measurement with 250 Msps
 - ▶ Optional sensor/calibration device under study
- **D-Egg Prototype Rev.2 shows**
 - ▶ High detection eff., 31% @ 365 nm
 - ▶ Dark rate comparable with IceCube DOM
 - ▶ Magnetic shielding by FINEMET works well
- **Deployment starts from 2021 as IceCube-Gen2 Phase1**
 - ▶ ~ hundreds D-Eggs