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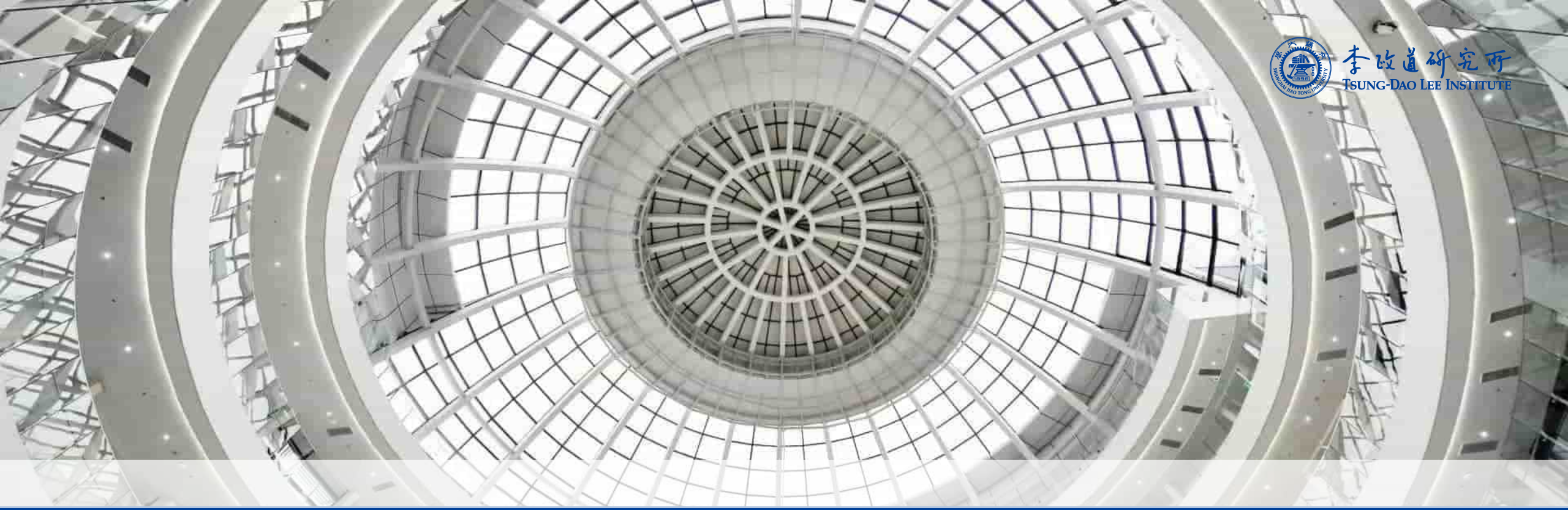
Characterization of the PMT System in the TRIDENT Pathfinder Experiment

Fuyudi Zhang, Ziping Ye, Fan Hu, Donglian, Xu

TRIDENT Collaboration

2022.08.11



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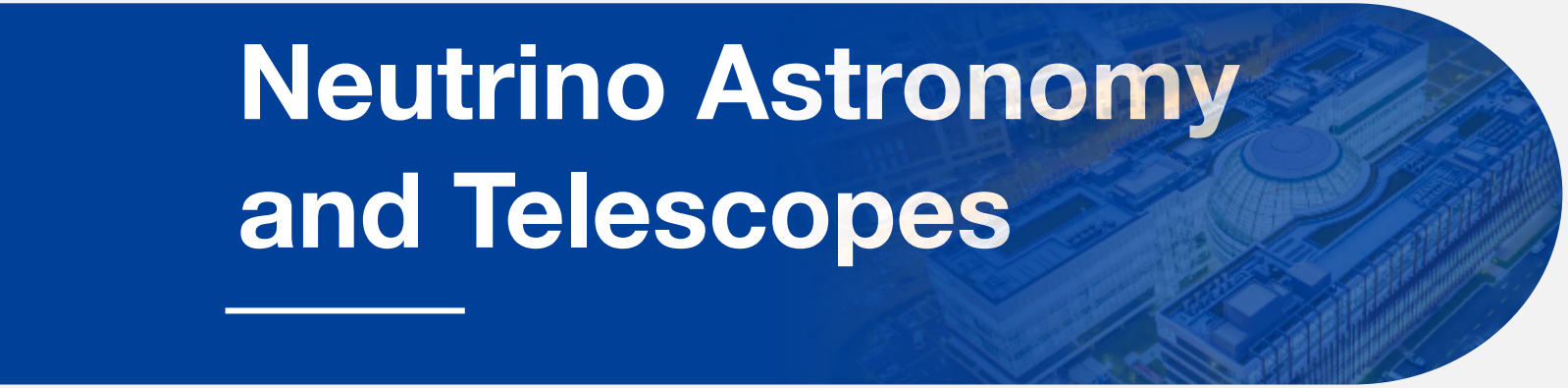
Neutrino Astronomy and Telescopes



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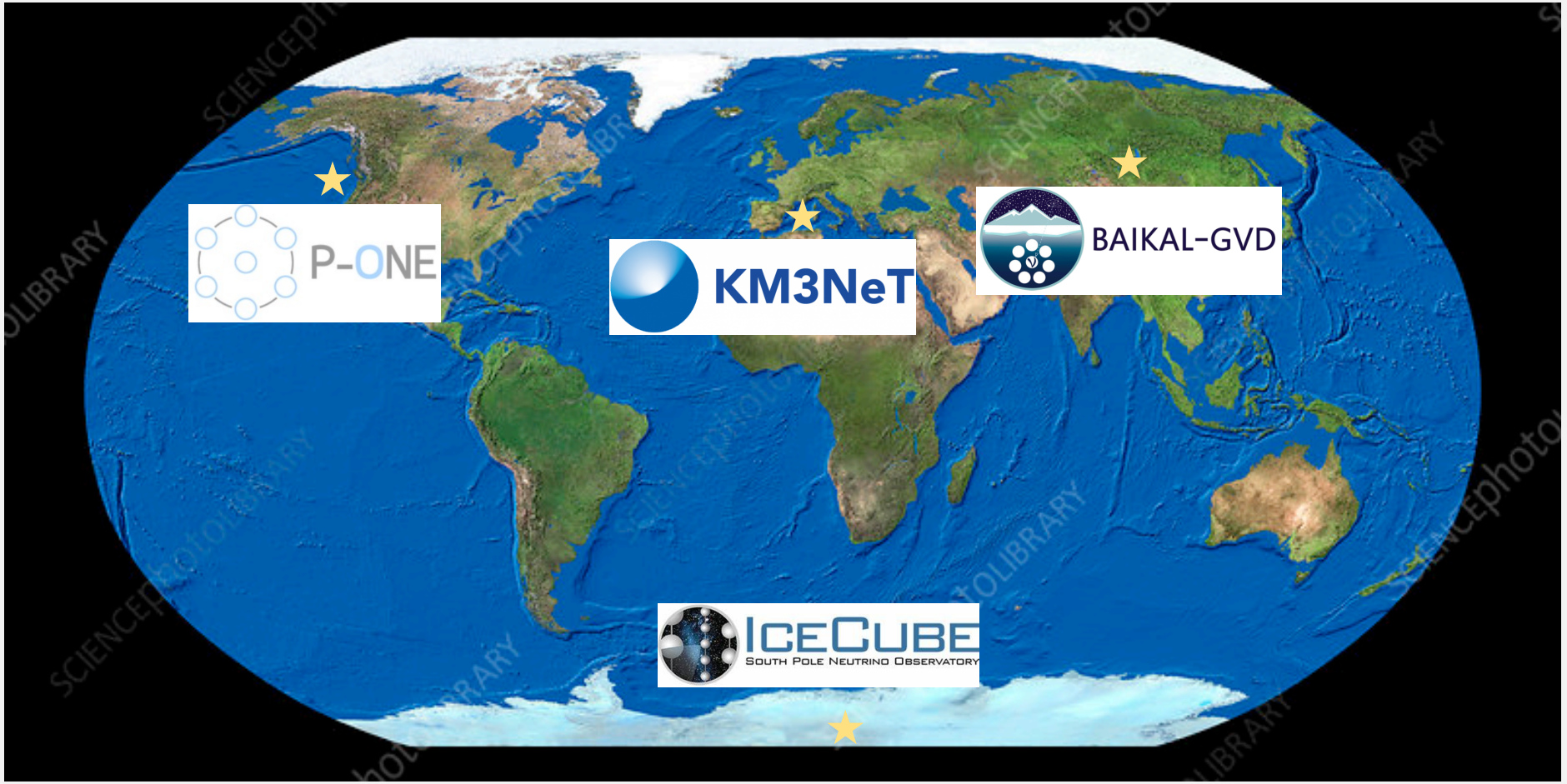
Neutrino Astronomy and Telescopes

- High energy neutrinos as astronomical messenger
- Neutrino telescopes in the world



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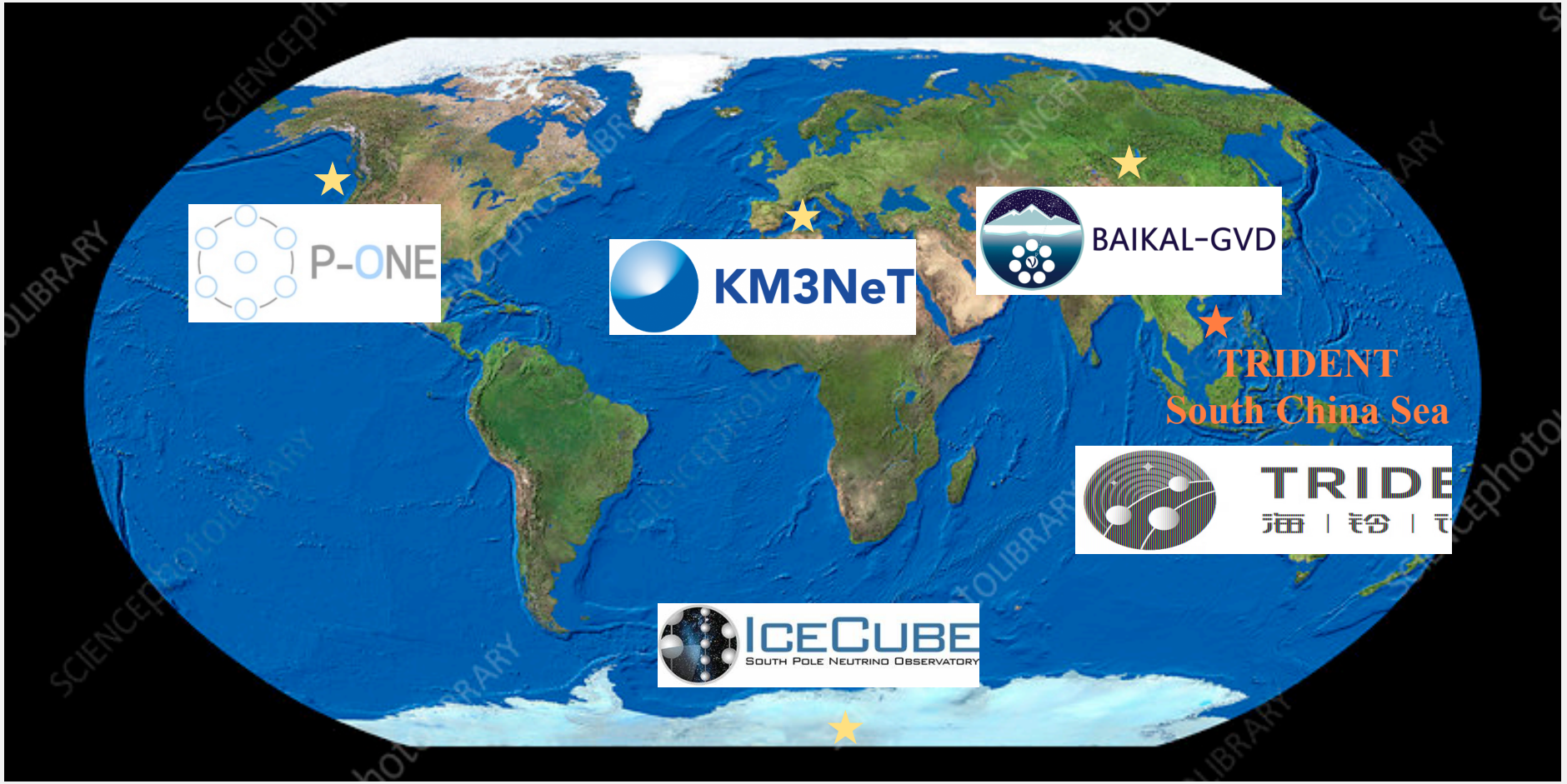

PART 02

TRIDENT Pathfinder Experiment

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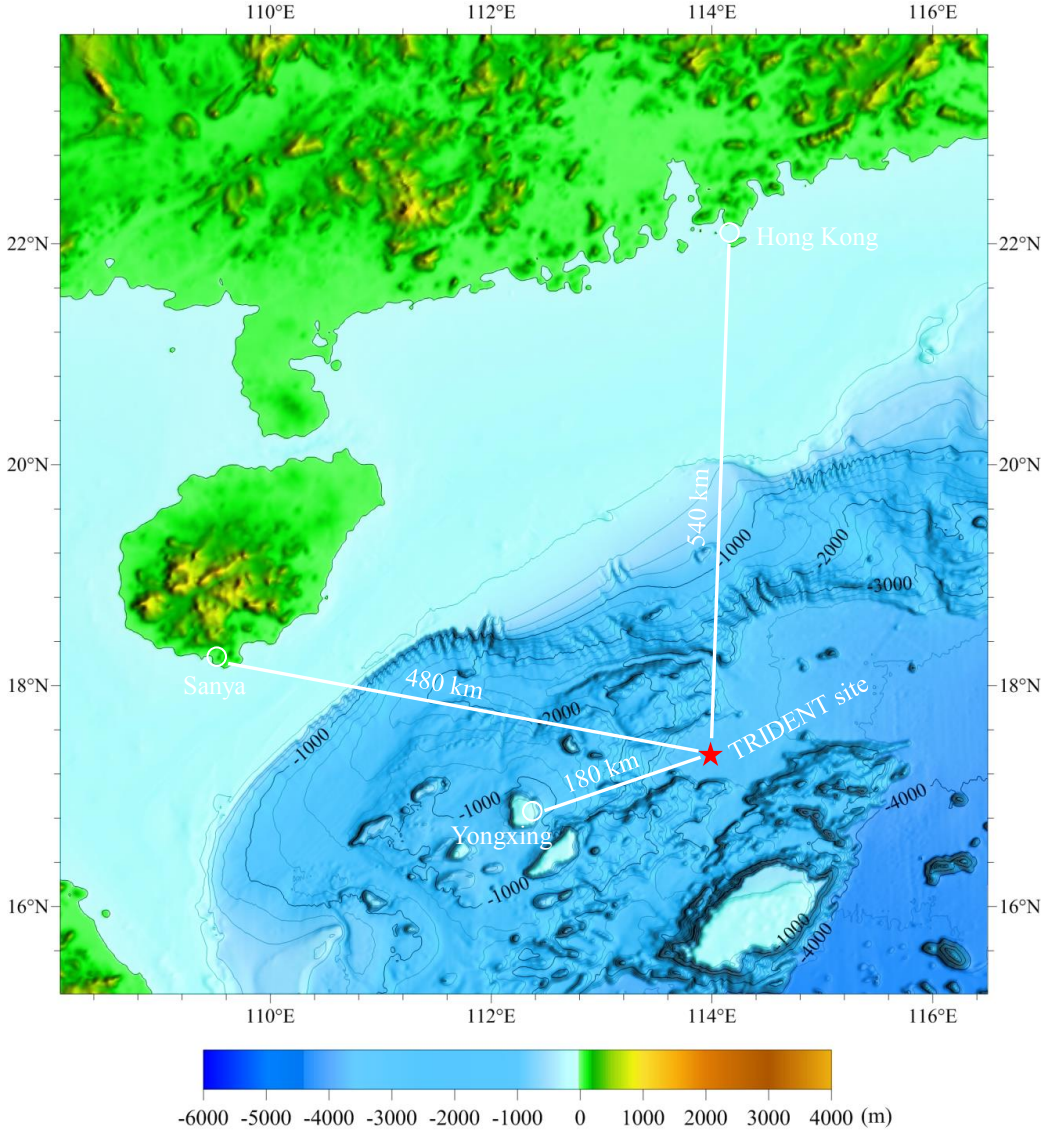
The tRopIcal Deep-sea Neutrino Telescope

- Selected Site: near 114.0°E, 17.4°N
  - Abyssal plain
  - full depth ~ 3.5km
  - 180 km away from Yongxing Island

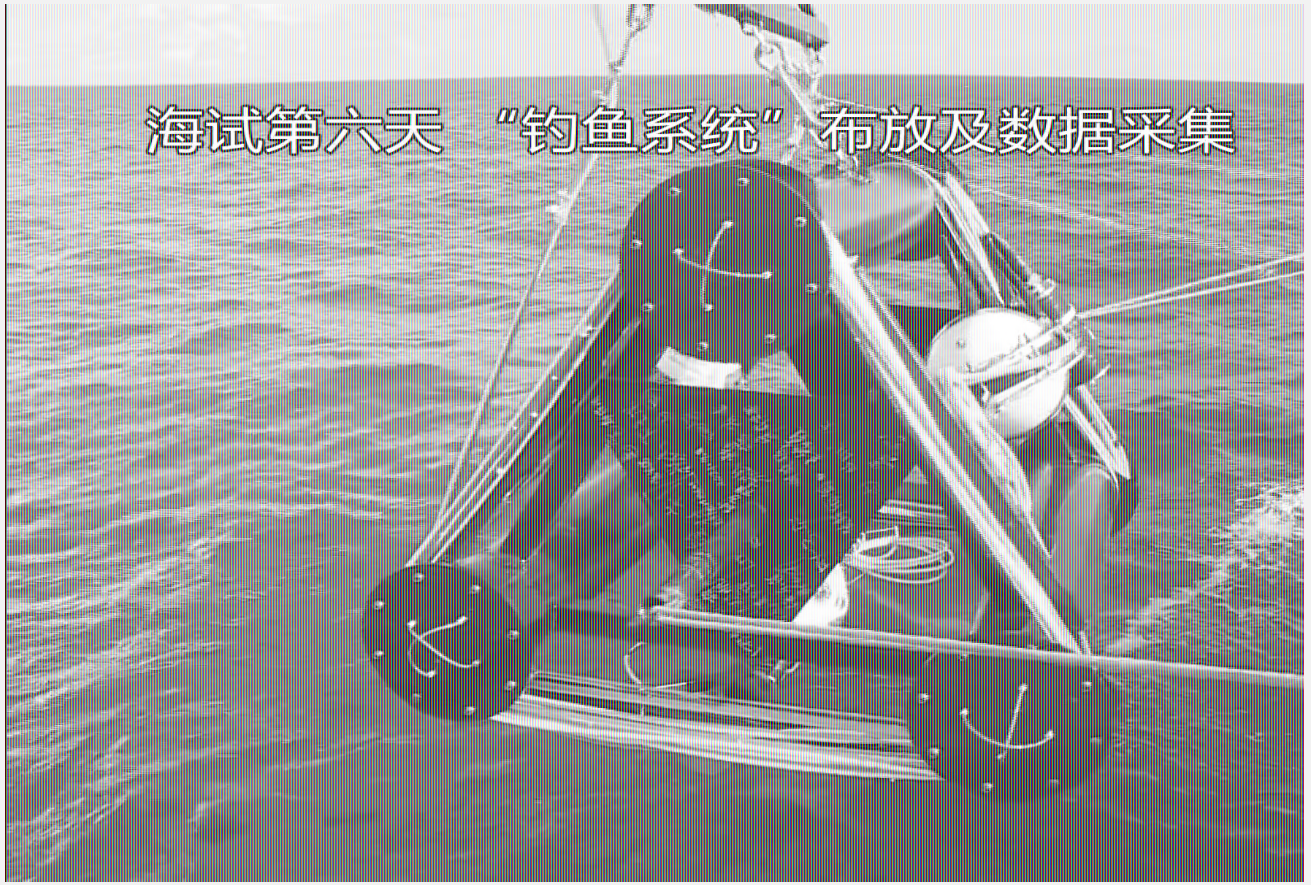


Z. P. Ye, et al., TRIDENT Collaboration, arXiv:2207.04519

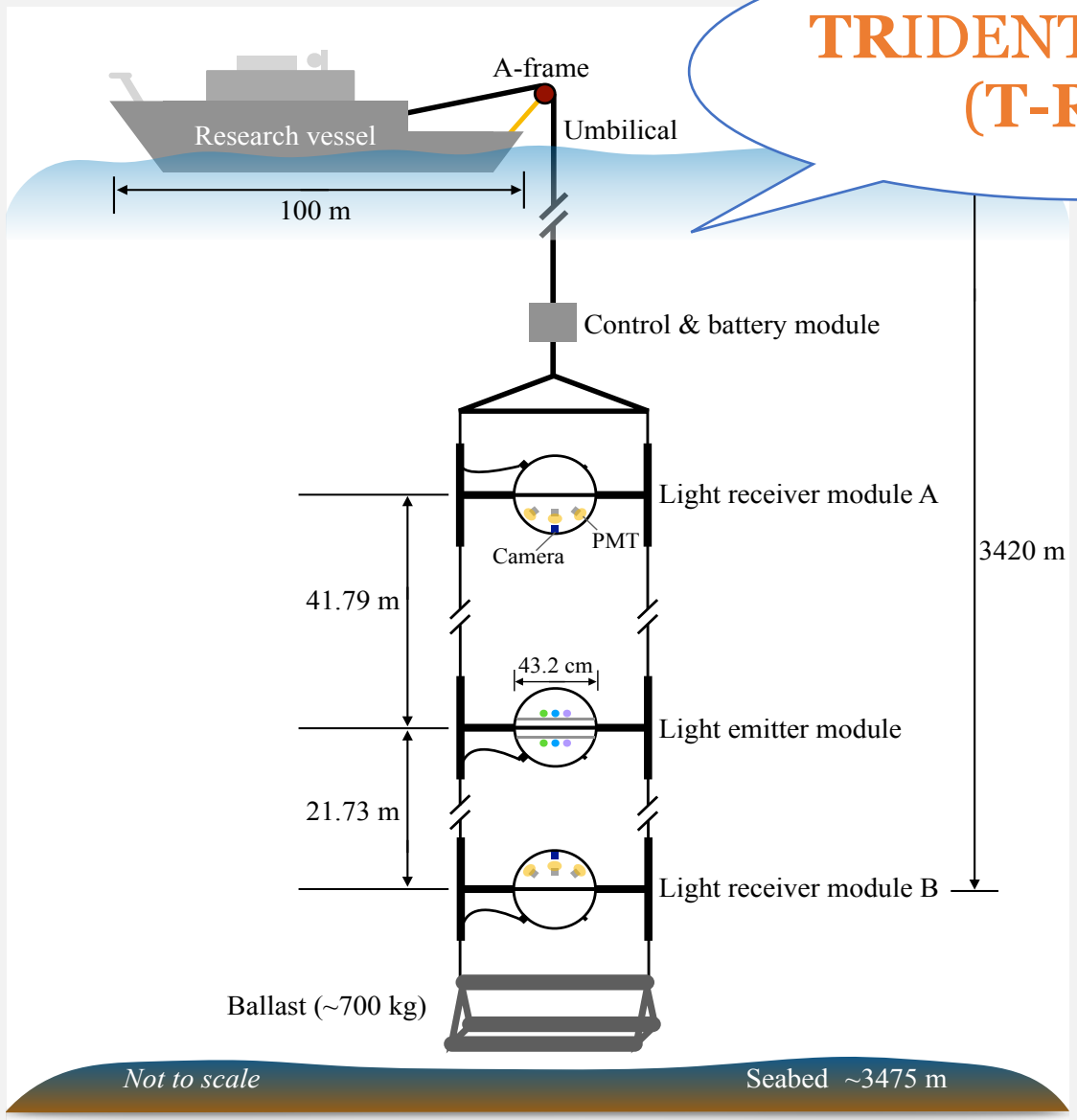
The tRopIcal Deep-sea Neutrino Telescope

- Selected Site: near 114.0°E, 17.4°N
  - Abyssal plain
  - full depth ~ 3.5km
  - 180 km away from Yongxing Island

- **TRIDENT Pathfinder Experiment**
  - carried out in 2021.09
  - *in-situ* measurements of optical properties



TRIDENT EXplorer (T-REX)



- Two measurement systems in Light Detection Modules:
  PMT and ***Camera***

See W. Tian's poster at Session IX(5): Particle Detector Technology

- Collecting data for ~ 2h
- (10, 50, 10) min for (405, 450, 525) nm pulsing LEDs, respectively
- Three 3-inch PMTs in each module
- PMTs are externally triggered in 10 kHz

PART 03

PMT System of T-REX

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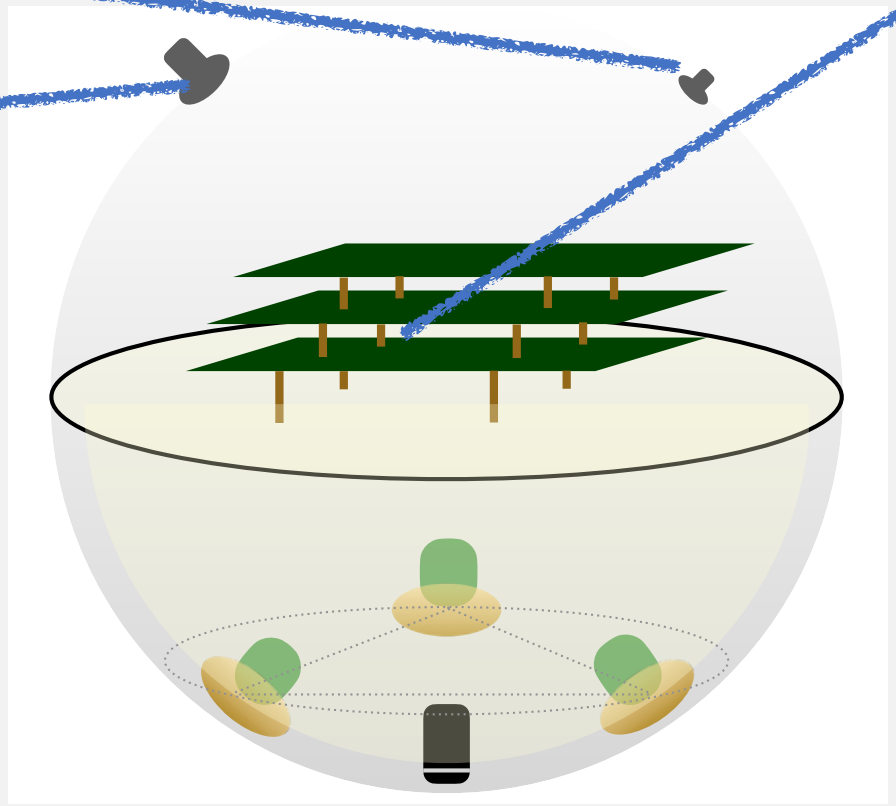
Light Detection Module

17-inch glass sphere

Penetrator & vacuum valve

Electronic boards for power supply, ADC and data transmission



See M. X. Wang's talk at Session VI(5): Particle Detector Technology

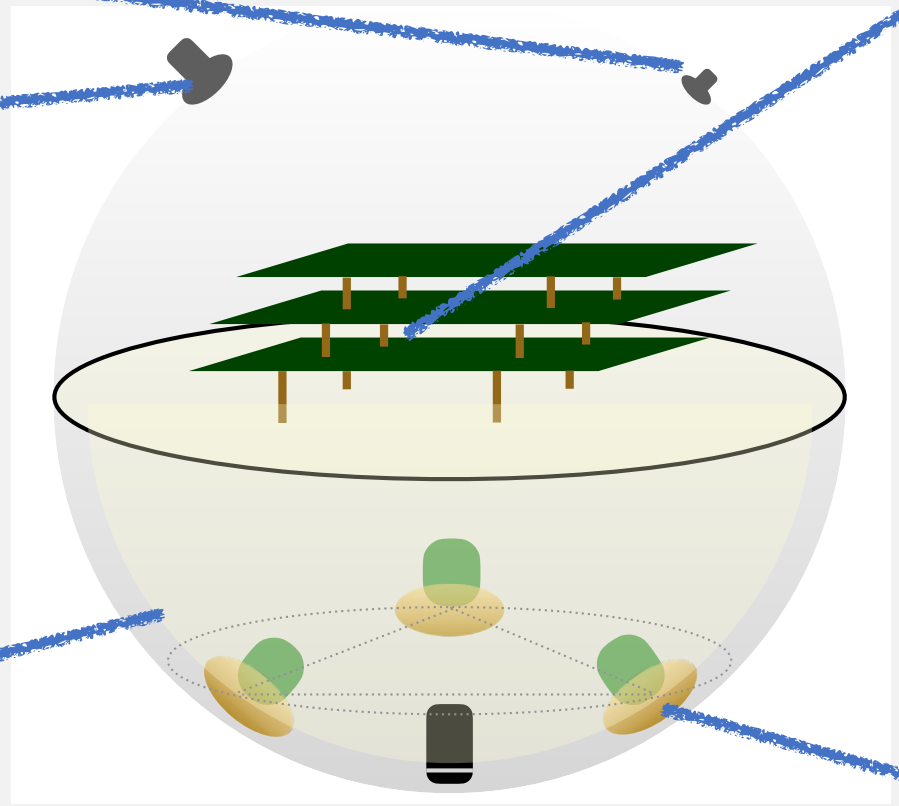
Light Detection Module

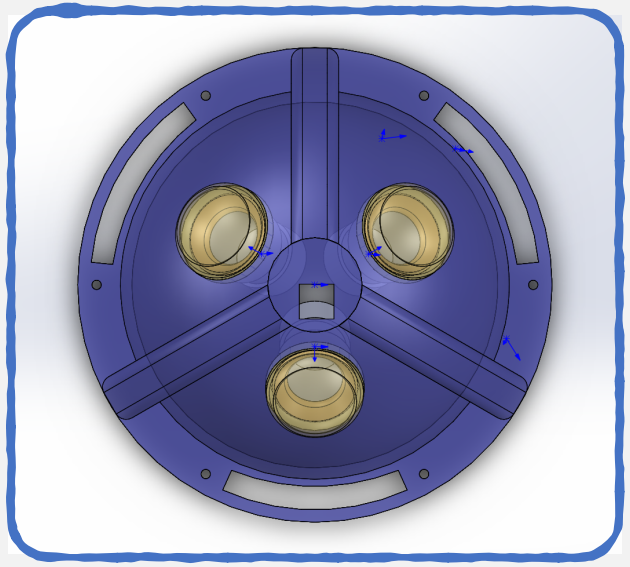
See M. X. Wang's talk at Session VI(5): Particle Detector Technology

17-inch glass sphere

Penetrator & vacuum valve

Electronic boards for power supply, ADC and data transmission





Optical gel

Three 3-inch PMTs

PMT Selection

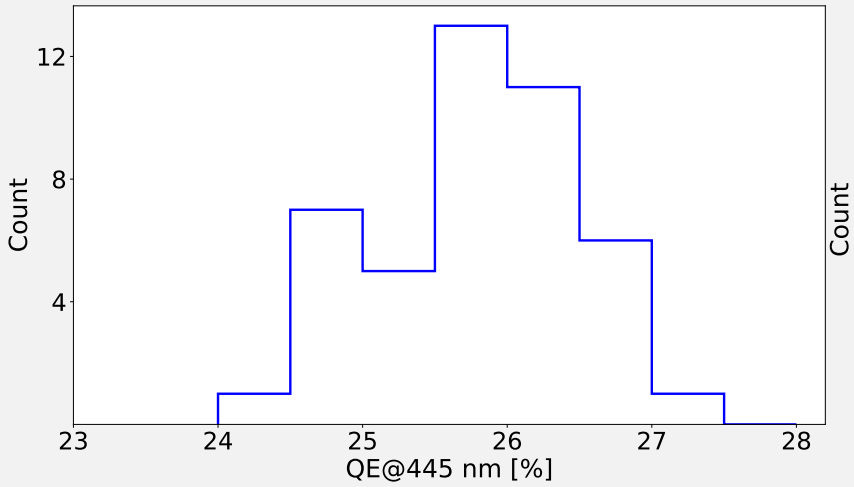
- HZC Photonics XP72B22 PMT

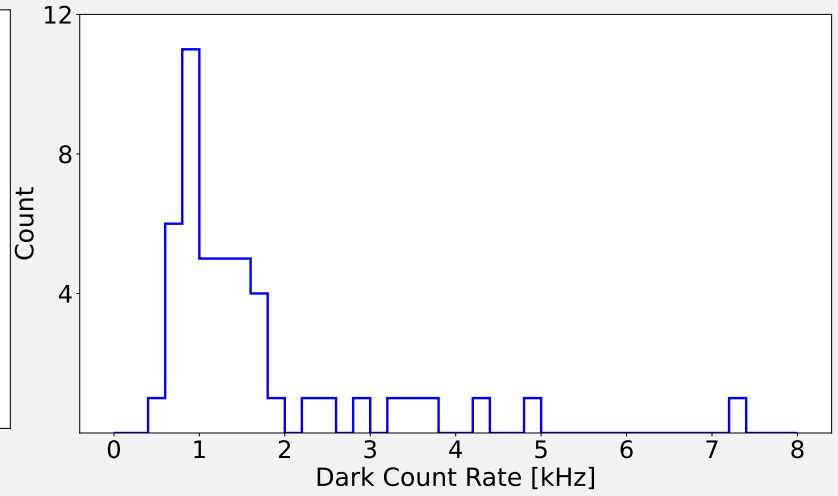
QE @ 404 nm	28%
Dark Noise	2 kHz, max
Gain	10^7
Supply Voltage	1500V, max

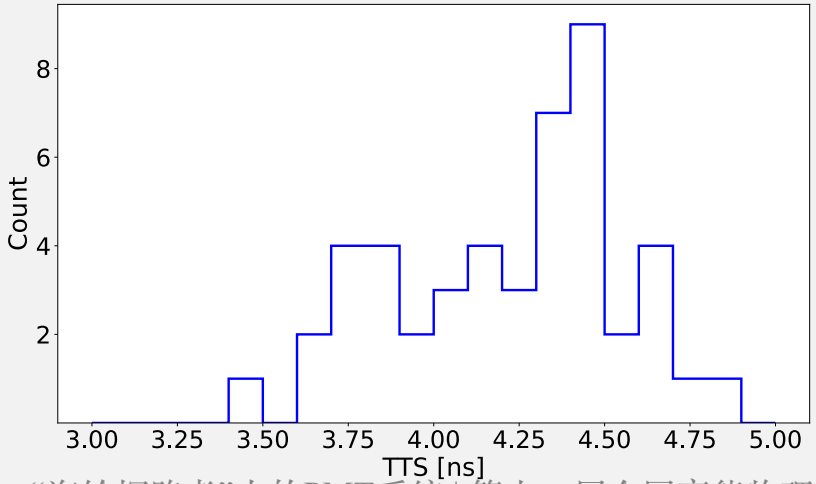
Typical characteristics of XP72B22 PMT given by datasheet

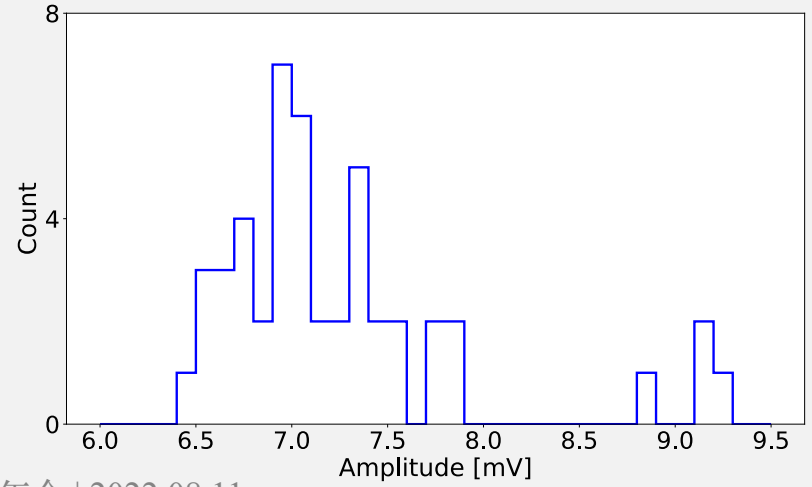
PMT Selection

- HZC Photonics XP72B22 PMT
- A sample of 50 PMTs were tested at USTC (by Zebo Tang's group)



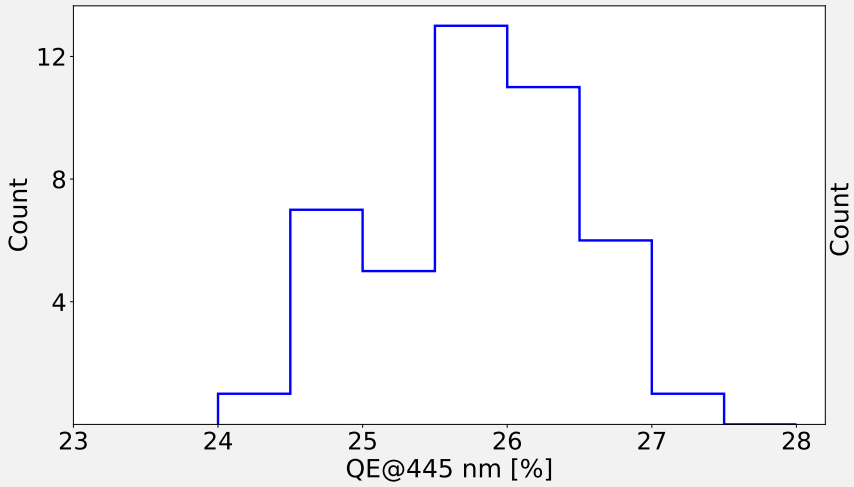


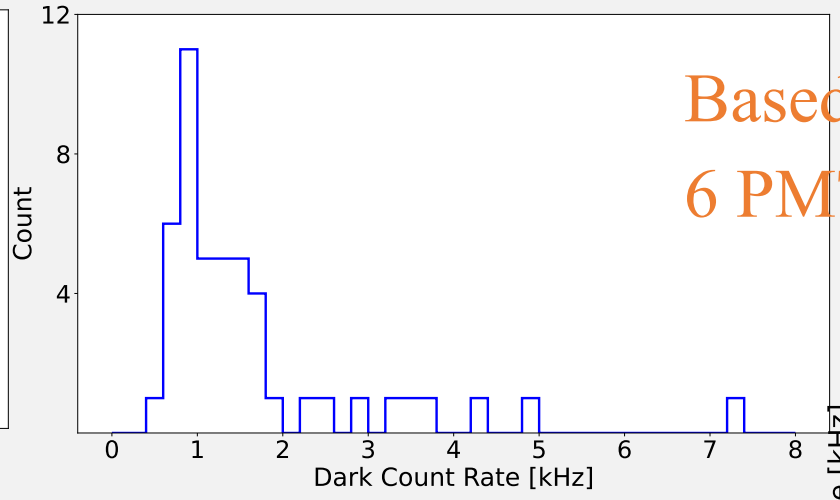




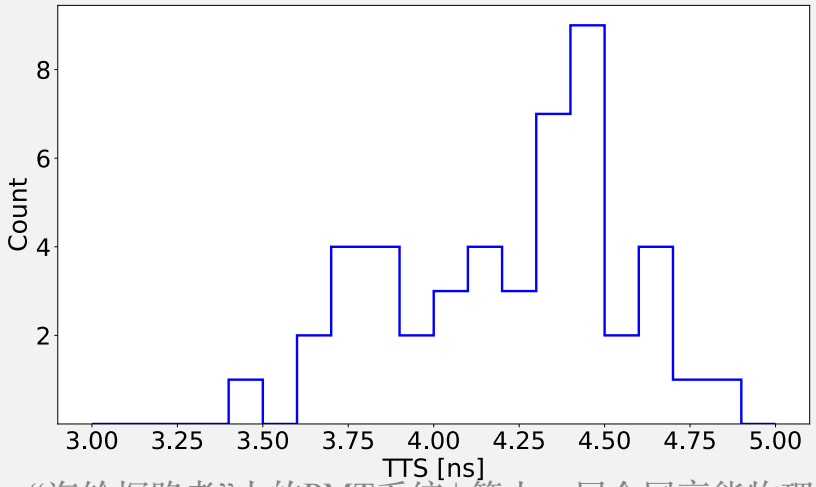
PMT Selection

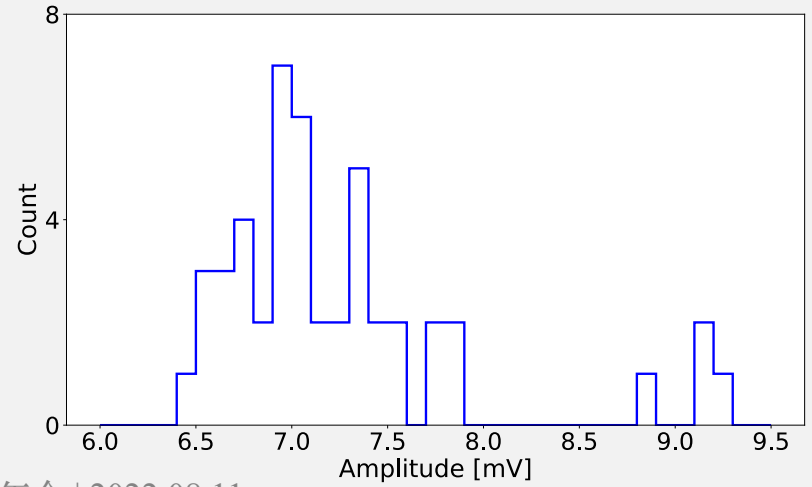
- HZC Photonics XP72B22 PMT
- A sample of 50 PMTs were tested at USTC (by Zebo Tang's group)

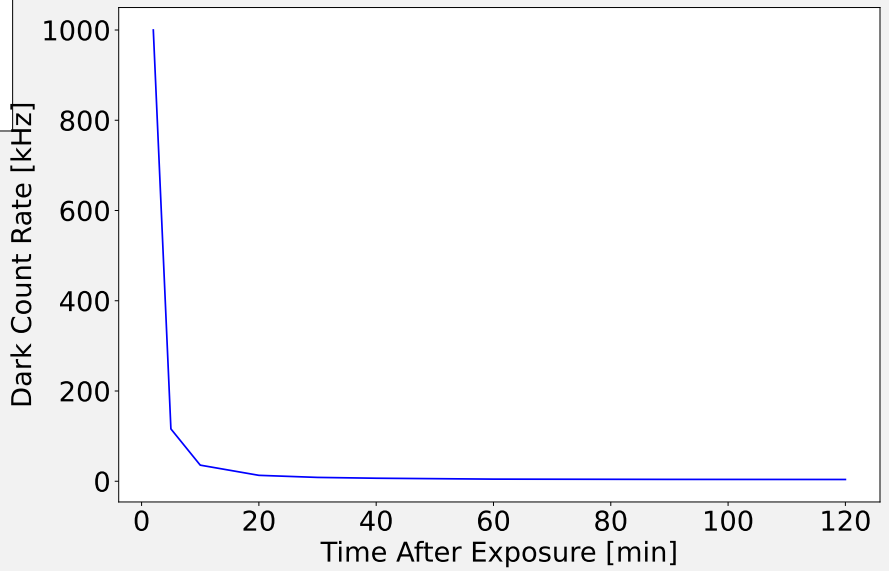




Based on these measurement results,
6 PMTs are selected







PART 04

Lab Calibration at a Low Temperature

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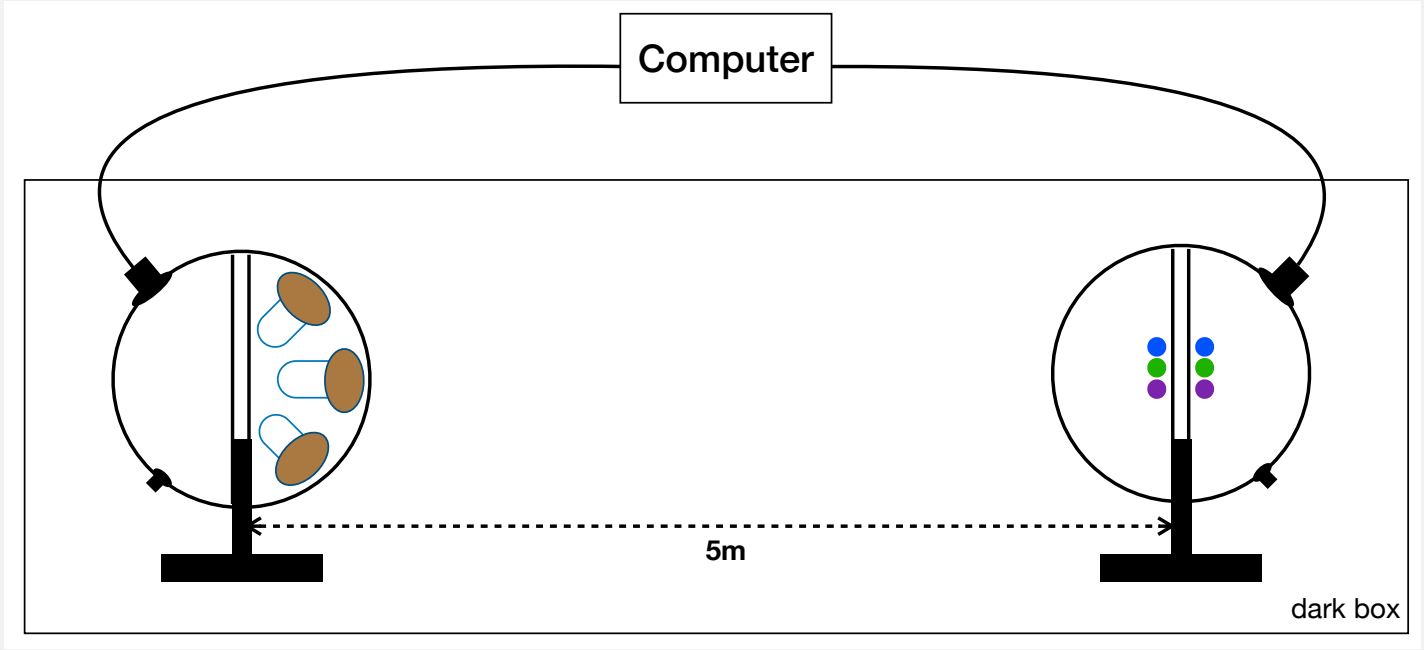
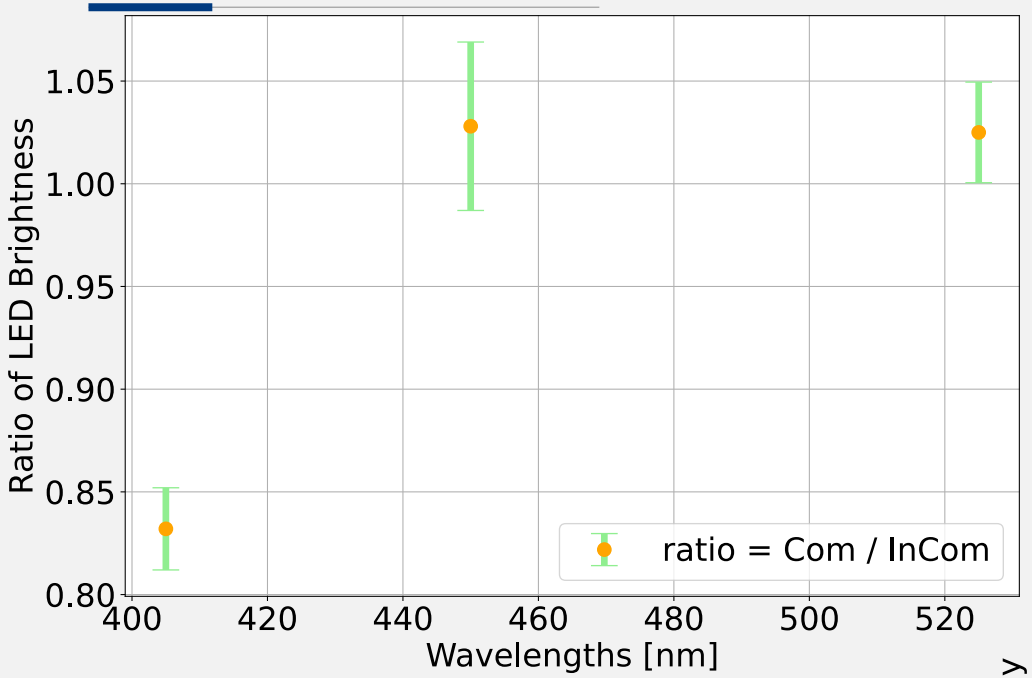
Calibration Setup

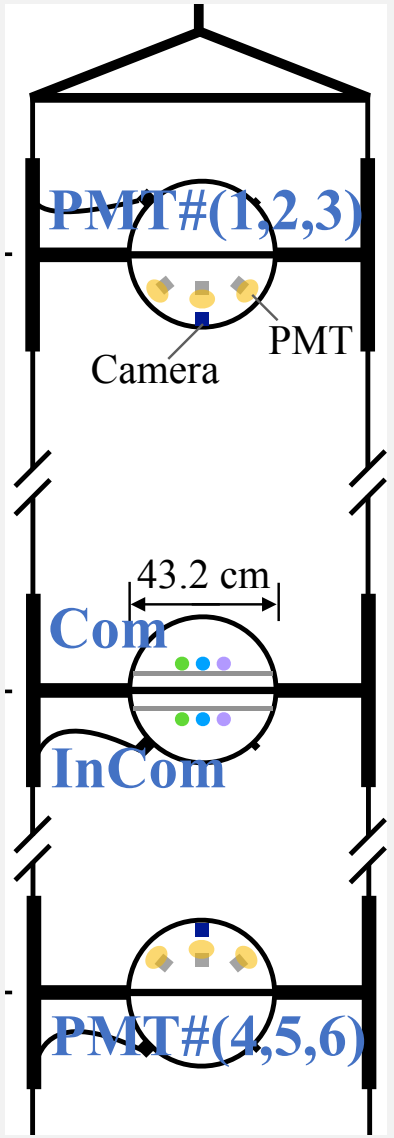


- Temperature controlled at ~ 2 degree
- To measure: LED brightness ratio,
  relative photon detection efficiencies,
  photon arrival time distribution in air.

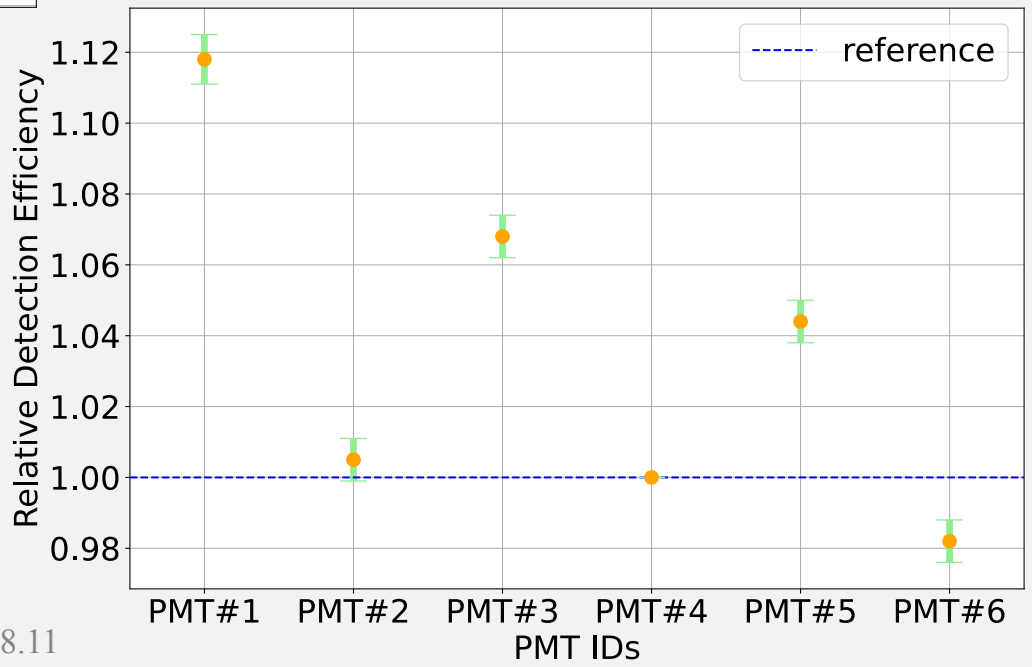
Results from Lab Calibration



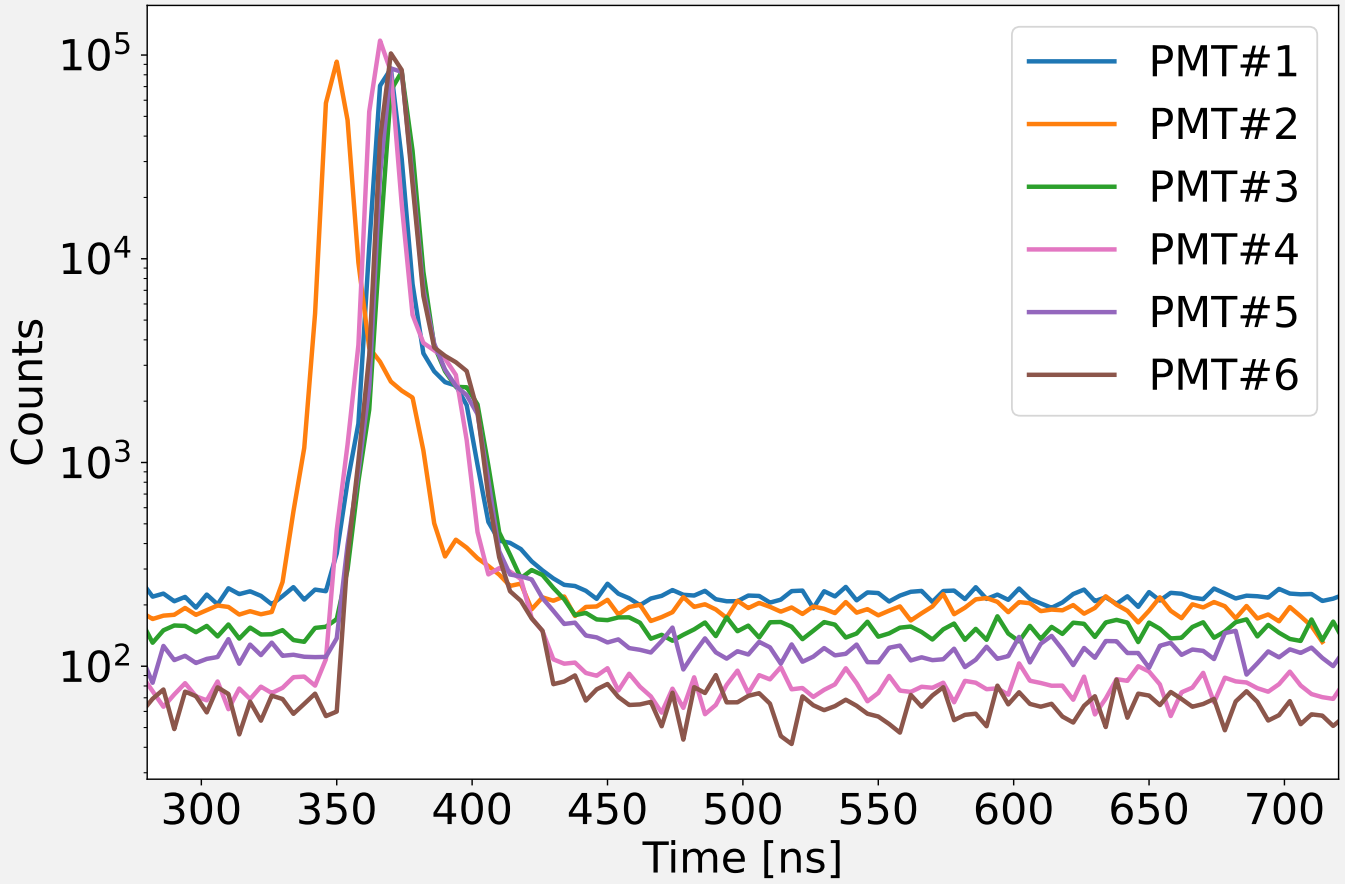
LED brightness ratio
for 3 wavelengths



Relative detection efficiency@450nm



Photon Arrival Time Distribution in Air



- Describe the LED pulsing profile & PMT response
- Used to construct model to fit optical properties (absorption/scattering length) of the sea water

PART 05

PMT Data Analysis

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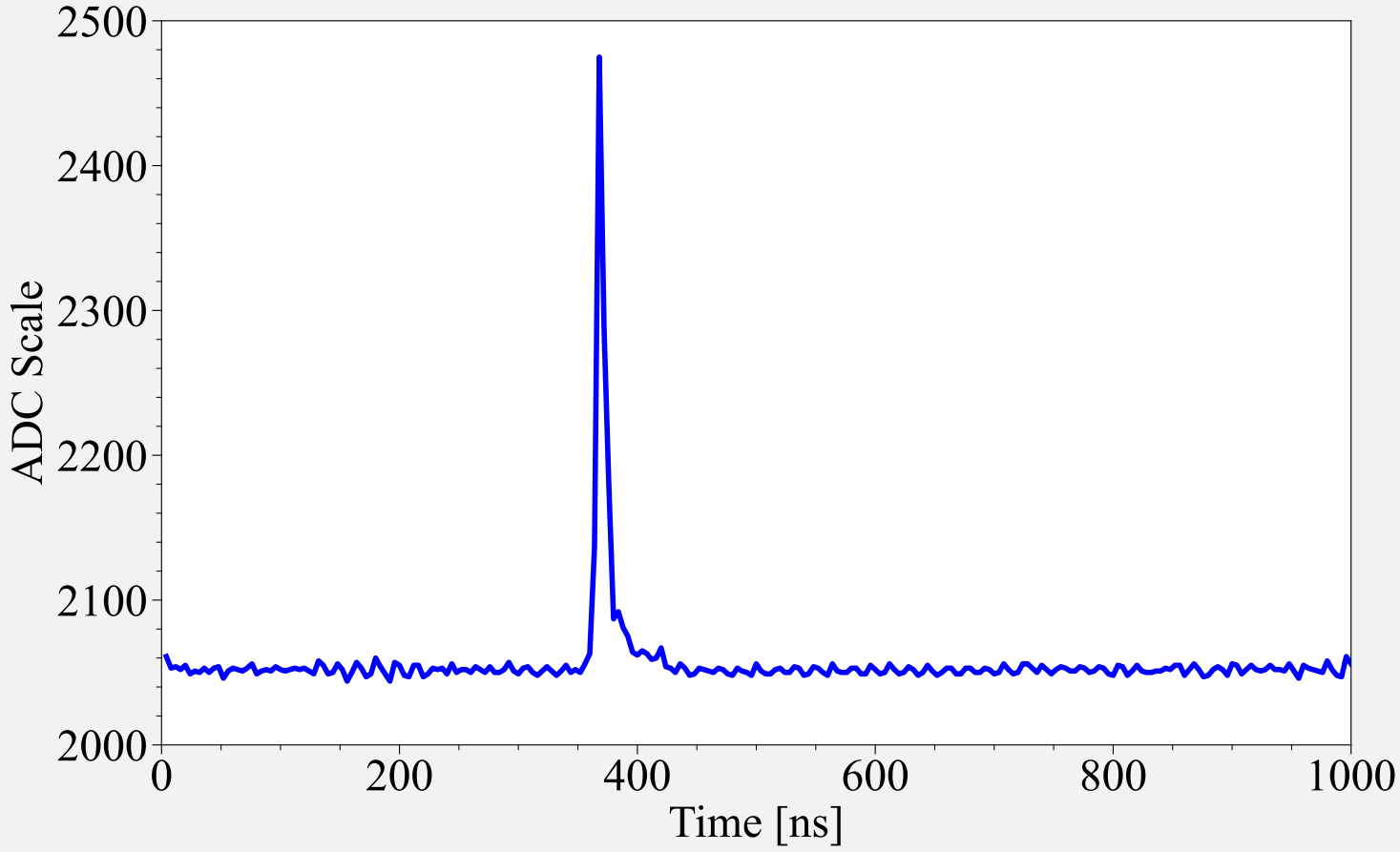
Decoding optical properties of sea water

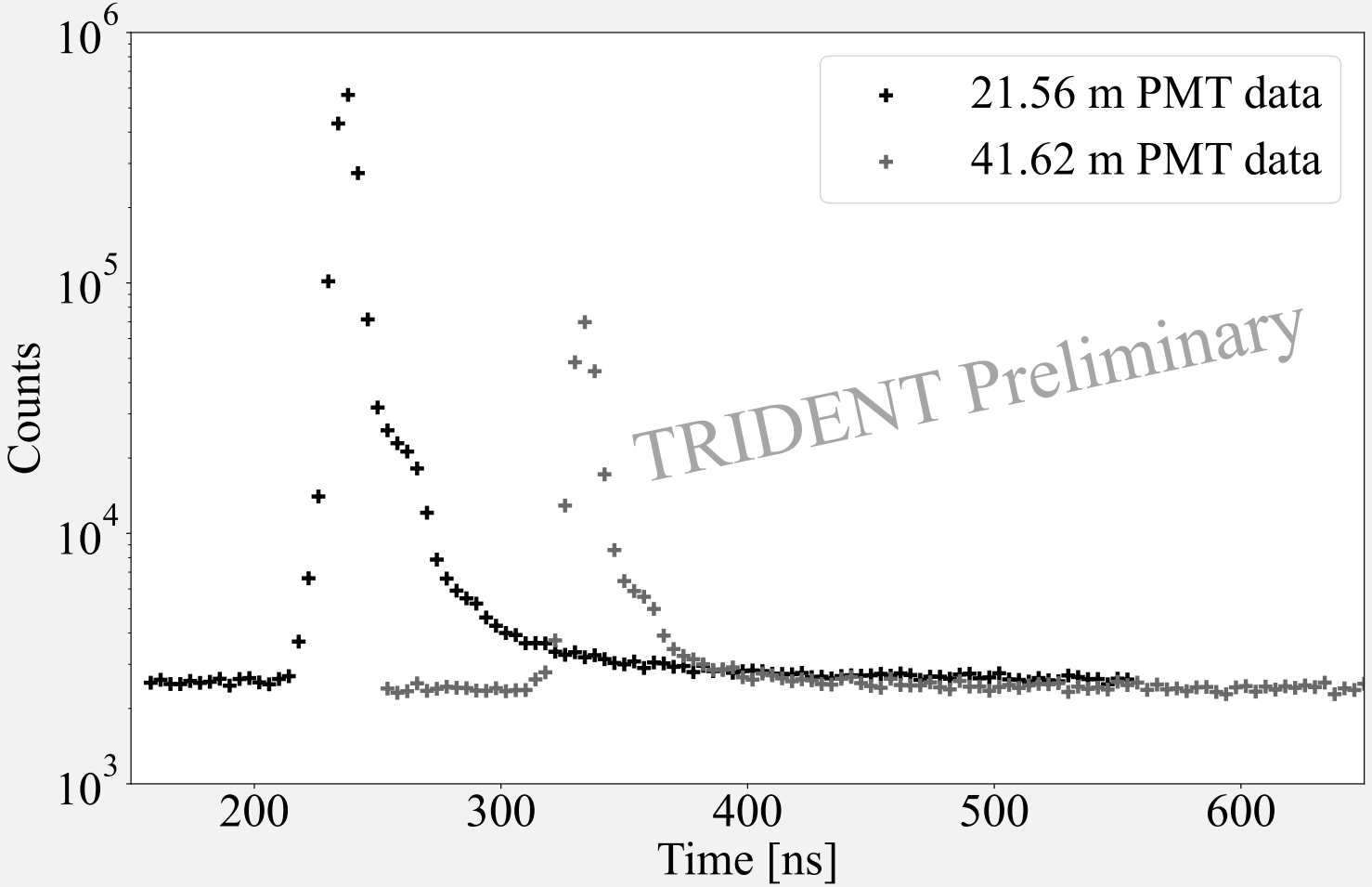
- Measurement strategy:
  - LEDs pulse per 0.1ms
  - ADC samples per 4 ns
  - 1000 ns waveform



A typical PMT waveform

Decoding optical properties of sea water

- Reconstruct photon arrival time distribution in sea-water (3 wavelengths, 6 PMT distributions for each wavelength)



one pair of PMTs measured photon arrival time distribution @ 450 nm

Fitting optical properties of sea water

- Reconstruct photon arrival time distribution in sea-water
  (3 wavelengths, 6 PMT distributions for each wavelength)
- Fitting experimental data with constructed model:

$$T_{\text{arrival}} = T_{\text{LED emission}} \otimes T_{\text{photon propagation}} \otimes T_{\text{PMT respsonse}}$$

Emission from pulsing LEDs

Propagation in the sea water

Detection by PMTs

Measured in calibration experiment at the freezer

Simulated by GEANT4

See Z. Y. Wei's poster at Session IX(5): Particle Detector Technology

Fitting optical properties of sea water

- Reconstruct photon arrival time distribution in sea-water
  (3 wavelengths, 6 PMT distributions for each wavelength)
- Fitting experimental data with constructed model:

$$T_{\text{arrival}} = T_{\text{LED emission}} \otimes T_{\text{photon propagation}} \otimes T_{\text{PMT respsonse}}$$

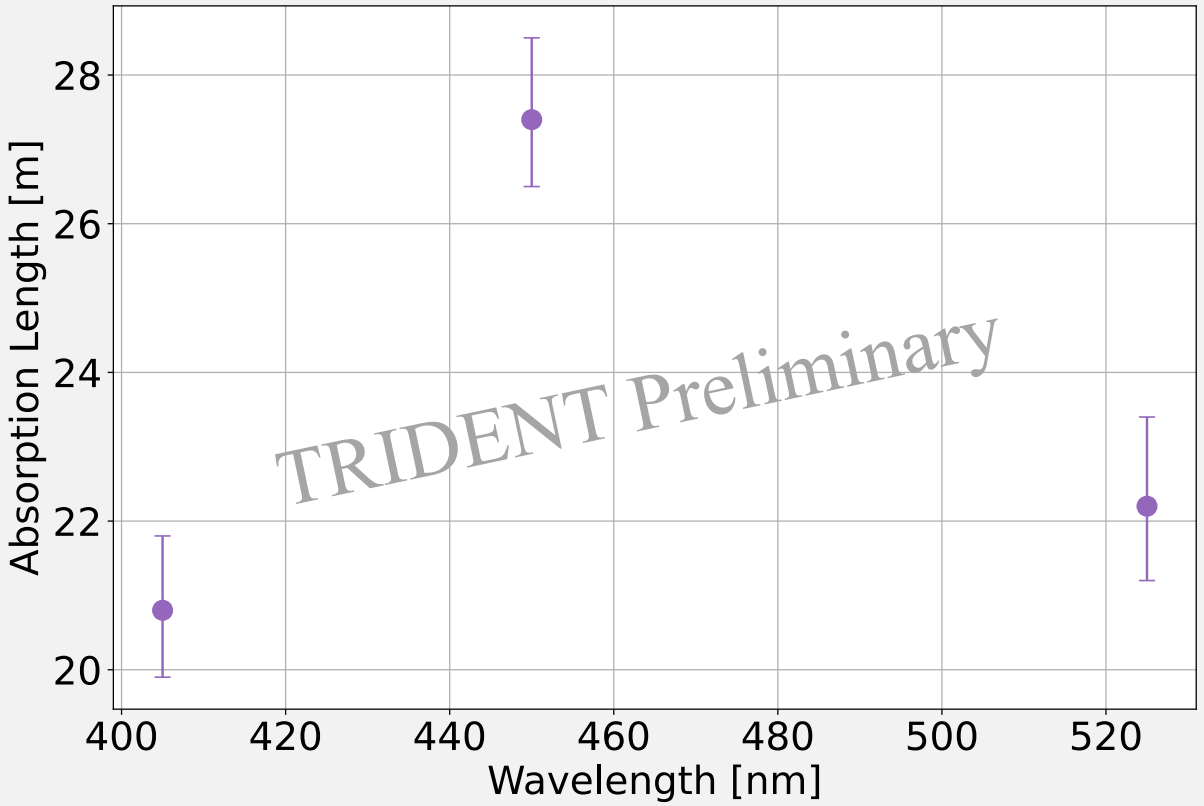
Emission from pulsing LEDs — **Propagation in the sea water** — **Detection by PMTs**

- Chi Square Test

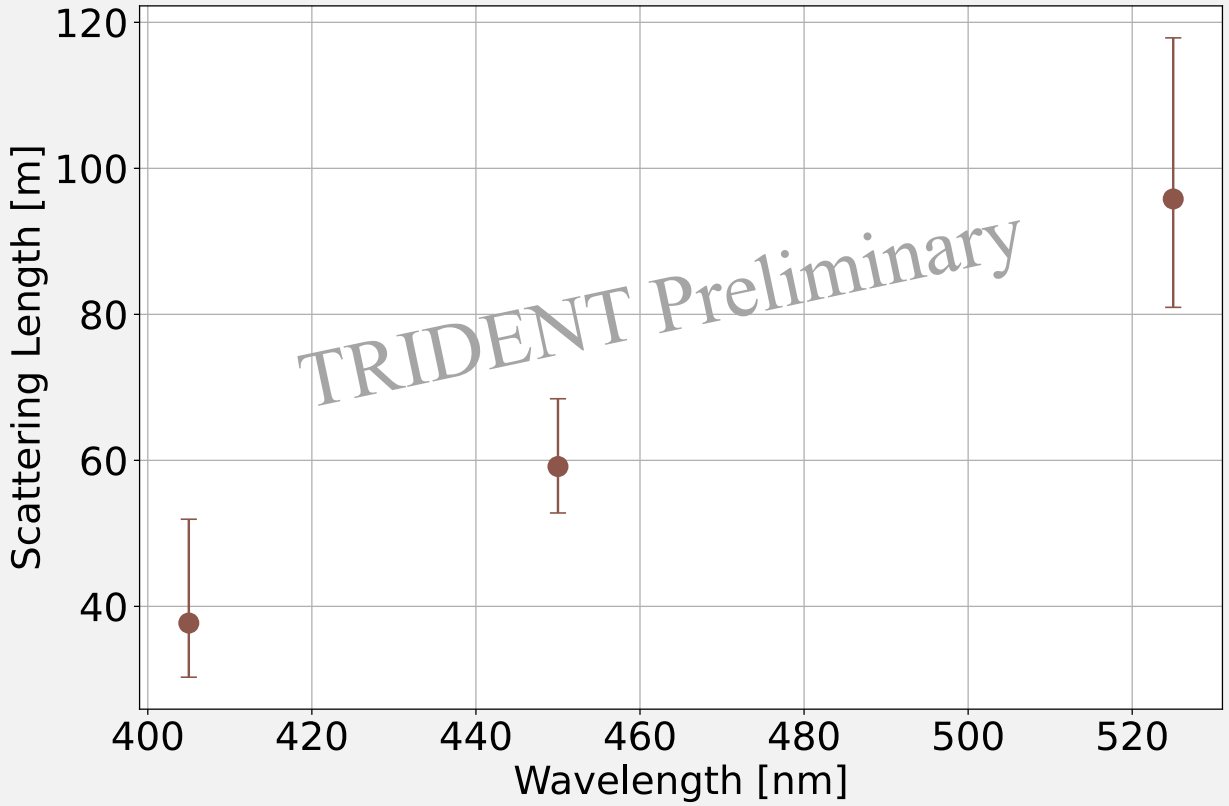
$$\chi^2 = \sum_{i=1}^{N} \frac{(D_i - M_i - \sum_{k=1}^{K} \beta_{ki} \cdot r_k)^2}{\sigma_i^2} + \sum_{k=1}^{K} r_k^2$$

Fitting optical properties of sea water

Absorption Length

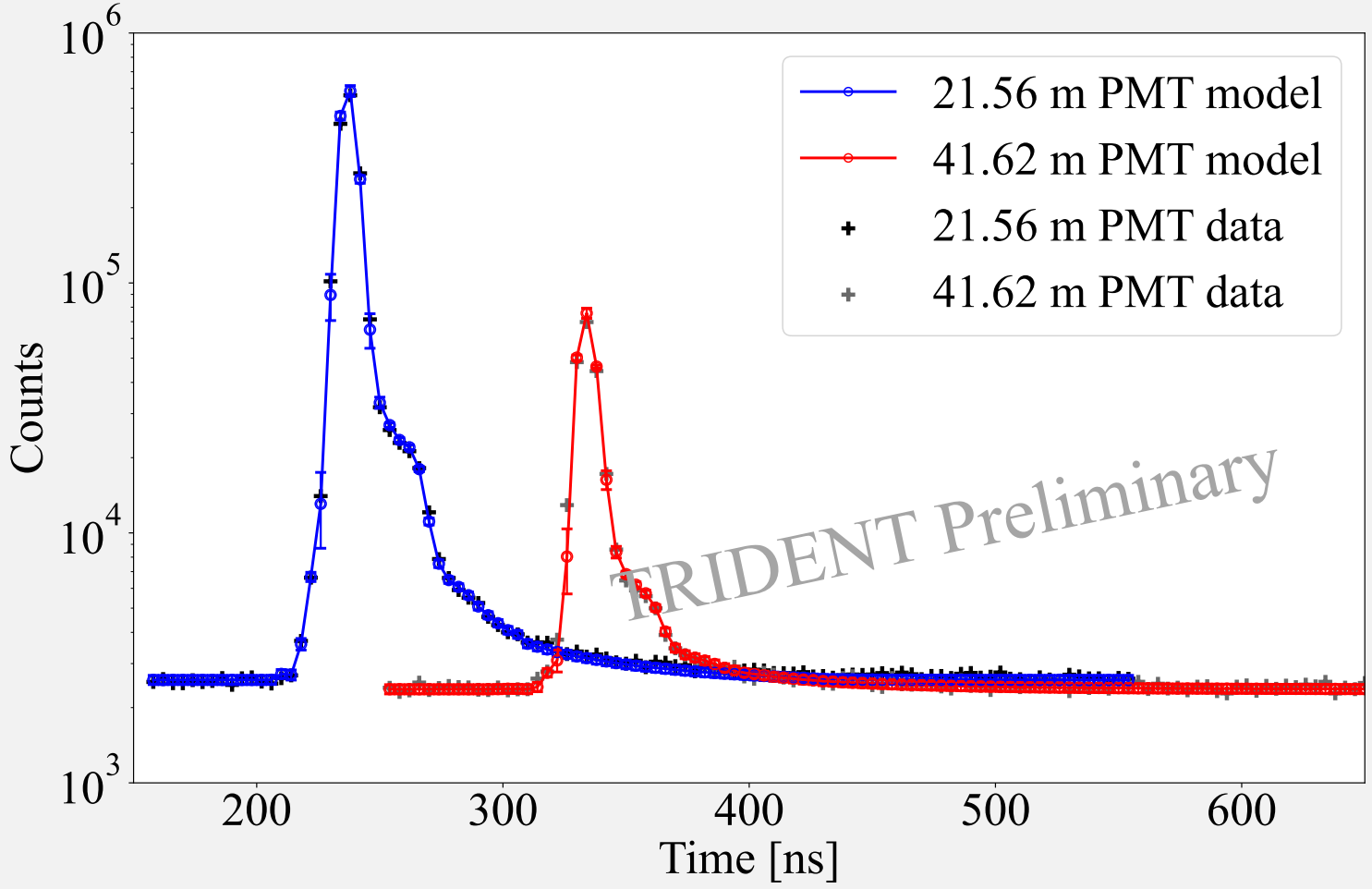


Scattering Length



$$\frac{1}{\lambda_{sca}} = \frac{1}{\lambda_{ray}} + \frac{1}{\lambda_{mie}}$$

Best fitted model@450nm



$$\lambda_{abs} = 27.4^{+1.1}_{-0.9}\,\mathrm{m}$$

$$\lambda_{ray} = 200^{+13}_{-10}\,\mathrm{m}$$

$$\lambda_{mie} = 84^{+12}_{-8}\,\mathrm{m}$$

$$\lambda_{att} = 18.7^{+3.0}_{-2.1}\,\mathrm{m}$$

$$\frac{1}{\lambda_{att}} = \frac{1}{\lambda_{abs}} + \frac{1}{\lambda_{ray}} + \frac{1}{\lambda_{mie}}$$

PART 06

Outlook and Summary

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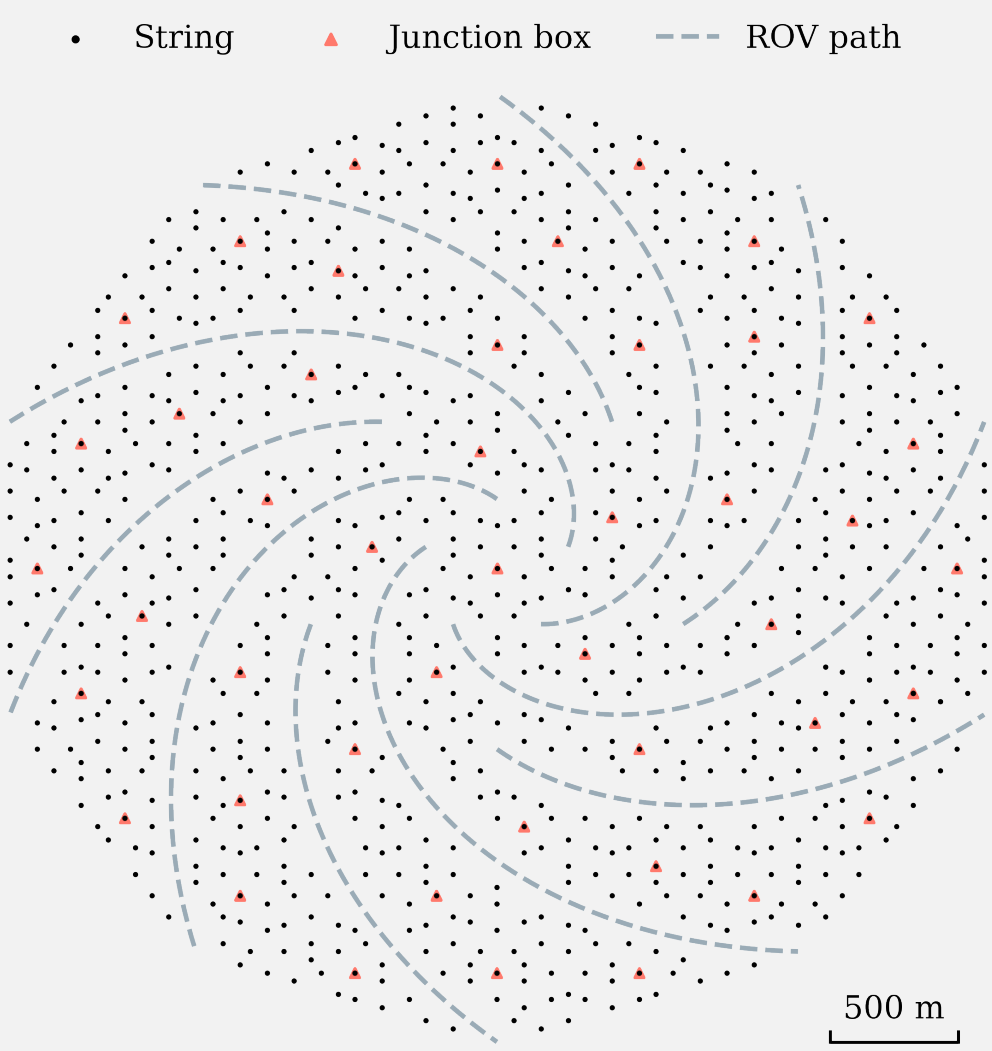
Future

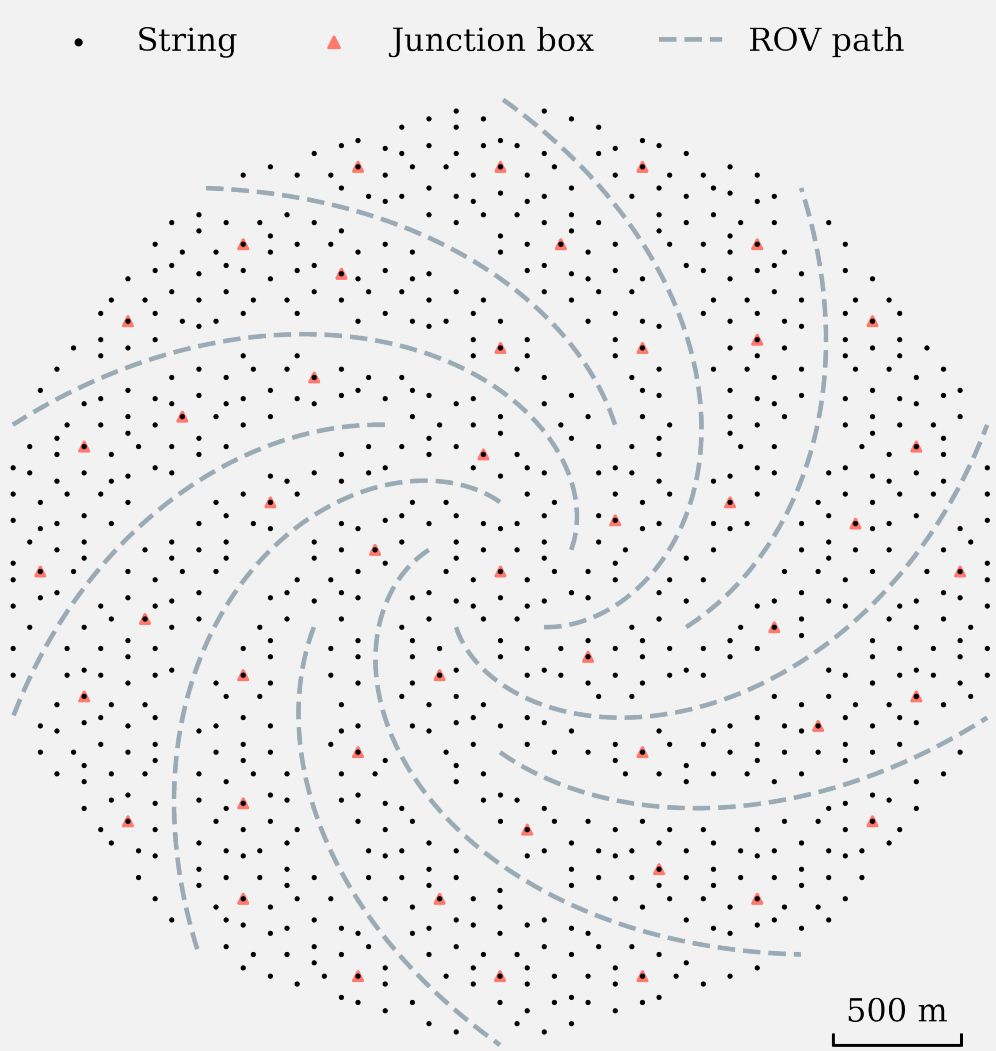
- Envisioned full detector:
  - volume ~ 8 km^3
  - 1211 strings
  - 30 hDOMs per string



Future

- Envisioned full detector:
  - volume of 7.5 km^3
  - 1211 strings
  - 30 hDOMs per string
  - hDOM = PMT + SiPM
  - in early 2030s

F. Hu, Z. Li, D. Xu,
PoS ICRC2021 (2021) 1043



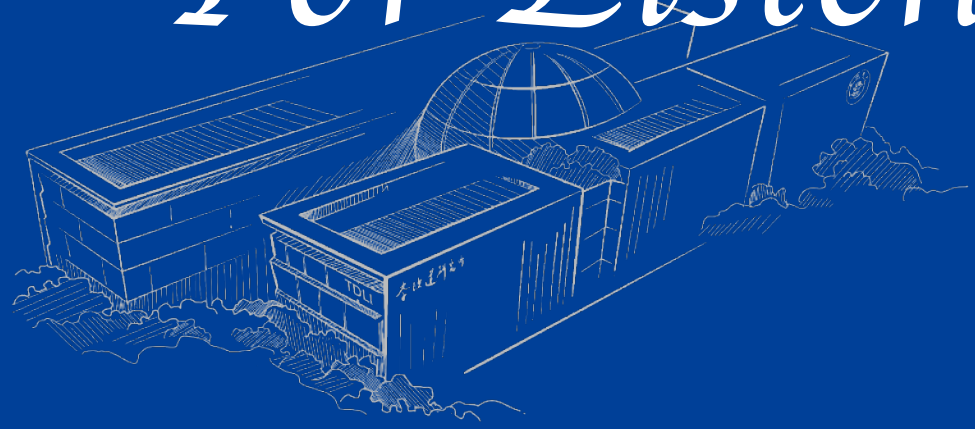
Summary and Outlook

- TRIDENT: envisioned neutrino telescope in South China Sea
- TRIDENT pathfinder experiment: measure optical properties at the selected site
- PMT System of T-REX: three 3-inch PMTs & pulsing LEDs@(405, 450, 525)nm

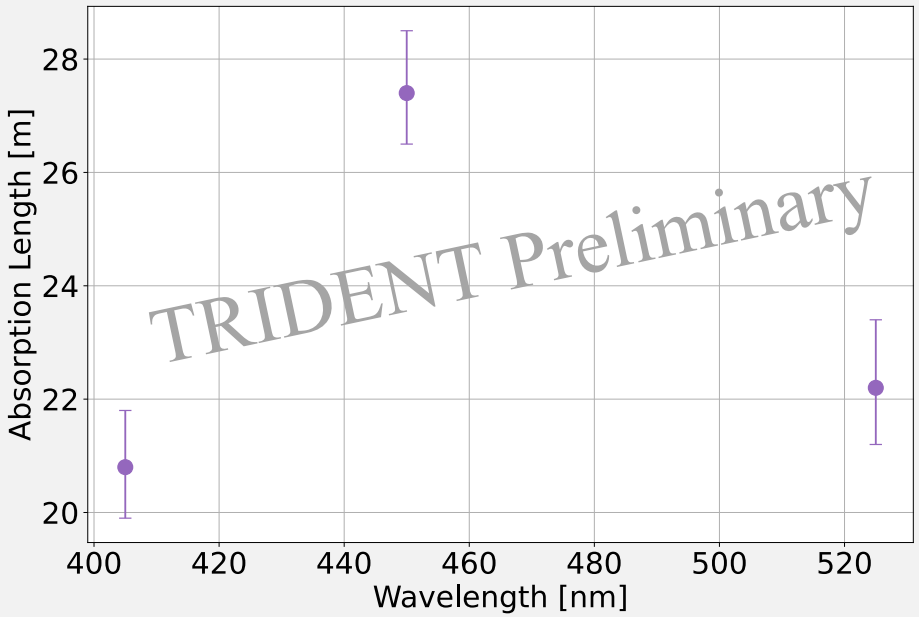
Summary and Outlook

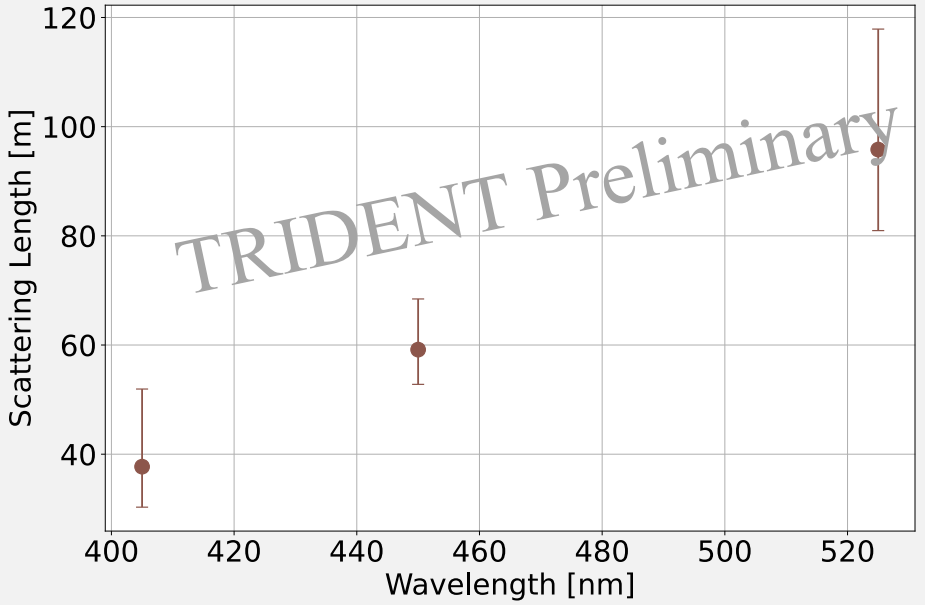
- TRIDENT: envisioned neutrino telescope in South China Sea
- TRIDENT pathfinder experiment: measure optical properties at the selected site
- PMT System of T-REX: three 3-inch PMTs & pulsing LEDs@(405, 450, 525)nm
- Further PMT selection among HZC Photonics, North Night Version and Hamamatsu
- Pilot project (2022-2026): 3 strings

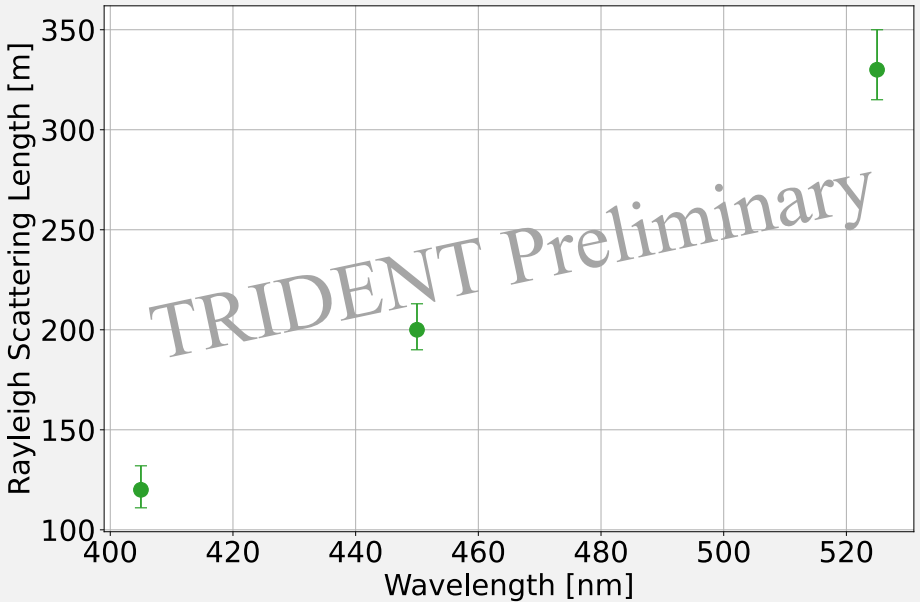
Thank You For Listening

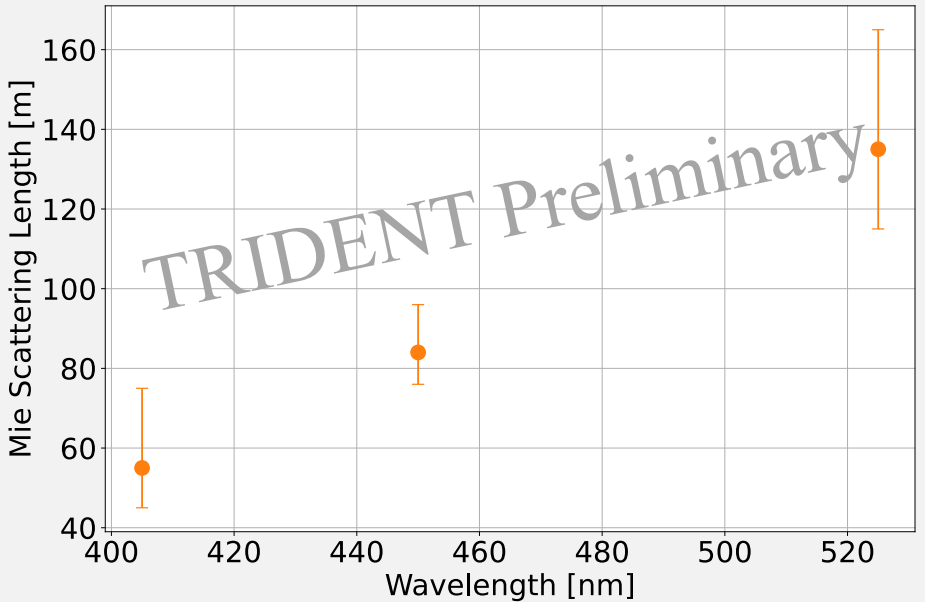


Fitting optical properties of sea water



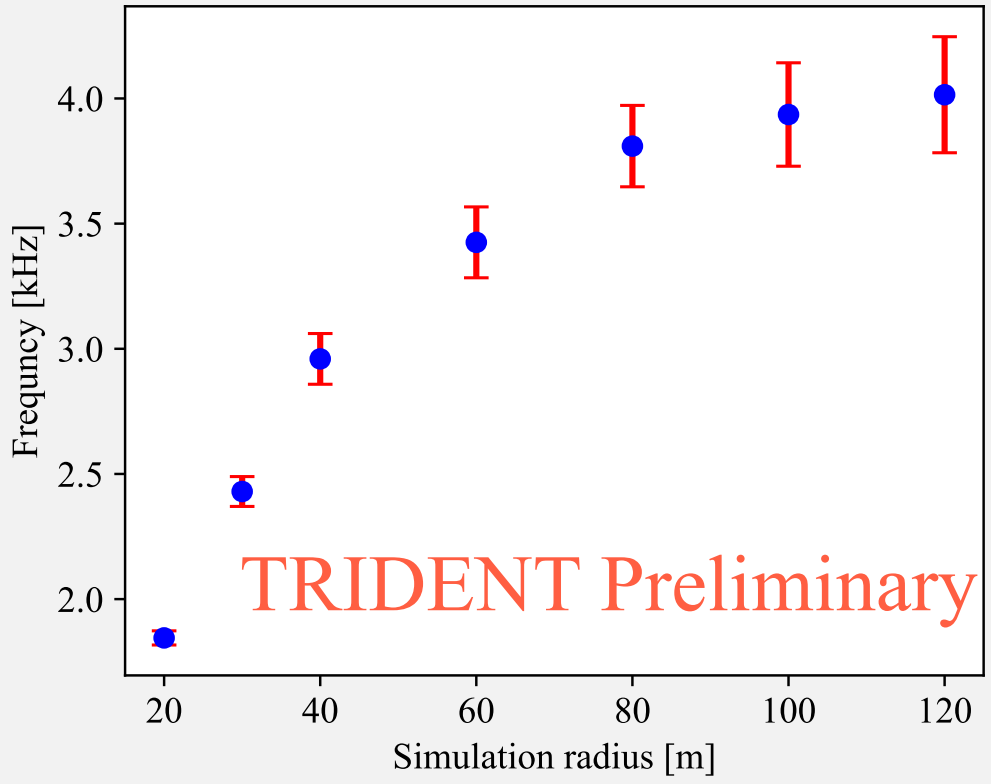


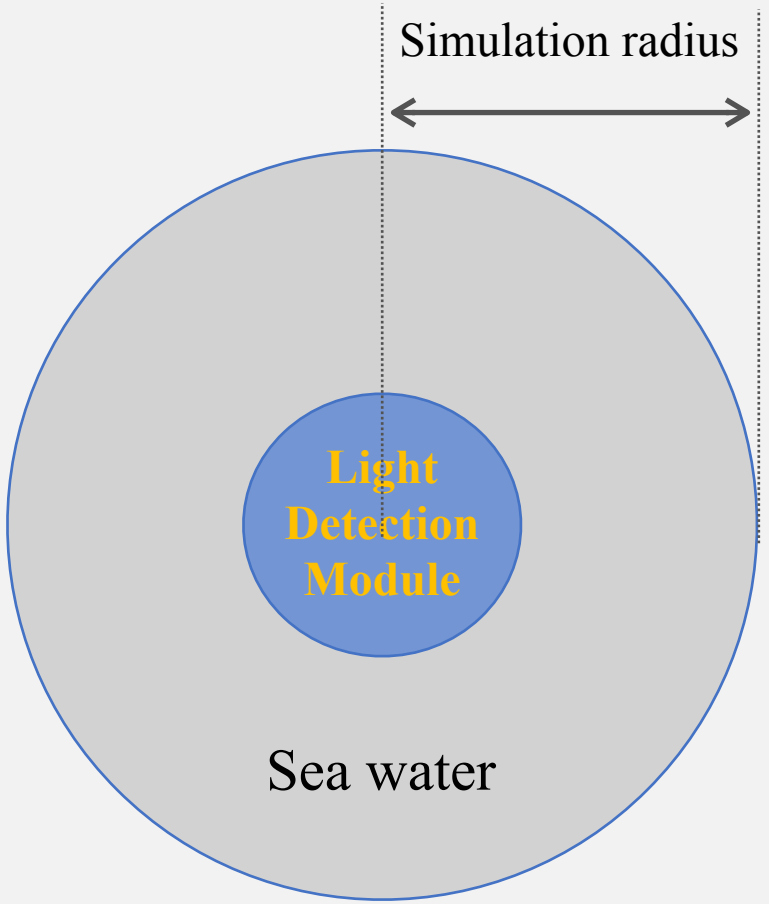




K40 Simulation

- abundance of K40: 10.78 ± 0.21 Bq/kg
  (Measured by PandaX Team at China Jingping Underground Laboratory)
- contribute to 4 kHz trigger rate per PMT





Simulation setup in GEANT4

Effective Attenuation Length

LED brightness ratio

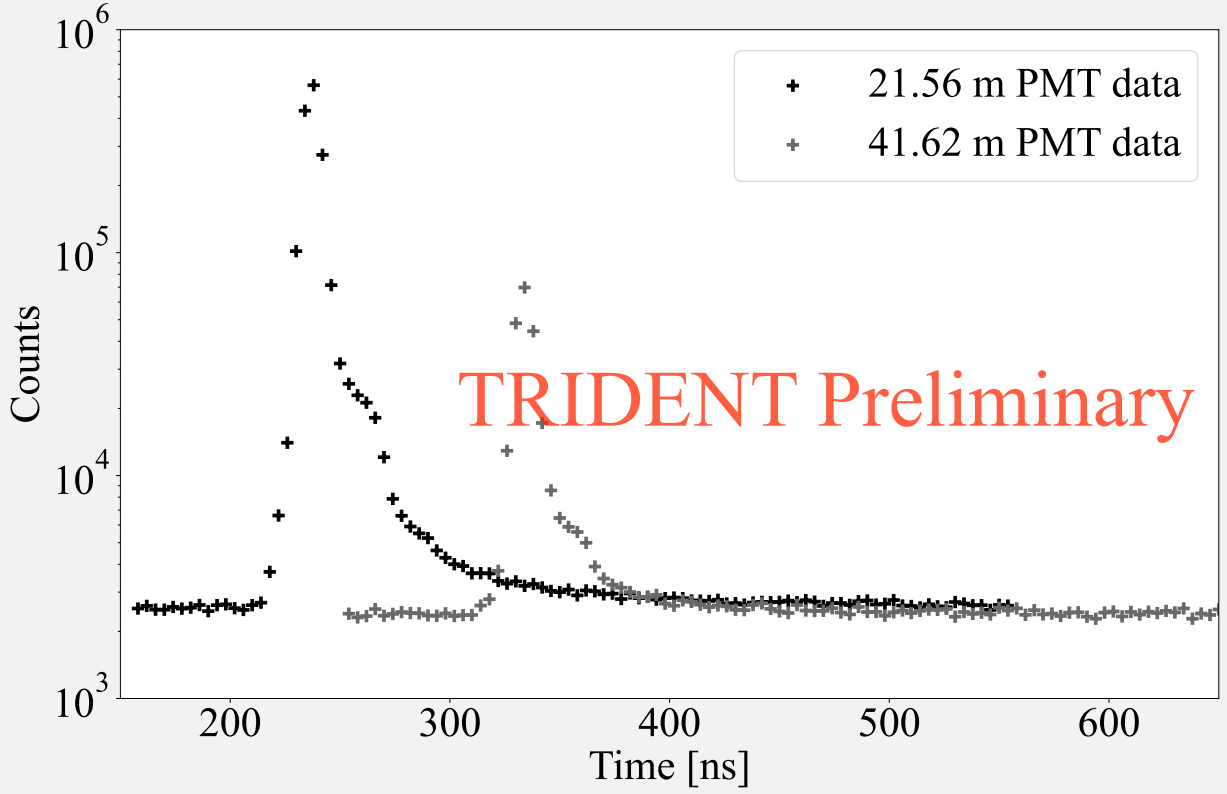
$$\frac{N_{PE}^{u}}{N_{PE}^{b}} = \frac{B_{LED}^{u}}{B_{LED}^{b}} \cdot \left(\frac{D^{b}}{D^{u}}\right)^{2} \cdot e^{-\frac{(D^{u}-D^{b})}{\lambda_{att,eff}}} \cdot \frac{\eta_{PMT}^{u}}{\eta_{PMT}^{b}}$$

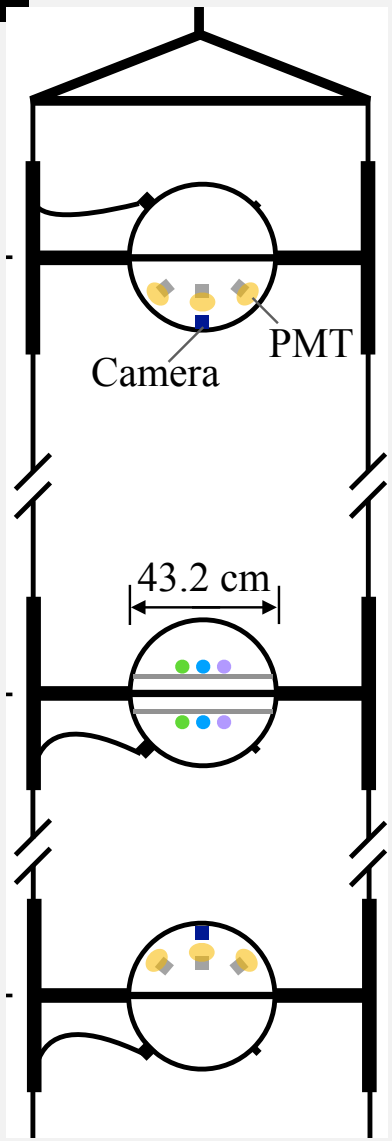
Total number of photons received by PMTs

Relative detection efficiency

$D^{b} = 21.56$ m

$D^{u} = 41.62$ m





Chi Square Test

$$\chi^2 = \sum_{i=1}^{N} \frac{(D_i - M_i - \sum_{k=1}^{K} \beta_{ki} \cdot r_k)^2}{\sigma_i^2} + \sum_{k=1}^{K} r_k^2$$

- uncorrelated uncertainty σ_i includes:
  - statistical fluctuation
  - electronic noise
  - uncertainty in the LED pulse profile and PMT time response
- β_{ki} is the contribution from the k^{th} correlated uncertainty, includes:
  - fluctuations in LED brightness
  - PMT gains
  - PMT detection efficiencies

Reference: Phys.Rev.D65:014012,2001