TRIDENT: Status and Prospects

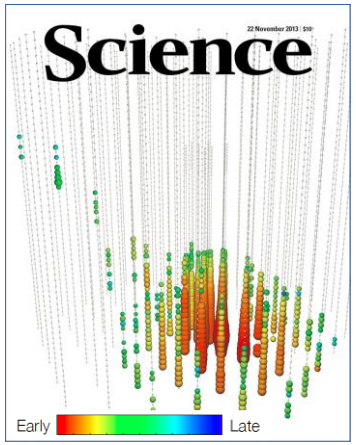
Hualin Mei (TDLI/SJTU)

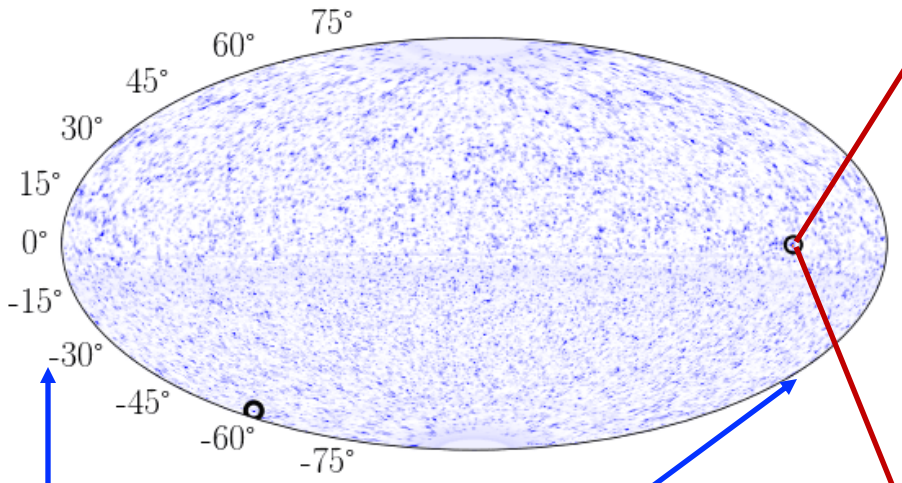
2025-11-30

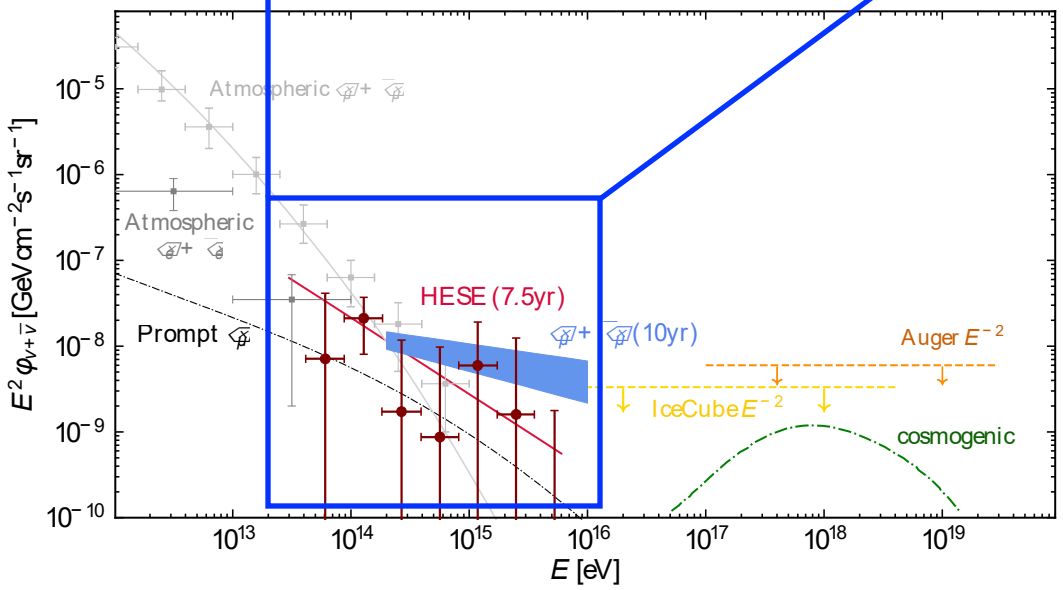
On behalf of TRIDENT Collaboration

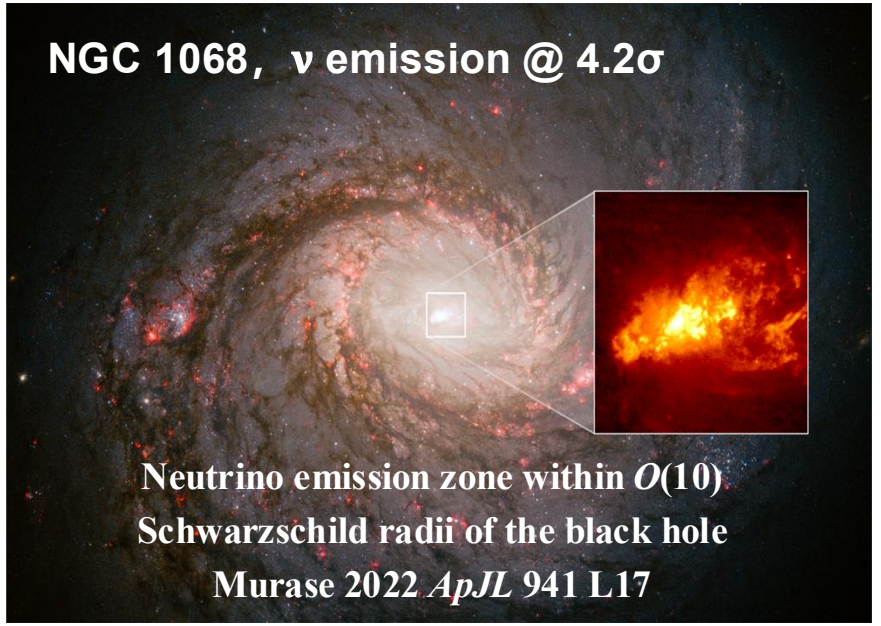
A New Era of Neutrino Astronomy

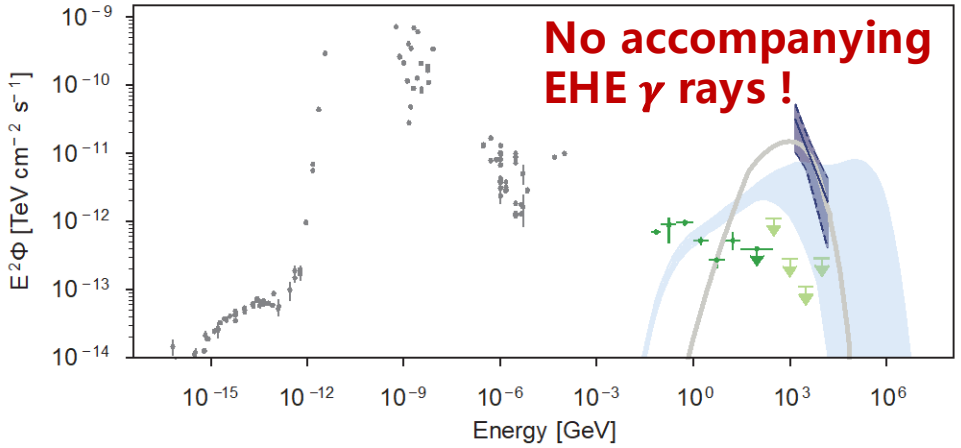
Science 342, 6161 (2013)
Science 361, eaat1378 (2018)
Science 361, eaat2890 (2018)
Science 378, 538 (2022)
Science 380, 1338–1343 (2023)









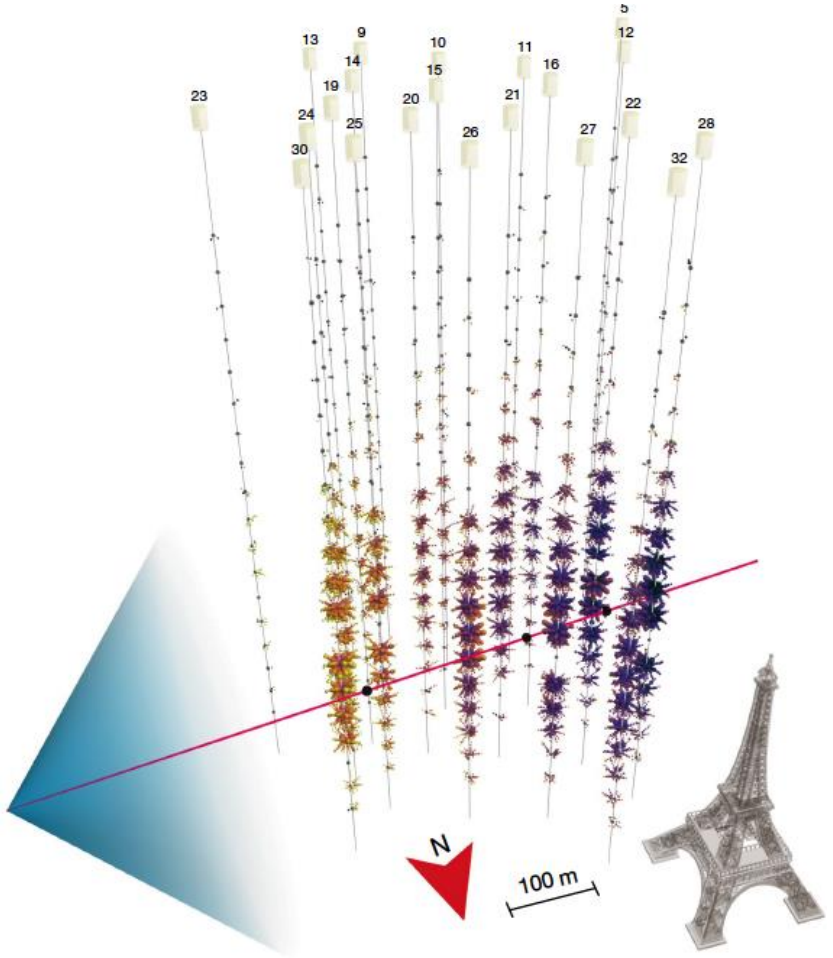


Origin mostly unknown → more telescopes with improved pointing & stats !

A New Era of Neutrino Astronomy

KM3NeT detected a neutrino event with **~ 220 PeV (KM3-230213A)**

→ **Most energetic neutrino event observed, but origin unknown !**

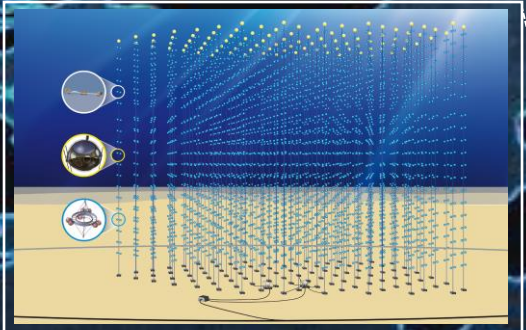


Potential Sources

- **Extragalactic ?**
  AGN or GRBs
- **Cosmological ?**
  - UHECR interacting with CMB
  - PBH evaporation
  - …
- **Galactic ?**
  No existing models

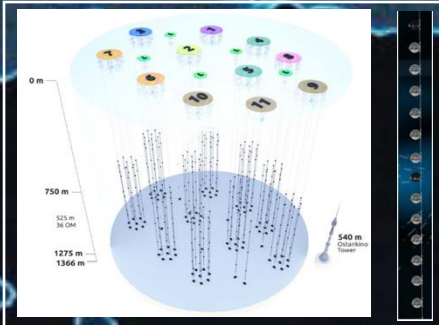
KM3NeT Coll., **Nature** 638, 376–382 (2025)
KM3NeT Coll., arXiv:2502.08508
KM3NeT Coll., arXiv:2502.08484
KM3NeT Coll., arXiv:2502.08387

Next-gen Neutrino Telescopes under Planning



KM3NeT (Mediterranean Sea)

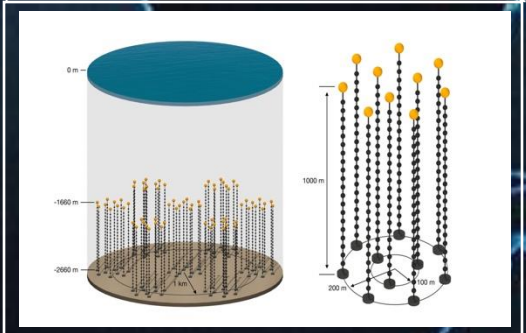
Medium: Deep-sea water
Depth: ~ 3.5 km (ARCA)
Volume: ~ 1 km^3
Number of strings : ~230



Baikal-GVD (Lake Baikal)

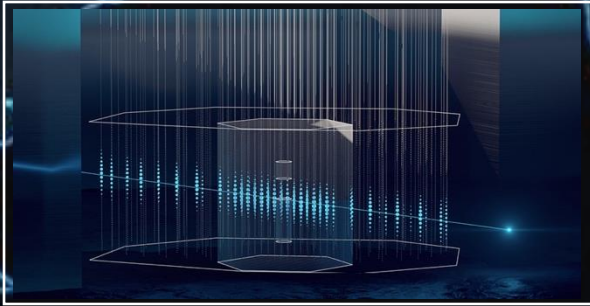
Medium: Deep-lake water
Depth: ~ 1.4 km
Volume: ~ 1 km^3
Number of strings : ~140

(HUNT, NEON)



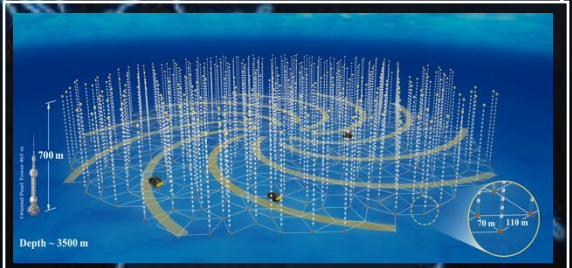
P-ONE (East Pacific Ocean)

Medium: Deep-sea water
Depth: ~ 2.6 km
Volume: ~ 1 km^3
Number of strings: ~70



IceCube Gen-2 (South Pole)

Medium: Glacial ice
Depth: ~ 2.5 km
Volume: ~ 8 km^3
Number of strings : ~210

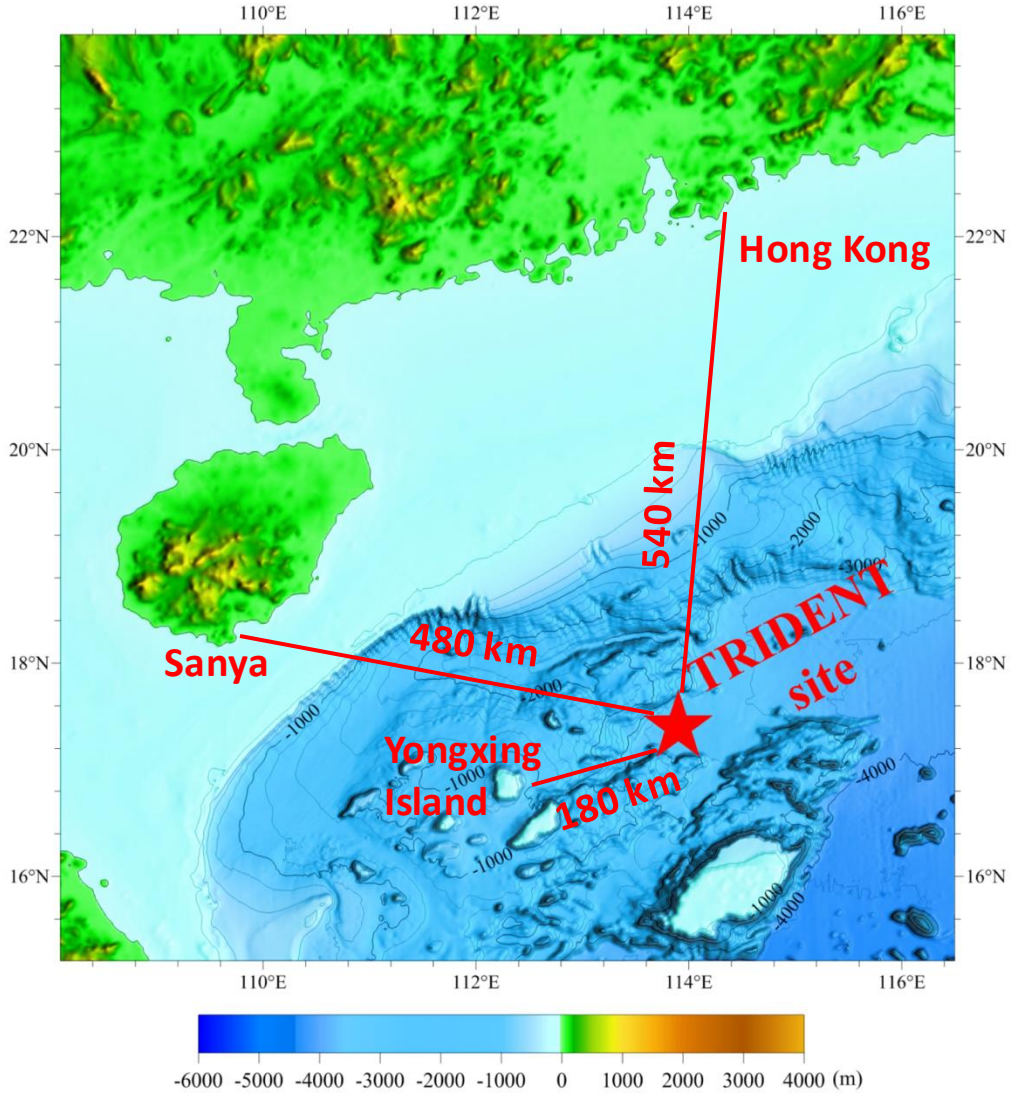


TRIDENT (West Pacific Ocean)

Medium: Deep-sea water
Depth: ~ 3.5 km
Volume: ~ 8 km^3
Number of strings : ~1000

Slide edited from
W. Tian @ ICRC2025

TRIDENT Pathfinder: T-REX 2021 "Hai-Ling Basin"



Site Selection Requirement

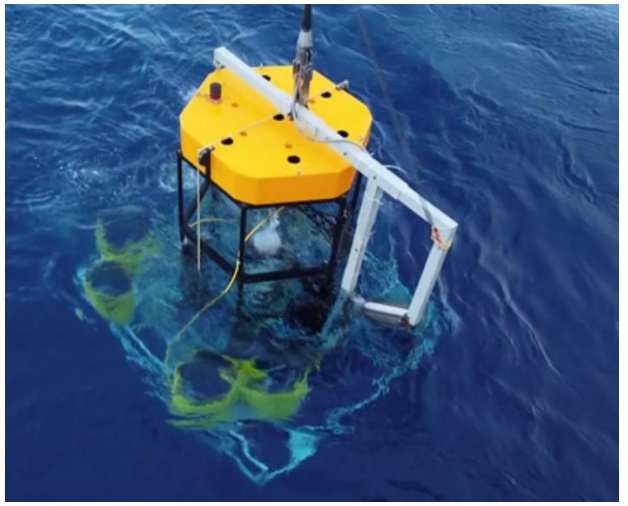
- Flat seabed
- No nearby high rises or deep trenches
- Depth >3km
- Close proximity to a shore

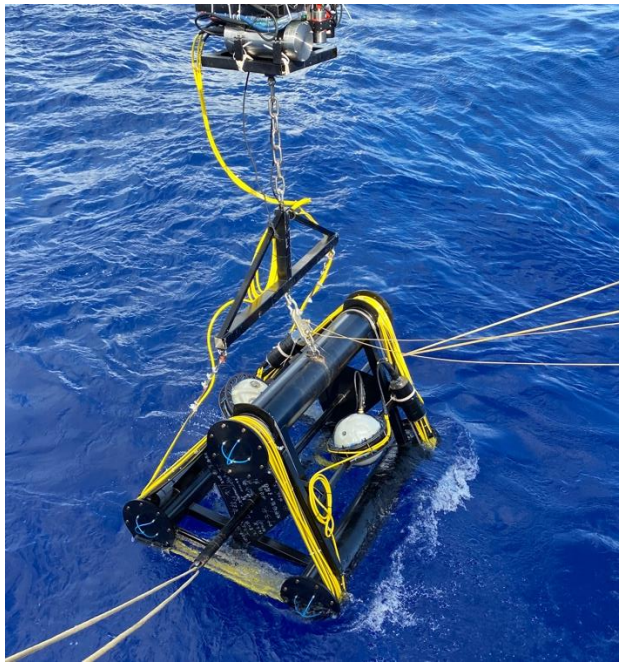
Measured

- **Optical properties**
- Current field
- Radioactivity

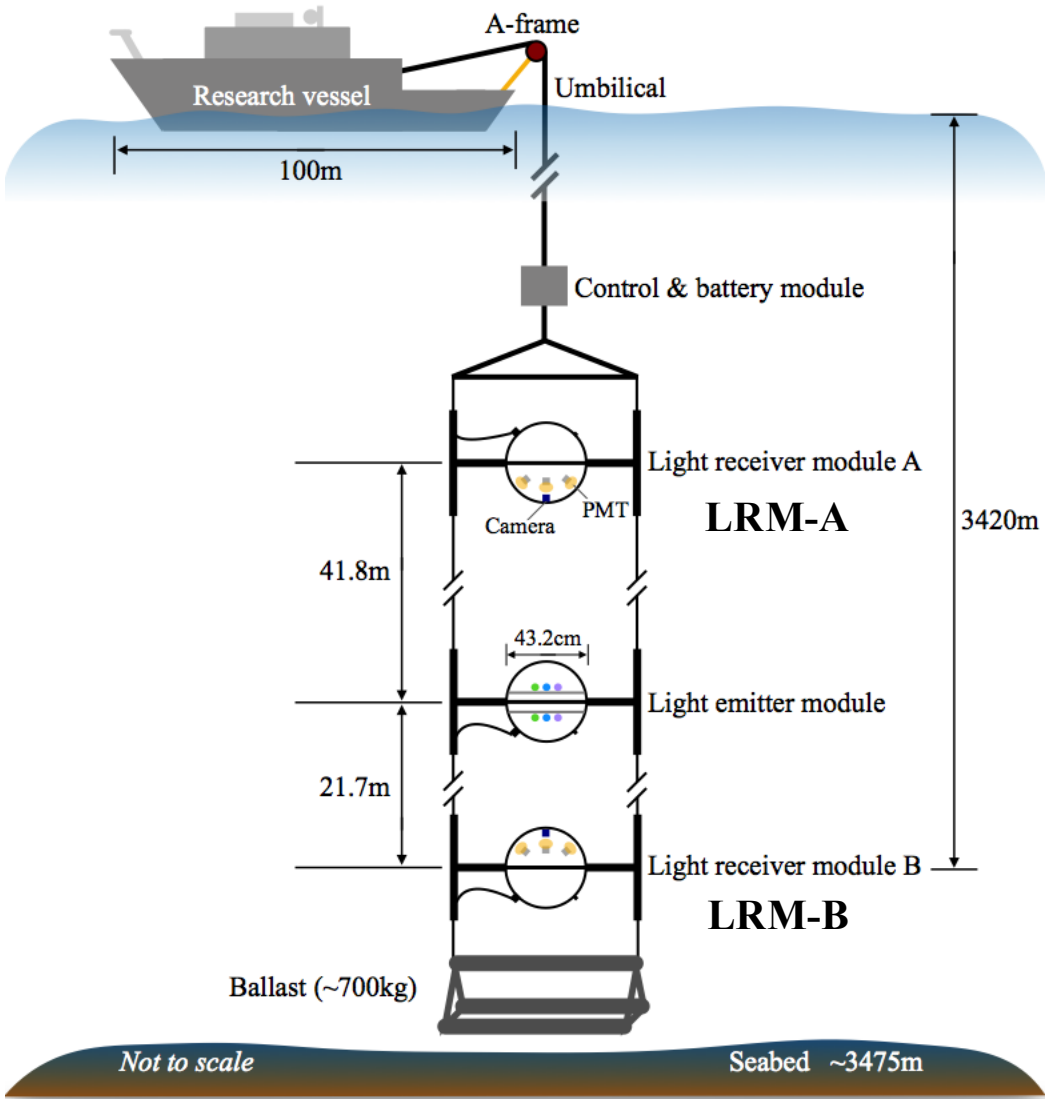
https://trident.sjtu.edu.cn/en

T-REX 2021: Apparatus

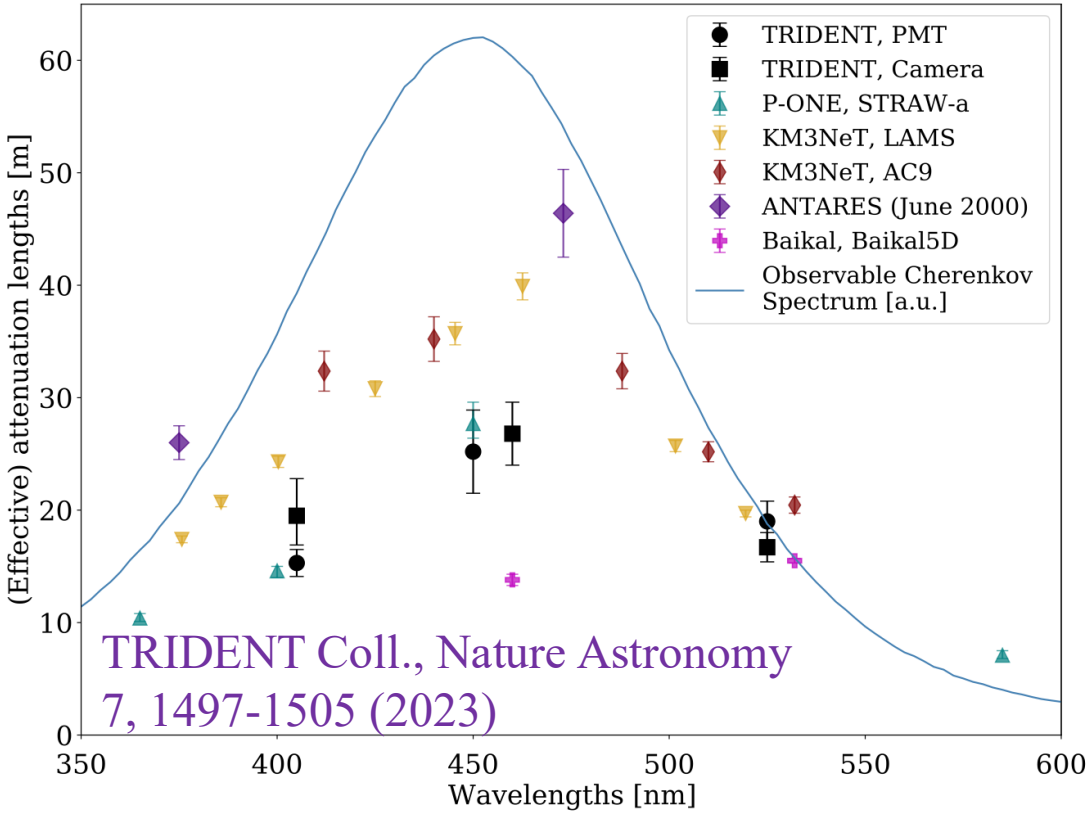




T-REX 2021 : Optical Properties

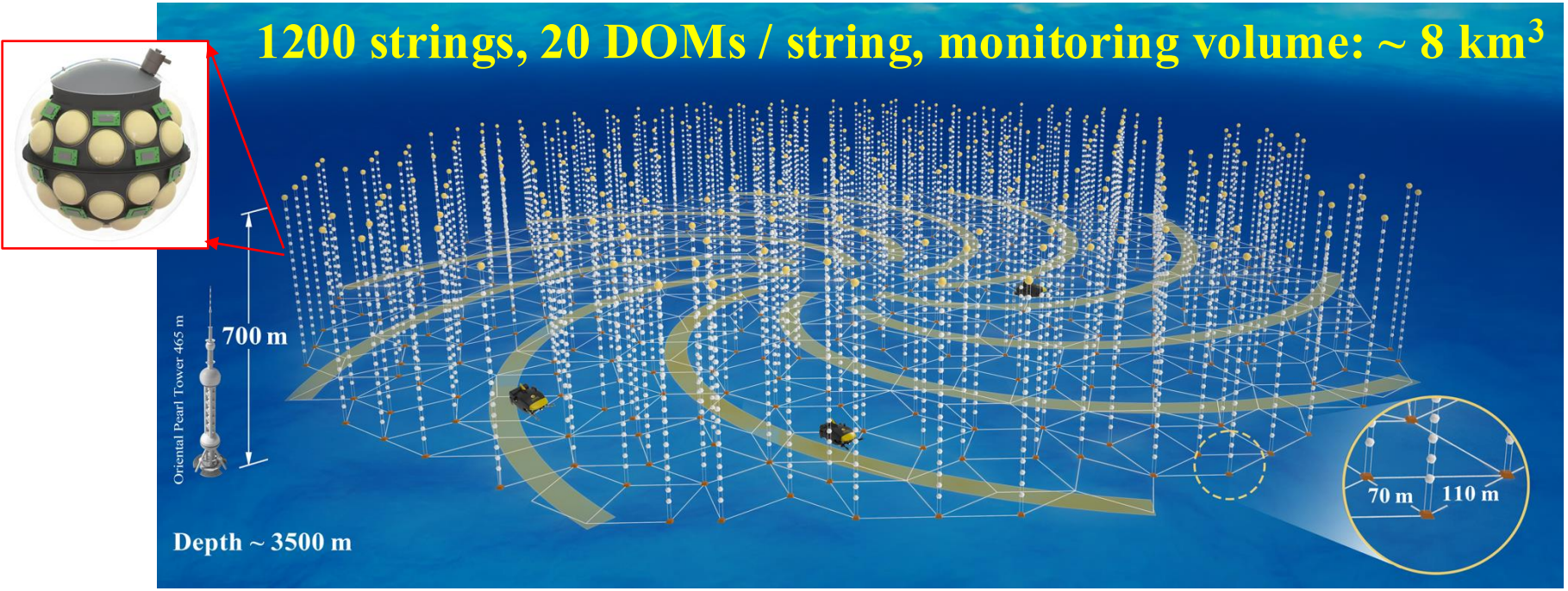


The optical properties are suitable for constructing large scale neutrino telescope

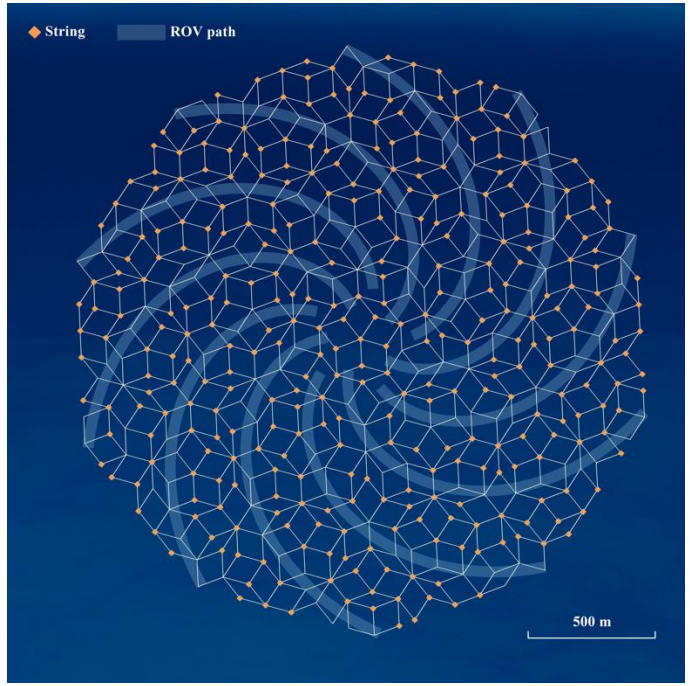


TRIDENT Geometric Layout

Full-array Conceptual Design



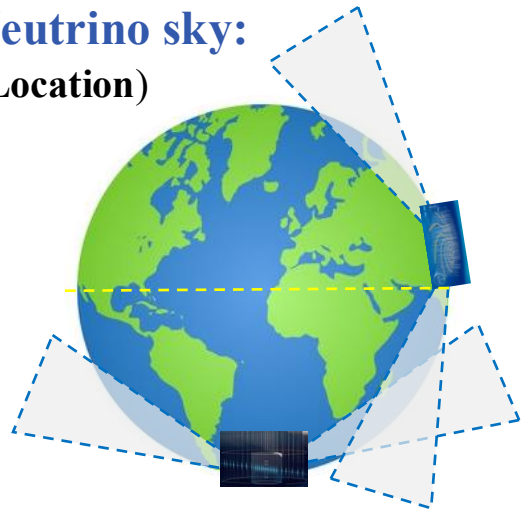
Penrose Tiling Layout



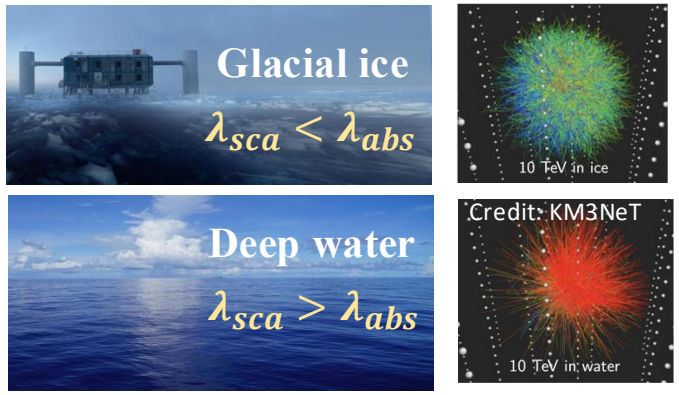
- **Uneven** inter-string spacing **70m** and **110m** → expanded energy window of **sub TeV – EeV**
- **No** translational or rotational **symmetry** → better rejection of "corridor" atmo. muons

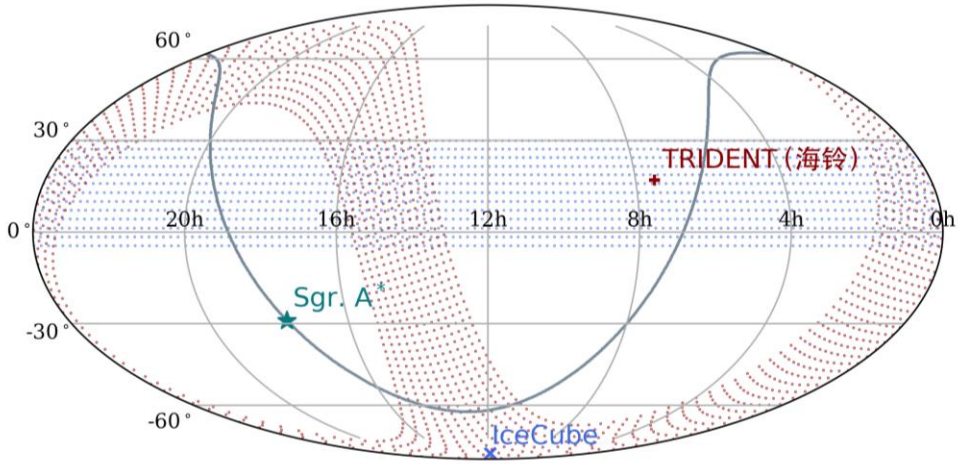
An all-sky Precision ν telescope

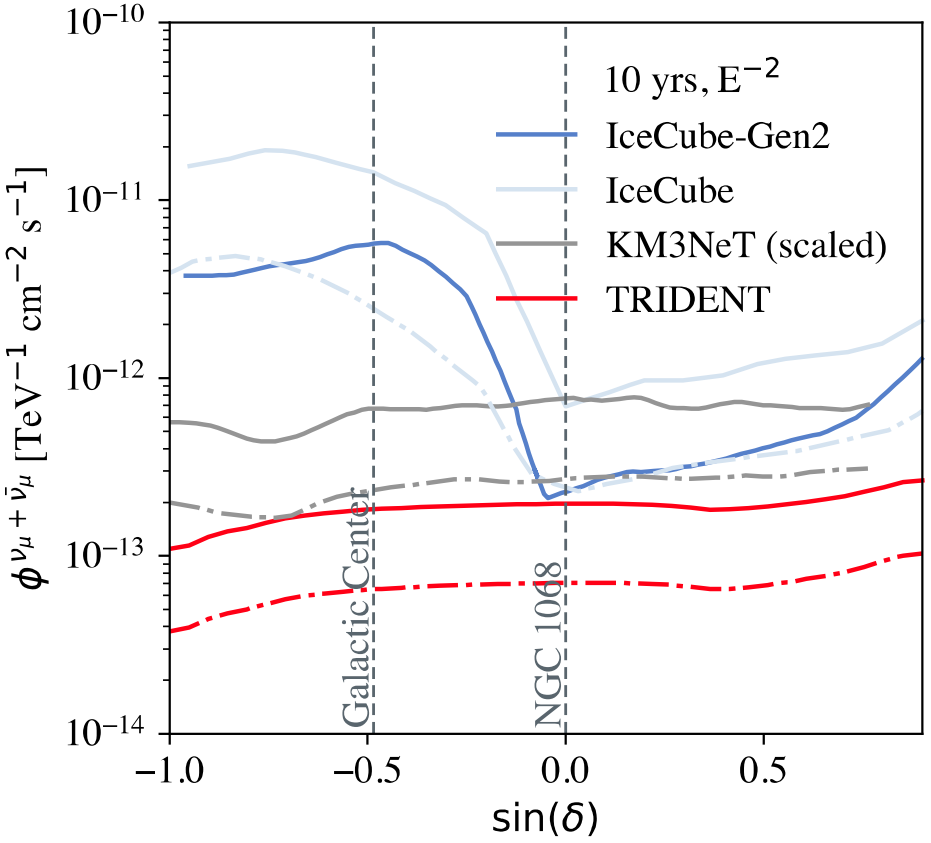
Neutrino sky:
(Location)



Angular/Energy resolution:
(**Optical medium**, Detector layout)





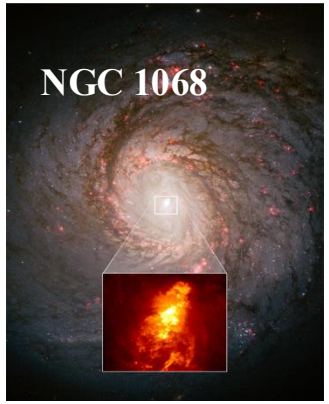


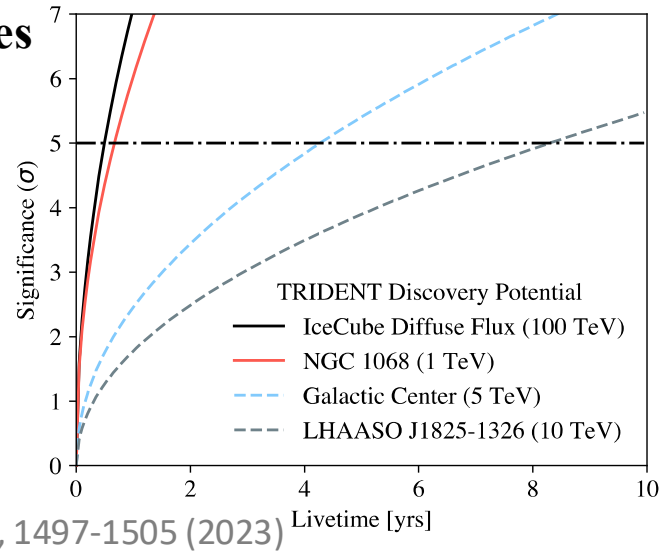
Near equator location → full sky coverage
Complementary to IceCube-gen2

Less scattering → better pointing resolution

Diverse Physics Potential

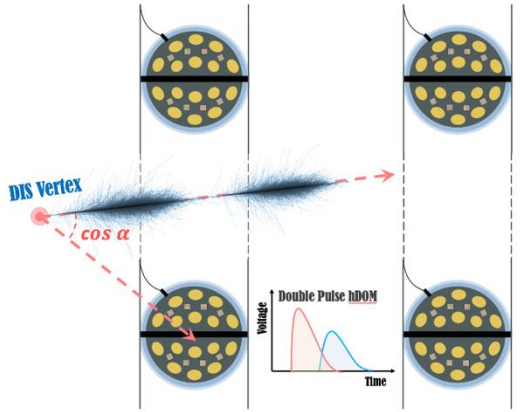
Point Source Searches

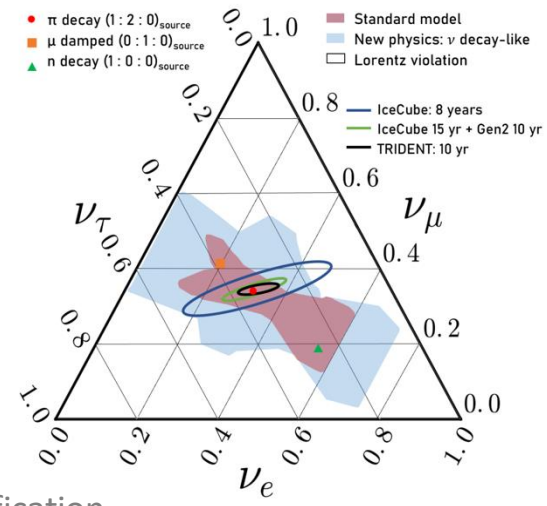




TRIDENT, Nature Astronomy 7, 1497-1505 (2023)

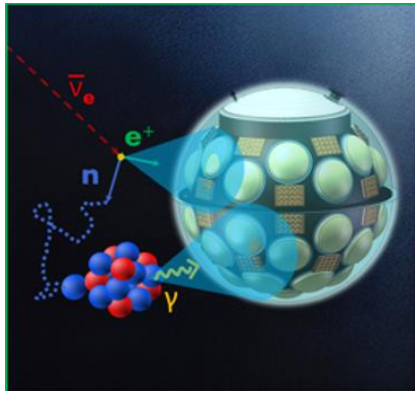
Flavor Ratio Physics

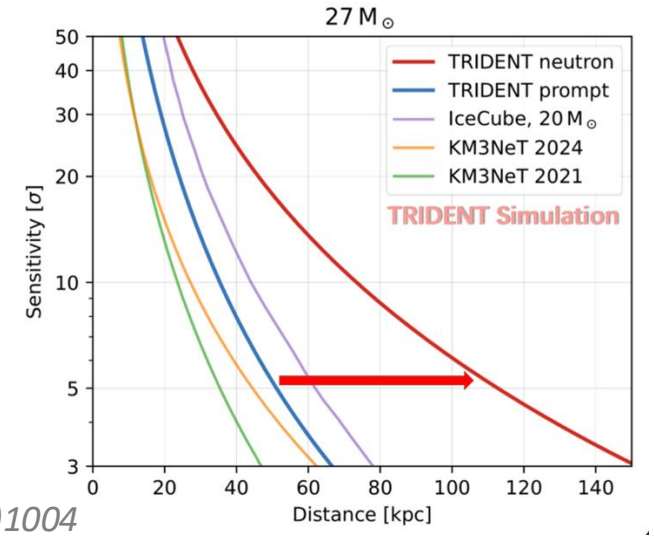




W. Tian (ICRC2025), Tau Neutrino Identification

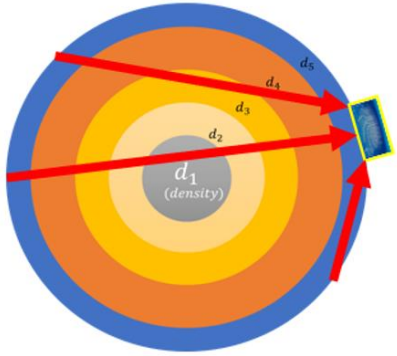
CCSN Detection

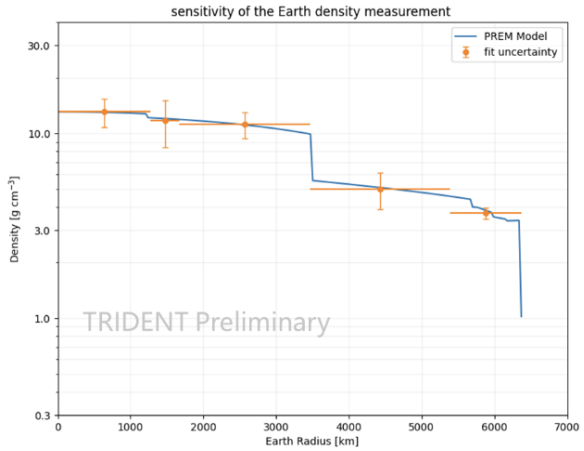




R. Cao (TRIDENT) PoS(ICRC2025)1004

Earth Tomography

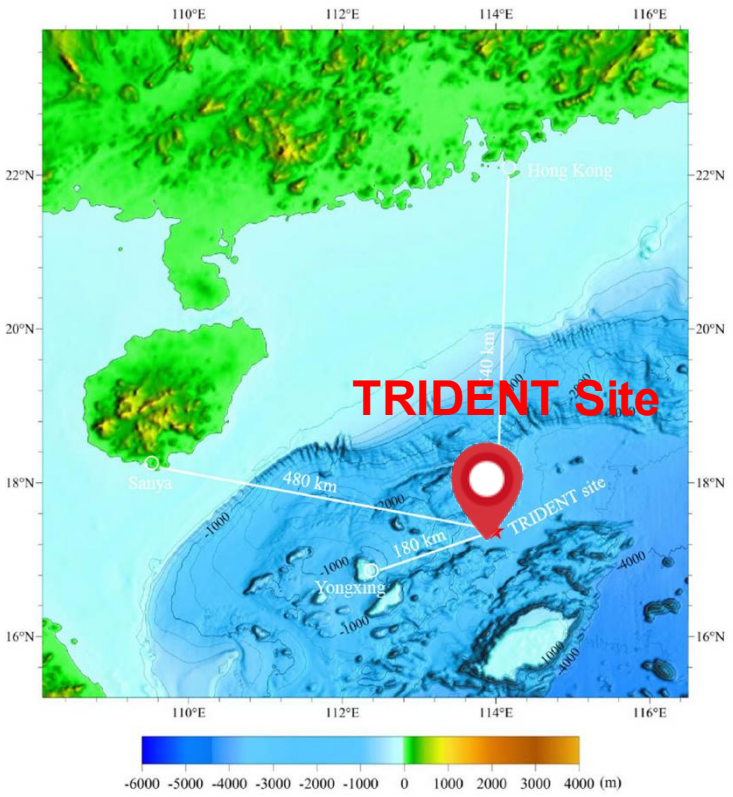


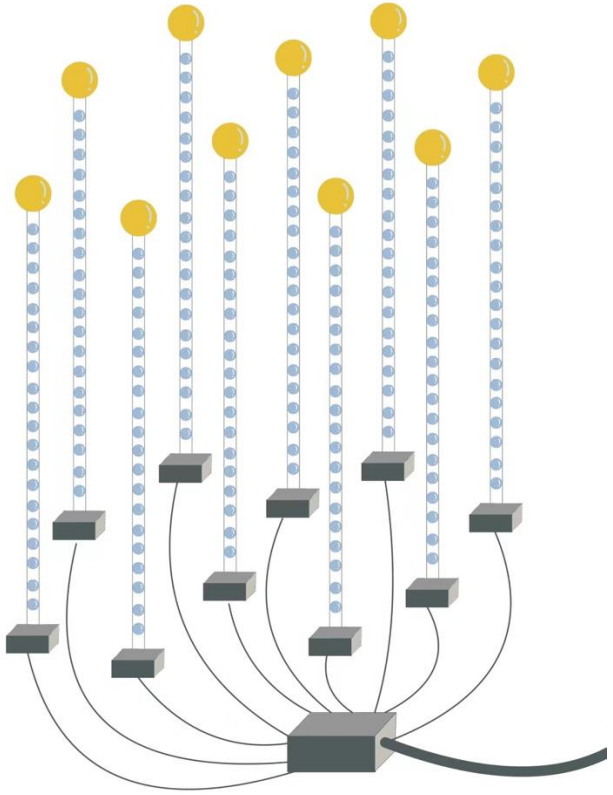


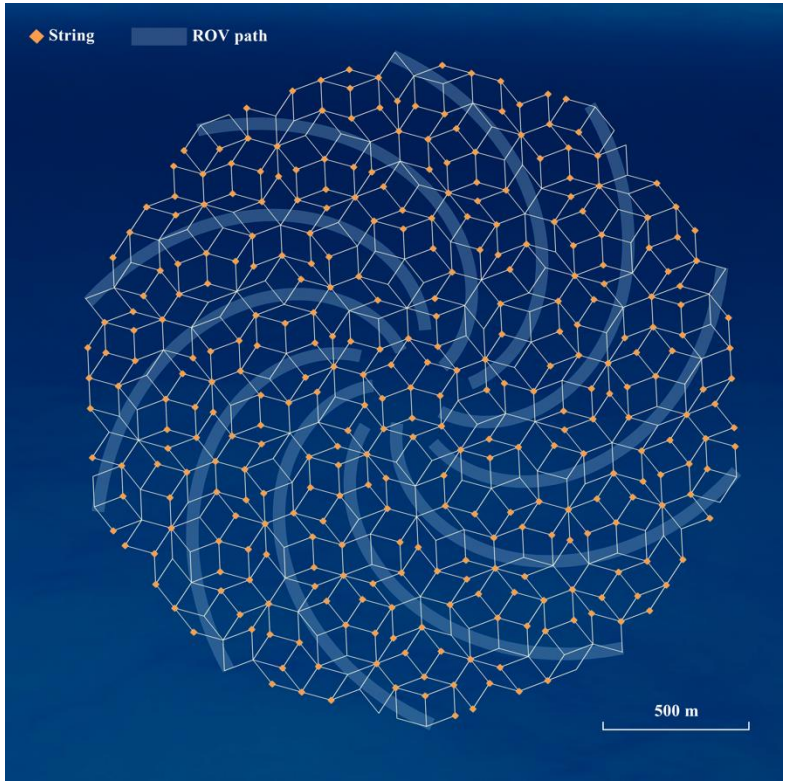
J. Huang (TRIDENT) PoS(ICRC2025)1059

Also indirect DM search, see backup

Overall Timeline





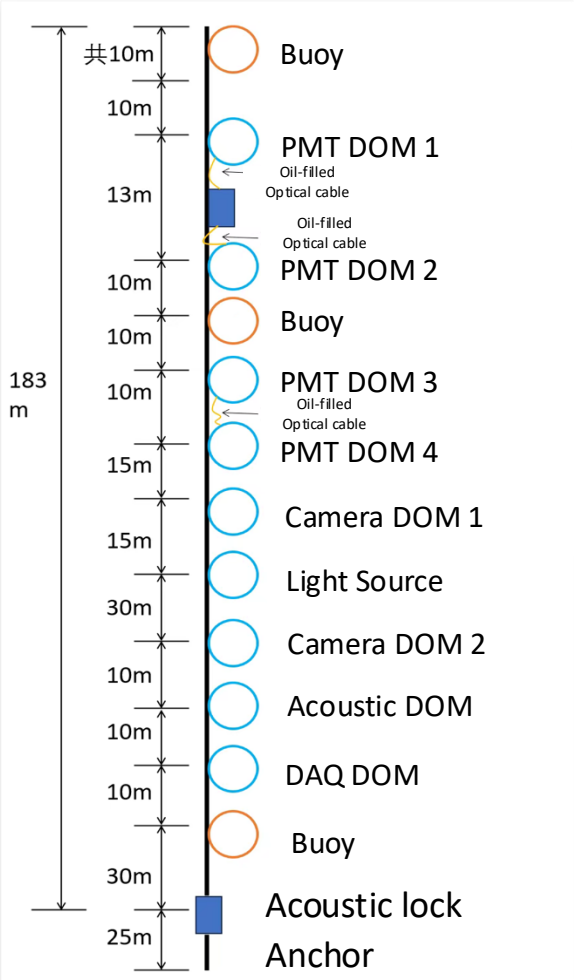


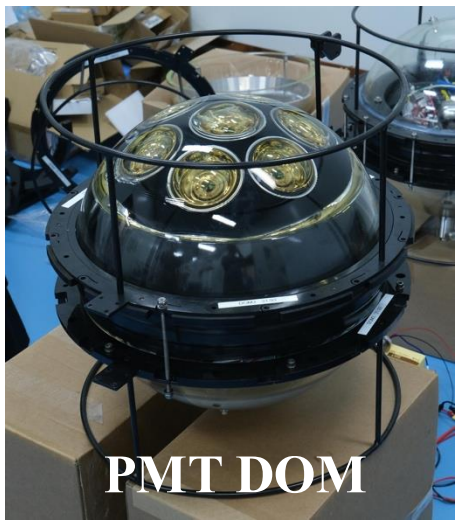
Pathfinder: 2019-2022 | **Phase I: 2022-2026** | **Full detector: 2026-**

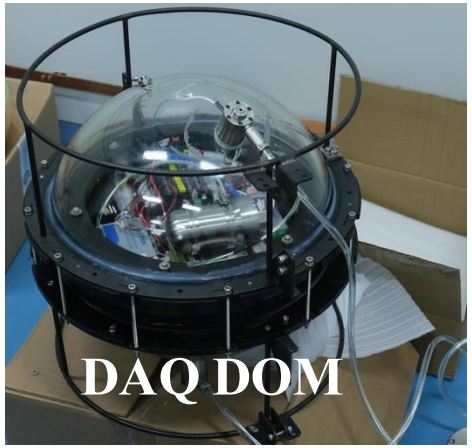
Sea Trial 2024 (T-REX 2024)

Deployed in Hai-Ling Basin:

2024.12.01 – 2025.03.26



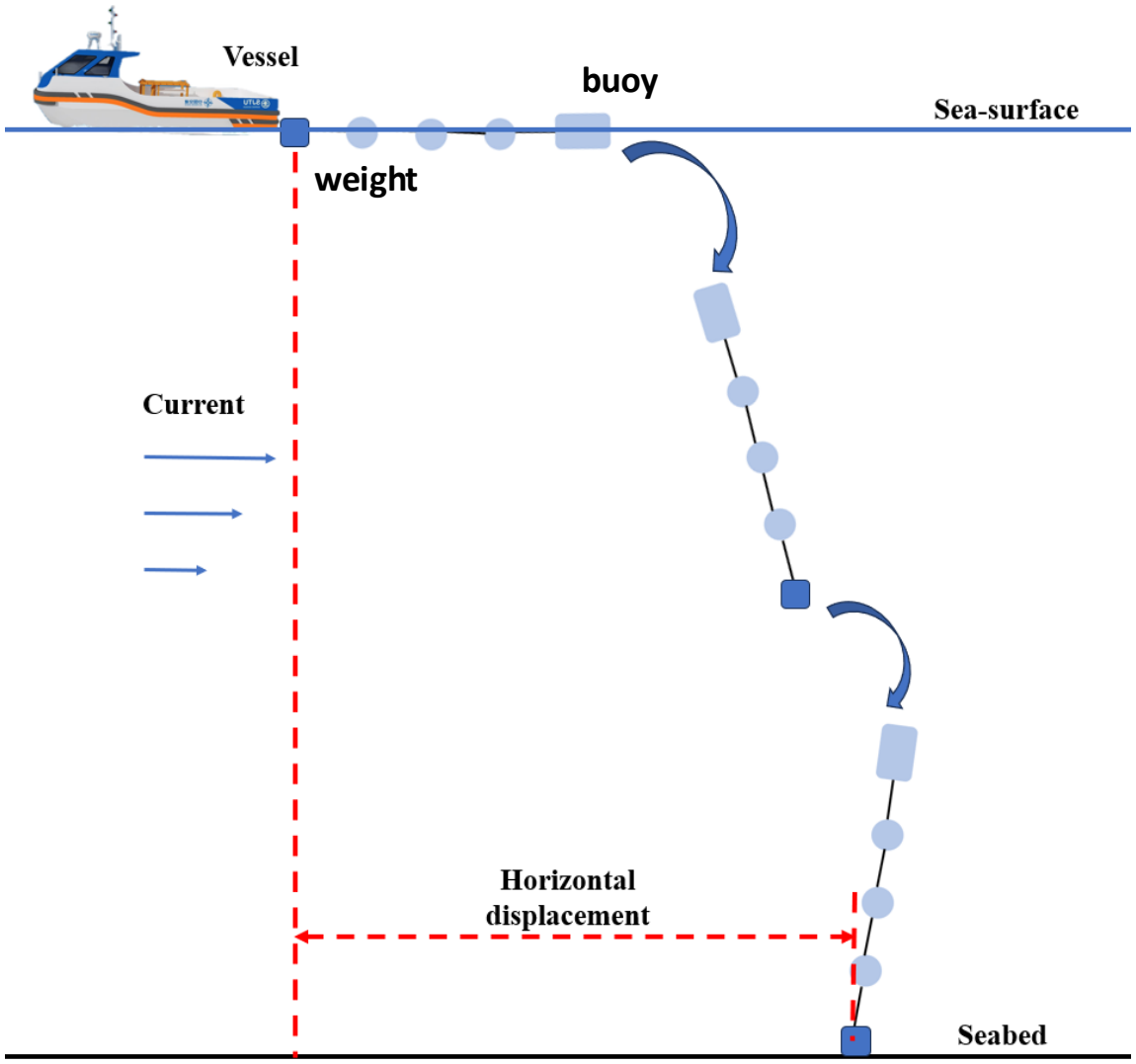




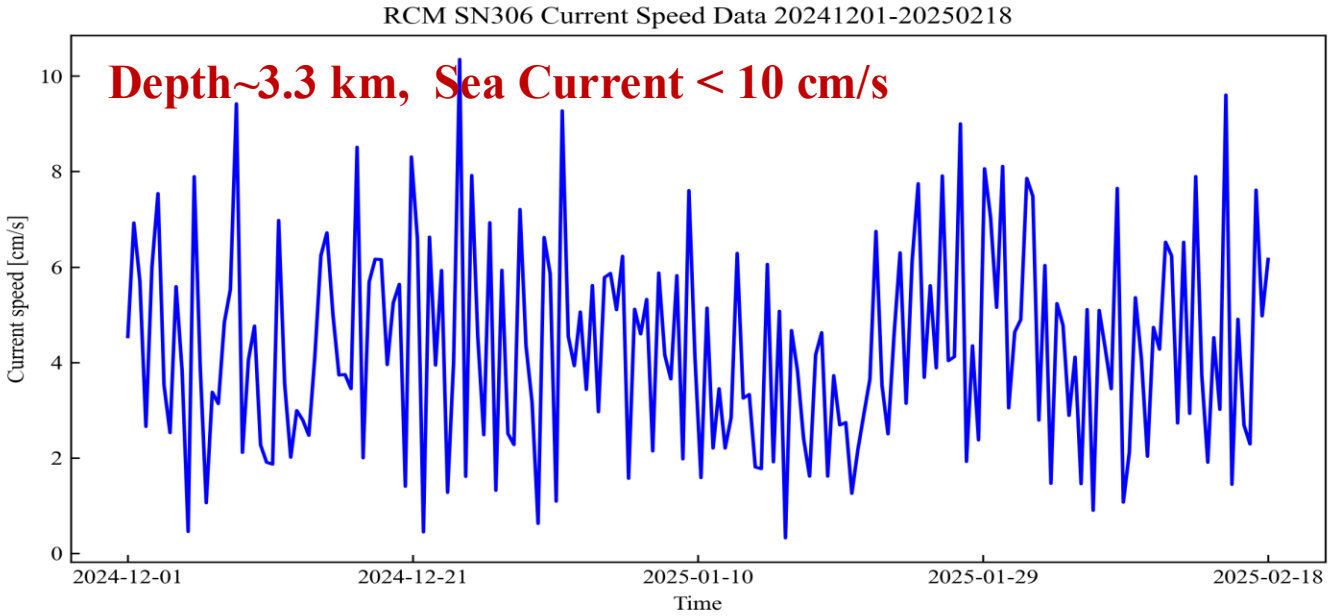
[1] *Updated camera system: PoS(ICRC2025)-1209*

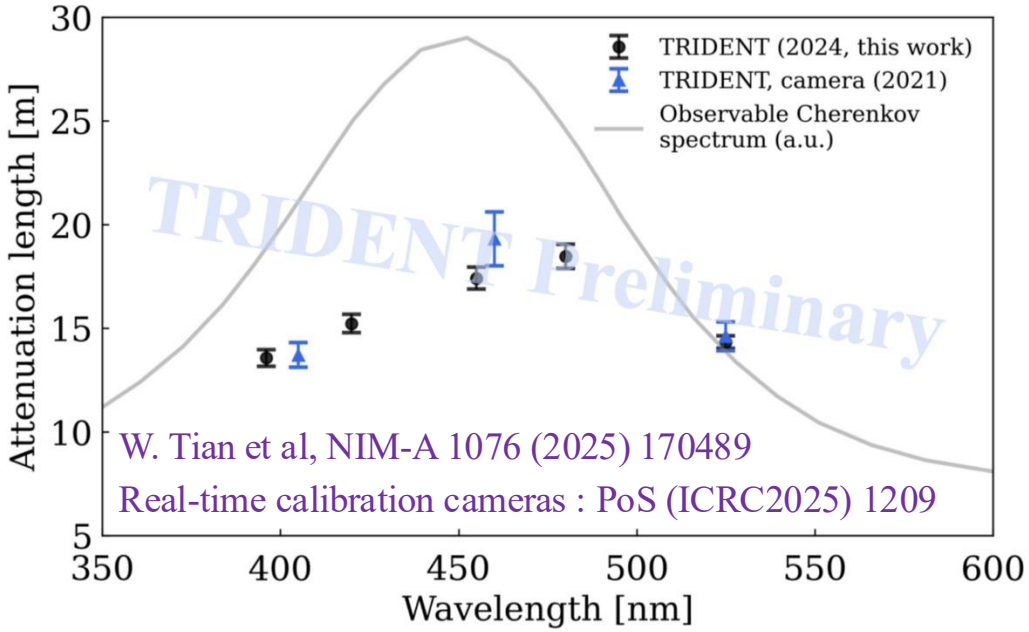
[2] *Acoustic sensor: PoS(ICRC2025)-1102* [3] *MuonSLab: PoS(ICRC2025)-440*

T-REX 2024 Deployment



T-REX 2024 Prelim Results



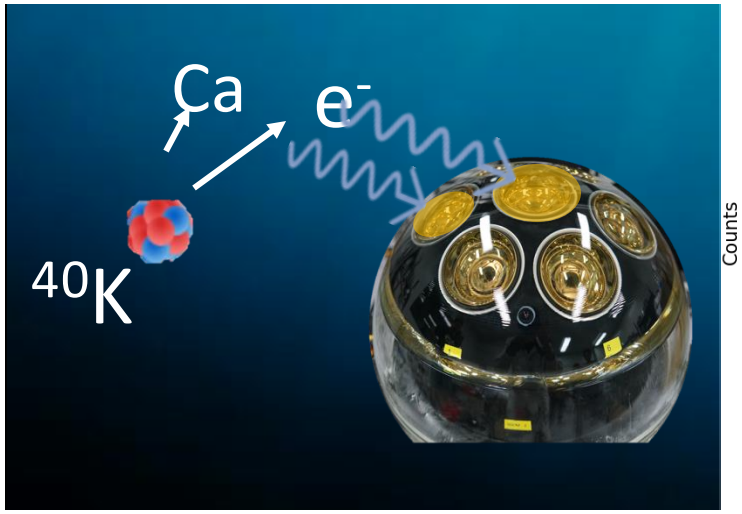


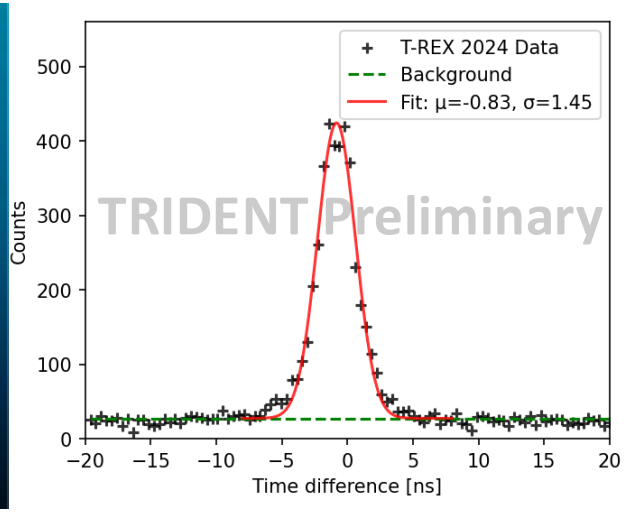
W. Tian et al, NIM-A 1076 (2025) 170489

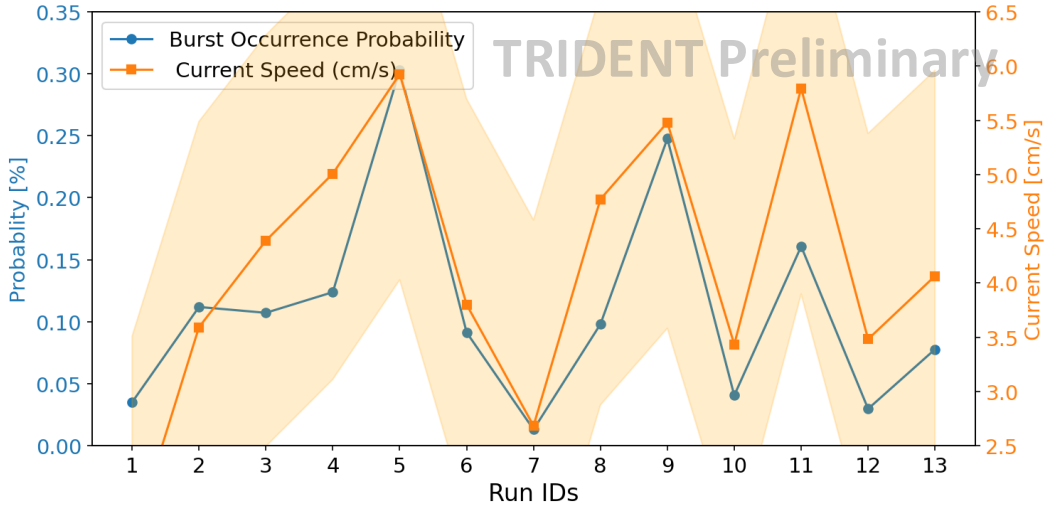
Real-time calibration cameras : PoS (ICRC2025) 1209

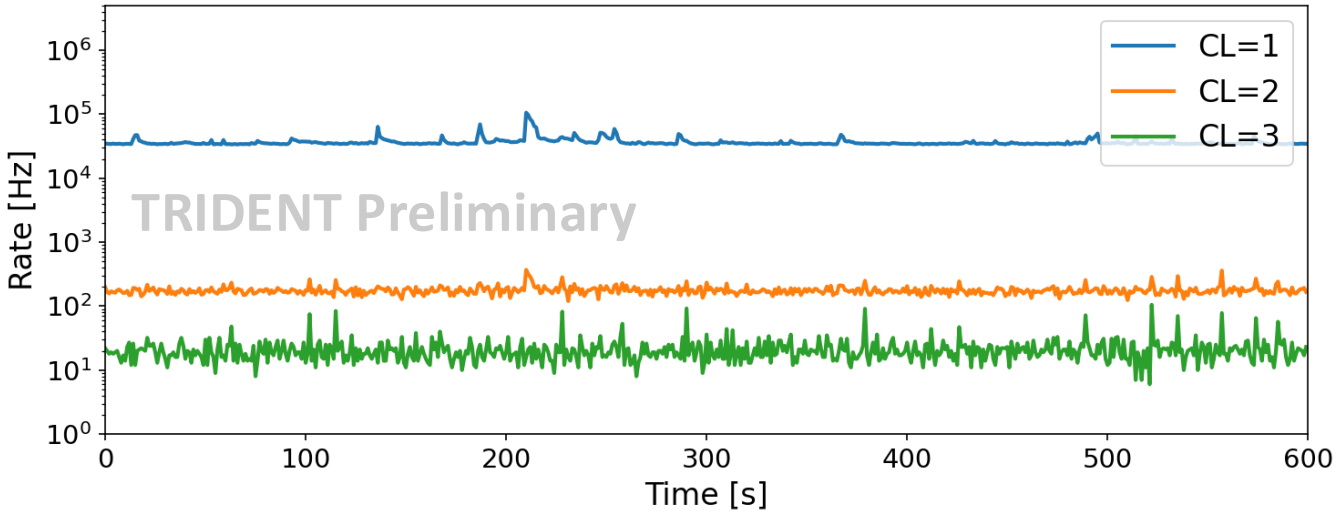
- No visual biofouling for 4-month operation at Hai-Ling Basin
- Updated *in-situ* optical properties measrement with camera system → consistent with T-REX 2021 results

T-REX 2024 Prelim Results





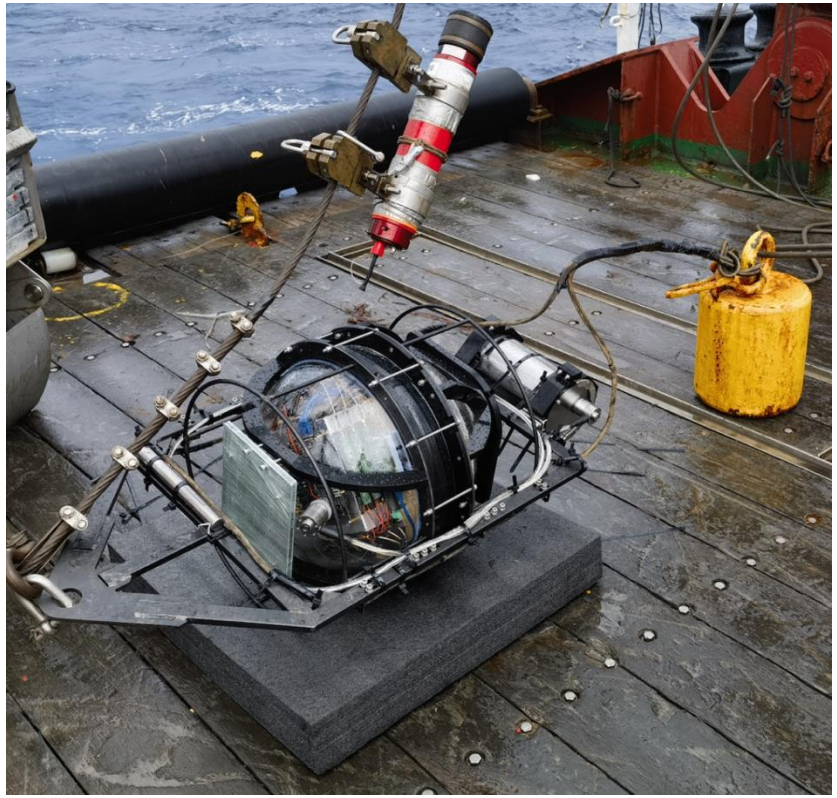


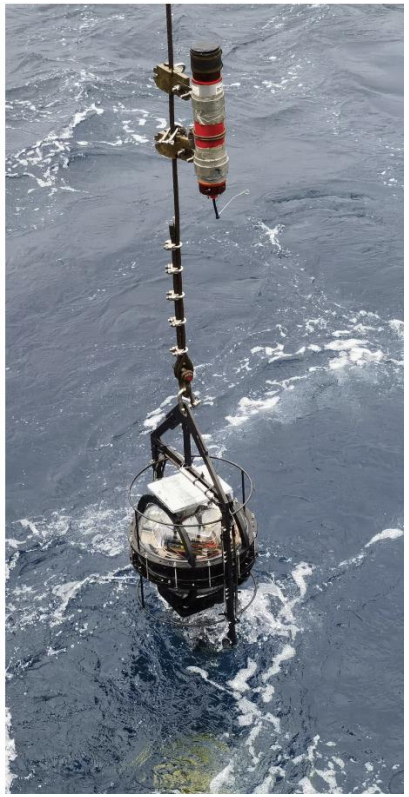


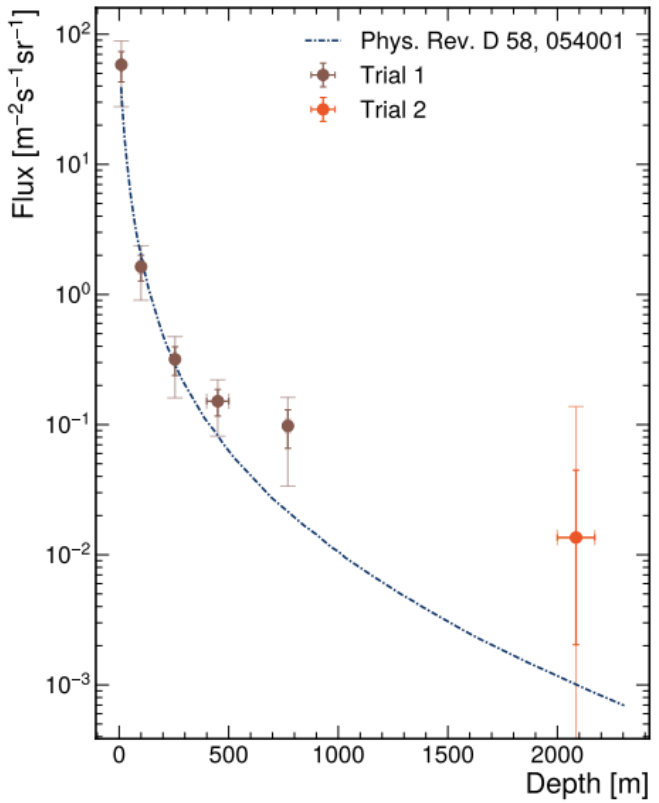
- **Baseline** rate per PMT: 5-8 kHz
- CL2: ~ O(100)Hz
- Observed burst mainly caused by bioluminescence
- Correlation btw. ocean current and the burst probability

F. Zhang, TAUP2025 (link)

T-REX 2024 Results





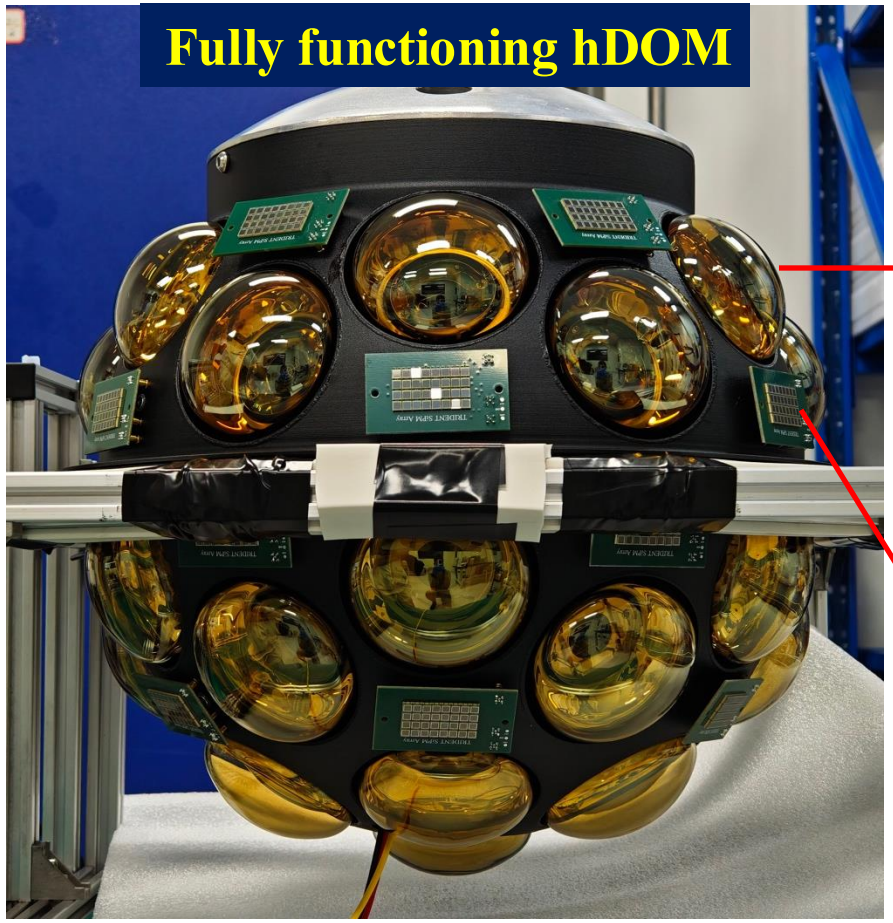


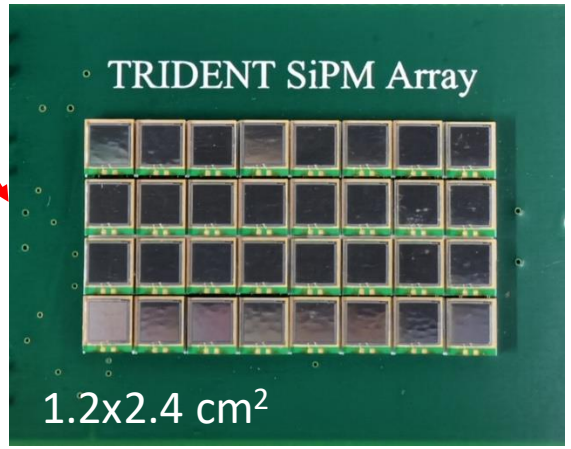
- MuonSlab: a plastic scintillator based detector

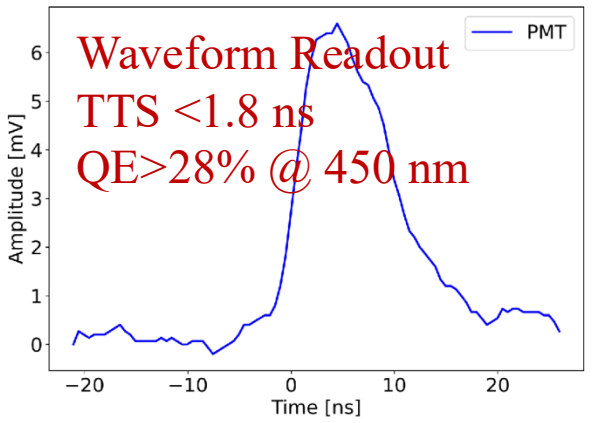
Jiacheng Wu et al 2025 JINST 20 P07035

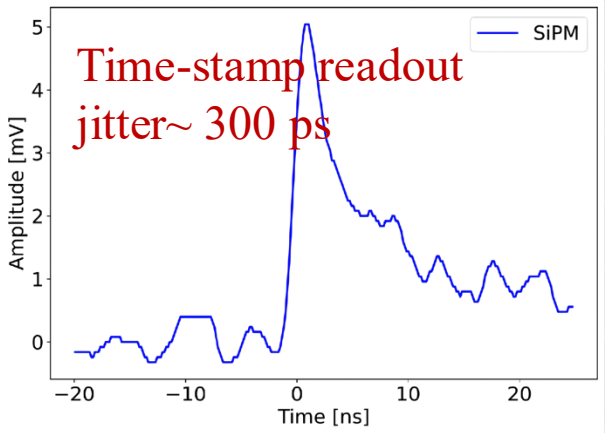
- First-time measured muon flux at various depths in South China Sea using plastic scintillators

Phase-I Detector









- Maximize photo-sensitive area & improve timing with SiPMs
- Event-by-event tau neutrino identification with PMT waveform readouts

→ **Track better than**

0.1^{o} @ E_{ν} > 100 TeV

PMTs

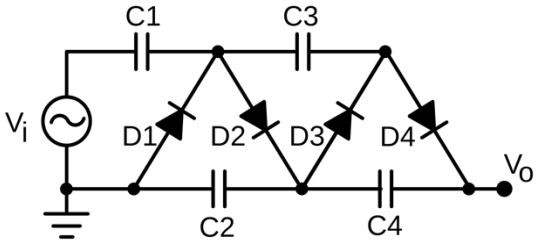
Massive PMT Testing Platform

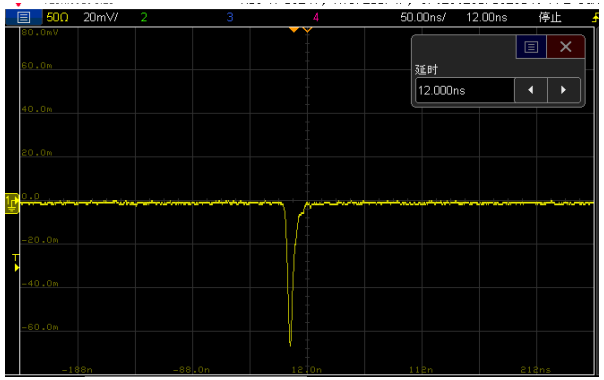
- Capable of characterizing 144 PMTs simultaneously in a 2 °C cold room.

X. Xin, TAUP2025 (link)

High Voltage Power Supply

Cockcroft-Walton



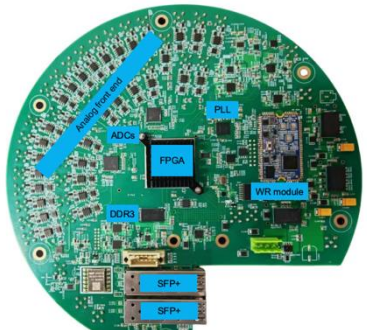


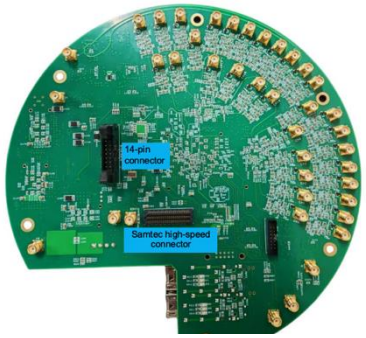
- **Cockcroft-Walton Circuit** : achieving a compact high-voltage module without HV cable
- **Independent Control**: Each PMT is powered separately.

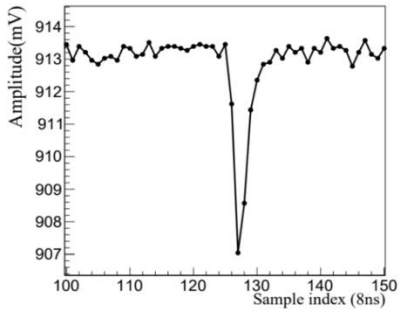
X. Xin, TAUP2025 (link)

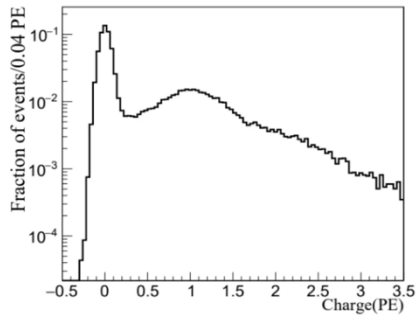
hDOM Electronics

Mother Board







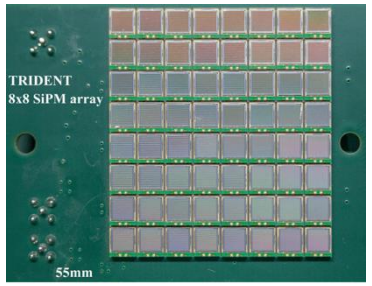


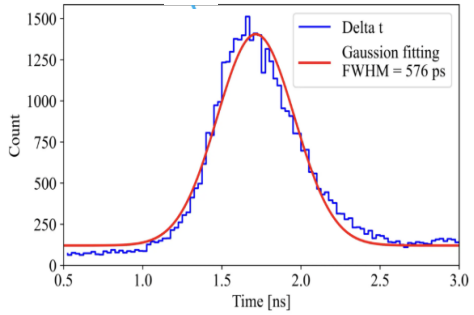
- **PMT readout**: 32-channel 125Msps ADC
- **Multi-board sync**: White Rabbit (WR) protocol for sub-ns time synchronization
- **FPGA-integrated TDC**: supports sub-ns TOT signal measurement

hDOM motherboard : PoS (ICRC2025) 1059

SiPM Electronics

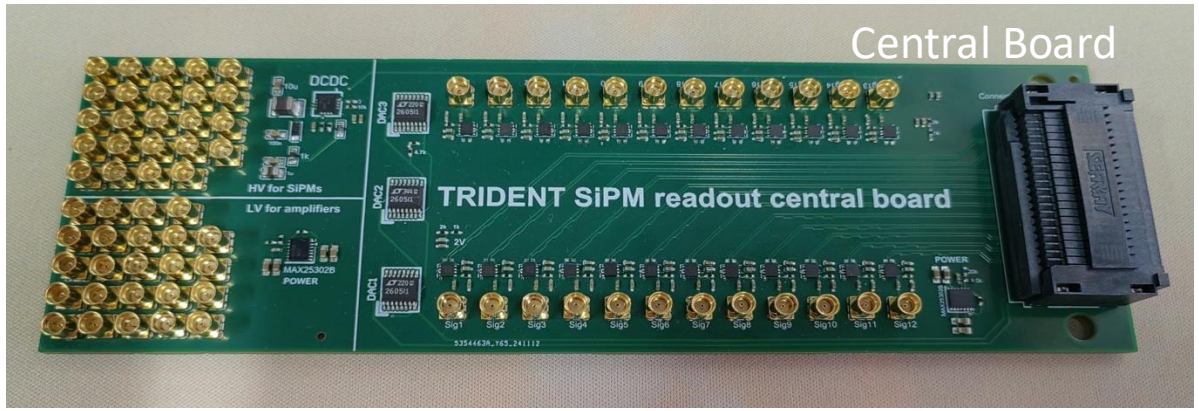
Excellent timing achieved for large-area SiPM arrays!

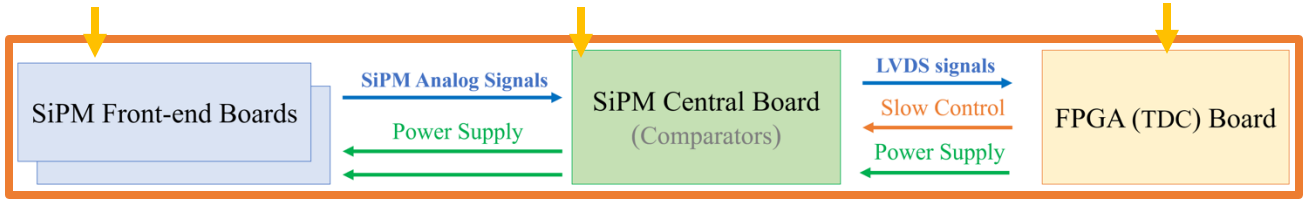




8*8 SiPM Arrays

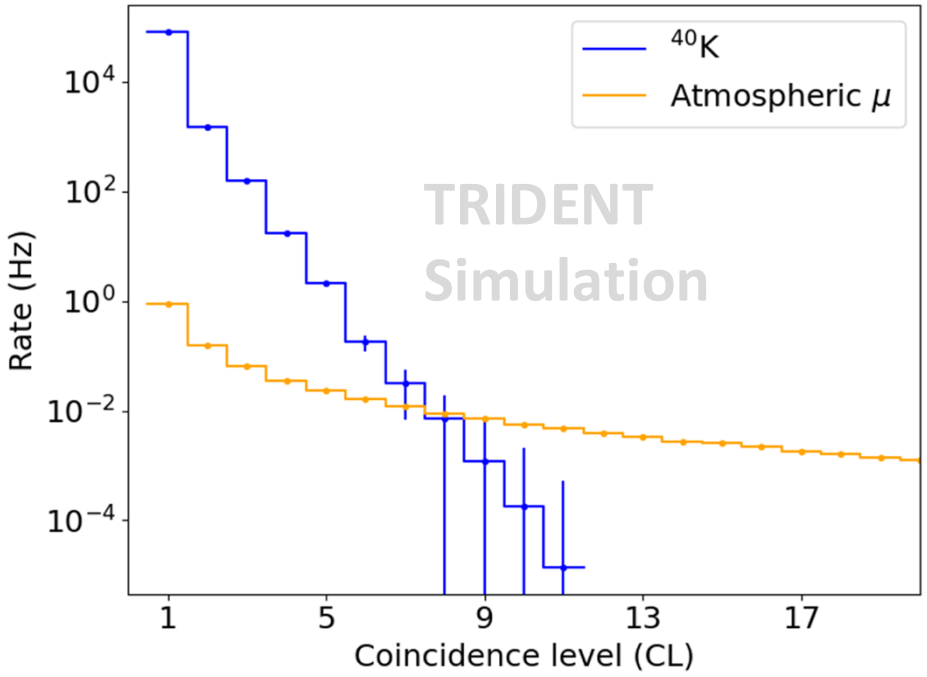
- SPTR < 600 ps
- Power consumption: 185 mW

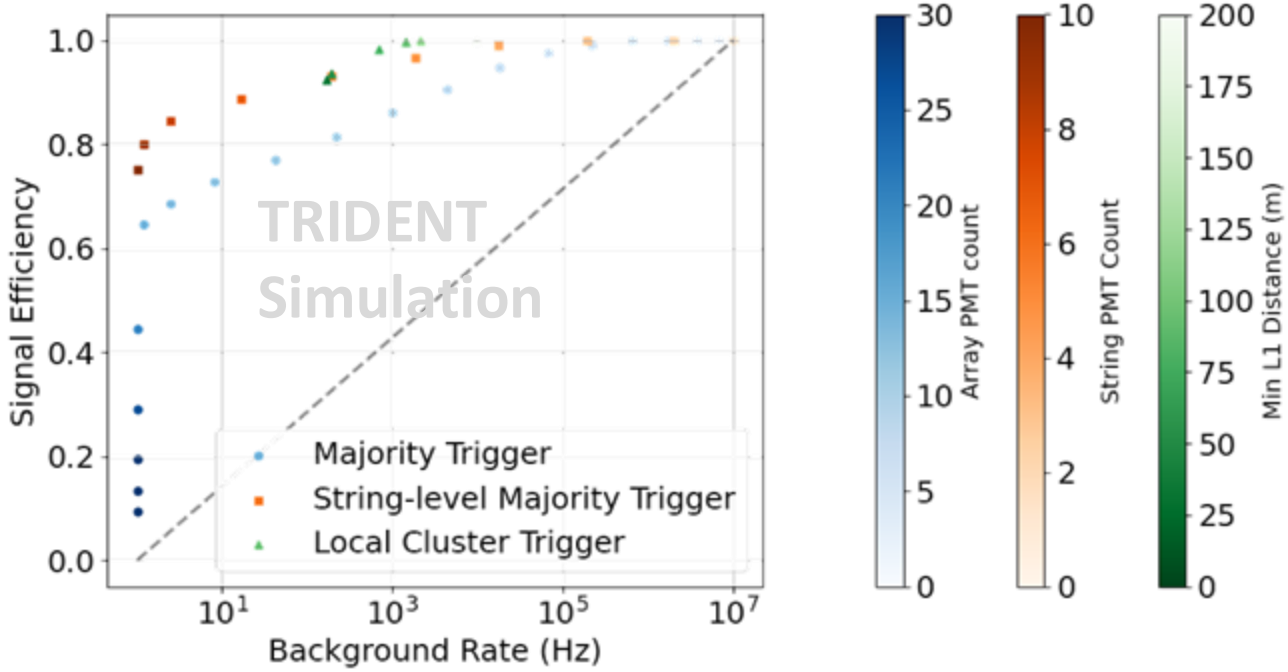




hDOM SiPM: PoS (ICRC2025) 1055

Trigger & DAQ



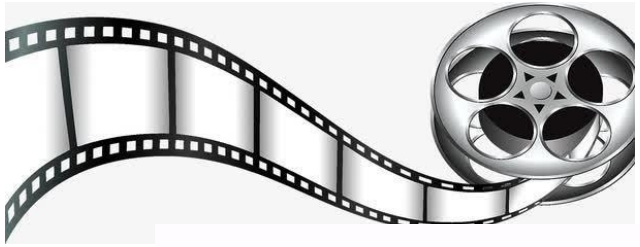


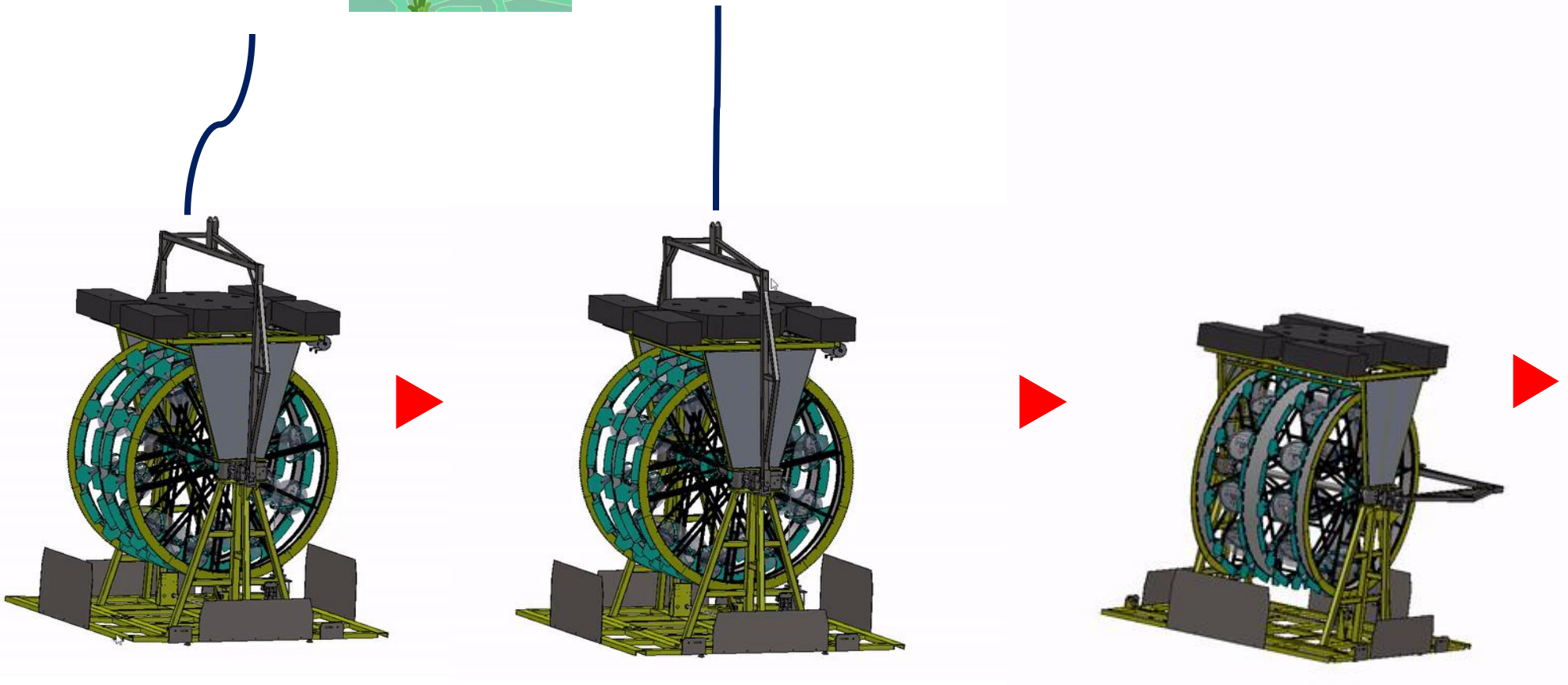
- High background rate (from K-40) + PMT waveform readout → large data throughput
  - ***O* (10Gbps) for Phase-I**
- Needs real time data processing and selection at various stages
- A combination of hardware (at hDOM motherboard) and software trigger (on-shore cluster)

TRIDENT trigger strategy:

PoS (ICRC2025) 1231

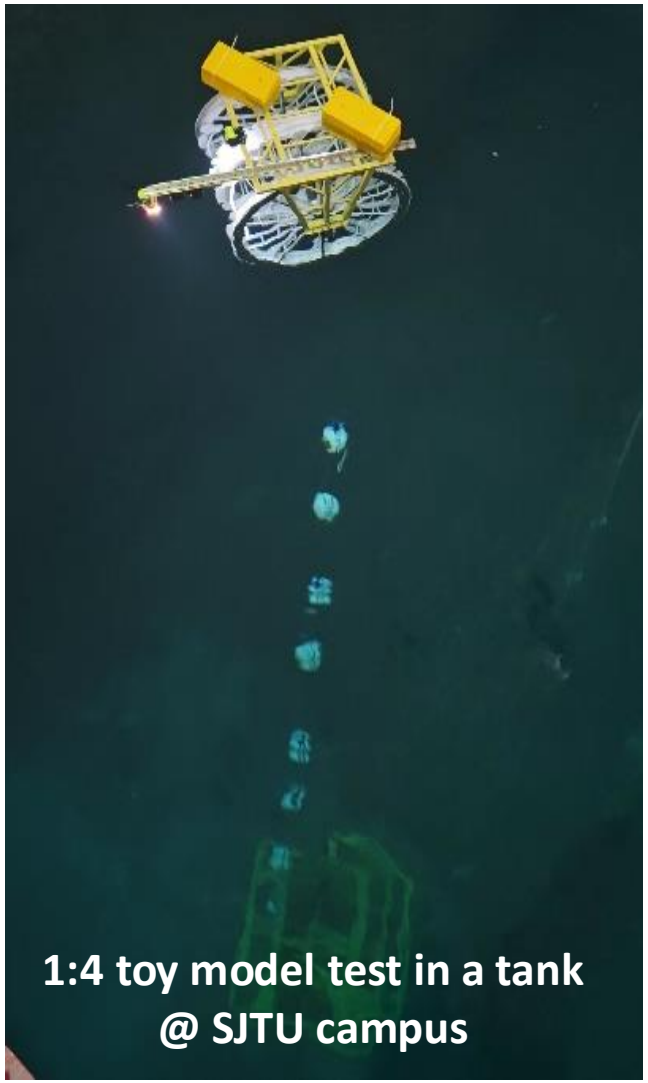
Deployment Strategy – Packaging



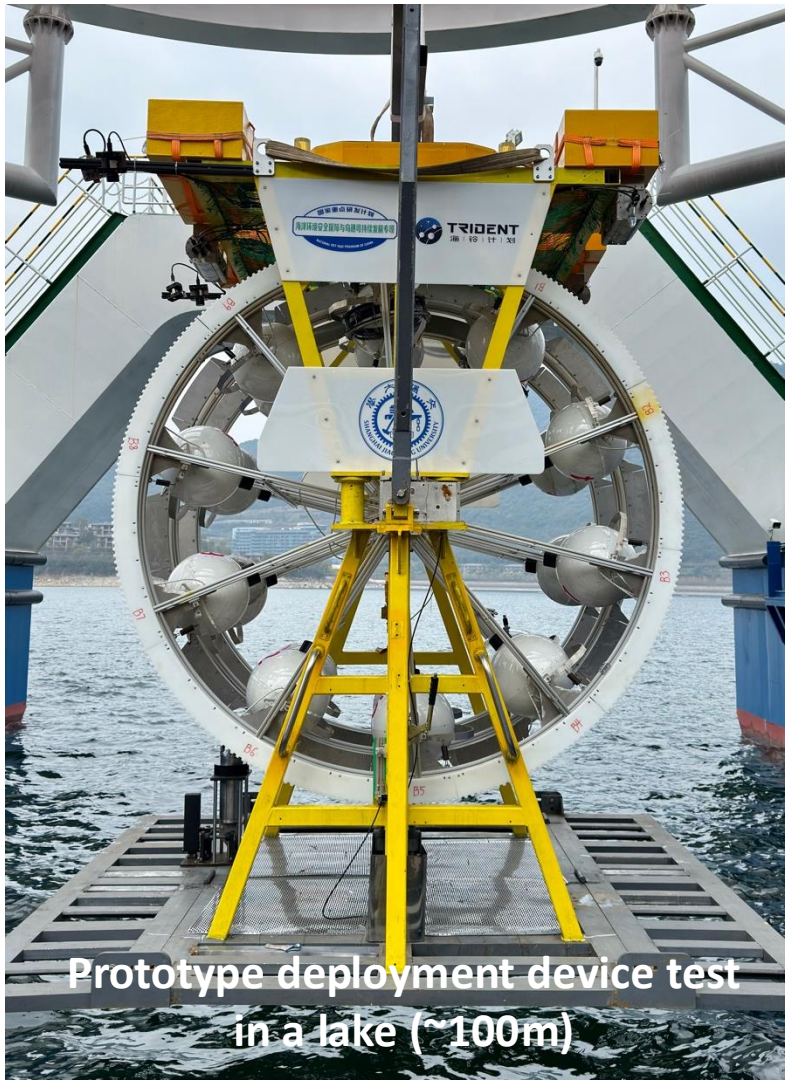


Pack → Deploy → Unfold

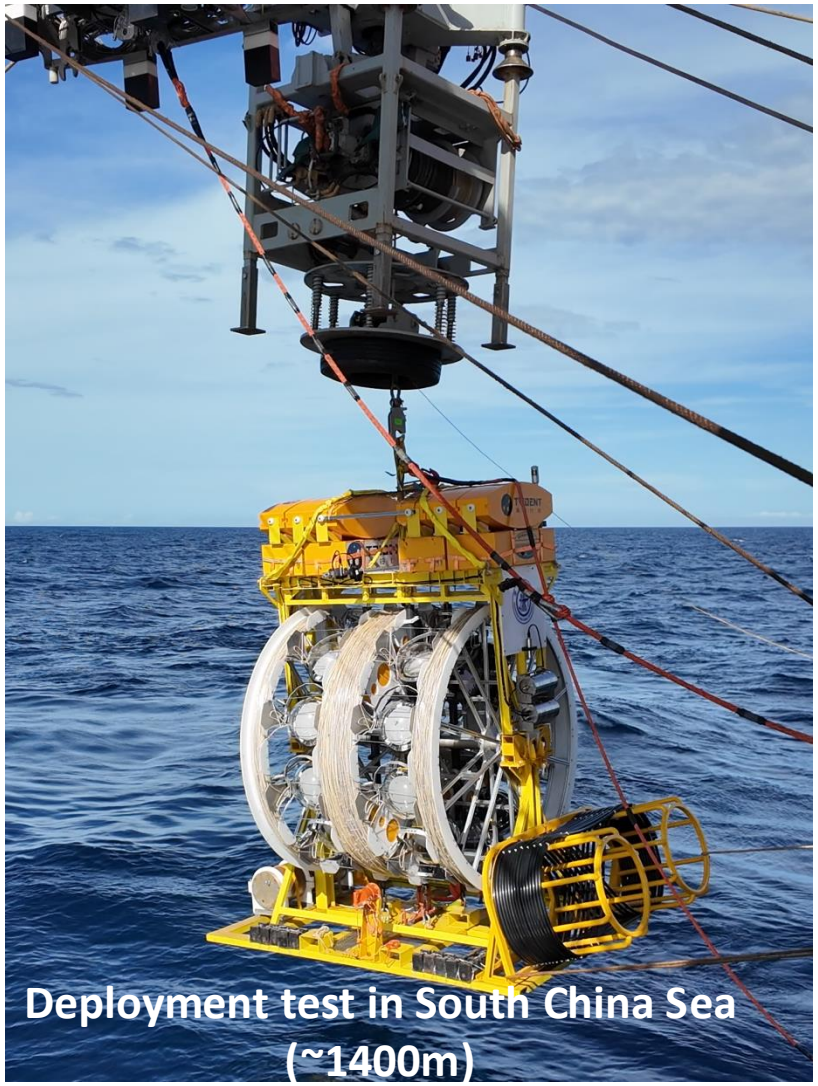
Deployment Strategy - Packaging



1:4 toy model test in a tank @ SJTU campus



Prototype deployment device test in a lake (~100m)

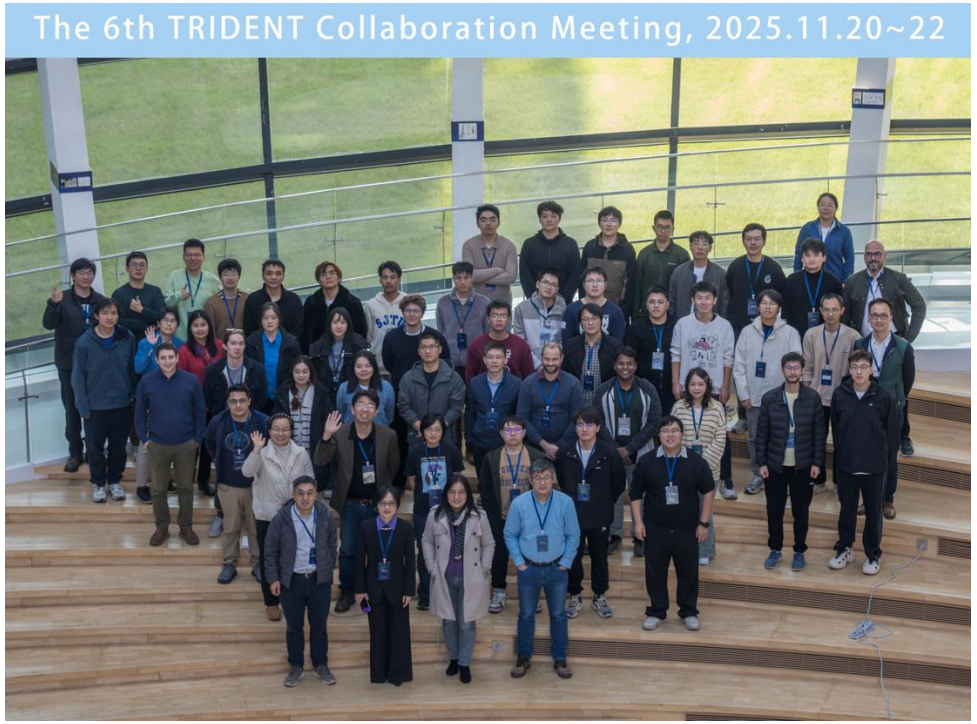


Deployment test in South China Sea (~1400m)

Y. Xue et al, Design and Lake Trial of a Deep-Sea Neutrino Detection Mooring Deployment System

https://trident.sjtu.edu.cn/en/gallery/videos

International Collaboration



~13 institutes, ~ 100 members

Assembly Lab in Sanya, Hainan

- A factory-style assembly lab (~1000m²) is being renovated at Sanya Yazhou Bay
- TRIDENT Phase-I's 200 hDOMs and 10 strings will be assembled and tested here
- **Hainan will be visa-free** to most global nationals starting **from 2026** → easy access to lab and equipment

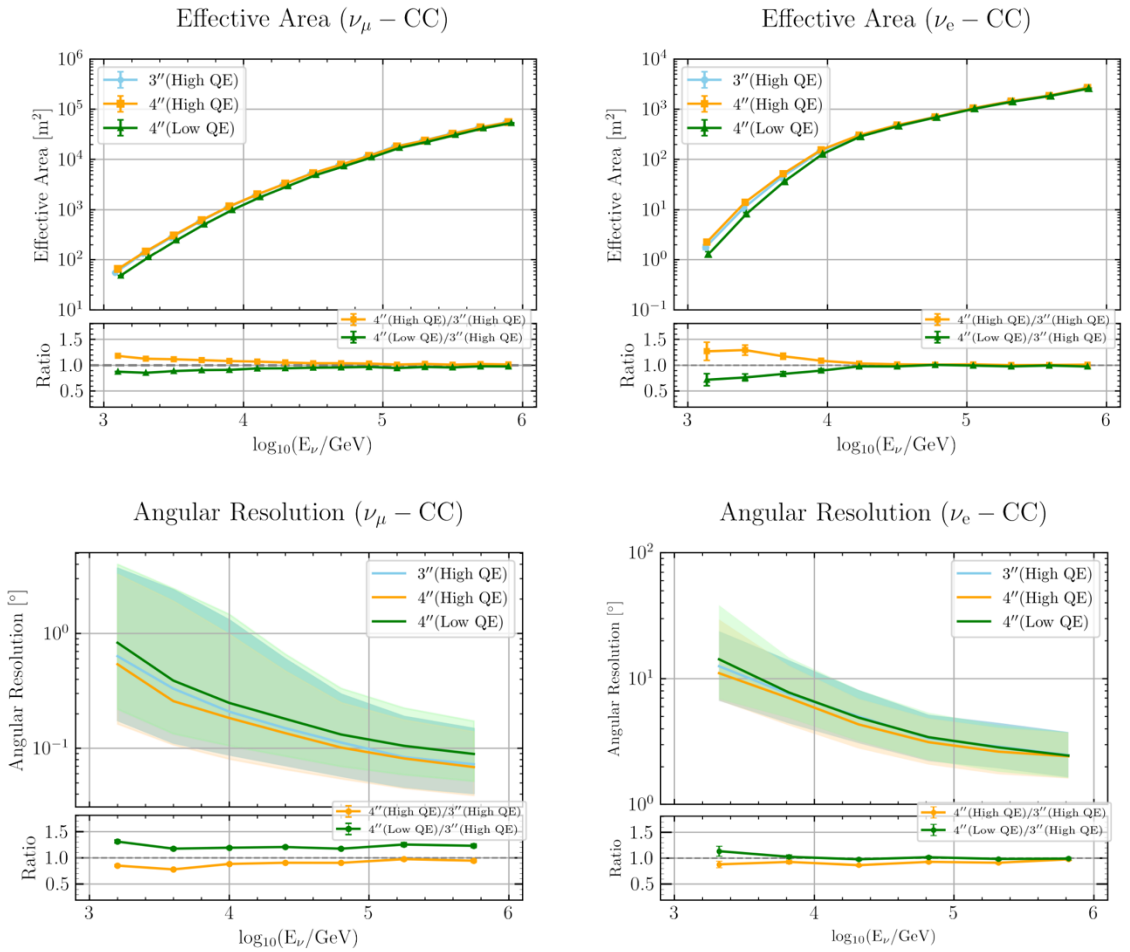
Future Direction (PMT: 3” → 4”)

arXiv:2507.10256

3” PMT Design

4” PMT Design

No Compromise in TRIDENT’s Physics Performance

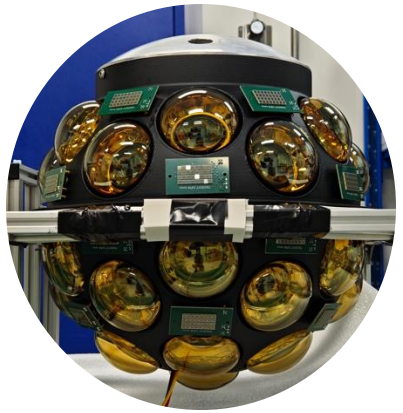


arXiv:2507.10256

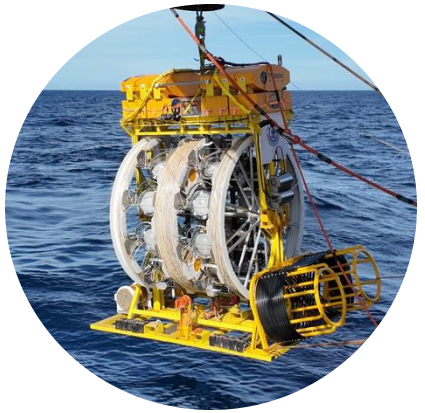
Summary

- **An Exicting New Era**: Opportunities in both neutrino astronomy and fundamental physics.
- **Hai-Ling Basin**: An ideal site for large-scale deep-sea neutrino telescope.
- **TRIDENT Phase-I**: the main technologies have been verified in sea trials. Stay tuned!

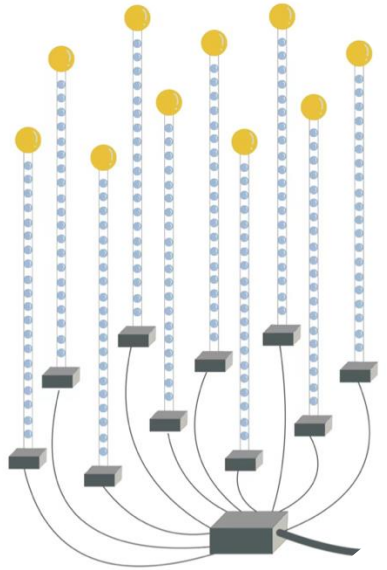
Successful Sea Trials



Fully Working Detector



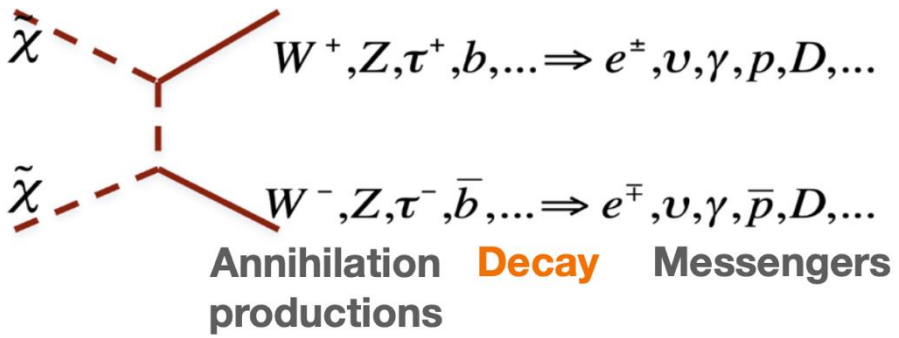
Deployment Verified

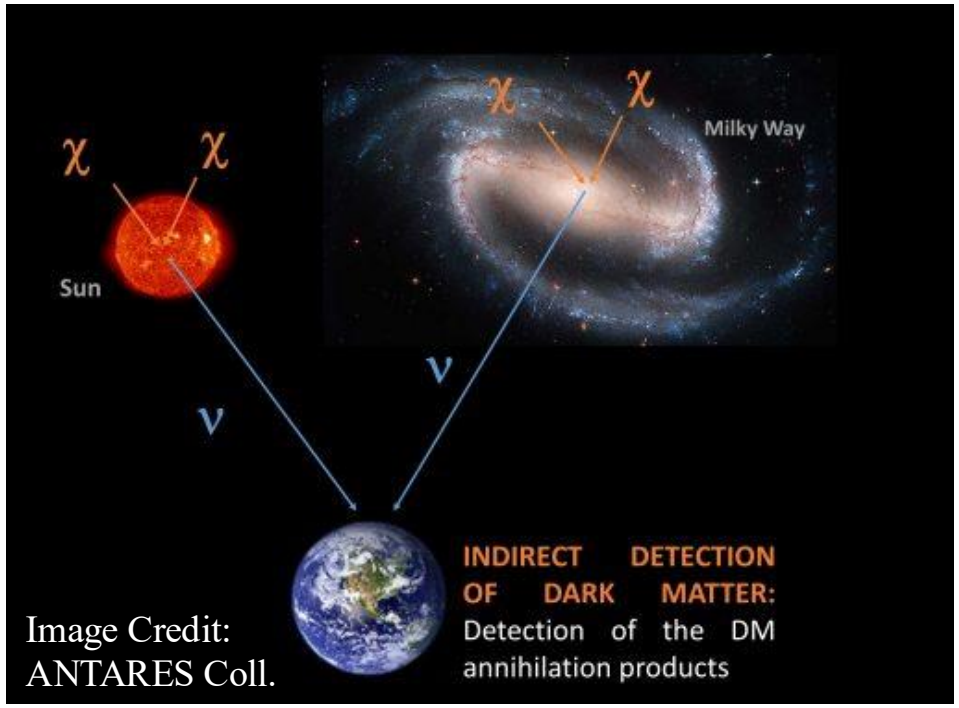


Welcome to join us !

Backup

TRIDENT Indirect DM Detection





Flux Produced

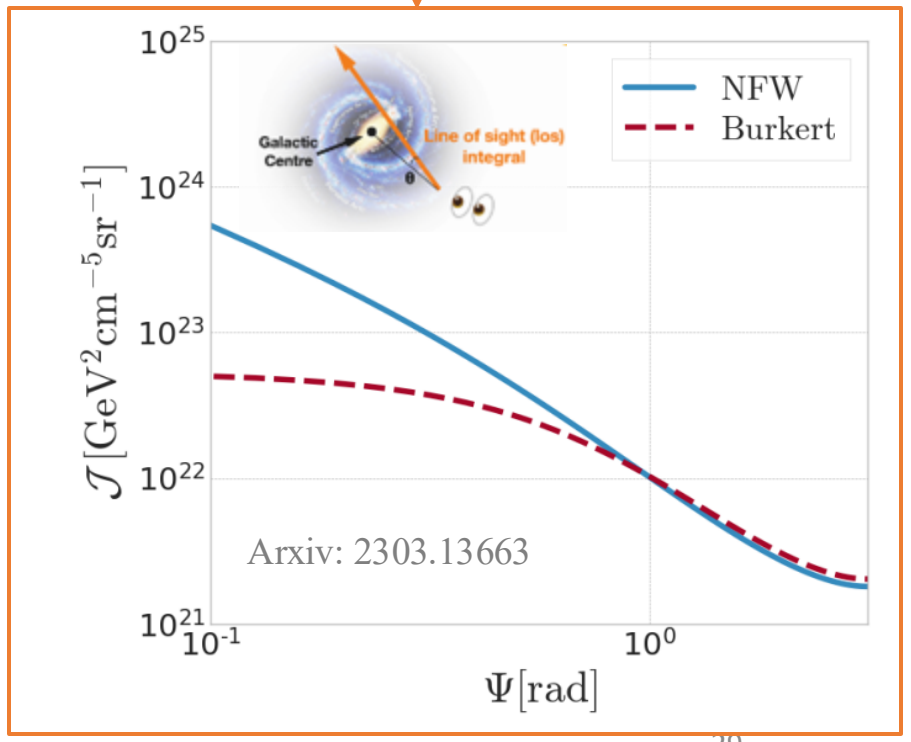
POI

ν energy spec

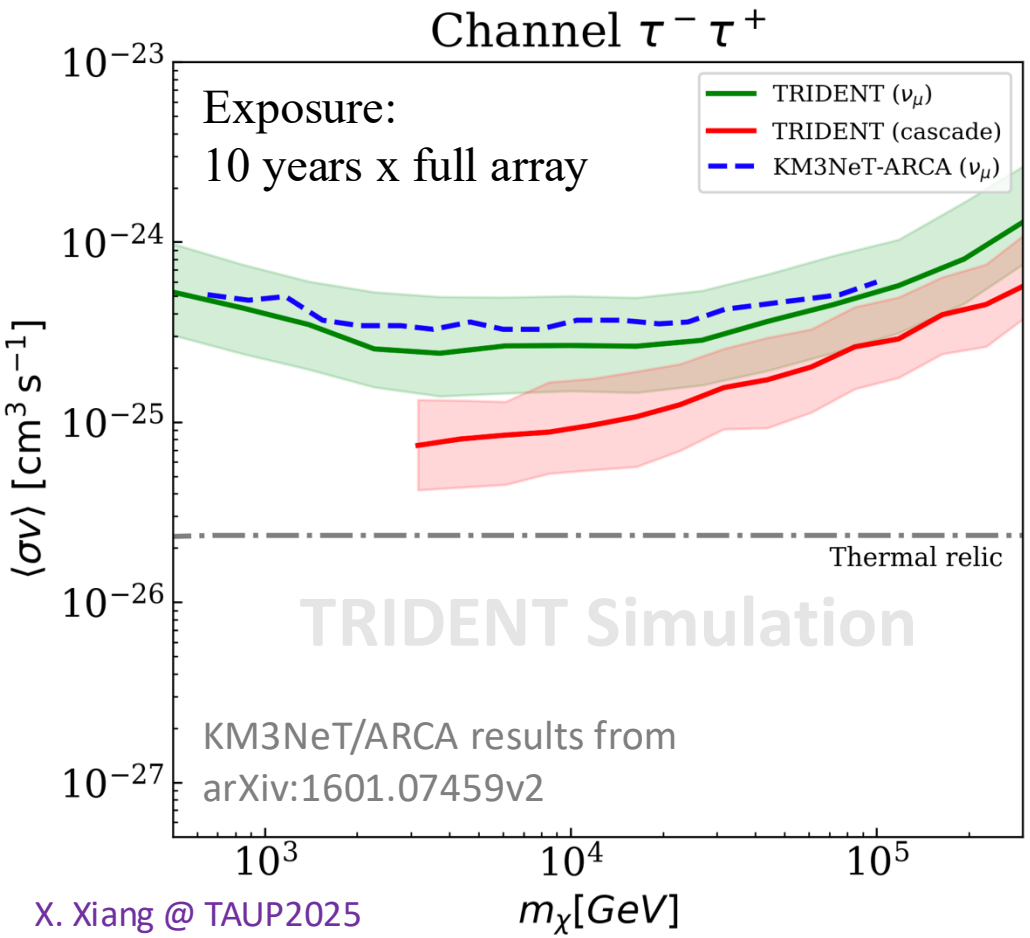
$$\frac{\mathrm{d}\phi_\nu}{\mathrm{d}E_\nu}(E_\nu, \Psi) = \frac{1}{4\pi} \frac{\langle\sigma v\rangle}{2m_\chi^2} \frac{\mathrm{d}N_\nu}{\mathrm{d}E_\nu} \int_{\Delta\Omega} \int_{\mathrm{l.o.s.}} \rho_\chi^2 \left(r(\ell, \Psi)\right) \mathrm{d}\ell \, \mathrm{d}\Omega,$$

2 if χ is Majorana, otherwise k=1

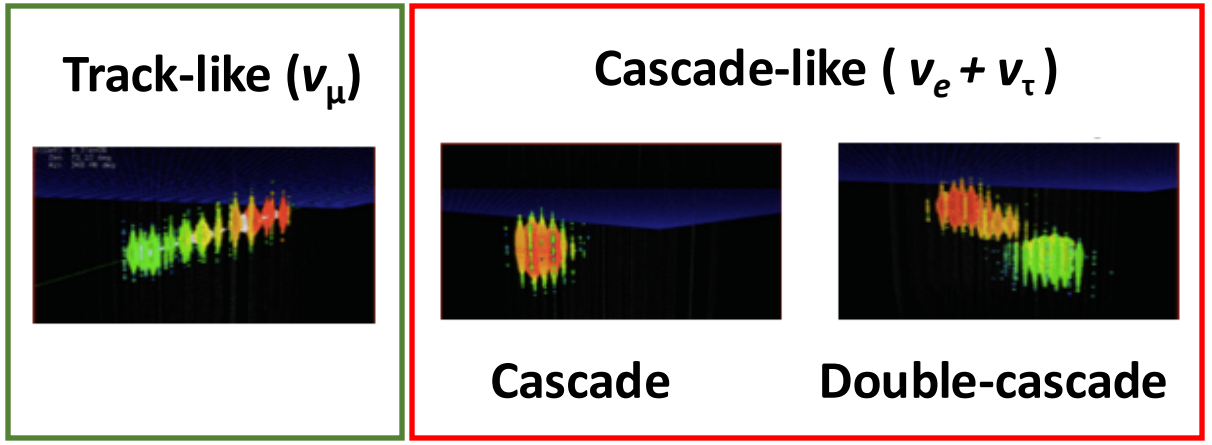
J-factor (line of sight)



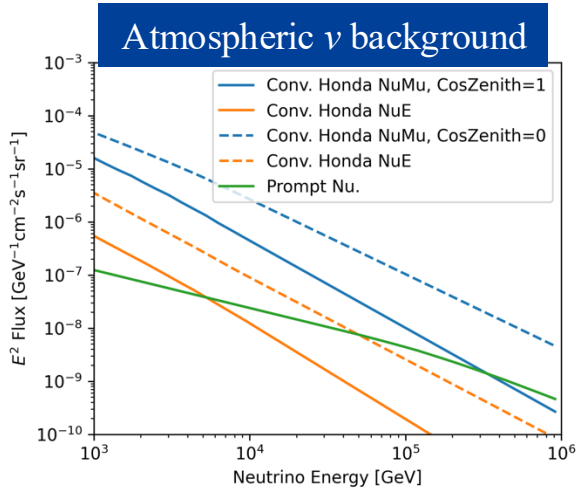
TRIDENT DM Sensitivity ($\chi\chi \rightarrow \tau^+\tau^-$)



X. Xiang @ TAUP2025

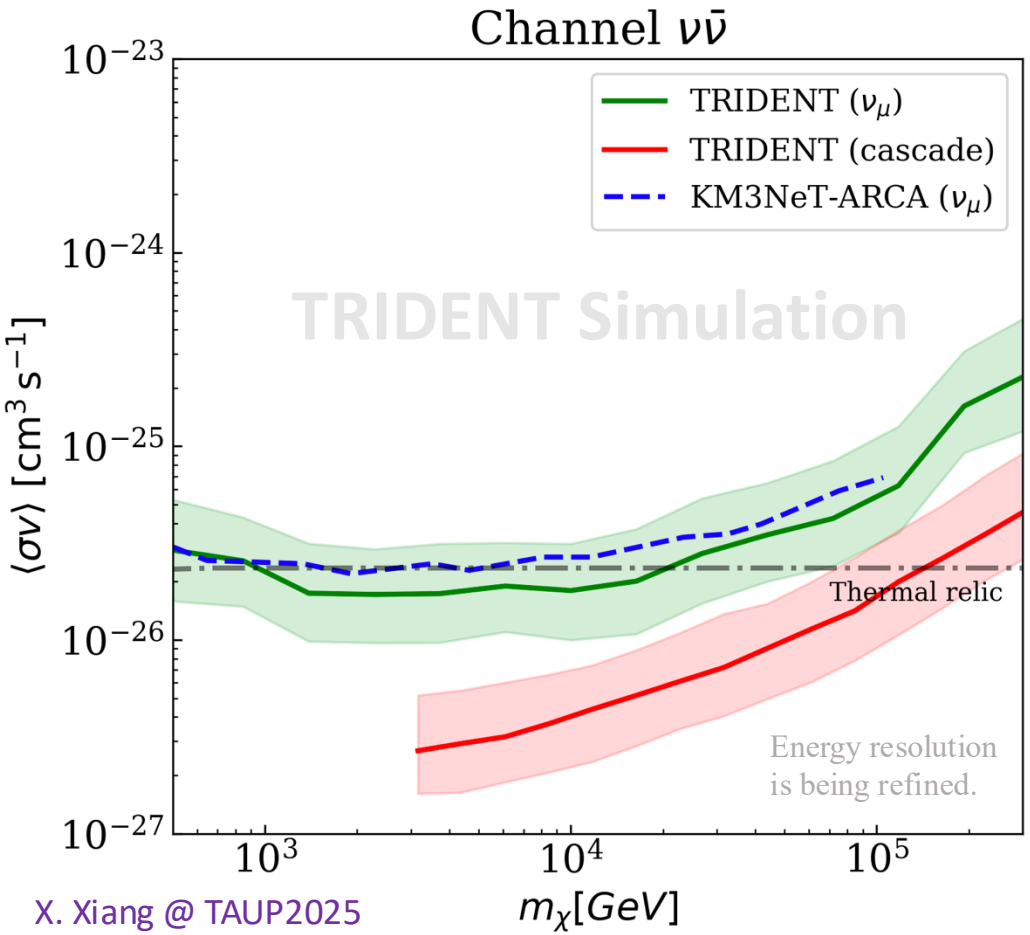


- **Background**:
  - Atmospheric ν (main bkg)
  - Diffused Astro. ν
  - Galactic ν (in progress)



- **Selection**:
  - Track-like: up-going triggered ν_μ (well-reco events only)
  - Cascade-like: all direction triggered $\nu_e + \nu_\tau$ (well-reco events only)

TRIDENT DM Sensitivity ($\chi\chi \rightarrow \nu\nu$)



Produces a monochromatic line spectrum (w/o EW correction):

$$\frac{dN_\nu}{dE} = 2\delta(m_\chi - E_\nu)$$

- Theoretically well-motivated, simple tree-level, two-body annihilation ("line")
- Good for background rejection ("a smoking gun")

"WIMP Miracle"