TRIDENT: Progress Toward a Next-Generation Deep-Sea Neutrino Observatory

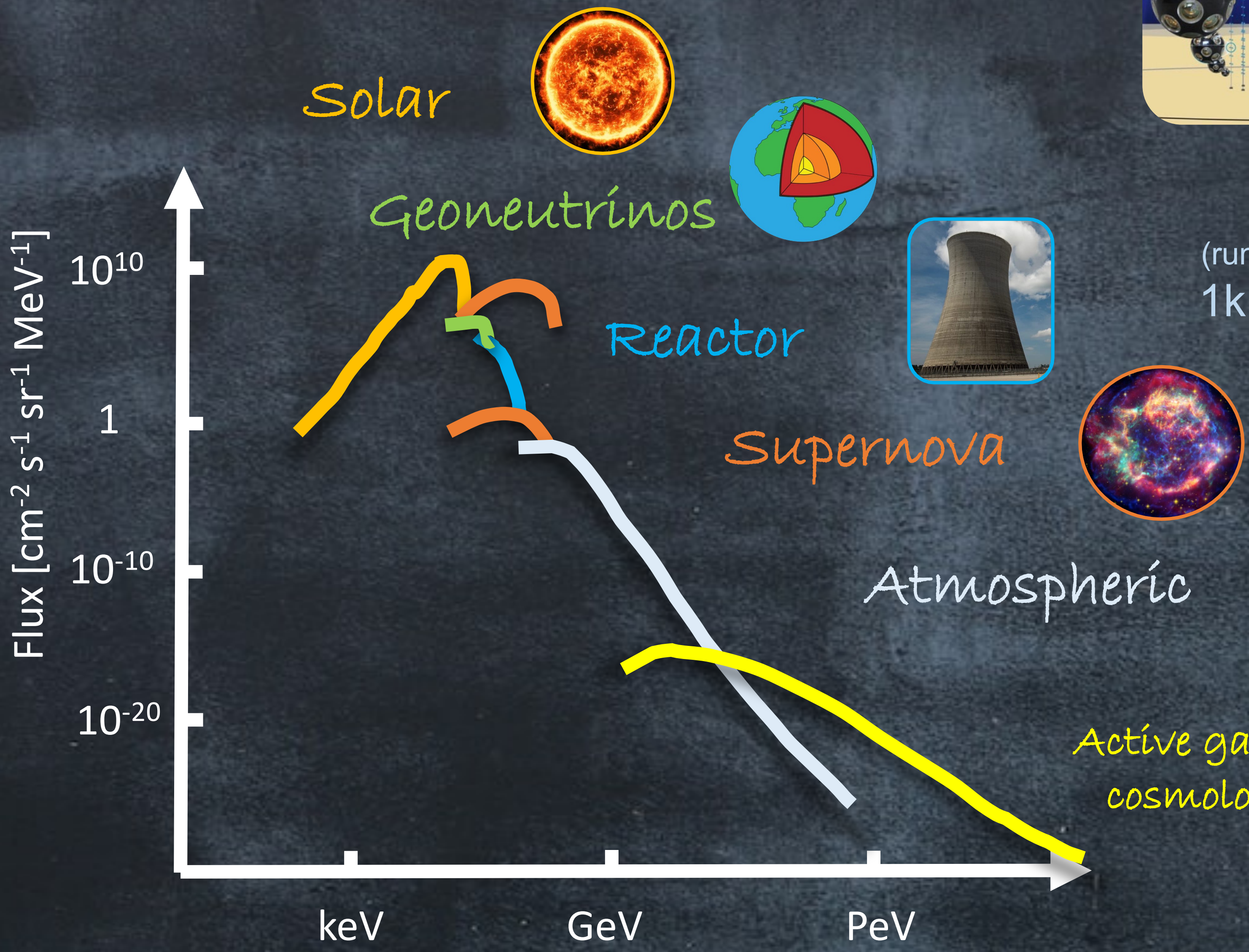
Iwan Morton-Blake, on behalf of the TRIDENT collaboration

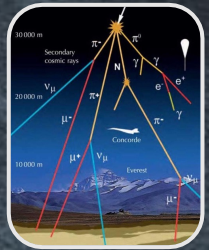
Tsung-Dao Lee Institute / Shanghai Jiao Tong University

CHEP 12th annual meeting 2026

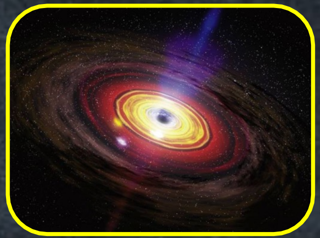
中国物理学会高能物理分会第十二届全国会员代表大会

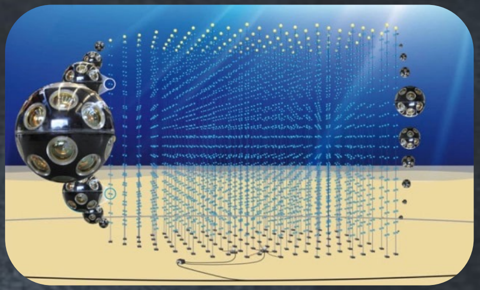
Neutrino Sources



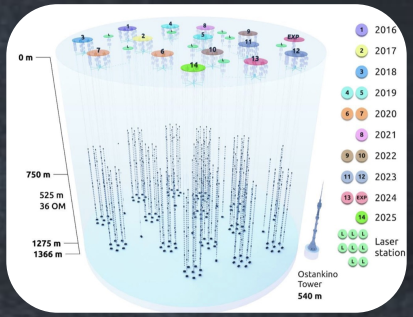


Active galactic nucleus,
cosmological sources



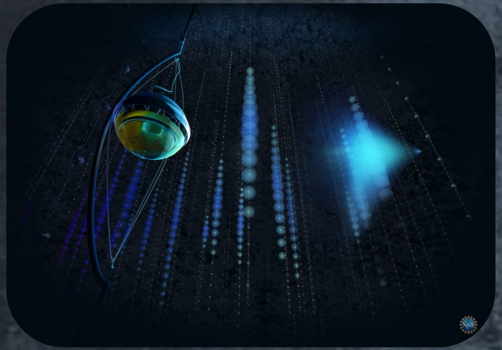


KM3NeT
ARCA/ORCA
(running, expanding)
1km^3 seawater

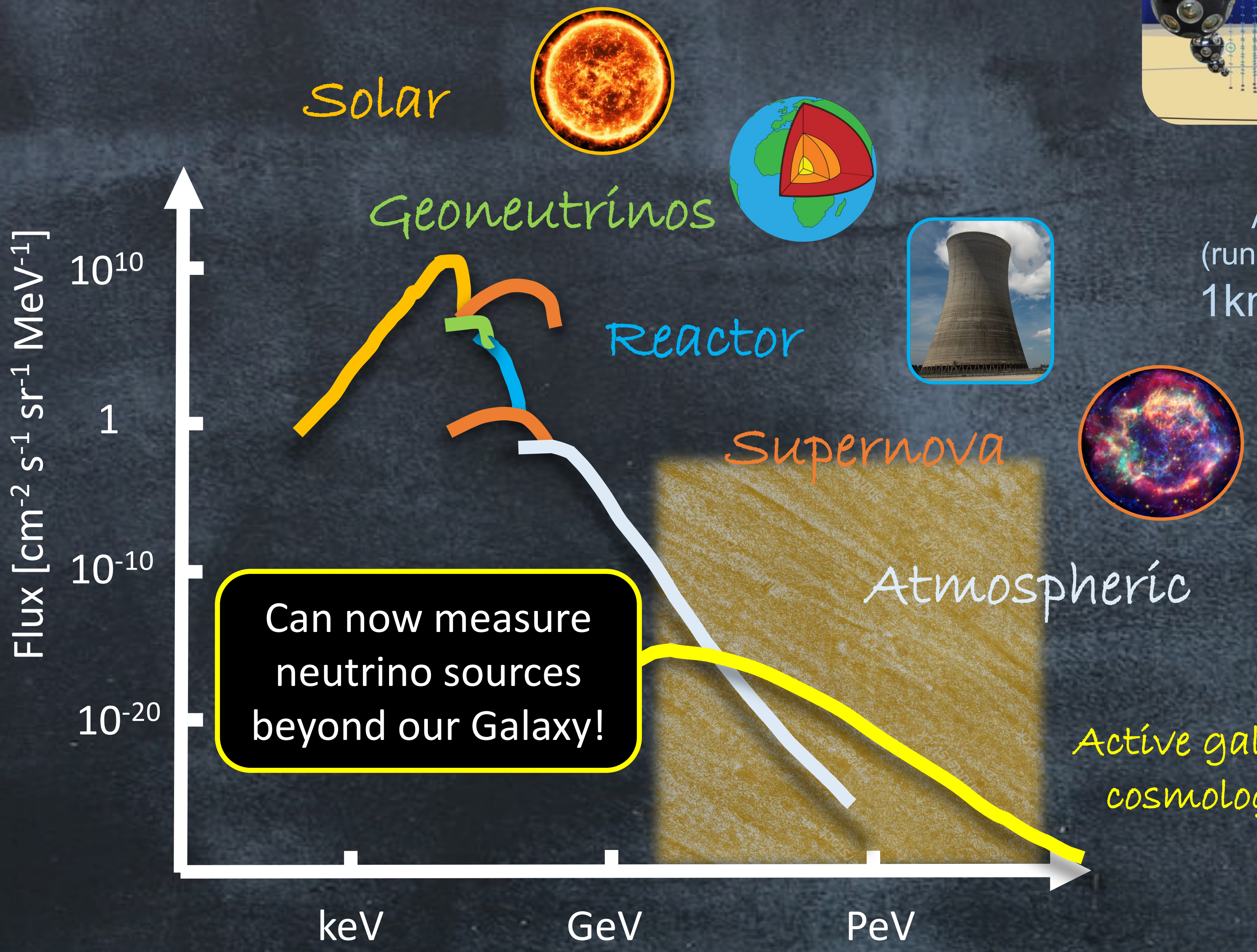


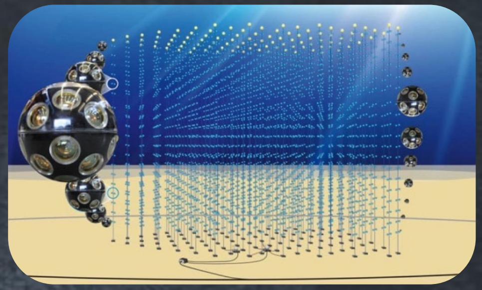
Baikal GVD
(running, expanding)
→ 1km^3 lake water

IceCube
~1km^3 Ice

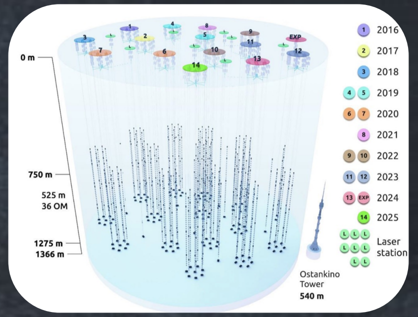


Neutrino Sources

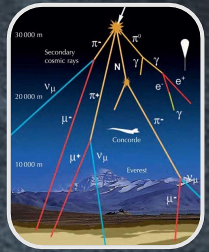




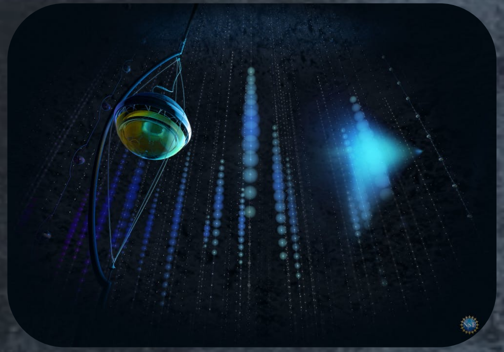
KM3NeT
ARCA/ORCA
(running, expanding)
1km^3 seawater



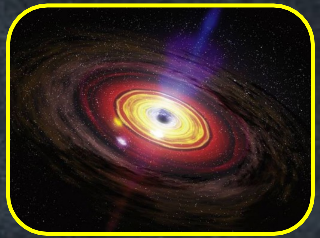
Baikal GVD
(running, expanding)
→ 1km^3 lake water



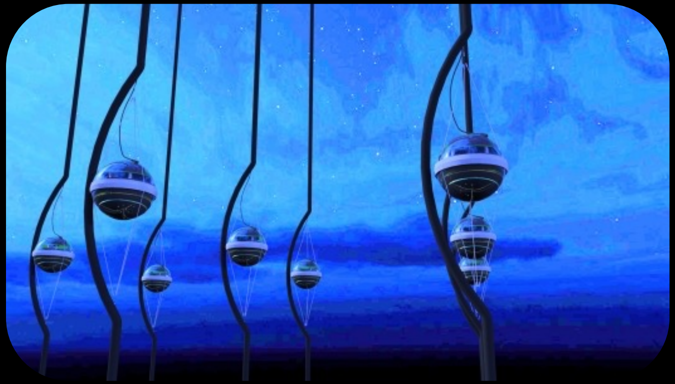
IceCube
~1km^3 Ice



Active galactic nucleus,
cosmological sources

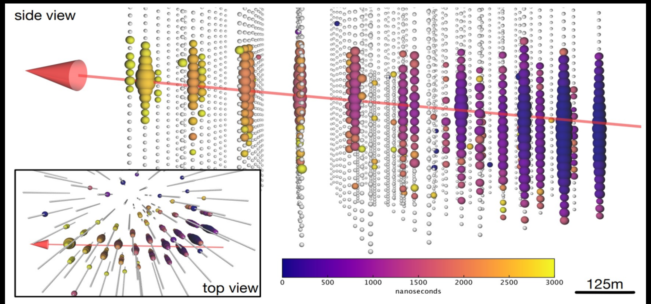


2013 → 2018 → 2022 → 2023



Detection of high-energy diffuse astrophysical neutrino flux

Science. 342 6161

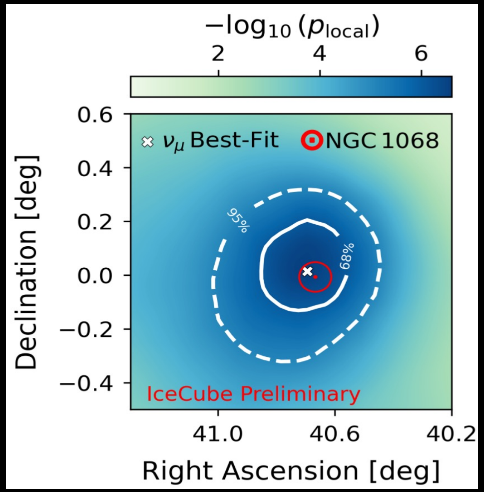


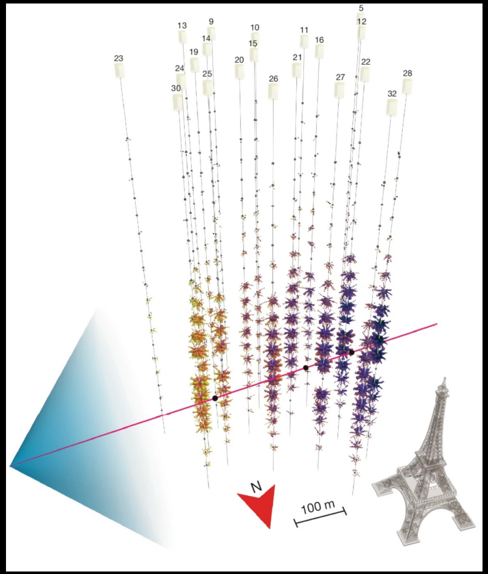
Evidence for neutrino emission from a flaring blazar

Science. 361 6398 (2018)

Neutrino emission from active galaxy NGC 1068 reaches 4σ

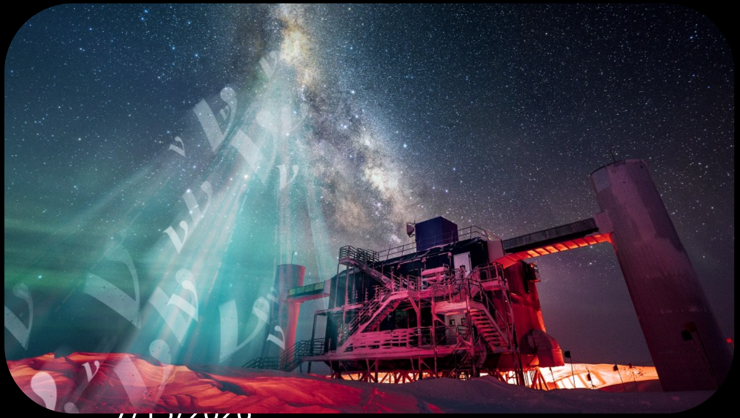
Science 378 538-543 (2022)



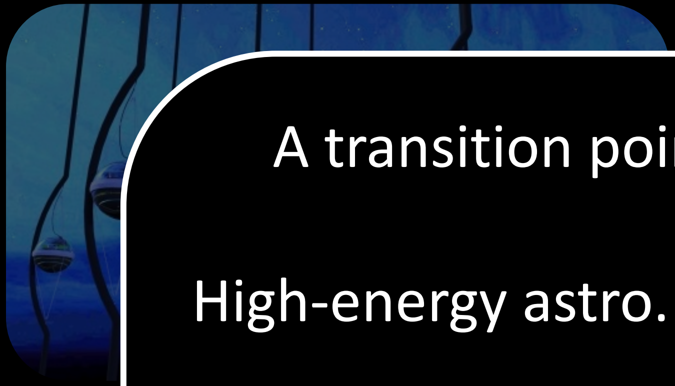


Ultra-high-energy cosmic neutrino measured by KM3NeT

Nature 638 376–382 (2025)



2013 → 2018 → 2022 → 2023 →

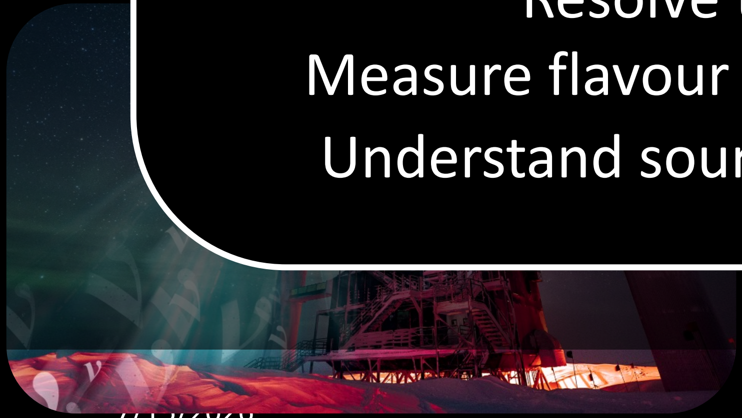


A transition point for Neutrino Astronomy?

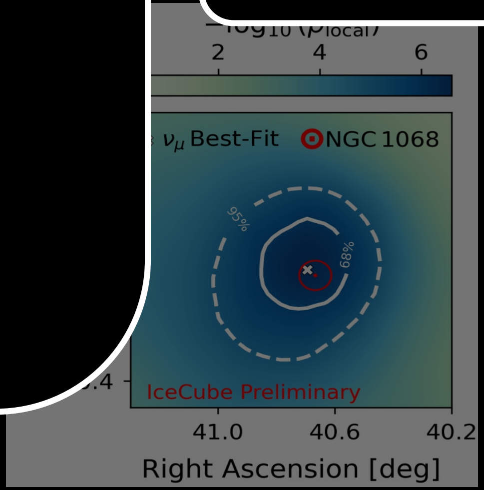
High-energy astro. neutrinos are now established

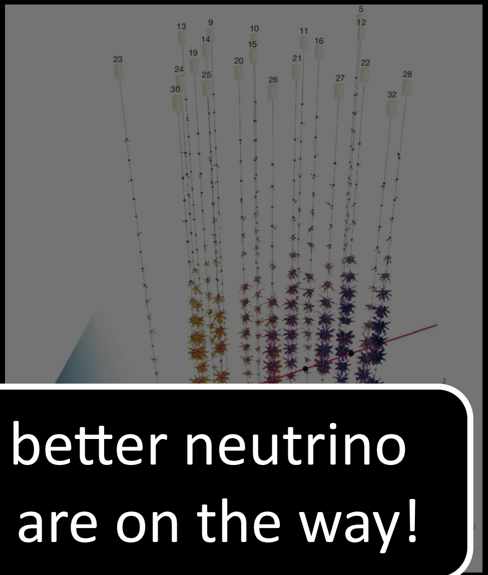
The next-generation aims to move:
Discovery → Precision

Resolve the neutrino sky
Measure flavour compositions (ν_μ, ν_e, ν_τ)
Understand source physics/mechanisms



rino emission
active galaxy
068 reaches 4σ





More and better neutrino telescopes are on the way!

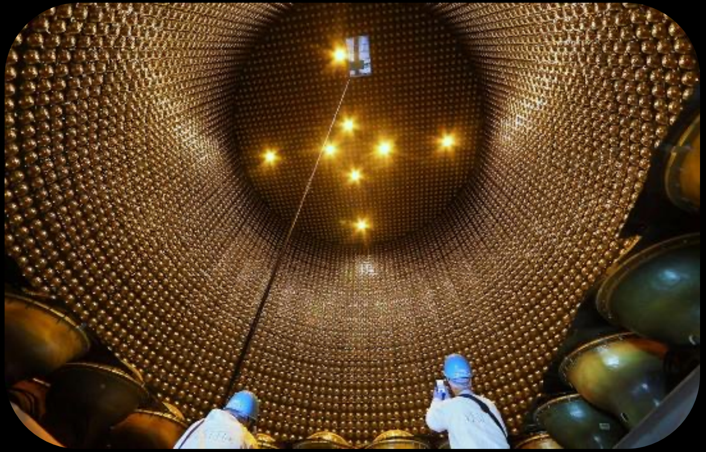
Ultra-high-energy cosmic neutrino measured by KM3NeT

Nature 638 376–382 (2025)

What do we need?

They grow up so fast 🥲

23 kilotons



3 kilotons

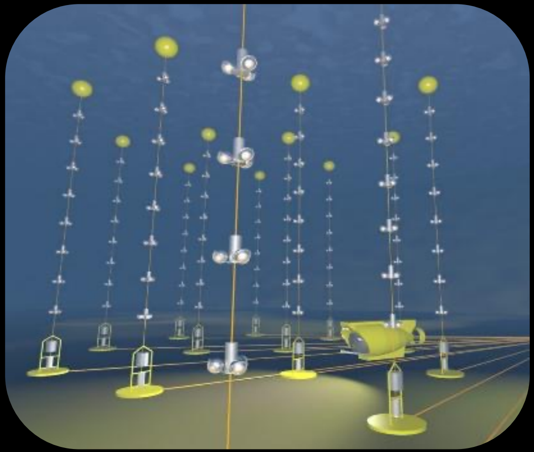
190 kilotons

?

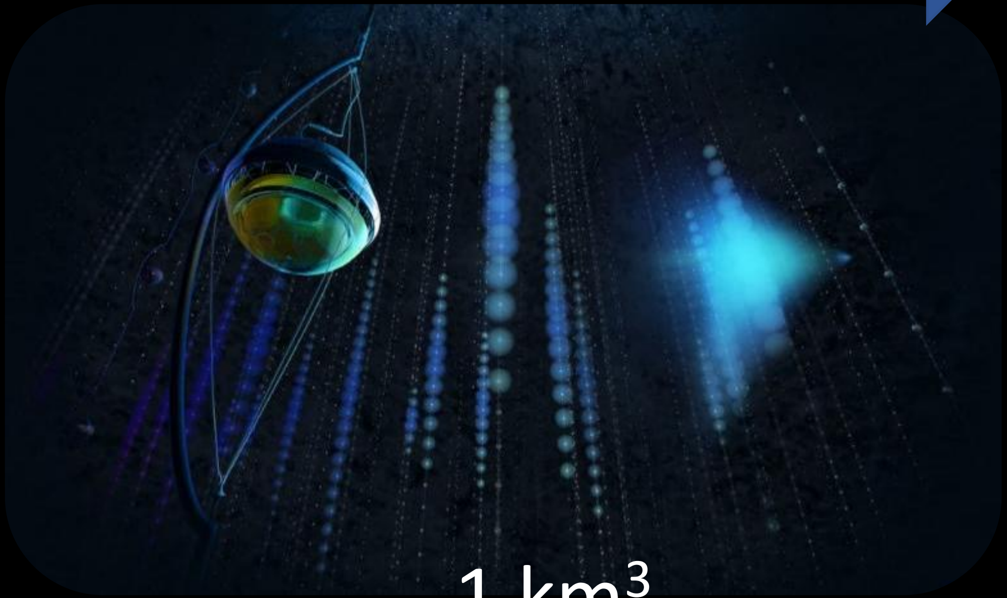
200 kgs

1 kiloton

1 kiloton



0.1 km^3



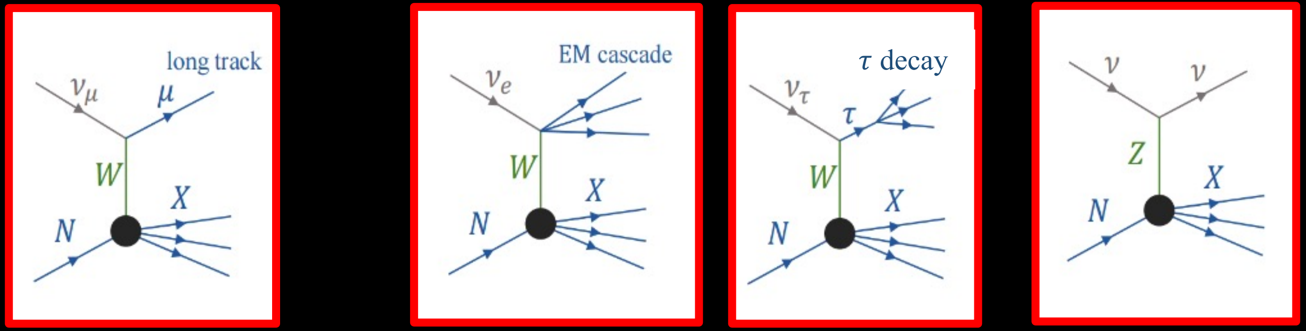
1 km^3

Event interaction types

Charged-Current

Neutral-Current

- Golden channel for pointing

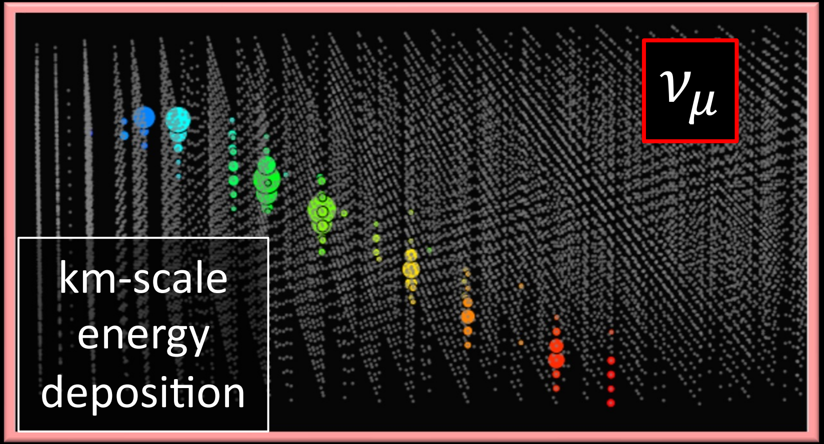


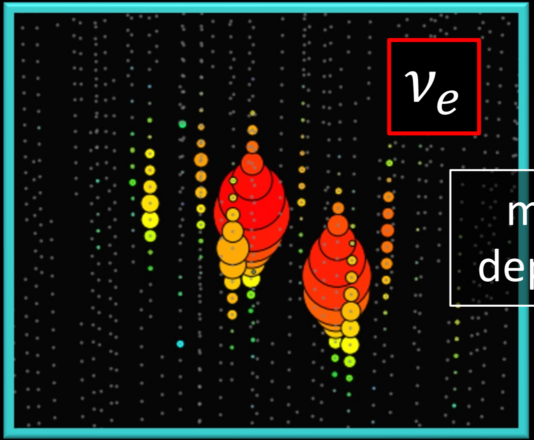
- Moderate pointing
- Better energy resolution
- Lower backgrounds
- Neutrino flavour separation

Muon tracks

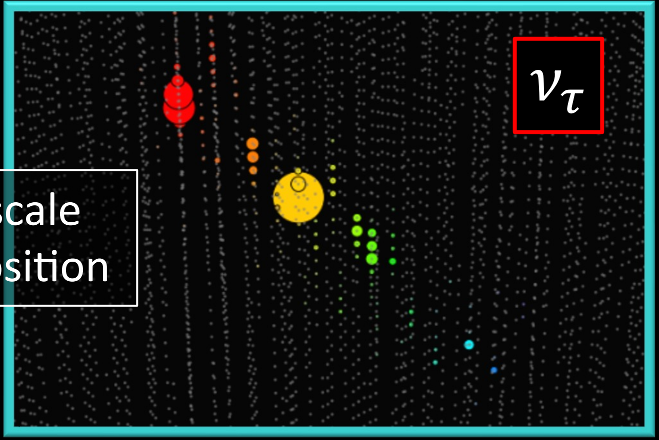
Cascades

(τ decay can also produce muons)



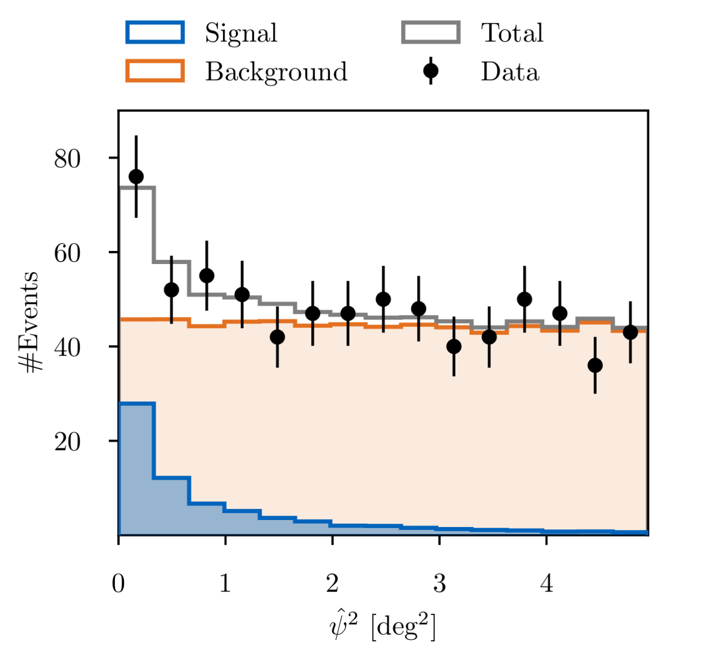


m-scale deposition



TRIDENT simulation

Upcoming Detector Needs



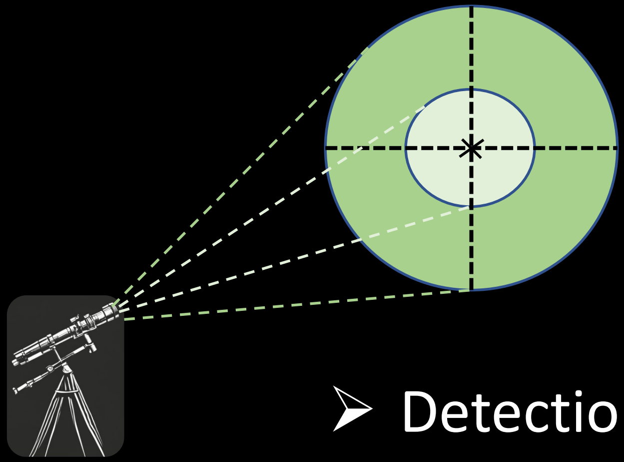
1) More Events

E.g. NGC1068 source candidate
~4σ after a decade by IceCube

Sig. $\propto \sqrt{N}$
(but $N \not\propto$ Volume?)

2) Better Pointing

➢ More and larger detectors



Backgrounds scale roughly with (angular resolution)^2

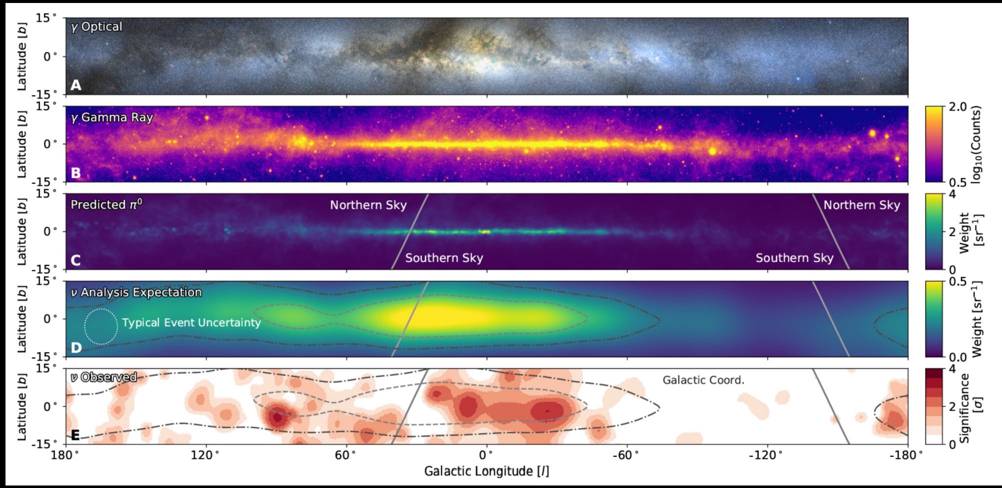
➢ Detection medium water vs ice

➢ Photodetection technology

Upcoming Detector Needs

1) More Events

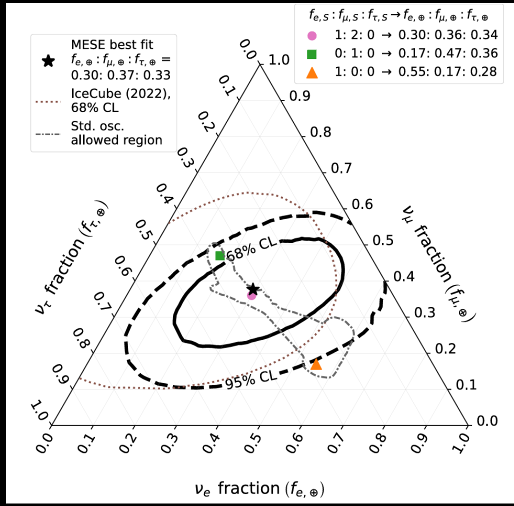
Galactic plane neutrinos at 4.5σ cascade events prove essential!



Observation of high-energy neutrinos from the Galactic plane, Science (2023)

2) Better Pointing

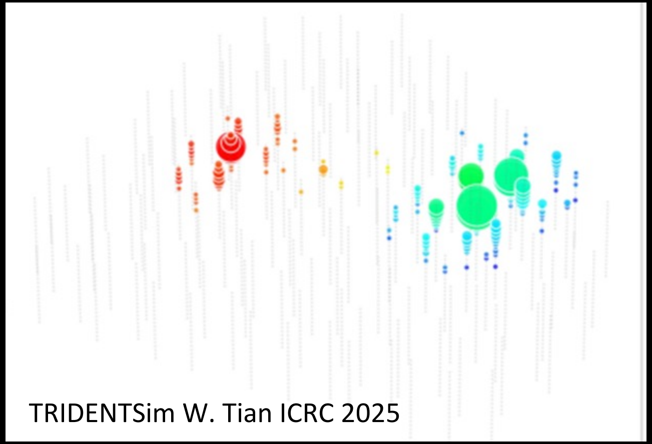
Characterization of the Three-Flavor Composition of Cosmic Neutrinos with IceCube, arXiv:2510.24957 (2025)



Flavour ratio 1σ contours now fully contained

3) ν_μ, ν_e, ν_τ detection/separation

➢ Detector hardware and size



1000s of ν_μ, ν_e, ~10 ν_τ candidates

Observation of Seven Astrophysical Tau Neutrino Candidates with IceCube PRL (2024)

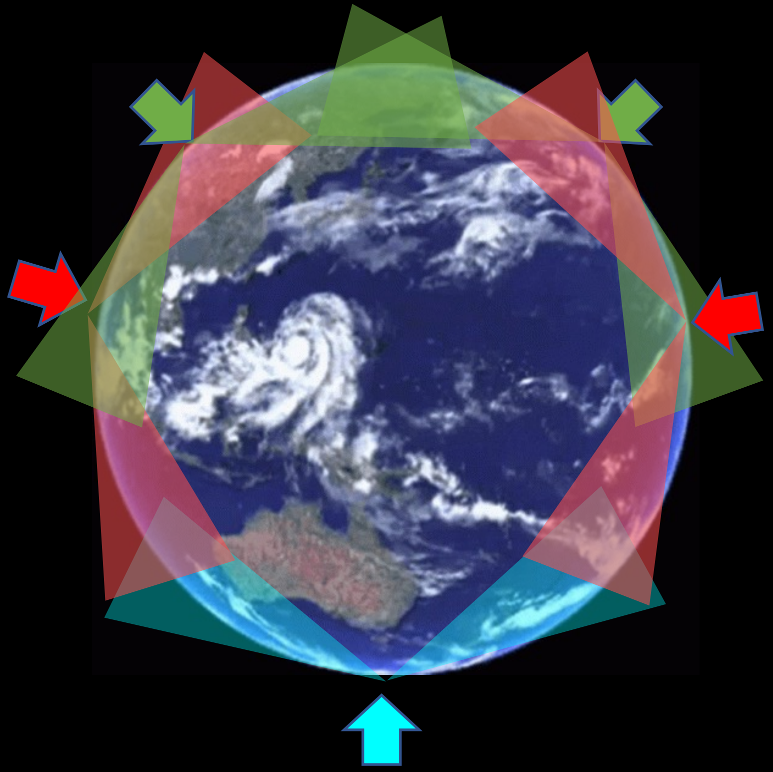
Upcoming Detector Needs

1) More Events

Global follow ups e.g.

Transient sources,
Rare UHE events

2) Better Pointing



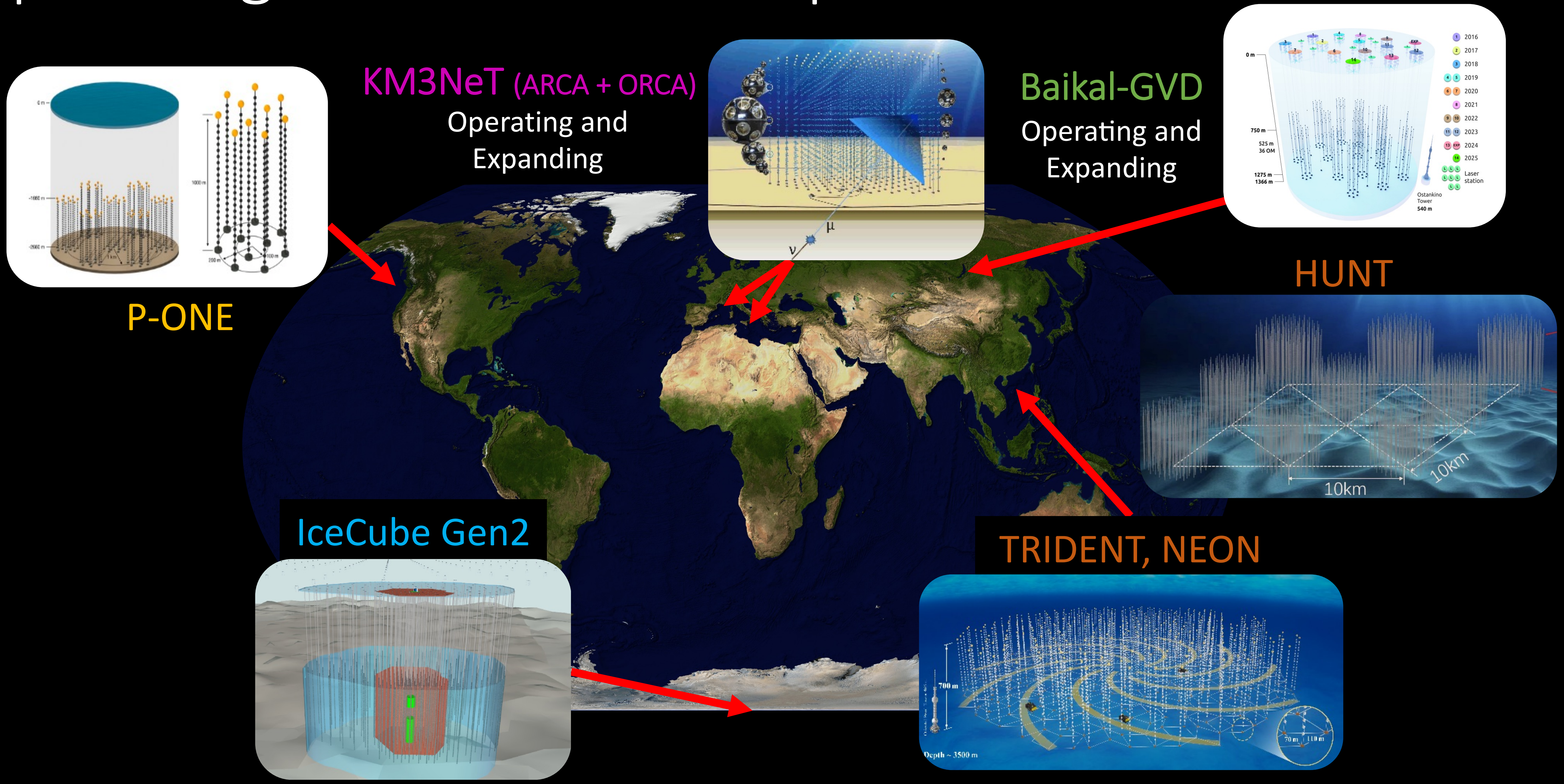
3) ν_μ, ν_e, ν_τ detection/separation

Optimal viewing angle of telescopes world wide covers the whole sky

4) Combined full-sky coverage

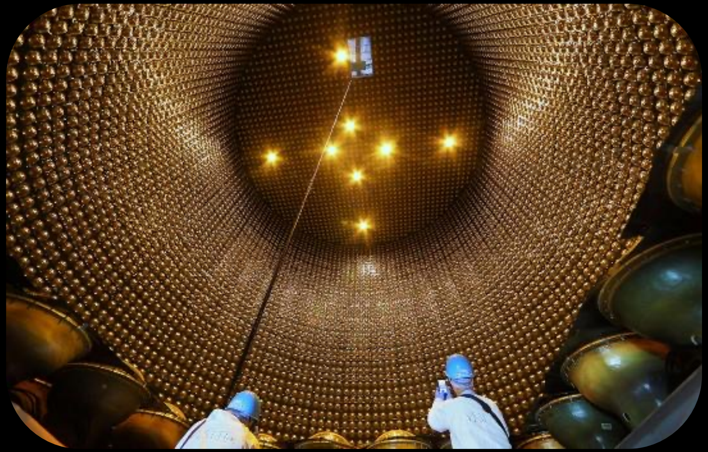
- Detectors world-wide
- Track and Cascade events

Upcoming Neutrino Telescope Network



They grow up so fast 🥲

23 kilotons



190 kilotons

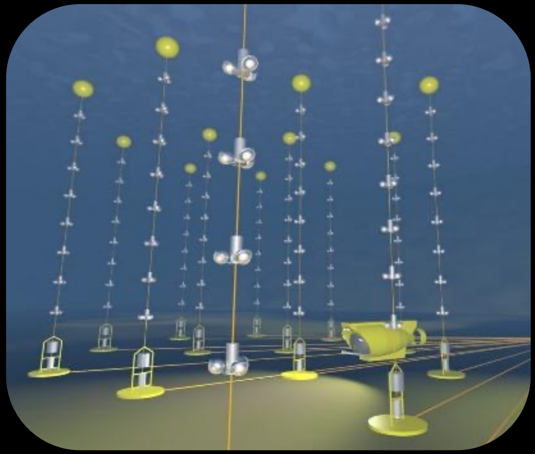
?

3 kilotons

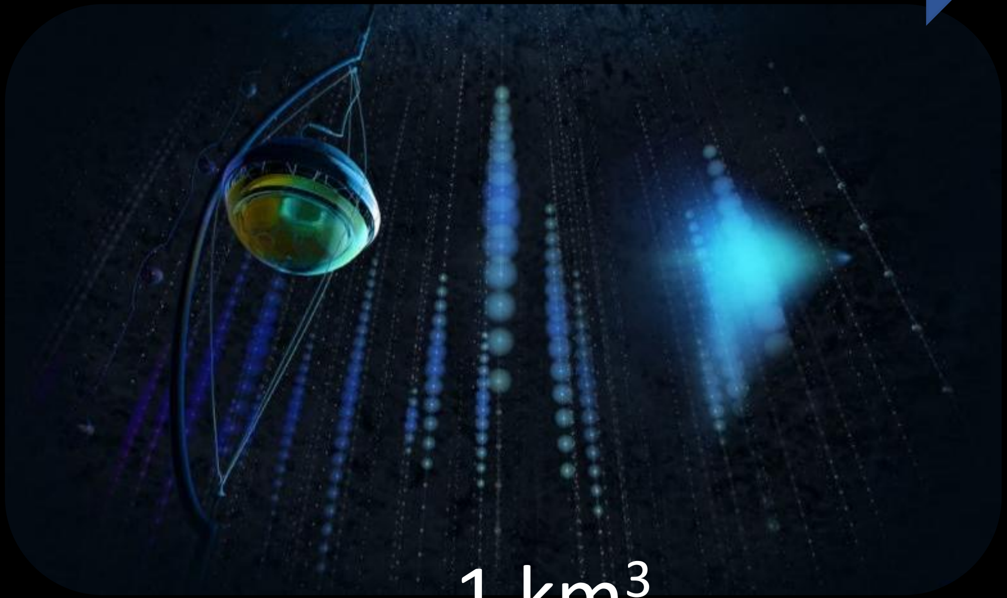
200 kgs

1 kiloton

1 kiloton



0.1 km^3



1 km^3

Ice and Water

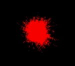
Optical photon scattering and absorption

Ice: $\lambda_{abs} > \lambda_{scat}$

Water: $\lambda_{abs} < \lambda_{scat}$

With efficient and precise photon collection in water:

→ Expect strong resolution of direction and topology of interactions!

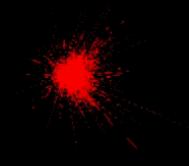


TRIDENT Simulation

***ν_μ track** in ice*

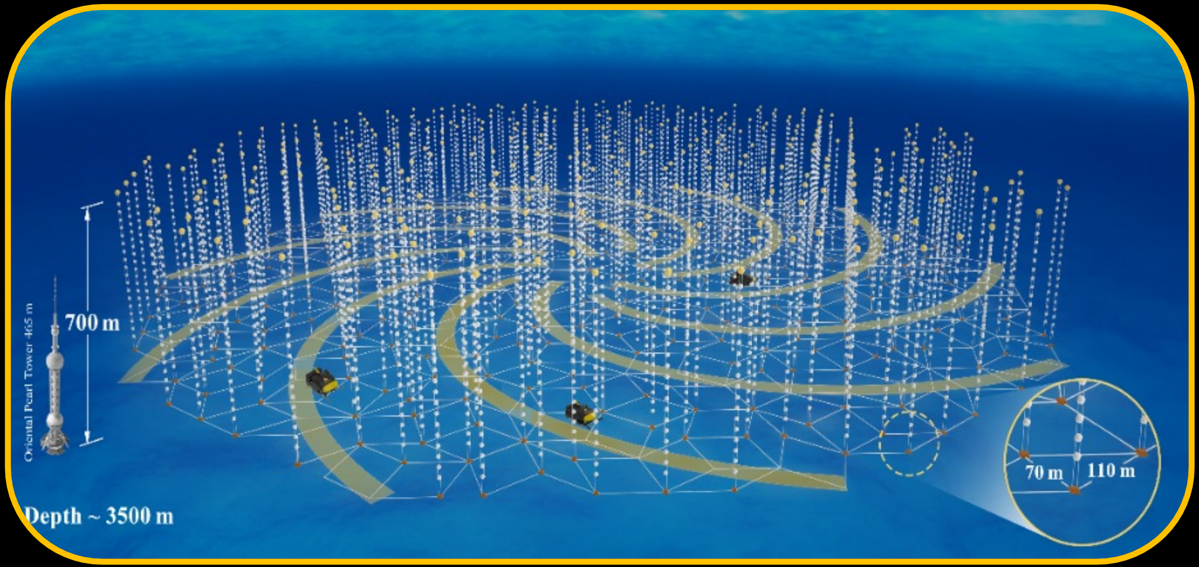
***ν_e cascade** in ice*

(x4 videos of simulated events)



***ν_μ track** in water*

***ν_e cascade** in water*

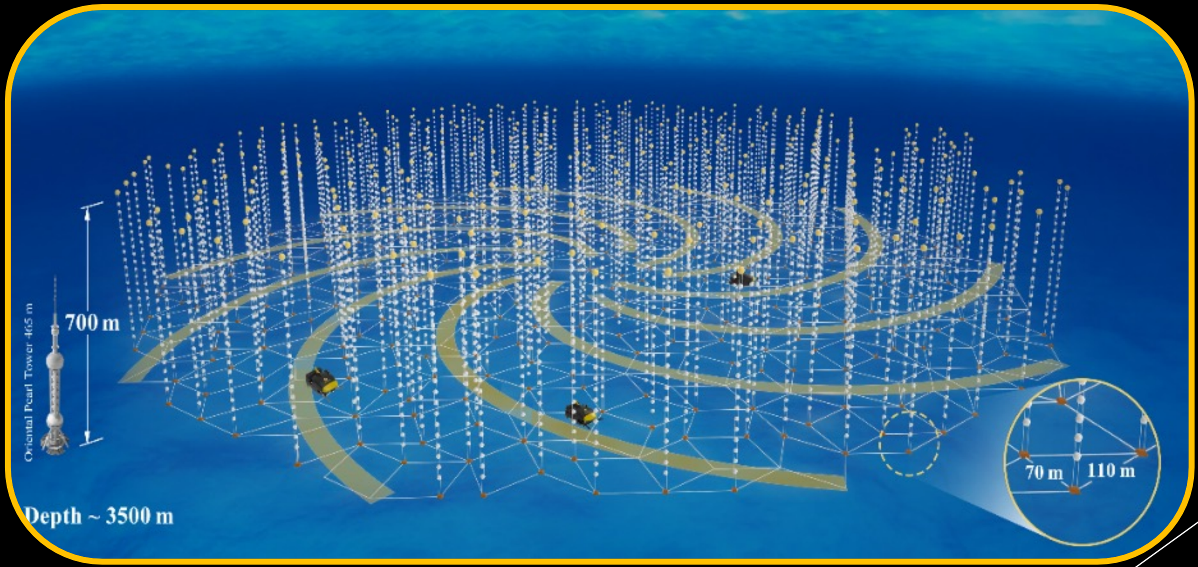


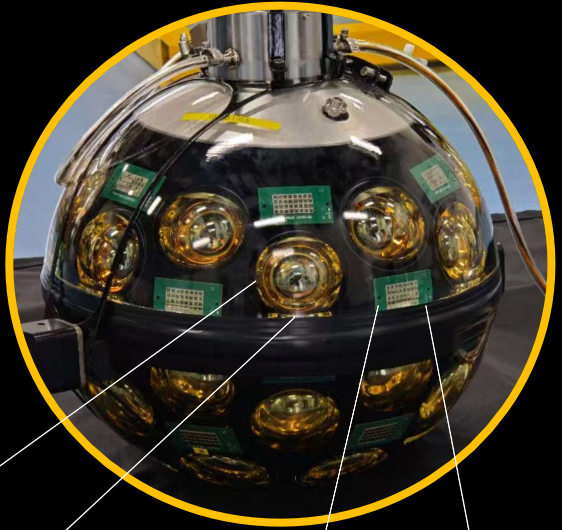
TRIDENT

or "Hai-ling"
(Ocean Bell)

Experimental goals:

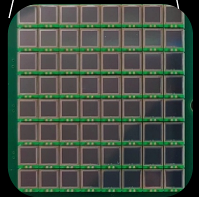
1) Rapidly discover neutrino sources
2) Sensitivity to all flavors





PMTs:
< 2ns TTS
~30% QE

SiPMs:
< 0.3 ns jitter



TRIDENT

or "Hai-ling"
(Ocean Bell)

Experimental goals:

1) Rapidly discover neutrino sources
2) Sensitivity to all flavors

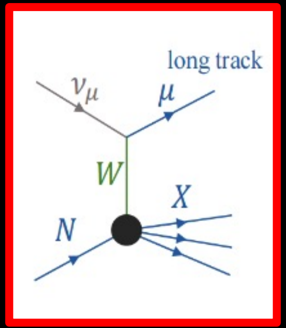
Pushing for next-gen performance

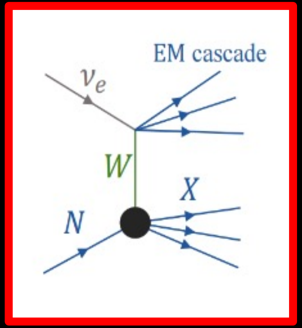
- 3.5km deep
- ~8 km^3, ~1000 strings
- 20 Hybrid DOMs per string
Strings 70, 110m apart

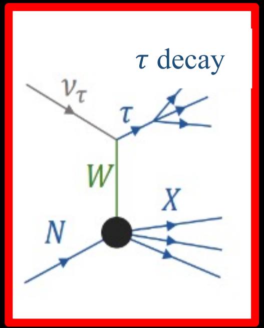
Event interaction types

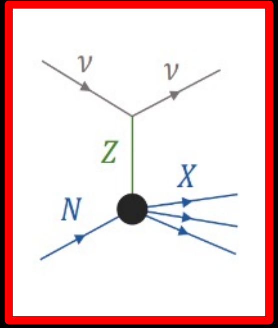
Charged-Current

Neutral-Current





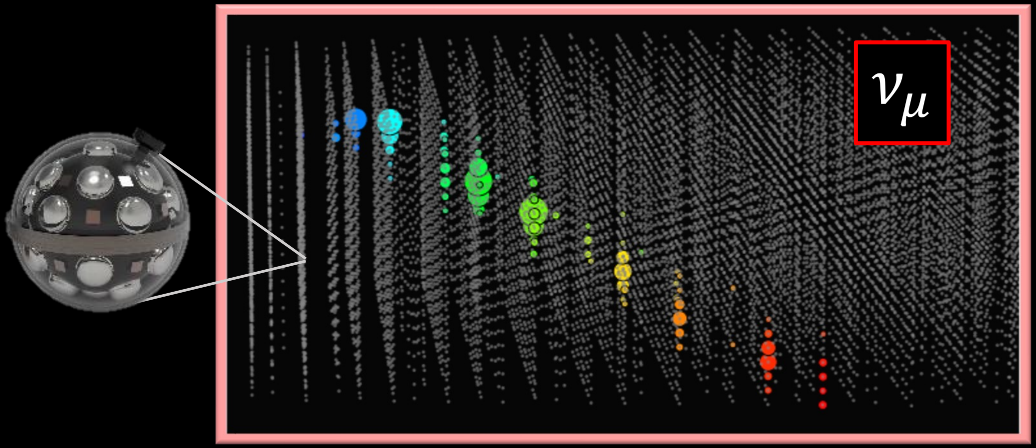


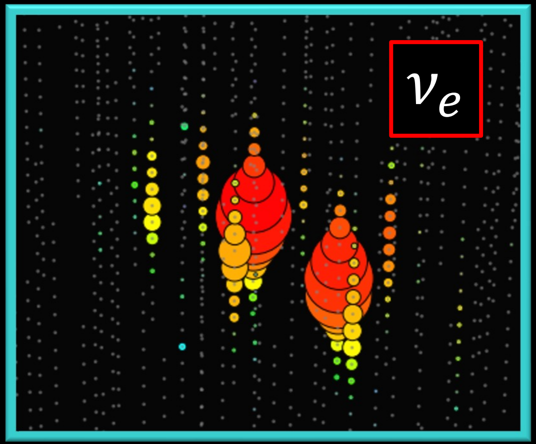


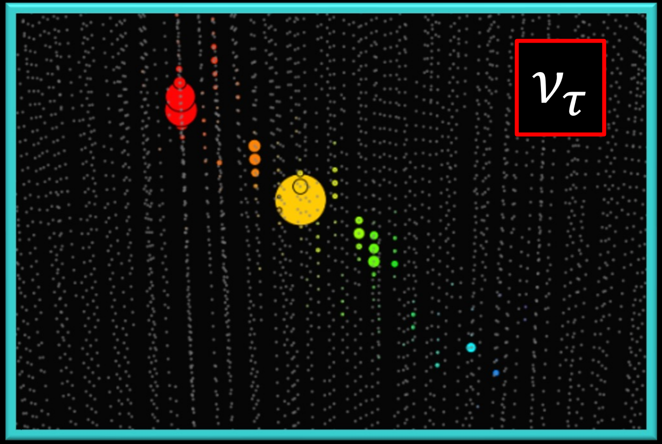
Muon tracks

Cascades

(τ decay can also produce muons)





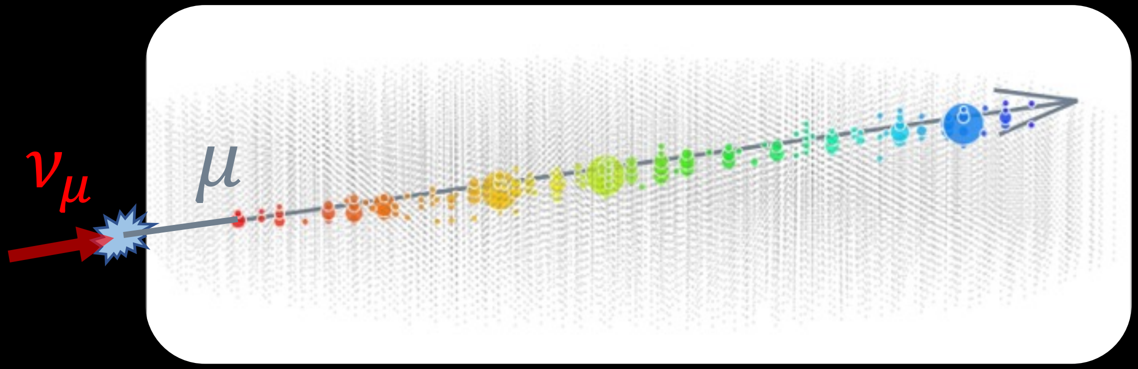


TRIDENT simulation

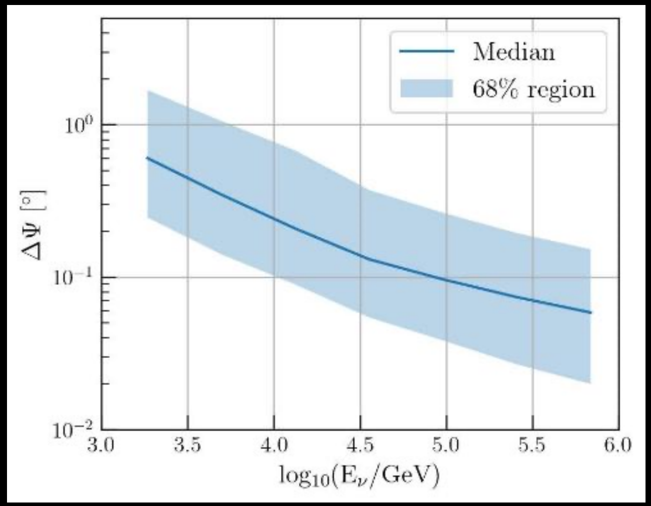
"Optimizing underwater neutrino telescopes for all-flavor point source sensitivity" Phys. Rev. D 113 (2026)

All-Flavour Detection

Simulated Track-like event in TRIDENT



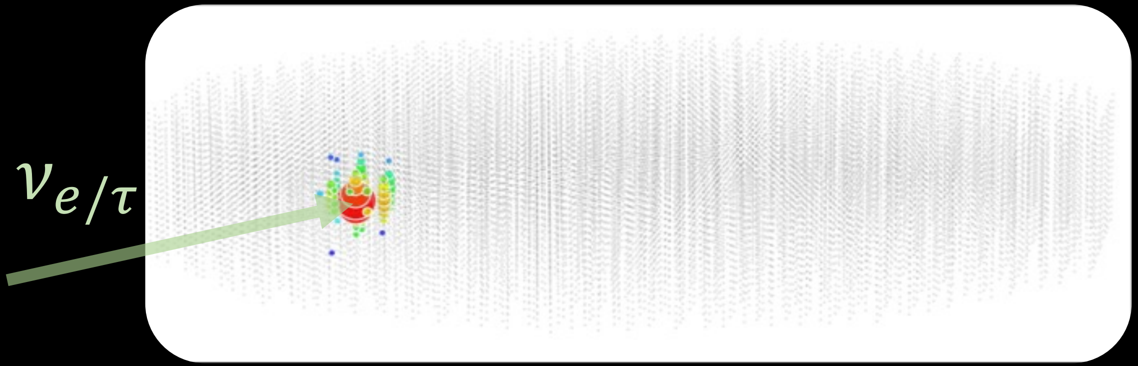
Track angular resolution



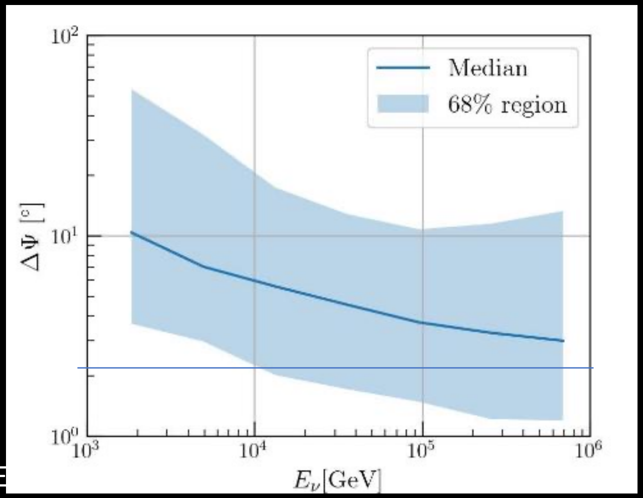
+ Strong pointing resolution
~ 0.1° @ 100TeV

- Poorer energy resolution

Simulated Cascade-like event in TRIDENT



Cascade angular resolution



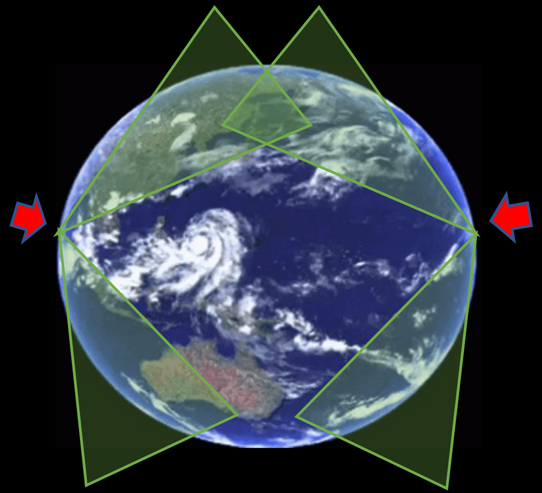
~ Moderate pointing resolution
~3° @ 100TeV

+ Improved energy resolution

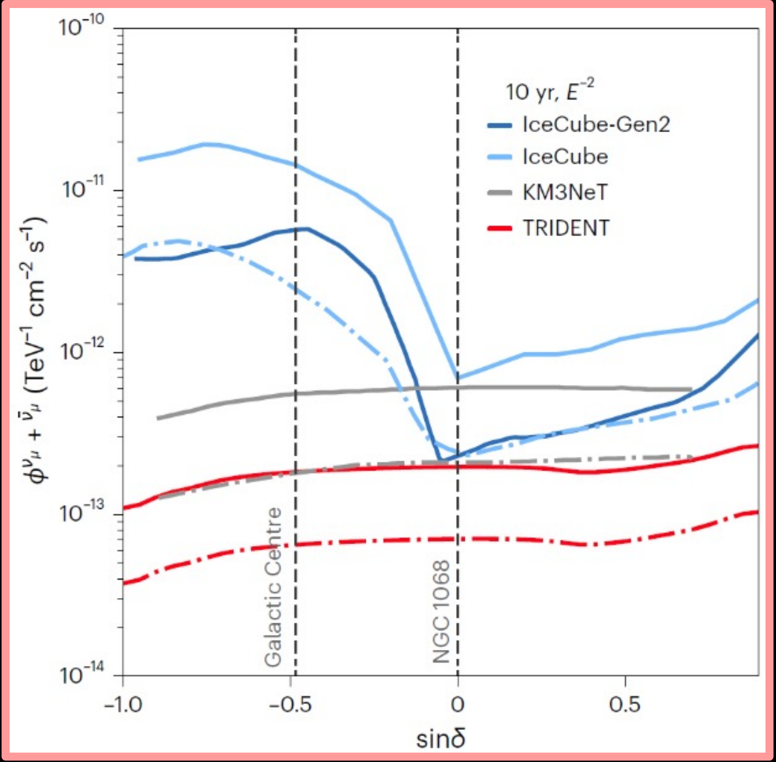
+ Lower atmospheric background

Rapid Discovery

Primary experimental goals:
1) Rapidly discover neutrino sources
2) Sensitivity to all flavors

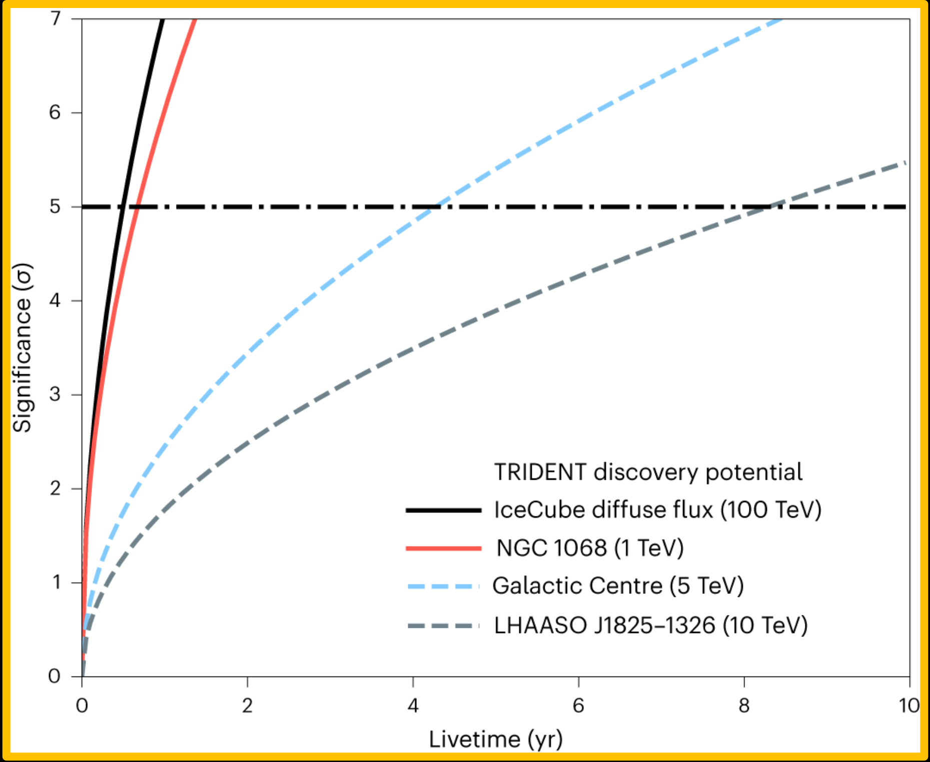


Sensitivity/Discovery Potential vs declination



"A multi-cubic-kilometre neutrino telescope in the western Pacific Ocean", Nature Astronomy, (2023)

Discovery significance vs time

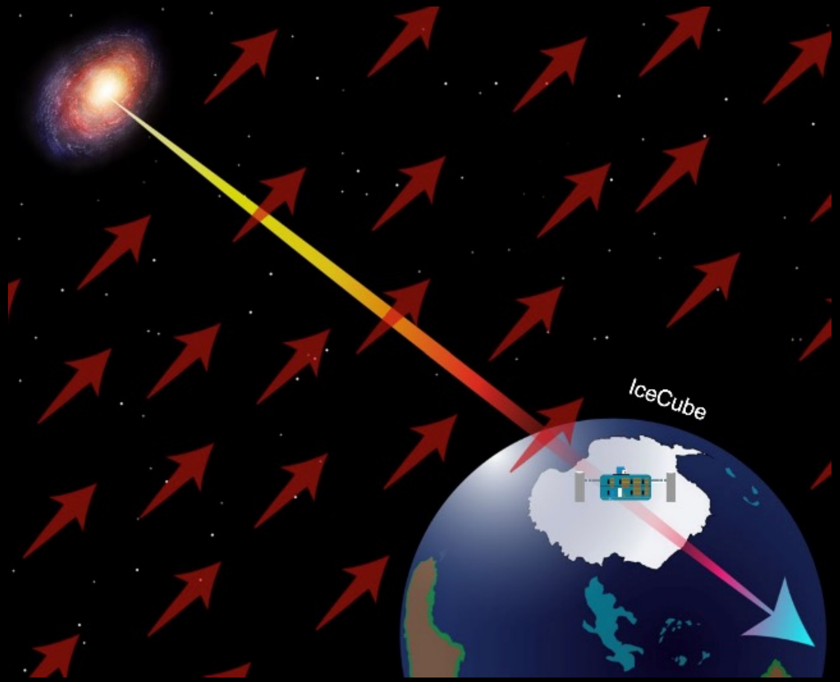


Expect 5σ detection of NGC1068 within a year of operation

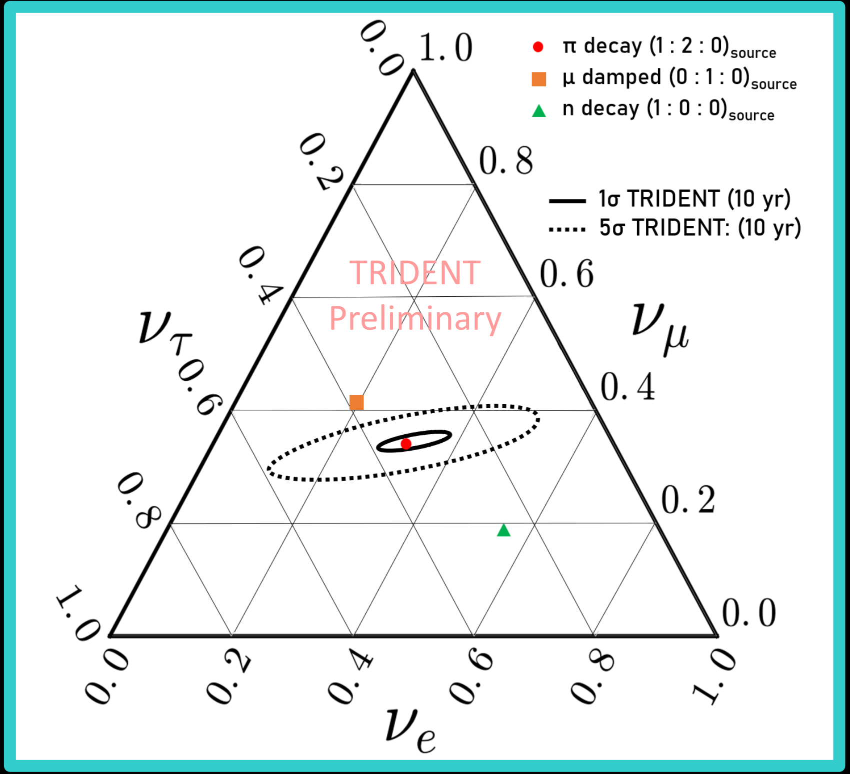
Flavour Separation

Primary experimental goals:
1) Rapidly discover neutrino sources
2) Sensitivity to all flavors

<u>High energy neutrino flavour discrimination</u>:
→ Probe ν production mechanisms
→ Astrophysical baseline oscillation, test BSM models



IceCube Coll., Nature Phys. 18 (2022) 11, 1287-1292

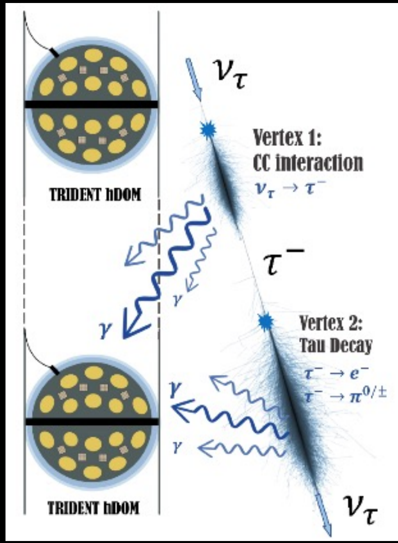


"Enhancing Neutrino Flavour Sensitivity in TRIDENT with Tau Neutrino Identification": PoS (ICRC2025) 1195
Publication in preparation

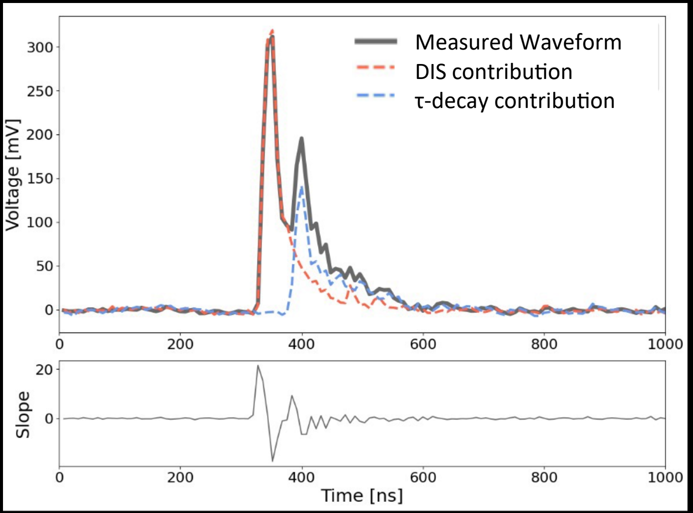
Flavour Separation

Primary experimental goals:
1) Rapidly discover neutrino sources
2) Sensitivity to all flavors

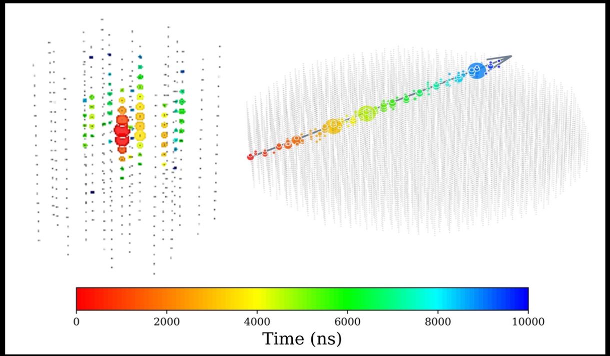
τ decay length ~ 5m / 100 TeV



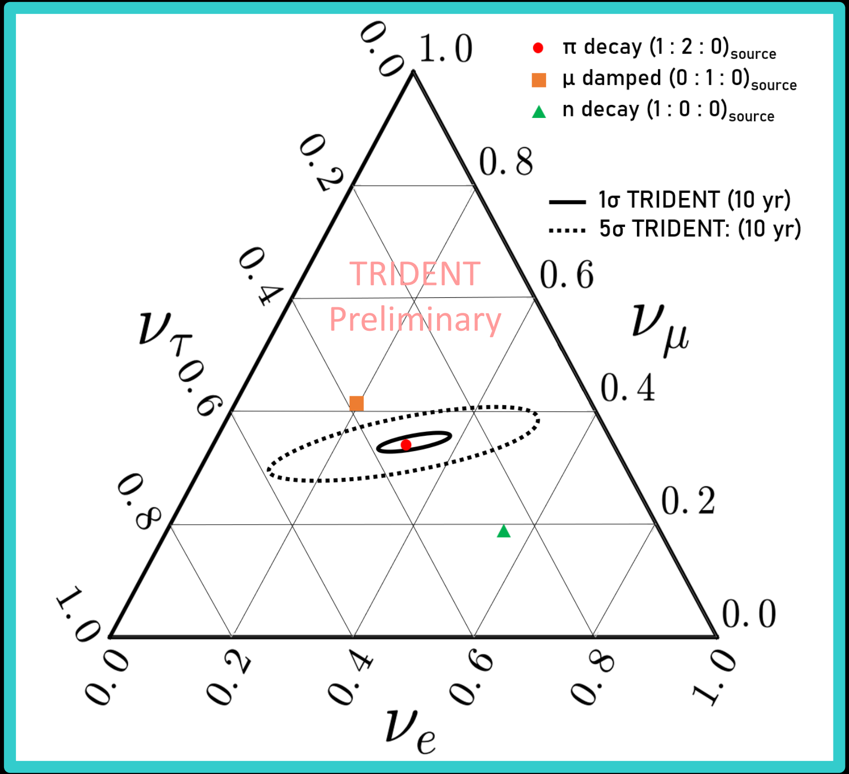
Identifying a ~10 TeV ν_τ



Track and cascade-like event identification



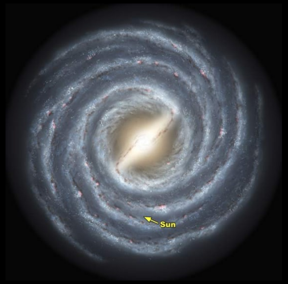
See talk by Shuhua Hao Fri 11:39



"Enhancing Neutrino Flavour Sensitivity in TRIDENT with Tau Neutrino Identification": PoS (ICRC2025) 1195
Publication in preparation

Dark Matter Annihilation Sensitivity

"Probing Dark Matter annihilation in the Galactic Centre with TRIDENT",
arXiv:2601.06817v1 (2026)

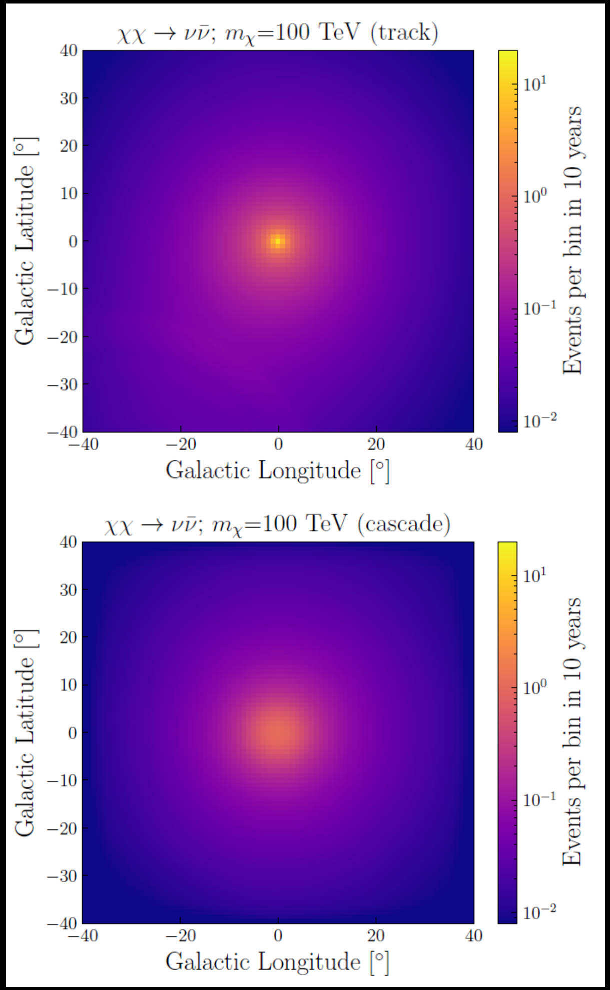


Searches in the Galactic Centre

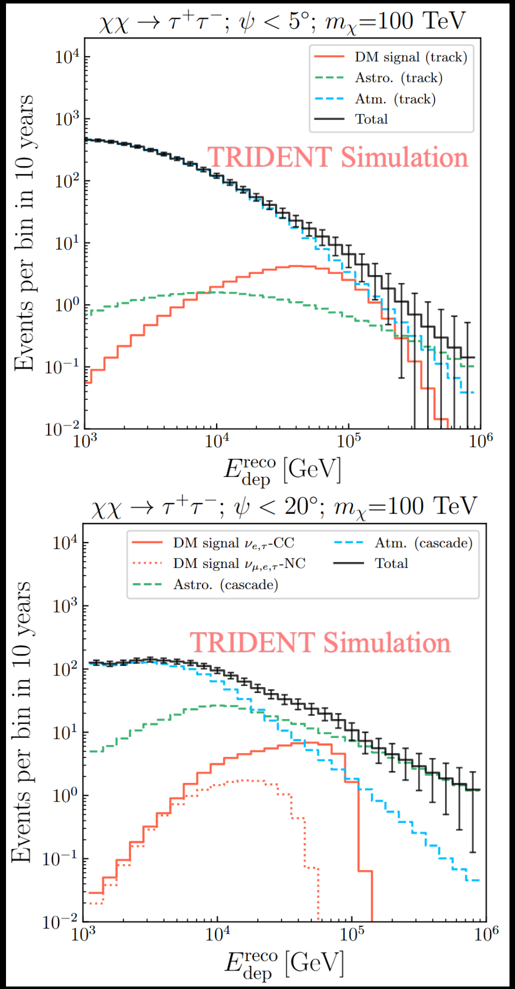
Tracks:

Cascades:

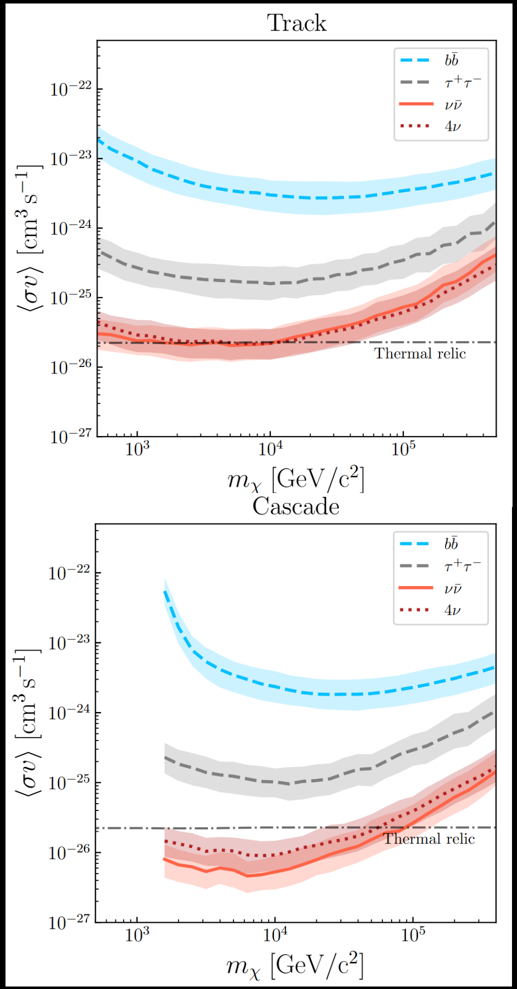
Signal



Energy



Sensitivity

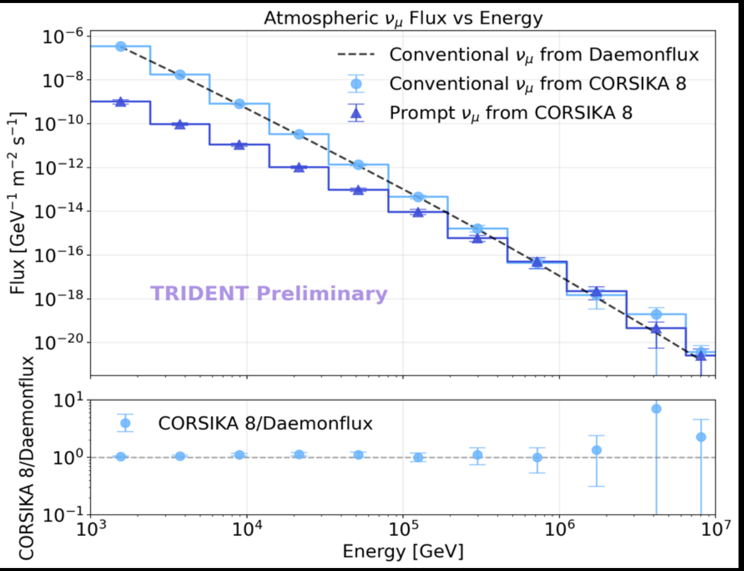


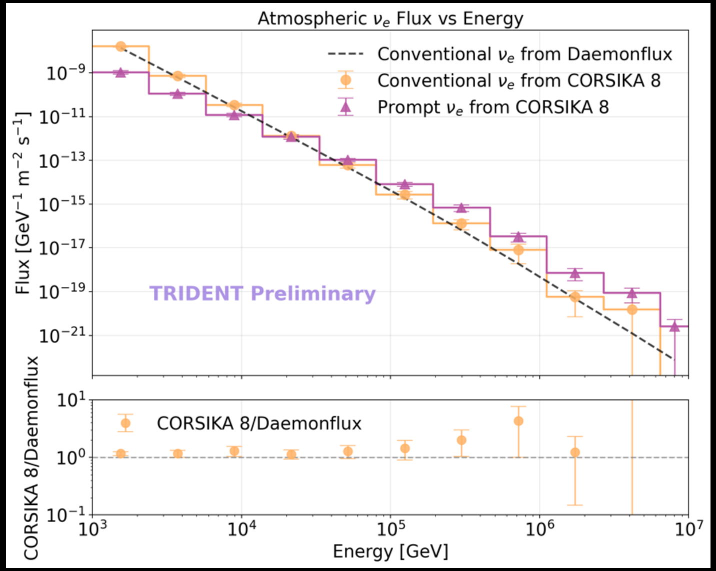
See talk by Yingwei Wang Fri 11:54

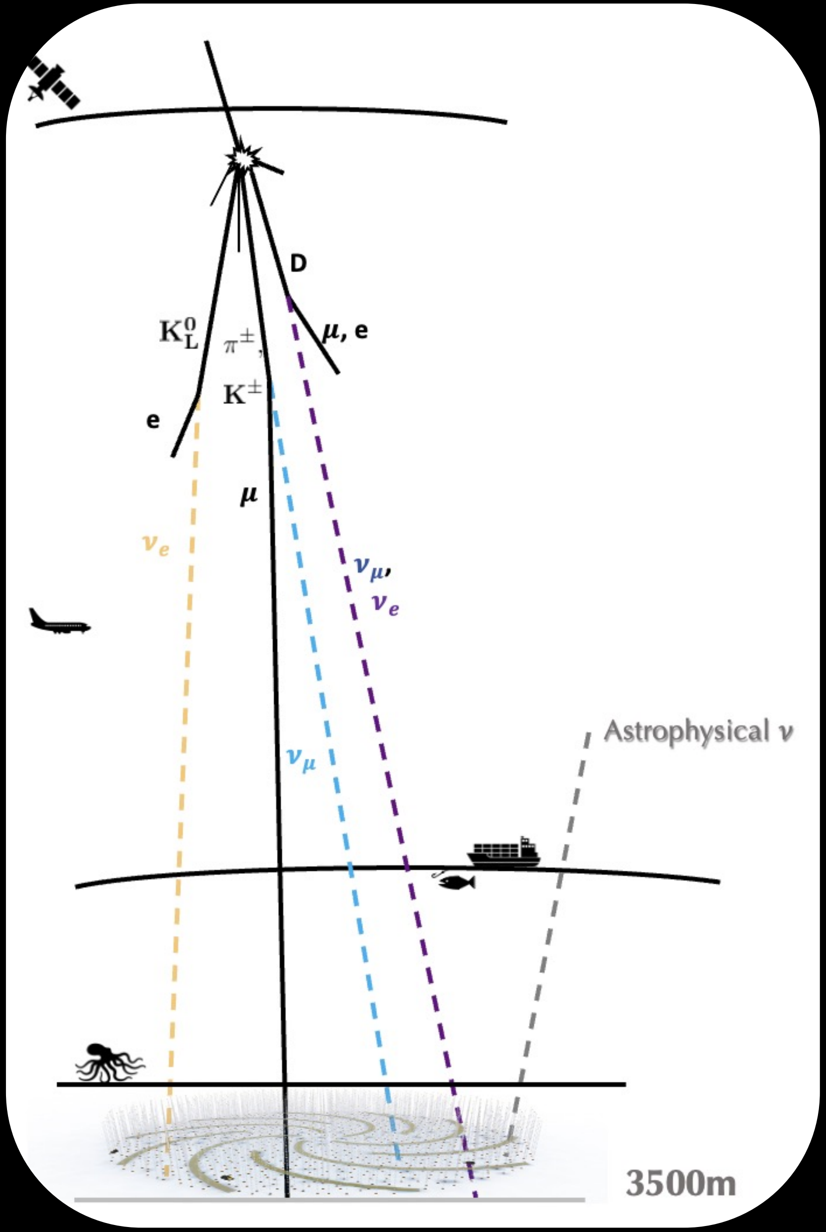
See talk by Xiang Xin Today 16:50

Prompt Atmospheric ν

The prompt component of atmospheric neutrinos, originating from the decay of charmed hadrons







Has not yet been experimentally measured

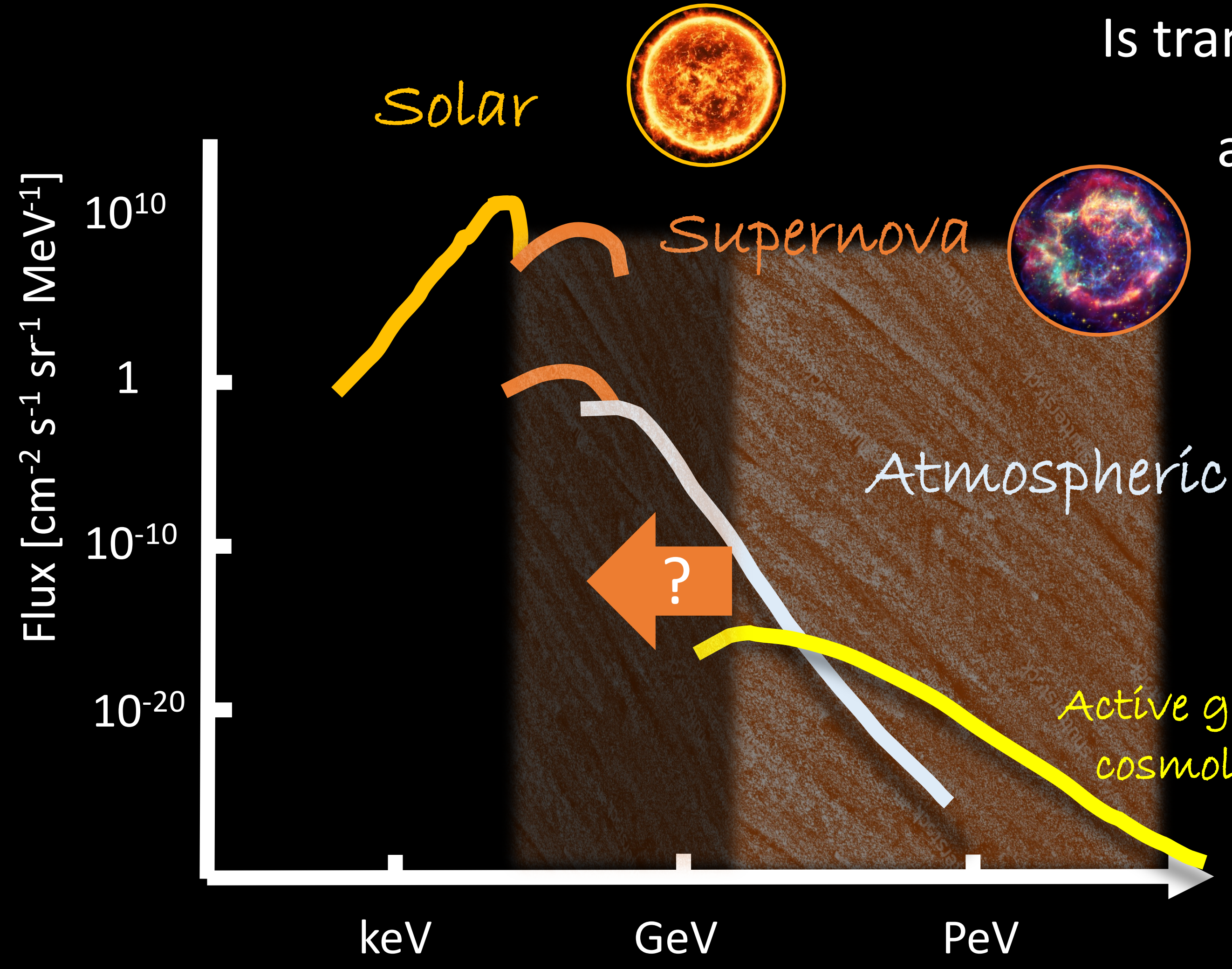
See talk by Weilun Huang
Fri 11:40

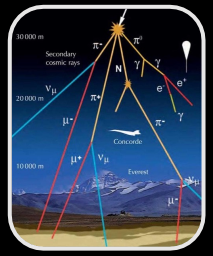
Beyond the TeV to EeV sky?

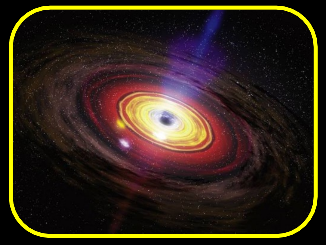
Is transient <u>MeV-scale</u> neutrino astronomy

also possible in giant telescopes?

e.g. CCSN detection





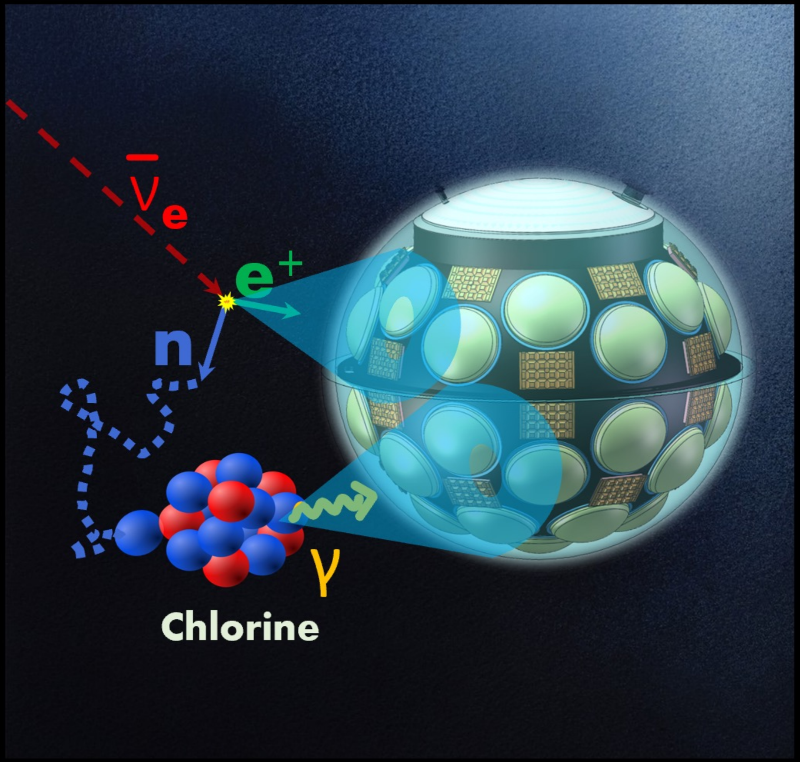


Low-Energy Detection

Core-collapse supernova ~MeV all-flavour neutrino emission

"Detecting the Next Galactic Core-Collapse Supernova with TRIDENT " PoS (ICRC2025) 1004

Publication in preparation



← Inverse Beta Decay Channel

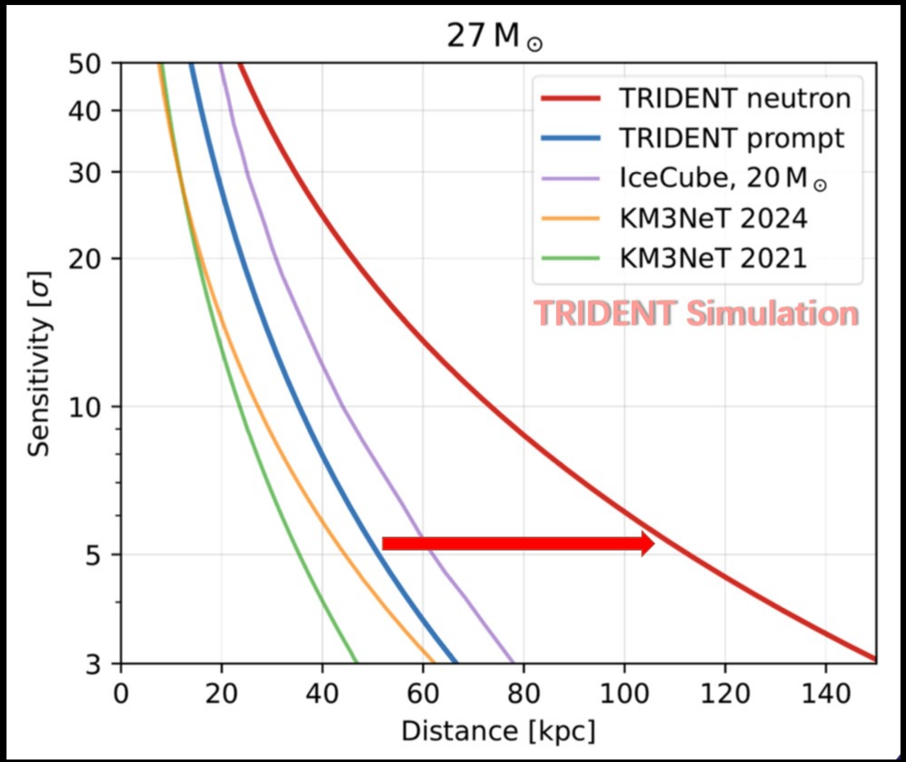
Prompt: e^+

Delayed: **Neutron capture on Cl** "New"!

CCSN alert efficiency →

Alert distance boosted by ~2 compared to e+ detection only

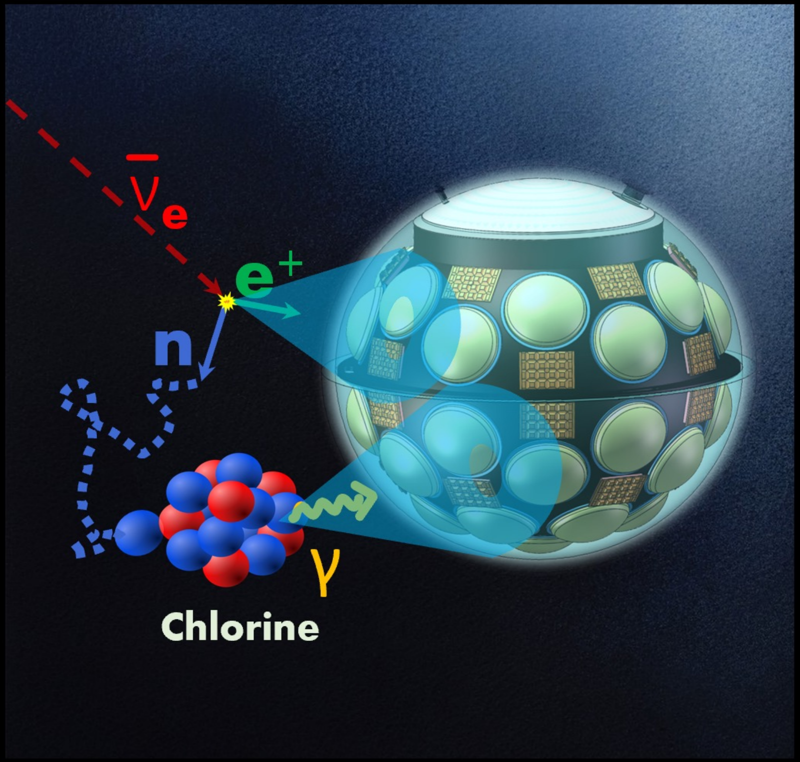
See talk by Ruike Cao
Fri 11:34



Low-Energy Detection

Core-collapse supernova ~MeV all-flavour neutrino emission

"Detecting the Next Galactic Core-Collapse Supernova with TRIDENT " PoS (ICRC2025) 1004
Publication in preparation



← Inverse Beta Decay Channel

Prompt: e^+

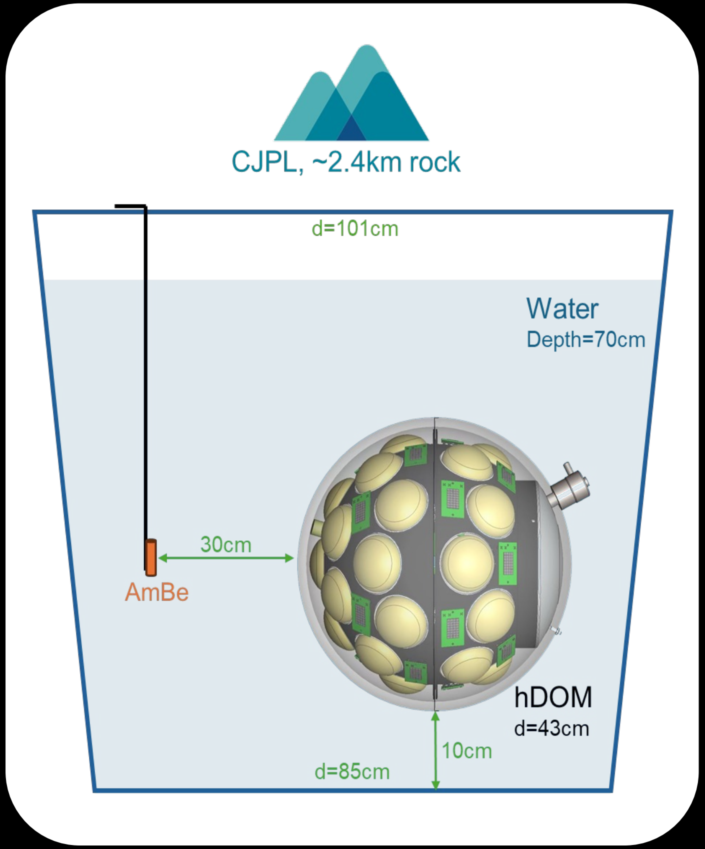
Delayed: **Neutron capture on Cl** "New"!

Experimental demonstration:

Placed hDOM 2.4km deep in Jinping lab (thanks to PandaX)

Placed neutron source in pure water, NaCl and KCl solutions, excess of pairs for solutions with Cl present

Coincidence events detected with Cl-loading



* PC: Ruike Cao

Experiment Status

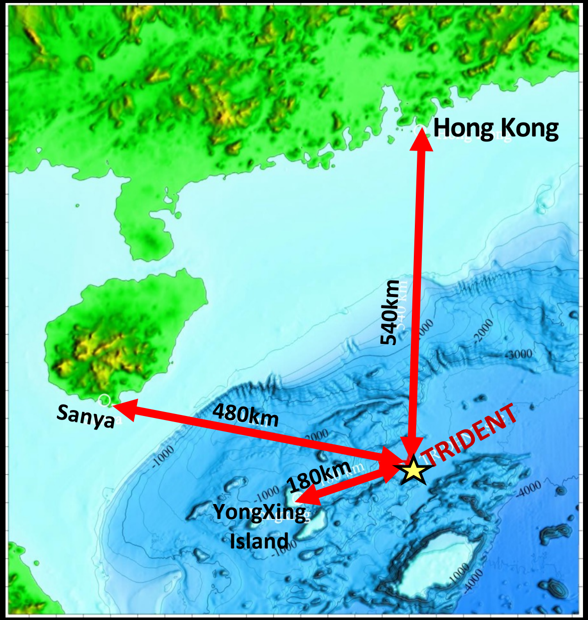
TRIDENT Explorer (T-REX) 2021

TRIDENT!

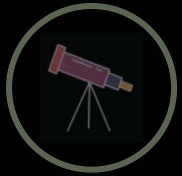
Detector site located the South China Sea

- 3.5 km deep
- Large, flat plane “Hai-ling Basin”

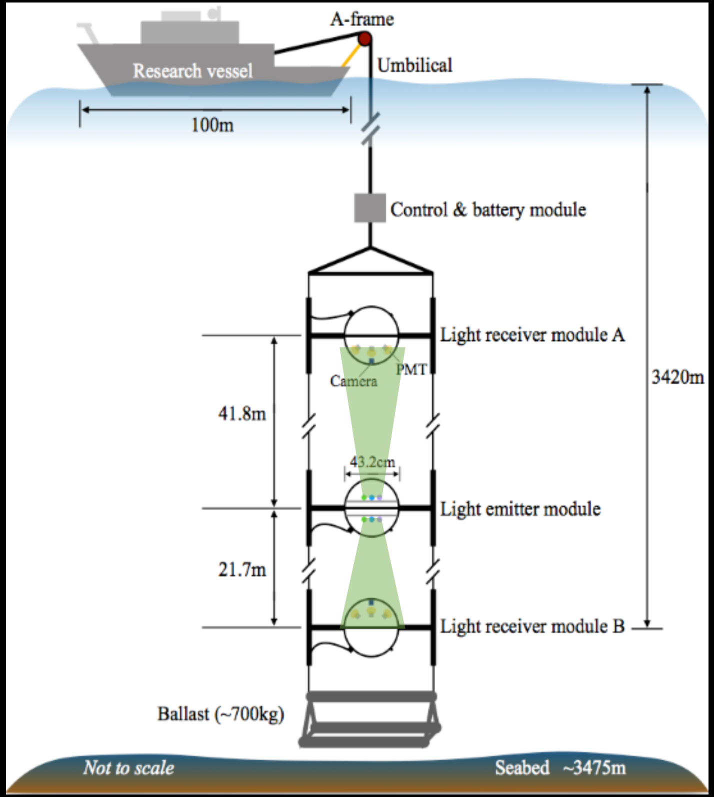
First expedition in Sep. 2021 to assess detector site conditions



Site Conditions: Optical Properties



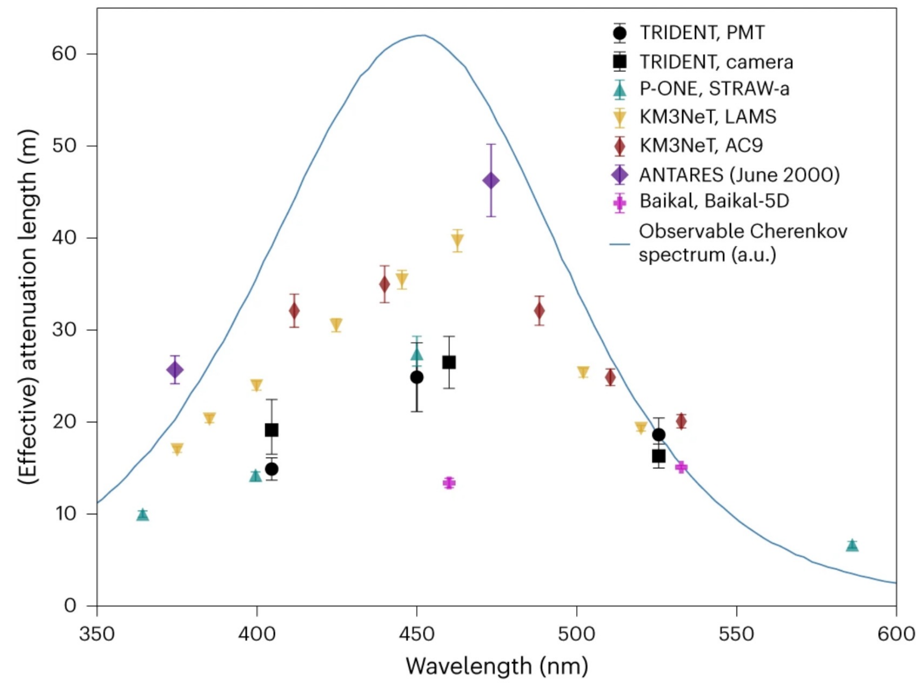
Water optical properties measured using both camera and PMT systems



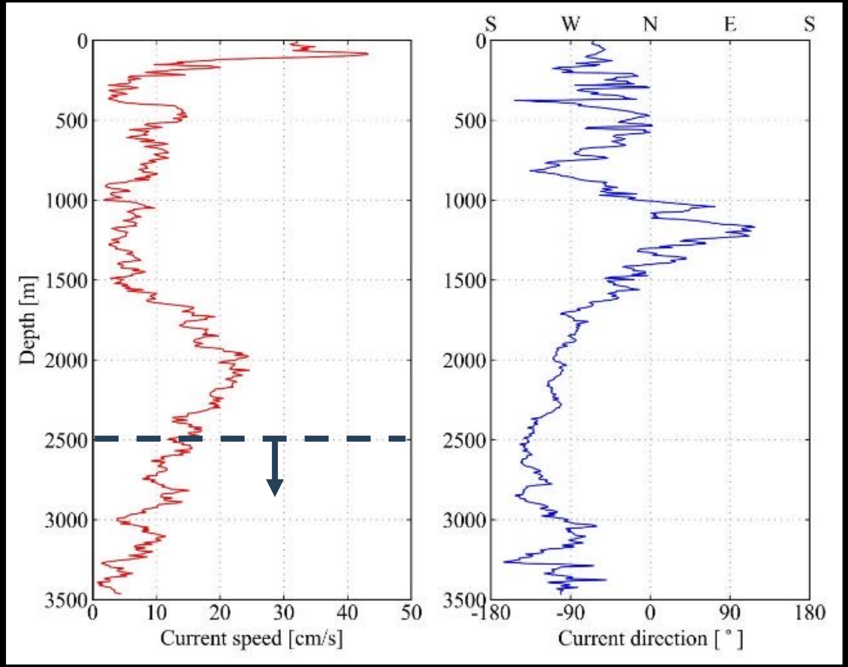
3” PMTs

Camera

Effective Attenuation Length

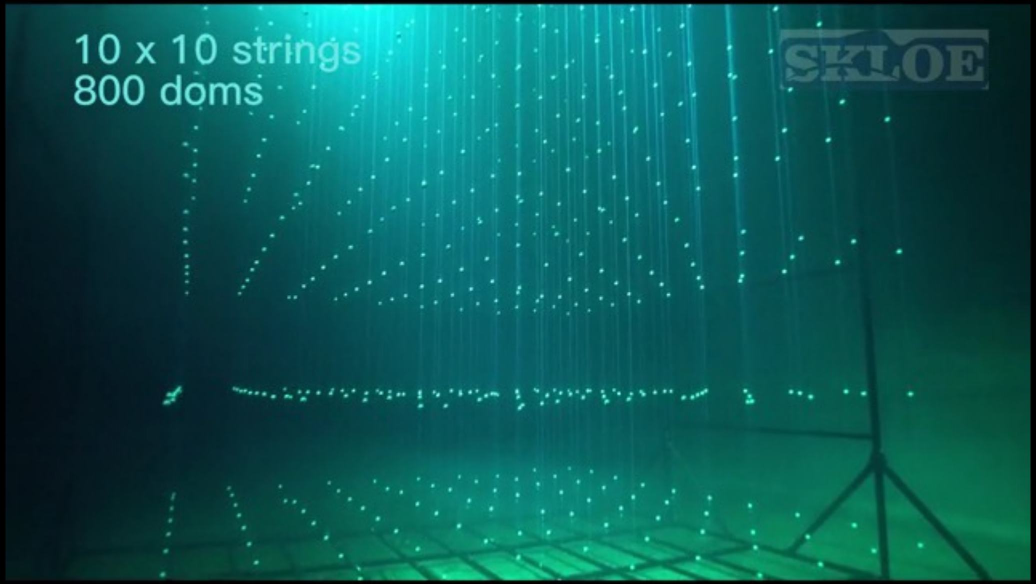


Site Conditions: Sea Currents



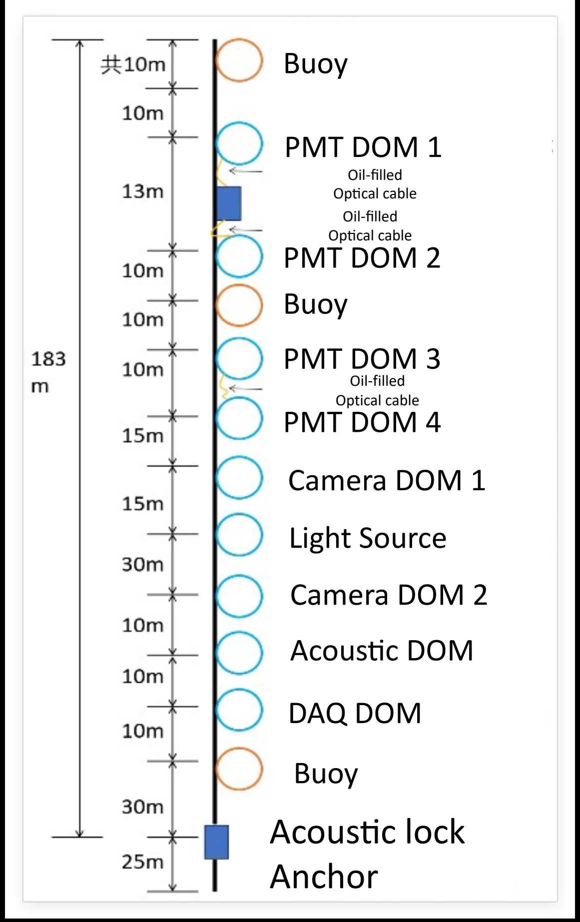
Low current speeds from
2.5-3.5 km deep

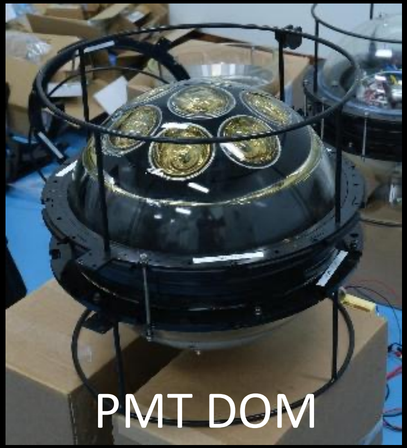
(30s video)

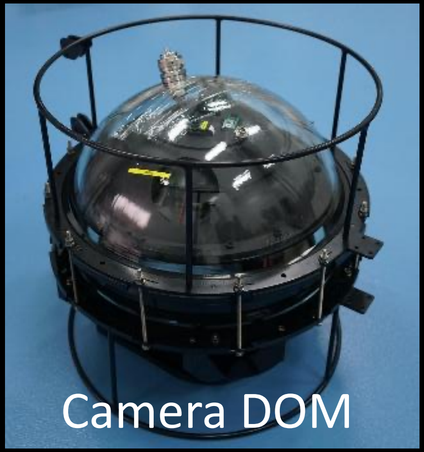


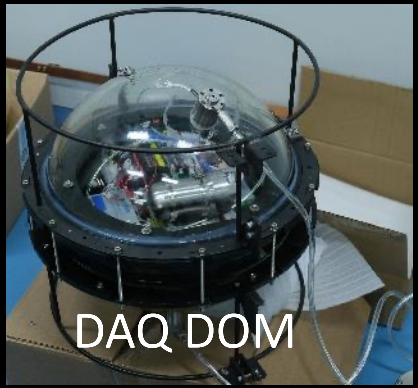
1:25 scale string models
in SJTU Ship-towing tank

T-REX 2024









Further deployments carried out in the Hai-Ling Basin:

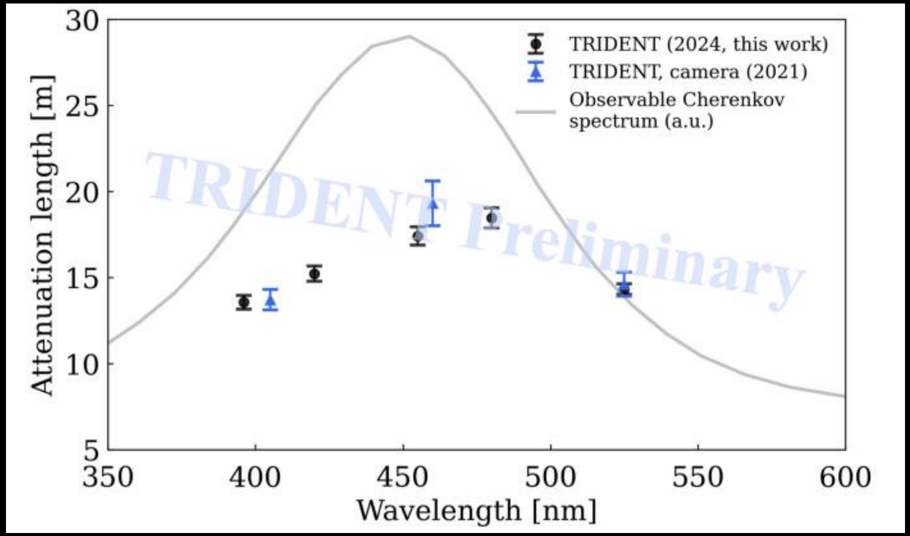
4-month operation: 2024.12.01 – 2025.03.26

T-REX 2024

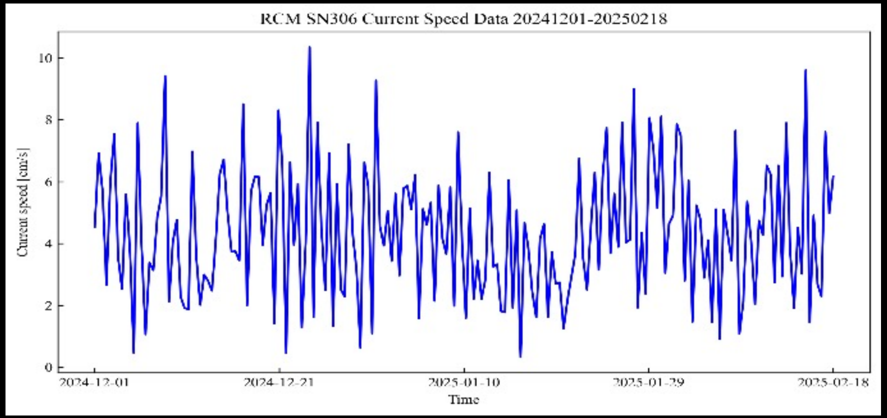
"A camera system for real-time optical calibration of water-based neutrino telescopes", NIM-A 1076 (2025)

"Preliminary design of the TRIDENT acoustic positioning system", PoS (ICRC2025) 1102

- Updated optical properties measurements
  → Consistent with T-REX 2021
- Stable sea currents (< 10cm/s) at detector depths

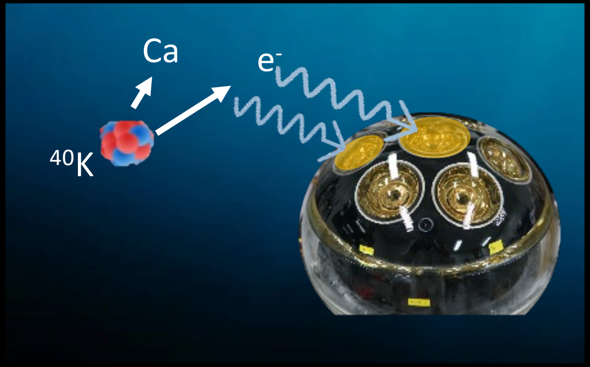


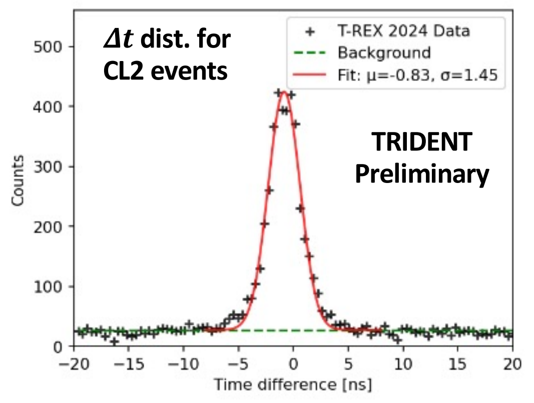
Retrieval on March 26th, 2025



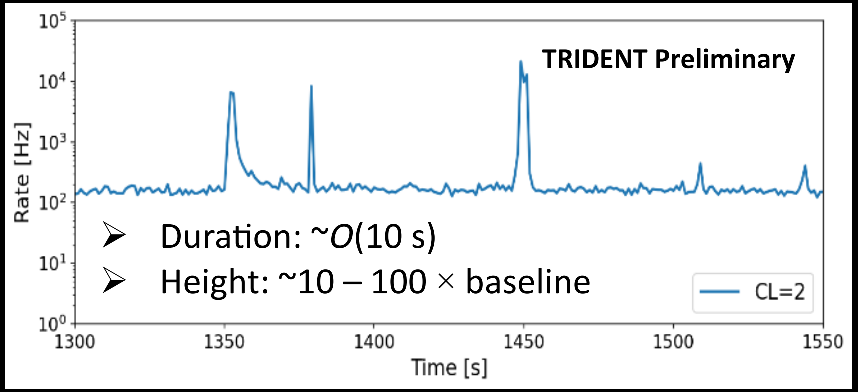
T-REX 2024

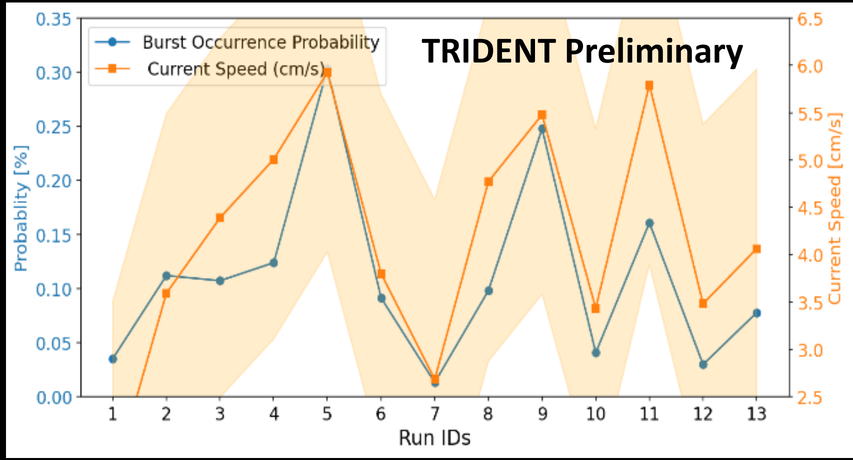
Multi-PMT testing: In-situ calibration with ^{40}K



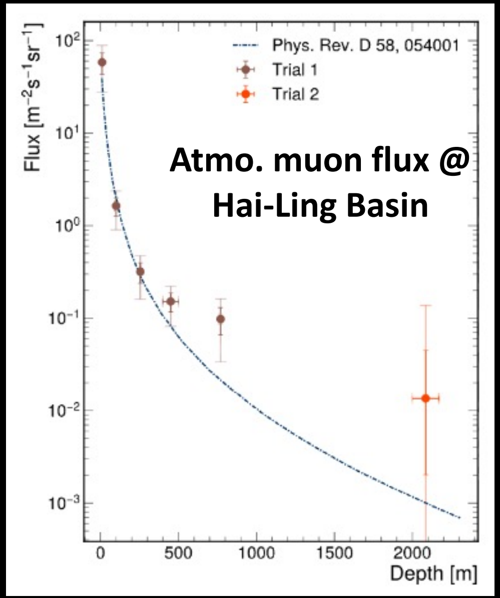


Light emission bursts from bioluminescence in water seen





Plastic scintillator slabs measure atmospheric muons

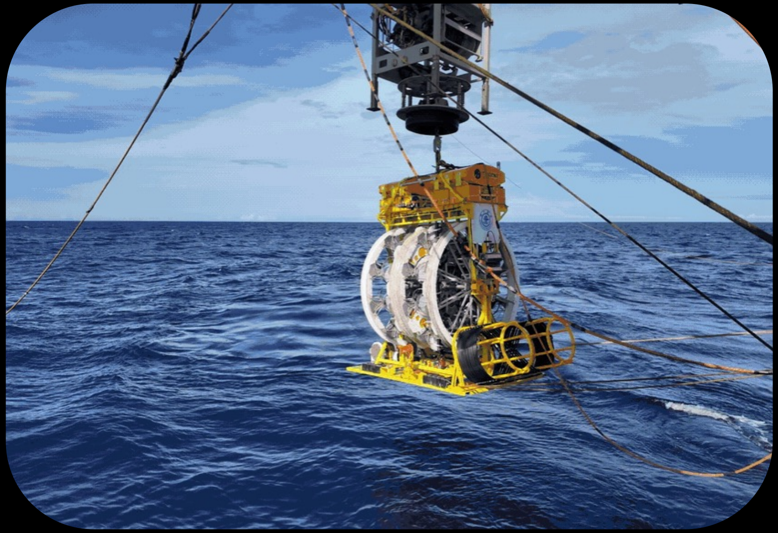


"Prototype Testing for TRIDENT, Performance of Multi-PMT Optical Modules", F. Zhang (TAUP 2025)

"MuonSLab, a plastic scintillator based detector for muon measurement in the deep ocean". *JINST* (2025)

Deployment Preparation

Testing string deployment system

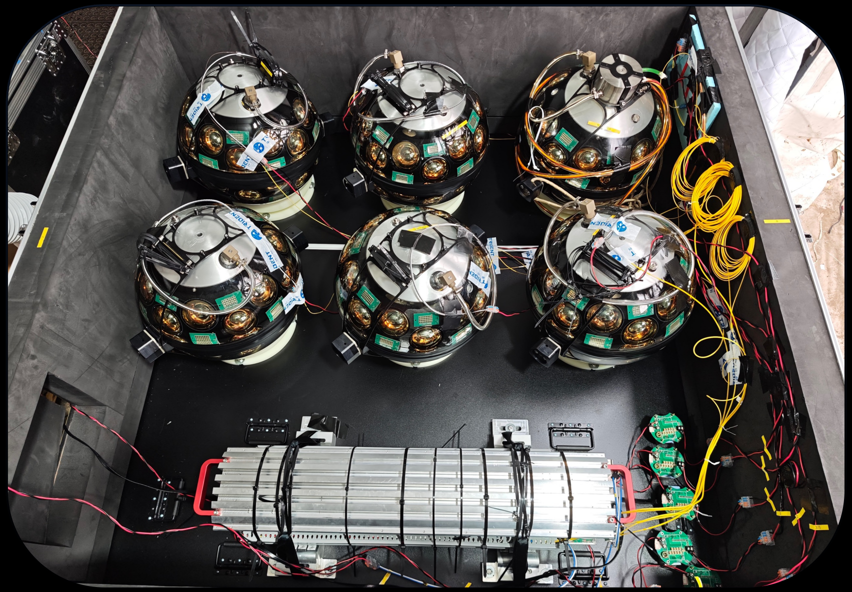


Design and lake trial of a deep-sea neutrino detection mooring deployment system, Ocean Engineering, 2025

Dedicated assembly lab in Sanya, starting mass production of detection modules

TRIDENT Prototype String

Ongoing: first Prototype hDOM-string testing

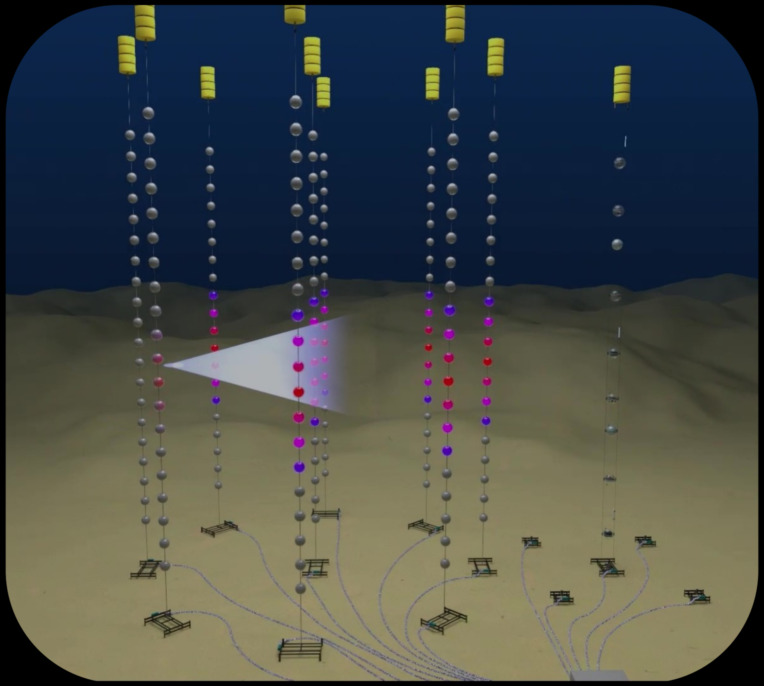


Electronic tests at low temperatures

Pressure testing

TRIDENT Phase-I

Deployment of first 10 optical strings + 1 calibration string



Deployment planned for 2027

Primary physics:
- ➢ TeV all-flavour atmos. ν in the Hai-ling Basin
- ➢ Join Astro. neutrino source search campaign (CCSN monitoring , southern sky sources)

Key technology demonstration:
- ➢ Precise Cherenkov light detection w/ hDOMs
- ➢ Long-distance power and data transmission
- ➢ Dynamic calibration strategies
- ➢ Data acquisition
- ➢ Deployment and maintenance strategies

มหาวิทยาลัยเชียงใหม่
CHIANG MAI UNIVERSITY

~13 institutes, ~ 100 members

Conclusion

- The next step in multi-messenger astro requires more, larger and better neutrino telescopes.

PC: Ruike Cao

- TRIDENT aims to deliver the next leap in detector scale and performance.

- Site established at a 3.5 km depth with ongoing in-situ validation.
- First deployments this year begin the path toward a full observatory. Phase-I in 2027

Backup

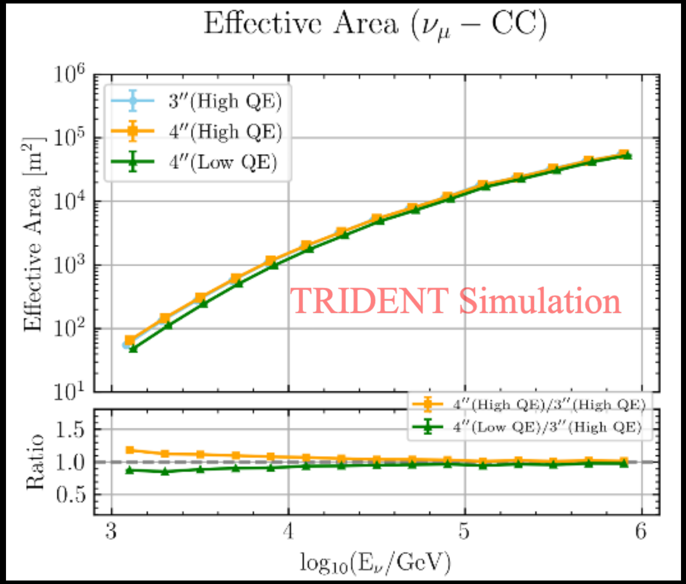
Detector Design – hDOMs

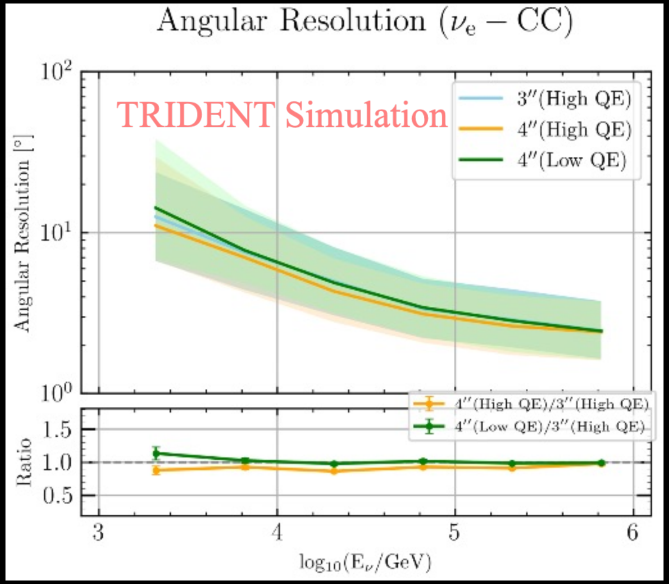
[“A Cost Effective Optimization of the hybrid-DOM Design for TRIDENT”](#)

3-inch PMT hDOM design
- 31 3” PMTs
- 24 SiPMs (4x8 array)

4-inch PMT hDOM design
- 19 4” PMTs
- 5 SiPMs (8x8 array)

Check / compare performances for various designs:
e.g. neutrino detection efficiency + angular resolution

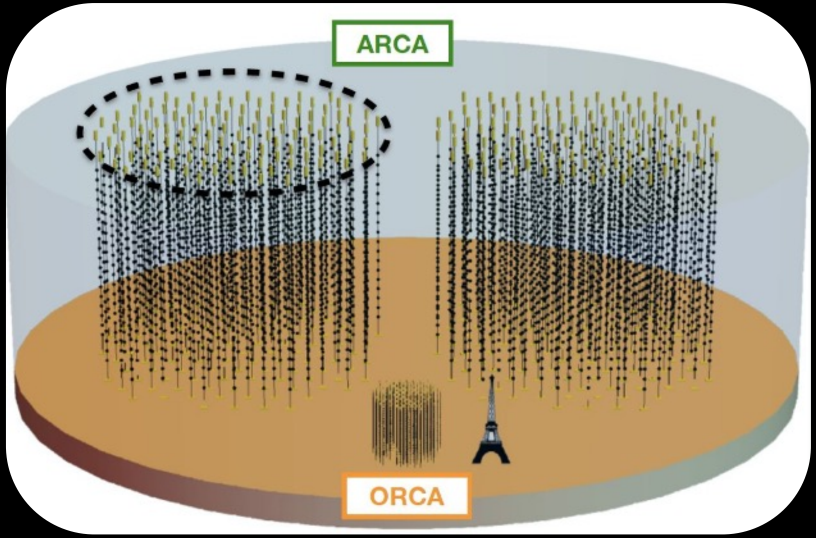




Detector Design – Geometry

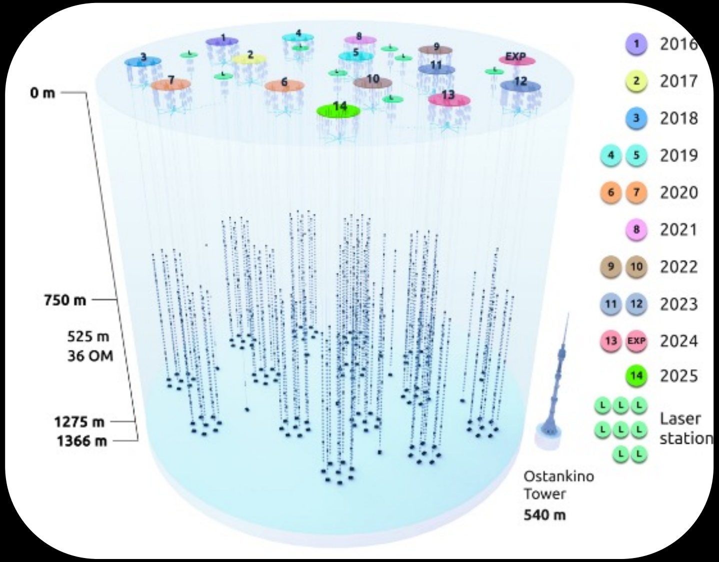
Nature Astronomy 7, p1497–1505 (2023)

KM3NeT



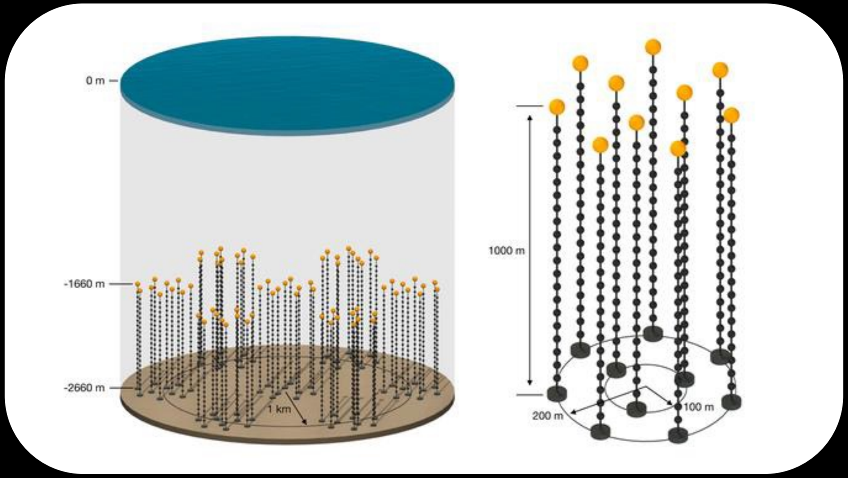
Lake Louise Winter Institute 2025,
Agustín Sánchez Losa

Baikal GVD



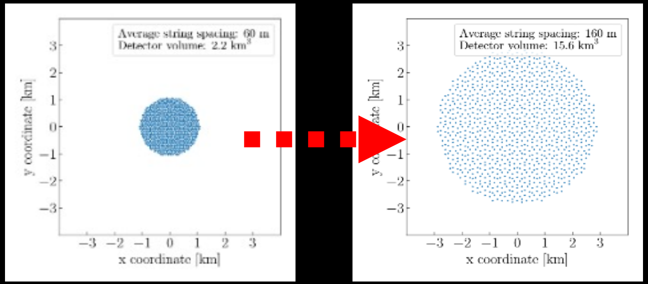
5th International Symposium on Cosmic Rays and Astrophysics, Zhan-Arys Dzhilkibaev

P-ONE



Nature Astronomy 4 913–915 (2020)

Source Discovery Potential



Assuming the "standard" geometry takes 5 years to discover a given source

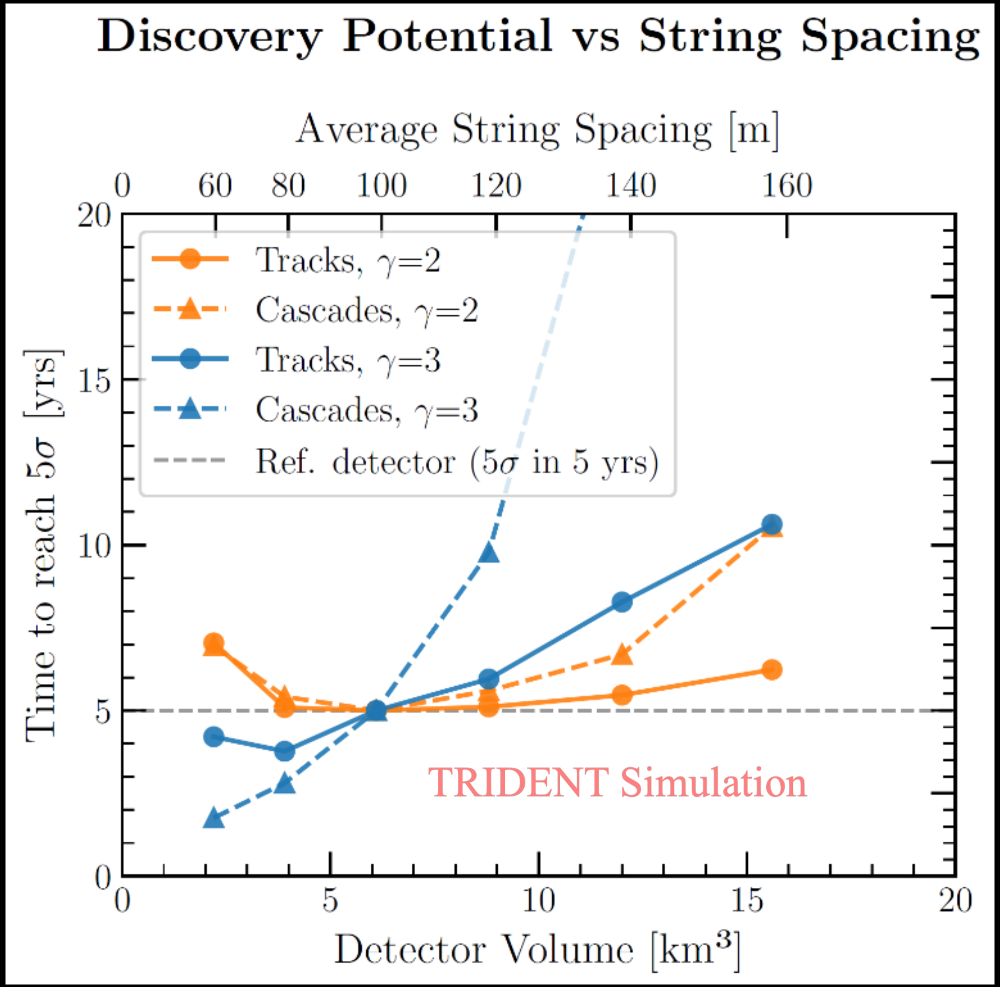
$$\phi(E_\nu) \propto \begin{cases} E^{-2} & \text{"hard" source} \\ E^{-3} & \text{"soft" source} \end{cases}$$

How much slower/faster can each geometry discover same source?

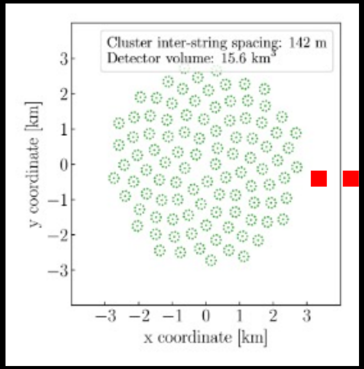
Bigger detector is **not necessarily better**

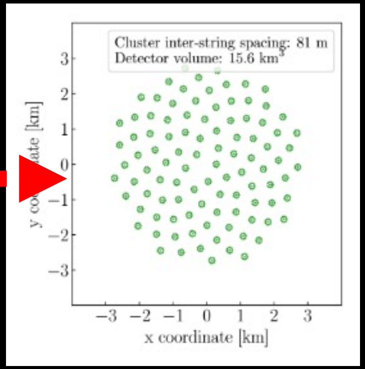
- Worse at low energies tracks and cascades:
- Worse at high energies tracks and cascades:

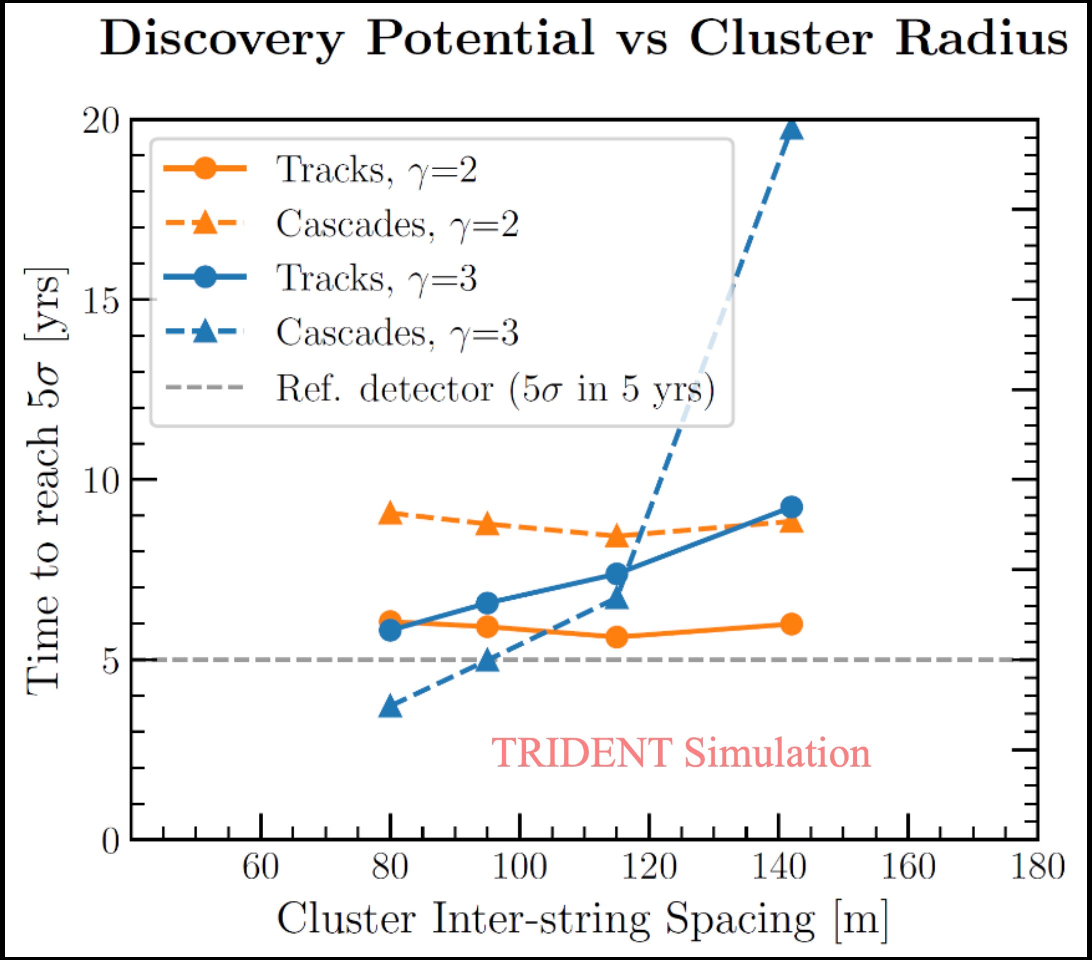
Dense detector favours low energy events



Source Discovery Potential – String Clustering







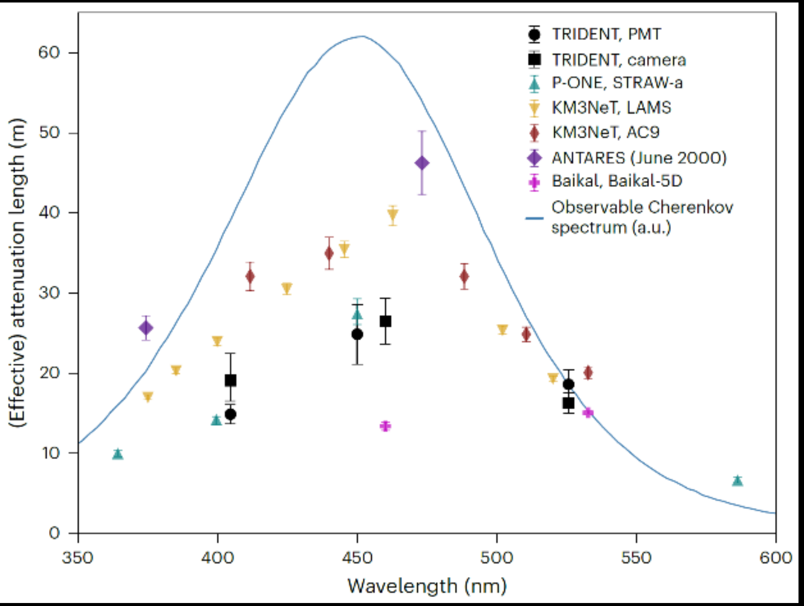
String clusters show poorer performance for all channels, except for low energy cascades.

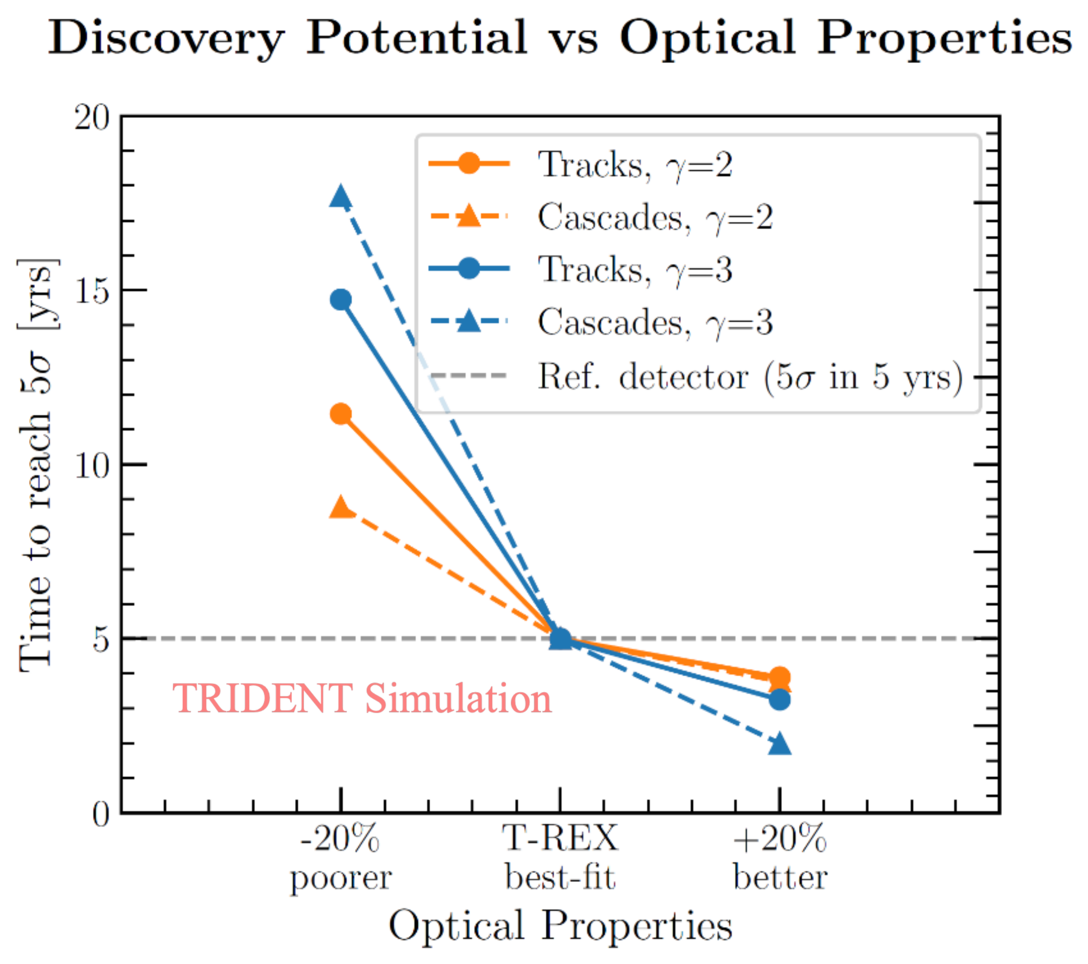
However, physics must be weighed against deployment & maintenance cost, safety

Source Discovery Potential – Optical properties

While geometry choice is significant,
water optical properties are essential!

→ Attenuation length can have larger impact than geometry choices





Source Discovery Potential – Optical properties

Photon detection efficiency should therefore lead the design of a detector.

Ongoing/future measurements at site and in TRIDENT Phase-1 will influence the final design choice