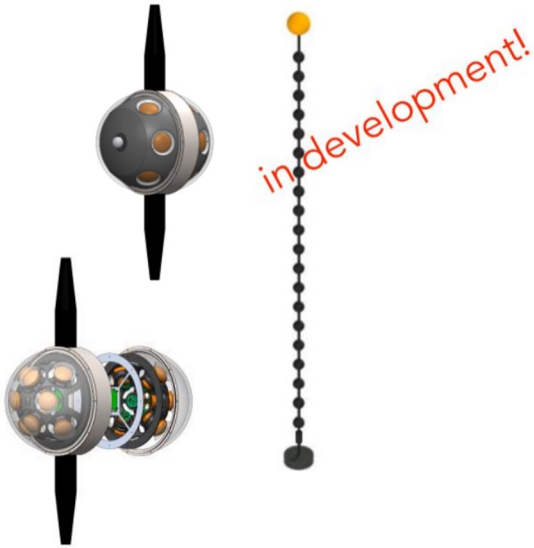
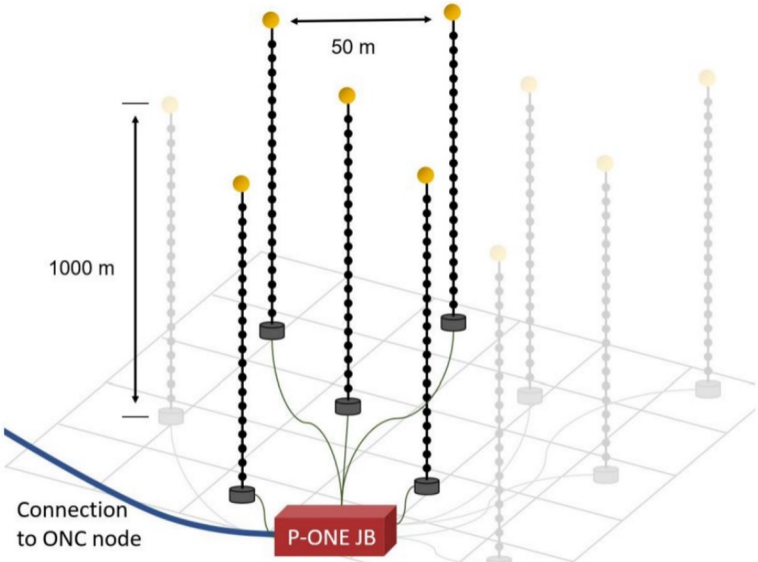
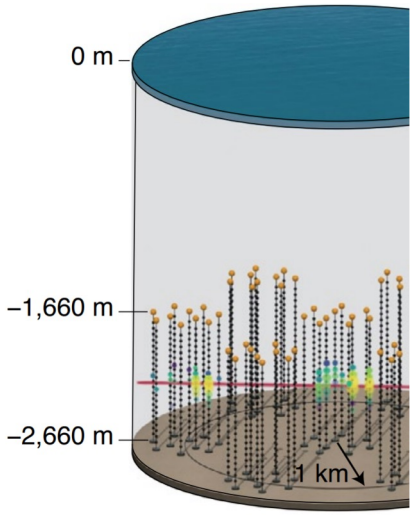
High-Energy Neutrino Astronomy

P-ONE
Pacific Ocean Neutrino Experiment







P-ONE pilot string
2025

P-ONE demonstrator
2025-2028

Teppei Katori
King's College London
PPAP community meeting, University of Birmingham, June 25, 2024

KING'S College LONDON

PAAP roadmap (2022), https://www.ukri.org/publications/particle-astrophysics-advisory-board-roadmap-2022/

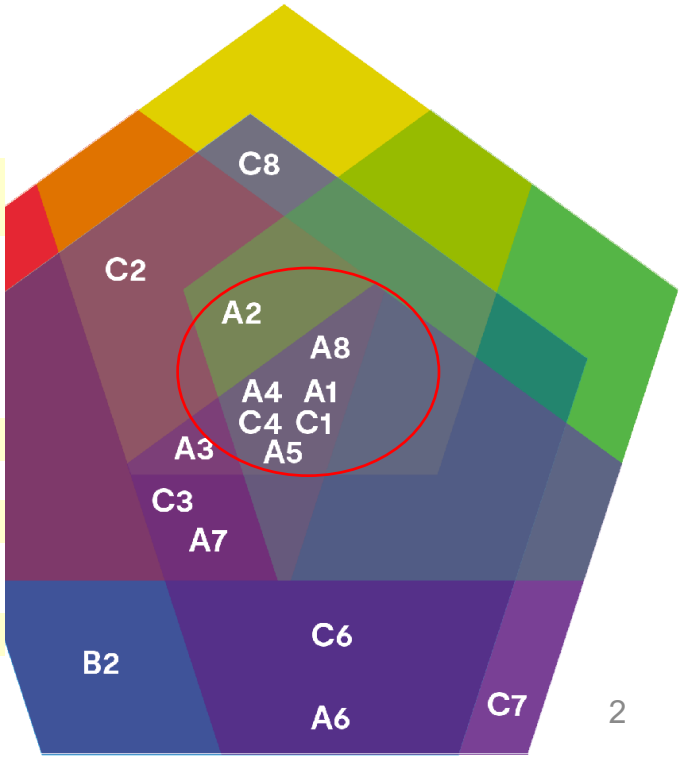
1. High-Energy Astrophysical Neutrinos

High-energy neutrino astronomy answer STFC key science challenges

A: how did the universe begin and how is it evolving?

Challenge C: what are the basic constituents of matter and how do they interact?

Gravitational waves
Very High Energy Gamma
Neutrino
Direct Dark Matter
Cosmic Microwave Background

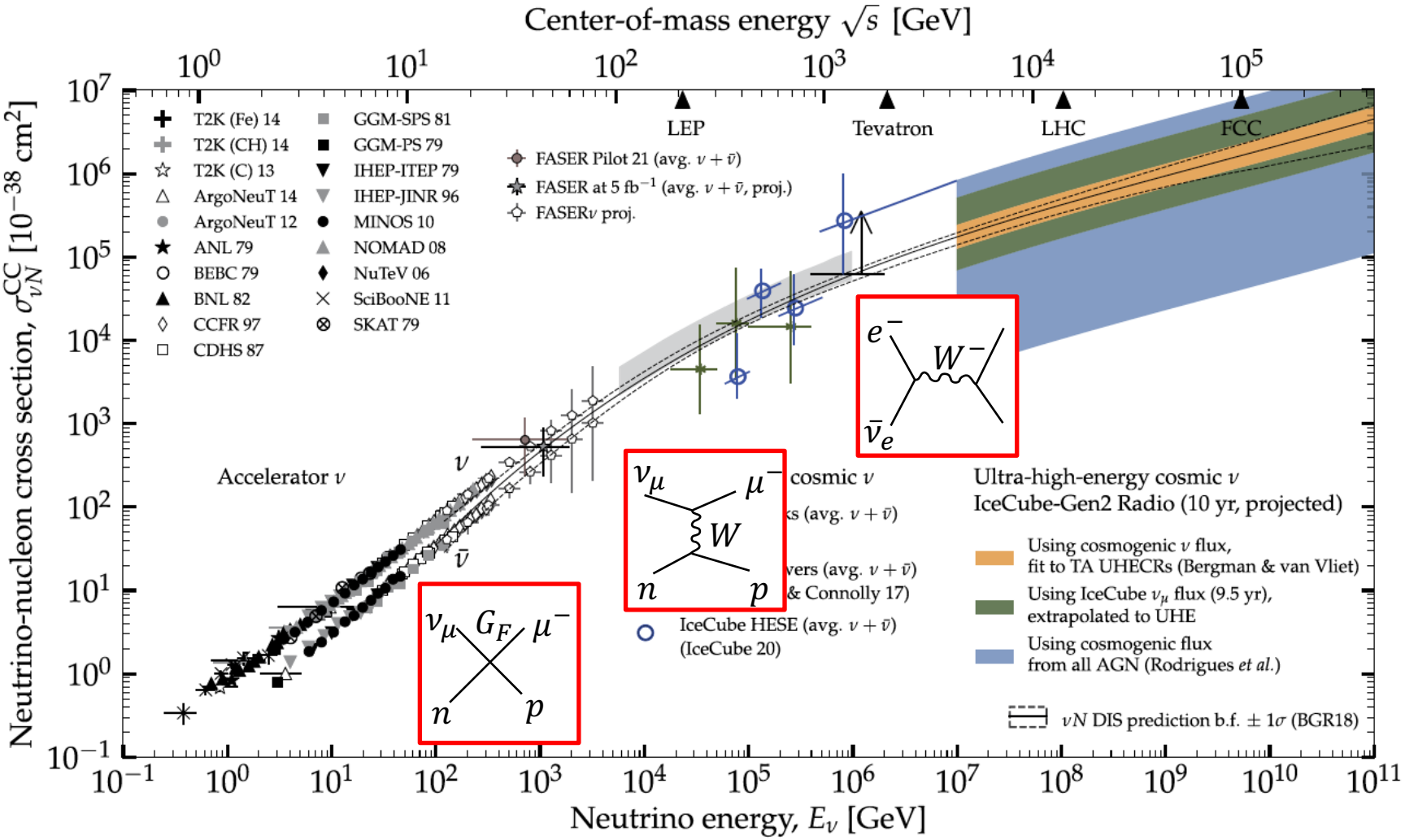


A1	What are the laws of physics operating in the early Universe?
A2	How did the initial structure in the universe form?
A3	How is the universe evolving and what roles do dark matter and dark energy play?
A4	When and how were the first stars, black holes and galaxies born?
A5	How do stars and galaxies evolve?
A6	How Do Nuclear Reactions Power Astrophysical Processes and Create the Chemical Elements?
A7	What is the True Nature of Gravity?
A8	What can gravitational waves and high-energy particles from space tell us about the universe?
B2	What effects do the Sun and other stars have on their local environment?
C1	What are the fundamental particles and fields?
C2	What are the fundamental laws and symmetries of physics?
C3	What is the nature of space-time?
C4	What is the nature of dark matter and dark energy?
C6	What is the nature of nuclear matter?
C7	Are there new phases of strongly interacting matter?
C8	Why is there more matter than antimatter?

Snowmass, JHEA36(2022)55

1. High-Energy Astrophysical Neutrinos

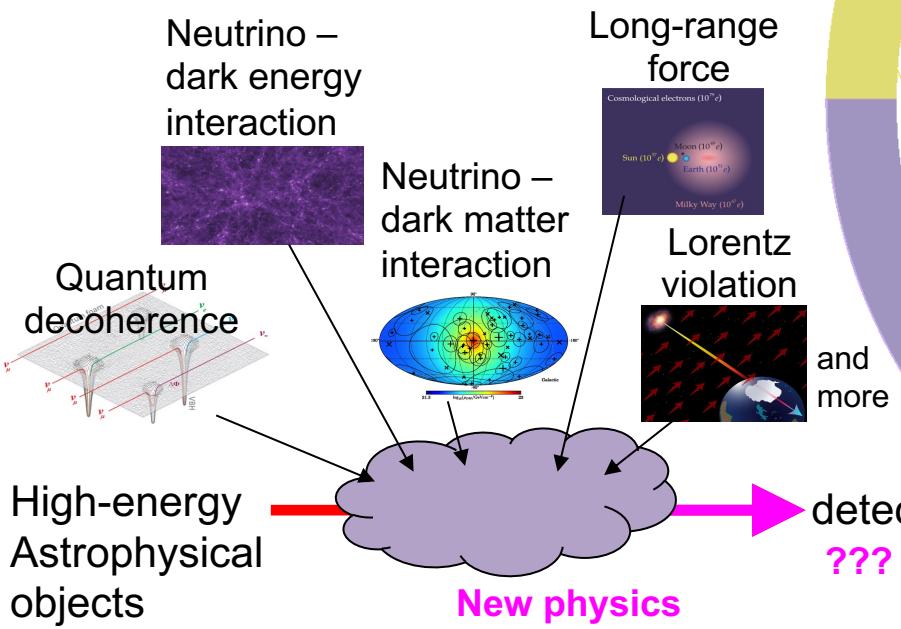
High-energy astrophysical neutrinos offer the highest energy fixed target experiments.
- Synergy with accelerator-based experiments.

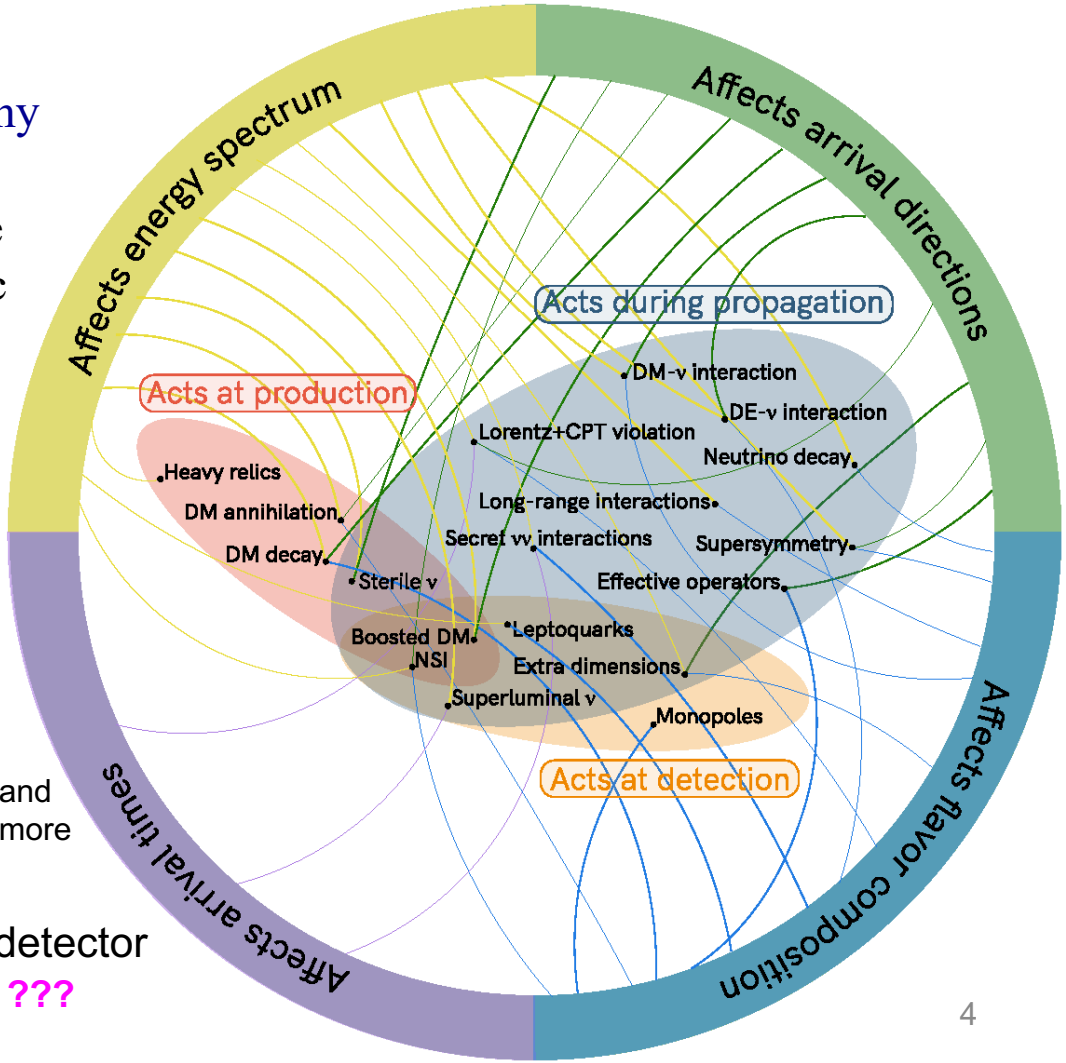


1. High-Energy Astrophysical Neutrinos

Rich scientific program to cover many BSM physics topics.
- Energy spectrum, arrival time, flavor are affected by production, propagation, detection of neutrinos

Synergy with multi-messenger astronomy
- Astrophysical neutrino model errors (spectrum, flavour contents, etc) will be reduced from gamma-ray astronomy etc





1. High-Energy Astrophysical Neutrinos

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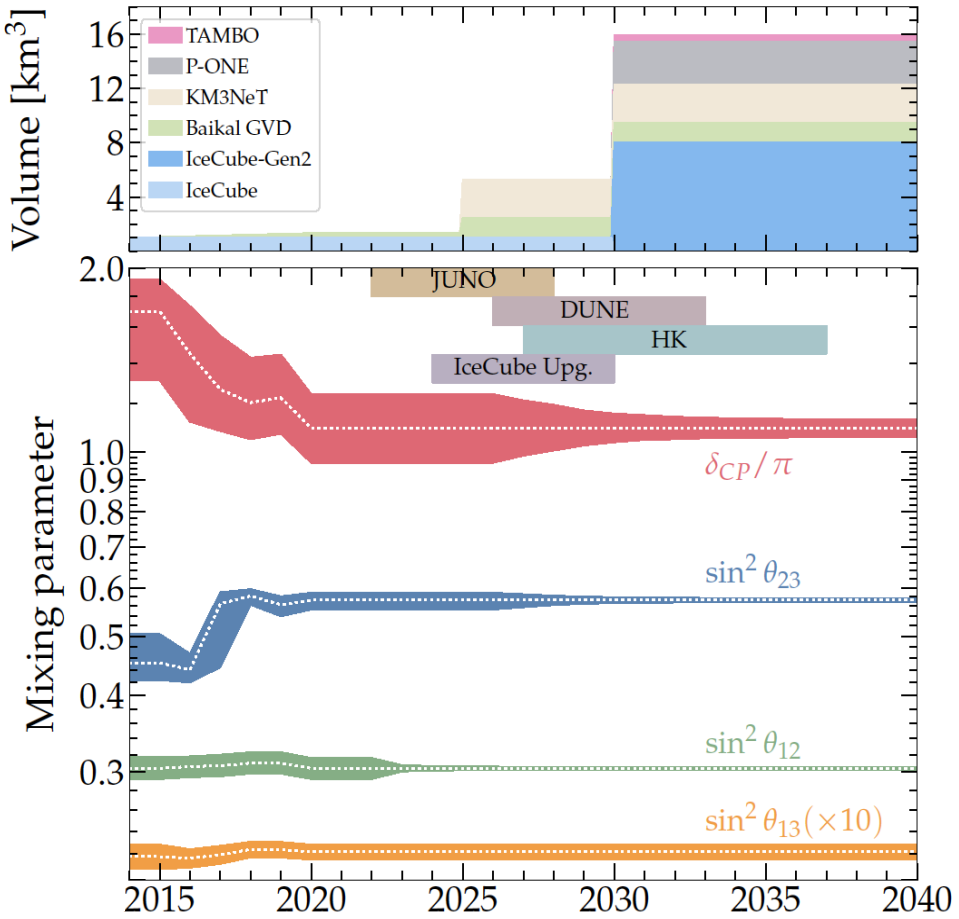
Synergy with multi-messenger astronomy

- Astrophysical neutrino model errors (spectrum, flavour contents, etc) will be reduced from gamma-ray astronomy etc

Synergy with neutrino oscillation physics

- Oscillation parameter errors will be reduced by future oscillation experiments

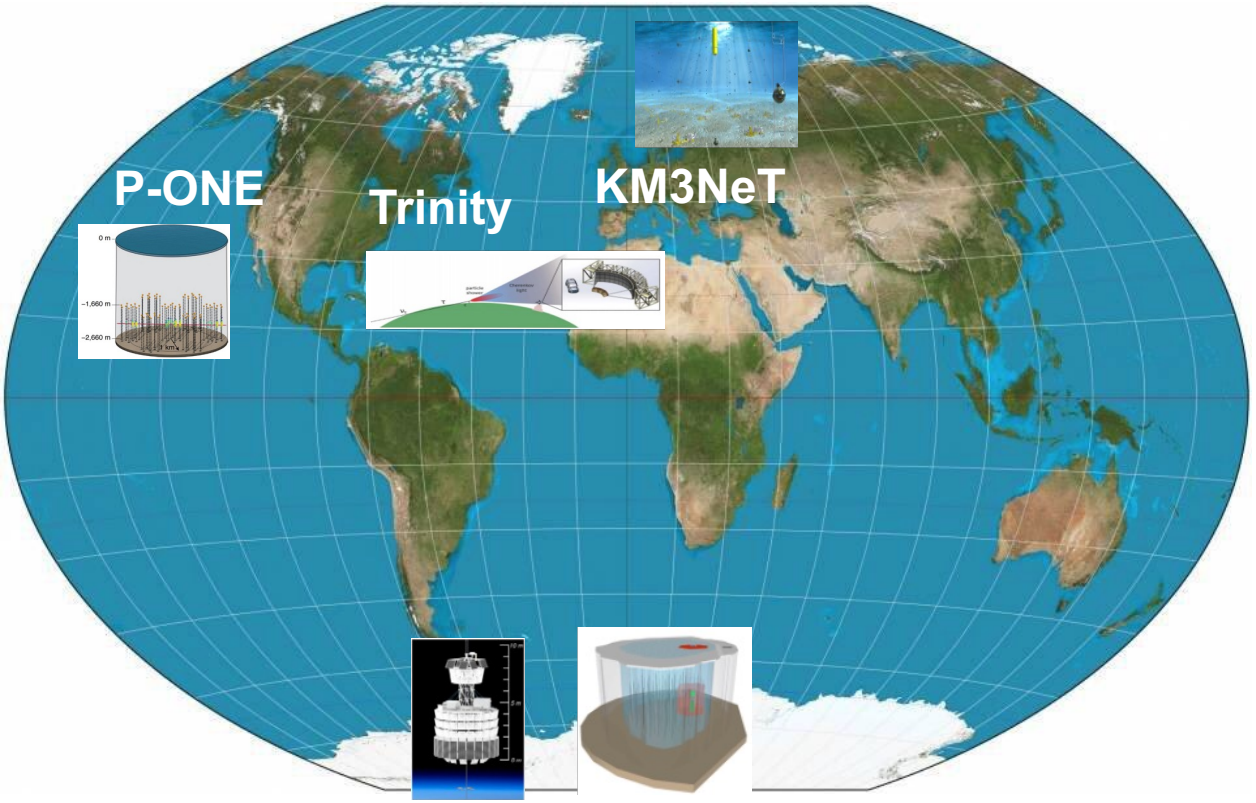
$$H \sim \frac{m^2}{2E} + V(new\ physics)$$
$$P \sim V(new\ physics) \cdot L$$



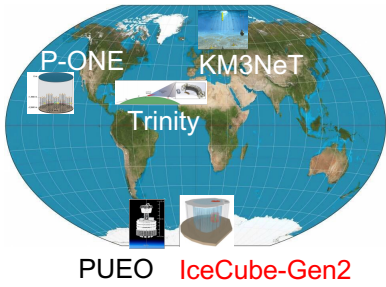
2. UK High-Energy Astrophysical Neutrino Consortium

5 projects contributed by UK groups

- **IceCube, PUEO, P-ONE, KM3NeT, Trinity**
- Experimental submission to PPGP (**IceCube**, **PUEO**, **P-ONE**)
  Near term plan: Exploit science from **IceCube** and **PUEO**
  Long term plan: **P-ONE** as a baseline UK project



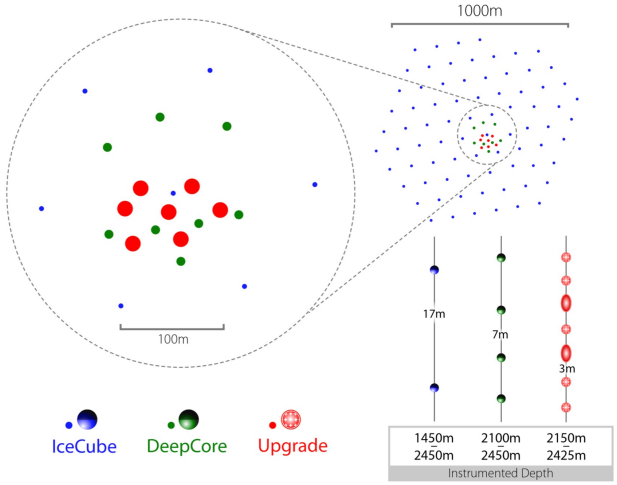
2. IceCube



Discovery of high-energy galactic neutrinos

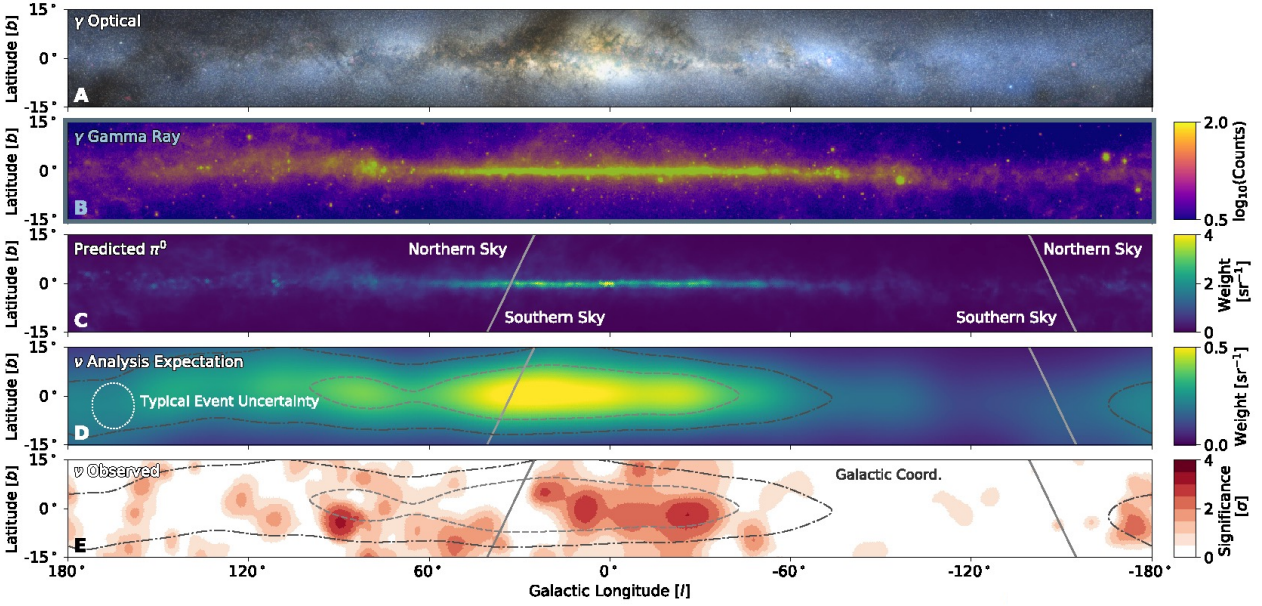
IceCube-Upgrade
- Deployment 2025/26 season

IceCube-Gen2
- Setback at South Pole infrastructure support
- Impact on IceCube-Gen2 is unknown

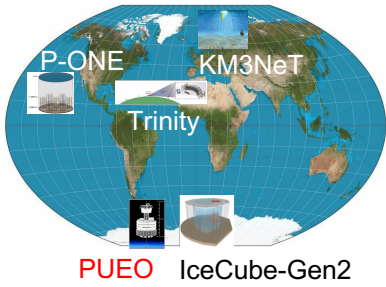


King's College London
- BSM physics analysis
- IceCube-Upgrade sensitivity
- Gen2 R&D

(scintillator-based detector)

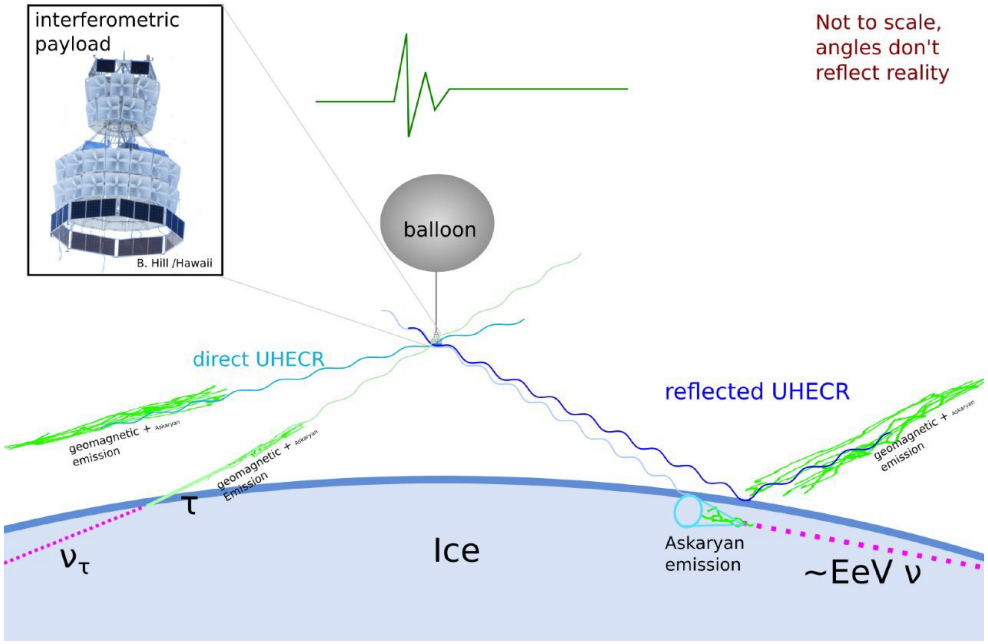


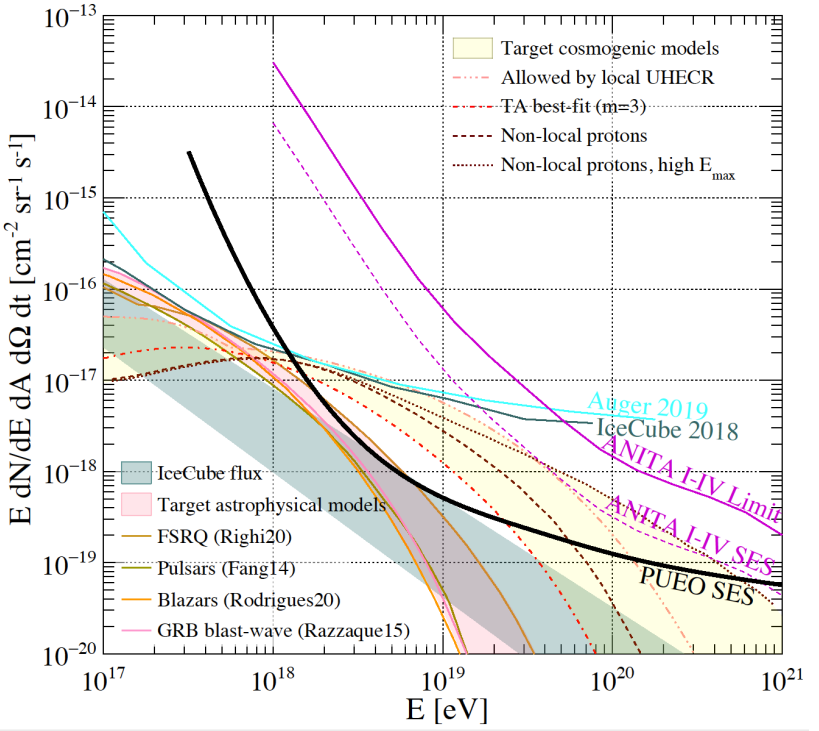
2. PUEO



Fifth generation of ANITA flight
- Flight plan on 2025
- Askaryan effect, skimming tau, UHECR, exotics

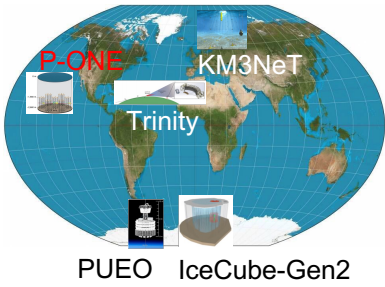
UCL
- Developing digitisation system based on XILINX RFSoC
- Working on main analysis (diffuse flux)





P-ONE, Nature Astronomy 4(2020)913, ICRC 2023, https://agenda.infn.it/event/37867/contributions/233998/

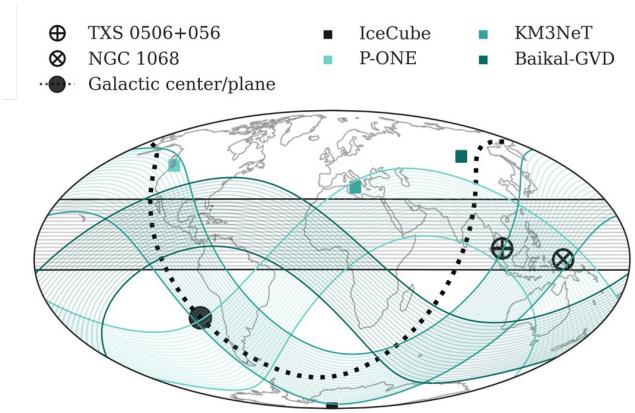
2. P-ONE

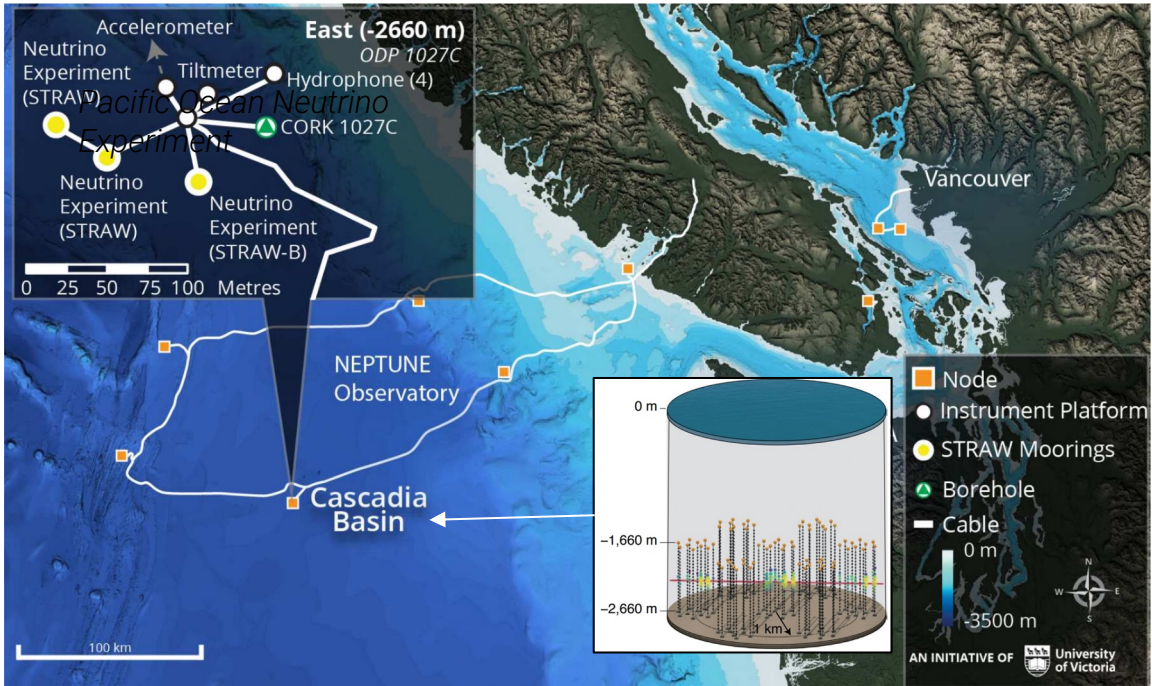


Next generation neutrino telescope
- IceCube expertise
- KM3NeT multi-PMT technology
- Baikal-GVD inspired string configuration
- Available underwater infrastructure

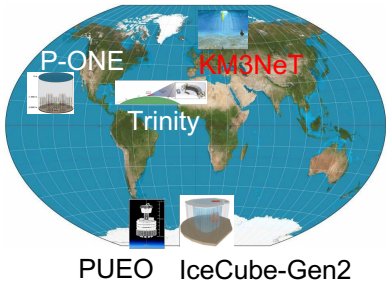
UCL
- Leading role for pathfinder analysis
- Forming multi-messenger community


KM3NeT IC-Upgrade HyperK P-ONE





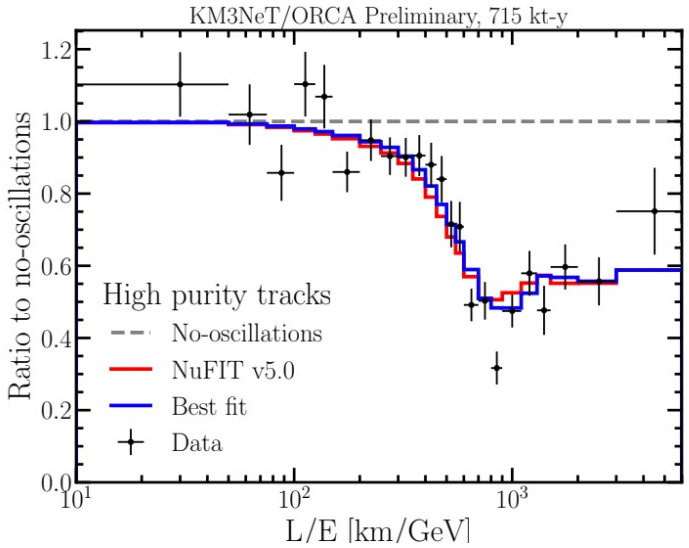
2. KM3NeT

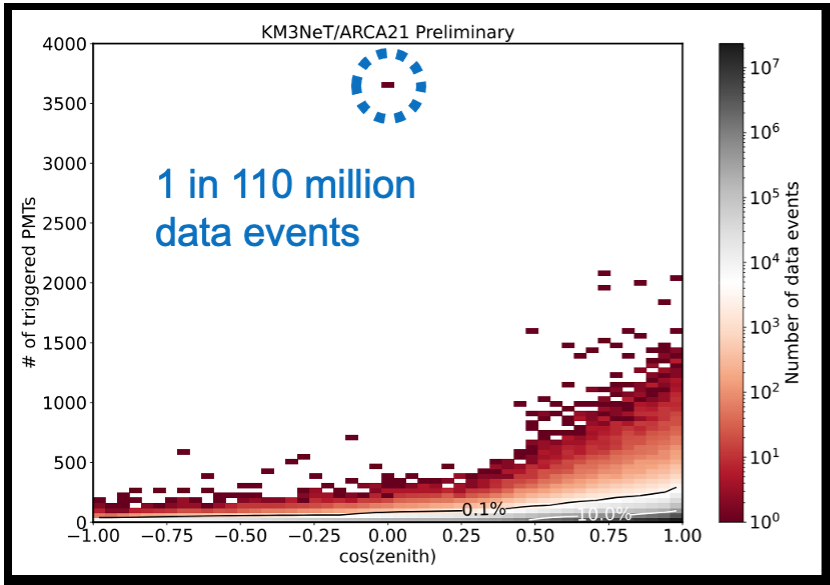


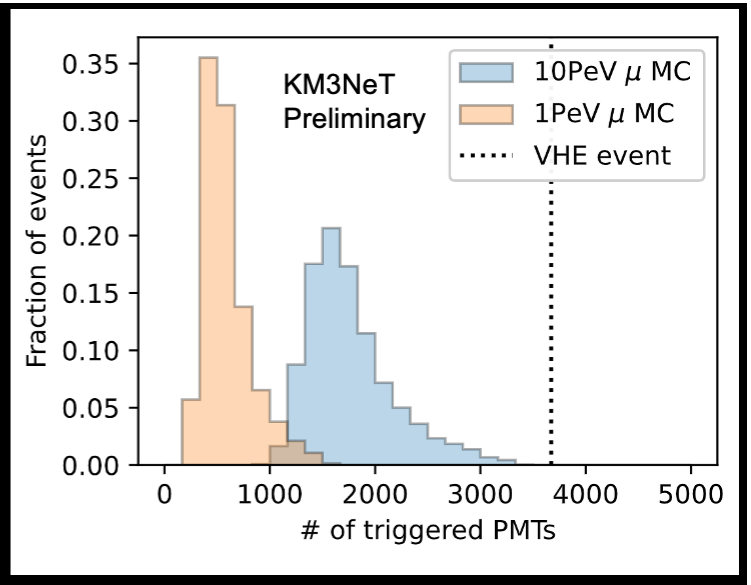
ORCA, Low energy array, ~10% made (23/115 lines)
- Oscillation physics

ARCA, High energy array, ~10% made (28/230 lines)
- Multi-10 PeV event (?!)

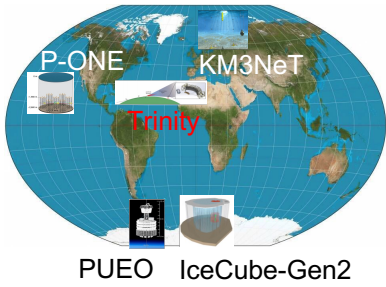
University of Hull (Astronomy)
- Tier 1 data site, HPC, ML, etc
- Core collapse SNe real time system





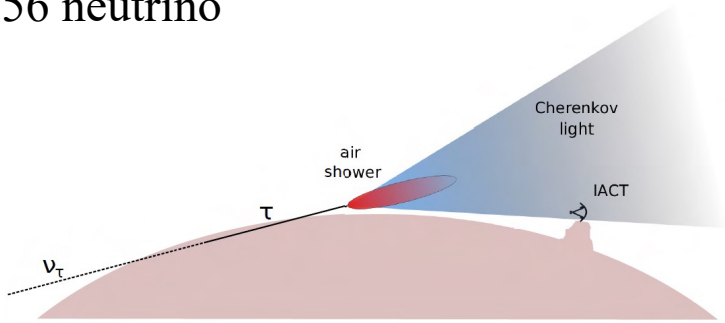


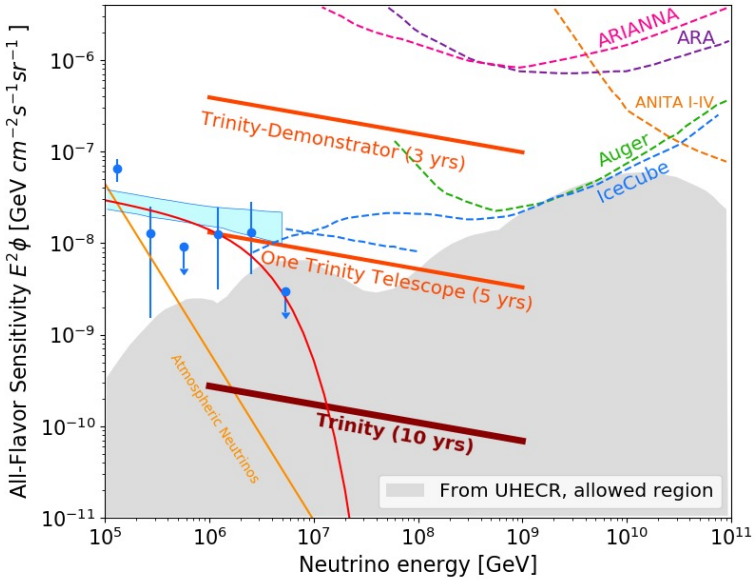
2. Trinity



Air shower telescope
- gamma-ray astronomy technology (CTA)
- Demonstrator is installed, targeting to see TXS0506+056 neutrino

University of Durham (astronomy)
- Calibration using drone
- Multi-messenger astronomy (gamma-ray astronomy)





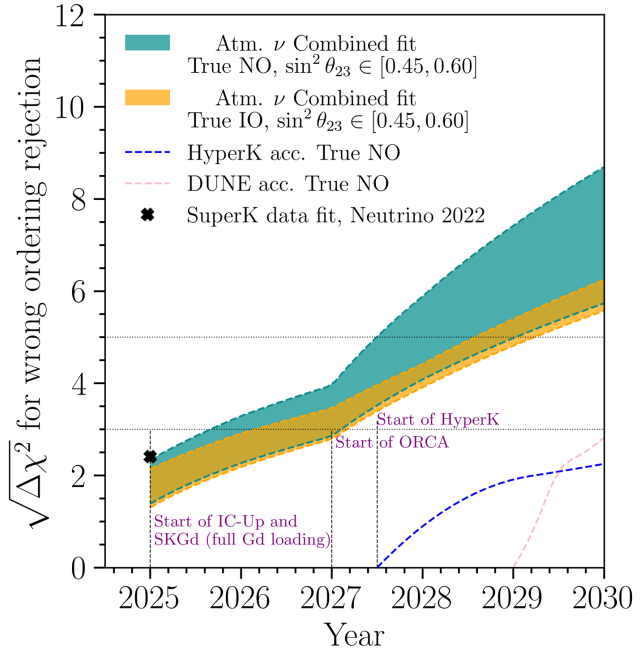
Argüelles, Fernandez, Martínez Soler, and Jin, PRX 13 (2023)

3. UK High-Energy Astrophysical Neutrino in PPAP

Near term plan: Exploit science from **IceCube** and **PUEO**

IceCube
- IceCube-Upgrade analysis for the first 3σ mass ordering result in 2028
- Maintain DMIce scintillator detector for calibration & cosmic ray physics

PUEO
- Pre-flight calibration
- Flight on-site support
- In-flight monitoring and maintain the monitoring system

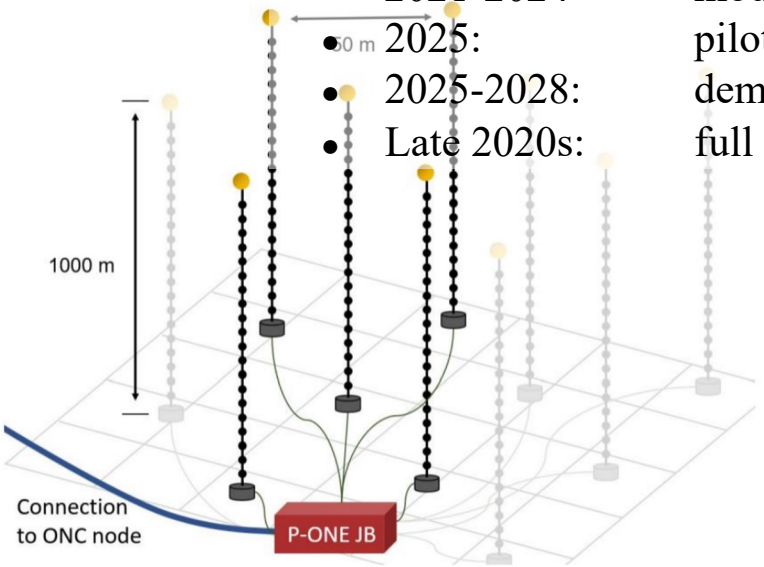


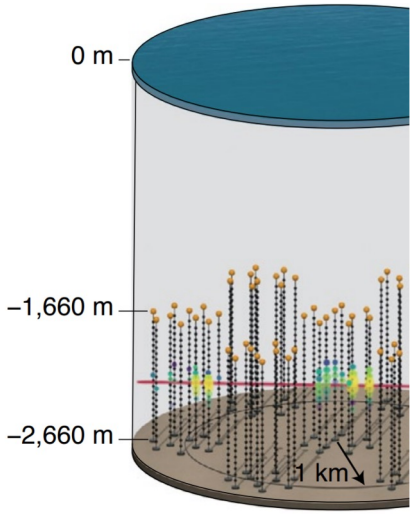
3. UK High-Energy Astrophysical Neutrino in PPAP

Long term plan: **P-ONE** as a baseline UK project
- Opportunities for UK groups to make significant contribution

Timeline:

- 2018-present: site validation
- 2020-2022: cable/infrastructure design
- 2021-2024 module technical design
- 2025: pilot string deployment
- 2025-2028: demonstrator
- Late 2020s: full detector construction





P-ONE pilot string
2025

P-ONE demonstrator
2025-2028

3. UK High-Energy Astrophysical Neutrino in PPAP

Long term plan: **P-ONE** as a baseline UK project
- Opportunities for UK groups to make significant contributions

- PMTs characterisation
- optical modules design and assembly
- optical modules read-out electronics
- FPGA online trigger
- Online monitoring systems
- Offline event reconstruction
- Simulation and Analysis frameworks
- Physics case:
  - BSM physics affecting the propagation of neutrinos over astronomical distances
  - Extragalactic point-sources (AGNs, starburst galaxies, tidal disruption events): detection sensitivity and model building
  - Milky Way in neutrinos: benchmarking mass tracers and spotting hot spots (DM production, gamma-ray point sources)
  - cross-disciplinary: marine biology and oceanography science

Conclusion

Neutrino telescopes are successful experiments

High-energy astrophysical neutrinos offer very exciting science for both particle physics and astrophysics

There are many planned projects with discovery potentials
- Near term plan: Exploit science from **IceCube** and **PUEO**
- Long term plan: **P-ONE** as a baseline UK project. there are opportunities to UK groups to make significant contributions on P-ONE.

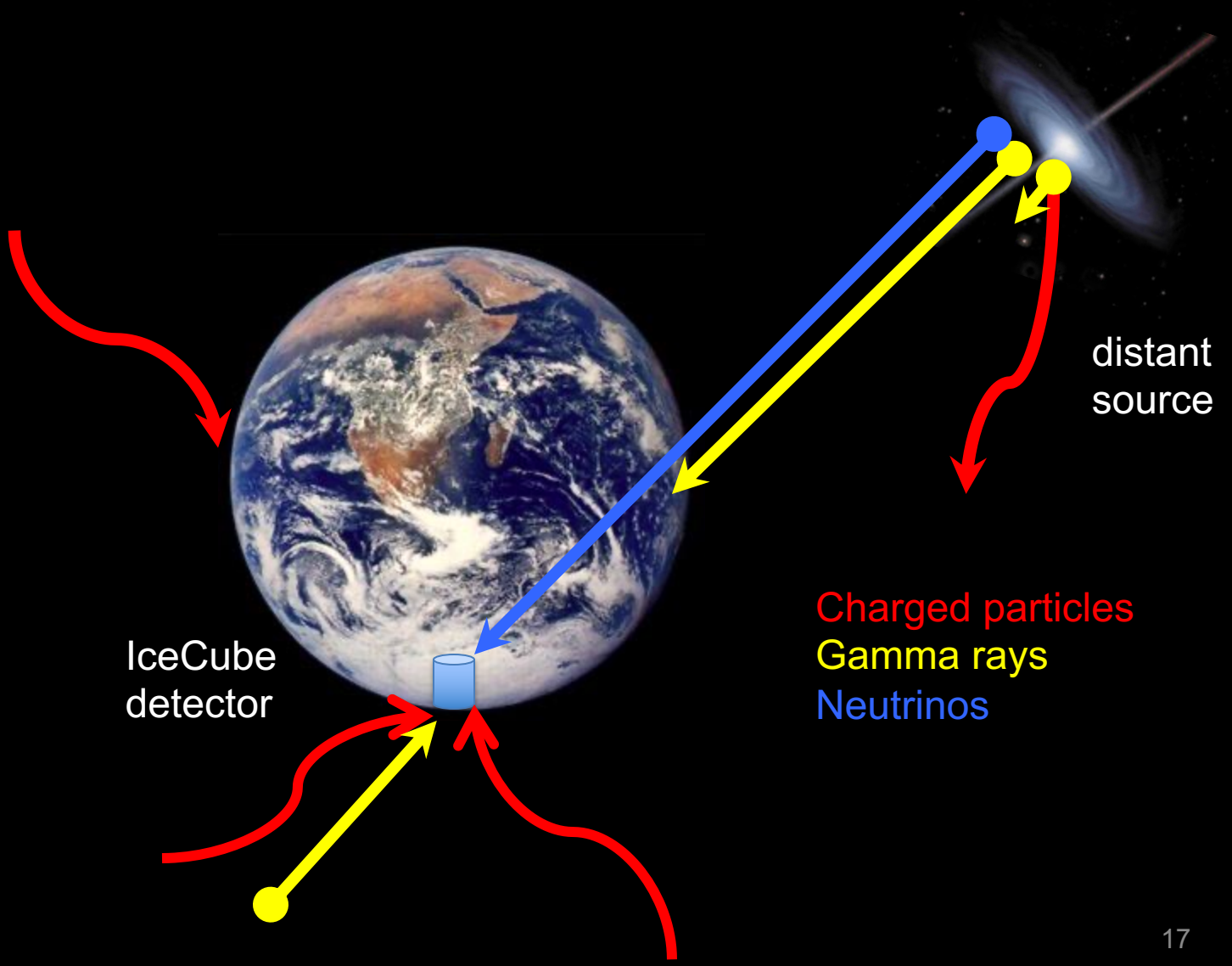
We are looking for more collaborators, and a way to work closely with UK astronomy community

Thank you for your attention!

Backup

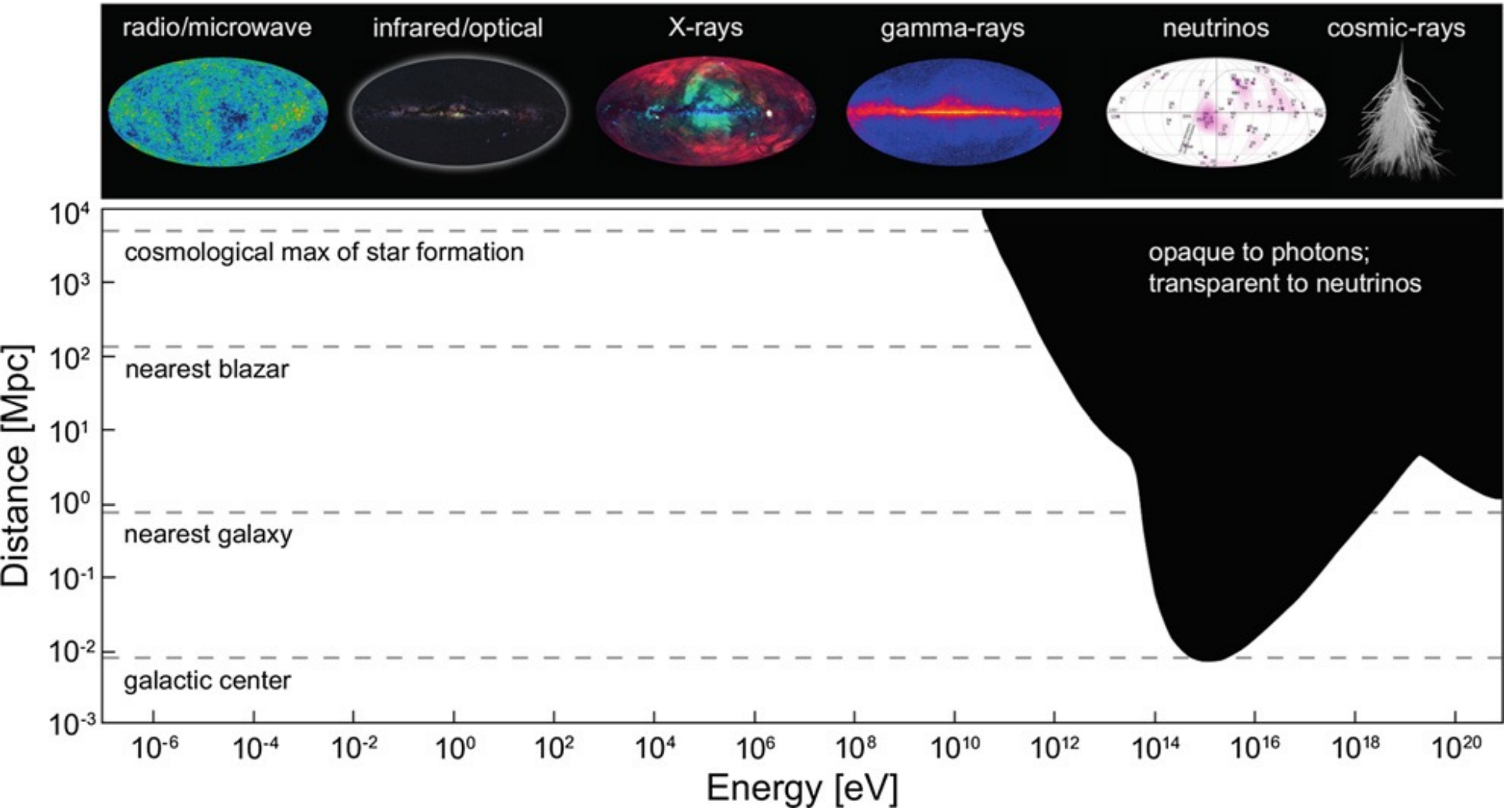
1. High-Energy Astrophysical Neutrinos

Direct messengers from the furthest celestial objects



1. High-Energy Astrophysical Neutrinos

Above ~10-100 TeV neutrinos are only direct extra-galactic messengers



Formaggio and Zeller, Rev.Mod.Phys.,84 (2012) 1307

1. High-Energy Astrophysical Neutrinos

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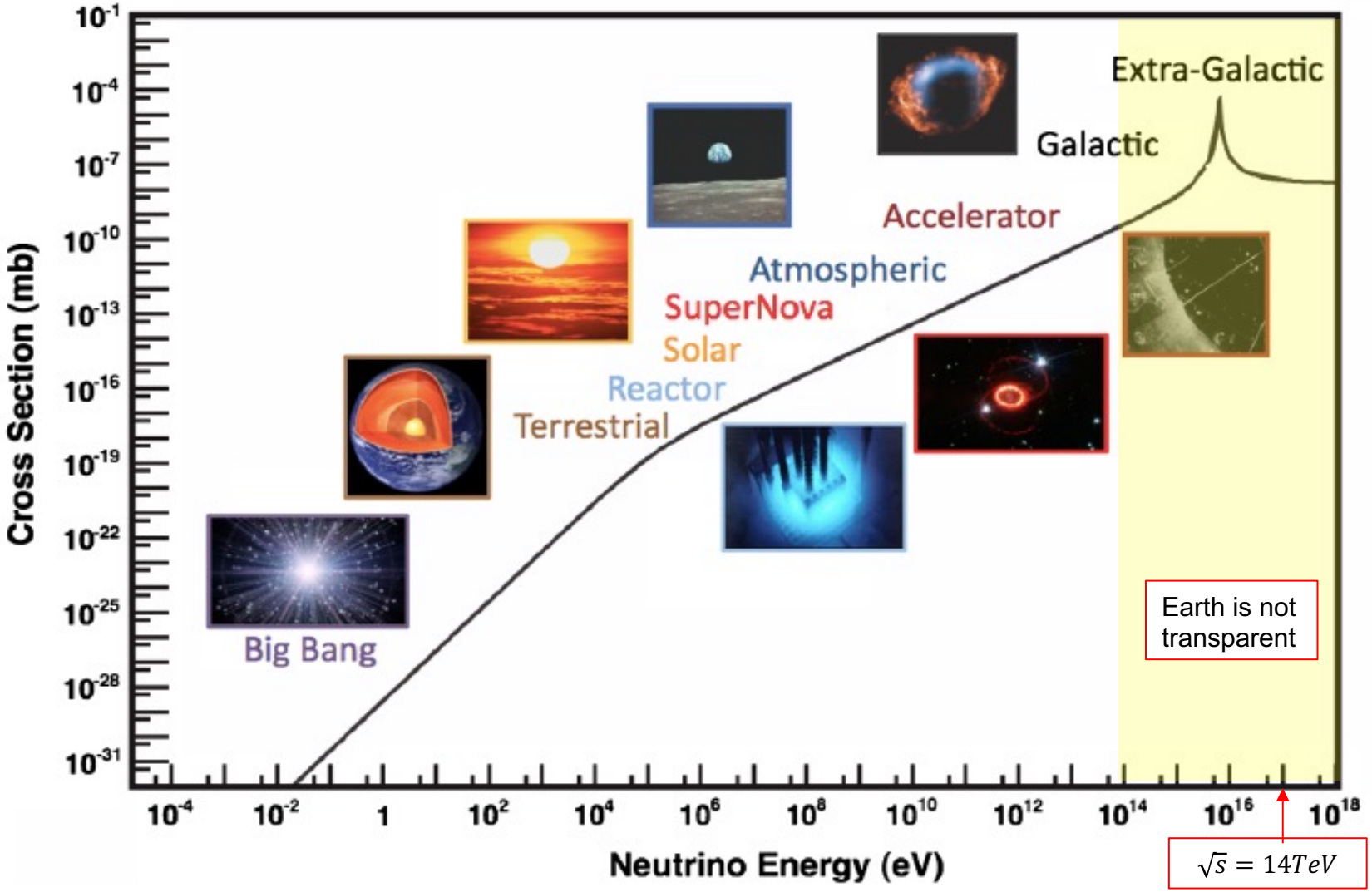
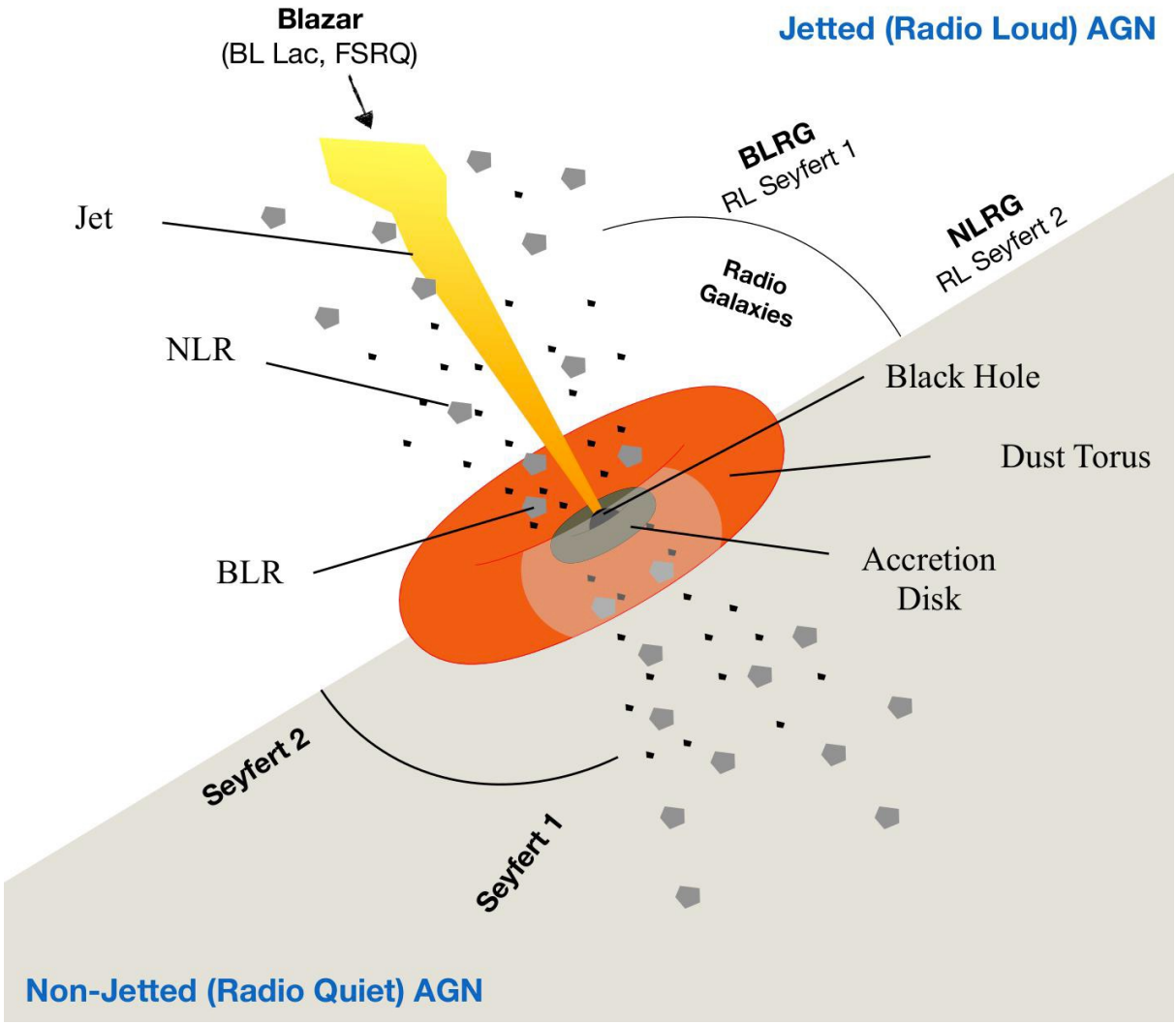
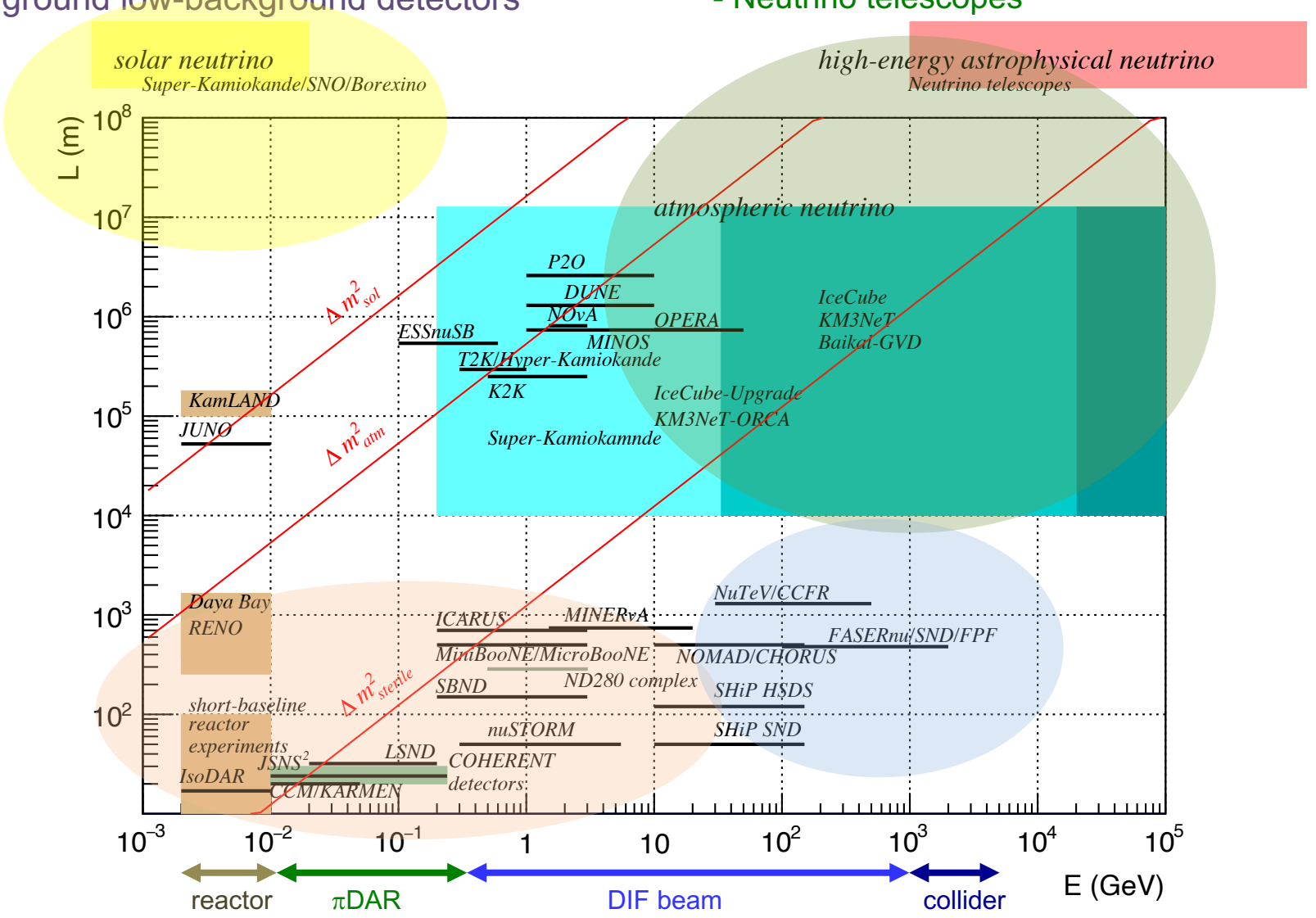


1. Active Galactic Nuclei (AGNs)



Low energy, long propagation experiments
- Underground low-background detectors

High energy, long propagation experiments
- Neutrino telescopes



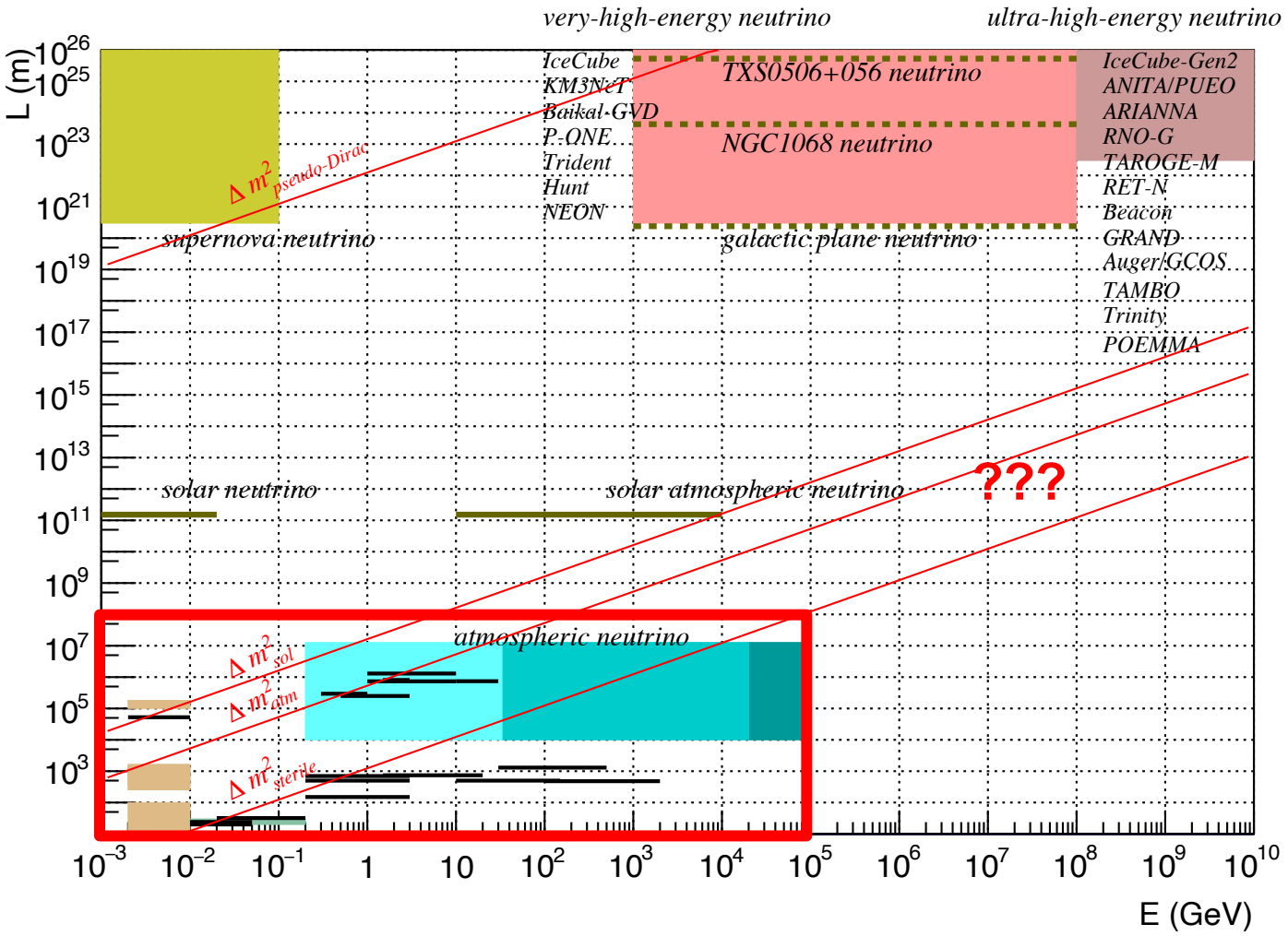
High intensity, high precision experiments
- Short-baseline experiments

High energy, high precision experiments
- Collider neutrino experiments

Neutrino 2024, https://agenda.infn.it/event/37867/contributions/234025/
Snowmass, JHEA36(2022)55

Low energy, long propagation experiments
- Underground low-background detectors

High energy, long propagation experiments
- Neutrino telescopes



Astrophysical neutrinos (both low and high energy) have sensitivity to pseudo-Dirac neutrinos

2. High-Energy Astrophysical Neutrinos

Many planned experiments targeting PeV-EeV neutrinos

Energy Range	Experiment	Technology	Detected Flavor	Ref.
$\lesssim 10^3$ GeV	JUNO	Liquid scintillator	All Flavors	[234]
$\lesssim 10^3$ GeV	DUNE	LArTPC	All Flavors	[671]
$\lesssim 10^3$ GeV	THEIA	WbLS	All Flavors	[486]
$\lesssim 10^3$ GeV	Super-Kamiokande	Gd-loaded Water C	All Flavors	[645]
$\lesssim 10^4$ GeV	Hyper-Kamiokande	Water Cherenkov	All Flavors	[483]
$\lesssim 10^5$ GeV	ANTARES	Sea-Water Cherenkov	ν_μ, $\bar{\nu}_\mu$ (CC)	[672]
$\lesssim 10^6$ GeV	IceCube/IceCube-Gen2	Ice Cherenkov	All Flavors	[433, 673]
$\lesssim 10^6$ GeV	KM3NeT	Sea-Water Cherenkov	All Flavors	[674]
$\lesssim 10^6$ GeV	Baikal-GVD	Lake-Water Cherenkov	All Flavors	[675]
$\lesssim 10^6$ GeV	P-ONE	Sea-Water Cherenkov	All Flavors	[676]
$1 - 100$ PeV	TAMBO	Earth-skimming WC	ν_τ, $\bar{\nu}_\tau$ (CC)	[677]
$\gtrsim 1$ PeV	Trinity	Earth-skimming Image	ν_τ, $\bar{\nu}_\tau$ (CC)	[678]
$\gtrsim 10$ PeV	RET-N	Radar echo	All Flavors	[679]
$\gtrsim 10$ PeV	IceCube-Gen2	In-ice Radio	All Flavors	[433]
$\gtrsim 10$ PeV	ARIANNA-200	On-ice Radio	All Flavors	[680]
$\gtrsim 20$ PeV	POEMMA	Space Air-shower Image	ν_τ, $\bar{\nu}_\tau$ (CC)	[681]
$\gtrsim 100$ PeV	RNO-G	In-ice Radio	All Flavors	[682]
$\gtrsim 100$ PeV	ANITA/PUEO	Balloon Radio	All Flavors	[683, 684]
$\gtrsim 100$ PeV	Auger/GCOS	Earth-skimming WC	ν_τ, $\bar{\nu}_\tau$ (CC)	[685, 686]
$\gtrsim 100$ PeV	Beacon	Earth-skimming Radio	ν_τ, $\bar{\nu}_\tau$ (CC)	[687]
$\gtrsim 100$ PeV	GRAND	Earth-skimming Radio	ν_τ, $\bar{\nu}_\tau$ (CC)	[688]