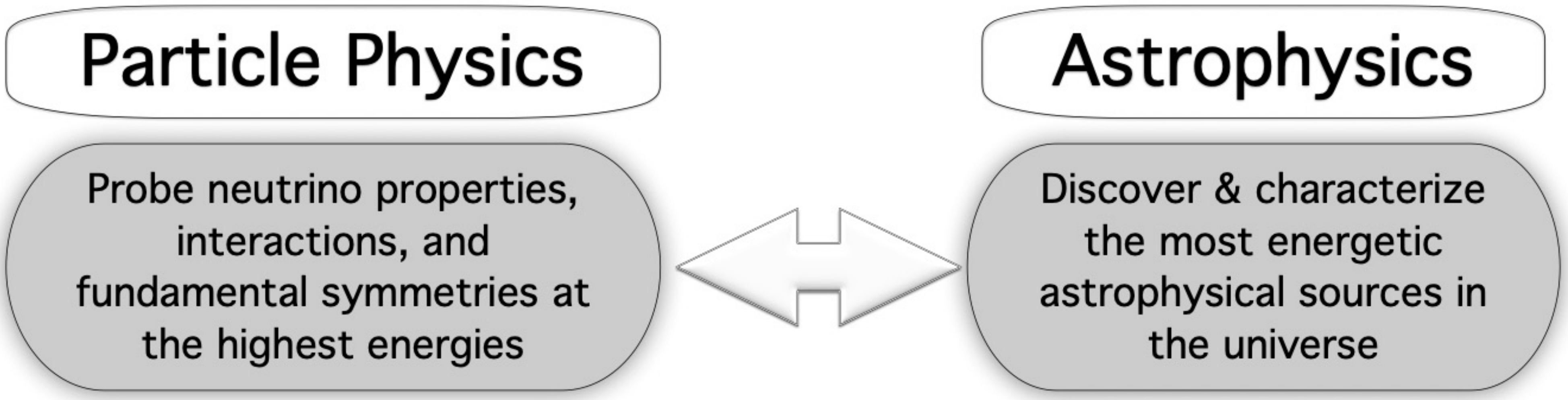
Neutrino astrophysics input (from the Uppsala perspective)


Particle Physics
Probe neutrino properties, interactions, and fundamental symmetries at the highest energies
Astrophysics
Discover & characterize the most energetic astrophysical sources in the universe

- Cosmic sources provide a beam of neutrinos at energies thousandfold higher and over vaster distances than accelerator experiments, allowing us to probe fundamental particle physics in ways not otherwise possible

- Astroparticle Physics links fundamental particle physics to high-energy phenomena of our Universe. For example, astrophysical neutrinos allow a glimpse inside the most extreme astrophysical environments and identify the particle physics processes that are central to the evolution of our Universe.

- Sweden was a founding member of IceCube (and precursor AMANDA), is a key player in RNO-G and the IceCube Upgrade, and is committed to the envisioned IceCube-Gen2.

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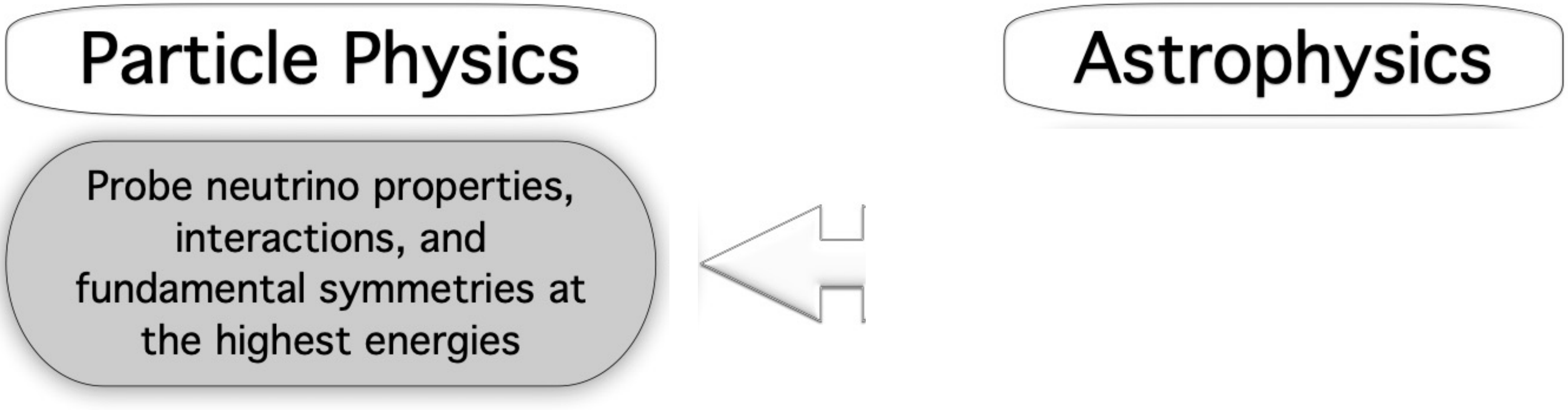
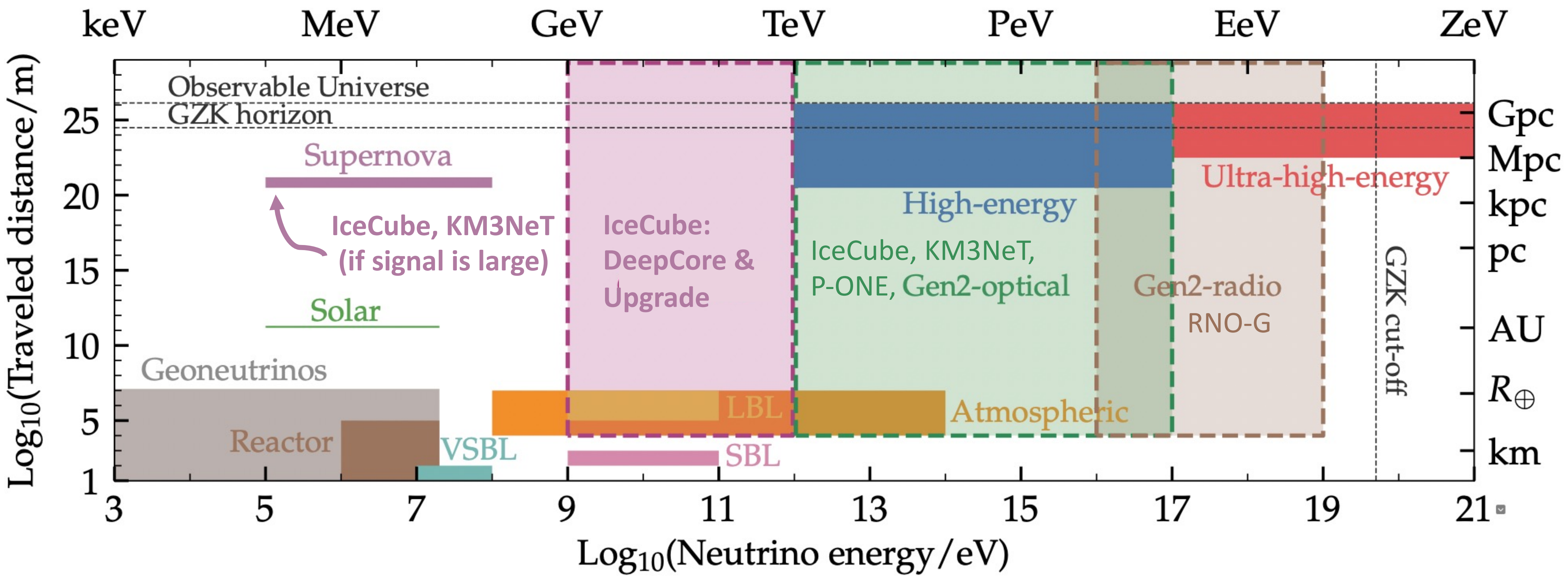
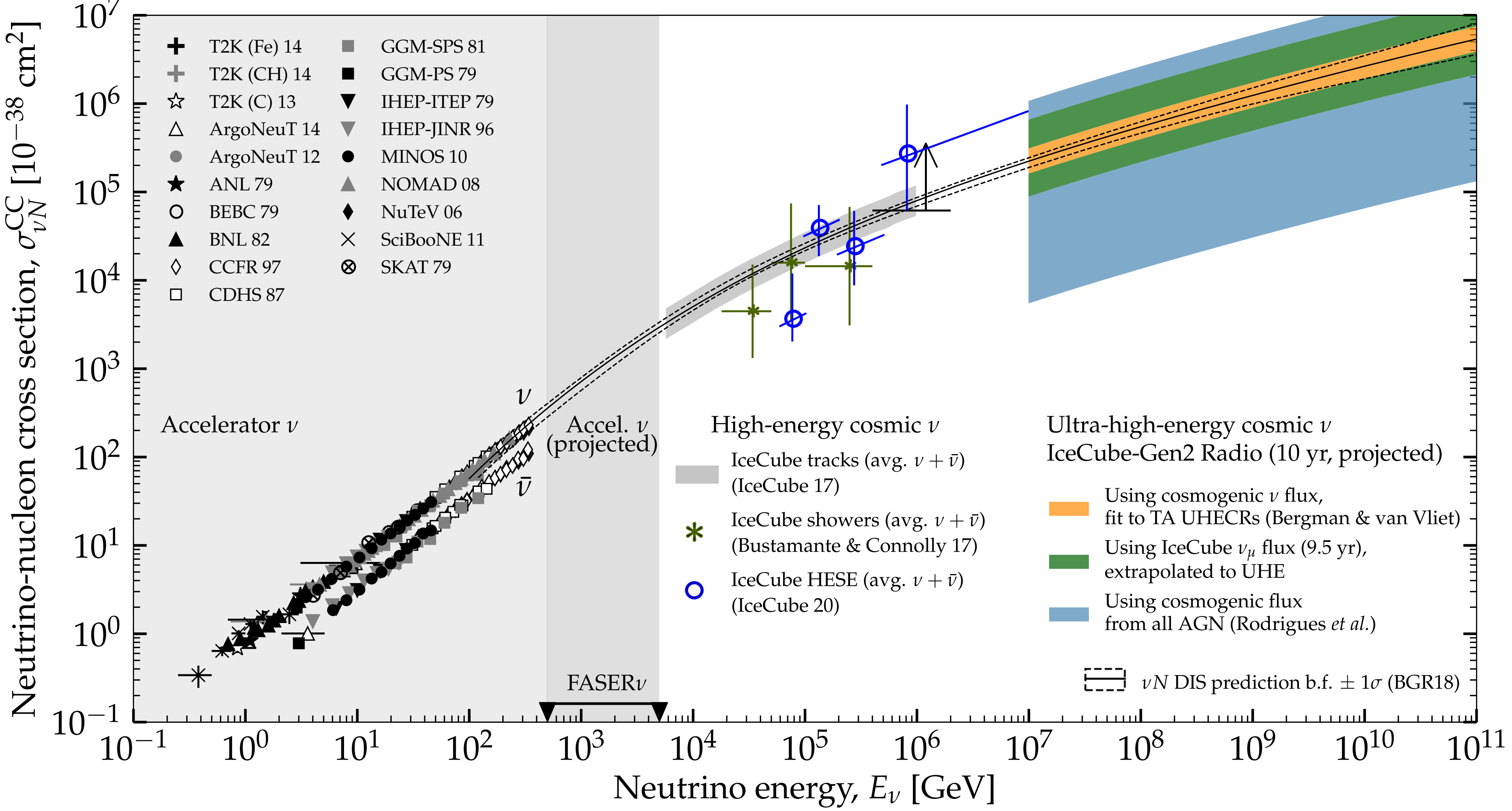




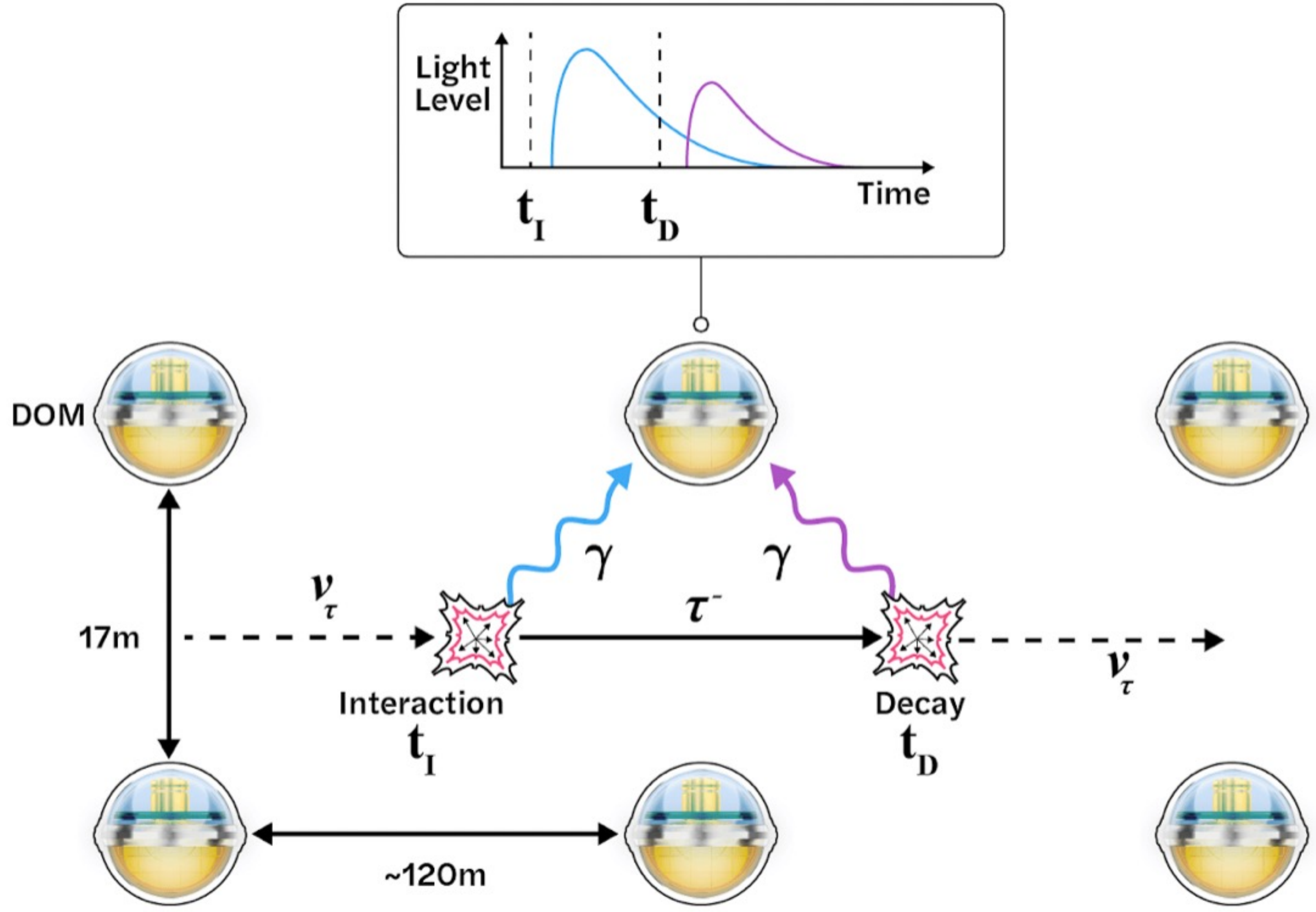
keV
MeV
GeV
TeV
PeV
EeV
ZeV
Observable Universe
GZK horizon
Supernova
IceCube, KM3NeT
(if signal is large)
IceCube:
DeepCore &
Upgrade
High-energy
IceCube, KM3NeT,
P-ONE, Gen2-optical
Gen2-radio
RNO-G
Ultra-high-energy
GZK cut-off
Solar
Geoneutrinos
Reactor
VSBL
LBL
SBL
Atmospheric
Gpc
Mpc
kpc
pc
AU
$R_\oplus$
km
Log10(Traveled distance / m)
Log10(Neutrino energy / eV)

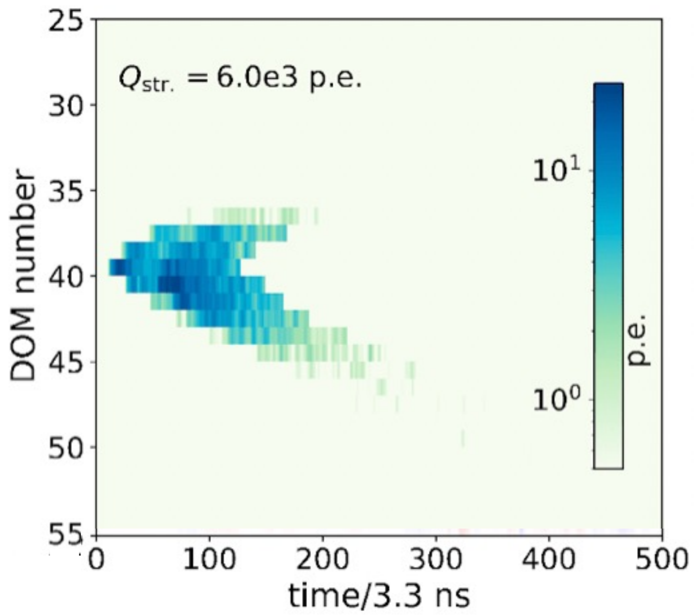
Highlight 1: High energy neutrino cross sections

Modified from Valera, Bustamante, **Glaser** et al. *JHEP* 06 (2022) 105



Highlight 2: Measuring tau neutrinos at high energy



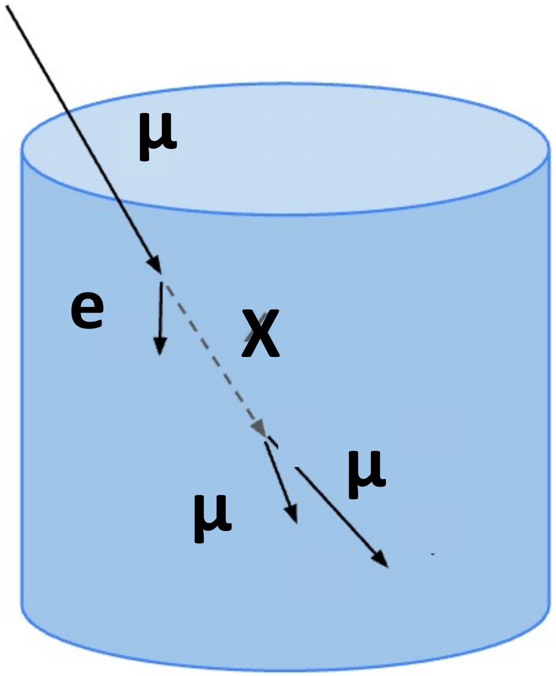


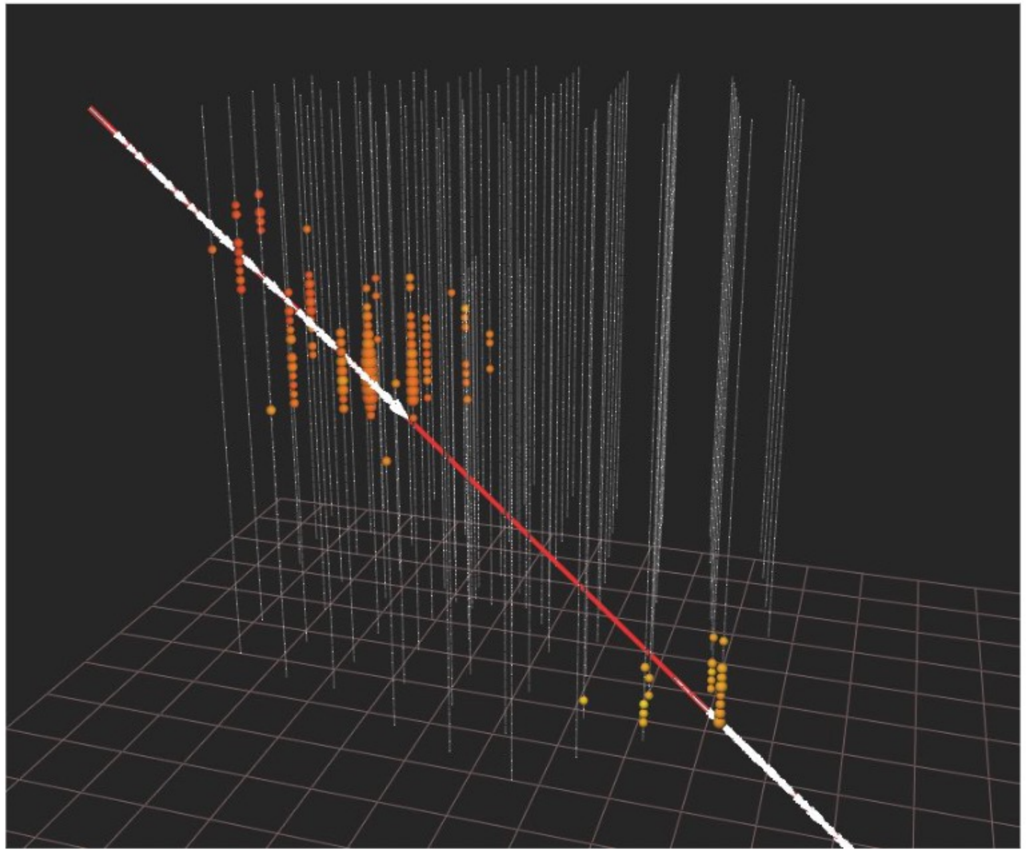
IceCube Collaboration, Phys.Rev.Lett. 132 (2024) 15, 151001

Measuring oscillations at cosmic baselines

Highlight 3: Searches for exotic particles

Searches for long-lived particles in IceCube
(local activity here in Uppsala)





(Simulation)

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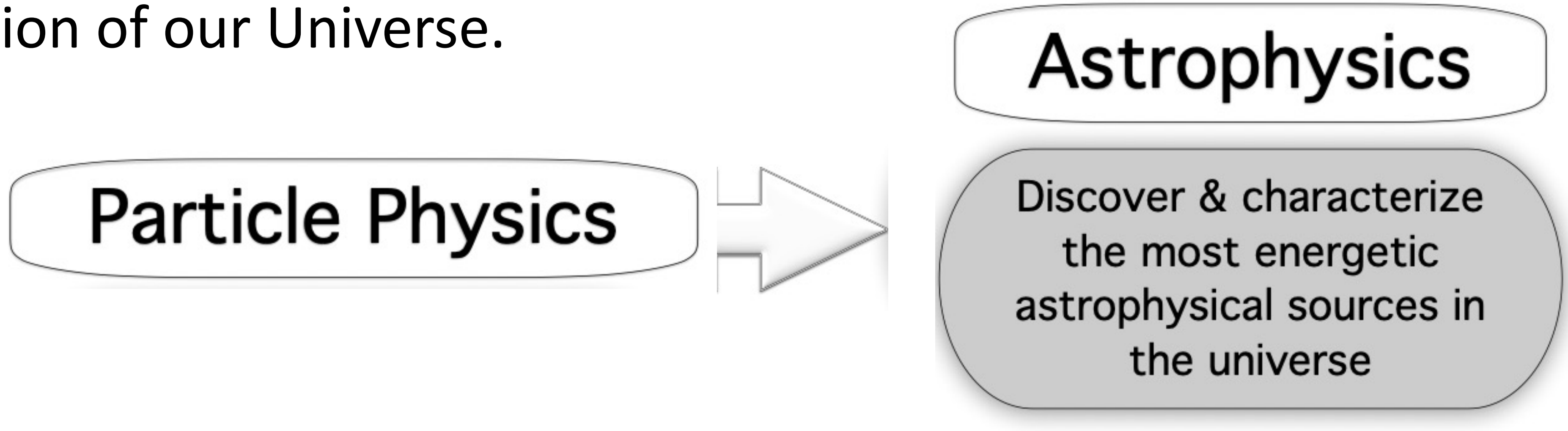


Neutrino astrophysics: particle physics using Nature's accelerators

$$\pi^0 \rightarrow \gamma + \gamma$$

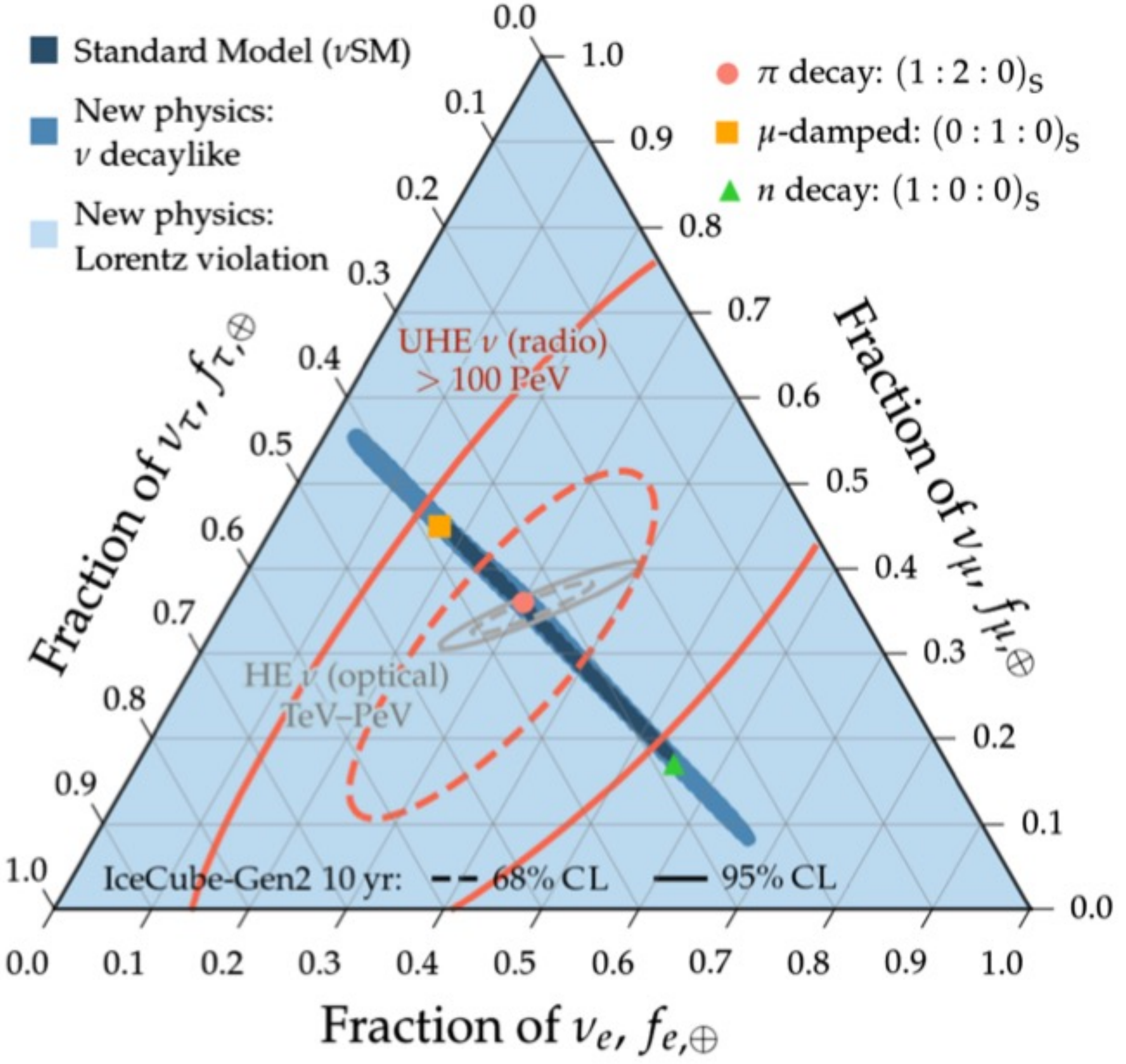
$$\mathbf{p + p/\gamma \rightarrow X + \{\pi^+, \pi^-, \pi^0\}}$$

$$\pi^{+/-} \rightarrow \mu^{+/-} + \nu_\mu$$

$$\mu^{+/-} \rightarrow e^{+/-} + \nu_e + \nu_\mu$$

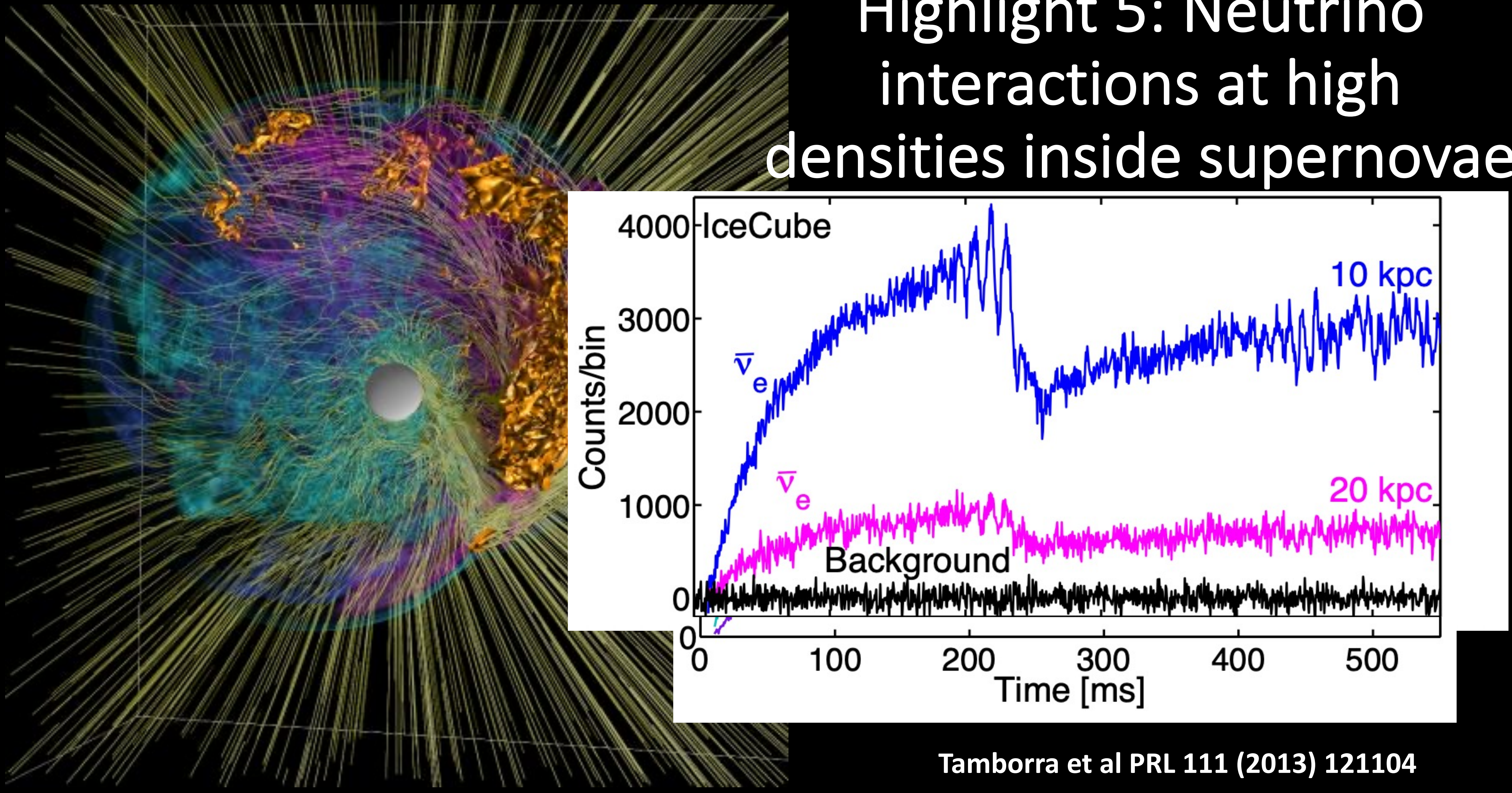
Highlight 4: Measuring particle production in nature's accelerators

Different production scenarios, new physics can produce different flavour content of the signal



Coleman, ***Ericsson***, ***Glaser***, *Bustamante, PRD 110 023044 (2024)*

Highlight 5: Neutrino interactions at high densities inside supernovae



Tamborra et al PRL 111 (2013) 121104

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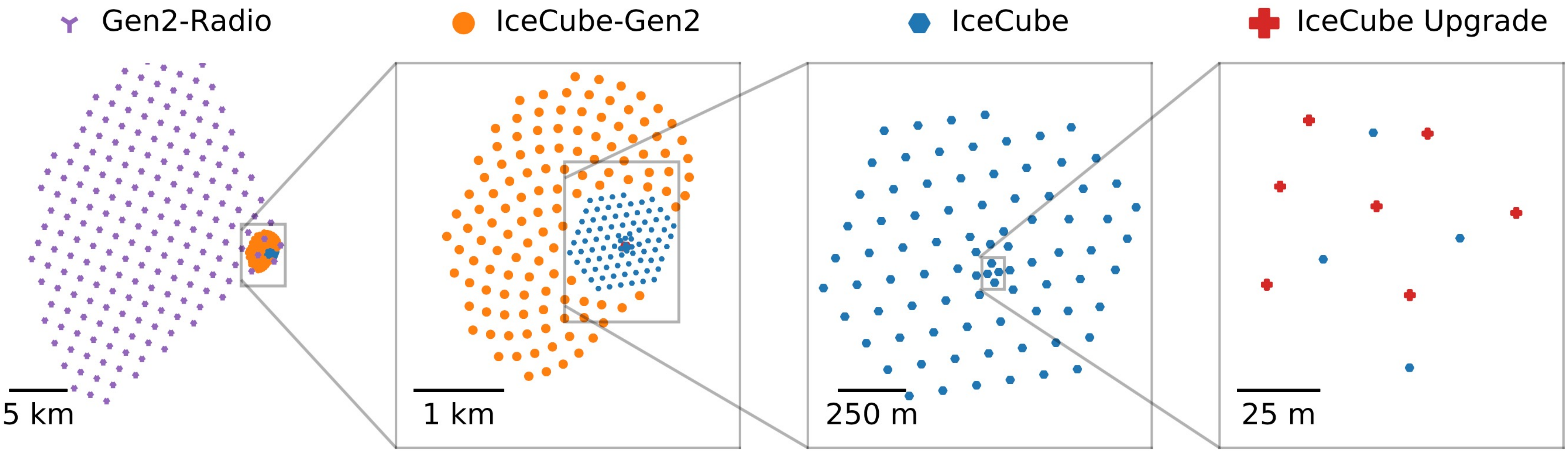
IceCube, Upgrade, and IceCube-Gen2: A multi-energy (GeV-EeV, and MeV bursts), multi-instrument facility (Optical, radio, surface)



Operating for over 10 years

2025/26

Lead of Gen2-radio working group (Glaser)

Radio DAQ development (UU)

Autonomous power systems/windgen development (Hallgren/UU)

Gen2 coordination committee (O'Sullivan)

Chair of publication committee (O'Sullivan)

Former spokesperson (Botner)

Low energy astro WG lead (O'Sullivan)

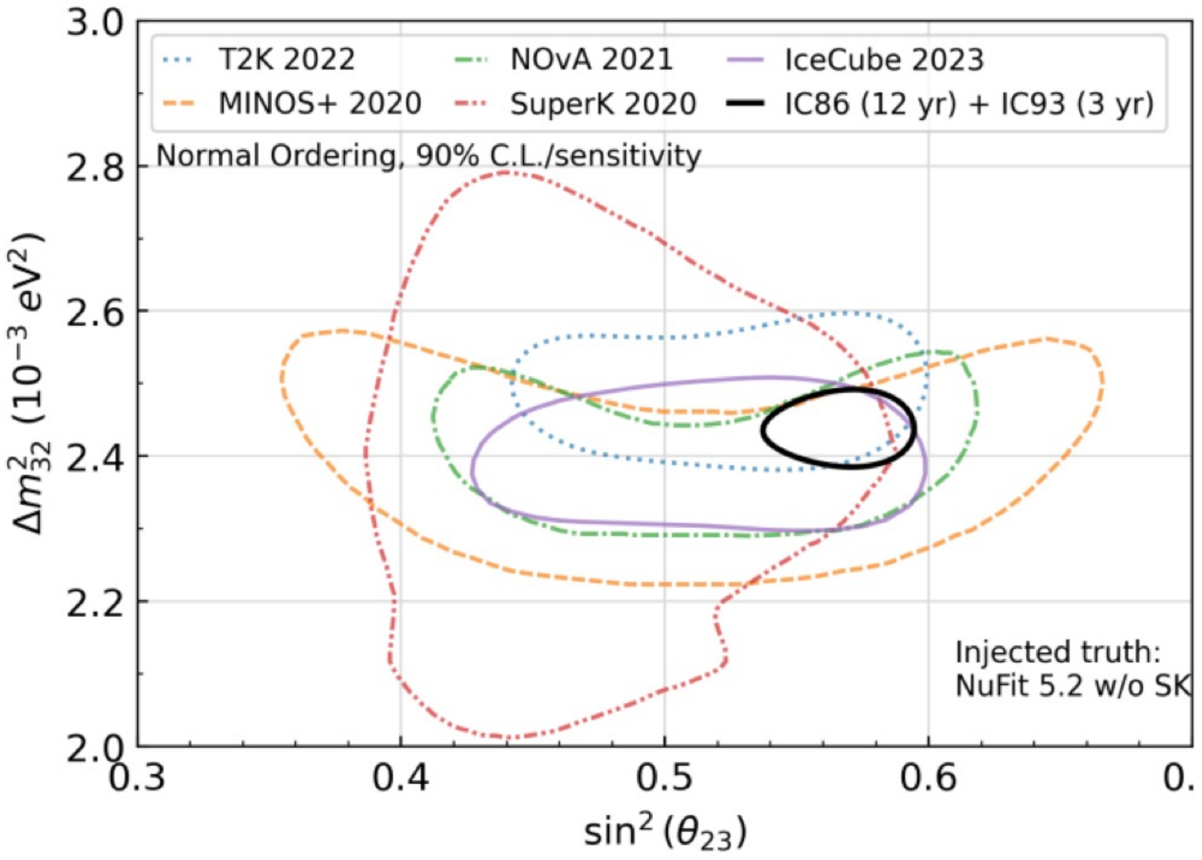
BSM WG lead (de los Heros)

Reco WG lead (Glüsenkamp)

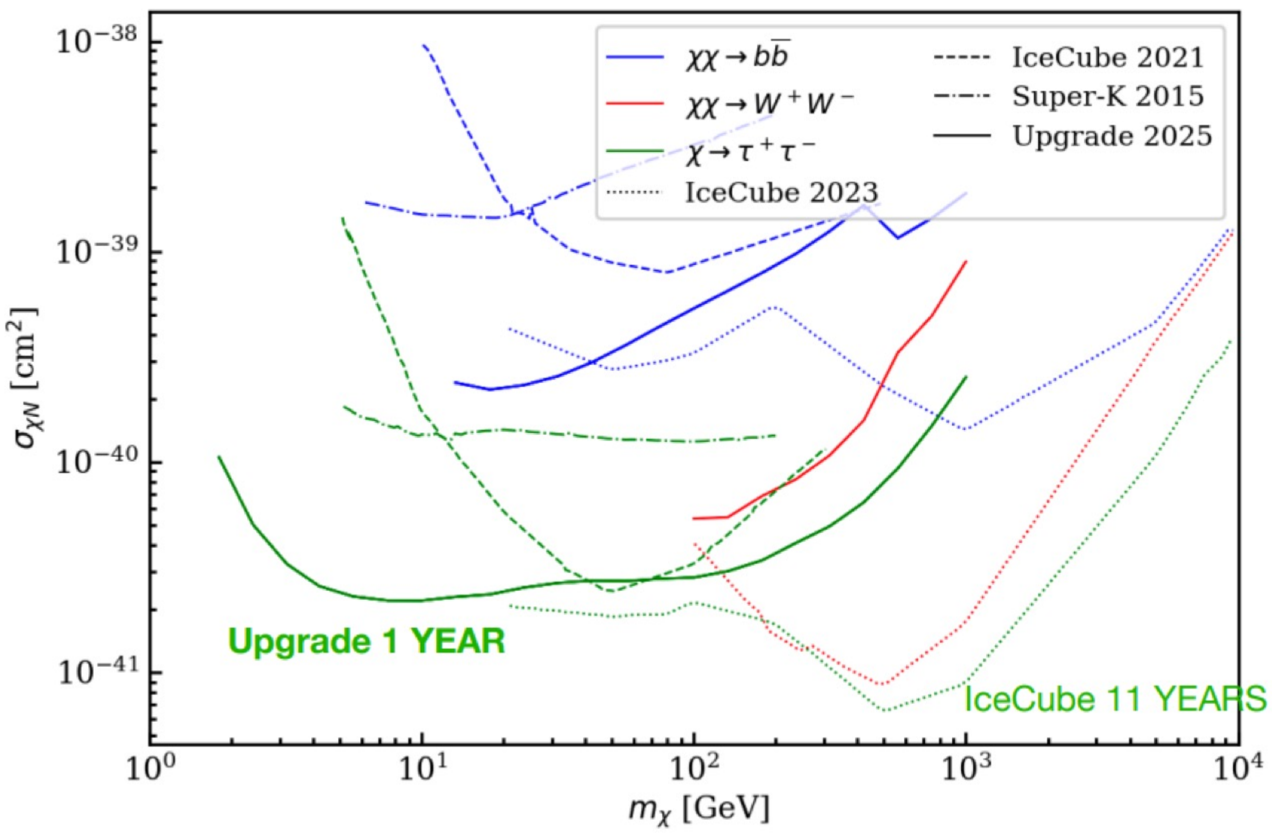
Development of an ice calibration device UU/SU (*Sweden camera*)

IceCube-Upgrade

Mass spectrum/mixing/ordering of neutrinos?

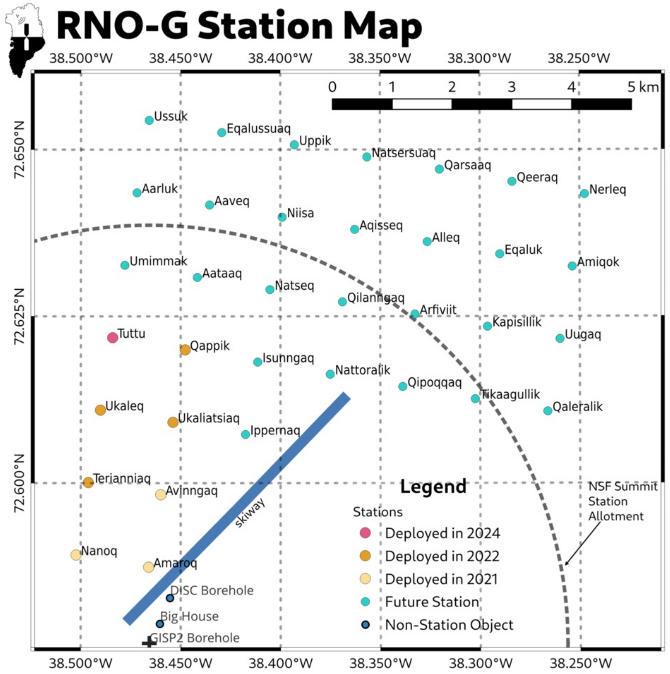


What is the nature of dark matter?



Radio Neutrino Observatory in Greenland (RNO-G) – a testbed for IceCube-Gen2

- Construction of RNO-G ongoing until 2028
- UU hardware contributions: power system, windgen, batteries, new DAQ system



Air shower and particle physics

- Test of prompt muon (charm) production (non-perturbative regime of quantum chromodynamics)
- Test of hadronic interaction in forward regime

*D. García-Fernández, A. Nelles, **C. Glaser**, PRD **102** 083011 (2020)*

***C. Glaser**, D. García-Fernández and A. Nelles, PoS(ICRC2021)1231,*

*L. Pyras, **C. Glaser**, S. Hallmann, A. Nelles, JCAP 10(2023)043*

***A. Coleman, C. Glaser**, R. Rice-Smith, S. Barwick, D. Besson, arXiv:2410.08615*

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i) Physics potential
ii) Long-term perspective
} Shown in the above slides

iii) Financial and human resources: requirements and effect on other projects

iv) Timing

v) Careers and training

vi) Sustainability

i) Physics potential

ii) Long-term perspective

iii) Financial and human resources: requirements and effect on other projects

iv) Timing Neutrino telescopes like IceCube-Gen2 are expected on a sooner timescale than future accelerators, could provide a bridge to advance particle physics while the next accelerators are developed

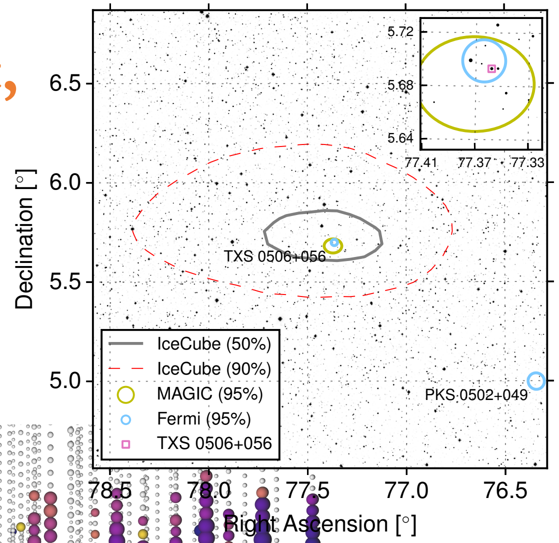
v) Careers and training

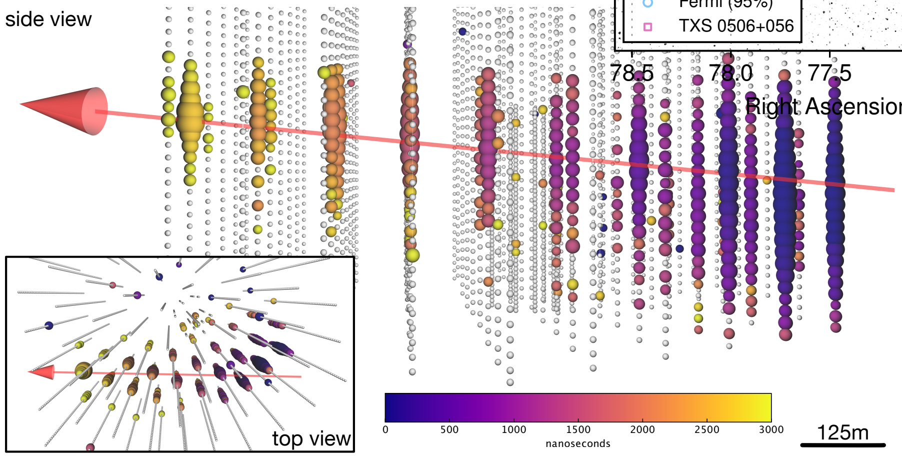
Our research lends itself particularly well to creating knowledge and training students in skills that are useful to society at large. We provide hands-on training with hardware, as well as experience with data analysis and deep learning techniques.

vi) Sustainability Development of tools for neutrino telescopes can drive advancements in sustainable energy (eg. Wind power in extreme environments). We also make important measurement in other fields such as glaciology and climate science.

First sources of high energy neutrinos

2017: First transient, multi-messenger source

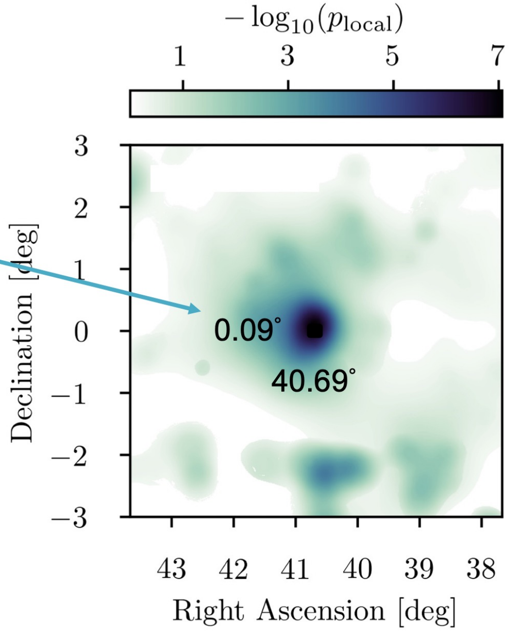




IceCube Collaboration, FERMI-LAT, MAGIC, ASAS-SN, H.E.S.S, INTEGRAL, KANATA, KISO, KAPTEYN, LIVERPOOL TELESCOPE, SUBARU, SWIFT/NUSTAR, VERITAS, VLA/17B-403, Science *361, issue 6398 (2018)*

2020: First steady-state source detected in neutrinos alone

IceCube Collaboration Science *378 (2022)*



2023: First image of the galaxy in high energy neutrinos