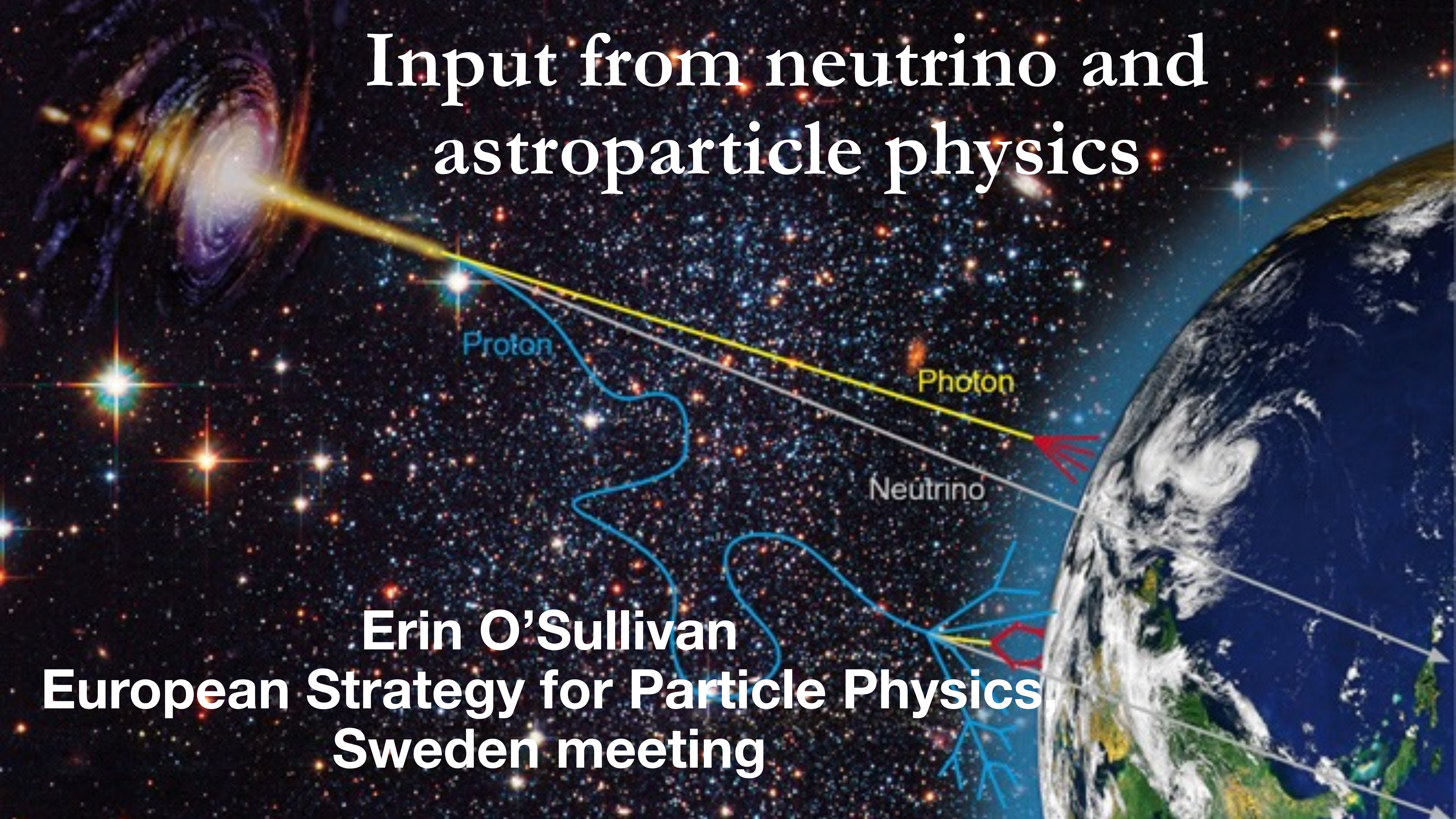
Input from neutrino and astroparticle physics



Erin O’Sullivan

European Strategy for Particle Physics, Sweden meeting

What are questions 4a-4c?

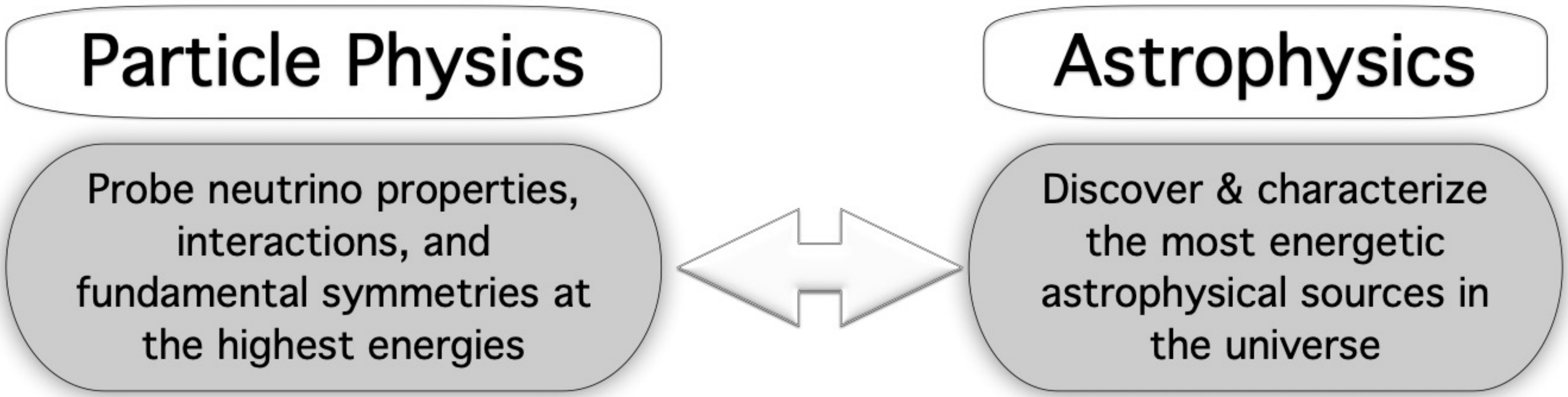
4) **The remit given to the ESG also specifies that "The Strategy update should also indicate areas of priority for exploration complementary to colliders and for other experiments to be considered at CERN and at other laboratories in Europe, as well as for participation in projects outside Europe." It would thus be most useful if the national inputs explicitly included the preferred prioritisation for non-collider projects. Specific questions to address:**

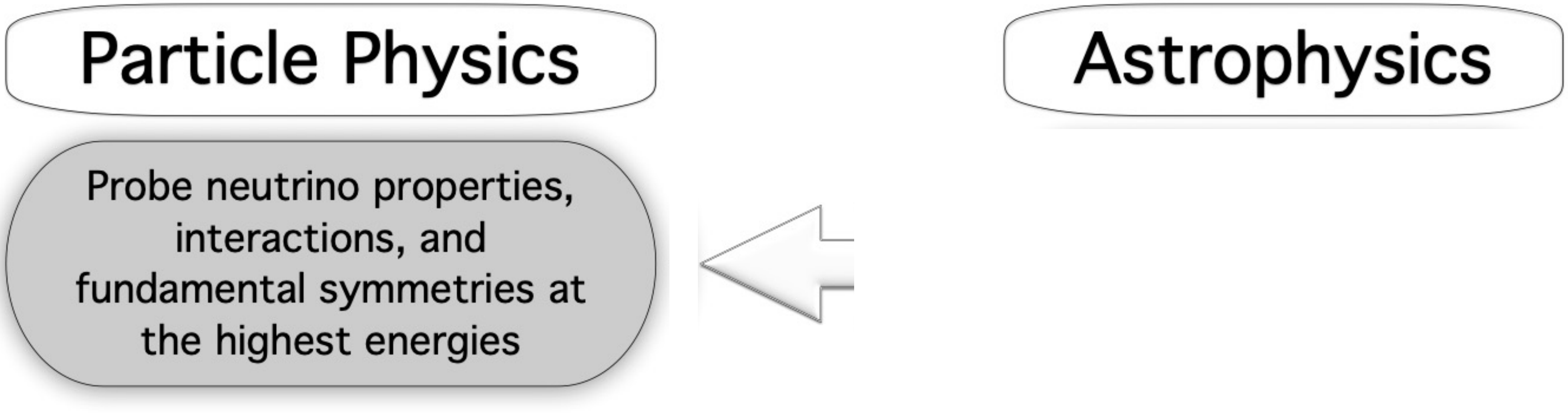
a) What other areas of physics should be pursued, and with what relative priority?

b) What are the most important elements in the response to 4a)? (The set of considerations in 3b should be used).

c) To what extent should CERN participate in nuclear physics, astroparticle physics or other areas of science, while keeping in mind and adhering to the CERN Convention? Please use the current level and form of activity as the baseline for comparisons.

In this talk, I will discuss why the particle physics community should persue astroparticle physics with high priority

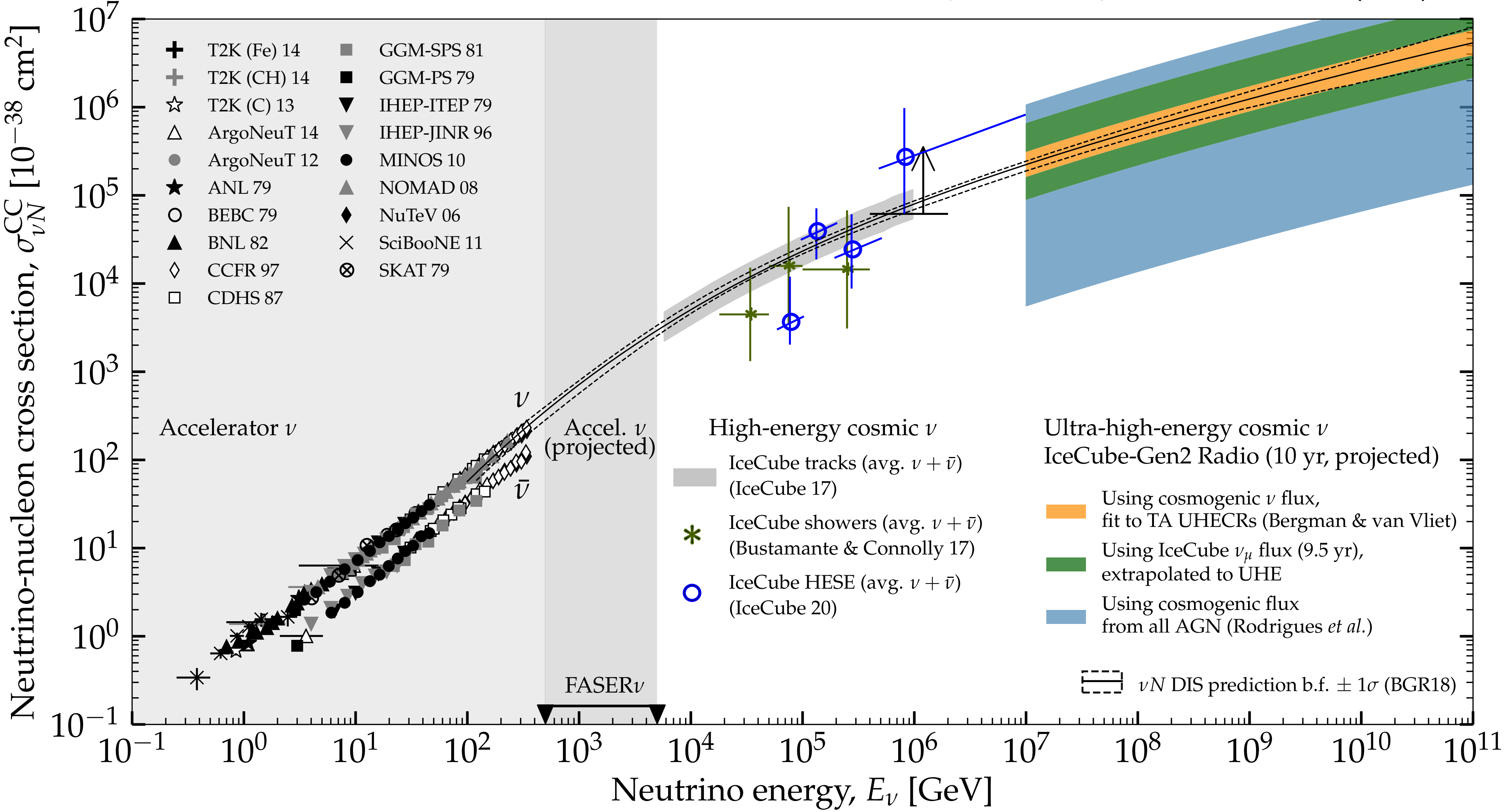

Particle Physics
Probe neutrino properties, interactions, and fundamental symmetries at the highest energies
Astrophysics
Discover & characterize the most energetic astrophysical sources in the universe



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

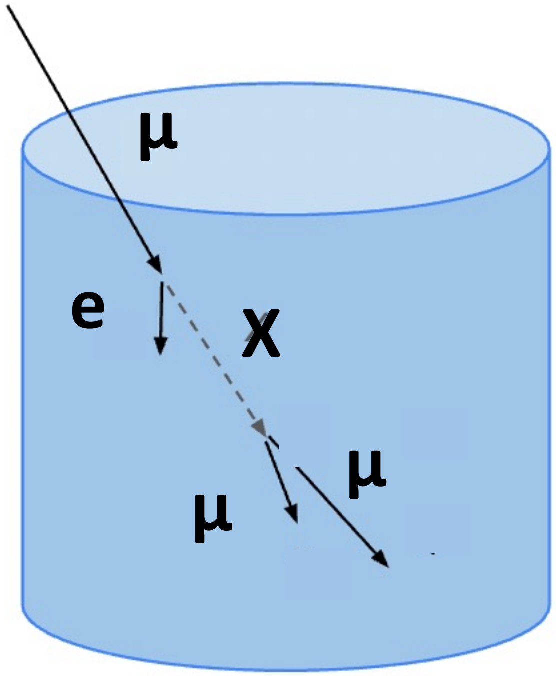
High energy neutrino cross sections

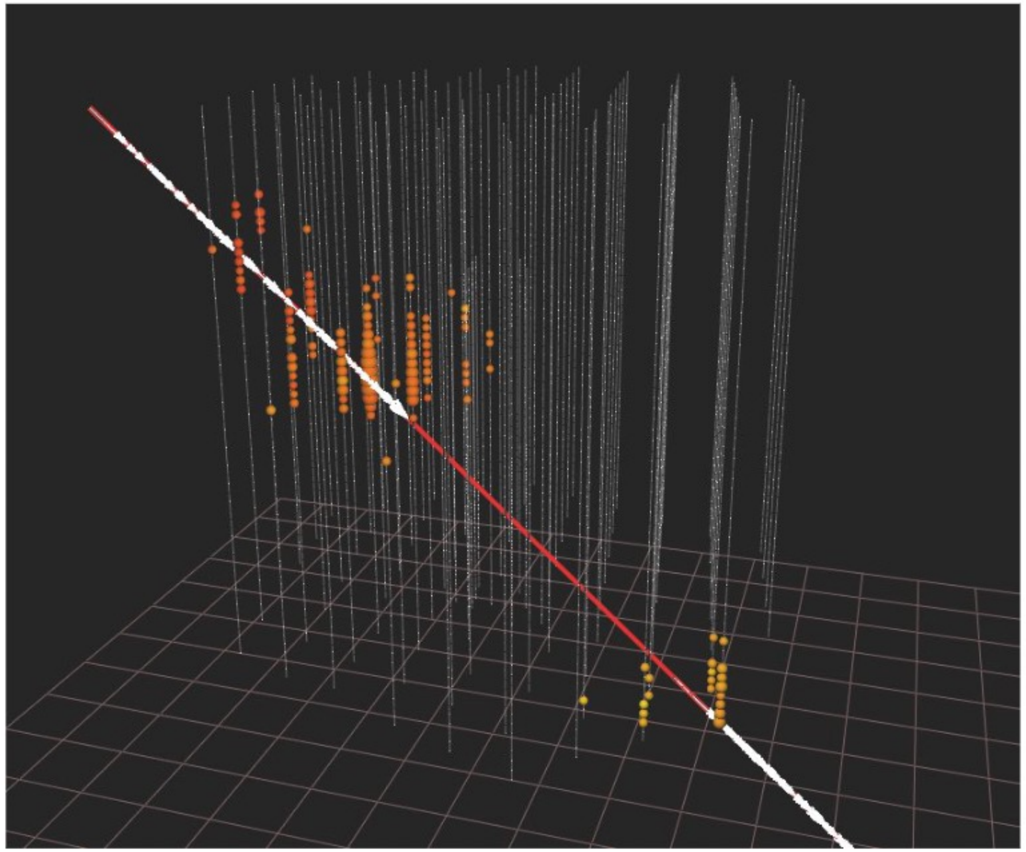
Modified from Valera, Bustamante, **Glaser** et al. *JHEP* 06 (2022) 105



Searches for exotic particles

Ex. Searches for long-lived particles
in IceCube



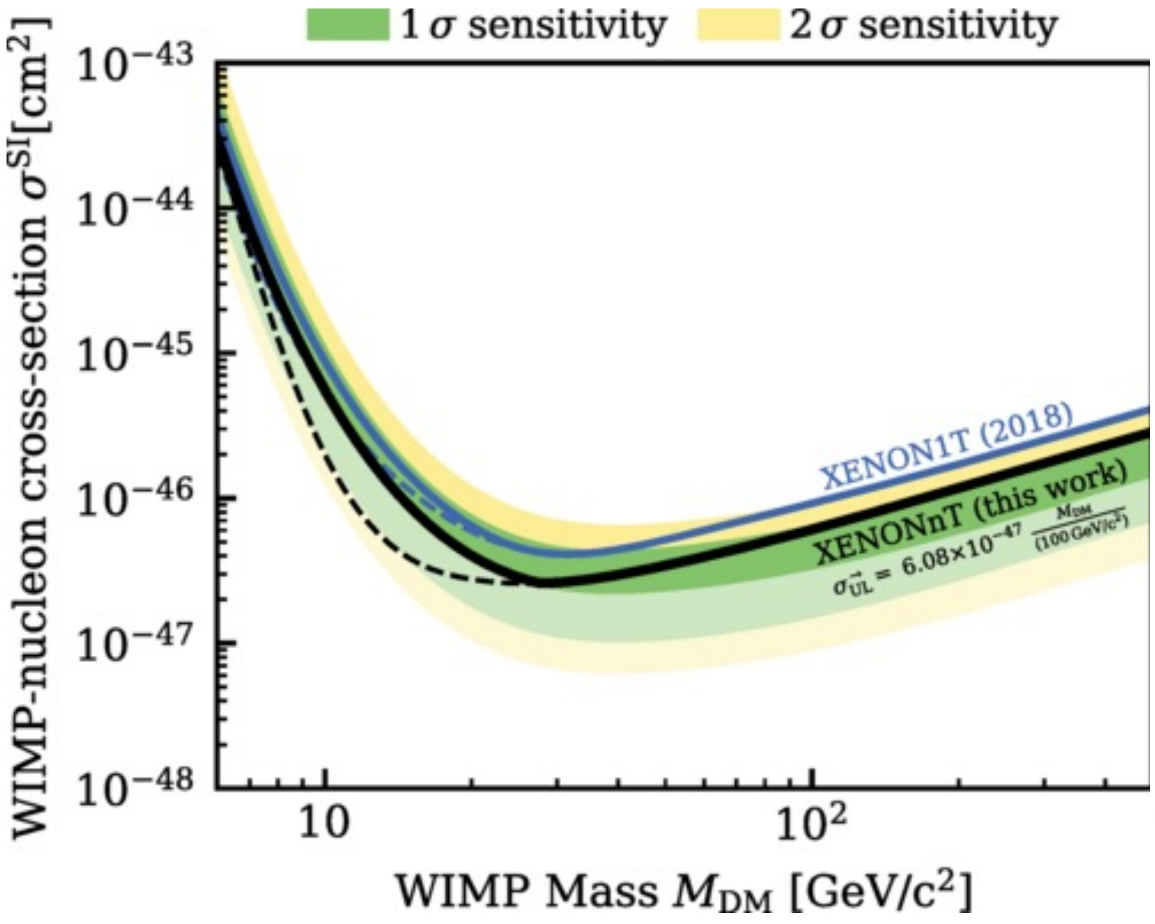


(Simulation)

Searches for astrophysical dark matter

(see Dave's talk next for LDMX)

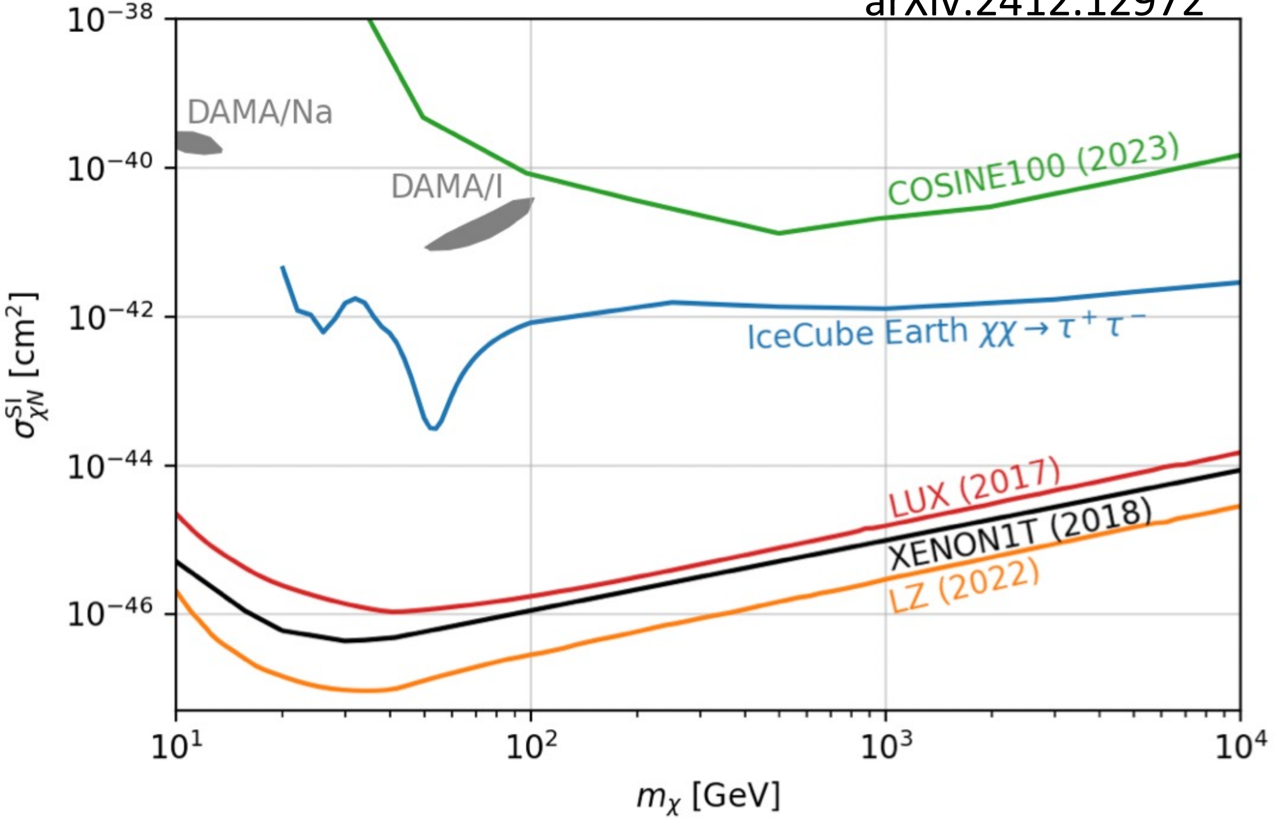
Latest results from XENONnT



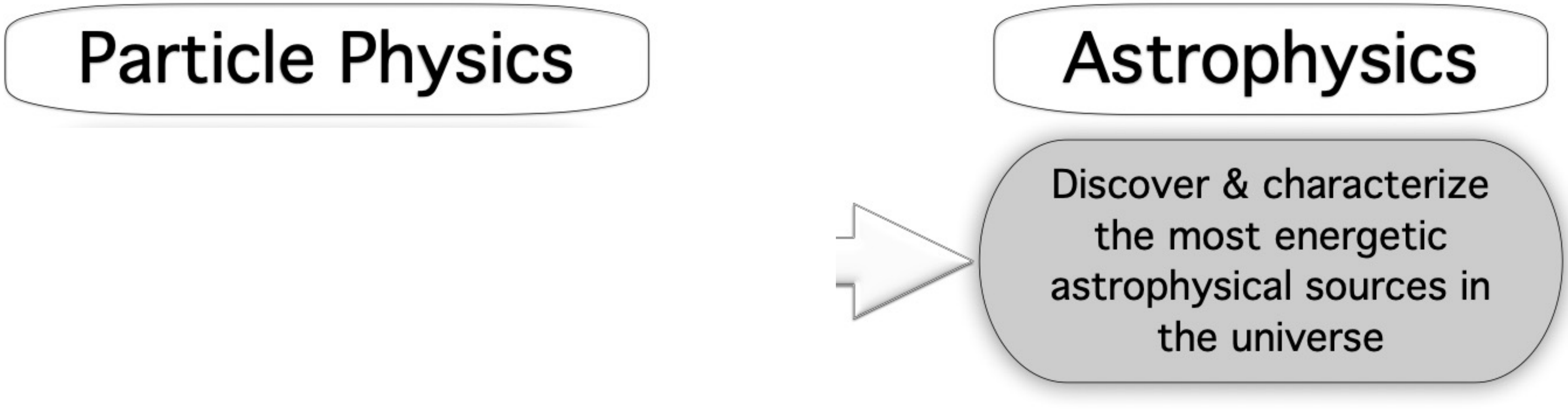
PRL **131**, 041003 (2023)

IceCube search for WIMP annihilation in Earth

arXiv:2412.12972



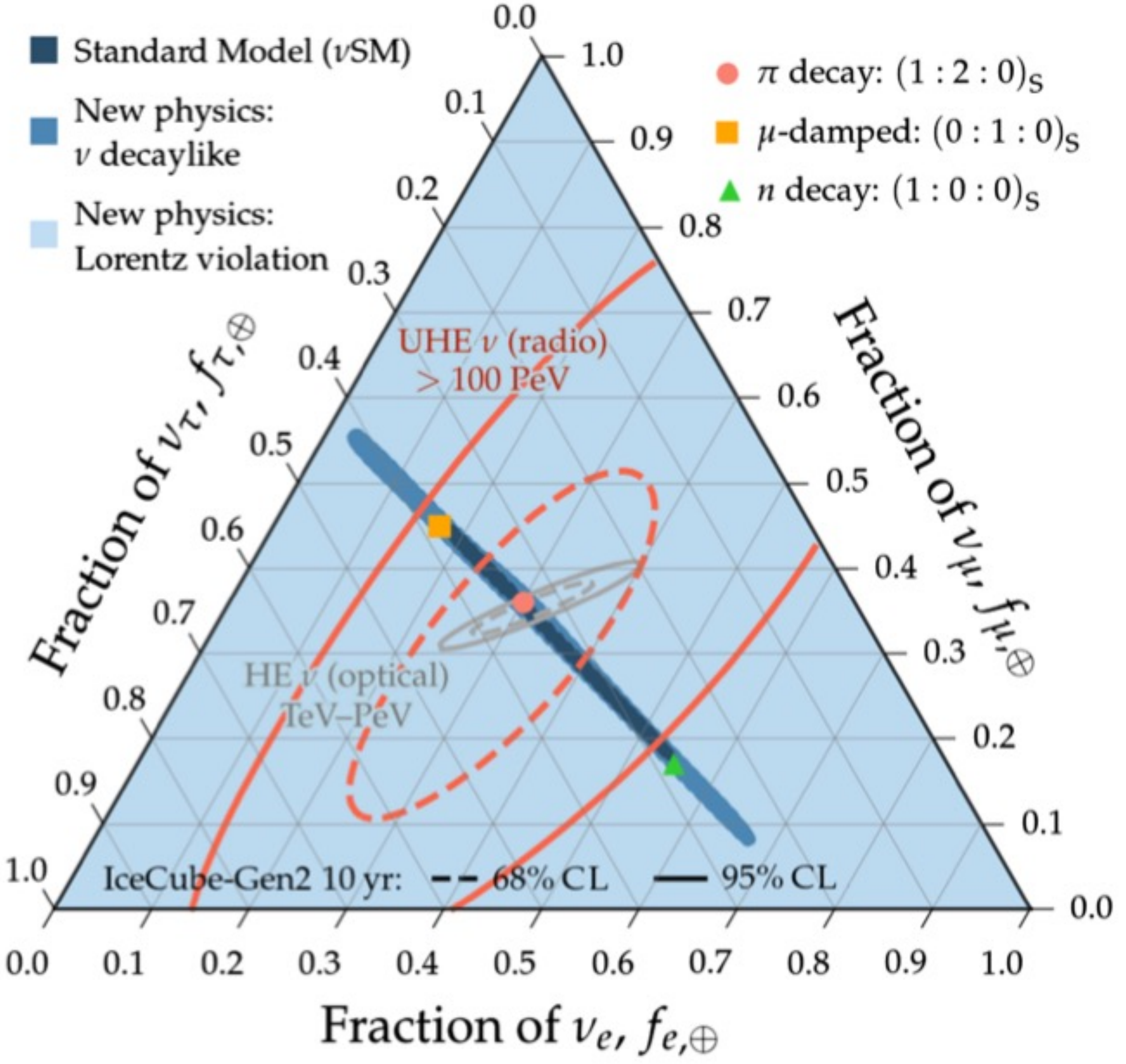
(complementary to direct detection: higher sensitivity to low velocities, also to longer timescales as Earth accumulates DM)



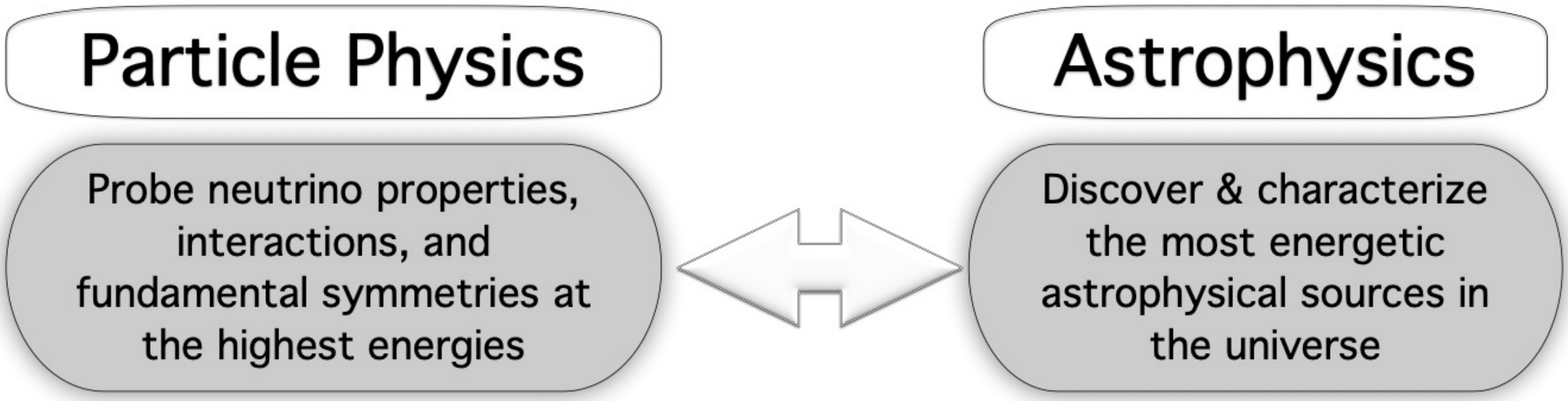
Astroparticle Physics links fundamental particle physics to high-energy phenomena of our Universe. For example, astrophysical neutrinos allow a glimpse inside the most extreme astrophysical environments and identify the particle physics processes that are central to the evolution of our Universe. Studying dark matter allows us to better understand the vast majority of matter in our Universe

Measuring particle production in nature's accelerators

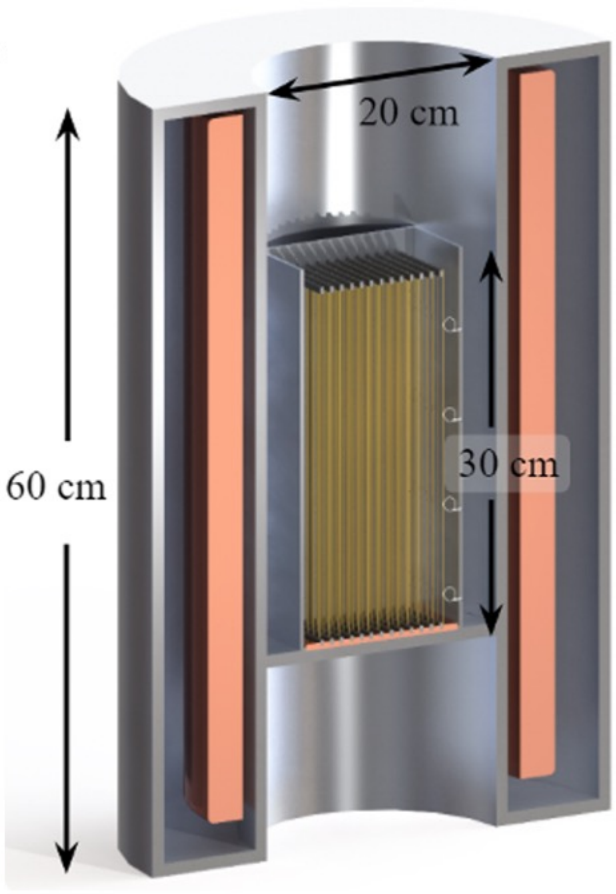
Different production scenarios, new physics can produce different flavour content of the signal



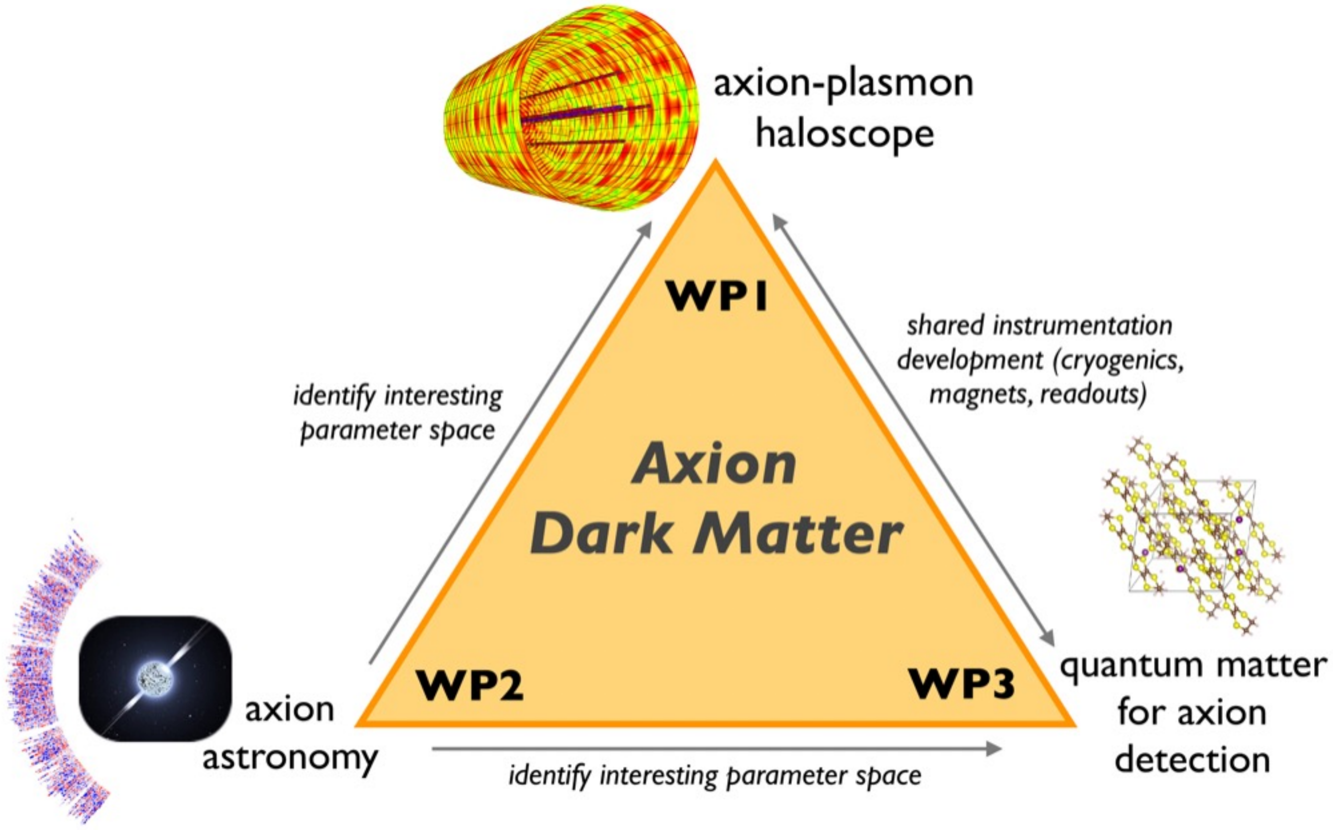
***Coleman**, **Ericsson**, **Glaser**, Bustamante, PRD 110 023044 (2024)*



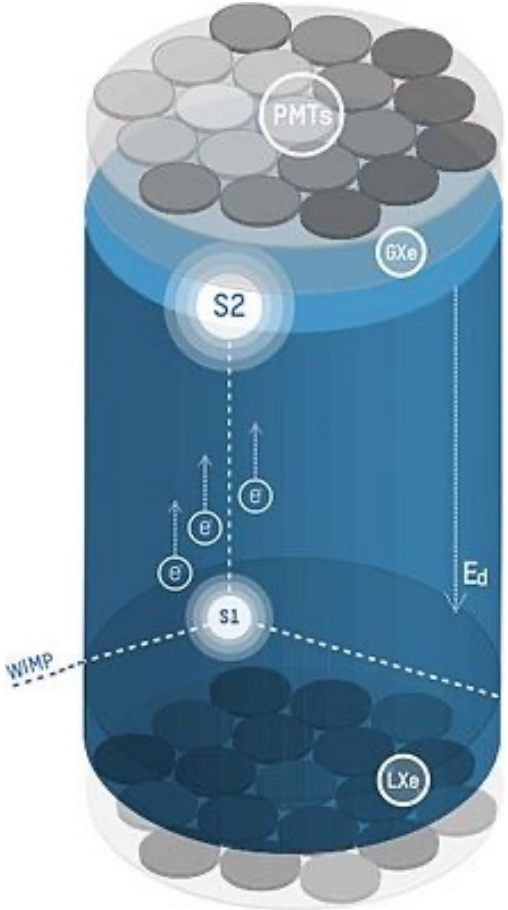
Sweden was a founding member of IceCube, is a key player in RNO-G and the IceCube Upgrade, XENON, and ALPHA, and is committed to the envisioned IceCube-Gen2. We have a strong theory community that works to advance our understanding of this field.

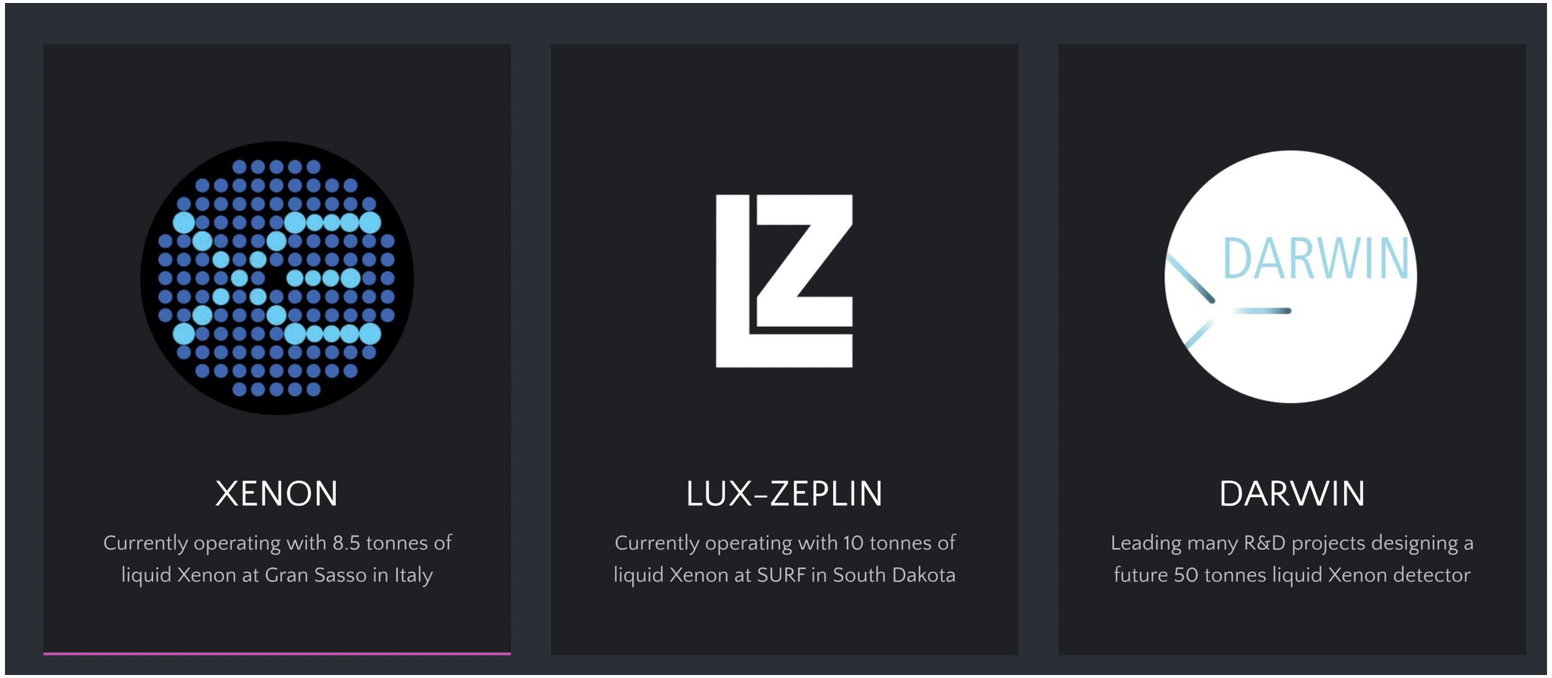


Axion telescope - ALPHA Pathfinder
https://axiondm.fysik.su.se/alpha/
https://arxiv.org/abs/2210.00017



XLZD (next gen joint effort between Xenon-based DM detecors

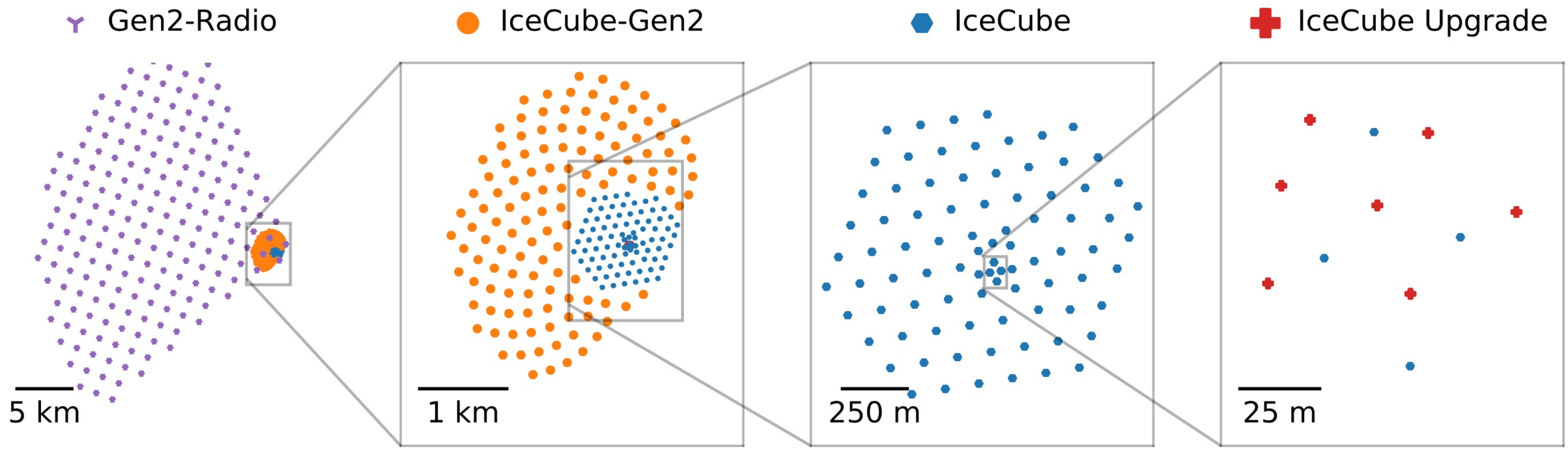




Direct dark matter detection - XENONnT

https://www.su.se/english/research/research-projects/entering-the-home-straight-for-wimp-dark-matter-xenonnt

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

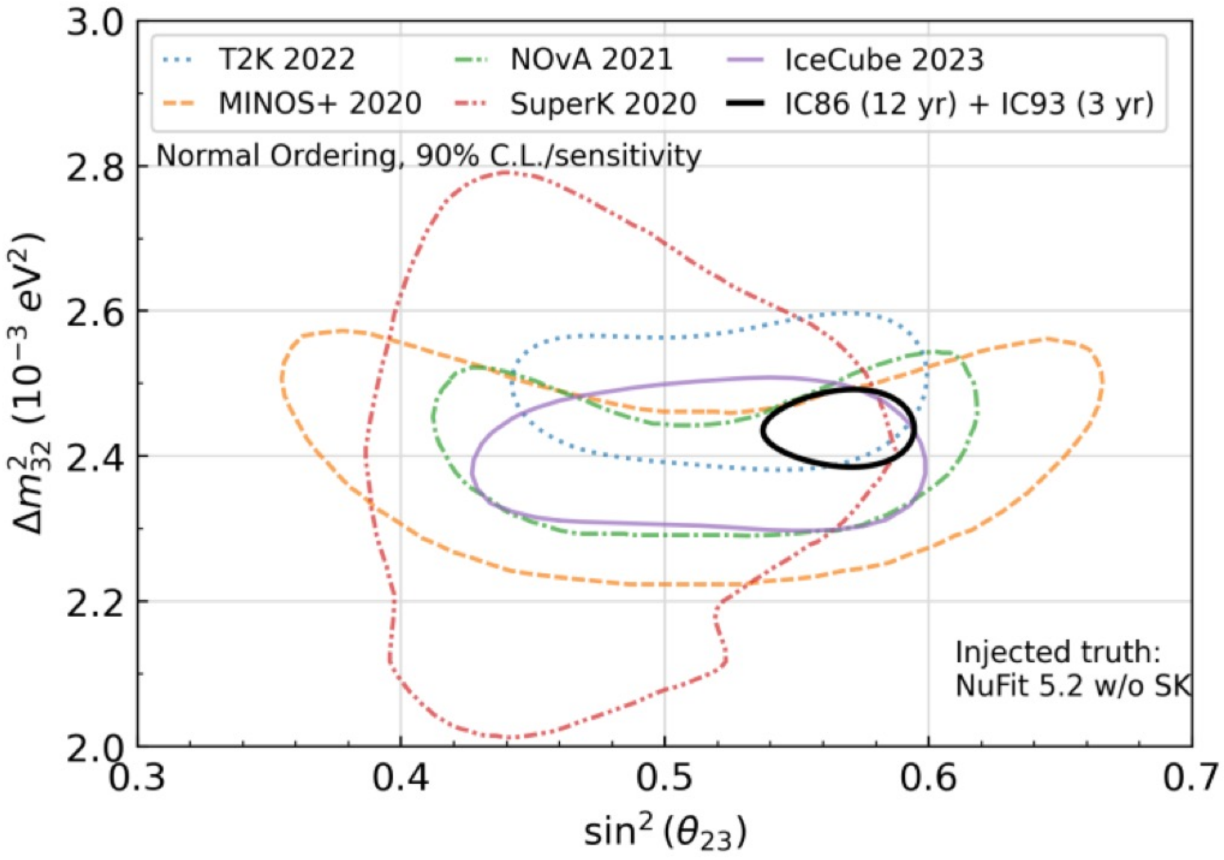


Operating for over 10 years

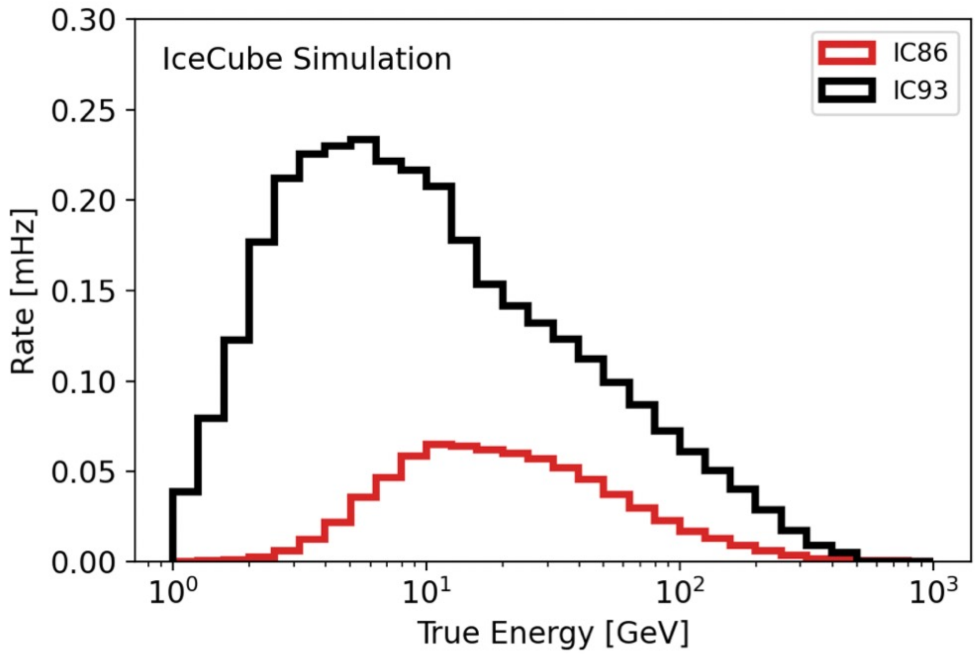
2025/26

IceCube-Upgrade

Mass spectrum/mixing/ordering of neutrinos

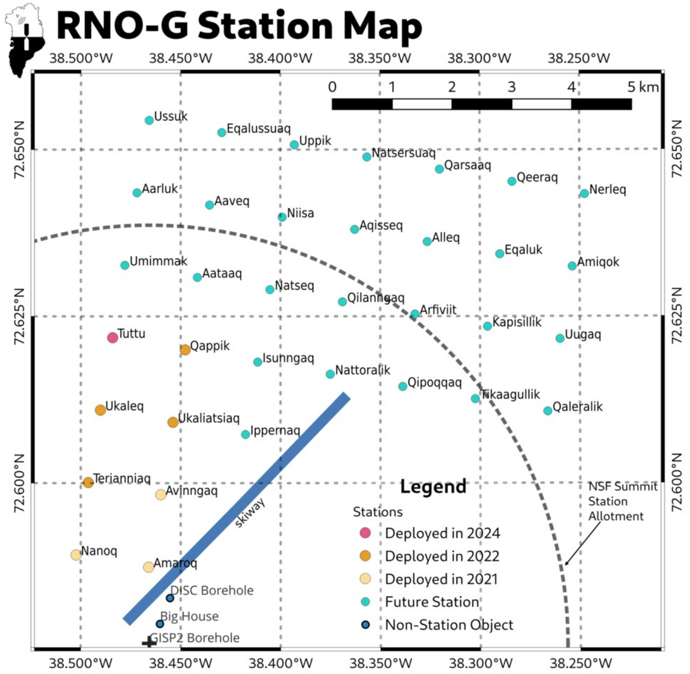


Enhanced rate of GeV neutrinos



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*

Theory activities in Sweden

- EuCAPT: the European Consortium for Astroparticle Theory (2 nodes in Sweden)
- Main lines of research: Dark matter (especially modelling of dark matter-nucleon and dark matter-electron interactions in materials, dark matter interactions in celestial bodies), axions, neutrino astrophysics and gravitational waves/phase transitions
- Leading contributions to tools used by the community, for example GAMBIT (https://arxiv.org/pdf/2405.17548)

Also, other related activities that border with astrophysics: FERMI, ASTROSAT, theorists working on cosmology

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4b *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

4b *i) Physics potential*

ii) Long-term perspective

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

Astroparticle physics experiments operate at more modest costs and human resources compared with large collider experiments and allow for a diverse particle physics program that is complementary and synergistic with collider programs

4b *i) Physics potential*

ii) Long-term perspective

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

iv) Timing

Timescales for next generation experiments are sooner than future accelerators, so could provide a bridge to advance particle physics while the next accelerators are developed

4b *i) Physics potential*

ii) Long-term perspective

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

iv) Timing

v) Careers and training

This research creates knowledge and trains students in skills that are useful to society at large. We provide hands-on training with hardware, as well as experience with data analysis, statistical inference, and deep learning techniques.

4b *i) Physics potential*

ii) Long-term perspective

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

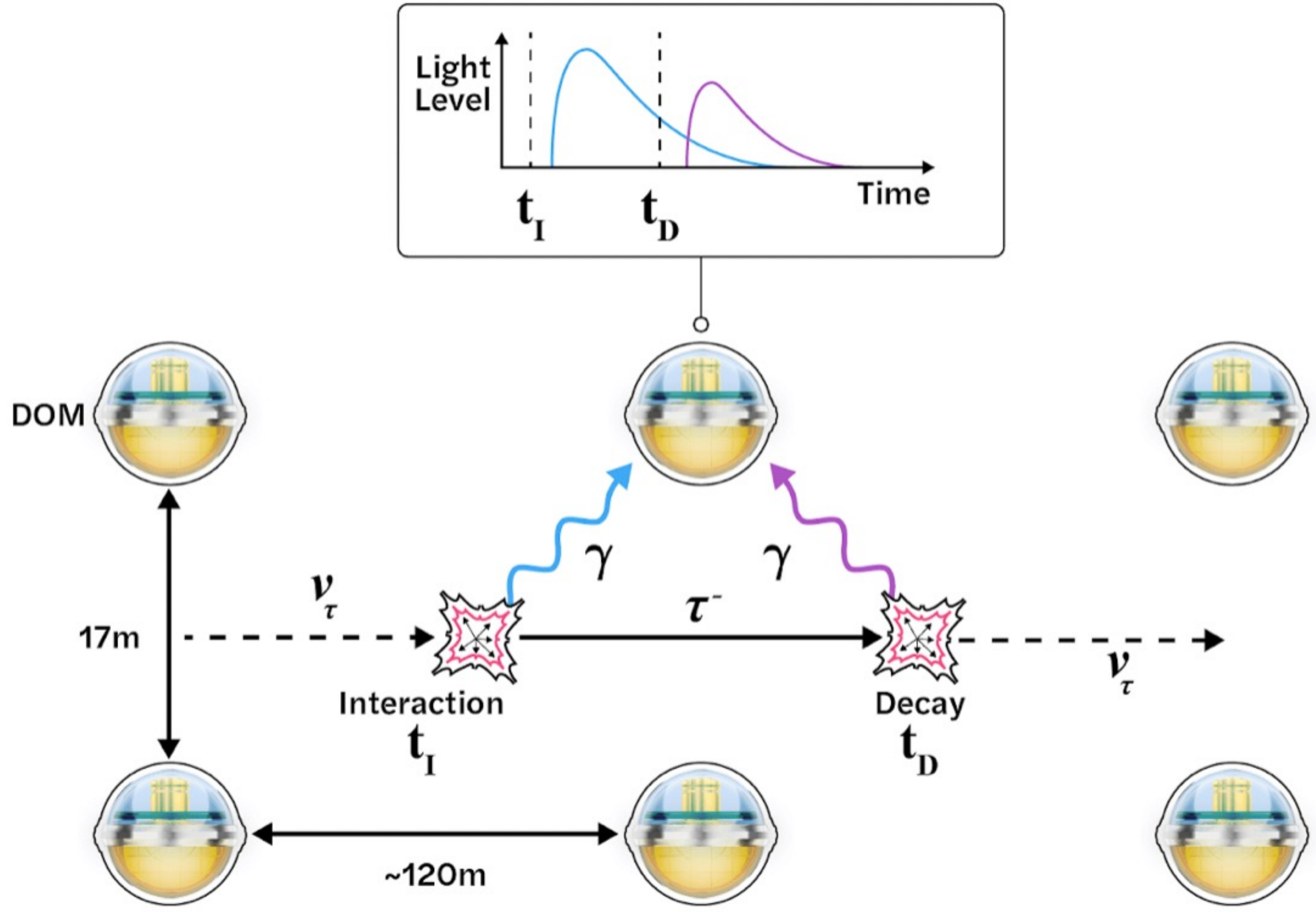
iv) Timing

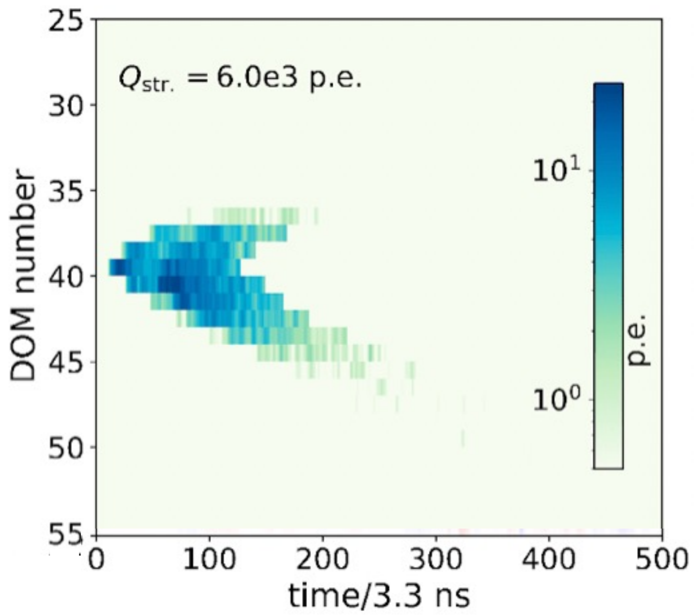
v) Careers and training

vi) Sustainability

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

Measuring tau neutrinos at high energy





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

Measuring oscillations at cosmic baselines

- 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. Studying dark matter allows us to better understand the vast majority of matter in our Universe.
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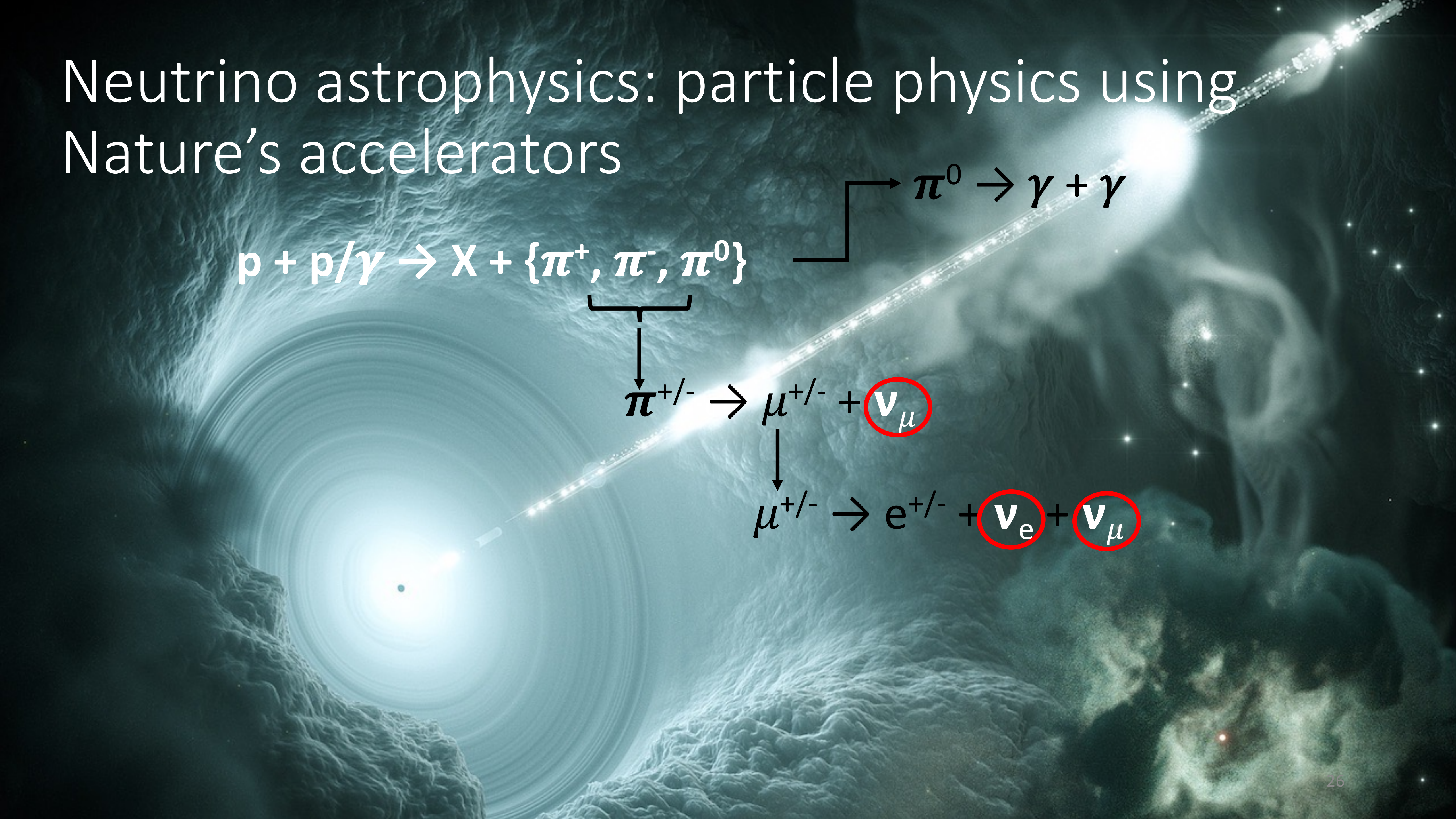
Neutrino astrophysics: particle physics using Nature’s accelerators



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

$$\boldsymbol{\pi}^{0} \rightarrow \gamma + \gamma$$

$$\boldsymbol{\pi}^{+/-} \rightarrow \mu^{+/-} + \boldsymbol{\nu}_{\mu}$$

$$\mu^{+/-} \rightarrow e^{+/-} + \boldsymbol{\nu}_{e} + \boldsymbol{\nu}_{\mu}$$

Dark matter references from Riccardo

theory of dark matter direct detection, where I focus on the modelling of dark matter-nucleon **(A)**

- https://arxiv.org/pdf/1612.09165
- (*) https://arxiv.org/pdf/1504.06554
- https://arxiv.org/pdf/1406.0524
- (*) https://arxiv.org/pdf/1405.2637

Dark matter references from Riccardo

dark-matter electron interactions in detector materials **(B)**

- (*) https://arxiv.org/pdf/2402.06817
- https://arxiv.org/pdf/2105.02233
- (*) https://arxiv.org/pdf/1912.08204

Dark matter references from Riccardo

dark matter in celestial bodies

- https://arxiv.org/pdf/1812.08270
- https://arxiv.org/pdf/1609.08967
- https://arxiv.org/pdf/1503.04109
- (*) https://arxiv.org/pdf/1501.03729

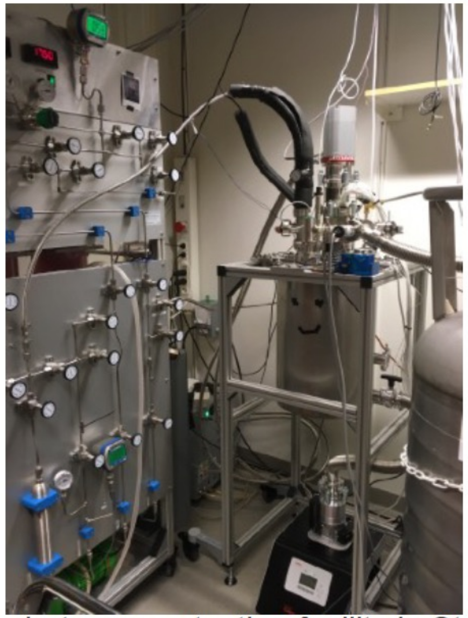
Stockholm University

(Conrad and Mahlstedt)

- Past contributions:
    - PMT testing in LXe and GXe
    - PMT array assembly and PMT commissioning and operation
    - Computing (coordination & data transfer)
    - PMT and xenon purchase
    - Analysis (high-end / inference)

- Technical capabilities / facilities
    - Photosensor testing facility (in LXe or GXe over several weeks, 14 PMTs simultaneously or novel photosensors - voltage supply up to 30kV)

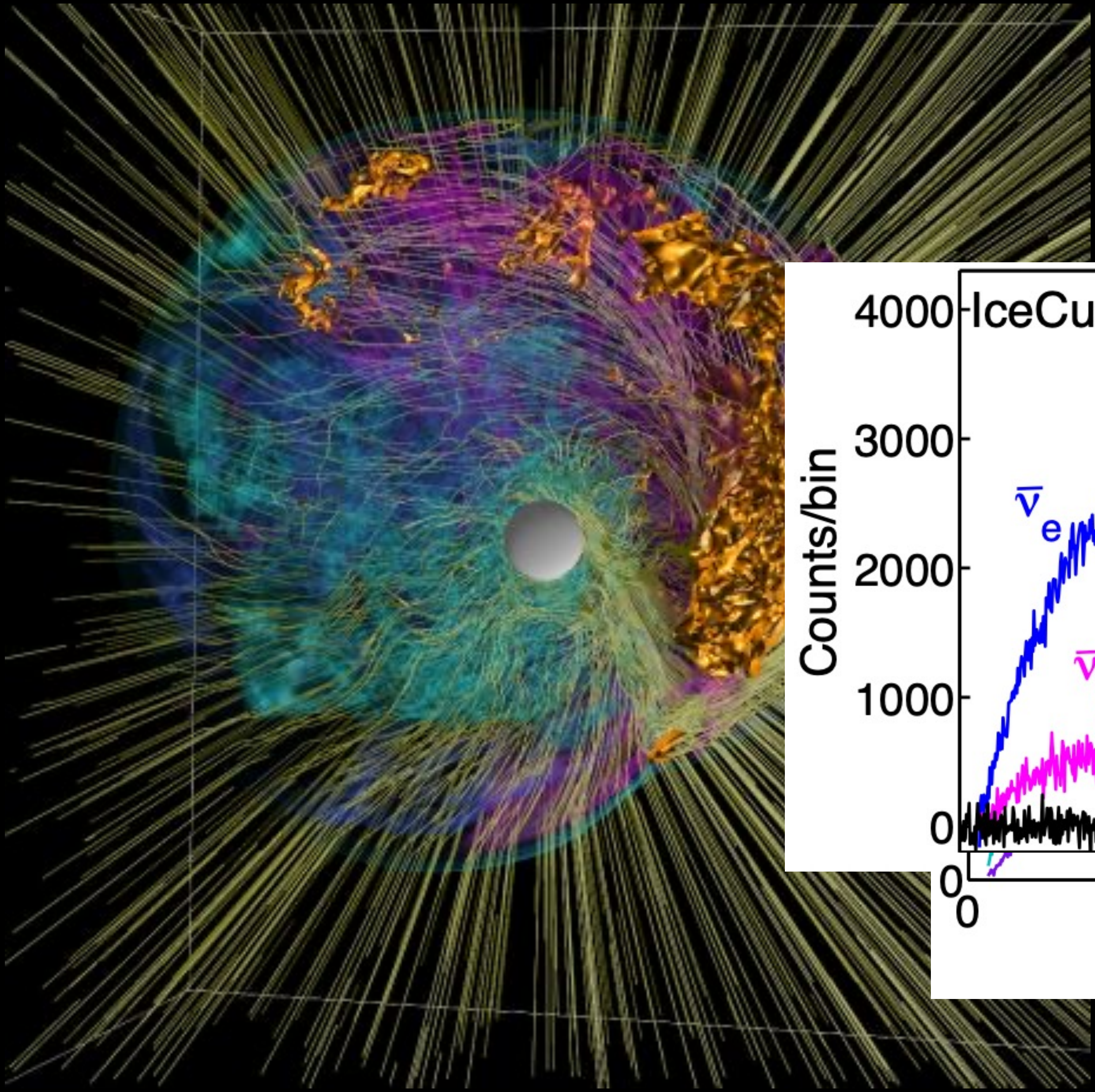
- Interest areas:
    - Novel photosensor R&D (ABALONE photosensor)
    - General photosensor testing (PMTs, SiPMs and ABALONE tested so far)
    - Photosensor array assembly
    - Analysis (high-end / inference)

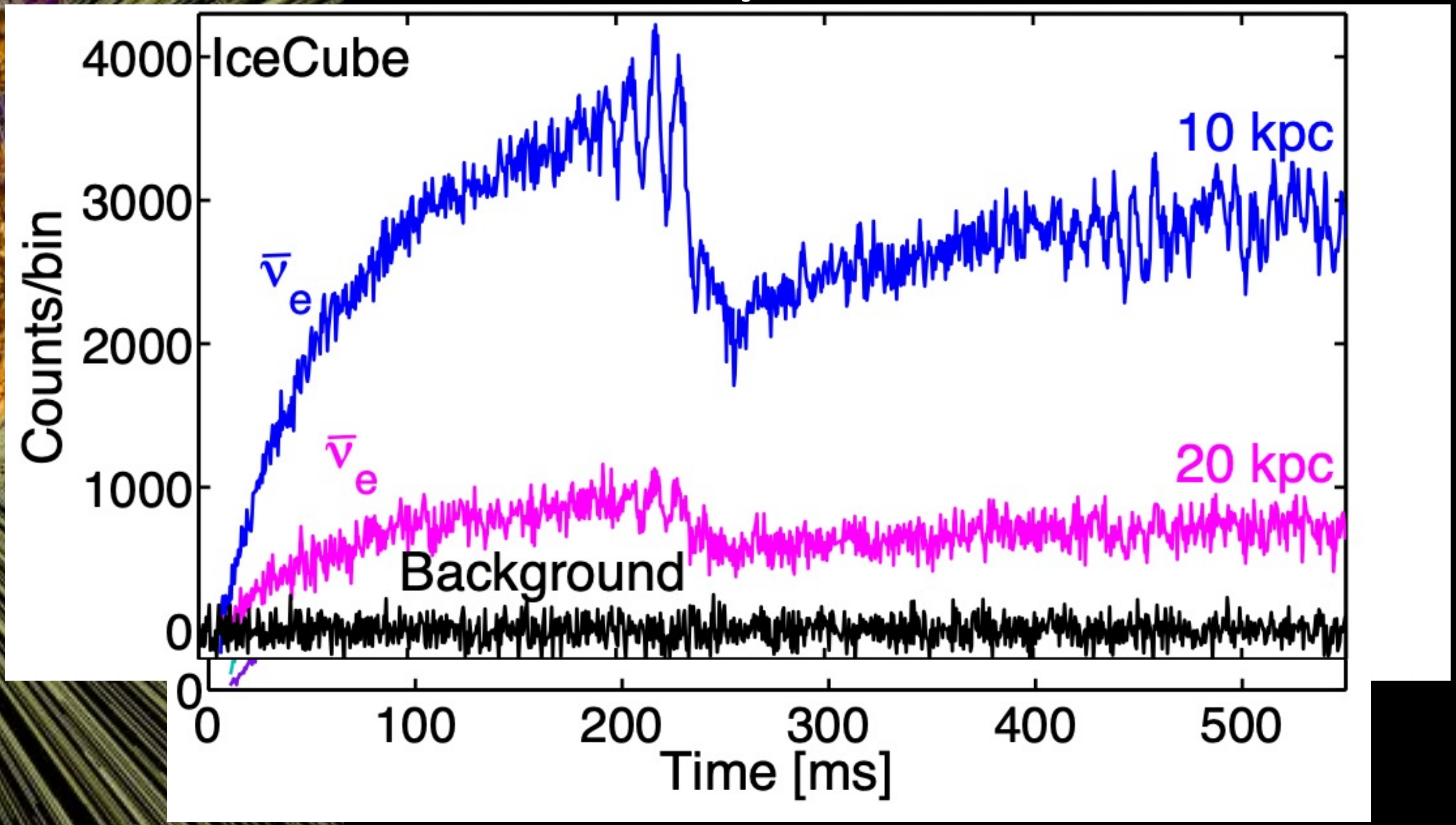


Cryogenic photosensor testing facility in Stockholm

ABALONE photosensor

Neutrino interactions at high densities inside supernovae





Tamborra et al PRL 111 (2013) 121104