# Highlights from IceCube & KM3Net

***Else Magnus***
*On behalf of the IceCube/KM3Net-IIHE team*

IIHE Annual Meeting – November 10, 2025

# IIHE – IceCube & KM3Net team

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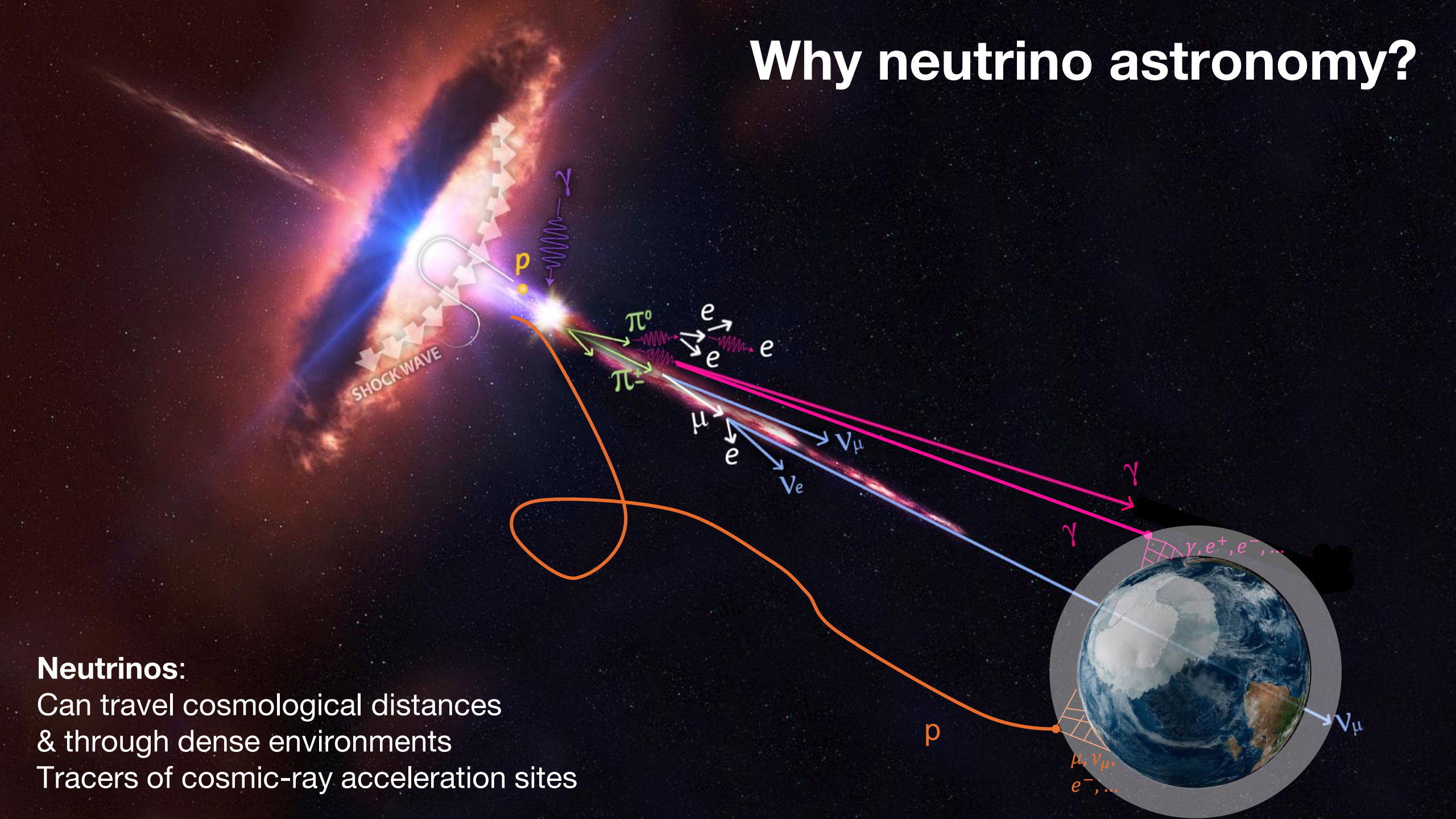
# Why neutrino astronomy?



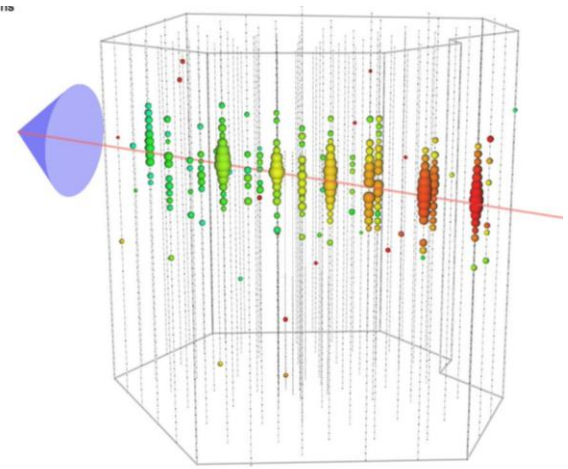

**Neutrinos**:
Can travel cosmological distances
& through dense environments
Tracers of cosmic-ray acceleration sites

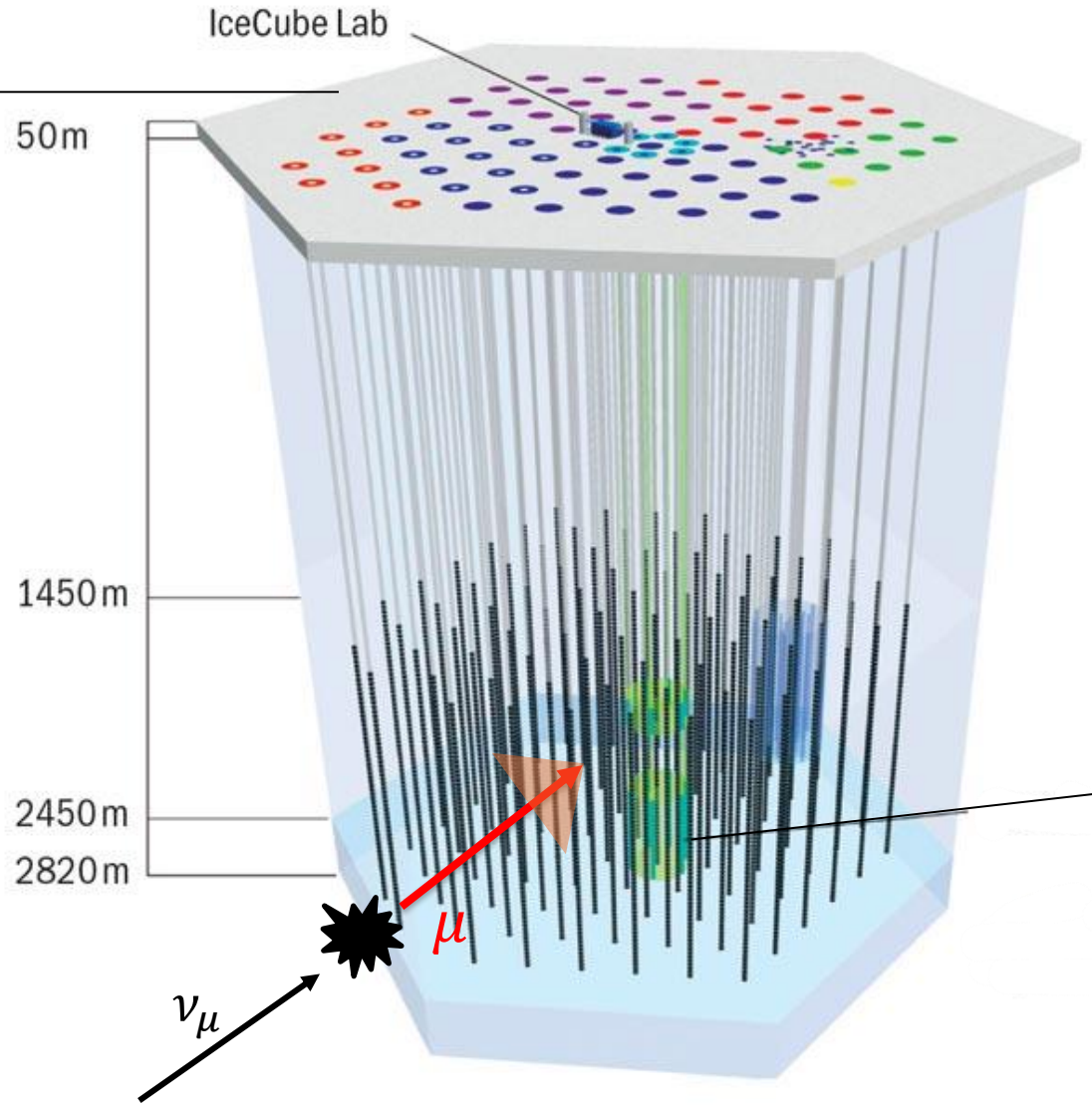
# IceCube Neutrino Observatory

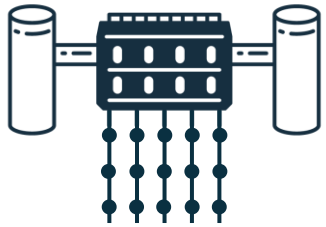
Located at the
South Pole

## IceTop
surface array
for veto and calibration
detect airshowers!

1 $km^3$
detector





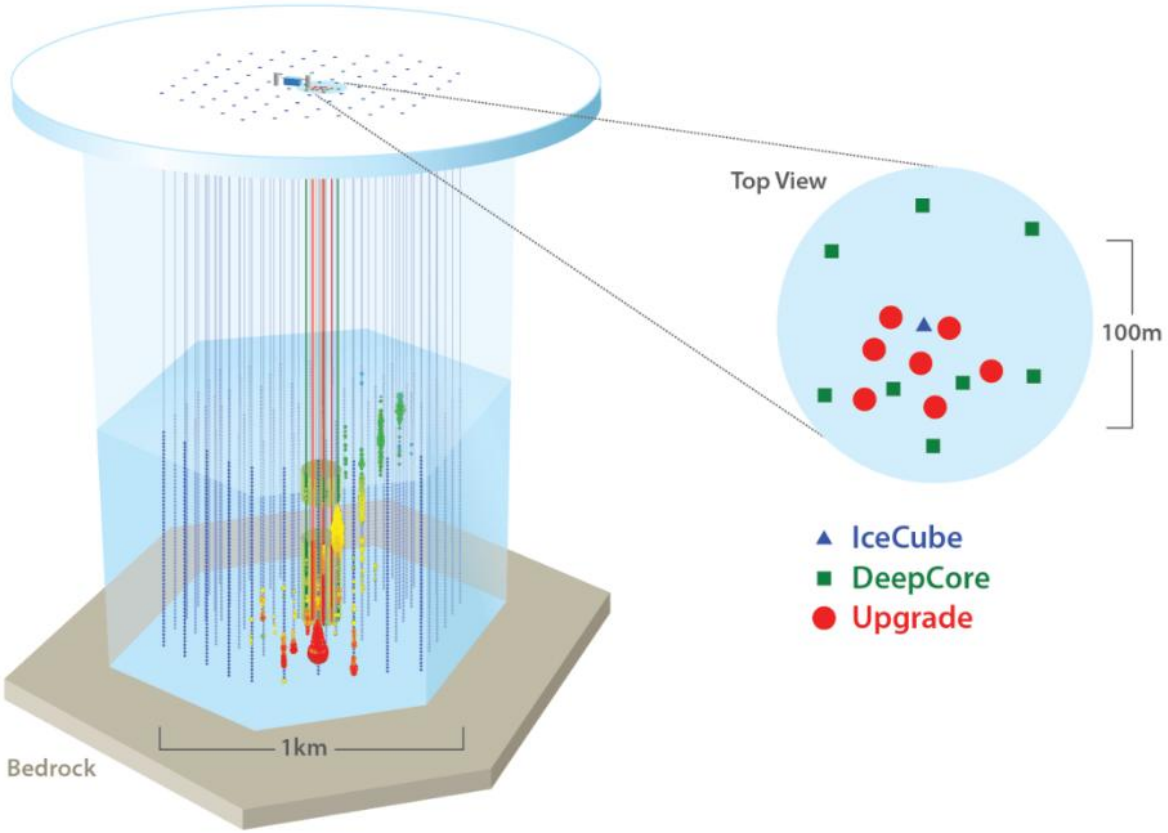



86 strings with
60 DOMs each

## DeepCore
8 denser strings
lowers energy threshold to 10 GeV
study neutrino oscillations!

5160
Digital Optical Modules

# IceCube Neutrino Observatory




**IceCube Upgrade**

Deploy 7 strings in 2025-2026.

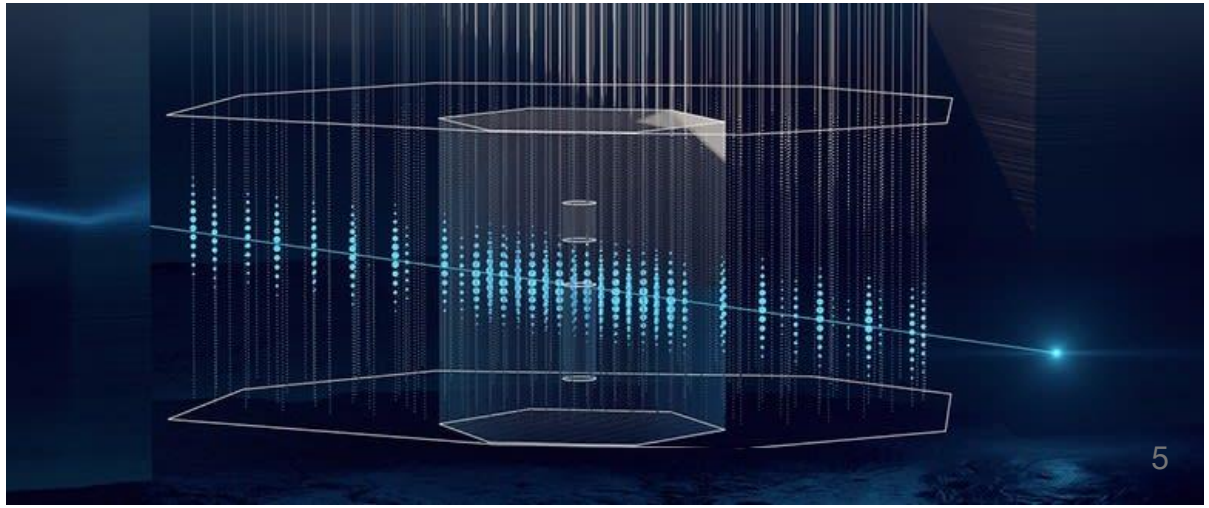
Aim: More precision, lower-energy events (GeV).

**IceCube Gen-2**

Make IceCube 8x larger + radio in-ice detectors.

Increase energy threshold to PeV-EeV.

☺ Make everything better!



# KM3Net

**ARCA**

Off-shore Sicily, Italy

High-energy astrophysical neutrinos

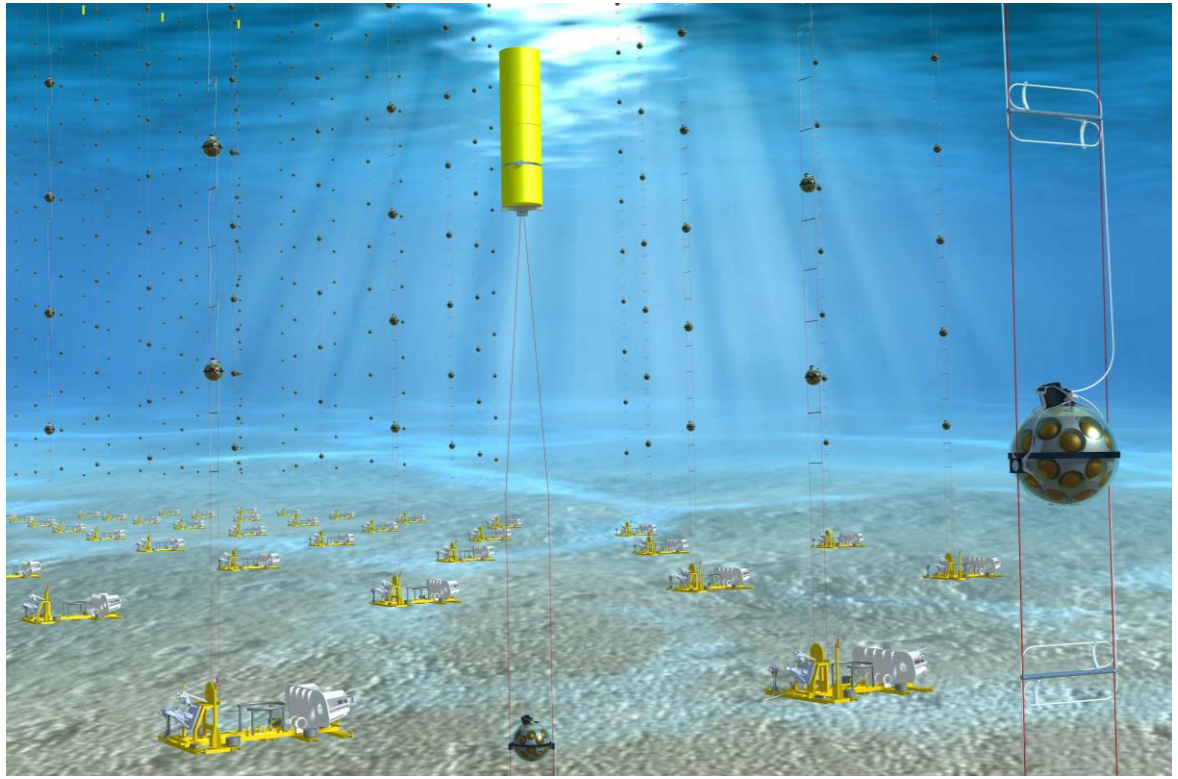
Deployed: 51 lines (of 230)

**ORCA**

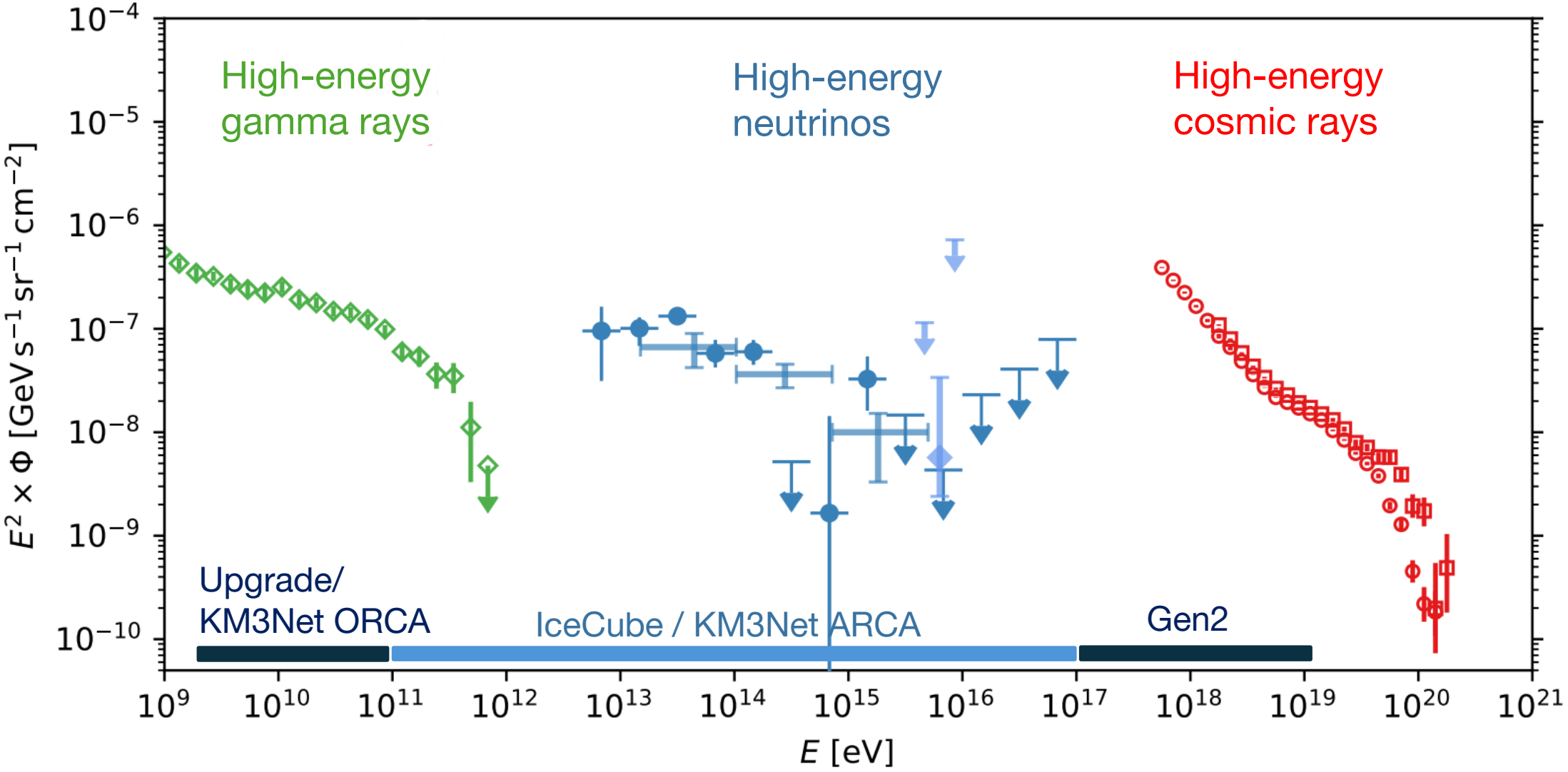
Off shore Toulon, France

Neutrino properties

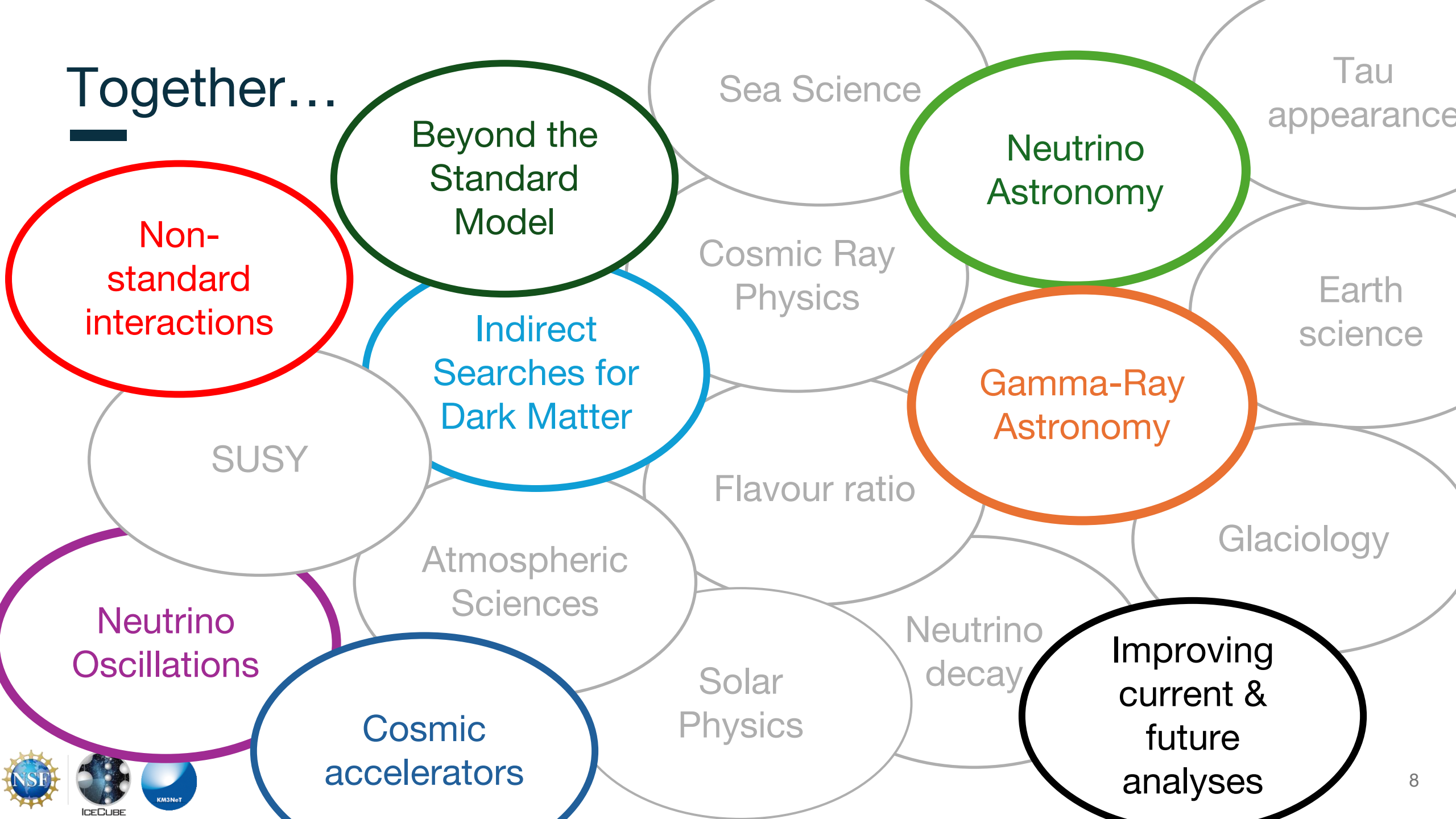
Deployed: 33 lines (of 115)

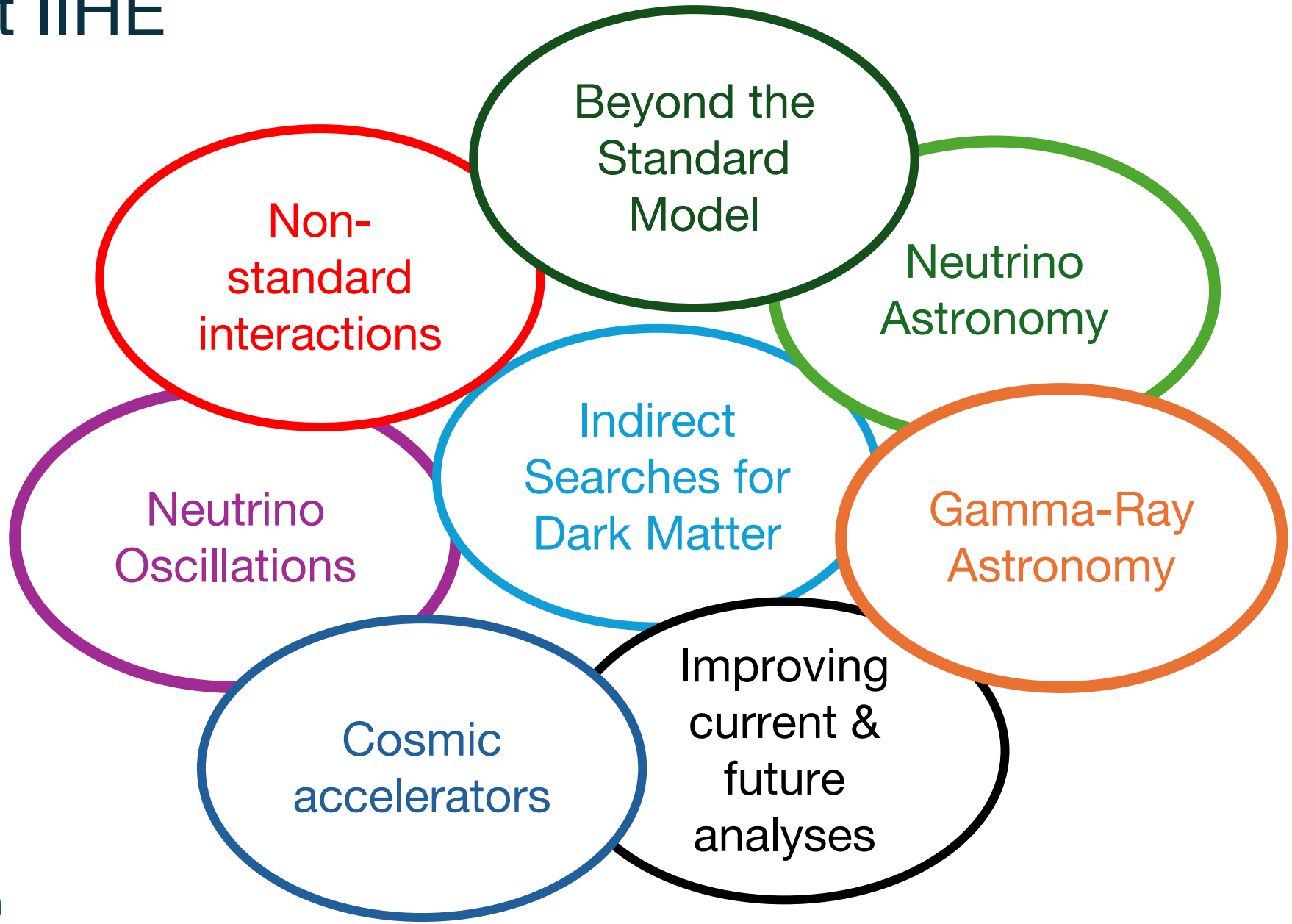
# High-energetic cosmic messengers



# Together…


Beyond the Standard Model
Non-standard interactions
Indirect Searches for Dark Matter
Neutrino Oscillations
Cosmic accelerators
Neutrino Astronomy
Gamma-Ray Astronomy
Improving current & future analyses
Sea Science
Tau appearance
Cosmic Ray Physics
Earth science
SUSY
Flavour ratio
Glaciology
Atmospheric Sciences
Neutrino decay
Solar Physics

# We at IIHE


Beyond the Standard Model
Non-standard interactions
Neutrino Astronomy
Indirect Searches for Dark Matter
Neutrino Oscillations
Gamma-Ray Astronomy
Cosmic accelerators
Improving current & future analyses

# Search for neutrino sources

Yarno

Search for the **origin of the astrophysical neutrino flux** observed by IceCube.

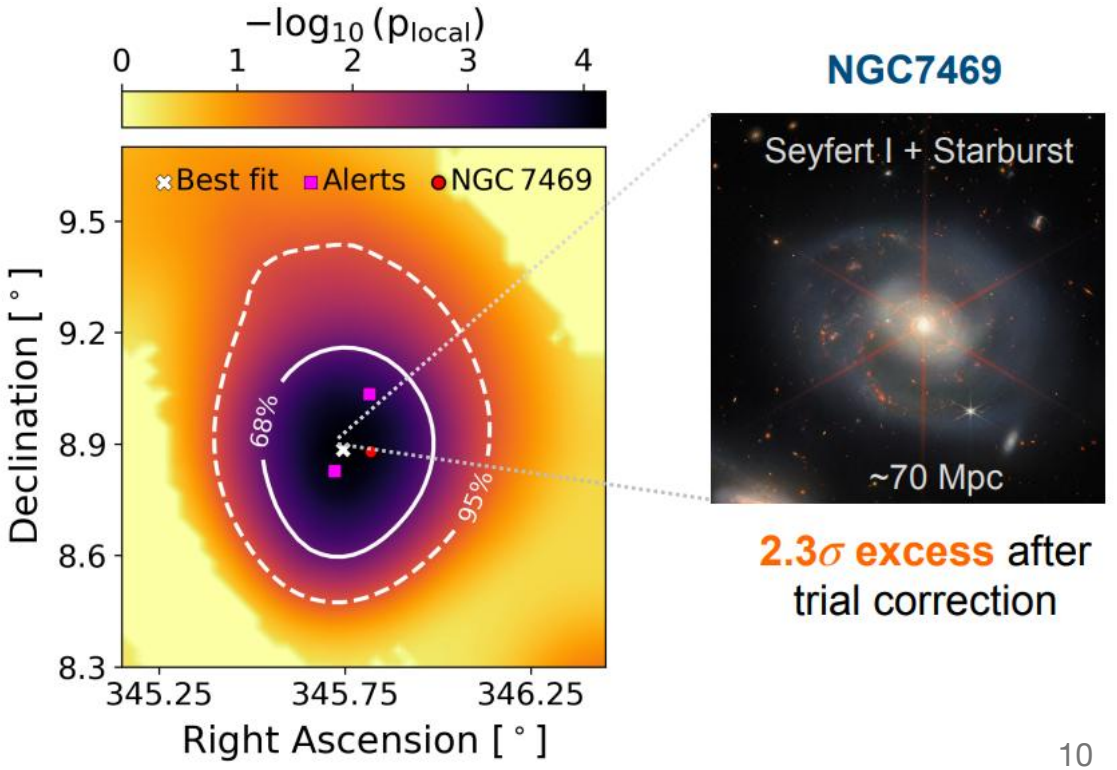
**(Ultra) Luminous Infrared Galaxies** are interacting/merging galaxies, with a lot of **starburst and/or AGN** activity.

? Do (U)LIRGs produce a significant fraction of the observed astrophysical neutrinos?

Key results:

- No significant excess for (U)LIRGs;
- Most significant excess for hybrid (AGN + starburst) source **NGC 7469**
- NGC 1068 is also a hybrid source

↪ Second identified neutrino source!



# Search for neutrino sources

Else

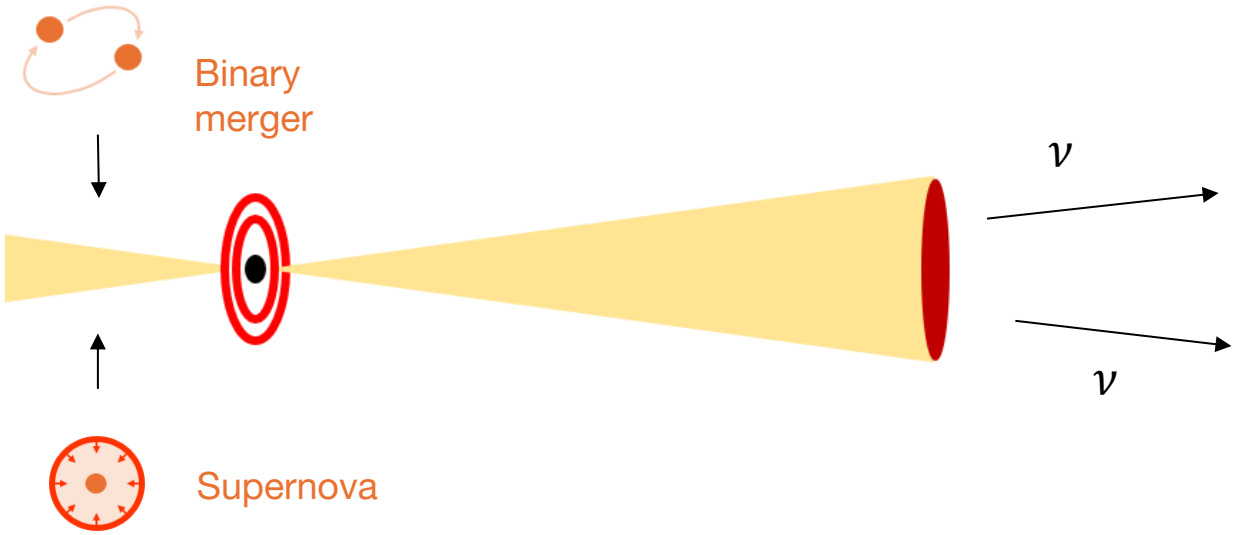
Search for the **origin of the astrophysical neutrino flux** observed by IceCube.

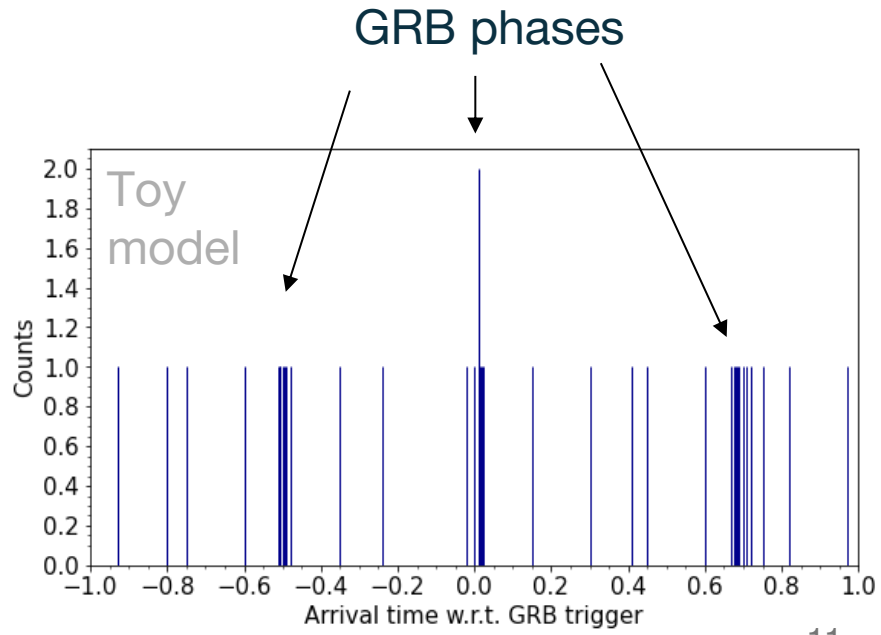
GRBs remain important candidates for neutrino production.

**Do GRBs produce high-energy neutrinos?**

Apply new method to become more sensitive on longer time scales: **Time Profile Stacking**, by stacking time intervals between neutrino arrival times.

Currently: Sensitivity studies to define best dataset, catalogue, time window, …



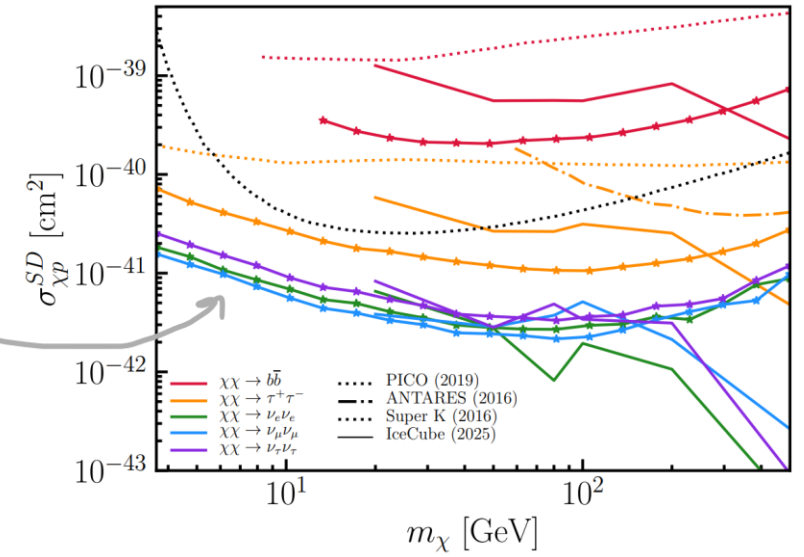



# Search for neutrino sources (BSM)

Eliot

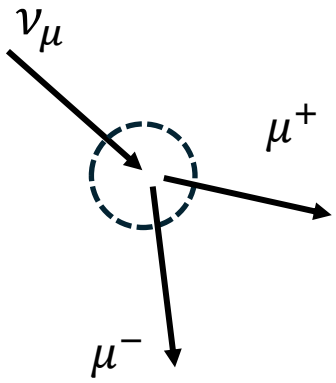
Search for neutrinos from **dark matter annihilation in the Sun**.

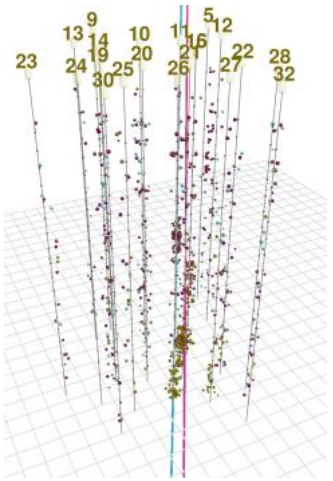
- If there is a dark matter halo, dark matter might accumulate in the Sun.
- ? **How sensitive is Upgrade to a neutrino signal from dark matter annihilation?**
  Strength of neutrino signal ∝ how much accumulation ∝ cross-section between matter and DM




Search for **dimuons** in KM3Net (SM & BSM process).

- Dimuons: Two muons from one neutrino interaction. They should be present in the data.
- ? **Can we find and reconstruct them?**
  Using machine learning and likelihood methods.



Injection of μμ in KM3Net

Nhan

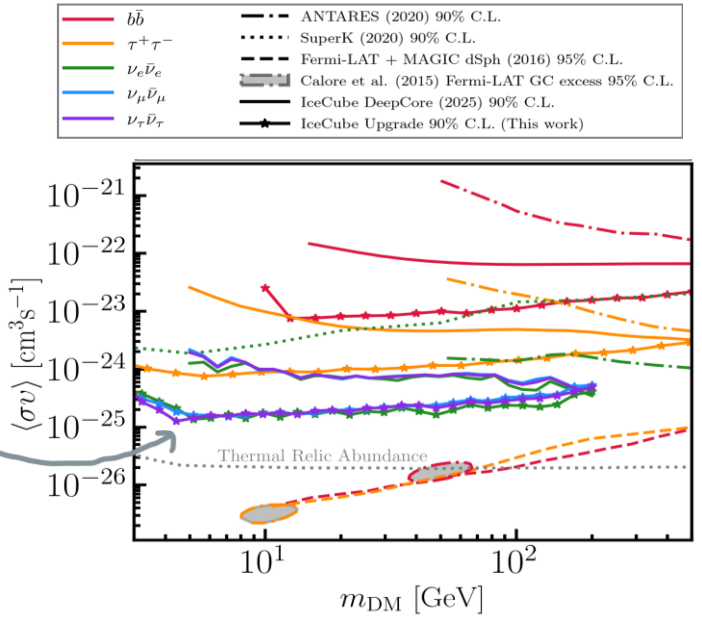
# Search for neutrino sources (BSM)

Search for neutrinos from **dark matter decay in the Galactic Center**.

? **Can we see a neutrino signal in IceCube DeepCore?**
**How sensitive is IceCube Upgrade to this signal?**

No DM found, putting limits to cross-section and lifetime.
Joint paper with Eliot for Upgrade sensitivity. in preparation!

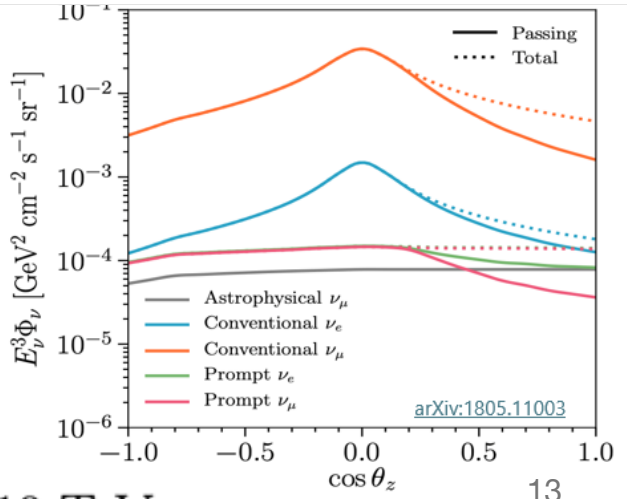
submitted!




Self-veto studies for oscillation analysis with IceCube DeepCore

Self-veto effect: Expected atmospheric neutrinos are suppressed (vetoed) by detectable muons from same cosmic-ray airshower.

? **Can we correct for this self-veto effect?**
Study this for GeV energies and apply for down-going atm. neutrino flux to reduce flux systematics in oscillation analysis.




$E_\nu = 10$ TeV

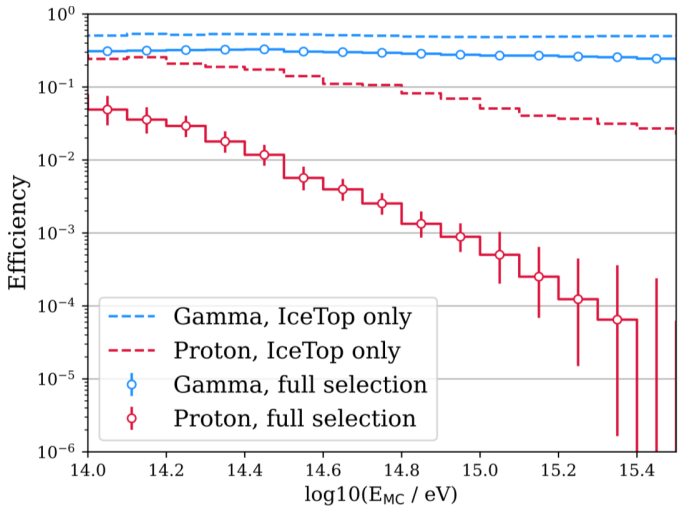
# Search for PeV gamma rays

Andrea

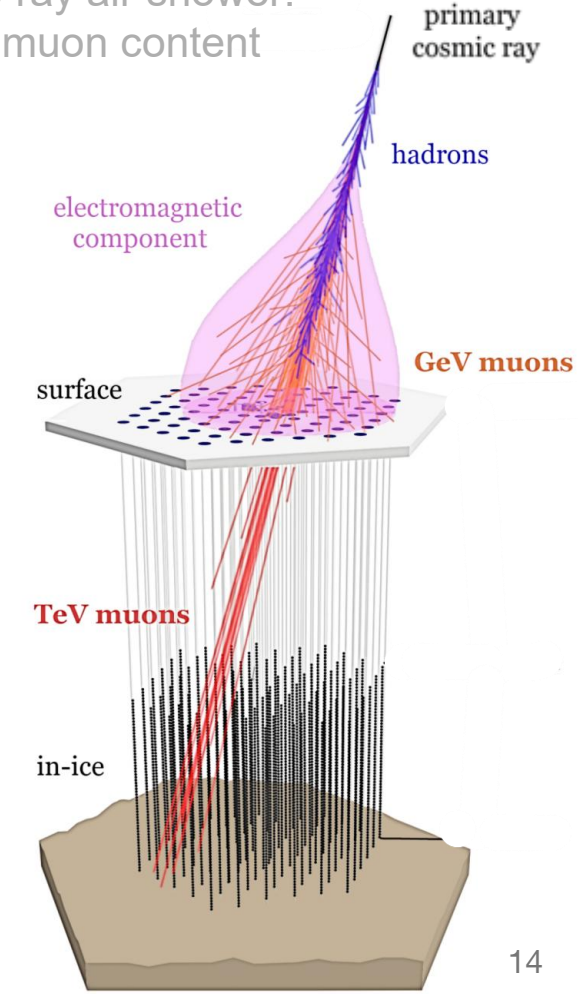
Measuring PeV gamma rays is crucial to unravel the cosmic-ray sources accelerating beyond PeV energies.

Both cosmic rays and gamma-rays result in **air showers**. How to distinguish between them in IceCube?

Andrea's work: Combination of IceTop and in-ice detector gives **higher gamma / hadron separation power** than previous searches with IceCube.




Gamma-ray air shower:
**lower** muon content
Cosmic-ray air shower:
**higher** muon content




IceTop reconstructs air shower

In-ice detector:
Muon signal? ✗
No muon signal? ✓

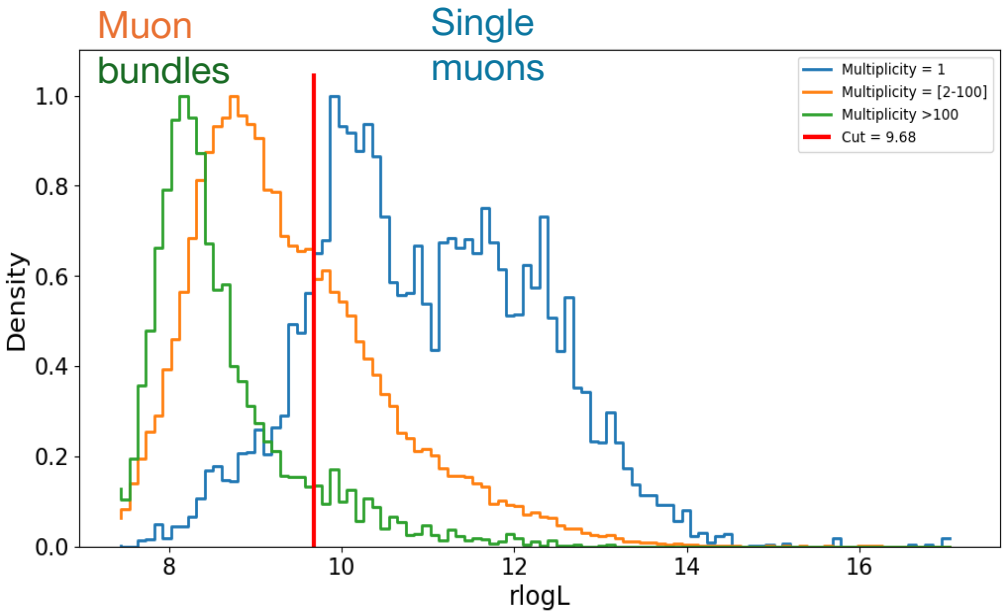
# Improving IceCube analyses

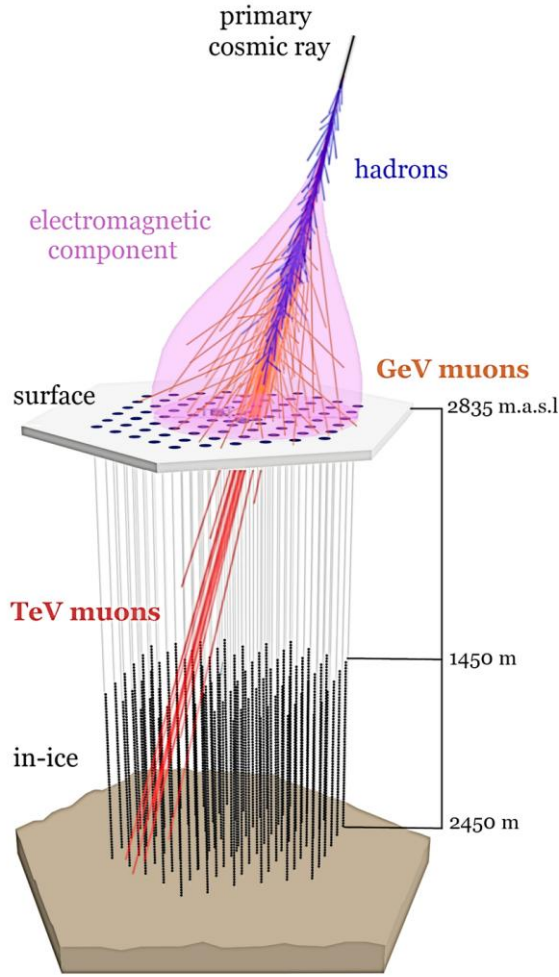
Thomas

Study muon bundles as background for extremely high energetic neutrinos (> 1 PeV)

- Muon bundles are produced in cosmic-ray airshowers and mimic the signal of a single muon with higher energy. This limits EHE analyses!

? **Can we distinguish single muons from muon bundles?**
Find a discriminator to identify single muons and muon bundles based on new geometry to reconstruct muon bundles.
This discriminator shows promising results!



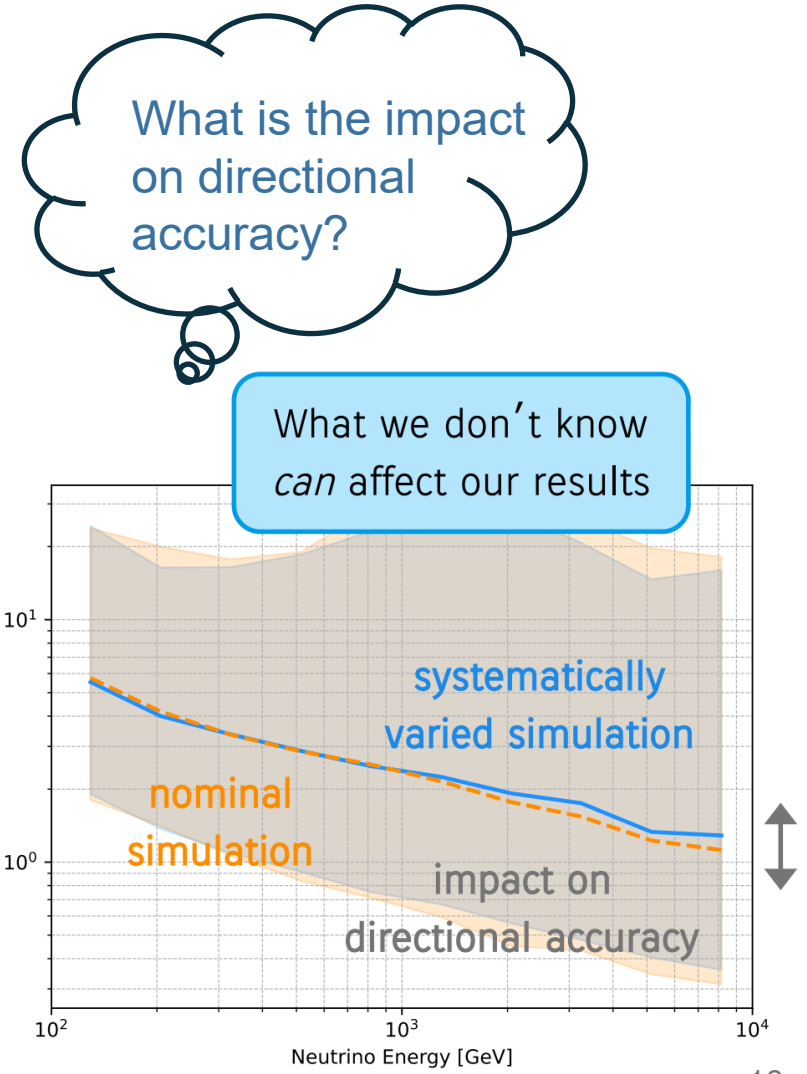

IceCube

# Improving IceCube analyses

Louise

Study of usually ignored detector and ice parameters.

- The detector and the ice are **not perfectly understood**; some subtle effects are often neglected.
- ? **What is the impact on directional accuracy?**
  Produce large simulated datasets with systematically varied detector and ice parameters.




Search for fractionally charged particles.

- BSM theories predict their existence, and they could leave **faint tracks** in the IceCube detector.
- ? **Can we see them with IceCube Upgrade?**
  Develop a simulator to assess Upgrade's potential to detect them.

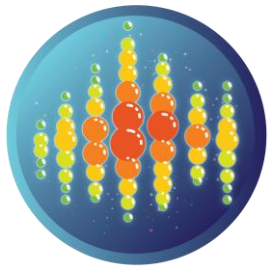
# Conclusion

The IIHE team is contributing to a wide range of research, from neutrino astronomy, to dark matter, to a better understanding of detector physics.

With IceCube Upgrade and KM3Net, we are ready for the next decade of neutrino discoveries!

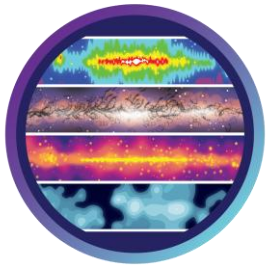
**ASTROPHYSICAL NEUTRINOS**
DISCOVERED
**2013**

**BLAZAR TXS 0506+056**
NEUTRINO EMISSION IDENTIFIED
**2018**

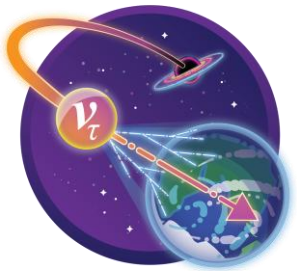


**GLASHOW RESONANCE**
NEUTRINO IDENTIFIED
**2021**

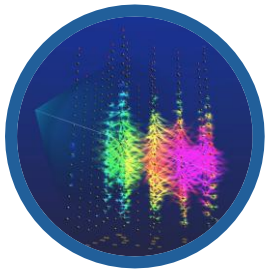
**ACTIVE GALAXY NGC 1068**
NEUTRINO EMISSION IDENTIFIED
**2022**



**MILKY WAY**
NEUTRINO EMISSION IDENTIFIED
**2023**



**ASTROPHYSICAL TAU**
NEUTRINOS IDENTIFIED
**2024**



**KM3-230213A**
HIGHEST-ENERGY NEUTRINO
**2024**

# BACK-UP SLIDES

# Particle physics with IceCube

## Dark matter search in the Galactic Center

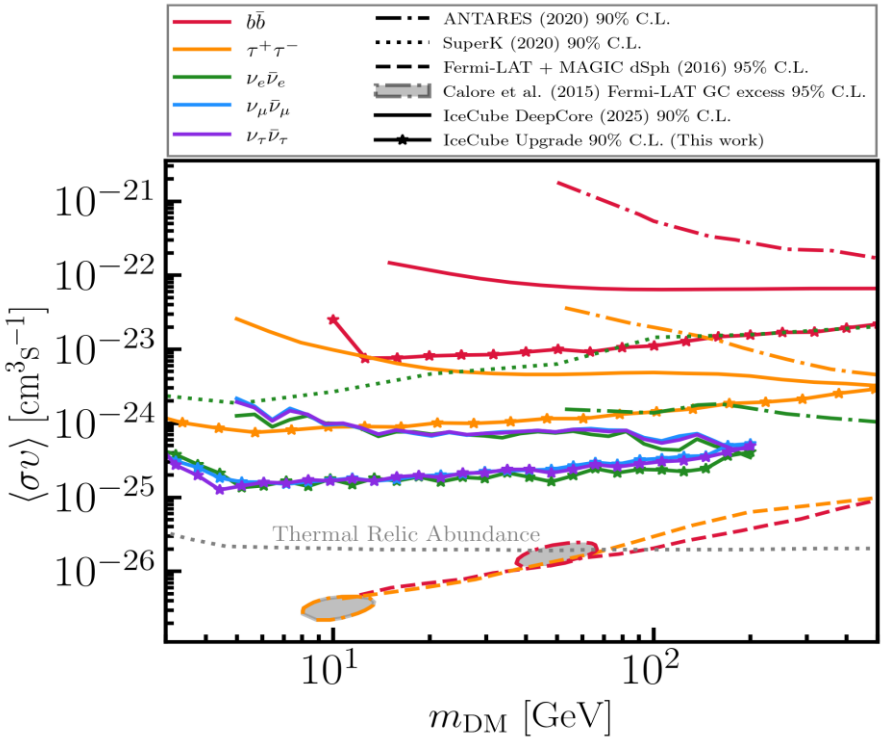
Search for spherical excess toward the direction of Galactic Center

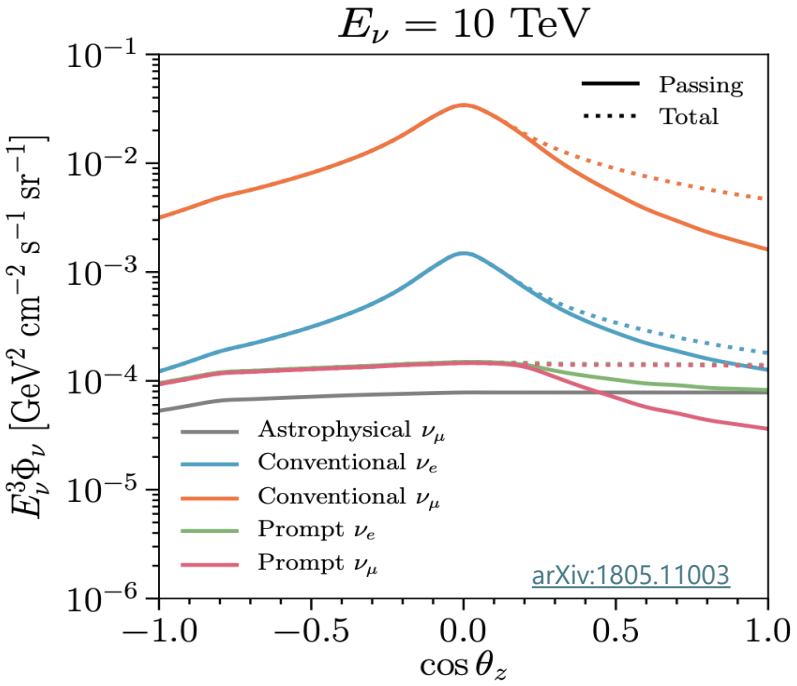
Search with 9.0 years of DeepCore's data:

- No DM found, putting limit to cross-section and lifetime
- Results to be published soon

Sensitivity studies with Upgrade:

- Joint sensitivity paper with Solar DM (in preparation)




## *Self-veto studies for oscillation analysis with DeepCore*

- Self-veto effect*: Expected atmospheric neutrinos suppressed (vetoed) by detectable muon from the same cosmic-ray airshower.*
- The effect has been studied for IceCube diffuse analysis at TeV energies but not been done for GeV energies (on-going work)
- Objectives:
  - Apply self-veto correction for down-going atm. neutrino flux
  - Using down-going neutrino flux as a control sample for reducing flux systematics in oscillation analysis

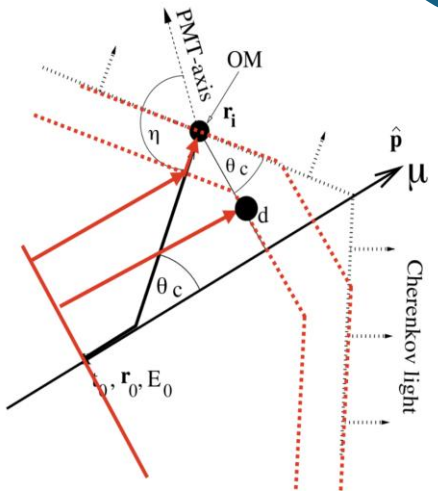
# Muon bundle discrimination for EHE analyses

## New reconstruction model

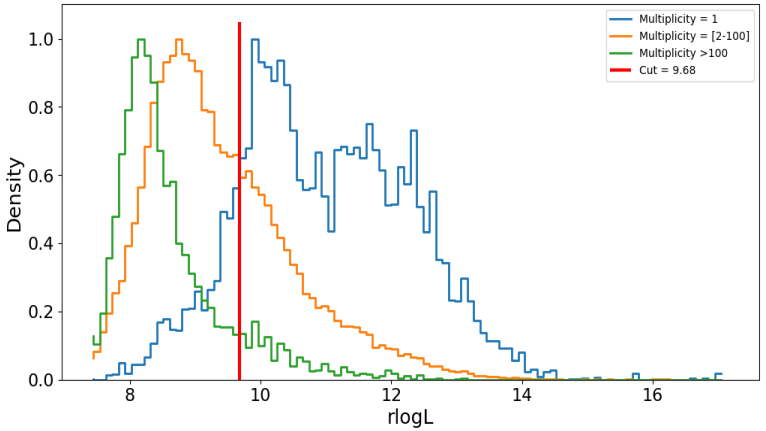
### Devil's Tower

Cherenkov cone
(black dotted line)

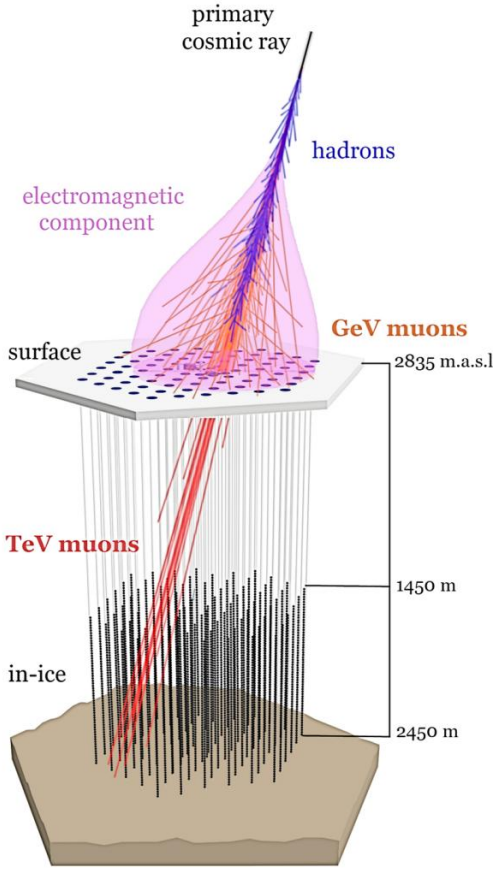
Truncated
Cherenkov cone
(red dotted line)




### Test the discrimination power



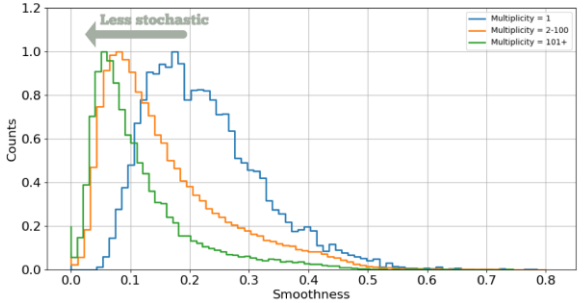

## What is a muon bundle?



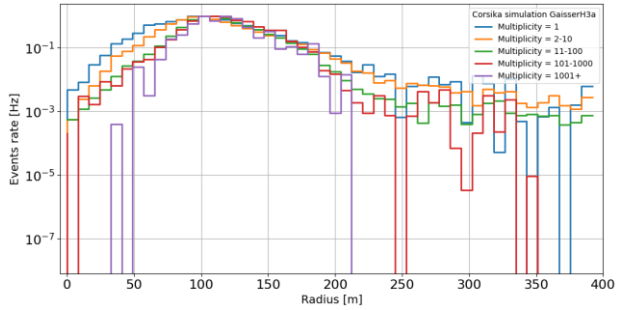

*Problem: mimic the signal produced by a single muon with higher energy*

## Features identification

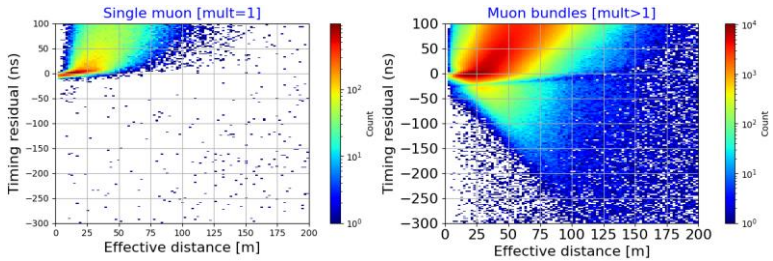
### Stochastic Losses



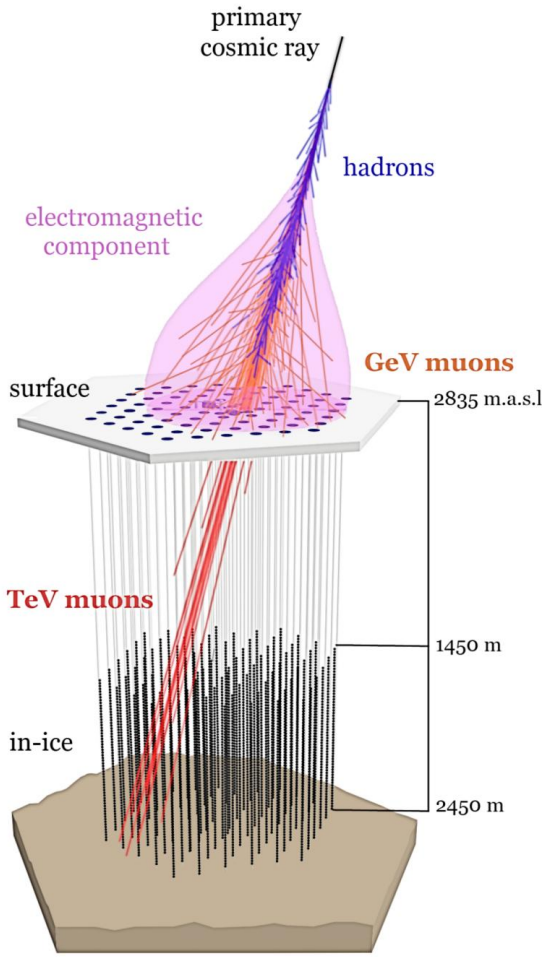

### Light Lateral extension




### Time Residual



# Searches for PeV Gamma Rays with IceCube

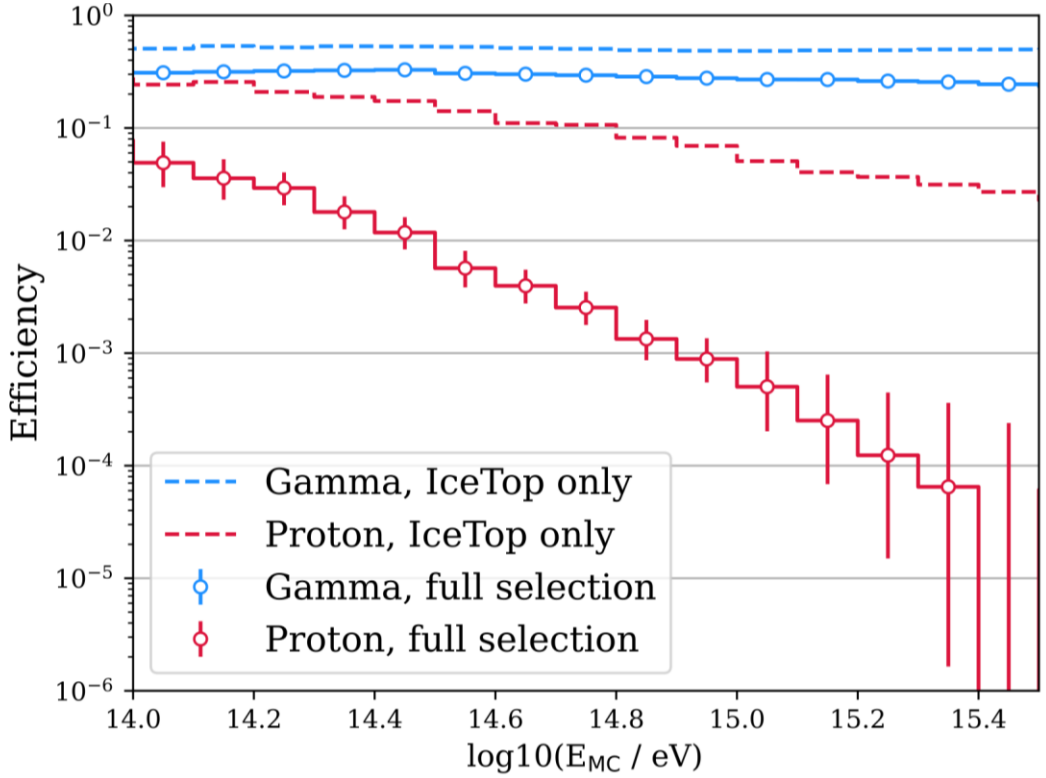



- Andrea Parenti, postdoc with Ioana Mariș

Unique view of the southern sky in the PeV range.

Use IceTop to reconstruct air-shower and in-ice detector as veto.

Gamma / hadron separation based on the muon content of the shower.




Goal: improve on previous searches, aiming for detection of PeV gamma rays.

# Calibration and BSM work (Louise)

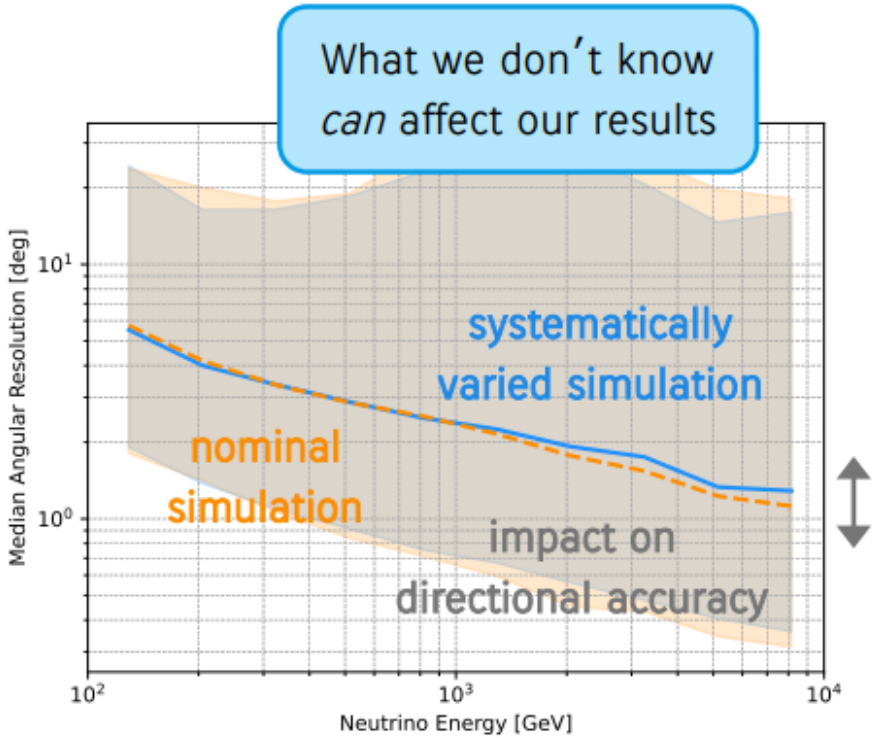
Calibration

## Study of usually ignored detector and ice parameters

⇨ Motivation: The IceCube detector and ice are not perfectly understood; some subtle effects are often neglected

⇨ Work: Producing large simulated datasets with systematically varied detector and ice parameters, and checking the impact on directional accuracy

⇨ Goal: Help collaborators to assess whether such effects can safely be ignored in their analyses




Beyond the Standard Model

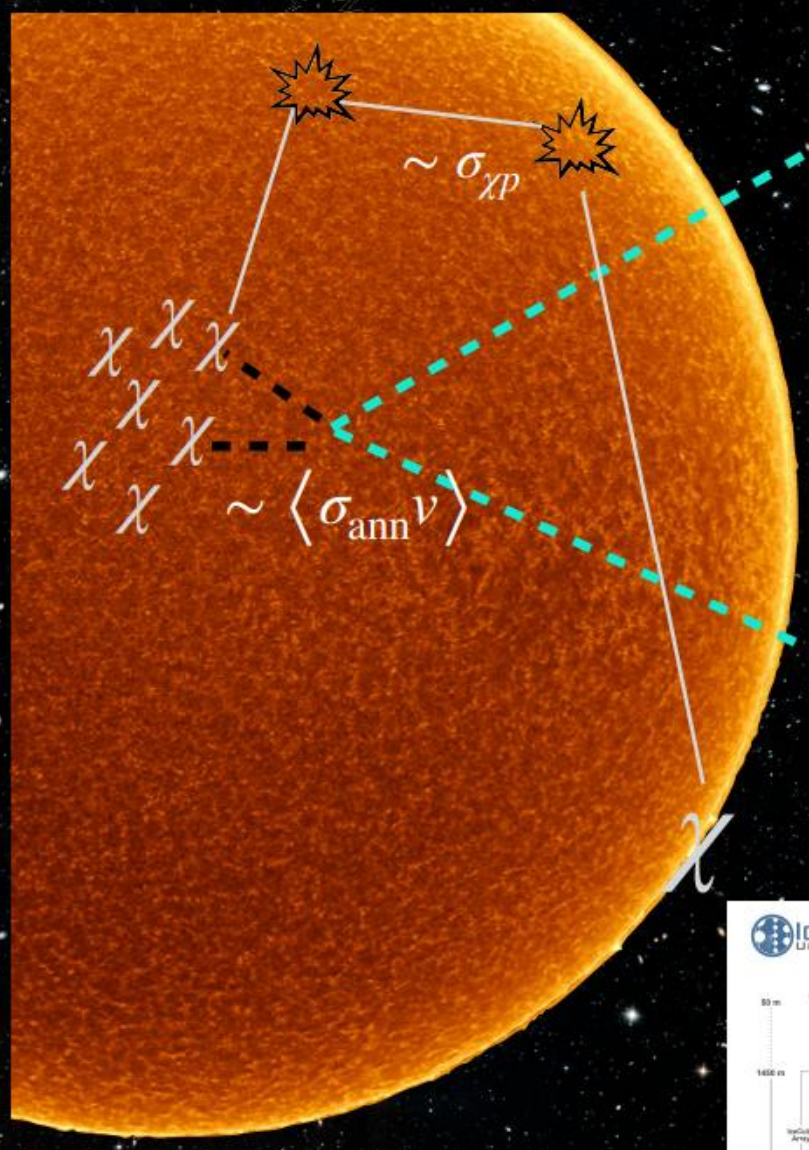
## Search for fractionally charged particles with the IceCube Upgrade

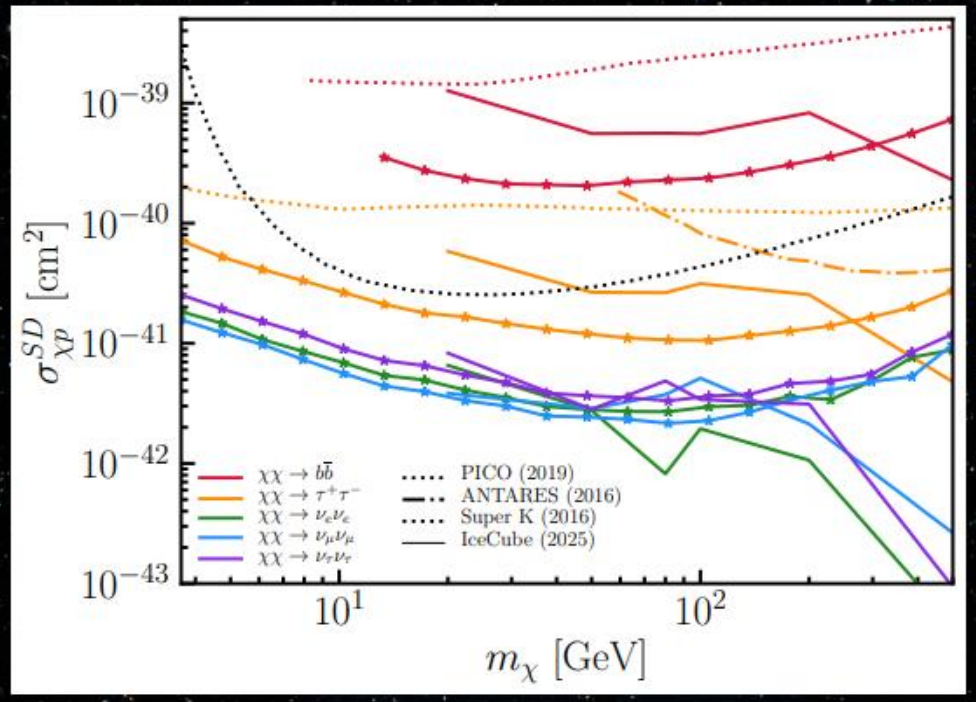
⇨ Motivation: Some extensions of the Standard Model predict low-charged particles that could be produced in the atmosphere and leave faint track signatures in the IceCube detector

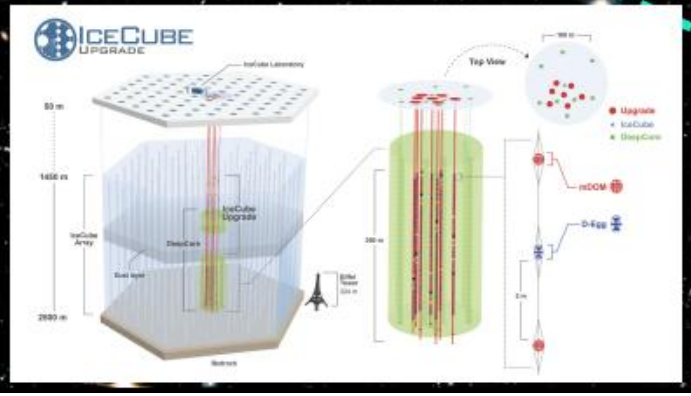
⇨ Work: Developing a simulator for such particles traveling through the Earth

⇨ Goal: Assess the IceCube Upgrade's potential to detect such particles

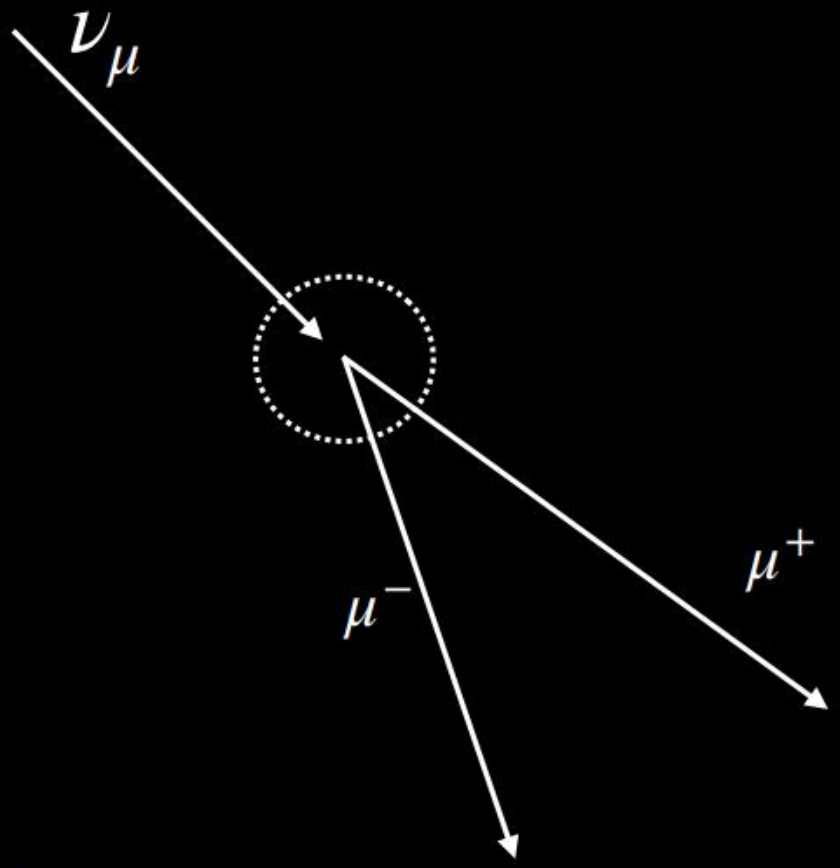
# Search for WIMPs in the Sun with IceCube

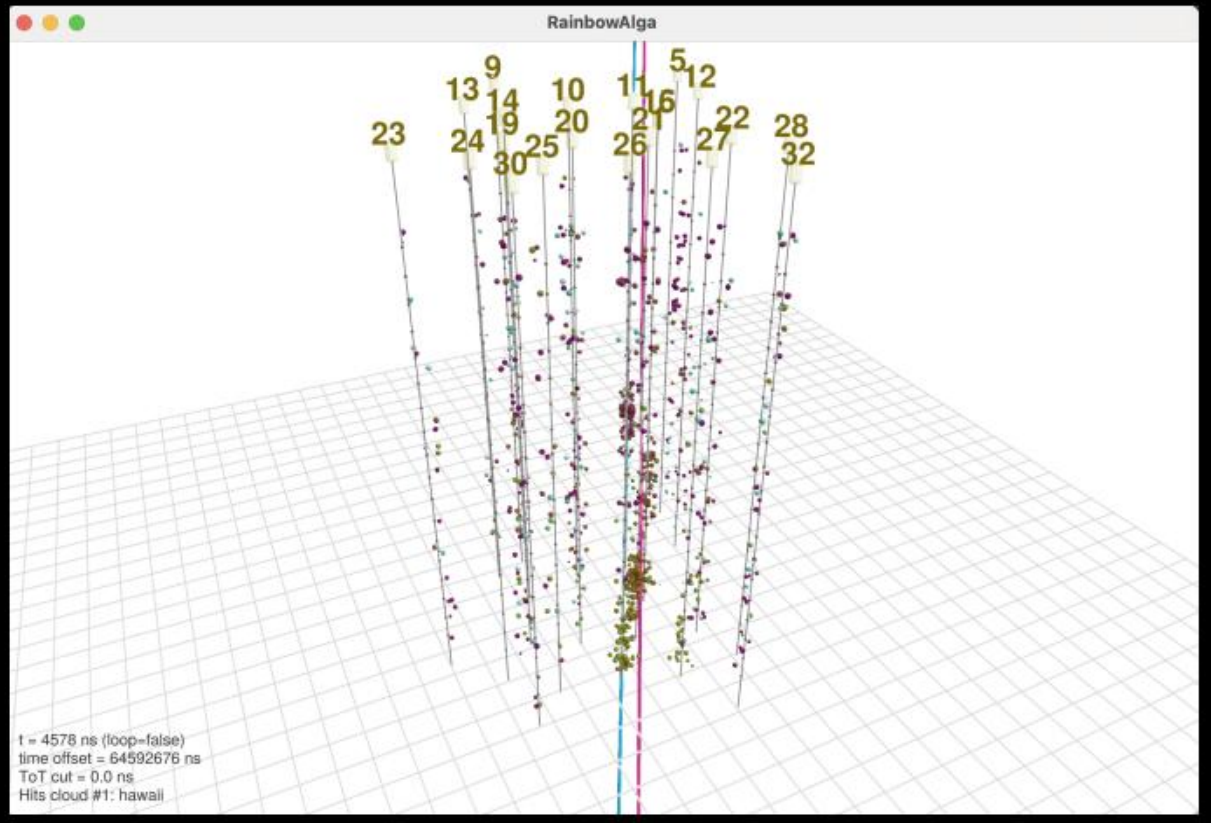



# Dimuons in KM3NeT




Injection of $\mu\mu$ in KM3NeT

- This project aims to reconstruct dimuons in KM3NeT using ML / LIkelihood method

# IceCube signals