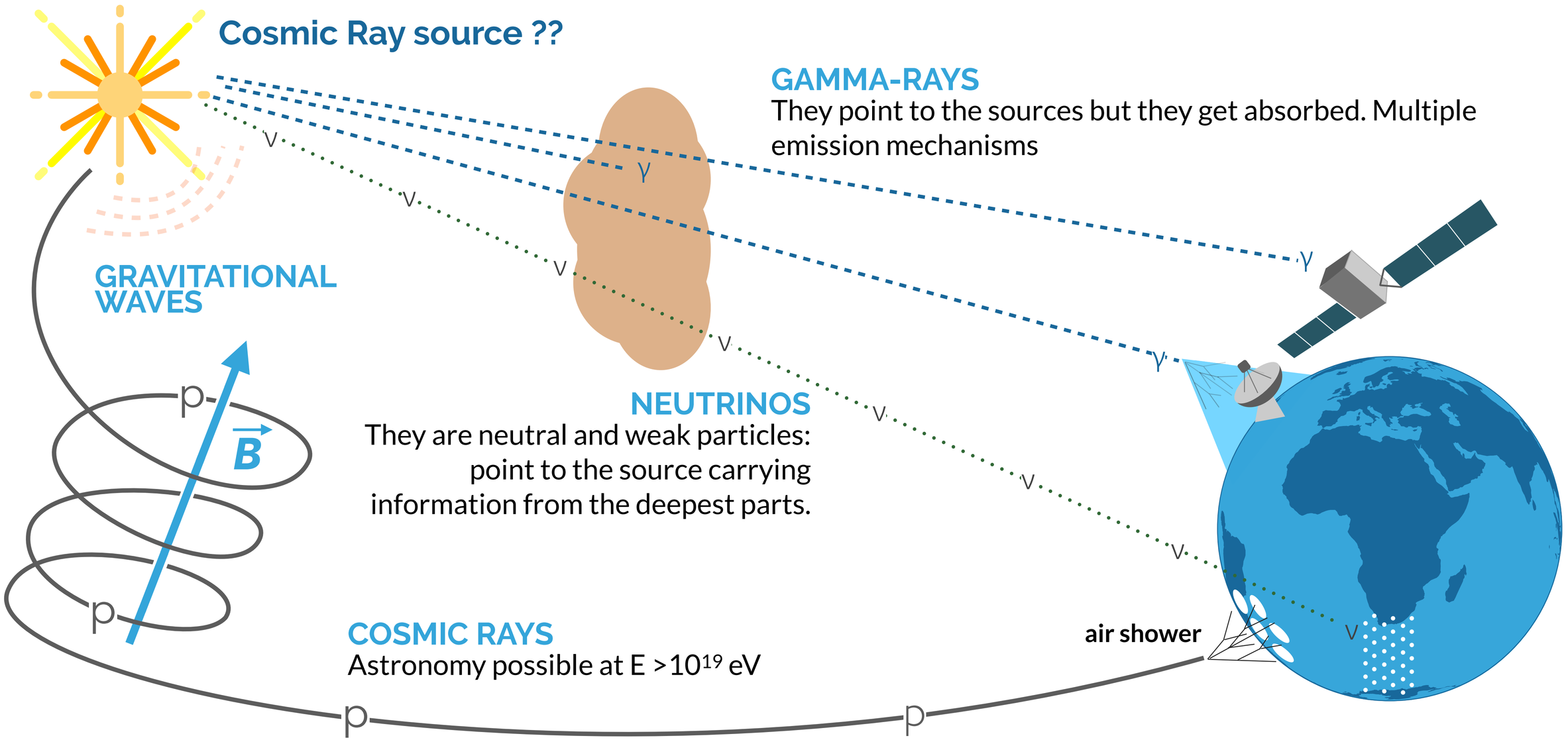
IceCube and Beyond

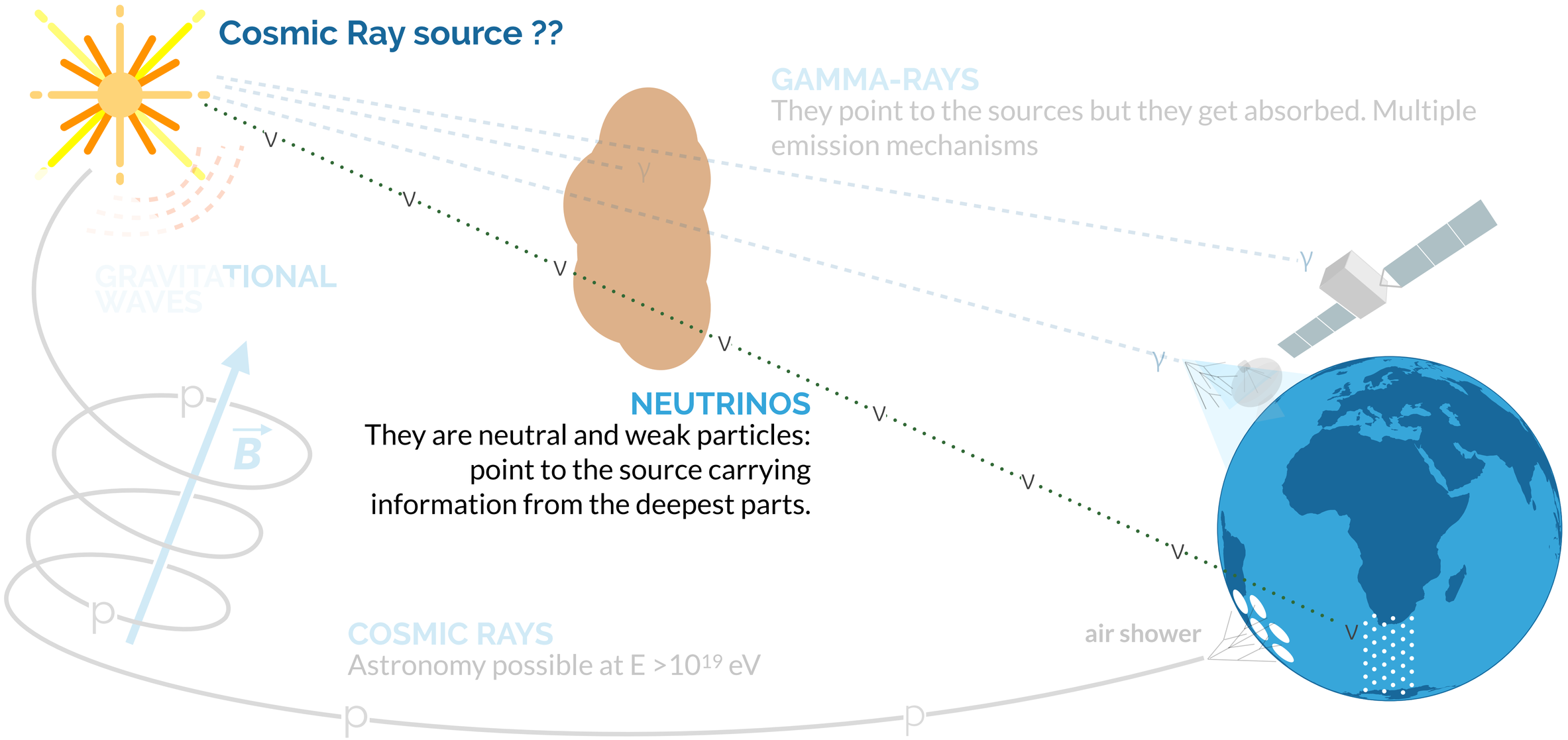
IIHE Annual Meeting

J. A. Aguilar on behalf of the IIHE IceCube group

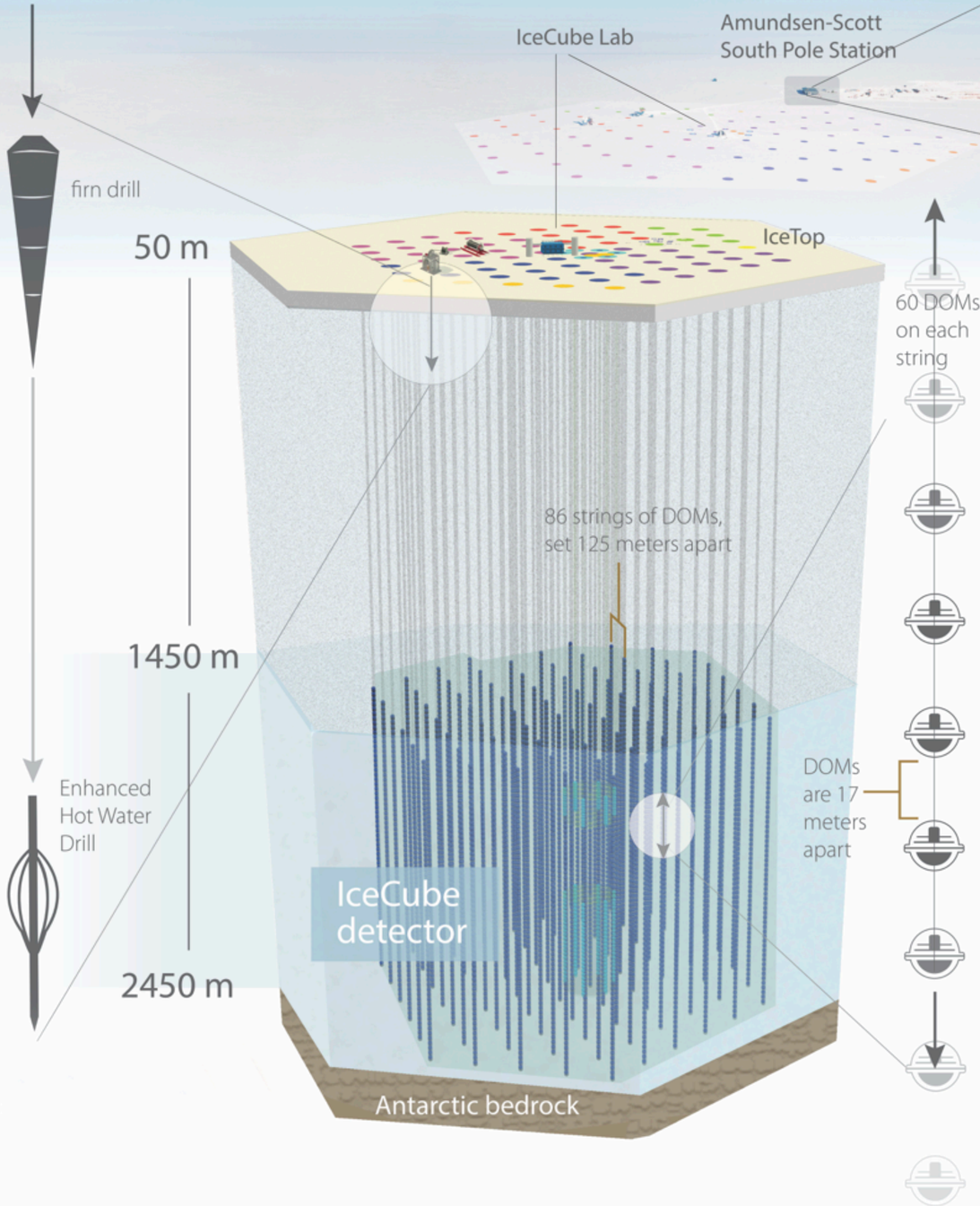
Multimessenger Astronomy



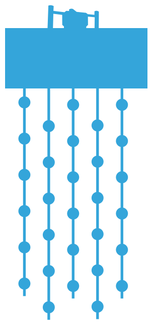
Neutrino Astronomy



IceCube Neutrino Observatory



5,160 Digital Optical Modules (DOMs)



86 string with 60 DOMs each

6 denser strings called **DeepCore**

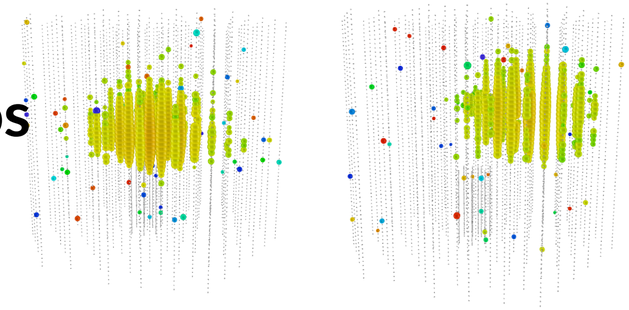
1 km^2 surface array with 324 DOMs: **IceTop**

Completion in December 2010

IceCube
A Decade of Discoveries

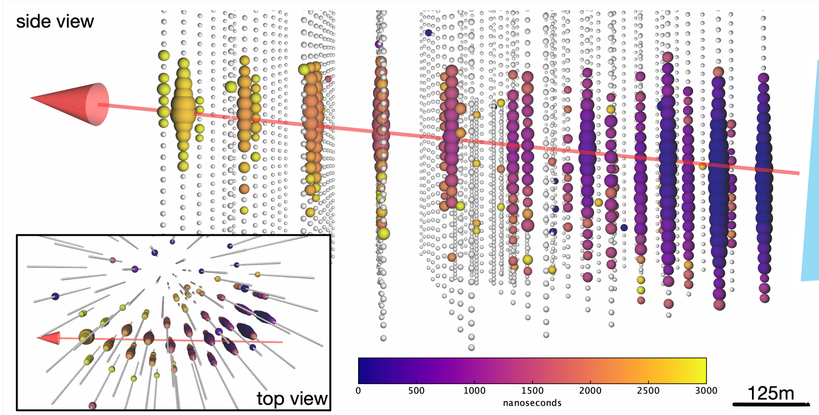
2013
Astrophysical Neutrinos

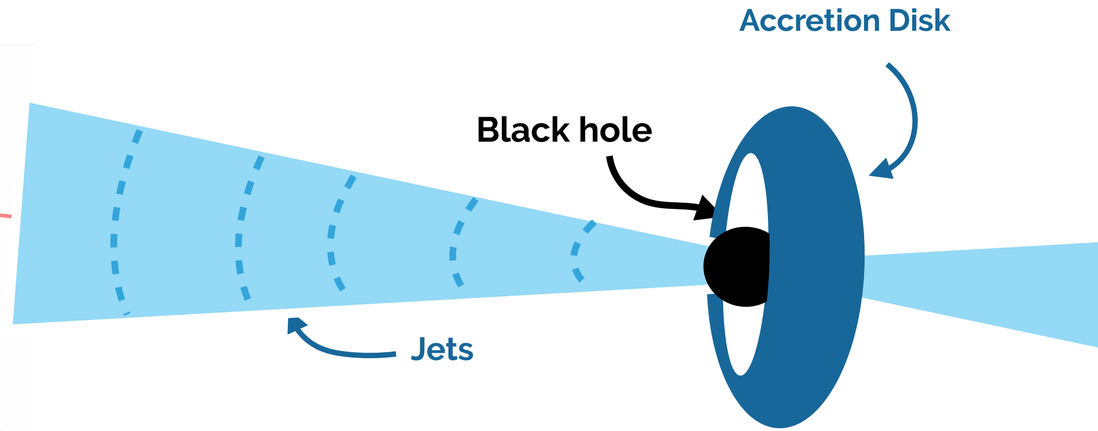
Detection of the first flux of astrophysical neutrinos

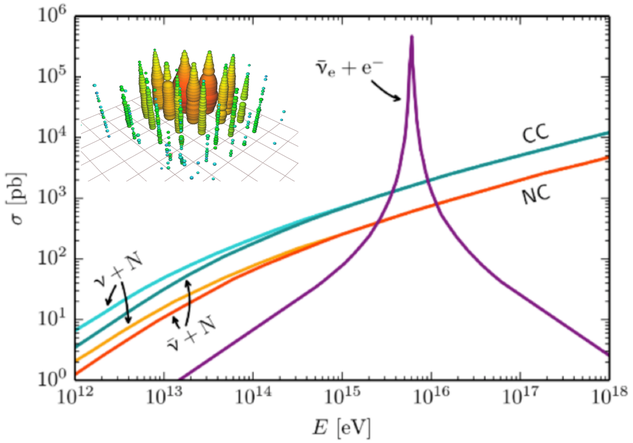


2017
TXS 0506+056

Coincidence of a neutrino event with a flare of gamma-rays from a Blazar





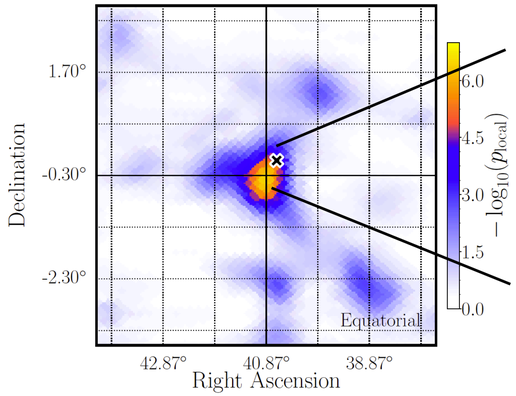


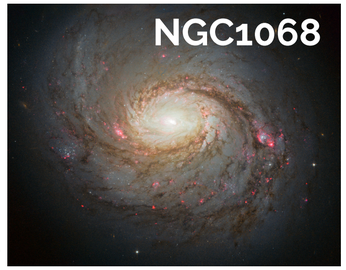
2021
Glashow Resonance Event

Observation of neutrino event at the Glashow energies (first $\overline{\nu}_e$)

2021
M77

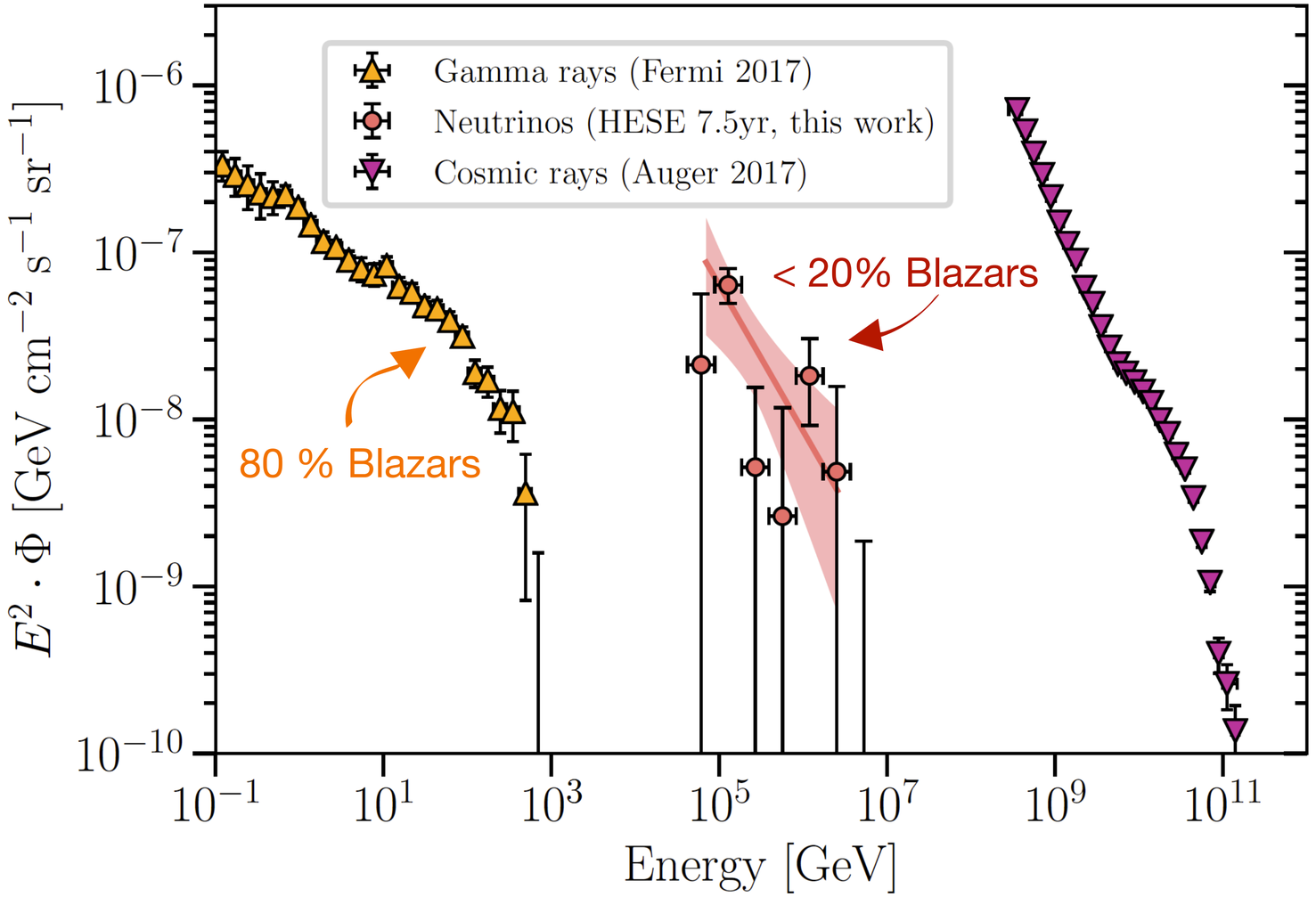
First hint of a point source in 10 years of data (2.9σ). Improved point source analysis on the way





Astrophysical Neutrinos

State-of-art

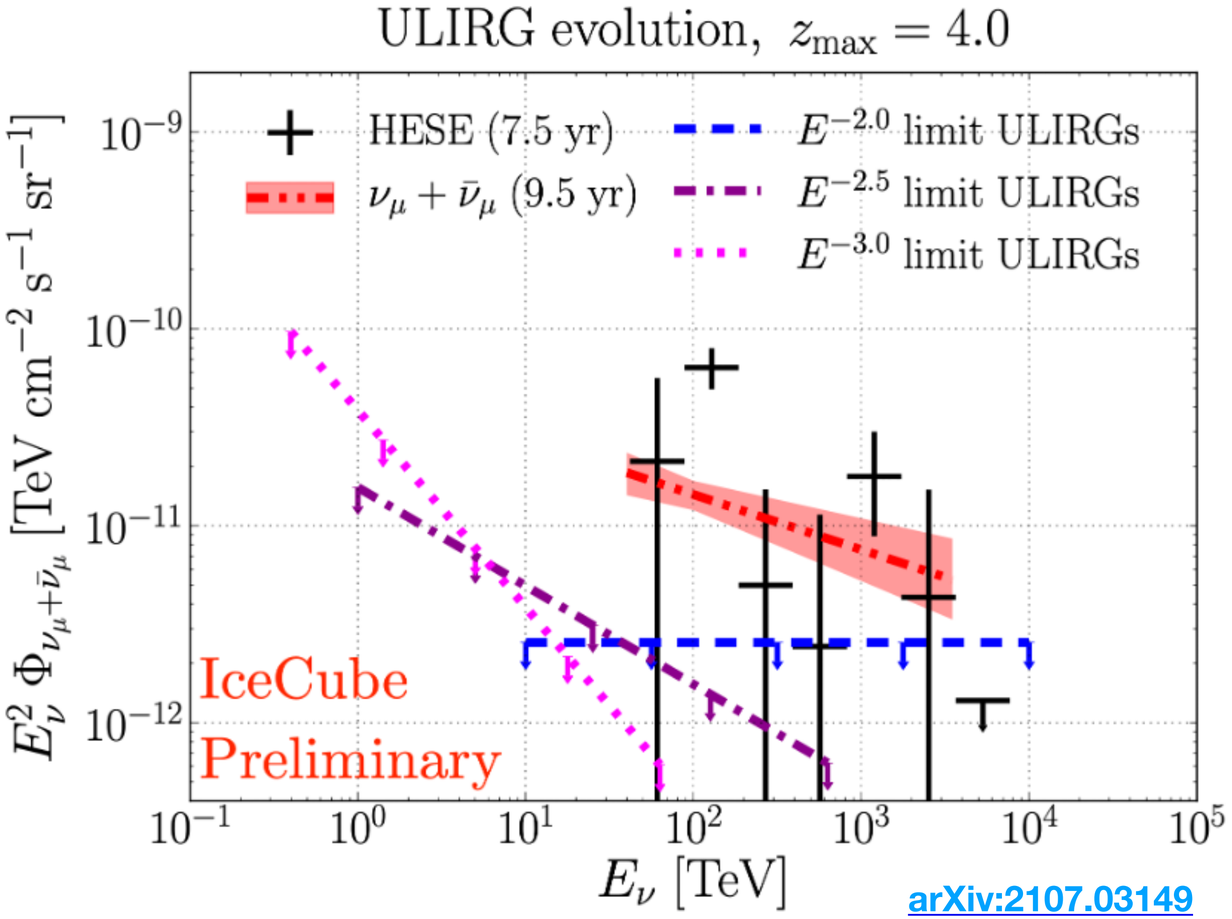


- Spectral index of astro. flux:
  $\gamma = 2.3 - 2.9$
  depends on analysis / energy range
- Similar energies among messengers … but also evidence for different origin!
- Gamma-obscured sources?

Astrophysical Neutrinos @ IIHE

Search for High-Energy Neutrinos from Ultra-Luminous Infrared Galaxies

- **ULIRGs**: $L_{IR} \geq 10^{12} L_{\odot}$ $(8 - 1000\ \mu\mathrm{m})$
  - Powered by starburst/AGN
  - Candidate neutrino sources
- **Stacking** analysis
  - 75 local ULIRGs (z ≤ 0.13)
  - 7.5 years of data
- **No neutrinos** found
  - Set upper limits
  - Constrained diffuse contribution of ULIRGs
  - Constrained model predictions

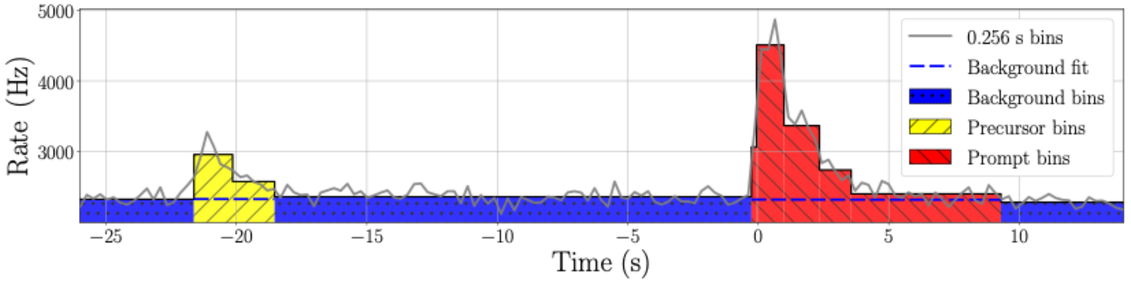


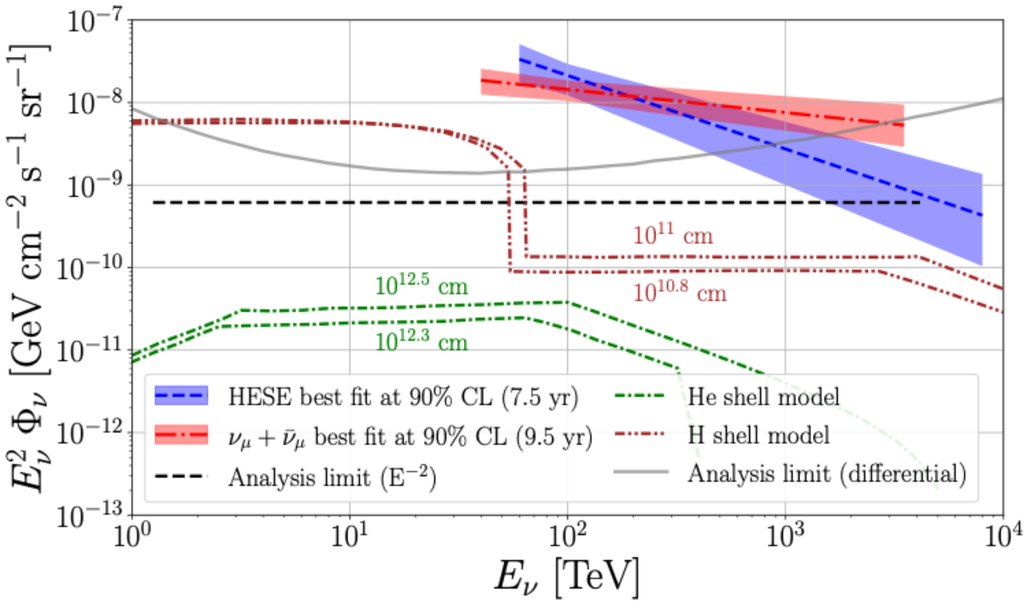
arXiv:2107.03149

Astrophysical Neutrinos @ IIHE

Neutrinos from gamma-ray burst precursors

- Transient events ofter a unique discovery opportunity.
- Analysed light curves of 2684 bursts from Fermi-GBM
  - 10% shows signs of precursor emission
  - New temporal features identified!
  - Published in PRD: [arXiv:2004.03246]
- Performed 2 searches with IceCube to look for coincident neutrinos
  - No significant coincidences observed
  - Able to limit model predictions!

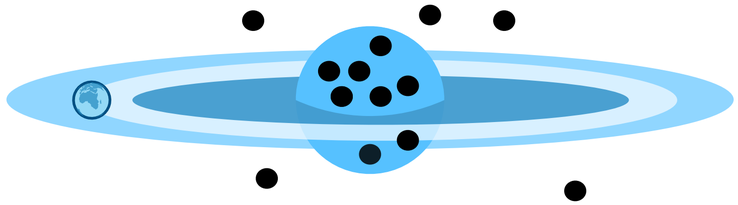




Paper in preparation

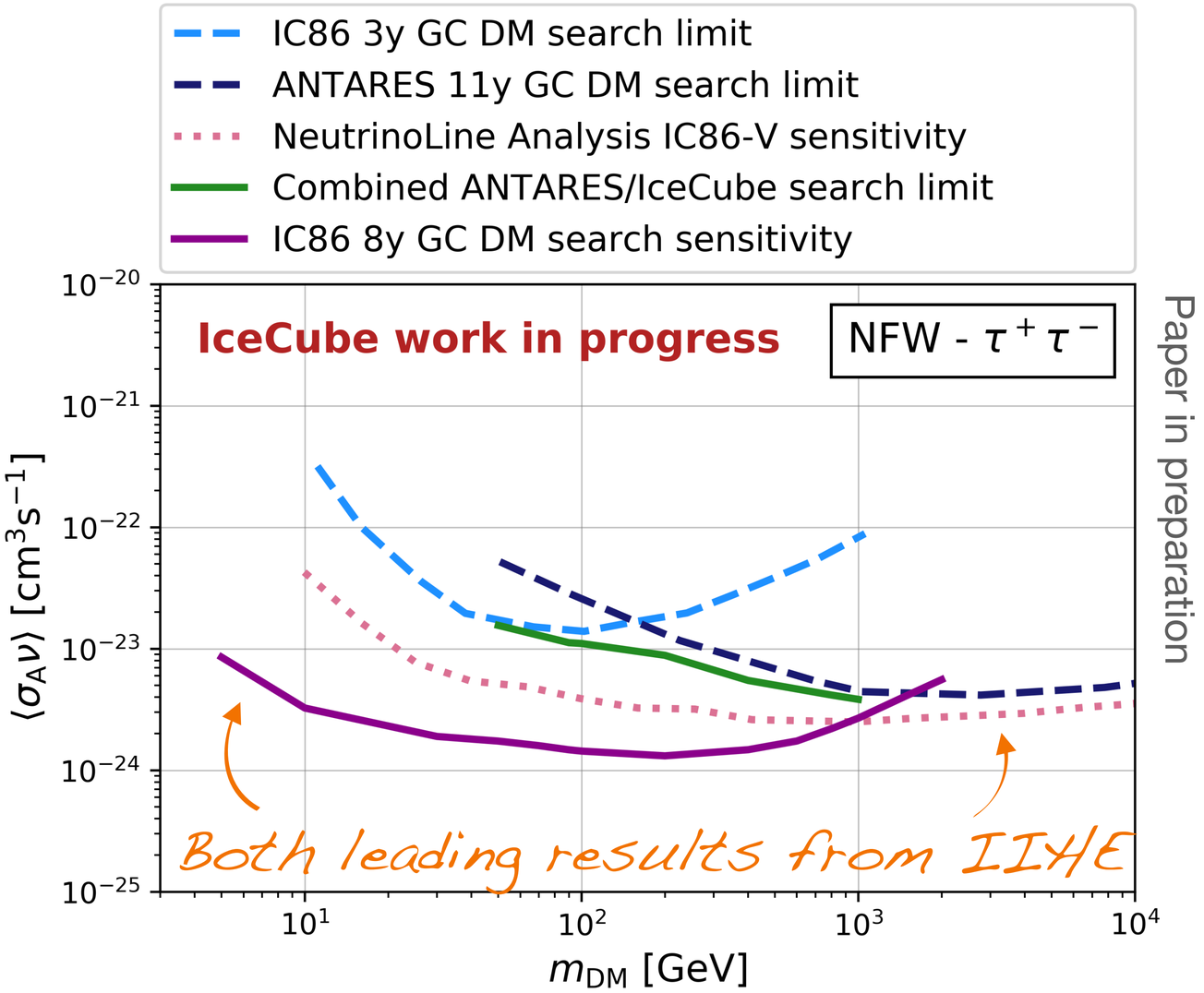
Particle Physics @ IIHE

Dark Matter Searches



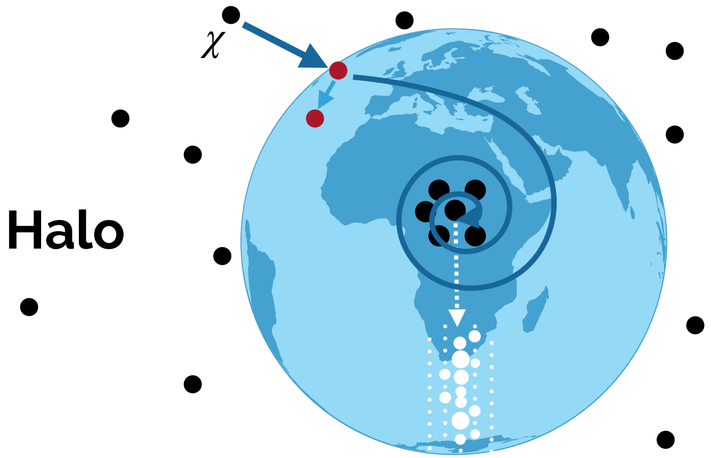
- Use neutrinos to search for annihilation/decay signatures of Dark Matter
  - Combined analysis with ANTARES using published data. [PhysRevD.102.082002]
- Performed 2 additional analyses:
  1. First analysis using energy and the neutrino spectra (Neutrino Lines) with the Service de Theory.
  2. Extending towards lower masses with Deep Core.

Best limits in neutrino channel in the whole mass range.



Particle Physics @ IIHE

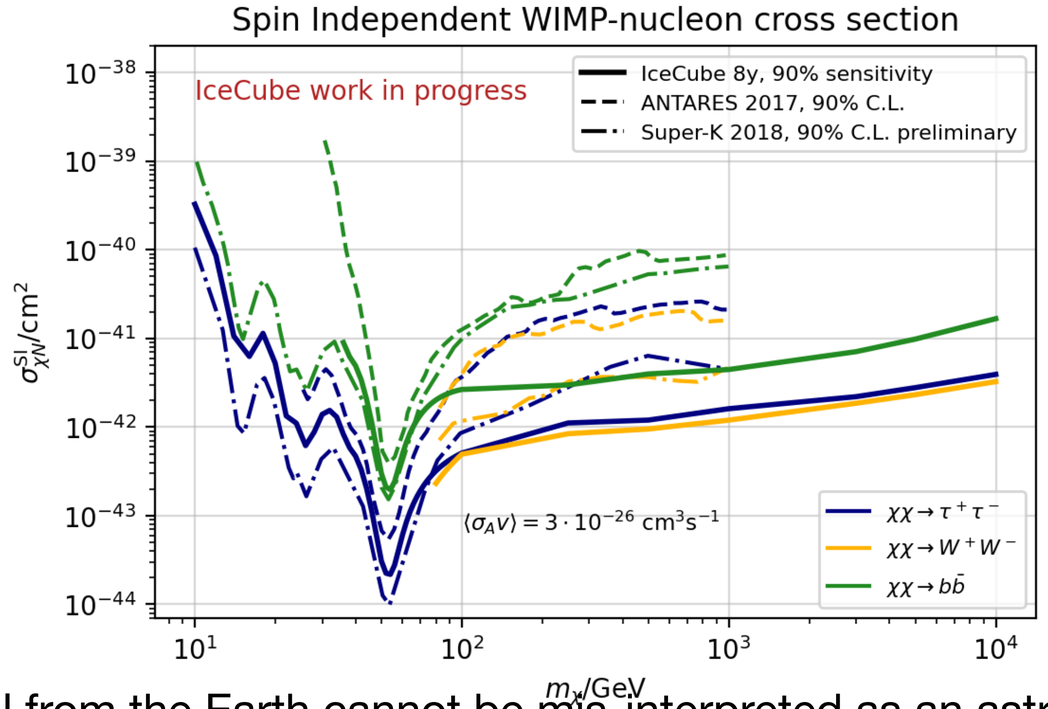
Dark Matter from the Center of the Earth



annihilation
σ_A

$$\frac{\mathrm{d}N}{\mathrm{d}t} = C_c - C_A N^2 - C_E N$$

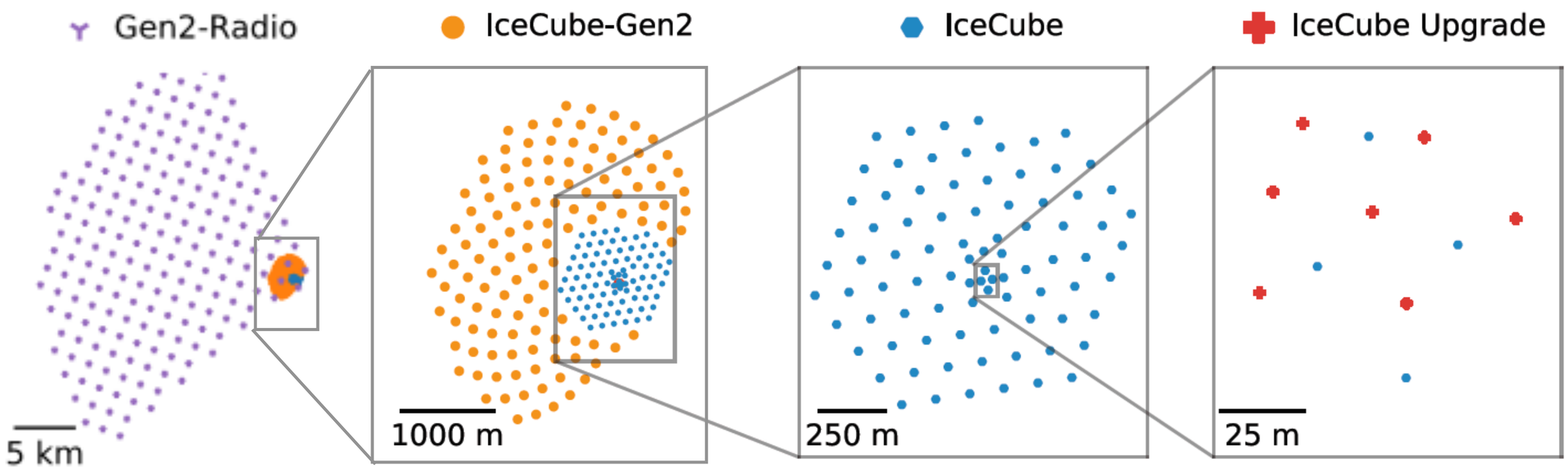
capture
$\sigma_{\chi-N}$



- Signal from the Earth cannot be mis-interpreted as an astrophysical source.
- We can relate the σ_A and $\sigma_{\chi-N}$
- IceCube has the best sensitivity above 100 GeV
- Analysis recently unblinded (no results public yet).

Future Extensions

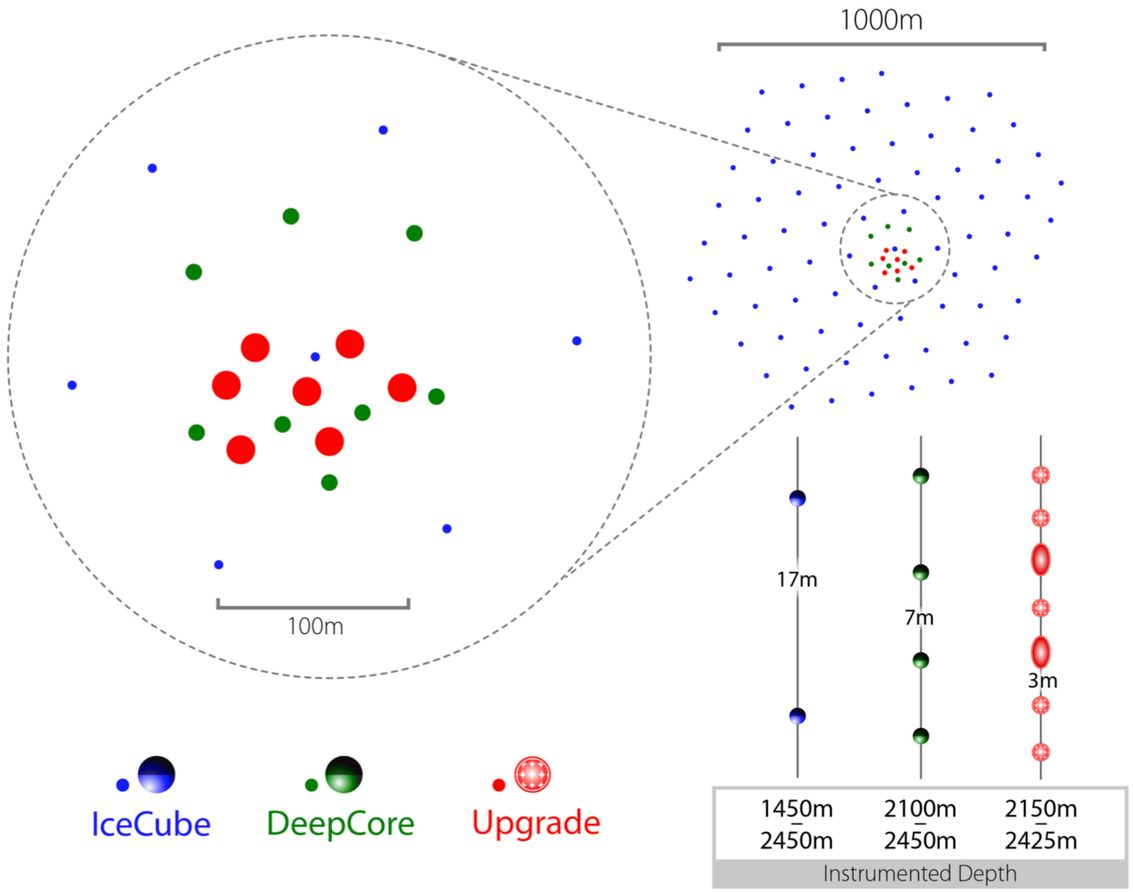
a.k.a IceCube Gen2 Phase I



EeV PeV TeV EeV E_ν

IceCube-Upgrade

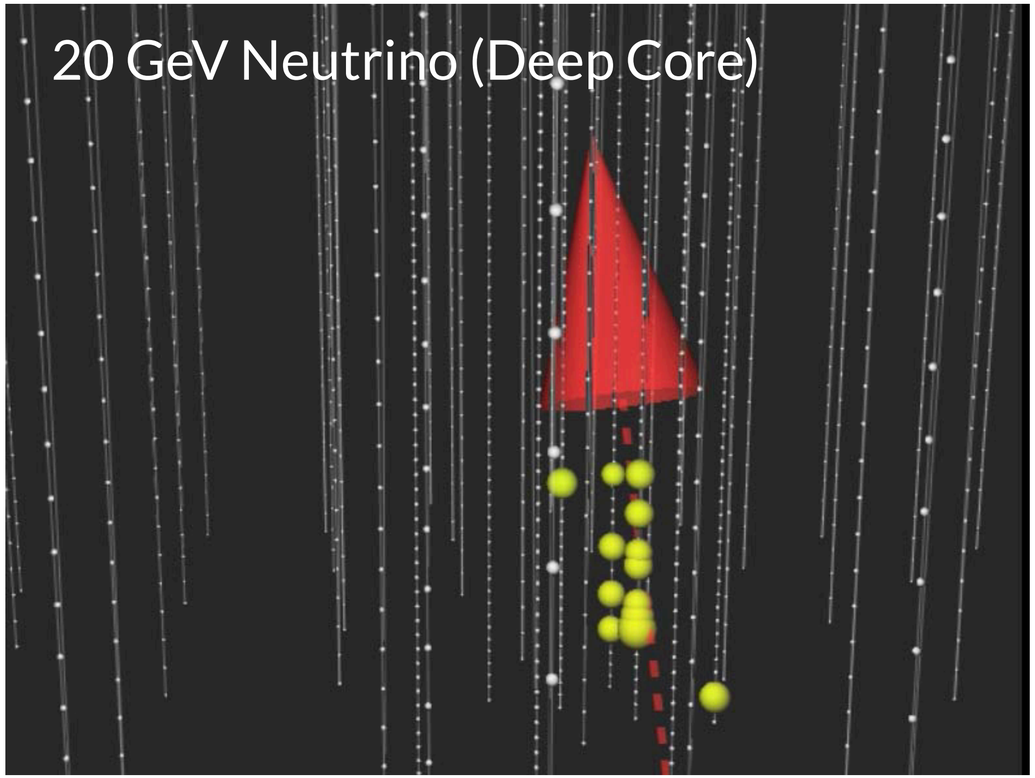
IceCube-Gen2 Phase I

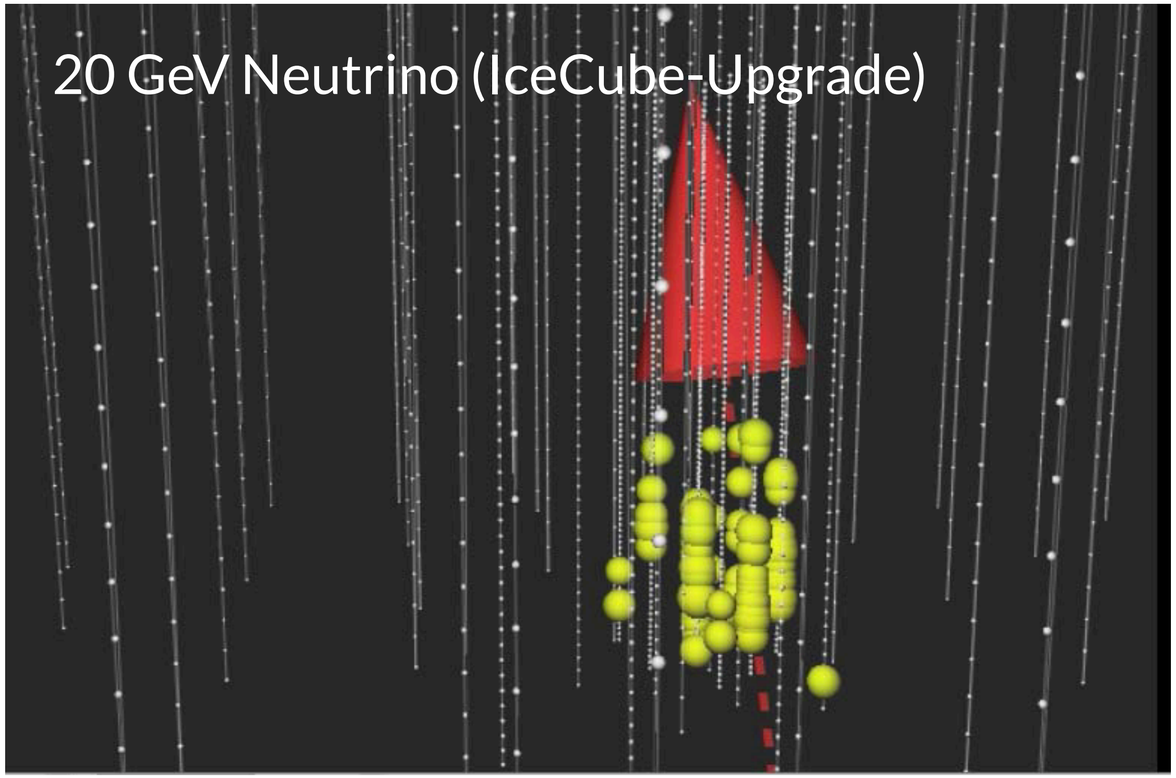


- Improved calibration of ice, reduced systematic uncertainties
- Improved angular and energy reconstructions.
- Precision measurement of atmospheric neutrino oscillations.
- Construction scheduled for 2022, delayed because COVID-19, rescheduling undergoing (1-2 years)

IceCube-Upgrade

Performance

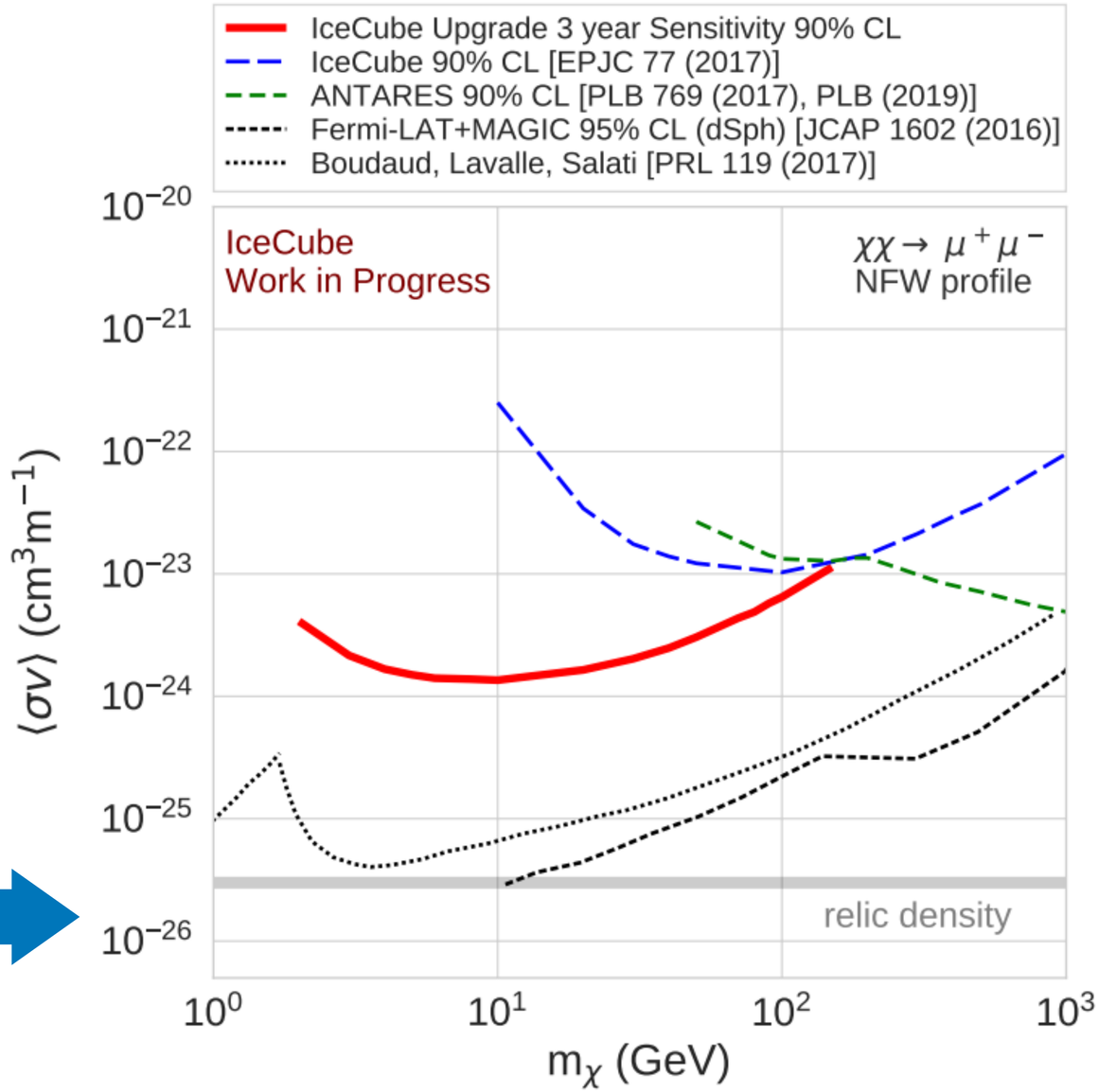




IceCube-Upgrade

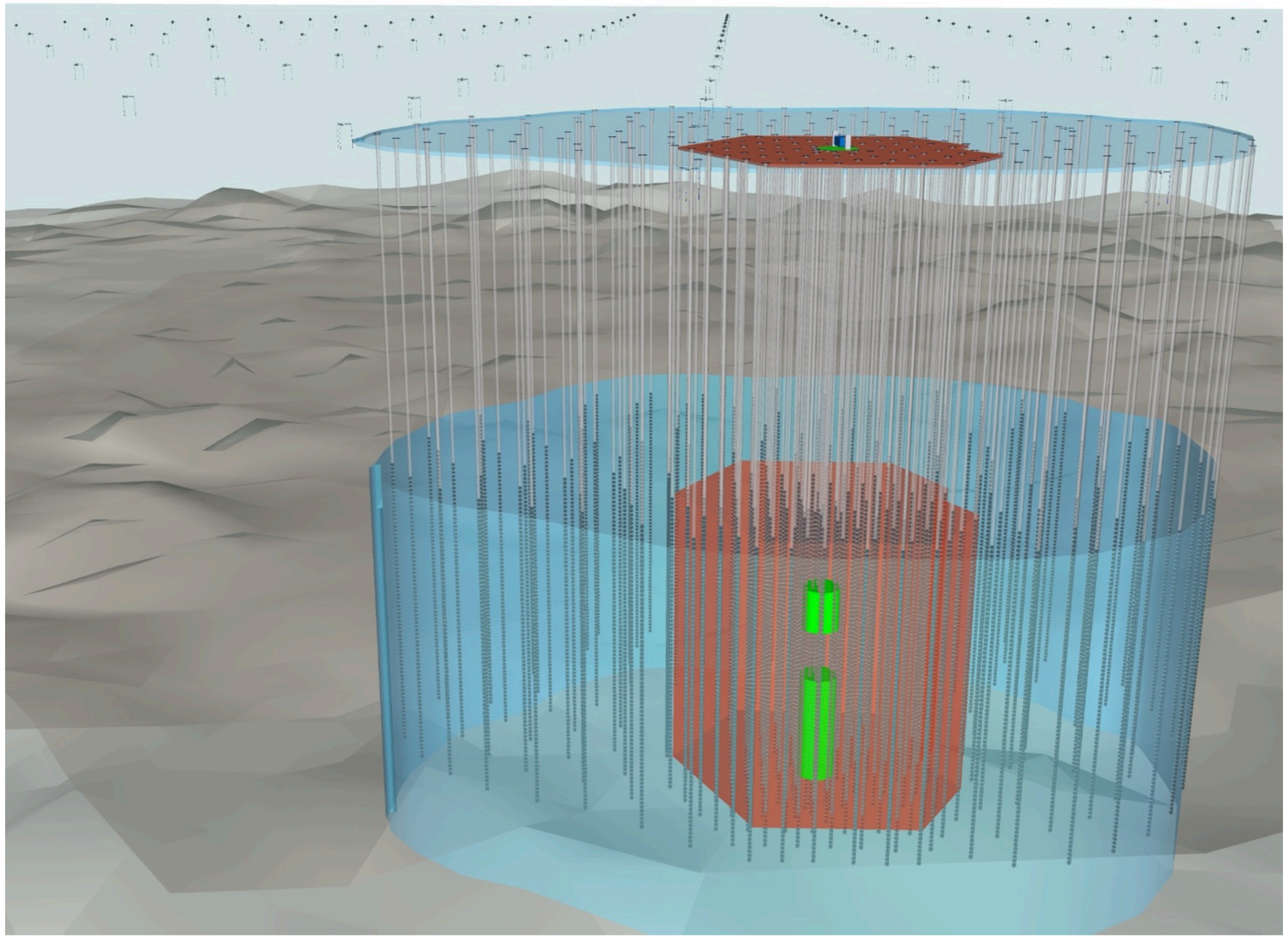
Science Case

- Unprecedented sensitivity to atmospheric neutrino mixing parameters and neutrino mass ordering
- Detailed calibration of ice properties.
- Expanding beyond the TeV-WIMP paradigm.
- Preliminary studies for DM made at the IIHE [PoS (ICRC2019) 506]



IceCube-Gen2

- Three new elements, leveraging complimentary technologies, to achieve sensitivity to MeV-EeV neutrinos:
  - Enlarge deep optical array
  - Surface Array extension
  - Shallow Radio Array

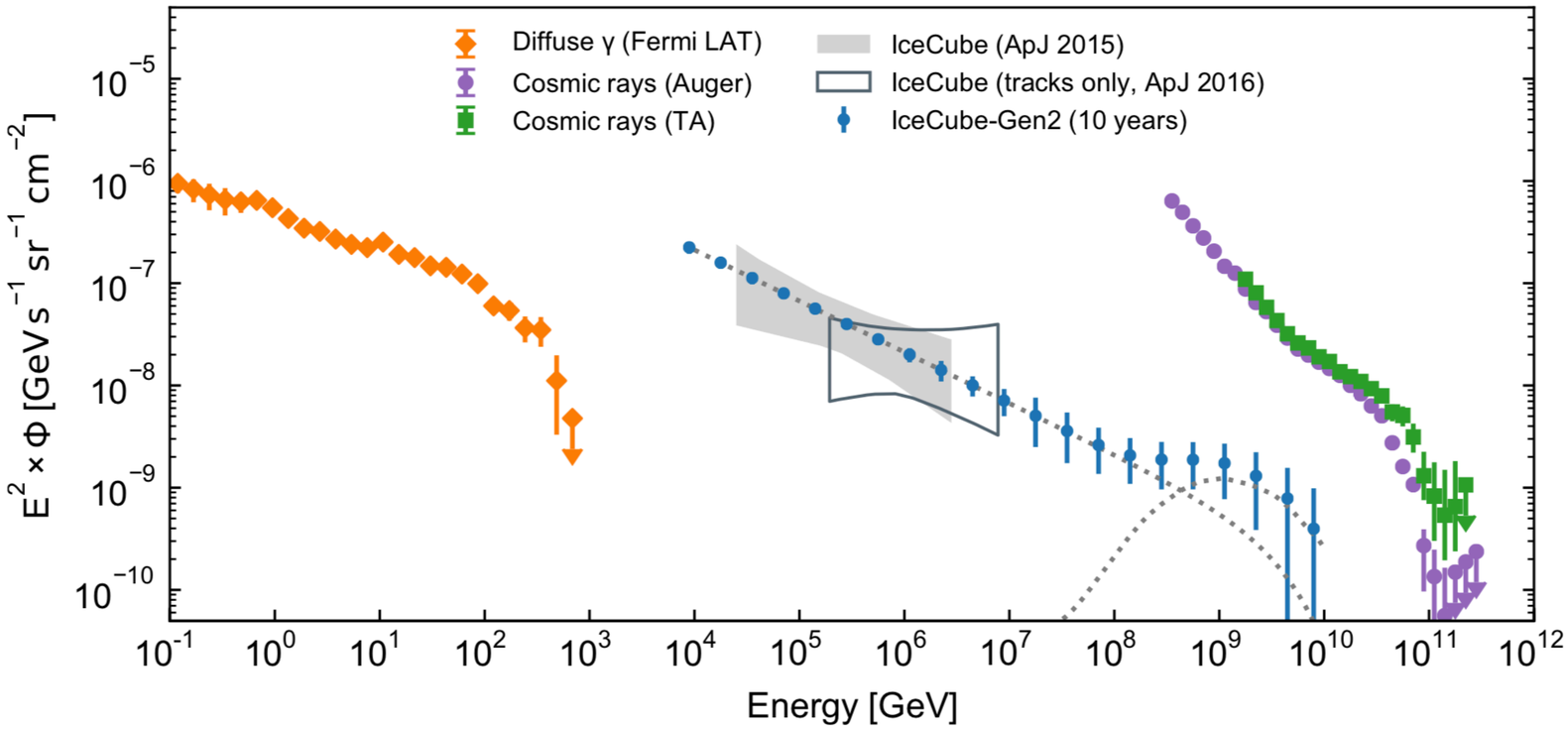


IceCube-Gen2

Science

- 5x improvement in effective area
- 2x improvement in angular resolution

Multimessenger spectroscopy

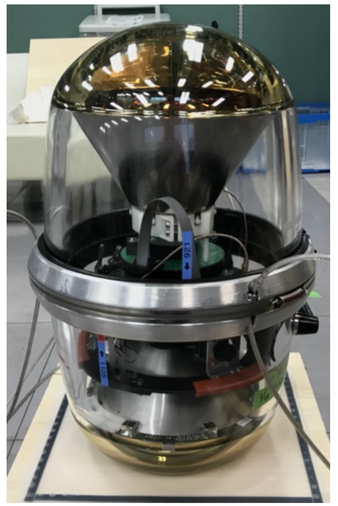


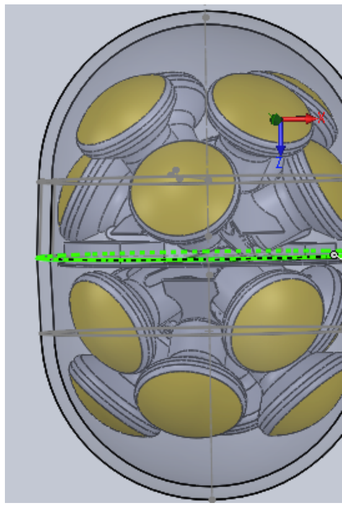
Is there a change in the spectrum?
Is there a cut-off?
Are there cosmogenic neutrinos there?

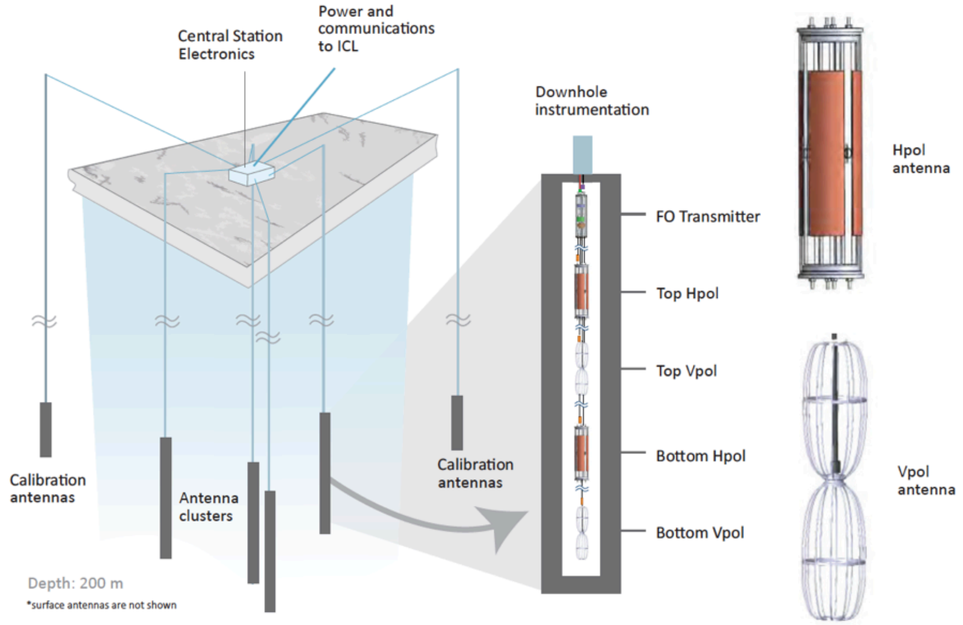
IceCube-Gen2

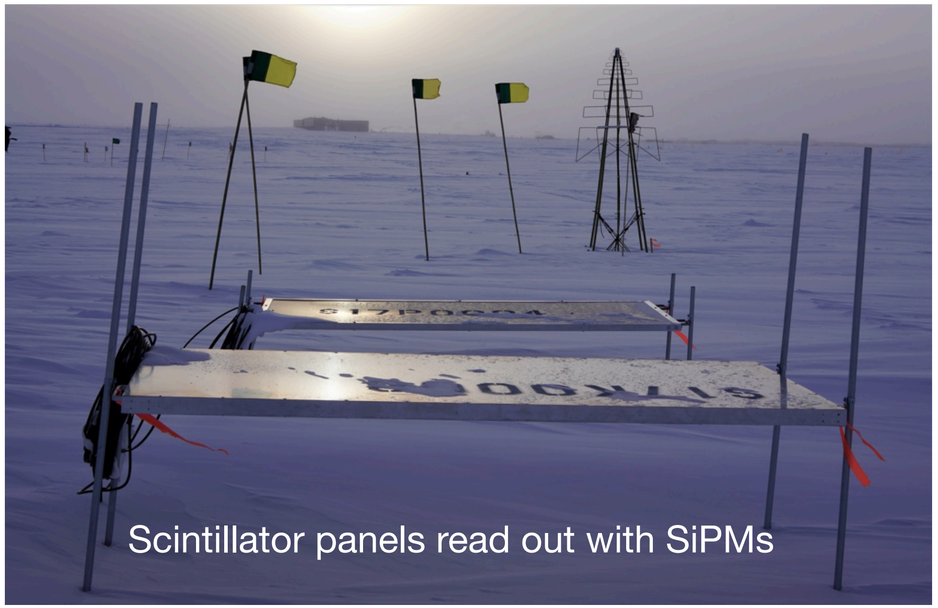
Instrumentation

Pixelated optical modules, surface technology, radio technology, …



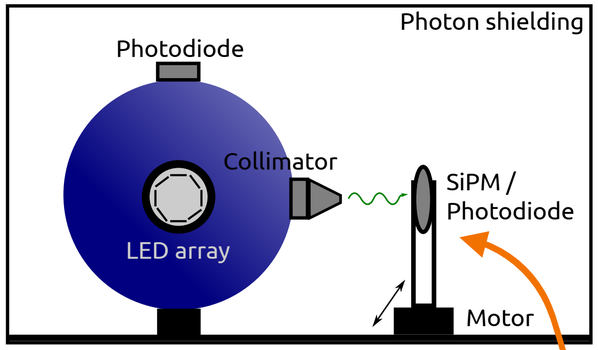






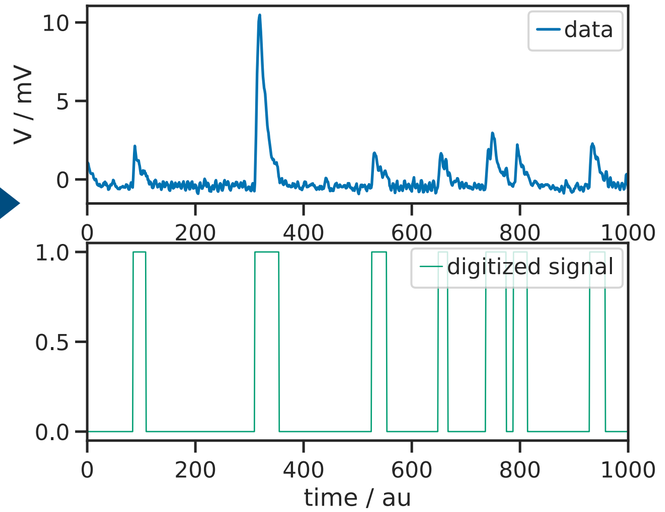
IceCube-Gen2 @ IIHE

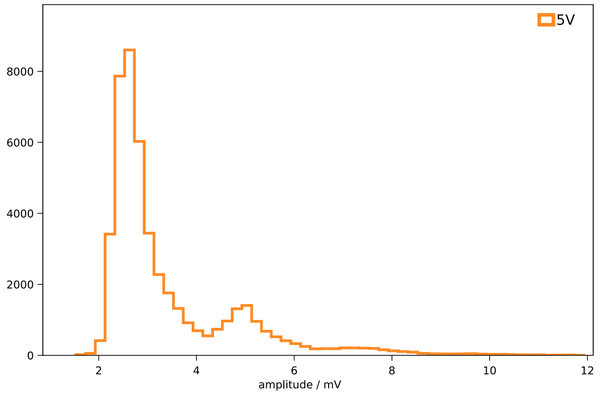
Calibration and Characterization of SiPMs

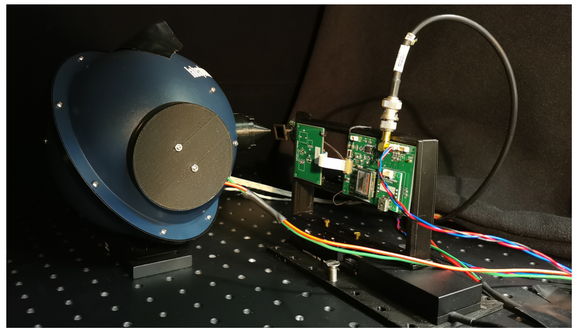


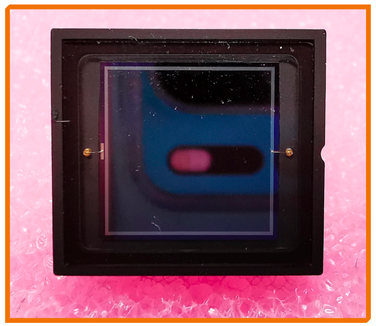
Signal Extraction

from raw traces









- Characterize the breakdown voltage, gain, resolution and noise.
- Measure the Photo Detection Efficiency.
- Future: Climate Chamber to estimate the properties at different temperatures.
- Applications to other experiments: Proton therapy, etc.

Conclusions

- IceCube just had its 10 years birthday!
- We witnessed several important results in this past decade, and the IIHE was very much involved but…
- …we need a bigger detector!
- IceCube-Gen2 is designed and optimized to harvest the enormous scientific opportunities.

Conclusions

- IceCube just had its 10 years birthday!
- We witnessed several important results in this past decade, and the IIHE was very much involved but…
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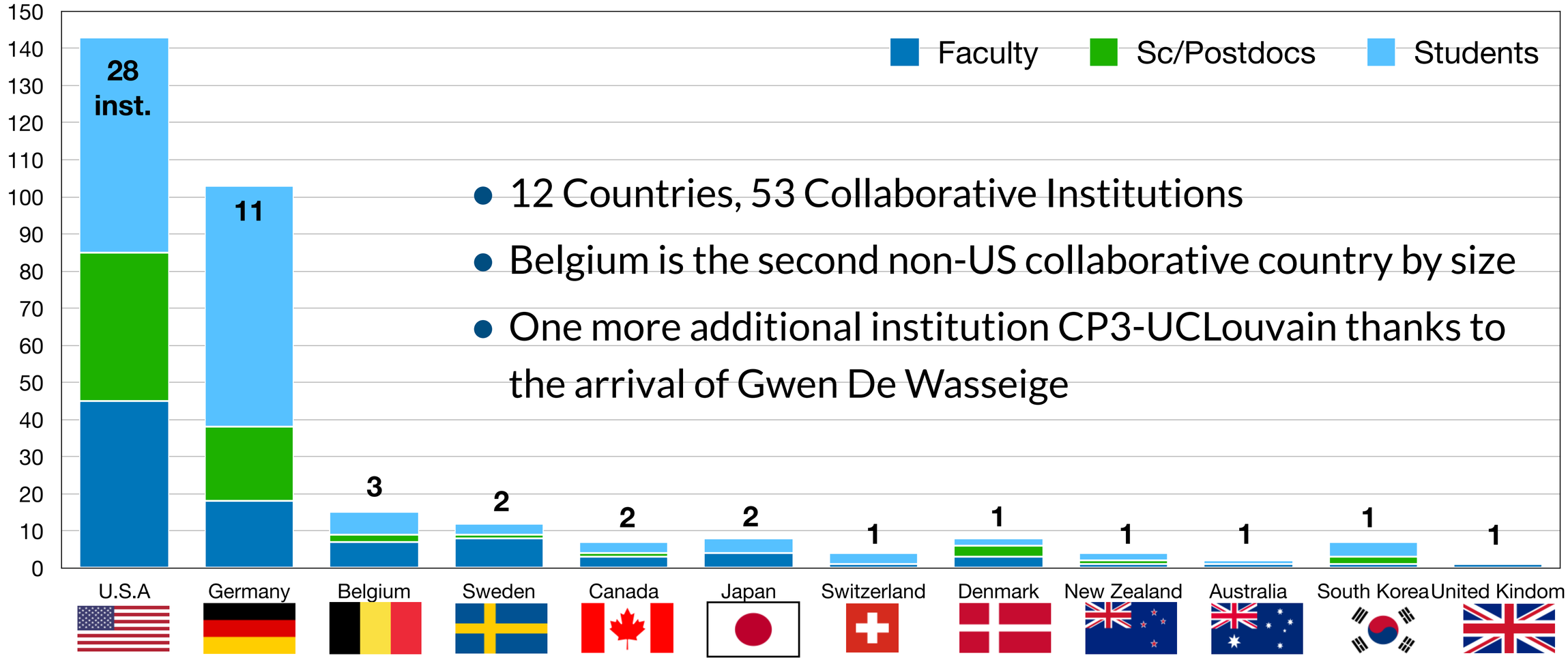
Backups

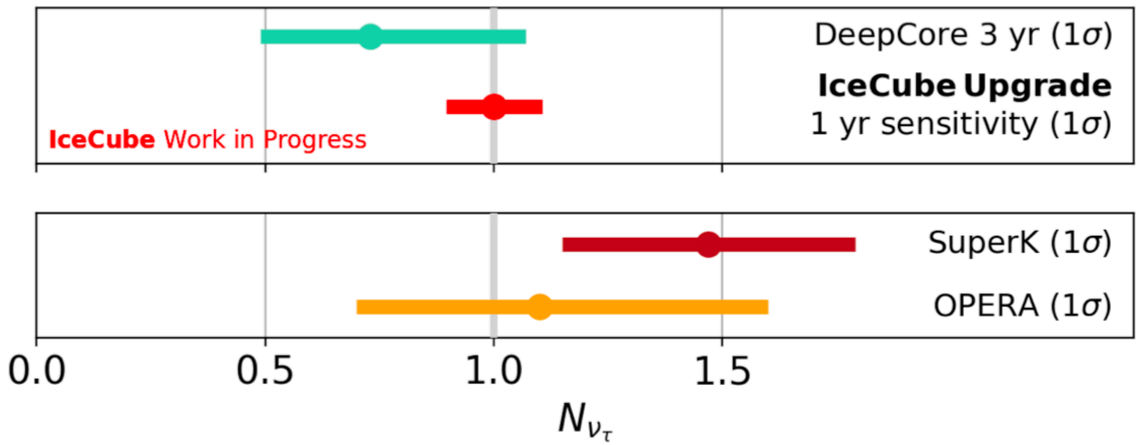
Belgium in IceCube

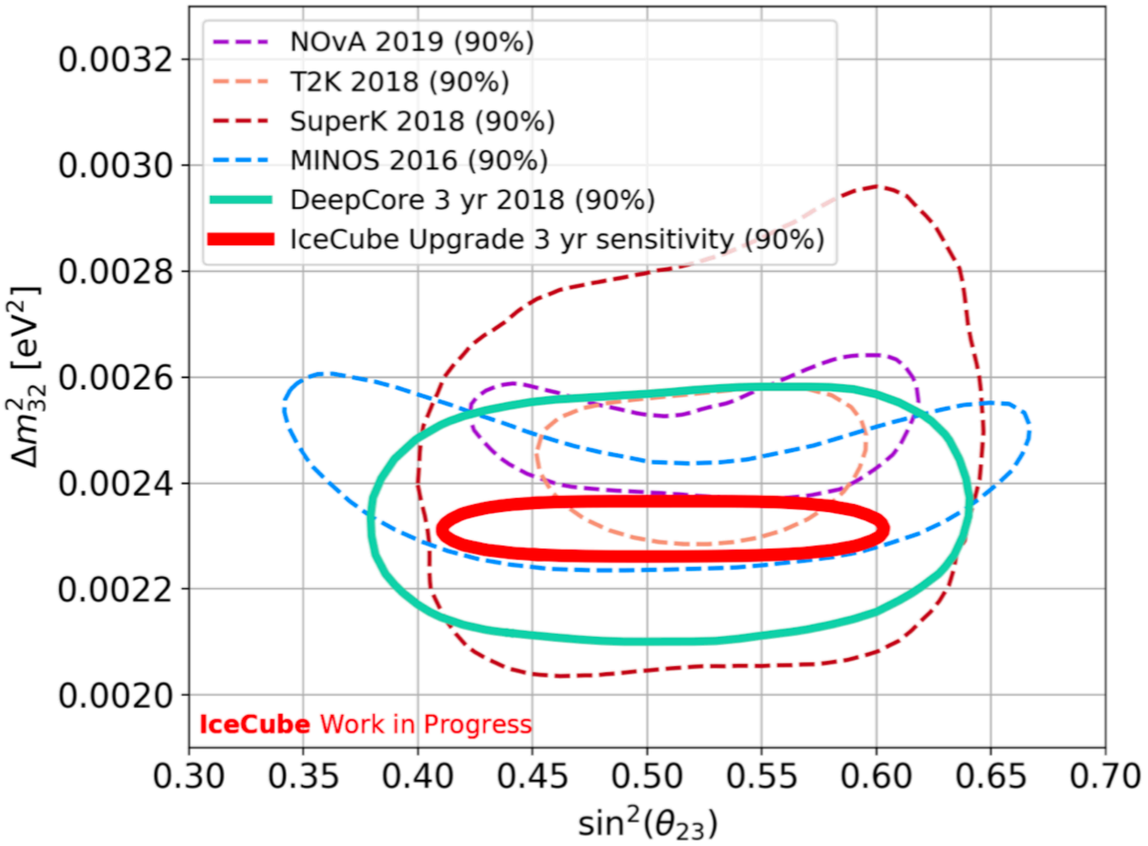


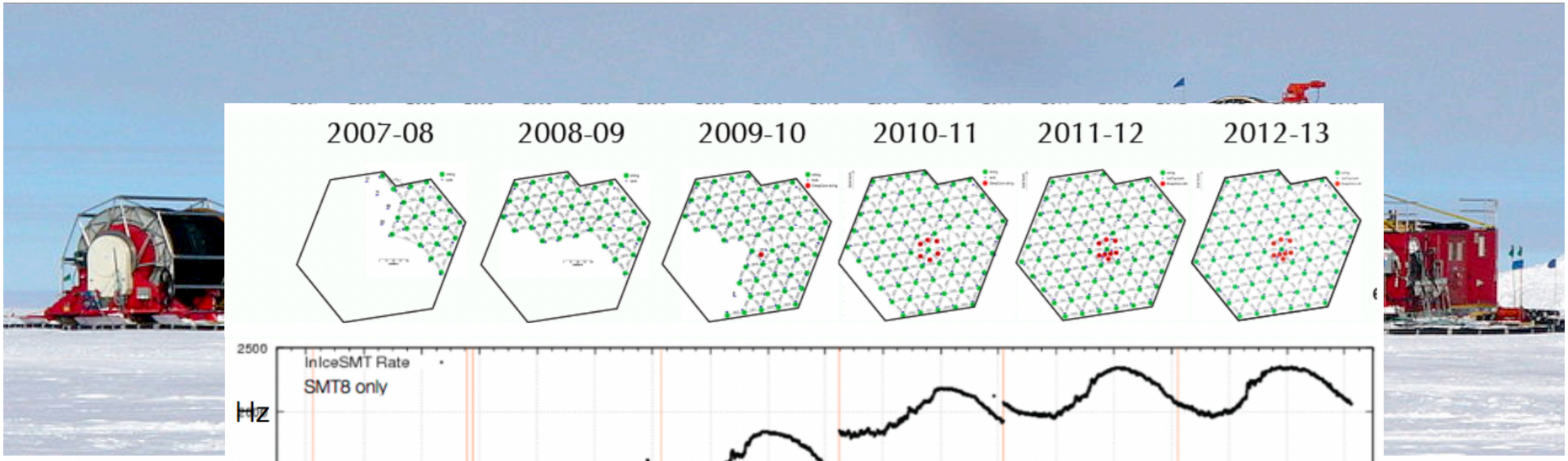
- 12 Countries, 53 Collaborative Institutions
- Belgium is the second non-US collaborative country by size
- One more additional institution CP3-UCLouvain thanks to the arrival of Gwen De Wasseige

IceCube GEN2

IceCube-Upgrade






2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
InIceSMT Rate
SMT8 only
Hz
2500
1500
1000
500
IC22
IC40
IC59
IC79
IC86_1
IC86_2
99.55% detector uptime
0.7% sensor drop-out post deployment
05/01 2007
09/01 2007
01/01 2008
05/01 2008
09/01 2008
01/01 2009
05/01 2009
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05/01 2010
09/01 2010
01/01 2011
05/01 2011
09/01 2011
01/01 2012
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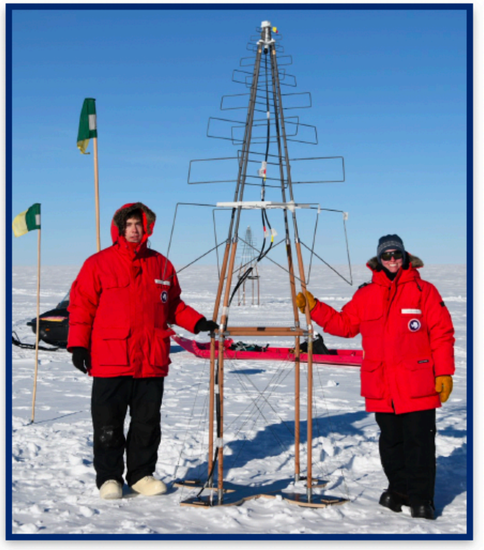
01/01 2013
05/01 2013

A

IceCube Installation

Operating sensors in the ice since 2006, with no evidence for aging

New surface technology



Scintillator / radio station deployed at South Pole (2019) (PoS ID 314)

IceCube Upgrade / Gen2 Phase 1

Deployment of next generation sensors (see next slide)

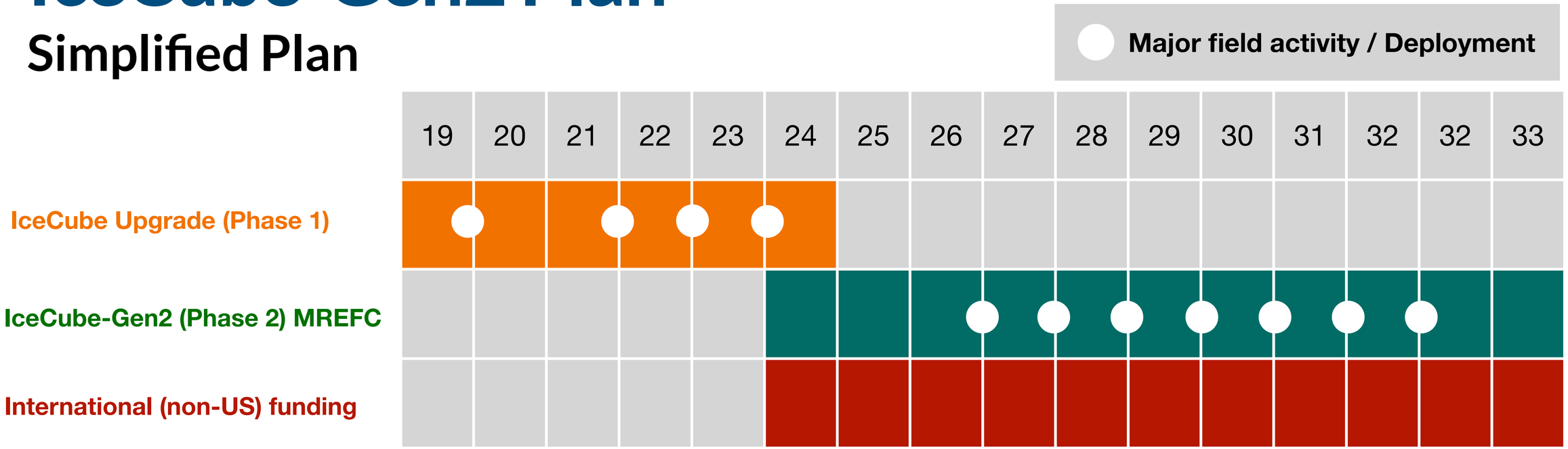
Radio-Tests in Greenland

Radio technology deployed in Greenland (2021, see S. Wissel et al., PoS ID 001)

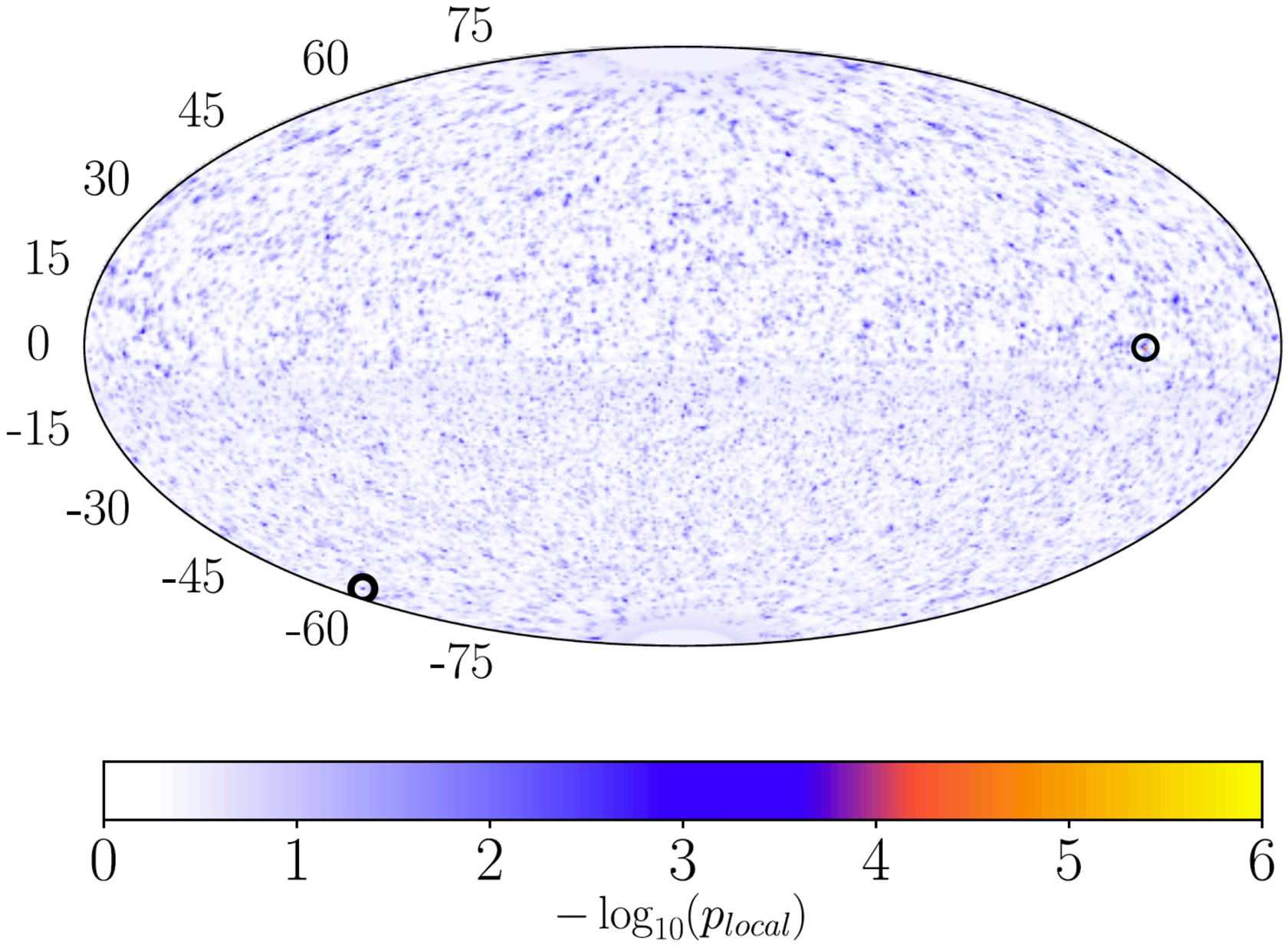
IceCube GEN2

IceCube-Gen2 Plan

Simplified Plan



IceCube GEN2


75
60
45
30
15
0
-15
-30
-45
-60
-75
0
1
2
3
4
5
6
$-\log_{10}(p_{local})$