

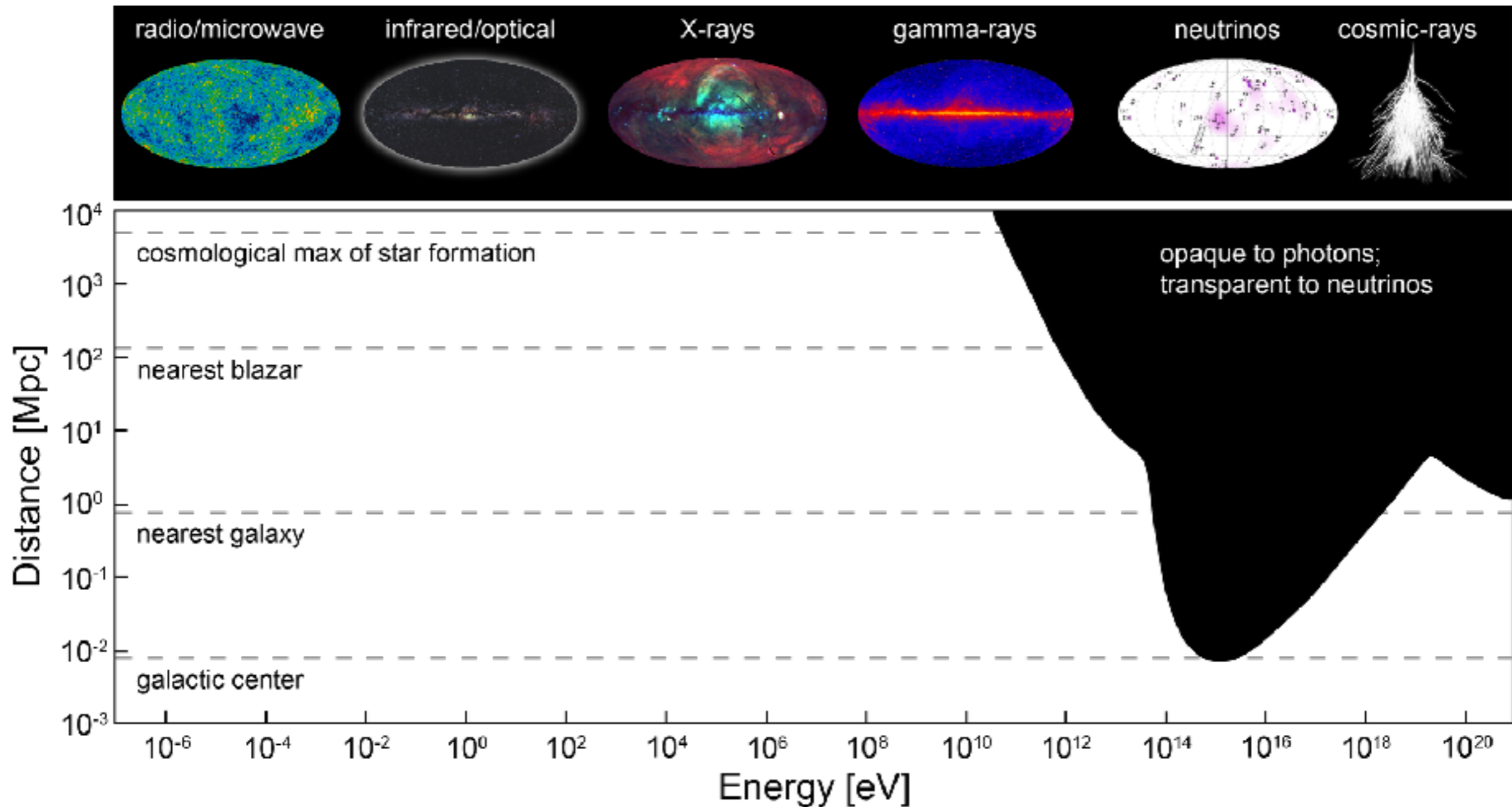


IceCube-Gen2 & IceCube-Upgrade

Marek Kowalski
DESY & Humboldt-University

NOW 2018

Science driver in a nutshell

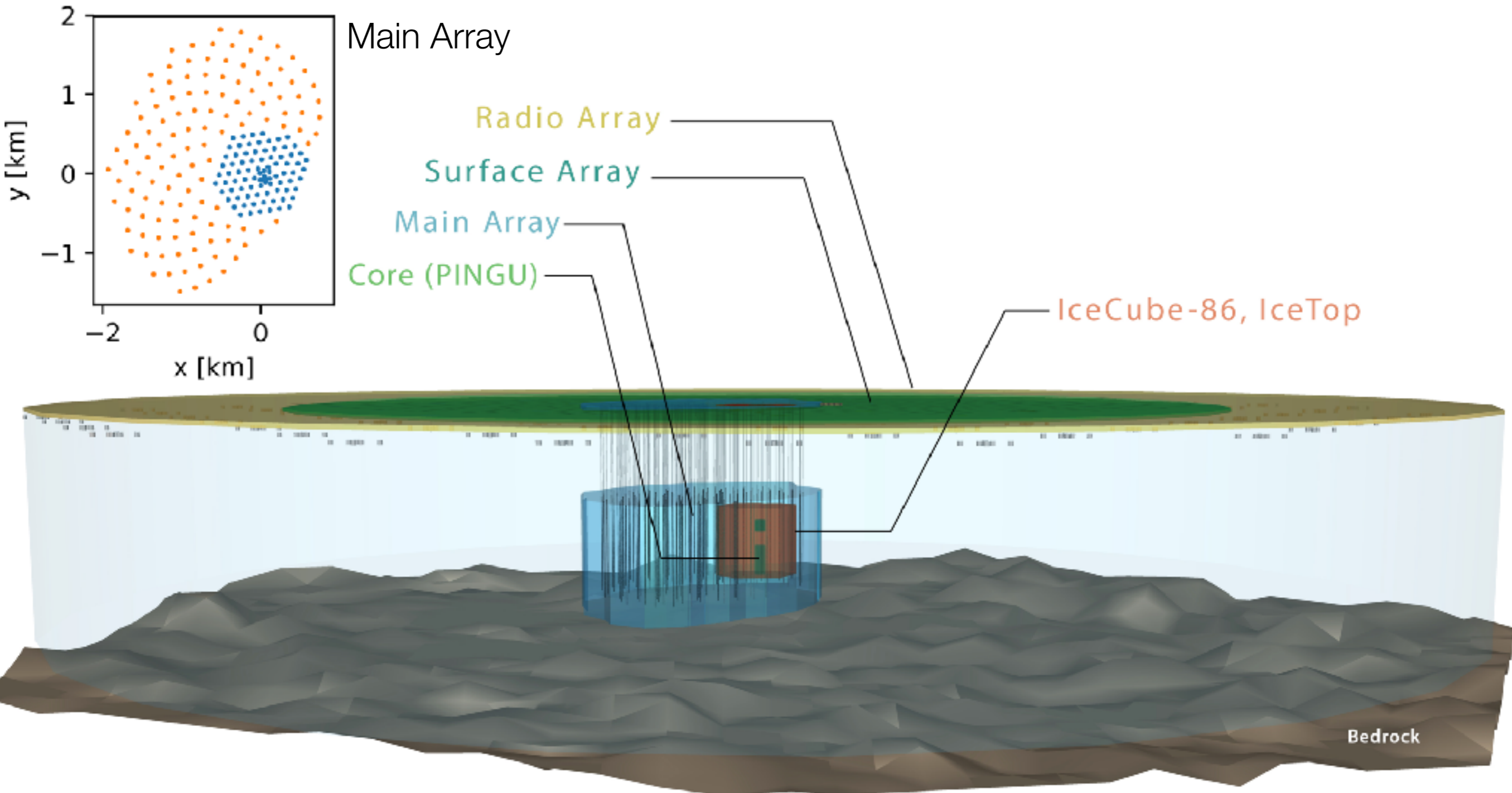


The Universe is opaque to EM radiation for $\frac{1}{4}$ of the spectrum, i.e. above 10-100 TeV where IceCube sees cosmic neutrinos.
 \Rightarrow explore this mostly uncharted territory with IceCube-Gen2

IceCube-Gen2 Facility



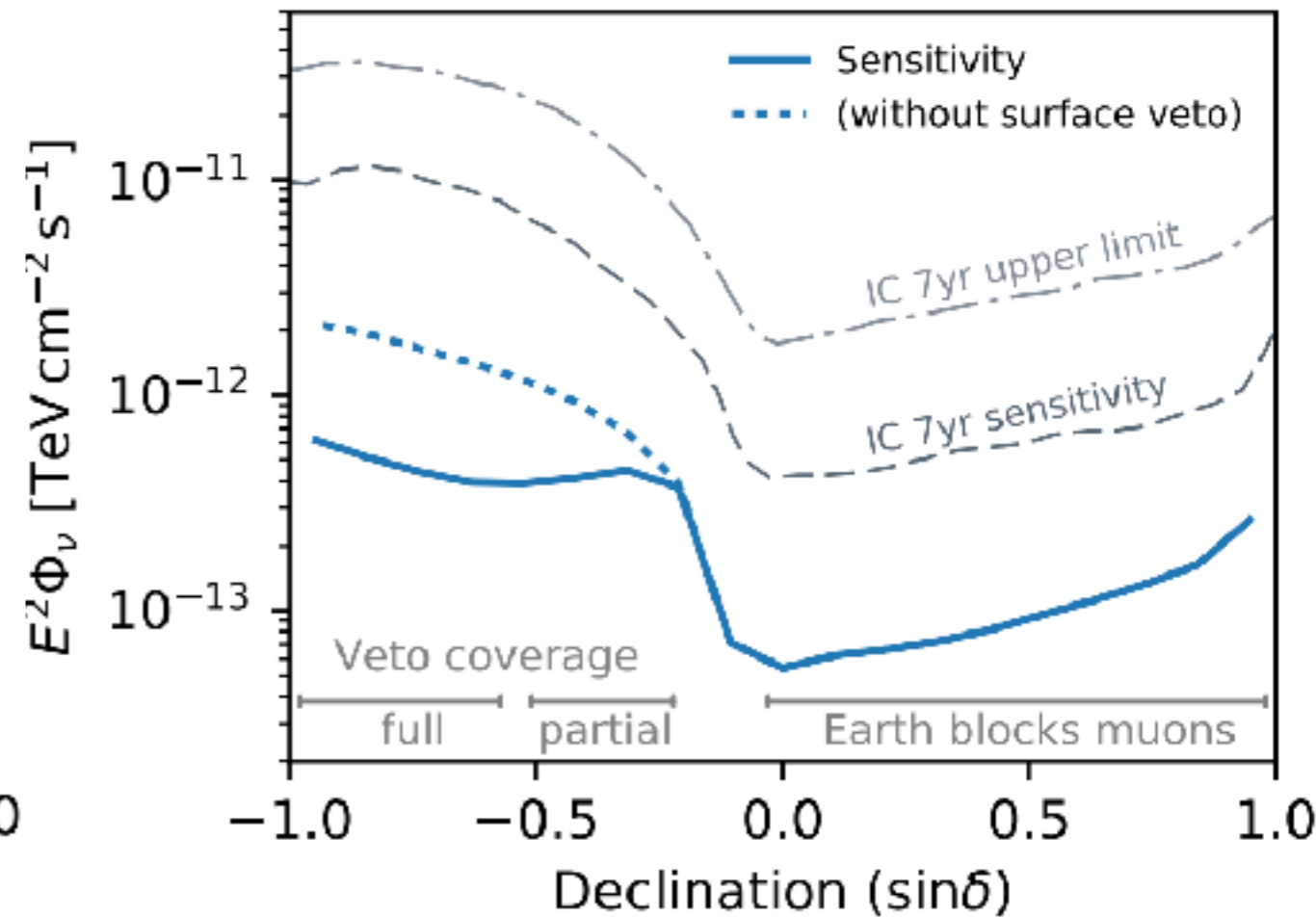
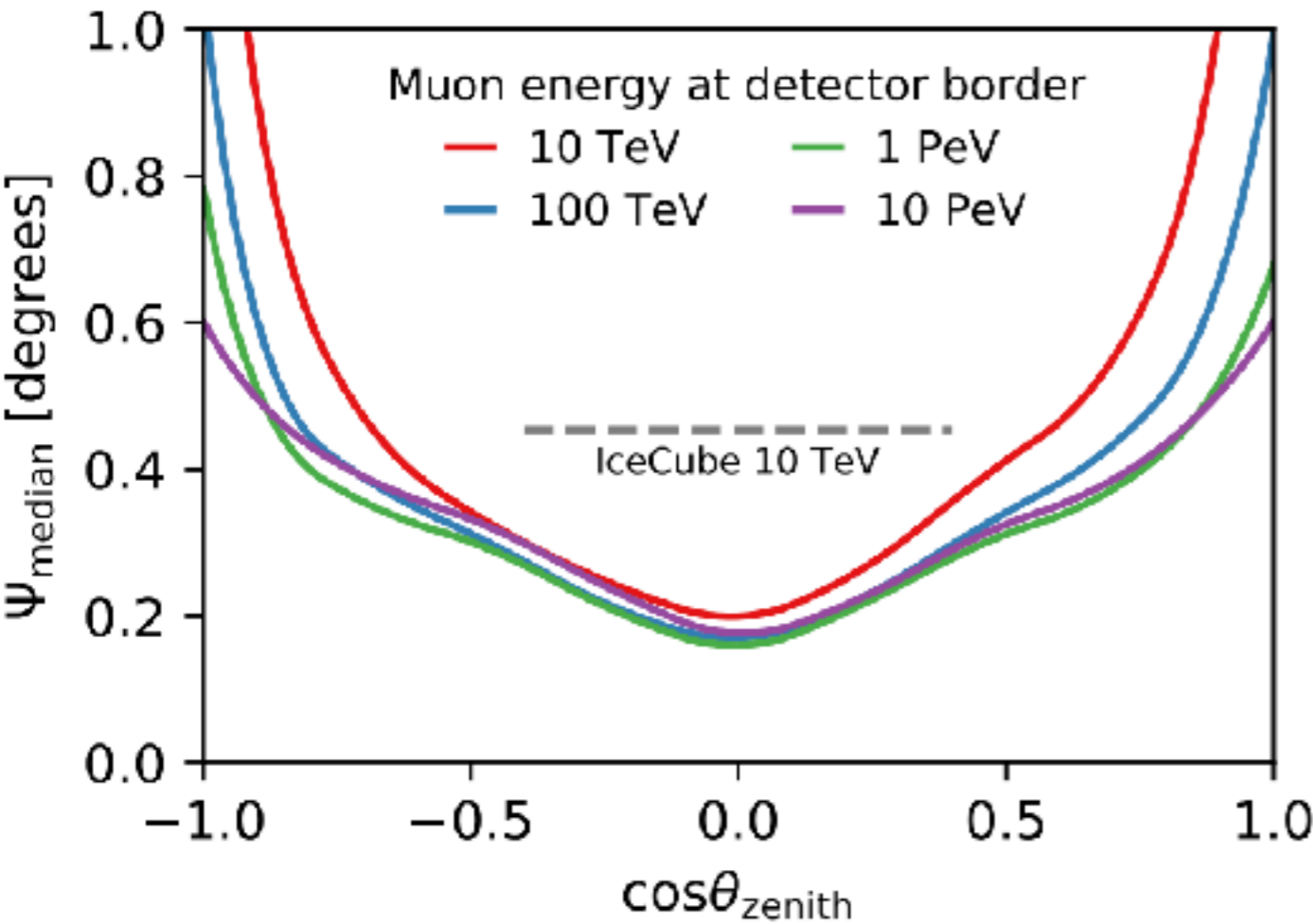
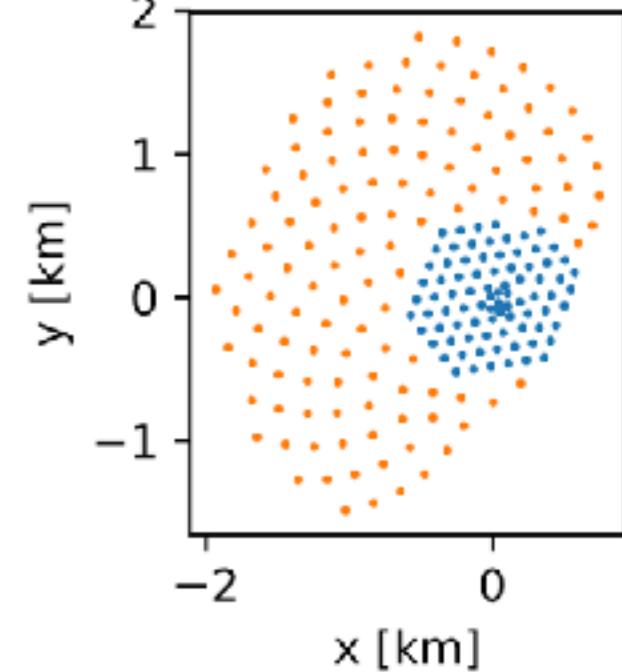
A wide band neutrino observatory (MeV – EeV) using several detection technologies – optical, radio, and surface veto – to maximize the science



Sensitivity to point sources

Projected sensitivity

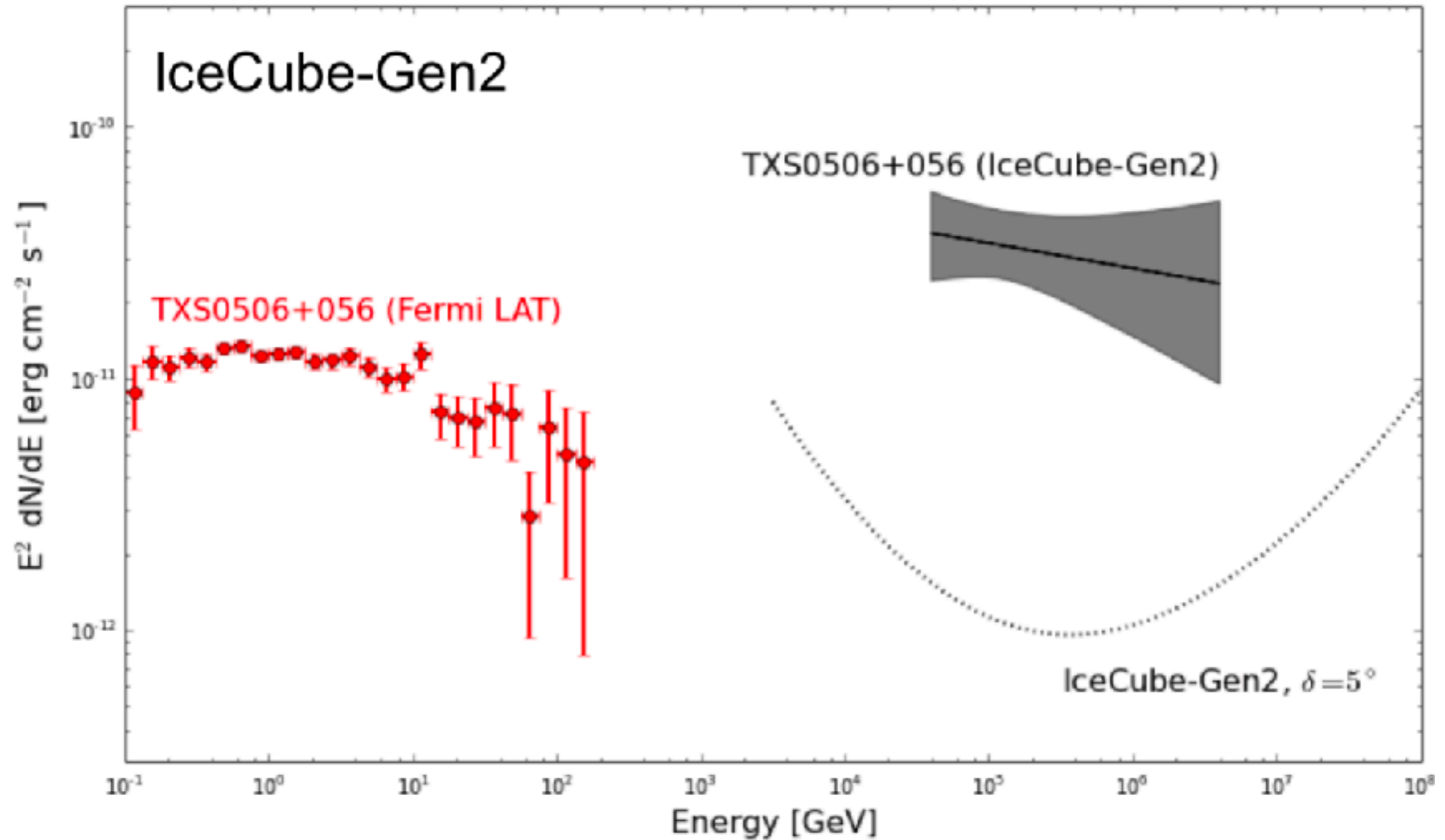
- Improved angular resolution
- Better point sensitivity, here shown for 15 y IC86 + 15 y IC-Gen2



PoS (ICRC2017) 991

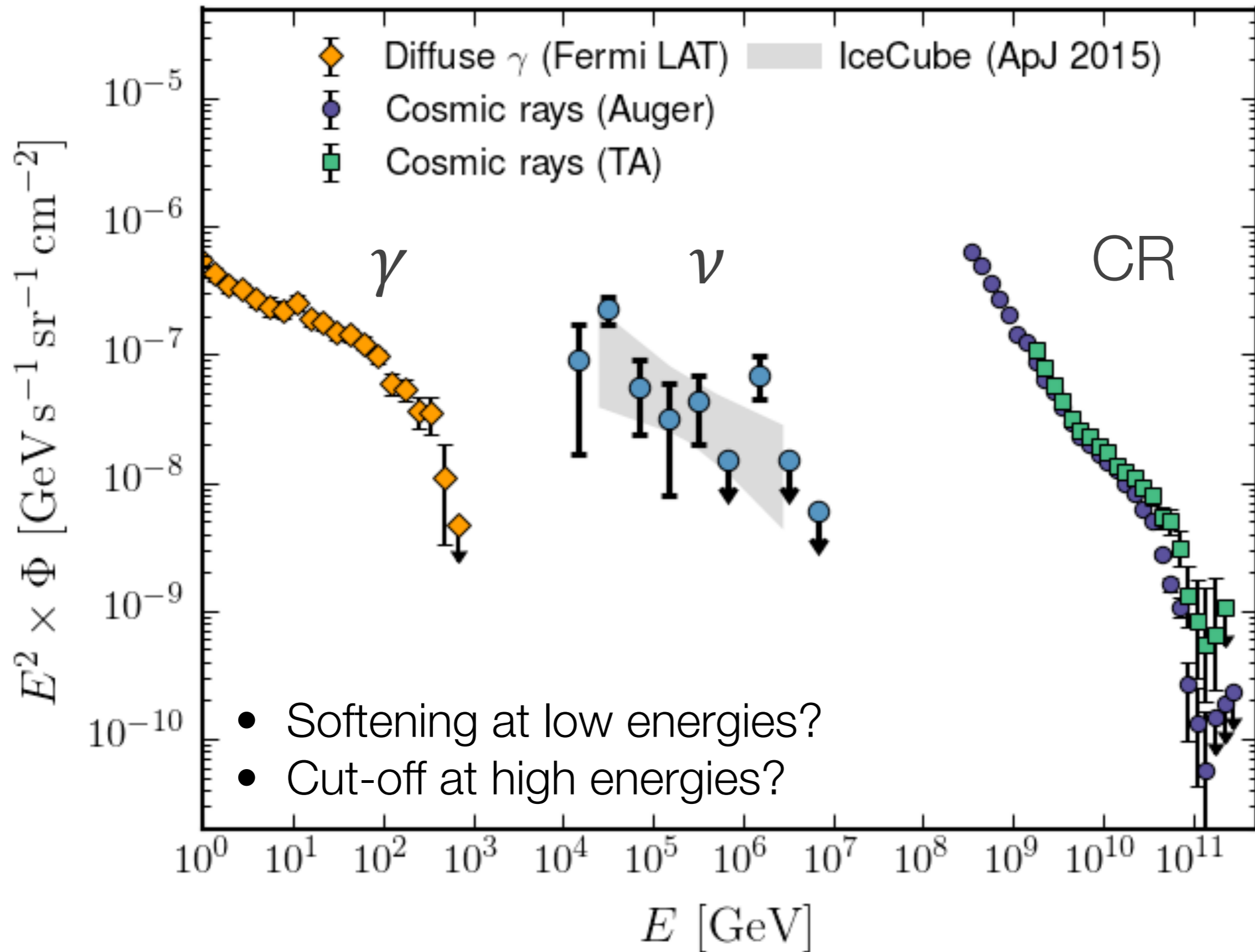
Sensitivity to point sources

Example: TXS0506+056-like source observed with Gen2

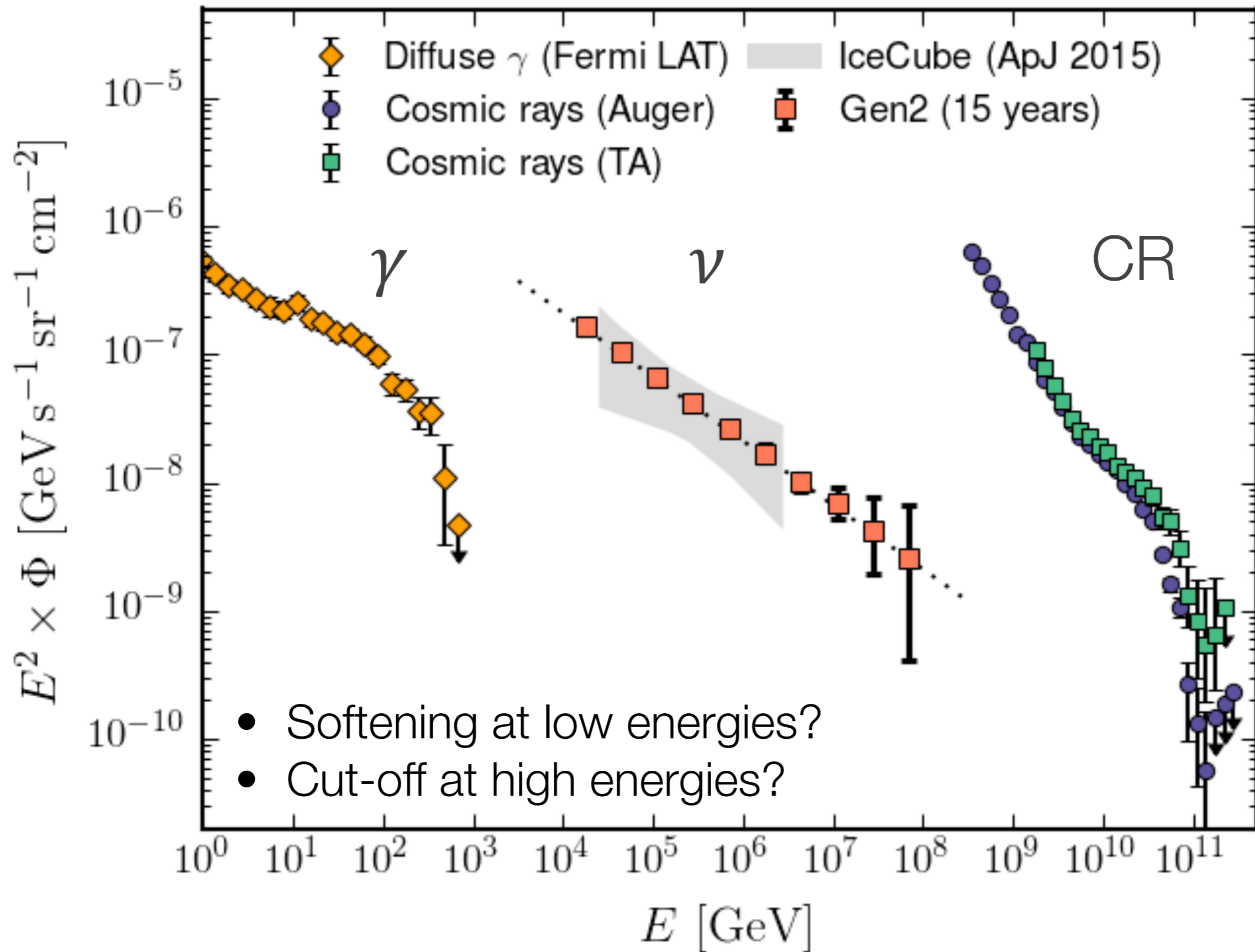


- Order of magnitude increase of # TXS0506+056-like flares observable with Gen2

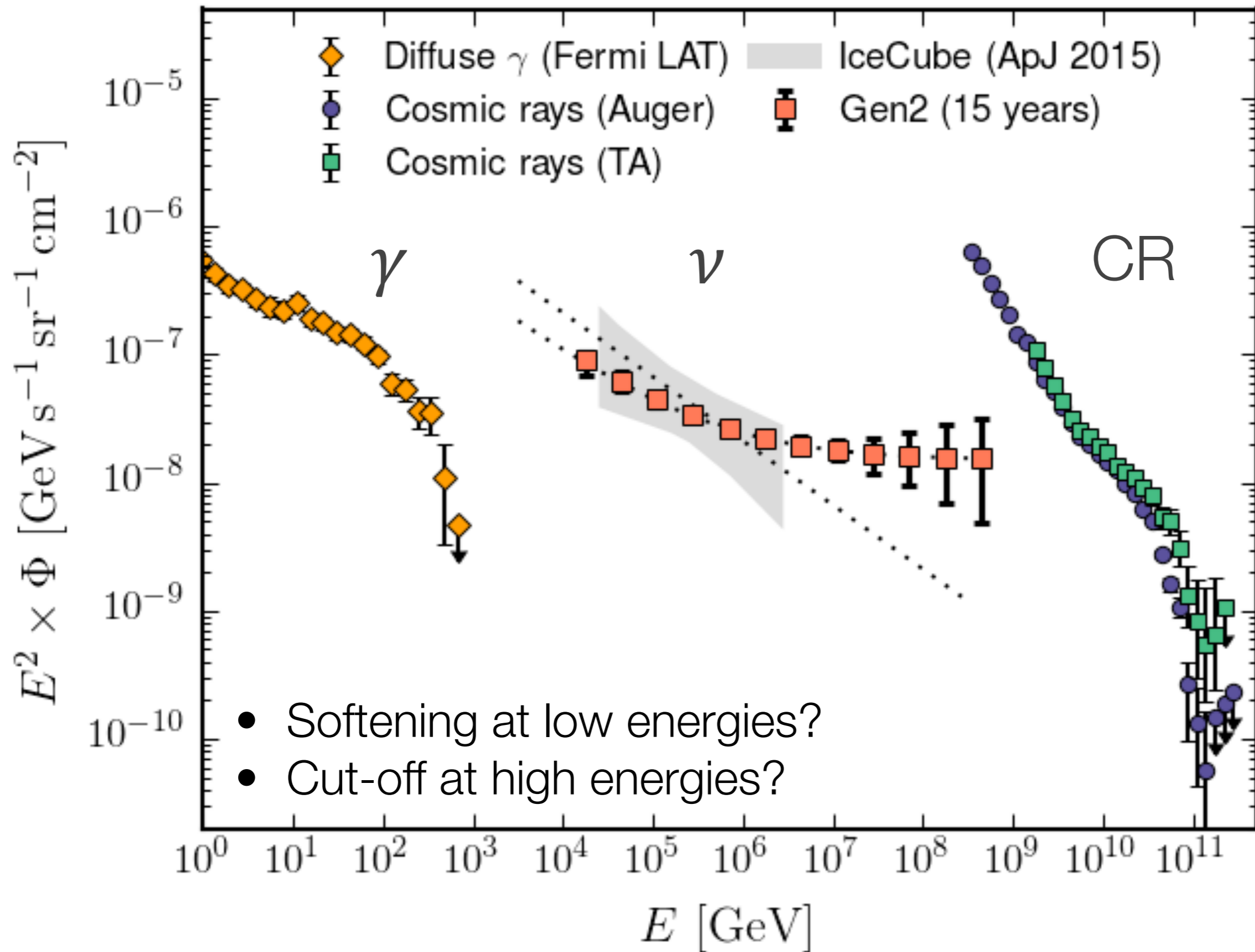
Resolving the mysteries of the UHE Universe



Resolving the mysteries of the UHE Universe



Resolving the mysteries of the UHE Universe

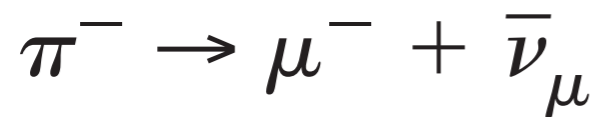


Flavor Physics with Astrophysical Neutrinos



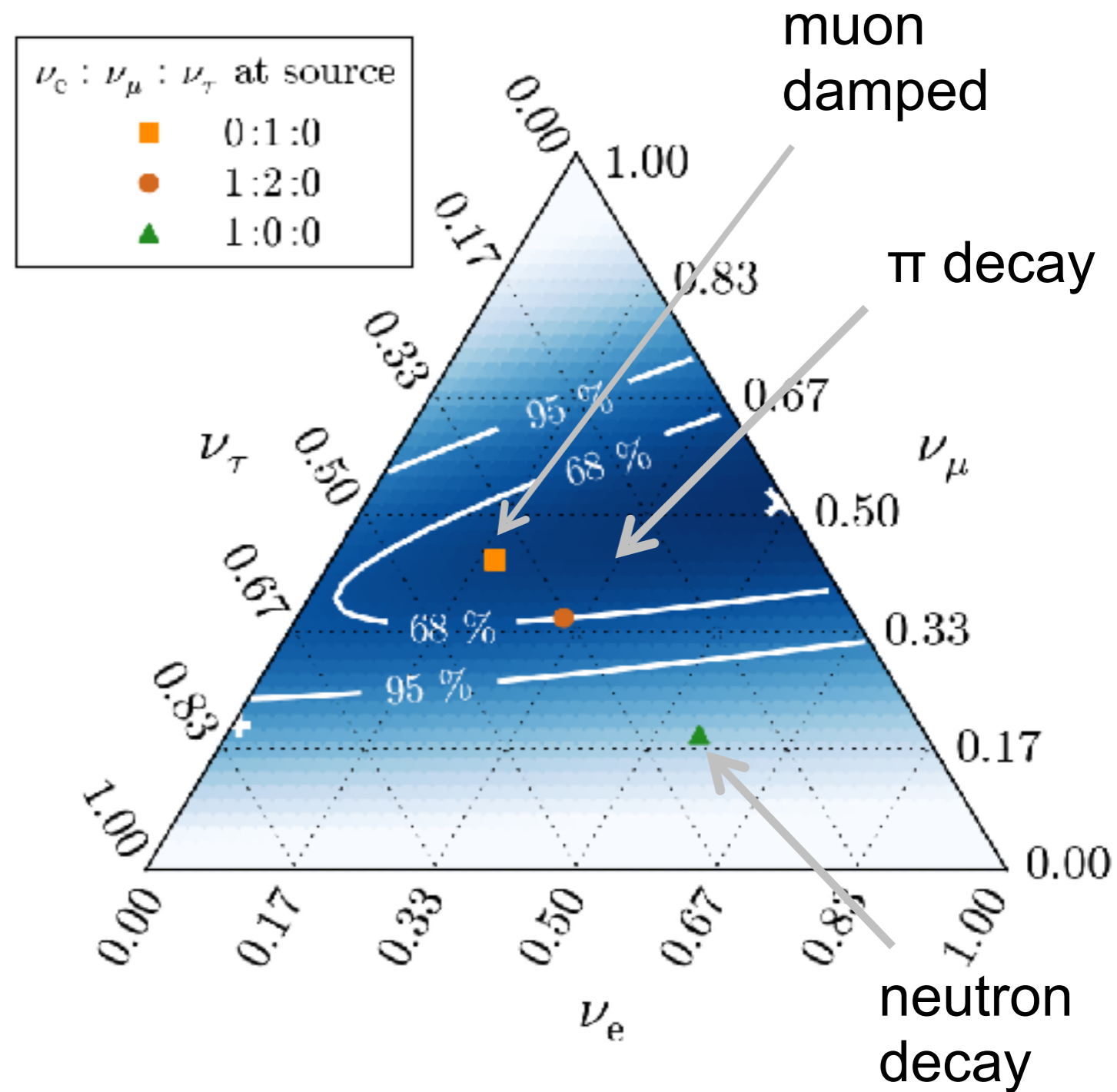
Flavor ratio constrain:

- conditions at source
e.g. magnetic fields



1:2:0

- neutrino physics, e.g. decay or new operators
(e.g. Bustamante et al. PRL 2015, Argüelles et al., PRL 2015 Rasmussen et al, PRD 2017)



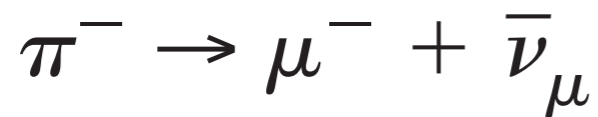
IceCube, ApJ 2015, see also PRL2015

Flavor Physics with Astrophysical Neutrinos



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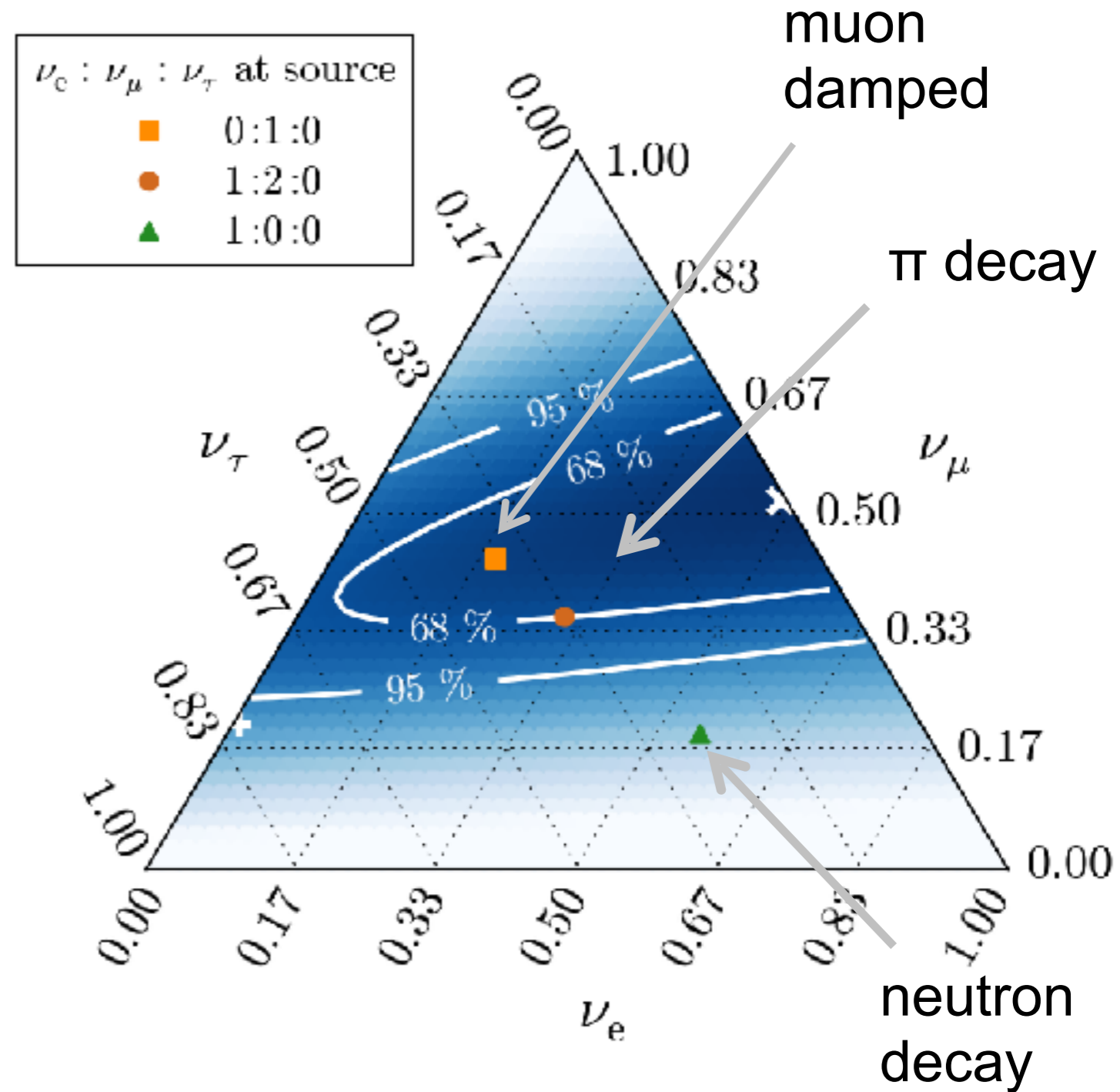


muon cooling



0:1:0

- neutrino physics, e.g.
decay or new operators
(e.g. Bustamante et al. PRL 2015, Argüelles et al., PRL 2015 Rasmussen et al, PRD 2017)



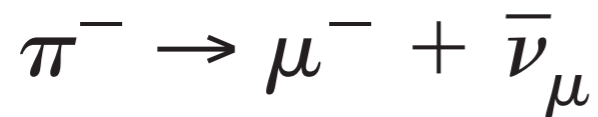
IceCube, ApJ 2015, see also PRL2015

Flavor Physics with Astrophysical Neutrinos



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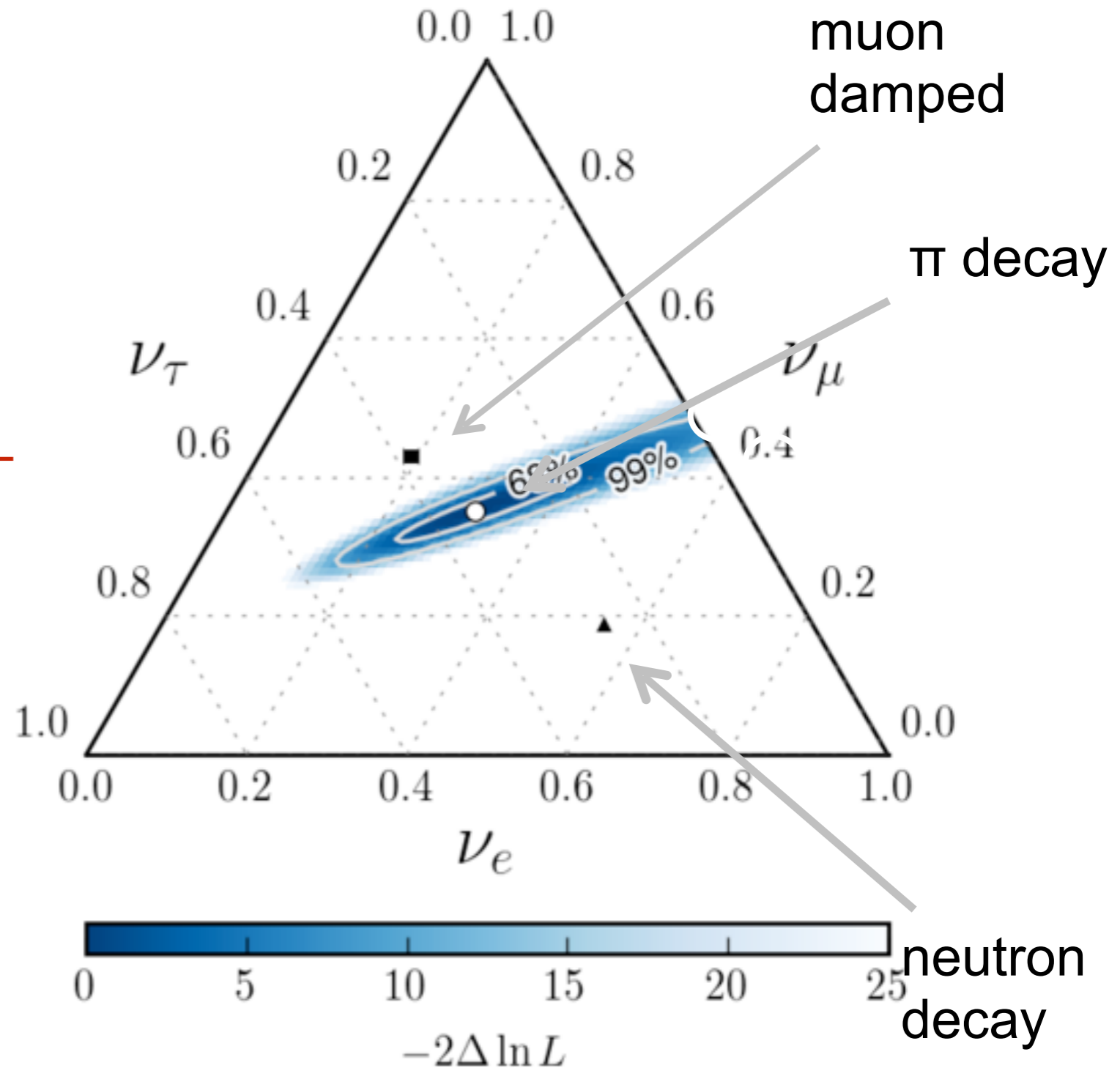


muon cooling



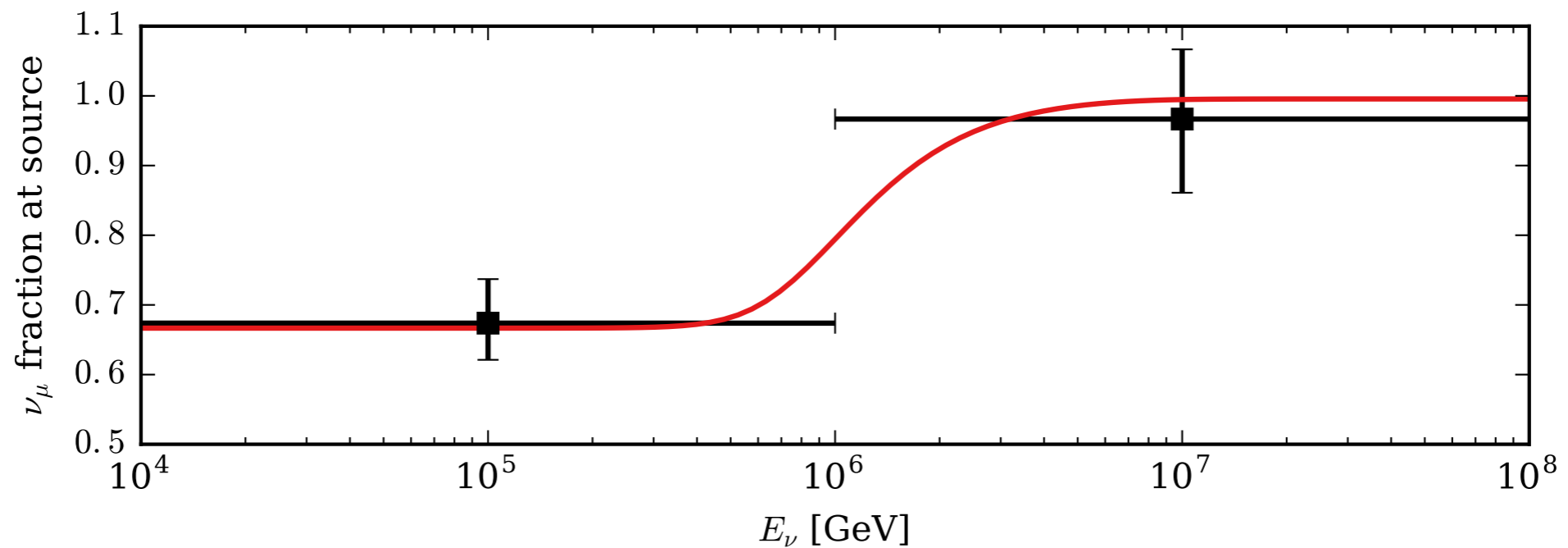
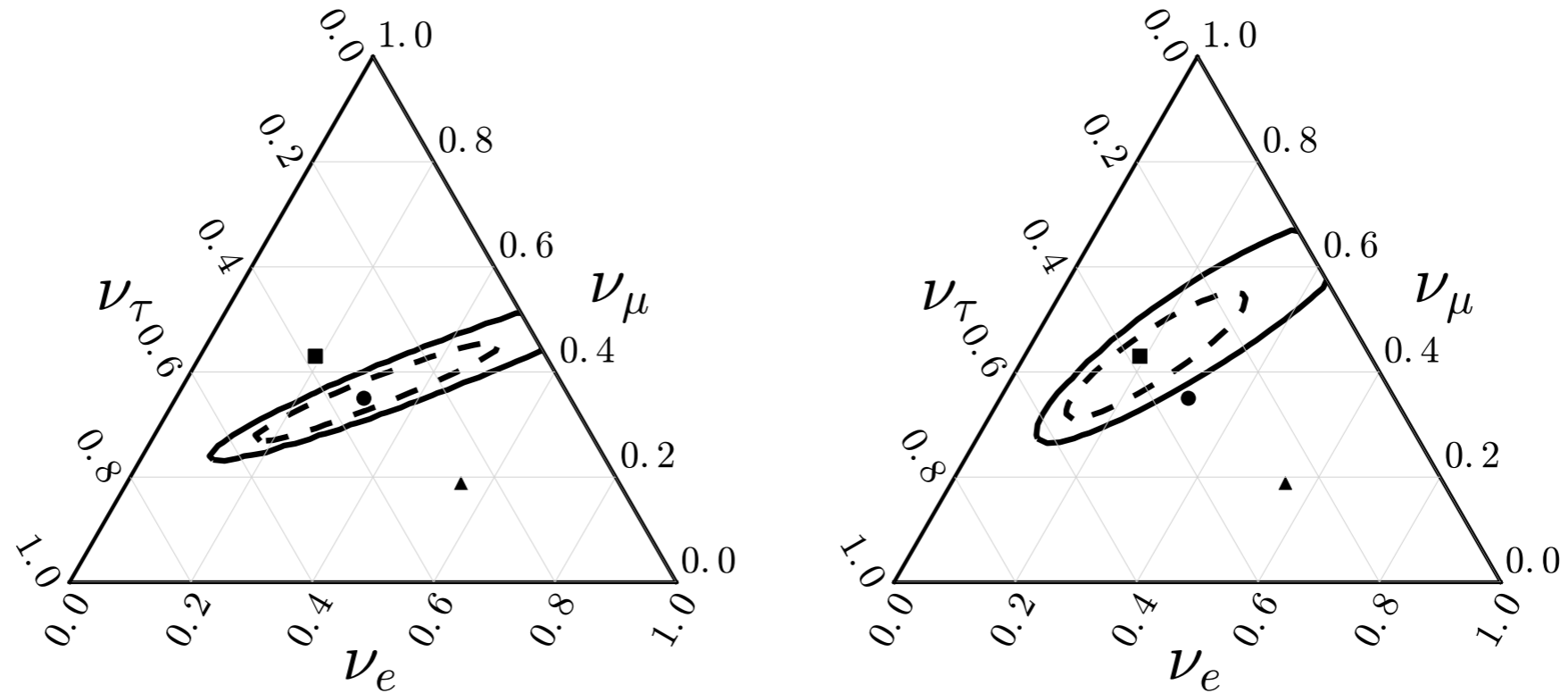
0:1:0

- neutrino physics, e.g.
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Gen2 (15 yrs)

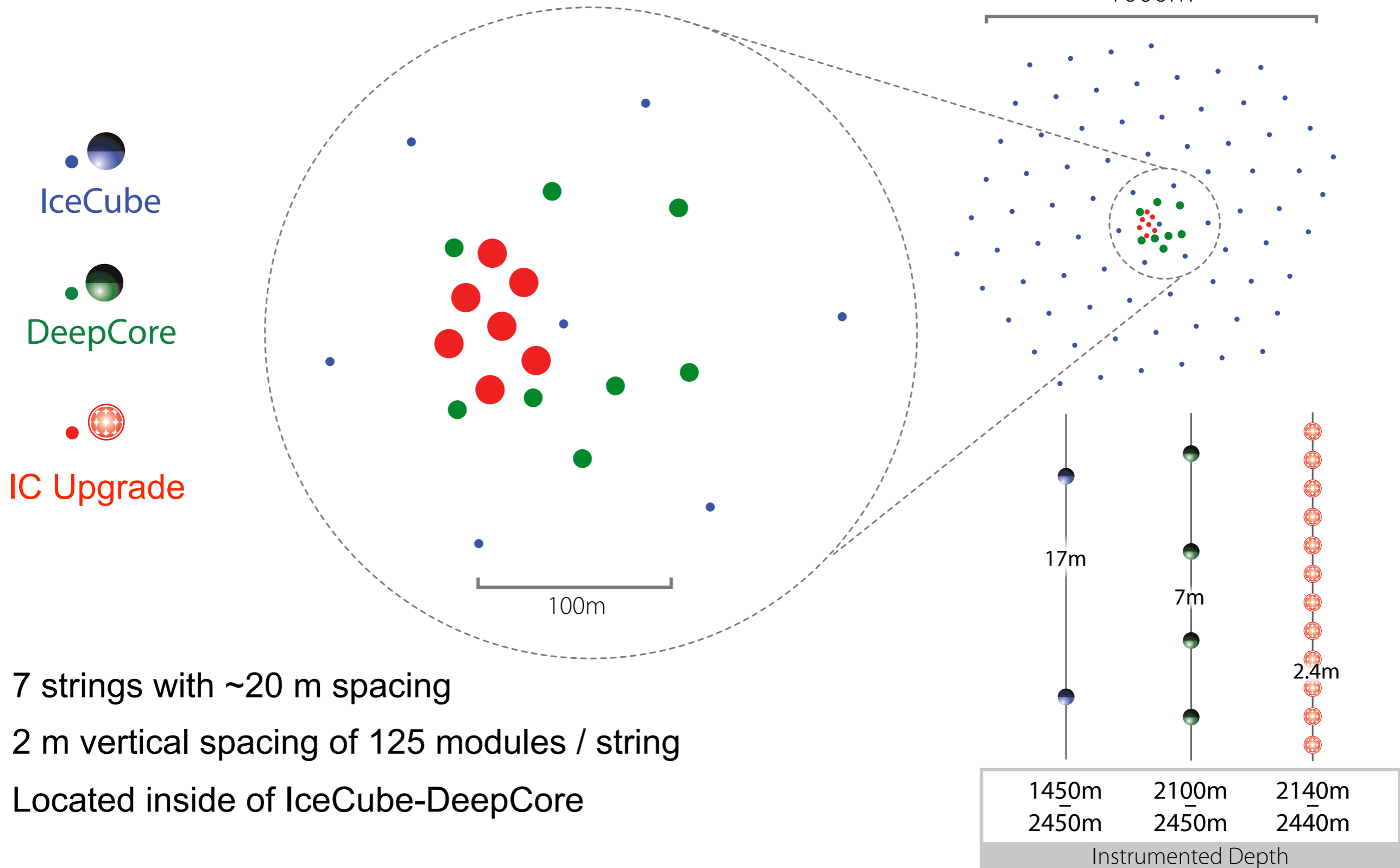
Flavor Physics - Energy Dependence



Sensitivity to source populations (Kasthi, Waxman 2005)

The IceCube Upgrade

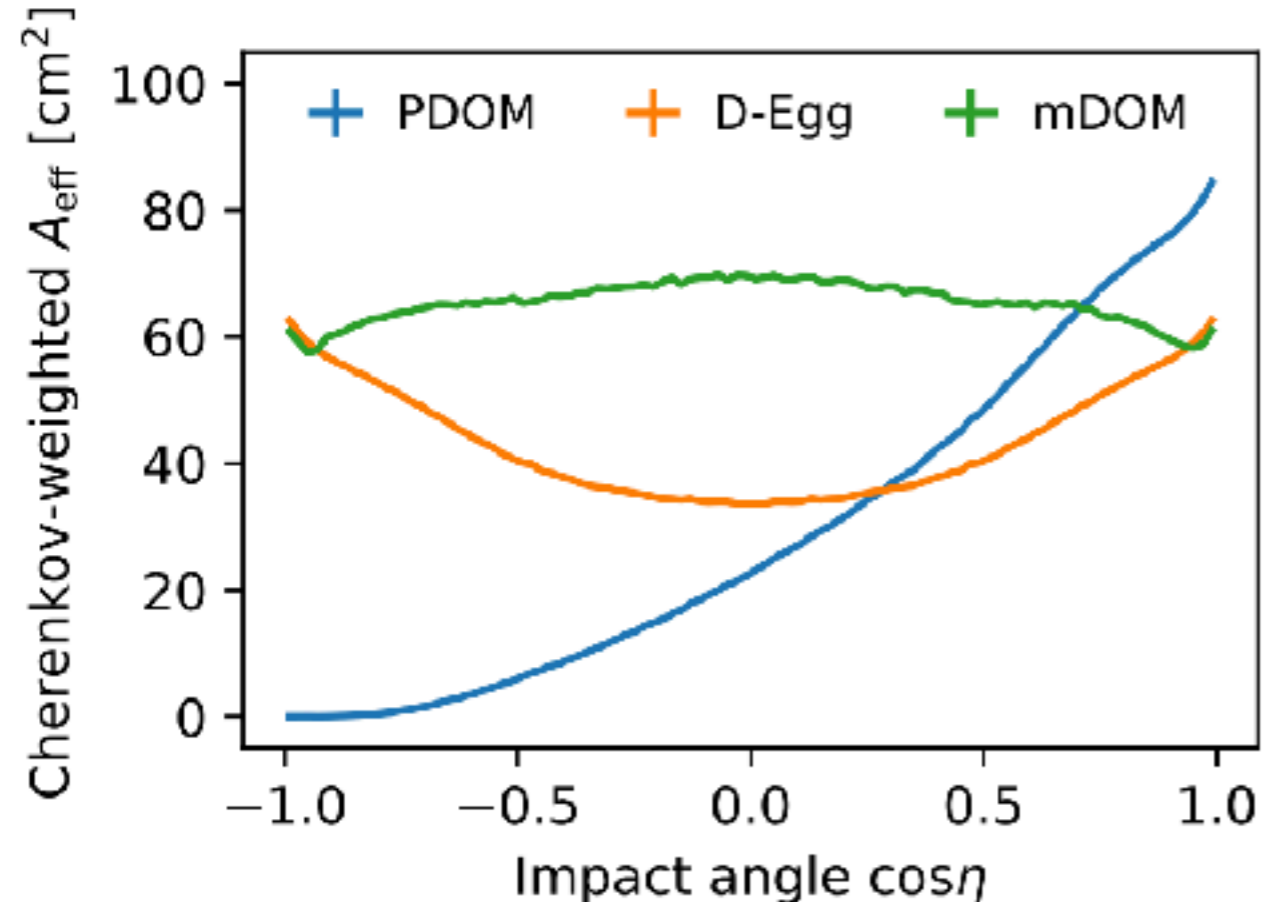
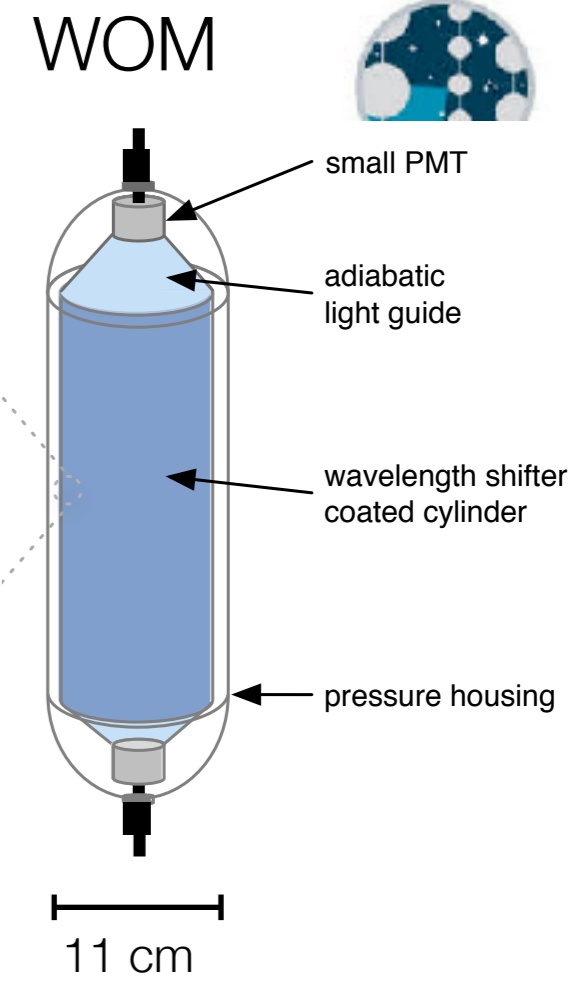
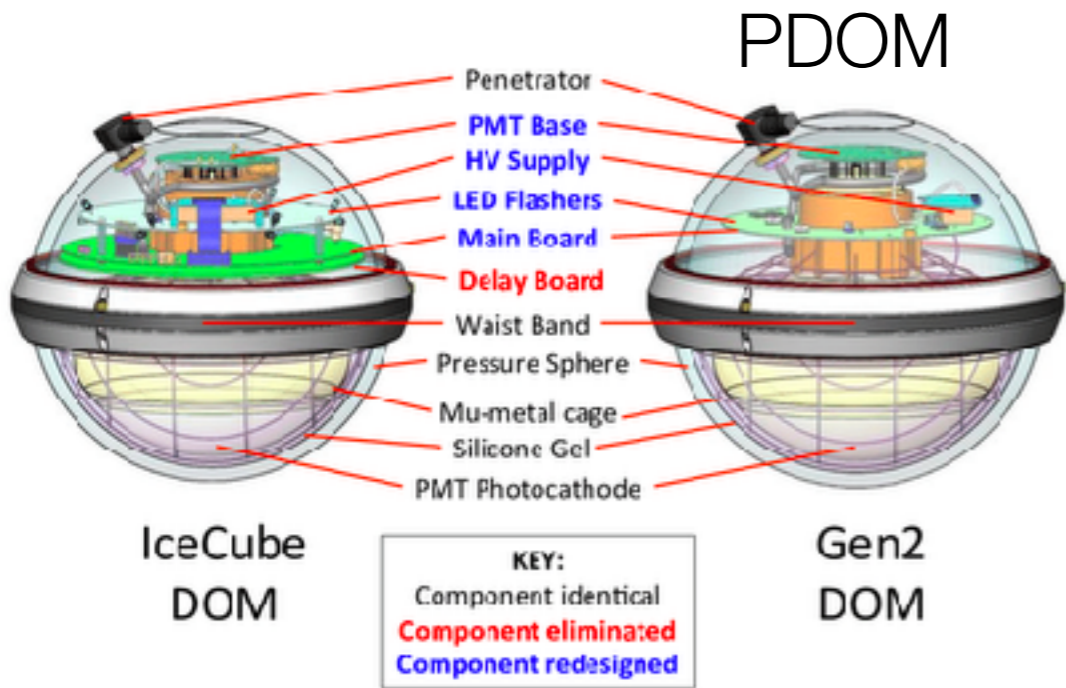
The next step in precision astroparticle physics with IceCube



- 7 strings with ~20 m spacing
- 2 m vertical spacing of 125 modules / string
- Located inside of IceCube-DeepCore

The IceCube Upgrade - R&D

In-situ testing of new optical modules



New sensor designs will incorporate one or more of the following:

- Upgraded electronics
- Smaller diameter
- Increased UV acceptance
- Larger and/or pixelated effective area

The IceCube Upgrade - Calibration

Deployment of new devices at better distances

Integrated devices

- LED flashers
- Acoustic sensors
- Optical cameras

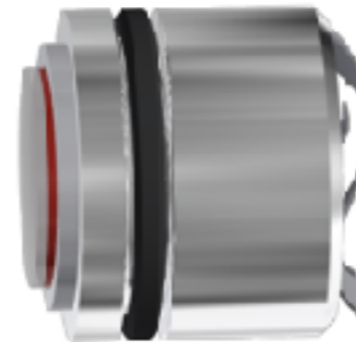
Stand-alone light sources

- Precision Optical Calibration Module (POCAM)
- “Movable” sub-ns pulsed LEDs with small opening angle

Reduce primary systematic uncertainties

- Better calibration of new and existing sensors
- Improved knowledge of glacial ice

Piezo-module^[1]



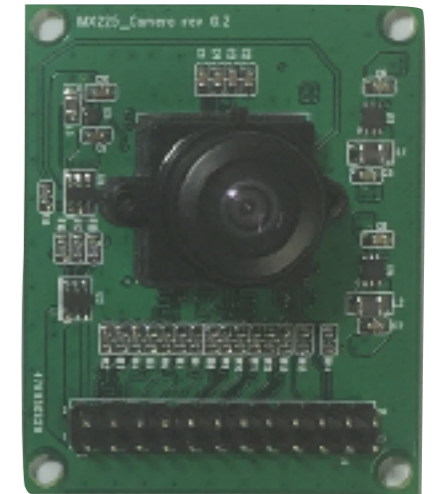
POCAM^[3]



CCD^[2]



CMOS^[2]



[1] <https://doi.org/10.1051/epjconf/201713506003>

[2] <https://doi.org/10.22323/1.301.1040>

[3] <https://doi.org/10.22323/1.301.0934>

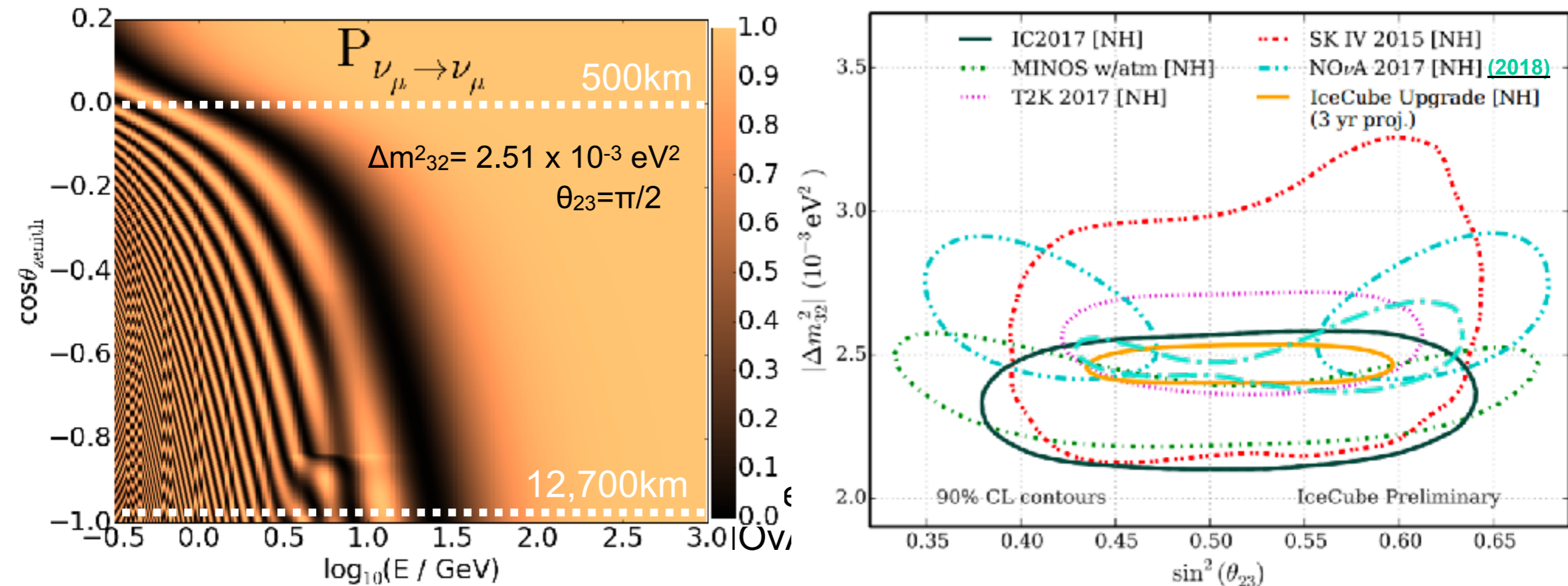
The IceCube Upgrade - Science

Precision atmospheric oscillation measurements



Similar physics program to DeepCore, just better!

- Oscillations, non-standard interactions, sterile neutrinos, dark matter...



- Enable atmos. mixing param. measurements with precision competitive with projected final T2K/NO ν A results, but different systematics and energy range

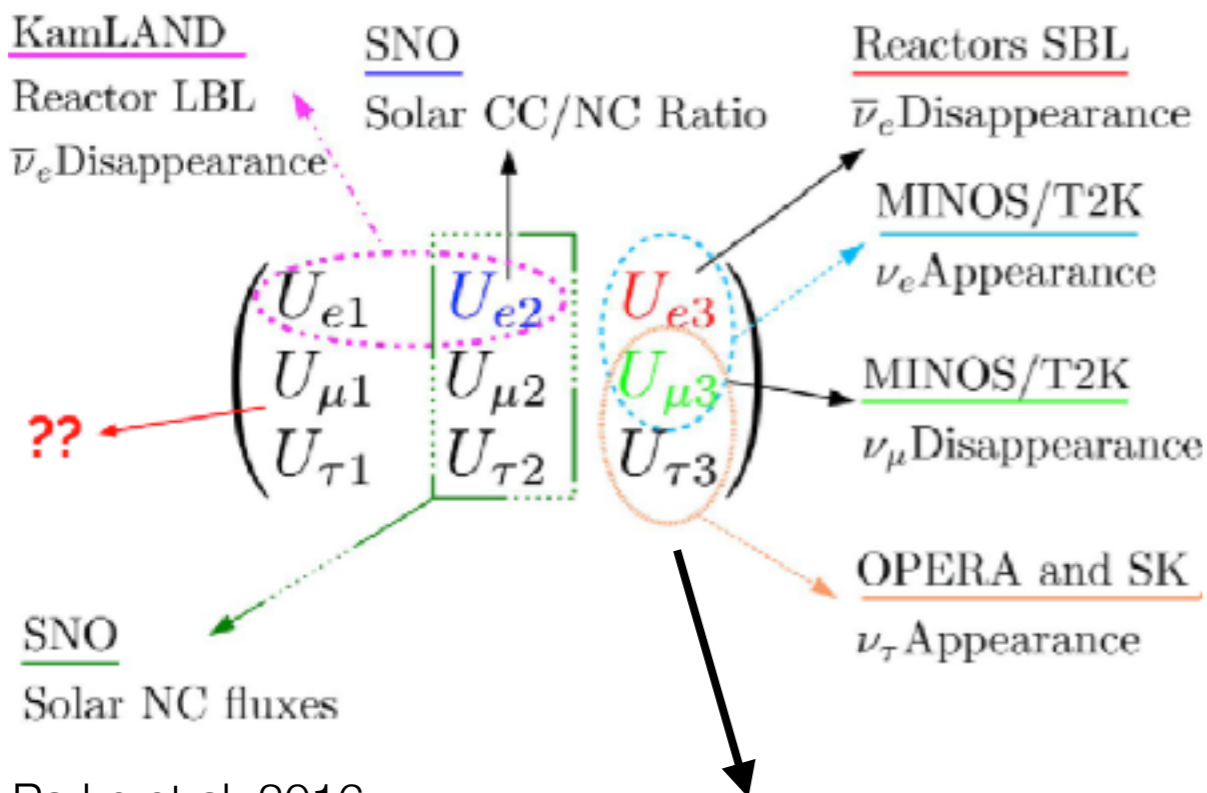
The IceCube Upgrade - Science

Precision atmospheric oscillation measurements



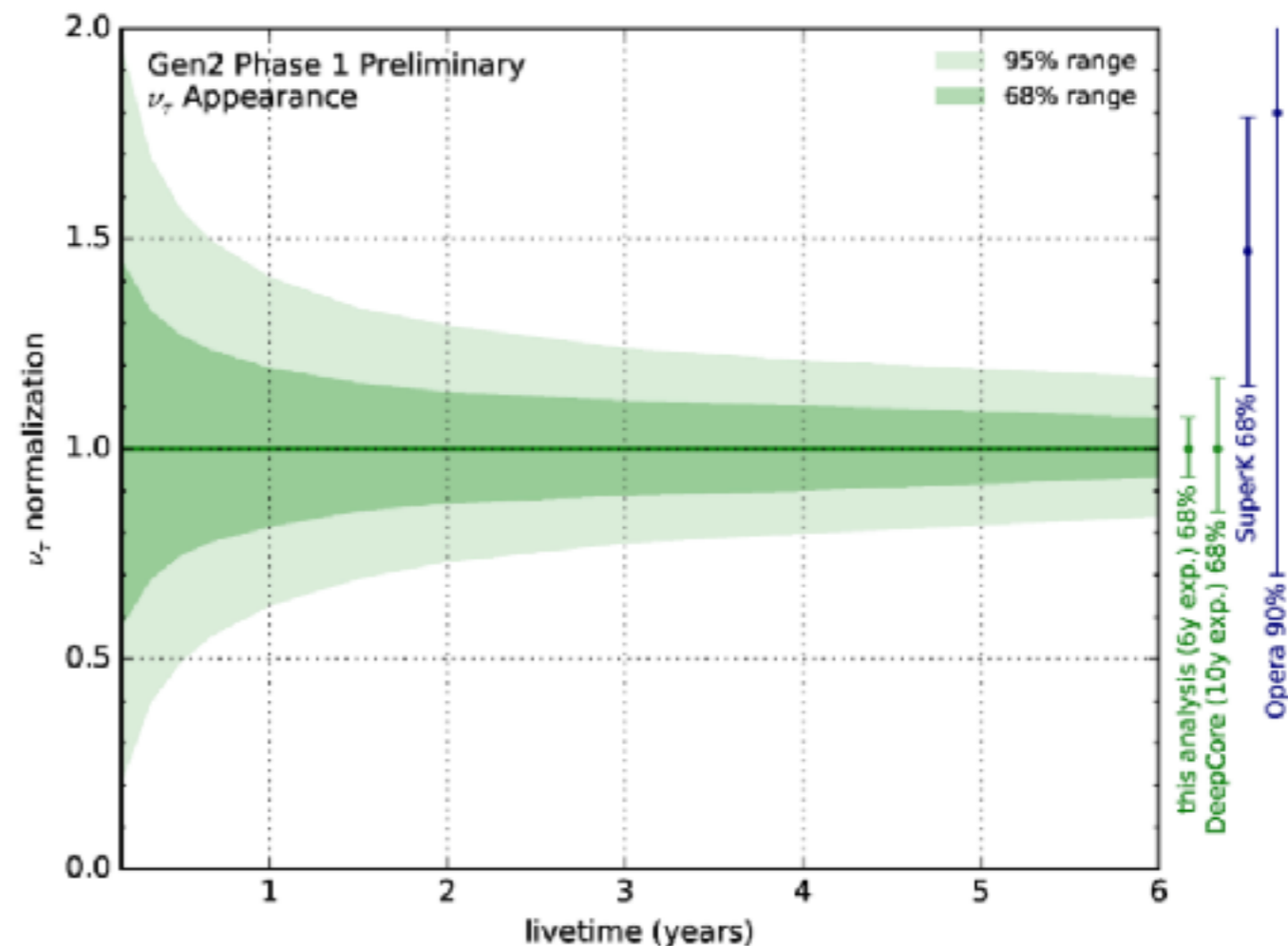
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- Oscillations, non-standard interactions, sterile neutrinos, dark matter...



Parke et al. 2016

poorest constrained element targeted directly with IC Upgrade

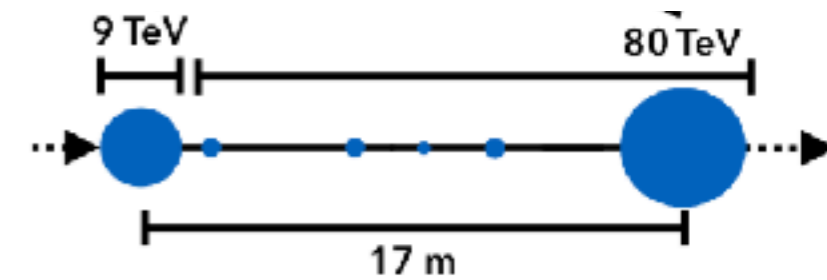
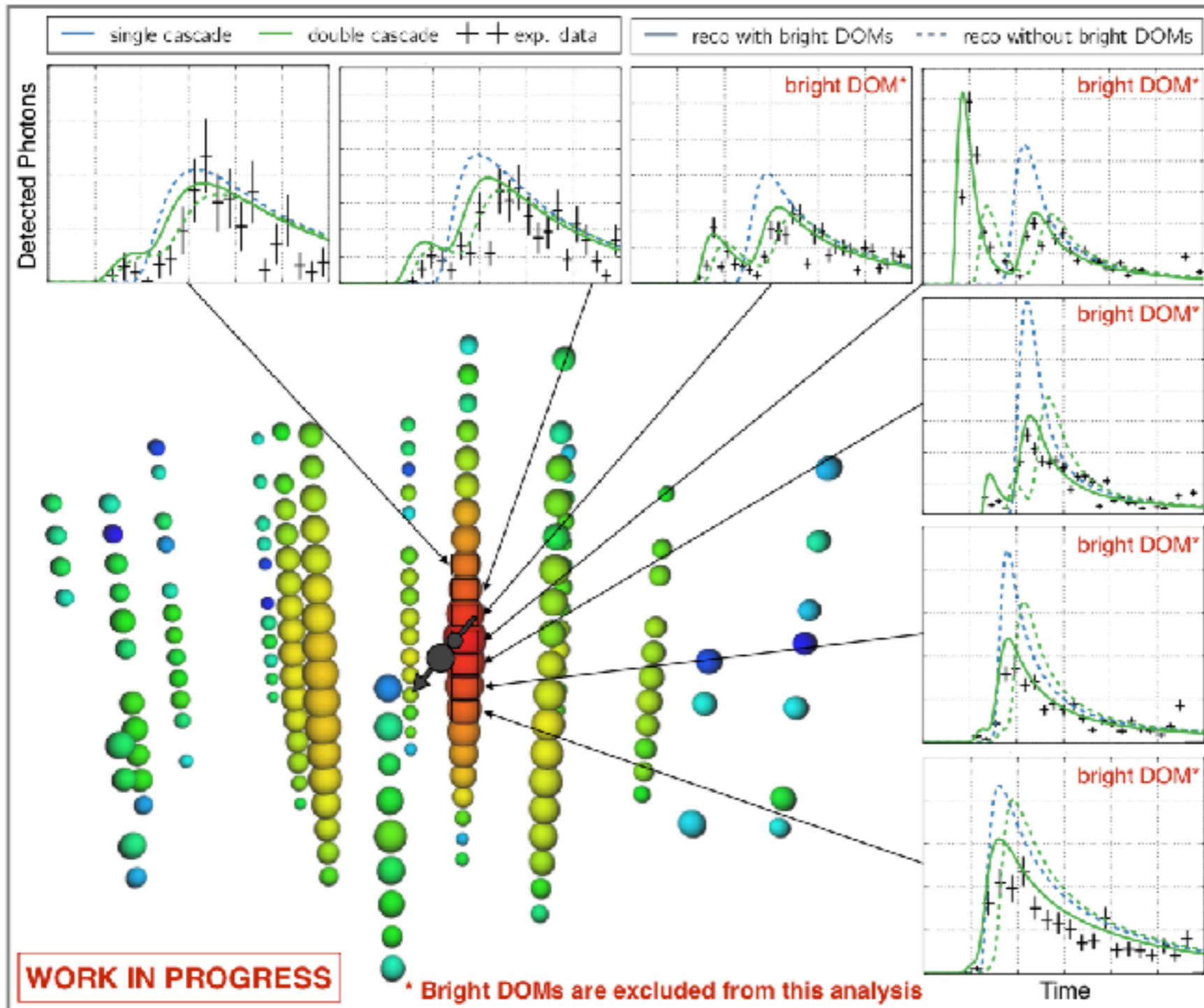


- World best constraints on tau appearance / Unitarity triangle

Recap: High-Energy Tau Neutrino Candidate



One of two events in the HESE 7.5 year identified by tau neutrino search



- observed light arrival pattern clearly favors double cascade hypothesis

Stachurska et al, Neutrino 2018

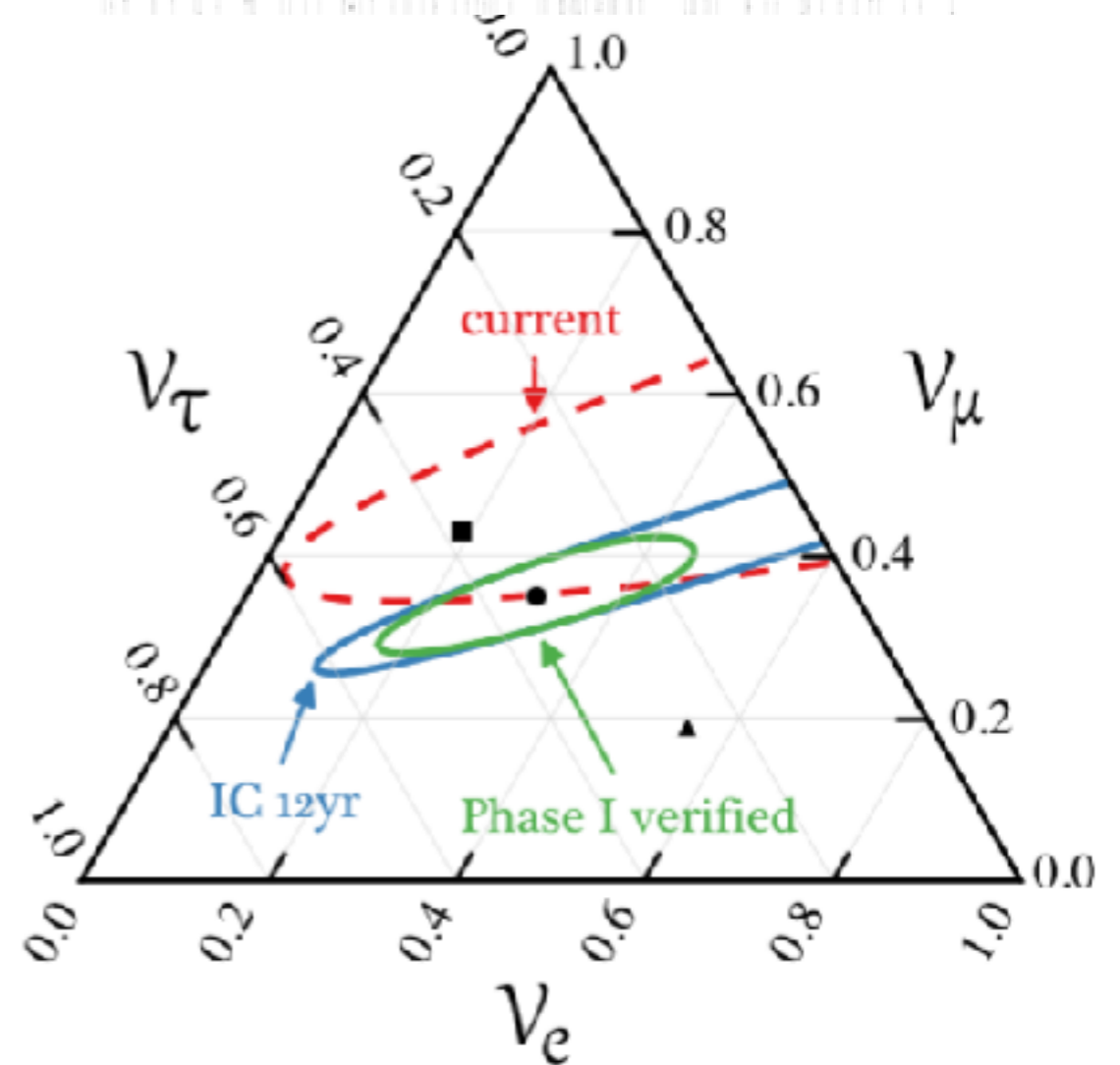
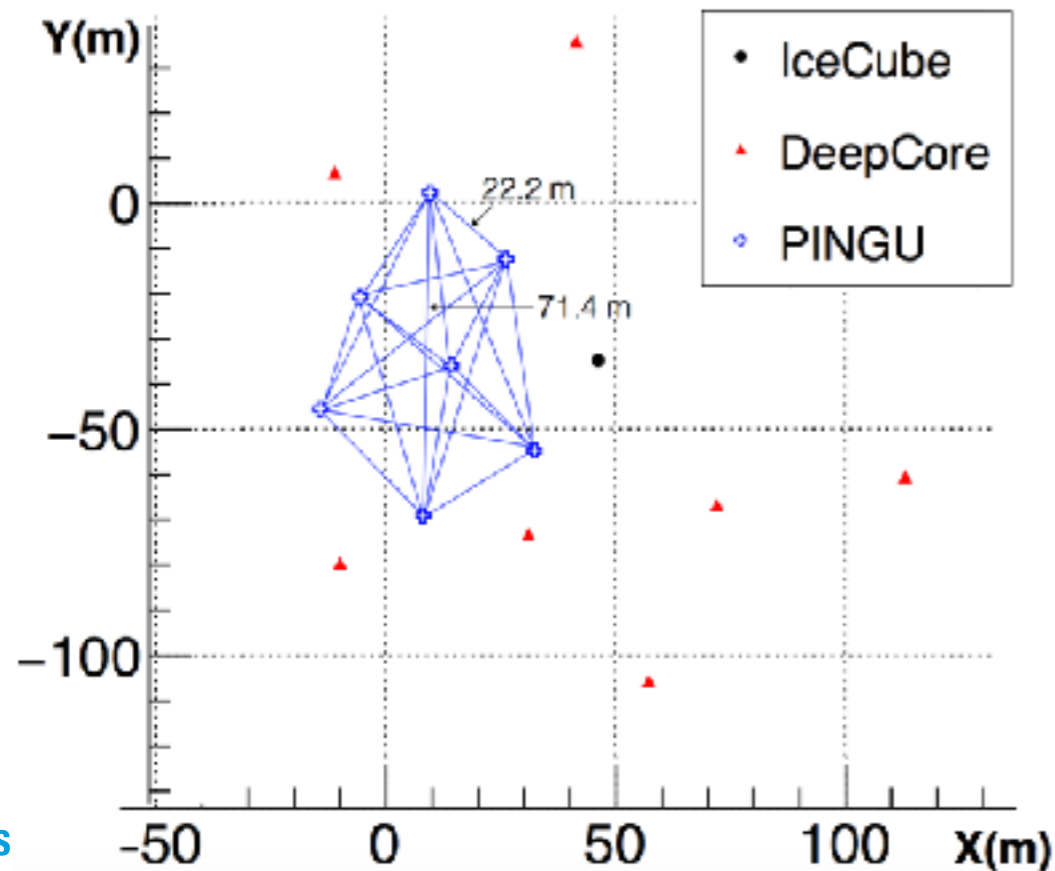
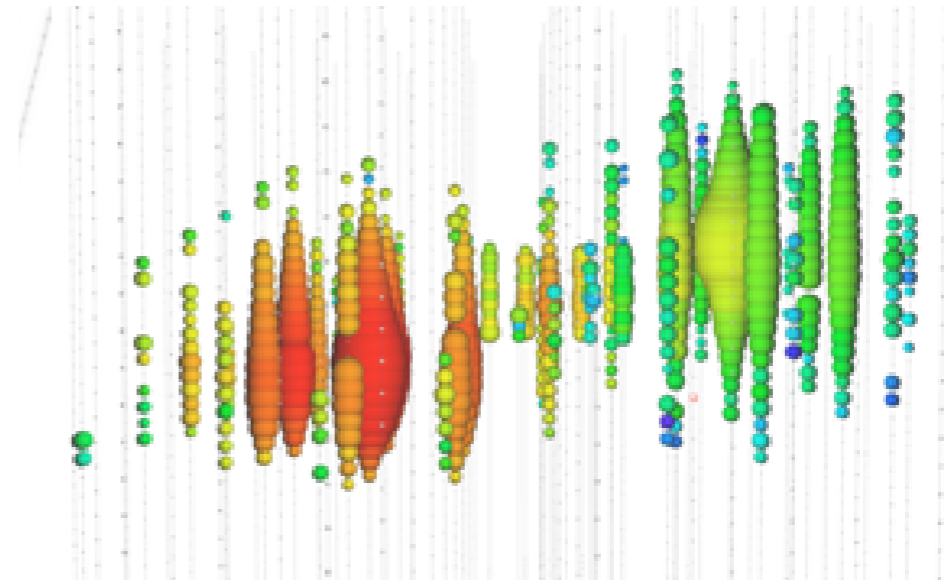
The IceCube Upgrade - Science



New calibration devices inside IceCube enhance HE science

- better control of systematics
- applicable to all IceCube data

IceCube Upgrade permits to generate double cascades with baselines of ~ 20 m

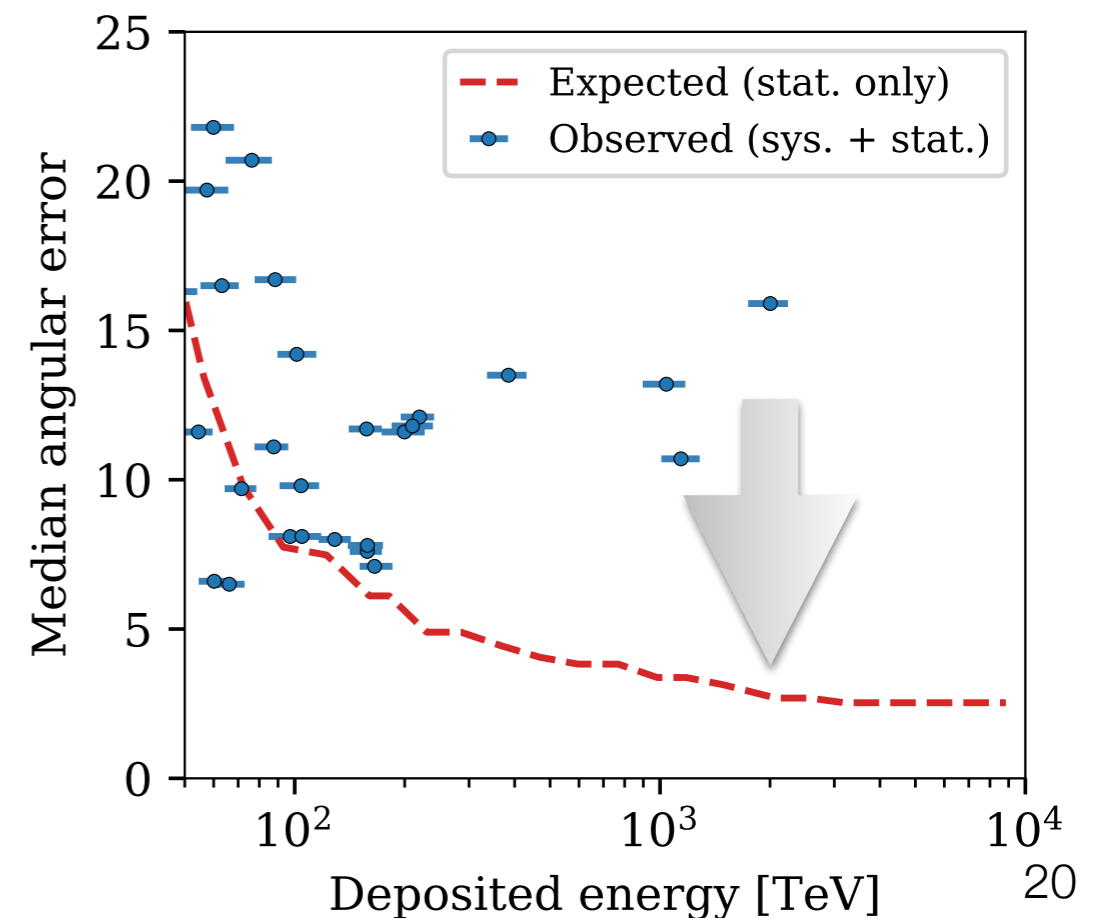
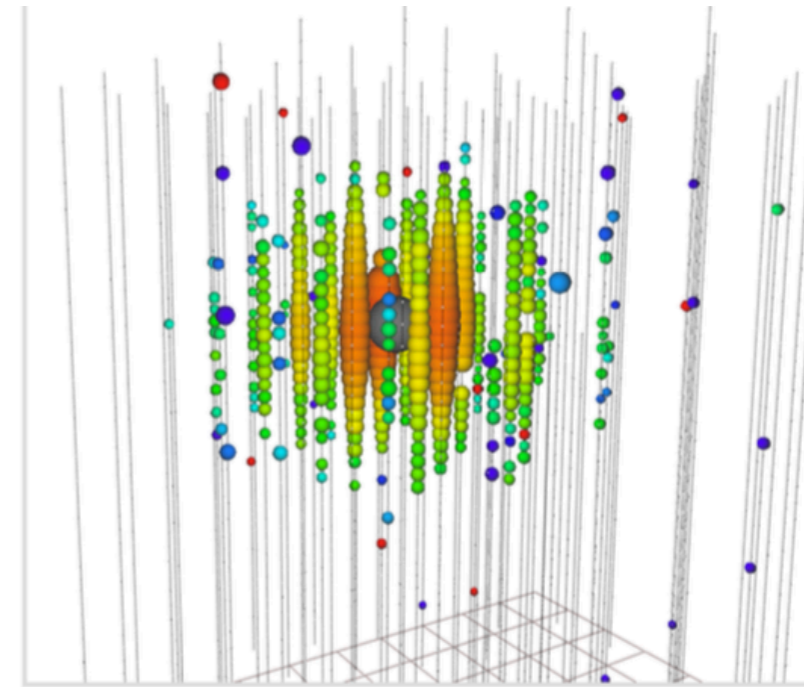


The IceCube Upgrade - Science



New calibration devices inside IceCube enhance HE science

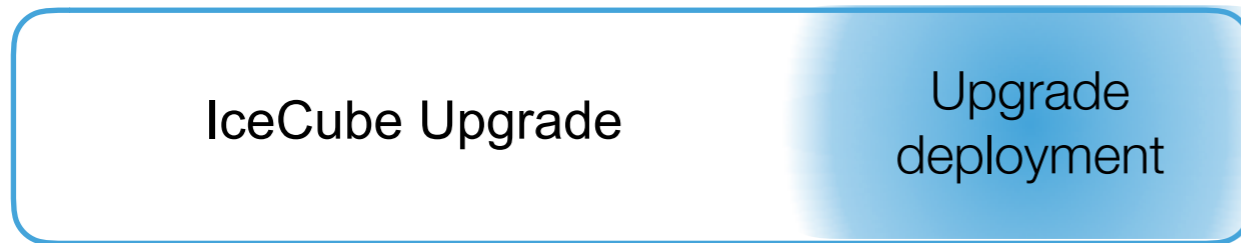
- better control of systematics
- applicable to all IceCube data
- improved reconstruction



Project-driven IceCube-Gen2 Timeline

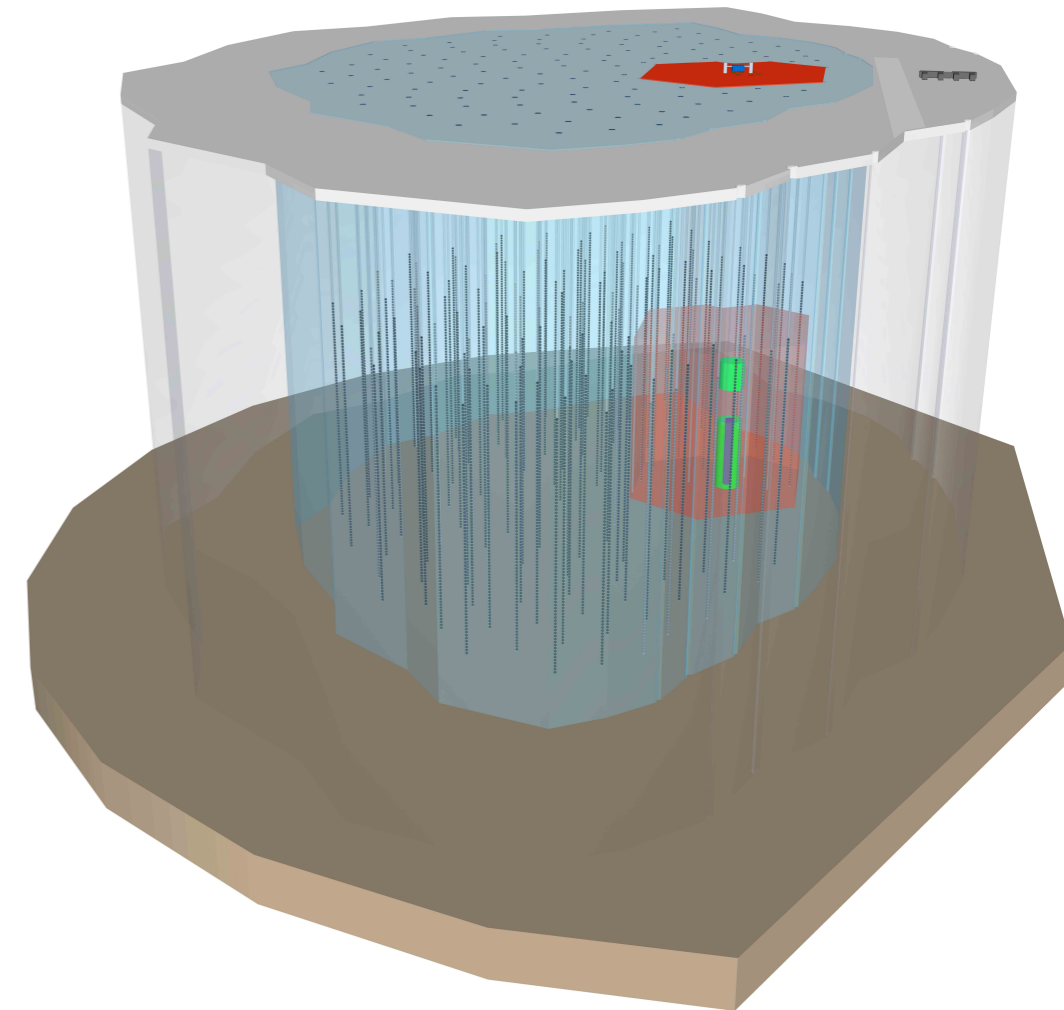


2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | ... | 2031



Conclusions

- IceCube-Gen2 is a unique cosmic neutrino observatory to explore uncharted territory
- Order of magnitude more astro. neutrinos
- Sensitivity to address questions raised by IceCube, expanding its energy reach by several orders of magnitude
- Gen2 costs comparable to that of IceCube
- IceCube Upgrade a first step, with a compelling science case on its own



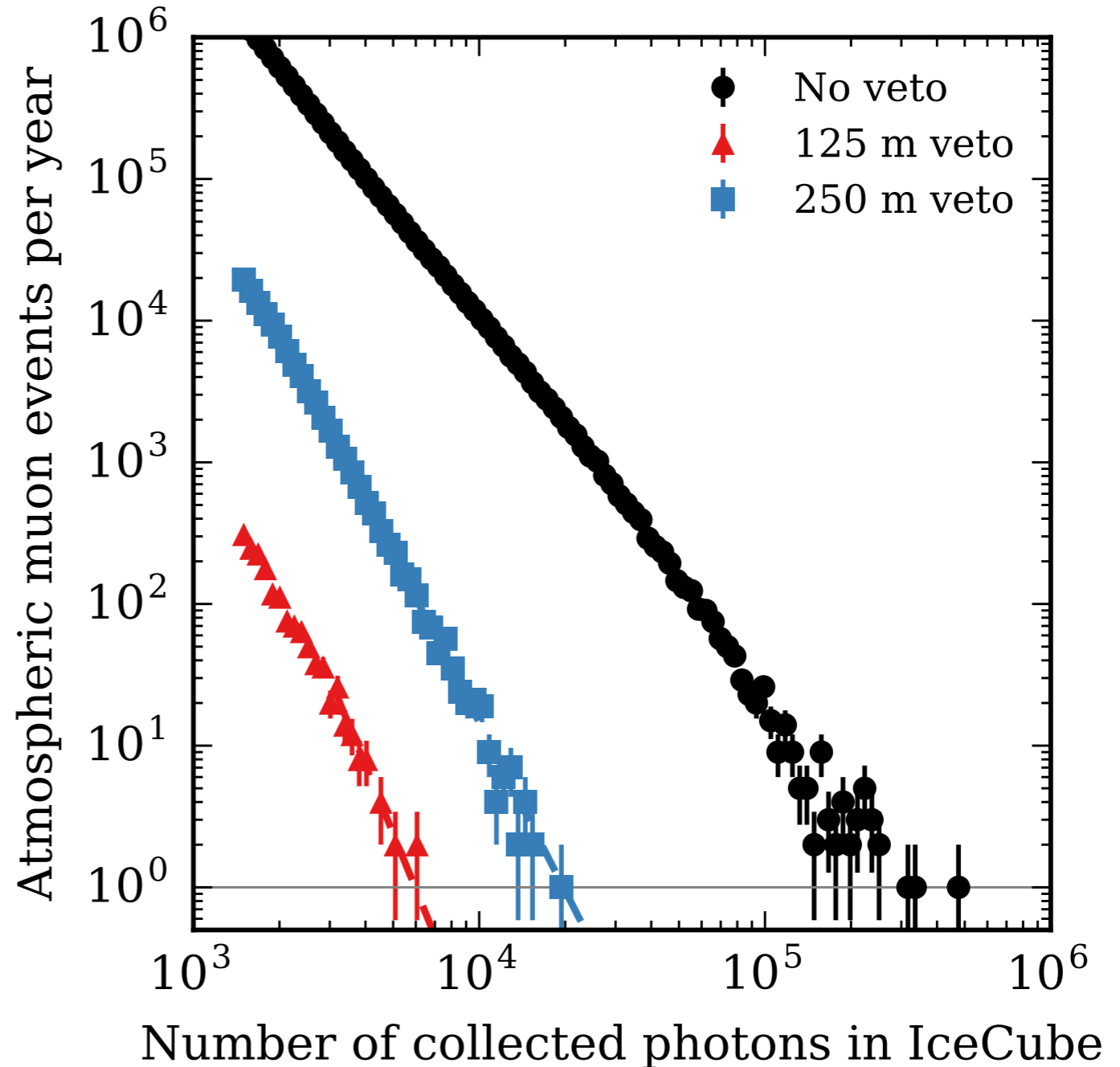
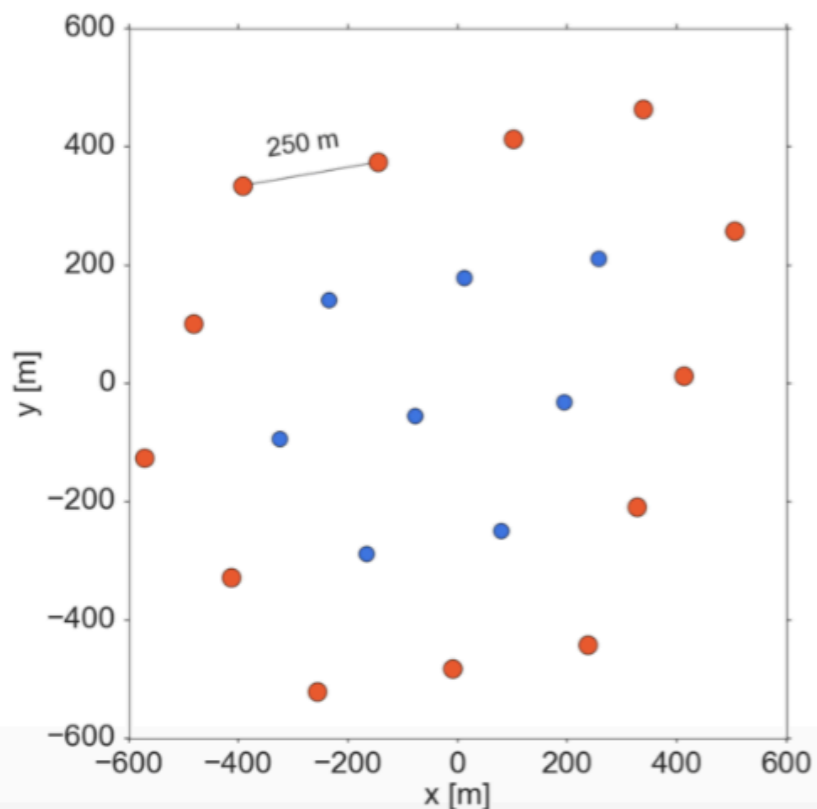
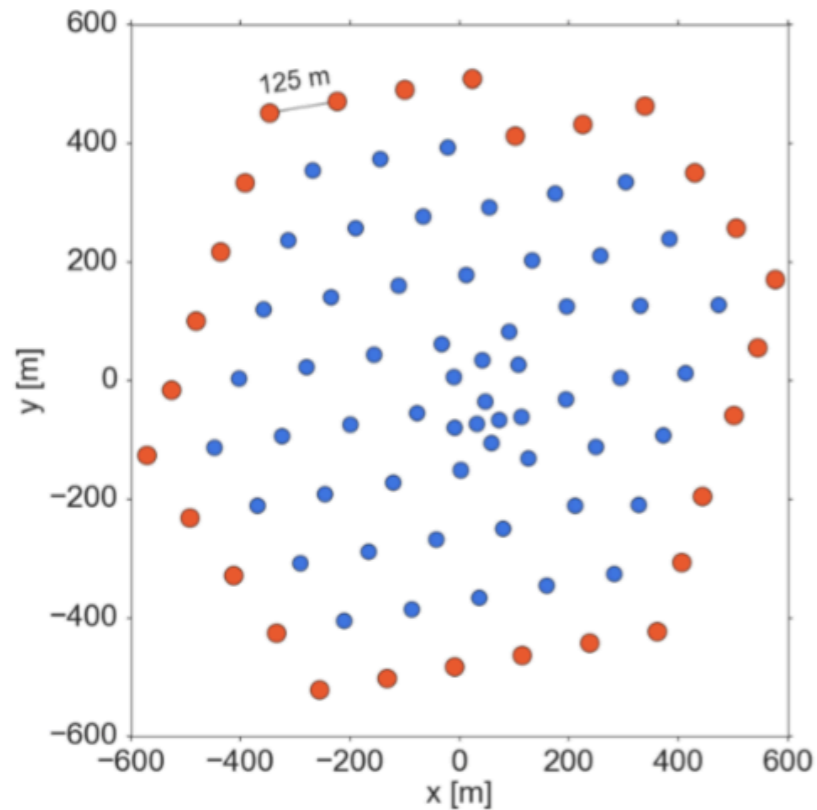
Backup



ICECUBE
GEN2

Vetoing atmospheric events: HESE for Gen2

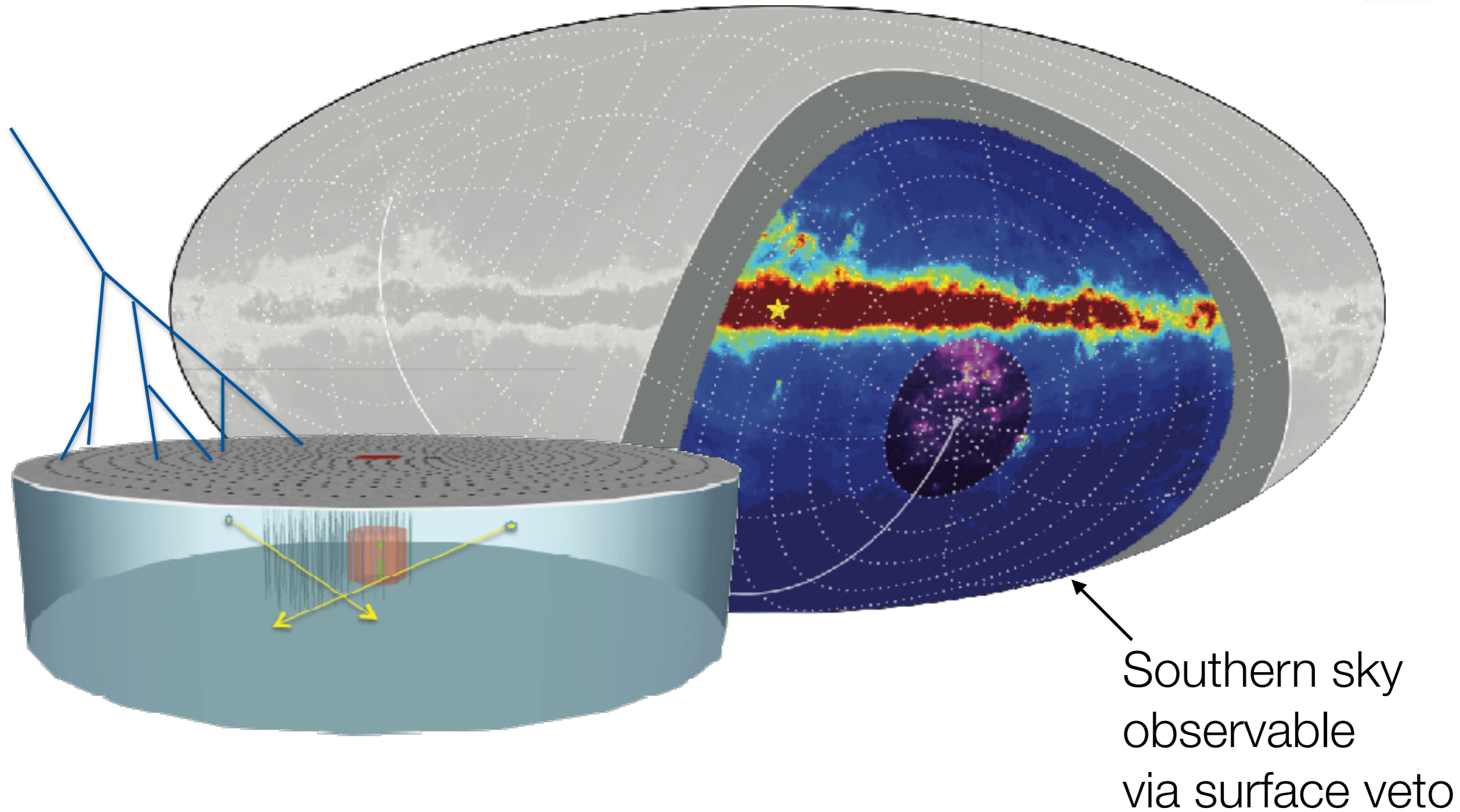
Evaluation of the veto passing rate from real data



Vetoing atmospheric events works just like in IceCube!

but with 3 x higher energy threshold

Extended surface veto



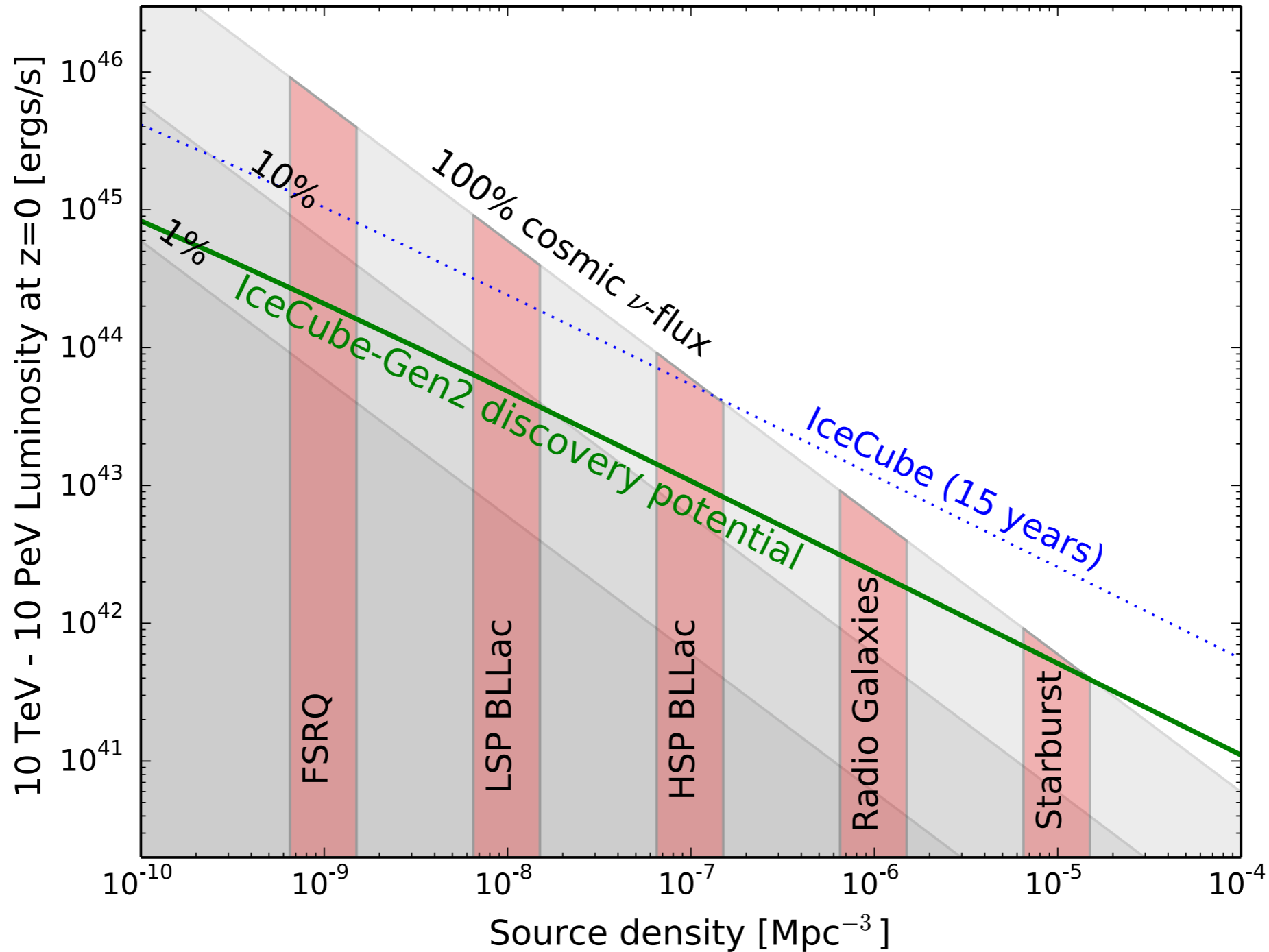
Potential gain for e.g. 75 km² veto:
~2x number of PeV tracks

Event statistics

Event type	Number of events per year in Gen2 (IceCube)			
	10–100 TeV	0.1–1 PeV	1–10 PeV	>10 PeV
Contained cascades	0 (2.6)	20 (4.4)	15 (1.6)	2 (0.2)
Surface vetoed μ	0 (0)	9.7 (0.12)	4.8 (0.053)	1.2 (0.014)
Upgoing μ	100 (37)	55 (16)	11 (3.2)	1.6 (0.47)

Table 2: Number of neutrino events per decade of neutrino energy expected per year in IceCube and Gen2, assuming an astrophysical neutrino flux of $\Phi_\nu = 0.95 \times 10^{-18} \left(\frac{E_\nu}{100 \text{ TeV}}\right)^{-2.13} \text{ GeV}^{-1} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$ per flavor. Surface vetoed μ are muon tracks that pass through the footprint of a 75 km^2 veto array above Gen2, or the 1 km^2 IceTop array in the case of IceCube, and reach the detector with more than 100 TeV.

Identifying the sources of IceCube's neutrinos



Five times IceCube's point source sensitivity required to detect any reasonable source scenario

*Sensitivity for source catalog search

New sensor designs for improved performance



mDOM



36

- Directional information
- More sensitive area per module

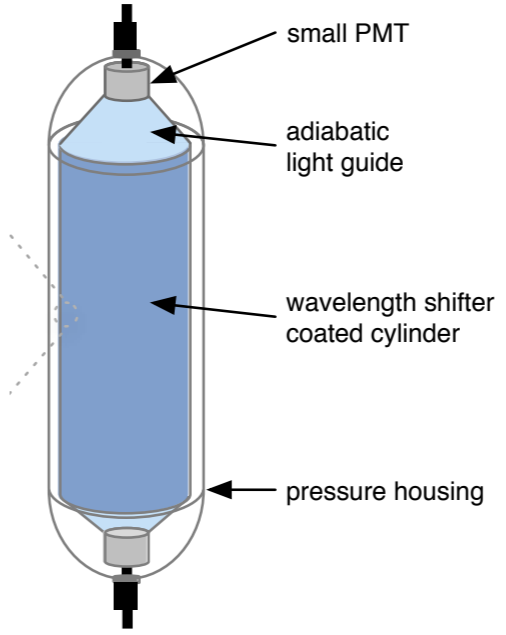
D-Egg



30

- Directional information
- More sensitive area per module
- Smaller geometry

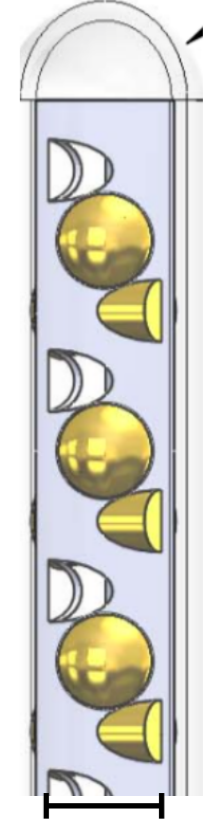
WOM



11

- more sensitive area per \$
- Small diameter
- Lower noise rate

LOM



13

- Small diameter
- Directional info.
- More area per module

Surface veto technologies under considerations

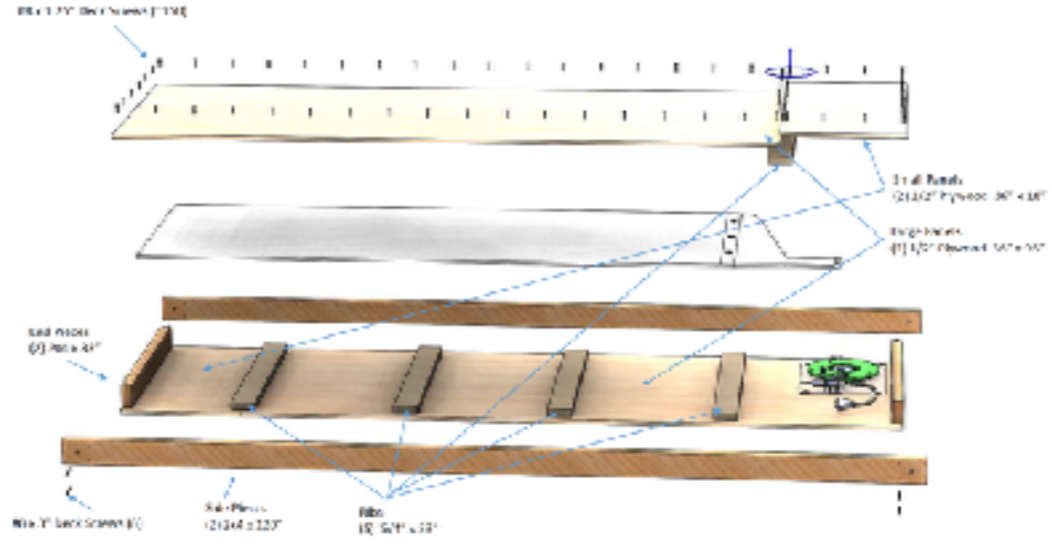


IceTop tanks



1.8 m

Scintillator panels



3 m

Additional concepts (ACTs, radio)



1 m

- Good CR detectors
- Operated at South Pole since 2007
- Deployment requires effort at Pole

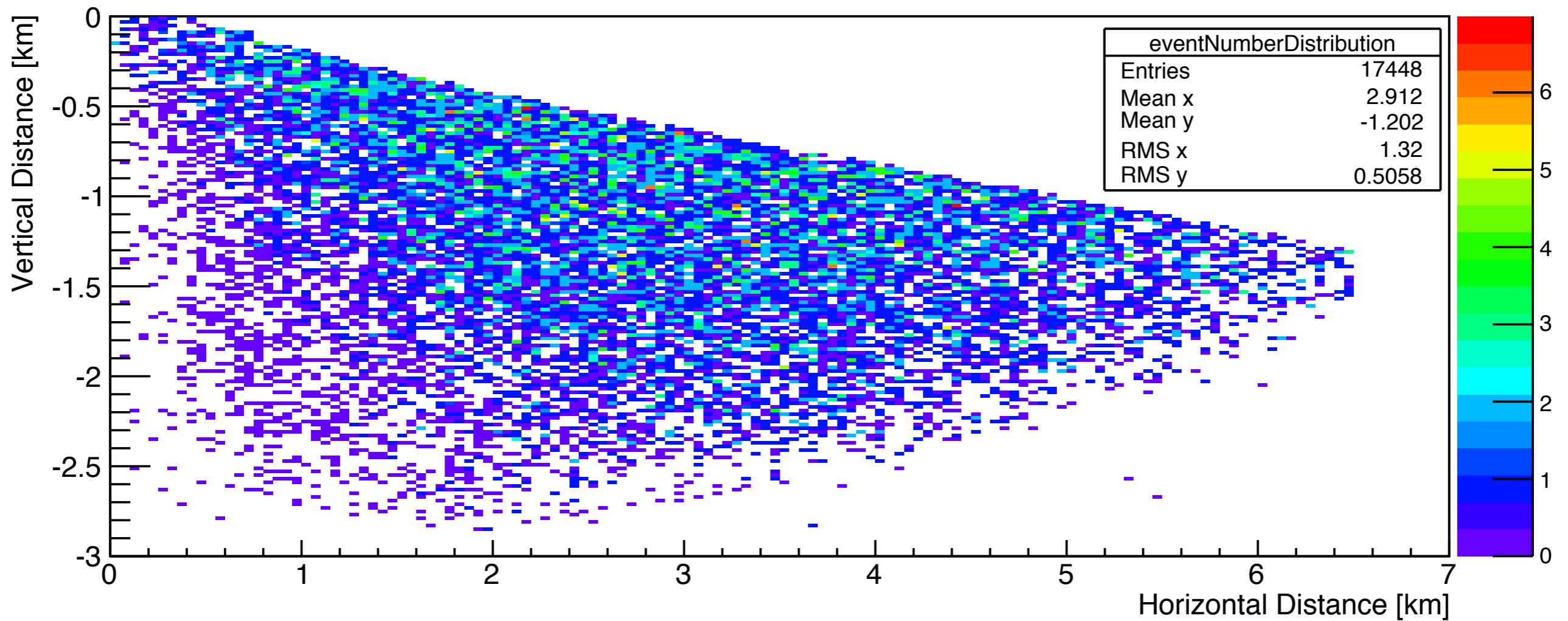
- Easier deployment
- Low cost (cheap materials and SiPMs)

- Reduced energy threshold
- Add resolution, particle ID,...

Radio detection of neutrinos at the South Pole



10^{19} eV Triggered Vertex Position

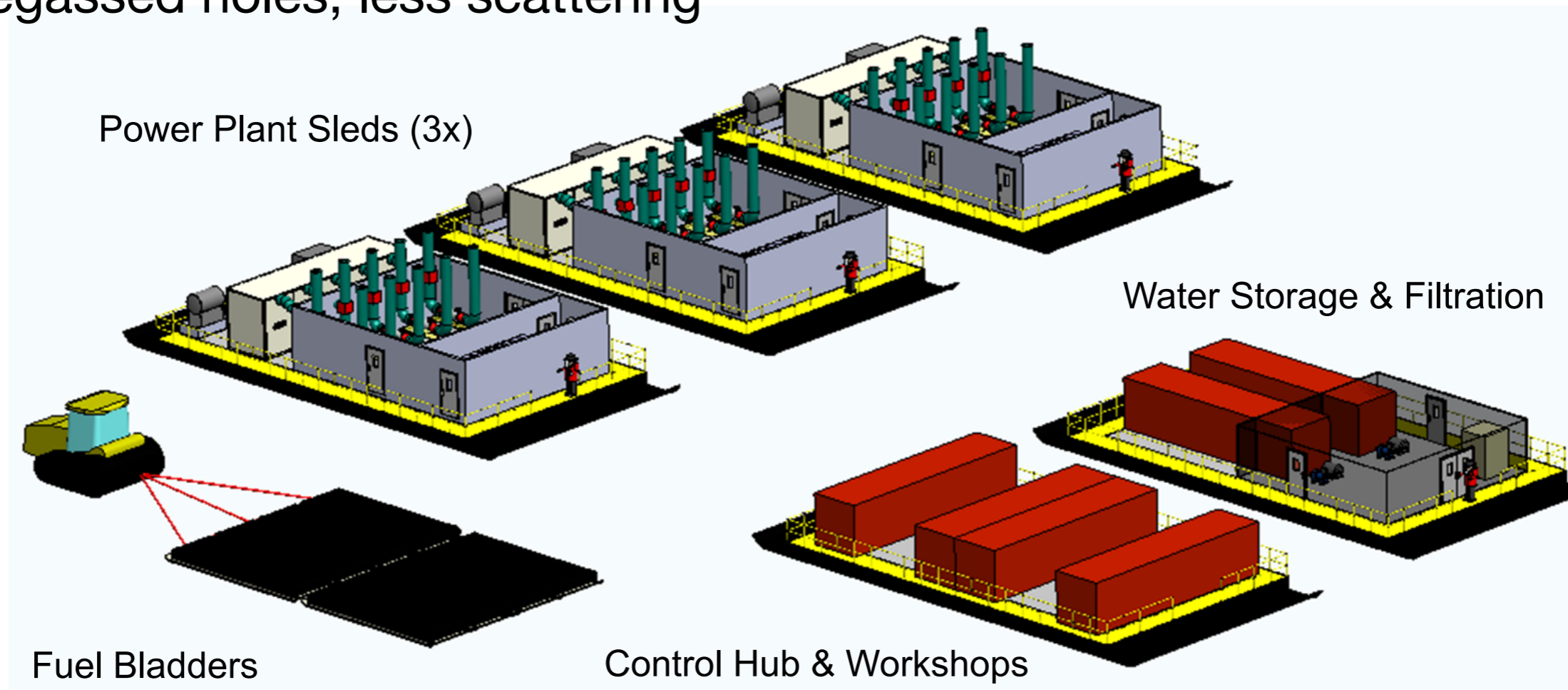


Simplified logistics:

- Equipment and fuel delivered to Pole via single traverse instead of air
- Reduced logistical footprint at Pole; smaller crew

Improved performance:

- New sensors allow for narrower holes \Rightarrow large fuel savings
- Faster drilling
- Degassed holes, less scattering



Surface veto technologies under considerations

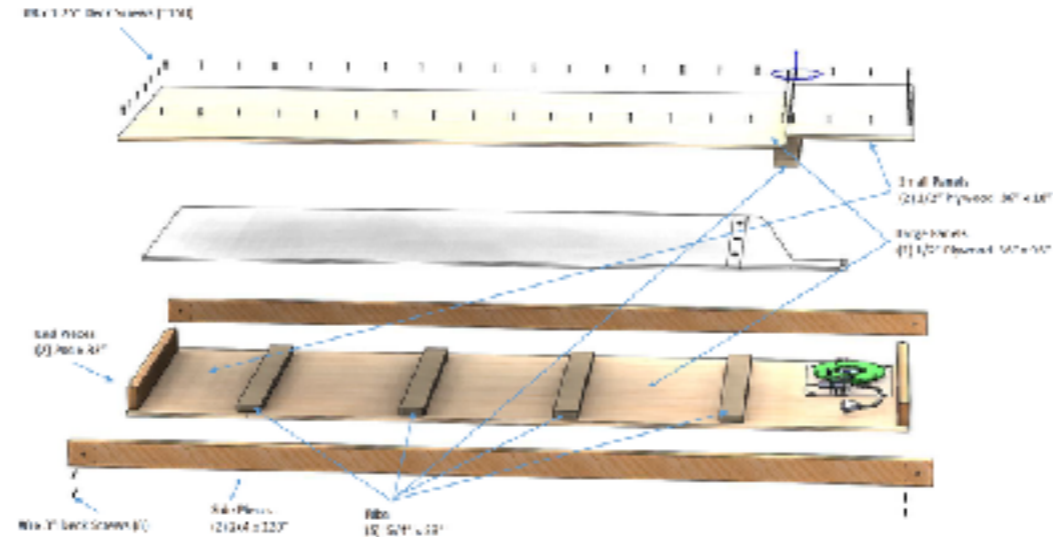
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Gen2-Phase I

- Seven new strings of multi-PMT mDOMs in the DeepCore region

- Inter-string spacing of ~ 22 m

- New calibration devices, incorporating lessons learned from a decade of IceCube calibration efforts

- Enhance IceCube's scientific capabilities at both high and low energy

