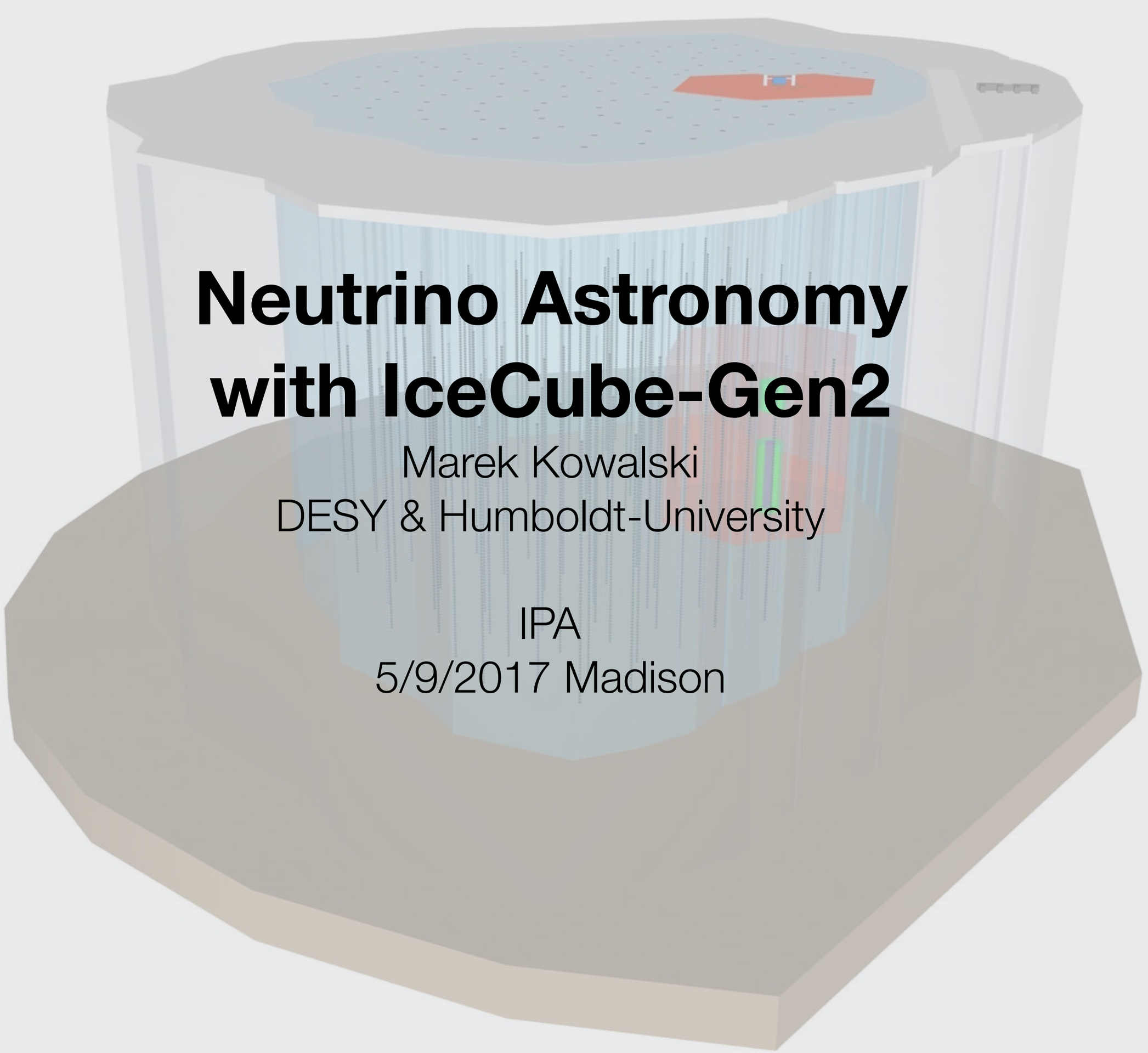
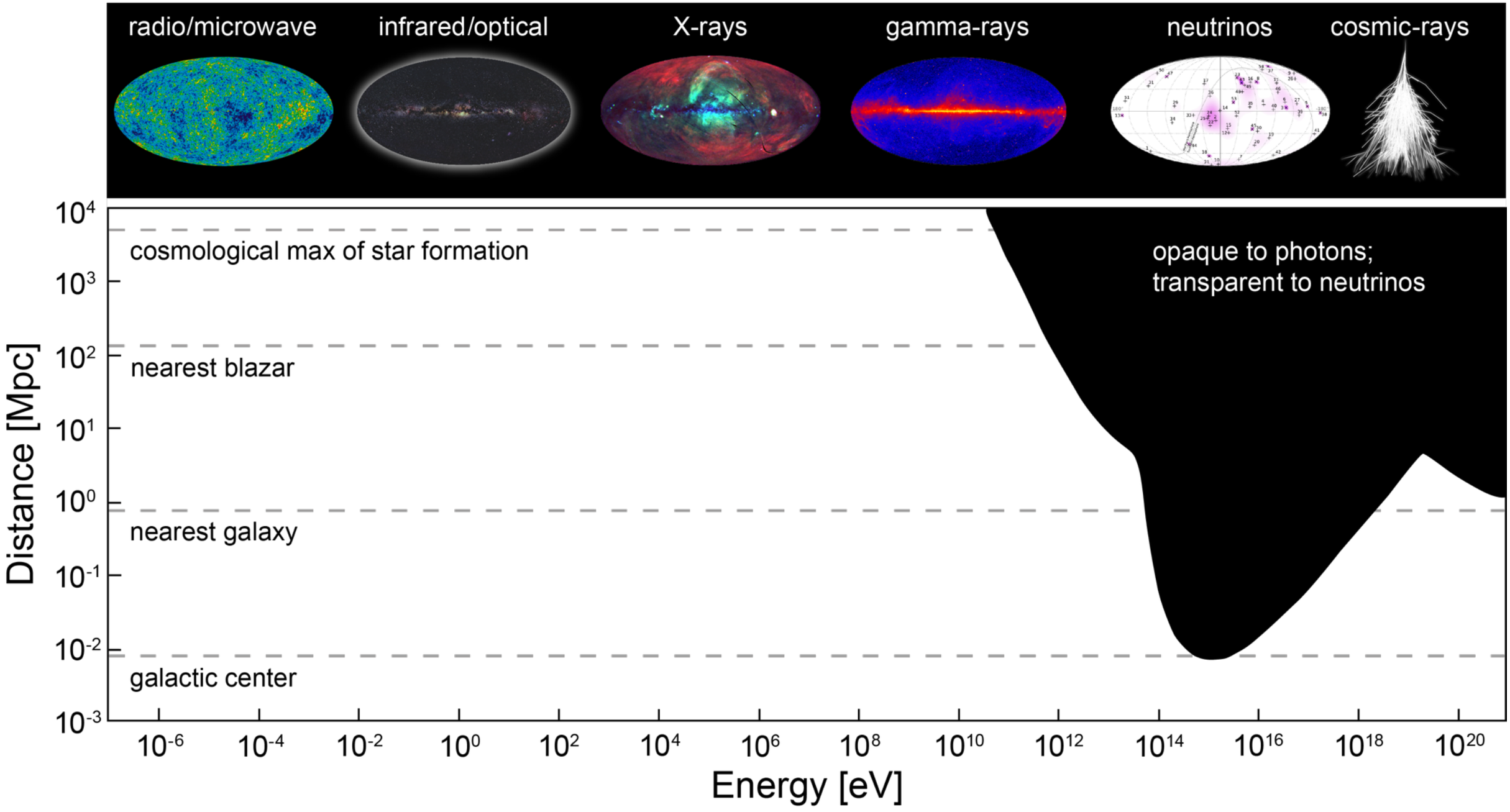


Neutrino Astronomy with IceCube-Gen2

Marek Kowalski
DESY & Humboldt-University

IPA
5/9/2017 Madison

Science driver in a nutshell



The Universe is opaque to EM radiation for ¼ of the spectrum,
i.e. above 10-100 TeV where IceCube sees cosmic neutrinos.

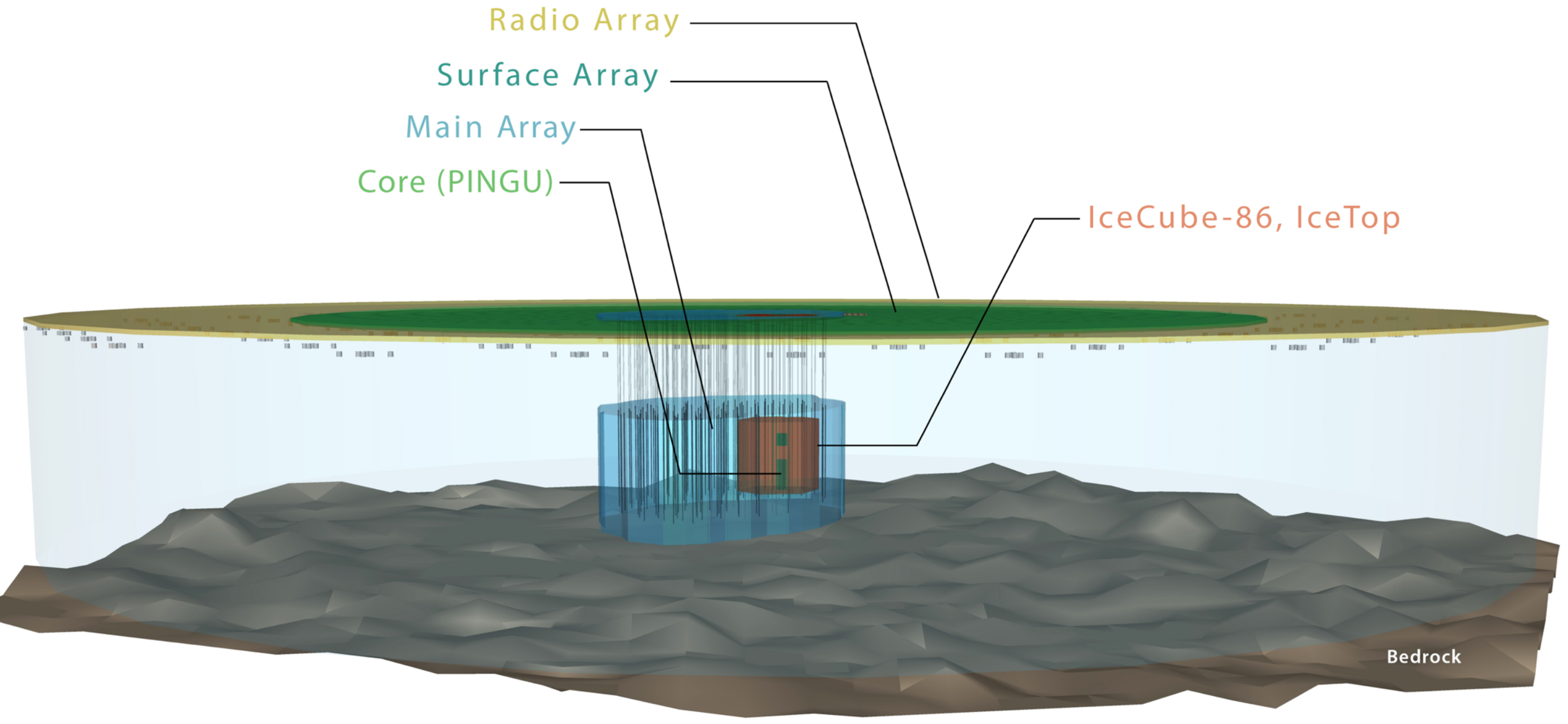
⟹ **explore this mostly uncharted territory with IceCube-Gen2**

Open questions for neutrino astronomy / Gen2

- Resolve the sources of IceCube's high energy astrophysical neutrinos
- Identify the sources of the highest energy cosmic rays
- Decipher the production mechanisms of high energy cosmic particles
- Obtain a unique multi-messenger view into the explosion of stars and the evolution of stellar remnants
- Explore active galaxies and the very high-energy Universe when it was most active
- Study of galactic and extra galactic propagation of CR with neutrinos as tracers
- Test nuclear, neutrino and BSM physics

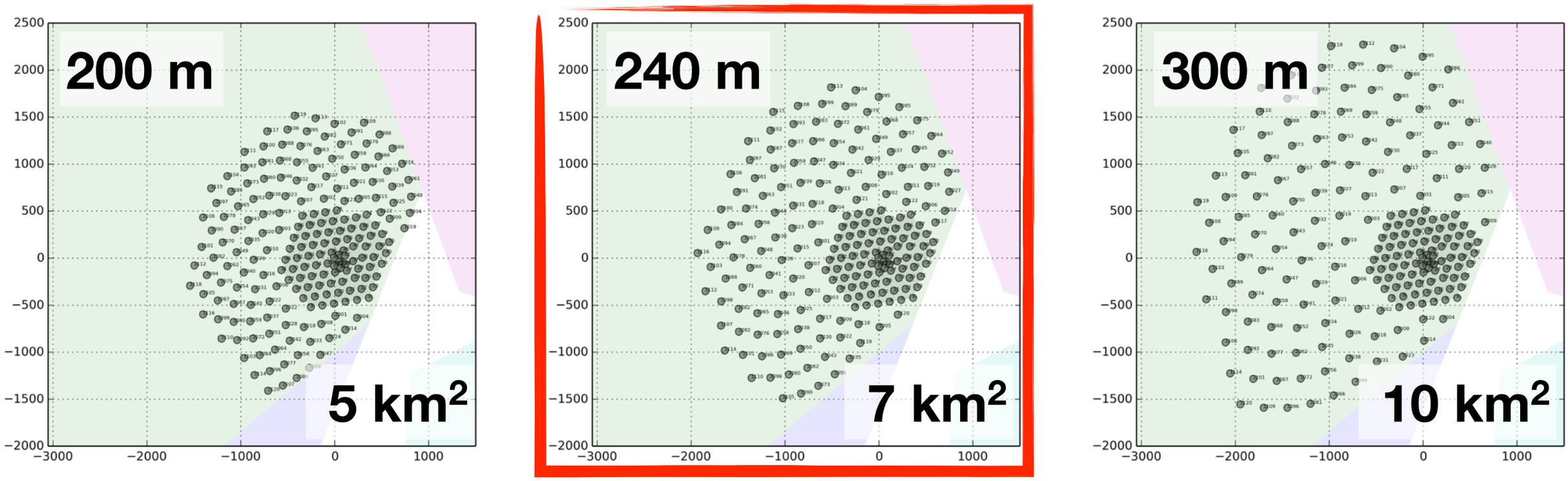
IceCube-Gen2 Facility

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



Geometry optimization

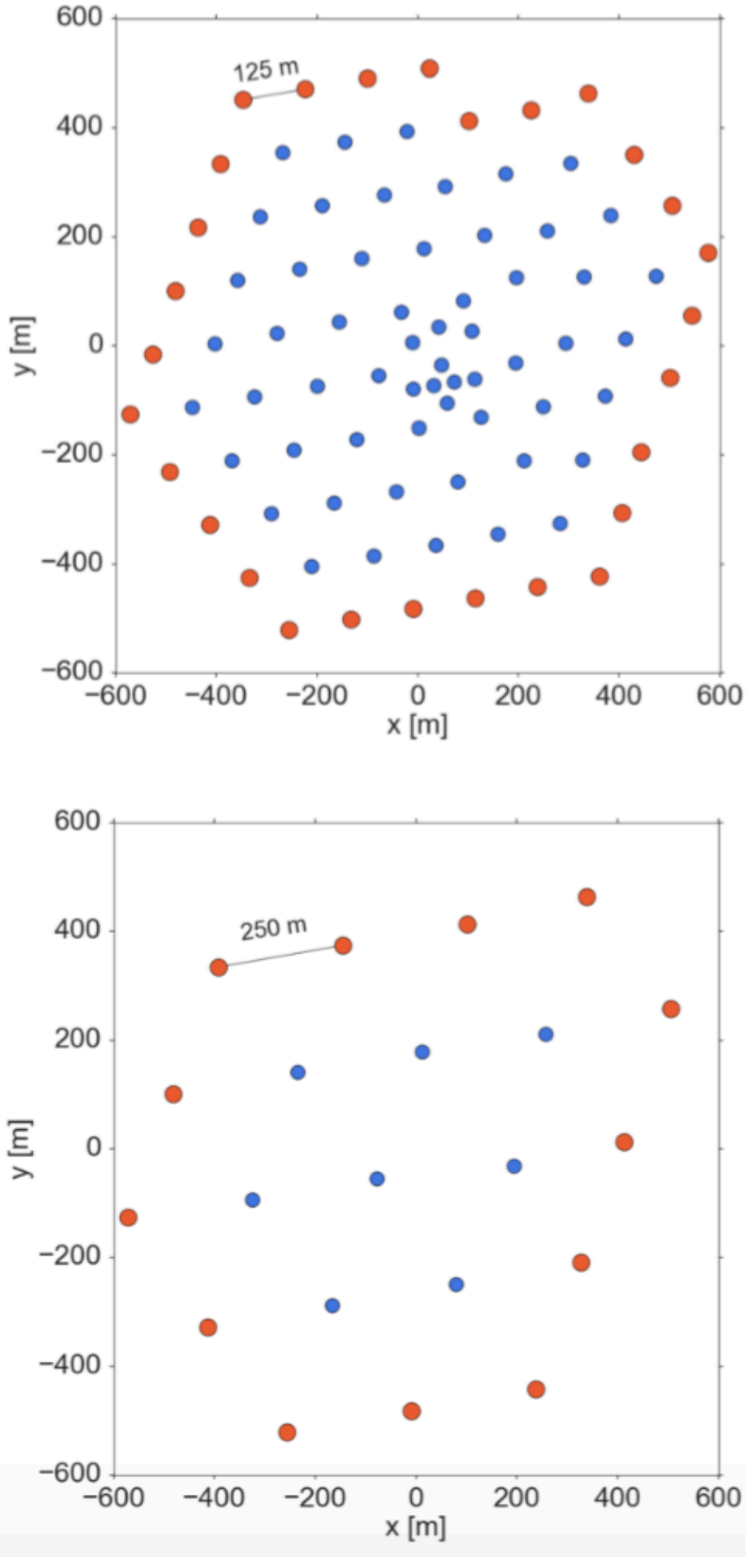
- Several layouts under evaluation
- Example: “Sunflower” geometry with different string spacings

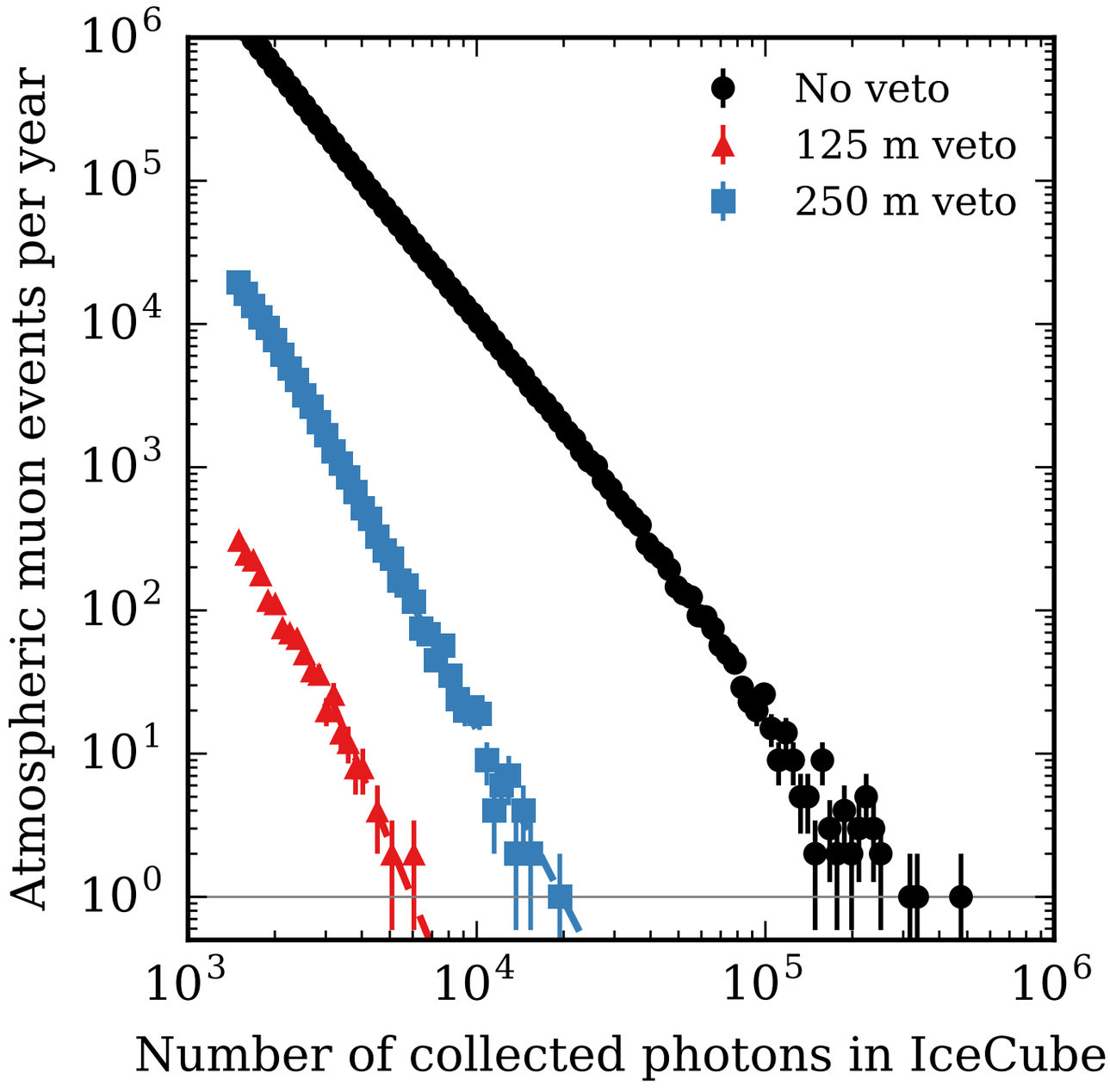


- ~120 new strings, 80 DOMs per string, instrumented over 1.25 km
- ~10 x IC volume for contained event analysis above 200 TeV

Vetoing atmospheric events with sparse detector

Evaluation of the veto passing rate from real data



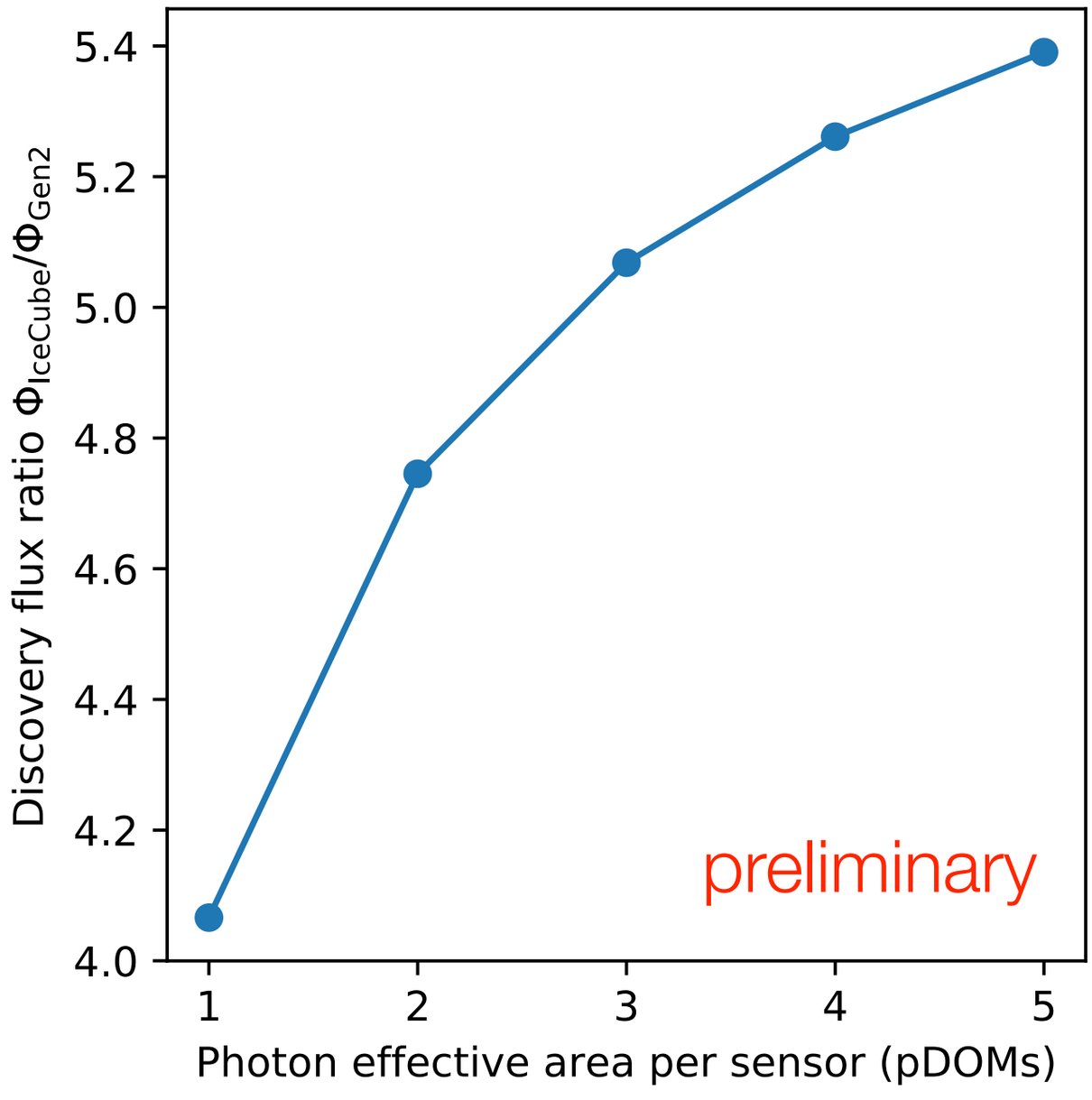


Vetoing atmospheric events works just like in IceCube!

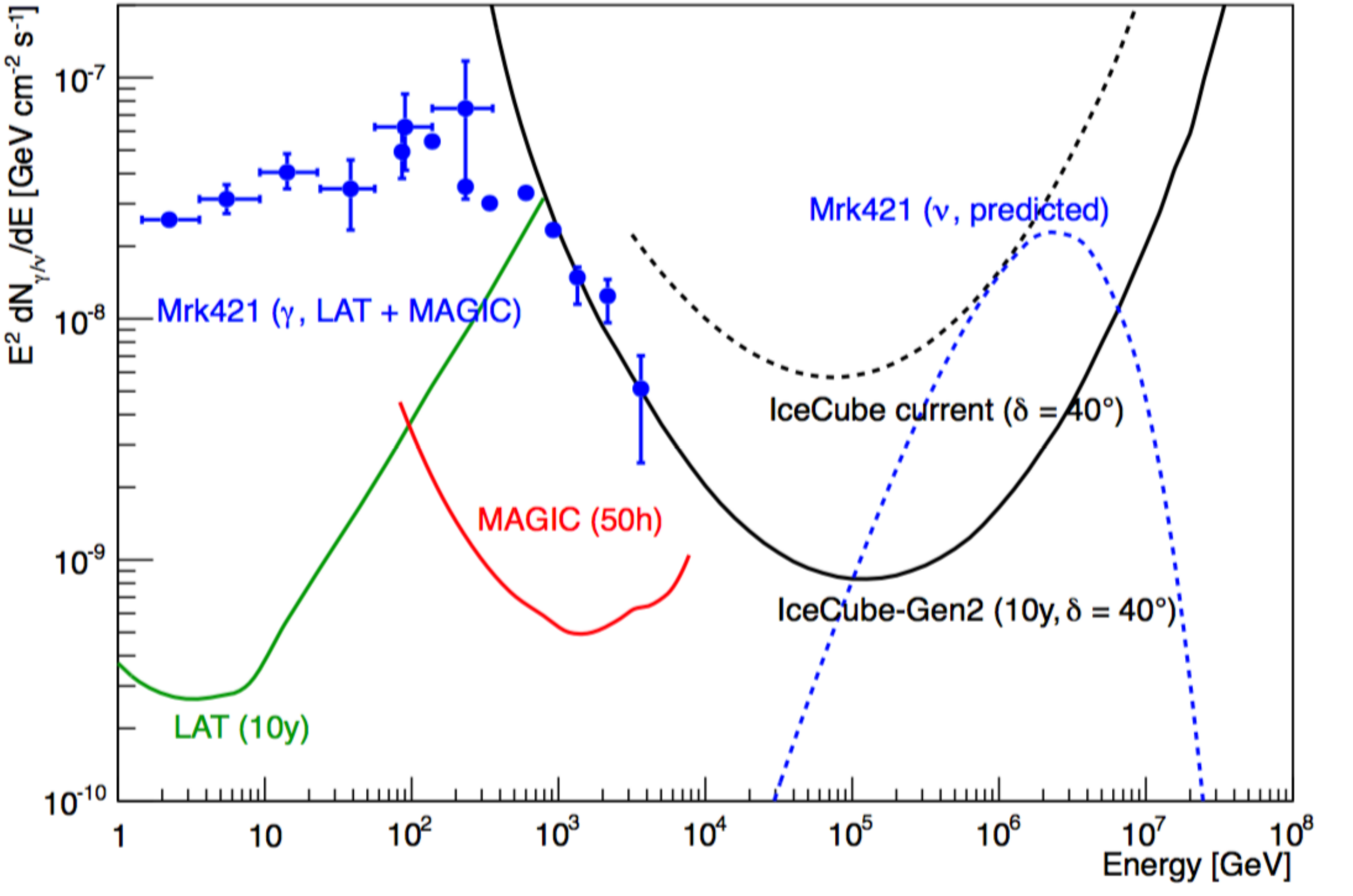
but with 3 x higher energy threshold

Point source sensitivity

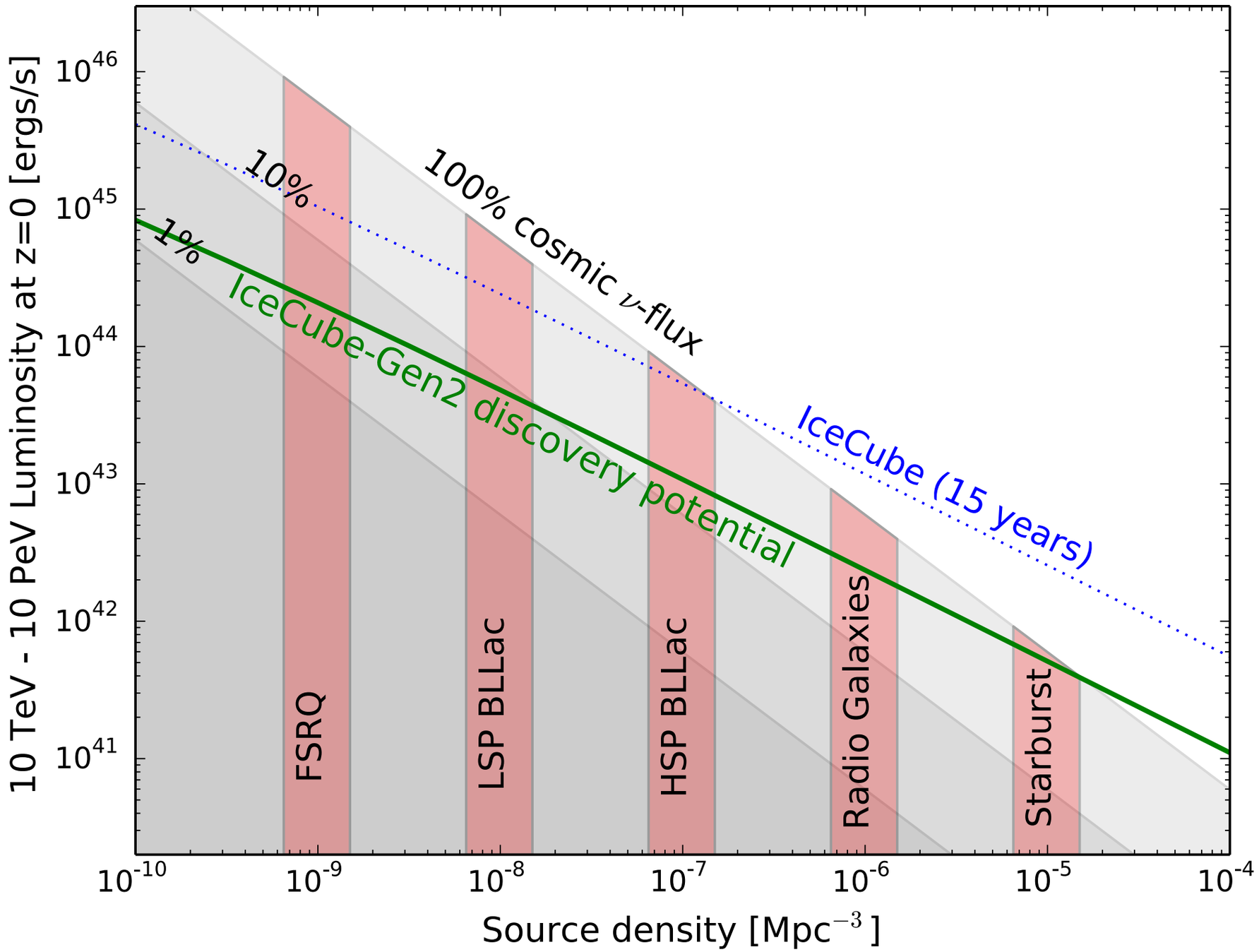
- "Just a big IceCube" has ~4 times its point source sensitivity
- > 25% performance improvements expected from new sensors



Point source sensitivity example: Mrk421



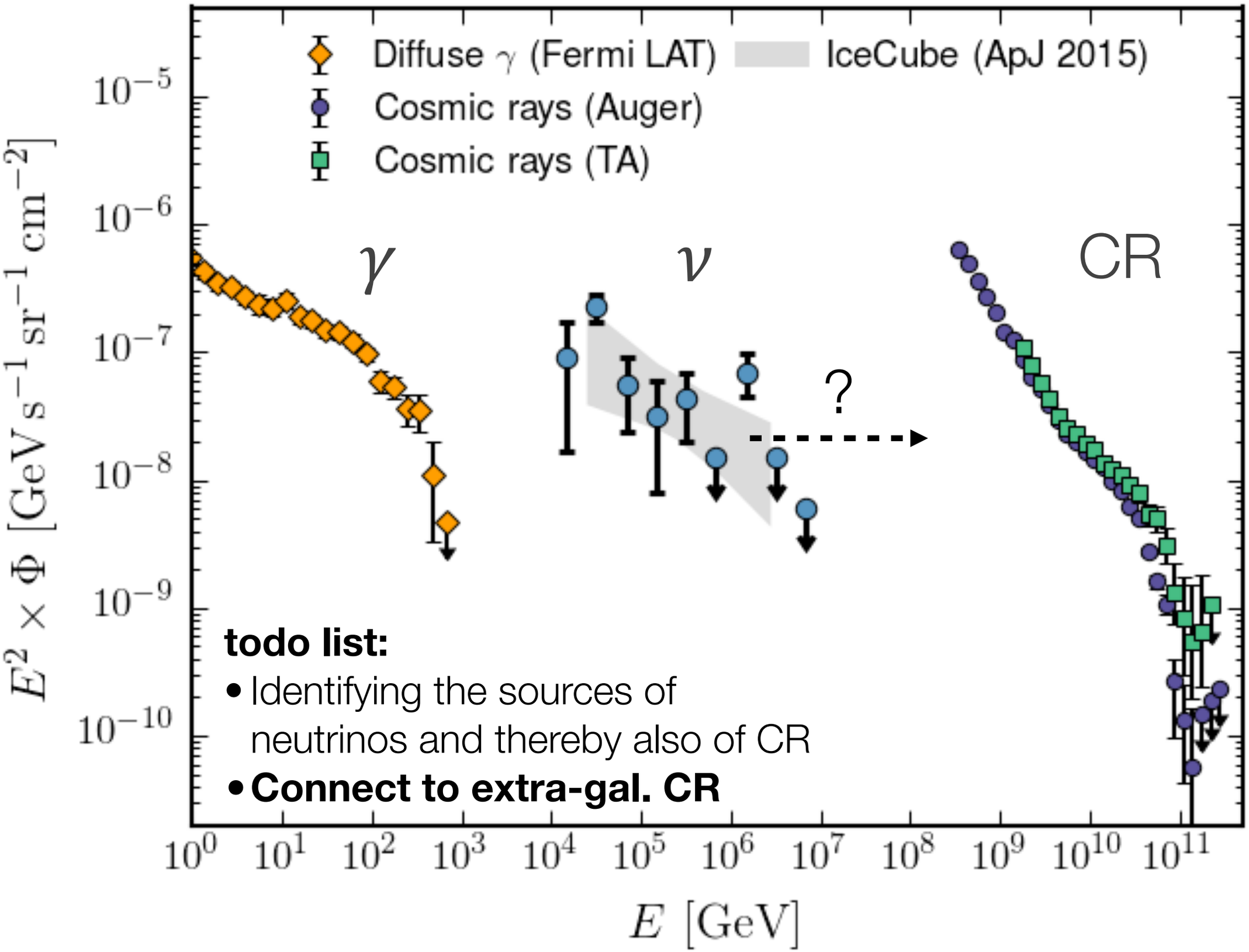
Identifying the sources of IceCube's neutrinos



Five times IceCube's point source sensitivity required to detect all reasonable source scenarios

*Sensitivity for source catalog search

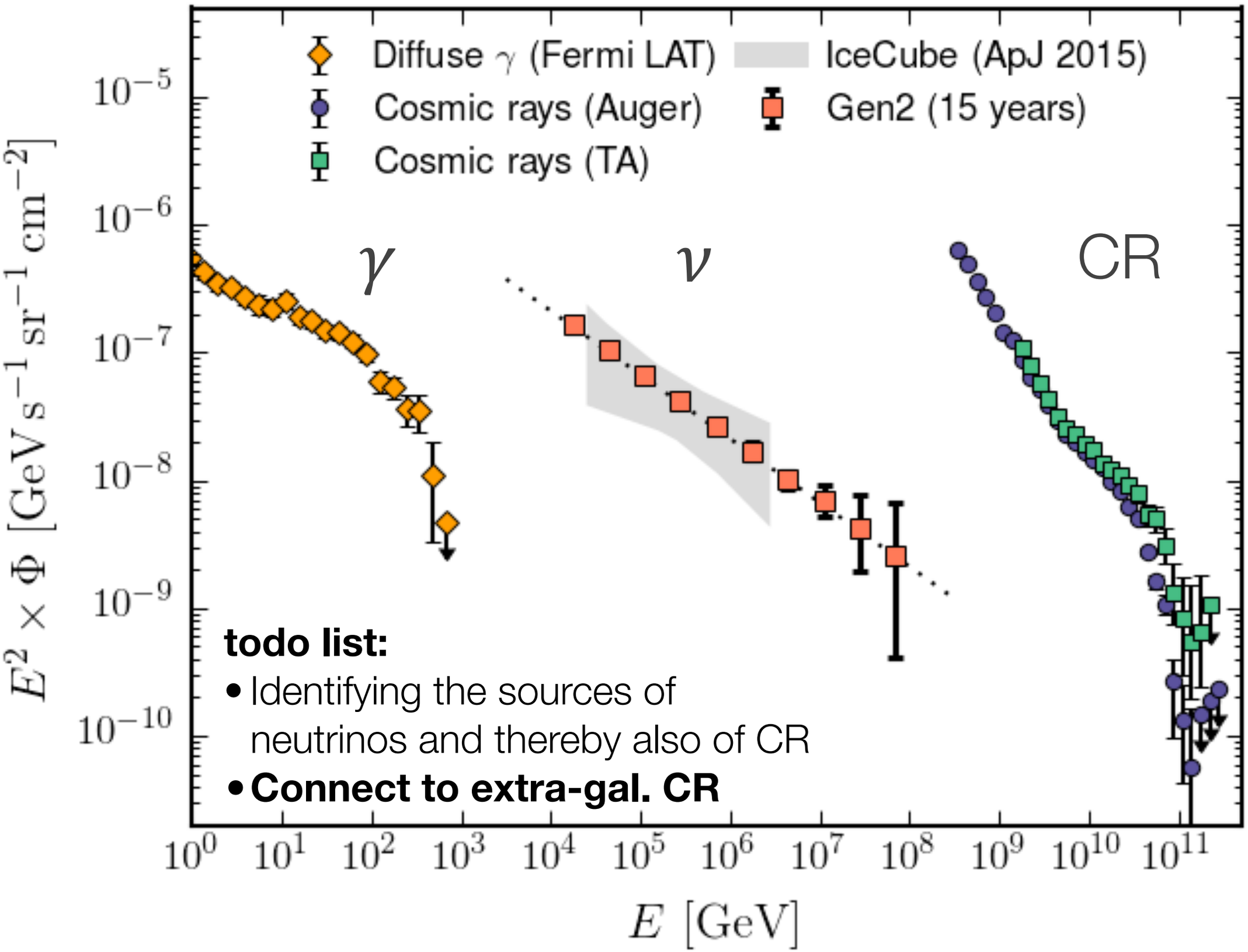
Resolving the mysteries of the UHE Universe



todo list:

- Identifying the sources of neutrinos and thereby also of CR
- **Connect to extra-gal. CR**

Resolving the mysteries of the UHE Universe



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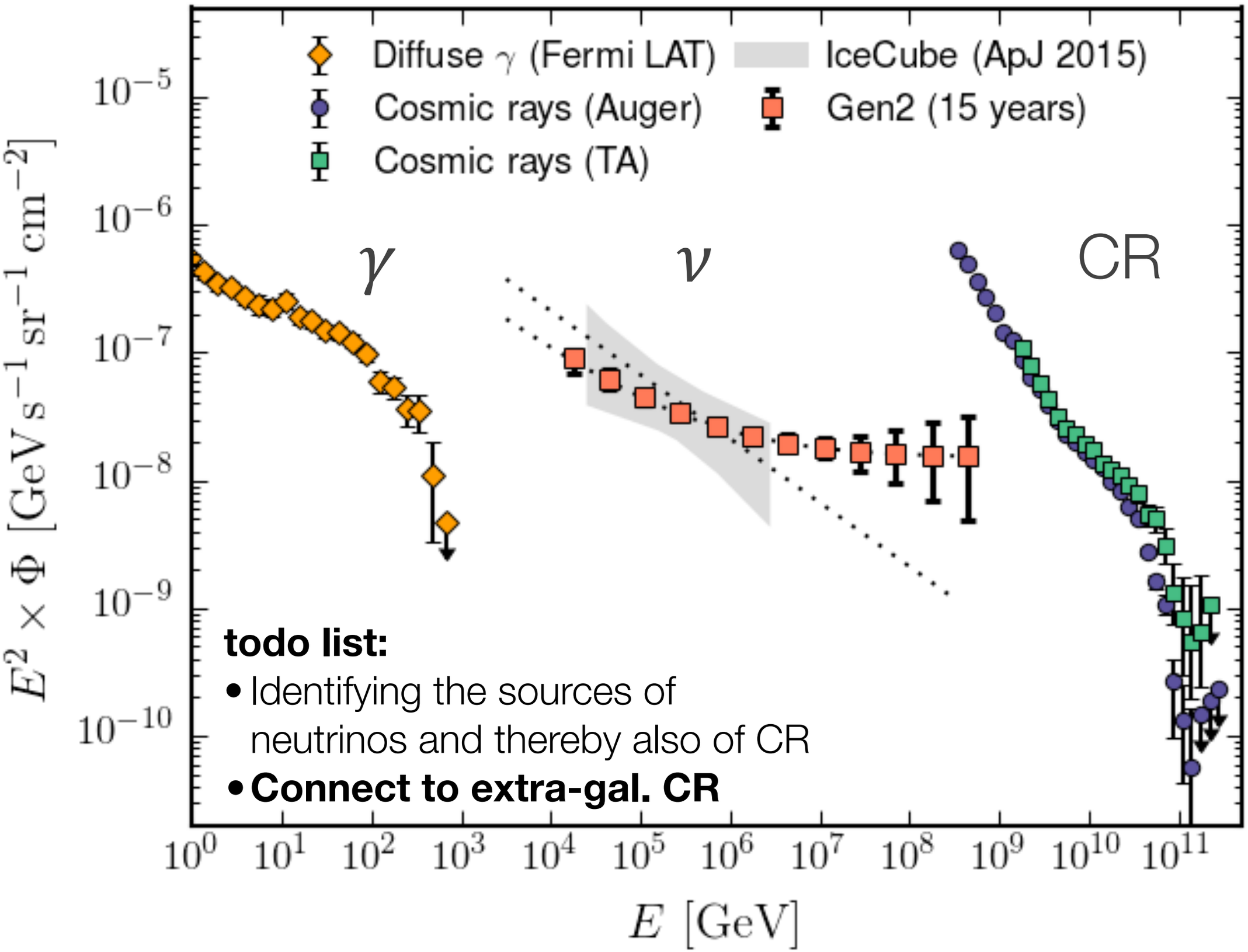

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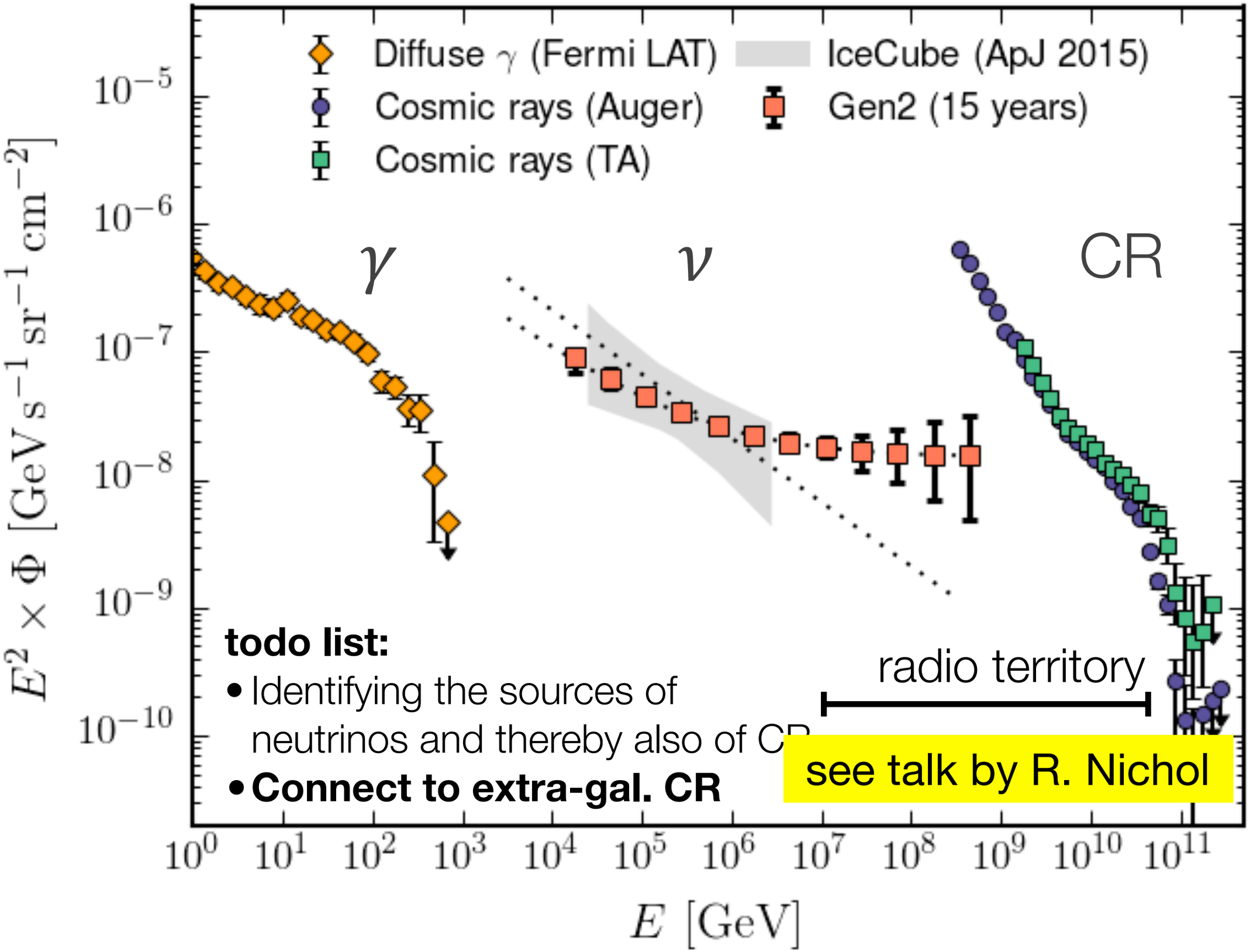


Flavor physics with astrophysical neutrinos

Flavor ratio constrain:

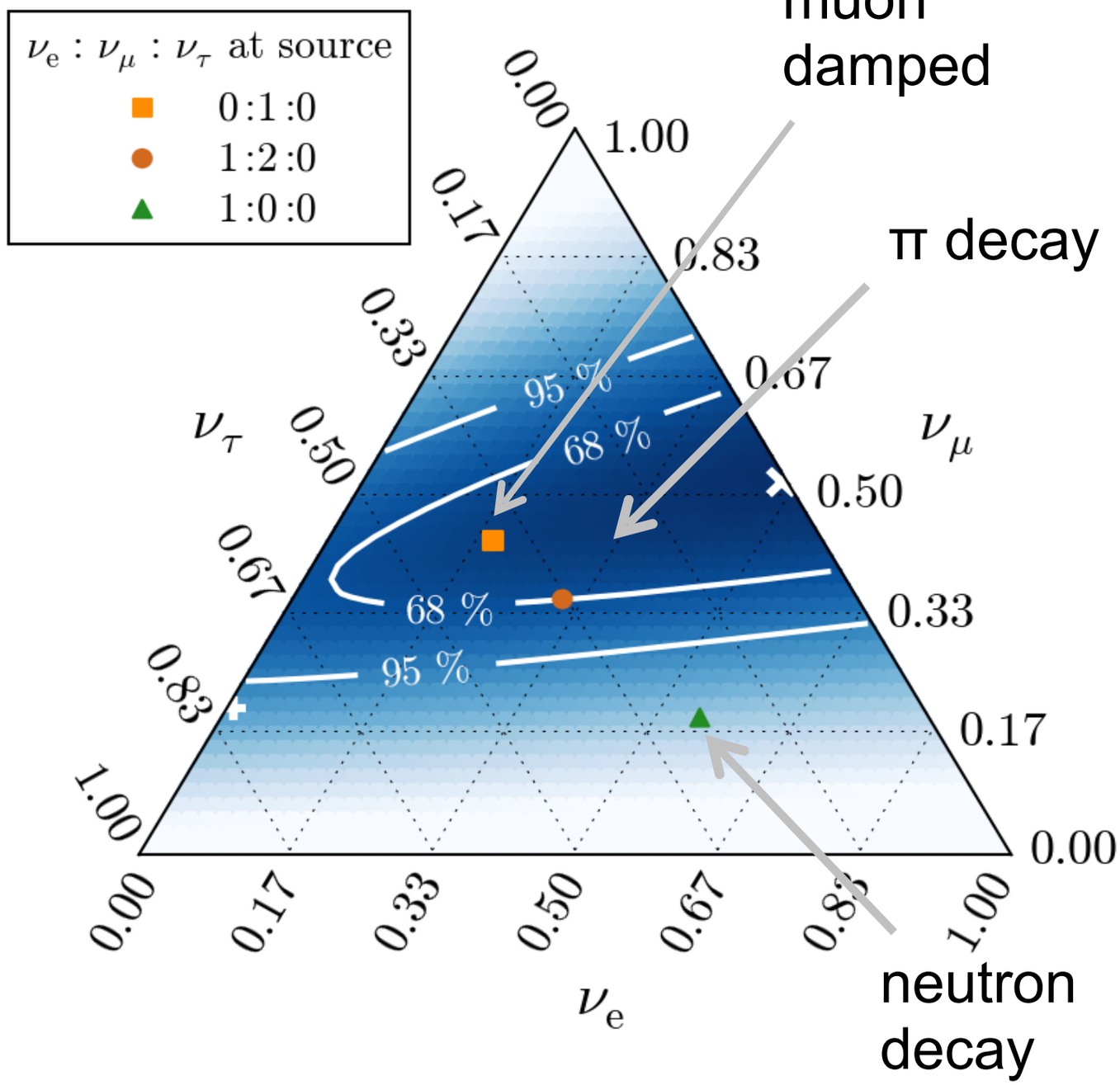
- conditions at source
  e.g. magnetic fields

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

$$\mu^- \rightarrow e^- + \bar{\nu} + \nu$$

⟶ 1:2:0

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



IceCube, **ApJ 2015**, see also PRL2015

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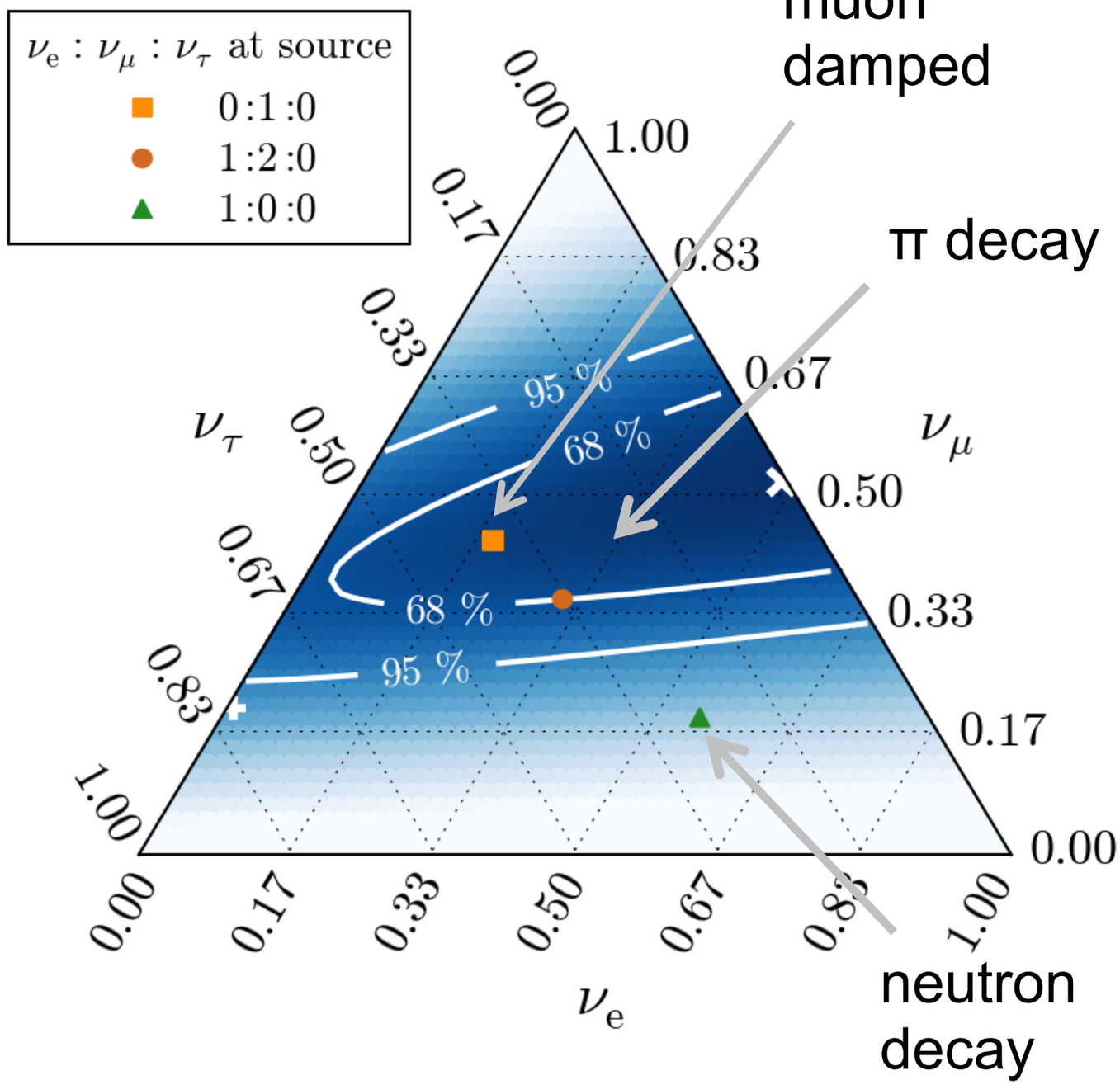

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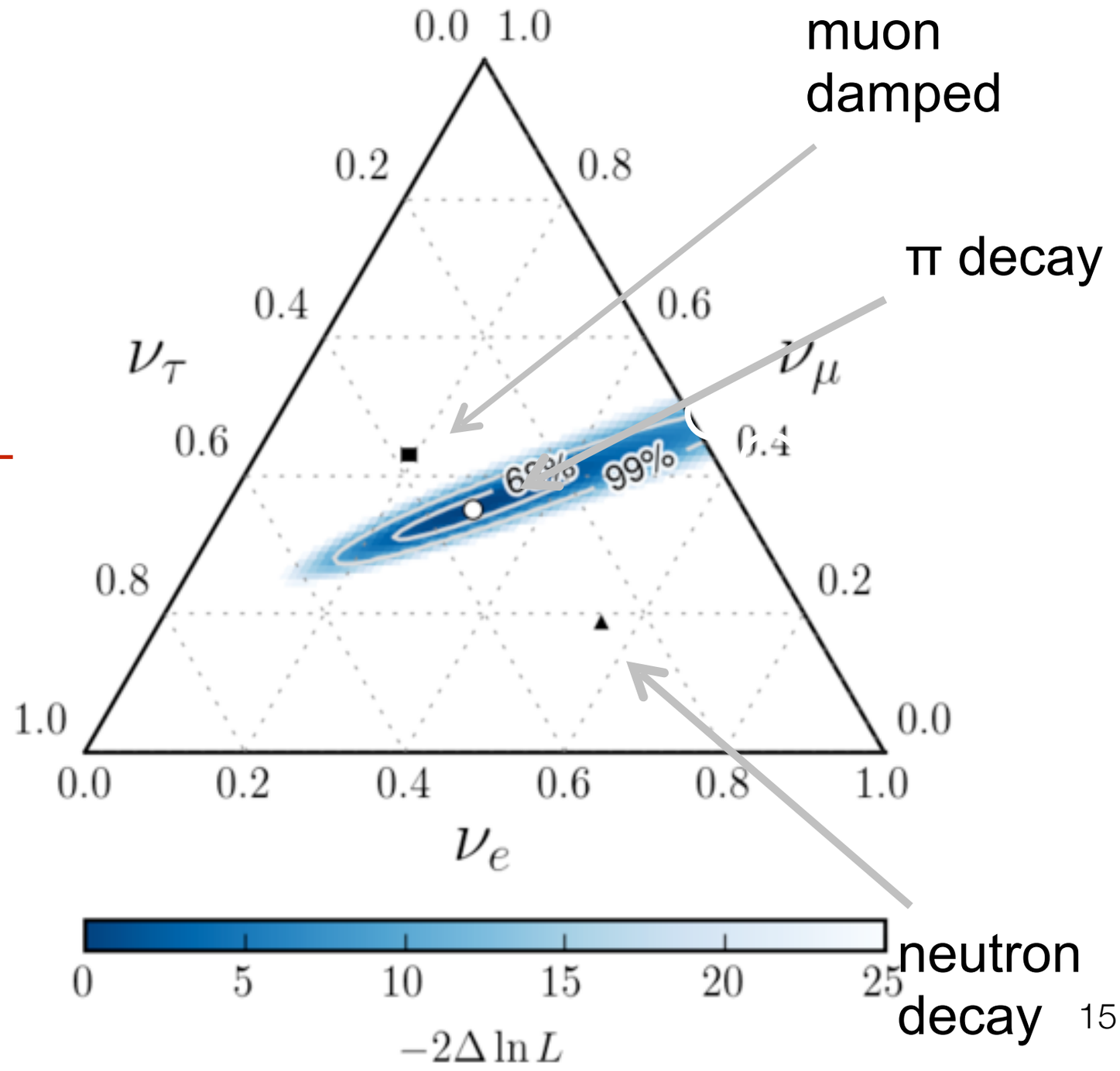
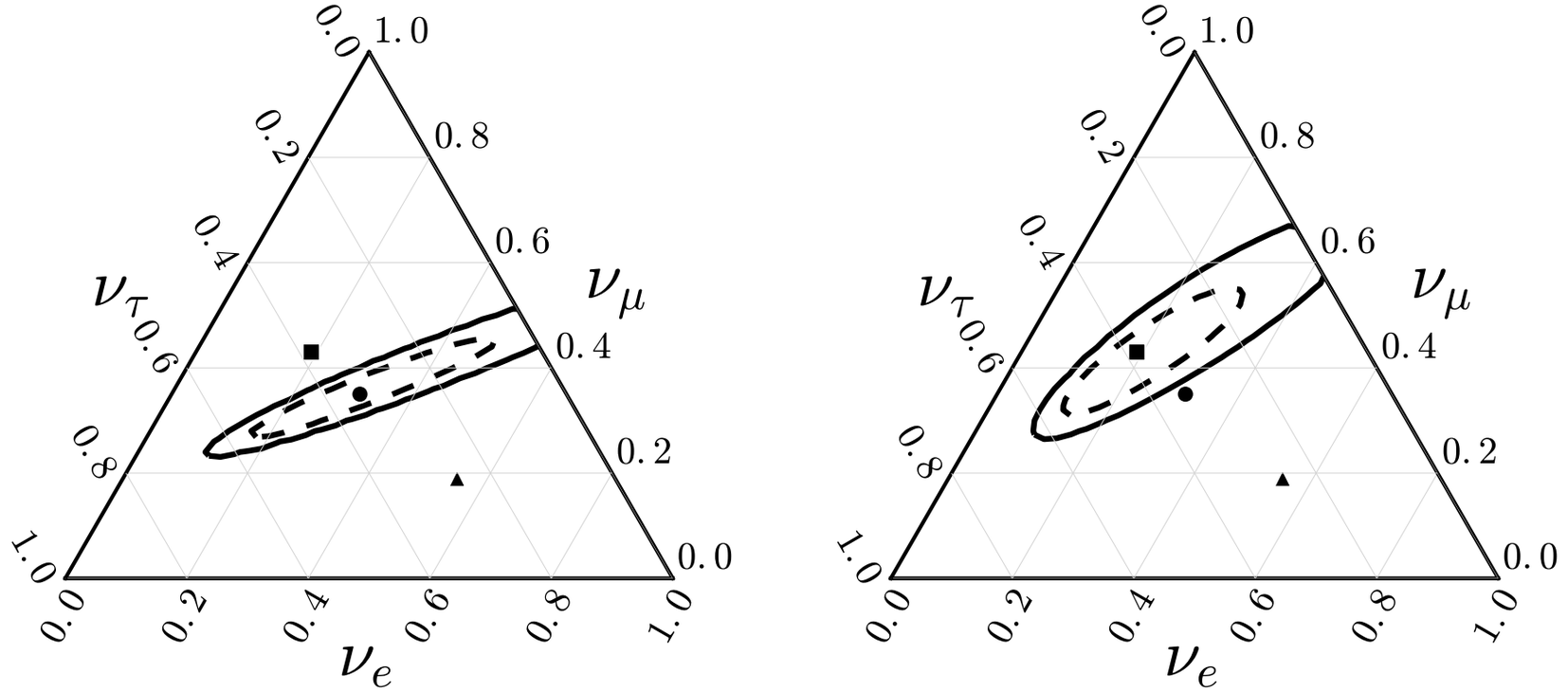
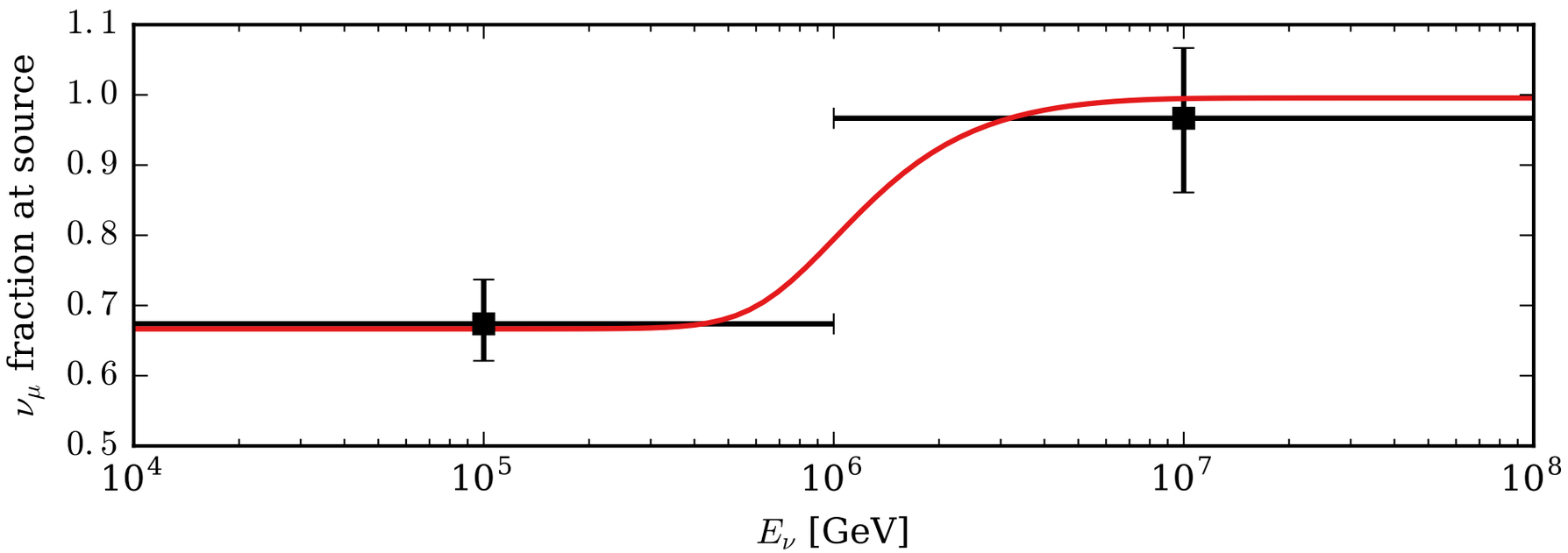


Gen2 (15 yrs)

Flavor physics - energy dependence

Sensitivity to source populations (Kasthi, Waxman 2005)





Gen2 (15 yrs)

New sensor designs for improved performance

mDOM

36

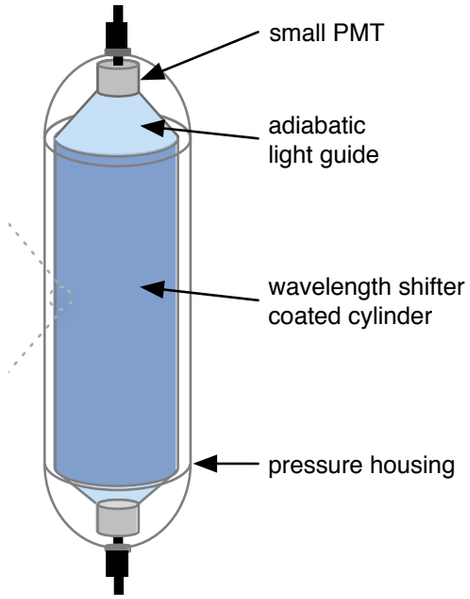
- Directional information
- More sensitive area per module

D-Egg

30

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

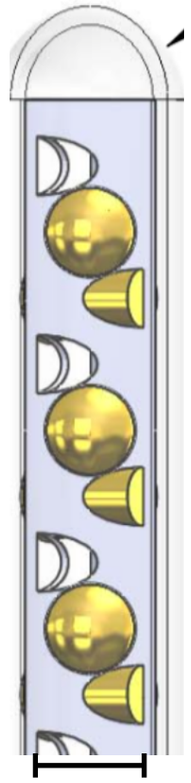
WOM



11

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

LOM



13

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

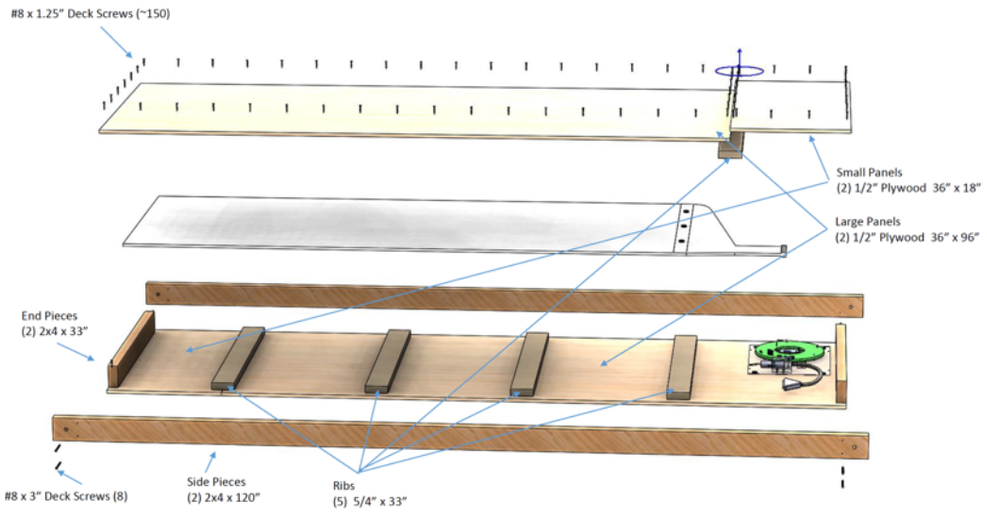
Surface veto technologies under considerations

IceTop tanks

1.8 m

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

Scintillator panels



3 m

- Easier deployment
- Low cost (cheap materials and small PMTs)

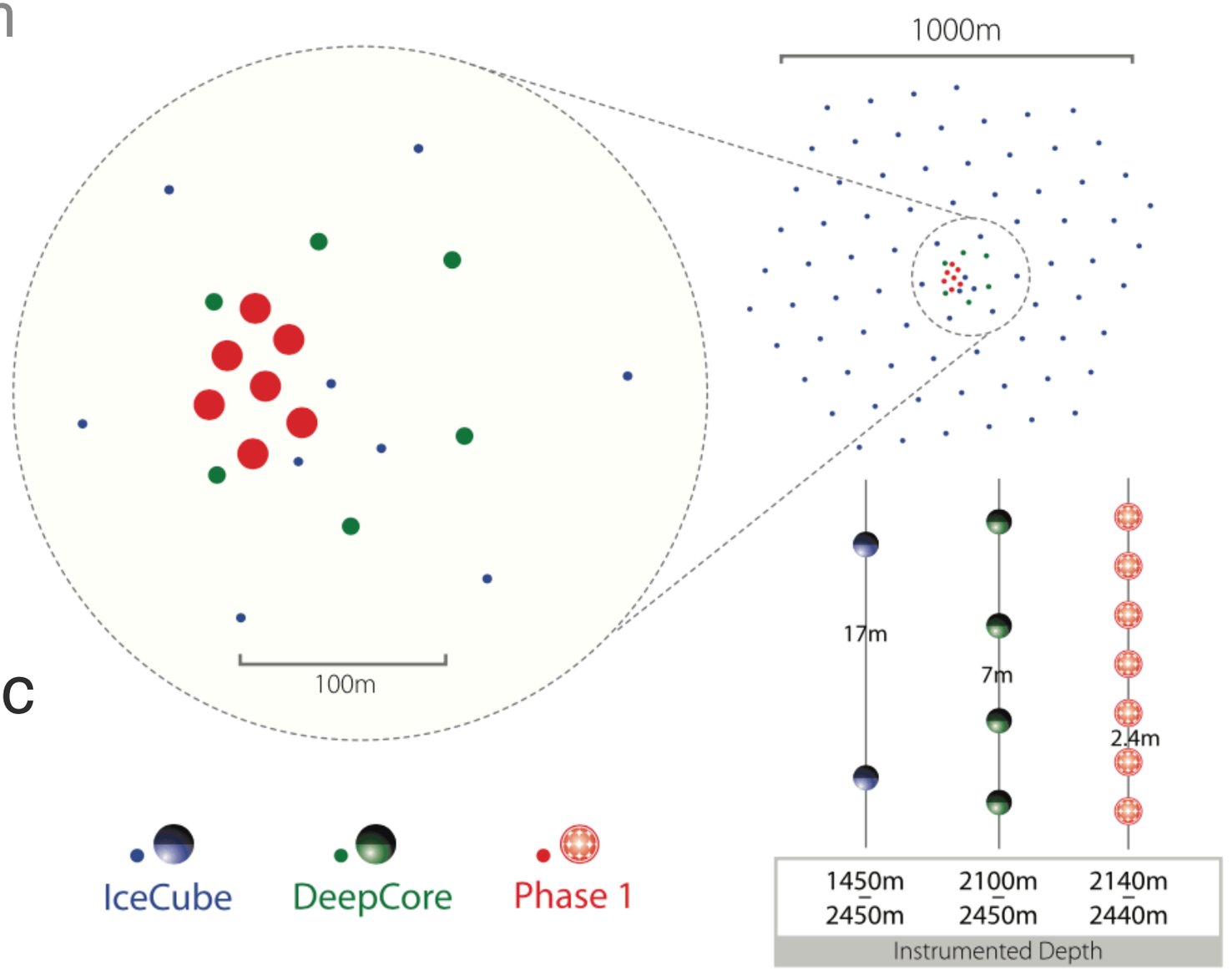
Additional concepts (ACTs, radio)

1 m

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

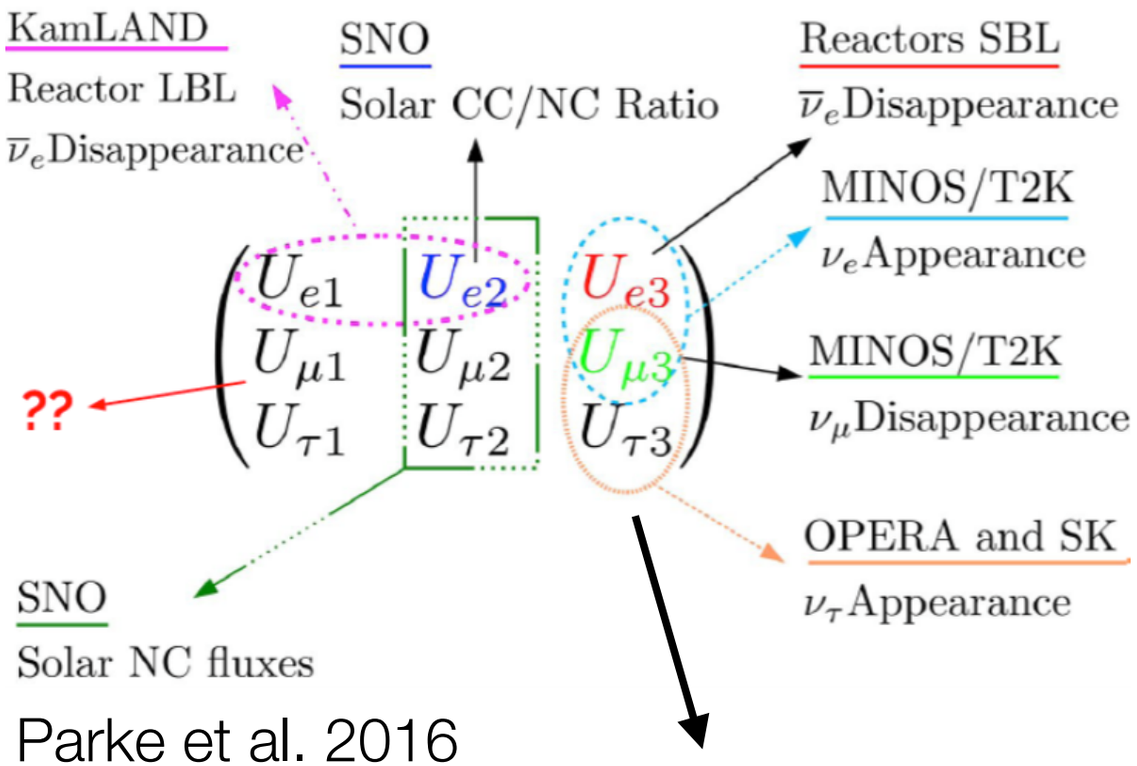
Gen2-Phase I

- 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 of capabilities at both high and low energy

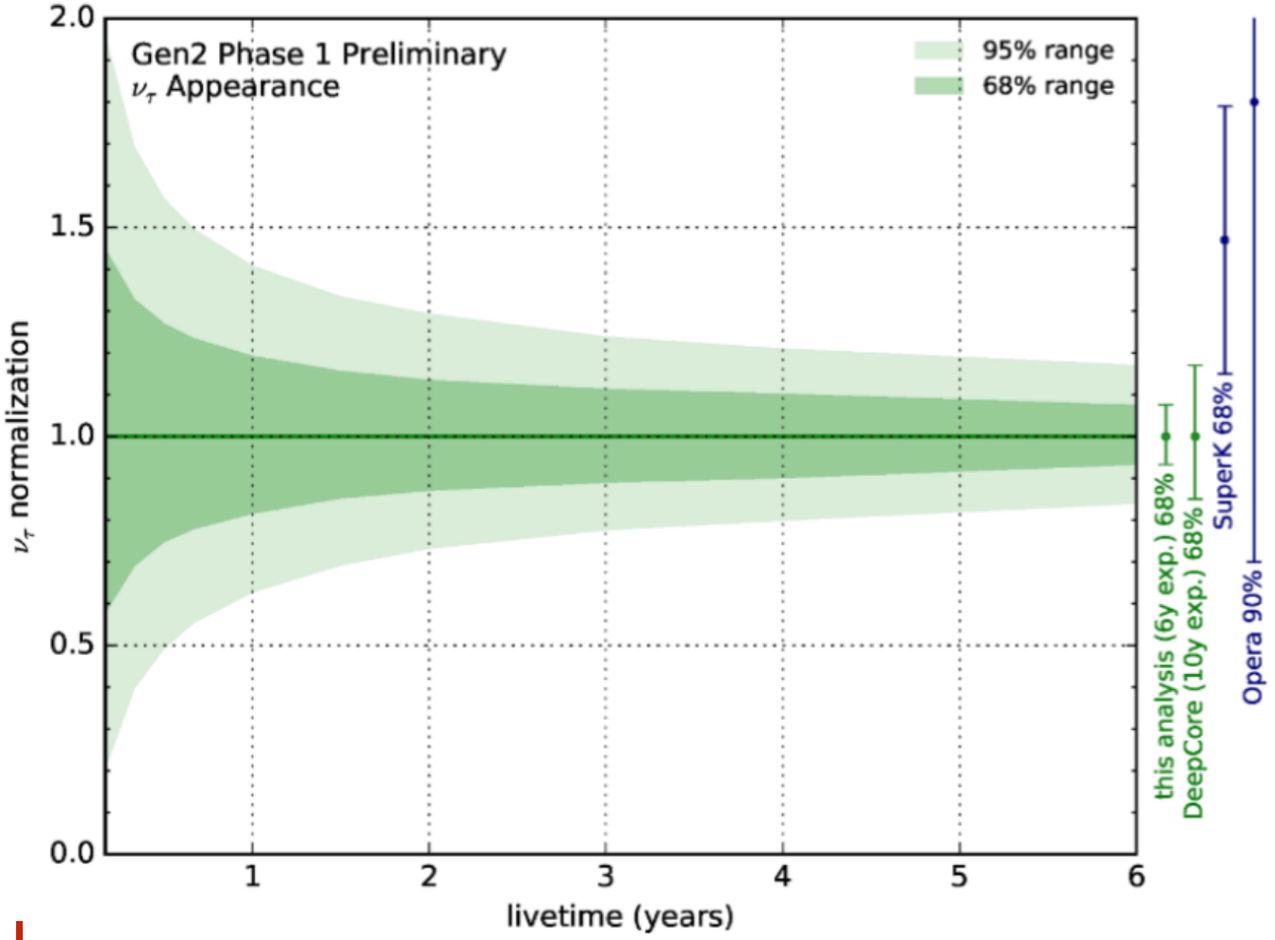


Gen2-Phase I: ν_τ appearance at low energies

World best constraints on tau appearance / Unitarity triangle



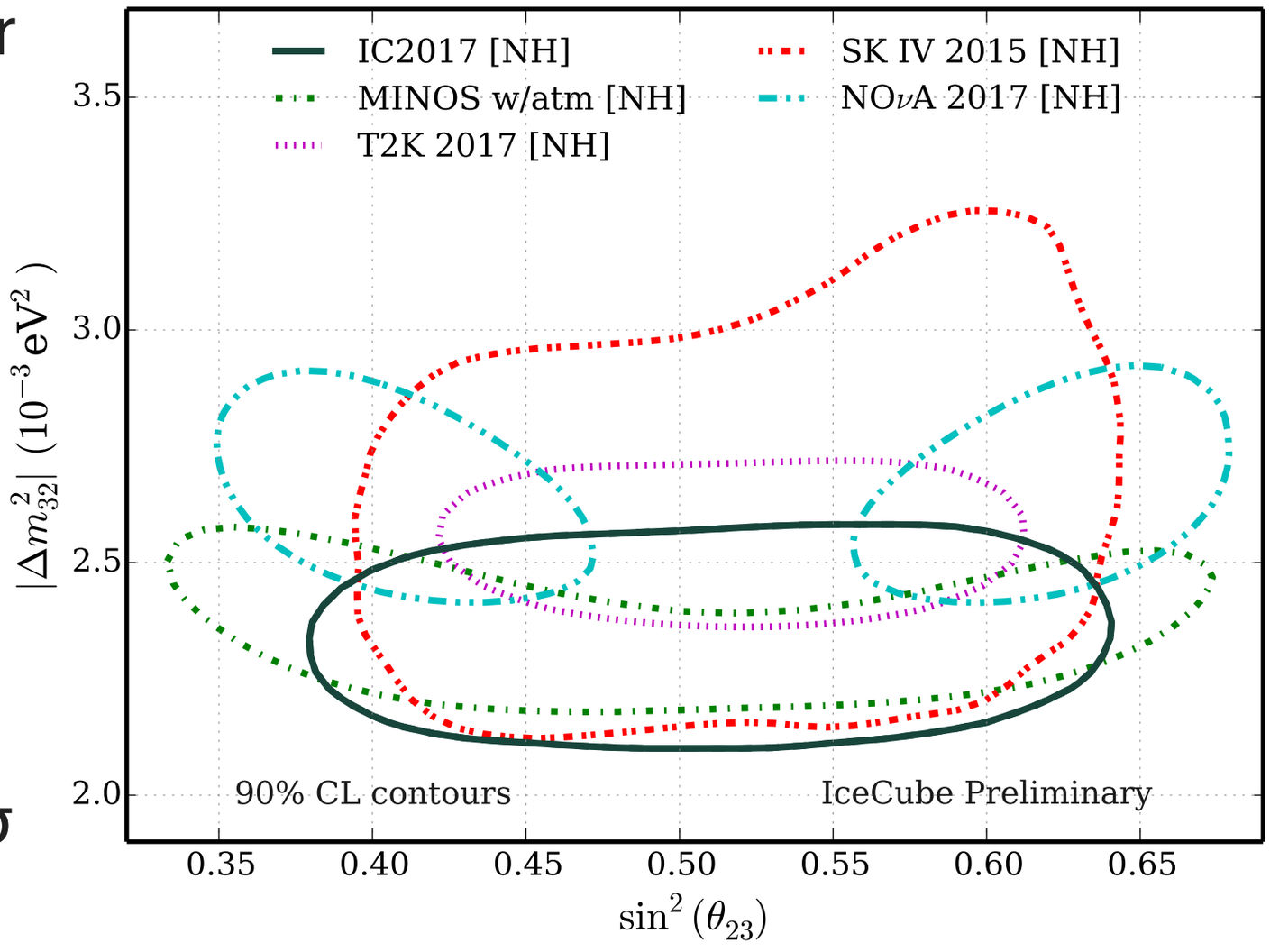
Parke et al. 2016



poorest constrained element
targeted directly with Gen2-Phase I

Gen2-Phase I: atmospheric neutrino oscillations

- Currently unclear whether $\sin^2 \theta_{23}$ is maximal
  - 3rd mass state made up of equal parts ν_μ, ν_τ
  - Evidence of new symmetry?
- T2K and IceCube prefer maximal mixing, NOvA disfavors maximal at 2.6σ



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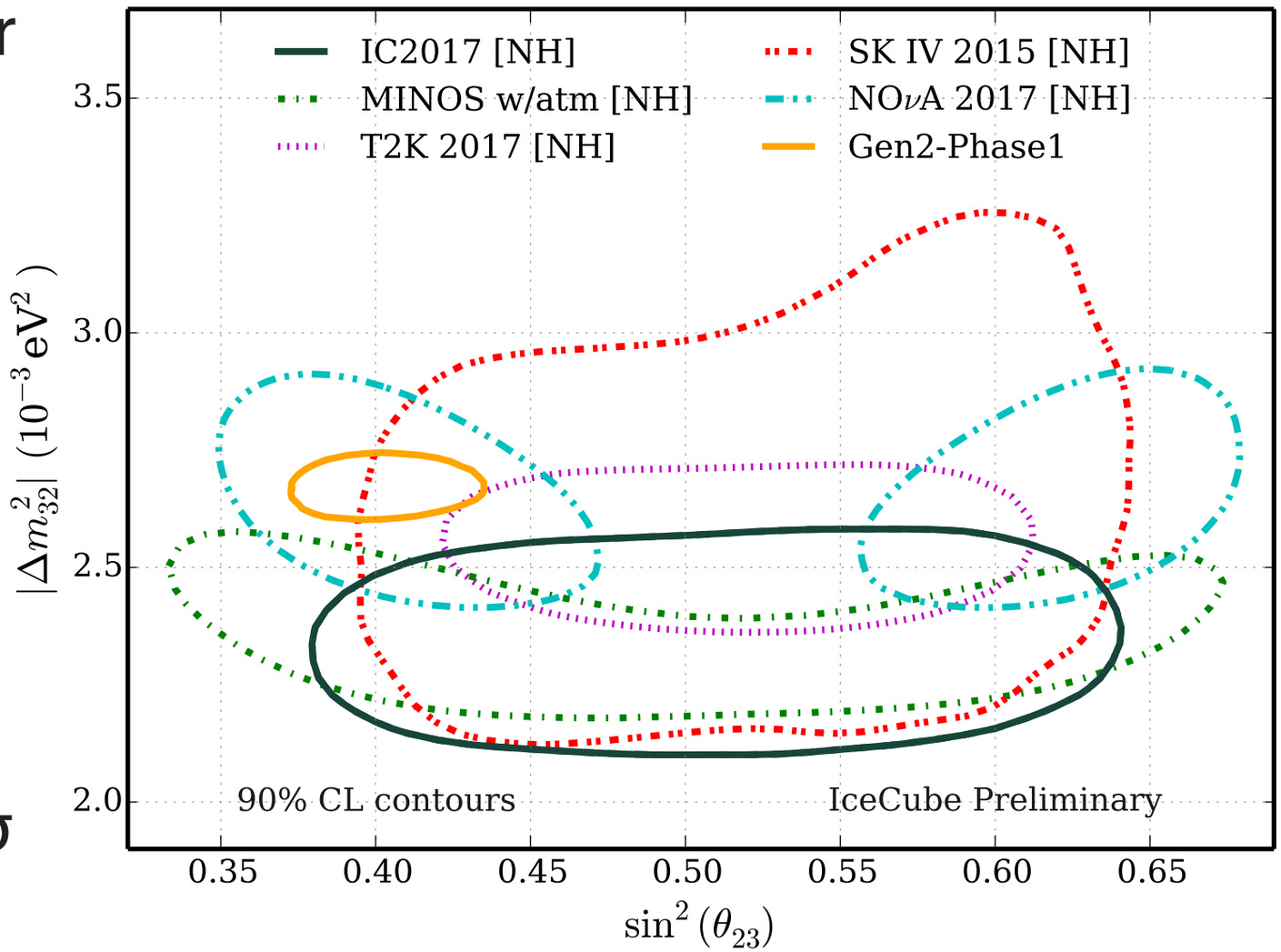

- Phase 1 will enable IceCube measurements with precision competitive with projected final T2K/NOvA results

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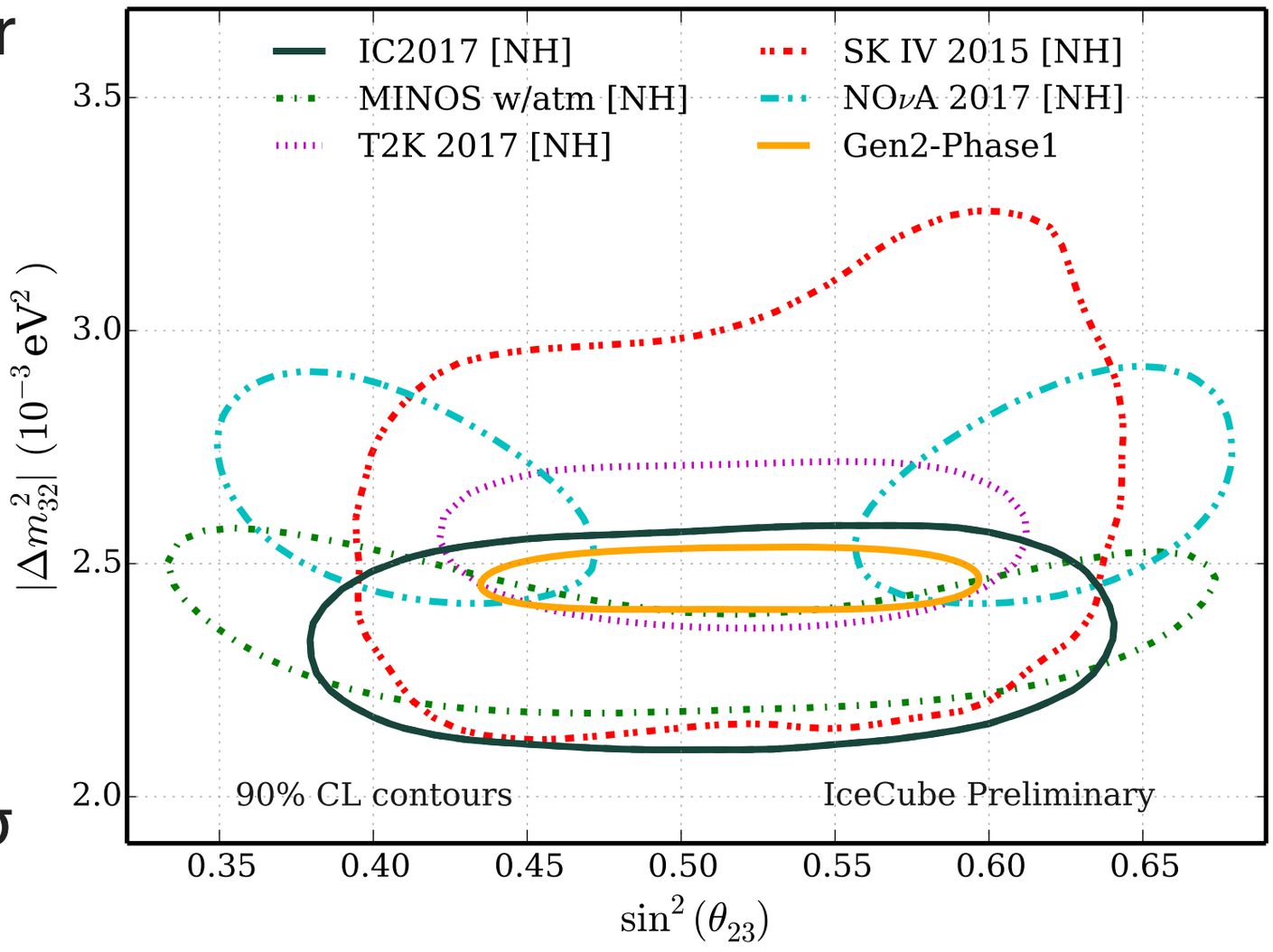

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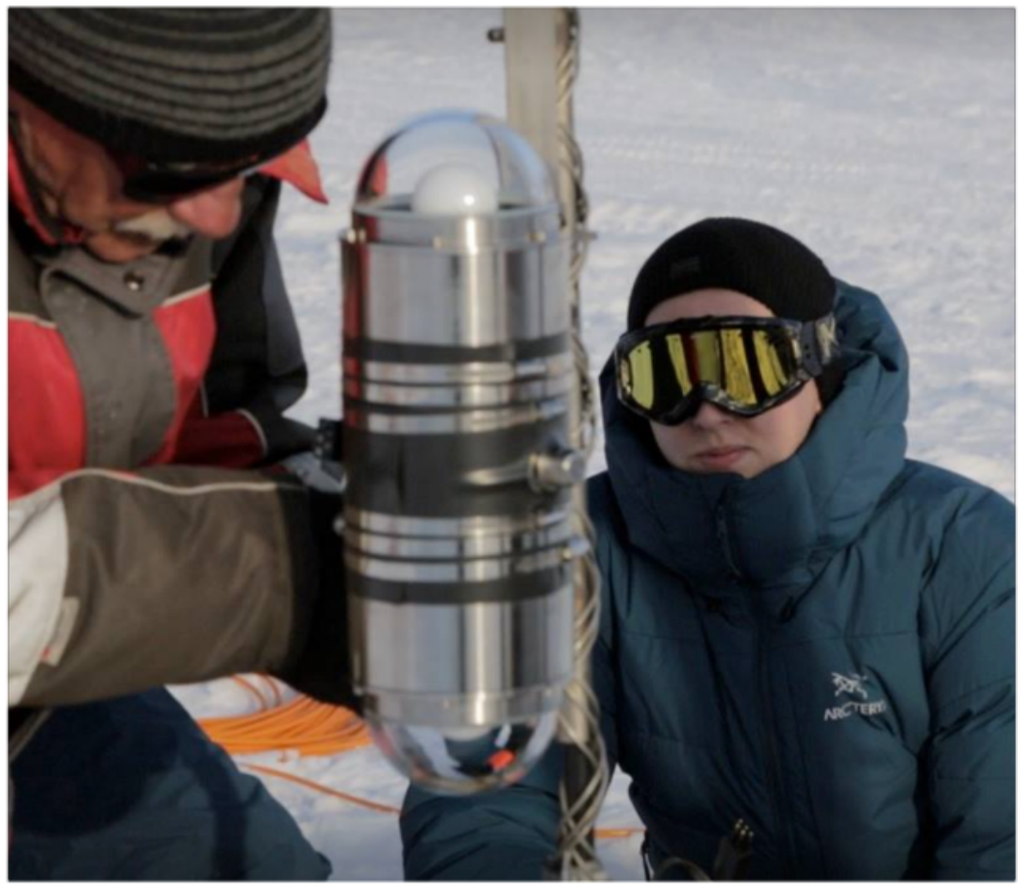
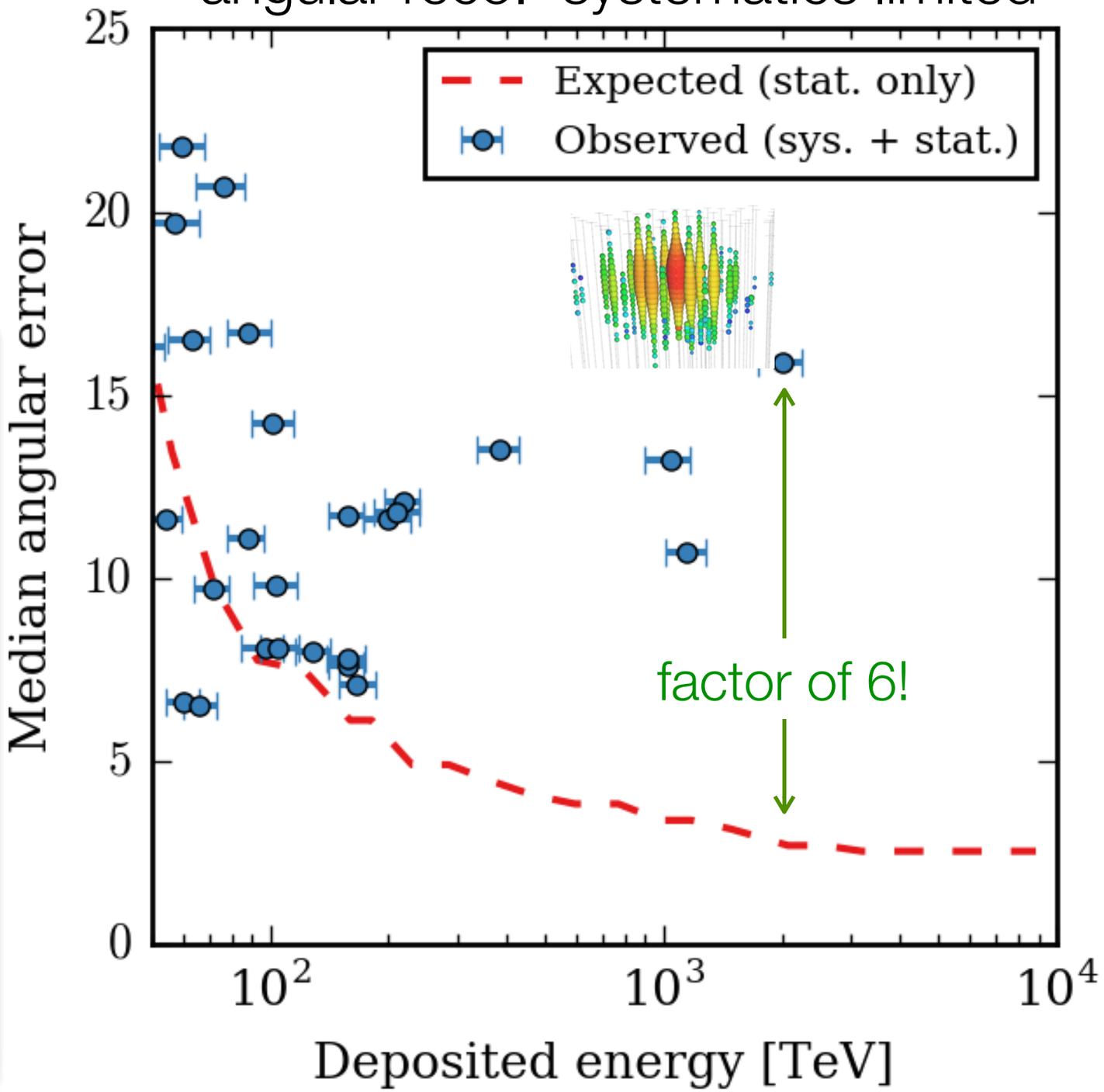
Gen2-Phase I: Enhancing IC high-energy science

New calibration devices inside IceCube enhance HE science

- **reconstructions**
- **tau flavor identification**

POCAM being deployed at Lake Baikal





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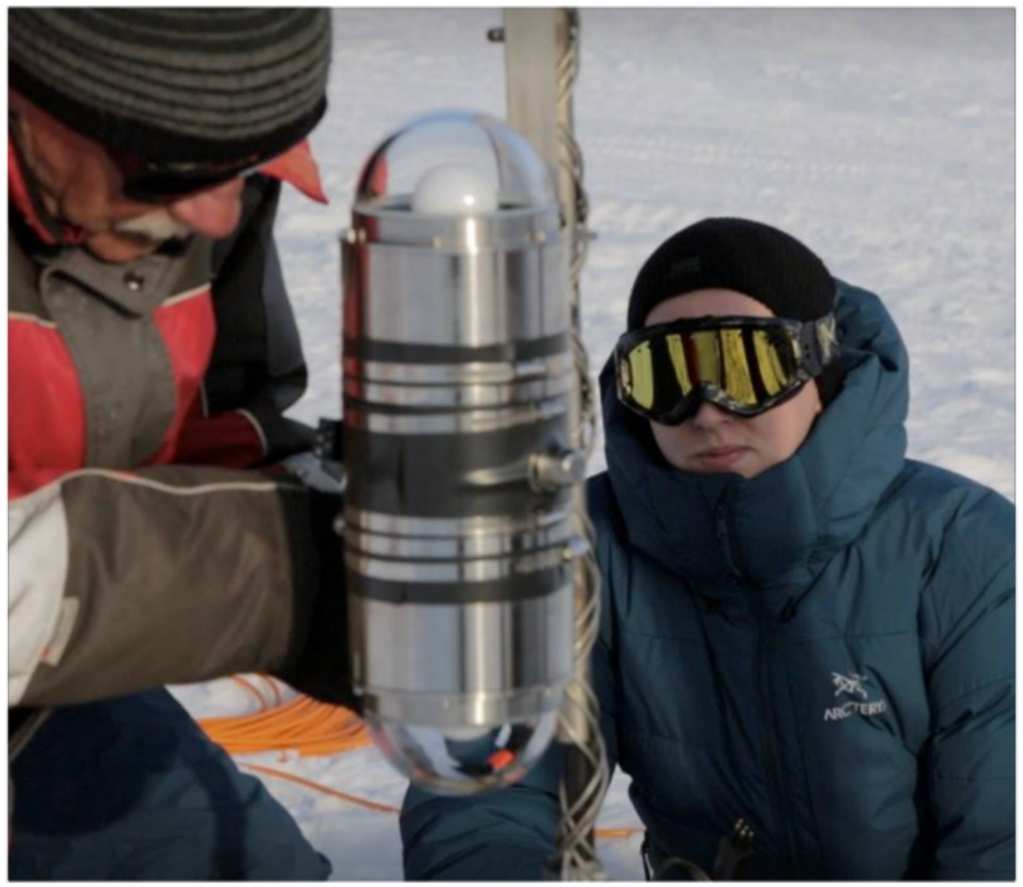

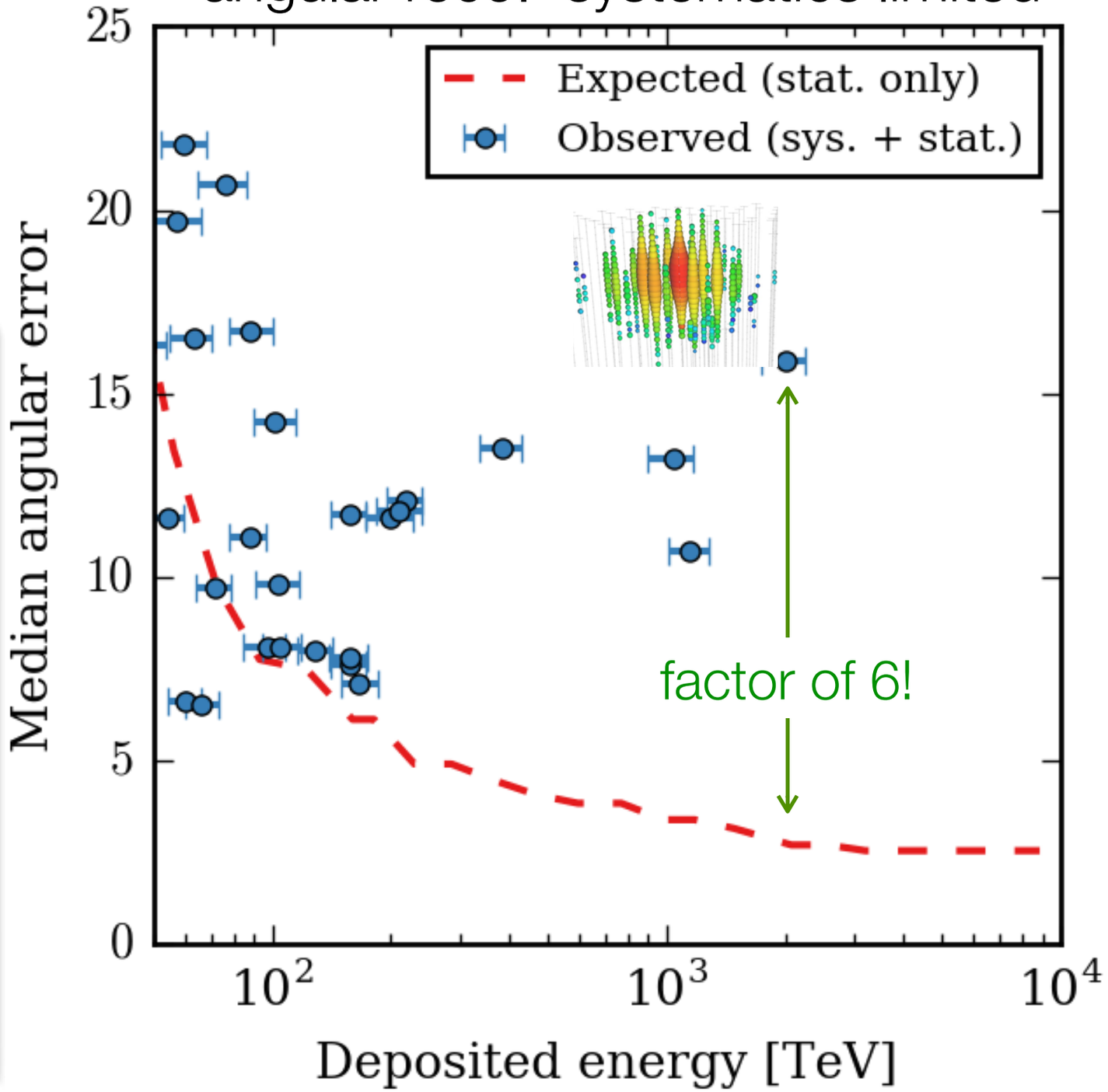

New calibration boosts the entire IceCube data set (> 10 yrs)

Gen2-Phase I: Enhancing IC high-energy science

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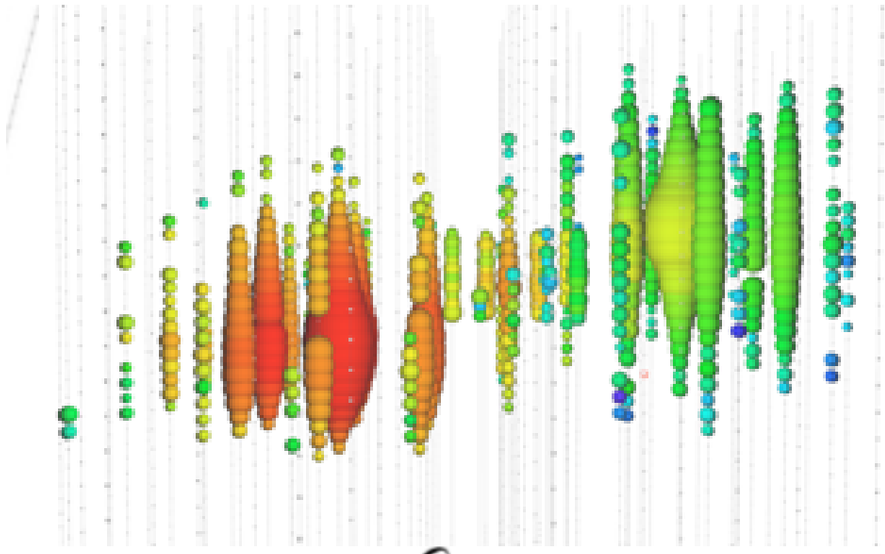
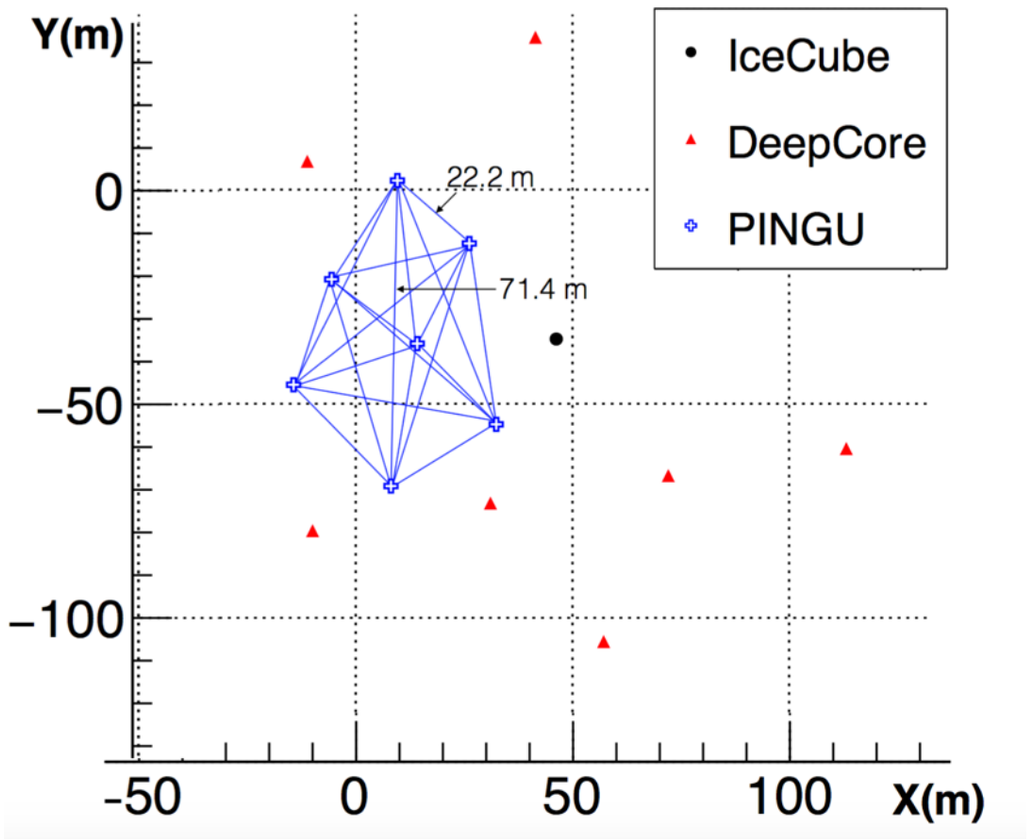
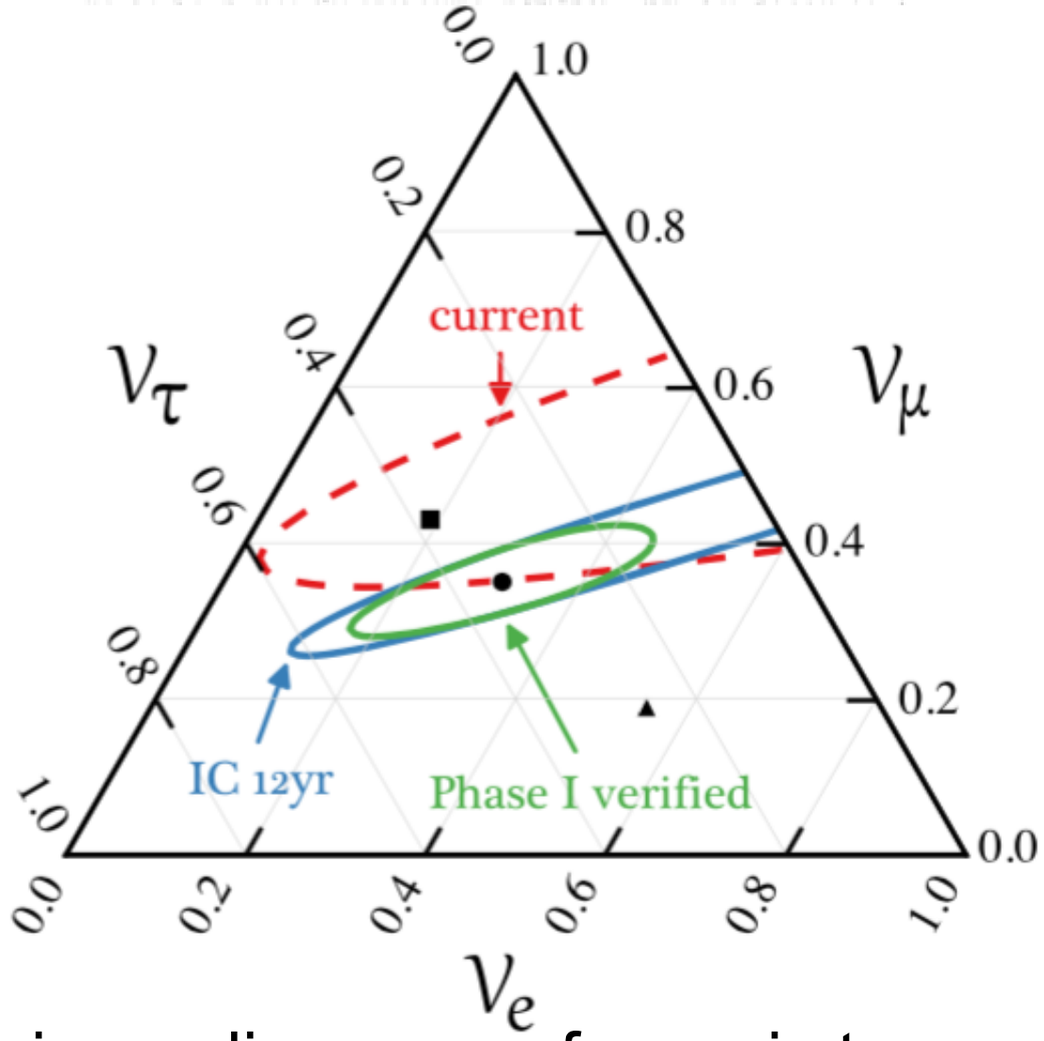
- reconstructions
- tau flavor identification



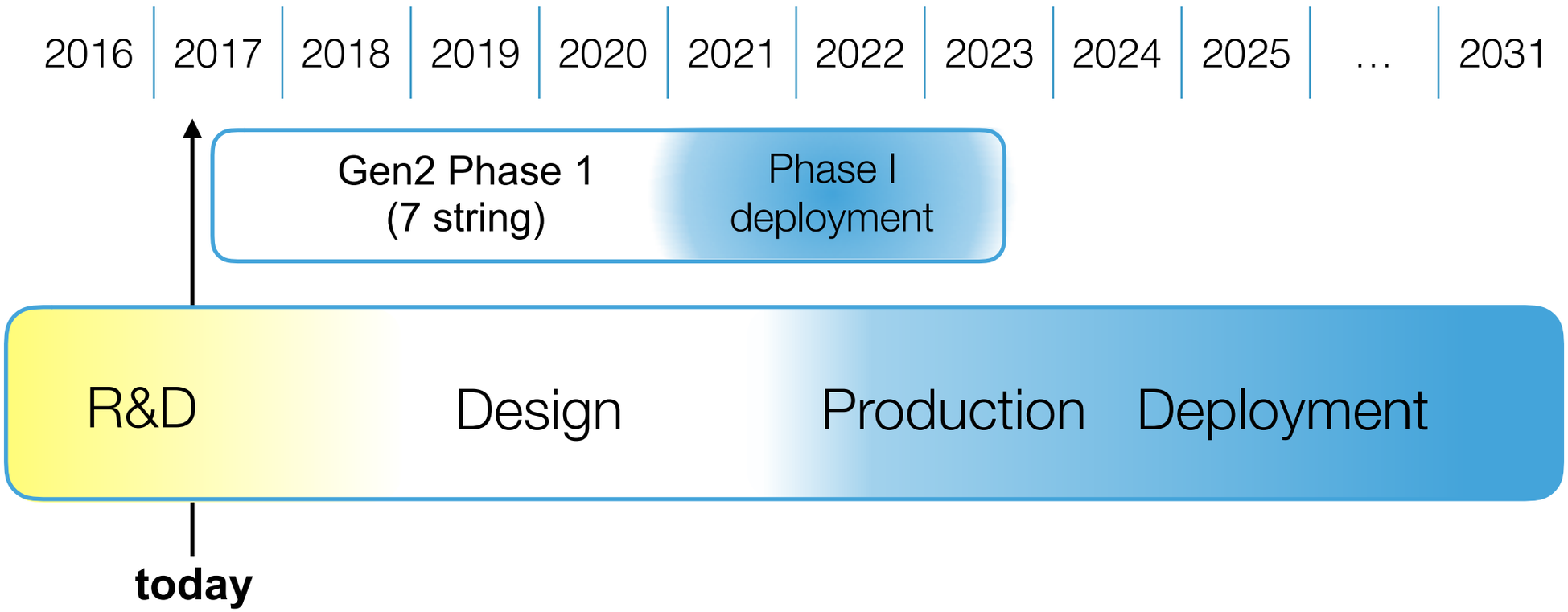
Phase 1 will permit to generate double flashes with baselines down to 22 m





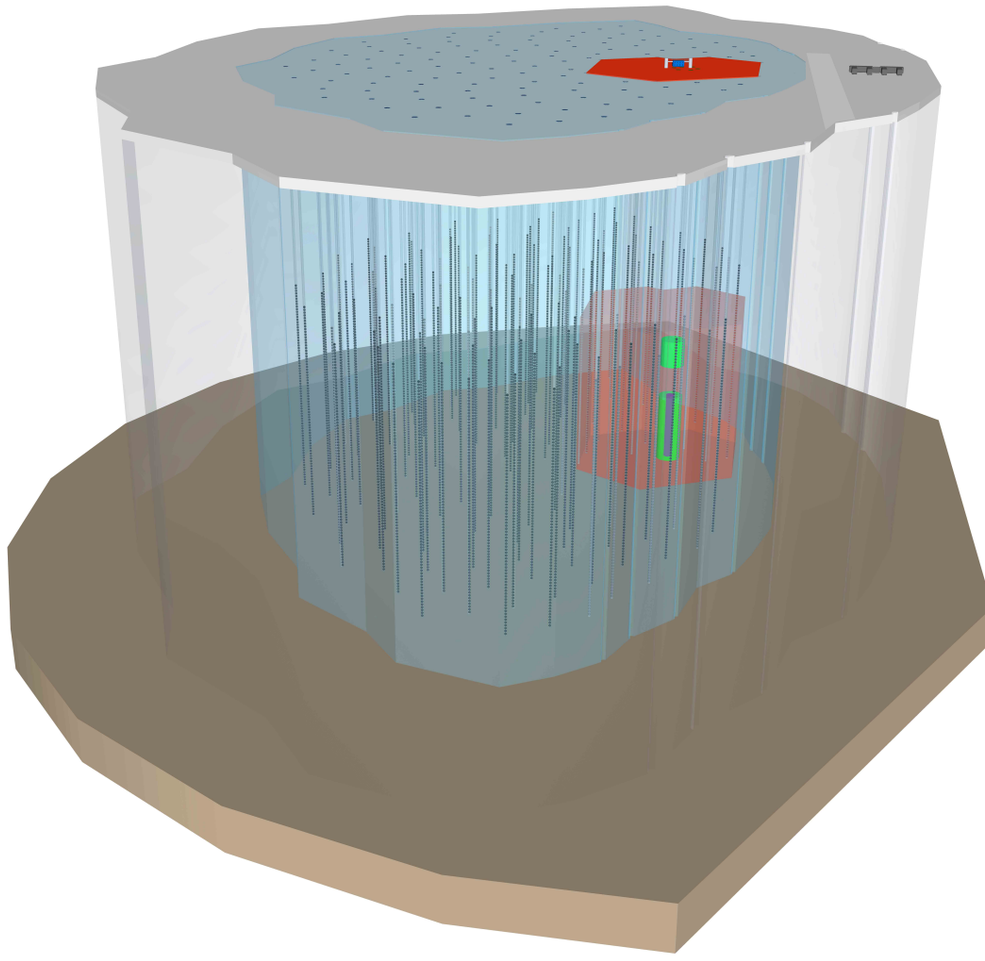
3 sigma discovery of cosmic tau neutrinos in 12 years of IceCube data

Gen2 - preliminary timeline



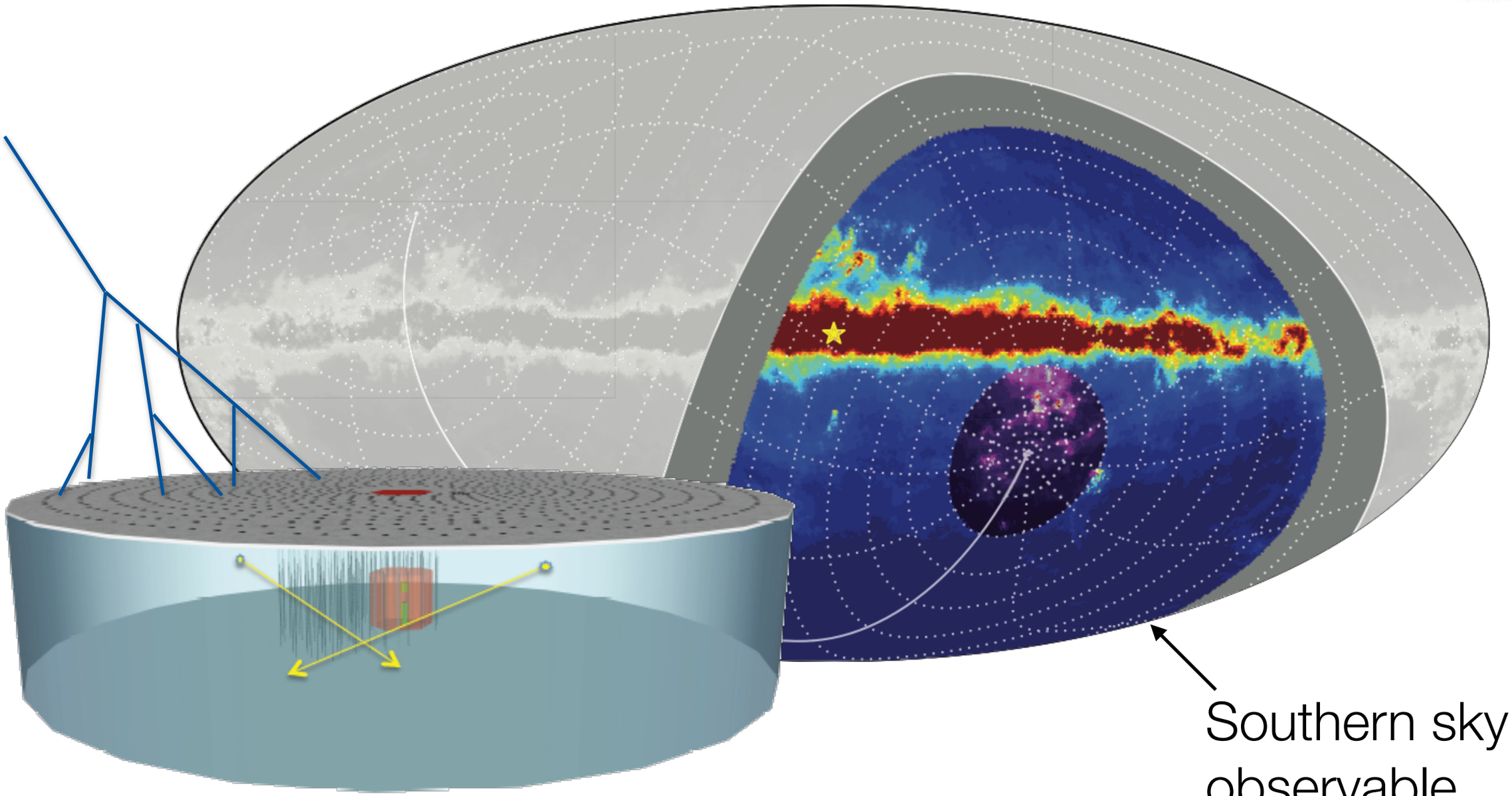
Conclusions

- 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
- Gen2-Phase 1 a first step, with a compelling science case on its own



Backup

Extended surface veto



Southern sky
observable
via surface veto

Potential gain for e.g. 75 km^2 veto:

~2x number of PeV tracks

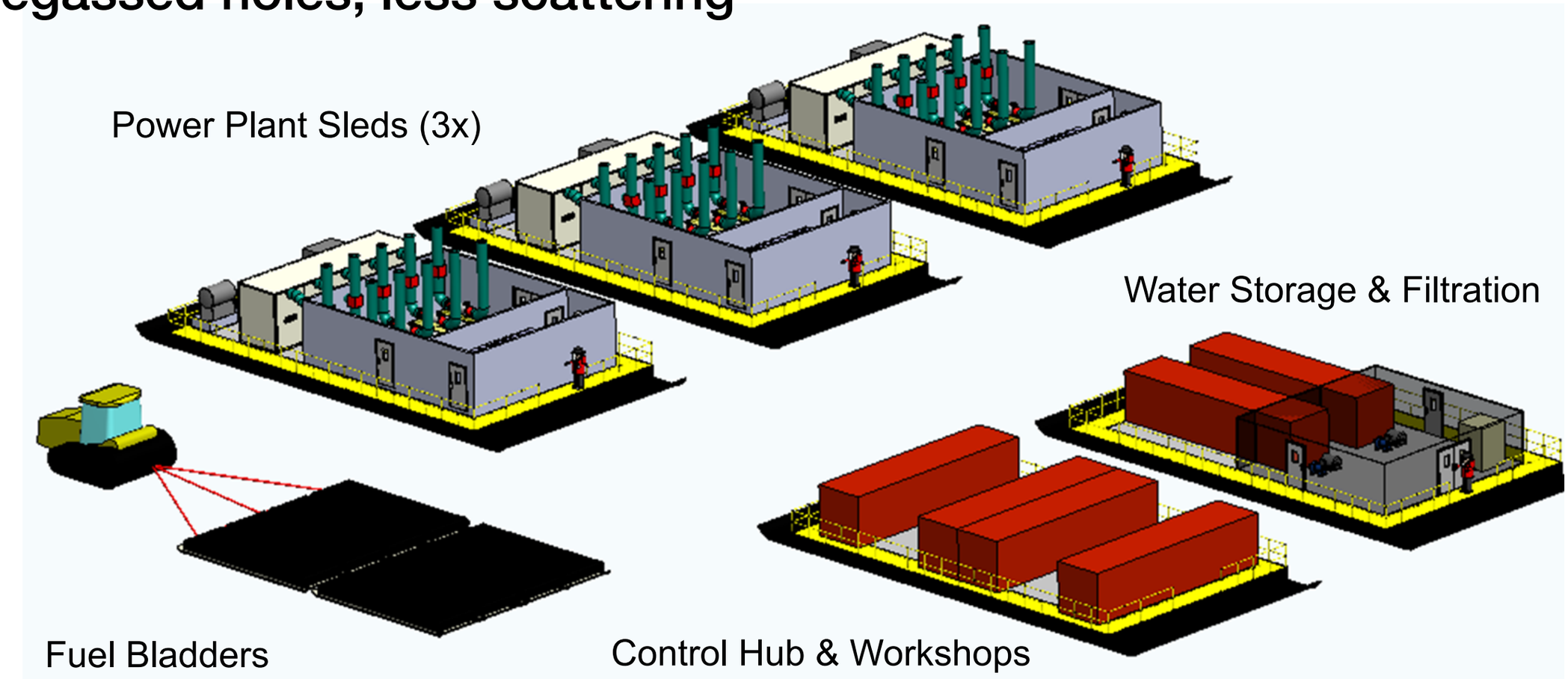
Simplified logistics & improved performance

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 ⟹ large fuel savings
- Faster drilling
- Degassed holes, less scattering



Radio detection of neutrinos at the South Pole