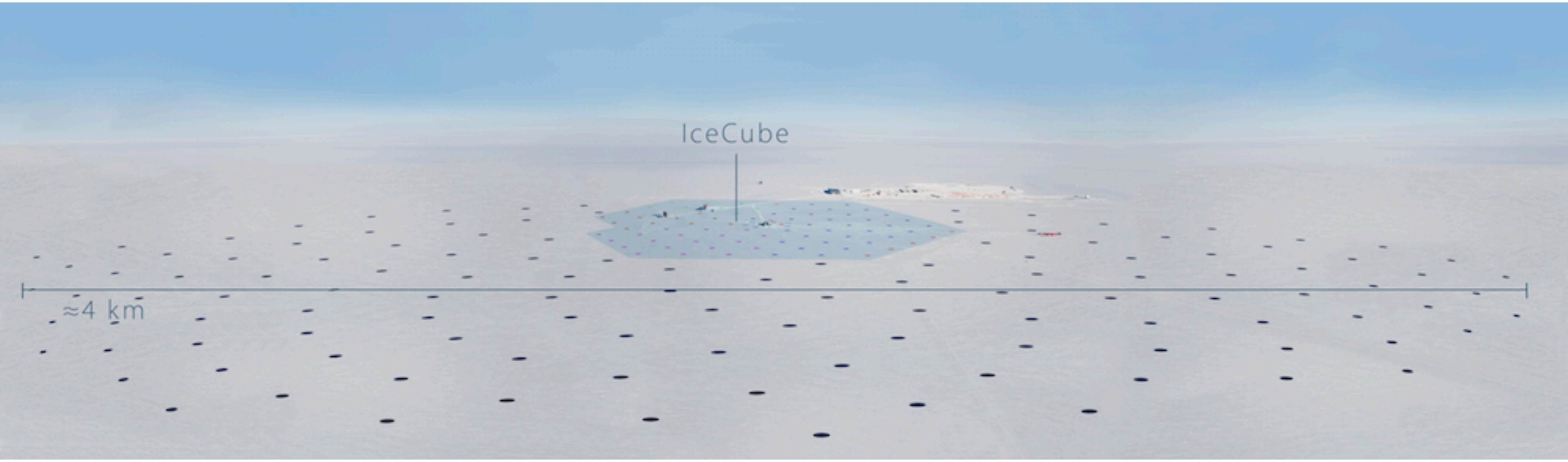
IceCube Upgrade and Gen-2



Summer Blot
for the IceCube-Gen2 collaboration
26 August 2018
TeVPA - Berlin

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

IceCube Neutrino Observatory

A pioneering multi-purpose detector

Astrophysics

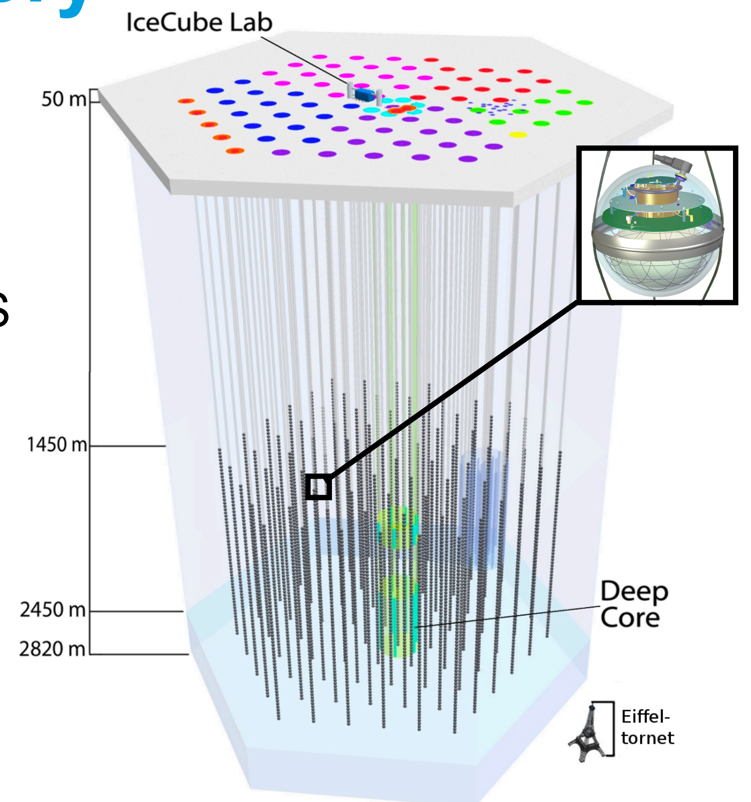
- Discovery of astrophysical neutrinos
- First evidence for neutrino point source with TXS
- Key partner in multi-messenger landscape
- Cosmic rays with IceTop

Particle Physics

- Atmospheric neutrino oscillations
- Neutrino cross-sections at TeV-scale
- Exotic/BSM physics searches

Earth science

- Glaciology
- Earth tomography



	Spacing [m]		Energy threshold [GeV]
	Horizontal	Vertical	
IceCube	125	17	~100
DeepCore	50	7	~5

IceCube limitations

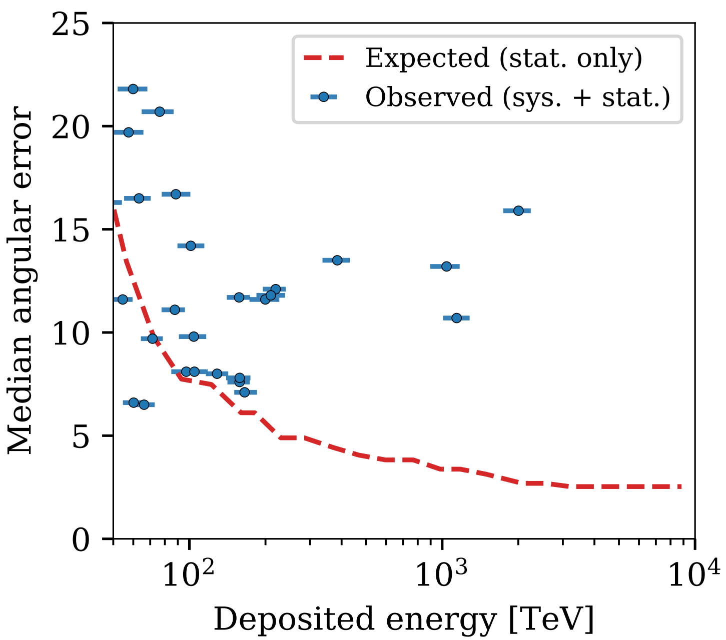
More potential to exploit!

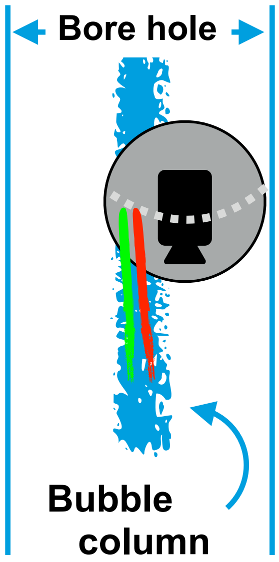
Angular resolution

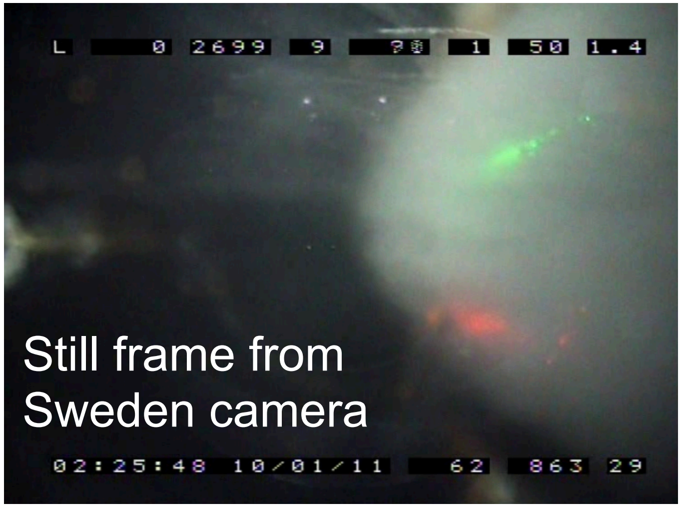
- Median error not scaling with photon statistics

Ice modelling systematic uncertainties

- Bubble column distorts angular acceptance
- Anisotropy of photon scattering and/or absorption lengths in ice

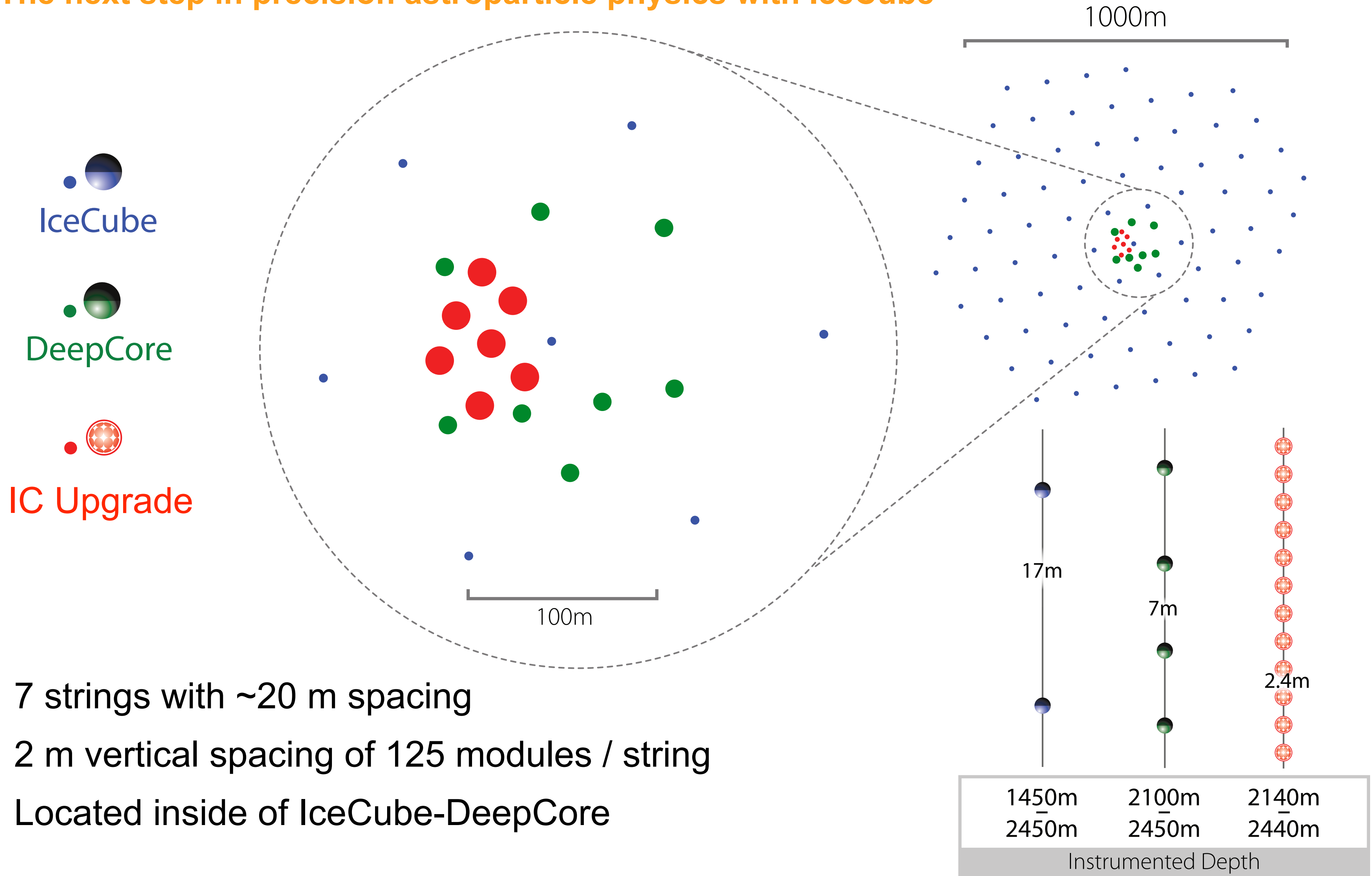






The IceCube Upgrade

The next step in precision astroparticle physics with IceCube

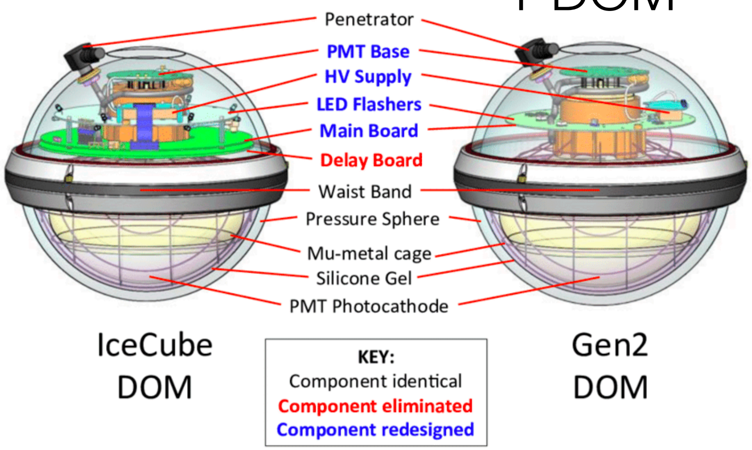


- 7 strings with ~20 m spacing
- 2 m vertical spacing of 125 modules / string
- Located inside of IceCube-DeepCore

The IceCube Upgrade - R&D

In-situ testing of new optical modules

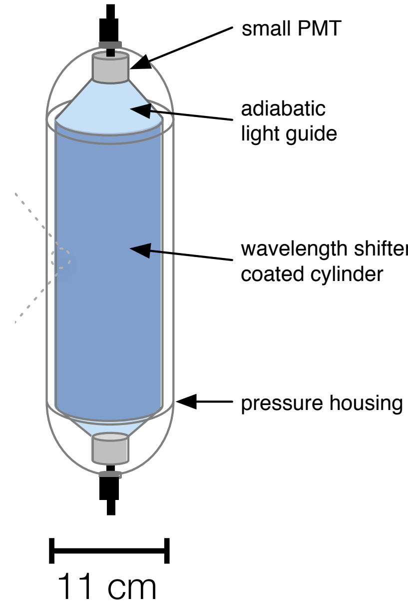
PDOM

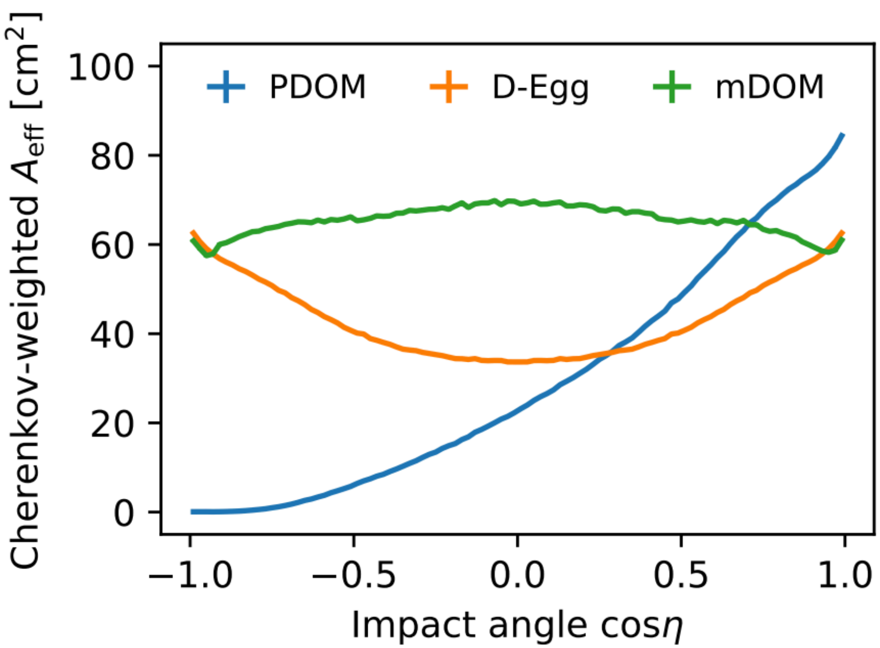


D-Egg

mDOM

WOM





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

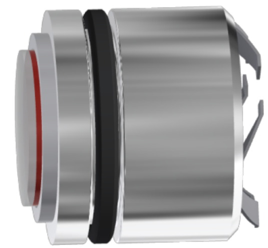
Stand-alone light sources

- Precision Optical Calibration Module (POCAM)
- ns-pulsed LEDs with small opening angle

Reduce primary systematic uncertainties

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

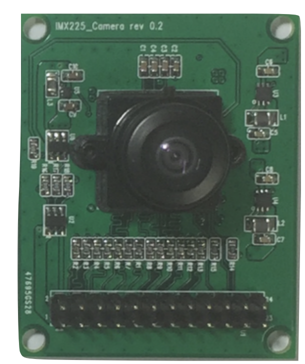
Piezo-module[1]



POCAM[3]

CCD[2]

CMOS[2]



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

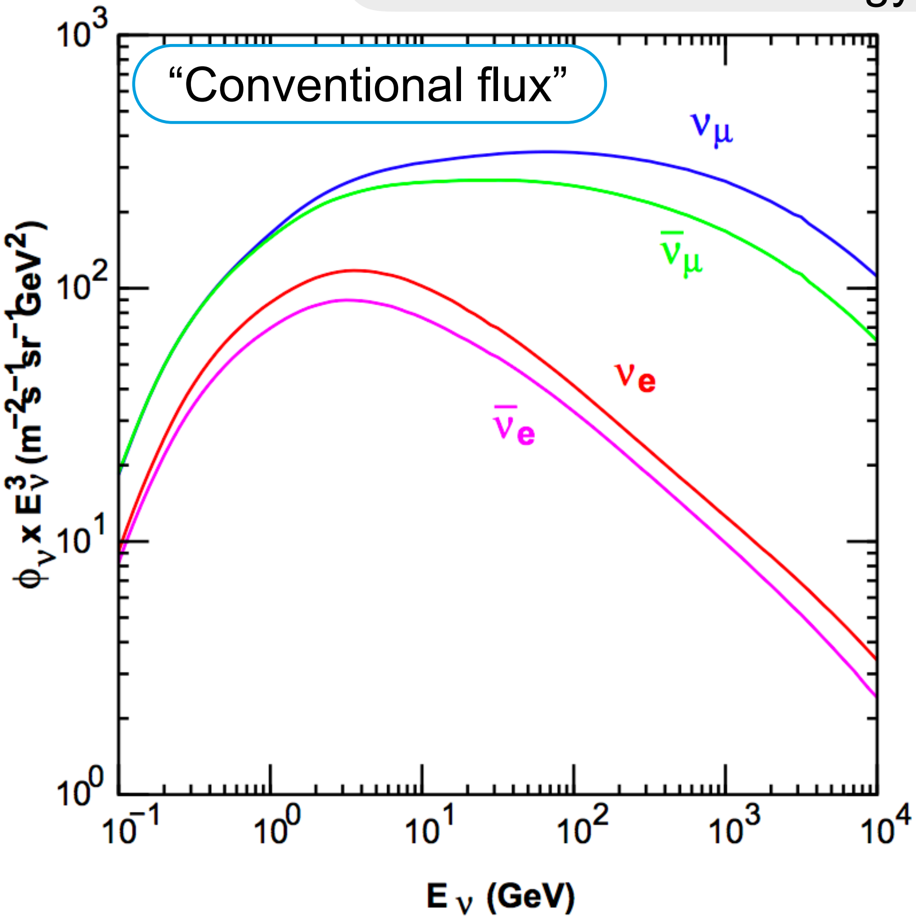
[2] https://doi.org/10.22323/1.301.1040

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

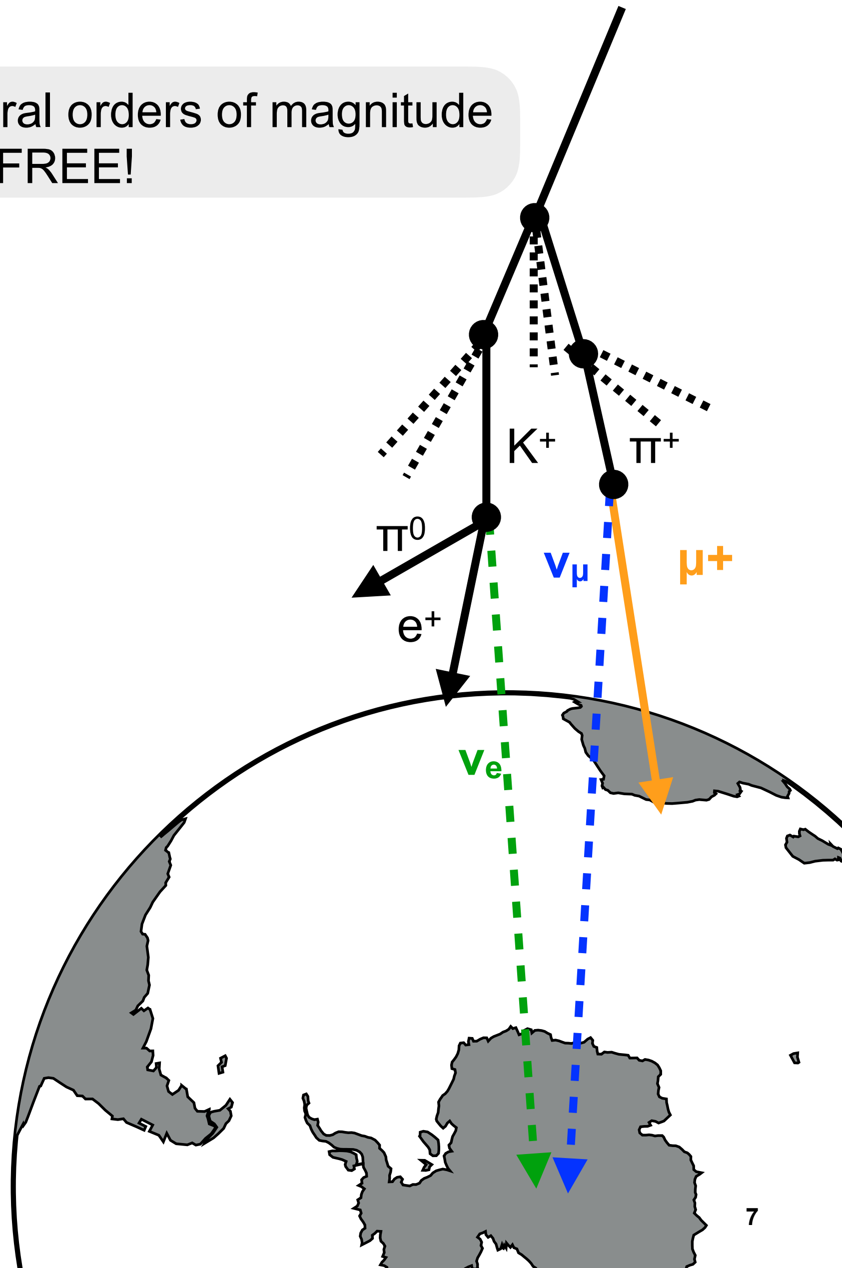
The IceCube Upgrade - Science

Not just for calibration and R&D!

High statistics sample over several orders of magnitude in energy FOR FREE!



Honda, et. al: https://arxiv.org/abs/1502.03916

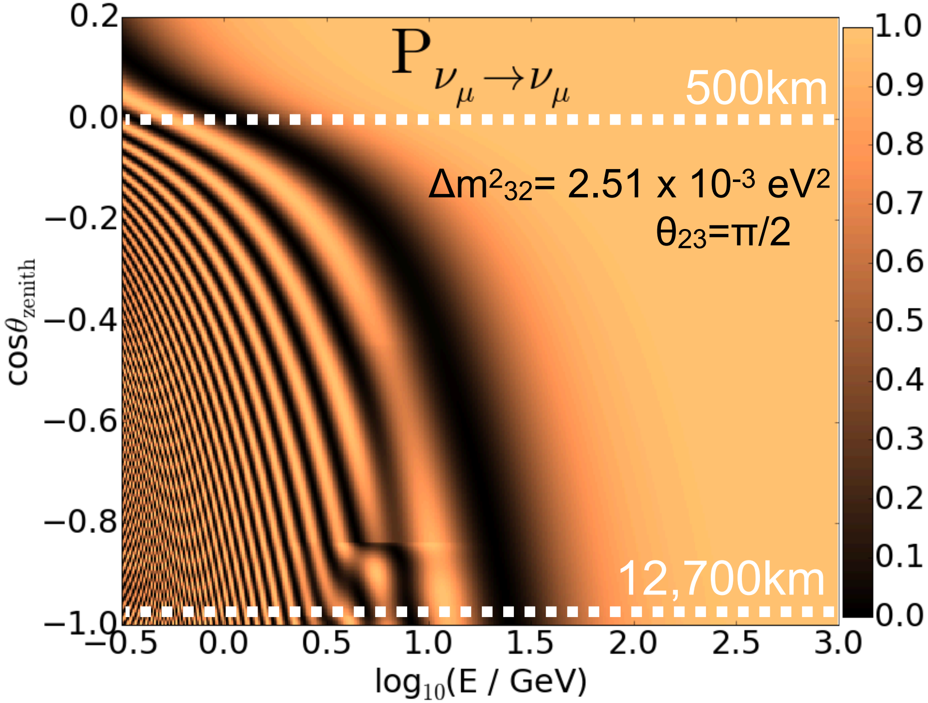


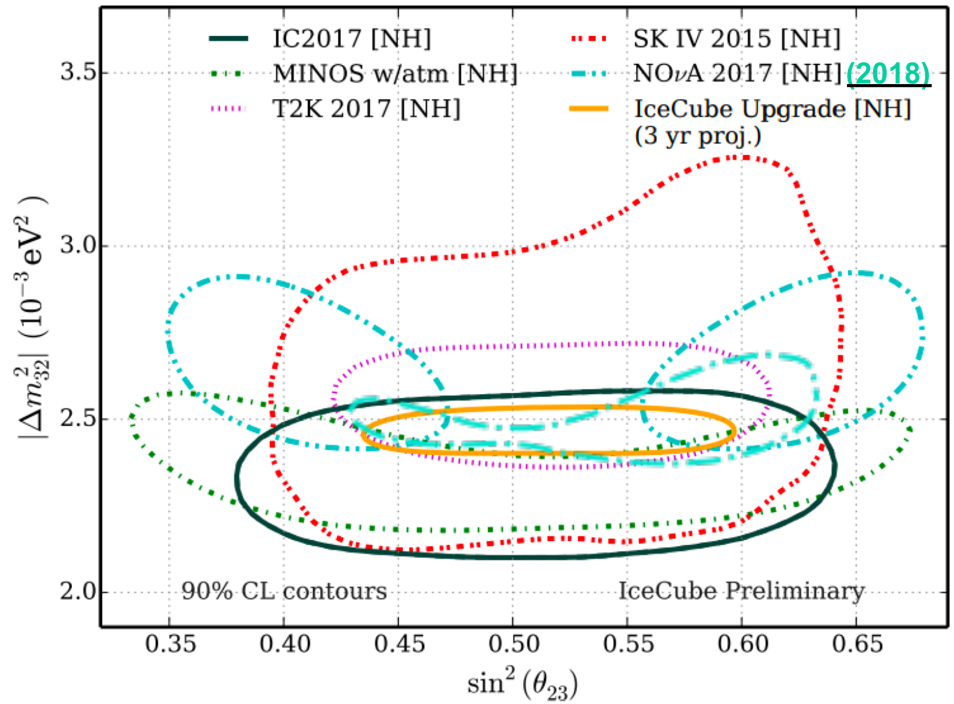
The IceCube Upgrade - Science

Precision atmospheric oscillation measurements

Similar physics program to DeepCore, just better!

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





First order effect for atmospheric neutrinos:

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2(2\theta_{23}) \sin^2\left(\Delta m^2_{32} \frac{L}{4E_\nu}\right)$$

The IceCube Upgrade - Science

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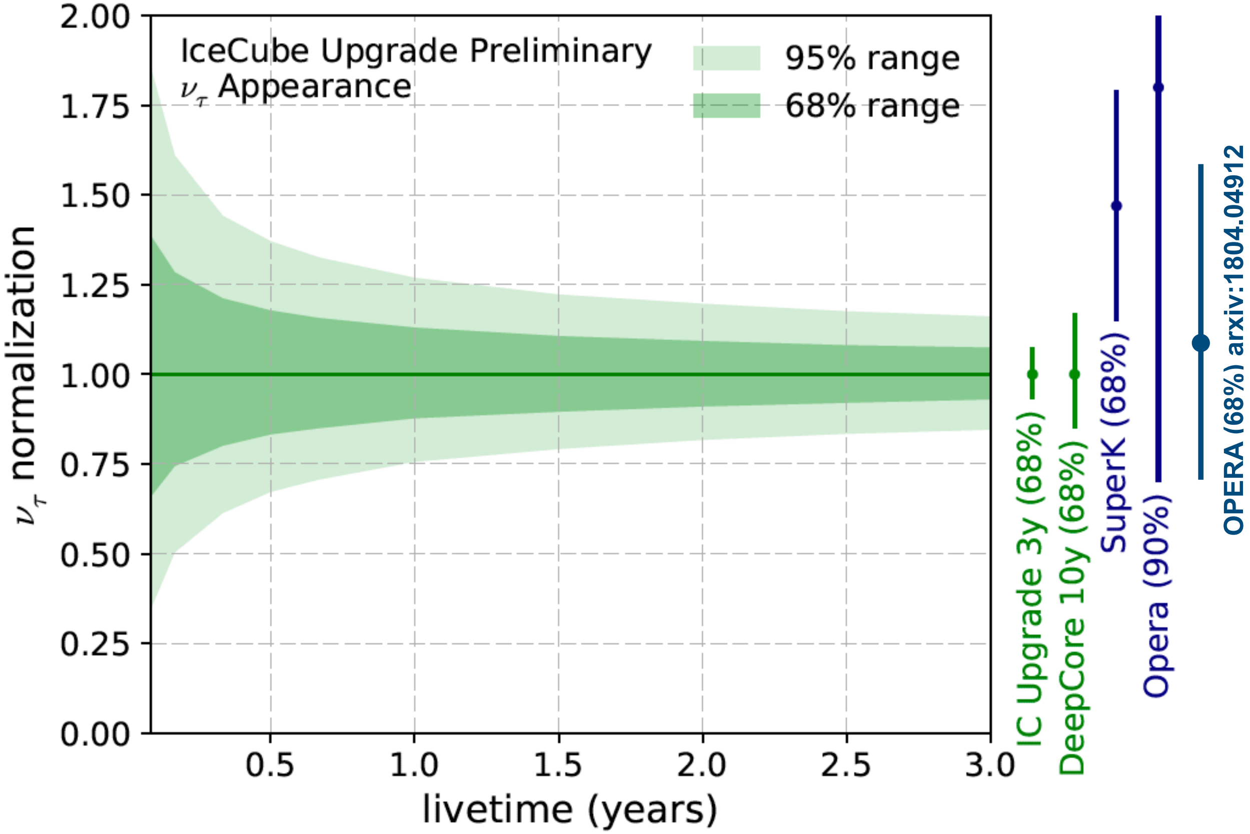


Projected sensitivities ***do not*** include reduced ice/OM systematics

IceCube-Gen2

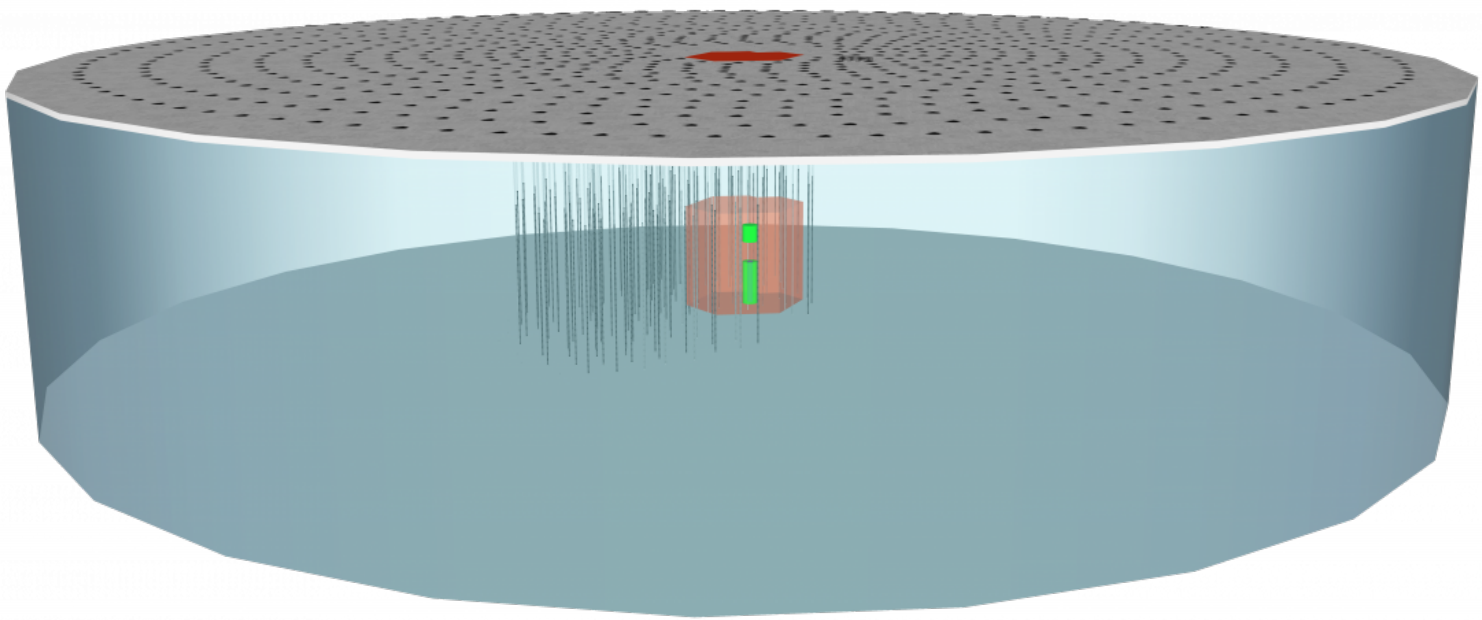
A vision for the future of neutrino astroparticle physics at the South Pole

High energy

- Find (more) neutrino point sources
- Characterise spectrum, flux, and flavour composition of astrophysical neutrinos with higher precision
- GZK neutrinos
- Continue search for BSM physics

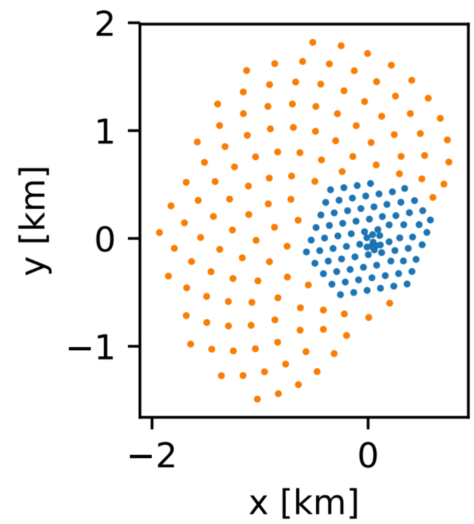
Low energy

- Precision measurements of atmospheric neutrino oscillations:
  - $\nu_\mu \rightarrow \nu_\tau$
  - Neutrino mass ordering
- Characterise atmospheric flux (hadronic interactions)
- Also continue search for BSM physics



IceCube-Gen2

High energy facility

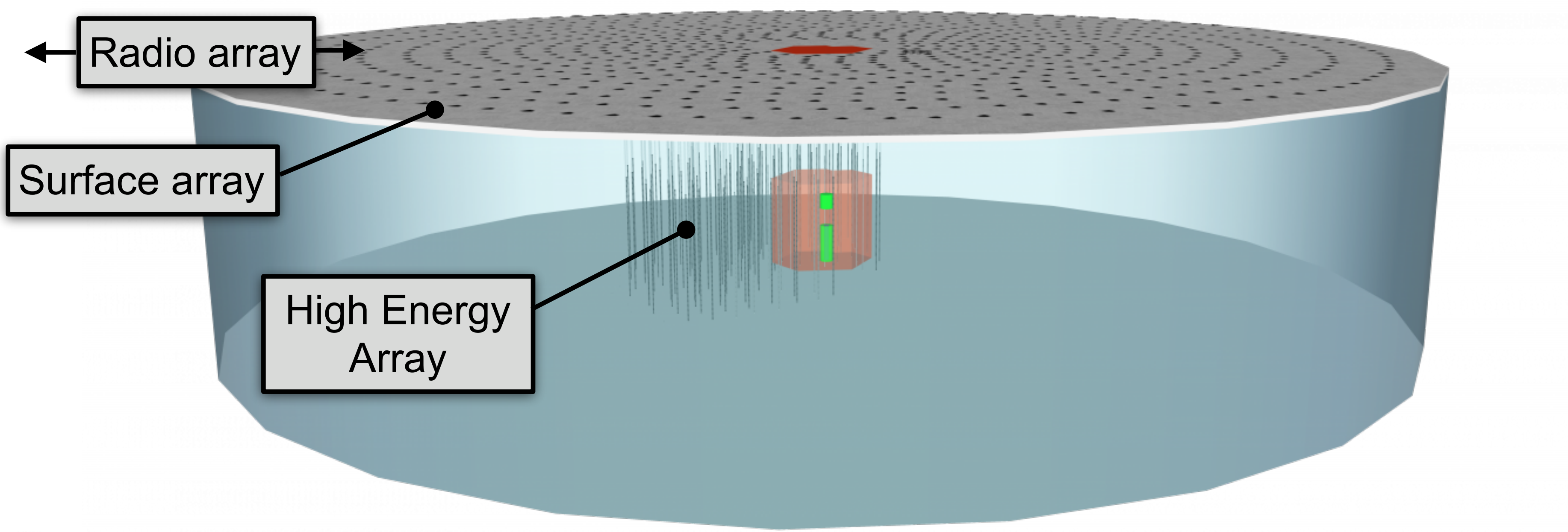


In-Ice High Energy Array (HEA)

- 120 strings with ~240 m spacing and 80 OMs each
- 6.2 - 9.5 km^3 instrumented volume (not yet fixed)

Surface array

- Under investigation: Air Cherenkov Telescope (IceAct) vs scintillator panels
- Prototypes of both systems deployed and operating at the South Pole



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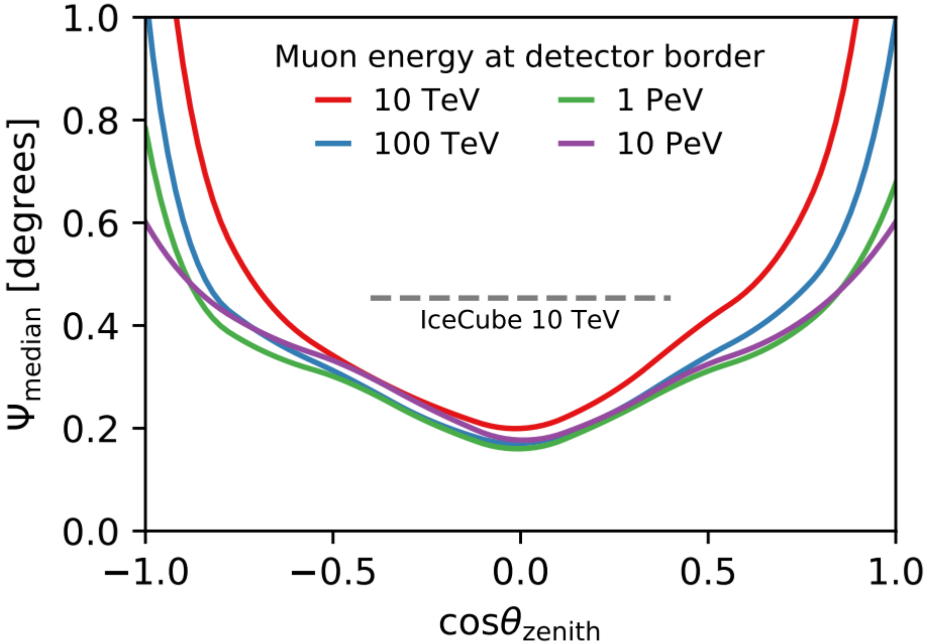
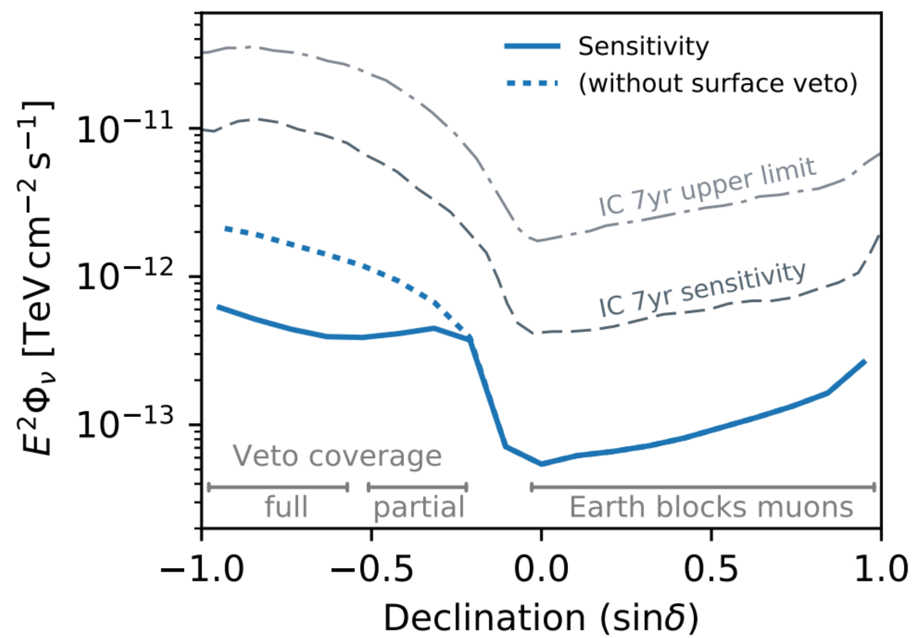
High Energy Array

Projected sensitivity

- Improved angular resolution
- Better point sensitivity, here shown for 15 y IC86 + 15 y IC-Gen2
  - Discovery potential ~2.5x better than sensitivity
- Surface veto (assumed 75 km²) improves sensitivity (discovery potential) by factor ~3





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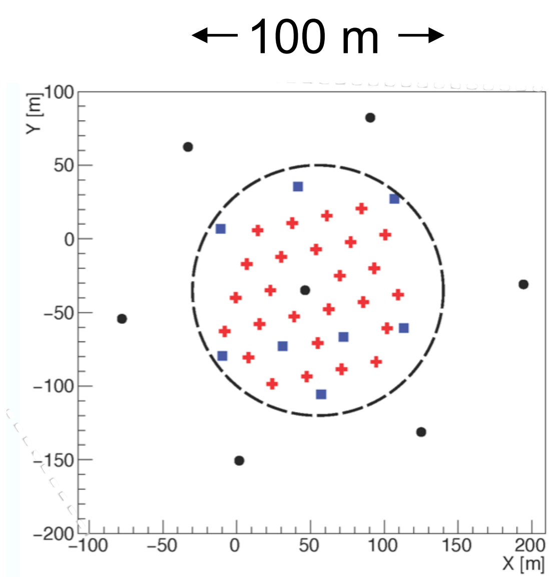
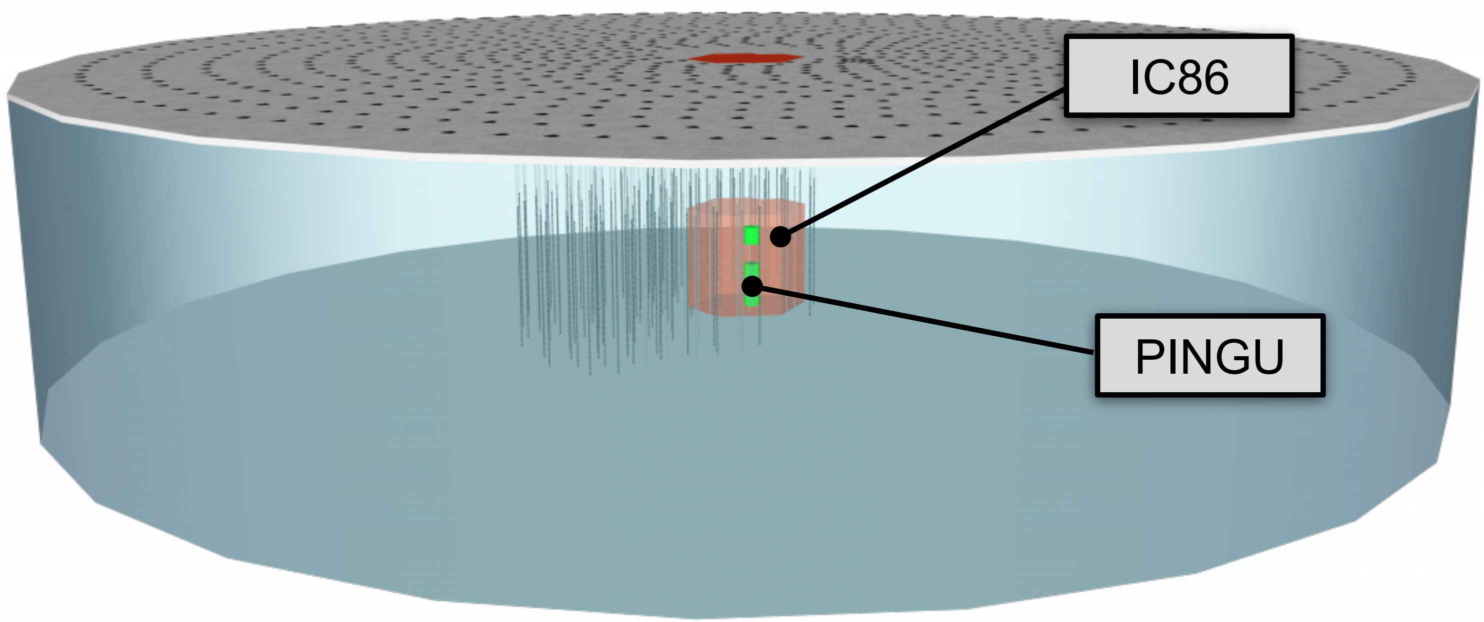
IceCube-Gen2

Low energy facility

Precision IceCube Next Generation Upgrade (PINGU)

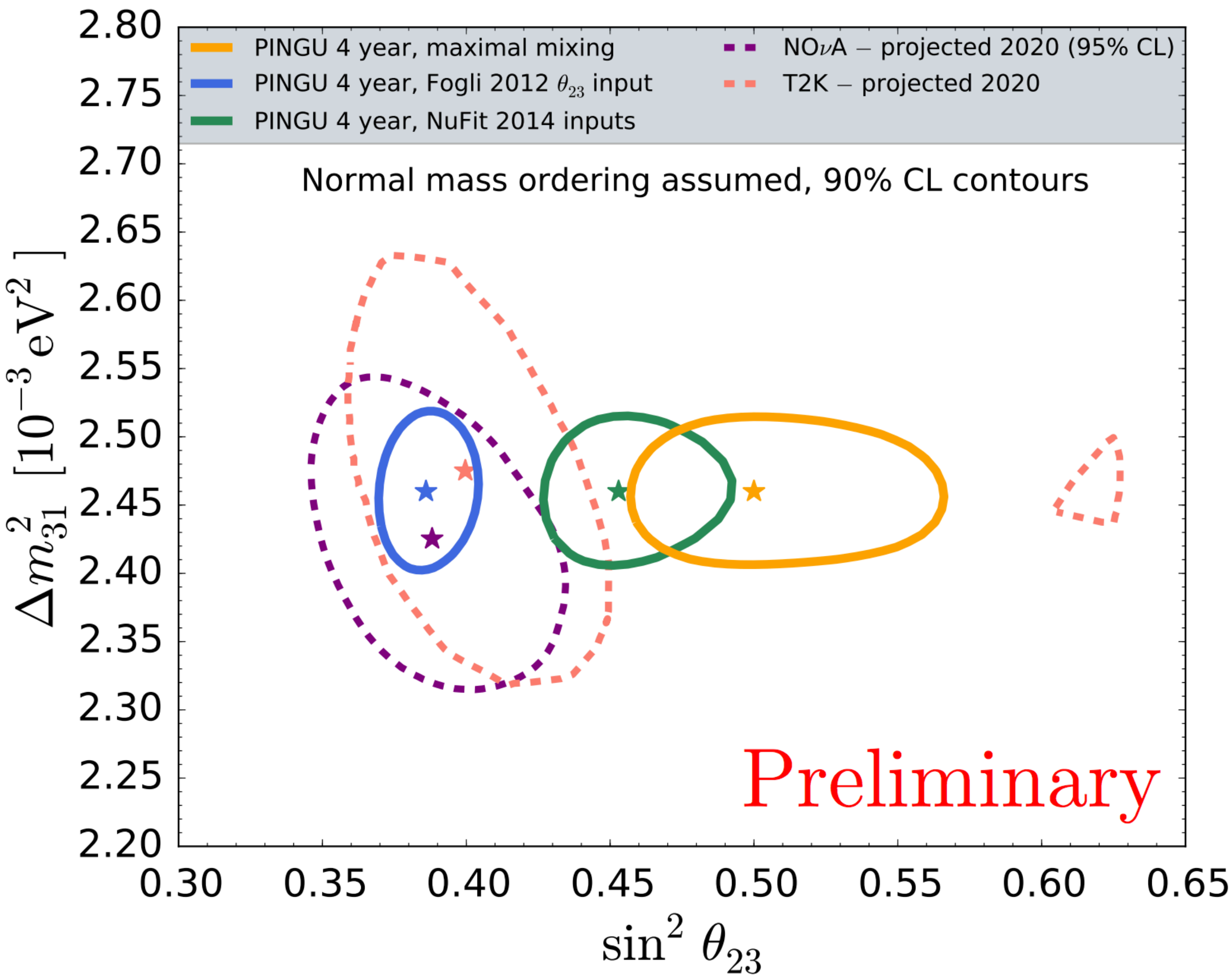
- 26 strings with ~20-30 m spacing and 125 OMs each
- Profit from surrounding 86-strings of IceCube-DeepCore as cosmic muon veto
- Lower energy threshold to ~100 MeV





Neutrino oscillations

Highest energy probe of atmospheric $\nu_\mu \rightarrow \nu_\tau$ mixing



Expected precision:

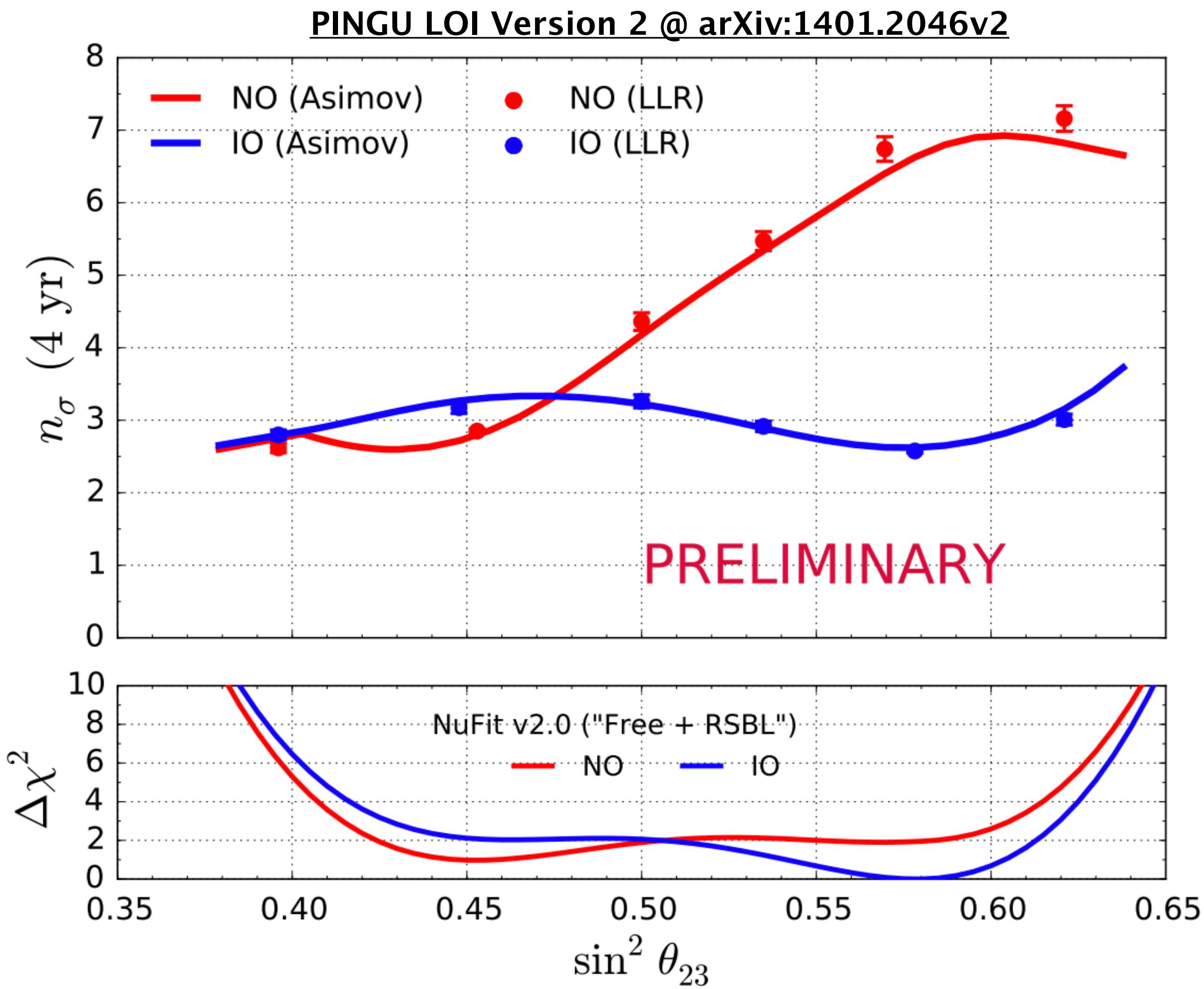
$\Delta m^2_{32} \sim 1\%$ (1σ)

$\theta_{23} \sim 4\%$ (1σ)

depends on NMO and true θ_{23}

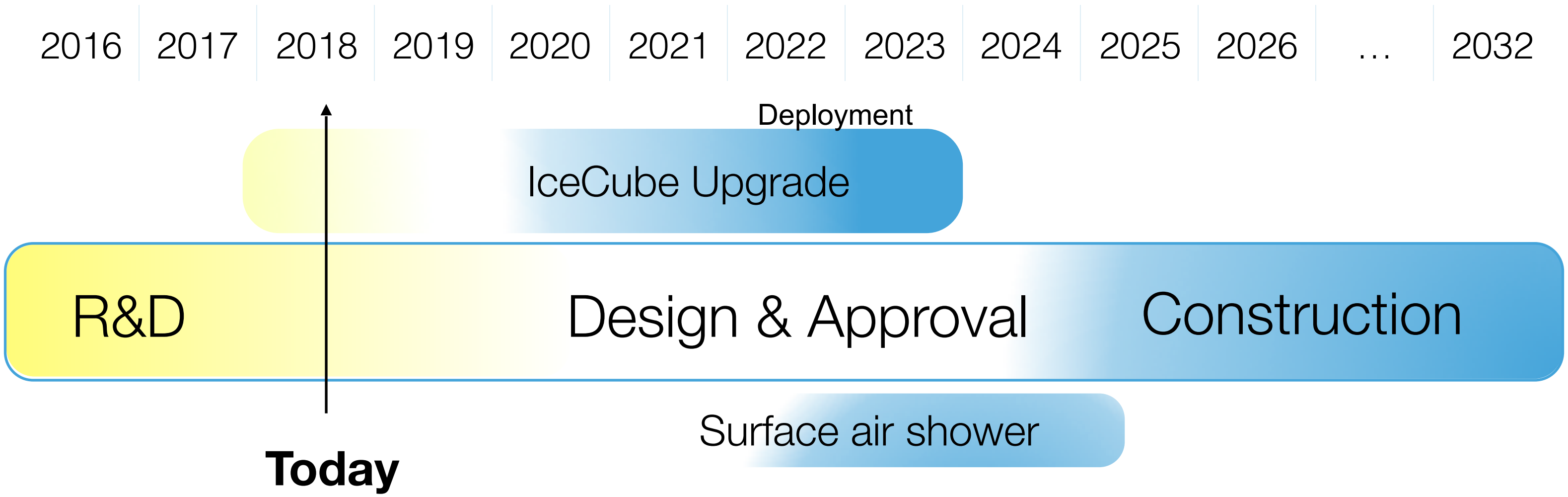
Neutrino oscillations

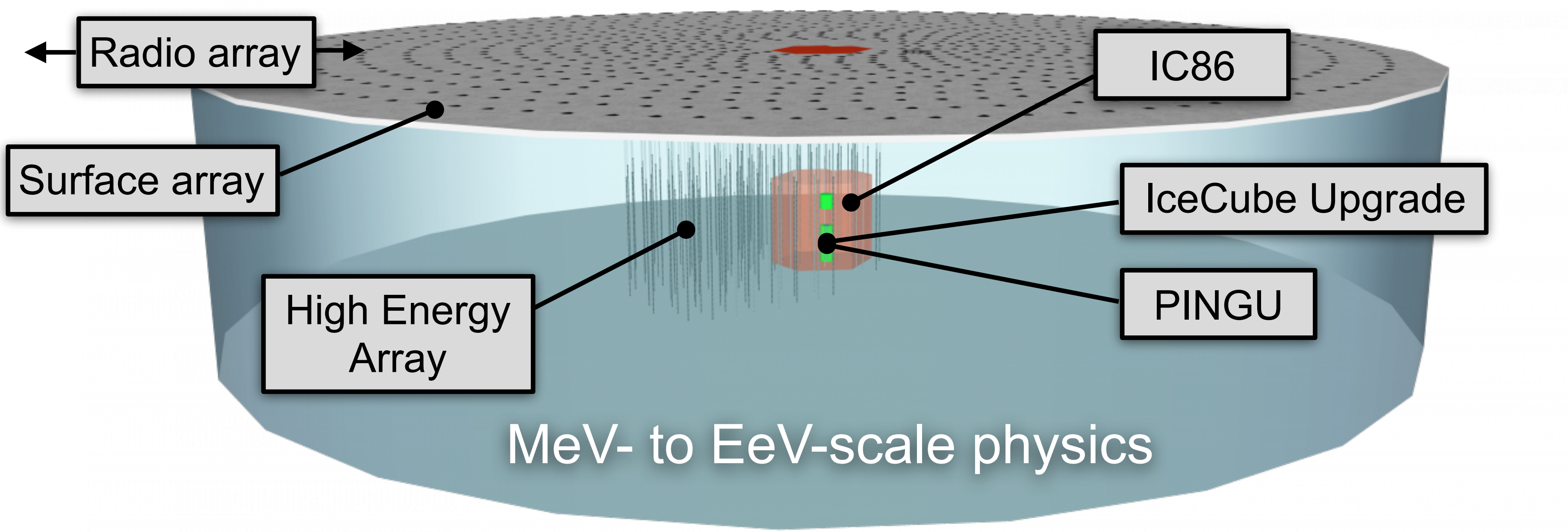
Neutrino Mass Ordering



The IceCube-Gen2 Facility

Preliminary timeline



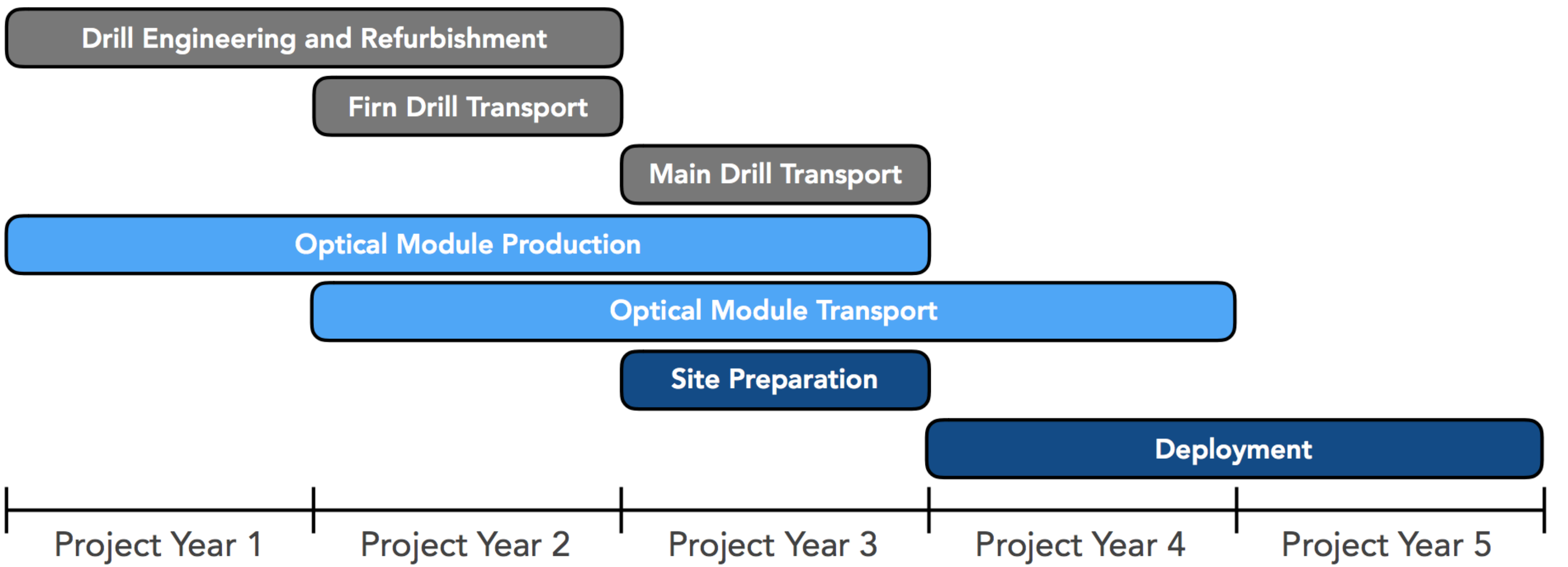


The future is bright for the next generation of IceCube

Thank you for your attention!

Backup

Timeline in project years



Atmospheric neutrino physics

Neutrino oscillations

$$|\nu_\alpha\rangle = \sum U^*_{\alpha k} |\nu_k\rangle$$

Flavour states

Mass states (not equal)

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \times \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix} \times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Atmospheric
Accelerator

Reactor
Accelerator

Solar
Reactor

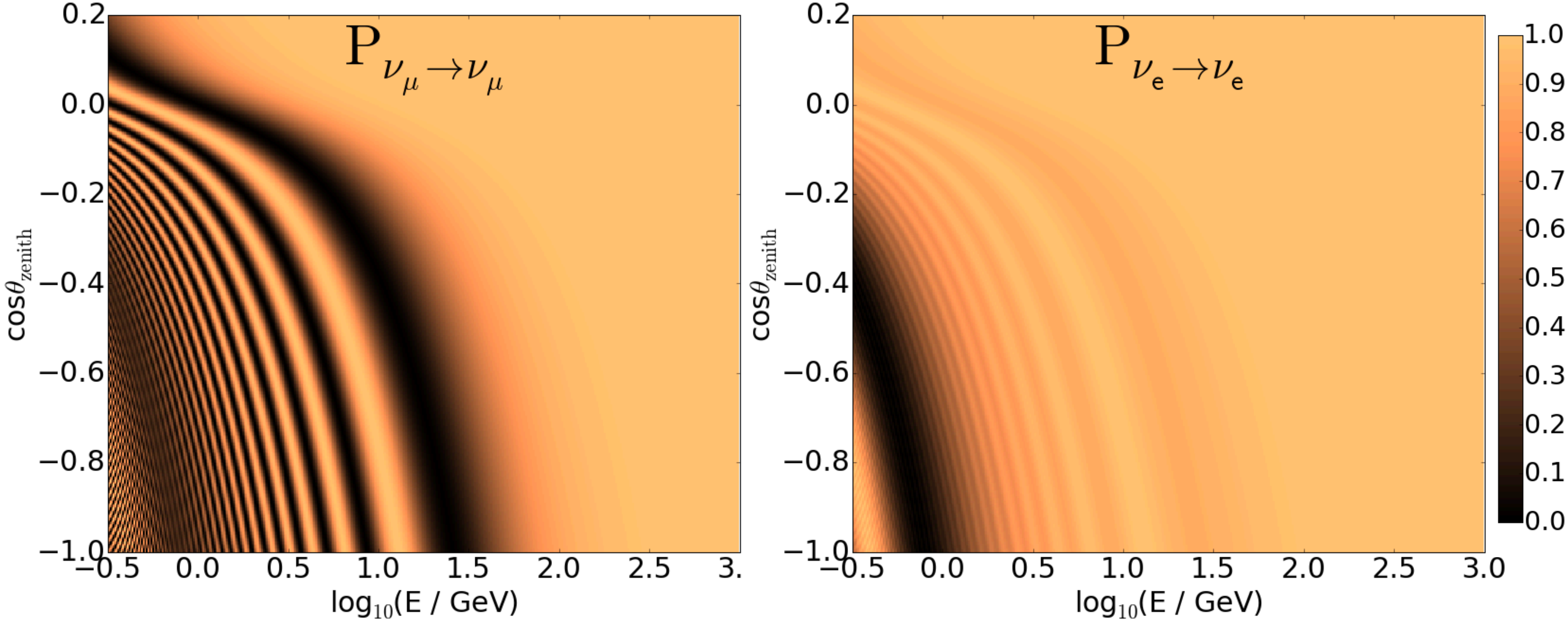
First order effect for atmospheric neutrinos:

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \sin^2(2\theta_{23}) \sin^2\left(\Delta m^2_{32} \frac{L}{4E_\nu}\right)$$

Neutrino oscillations

Vacuum oscillations

*Normal mass ordering assumed



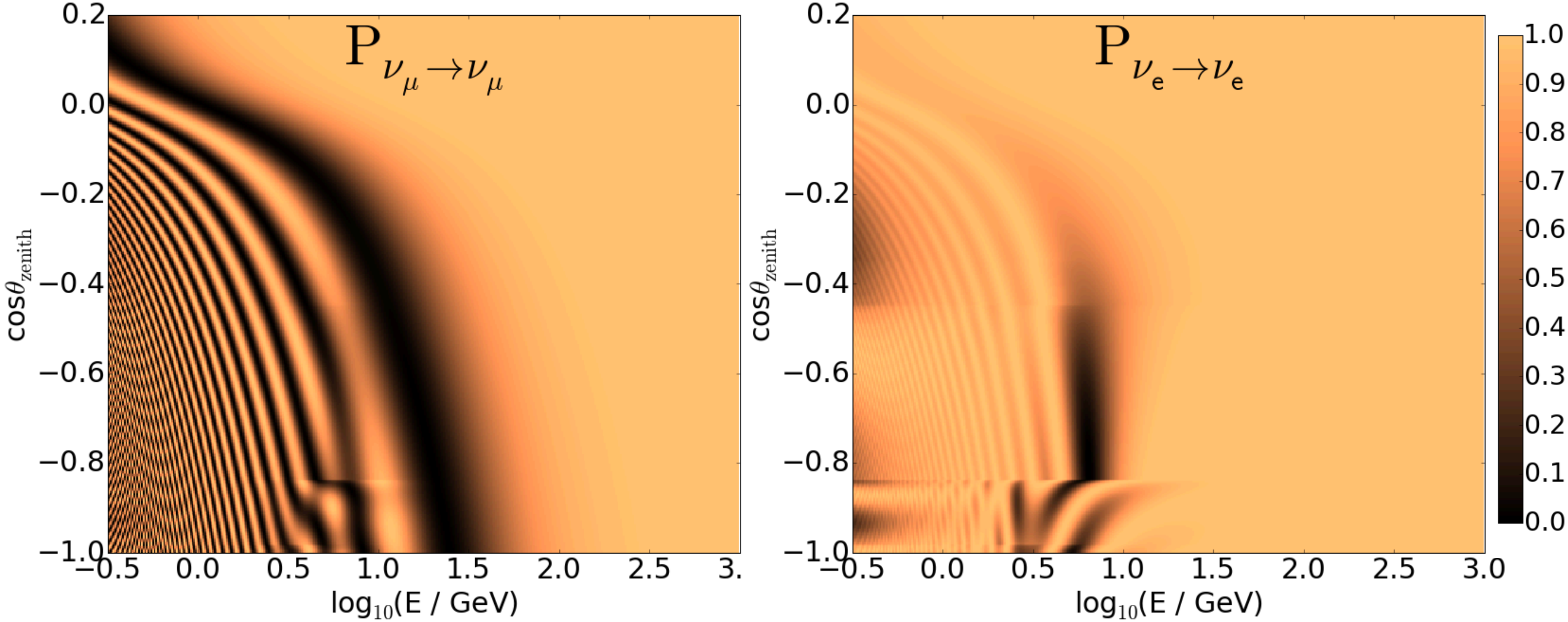
$\theta_{23} = \pi/2$

$\Delta m^2_{32} = 2.51 \times 10^{-3}\ eV^2$

Neutrino oscillations

Including matter effects

*Normal mass ordering assumed



$\theta_{23}=\pi/2$

$\Delta m^2_{32}= 2.51 \times 10^{-3}\ eV^2$

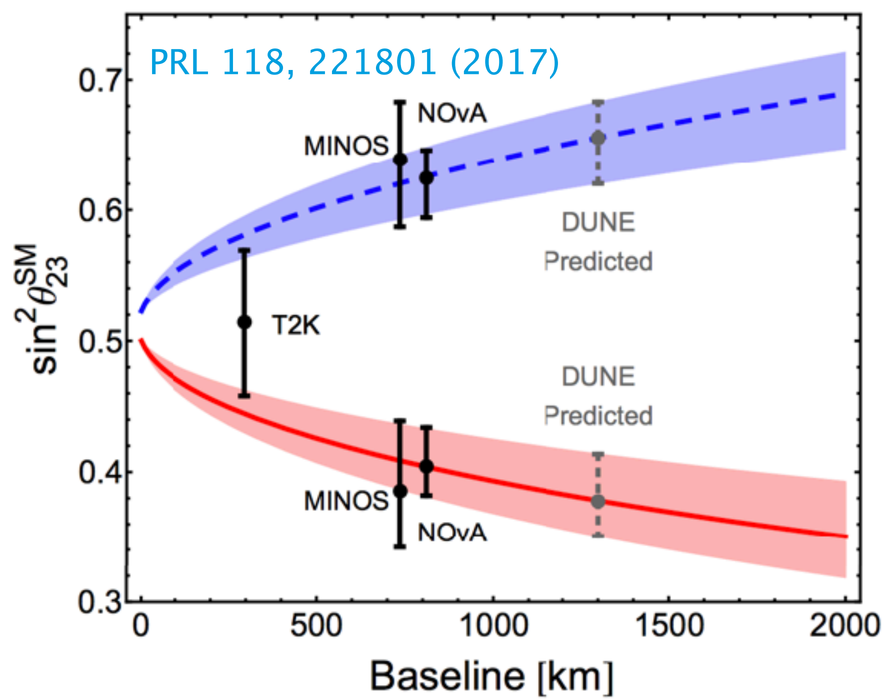
$$\hat{H}_F = \frac{1}{2E_\nu}\mathbf{U}\hat{M}^2\mathbf{U}^\dagger + \hat{V}_{int}$$

A probe for new physics

The matter matters!

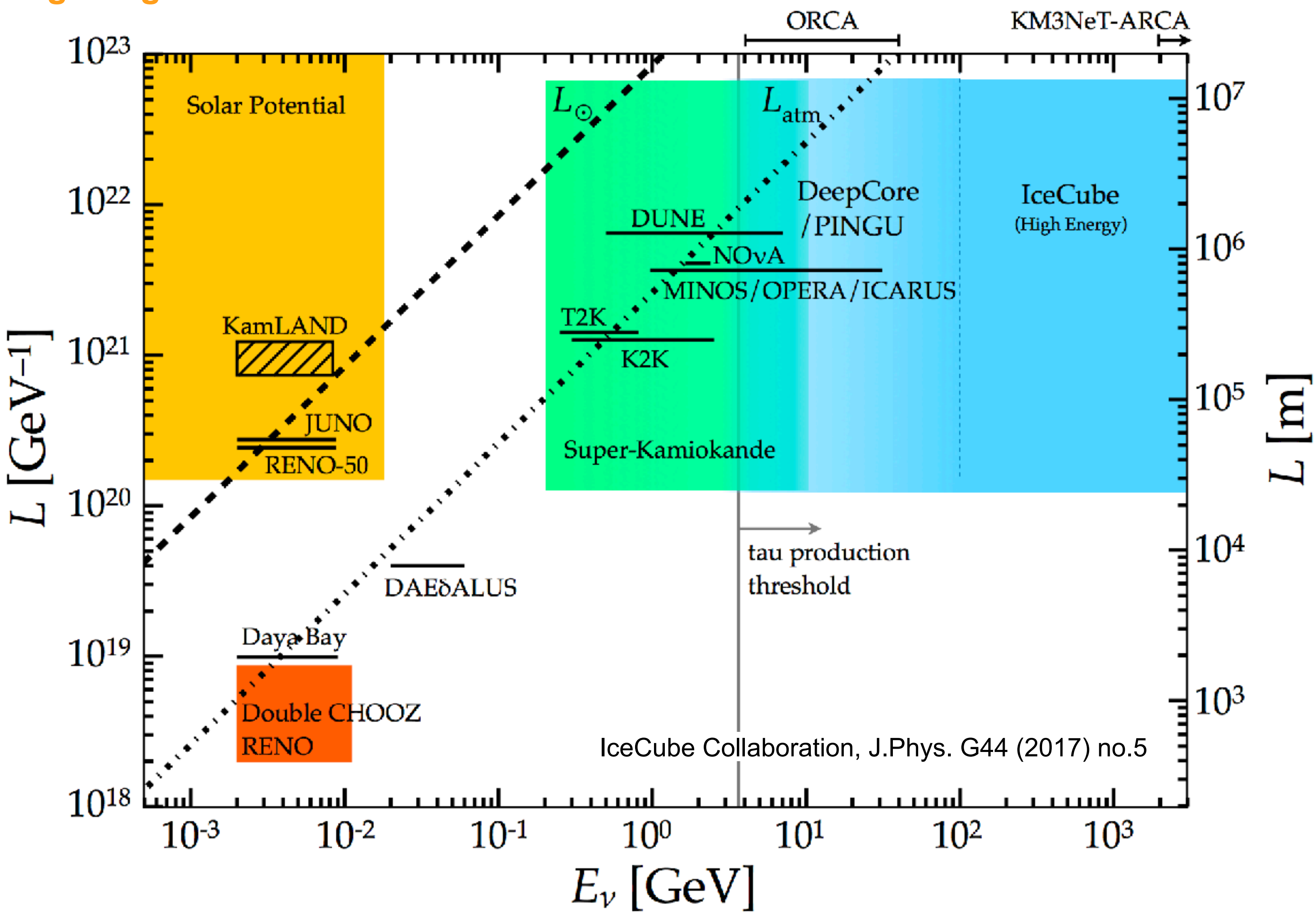
New Physics

- Unitarity of PMNS matrix
- Non-standard interactions
  - Flavour changing
  - Cross-section enhancement
- Environmental decoherence



The global picture

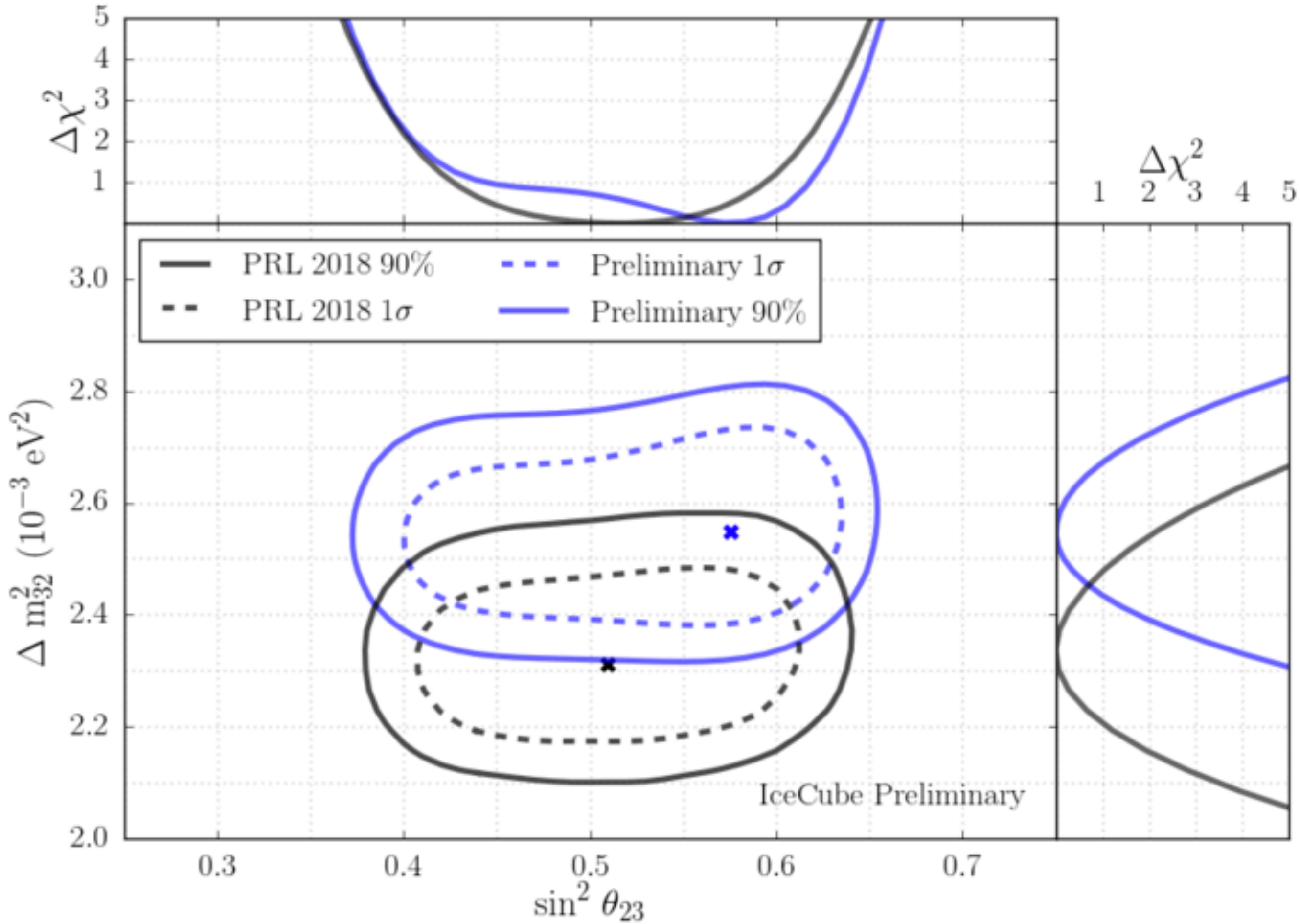
Putting things in context



Neutrino oscillations

DeepCore NuMu Disappearance

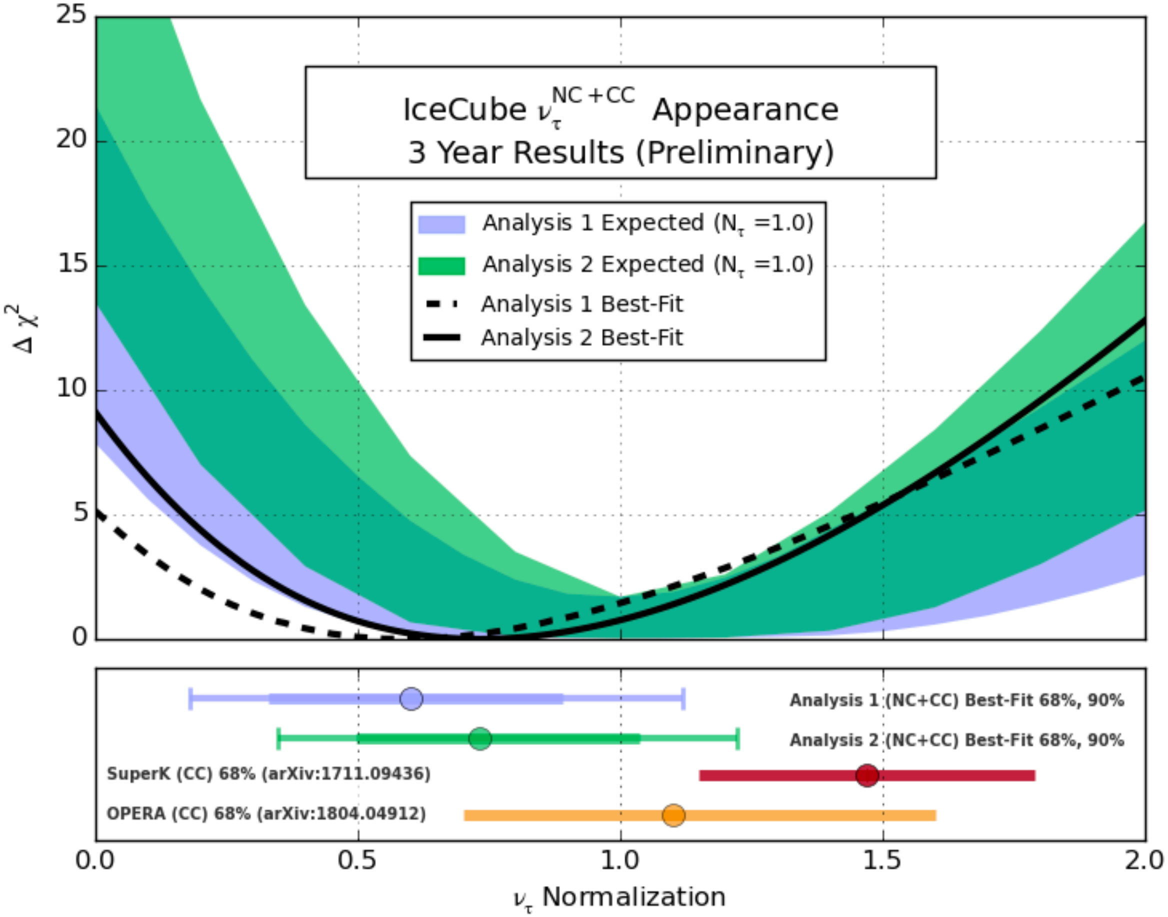
See talk by T. DeYoung
Neutrino Astronomy 5



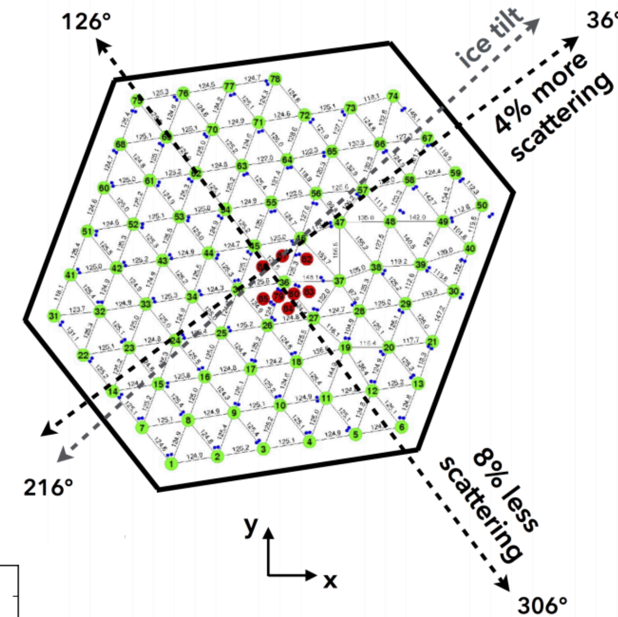
Neutrino oscillations

DeepCore NuTau Appearance

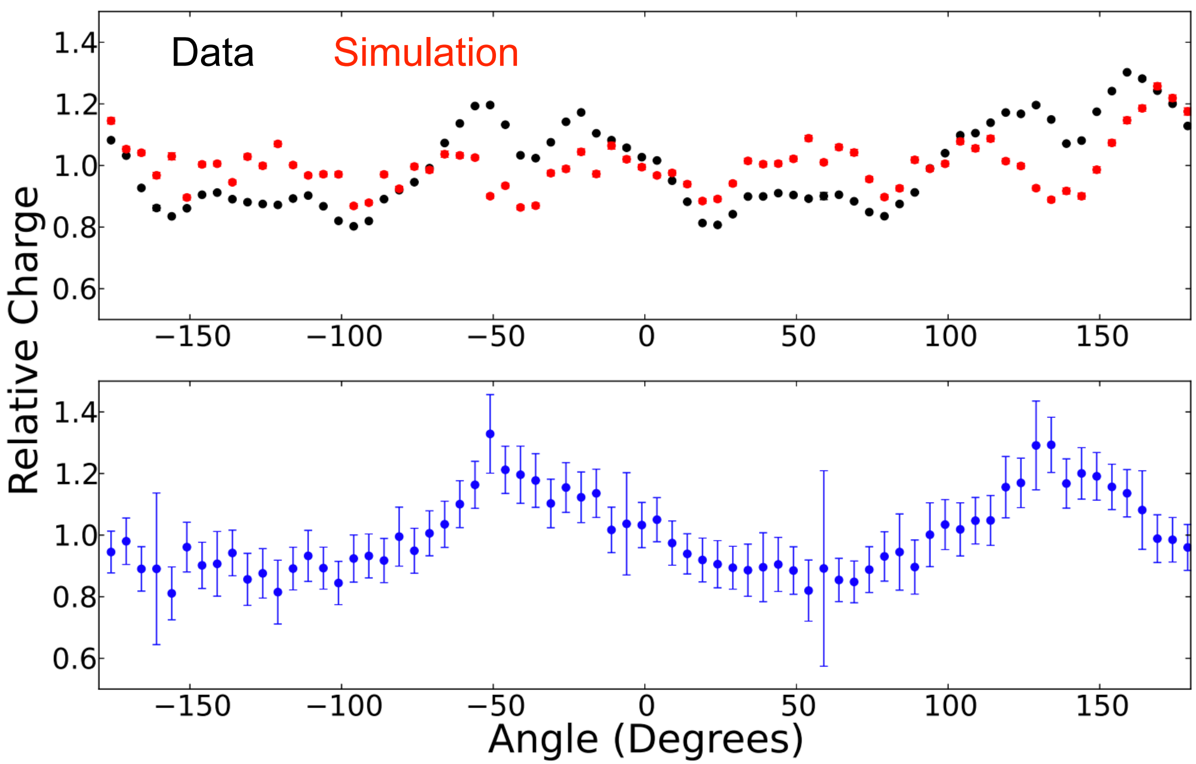
See talk by T. DeYoung
Neutrino Astronomy 5



Ice anisotropy

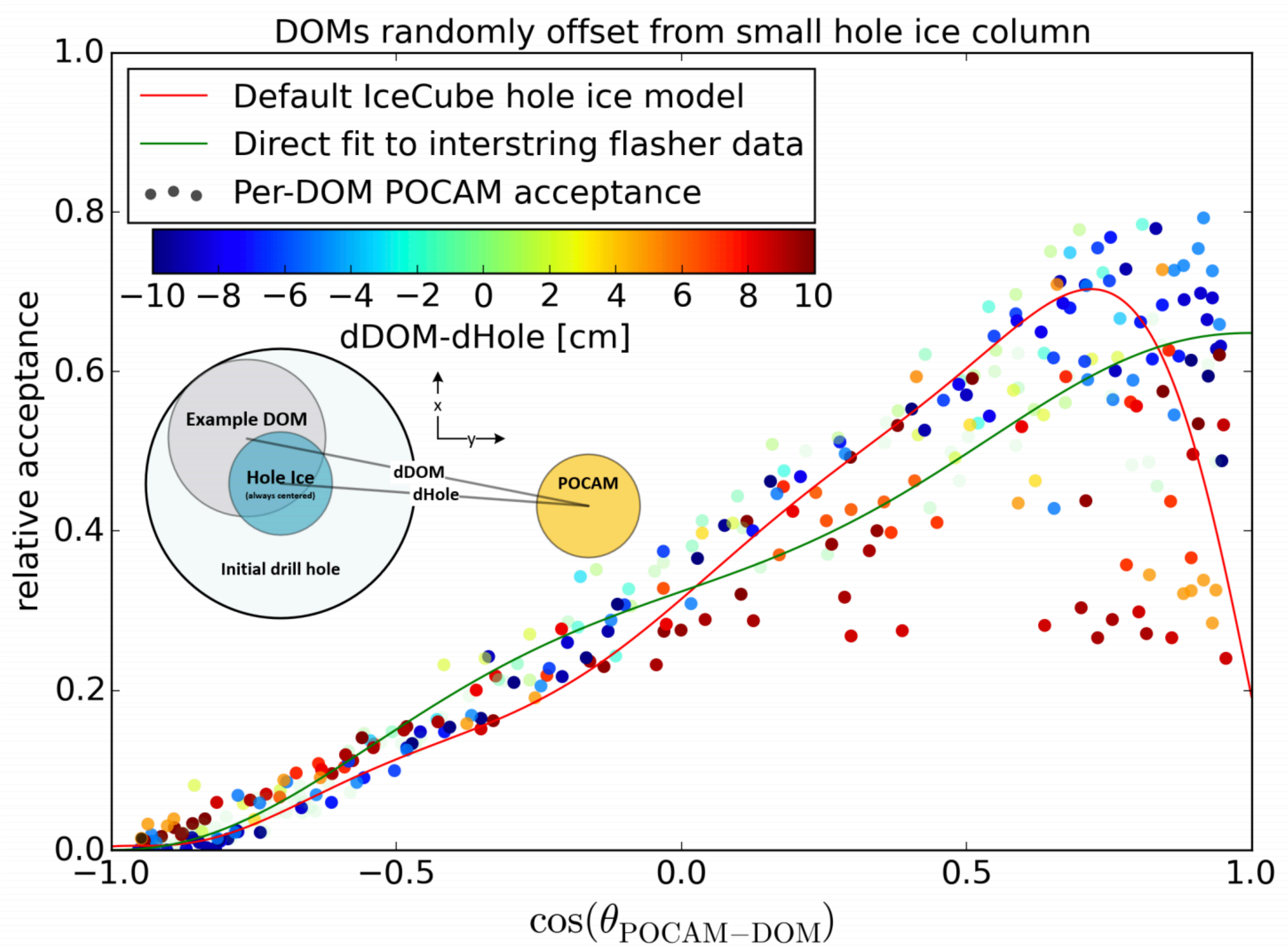


South Pole ice anisotropy: Proceedings of ICRC2013 0580, 2014



The IceCube Upgrade - Calibration

Example: POCAM triangulation and characterisation of bubble column



https://doi.org/10.22323/1.301.0934

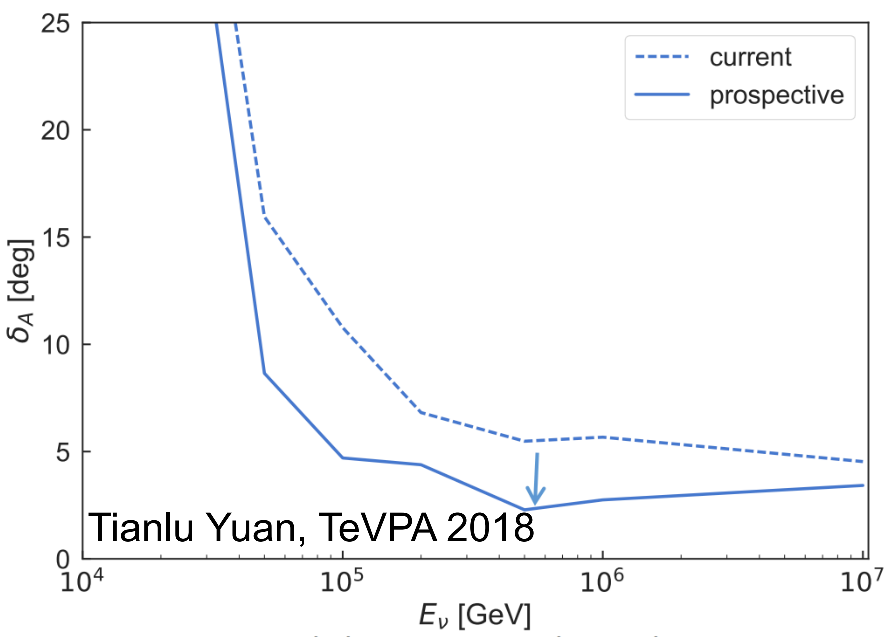
The IceCube Upgrade - Science

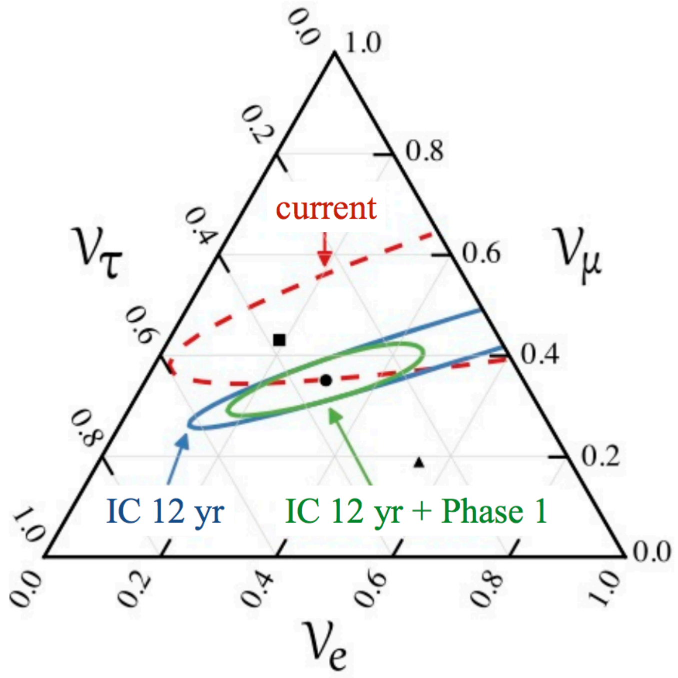
Improved reconstruction of high energy interactions

Improved cascade angular resolution

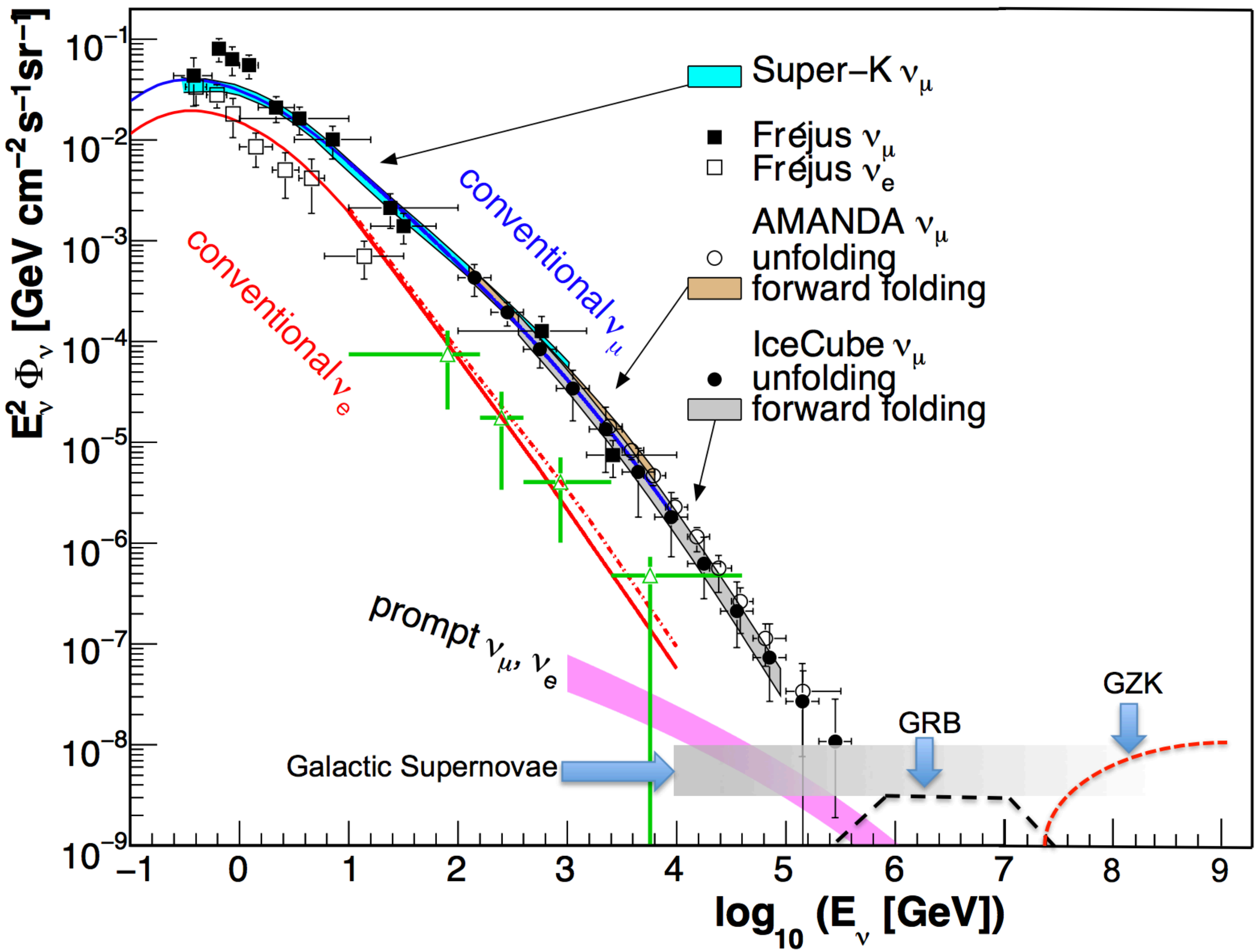
Improved identification of astrophysical ν_τ

- Use POCAMs to mimic double-bang with 20m spacing
- Reduced uncertainty on ice anisotropy



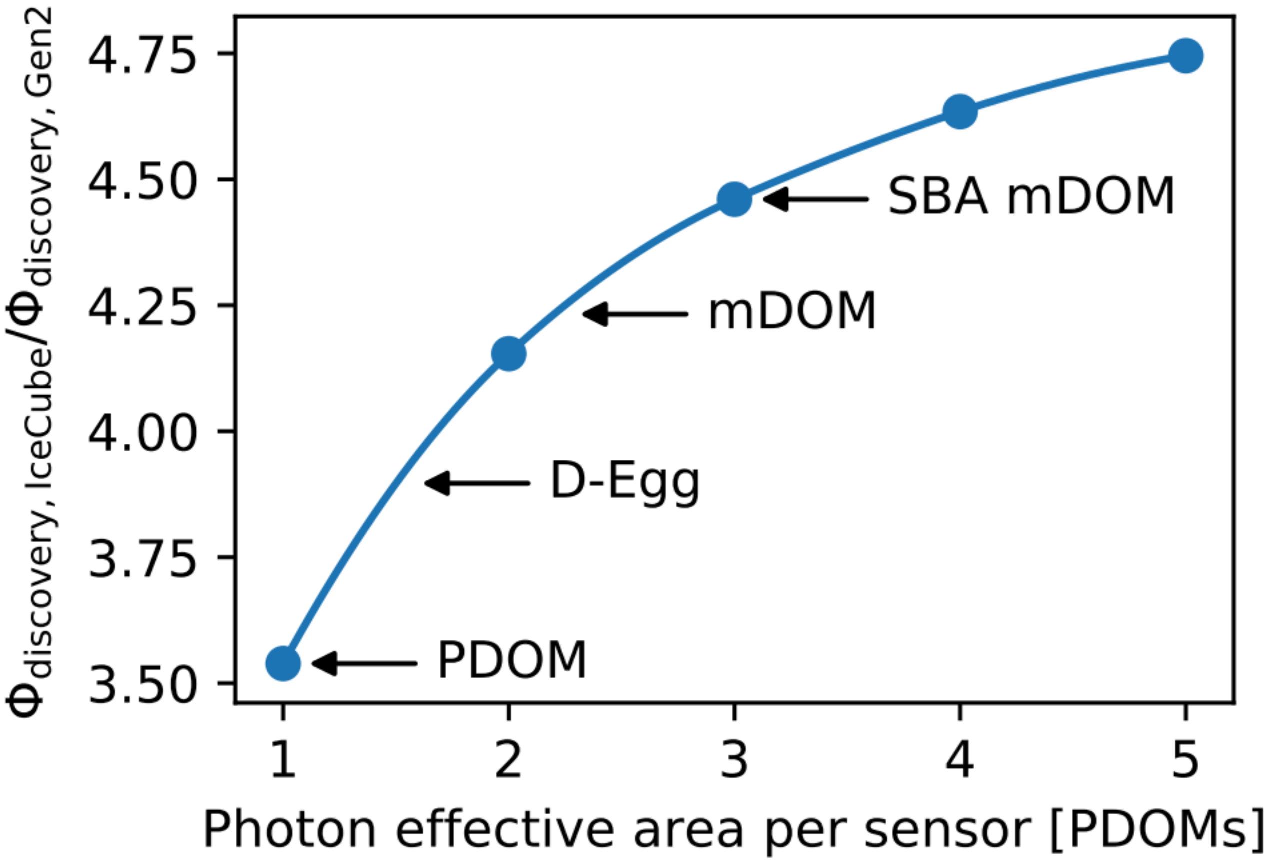


https://arxiv.org/pdf/1412.5106.pdf



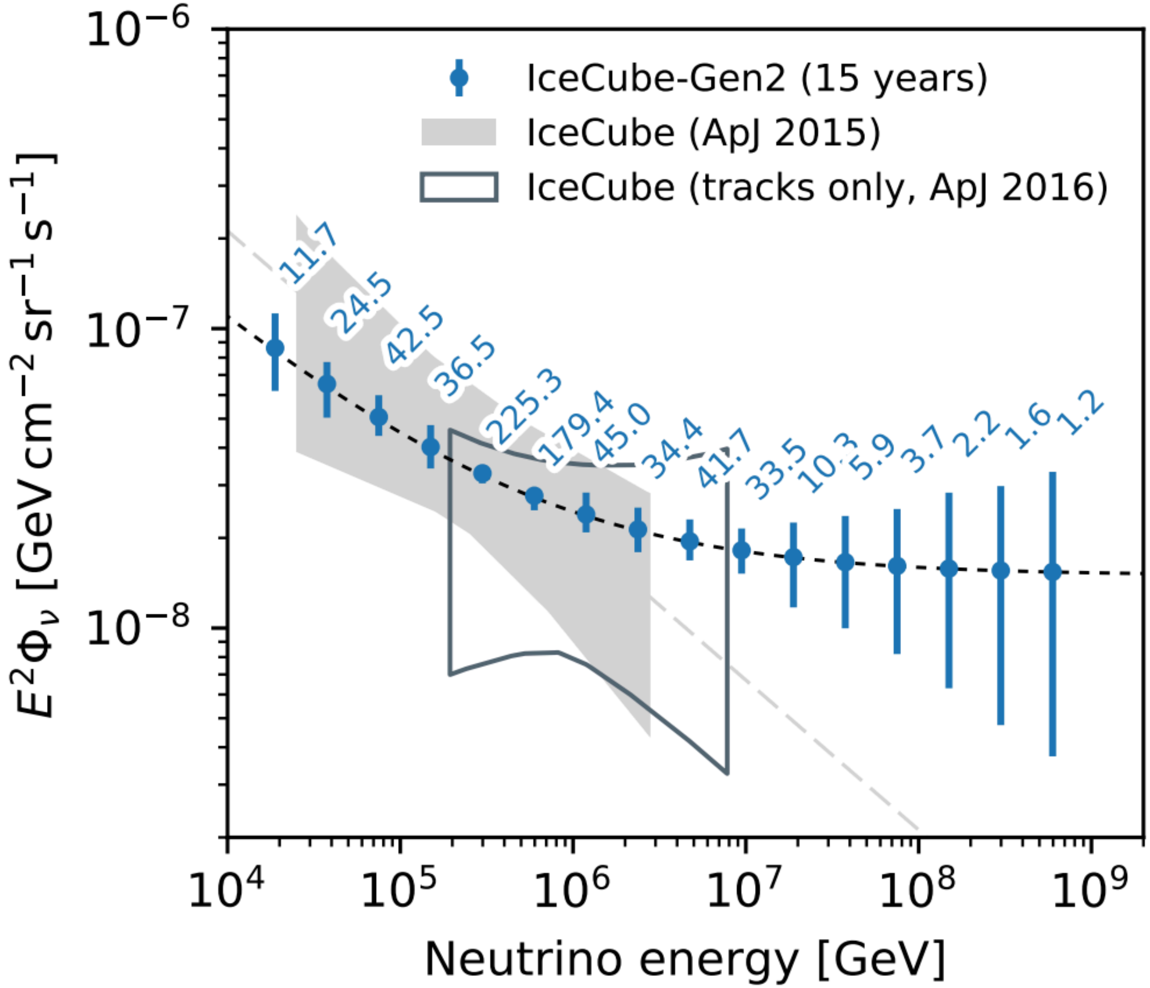
DESY.

Improved physics reach with new sensors



High Energy Array

Precise measurement of diffuse flux



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