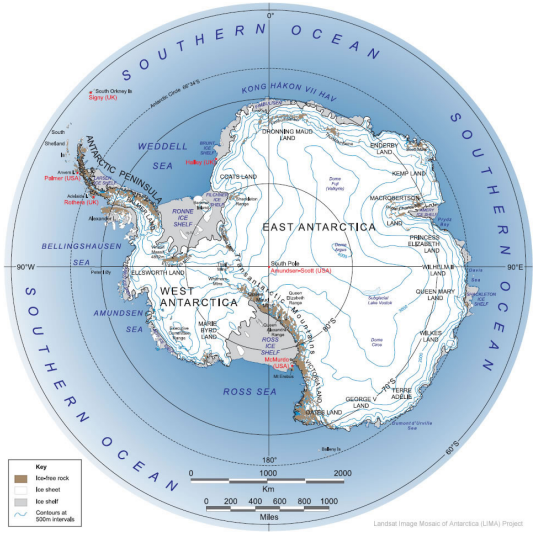
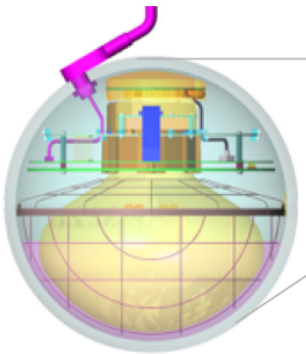
PINGU — LoI and beyond

Thomas Ehrhardt for the IceCube-PINGU Collaboration

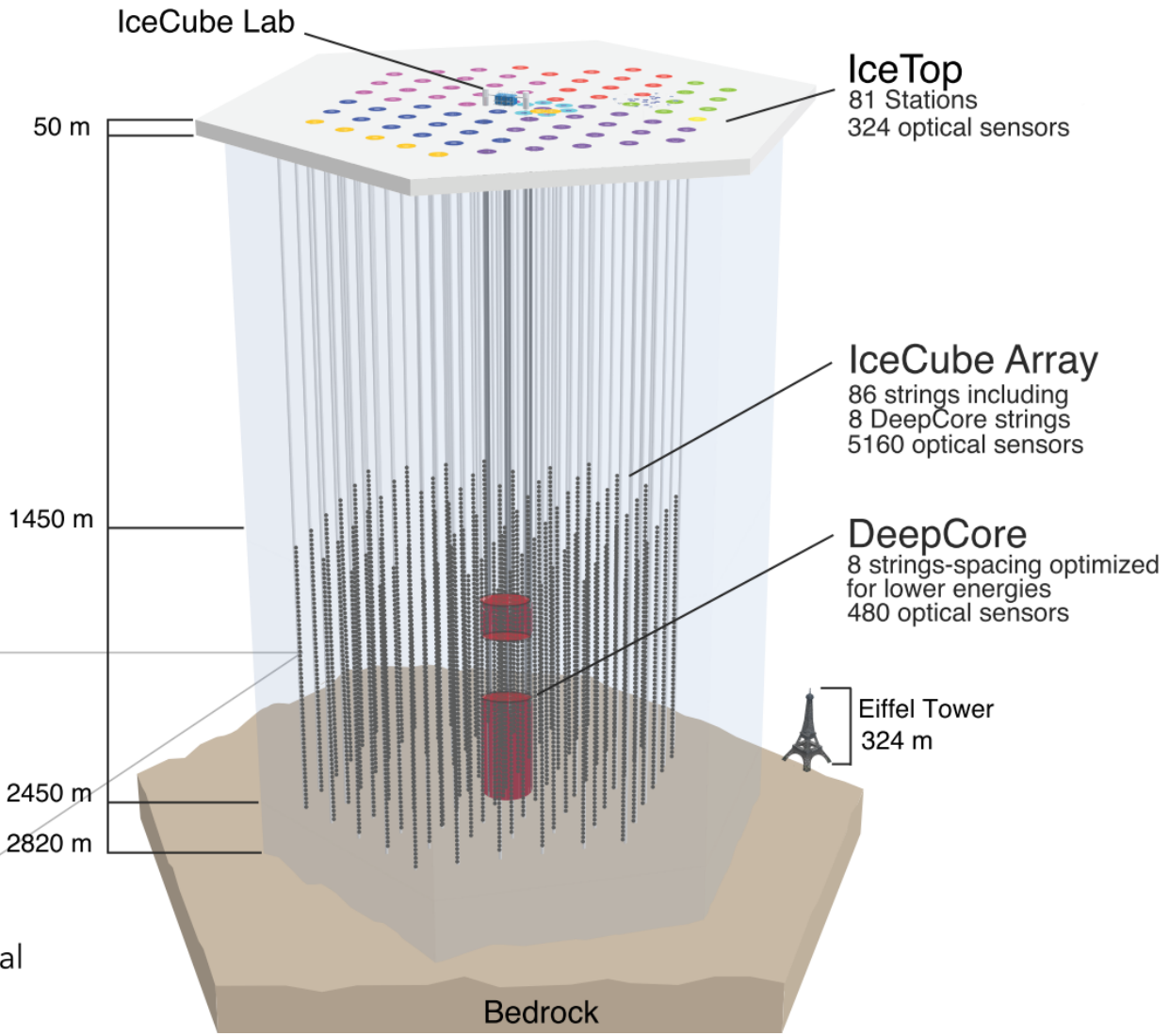
MANTS | Mainz | October 1st 2016

IceCube/DeepCore





IceCube Digital Optical Module (DOM)



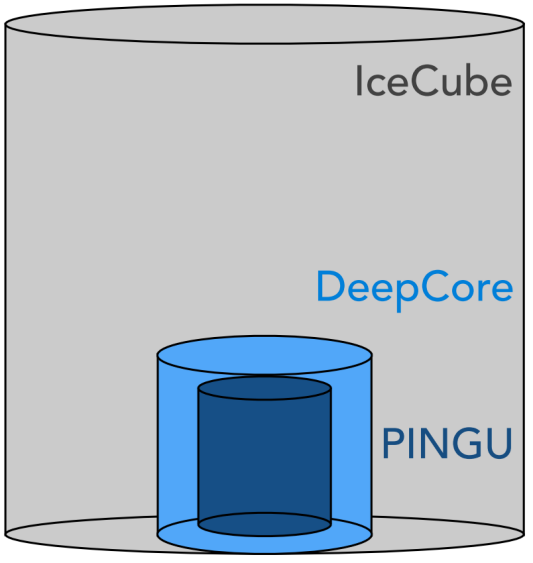
Precision

IceCube

Next

Generation

Upgrade



"A Vision for Neutrino and Particle Physics at the South Pole"

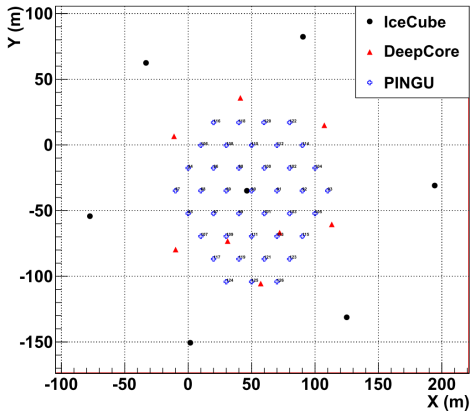
arXiv:1607.02671

PINGU Geometry Optimisation

previous:

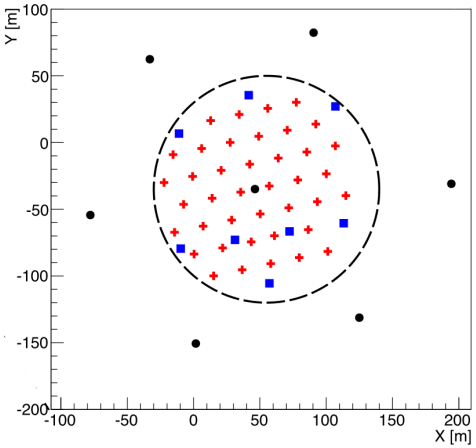
arXiv:1401.2046

- 40 strings w/ 60 DOMs each
- 20 m horizontal spacing
- 5 m DOM-DOM spacing



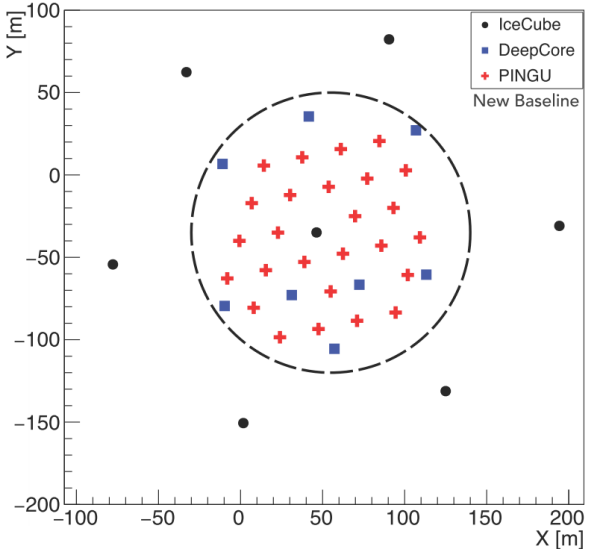
various conferences

- 40 strings w/ 96 DOMs each
- 22 m horizontal spacing
- 3 m DOM-DOM spacing



current (arXiv:1607.02672):

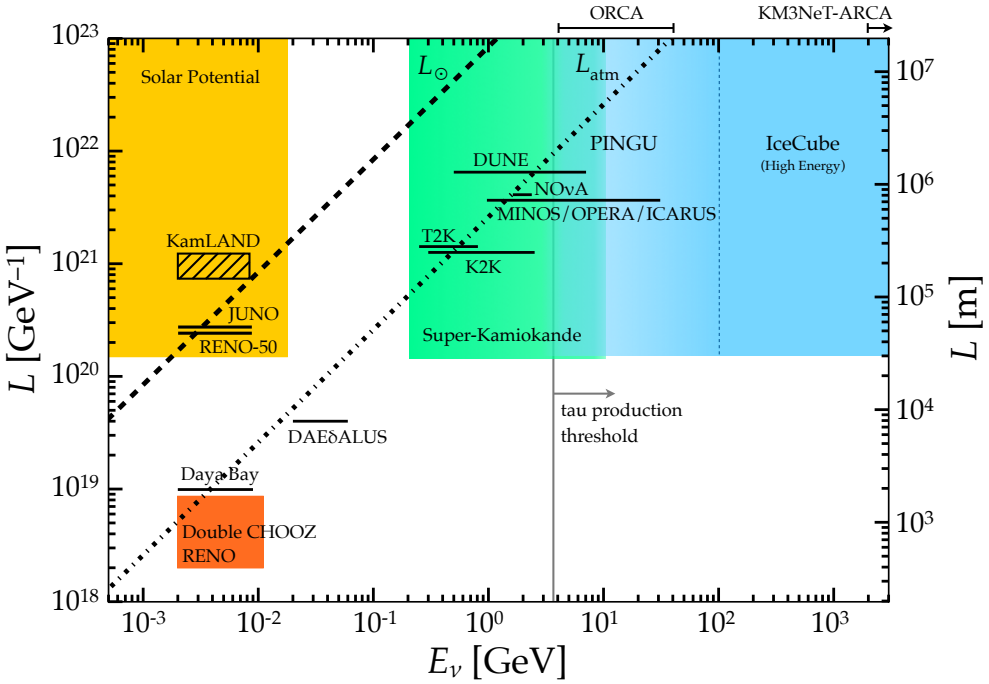
- 26 strings w/ 192 DOMs each
- 24 m horizontal spacing
- 1.5 m DOM-DOM spacing



- reduced no. of holes to drill
- higher photocathode density
- **performance just as good!**

PINGU Science

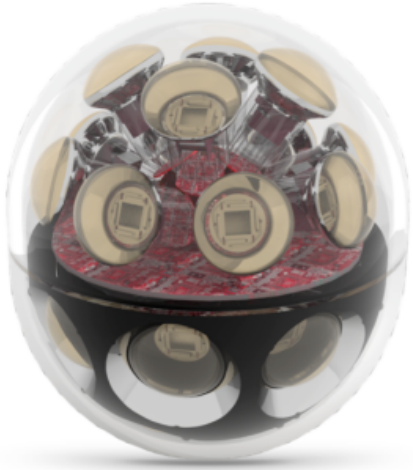
- lower energy threshold to a few GeV $\Rightarrow$ open up new physics opportunities
- close to 70k upgoing atmospheric neutrinos per year
- neutrino mass ordering and θ_{23} octant sensitivity
- probe unitarity of PMNS-matrix (> 3k ν_τ per year)

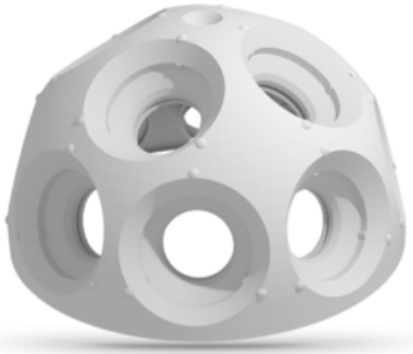


- + additional science (WIMP dark matter, Earth tomography, SNe)

Detector Technology

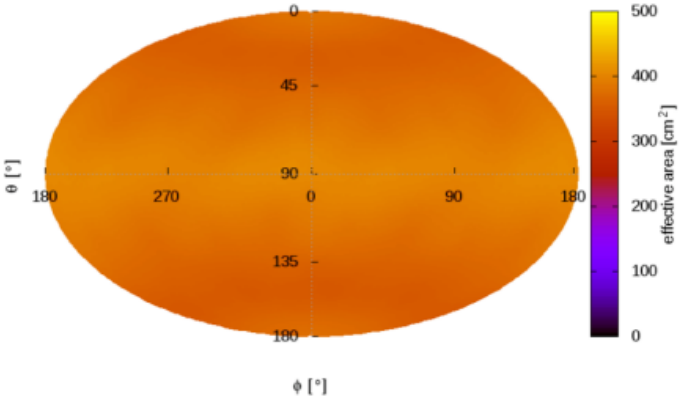
- various sensor designs continuously studied
- possibility of using multiple-PMT optical modules:
  - 24 × 3 inch PMTs in 14 inch spherical glass housing
  - photon acceptance isotropic
  - potential to exploit directional information

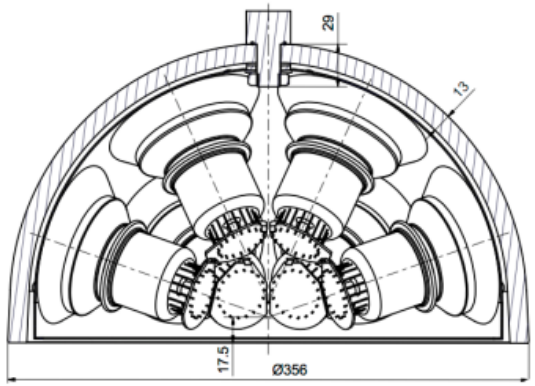




support structure

4π effective area map





Timeline and Logistics

- five-year period from construction start to full deployment anticipated (2-season deployment)

1 less drill season

- submission of proposal to NSF foreseen for this fall
- detailed version of LoI short summary (arXiv:1607.02671) expected to be out shortly

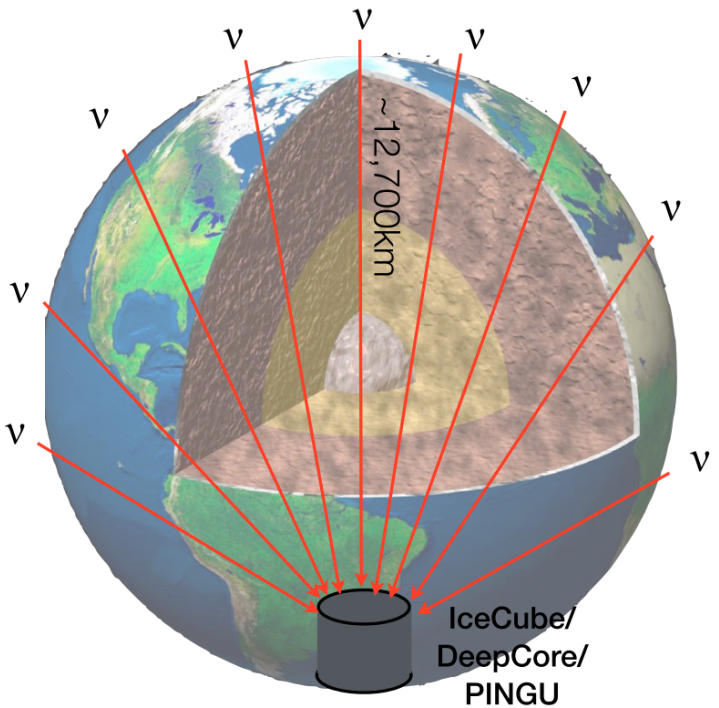
Cost

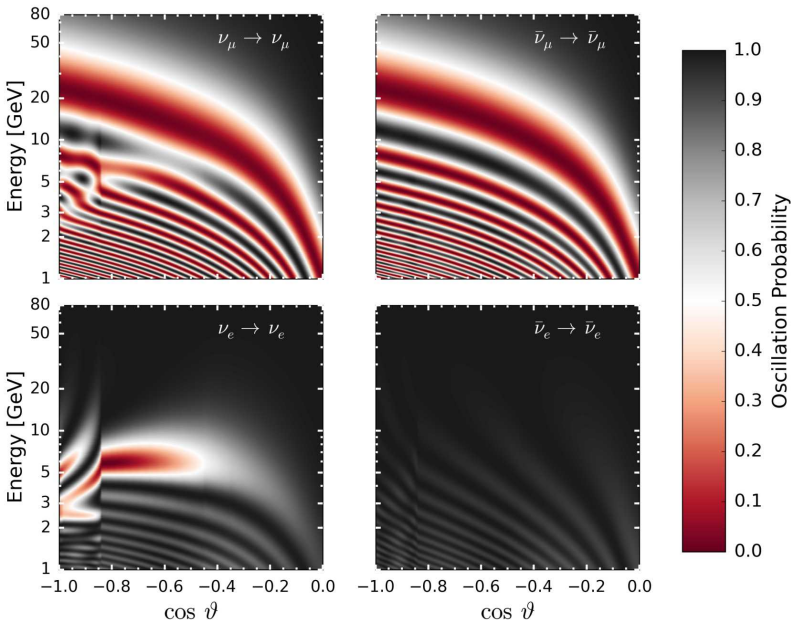
	Cost (20 Strings)	Cost (26 Strings)
Drill refurbishment	\$5M	\$5M
Deployment (labor)	\$5M	\$5M
Instrumentation	\$25M	\$33M
Management & other costs	\$5M	\$5M
Total	\$39M	\$47M
Fuel	146,000 gal	190,000 gal

- compared to orginal configuration: reduced no. of strings cuts costs significantly in several areas:
  - no need for 3$^{\mathrm{rd}}$ drilling season $\Rightarrow$ reduced personnel costs
  - hot water drill fuel, cables, logistical support expenses almost halved
  - refurbish and reuse on-ice IceCube hot water drill instead of replacing

Atmospheric Neutrinos

- steady ν flux available over large range of neutrino energies E_ν and oscillation baselines L
- for vertically upgoing ν_μ, first survival probability minimum at $E_\nu \sim 25\,\mathrm{GeV}$

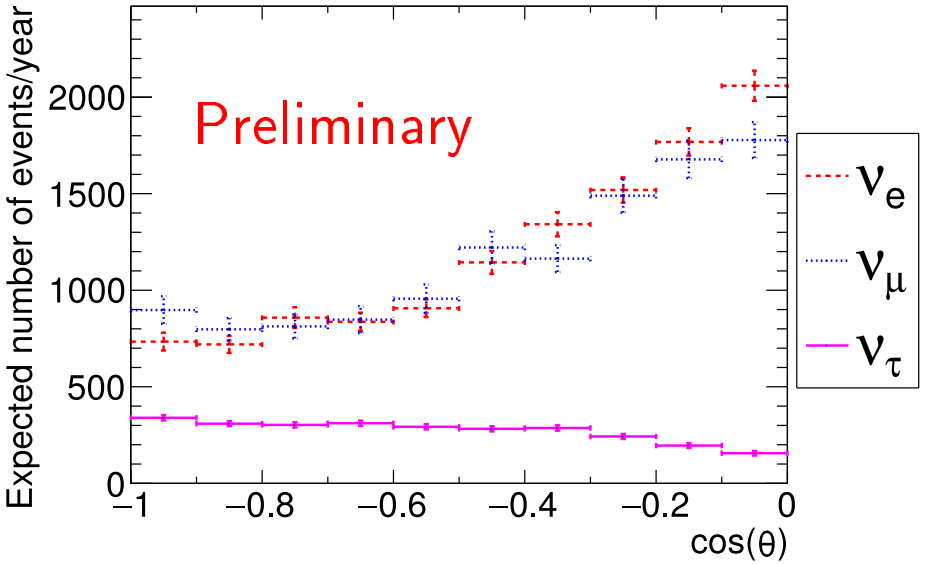


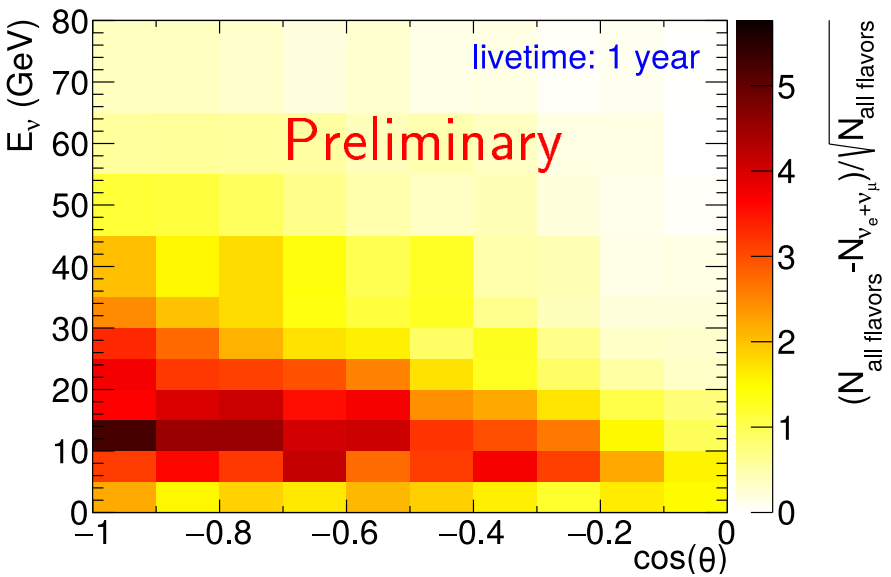


- Earth matter effects: characteristic modifications of oscillation probabilities below $\sim 10\,\mathrm{GeV}$, depending on neutrino mass ordering (NMO)

ν_τ Appearance—Signature

- expect $>$ 3k ν_τ appearing per year
- increased PINGU density $\Rightarrow$ improve discrimination between tau- and muon-type interactions
- search for energy-zenith angle dependent excess over no-ν_τ appearance hypothesis in cascade channel
- unique probe of $|U_{\tau 3}|^2$ $\Rightarrow$ unitarity of neutrino mixing matrix

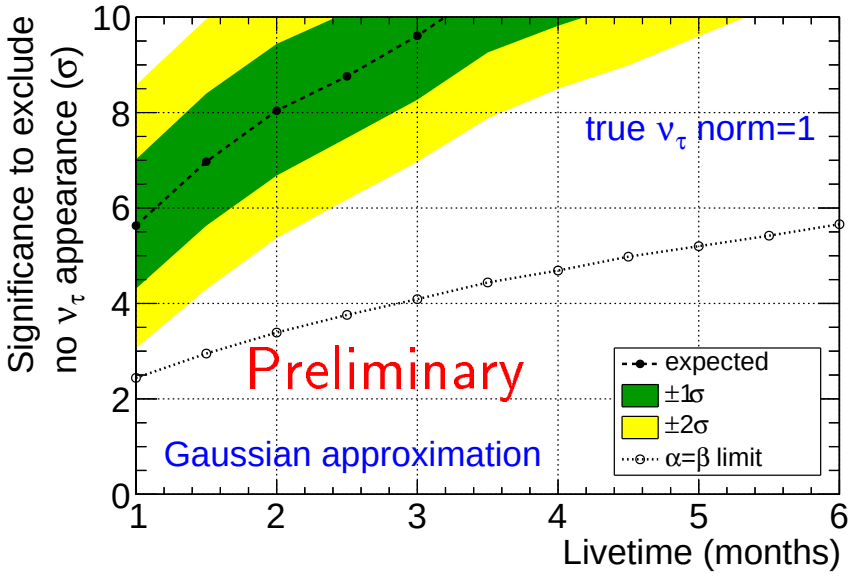


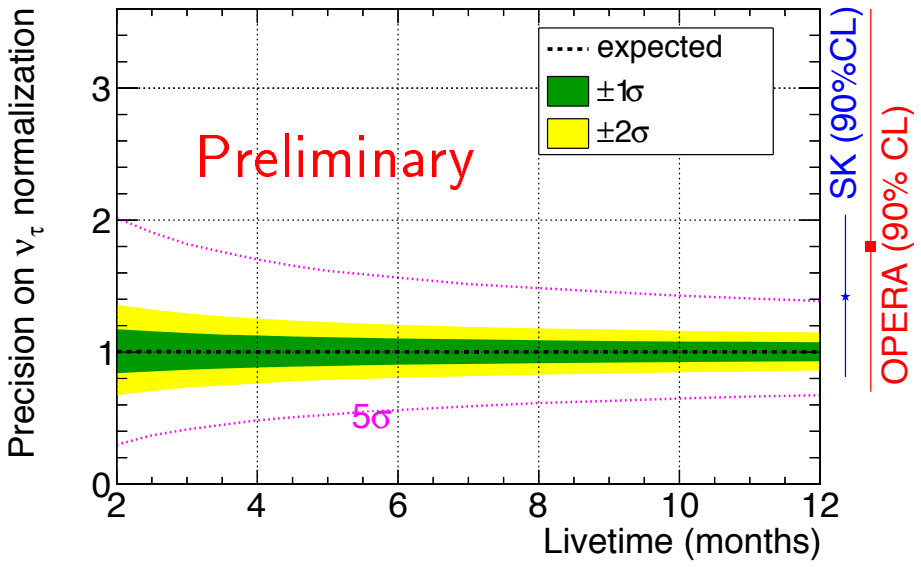


ν_τ Appearance—Sensitivity

with expected ν_τ appearance from standard 3-flavour oscillations:

- expect to reach 5σ exclusion of no ν_τ appearance with a month of data
- expect better than 10 % precision after one year of measurement





NMO Asymmetry of Flux/Rates

- up to few 10 % differences in oscillation probabilities, depending on which NMO realised

- effect to 1st order symmetric w.r.t. flip of NMO & $\nu \leftrightarrow \bar{\nu}$

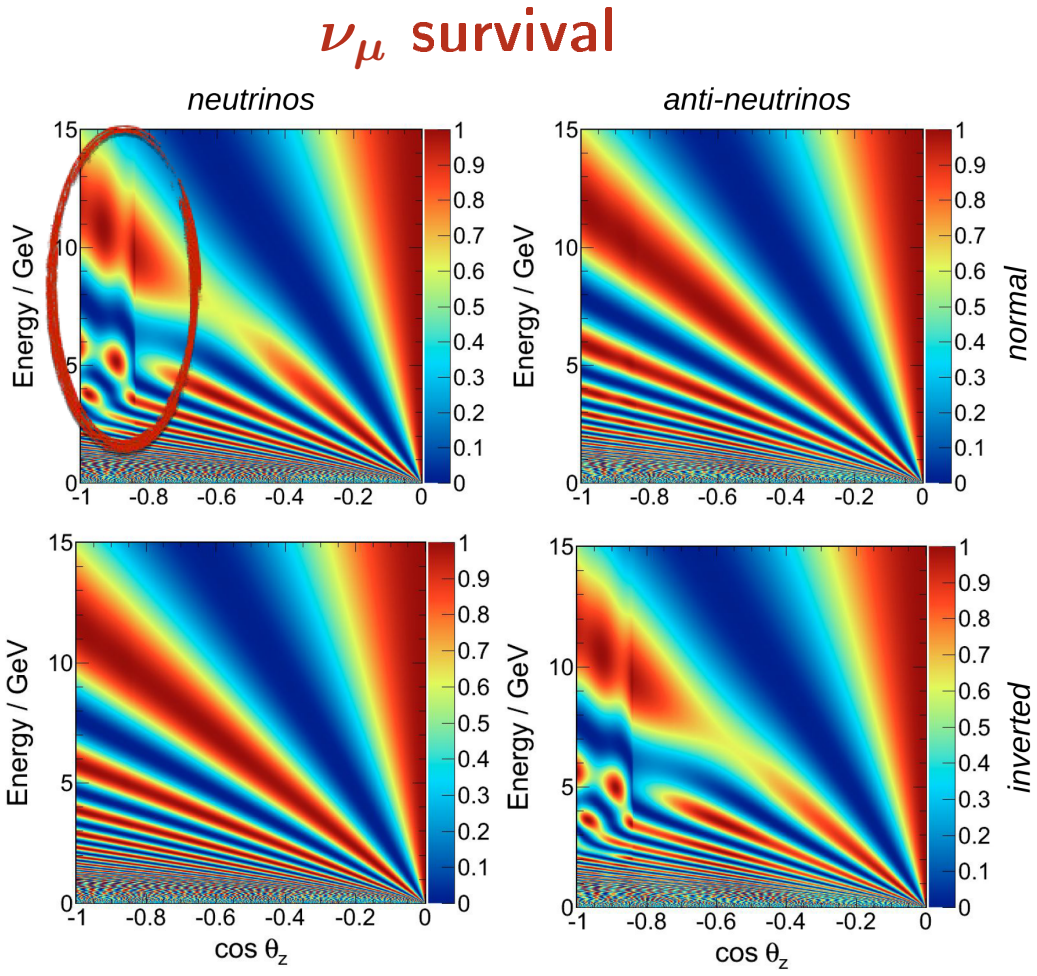
but:

- atmospheric flux $\Phi_\nu / \Phi_{\bar{\nu}} \sim 1.3$

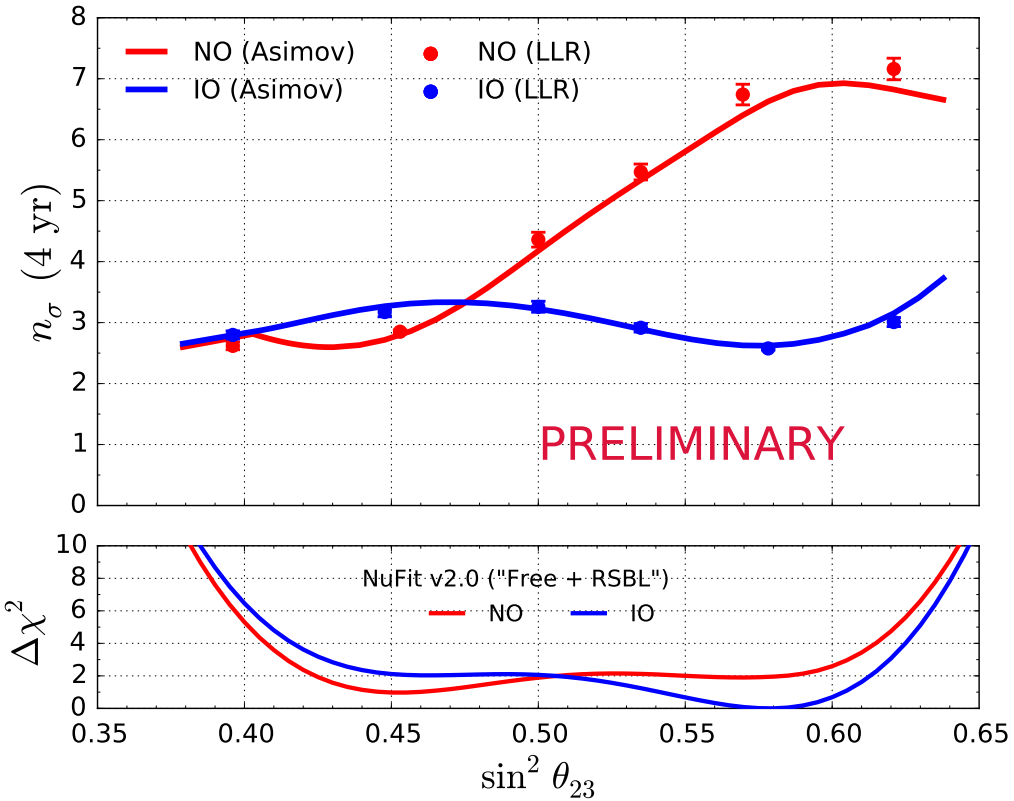
- x-sections $\sigma_{\nu N} / \sigma_{\bar{\nu} N} \sim 2$

$\Rightarrow$ few percent residuals even w/o ν vs. $\bar{\nu}$ discrimination

- massive O(Mton) detectors required for sufficient event statistics

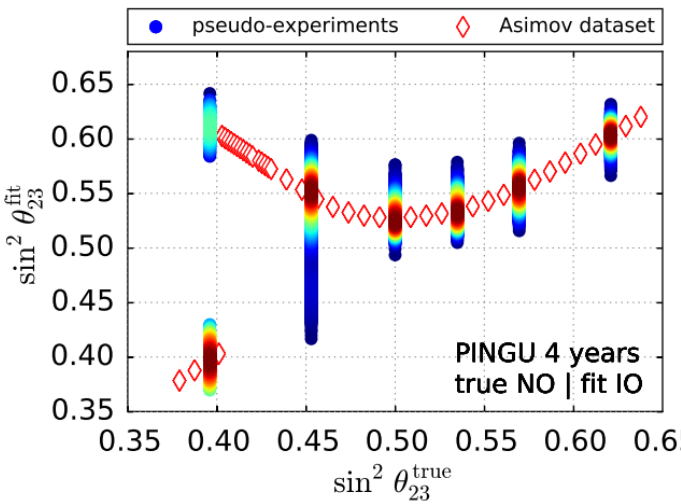


PINGU NMO Measurement



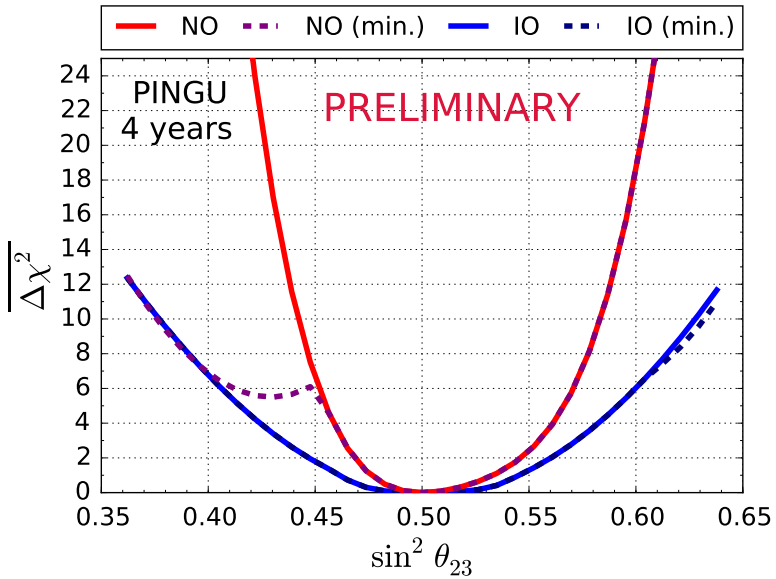
only fully deployed PINGU data shown

- profit from taking into account signals in cascade & track channel
- good agreement between Asimov and pseudo-data (LLR) studies
- sensitivity strongly dependent on true value of θ_{23} (amplitude of matter effect)

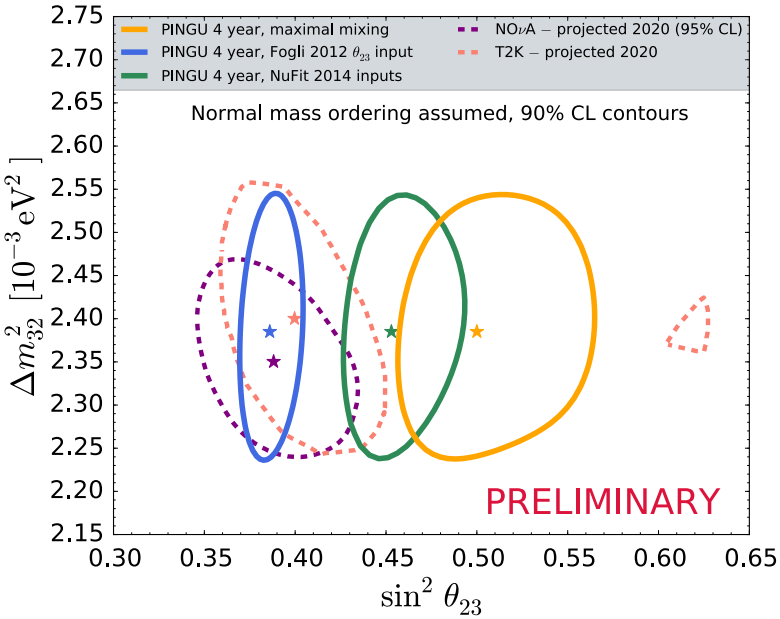


- NMO $\leftrightarrow$ θ_{23} degeneracies for both NMO's

Atmospheric Oscillation Parameters



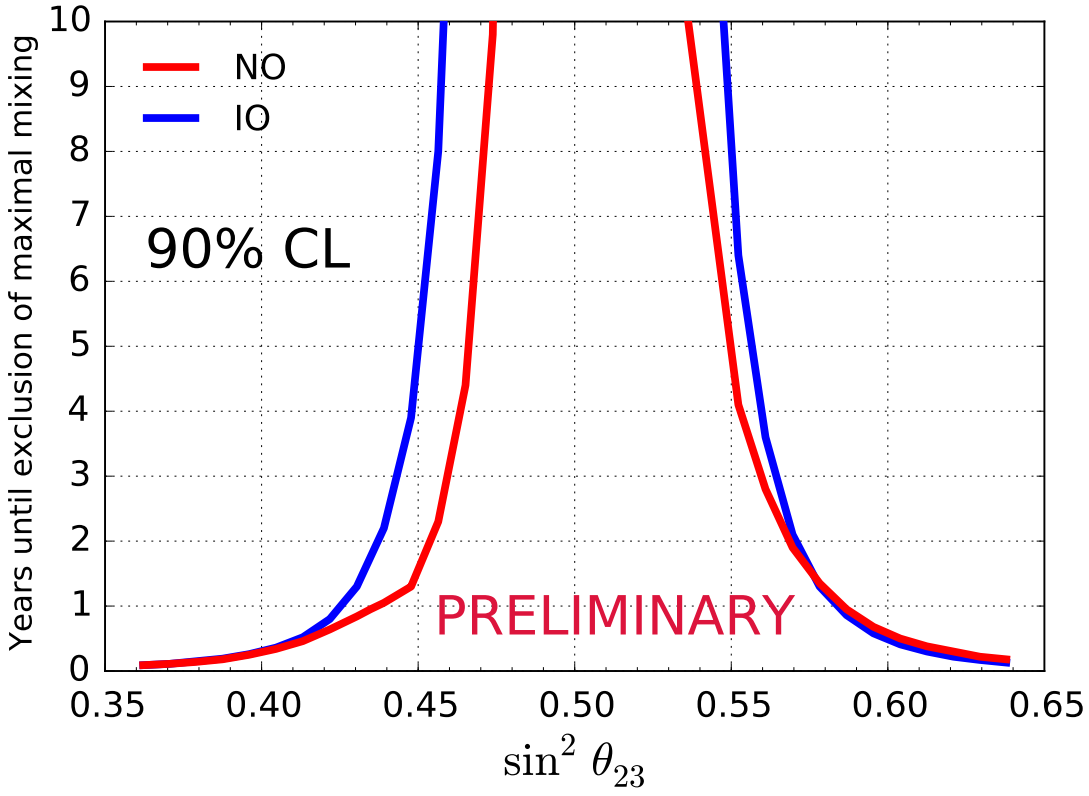
- 4-year octant sensitivity $\gtrsim 3\sigma$ if
  - IO: $\sin^2\theta_{23} \lesssim 0.385$ or $\gtrsim 0.625$
  - NO: $\sin^2\theta_{23} \lesssim 0.38$ or $\gtrsim 0.58$
- for first octant and NO, profit greatly from knowing the NMO



- precision of $\sin^2\theta_{23}$ and Δm^2_{32} measurement for different true $\sin^2\theta_{23}$ and NO
- compared to projected accelerator constraints

Maximal Mixing

- number of years to exclude $\sin^2\theta_{23} = 0.5$ at 90 % C.L.



- with 3 years of data, maximal mixing excluded *in any case* for:

$$\sin^2\theta_{23} \lesssim 0.44;$$

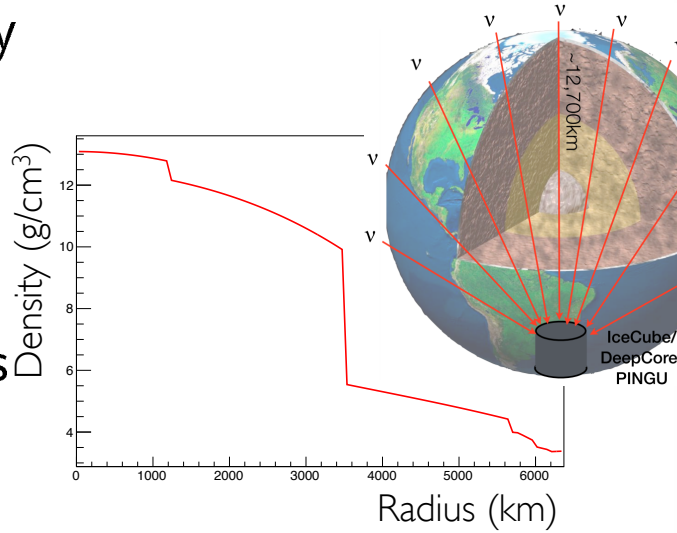
$$\sin^2\theta_{23} \gtrsim 0.57$$

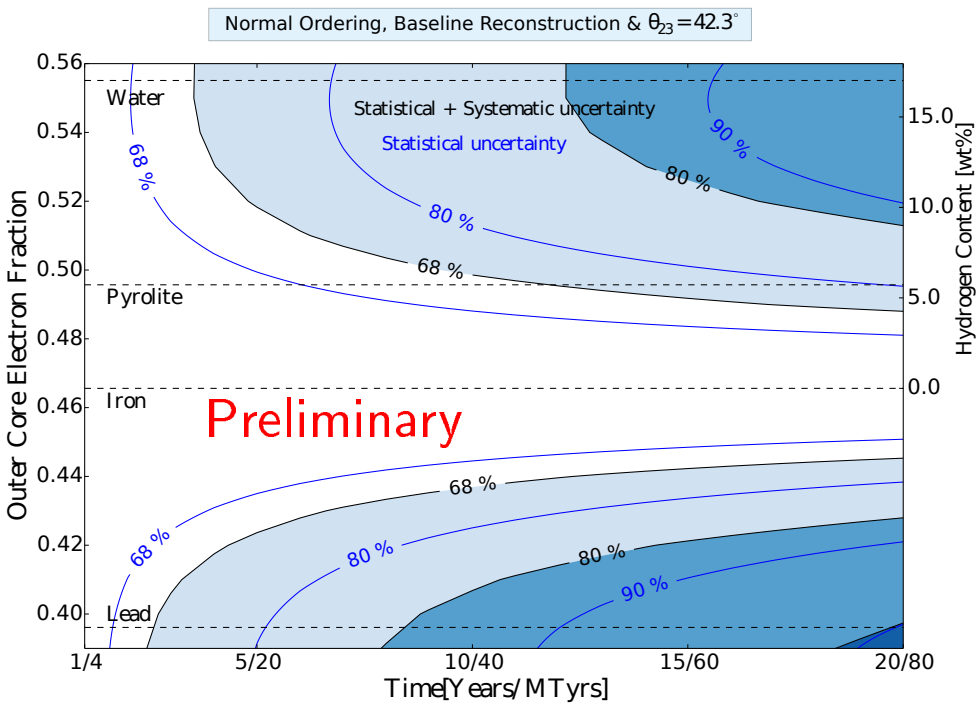
- as search does not include opposite octant

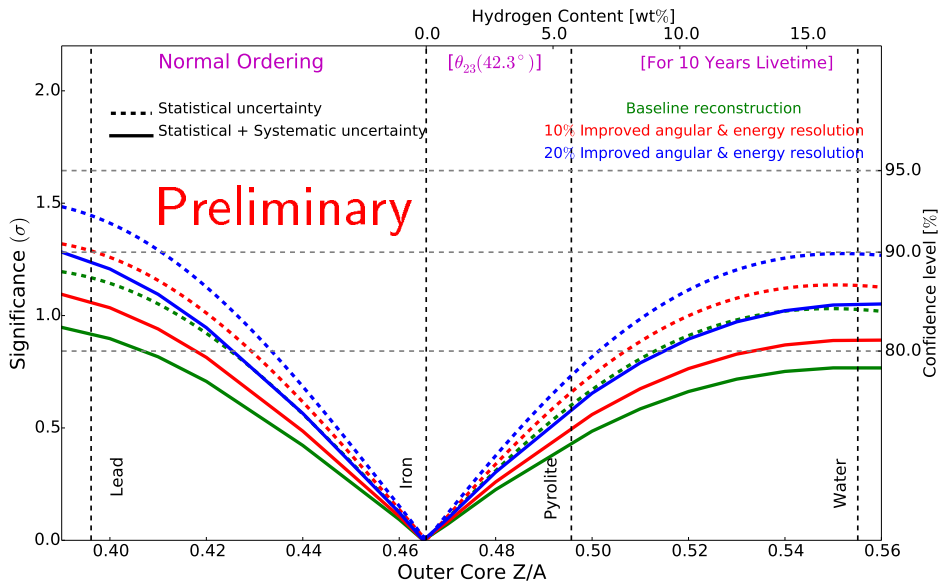
$\Rightarrow$ only minor impact of NMO ambiguity on measurement

Earth Tomography

- oscillations in matter affected by electron density
  $\Rightarrow$ measure Earth's interior composition
- sensitive region same as for NMO measurement (core/mantle resonances in 2 – 6 GeV range)
- similar effect of 20 % improvement in resolutions and assuming 2nd octant θ_{23}







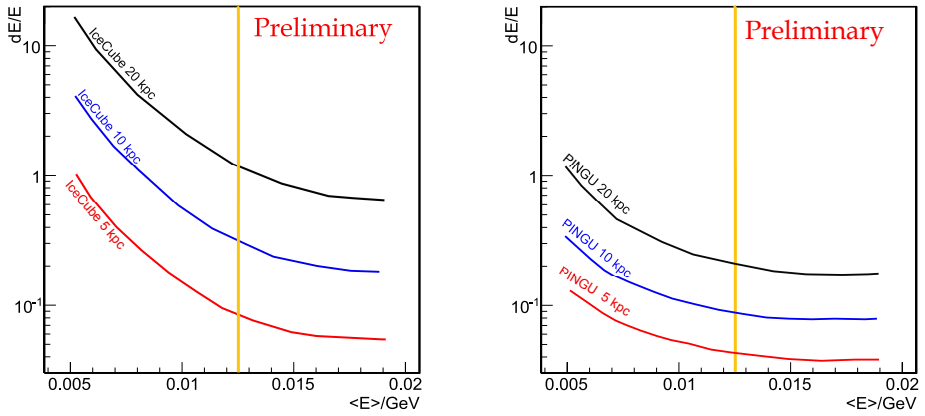
Supernovae

- $\mathcal{O}(10\,\text{MeV})$ instead of $\mathcal{O}(1\,\text{GeV})$ energies $\Rightarrow$ below energy threshold

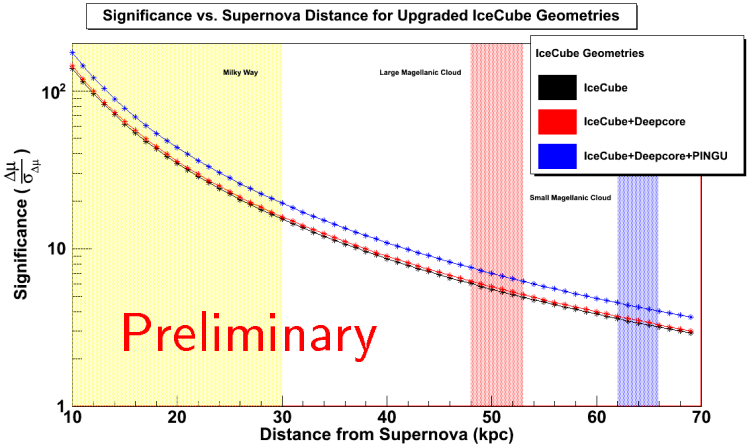
Different Detection Method

20×60 DOM configuration

- search for short-term correlated increase in all DOMs' signal rates
- increased coincident hit probability in PINGU



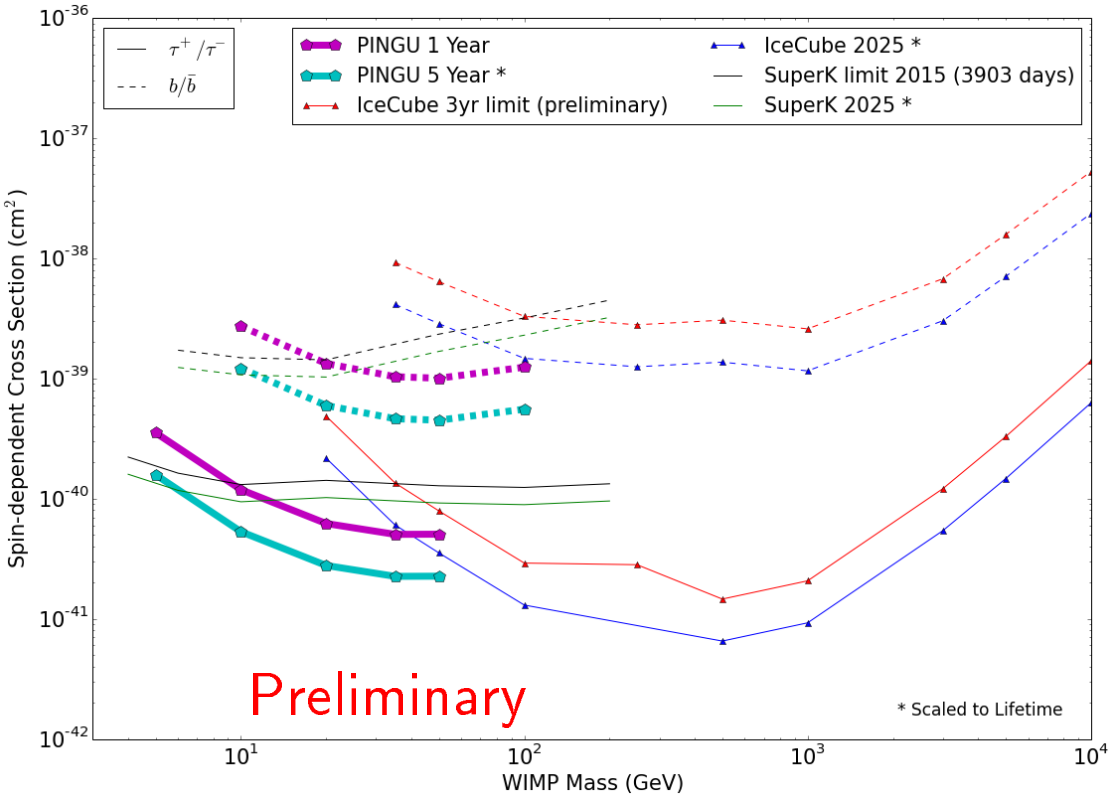
- $\sim$ order of magnitude improvement of energy resolution compared to IC
- $\sqrt{2}$ detection sensitivity improvement for $8.8 M_\odot$ SN



40×96 DOMs

Dark Matter

- indirect detection via search for neutrinos from dark matter self-annihilation, e.g. WIMP
- PINGU can substantially enhance IceCube/DeepCore sensitivity to WIMP-proton scattering cross-section for WIMP masses $\lesssim 50\,\mathrm{GeV}$



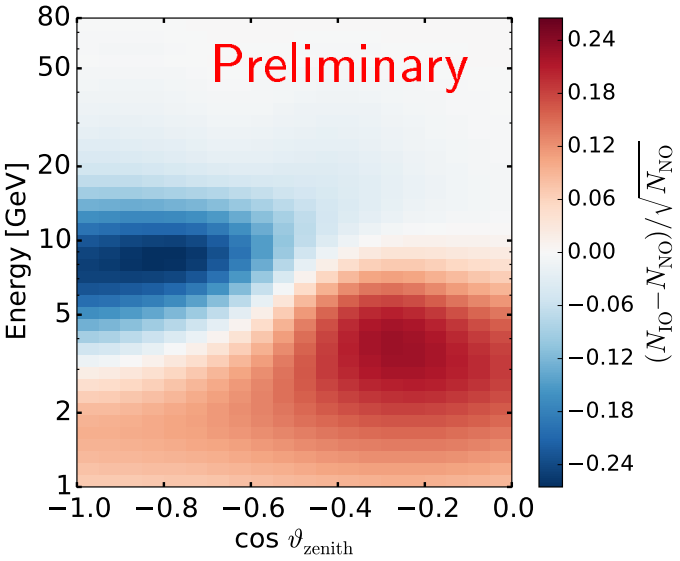
- solar WIMP self-annihilation
- all-flavour analysis
- conservative, since based on standard IceCube/DeepCore analysis methodologies

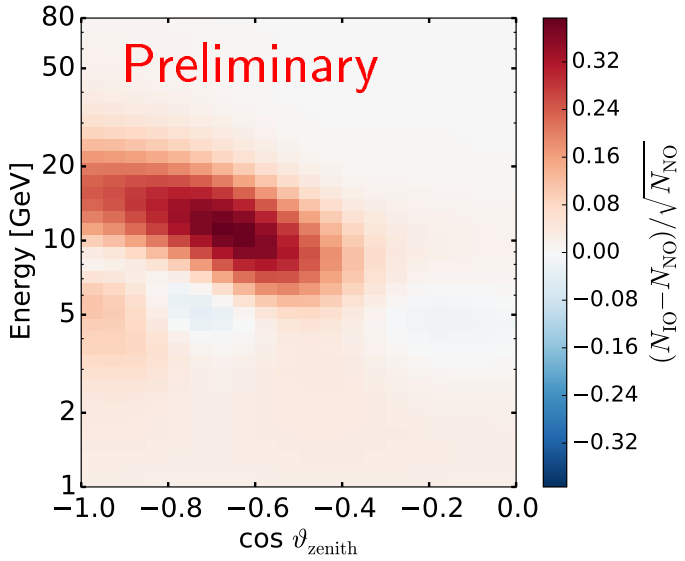
PINGU Summary

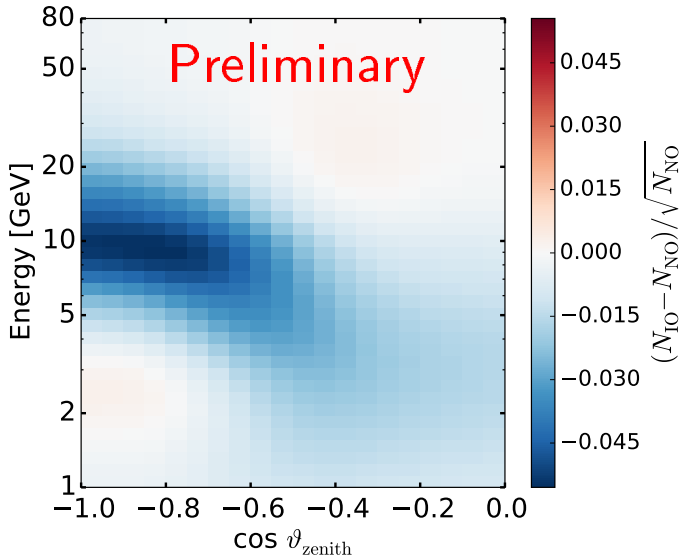
- cost-effective extension to IceCube/DeepCore
- fewer-string configuration allows for rapid deployment and provides substantial cost reduction in several areas
- expands IceCube/DeepCore physics reach (ν_τ appearance, NMO, θ_{23}, Supernovae, Solar/GC Dark Matter) and opens up novel opportunities (Neutrino Earth Tomography)
- improved sensor design potentially benefits calibration, constraining of detector related systematics as well as physics studies
- NSF fall proposal in preparation


BACKUP

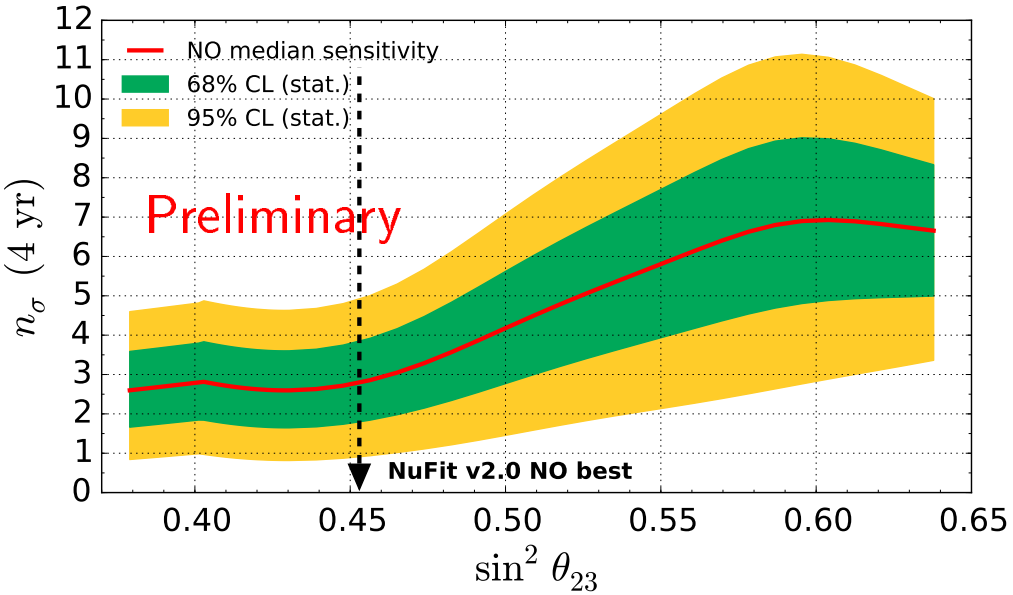
NMO—Akhmedov Plots

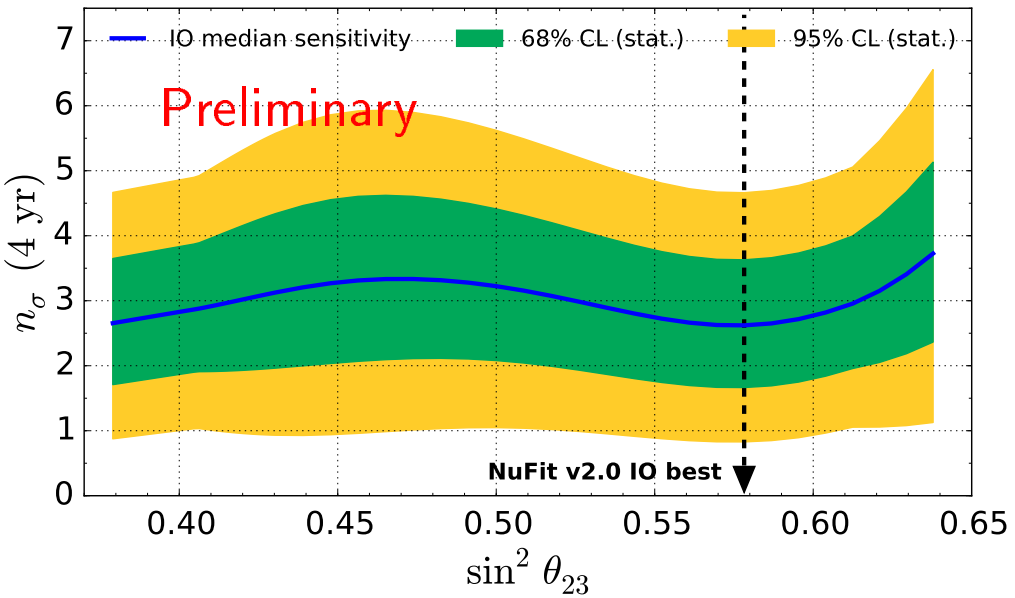






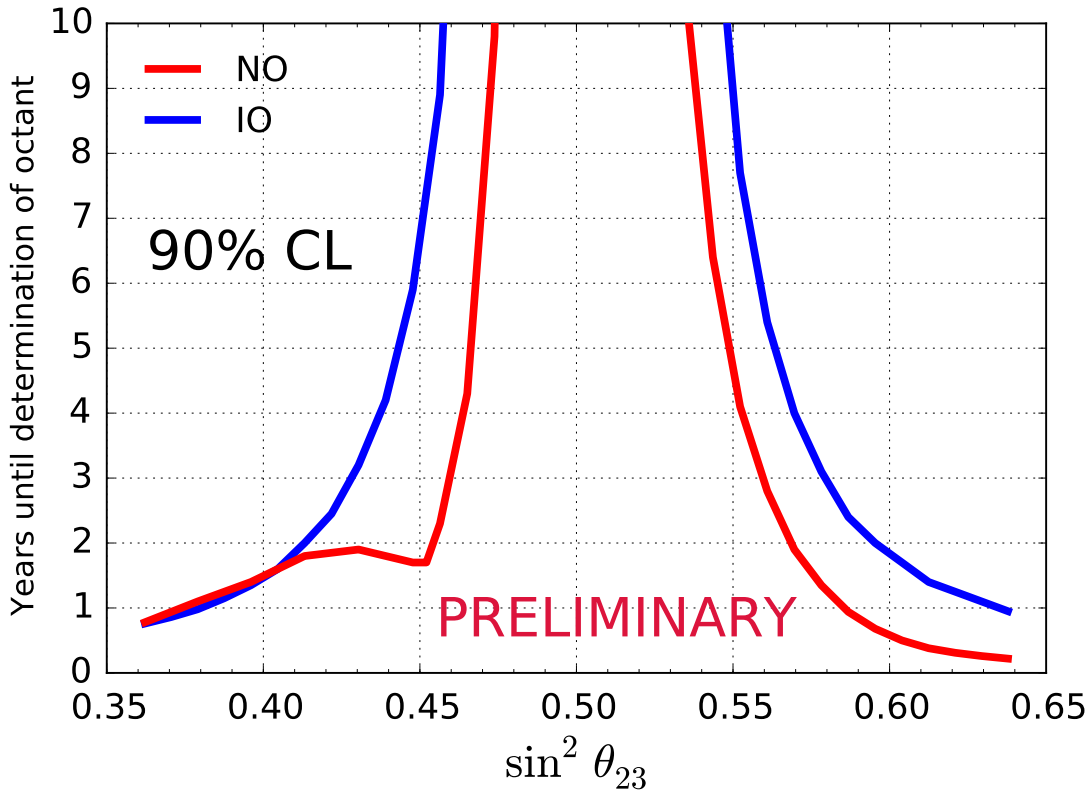
NMO Sensitivity—Brasilian Flag Plots





Determining Octant of θ_{23}

- years until wrong octant excluded at 90 % C.L.



Oscillation Parameter Contours IO