

PINGU

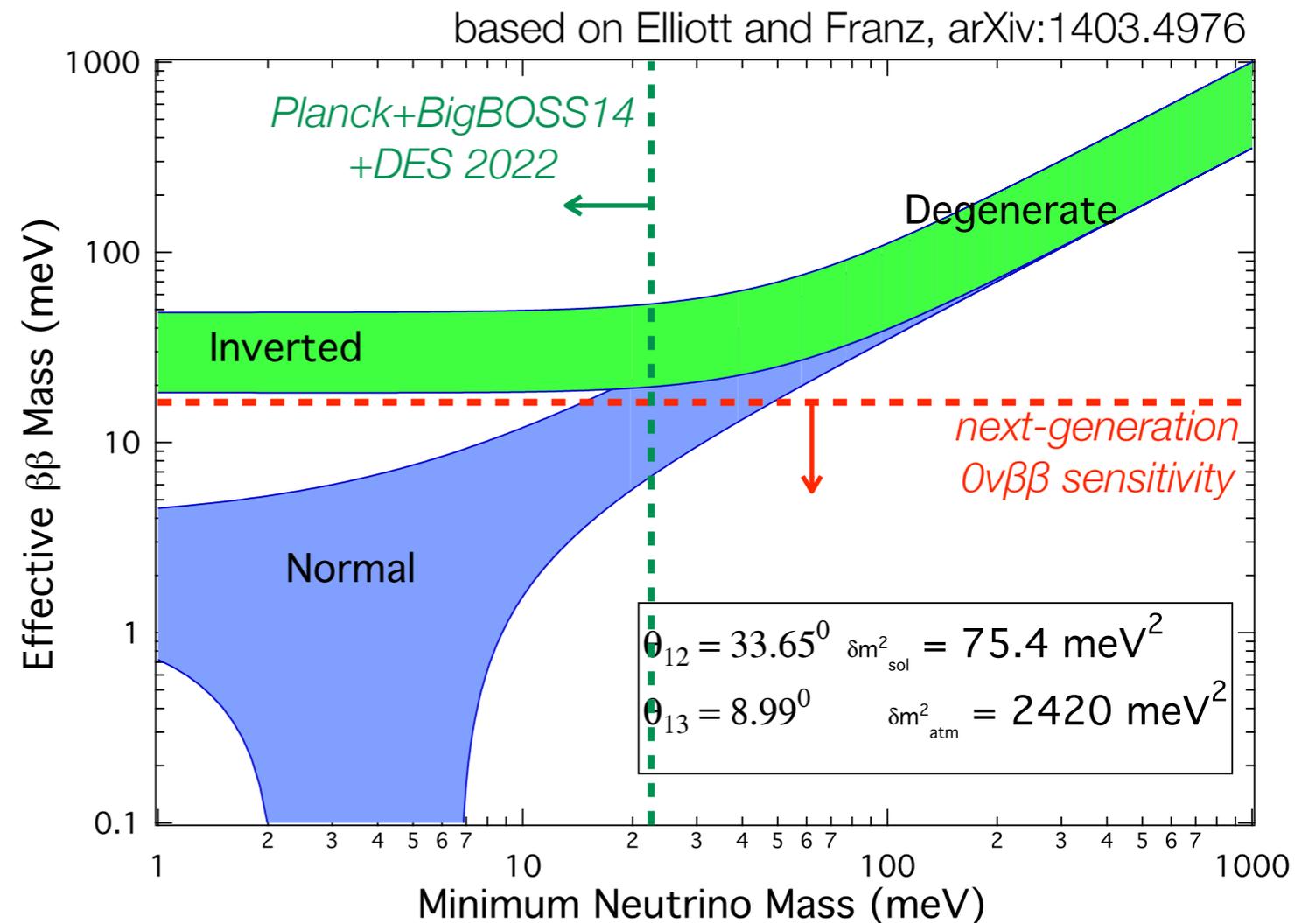
the Precision IceCube Next Generation Upgrade

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$0\nu\beta\beta$ and the Neutrino Mass Hierarchy

- Relationship between effective mass for $0\nu\beta\beta$ and lightest neutrino eigenstate depends on neutrino mass hierarchy
- If the hierarchy were known to be inverted, a null result from next-generation $0\nu\beta\beta$ experiments with $O(15 \text{ meV})$ sensitivity could rule out Majorana nature of neutrinos
 - In the absence of external constraints on the hierarchy, a null result would be inconclusive



IceCube DeepCore and PINGU

- IceCube Neutrino Observatory

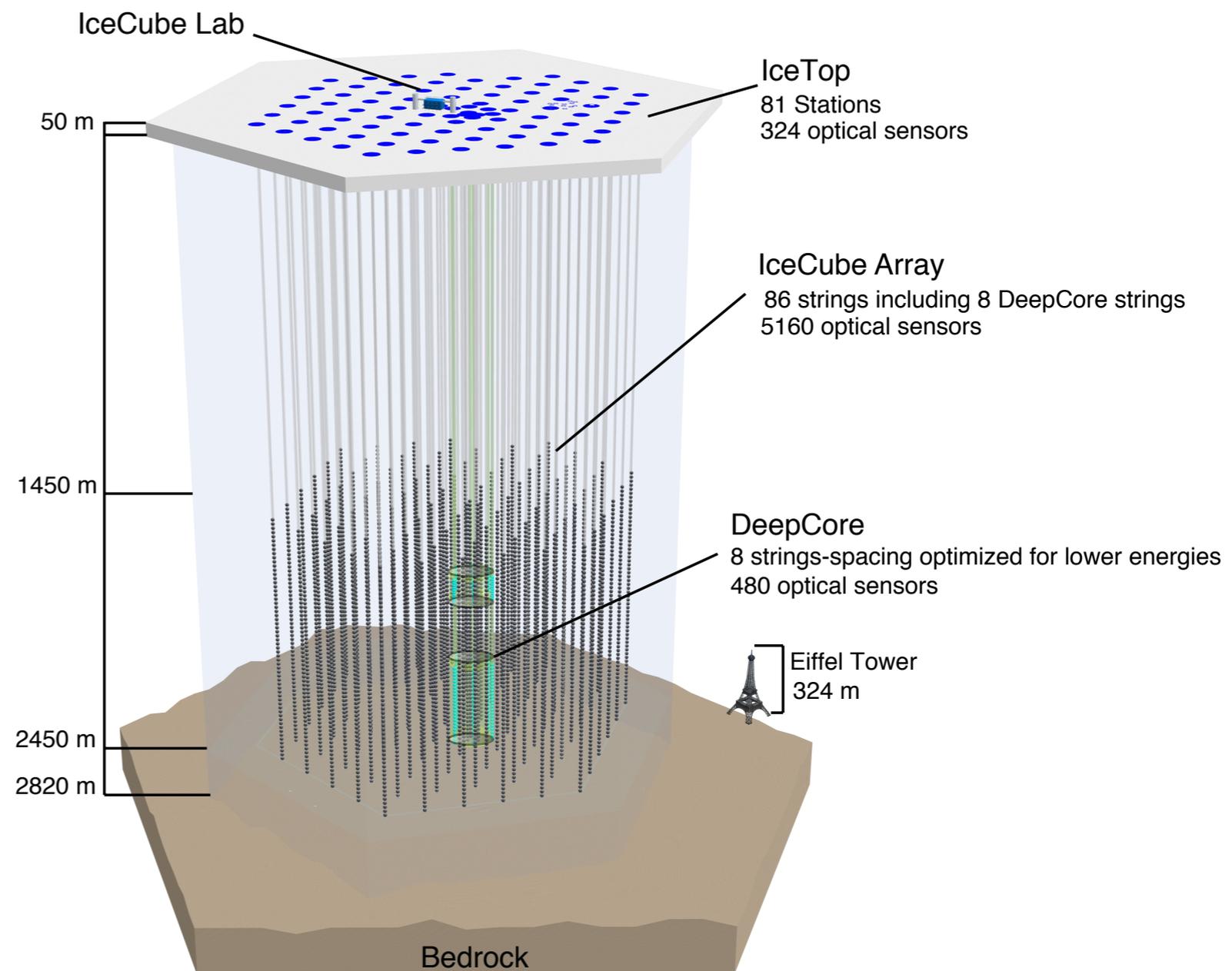
- km³ ice Cherenkov detector at the South Pole
- TeV-PeV neutrinos from astrophysical accelerators

- DeepCore

- Infill array designed for 10-100 GeV neutrinos
- Operational since 2010

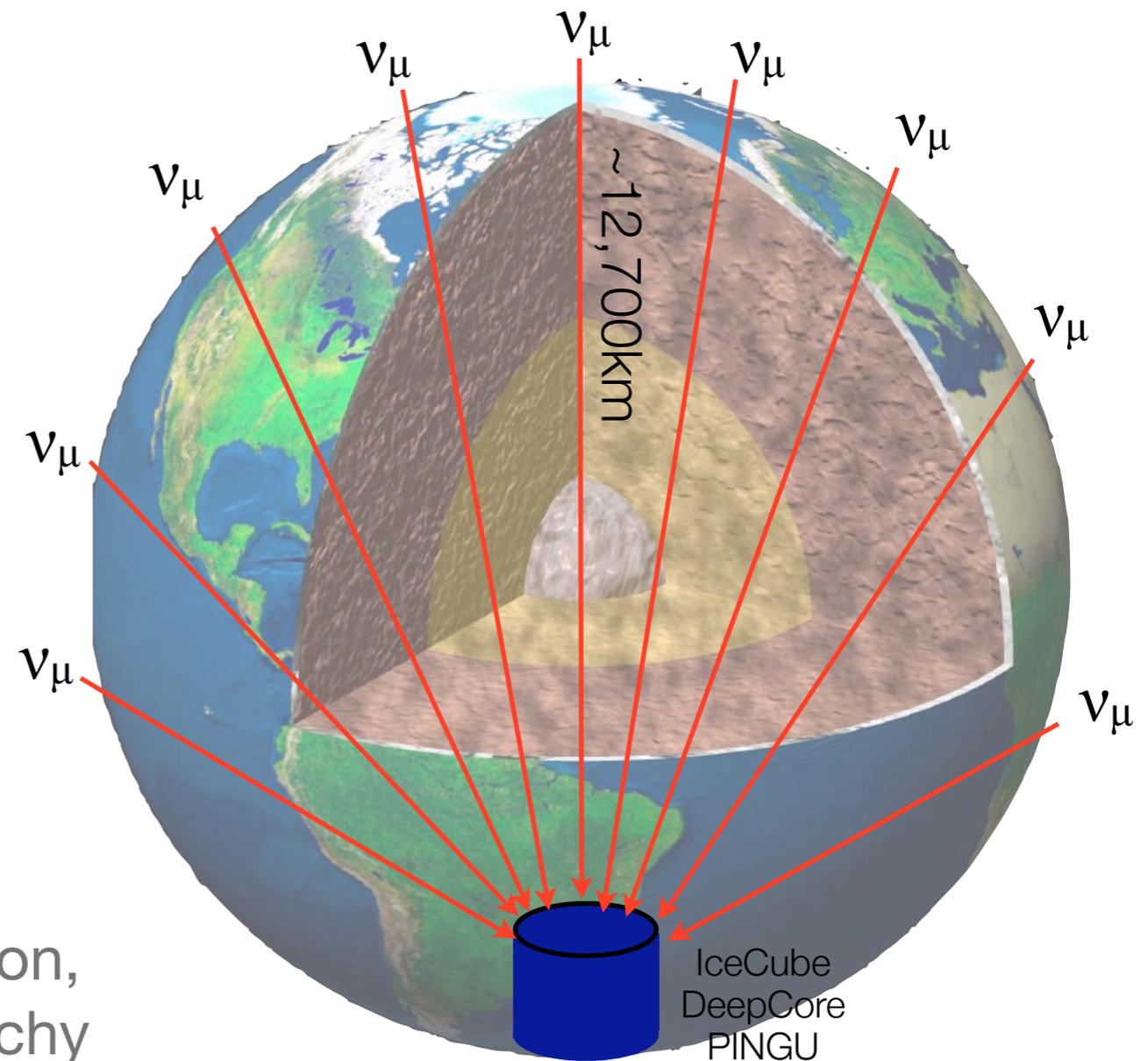
- PINGU

- Proposed further infill to reach few GeV threshold



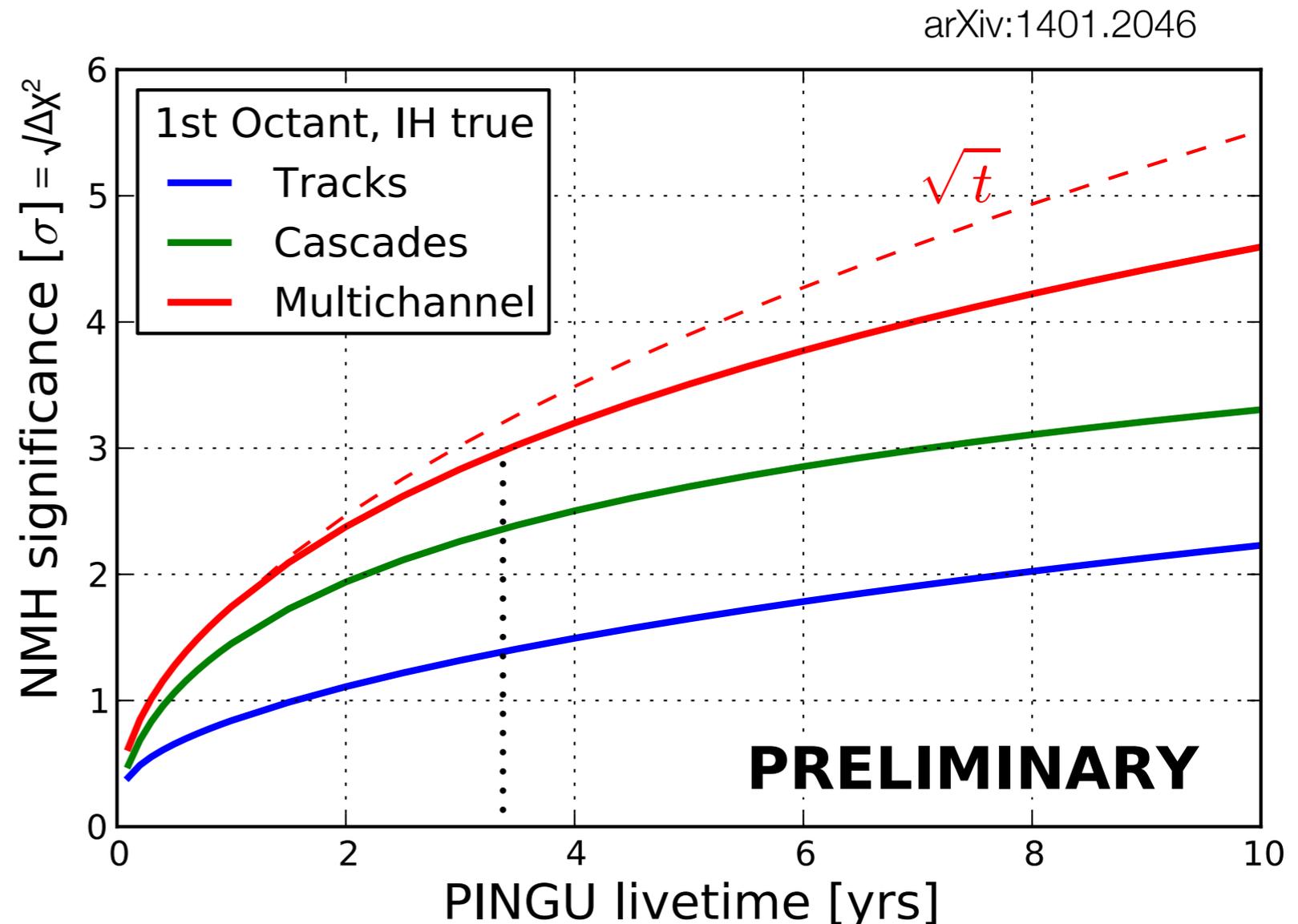
Oscillation Physics with Atmospheric Neutrinos

- Neutrinos available over a wide range of energies and baselines
 - Oscillations produce distinctive patterns in energy-angle space
 - Approach: control systematics using events in “side band” regions – trade statistics for constraints on systematics
- Hierarchy-dependent matter effects on ν or $\bar{\nu}$ (MSW etc.) below 10-20 GeV
 - No direct discrimination: rely on differences in flux and cross section, high statistics to determine hierarchy



PINGU Sensitivity to the Mass Hierarchy

- With baseline geometry, a determination of the mass hierarchy with 3σ median significance appears possible with 3.5 years of data (first octant: worst case)
 - Maximal mixing or the second octant improve expected significance
- Based on full Monte Carlo simulations of detector performance
 - Primary systematics: ν and $\bar{\nu}$ cross sections, energy calibration
 - More detailed studies of systematics underway

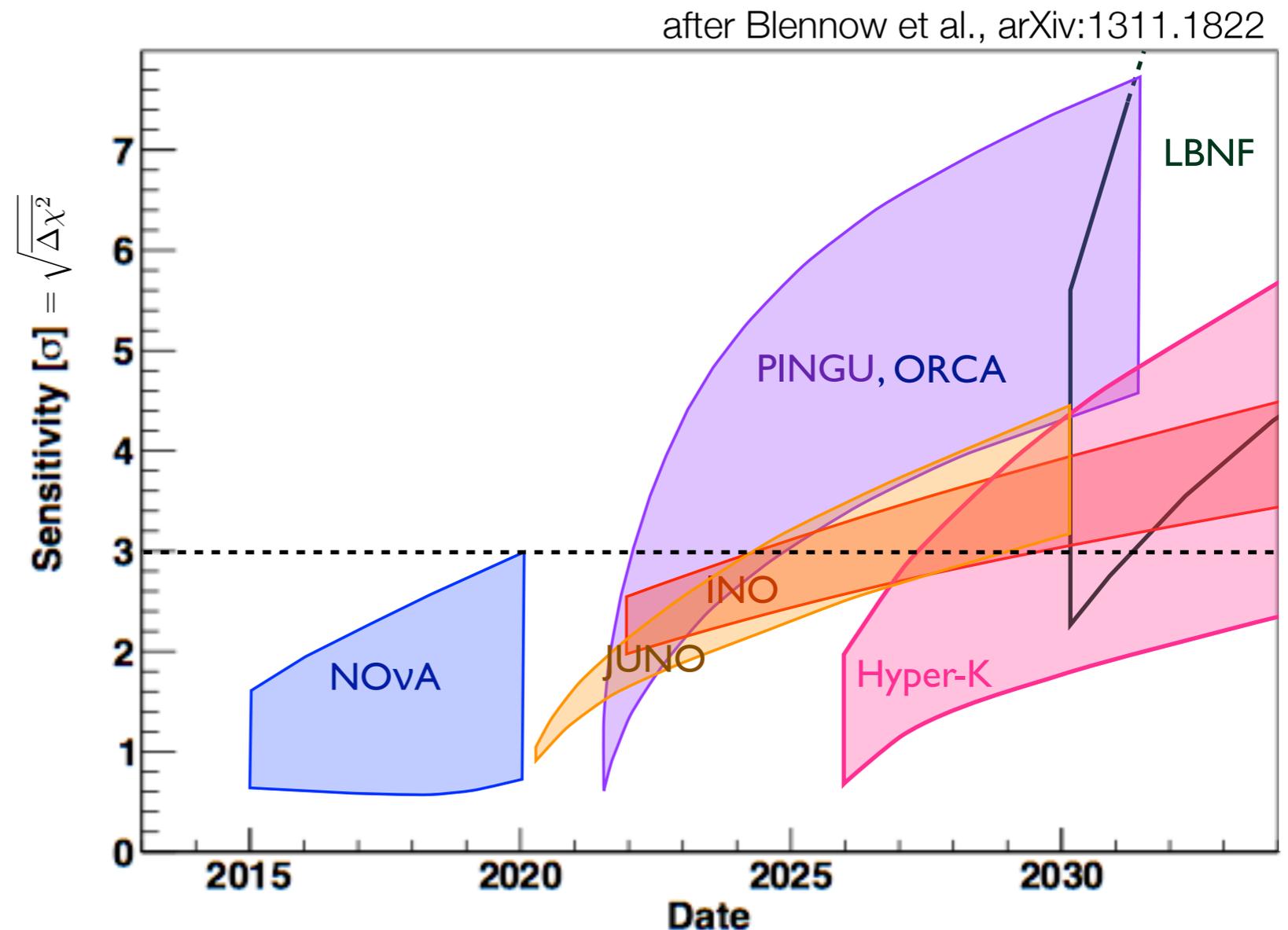


The Experimental Landscape

- A very large volume atmospheric neutrino detector such as PINGU seems to offer the best experimental opportunity for measuring the hierarchy in the coming decade

- Bands show median results (i.e., 50% chance of better or worse outcome), widths illustrate impact of main uncertainty

- LBNE/NOvA: δ_{CP}
- JUNO: σ_E (3.0-3.5%)
- PINGU/INO: θ_{23}
(38.7° – 51.3° , 40° – 50°)



Supernova Neutrinos with PINGU

- Multi-megaton fiducial volume will allow very high statistics observation of neutrino emission by a Galactic supernova
 - Individual events are below threshold, but the collective effect of many interactions raises the overall light level detected by photosensors
- Millisecond time resolution on neutrino light curve
 - Directly measure neutrino+antineutrino luminosity
 - Constrain neutrino energy spectrum via ratio of isolated to coincident photons

PINGU and IceCube GenTwo

- An expanded IceCube-based facility is being proposed for the South Pole following the discovery of high energy astrophysical neutrinos
 - PINGU for GeV-scale physics (neutrino oscillations, dark matter, SNe)
 - A high energy expansion for 100 TeV – PeV scale neutrinos
- Design will closely follow that of IceCube
 - Similar photodetectors with upgraded electronics
 - Reduces R&D cost and technical, schedule and budget risk
- Estimated PINGU share of facility cost: \$55M US + \$25M non-US
 - PINGU to be deployed first, as early as late 2018 through early 2021 in a favorable funding scenario
 - Statistically significant determination of the hierarchy possible by 2024

The IceCube-PINGU Collaboration



International Funding Agencies

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