Paper Meeting

Abstract

- Combined JUNO + IceCube Upgrade
- Two methods: JUNO looks at energy spectrum for electron anti-nu , IceCube studies atmospheric neutrinos which traverse the Earth.
- In a joint fit, tension leads to excluding the wrong mass ordering at > 5σ

The ordering of the neutrino mass eigenstates is one of the fundamental open questions in neutrino physics. While current-generation neutrino oscillation experiments are able to produce moderate indications on this ordering, upcoming experiments of the next generation aim to provide conclusive evidence. In this paper we study the combined performance of the two future multi-purpose neutrino oscillation experiments JUNO and the IceCube Upgrade, which employ two very distinct and complementary routes towards the neutrino mass ordering. The approach pursued by the 20 kt medium-baseline reactor neutrino experiment JUNO consists of a careful investigation of the energy spectrum of oscillated $\bar{\nu}_e$ produced by ten nuclear reactor cores. The IceCube Upgrade, on the other hand, which consists of seven additional densely instrumented strings deployed in the center of IceCube DeepCore, will observe large numbers of atmospheric neutrinos that have undergone oscillations affected by Earth matter. In a joint fit with both approaches, tension occurs between their preferred mass-squared differences $\Delta m^2_{31} = m^2_3 - m^2_1$ within the wrong mass ordering. In the case of JUNO and the IceCube Upgrade, this allows to exclude the wrong ordering at $> 5\sigma$ on a timescale of 3–7 years — even under circumstances that are unfavorable to the experiments' individual sensitivities. For PINGU, a 26-string detector array designed as a potential low-energy extension to IceCube, the inverted ordering could be excluded within 1.5 years (3 years for the normal ordering) in a joint analysis.

Introduction

- Neutrino mass ordering: limits the sum of the neutrino masses in cosmology, implication for lepton mixing, CP violation etc.
  $\Delta m_{31}^2 > 0$: normal ordering
  < 0: inverted ordering

- Global fits begin to show preference for NO: NovA, T2K, Super-K. Medium-baseline reactors lead to tension for the preferred value of Δm_{31}^2 within IO

- Explore sub-leading survival probability terms between Δm_{31}^2 and Δm_{32}^2 at ~ 50 m baseline. Expect enhancement in sensitivity by combining with next-generation long-baseline data.

Intermezzo

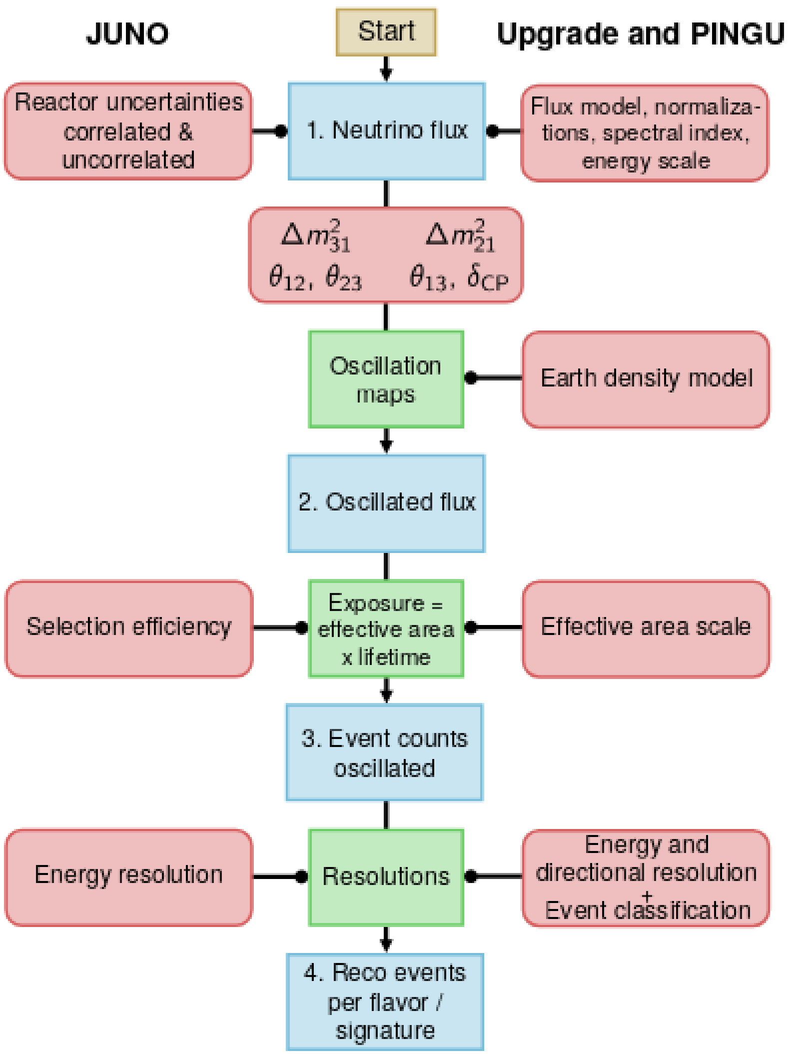
- “The individual published projected NMO sensitivites of JUNO and PINGU”
- Using the word synergy

Introduction

- JUNO – 20 kt liquid scintillator, measure MeV scale electron anti-nu disappearance. Converts positrons via IBD, resulting in a prompt + delayed photon shower detected by PMTS. 8 or 10 reactor cores.

- IceCube Upgrade/PINGU - 7/26 additional densely-instrumented strings in IceCube Deep Core.

Generation of Spectra



Generation of Spectra

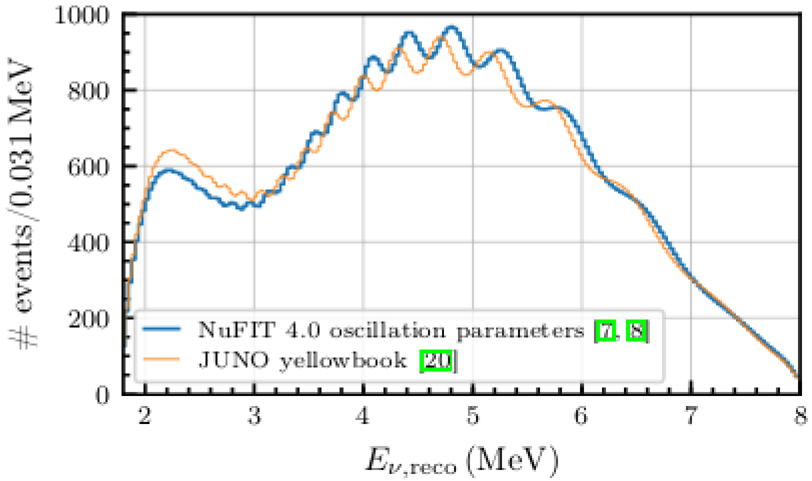


Figure 2. Expected distribution of reconstructed energies $E_{\nu,\text{reco}}$ of reactor $\bar{\nu}_e$ events in JUNO given true NO for our analysis binning after 6 years of operation (1800 days), without any background contribution. Shown is the expected spectrum assuming the nominal oscillation parameter inputs from [20] (thin orange line) and the spectrum assuming the inputs from Table III (thick blue line).

→ 3.2σ for true NO after 6 yrs livetime

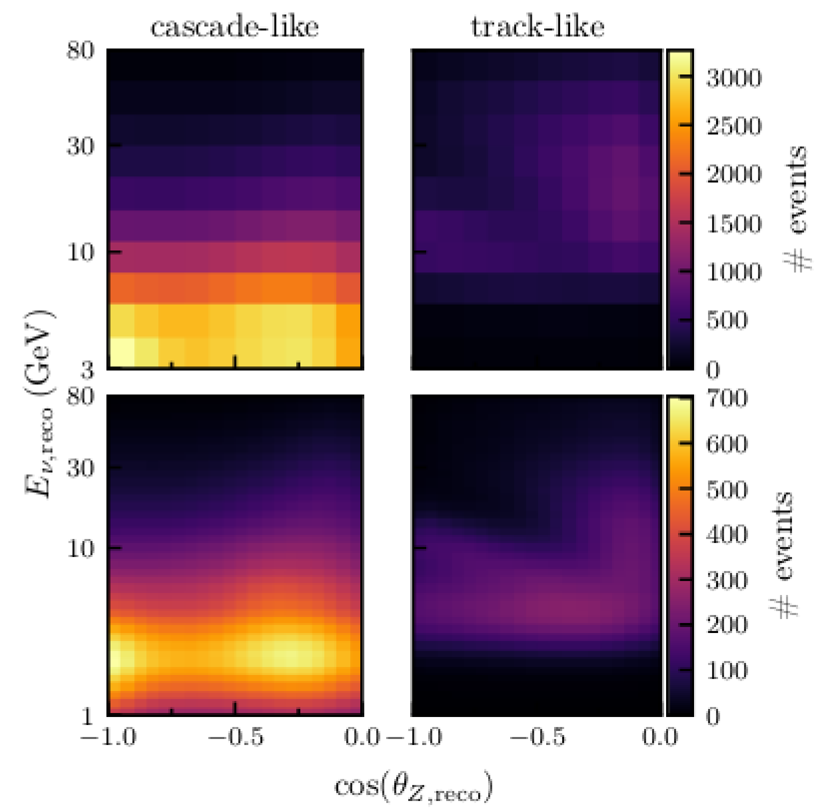


Figure 3. Nominal expected event distributions given true NO for our analysis binning in reconstructed neutrino cosine zenith $\cos(\theta_{Z,\text{reco}})$ and reconstructed neutrino energy $E_{\nu,\text{reco}}$ for the IceCube Upgrade (top) and PINGU (bottom) after 4 years of operation.

→ 3.2σ for true NO after 4 yrs livetime (PINGU)

III. Expected NMO sensitivities

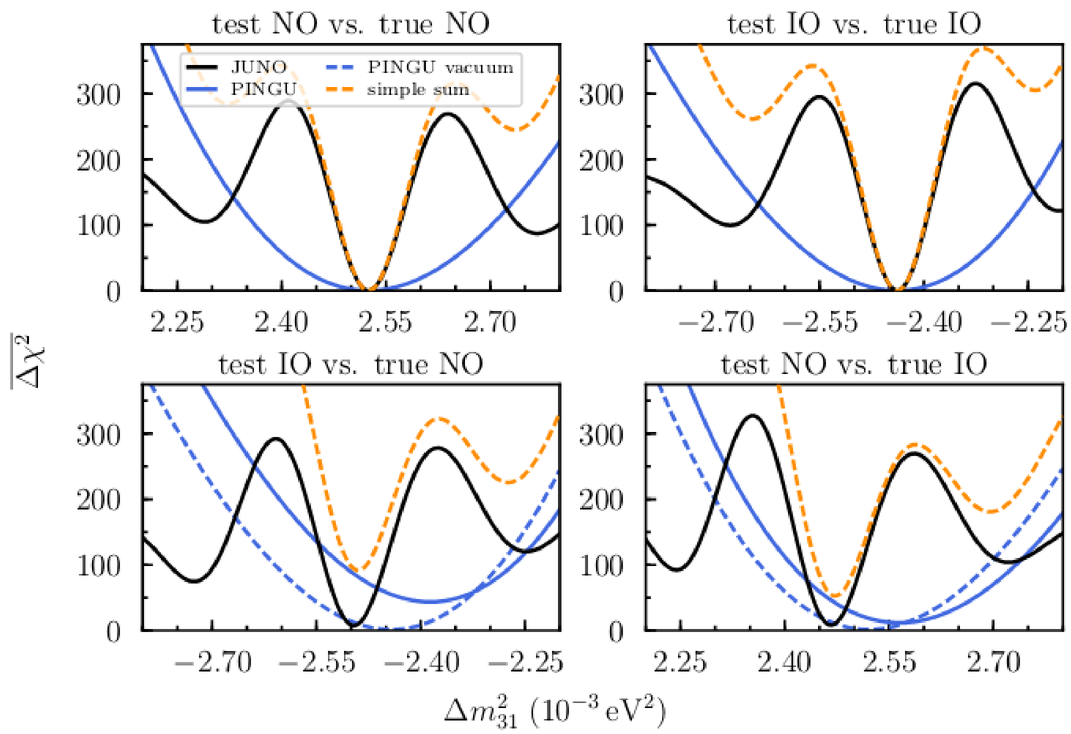


Figure 4. $\overline{\Delta\chi^2}$ profiles as function of the tested/fit values of Δm^2_{31} within the true ordering (upper panels) and the wrong ordering (lower panels) for a livetime of 6 years for both experiments. On the left (right), the NO (IO) is assumed to be true. The scans within the wrong ordering illustrate the synergy effect of performing a combined fit. Here, a tension in the best-fit values of Δm^2_{31} for PINGU and JUNO is visible that is greater than the "resolution" of the two experiments. Shown in addition are the hypothetical wrong-ordering profiles assuming a vanishing matter density along all neutrino trajectories in the case of PINGU (labeled "PINGU vacuum"). The line labeled "simple sum" (dashed orange) is the sum of the "JUNO" and "PINGU" curves at each tested value of Δm^2_{31}.

IV. Sensitivities for 6 yrs

	JUNO (eight cores)	Upgrade	JUNO	PINGU
stand-alone	$2.4\sigma/2.5\sigma$	$3.8\sigma/1.8\sigma$	$2.8\sigma/2.9\sigma$	$6.6\sigma/3.5\sigma$
statistical contribution	$2.6\sigma/2.6\sigma$	$5.8\sigma/4.3\sigma$	$3.2\sigma/3.3\sigma$	$8.5\sigma/6.3\sigma$
combined analysis	$6.5\sigma/5.1\sigma$		$9.6\sigma/7.3\sigma$	

Table IV. Expected NMO sensitivities (true NO/true IO) after 6 years of operation, for the stand-alone experiments as well as for their combined analysis (JUNO with eight cores and the IceCube Upgrade, JUNO and PINGU), including the statistical contributions within the latter.

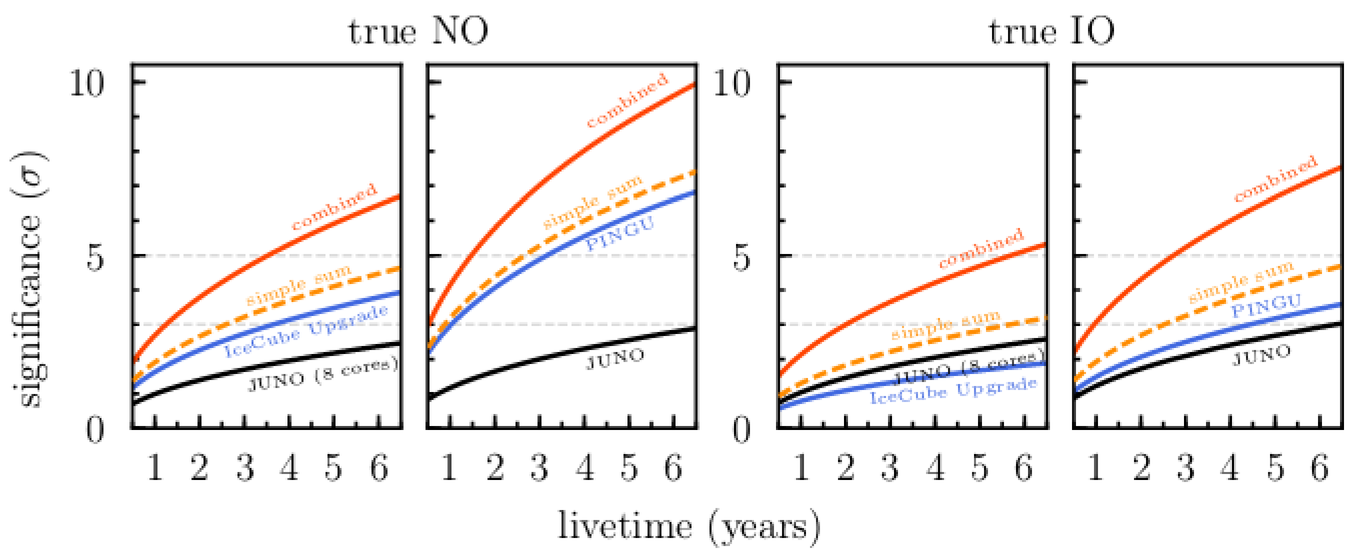


Figure 6. Livetime evolution of the NMO sensitivity of each considered pair of experiments: stand-alone, the simple (quadratic) sum, and the combination. Results for the nominal JUNO configuration and PINGU are shown side-by-side with the 8-core JUNO configuration (labeled as “JUNO (8 cores)”) and the IceCube Upgrade. The two panels on the left assume true NO, while the two panels on the right assume true IO.

Conclusion