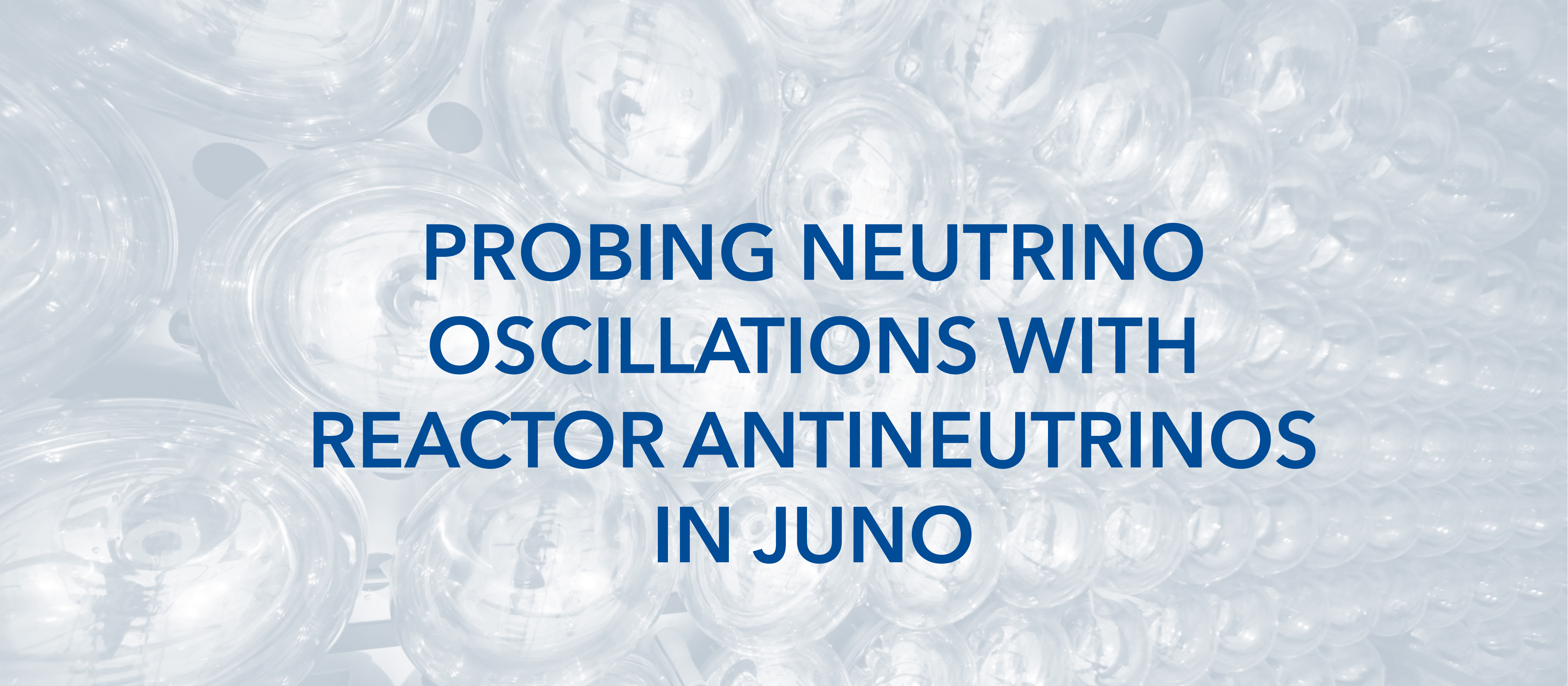

PROBING NEUTRINO OSCILLATIONS WITH REACTOR ANTINEUTRINOS IN JUNO

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JUNO
INFN
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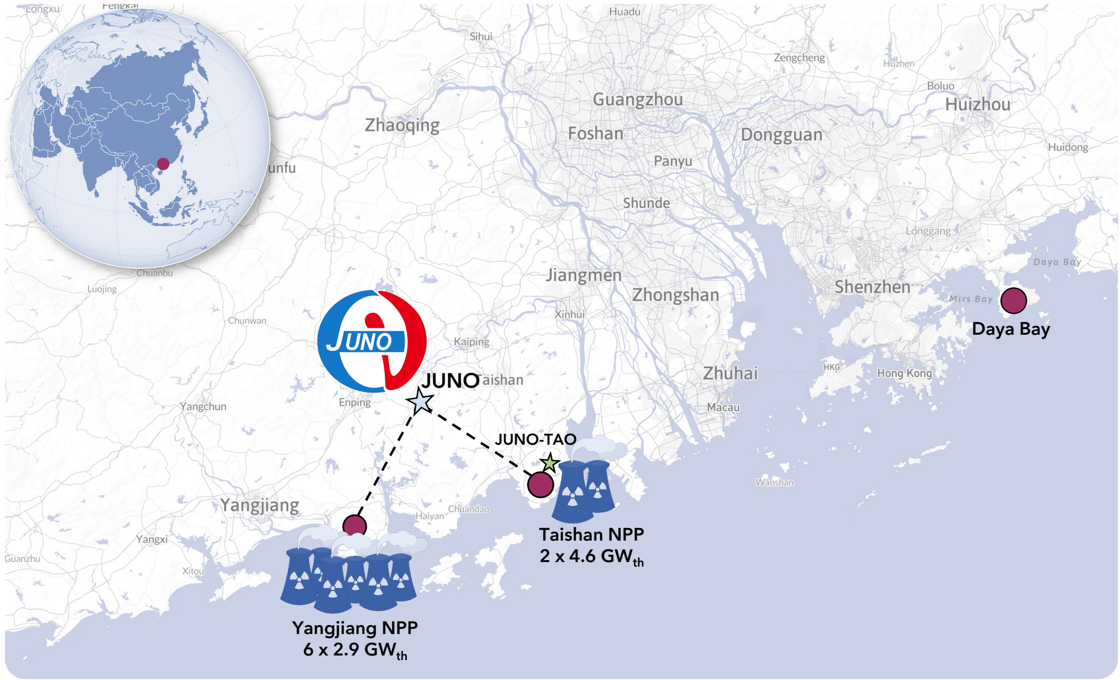
THE JUNO EXPERIMENT

PPNP 123 (2022) 103927

The **J**iangmen **U**nderground **N**eutrino **O**bservatory (**JUNO**) is a multi-purpose neutrino experiment currently under construction in southern China

Where?

- ✶ 52.5 km from two Nuclear Power Plants



What do we measure?

- ✶ Reactor antineutrinos
- ✶ Pure and intense source of electron-flavor antineutrinos $\bar{\nu}_e$ @ 1-10 MeV
- ✶ Measure deficit in $\bar{\nu}_e$ interactions → $\boldsymbol{\bar{\nu}_e}$ survival probability

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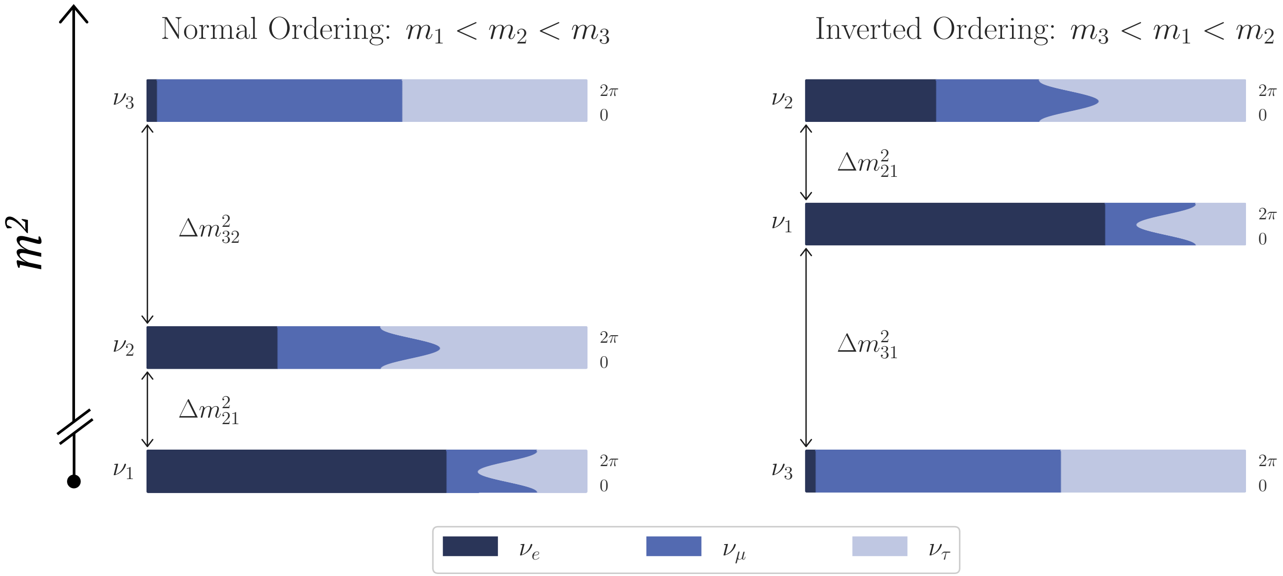


Main goal

- ✶ Determination of the **Neutrino Mass Ordering** (NMO)

→

Vacuum-dominant regime
No dependence on $\boldsymbol{\delta_{CP}}$ and $\boldsymbol{\theta_{23}}$
Complementary to long baseline experiments

ANTINEUTRINO OSCILLATIONS IN JUNO

$\bar{\nu}_e$ survival probability

$$\mathcal{P}_{ee} = 1 - \mathcal{P}_{21} - \mathcal{P}_{31} - \mathcal{P}_{32}$$

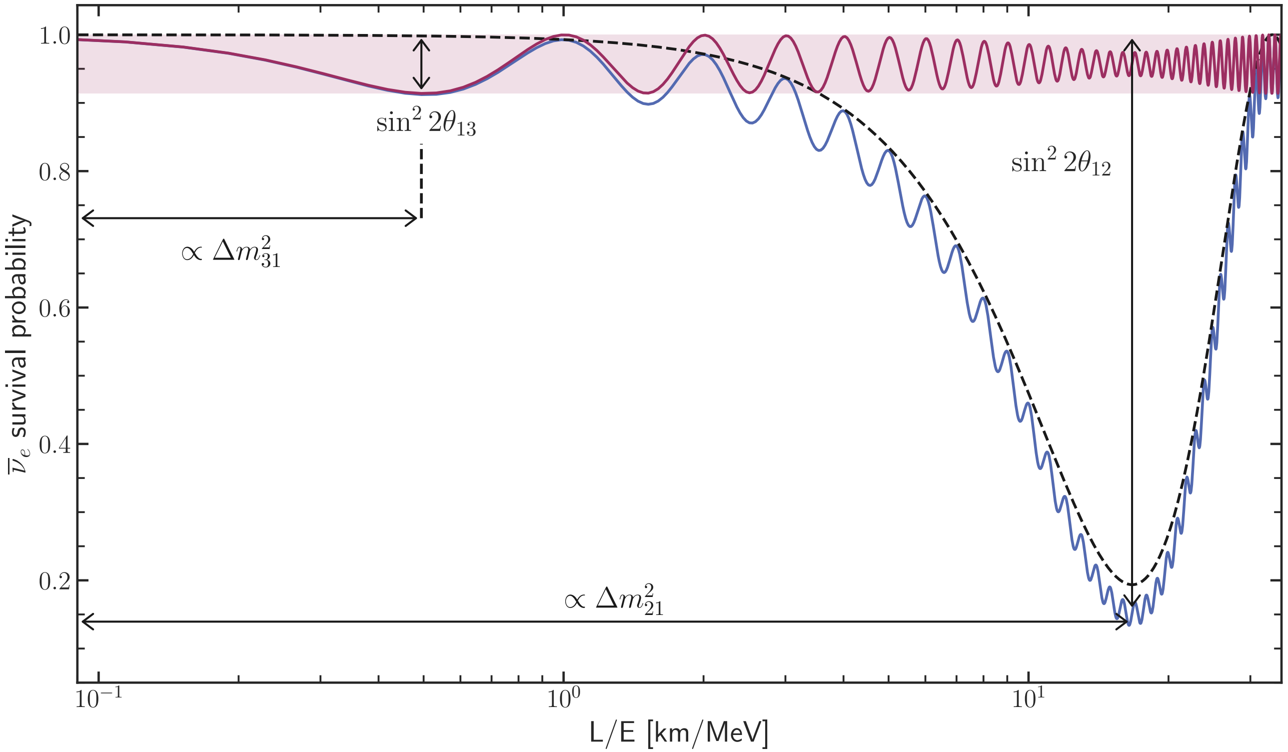
$$\mathcal{P}_{21} = \sin^2 2\theta_{12} c_{13}^4 \sin^2 \Delta_{21}$$

SLOW

$$\mathcal{P}_{31} = \sin^2 2\theta_{13} c_{12}^2 \sin^2 \Delta_{31}$$

$$\mathcal{P}_{32} = \sin^2 2\theta_{13} s_{12}^2 \sin^2 \Delta_{32}$$

FAST



ANTINEUTRINO OSCILLATIONS IN JUNO

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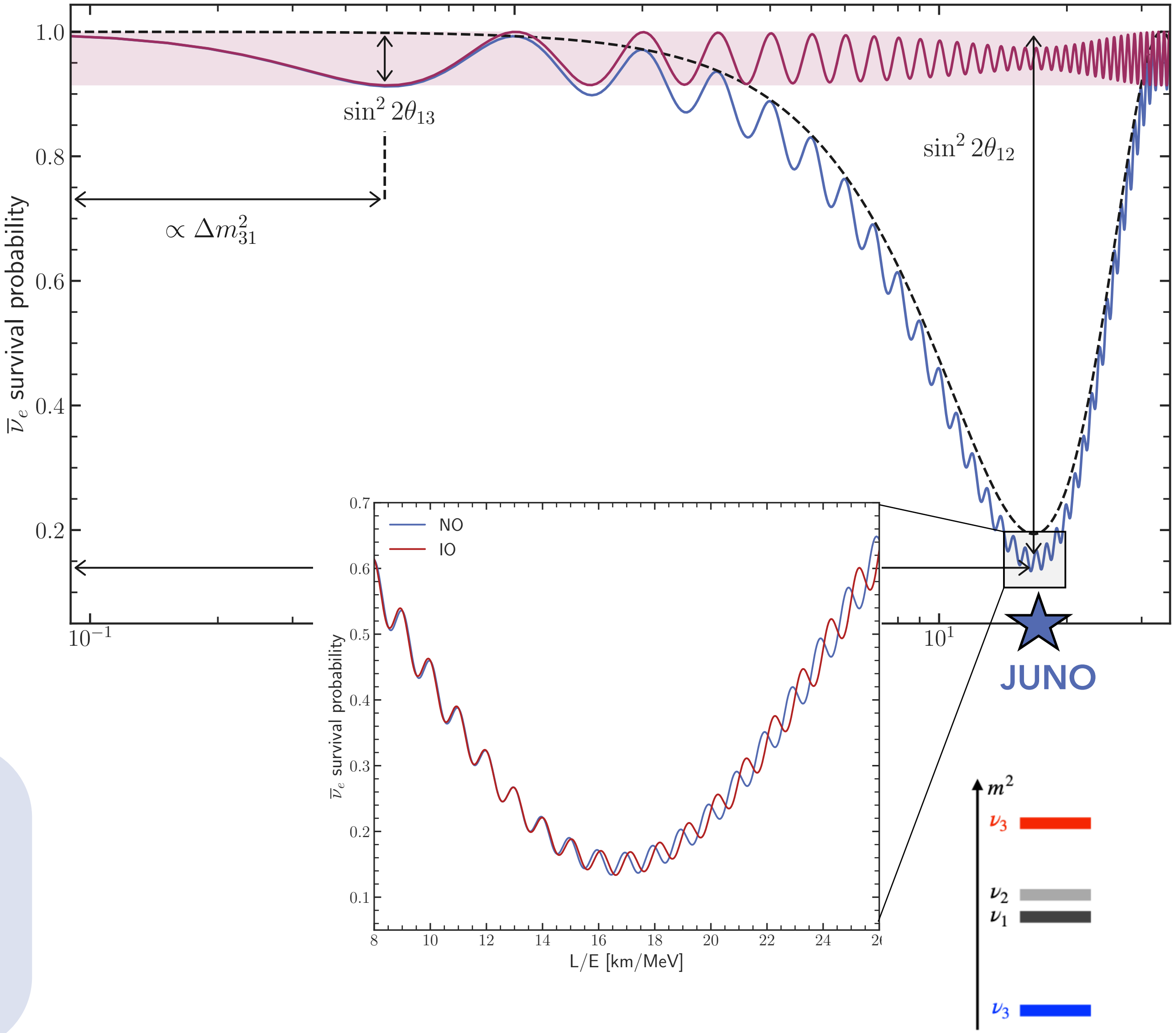
FAST

$$c_{ij} \equiv \cos\theta_{ij},\ s_{ij} \equiv \sin\theta_{ij},\ \Delta_{ij} = \Delta m^2_{ij} L/4E$$

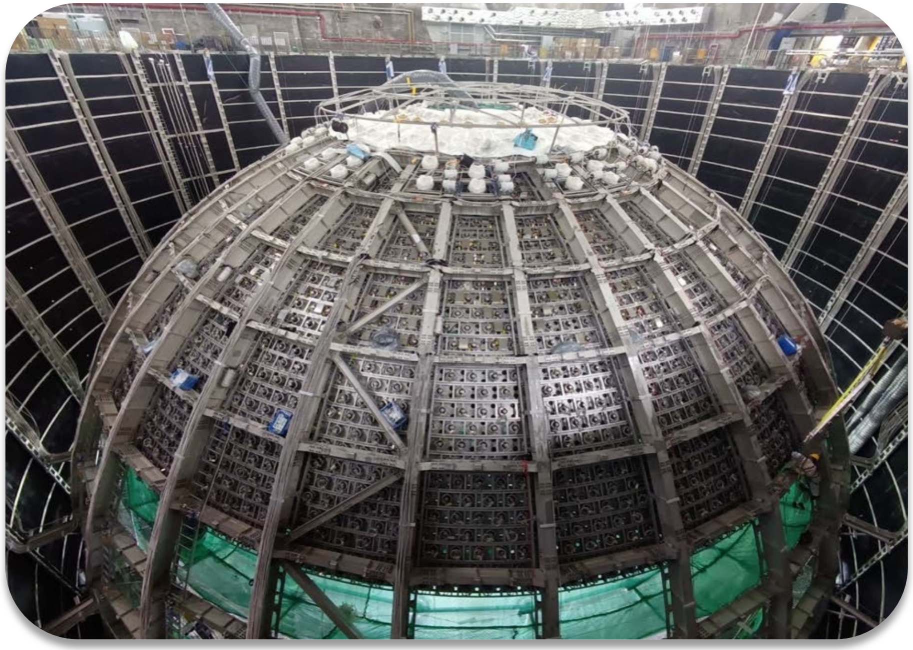


- ✶ Probe the effects of oscillations on both solar ($\boldsymbol{\Delta m^2_{21}}$) and atmospheric ($\boldsymbol{\Delta m^2_{31}}$) scales
- ✶ Optimized baseline for the determination of the Neutrino Mass Ordering (NMO)

EXPERIMENTAL CHALLENGES

JHEP 03 (2021) 004

- ✶ Large antineutrino statistics
  - ✓ **20 kton** LS target
- ✶ Energy resolution ≈ **2.95 % @ 1 MeV**
  - ✓ Total photocoverage ≈ 78%
  - ✓ Light yield ≈ **1660 PE/MeV**
- ✶ Energy scale uncertainty < 1%
  - ✓ Comprehensive **calibration** program
- ✶ Good knowledge of the unoscillated antineutrino spectrum
  - ✓ Short baseline satellite detector Taishan Antineutrino Observatory (TAO) to provide model-independent reference spectrum

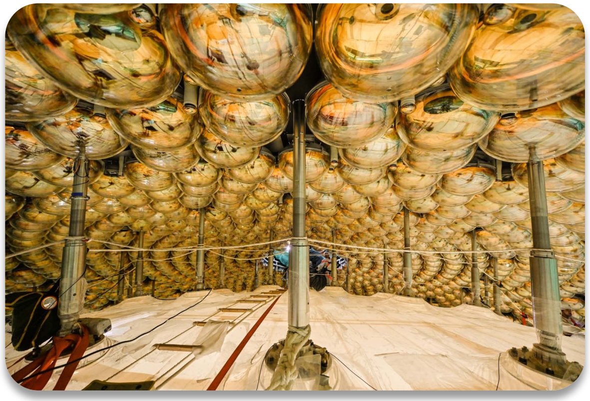


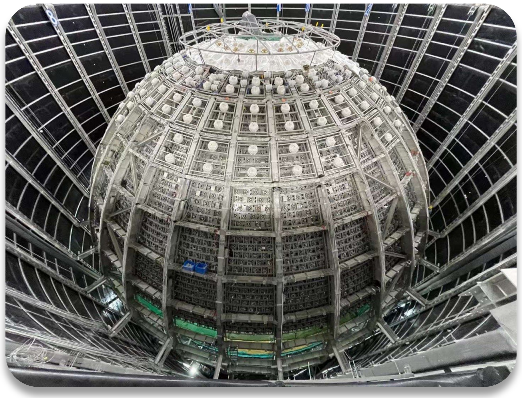
CONCLUSIONS

JUNO will probe **neutrino oscillations with unprecedented precision**

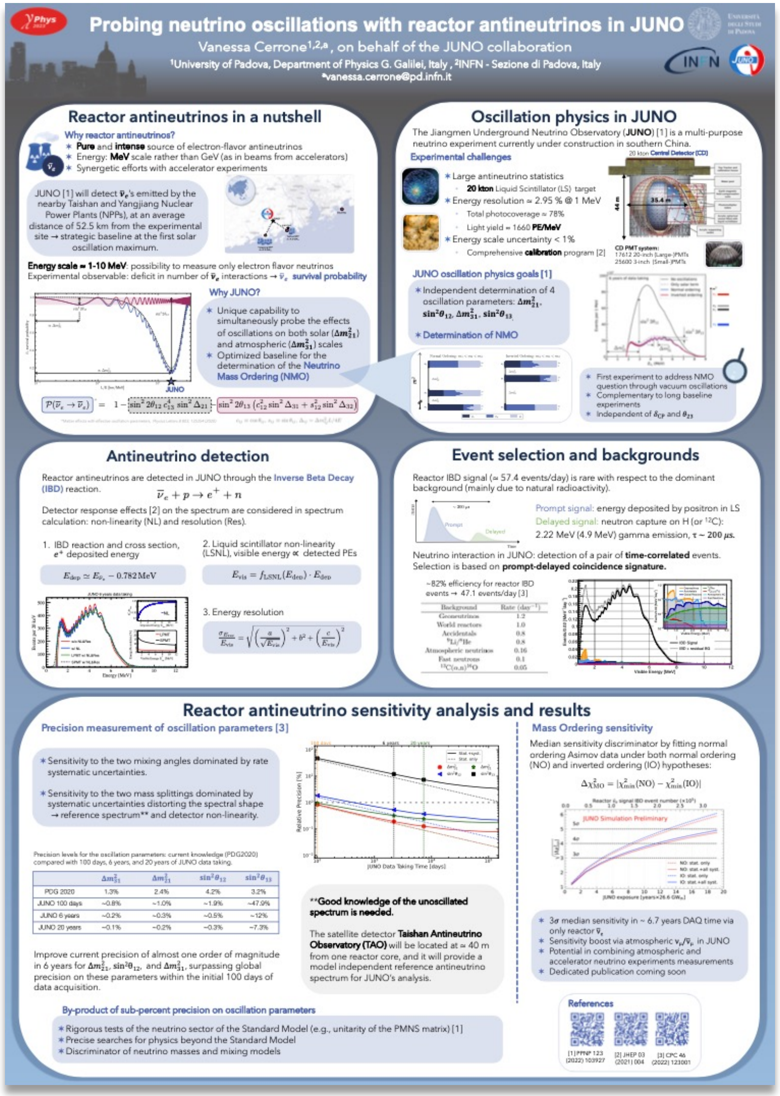
- ✶ Sub-percent precision in less than 2 years on Δm^2_{21}, $\sin^2\theta_{12}$, and Δm^2_{31}
- ✶ 3σ NMO median sensitivity in ~ 6.7 years DAQ time via only reactor $\bar{\nu}_e$

Thank you!





More information in my poster



Probing neutrino oscillations with reactor antineutrinos in JUNO

Vanessa Cerrone[1,2,a], on behalf of the JUNO collaboration
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[a]vanessa.cerrone@pd.infn.it

Reactor antineutrinos in a nutshell

Why reactor antineutrinos?

- ✶ **Pure** and **intense** source of electron-flavor antineutrinos
- ✶ Energy: **MeV** scale rather than GeV (as in beams from accelerators)
- ✶ Synergetic efforts with accelerator experiments

JUNO [1] will detect $\bar{\nu}_e$'s emitted by the nearby Taishan and Yangjiang Nuclear Power Plants (NPPs), at an average distance of 52.5 km from the experimental site → strategic baseline at the first solar oscillation maximum.

Energy scale ≈ 1-10 MeV: possibility to measure only electron flavor neutrinos
Experimental observable: deficit in number of $\bar{\nu}_e$ interactions → $\bar{\nu}_e$ survival probability

Why JUNO?

- ✶ Unique capability to simultaneously probe the effects of oscillations on both solar (Δm^2_{21}) and atmospheric (Δm^2_{31}) scales
- ✶ Optimized baseline for the determination of the Neutrino Mass Ordering (NMO)

$$\mathcal{P}(\bar{\nu}_e \to \bar{\nu}_e) = 1 - \sin^2 2\theta_{12}\, c^4_{13} \sin^2\Delta_{21} - \sin^2 2\theta_{13}\left(c^2_{12}\sin^2\Delta_{31} + s^2_{12}\sin^2\Delta_{32}\right)$$

Oscillation physics in JUNO

The Jiangmen Underground Neutrino Observatory (**JUNO**) [1] is a multi-purpose neutrino experiment currently under construction in southern China.

Experimental challenges

- ✶ Large antineutrino statistics
  - **20 kton** Liquid Scintillator (LS) target
- ✶ Energy resolution ≃ 2.95 % @ 1 MeV
  - Total photocoverage ≃ 78%
  - Light yield ≃ 1660 **PE/MeV**
- ✶ Energy scale uncertainty < 1%
  - Comprehensive **calibration** program [2]

20 kton Central Detector (CD)

CD PMT system:
17612 20-inch (Large-)PMTs
25600 3-inch (Small-)PMTs

JUNO oscillation physics goals [1]

- ✶ Independent determination of 4 oscillation parameters: Δm^2_{21}, $\sin^2\theta_{12}$, Δm^2_{31}, $\sin^2\theta_{13}$
- ✶ Determination of NMO

- ✶ First experiment to address NMO question through vacuum oscillations
- ✶ Complementary to long baseline experiments
- ✶ Independent of δ_{CP} and θ_{23}

Antineutrino detection

Reactor antineutrinos are detected in JUNO through the Inverse Beta Decay (IBD) reaction.

$$\bar{\nu}_e + p \to e^+ + n$$

Detector response effects [2] on the spectrum are considered in spectrum calculation: non-linearity (NL) and resolution (Res).

1. IBD reaction and cross section, e^+ deposited energy

$$E_{dep} \simeq E_{\bar{\nu}_e} - 0.782\,\mathrm{MeV}$$

2. Liquid scintillator non-linearity (LSNL), visible energy ∝ detected PEs

$$E_{vis} = f_{LSNL}(E_{dep}) \cdot E_{dep}$$

3. Energy resolution

$$\frac{\sigma_{E_{vis}}}{E_{vis}} = \sqrt{\left(\frac{a}{\sqrt{E_{vis}}}\right)^2 + b^2 + \left(\frac{c}{E_{vis}}\right)^2}$$

Event selection and backgrounds

Reactor IBD signal (≃ 57.4 events/day) is rare with respect to the dominant background (mainly due to natural radioactivity).

Prompt signal: energy deposited by positron in LS
Delayed signal: neutron capture on H (or ^{12}C): 2.22 MeV (4.9 MeV) gamma emission, $\tau \sim 200\,\mu s$.

Neutrino interaction in JUNO: detection of a pair of **time-correlated** events. Selection is based on **prompt-delayed coincidence signature.**

~82% efficiency for reactor IBD events → 47.1 events/day [3]

Background	Rate (day^{-1})
Geoneutrinos	1.2
World reactors	1.0
Accidentals	0.8
^{9}Li/^{8}He	0.8
Atmospheric neutrinos	0.16
Fast neutrons	0.1
^{13}C(α,n)^{16}O	0.05

Reactor antineutrino sensitivity analysis and results

Precision measurement of oscillation parameters [3]

- ✶ Sensitivity to the two mixing angles dominated by rate systematic uncertainties.
- ✶ Sensitivity to the two mass splittings dominated by systematic uncertainties distorting the spectral shape → reference spectrum** and detector non-linearity.

Precision levels for the oscillation parameters: current knowledge (PDG2020) compared with 100 days, 6 years, and 20 years of JUNO data taking.

	Δm^2_{31}	Δm^2_{21}	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$
PDG 2020	1.3%	2.4%	4.2%	3.2%
JUNO 100 days	~0.8%	~1.0%	~1.9%	~47.9%
JUNO 6 years	~0.2%	~0.3%	~0.5%	~12%
JUNO 20 years	~0.1%	~0.2%	~0.3%	~7.3%

Improve current precision of almost one order of magnitude in 6 years for Δm^2_{21}, $\sin^2\theta_{12}$, and Δm^2_{31}, surpassing global precision on these parameters within the initial 100 days of data acquisition.

Good knowledge of the unoscillated spectrum is needed.

The satellite detector **Taishan Antineutrino Observatory (TAO)** will be located at ≃ 40 m from one reactor core, and it will provide a model independent reference antineutrino spectrum for JUNO's analysis.

By-product of sub-percent precision on oscillation parameters

- ✶ Rigorous tests of the neutrino sector of the Standard Model (e.g., unitarity of the PMNS matrix) [1]
- ✶ Precise searches for physics beyond the Standard Model
- ✶ Discriminator of neutrino masses and mixing models

Mass Ordering sensitivity

Median sensitivity discriminator by fitting normal ordering Asimov data under both normal ordering (NO) and inverted ordering (IO) hypotheses:

$$\Delta\chi^2_{MO} = |\chi^2_{min}(NO) - \chi^2_{min}(IO)|$$

- ✶ 3σ median sensitivity in ~ 6.7 years DAQ time via only reactor $\bar{\nu}_e$
- ✶ Sensitivity boost via atmospheric $\nu_\mu/\bar{\nu}_\mu$ in JUNO
- ✶ Potential in combining atmospheric and accelerator neutrino experiments measurements
- ✶ Dedicated publication coming soon

References

[1] PPNP 123 (2022) 103927
[2] JHEP 03 (2021) 004
[3] CPC 46 (2022) 123001