Physics Prospects of The JUNO Experiment

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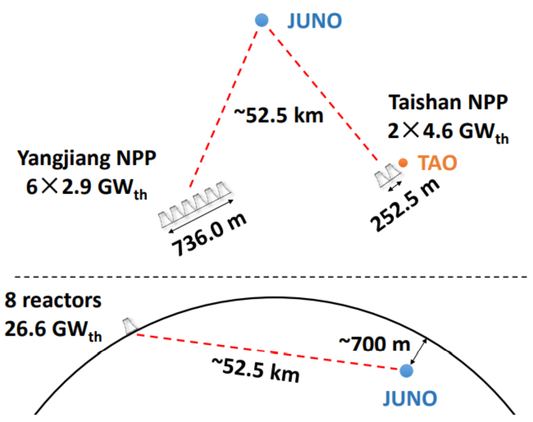
Jiangmen Underground Neutrino Observatory Experiment:

Construction in south China to be completed by the end of 2023.

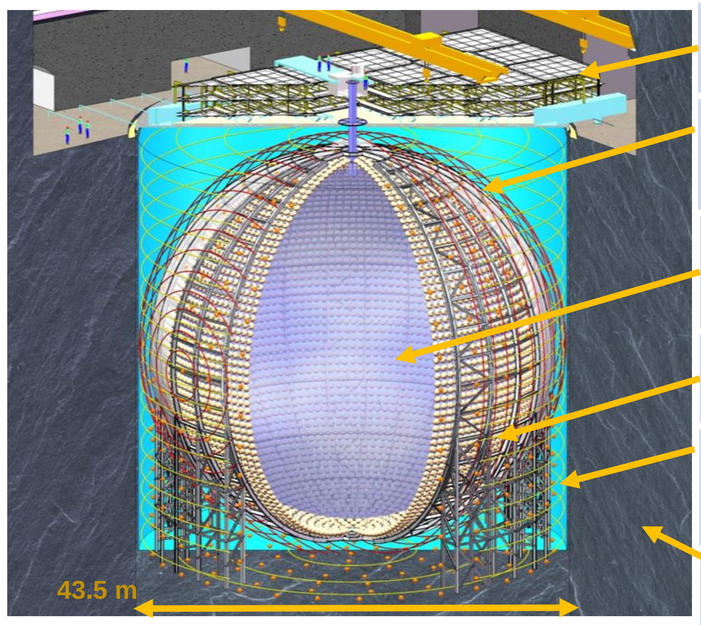
JUNO is the first multi-kton liquid scintillator (LS) detector ever built.
Main goal: determination of the Neutrino Mass Ordering (NMO) [1,2]



Rate of reactor $\bar{\nu}_e$ at 52.5 km with 26.6 Gw_{th} and 20 kton LS: 47 $\bar{\nu}_e$/day after selection cuts [3]

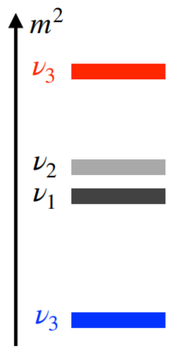
- Excellent energy resolution: $3\%/\sqrt{E(MeV)}$
- 1% energy scale uncertainty, controlled by several calibration sources: γ/α/β, UV-laser, and light pulses sources.
- High photon yield (10^4 photons/MeV)

- Other detectors related to JUNO under construction:
  - The OSIRIS detector: [4]
    - Monitors radiopurity of the liquid scintillator during filling.
  - Satellite detector TAO (Taishan Antineutrino Observatory):
    - 2.8 ton Gd-loaded liquid scintillator detector at ~30 m baseline from the Taishan (1 reactor core).
    - Energy resolution < 2% at 1MeV.
    - Reference reactor spectrum for JUNO.



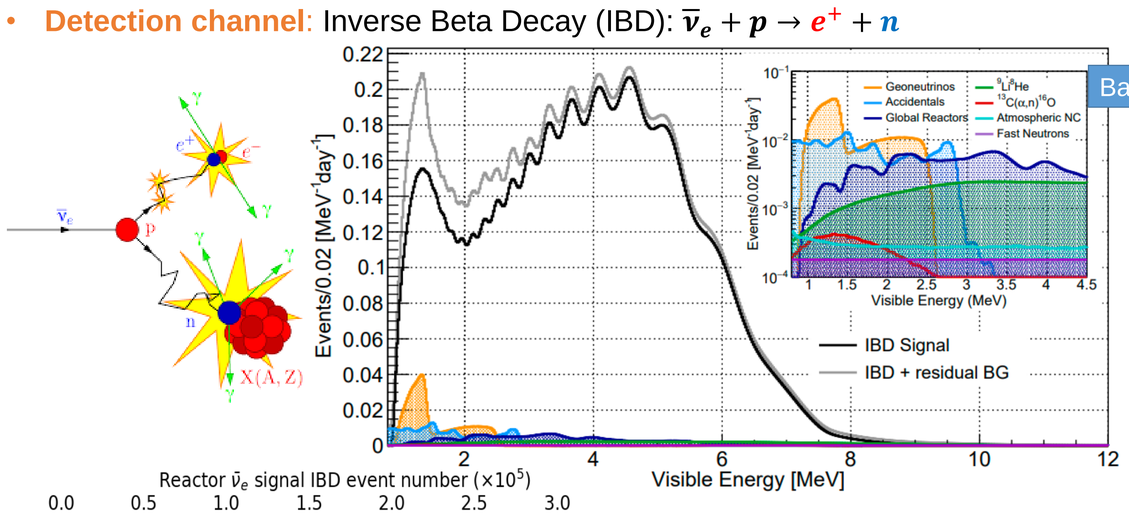
Reactor $\bar{\nu}_e$ oscillations: [1,2]

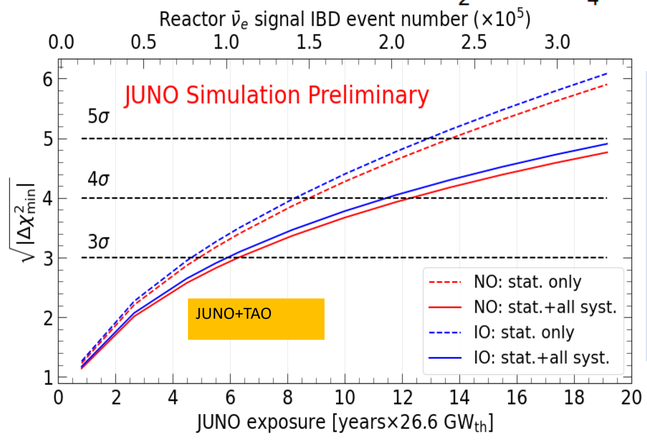
- **Determination of the Neutrino Mass Ordering via vacuum oscillation of reactor $\bar{\nu}_e$**: Normal or Inverted Ordering (N/IO)
  - Used only by JUNO and independent of θ_{23} and δ_{cp}
    - $P_{\bar{\nu}_e\to\bar{\nu}_e} = 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\frac{\Delta m^2_{12}L}{4E}$ Solar parameters
      $- \sin^2 2\theta_{13}\left(\cos^2\theta_{12}\sin^2\frac{\Delta m^2_{31}L}{4E} + \sin^2\theta_{12}\sin^2\frac{\Delta m^2_{32}L}{4E}\right)$
      Atmospheric parameters
  - Complementary to other experiments measuring NMO via matter effects on neutrinos oscillations (DUNE, PINGU ..) [5]



NO: $m_3 > m_2 > m_1$
IO: $m_3 < m_1 < m_2$

- **Detection channel**: Inverse Beta Decay (IBD): $\bar{\nu}_e + p \to e^+ + n$





- $|\Delta\chi^2_{min}| \equiv |\chi^2_{min}(NO) - \chi^2_{min}(IO)|$
- **Backgrounds: 4.11 /day**
- JUNO NMO sensitivity: **3σ (reactors only) @ ~6 yrs * 26.6 GW$_{th}$ exposure**

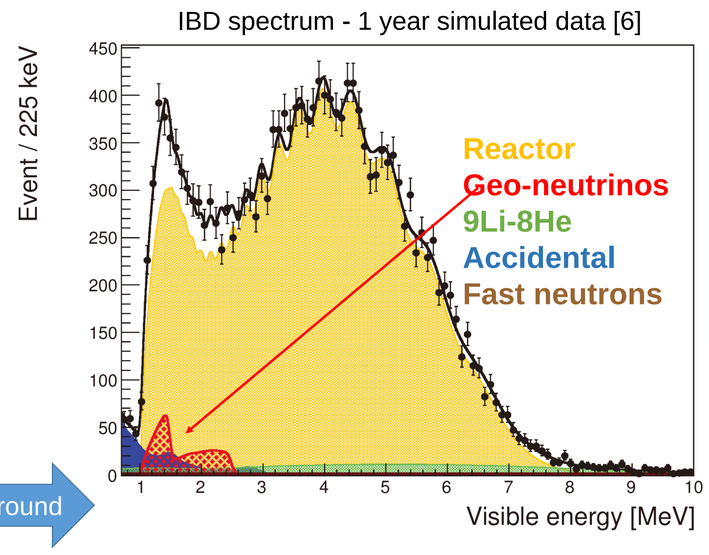
Best precision measurement of the oscillated parameters for the foreseeable future with JUNO

[3]

	Δm^2_{31}	Δm^2_{21}	$\sin^2\theta_{12}$
JUNO 6 years	~0.2%	~0.3%	~0.5%
PDG2020	1.4%	2.4%	4.2%

Geo-neutrinos: [6]

Main goal: understanding the radiogenic heat in the Earth



- Geo-neutrinos from ^{238}U and ^{232}Th decay chains in the Earth: 400/year
- Detected channel: Inverse Beta Decay (IBD)
- JUNO will be sensitive to U/Th ratio
- Ongoing geological study of the local crust

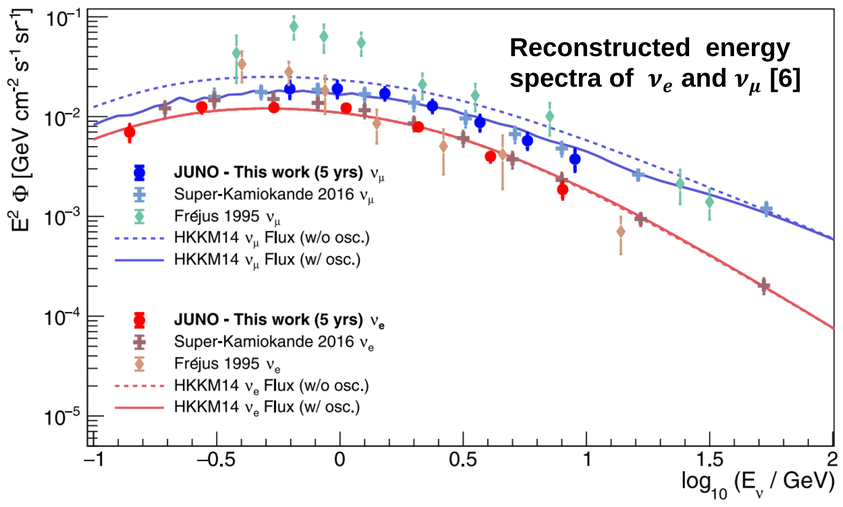
JUNO can reach 17% precision within the first year and 6% after 10 years -> outnumbers the current precision of Borexino and KamLAND

Atmospheric neutrinos: [1,7]

First measurement with liquid scintillator

Complementary NMO measurement via matter effects on the oscillation

Applied an unfolding method to extract the energy spectrum: 25% precision after 5 years



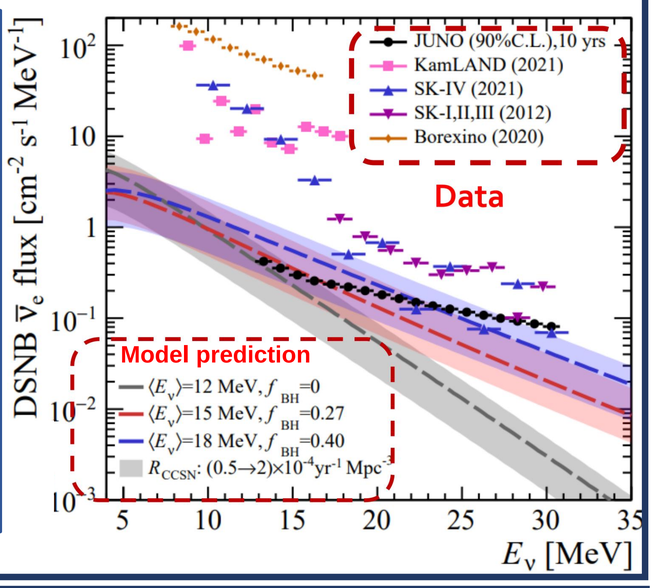
- Detection via CC interaction
- Baseline ~15 km – 13000km
- Energy range: 0.1 – 100 GeV
- Possibility to investigate sub-GeV energy range with JUNO.
- Develop further reconstruction technique for energy and directionality

JUNO NMO sensitivity: 0.7~1.4 σ (atmospheric only) @ ~6 yrs exposure [1]

Diffuse Supernova Neutrino Background [1]

DSNB discovery potential: 3σ in 3 years with nominal models

- **DSNB:** isotropic flux of neutrinos from extra-galactic supernovae
- Detection via IBD
- It holds the precise information on:
  - The average core-collapse SN neutrino spectrum
  - The cosmic star formation rate
  - The fraction of failed black hole forming SNe
- **Background:**
  - NC interaction of atmospheric ν
  - Fast neutrons

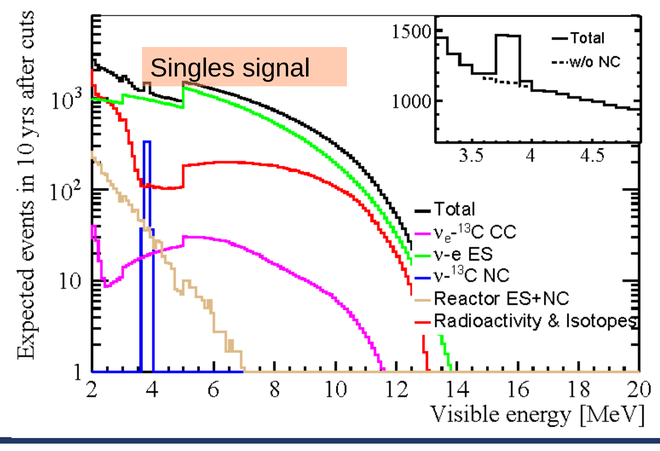


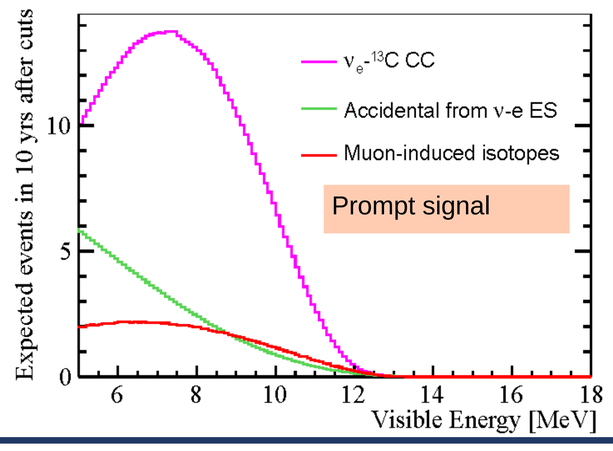
^{8}B solar neutrinos

publication is coming soon!

- Model independent of ^{8}B neutrino flux measurement via Elastic Scattering (ES), Charge-Current (CC), and Neutral Current (NC)
- ^{8}B neutrino flux will reach 5% precision in 10 years, $\sin^2\theta_{12} \sim 9\%$, and Δm^2_{21} ~25% without SNO constraint

- Measuring MSW-transition region
- Detection via CC and NC interaction 13C (0.2 kt 13C)
- Low threshold of 2 MeV for ES





JUNO sensitivity to intermediate energy solar neutrinos

publication is coming soon!

- **^{7}Be:** in 1-2 years time < 2.7% for all radiopurity scenarios
- **Pep:** in 1-2 years time < 17% for most of the radiopurity scenario
- **CNO:** constraining pep solar neutrino rate is crucial
  - Independent measurement ^{13}N and ^{15}O and 20% precision without constraint on ^{210}Bi internal background might be feasible for the first time

JUNO will improve the precision of the existing Borexino measurements

References

[1] JUNO physics and detector, Progr. Part. Nucl. Ph. 123 (2022) 103927
[2] Yellow Book: J. Phys. G: Nucl. Part. Phys. 43 (2016) 030401
[3] Sub-percent Precision Measurement of Neutrino Oscillation Parameters with JUNO, arXiv:2204.13249
[4] OSIRIS, Eur. Phys. J. C 81 (2021) 973.
[5] **Combined sensitivity to the neutrino mass ordering with JUNO, the IceCube Upgrade, and PINGU**, ***Physical Review D* 101 (2020) 032006**
[6] Geo-neutrinos: Chin. Phys. C 40,3 (2016) 033003
[7] JUNO sensitivity to low energy atmospheric neutrino spectra, Eur. Phys. J. C 81 (2021) 887