

JUNO Physics program

Cécile Jollet (CENBG - CNRS/IN2P3) on behalf of JUNO collaboration ICHEP 2020







Neutrino oscillations with reactor neutrinos

Reactor oscillation experiments aim at the measurement of oscillation parameters (θ_{13} , θ_{12} , mass • splittings) through the observation of $\overline{v}_e \rightarrow \overline{v}_e$ transition.



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JUNO experiment

- JUNO (Jiangmen Underground Neutrino Observatory) is a medium-baseline (53 km) reactor neutrino experiment.
- The baseline has been optimized for neutrino mass ordering determination.
- JUNO will be the largest liquid scintillator detector ever built (20 kilo-tonnes)



JUNO detector design

• The experiment consists of a very large target made of 20 kton liquid scintillator detector.



Posters: « Status of the Veto Systems of JUNO » (JP De Andre),
« The 3-inch Photomultiplier system » (C. Jollet).

JUNO collaboration

JUNO is an in union nal collaboration made of 669 members from 77 institutes spread over 18 countries.



Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	IMP-CAS	Germany	FZJ-IKP
Belgium	Universite libre de Bruxelles	China	SYSU	Germany	U. Mainz
Brazil	PUC	China 🔮	Tsinghua U.	Germany	U. Tuebingen
Brazil	UEL	China	UCAS	Italy	INFN Catania
Chile	PCUC	China 🤎	USTC	Italy	INFN di Frascati
Chile	UTFSM	China	U. of South China	Italy	INFN-Ferrara
China	BISEE	China	Wu Yi U.	Italy	INFN-Milano
China	Beijing Normal U.	China	Wuhan U.	Italy	INFN-Milano Bicocca
China	CAGS	China	Xi'an JT U.	Italy	INFN-Padova
China	ChongQing University	China 🛄	Xiamen University	Italy	INFN-Perugia
China	CIAE	China 🛛	Zhengzhou U.	Italy	INFN-Roma 3
China	DGUT	China 🚽 🔪	NUDT	Latvia	IECS
China	ECUST	China 💦	CUG-Beijing	Pakistan 💦	PINSTECH (PAEC)
China	Guangxi U.	China	ECUT-Nanchang City	Russia	INR Moscow
China	Harbin Institute of Technology	Croatia	UZ/RBI	Russia	JINR
China	IHEP	Czech	Charles U.	Russia	MSU
China	Jilin U.	Finland	University of Jyvaskyla	Slovakia	FMPICU
China	Jinan U.	France	LAL Orsay	Taiwan-China	National Chiao-Tung U.
China	Nanjing U.	France	CENBG Bordeaux	Taiwan-China	National Taiwan U.
China	Nankai U.	France	CPPM Marseille	Taiwan-China	National United U.
China	NCEPU	France	IPHC Strasbourg	Thailand	NARIT
China	Pekin U.	France	Subatech Nantes	Thailand	PPRLCU
China	Shandong U.	Germany	FZJ-ZEA	Thailand	SUT
China	Shanghai JT U.	Germany	RWTH Aachen U.	USA	UMD-G
China	IGG-Beijing	Germany	TUM	USA	UC Irvine
China	IGG-Wuhan	Germany	U. Hamburg		





Physics possibilities of JUNO

JUNO is a multipurpose Neutrin astrophysics (J.Phys. G43 (2016)nc

has a rich program in neutrino physics and



From J. Pedro Ochoa-Ricoux's Nufact 2019

NEUTRINO

- Neutrino mass ordering
- Precision measurement of oscillation parameters
- Supernova neutrinos
- Diffuse Supernova neutrino background
- Transient events (multi-messenger astronomy)
- Solar neutrinos
- Atmospheric neutrinos
- Geo-neutrinos
- Nucleon decay & exotic searches

low)

Mass hierarchy determination

• Reactor anti-neutrinos are detected via inverse beta decay (IBD).

$$P_{ee} = 1 - \cos^{4} \theta_{13} \sin^{2} 2\theta_{12} \sin^{2} (\Delta_{21}) \\ - \sin^{2} 2\theta_{13} \sin^{2} (|\Delta_{31}|) \\ - \sin^{2} \theta_{12} \sin^{2} 2\theta_{13} \sin^{2} (\Delta_{21}) \cos (2|\Delta_{31}|) \\ - \sin^{2} \theta_{12} \sin^{2} 2\theta_{13} \sin^{2} (\Delta_{21}) \cos (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{ps} \frac{\Delta m_{31}}{k} \frac{\sin \theta_{12}}{\sin \theta_{12}} \\ \frac{\Delta m_{21}}{2} \frac{\sin^{2} \theta_{12}}{2} \sin^{2} 2\theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} 2\theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} 2\theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} \theta_{12} \sin^{2} \theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} \theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} \theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} \theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} \theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{12} \sin^{2} \theta_{13} \sin (2\Delta_{21}) \sin (2|\Delta_{31}|) \\ \frac{\Delta m_{21}}{2} \sin^{2} \theta_{13} \sin$$



Sensitivity for 100 k IBDs

(20 kton×35 GW×6 years).



 Several conditions on baseline and energy resolution are necessary to perform such a measurement.

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Mass hierarchy sensitivity: impact of energy resolution

The **energy resolution** (photo-electron statistics) is a critical parameter in the achievable sensitivity. The goal is to achieve $3\%/\sqrt{E[MeV]}$.



• To reach the required energy resolution: high light yield + large PMT coverage + good calibration.

(poster from GuiHong Huang « Energy and vertex reconstruction in JUNO » and from Ziyuan Li « Vertex reconstruction and deep learning applications in JUNO »)

• To keep the energy scale uncertainty at the sub-percent precision, a comprehensive calibration strategy is foreseen.

(poster from Kangfu Zhu « JUNO calibration strategy and its simulation »)

• Knowledge of the reference spectrum with high energy resolution.

JUNO TAO detector

Taishan Antineutrino Observatory (TAO), a ton-level, high energy resolution LS detector at 30 meters from one of the Taishan reactor cores, is a satellite detector of JUNO.

Purposes:

- Precisely measure the reactor antineutrino spectrum
- Provide a model-independent reference spectrum for JUNO.
- Benchmark for investigation of the nuclear database.
- Reactor monitoring and safeguard
- Search for sterile neutrino

Detector design (CDR on arXiv:2005.08745):

- 30-35 meters from one of the Taishan reactor cores (4.6 GW_{th}).
- Ton-level Liquid Scintillator (Gd-LS)
- 10 m² of SiPM for a > 90% coverage.
- Operate at -50°C (SiPM darknoise).
- 4500 p.e./MeV.



TAO installation and commissioning in 2022

Precision measurements

• By measuring the energy spectrum, JUNO will be sensitive to solar parameters and mass hierarchy.

•	The current	precision	on the	oscillation	parameters is:
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	Δm_{21}^2	$ \Delta m_{31}^2 $	$\sin^2 \theta_{12}$	$\sin^2 \theta_{13}$	$\sin^2 \theta_{23}$	δ
Dominant Exps.	KamLAND	T2K	SNO+SK	Daya Bay	$NO\nu A$	T2K
Individual 1σ	2.4%	2.6%	4.5%	3.4%	5.2%	70%
Nu-FIT 4.0	2.4%	1.3%	4.0%	2.9%	3.8%	16%



Precision that can achieve JUNO

	Nominal	+ B2B (1%)	+ BG	+ EL (1%)	+ NL (1%)
$\sin^2 \theta_{12}$	0.54%	0.60%	0.62%	0.64%	0.67%
Δm_{21}^2	0.24%	0.27%	0.29%	0.44%	0.59%
$ \Delta m_{ee}^2 $	0.27%	0.31%	0.31%	0.35%	0.44%

Table 3-2: Precision of $\sin^2 \theta_{12}$, Δm_{21}^2 and $|\Delta m_{ee}^2|$ from the nominal setup to those including additional systematic uncertainties. The systematics are added one by one from left to right.

• Precision measurements essential to test consistency of neutrino oscillation framework.

Solar neutrinos

- Challenging measurement due to:
 - low overburden but new veto strategies for cosmogenic isotopes.
 - detection via neutrino-elastic scattering, so higher requirements in terms of radiopurity:
 - assuming an intrinsic ²³⁸U and ²³²Th radioactivity level of 10⁻¹⁷ g/g, a 2 MeV analysis threshold can be achieved.
 - fiducial volume energy dependent cut.
- With 10 years of data taking, about 60000 signal and 30000 background events are expected:
 - shed new light on current tension in Δm^2_{21} between solar and reactor neutrinos measurement with the same detector.



arXiv: 2006.11760

Supernova neutrinos

- Diffuse Supernova Neutrino Background (DSNB): integrated neutrino flux from all past core-collapse events.
 - Expected detection of $\sim 3\sigma$ after 10 years.
 - Leading constraint if DSNB is not observed (the upper limit on the flux above 17.3 MeV would be ~ 0.2 cm⁻²s⁻¹ after 10 years).
- Galactic core-collapse supernova neutrinos (CCSN): . •
 - Determination of flavor content, energy spectrum and time evolution
 - Low energy threshold: ~0.2 MeV —
 - Golden channel: IBD, ~5000 events for SN@10 kpc
 - information about v_x thanks to v-p ES channel.
- JUNO is part of the SNEWS project (SuperNova Early Warning System).
- **Multi-messager astrophysics:**
 - Lower the energy threshold down to O(10) keV —
 - Realtime monitoring of the MeV transient neutrino sky.



Ed dN/dEd

1

0.1

0.2



E_d [MeV]

10

12NCC, EN 17.3 Me

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50

100

Atmospheric and geo-neutrinos

- **Atmospheric neutrinos:**
 - Additional measurement of mass hierarchy with matter _ effects.

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Sensitivity t _ (0.9σ) for the



 $_3$ octant could be ruled out at 1.8 σ) hierarchy and $\theta_{23} = 35^{\circ}$).

Combined studies of oscillation from different sources.



Geo-neutrinos:

- Explore origin and thermal evolution of the Earth -
- 400-500 neutrinos per year
- Precision 6% in 10 years



Proton decay

- Competitive sensitivity to proton decay searches exploiting the $p \rightarrow \overline{v} + K^+$
 - clear identification: 3 signals in coincidence.
 - background from atmospheric neutrinos.
- After 10 years of data taking, JUNO will be sensitive to $\tau \sim 2 \times 10^{34}$ years.



poster from Yuhang Guo « Prospects for proton decay searches in JUNO »

Timeline



- JUNO is a multipurpose neutrino observatory with a rich program in neutrino physics and astrophysics: determination of neutrino mass ordering, sub-percent measurement on θ_{12} and Δm^2_{12} , detection of solar and atmospheric neutrinos, observation of supernova neutrinos, geo-neutrinos and sensitivity to proton decay, etc...
- Production programme and progress are well underway.
- The JUNO experiment is expected to start data taking in 2022.