Precision measurements of neutrino oscillations with JUNO

RENAFAE Annual Meeting - 2022

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For the JUNO Collaboration

Outline:
- Introduction to JUNO: institutions, objectives, detector
- Precision measurements of oscillation parameters
- Final remarks

The JUNO collaboration

77 institutions
660 collaborators

2 in Brazil:

PUC-Rio

-) Collaborator: H.Nunokawa

-) Other group members not in JUNO: A.Esmaili (Professor), A.A.Quiroga (Pos-doc), A.M.Garcia Trzeciak (PhD Stud.)

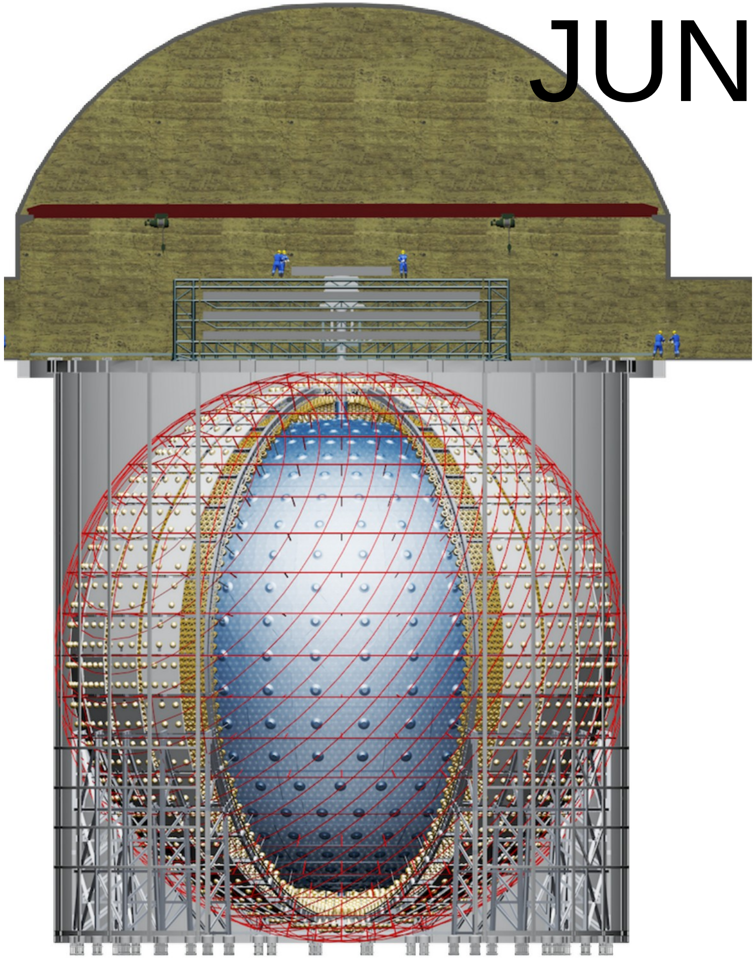
UEL

-) Collaborator: P.Chimenti

-) Other group members not in JUNO: C.F.Martins (Professor), B.Araujo (Grad.Student), O.Villanueva Filho(Student), Gustavo Barreto (Student), J.Chamorro.

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		
China	ECUST	China	CUG-Beijing	Latvia	IECS
China	Guangxi U.	China	ECUT-Nanchang City	Pakistan	PINSTECH (PAEC)
China	Harbin Institute of Technology	Croatia	UZ/RBI	Russia	INR Moscow
China	IHEP	Czech	Charles U.	Russia	JINR
China	Jilin U.	Finland	University of Jyvaskyla	Russia	MSU
China	Jinan U.	France	IJCLab Orsay	Slovakia	FMPICU
China	Nanjing U.	France	CENBG Bordeaux	Taiwan-China	National Chiao-Tung U.
China	Nankai U.	France	CPPM Marseille	Taiwan-China	National Taiwan U.
China	NCEPU	France	IPHC Strasbourg	Taiwan-China	National United U.
China	Pekin U.	France	Subatech Nantes	Thailand	NARIT
China	Shandong U.	Germany	FZJ-ZEA	Thailand	PPRLCU
China	Shanghai JT U.	Germany	RWTH Aachen U.	Thailand	SUT
China	IGG-Beijing	Germany	TUM	USA	UMD-G
China	IGG-Wuhan	Germany	U. Hamburg	USA	UC Irvine

JUNO: intro



-> Large Liquid Scintillator Detector
-> Basic parameters:
Mass and Resolution

Experiment	Mass	Resolution
DC/DYB/RENO	0.02 kt	8%
Borexino	0.3 kt	5%
KamLAND/SNO+	1 kt	6%
JUNO	20 kt	3%

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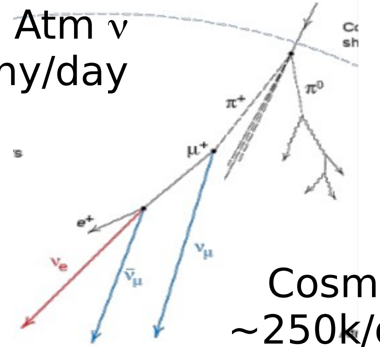
Scientific Goals

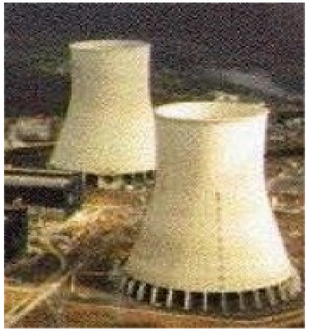
Solar ν
(10~1000)/day

Supernova ν
~10^4 in 10s
(@10kpc)

Atm ν
many/day

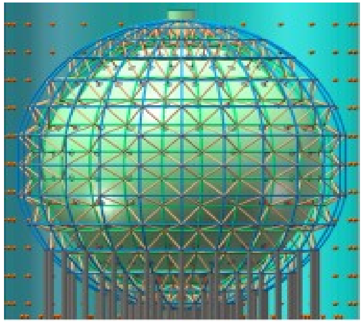


Cosmic μ
~250k/day
215 GeV (10% bundles)

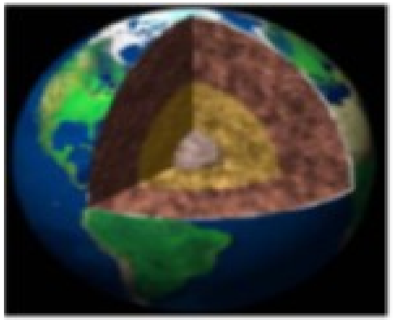


Reactor ν
~60/day

Proton
decay



Geo ν
(1~2)/day



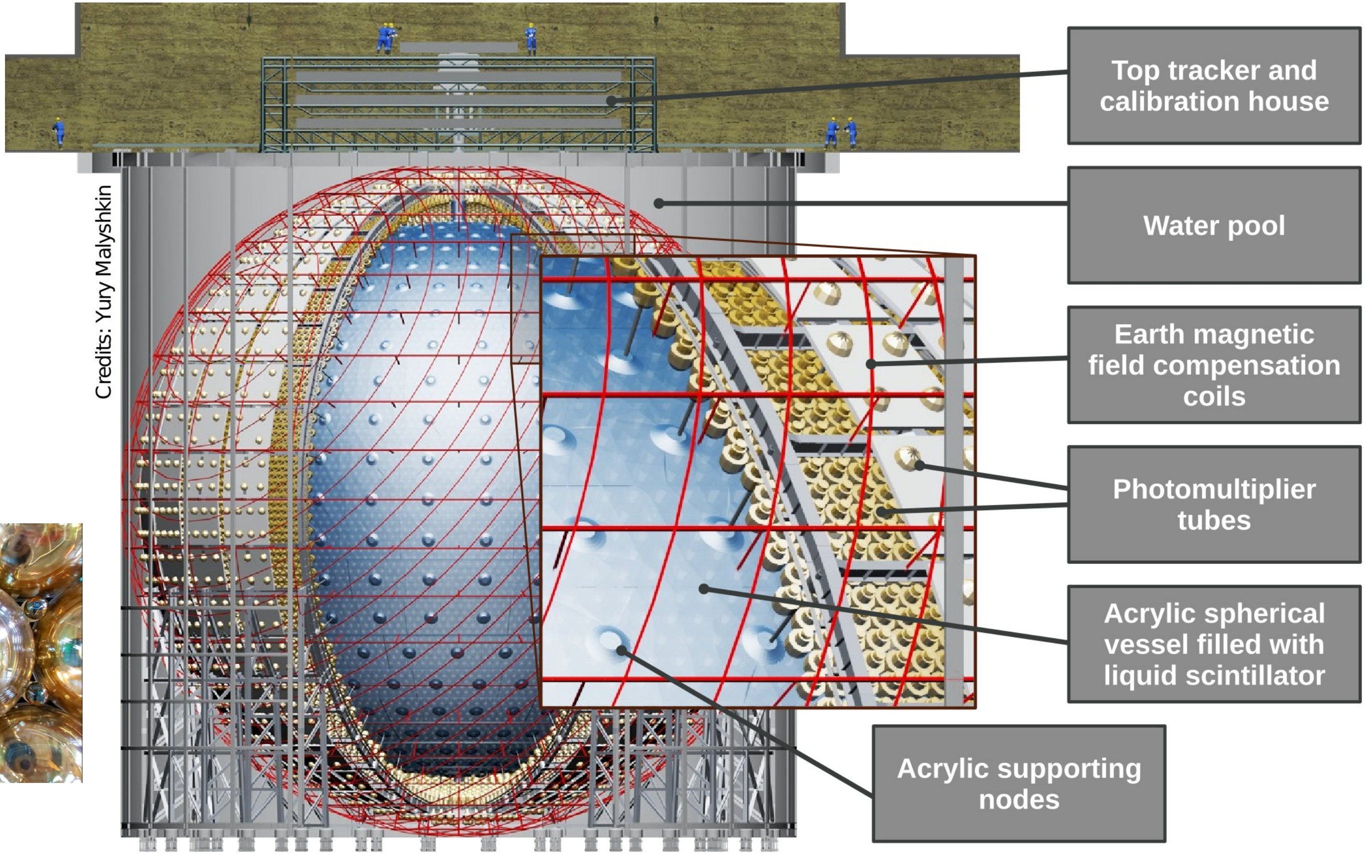
Detector Design

Highlights:

Liquid Scintillator

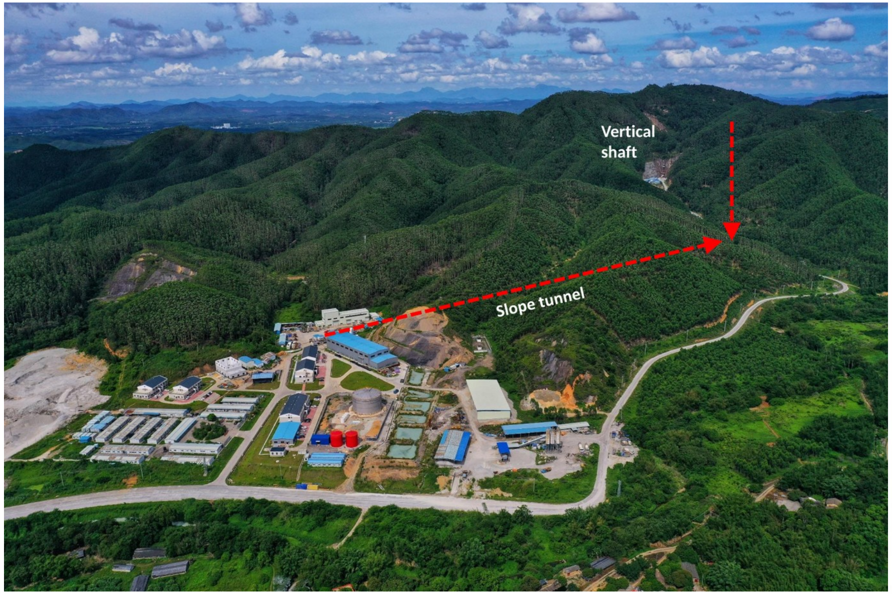
- Not doped
- High transparency (>20m)
- High emission efficiency ($\sim 10^4$ Photons/MeV)

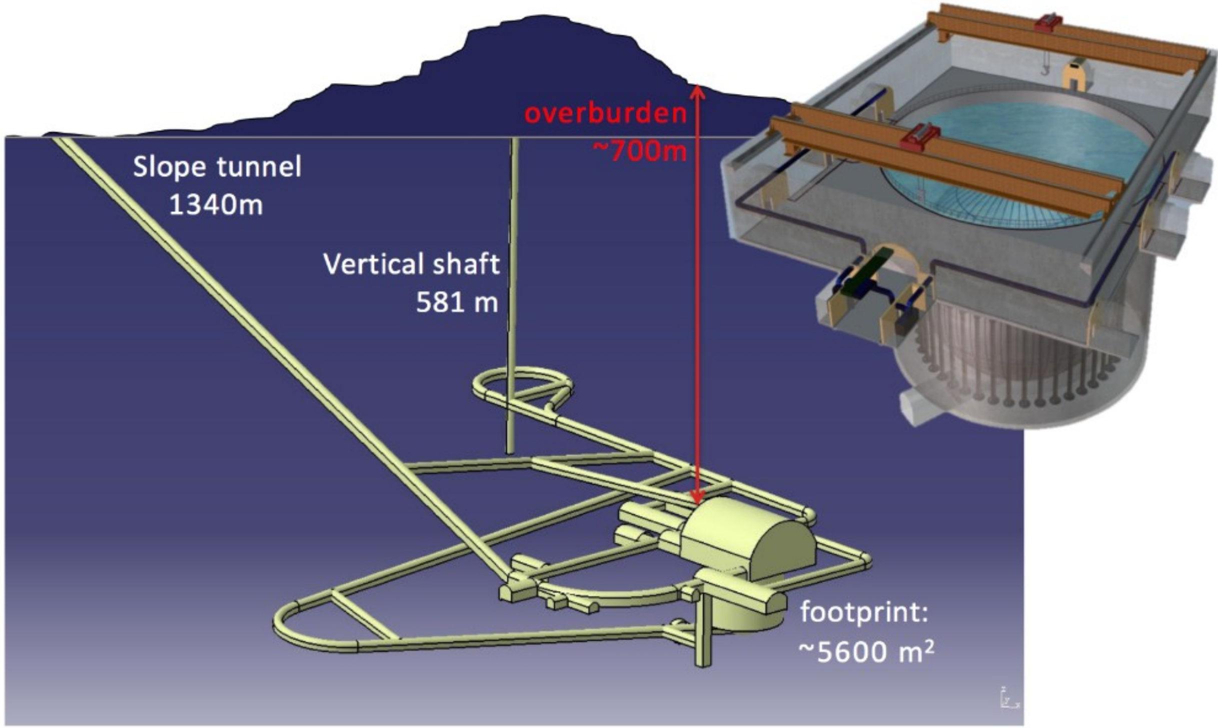
Two types of Photomultipliers:
18k 20-inch
26k 3-inch



Civil construction

Underground laboratory (700m “overburden”).





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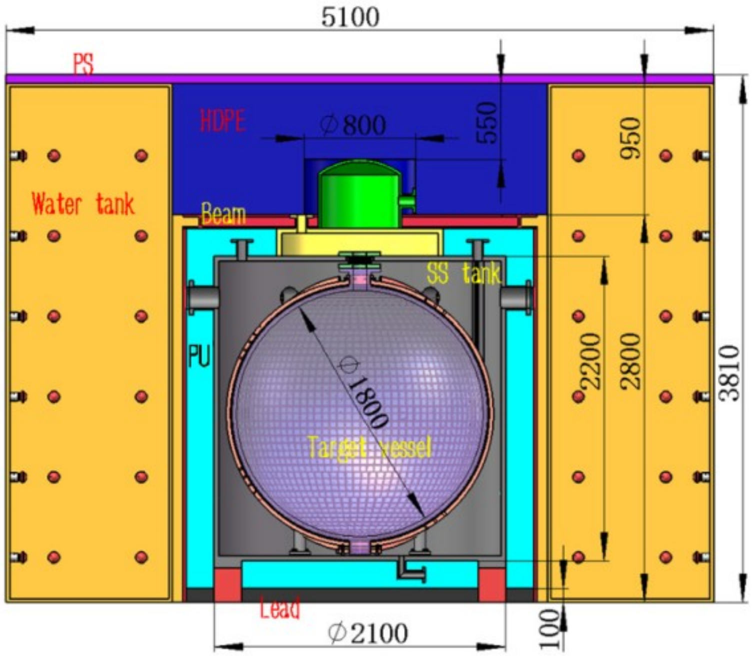
JUNO TAO

-> Taishan Antineutrino Observatory

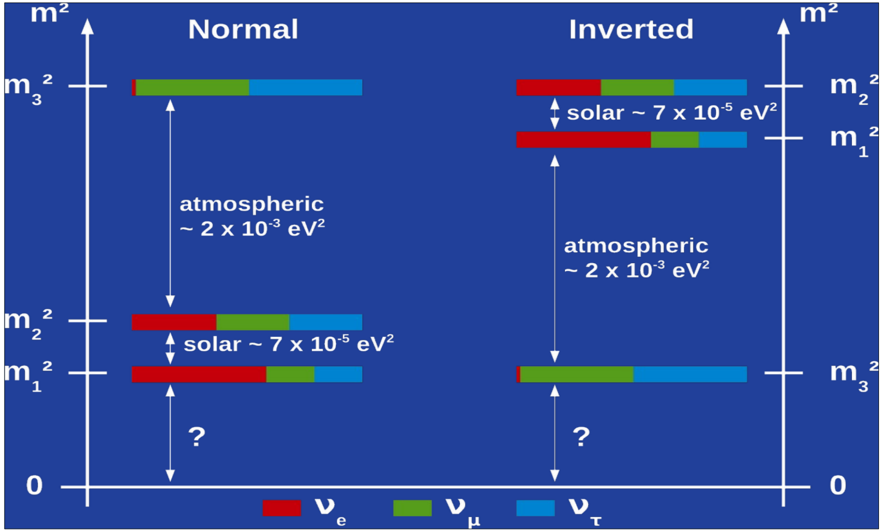
- ~30 m from a 4.6 GW_{th} reactor
- 1 ton Gd-LS @ -50°C
- 2,000 IBD's/day
- 10 m^2 SiPM (>95% photo-coverage)
- Energy resolution: < 2% @ 1 MeV!!! (4500PE/MeV)

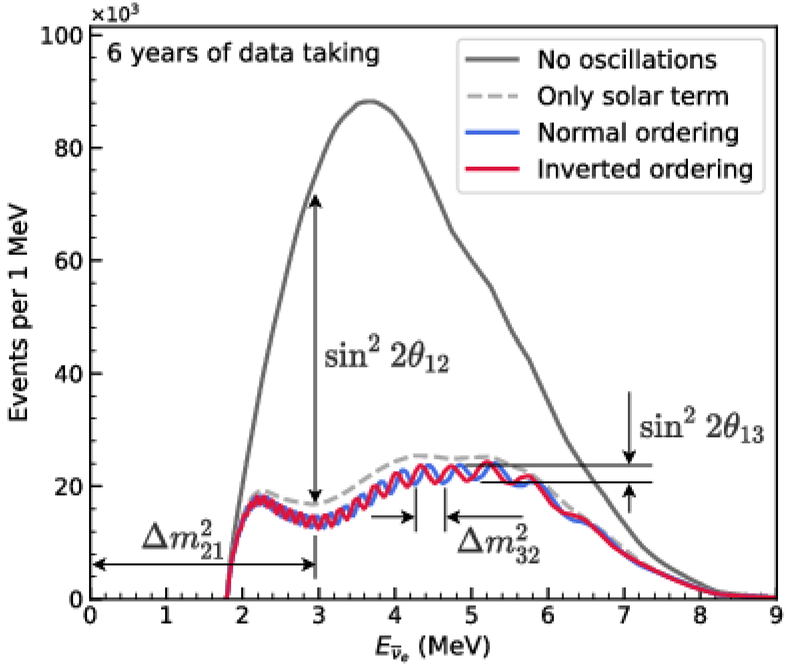
-> Mesurement of antineutrino spectrum with unprecedented resolution

- *Benchmark* for JUNO and other projects
- Search for sterile neutrinos
- Study spectral evolution with reactor fuel burnup
- To be *online* by the end of 2022!



ν oscillation in JUNO





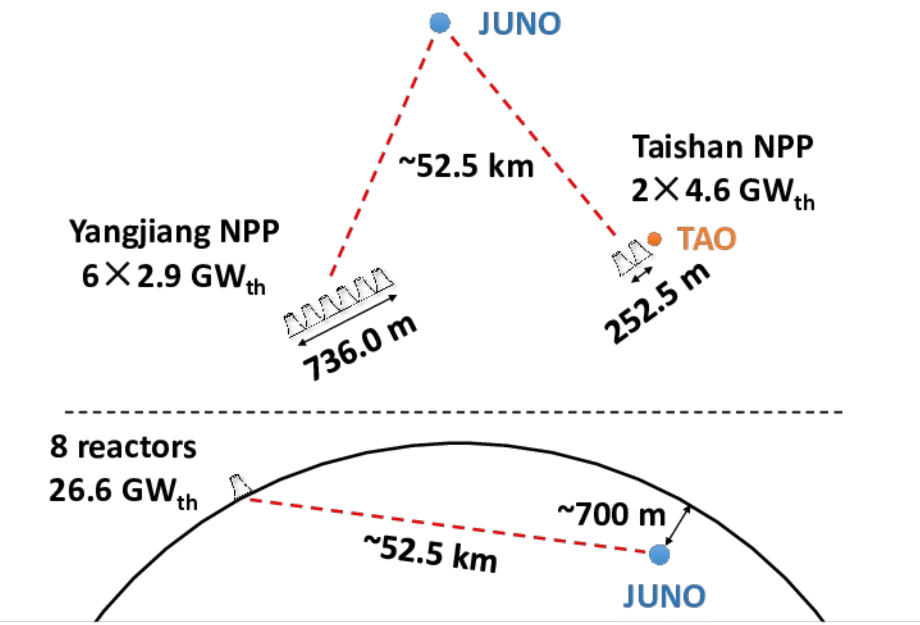
-> Neutrino Mass Ordering:

- Measurement of the fine structure in the oscillation pattern
- >3σ after 6 years of data

-> Measurements of Δm^2_{31}, Δm^2_{21} and $\sin^2(\theta_{12})$ with 1% or better

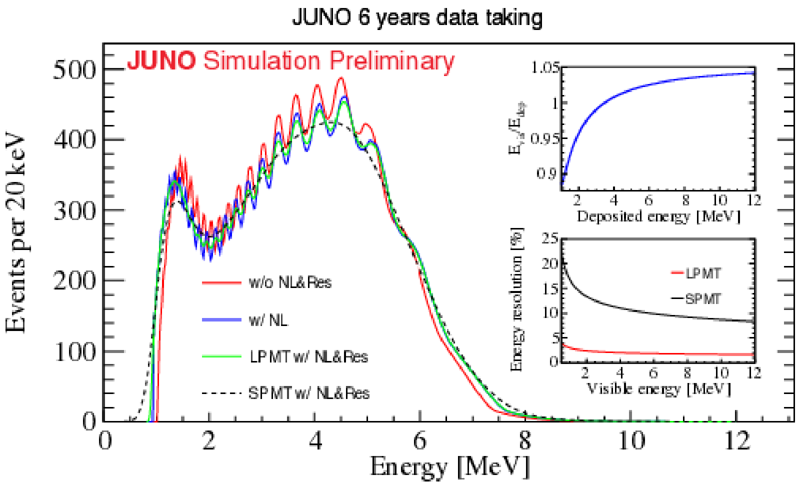
Baselines and Fluxes

$$P_{\bar{\nu}_e\to\bar{\nu}_e} = 1 - \sin^2 2\theta_{13}\left(\cos^2\theta_{12}\sin^2\frac{\Delta m^2_{31}L}{4E} + \sin^2\theta_{12}\sin^2\frac{\Delta m^2_{32}L}{4E}\right) - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2\frac{\Delta m^2_{21}L}{4E}$$

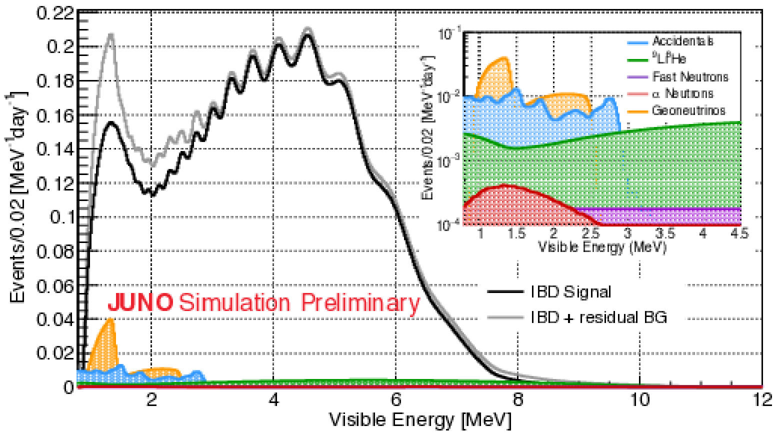


Reactor	Power (GW_{th})	Baseline (km)	IBD Rate (day^{-1})	Relative Flux (%)
Taishan	9.2	52.71	15.1	32.1
Core 1	4.6	52.77	7.5	16.0
Core 2	4.6	52.64	7.6	16.1
Yangjiang	17.4	52.46	29.0	61.5
Core 1	2.9	52.74	4.8	10.1
Core 2	2.9	52.82	4.7	10.1
Core 3	2.9	52.41	4.8	10.3
Core 4	2.9	52.49	4.8	10.2
Core 5	2.9	52.11	4.9	10.4
Core 6	2.9	52.19	4.9	10.4
Daya Bay	17.4	215	3.0	6.4

Expected spectrum



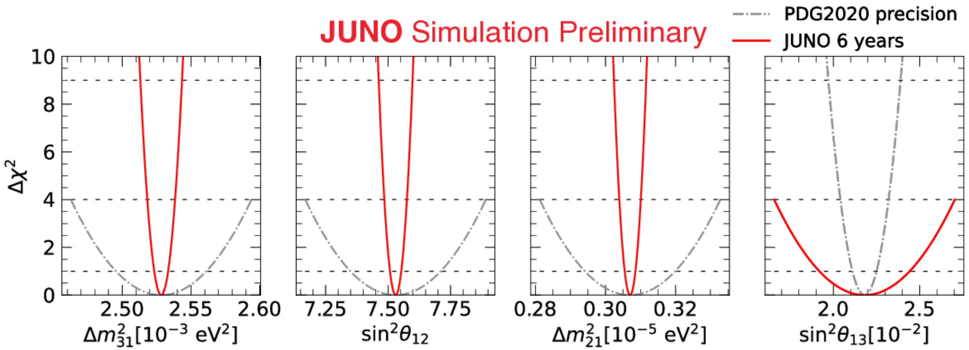
Detector response impact on the IBD Spectrum: expected deposited energy spectrum of reactor antineutrinos in ~6 years of JUNO data considering detector resolution and non-linearity.



Visible energy spectrum expected at JUNO as measured with the large PMT system.

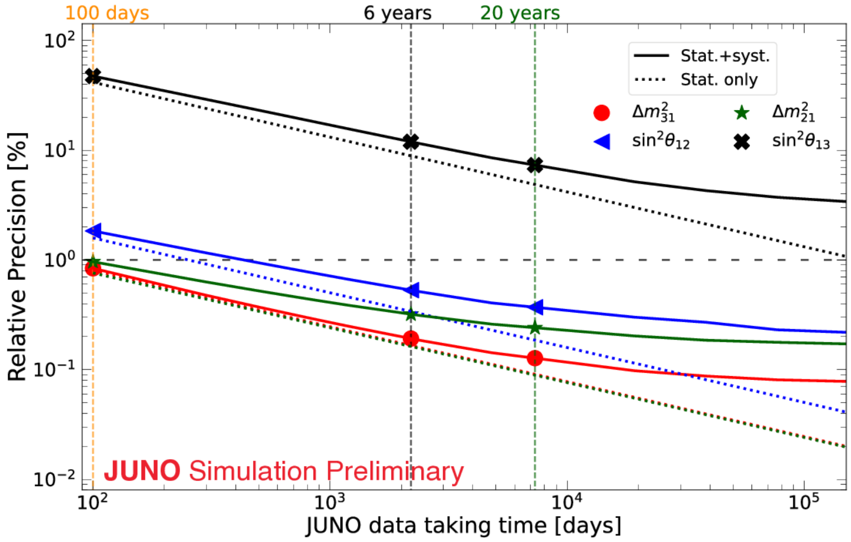
Background	Rate (day^{-1})
Geo-neutrinos	1.2
Accidentals	0.8
^{9}Li/^{8}He	1.4
Fast neutrons	0.1
^{13}C(α,n)^{16}O	0.05

Expected sensitivity



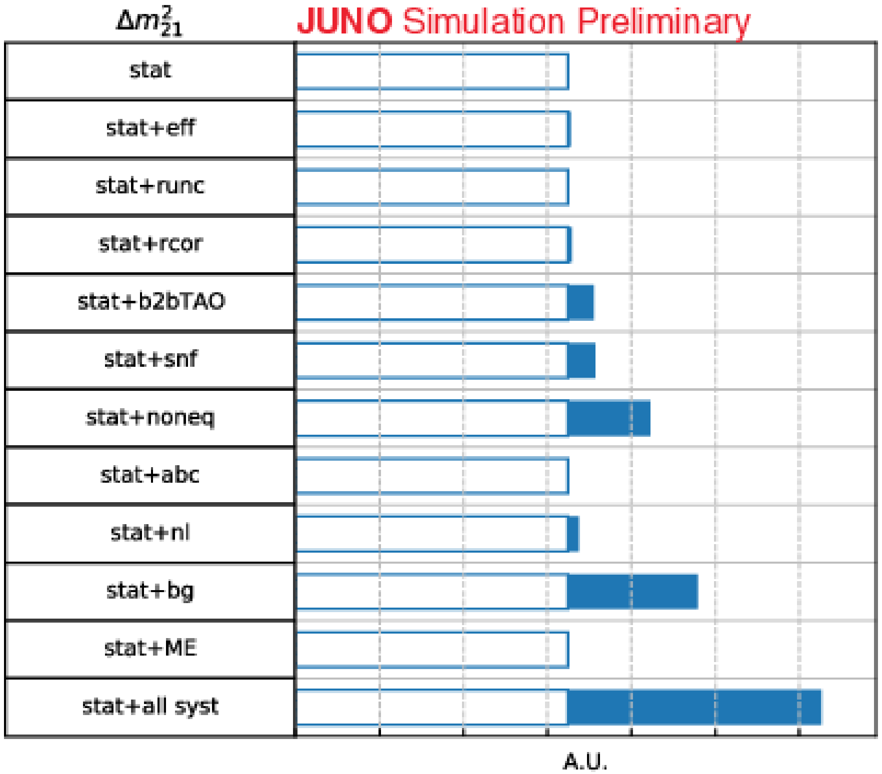
Comparison of $\Delta\chi^2$ distributions of the four oscillation parameters: Today (PDG2020, dot-dashed gray line) v.s. projection with 6~years of JUNO data (solid red line).

	Δm^2_{31}	Δm^2_{21}	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$
JUNO 6 years	~0.2%	~0.3%	~0.5%	~12%
PDG2020	1.4%	2.4%	4.2%	3.2%



Relative precision of different oscillation parameters as a function of JUNO data taking time.

Error Budget (1)

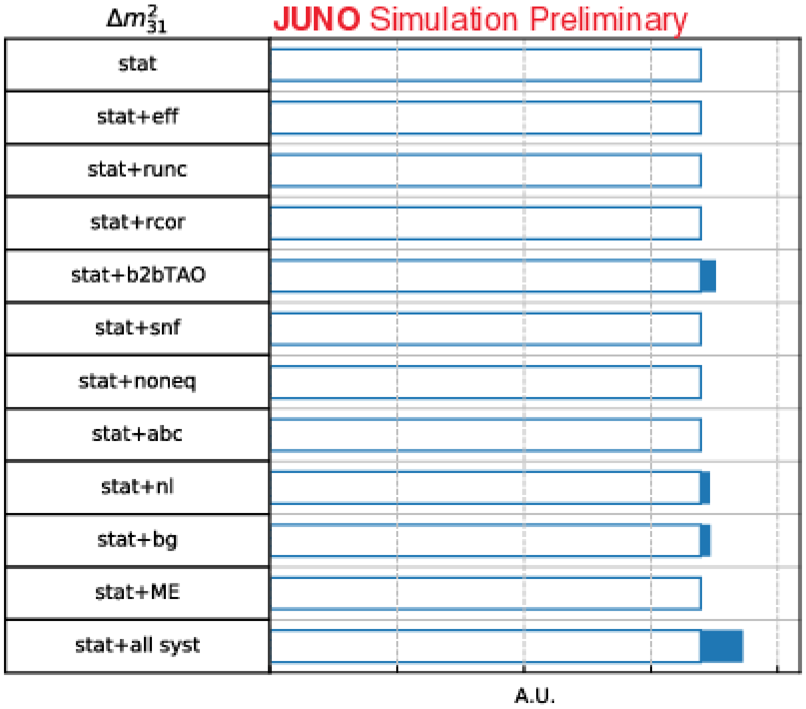


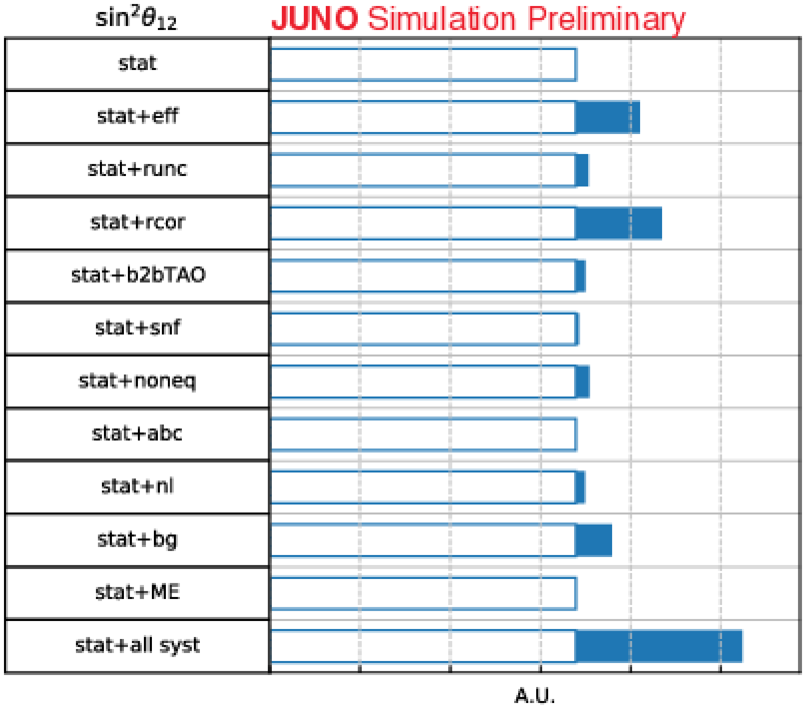
An illustration of the relative impact of individual sources of uncertainty on the total precision of each oscillation parameter.

stat	Statistical (reactor $\bar{\nu}_e$ events only)
eff	Detection efficiency
runc	Reactor $\bar{\nu}_e$ flux reactor-uncorrelated
rcor	Reactor $\bar{\nu}_e$ flux reactor-correlated
b2bTAO	Reactor $\bar{\nu}_e$ spectrum shape based on TAO measurement
snf	$\bar{\nu}_e$ flux from spent nuclear fuel)
noneq	Non-equilibrium correction to reactor $\bar{\nu}_e$ flux
abc	Energy resolution (JHEP03,004(2021))
nl	Liquid scintillator non-linearity (NIMA940,230(2019))
bg	Backgrounds
ME	Earth's matter density
all syst	All systematics above

Error Budget (2)

An illustration of the relative impact of individual sources of uncertainty on the total precision of each oscillation parameter.





Recent publications

Recent Collaboration papers:

- "Sub-Percent Precision Measurement of Neutrino Oscillation Parameters with JUNO", submitted to Chinese Physics C
- "JUNO physics and detector", Prog.Part.Nucl.Phys. 123 (2022), 103927
- "Damping signatures at JUNO, a medium-baseline reactor neutrino oscillation experiment", e-Print: 2112.14450
- "Radioactivity control strategy for the JUNO detector", J. High Energ. Phys. 2021, 102 (2021)
- "The design and sensitivity of JUNO's scintillator radiopurity pre-detector OSIRIS", Eur.Phys.J.C 81 (2021) 11, 973
- "JUNO sensitivity to low energy atmospheric neutrino spectra", Eur.Phys.J.C 81 (2021) 10
- "Calibration Strategy of the JUNO Experiment", J. High Energ. Phys. 2021, 4 (2021)
- "Optimization of the JUNO liquid scintillator composition using a Daya Bay antineutrino detector", Nucl.Instrum.Meth.A 988 (2021) 164823
- "Feasibility and physics potential of detecting 8B solar neutrinos at JUNO", 2021 Chinese Phys. C 45 023004

Other papers related to JUNO:

- A.Cabrera et al. "Synergies and prospects for early resolution of the neutrino mass ordering",Sci.Rep. 12 (2022) 1, 5393
- E.A.Delgado et al. "Probing neutrino decay scenarios by using the Earth matter effects on supernova neutrinos", JCAP 01 (2022) 01, 003
- Y.P.Porto-Silva et al. "Constraining visible neutrino decay at KamLAND and JUNO", Eur.Phys.J.C 80 (2020) 10, 999
- A.N.Khan et al. "Why matter effects matter for JUNO", Phys.Lett.B 803 (2020) 135354

Final Considerations

JUNO construction is well underway and data-taking is expected to start in 2023.

The importance of JUNO for Latin American institutions has been discussed in the “Latin American Strategy for Research Infrastructures for High Energy, Cosmology, Astroparticle Physics - LASF4RI for HECAP”.

In 2022 the M&O cost due by the Brazilian Institutions amount to 8,81k€.

The Brazilian contribution to JUNO has been discussed within RENAFAE at several previous meetings.

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Obrigado!

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