JUNO Status

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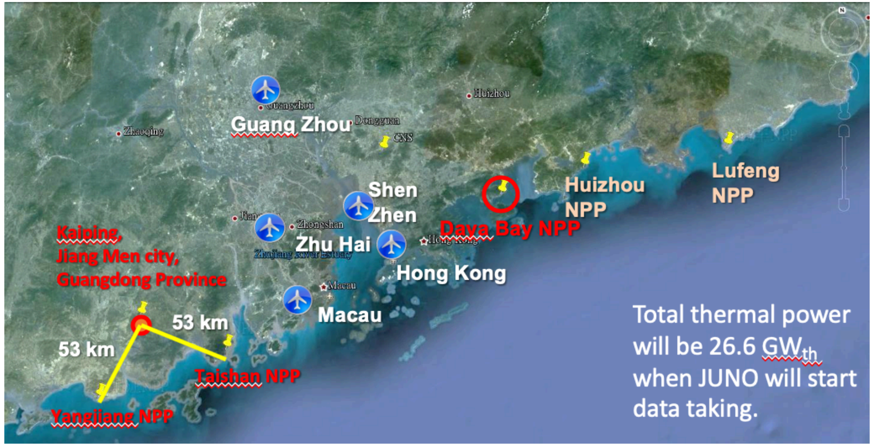
On behalf of the JUNO collaboration

Content

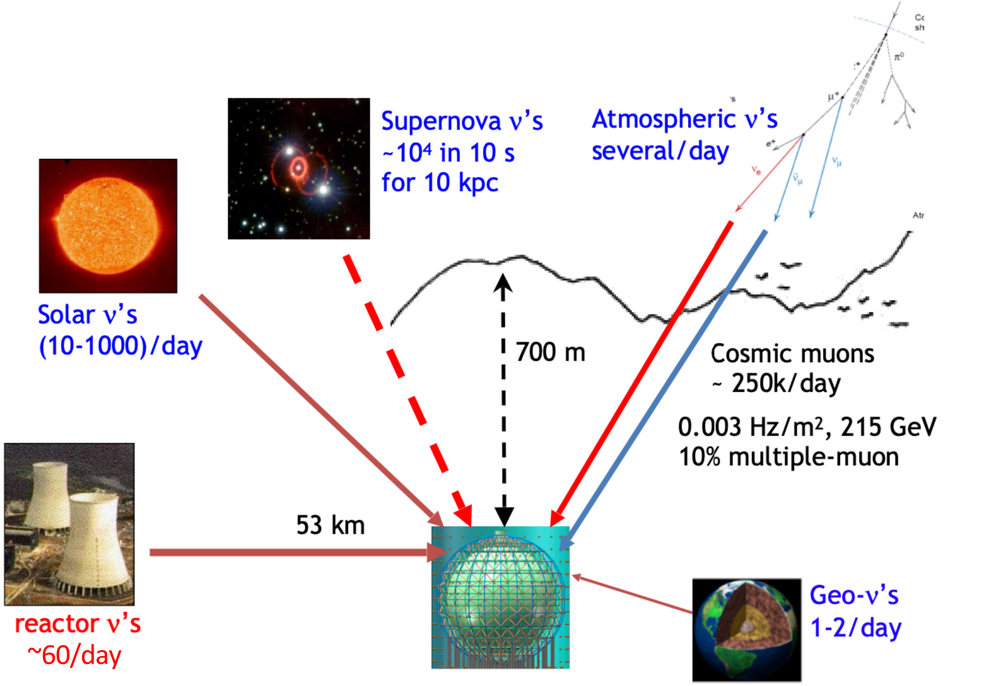
- Introduction to JUNO
- Physics Prospects
- Detector and Status
- Timeline
- Summary
- JUNO Posters

Jiangmen Underground Neutrino Observatory (JUNO)

- JUNO has a rich program in neutrino physics and astrophysics



Nuclear power plant	Status	Power
Daya Bay	Operational	17.4 GW
Huizhou	Planned	17.4 GW
Lufeng	Planned	17.4 GW
Yangjiang	Operational	17.4 GW
Taishan	Operational	9.2 GW (2 reactors online now)



From J. Pedro Ochoa-Ricoux's Nufact 2019

Physics Prospects

$$P_{ee}(L/E) = 1 - P_{21} - P_{31} - P_{32}$$
$$P_{21} = \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21})$$
$$P_{31} = \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31})$$
$$P_{32} = \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32})$$

$$\Delta_{ij} = 1.27\Delta m^2_{ij} L/E$$

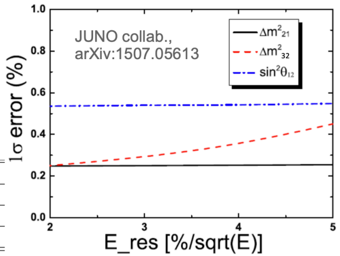
Neutrino mass ordering

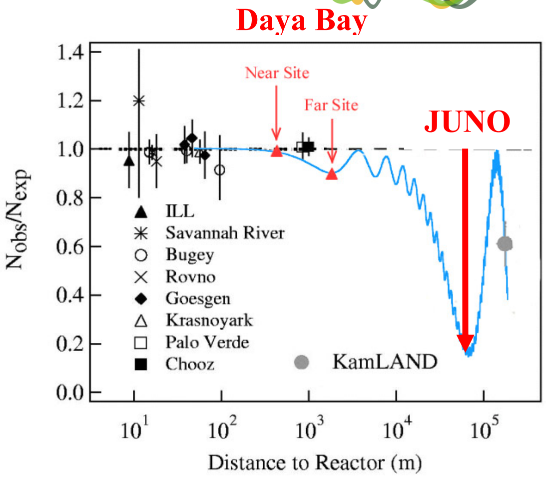
- 3σ neutrino mass ordering sensitivity within 6 years.
- 4σ with Δm^2_{32} input from accelerator experiments.
- > 5σ combined analysis with IceCube within 3–7 years or PINGU in 2 years (arXiv: 1911.06745)

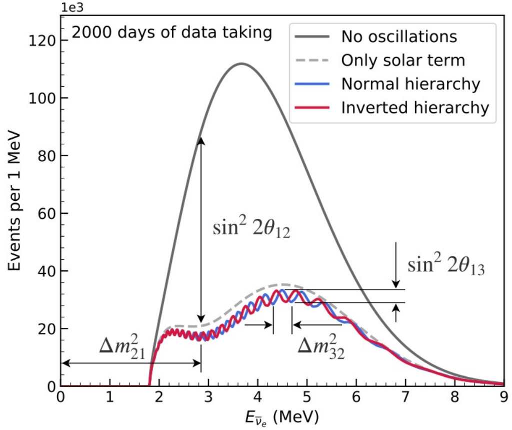
Neutrino oscillation parameters

- Sub-percent accuracy for θ_{12}, Δm^2_{21} and Δm^2_{31}
- Current precision

	Δm^2_{21}	$\|\Delta m^2_{31}\|$	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	δ
Dominant Exps.	KamLAND	T2K	SNO+SK	Daya Bay	NOνA	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%





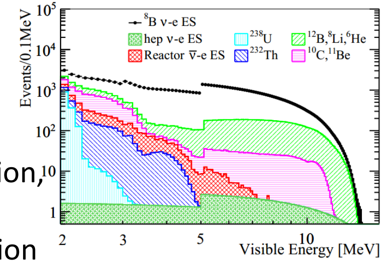


From CERN Courier

Physics Prospects

Solar neutrinos

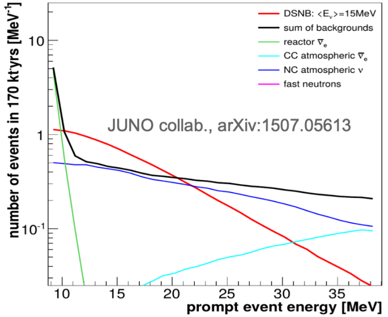
- ^8B solar neutrino detection via neutrino-electron elastic scattering in JUNO
- Large target mass, effective cosmogenic background rejection, background (10^{-17} g/g U/Th)
- Shed new light on current tension in Δm^2_{21} between solar and reactor neutrinos measurement with the same detector



Expected signal and background spectrum
arxiv: 2006.11760

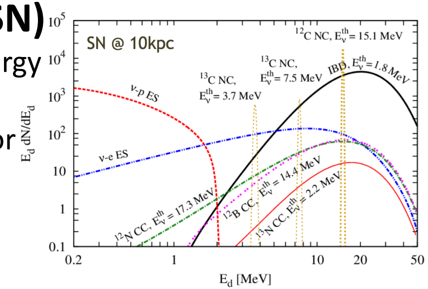
Diffuse Supernove Neutrino Background (DSNB)

- 3σ sensitivity in 10 years or strongest constraint
- Star formation rate and core collapse neutrino spectrum



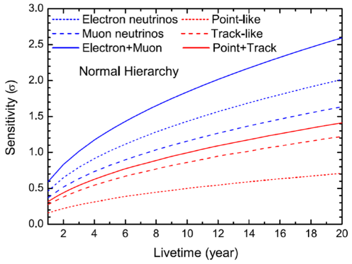
SuperNOVA neutrinos (SN)

- Sensitivity: flavor content, energy spectrum, time evolution
- 10000 events (5000 via IBD) for SN @ 10kpc
- Low threshold 0.2 MeV



Atmospheric neutrinos

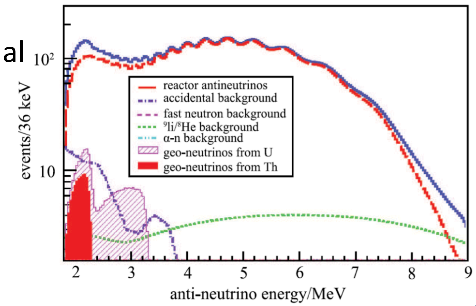
- Measure θ_{23} with 6° precision
- Complimentary neutrino mass ordering sensitivity via matter effect



Physics Prospects

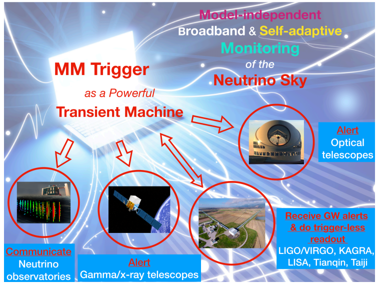
Geo-neutrinos

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



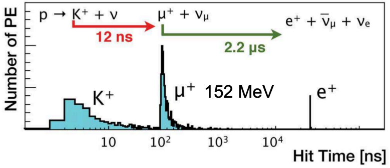
Multi-messager astrophysics

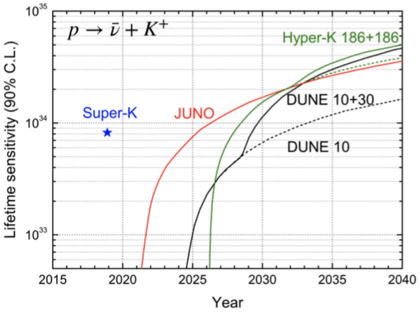
- lower the energy threshold of the detector down to O(10) keV
- Realtime monitoring of the MeV transient neutrino sky



Proton decay

- Competitive sensitivity to proton decay searches
- Triple coincidence signal





- Reactor flux shape precise measurement
- Sterile neutrinos
- Other exotic searches, etc

JUNO Collaboration

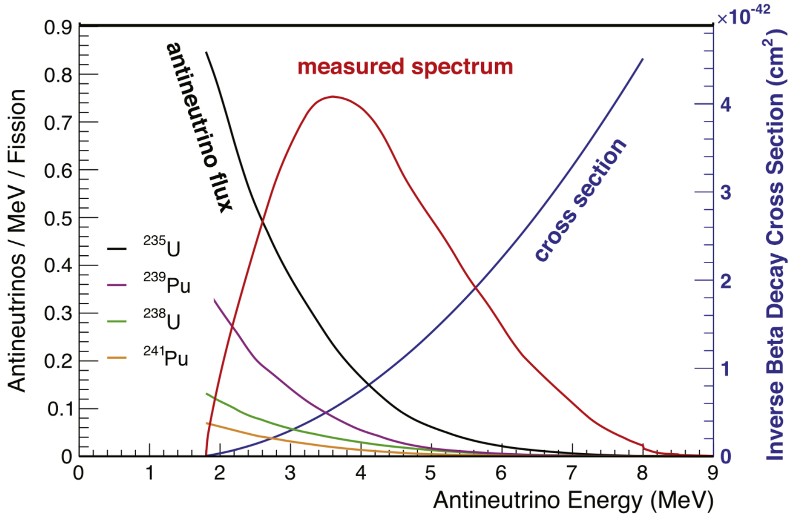
Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	IMP-CAS	Germany	FZJ-IKP
Belgium	Universite libre de Bruxelles	China	SYSU	Germany	U. Mainz
Brazil	PUC	China	Tsinghua U.	Germany	U. Tuebingen
Brazil	UEL	China	UCAS	Italy	INFN Catania
Chile	PCUC	China	USTC	Italy	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	PDZ/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
China	IGG-Beijing	Germany	TUM	USA	UC Irvine
China	IGG-Wuhan	Germany	U. Hamburg		

77 institutes
669 members

Neutrino detection

Detection via inverse beta decay (IBD) event

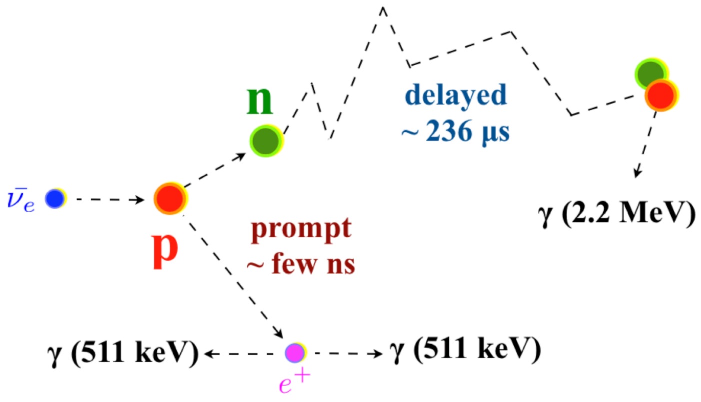
$$\bar{\nu}_e + p \rightarrow e^+ + n$$



The observable electron anti-neutrino spectrum (red line)

The cross section of inverse beta decay (blue line)

The signal signature



- Prompt photons from e^+ ionization and annihilation (1-8 MeV)
- Delayed photons from n capture on Hydrogen (2.2 MeV)
- Time (τ ~ 200 μs) and spatial correlation

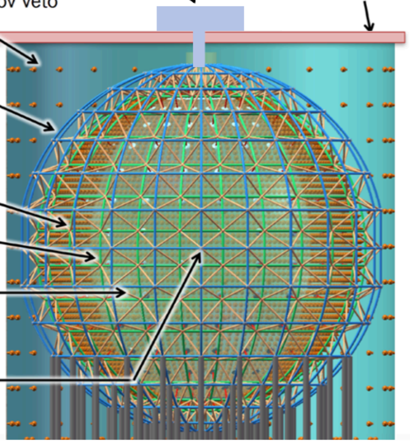
Keys for the JUNO detector

1. Optimal baseline for the detector
2. Large statistics
   - 26.6 GW_{th} power
   - ~60 IBD events per day
3. Energy resolution < 3%/√E between 1 MeV and 8 MeV

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

a: the statistical term
b: a constant term independent of the energy, dominated by position non-uniformity
c: the contribution of a background noise term

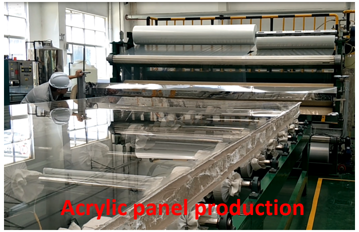
4. Energy scale uncertainty < 1%
   - Comprehensive calibration strategy
5. Background control

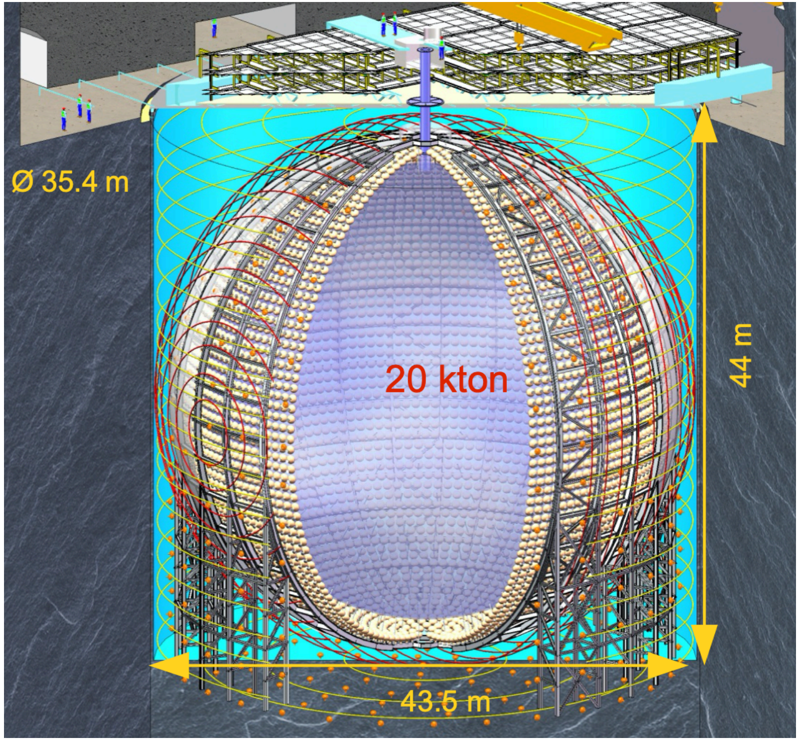


Experiment	Daya Bay	Borexino	KamLAND	JUNO
Target mass [tons]	8 x 20	~300	~1,000	20,000
Photo electron collection [p.e./MeV]	~160	~500	~250	~1200
Energy resolution	~8.5%	~5%	~6%	~3%
Photocathode coverage	12%	34%	34%	75%
Energy calibration uncertainty	0.5%	1%	2%	<1%

Central detector (CD)

- 35 m diameter acrylic sphere
- Stainless steel truss
- 20,000 tons purified liquid scintillator
- 18,000 20-inch PMTs
- 25,600 3-inch PMTs
- Filling/Overflow/Circulation (FOC) system

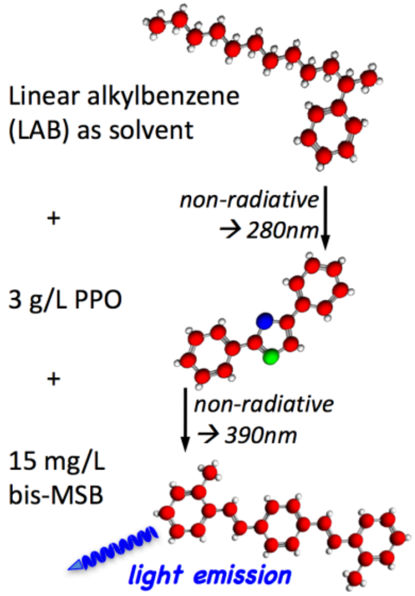




Liquid scintillator

Liquid scintillator (LS) recipe:

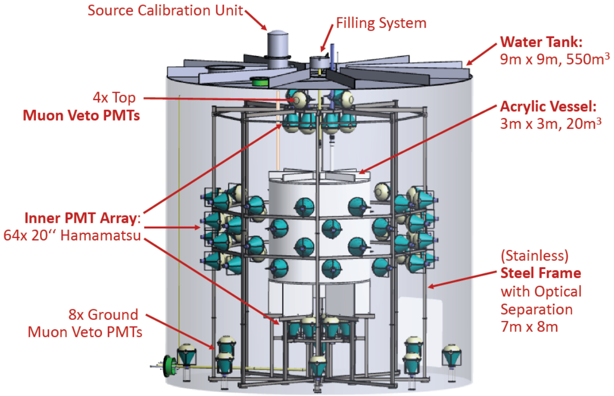
- 2.5 g/L PPO + (1-4) mg/L bis-MSB



LS recipe from Daya Bay

Attenuation Length: > 20 m @430 nm

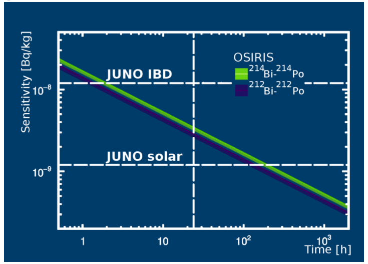
- Improve raw materials and production process
- Purification systems (Al_2O_3 Filtration column, water extraction, gas stripping)



Online **S**cintillator **I**nternal **R**adioactivity **I**nvestigation **S**ystem **(OSIRIS)**

Low radioactive backgrounds:

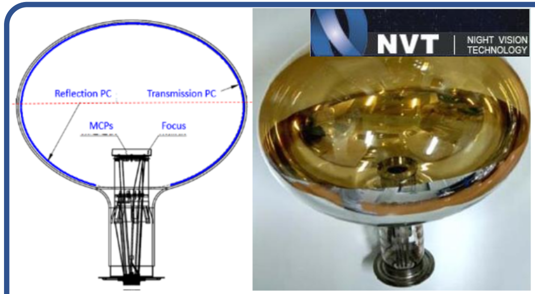
- 10^{-15} g/g for neutrino mass ordering determination
- 10^{-17} g/g for solar neutrino detection



OSIRIS detection sensitivity

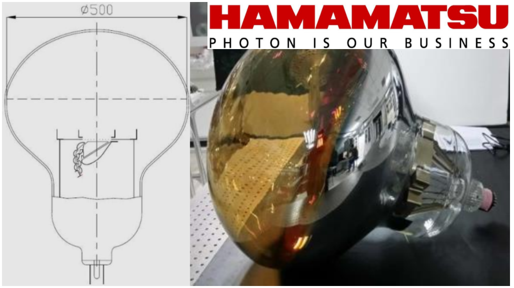
20-inch PMTs

18,000 20-inch PMTs
- 13,000 Micro-channel plates PMTs (Northern Night Vision Technology (NNVT), MCP-PMT)
- 5,000 Dynode PMTs (Hamamatsu, R12860HQE)



- Develop for JUNO
- Use of transmission and reflection cathodes to increase quantum efficiency

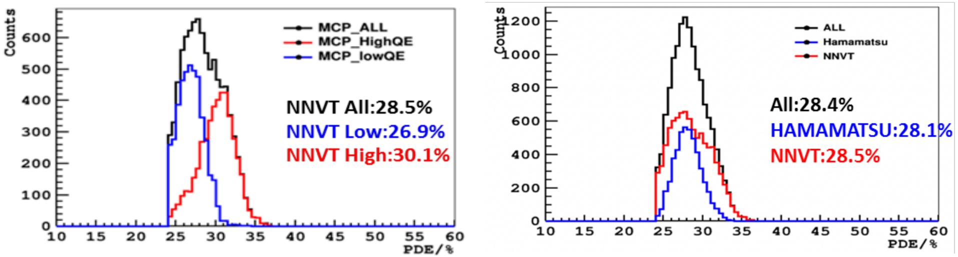
Microchannel plate (MCP) PMTs



- New type of bialkali photocathode
- Excellent TTS (2.7 ns FWHM)

Dynode PMTs

- The photon detection efficiency (PDE): MCP PMT >29% and Dynode PMT is 28.1%
- HV dividers mass production is ongoing
- 7000 PMTs have been potted with multiple waterproof layers
- Implosion protection covers were designed and produced



PDE of 20-inch PMTs

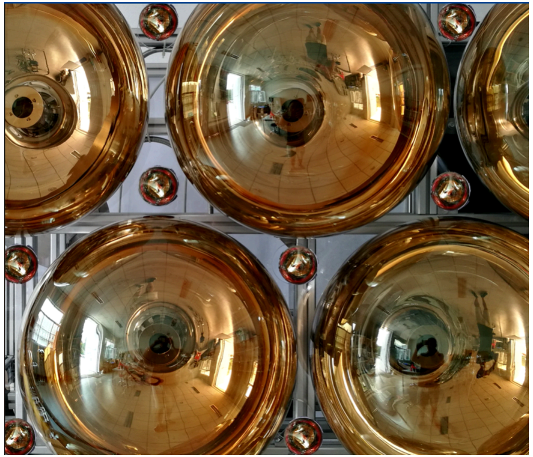
3-inch PMTs

25,600 3-inch HZC Photonics PMTs
- Control systematic uncertainty
  - ➢ Correct non-linearity response of 20-inch PMTs
- Increase dynamic range
  - ➢ Improve muon reconstruction resolution
  - ➢ Supernova detection (if very near)
- Standalone measurement of solar parameters

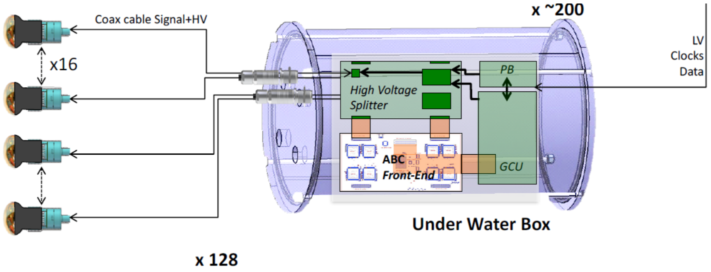
Status
- 26,000 photomultipliers already produced
- Delivery of the full electronics in 2021

XP72B22

Custom 3-inch PMTs for JUNO



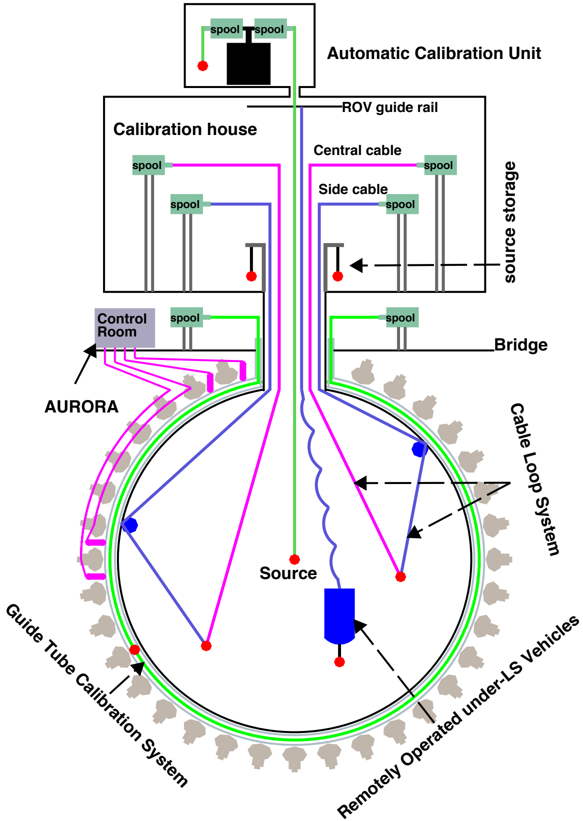
20-inch and 3-inch PMTs interleaving



PMT digitization design

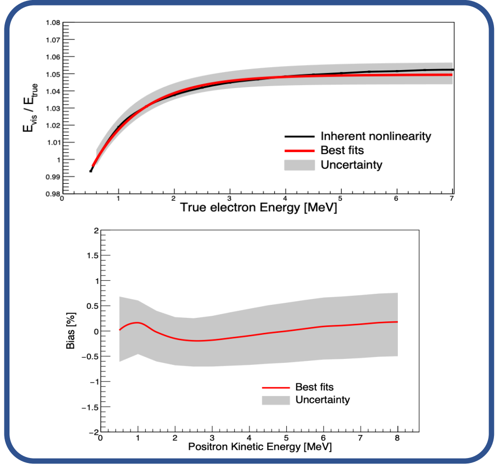
Calibration System

Calibration layout

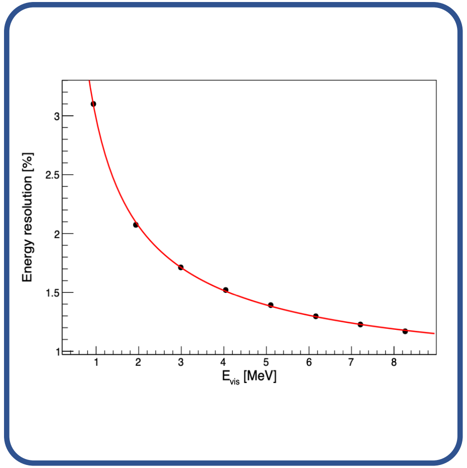


- **1D:** Automatic Calibration Unit (ACU)
- **2D:** Cable Loop System (CLS) and Guide Tube Calibration System (GTCS)
- **3D:** Remotely Operated Vehicle (ROV)
- **Auxiliary systems:** Calibration house, Ultrasonic Sensor System (USS), CCD and A Unit for Researching Online the LSc tRAnsparency (AURORA)

Non-linearity and non-uniformity correction



Effective Energy resolution



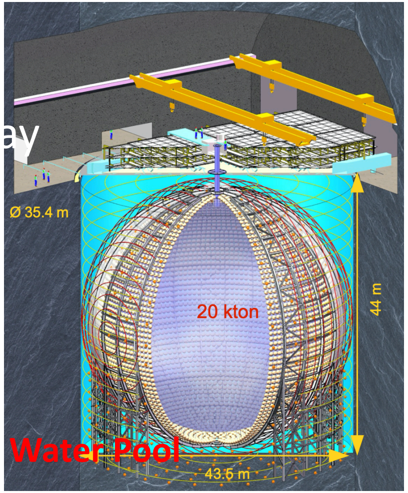
- The bias in the reconstructed energy is expected to be less than 1%.
- The effective energy resolution is expected to be less 3.0% between 1 MeV and 8 MeV.

Muon Veto System

- Active and passive shielding for CD

Water Cherenkov detector:

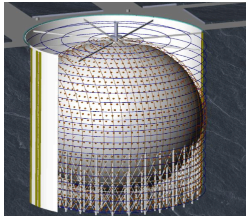
- Shield CD from ambient radioactivity and neutrons induced by cosmic rays
- Veto muon induced backgrounds
- ~2400 20-inch MCP-PMT used
- 35 ktons ultrapure water with circulation
- Detector efficiency is expected to be larger than 99%



Top tracker (TT):

- Reuse the Target Tracker walls of the OPERA experiment
- 3-layers plastic scintillator modules are already at JUNO site

A magnetic field (EMF) shielding system



- Shielding earth magnetic field for 20” PMTs
- Double coil system

JUNO TAO

Taishan Antineutrino Observatory (TAO) is a satellite detector of JUNO

Purposes

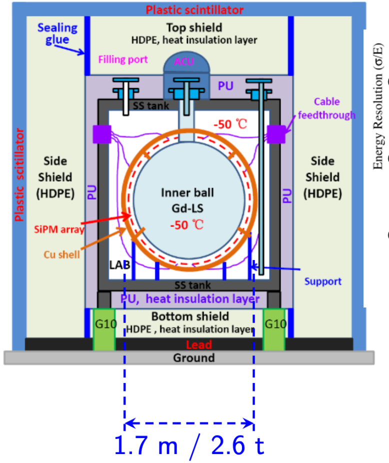
- Precisely measure the reactor antineutrino spectrum
- Provide a model independent reference spectrum for JUNO
- Provide isotopic yields and spectra
- Reactor monitoring and safeguard
- Search for sterile neutrino

Detector design

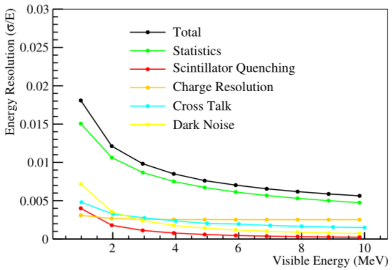
- 30-35 m from a Taishan reactor core (4.6 GWth)
- Ton-level Gadolinium-doped LS at -50 ℃
- 10 m^2 SiPM with PDE>50% and >90% coverage
- Sub-percent energy resolution

TAO installation and commissioning in 2022

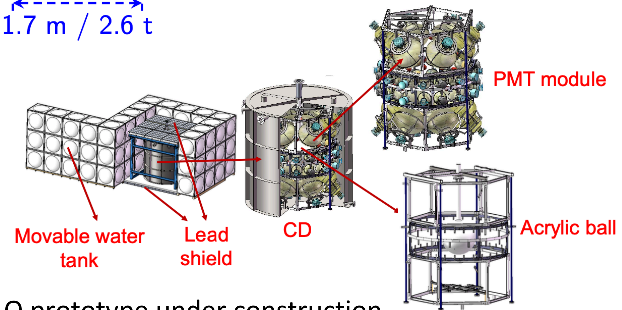
TAO detector design



CDR (arXiv:2005.08745)

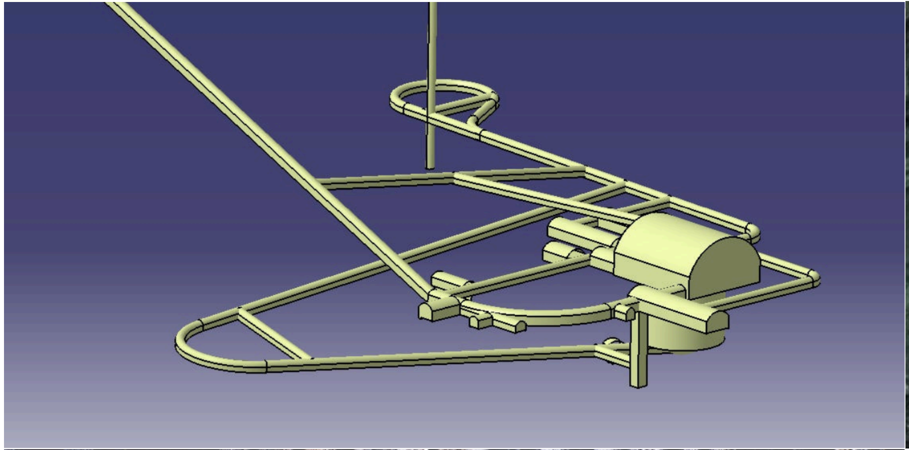


Energy resolution



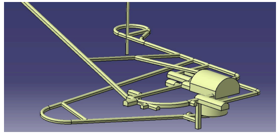
TAO prototype under construction

Civil Construction



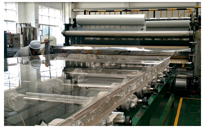
- Slope tunnels and vertical shafts are finished.
- Experimental cavern digging is ongoing.
- Expect to finish in 2020.

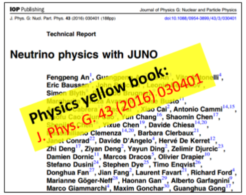
JUNO Timeline



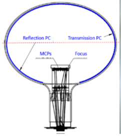
2014
- International collaboration established
- Conceptual design

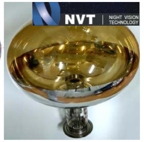
2015
- PMT production line setup
- CD parts R&D
- Civil construction start





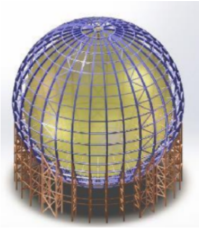
2016
- PMT production start
- CD parts production start
- Yellow book published





2017
- PMT testing start
- TT arrived

2018
- PMT potting
- Start delivery of surface building
- Start production of acrylic sphere



2019-2021
- Electronics production starts
- Civil construction and lab preparation completed
- Detector construction

2022
- Detector ready for data taking

Summary

- JUNO has rich physics topics, including determining neutrino mass ordering, precisely measuring the oscillation parameters, detecting solar neutrinos, observing supernove neutrinos, geo-neutrinos, atmospheric neutrinos, etc.
- JUNO sub-system R&D and production programme well underway.
- JUNO experiment is expected to start data taking in 2022.

JUNO Posters

- **#11, Huiling Li**, Early Warning from the Detection of Pre-supernova Neutrinos in Future Large Liquid-scintillator Detectors
- **#48, Cedric Cerna**, The 3-inch Photomultiplier System of the JUNO Experiment
- **#86, Jie Cheng**, Diffuse Supernova Neutrino Background Detection at JUNO
- **#100, Yang Han**, Dual-calorimetry in JUNO
- **#105, Alexandre Gottel**, OSIRIS - A 20 ton liquid scintillator detector as a radioactivity monitor for JUNO
- **#129, Donglian Xu**, Multi-messenger and low-energy triggger system for JUNO
- **#151, Cleanliness Control Group**, Radioactive Cleanliness Control for the JUNO Experiment
- **#152, Yue Meng**, Calibration System of the JUNO Experiment
- **#154, Ziping Ye**, Real-time Monitoring of Transient Phenomena with JUNO
- **#206, Giulio Settanta**, Atmospheric Neutrino Physics with JUNO
- **#207, Cristina Martellini**, Supernova neutrino Physics with the JUNO detector
- **#242, Tobias Sterr**, Performance of the PMT Mass Testing System for the JUNO Experiment
- **#243, Paolo Montini**, Taishan Antineutrino Observatory (TAO) Project
- **#336, Matthias Raphael Stock**, Measuring the Fluorescence Time Profile of the JUNO Liquid Scintillator using Gamma Radiation and a Pulsed Neutron Beam
- **#360, Yu Chen**, Measurements on the afterpulse of the 20-inch Photomultiplier Tubes for the JUNO experiment
- **#370, Zhonghua, Qing**, Status of 20-inch PMT Instrumentation for the JUNO experiment
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