Prospects and Status of the JUNO detector

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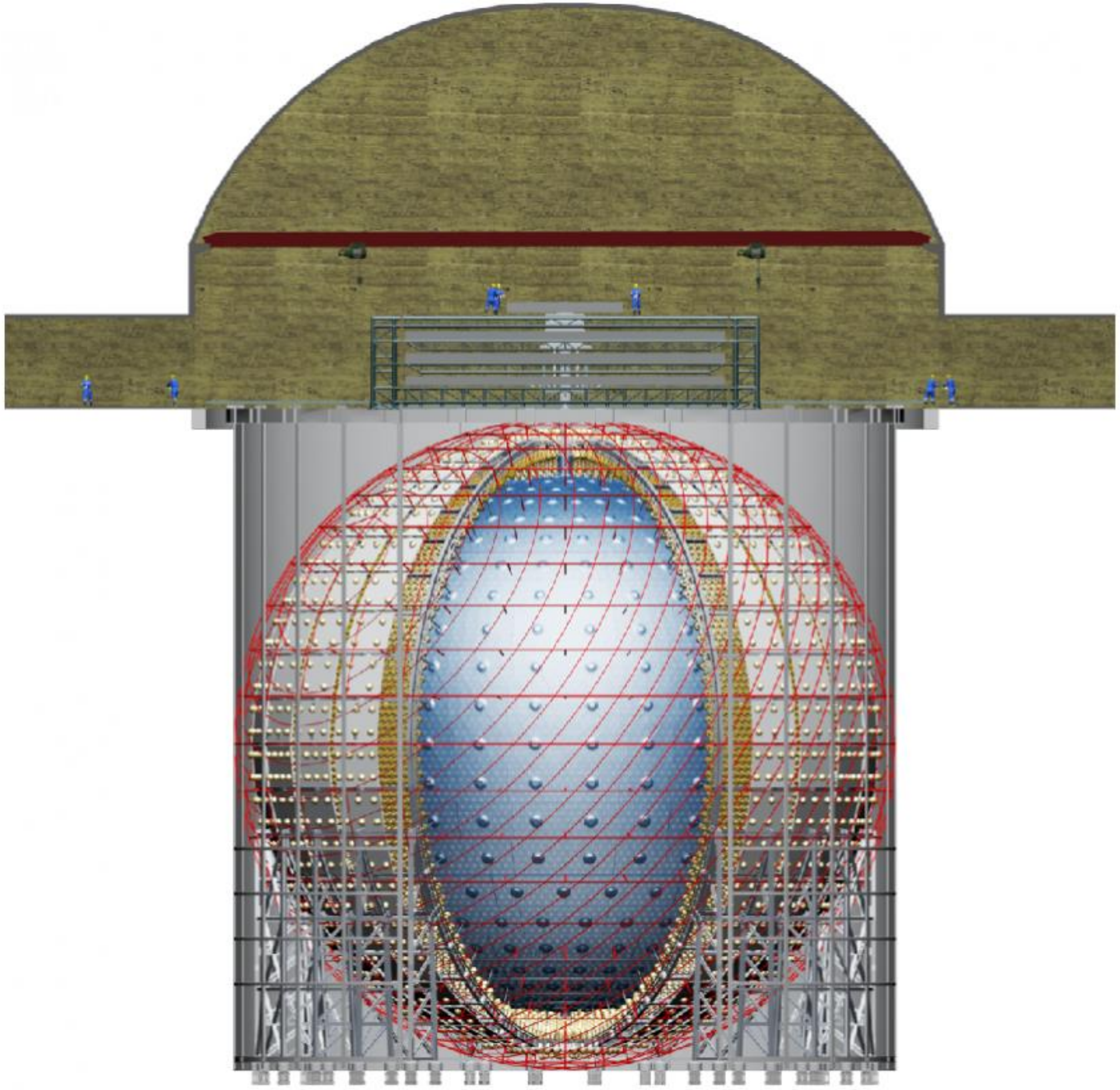
On Behalf of the JUNO collaboration

Outline

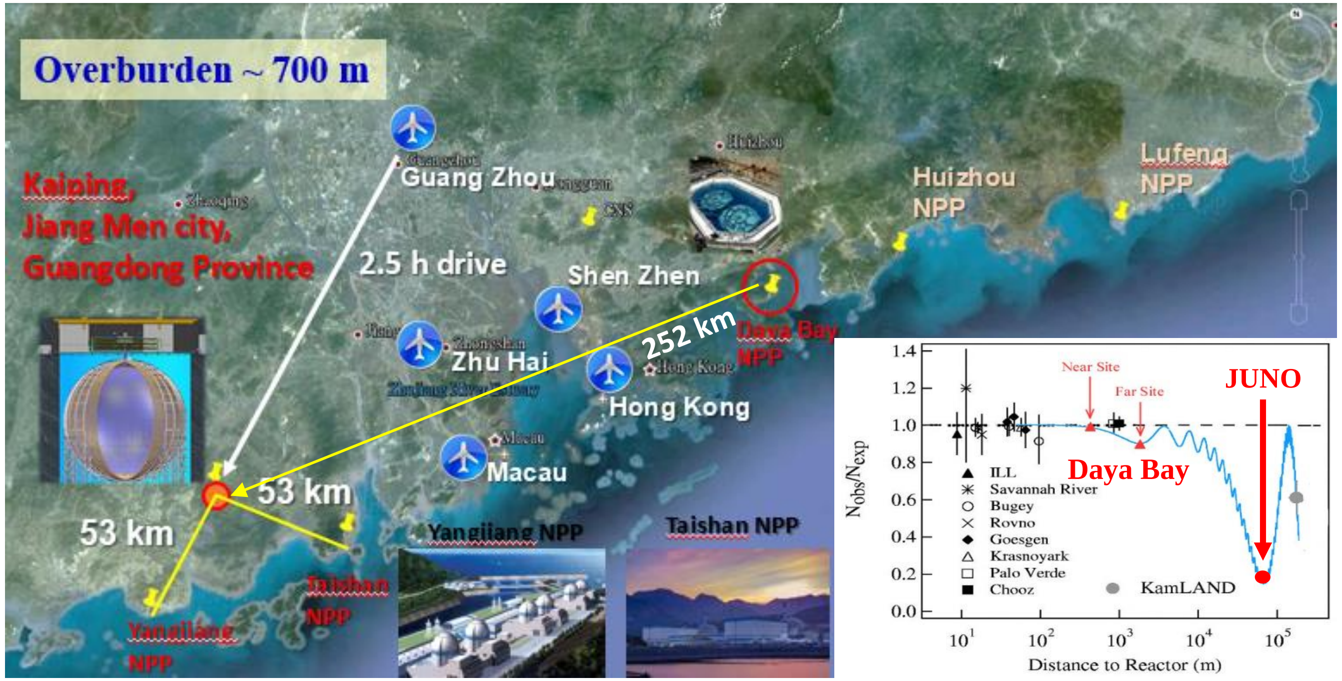
- ➢ *An overview of JUNO*
- ➢ *Physics prospects*
- ➢ *The project status of JUNO*
    - *Liquid scintillator*
    - *Central detector*
    - *PMT*
    - *Veto detector*
    - *Calibration system*
    - *TAO detector*
- ➢ *Conclusion*

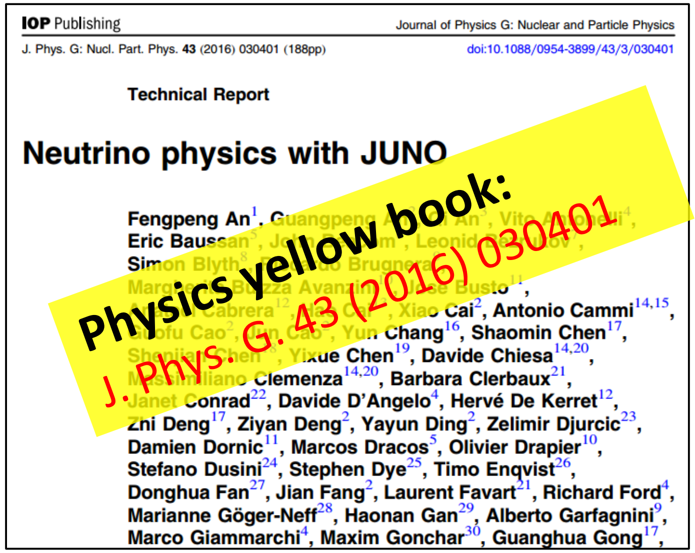


Jiangmen Underground Neutrino Observatory

Project:

- *Major goal： NMO determination；*
- *Main Source : Reactor neutrinos;*
- *Target: 20 kton liquid scintillator ;*
- *Location: 700m underground;*
- *Approved in 2013, Construction since 2015, operation in 2023;*





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Technical Report

Neutrino physics with JUNO

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Physics yellow book:
J. Phys. G. 43 (2016) 030401

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operation	Planned	Planned	Operation	Operation
Power	17.4 GW_{th}	17.4 GW_{th}	17.4 GW_{th}	17.4 GW_{th}	9.2 GW_{th}

JUNO Collaboration

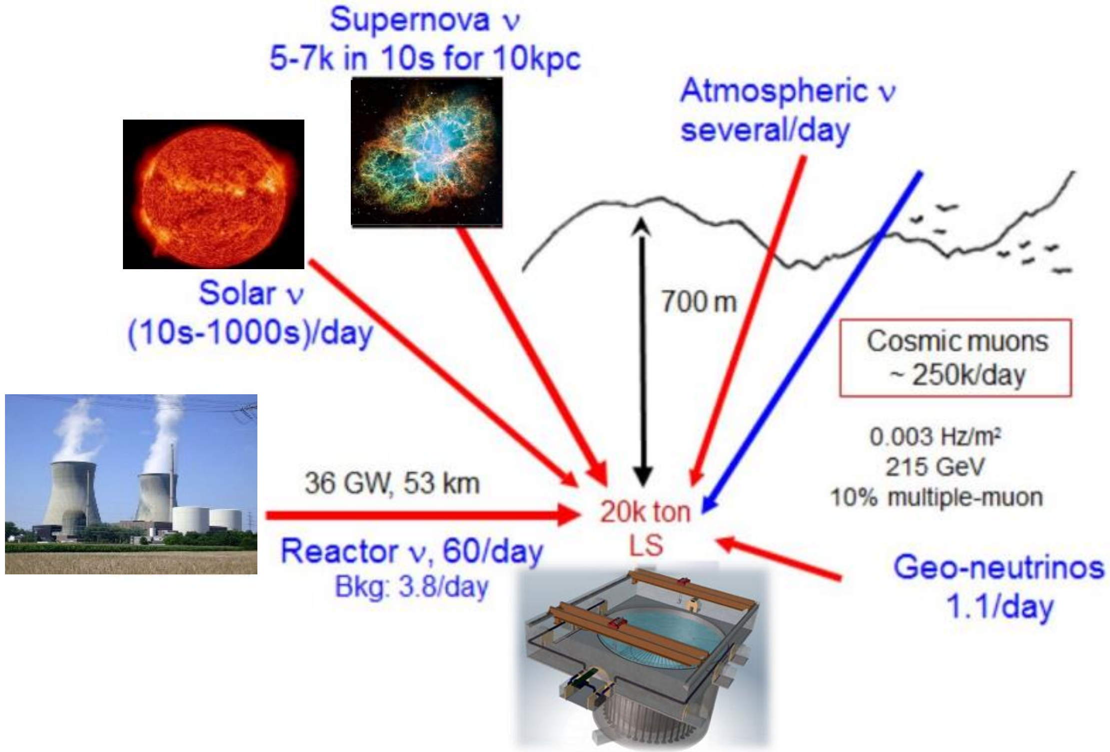
Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	IMP-CAS	Germany	FZJ-IKP
Belgium	Universite libre de Bruxelles	China	SYSU	Germany	U. Mainz
Brazil	PUC	China	Tsinghua U.	Germany	U. Tuebingen
Brazil	UEL	China	UCAS	Italy	INFN Catania
Chile	PCUC	China	USTC	Italy	INFN di Frascati
Chile	SAPHIR	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	IJCLab 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 Prospects

JUNO：A multipurpose neutrino experiment

Phyiscs:

- *Determine neutrino mass ordering;*
- *Precise measurements of three neutrino oscillation parameters;*
- *Supernova neutrinos;*
- *Solar neutrinos;*
- *Atmospheric neutrinos;*
- *Geo-neutrinos;*
- *Exotic searches, proton decay;*



Neutrino Mass Ordering

$$P_{\bar{\nu}_e \to \bar{\nu}_e}(L/E) = 1 - P_{21} - P_{31} - P_{32}$$

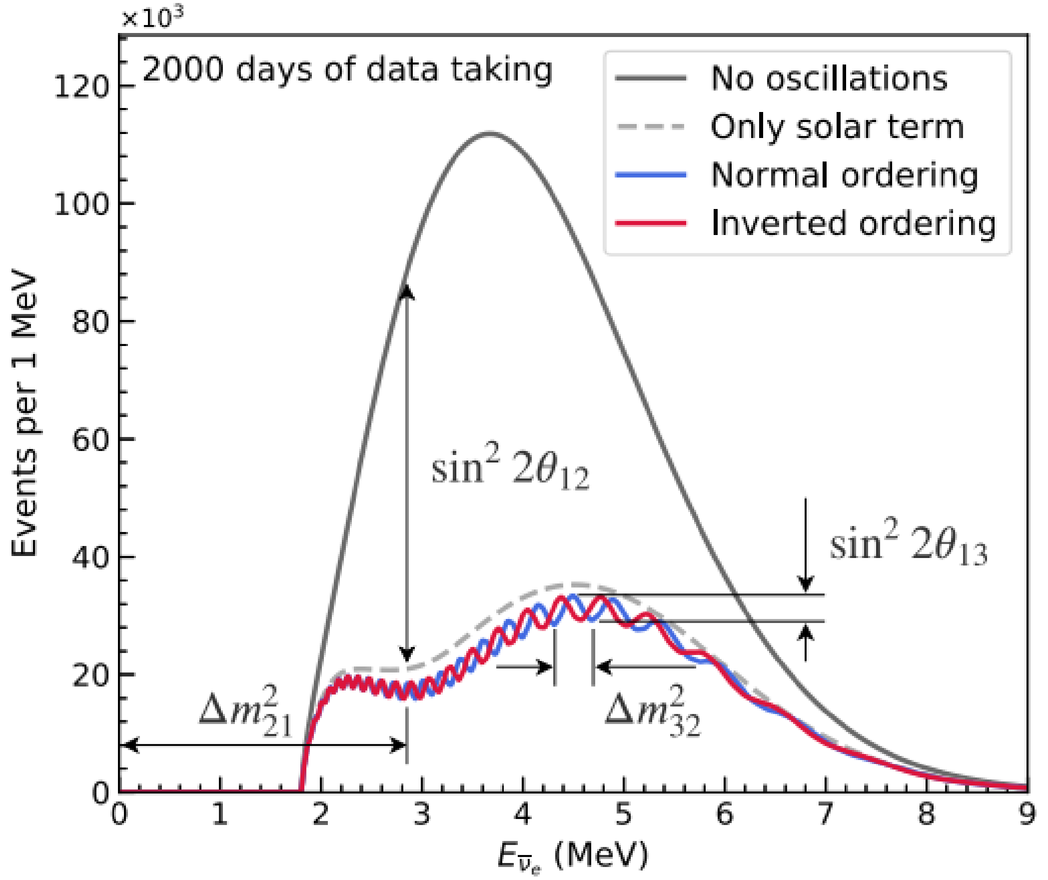
$$P_{21} = \cos^4(\theta_{13}) \sin^2(2\theta_{12}) \sin^2(\Delta_{21})$$

$$P_{31} = \cos^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{31})$$

$$P_{32} = \sin^2(\theta_{12}) \sin^2(2\theta_{13}) \sin^2(\Delta_{32})$$

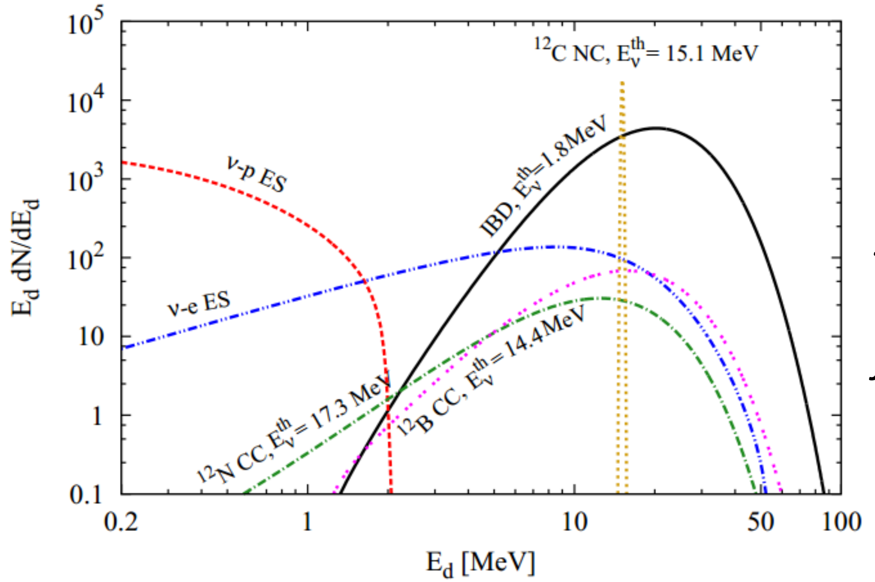
$$\Delta_{ij} \equiv \Delta m^2_{ij} L / 4E_\nu (\Delta m^2_{ij} \equiv m_i^2 - m_j^2)$$

- JUNO determines the NMO using the oscillation interplay between $\Delta m^2{}_{31}$ and $\Delta m^2{}_{32}$ at a medium reactor baseline (~53 km).;
- JUNO will resolve the NMO using precision spectral measurements of reactor antineutrinos；
- 3σ neutrino mass ordering sensitivity within 6 years.
- **Key: Energy resolution(3%@1MeV);**

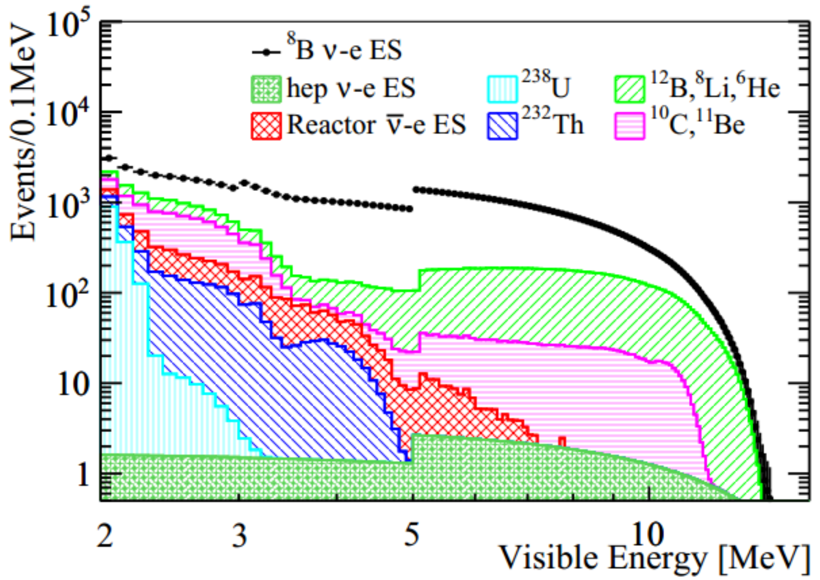


Physics Prospects

- **Supernova neutrinos**
  - Sensitive to flavor content, energy spectrum, time evolution;
  - 10000 events (5000 via IBD) for SN @ 10kpc;
- **Solar neutrinos**
  - ~60k signals and 30k backgrounds are expected in 10 years；
  - Shed new light on current tension in Δm^2_{21} between solar and reactor neutrinos measurement with the same detector;



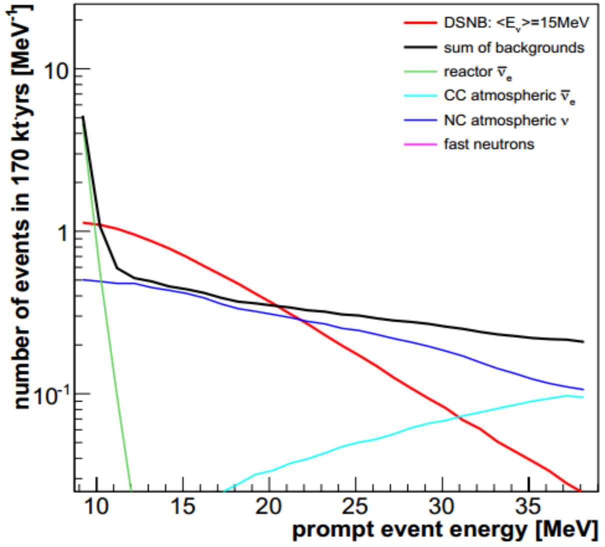
The neutrino event spectra with respect to the visible energy for a typical SN @ 10kpc



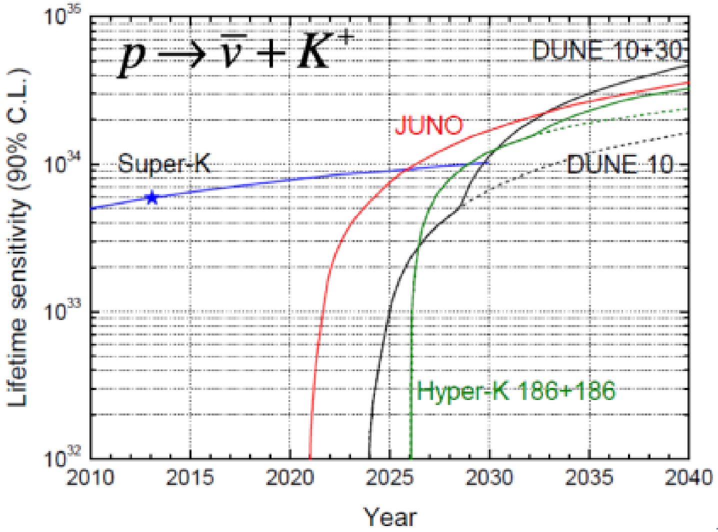
Expected signal and background spectrum of ^{8}B neutrino

Physics Prospects

- **Diffuse Supernova Neutrino Background (DSNB)**
  - 3σ sensitivity in 10 years or strongest constraint;
  - 2-4 IBDs per year above reactor neutrino energy range;
- **Atmospheric neutrinos**
  - Complimentary neutrino mass ordering sensitivity via matter effect
- **Geo-neutrino**
  - Explore origin and thermal evolution of the Earth
  - 400 - 500 neutrinos per year
- **Proton decay**
  - Competitive sensitivity through $p \rightarrow \bar{\nu} + K^{+}$



The DSNB signal dominates in the energy range of 11-22 MeV



JUNO Detector

Top Tracker

Pure water Room

Earth Magnetic Field shielding coils

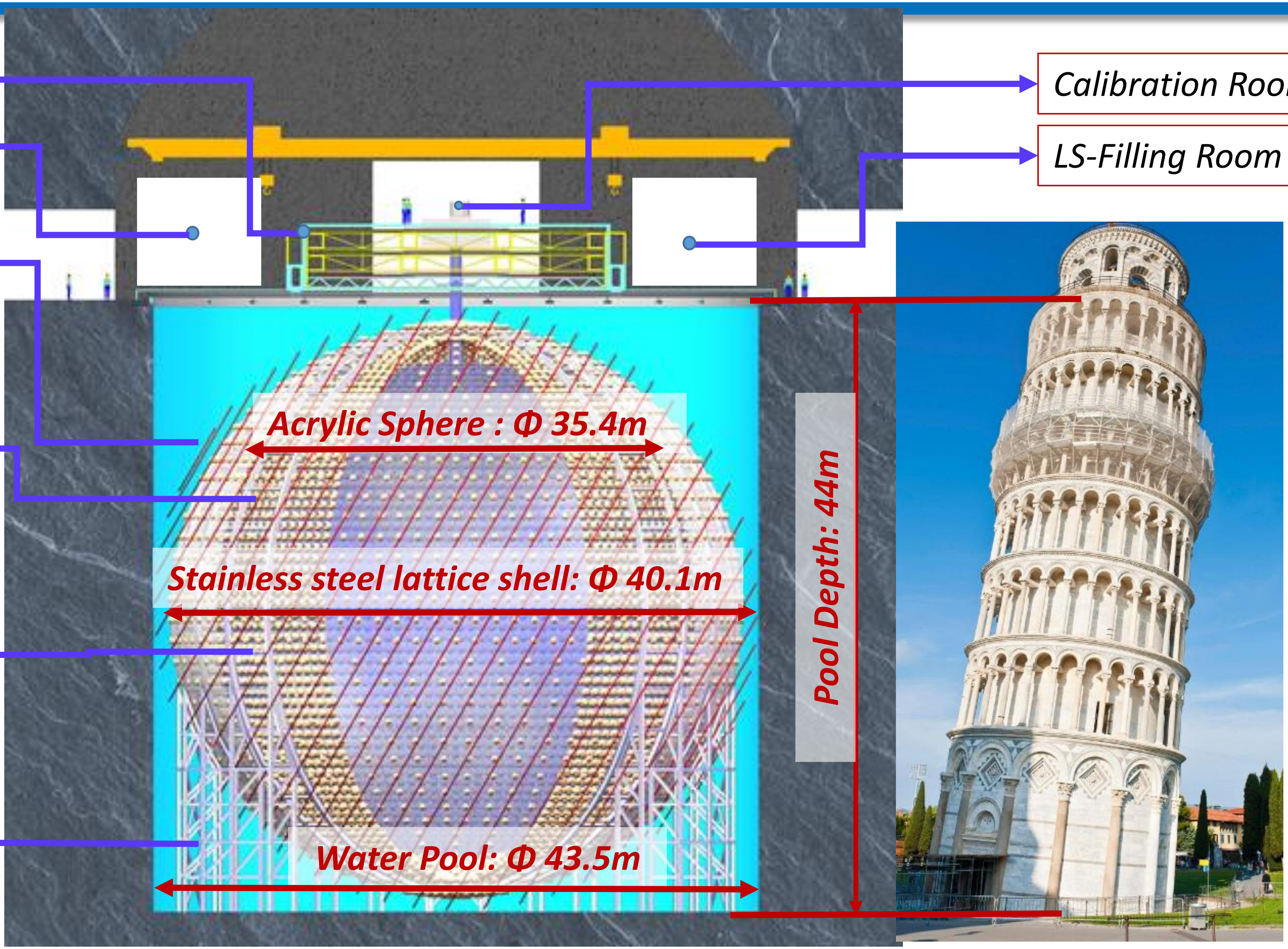
Central detector:
- Steel structure
- Acrylic Sphere
- 20kton LS

PMT:
- 17612 20’’ PMTs
- 25600 3’’ PMTs
- 77.5% Coverage

WCD:
- 40 kton Pure water
- 2400 20’’ PMTs

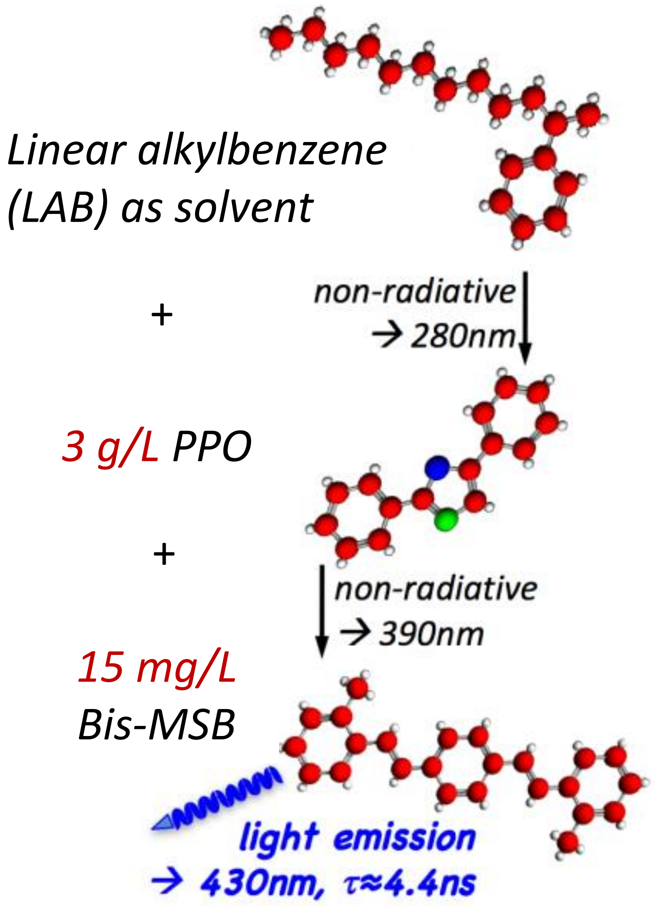
Calibration Room

LS-Filling Room



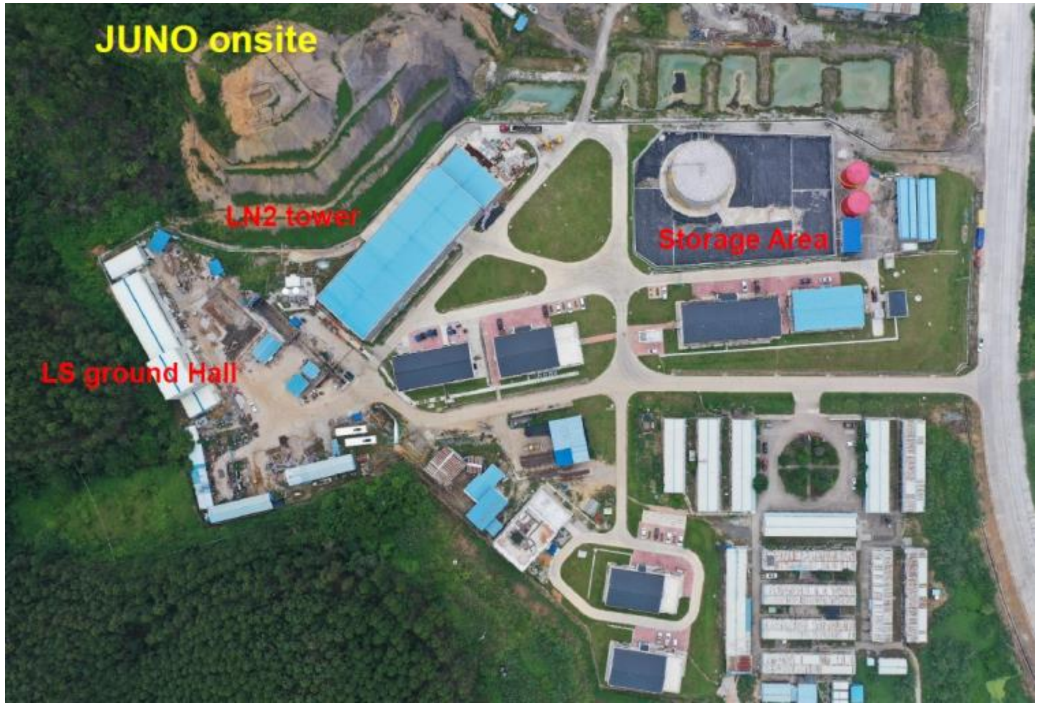
Status : Liquid Scintillator

- Using a recipe optimized from Daya Bay's experience;
- Tested and changed to be more suitable for JUNO;
- Higher light yield and more transparent;
  - 2.5g/L PPO;
  - 3mg/L Bis-MSB;
  - Filtration with Al_2O_3 column(Based on the "absorption" technique to remove the impurities and increase the attenuation length of LAB);
- Low background, 10^{-15} U/Th for reactor neutrinos and 10^{-17} U/Th for solar neutrinos;
  - Distillation: Remove heavy metal and improve transparency ;
  - Water extraction: Remove U/Th/K;
  - Gas stripping: Remove Ar/Kr/Rn;



The recipe of Daya Bay LS

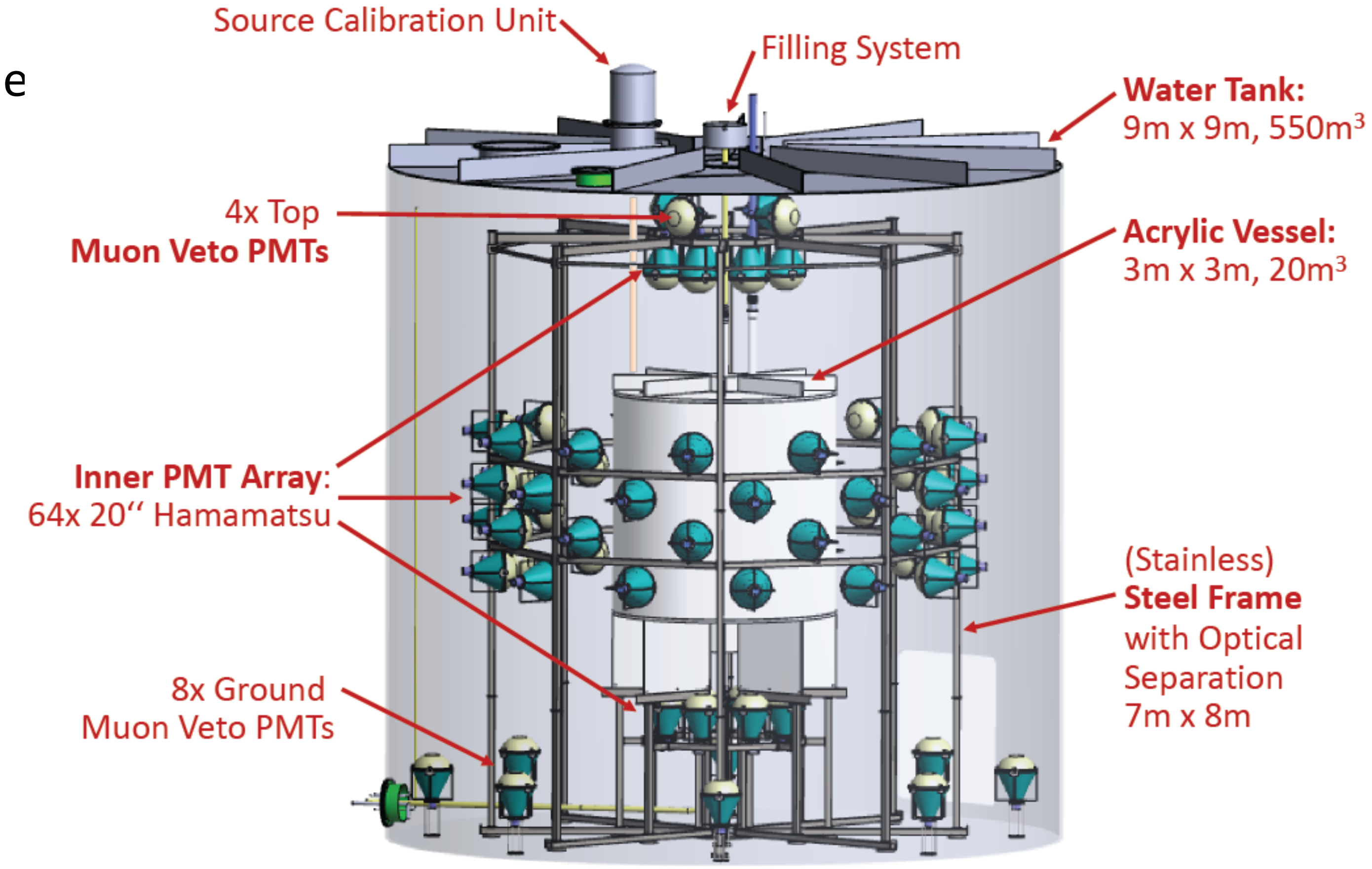
Status : Liquid Scintillator



- 5 kton LS storage tank and LN2 tower are ready, inner pressure of LS tank is ~0.5bar;
- Alumina Filtration Plant has been delivered onsite;
- Other work is well in progress;

Status : OSIRIS

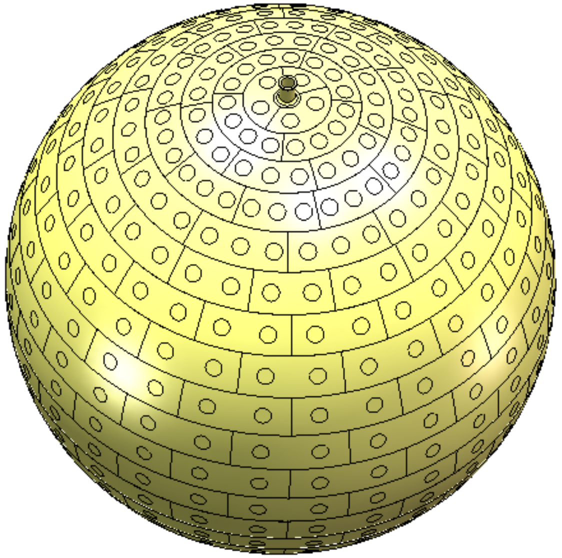
- Online Scintillator Internal Radioactivity Investigation System (OSIRIS);
- Monitor the radio-purity of the LS during the 6-months filling of JUNO, to ensure that no contaminated scintillator arrives inside CD.
- *Sensitivity: 10^{-16}g/g for U/Th within 24h measurement;*
- *Measure ~19 t LS per day;*
- *Detector:*
  - *Φ3m*H3m Acrylic tank;*
  - *81 20'' PMTs for photon detection;*
  - *2.5m water shielding + 12 20'' PMTs;*
- *Water tank is onsite, acrylic vessel is under production, others are well in progress;*



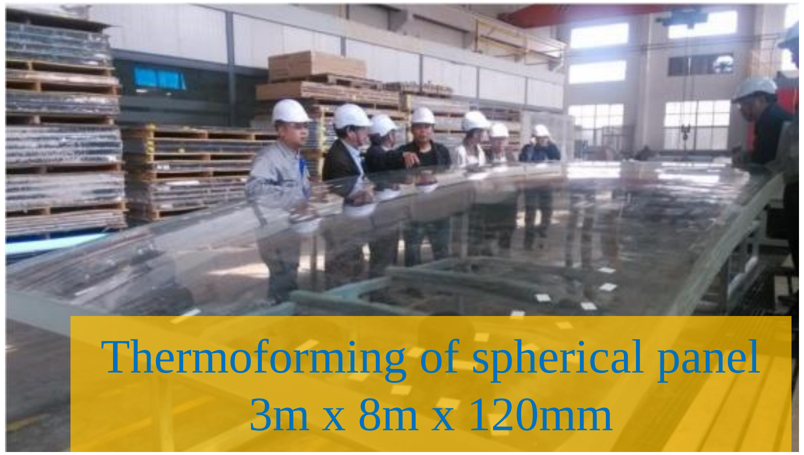
The OSIRIS facility

Status : CD Acrylic

- *Central Detector(CD): Acrylic Sphere + Stainless Steel Support ;*
- *The acrylic sphere is composed of 265 pieces of spherical panels;*
- *Thickness:120mm, Net weight: ~600 tons;*
- *Transparency > 96% in pure water;*
- *DonChamp won the bid at 2017.02*
  - *Flat panel production finished and thermal forming is in progress;*
- *Process control for low radiation background:*
  - *Filter in MMA material & Special reaction kettle/pipe;*
  - *Moulding: pure water/clean room;*
  - *Thermoforming: film or placket to shield the dust and radon;*
  - *Bonding: filled with clean air or N_2;*
  - *Shield Rn: plastic film on the surface of the acrylic;*
  - *Clean the inner surfaces of the acrylic sphere:*
- *The samples for acrylic has met the 1ppt requirement for U/Th;*



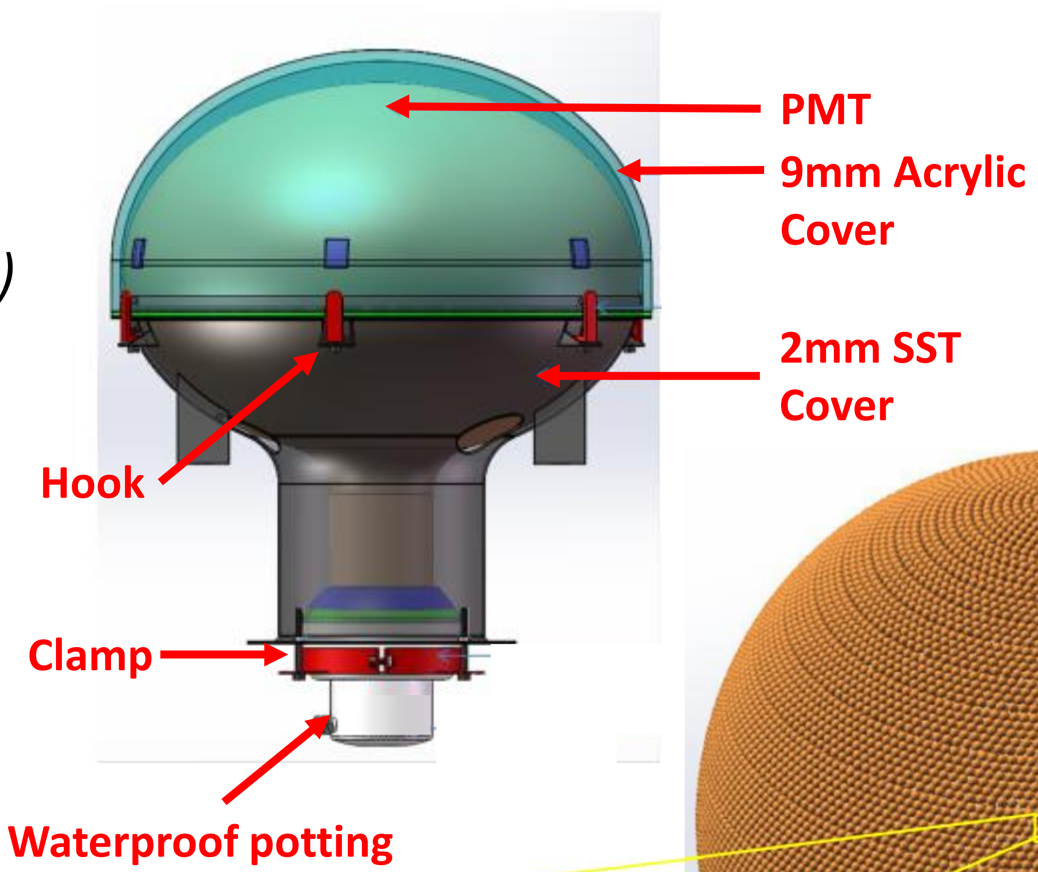
The Acrylic Sphere

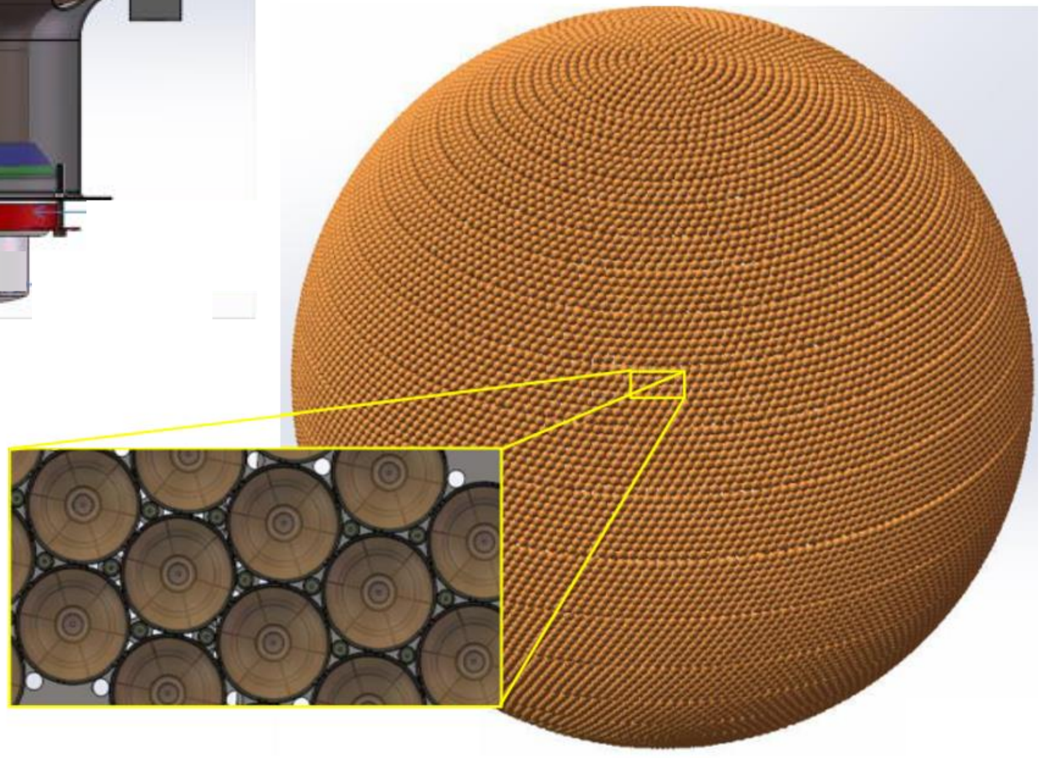


Thermoforming of spherical panel
3m x 8m x 120mm

Status : JUNO PMTs

- ➢ *Two sizes of PMTs will be used to fully(~78%) cover CD;*
  - *17612 20'' PMTs for CD (~75%) + 2400 20'' PMTs for Veto;*
  - *25600 3'' PMTs(~2.7%);*
- ➢ *Implosion protection;*
- ➢ *Waterproof potting;*
- ➢ *Custom-made divider and electronics;*
- ➢ *Stringent quality control*
  - *All PMTs will be tested before and after potting;*

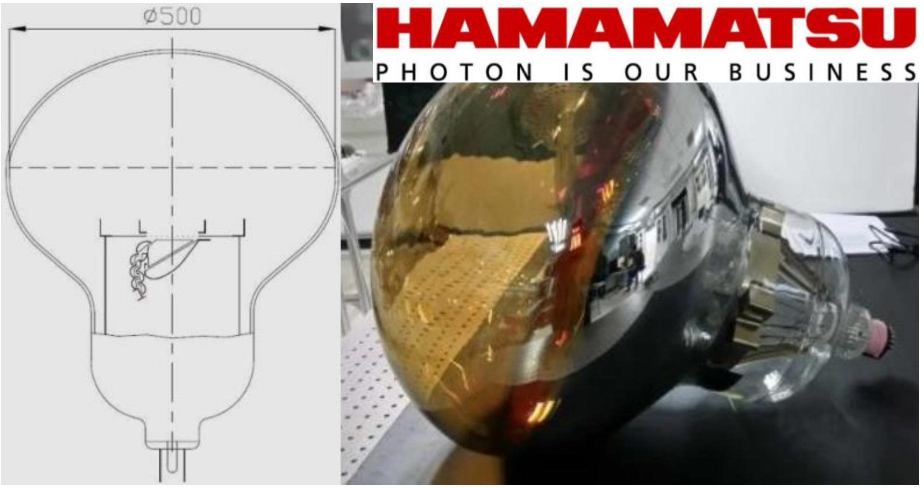


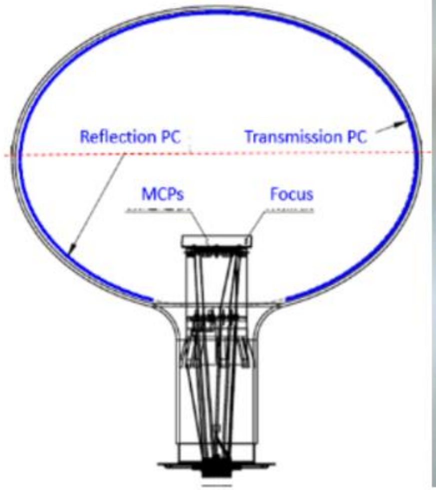


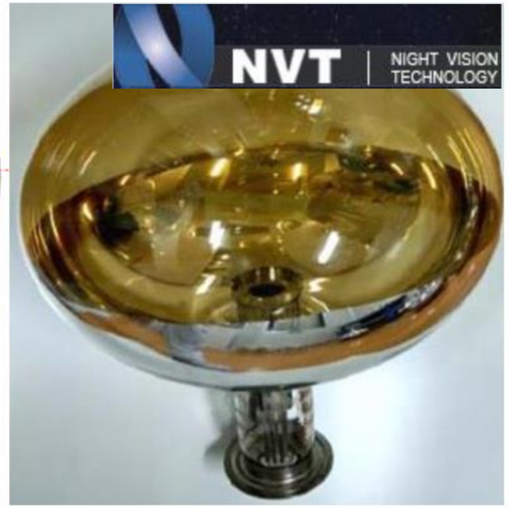
Status : Large PMT

- *Two types of 20'' PMTs will be used:*
  - *15,000 Micro-channel plates PMTs (MCP-PMT,NNVT);*
  - *5,000 Dynode PMTs (Hamamatsu, R12860HQE) ;*
- *MCP-PMTs are custom designed and manufactured for JUNO ;*
- Bare PMT testing completed, mass potting is on-going;

Characteristic	Unit	MCP-PMT	Dynode PMT
Detection efficiency (QE*DE)	%	28.7	28.1
P/V of SPE	ns	3.5, >2.8	3, >2.5
TTS on top point	ns	~12, <15	2.7, <3.5
Rise/Fall time	ns	2/12	5/9
Anode dark count	Hz	20K, <30K	10K, <50K
After pulse rate	%	1, <2	10, <15
Radioactivity of glass	ppb	^{238}U: 75 ^{232}Th: 74 ^{40}K: 4	^{238}U: 400 ^{232}Th: 400 ^{40}K: 40







Status : Small PMT

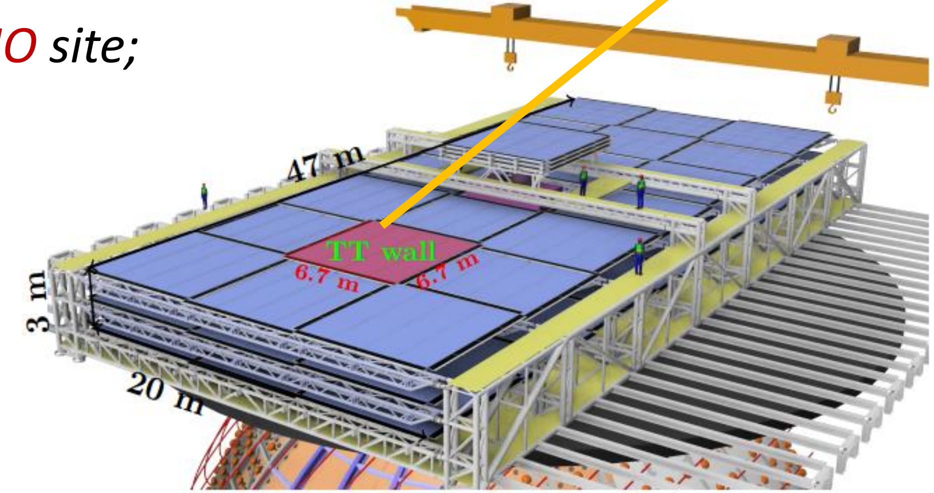
- *Improve the energy scale precision, in particular, the coupling of non-linearity and non-uniformity.*
  - *SPMTs almost always work at SPE mode for IBD events and are expected to have almost zero dynamic range, hence virtually no non-linearity, thus providing a linear reference to LPMT;*
- *25600 3'' PMTs contracted to HZC, the production and bare tests are done, test after potting is ongoing;*

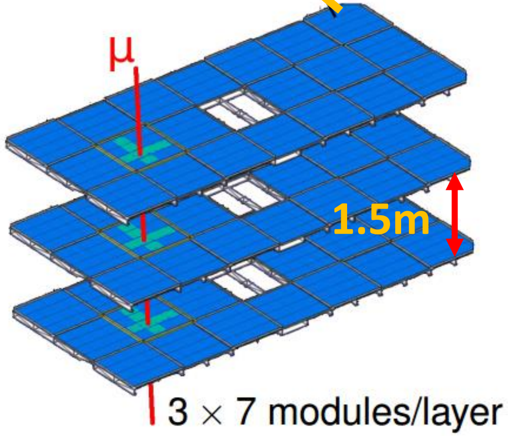
Parameters	Unit	Requirement	Data/Mean
Detection efficiency (QE*CE)	%	>22(Mean>24)	24.9
HV@2*10^6 gain	V	900-1300	1113
SPE resolution	%	<45(Mean<35)	33.2
P-V ration		>2(Mean>3)	3.2
Dark Rate@0.25P.E.		<1.8K(Mean<1K)	512
SPE TTS(FWHM)	ns	<5	3.7
QE non-uniformity	%	<11	4.9
Effective Diameter of cathode	mm	>74(Mean>76)	77.2
Spectral response range	%	QE320>5	10.2
		QE550>5	8.6

3'' PMTs

Status : Top Tracker

- *The top tracker(TT) precisely measure the muon tracking and provide valuable information for cosmic muon induced background study;*
- *Reusing the plastic scintillators from OPERA Target Tracker ;*
  - *62 modules covered half of the top area;*
  - *3 TT layers spaced by 1.5 m ,each layer have x,y readout;*
- *New electronics cards being designed to account for 100 × higher radioactivity from rock in JUNO site ;*
- *The plastic modules are already at JUNO site;*
  - *No significant aging observed;*

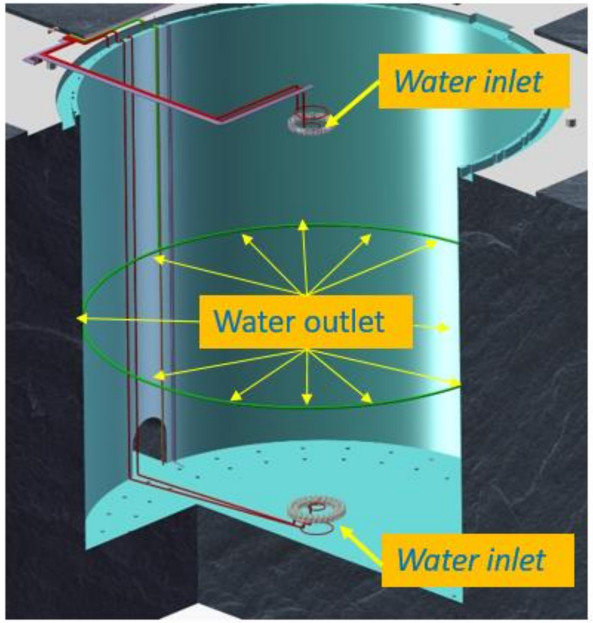


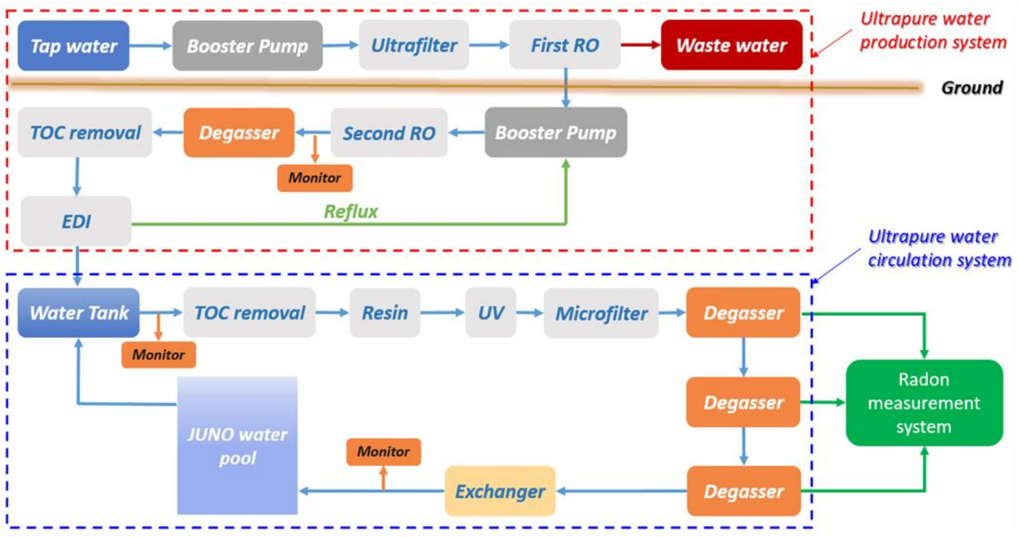


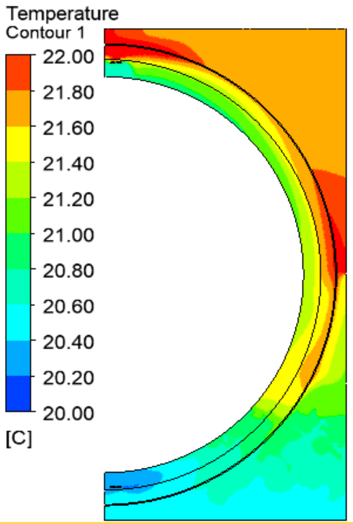
JUNO Site (Mar 2019)

Status : Water Cherenkov Detector

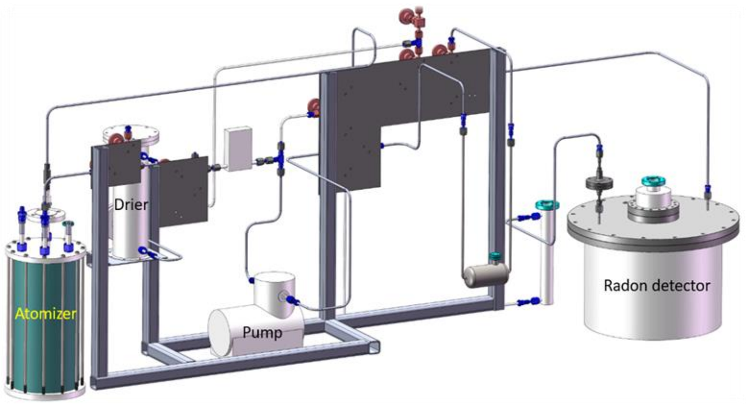
- A pool filled with 35 ktons of ultrapure water and instrumented with 2400 MCP-PMTs to form the water Cherenkov detector;
- Muon tagging efficiency is ~99.5%;
- Fast neutron background ~0.1/day;
- Water System:
  - Radon in water for JUNO prototype :< 10mBq/m^3;
  - Calculation results show 20℃< T_{water} <22℃;







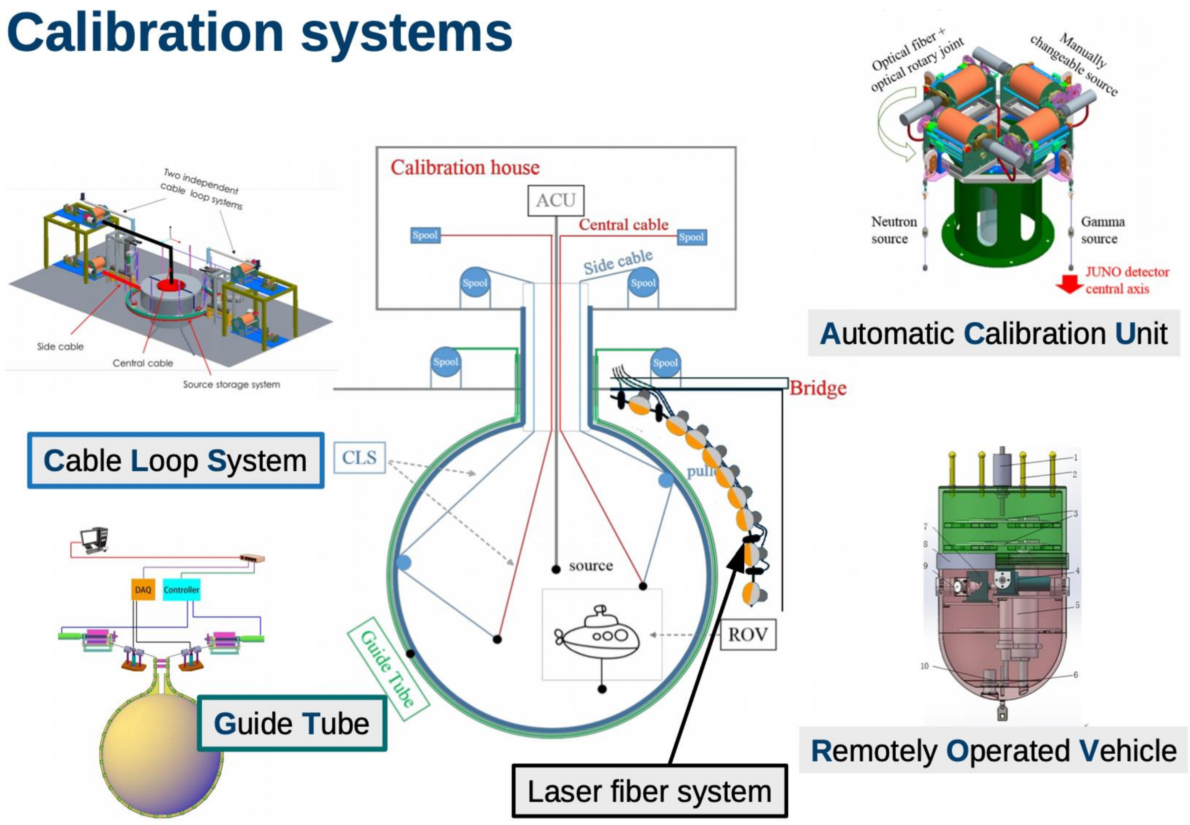
Temperature distribution



Radon measurement system

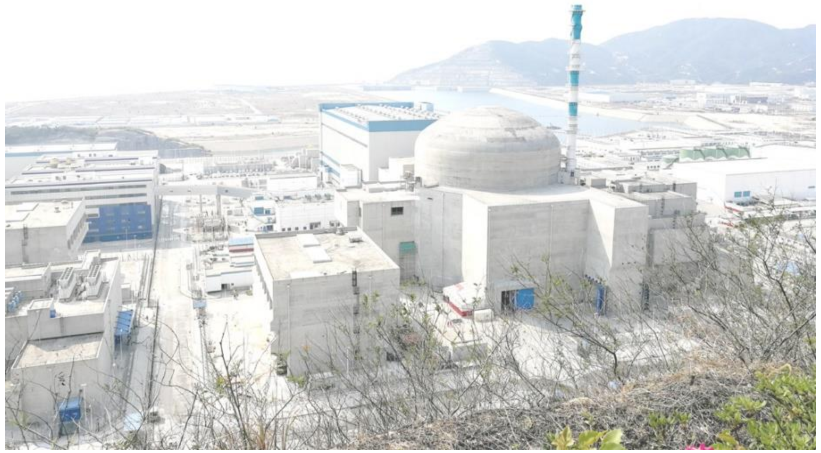
Status : Calibration system

- The calibration system need to accurately address both the non-uniformity and non-linearity in the detector energy response ;
- *Energy scale uncertainty < 1%;*
- Four complementary subsystems:
  - 1-D: Automated calibration unit(ACU);
    - → Scan the central axis;
  - 2-D: Cable loop system(CLS);
    - → Scan vertical plane;
  - 2-D: Guide tube calibration system(GTCS);
    - → Scan CD outer surface;
  - 3-D: Remotely operated vehicle(ROV);
    - → Full detector scan;
- Radioactive Sources:
  - γ、e+、n sources
  - ^{137}Cs、^{54}Mn、^{60}Co、^{40}K、^{68}Ge、^{241}Am-Be，^{241}Am-^{13}C ；



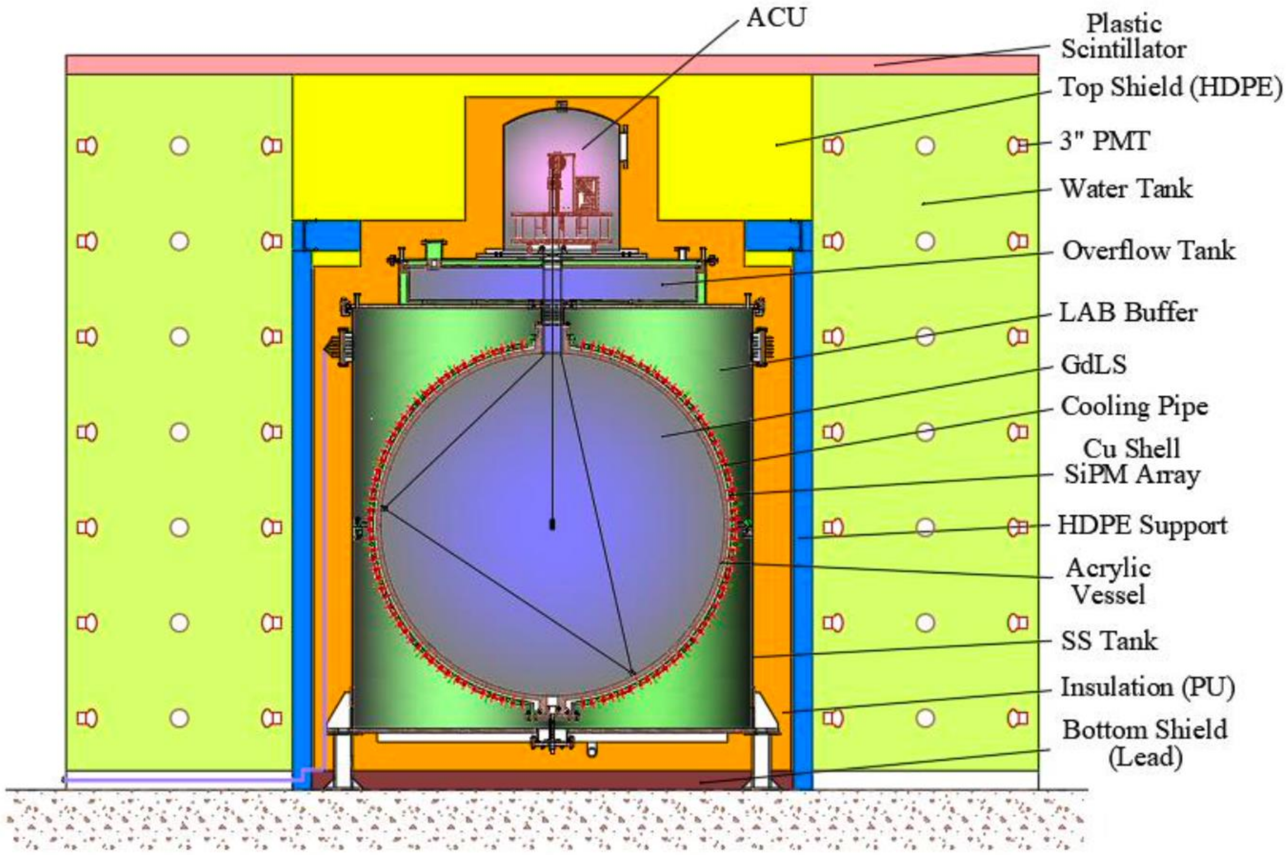
Status : JUNO-TAO

- Taishan Antineutrino Observatory (TAO), a ton-level, high energy resolution LS detector at 30m from the core, a satellite experiment of JUNO;
- To measure the fine structure of the reactor neutrino spectrum, and eliminate the model dependence of JUNO MO determination;
- TAO will be located at Taishan nuclear power plant;
    - 4.6 GW_{th} in operation;
    - Spacious room at 10 m underground;
    - ~30m horizontally from core;
- Event rate: ~2000 IBD/day;
- Energy resolution: ~2%@1MeV；



R&D status : TAO

- Target:
  - Gd-LS, 2.6 ton in total and 1 ton fiducial volume;
- Detector:
  - Gd-LS + Acrylic + LAB + SiPM;
- Full coverage with SiPMs, PDE>50%
- Light yield: 4500 P.E./MeV;
- Operated at -50 Centigrade (SiPM dark noise);
- A 1:1 prototype is under construction and it will be tested without full SiPM;
- TAO is expected to start operation in 2022;



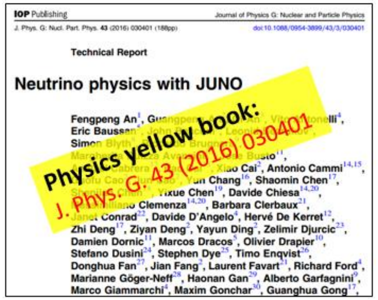
R&D status : Civil construction

- Blasting completed on Dec. 30, 2020 ;
- We are in the period of transition from civil construction to experimental installation;

Milestones & Schedule

2014
- International collaboration established;

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



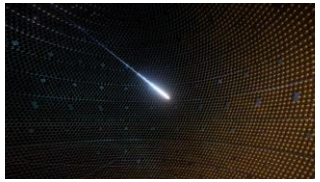
2016
- PMT production start
- CD parts production start
- Yellow book published

2017
- PMT testing start
- TT arrived

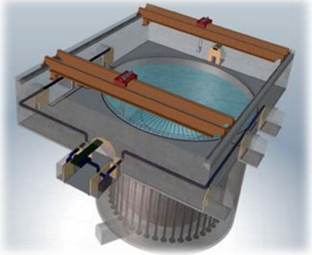
2018
- PMT potting
- Start delivery of surface building
- Start production of acrylic sphere

2020
- Civil construction completed
- Electronics mass production

2021-2023
- Detector installation,
- Detector ready for data taking



Neutrino detected



Summary

- ***JUNO: Rich neutrino physics prospects***
  - ***Determine MO with 3-4σ with 6 years data;***
  - ***Measure the neutrino oscillation parameters $\sin^2 2\vartheta_{12}$, Δm^2_{21}, and $|\Delta m^2_{32}|$ to a precision of better than 0.6%;***
  - ***Study neutrinos from supernova、the Sun、the Earth;***
  - ***…..;***
- ***The detector: A massive LS detector with excellent energy resolution***
  - ***The largest acrylic sphere ever constructed;***
  - ***20 ktons of highly transparent LS;***
  - ***Instrumented with 20000 20'' PMTs and 25600 3'' PMTs;***
  - ***4 calibration subsystems;***
  - ***Reference measurement of reactor neutrino energy spectrum with TAO;***
- ***Experimental installation will start soon, data taking expected to start in 2023 .***

Thanks for your attention!