An Introduction of JUNO

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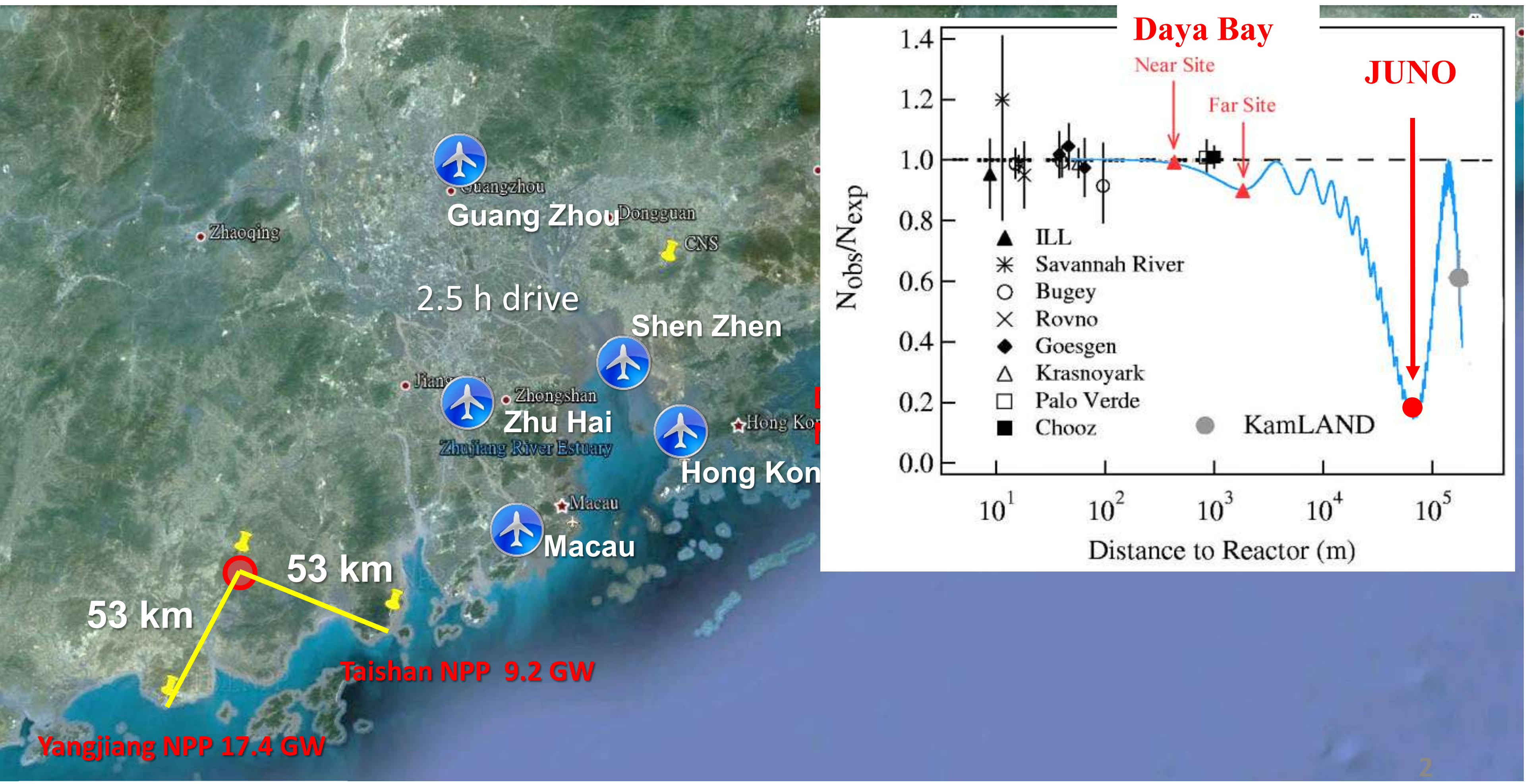
JUNO Experiment

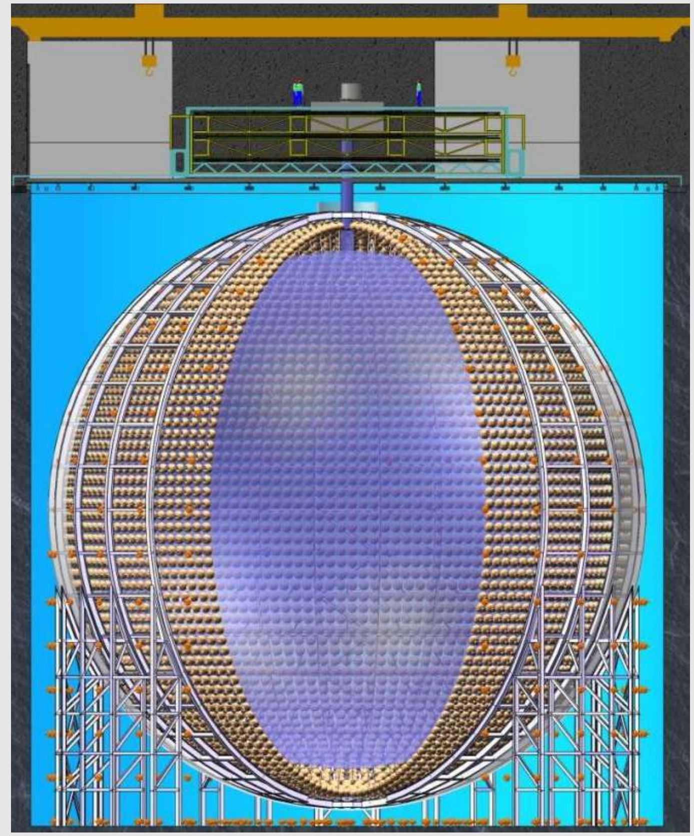
- Reactor neutrino spectrum by liquid scintillator for mass hierarchy
- Equal baseline to two reactor power plants: Yangjiang and Taishan
- Approved in 2013, construction in 2015-2024



Concept of JUNO for Mass Ordering

- A minimum target mass of 20 kt liquid scintillator for sufficient statistics → × 20 KamLAND
- A key requirement: energy resolution < 3%@ 1MeV → 1200 PE/MeV

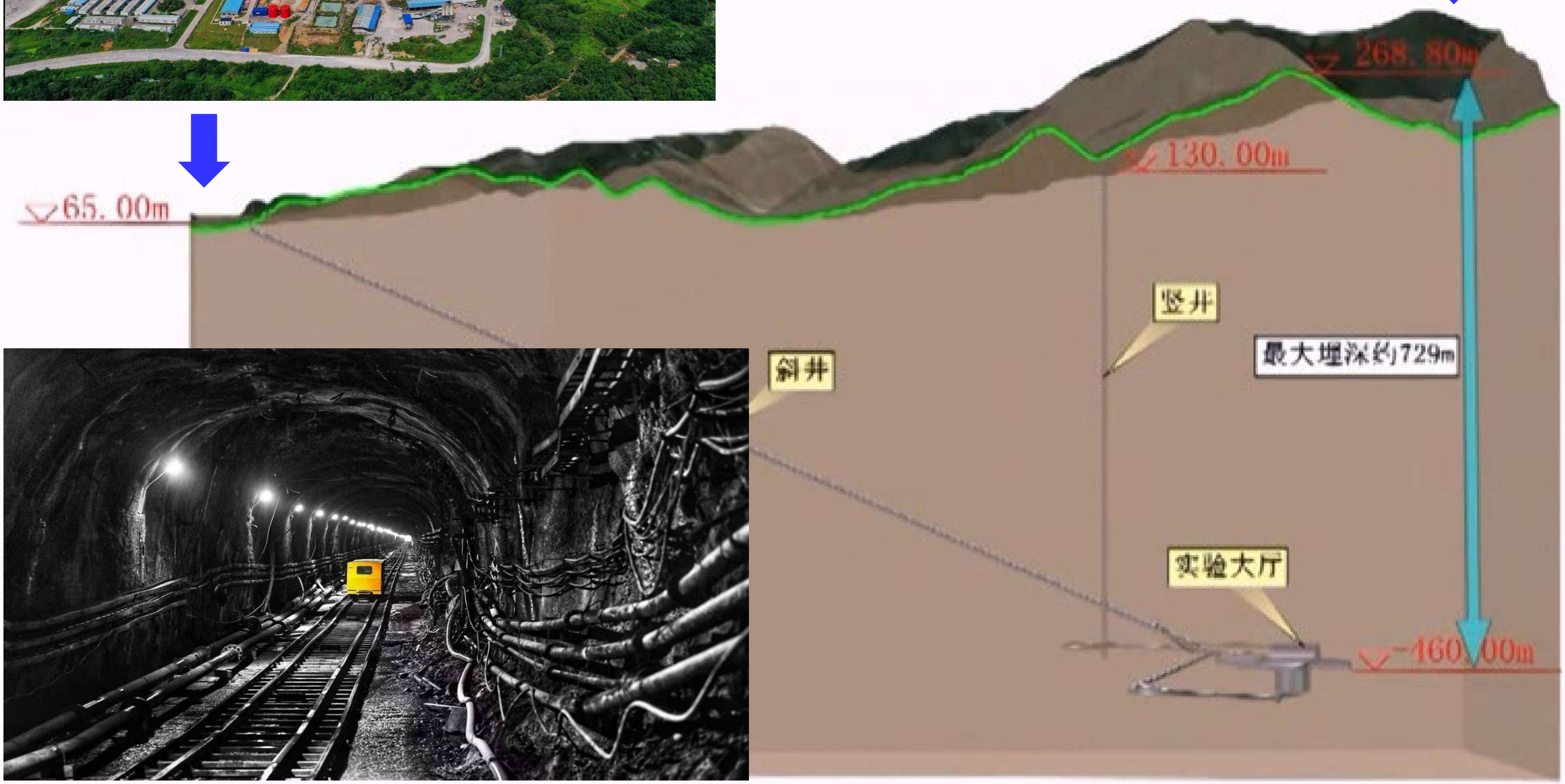
	KamLAND	JUNO	Ratio
Light yield	250 p.e./MeV	1200 p.e./MeV	5
PMT coverage	34%	75%	2.2
Detection Eff.(QE×CE)	~15%	30%	~ 2
LS transparency	12 m	> 24 m	-



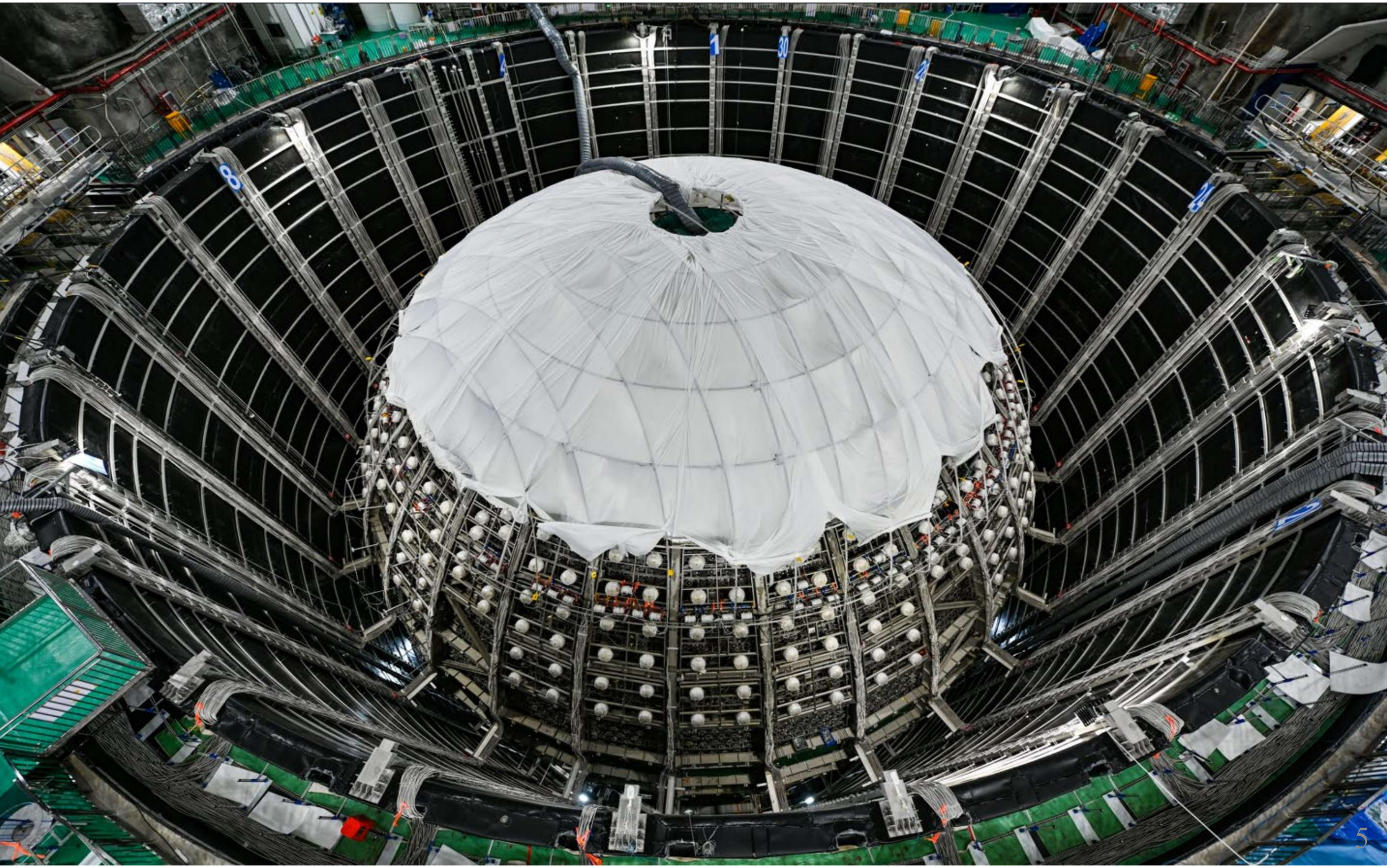
A two-layers structure for simplicity and cost: water as buffer and shielding → radiopurity and Rn control of water

- Technology R&D needed:
  - 20” high eff. PMTs
  - Transparent LS
  - Radiopurity control for 20 kt LS

~ 600m vertical shaft,
~1300m sloped tunnel
Underground cavern with
50m diameter, 70 m height



Aerial view



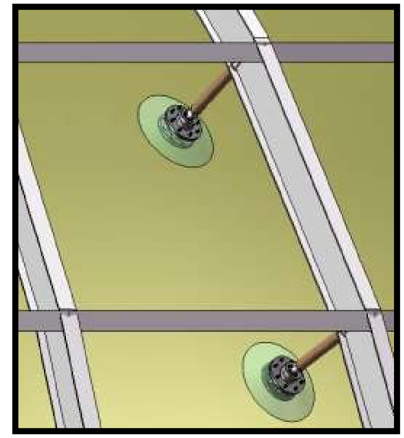
JUNO Collaboration

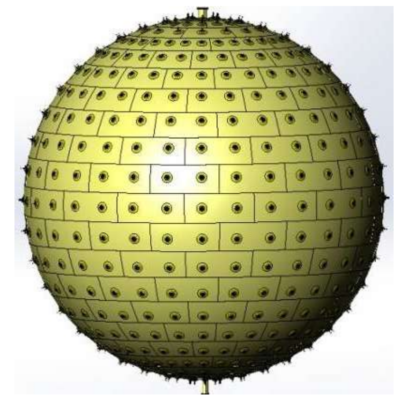
17 countries & regions
74 institutions
>700 members

Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	SYSU	Germany	U. Mainz
Belgium	Universite libre de Bruxelles	China	Tsinghua U.	Germany	U. Tuebingen
Brazil	PUC	China	UCAS	Italy	INFN Catania
Brazil	UEL	China	USTC	Italy	INFN di Frascati
Chile	PCUC	China	U. of South China	Italy	INFN-Ferrara
Chile	SAPHIR	China	Wu Yi U.	Italy	INFN-Milano
Chile	UNAB	China	Wuhan U.	Italy	INFN-Milano Bicocca
China	BISEE	China	Xi'an JT U.	Italy	INFN-Padova
China	Beijing Normal U.	China	Xiamen University	Italy	INFN-Perugia
China	CAGS	China	Zhengzhou U.	Italy	INFN-Roma 3
China	ChongQing University	China	NUDT	Pakistan	PINSTECH (PAEC)
China	CIAE	China	CUG-Beijing	Russia	INR Moscow
China	DGUT	China	ECUT-Nanchang City	Russia	JINR
China	Guangxi U.	China	CDUT-Chengdu	Russia	MSU
China	Harbin Institute of Technology	Czech	Charles U.	Slovakia	FMPICU
China	IHEP	Finland	University of Jyvaskyla	Taiwan-China	National Chiao-Tung U.
China	Jilin U.	France	IJCLab Orsay	Taiwan-China	National Taiwan U.
China	Jinan U.	France	LP2i Bordeaux	Taiwan-China	National United U.
China	Nanjing U.	France	CPPM Marseille	Thailand	NARIT
China	Nankai U.	France	IPHC Strasbourg	Thailand	PPRLCU
China	NCEPU	France	Subatech Nantes	Thailand	SUT
China	Pekin U.	Germany	RWTH Aachen U.	U.K.	U. Warwick
China	Shandong U.	Germany	TUM	USA	UMD-G
China	Shanghai JT U.	Germany	U. Hamburg	USA	UC Irvine
China	IGG-Beijing	Germany	FZJ-IKP		

Central Detector: Design

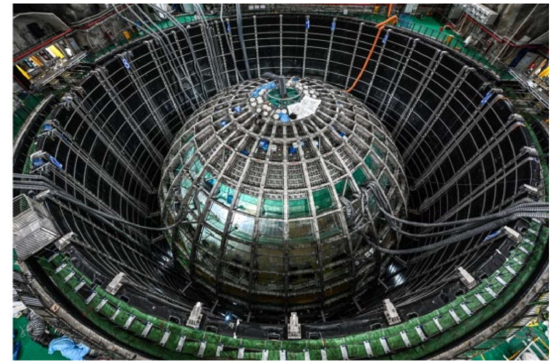
- **A ϕ~40m SS structure to hold a ϕ~35m acrylic sphere and to mount PMTs**
  - ⇨ Acrylic sheets: 8m × 3m ×12 cm
  - ⇨ Supporting bar to hold the Acrylic tank
- **Main issues:**
  - ⇨ Mechanical precision for minimum PMT clearance (3 mm)
  - ⇨ No welding, Screw clearance(1mm)
  - ⇨ Thermal expansion matching: 21°C ± 1°C
  - ⇨ Earth quake safety with liquid in acrylic sphere
  - ⇨ Acrylic:
    - Aging, creep, crazing,
      - 80% after 20 years
      - No creep & crazing under 5.5 Mpa
    - Bonding: fast and good quality
      - 70 -80 % strength
    - Strength of the supporting rod at bottom:
      - ~ 50 t (safety factor ~ 4)





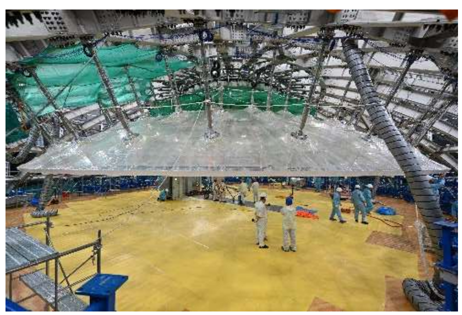
Density difference between Water and LS (0.15g/cc) leads to <~6m water pressure to the acrylic tank
➔ ÷5 Aquadom in Berlin

Central Detector Status

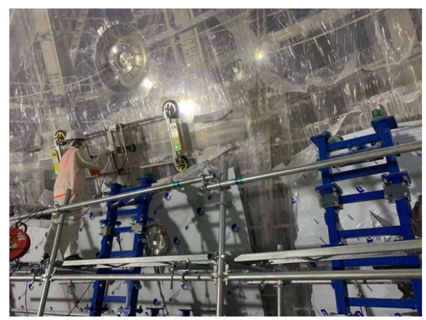


- **SS structure completed except bottom 4 layers**
- **Acrylic Panel Production at the factory: no issue**
  - ✓ Sanding, polishing, cleaning of panels to have good transparency(>96%) and low background (< 1 ppt U/Th)
- **Acrylic Sphere construction onsite**
  - ✓ Lifting platform works well: diameter and height changed several times
  - ✓ Started from the top, 13/23 layers finished （positioning, bonding, annealing, sanding, polishing, cleaning, film protection, etc.) ➔ defects appeared and repaired
  - ✓ SS bars connecting the acrylic and SS, sensors on them for stress monitoring
  - ✓ Fresh air from chimney down to the lifting platform, temperature, Rn and dust under control

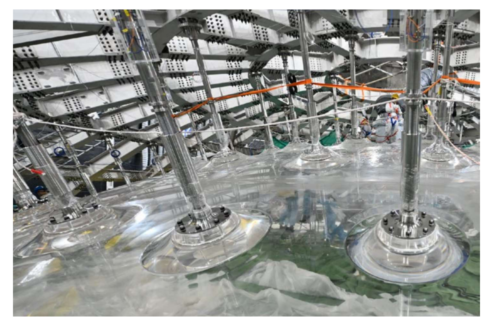
Lifting platform before serve



The first five layers



Sanding and polishing



Bars between SS and acrylic

Inside surface to be cleaned once finished and before the LS filling

Veto

- 5 mm thick HDPE lining in the water pool and cable trench to stop Rn and for the cleanness of water ➔ completed
- Supporting structure for cable routing on the wall installed
- Veto PMT modules, magnetic field shielding system installation tested
- 100 t/hr. ultrapure water system installed and partially tested
  - Test results: U/Th < 10^{-15} g/g and Rn < 10 mBq/m^3
- TT modules and electronics in good shape, support structure under production
- Others: Water pool top and bottom structure, cover, water pipes in the pool, etc.

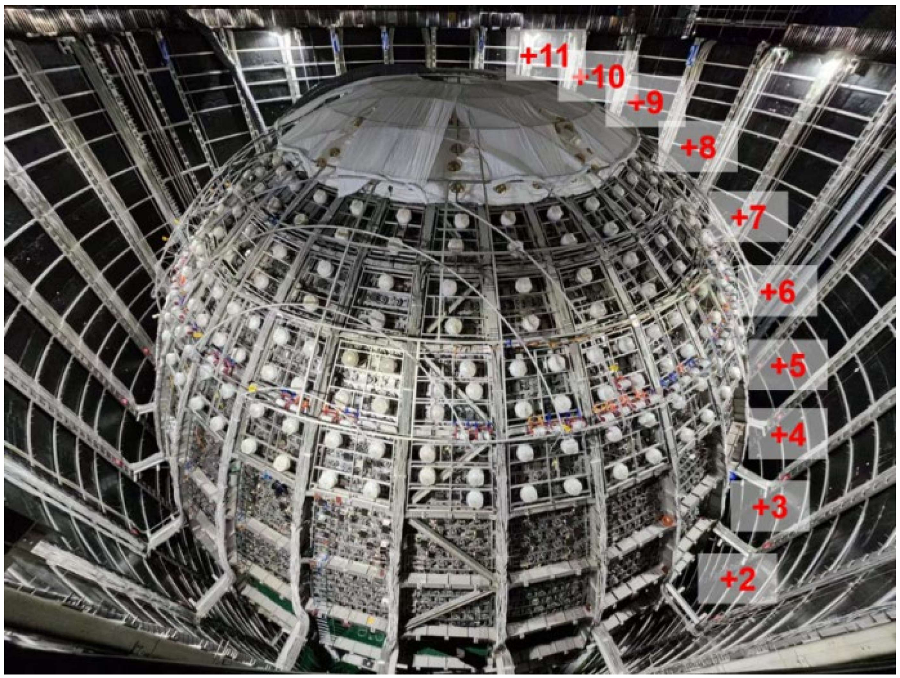
HDPE lining, VETO PMT modules, EMF, cable trench

Ultra Purity Water system

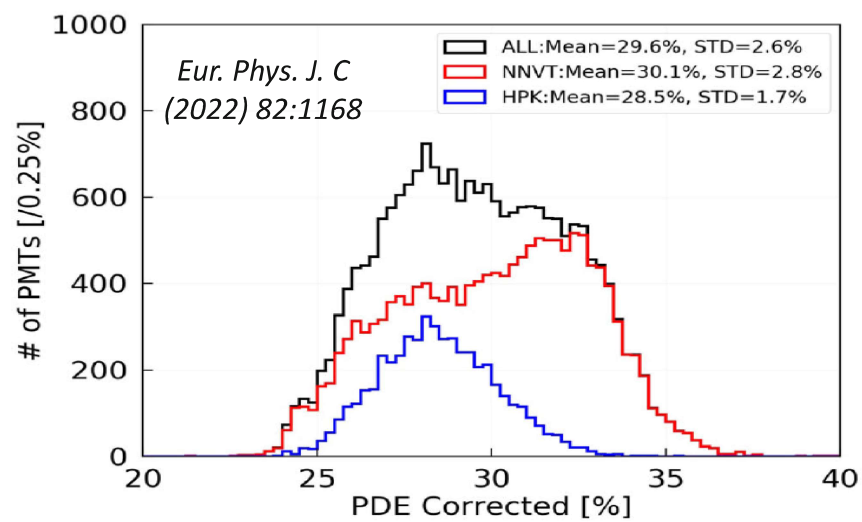
TT Electronics

PMT & Electronics Installation

- layer +11 to layer +2 finished now, in total 22 layers + 2 poles
- 7225 (out of 20012) 20-inch PMTs + 1783 (out of 6881) Electronics boxes installed
- 9223 (out of 25600) 3-inch PMTs + 83 (out of 200) Electronics boxes installed

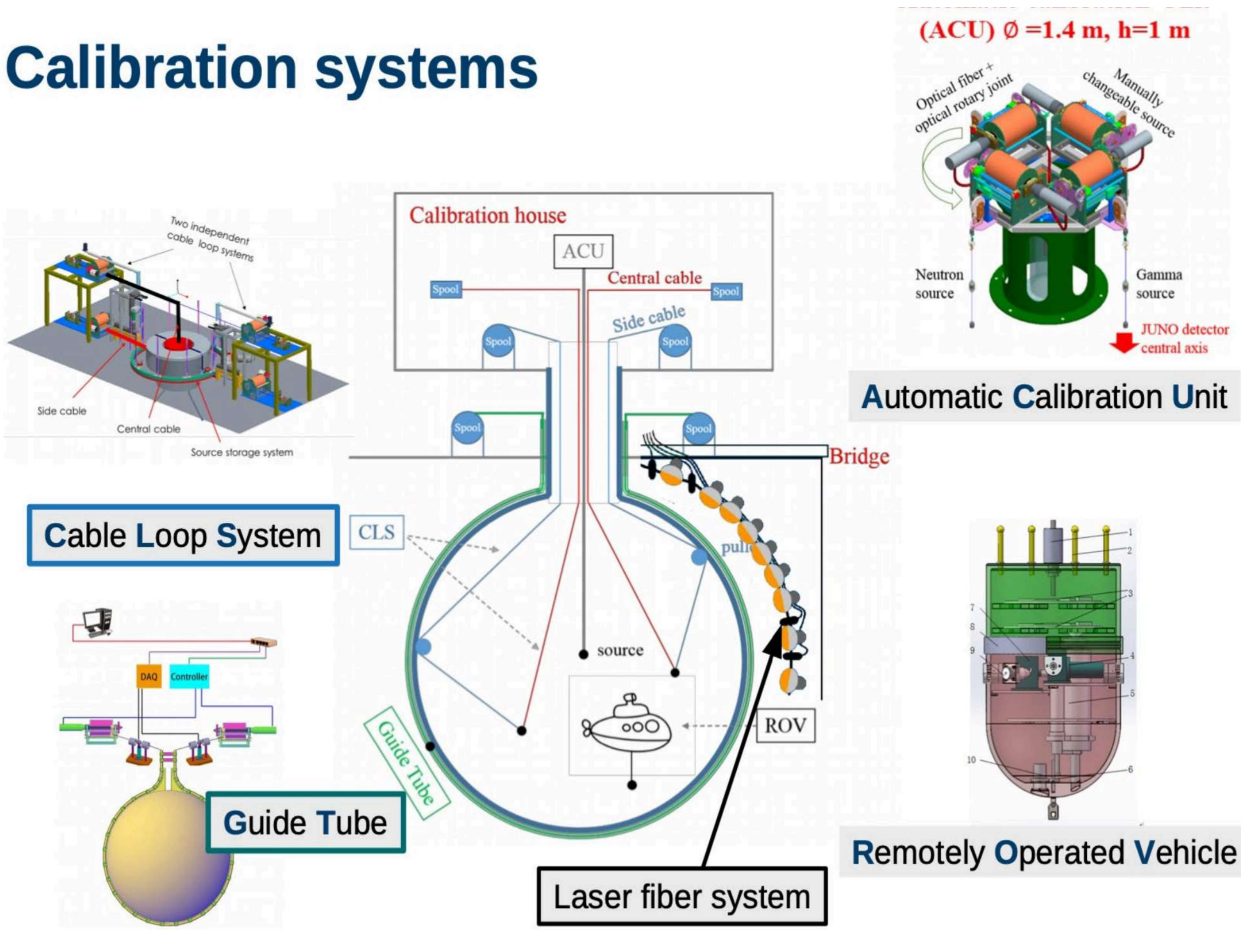


- New type of MCP-PMT developed by IHEP & NNVC jointly
- Based on performance, cost, risk,
  - MCP-PMT: 15000
  - Dynode PMT(Hamamatsu): 5000



Calibration

Calibration systems



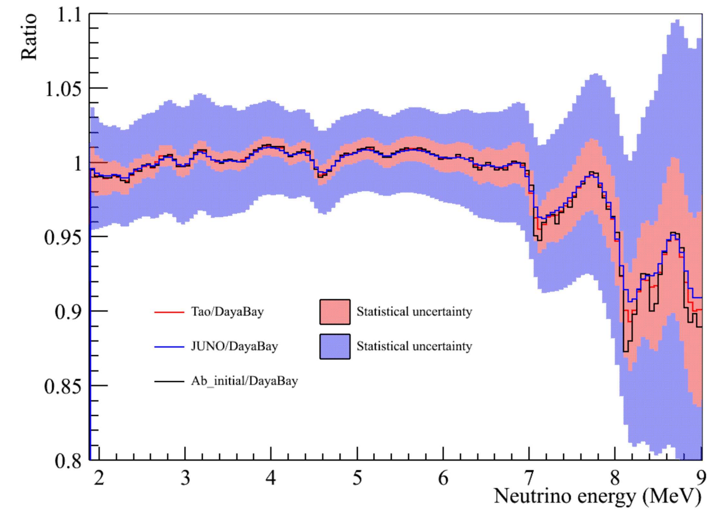
CLS testing

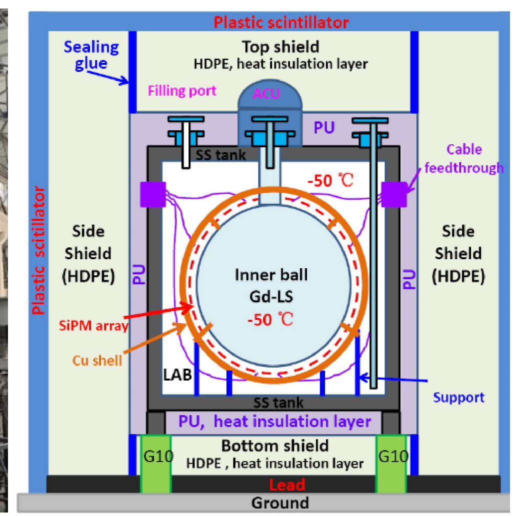
USS

- Highly redundant, multiple sources, full coverage
- For optical transmission, PMT response, energy nonlinearity, position dependence etc.
- Hardware production and Installation on the way, according to schedule

JUNO-TAO

- Goal: precisely measure reactor ν spectrum
  - to constrain spectrum uncertainties for MH determination
  - Sterile neutrinos, nuclear data base etc.
- Detector design
  - ~40 m from Taishan core (4.6 GW)
  - 4500 p.e./MeV, <2% resolution @ 1MeV
  - Fully covered by ~10 m^2 of SiPM(PDE>50%)
  - 2.8 ton Gd-LS at -50 ℃ (for SiPM dark noise)
- Status:
  - R&D successful, new LS receipt at -50 ℃
  - SiPM purchased and tested OK
  - Electronics in production
  - Cryogenics and detector system under assembly
  - Permission from the power plant obtained





Liquid Scintillator Design & Status

- System design & goal:
  - ⇨ LS attenuation length: 15m ➔ >20m
    - ✓ Purification
      - – Al_2O_3 Filtration column
      - – Distillation
      - – Water extraction
      - – Nitrogen stripping
  - ⇨ LS receipt for highest possible light yield:
    - ✓ LAB + 2.5 g/L PPO + 3 mg/L Bis-MSB
  - ⇨ Low radioactive backgrounds:
    - ✓ 10^{-17} g/g for IBD & solar neutrinos
  - ⇨ OSIRIS
    - ✓ An online detector with 20t LS for a sensitivity of 10^{-15} g/g per day
- Status:
  - ⇨ All mixing, purification and auxillary system installed, under commissioning now
  - ⇨ LAB attenuation length > 25m

LS hall near the entrance

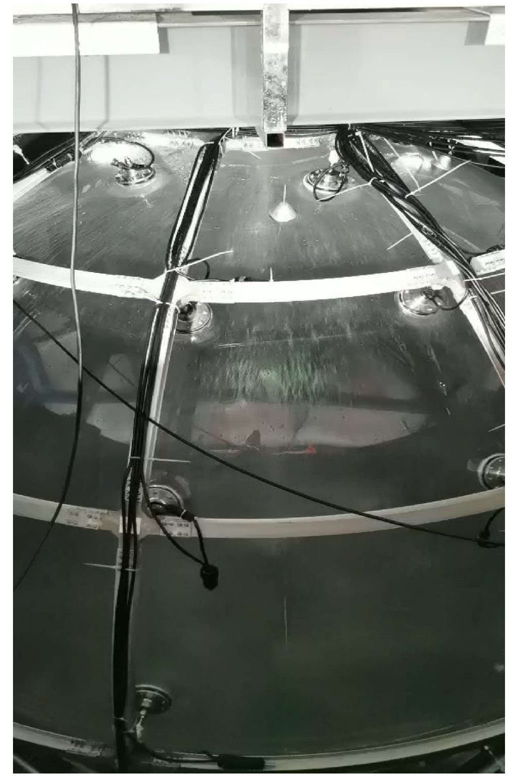
Underground LS hall

LS Filling

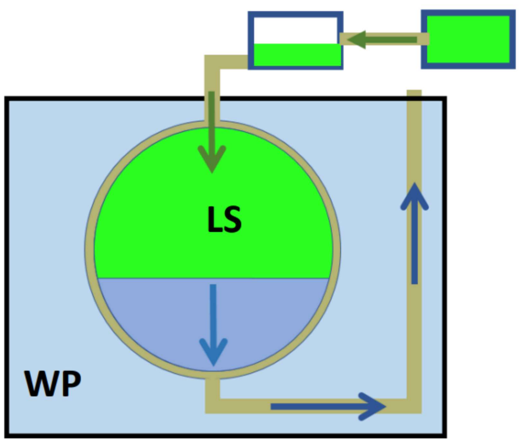
Unique

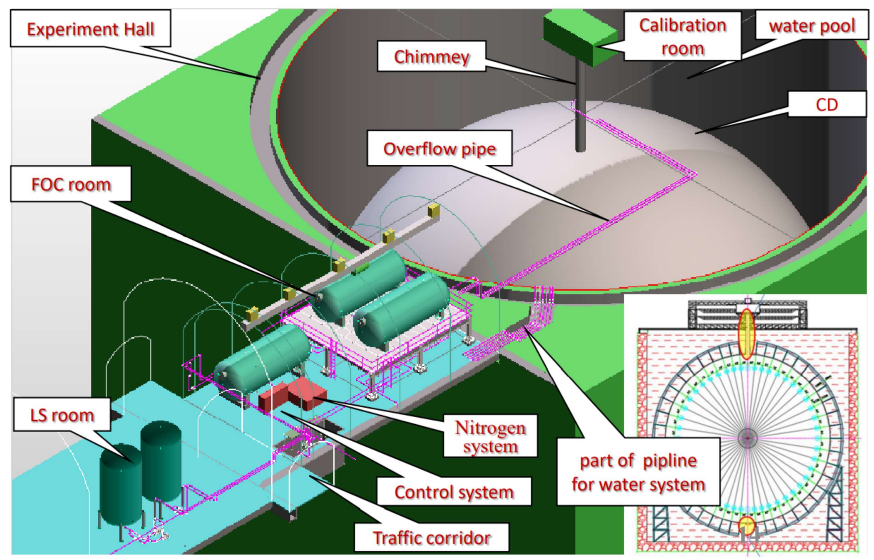
Reduce dust/Rn to 1% level

Complete CD construction → 1-2 weeks settlement with proper moisture → Remove the protective film and wash the acrylic surface by the high pressure water spray → Fill CD by high purity water → LS filling by replacing water



- Water for filling: U/Th<10^{-15} g/g, ^{226}Ra<0.1 mBq/m^3
  ➔ test results OK !





Radiopurity control

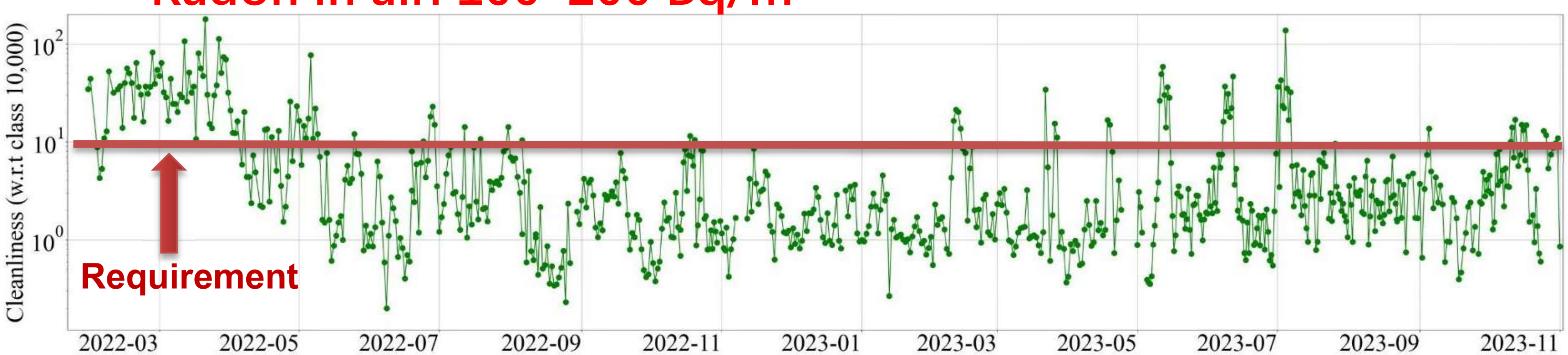
Material screening

	Requirement	Measurement
Acrylic	< 1 ppt	0.62 ppt U, 0.72 ppt Th
PPO	< 0.1 ppt	0.066 ppt U, 0.099 ppt Th
bisMSB	< 30 ppt	~20 ppt U/Th
LAB/LS	~ 0.01-0.1 ppq	Sensitivity: 2-5 ppq (validated) 0.1 ppq (in progress)
HP-N_2	^{222}Rn <10 μBq/m^3, ^{85}Kr <50 μBq/m^3	5 μBq/m^3 ^{222}Rn, 2-20 μBq/m^3 ^{85}Kr
HP-water (5 t system)	^{226}Ra <100 μBq/m^3, ^{222}Rn < 10 mBq/m^3	50 μBq/m^3 ^{226}Ra, 5 mBq/m^3 ^{222}Rn

Detector cleaning and protection

Truss	Four times cleaning
Pool liner	Three times cleaning
Veto PMT	Cover with clean cloth
LS system cleaning	degreasing → pickling → passivation → DI water cleaning
Acrylic surface	sanding → polishing → cleaning → film protection
Filling system	seal + spray → water jet cleaning → water filling → LS filling

- **Underground Lab environment**
  - **Cleanliness: equivalent to Class 10,000-100,000**
  - **Radon in air: 100-200 Bq/m^3**

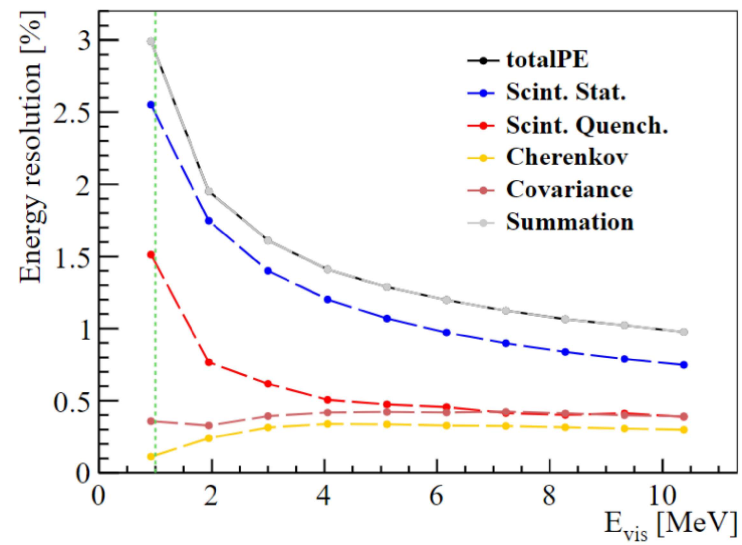


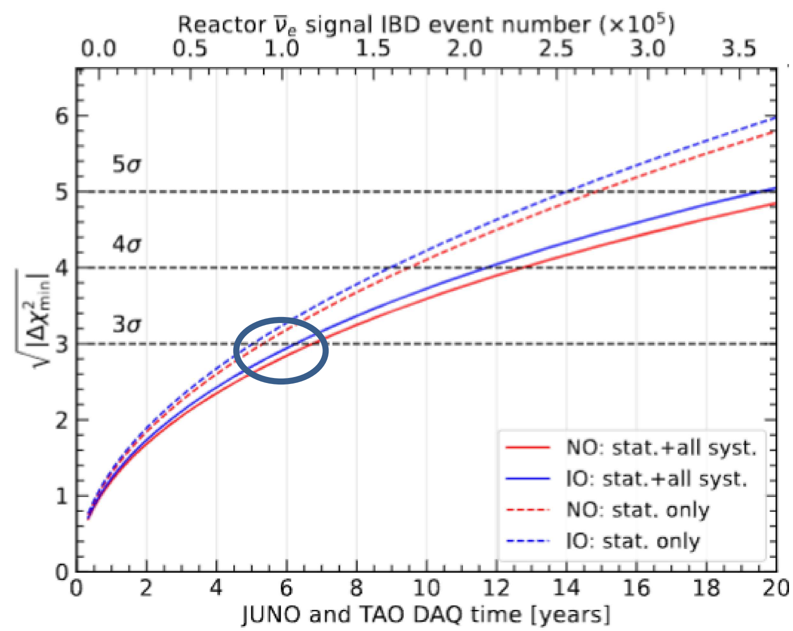
Physics Reach：Reactor Neutrinos

- $^{238}U/^{232}Th$ Backgrounds in LS can easily reach <10^{-15} g/g for MH
- From PMT testing, LS and acrylic transparency, simulation of calibration and reconstruction, the Energy Resolution is expected to be < 3%@1MeV, and in 6 yrs MH can be determined to be
  - ~3 σ from reactor neutrinos
  - ~1 σ from atmospheric neutrinos
- Oscillation parameters can be determined:

	Current (PDG2020)	JUNO (100 d)	JUNO (6 y)
$\Delta m^2_{31}/\Delta m^2_{32}$	1.3%	0.8%	0.2%
Δm^2_{21}	2.4%	1.0%	0.3%
$\sin^2\theta_{12}$	4.2%	1.9%	0.5
$\sin^2\theta_{13}$	3.2%	47.9%	12.1%

arXiv:2204.13249, Chin. Phys. C 46 (2022) 123001

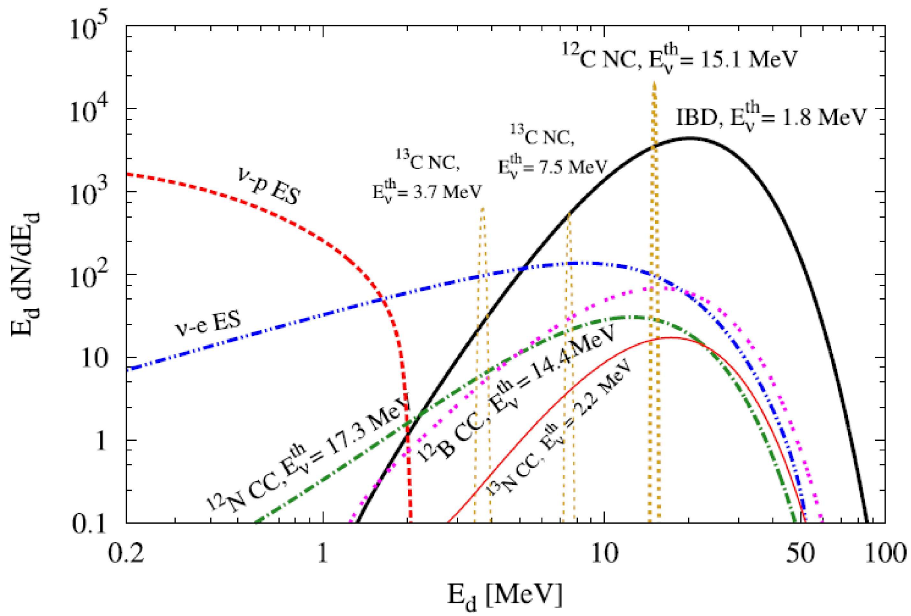




Supernova Neutrinos

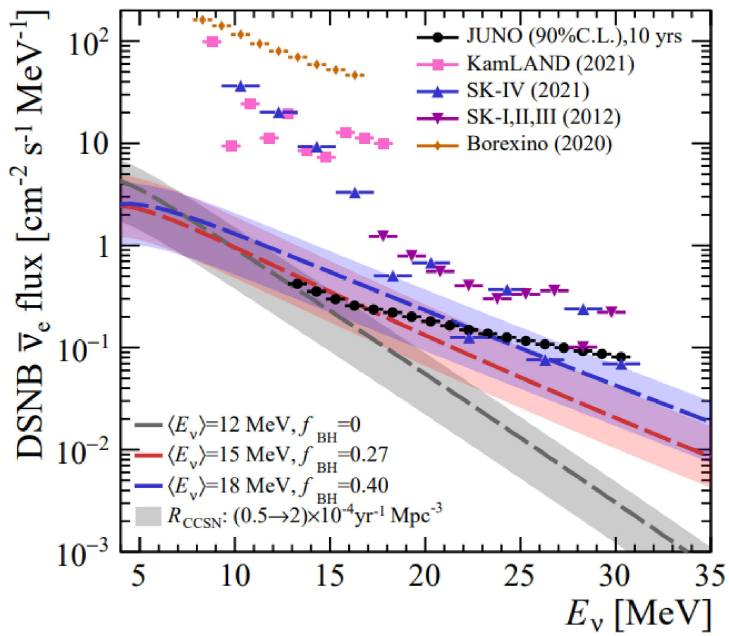
Burst supernova neutrinos

~5000 IBD, ~300 eES, ~2000 pES, ~200 ^{12}C CC, ~300 ^{12}C NC @10 kpc



PRD 99 (2019) 123009

Diffused supernova neutrinos



arXiv: 2205.08830, JCAP 10 (2022) 033

Solar Neutrinos

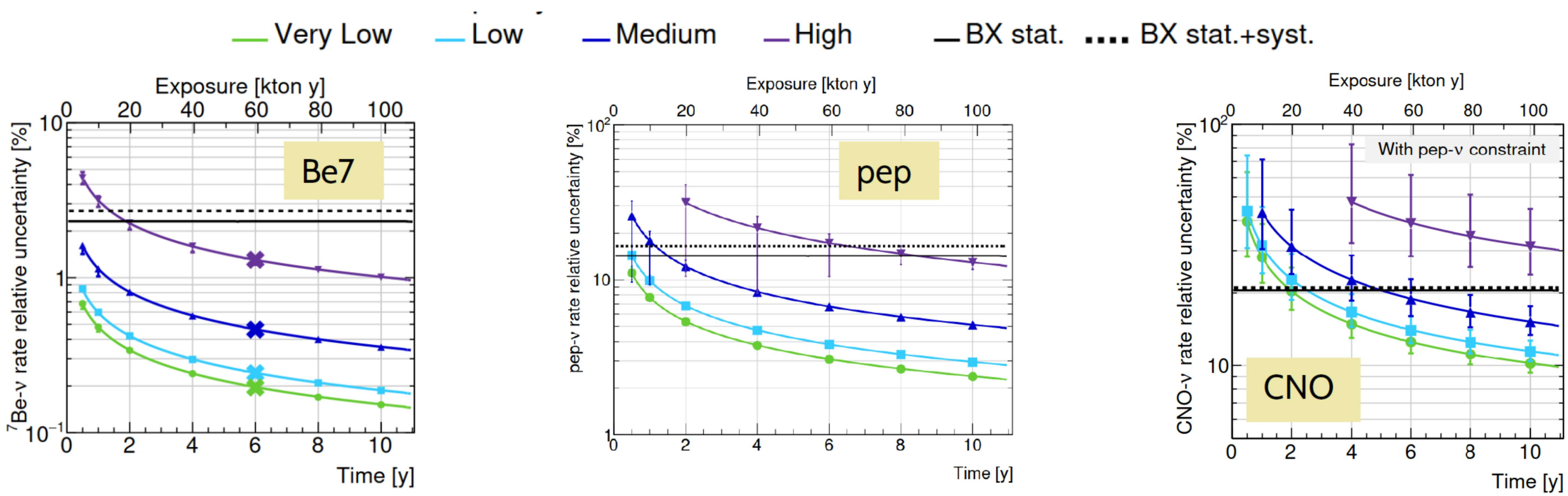
Comprehensive studies under different radioactivity levels using a Multivariate fitting strategy

"Very-Low radioactivity scenario": radio-purity of Borexino Phase-3;

"Low radioactivity scenario": ^{238}U and ^{232}Th 10^{-17} g/g ➔ most probable

"medium radioactivity scenario": ^{238}U and ^{232}Th 10^{-16} g/g

"high radioactivity scenario": ^{238}U and ^{232}Th 10^{-15} g/g (minimum requirement for MH discrimination)



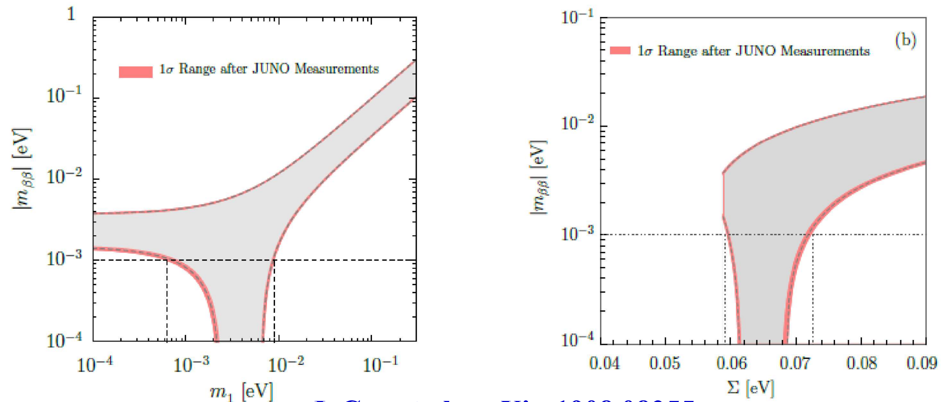
Chin. Phys. C 45 (2021) 023004

Compared to Borexino's solar nu measurement:

- **^{7}Be and pep**: will be improved in all radiopurity scenarios after few years of data-taking
- **CNO**: will be improved in most the radiopurity scenarios except for the worse one; can reach ~ 10% level

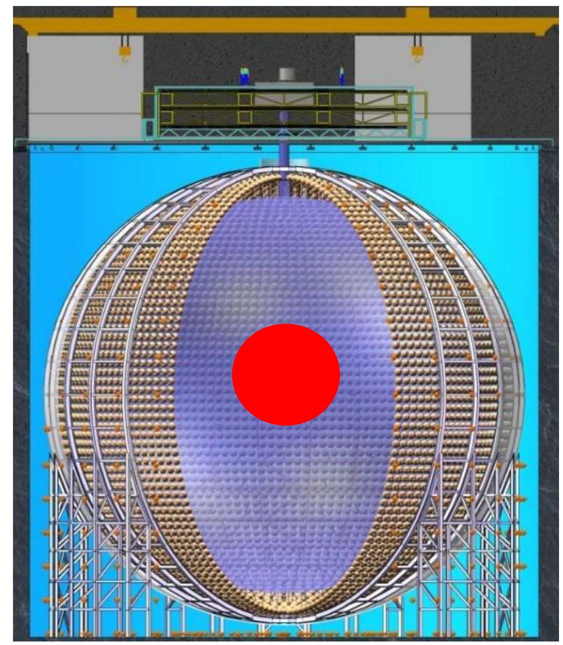
JUNO-$\beta\beta$

- In ten years from now, oscillation will be mostly understood.
- $0\nu\ \beta\beta$ decay will be the next focus point:



J. Cao et al., arXiv:1908.08355

	Isotope	Mass(t)	$<m_{\beta\beta}>$,meV
SNO+	^{130}Te	8	19-46
KamLAND2-Zen	^{136}Xe	1	~20
NEXT-HD	^{136}Xe	1	14-40
nEXO	^{136}Xe	5	7-22
Darwin/Panda-nT	^{136}Xe	3-5	7-22
LEGEND-1000/CDEX-1t	^{76}Ge	1	10-40
AMoRE-II	^{100}Mo	0.1	12-22
CUPID	^{100}Mo	0.24	12-20
CUPID-1T	^{100}Mo	1	4-7
JUNO-$\beta\beta$	^{136}Xe	50	4-10
	^{130}Te	100	3-14



Insert a balloon filled with ^{136}Xe-loaded LS(or ^{130}Te) into the JUNO detector

Zhao et al., arXiv: 1610.07143, CPC 41（2017）5

A long Journey

- Daya Bay is a start of the neutrino physics in China (from ~ 2003)
- JUNO will bring us to a new stage (from ~ 2013)
- JUNO-$\beta\beta$ will be the next step, hopefully from 2033