GDR Neutrino meeting

Bordeaux, October 2019

The JUNO experiment

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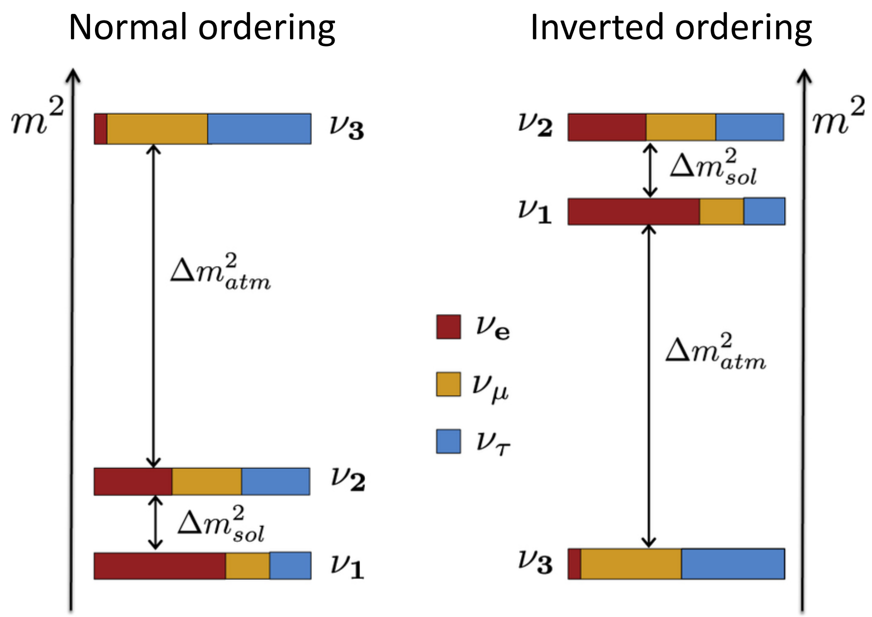
on behalf of the JUNO collaboration

Outline

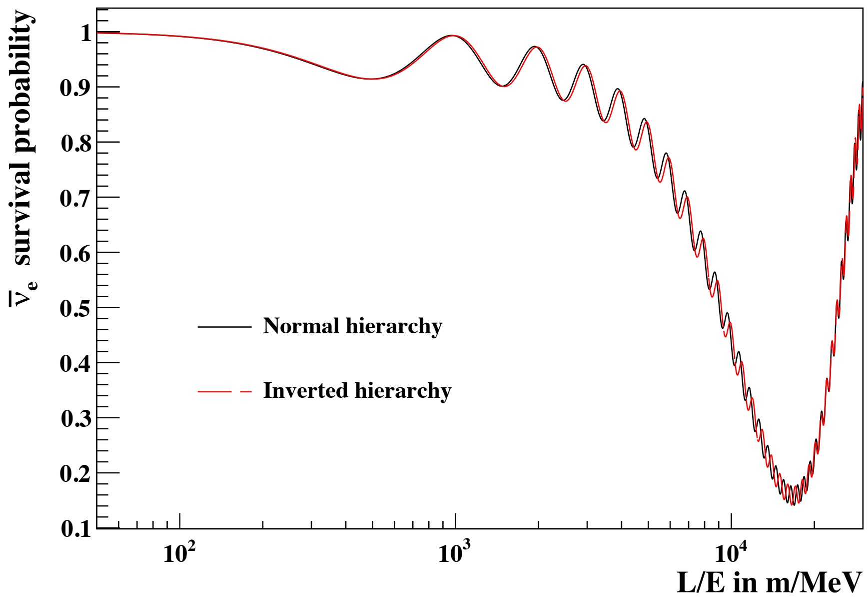
- Neutrino mass ordering
  - Reactor neutrinos
  - Mass ordering determination with reactors
- The JUNO experiment
  - Experimental layout and concept
  - The JUNO multi-purpose detector
- Physics reach
  - Mass ordering
  - Precision measurements, etc …
- Current status
  - Schedule
  - Ending themes

Neutrino mass ordering



- Previous experimental work has determined that m_2 is more massive than m_1, i.e., $m_2>m_1$
- We still don't know whether m_3 is lighter or heavier than m_1
  - The $m_3>m_1$ case is coined the Normal Ordering (NO) and the $m_3<m_1$ case the Inverted Ordering (IO)

$\bar{\nu}_e$ disappearance



$$P_{\bar{\nu}_e \to \bar{\nu}_e} = 1 - \sin^2(2\theta_{13}) \cos^2(\theta_{12}) \sin^2 \Delta_{31} - \sin^2(2\theta_{13}) \sin^2(\theta_{12}) \sin^2 \Delta_{32} - \sin^2(2\theta_{12}) \cos^4(\theta_{13}) \sin^2 \Delta_{21}$$

$$\Delta_{ij} = \frac{L}{4E_\nu} \Delta m^2_{ij}$$

- Distinctive oscillation patterns for the cases of NO and IO
- Precise measurement of $\sin^2(\theta_{12})$, Δm^2_{21} and Δm^2_{31}
- Complementary searches through ν_μ disappearance and ν_e appearance

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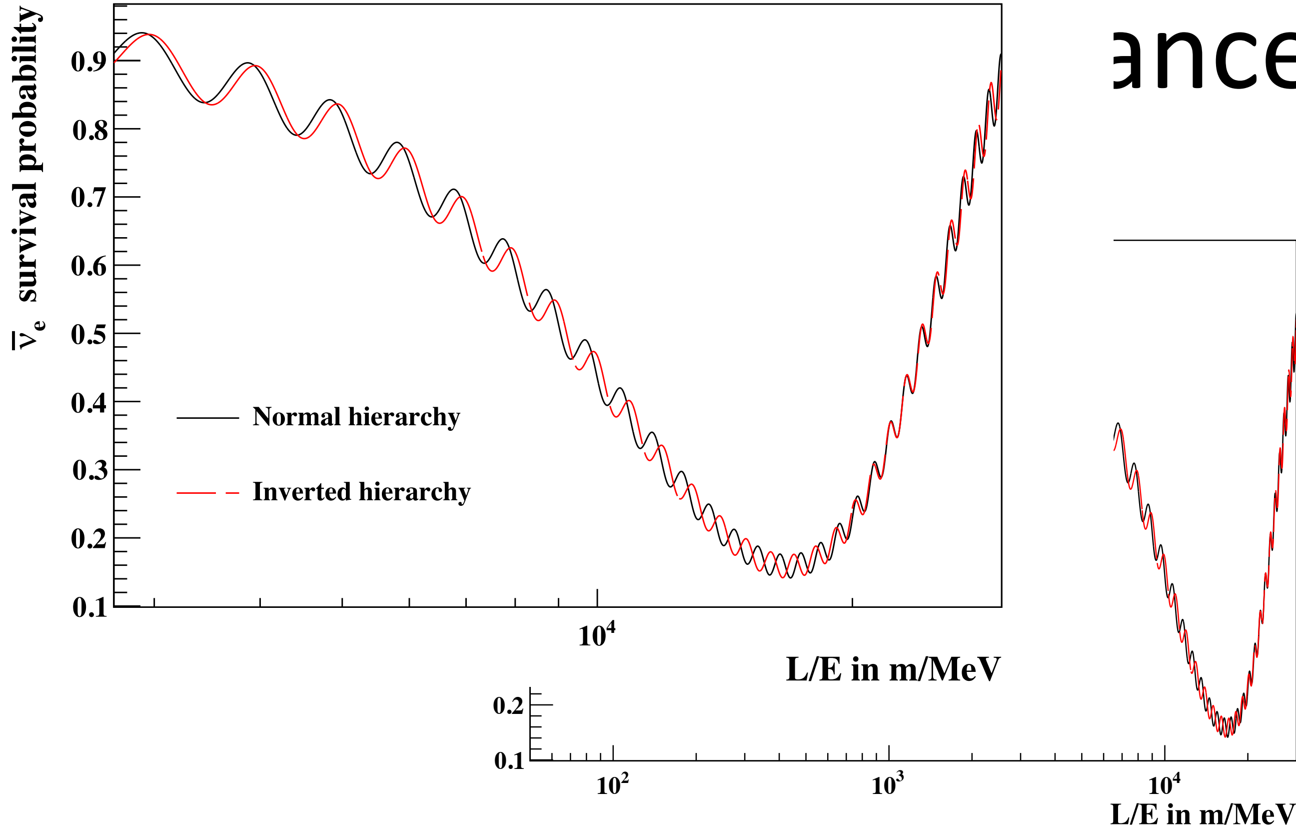

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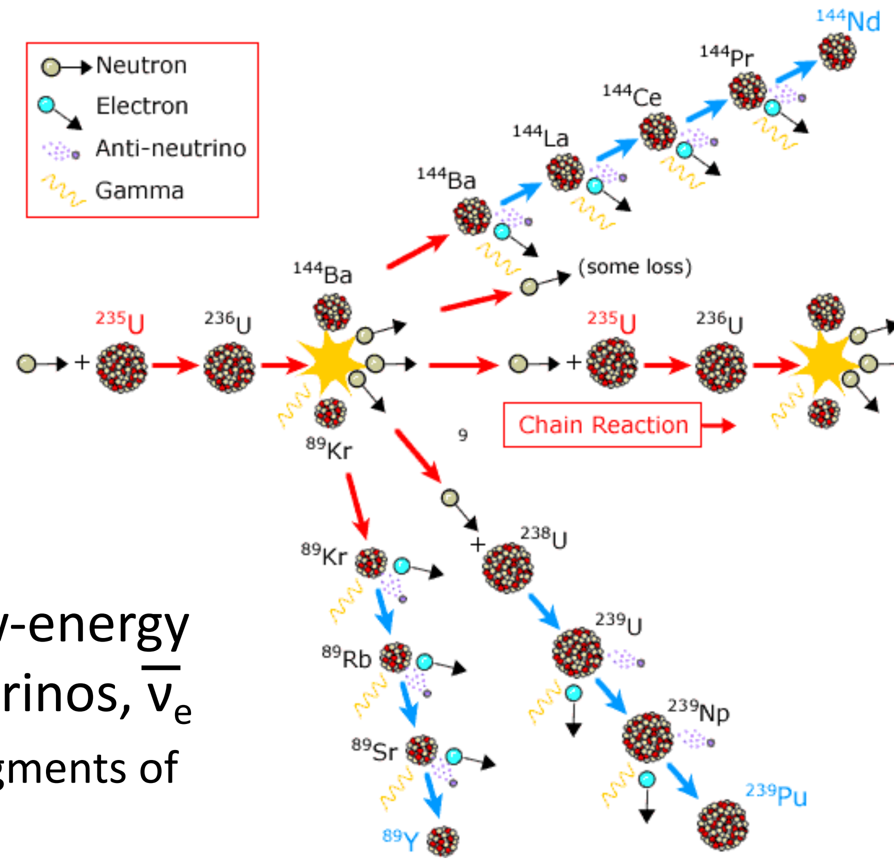
Reactor antineutrinos

Bugey (Saint-Vulbas, France)



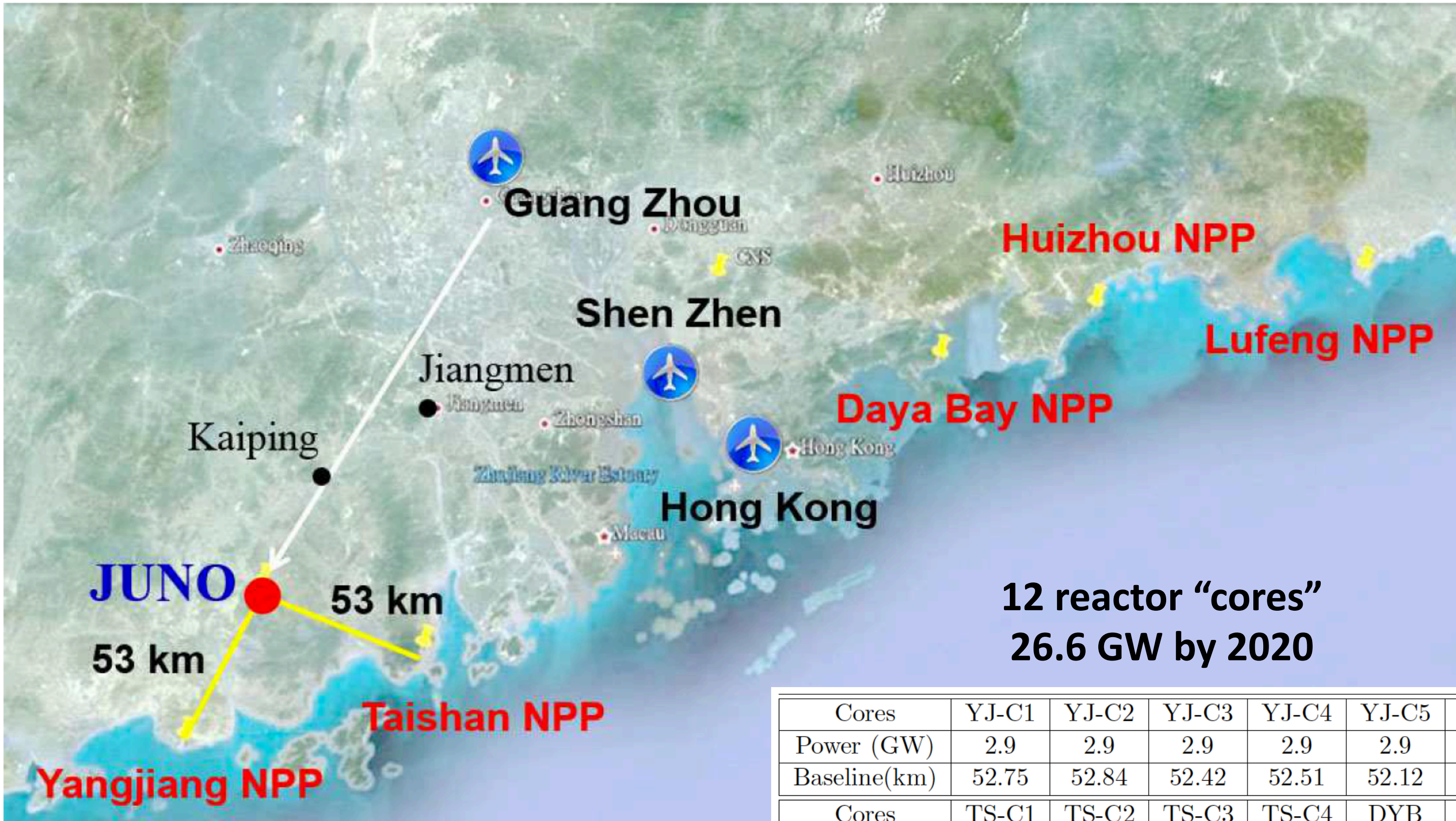
- Reactors are copious sources of low-energy (up to ~ 10 MeV) electron antineutrinos, $\overline{\nu}_e$
  - Beta decays of neutron-rich fission fragments of ^{235}U, ^{239}Pu, ^{241}Pu and ^{238}U
  - Approximately 2×10^{20} $\overline{\nu}_e$ per second for 1 GW of thermal power

JUNO collaboration

Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	IMP-CAS	Germany	U. Mainz
Belgium	Universite libre de Bruxelles	China	SYSU	Germany	U. Tuebingen
Brazil	PUC	China	Tsinghua U.	Italy	INFN Catania
Brazil	UEL	China	UCAS	Italy	INFN di Frascati
Chile	PCUC	China	USTC	Italy	INFN-Ferrara
Chile	UTFSM	China	U. of South China	Italy	INFN-Milano
China	BISEE	China	Wu Yi U.	Italy	INFN-Milano Bicocca
China	Beijing Normal U.	China	Wuhan U.	Italy	INFN-Padova
China	CAGS	China	Xi'an JT U.	Italy	INFN-Perugia
China	ChongQing University	China	Xiamen University	Italy	INFN-Roma 3
China	CIAE	China	Zhengzhou U.	Latvia	IECS
China	DGUT	China	NUDT	Pakistan	PINSTECH (PAEC)
China	ECUST	China	CUG-Beijing	Russia	INR Moscow
China	Guangxi U.	China	ECUT-Nanchang City	Russia	JINR
China	Harbin Institute of Technology	Czech R.	Charles University	Russia	MSU
China	IHEP	Finland	University of Jyvaskyla	Slovakia	FMPICU
China	Jilin U.	France	LAL Orsay	Taiwan-China	National Chiao-Tung U.
China	Jinan U.	France	CENBG Bordeaux	Taiwan-China	National Taiwan U.
China	Nanjing U.	France	CPPM Marseille	Taiwan-China	National United U.
China	Nankai U.	France	IPHC Strasbourg	Thailand	NARIT
China	NCEPU	France	Subatech Nantes	Thailand	PPRLCU
China	Pekin U.	Germany	FZJ-ZEA	Thailand	SUT
China	Shandong U.	Germany	RWTH Aachen U.	USA	UMD1
China	Shanghai JT U.	Germany	TUM	USA	UMD2
China	IGG-Beijing	Germany	U. Hamburg	USA	UC Irvine
China	IGG-Wuhan	Germany	FZJ-IKP		

- 77 members in total from 17 countries
- 3 observer institutes
  - University of Malaya, University of Zagreb and Yale

Experimental layout

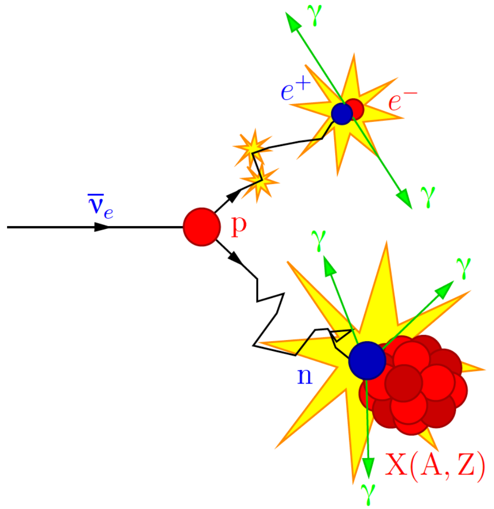


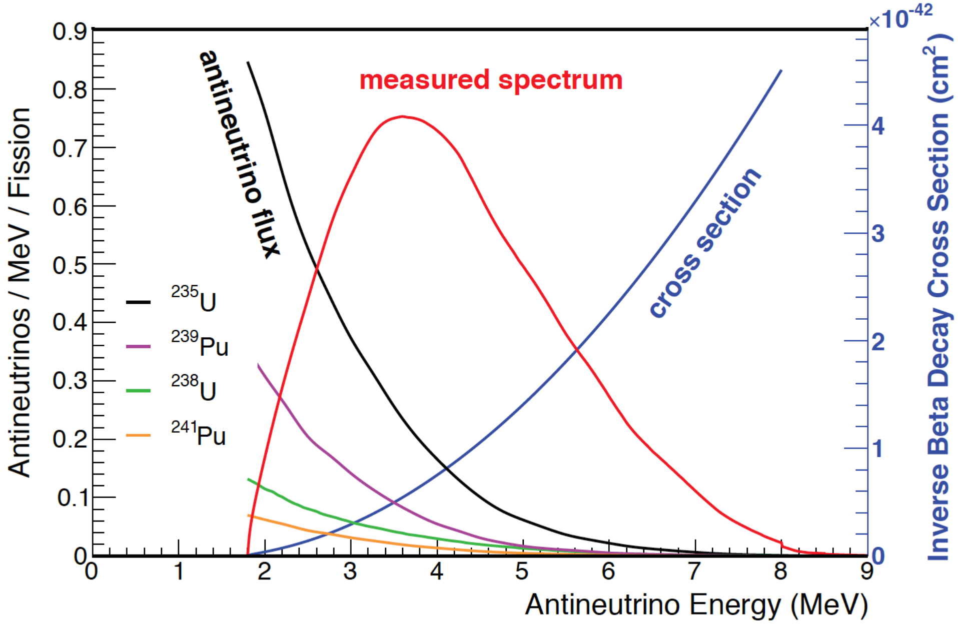
12 reactor "cores"
26.6 GW by 2020

Cores	YJ-C1	YJ-C2	YJ-C3	YJ-C4	YJ-C5	YJ-C6
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9
Baseline(km)	52.75	52.84	52.42	52.51	52.12	52.21
Cores	TS-C1	TS-C2	TS-C3	TS-C4	DYB	HZ
Power (GW)	4.6	4.6	4.6	4.6	17.4	17.4
Baseline(km)	52.76	52.63	52.32	52.20	215	265

Detection principle

Inverse Beta Decay (IBD)

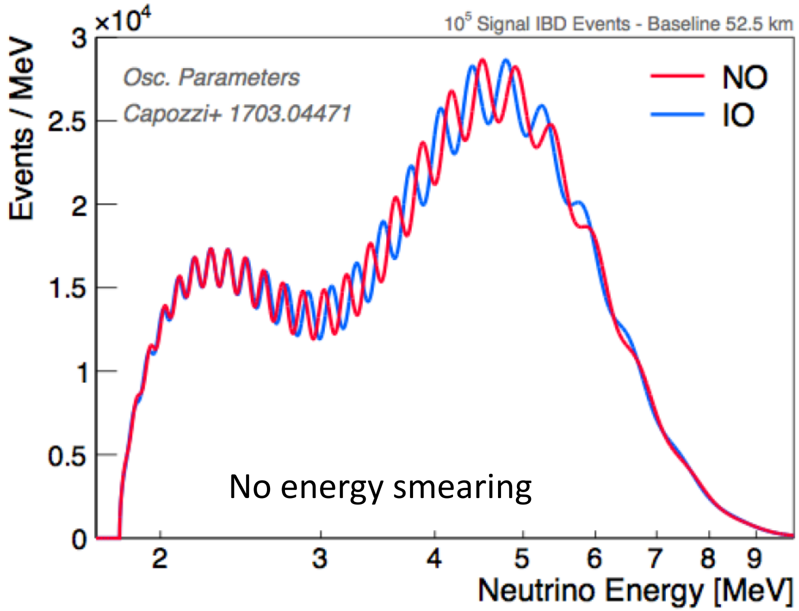


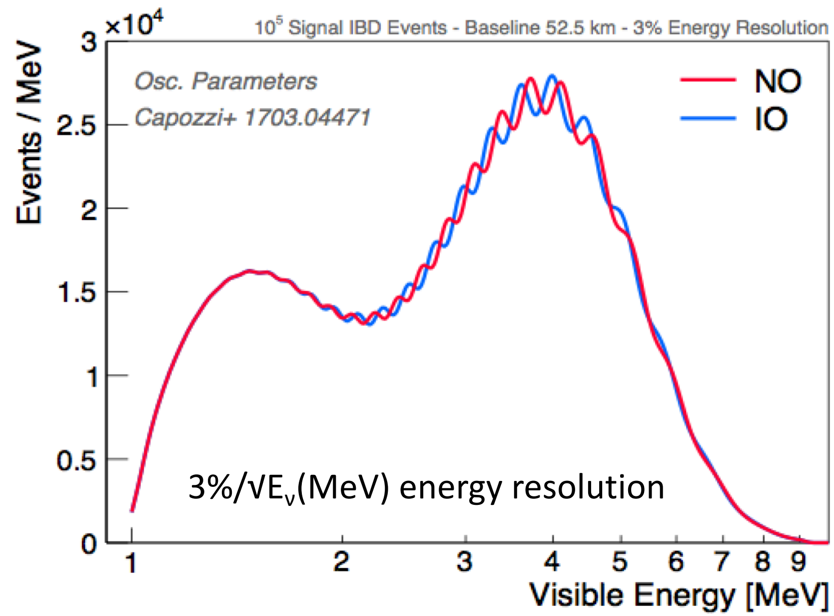


- Well-understood low energy cross-section
- Threshold at ~ 1.8 MeV
- Large number of free protons available in liquid scintillator detectors

- ***Prompt signal***: electron energy loss and annihilation
- ***Delayed signal***: neutron capture on nuclei
- The pair is correlated in time and space

Mass ordering signature in JUNO

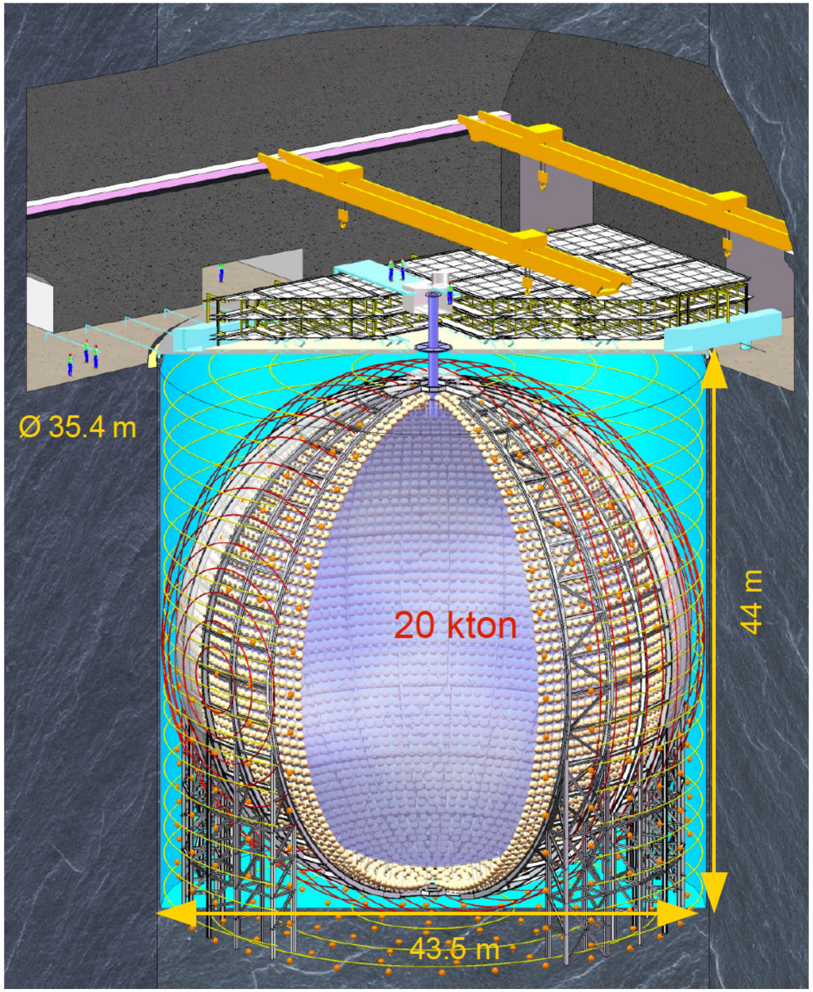




- Large reduction (dip) in the flux due to neutrino oscillations in the "solar" regime
- Fast oscillation due to interference between Δm^2_{31} and Δm^2_{32}
  - Sensitive to the mass ordering
- Energy resolution is the key !
  - Significant light yield and control of systematics

JUNO detector

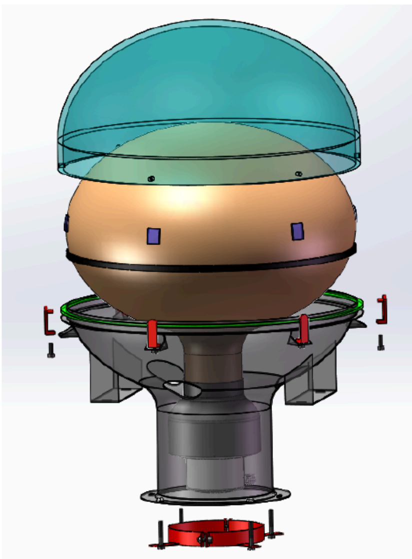
- Central detector
  - Acrylic sphere with 20 kton liquid scintillator
  - 20” and 3” PMTs in water buffer
  - 78% photocathode coverage
- Water Cherenkov muon veto
  - 2000 20” PMTs
  - 35 kton ultra-pure water
- Top tracker
  - Three layers of plastic scintillator panels
  - Precise muon tracking

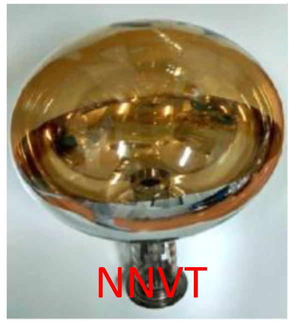


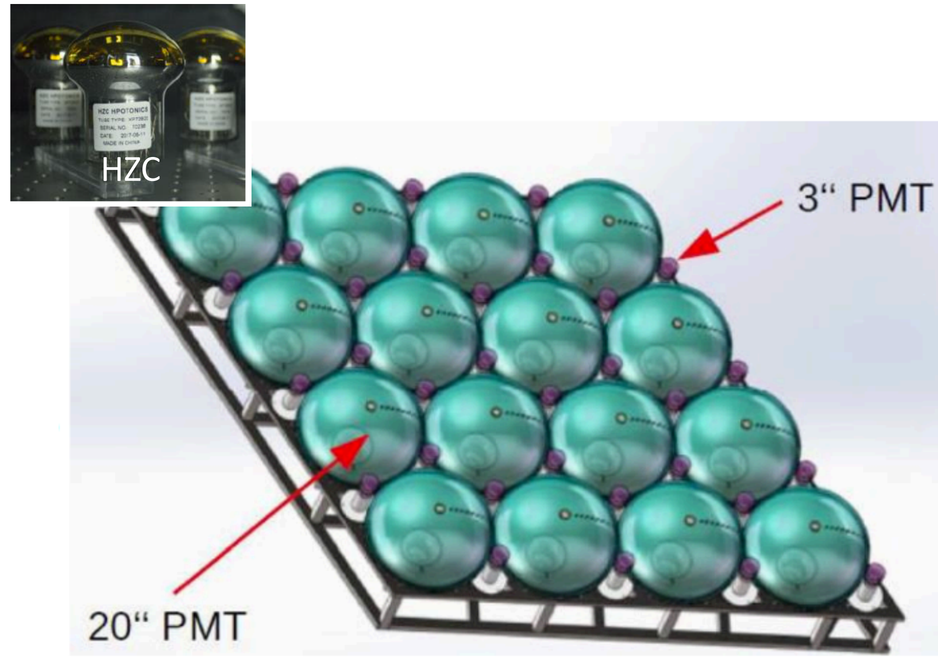
Liquid scintillator

- Daya Bay scintillator (LAB) was used as baseline
  - High light yield, 10^4 photons/MeV
  - High transparency and large attenuation length, > 20 m
- Four step purification:
  - Al_2O_3 filtration column
  - Distillation
  - Water extraction
  - Steam/Nitrogen stripping
- Purification pilot plant under operation at Daya Bay

Central Detector photomultipliers

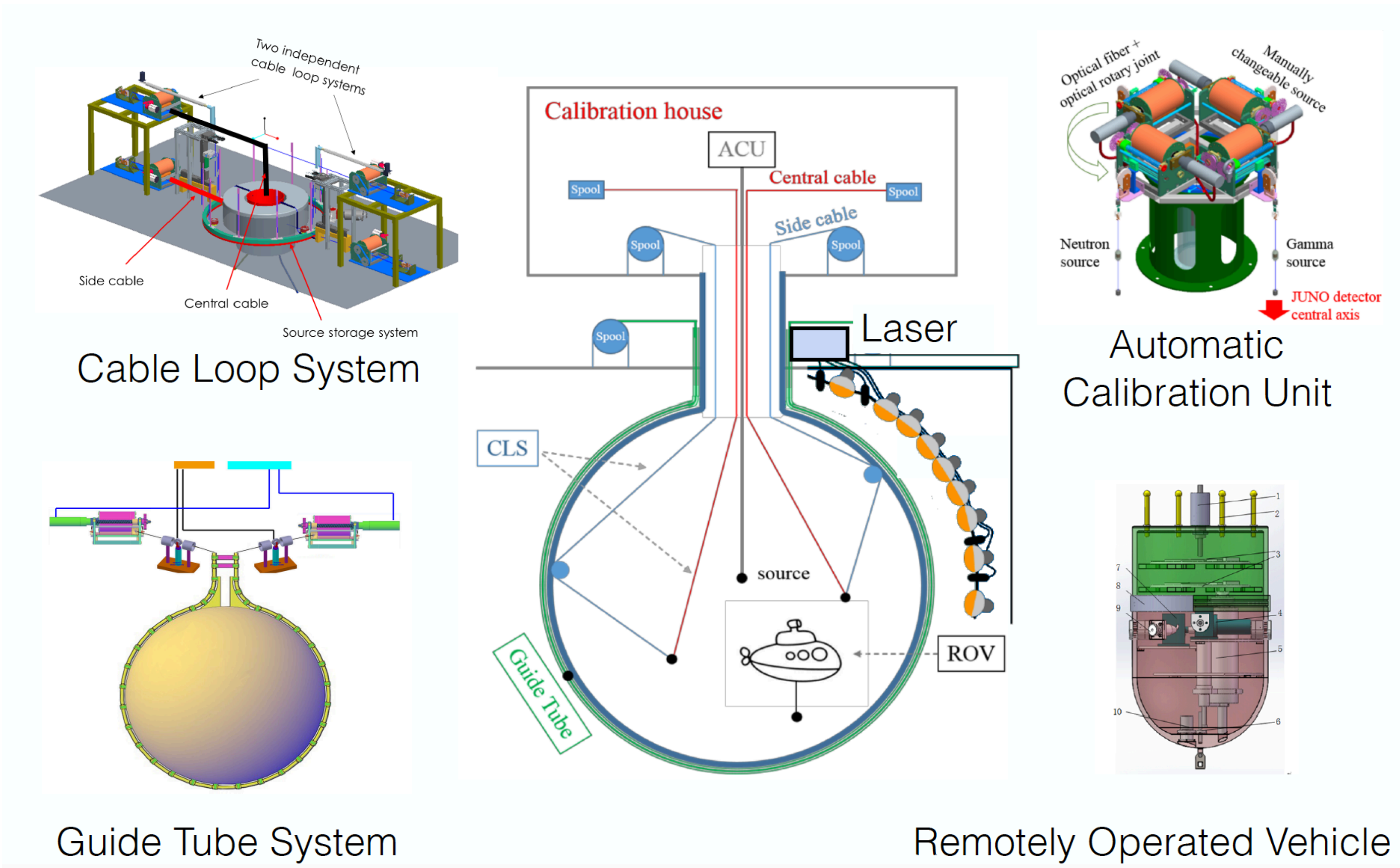






- 15000 20" MCP-PMTs from NNVT and 5000 dynode 20" PMTs from Hamamatsu
  - High quantum and collection efficiencies (detection efficiency ~ 30%)
- 25600 3" PMTs from HZC for double calorimetry
  - Increases light yield and gives better control on the systematics

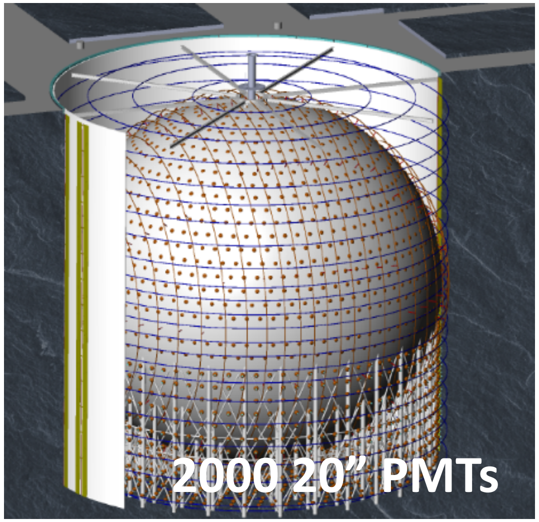
Calibration systems

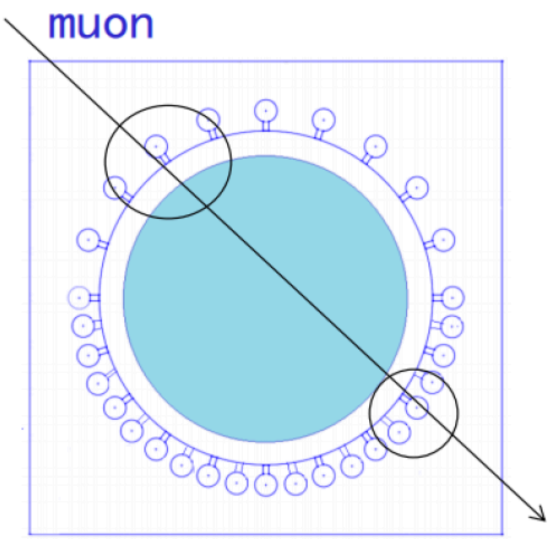


Goal : ensure an energy measurement with a precision better than 1% !

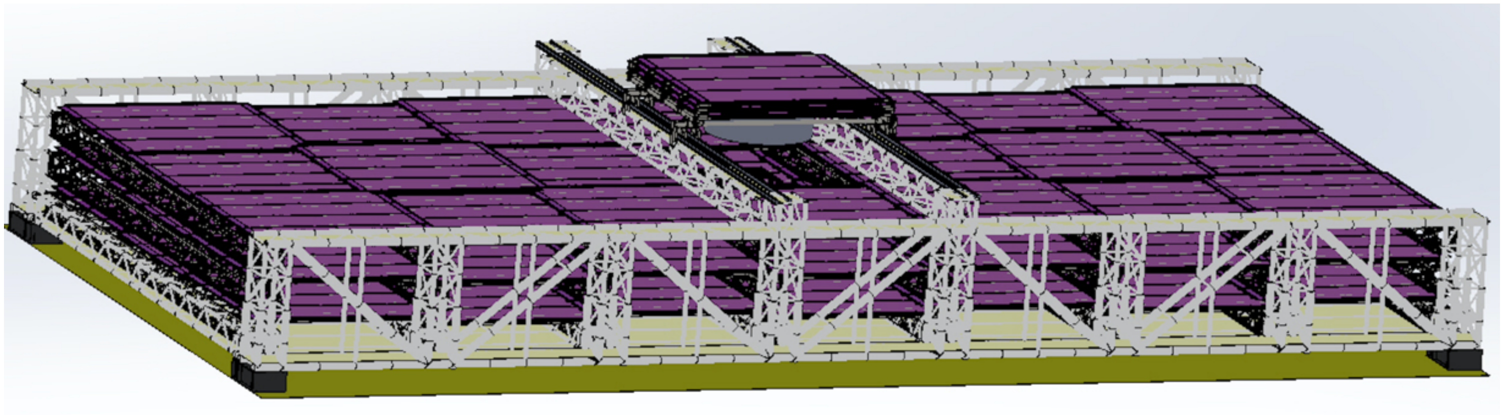
Cherenkov Water Veto

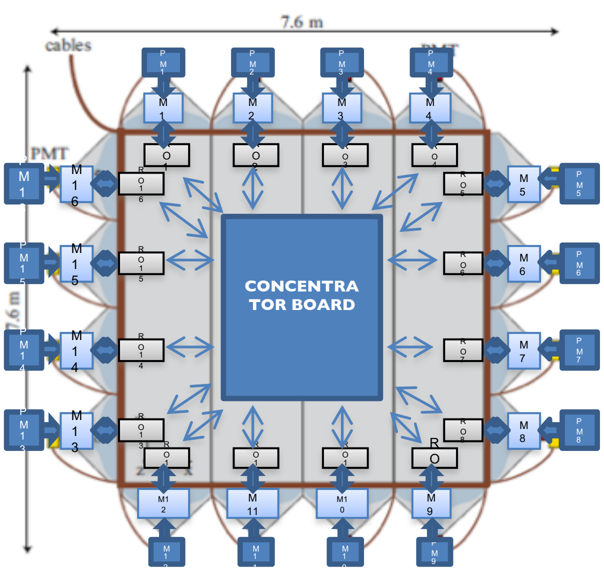
- The JUNO detector rock overburden is ~ 2000 mwe
  - Muon rate of 0.003 Hz/m^2
- The water veto is needed to:
  - Provide passive shielding to radioactivity and fast neutrons
  - Tag through-going muons via Cherenkov radiation
- Pool lining: HDPE
- Earth magnetic field compensation coil





Top tracker

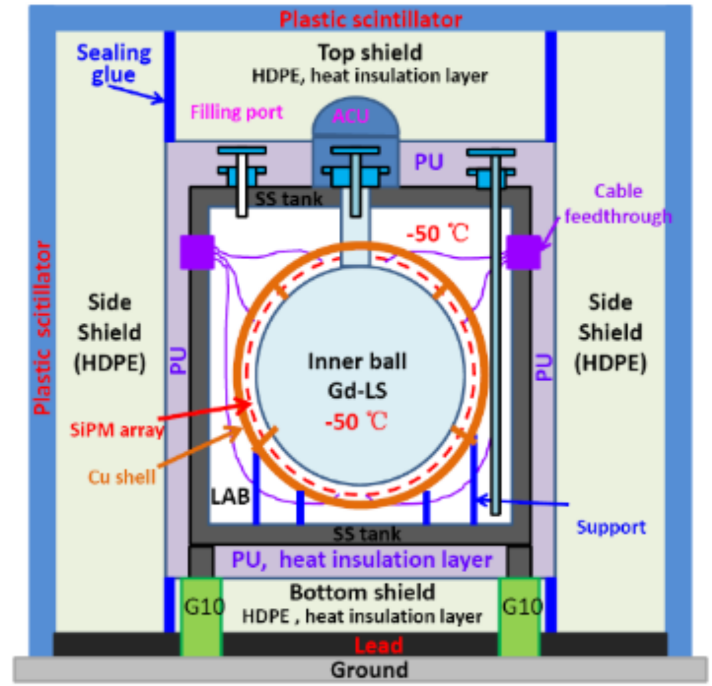




- Three layers of plastic scintillator modules
  - Modules from the decommissioned OPERA experiment (no significant aging observed)
  - 60% coverage of the water veto
  - Already moved in China
- New electronics under production
  - Trigger optimization to reduce fake rates from natural radioactivity

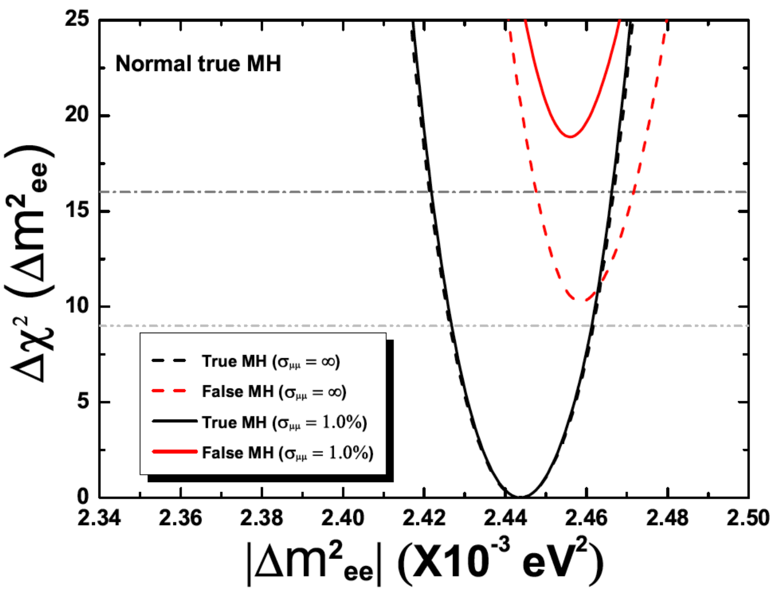
Taishan Antineutrino Observatory (TAO)

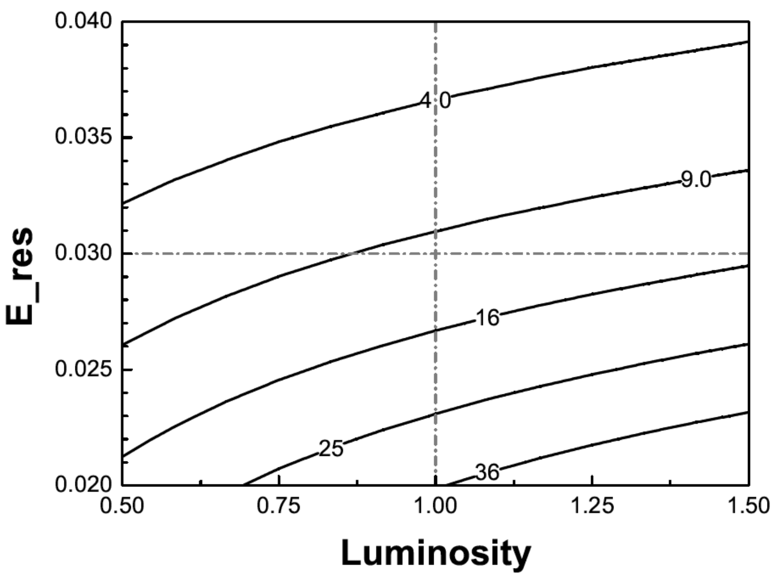
- Measure reactor spectrum with 1.5%/$\sqrt{E_\nu}$(MeV) resolution
  - Possible fine structure can impact an unambiguous determination of the mass ordering
  - Reduces reactor systematics
- 2.6 ton Gd loaded liquid scintillator in a spherical vessel
  - ~ 30 m away from a Taishan core
  - With 1 ton fiducial volume one expects ~ 2000 ν's per day



- 10 m^2 SiPM of 50% photon detection efficiency
  - Operating at -50 °C
  - Reduces dark noise

Mass ordering sensitivity





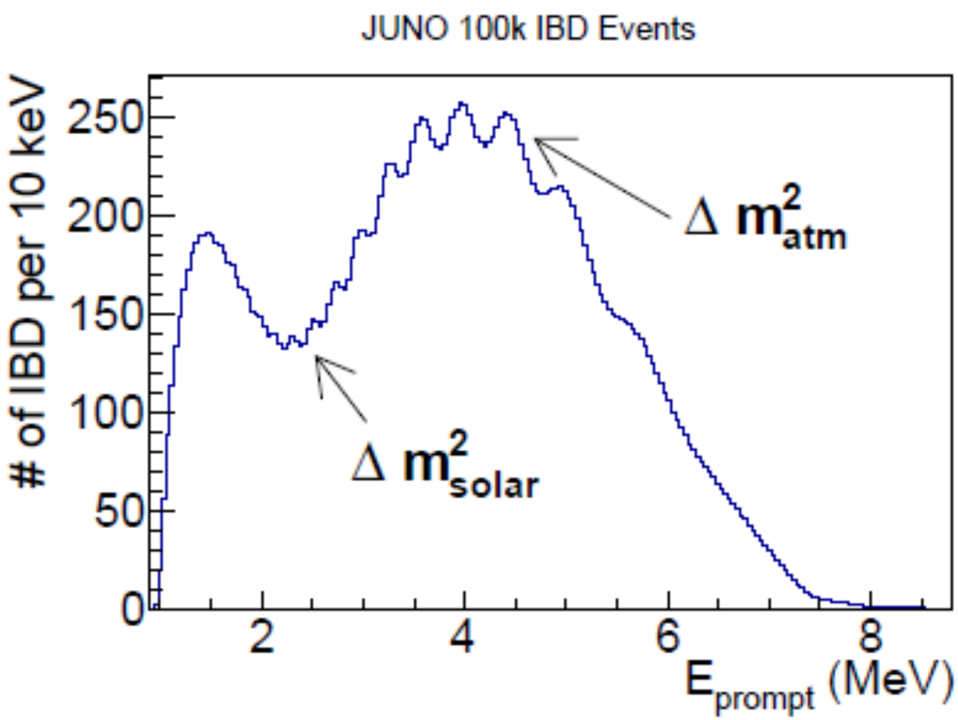
- A 3σ discrimination of the neutrino mass ordering can be achieved after 6 years of running with JUNO
  - Note that this depends heavily on the energy resolution
  - It also depends on the actual values of Δm^2_{21} and Δm^2_{31}
- A combination with other experiments can provide a 5σ result
  - Especially with ORCA or PINGU (no degeneracies with δ)

Precision measurements

Current precision

	Δm^2_{21}	$\lvert\Delta m^2_{31}\rvert$	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	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%

Probing the unitarity of the mixing matrix to better than 1% !

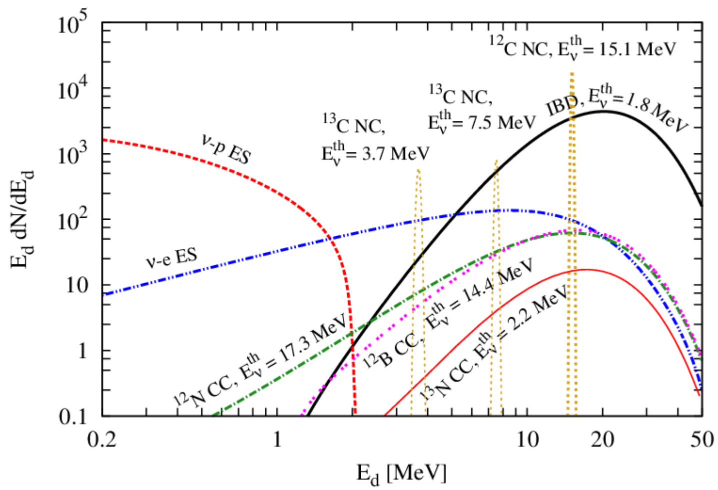


	Error
$\sin^2(\theta_{12})$	0.67%
Δm^2_{21}	0.59%
Δm^2_{31}	0.44%

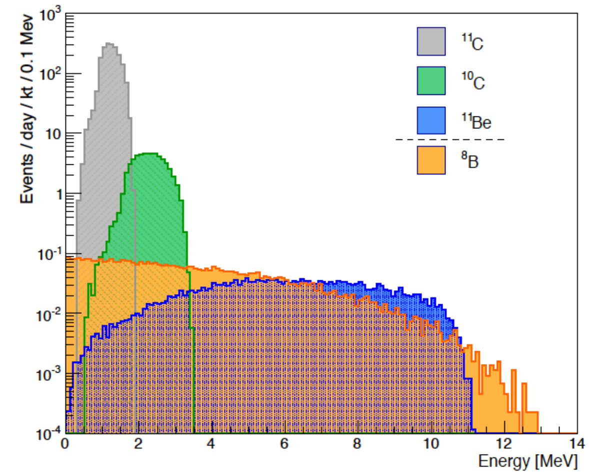
This excellent precision can be achieved only by JUNO !

Diverse physics program

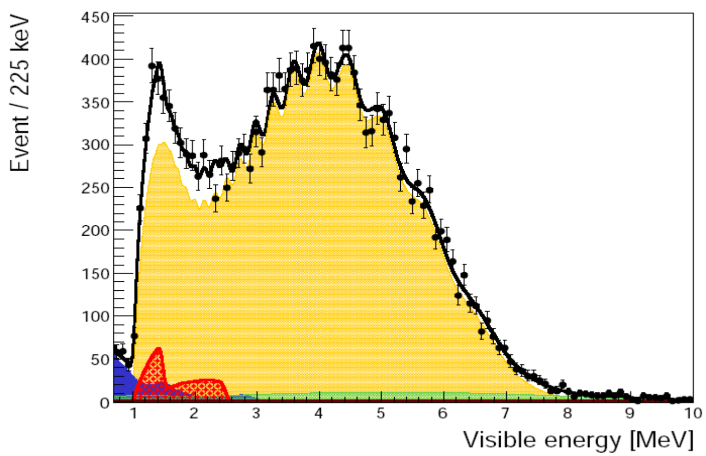
Supernova neutrinos



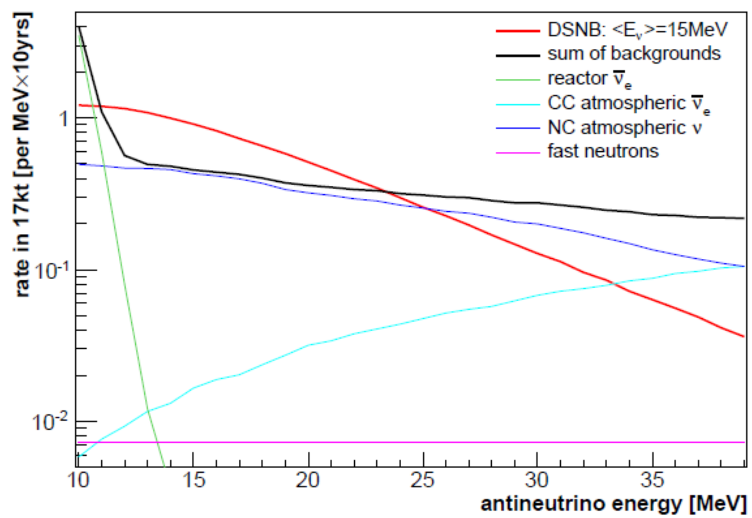
Solar neutrinos



Geoneutrinos



Diffuse supernova neutrino background



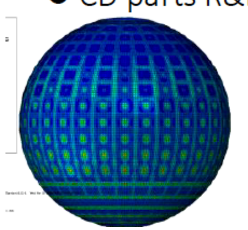
Diverse physics program (cont'd)

- Atmospheric neutrinos
  - Measure both lepton and hadron energy
  - Tracking and good energy resolution
- Proton decay
  - Search in the $p \longrightarrow K^{+} + \overline{\nu}$ channel
- Exotic searches
  - Non-standard interactions
  - Lorentz violation
  - Sterile neutrinos
  - Future double beta decay searches
  - Etc …

Timeline

2014:

- International collaboration established
- Start civil construction



2015:

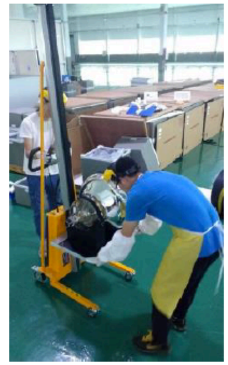
- PMT production line setup
- CD parts R&D

2016:

- Start PMT production
- Start CD parts production

2017:

- Start PMT testing
- TT arrived

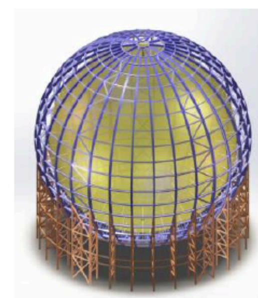


2018:

- PMT potting
- starts Delivery of surface buildings
- Start production of acrylic sphere

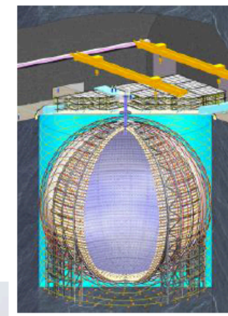
2019-2020:

- Electronics production starts
- Civil work and lab preparation Completed
- Detector constructing



2021:

- Detector ready for Data taking!



Ending themes

- The JUNO detector will be a multi-purpose instrument capable of performing precise neutrino physics
  - Large target mass
  - Strict radiopurity requirements
  - Excellent energy resolution and calibration
- After $\sim$ 6 years of operation it will be able to produce many important results in a diverse range of physics
  - Neutrino mass ordering determination at 3σ
  - Sub-percent measurement of oscillation parameters
  - Solar neutrinos, geoneutrinos, supernova neutrinos, proton decay, …
- The experiment is currently in construction phase
  - Design and R&D are done
  - Construction to be completed by 2021

Thank you for your attention !

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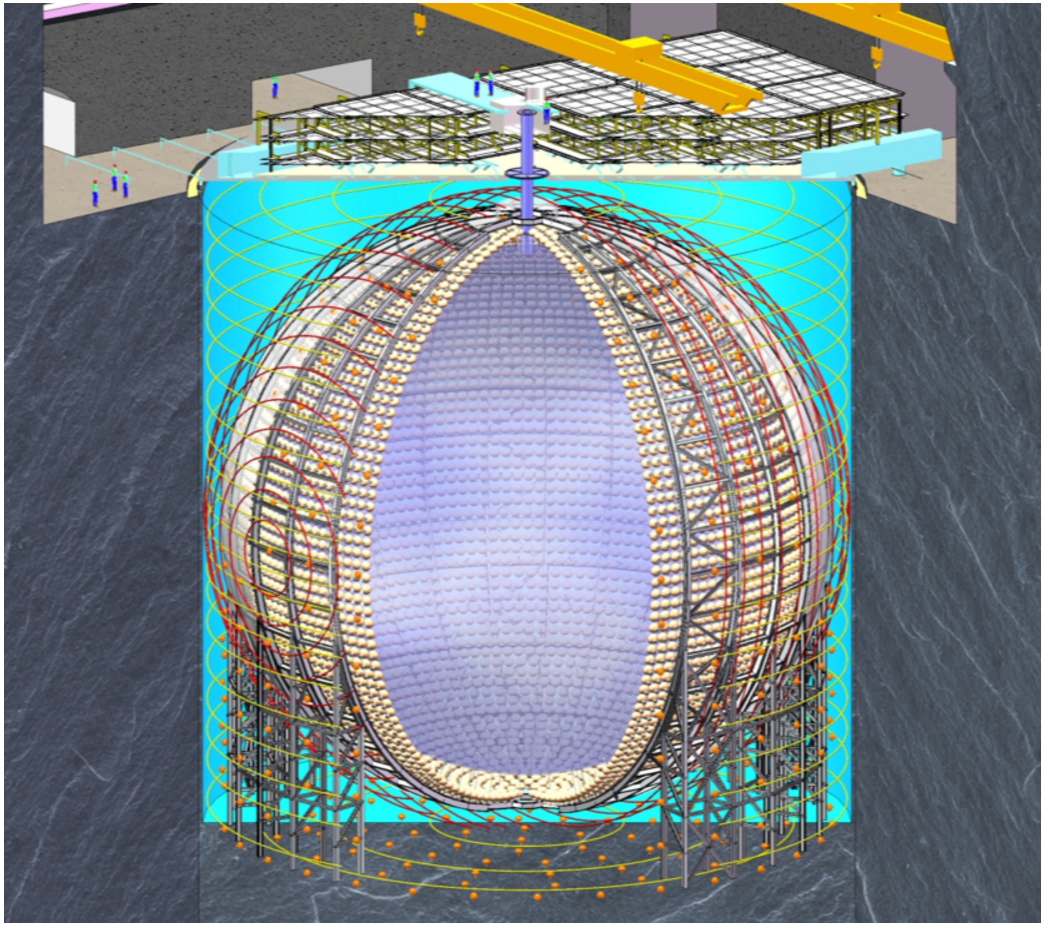
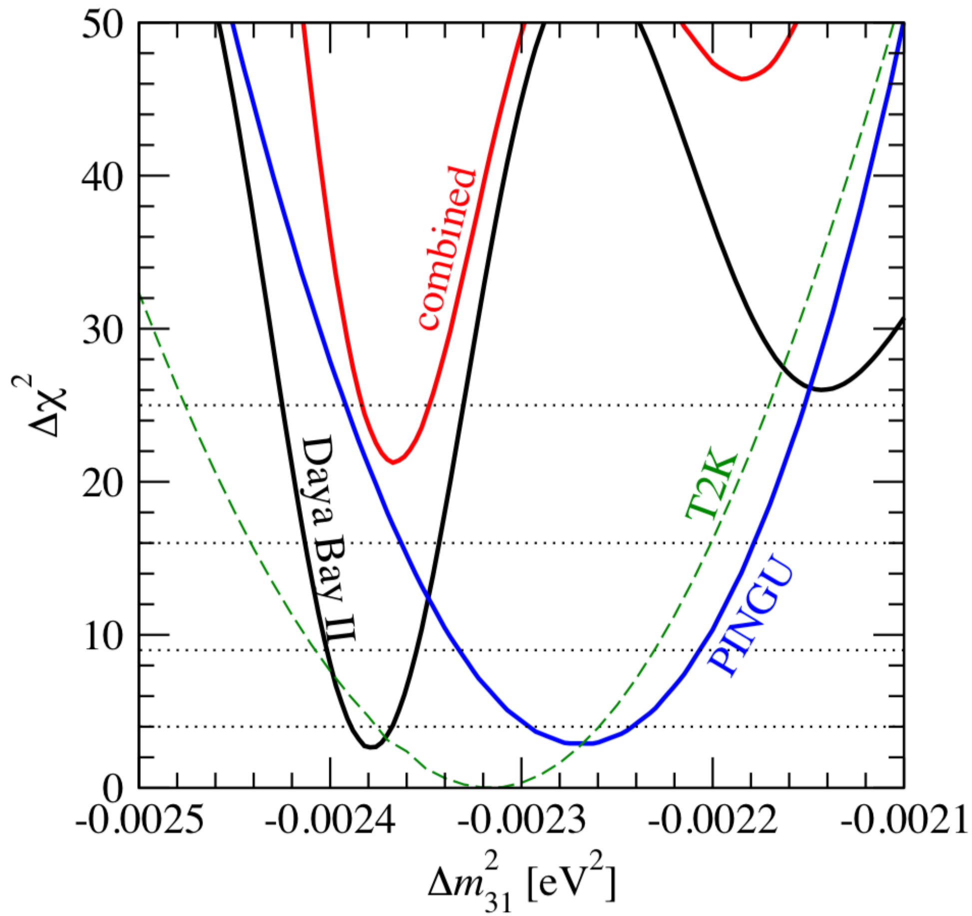


SPARES

JUNO/PINGU synergy



Supernova vs

Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \to e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \to \nu + p$	NC	0.6×10^3	1.2×10^3	2.0×10^3
$\nu + e \to \nu + e$	ES	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}\mathrm{C} \to \nu + {}^{12}\mathrm{C}^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}\mathrm{C} \to e^- + {}^{12}\mathrm{N}$	CC	0.5×10^2	0.9×10^2	1.6×10^2
$\overline{\nu}_e + {}^{12}\mathrm{C} \to e^+ + {}^{12}\mathrm{B}$	CC	0.6×10^2	1.1×10^2	1.6×10^2