



# The JUNO Experiment

Eric Baussan

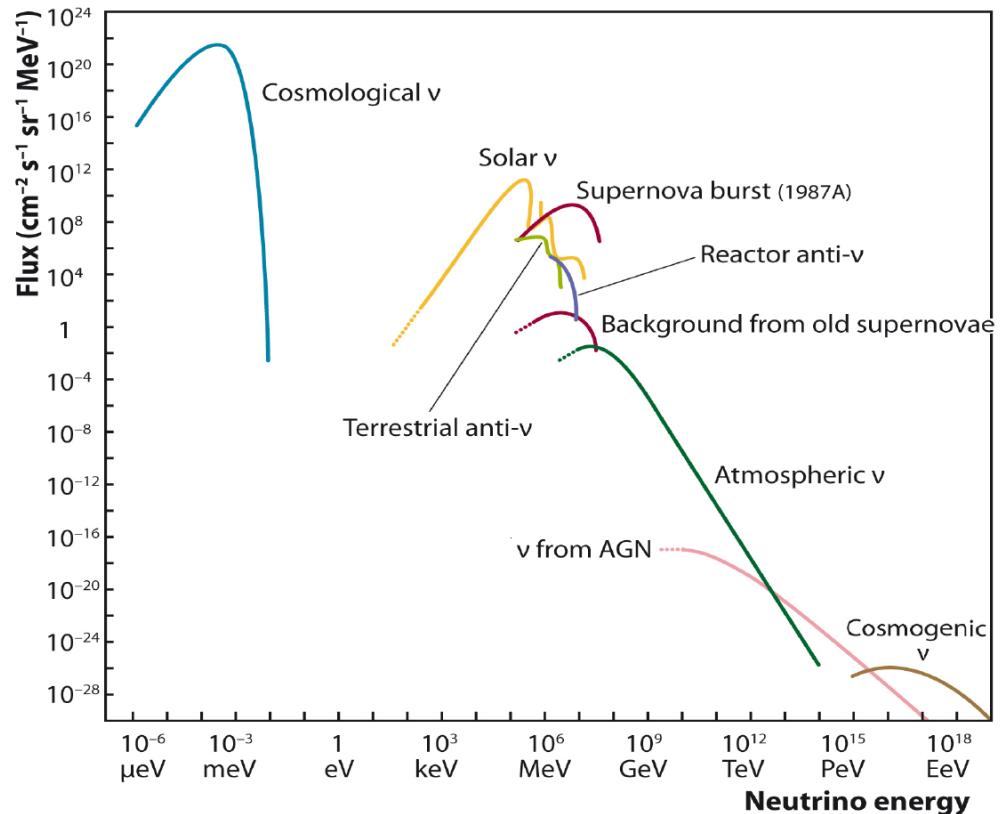
On behalf of the JUNO Collaboration

TeV Particle Astrophysics

September 12-16, 2016.

# Experimental context

- Large variety of neutrino sources from terrestrial to cosmic origin
- Essential to improve/crosscheck our knowledge of underlying production mechanism
- Understand fundamental properties of neutrino



=> Next generation of neutrino experiments at kt-scale provide a rich program complementary to gamma observations

# Experimental context

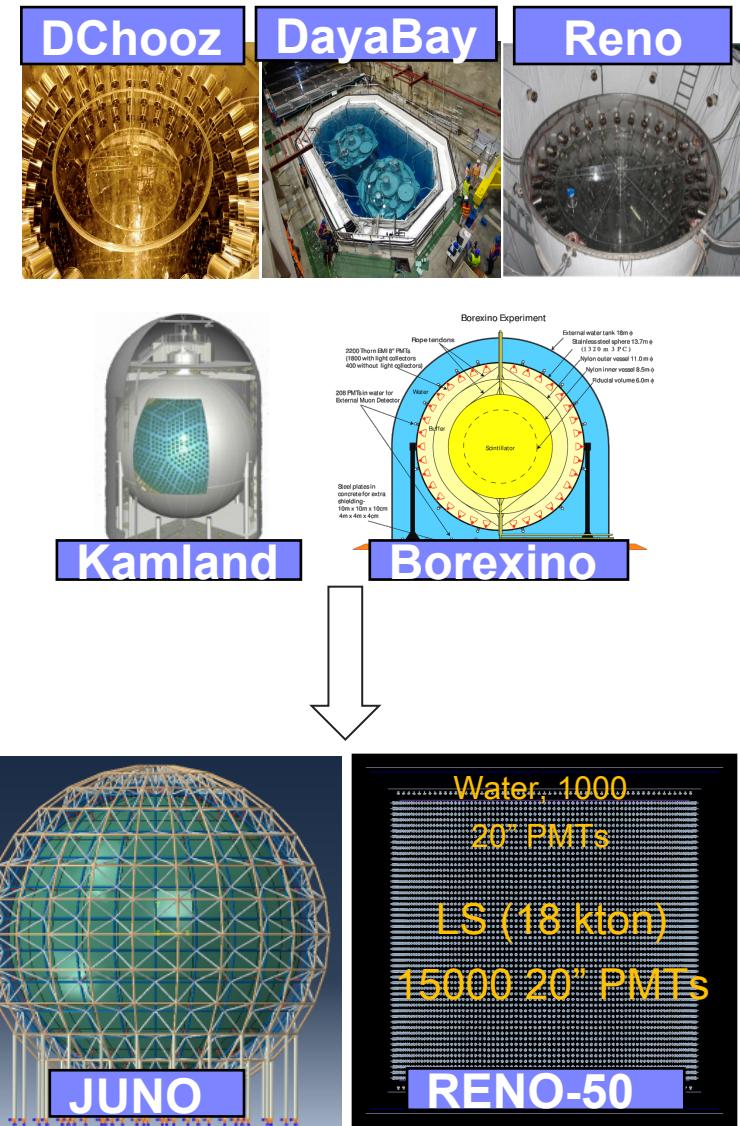
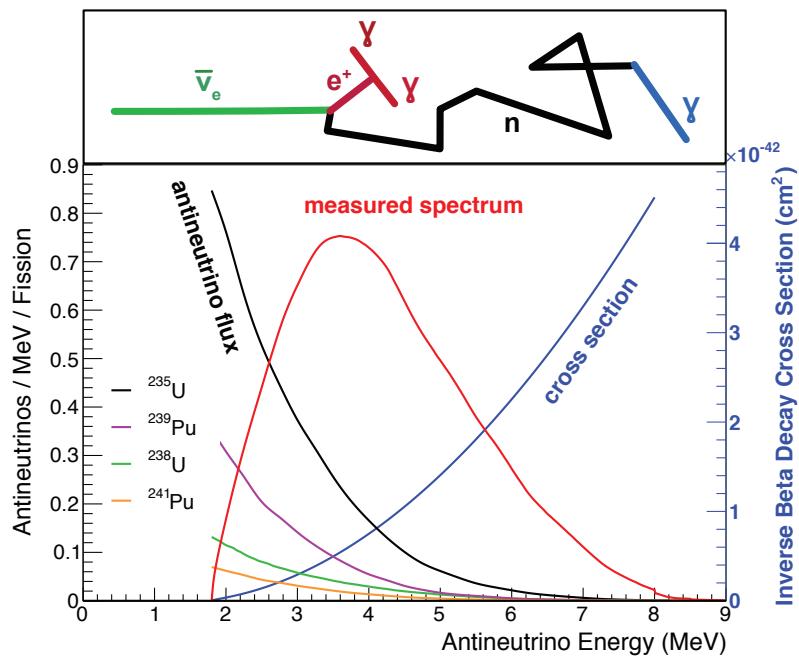
Detector Type	Experiment	Location	Size (kt)	Status	Solar	Geo	SNe
Liquid Scintillator	Borexino	Italy	0.3	Operating	**	**	*
Liquid Scintillator	KamLAND	Japan	1.0	Operating	**	**	*
Liquid Scintillator	SNO+	Canada	1.0	Construction	**	**	*
Liquid Scintillator	RENO-50	South Korea	10	Design / R&D	*	*	**
Liquid Scintillator	JUNO	China	20	Construction	*	*	**
Liquid Scintillator	Hanohano	TBD (USA)	20	Design / R&D	*	**	**
Liquid Scintillator	LENA	TBD (Europe)	50	Design / R&D	*	**	**
Liquid Scintillator	LENS	USA	0.12	Design / R&D	**		*
Water Cherenkov	Super-K	Japan	50	Operating	**		**
Water Cherenkov	IceCube	South Pole	>2000	Operating			**
Water Cherenkov	MEMPHYS	TBD (Europe)	685	Design / R&D	**		**
Water Cherenkov	Hyper-K	Japan	990	Design / R&D	**		**
Liquid Argon	LBNF/DUNE	USA	35	Design / R&D	*		**

Modified from arXiv:1310.4340v1

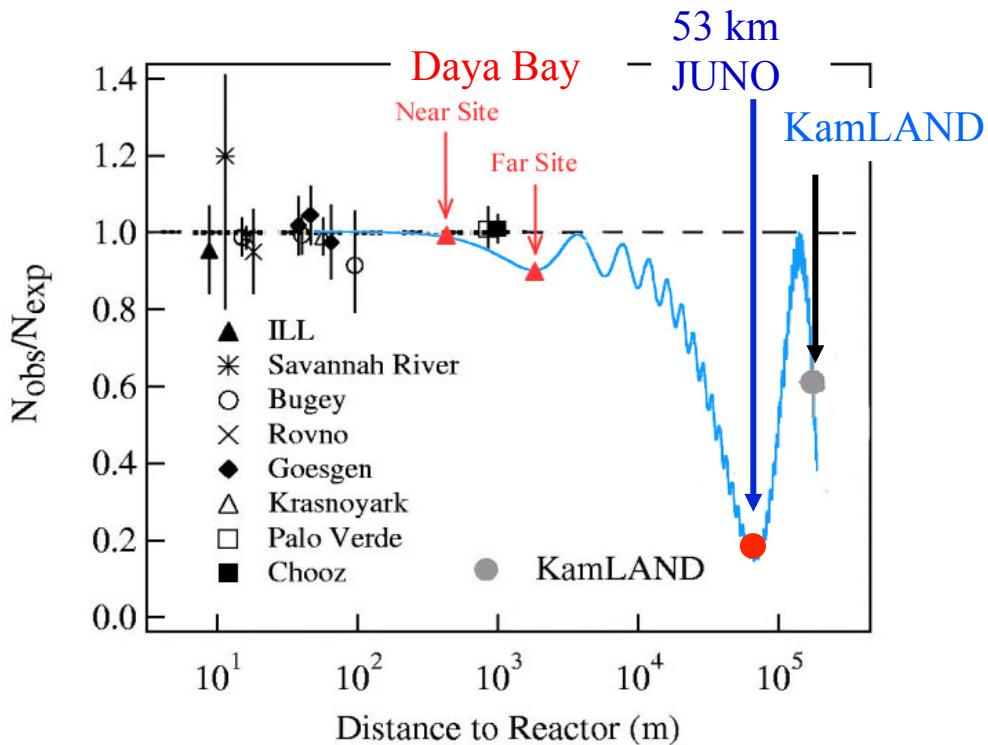
# Experimental context

## Liquid scintillator detectors

- Widely used in reactor experiments
- Low energy threshold
- Good energy resolution
- Detection principle (Inv. Beta Decay)



- 27-36 GW reactor power, 20 kton LS detector
- $3\%/\sqrt{E}$  energy resolution,  $<1\%$  energy non-linearity



## Rich physics possibilities

- Neutrino MH using reactor neutrinos
- Precision measurement of oscillation parameters
- Supernova and Diffuse supernova neutrinos
- Solar neutrinos, Geo-neutrinos, Sterile neutrinos
- Atmospheric neutrinos and Dark matter searches
- Nucleon decay and other exotic searches

Neutrino Physics with JUNO, J. Phys. G 43, 030401 (2016)

## Survival Probability:

$$P(\bar{\nu}_e \rightarrow \bar{\nu}_e) = 1 - \sin^2 2\theta_{13} \left( \cos^2 \theta_{12} \sin^2 \Delta_{31} + \sin^2 \theta_{12} \sin^2 \Delta_{32} \right) - \cos^4 \theta_{13} \sin^2 2\theta_{12} \sin^2 \Delta_{21}$$

$$= 1 - 2s_{13}^2 c_{13}^2 - 4c_{13}^2 s_{12}^2 c_{12}^2 \sin^2 \Delta_{21} + 2s_{13}^2 c_{13}^2 \sqrt{1 - 4s_{12}^2 c_{12}^2 \sin^2 \Delta_{21}} \cos(2\Delta_{32} \pm \phi)$$

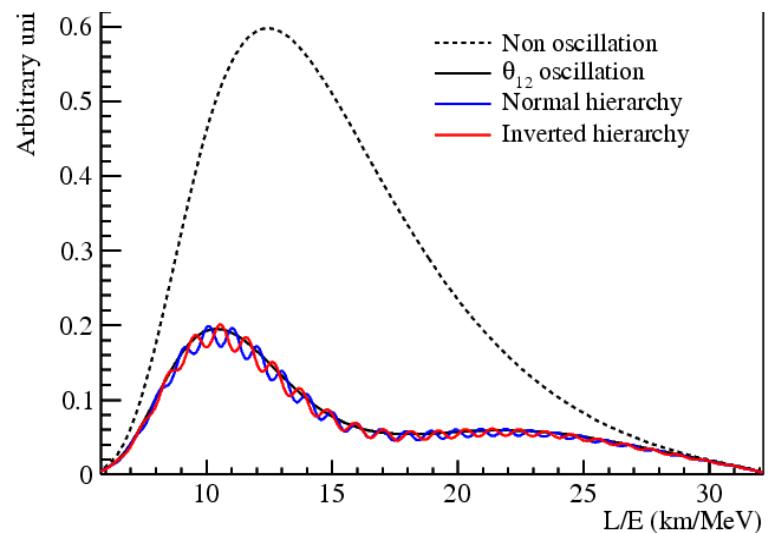
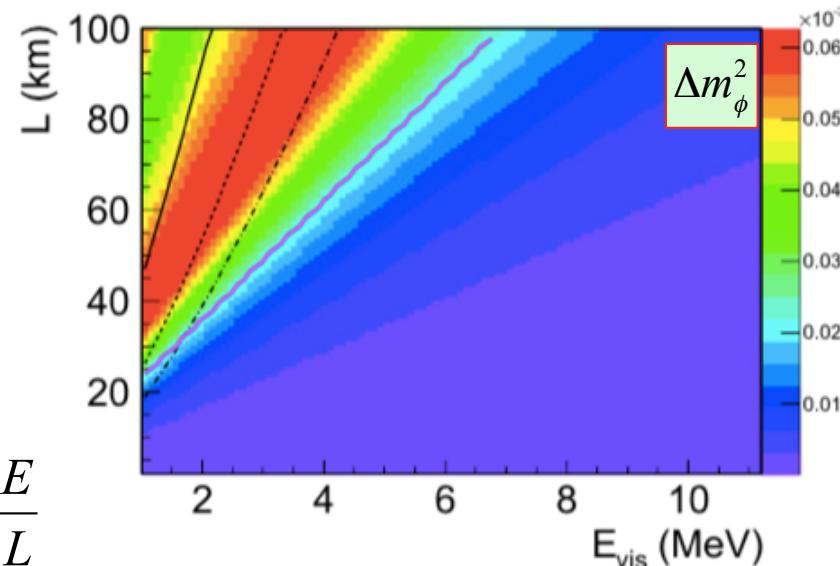
$$\Delta_{ij} = 1.27 \frac{|\Delta m_{ij}^2| L}{4E} \quad \tan \Phi = \frac{c_{21}^2 \sin(2\Delta_{21})}{c_{21}^2 \cos(2\Delta_{21}) + s_{21}^2} \quad \Delta m_{\phi}^2 = \frac{\phi}{1.27} \frac{E}{L}$$

Phys Rev D 87 033005

Sign of the phase shift depends on the inverted/normal hierarchy.

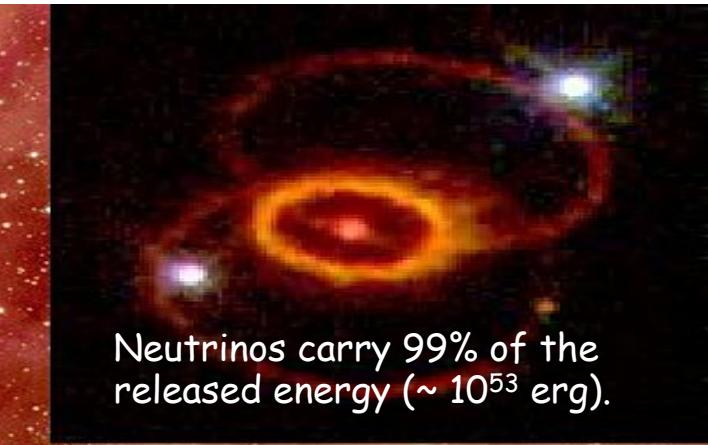
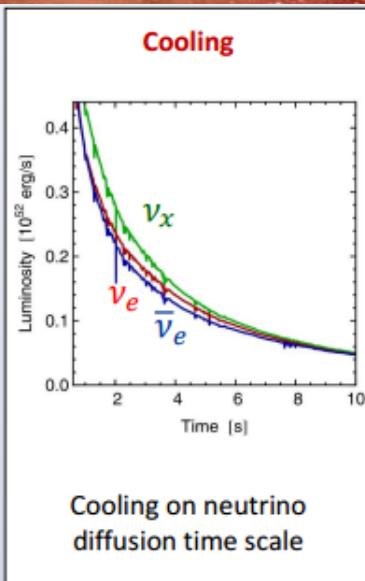
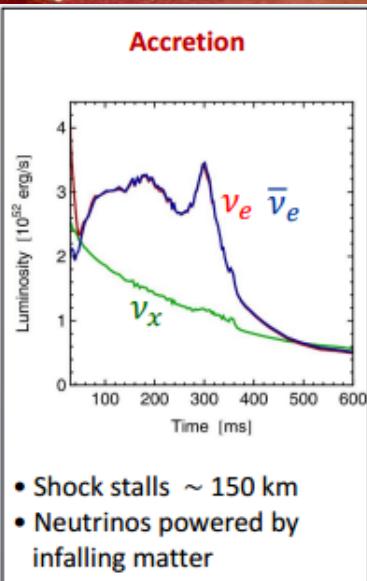
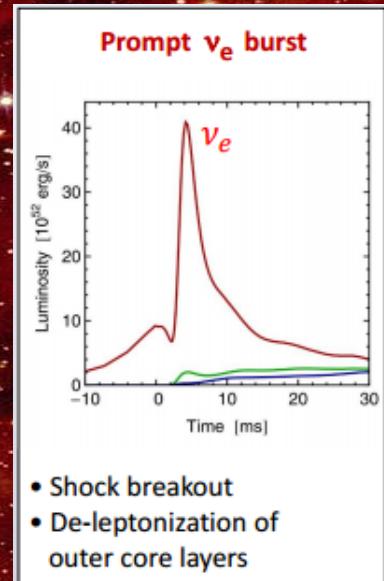
Sensitivity on MH:

- ⇒ High statistic
- ⇒ Need excellent energy resolution
- ⇒ Precision on oscillation parameters...

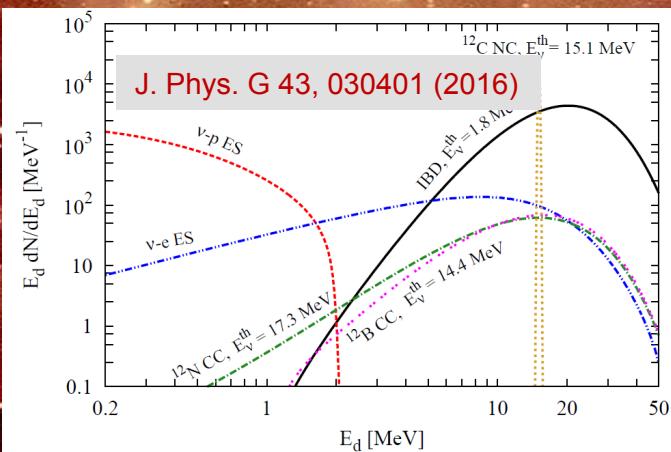


# Supernovae neutrinos

## Neutrino emission phases:



Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\bar{\nu}_e + p \rightarrow e^+ + n$	CC	$4.3 \times 10^3$	$5.0 \times 10^3$	$5.7 \times 10^3$
$\nu + p \rightarrow \nu + p$	NC	$6.0 \times 10^2$	$1.2 \times 10^3$	$2.0 \times 10^3$
$\nu + e \rightarrow \nu + e$	NC	$3.6 \times 10^2$	$3.6 \times 10^2$	$3.6 \times 10^2$
$\nu + {}^{12}\text{C} \rightarrow \nu + {}^{12}\text{C}^*$	NC	$1.7 \times 10^2$	$3.2 \times 10^2$	$5.2 \times 10^2$
$\nu_e + {}^{12}\text{C} \rightarrow e^- + {}^{12}\text{N}$	CC	$4.7 \times 10^1$	$9.4 \times 10^1$	$1.6 \times 10^2$
$\bar{\nu}_e + {}^{12}\text{C} \rightarrow e^+ + {}^{12}\text{B}$	CC	$6.0 \times 10^1$	$1.1 \times 10^2$	$1.6 \times 10^2$



- Real-time meas. of three-phase  $\nu$  signals
- Distinguish between different  $\nu$  flavors
- Reconstruct  $\nu$  energies and luminosities
- Almost background free due to time info

# Solar neutrinos

## Main challenges:

Neutrino energy at MeV scale

Accurate  $\nu$  flux measurement ( $^7\text{Be}$ ,  $^8\text{B}$ ,...)

Will provide some hints for metalliticy problem

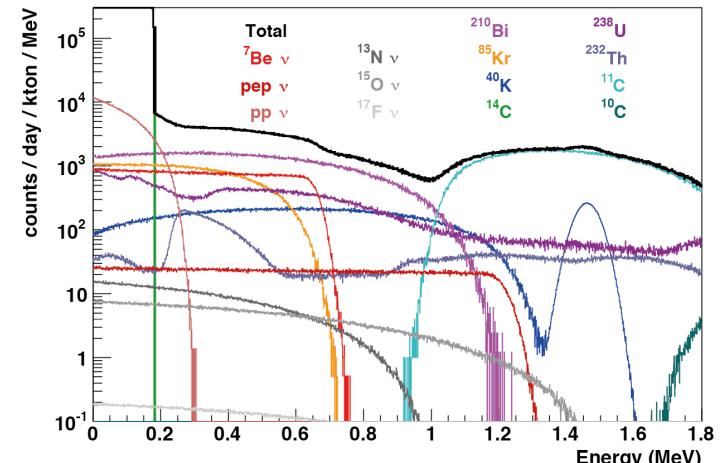
Internal radiopurity requirements		
	Baseline	Ideal
$^{210}\text{Pb}$	$5 \times 10^{-24} (\text{g g}^{-1})$	$1 \times 10^{-24} (\text{g g}^{-1})$
$^{85}\text{Kr}$	500 (counts/day/kton)	100 (counts/day/kton)
$^{238}\text{U}$	$1 \times 10^{-16} (\text{g g}^{-1})$	$1 \times 10^{-17} (\text{g g}^{-1})$
$^{232}\text{Th}$	$1 \times 10^{-16} (\text{g g}^{-1})$	$1 \times 10^{-17} (\text{g g}^{-1})$
$^{40}\text{K}$	$1 \times 10^{-17} (\text{g g}^{-1})$	$1 \times 10^{-18} (\text{g g}^{-1})$
$^{14}\text{C}$	$1 \times 10^{-17} (\text{g g}^{-1})$	$1 \times 10^{-18} (\text{g g}^{-1})$

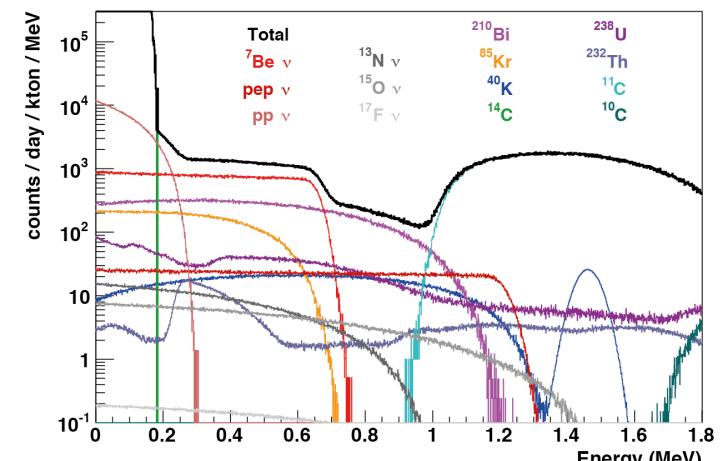
Cosmogenic background rates (counts/day/kton)		
$^{11}\text{C}$	1860	
$^{10}\text{C}$	35	

Solar neutrino signal rates (counts/day/kton)		
pp $\nu$	1378	
$^7\text{Be}$ $\nu$	517	
pep $\nu$	28	
$^8\text{B}$ $\nu$	4.5	
$^{13}\text{N}/^{15}\text{O}/^{17}\text{F}$ $\nu$	7.5/5.4/0.1	



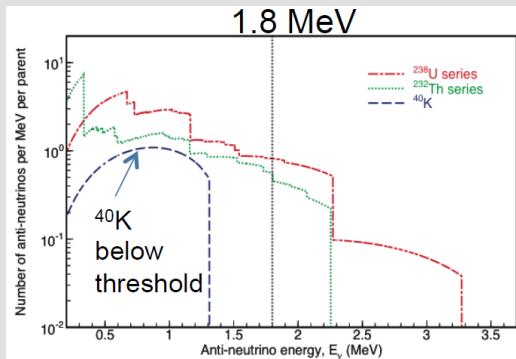
Baseline Scenario S:B≈1:3



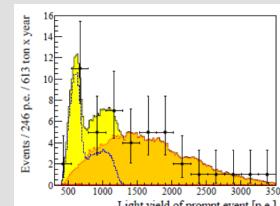
Ideal Scenario S:B≈2:1

# Geo-neutrinos

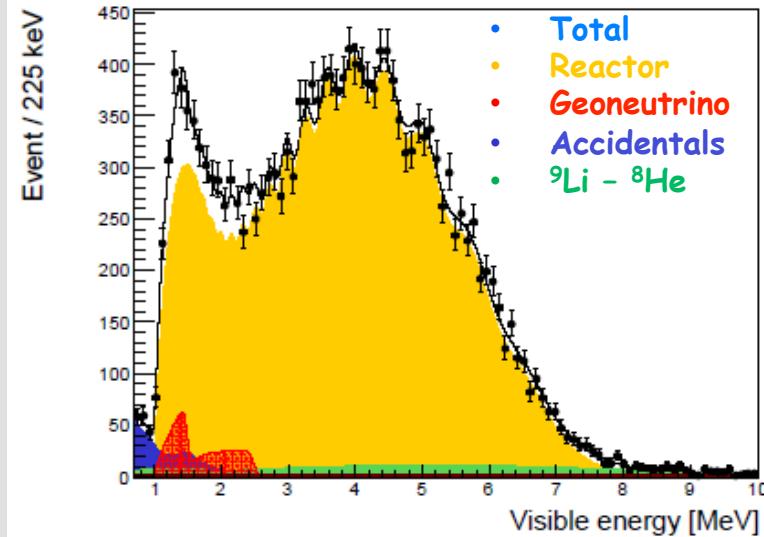
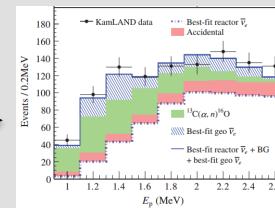
- **Geoneutrino:** antineutrino from the decay of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  in the Earth, occupying 99% radiogenic heat in the earth. *Nature.* 310 (5974): 191-198



- Results from Kamland:
  - PRD 88 (2013) 033001
  - 2002-2012 data: geoneu.



- Results from Borexino:
  - PLB 722 (2013) 295
  - 2007-2012 data: geoneu

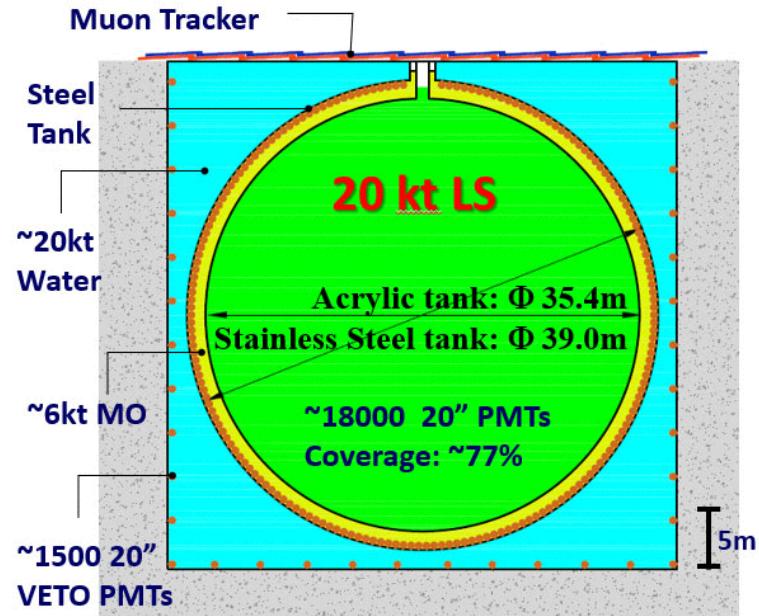


**Result of a single toy Monte Carlo for 1-year measurement of JUNO**

- FV 18.35 kton (17.2 m radial cut)
- 80% detection efficiency;
- 3% @ 1 MeV energy resolution

- JUNO's unprecedented size and sensitivity allows for the recording of  $\sim 400$  geoneutrinos per year. 6 months JUNO would match the present world sample of recorded geoneutrinos in the world.
- Earth's surface heat:  $46 \pm 3$  TW, debating it is from primordial or radioactive sources.

- Sources: reactor neutrinos, 6+4 cores (Yangjiang and Taishan NPP, under construction)
- Detection: inverse beta decay reaction
- Baseline : 53km
- Under 700 m deep underground for muon flux reduction.
- Detector: 20-kton liquid scintillator with 17k 20'' photomultiplier tubes (PMTs) + 34k 3'' PMT

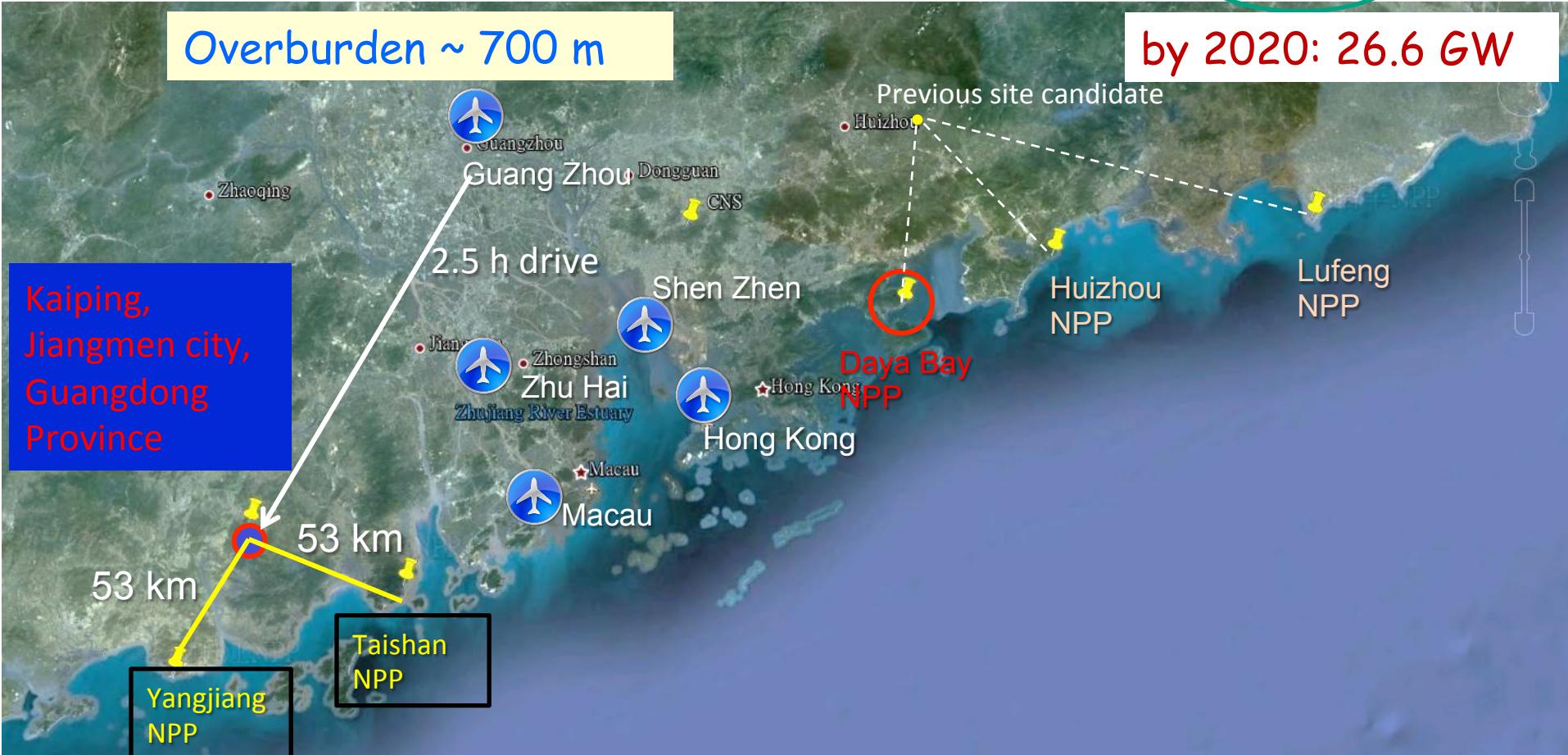


	Kamland	Borexino	JUNO
LS Mass	1. kton	0.5 kton	20 kt
Energy Resolution	6%/ $\sqrt{E}$ (MeV)	5%/ $\sqrt{E}$ (MeV)	3%/ $\sqrt{E}$ (MeV)
Light Yield	250 pe/MeV	511 pe/MeV	1200 pe/MeV
Photocathode Coverage	34%	34%	80%

⇒ 3% at 1 MeV energy resolution, <1% energy non-linearity

# JUNO Location

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW



# JUNO Collaboration



Country	Institute
Armenia	Yerevan Physics Institute
Belgium	Universite libre de Bruxelles
Brazil	PUC
Brazil	UEL
Chile	PCUC
Chile	BISEE
China	Beijing Normal U.
China	CAGS
China	ChongQing University
China	CIAE
China	DGUT
China	ECUST
China	Guangxi U.
China	Harbin Institute of Technology
China	IHEP
China	Jilin U.
China	Yerevan Physics Institute
China	Jinan U.
China	Université libre de Bruxelles
China	Nanjing U
China	PCUC
China	Nankai U
China	BISEE
China	NCEPU
China	Pekin U.
China	Shandong U.
China	Shanghai JT U.
China	IMP-CAS
China	SYSU
China	Tsinghua U.
China	UCAS
China	USTC
China	U. of South China
China	WPA particle Astrophysics
China	Wuhan U.
China	Xi'an JT U.

2016

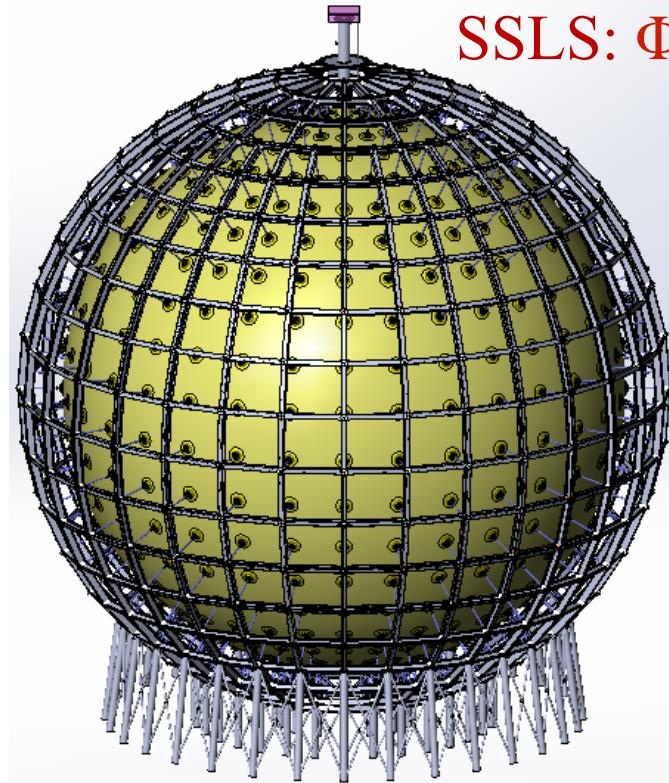


**Collaboration established in July  
2015**  
**Now: 66 institutions**  
**444 collaborators**  
**8 observers**

China	Xiamen University
China	NUDT
Czech	Charles U.
Finland	University of Oulu
France	APC Paris
France	CPPM Marseille
France	IPHC Strasbourg
France	LLR Palaiseau
France	Subatech Nantes
Germany	Forschungszentrum Julich
Germany	RWTH Aachen U.
Germany	TUM
Germany	U. Hamburg
Germany	IKP FZI Jülich
Germany	U. Mainz
Germany	U. Tuebingen
Italy	INFN Catania
Italy	INFN di Frascati
Italy	INFN Ferrara
Italy	INFN Genova
Italy	INFN Milano
Italy	INFN Milano Bicocca
Italy	INFN Roma 1
Italy	INFN Padova
Italy	INFN Perugia
Italy	INFN-Roma 3
Pakistan	PINSTECH
Russia	INR Moscow
Russia	JINR
Russia	MSU
Taiwan	National Chiao-Tung U.
Taiwan	National Taiwan U.
Taiwan	National United U.
Thailand	SUT
USA	UMD1
USA	UMD2

# JUNO: Central Detector

## CD View



AS:  $\Phi 35.4\text{m}$

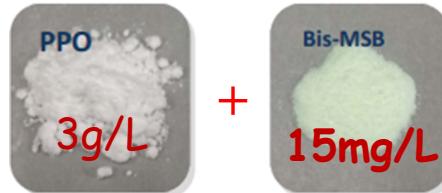
SSLS:  $\Phi 40.1\text{m}$



- **Temperature control:**  $1^\circ\text{C} \rightarrow 20\text{m}^3$  LS volume change
- **Seismic load:** still need more test to understand the liquid case.

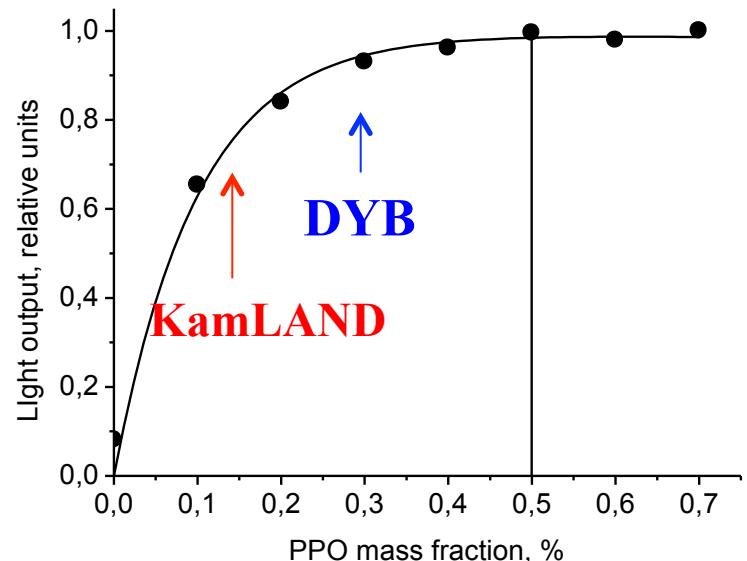
- ✓ Thickness of Acrylic: 120 mm
- ✓ Acrylic panels ~260 pieces
- ✓ Connecting nodes: ~590
- ✓ Total weight: 600 tons of acrylic and 600 tons of steel

## Requirement for LS:



(Based on Daya Bay)

- Long Attenuation Length: >20m@430nm
- Low background:
  - Less risk, since no Gd
  - $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K} < 10^{-15}\text{g/g}$

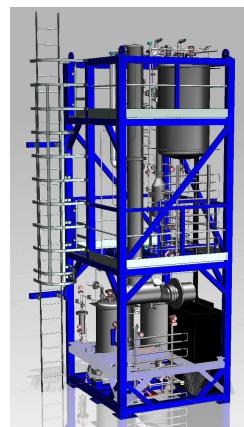


## Purification for 20 kton LS

- LS A.L. is increased by  $\text{Al}_2\text{O}_3$  column
  - Distillation, water extraction and steam stripping will be used to reduce the radiation background.
- ⇒ 4 main LS pilot plants have been installed in DYB LS Hall and Joint commissioning will take place this Oct.



Distillation system

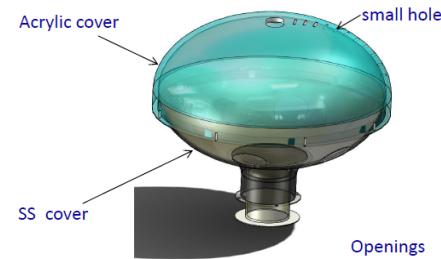


Steam stripping

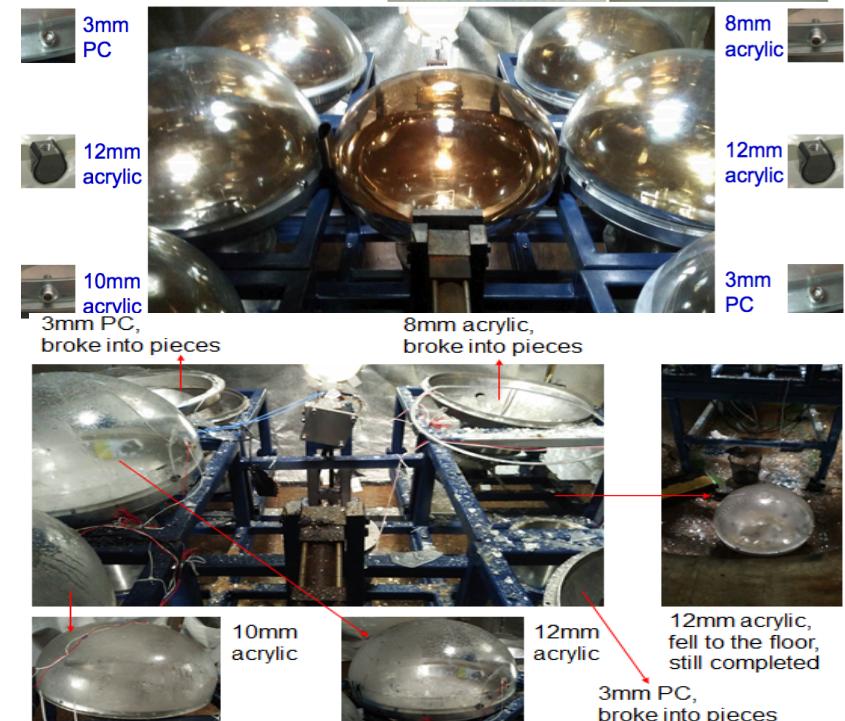
# Photodetector 20"

20-inch Hamamatus PMT Dynode Ellipsoidal Glass	20-inch IHEP MCP-PMT Horizontal MCPs Ellipsoidal Glass
HQE 1#, 2#, 3#	76#, 77#, 78#, 79#

PMT protection is designed to prevent chain reaction due to shockwave from PMT implosion



Two implosion tests shows All four 12mm acrylic cover survived and is reliable to be our baseline.



Characteristics	MCP-PMT (NNVT)	R12860 (Hamamatsu)
Detection Eff. (QE×CE*area) (%)	27%, >24%	27%, >24%
P/V of SPE	3.5, >2.8	3, >2.5
TTS on the top point (ns)	~12, <15	2.7, <3.5
Rise time/Fall time(ns)	R~5; F~12	R~5, <7; F~9, <12
Anode Dark count(Hz)	20k, <30k	10k, <50k
After Pulse Percentage(%)	1,<2	10,<15
Glass Radioactivity(ppb)	$^{238}\text{U}$ :50 $^{232}\text{Th}$ :50 $^{40}\text{K}$ :20	$^{238}\text{U}$ :400 $^{232}\text{Th}$ :400 $^{40}\text{K}$ :40

# JUNO's Double Calorimetry System...

**Additional readout system (~36,000 3" PMTs): 2 independent readouts embedded within same detector. Many purposes...**

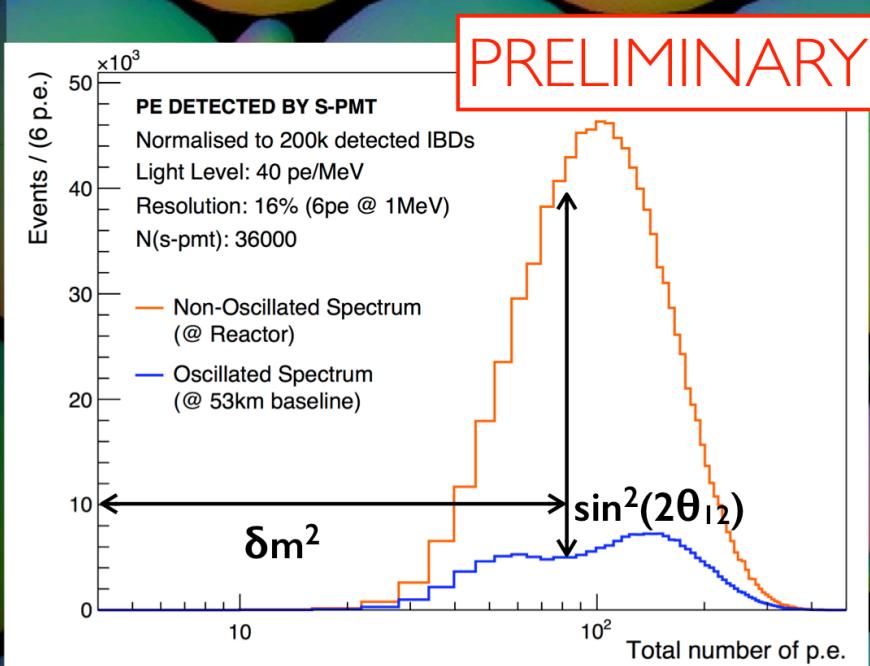
- **(high precision calorimetry for  $\pm\Delta m^2$ )** response aid to 20" PMTs for non-stochastic systematics ( $\leq 3\% @ 1 \text{ MeV}$ ).  
Main goal control of response non-linearities.
- **$(\theta_{12} \oplus \delta m^2)$  internal redundancy oscillation parameter measurement:** systematics cross-check (<1% precision)
- **( ${}^9\text{Li}$  background)** enhanced  $4\pi$ - $\mu$ -tracking for cosmogenic ion production on C tagging/vetoing:  ${}^{12}\text{B}/{}^9\text{Li}/{}^8\text{He}$ .
- **(supernova readout complementarity)** double-readout to ensure unbiased both energy and rate measurement
- **(readout $\oplus$ trigger complementarity)** complementary time resolution, dynamic range & trigger (position) information  $\rightarrow$  further empower event reconstruction



**3" PMT**

**(several options)**

- MELZ (RU)
- HZC (CH)
- ETL (UK)
- Hamamatsu (JP)



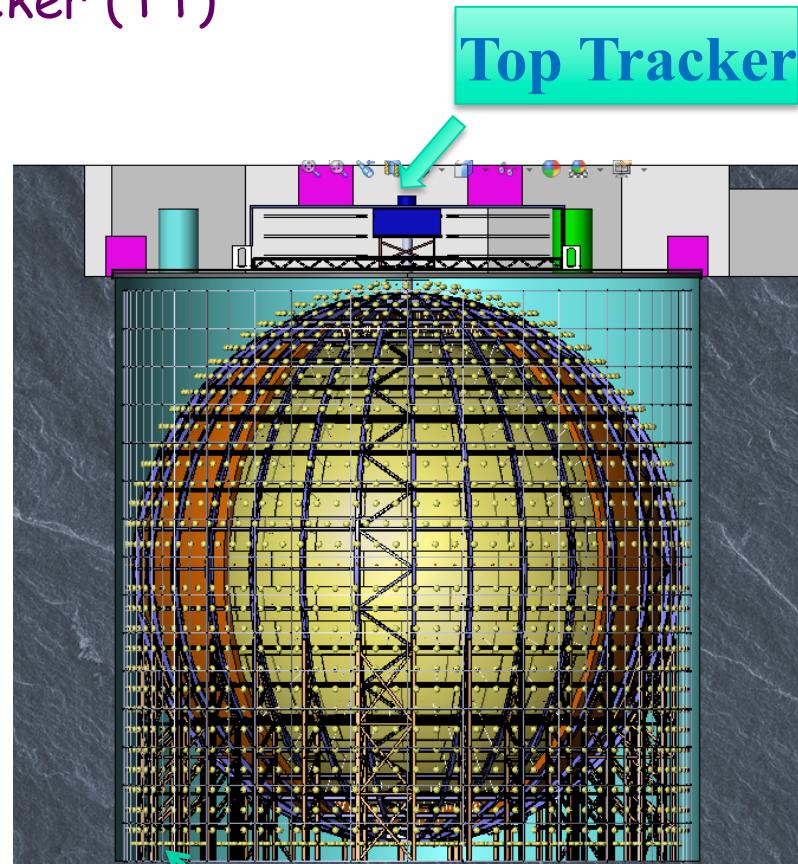
complementary  $(\theta_{12}, \delta m^2)$  measurement

Due to low background requirement, the detector is equipped with a **multi-veto systems**: Outer Veto (OV) & Top Tracker (TT)

- Cosmogenic isotopes reduction ( $^9\text{Li}/^8\text{He}$ )
  - requires a precise muon track reconstruction
- Fast neutrons background rejection
  - passive shielding and possible tagging
- Radioactivity from rock
  - passive shielding by water

Selection	IBD efficiency	IBD	Geo- $\nu s$	Accidental	$^9\text{Li}/^8\text{He}$	Fast $n$	$(\alpha, n)$			
-	-	83	1.5	$\sim 5.7 \times 10^4$	84	-	-			
Fiducial volume	91.8%	76	1.4	410	77	0.1	0.05			
Energy cut	97.8%	73	1.3							
Time cut	99.1%		71							
Vertex cut	98.7%	60	1.1		1.1					
Muon veto	83%		0.9	1.6						
Combined	73%	60			3.8					

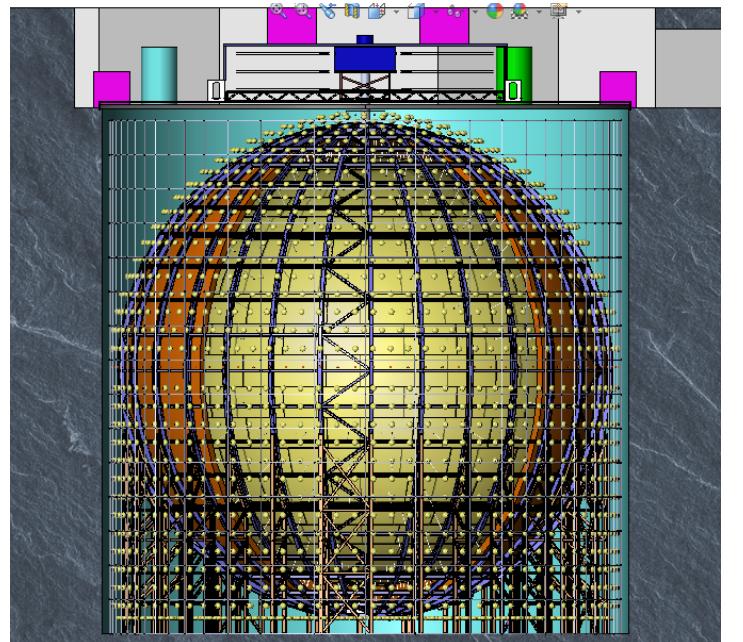
Event selection (Expect signal/background)



Outer veto

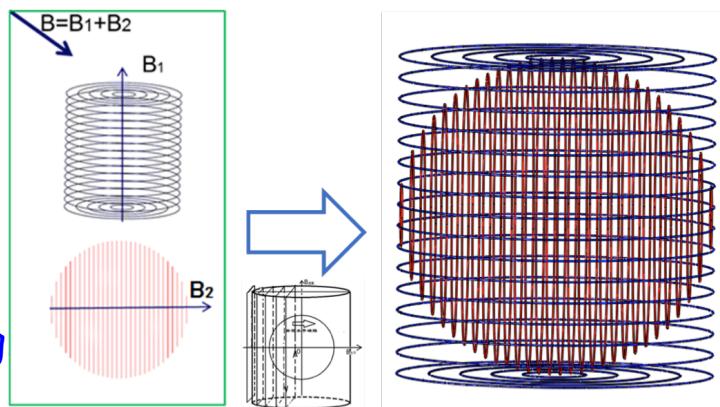
## Detector Characteristics

- 2000 PMT's (20'')
- PMTs put on the surface of the sphere and of the wall of water pool after optimization
- 20-30 kton ultrapure water
- Tyvek reflector film coated on surface to increase light collection efficiency
- Detector efficiency is expected to be > 95%



## Compensation coils system protect against earth magnetic field:

- Magnetic intensity on site : ~0.5 Gauss.
- Reduce influence on the PMT performance.
- Two separated compensation coils
- Residual field intensity <10% after coil shielding

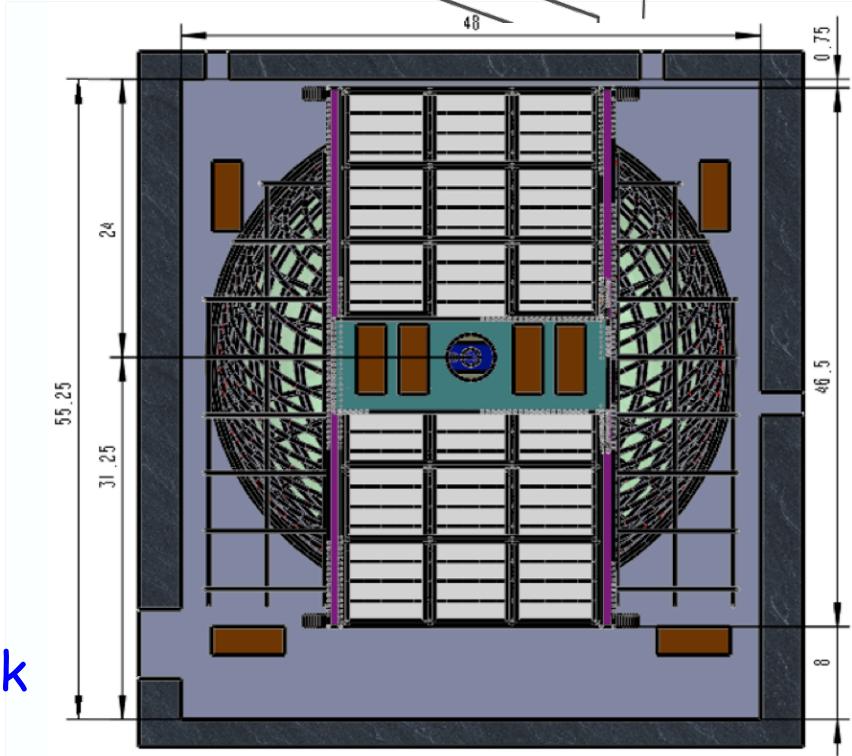
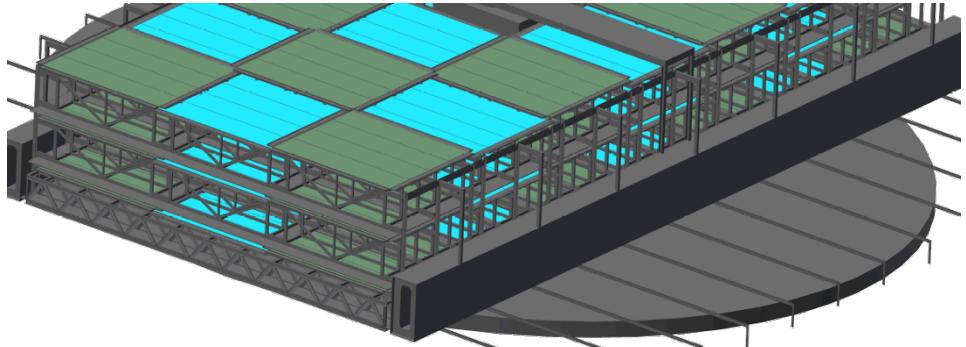


## Detector Characteristics:

- OPERA target tracker:  $2783\text{ m}^2$  (x-y readout)
- 56 x-y walls ( $6.7\text{m}\times6.7\text{m}$  each)
- Covered area is about  $630\text{m}^2$



=> Perform accurate muon track reconstruction



## Ground breaking in Jan. 2015

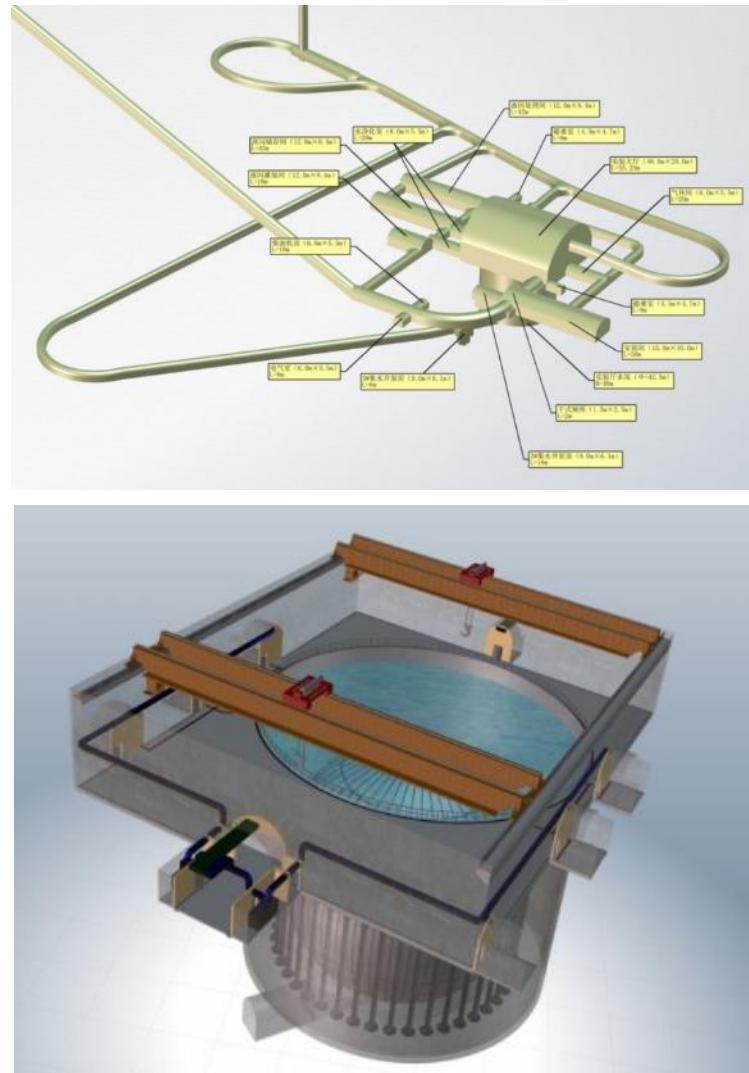
- 900 m slope tunnel excavated out of 1340 m
- 330 m vertical shaft excavated out of 611 m

## Schedule:

- Civil preparation: 2013-2014
- Civil construction: 2014-2018
- Detector component production: 2016-2017
- Detector assembly & installation: 2018-2019
- Filling & data taking: 2020

## Future Plan

- Run for 20-30 years
- Likely, double beta decay experiment in 2030



# Civil Progress



# Outline

- Next generation of LS at kt scale will be able to determining the MH and the oscillation parameter at the percent level
- Offer a rich physics program in neutrino but also in other fields
- JUNO is on schedule and data taking should start by 2020