Status of JUNO

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Outline

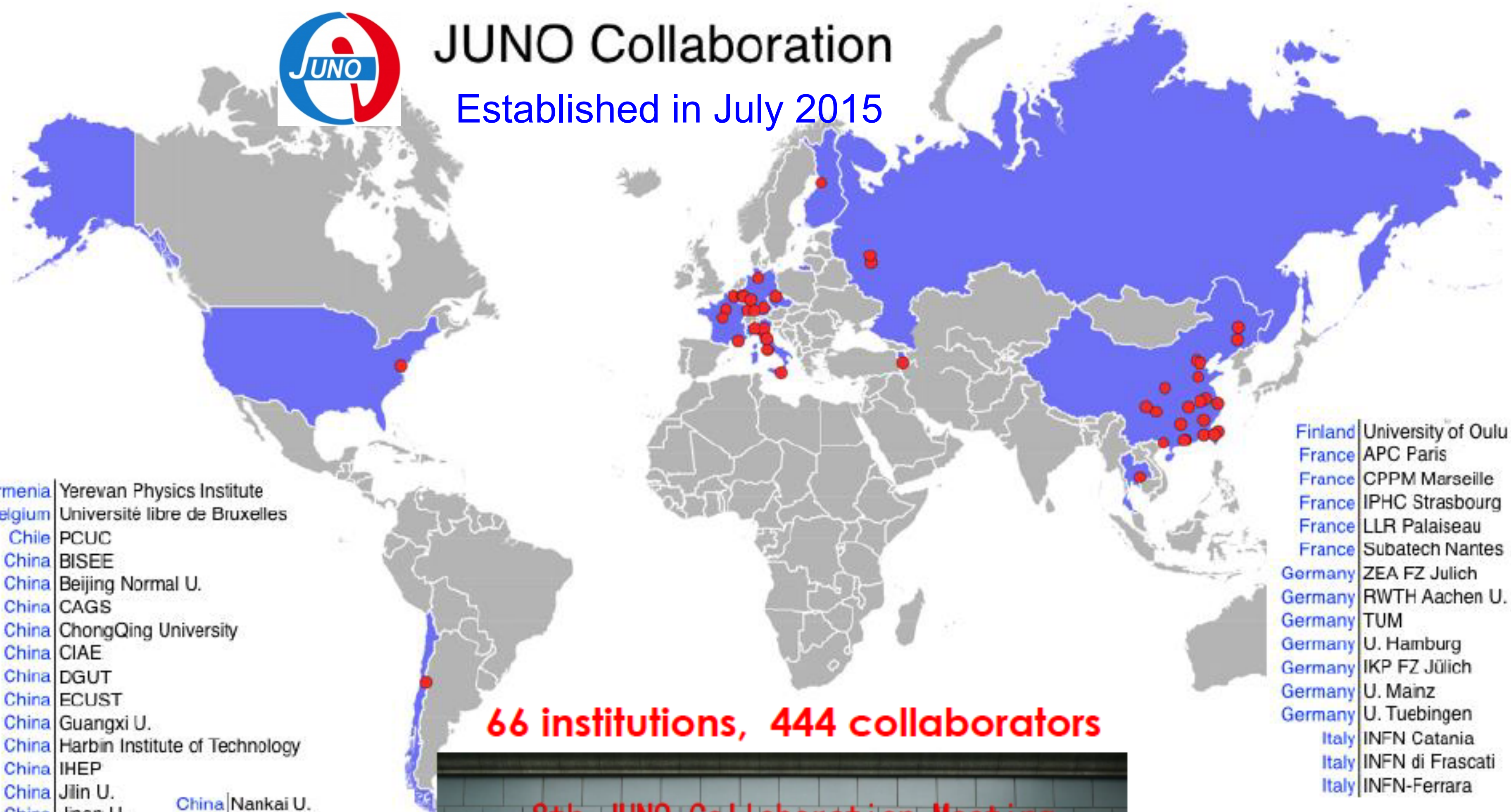
- *Introduction to JUNO experiment*
- *JUNO Detector Status*
- *JUNO Civil Progress*
- *Summary*

Jiangmen Underground Neutrino Observatory

the first multi-kton liquid scintillator detector ever

JUNO Collaboration

Established in July 2015



66 institutions, 444 collaborators

Armenia	Yerevan Physics Institute
Belgium	Université libre de Bruxelles
Chile	PCUC
China	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	Jinan U.
China	Nanjing U.

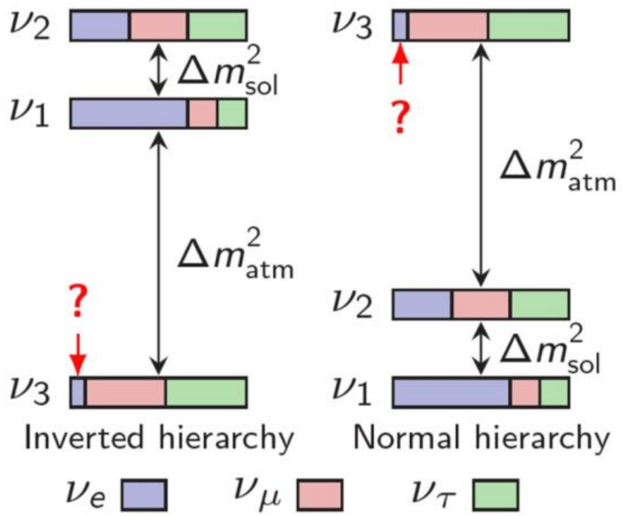
China	Nankai U.
China	NCEPU
China	Pekin U.
China	Shandong U.
China	Shanghai JT U.
China	Sichuan U.
China	SYSU
China	Tsinghua U.
China	UCAS
China	USTC
China	U. of South China
China	Wu Yi U.
China	Wuhan U.
China	Xi'an JT U.
China	Xiamen University
Czech	R. Charles U. Prague

Finland	University of Oulu
France	APC Paris
France	CPPM Marseille
France	IPHC Strasbourg
France	LLR Palaiseau
France	Subatech Nantes
Germany	ZEA FZ Julich
Germany	RWTH Aachen U.
Germany	TUM
Germany	U. Hamburg
Germany	IKP FZ Jülich
Germany	U. Mainz
Germany	U. Tuebingen
Italy	INFN Catania
Italy	INFN di Frascati
Italy	INFN-Ferrara

Italy	INFN-Milano
Italy	INFN-Milano Bicocca
Italy	INFN-Padova
Italy	INFN-Perugia
Italy	INFN-Roma 3
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

Neutrino Mixing

In a 3-ν framework



$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\Delta m^2_{sol} : \Delta m^2_{21}$ $\Delta m^2_{atm} : \Delta m^2_{31}, \Delta m^2_{32}$

Values of θ_{12}, θ_{23} and θ_{13} have been determined by different methods of neutrino experiments.

$$\mathrm{NH} : |\Delta m^2_{31}| = |\Delta m^2_{32}| + |\Delta m^2_{21}|, \quad |\Delta m^2_{31}| > |\Delta m^2_{32}| \qquad \Delta m^2_{31} > 0$$

$$\mathrm{IH} : |\Delta m^2_{31}| = |\Delta m^2_{32}| - |\Delta m^2_{21}|, \quad |\Delta m^2_{31}| < |\Delta m^2_{32}| \qquad \Delta m^2_{31} < 0$$

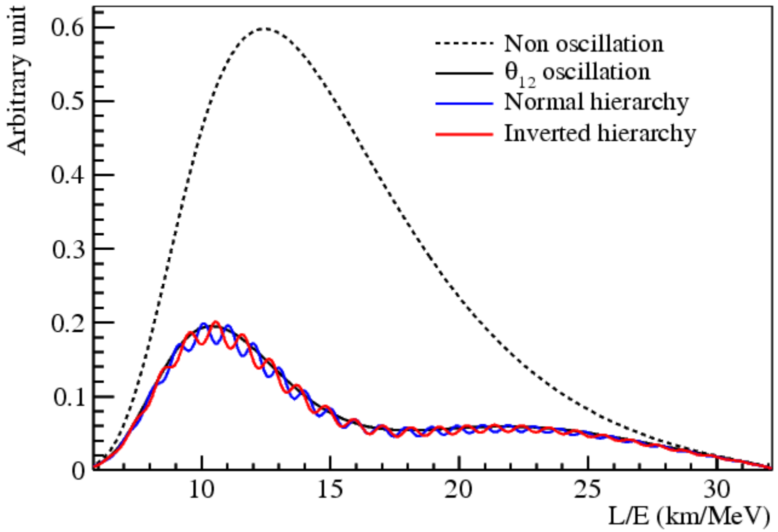
Next generation neutrino experiments mainly focus on the determination of *mass hierarchy (MH)* and measurement *of CP Phase.*

- ***Measuring Mass Hierarchy with Reactor neutrinos***
  - Place detector at medium baseline (~50 km) from reactors
  - Measure the distortion of energy spectrum
  - Oscillation probability independent of CP phase and θ_{23}

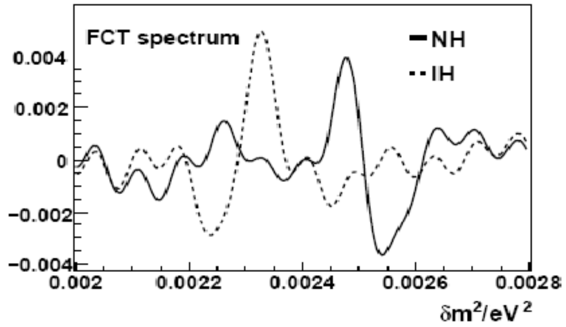
Antineutrino survival probability:

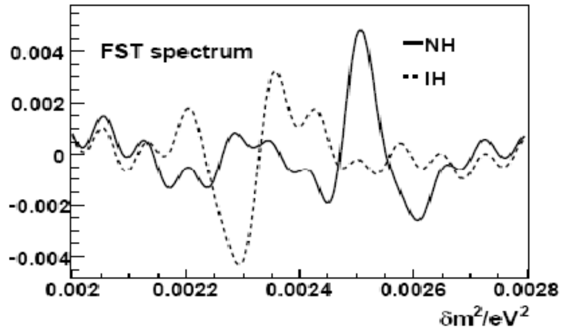
$$
\begin{aligned}
P_{ee}(L/E) &= 1 - P_{21} - P_{31} - P_{32} \\
P_{21} &= \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \\
P_{31} &= \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31}) \\
P_{32} &= \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32})
\end{aligned}
$$

where $\Delta_{ij} = 1.27\Delta m^2_{ij} L/E$, Δm^2_{ij} is the neutrino mass-squared difference $(m_i^2 - m_j^2)$ in eV^2



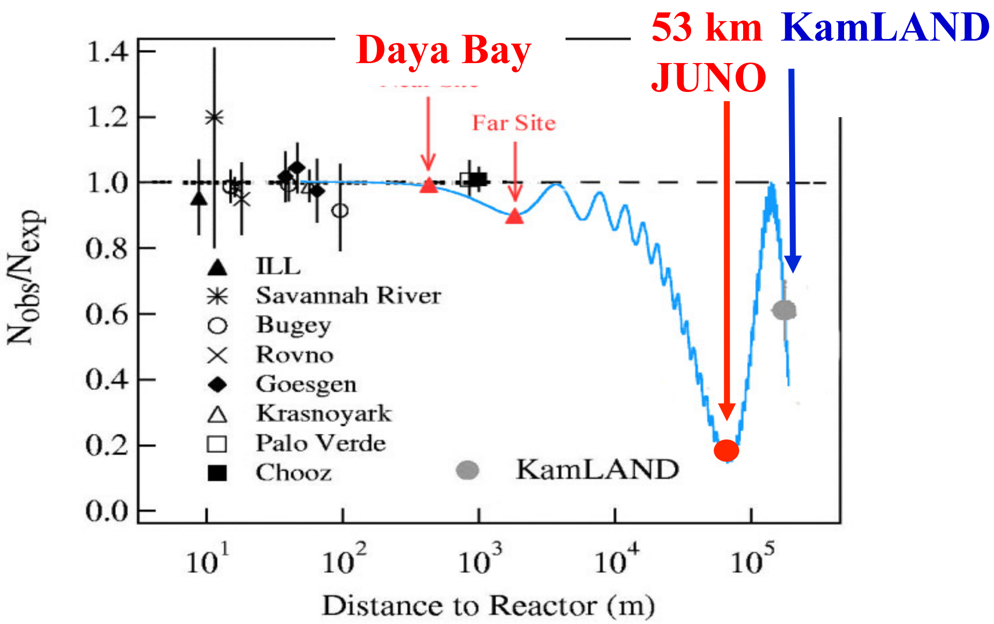
Fourier transform to show the interference





S.T. Petcov et al., PLB533(2002)94
S.Choubey et al., PRD68(2003)113006
J. Learned et al., Phys.Rev. D78 (2008) 071302
Zhan, Y. Wang, J. Cao, L. Wen, PRD78:111103, 2008; PRD79:073007, 2009

Jiangmen Underground Neutrino Observatory



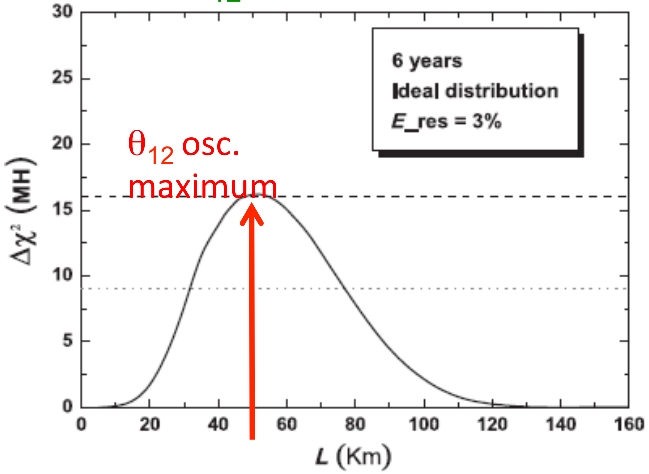
Nominal experiment setup

- 700 m deep underground
- 36 GW reactor power
- 53 km baseline;
- 20 kton LS detector
- 3% energy resolution@1MeV
- Running time: 6 years

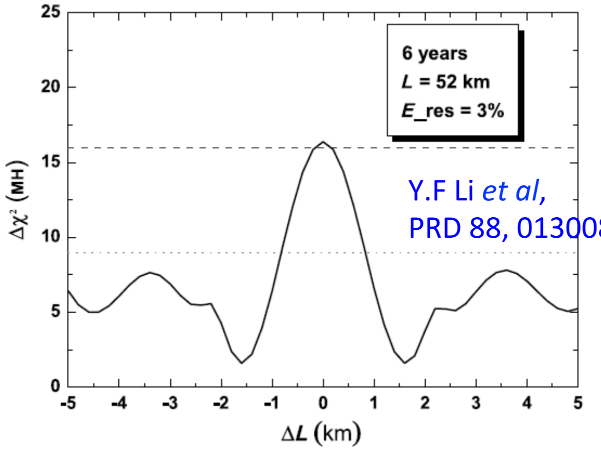
MH sensitivity study

$$\Delta\chi^2_{\rm MH} = |\chi^2_{\rm min}(\rm N) - \chi^2_{\rm min}(\rm I)|,$$

Optimization baseline at the oscillation maximum of θ_{12}



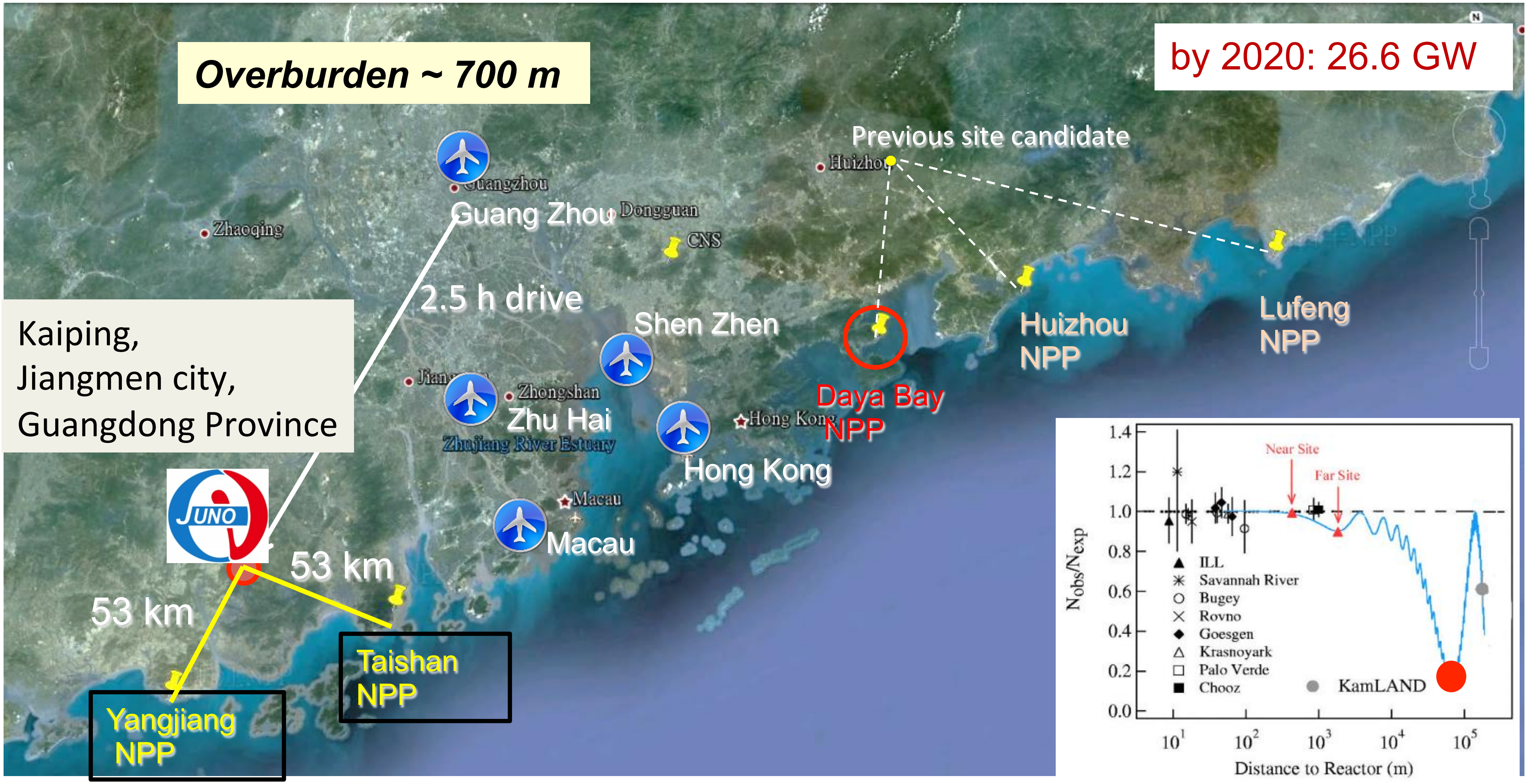
Multiple reactor cores may reduce the MH sensitivity (Baseline difference can not be more than 0.5km)



Y.F Li *et al*,
PRD 88, 013008 (2013)

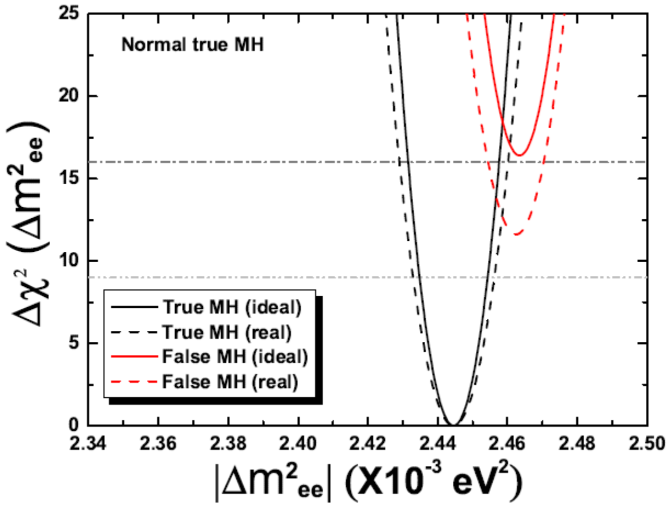
Location of JUNO

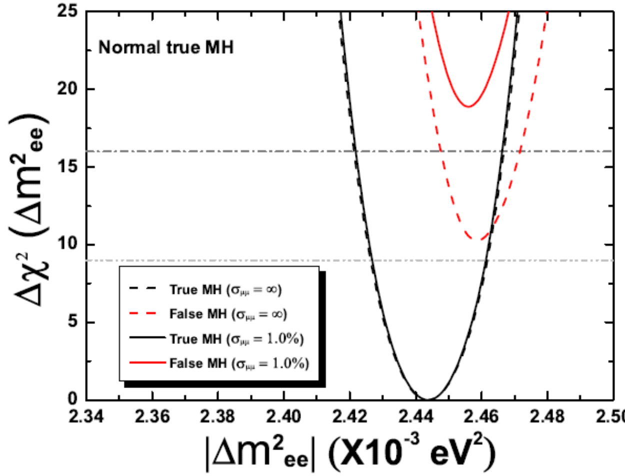
NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW



Mass hierarchy sensitivity

Improved by $\Delta m^2_{\mu\mu}$ precision of 1%



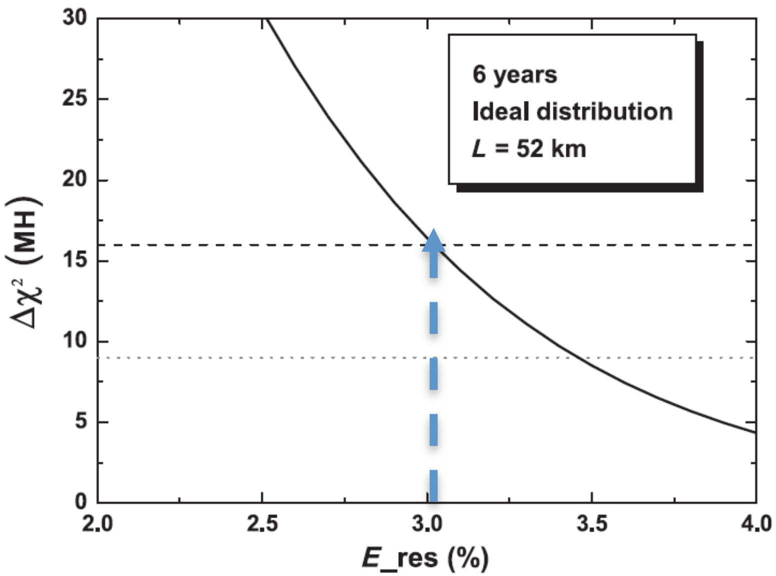


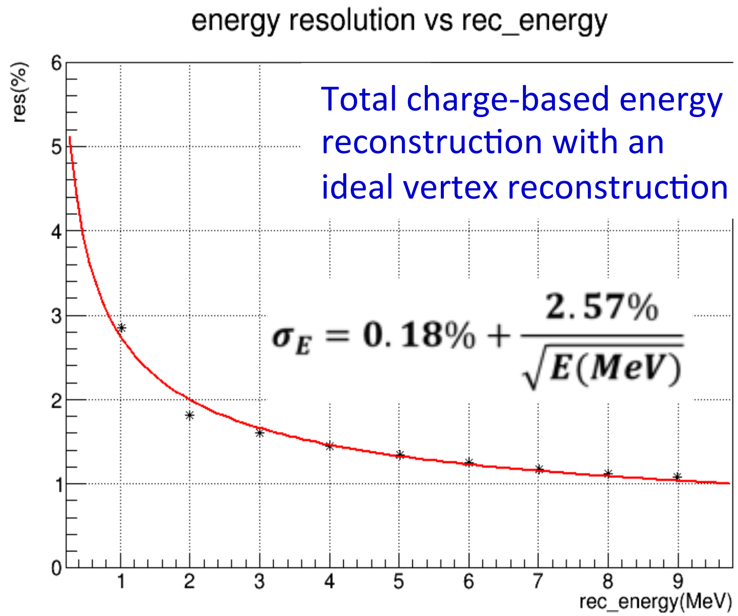
√ $\Delta\chi^2$	**Without Δm^2_{uu} input**	**With Δm^2_{uu} input (1%)**
Equal baseline(ideal)	4	5
Core distribution(real)	3	4

$$\Delta m^2_{ee} \simeq \cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32},$$
$$\Delta m^2_{\mu\mu} \simeq \sin^2\theta_{12}\Delta m^2_{31} + \cos^2\theta_{12}\Delta m^2_{32} + \sin 2\theta_{12}\sin\theta_{13}\tan\theta_{23}\cos\delta\Delta m^2_{21}.$$

Y.F Li *et al*,
PRD 88, 013008 (2013)

Mass hierarchy sensitivity vs energy resolution



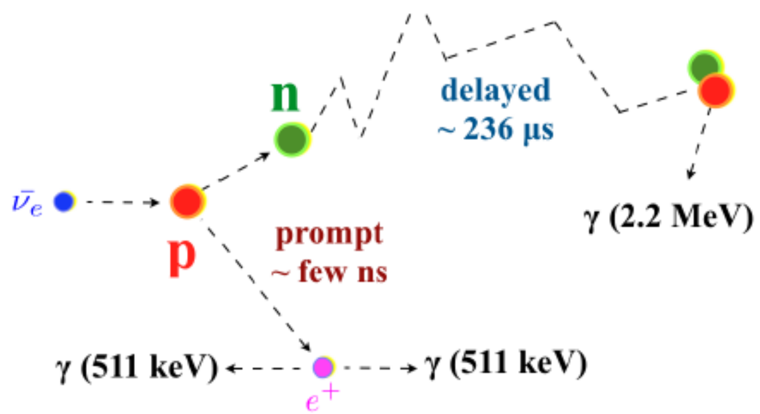


- Energy resolution:
  - 3%@1MeV energy resolution for 4 sigma sensitivity at ideal distribution.
- Experiment requirements to achieve such an unprecedented energy resolution
  - PMT coverage: 75%
  - High QE PMT: 35%
  - Liquid scintillator attenuation length >20 m@430nm

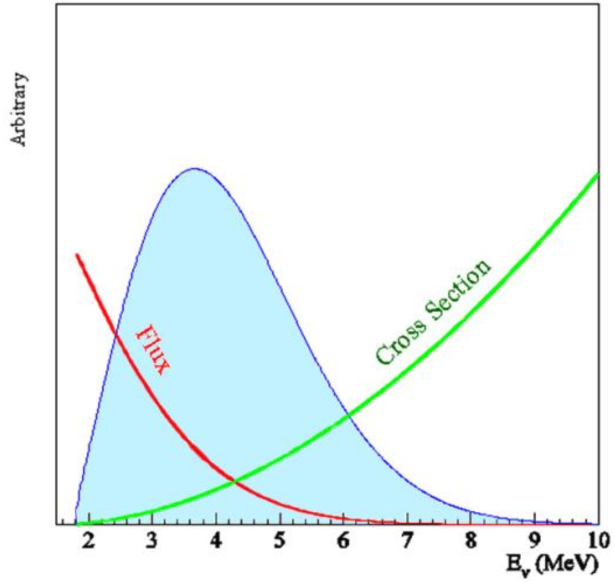
Antineutrino detection

- Signal: Inverse beta decay reaction (IBD)

$\bar{\nu} + p \rightarrow n + e^{+}$ E_{ν}>1.8 MeV



Antineutrino spectrum



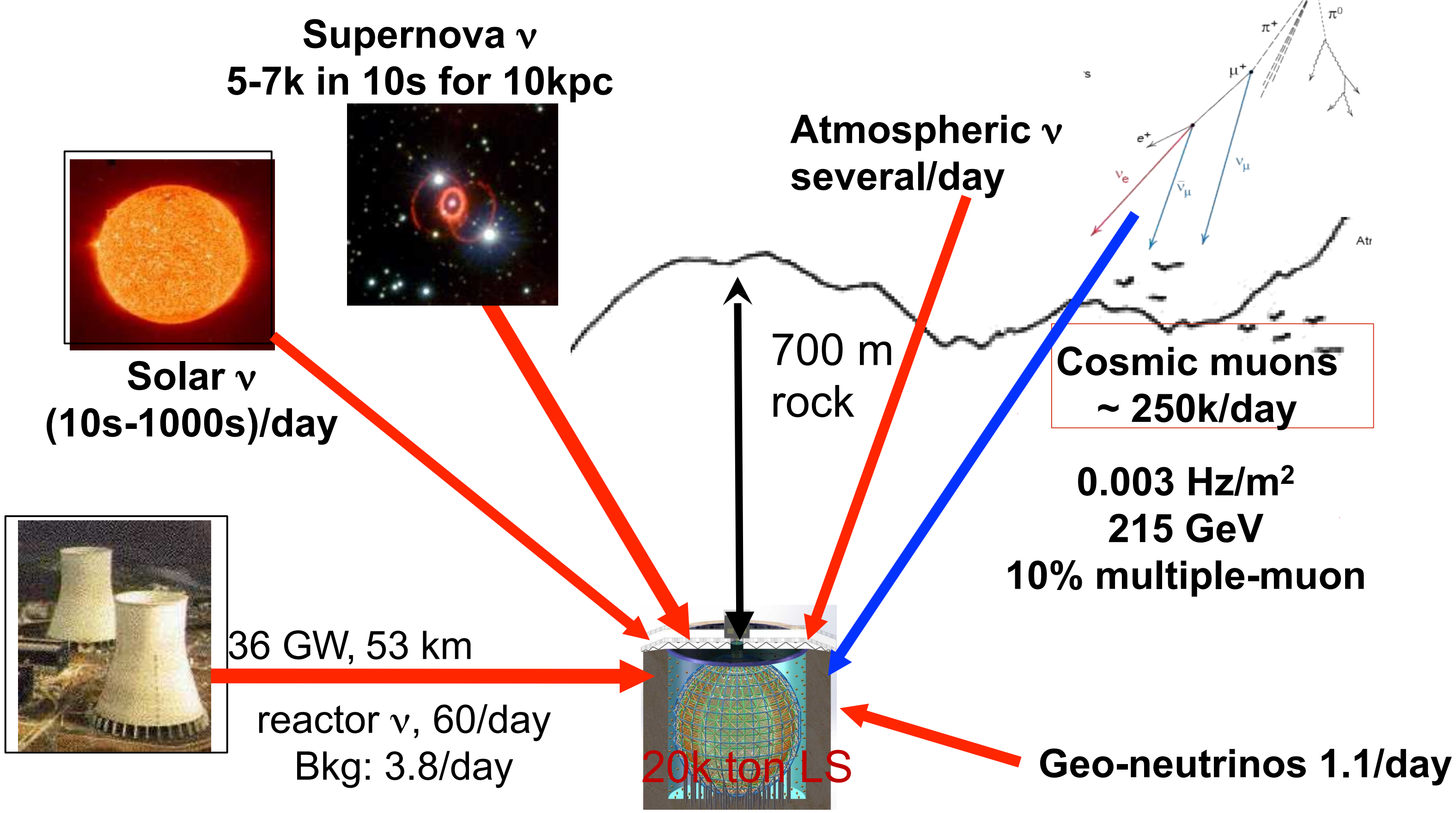
Anticipated signal/background per day

<table>
<tr><th>Selection</th><th>IBD efficiency</th><th>IBD</th><th>Geo-νs</th><th>Accidental</th><th>^{9}Li/^{8}He</th><th>Fast n</th><th>(α, n)</th></tr>
<tr><td>-</td><td>-</td><td>83</td><td>1.5</td><td>$\sim 5.7 \times 10^4$</td><td>84</td><td>-</td><td>-</td></tr>
<tr><td>Fiducial volume</td><td>91.8%</td><td>76</td><td>1.4</td><td rowspan="3">410</td><td>77</td><td rowspan="5">0.1</td><td rowspan="5">0.05</td></tr>
<tr><td>Energy cut</td><td>97.8%</td><td rowspan="3">73</td><td rowspan="3">1.3</td><td rowspan="3">71</td></tr>
<tr><td>Time cut</td><td>99.1%</td></tr>
<tr><td>Vertex cut</td><td>98.7%</td><td>1.1</td></tr>
<tr><td>Muon veto</td><td>83%</td><td>60</td><td>1.1</td><td>0.9</td><td>1.6</td></tr>
<tr><td>Combined</td><td>73%</td><td>60</td><td colspan="5">3.8</td></tr>
</table>

Rich physics possibilities of JUNO

- Precision of three parameters (Δm^2_{21}, Δm^2_{ee} and $\sin^2\theta_{12}$) will reach sub-percent level, several times improvement compared with current precision.
- Probing the unitarity of U_{PMNS} to ~1% level.

Event Rate (after selection)



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

Detector structure and layout

Electronics

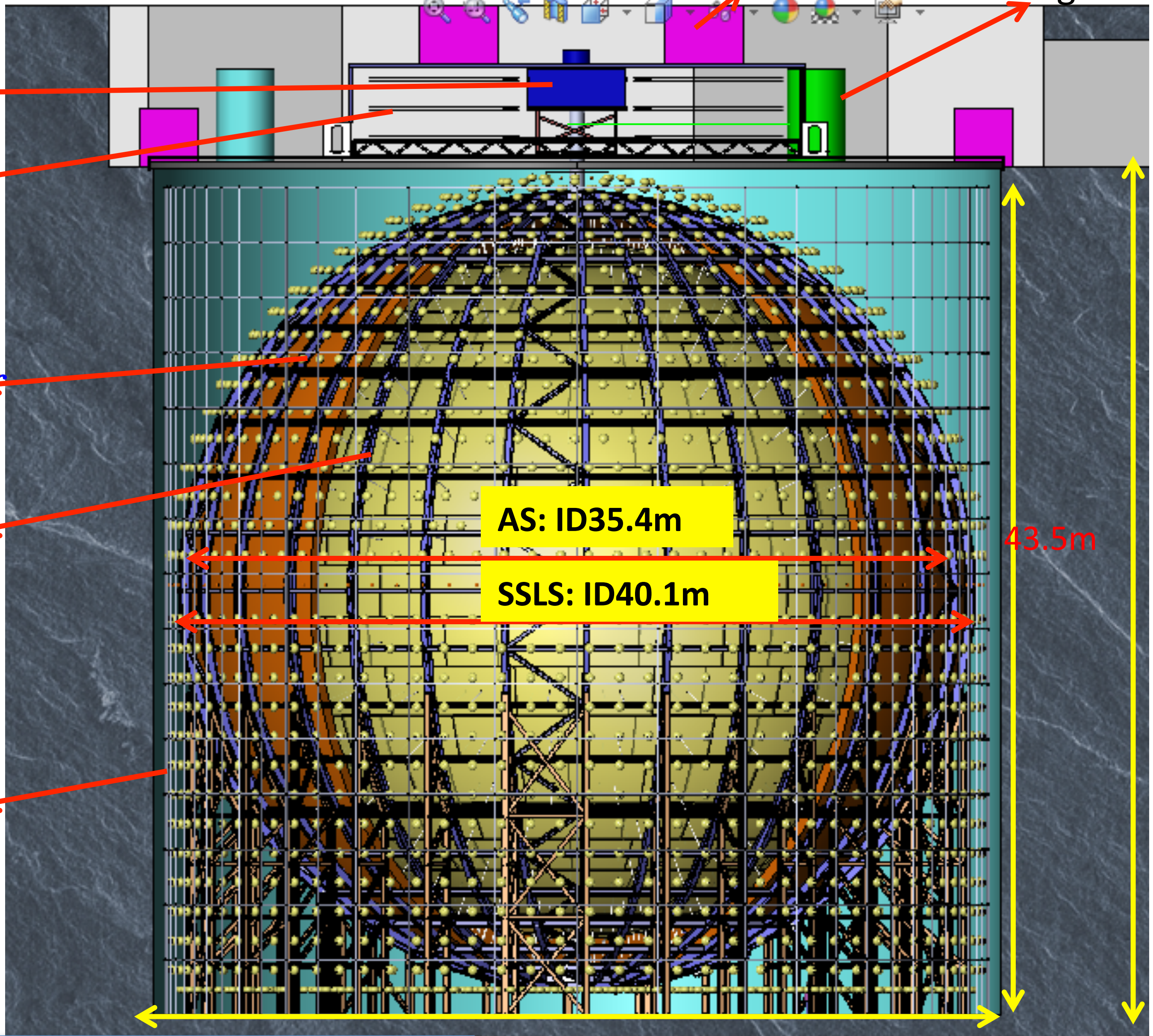
Filling + Overflow

Calibration

Top Tracker

Central detector
Acrylic sphere+
20kt Liquid Scint+
~18000 20'' PMT+
~36000 3'' small PMT

Water Cherenkov
~2000 20'' PMT

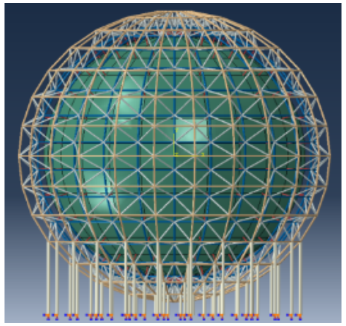


D43.5m

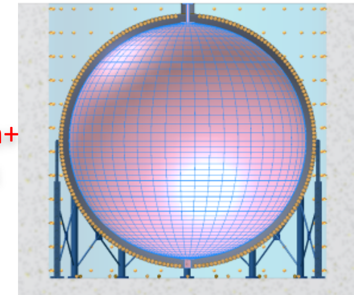
AS: Acrylic sphere; SSLS: stainless steel lattice shell

Central Detector(CD)

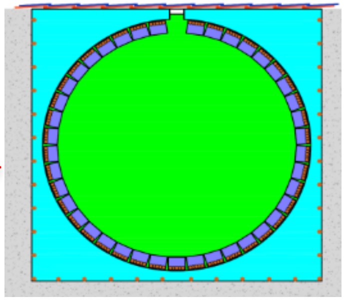
Acrylic sphere+ SS truss



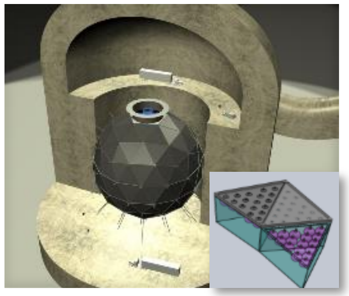
Balloon+ SS tank



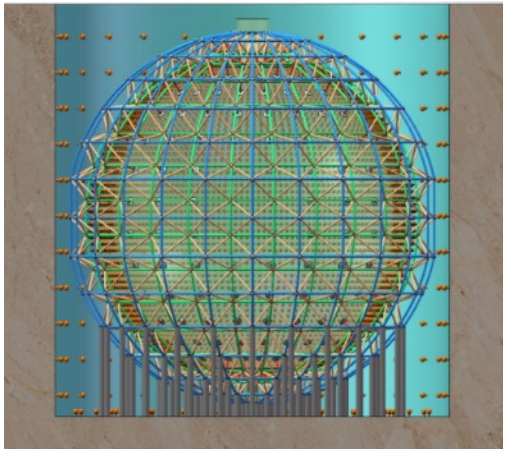
Acrylic module+ SS tank



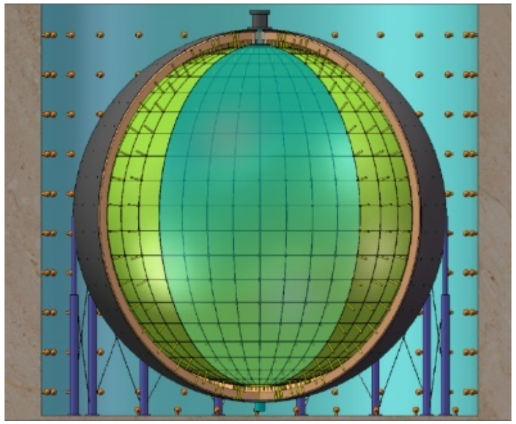
Acrylic sphere+ SS tank



March 2014



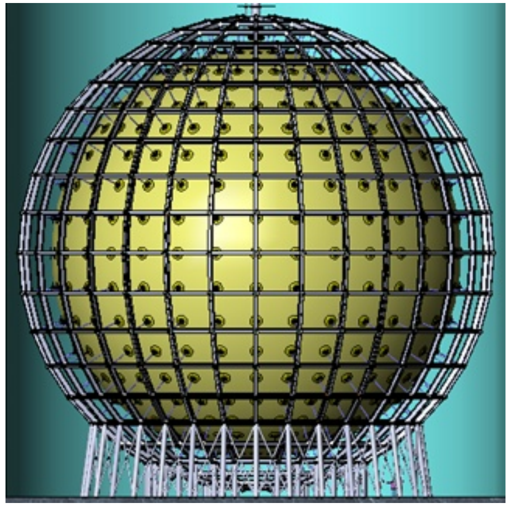
SS truss+ Acrylic sphere



Balloon + Acrylic support+ SS tank

July 2015

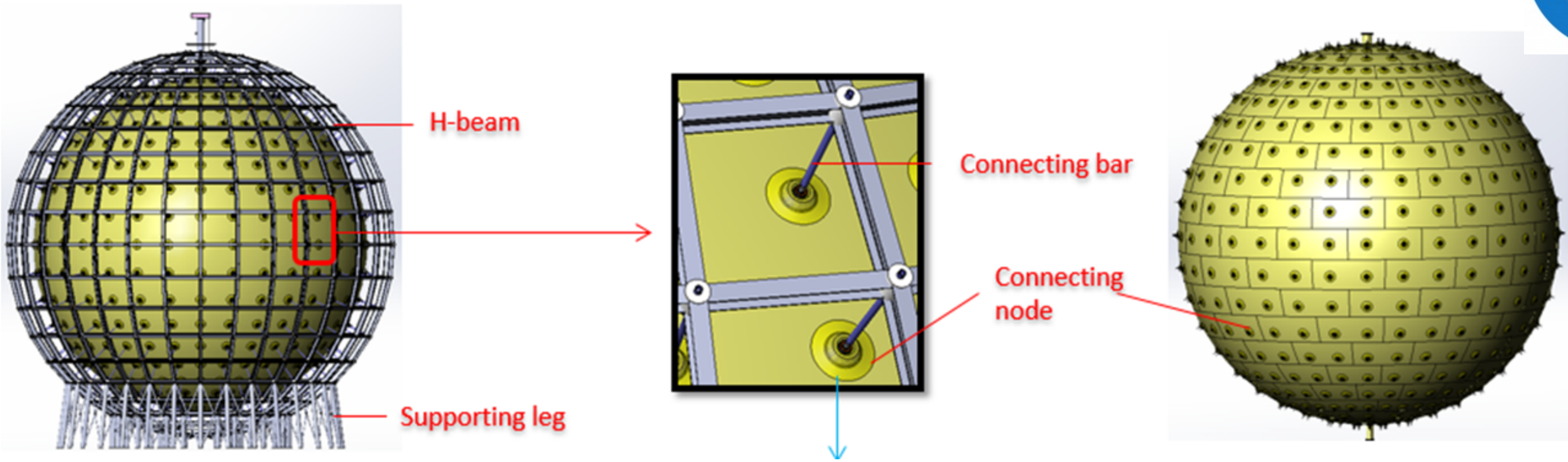
Final decision:
Acrylic sphere + SS truss

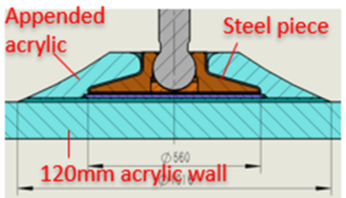


Key features

- ✓ Thickness of Acrylic: 120mm
- ✓ Acrylic panels(21/23 layers + top chimney+ bottom flange): ~260 pieces
- ✓ Connecting nodes: ~590
- ✓ Total Weight: 600 tons of acrylic and 600 tons of steel

Acrylic sphere R&D

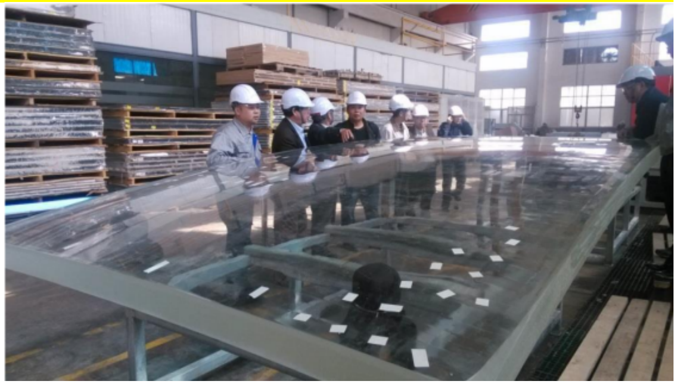




Prototype of spherical panel

Acrylic connection nodes

Forming panel size: 3m x 8m x 120mm

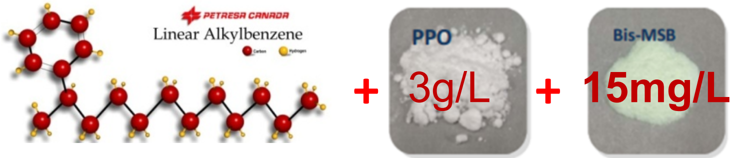


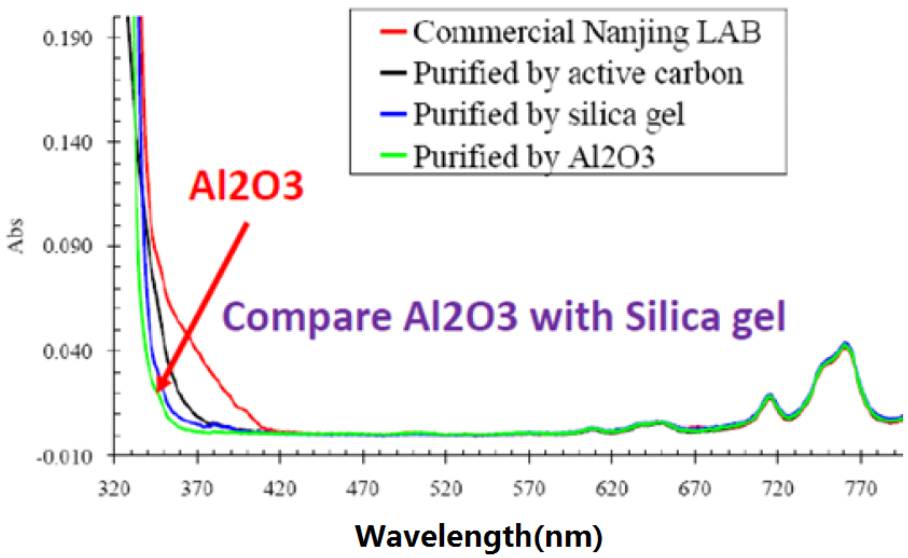
Problems of shrinkage and shape variation were resolved.

Liquid scintillator (LS)

Requirement for LS:

- **Long Attenuation Length: >20m@430nm**
- **Low background: ^{238}U, ^{232}Th, ^{40}K <10^{-15}g/g**
- **Preliminary recipe(based on Daya Bay)**





LS Production:

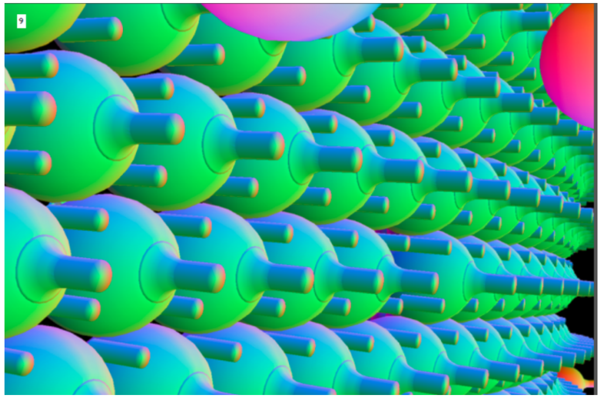
In order to get good quality LS

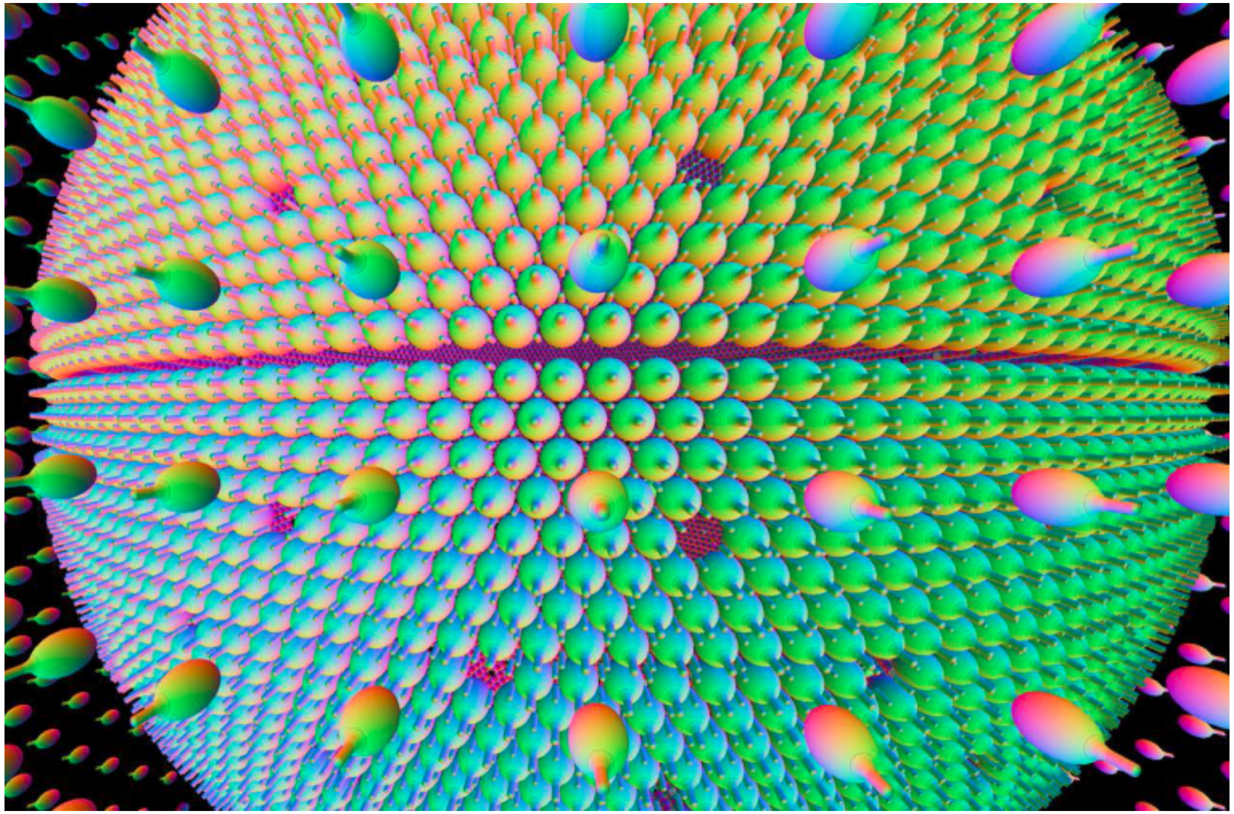
- Use Al_2O_3 column for LS purification to increase the attenaution length;
- Use distillation, water extraction and steam stripping to reduce the radioactive background for background control.

LS purification pilot plant has been bulit in Daya Bay LS hall as a pre-study for JUNO LS mass production.

PMT coverage

- ~18000 20” PMT -> 75% photocathode coverage；
- Goal is to detect the largest light level ever detected in LS detector ~1200 pe/MeV
- Daya Bay 160 pe/MeV-KamLAND 250 pe/MeV-Borexino 500 pe/MeV





20" high QE PMTs

Two types of 20" PMTs used in JUNO

- 15k NNVT MCP-PMT: newly developed by North Night Vision Technology (NNVT), used for central detector and veto detector.
- 5k Hamamatsu R12860: used for central detector.

NNVT MCP-PMT

Hamamatsu R12860

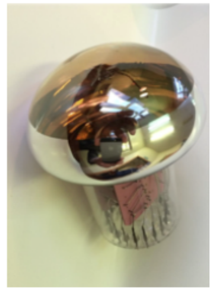
Characteristics	MCP-PMT (NNVT)	R12860 (Hamamatsu)
Detection Eff. (QE×CE*area) (%)	27% > 24%	27% > 24%
P/V of SPE	3.5 > 2.8	3 > 2.5
TTS on the top point (ns)	~12 < 15	2.7 < 3.5
Rise time/Fall time(ns)	R~5; F~12	R~5 <7; F~9 <12
Anode Dark count(Hz)	20k < 30k	10k < 50k
After Pulse Percentage(%)	1% < 2%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

3" PMTs

- Double Calorimetry for Central Detector
  - ~36000 3" PMT
  - 3" PMTs are put into the gap between large 20" PMTs

HZC
3-inch
XP53B20

Hamamatsu
3-inch
R6091

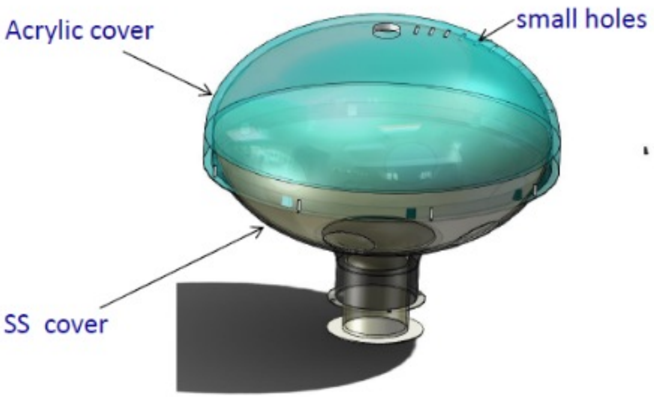


MELZ
3-inch
10 dynodes

- ➢ An Independent system to cross calibrate the 20" PMT system;
- ➢ Extend the energy dynamical range beyond the region where large PMT are no more linear or even saturated;
- ➢ Lower TTS of small PMTs with good time resolution for vertex reconstruction improvement;
- ➢ Improve muon tracking reconstruction with better timing for better 9Li/8He backgrounds control.

PMT cover protection

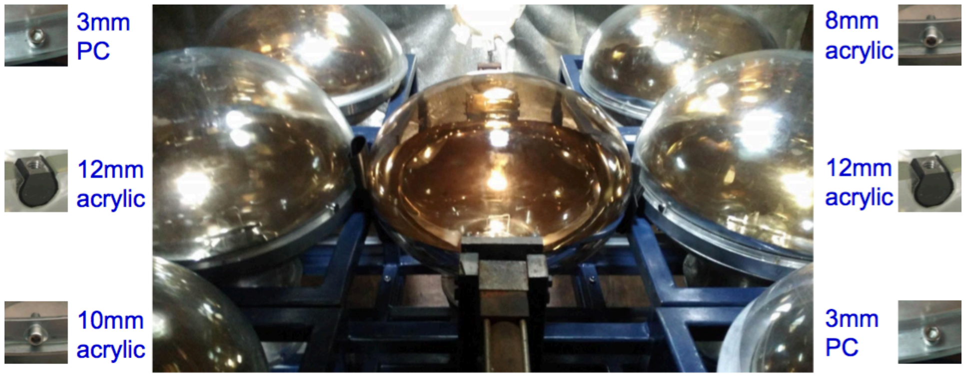
- PMT cover protection design
  - Prevent chain reaction due to shockwave from one PMT accidental implosion;
  - Including top cover(acrylic cover) and back cover(stainless steel cover);

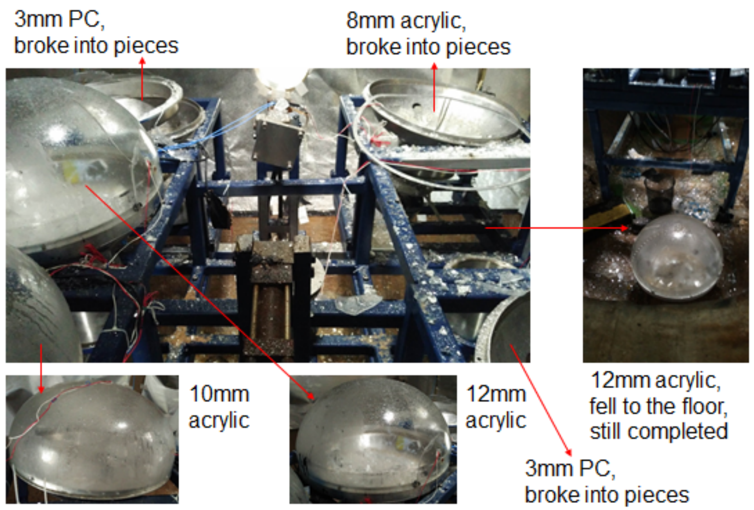


Implosion test in water

•Use one PMT implosion for trigger;

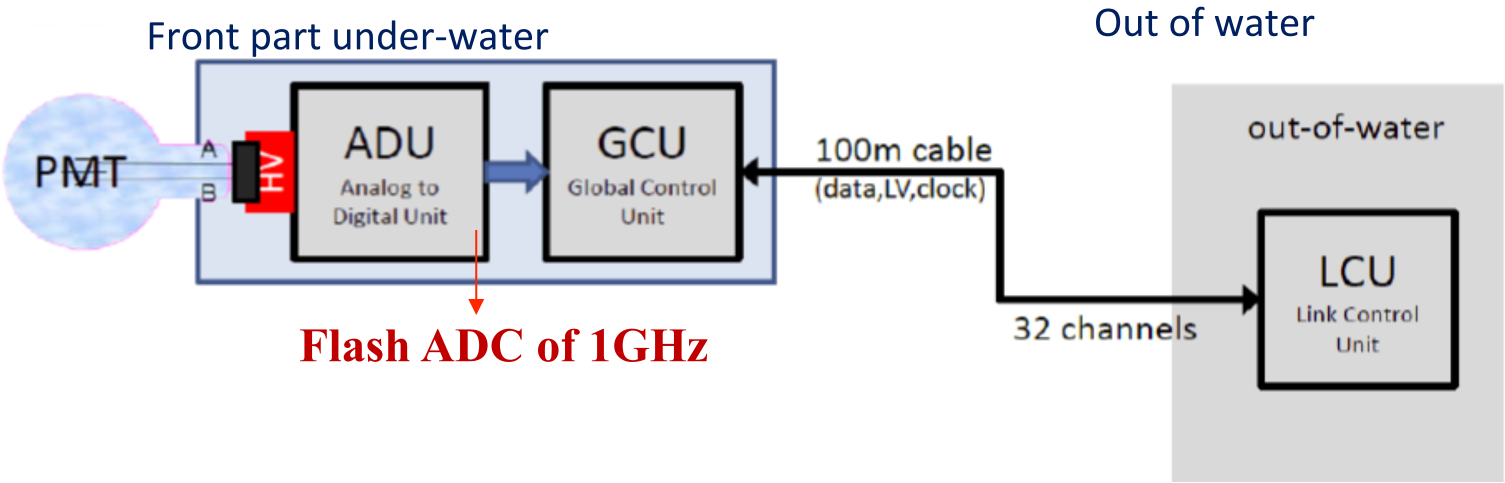
•Adjacent PMT with different types cover;





- ☐ All four 12mm acrylic covers survived after two implosion tests and is reliable to be our baseline.
- ☐ Stainless steel cover is strong enough for protection.

PMT Readout



- Put most of electronics underwater and sealed with BASE, HV together.
- Use a **CAT5+ cable** to transfer data, hit, clock, power and trigger

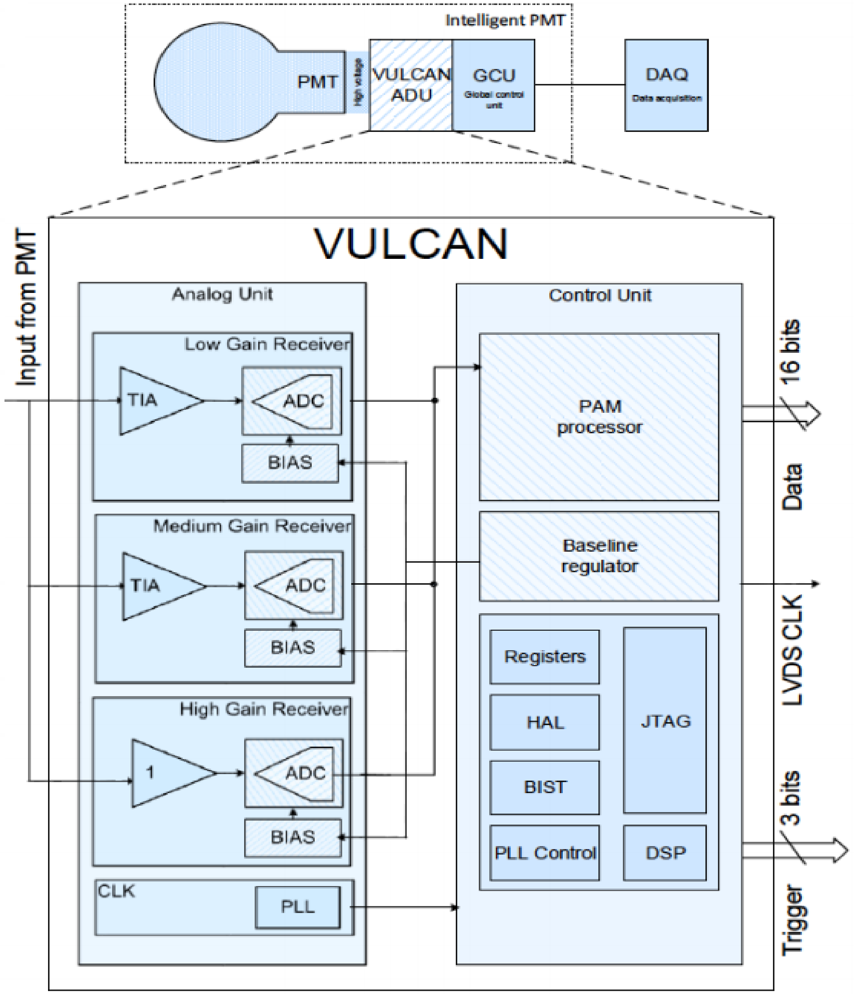
- Needs to consider the integration and potting structure with PMT
- Replacement under water is almost impossible, need high reliability of potting, electronics and HV

Electronics Design

Key Features

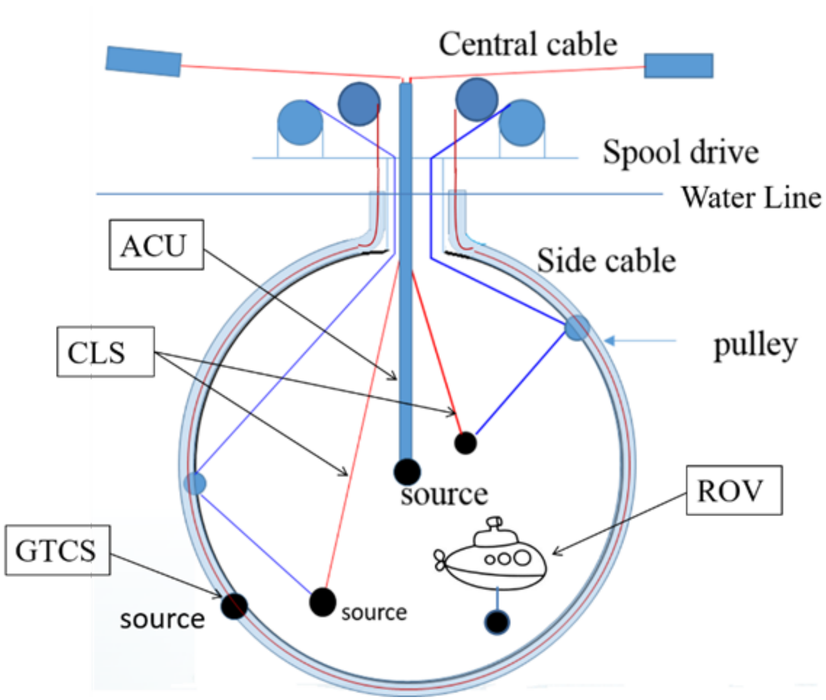
Sampling rate	1 GHz
Bandwidth	500 MHz
Input impedance	<10 Ω
Dynamic range	$\frac{1}{16}$ - 2000 p.e.
ADC resolution	8 bit [3 ×]
High gain	0.06 p.e./bit
Medium gain	0.4 p.e./bit
Low gain	8 p.e./bit
Power	1 W
Area	22.09 mm^2

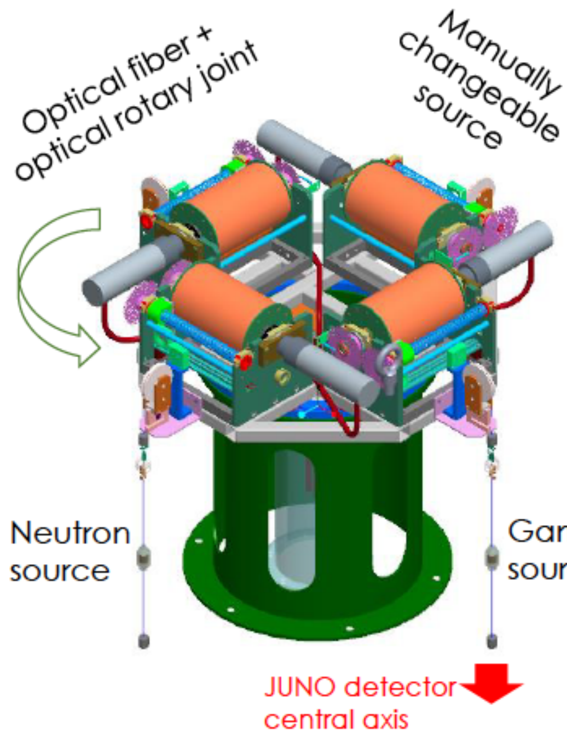
Block diagram



Calibration system

- Requirement: 3% energy resolution@1MeV and 1% energy scale uncertainty.
- Different tools for detector calibration
  - Automatic Calibration Unit (ACU): scan center axis
  - Cable Loop System (CLS): scan one vertical plane(2D)
  - Guide Tube Calibration System(GTCS): scan CD outer surface(boundary)
  - Remotely Operated under-liquid-scintillator Vehicles(ROV): scan whole CD(3D)





Calibration source selection:

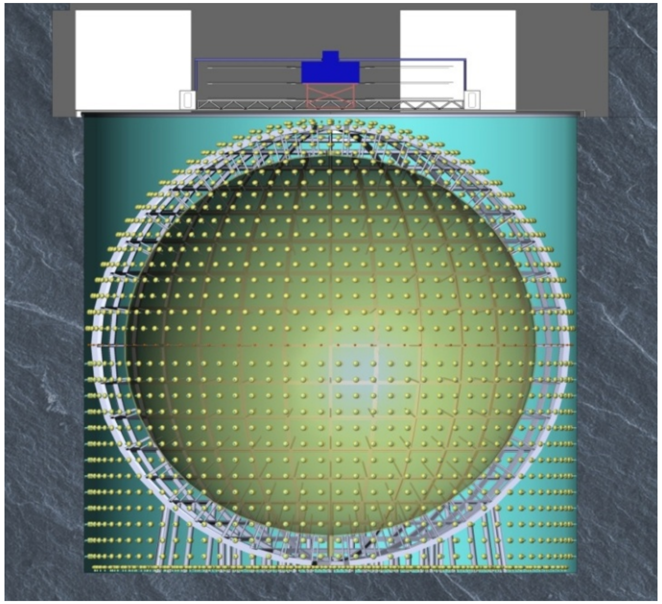
1. Radioactive sources:

Source	Type	Radiation
^{137}Cs	γ	0.662 MeV
^{54}Mn	γ	0.835 MeV
^{60}Co	γ	1.173 + 1.333 MeV
^{40}K	γ	1.461 MeV
^{68}Ge	e^+	annil 0.511 + 0.511 MeV
^{22}Na	e^+	annil + 1.275 MeV
^{40}K	e^-	0~1.31 MeV
^{90}Sr	e^-	0~2.28 MeV
^{241}Am-Be	n, γ	neutron + 4.43 MeV
^{241}Am-^{13}C or ^{241}Pu-^{13}C	n, γ	neutron + 6.13 MeV
^{252}Cf	multiple n, multiple γ	prompt γ's, delayed n's

2. Optical source: fast Laser (ns) /LED + Fiber + Diffuser

Veto system

- **Veto system**
  - Water Cherenkov detector+Top tracker system
    - Cosmogenic isotope reduction ($^{9}Li/^{8}He$)→ requires a precise muon track reconstruction
    - Fast neutrons background rejection → passive shielding and possible tagging
    - Radioactivity from rocks → passive shielding by water



- **Water Cherenkov detector**
- **Detector Characteristics**
  - ~2000 20-inch MCP-PMTs used for veto system
  - Tyvek reflector film coated on surface to increase light collection efficiency
  - Detector efficiency is expected to be > 95%
  - **Background Estimation:**
    - Fast neutron background ~0.1/day
- **Water system:**
  - 20-30 kton ultra pure water in the pool
  - Employ a circulation/polishing water system (~2 weeks for one volume circulation)
  - Keep a good water quality including radon control (<0.2 Bq/m^3)

Top Tracker

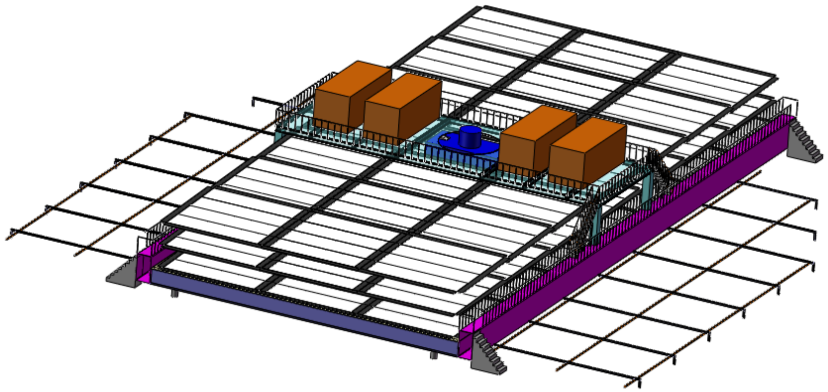
Total 62 TT walls will be rearranged in three horizontal layers to cover half of the top area. The three layers are spaced by 1 m .

This geometry allows to :

•Select “gold” muons for radioactive events reduction

•Ensure good muon tracking

•Perform a precise muon tracking and provide valuable information for cosmic muon induced $^{9}Li/^{8}He$ study



The detector will reuse the Target Tracker of the OPERA experiment.

The Target Tracker consists of several walls. Each wall consists of 4 modules in horizontal position and 4 modules in vertical position, allowing a good tracking reconstruction capability.

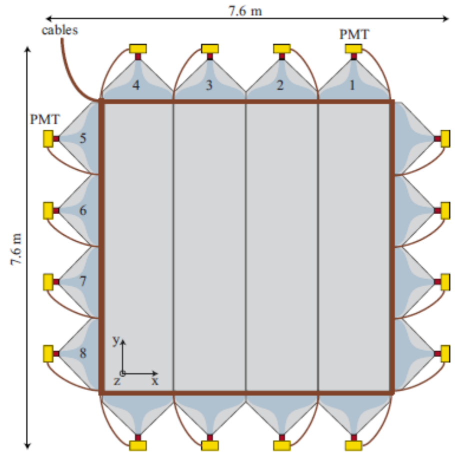


Fig. 3. Schematic view of a plastic scintillator strip wall.

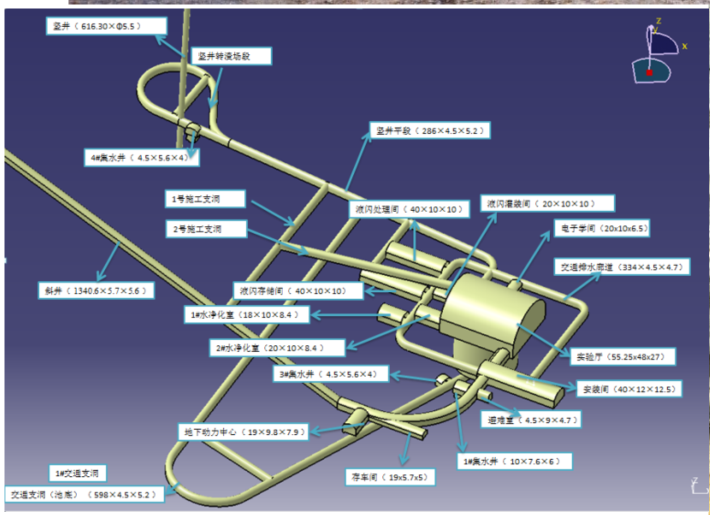
JUNO Civil Progress

Ground breaking in Jan. 2015

–1020 *m* slope tunnel excavated out of 1340 *m*

–485 *m* deep vertical shaft excavated out of 611 *m*

The civil construction will be completed in 2018



Summary

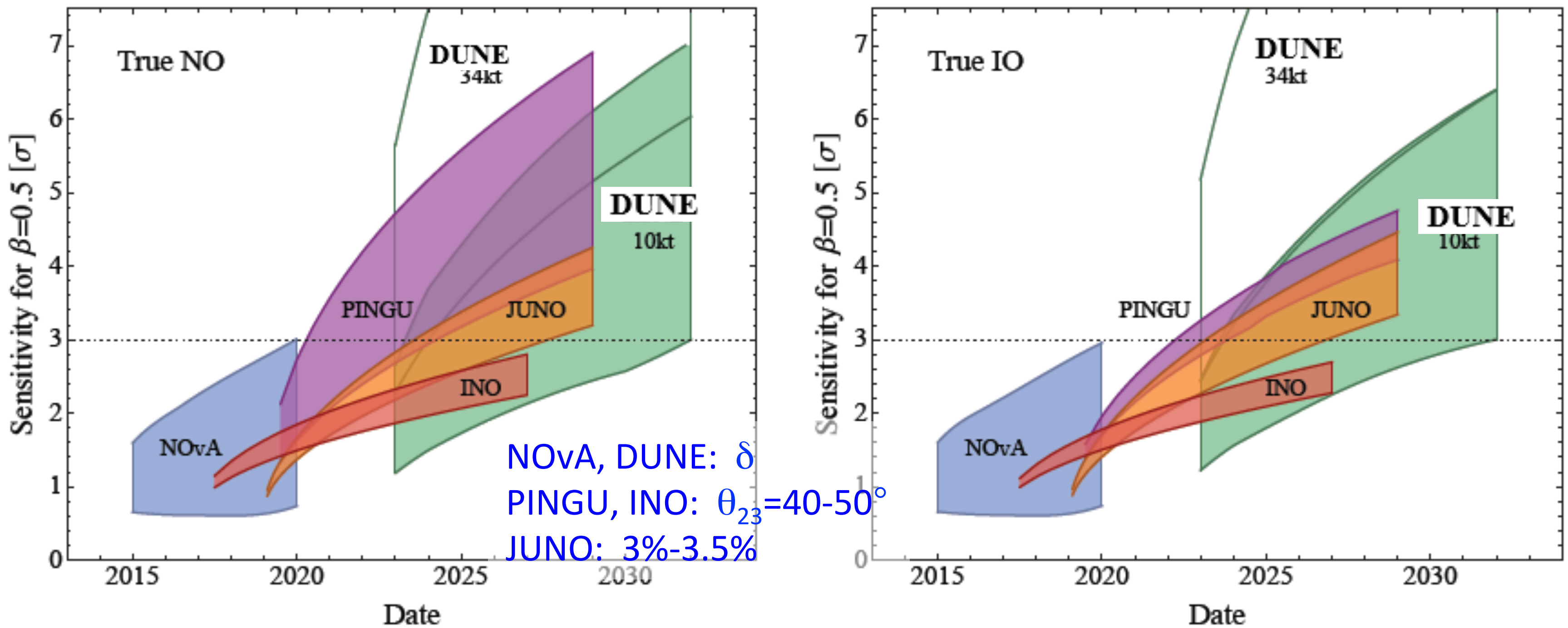
JUNO will measure mass hierarchy (3-4 σ by 2026) and 3 oscillation parameters to <1% level.
JUNO also has a rich physics potential in supernova neutrinos, geo-neutrinos, solar neutrinos, and other oscillation physics such as searches for sterile neutrinos, among others.

•Curent Schedule as following:

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

Comparison with Other Experiments

M. Blennow et al., JHEP 1403 (2014) 028



- JUNO is unique for measuring MH using reactor neutrinos
  - Independent of the CP phase and free from the matter effect: complementary to accelerator-based experiments
  - Competitive in time
  - Many other science goals


Thank you!

Back up