The status of JUNO

(Jiangmen Underground Neutrino Observatory)

Yuekun Heng, IHEP
On behalf of the collaboration

Feb 11, 2016

Lake Louise Winter Institute 2016

JUNO Members

Europe (24)

France(5)
- APC Paris
- CPPM Marseille
- IPHC Strasbourg
- LLR Paris
- Subatech Nantes

Czech Rep.(1)
- Charles U .

Finland(1)
- U.Oulu

Russia(2)
- INR Moscow
- JINR

Italy(7)
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- INFN-Ferrara
- INFN-Milano
- INFN-Mi-Bicocca
- INFN-Padova
- INFN-Perugia
- INFN-Roma 3

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- FZ Julich
- RWTH Aachen
- TUM
- U.Hamburg
- U.Mainz
- U.Tuebingen

America(3)

US(2)
- UMD
- UMD-Geo

Chile(1)
- Catholic Univ. of Chile

Observers:

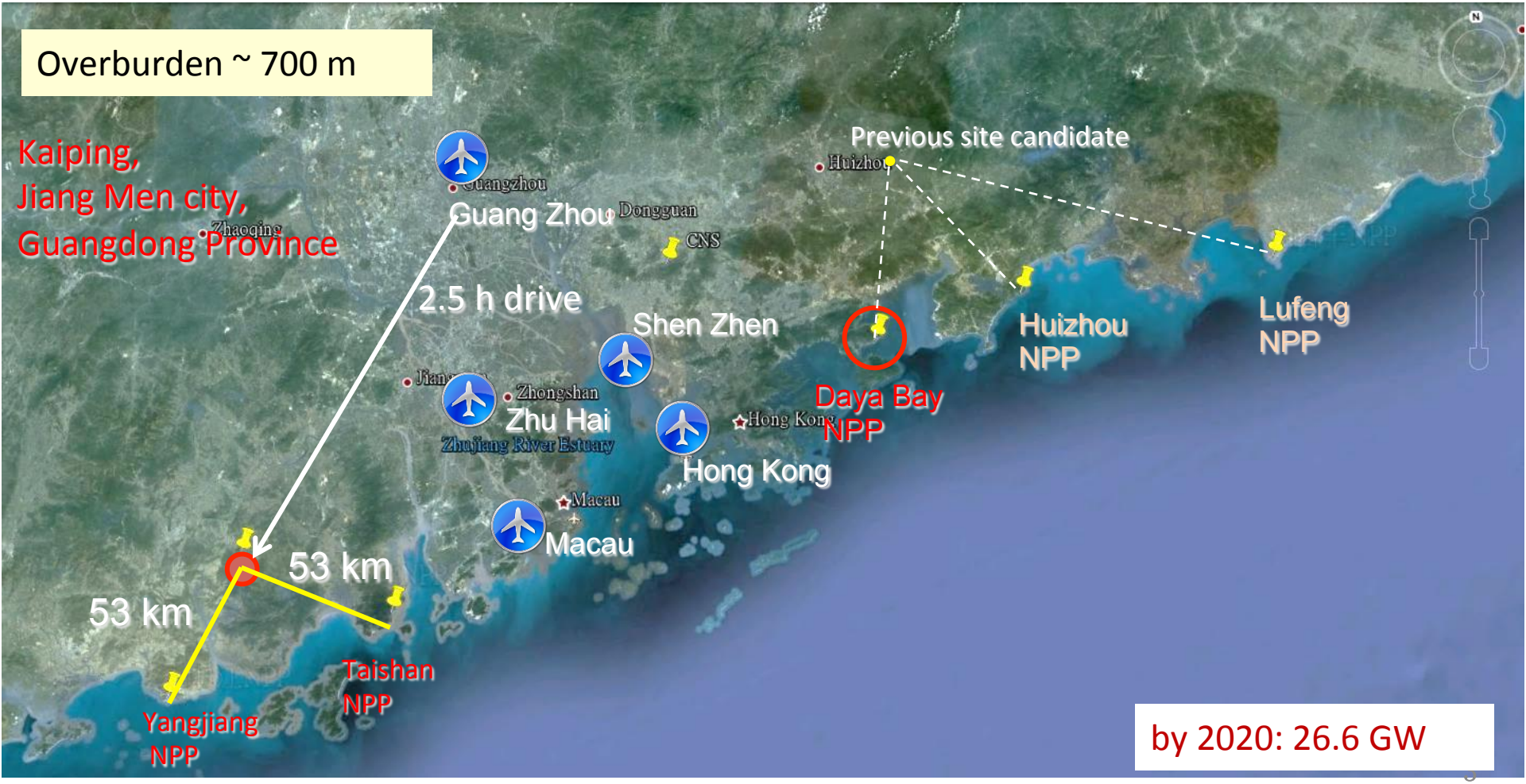
- Jyvaskyla U.
- HEPHY Vienna
- PUC Rio
- Uni. Fed. ABC S. Paolo

Asia (28)

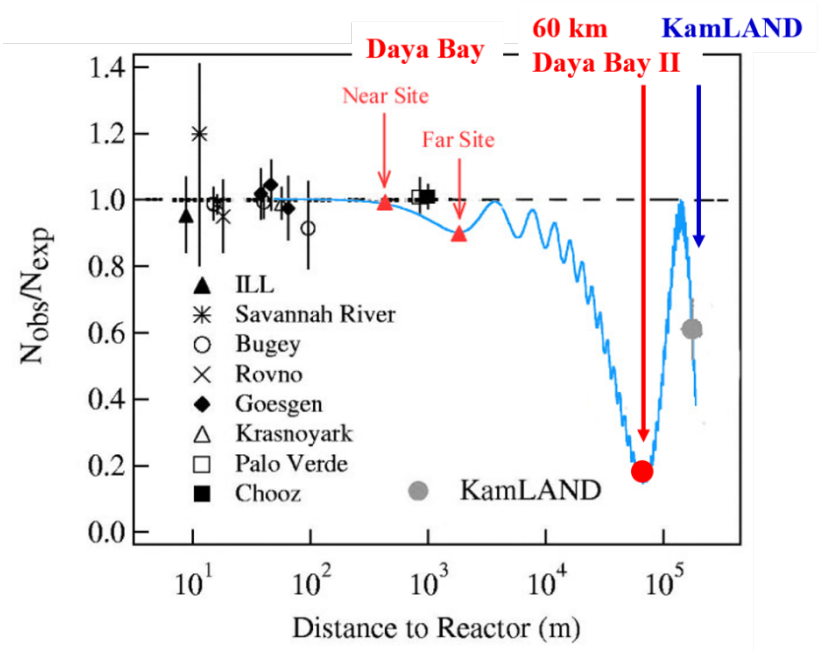
- BJ Nor. U.
- CAGS
- Chongqing U.
- CIAE
- DGUT
- ECUST
- Guangxi U.
- HIT
- IHEP
- Jilin U.
- Nanjing U.
- Nankai U.
- Natl. Chiao-Tung U.
- Natl. Taiwan U.
- Natl. United U.
- NCEPU
- Pekin U.
- Shandong U.
- Shanghai JT U.
- Sichuan U.
- SYSU
- Tsinghua U.
- UCAS
- USTC
- Wuhan U.
- Wuyi U.
- Xi'an JT U.
- Xiamen U.

Location of JUNO

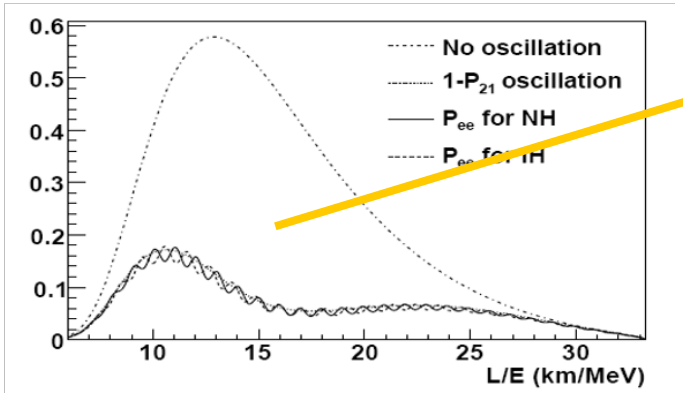
NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW



What JUNO will get?



L/E spectrum



Under very powerful reactors of 36 GW, JUNO will get Rich physics possibilities

- Mass hierarchy
- Precision measurement of 3 mixing parameters
- Supernovae neutrino
- Geoneutrino
- Sterile neutrino
- Atmospheric neutrinos
- Exotic searches

By neutrino energy spectrum of fine structure to get the Mass-Hierarchy!

If Δm^2_{32} at 1% precision from T2K and Nova in the future， mass hierarchy could be determined to ~5σ in 6 years.

Precision measurement of mixing parameters

- Fundamental to the Standard Model and beyond
- Probing the unitarity of U_{PMNS} to ~1% level !
  - Uncertainty from other oscillation parameters and systematic errors, mainly energy scale, are included

Neutrino Mixing: PMNS Matrix

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

Atmospheric, K2K, MINOS, T2K, etc. $\theta_{23} \sim 45^0$

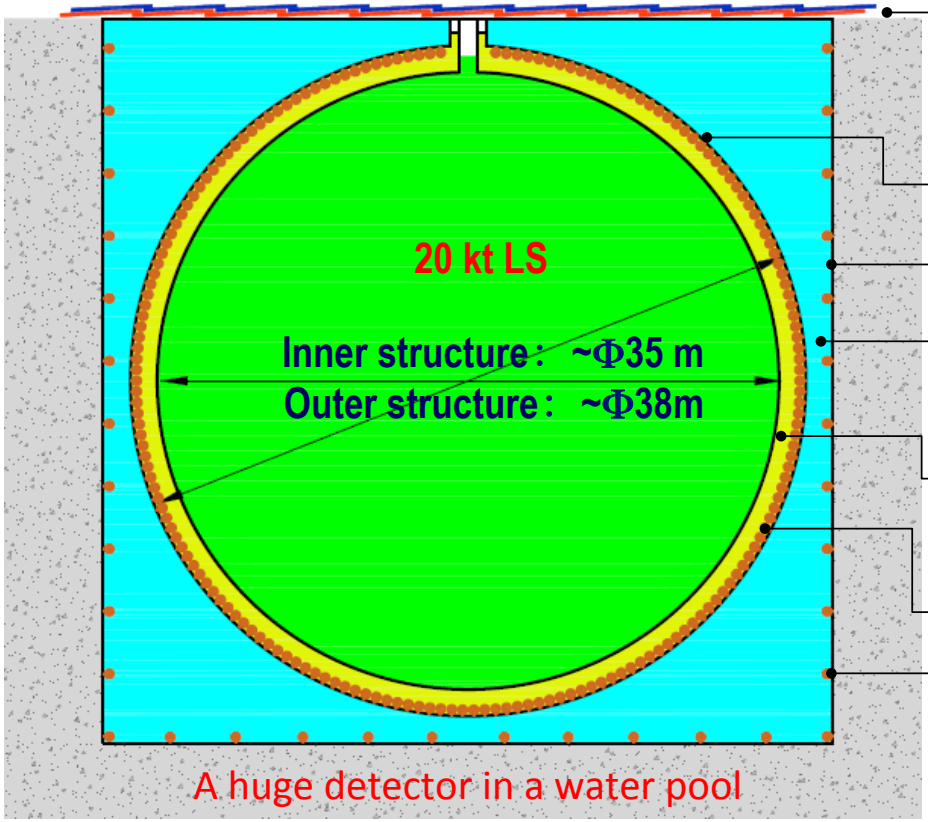
Reactor Accelerator $\theta_{13} < 12^0$

Solar KamLAND $\theta_{12} \sim 30^0$

	Current	JUNO
Δm^2_{12}	3%	0.6%
Δm^2_{23}	5%	0.6%
$\sin^2\theta_{12}$	6%	0.7%
$\sin^2\theta_{23}$	20%	N/A
$\sin^2\theta_{13}$	5%	~ 15%

Will be more precise than CKM matrix elements !

Concept Design



Muon detector

Outer structure

Water seal

20kt water

6kt MO

~17000 20" PMTs+ ~34000 SPMTs
coverage: ~75%

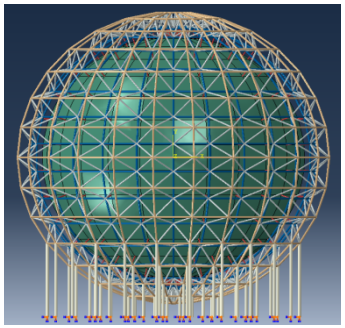
2000 20" VETO PMTs

Issues and challenge:

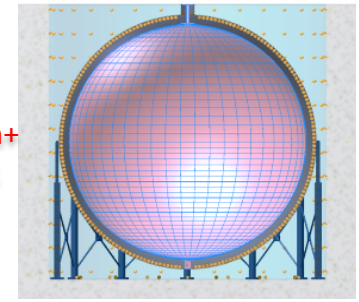
- Engineering: mechanics, safety, lifetime, …
- Physics: cleanness, light collection, …
- Assembly & installation: time, cost,…

Option Selection

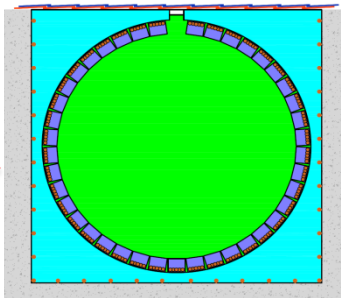
Acrylic sphere+ SS truss



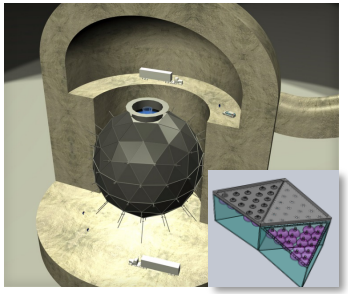
Balloon+ SS tank



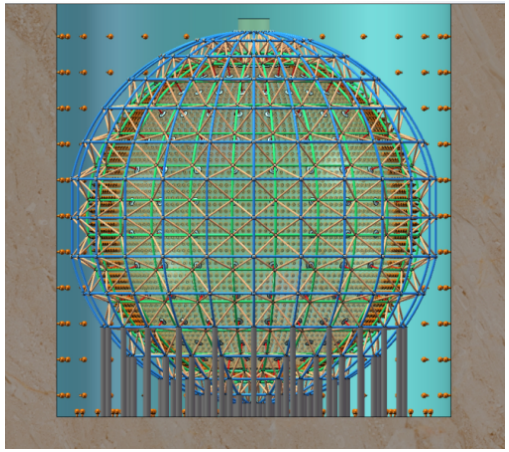
Acrylic module+ SS tank



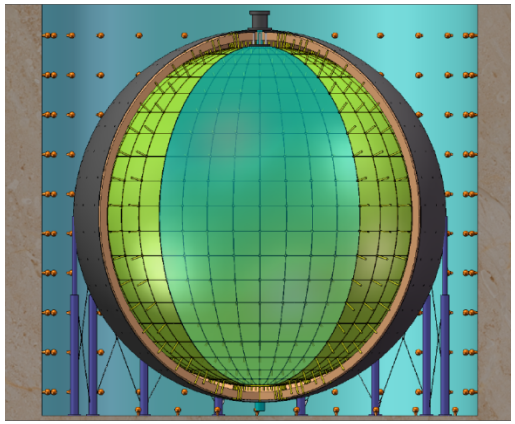
Acrylic sphere+ SS tank



March, 2014

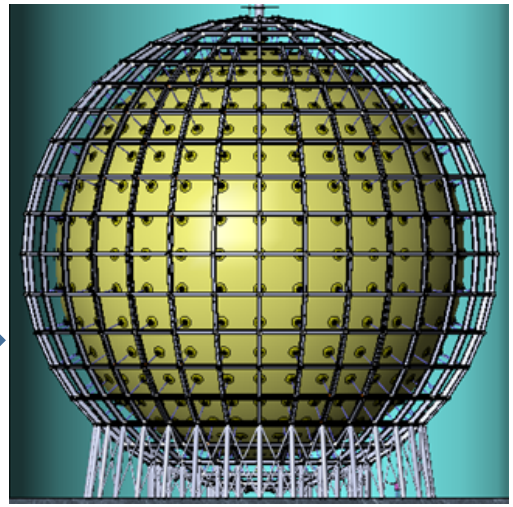


SS truss+ Acrylic sphere

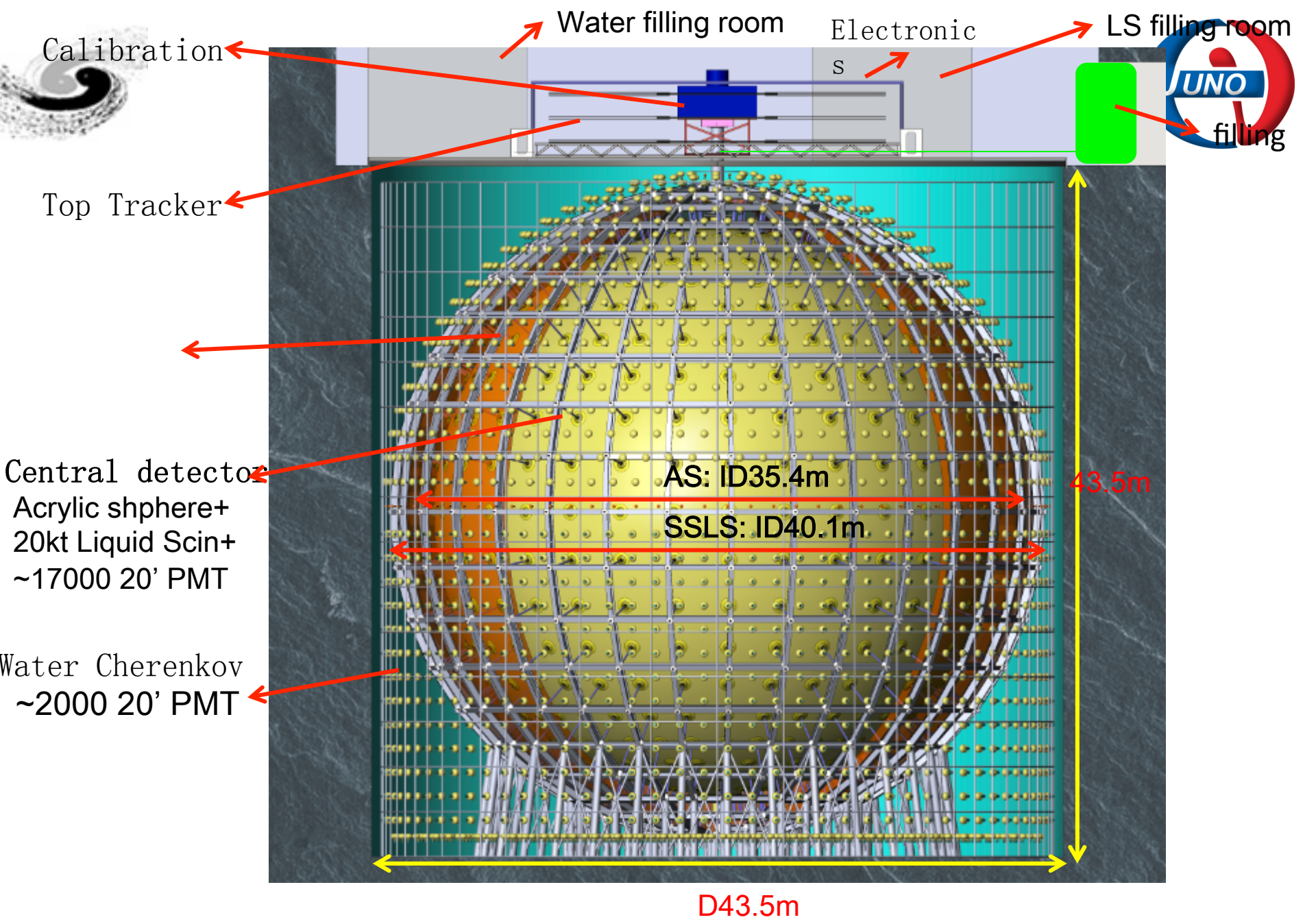


Balloon + Acrylic support+ SS tank

July, 2015



Final decision:
Acrylic sphere + SS truss

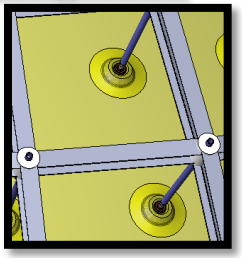


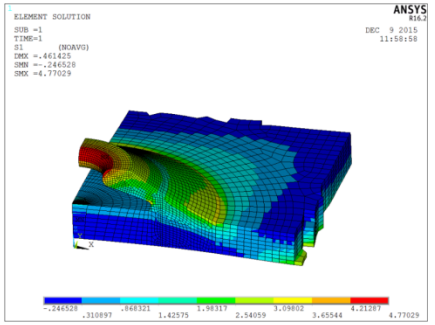
AS: Acrylic sphere; SSLS: stainless steel latticed shell

How to make the acrylic safe?

Acrylic stress is a critical issue for engineering design

The maximum stress of acrylic is concentrated at connecting node





How to reduce the stress on acrylic node?

a. Lower the load on connecting bar

b. Improve the design of connecting node

Worst case: running, the total vertical load is ~2600t ↑

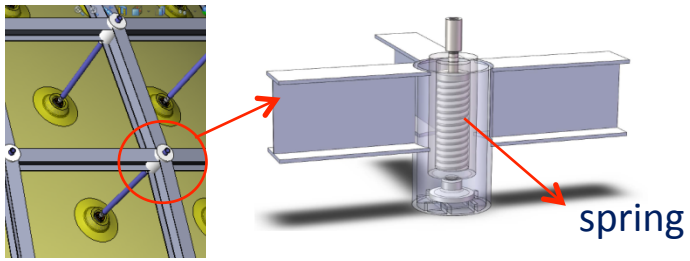
~560 connecting nodes will carry this load

a. How to lower the max load on connecting bar?

- Add the quantity of bar ⟶ Add light block X
- Improve the load distribution on bars ✓

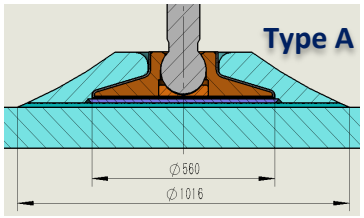
How to improve the load distribution on bars?

Adjust the stiffness of some connecting bars , to get a better distribution of load on whole sphere

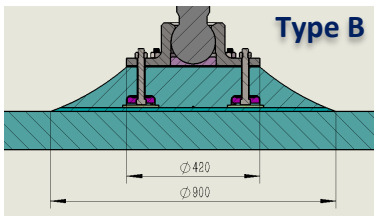


b. How to improve the node design

- Optimize the structure of node
- Two kinds of node for compressive area or tensile area



High tensile strength

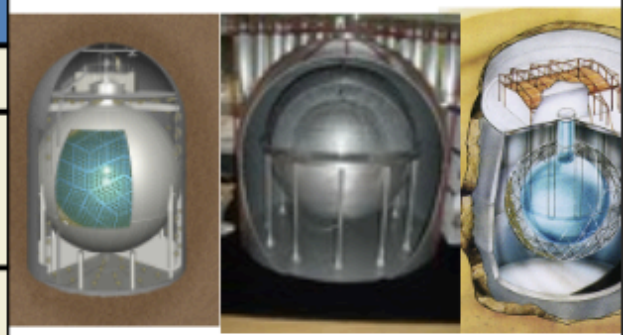


High compressive strength

Physics Requirements for Detectors

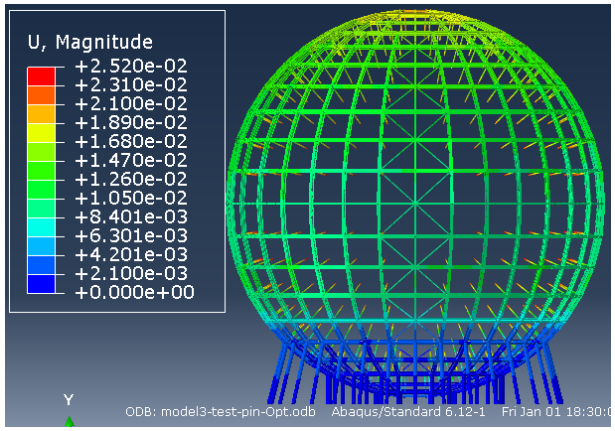
1. **Statistical error-->Target Mass: 20 ktons, biggest LS Detector**
2. **Best Energy Resolution for LS Detector: 3%**
   - → **~75% PMT: coverage**
   - → **Photon Detection Efficience double** 30% **Quantum Effi. + 90% Collection Efficience of PMT**
   - →**Transparent LS**
3. **Energy and Vertex reconstruction and correction:**
   symmetrical structure, time and charge measurement by PMT
4. **Energy range and linearity: PMT response and electronics**
5. **Background Radiation Rate, fiducial volume cut, Material, Clean consideration**

	KamLAND	Borexino	Daya Bay	JUNO
LS mass	~1000 t	~300 t	~170t	20000t
Energy Resolution	6%/√E	5%/√E	7.5%/√E	3%/√E
Light yield	250 p.e./MeV	500p.e./MeV	200p.e./MeV	1200 p.e./MeV

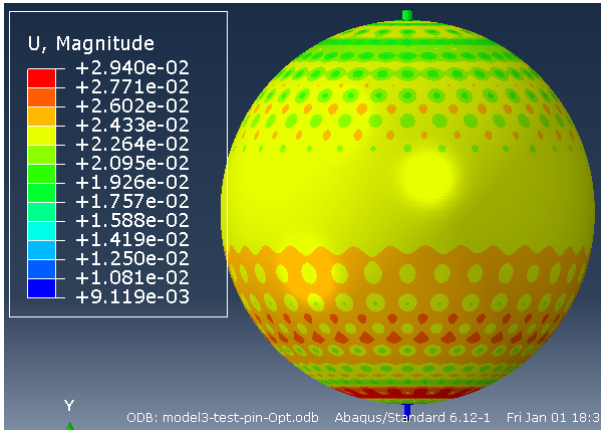


Kamland Borexino SNO

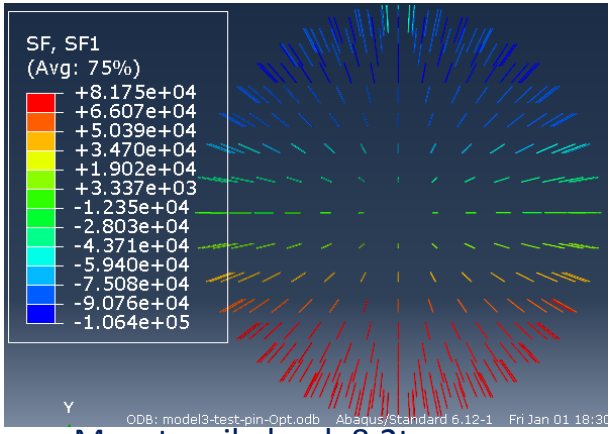
Mechanics calculation for the structure in worst case



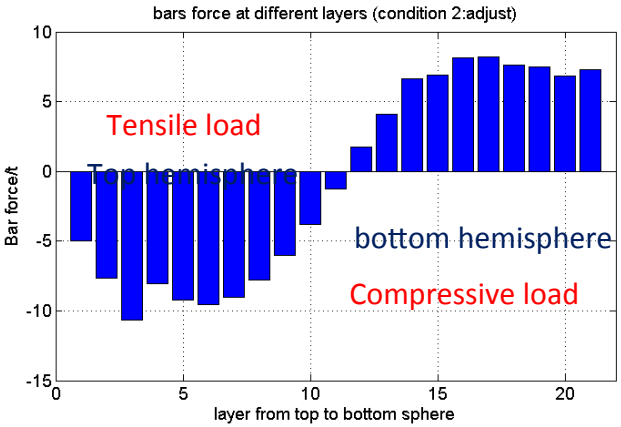
Deformation of latticed shell: ~25mm



Deformation of Acrylic sphere: ~30mm



Max. tensile load: 8.2t
Max. Compressive load: 10.6t



Load distribution on bars for each layer

When reducing the bar's stiffness at bottom hemisphere

- The load distribution on each bar is most even
- The maximum tensile load was decreased from 14t to 8.2t

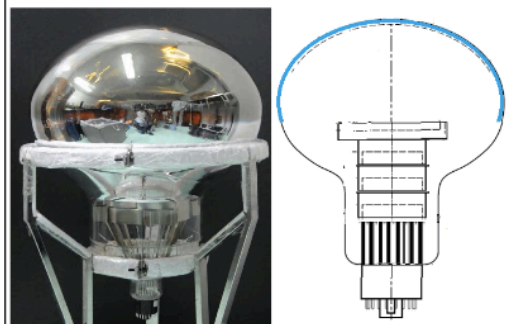
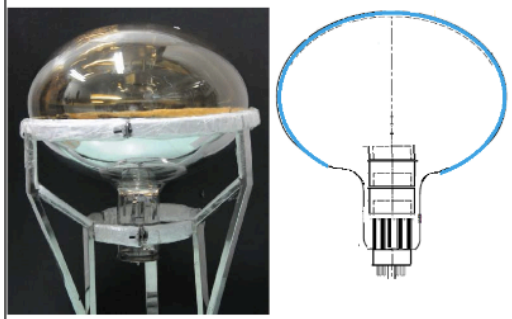
When the tensile load reduced to 8.2t

The maximum stress of acrylic ＜3.5Mpa (what we hope to get)

Other FEA result

- Temperature variation: dropping is worse than increasing, need control temperature during building
- Seismic load: need more test to understand the earthquake resistance of detector in liquid

R&D for 20’’ MCP-PMT

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

20’’ PMT Selection Results

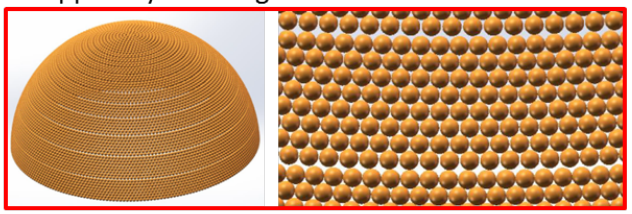
--15000 MCP-PMT(By China); --5000 Dynode PMT (By Japan)

Characteristics	unit	MCP-PMT（IHEP）	R12860 （Hamamatsu）
Electron Multiplier	--	MCP	Dynode
Photocathode mode	--	reflection+ transmission	transmission
Quantum Efficiency（400nm）	%	26 (T), 30 (T+R)	30(T)
Relativity Detection Efficiency	%	~ 110 %	~ 100 %
P/V of SPE		> 3	> 3
TTS on the top point	ns	~12	~3
Rise time/ Fall time	ns	R~2 , F~10	R~7 , F~17
Anode Dark Count	Hz	~30K	~30K
After Pulse Time distribution	us	4.5	4, 17
After Pulse Rate	%	3	10
Glass	--	Low-Potassium Glass	HARIO-32

PMT arrangement

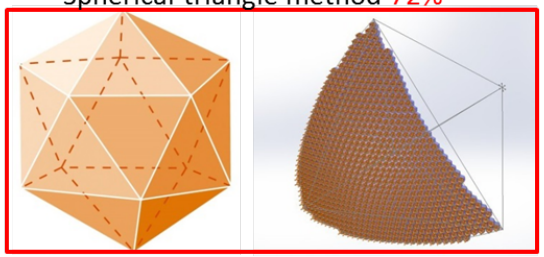
Supper layer arrangement method 77.8%

✓ 1



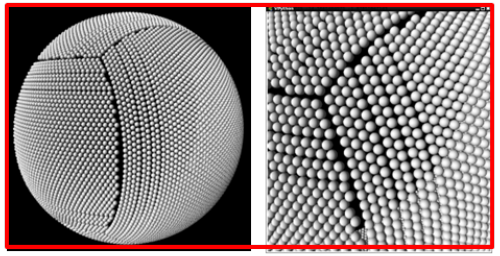
Spherical triangle method 72%

2



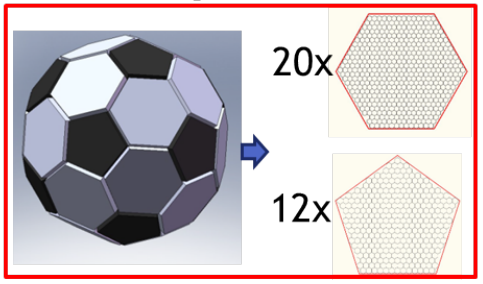
Volleyball arrangement method 75.96%

3

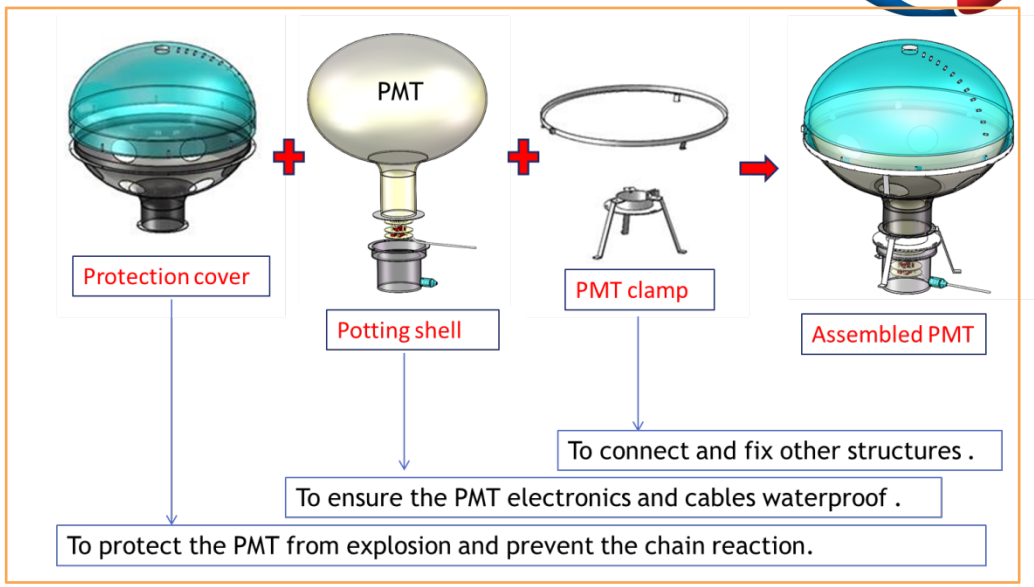


Football arrangement method 74.08%

4

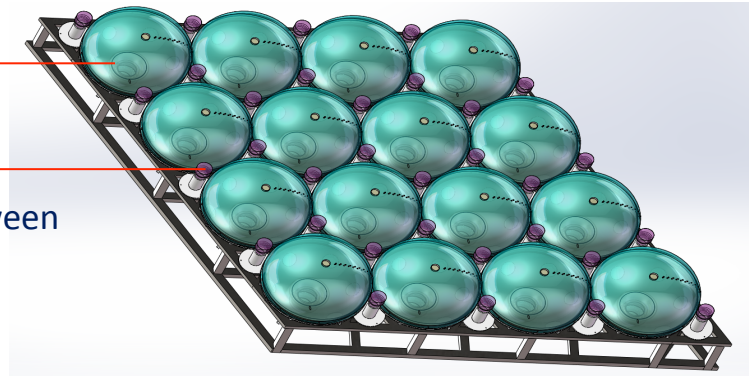


Coverage for different arrangement tries



20” PMT

3” sPMT
Arranged between
20” PMTs



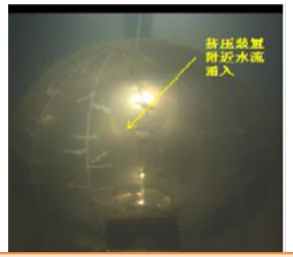
The supper layer method is the best one in four arrangement tries, also easy for sPMTs inserting

PMT Implosion Protection

Protection requirement:

- Protect PMT from chain implosion
- optical transparent for the front cover: ~1% in light blocking
- least possible impact on the coverage

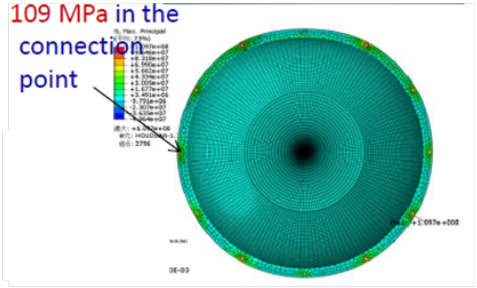
1. Try with acrylic cover

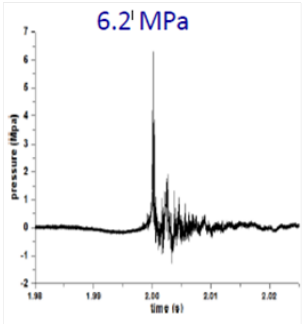


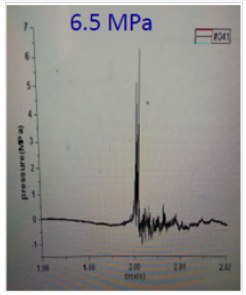
2. Try with layer of film

3. Try with gas chamber

Three tests tried with conceptual design of protection







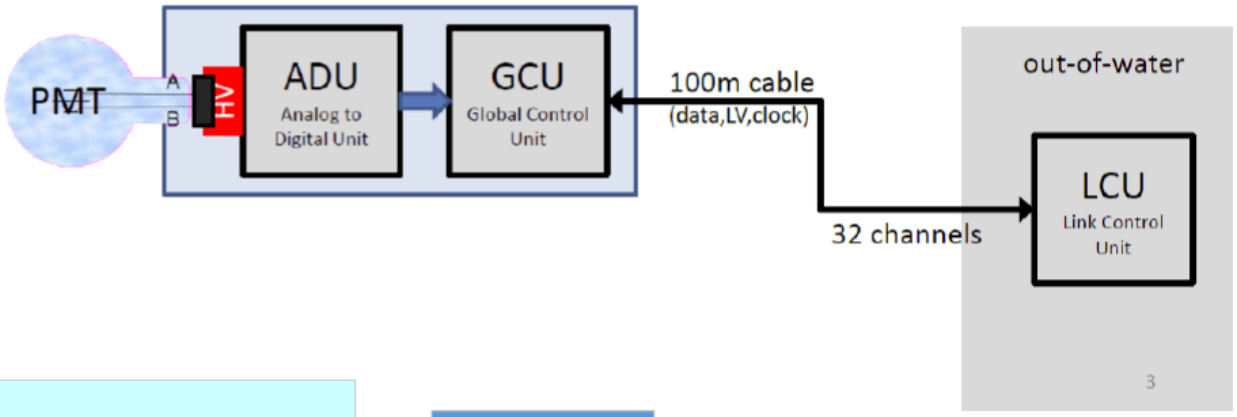
Lessons from the initial tests

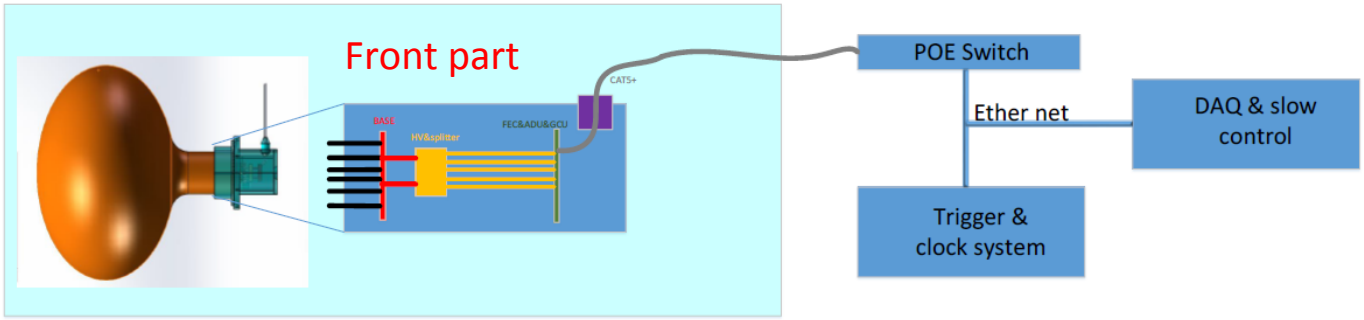
- need a stronger acrylic cover and proper design of the connecting
- The film is flexible, need a rigid support;
- Air chamber is difficult in real JUNO condition;

- First tries with the protected PMTs give us important experience and lessons;
- A prototype of the protective cover with Acrylic + SS is under study, design and test

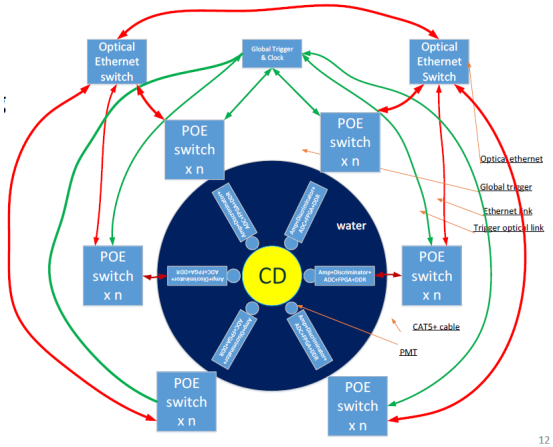
PMT Readout

The final decision for under-water electronic





Backend part-"Dry" part



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

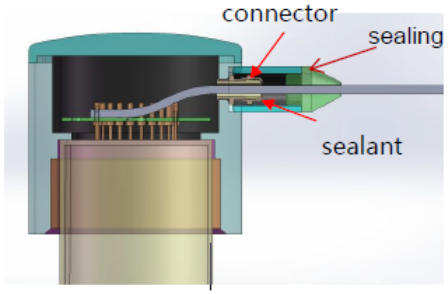
Needs consider the integration and potting structure with PMT
Replacement under water is almost impossible
Need high reliability of potting

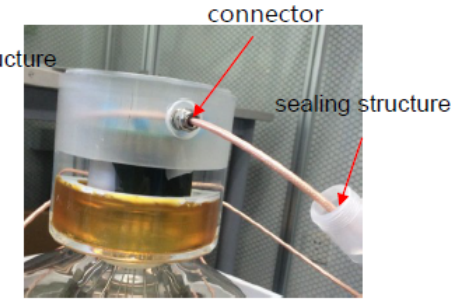
PMT Potting

Potting requirement:

- Base, H.V. & electronics encapsulated in the potting shell
- Working under 45m high-purity water;
- 20 years lifetime

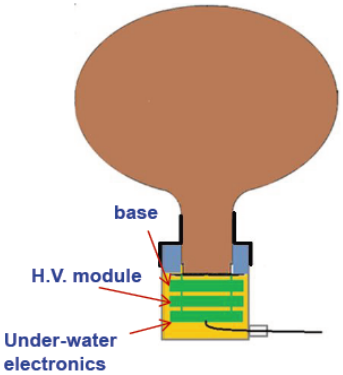
Design used for the prototype



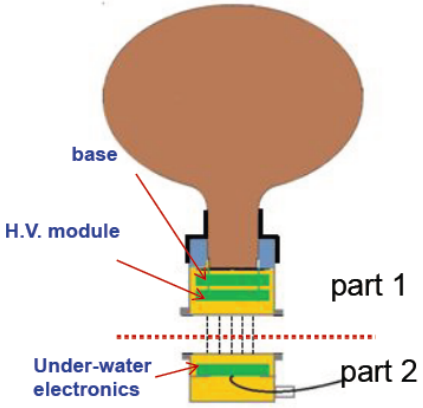


41 PMTs of 5 types were potted and tested for JUNO prototype

Get good experience from JUNO prototype.



1. Potting Base& H.V. & electronics in one shell

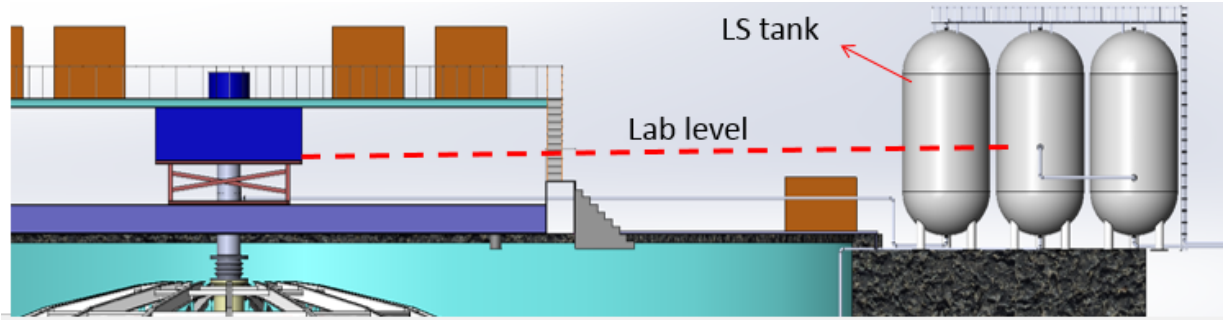


2. Potting electronics separately Sealing two parts by O-ring

- Since HV and the electronic will also be encapsulated in the potting shell, potting difficulty of JUNO PMT is bigger than prototype.
- Study on potting sealants, pouring device and the thermo-conductivity is ongoing
- Two options of JUNO potting need more comparing and tests for final decision

Two options for JUNO PMT potting

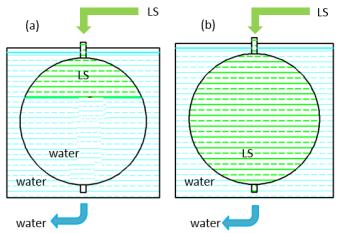
Filling and overflow consideration



Function of LS tank：

Filling+Overflow+Circulating

Two filling methods



1. Clean water exchanging

- Cleaning acrylic inside +1
- Checking acrylic sphere
- Filling the water both into the acrylic sphere and water pool → longer time
- The radon more easily dissolved into LS → more background into LS

2. Nitrogen exchanging

- Huge volume of nitrogen → safety for people

Key points for filling and overflow system

Automatically

Monitor: the liquid level, flux, acrylic stress

Sealing with the nitrogen

Two overflow methods

1. No pump method:

Needs big cross section of the total overflow

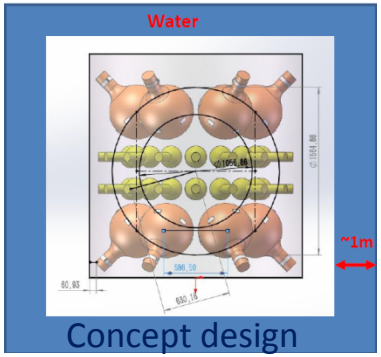
2. Pump method:

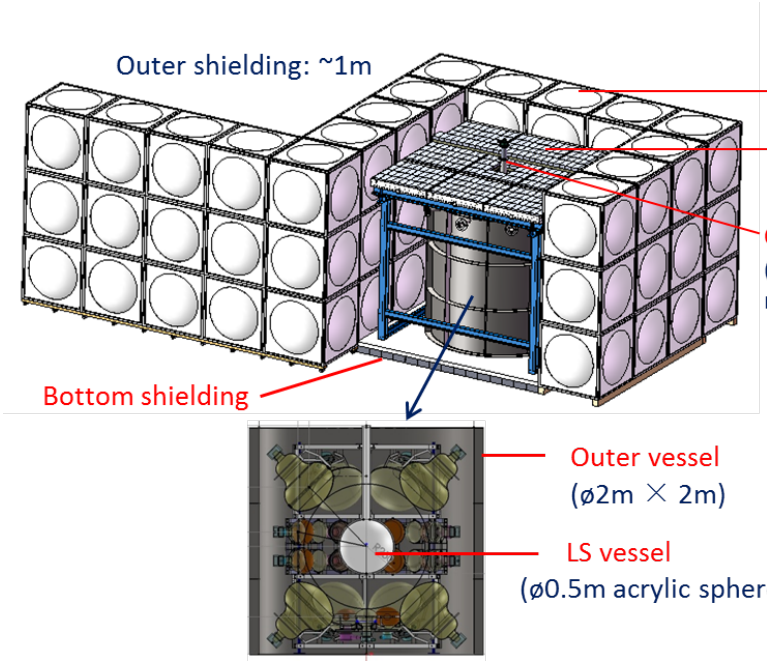
- Monitor the level changing and automatically balance the level with the pump
- Needs to be very reliable

JUNO Prototype

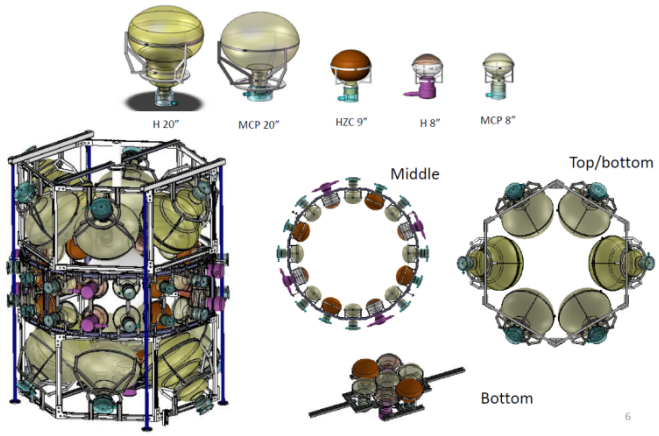
Goal:

- Study/Comparison of PMTs' performances in a real LS detector
- Other possibilities
  - Testing PMT potting
  - PMT supporting
  - Waveform readout detector study
  - LS background …





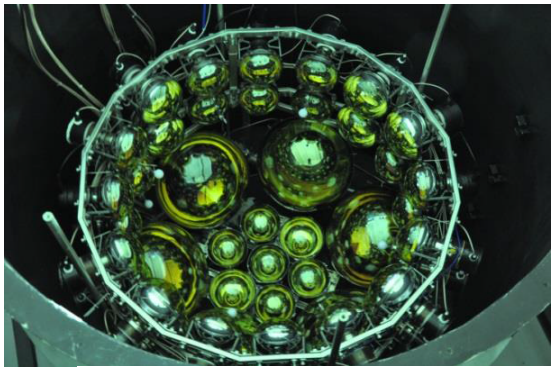
Main components of CD prototype

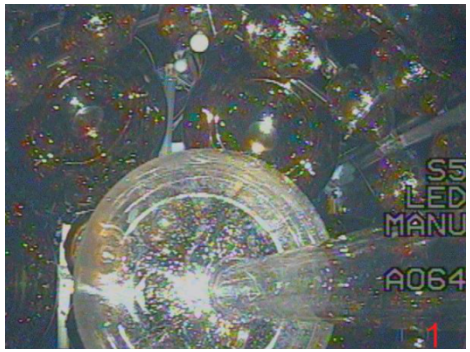


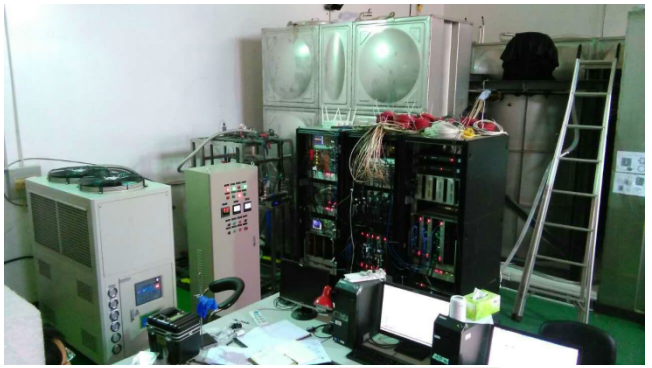
- Electronics:
  Waveform readout
  Positive HV
- Trigger rates:
  <~100Hz@>0.7MeV

PMT number: 51, Coverage: ~56%
20": H 4, MCP 8;
8": H 10, MCP 18;
9": HZC 11;
Resolution: ~4%@1MeV e-

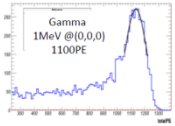
JUNO Prototype

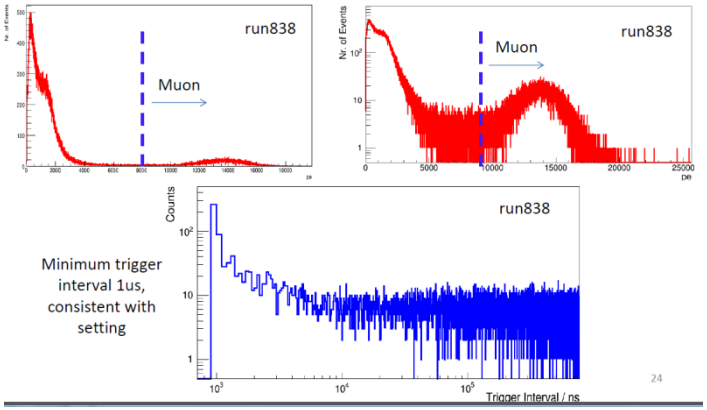




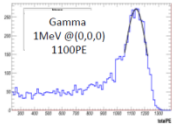


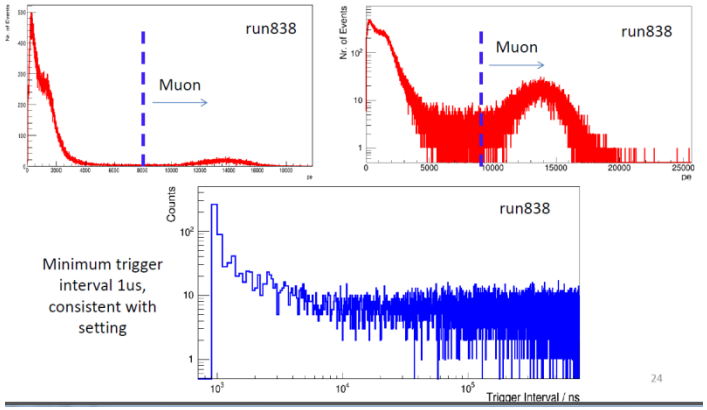
Energy spectrum





Energy spectrum

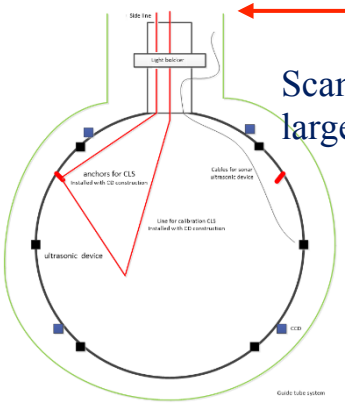




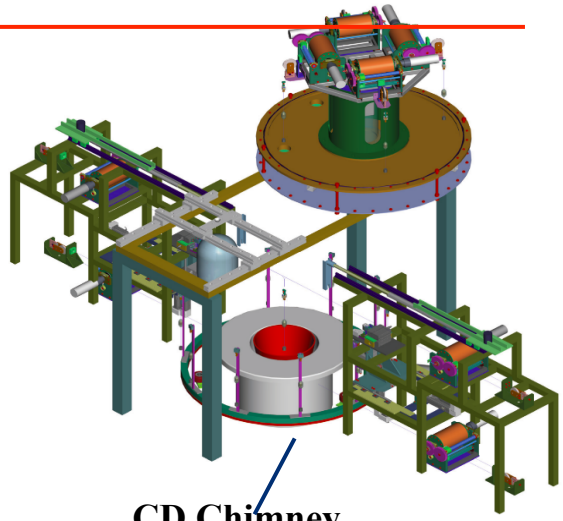
- The end of 2015, finished construction/filling, start data taking
- Preliminary analysis shows:
  - –all sub-system reached designed goal: detector\ electronics\water system
  - –PMT water potting working well
- More tests and understanding are doing…

Calibration system

Cable Loop System (CLS)



Scan the position at large



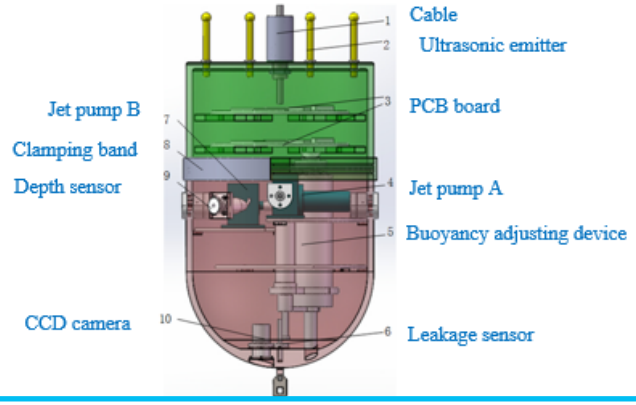
CD Chimney

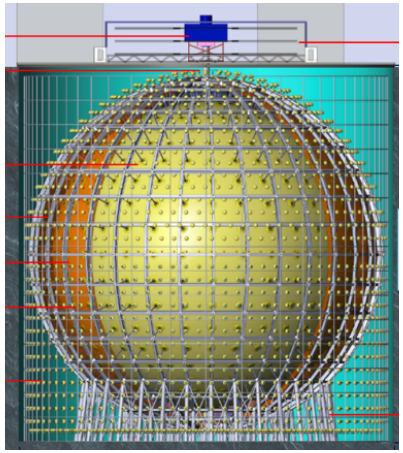
Key: automatically take source from the storage and guide it into the electronic hands.

Three methods

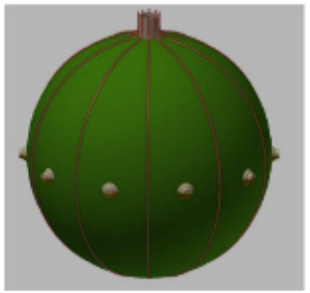
1. ACU：cable loop
2. ROV: “submarine”
3. Surface guide tube

Remotely Operated Vehicle(ROV)





- Regular deployment (every week)
- Deployment of radioactive and **Guide Tube (GT)**

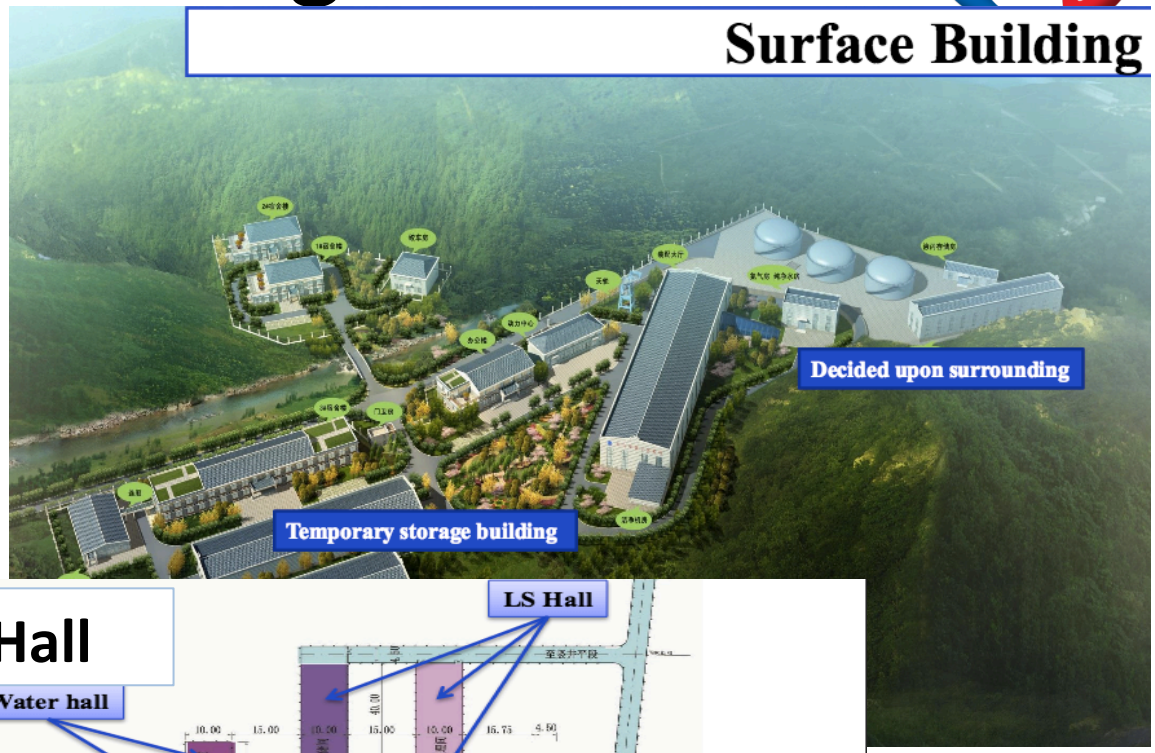


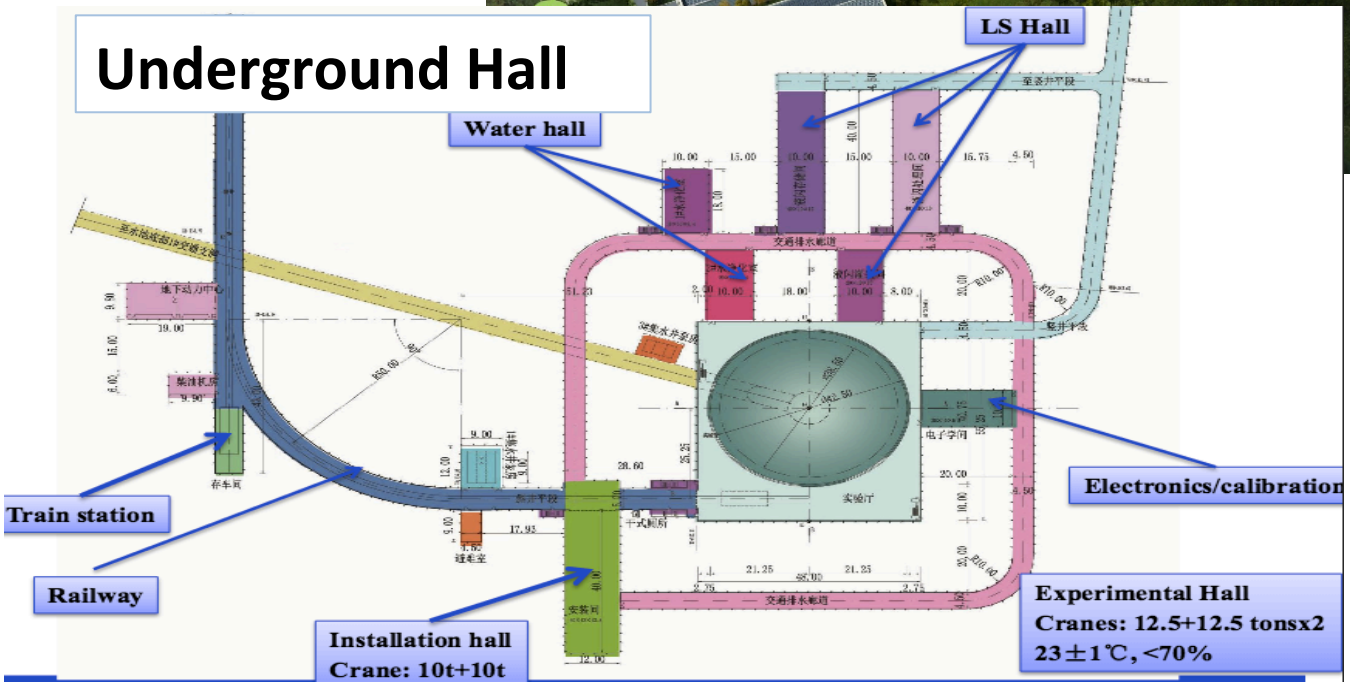
Scan outer surface of CD

The radiation source is driven with rope pulled by step motors

Civil Progress

- Completed until now Sloped tunnel: 827 m
  Vertical shaft: 245m
- Plan to finishing: Feb. 21, 2018





Milestones

		Start	end	condition
1	Underground lab construction	2015.1.1	2018.2.23	
2	Water pool cleaning and CD construction preparation	2018.2.24	2018.2.27	1
3	CD & water poll equipment installation	2018.2.28	2019.3.1	2
4	PMT base(& to be sealed electronics) design finalized	2016.12.31	2016.12.31	
5	PMT base production and aging test	2017.1.1	2018.1.1	4
6	PMT bidding	2015.7.1	2015.12.31	
7	PMT mass production	2016.1.1	2018.12.31	6
8	PMT testing	2017.4.4	2019.1.30	
9	PMT potting and testing	2017.12.1	2018.1.30	5
10	CD & VETO PMT installation	2019.3.4	2019.7.1	
11	Readout electronics design finalized	2017.1.2	2017.5.31	
15	CD & water pool cleaning	2019.8.1	2019.9.1	
19	AD & VETO water filling	2019.9.4	2019.11.1	18
20	LS filling	2019.11.4	2020.2.3	19
21	Test run	2020.2.4	2020.5.4	20

Summary

- Neutrino physics: mass hierarchy, 3 mixing parameters, supernovae neutrino, geoneutrino, sterile neutrino, atmospheric neutrino, exotic
- Huge LS detector: 20 ktons
  with precise energy resolution: 3%/sqrt(E)
- Structure: biggest acrylic sphere Φ35.4m
- Transparent LS: attenuation length over 20m
- 20'' PMT: new MCP-PMT
- Readout: Flash ADC directly connecting PMT
- Taking data in 2020