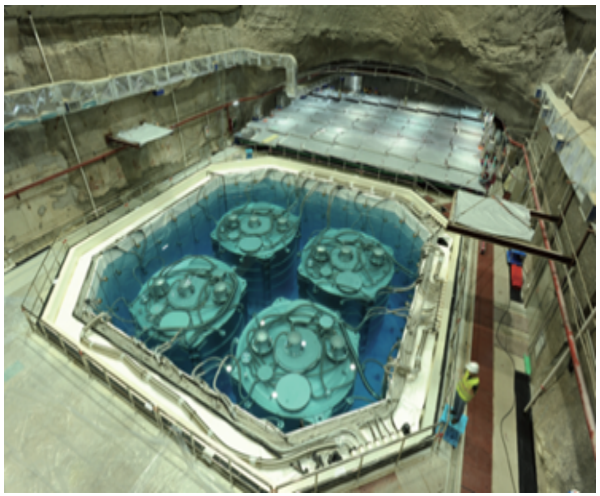
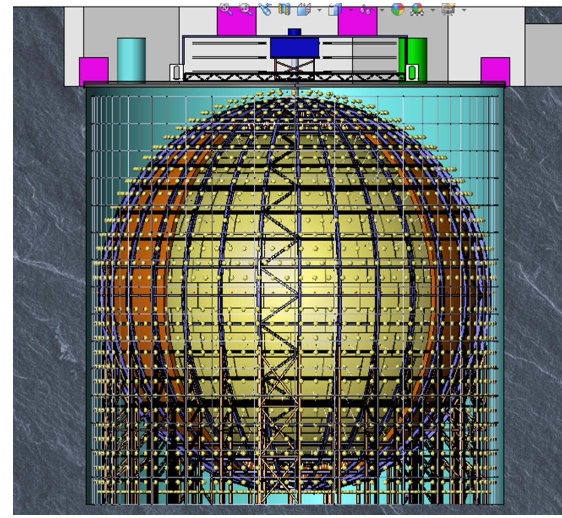
The Instrumentation of JUNO
(Jiangmen Underground Neutrino Observatory)





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On behalf of the Collaboration JUNO
@Novosibirsk, INSTR2017
2017-03-01

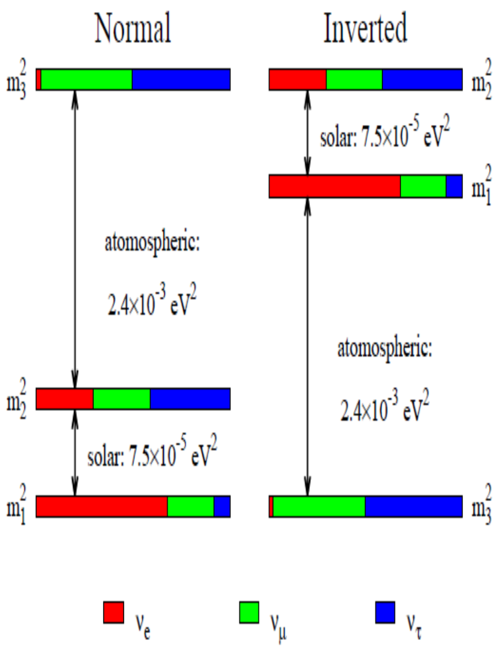
Outline

- Physics targets of JUNO
  - Mass hierarchy
  - Precision measurement of neutrino oscillation
  - Supernova, geo-neutrino, solar neutrino
- Instruments of JUNO
  - Detector structure
  - R&D of transparent liquid scintillator
  - R&D of MCP-PMT with the diameter of 20 inches
  - PMT readout and water proof
  - Calibration system
  - Veto system
- summary

What are neutrino experimental focuses?

Basic questions

- Neutrino mass hierarchy: normal or inverted?
  - Medium baseline reactor experiments: JUNO, RENO-50
  - Long baseline accelerator experiments: NOvA , DUNE
  - Atmospheric experiments: INO, PINGU,ORCA, DUNE
- Is there CP violation in neutrino mixing?
- Are neutrinos their own antiparticle? (Dirac or Majorana)
- How many neutrinos are there? (Sterile neutrinos?)
- What is the absolute mass scale?
- Neutrino cross-section?

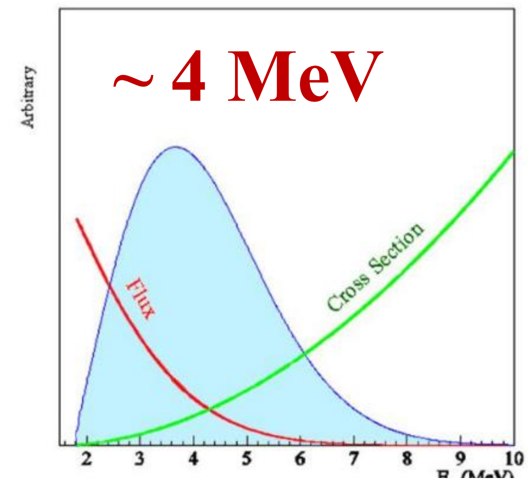


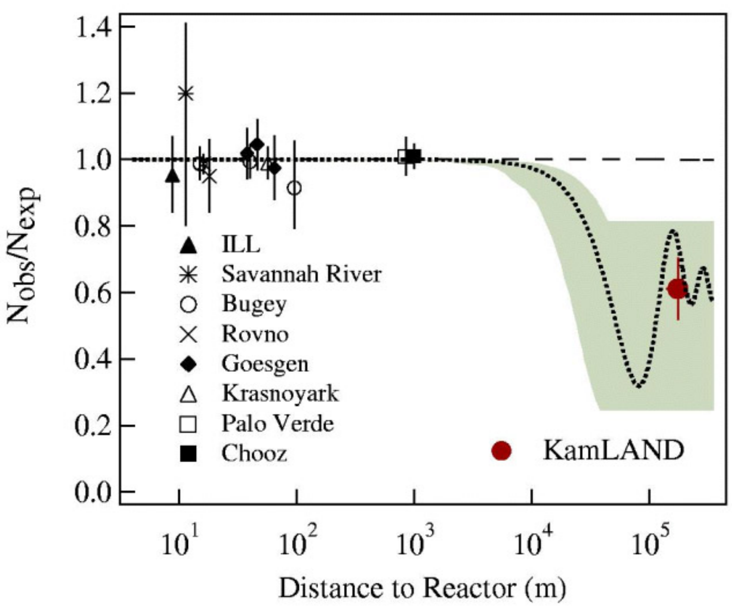
Neutrino as a telescope to study:

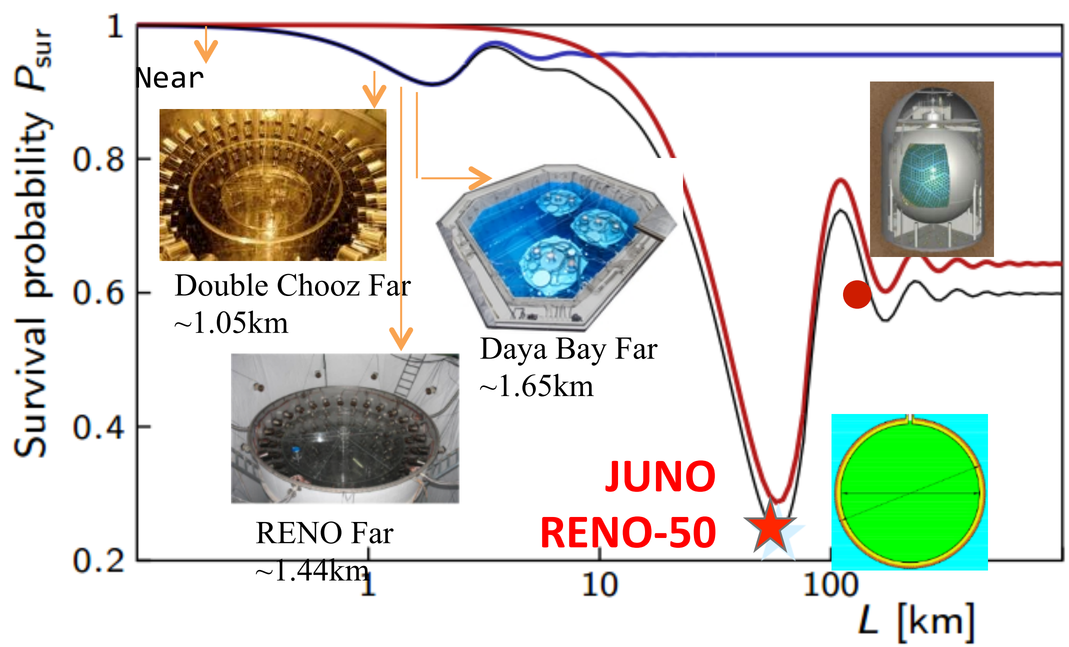
- The earth, the sun, the supernova, the astrophysics neutrinos……

Reactor Neutrino Experiments

- Measuring θ_{13} and Δm^2_{ee}
  - Daya Bay, Double Chooz, RENO
  - Ultimate precision ~3%
- Determining Mass Hierarchy & precision measurement of θ_{12}, Δm^2_{21} and Δm^2_{ee}
  - JUNO, RENO-50



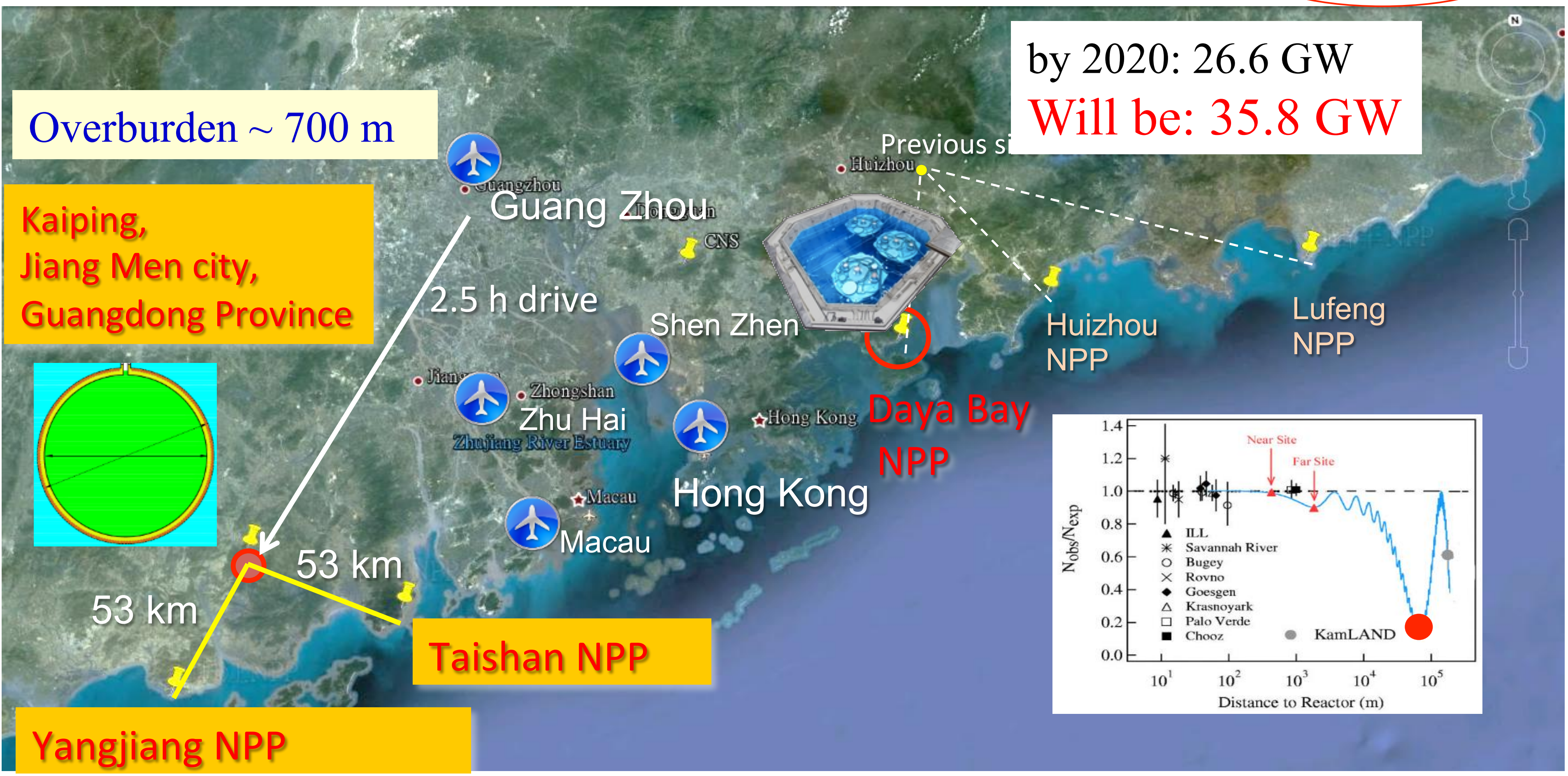




JUNO Site

JUNO has been approved in Feb. 2013. ~300 M$ by China

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

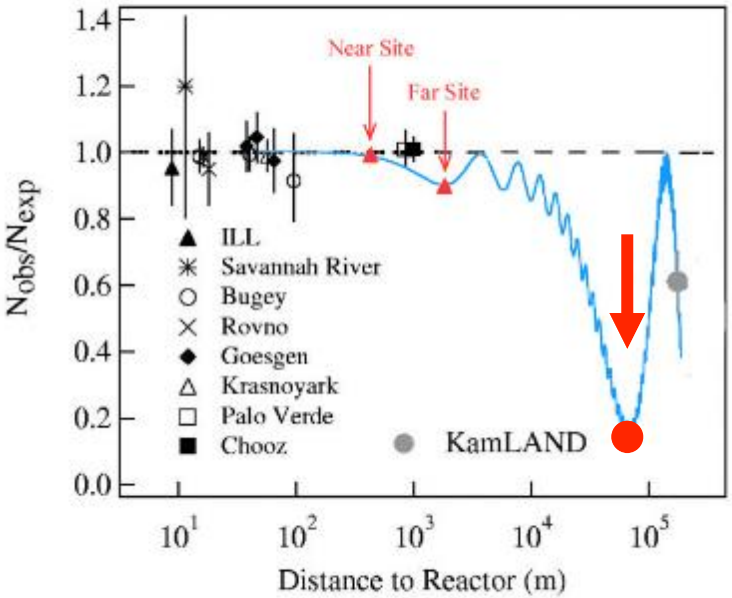
try	Institute
ia	Yerevan Physics Institute
m	Universite libre de Bruxelles
	PUC
	UEL
	PCUC
	UTFSM
	BISEE
	Beijing Normal U.
	CAGS
	ChongQing University
	CIAE
	DGUT
	ECUST
	Guangxi U.
	Harbin Institute of Technology
	IHEP
	Jilin U.
	Jinan U.
	Nanjing U.
	Nankai U.
	NCEPU
	Pekin U.
	Shandong U.
	Shanghai JT U.
	IMP-CAS
	SYSU
	Tsinghua U.
	UCAS
	USTC
	U. of South China
	Wu Yi U.
	Wuhan U.
	Xi'an JT U.
	Xiamen University

Collaboration established in July 2015
Now: 71 institutions
over 400 collaborators
2 observers

China	NUDT
Czech	Charles U.
Finland	University of Oulu
France	APC Paris
France	CENBG
France	CPPM Marseille
France	IPHC Strasbourg
France	LLR Palaiseau
France	Subatech Nantes
Germany	Forschungszentrum Julich ZEA2
Germany	RWTH Aachen U.
Germany	TUM
Germany	U. Hamburg
Germany	IKP FZJ
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
Pakistan	PINSTECH (PAEC)
Russia	INR Moscow
Russia	JINR
Russia	MSU
Slovakia	FMPICU
Taiwan	National Chiao-Tung U.
Taiwan	National Taiwan U.
Taiwan	National United U.
Thailand	NARIT
Thailand	PPRLCU
Thailand	SUT
USA	UMD1
USA	UMD2

Determine MH with Reactors

Method from Petcov and Piai, Physics Letters B 553, 94-106 (2002)

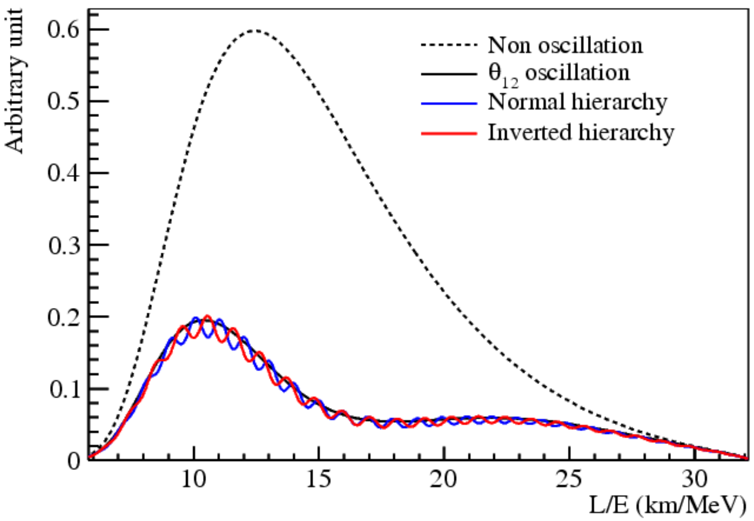


Also refer to arXiv1210.8141

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

$$P_{ee} = 1 - \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2(\Delta_{21}) - \sin^2 2\theta_{13}\sin^2(|\Delta_{31}|) - \sin^2\theta_{12}\sin^2 2\theta_{13}\sin^2(\Delta_{21})\cos(2|\Delta_{31}|) \pm \frac{\sin^2\theta_{12}}{2}\sin^2 2\theta_{13}\sin(2\Delta_{21})\sin(2|\Delta_{31}|)$$

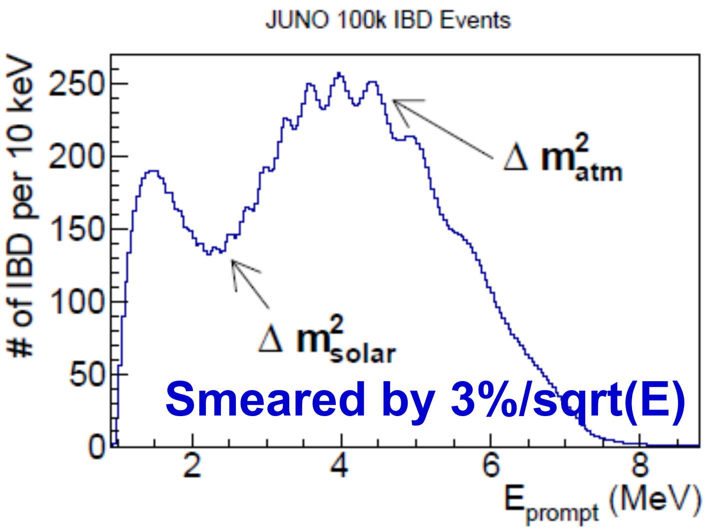
+ NH
- IH



- The big suppression is the "solar" oscillation → Δm^2_{21} , $\sin^2\theta_{12}$
- "Large" value of θ_{13} is crucial
- **The NH or IH can be seen if the neutrino spectrum is as clear as 3% @ 1MeV**

Other MH Experiments
- Long baseline Accelerator: NOvA/DUNE
- Atmospheric neutrino: INO/PINGU/HyperK

Precision Measurements



Global results of oscillation parameters

	Δm^2_{21}	$\|\Delta m^2_{31}\|$	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
Dominant Exps.	KamLAND	MINOS	SNO	Daya Bay	SK/T2K
Individual 1σ	2.7% [121]	4.1% [123]	6.7% [109]	6% [122]	14% [124, 125]
Global 1σ	2.6%	2.7%	4.1%	5.0%	11%

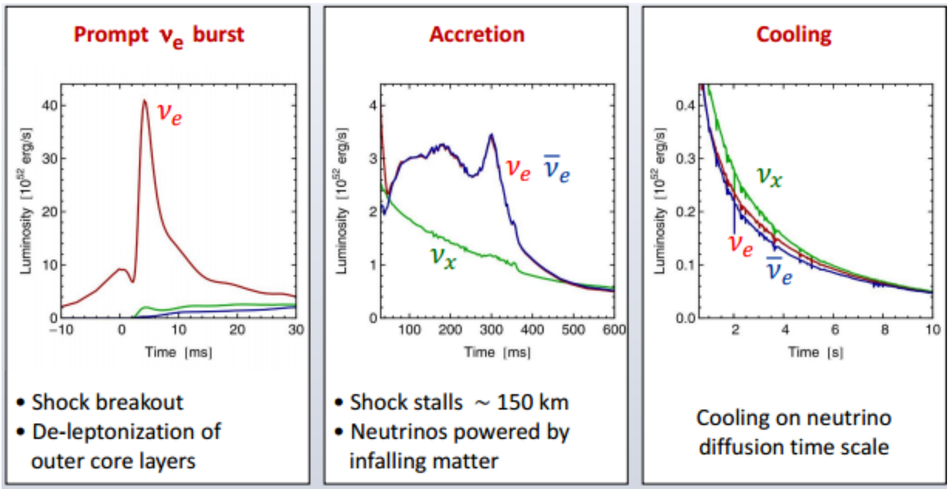
$$P_{ee}(L/E) = 1 - P_{21} - P_{31} - P_{32}$$
$$P_{21} = \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21})$$
$$P_{31} = \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31})$$
$$P_{32} = \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32})$$

$$\Delta m^2_{ee} = \cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32}$$

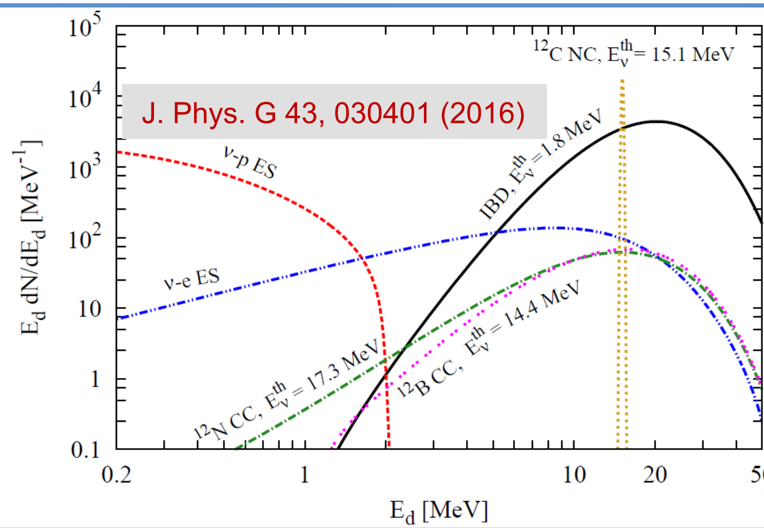
	Statistics	Systematics considering: BG+1% b2b+1% Scale +1% EnonL
$\sin^2\theta_{12}$	0.54%	0.67%
Δm^2_{21}	0.24%	0.59%
Δm^2_{ee}	0.27%	0.44%

- **Measure 3 oscillation parameters is better than 1%**
- **Test the unitarity of U_{PMNS} to ~1%**
- **Narrow down the parameter space for 0νββ**
- **Be a powerful discriminator for the $|\Delta m^2_{ee}|$ ...ls of the neut $|\Delta m^2_{\mu\mu}|$ ...sses and mixing**
- **together w/ → test the sum: $\Delta m^2_{13} + \Delta m^2_{21} + \Delta m^2_{32} \stackrel{?}{=} 0$**
- **reveal additional information**

Supernova Detection



Three phases of supernova, Fischer et al. (Basel group), A&A 517:A80, 2010 [arxiv:0908.1871]



The neutrino event spectra with respect to the visible energy *E*d in the JUNO detector for a SN at 10 kpc

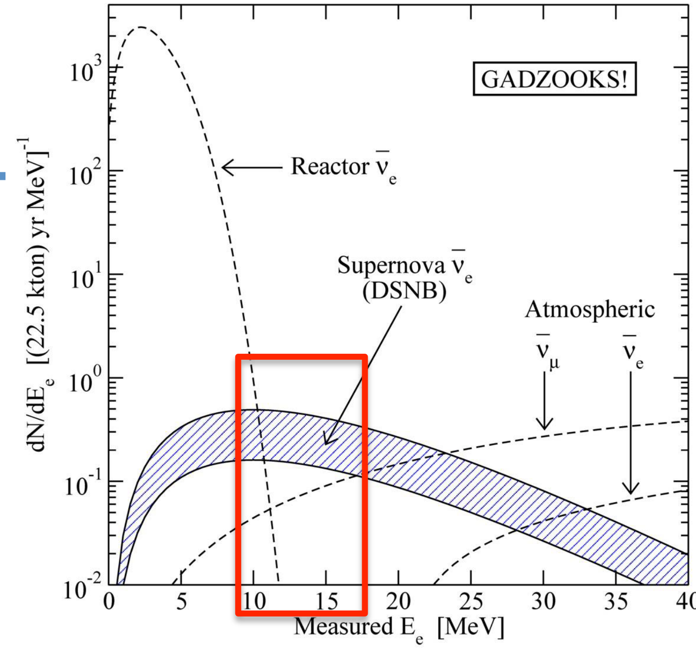
Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \to e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \to \nu + p$	NC	6.0×10^2	1.2×10^3	2.0×10^3
$\nu + e \to \nu + e$	ES	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \to \nu + {}^{12}C^*$	NC	1.7×10^2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

- Be able to detect ~5000 neutrinos for a SN at 10kpc VS 13 (1987A)
- Distinguish the different ν flavors
- Reconstruct ν energies and luminosities
- Almost background free due to time information

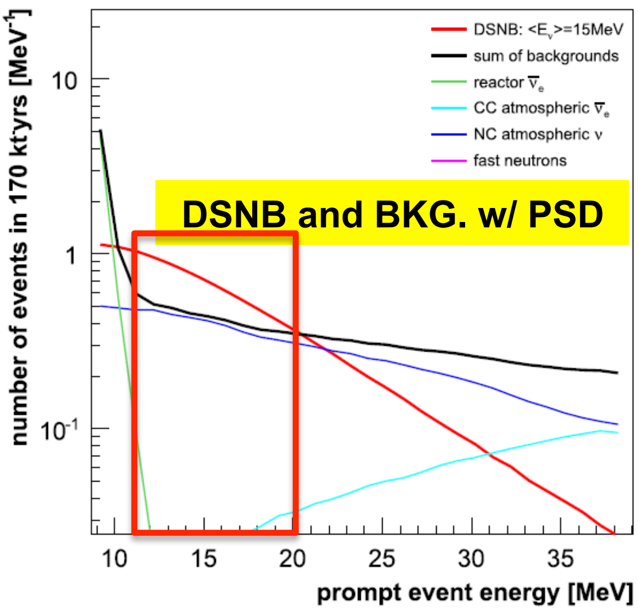
- Time evolution, energy spectra, neutrino-driven explosion
- Astronomy/astrophysics/particle physics: neutrino mass/ordering
- Together with gravitational wave and Hyper-k

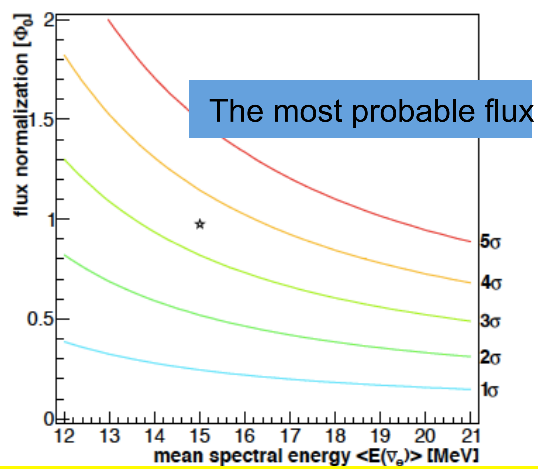
DSNB

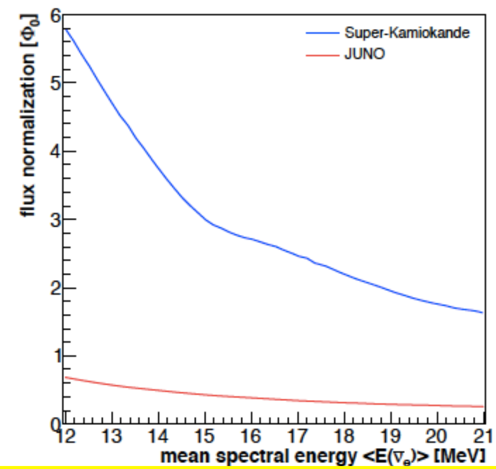
- DSNB, Diffuse Supernova Neutrino Background
  - Approx. 10 core collapses/sec in the visible universe
  - Emitted ν energy density : ~ 10% of CMB density
  - Detectable ν_e flux at Earth: ~$10 cm^{-2}s^{-1}$
- Confirm star-formation rate
- More info: neutrino emission from average core collapse & black-hole
- Pushing frontiers of neutrino astronomy to cosmic distances!



Window of opportunity between reactor ν_e and atmospheric ν





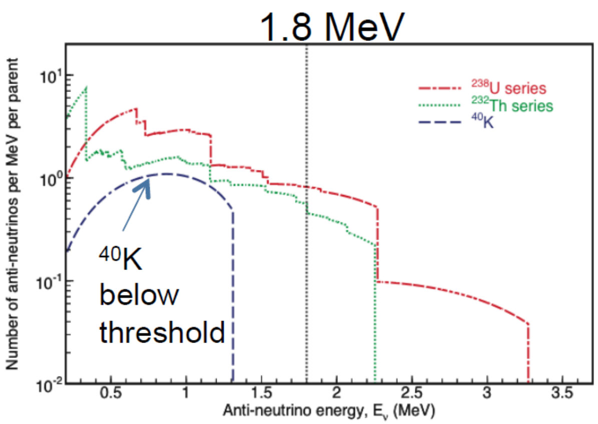


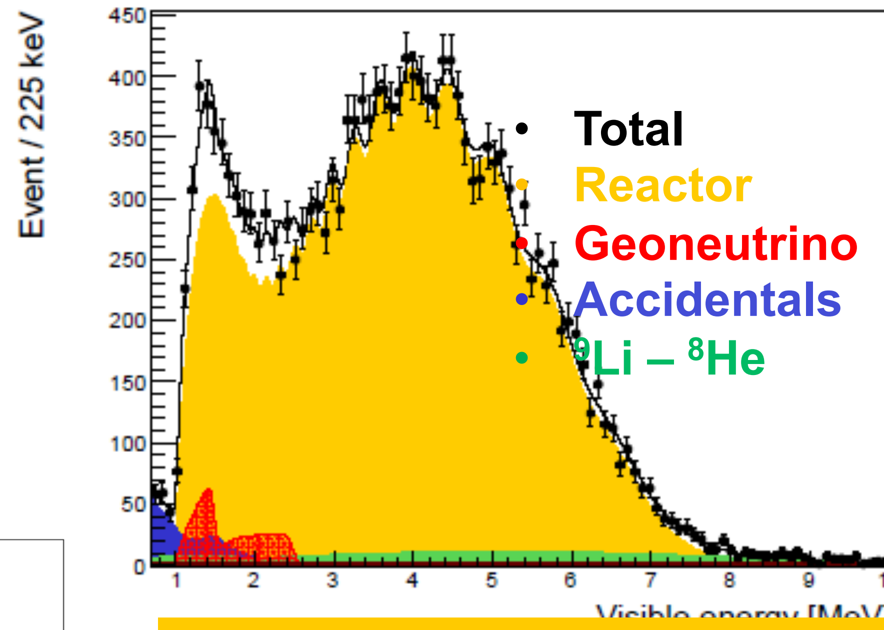
Right) Detecting capability: 3 σ can be obtained with the prediction

Left) 90% CL exclusion curves if no detection: Super K VS JUNO 10 yrs w/ PSD

Geoneutrino detection

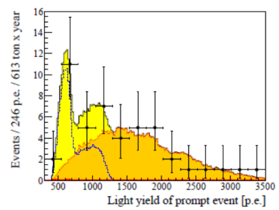
- **Geoneutrino: antineutrino from the decay of ^{238}U, ^{232}Th, ^{40}K in the Earth, occupying 99% radiogenic heat in the earth. Nature. 310 (5974): 191–198**





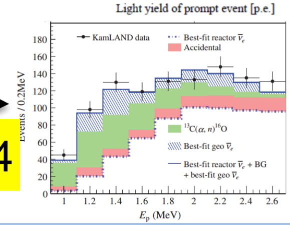
- **Results from Kamland:**
  - **PRD 88 (2013) 033001**
  - **2002-2012 data: geoneu.**

116$\pm^{27}_{28}$



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

14.3±4.4

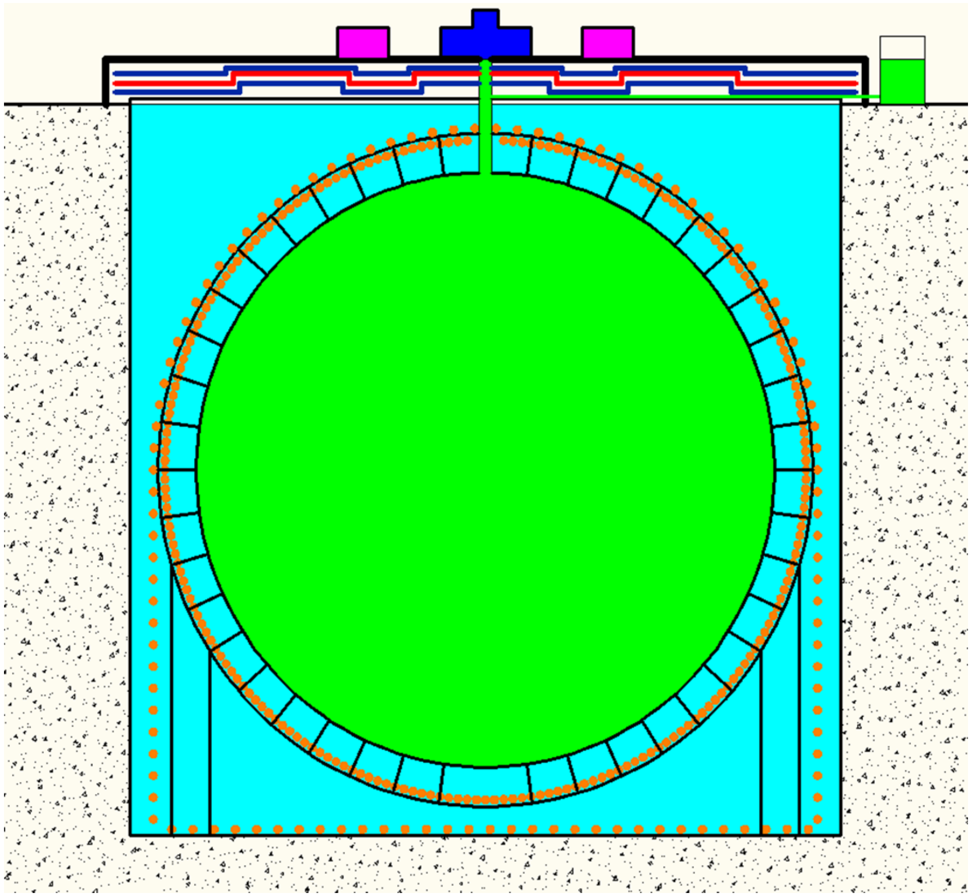


Result of a single toy Monte Carlo for 1-year measurement of JUNO
- FV 18.35 kton (17.2 m radial cut)
- 80% detection efficiency;
- 3% @ 1 MeV energy resolution

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

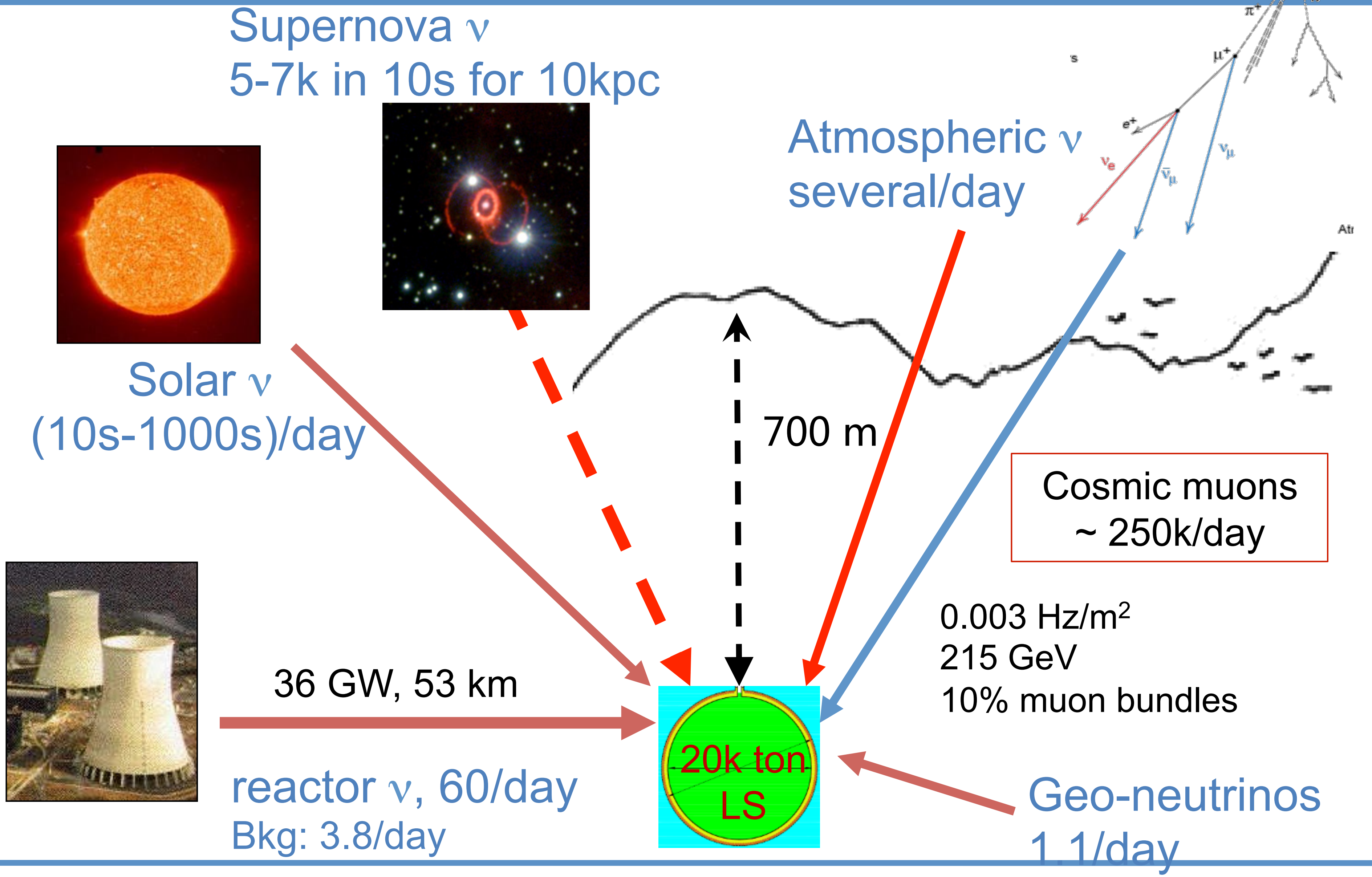
Any other Physics in JUNO?

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



- **20 kton LS detector**
- **3% energy resolution**
- **700 m underground**
- **Rich physics possibilities**
  - **Reactor neutrino for Mass hierarchy**
  - **precision measurement of oscillation parameters**
  - **Supernovae neutrino**
  - **Geoneutrino**
  - **Solar neutrino**
  - **Atmospheric neutrino**
  - **Exotic searches** including proton decay, dark matter

JUNO Event Rates after selection



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  - PMT readout and water proof
  - Calibration system
  - Veto system
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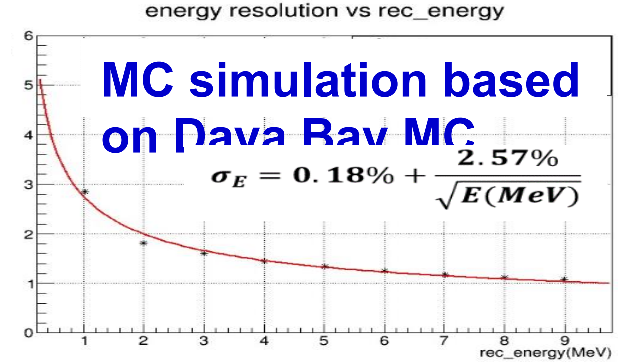
Main Challenges for JUNO Detector

1. Big volume of target → more neutrinos
   -- Quantity, 20 ktons LS
2. Good energy resolution → precisely
   -- 3%/sqrt(E) energy resolution



	KamLAND	BOREXINO	JUNO
LS mass	1 kt	0.5 kt	20 kt
Energy Resolution	6% @ 1MeV	5% @ 1MeV	3% @ 1MeV
Light yield	250 p.e./MeV	511 p.e./MeV	1200 p.e./MeV

KEY: MORE PHOTOELECTRONS

Statics Increasing
- PMT peak QE: 30% + 75% photocathode coverage
- LS Attenuation length of 20 m → abs. 60 m + Rayl. scatt. 30m

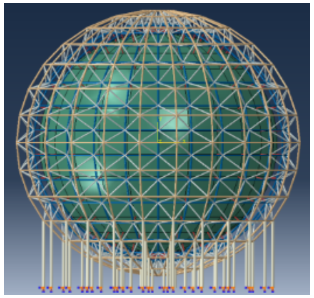
+

Non statistical factors
- Dark noise of PMT and electronics
- Non-uniformity
- Vertex resolution
- PMT charge resolution

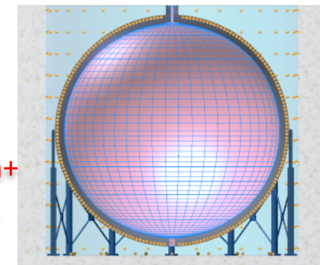
= 3% @ 1MeV

Detector design options

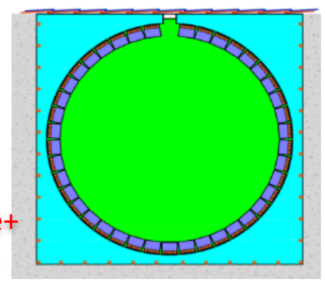
Acrylic
sphere+
SS truss



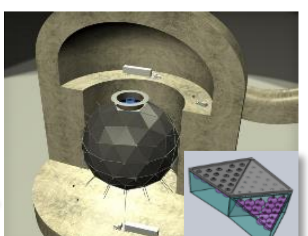
Balloon+
SS tank



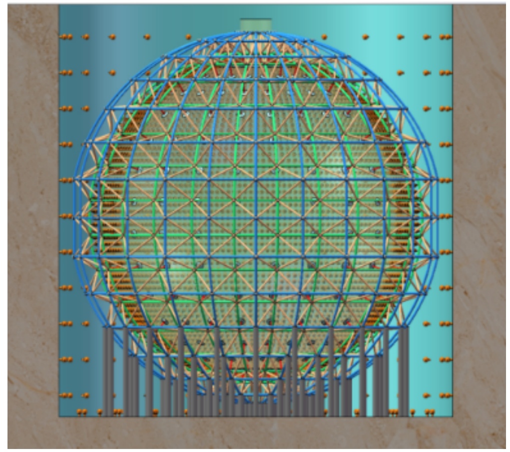
Acrylic
module+
SS tank



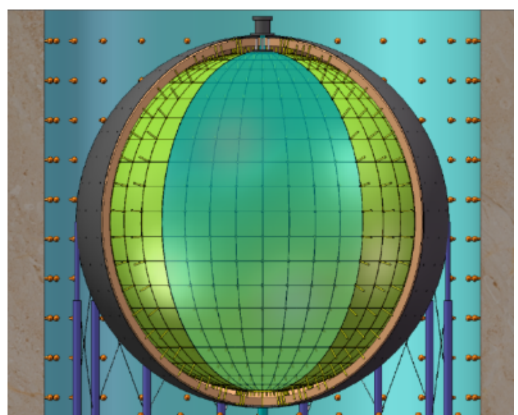
Acrylic
sphere+
SS tank



March,
2014

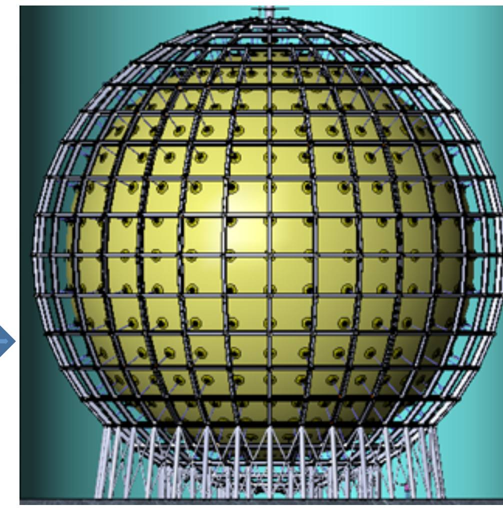


SS structure+ Acrylic sphere

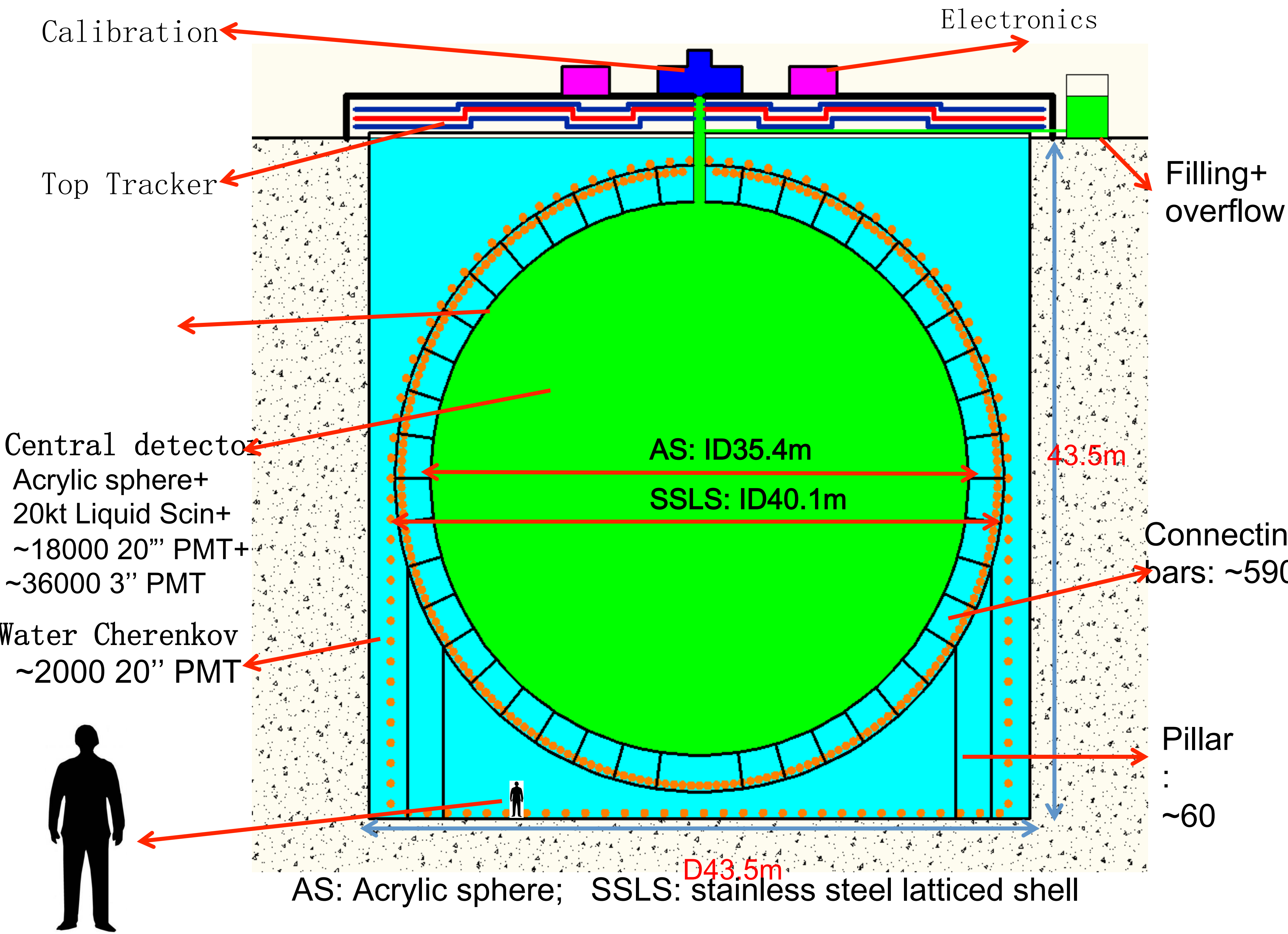


Balloon + Acrylic support+ SS tank

July,
2015

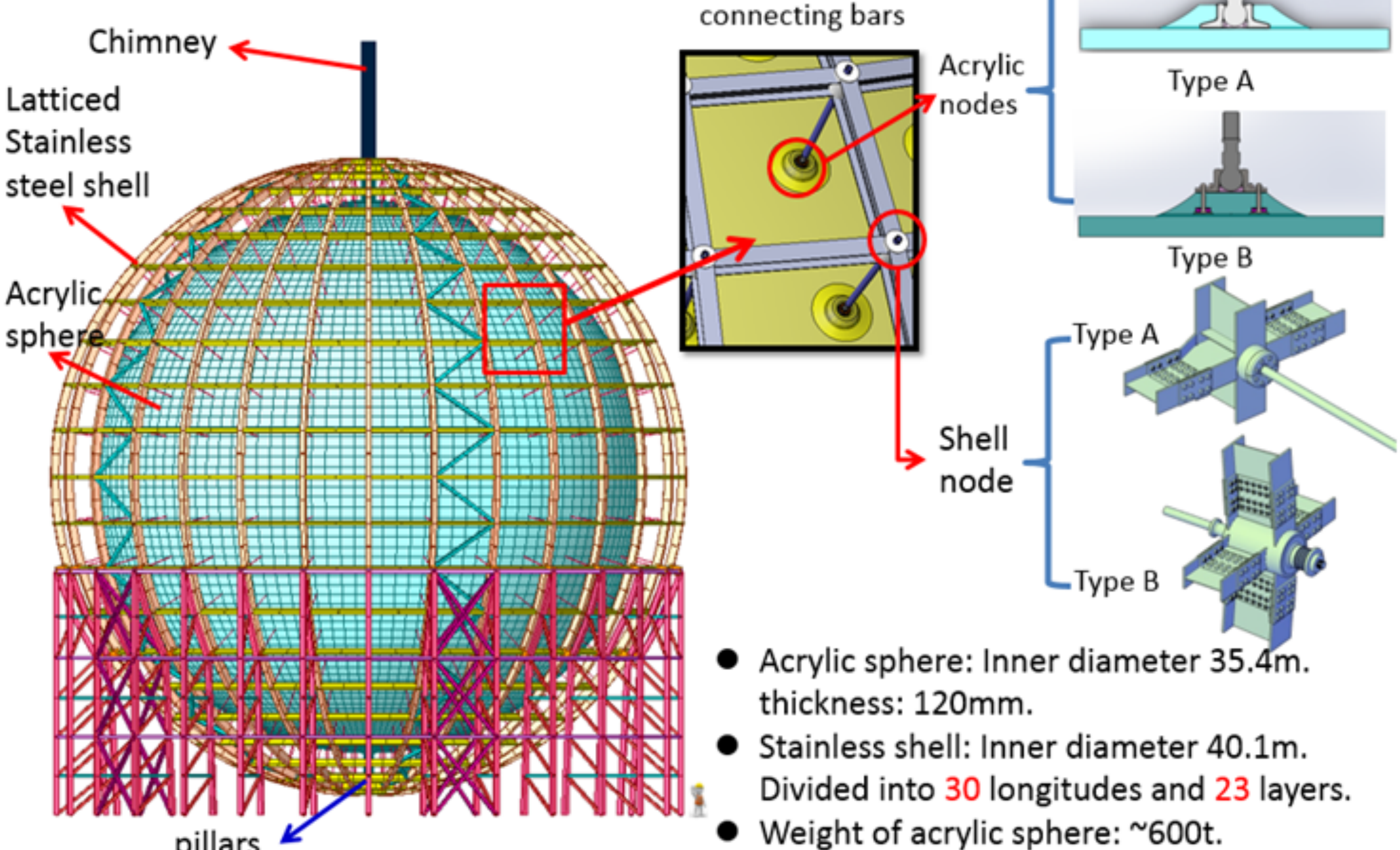


Final decision
Acrylic sphere + SS structure


Calibration
Electronics
Top Tracker
Filling+
overflow
Central detector
Acrylic sphere+
20kt Liquid Scin+
~18000 20"' PMT+
~36000 3'' PMT
AS: ID35.4m
SSLS: ID40.1m
43.5m
Connectin
bars: ~590
Water Cherenkov
~2000 20'' PMT
Pillar
:
~60
D43.5m
AS: Acrylic sphere; SSLS: stainless steel latticed shell

CD main structure

Latest design of CD



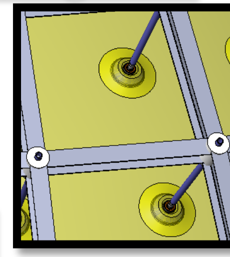
Acrylic sphere supported by stainless steel shell

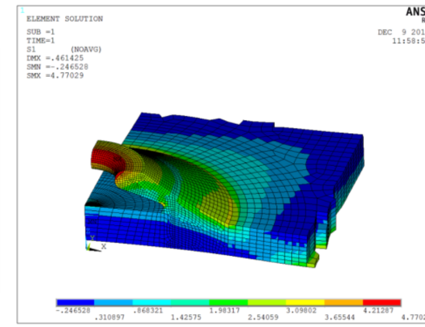
- Acrylic sphere: Inner diameter 35.4m. thickness: 120mm.
- Stainless shell: Inner diameter 40.1m. Divided into 30 longitudes and 23 layers.
- Weight of acrylic sphere: ~600t.
- Weight of shell: ~590 t.
- No. of connecting bars: 590

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 ↑

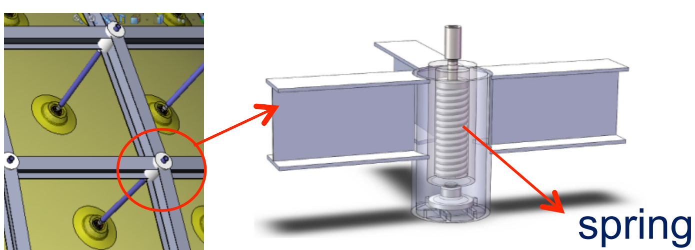
~560 connecting nodes will carry this load

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 ✓

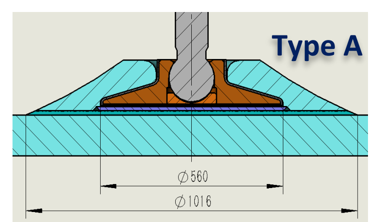
How to improve the load distribution on bars?

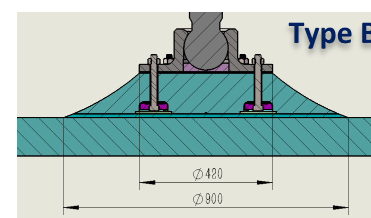
Adjust the stiffness of some connecting bars , to get a better distribution of load on whole sphere



b. How to improve the node design

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

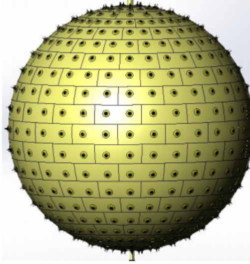




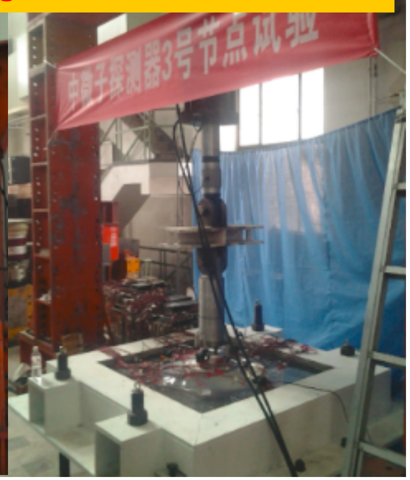
High tensile strength

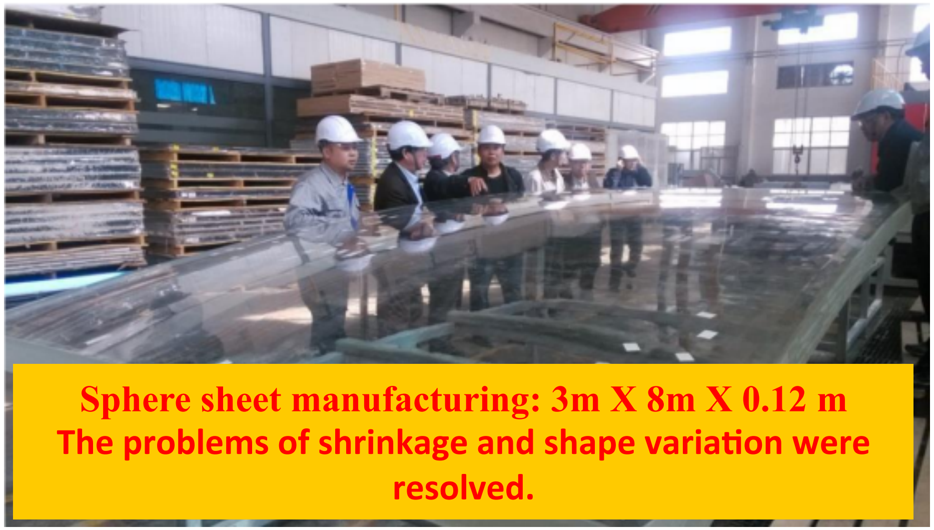
High compressive strength

Highlights: Acrylic Sphere R&D



Acrylic nodes test:
Upto 300~500 kN pulling forces when it breaks



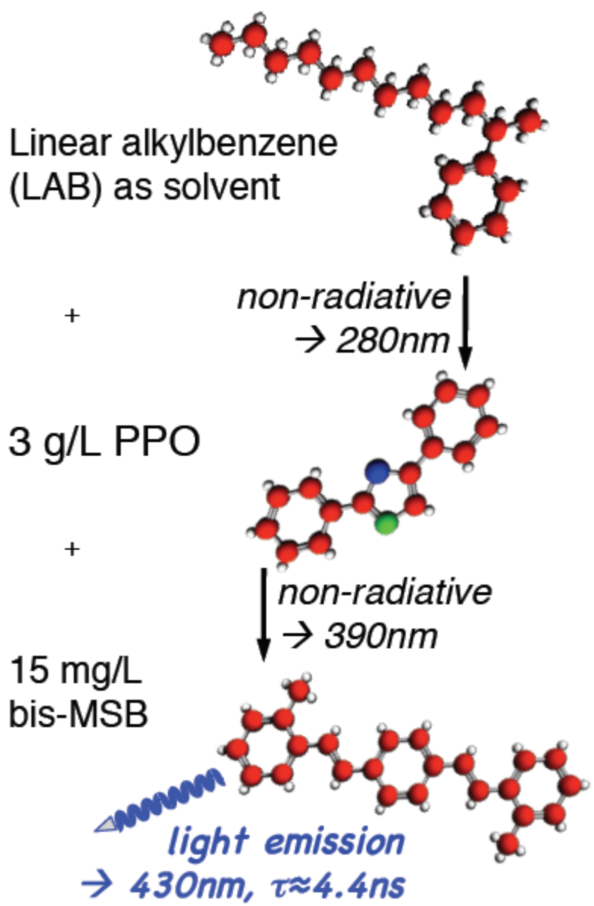


Sphere sheet manufacturing: 3m X 8m X 0.12 m
The problems of shrinkage and shape variation were resolved.

Part of sphere are manufactured to test the techniques

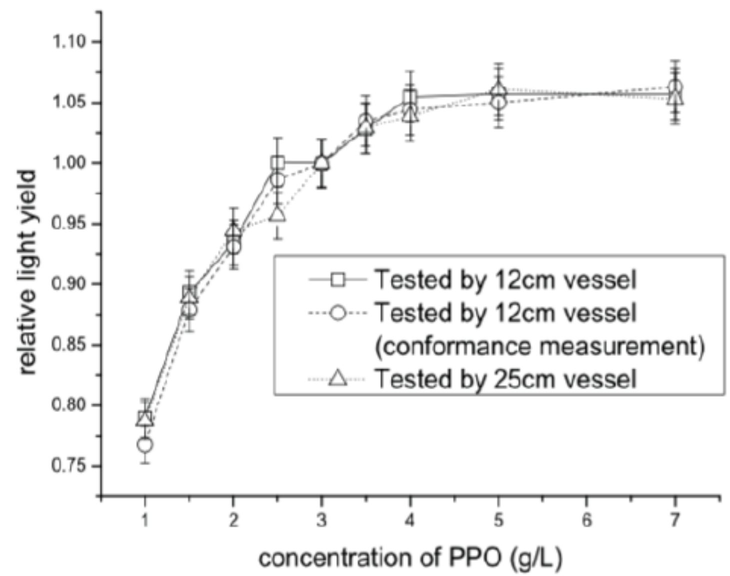
R&D of Liquid Scintillator:
Composition and Properties

Liquid scintillator composition



Required properties:

- **High light yield**: ~10^4 ph/MeV
  → pure organic solvent
  → high fluor (PPO) concentration
- **High transparency:** ~20m
  → choose transparent solvent → **LAB**
  → the producer matters!
- → shift light to long wavelength → **bisMSB**



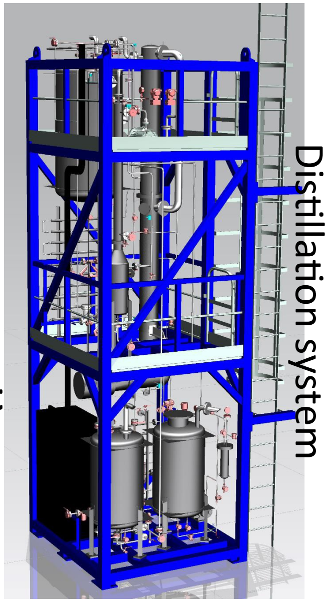
R&D of Liquid Scintillator:
LS Pilot plant

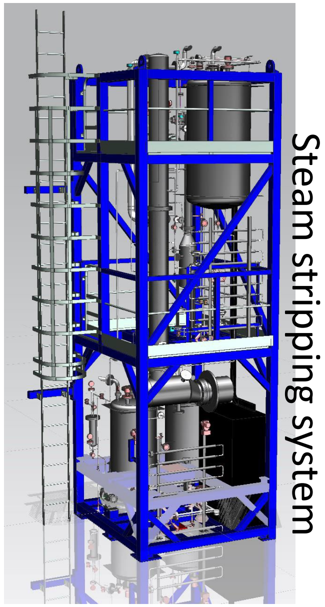
- Purify 20 ton LAB to test the overall design of purification system at Daya Bay. Plan to replace the target LS in one detector.

- Quantify the effectiveness of subsystems
  - Transparency : >20m A.L @430nm
  - Radio-purity: < 10^{-15} g/g (U, Th)
- Test the 4 sub-systems
  - Al_2O_3, distillation, gas striping, water extraction

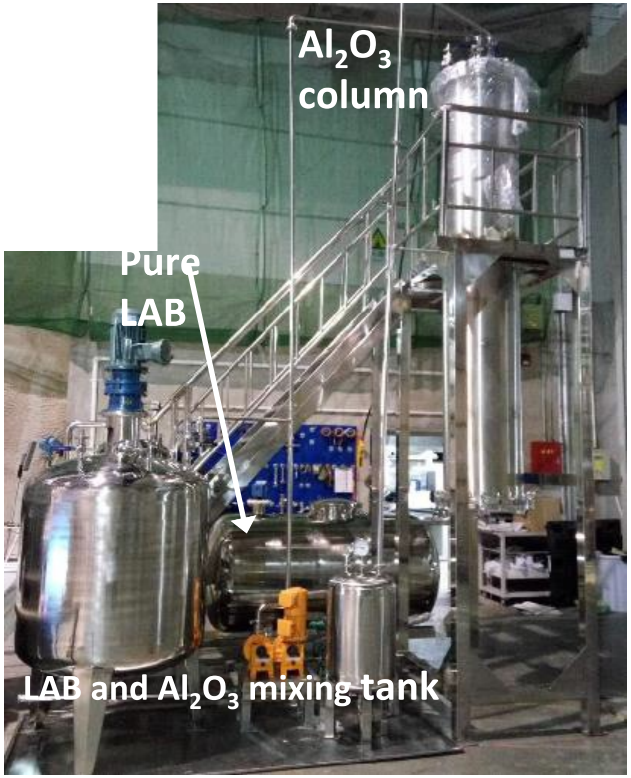
Distillation and steam stripping

Installed at Daya Bay



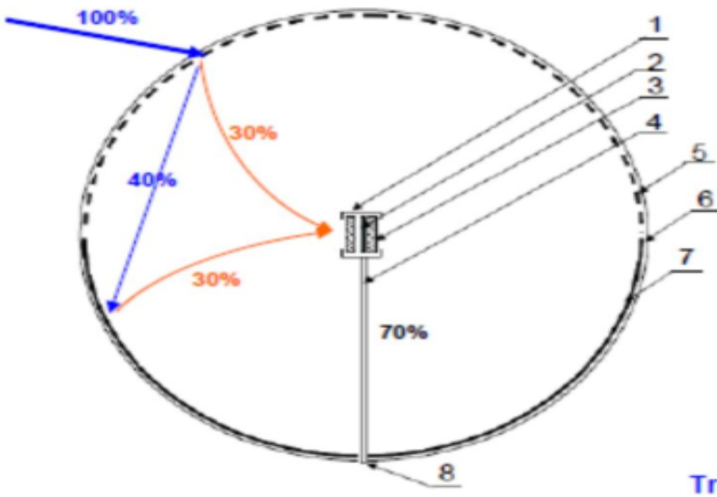


Al_2O_3 column pilot plant installed in Daya Bay LS hall

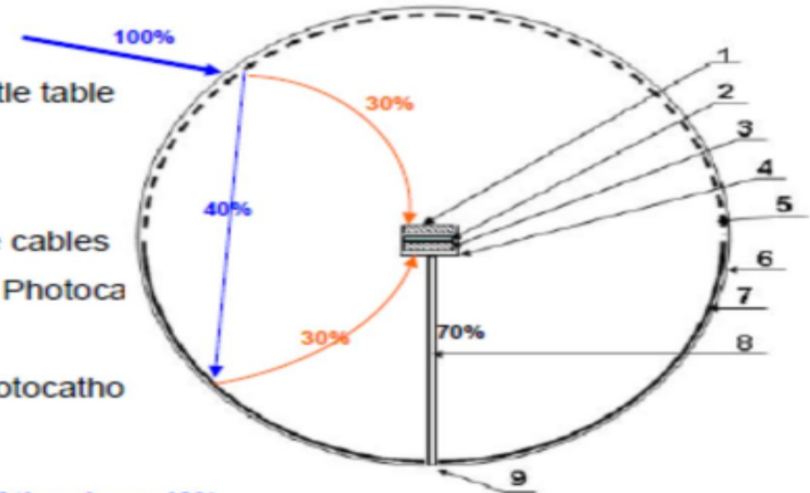


R&D of 20'' MCP-PMT: New Idea

1) Using two sets of Microchannel plates (MCPs) to replace the dynode chain
2) Using transmission photocathode (front hemisphere) and reflection photocathode (back hemisphere) } ~ 4π viewing angle!



1.Insulated trestle table
2.Anode
3.MCP dodule
4.Bracket of the cables
5.Transmission Photoca
6.Glass shell
7.Reflection Photocatho
8.Glass joint

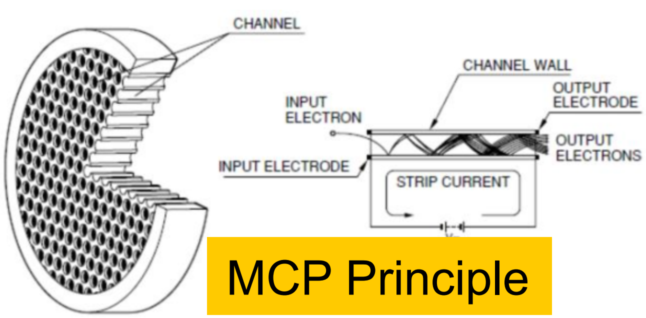


Transmission rate of the glass: 40%

Quantum Efficiency (QE) : of Transmission Photocathode 30% ; of Reflection Photocathode 30% ;

Collection Efficiency (CE) of MCP : 70%;

$$PD = QE_{Trans}{}^{*}CE + TR_{Photo}QE_{Ref}{}^{*}CE = 30\%{}^{*}70\% + 40\%{}^{*}30\%{}^{*}70\% = 30\%$$



MCP Principle

中国科学院高能物理研究所
Institute of High Energy Physics, CAS

effort by **Yifang Wang**

北方夜视技术股份有限公司
NORTH NIGHT VISION TECHNOLOGY CO.,LTD

南京大学

中国科学院西安光学精密机械研究所
XIAN INSTITUTE OF OPTICS AND PRECISION MECHANICS OF CAS

中核（北京）核仪器厂
CNNC Beijing Nuclear Instrument Factory

Project Team

R&D of 20'' MCP-PMT: Road Map

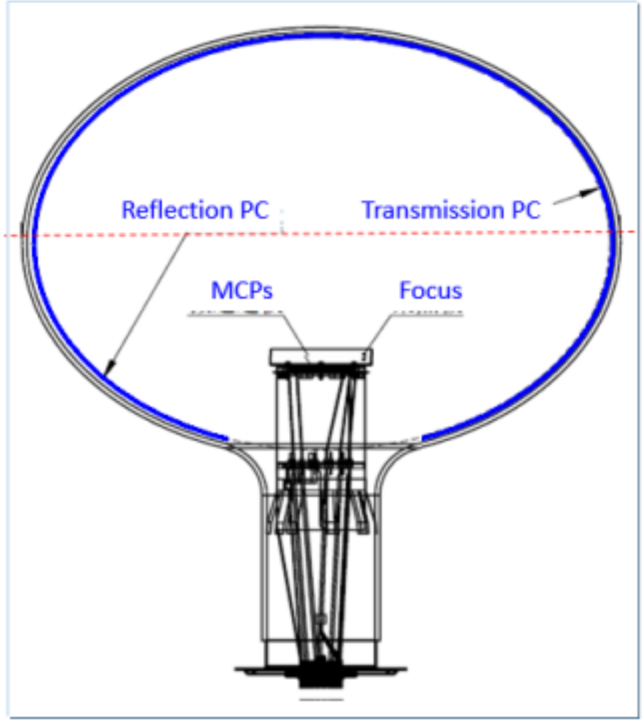
- 2009: the design of the MCP-PMT;
- 2010~2011: 5"MCP-PMT prototype without SPE;
- 2012: 8"MCP-PMT prototype without SPE;
- **2013: 8"prototypes with normal performance;**
- **2014: 20" prototypes with normal performance;**

QE ~ 25%@410nm; CE ~ 60%; P/V of SPE> 2.0;

- **2015: 20" prototypes with HDE performance;**

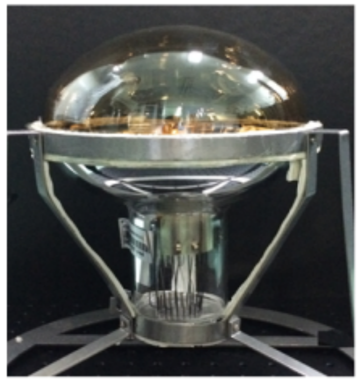
QE ~ 26%@410nm; CE ~100%; P/V of SPE> 3.0;

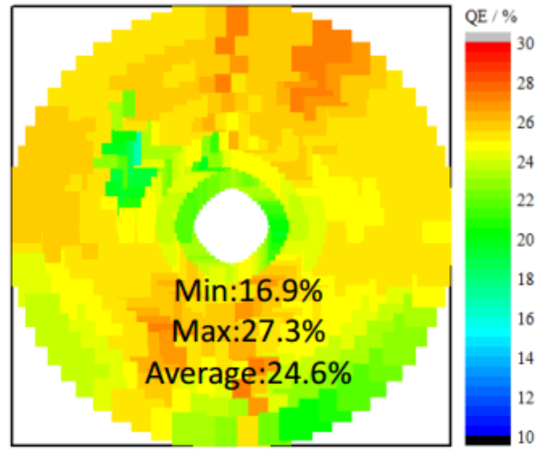
- 2016: for the high QE improvement.

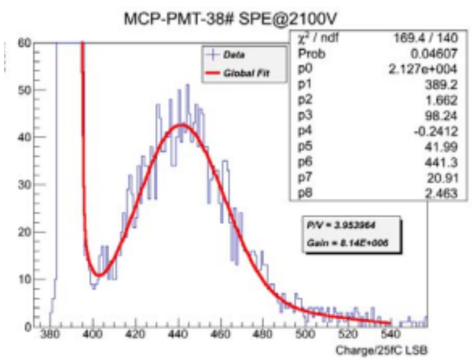


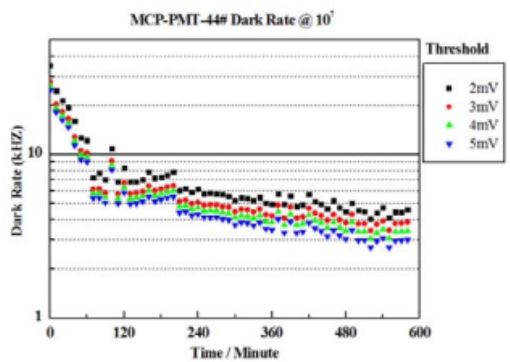
Final Design

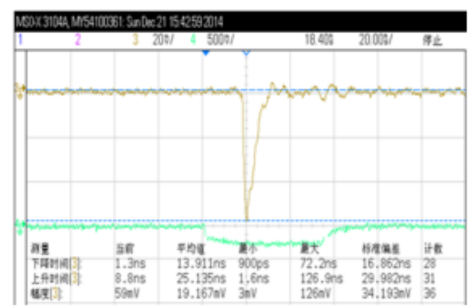
R&D of 20’’ MCP-PMT:
8’’ prototype performance 2013

8-inch IHEP MCP-PMT Vertical MCPs Sphere Glass	8-inch IHEP MCP-PMT Horizontal MCPs
	



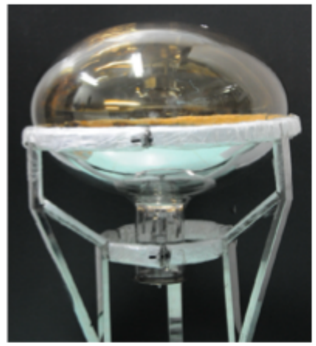


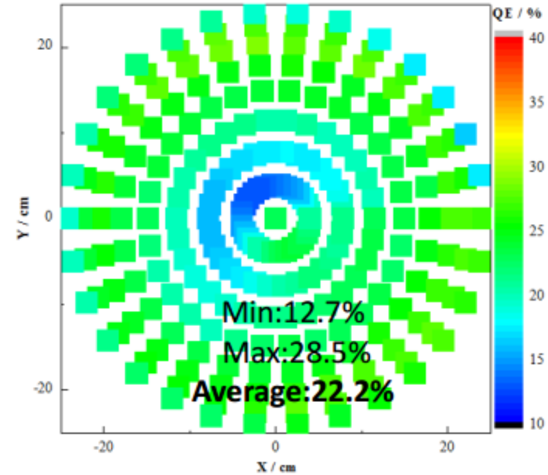


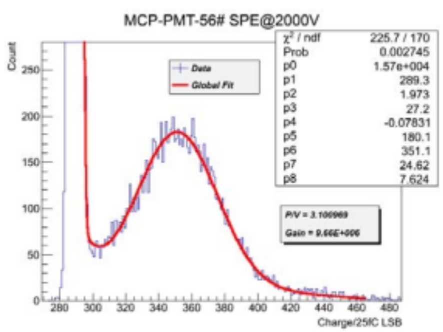


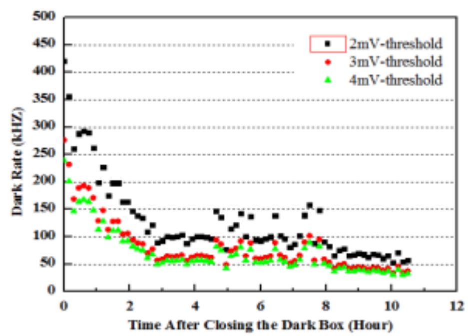
HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2100V	~1E7	~4	~1.3ns	~8.8ns	~3kHz

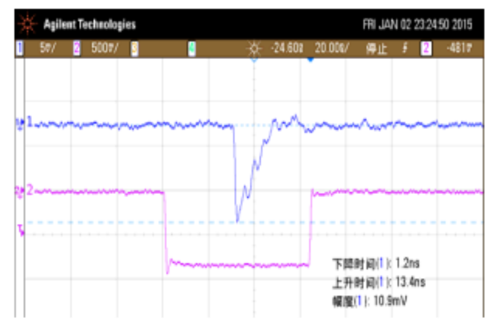
R&D of 20’’ MCP-PMT:
20’’ prototype in 2014

20-inch IHEP MCP-PMT Vertical MCPs Sphere Glass	20-inch IHEP MCP-PMT Horizontal MCPs Ellipsoidal Glass
	





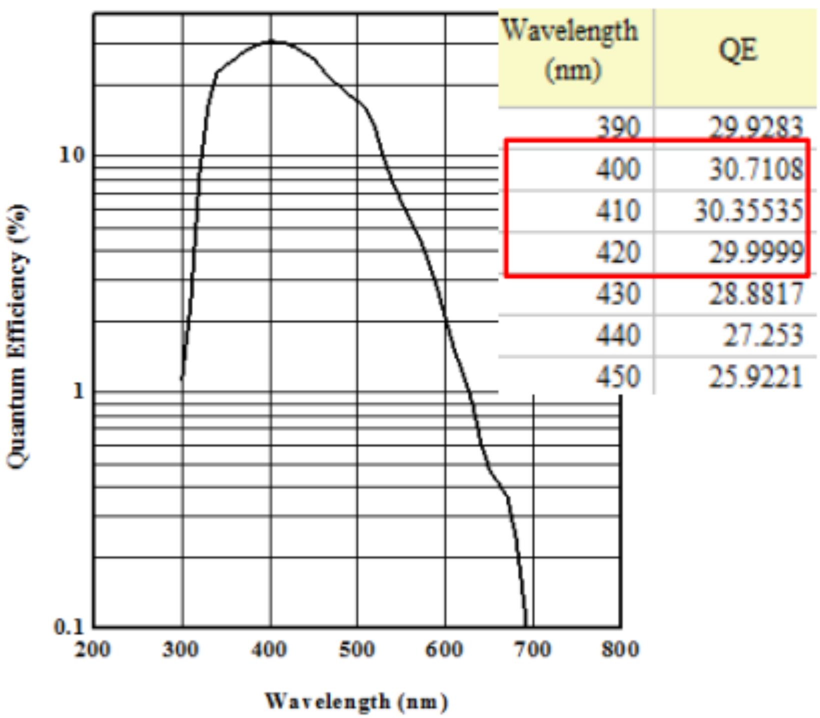




HV	Gain	P/V	Rise Time	Fall Time	Dark rate @1E7 Gain(0.25PE)
2000V	~1E7	~3	~1.2ns	~15ns	~50kHz

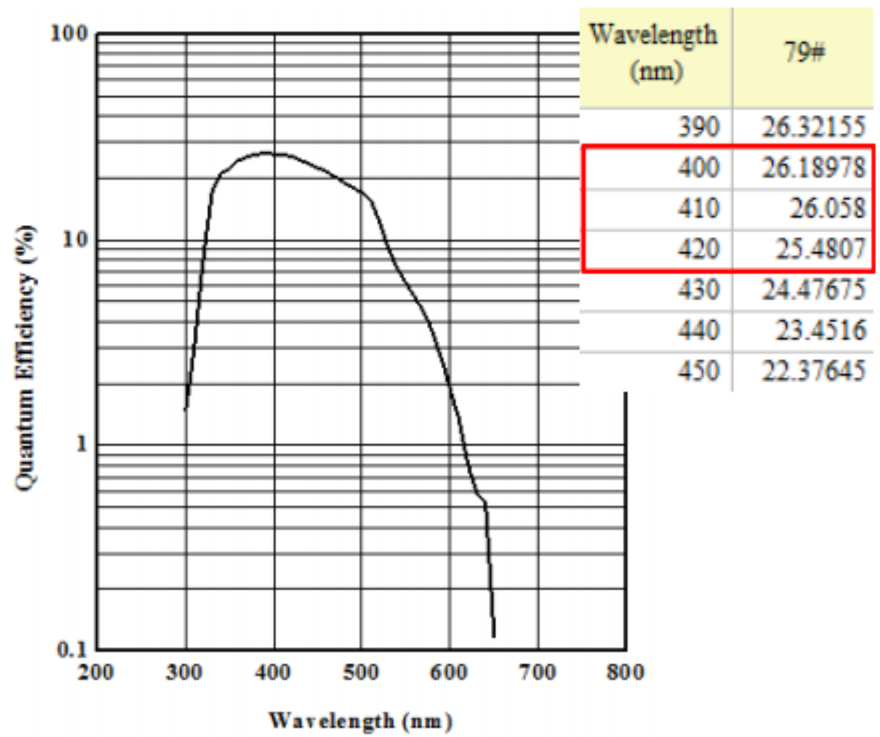
R&D of 20'' MCP-PMT: Quantum efficiency

20 inch Prototype	R12860	MCP-PMT
QE@410nm	~30%	~26%



Wavelength (nm)	QE
390	29.9283
400	30.7108
410	30.35535
420	29.9999
430	28.8817
440	27.253
450	25.9221

Hamamatsu R12860

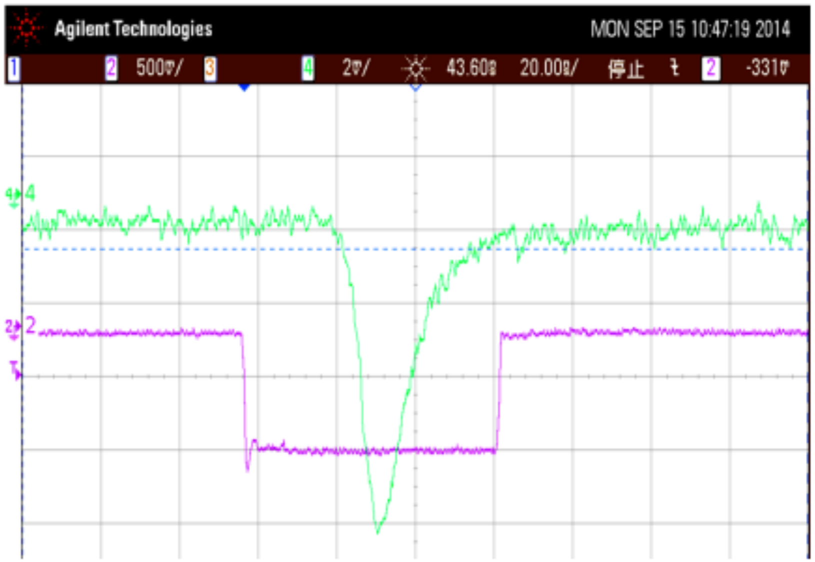


Wavelength (nm)	79#
390	26.32155
400	26.18978
410	26.058
420	25.4807
430	24.47675
440	23.4516
450	22.37645

MCP-PMT

R&D of 20’’ MCP-PMT: Waveform of single p.e.

	Rise Time	Fall Time
R12860	~6.7ns	~17.7ns
MCP-PMT	~2.2ns	~10.2ns

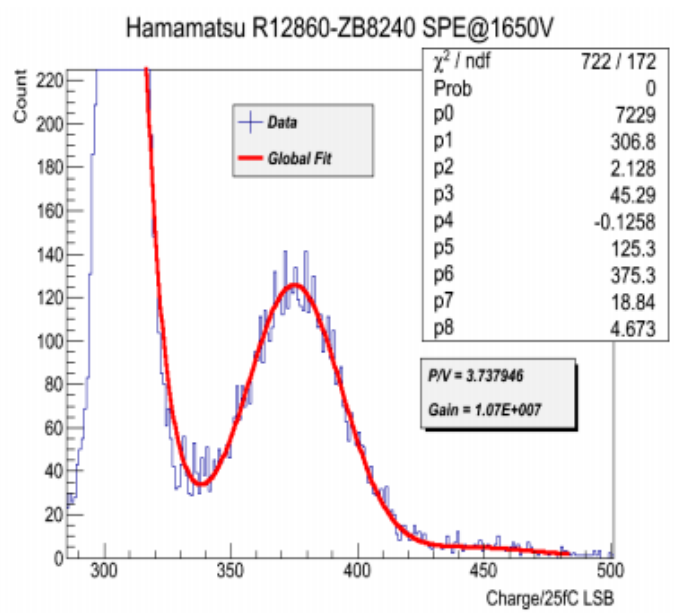


Hamamatsu R12860

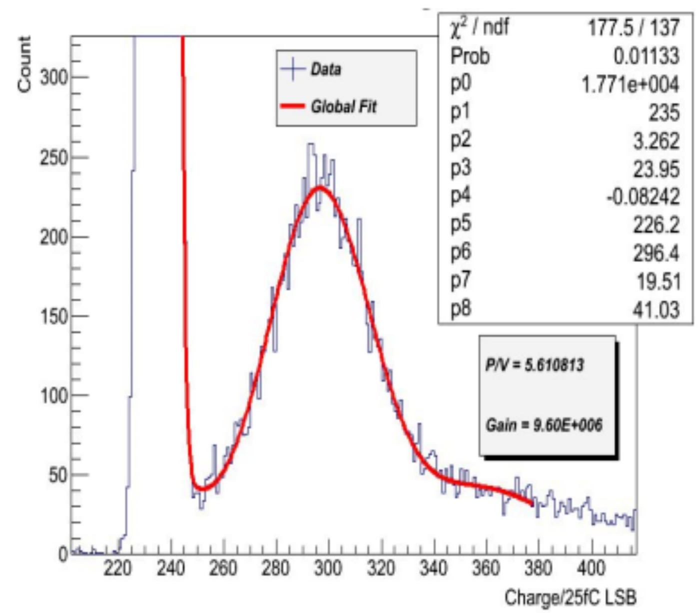
MCP-PMT

R&D of 20'' MCP-PMT:
Charge spectrum of single p.e.

	HV	Gain	P/V
R12860	1650V	~1.1E7	~3.7
MCP-PMT	1930V	~9.6E6	~5.6



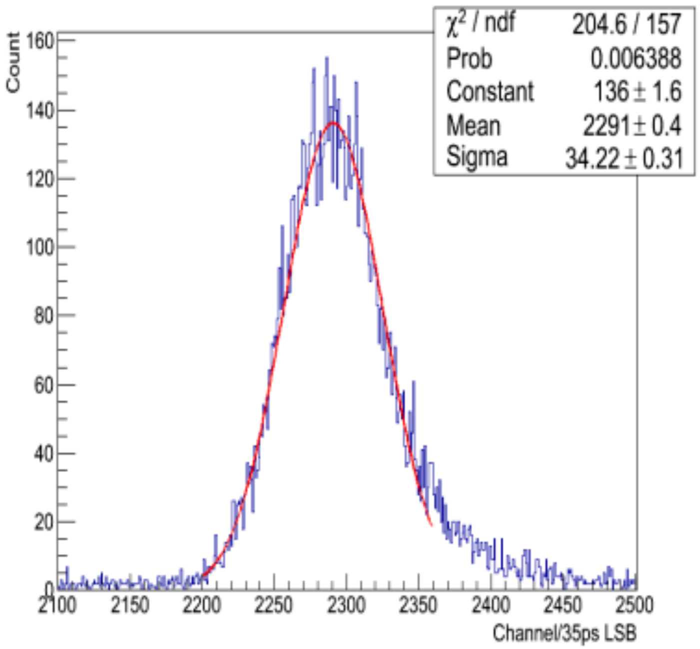
Hamamatsu R12860



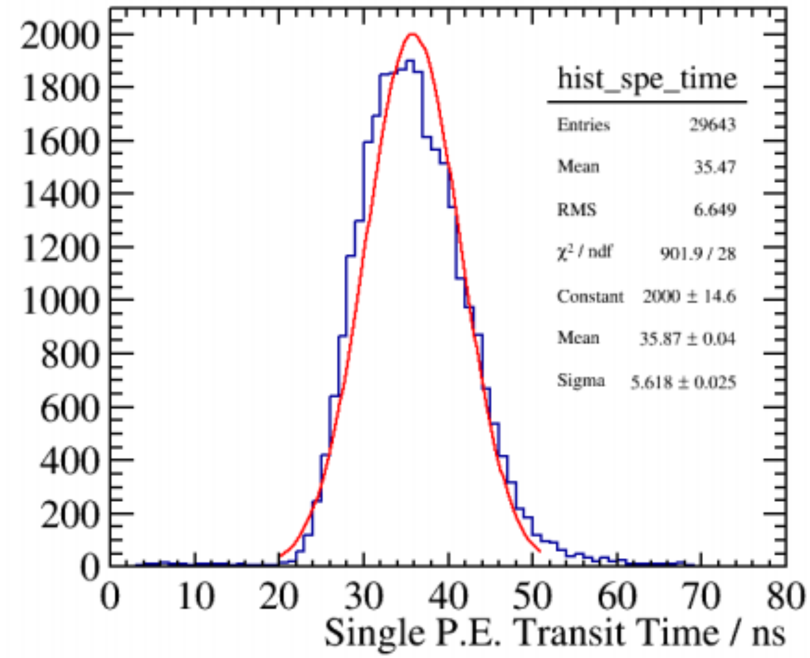
MCP-PMT

R&D of 20'' MCP-PMT: TTS

	HV	Gain	TTS @ top center
R12860	1650V	~1.1E7	~2.8ns
MCP-PMT	1930V	~9.6E6	~12ns



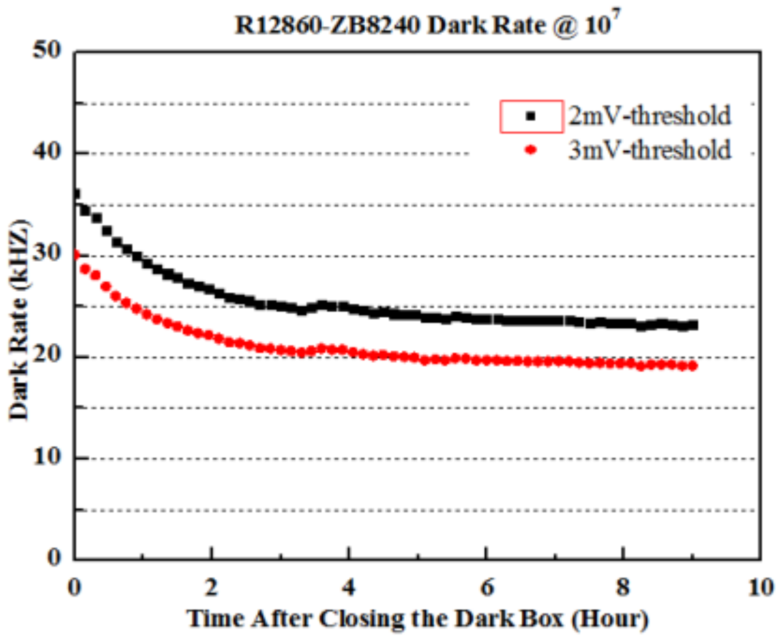
Hamamatsu R12860



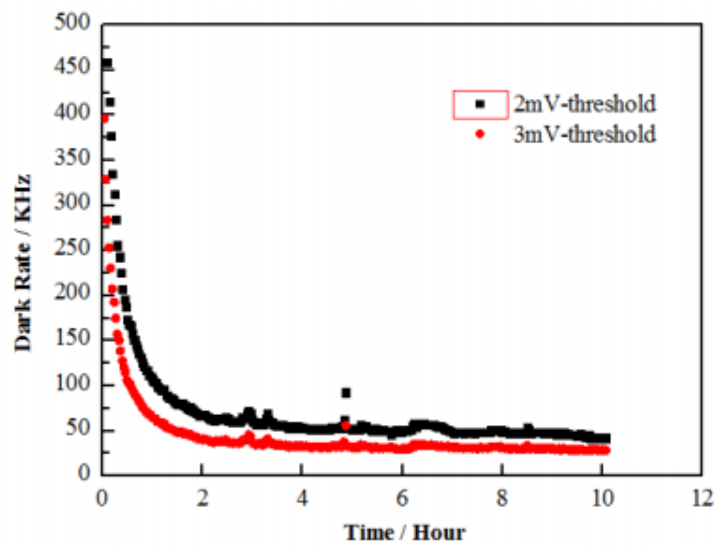
MCP-PMT

R&D of 20’’ MCP-PMT: Dark rate

	HV	Gain	Dark rate @ 0.25PE
R12860	1650V	~1.1E7	~25kHz
MCP-PMT	1930V	~9.6E6	~ 30kHz



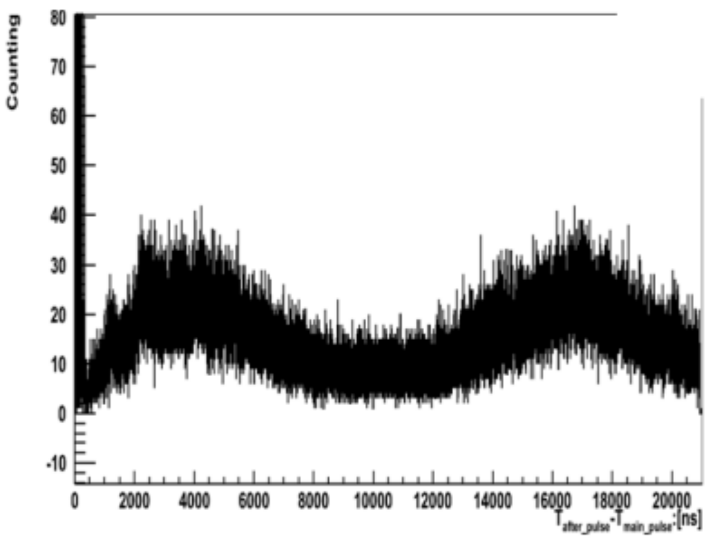
Hamamatsu R12860



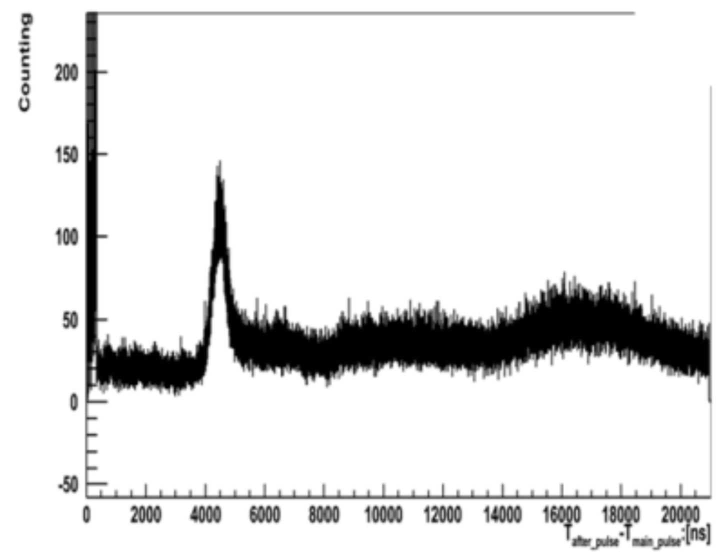
MCP-PMT

R&D of 20'' MCP-PMT: After pulse rate

	Time distribution	After Pulse Rate
R12860	4us, 17us	10%
MCP-PMT	4.5us	2.5%



Hamamatsu R12860



MCP-PMT

R&D of 20'' MCP-PMT:
Relative detection efficiency

	HV	Gain	Relativity PDE
R12860	1650V	~1.1E7	100%
MCP-PMT	1930V	~9.6E6	110%

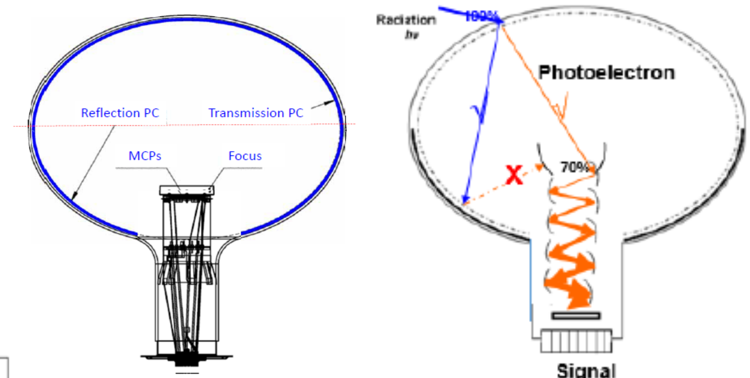
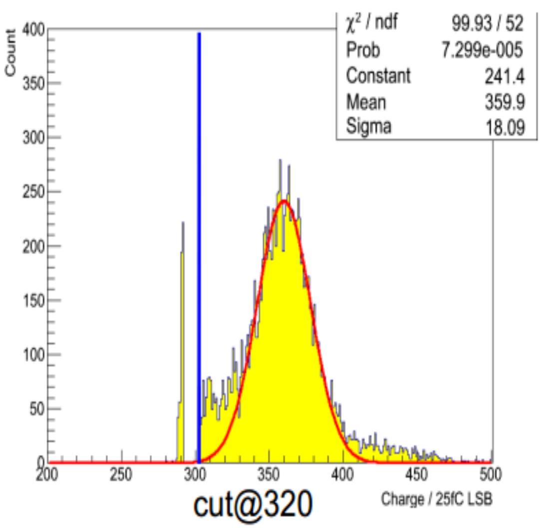
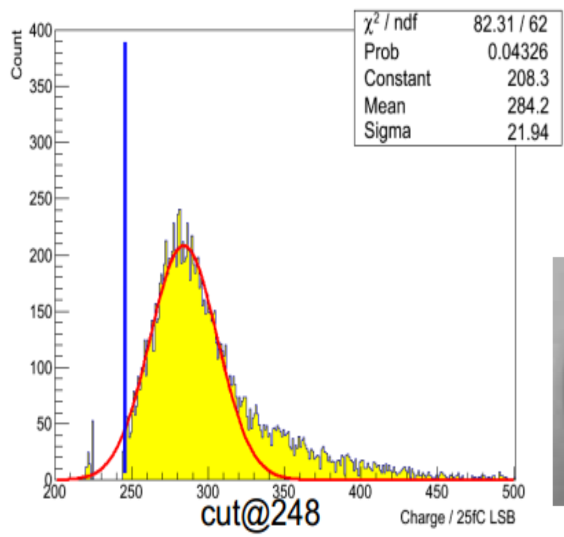


Fig. Photo cathode comparison



Hamamatsu R12860



MCP-PMT

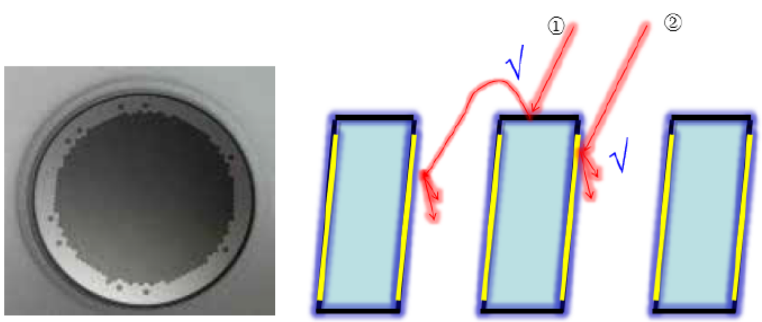
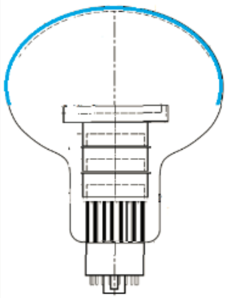
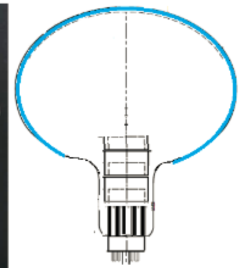


Fig. Collection Efficiency:
70% direct into hole + 30% indirect

Comparison of performances

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

20” PMT bidding

20-inch Hamamatus PMT Dynode Ellipsoidal Glass	20-inch IHEP MCP-PMT Horizontal MCPs Ellipsoidal Glass
 	 

Characteristics	unit	MCP-PMT（NNVC）	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~2 , F~12	R~5, <7; F~9, <12
Anode Dark Count	Hz	20K, < 30K	10K, < 50K
After Pulse Rate	%	1, <2	10, < 15
Radioactivity of glass	ppb	238U:50 232Th:50 40K: 20	238U:400 232Th:400 40K: 40

20’’ MCP-PMT
- Higher collection efficiency
- Low Background
- Better P/V value

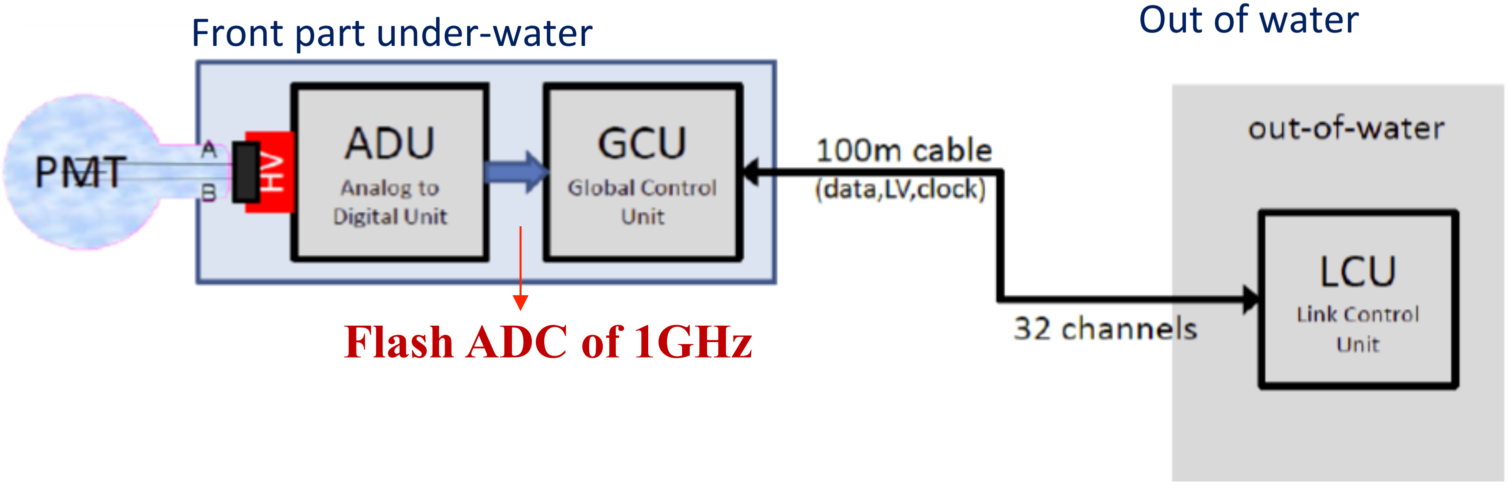
Evaluate the impact of the PMT characteristics on the MH as well as the cost → Finished 20” PMT bidding at the end of 2015:

-- 15,000 MCP-PMT (NNVT)

-- 5,000 Dynode-PMT (Hamamatsu)

PMT Readout

Flash-ADC is placed very front, at the end of PMT:
Good for the transmission from analog to digitalization



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

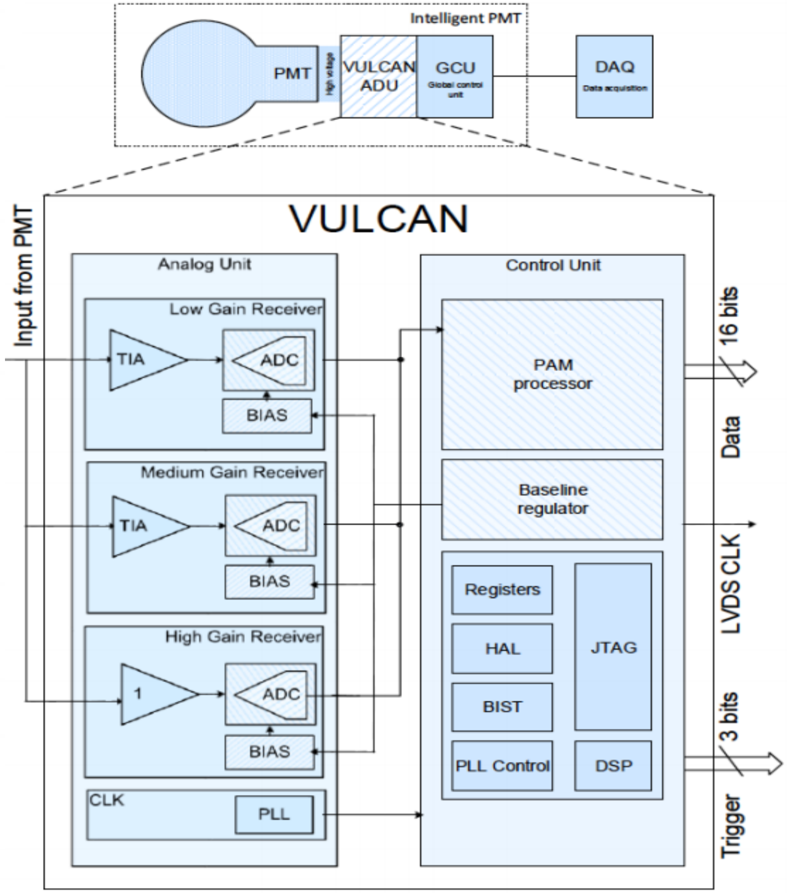
- Needs to consider the integration and potting structure with PMT
- Replacement under water is almost impossible, need high reliability of potting, electronics and HV

PMT Electronics Designs

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

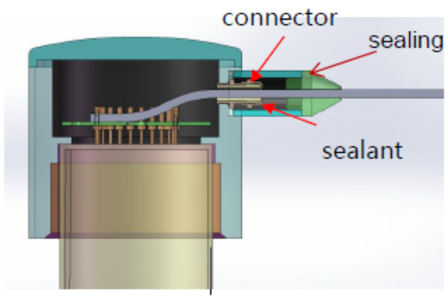


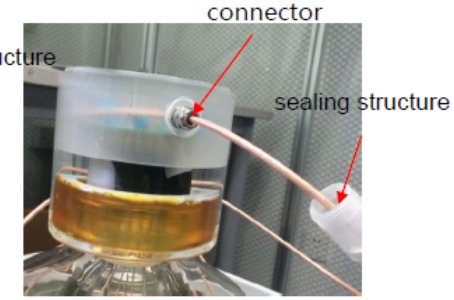
PMT readout waterproof: potting

Potting requirement:

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

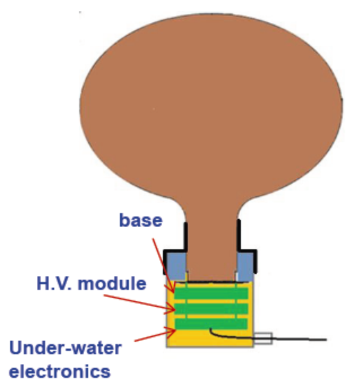
Design used for the prototype





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

Get good experience from JUNO prototype.



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

- Since HV and the electronic will also be encapsulated in the potting shell, the potting becomes difficult.
- 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

JUNO Double Calorimetry

- 2 independent read-put systems
  - 18,000 20-inch Large PMTs (LPMTs) ~1200 p.e./MeV
  - 36,000 3-inch Small PMTs (SPMTs) ~100 p.e./MeV
  - Concept approved in July 2015
  - Optimization of the final number ongoing

Candidates of 3" PMT

PHOTOMULTIPLIER TUBE
R12199

Hamamatsu

HZC from Photonis

XP72B20

20" PMT

- 75% photo-covergae
- Stochastic term: 3%/sqrt(E)
- Slower and worse p.e. resolution
- Large dark noise

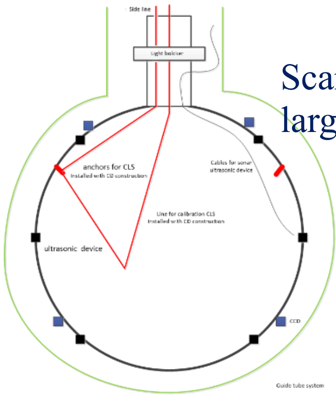
3" PMT

- 3% photo-covergae
- Stochastic term: 10%/sqrt(E)
- Faster and better p.e. resolution
- Small dark noise

- Reducing non-stochastic terms in the energy resolution dependence
- Extending the dynamical range
- Improving time and vertex resolution, muon reconstruction
- Importance in high-rate SN detection

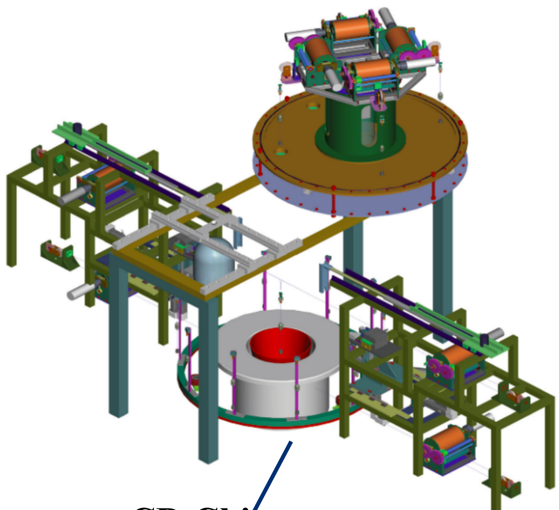
Calibration system

Cable Loop System (CLS)



Scan the position at large

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

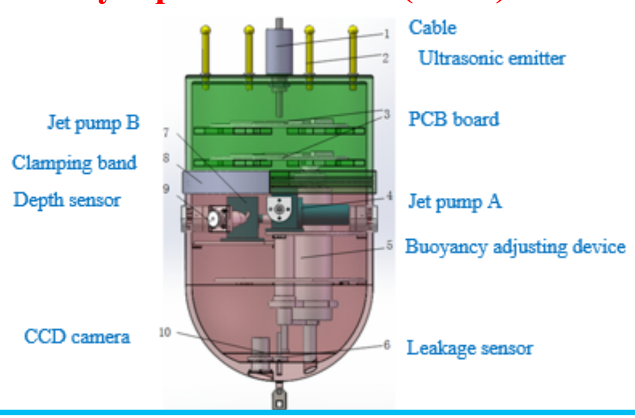


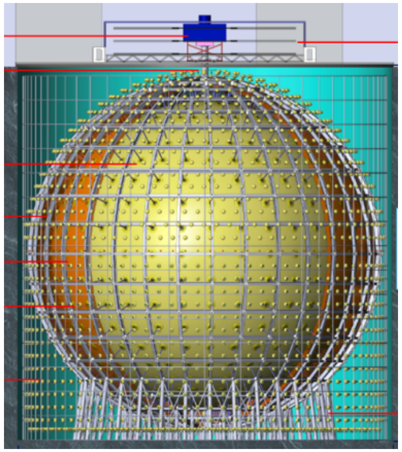
CD Chimney

Four methods

1. ACU: center line
2. Cable loop system:
3. ROV: "submarine"
4. Surface guide tube

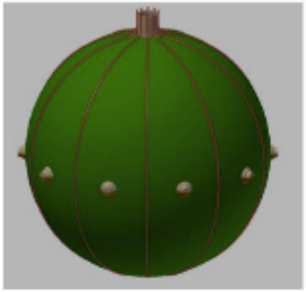
Remotely Operated Vehicle(ROV)





- Regular deployment (every week)
- Deployment of radioactive and

Guide Tube (GT)

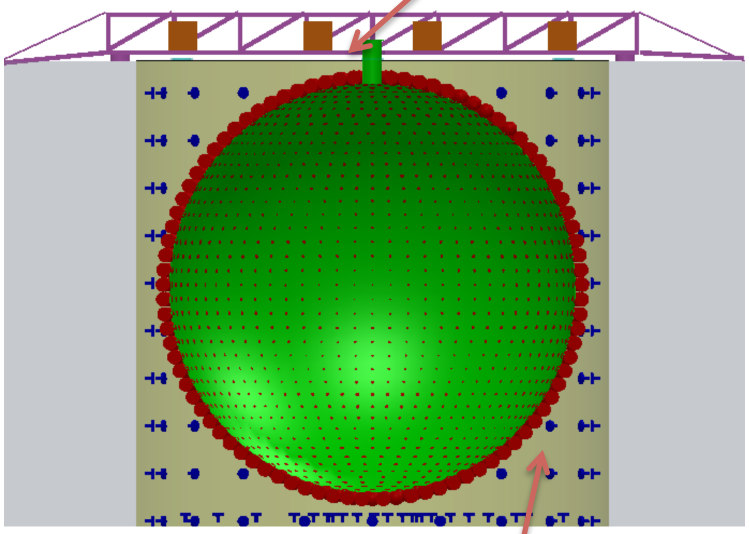


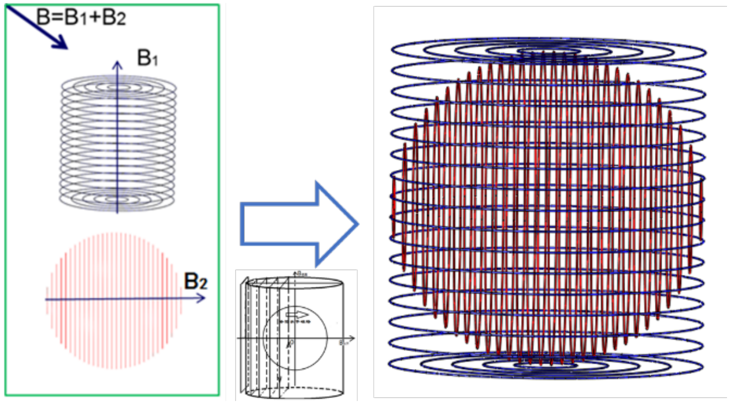
Scan outer surface of CD

The radiation source is driven with rope pulled by step motors

Highlights: Veto Detectors

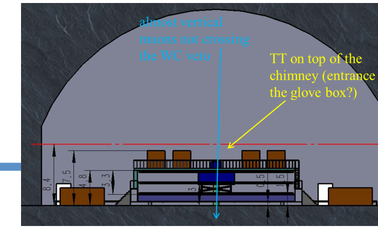
- Cosmic muon flux
  - Overburden： ~700 m
  - Muon rate： 0.0031 Hz/m^2
    - Hit on CD: ~several Hz
  - Average energy： 214 GeV
- Water Cherenkov Detector
  - > 3.9 m water shielding, Radon: <0.2 Bq/m^3
  - ~2000 20"PMTs
  - 40 kton pure water, HDPE lining
  - Similar technology as Daya Bay (99.8% efficiency)
- Compensation Coil for EMF shield
- Top muon tracker
  - Decommissioned OPERA plastic scintillator



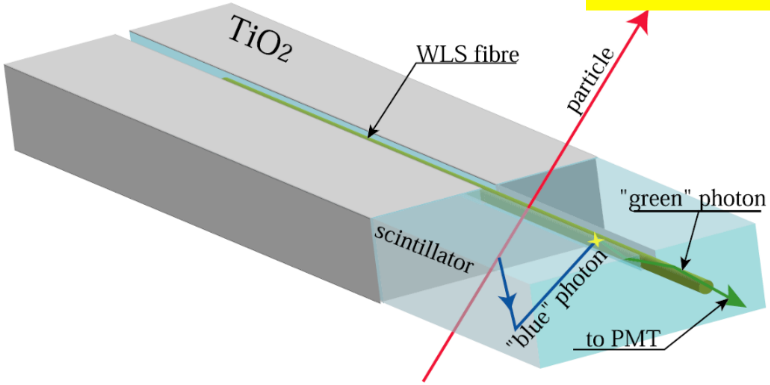


Target Tracker

(Bern, Brussels, CERN, Dubna, Neuchâtel, LAL, Strasbourg)



Contributed from OPERA

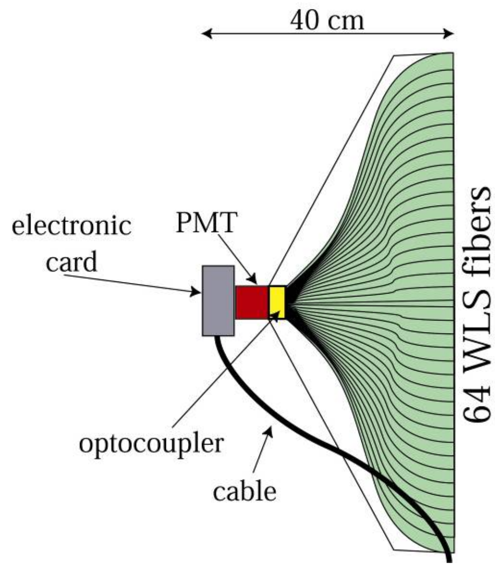


detection technique: polystyrene scintillating strips (plastic)

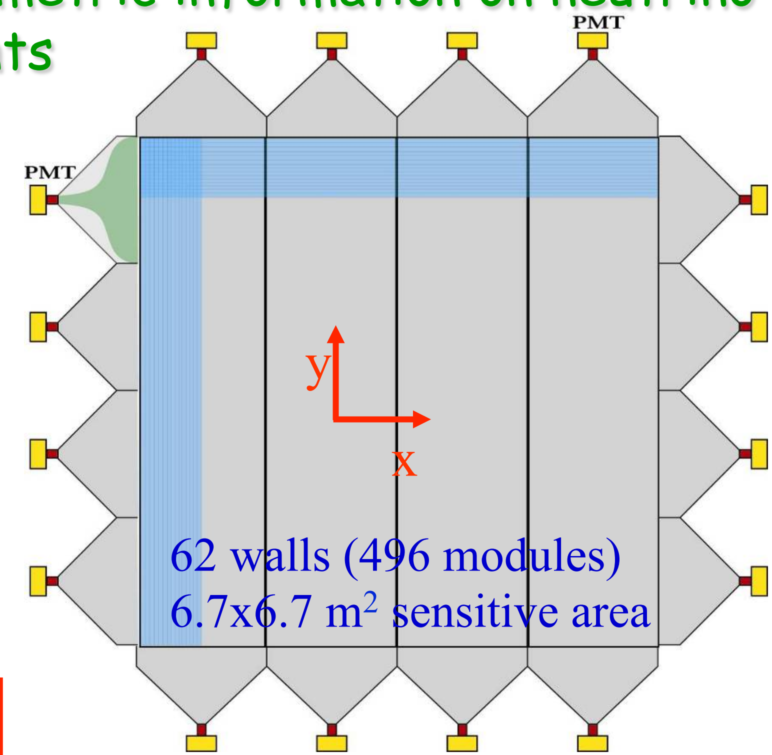
role:

- find the "good" Pb/emulsion brick
- calorimetric information on neutrino events

Hamamatsu MA-PMT (64 channels) 3x3 cm^2

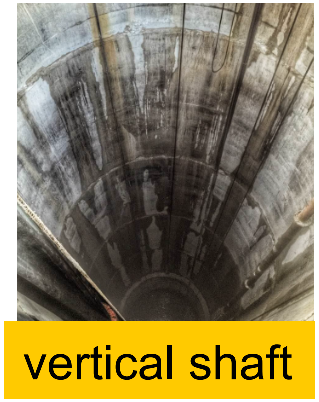


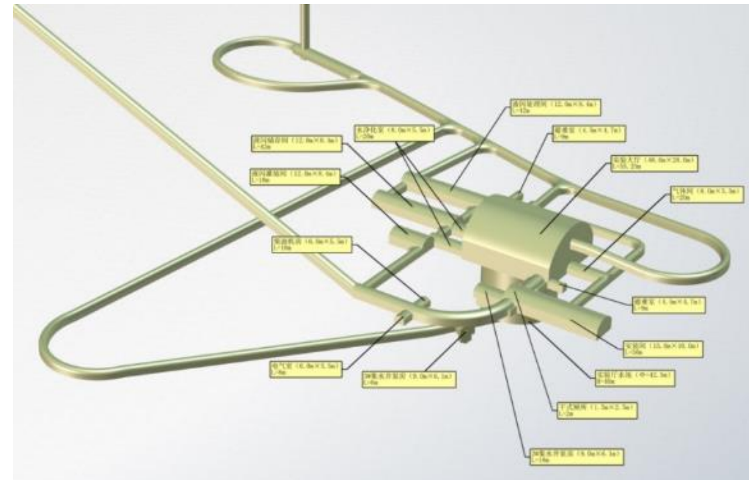
TT wall thickness<36 mm



JUNO Schedule and Progresses

Ground breaking in Jan. 2015



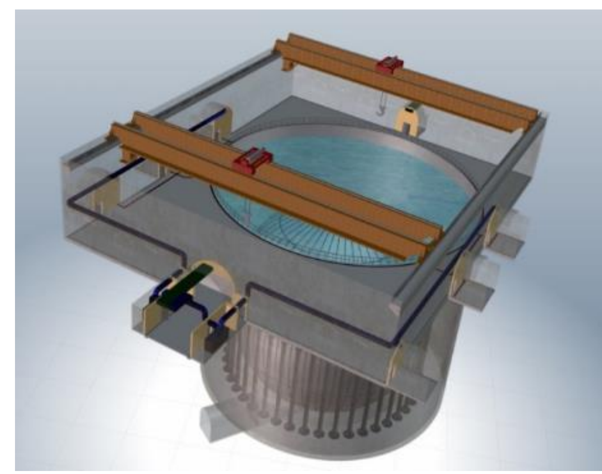


Schedule:

- Civil preparation：2013-2014
- Civil construction：2014-2018
- Detector component production：2016-2017
- Detector assembly & installation：2018-2019
- **Filling & data taking：2020-2021**

Future Plan

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



Summary

- **JUNO has a lot of neutrino physics capabilities**
  - **Mass hierarchy, precise measurement of oscillation, supernova neutrino, solar neutrino, geo-neutrino ……**
- **Instruments of JUNO**
  - **Huge detector(20 ktons) with good energy resolution(3%/sqrt(E)) is very challenging**
  - **Huge acrylic sphere with the diameter of 35.4 m**
  - **R&D of liquid scintillator: high transparency and low background**
  - **R&D of 20'' MCP-PMT: two cathodes, high collection efficiency, better P/V, low background**
  - **PMT readout by FADC, placed in very front end with waterproof design**
  - **Calibration: 4 independent systems**
  - **VETO: water Cherenkov + top tracker**

Thank you for your attention!

backup

JUNO Event Rates after selection