Status of the JUNO detector system

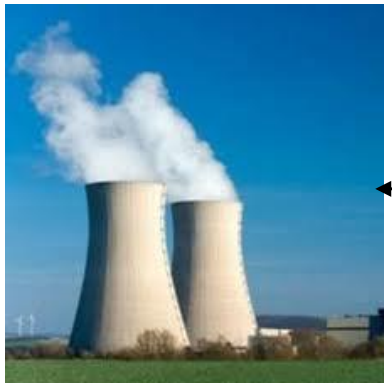
Miao HE
IHEP, Beijing
On behalf of the JUNO collaboration

2017-03-29

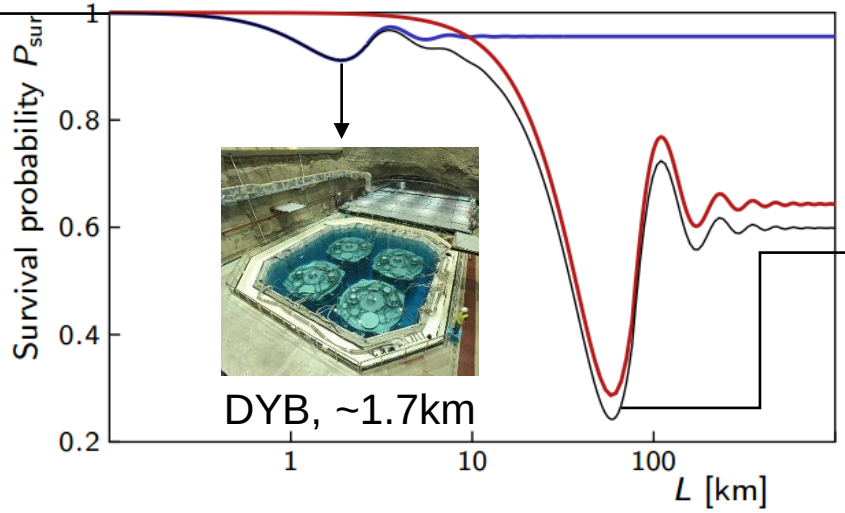
10th workshop of the France China Particle Physics Laboratory

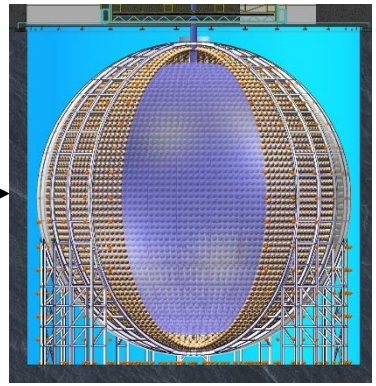
Jiangmen Underground Neutrino Observatory

- JUNO: a multipurpose neutrino experiment
  - 20kton liquid scintillator, 3%@1MeV energy resolution, 700m underground
  - A unique way to determine mass hierarchy using reactor antineutrinos by the interference between Δm^2_{31} and Δm^2_{32}.
  - First experiment to measure solar and atmospheric mass splitting simultaneously. <1% precision to θ_{12}, Δm^2_{21} and Δm^2_{31} (Δm^2_{32}).
  - Large detector volume, good resolution and low background allow rich physics goals: supernova, geo-, solar … neutrinos
  - Long term possibility under consideration: accelerator neutrino, $0\nu\beta\beta$ …



Reactors





JUNO, ~53km

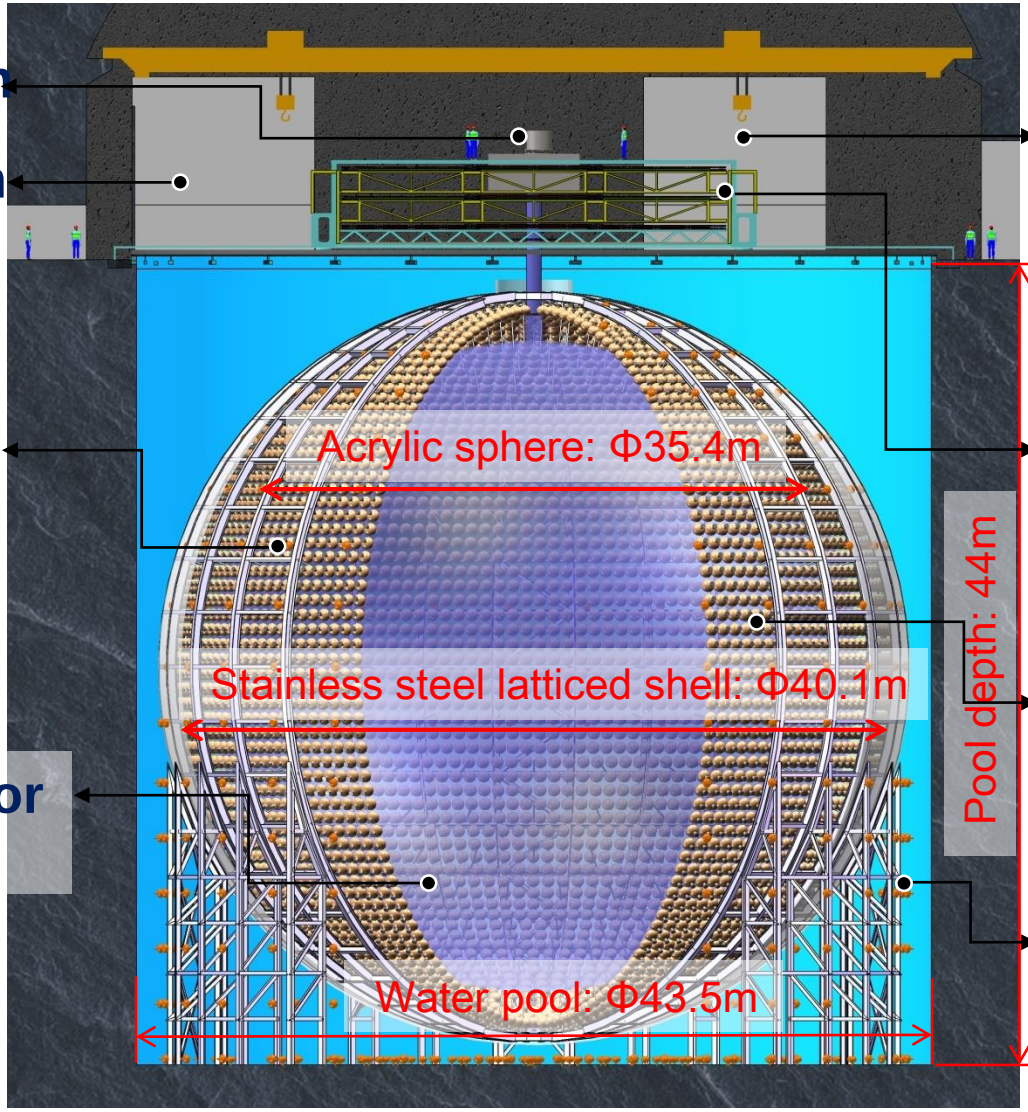
JUNO detector

Calibration room

Pure water room

Central detector
SS latticed shell
Acrylic sphere

Liquid scintillator
20 kton



LS Filling room

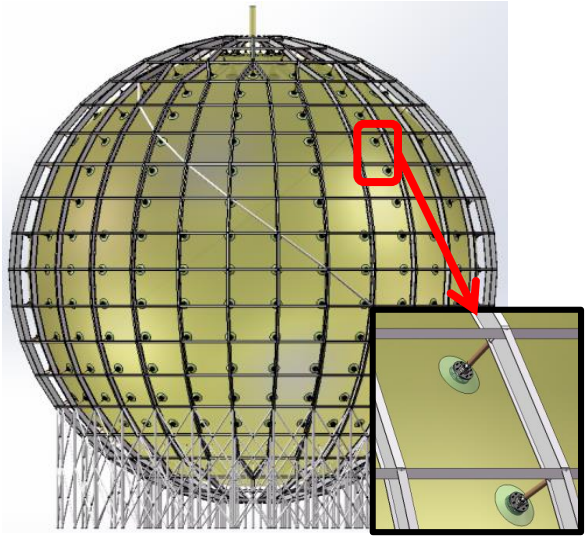
Top Tracker

PMT
~18,000 20” PMTs
+ ~36,000 3” PMTs:
coverage >75%

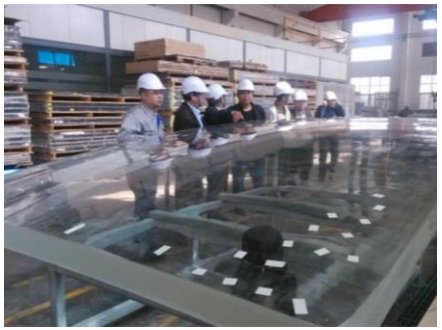
Water Cherenkov
35 kton pure water
2,000 20” veto PMTs

Central detector: engineering design

Final design approved in July 2015: Acrylic sphere + Stainless steel latticed shell

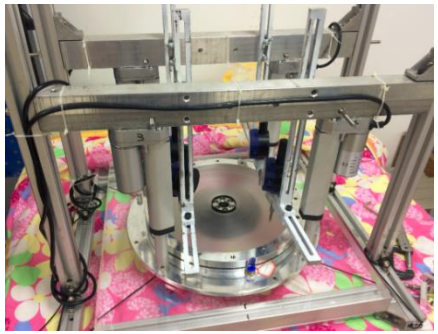


- Acrylic sphere: ID35.4m, thickness: 120mm. >200 pieces of 3m×8m panels bonded on site.
- Stainless steel: ID40.1m, OD41.1m, divided into 30 longitudes and 23 layers
- Weight of acrylic sphere: ~600 t.
- Weight of stainless steel: ~590 t.
- No. of connecting bars: 590
- No. of shell's pillars: 60

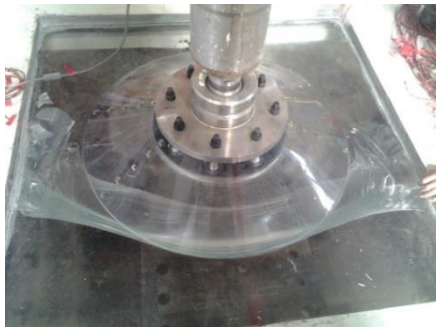


Acrylic panel

Onsite assembly



Bonding machine



Node test

Central detector progress

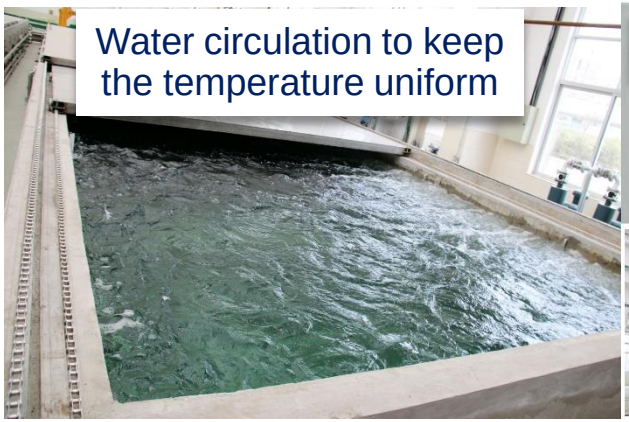
- An international review in Sep. 2016
  - 11 committee member: 4 SNO members, 2 Daya Bay US engineers, as well as Italy, UK, China on material, mechanics and physics
  - The committee feels the detector has the big challenges on technical, schedule…close collaboration and coordination is necessary
- Finished bidding of acrylic sphere in Feb. 2017
  - Donchamp acrylic company (汤臣新材料) won the bid and got the contract of acrylic production and building, due to the better production capacity, equipment, management, preparation for our project.
- Bidding of SS shell in a few months
- 1:10 scale prototype is in preparation

Preparation for acrylic production

Cleaning production center for thicker acrylic panel

Pure water treatment

Water pool for polymerization



Water circulation to keep the temperature uniform

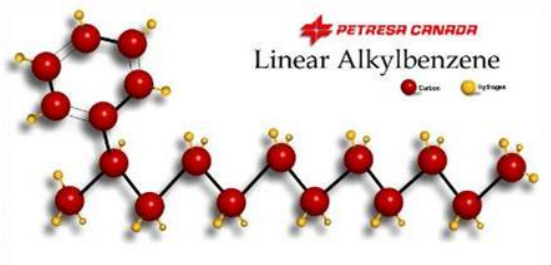
Heating room

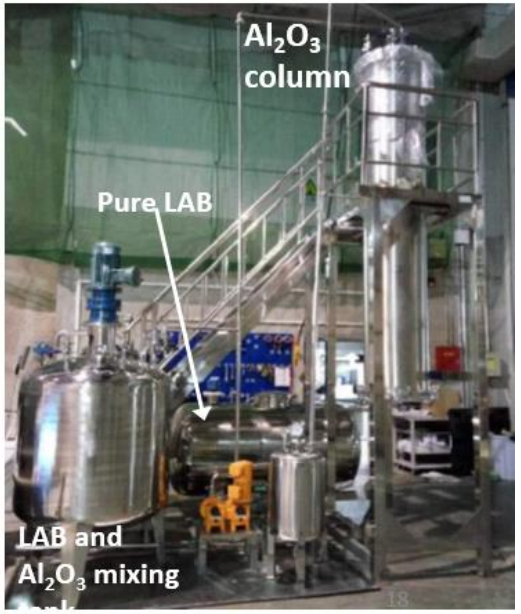
CNC machining center

- Built the new workshop for producing acrylic panel according to our special requirement
- Prepare the equipment for acrylic forming and machining

Liquid scintillator

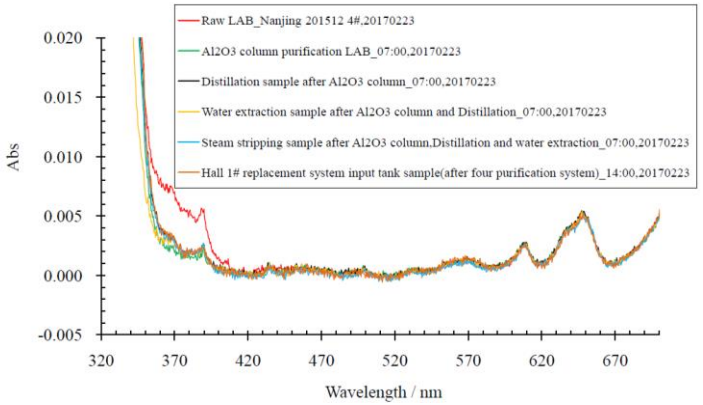
- Requirements for JUNO LS
  - Lower background for $\bar{\nu}_e$ physics: $^{238}U<10^{-15}g/g$, $^{232}Th<10^{-15}g/g$, $^{40}K<10^{-17}g/g$
  - High light yield: concentration of fluor need to be optimized
  - Long attenuation length: >20m@430nm
- LS Purification methods
  - Distillation, column purification, filtration, water extraction, stripping…
- Preliminary LS recipe (based on DYB experiment)
  - 3g/L PPO, 15mg/L bis-MSB in LAB
  - PPO: 2,5-Diphenyloxazole
  - Bis-MSB: 1,4-di-(2-methylstyryl)benzene, p-bis(o-methylstyryl)benzene
  - LAB: linear alkyl benzene





LS pilot plant at Daya Bay

- Study of JUNO liquid scintillator with one of Daya Bay detector, led by INFN and IHEP
  - Pre-study of 20t mass production
  - Optimization of fluorescent materials
  - Study of radioactivity background
  - Test of purification methods

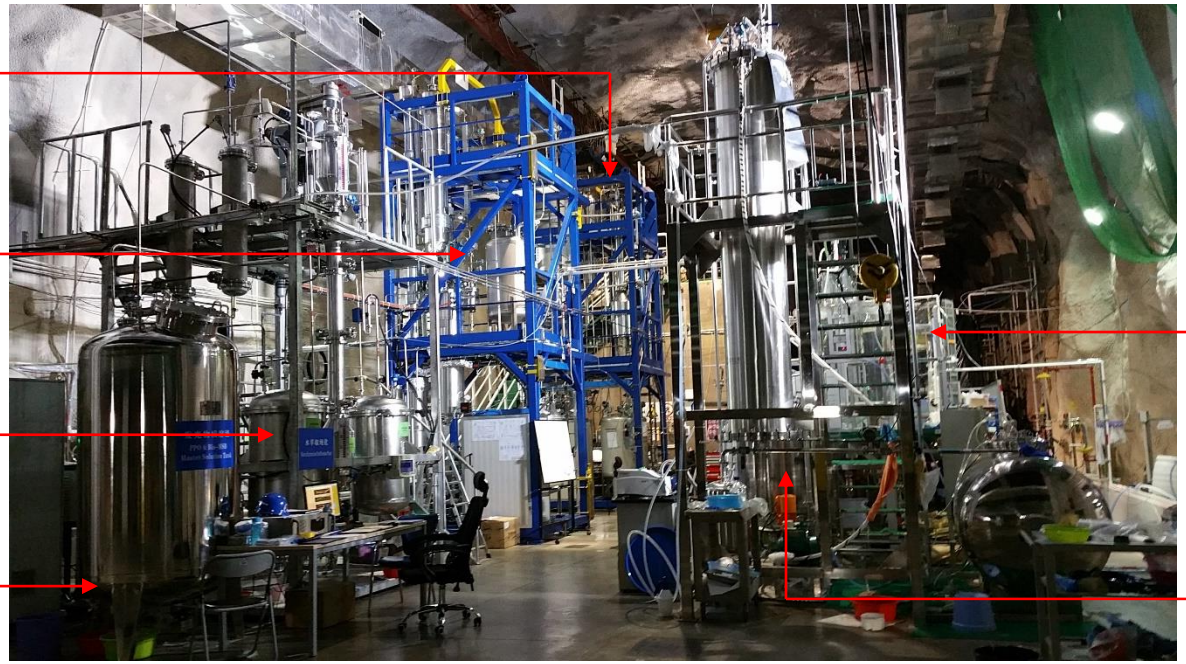


Distillation system

Steam stripping system

Water extraction

Ultra-pure nitrogen

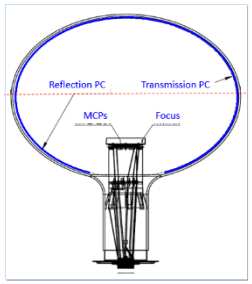


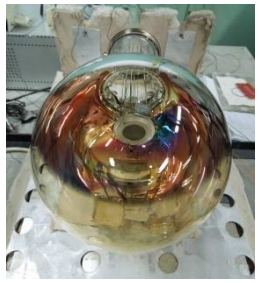
LAB storage tank

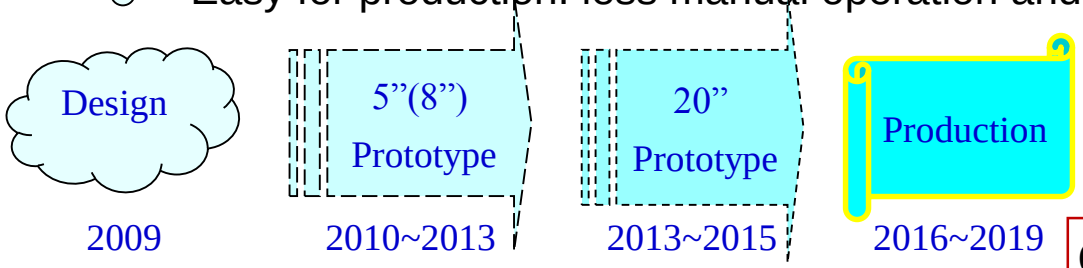
Al_2O_3 column

20-inch PMT

- A new design of large area MCP-PMT by Chinese team
  - Higher QE: transmissive photocathode at top + reflective photocathode at bottom
  - High CE: less shadowing effect
  - Easy for production: less manual operation and steps







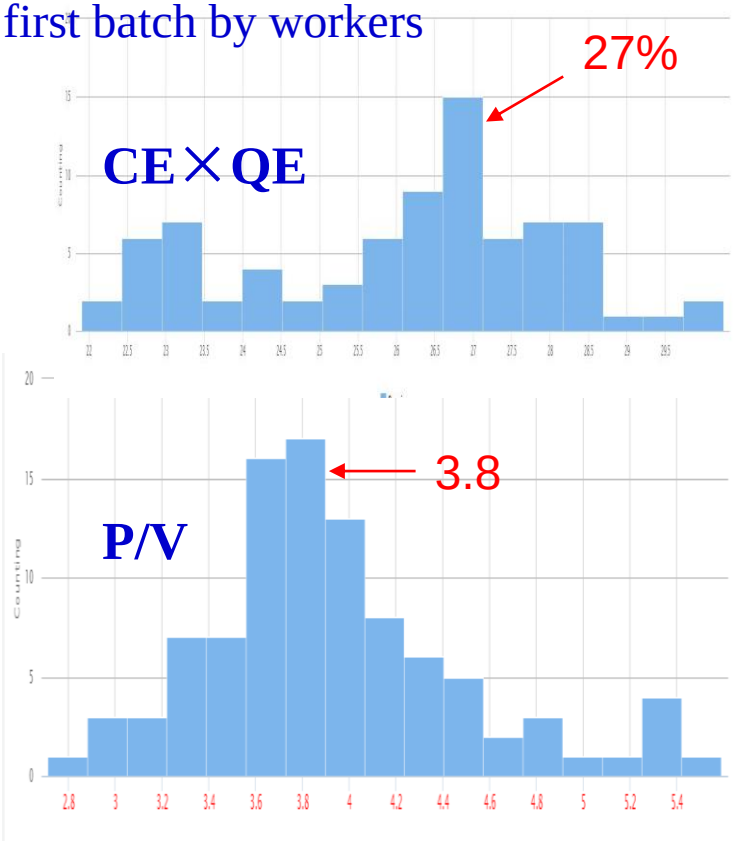
Characteristics	unit	MCP-PMT (NNVC)	R12860 (Hamamatsu)
Detection Efficiency (QE*CE*area)	%	27%, > 24%	27%, > 24%
P/V of SPE		3.5, > 2.8	3, > 2.5
TTS on the top point	ns	~12, < 15	2.7, < 3.5
Rise time/ Fall time	ns	R~2, F~12	R~5,F~9
Anode Dark Count	Hz	20K, < 30K	10K, < 50K
After Pulse Rate	%	1, <2	10, < 15
Radioactivity of glass	ppb	238U:50 232Th:50 40K: 20	238U:400 232Th:400 40K: 40

Contracts were signed in 2015
15k MCP-PMT (75%) from NNVT
5k Dynode(25%) from Hamamatsu

Mass Production at NNVT

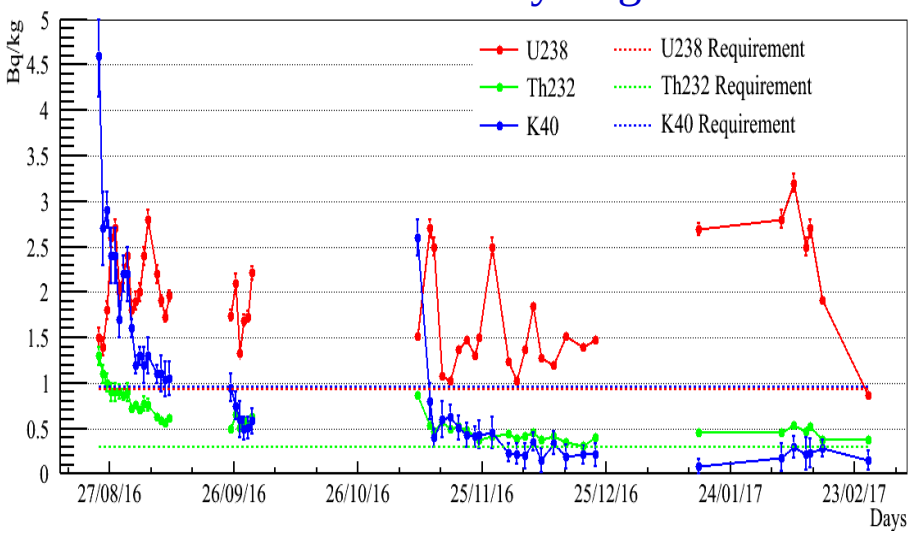
- Production equipment all in hands
- Training workers, tuning equipment
- All parts in hand
- A few hundreds of products

first batch by workers



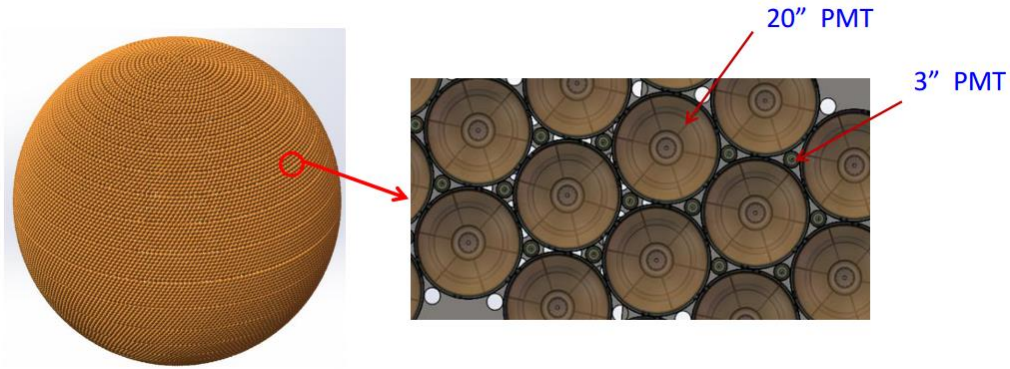
Gain vs HV

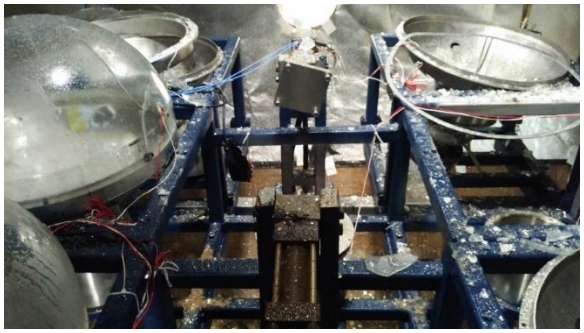
Radioactivity of glass



PMT instrumentation

- Characterization, installation and protection of ~50,000 PMTs with largest optical coverage in the neutrino world, under up to 45m pure water and running for 20-30 years.

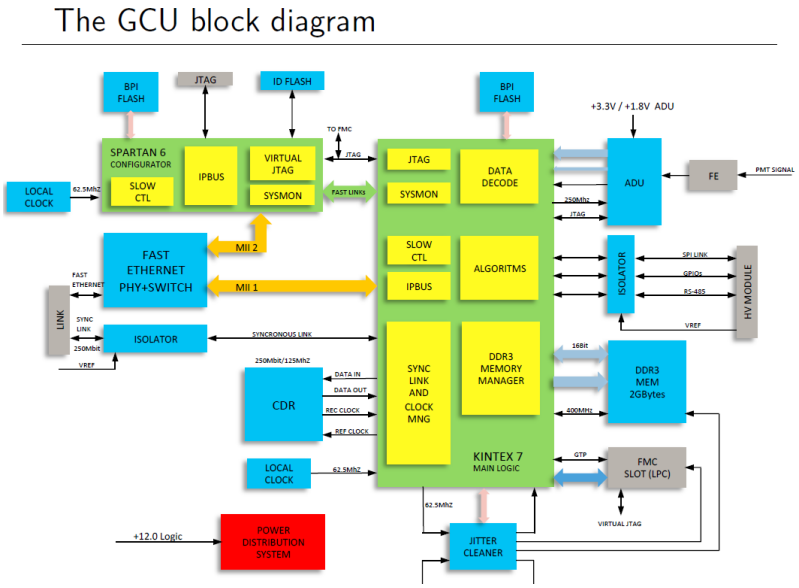


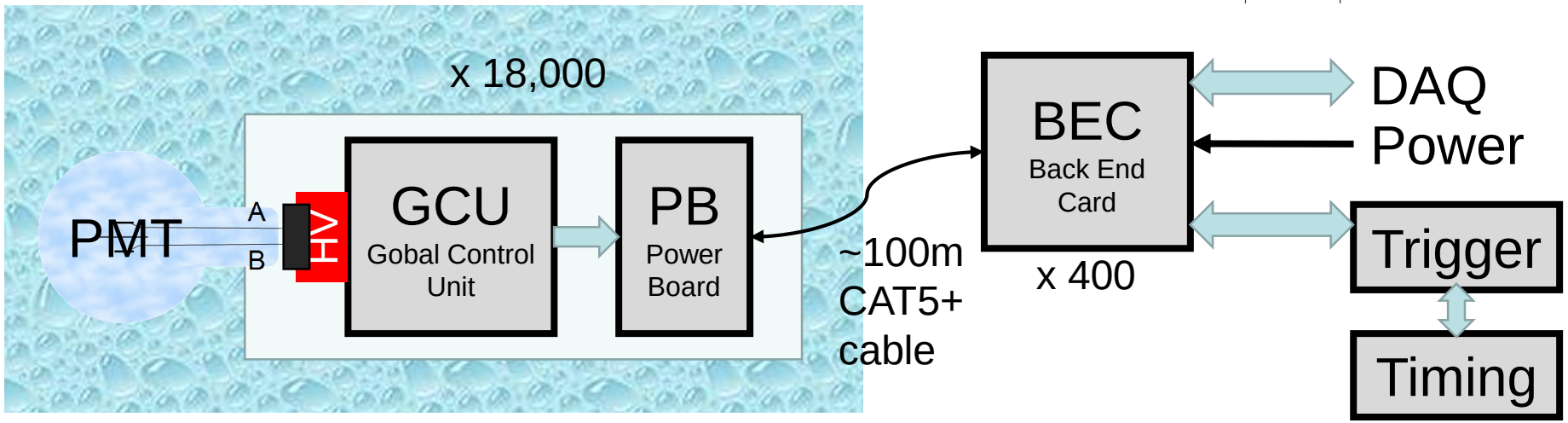


- Mass testing: four test facilities were built and reviewed in Hamburg, on the way to China. System integration and testing near JUNO site.
- Waterproof potting: target failure rate <0.5% for the first 6 years. Designed as multiple waterproof layers: putty + glue + pouring sealant.
- Implosion protection: acrylic + stainless steel protection covers. >50 prototypes and several underwater tests. Thickness optimizing.
- Installation: module was designed to achieve 75% coverage. Installation in parallel to acrylic sphere is preferred.

Readout electronics

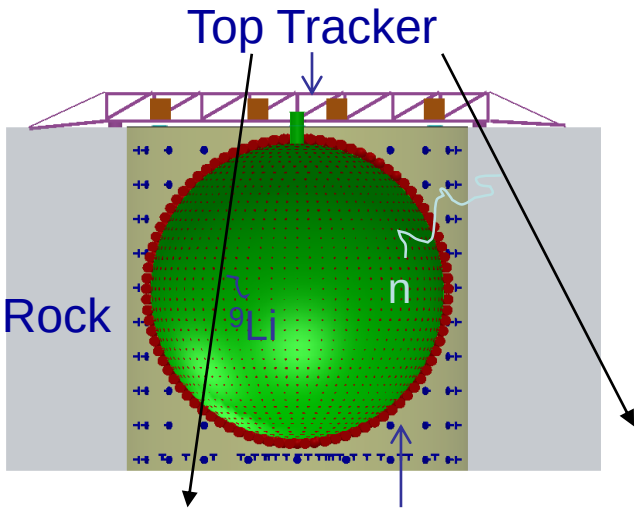
- Front part under-water, encapsulated on back of PMT with HV module and divider.
- Transmission of data, hit, clock, power and trigger by ~100m CAT5+ cable
- Integration of prototype in 2017



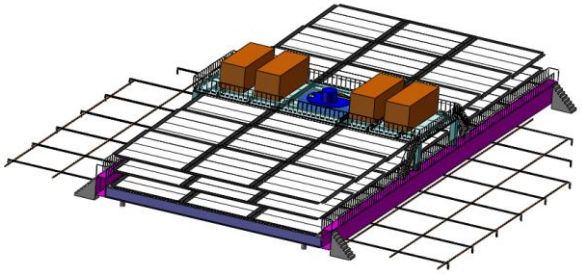


Muon veto system

- Goals of veto
  - Fast neutron background rejection
  - Help muon tracking and cosmogenic isotopes study
  - Gamma background passive shielding
  - Earth magnetic field shielding
- Water cherenkov detector
  - ~2000 20” PMT
  - 35 kton ultrapure water with a circulation system
  - Detector efficiency is expected to be > 95%
  - Fast neutron background ~0.1/day.
- Top tracker (details in Marcos’ talk)
  - Re-using the OPERA’s Target Tracker
  - Cover half of the top area



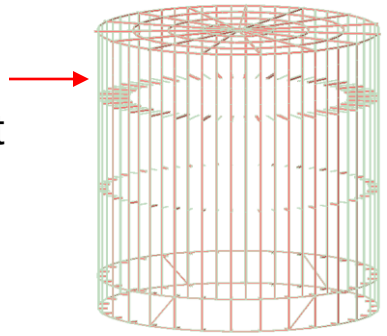
Water Cherenkov Detector

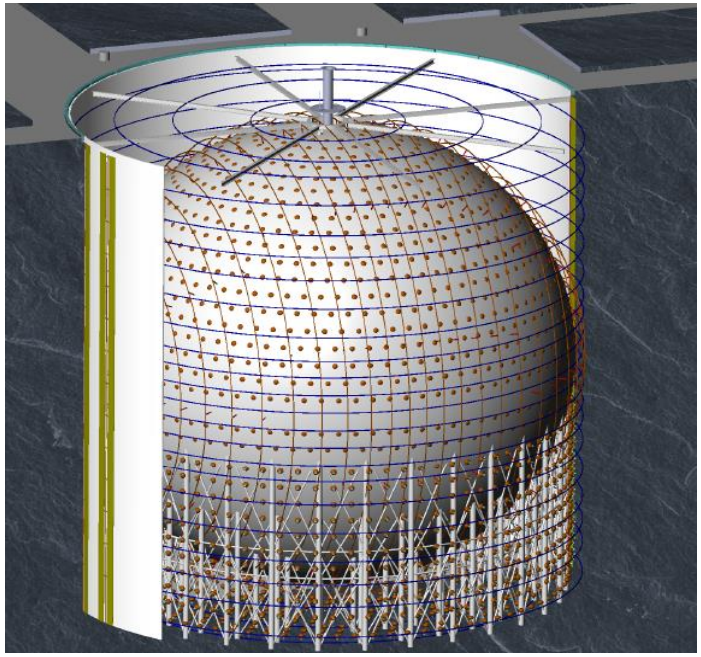


Top Tracker

Water Cherenkov detector

- Mechanical structure
  - A “bird cage” structure was designed for support veto PMTs, tyvek films, cables and water pipes.
- Water system
  - Employ a circulation/polishing water system (~2 week one volume circulation).
  - Keep a good water quality including radon control (<0.2 Bq/m^3).

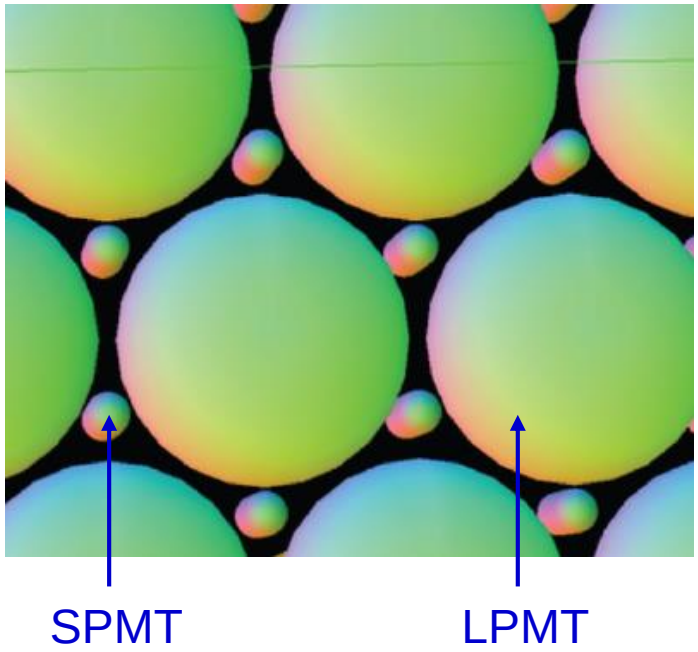




- Earth magnetic field (EMF) shielding system
  - Use double coils system for EMF shielding。
  - A prototype of compensation coils system was built in IHEP.
  - The theoretically calculation and prototype data are consist with each other. It’s a good validation for compensation coils design of JUNO.

The Small PMT (SPMT) system

- Consists of up to 36,000 3-inch PMTs and readout electronics
- Physics concept was approved in 2015.07
- Detector system was established in 2016.01
- A joint FCPPL project started in 2016, now led by Anatael CABRERA in France and Miao HE in China.



FCPPL Project application for 2016

AST-IHEP-APC-JUNO: JUNO detector and readout studies/optimisation

Members	French Group			Chinese Group		
	Name	Title	Affiliation (institute)	Name	Title	Affiliation (institute)
	Anatael CABRERA	Dr	APC (Paris)	*Zheng WANG*	Dr	IHEP (Beijing)
	Herve DE KERRET	Dr	APC (Paris)	Jun CAO	Prof	IHEP (Beijing)
	Alexis NOURY	Eng	APC (Paris)	Xiaoshan JIANG	Dr	IHEP (Beijing)
	Jose BUSTO	Prof	CPPM (Marseille)	Miao HE	Dr	IHEP (Beijing)
	Damien DORNIC	Dr	CPPM (Marseille)	Ziyan DENG	Dr	IHEP (Beijing)
	Stefan BEURTHEY	Eng	CPPM (Marseille)	Wei WANG	Prof	SYSU (Guangzhou)
	Margherita BUIZZA-AVANZINI	Dr	LLR (Paris)			
	Selma CONFORTI	Dr/Eng	OMEGA (Paris)			
	Christophe DE LA TAILLE	Dr	OMEGA (Paris)			
	Gisele MARTIN-CHASSARD	Eng	OMEGA (Paris)			
	Thiago JUNQUEIRA	Dr	SUBATECH (Nantes)			
	Frederic LEFEVRE	Dr/Eng	SUBATECH (Nantes)			
	Frederic YERMIA	Prof	SUBATECH (Nantes)			

Funding from France
only for travel & collaboration - No material!

Description:	Euro/unit	Nb of units	Total (euros)	Requested to (IN2P3, CEA ...)
Flight Ticket France-China	1000	11	11000	IN2P3
Hotel + Per Diem (per week in China)	700	11	7700	IN2P3
Flight Ticket within Europe	250	4	1000	IN2P3
Hotel + Per Diem (per week in Europe)	700	4	2800	IN2P3
		Total	22500	

Funding from China
only for travel & collaboration - No material!

Description:	Yuan/Unit	Nb of units	Total (Yuan)	Requested to (Chinese Uni or Institute...)
		Total		

Application 2016

FCPPL Project application for 2017

AST-IHEP-APC-JUNO: JUNO detector and readout studies/optimisation

French Group			Chinese Group		
Name	Title	Affiliation (institute)	Name	Title	Affiliation (institute)
Anatael CABRERA	Dr	APC (Paris)	*Miao HE*	Dr	IHEP (Beijing)
Herve DE KERRET	Dr	APC (Paris)	Jun CAO	Prof	IHEP (Beijing)
Alexis NOURY	Eng	APC (Paris)	Xiaoshan JIANG	Dr	IHEP (Beijing)
Cayetano SANTOS	Eng	APC (Paris)	Zheng WANG	Dr	IHEP (Beijing)
Jose BUSTO	Prof	CPPM (Marseille)	Ziyan DENG	Dr	IHEP (Beijing)
Stefan BEURTHEY	Eng	CPPM (Marseille)	Wei WANG	Prof	SYSU (Guangzhou)
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Thiago JUNQUEIRA		SUBATECH (Nantes)			
Frederic LEFEVRE	Dr/Eng	SUBATECH (Nantes)			
Frederic YERMIA	Prof	SUBATECH (Nantes)			

Please provide here details on members of your FCPPL project participating in exchange programs (now and future) between laboratories involved in this proposal:

NAME	Funding program (Eiffel, CSC, a b, CNRS...)	Funding status (submitted, accepted)	Status (PhD student, Post doc...)	Expected date of defense	Lab of origin	Host lab	Expected dates in host lab

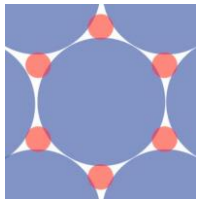
Funding from France *only for travel & collaboration – No material!*

Application 2017

Small PMT physics

- Double-calorimetry: calibration of non-linear response of LPMT (primary), increase optical coverage by ~3% (secondary)
- Solar parameters measurements with *partly independent* systematics
- Help reconstruction for high energy physics: muon, atmospheric ν…
- Help detection of supernova neutrino

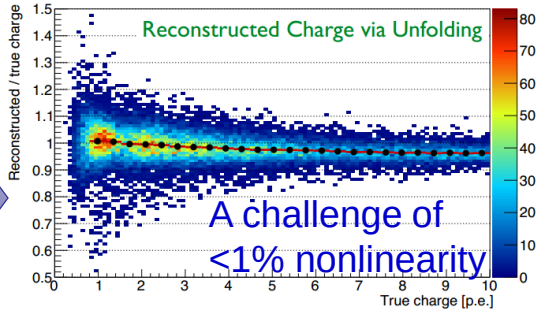
Double calorimetry



● Large-PMT (LPMT): measure energy via “charge integration”, increase photon statistics → stochastic effect

● Small-PMT (SPMT): measure energy via “photon counting”, control systematics → non-stochastic effect

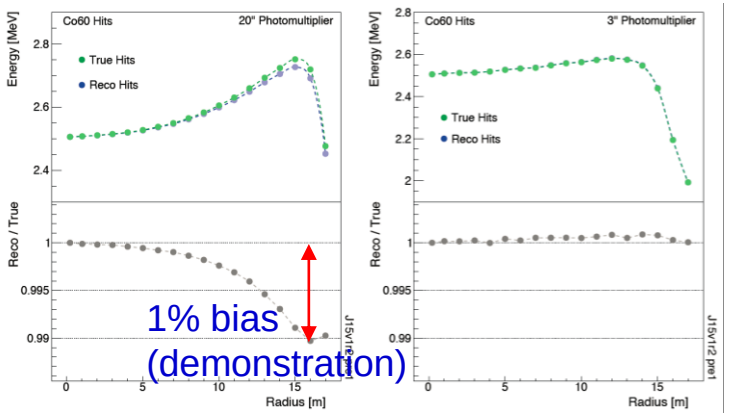
Nonlinear response of LPMT due to the distortion of output waveform



Non-linearity
(single channel)

Non-uniformity
(position dependent)

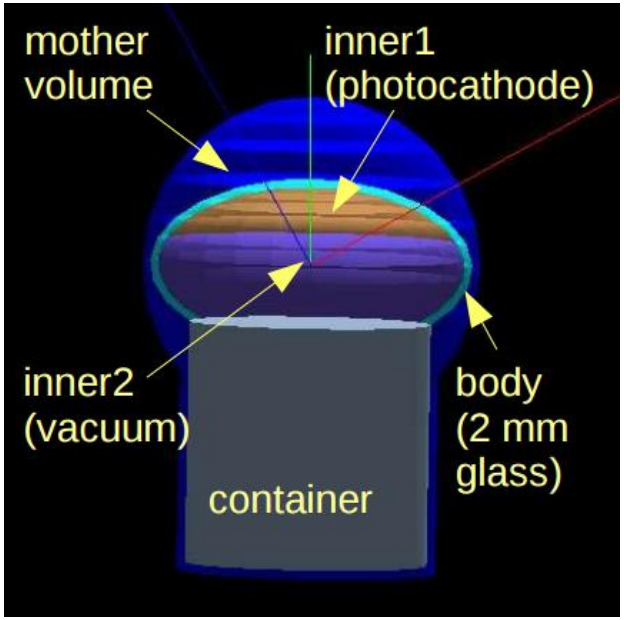
Resolution deterioration
(full detector)



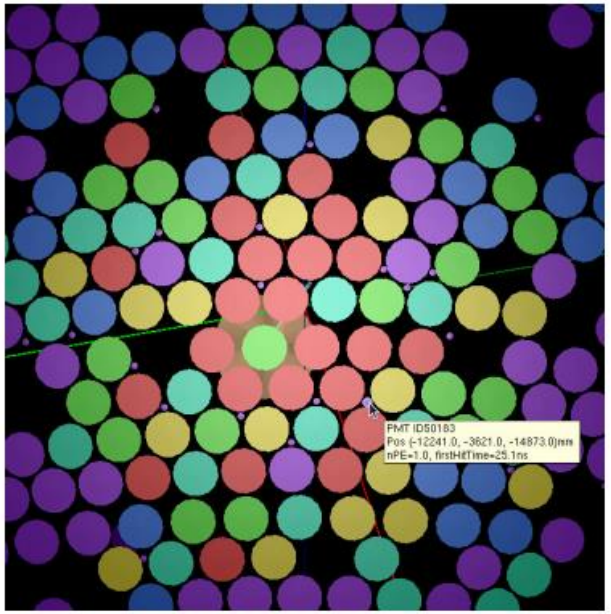
Comparison of reconstructed energy and true energy of LPMT and SPMT

Small PMT simulation

- Implementation of two PMT systems with Geant4 in the JUNO offline software framework.
- With realistic geometry and photon detection efficiency, ~45 PEs/MeV for 36,000 SPMTs, 3%~4% of LPMTs.

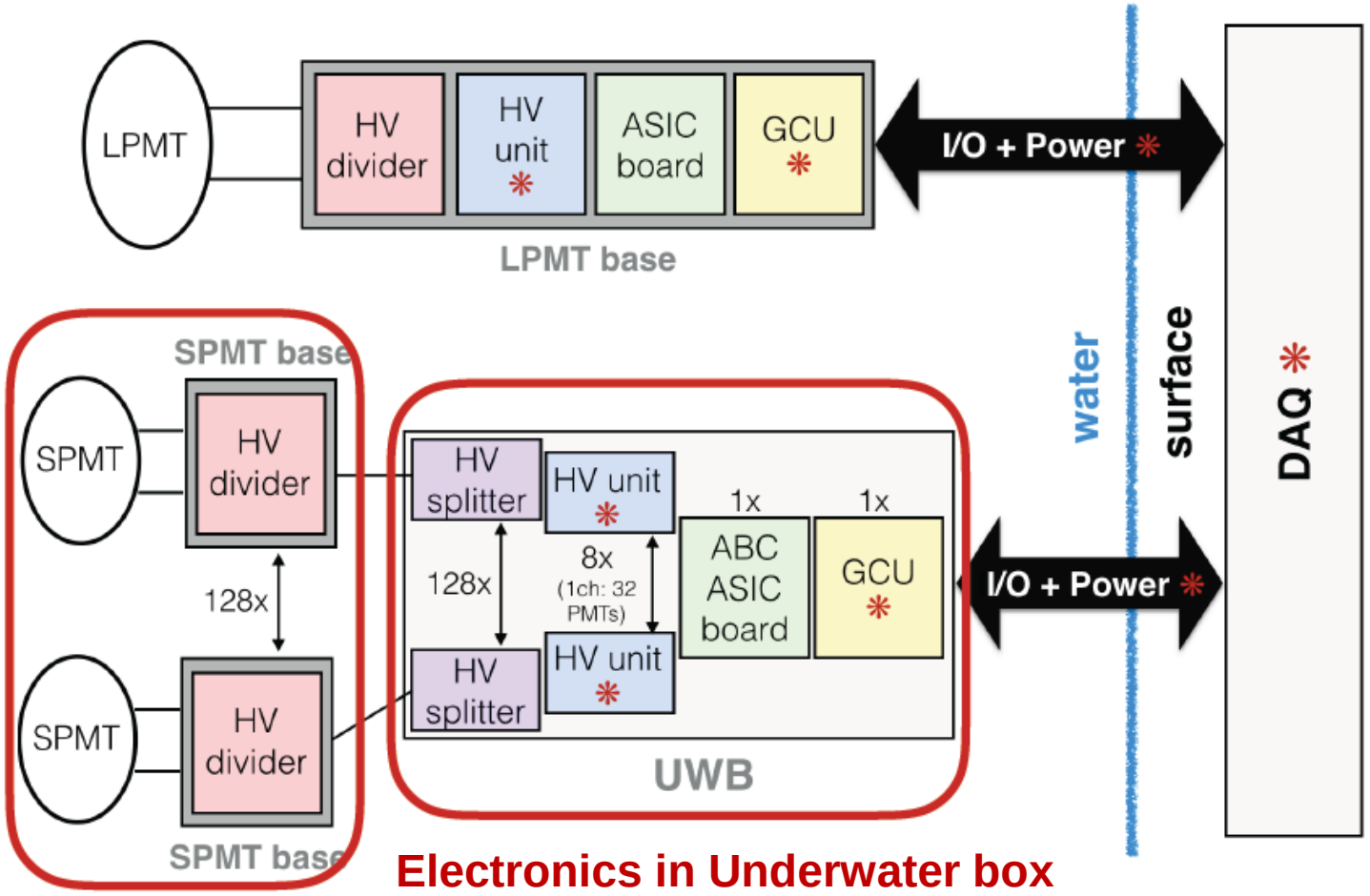


Implementation of a single small tube in Geant4.



A simulated event with PMT responses, color corresponds to number of PEs in a PMT.

Small PMT hardwares



TASKS ORGANIZATION

PIs
- *A.Cabrera (APC)*
- *P.Ochoa (PUC)*
- *M.He (IHEP)*

Tech. Coordinator
C.Cerna (CENBG)

Photomultipliers
- **Specifications**
  φsics - System
- **Tender**
  IHEP
- **Mass testing**
  Moscow + Taïwan
- **Divider**
  IHEP
- **Potting**
  IHEP
- **Mechanics**
  IHEP

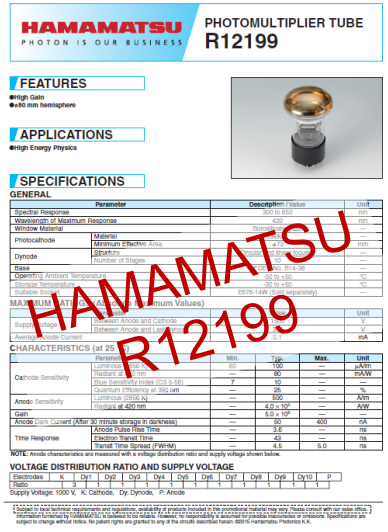
ELEC
- **ABC (Front-End)**
  - **ASIC**
  - **Design → Production**
  - **Firmware/Software**
- **Global Control Unit**
  - **Design → Production**
  - **Firmware/Soft**
- **High Voltage (Build/Decoupling)**
  Chile

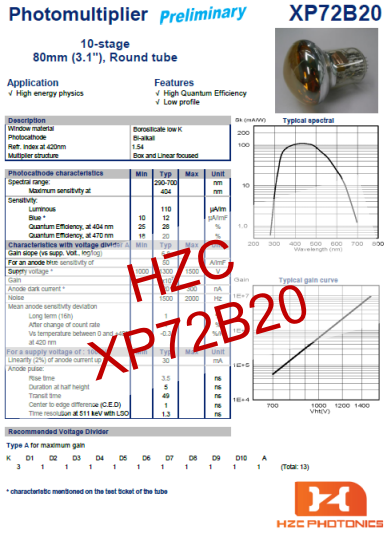
UWB
Chile
- **UWB Conception**
  FR
- **UWB Prototyping**
  FR
- **UWB Production**
  Chile
- **PMT Cabling ?**
- **Connectors ?**

Integration
China
- **Installation**
  China

SPMT specification and bidding

- Close contact with suppliers: Hamamatsu, HZC and ETL.
- Sample tubes basically meet JUNO's requirements.
- Specification is finalizing.
- Bidding in April.



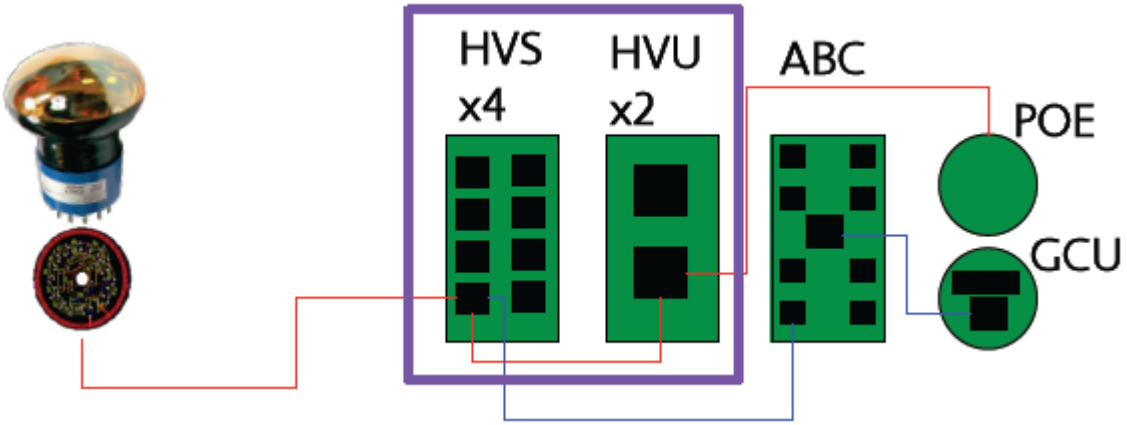


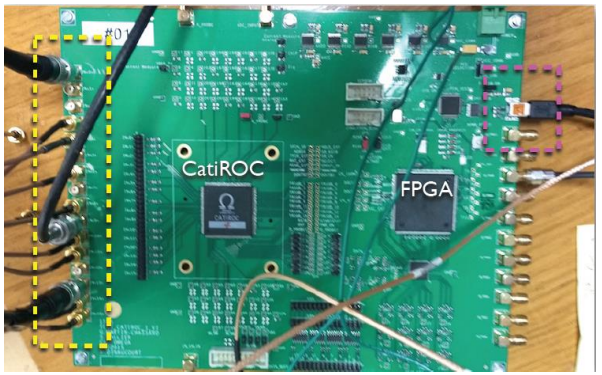
NO.	Parameter	Value
1	Diameter of Bulb	<82mm
2	Effective Diameter of Cathode	>72mm
3	QE×CE@420nm	Minimum>22%, Average>24%
4	TTS（FWHM）	<6ns
5	HV@ 3×10^6 gain	<1300V
6	P-V Ratio	Minimum>2, Average>2.5
7	Resolution of SPE（σ）	<35%
8	Dark Rate@ 0.25 PE	<1.5kHz
9	Dark Rate @ 0.3 PE	<5Hz
10	Uniformity of QE	<15%
11	Prepulse Ratio After Pulse Ratio	<5%, <5%
12	Spectral Response Range	300-650 nm
13	Stability	Gain fluctuate(1 week): 5% Gain fluctuate(1 year): 10%
14	Glass radiation level(ppb)	^{238}U: < 400ppb, ^{232}Th: <400ppb, ^{40}K: <200ppb
15	Minimum compressive	1.0MPa
16	Lifetime (Working @JUNO)	>20 years
17	Working current of base	<9μA
18	Nonliner	<10%@1-100p.e.

Under optimization

Specification in the bidding document

Electronics

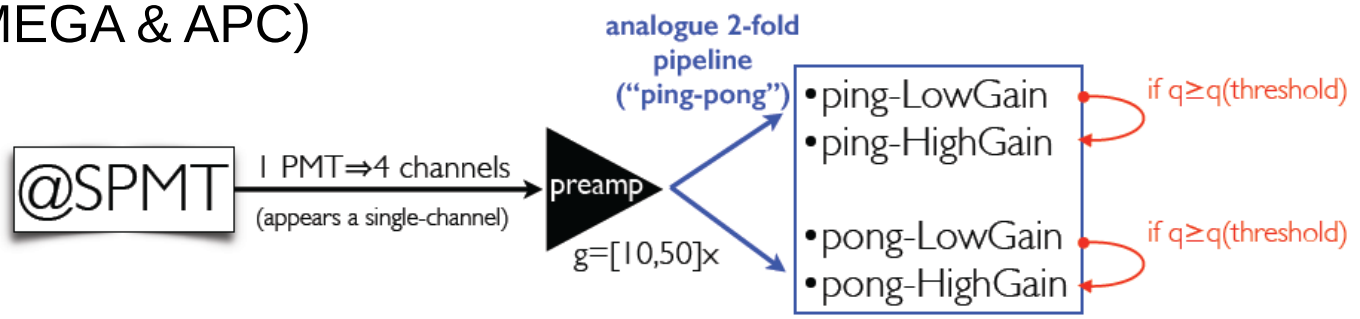




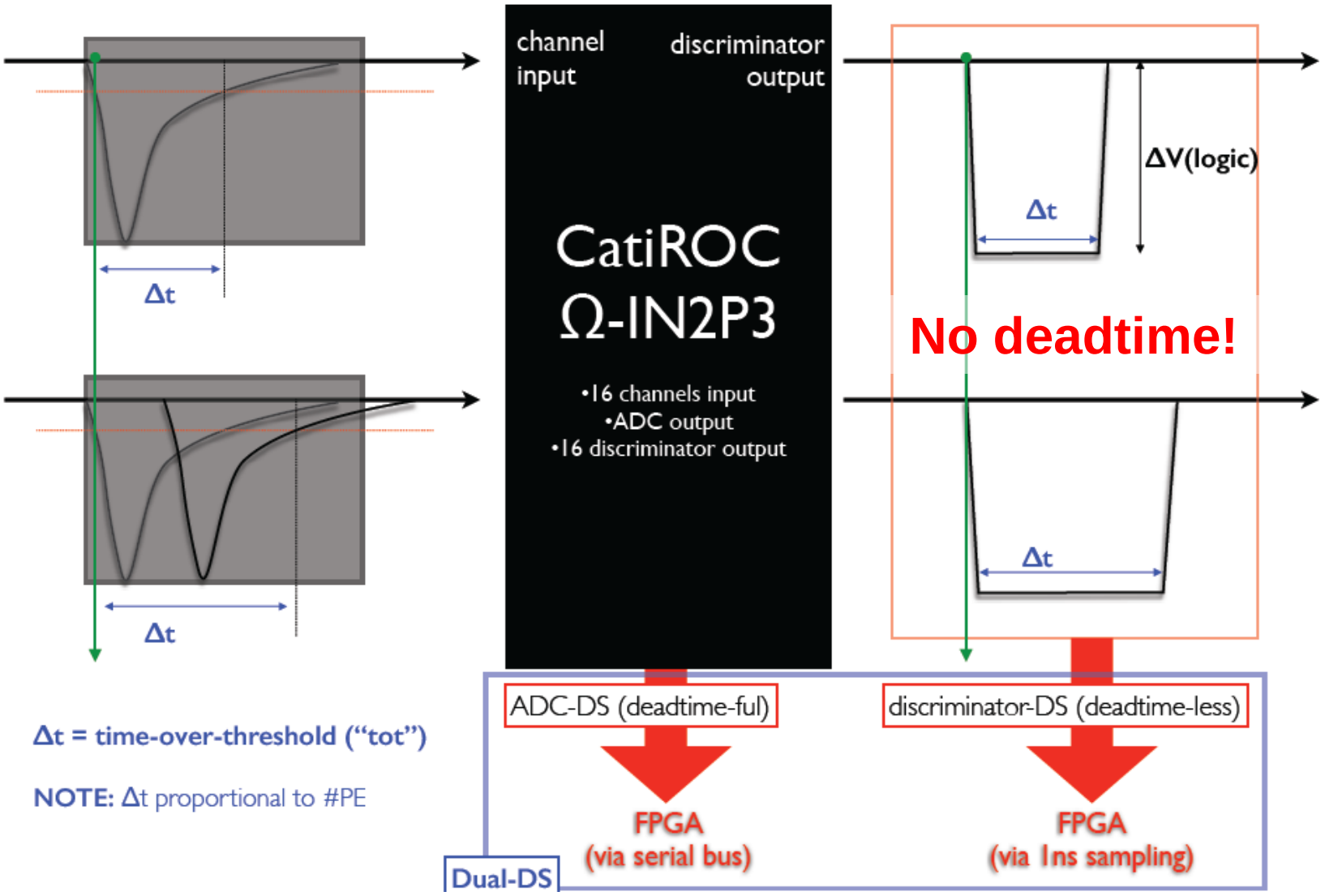
Test board

- HV unit and GCU: same as LPMT
- HV splitter study to start soon
- ASIC Battery Card (8×CatiROC) being designed, prototypes(v0+v1) in 2017. Test board on hand. Good timing and charge resolution.
- CatiROC (OMEGA & APC)

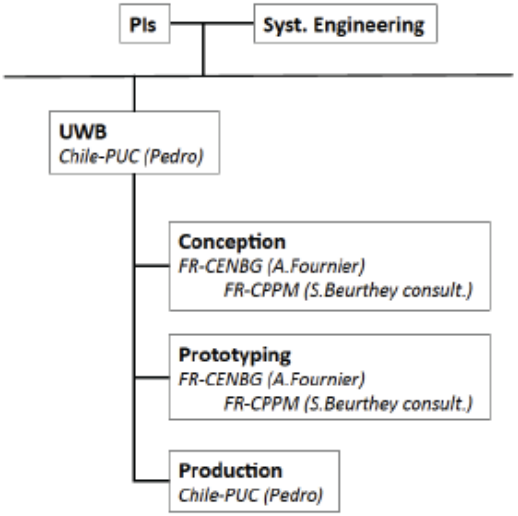
Dual-Data Stream output with no dead time



CatiROC @ Dual-Data Stream output

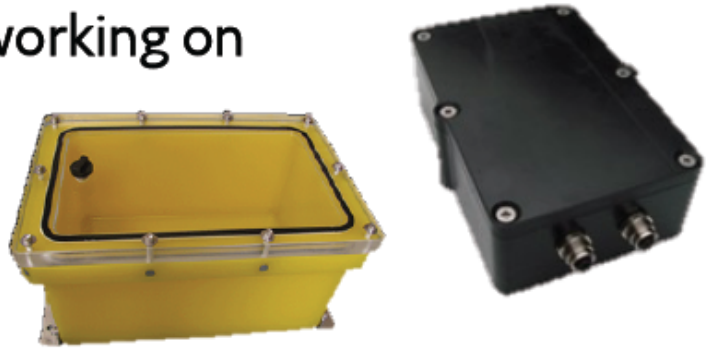


Underwater box



← An organization now in FR
- CENBG - Bordeaux to conduct prototyping
- CPPM – Marseille as support experts
- PUC – Chile for production

← Some engineers working on



2 options under consideration:

- Home made SS box filled with oil or potted
- Direct contact with companies providing junction boxes (50-300m depth with electrical feedthrough)

First prototype in July
PDR by end of 2017
FDR by mid-2018

Mass testing and integration

All tubes will have a simple (TBD) testing @ production

A sub-sample (TBD) of them will be fully characterized

- Test setup specified by JUNO
- Manpower company + JUNO supervision

Potting+cabling

@PMT Vendor site

Fully tested @ production

INTEGRATION SITE

- Acceptance test for the tubes (ON/OFF→signal)
- Assembly and verification test of the electronics in the UWB
- Assembly of the Medusas
- Medusa's commissioning

Candidates: Dongguan, Zhongshan

Summary

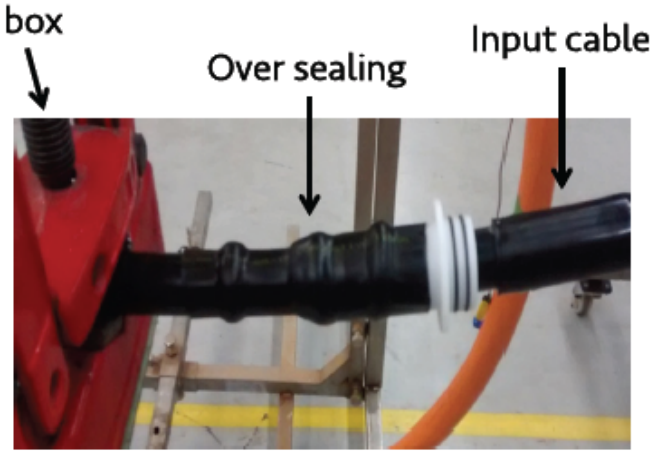
- JUNO was approved in 2013, and started civil construction in 2015.
- The detector design was finalized, and the construction of each system is in good progress.
- Plan to start operation in 2020, with 20-30 years life time.
- France and China work in close cooperation on the Top Tracker and the Small PMT system.

backup

Underwater connector

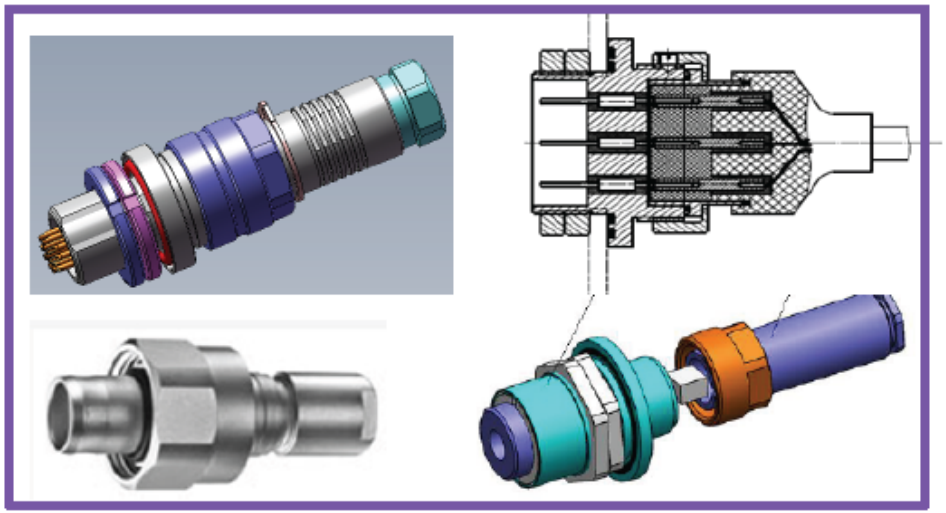
- An additionnal connector may simplify a lot the installation
- Issues :
  - Specifications (HV, Crosstalk, Water-proofing)
  - Price/channel

R&D in France and China



Over sealing technics @ IN2P3

- 4 types of connectors have been developed for 20" PMT;
- The reliability of the connector have to be verified;



- Start contact with axon' CABLE & INTERCONNECTIQUE and RADIALL The next conneXion companies

Installation

- Two scenarios
- No connector: install PMT one by one on the platform
- With connector: install PMT and UWB on surface