Double Calorimetry System in JUNO

Miao HE

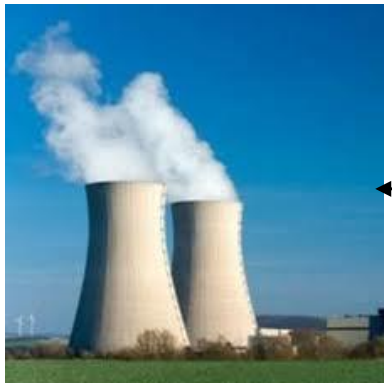
On behalf of the JUNO collaboration

TECHNOLOGY AND INSTRUMENTATION IN PARTICLE PHYSICS'17

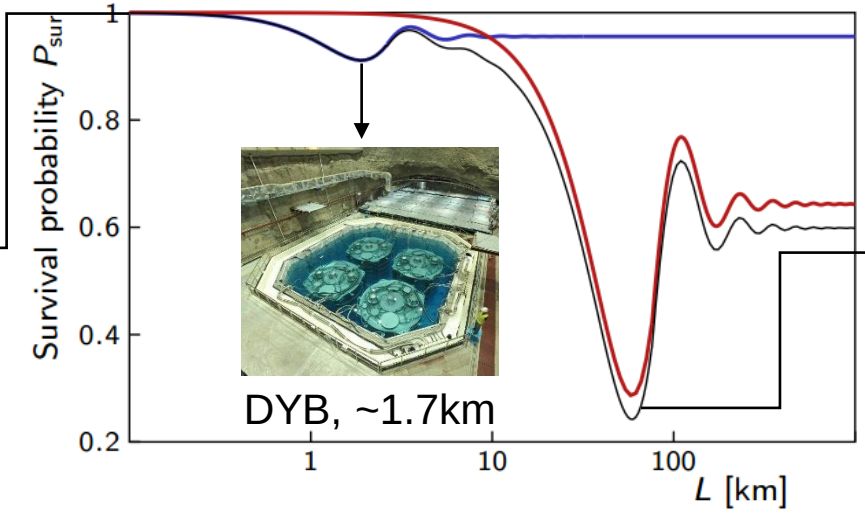
Beijing, China, 2017/05/23

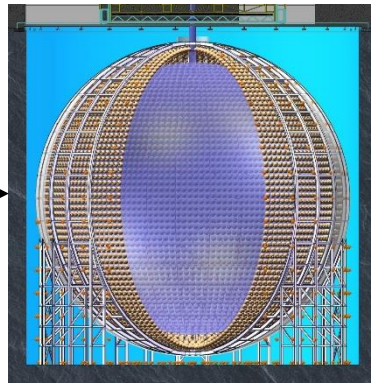
Jiangmen Underground Neutrino Observatory

- JUNO: a multipurpose neutrino experiment in Guangdong, China
  - 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

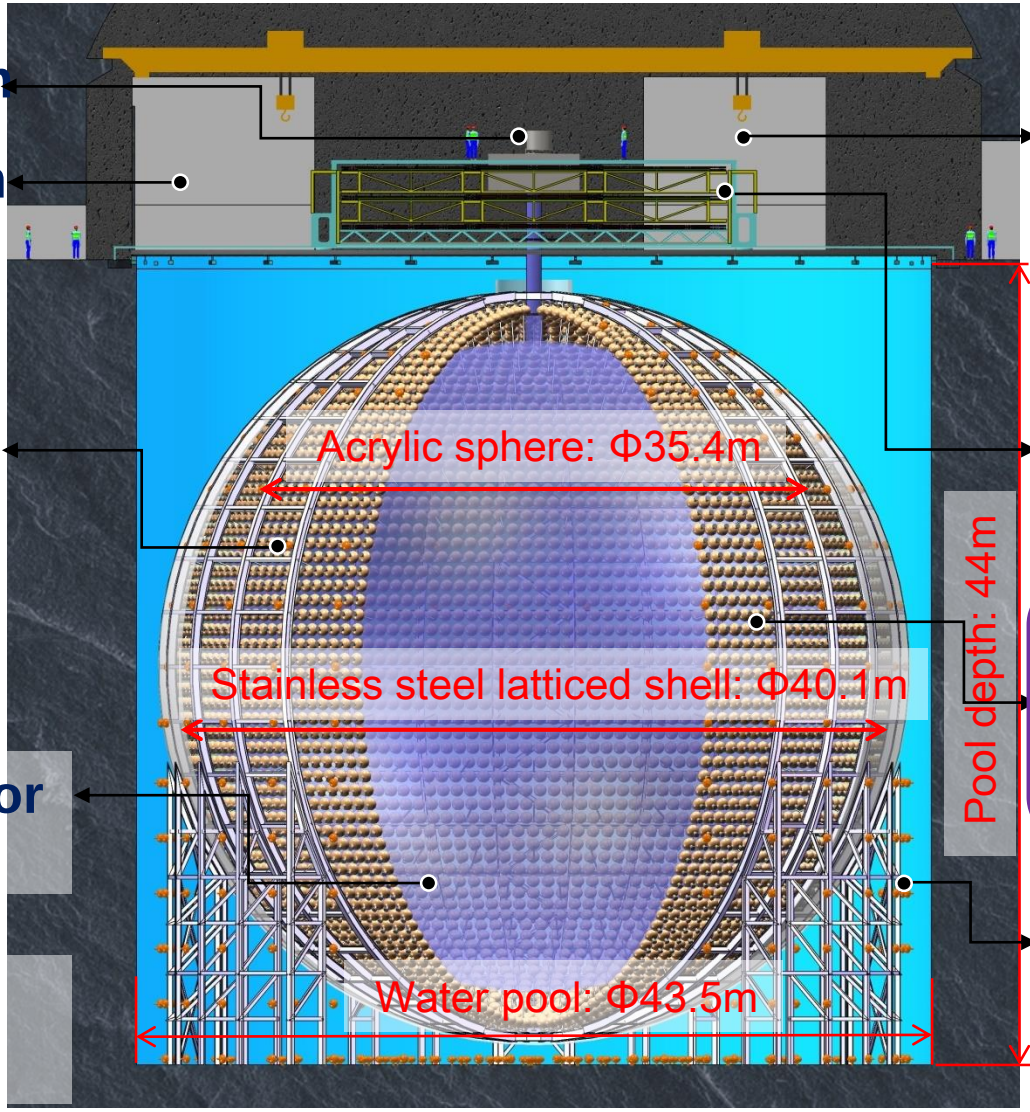
Calibration room

Pure water room

Central detector
SS latticed shell
Acrylic sphere

Liquid scintillator
20 kton

700m underground



LS Filling room

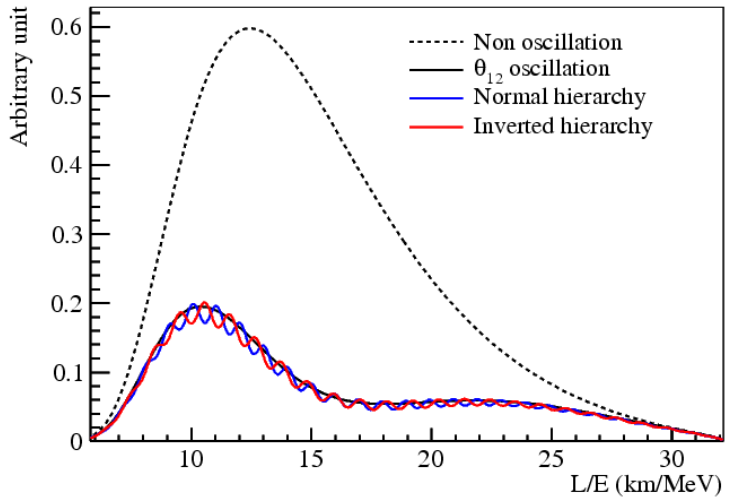
Top Tracker

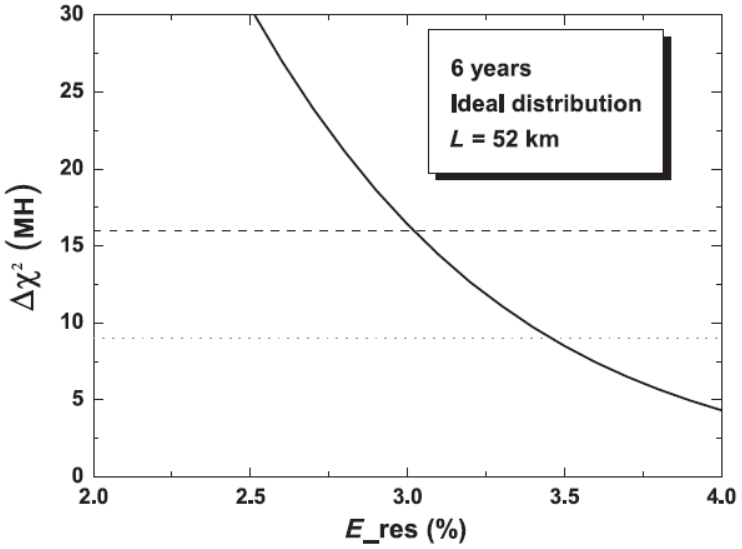
PMT
~18,000 20” PMTs +
~25,000 3” PMTs:
coverage >75%

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

Energy resolution

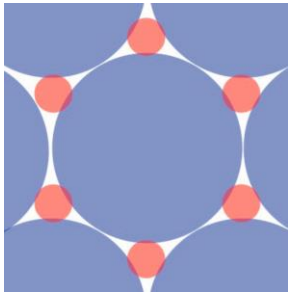
- Determination of mass hierarchy requires precision measurement of energy spectrum
- Sensitivity heavily depends on the energy resolution
- JUNO aims for 3%/√E(MeV)
  - Large number of photoelectrons: high light yield, high transparency liquid scintillator, high optical coverage and high QE 20-inch PMT.
  - ~1200PE@1MeV→2.89% statistical fluctuation
  - Room for systematics: <1%



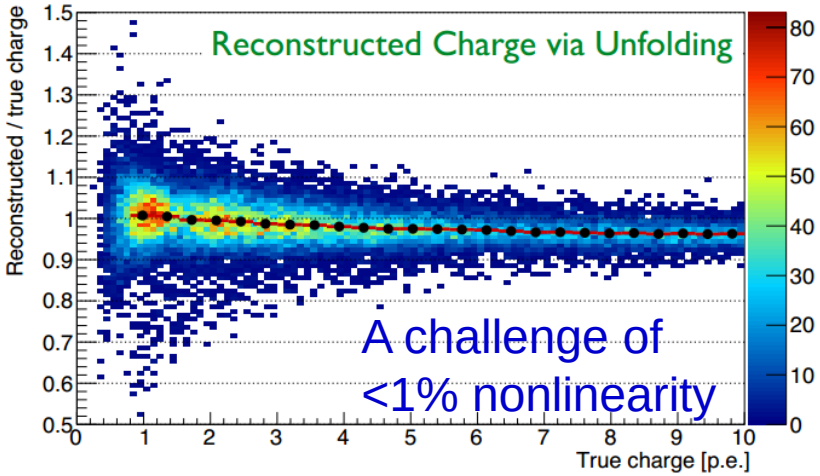


Double Calorimetry

- 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)

↓

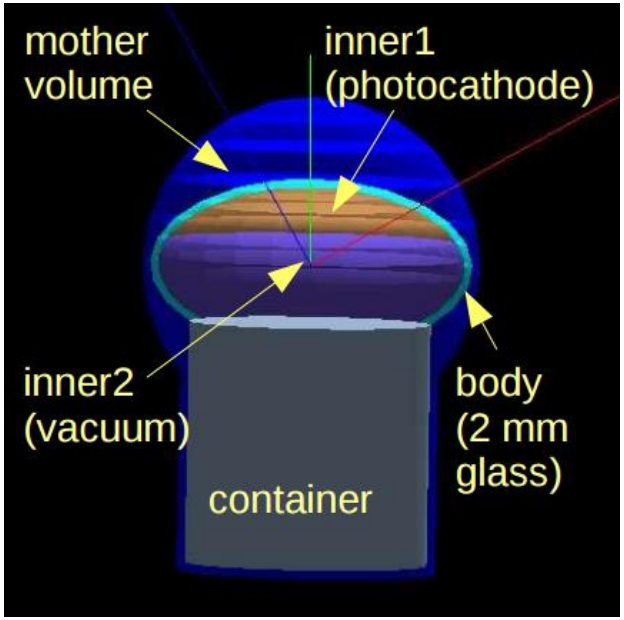
Resolution deterioration
(full detector)

SPMT physics

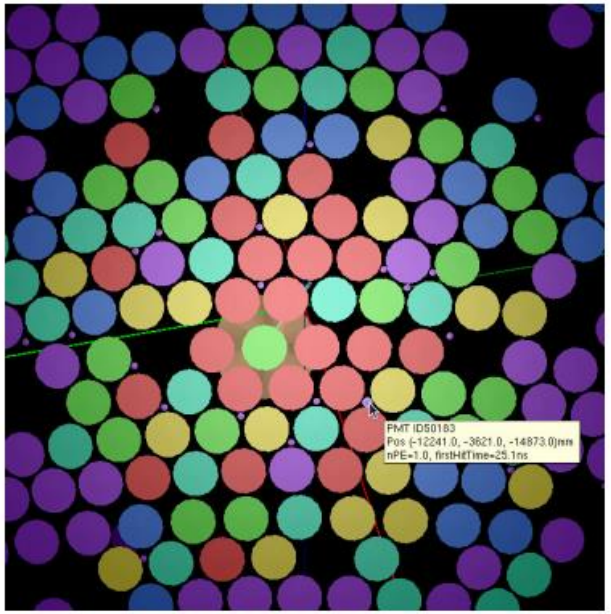
- Calibration of non-linear response of LPMT
- Solar parameters measurements with *partly independent* systematics
- Help reconstruction for high energy physics: muon, atmospheric ν…
- Help detection of supernova neutrino

Small PMT simulation

- Implementation of two PMT systems with Geant4 in the JUNO offline software framework.
- With realistic geometry and photon detection efficiency, ~30 PEs/MeV for 25,000 SPMTs, 2% of LPMTs.

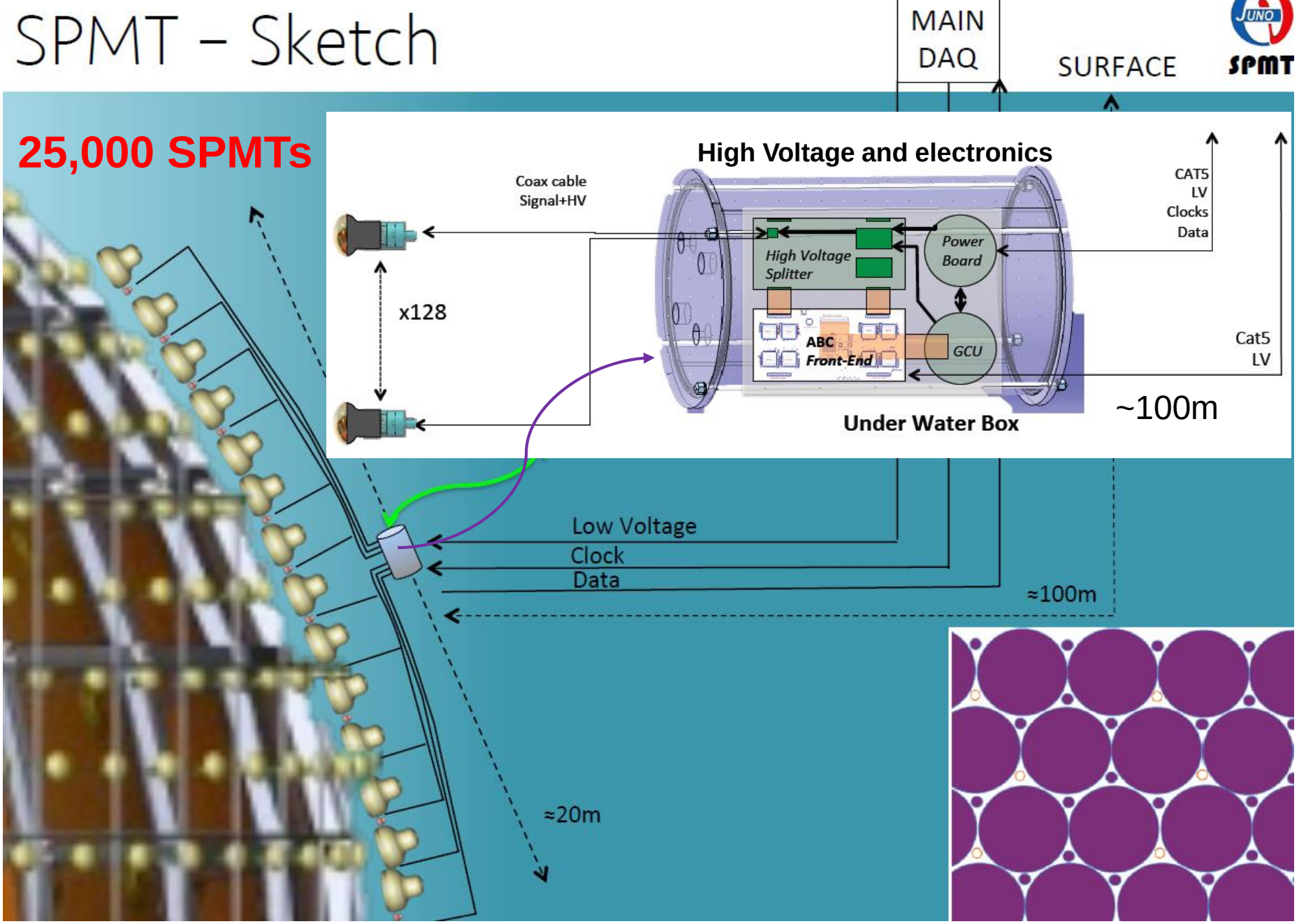


Implementation of a single small tube in Geant4.



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

SPMT – Sketch


MAIN DAQ
SURFACE
SPMT
25,000 SPMTs
High Voltage and electronics
Coax cable
Signal+HV
x128
High Voltage Splitter
Power Board
ABC Front-End
GCU
CAT5
LV
Clocks
Data
Cat5
LV
~100m
Under Water Box
Low Voltage
Clock
Data
≈100m
≈20m

Bidding of SPMT

- An international bidding on May 8.
- Hainan Zhanchuang (HZC) photonics have been chosen as our supplier.
- HZC will provide 25,000 (+1,000 spares) 3.1-inch XP72B22 tubes in the next 2.5 years.
- HZC is also going to produce HV divider and do potting for all PMTs.
- Contract to be signed this week.

海南展创光电技术有限公司 HZC PHOTONICS

XP72B22 performances

Parameters	HZC's response
QE×CE @ 420 nm	24% (>22%)
TTS(FWHM) of SPE	<5ns
P/V ratio of SPE	3 (>2)
SPE signal width (sigma)	35% (<45%)
Dark rate @ ¼ PE	1kHz (<1.8kHz)
QE uniformity	<30% in Φ60mm
Pre/after pulse ratio	<5%, < 15%
Nonlinearity	<10%@1-100PE
Radioactivity	238U: <400ppb, 232Th: <400ppb, 40K: <200ppb

HZC's 3.1" PMT

Photomultiplier

XP72B22

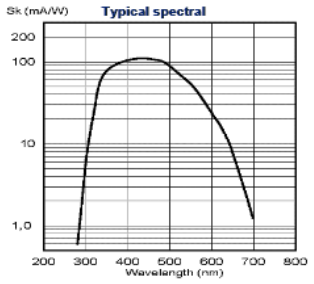
10-stage
80mm (3.1"), Round tube

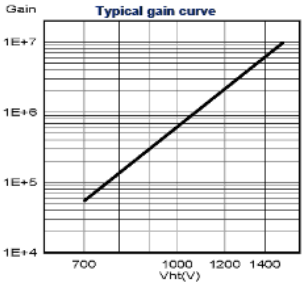
Application
√ High energy physics

Features
√ High Quantum Efficiency
√ Low profile

Description	
Window material	Borosilicate low K
Photocathode	Bi-alkali
Refr. Index at 420nm	1.54
Multiplier structure	Box and Linear focused

Photocathode characteristics	Min	Typ	Max	Unit
Spectral range:		290-700		nm
Maximum sensitivity at		404		nm
Sensitivity:				
Luminous		110		µA/lm
Blue *	10	12		µA/lmF
Quantum Efficiency, at 404 nm	22	25		%
Quantum Efficiency, at 470 nm	18	20		%
Characteristics with voltage divider A	**Min**	**Typ**	**Max**	**Unit**
Gain slope (vs supp. Volt., log/log)		6.8		
For an anode blue sensitivity of		50		A/lmF
Supply voltage *	900	1150	1300	V
Gain		$3x10^6$		
Anode dark current *		10	30	nA
Noise		1000	2000	Hz
Mean anode sensitivity deviation				
Long term (16h)		1		%
After change of count rate		1		%
Vs temperature between 0 and +40°C at 420 nm		-0.3		%/K
For a supply voltage of : 1000V	**Min**	**Typ**	**Max**	**Unit**
Linearity (2%) of anode current up to		30		mA
Anode pulse:				
Rise time		3.5		ns
Duration at half height		5		ns
Transit time		49		ns
Center to edge difference (C.E.D)		1		ns
Time resolution at 511 keV with LSO		1.3		ns





Recommended Voltage Divider

Type A for maximum gain

K	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	A	
3	1	1	1	1	1	1	1	1	1	1		(Total: 13)

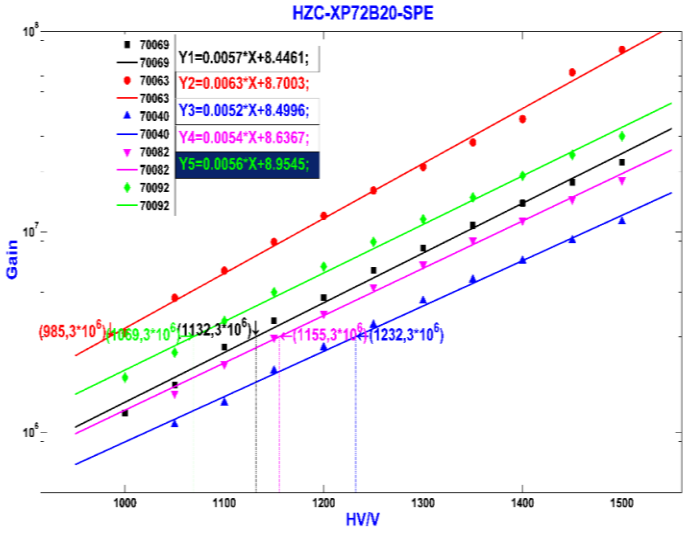
* characteristic mentioned on the test ticket of the tube

HZC PHOTONICS

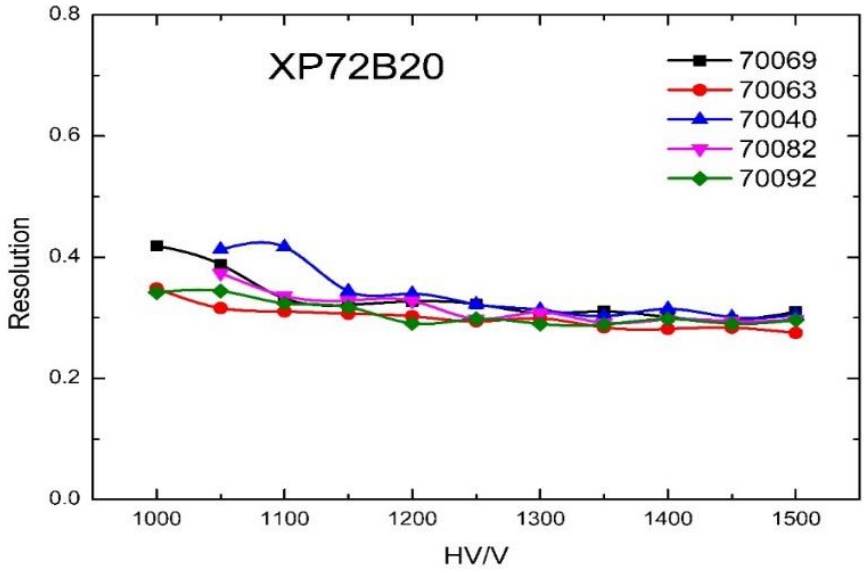
- **XP72B22**: a JUNO custom design
  - Upgrade of XP72B20
  - Dedicated R&D of better timing with JUNO input
- 35 + 5(with potting) PMT samples on hand

XP72B20 samples test

Company	PMT	No. of PMT	Voltage for Gain 10^7 /V	P-V Ratio	Resolution/ %	QE @420nm/ %	TTS/ns	Dark Rate @1/3PE /Hz
HZC	XP72B 20	70069	1400	5.6@3X10^6 gain 7.1@1X10^7 gain	35.2%@3X10^6 gain 29.9%@1X10^7 gain	23.9	4.5	394



Gain VS high voltage

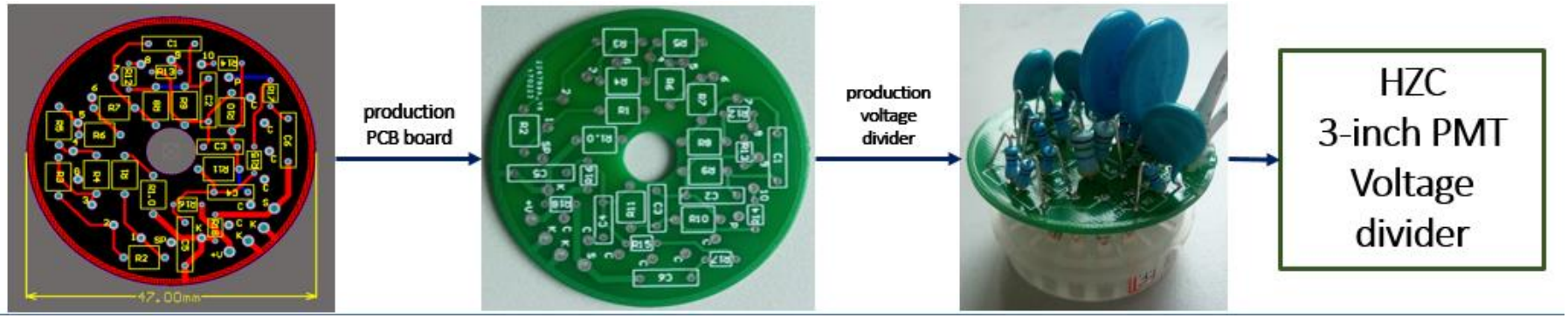


Good single photon resolution: ~35%

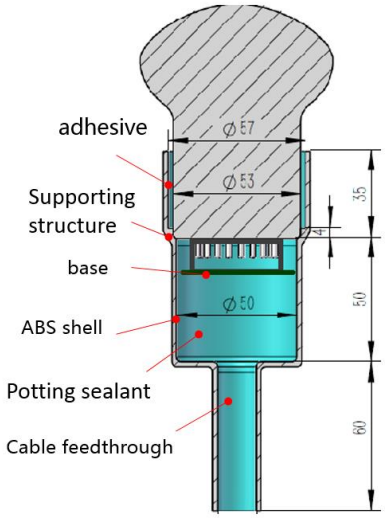
HV divider and Potting

Being designed by IHEP, implemented by HZC

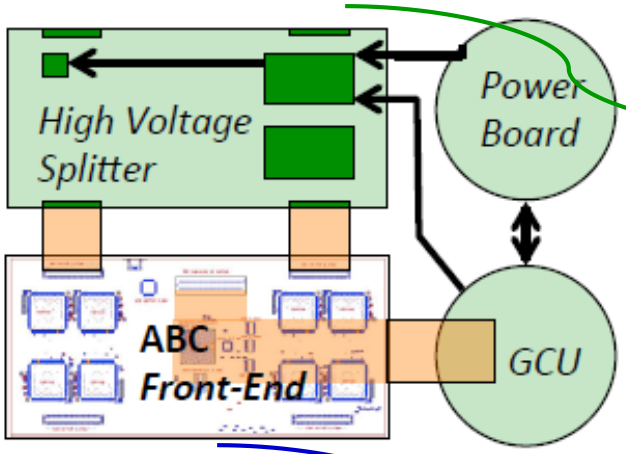
- Re-design of the divider to fit the potting shell: Φ<48mm

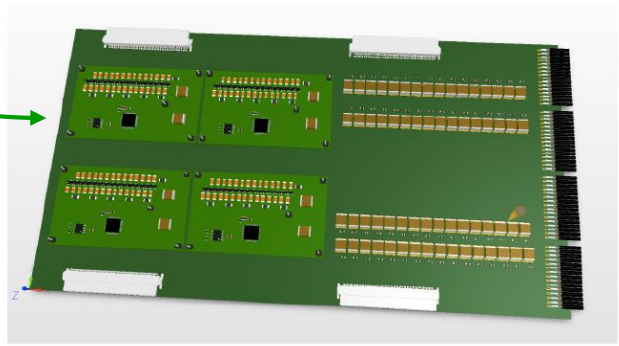


- Preliminary design and 50 dummy PMTs potting test



Electronics

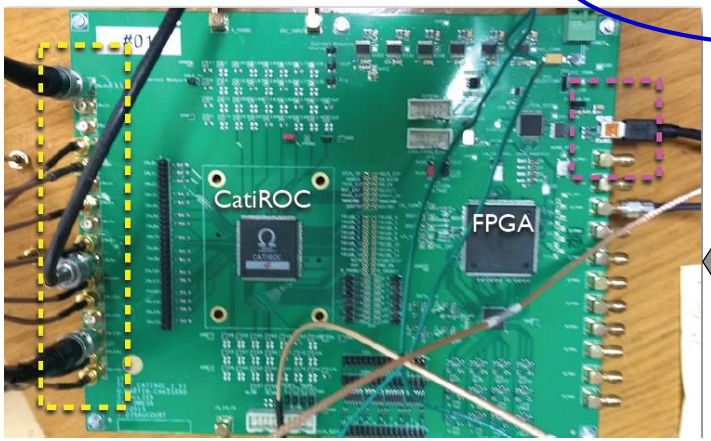




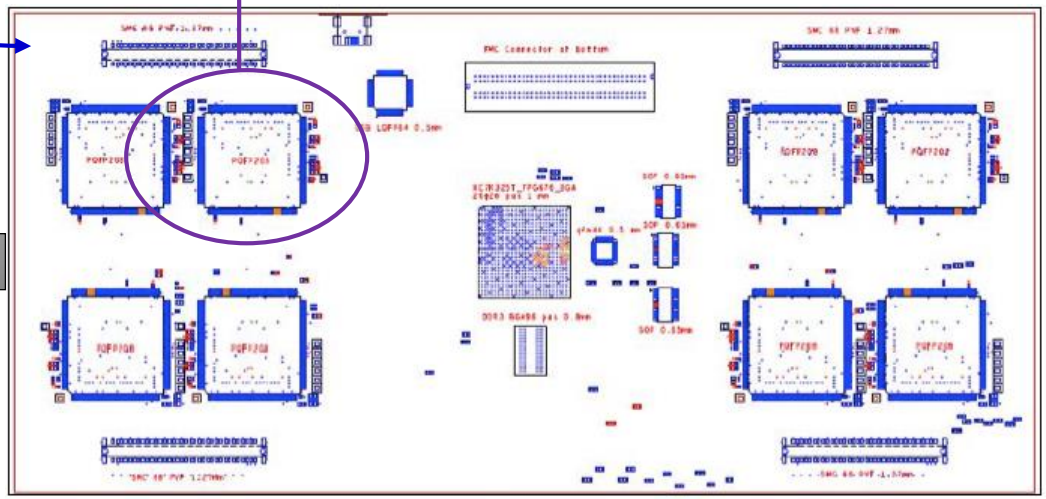
HV splitter: 1 or 2 board per box

CatiROC: a multichannel front-end ASIC

Selma's talk May 23 afternoon, session R3

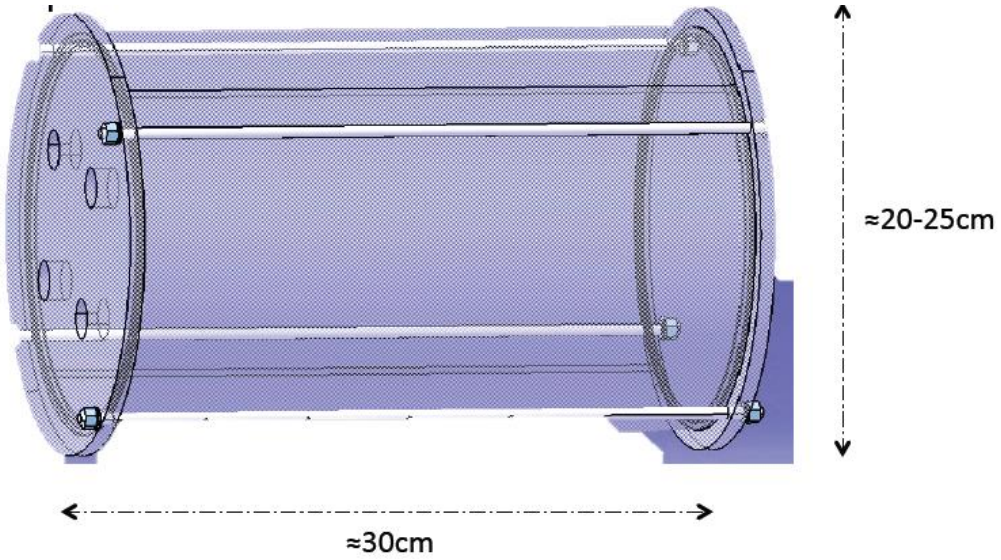


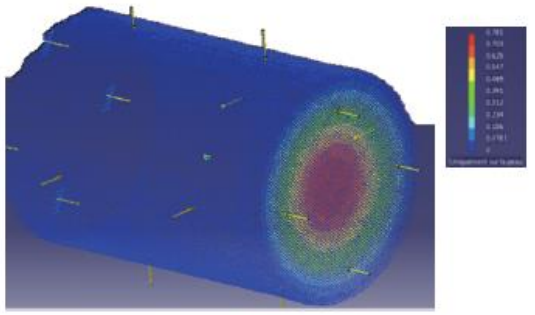
Test board: good timing and charge resolution



ASIC Battery Card (ABC) with 8×CatiROC

Underwater box





FEA for underwater box

Preliminary design: a stainless steel container

- ≈5mm thickness commercial tube
- 2 caps ≈12mm thickness
- Final dimensions to be defined with electronics
- R&D of HV + waterproofing connector with reasonable price for easier installation

Multichannel connector

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

Candidate: DGUT in Dongguan

Summary

- Double calorimetry system in JUNO:
  18,000 LPMT + 25,000 SPMT
  - Control both statistical uncertainty and systematics for 3% energy resolution
- Production of SPMTs is started soon, finished by the end of 2019
- Electronics and underwater box are being designed and optimized.
- Finish integration and installation in 2020