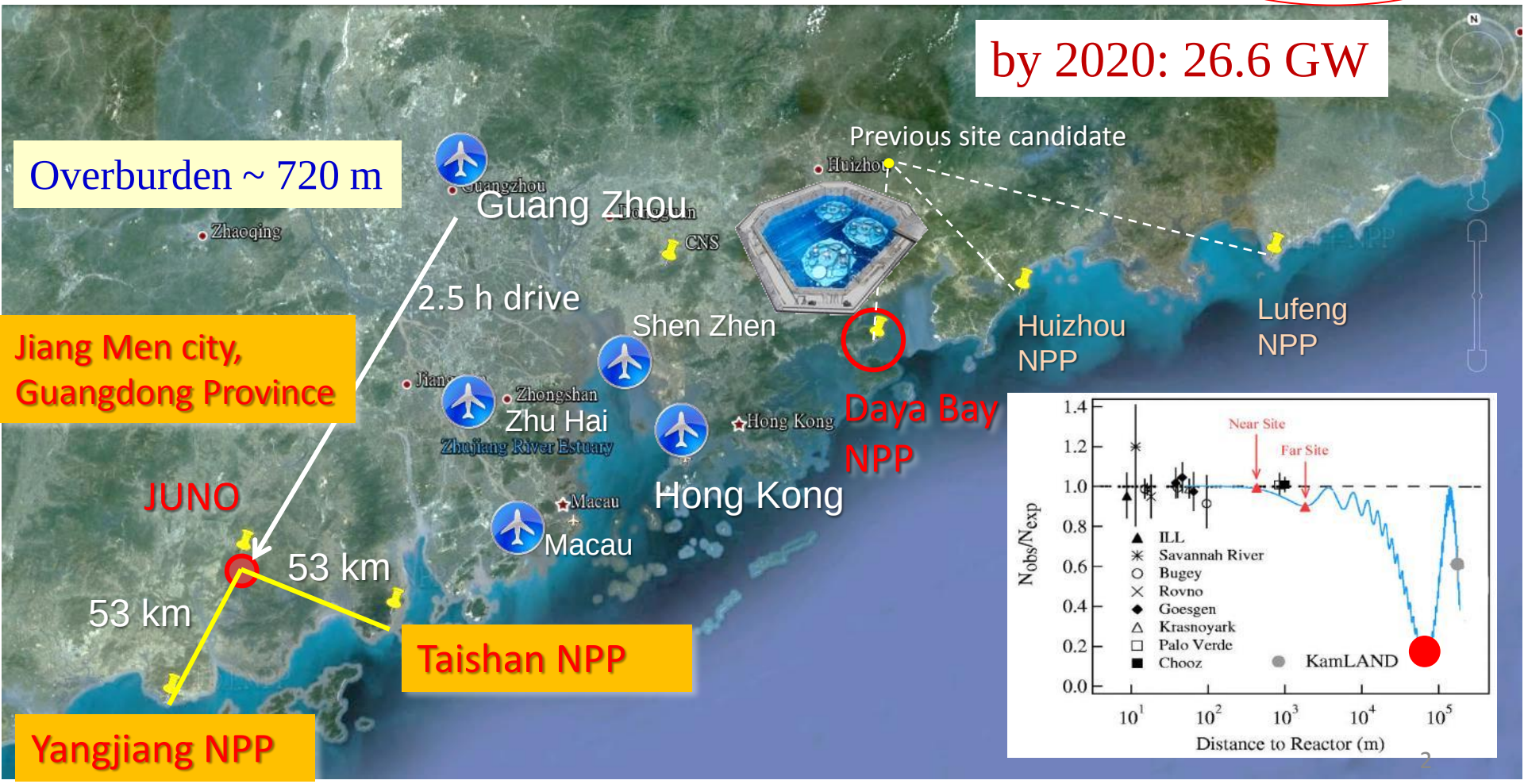
# PMT Instrumentation of JUNO

Zhonghua Qin
(IHEP, Beijing)

On behalf of JUNO collaboration
qinzh@ihep.ac.cn
NNN2016, Nov. 3rd-5th , Beijing

# JUNO experiment

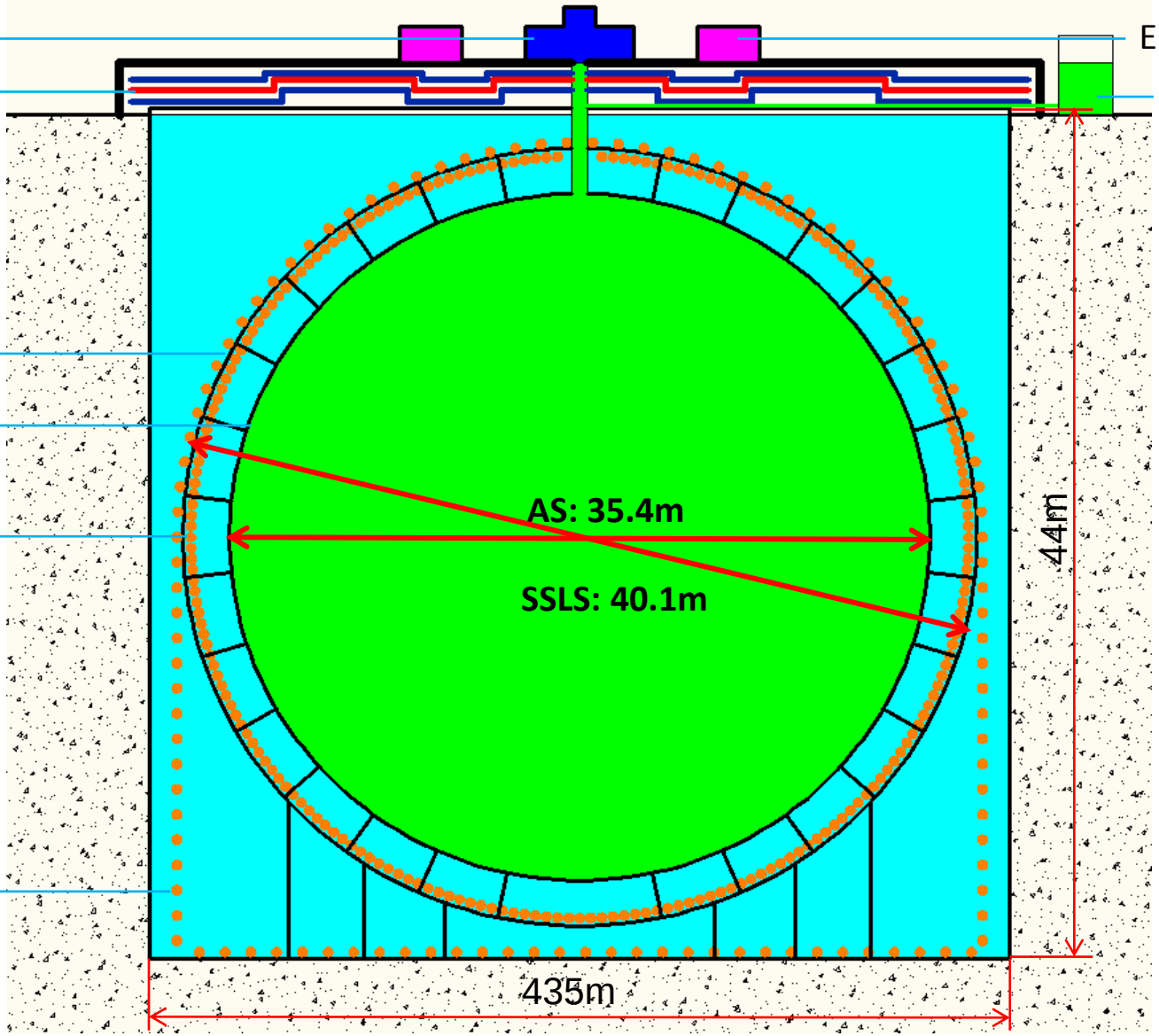
| NPP | Daya Bay | Huizhou | Lufeng | Yangjiang | Taishan |
|---|---|---|---|---|---|
| Status | Operational | Planned | Planned | Under construction | Under construction |
| Power | 17.4 GW | 17.4 GW | 17.4 GW | 17.4 GW | 18.4 GW |



# JUNO Collaboration

**Collaboration established in July 2015**
**Now: 66 institutions**
**444 collaborators**
**8 observers**

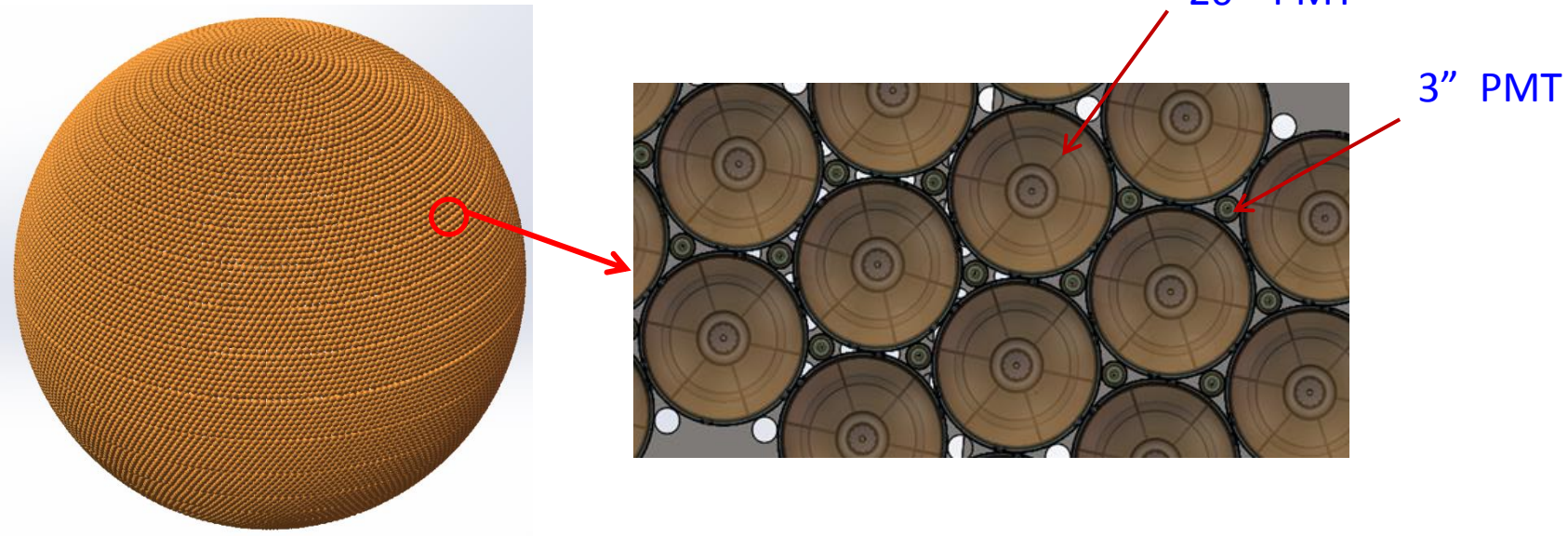
# JUNO detector




AS: Acrylic sphere; SSLS: stainless-steel structure

# Overview of PMT instrumentation

- Totally 20000 20-inch PMTs for CD and VETO detector
  - 15000 MCP-PMTs from of NNVT (North Night Vision of Technology CO., LTD),
  -5000 dynode-PMTs from Hamamatsu company
- Maximum 36000 3-inch PMTs for CD

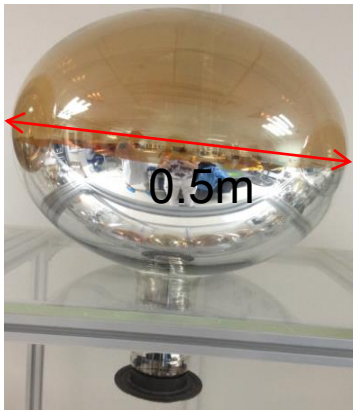



- The PMT instrumentation covers the PMT testing/Characterization, HV divider, earth magnetic field shielding, waterproof potting, implosion protection and PMT installation.

# Requirement on PMT performance

- The main Parameters for each PMT:

| Parameter list | typical value ( lower limit) | | |
|---|---|---|---|
| | MCP PMT | Dynode PMT | 3 inch PMT |
| PDE (QE*CE) @420nm | 27% (>24%) | 27% (>24%) | 25% (QE) |
| Non-uniformity of PDE | 8% (< 10%) | 5% (<15%): within ±70°; 20%(<30%): within ±80°; | / |
| Gain | $10^7$ | $10^7$ | $10^6$ |
| HV | 2500 V (<2800V) @Gain=$10^7$ | 2000V (<2500V) @Gain=$10^7$ | 1000V@$10^6$ |
| P/V | 3.5 (>2.8) | 3 (>2.5) | ≥2 |
| TTS(FWHM) | 12ns (<15ns ) | 2.7ns (<3.5ns) | ≤3.5 |
| Rise/Fall time | 1.7ns / 12ns | 5ns / 9ns | / |
| Dark rate | 20kHz (<30kHz) | 10kHz (<50kHz) | ≤1.5KHz |
| Ratio of Pre-pulse/After pulse | 0.5% (<1%) / 1% (<2%) | 0.8% (1.5%) / 10% (<15% ) | / |
| Non-linearity @ Gain=$10^7$, 0-1000pe | < 10% | < 10% | / |
| Radioactivity level (ppb) | $^{238}$U:50, $^{232}$Th:50, $^{40}$K:20 | $^{238}$U:400, $^{232}$Th:400, $^{40}$K:40 | / |
| Pressure tolerance | Up to 0.8MPa | Up to 0.8MPa | Up to 0.8MPa |



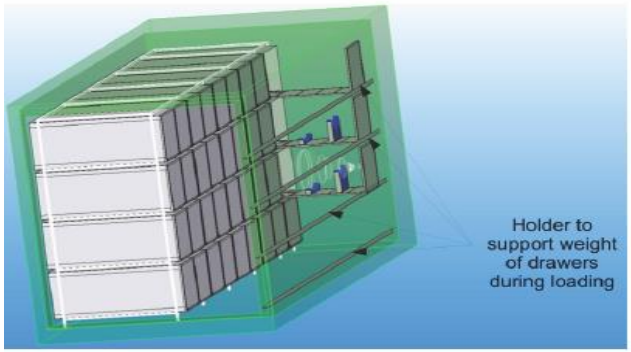
MCP-PMT

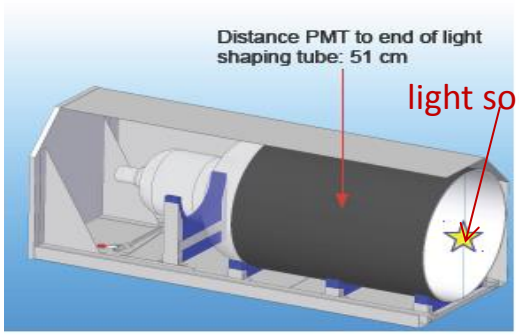
Dynode -PMT

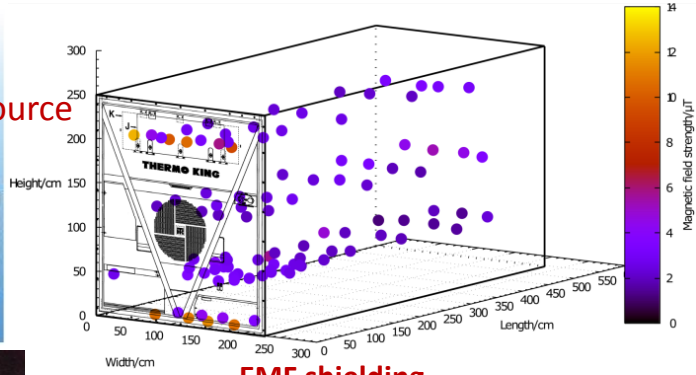
3inch-PMT

# PMT mass testing /characterization (1)

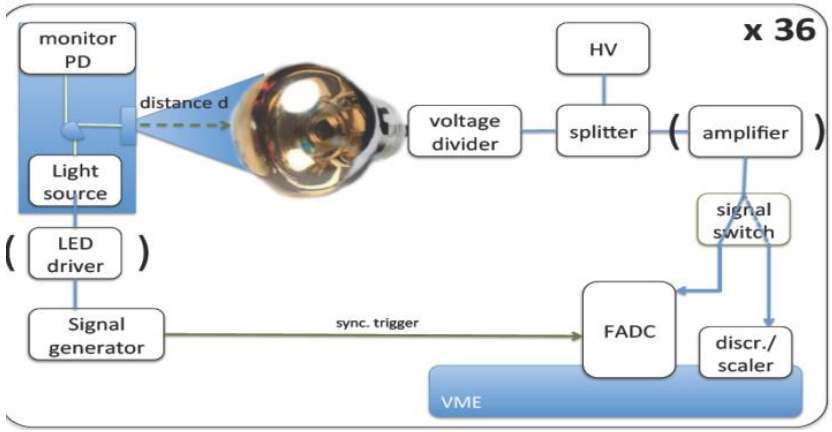
- Four test facilities will be equipped in standard commercial container
  - each container can test 36 PMTs in parallel;
  - LED located in each testing drawer box;
  - homogeneous light field produced by the light shaping tube;
  - earth magnetic field shielded to less than 10%;
  - commercial electronics used for the first two containers and JUNO electronics for the rest;
  - the first test facility will be available by end of 2016;

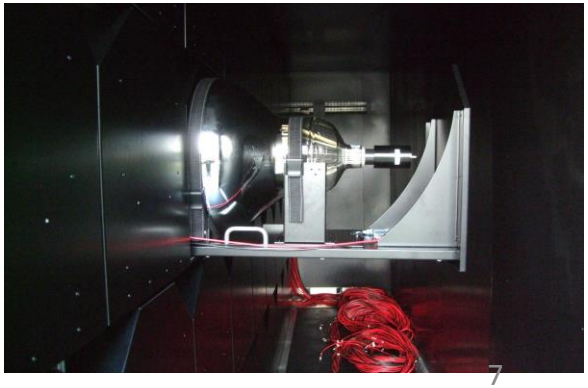


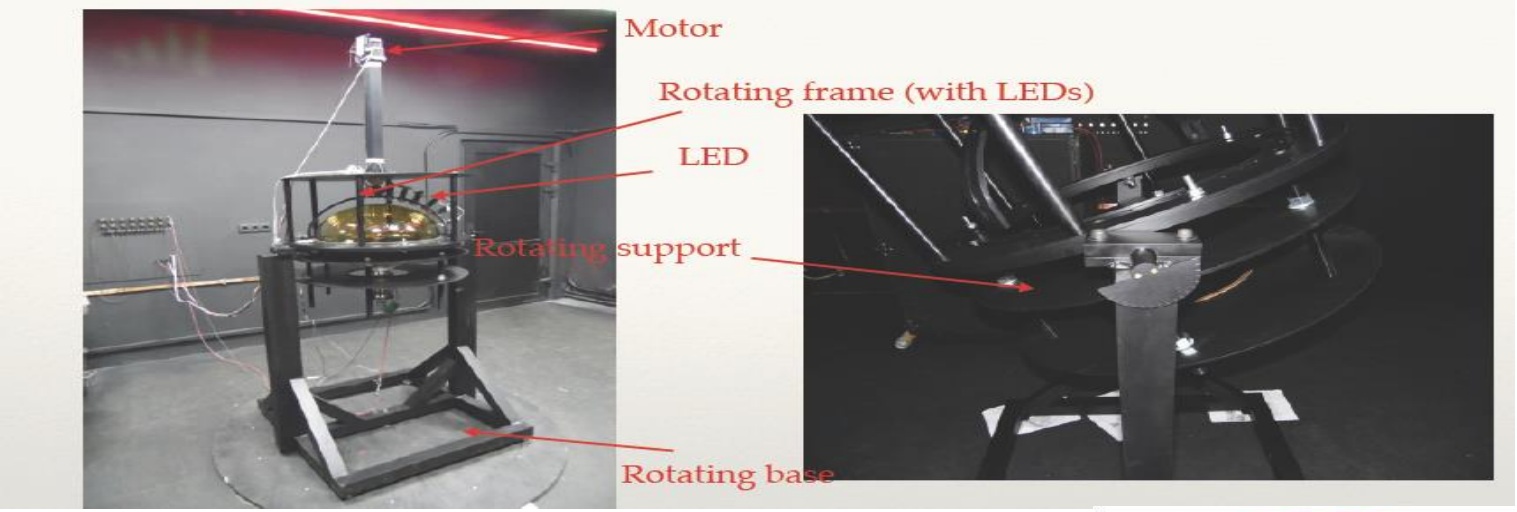

EMF shielding

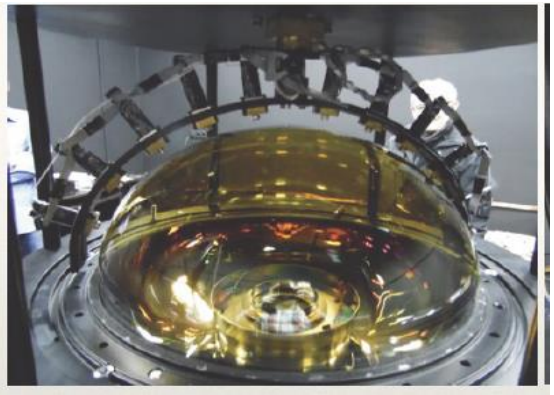


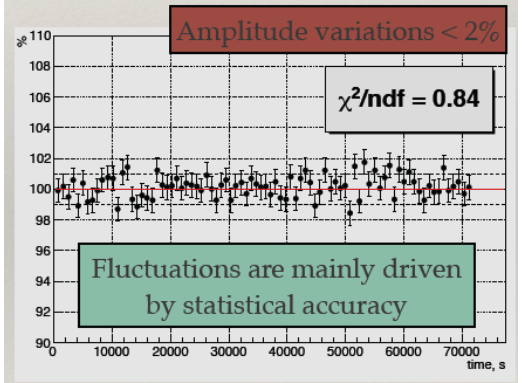



# PMT mass testing /characterization (2)

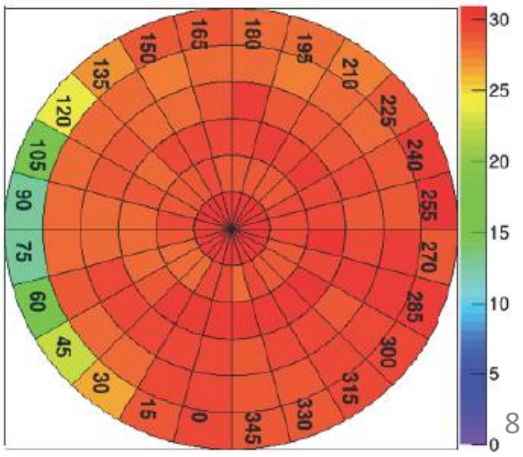
- Three scanning stations is designed for PDE (Photon detection efficiency) non-uniformity measurement and detailed study of PMT performance
  - automatically scanning the PDE non-uniformity of the photo-cathode;
  - 14 stabilized LEDs for PDE scanning of about 3-5% of the total PMTs;
  - detailed study can be performed by the scanning station;






LED source stability measured by 20″ Hamamatsu 12860 HQE PMT in a single point



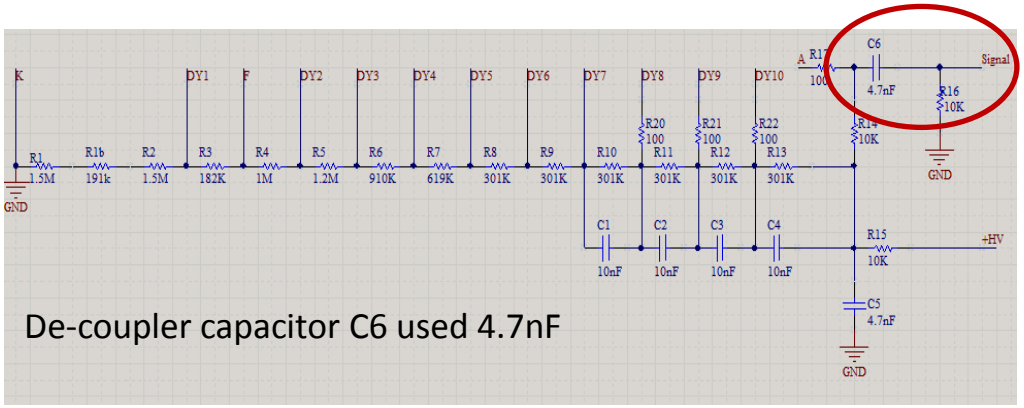
test result of PMT sample

# PMT High Voltage Divider (1)

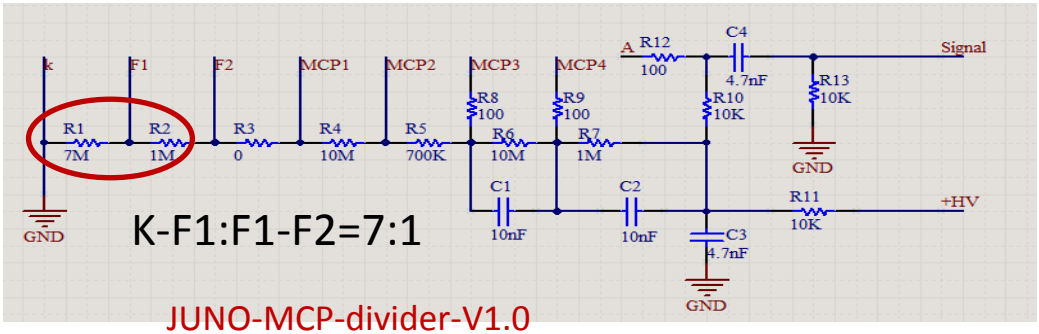
- JUNO Requirements for HV Divider:

- Different design for MCP PMT and dynode PMT
- Gain : 1 ×$10^7$ (5 ×$10^6$ to 2 ×$10^7$ )
- HV & DC current : <300μA@3000V
- Linearity & Dynamic range
  up to 1000p.e. with non-linearity < 10% ;
  up to 4000p.e. dynamic range;
- Life time: failure rate < 0.1%/year
  (or 0.5% in 6 years) ;
- Overshoot and ringing minimization:
  about 1% with 50Ω load impedance;
- Flasher elimination
- Overvoltage protection
- Support for electronics PCBs
  PMT-PCB connection ;
  Integration with HV unit;
  connection between PCBs;

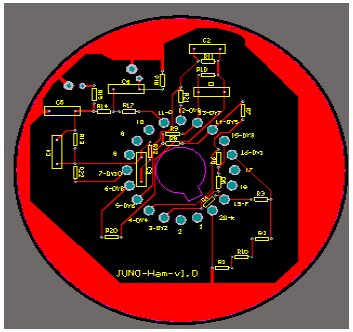
-Pluggable for PMT mass testing system




JUNO-Dynode-divider-V1.0

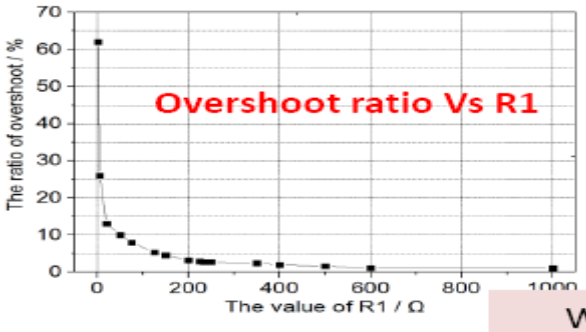


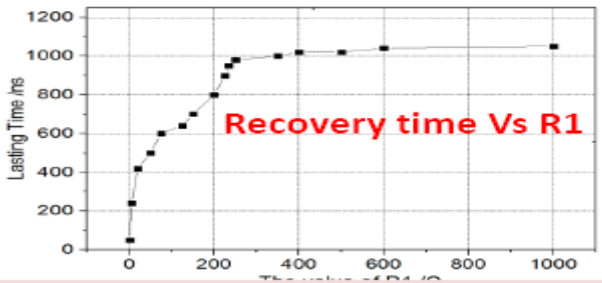

JUNO-MCP-divider-V1.0



# PMT High Voltage Divider (2)

- Overshoot optimization to 1% level



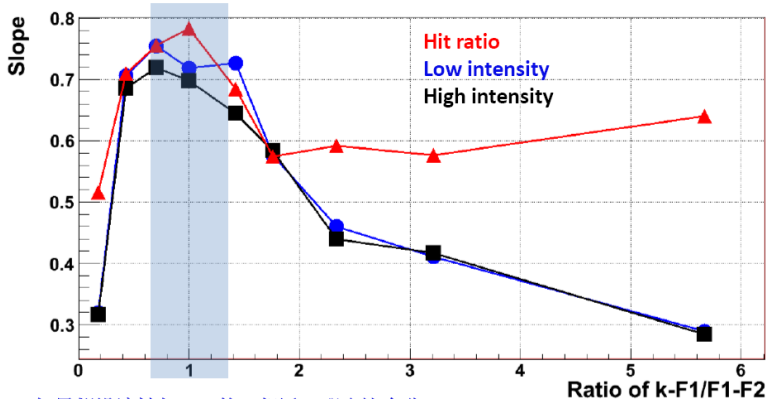



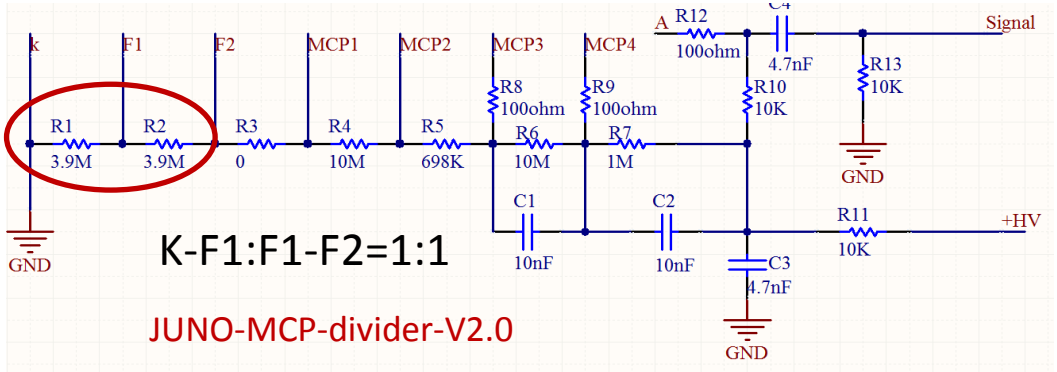

With the test, reaching 1% overshoot recovering in ~us is possible.

C1=4.7nF, C2=22nF, R2=50 Ω

| Overshoot ratio | R1=10 k | R1=50 Ω |
|---|---|---|
| MCP-PMT 8" | ~1% | ~11% |
| MCP-PMT 20" | ~1% | ~11% |
| Hamamatsu 20" | ~1% | ~10% |
| HZC 9" | ~1% | ~10% |

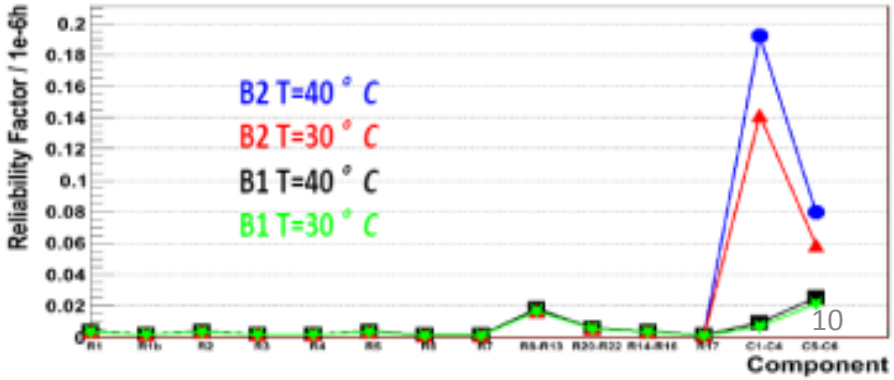
- HV ratio optimization for MCP PMT




- Reliability study

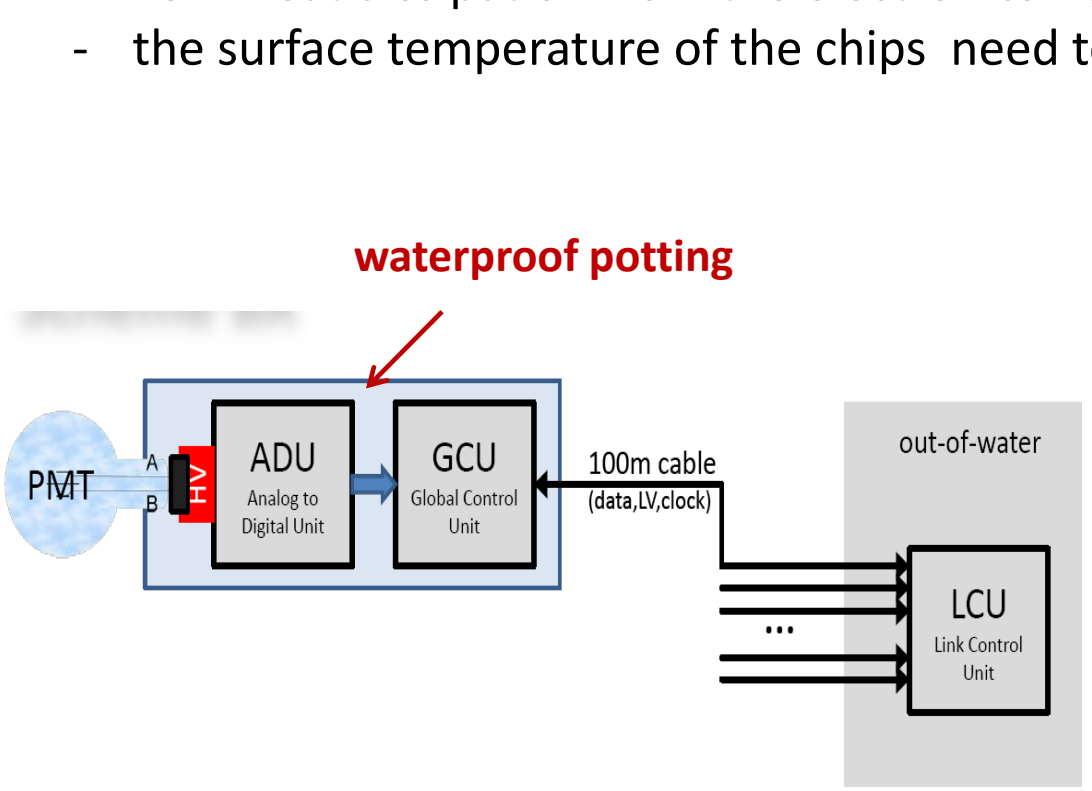
  - Capacitor has lower reliability
  - Temperature impacts on reliability

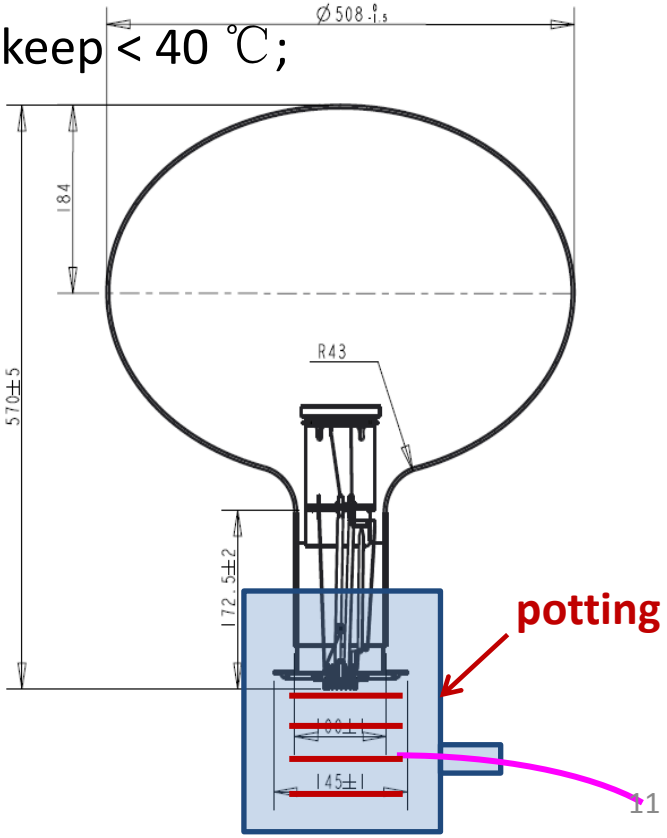


# Waterproof Potting (1)

- JUNO Requirements and Challenges:

- HV divider, HV module, and the front-end electronics including ADC, GCU etc. need to be waterproof potted;
- Working under 45m-deep high-purity water;
- 20 years life-time, with a failure rate ＜0.5% for the first 6 years, 5% for all years;
- 15W heat dissipation from the electronics need to be removed
- the surface temperature of the chips need to keep < 40 ℃;



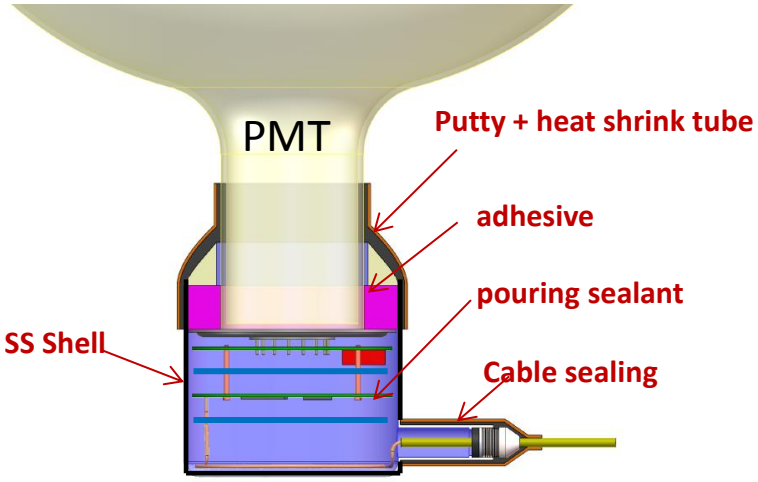
# Waterproof Potting (2)

- preliminary design of the potting scheme

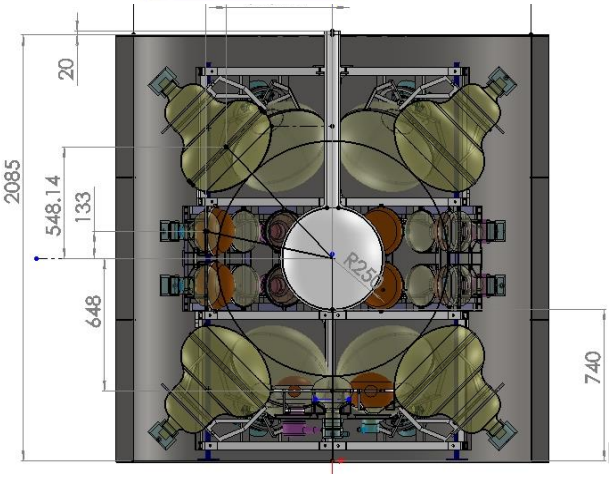
-with multiple waterproof layers: putty + glue + pouring sealant;

- a stainless-steel shell will be the encloser for heat conducting;

- HDPE as the cable jacket for easier surface treatment;

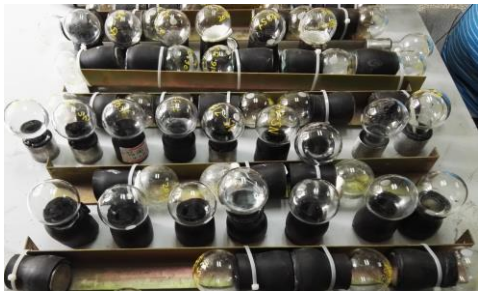


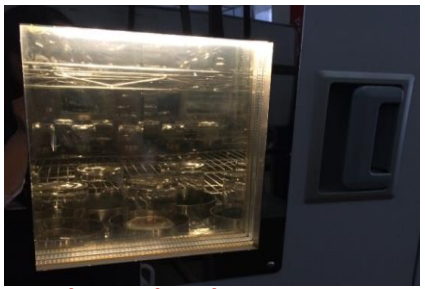

- Potting for JUNO prototype
  - only HV divider was there;
  - totally 40 PMTs with different types potted;




- work on going: many samples for heat conducting test, puttty test, thermal cycle test , and connector study.


Heat conducting test


Test of putty


thermal cycle test


connector prototype

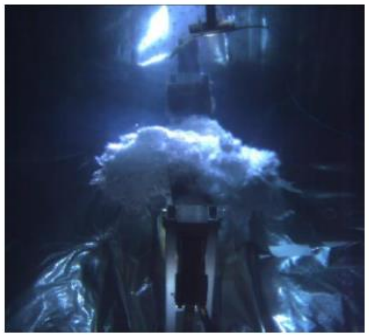
# PMT implosion Protection (1)

- Requirements for PMT protection

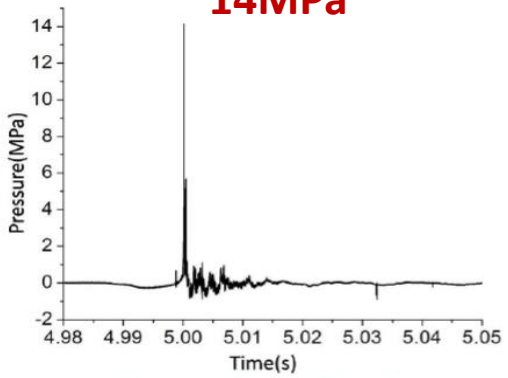
  - Prevent chain reaction triggered by one PMT implosion;

- Study with naked PMT

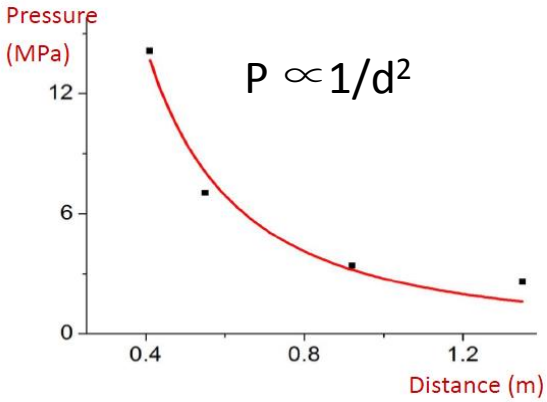
PMT start break



shockwave initiated




the wave form of shockwave

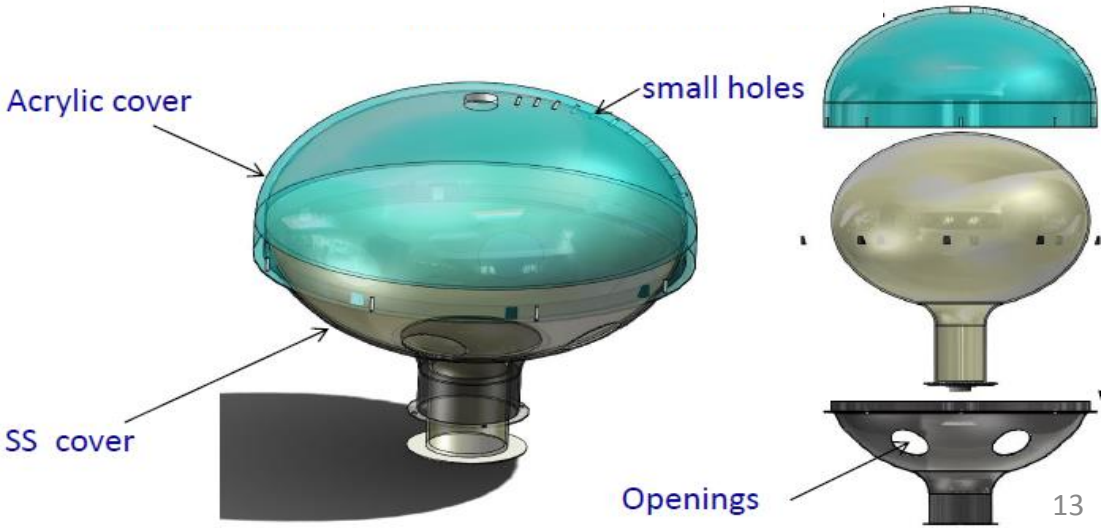



- Requirement on Protective cover

  - good transparency, least possible light absorption and attenuation;

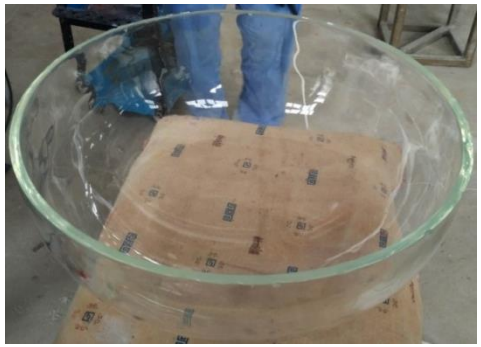
  - thinnest possible, minimize the impact on PMT coverage;

  - compatible with pure water and low radioactivity;

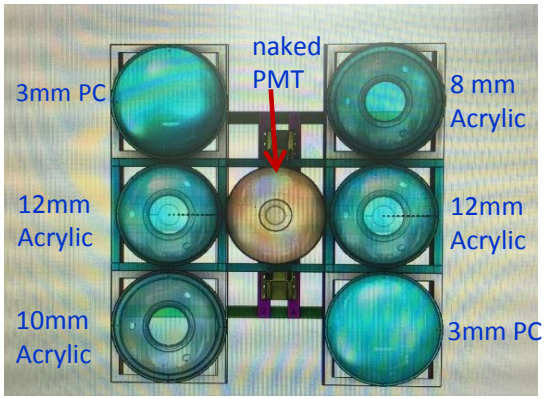


# PMT implosion Protection (2)

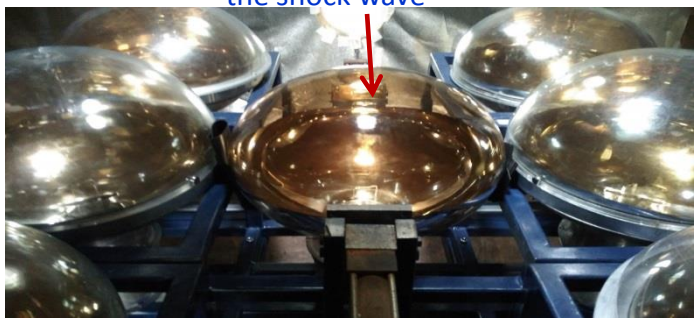
- Protective cover prototyping
  - totally produced 20 acrylic samples
  - done by different manufacturing technique
  - also produced some PC(polycarbonate) and PETG (Polyethylene terephthalate) cover for test

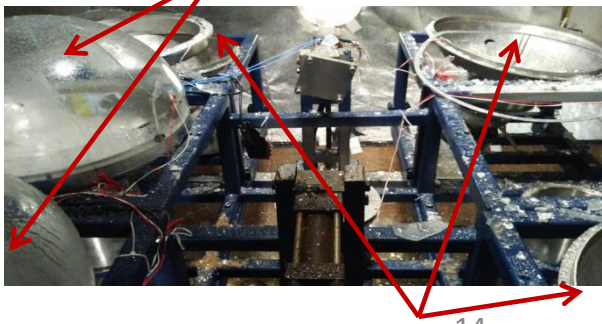
- Implosion test with multiple PMTS
  - tried 3 times this year;
  - with different configurations;




Naked PMT for triggering the shock wave



10mm and 12mm thick acrylic covers are survived;



others are broken

# PMT implosion Protection (3)

- Summary of the tests in 2016

| Cover material | Average thickness(mm) | Minimum thickness (mm) | Number of tested | Number of failed |
|---|---|---|---|---|
| Acrylic | 12 | 11.5 | 5 | 0 |
| Acrylic | 10 | 8.5 | 2 | 0 |
| Acrylic | 9 | 6.8 | 2 | 1 |
| Acrylic | 8 | 6.5 | 1 | 1 |
| PC(polycarbonate) | 3 | 3 | 2 | 2 |
| PETG | 3/5 | 3/5 | 3 | 3 |
| Stainless-steel | 2-2.5 | 1.5 | 15 | 0 |

- The main conclusions

PC and PETG will not work if their thickness < 5mm;

but there will be significant loss of light if the thickness > 5mm, for both PC and PETG;

Acrylic cover with a minimum thickness about 9mm are always survived, so it's a good choice for JUNO.

# PMT coverage and module design

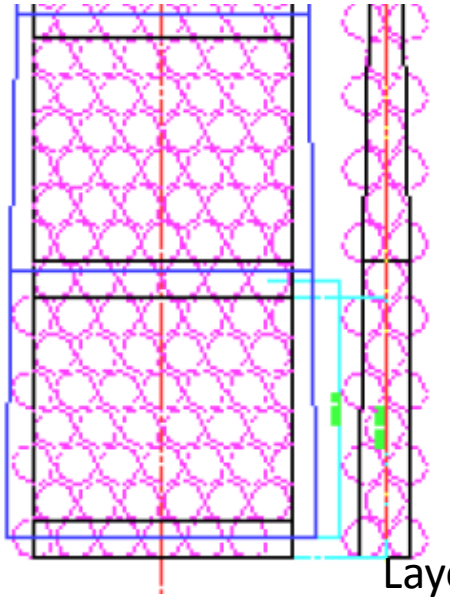
- Require the PMT coverage > 75% to connect as many as possible photons;
- A preliminary layout from engineering showing: 75% coverage seems promising, for different PMT module design:

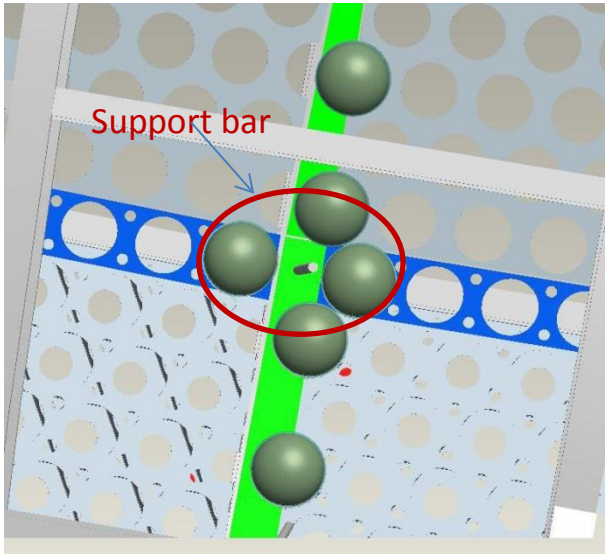
**option 1:**

1) with one largest possible module in the window, and smallest possible modules on the back of truss;

2) layout starting from the middle of the window, minimizing the influence from the support bars;

3) 17510 PMTs in total, coverage is 75.1%





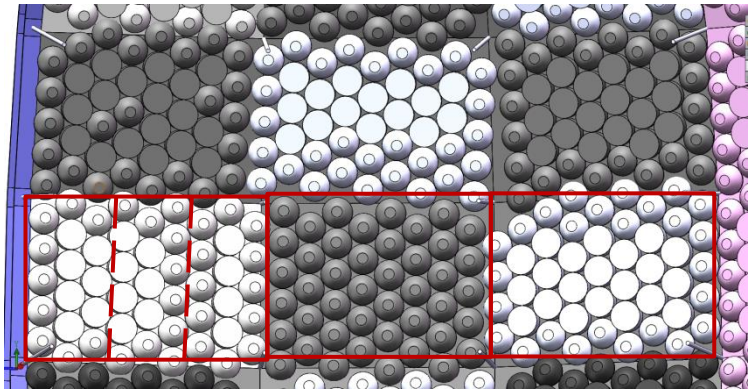

Layer 10, 11

**option 2 :**

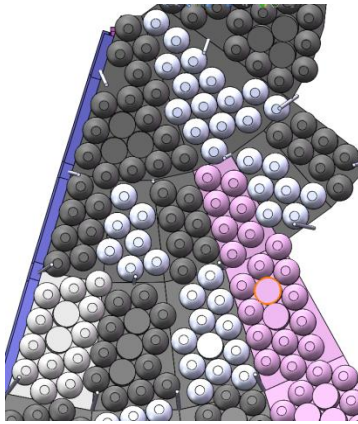
1) divided into several modules (3, or2, or 1) in the window but with 3 windows as one unit

2) minimize the influence from the support bars.

3) 17570 PMTs in total, coverage is 75.4%



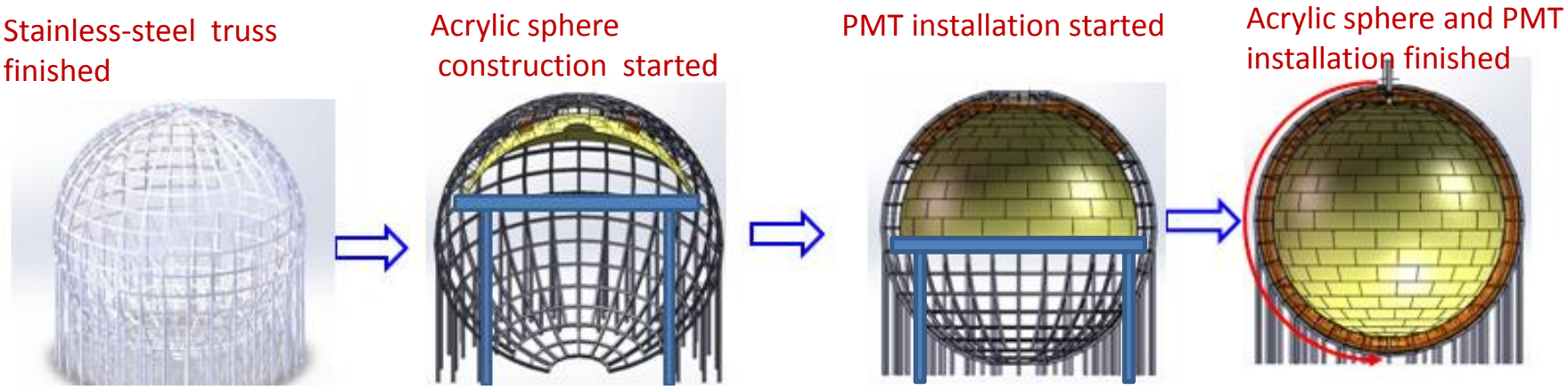
Layer 10, 11



Layer 1, 2, 3

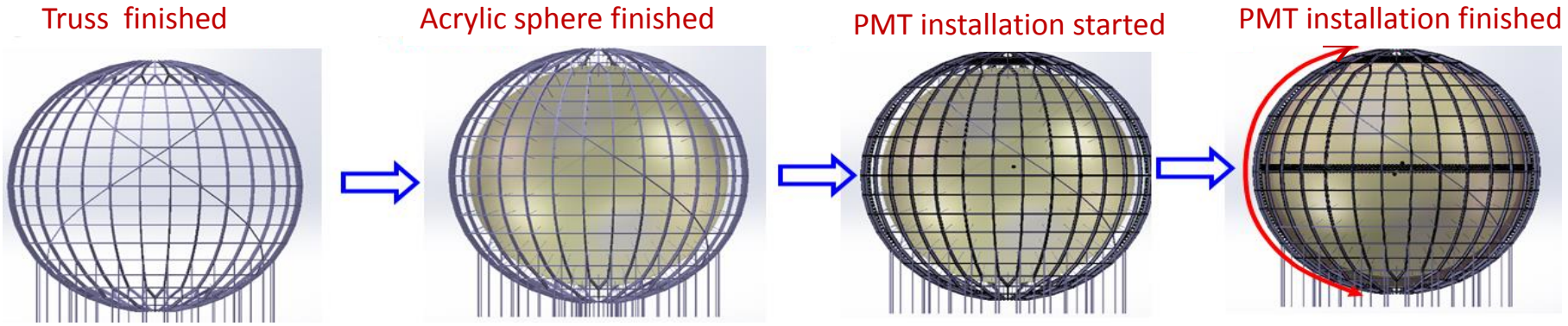
# PMT Installation consideration (1)

- Option 1, the baseline option: PMT installation in parallel to acrylic sphere construction;




- advantage: save the total construction time;
- disadvantage: interference between PMT installation and acrylic sphere construction

- Option 2: PMT installation after acrylic sphere constructed

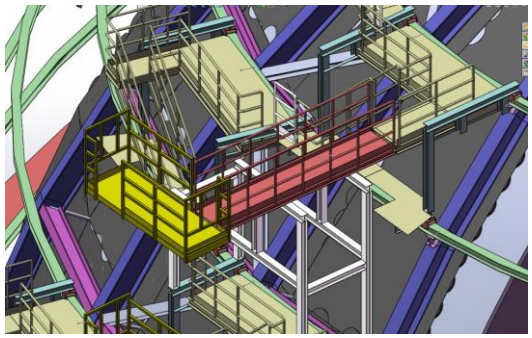



- advantage: no inference
- disadvantage: more time. But the installation can be in parallel for upper and lower semi-sphere.

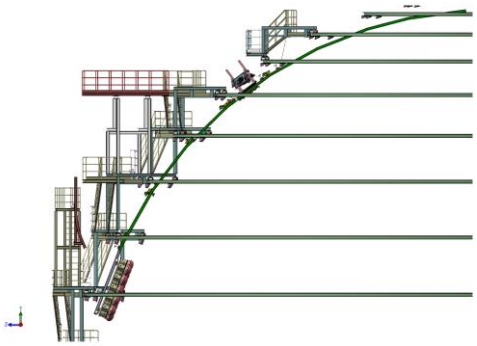
# PMT Installation consideration (2)

- conceptual design of Platforms, tools for PMT installation

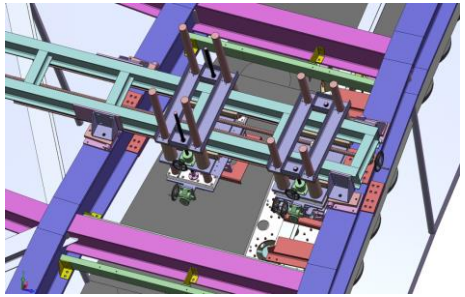
- for option 1: outside track for platform movement, and inner track for PMT module movement

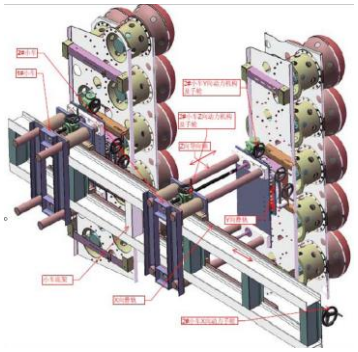


platform moving on sliding track



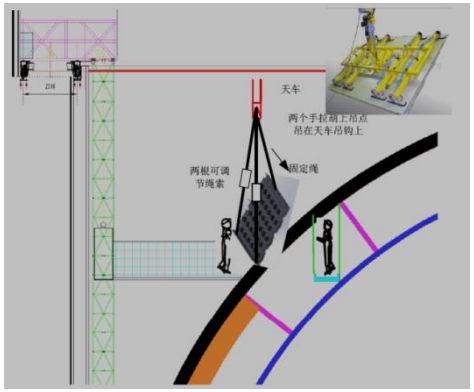
PMT module moving on sliding track

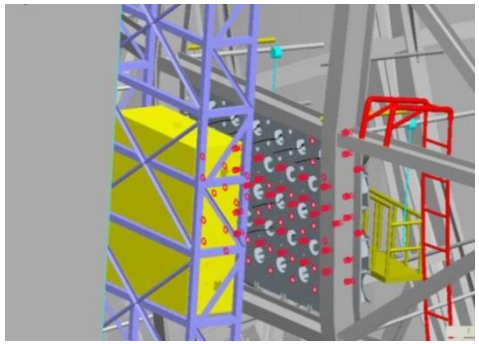




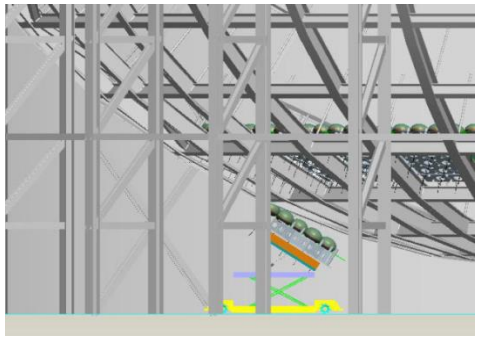
PMT module positioning

- For option 2: rotating platform outside of the truss and suspended platform inside, module carried by overhead travelling crane or lifting platform with posture adjustable;



Rotating and suspended platform



Posture adjustable Lifting platform

Normal Lifting platform

# Schedule for PMT instrumentation

- PMT mass testing/characterization: 2017.1 - 2019.1

  Both PDR and FDR were finished;
- PMT HV divider mass production: 2018.1 - 2019.7

  PDR will be in 2017.6;

  FDR will be 2017.12;
- PMT potting: 2018.7 - 2019.7

  PDR will be in 2017.6;

  FDR will be in 2017.12;
- PMT implosion protection mass production: 2018.1 - 2019.1

  PDR will be in 2017.1;

  FDR will be in 2017.7;
- PMT installation: 2018.12 - 2019.7

  PDR will be in 2017. 6;

  FDR will be in 2017.12;

and JUNO will be running in about 2020. 5 as current schedule .

Thank you for your attention !