Challenges and technologies of JUNO central detector structure

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On behalf of JUNO collaboration

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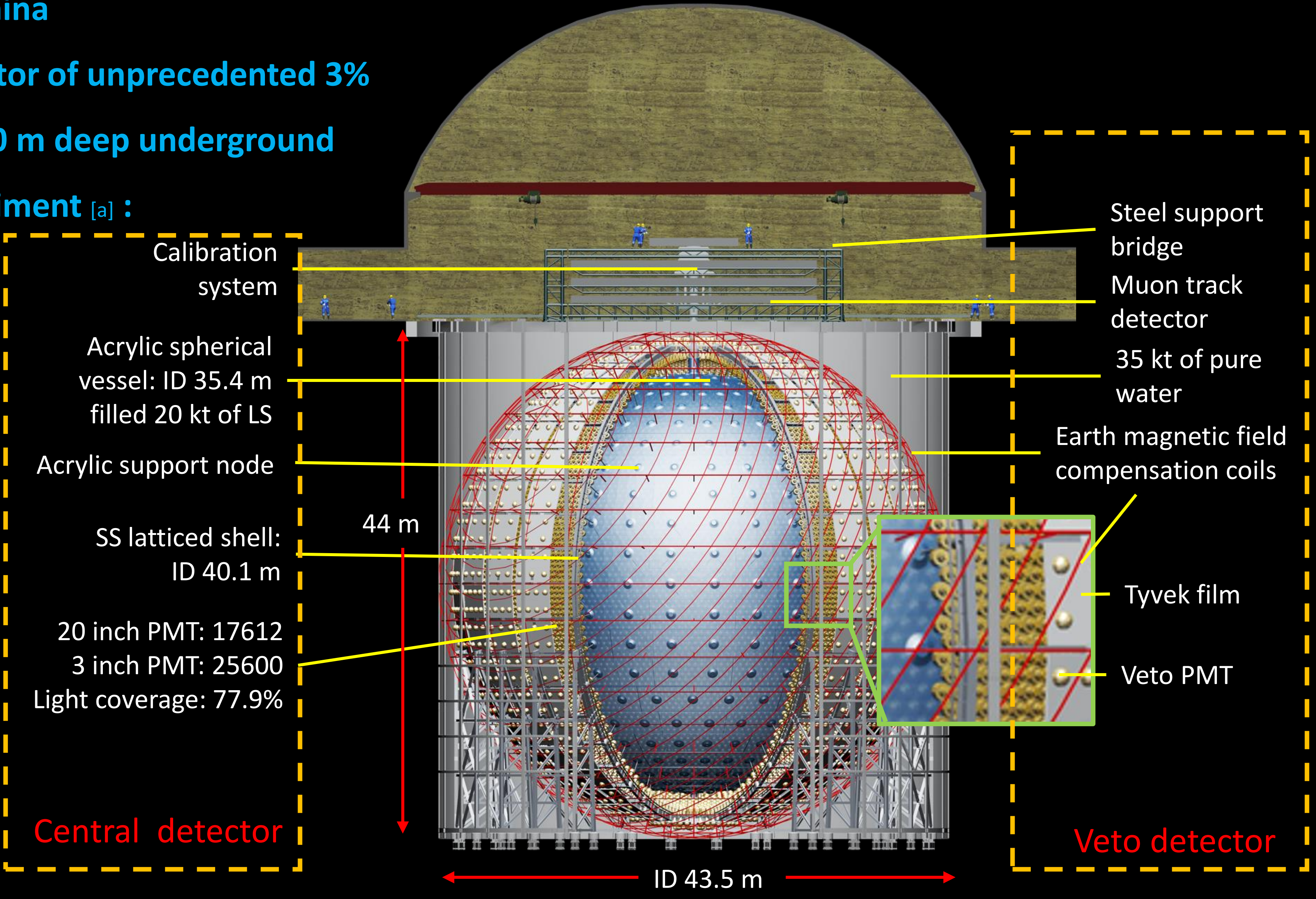
About Jiangmen Underground Neutrino Observation (JUNO)

- **Located in Guangdong Province, China**
- **A 20 kt liquid scintillator (LS) detector of unprecedented 3% energy resolution (at 1 MeV) at 700 m deep underground**
- **A multiple purpose neutrino experiment** [a] **:**
  - ➢Reactor neutrinos: Mass Hierarchy & Precision measurement of mixing parameters
  - ➢Supernova neutrinos
  - ➢Solar neutrinos, Geo-neutrinos, Atmospheric neutrinos
  - ➢Sterile neutrinos and Dark matter searches
  - ➢Nucleon decay and other Exotic searches



Detector structure of JUNO

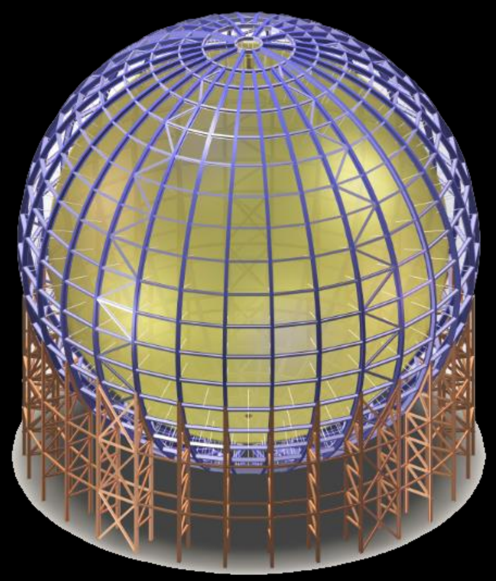
[a]JUNO Collaboration: J. Phys. G 43 (2016) 030401

Challenges and technologies during the design and constructure of detector

- The central detector of JUNO will be the largest liquid scintillator detector, constructing the largest acrylic spherical vessel to hold LS
- The main structure of central detector—Stainless steel latticed shell + acrylic spherical vessel
- ➢ The shell is the main support of the whole structure
- • supporting structure of acrylic vessel
- • PMTs are mounted in it;
- • Earth magnetic field compensation coils on it
- Challenges and Technologies
- ➢ Design: 1) How to design structure to ensure reliability; 2) Long time performance of acrylic: creeping and aging
- ➢ Production: 1) Manufacture the acrylic spherical panel; 2) Low background radioactivity material production: acrylic (U238/Th232/K40< 1ppt)
- ➢ Construction: 1) How to increase the bonding quality——bonding and annealing; 2) How to construct the latticed shell and the acrylic vessel in a short time

SNO

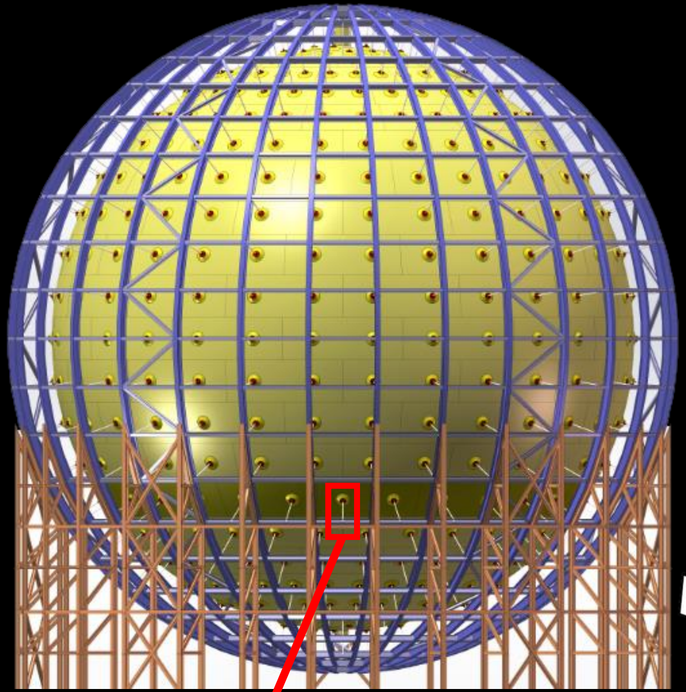
JUNO

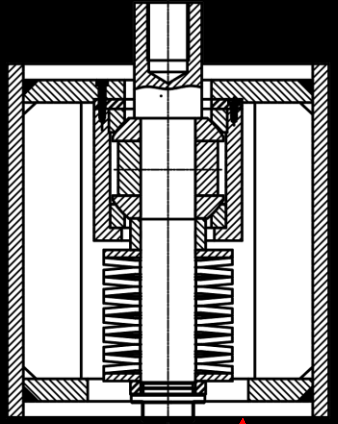


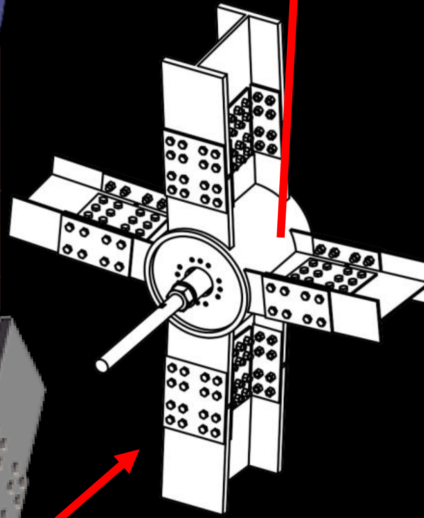
Main structure of central detector

Central detector structure design

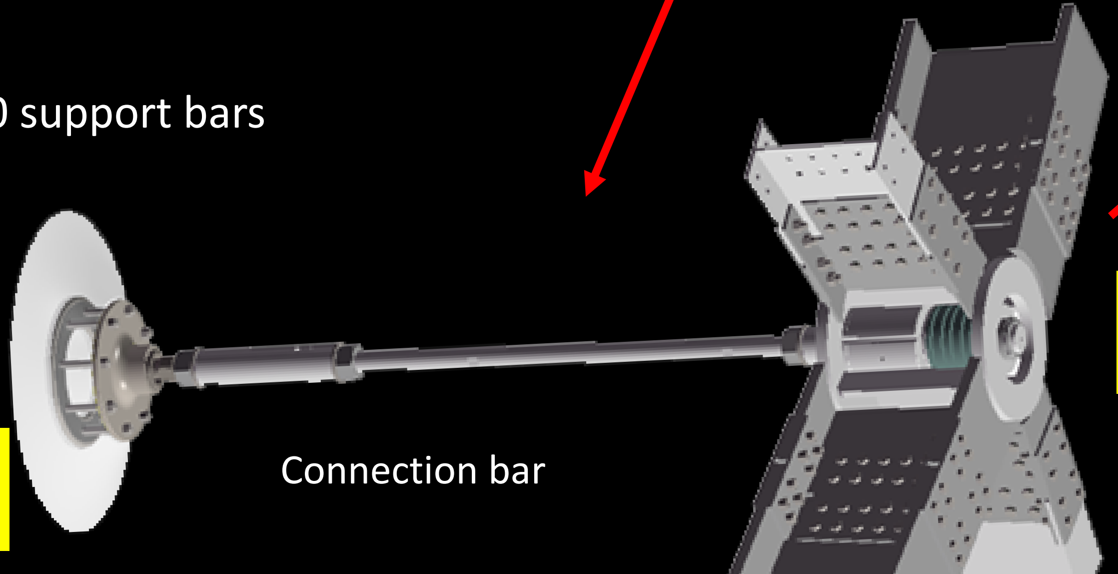
- ☐ Acrylic Vessel is more weakness than the steel shell
- ☐ Size of acrylic vessel: ID 35.4m, Thickness:120mm
- ☐ Load of acrylic vessel
  - ➢ Buoyancy for the density difference during running: 3250 t
  - ➢ Weight of the vessel: ~600 t
- ☐ Structure design requirement for detector 20 years running:
  - ➢ Stress of acrylic < 3.5 MPa
  - ➢ Force of support bar: < 9 t for pulling force & < 15 t for pushing force
- ☐ Main Challenges:
  - ➢ How to distribute the load reasonably on the 590 support bars
  - ➢ Design a strong acrylic support node

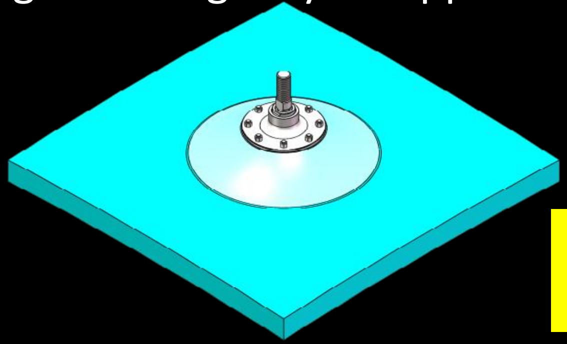






Steel node with disc spring

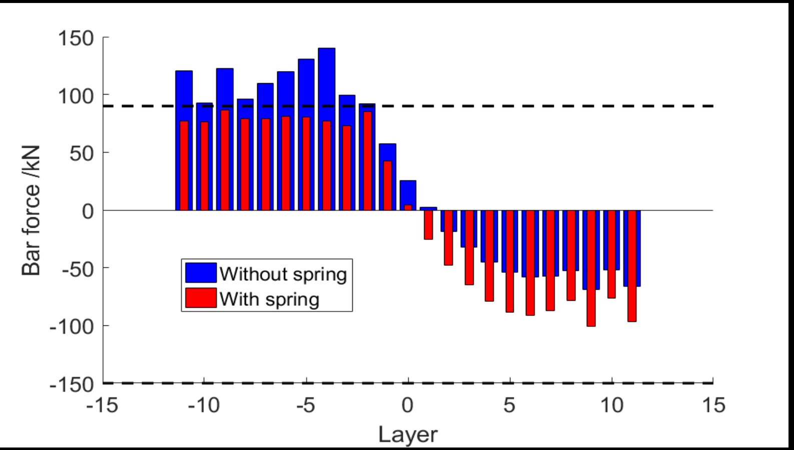




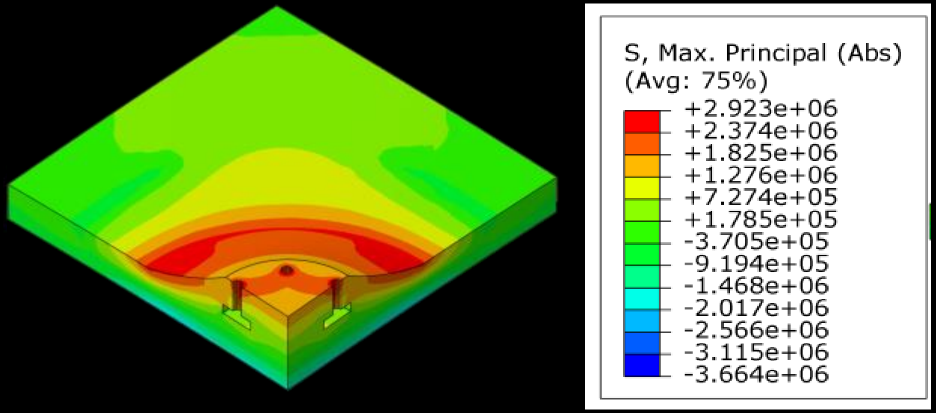
Acrylic support node

Key design of the central detector structure

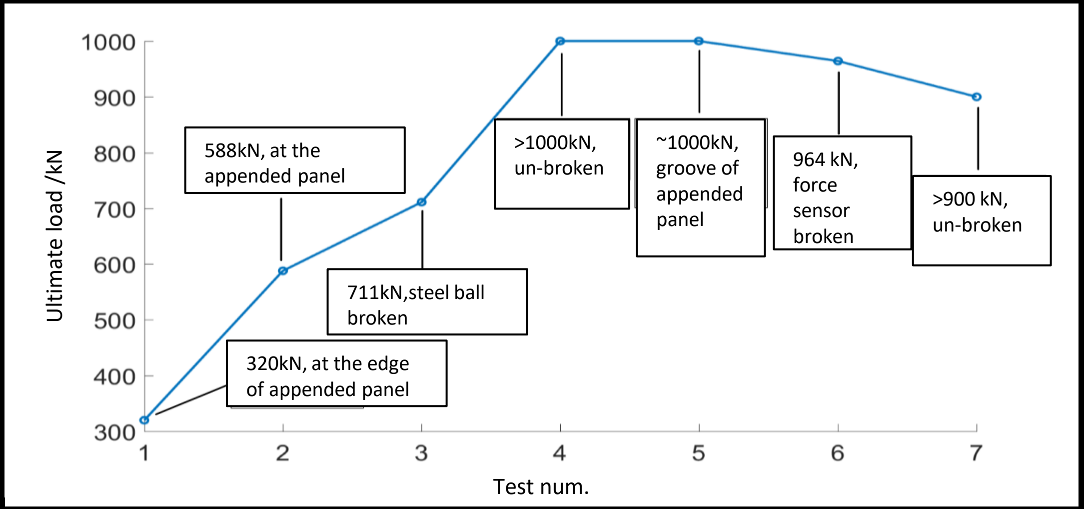
- Adjust the support bar force by designing the dis spring with certain stiffness
- The acrylic node becomes stronger by optimizing its structure, ultimate load: ~100 t



Bar force of each layer



Stress of acrylic node



Ultimate load of the acrylic support node

Acrylic node test

Long time performance of acrylic

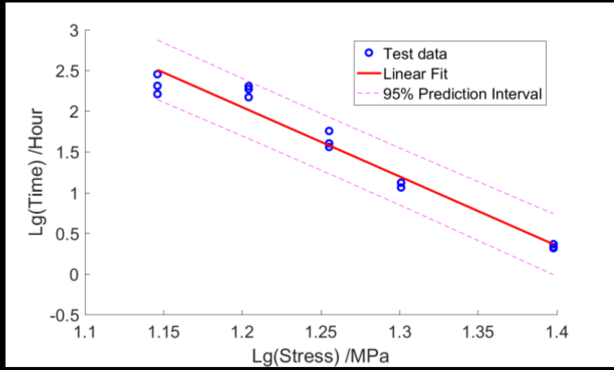
- Requirement: material is safe for 20 years running at JUNO's environment
- Environment: loading all the time in 20 ℃ water and LS
- Weak point: bonding line
- Long term performance:

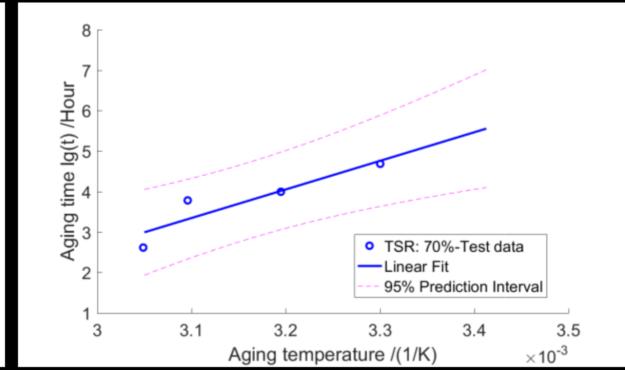
➢ Creeping:
- Ref. ASTM D 2990-01,
- Condition: 20 °C soaking in water and LS, stress: 30~12 MPa
- Result: creaking time: 104 years under 3.5 MPa stress

➢ Aging:
- Ref. standard: GB/T 7142-2002,
- Condition: 5.5 MPa soaking in water and LS, temperature: 30~50°C,
- Result: 50 years for tensile strength decreasing 30%

Creeping machine

Aging device





Creeping and aging performance of sample with bonding line

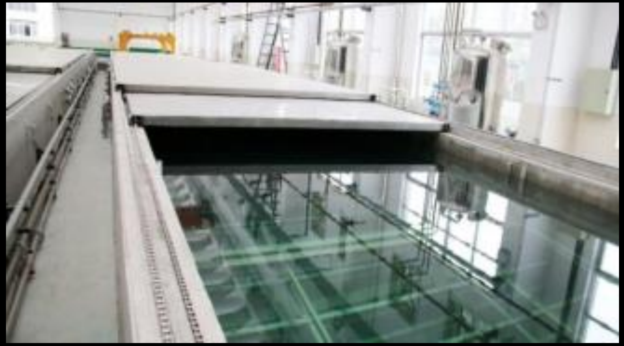
Radioactivity control of acrylic

- Radioactivity control :
  - Special pipeline for MMA transportation
  - Surface grinding and cleaning before factory delivery
  - Radioactivity measurement by IHEP.CAS
    - U238: < 0.3 ppt
    - Th232: 0.4±0.02 ppt

MMA $\xrightarrow{\text{Polymerization}}$ Flat panel $\xrightarrow{\text{Thermoforming}}$ Spherical panel → Machining → Acrylic node manufacturing → Grinding, cleaning and filming

Main progress of spherical panel production

Special pipeline for MMA transportation



Pool for panel polymerization

Filming

Thermoforming

Machining

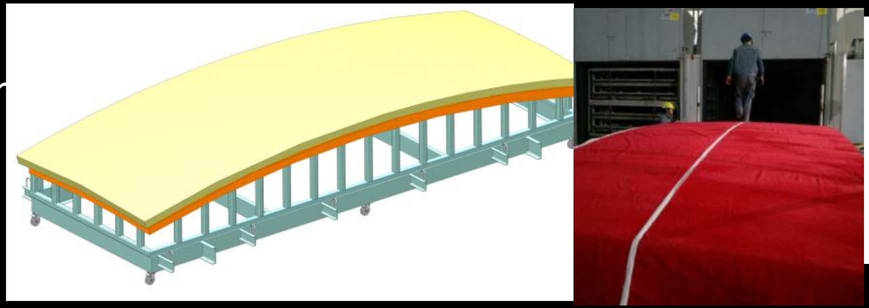
Grinding and polishing

Cleaning

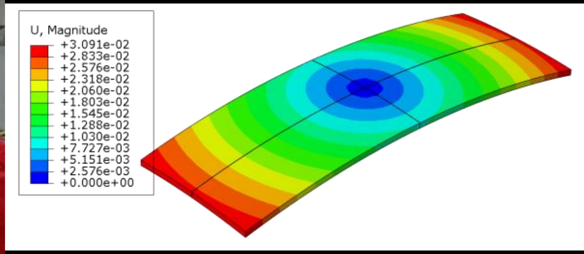
Filming

Manufacture of the acrylic spherical panel

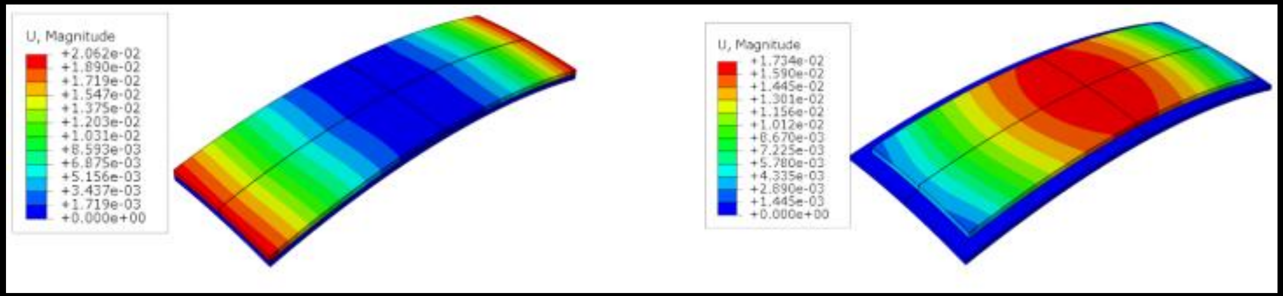
- Maximum size of panel: ~3*8 m, thickness 120 mm
- Difficulty in production: Flat < cylinder < sphere
- Challenges:
  - Panel would shrink during cooling
  - Long time thermoforming would make panel become yellow (Transmittance rate >96% @420nm for 120 mm thick panel)
- Scheme:
  - Optimize thermoforming curve to shorten the time
  - Adjust the dimension of mold



Spherical thermoforming mold



Shrinkage during cooling

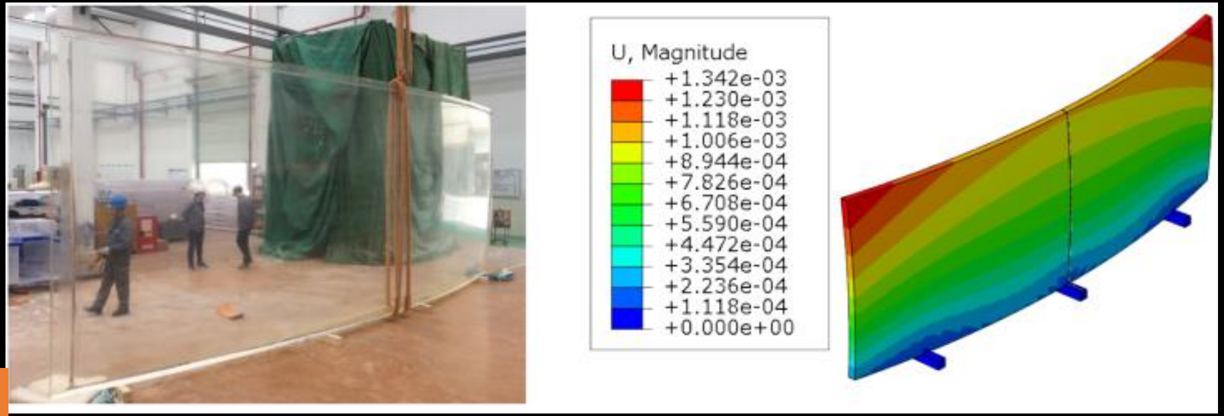


Panel on difference radius mold

Table: Measurement of first spherical panel （sample）

	Radius /mm
Mold	17799
Panel put on mold horizontally	17741
Panel stands in vertical position	17217

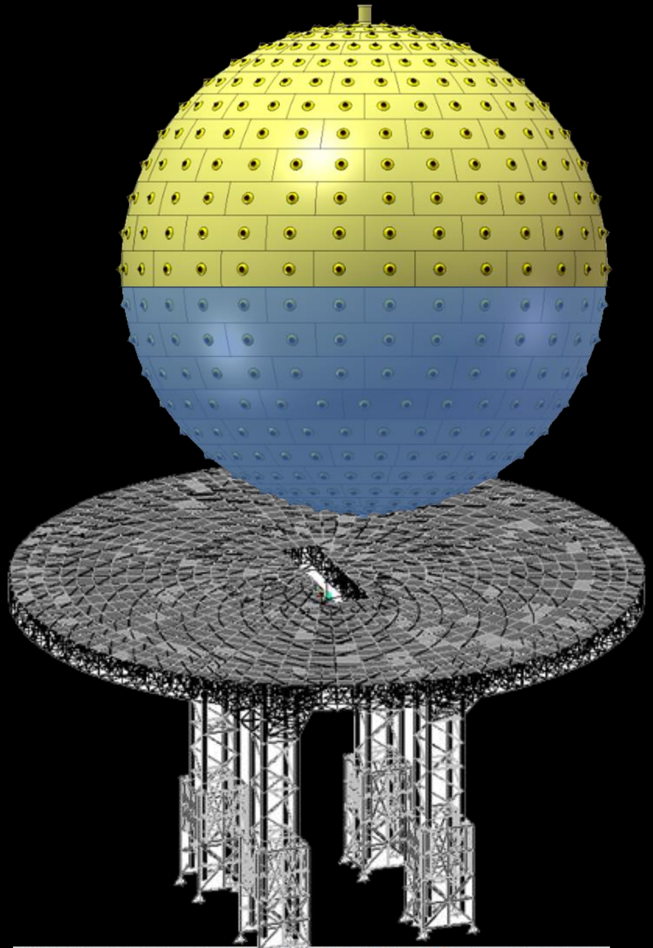
Design radius: 17700mm



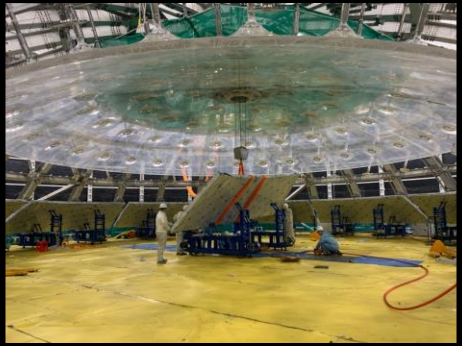
Panel measurement in vertical position and simulation by fea

Construction of the acrylic vessel

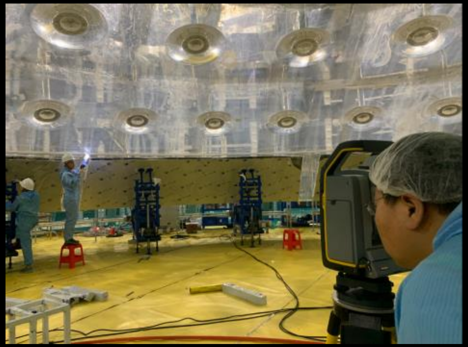
- 263 pieces of panel, 23 layers, constructed from top to bottom
- Installation platform: able to lift and expand



Construction progress of the acrylic vessel



Hoisting panel on the platform



Adjustment and measurement

Polymerization

Annealing

Install connection bar

Bonding line grinding

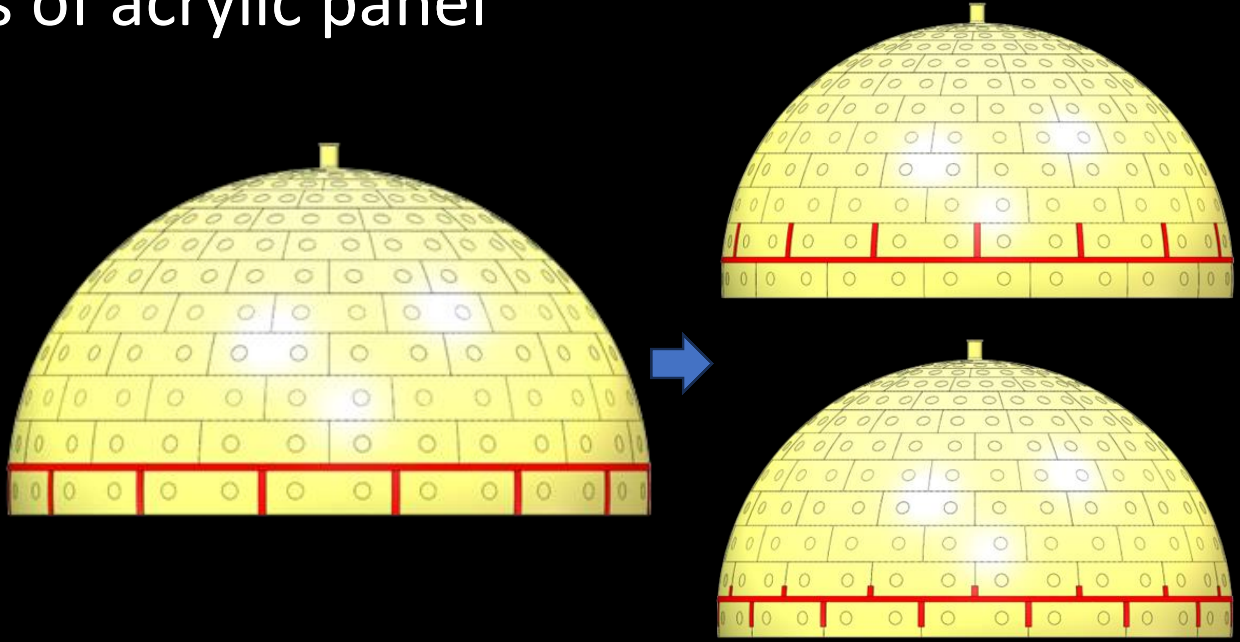
Cleaning

Filming

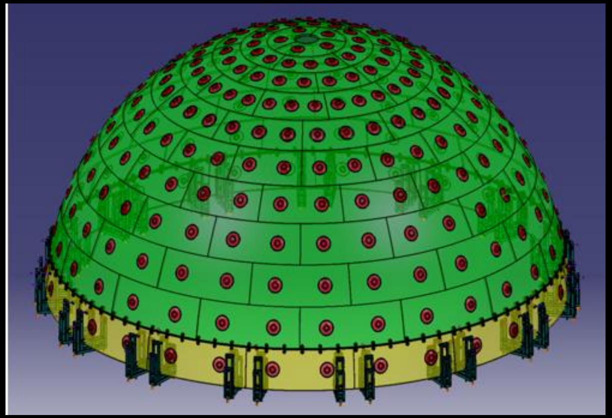
Installation platform

Key technologies of acrylic panel

- Bonding the 15 panels at the same time (15 vertical and 1 circle bonding lines) to shorten construction time
- Need to anneal the bonding lines for high bonding quality
- Challenges and technologies:
  - Glue volume decreases during polymerization →glue shortage in the bonding line → make a dam that can hold more MMA
  - Cracking during annealing→change the annealing method
  - Developed the stress monitor device

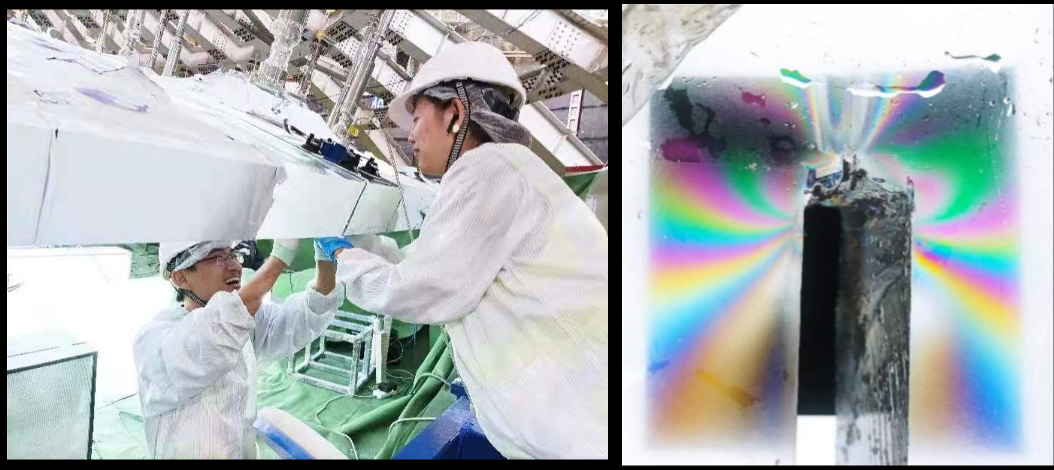


Annealing schemes



Vertical and circle bonding line

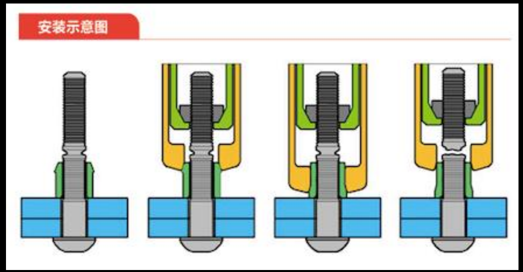
Cracking during annealing



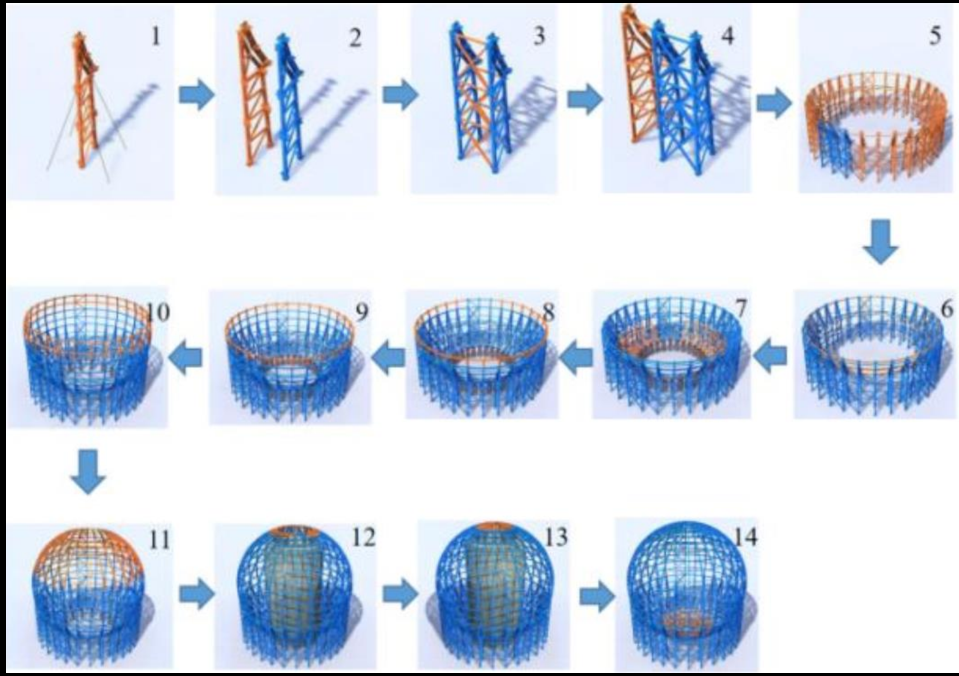
Stress monitoring device

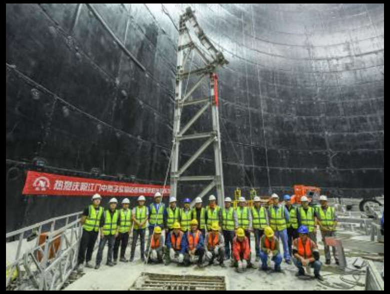
Key technologies of SS latticed shell during construction

- The shell is connected by bolts instead of welding: ~140,000 bolts➞req. high friction SS face >0.45(normally <0.2) ➞ SS surface coarsening process to increase the friction coefficient to be ~0.5
- High strength lockbolt, special riveting equipment: fast speed, prevent loosen, reliable, avoid seizing on nut, easy for installing and removing. High accuracy for the small hole clearance.
- The latticed shell was completed within ~ 5 months.
- Radius of latticed shell: measurement: 20530 mm， design: 20550 mm, difference 20 mm



High strength lockbolt





Construction progress of SS latticed shell

Status of detector

- The equator of the acrylic vessel is completed.
- Replace PE film with water soluble paper

Status of detector

- The SS latticed shell is completed except bottom four layers
- PMTs and electronics are being installed on the shell
- Hope to finish construction next year

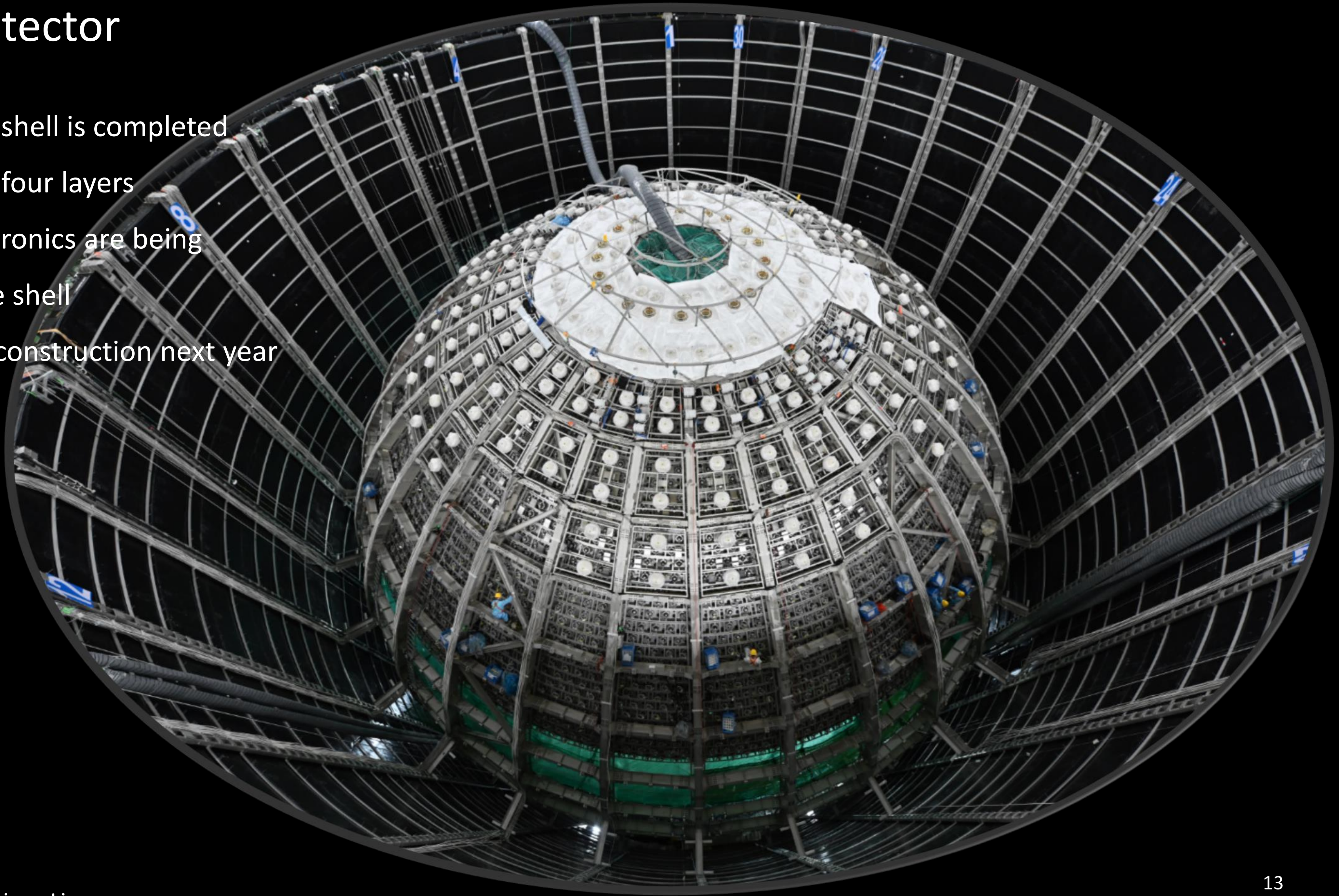


Photo provided by Yuexiang Liu

Summary

A lot of challenges are encounter during design and construction:

- The disc spring is used to solve the stress problem of acrylic vessel by distributing the force of supporting bar reasonably;
- A strong acrylic node is designed to ensure the safety of the acrylic vessel;
- Study the long-term performance (creep and aging) of acrylic to ensure the long-term reliability of detectors;
- The special production process provides JUNO with low radioactive background material;
- Study the thermoforming process of acrylic panel to improve its accuracy of curvature radius;
- The adoption of non-moving panel polymerization process makes it possible to polymerize multiple bonding lines at the same time that shorten the construction time;
- The optimized annealing process avoids the cracking of the bonding line;
- The surface treatment process of stainless steel improves the friction coefficient to be ~0.5, which makes it possible to construct stainless steel shell by bolts;
- The accuracy of the shell is improved by high strength lockbolt. The radius of the shell is only 20 mm smaller than design.