JUNO Central Detector R&D

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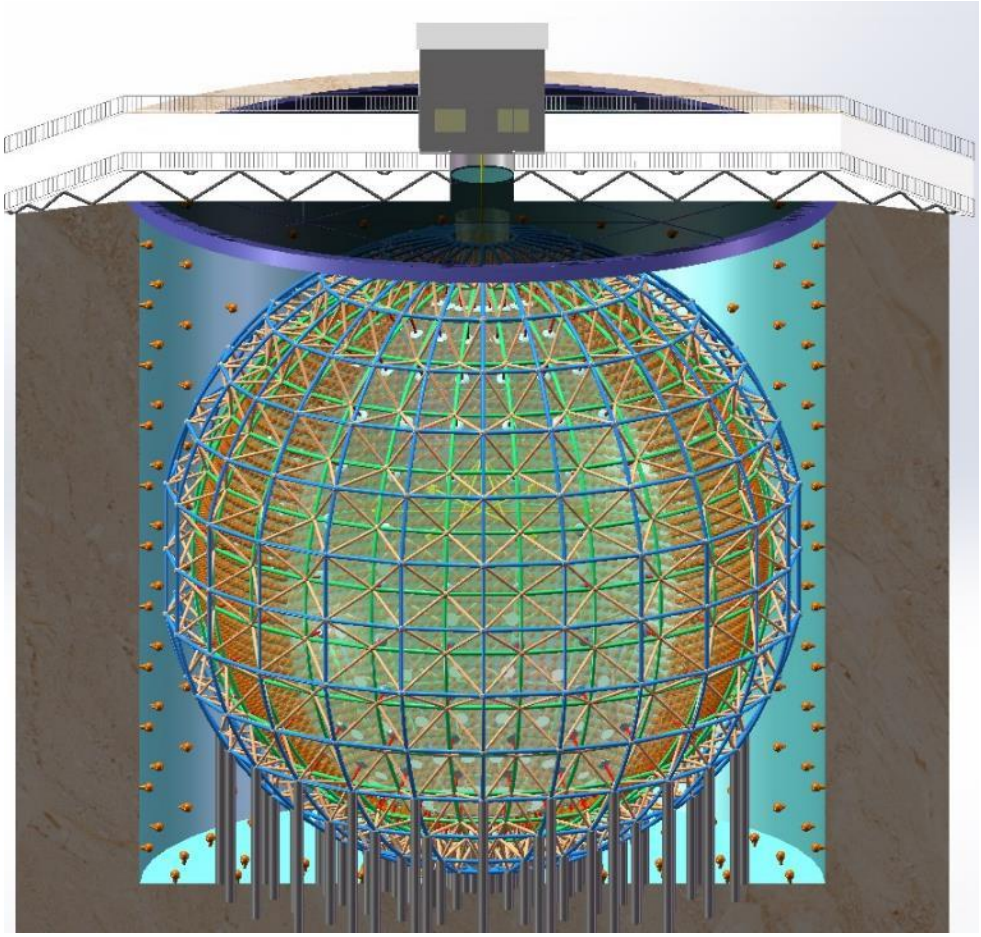
Outline

- Scheme of CD:
  - ⇨ Design requirement
  - ⇨ Central detector structure
- Central detector R&D:
  - ⇨ Strength analysis (steel truss, acrylic vessel and supporting point)
  - ⇨ Acrylic vessel assembly and bonding
  - ⇨ Properties of acrylic materials
- Onsite detector building R&D:
  - ⇨ Stainless steel truss
  - ⇨ Acrylic vessel
  - ⇨ PMT

The JUNO Experiment

- **Jiangmen Underground Neutrino Observatory, a multiple-purpose neutrino experiment, approved in Feb. 2013. ~ 300 M$.**

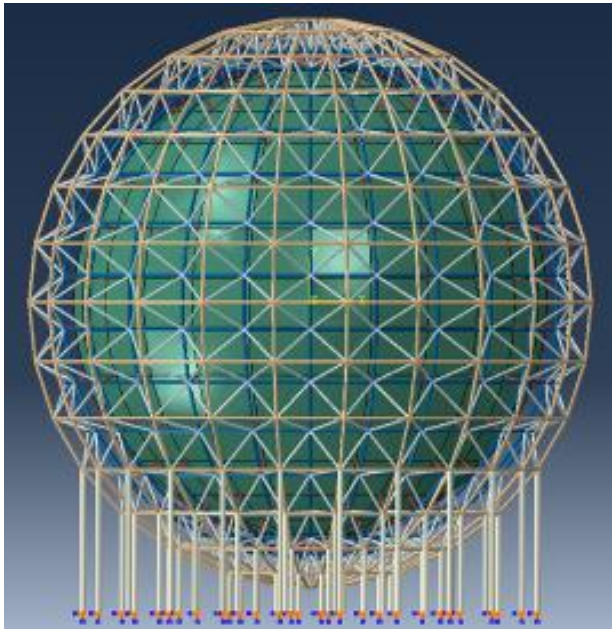


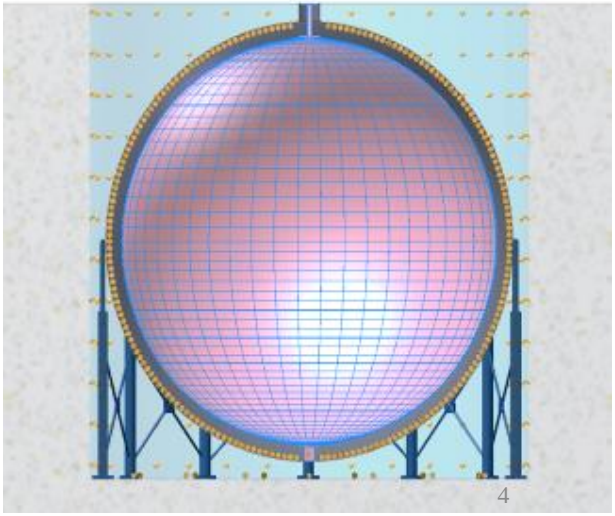
- **20 kton LS detector**
- **3% energy resolution**
- **700 m underground**
- **Rich physics possibilities**
  - **Reactor neutrino for Mass hierarchy and precision measurement of oscillation parameters**
  - **Supernovae neutrino**
  - **Geoneutrino**
  - **Solar neutrino**
  - **Atmospheric neutrino**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

Talk by Y.F. Wang at ICFA seminar 2008, Neutel 2011; by J. Cao at Nutel 2009, NuTurn 2012 ;
Paper by L. Zhan, Y.F. Wang, J. Cao, L.J. Wen, PRD78:111103, 2008; PRD79:073007,2009

JUNO Central Detector (CD)

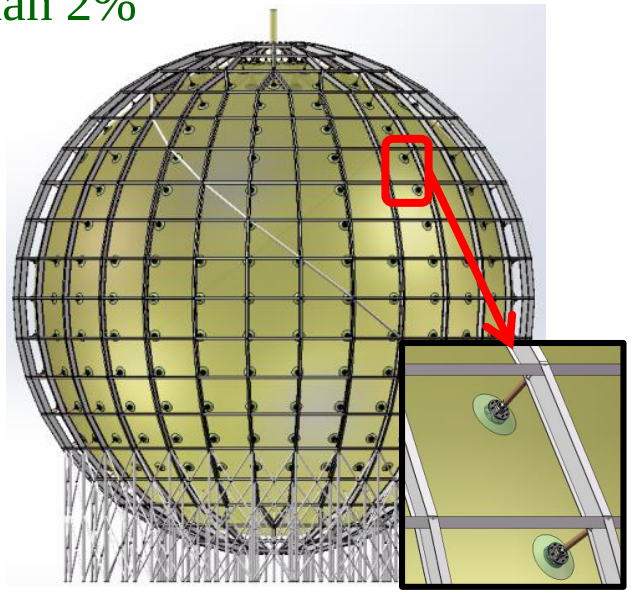
- Some basic numbers:
  - ⇨ Target: 20 kt LS
  - ⇨ Backgrounds/reactor signal: Accidentals (~2%), $^{9}Li/^{8}He$ (~3%), fast neutrons (<1%)
- A huge detector in a water pool:
  - ⇨ Default option: acrylic tank (D~35m) + SS truss
  - ⇨ Alternative option: SS tank (D~39m) + acrylic structure + balloon
- Challenges:
  - ⇨ Engineering: mechanics, safety, lifetime, …
  - ⇨ LS: high transparency, low background
  - ⇨ PMT: high QE, high coverage
- Final choice:
  - ⇨ Acrylic tank + single layer SS truss
  - ⇨ Better stability and low risk





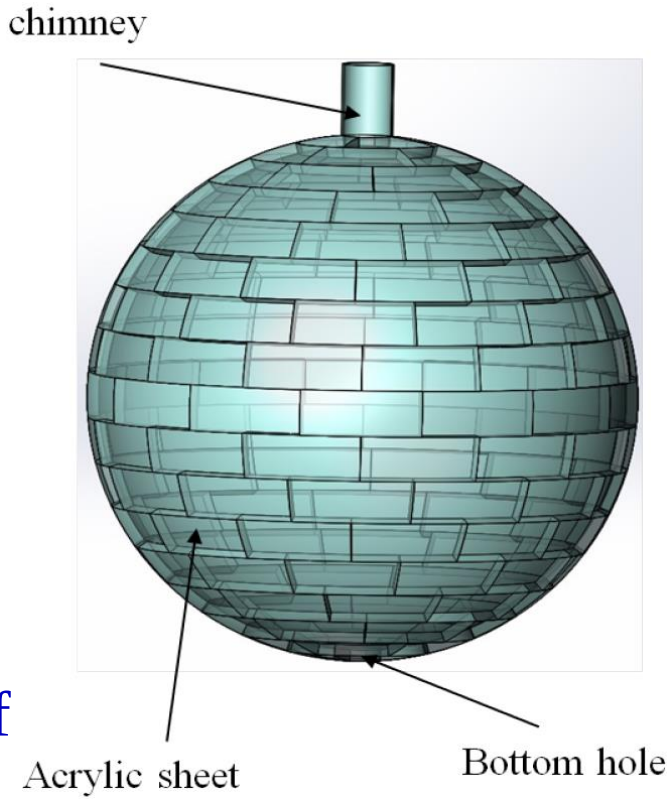
Scheme of CD

- Design requirement:
  - ⇨ **Stability:** reliable structure to ensure long-term stable operation for more than 20 years and acrylic sphere's stress is less than 5 MPa
  - ⇨ **Steel structure:** stainless steel's stress is less than 185 MPa, and displacement of whole structure is less than 1/250 its diameter
  - ⇨ **Material:** low background material and compatible with water or LS(<1%)
  - ⇨ **Supporting rods:** Light blocking rate is less than 2%
- Central detector building:
  - ⇨ Acrylic sphere supported by single-layer shell
  - ⇨ **Acrylic sphere**: Φ35.4m, 600t
  - ⇨ **Stainless steel frame**: Φ40m, ~340t
    - Connecting nodes: ~500
    - Diagonal brace: increasing stability
  - ⇨ **20 inch PMT**: ~17000



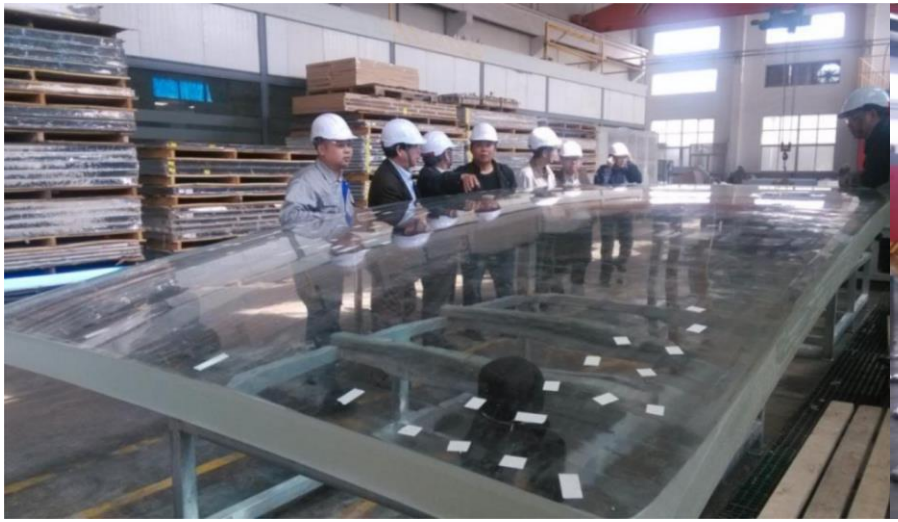
The acrylic sphere

- More than 170 pieces of acrylic will be assembled and bonded onsite to be a 35m sphere.
  - ⇨ Forming panel size: ~ 3m x 8m x 120mm
- A chimney of about 1 m diameter is designed on top of the acrylic sphere
  - ⇨ It will be used as the filling port and interface to the calibration system.
- An outlet may be designed on the bottom of the sphere
  - ⇨ For cleaning of the sphere and LS recycling during detector running.



Practice of forming spherical panel

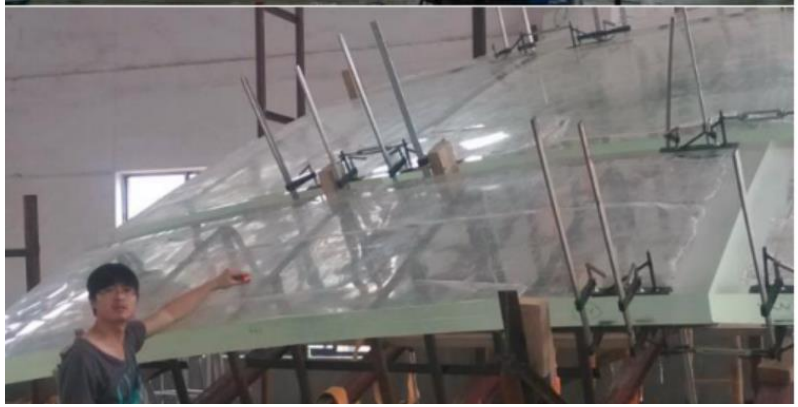
- The companies have successfully done the thermoforming practice.
- Forming panel size: ~ 3m x 8m x 120mm, R=17.7m

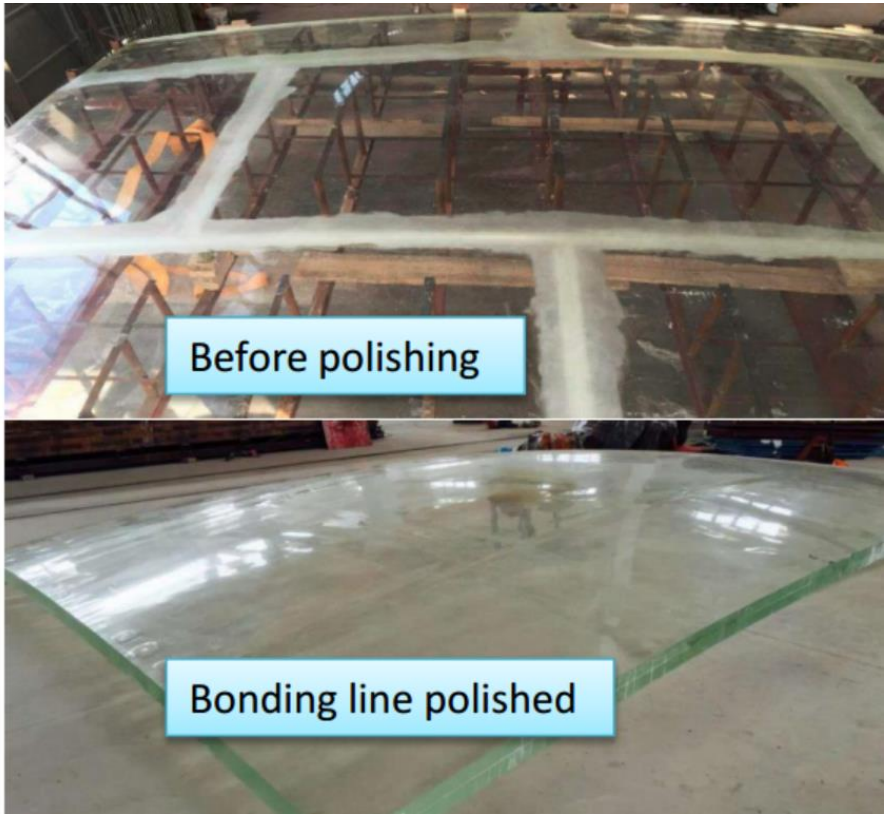


- The panel was polished and surveyed
  - ⇨ Deviation of most survey points is less than 6mm, several edge points have a little more deviation
  - ⇨ This forming is satisfied for us, the companies think they can do it better in future.

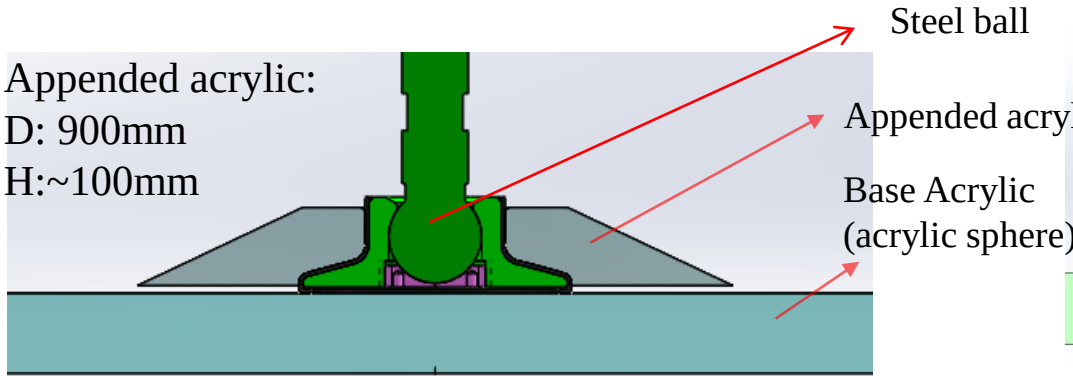
Practice of on-site assembly and bonding

- Size of Prototype section: 6 x 8m, 1/80 of total sphere
- Bonding method: quick bonding (~6h for curing)

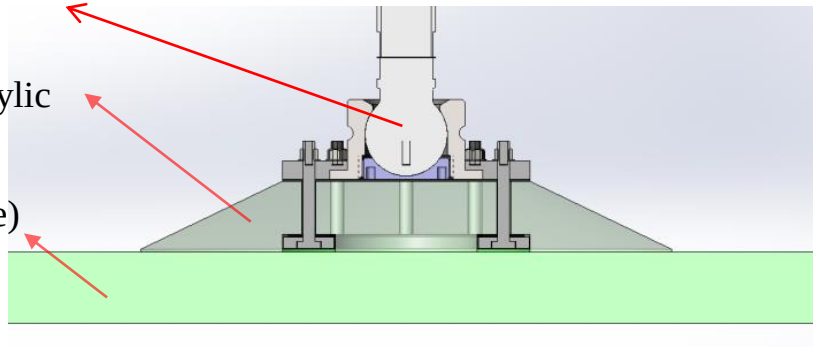




Joint of the Acrylic and Truss

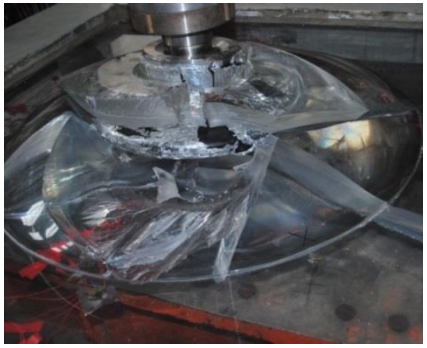


Node A



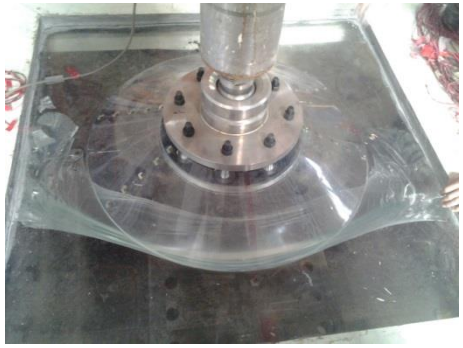
Node B

1:1 Prototype



Node A

Breaking strength: **51tons**



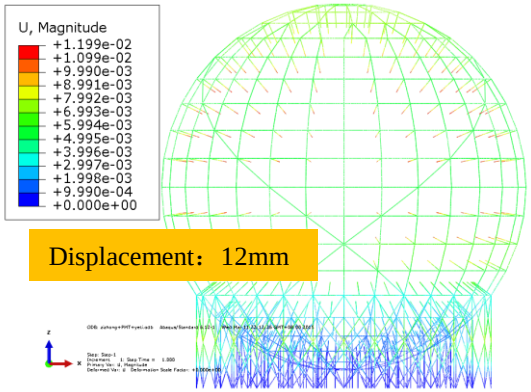
Node B

Breaking strength: 32ton

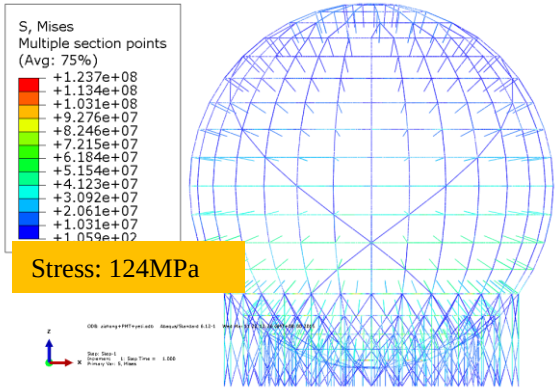
- The maximum breaking strength of scaled node is above 51tons, more than 3 times higher than running conditions, ~14/16 tons.
- Need to improve node structure and its processing technology to further reduce node's stress and ensure its quality.

Finite Element Analysis (shell)

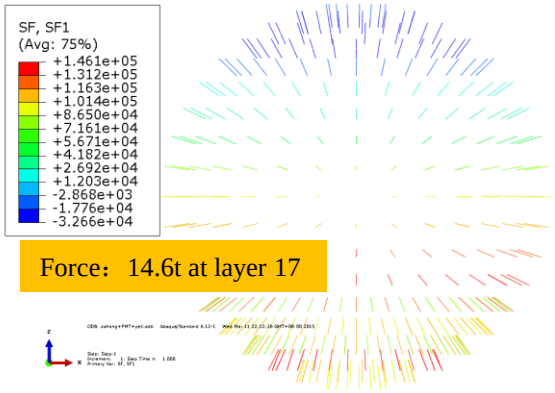
Global FEA (shell)



Displacement：12mm



Stress: 124MPa

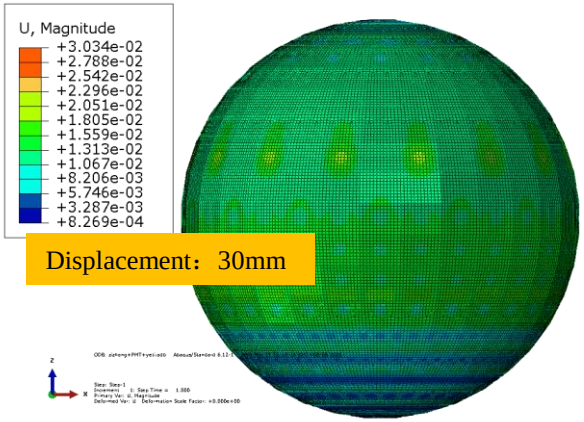


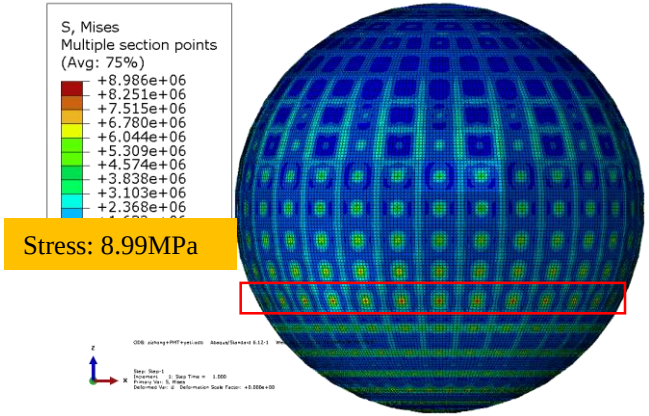
Force：14.6t at layer 17

- Shell is strong enough to support acrylic sphere:
  - ⇨ Displacement is less than 1/250 shell's diameter
  - ⇨ Stainless steel stress is less than 185MPa
  - ⇨ Structure's safety factor(Dual nonlinear buckling) is 2.8, higher than 2 that the standard expressly provided
- Reducing axial force of the supporting bar:
  - ⇨ Before filling, pre-loading supporting bars at layer 17 about 3 tons
  - ⇨ Increasing liquid level inside sphere higher than that outside's, about 3m.

Finite Element Analysis (acrylic sphere)

Global FEA (acrylic sphere)

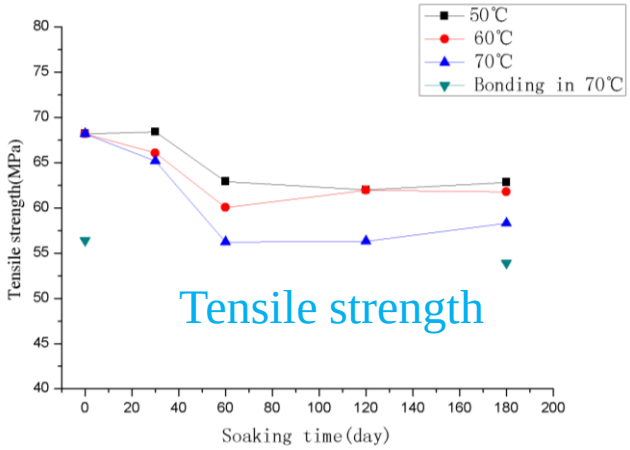




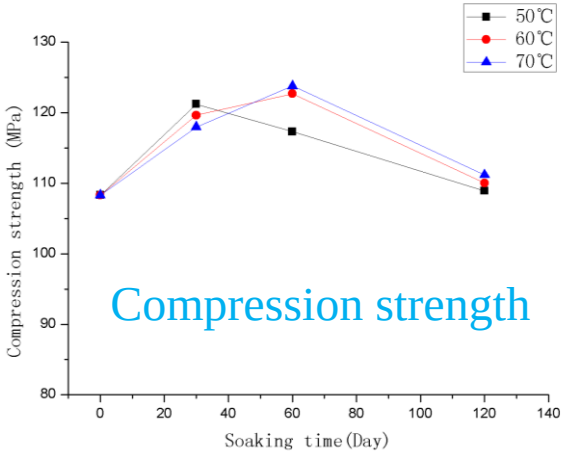
- The maximum displacement is ~30mm at south pole.
- Acrylic sphere's stress is less than 5 MPa
  - ⇨ From global FEA, the maximum stress is 8.99 MPa at supporting nodes. It's singularity point.
  - ⇨ From local FEA, the maximum stress is 5.1 MPa.
  - ⇨ If the axial force of the supporting bar is reduced to be less than 10 tons, the maximum stress will be ~4MPa.

Properties of the acrylic material

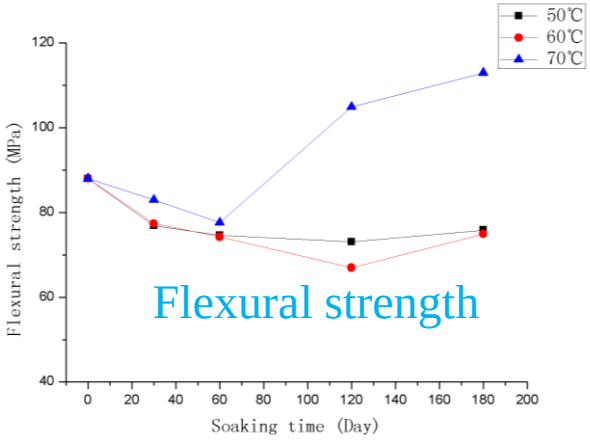
- Mechanical property test:
  - ⇨ Tensile, compression, flexural strength: 68.2 MPa, 108.3 MPa, 88.0 Mpa
- Heat aging test in LAB:
  - ⇨ It is known that 60 days at 70 degrees corresponds to 16 years at 20 degrees
  - ⇨ The tensile strength of acrylic will decrease by about 18% after 16 years at 20^{o} temperature in LAB.



Tensile strength



Compression strength



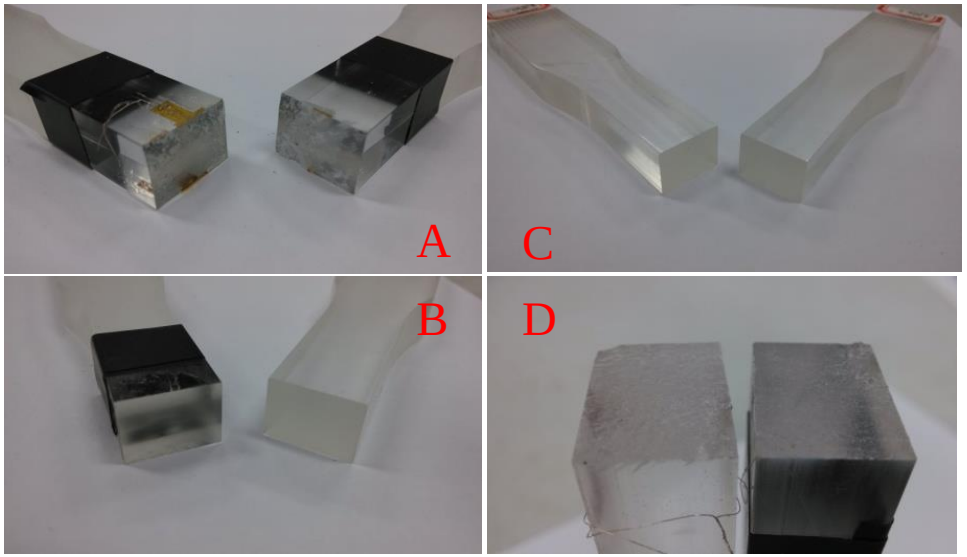
Flexural strength

- Aging by outdoor exposure:
  - ⇨ After 14 years and 17 years aging, the tensile strength decreased by 17% and 21.4% respectively.

Properties of the acrylic material

- In the process of making acrylic sphere, a lot of bonding work should be done on site, so bonding quality and time-consuming have to be controlled:

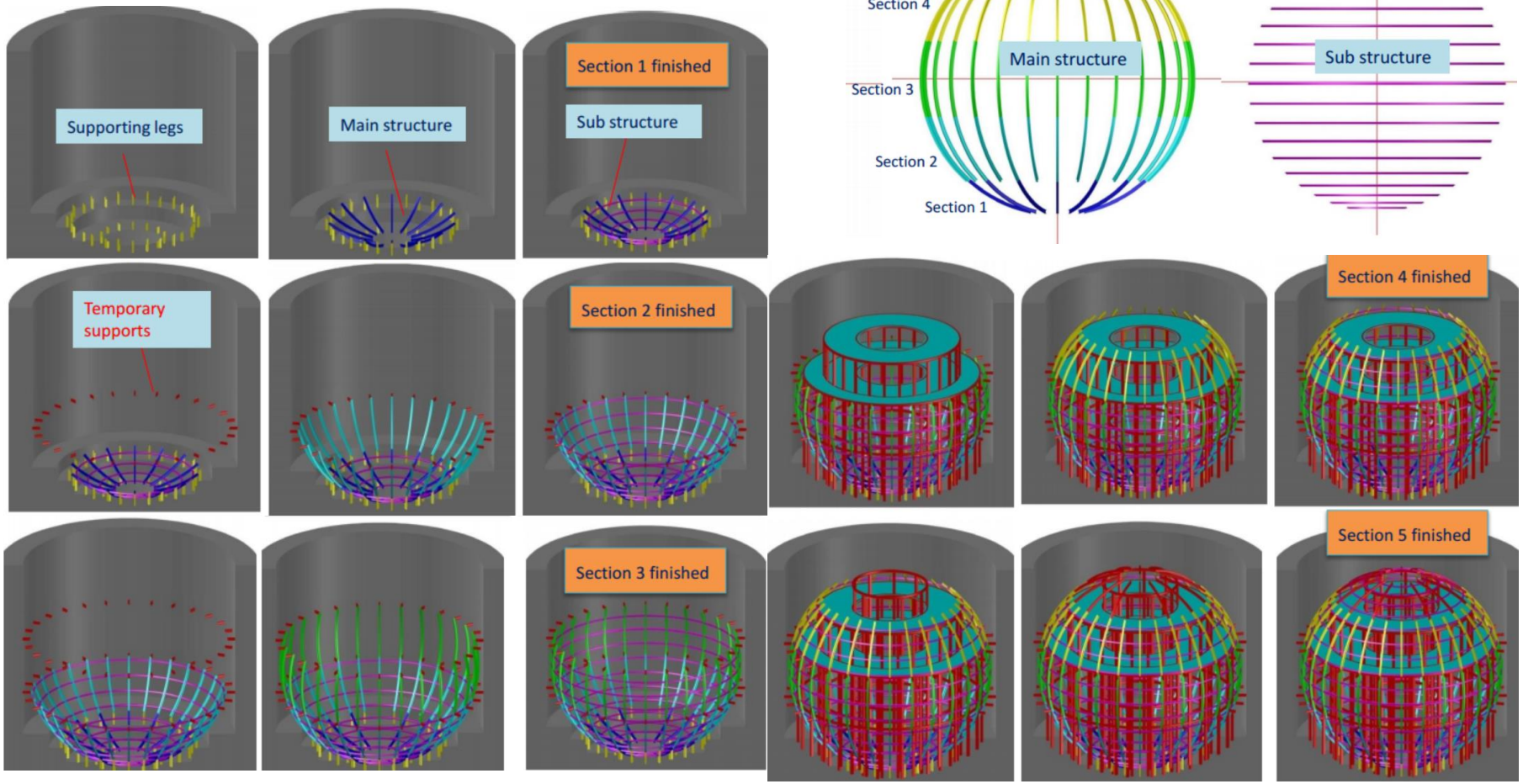
Bonding methods		Time consuming	Tensile strength/MPa	Percentage of strength
Normal sheet without bonding			68.2	100%
Conventional bonding (A)		12 hours	56.4	82.7%
UV light catalyzed bonding	**Without annealing (B)**	3 hours	37.2	54.5%
	Annealing (C)	7 hours	46.5	68.2%
Fast bonding (D)		4 hours	55.3	81.1%



Fractures of A and D are tough, and they locate in the middle of bonding area. While fractures of B and C are smooth, and they locate at the interface of the bonding area, which indicate poor bonding quality.

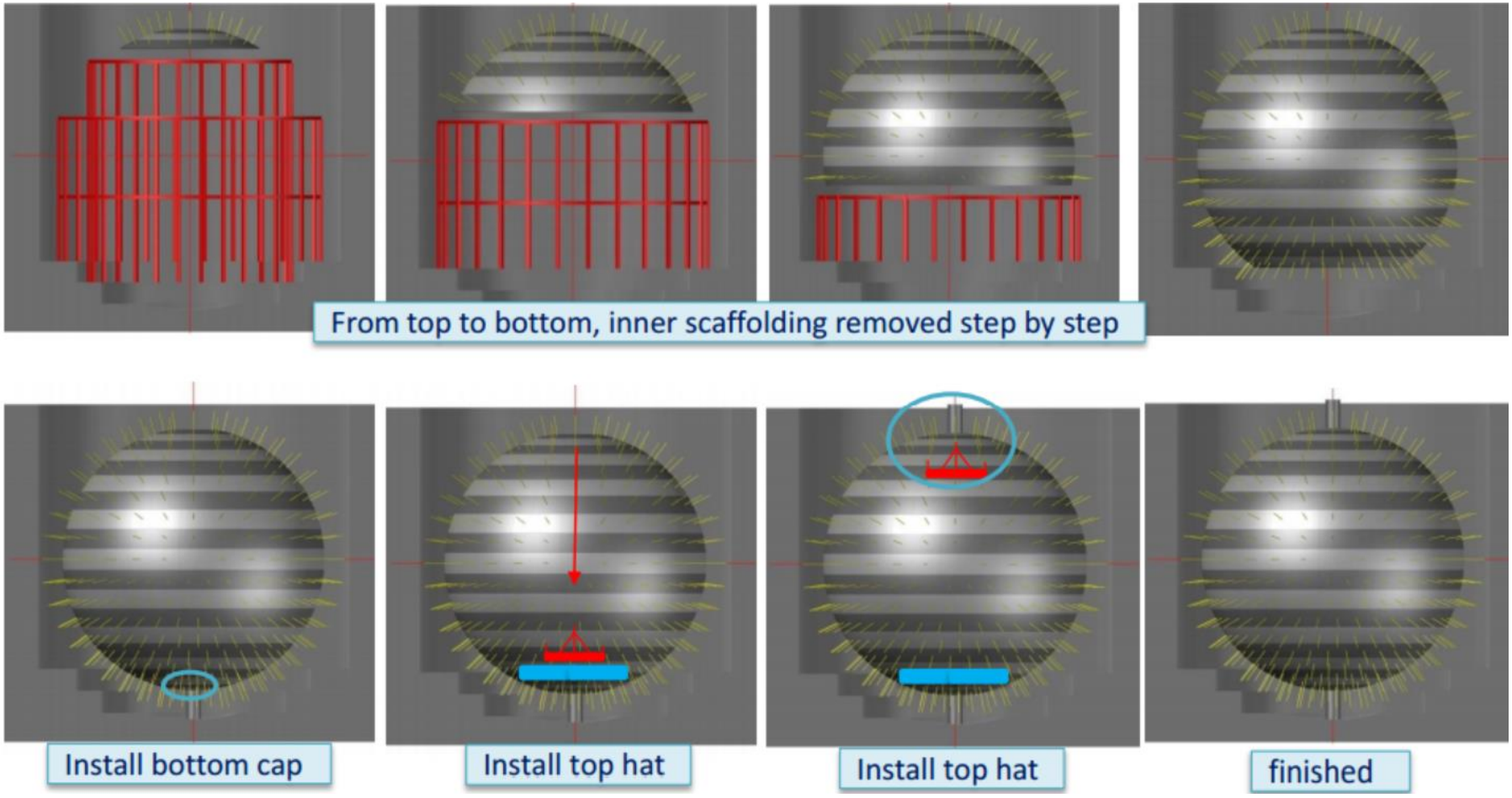
General idea of detector building

- Building sequence: steel frame—Acrylic sphere—PMT installation
- **Steel frame** built: from bottom to top



General idea of detector building

- Building sequence: steel frame—Acrylic sphere—PMT installation
- **Acrylic sphere** built: from top to bottom



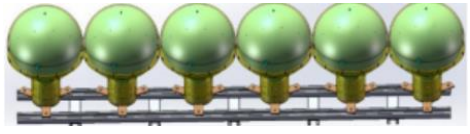
General idea of detector building

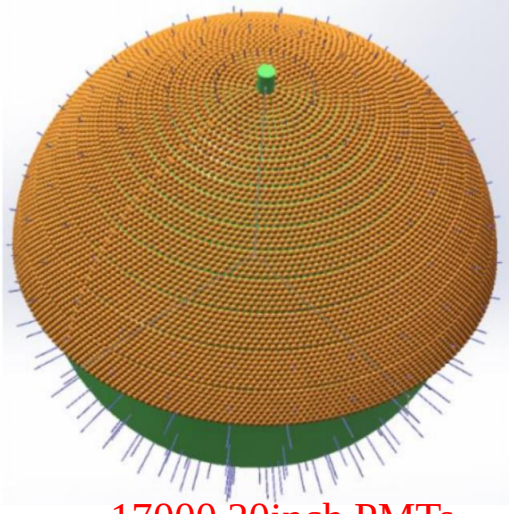
- Building sequence: steel frame—Acrylic sphere—PMT installation
- **PMT installation**: from top to bottom, window element

  ⇨ **Left:** Install the PMTs behind main structure beam
  2 PMTs as an element

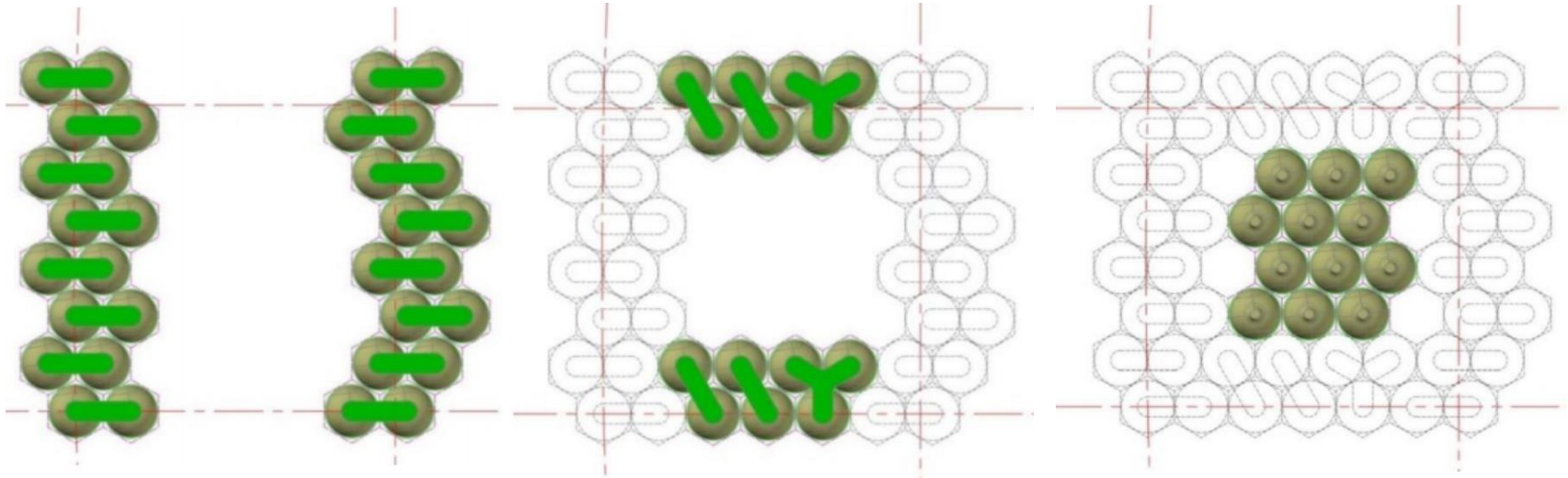
  ⇨ **Middle:** Install the PMTs behind sub structure beam
  2 or 3 PMTs as an element

  ⇨ **Right:** Install the PMTs in the windows
  Lots of PMTs as an element





~17000 20inch PMTs



Milestones

- Integration drawing of engineering: 2016.7
- Truss assembly onsite: 2018.4.1 ~2018.6.30
- Acrylic assembly onsite: 2018.7.1~2019.3.31
- PMT installing: 2019.4.1~2019.6.30
  - ⇨ Including PMT and electronics installing and check
- Filling: 2019.8.1~2019.12.31
  - ⇨ Filling water both in water pool and CD: 2 months
  - ⇨ Replacing water with LS in CD: 3 months
- Data taking: 2020 beginning

Summary

- Acrylic option is chosen as JUNO central detector.
- Central detector R&D
  - Strength analysis
    - The stainless steel shell is strong enough to support acrylic sphere
    - Maximum stress of acrylic sphere can be ~4MPa
    - The maximum breaking strength of scaled node is above 51tons, more than 3 times higher than running conditions, ~14/16 tons.
  - Properties of acrylic material:
    - The tensile strength of acrylic will decrease by about 18% after 16 years at 20^{o} temperature in LAB.
    - A lot of bonding test has been done.
- Onsite detector building R&D
  - ⇨ The companies have successfully done the thermoforming practice.
  - ⇨ Building sequence: Steel frame—Acrylic sphere—PMT installation
  - ⇨ Data taking will be started at the beginning of 2020.

Thanks !