Linear Collider Detector Project HCAL Construction

Ronan McGovern

Diego Perini

Wolfgang Klempt

Key Questions

1. Can a tungsten HCAL detector be designed with acceptable:
    1. Physics performance?
    2. Stress levels and deformation?
    3. Cost?
2. How can such a detector be analysed from a structural point of view?
3. What are the key structural, assembly and manufacturing issues associated with a tungsten HCAL?

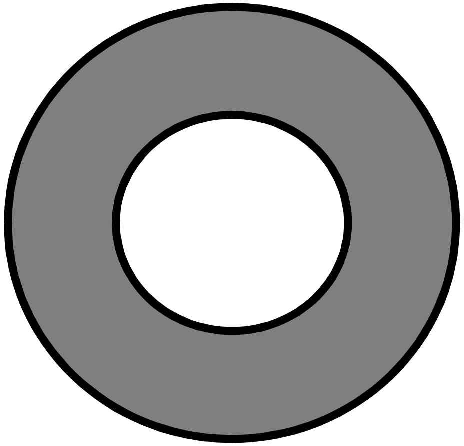
Design Approach

1. Establishment of HCAL specifications
   - Physicist's requirements
   - Known physical limits (e.g. superconductor diameter)
2. Determination of Tungsten plate availability and mechanical behaviour
3. Initial design of HCAL geometry
4. Structural analysis of HCAL

HCAL Specifications

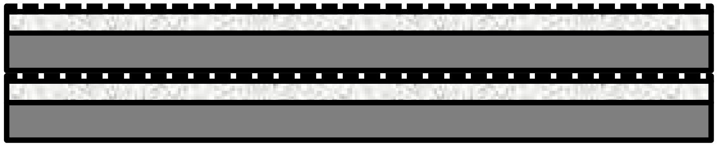
Detector Dimensions

- Inner Diameter: 2800 mm
- Outer Diameter: 5800 mm
- Detector Length: 3500 mm
- Total W radial thickness: 700 mm



Layer Composition

- Gap: 1 mm
- Scintillator thickness: 7 mm
- W plate thickness: 12 mm
- Number of Layers: ≈ 60



Tungsten Plate Characteristics I

- Mechanical properties of pure W and alloys
  - Density of 17-19 g/cm^3
  - Young's modulus of 350-400 GPa
  - Elongation of less than 5% (close to 0 for pure W)
- Cost
  - Introducing holes/cutouts in plates and subsequent stress concentrations remain an issue
    - Such cutouts are essential in current designs

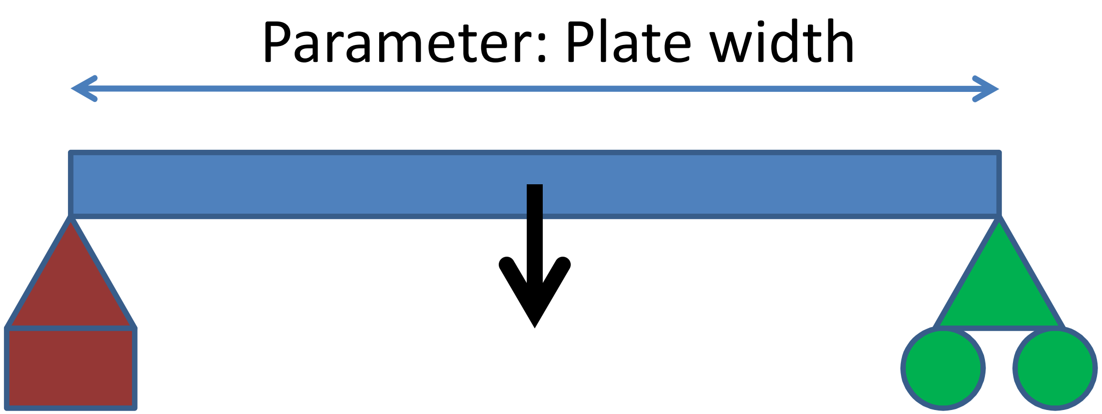
Tungsten Plate Characteristics II

Maximum W plate size

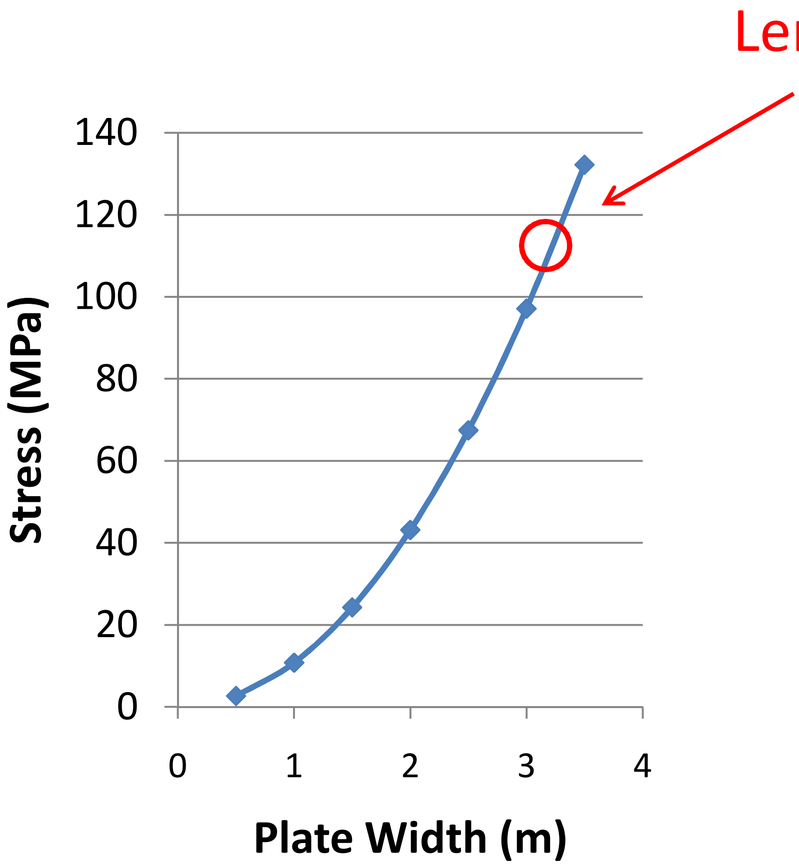
Metal	Tungsten INERMET 176	
Young's Modulus	350	GPa
Poisson's Ratio	0.3	-
Thickness	0.012	m
Density	17600	kg/m^3
Plate Length	1	m

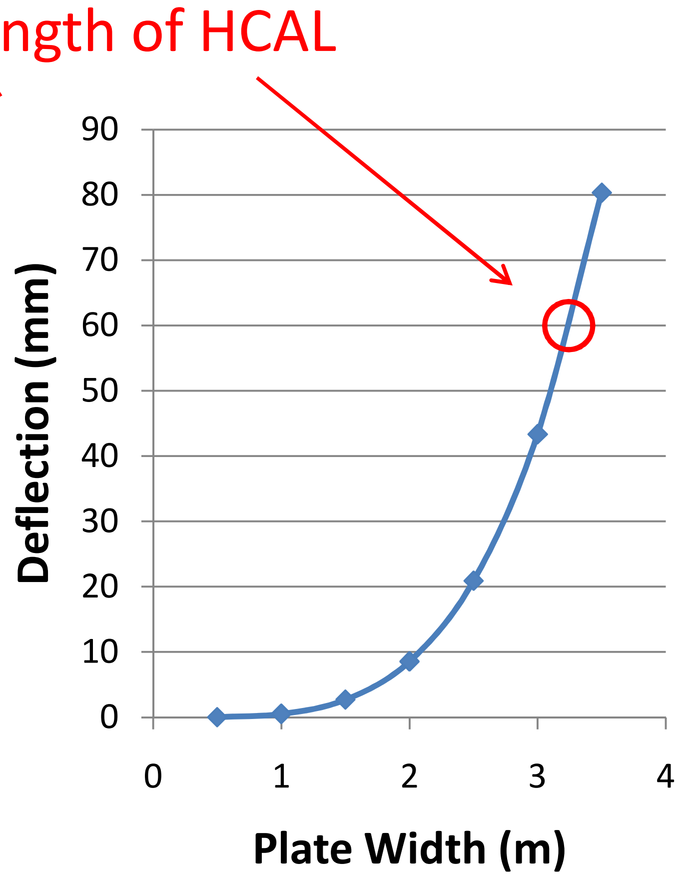
Calculate:

1. Max Stress
2. Deflection at Centre



Maximum W plate size – Results





Stress is proportional to plate width squared

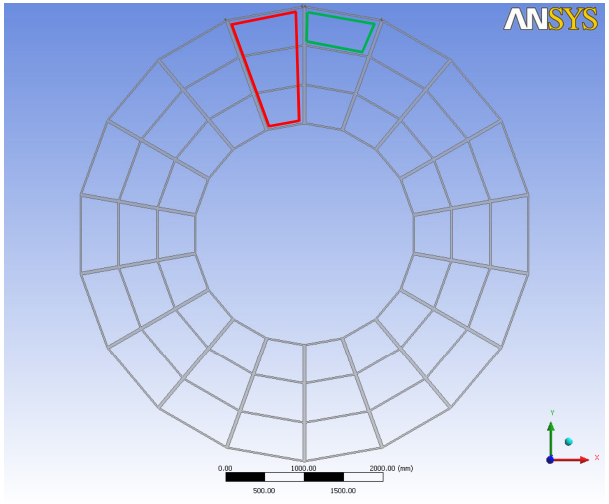
Deflection is proportional to 4th power of plate width

Tungsten Plate – Conclusions

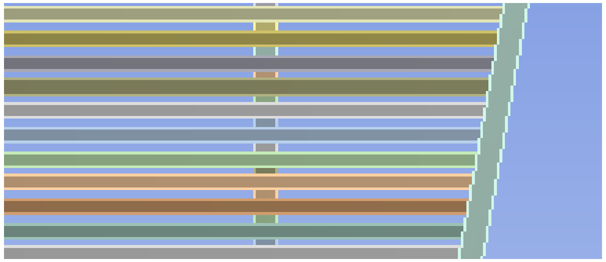
- Use of plates 3.5 m long, 1 m wide and 12 mm is theoretically possible.
- At present, plates available are:
  - 12 mm thick
  - 1.2 m wide
  - 1.6 m long
- It is hoped that improvements in manufacturing processes will make longer plates (3.5 m) available.
- Bolting and overlapping of plates may allow smaller plates to be used.

Geometry Choice and Analysis Outline

- 18 symetrical sectors
- 3 "boxes" per sector
- Plates bolted together using washers to provide gap for scintillators



- Lattice
- Sector
- Box



Analysis Outline

- How should one support the HCAL?
- What is the global detector deformation?
- What are the max stresses in the <u>steel lattice</u>?
  - Where do they occur?
- What are the max stresses in the <u>bolts</u> and <u>tungsten plates</u>?
  - Where do they occur?

3-Step Approach

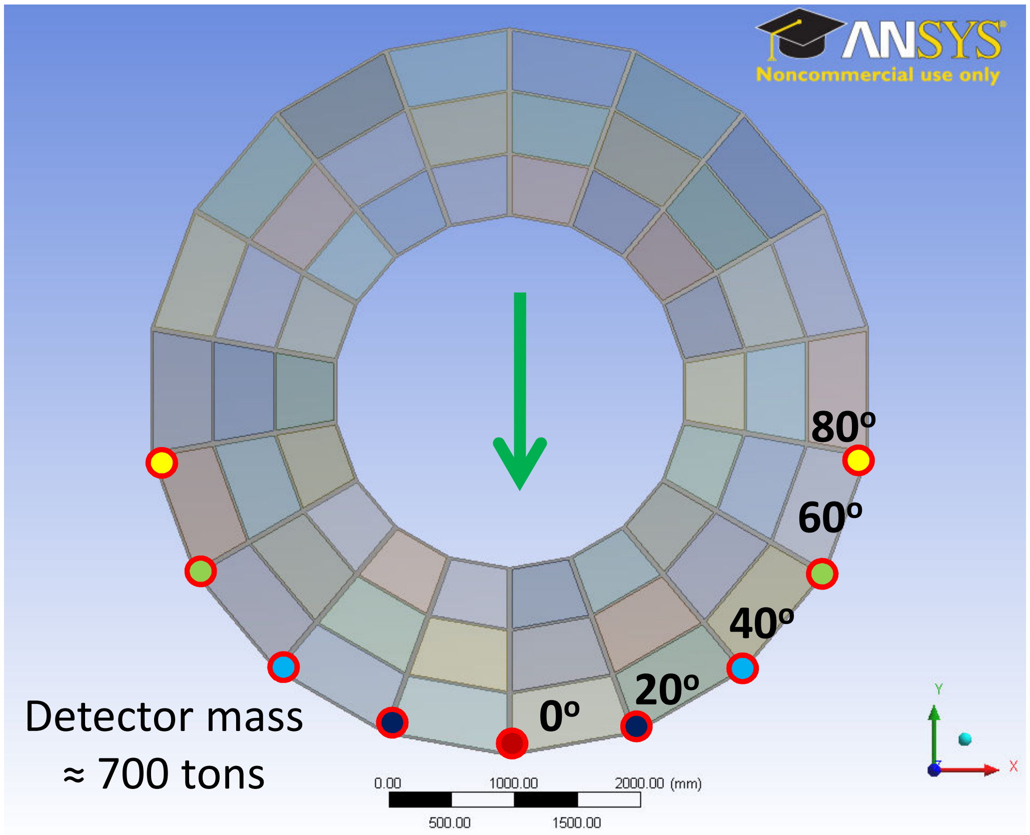
Model is almost 2D – apart from bolts

Solution:

1. Model the entire detector (18 sectors) in 2D
   a. Determine optimal support position
   b. Determine global deformation
   c. Determine forces acting on each sector
2. Adjust and validate 2D model by comparing a 2D and a 3D sector
3. Apply forces obtained from 2D model to a 3D sector to analyse the 3D state of stress in a sector

Optimal Support Position

Optimal Support Position



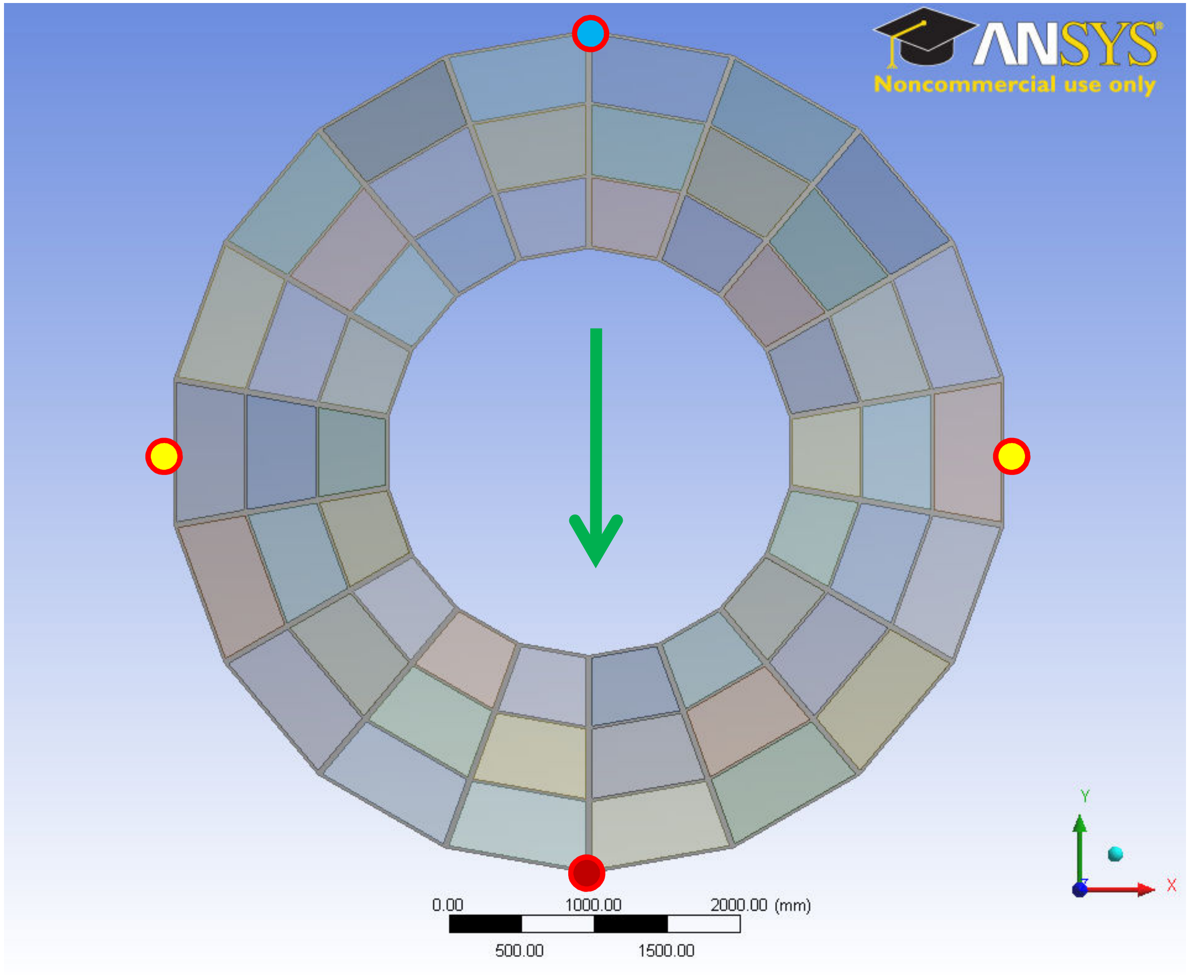
Detector mass ≈ 700 tons

✓Weight of Tungsten included

➢Rigidity of Tungsten neglected

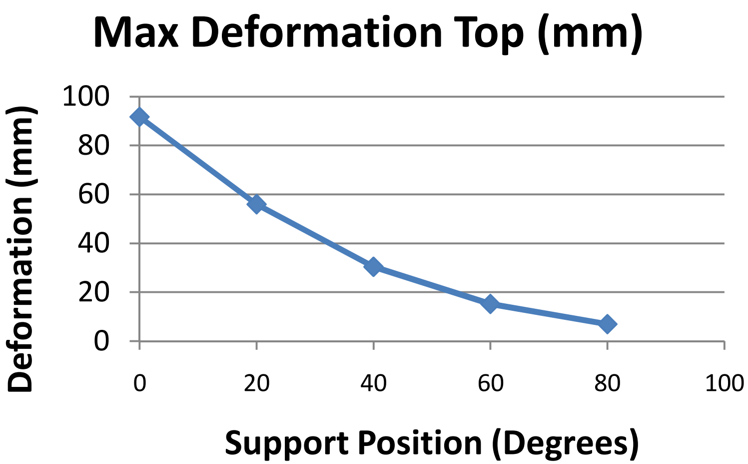
1. Consider different support configurations at 20º intervals
2. Apply earth gravity
3. Calculate deformation for each support configuration

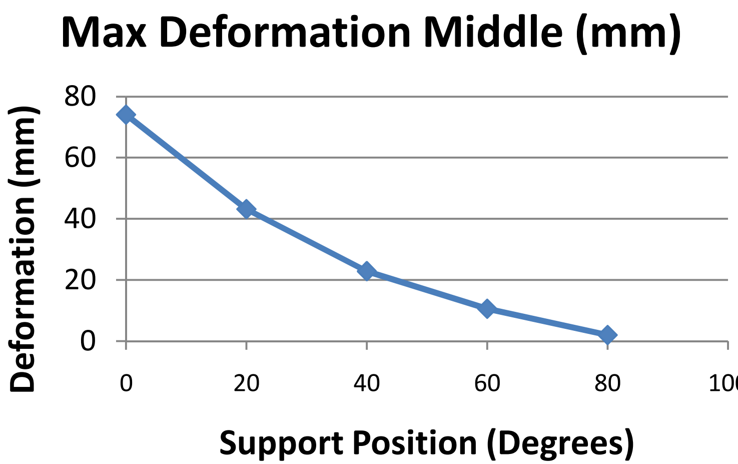
Optimal Support Position

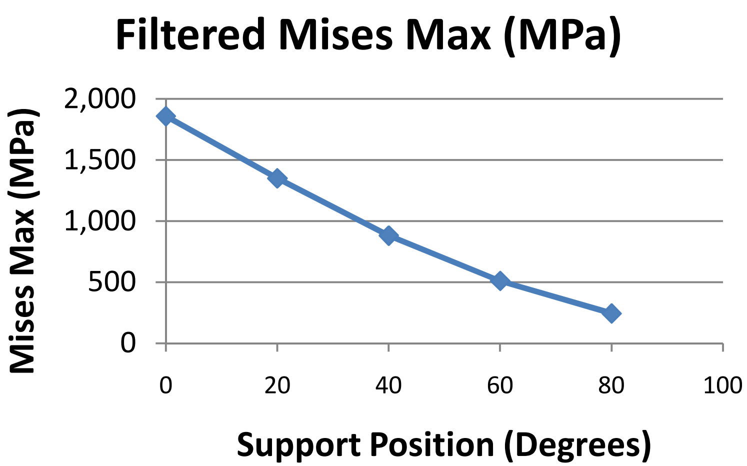


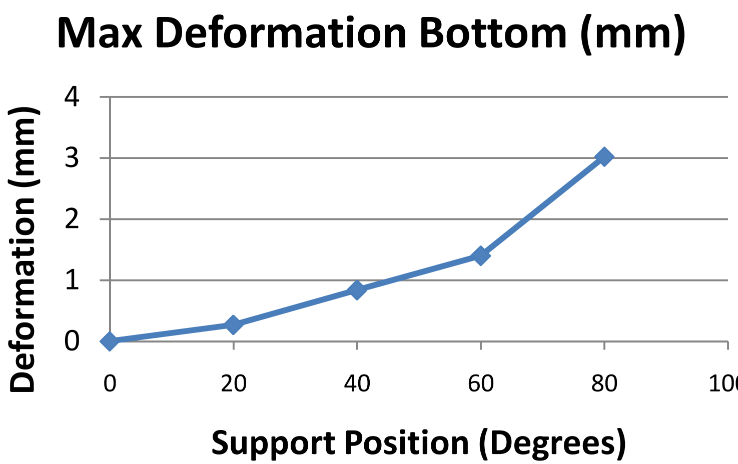
Observe deformation at top, middle and bottom points

Optimal Support Position



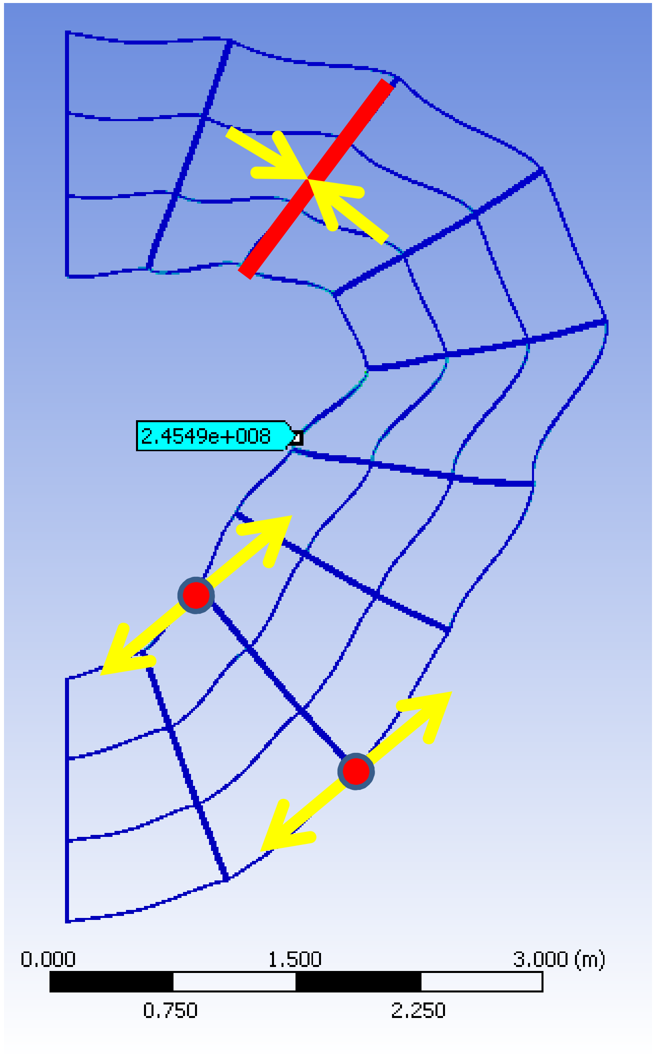






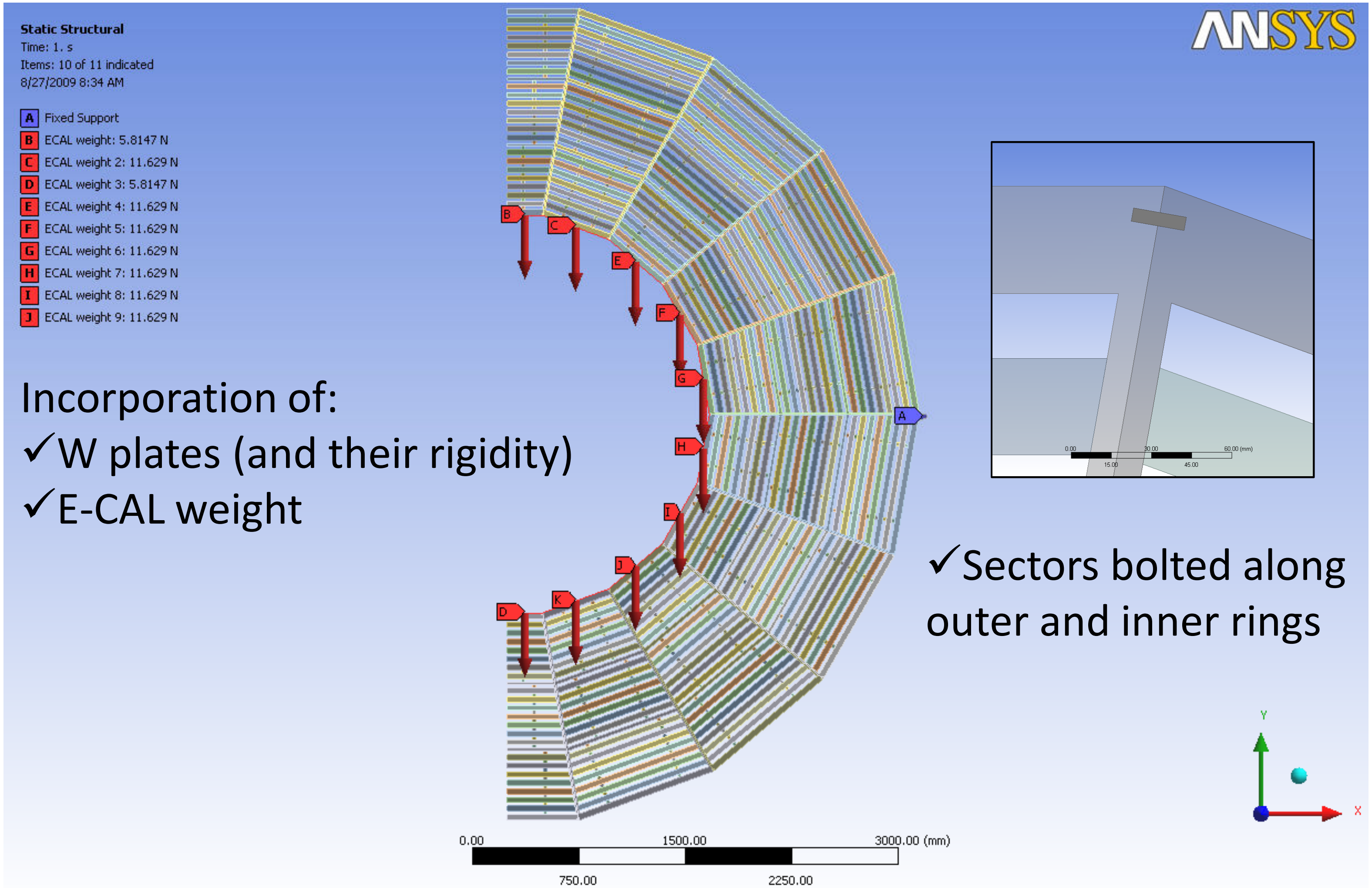
Optimal Support Position

- Optimal Support Position is at 3 and 9 o'clock
- Note: For this configuration:
  - Top sectors – compression
    - Force passes by face to face contact between sectors
  - Bottom sectors – traction
    - Force passes solely through bolts in tension



Global Deformation Analysis

Global Deformation Analysis



Incorporation of:

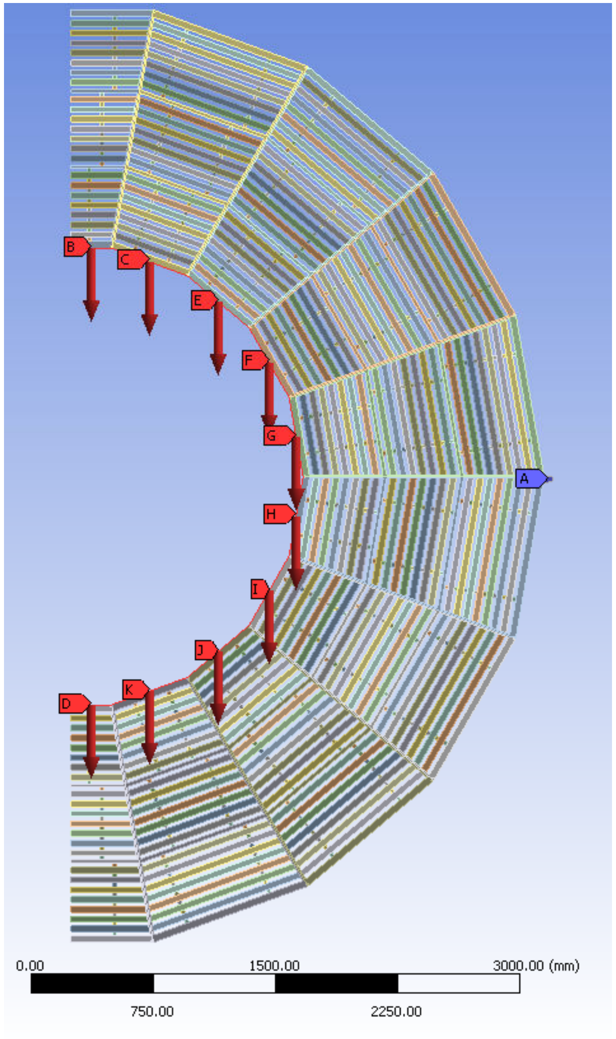
✓W plates (and their rigidity)

✓E-CAL weight

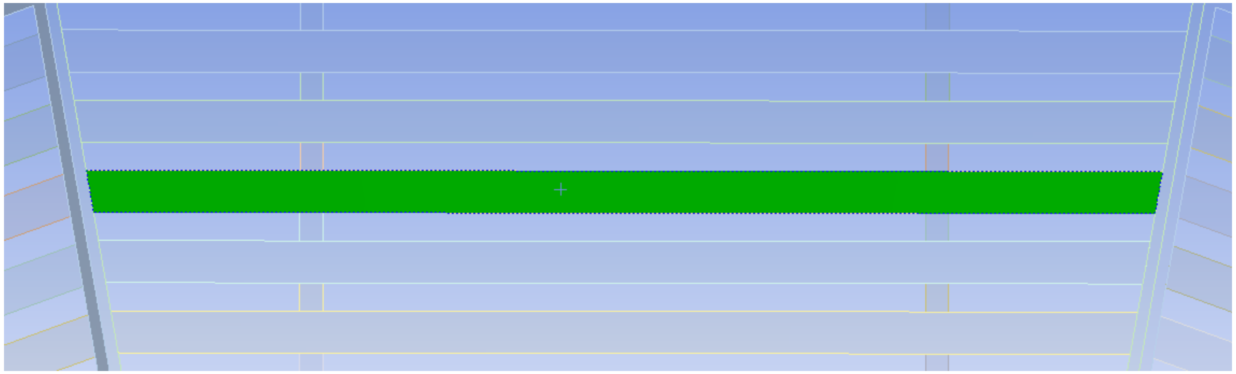
✓Sectors bolted along outer and inner rings

Detector Masses & Supports

- HCAL Spec.
  - Fixed outer supports at 3 & 9 o'clock positions
  - W mass: 612 tons
  - SS mass: 29 tons
  - Scintillator mass: 26 tons
    - 7 mm layers (1300 kg/m^3)
  - Total HCAL mass: 667 tons
- ECAL Spec.
  - 75 tons
  - Distributed and attached to inner faces of HCAL

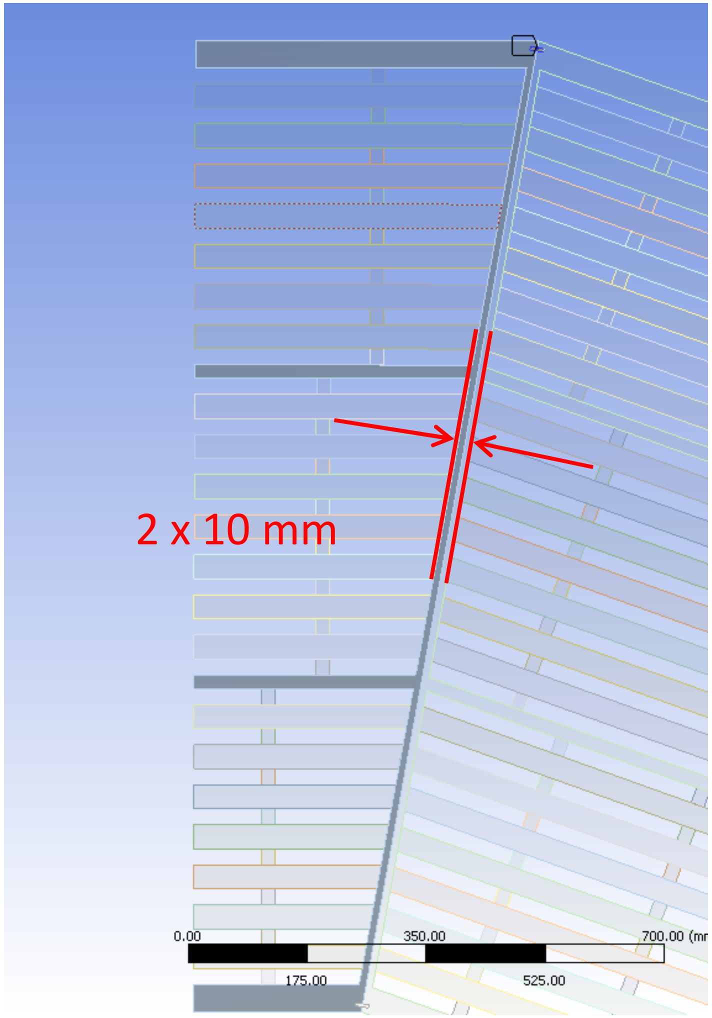


Detector Plates



- Tungsten Plates
  - 21 plates per sector
    - Will be increased to full 66 for final simulation
  - 12 mm per plate (scaled to 36 mm for sim.)
  - 8 mm for scintillators & gap (scaled to 24 mm for sim.)

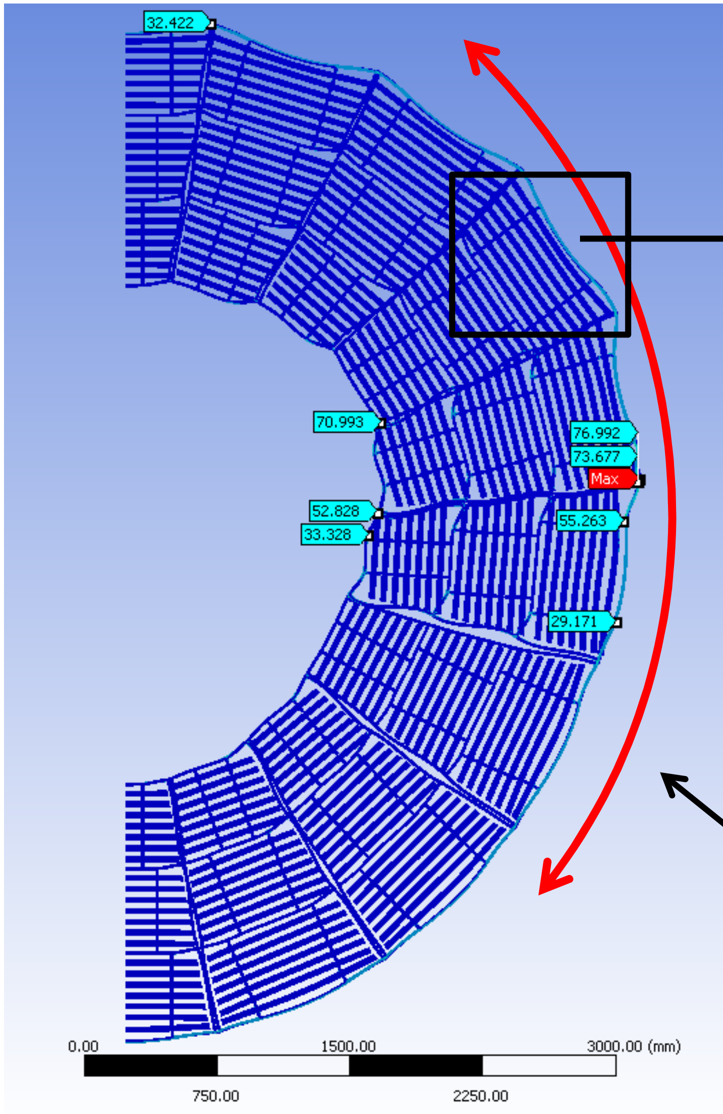
Steel Lattice Dimensions I

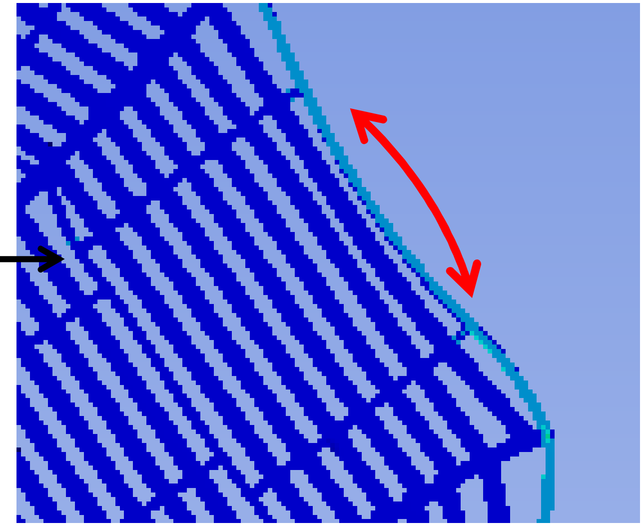


- Diagonal thickness: 10 mm
  - Maximise circumferential scintillator coverage

‼ Caution necessary during assembly due to deformation and high stress levels

Steel Lattice Dimensions I

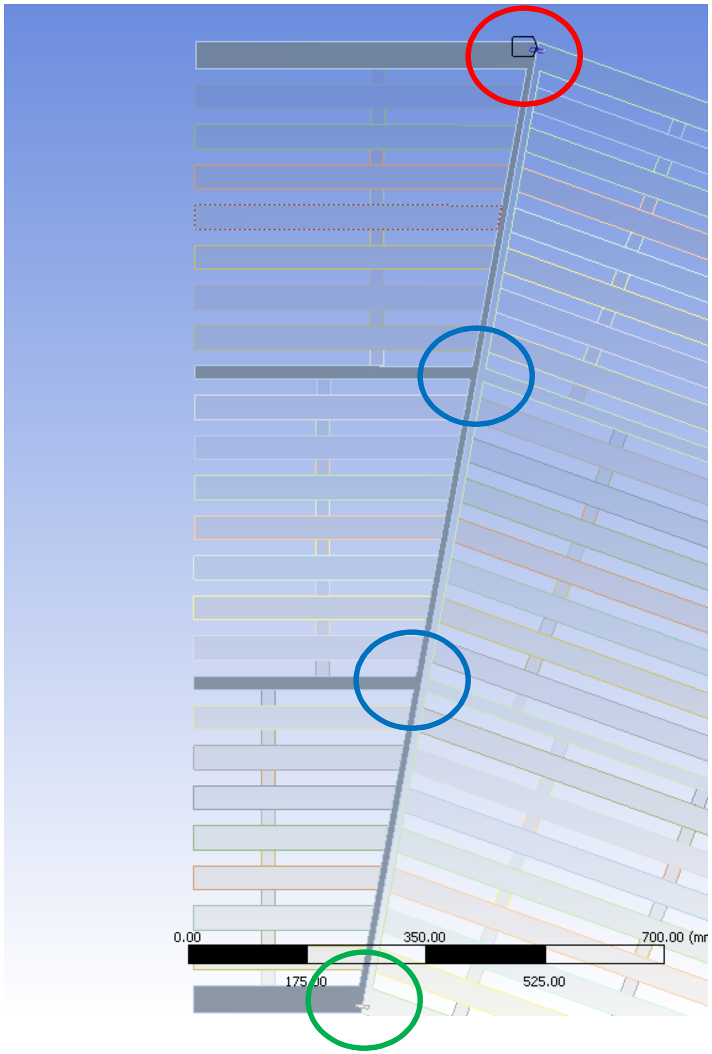




- Reduce stress along outside
  - Outer Thickness: 40 mm

Previous model showing stress concentration along outside of lattice

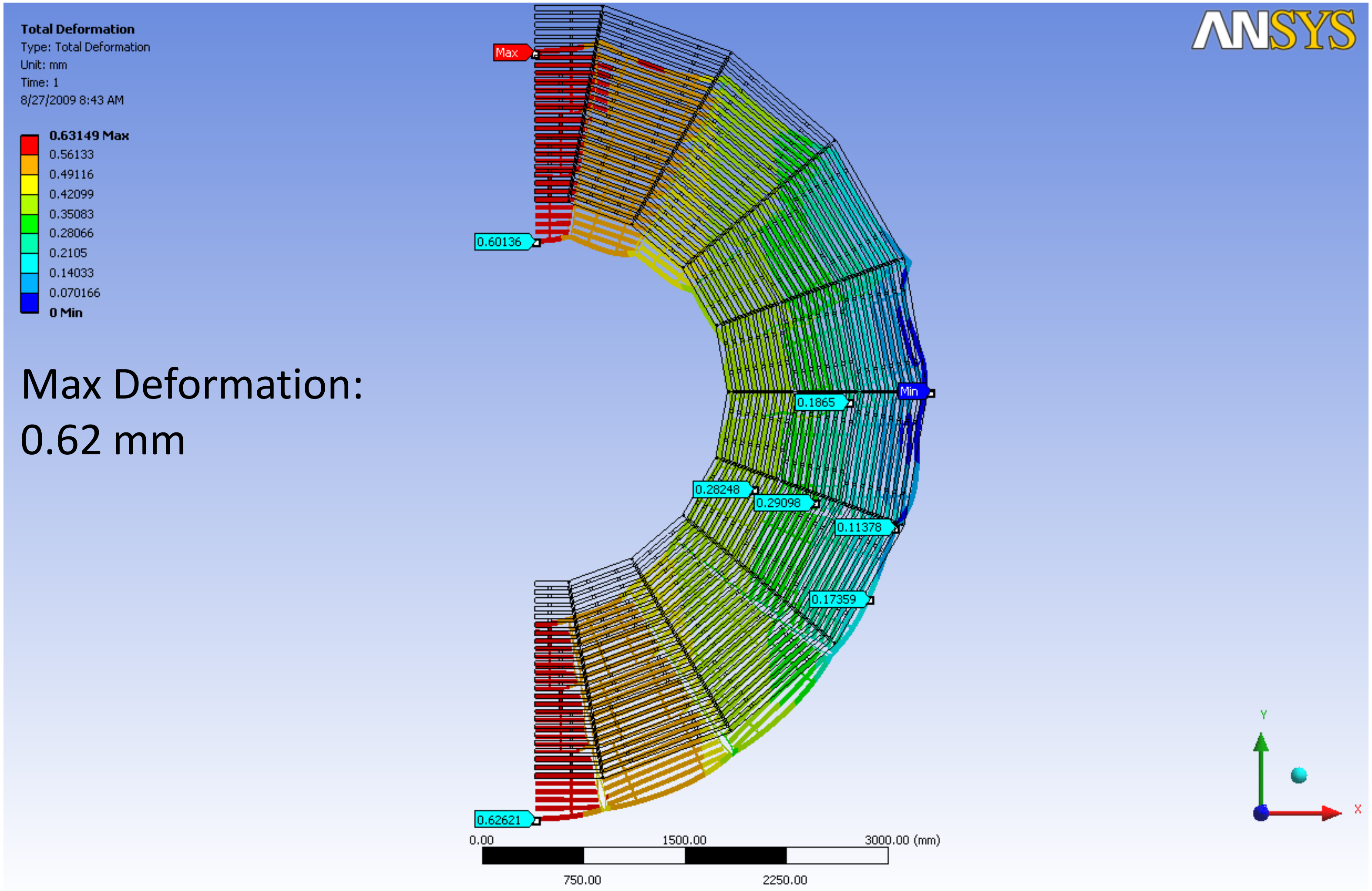
Detector Steel Lattice Thickness II



- Provide sufficient thickness for bolting and clamping
  - Outer Thickness: 40 mm
    - Inter-sector connection
  - Intermediate Thickness: 20 mm
    - Intra-sector connection
    - Perpendicular connection
  - Inner Thickness: 40 mm
    - Inter-sector connection

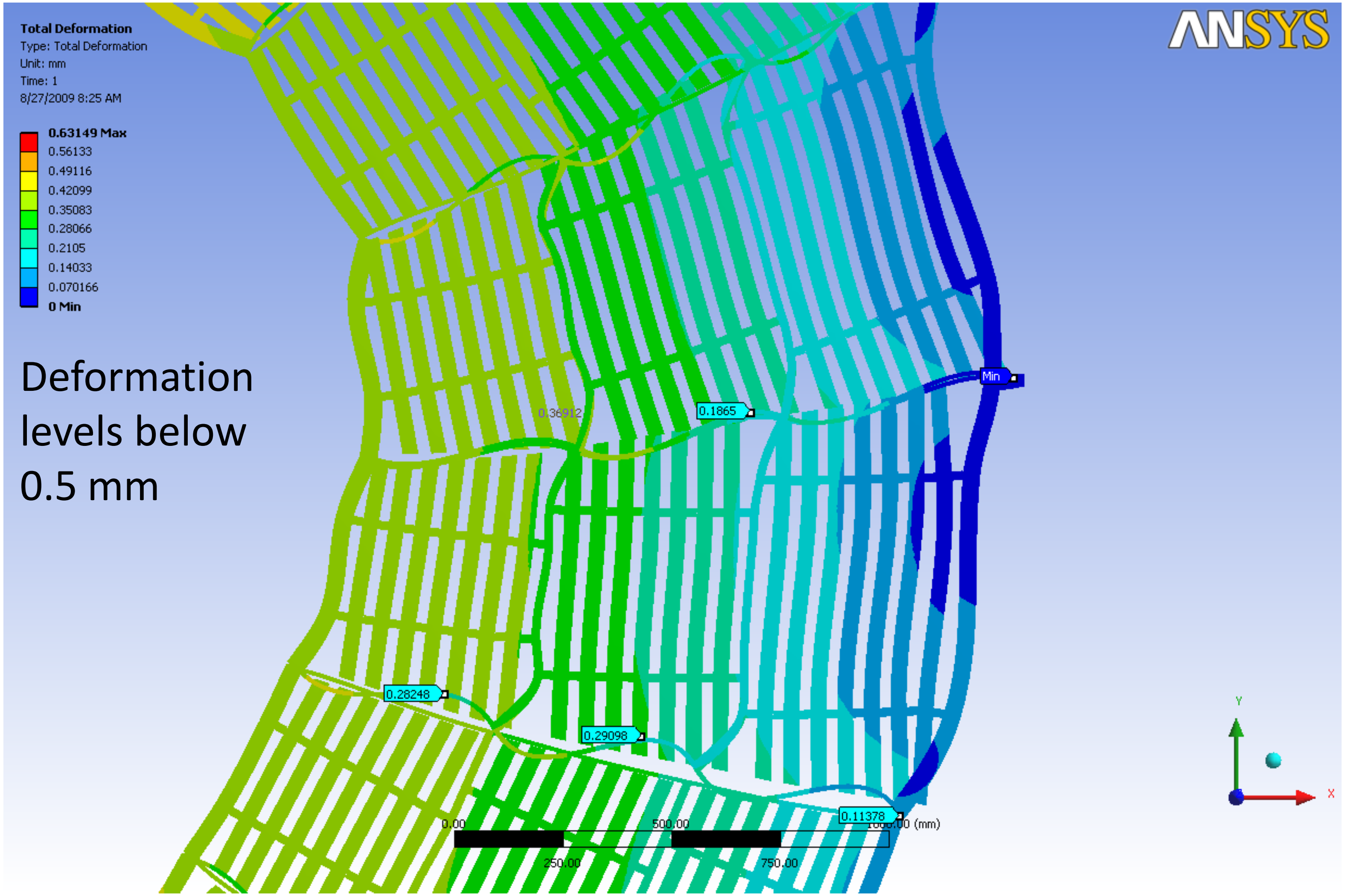
Note: Welding is also a possibility
–More likely for building a sector than for joining sectors together

Global Deformation Distribution



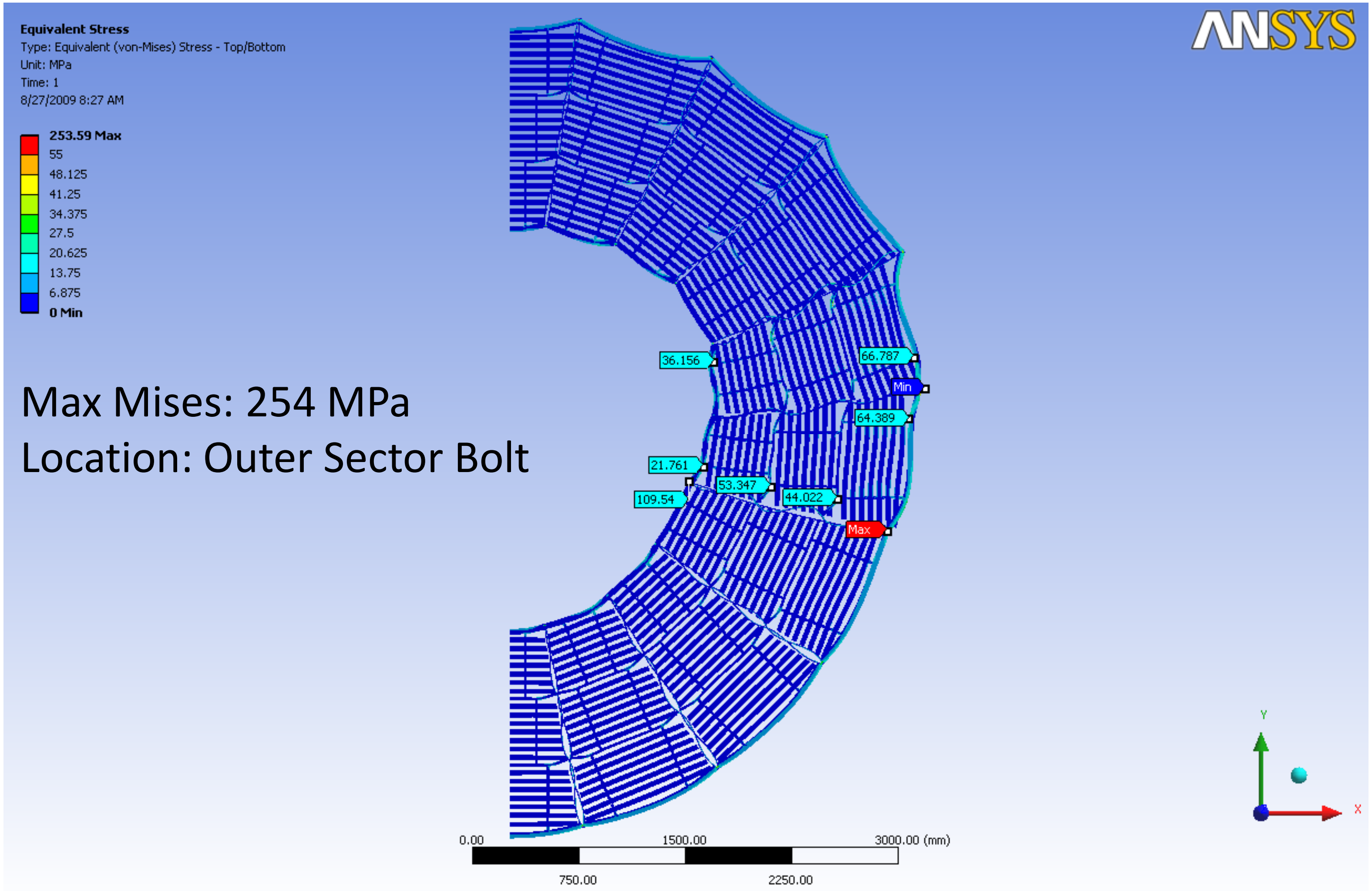
Max Deformation:
0.62 mm

Local Deformation Example



Deformation levels below 0.5 mm

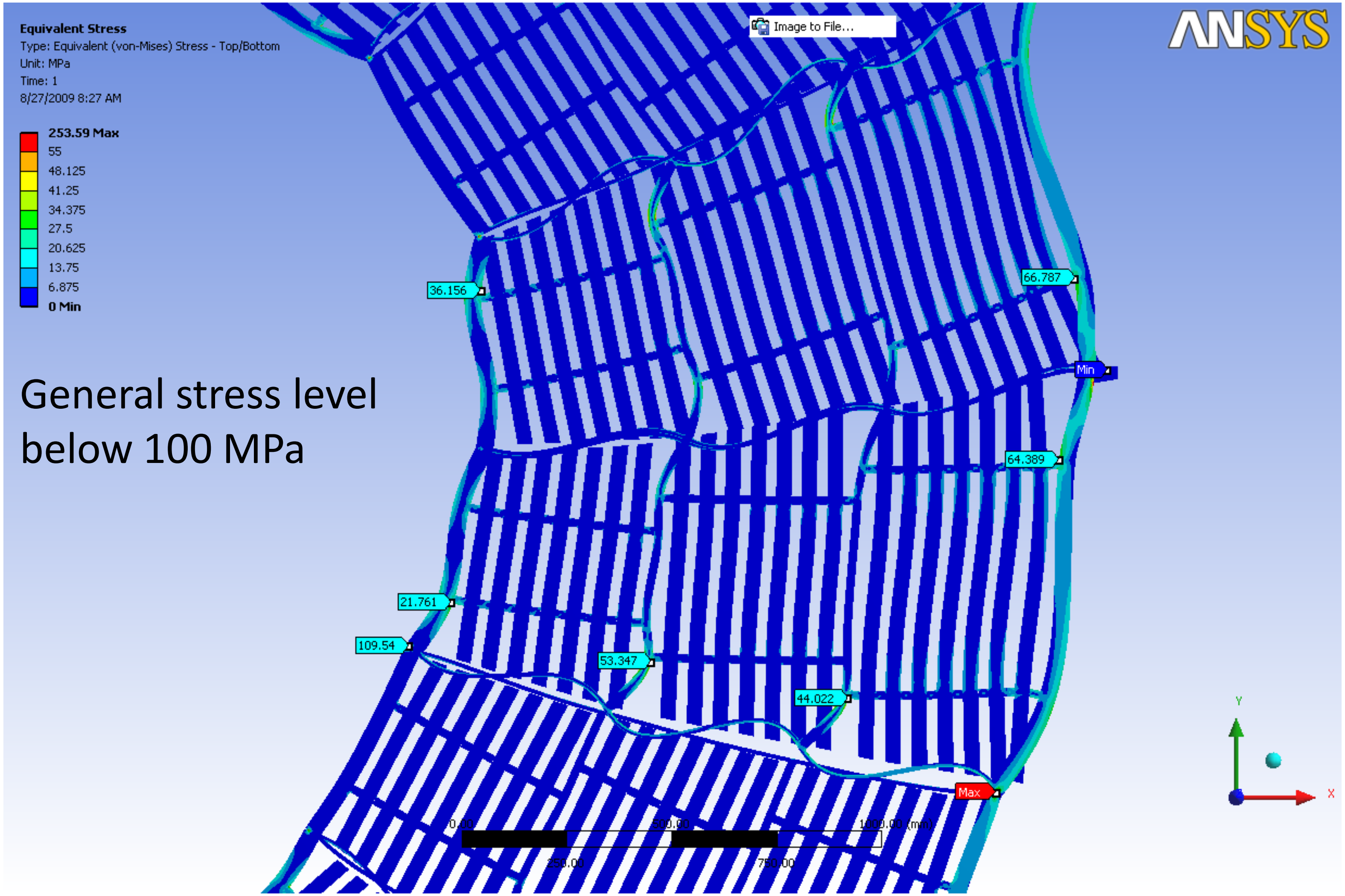
Global Stress



Max Mises: 254 MPa

Location: Outer Sector Bolt

Local Stress



General stress level below 100 MPa

2D deformation - conclusions

- Error sources:
  - Underestimated deformation
    - Use of seven 36 mm plates rather than twenty-two 12 mm plates for simulation (factor of 2 error)
    - Use of 2D bolts (infinite depth) rather than 3D bolts (factor of 2 error)
    - Neglecting of plate slipping due to manufacture tolerances (unknown effect)
  - Overestimated deformation
    - No contact between edge of W plates and steel lattice
    - No face-face contact between adjacent sectors

    ❖Both errors unknown but favourable

❑ Conclusion: Global deformation will be determined by manufacturing tolerances

2D stress - conclusions

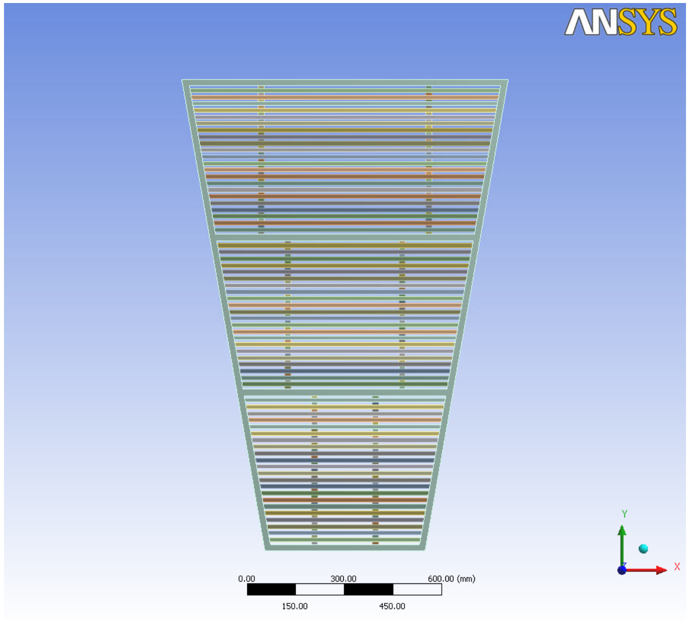
- Error sources:
  - Underestimated stress levels
    - Use of seven 36 mm plates rather than twenty-two 12 mm plates for simulation
    - Use of 2D bolts (infinite depth) rather than 3D bolts
      - 3D stresses should be extrapolated
  - Overestimated deformation
    - No contact between edge of W plates and steel lattice
      - Expected to greatly reduce stresses in plate bolts
    - No face-face contact between adjacent sectors
      - Expected to greatly reduce stresses in sector bolts

❑ Conclusion: 3D model is necessary to obtain stress information

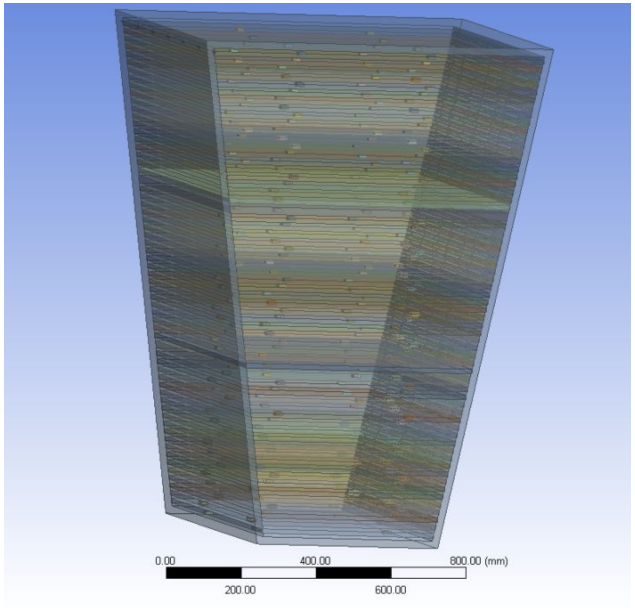
2D model validation with 3D

Validation of 2D with 3D

- 2-Dimensional



- 3-Dimensional

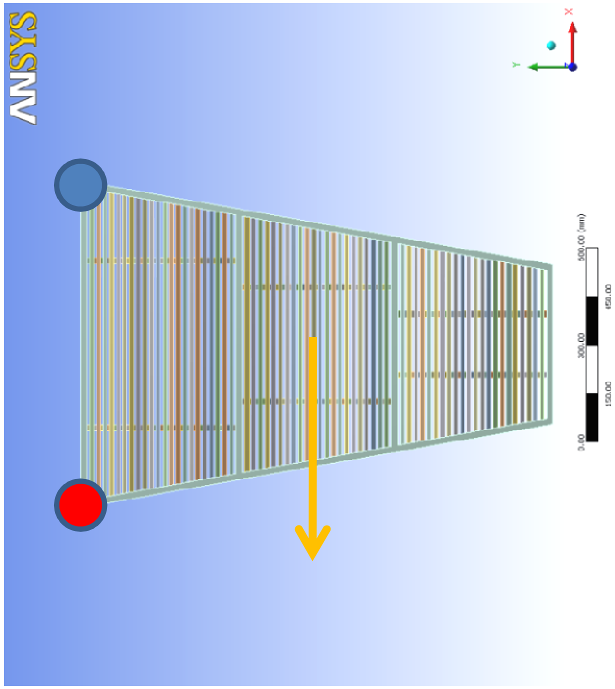


❖Key Difference: 2D bolts

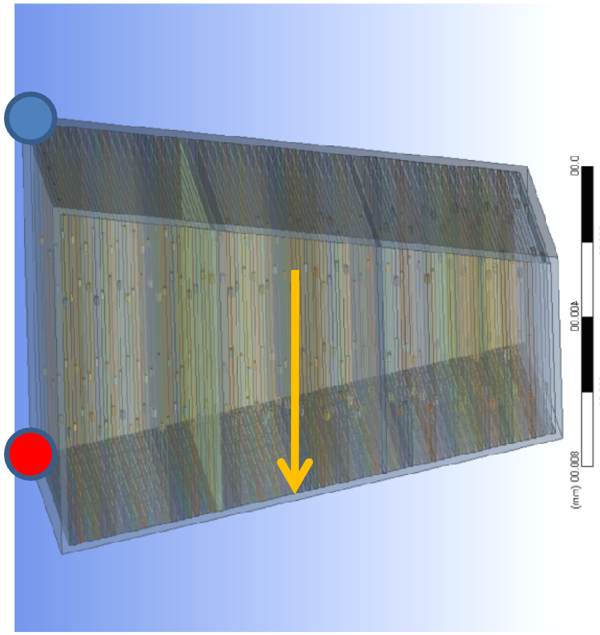
➢We wish to compare the rigidity of each sector

Validation of 2D with 3D - test

- 2-Dimensional



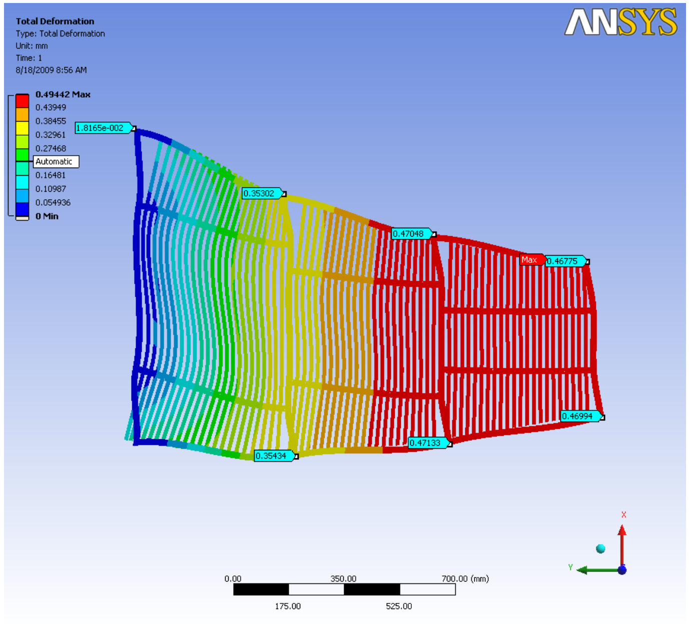
- 3-Dimensional



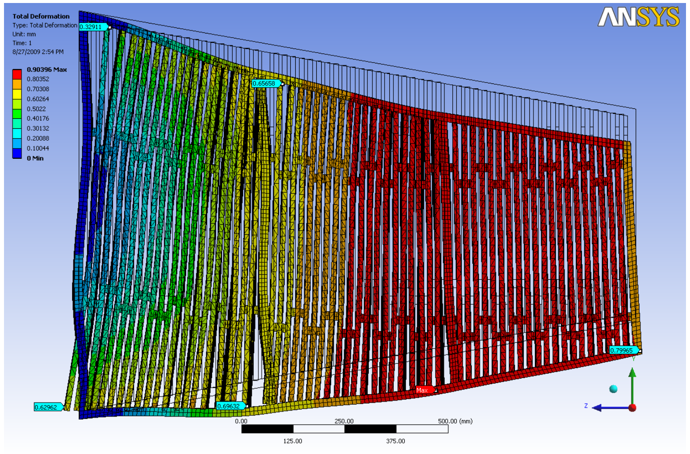
❖Horizontal position
❖Support from the left-hand side
❖Measure max deformation and stress

Validation of 2D with 3D - Deformation

- 2-Dimensional
- 3-Dimensional



Max Deformation 0.5 mm

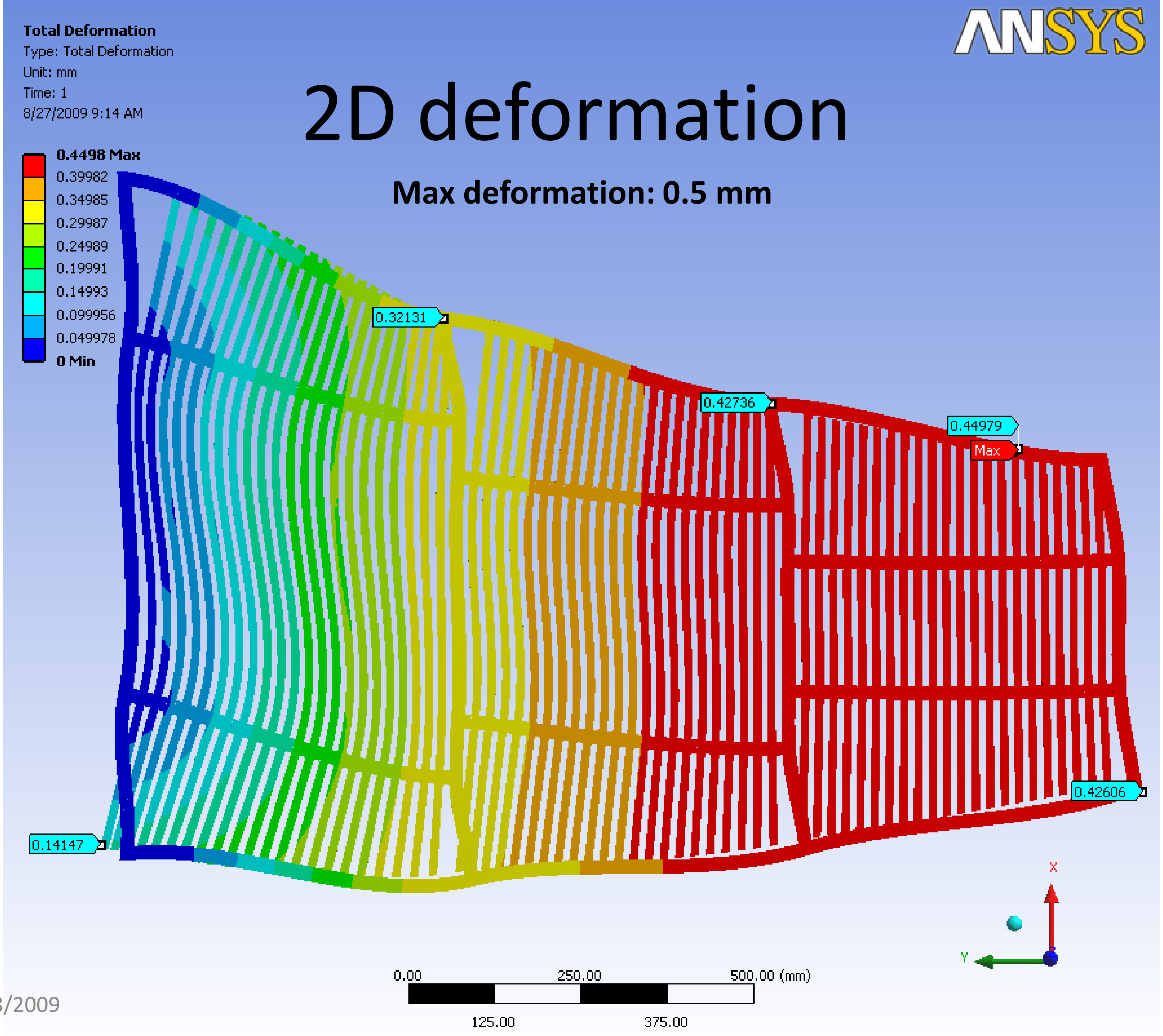


Max Deformation 0.9 mm

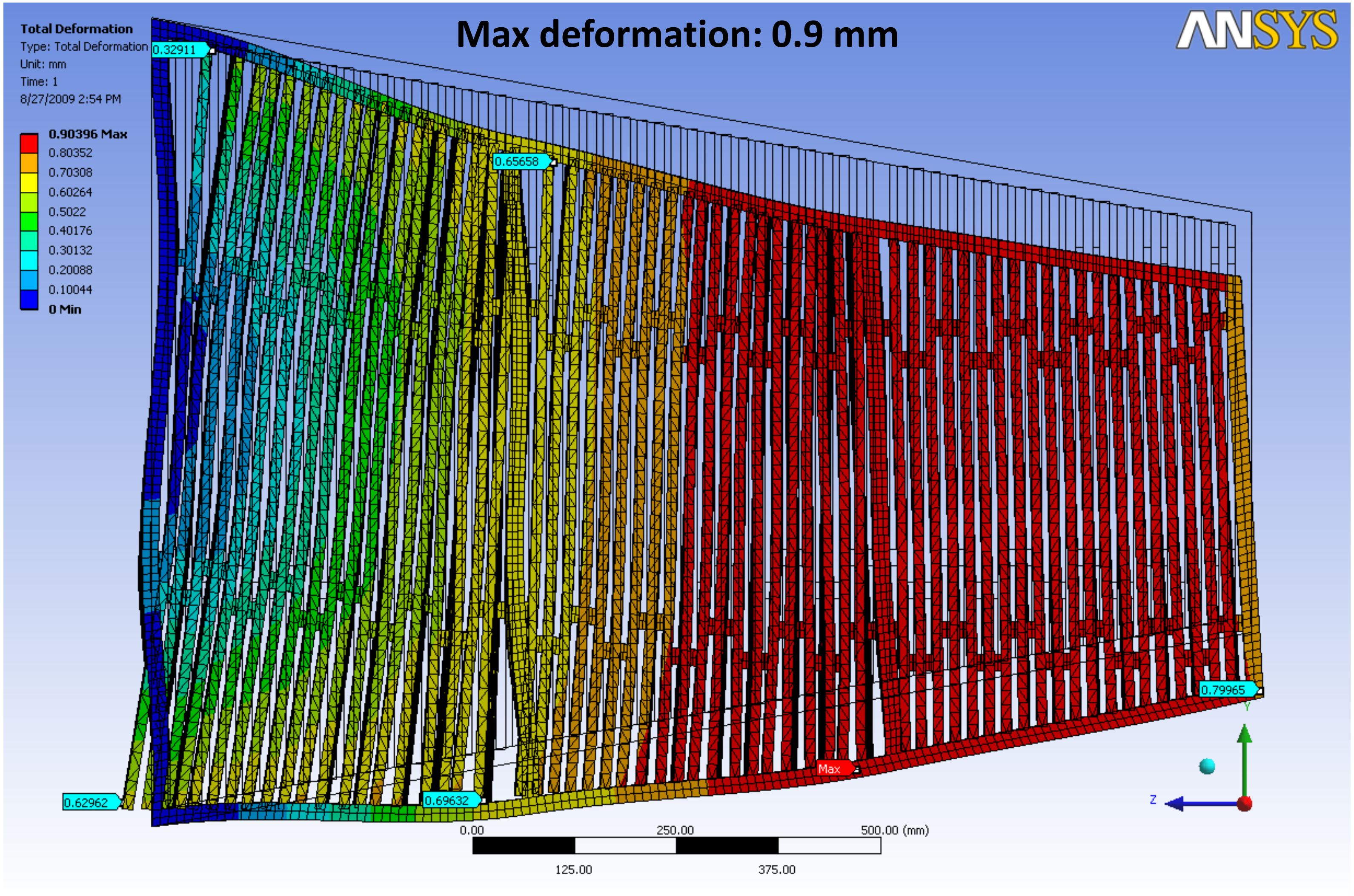
❖Both deform in a similar manner

2D deformation

Max deformation: 0.5 mm



3D deformation



Validation of 2D with 3D - Conclusions

- Max 3D deformation is approximately double 2D
  - This suggests that the rigidity of a 2D sector is close to 3D
  - Having found a global HCAL deformation of 0.6 mm, we can be satisfied that in the 3D case, this will not surpass 5 mm
- Stress
  - Further simulations are required to determine the stress concentration in passing from 2D to 3D.

Important Considerations I

- Rails on HCAL exterior
  - Room should be left so that rails fit within the 5800 mm diameter imposed
  - Design of such rails is not trivial
  - The possibility of supporting the detector from each end should also be considered
- Depending on the thickness of W required, a composite layer of steel and tungsten could be introduced to reduce cost
  - Structural benefits associated with such a composite layers are <u>not</u> considerable

Important Considerations II

- In order to benefit from the high rigidity of W, adjacent sectors must be joined together in as secure a manner as possible
  - Novel bolting, clamping, interlocking or welding solutions need to be further examined and developed
- Later on in the analysis, earthquake effects corresponding to a lateral force of 0.3g should be analysed.