Tungsten HCal Mechanics

CERN Linear Collider Detector Project

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On behalf of
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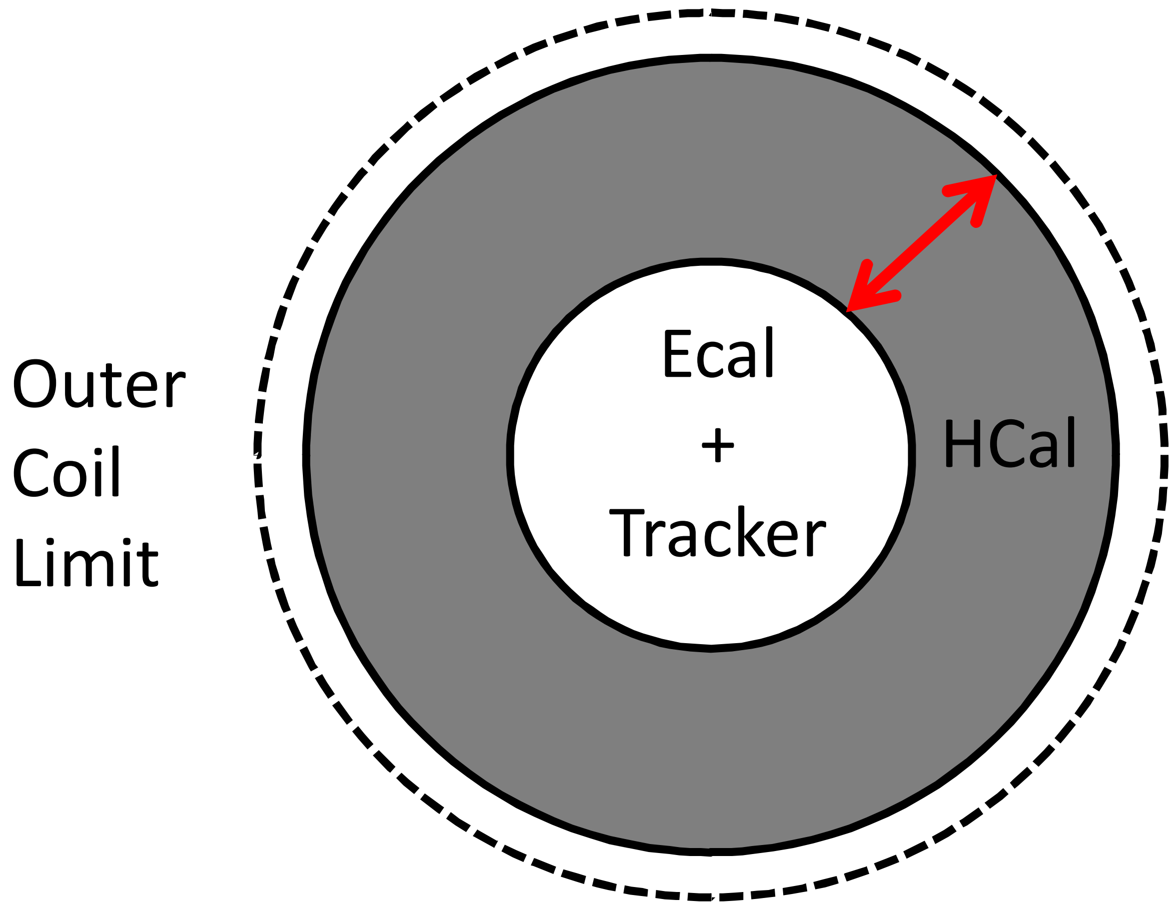
Motivation

Why choose Tungsten?

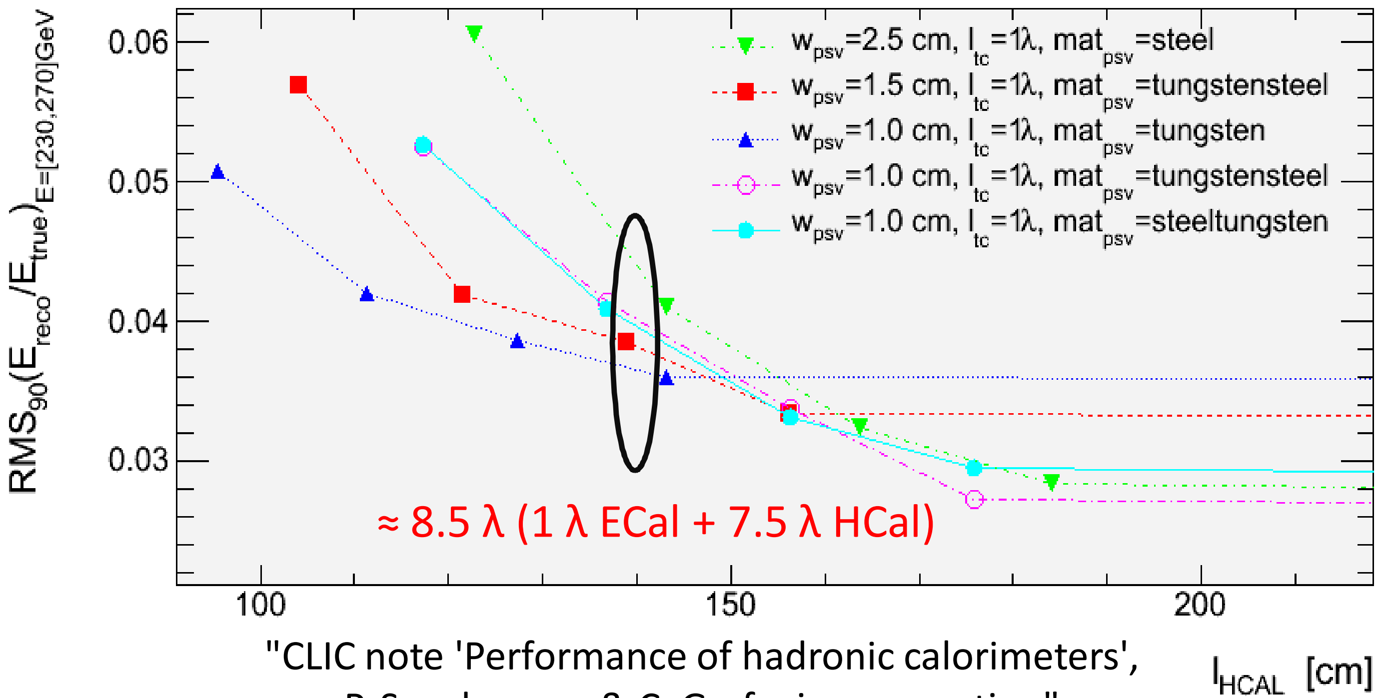
Motivation

- HCal thickness is limited to ≈ 140 cm due to outer coil size



Motivation

- HCal thickness is limited to 140 cm due to outer coil size
- For this depth tungsten provides:
  - Better resolution



"CLIC note 'Performance of hadronic calorimeters', P. Speckmayer & C. Grefe, in preparation"

Engineering Questions?

- What detector structure is needed?
- What manufacturing requirements are needed?
  - Entire detector structure
    - Tungsten Plates

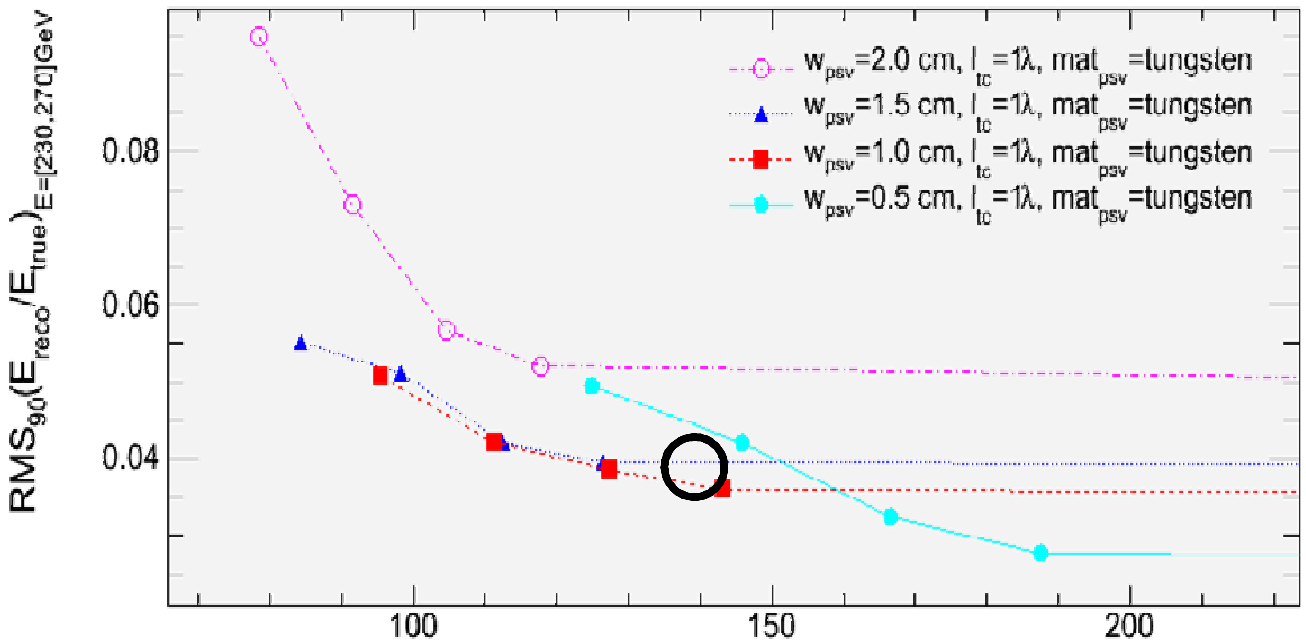
Approach

1. Establishment of HCal specifications
   – Physicist's requirements
   – Known physical limits (Coil diameter)
2. Determination of tungsten's characteristics
   1. Mechanical properties
   2. Availability
3. Design of HCal geometry
4. Finite element analysis of HCal structure

1. HCal Specifications

Plate Thickness

$E_{MC} \approx 250$ GeV



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For 140 cm HCAL depth

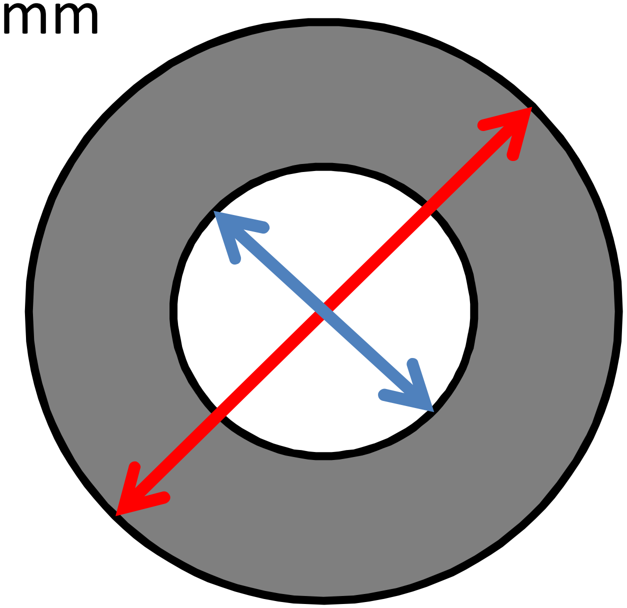
- Plate thickness of between 1 cm and 1.5 cm is optimal

HCal Specifications

Layer Composition

- W plate thickness: 12 mm
- Gap: ≈ 8 mm
  - Scintillator thickness: ≈ 5 mm
  - Sensors and electronics: ≈ 2 mm

Detector Dimensions



- Outer diameter: 5.8 m
- Inner diameter: 2.8 m
- Detector Length: 3.5 m
- Number of Layers: ≈ 70

2. Tungsten Characteristics

I. Mechanical properties
II. Plate size and tolerances
III. Machinability
IV. Cost

Tungsten Characteristics

I. Mechanical properties

	Pure W	INERMET 176*	Steel
% Tungsten	100	92.5	-
Alloying materials	-	Cu, Ni	-
Elasticity (Young) [GPa]	400	350	200
Density [g/cm^3]	19.3	17.6	7.85
% Elongation at yield	< 5**	5	30-50

*Alloys used must be paramagnetic, **Tests required

Tungsten Characteristics

II. Plate size and tolerances

- Currently available plate sizes

Pure Tungsten	INERMET
1200 mm x 1600 mm	400 mm x 600 mm

- Thickness of 12 mm is feasible for both
- Flatness tolerance ca. 1.5 mm
  - $<$ 1 mm possible
- Thickness tolerance ± 0.5 mm
  - With machining ± 0.1 mm (cost ↑)

Tungsten Characteristics

III. Machinability

- Abrasive water jet cutting is suitable
- Holes, slots & various cut-outs are possible
- Precision of ± 0.1 mm is possible

Tungsten Characteristics

IV. Cost

- €70 – €115 per kg
- Circa 5% extra for machining cut-outs
  - Due to breakage
- Extra cost to improve flatness and thickness tolerance by machining
  - Due to loss of non-recoverable material

3. HCal Geometry

- Tungsten plate dimensions
- Propositions for structure
  A. Box design
  B. Staircase design

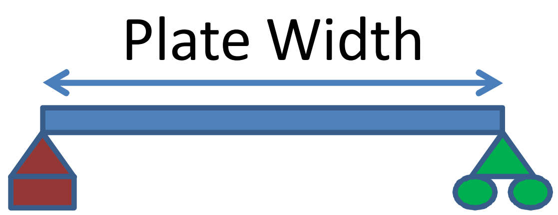
Tungsten Plate Dimensions

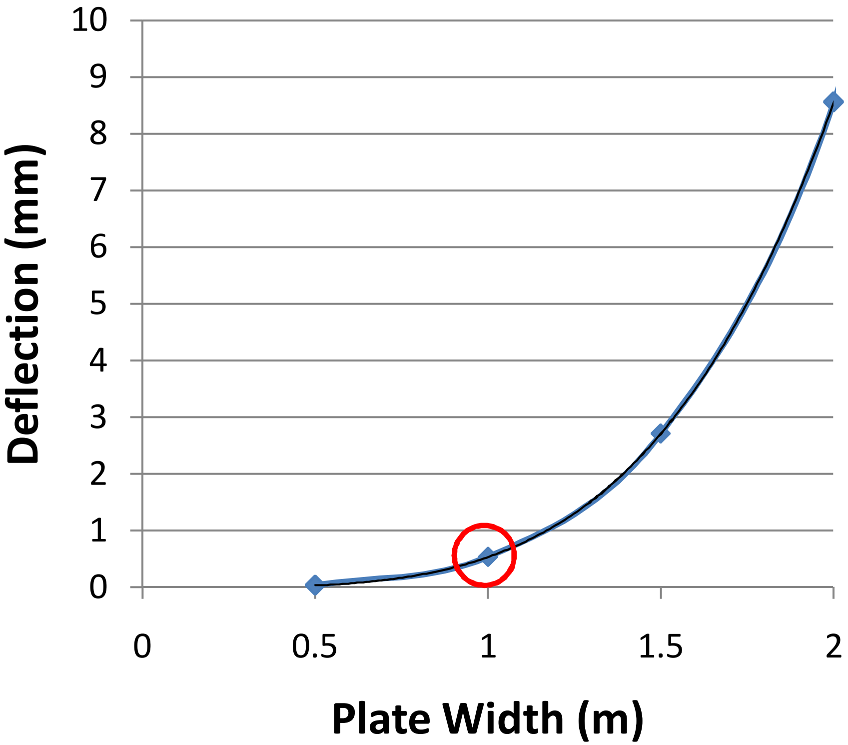
Plate Thickness: 12 mm

✓Physics

Plate Length: 3.5 m

✓Detector Length





- Plate width of about 1 m is optimal
  - ✓Deflection does not interfere with detector layer

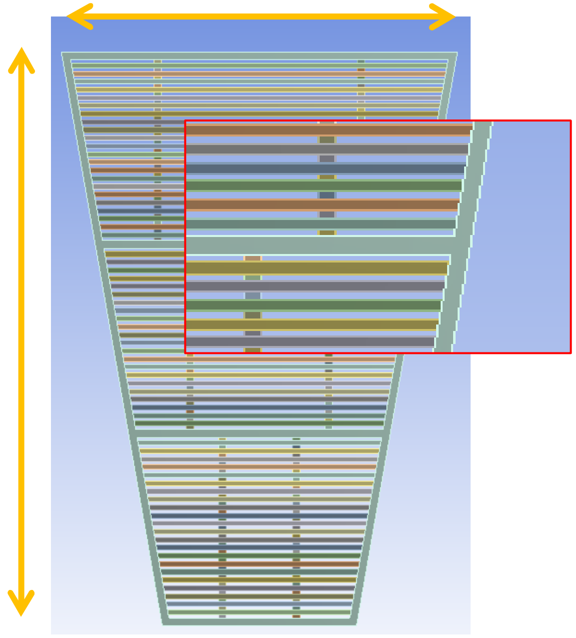
Propositions

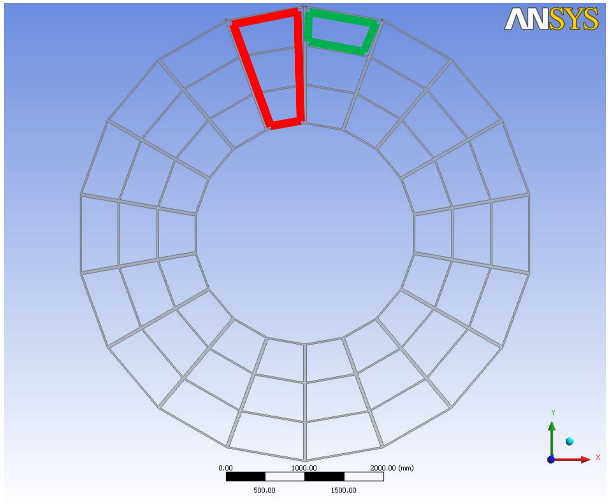
A. Box Design

- 18 symmetrical sectors
- 3 "boxes" per sector

Width: 1007 mm

Height: 445 mm





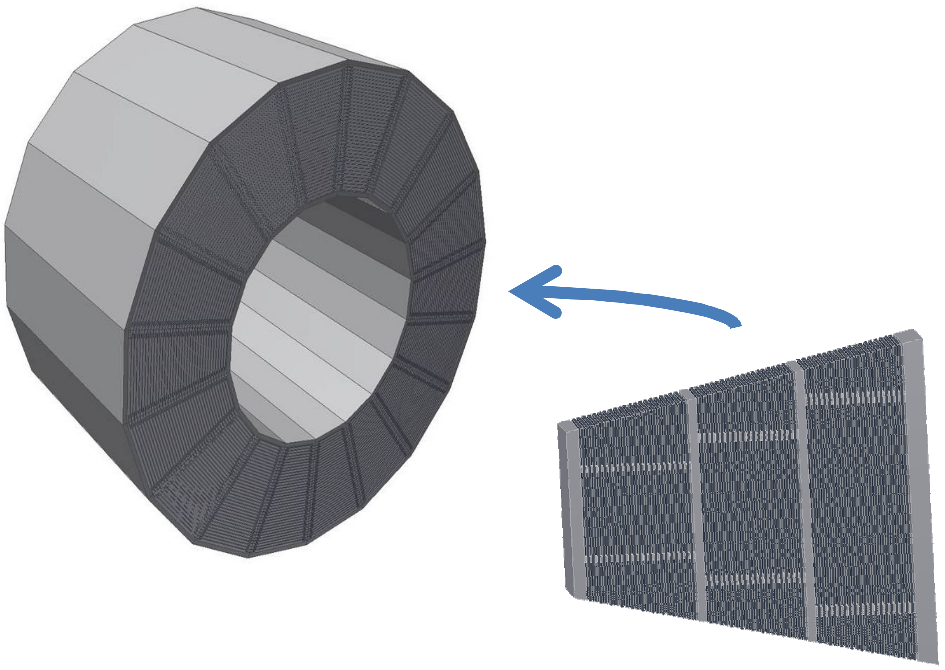
➢Lattice
➢Sector
➢Box

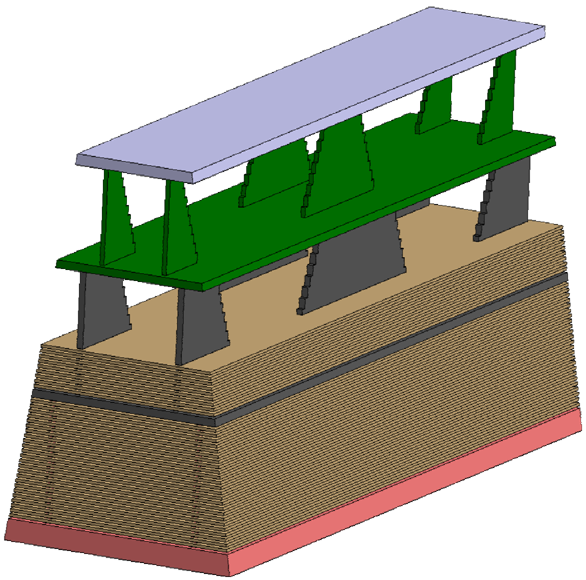
Plates bolted together using washers to provide gap for detecting layer

Propositions

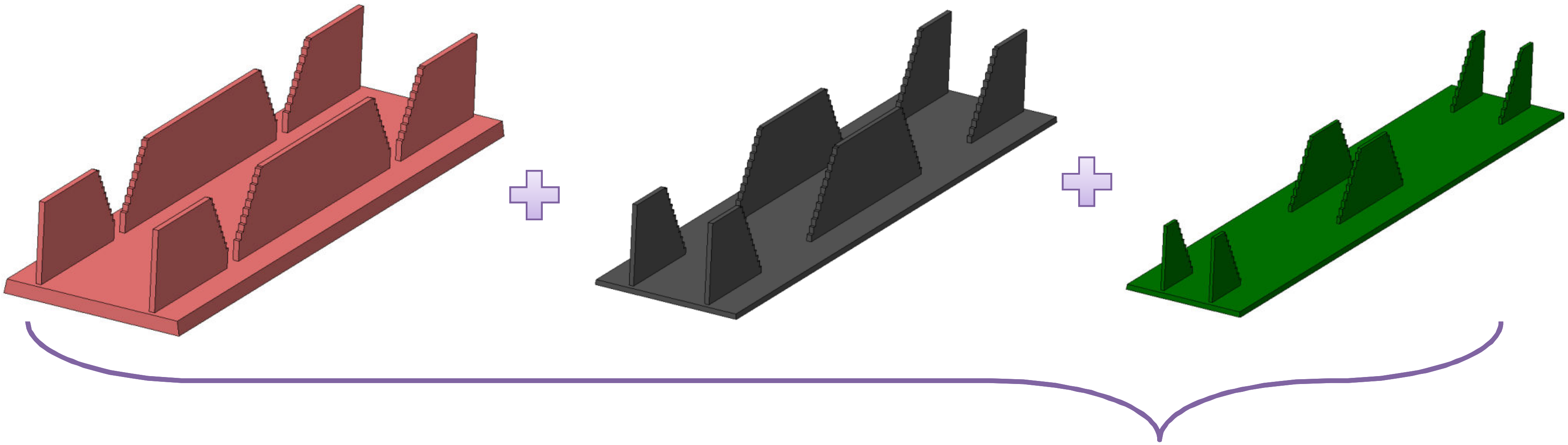
B. Staircase Design

- 18 symmetrical sectors
- 3 modules per sector

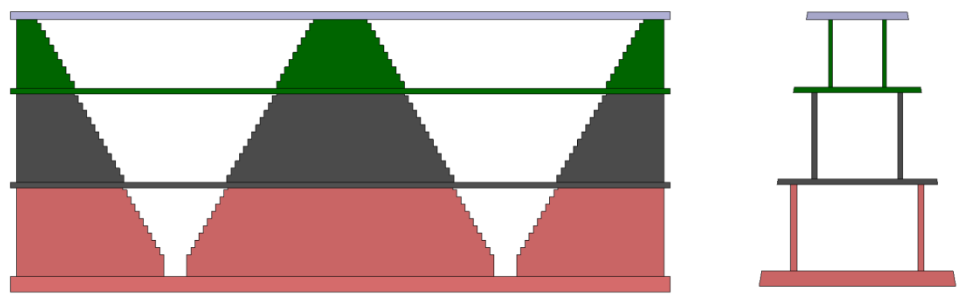




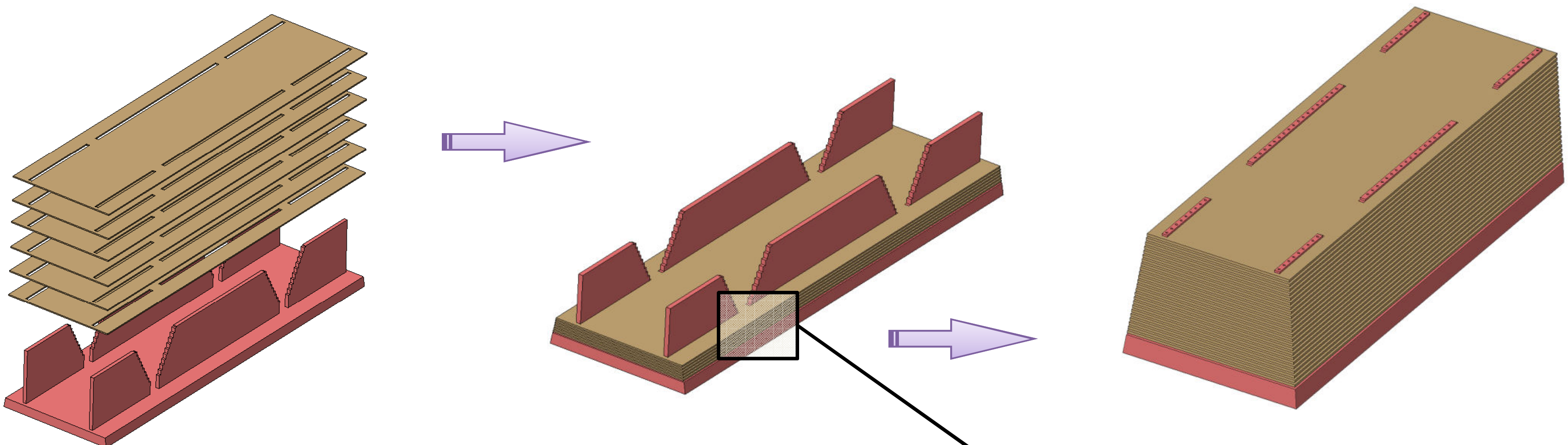
Staircase Sector Composition

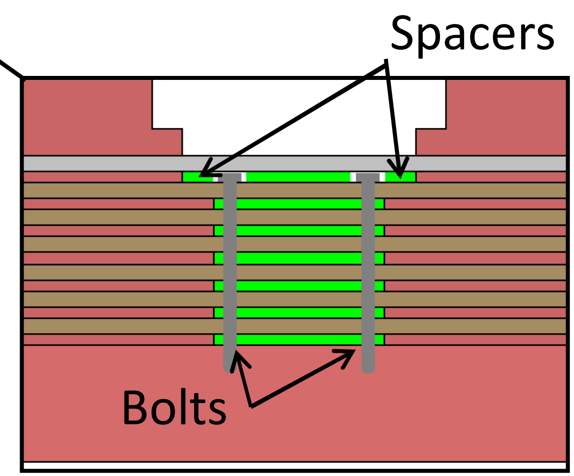


3 staircase modules bolted together to form one sector



Staircase Plate Bolting

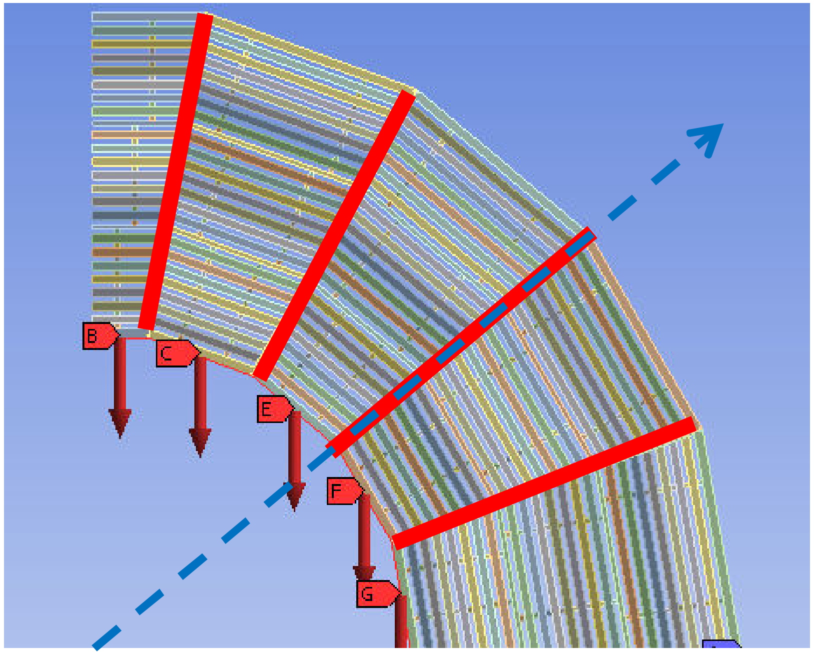




- The first 6 plates in each module are bolted simultaneously using spacers
- Subsequent plates are bolted two at a time

Comment

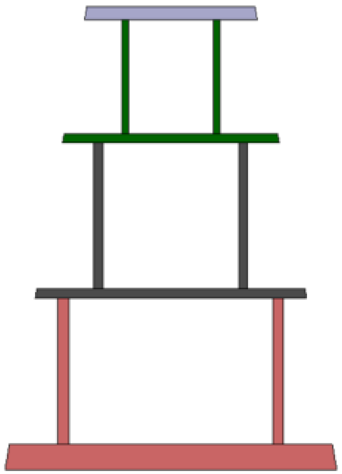
Vertex pointing steel plates

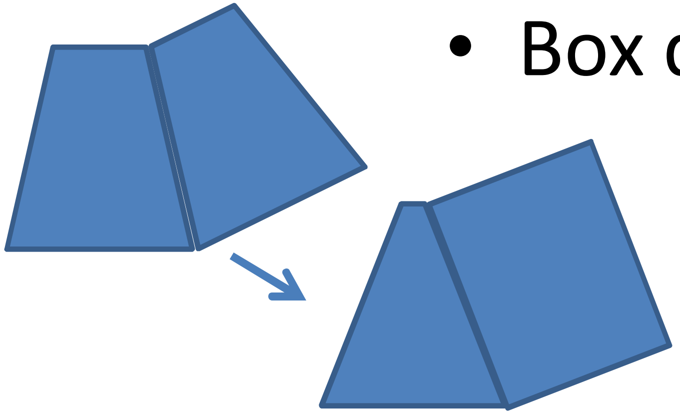


Comment

Vertex pointing steel plates

- May be beneficial to
  - Avoid vertex-pointing dead zones
- Staircase design satisfies this criterion





- Box design easily altered
  - Structural performance largely unaffected

4. HCal Mechanics

I. Support Position

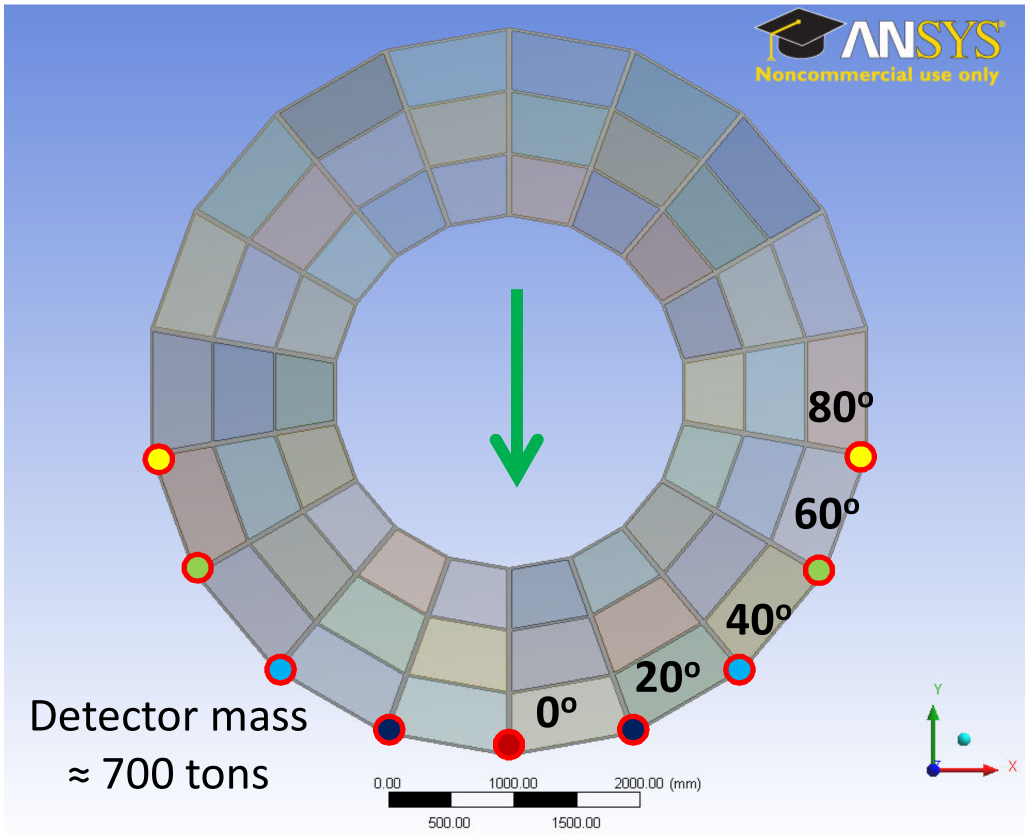
II. Global deformation

III. Internal stresses

   a. Steel lattice/staircase

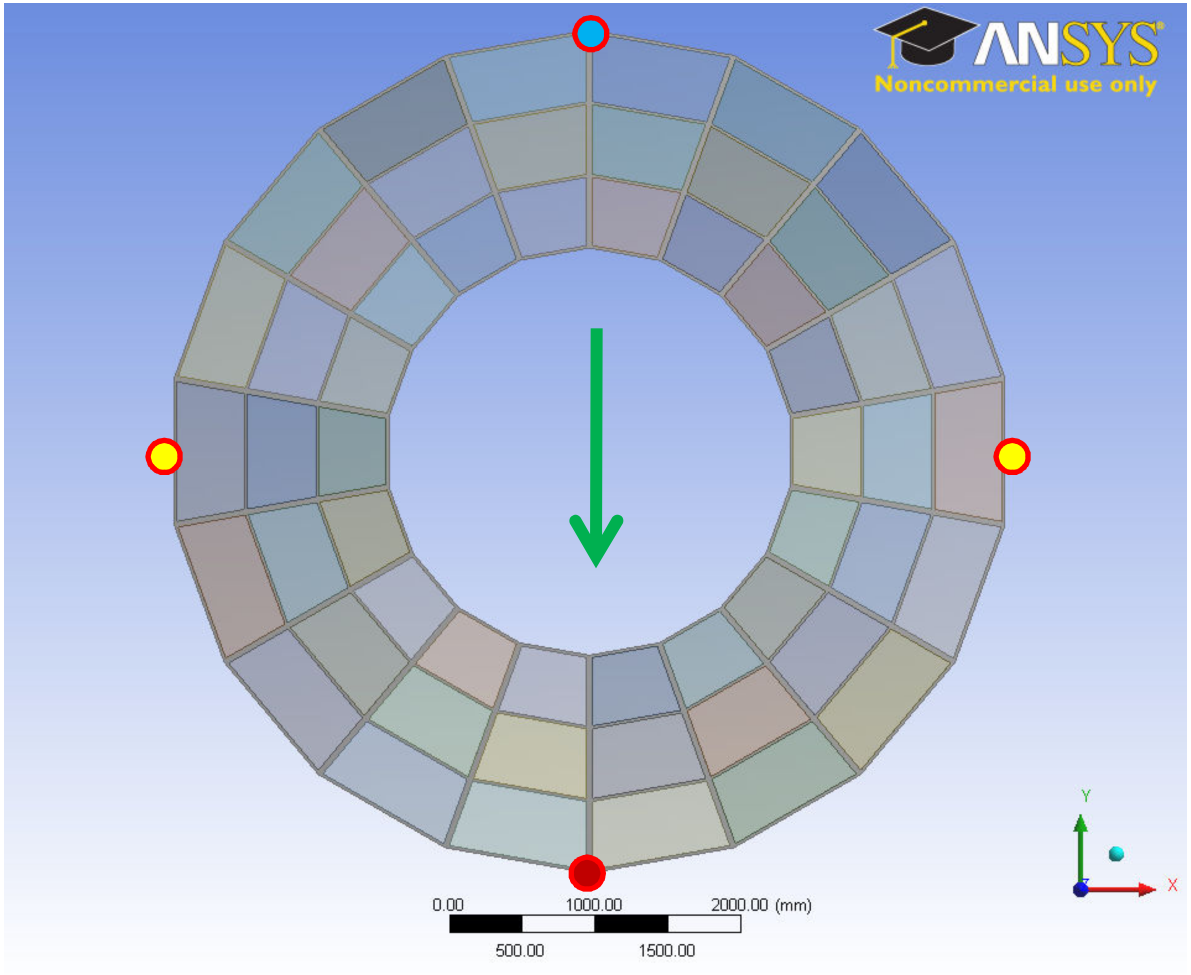
   b. Tungsten plates

I. Support Position



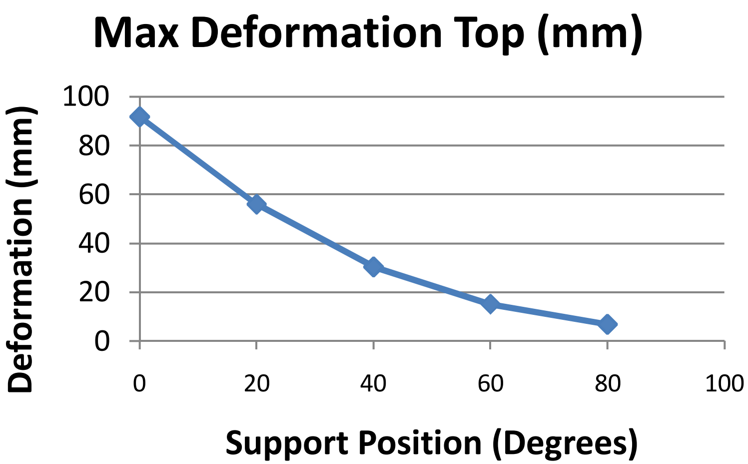
1. Choose different support configurations at 20º intervals
2. Apply earth gravity
3. Calculate deformation for each support configuration

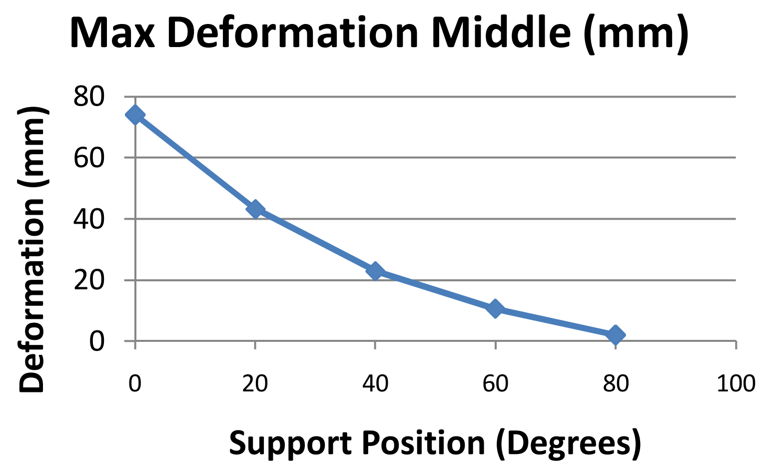
Support Position

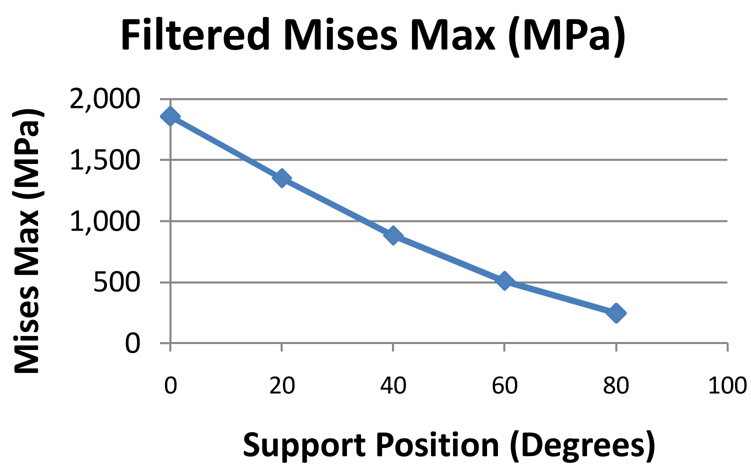


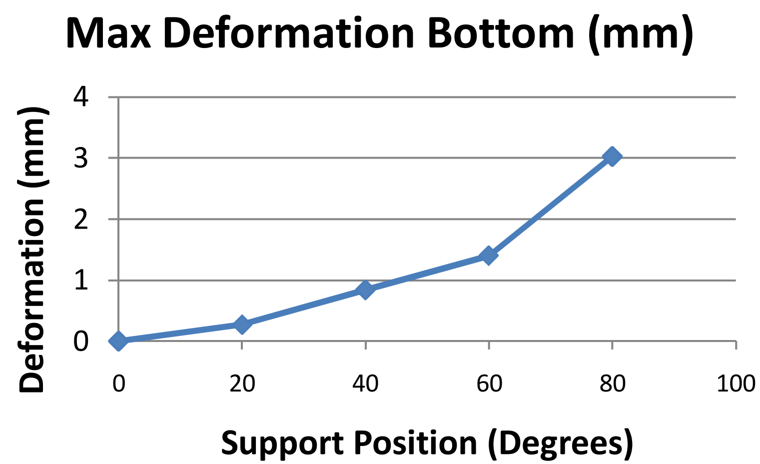
Observe deformation at top, middle and bottom points

Support Position



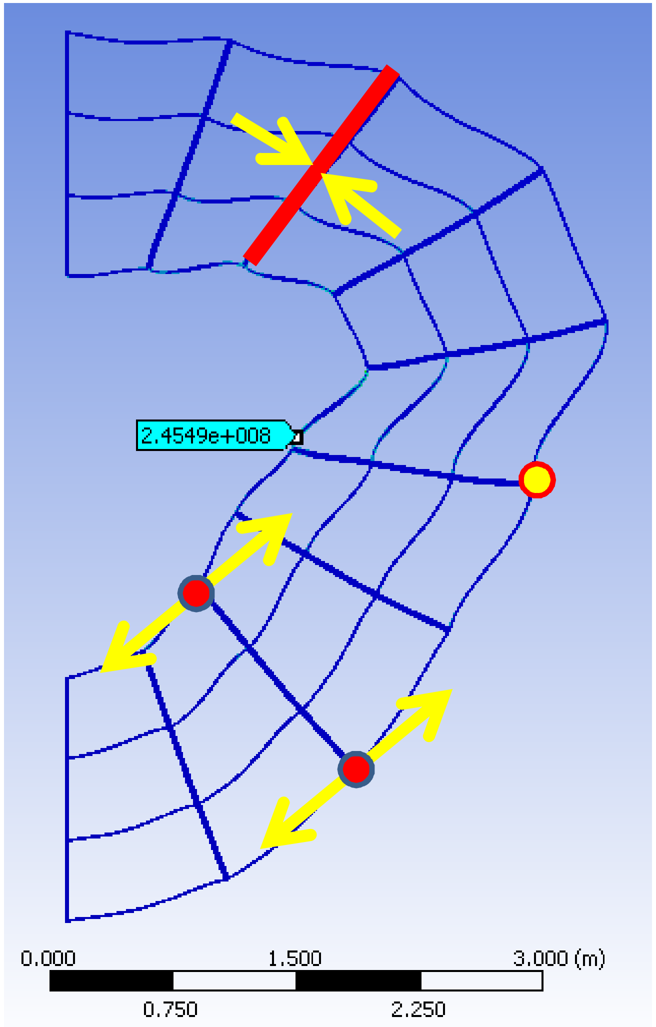






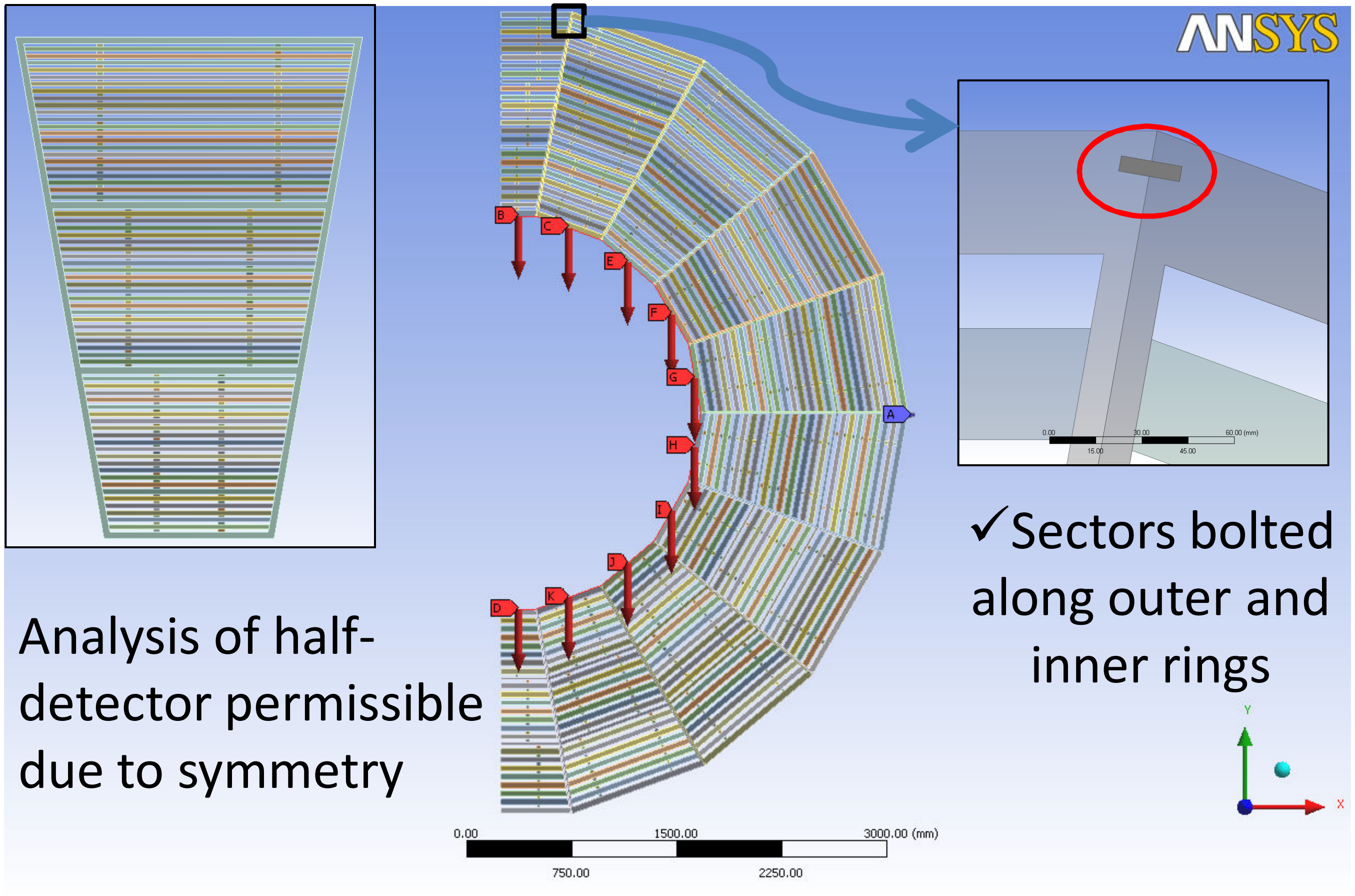
Conclusion - Support

- 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



II. Global Deformation

Box Model

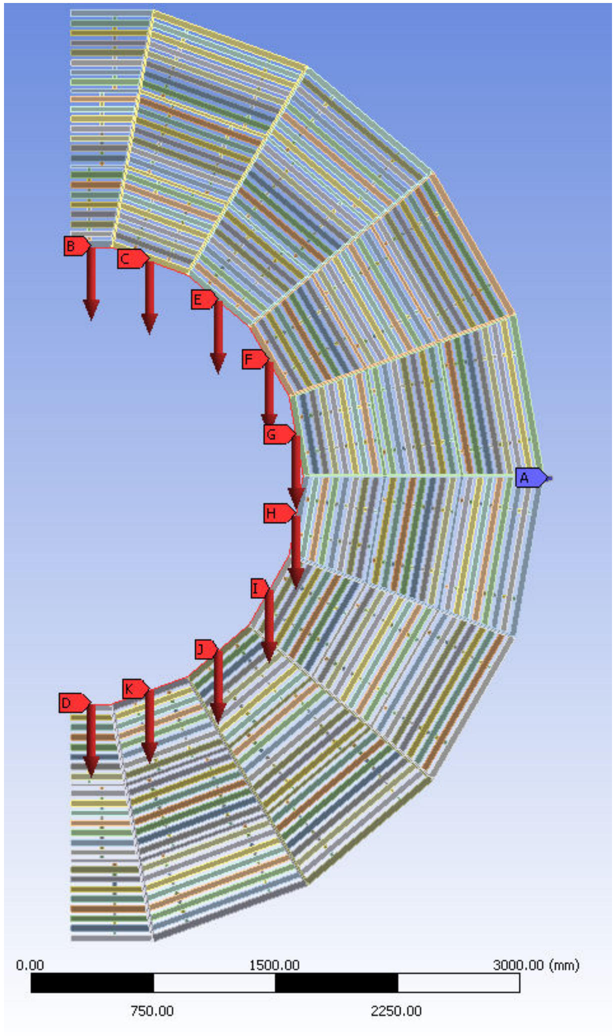


Analysis of half-detector permissible due to symmetry

✓Sectors bolted along outer and inner rings

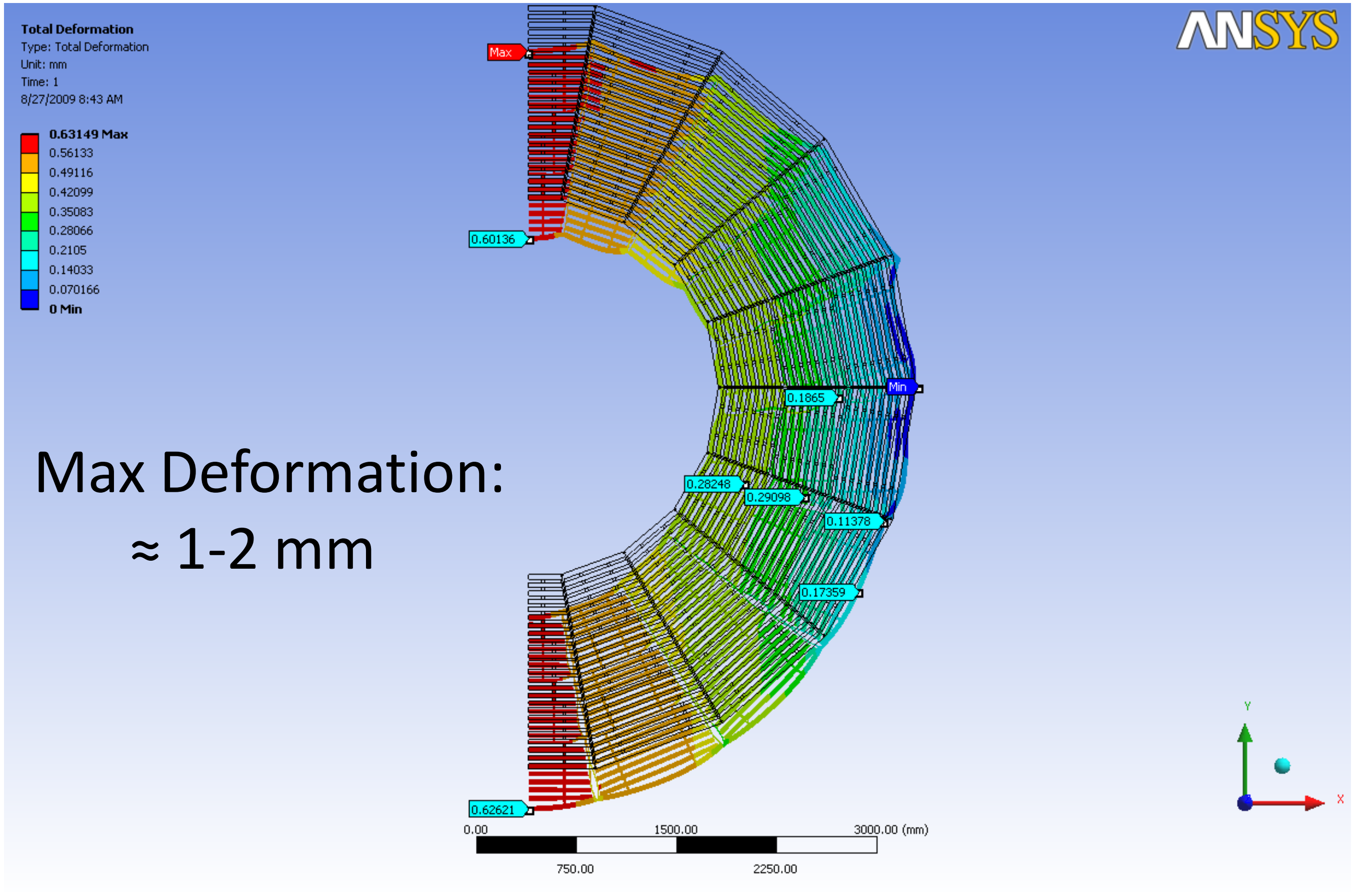
Masses & Supports

- HCal Spec.
  - Fixed outer supports at 3 & 9 o'clock
  - 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
  - Applied to inner faces of HCal



Global Deformation

Box Model



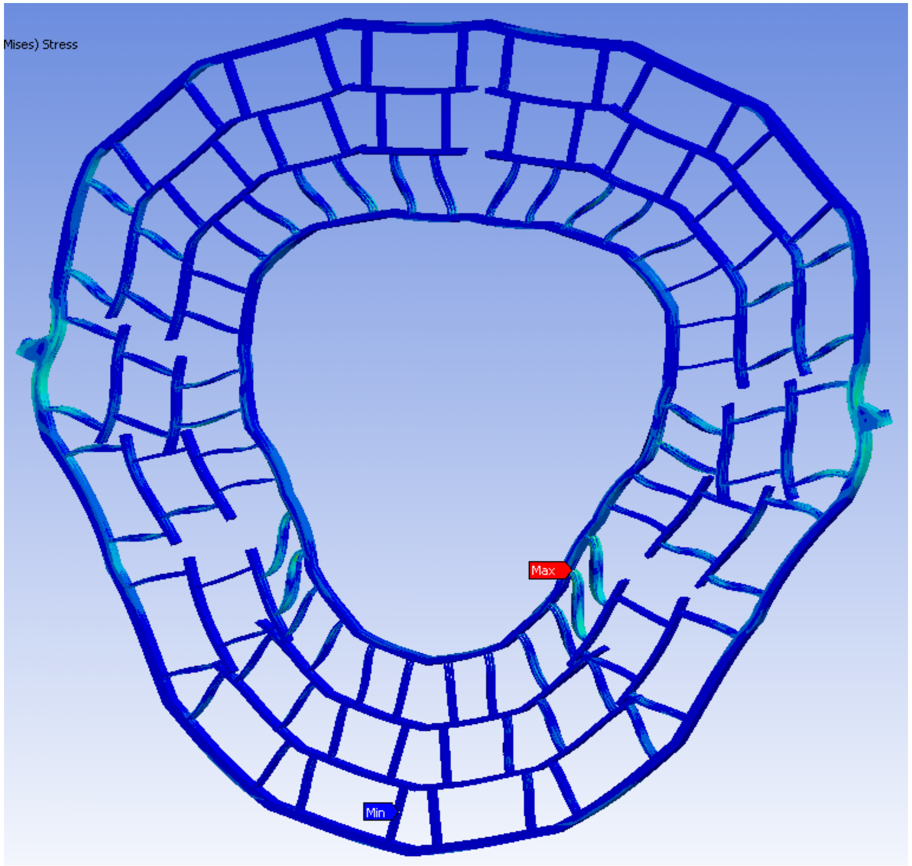
Max Deformation:

≈ 1-2 mm

Global Deformation

Staircase Model

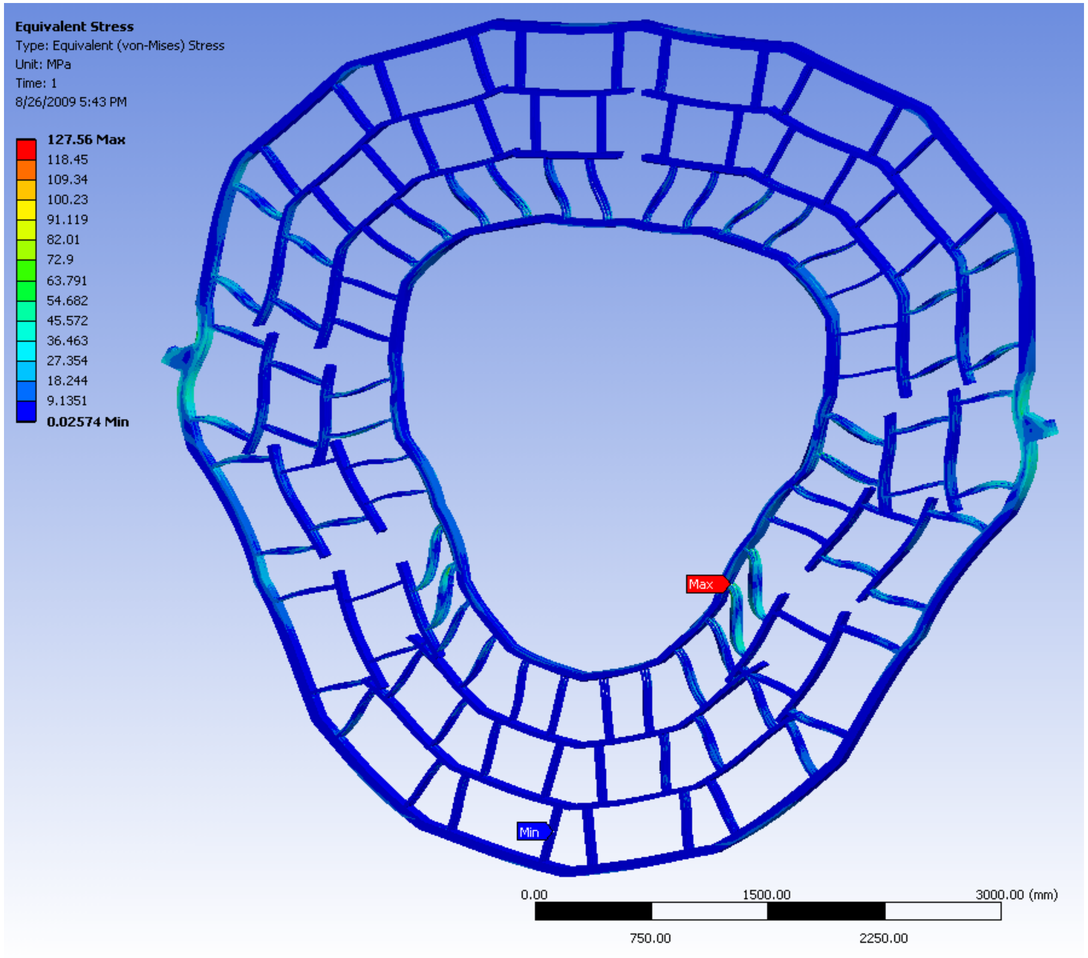
- Max. Deformation:
  ≈ 1-2 mm



III.a Steel Lattice Stress

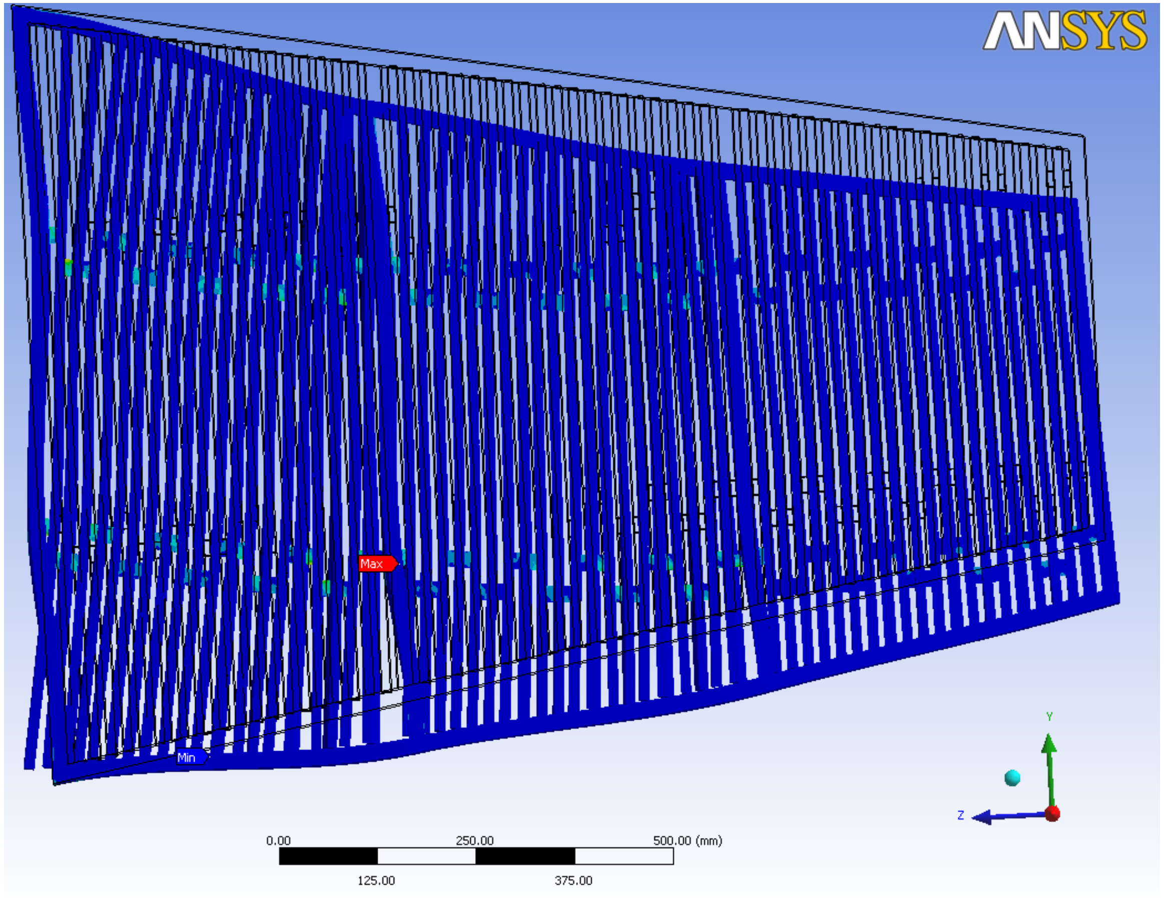
Staircase Model

- Stress Levels of
  ≈ 130 MPa
- Relevant Stress Limit:
  ≈ 138 MPa



III.b Tungsten Plate Stress

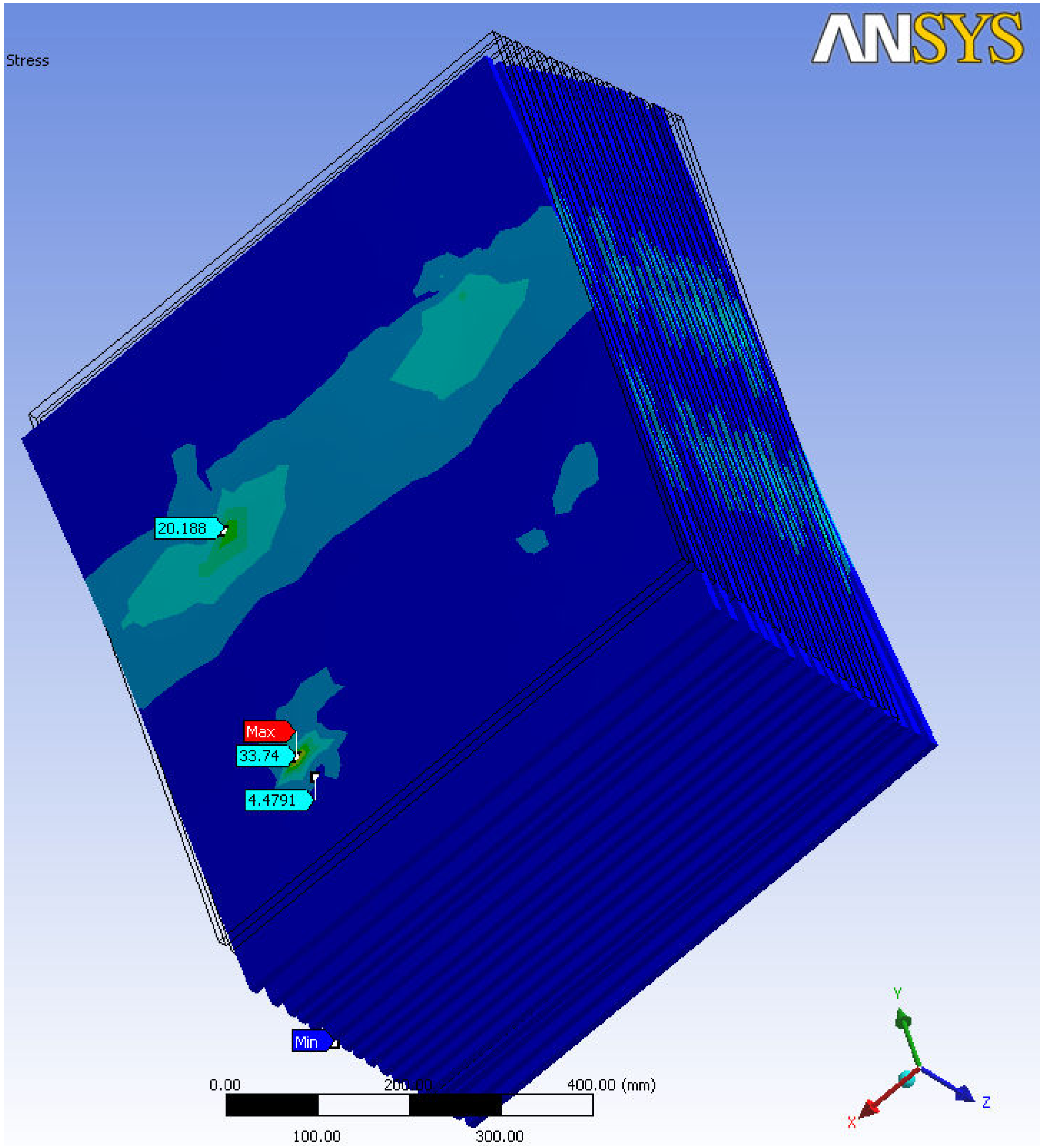
Box Model



Horizontal sector supported from side

Magnification

Max stress in tungsten plates:
- ✓35 MPa



Structural Conclusions

- Deformation in the case of both models examined is of the order of 1-2 mm
  - This is less than 0.1% of the detector diameter
- Stress levels in the steel lattice remain below material limits
- No structural showstoppers for proposed geometries

Further Analyses

- Design of supports for HCal from superconducting coil
- Design of inter-sector clamping and/or bolting mechanisms
- Design of intra-sector bolts and clamps

❖Much is already known in these areas from the construction of previous detectors

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