Conceptual Design of ILD Yoke

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DESY

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Outline

- Design requirements
- Magnetic Stray Field and Forces
- Present status of design
  - Barrel
  - End-cap
- Yoke Assembly
- Options/Optimization
- Conclusions

Mainly report on progress at DESY

- K.Büsser, M.Lemke, B.Krause, C.Martens, A.Petrov, K.Sinram, U.S., R.Stromhagen (all part time)

Function and Challenges of Iron Yoke

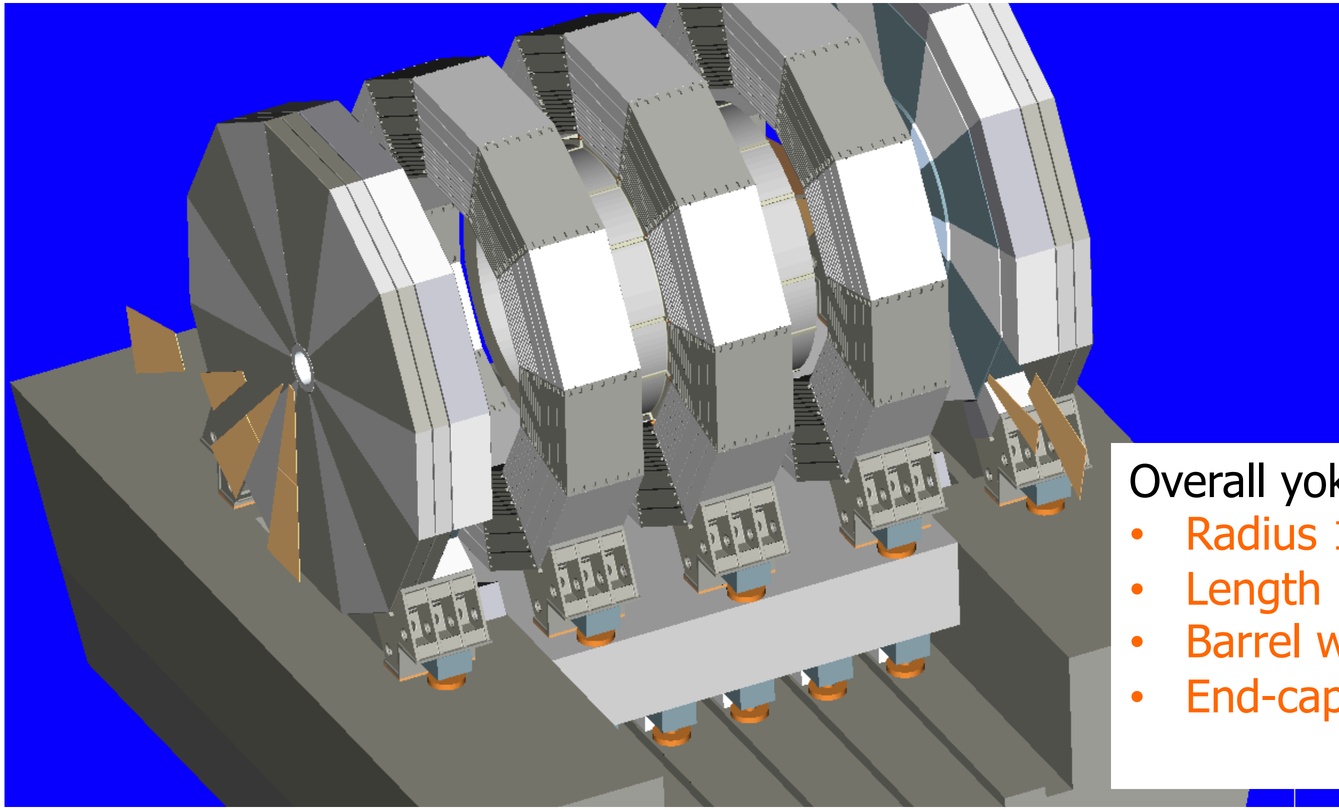
- Muon identification and hadron rejection
  - Muon momentum measurement done with inner tracking detectors
  - Some muon ID with calorimeter, but need high purity and redundancy
  - Rejection of beam halo-muons
- Tail-catcher/backing calorimeter
- Flux return
  - Field homogeneity in TPC
  - Stray field
  - Large magnetic forces
- Main mechanical structure of detector
- Radiation shielding
  - Detector should be self-shielding, T.Sanami, Warsaw ECFA Workshop

- Main challenges of yoke design
  - Reduce stray field to acceptable level Determines total thickness and cost of iron
  - Huge magnetic forces on end-caps
  - Optimize design w.r.t. to performance, site requirements and cost

Yoke Design Overview

Design based on CMS

- Large volume, 4T magnet
- Assembly in surface hall, moved to IR hall through vertical access shaft
- 3 instead of 5 (CMS) barrel rings
- End-cap option split into inner and outer pieces

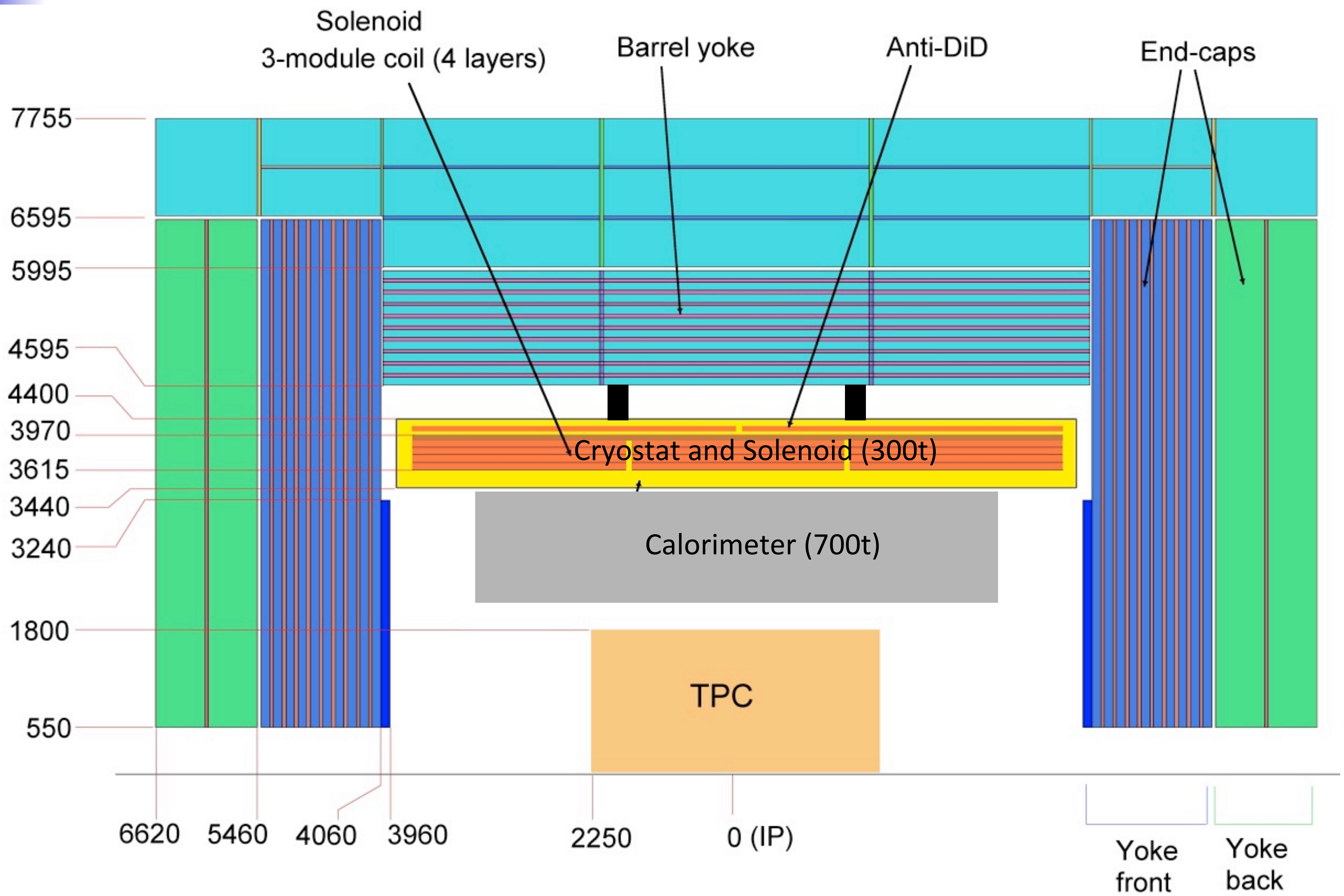


Overall yoke dimensions

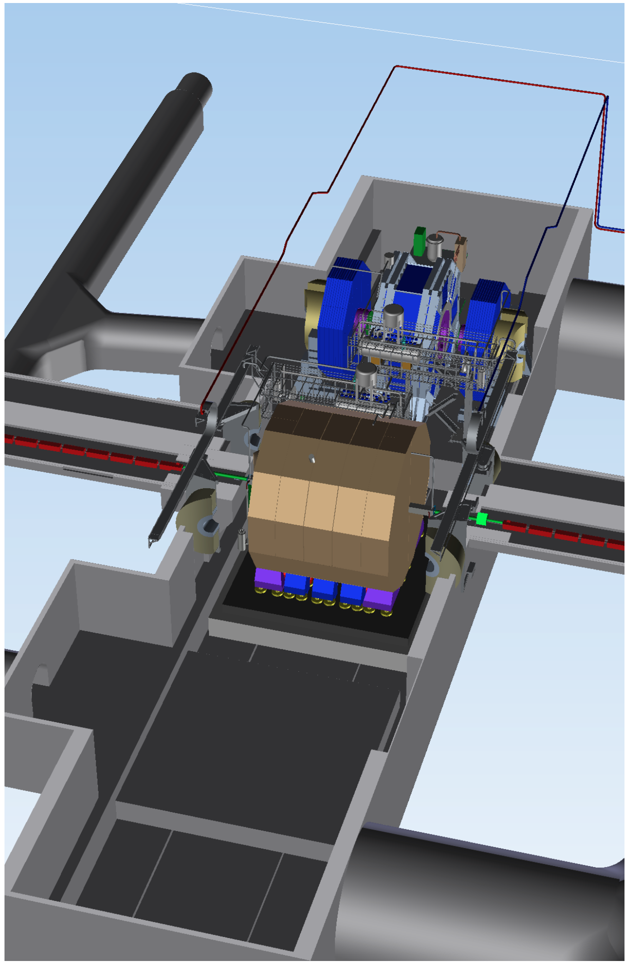
- Radius 15.5m
- Length 13.2m
- Barrel weight 6900t
- End-cap weight 6500t

total 13400t

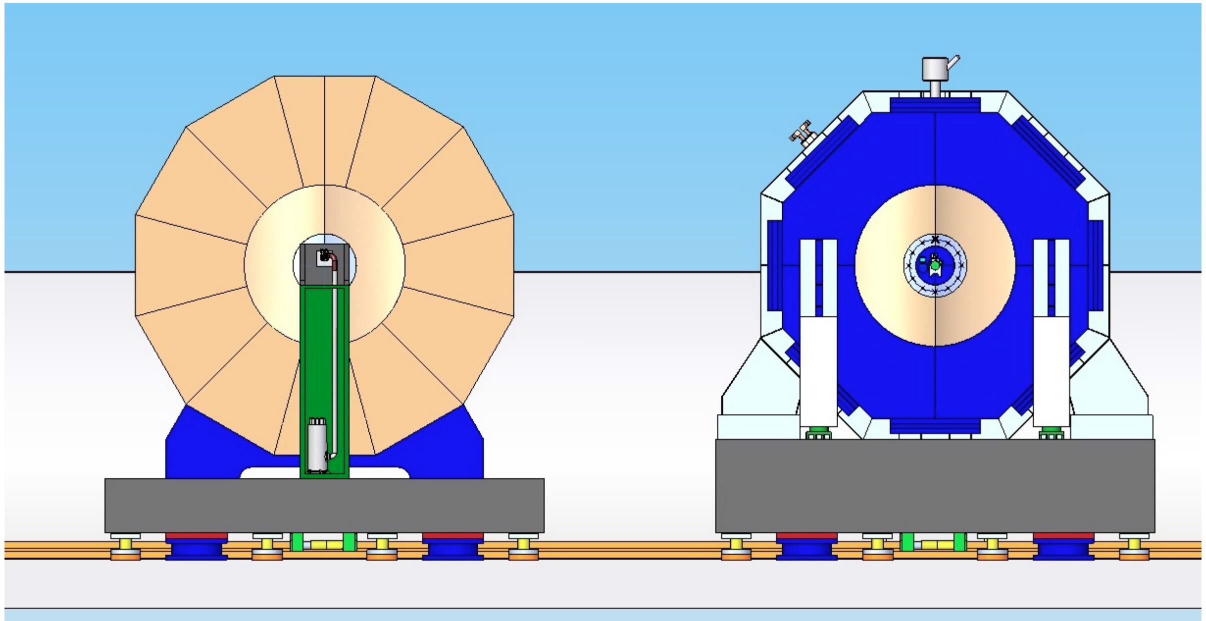
Yoke Cross-Section Overview



ILC Experimental Hall



- Two detectors in hall, in beam and in park position
- On platform for fast movement in/out of beam position
- Requirements on stray field
  - 50G in 15m radial distance from detector center based on CMS experience



Segmentation of Iron Yoke

Barrel

- 10 100mm thick steel plates with 40mm gaps for chambers
- 3 560mm thick steel plates with 40mm gaps for chambers

End-cap

- 100mm field shaping plate
- 10 100mm thick steel plates with 40mm gaps for chambers
- 2 560mm thick steel plates with 40mm gaps for chambers

- Thickness of inner 10 plates determined by physics requirements: energy measurement of hadronic showers (tail catcher) and muon identification
- Total amount of outer plates determined by requirements on stray field
  - Limit of 50G may be relaxed (100G?)

    => could reduce amount of iron and hence cost
  - Quite some uncertainty in field calculation, FEM simulations at limit

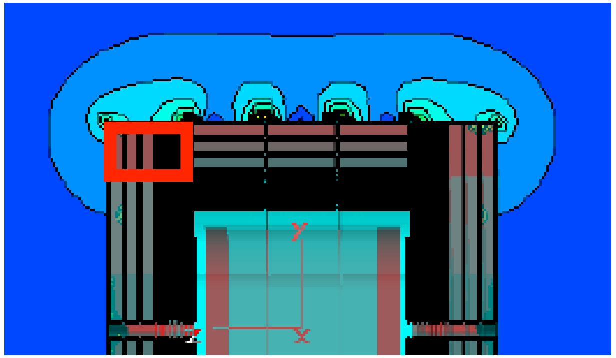
    => may keep present iron thickness

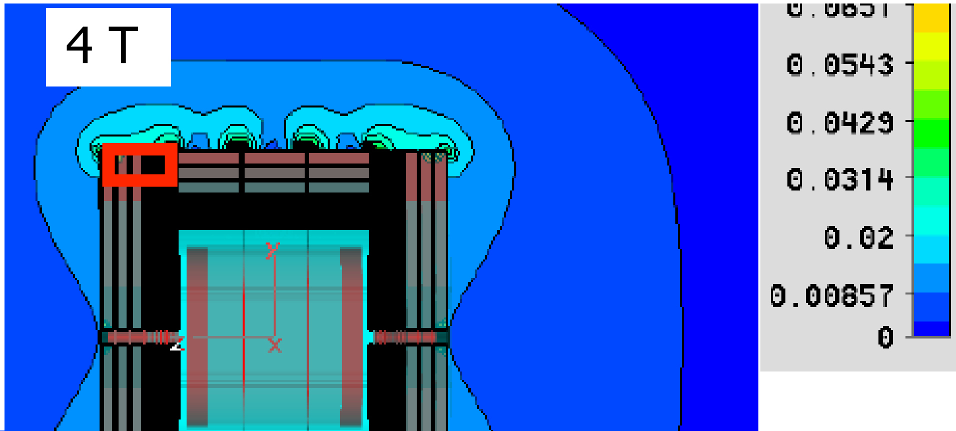
Stray Field Calculations

A. Petrov, 2008

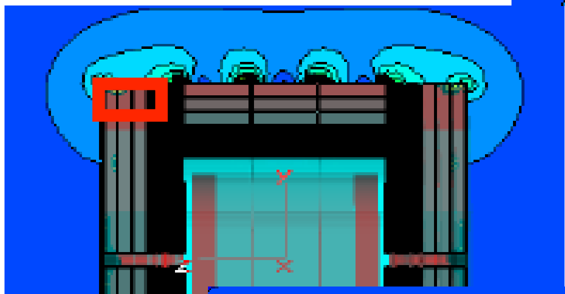
3.5 T

gaps filled

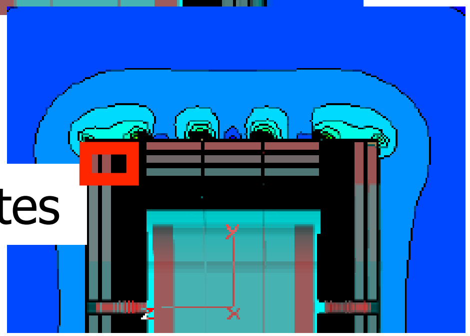




gaps partly filled

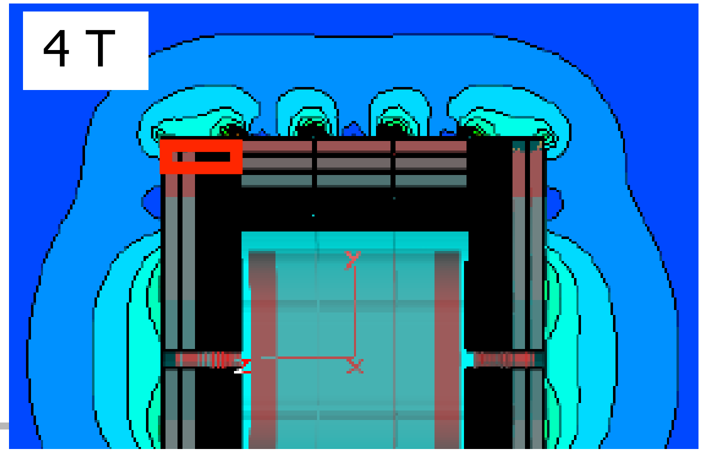


gaps partly filled, EC 2 plates



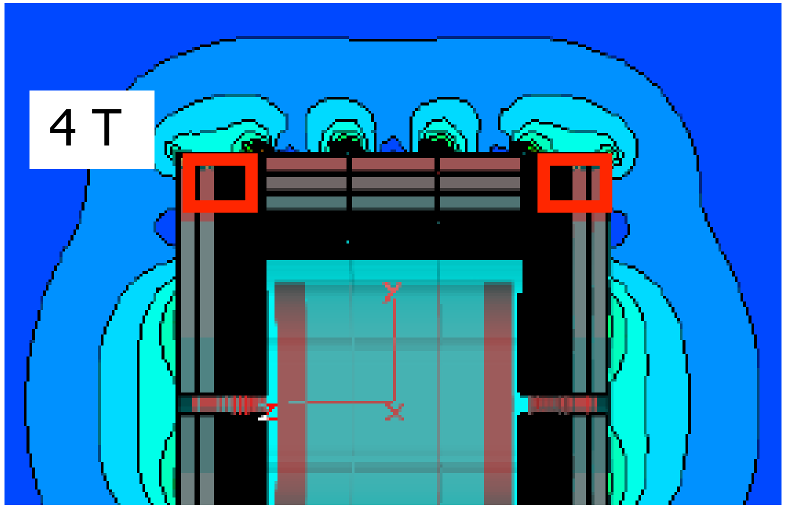
Seoul mtg

iron thickness 2.68/2.12m
total thickness 3.16/2.56m
r_{out} = 7.655m, z = 6.605m



Magnetic Stray Field

Did extensive field calculation for several geometries



	B	EC
iron thickness	2.68/2.12m	
total thickness	3.16/2.56m	

r_{out} = 7.655m, z = 6.605m

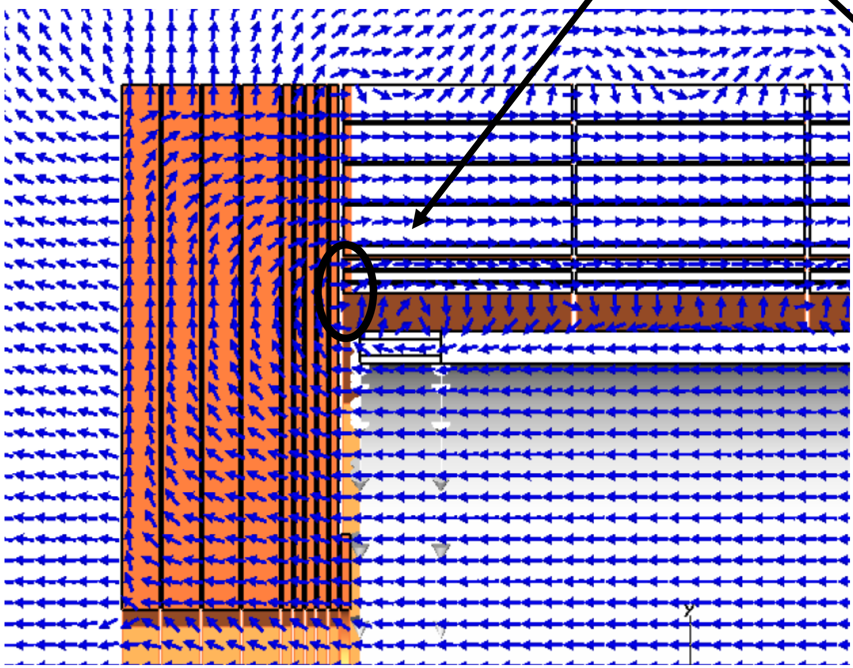
- Achieved goal of < 50G at 15m from beam line for 4 T
- Thickness of iron and size of detector is determined by stray field requirements
- Important to close gaps as much as possible
- Stray field requirements may be relaxed (100G?)
  -> Yoke could be slightly smaller
- New FEM calculations give larger stray field. In addition, at limit of FEM.
  -> Will probably keep present iron thickness
- Need better understanding of FEM calculations

Forces on Barrel

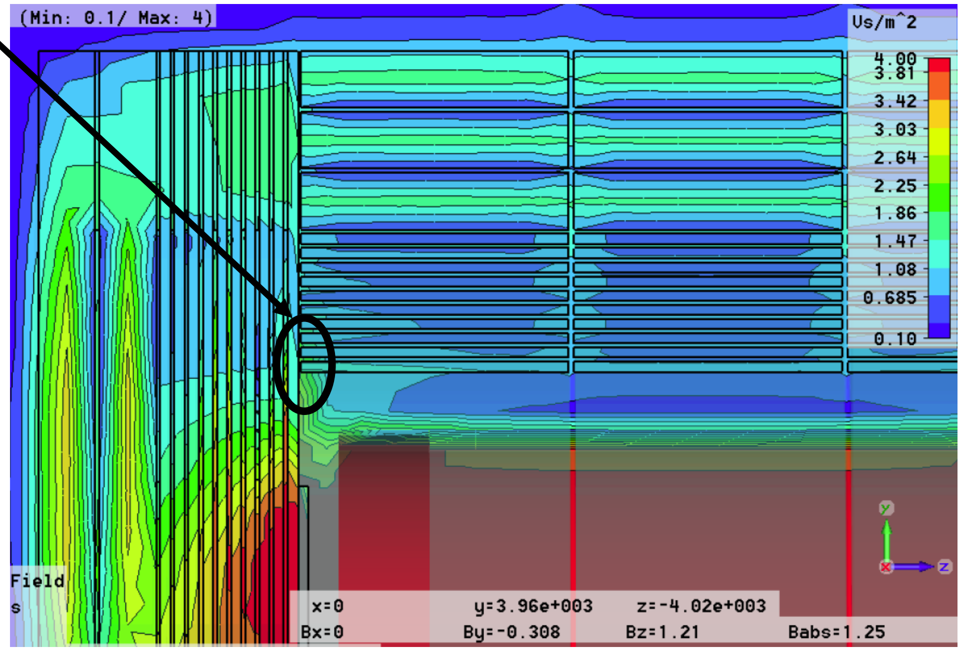
- Magnetic forces acts in z-direction. Barrel is compressed. No problem.
- Exception: magnetic force on innermost plate of outer wheels
- Unlike end-cap, radial forces on barrel are mainly to due gravity

A.Petrov

B field direction



B field

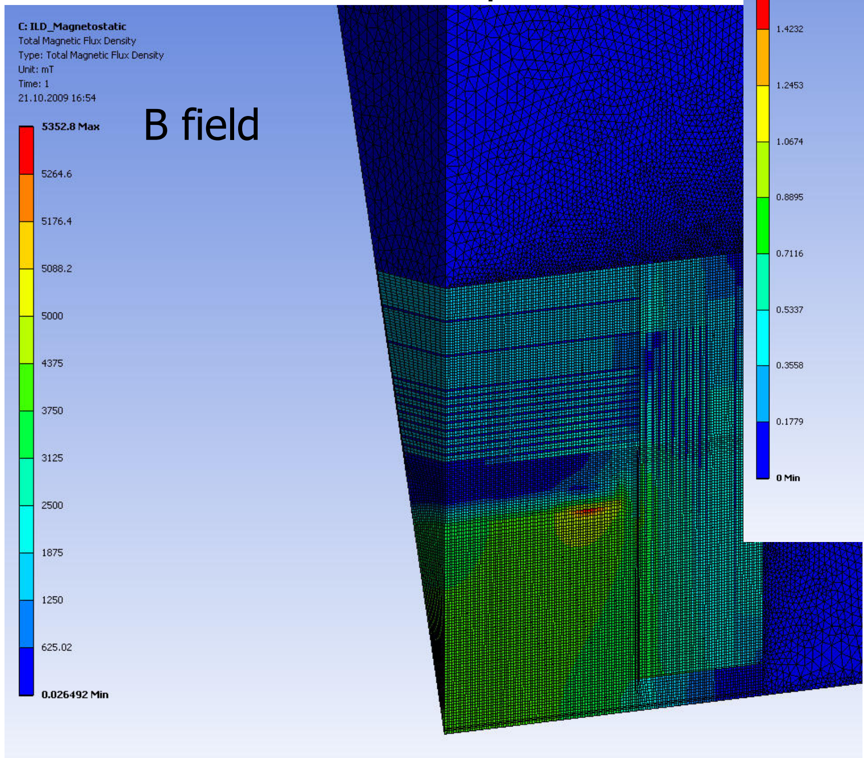


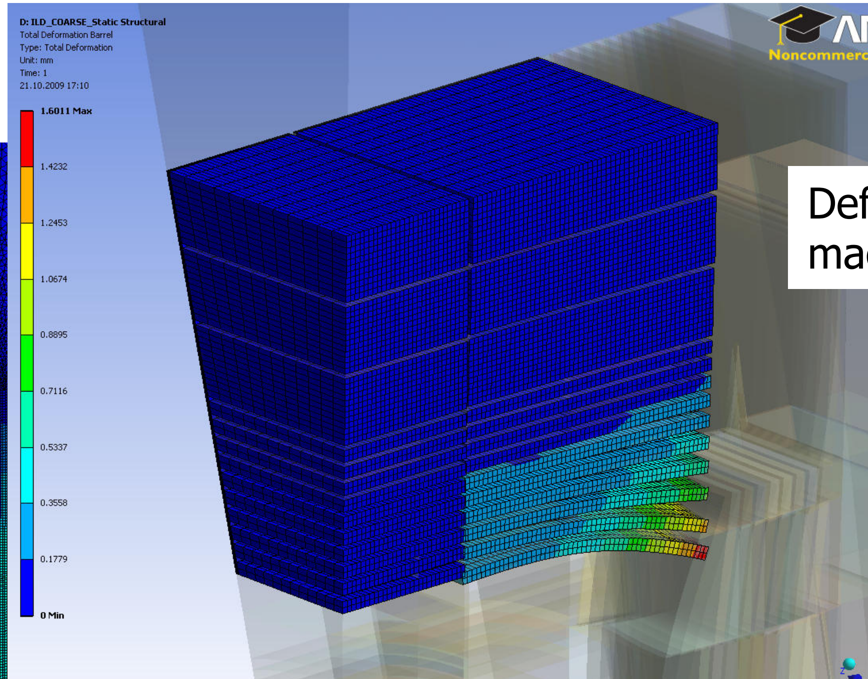
Magnetic Forces on Barrel

M.Lemke

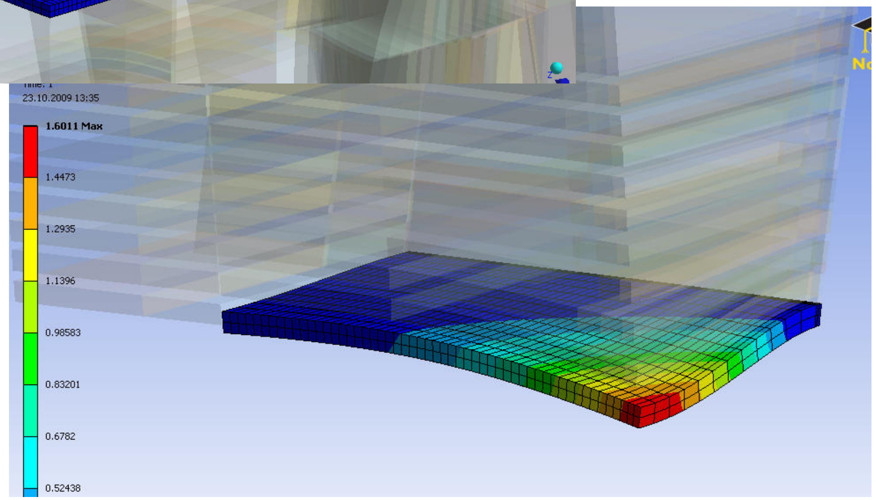
Forces much weaker than for end-cap

B field



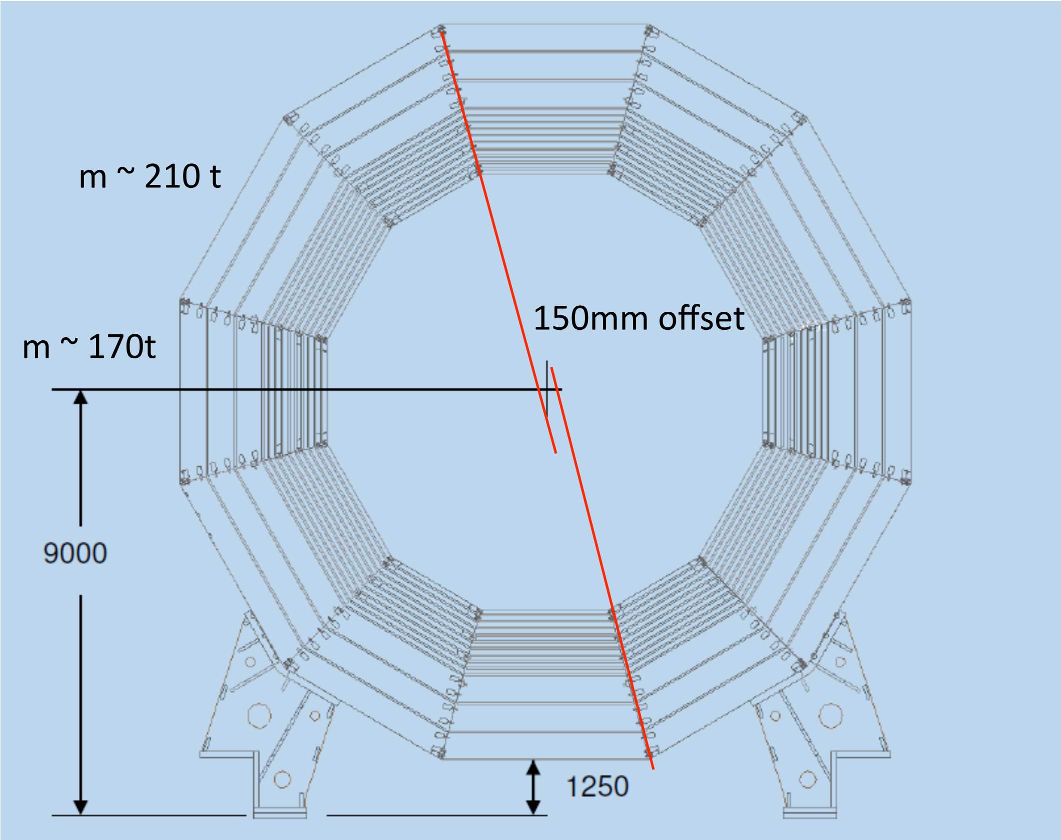


Deformation due to magnetic forces



Deformation of inner plate of outer wheel 1.5mm
No problem

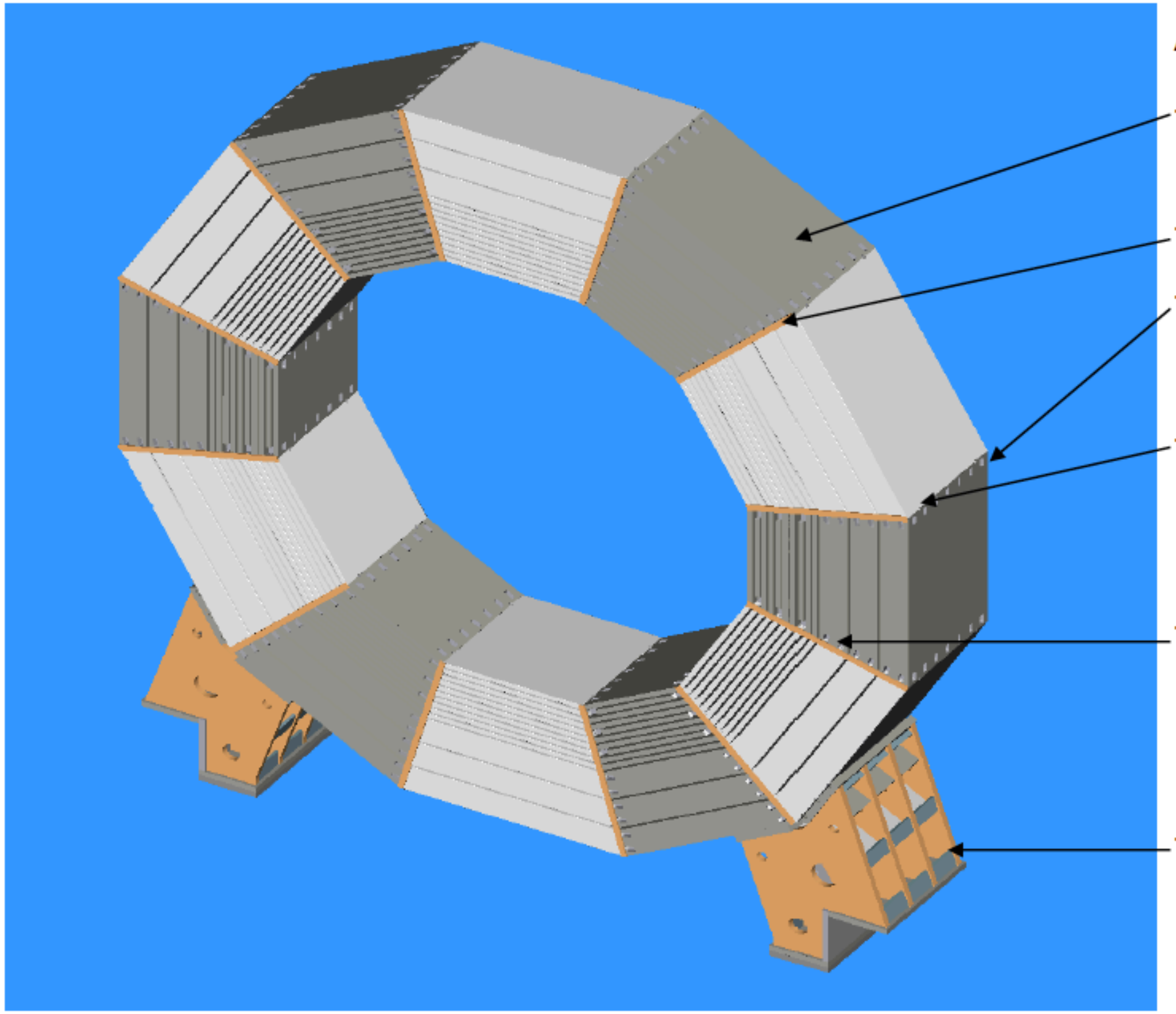
Design of Barrel



- Three barrel wheels, each consisting of 12 segments
  - Segments with welded plates
  - Segments bolted together
- Iron Segmentation
  - Inner part: 10 plates 100mm, 4mm gaps for detectors
  - Inner part: 10 plates 100mm, 4mm gaps for detectors
- Thickness of iron given by stray field requirements
- Radial iron thickness 2.68 m

Barrel Design

R. Stromhagen



Assembly:

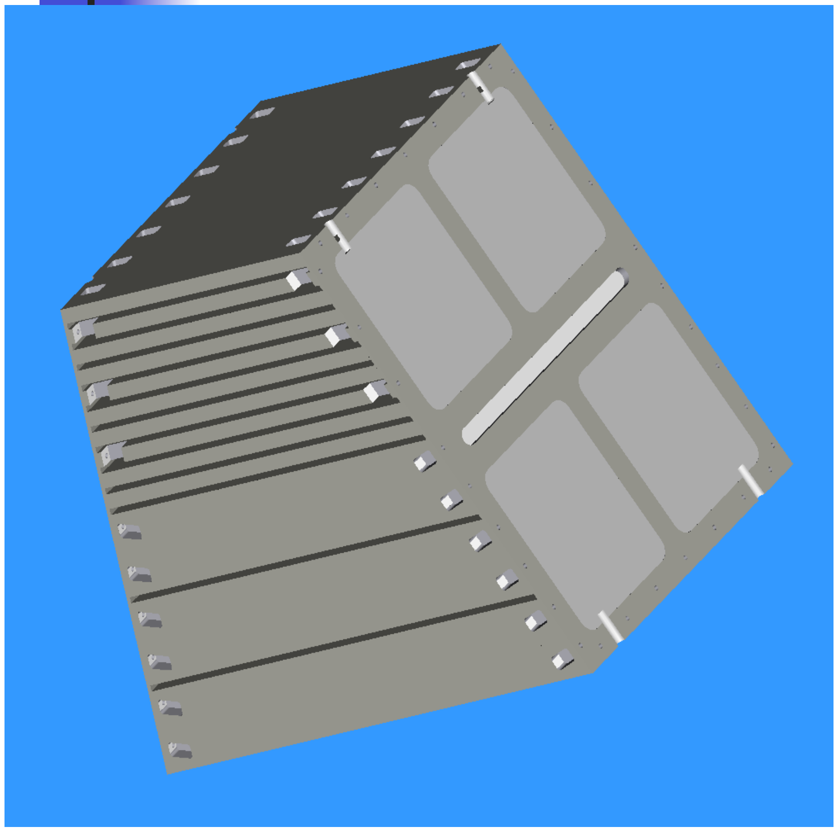
- segments ~ 200 t.
  welded
- shoulder for end-stop
- screws min. M30 /

  (min. 32 pieces)
- bolds (4 pieces

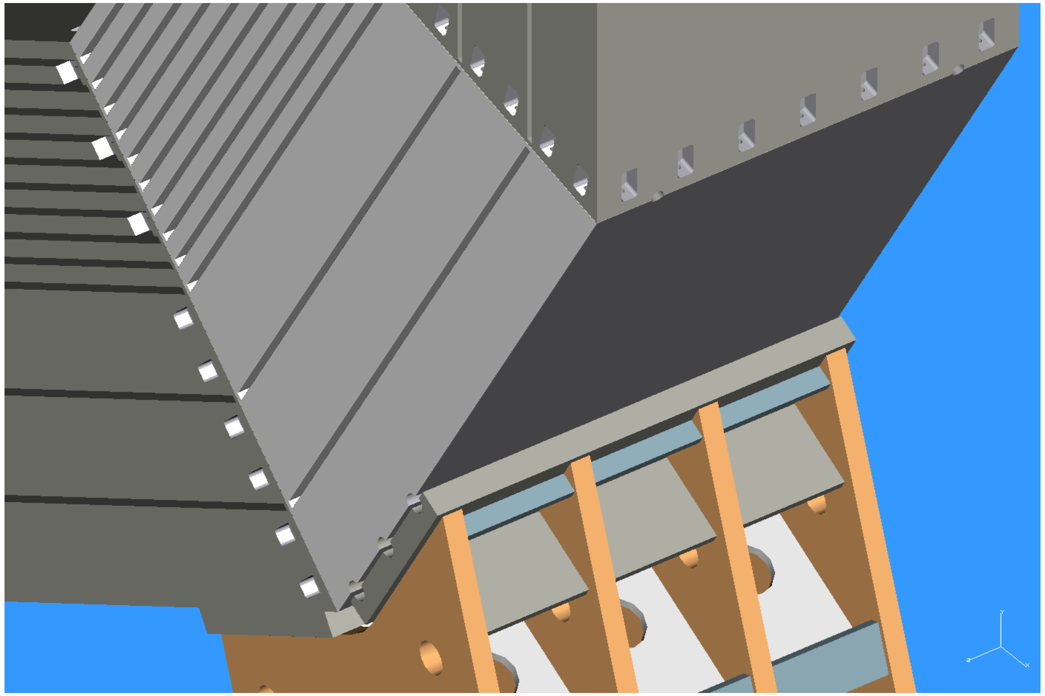
  d ~ 120, lg. 350
  assembling bore)
- key ledge, horizontal
  (1 per segment
  160x160, 2200 lg.
  mm)
- stand (screws min. M30,

  d ~ 120, lg. 350,
  assembling bore)

Barrel Segment Design



Segment weight ~210 t

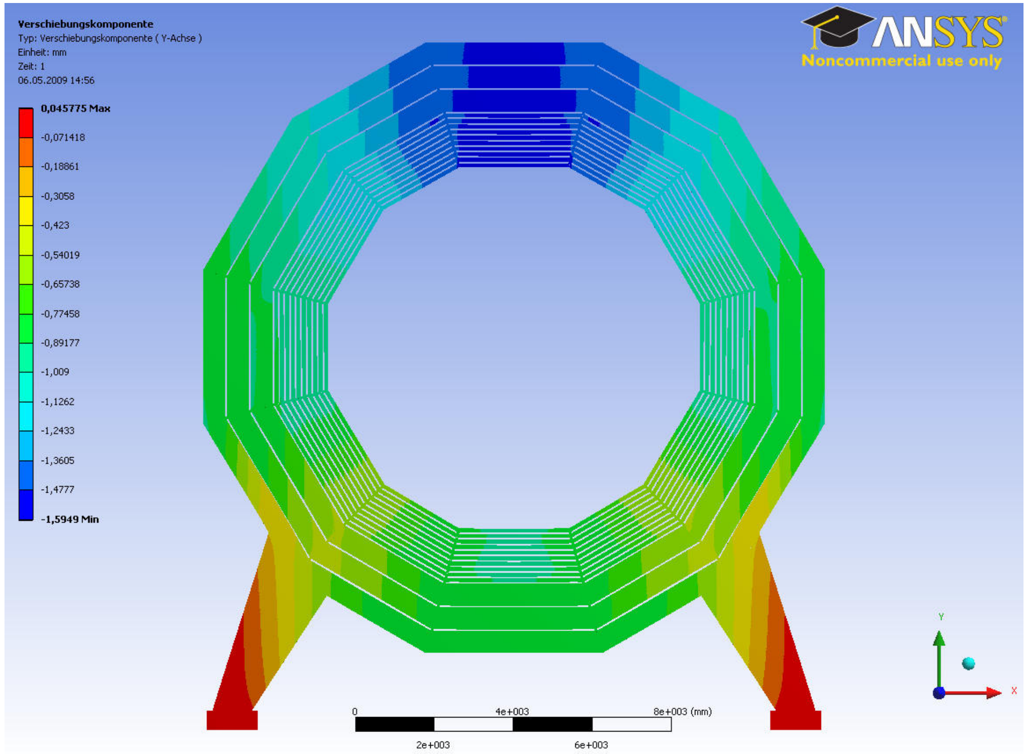


Deformation due Gravitational Load

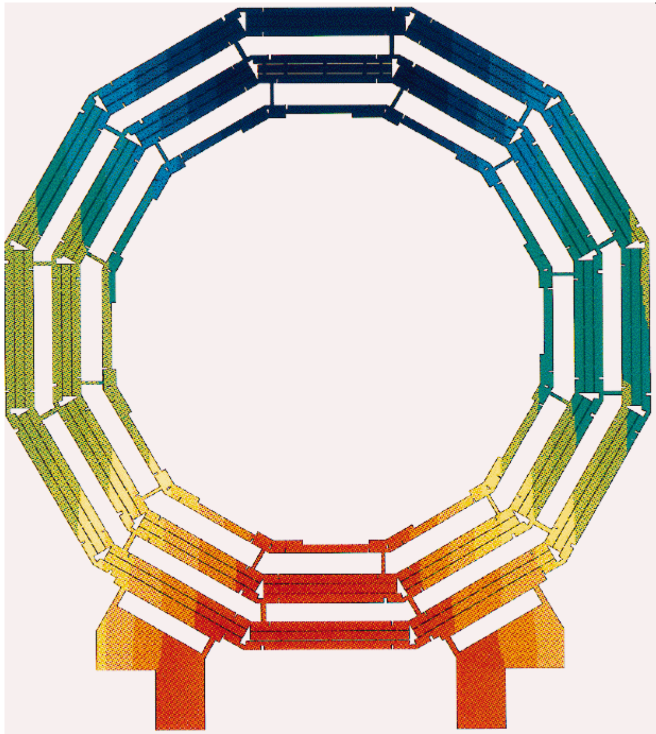
Vertical deformation of outer wheel

- Assuming solid connection between segments
- Max. deformation 1.6mm

  (Support feet too small, simplified)



CMS



Max. vertical deformation 4.1mm

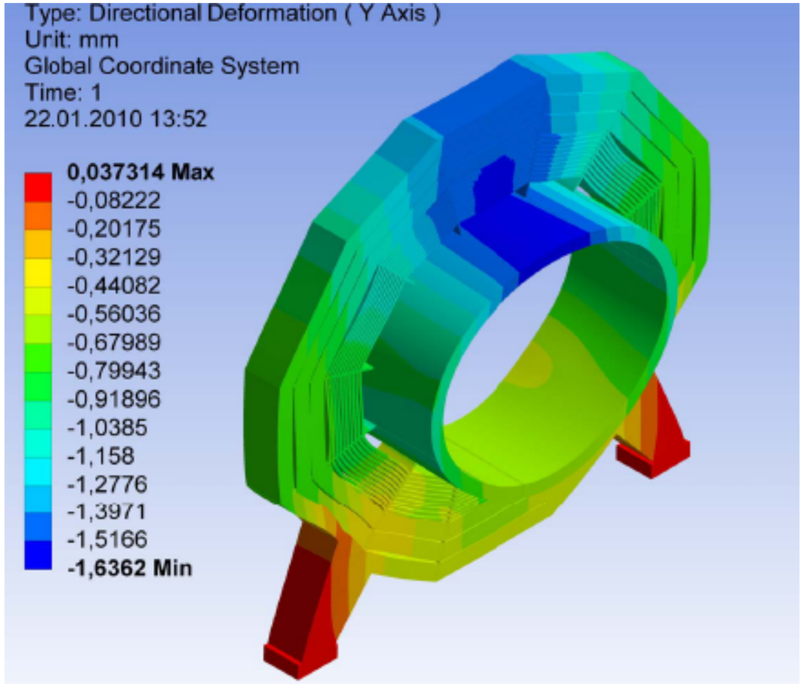
Deformation and Stress

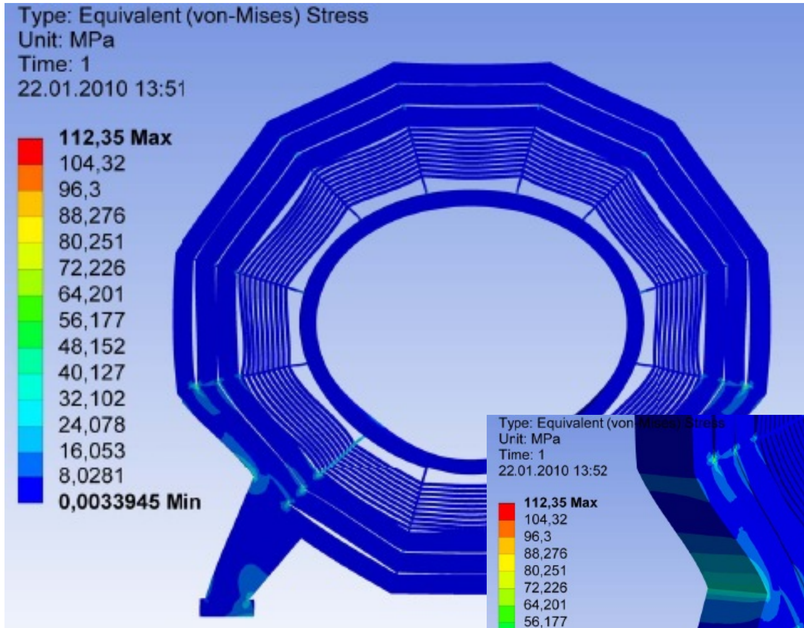
Vertical deformation of central wheel

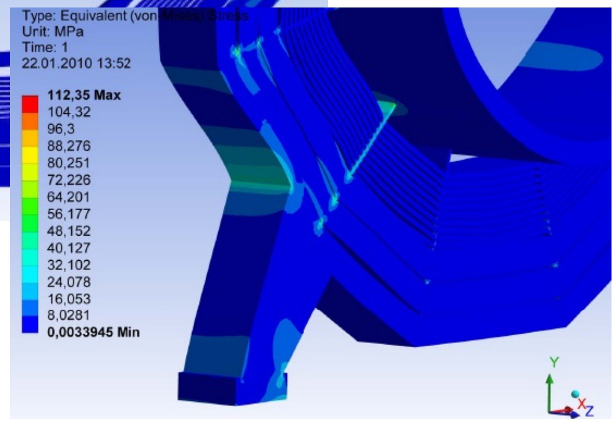
M.Lemke

- Including load of cryostat, coil and calorimeter of 1000t
- Assuming cryostat solid with scaled up density

Caveat: cryostat much too stiff in this model





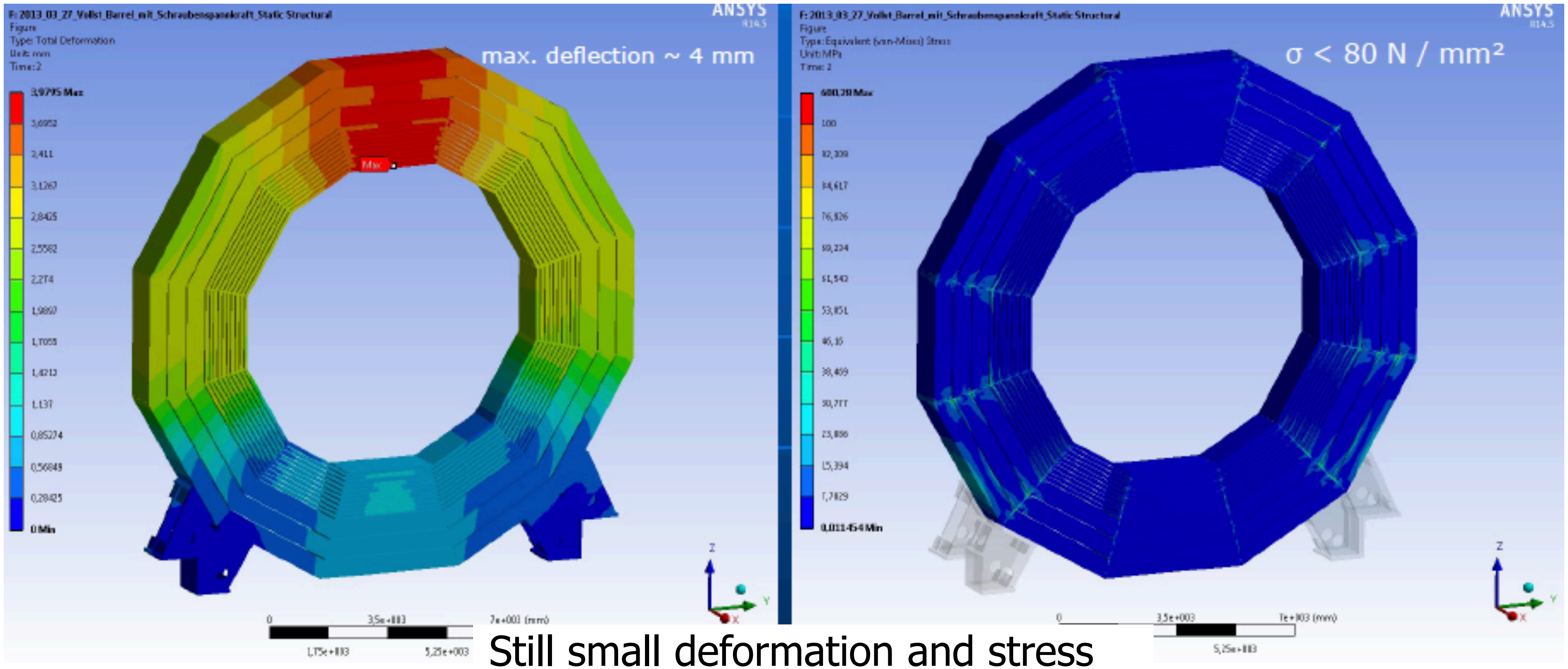


Small deformation and stress

Barrel Deformation and Stress

Total Deformation due to gravitational load and stress
New FEM model

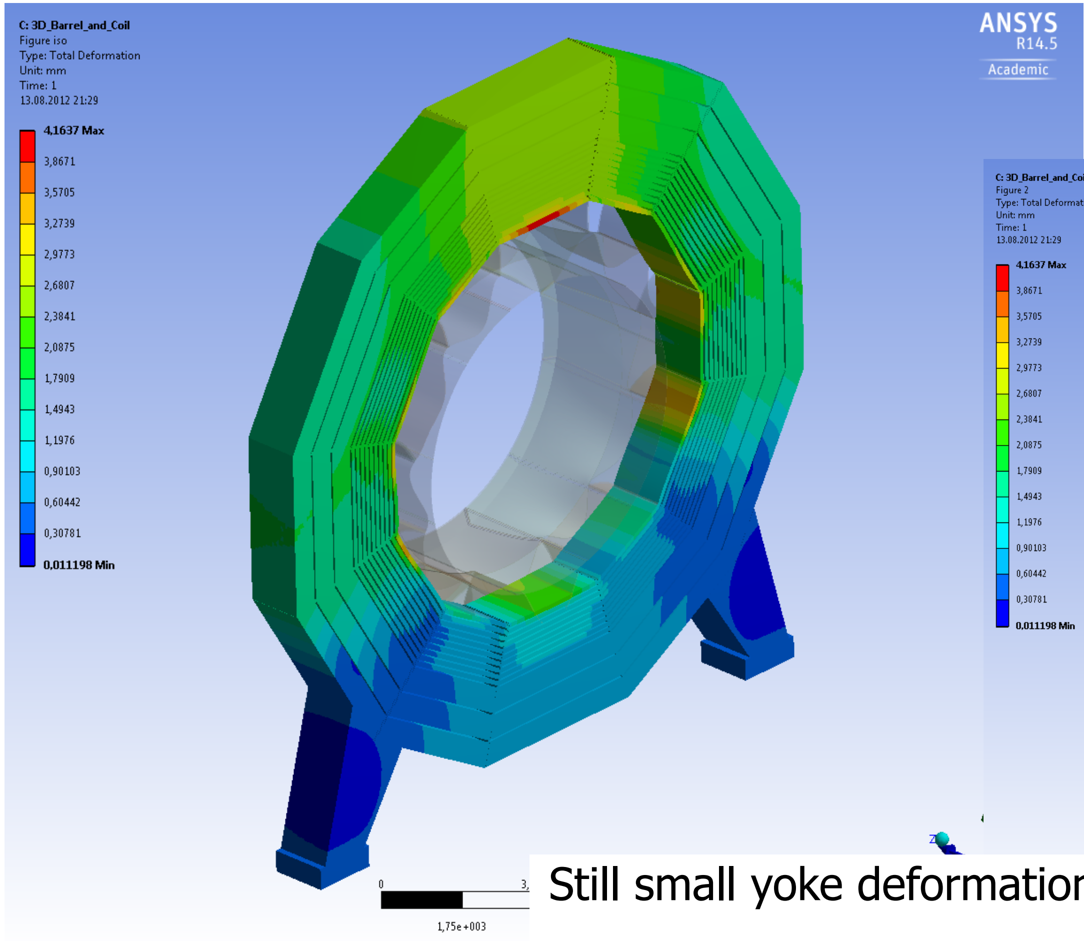
- Including bolts between segments
- Not solid model anymore



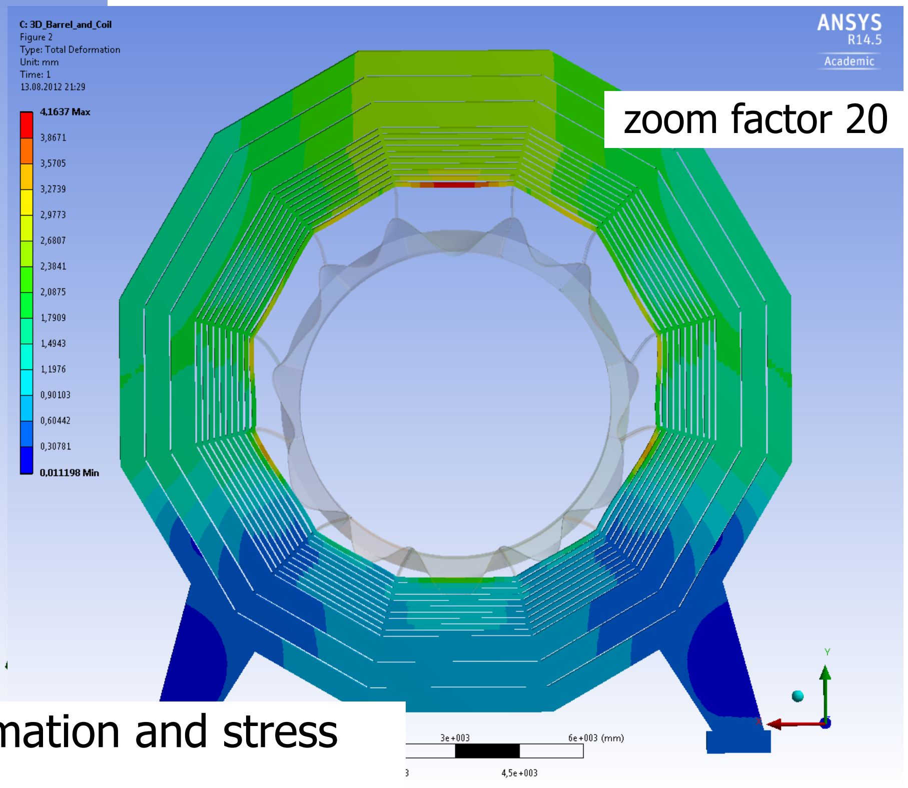
Still small deformation and stress

Barrel Deformation – Central Wheel

Total Deformation due to gravitational load including coil and HCAL load
Bolts between segments, not solid model anymore



Density of outer cryostat wall increased to simulate full load (1000t)



zoom factor 20

Still small yoke deformation and stress

Magnetic Forces on End-Cap

FEM Calculations 4T B field

CST EM Studio

- Force on center of each segment

  → total force F_z = 20000t

  Model floor with support feet and steel plate in floor

ANSYS

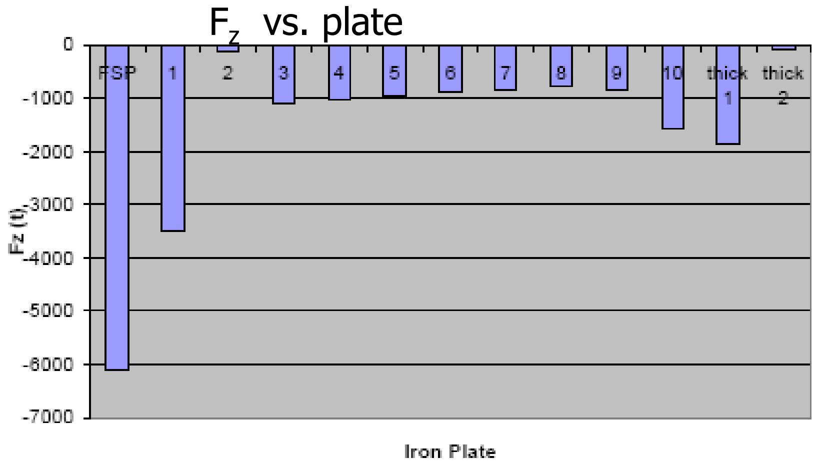
- Force at each segment node

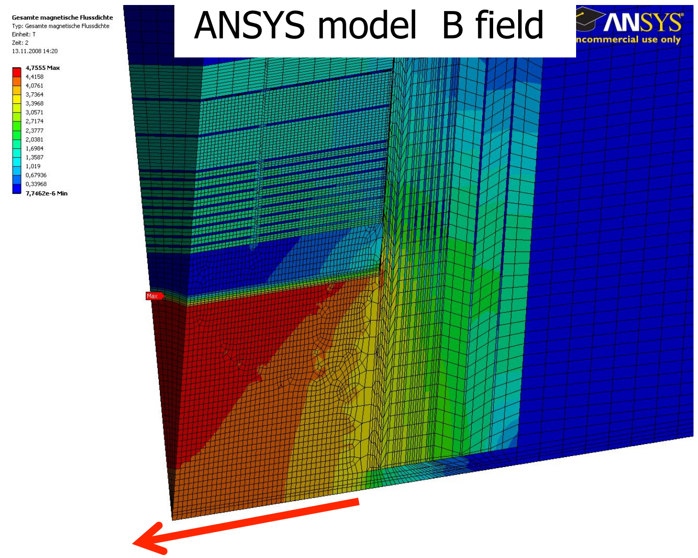
  Resulting force on hard stop

  → F_z = 19000t for 3 thick EC plates

  F_z = 18000t for 2 thick EC plates

  Model with open gaps



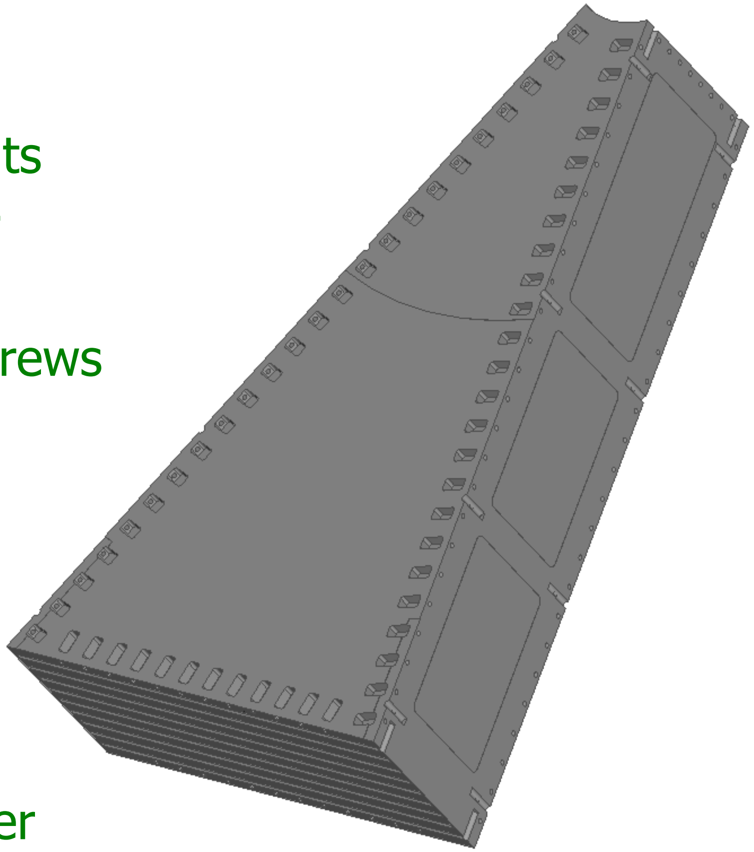


~ 20000t force acting on end-cap

End-cap Design

Inner end-cap

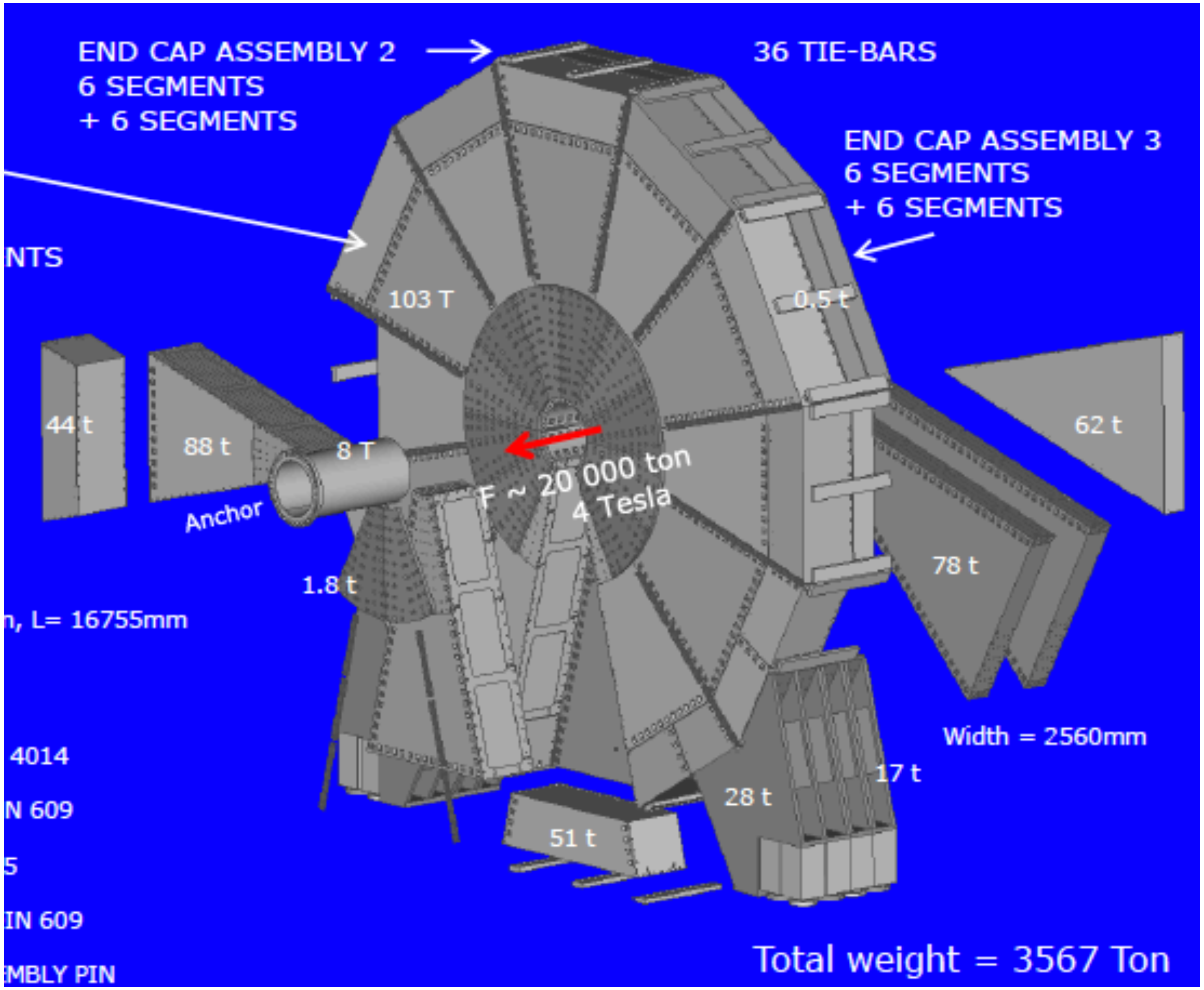
- Consisting of 12 wedge-shaped segments
- 10 100mm thick plates welded together
  25x 40mm^2 spacers
- Segments bolted together using M36 screws
- Field shaping plate 100mm part of or attached to first plate
  - Welded, giving 200mm total thickness or
  - Bolted to plate segments



Outer end-caps

- Two disks, 560mm thick plates
- Wedge-shaped segments bolted together
- In addition on outer radius iron pieces to close gaps of inner end-cap gaps

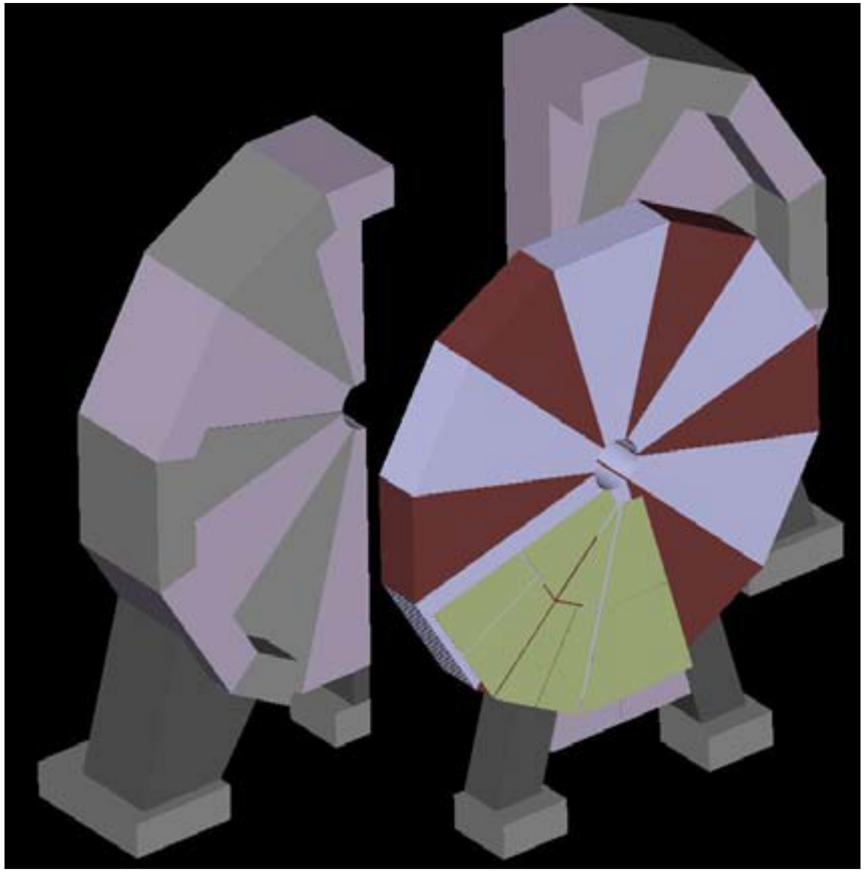
Mechanical Design of End-Cap



Comments

- Quite detailed study (R.Stromhagen)
- Should separate inner and outer EC again
- Unclear whether separate inner plates necessary

Inner and Outer End-caps



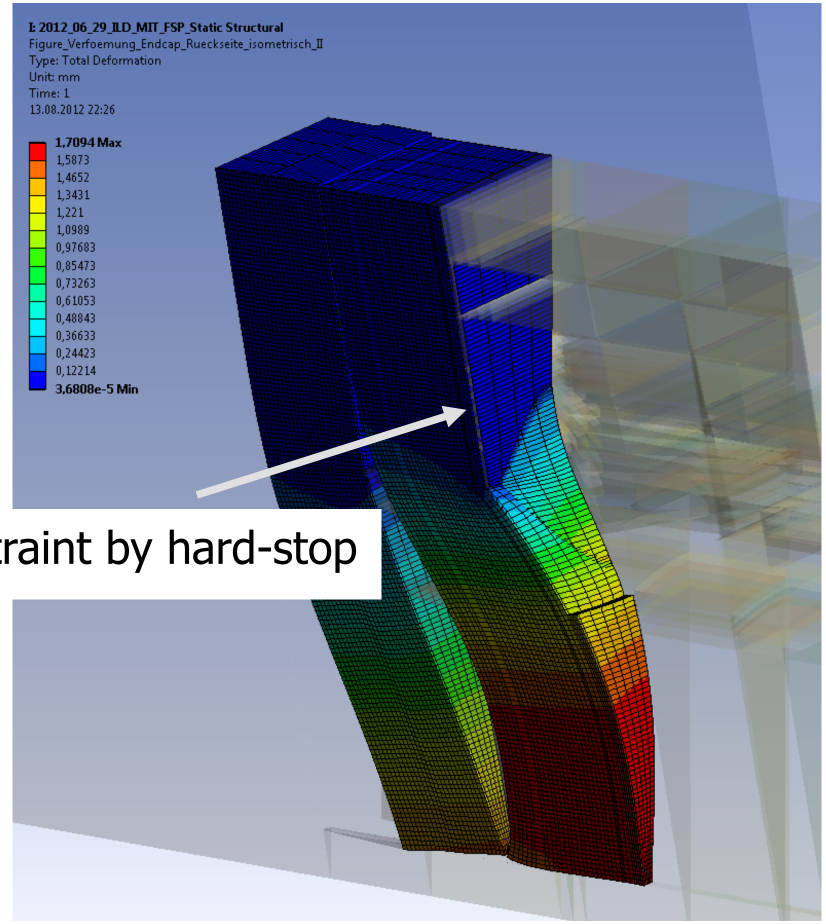
Option: inner and outer end-caps split in z-direction, not vertically

- Fast access to muon chambers in inner EC
- Reduce weight of movable parts

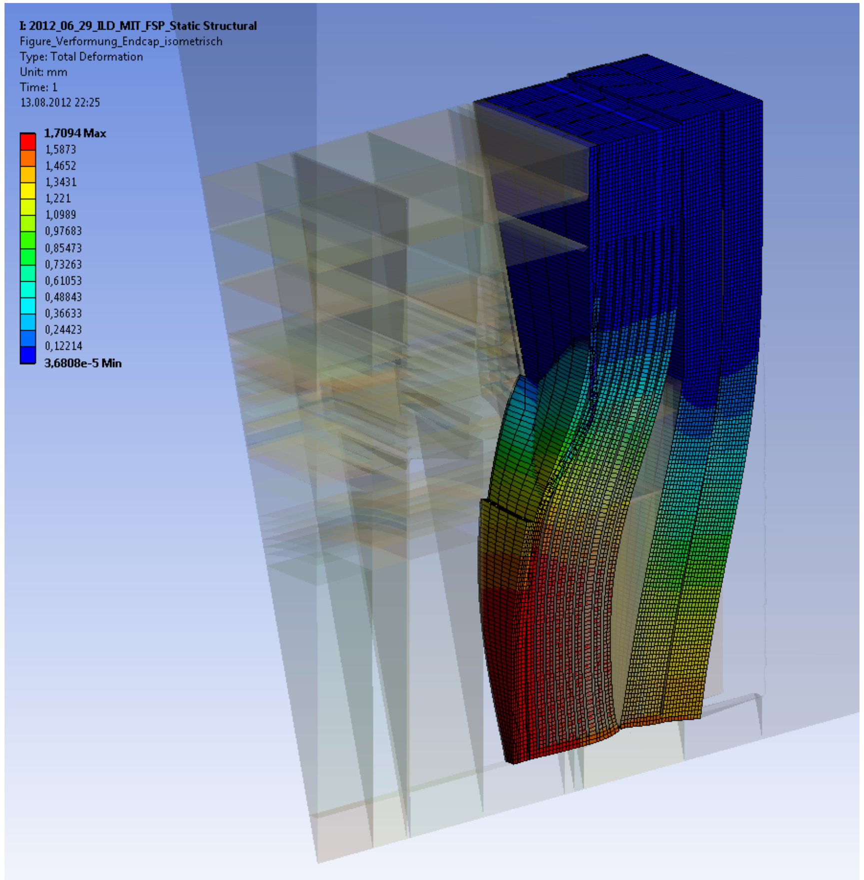
Model not up date. Outer EC not split vertically

End-cap Deformation

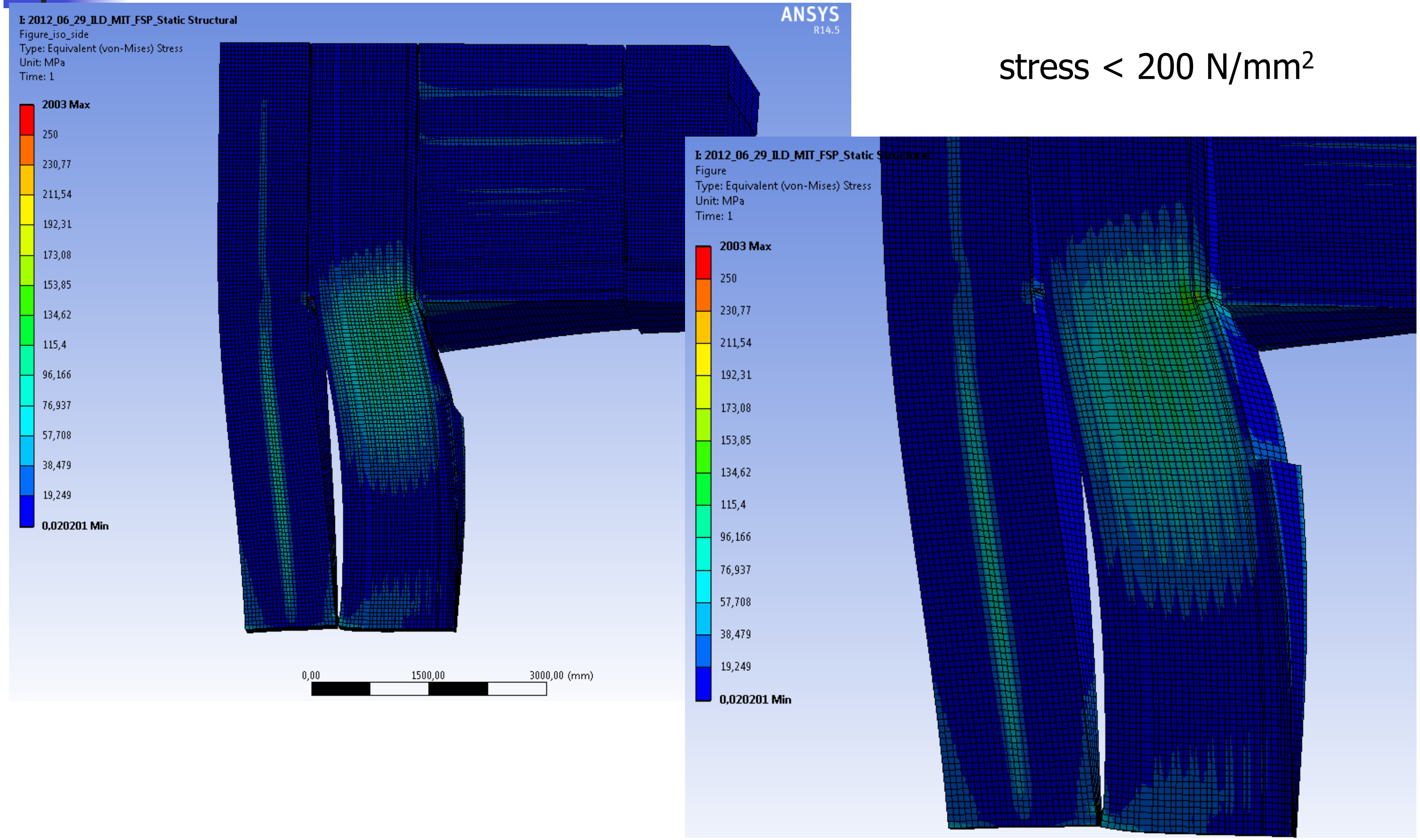
Max. deformation ~ 2mm
due to magnetic force



Constraint by hard-stop



End-cap Stress



stress < 200 N/mm^2

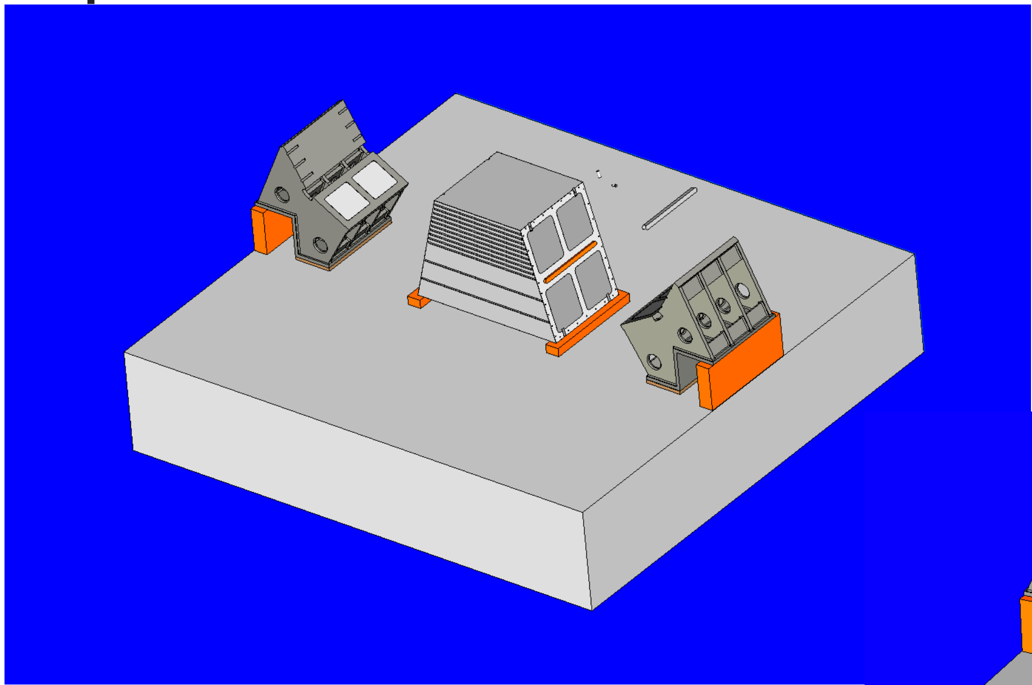
Yoke Assembly

In principle, yoke design and assembly based on CMS assembly

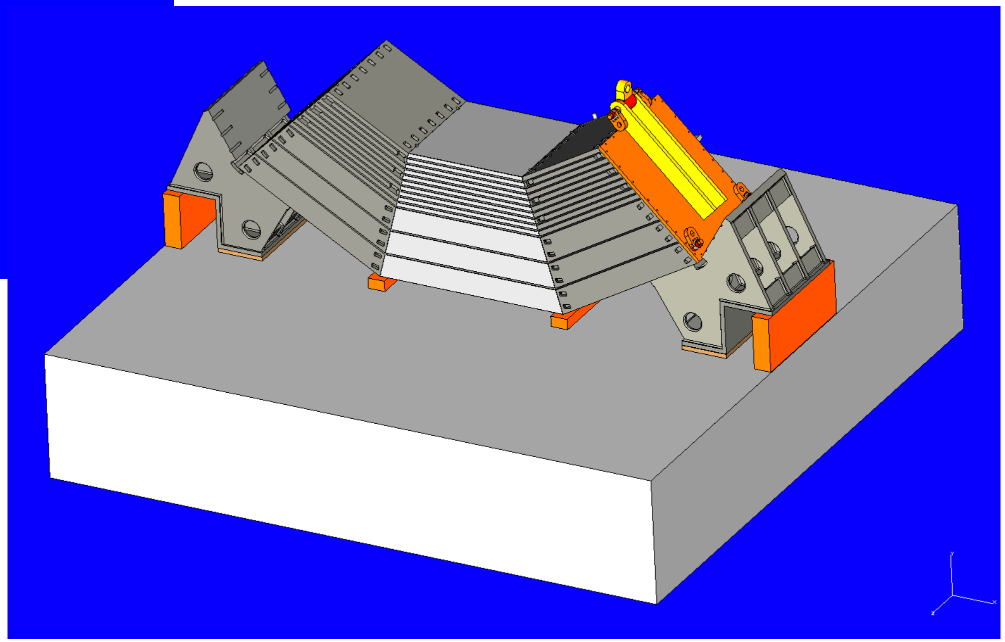
- Barrel consists of 3 large wheels (CMS 5)
  - Barrel segments form a rigid structure
  - No “mandrel” or Ferris wheel needed for assembly
- Each end-cap consists of 1 (or 2) large large disk (CMS 3)
  - Similar shape and assembly
- Original CMS-style assembly (vertical access)
  - All machining and pre-assembly at manufacturer site
  - Assemble wheels and disks in surface building
  - Disassembled again, segments shipped to ILC site
  - Lower wheels/disks into IR hall
- Now, Japanese mountain site IR hall (horizontal access)
  - Yoke design, manufacturing and shipment unchanged
  - Segments (max. weight ~210t, gross weight ~250t) moved to IR hall
  - Barrel wheels and end-caps assembled in IR hall

Barrel Assembly

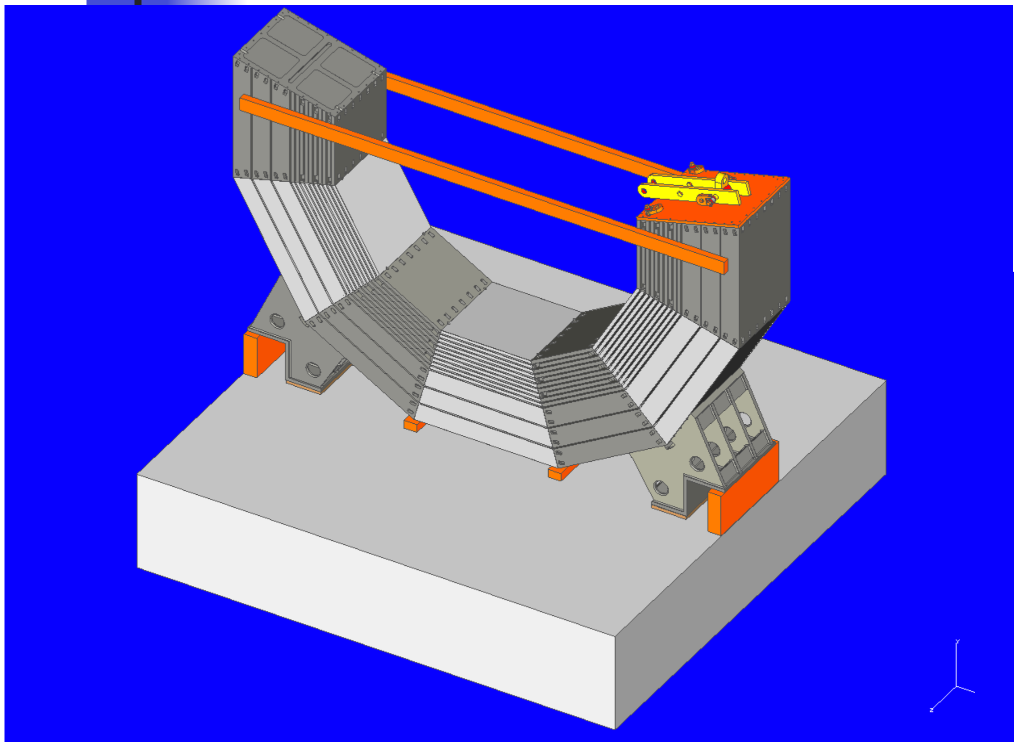
R.Stromhagen

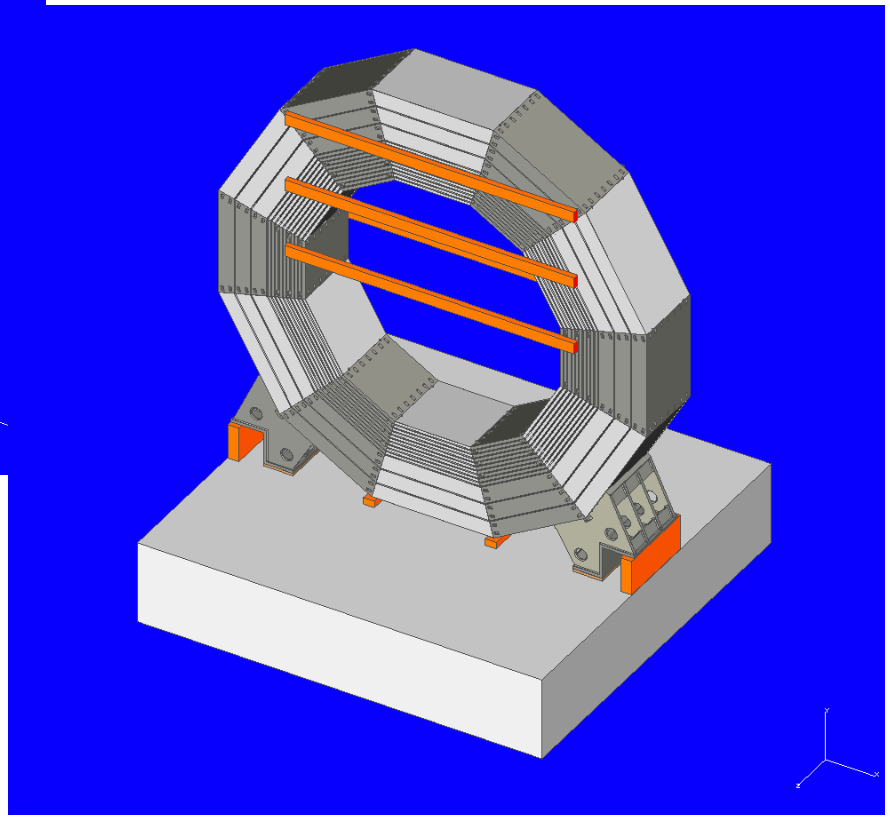


Tools needed:
- 250 t crane
- Hoists
- Support structures
- Survey

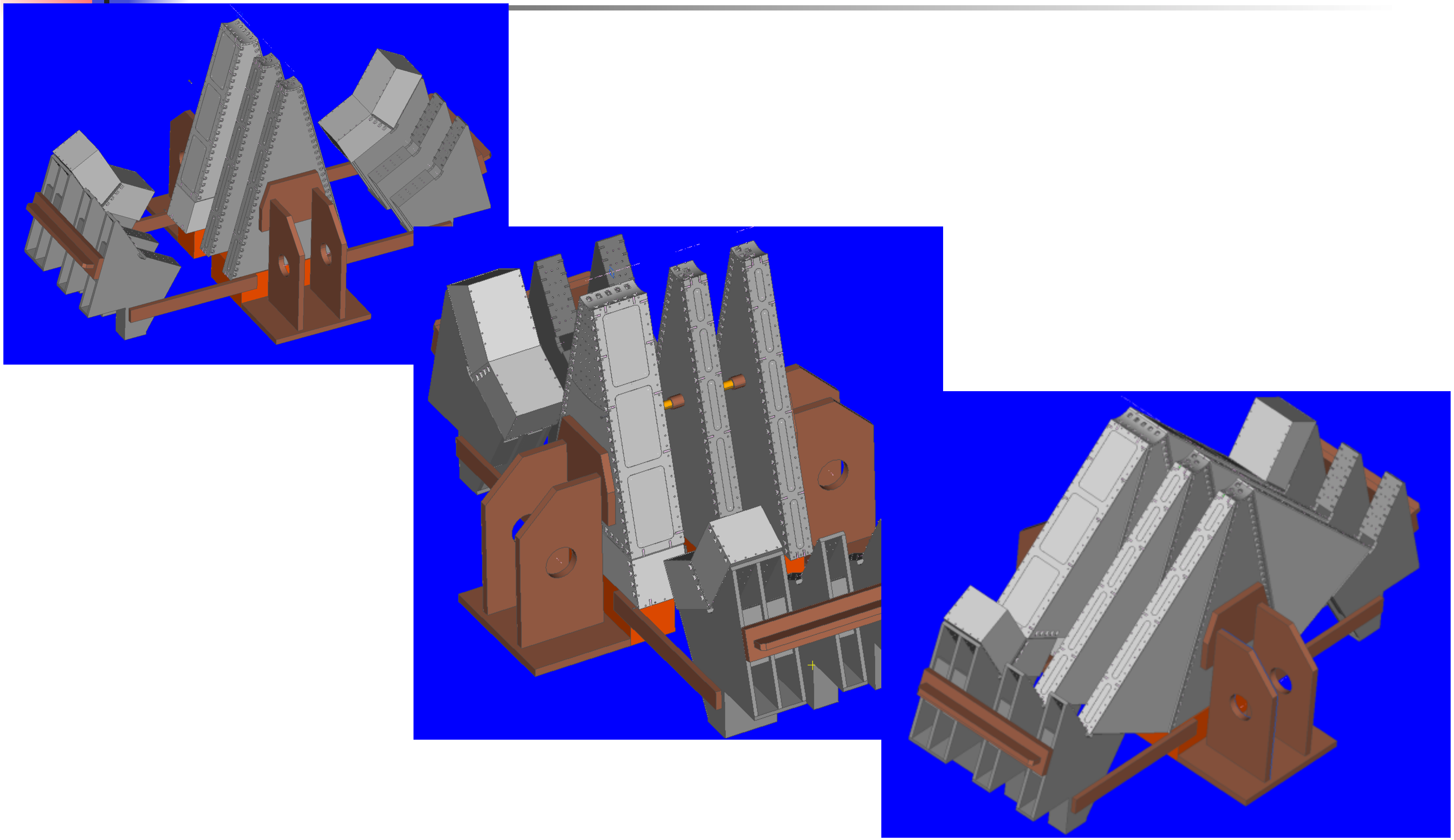


Barrel Assembly

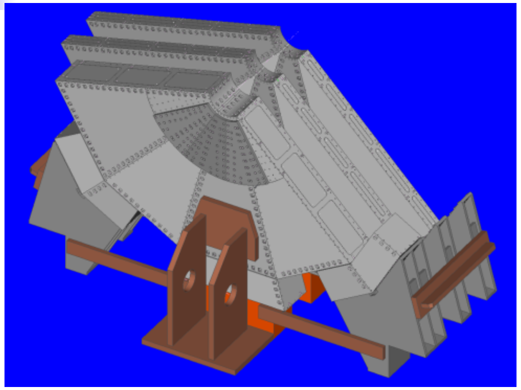




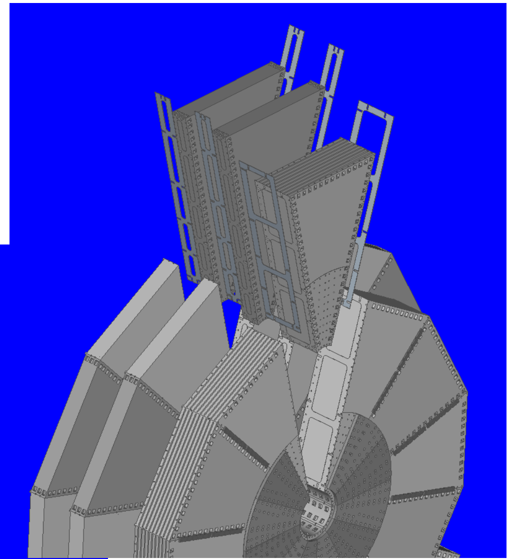
End-cap Assembly

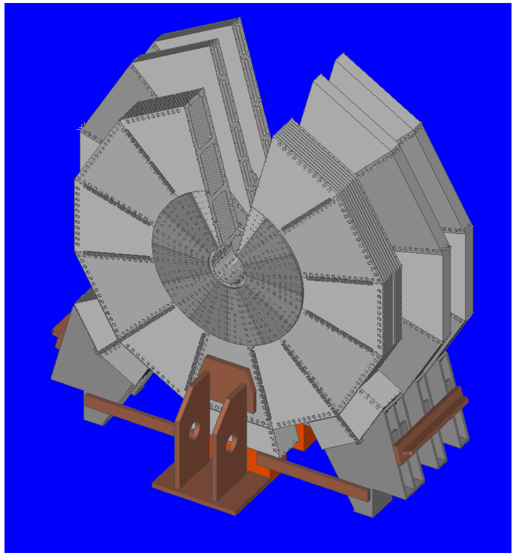


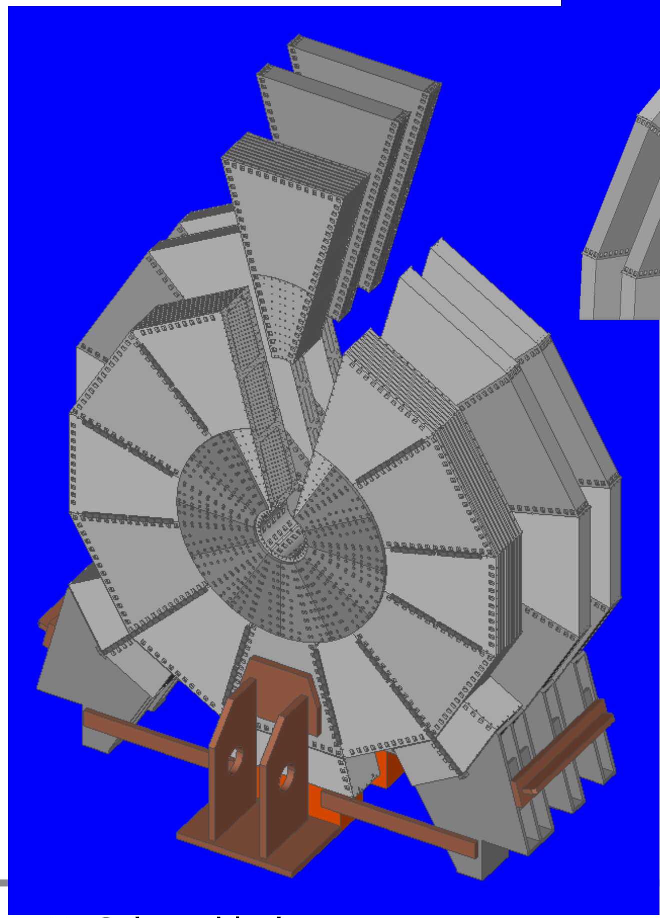
End-cap Assembly



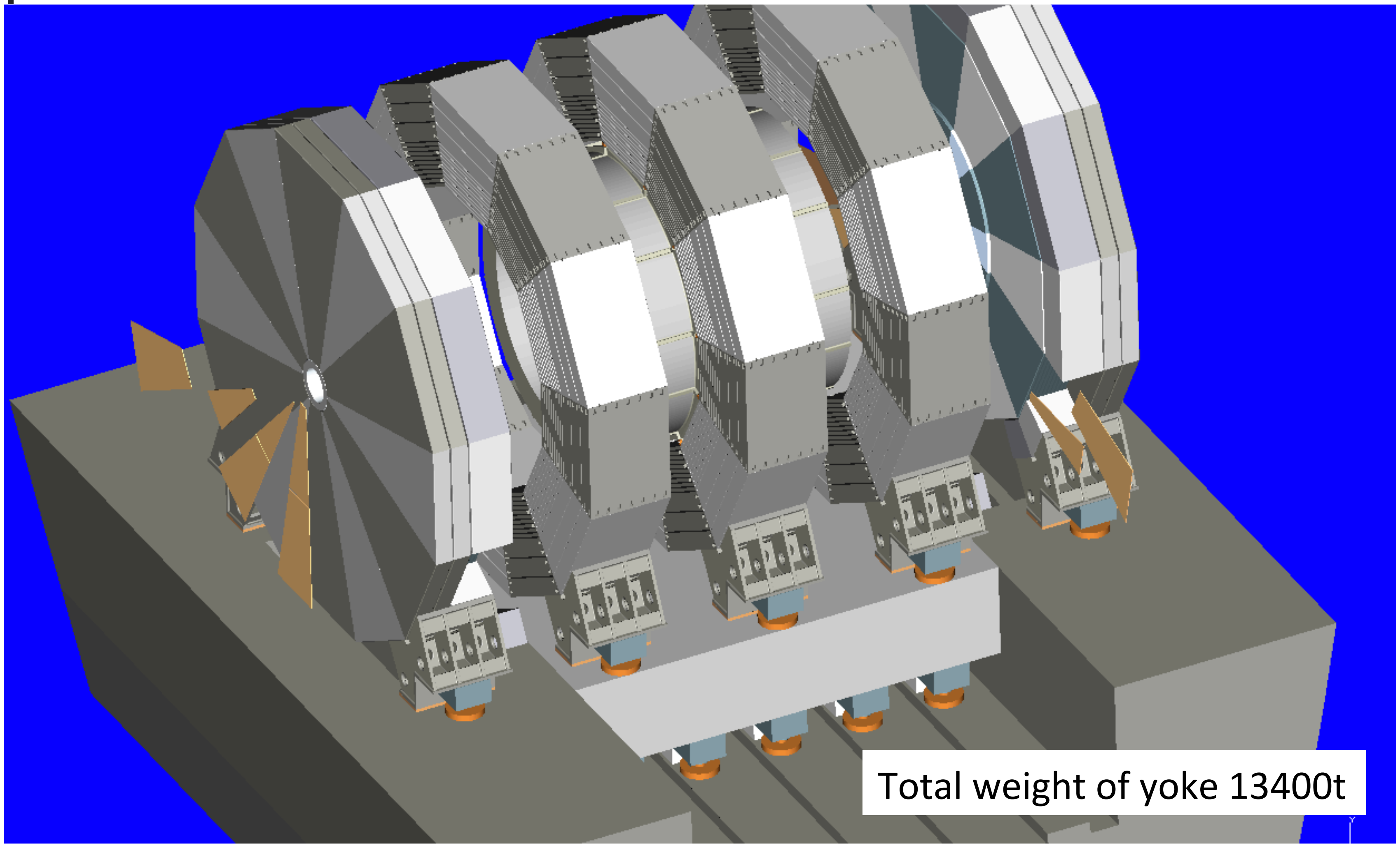
Final segment:
precision machined
or adjusted with shims







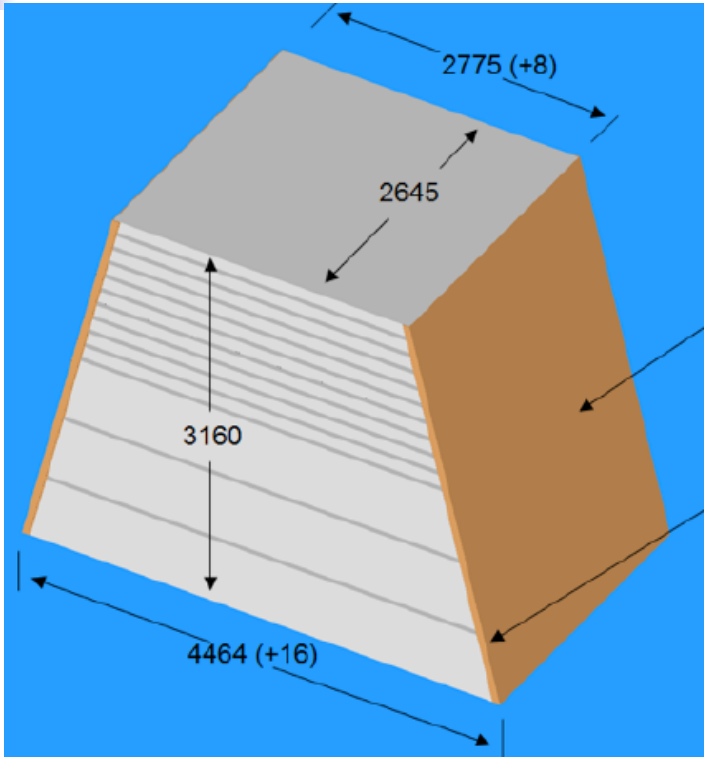
Assembled Iron Yoke



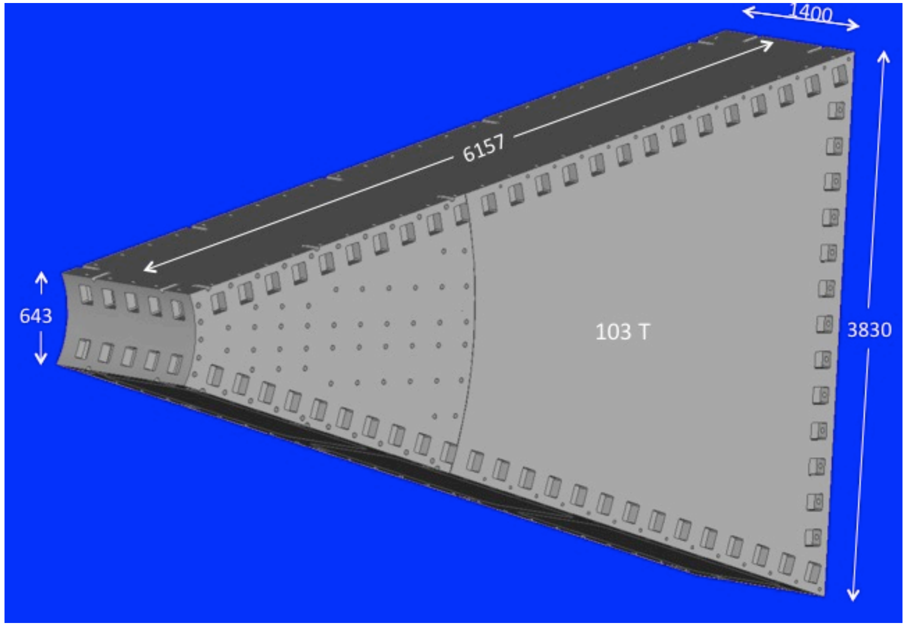
Yoke Transportation

- Have to check transportation limits in Japan
  - Are ~250t transports a problem?
  - Are less heavy transports significantly cheaper?
  - In Europe <100t straight forward. Much more difficult if heavier, need special permit

Segment Dimensions



Barrel
- Weight ~210t 18 pieces
- Plus 18 slightly smaller pieces weight ~170t



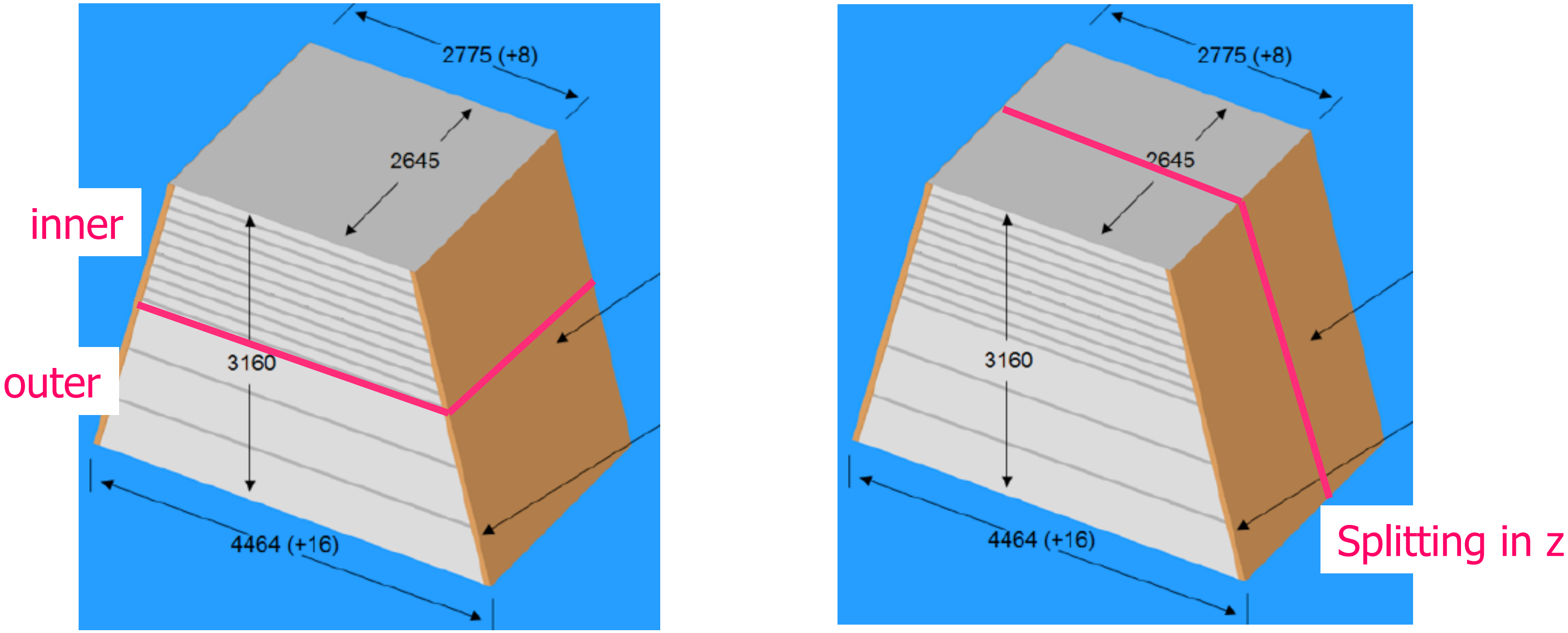
Inner end-cap
- Weight ~100t 6 pieces
- Plus 6 slightly

+ outer end-caps

Barrel Segment Dimensions

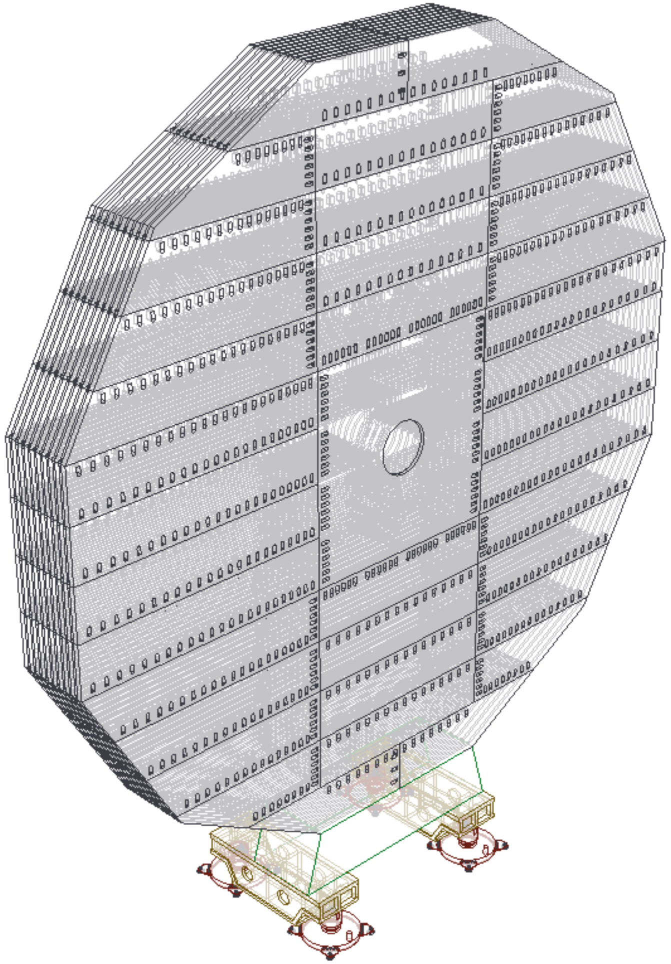
Could reduce segment size and weight

- Splitting into inner and outer segments
  - Need additional mounting/connection plates between inner and outer
  - Achieving tolerance during machining more difficult
- Splitting in z-direction
  - No problem with forces. Magnetic force acting in z-direction. Compressing wheels
  - Achieving tolerances easier



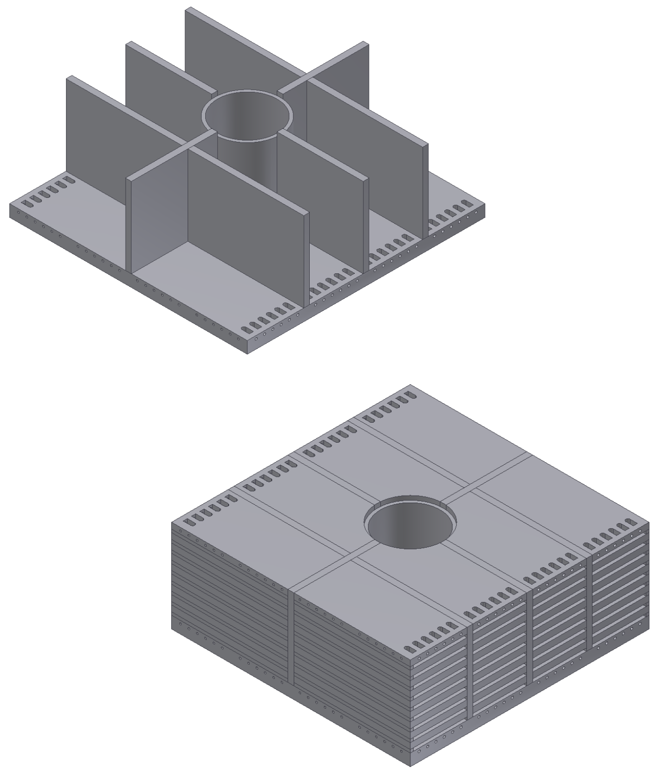
Alternative End-Cap Design

Design by Hubert Gerwig and Nicolas Siegrist, CMS/CERN



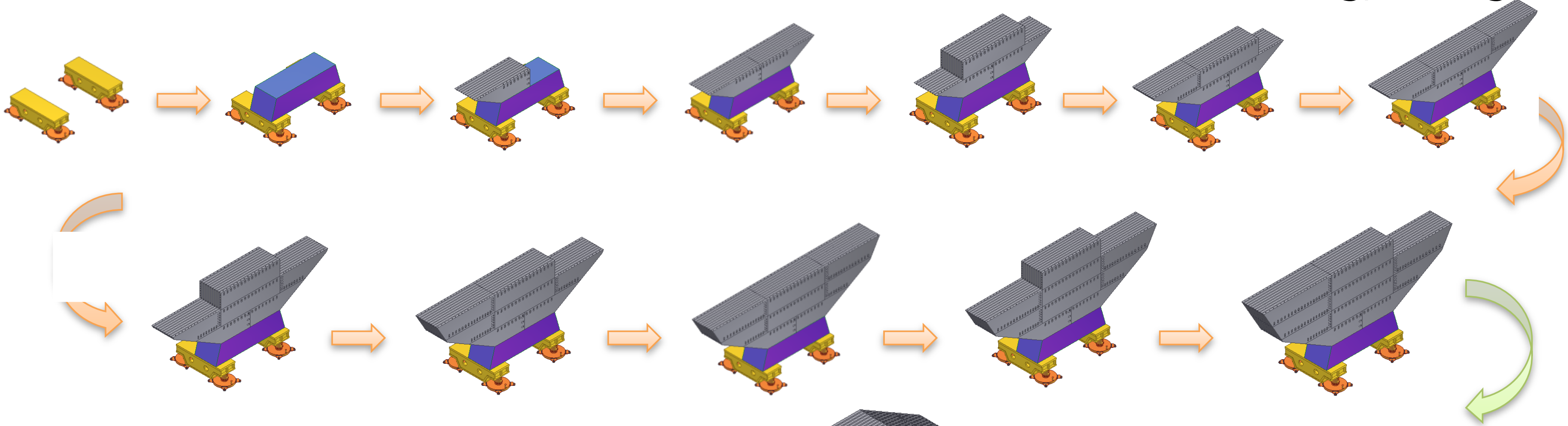
Segments of 40t

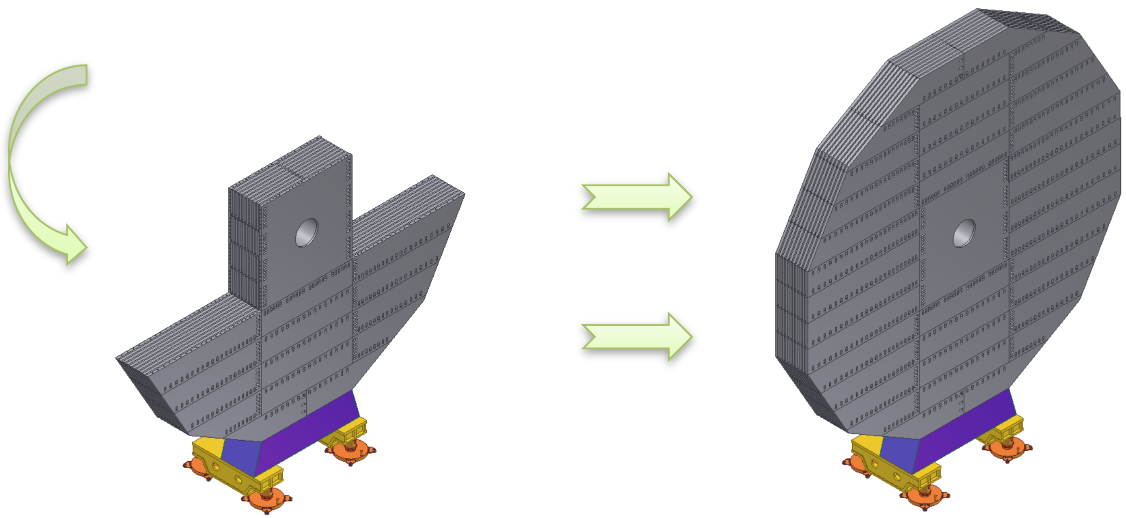
Central part 120t



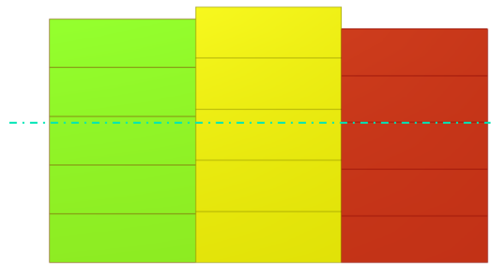
Alternative End-Cap Design

H.Gerwig, N.Siegrist





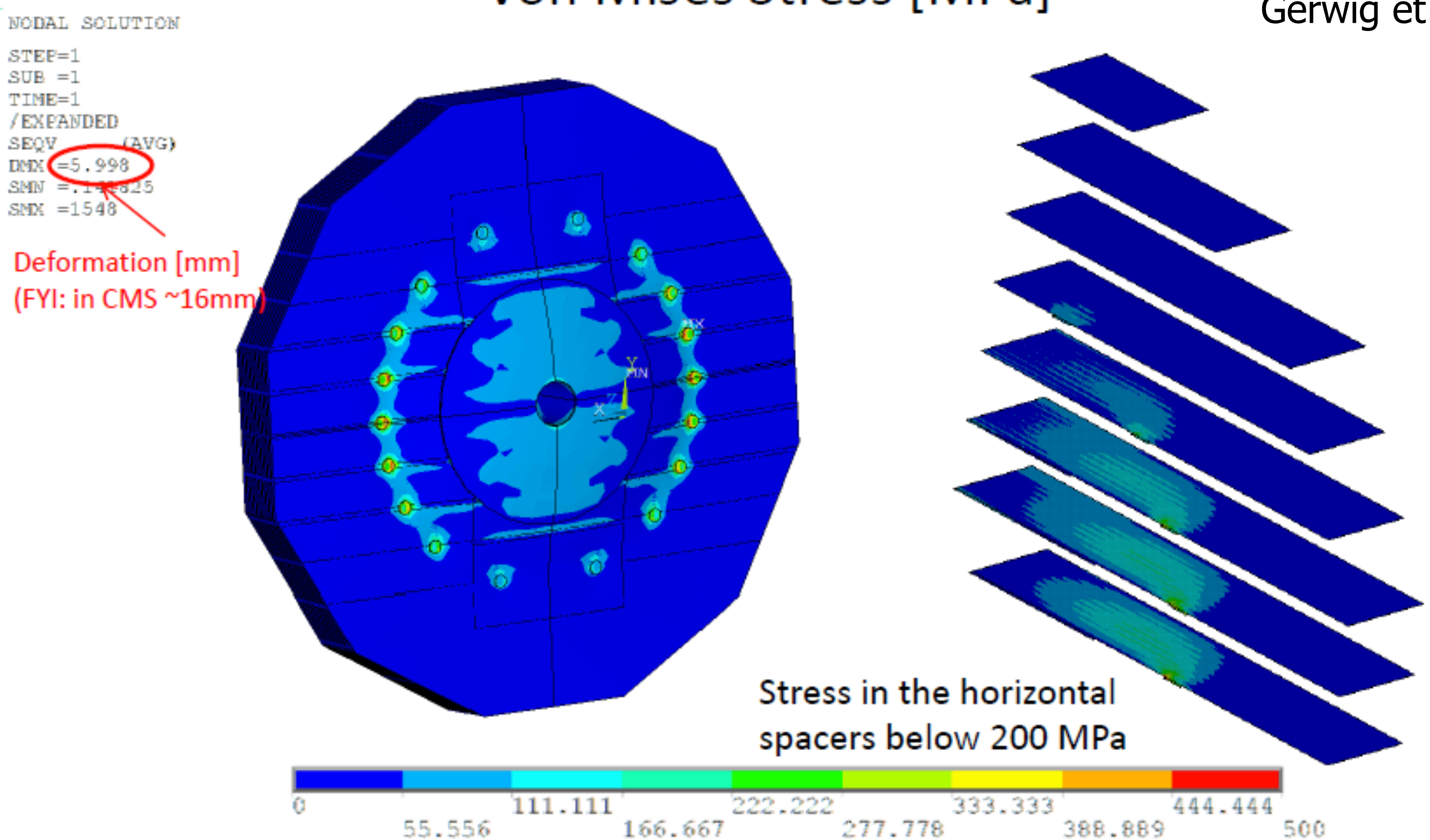
Allow length difference for mounting (+/- 0.2 for each block):



End-Cap Design Horizontal Supports

CLIC note 2010-10
Gerwig et al.

Von Mises Stress [MPa]



Considering to use better quality steel

Comparison of Inner End-cap Designs

- Radial reinforcement design
  - ϕ symmetric deformation and stress
  - Iron and magnetic field ϕ symmetric
  - Hard stops straight forward
  - Symmetric forces acting on barrel
  - 12 segments plus small inner support tube
  - Fewer surfaces to be machined precisely
  - Half as much reinforcement (and dead space)
    - Present models (2x25mm) radial vs. (2x50mm) horizontal supports

      -> dead space 3% vs. 12%.
- Horizontal reinforcement design
  - Deformation and stress somewhat higher
  - 36 segments segments plus big central piece
  - Assembly somewhat easier
  - Installation of muon chambers easier
- Should do cost comparison (manufacturing, transport, assembly)

Material Properties - Tolerances

Preliminary

- Mechanical properties
  - Yield strength > ~250 MPa
  - Ultimate strength > ~350 MPa
  - Good weldability (low carbon content)
- Magnetic
  - Absolute properties not essential since highly saturated
  - Relative permeability should be uniform
- Tolerances
  - Outer dimensions ~ ± 5mm
  - Inner dimensions tolerances up to manufacturer
    - No gaps, surfaces must fit

Conclusions

Present conceptual design quite advanced

- Not yet cost optimized

Several options/open issues

- Thickness of iron (determines cost)
  - Required stray field limit?
  - Need better understanding of stray field calculations
  - Reliability of FEM calculations. Is 0.1% accuracy realistic?
- Need critical assessment of design and construction method
  - Cost and performance optimization
  - Size and weight of yoke segments
  - Manufacturing, transport and assembly of small vs. large segments
  - Time of construction and assembly
  - Decide of end-cap options
- In contact with Japanese industry. Will visit KHI on Friday