Progress on ILD Yoke Design

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DESY
16.02.2009

ILD Meeting, Seoul

Outline

- Function of iron yoke
- Gaps between barrel rings, gap between barrel and end-cap
  - Cables and services
- Magnetic field calculations
  - (Effect of field shaping plate)
  - Stray field
  - Magnetic forces
- Progress on mechanical design of end-cap
  - Geometrical options
  - Deformation and stress due to magnetic forces
  - Mechanical engineering
  - End-cap opening options
- Coil and Yoke dimensions

Mainly report on progress at DESY

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

Function 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
  - Rejection of beam halo-muons
- Tail-catcher/backing calorimeter
- Main mechanical support structure
- Flux return
  - Stray field
  - Large magnetic forces
- Radiation shielding
  - Detector should be self-shielding
  - Study by T.Sanami presented in Warsaw, ECFA 2008

ILD Parameters Reference Detector

ILD parameters fixed in or since Cambridge Meeting

- Dimensions of tracking detectors and calorimeter
- Dimensions of coil cryostat
- B field: nominal 3.5T, maximal 4 T
- Iron yoke
  - Shape 12-fold
  - Segmentation
    - 100mm field shaping plate only end-cap
    - 10 x (100mm + 40mm gap)
    - n x (560mm + 40mm gap)

Presently, no study of muon detection and performance (muon finding efficiency and purity, yoke segmentation and detector technology).

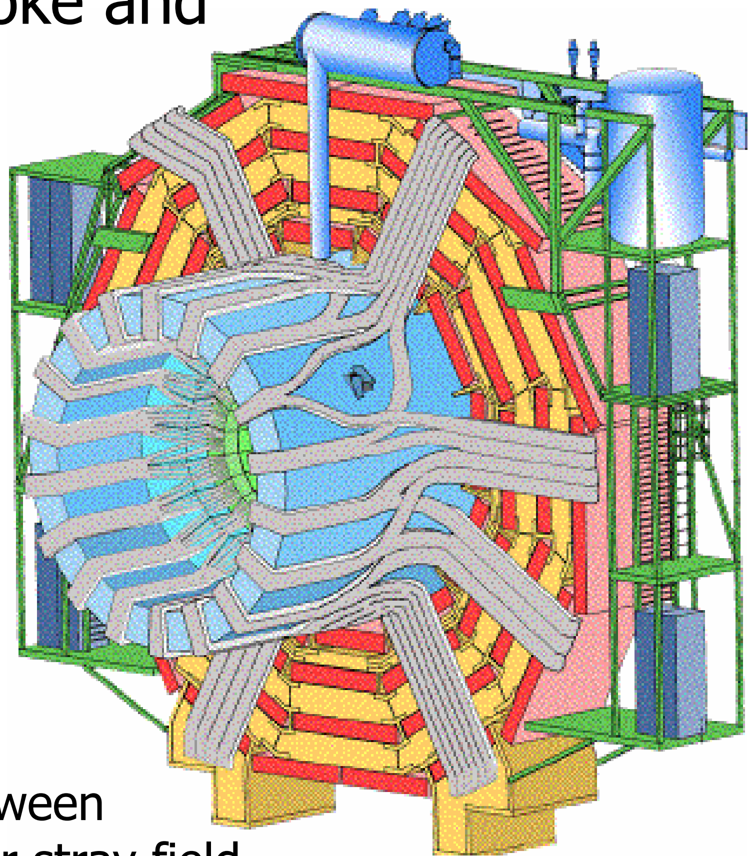
Unclear whether tail catcher with fine (10cm) segmentation is really needed.

Won’t have final results for LOI end of March.

→Assuming fine segmentation for the mechanical design (worst case).
Mechanical design with thicker plates will be easier.

Space between Cryostat and Yoke

Space between cryostat and yoke and space between barrel rings



CMS style assembly

- Barrel consists of 5 rings (ILD 3)
- All inner detector (tracking, calori-meter) services are routed between the outside of the cryostat and the first layer of muon chambers and between barrel rings

Radial space between cryostat and muon chambers is about 30cm

Small gaps between barrel rings and between barrel and end-caps are very essential for stray field

Space between Cryostat and Yoke

Asked components for required space for services between cryostat and yoke. Rough guess so far.
d radial thickness, assuming evenly distributed along the circumference

	area (m^2)	d(mm)	
TPC	0.1	4	R.Settles
ECAL	0.0250	1	C.Clerk, H.Videau, R.Poeschl
AHCAL	0.3026	11	M.Reinecke, K.Gadow
DHCAL	0.176	7	Laktineh
SET	small	~1	A.Savoy-Navarro
Sum		17	
Assuming factor 2 for routing and not included items:		34	

(ECAL space/sector: 25mm x 120mm in $r\varphi$)

Space between Cryostat and Yoke

	d(mm)	
▪ Component services	34	
▪ Barrel yoke vertical deformation	6	taken from CMS
▪ Assembly tolerances	5	
▪ Deformation of outer cryostat	10	CMS
▪ Clearance for moving barrel ring	50	CMS
▪ Space for inner muon chambers	50	
Sum	155	

In principle, space available in barrel corners

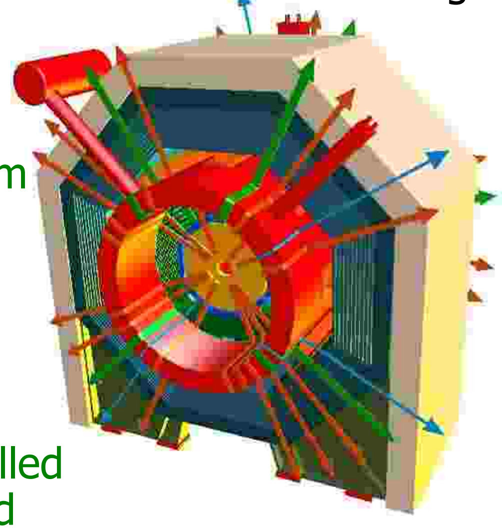
- In CMS space was taken by alignment systems
- Probably won't need 12 alignment systems, only a few
- CMS needs additional space for cooling of cables. ILD expecting much less heat due to power cycling. Readout mainly via glass fibers.

Conclusion, should keep at least 16 cm between cryostat and first barrel iron plate. Presently, using 250mm for field calculations at DESY.

Space between Barrel Rings

- 50mm gaps between barrel rings agreed in Sendai
- Need 34mm for cables and services plus 10mm for hard stops → about 44mm in total.
  - Assumes that both sides of central barrel rings will be covered with cables.
  - No access to muon chambers. Might not be a problem for scintillator strips.
  - Otherwise need about 78mm
  - Increasing gap would increase stray field
- Access to muon chambers (A.Herve, CMS)
  - Separate cables and services in what should be installed permanently (pipes, optical fibers and HV cables) and what can be disconnected (mainly LV cables).
- Conclusion: 50mm gaps as foreseen are fine
- In addition, need holes for cryostat supply and current leads (CMS two ≥ 400mm diameter holes)

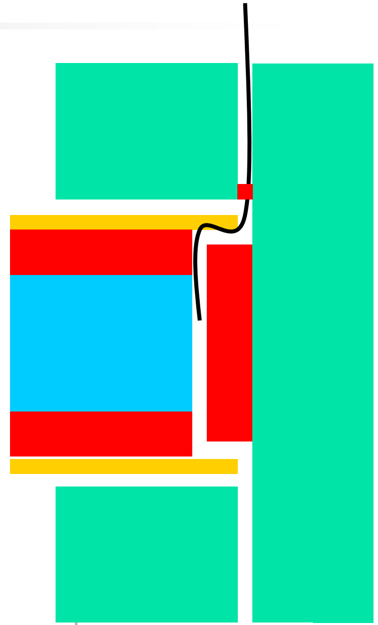
Tesla detector design

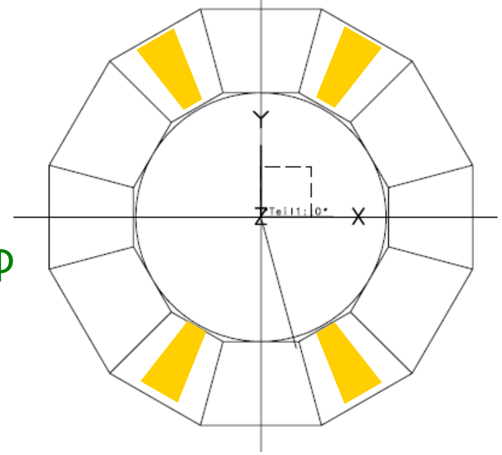


Space between Barrel and End-cap

- Foreseen gap between barrel and end-cap 25mm
- Rough estimate of end-cap E/HCAL cables (C.Clerc)
  - Surface of sensors ECAL: each EC is ¼ of full barrel
  - Sensors HCAL: each EC 40% of full barrel
    → area 0.078 m^2 x 2 (for installation, tolerances)
    → space (thickness) assuming evenly distributed: 7mm without muon chambers and ETD
  - Plus about 10mm for hard stops
    → Need 17mm. In principle, 25mm gap is fine.
- Routing all cables in a space of <15mm is probably unrealistic
  - Need more detailed engineering study
- Other option: reduce gap, route cables in few channels
  - Reduce gap to 10mm (for hardstops)
  - 4 channels of 100mm x 825mm distributed in φ

  Would slightly decrease stray field, local increase
  - Needs 3D field simulation





Space between Barrel and End-cap

Increasing gap between barrel and end-caps

Options:

- Moving end-cap out would reduce the field uniformity in TPC volume
  - Could increase (double?) thickness of FSP
  - Needs detailed study of central field
  - Would increase material in front of tail-catcher
- Reduce thickness of first end-cap iron plate at position of cable channels
  - Not a good idea, plates are thin (weak) anyway
- Preferred option: Make local cut-outs in barrel
  - No effect on mechanical stability
  - Some barrel muon chambers with slightly reduced length

Propose to keep 25mm gap for LoI

Magnetic Stray Field

Programs for field calculations used at DESY

- CST EM Studio 3 D calculations (A.Petrov)
- Opera 2 D calculations (B.Krause)

CMS experience A.Gaddi, CERN

- < 50 G: no special precaution
- 50 – 150 G: more and more difficult,
  - Non-magnetic tool mandatory
  - Massive local iron pieces generate high field gradients
- > 150 G: real difficult work
  - Dangerous above 200 G
  - Avoid extensive mechanical activities

Chicago ILC/MDI meeting:

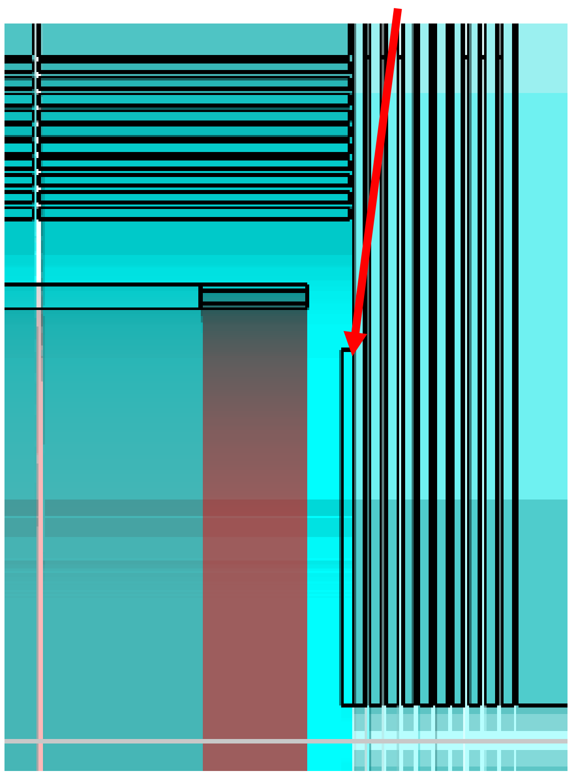
- Goal <50 G at 15m from beam line. Borderline between two detector.

Field Shaping Plate

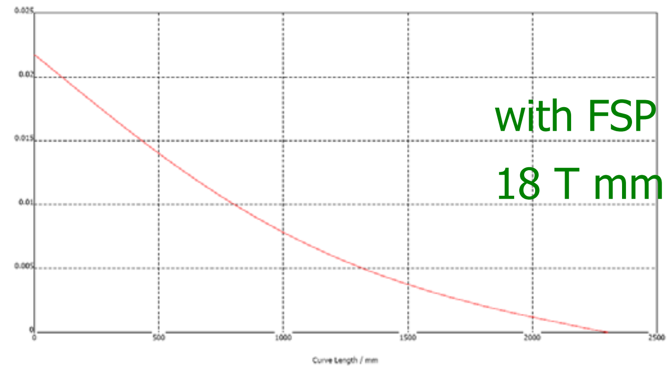
Field shaping plate in front of end-cap in order to improve field quality in TPC region

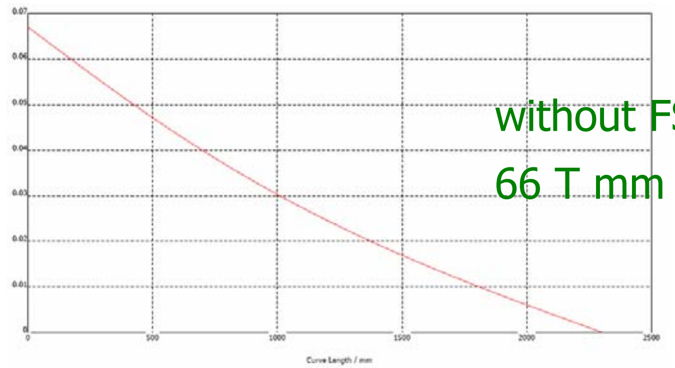
- Field within coil is optimized by F.Kircher et al.
- DESY studies focusing on optimizing stray field

100mm thick plate



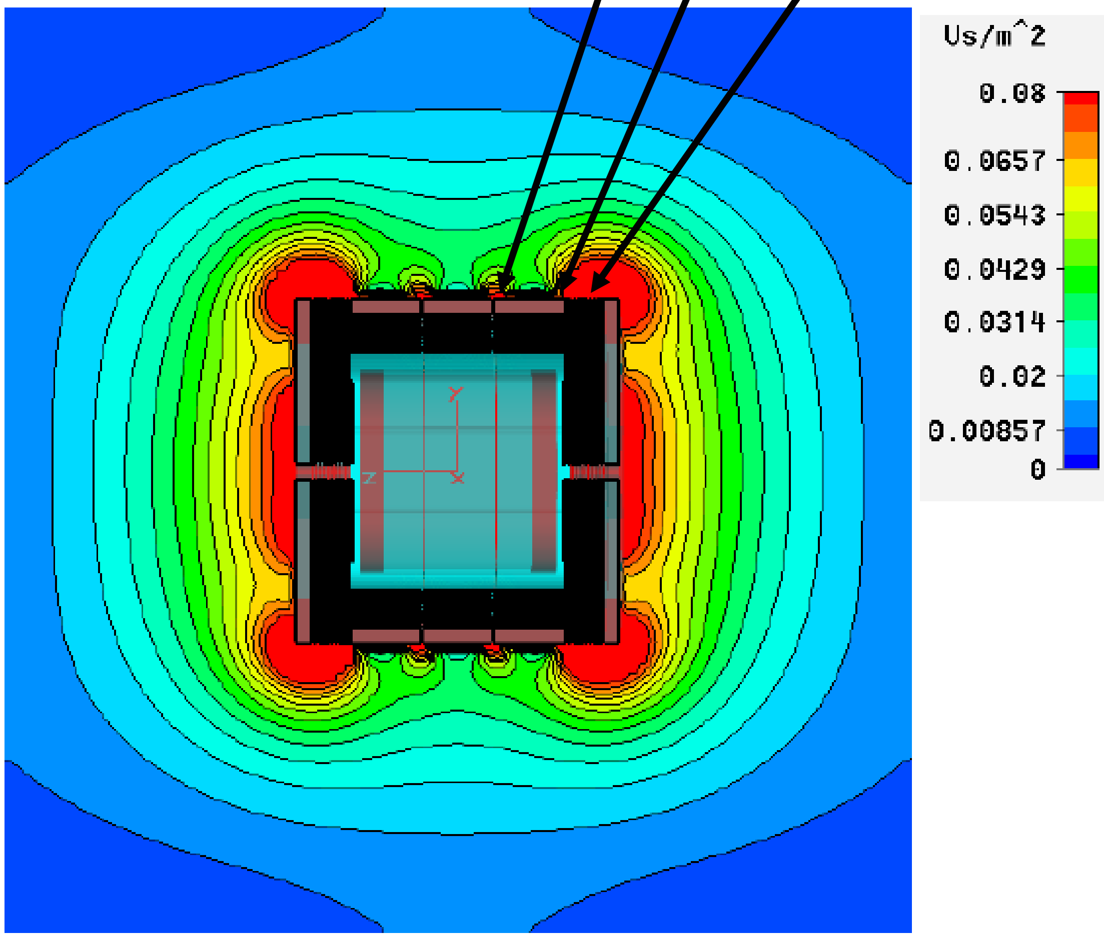
Field integral ∫ B_r dz vs. z





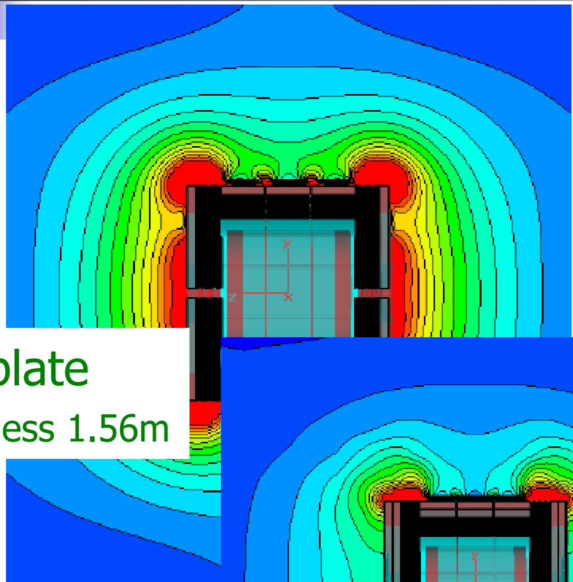
Stray Field Calculations

Central field 3.5 T gaps 50 25 40mm



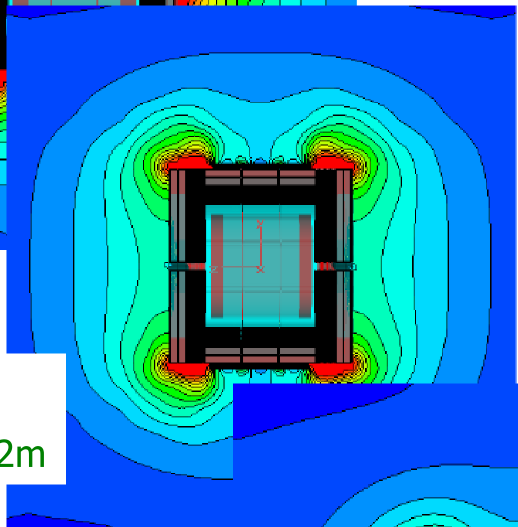
Stray Field Calculations

3.5 T



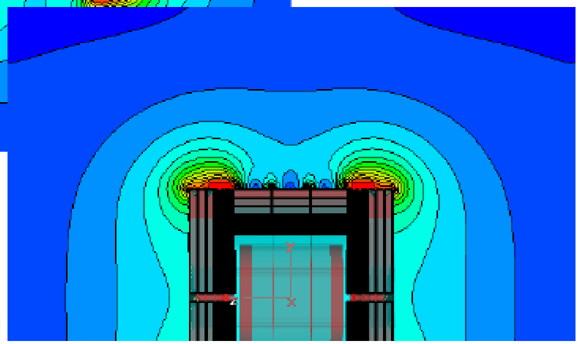
1 thick plate

iron thickness 1.56m



2 thick plates

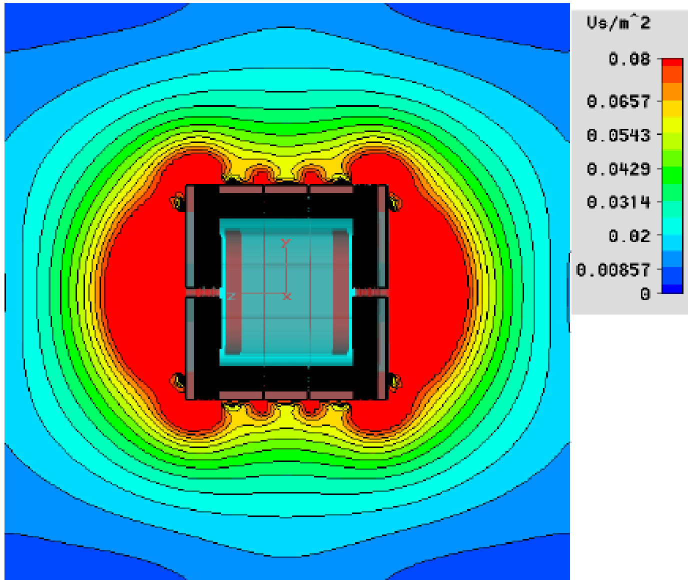
iron thickness 2.12m



3 thick plates

iron thickness 2.68m

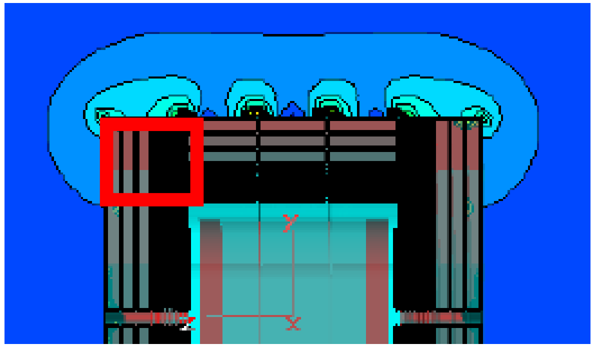
4 T

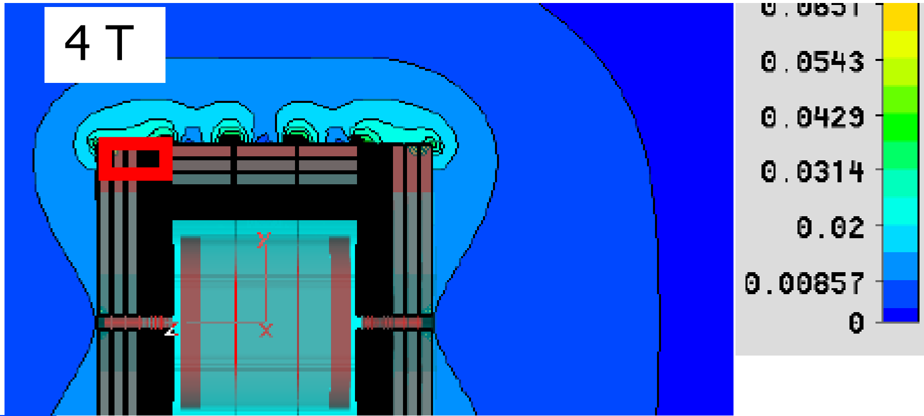


Stray Field Calculations

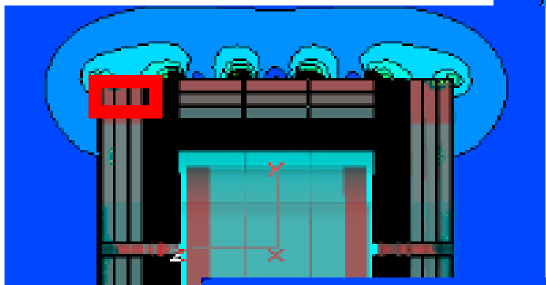
3.5 T

gaps filled

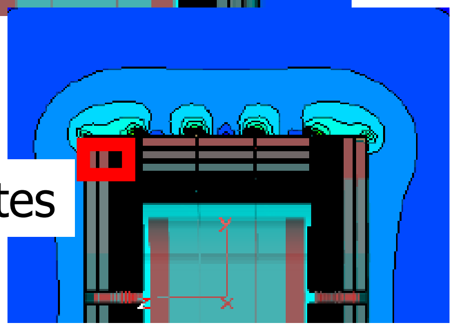




gaps partly filled

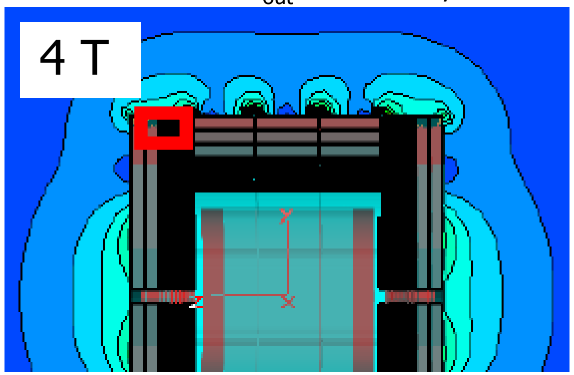


gaps partly filled, EC 2 plates



Update

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



Stray Field Calculations

Stray field at distance from beam line (y) and distance from iron yoke (d)

CST EM Studio (A.Petrov)

central field 3.5 T

update 4 T

iron yoke	3 thick plates		3 thick plates EC filled		3 thick plates EC partly filled		3/2 thick plates EC partly filled		3/2 thick plates EC partly filled	
B (T)	3.6		3.6		3.6		3.6		4	
z (m)	0	5.4	0	5.4	0	5.4	0	5.4	0	5.4
B stray (G)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)
200	7.7	11.3	7.6	7.9	7.6	7.9	7.6	8.2	7.6	8.4
100	13.4	13.9	10	10.3	10	10.3	10	10.3	10.5	10.6
50							13.2	12.6	13.7	13.2
	d (m)	d (m)	d (m)	d (m)	d (m)	d (m)	d (m)	d (m)		
200	0	3.6	0	0.3	0	0.2	0	0.5	0	0.7
100	5.7	6.2	2.3	2.6	2.3	2.6	2.3	2.6	2.8	2.9
50							5.5	4.9	6	5.5

Stray field < 50G at 15m from beam line for 4 T.

Limit as discussed in Chicago MDI meeting.

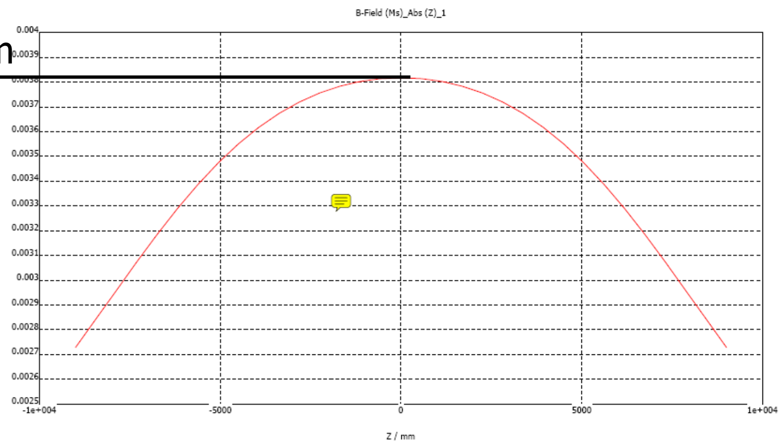
Stray Field Calculations

Central field 4 T

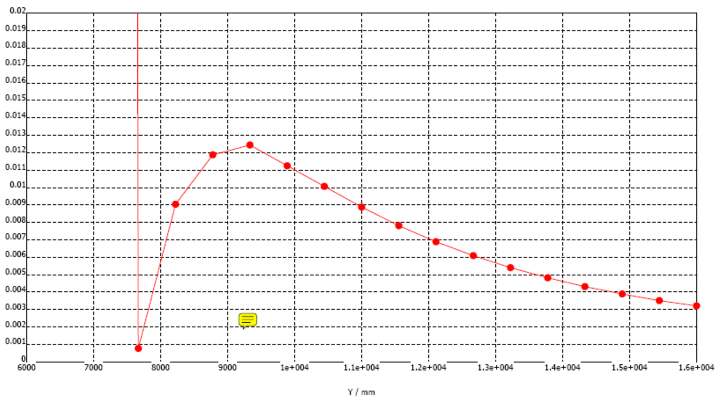
Gaps partly filled

B 15m from beam line vs. z

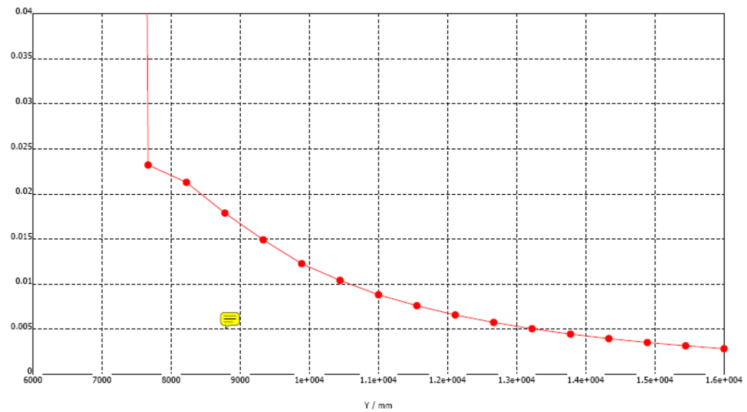
38 G at 15m



B vs. y at z = 0

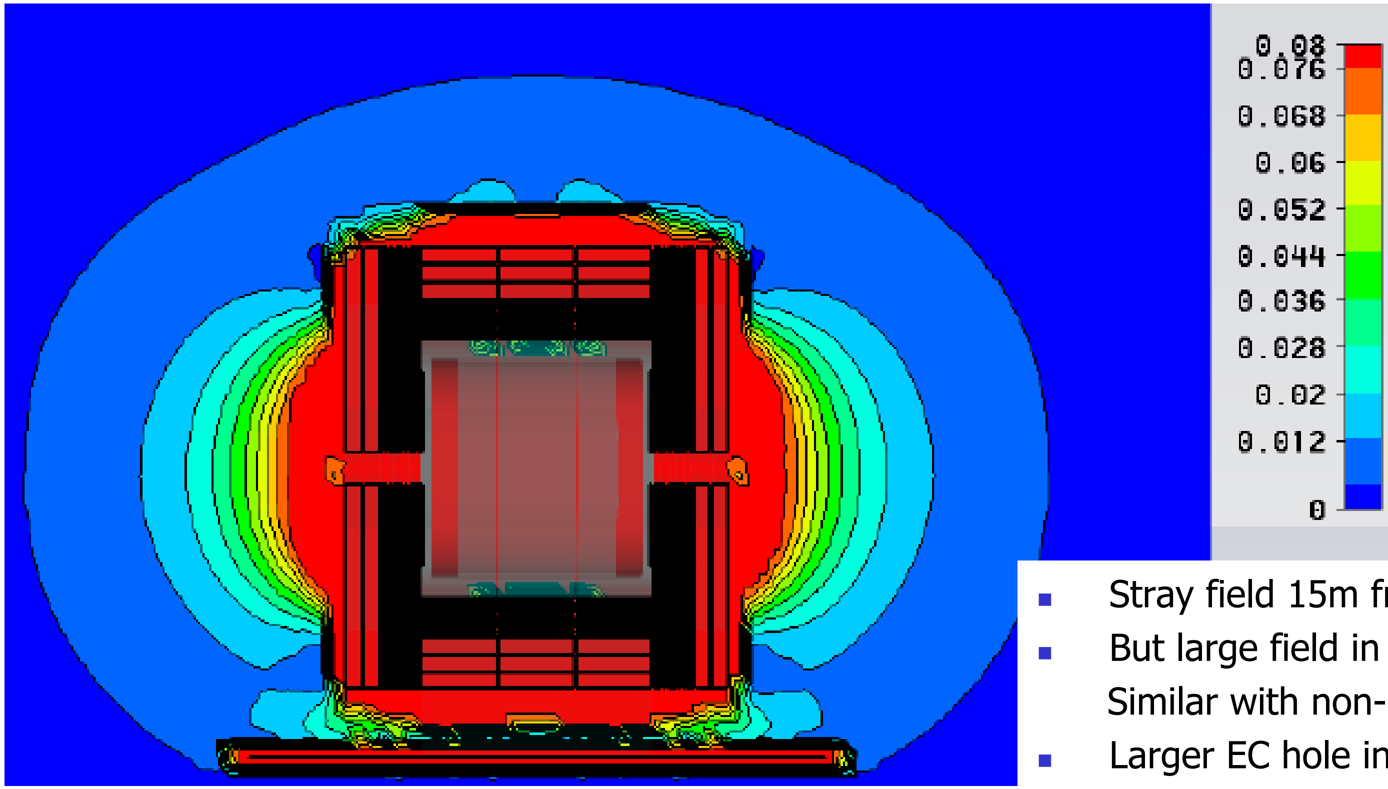


B vs. y at z = 5.425m



Stray Field Calculations

- Simple iron support feet (only outer barrel ring) 4 T field
- Floor with steel plate (20m x 20m 60mm thick)
- Increased end-cap hole to 1.1m diameter to accommodate rectangular support tub



- Stray field 15m from beam line ~ 30G
- But large field in steel floor 1.6T
  Similar with non-magnetic feet
- Larger EC hole increases stray field in z
  Circular support tube would be better

Magnetic Forces – Rough Estimate

Rough estimate of total magnetic force (z direction) on end-cap

- Maxwell Stress Tensor

$$\sigma_{ij} = \frac{1}{\mu_0} B_i B_j - \frac{1}{2}\frac{1}{\mu_0} B^2 \delta_{ij}$$

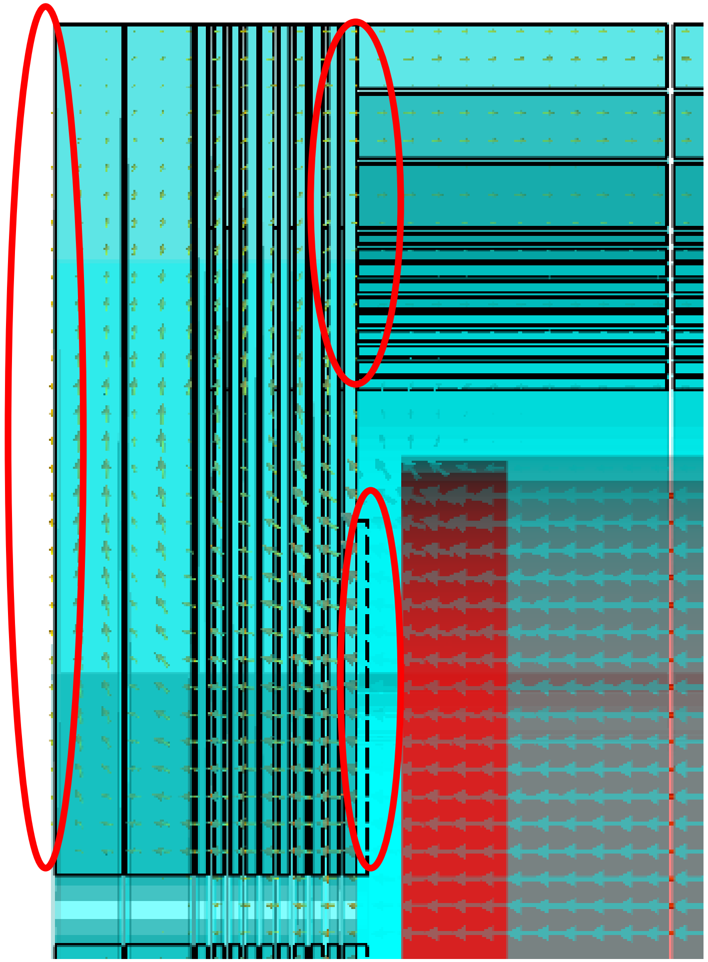
- Only considering stress nominal to surface

$$\sigma_{11} = \frac{1}{2}\frac{1}{\mu_0} B^2$$

- Estimate average B field and area
- Neglecting gaps for muon chambers

Compare CMS and ILD end-caps

Magnetic Forces on ILD End Cap



Inner surface of end cap

- Inside coil
  - r_0= 3.4m,inner hole 1m²
  - area 35m²
  - ave B = 3.5 T
  - ➔ F_z = 17100 t
- outside coil (between barrel and end cap
  - r_0= 7.66m, r_i= 3.8m
  - area 139m²
  - ave B = 0.5 T
  - ➔ F_z = 1400 t

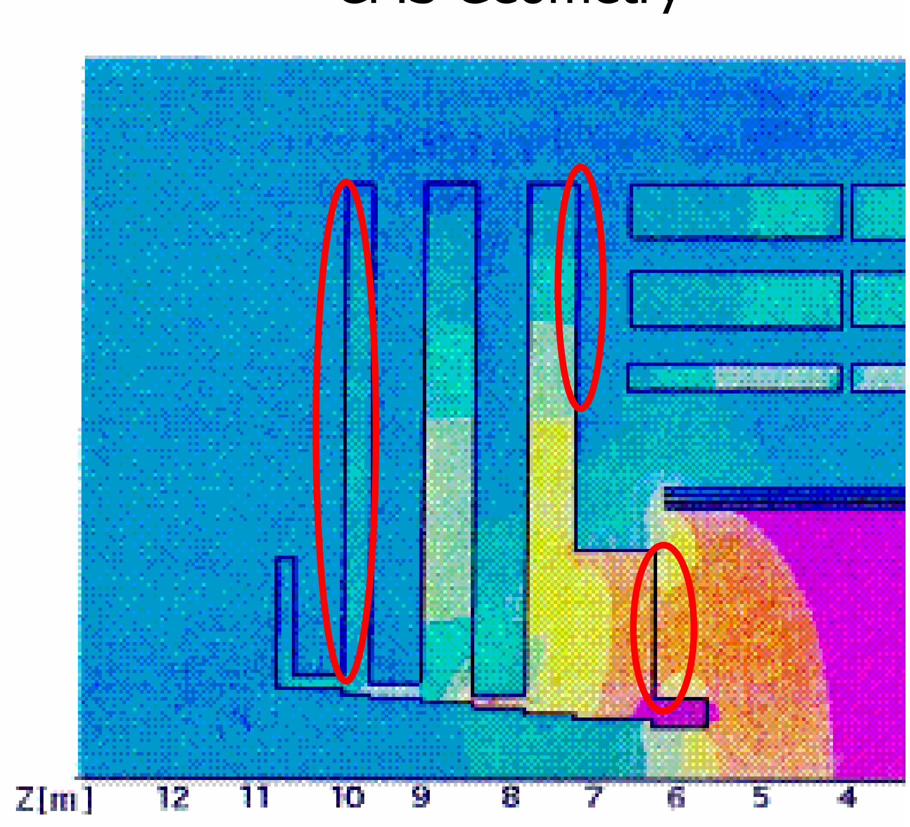
Rear surface

- area 183m², ave B=0.08T
- ➔ F_z = 43 t

Total force 18500 t (in z direction)

Magnetic Forces on CMS End Cap

CMS Geometry



Inner surface of end cap

- Inside coil
  - r_0= 2.7m,inner hole 1m^2
  - area 20m^2
  - ave B = 3.5 T
  - ➔ F_z = 9900 t
- outside coil (between barrel and end cap
  - r_0= 7m, r_i= 5m
  - area 73m^2
  - ave B = 1 T
  - ➔ F_z = 2900 t

Rear surface
  - area 147m^2, ave B=0.75T
  - ➔ F_z = 3400 t

Total force 9400 t (in z direction), CMS Magnet Report 9000 t

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

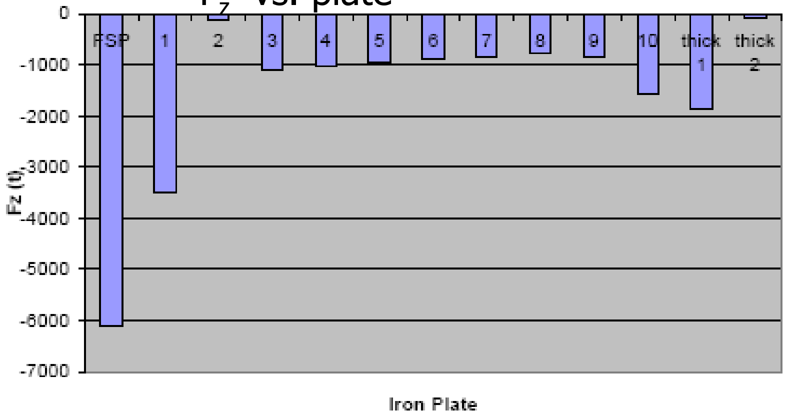
  Resulting force on hard stop

  → F_z = 19000t for 3 thick EC plates

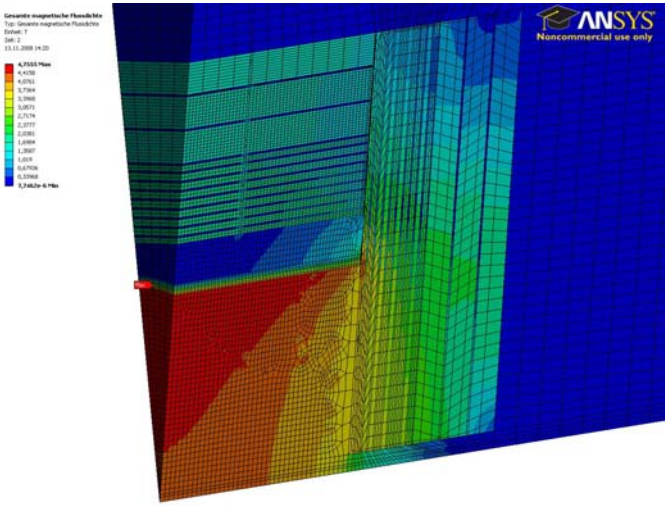
  F_z = 18000t for 2 thick EC plates

  Model with open gaps

F_z vs. plate



ANSYS model B field



New model contains FSP

Mechanical Design of Yoke

- Magnetic forces on end-caps are much larger than for barrel and gravity

  ➔ Started on mechanical design of EC.   4 T B field
  - So far mainly considering magnetic forces
  - Design of barrel segments probably similar to EC segments
- Rough estimate of end-cap deformation (formulas in Dubbel)

r (mm)	d (mm)	F (t)	F (N)	f (mm)	
7650	2120	19000	1.86E+08	1.2	10x10, 2x56 massive iron plate, no gaps
7650	2560	19000	1.86E+08	0.7	10x14, 2x60 massive iron plate, gaps filled
7650	1000	17000	1.67E+08	10.3	10x10, massive iron plate, no gaps
7650	1400	17000	1.67E+08	3.8	10x14, massive iron plate, gaps filled
6955	600	7000	6.87E+07	16.2	CMS inner end-cap

Massive circular plate

Support at outer radius, not fixed

Uniformly distributed force

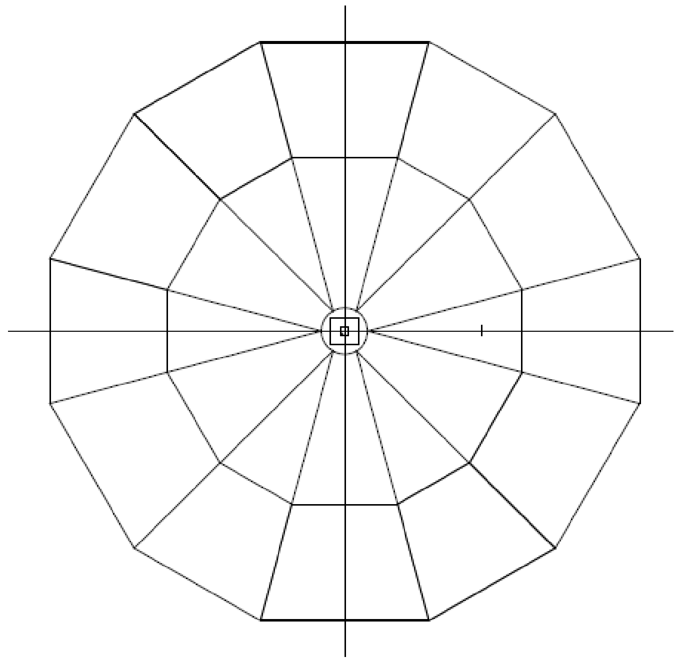
r (mm)	b(mm)	d (mm)	F (t)	F (N)	f (mm)	
7650	3490	2120	17000	1.7E+08	2.2	10x10, 2x56 massive iron plate, no gaps
7650	3490	2560	17000	1.7E+08	1.2	10x14, 2x60 massive iron plate, gaps filled
7650	3490	1000	15000	1.5E+08	18.3	10x10, massive iron plate, no gaps
7650	3490	1400	15000	1.5E+08	6.7	10x14, massive iron plate, gaps filled

Uniformly distributed central force inside coil

End-Cap Geometrical Options

Inner end-cap

- Radial support rips
  - Best mechanical solution
  - Support rips in direction of main stress
  - Decreasing distance between rips at increasing magnetic force
  - Position of hard stops straightforward
  - Symmetric in φ
  - Muon chamber r,φ measurements
  - Problem installation and access of bottom muon chambers



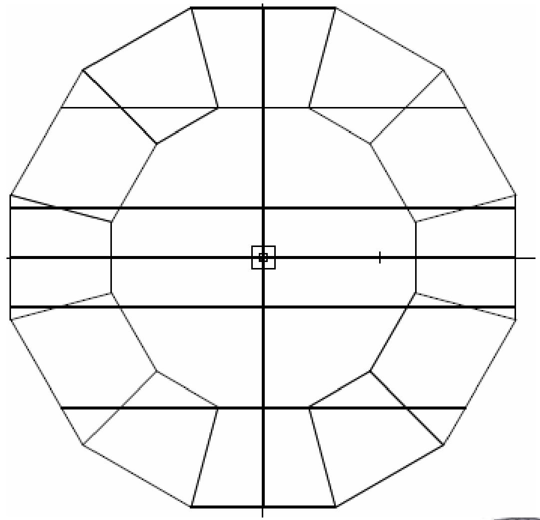
- Status
  - FEM calculations (deformation and stress) available
  - Looked into two different design options
  - Recently, looked into support feet and installation of muon chambers

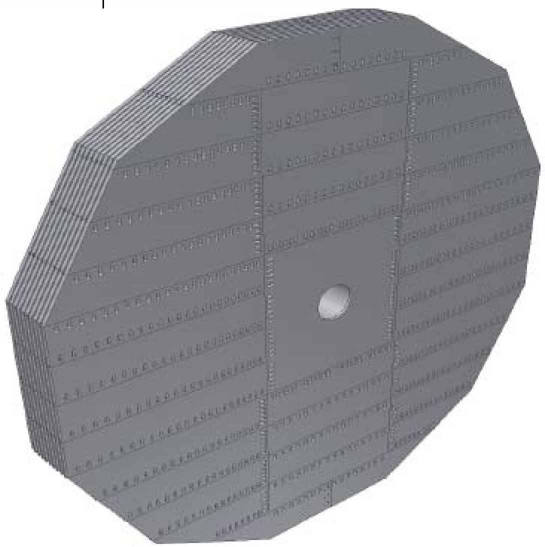
End-Cap Geometrical Options

- Horizontal supports rips
  - Mechanically not as good as radial rips
  - Non-symmetric in φ
  - Muon chamber x,y measurements
  - Main advantage easy installation and access of muon chambers
- Status
  - Started mechanical design with bolted iron plates
  - First FEM calculations now available

  - Recently, study by H.Gerwig and N.Siegrist at CERN

    Presented at ILD/CMS Engineering Mtg. Jan.2009



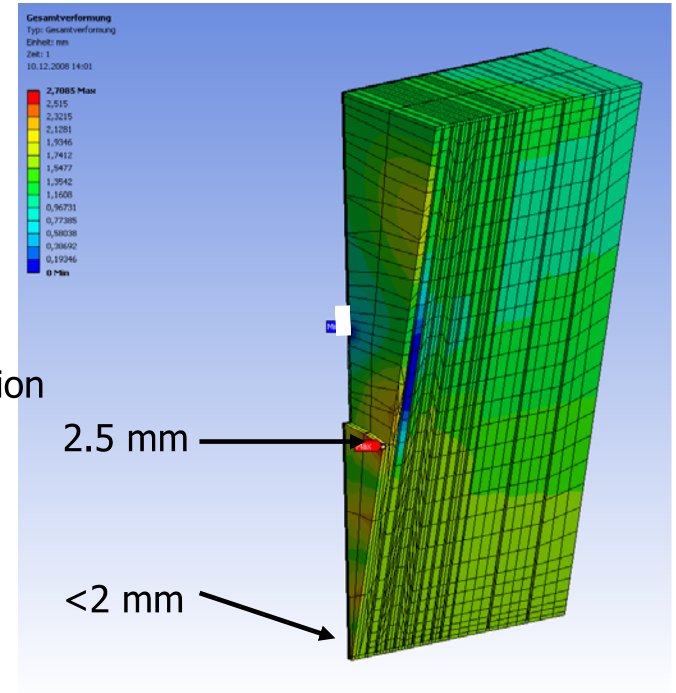


Mechanical Design of End-Cap

ANSYS calculations: end-cap deformation and stress   C.Martens, M.Harz

- Plates connected via radial rip (25mm wide), 1 per sector (1/12)
- Plates at outer and inner radius attached
- Pushing against hard stop 20x20cm at innermost barrel yoke plate
- Field shaping plate included

Deformation

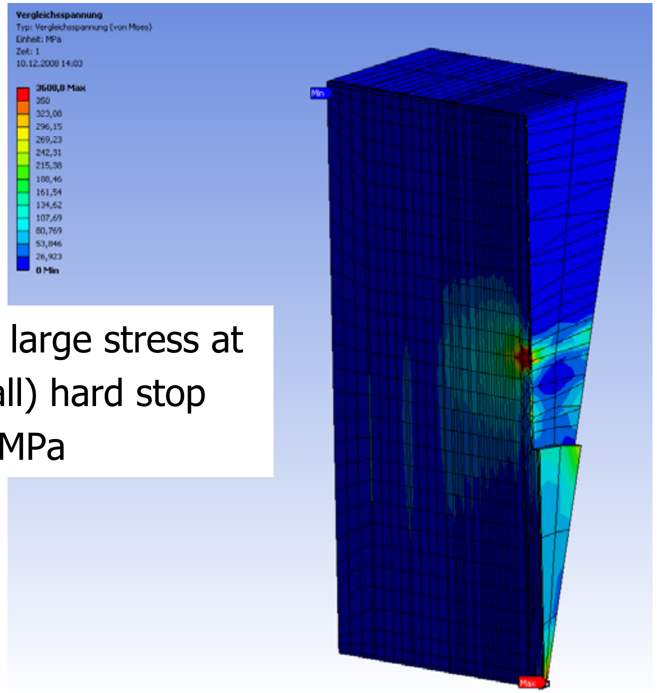


Deformation

2.5 mm

<2 mm

von Misses stress

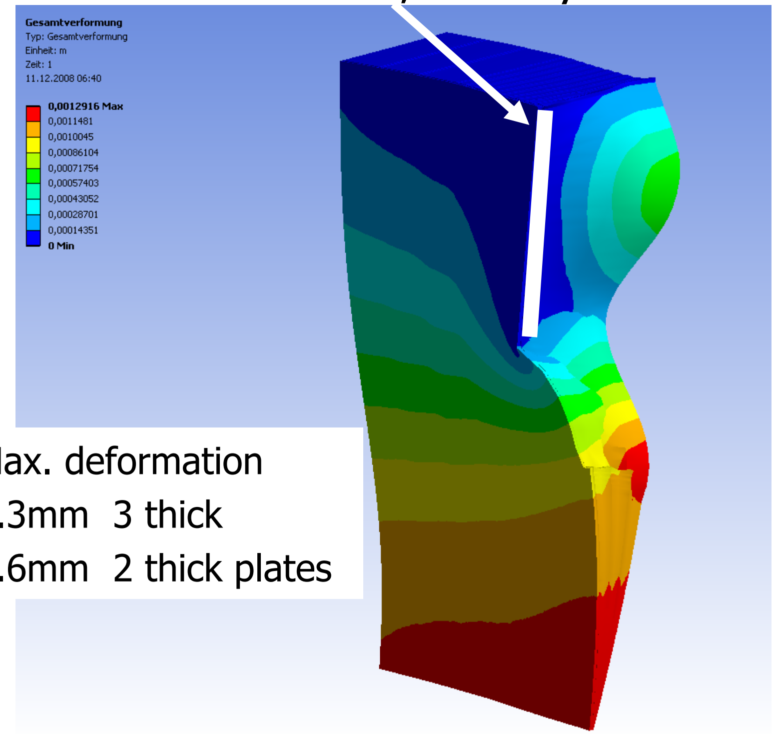


Very large stress at (small) hard stop 480 MPa

Mechanical Design of End-Cap

Same as previous page, but with modified hard stop

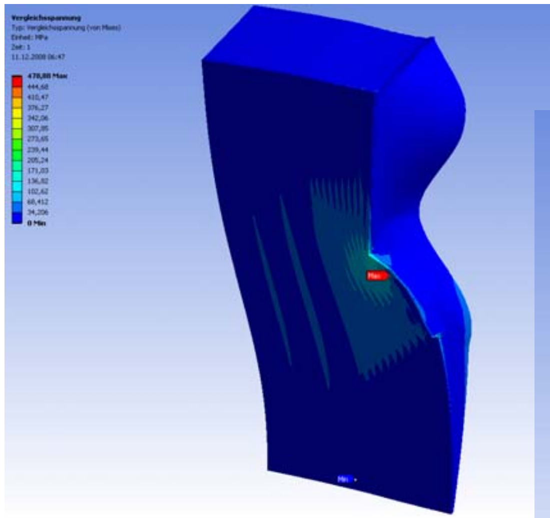
20cm wide, radially extending from first to last barrel iron plate



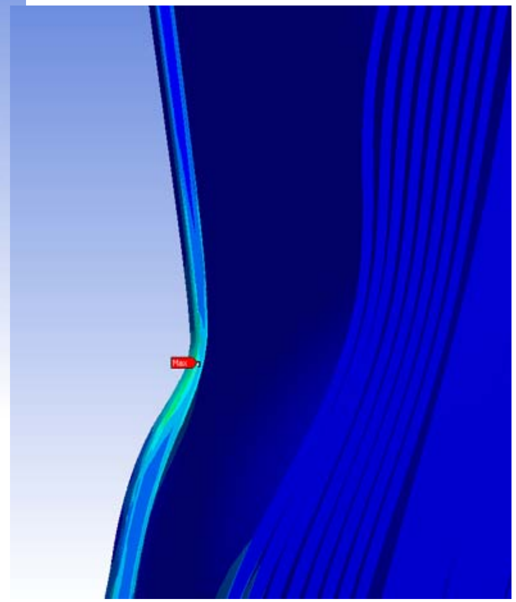
Max. deformation

1.3mm 3 thick

1.6mm 2 thick plates



Stress now <200 MPa

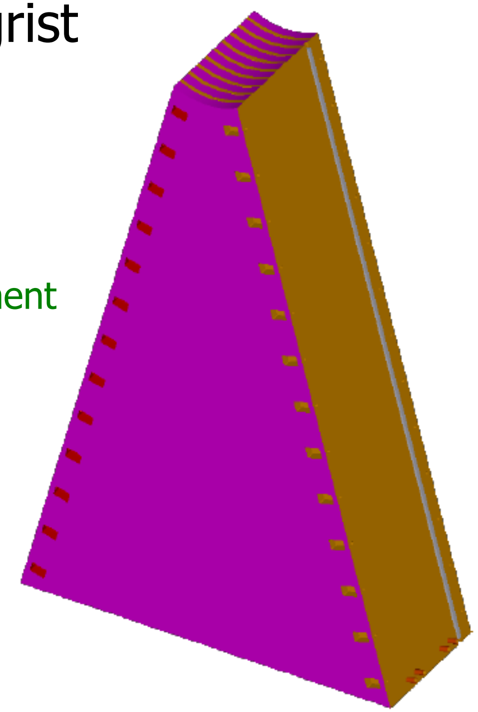


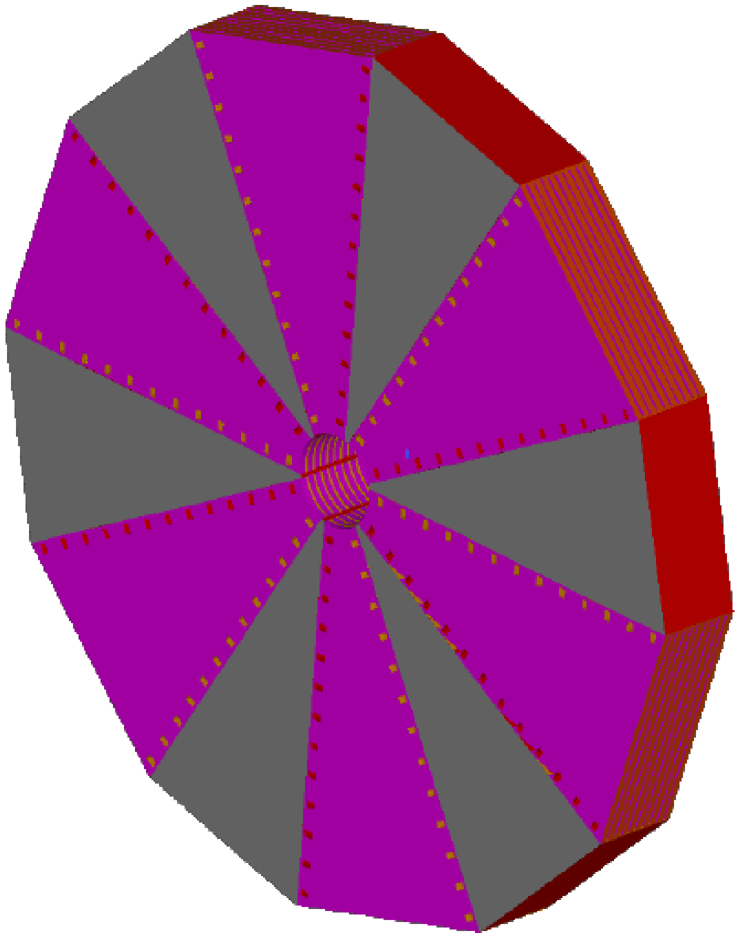
Mechanical Design of End-Cap

Recently, started looking into design of segments with welded plates. Somewhat similar to ZEUS yoke and proposal by H.Gerwig and N.Siegrist

R.Stromhagen/U.S.

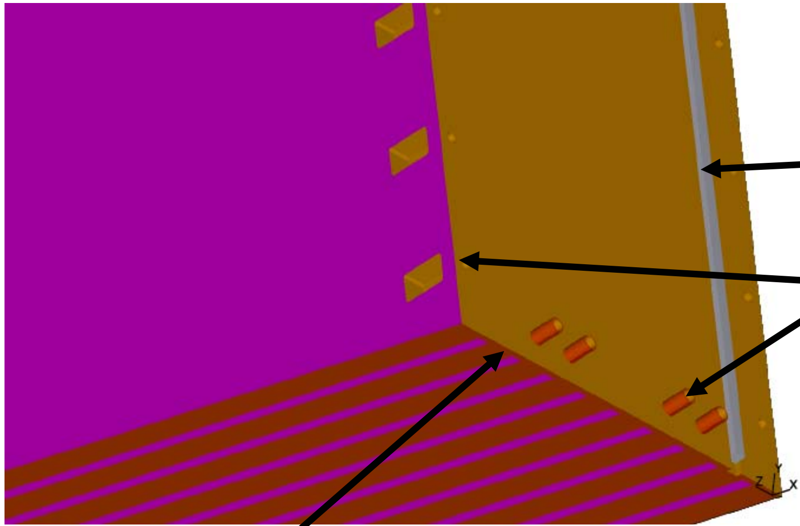
weight of segment
about 90t





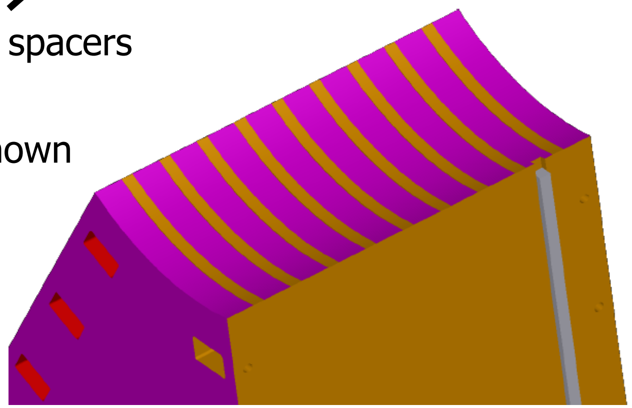
Assembly of End-Cap Segments

Details of inner end-cap part



Plates welded to spacers

Inner ring not shown



Segment assembly:

Gravitational load

- Using shear keys and tension springs
- Segments connected by M30 bolts

Magnetic load

First calculation of tangential force between segments about 2000t on IP side. To be checked.

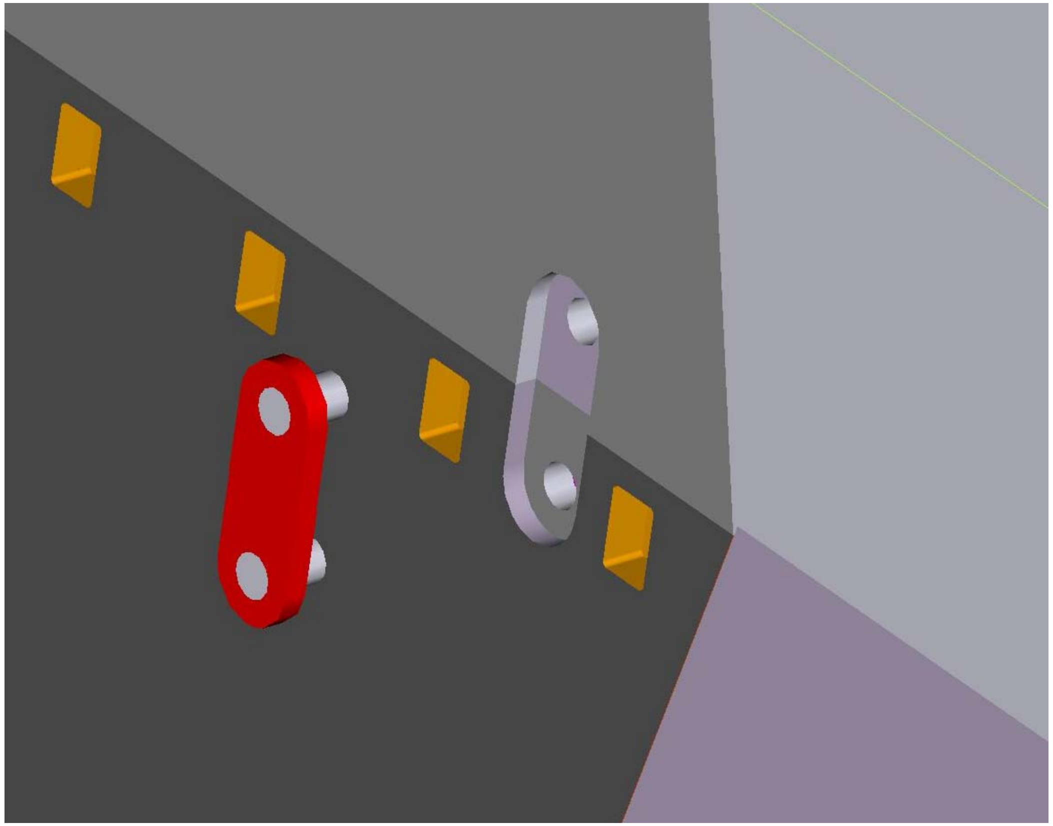
Connection of segments

- Using shear pins in FSP and first plate. Similar to proposal in CMS Magnet TDR.

(Joining segments by welding not recommended)

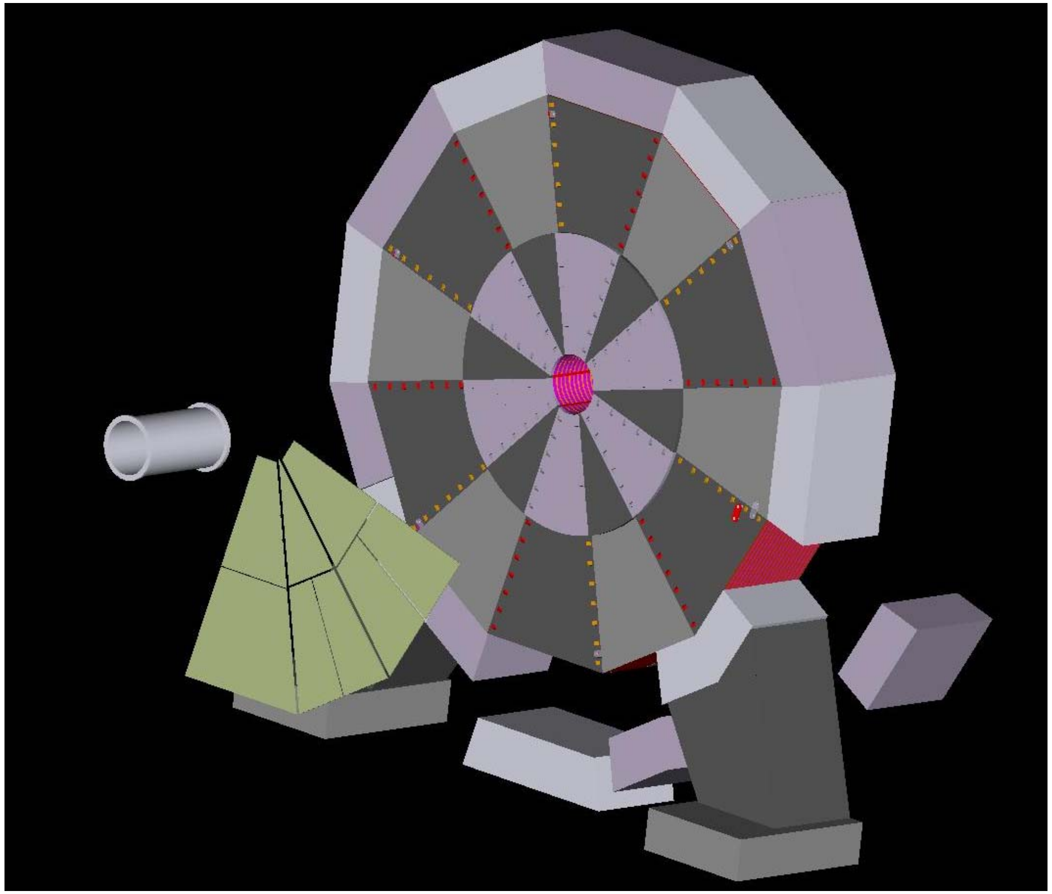
Mechanical Design of End-Cap

Connections of segments using plates and shear pins on first and last plate and FSP. Stress acceptable.

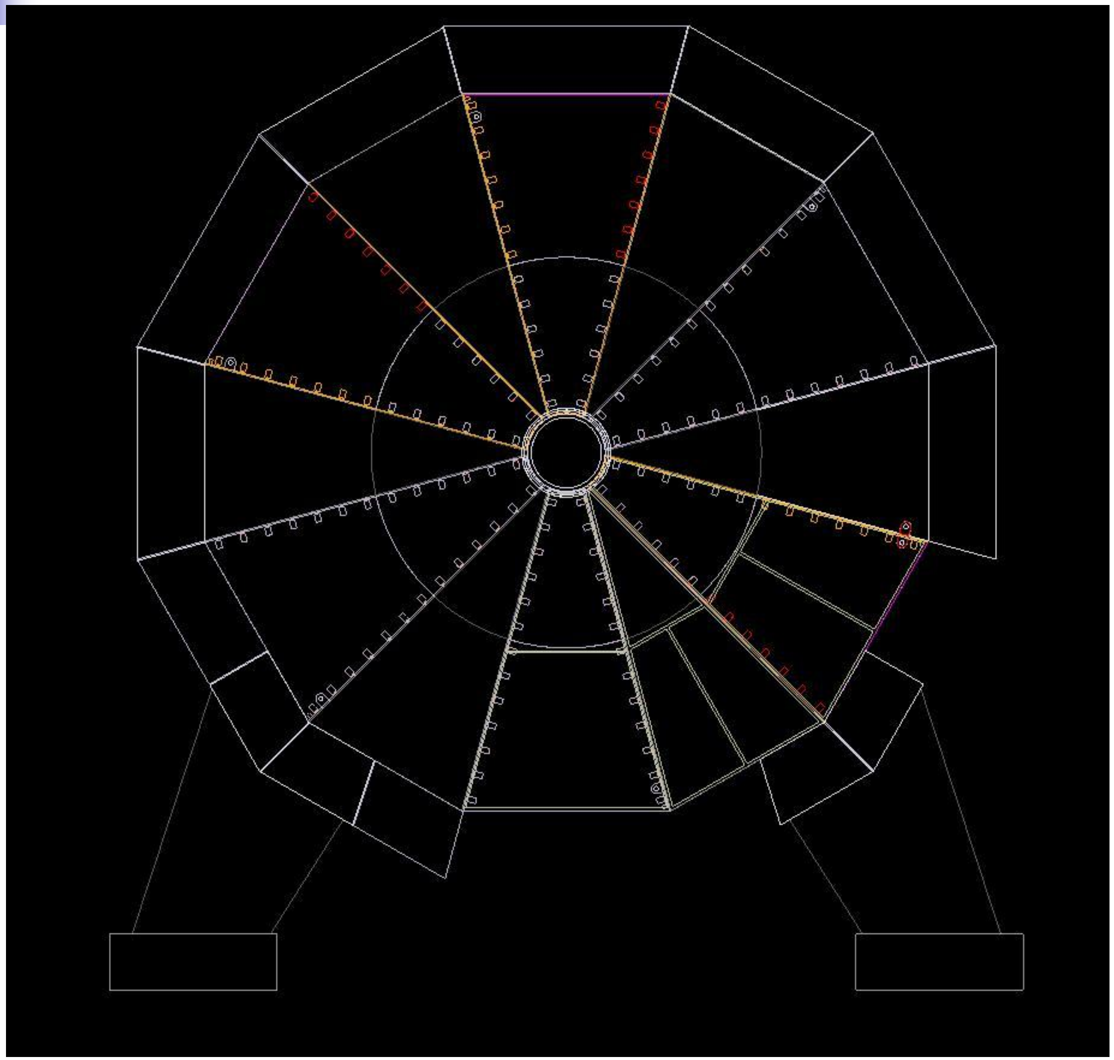


Mechanical Design of End-Cap

End-cap with support feet, inner ring, outer filling pieces and muon chambers



Design of End-Cap – Muon Chambers

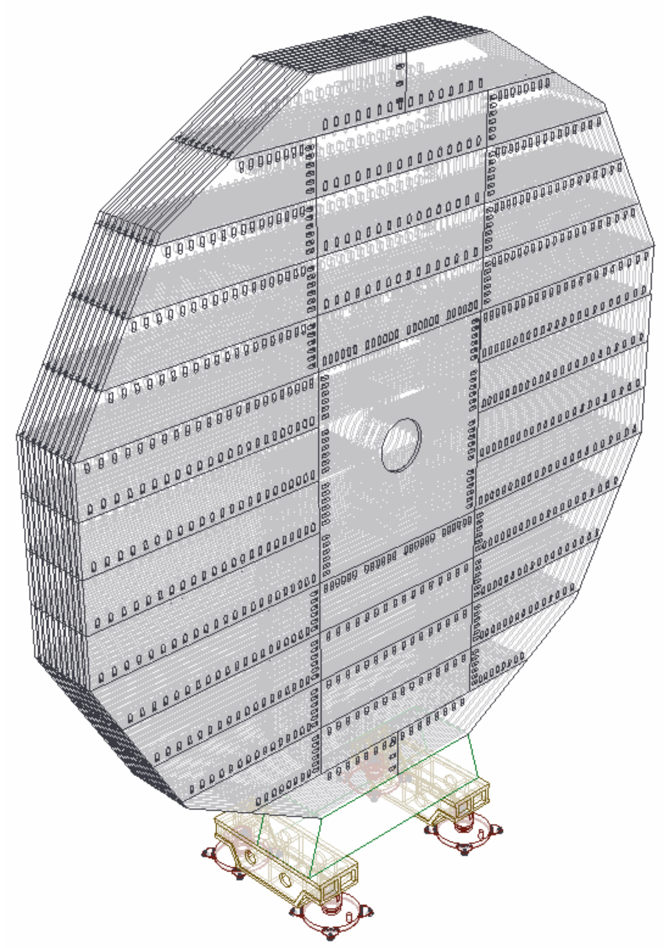


Muon chambers

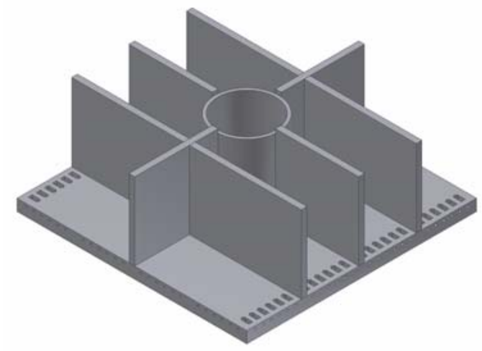
Filling pieces removed for muon chamber installation

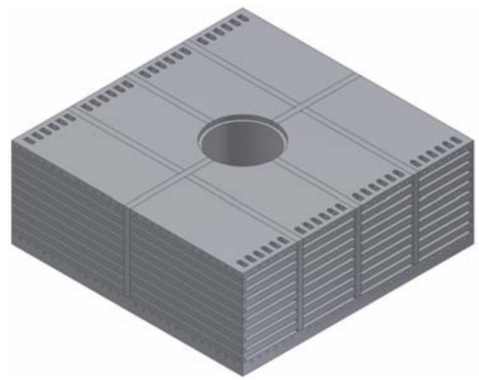
End-Cap Design Horizontal Rips

Design by Hubert Gerwig and Nicolas Siegrist, CMS/CERN



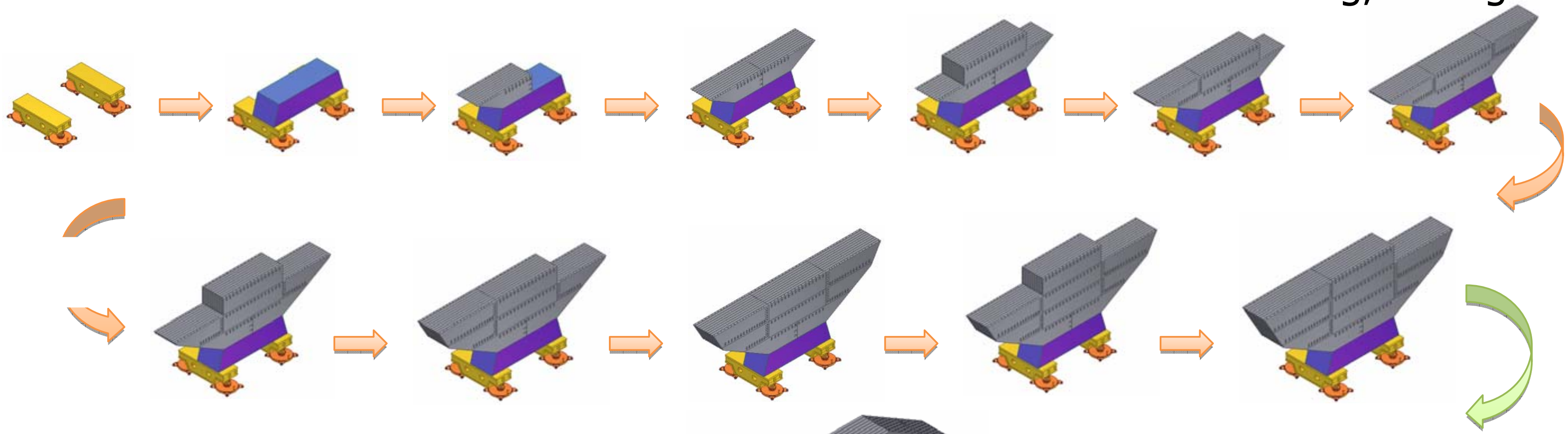
Central part (120t)

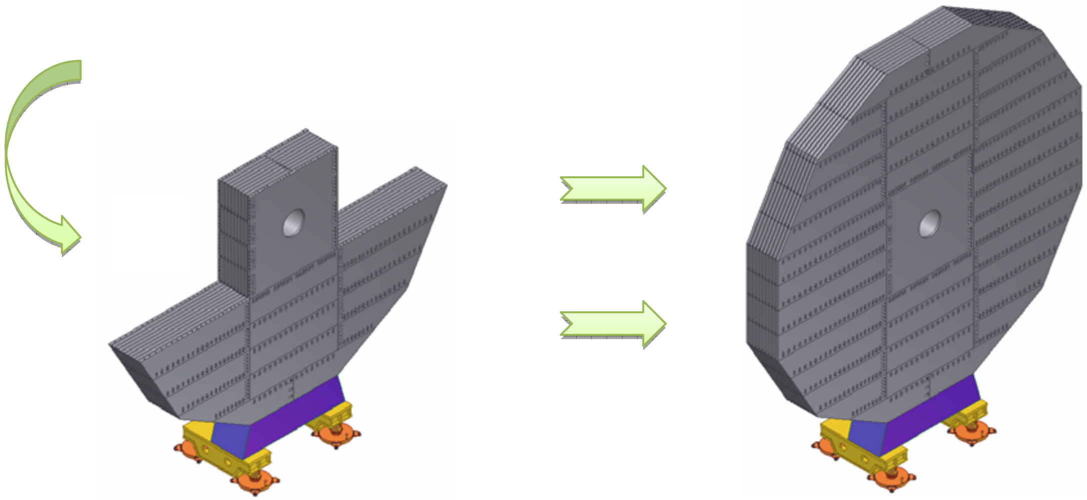




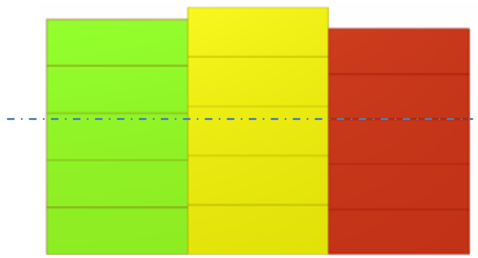
End-Cap Horizontal Rips Assembly

H.Gerwig, N.Siegrist





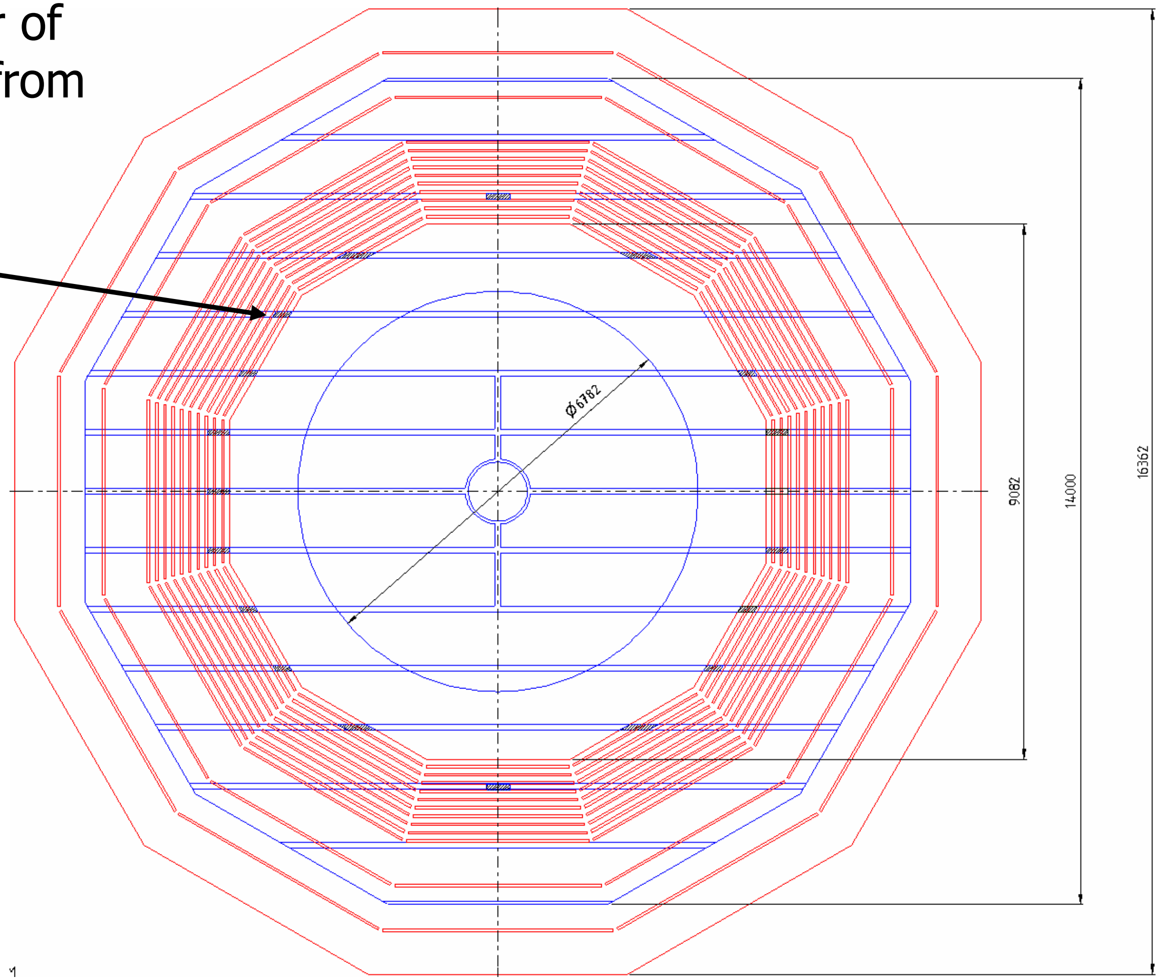
Allow length difference for
mounting (+/- 0.2 for each block):



End-Cap Design Horizontal Rips

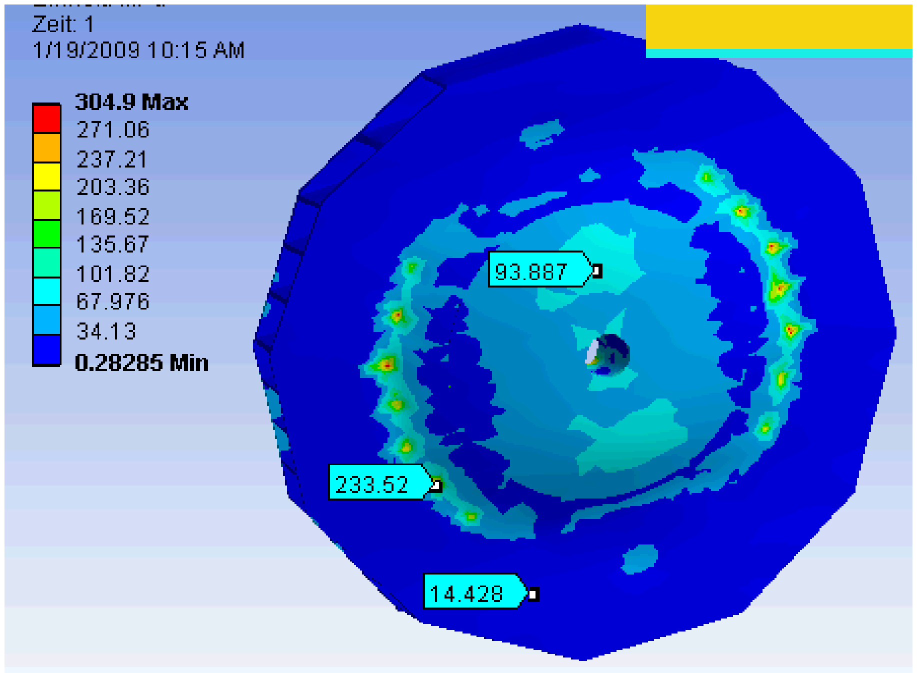
Problem: transfer of magnetic forces from end-cap to barrel

Distribution of (z) hardstops

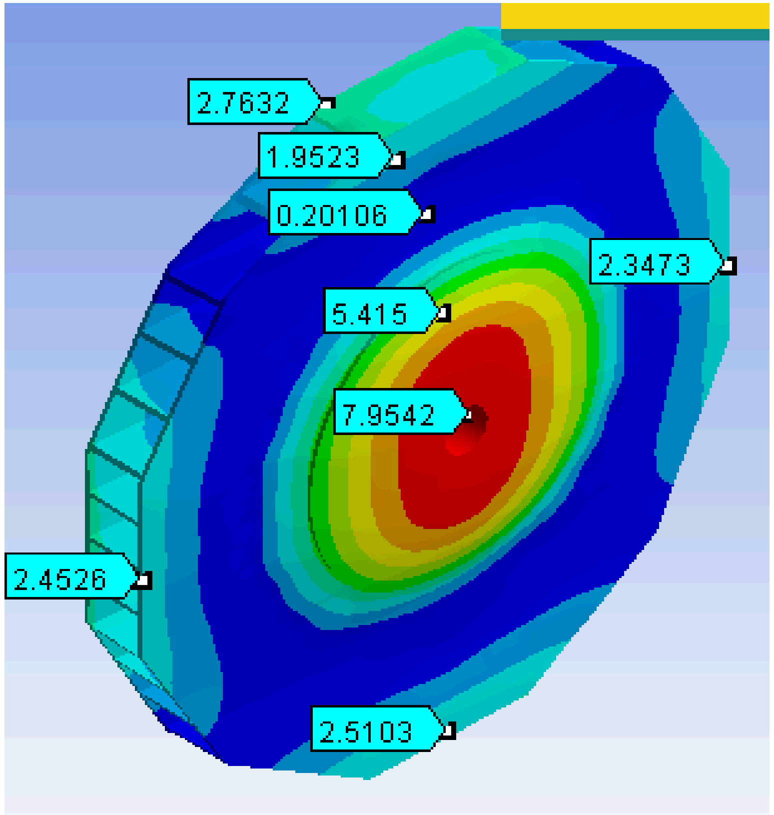


End-Cap Design Horizontal Rips

Stress (MPa)



Deformation (mm)



So far simple FEM model. Only rear and front plates and FSP.
Assuming constant force/surface.

Comparison Radial/Horizontal Rip Designs

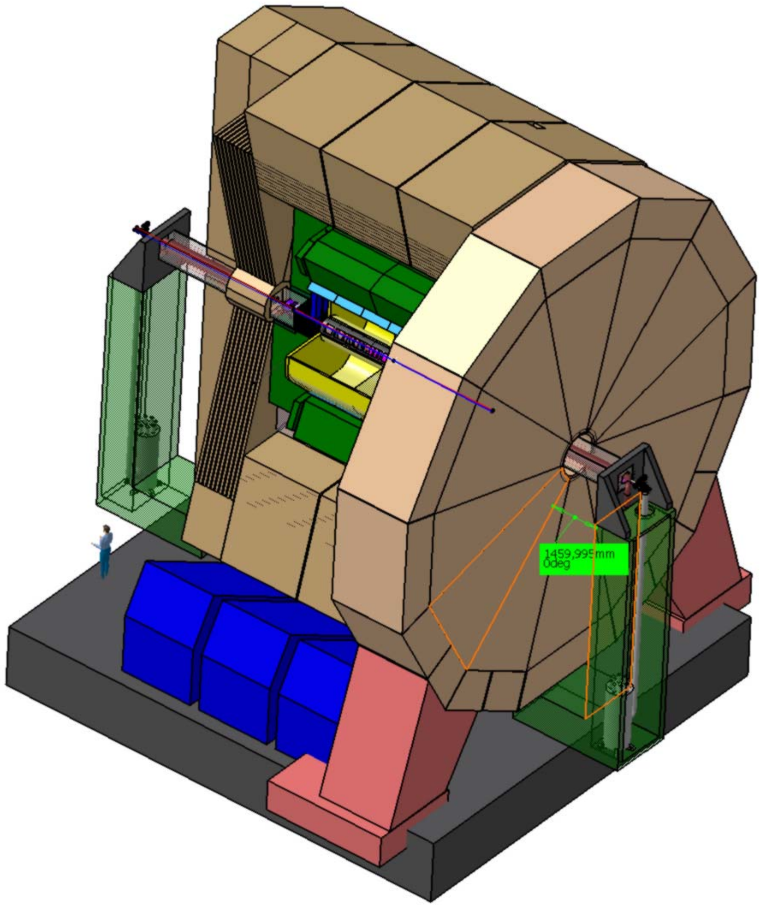
- Radial rip design φ symmetric deformation and stress. Hard stops straight forward.
- Radial rip design half as much supports (and dead space) for same support width.
  - Present models (2x25mm) radial, (2x50mm) horizontal rips

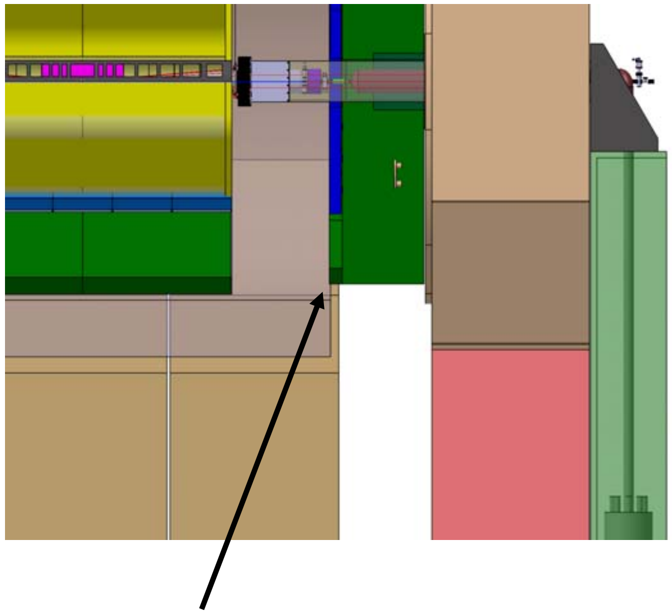
    -> dead space 3% vs. 12%.
  - Both models to be optimized. Horizontal model planning to increase segment size (height by 20-30%).
  - Radial model, may have to increase width of rips slightly
- Horizontal rips easy installation of muon chambers

Both designs have acceptable deformation (few mm) and acceptable stress

End-Cap Opening

Yoke and QD0 support pillars (M.Joré)

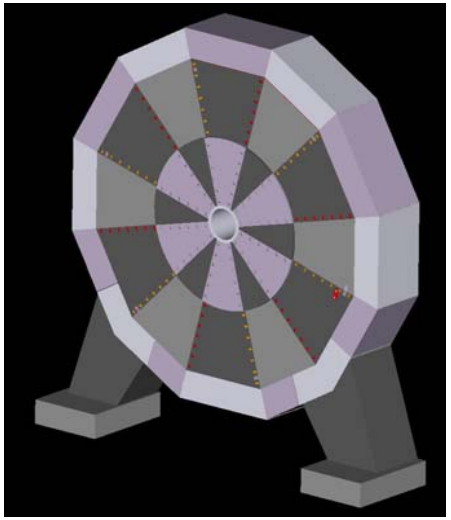




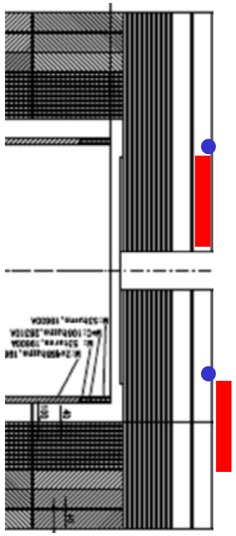
No access between HCAL and EC HCAL when (unsplit) end-cap is opened

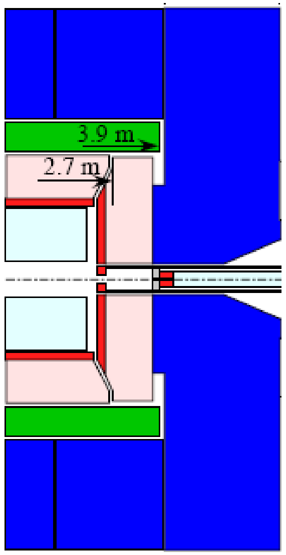
End-cap Opening Options

One end-cap



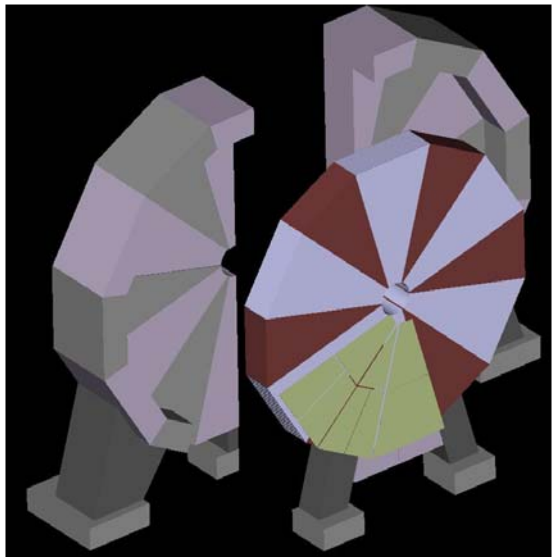
Central iron piece opened





Frustum shaped hole

Split end-cap



End-cap Opening

In beam position

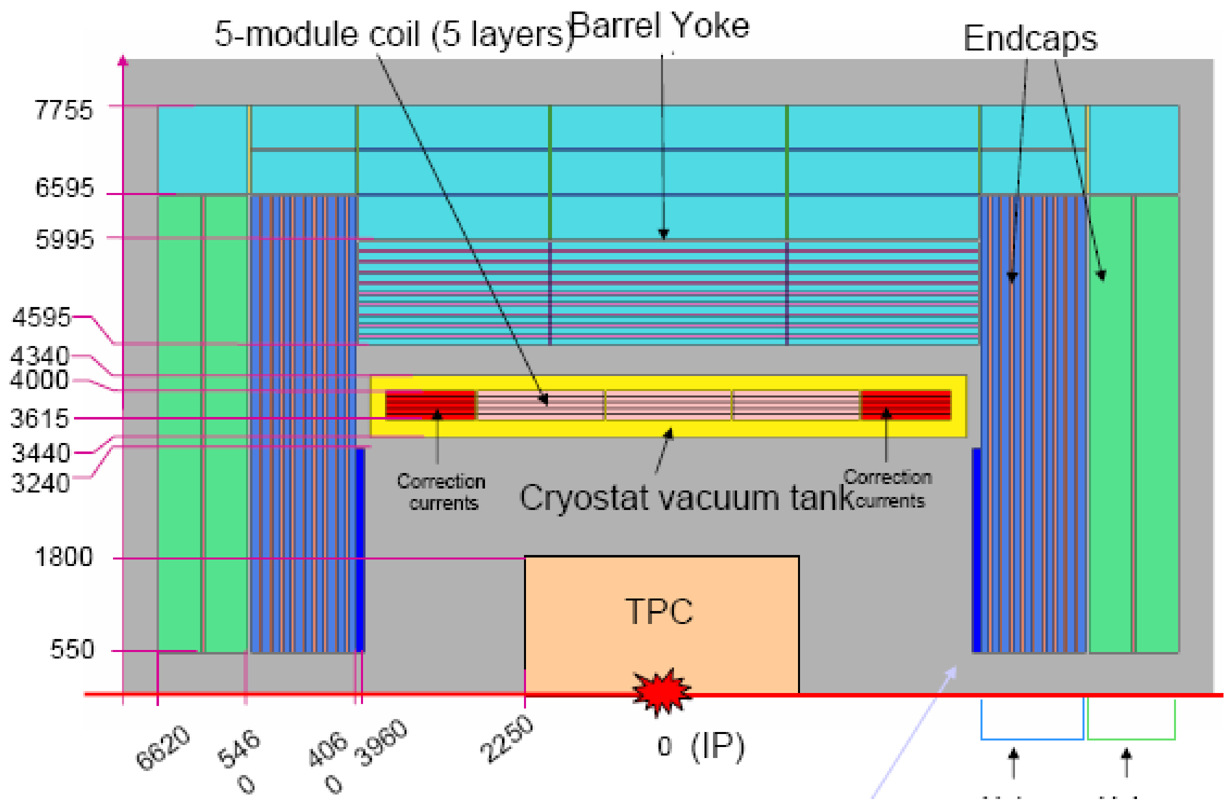
- Access should be very fast. End-cap opening ≤1h
- Access to essential detector components, i.e. TPC and CAL, not muon chambers

	one end-cap	split end-cap 3pieces
movement	in z direction	in x and z directions
cables trays	allow for z movement	allow for x and z movement (if muon chamber in outer EC)
time for opening	fast	about twice as long
Access	limited (TPC, CAL)	better access: more space be-, tween B/EC, access to muon ch.
mechanics	more stable	stable
alignment	just one piece	3 pieces to be positioned conflict with Monalisa platforms?
surface to exp.hall	heavy ~ 3200t	EC maximum ~1500t

Should try to avoid pillar by supporting QD0 from tunnel in order gain space

Coil and Yoke Dimensions

- Still had different coil and yoke dimensions
- Since ILD/CMS meeting agreed to use:
  - Coil values from F.Kircher (inner radius unchanged, outer +150mm)
  - Yoke dimensions of DESY model (radius +100mm)



Conclusions

Good progress on

- Stray field
  - Goal of <50G stray field at 15m from beam line is achievable
- End-cap mechanical design with fine segmentation
  - Radial rip option
    - Small deformation, tolerable stress at hard-stops
    - Simple geometry
  - Horizontal rip option
    - Design by H.Gerwig and N.Siegrist, CMS/CERN
    - Deformation and stress fine, but more support structure (dead space)
    - Easier installation of muon chambers
  - Will study whether split end-cap can be avoided

Have fixed coil and yoke dimensions (not EC mechanical design) since ILD/CMS engineering meeting in January

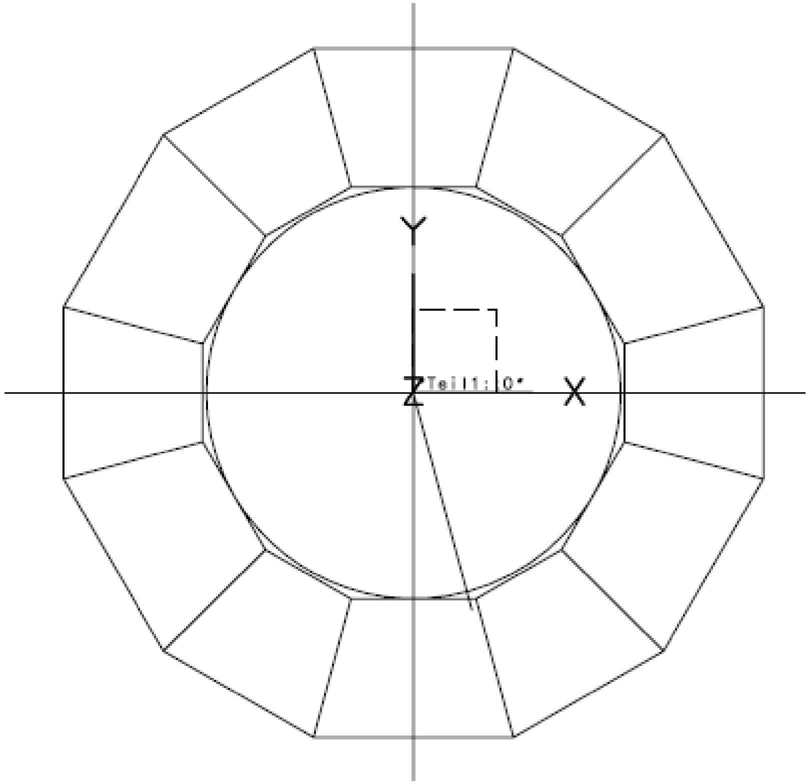
Backup Slides

- Barrel and end-cap shape
- Radial rip design
  - Deformation of inner part
  - Outer part
- Details on horizontal rip design

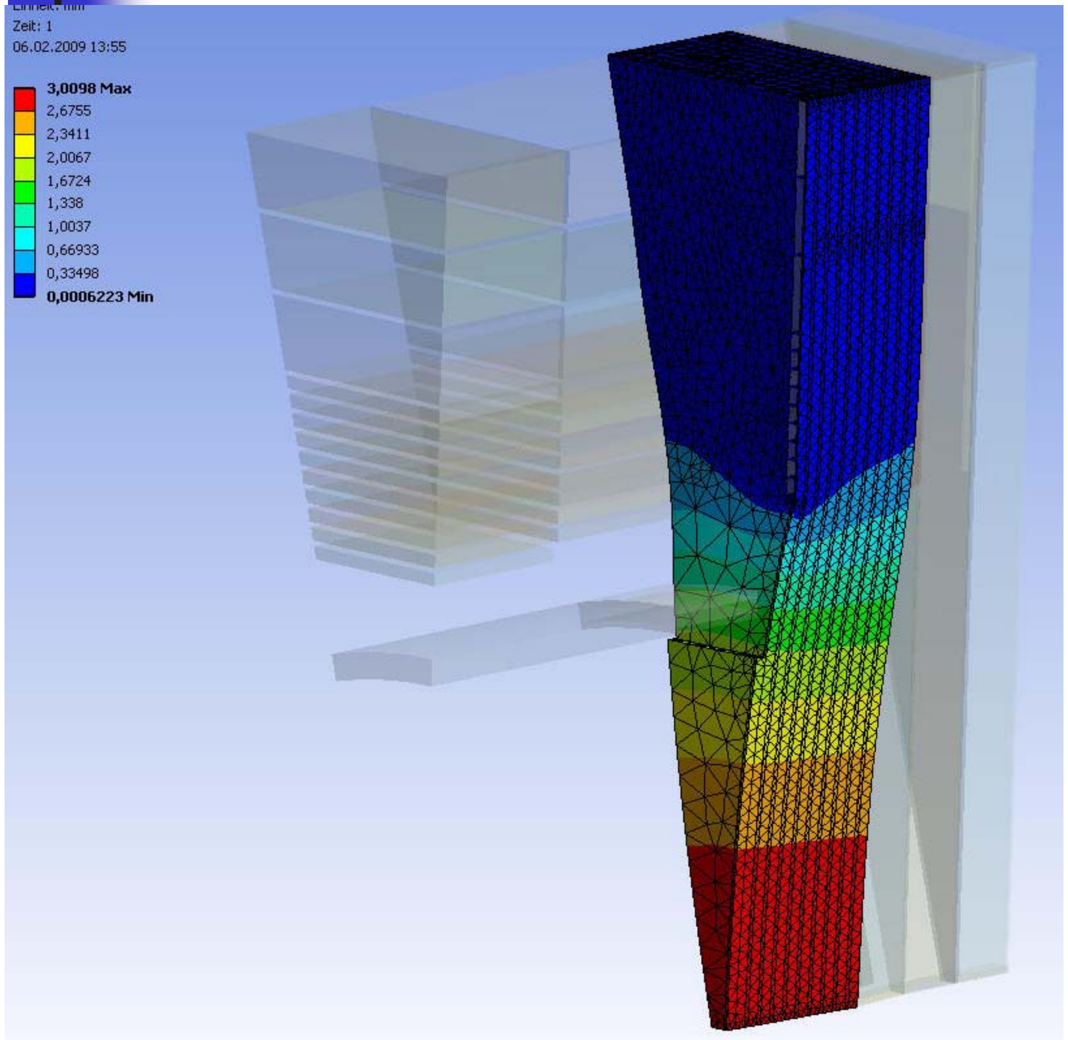
Barrel and End-cap Shape

- Dodecagonal shape
- Propose slight offset (150mm) in order to avoid cracks (dead space) pointing towards IP
  - high momentum muons

→ Two types of barrel and end-cap segments



Mechanical Design of End-Cap



Deformation of inner part (10 x 100mm) plates.
Hard stop 20cm wide, radially extending from first to last barrel iron plate.
Filling pieces included.

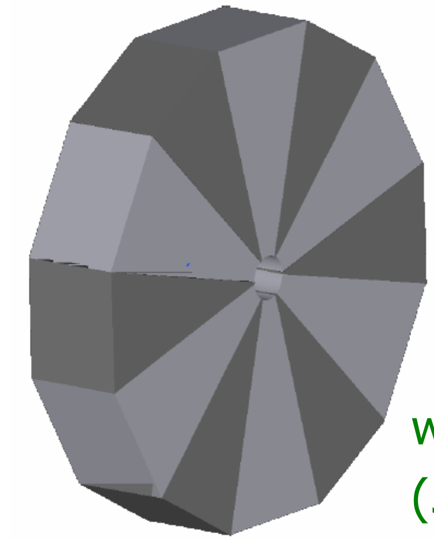
- Max. deformation 3mm
- But, outer part clamped due to filling pieces, hard stop and magnetic force

Mechanical Design of End-Cap

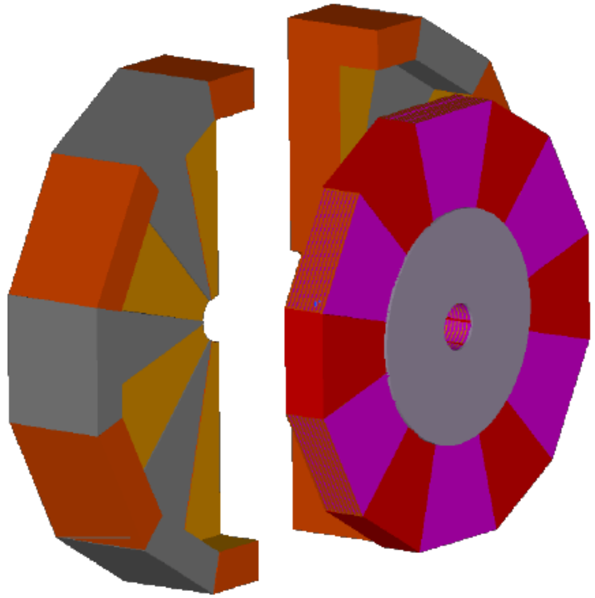
Outer part of end-cap

- Two thick segmented disks
- Segments bolted or welded together

Similar to CMS

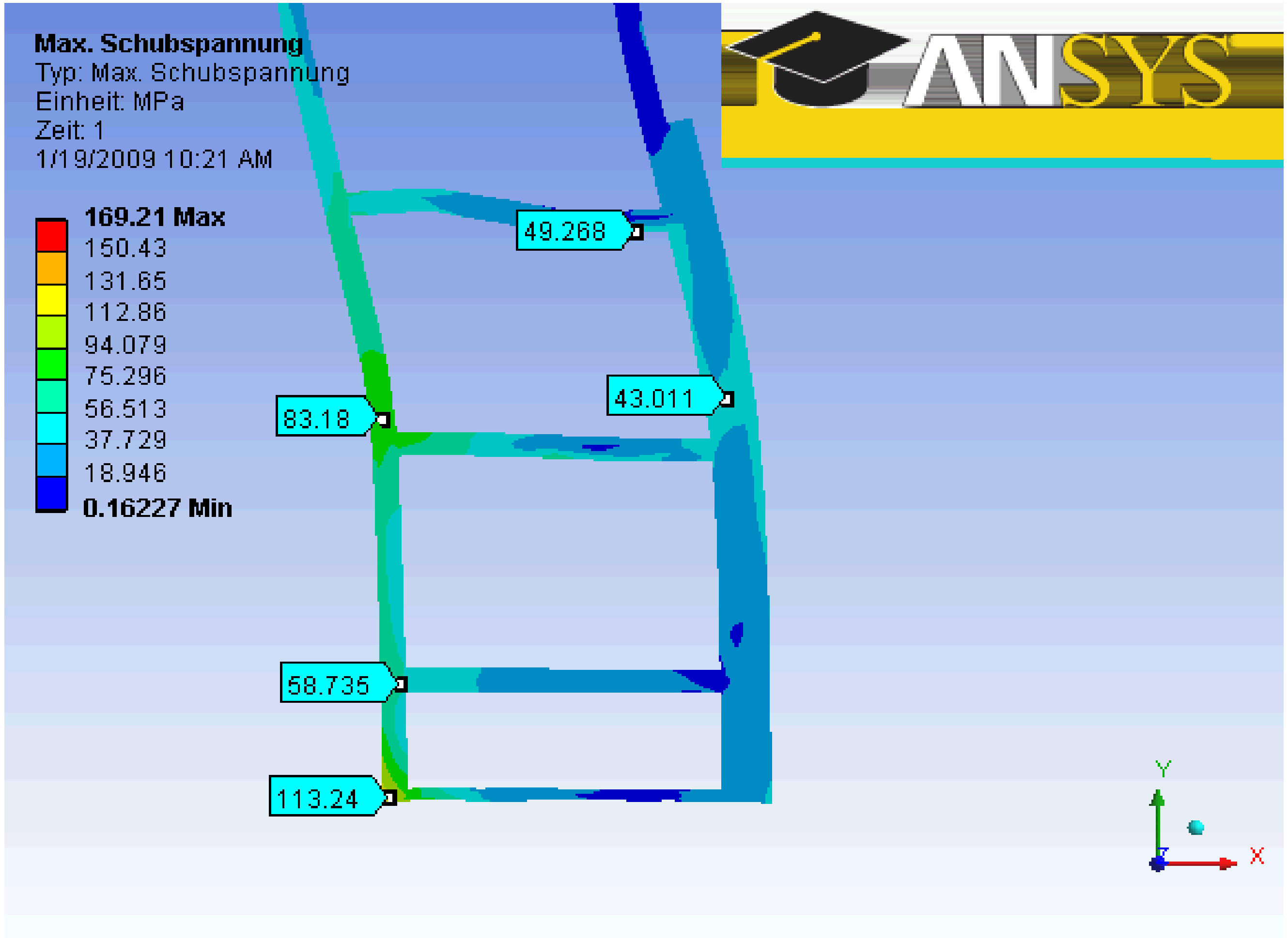


weight of segment (560mm thick) about 70t

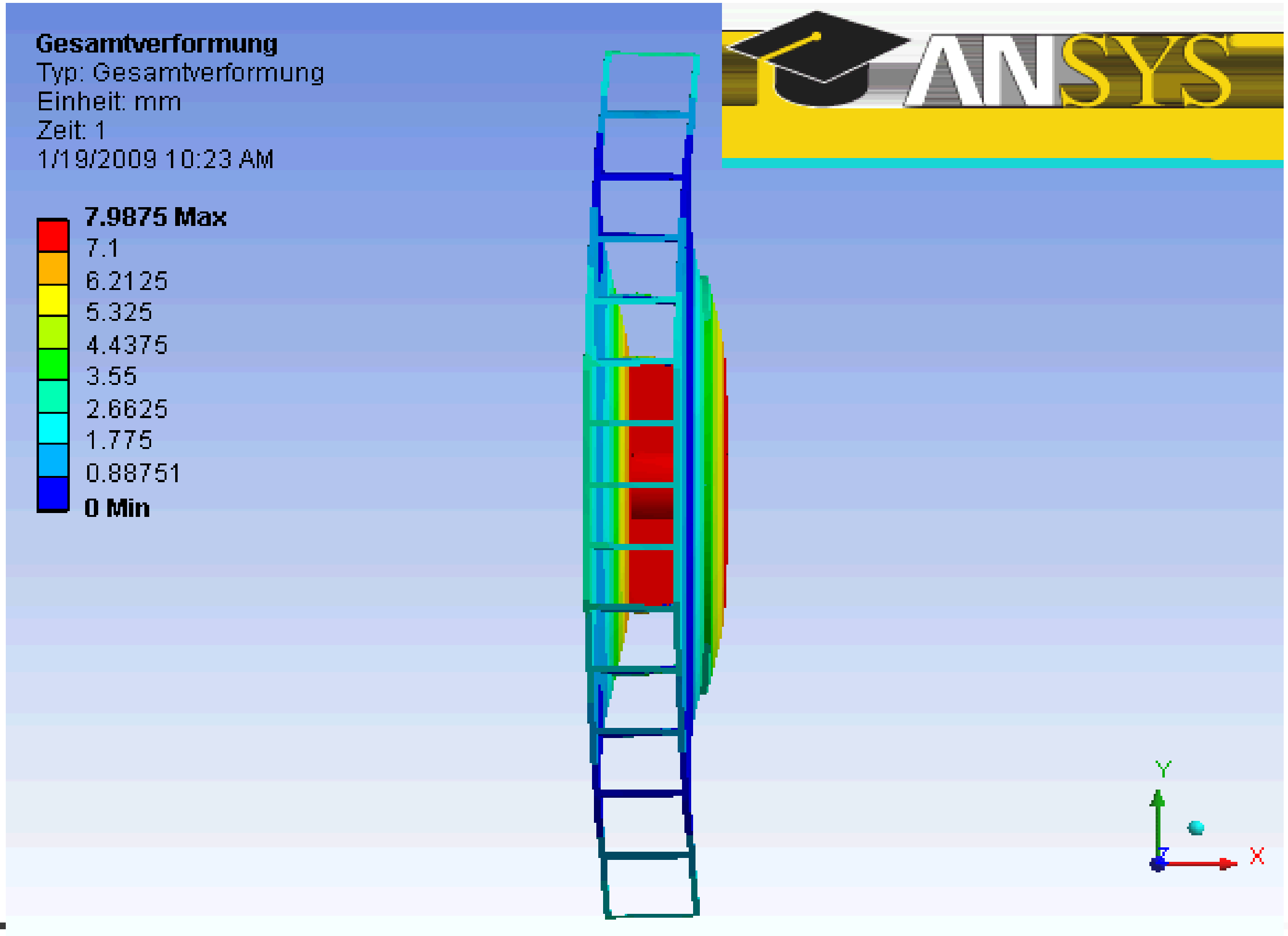


Split end-cap option

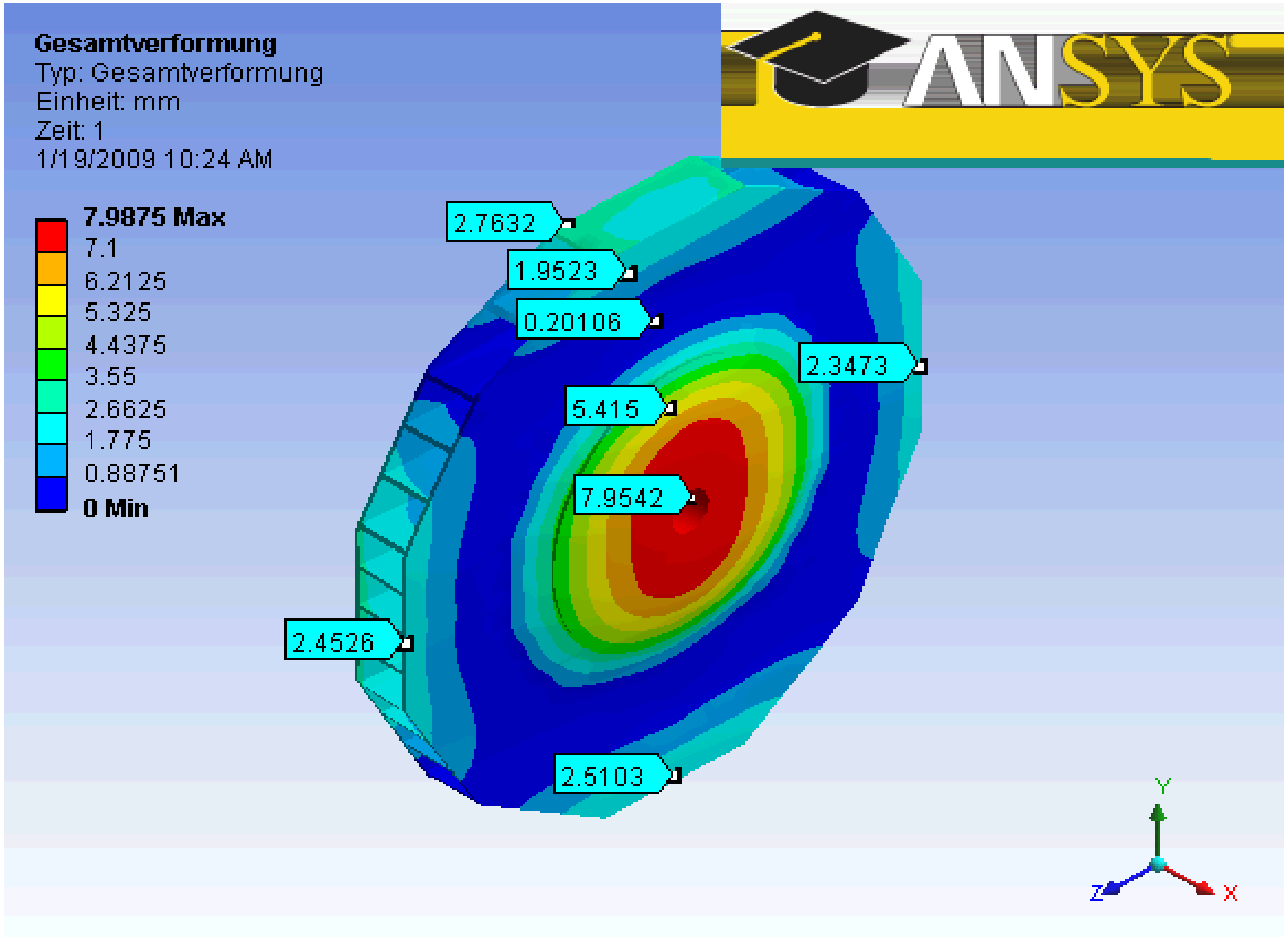
SHEAR STRESS



TOTAL DEFORMATION



TOTAL DEFORMATION



BEHAVIOUR WITH LESS Z-STOPS