Progress on ILD Yoke Design

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DESY

20.01.2009

ILD Engineering Meeting, CERN

Outline

- Function of iron yoke
- Inner radius of barrel yoke
- Gap between barrel rings
- 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
- Lifting capacity of hall cranes

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
  - 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 Parameter 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.

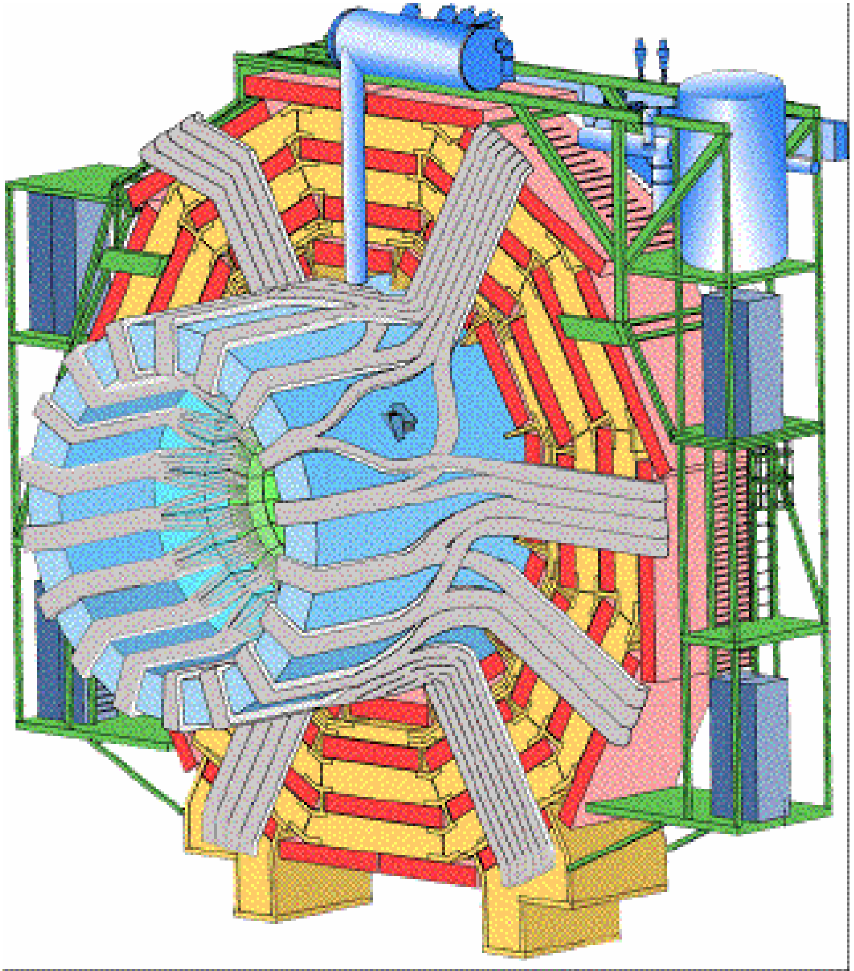
→Assuming fine segmentation for the mechanical design (worst case)
Mechanical design with thicker plates will be easier.

Space between Cryostat and Yoke

CMS style assembly

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

Radial space between cryostat and muon chambers is about 30cm



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 rφ)

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

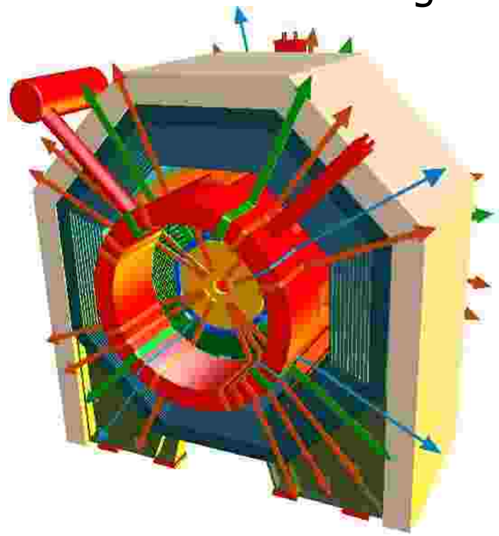
- In CMS space was taken by alignment systems
- Probably won't need 12 alignment systems, only a few
- CMS needs additional space for cooling of cables. ILD expecting much less heat due to power cycling. Readout mainly via glass fibers.

Conclusion, should keep about 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 hole for cryostat supply

Tesla detector design

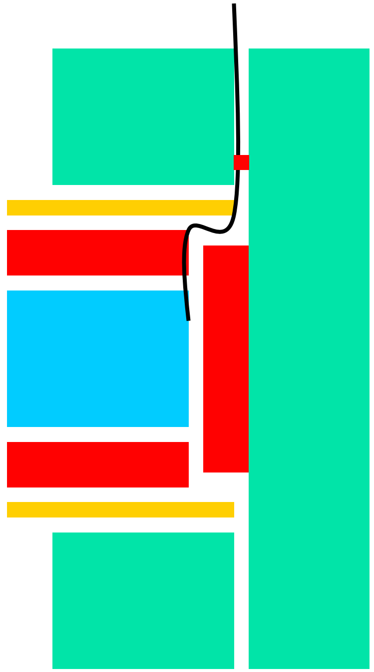


Space between Barrel and End-cap

- 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 cable channels
  - Reduce gap to 10mm (for hardstops)
  - 4 channels of 100mm x 825mm distribute in φ

  Would slightly decrease stray field, local increase
  - Needs 3D field simulation (EM Studio)



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
- Reduce thickness of first end-cap iron plate at position of cable channels
  - Not a good idea, plates are thin (weak) anyway
- 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

- Sendai
  - Goal 200G at 0.5m distance from iron yoke
- Cambridge
  - 200 G at 0.5m very difficult
  - Should keep 200 G for safety at 1 – 1.5m
- Interface document, similar to CERN Safety Rules
  - Surface of 'on-beamline' detector < 2kG (limit for working day)
  - Non-restricted area (including 'off-beamline' detector) < 100 G
- 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

B Field Calculations

CST EM Studio 3 D calculations (A.Petrov)

- Now variable mesh size, 3 to 4 10^6 cells

Opera 2 D calculations (B.Krause)

Yoke segmentation (as in reference detector note)

- 100mm field shaping plate only end-cap
- 10 x (100mm + 40mm gap)
- n x (560mm + 40mm gap)

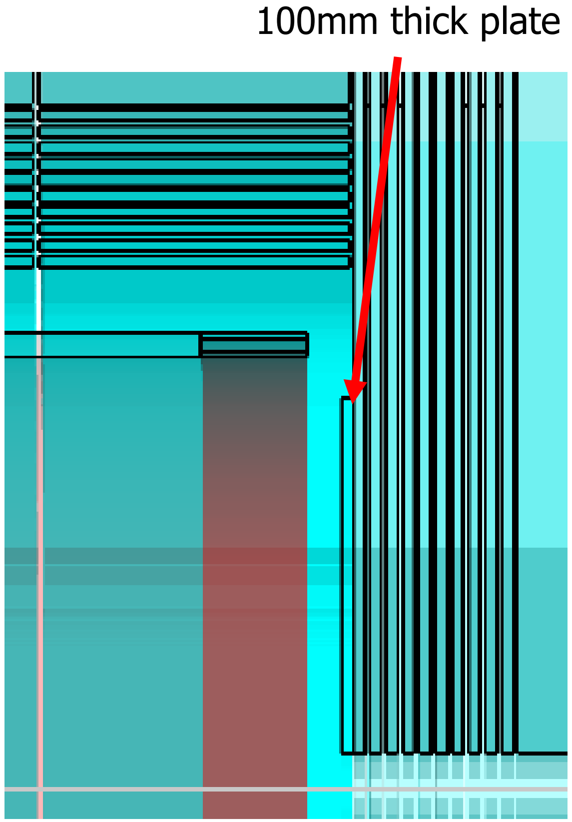
Chicago ILC/MDI meeting:

- Goal <50 G at 15m from beam line

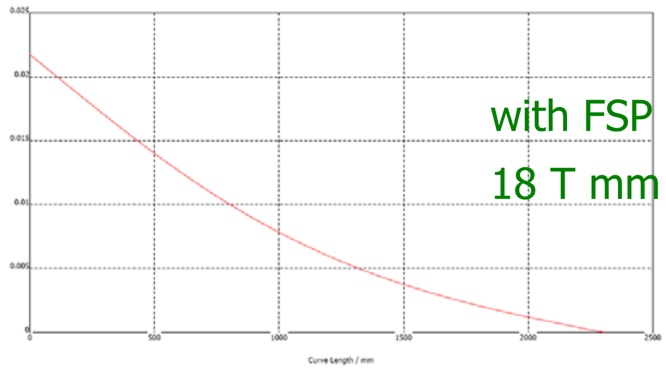
Effect of Field Shaping Plate

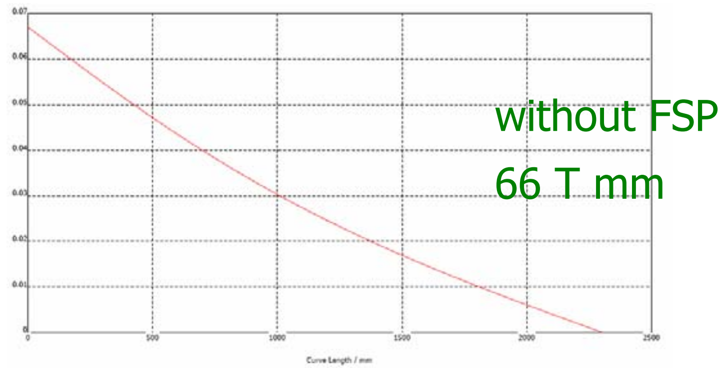
Field shaping plate in front of end-cap in order to improve field quality in TPC region

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



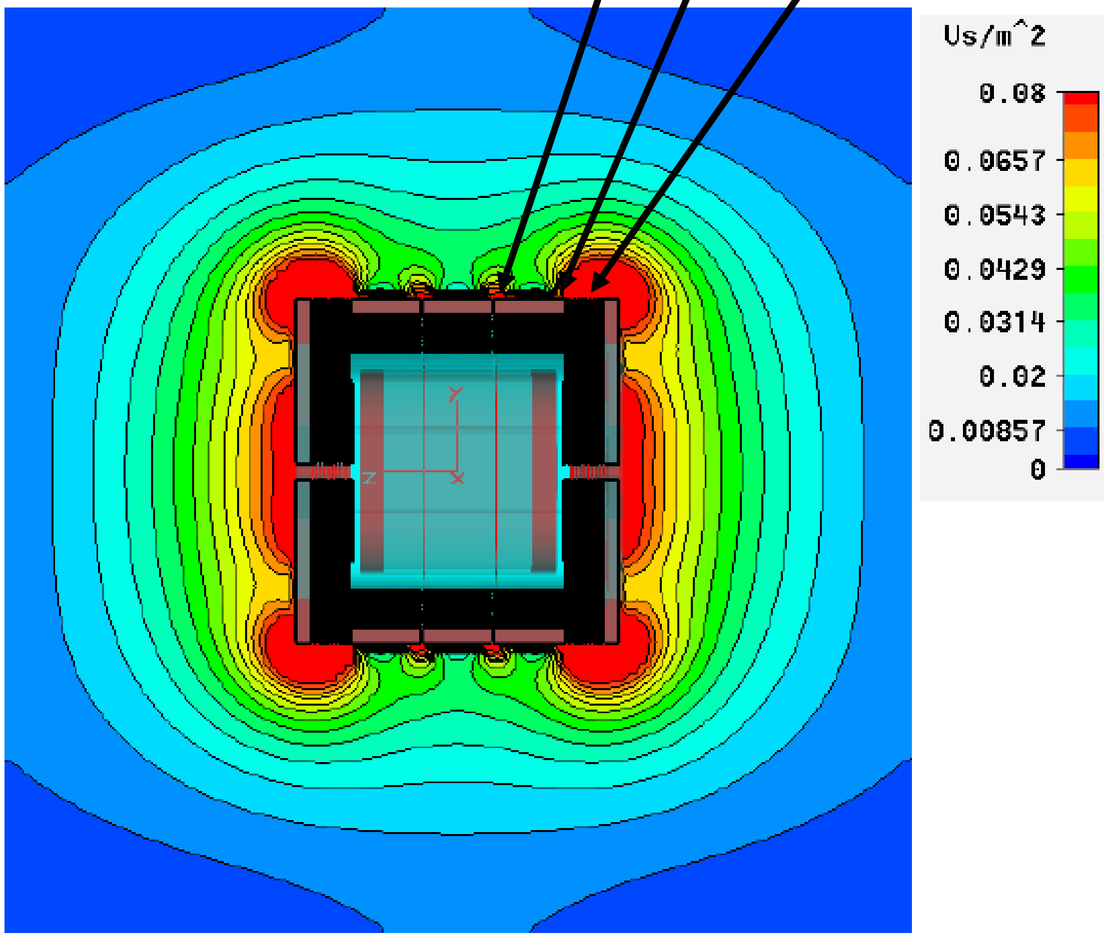
Field integral $\int B_r \, dz$ vs. z





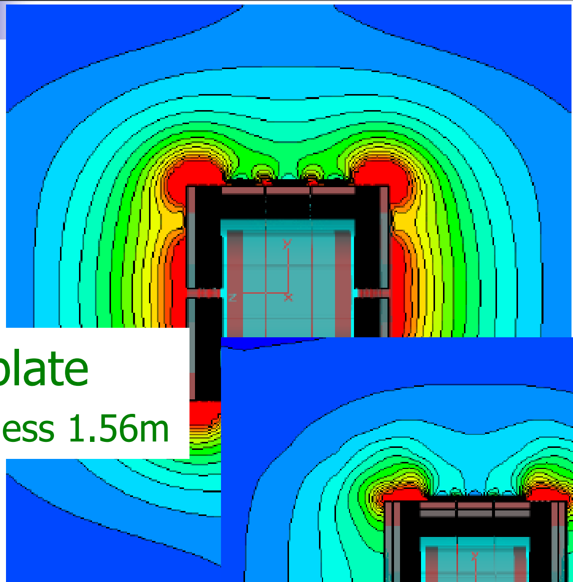
Stray Field Calculations

Central field 3.5 T gaps 50 25 40mm



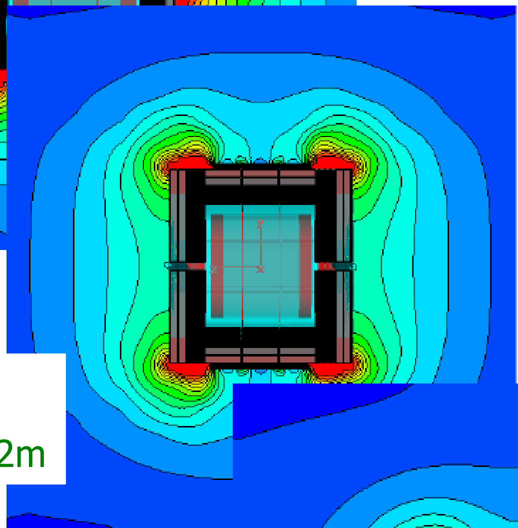
Stray Field Calculations

3.5 T



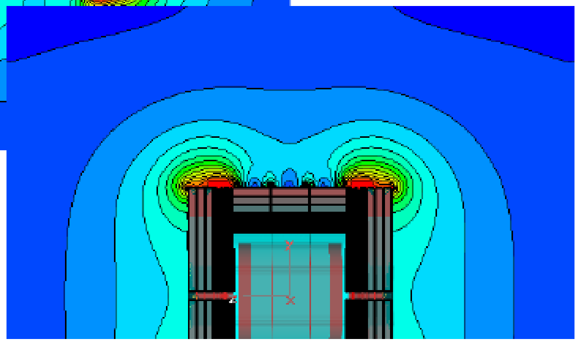
1 thick plate

iron thickness 1.56m



2 thick plates

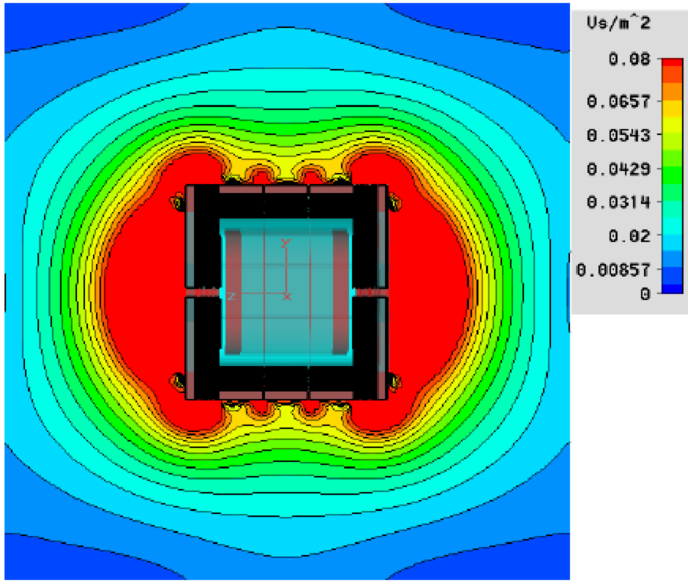
iron thickness 2.12m



3 thick plates

iron thickness 2.68m

4 T



Stray Field Calculations

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

CST EM Studio (A.Petrov)

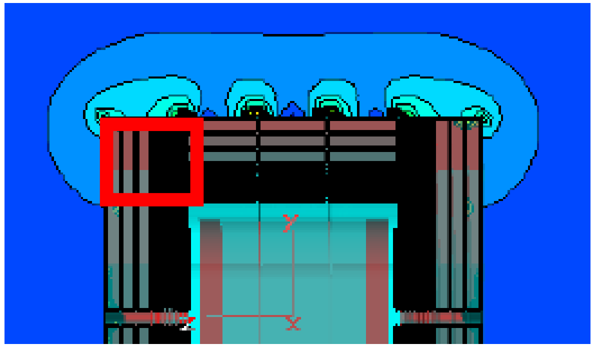
central field 3.5 T — 4 T

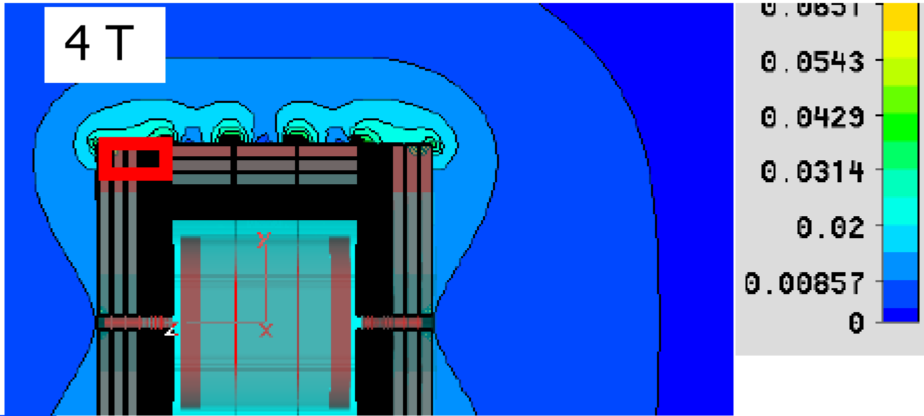
iron yoke	1 thick plate		2 thick plates		3 thick plates		1 thick plate	
B (T)	3.6		3.7		3.6		3.9	
z (m)	0	5.4	0	5.4	0	5.4	0	5.4
B stray (G)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)	y (m)
200	11.5	11.8	7.1	11.8	7.7	11.3	13.4	
100	16	15.1	14.1	15.8	13.4	13.9	~ 18	~ 17
	d (m)	d (m)	d (m)	d (m)	d (m)	d (m)	d (m)	d (m)
200	5	5.3	0	4.7	0	3.6	6.9	6.6
100	9.5	8.6	7	8.7	5.7	6.2	~ 11.5	~ 10.5

Stray Field Calculations

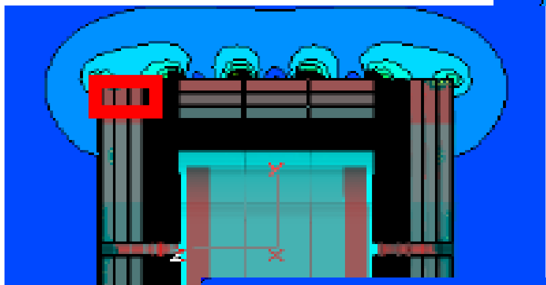
3.5 T

gaps filled

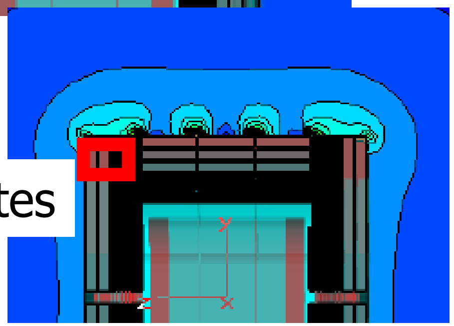




gaps partly filled

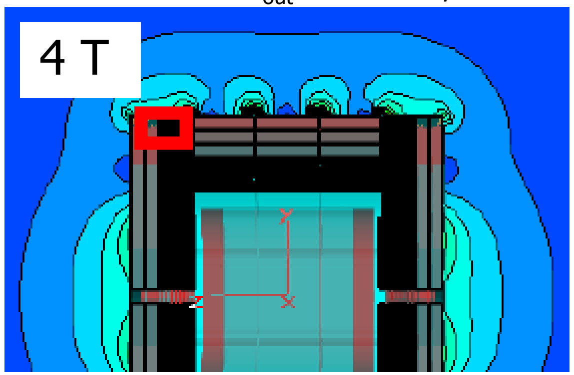


gaps partly filled, EC 2 plates



Update

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



Stray Field Calculations

Chicago
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.

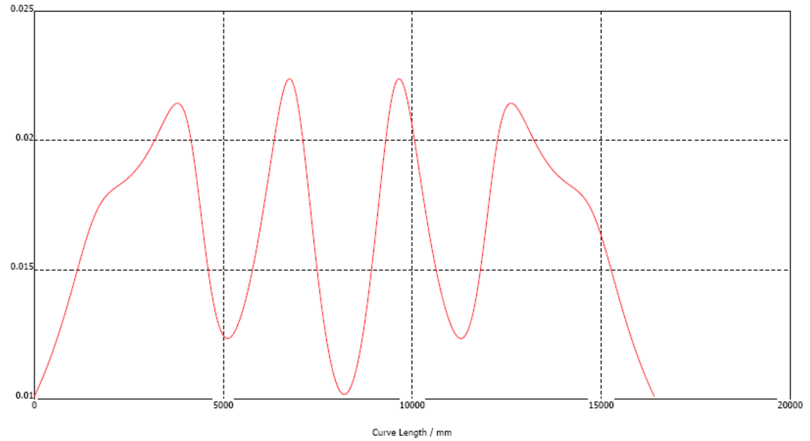
Limit as discussed in Chicago MDI meeting.

Stray Field Calculations (Chicago)

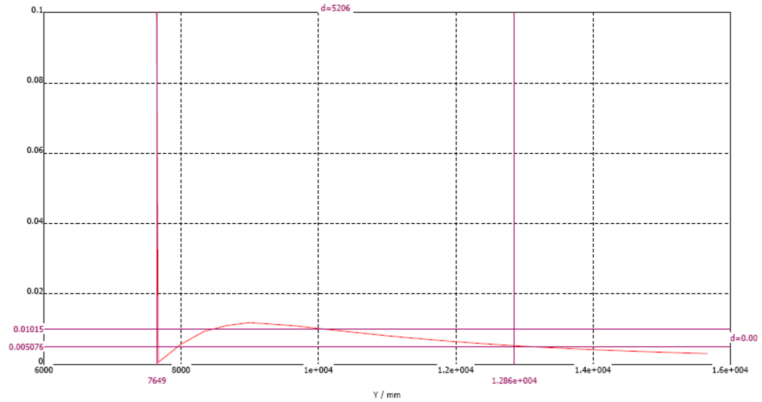
Central field 3.5 T

Gaps partly filled

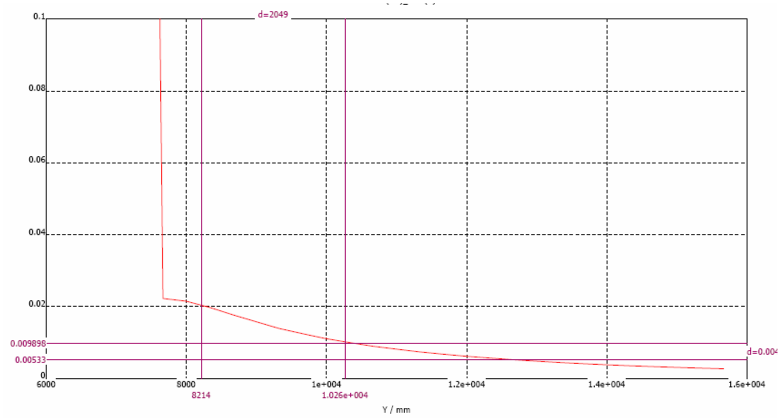
B 0.8m from iron yoke vs. z



B vs. y at z = 0



B vs. y at z = 5.425m



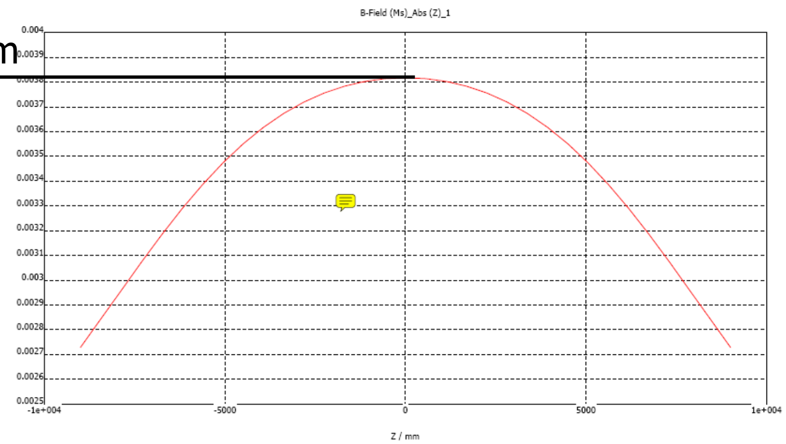
Stray Field Calculations

Central field 4 T

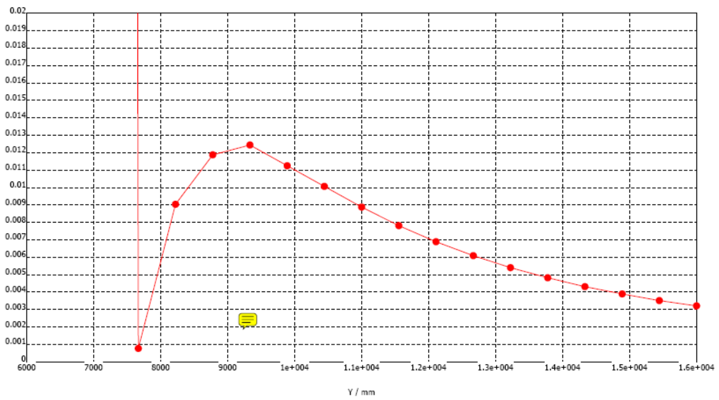
Gaps partly filled

B 15m from beam line vs. z

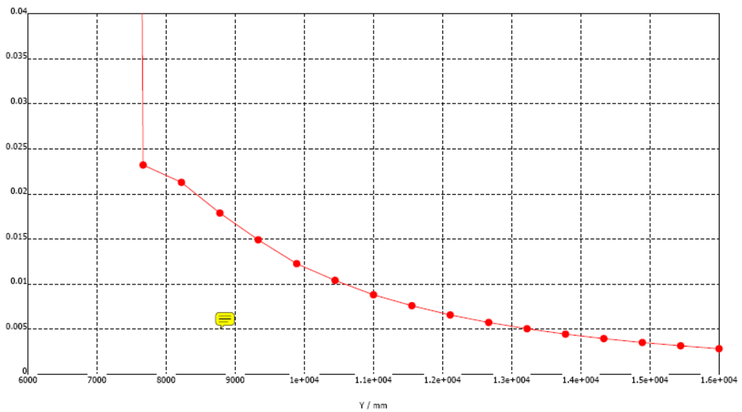
38 G at 15m



B vs. y at z = 0



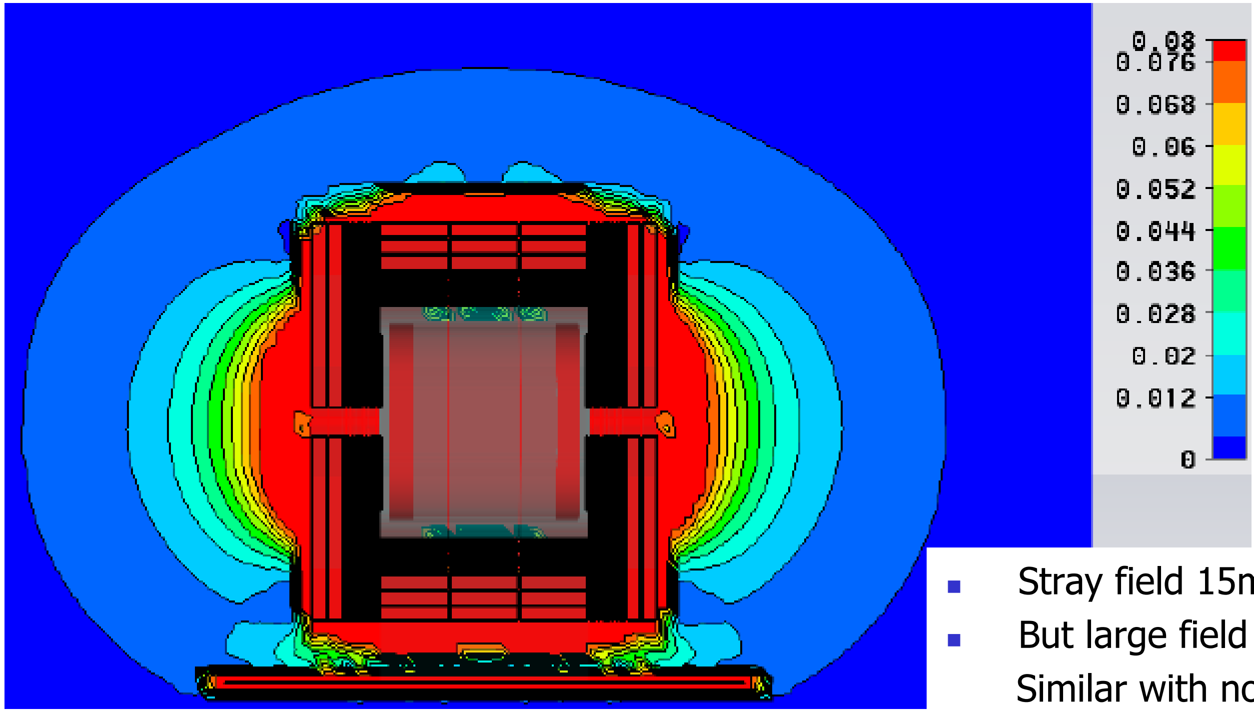
B vs. y at z = 5.425m



Stray Field Update

- Simple iron support feet (only outer barrel ring)
- Floor with steel plate (20m x 20m 60mm thick)
- Increased end-cap hole to 1.1m diameter to accommodate rectangular support tube
- (New program version)

4 T field

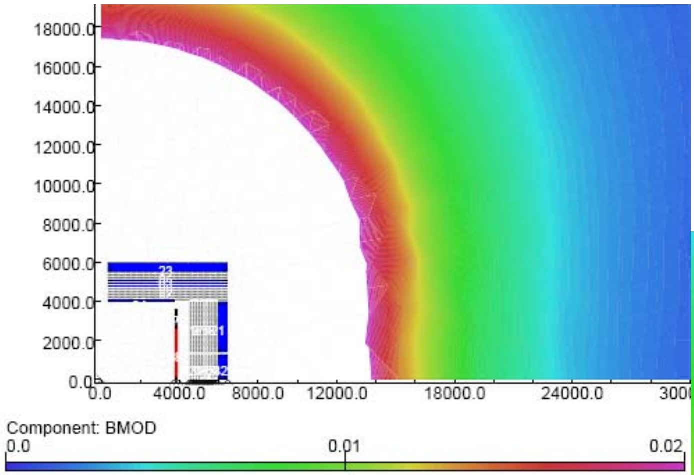


- Stray field 15m from beam line ~ 30G
- But large field in steel floor 1.6T
  Similar with non-magnetic feet
- Larger EC hole increases stray field in z
  Circular support tube would be better

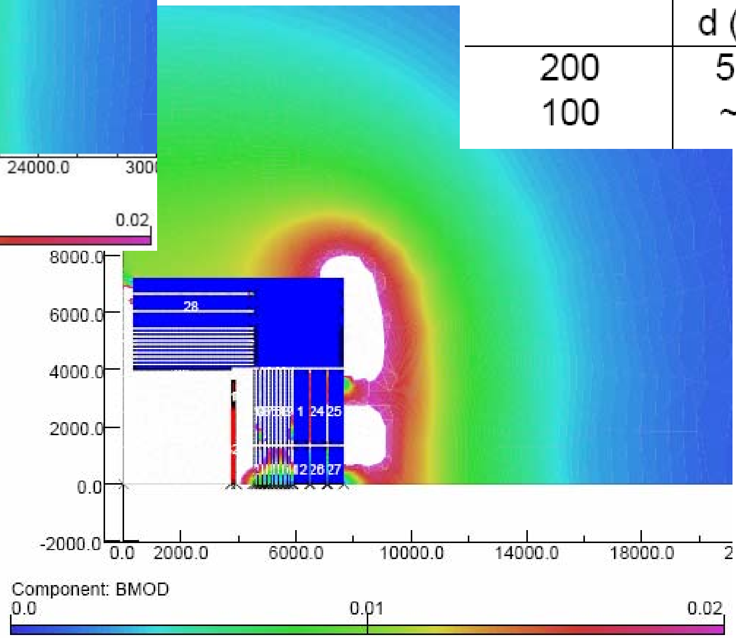
Stray Field Calculations

Opera 2 D calculations now available (B.Krause)

3.5 T 1 thick plate



iron yoke	Opera 1 thick plate	EM St.	Opera 3 thick gaps filled	EM St.
z (m)	5.4		5.4	
B stray (G)	y (m)	y (m)	y (m)	y (m)
200	13.5	11.8	9	7.9
100	~17	15.1	11.3	10.3
	d (m)	d (m)	d (m)	d (m)
200	5.9	5.3	1.4	0.2
100	~9	8.6	3.7	2.6



Results of both programs in good agreement

3 thick plates, gaps filled

Magnetic Forces – Rough Estimate

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

- Maxwell Stress Tensor

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

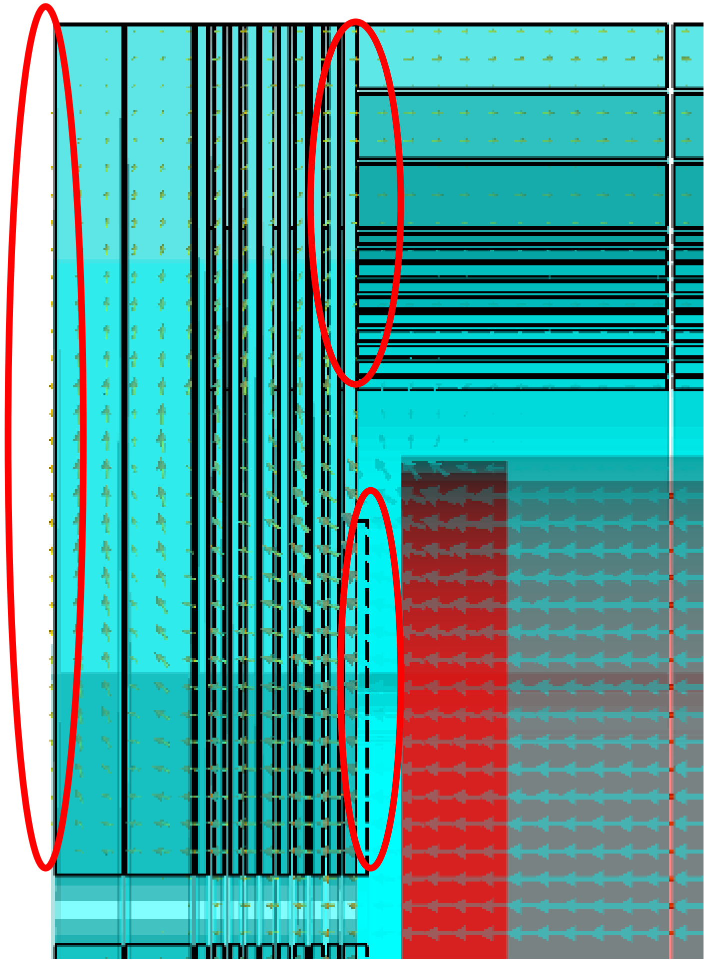
- Only considering stress nominal to surface

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

- 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

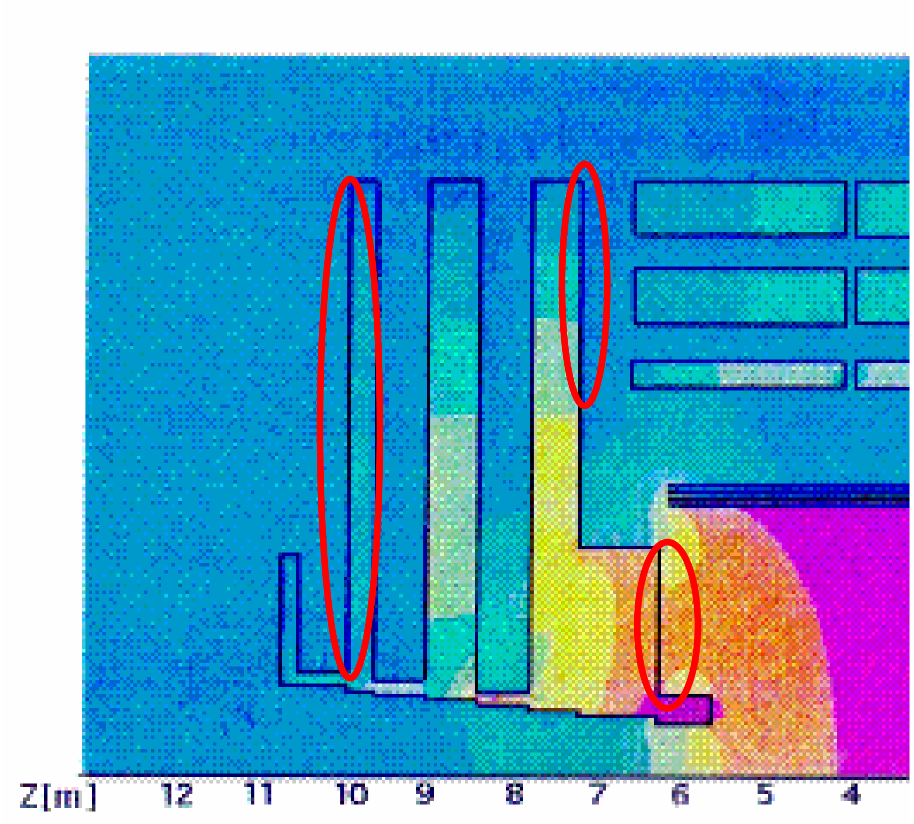
- Inside coil
  - r_0= 3.4m,inner hole 1m^2
  - area 35m^2
  - ave B = 3.5 T
  - ➔ F = 17100 t
- outside coil (between barrel and end cap
  - r_0= 7.66m, r_i= 3.8m
  - area 139m^2
  - ave B = 0.5 T
  - ➔ F = 1400 t

Rear surface

- area 183m^2, ave B=0.08T
- ➔ F = 43 t

Total force 18500 t

Magnetic Forces on CMS End Cap



Inner surface of end cap

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

Rear surface

- area 147m^2, ave B=0.75T
- ➔ F = 3400 t

Total force 9400 t,
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

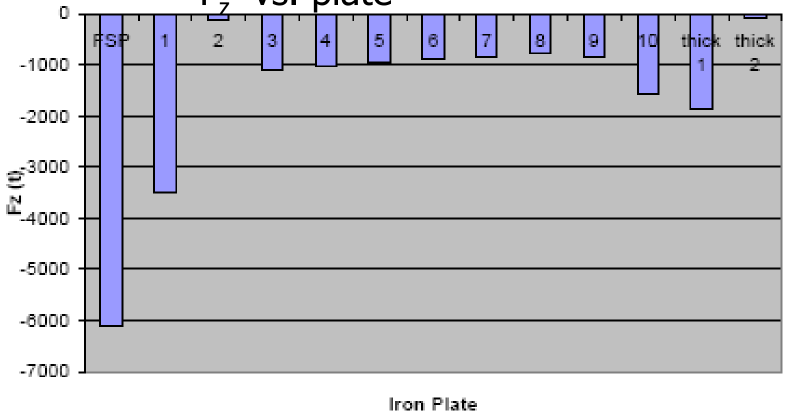
  Resulting force on hard stop

  → F_z = 19000t for 3 thick EC plates

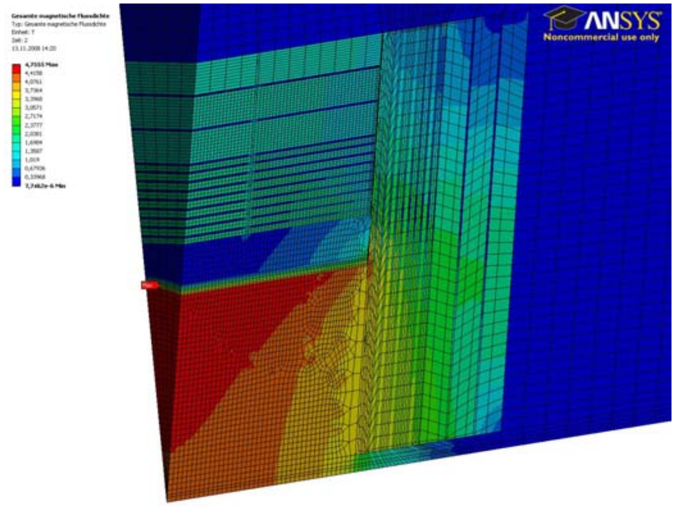
  F_z = 18000t for 2 thick EC plates

  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

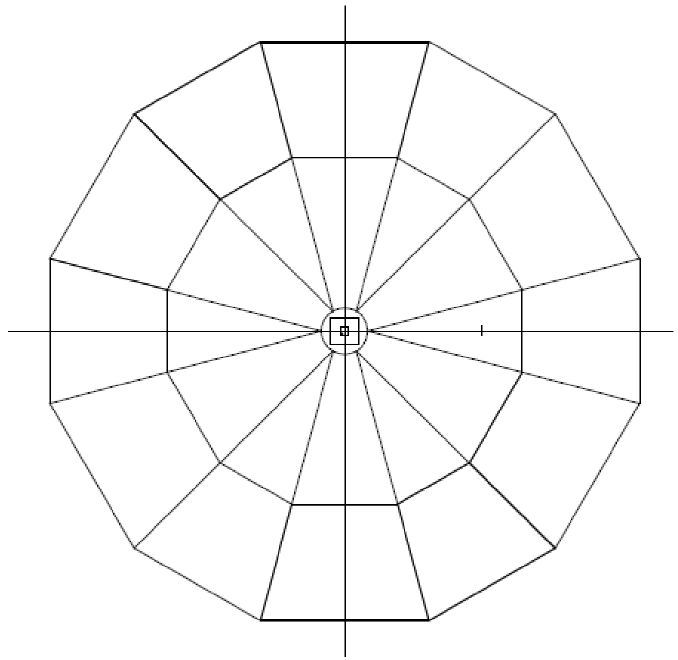
r (mm)	b(mm)	d (mm)	F (t)	F (N)	f (mm)	
7650	3490	2120	17000	1.7E+08	2.2	10x10, 2x56 massive iron plate, no gaps
7650	3490	2560	17000	1.7E+08	1.2	10x14, 2x60 massive iron plate, gaps filled
7650	3490	1000	15000	1.5E+08	18.3	10x10, massive iron plate, no gaps
7650	3490	1400	15000	1.5E+08	6.7	10x14, massive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



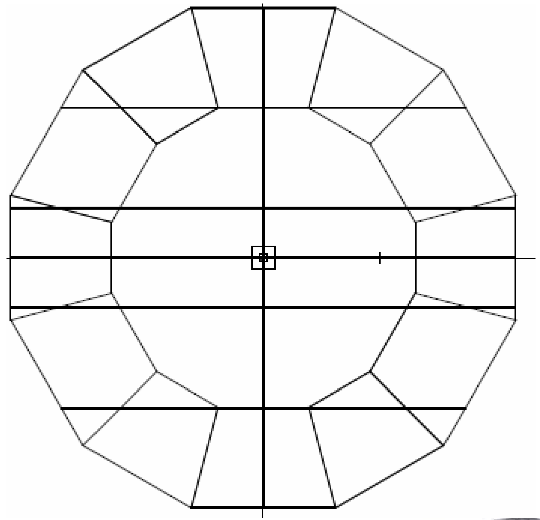
- Status
  - FEM calculations (deformation and stress) available
  - Looked into two different design options
  - Recently, looked into support feet and installation of muon chambers

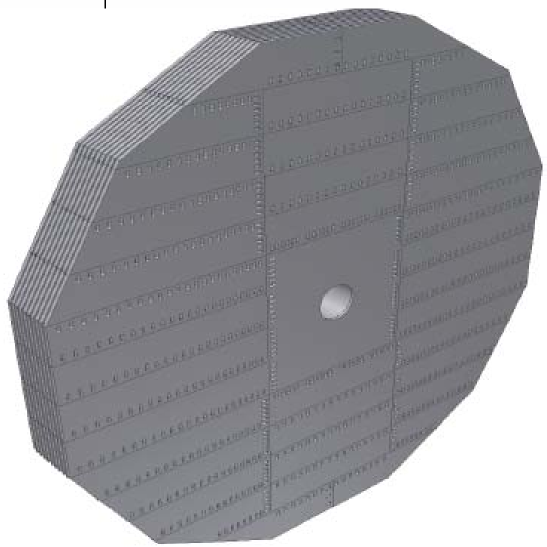
End-Cap Geometrical Options

- 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
  - FEM calculations not yet available

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

    Presentation by N.Siegrist

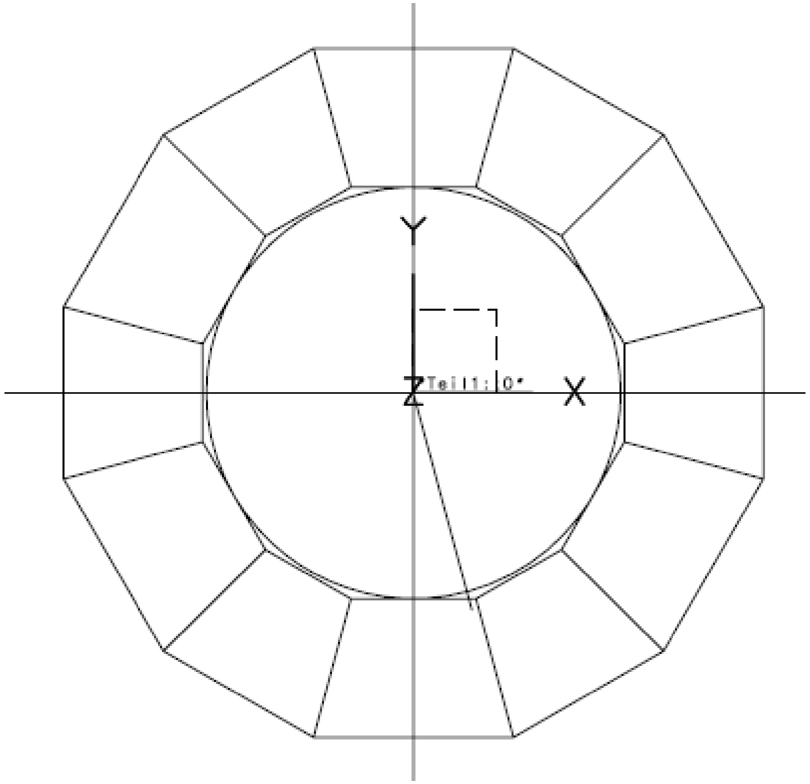




Barrel and End-cap Shape

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

→ Two types of barrel and segments

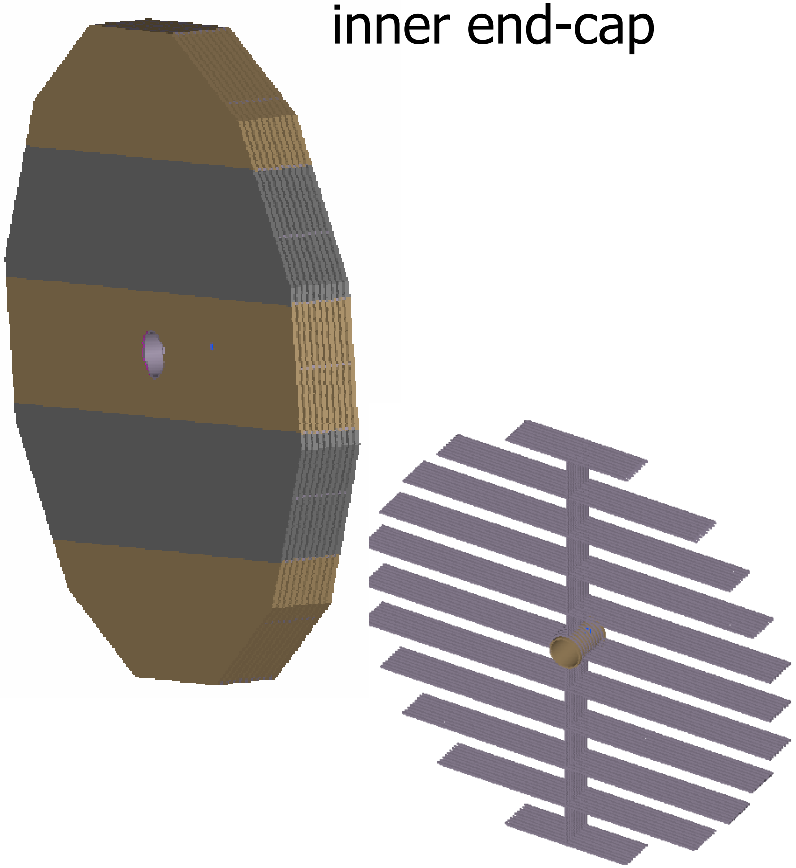


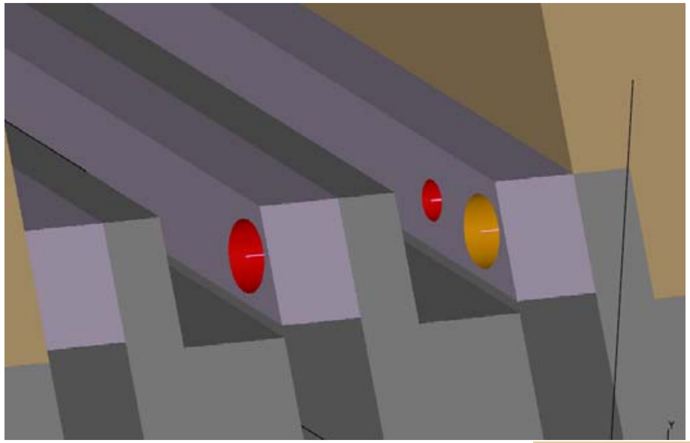
Mechanical Design of End-Cap

Bolted design with horizontal supports rips

R.Stromhagen

inner end-cap





Need about 10000 bolts (M24) for inner section of one end-cap.

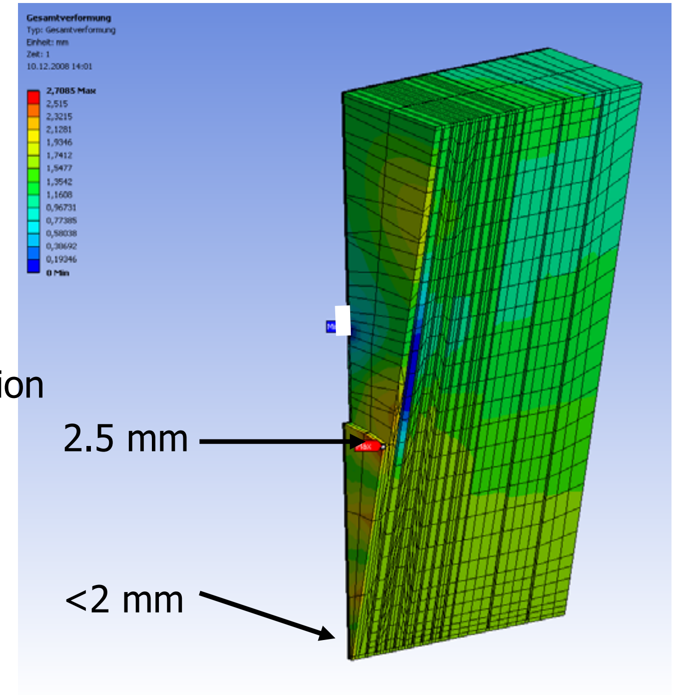
→ Bolted plate design not good for thin plates

Mechanical Design of End-Cap

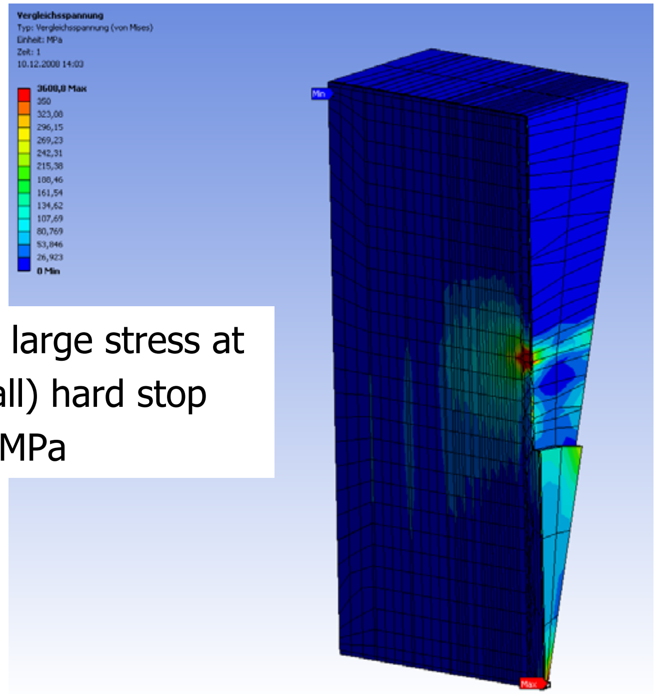
ANSYS calculations: end-cap deformation and stress C.Martens, M.Harz

- Plates connected via radial rip, 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



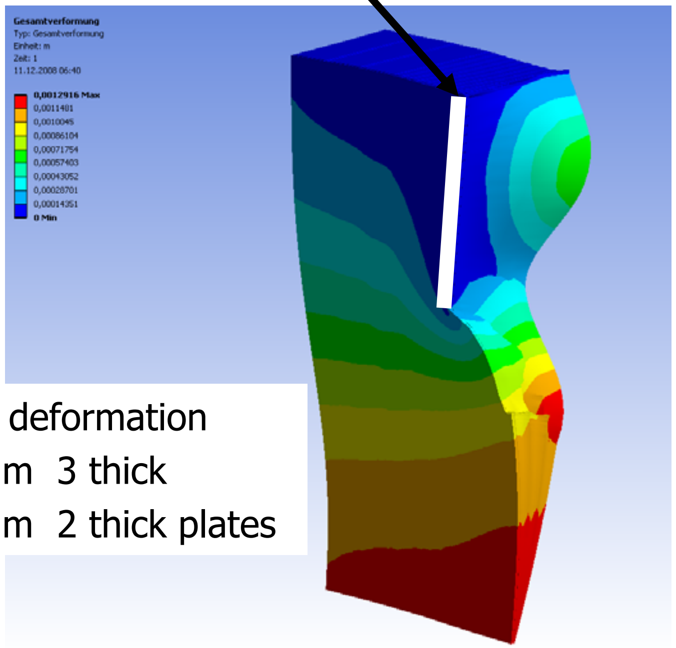
von Misses stress



Mechanical Design of End-Cap

Same as previous page, but with modified hard stop

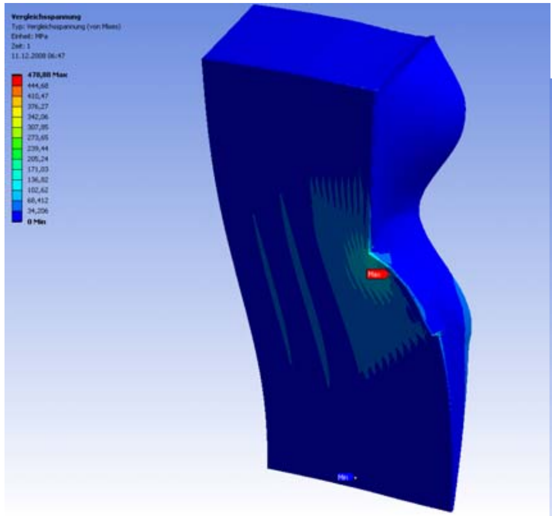
20cm wide, radially extending from first to last barrel iron plate



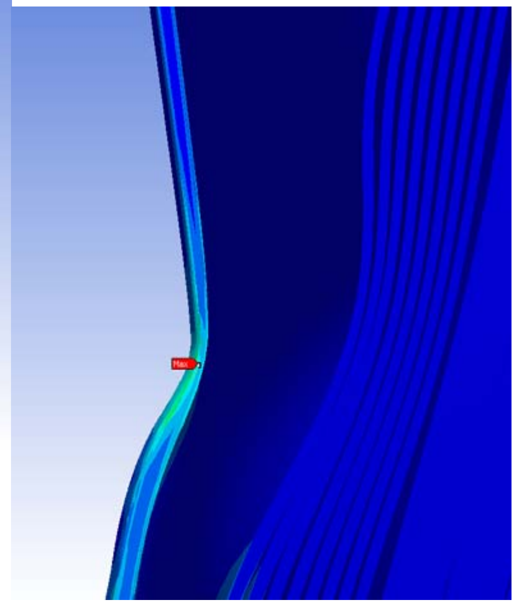
Max. deformation

1.3mm 3 thick

1.6mm 2 thick plates



Stress now <200 MPa



Next steps:

- Split inner and outer parts
- Force and stress between segments

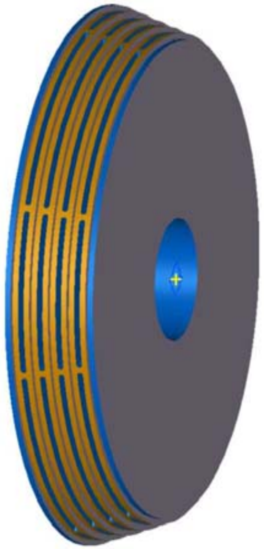
Mechanical Design of End-Cap

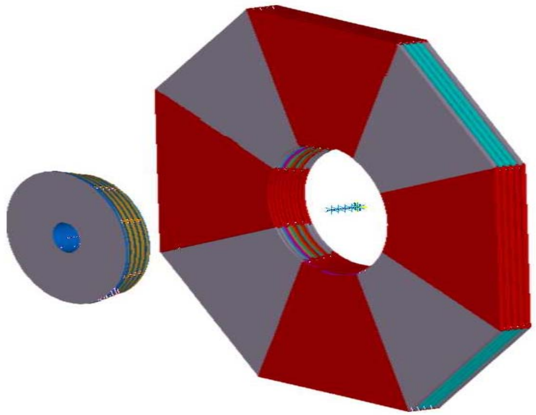
R.Stromhagen

Radial support rips

Initially, looked into spheroidal cast iron design

- Advantages
  - Mechanically very stiff
  - Solid structure, few joints
  - Relatively few pieces
- Concerns
  - No experience with cast iron
  - Is quality sufficient? Probably matter of specification and price
  - Probably more expensive than using steel plates



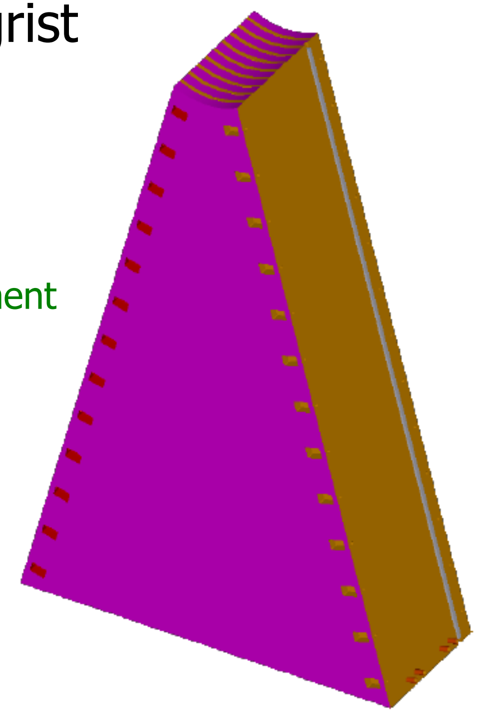


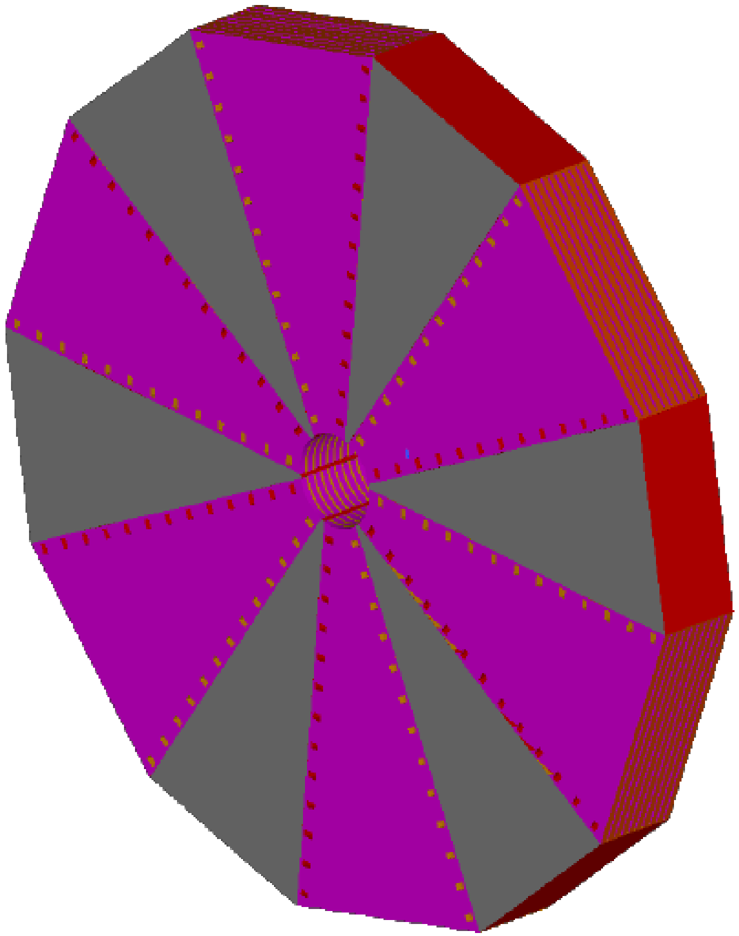
Mechanical Design of End-Cap

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.

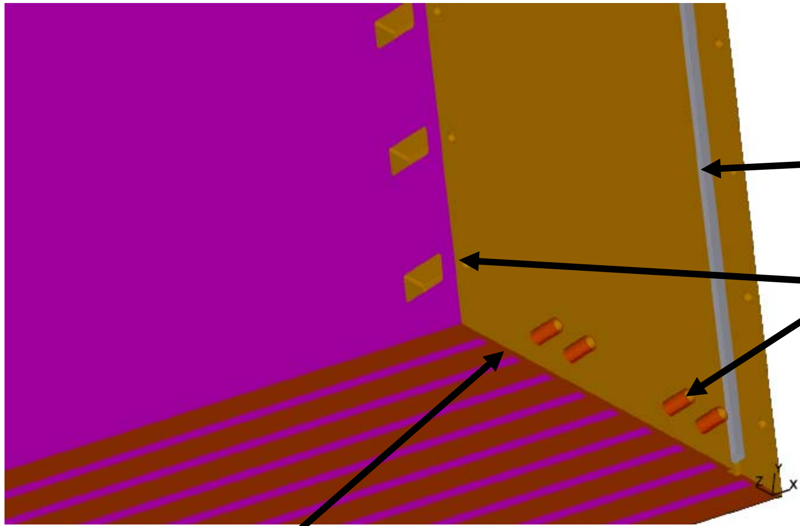
weight of segment about 90t





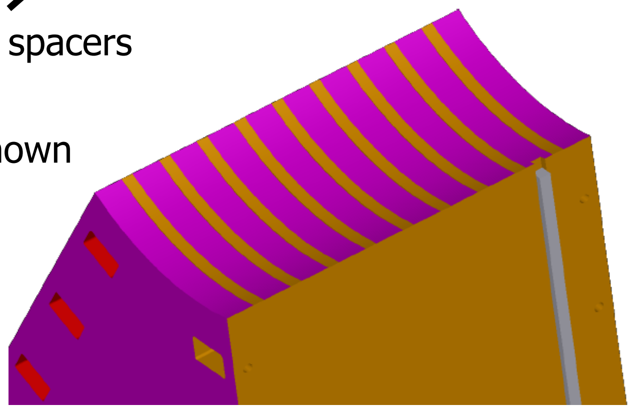
Assembly of End-Cap Segments

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

So far no calculation of tangen-tial force between segments. CMS 2000t on IP side.

Options

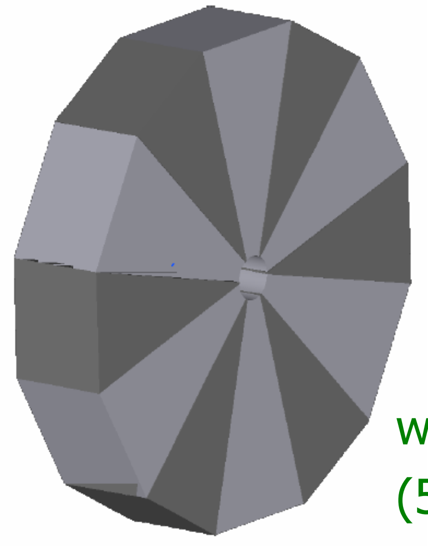
- Join segments by welding
- Connect segments using shear pins in FSP and first plate

Mechanical Design of End-Cap

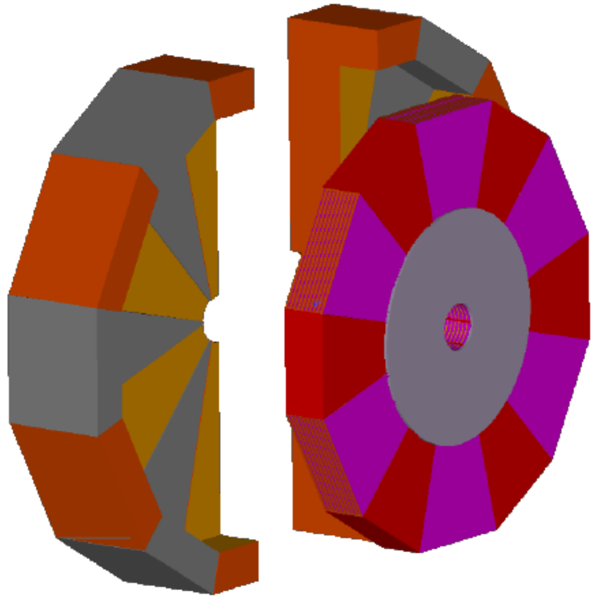
Outer part of end-cap

- Two thick segmented disks
- Segments bolted or welded together

Similar to CMS

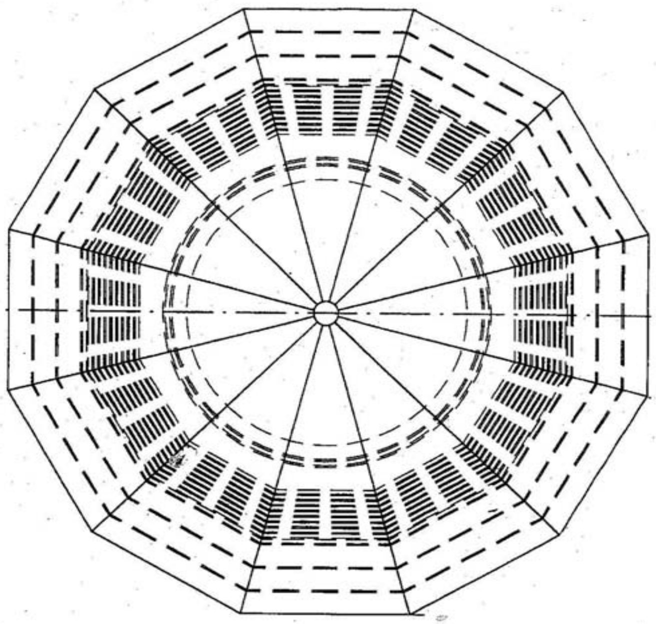


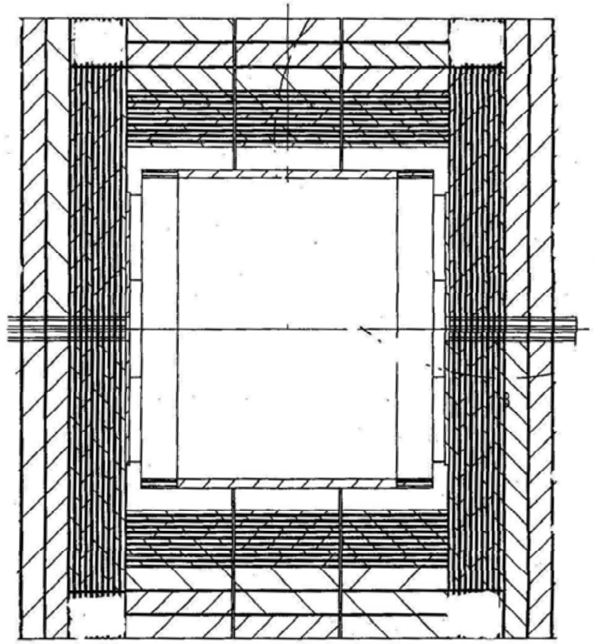
weight of segment
(560mm thick)
about 70t



Slit end-cap option

Support Feet/Installation of μ Chambers



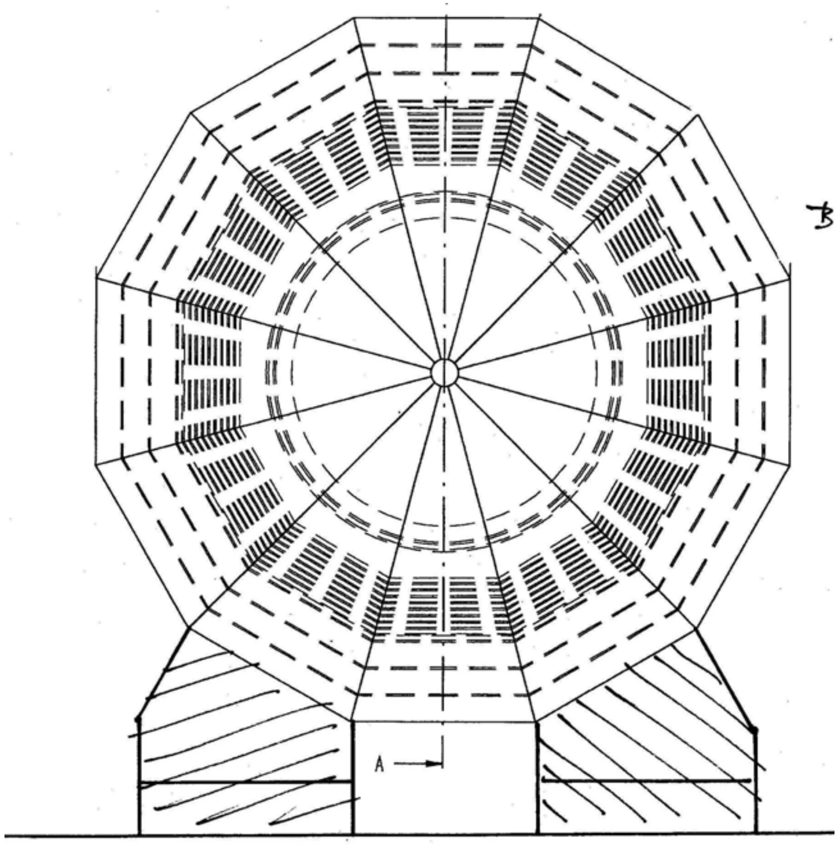


Some thoughts on

- Support feet
- Shape of end-cap muon chambers and
- Installation of end-cap (bottom) muon chambers for radial rip design

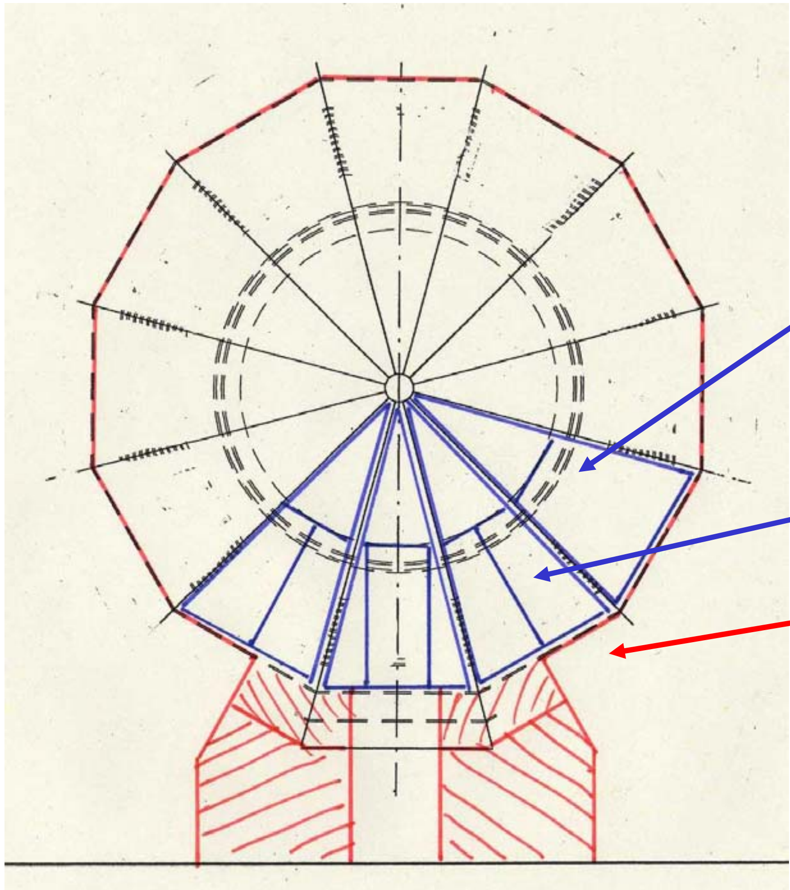
Yoke Design – Support Feet

Barrel supports (similar to CMS)



Support Feet/Installation of μ Chambers

Inner part of end-cap



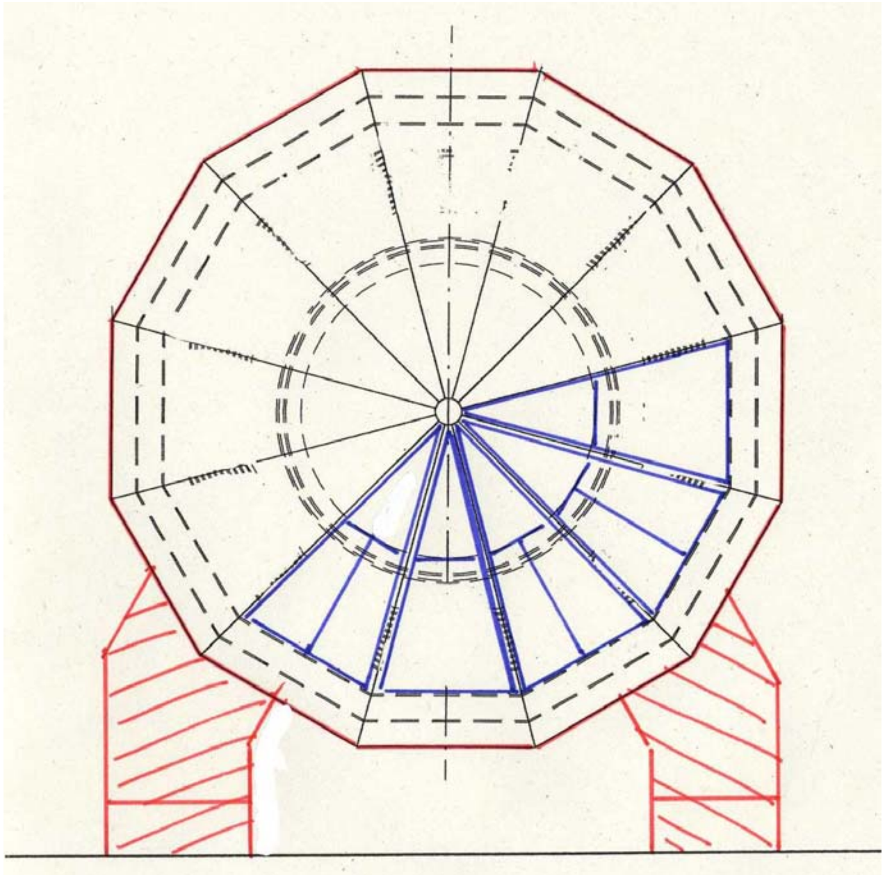
Each sector

- 2 muon chambers (inner and outer) about 2.5m long
- bottom segments
  - outer muon chambers split for installation

Outer iron blocks removed for installation of muon chambers

Support Feet/Installation of µ Chambers

Outer part of end-cap



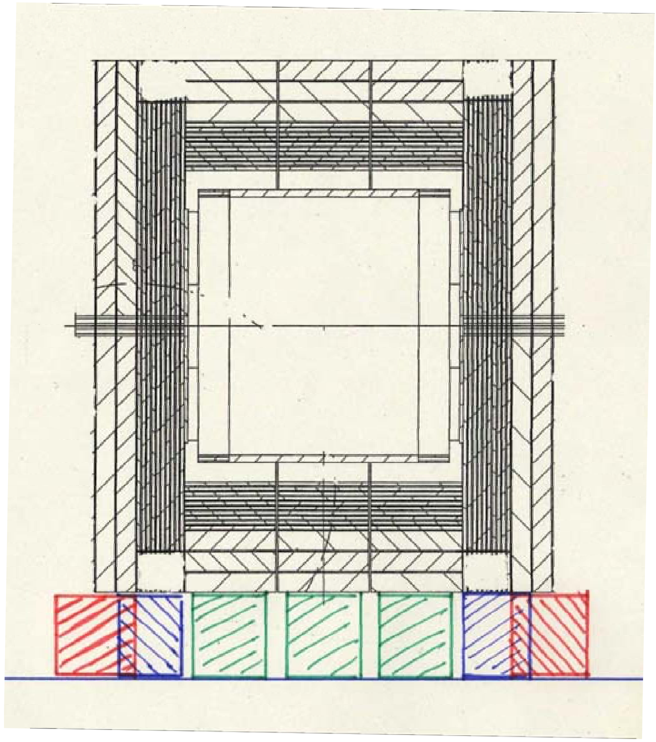
Installation of bottom muon chambers

Options:

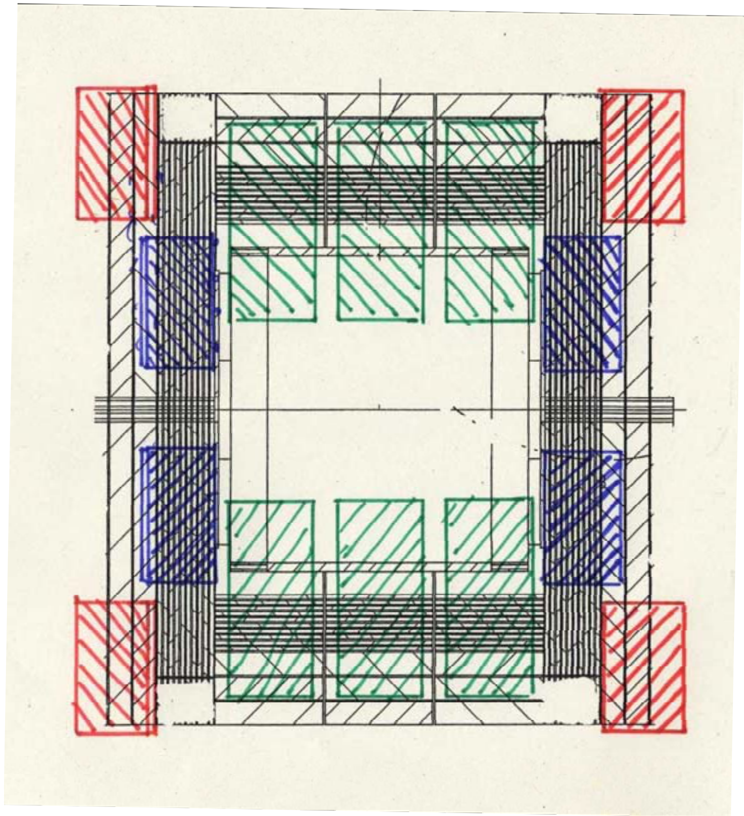
- Install muon chambers during assembly of EC,
- remove bottom outer iron blocks or
- hole in floor (platform)

Support Feet/Installation of μ Chambers

side view



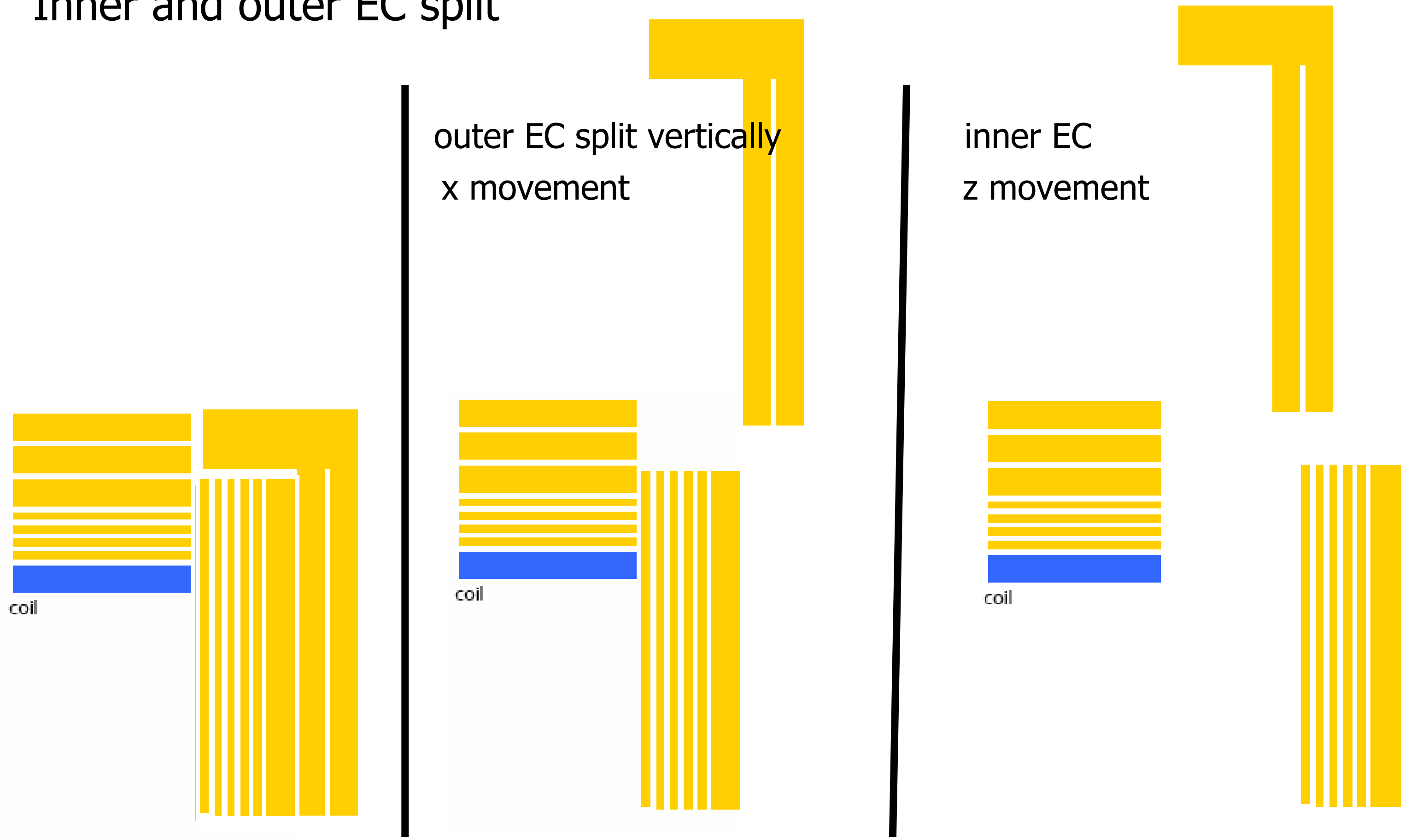
top view



End-cap Design Option

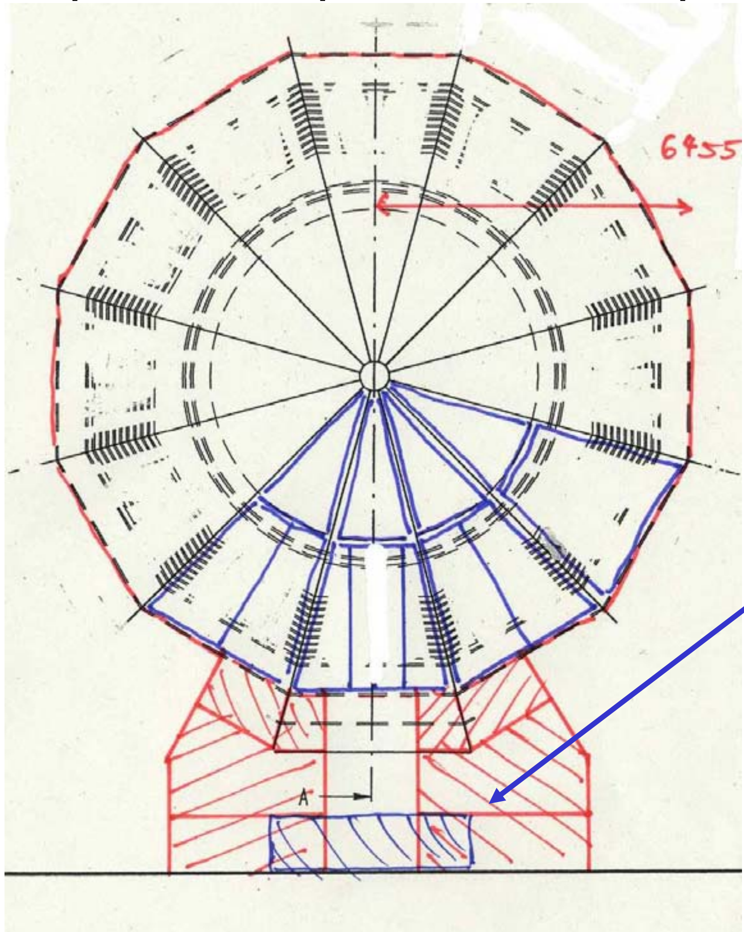
Option: Split end-cap in case not enough space when end-cap opened

Inner and outer EC split



Support Feet/Installation of μ Chambers

Split end-cap: inner end-cap

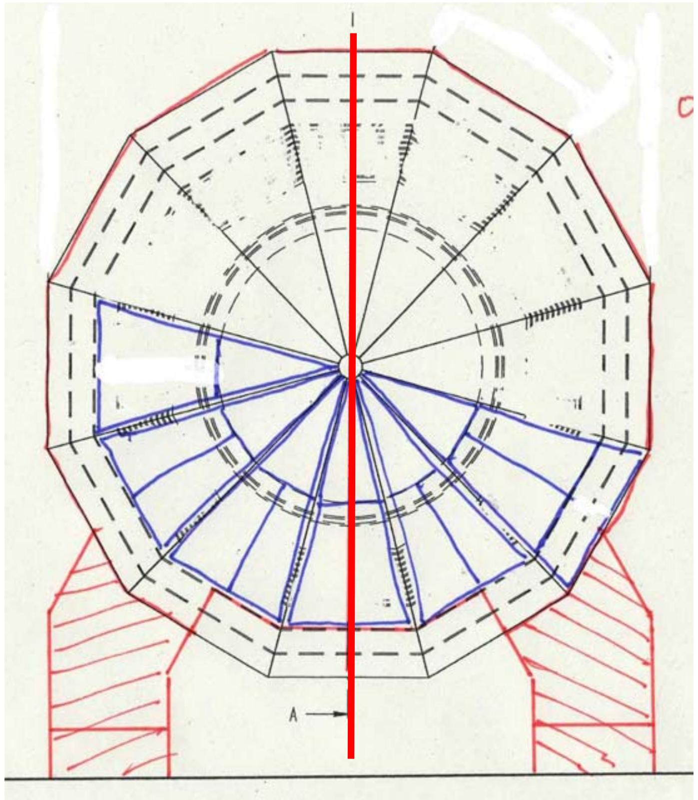


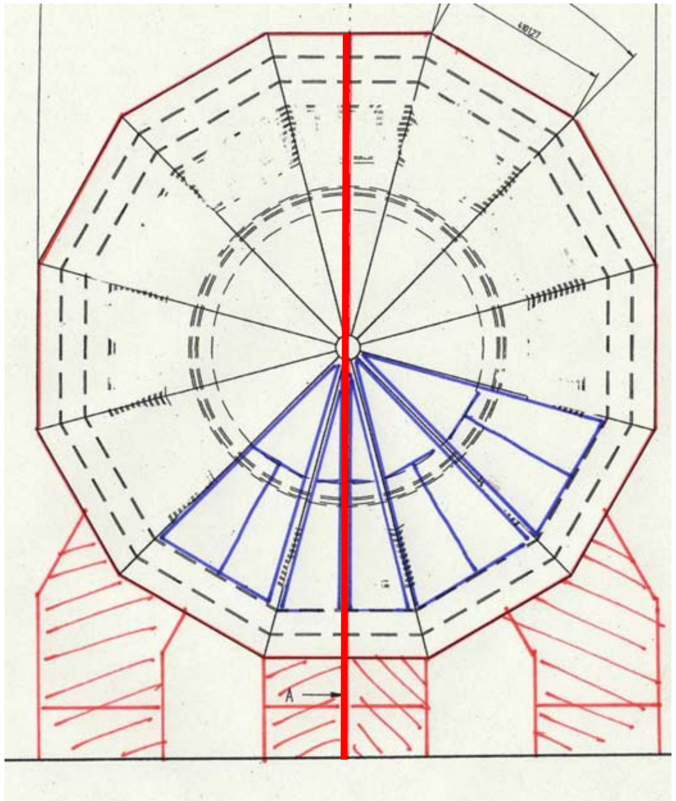
Similar to non-split end-cap

Addition support E/HCAL cantilever

Support Feet/Installation of µ Chambers

Split end-cap: outer EC



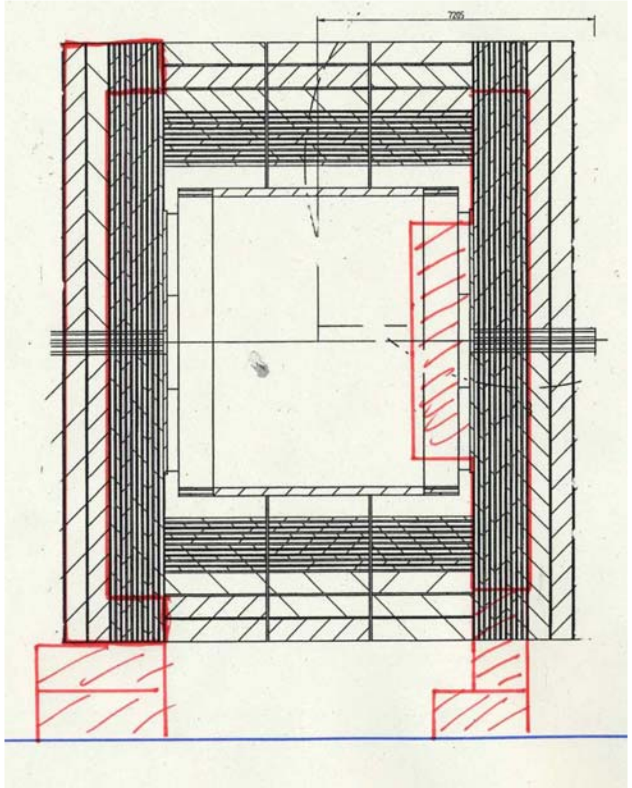


Additional support

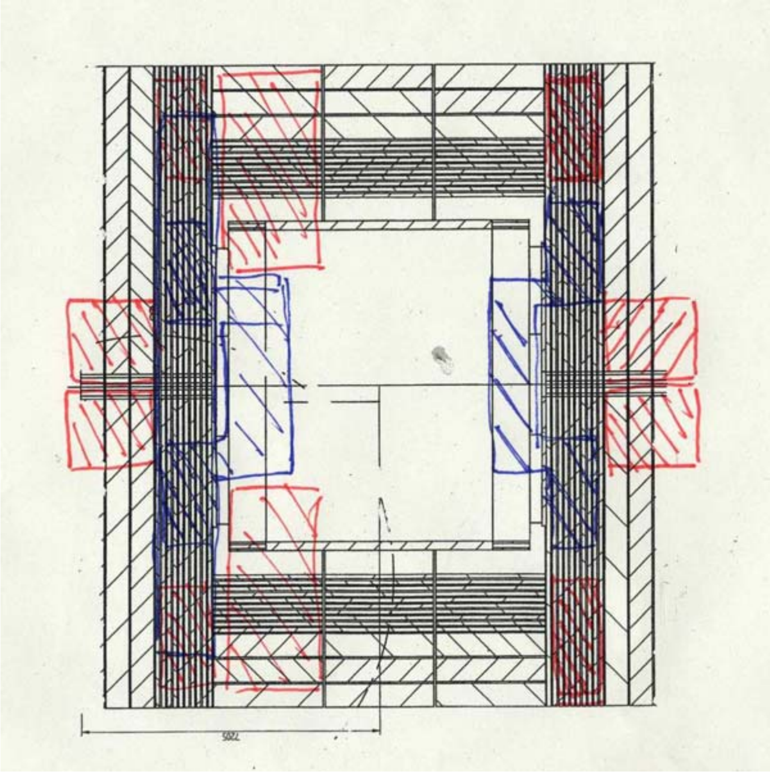
Yoke Design

Split end-cap

side view



top view



Lifting capacity of Hall Cranes

Should agree on lifting capacity of hall crane for LOI.

May determine size and weight of yoke segments

- RDR experimental hall 400t crane (GLD assembly)
- Not really needed in experimental hall assuming CMS style assembly

Surface hall

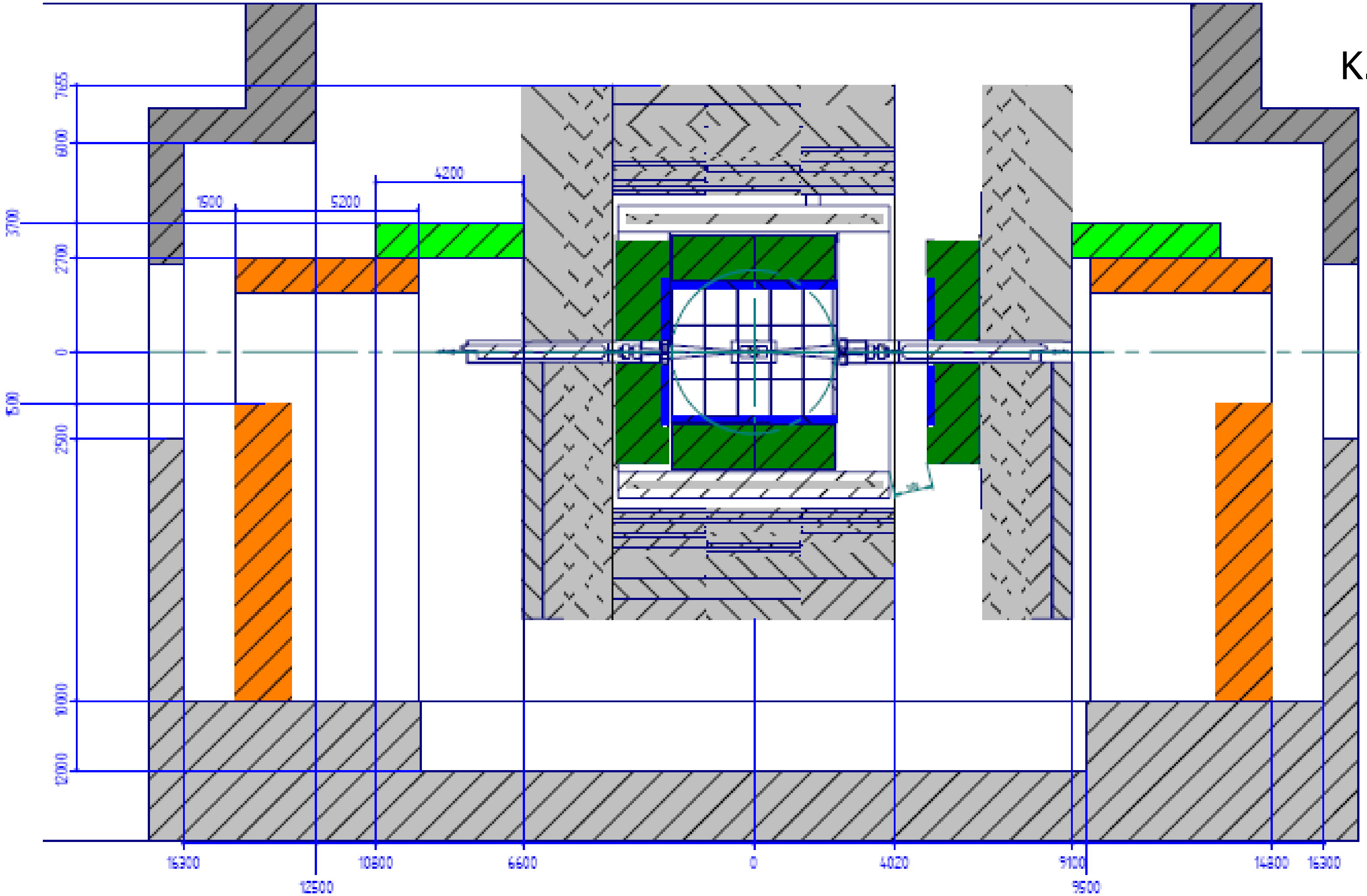
- Heaviest load yoke segments
- Propose 2 100t cranes → 200t max. load
  (CMS 2 80t cranes, experience: a bit too small)

Experimental hall

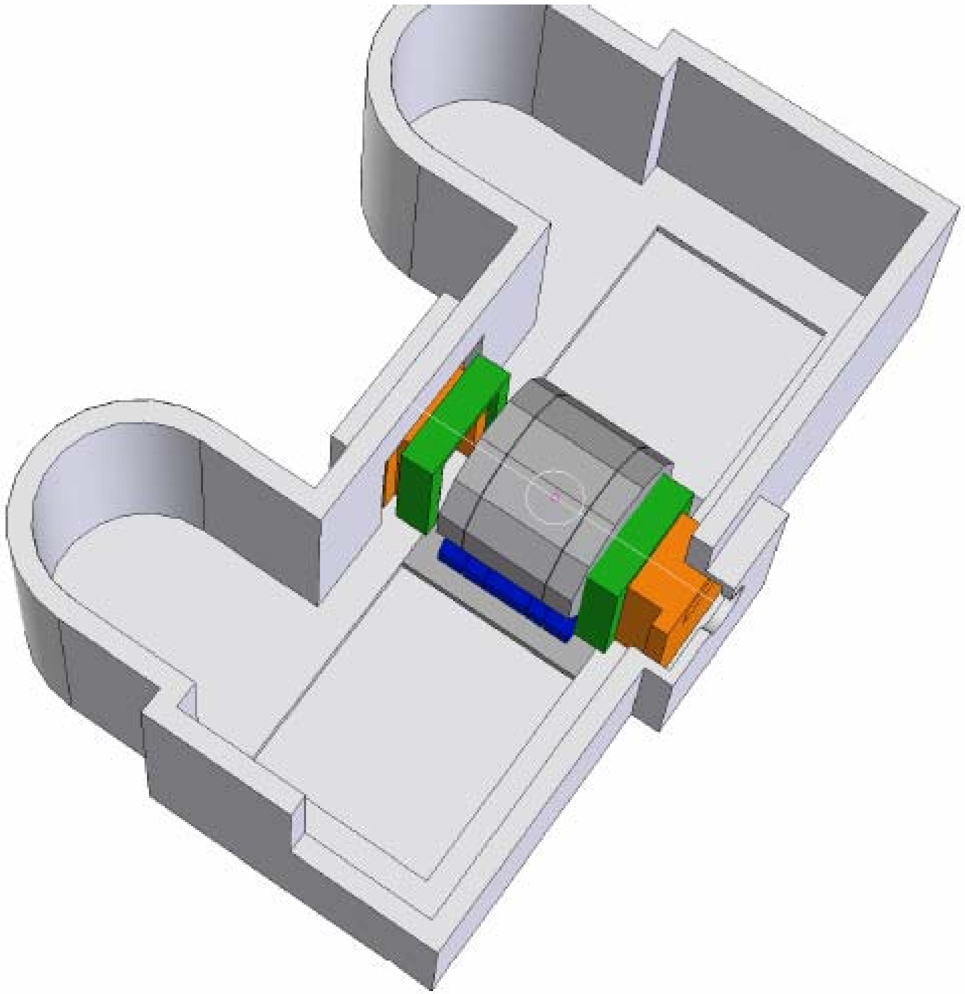
- Heaviest load?

Experimental Hall

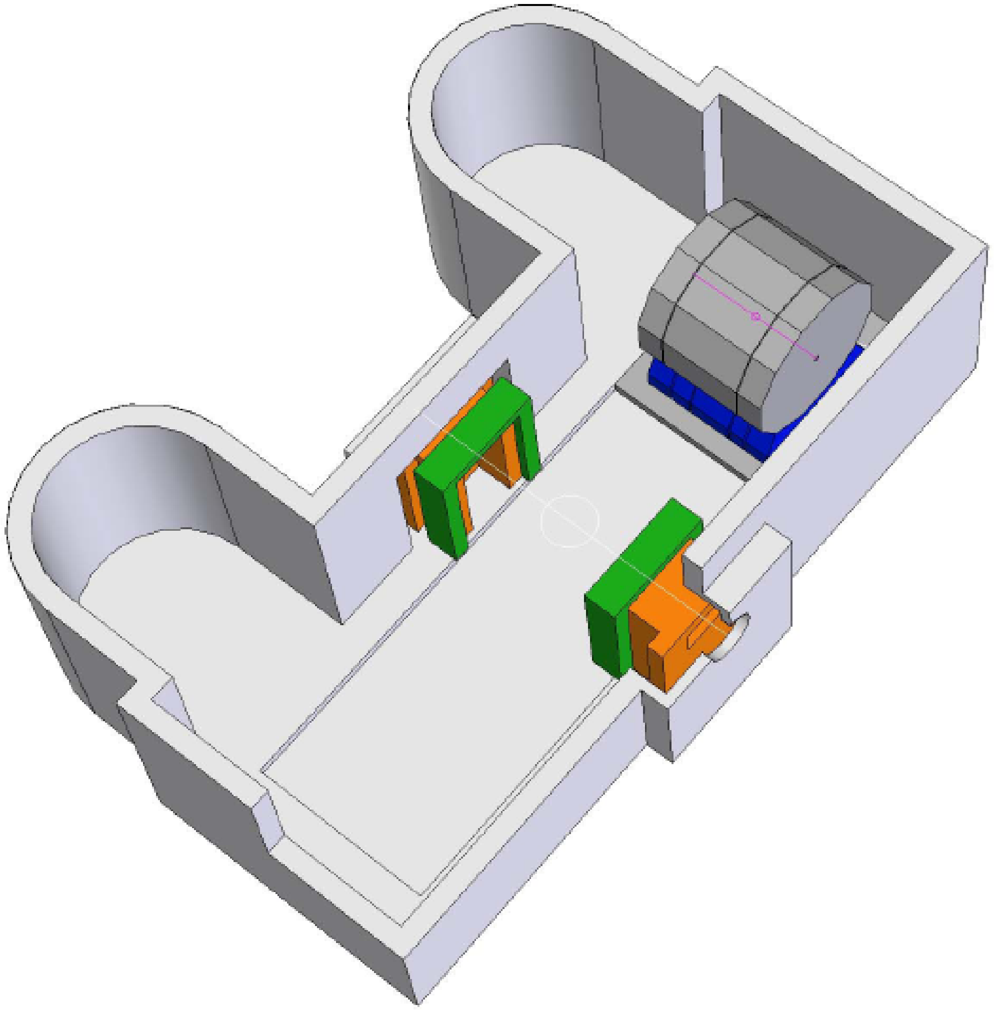
K.Sinram



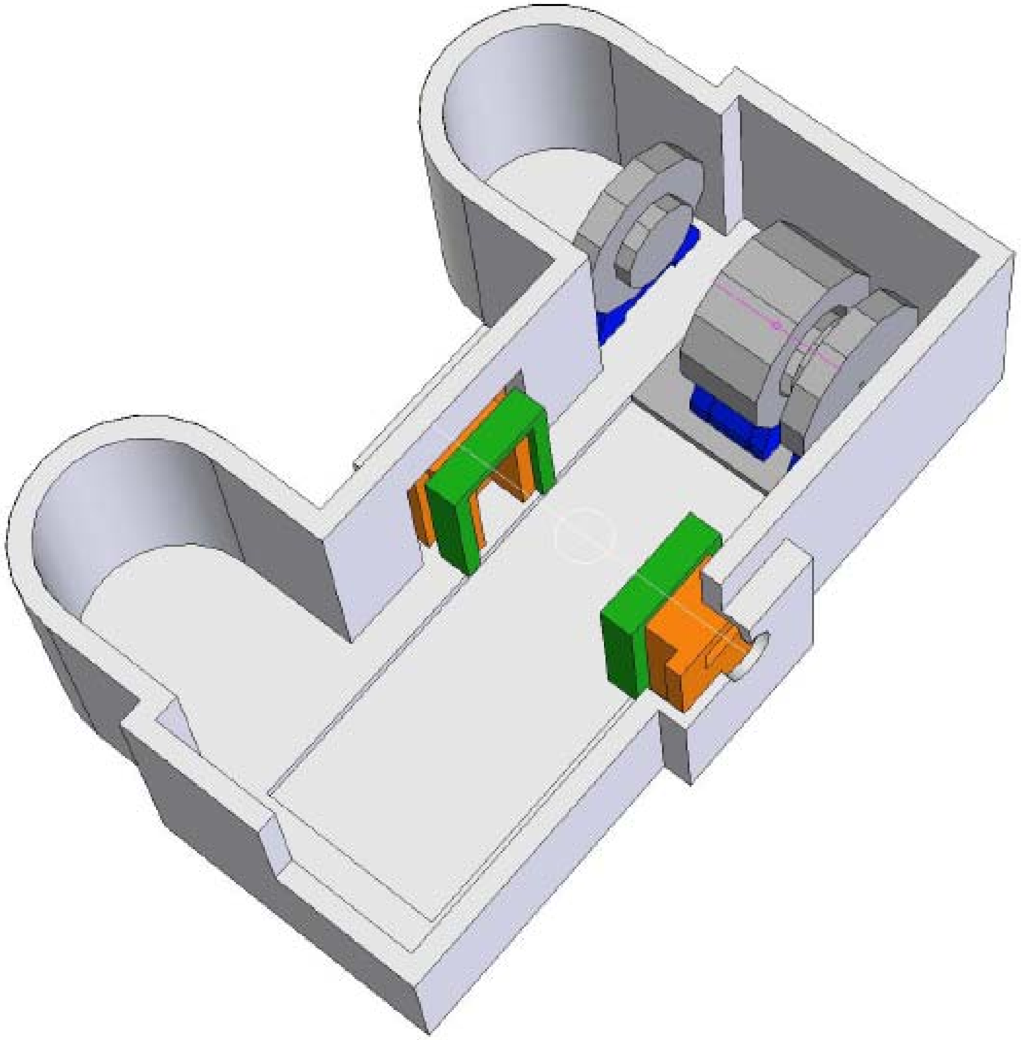
Experimental Hall



Experimental Hall



Experimental Hall



Conclusions

Good progress on

- Stray field
  - Goal of <50G stray field at 15m from beam line is achievable
- End-cap mechanical design
  - Radial rip option
    - Small deformation, tolerable stress at hard-stops
    - Simple geometry of
    - Installation of bottom muon chambers should be possible
  - Horizontal rip option
    - Initial mechanical design, no FEM calculations
    - Now being studied by H.Gerwig and N.Siegrist

Have to decide on

- End-cap design options
  - Geometry and construction
- Split or non-split end-cap (hall size, space for access)
- Hall crane lifting capacity