Yoke Integration Challenges

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DESY

ILD Meeting, Krakow
25.09.2013

Outline

- Design requirements
- Present status of design
- Reconsider/Optimize Design
  - Options
  - Discussion
- Planning of future activities

Function and Challenges of Iron Yoke

- Flux return
  - Field homogeneity in TPC
  - Stray field
  - Large magnetic forces
- 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
- 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

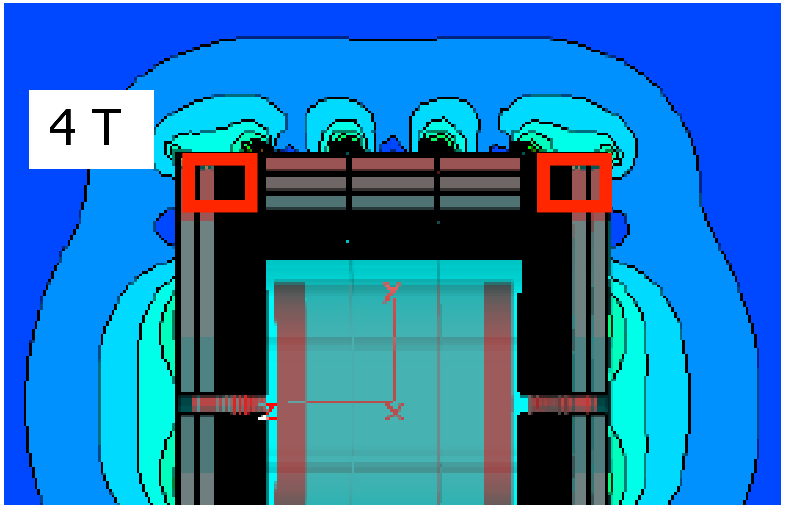
ILD Parameters Reference Detector

- Segmentation of yoke
  - 100mm field shaping plate only end-cap
  - 10 x (100mm + 40mm gap)
  - n x (560mm + 40mm gap)
- Segmentation was fixed by steering group for good muon detection and tail catching based on common sense. Detailed studies not available when decision made
- Worst case in view of mechanical design. Thick iron plate design would be easier

- Decision confirmed by detailed muon study
  - However, fine segmentation may not be necessary at 'low' energy
  - Option
    - Initially, could instrument every second layer
    - Install remaining layers for high energy upgrade

Magnetic Stray Field

Did extensive field calculation for several geometries



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

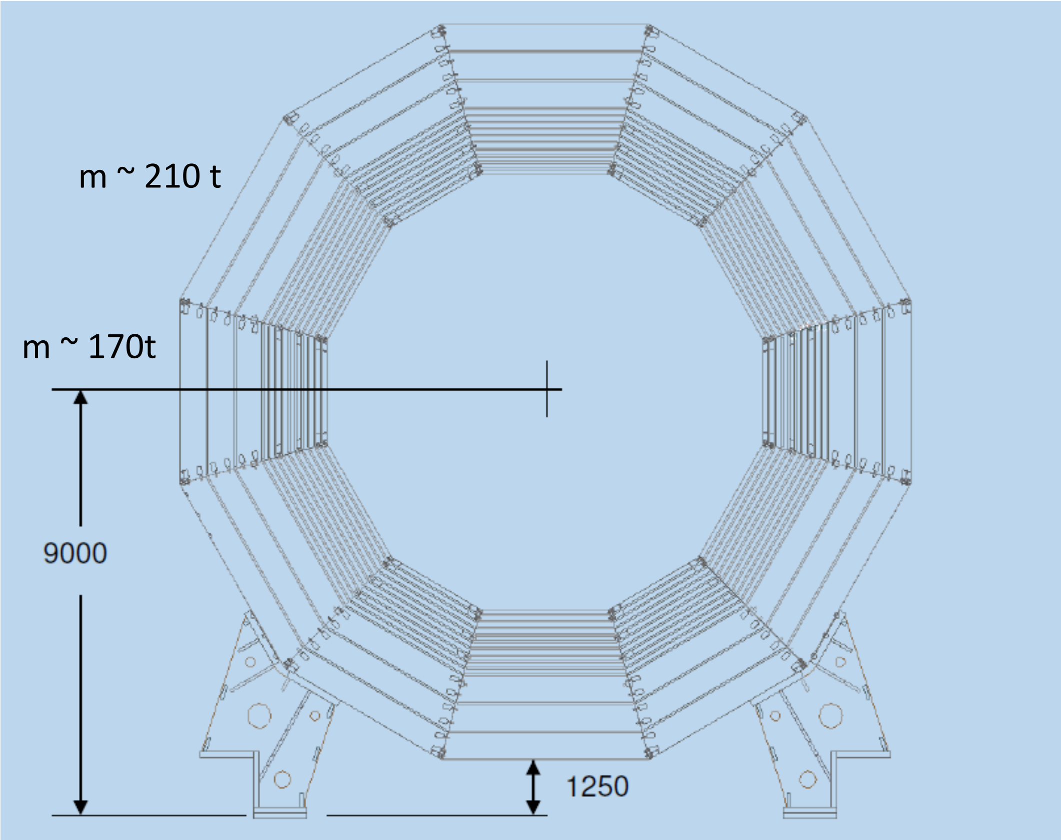
r_{out} = 7.655m, z = 6.605m

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

- 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

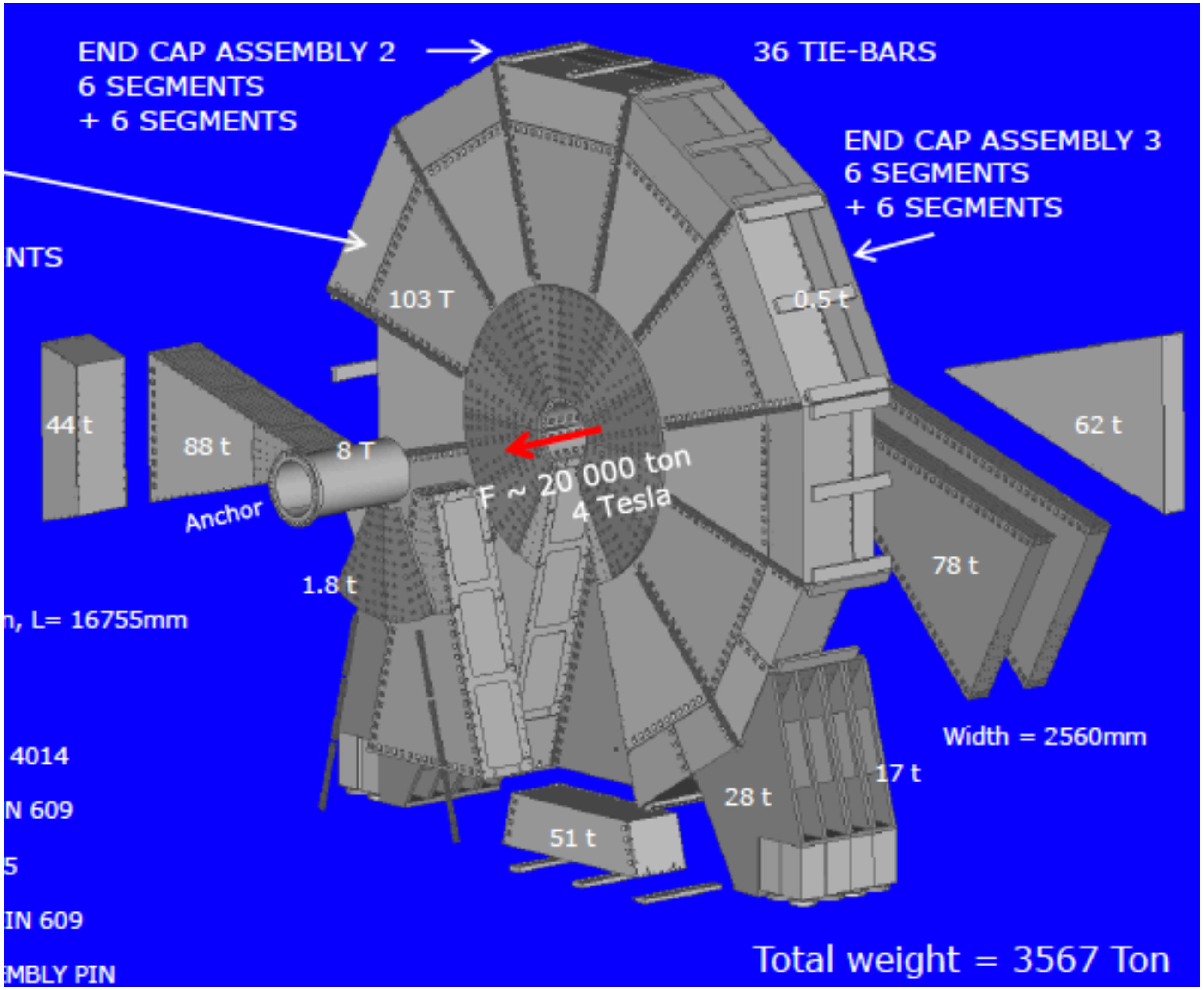
Design of Barrel



- Three barrel wheels, each consisting of 12 segments
  - Segment with welded plates
  - Segments could be split into inner and outer piece to reduce size and weight
- Same segmentation and plate thickness as for end-cap
  - Barrel design does not depend as much on segmentation and plate thickness as end-cap design
- Thickness of iron given by stray field requirements
- Radial iron thickness 2.68 m

Very stiff structure. Small deformation. Low mechanical stress.

Mechanical Design of End-Cap



Comments

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

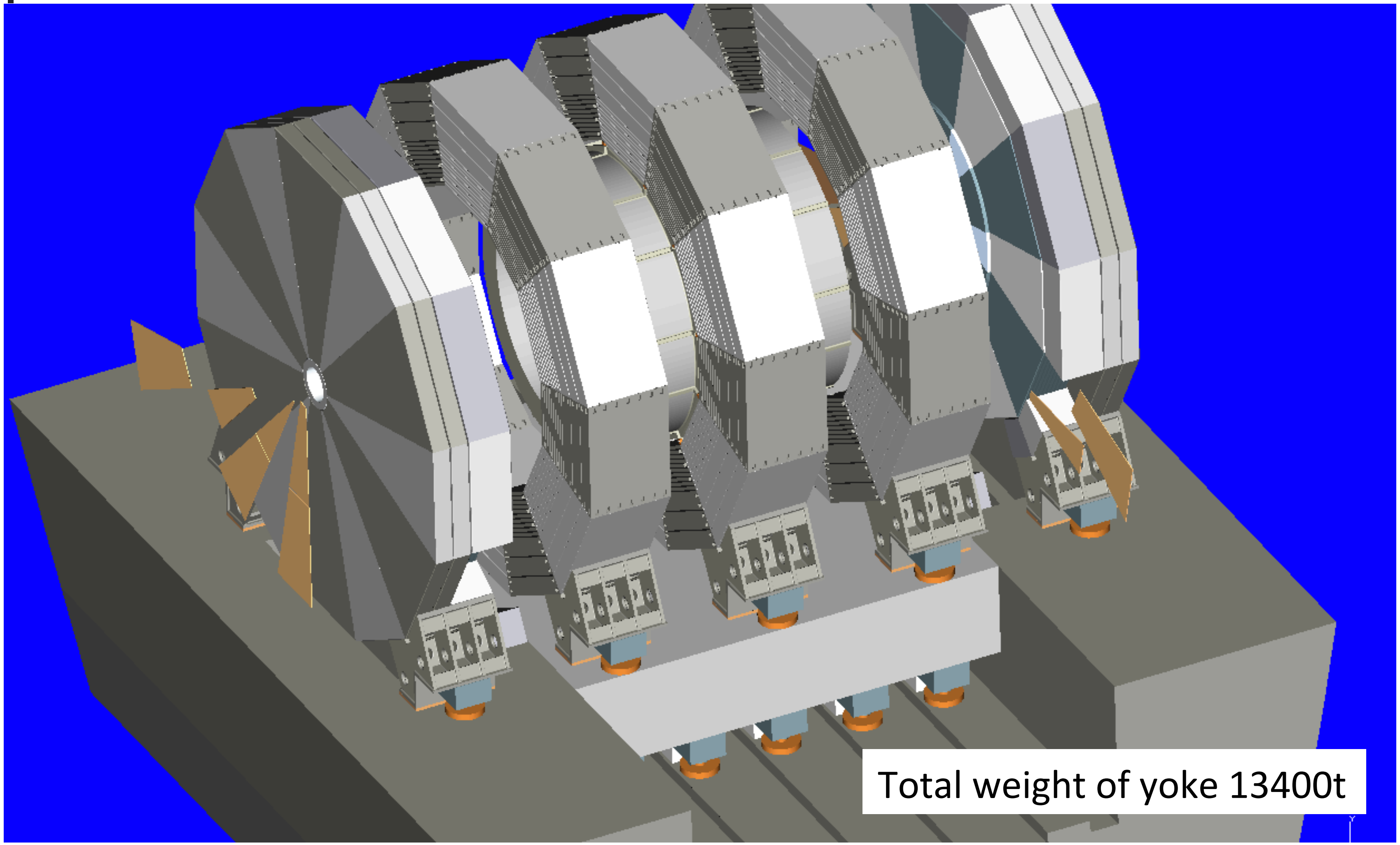
Yoke Assembly

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

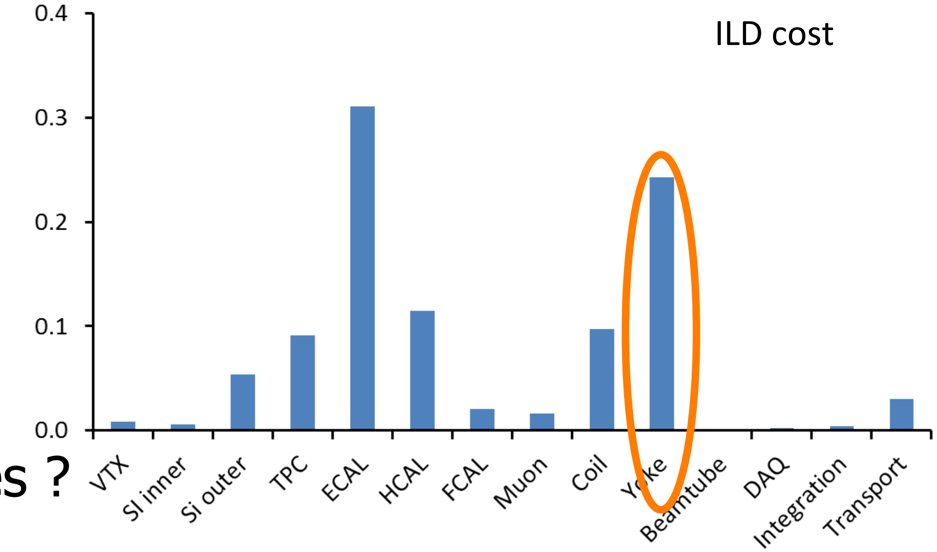
- Original CMS-style assembly (vertical access)
  - Pre-assembly at manufacturer site
  - Assemble wheels and disks in surface building
  - Lower wheels/disks into IR hall
- Recent study, Japanese mountain site IR hall (horizontal access)
  - Yoke design unchanged
  - Size of items mainly limited by weight and crane capacity in IR hall (200 t)
  - Assembled segments (max. weight 200t) moved to IR hall
  - Barrel wheels and end-cap disks assembled in IR hall

Assembled Iron Yoke



Reconsider/Optimize Design

- Questions/Options
- Reduce iron (cost saving)?
  - Coil Geometry
  - Additional end cap coils
  - Reduce iron thickness
  - Stray field
- Yoke segmentation ?
- One instead of 3 barrel pieces ?
  - One solid structure
  - Better for coil and calorimeter support
  - Access to muon chambers (no strong argument)
  - Weight and size of pieces would be be problem
- End cap geometry ?
  - Radial versus horizontal supports (and muon chambers)
  - Weight and size of segments
- Cost optimization (not yet done)
  - In principle, significant saving possible if iron reduced



Provocative Statement

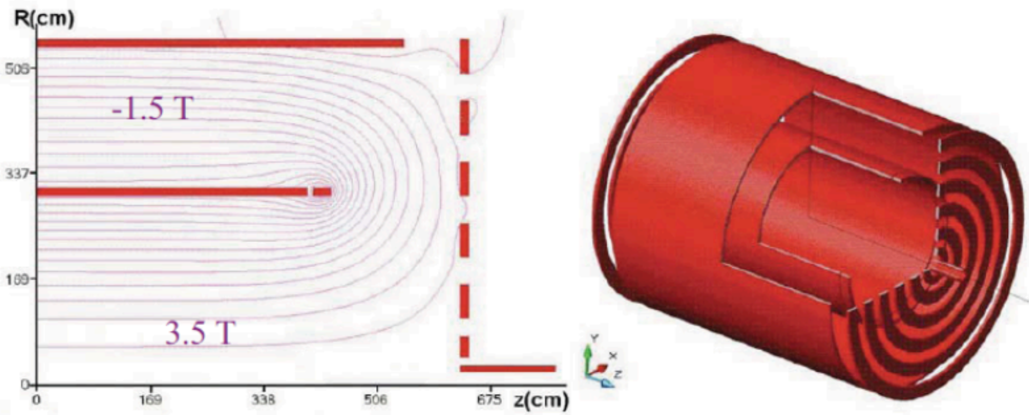
Iron or actively shielded solenoid

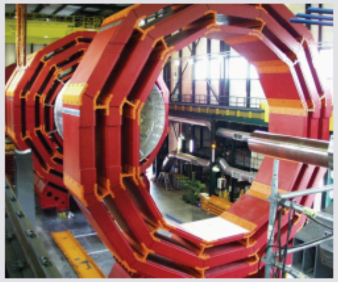
Herman ten Kate,
ATLAS Magnet Project
Leader, at LHeC Workshop

Flux return by active outer solenoid in stead of iron:
much lighter, more elegant, muon tracking
space for "free", possibly cheaper as well

4th detector design for ILC
3.5T in 6mD - 9mL

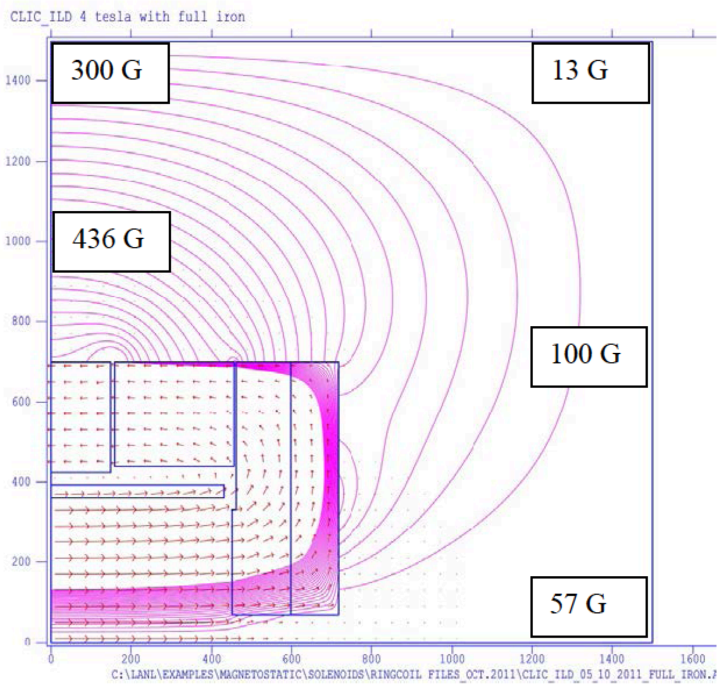
- inner solenoid like CMS
- outer solenoid and end coils driven in opposite direction
- zero fringe field
- outer solenoid is "only" big
- iron-free (less massive by 15,000 t)

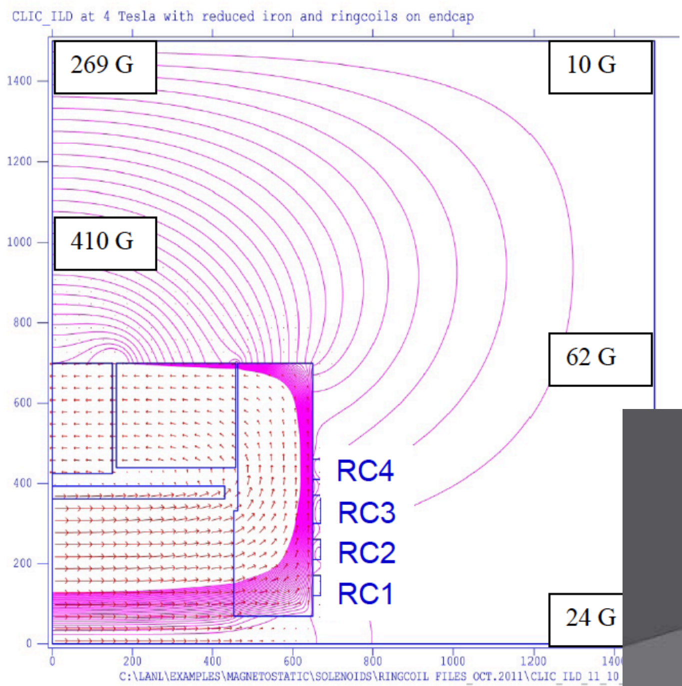




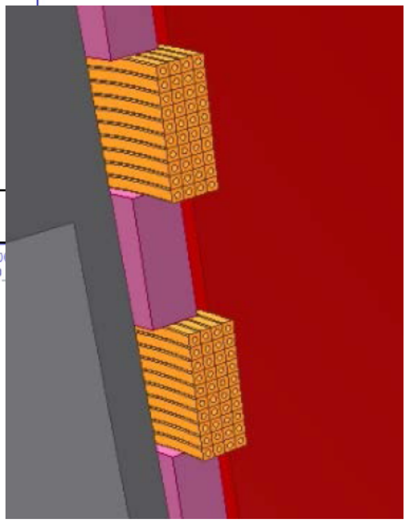
Not planning to change ILD design

Additional Coils in End-Cap - CLIC





H.Gerwig
LCDNote



Enables moving final focusing magnets closer to IP

- Saving 660mm of steel in z on each side
- Save 1400t of steel (both ECs), 8.4 MSF
- Cost of coils about 1.2 MSF (copper), power supplies, …
- Very crude estimate of power cost 2.3M€/y (US)

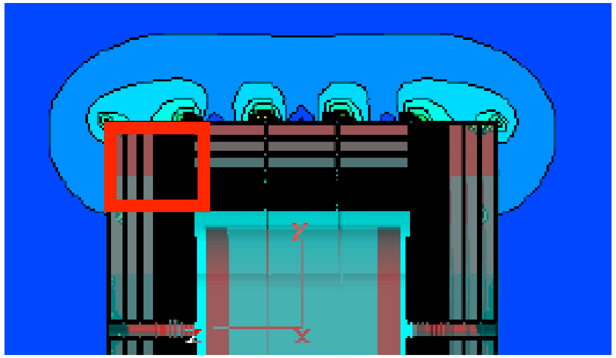
Not planning to change ILD design

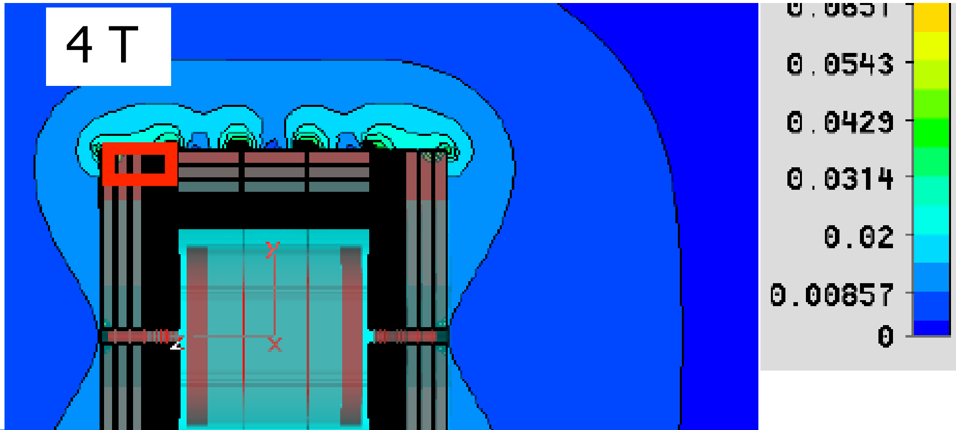
Stray Field Calculations

A. Petrov, 2008

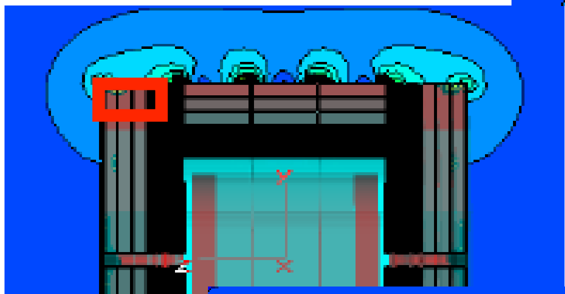
3.5 T

gaps filled

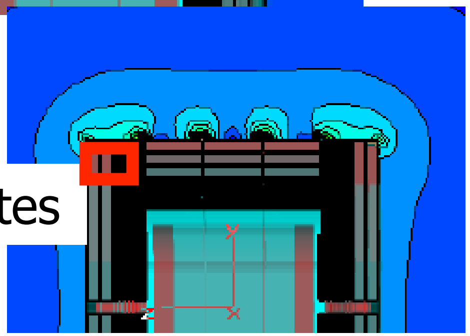




gaps partly filled

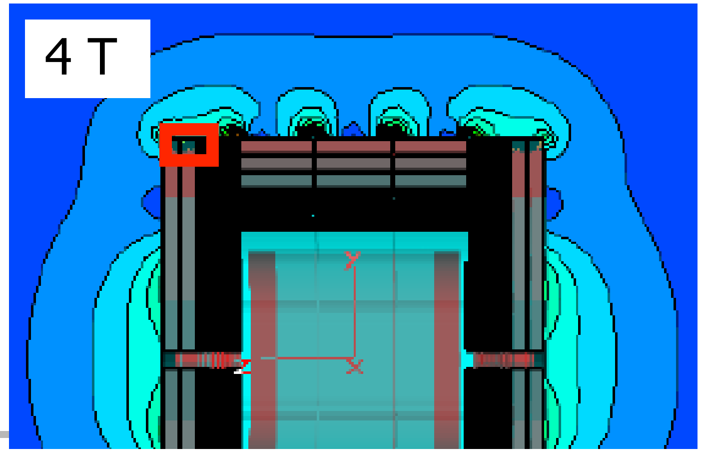


gaps partly filled, EC 2 plates



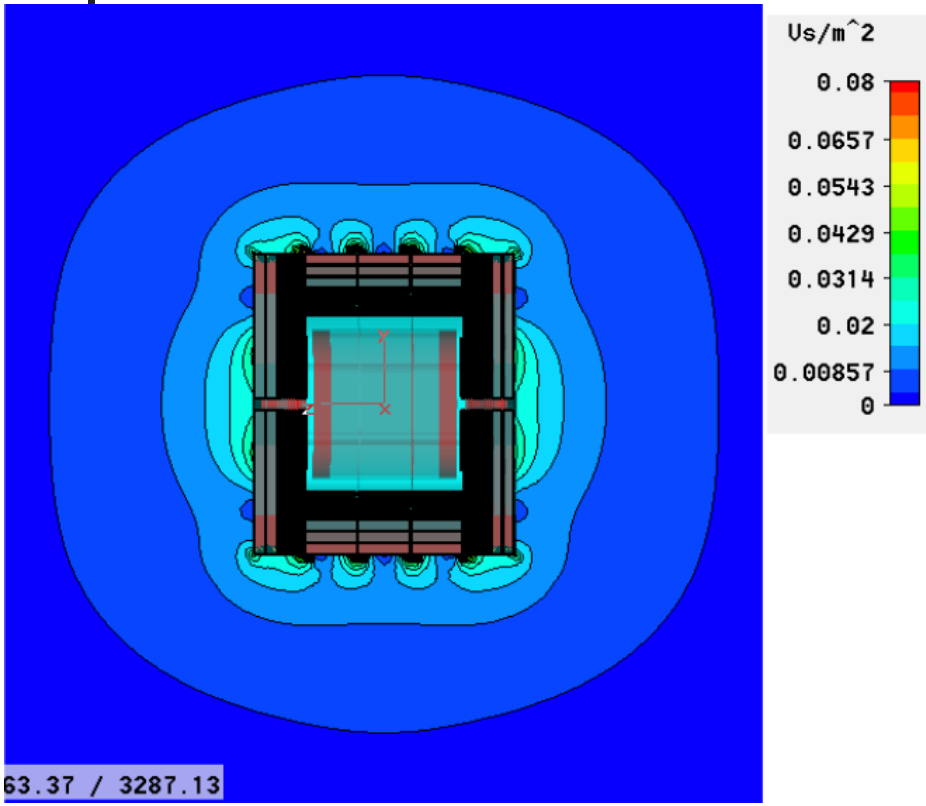
Seoul mtg

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

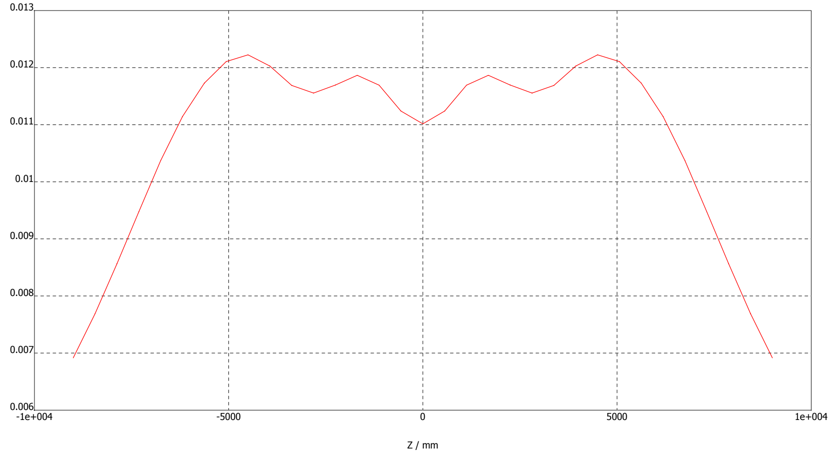


Stray Field Calculations

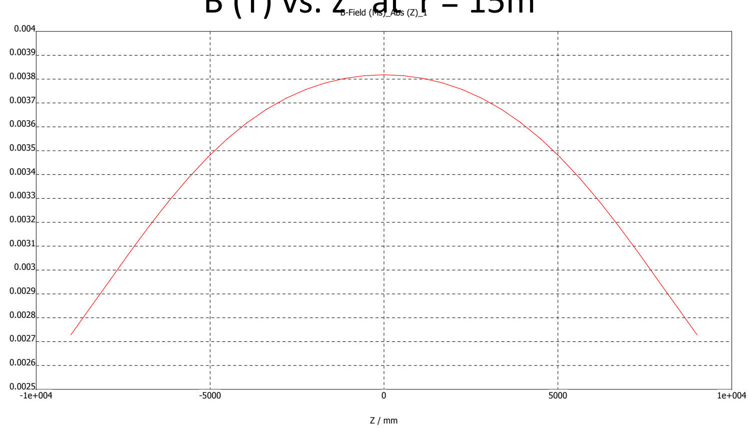
A. Petrov, 2008



B (T) vs. z at r = 10m



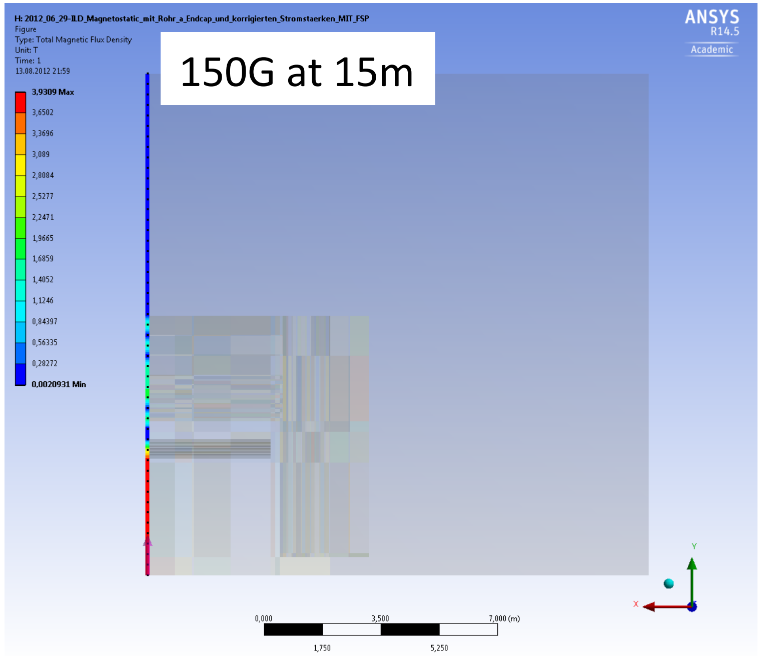
B (T) vs. z at r = 15m

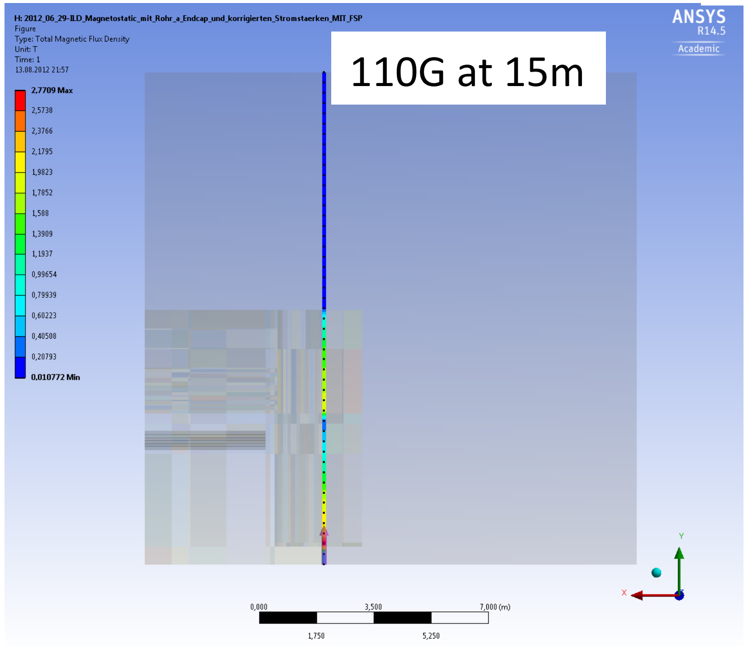


- Stray field close to yoke determined by gaps
- Should study effect of gaps far from yoke
- Question whether 1 instead of 3 barrel rings would be better
  - Only gaps between B and EC, total gap width unchanged

Recent Stray Field Calculations

M. Lemke

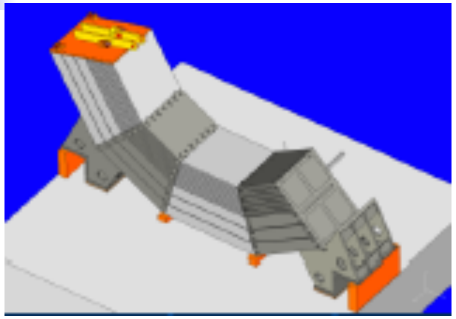
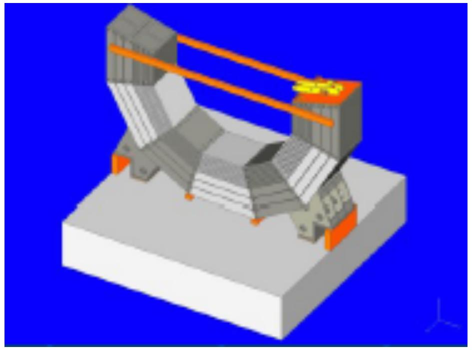
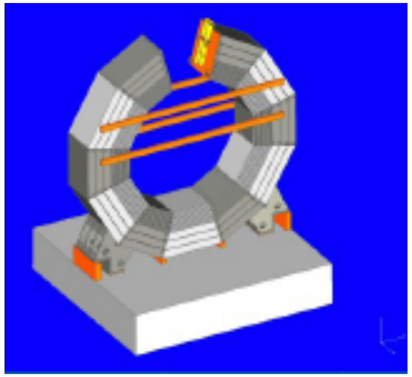




Requirement (agreement) 50G at 15m

- New FEM calculations much higher
- At limit of FEM calculations; required stray field 50G, central field 4T
- Discussions with H. Gerwig: "FEA calculation of B field in air with 0.1% uncertainty unrealistic"

Yoke Assembly

Design assumptions

- All machining and pre-assembly at manufacturer
- Disassembled again, segments shipped to ILC site
- Presently max weight of segments ~210t, gross transport weight ~250t
- 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

Yoke Segmentation - Alternatives

CLIC

E. v.d. Kraaij

To test models with different layouts of muon layers, one Mokka model was created with 18 layers at equal distances of 14 cm (10 cm steel, 4cm active layer)

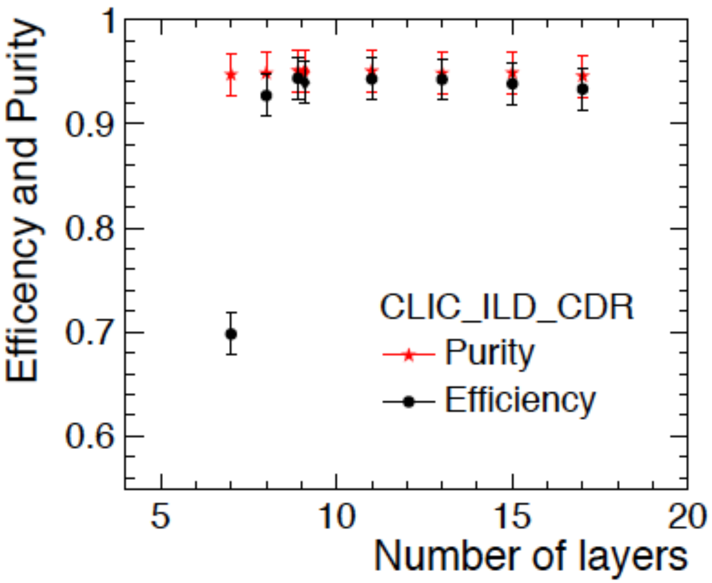
- In the reconstruction step, layers can then be included/excluded.
  - 8 models with #layers varying from 7 to 17 were tested:

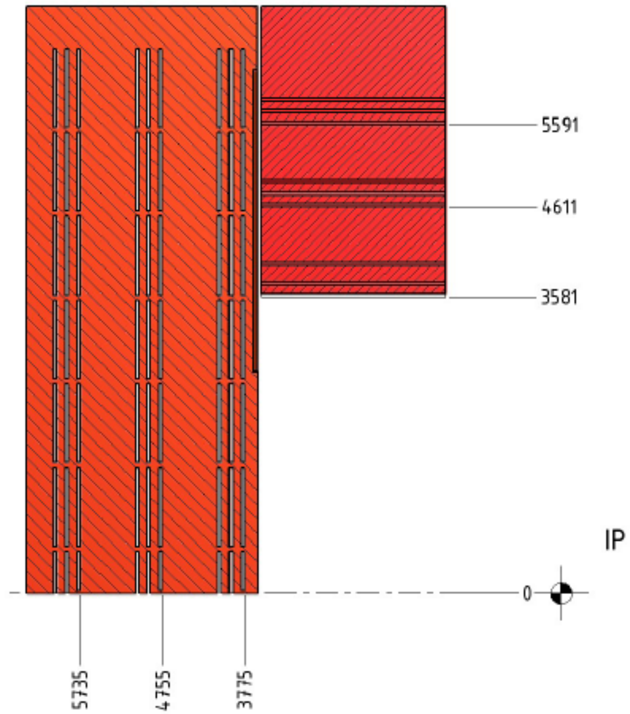
Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
7	X	X	X				X				X			X			X
8	X	X	X					X		X		X			X		X
→ **9a**	X	X	X				X		X		X		X		X		X
→ **9b**	X	X	X					X	X	X					X	X	X
11	X	X	X				X	X		X	X		X	X		X	X
13	X	X	X		X	X		X	X	X		X	X	X		X	X
15	X	X	X			X	X	X	X	X	X	X	X	X	X	X	X
17	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Always 3 layers for the tailcatcher

Yoke Segmentation - Alternatives

CLIC CDR





Remarks

Performance

- Efficiency drops for < 8 layers
- Two 9 layer geometries equal
- Performance of tail catcher should be better with equal spacing

Proposed CLIC design

- Fine for muon system
- Good for large magnetic forces
- Not optimal for tail catcher

Not planning to change ILD design

Muon System / Tail Catcher

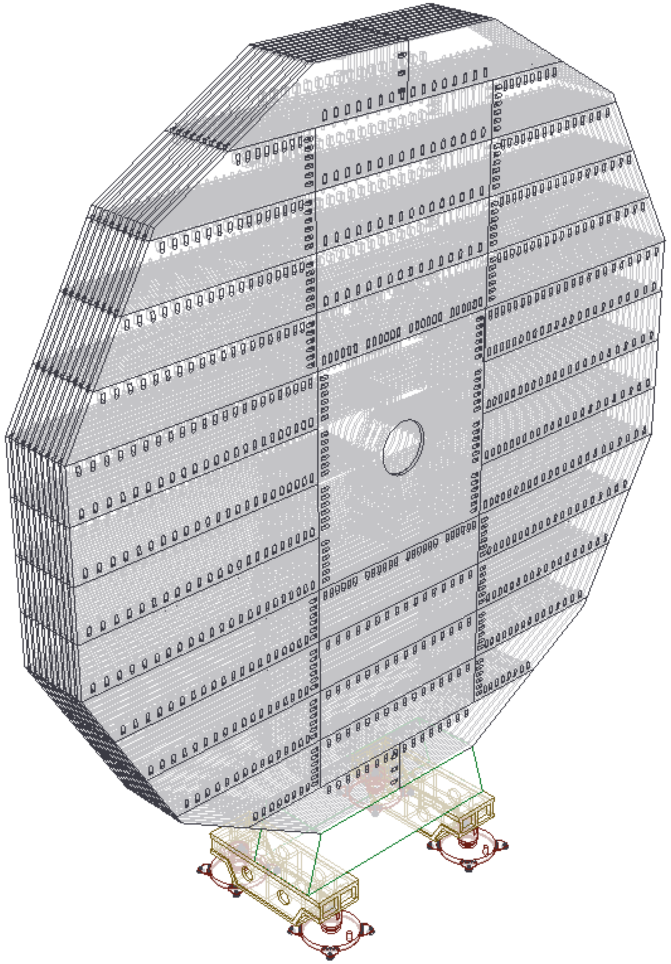
Performance Summary, V.Saveliev

Tail Catcher:

- Improves energy resolution. In particular at high energies
- Full thickness of yoke important for pion rejection
- Instrumentation of outer (thick) layers is useful for pion rejection. Much better than just one muon chamber layer on the very outside.
- Increasing iron plate thickness from 10 to 20cm probably fine at low energies (low MC statistics so far), but significant degradation at high energies
  - Every second layer could be added as part of high-energy upgrade (US)

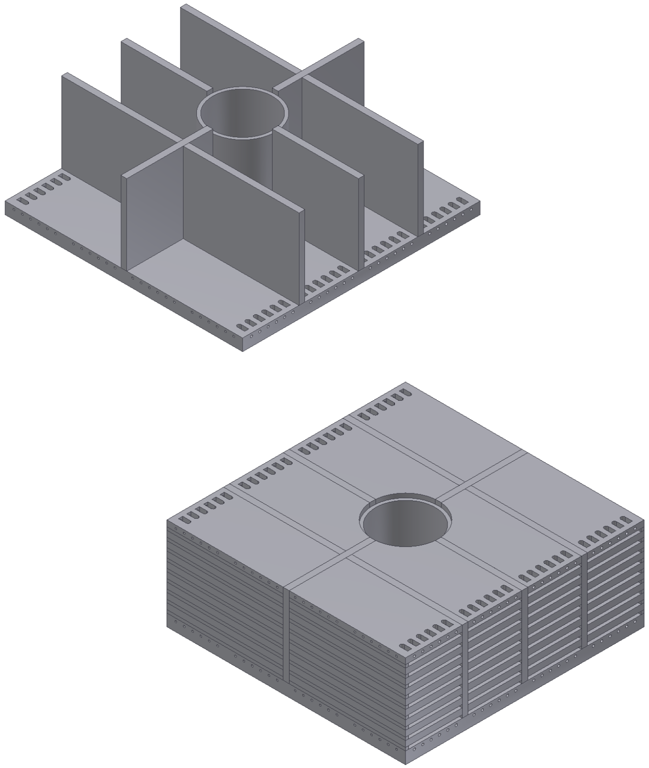
Alternative End-Cap Design

Design by Hubert Gerwig and Nicolas Siegrist, CMS/CERN



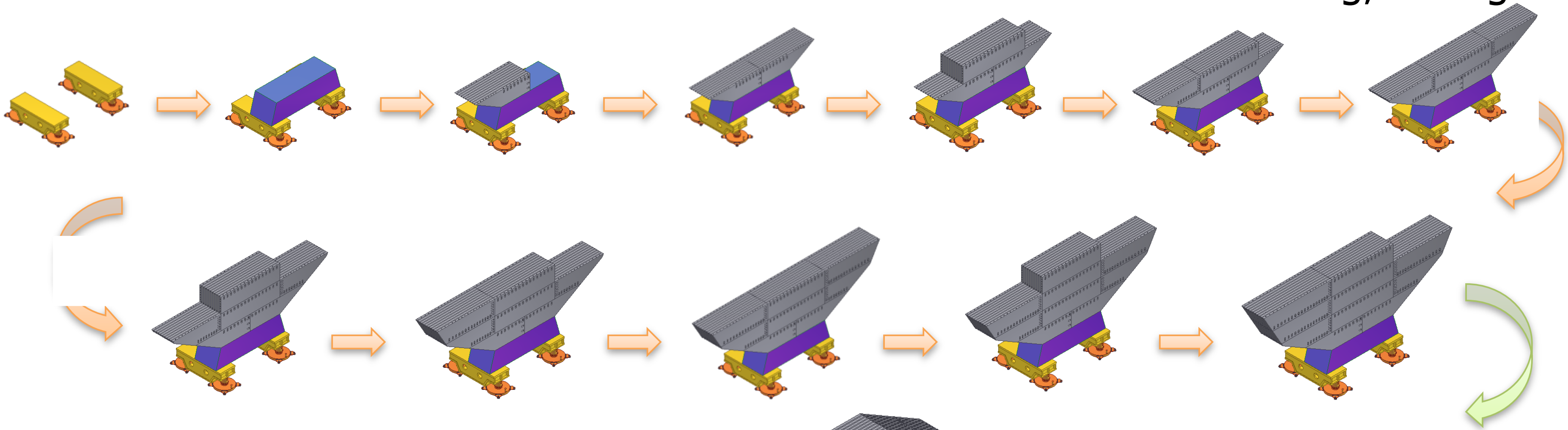
Segments of 40t

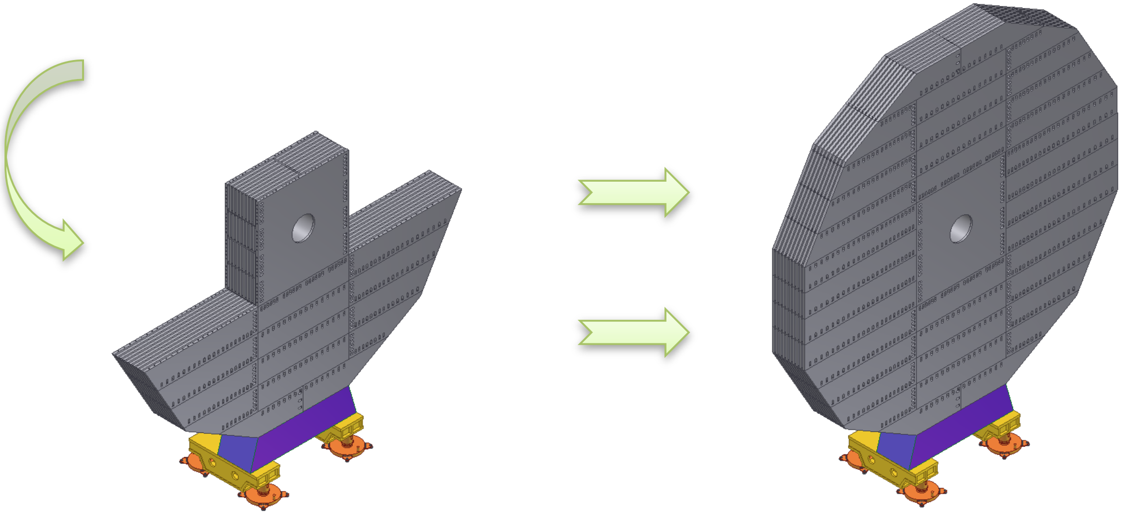
Central part 120t



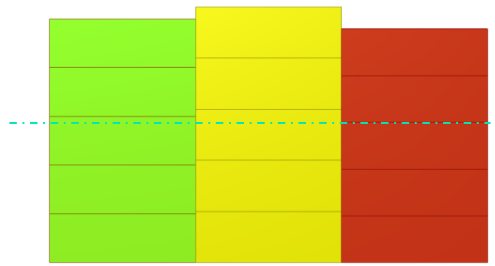
Alternative End-Cap Design

H.Gerwig, N.Siegrist





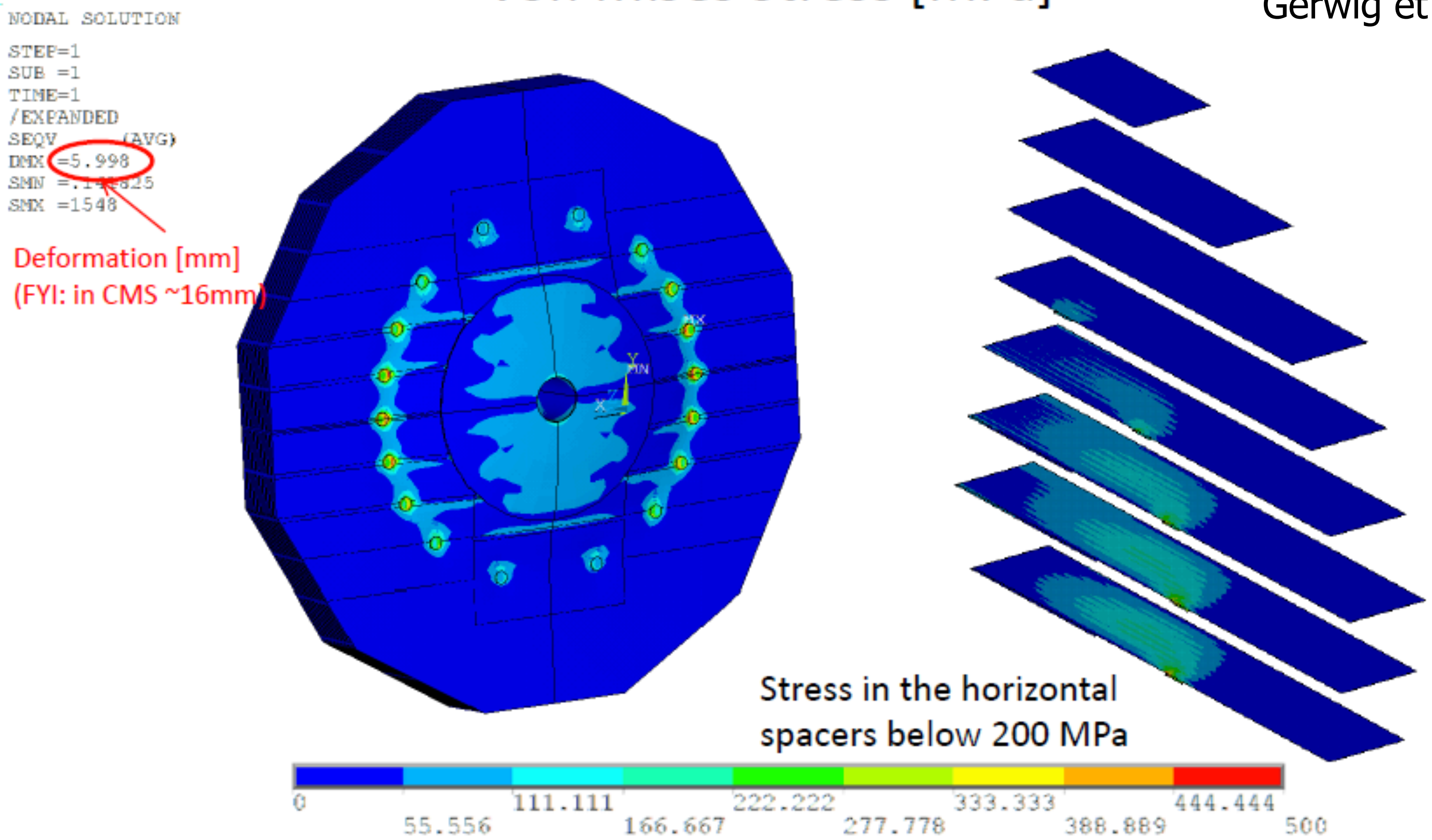
Allow length difference for
mounting (+/- 0.2 for each block):



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 compression (manufacturing, transport, assembly)

Proposed Plan - Conclusions

- Keep present segmentation (steel plate thickness)
  - Possible cost saving: instrument every 2nd layer (low energy)
- Reconsider stray field limit of 50 G
- Redo stray field calculations
  - Possibly less iron, although significant uncertainties in FEM calculations
- Cost/performance optimization of weight and size of yoke segments
  - Manufacturing of small vs. large segments
  - Trial and final assembly (small vs. large segments)
  - Road transport weight limits and requirements of Kitakami site
  - Geometry of end-caps
- Need contact/discussion with potential manufacturer
  - Had some contact with MAN, Germany (CMS barrel) some years ago, but reluctant to continue
  - ILD yoke very likely to be built in Asia (Japan, China, Korea,…)
    - Very experienced and competitive in fabrication of heavy items
- Set up working group with KEK experts and potential manufacturer in Japan