Integrated magnet block design and production for MAX IV

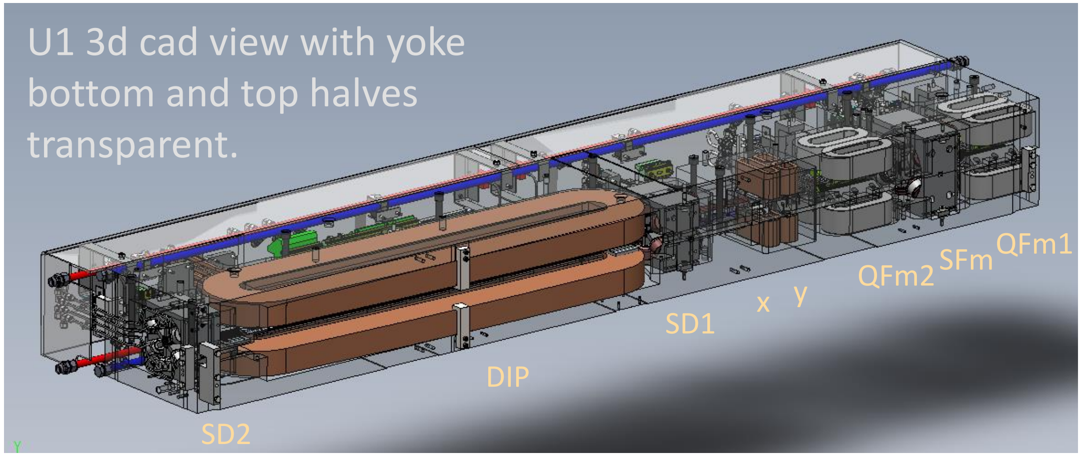
Martin Johansson, Workshop on Special Compact and Low
Consumption Magnet Design, CERN 26-28 November 2014

MAX IV 3 GeV ring magnets key aspects:

- Relatively small magnet aperture of Ø25 mm.
- magnet block concept → integrated unit containing several consecutive magnet elements.

Contents of this presentation:

1) The MAX IV facility and its 3 GeV ring magnet design.
2) magnet production



The MAX IV Laboratory

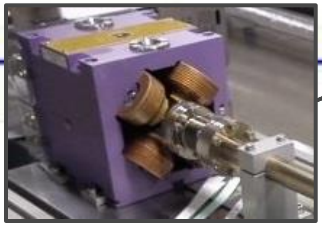
- Currently in construction just outside Lund, Sweden.
- Facility dedicated to synchrotron radiation research.

- MAX I-III (old MAX-lab located in Lund University campus) remains in operation until end of 2015.

Nov. 7th, 2014 photo: Perry Nordeng

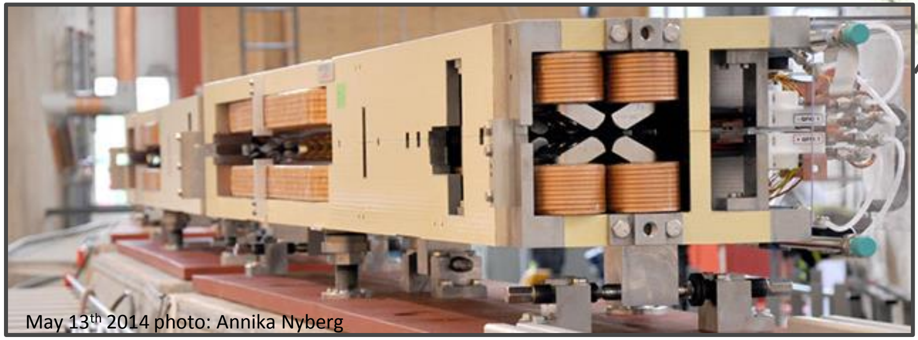
MAX IV magnets overview

- linac & transfer lines – various conventional magnet types

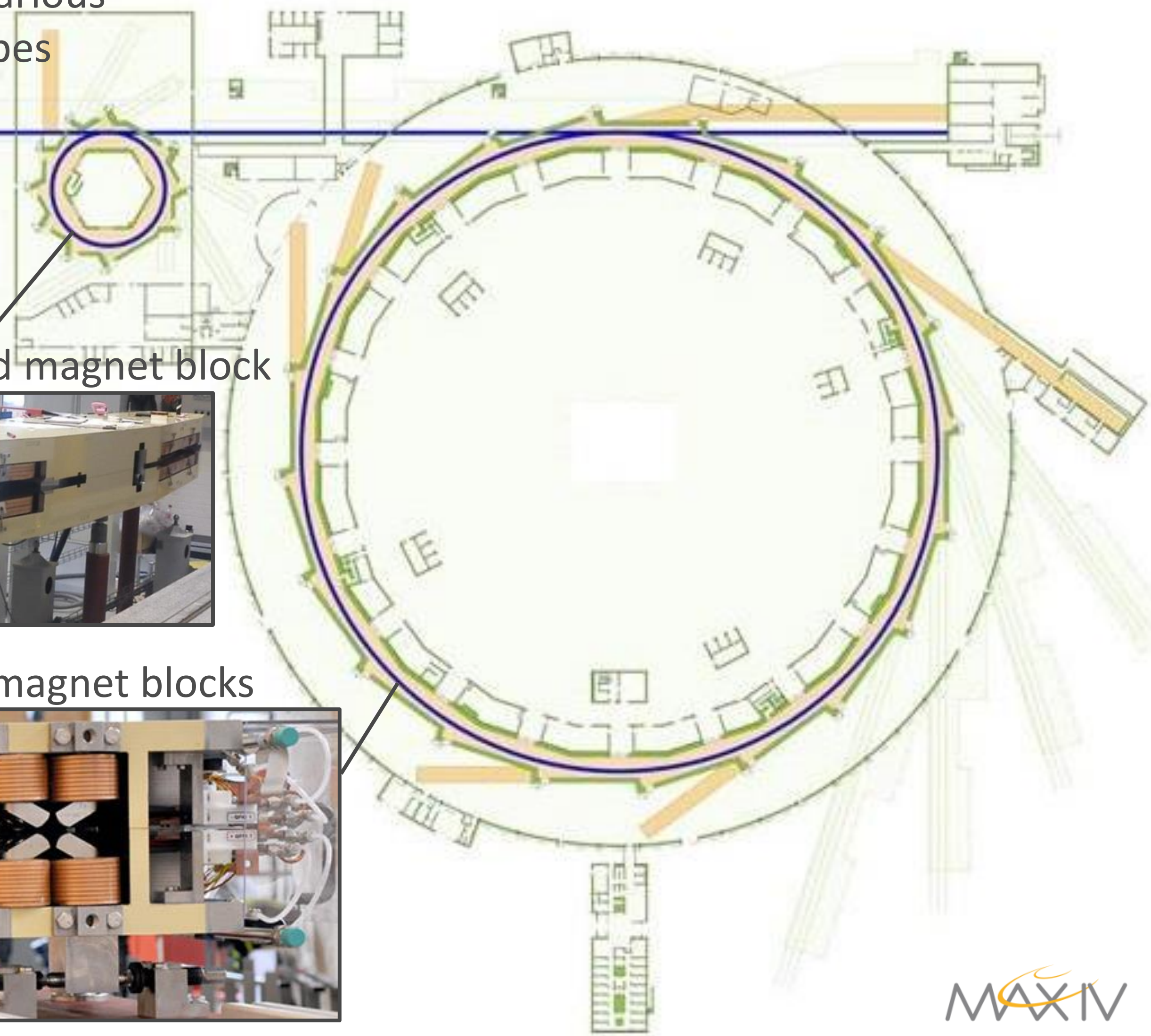


- 1.5 GeV ring – integrated magnet block

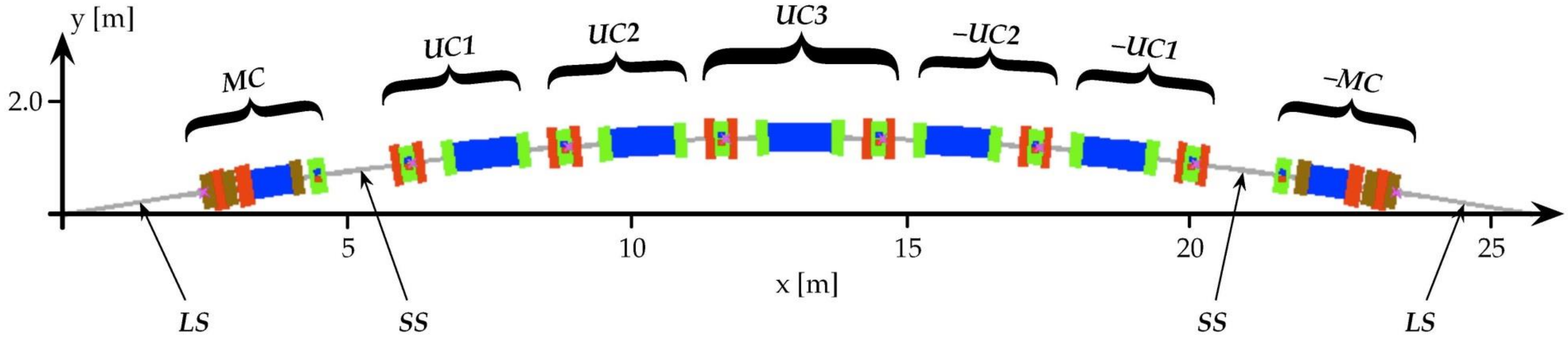
- 3 GeV ring – integrated magnet blocks



May 13th 2014 photo: Annika Nyberg



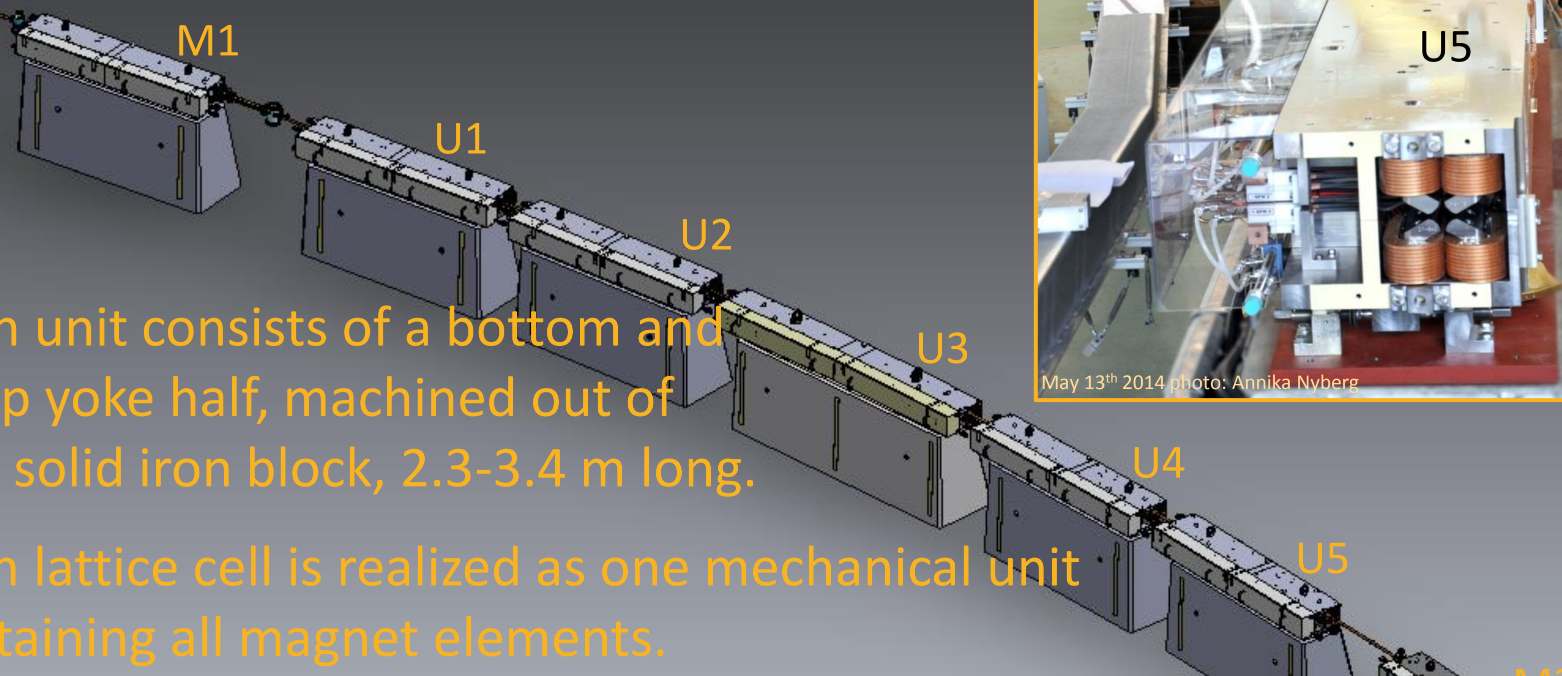
The MAX IV 3 GeV ring lattice



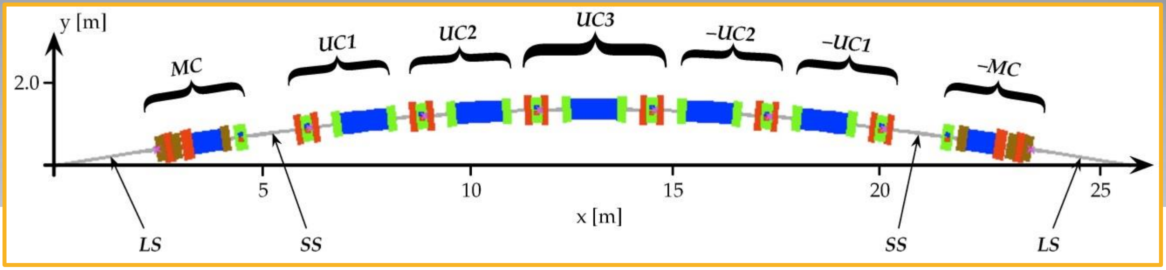
- Each achromat consists of five unit cells and two matching cells.
- 20 achromats x 7 cells = 140 cells total
- achromat length = 26.4 m
- ring circumference = 26.4 x 20 = 528 m
- bare lattice emittance = 0.33 nmrad

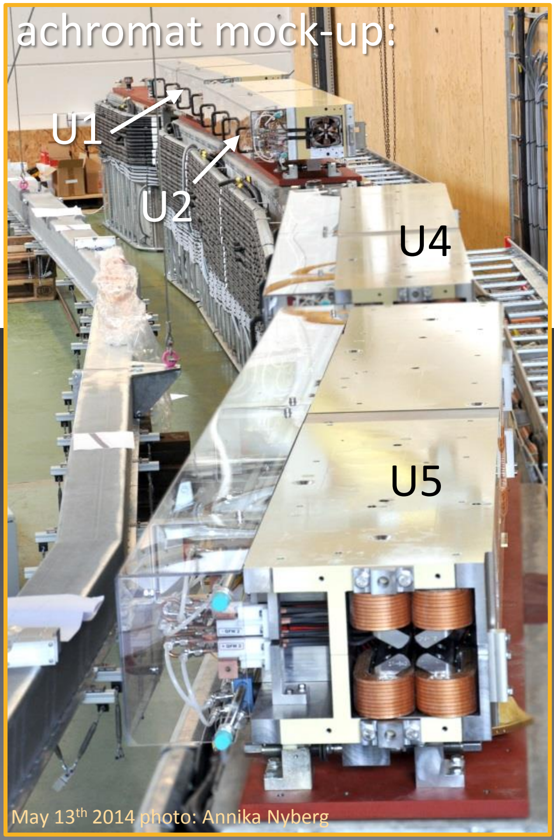
3 GeV ring achromat

- 3d cad assembly:



- Each unit consists of a bottom and a top yoke half, machined out of one solid iron block, 2.3-3.4 m long.
- Each lattice cell is realized as one mechanical unit containing all magnet elements.



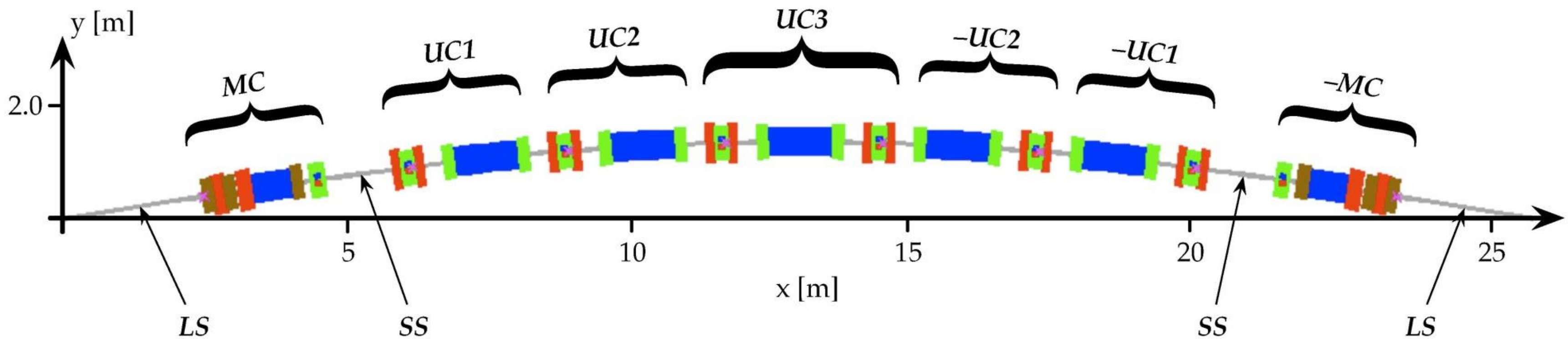


inside the 3 GeV ring tunnel

- Achromat 14: magnet blocks on support stands awaiting vacuum chamber installation.
- Achromat 13 vacuum chamber installation ongoing.

Nov. 18th, 2014 photo: Jonny Ahlbäck

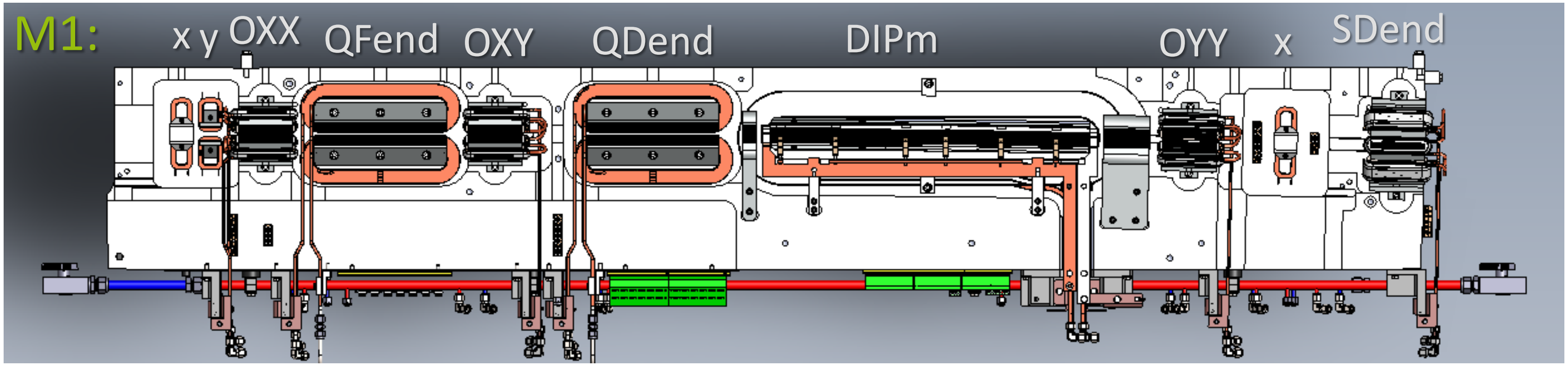
3 GeV ring magnet block layout

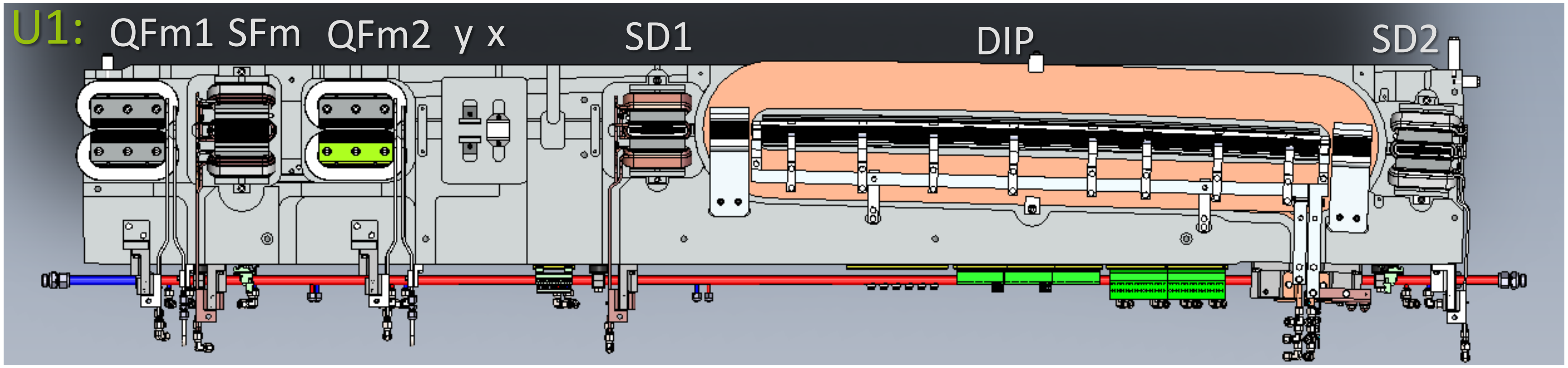


- The 3 GeV ring lattice has two cell types, unit cells and matching cells.
- -MC is mirror image of MC.
- UC1 and UC2 have identical magnet lengths and distances between elements, but different strengths for quads and one sextupole.
- -UC1 and -UC2 are mirror images of UC1 and UC2.
- UC3 is symmetric around its center, with layout identical to other UC.

3 GeV ring magnet block layout

… correspondingly, there are two basic magnet block layouts, shown here in 3d cad, bottom halves view from top,

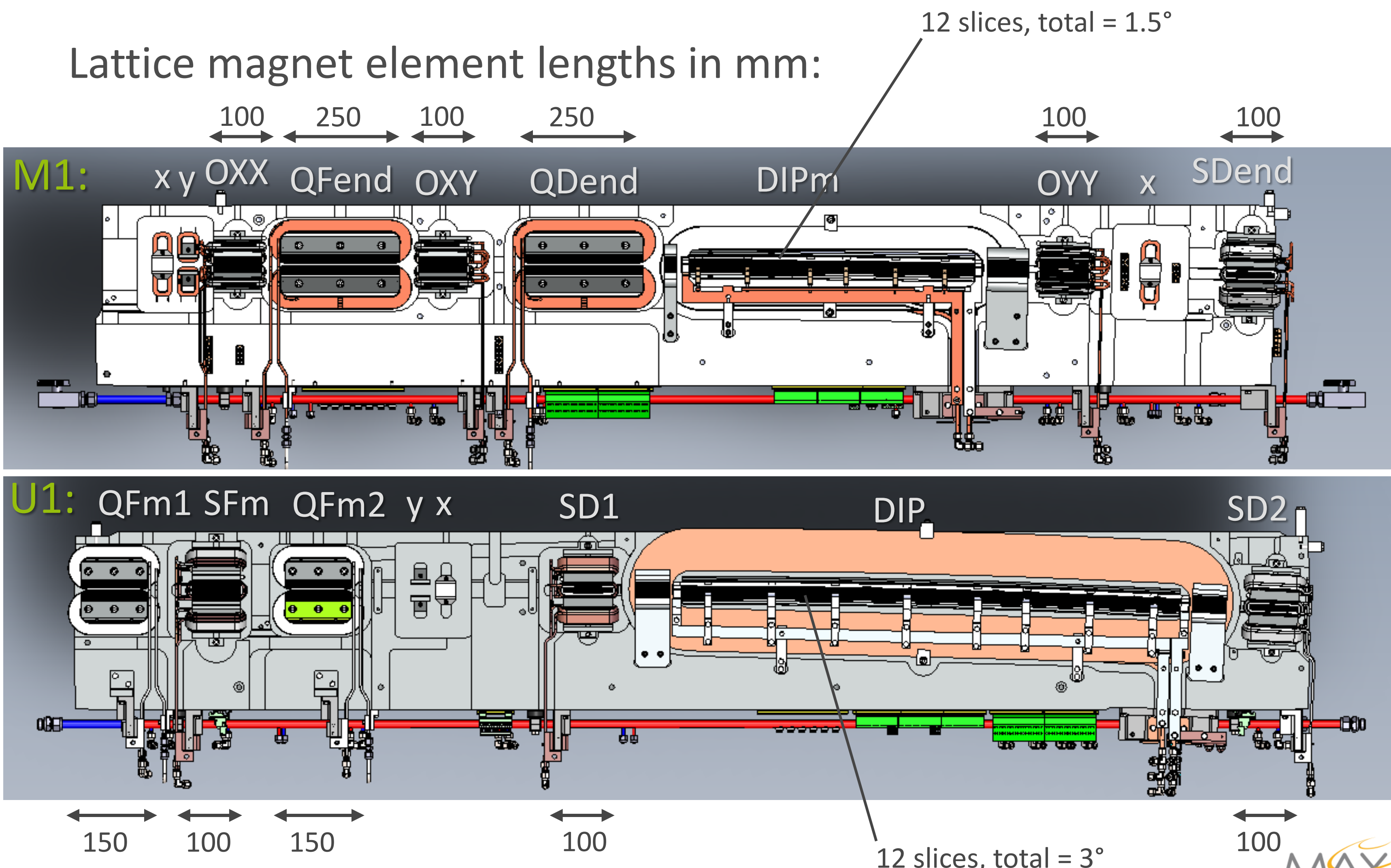




- U2, U3, U4, U5 and M2 are identical/mirror of U1 and M1.

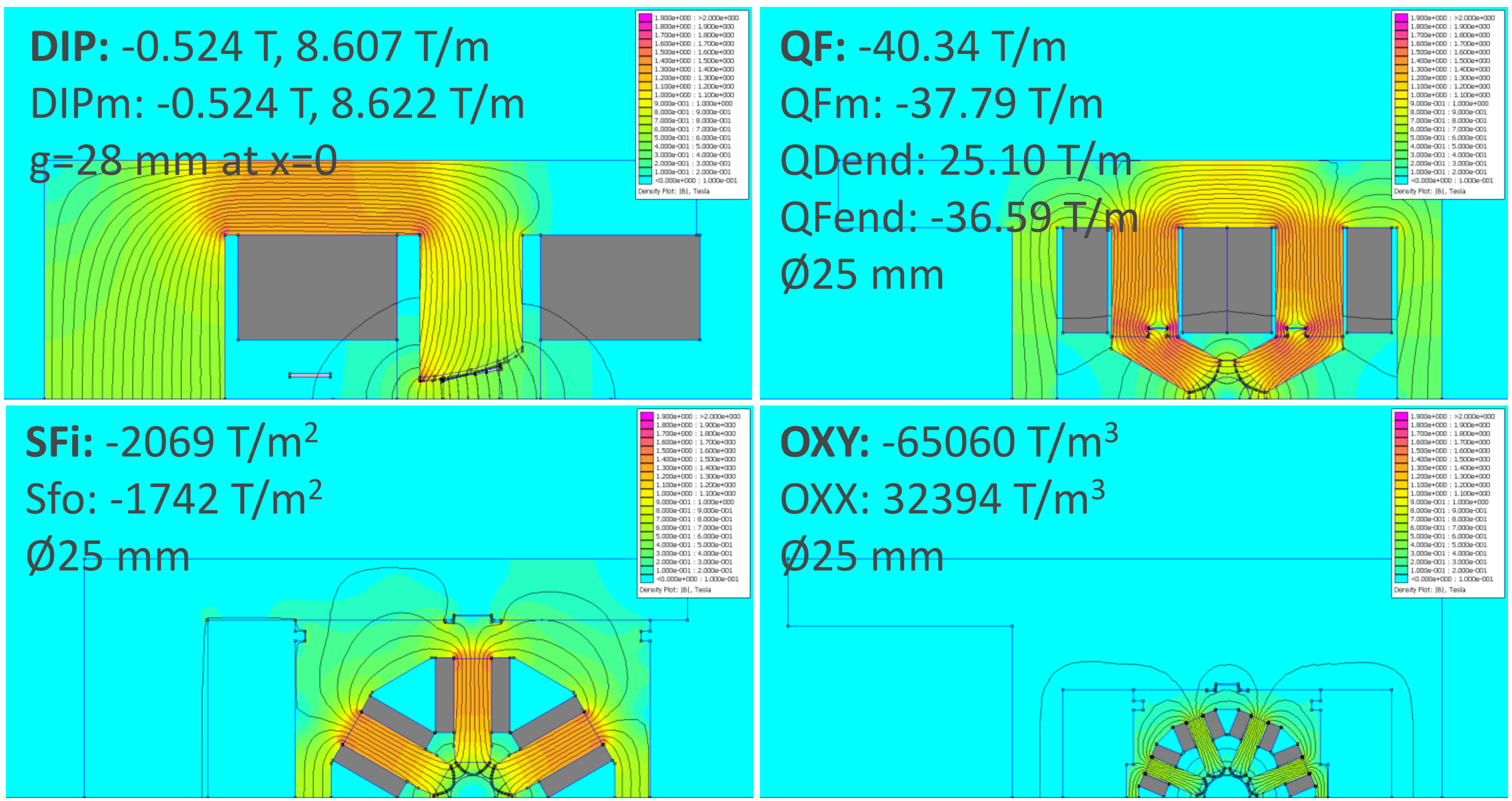
3 GeV ring magnet block layout

Lattice magnet element lengths in mm:



3 GeV ring magnet elements

2d simulations made from cross sections exported from the magnet block 3d cad models:



+ SFm, SD, SDend (Ø25 mm), OYY (Ø36 mm), x/y (g = 25 mm).

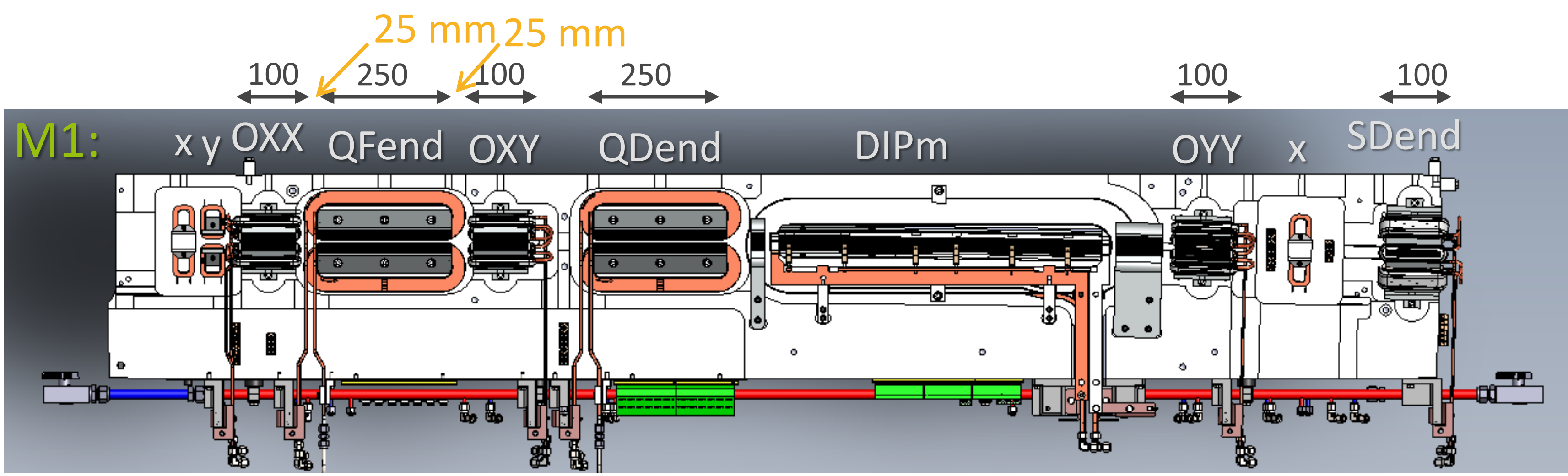
Ø25 mm aperture

- Was required from the lattice design, since…
- the pole aperture has a direct influence on lattice compactness,
  - by defining minimum distance between elements
  - and by defining minimum lengths for quads, 6poles, ...
- The aperture also has an indirect influence on lattice compactness through coil design, in that the required NI is proportional to g for dipoles, r^2 for quads, r^3 for 6poles, ... making it easer to fit the coil ends longitudinally.
- For the MAX IV 3 GeV ring design, the enabling factor for Ø25 mm magnet aperture is the choice of NEG-coated copper vacuum chambers throughout the achromats.

Ø25 mm aperture

… by defining minimum distance between elements?

- Rule of thumb used for MAX IV: min. distance ≈ one pole gap
- If shorter, fringe fields overlap, destroying field quality.
- We are at this limit in M1 and M2:

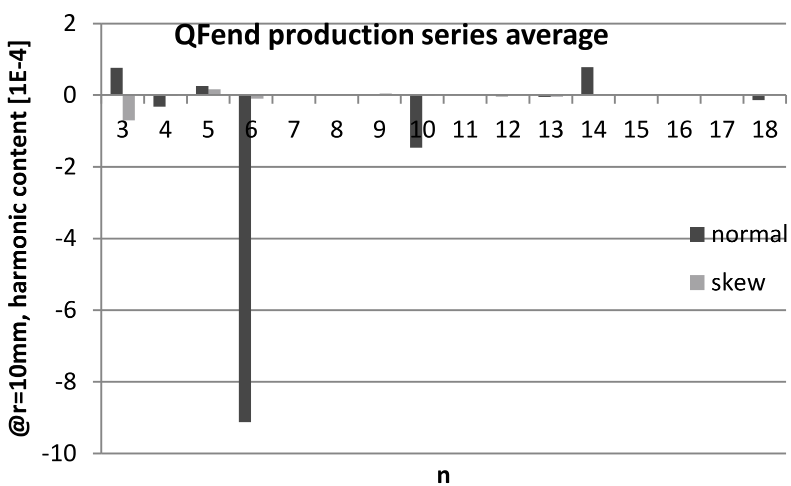


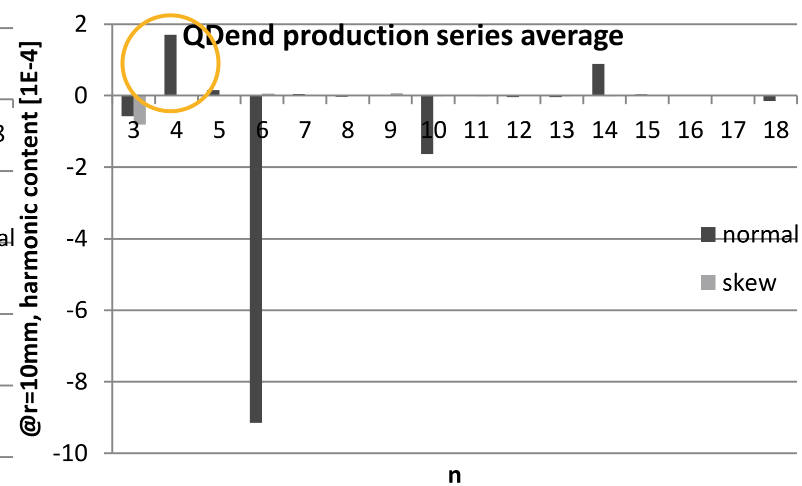
- U1-5 are more relaxed, 75 mm between SF and adjacent QF.

Ø25 mm aperture

… so, one pole gap distance between consecutive elements, does it work?

- Compare QFend and QDend harmonic content:





- These two elements see different iron surroundings, difference in n=4 could come from this …
- … but this difference is negligible. Ie, our data data indicates that in this case one pole gaps distance is enough.

Ø25 mm aperture

… by defining minimum lengths for focusing elements?

- Assuming a fixed max pole tip field, B_{pt}, max quad gradient = B_{pt}/pole r
- We have chosen max $B_{pt} \approx 0.5$ T, which keeps the whole pole face in the linear region of the iron B(H) curve. Resulting max G ≈ 40 T/m.
- Our quads are at this strength, so with larger pole radius, they would have needed to be longer.
- Our strongest sextupoles have ca 0.3 T at the pole tip…
- max $B_{pt} \approx 0.5$ T is quite conservative. It allows us to have a mechanically simple quad design with upright standing pole roots, and racetrack coil. There are no tapered coils in any of our magnets.

MAX IV

Ø25 mm aperture

- A negative aspect is that with smaller pole gap, the relative strength of random field errors due to manufacturing tolerances increase, since the tolerances are fixed, constituting a larger fraction of the pole gap.
- A positive side effect of small aperture is that the power consumption goes down. MAX IV 3 GeV ring magnets total = 339 kW.

The magnet block concept

Does is have an impact on compactness?

- In principle no.
- Practically, maybe in how close you dare to place adjacent coils. But that can just as well be handled through appropriate spec. and QA.

MAX IV choice was made for,

- Vibration stability.
- Ease of installation.
- The magnet block being an alignment concept which is totally outsourced to industry.

3 GeV ring magnet production

Background:

- Production sourced as build to print-contracts for fully assembled and tested magnet blocks, with MAX-lab providing technical specifications and full sets of manufacturing drawings.
- Suppliers responsible for mechanical tolerances, ±20 µm for the yoke bottom and top blocks (2.3-3.4 m long), and for performing field measurements according to MAX-lab spec.
- MAX-lab responsible for magnetic field properties!
- Contracts signed Sept 2011:
    - Danfysik A/S: M1, M2 and U3 = 60 magnet block units.
    - Scanditronix Magnet AB: U1, U2, U4 and U5 = 80 magnet block units.

3 GeV ring magnet production

Expected challenges were,

- Meeting the ±20 µm mechanical tolerances.
- Performing Hall mapping with the same level of positioning accuracy.
- Solving rotating coil meas access while also meeting specified accuracy.
- And doing all this with required production pace!

MAX IV

3 GeV ring magnet production

Outcome,

- The two magnet suppliers subcontracted the yoke machining to three different CNC machining companies,
  - Required extra visits to these companies at intervals in the early stage, and in depth review of 3d CMM tolerance verification.
  - But no hands on problem solving in how to perform the machining. Our conclusion: ±20 μm is a tolerance level that can be met without needing a key person at the accelerator lab to go into the details of how to perform the machining.
  - Required continuous monitoring from us to keep pace.

3 GeV ring magnet production

Outcome,

- Both suppliers chose to procure both new Hall mapping benches, and new rotating coil systems,
  - Necessitated by meeting the specified accuracy, and/or keeping their previous existing measurement equipment available for other customers during the MAX IV production phase.
  - Also, rotating coil mechanical layout necessitated by our magnet block concept.
- Establishing the measurement procedures according to spec required both in depth review and hands on problem solving from our side.

3 GeV ring magnet production

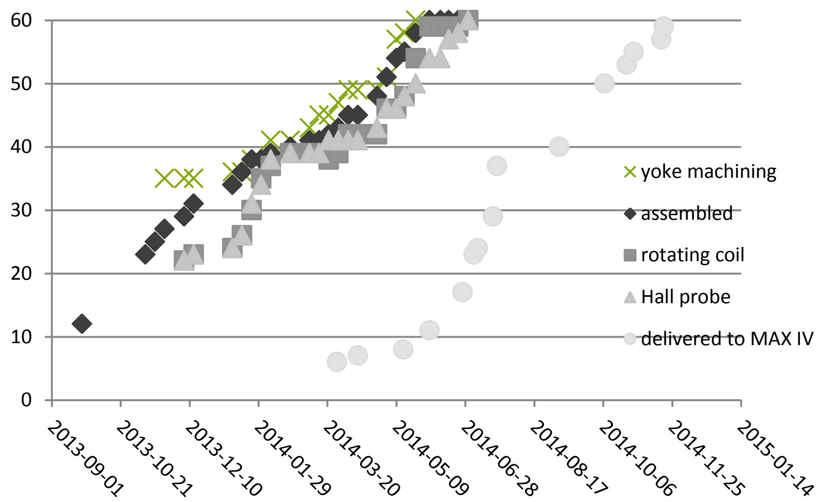
Outcome,

- In addition to the expected challenges, the total workload was also challenging for the suppliers. Project meetings were required at monthly, bi-weekly, or at times even weekly interval.
- A positive outcome was that during the project we did not sacrifice any performance requirements!

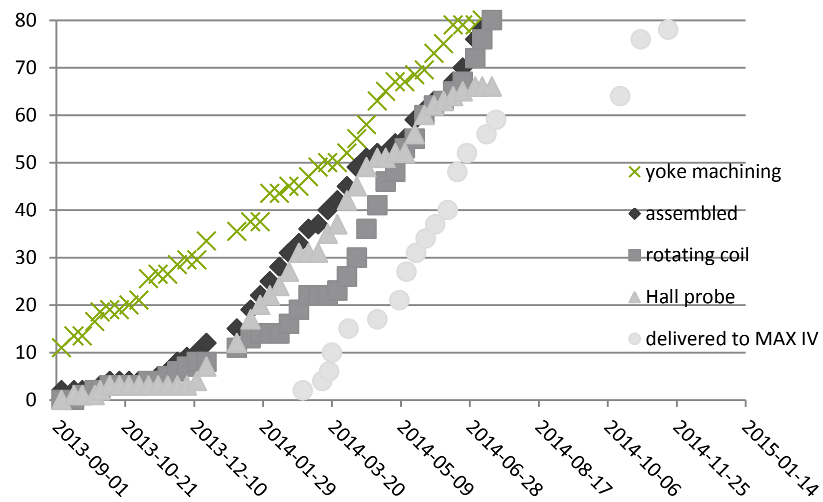
3 GeV ring magnet production

Production statistics from suppliers weekly status reports,

Danfysik M1, M2 and U3:



Scanditronix Magnet U1, U2, U4 and U5:



- Yoke machining pace = 1-2 yoke halves/week average
- Field meas pace = 1 Hall and 1 rot. coil /day possible

3 GeV ring magnet production

Status Nov. 2014 summarized,

- Production series was completed summer 2014
- Of the 140 3 GeV ring magnet blocks, 137 are delivered.
- 3 approved magnet blocks remain at suppliers for extra field characterization beyond spec. (Cross talks etc).
- Installation is ongoing
- Subsystem tests (installed magnet + ps) will commence Jan. 2015.
- …

photo: Annika Nyberg

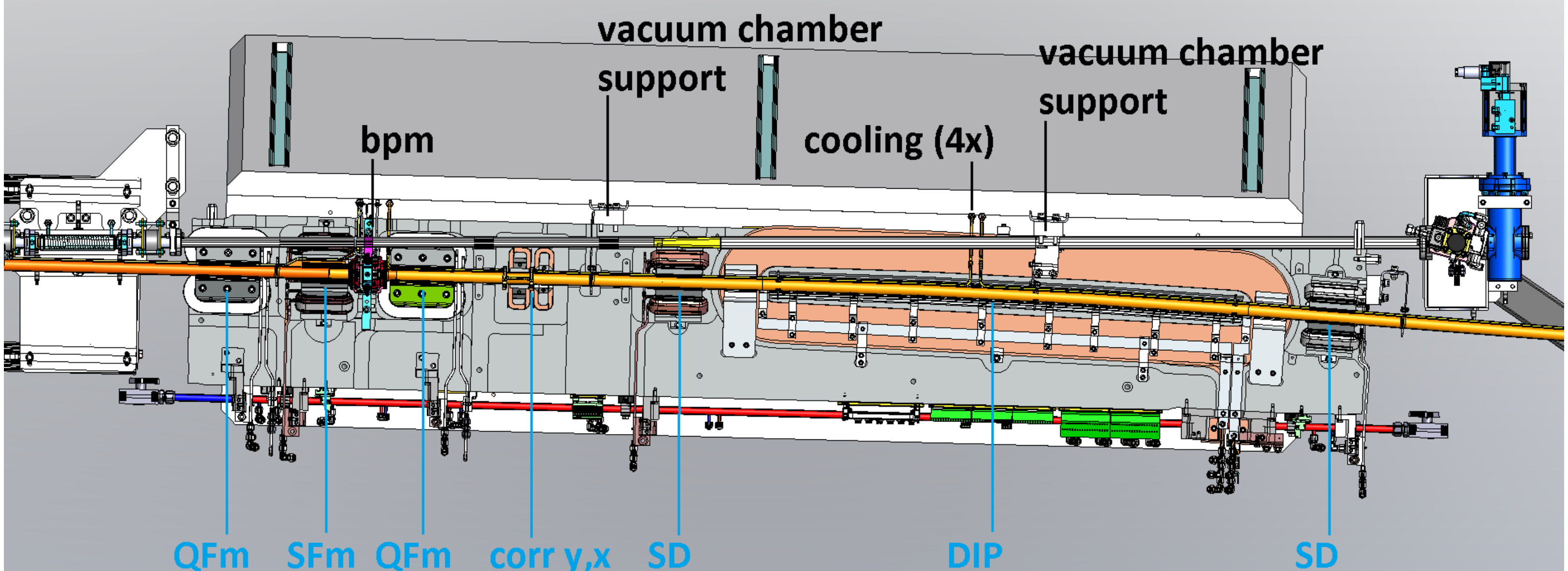
Extra slides …

3 GeV ring magnet block features

- Dismountable at horizontal midplane.
- all yoke parts = Armco low carbon steel.
- Quad and corrector pole tips mounted over the coil ends.
- 6pole and 8pole magnet halves mounted into guiding slots in yoke block.
- Electrical and water connections located towards storage ringer inner side.

3 GeV ring magnet block features

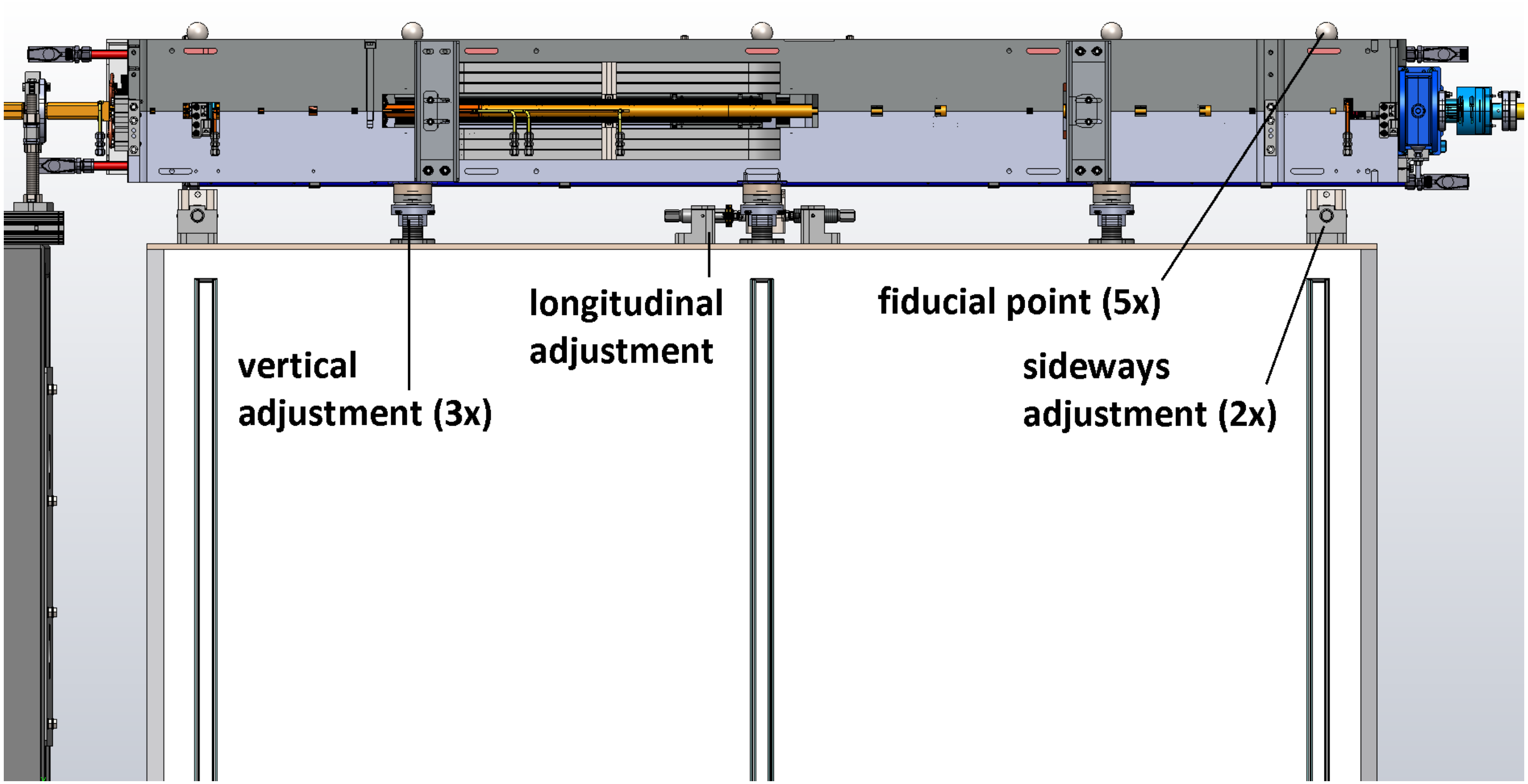
- 3d cad view from top of U1 magnet block bottom half with vacuum chamber in place:



- Vacuum chamber bolted to magnet block at bpm and two support brackets.
- Vacuum chamber cooling and signal connections located towards outer side.

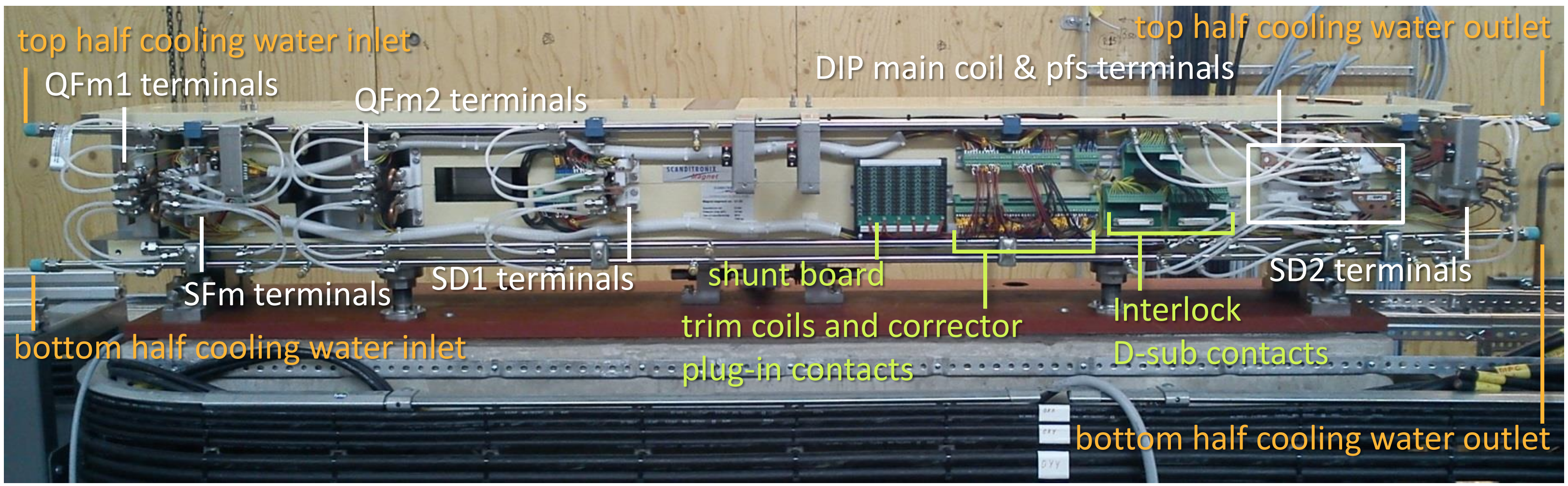
3 GeV ring magnet block features

- 3d cad view from outer side of M1 magnet block with vacuum chamber in place, on concrete support stand:



3 GeV ring magnet block features

- U1 magnet block with plastic cover removed; view from inner side, where cooling and electrical connections are located:



- Water cooling circuits are separate for bottom and top halves.
- Electrical connections across the midplane has to be disconnected when dismounting top half – bus bars/external cables for main coils and plug in contacts for corr, trim and thermoswitches.