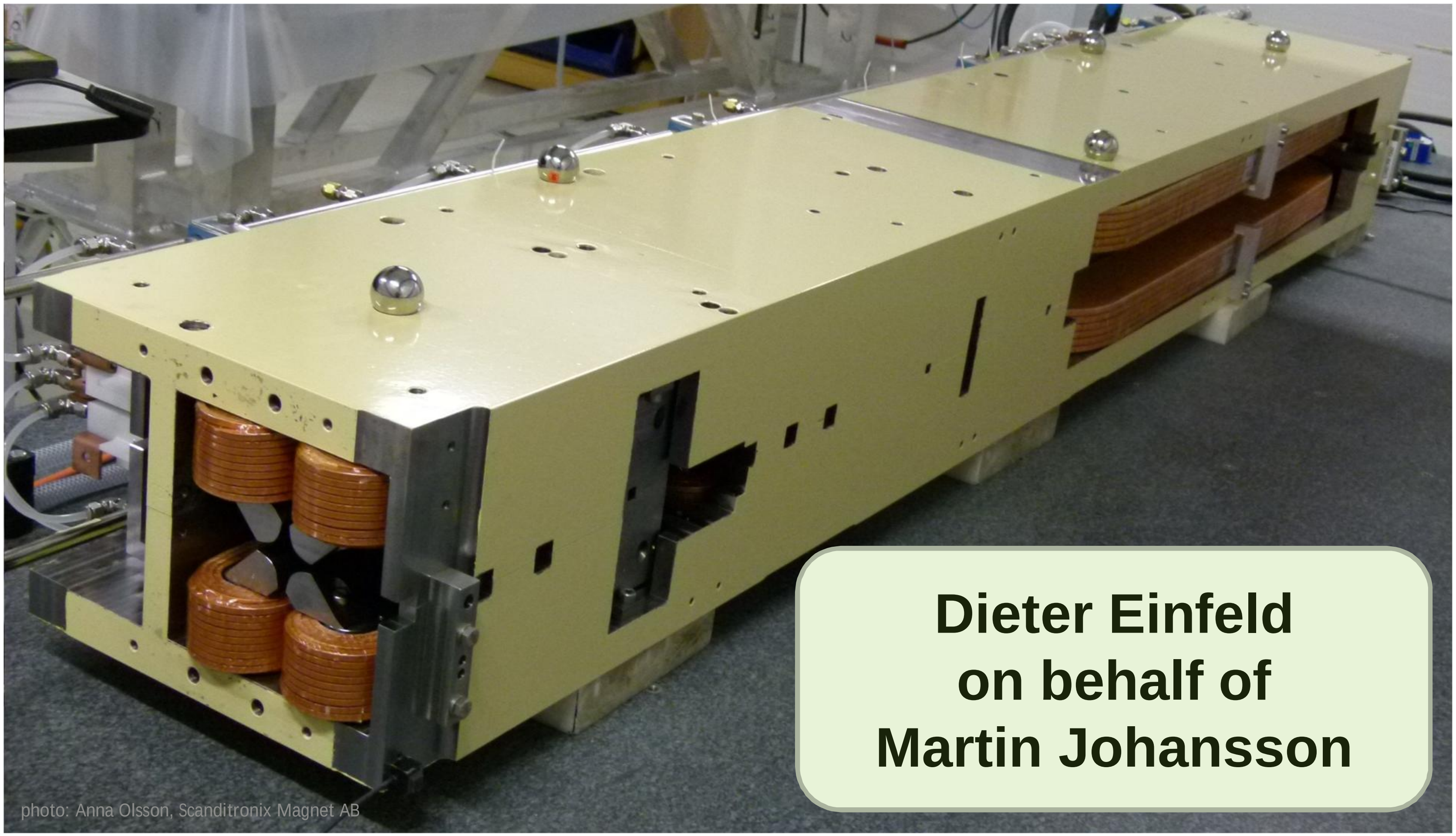
Magnets for MAX IV



**Dieter Einfeld
on behalf of
Martin Johansson**

Magnets for MAX IV

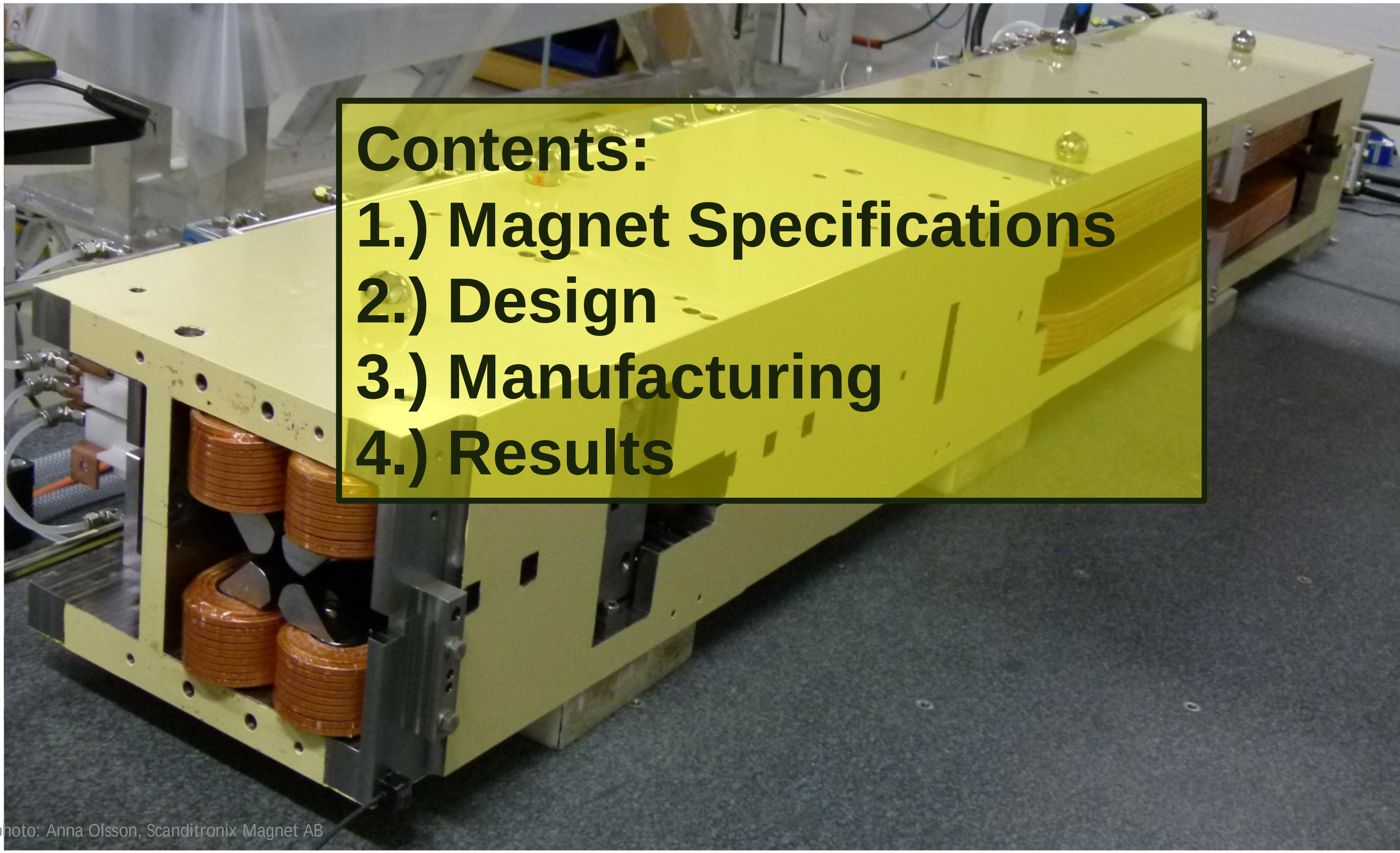
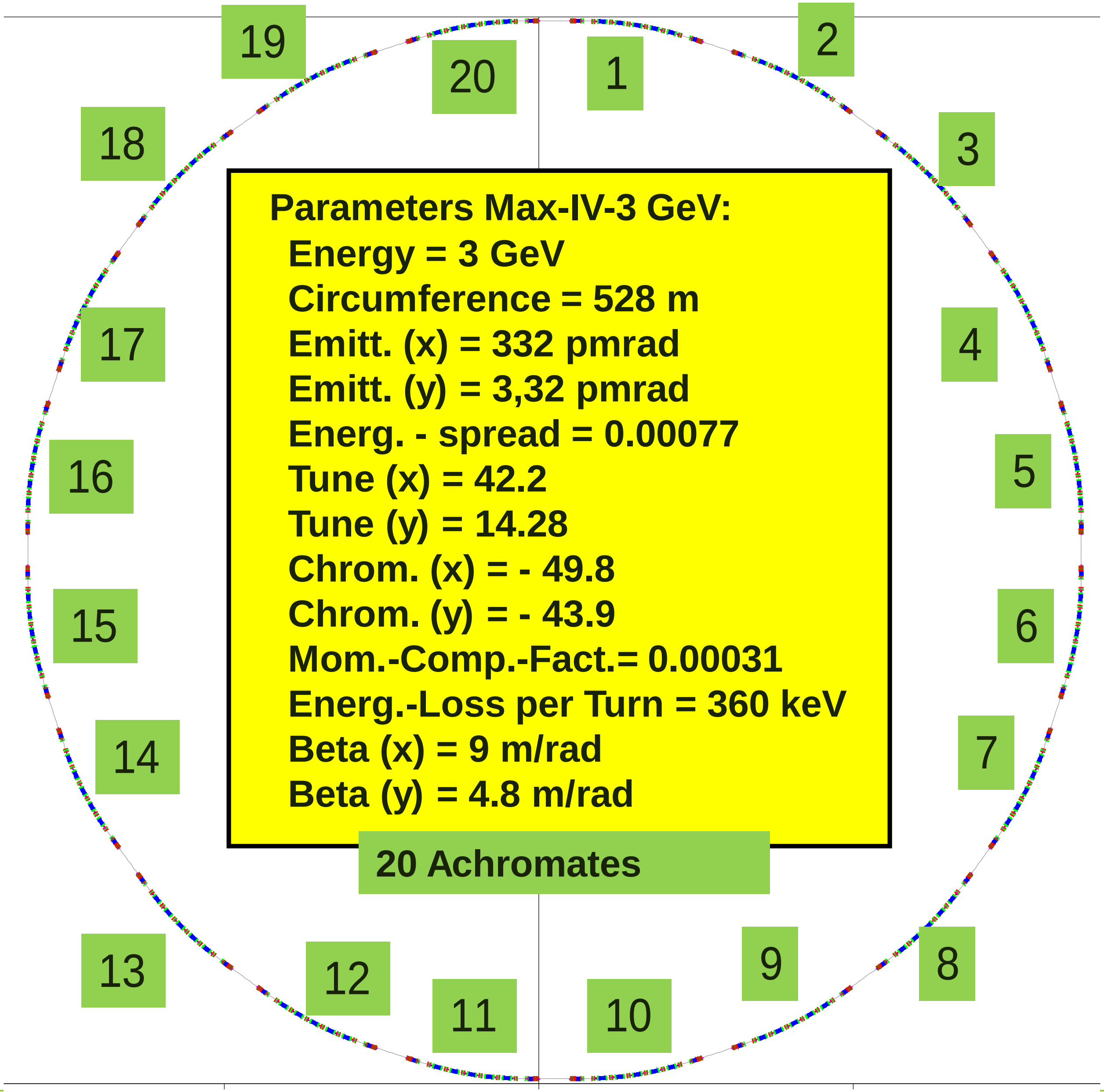


photo: Anna Olsson, Scanditronix Magnet AB

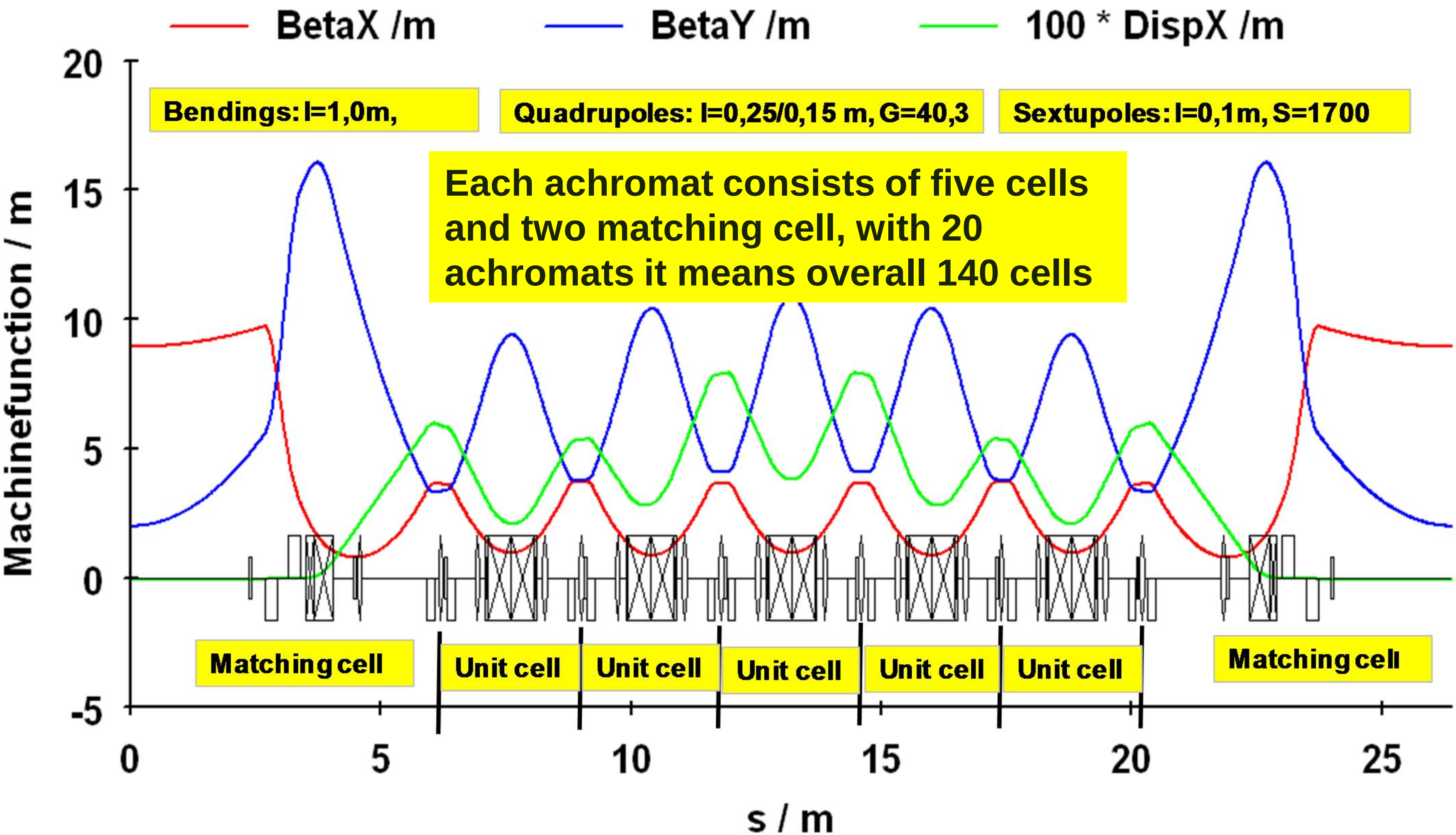
Contents:

1.) Magnet Specifications
2.) Design
3.) Manufacturing
4.) Results

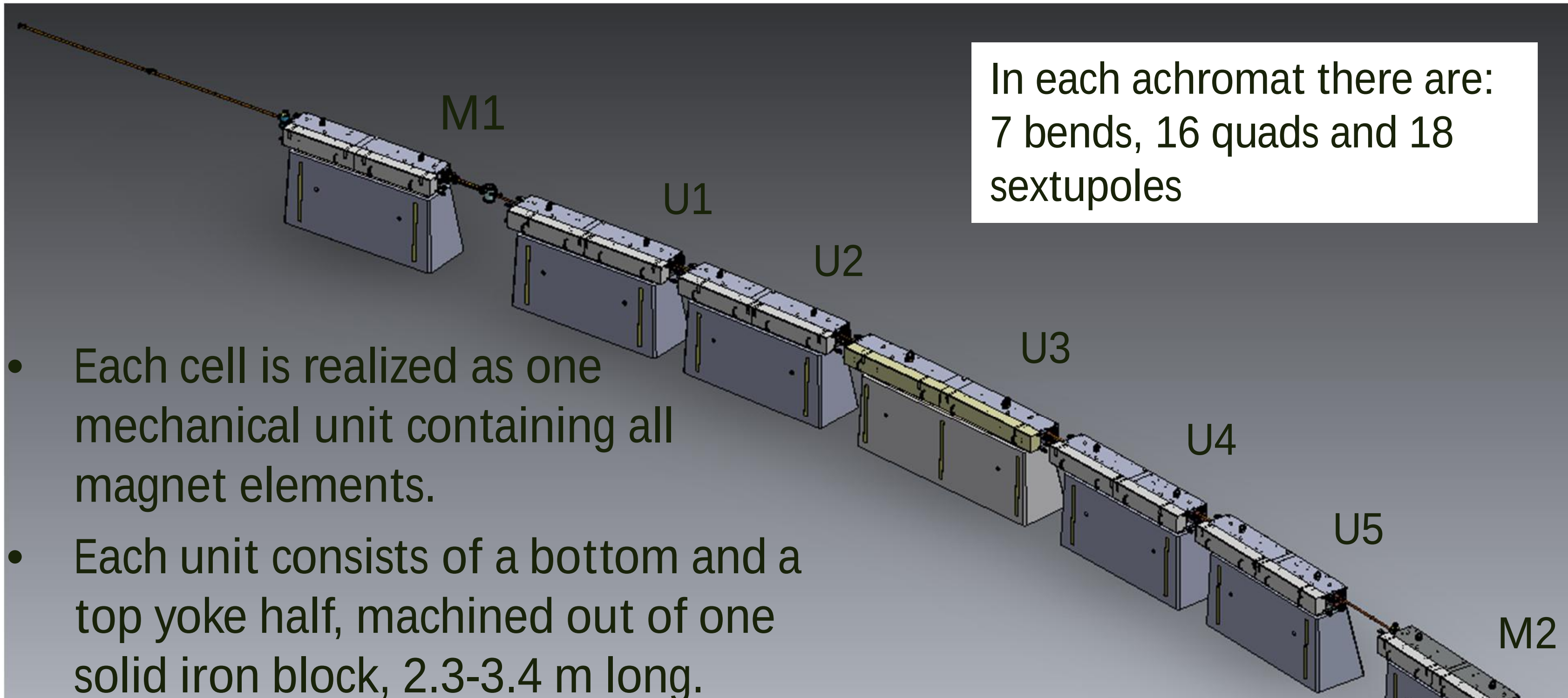


Parameters Max-IV-3 GeV:

- **Energy = 3 GeV**
- **Circumference = 528 m**
- **Emitt. (x) = 332 pmrad**
- **Emitt. (y) = 3,32 pmrad**
- **Energ. - spread = 0.00077**
- **Tune (x) = 42.2**
- **Tune (y) = 14.28**
- **Chrom. (x) = - 49.8**
- **Chrom. (y) = - 43.9**
- **Mom.-Comp.-Fact.= 0.00031**
- **Energ.-Loss per Turn = 360 keV**
- **Beta (x) = 9 m/rad**
- **Beta (y) = 4.8 m/rad**

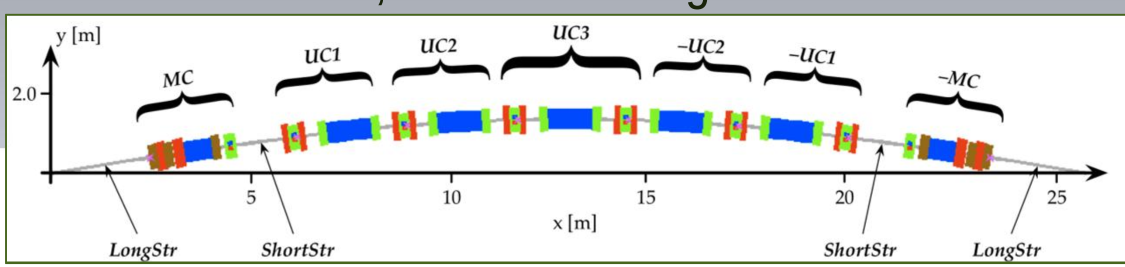

BetaX /m
BetaY /m
100 * DispX /m
Bendings: l=1,0m,
Quadrupoles: l=0,25/0,15 m, G=40,3
Sextupoles: l=0,1m, S=1700
Each achromat consists of five cells and two matching cell, with 20 achromats it means overall 140 cells
Machinefunction / m
Matching cell
Unit cell
Unit cell
Unit cell
Unit cell
Unit cell
Matching cell
s / m
20
15
10
5
0
-5
0
5
10
15
20
25

Achromat 3D cad assembly:



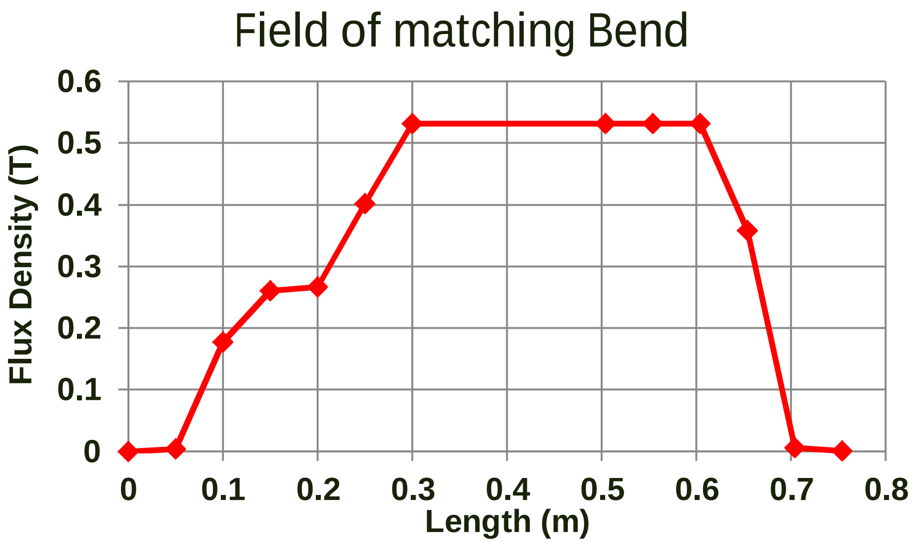
In each achromat there are: 7 bends, 16 quads and 18 sextupoles

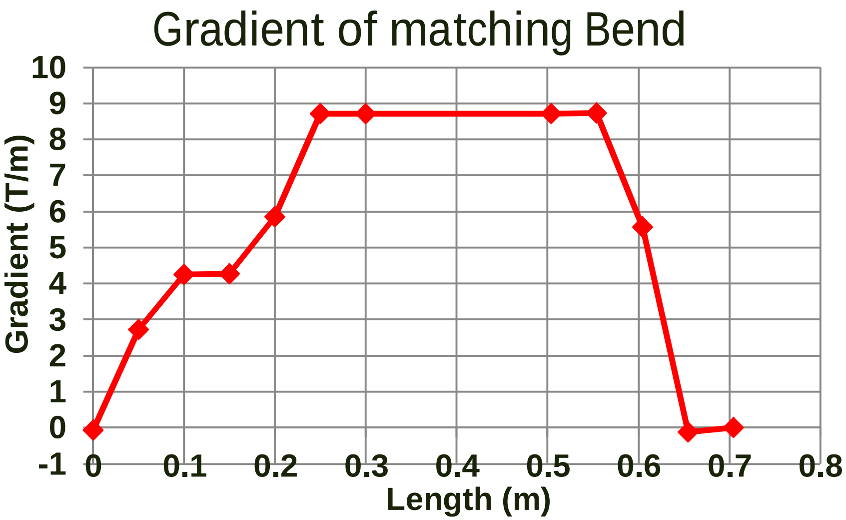
- Each cell is realized as one mechanical unit containing all magnet elements.
- Each unit consists of a bottom and a top yoke half, machined out of one solid iron block, 2.3-3.4 m long.

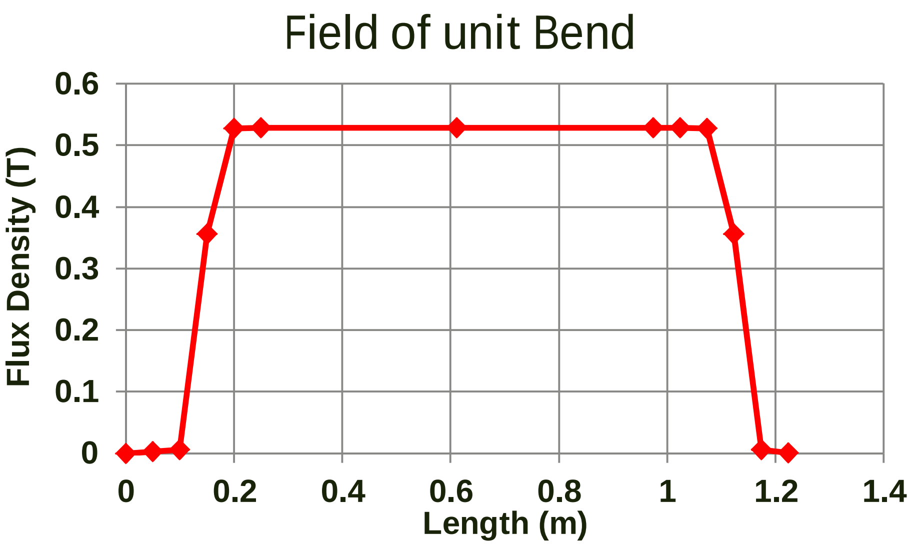


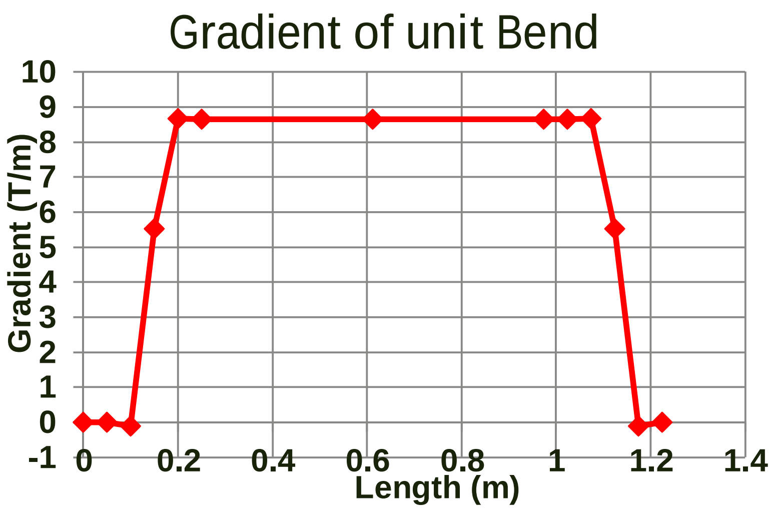
MAX IV LABORATORY

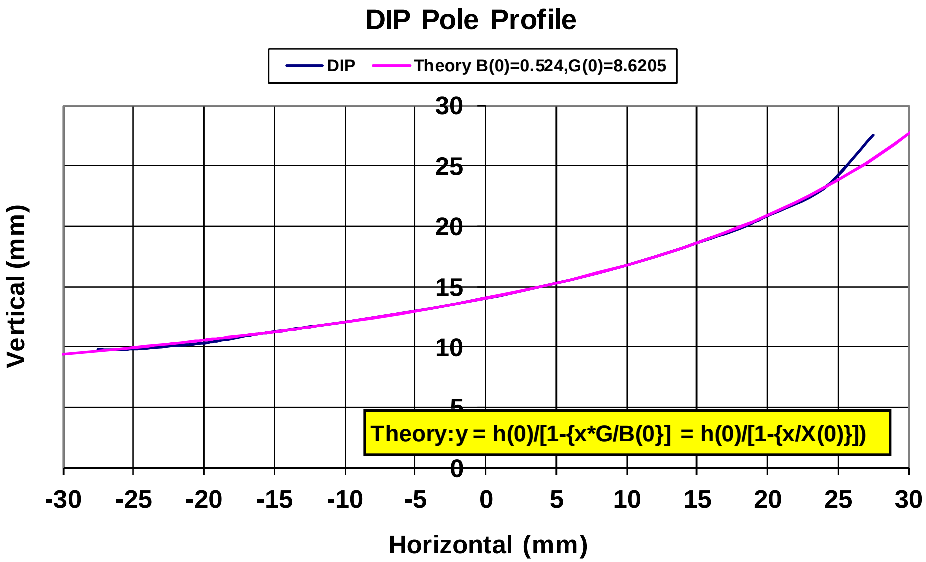
Bendings: Field and Gradient

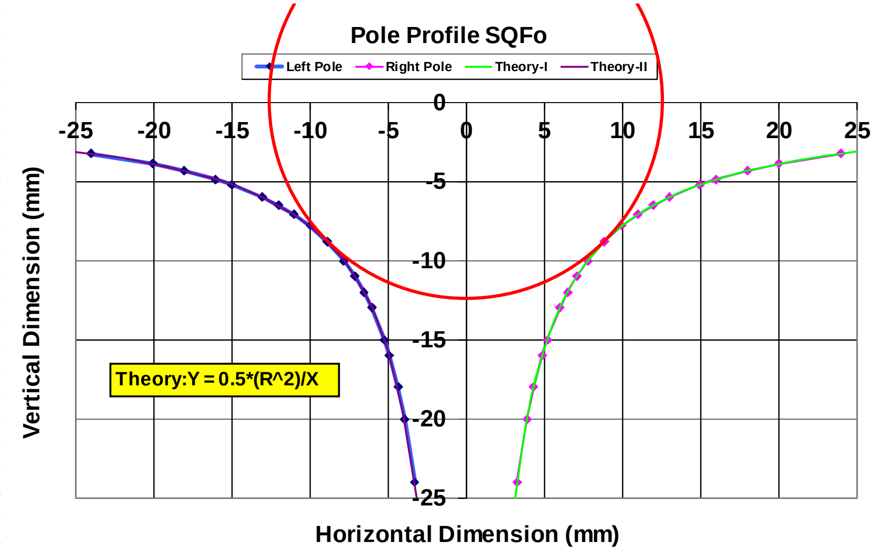




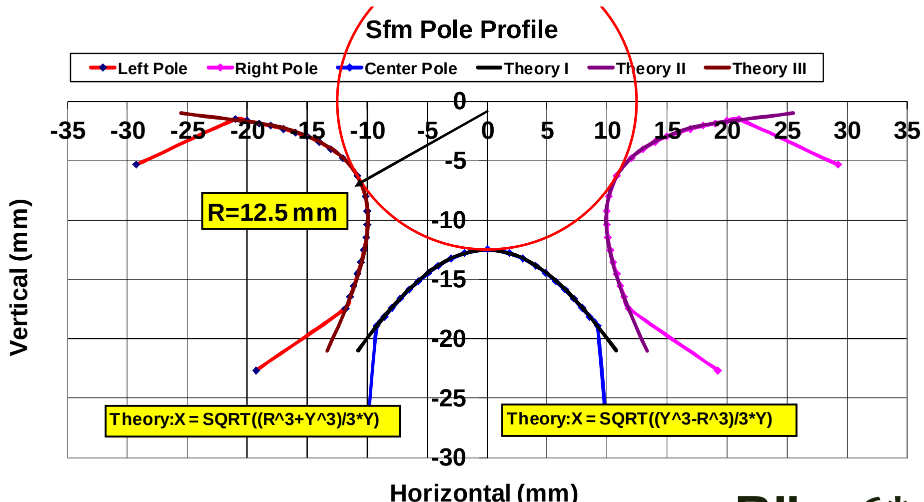


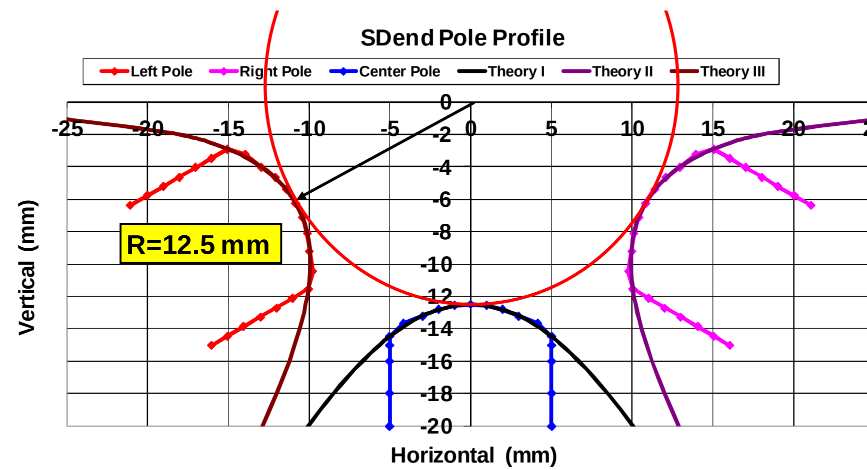






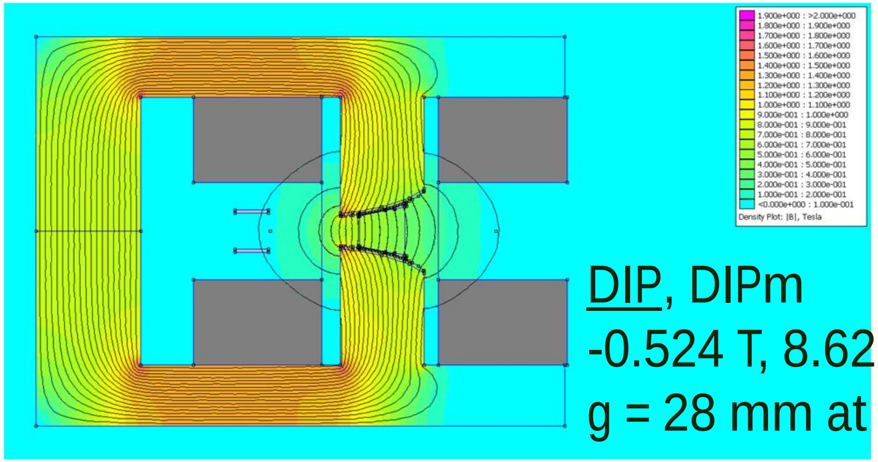
$$G=2*\mu(0)*N*I/(R^2)$$



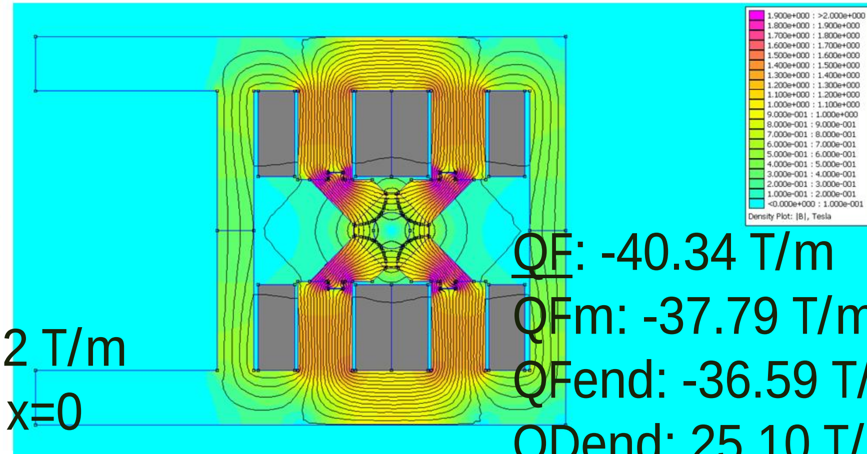


$$B''= 6*\mu(0)*N*I/(R^3)$$

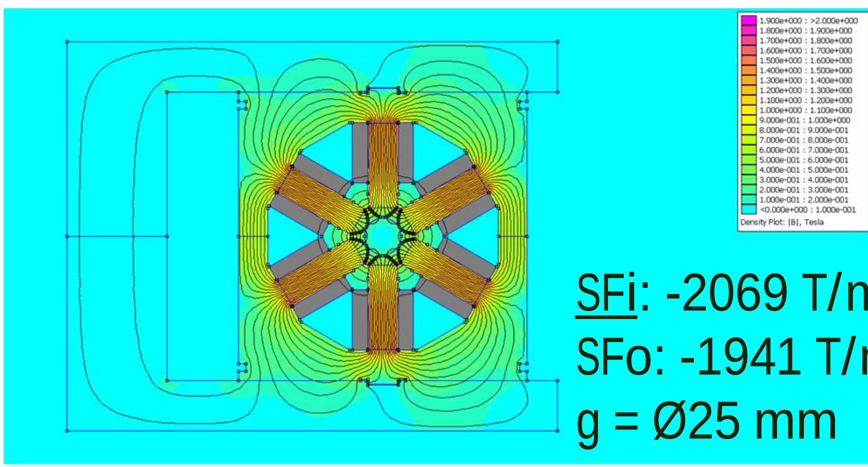
magnet elements:



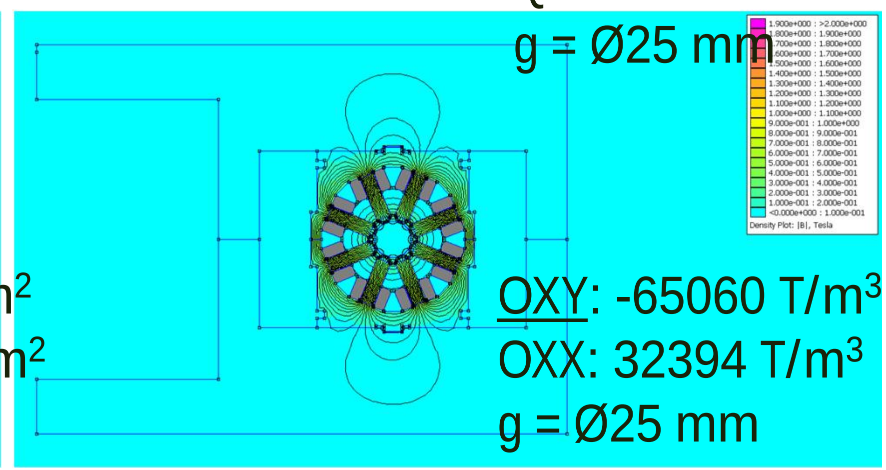
DIP, DIPm
-0.524 T, 8.622 T/m
g = 28 mm at x=0



QF: -40.34 T/m
QFm: -37.79 T/m
QFend: -36.59 T/m
QDend: 25.10 T/m
g = Ø25 mm



SFi: -2069 T/m^2
SFo: -1941 T/m^2
g = Ø25 mm



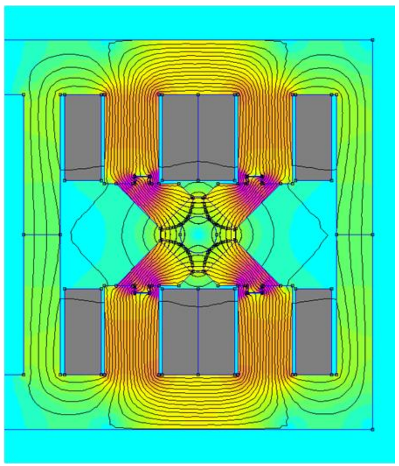
OXY: -65060 T/m^3
OXX: 32394 T/m^3
g = Ø25 mm

... + SFm, SD, SDend (g = Ø25 mm), OYY (g = Ø36 mm) and corr h/v (g = 25 mm)

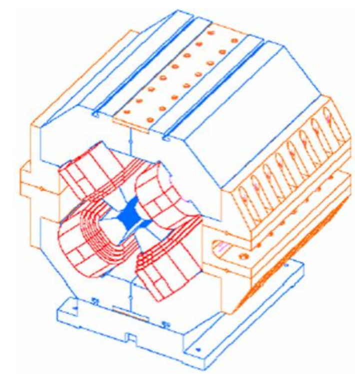
Magnets in Max-IV 3 GeV (Dec. 2012)

Section:	Magnets	Length	B / k / m	Gr. / B"	Current	N*I	B(pole)
MC1	QFend	0.25	3.654	36.570	58.3	2273.7	0.457
	QDend	0.25	-2.504	-25.058	40	1560	0.314
	DIP (soft)	0.15	0.377	5.837	395	11850	0.266
	Dip (hard)	0.4	0.513	8.608	395	11850	0.532
	SDend	0.1	-134.000	-2682.305	53.45	694.85	0.210
U1	QFm	0.15	3.774	37.772	60.25	2349.75	0.472
	SFm	0.1	160.000	3202.752	63.82	829.66	0.250
	QFm	0.15	3.774	37.772	60.25	2349.75	0.472
	SD	0.1	-116.625	-2334.506	54.98	604.78	0.182
	DIP	1	0.524	8.608	681	36774	0.528
	SD	0.1	-116.625	-2334.506	54.98	604.78	0.182
U2	QF	0.15	-4.030	-40.335	64.3	2507.7	0.504
	SFo	0.1	170.000	3402.924	58.76	881.4	0.266
	QF	0.15	-4.030	-40.335	64.3	2507.7	0.504
	SD	0.1	-116.625	-2334.506	54.98	604.78	0.182
	DIP			0.000	681	36774	0.528
	SD	0.1	-116.625	-2334.506	54.98	604.78	0.182
U3	QF	0.15	4.030	40.335	64.3	2507.7	0.504
	SFi	0.1	207.412	4151.807	71.7	1075.5	0.324
	QF	0.15	4.030	40.335	64.3	2507.7	0.504
	SD	0.1	-116.625	-2334.506	54.98	604.78	0.182
	DIP			0.000	681	36774	0.528
	SD	0.1	-116.625	-2334.506	54.98	604.78	0.182
	QF	0.15	4.030	40.335	64.3	2507.7	0.504
	SFi	0.1	207.412	4151.807	71.7	1075.5	0.324
	QF	0.15	4.030	40.335	64.3	2507.7	0.504

Comparison between ALBA and MAX IV Quads

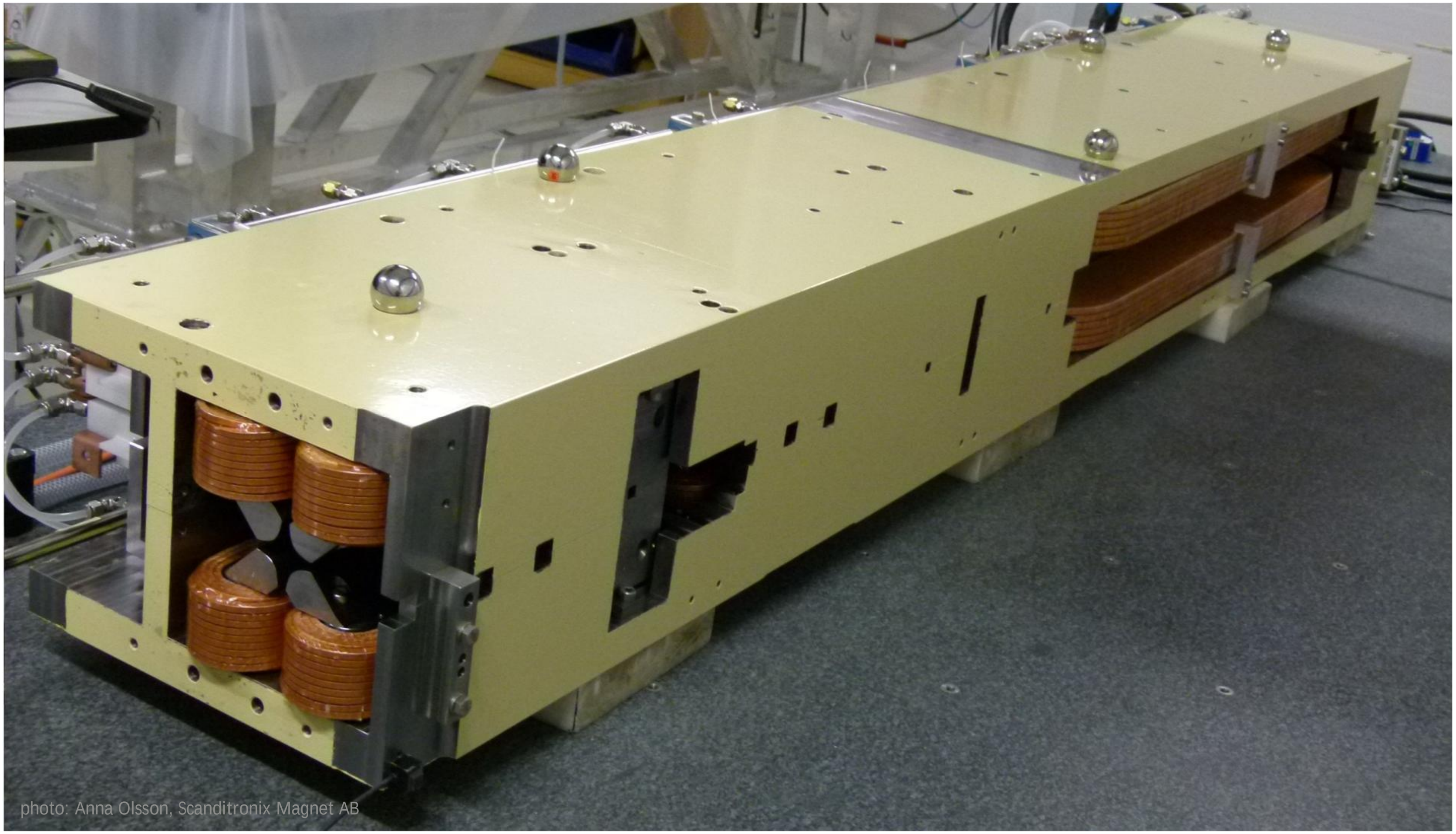


		MAX IV	ALBA
Gradient	(T/m)	40.24	20.1
Length	(m)	0.15	0.31
Grad.* length	(T)	6.04	6.23
Bore radius	(mm)	12.5	30.5
B(pole)	(T)	0.5	0.61
Turns per coil		39	46
Current	(A)	72.3	161
Power	(W)	250	1670



G=2*μ(0)*N*I/(R^2)

MAX IV magnet design



Iron blocks delivered to Max-Lab

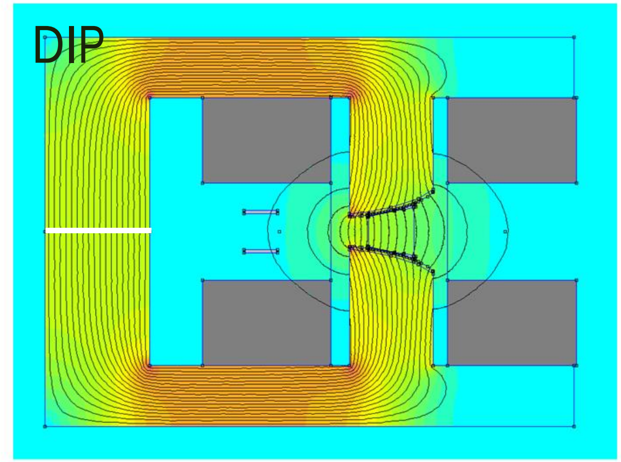
why the magnet block concept?

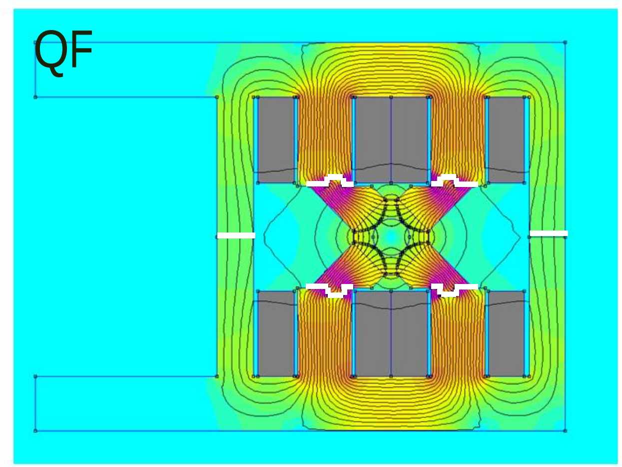
As opposed to standalone magnets not sharing a common return yoke...

- First of all, separate magnets on individual adjustment stands were never considered, because
  - we assumed that optical alignment would be less accurate between consecutive elements.
  - given the small footprint of our magnet elements, designing adjustment stands stiff enough to give the same level of vibration stability would have been difficult.
- So, from the perspectives of alignment and vibration stability, we were looking at a solution with several consecutive magnet elements in the same mechanical unit.

why the magnet block concept?

- DIP and QF cross sections →
- Separate magnets on a girder requires one more mating surface, decreasing the alignment accuracy. Therefore the magnet block concept.
- Expected rms alignment as sum of squares of parts, x,y = ±0.016,±0,020 for dipoles, = ±0.018,±0,021 for quads, = ±0.023,±0,025 for quads, with pessimistic assumption each part at max tolerance.
- Also, it is easier to achieve good vibrational stability with the magnet block concept. Lowest eigenfrequency ≈ 90 Hz for MAX IV, vs ≈ 30 Hz for MAX II.

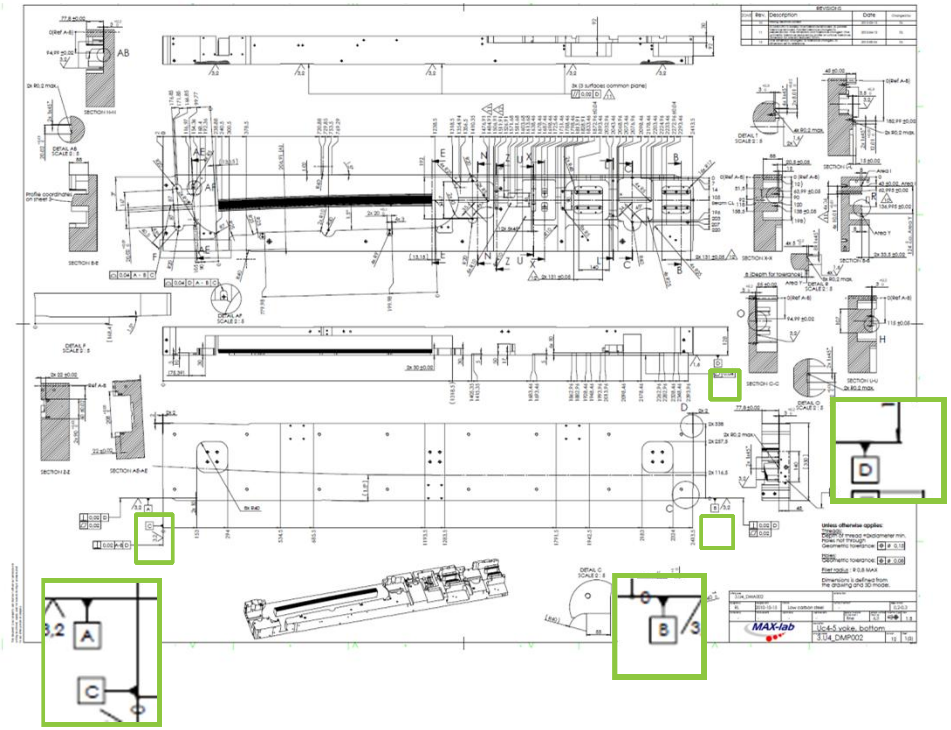




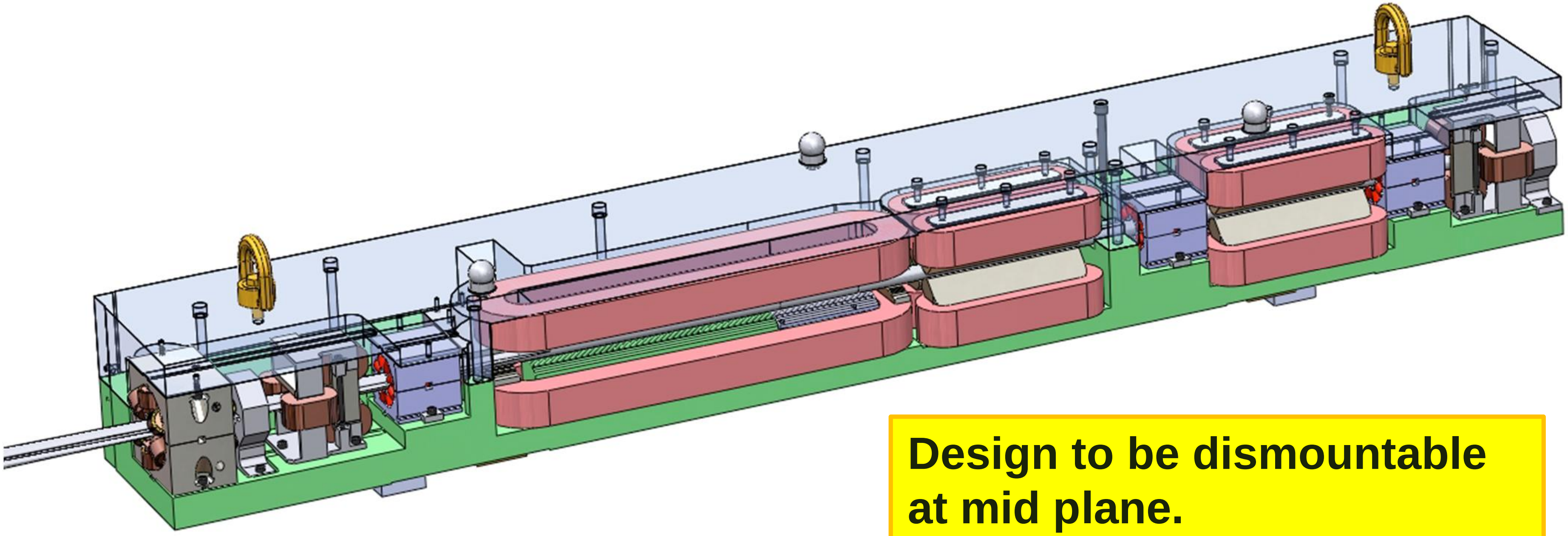
why the magnet block concept?

- At MAX IV, we typically want to subcontract as much work as possible to industry, minimizing the internal personnel need.
- We therefore chose an alignment concept based on mechanical tolerances over field meas. believing this is easier to subcontract to industry.

specification



- Suppliers deliver magnet blocks fully assembled and wired, ready to put directly in ring tunnel and connect ps and water.
- Suppliers are responsible for mechanical tolerances on parts.
- MAX IV is responsible for magnetic design.
- Mechanical tolerances on the yoke bottom and top pieces are defined relative to reference planes A, B, C and D.
- Dipole surface and quad/6pole/8pole guiding surfaces have ±0.02 mm tolerance relative to D, A-B and C.
- Suppliers perform field measurements of all magnet elements to MAX IV instructions.



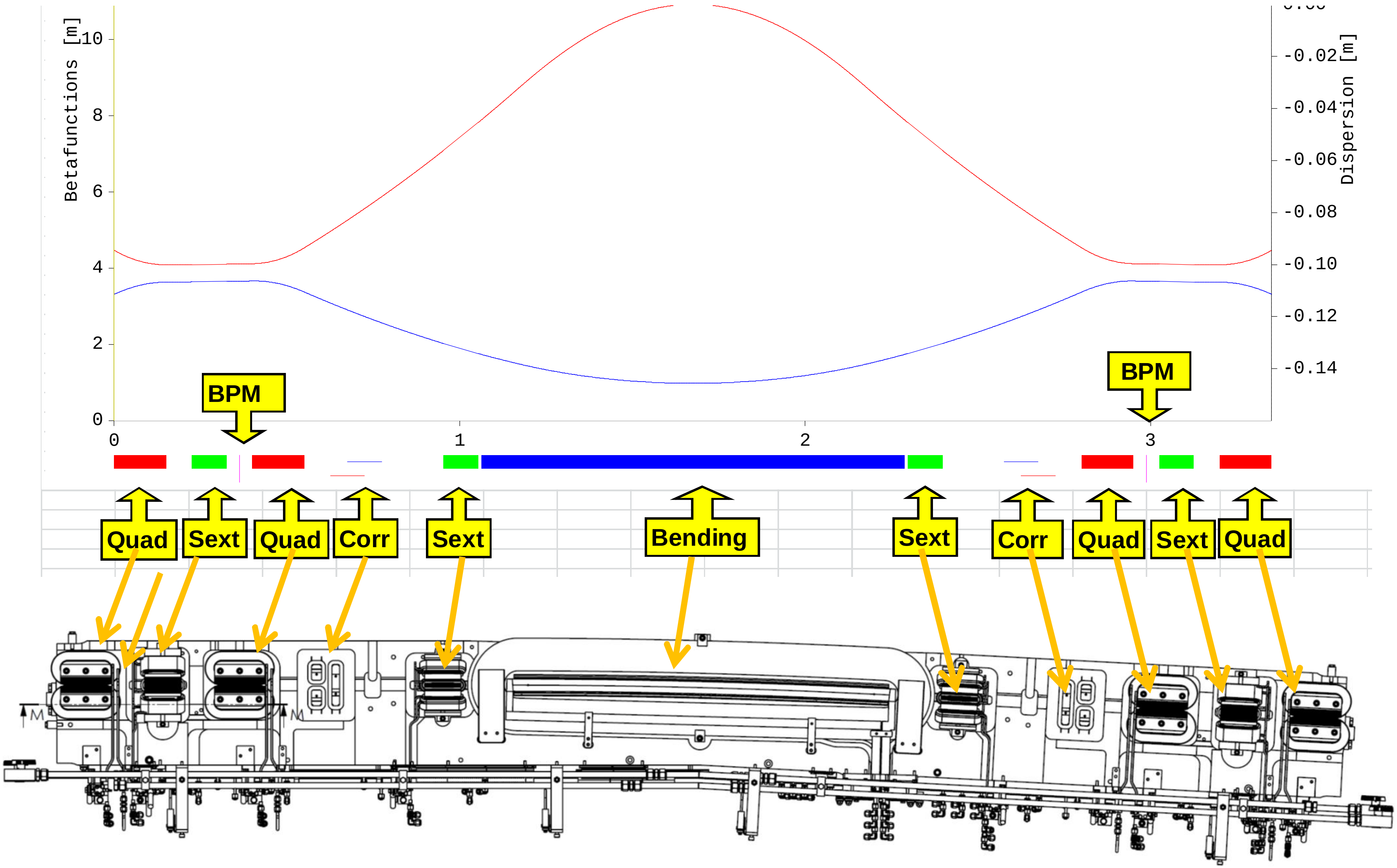
Design to be dismountable at mid plane.

Coils can be exchanged without breaking the vacuum.

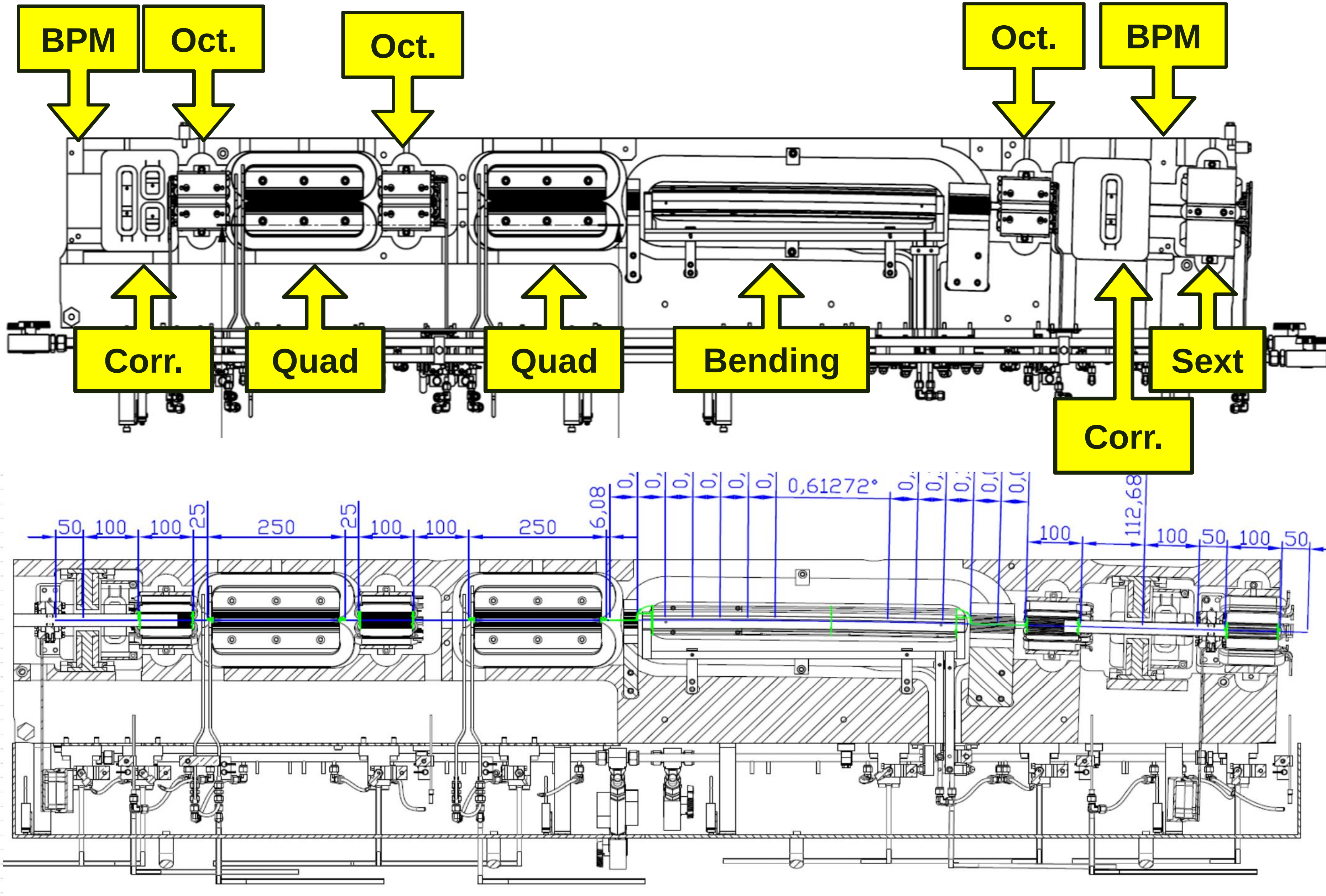
Magnets connected to the same PS can be shunted to the same strength.

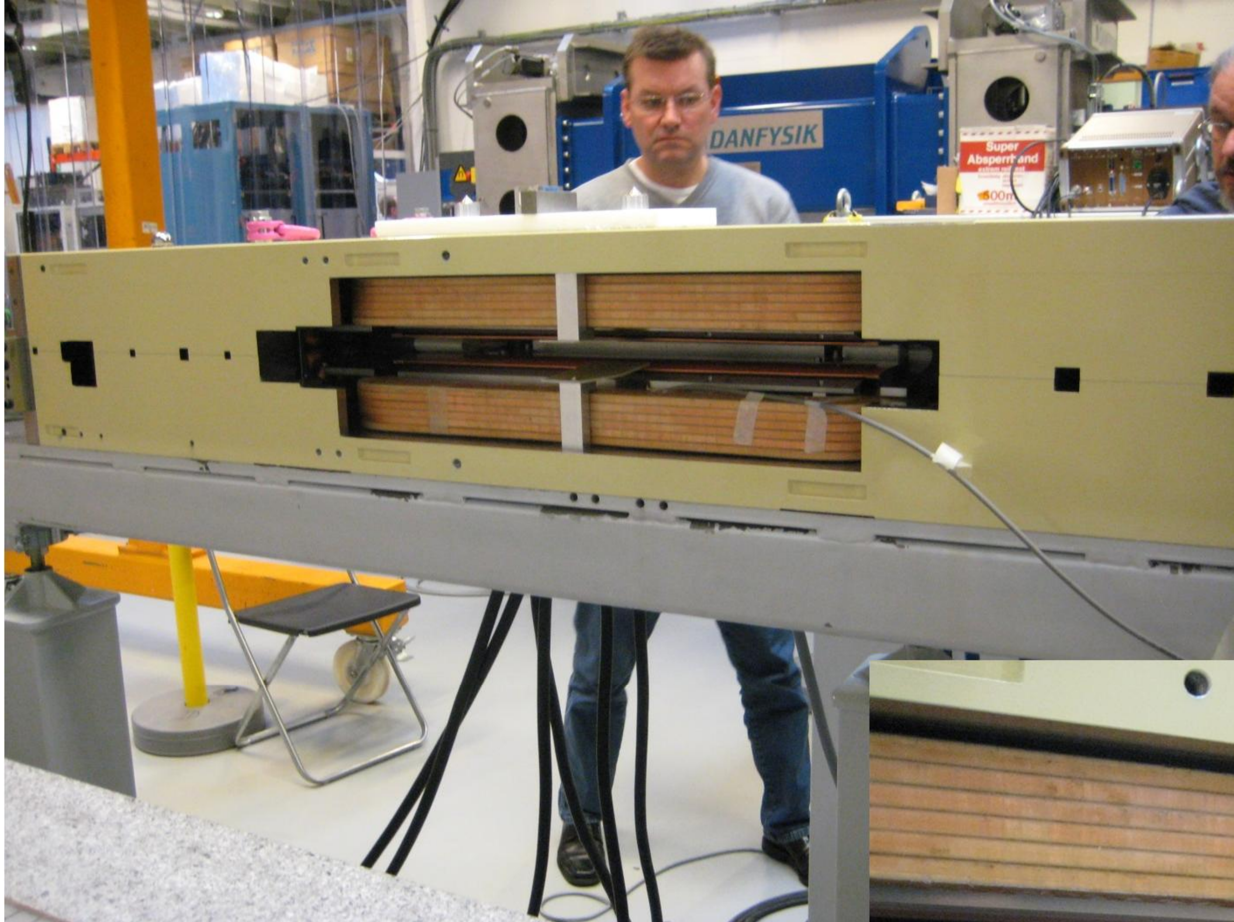
Each cell is realized as one mechanical unit with several magnet elements.

MAX IV: Unit Cell



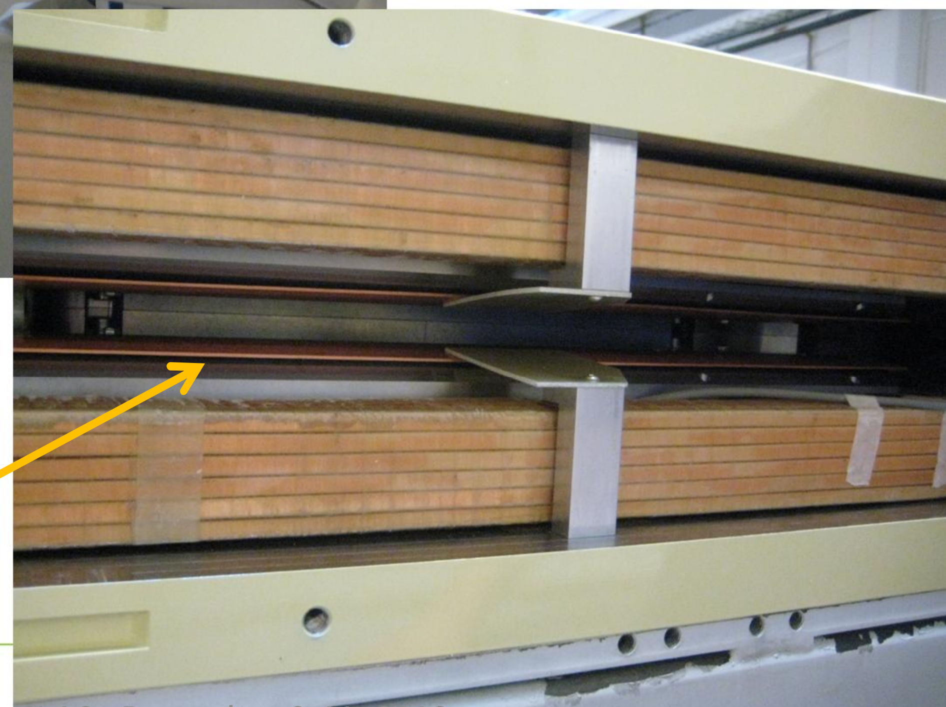
MAX IV: Matching Cell



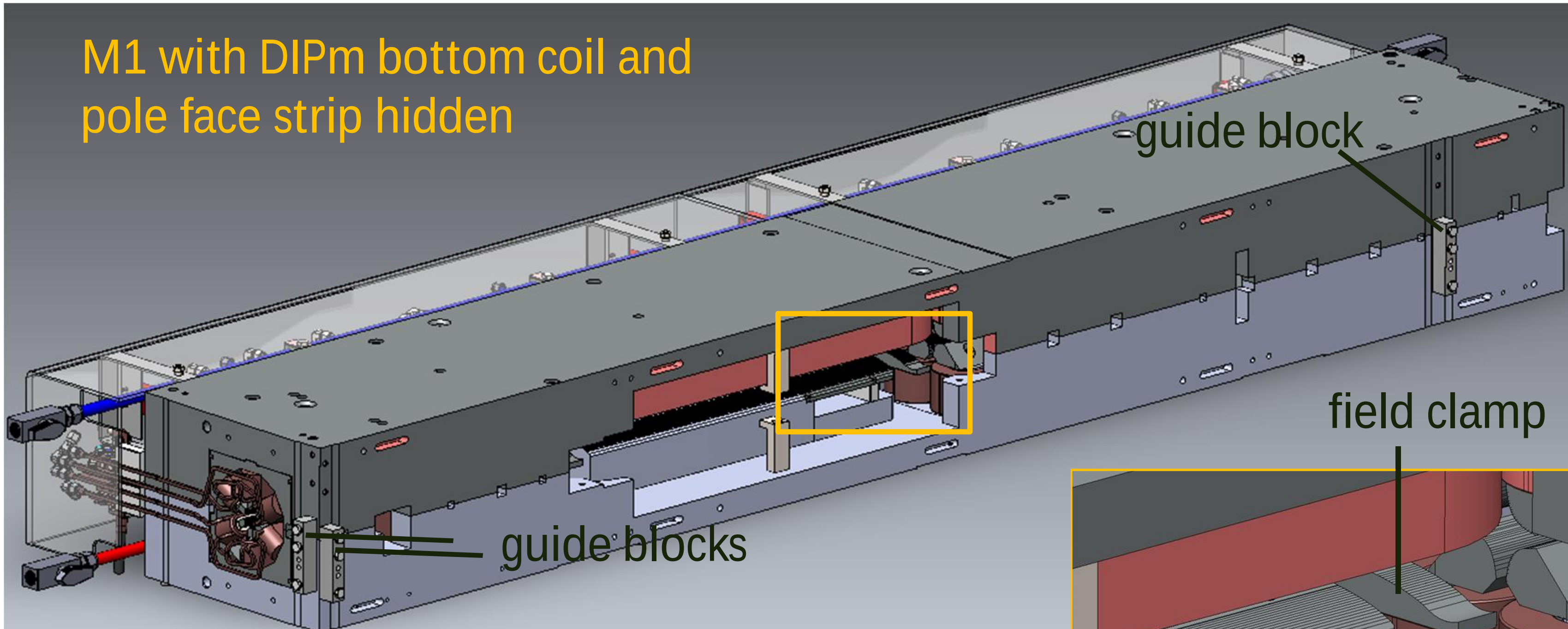


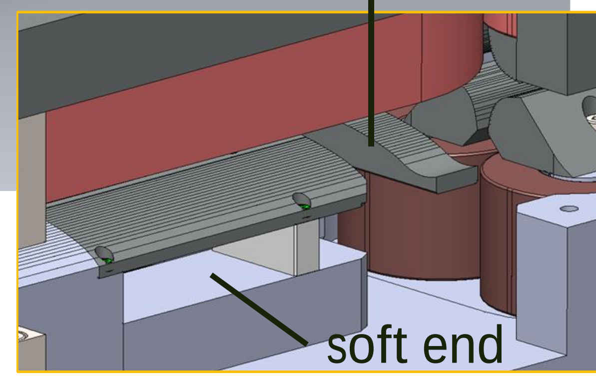
The magnet block for UC3 with the openings to make Hall probe measurements

The bending magnets have pole face windings to change the gradient by +/- 4 %



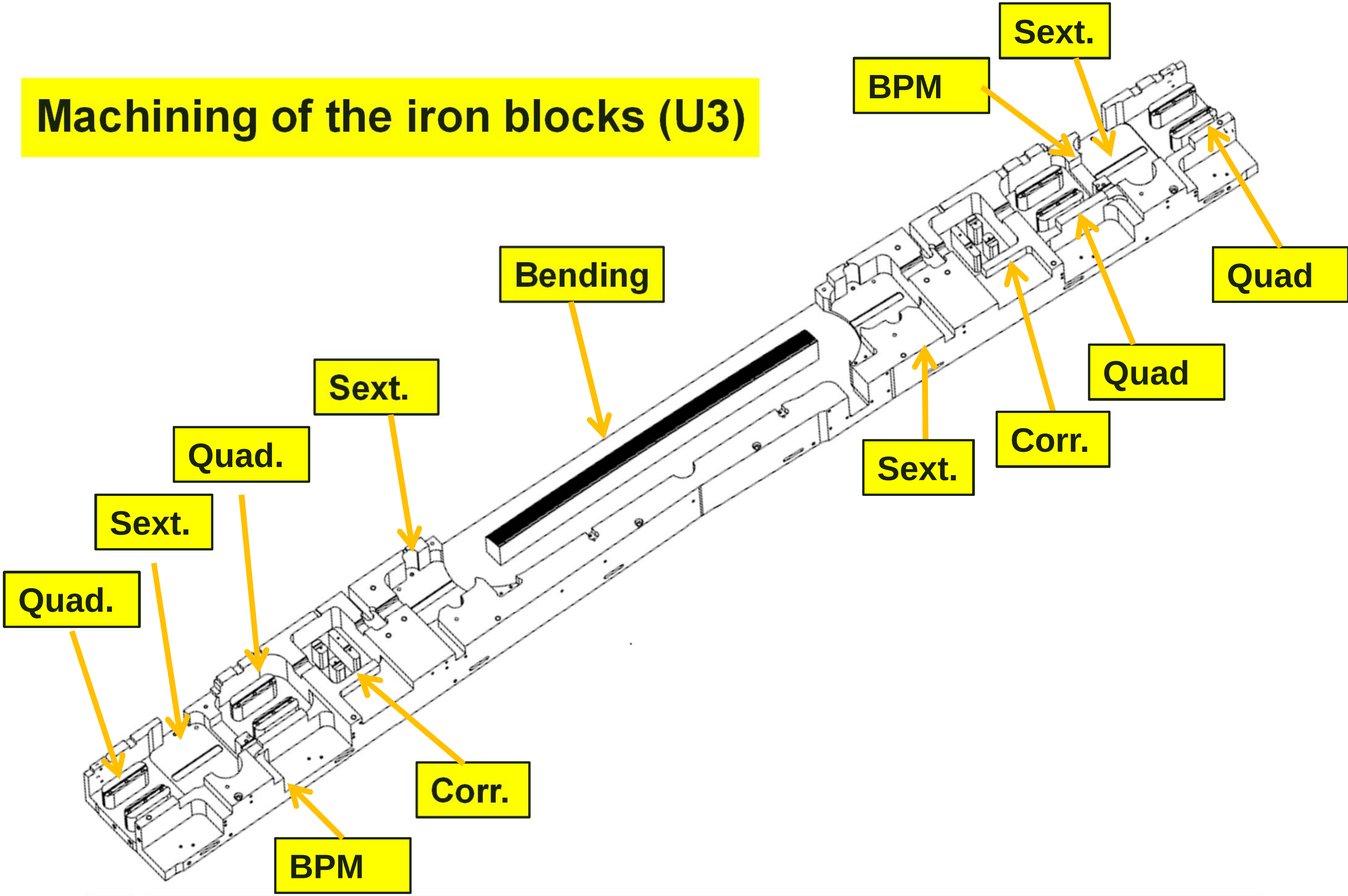
more details:



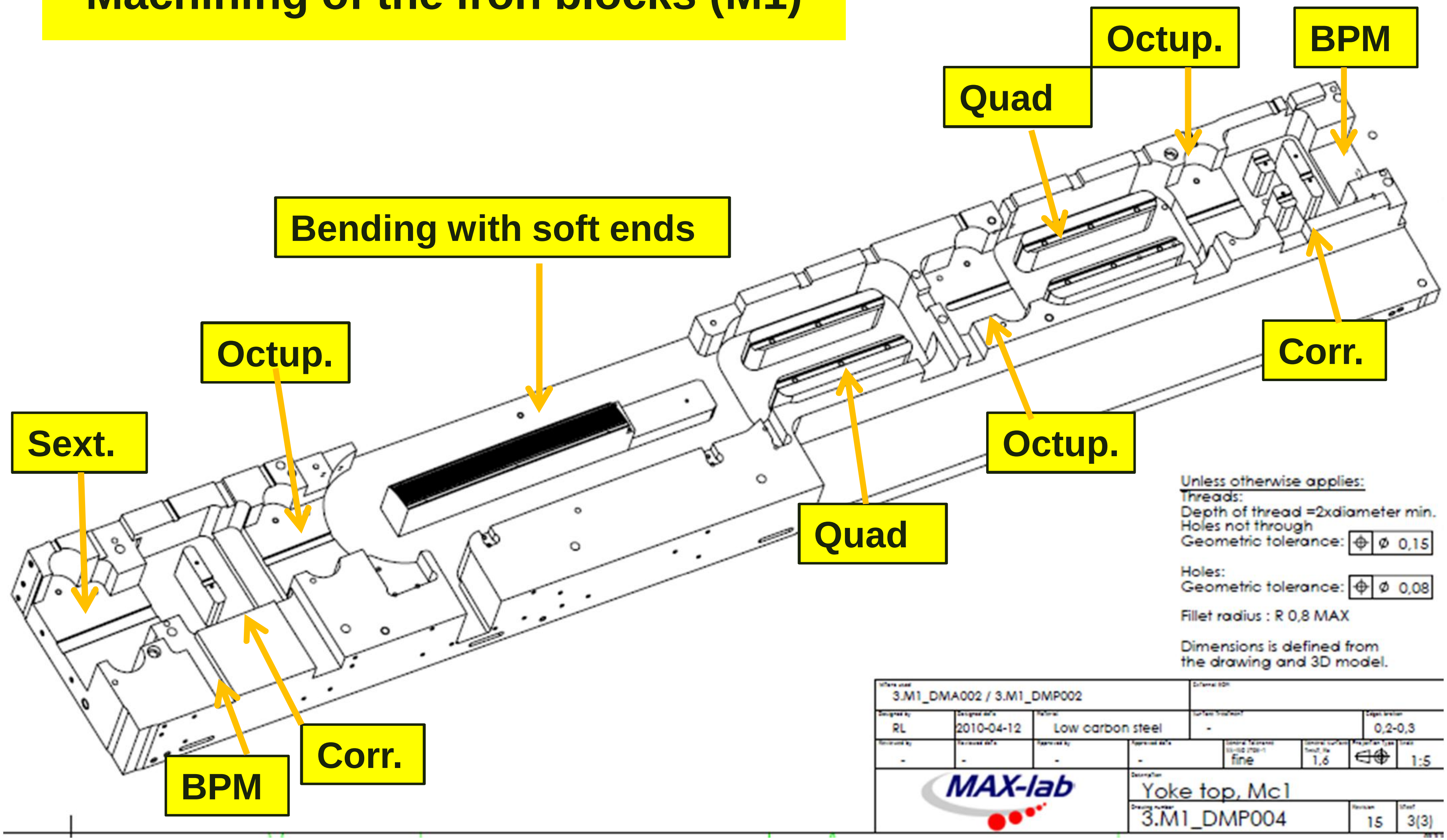


- Top half aligned to bottom half by 3 guiding blocks on bottom + top outer reference surfaces.
- Field clamps reduce the dipole fringe field distribution sensitivity to coil shape.
- M1/M2 DIPm soft end reduces thermal load to the long straight.

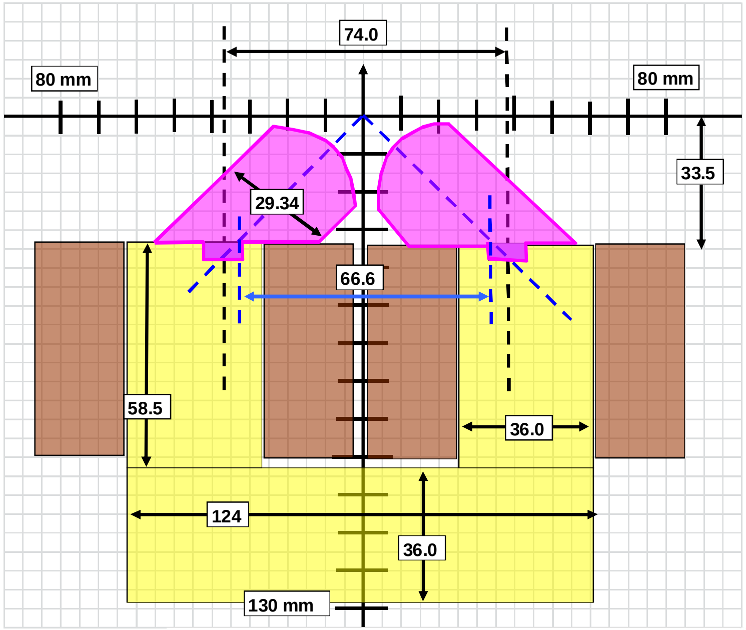
Machining of the iron blocks (U3)

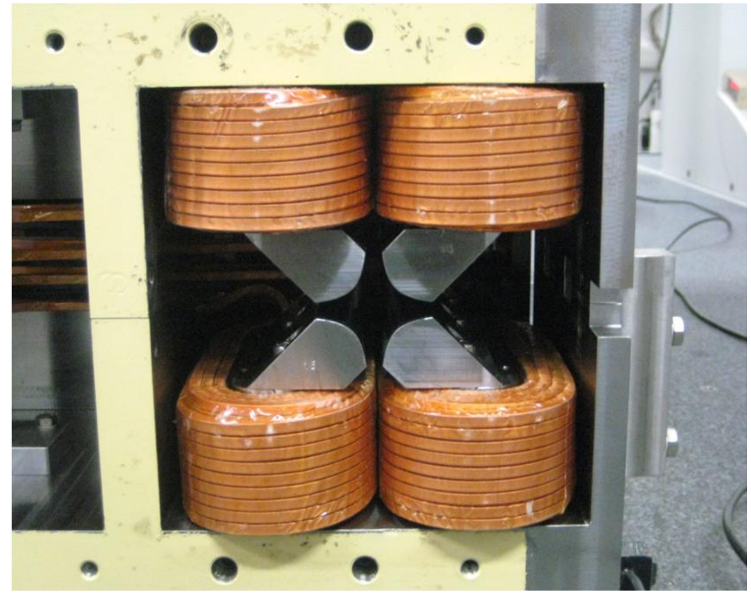


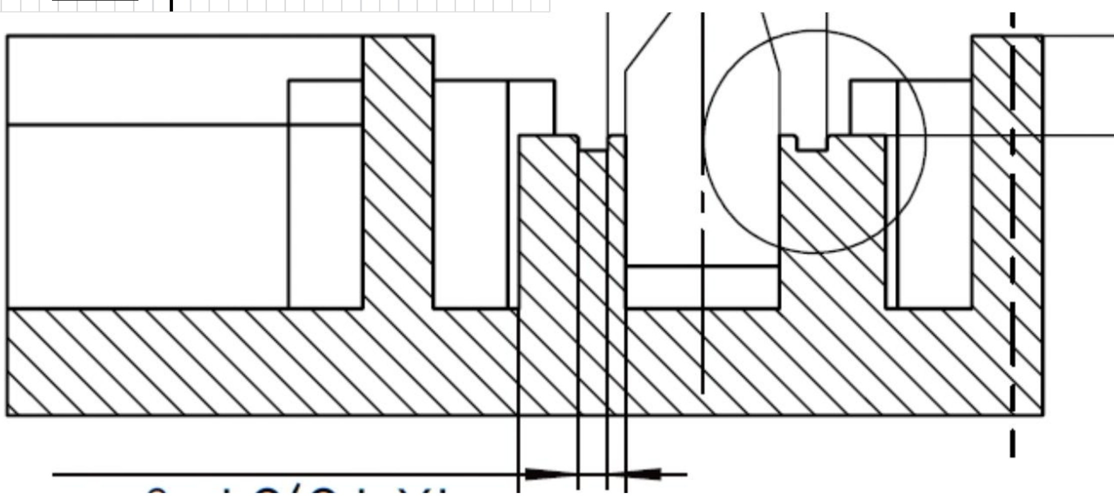
Machining of the iron blocks (M1)

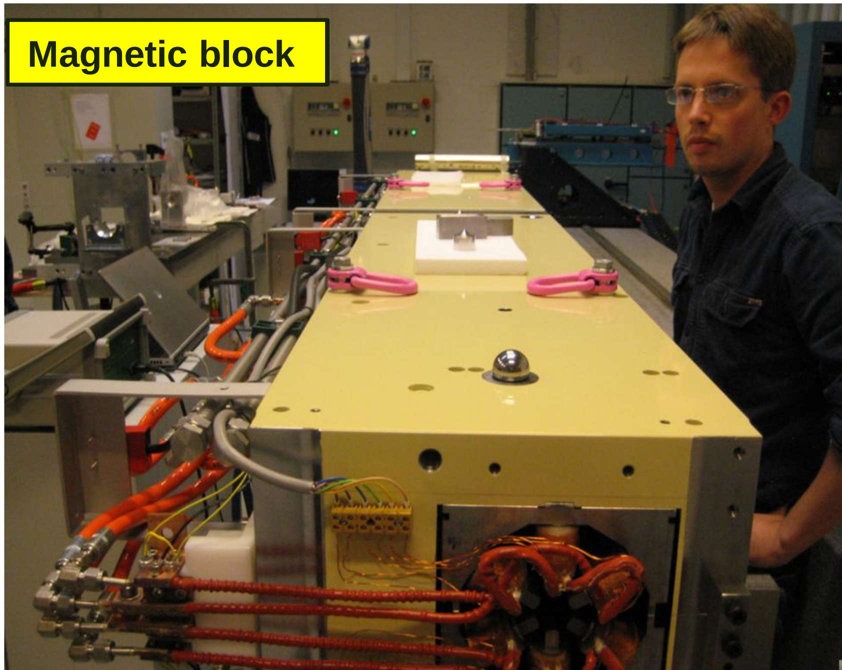


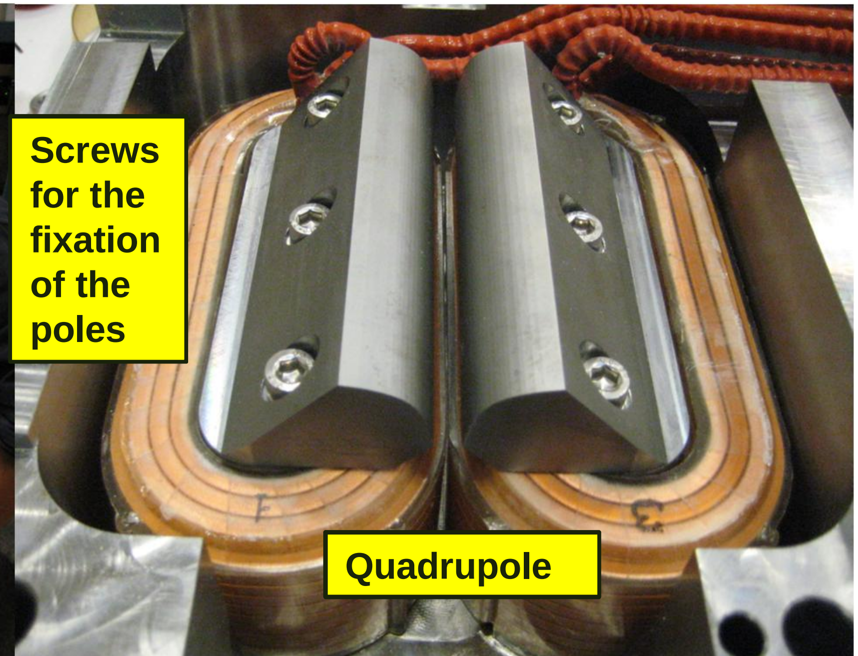
Machining of the Quadrupoles

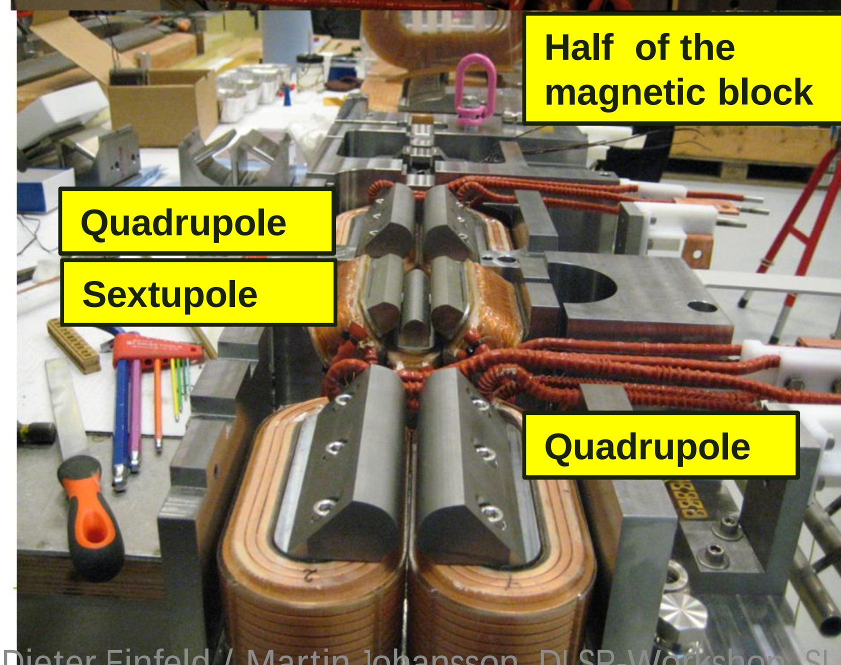


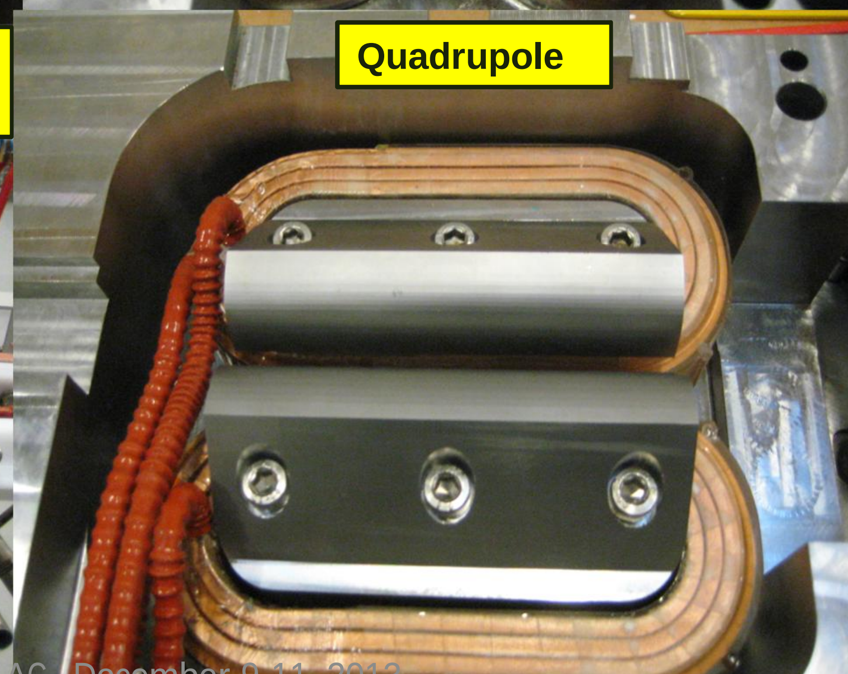





Magnetic block

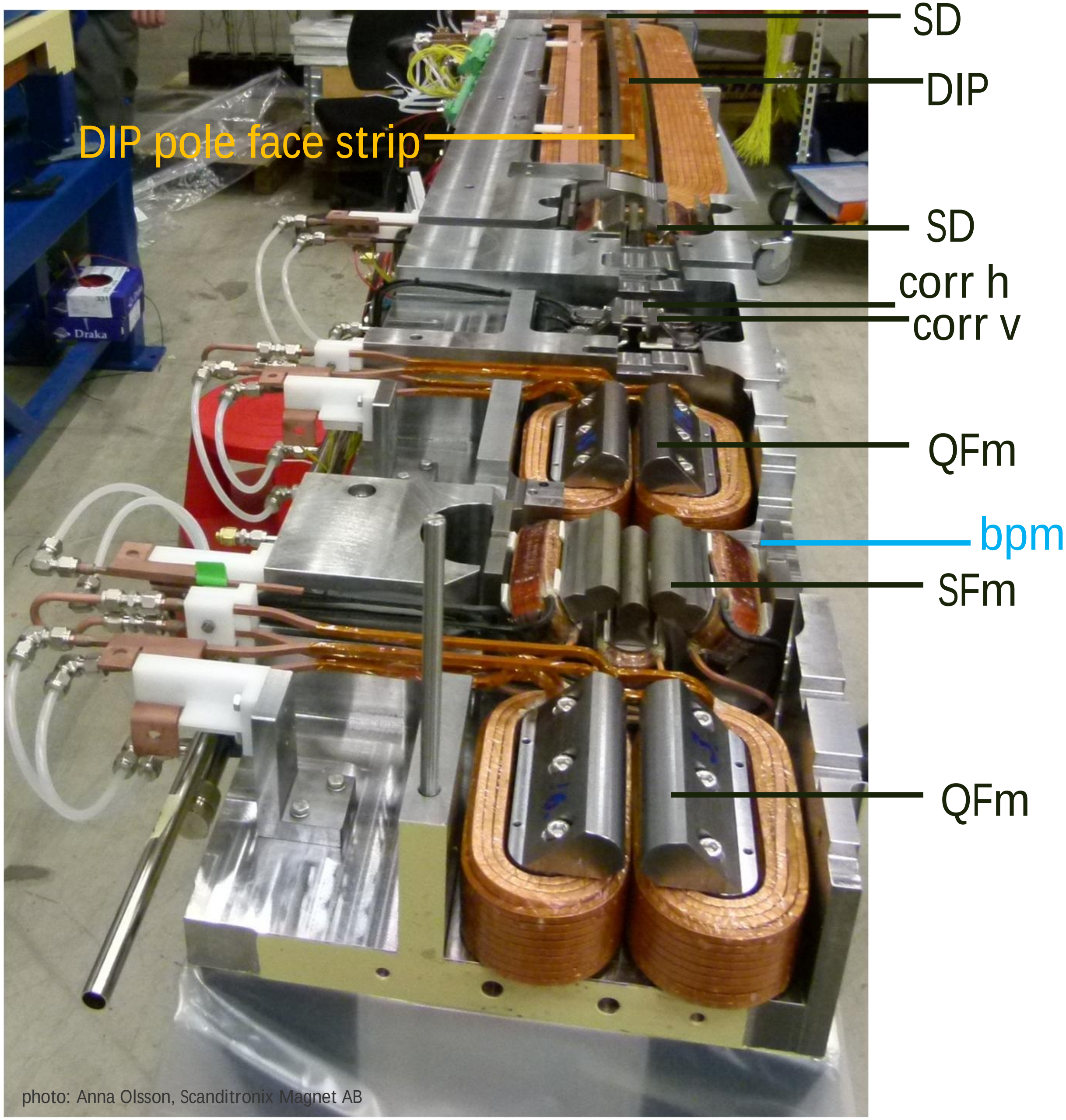

Screws for the fixation of the poles
Quadrupole


Half of the magnetic block
Quadrupole
Sextupole
Quadrupole

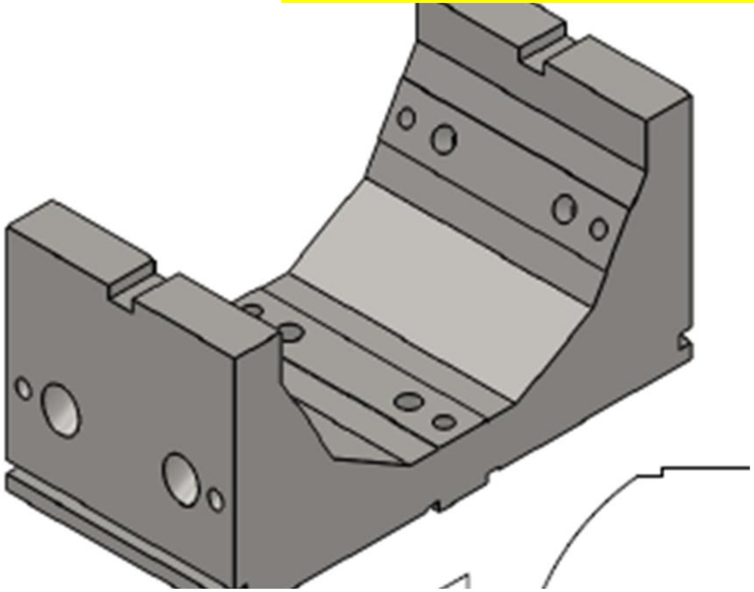

Quadrupole

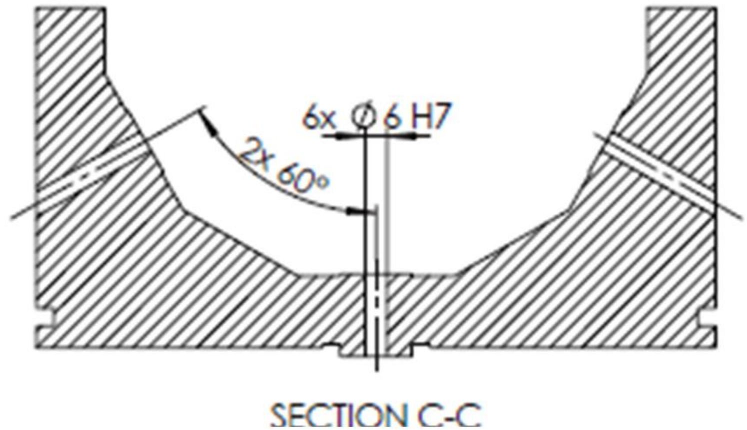
a MAX IV magnet block:

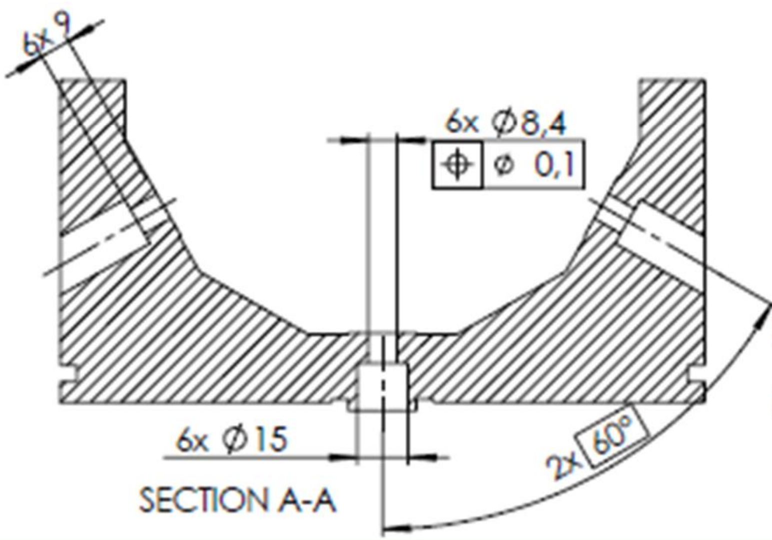
- Dismountable at horizontal midplane.
- all yoke parts = Armco low carbon steel.
- Quad and corr pole tips mounted over the coil ends.
- 6pole and 8pole magnet halfs mounted into guiding slots in yoke block.
- Electrical and water connections located towards inside.

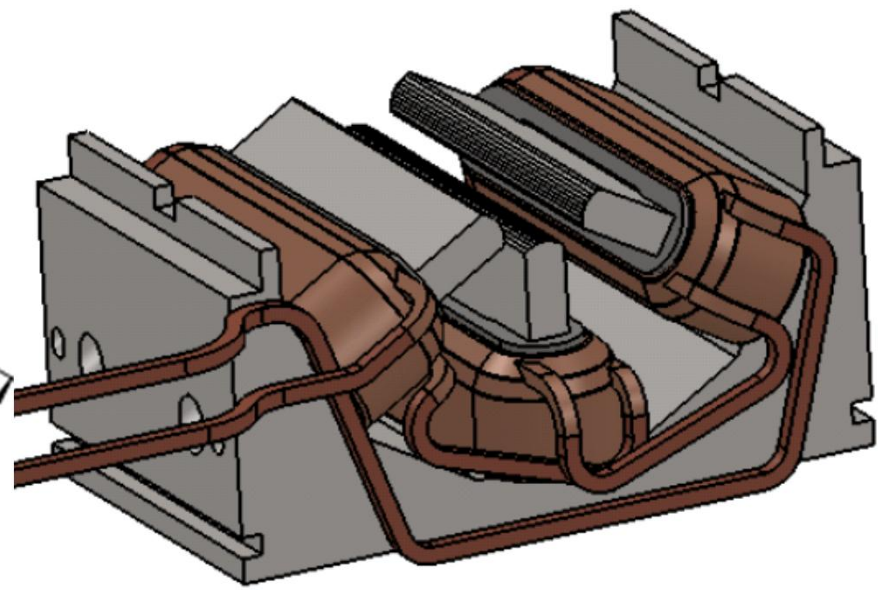


Machining of the Sextupoles





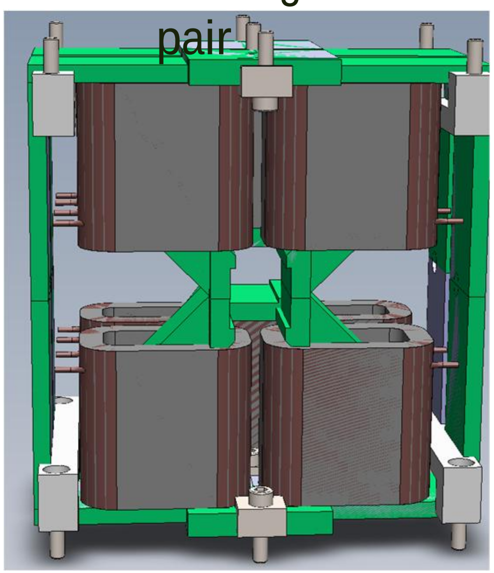




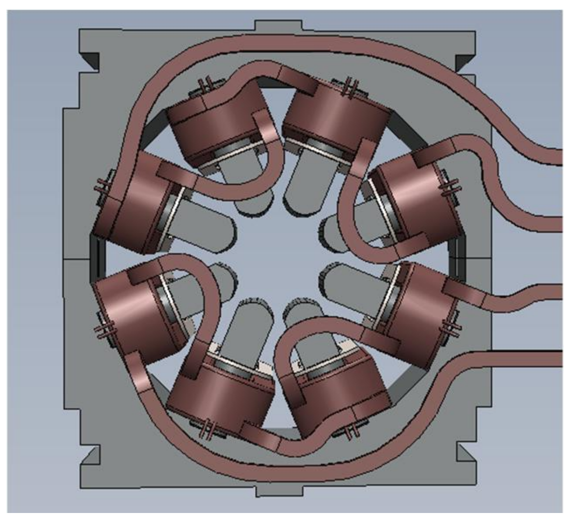
Small magnets

- The smaller magnets (25 mm) define the chamber aperture
- All magnets are made in an upper and a lower half that may be opened in the mid plane

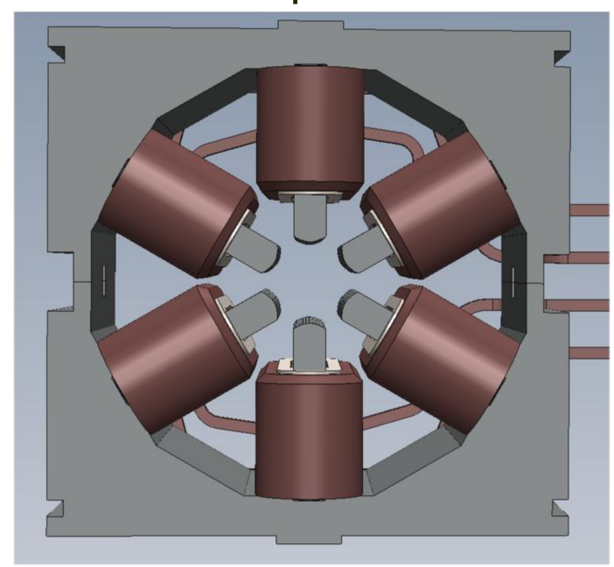
Corrector magnet pair



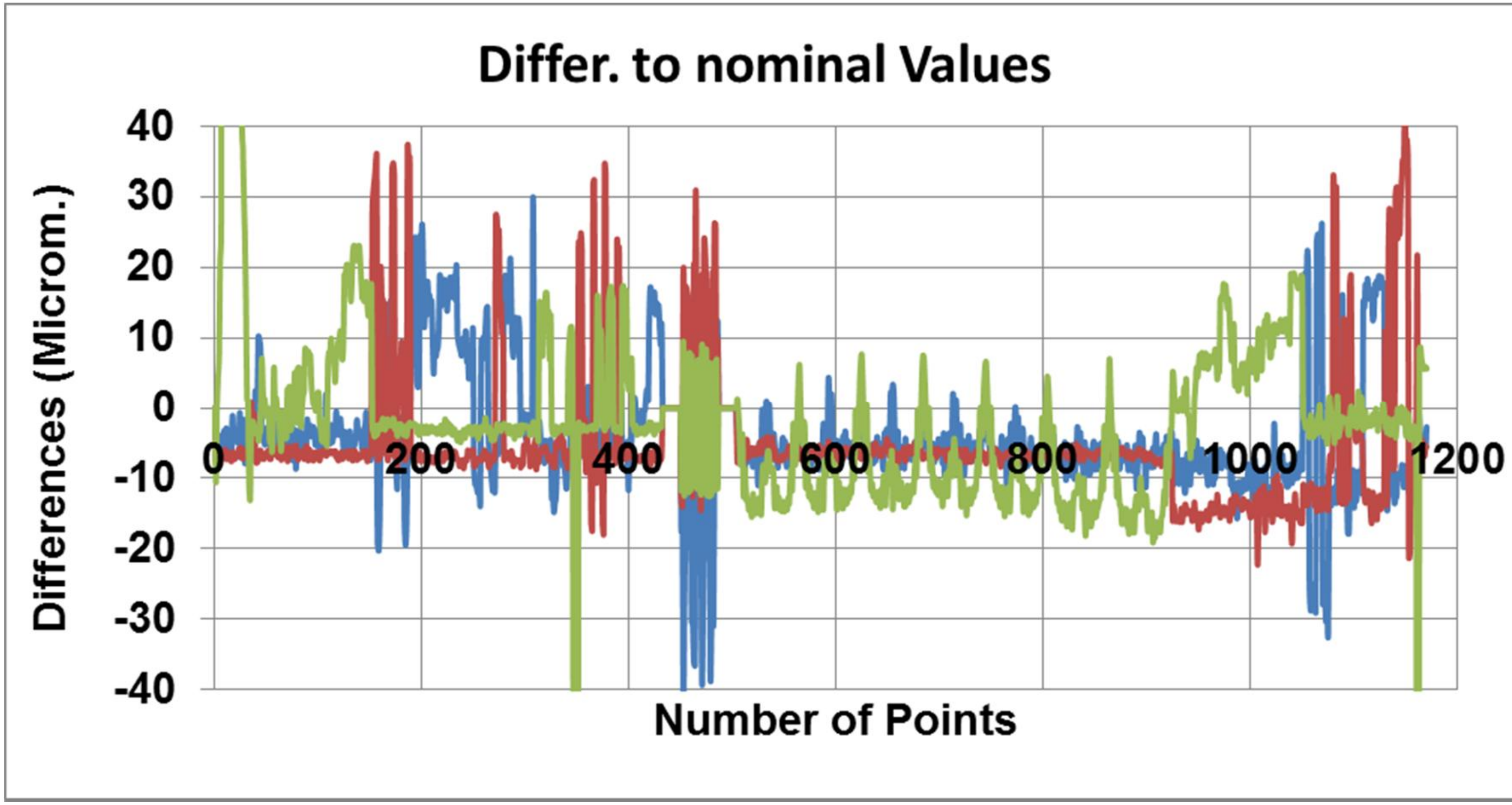
Octupole



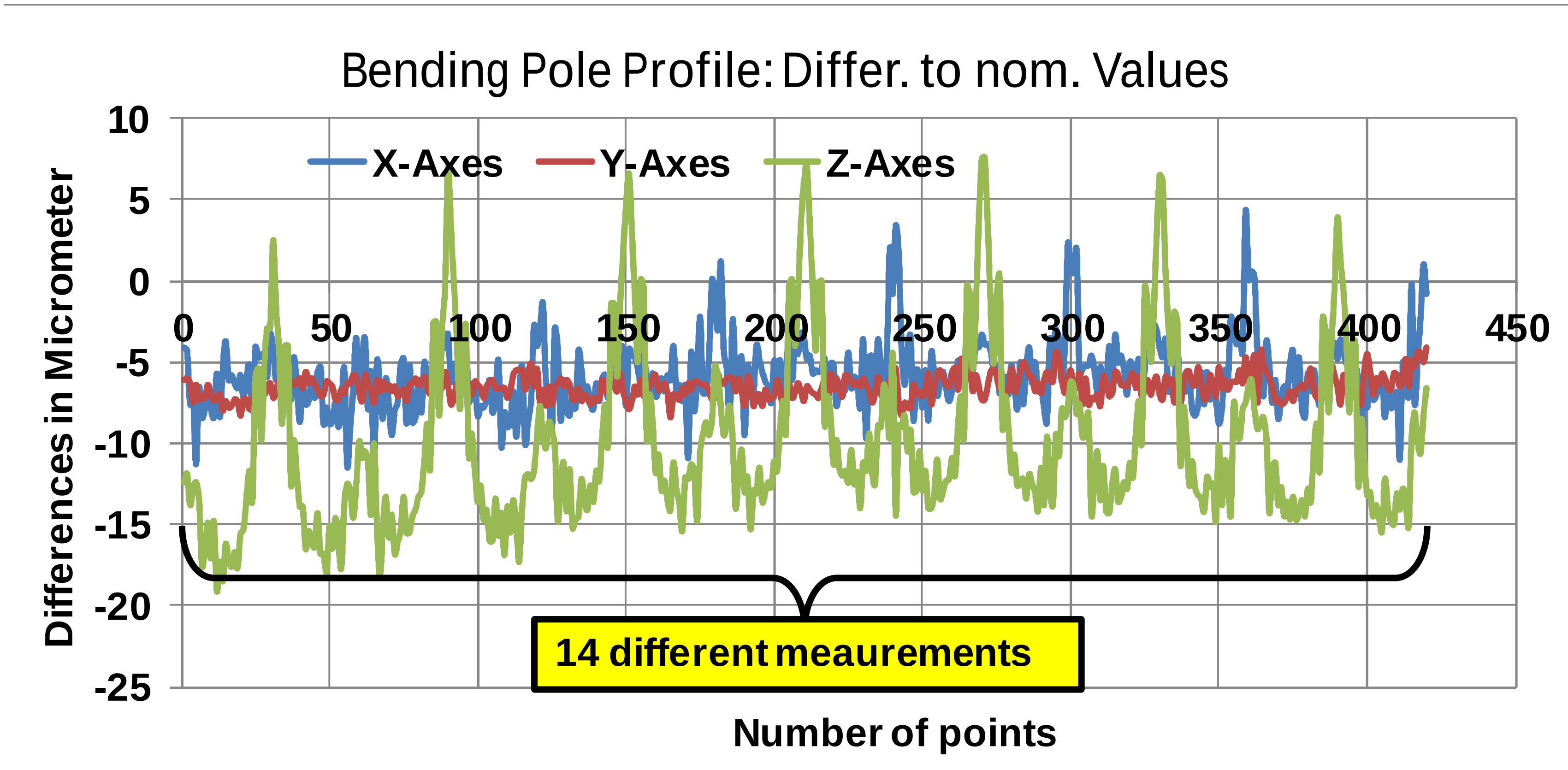
Sextupole



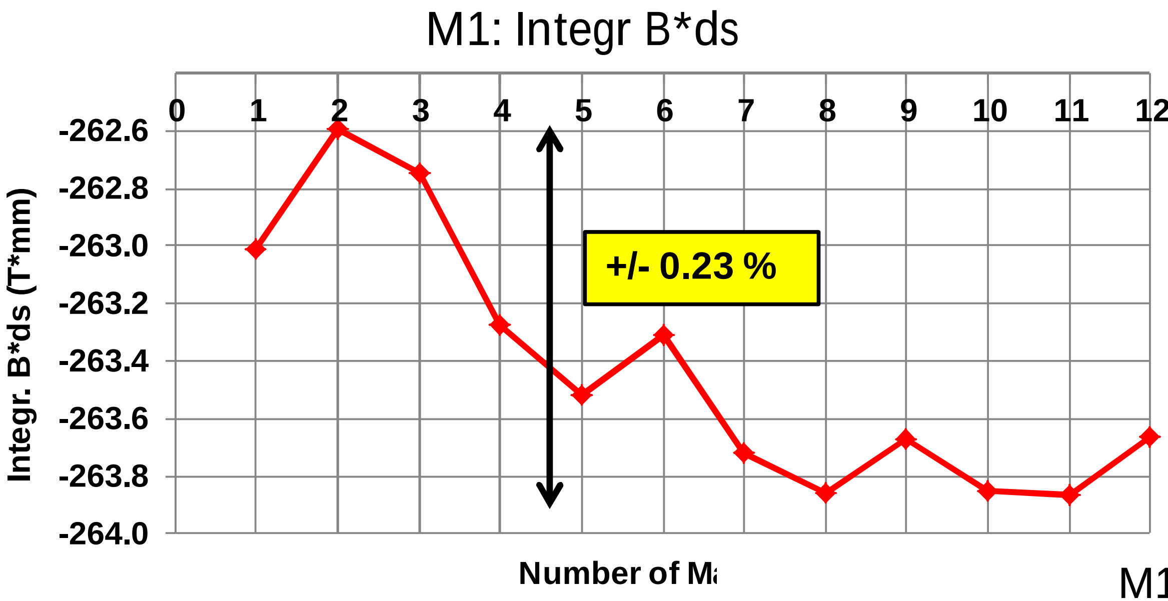
Machining Accuracy



Machining Accuracy

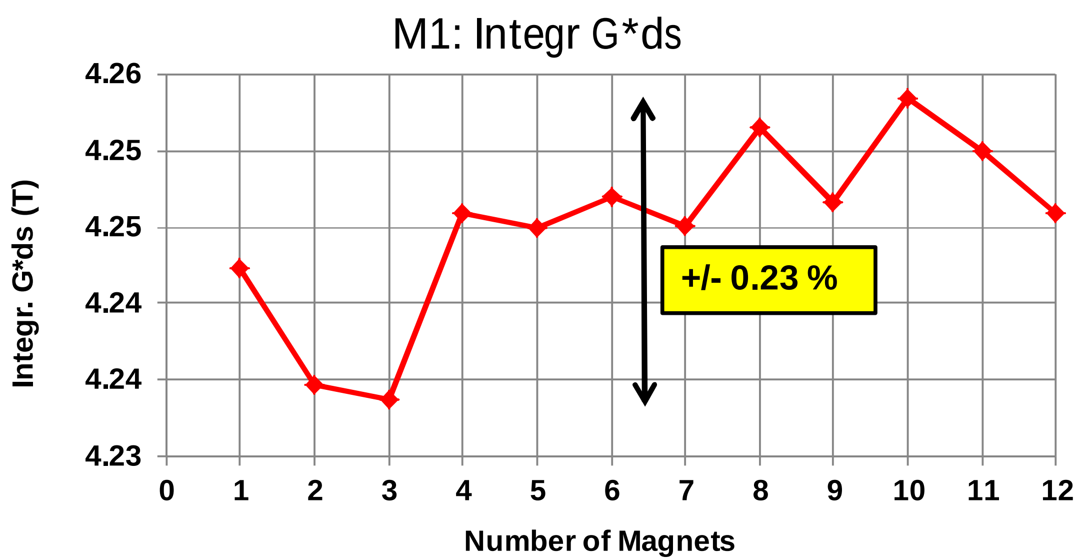


Measurement Results (M1)

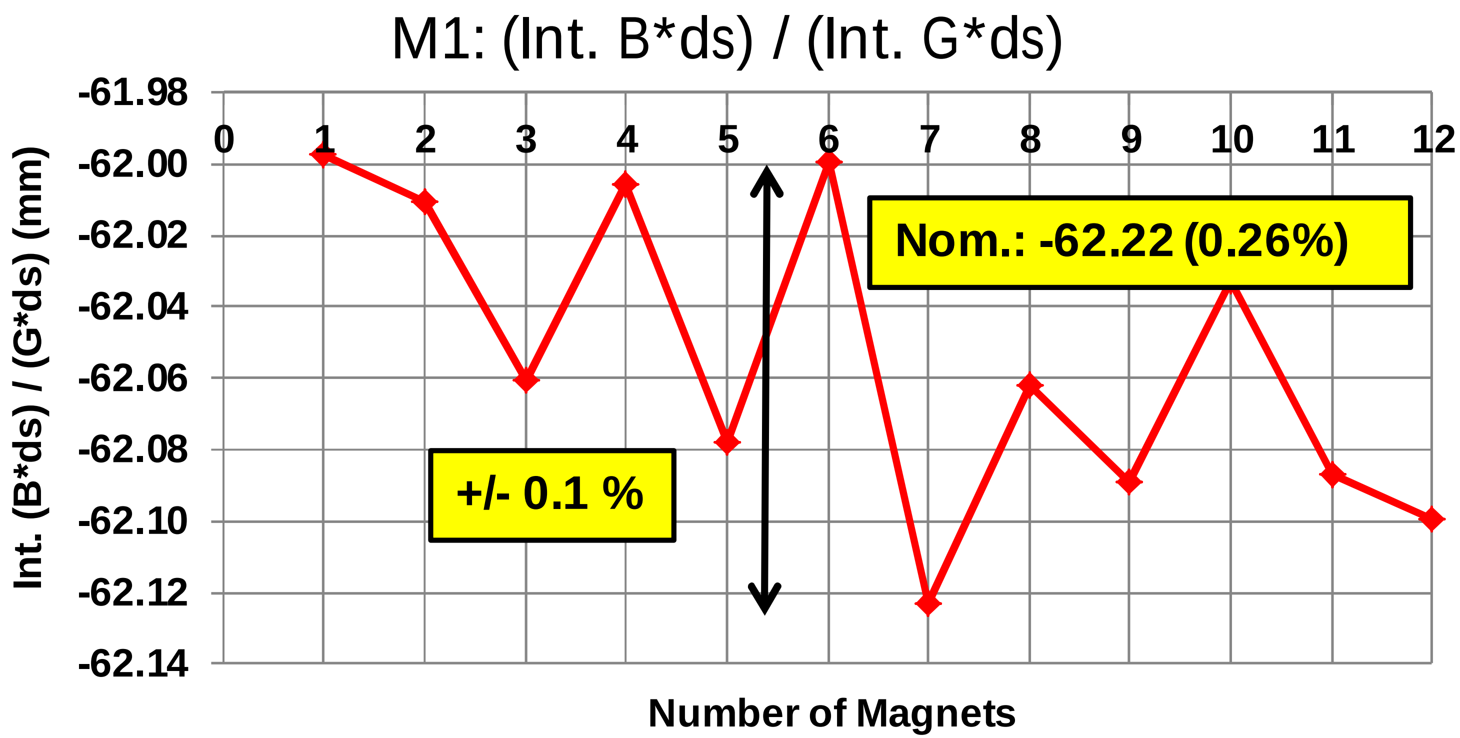


Nominal: 262.0 (T*mm)

Nominal: 4.21 (T)



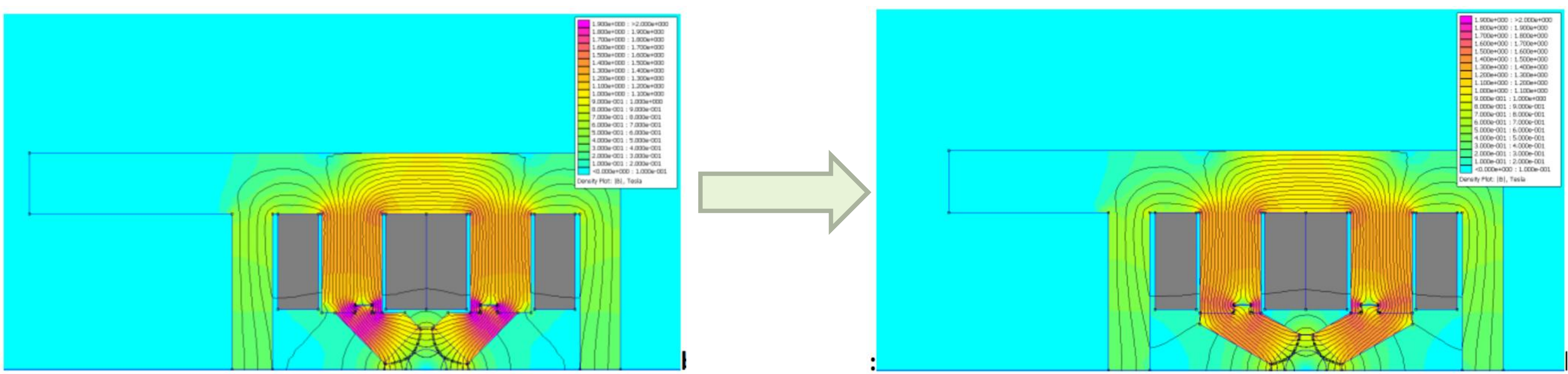
Measurement Results (M1)



The difference can be adjusted with the pole face windings

Rotating Coil Measurements

Early measurements indicated saturation problems in QF, QFms and led to a new design.

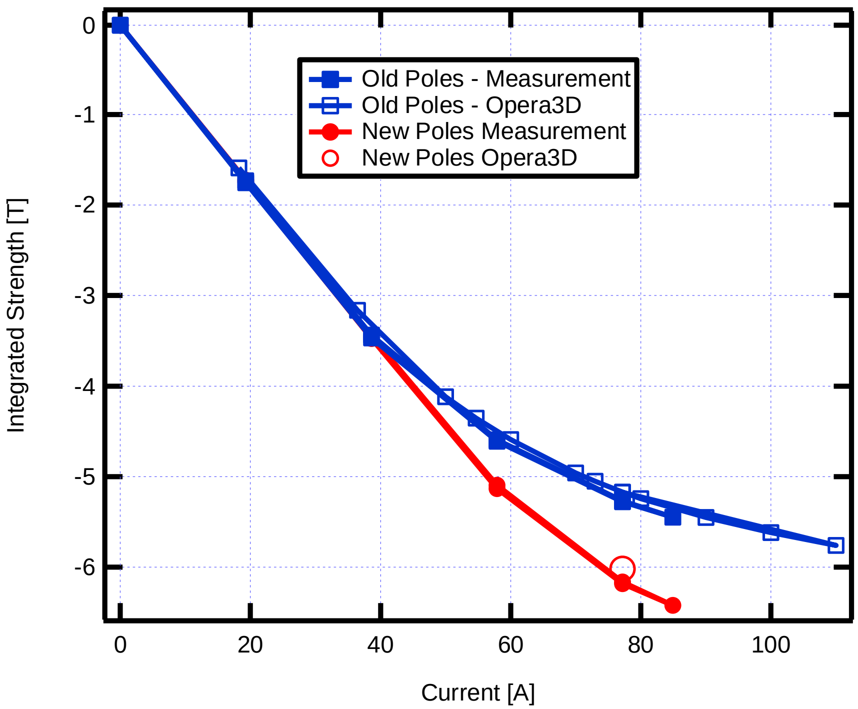


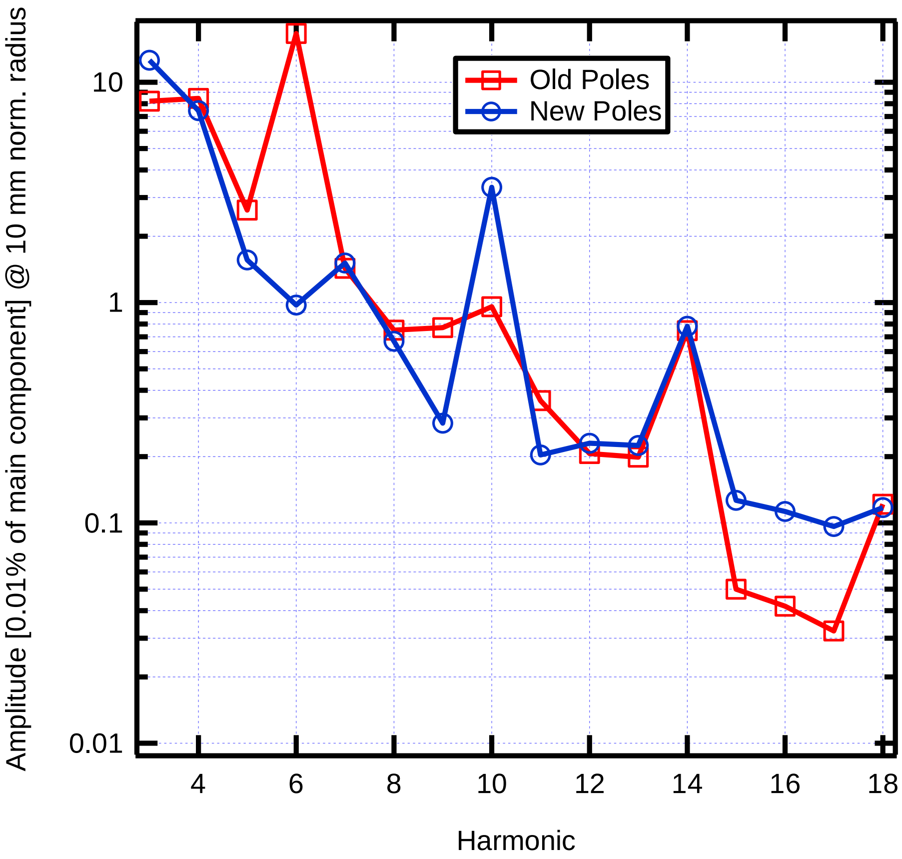
Images: Martin Johansson

Rotating coil measurements

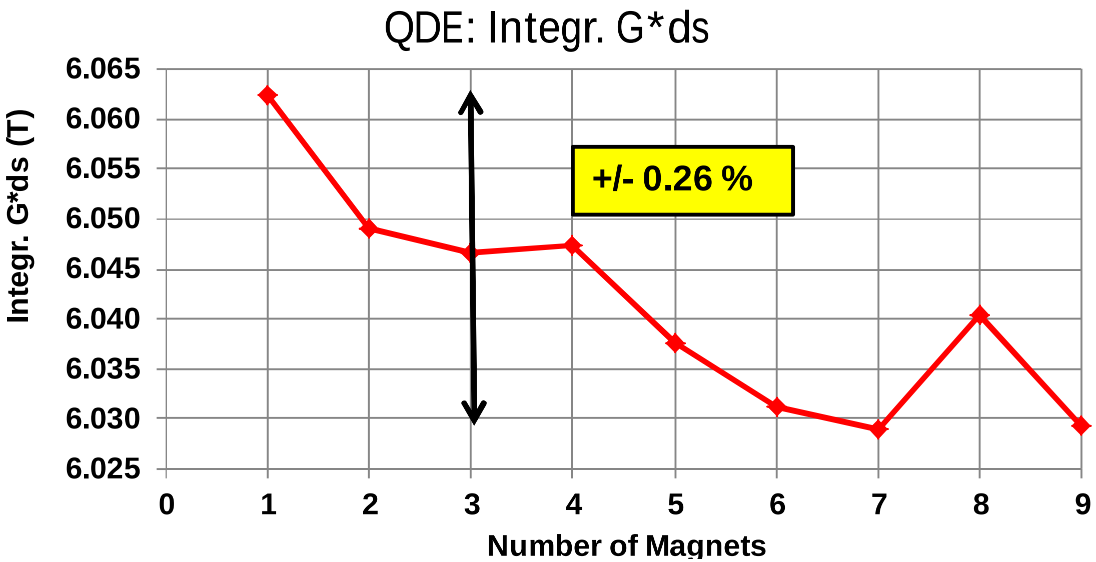
New poles were manufactured, tested.

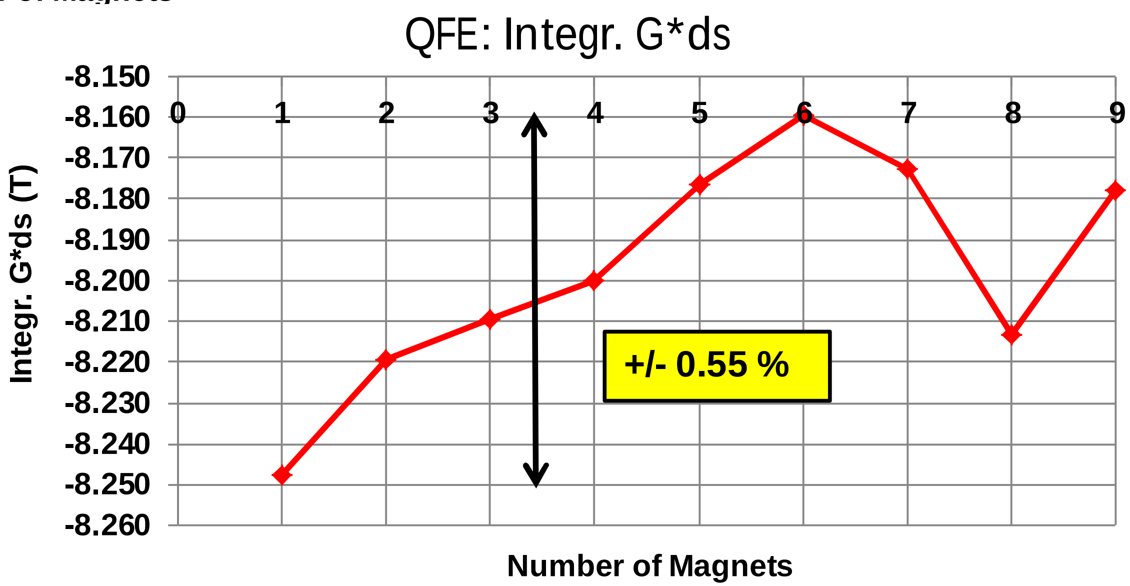
New design is approved for production.



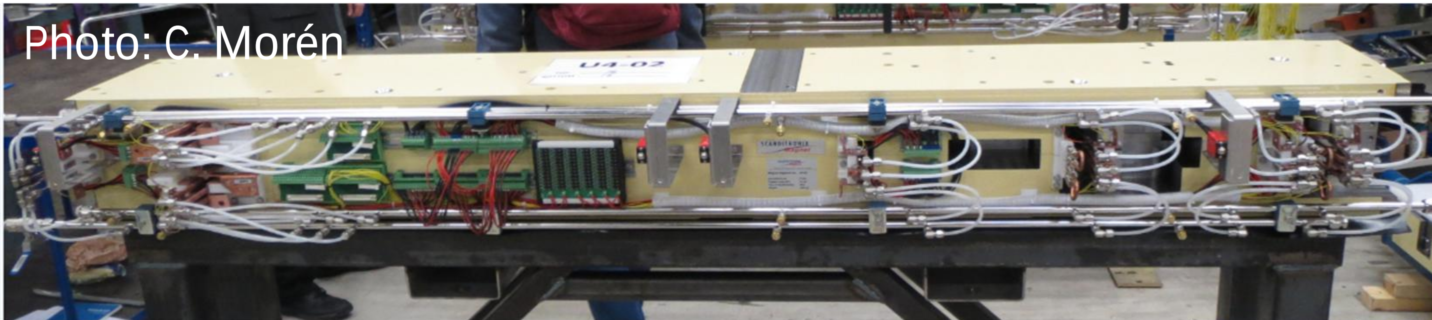


Measurement Results (M1)



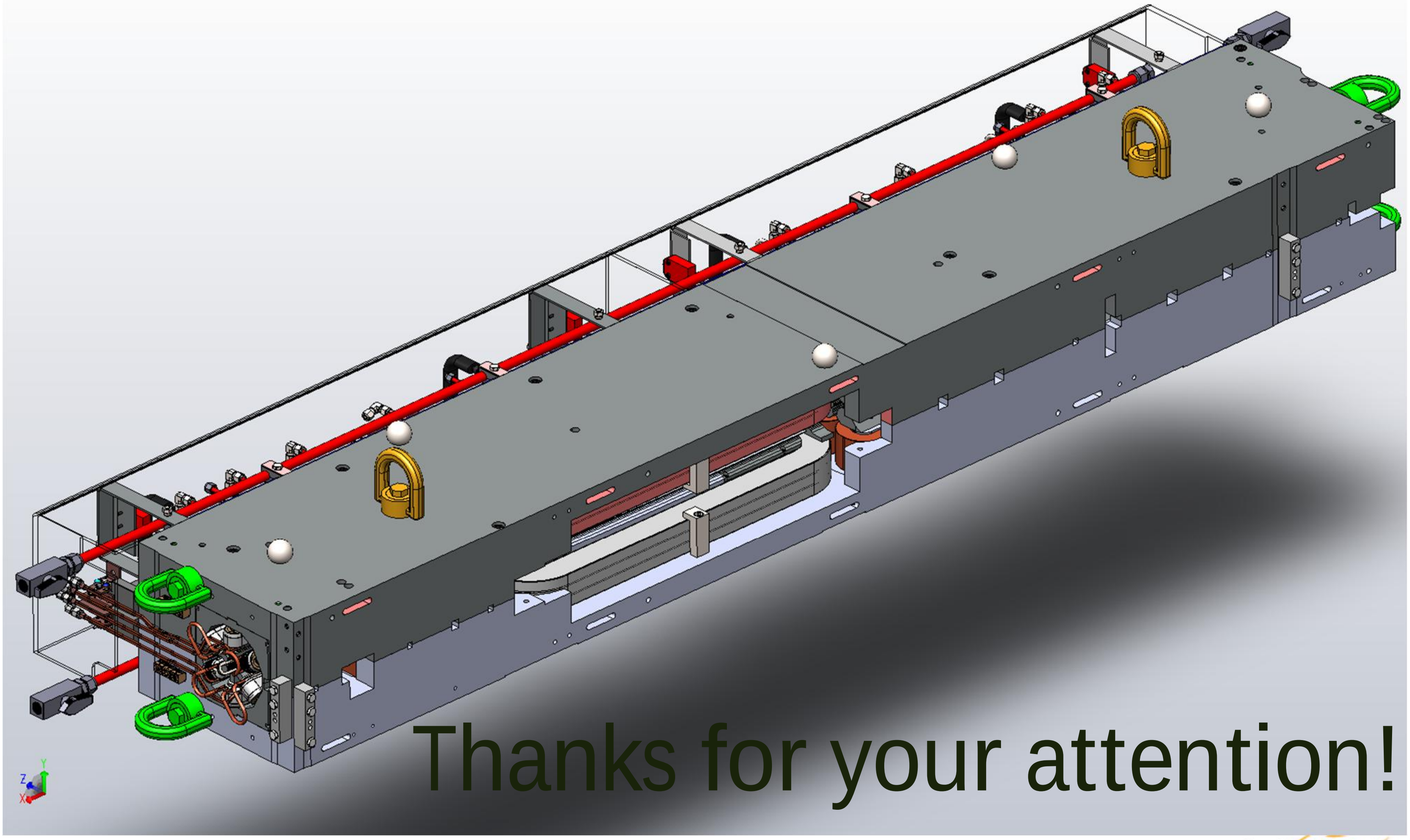


3 GeV Ring Magnets



- Series production ongoing
- All M1, M2 blocks machined
- About 50% of the U1,U2,U4,U5 machined
- Full Delivery until July 2014

MAX IV Magnets



Thanks for your attention!