MEASUREMENTS OF MAX-IV GIRDER SYSTEMS

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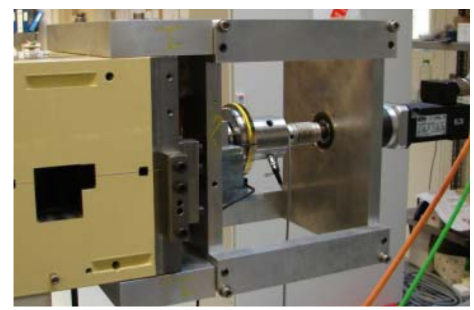
Outline

- MAX IV magnet girders
  - Description of Max IV girders

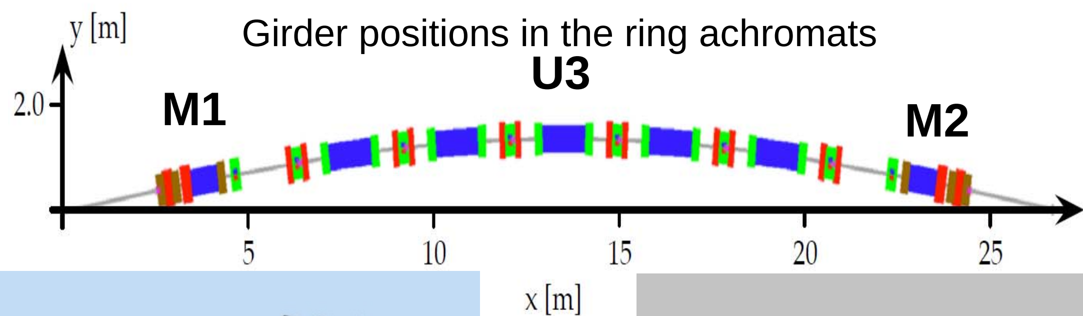
- Hall probe field mapping
  - Description of concept
  - Stability of alignment
  - Some measurements results

- Harmonic coil measurements
  - Description of concept
  - Stability of the measurements
  - Some measurement results

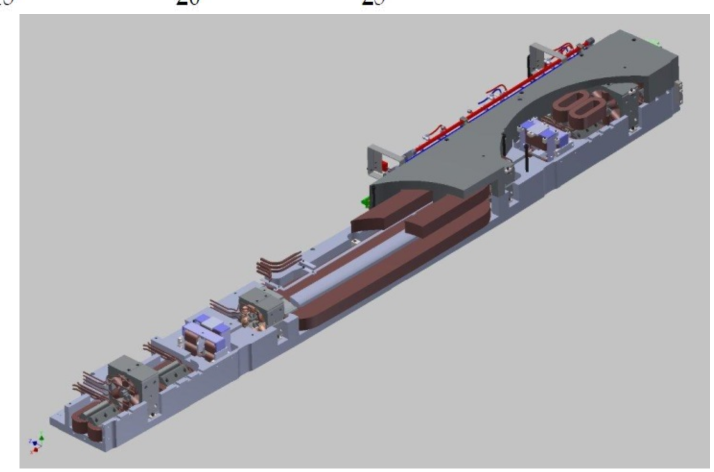


Production of MAX IV magnet girders

- MAX IV designed for 3 GeV with very low emittance(multi-bend achromat)
- Danfysik is producing 20 each of **M1**, **M2** and **U3** with 10-13 magnets
- Designed by Maxlab*
- In total 60 dipoles, 220 steerers, 160 quads, 120 sextupoles, 120 octupoles
- **680 magnets in total**
- Small Ø25 mm aperture in the multipoles

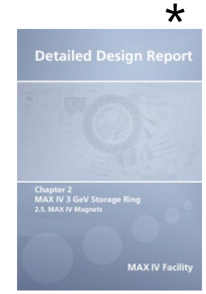


M1



U3

*



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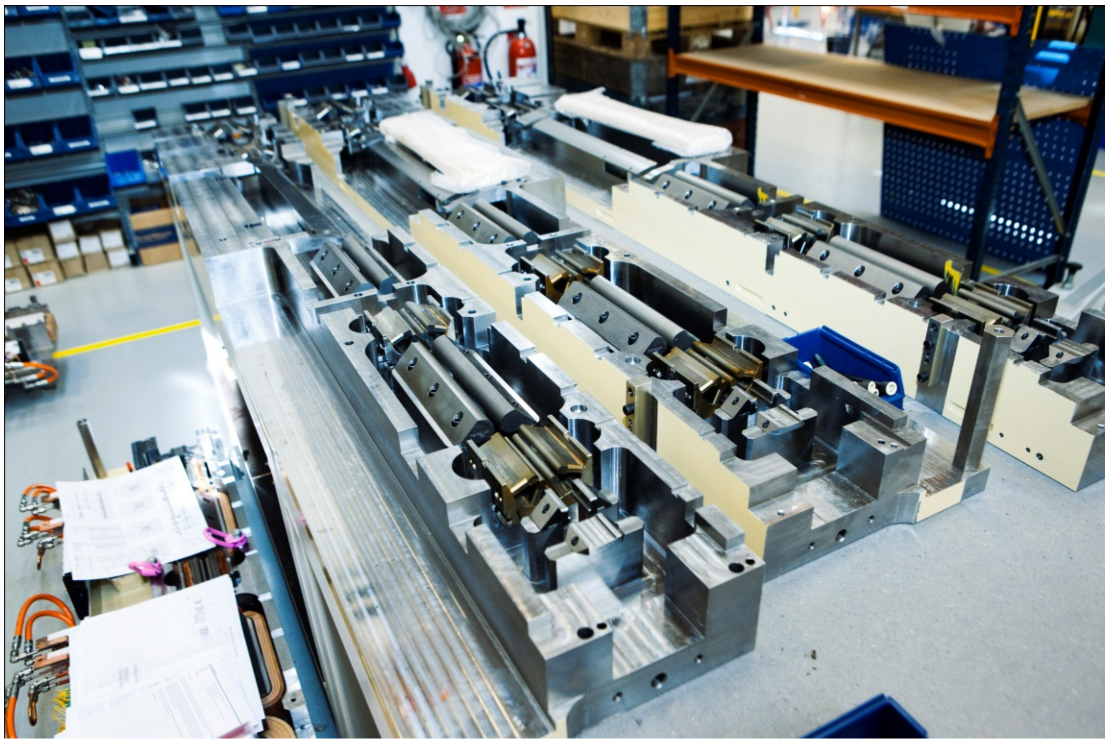
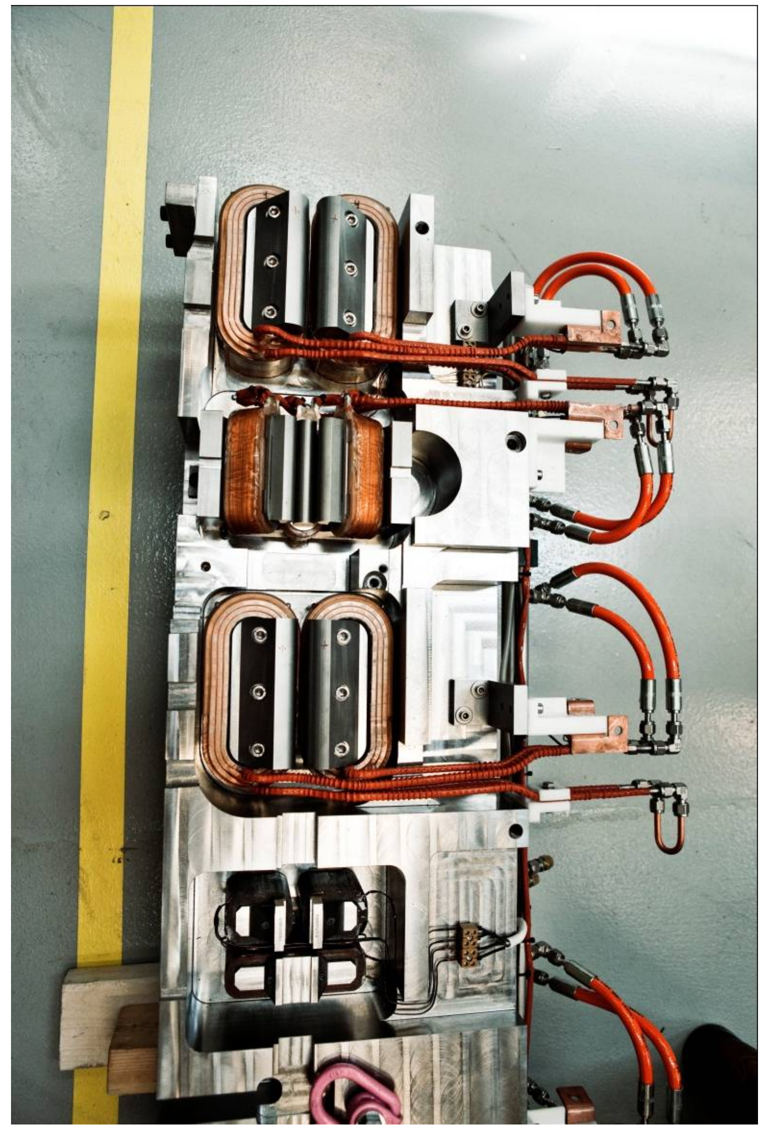
Girders as produced





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Top/bottom M1 girder as produced

Combined function dipole with pole face strips

Soft ends

Quadrupole

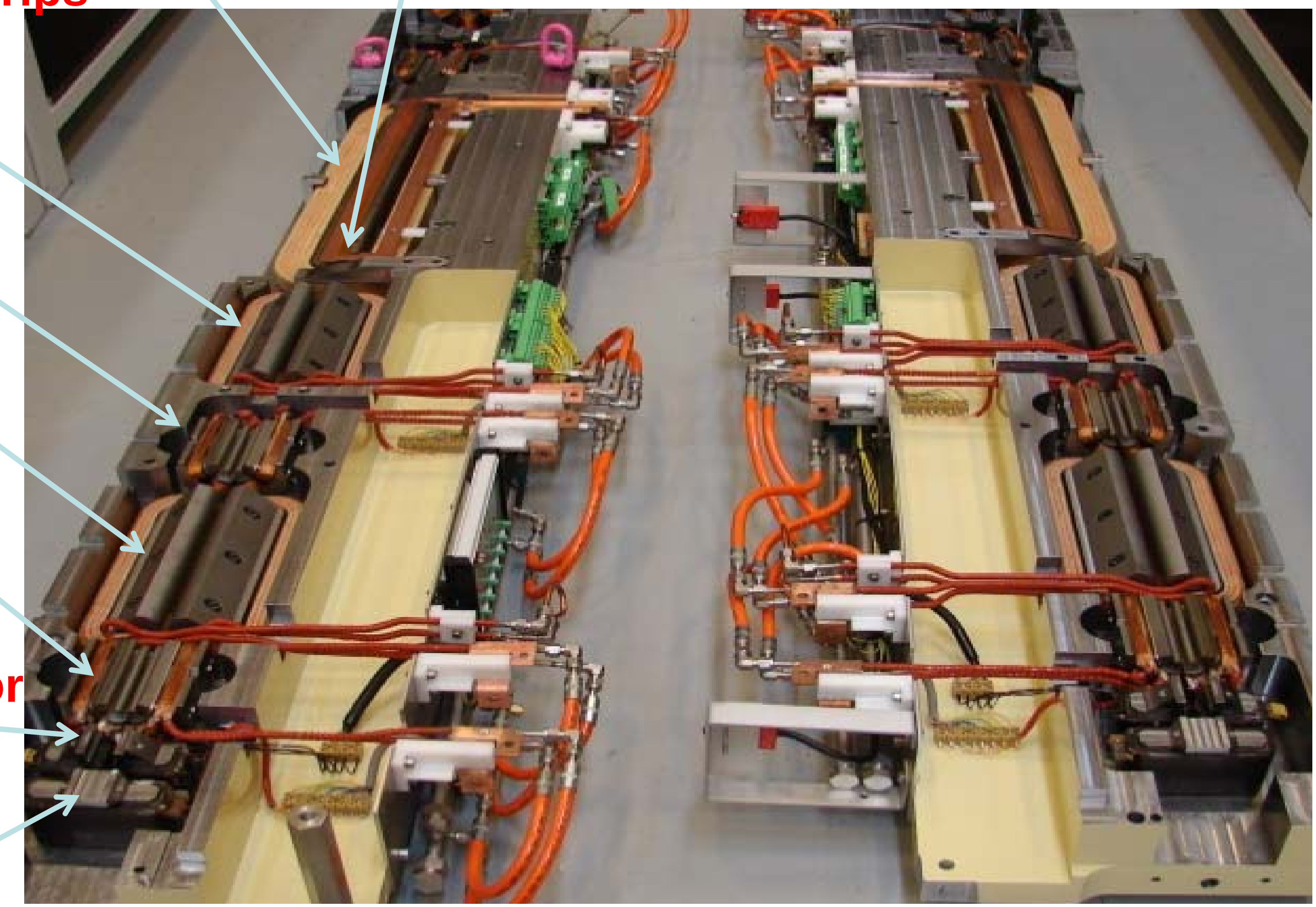
Octupole

Quadrupole

Octupole

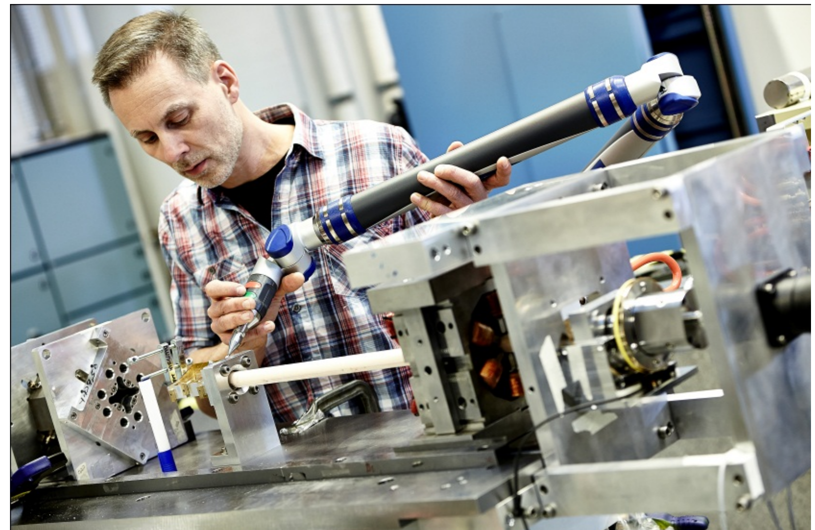
Skew corrector

Normal corrector



Measuring challenge

- Harmonic coil measurement
  - How to affix coil assembly
  - Choice of bearings
- Hall mapping
  - Purchase of new 7 m Hall bench
  - Build Hall probe(KSY 14) with temperature correction, and Hall supply
  - Long measurement campaigns
- Large volume of measurements
  - 680 individual sub segments in total
  - Demands for data handling
- Requirements for automatisation, to measure all of this efficiently



Extensive tests for First Articles

Extended set of measurements (coil and Hall)

Remove magnet from bench

Extended set of measurements (coil and Hall)

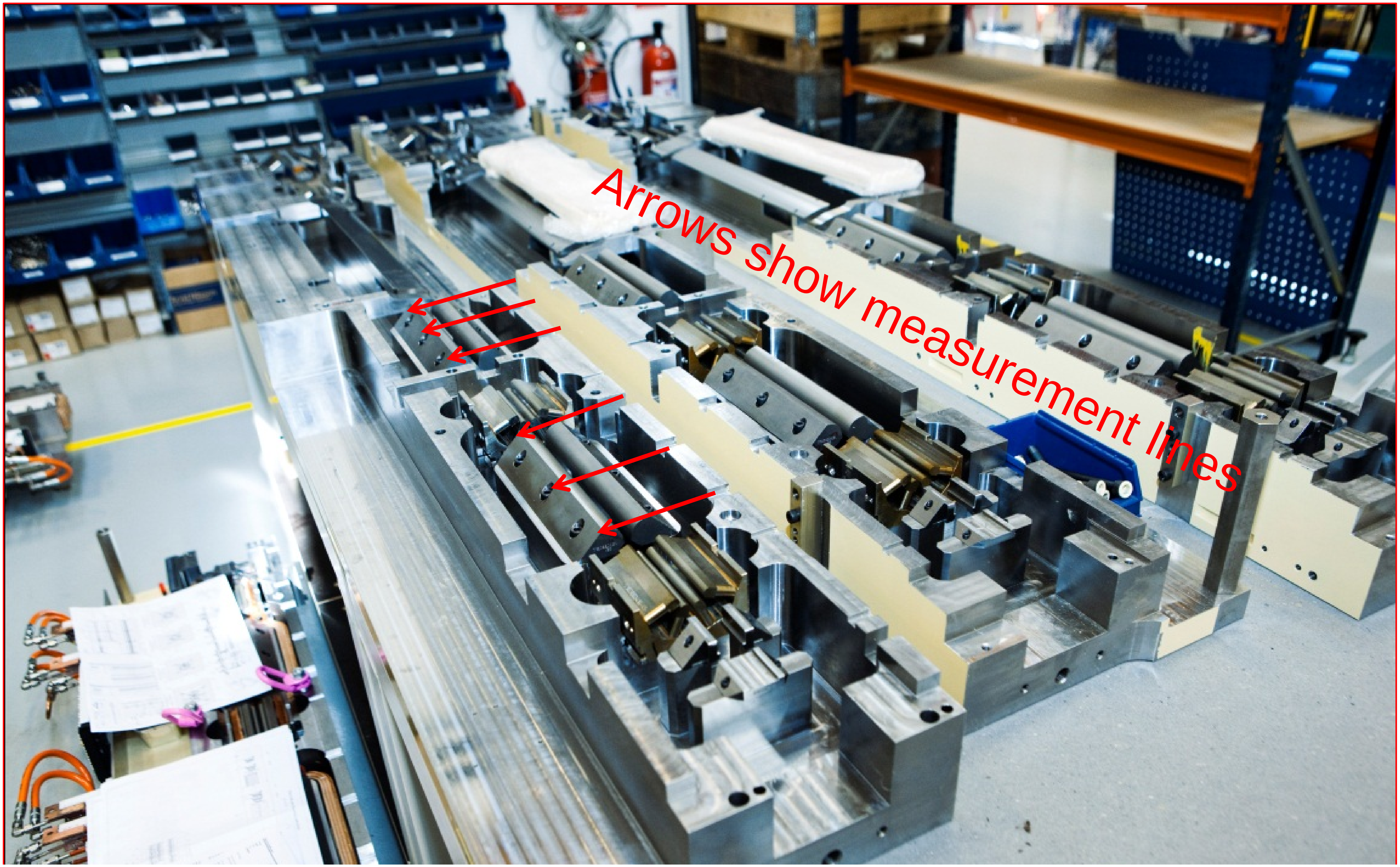
Remove top of magnet girder, reinstall and remeasure from bench

Extended set of measurements (coil and Hall)

Hall measurement requirements

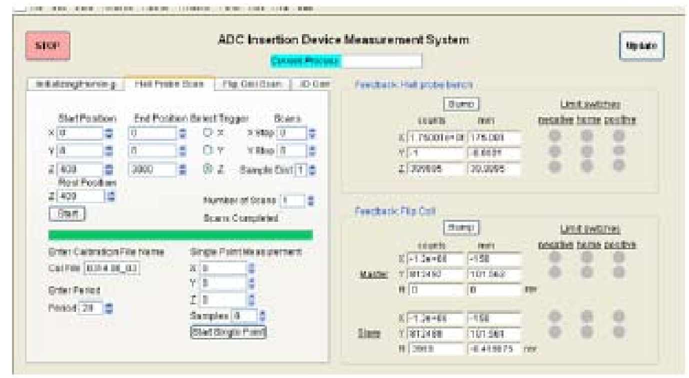
- Hall scans along the nominal trajectory, ± 15 mm(**Dipole**)
  - Accomplished by scanning rectangular grid, followed by interpolation
  - On-the fly(like insertion device mapping)
  - Time for complete dipole map. Around 3 hours
- Excitation curves(**Dipole**)
- Excitation curves(**Quadrupoles**)
  - Through available access holes
  - S=0, x= ± 5 mm
- Horizontal scans of quadrupoles
  - X=±15 mm. S=-115,0,115

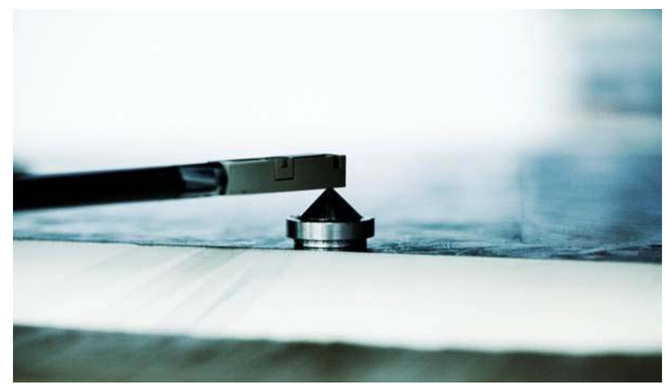
Hall measurement of quadrupoles



Details on software for Hall bench

- Fully automated measurements
  - Magnet is powered up, and held for appropriate wait time
  - Hall probe is zeroed in mu-metal shield prior to measurement
  - Probe is homed on magnetic cone
  - Measurement is carried out
    - Dipole map, excitation, etc.
  - Probe zero is checked in mu-metal after measurement, and data is corrected for drift
  - Off-line correction for temperature
- Voltage/NTC logged with Keithley 2701
- Power supply control and motion control within Igor

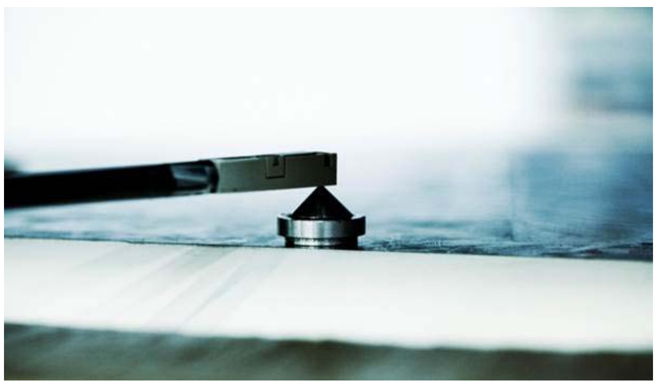




Hall probe mapper setup

- Precision Hall mapper on long granite table
- Laser feed back on longitudinal z-axis and linear encoders on x,y-axes
- Alignment by scanning over magnetic pins, knife-edges
- Short term position st.dev. < 2 μm, long term drift <10 μm

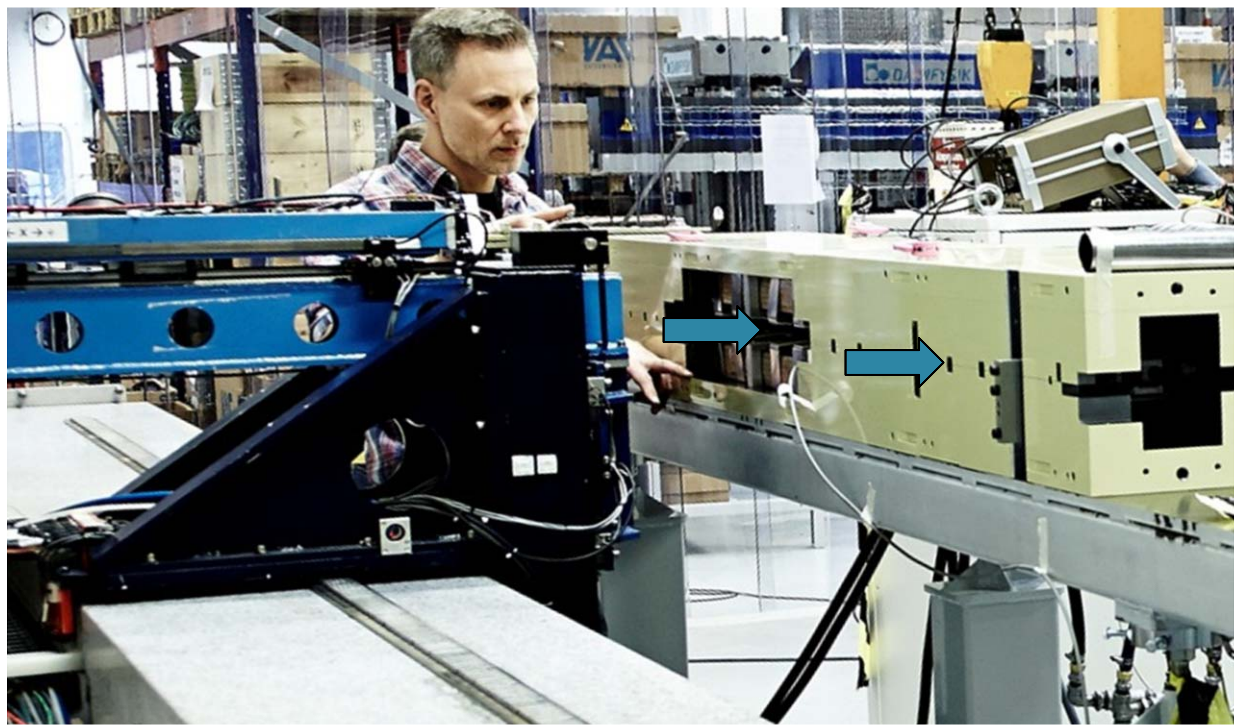
Alignment with magnet tip



Short term repeatability

	Z (mm)	X (mm)
Round 1	2888.7707	-61.7454
Round 2	2888.7697	-61.7483
Round 3	2888.7695	-61.7465
Round 4	2888.7698	-61.7491
Round 5	2888.7709	-61.7448
St. Dev.	**0.0006**	**0.0016**

Scanning dipole from side & quadrupoles through small holes in yoke

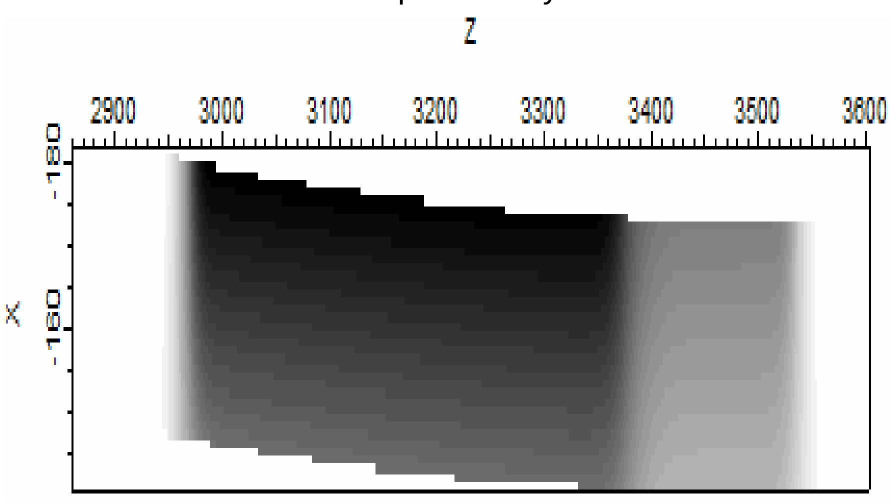


Hall probe field mapping

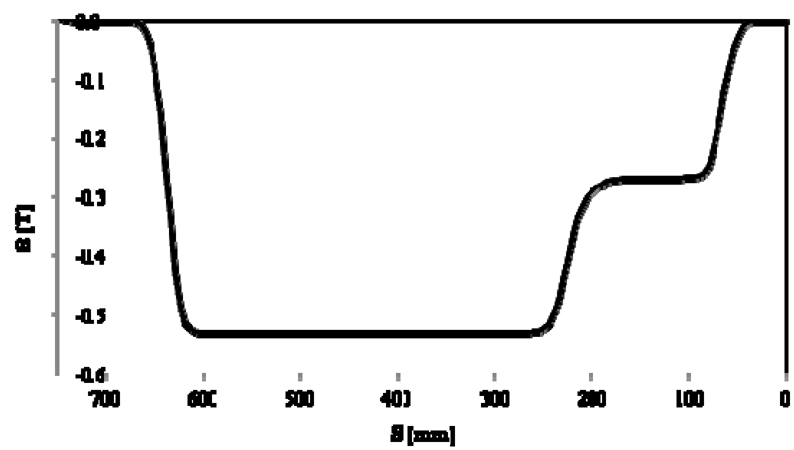
- High stability temperature calibrated Hall probe allows on-the-fly mapping
- Large field grid measured on-the-fly of the combined function dipoles
- Interpolated on-the-fly data agree with step-and-go data within $1.6 \cdot 10^{-4}$
- Repeated measurements of field integral stable within $7 \cdot 10^{-5}$

➡ **Very good alignment and stability**

Field map on-the-fly in 1.5 h



Interpolated field values along trajectory



Harmonic coil measurements

- Several things to consider
  - Single long coil vs short segmented coils
  - Compensated vs non-compensated
  - Integration vs voltage measurements
  - Radial vs tangential coil
- Other
  - Support material
  - Choice of bearings

Harmonic coil measurements

- Several things to consider
  - Single long coil vs **short segmented coils**
  - Compensated vs **non-compensated**
  - **Integration** vs voltage measurements
  - Radial vs **tangential coil**
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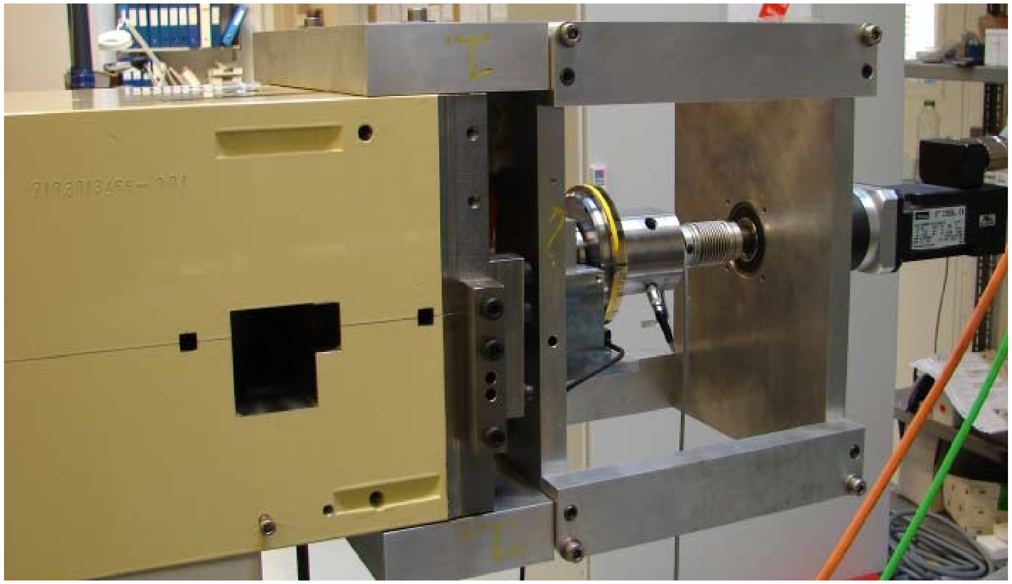
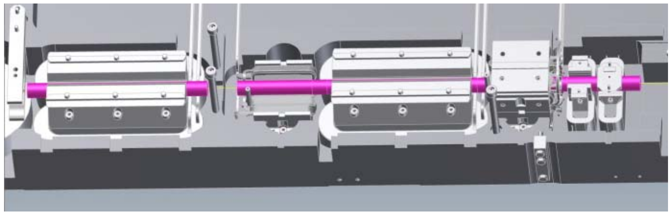
Harmonic insertion coil concept

New concept (For us, anyway……)

- Coil inserted from girder end with external encoder and motor
  - Precision Heidenhain encoder(scale drum) ERA 4202 C
- Mechanical coil positioning from girder reference surfaces
- 15 º tangential coil with a 10.7 mm measurement radius
- One short harmonic coil segment for each magnet
  - Coil lengths between 150 mm and 250 mm
- 3-5 coil segments per support rod, 13 segments in total
- Calibration of each segment → phase and gradient strength
- Voltage integration using 1 channel Metrolab 5150 with Trigger module

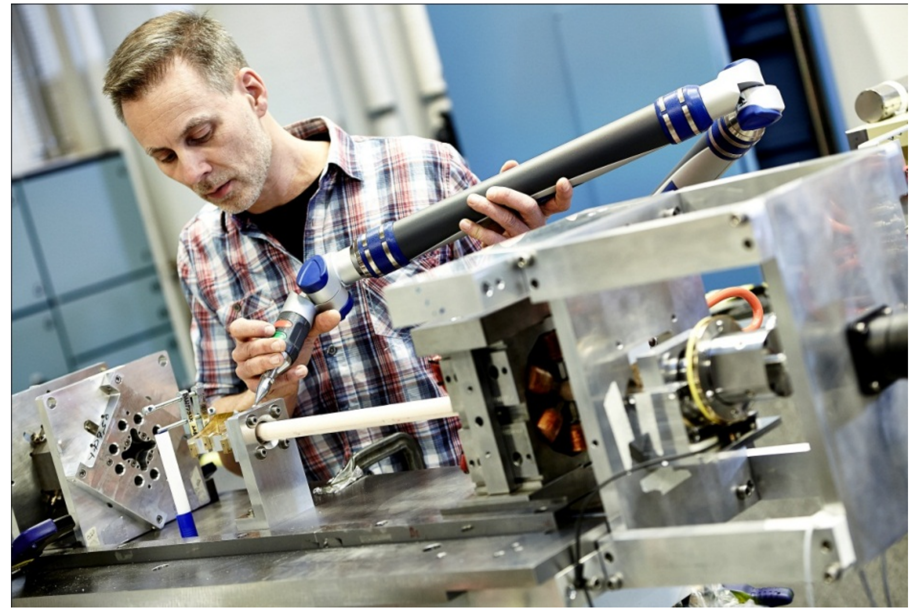


Coil segment positions for long M1 & M2 ends



Sub coil calibration

- Phase and strength calibration
- Due to differing coils lengths, several reference magnets are needed
- For 150 mm segments, 100 mm EM sextupole is used
- For 200-250 mm segments, temperature stabilized permanent magnet quadrupole is used
- Magnet is rotated 180 degrees to find coil phase error relative to mechanical reference.
- Compare with Hall/ stretch-wire results
- Appropriate Gain/Phase chosen when measuring sub-magnets



Magnet	Segment	Gain	Phase [Grad]
QDE	1	1.00113	-65.507
OXY	2	1.01146	-65.516
QFE	3	1.01083	-19.868
OXX	4	1.00818	-65.429
COA (By/Bx)	5	1.02909	-19.892

Calibration data for sample 5 segment coil

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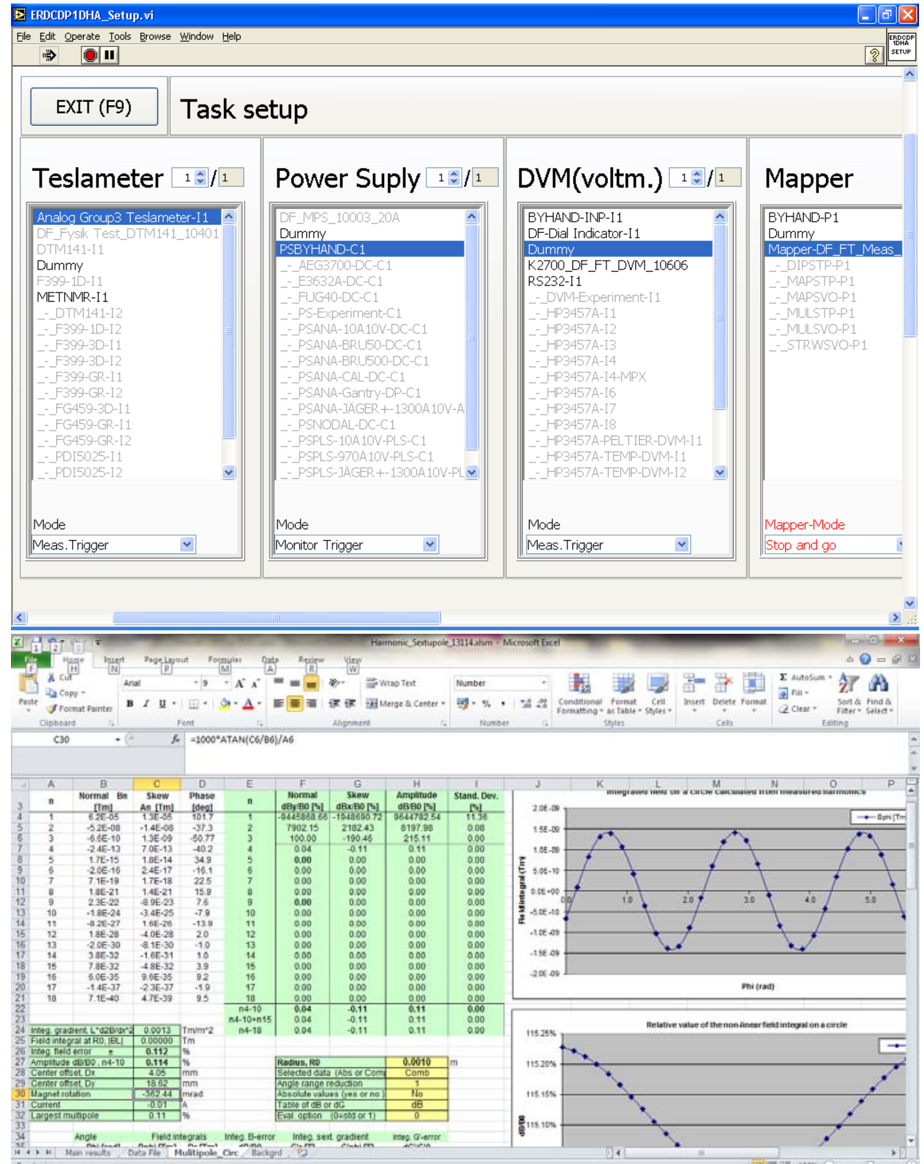
Details on software for coil bench

- Running under Labview
- Each coil segment is saved, with reference, to intrinsic phase and strength
- User chooses appropriate coil to measure correct magnet sub segment.
- Power supply control within Labview, and excitation cycle runs automatically
- EXCEL templates developed
  - Traceability to calibrations and coils used



Stability of the harmonic measurements

- Short term repeatability test
  - Field gradient variation $0.4 \cdot 10^{-4}$
  - Higher harmonics below 0.1 unit
  - Magnet rotation variation 0.01 mrad
  - Very stable
- Simple test of thermal stability
  - Field gradient drift 0.2 unit/°C
  - Magnet rotation drift -0.03 mrad/°C
  - Low thermal drift
- Long term stability, average for 6 quads
  - Disassembly of test jig and yoke
  - Three measurements over several days
  - Field gradient variation $2 \cdot 10^{-4}$

Short term repeatability test on a quad

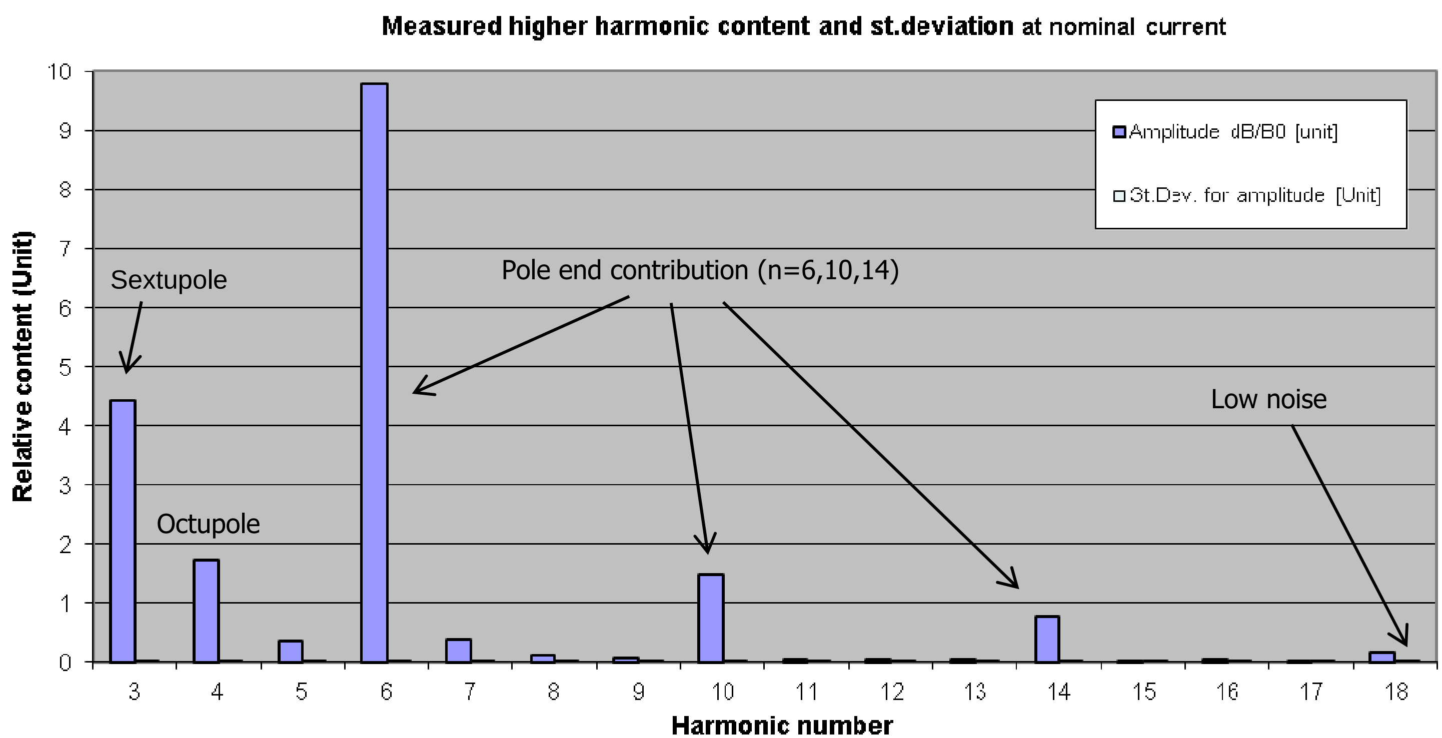
Test on M1 quad	Repeatability	Thermal change/°C	
Field gradient strength	0.4	0.2	Unit, 10^{-4}
Higher harmonics, n3-4	< 0.1	0.2	Unit, 10^{-4}
Higher harmonics, n≥5	< 0.03	0.2	Unit, 10^{-4}
Magnet center dX, dY	< 0.001	< 0.001	mm
Magnet rotation	0.01	-0.03	mrad

Long term stability with jig/yoke disassembly

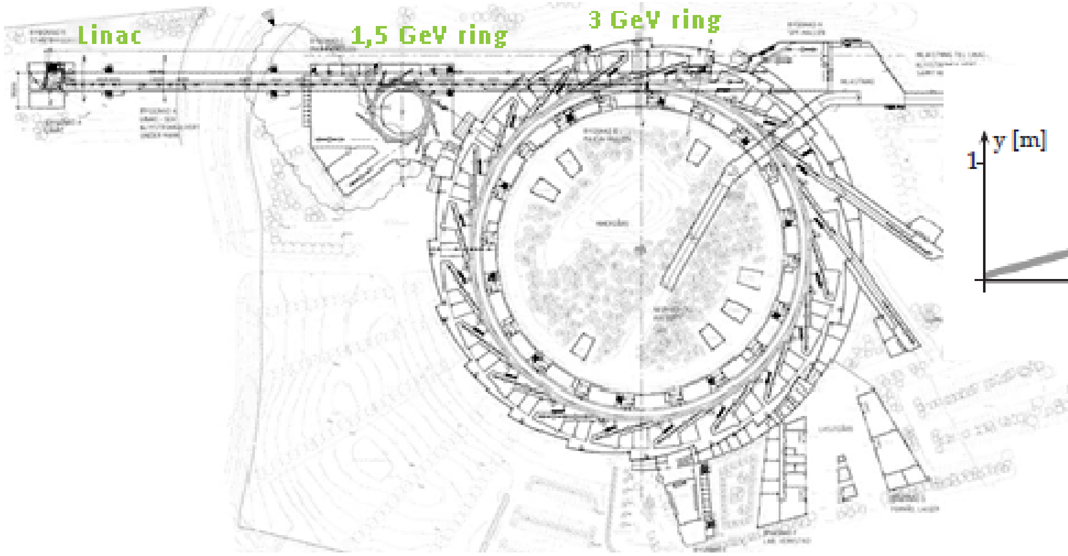
Average result, 6 quads	Stability	
Field gradient strength	2	Unit, 10^{-4}
Higher harmonics, n3-6	< 0.4	Unit, 10^{-4}
Higher harmonics, n≥7	< 0.1	Unit, 10^{-4}
Magnet center dX,dY	0.004	mm
Magnet rotation	0.14	mrad

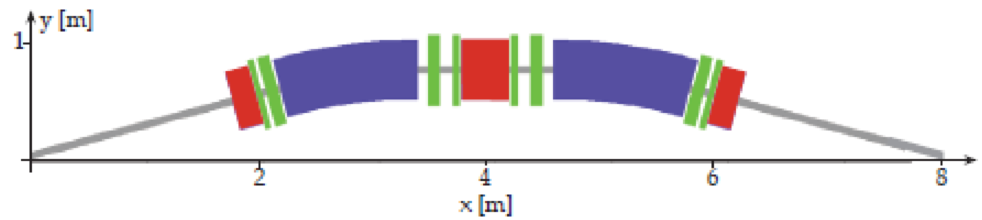
Higher harmonics of a M2 quadrupole

- Pole end contributions n=6,10,14 -> reduced for U1-5 quads by chamfering
- Remaining harmonic errors: mainly sextupole (n=3) and octupole (n=4)
- Remaining terms typically below 1 unit = 0.01%
- Measuring noise level is low
- Similar pattern for sextupole and octupole magnets



Next Project: Max IV 1.5 GeV

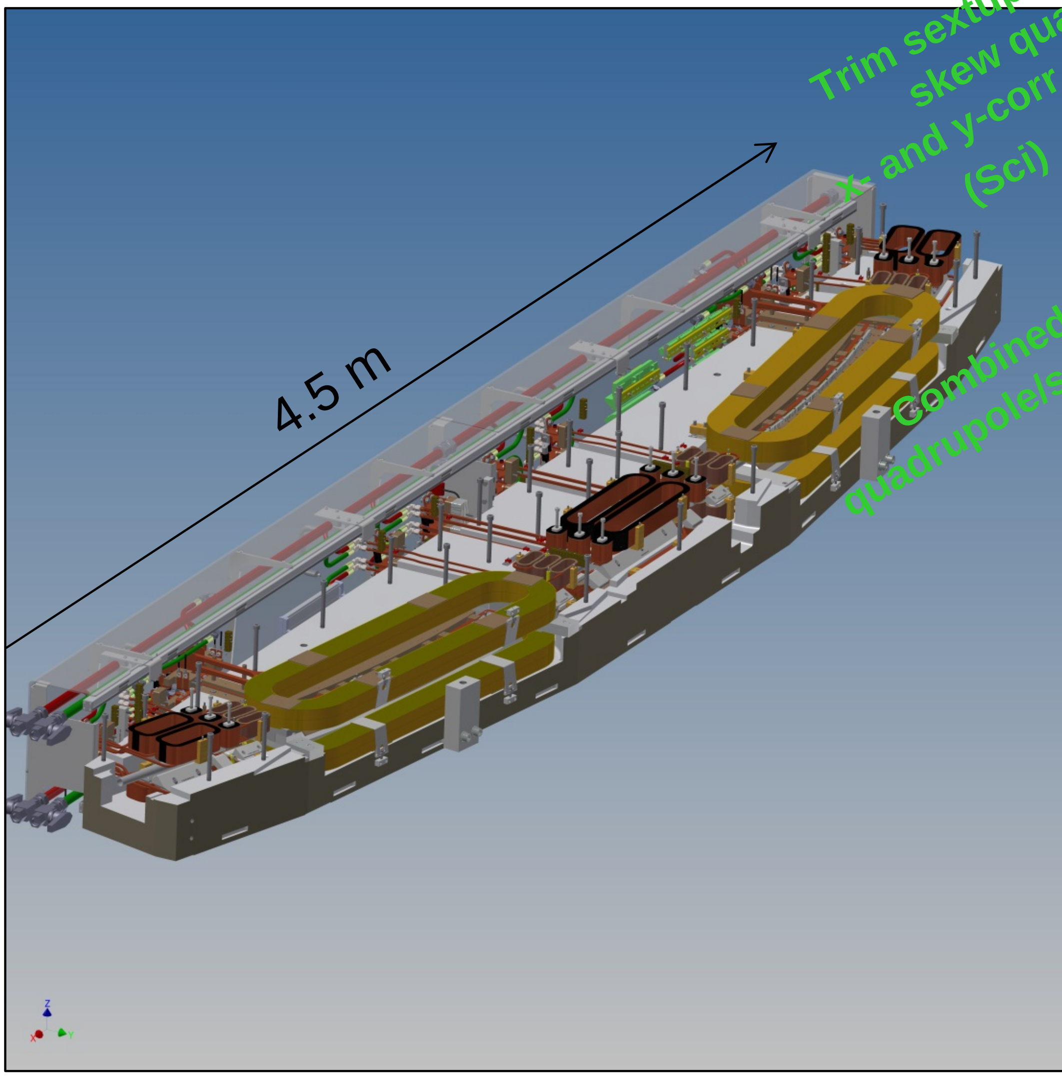


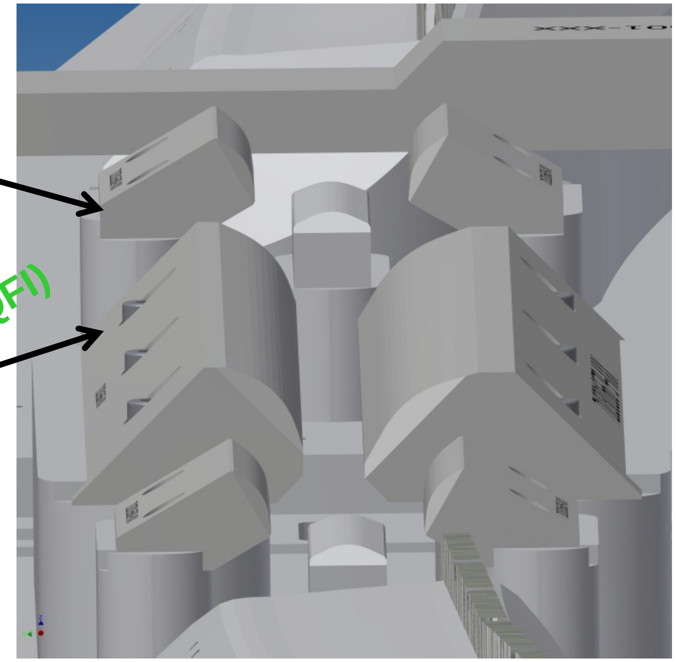


- Same concept
- 12 identical double-bend achromats
- 96 m circumference
- 6 nm horizontal emittance
- These magnets are much larger(around 4.5 m)
- Exotic combined-function elements
- Same exact order for Solaris in Krakow

Element	Description
SQFo	Combined function quadrupole/sextupole
SCo	Trim sextupole with skew quad, x- and y-corr windings
SDo	Sextupole
DIP	Gradient dipole with pole face strips
SDi	Sextupole
SCi	Trim sextupole with skew quad, x- and y-corr windings
SQFi	Combined function quadrupole/sextupole

Still in design phase





Challenge related to measuring central multipoles, due to limited access

Summary

- We have devised a measurement scheme to measure Maxlab girders with high stability
- Hall system shows high positional reproducibility, and stability
- Succesful implementation of tangential, segmented coils
- Harmonic coils can be reproducibly “lodged” in the girder
- High degree of automatization implemented in Igor and Labview
- Awaiting MaxLab 1.5 GeV girders for measurement

Acknowledgements

- Claus Hansen: **Project Manager**
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