MAX IV AND SOLARIS 1.5 GeV STORAGE RINGS MAGNET BLOCKS

Martin Johansson, NAPAC 2016,
Chicago, USA, Oct 9th-14th, 2016

Outline

- MAX IV and Solaris
- the magnet block concept
- production series measurement results

The MAX IV Laboratory

- Located in Lund, Sweden.
- Facility dedicated to synchrotron radiation research. National Laboratory, hosted by Lund University, with ca 200 employees.

- Old MAX-lab located in Lund University campus (MAX I-III) was shut down Dec. 2015 and is currently being decommissioned.

MAX IV

June 2016 photo: Roger Eriksson

Solaris National Synchrotron Radiation Centre

- Located in Krakow, Poland.
- Organization created 2010, hosted by Jagiellonian University, with ca 50 employees.
- 1.5 GeV storage ring identical to MAX IV.
- 600 MeV linac, components identical to MAX IV.
- To begin user operation in Jan. 2017.

SOLARIS
NATIONAL SYNCHROTRON
RADIATION CENTRE

Photo courtesy of Solaris.

Two identical 1.5 GeV storage rings

Solaris

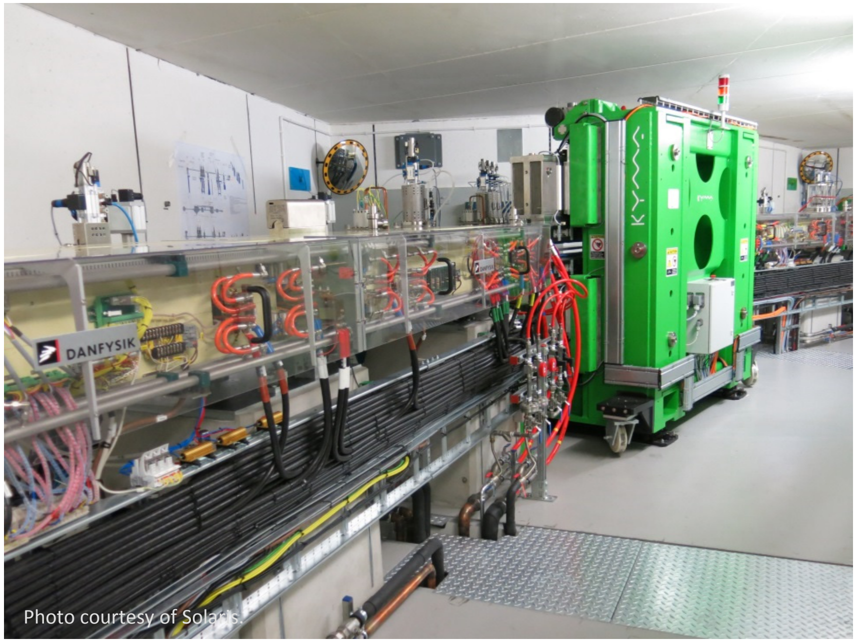


Photo courtesy of Solaris.

MAX IV


Sept. 2016 photo: Madeleine Schoug

- where each double bend achromat is realized as one “magnet block”.

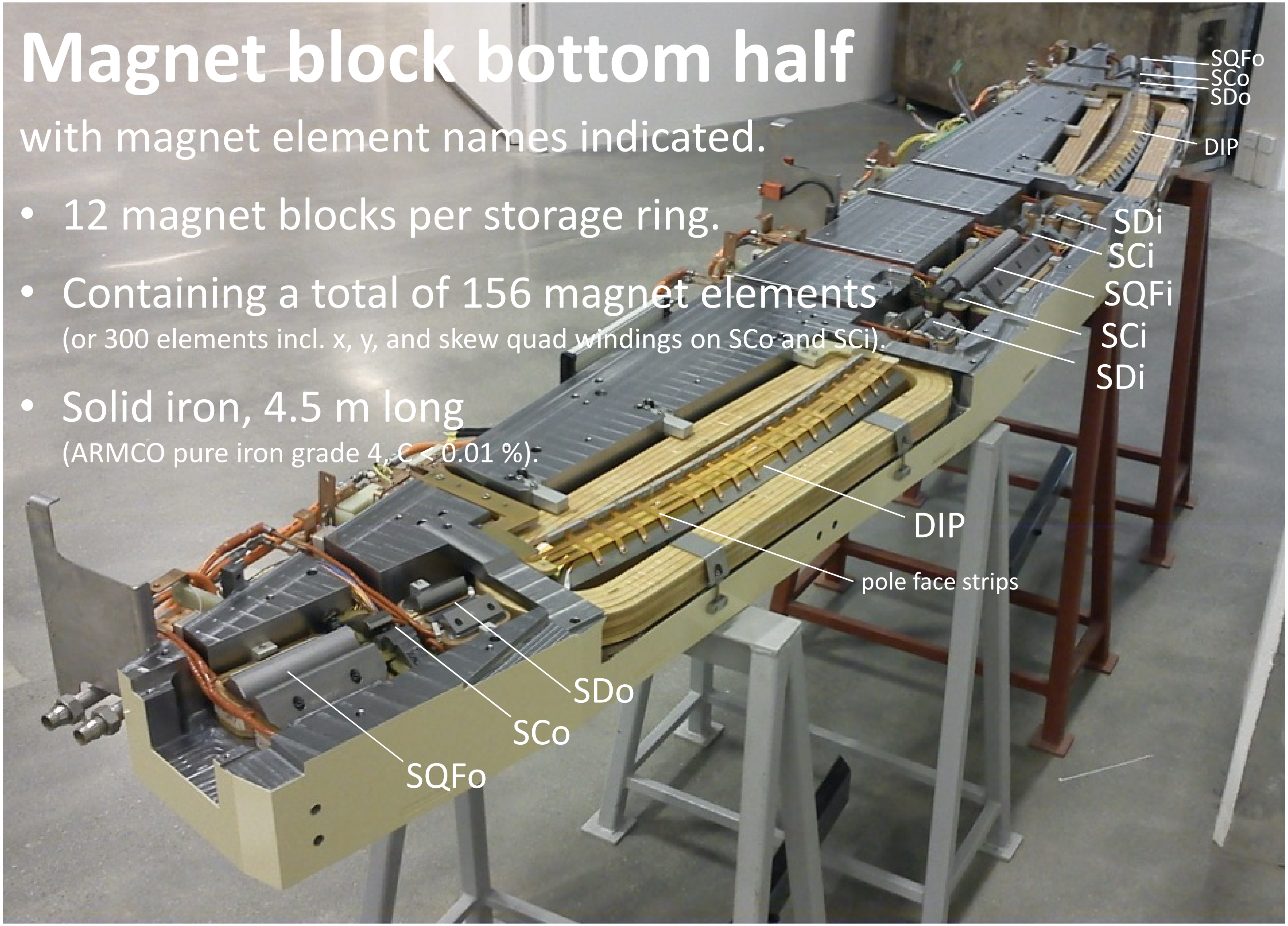

2014 photo courtesy of Solaris.

MAX IV

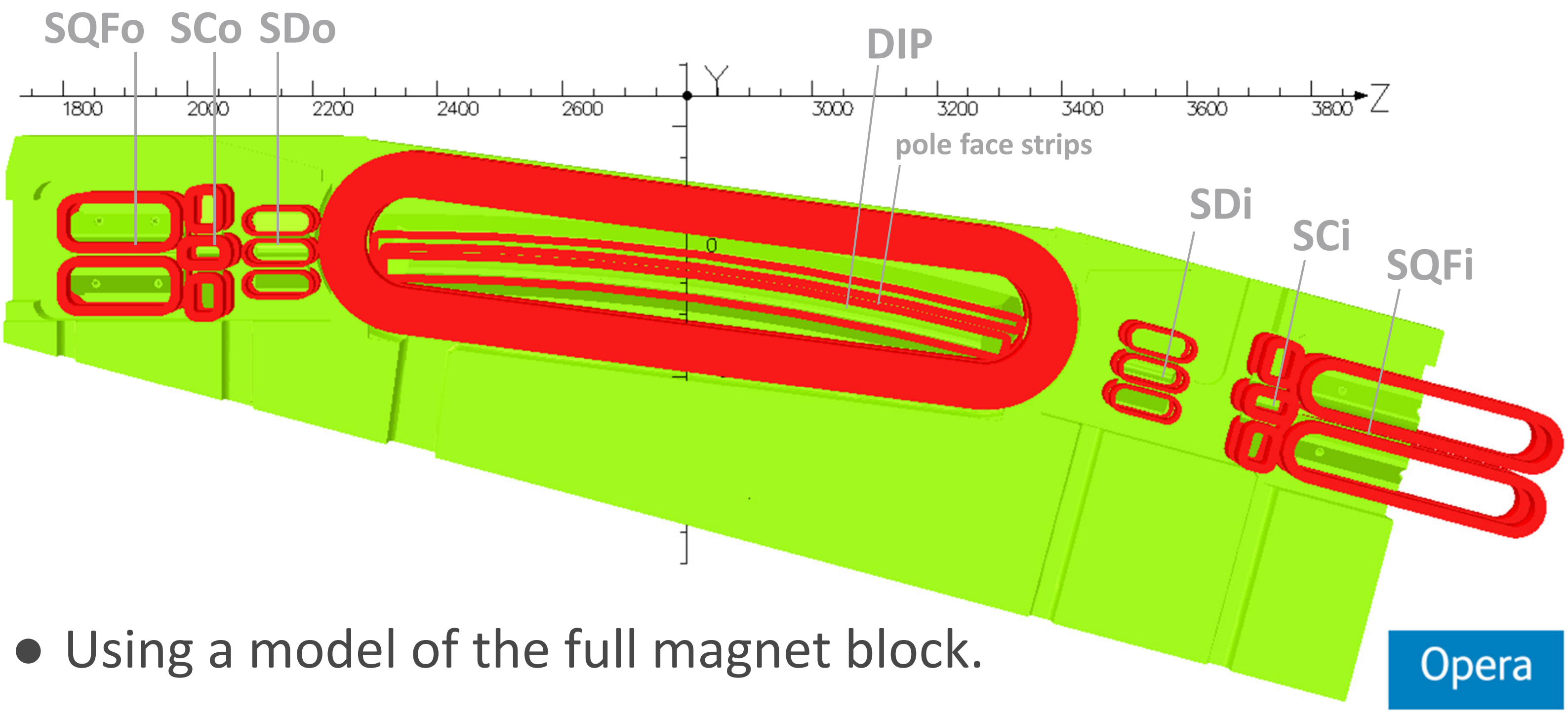
Magnet block bottom half

with magnet element names indicated.

- 12 magnet blocks per storage ring.
- Containing a total of 156 magnet elements
  (or 300 elements incl. x, y, and skew quad windings on SCo and SCi).
- Solid iron, 4.5 m long
  (ARMCO pure iron grade 4, C < 0.01 %).

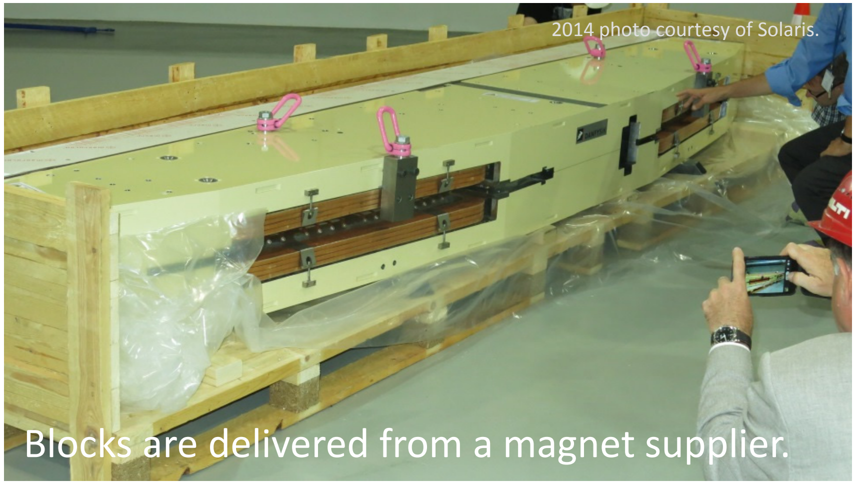


Designed using Opera-3d

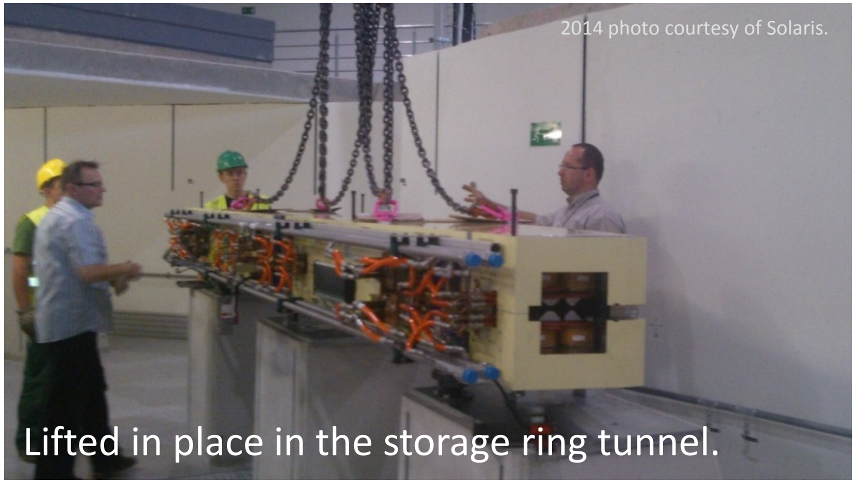


- Using a model of the full magnet block.
- Exported to 3D cad format as basis for manufacturing drawings.

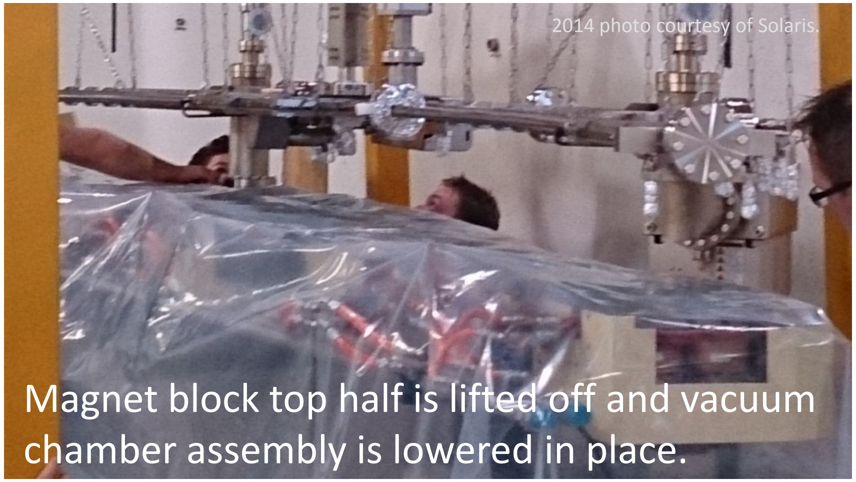
Concept chosen to minimize installation work
- no pre-assembly or field measurement at the accelerator lab.



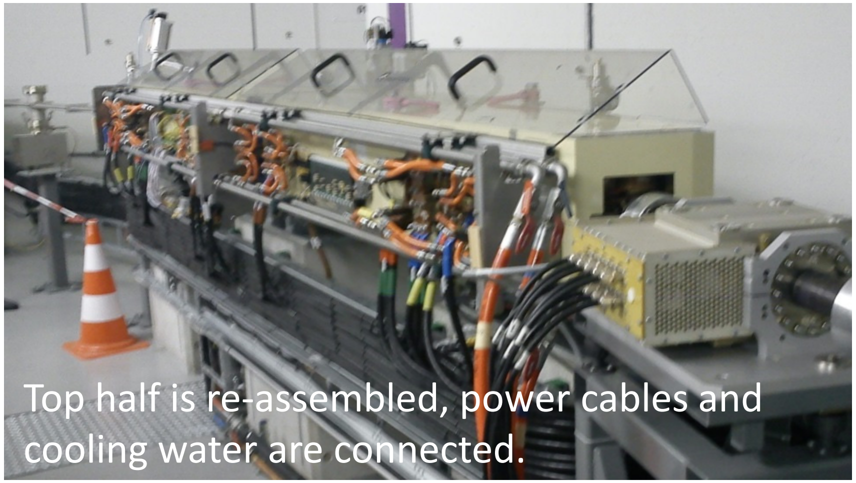
Blocks are delivered from a magnet supplier.



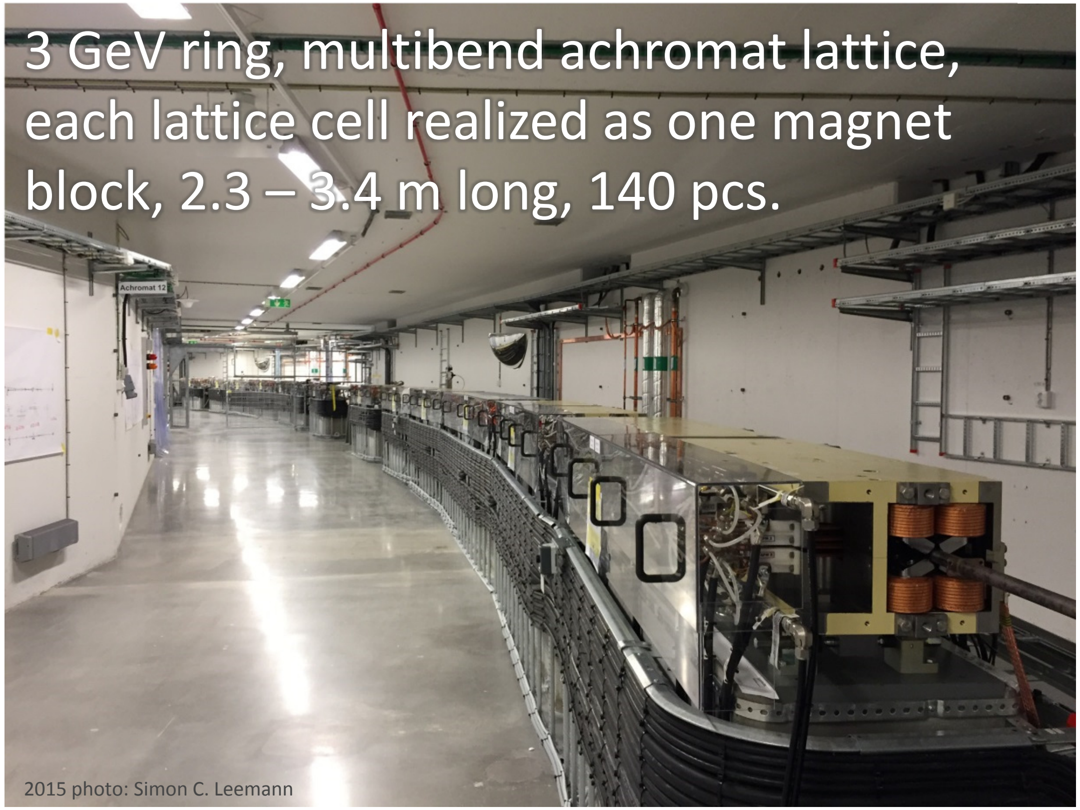
Lifted in place in the storage ring tunnel.



Magnet block top half is lifted off and vacuum chamber assembly is lowered in place.


Top half is re-assembled, power cables and cooling water are connected.

Same magnet concept as MAX IV 3 GeV ring



3 GeV ring, multibend achromat lattice, each lattice cell realized as one magnet block, 2.3 – 3.4 m long, 140 pcs.

2015 photo: Simon C. Leemann

Same concept used in earlier MAX-lab machines – recirculator linac and MAX III.

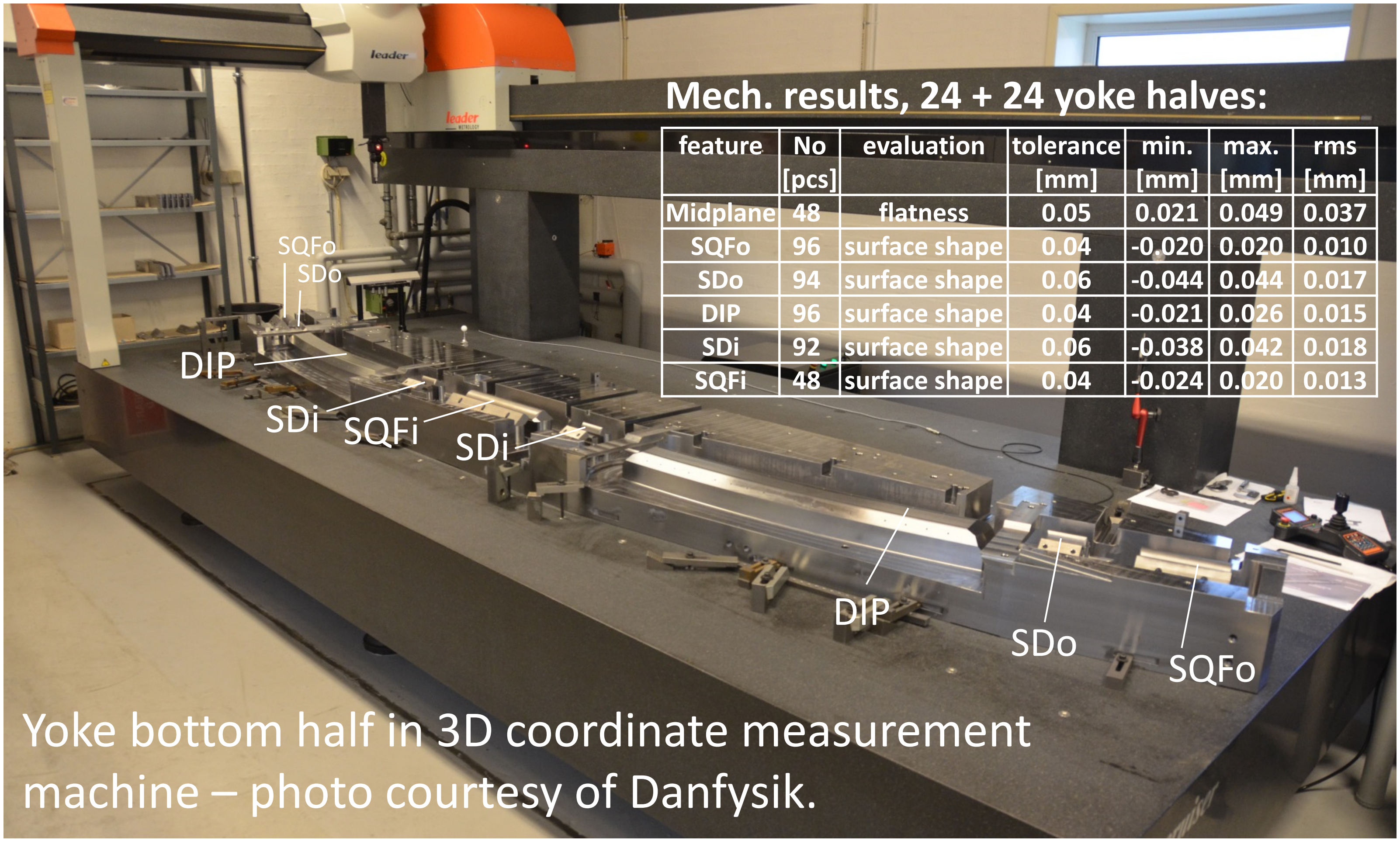
MAX III magnet block bottom half

Note that there are, on purpose, no built in position adjustment – alignment and field quality depends entirely on the precision of CNC machining.

Specification and procurement

- Magnet blocks procured as fully assembled and tested units.
- Supplier responsible for
  - mechanical tolerances - ±0.02 mm over 4.5 m block length!
  - performing field measurements according to MAX-lab spec.
- MAX-lab responsible for magnetic field properties.
- Contract awarded to Danfysik A/S, Denmark.
  - MAX IV contract signed fall 2012.
  - Solaris contract soon after, 12 + 12 magnet blocks to both facilities was one production series.
  - Delivery completed spring 2015.

Mechanical measurement results



Mech. results, 24 + 24 yoke halves:

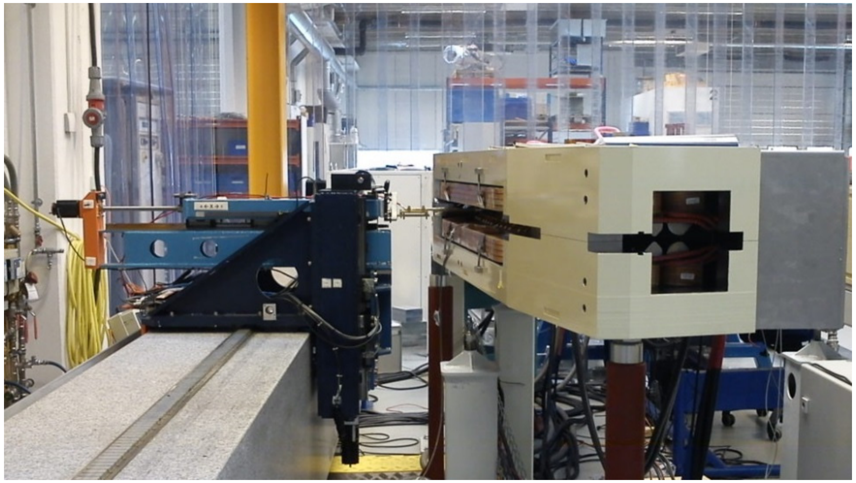
feature	No [pcs]	evaluation	tolerance [mm]	min. [mm]	max. [mm]	rms [mm]
Midplane	48	flatness	0.05	0.021	0.049	0.037
SQFo	96	surface shape	0.04	-0.020	0.020	0.010
SDo	94	surface shape	0.06	-0.044	0.044	0.017
DIP	96	surface shape	0.04	-0.021	0.026	0.015
SDi	92	surface shape	0.06	-0.038	0.042	0.018
SQFi	48	surface shape	0.04	-0.024	0.020	0.013

Yoke bottom half in 3D coordinate measurement machine – photo courtesy of Danfysik.

Field measurements
- performed by supplier for every individual magnet element.

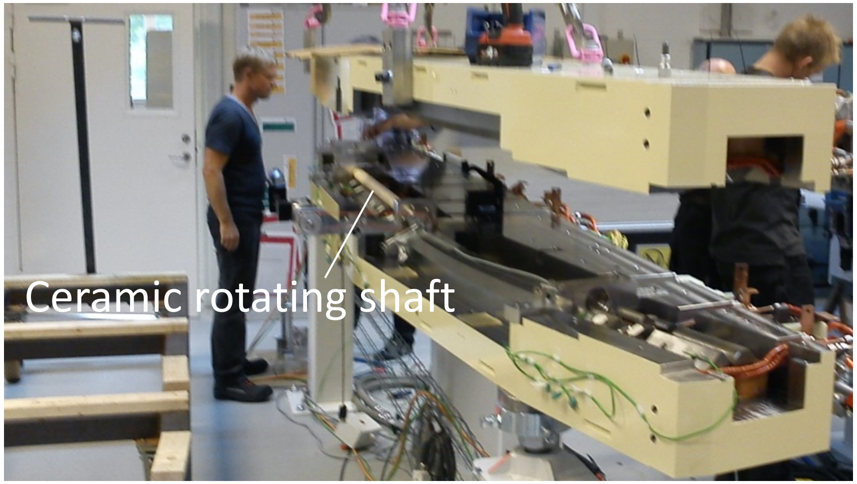
Hall probe

An insertion device mapping bench – same as was previously used for the MAX IV 3 GeV ring magnets.



Rotating coil

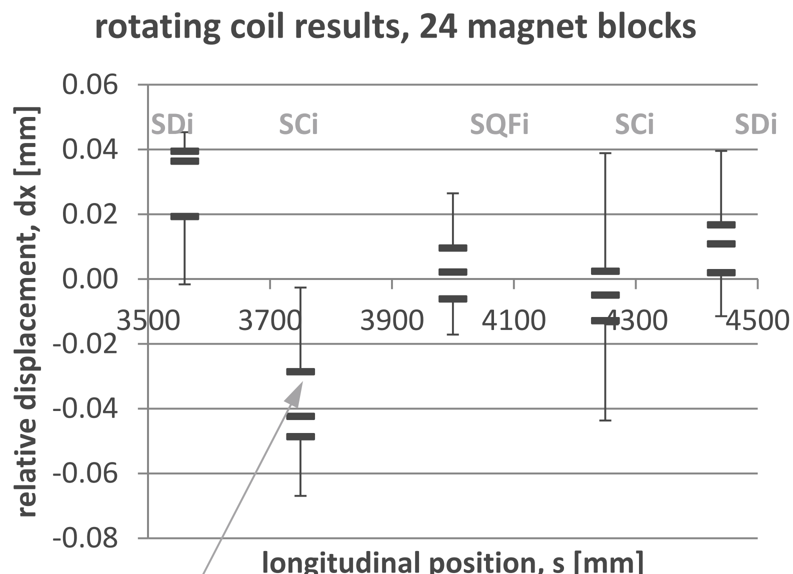
Several longitudinally spaced meas. coils in a common rotating shaft for access inside the magnet blocks.



No field measurements were performed at MAX-lab nor Solaris!

Field measurement results - alignment

- With the chosen rotating coil method, we can see relative alignment among consecutive magnet elements.
- For 3 GeV, this analysis indicated rms <10 µm alignment.
- But for 1.5 GeV, the results are not as conclusive ↗
- If SCi's are ignored, SDi-SQFi-SDi rel. alignment rms = 12 µm.



- **1st SCi appears to be shifted sideways.**
- **The SCo show the same tendency.**
- **Unknown if real, artifact or interpretation error.**

Field measurement results - strengths

- Integrated strength of all magnet elements known from Hall map or rotating coil →
- Measured max-min spread
  - roughly agrees with estimated from pole radius and pole shape tolerance.
- Meaning that we see no clear indication of additional spread in field strength from material properties.

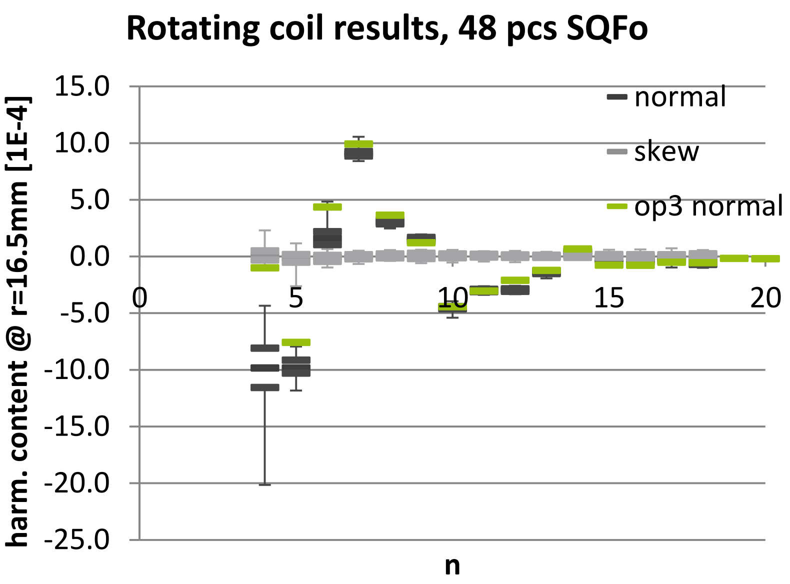
Results for 24 magnet blocks.

magnet	No [pcs]	int. strength at nom. I	est. [%]	min. [%]	max. [%]	rms [%]
DIP	47	-1.313 Tm	**±0.14**	**-0.12**	**0.12**	0.07
		6.768 T		-0.36	0.38	0.17
SQFo	48	-5.861 T	**±0.23**	**-0.29**	**0.43**	0.13
		-45.42 T/m		-0.69	0.56	0.27
SQFi	24	-10.14 T	**±0.17**	**-0.14**	**0.16**	0.08
		-58.04 T/m		-0.40	0.30	0.18
SDo	48	51.70 T/m	**±0.35**	**-0.29**	**0.19**	0.10
SDi	48	37.83 T/m	**±0.35**	**-0.32**	**0.39**	0.19
SCo	46	5.08 T/m		-0.81	0.63	0.36
x	48	1.18 Tmm				
y	48	-1.25 Tmm				
sk q	48	-0.183 T		-0.59	0.50	0.26
SCi	48	4.75 T/m		-0.96	0.82	0.46
x	48	1.17 Tmm				
y	48	-1.24 Tmm				
sk q	48	-0.147 T		-0.43	0.36	0.22

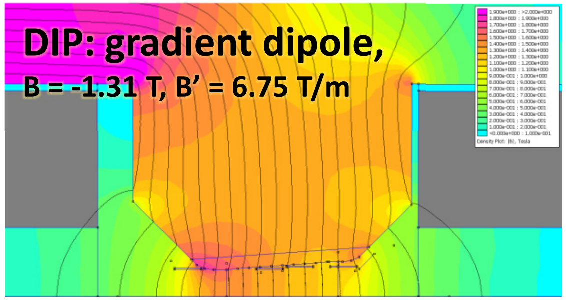
MAX IV

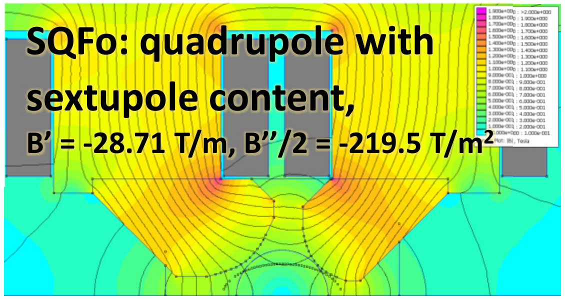
Field measurement results – harmonic content

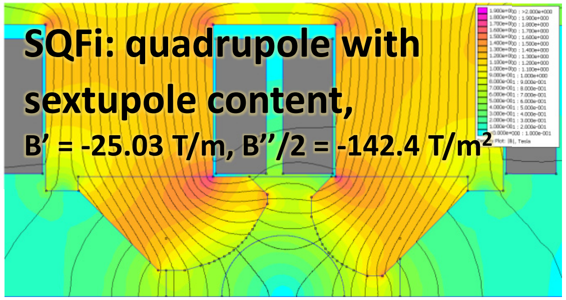
- Example data, harmonic content higher order terms, for one magnet type →
  - error terms directly above the main term have the largest spread
  - average agrees fairly well with Opera-3d
- Similar level of agreement to Opera-3d for all magnet types.
- Similar spread for SQFi, SDo, SDi.
- Higher spread for SCo/SCi, as expected (coarser tolerances).



Field measurement results – combined function magnets







- Series average integrated strengths, combined term scaled difference to nominal,
  - DIP = +0.09%, SQFo = +1.37%, SQFi = +0.66%
  - well within adjustment range of DIP pole face strips and SCo/SCi sextupoles.
- #001 results were accepted without any changes to pole designs.
- **All our 1.5 GeV storage ring magnet results are the outcome of a production series executed directly from Opera-3d modeling, without any intermediate prototyping.**

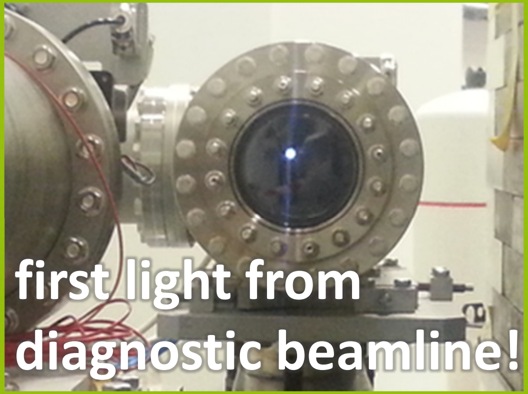
status

Solaris

- Commissioning started May 2015
- First turns at injection energy early June 2015.
- Stacking late June 2015.
- First ramp to full energy Oct 2015.
- June 2016: 400 mA at 1.5 GeV.
- To begin user operation Jan. 2017.

MAX IV

- Installation and subsystem tests completed Aug 2016.
- Beam commissioning started Sept 2016.
- Stacking to 1.6 mA Sept. 30th.



- To be continued ...

Thanks to my co-authors: Robert Nietubyc and Krzysztof Karas of Solaris.

Thanks to Dieter Einfeld (ESRF).

And thank you for your attention!