High field wigglers and combined function magnets at MAX-lab

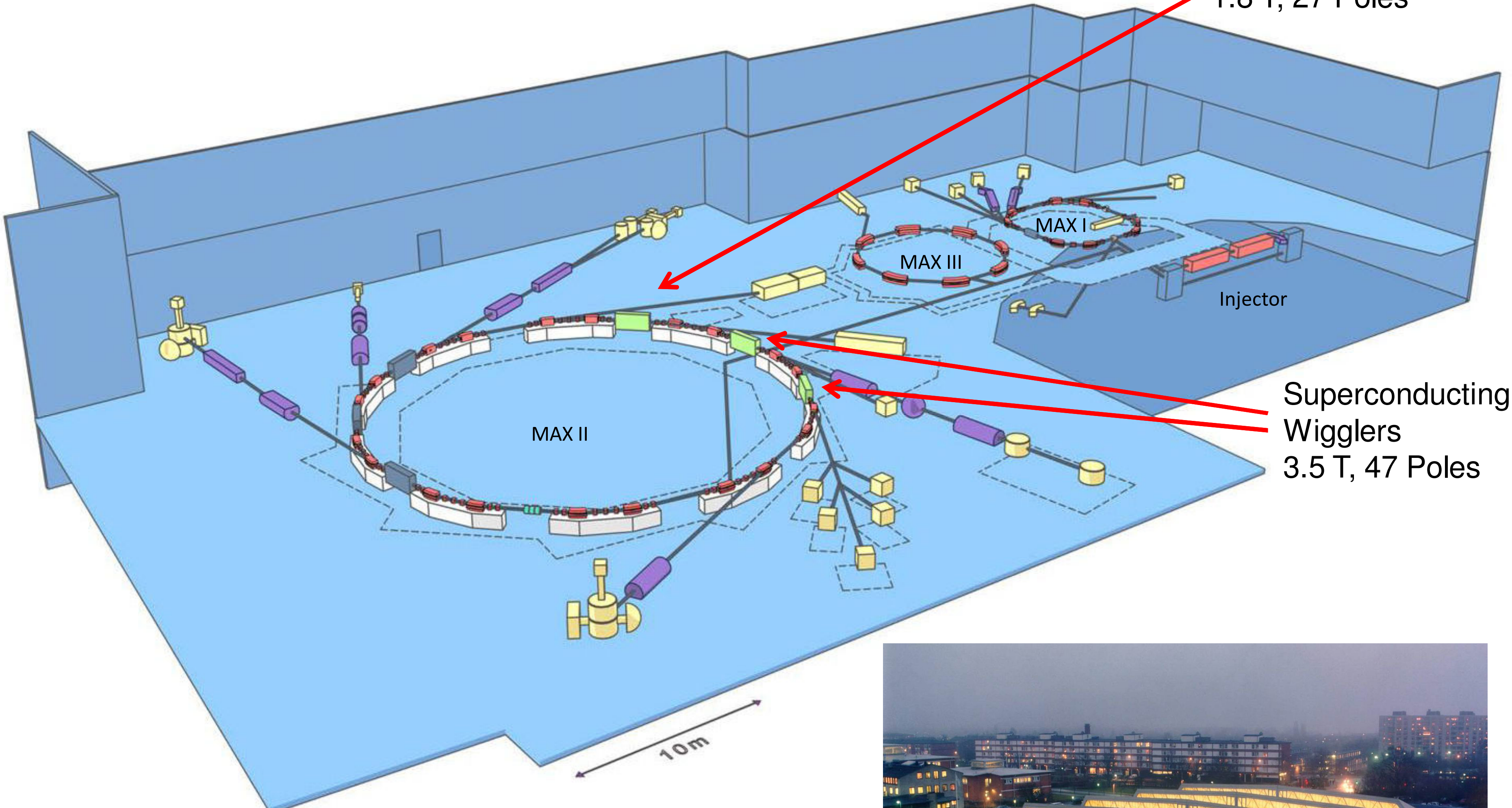
Erik Wallén

Outline:

- MAX-lab today and tomorrow
- The superconducting MAX-wiggler
- Wigglers for the MAX IV 3 GeV Storage Ring
- Combined function magnets at MAX III
- Magnets for the MAX IV 3GeV Storage Ring

Low Emittance Rings Workshop 2010 (LER2010)
CERN, 12-15 January, 2010

MAX-lab accelerator system today

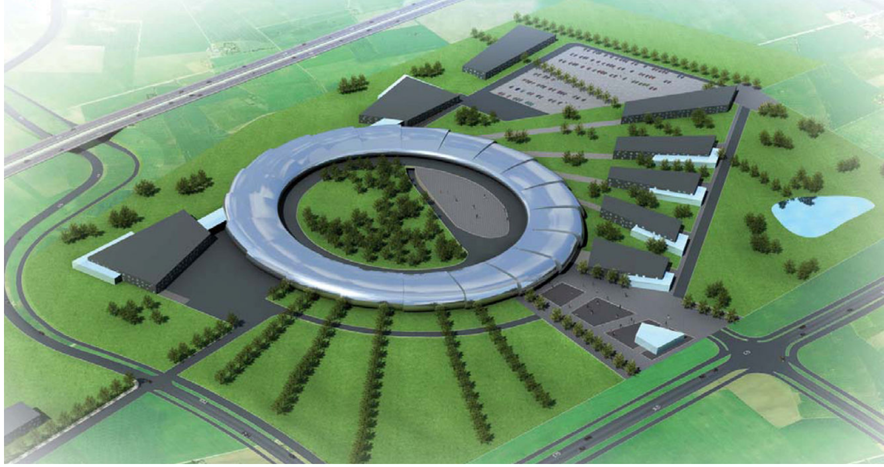


MAX I	500 MeV	~1985,
MAX II	1.5 Gev	~1995, New 100 Mhz RF system 2005
MAX III	700 MeV	~2005
MAX IV	Project started on April 27, 2009.	

MAX-lab tomorrow:

The MAX IV Light Source

spectral range: infrared <> hard X-rays
time structure: average flux <> short pulses



3 GeV linac: Full-energy injector for the storage rings
S-band 3 GHz structures with SLED cavities
short pulse facility delivering X-ray pulses < 100 fs @ 100 Hz
Spontaneous radiation, later upgraded to a seeded/cascaded FEL

3 GeV ring*: 528 m circumference, 500 mA, 0.3 nmrad Hor. Emittance
19 straight sections available for insertion devices
Spectral range 1-100 keV

1.5 GeV ring 96 m circumference, 500 mA, 5.6 nmrad Hor. Emittance
11 straight sections available for insertion devices
Spectral range IR-1000 eV
This ring replaces the existing MAX I, MAX II, and MAX III rings
No dark period during the construction of the MAX IV Light Source

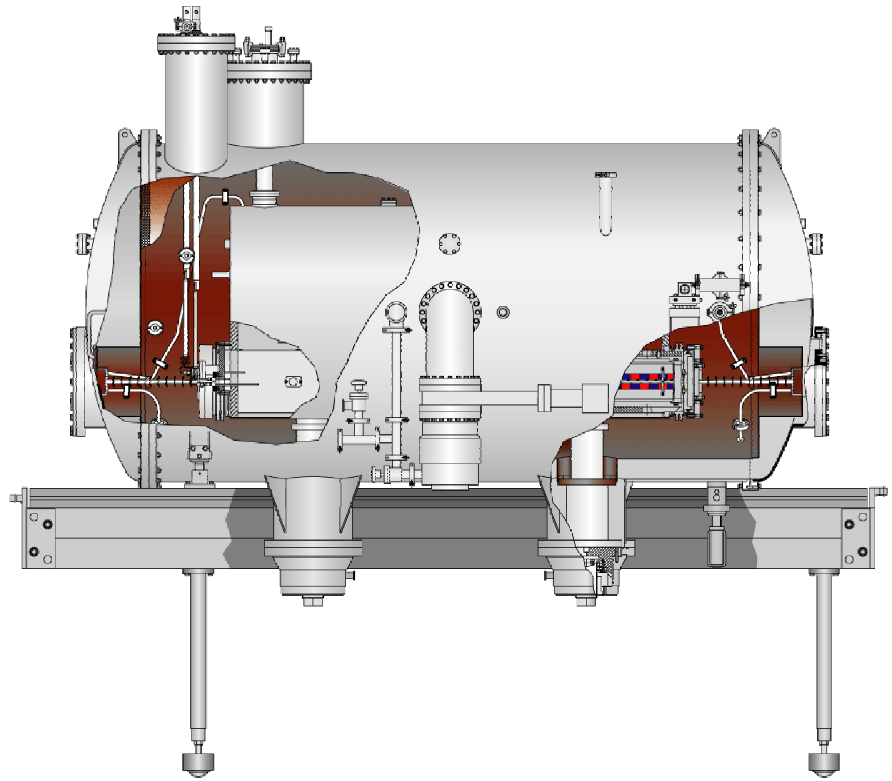
* "Beam dynamics for the MAX IV 3 GeV storage ring", S.C.Leemann, A. Andersson, M. Eriksson, L.-J. Lindgren, E. Wallen, J. Bengtsson, A. Streun, Physical Review Special Topics – Accelerators and Beams 12, 120701 (2009).

The MAX-Wiggler.

Two wigglers have been built for the beamlines I811 and I911 at MAX II.

Parameter list of the MAX-Wiggler.

Wiggler period	61 mm
Vertical Aperture	10.2 mm
Horizontal Aperture	70 mm
Total Length of Magnetic Assemblies	1472 mm
Number of Full Size Poles	47
Total Number of Poles	49
Peak Field	3.54 T
Peak Field for End Poles	2.10 T
K, Deflection Parameter	21.2
Total emitted power, 200 mA beam	5.0 kW
Stored magnetic energy	48 kJ



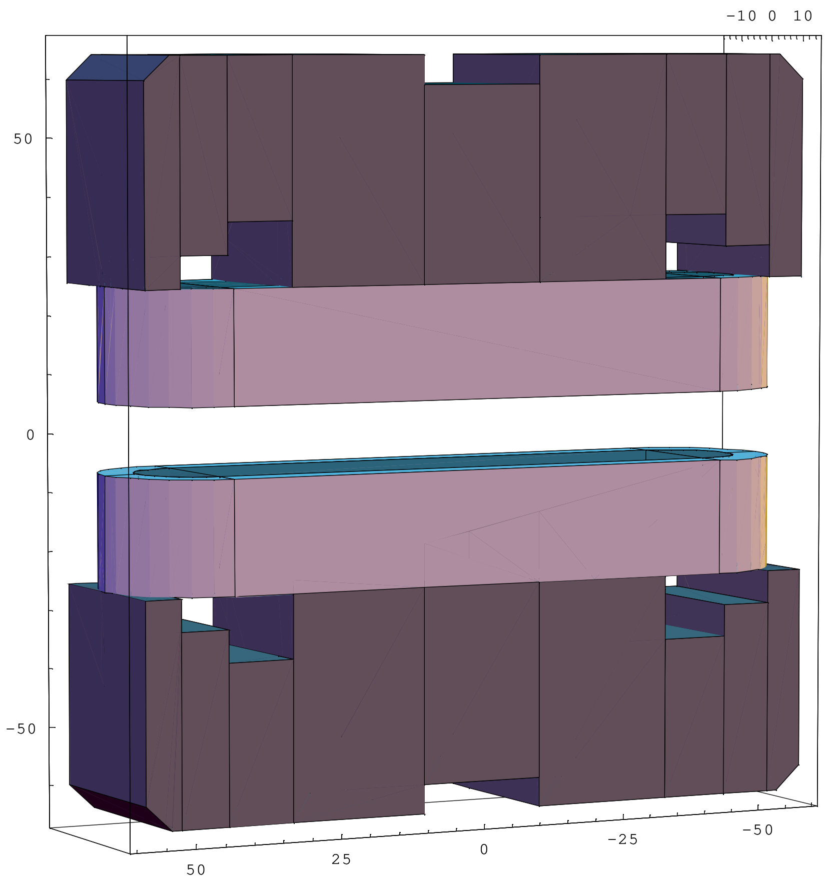
The MAX-Wiggler, a cold bore superconducting wiggler with 47 3.5T poles, [E. Wallén, G. LeBlanc, and M. Eriksson] Nuclear Instruments and Methods in Physics Research A 467-468 (2001) 118-121.

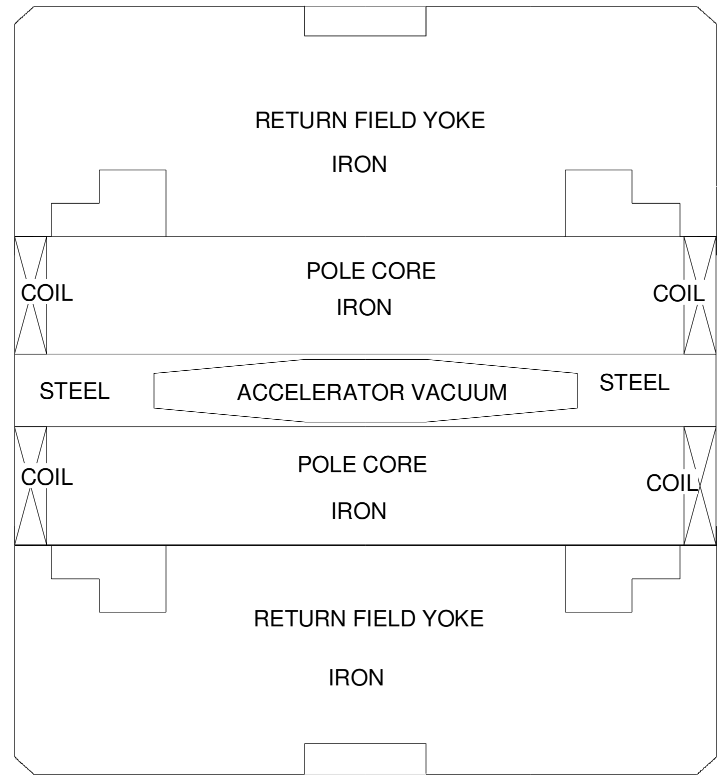
Quench Analysis of a Superconducting Magnet with 98 Coils Connected in Series [E. Wallén] IEEE Transactions on Applied Superconductivity, Vol. 13, (2003) 3845-3855.

Evaluation of the MAX-Wiggler, [G. LeBlanc and E. Wallén] Nuclear Instruments and Methods in Physics Research A 521 (2004), 530-537.

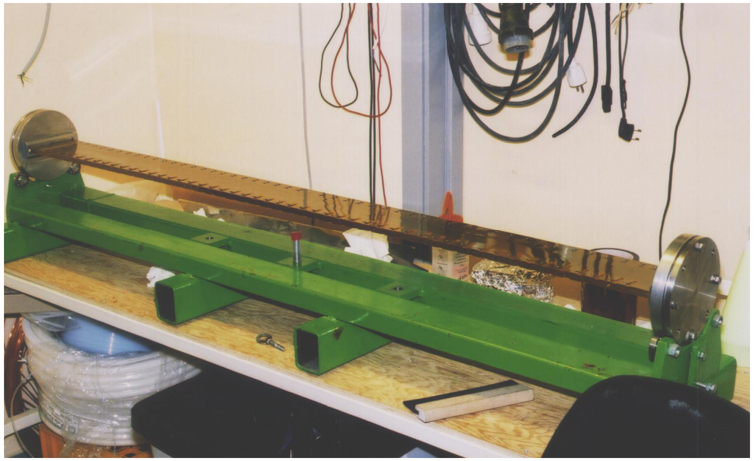
Cryogenic system of the MAX-Wiggler, [E. Wallén and G. LeBlanc] Cryogenics 44 (2004) 879–893.

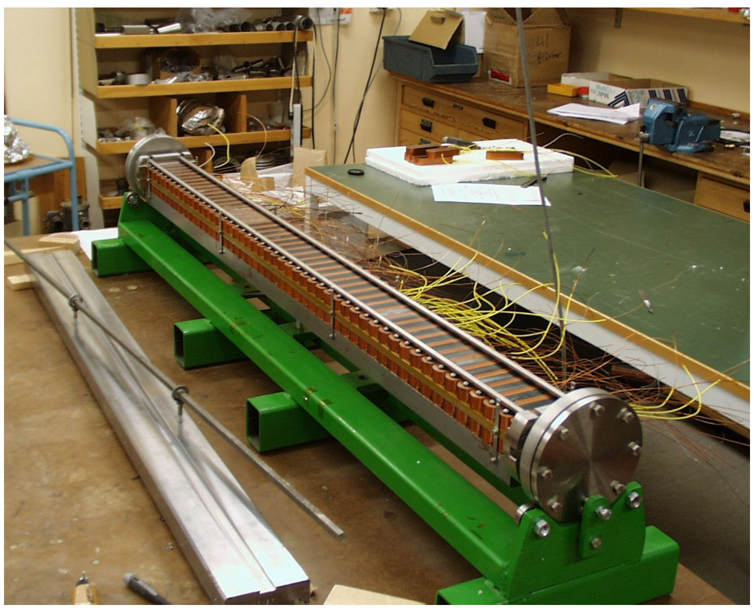
Superconducting Pole Pair

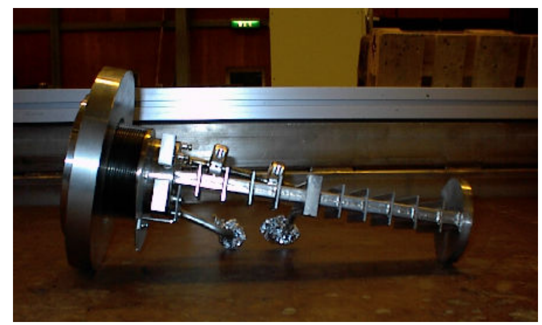


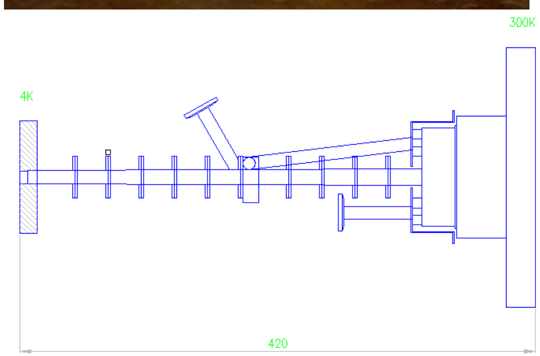


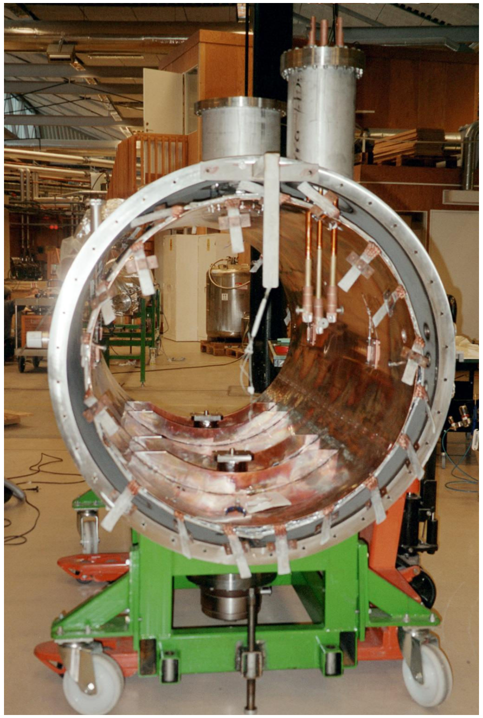
The aperture of the accelerator vacuum tube is 10.2 mm vertically and 70 mm horizontally.

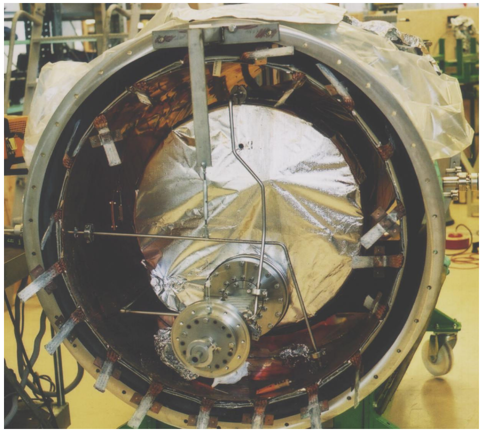


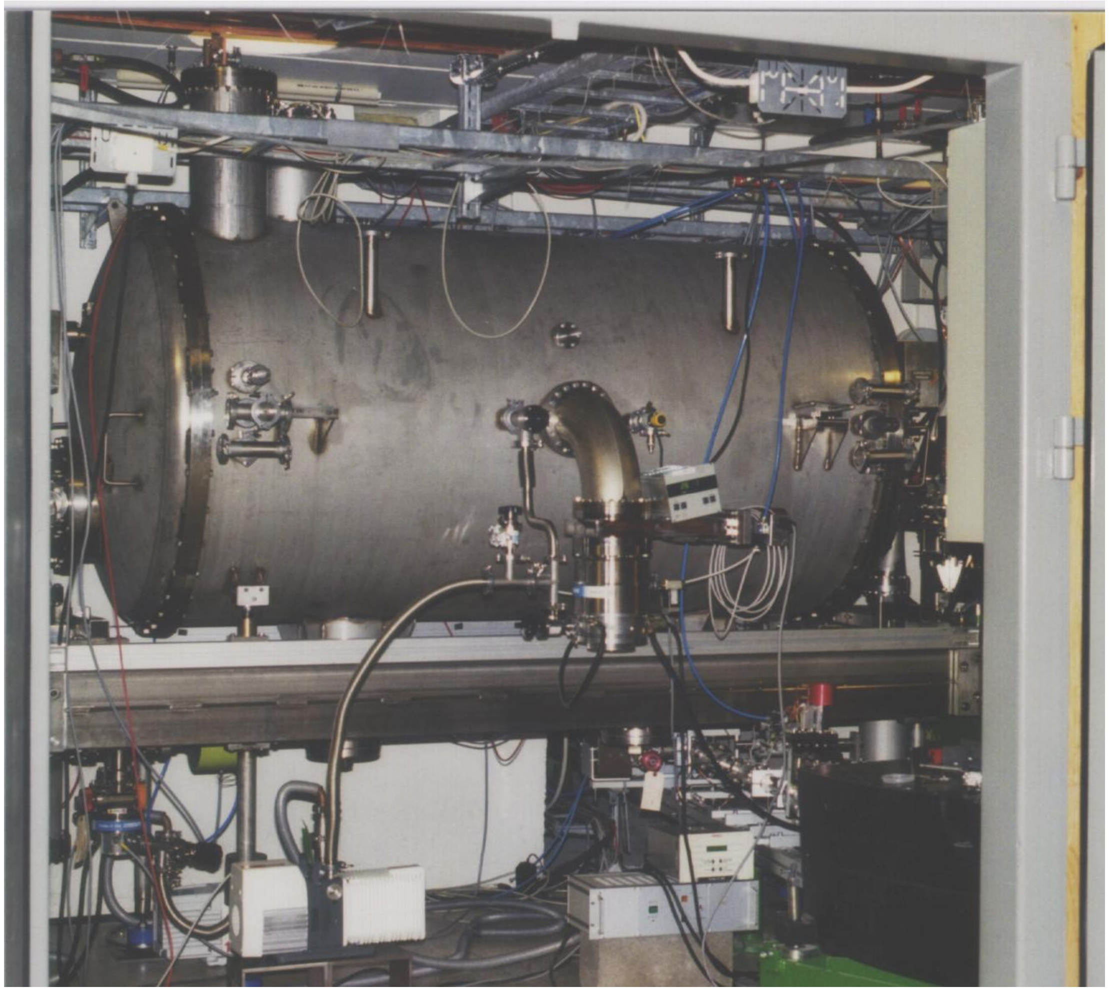





300K
4K
420







Situation at MAX-lab today

2 superconducting wigglers in operation since 2001/2002

Average boil-off with Landau cavity in operation <= 3 litres/hour/wiggler

Average boil-off without Landau cavity in >= 3 litres/hour/wiggler

- The production and handling of liquid He takes large resources

+ The superconducting wigglers gave access to hard x-rays at the MAX II ring

Several wigglers similar to the MAX-Wiggler have been built recently

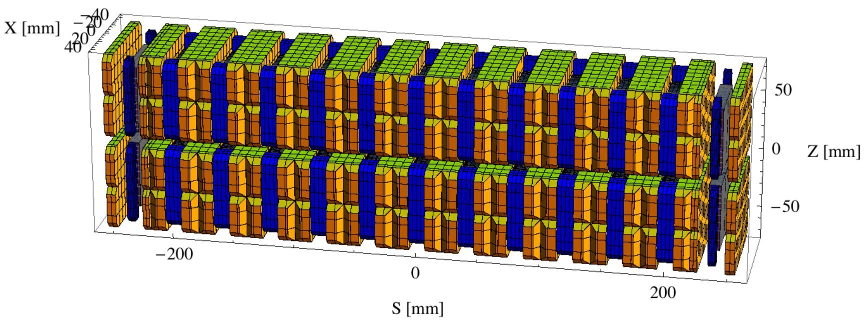
List of superconducting wigglers with period < 70 mm produced by Budker INP, Russia

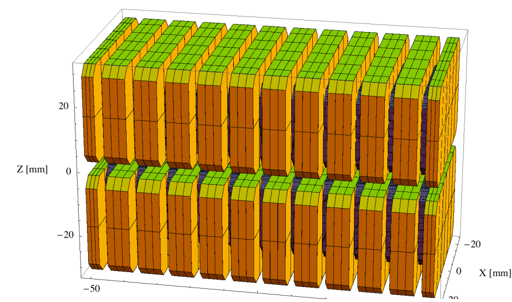
	Year	Magn.Field [T] (max)	# of full size poles	Period [mm]	Magn. Gap [mm]	Vert. Apert. [mm]	Liq. He Cons. [litre/hr]
Multipole wiggler for ELETTRA (Italy)	2002	3.7	45	64	16.5	11	≈0.5
Multipole wiggler for CLS (Canada)	2005	2.2	61	34	13.5	9.5	<0.05
Multipole wiggler for DIAMOND (England)	2006	3.75	45	60	16.5	11	<0.05
Multipole wiggler -2 for CLS (Canada)	2007	4.34	25	48	14.5	10	<0.05
Multipole wiggler for DIAMOND (England)	2009	4.25	45	48	13.5	10	<0.05
Multipole wiggler for LNLS (Brazil)	2009	4.19	31	60	18.4	14	<0.05
Multipole wiggler for ALBA-CELLSc(Spain)	2009	2.1	117	30.15	12.6	8.5	<0.05

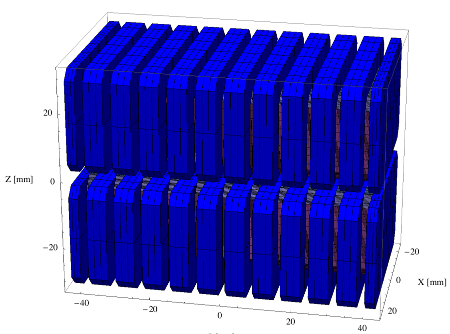
Contact person at Budker INP, Novosibirsk: Nikolai Mezentsev, Email: N.A.Mezentsev@inp.nsk.su

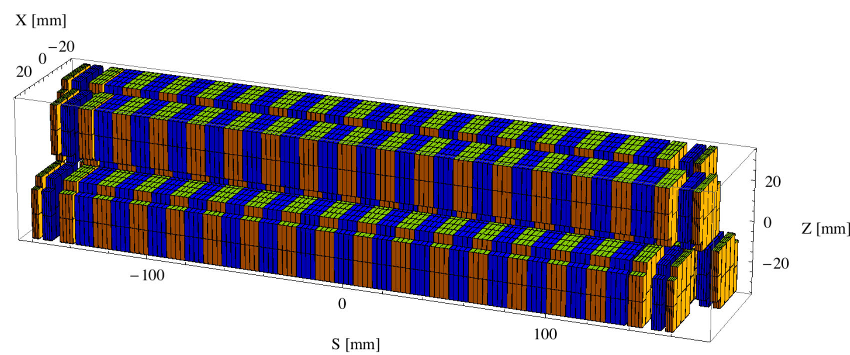
Proposed insertion devices the MAX IV 3 GeV ring

Beamline	Type	Length	Period
SXB, MAG	Hybride type wiggler	1.0 m	80 mm
MSC, TOM	Hybride type wiggler	4.0 m	80 mm
PX1, NF1, NF2	In-vacuum undulator	3.8 m	18.5 mm
MUS, HIK	In-vacuum undulator	3.8 m	20.0 mm
ENV	In-vacuum undulato	3.8 m	22.0 mm
PX2	Cryo-cooled in-vacuum undulator	3.8 m	15.6 mm
SXM	Cryo-cooled in-vacuum undator	3.8 m	16.4 mm
HRS, MAG	Elliptically polarising undator	4.0 m	38.0 mm







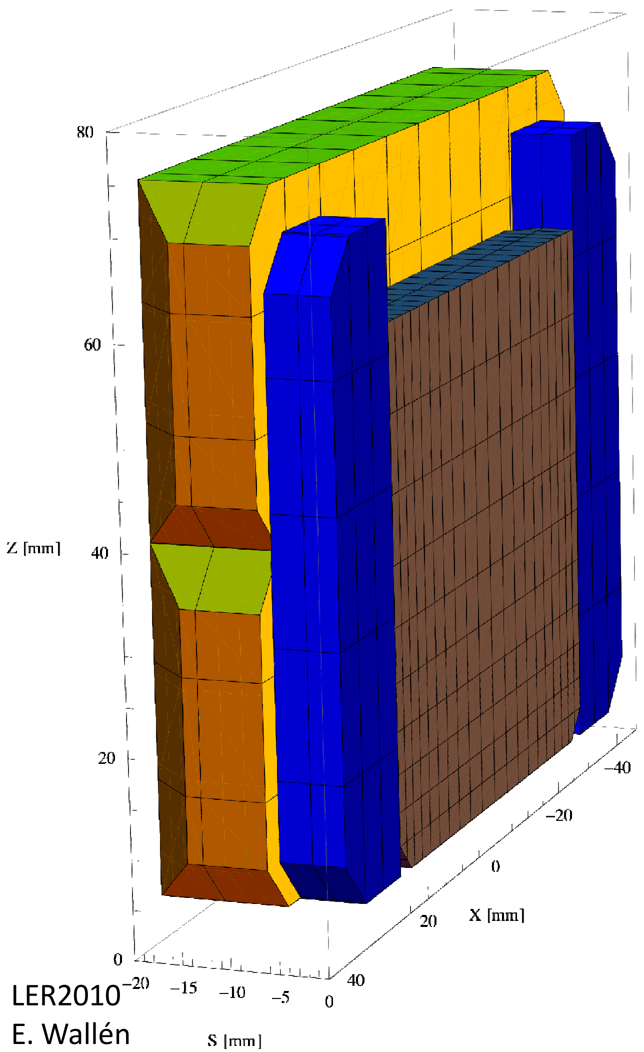


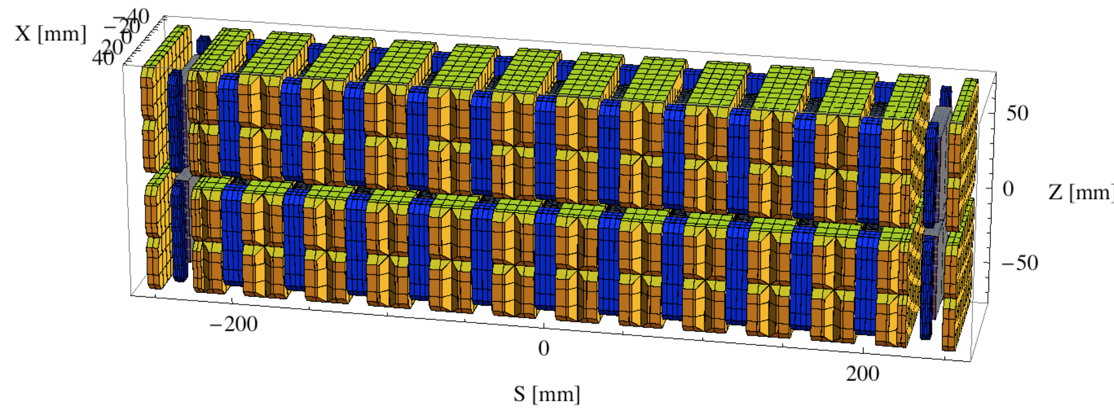
The insertion devices have been modelled with the Radia* code

[*] O.Chubar, P.Elleaume and J.Chavanne, Journal of Synchrotron Radiation, 1998, vol.5, p.481, and http://www.esrf.fr/machine/groups/insertion_devices.

Damping wigglers for the MAX IV 3 GeV ring

The proposed damping wigglers are of hybrid type using permanent magnet material since they have lower running costs than superconducting wigglers.





The damping wigglers of hybride type are built from three basic building blocks

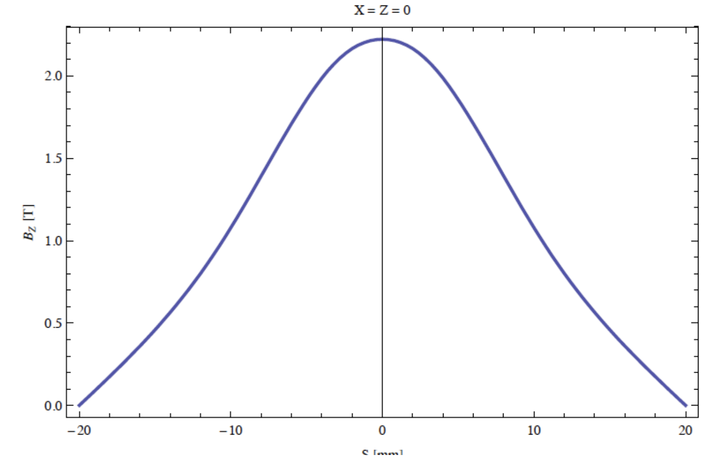
The main blocks, (yellow) of NdFeB
Remanence 1.25 T, Intr. Coerc. 25 kOe

The side blocks (blue) of NdFeB
Remanence 1.28 T , Intr. Coerc. 21 kOe

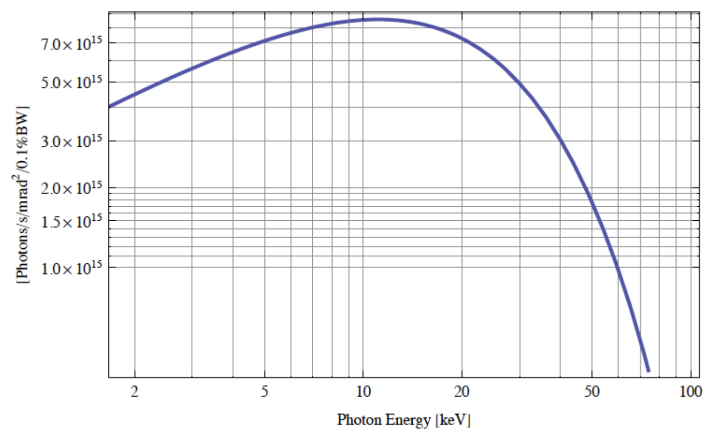
The poles (grey) of Vanadium Permendur
(Fe : 49%, Co: 49%, V:2%),

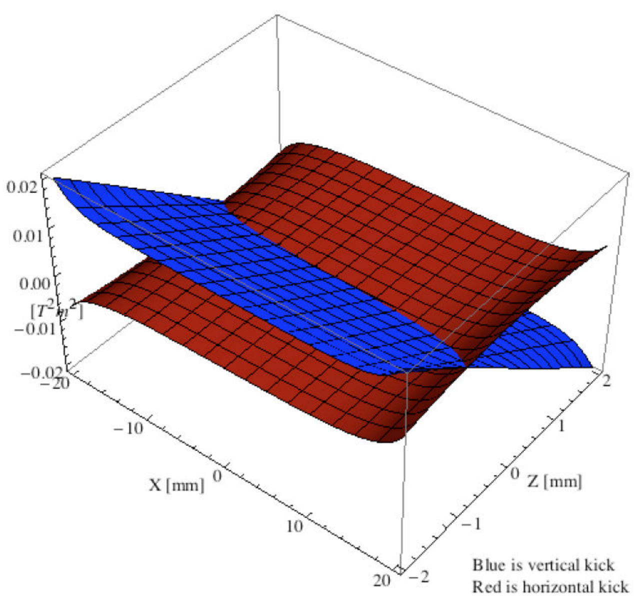
Damping wigglers for the MAX IV 3 GeV ring

Period	80.0	mm
Gap	9.0	mm
Peak Field	2.223	T
Effective Field	1.886	T
Peak k-value	16.611	
Effective k-value	14.096	
Higher Order Contr.	17.00	%
Maximum e-beam deflection	2.27	mrad
Electron Beam Energy	3.0	GeV
Electron Beam Current	500	mA
Max Critical Energy	13.305	keV
Emitted Power	40.434	kW
Photon Energy, n = 1	0.011	keV
Total Length	3990.7	mm



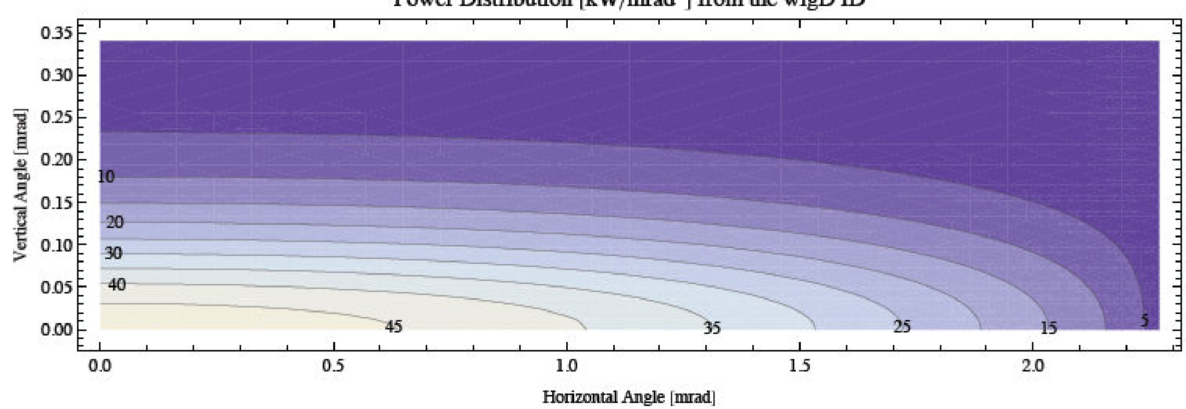
Spectral flux density from the wigD ID



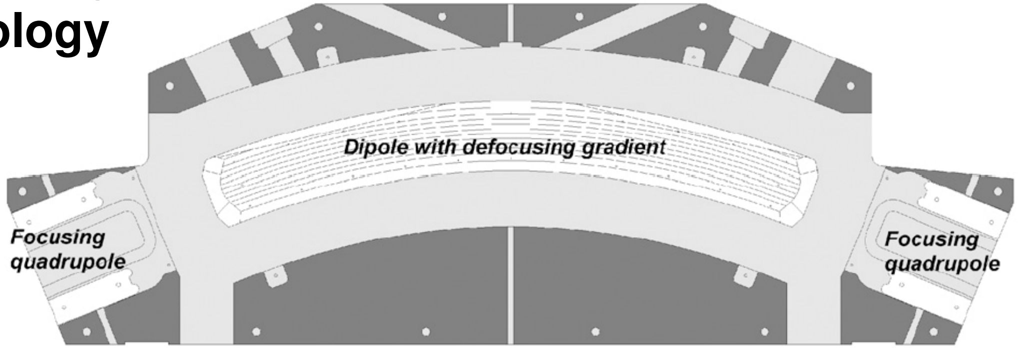


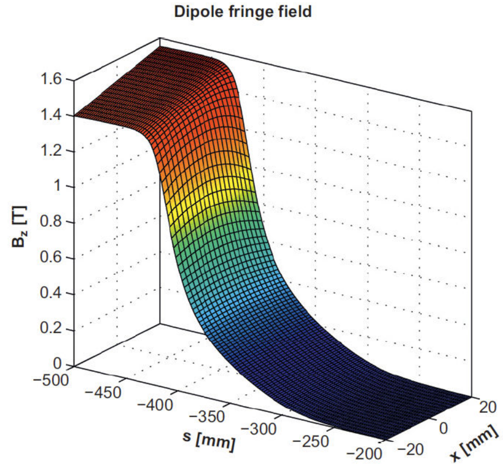
Blue is vertical kick
Red is horizontal kick

Power Distribution [kW/mrad^2] from the wigD ID



MAX III Magnet Technology





LER2010
E. Wallén

The MAX III storage ring [M.Sjöström, E.Wallén,M.Eriksson, L.-J. Lindgren] Nucl.Insrt.and Meth. A 601 (2009) 229–244.

Dipole with gradient

	Dipole	Quadrupole	End-sextupole
	n = 0	*n = 1*	*n = 2*
Lattice design values			
Strength	1.46709	3.52	-
Integrated strength	1.8339	4.40	8.73
Magnetic length	1.250	1.250	-
Magnet design simulation (RADIA)			
Strength	1.46709	3.67	-
Integrated strength	1.8339	4.40	8.9
Magnetic length	1.250	1.198	-
Prototype measurement (Hall probe)			
Strength	1.469	3.79	-
Integrated strength	1.842	4.53	8.7 – 9.0
Magnetic length	1.254	1.194	-

Discrepancy between the RADIA design value and the prototype value for the bulk field gradient. Compensated for using pole face strips.

Cross-talk between the quadrupoles and the main dipole were over-estimated in the RADIA design simulations, as all cuts could not be modelled.

MAX III Hall probe measurements on dipole magnet

Each magnet cell was connected to a powersupply prior to ring assembly, and the field was measured at two points using a Hall probe. Note that:

- They were not connected in series
- Pole face strips were not excited
- Cell 1 and 2 were only measured at one point.

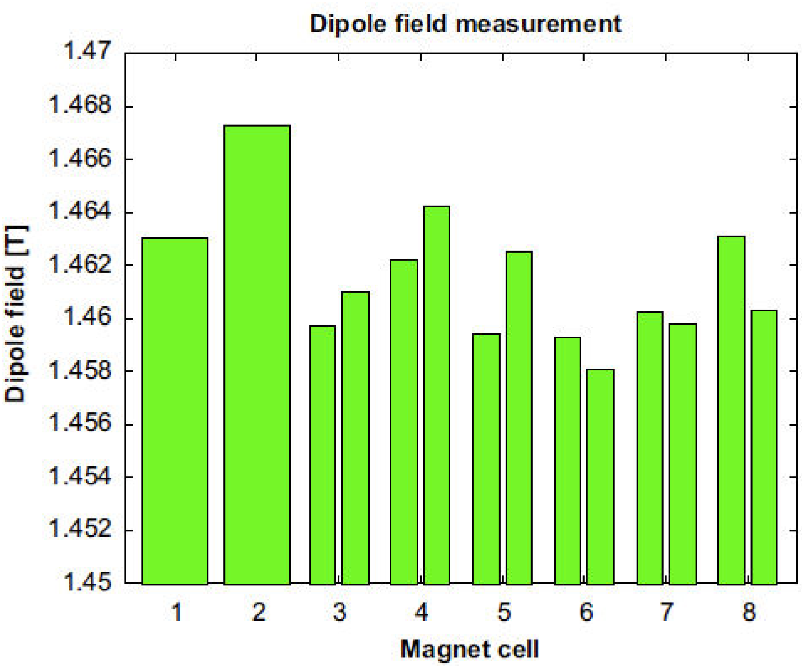


Fig. 8. MAX III dipole field strength measured for 500 A magnet excitation current by a Hall probe. The dipoles in cell 1 and 2 were evaluated in one point only; in cells 3–8 dipoles were evaluated in two points. Pole face strips were not excited during the measurement.

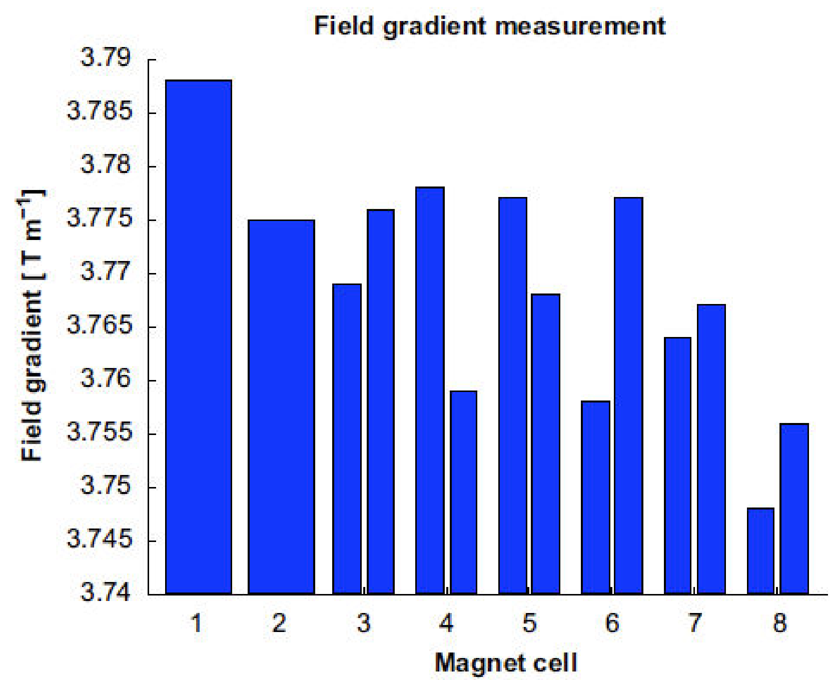
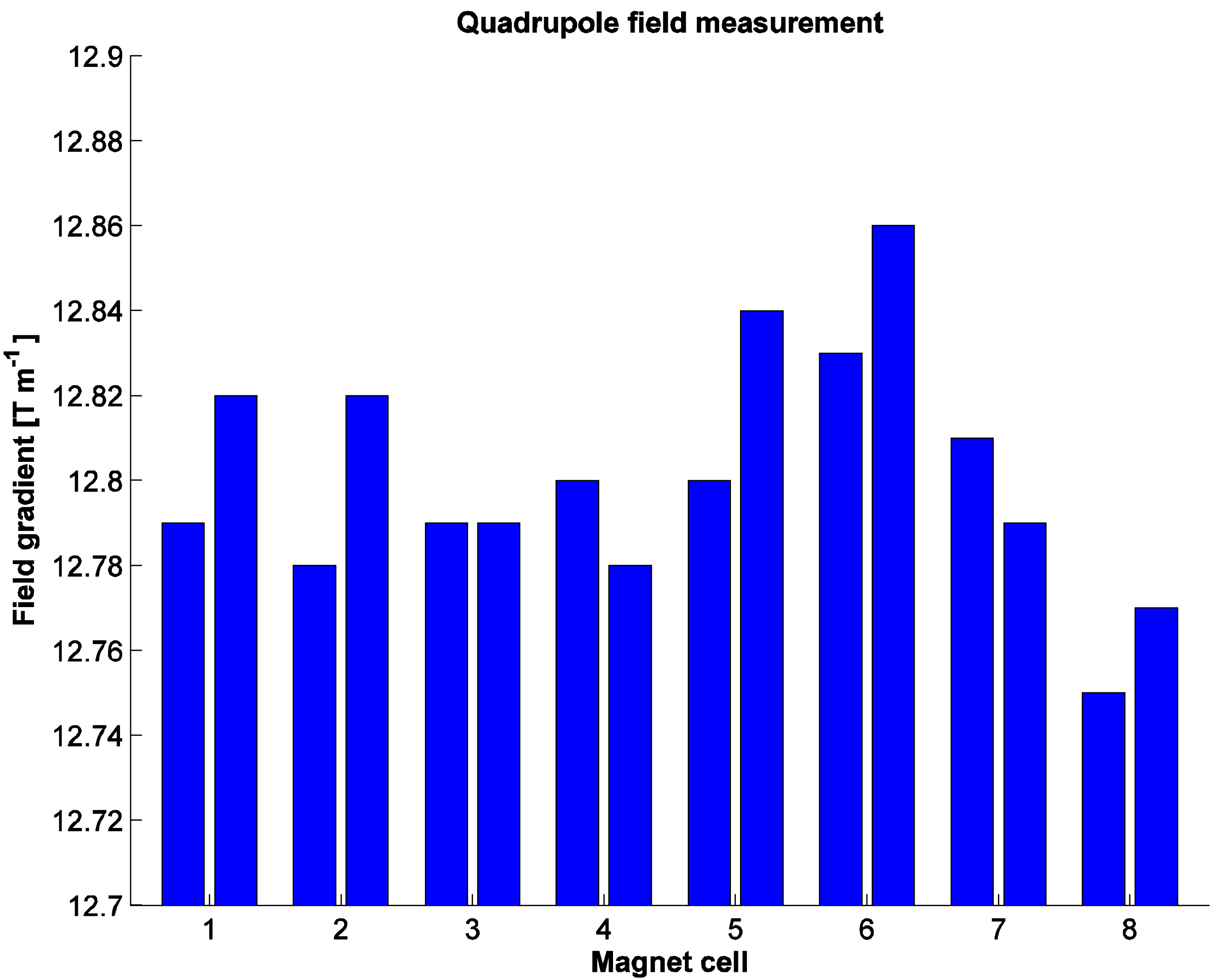


Fig. 9. MAX III dipole field gradient measured for 500 A magnet excitation current by a Hall probe. The dipoles in cell 1 and 2 were evaluated in one point only; in cells 3–8 dipoles were evaluated in two points. Pole face strips were not excited during the measurement.

MAX III Quadrupole with sextupole

	Dipole	Quadrupole	Sextupole
	n = 0	*n = 1*	*n = 2*
Lattice design values			
Strength	0	13.99	30.7
Integrated strength	0	2.798	6.14
Magnetic length	-	0.2	0.2
Magnet design simulation (RADIA)			
Strength	$2.5 \cdot 10^{-3}$	13.99	32.32†
Integrated strength	$5.0 \cdot 10^{-4}$	2.798	6.14†
Magnetic length	0.2	0.2	0.19
Prototype measurement (Hall probe)			
Strength	$8.06 \cdot 10^{-4}$	13.98	33.3
Integrated strength	$1.61 \cdot 10^{-4}$	2.78	6.16
Magnetic length	0.2	0.199	0.185

† *Value includes a 1.85 T m^{-2} sextupole leak field from the excited dipole.*


Quadrupole field measurement
12.9
12.88
12.86
12.84
12.82
12.8
12.78
12.76
12.74
12.72
12.7
Field gradient [T m-1]
1
2
3
4
5
6
7
8
Magnet cell

MAX III LOCO measurements

Pole face strips were excited.
Error bars are 1σ estimates obtained from 4 measurements.

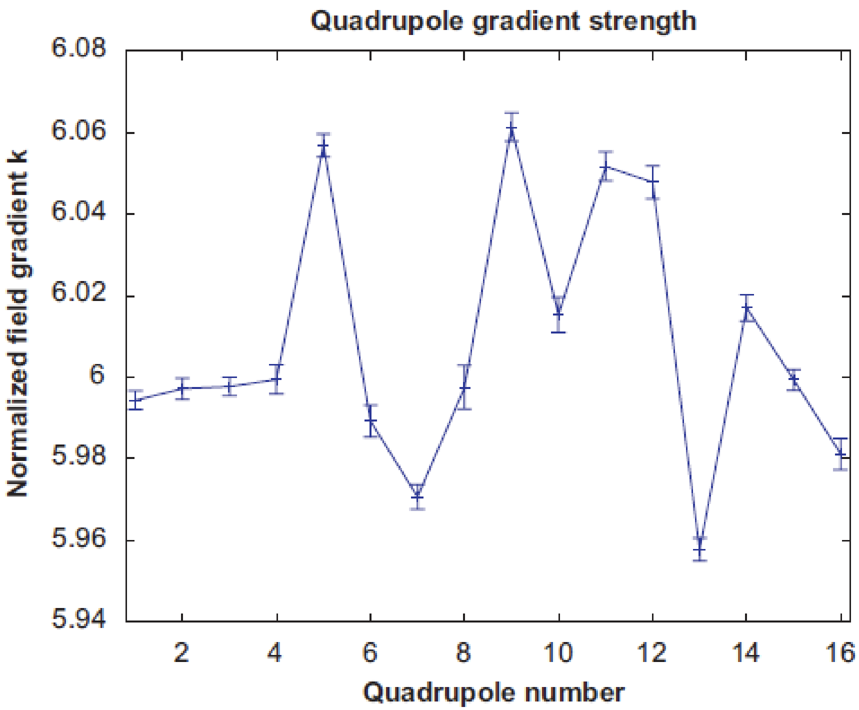


Fig. 26. Measured quadrupole gradients using LOCO. Error bars represent the 1 sigma standard error, computed from four different response matrix measurements over the period 2008-01-23 to 2008-06-17.

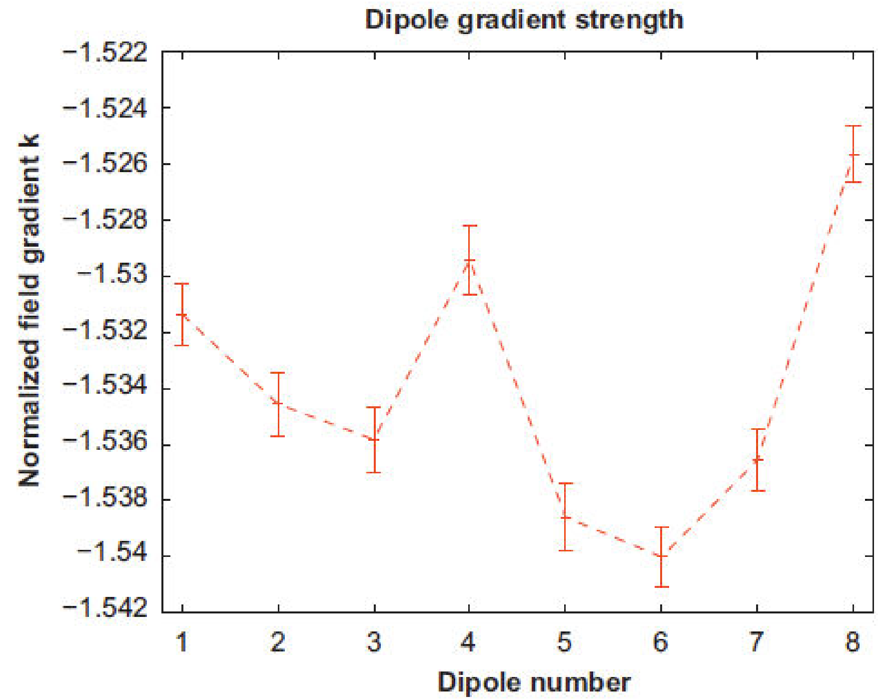


Fig. 27. Measured quadrupole gradients using LOCO. Error bars represent the 1 sigma standard error, computed from four different response matrix measurements over the period 2008-01-23 to 2008-06-17.

MAX III pole face strips

The pole face strips are efficient for changeing the tune and chromaticity

The pole face strips can be used for compensating errors in the production of the magnets

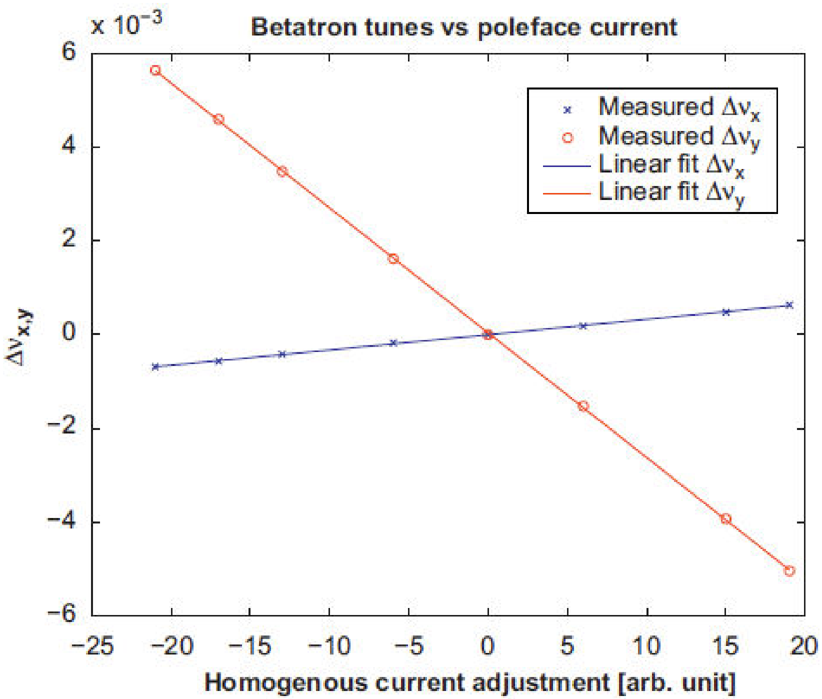


Fig. 28. $\nu_{x,y}$ response to an equally large current adjustment in all poleface strips.

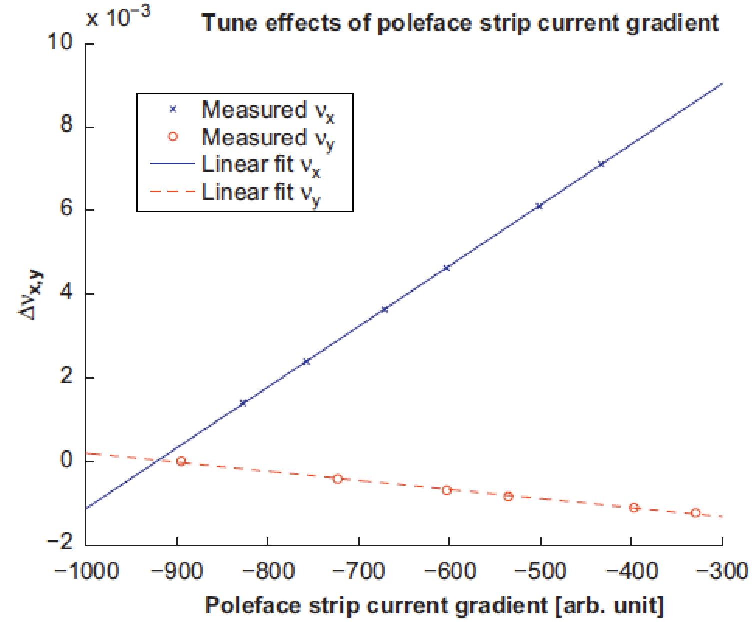


Fig. 29. $\nu_{x,y}$ response to a change of current gradient across the four poleface strips.

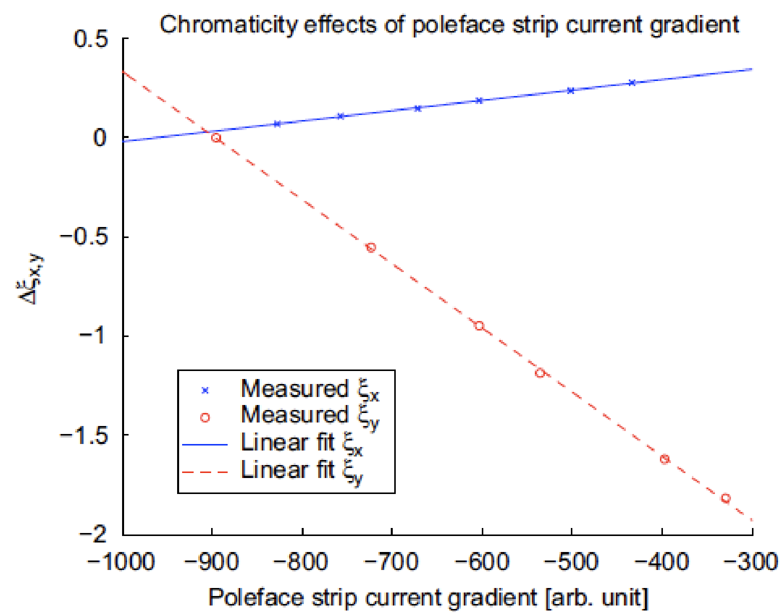
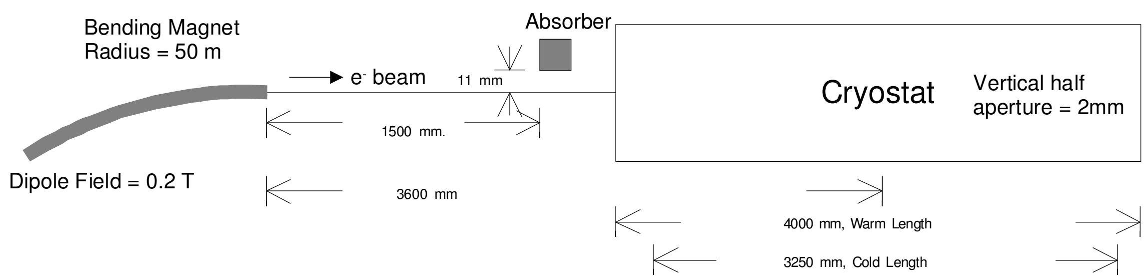


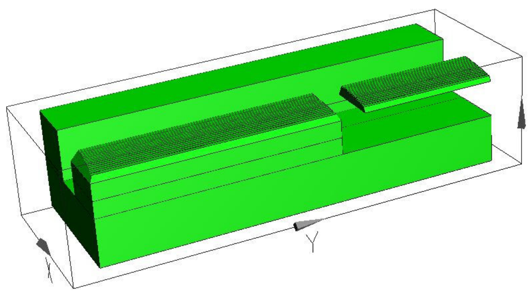
Fig. 30. $\xi_{x,y}$ response to a change of current gradient across the four poleface strips.

Matching Cell Dipole with Soft End (2004)

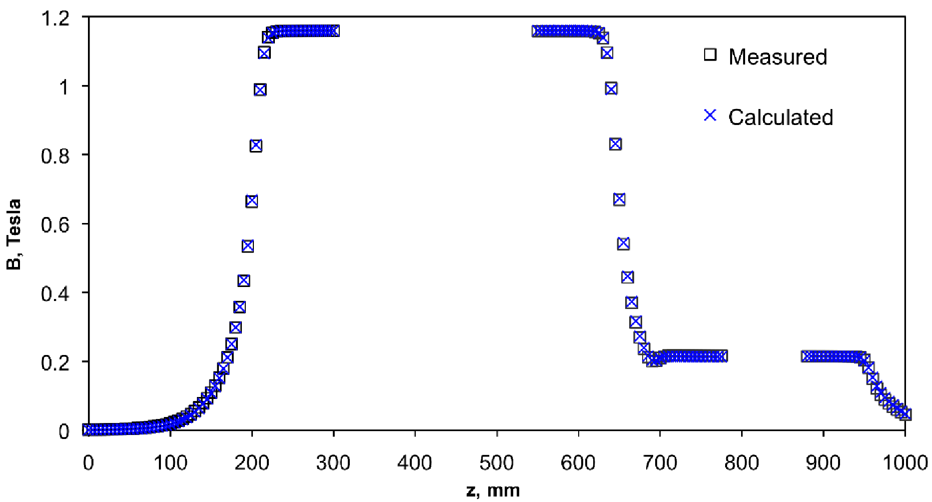
The synchrotron radiation power hitting the cold bores is restricted by the introduction of soft end magnet preceding the SC ID.

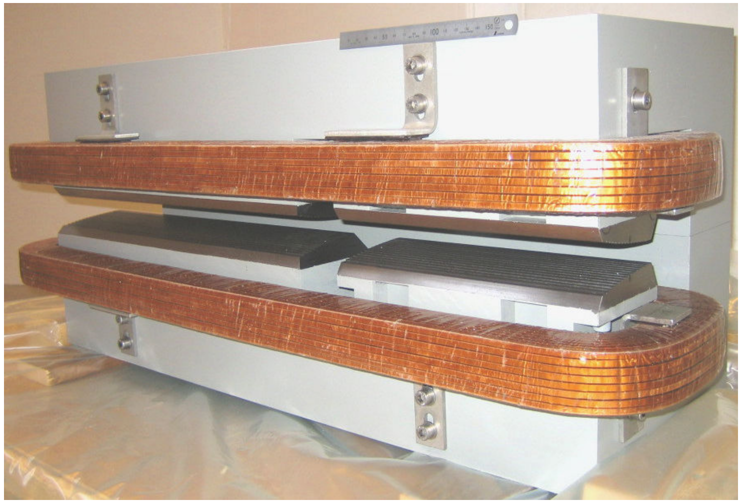
SR Power ~ 1/ρ





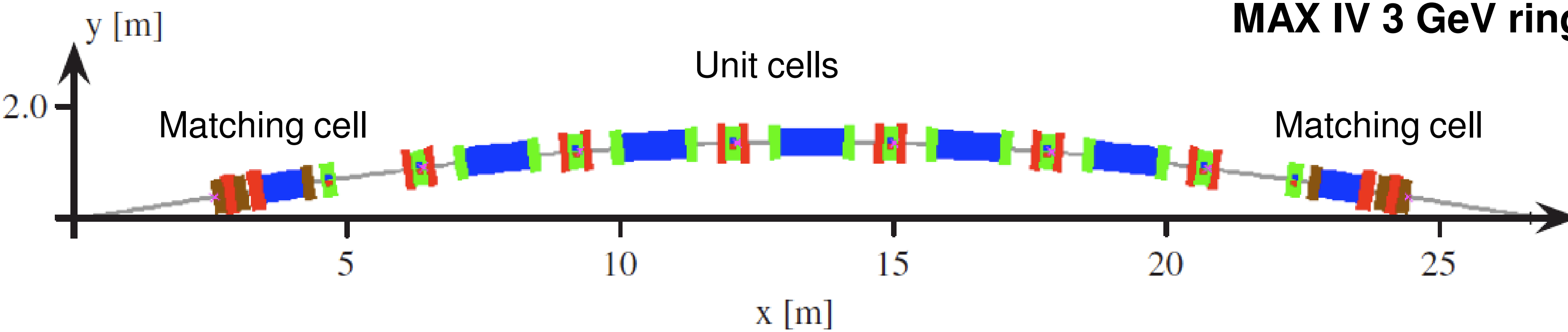
Magnetic field along the centre of the soft dipole magnet





[H. Tarawneha, and E. Wallén] Nuclear Instruments and Methods in Physics Research A 527 (2004) 652–656.

MAX IV 3 GeV ring



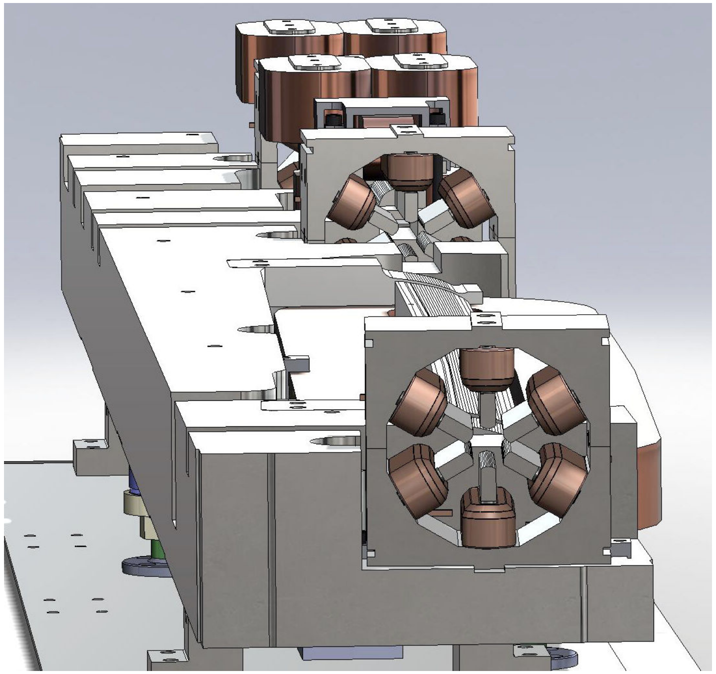
Dipole field and quadrupole gradients

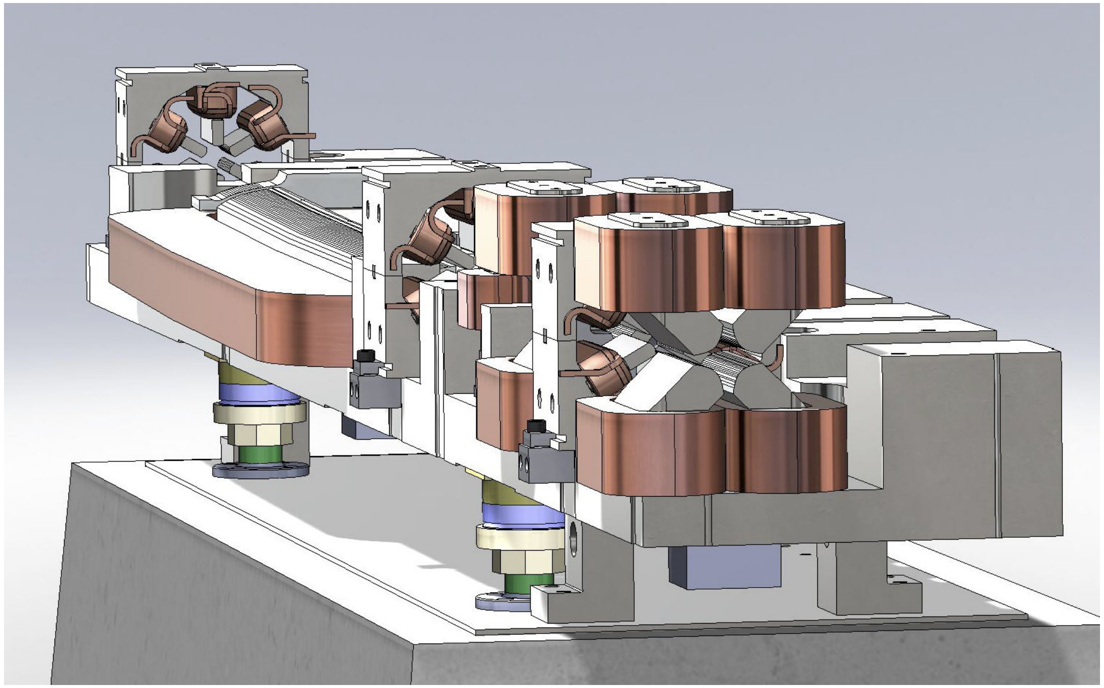
	Length [m]	Dipole peak field [T]	Quadrupole gradient [T/m]
Dipole (unit cell)	0.974	0.524	−8.69
Soft-end dipole (matching cell)	0.554	0.524	−8.69
Focusing quadrupole (unit cell)	2×0.15	···	40.39
Focusing quadrupole (facing matching cell)	2×0.15	···	37.80
Final focusing quadrupole (matching cell)	0.25	···	35.34
Final defocusing quadrupole (matching cell)	0.25	···	−22.40

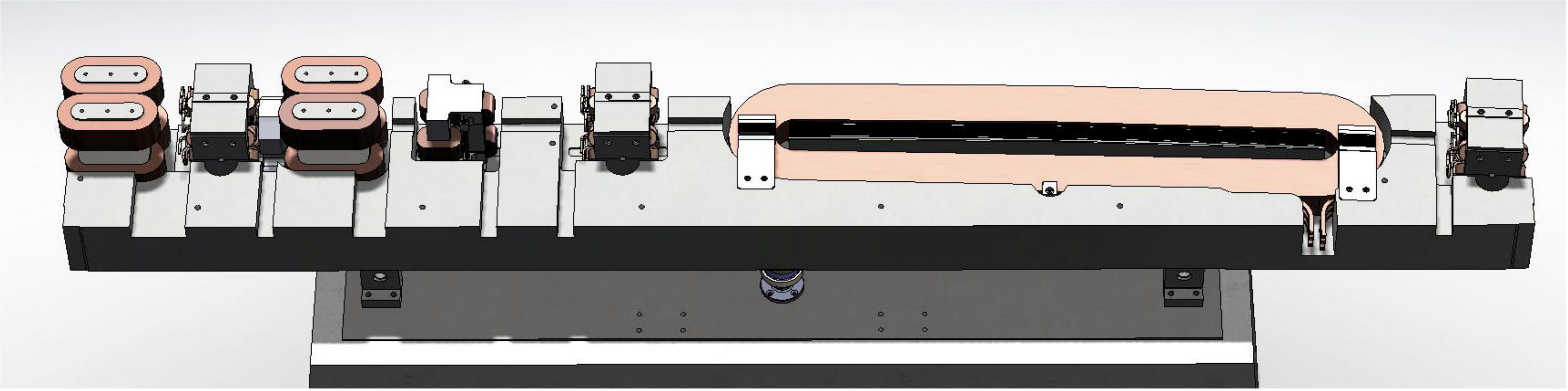
Sextupole and octupole gradients

	Length [m]	Sextupole gradient [T/m^2]	Octupole gradient [T/m^3]
Focusing sextupoles (unit cell)	0.1	2148/1700/1600	···
Defocusing sextupole (unit cell)	0.1	−1179	···
Defocusing sextupole (matching cell)	0.1	−1340	···
Focusing octupole (matching cell)	0.1	···	21 814
Defocusing octupoles (matching cell)	0.1	···	−13 143/ − 6886

MAX IV 3 GeV ring
Unit Cell







MAX IV 3 GeV ring
Matching Cell