Status of the MAX IV Storage Rings

Multibend achromats for ultralow emittance (0.3 nm rad)

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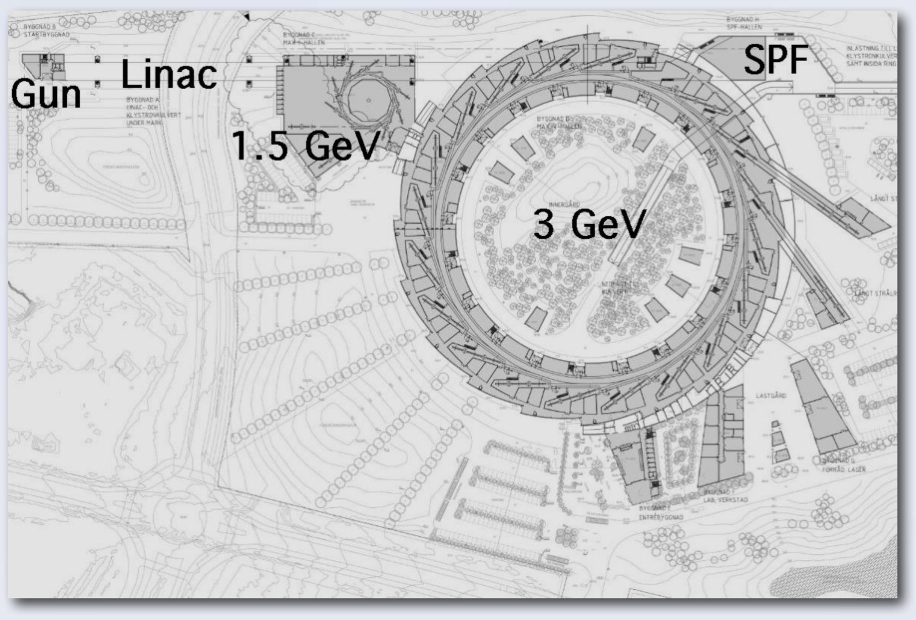
At a Glance

Timeline
- April 2009: MAX IV Facility granted funding by Swedish authorities
- 2011: Start of construction (next to future ESS site)
- 2013-2014: Commissioning of guns, linac, and both storage rings
- 2015: Regular user operation begins

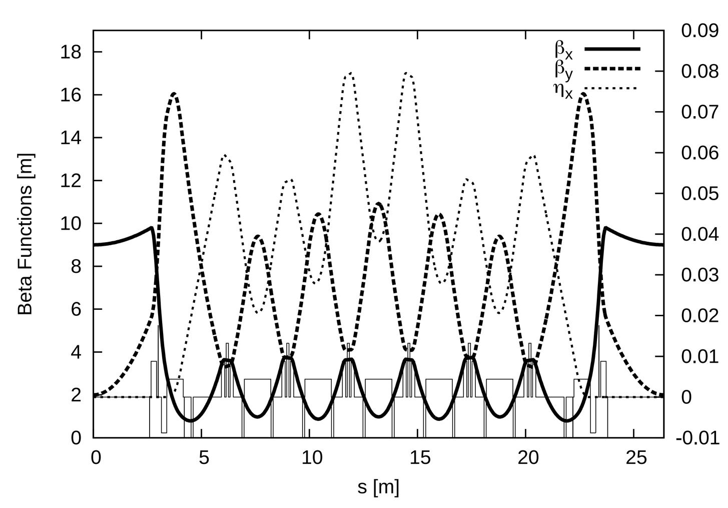
Facility Overview
- MAX IV uses different machines [1] tailored to different user demands
- MAX IV consists of
  - *Short-pulse facility* (SPF) [2] and *FEL* (Phase 2)
  - ***3 GeV storage ring*** (→ x-ray users) [3]
  - ***1.5 GeV storage ring*** (→ IR and UV users)
- The **MAX IV 3.4 GeV linac** drives the SPF/FEL and acts as a full-energy injector for both storage rings (via two transfer lines) → continuous top-up

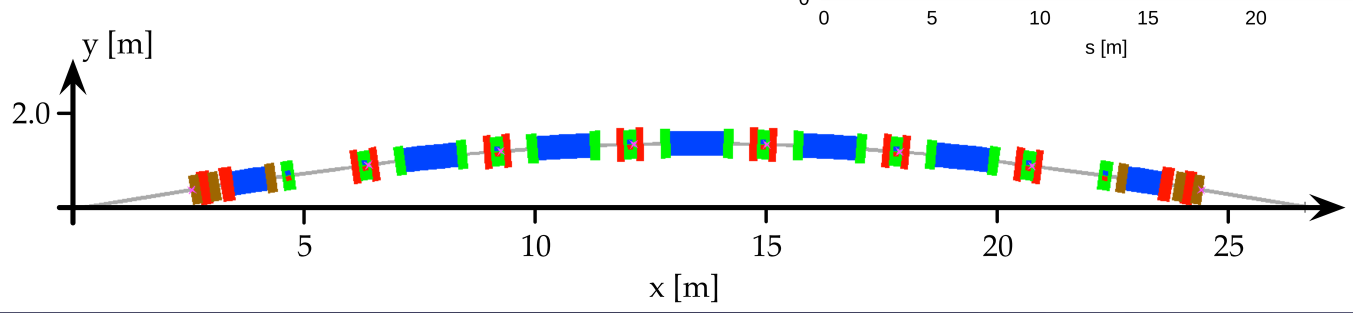


3 GeV Storage Ring

- Detailed design completed [3]
- Multibend achromat (MBA): $\varepsilon_x < 0.3$ nm rad
- 528 m circumference, 500 mA top-up
- 20 MBAs, 19 ID straights
- Nonlinear optimization with octupoles [4]
- Improvements over published design:
  - Fully-integrated magnet design in all cells
  - NEG-coated Cu vacuum chamber
  - Pulsed-sextupole injection
    → no injection bump required
    → transparent injection
- Ongoing studies:
  - Design and optimization of IDs [5]
  - Orbit feedback studies
  - Coupling correction
  - Suppression of vertical dispersion

Energy [GeV]	3.0
Main radio frequency [MHz]	99.931
Harmonic number	176
Circulating current [mA]	500
Circumference [m]	528
Number of achromats	20
No. of long straight sections available for IDs	19
Betatron tunes (horizontal / vertical)	42.20 / 14.28
Natural chromaticities (horizontal / vertical)	−49.8 / −43.9
Corrected chromaticities (horizontal / vertical)	+1.0 / +1.0
Momentum compaction factor	3.07×10^{-4}
Horizontal damping partition J_x	1.86
Horizontal emittance (bare lattice) [nm rad]	0.326
Horizontal emittance (with 4 PMDWs) [nm rad]	0.263
Radiation losses per turn (bare lattice) [keV]	360.0
Radiation losses per turn (with 4 PMDWs) [keV]	572.1
Natural energy spread	0.077%
Energy spread (with 4 PMDWs)	0.096%
Required dyn. acceptance (hor. / ver.) [mm mrad]	7.1 / 1.3
Required lattice momentum acceptance	±4.5%





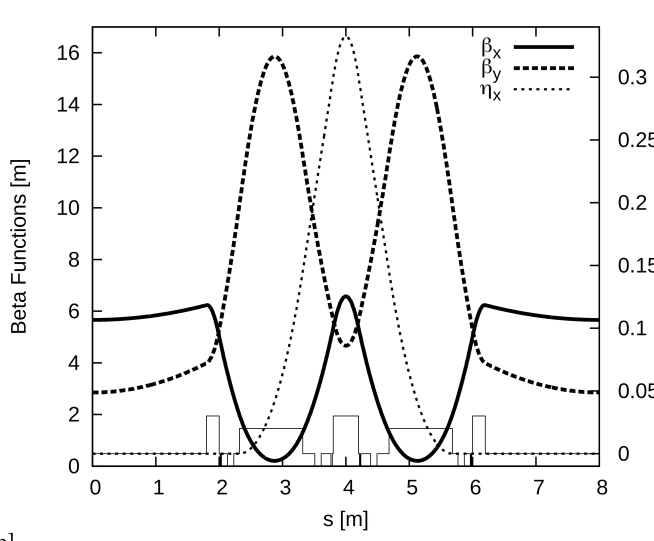
1.5 GeV Storage Ring

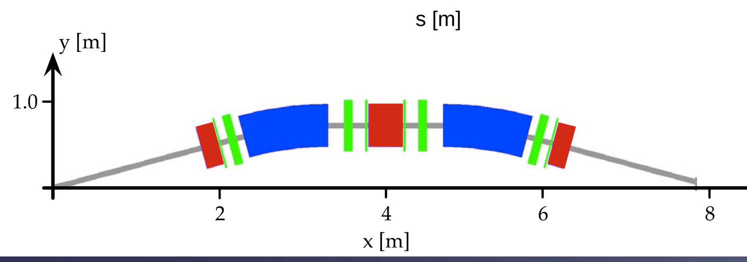
- Detailed design ongoing
- Some MAX II & III IDs will move to this ring
- Double-bend achromat (DBA): $\varepsilon_x = 6$ nm rad
- 96 m circumference, 500 mA top-up
- 12 DBAs, 10 ID straights, 2 RF cavities + LCs
- Heavy emphasis on combined-function magnets and magnet integration
  - Dipoles contain defocusing gradient
  - Focusing quads contain sextupoles
  - DBA machined from one solid block

  → Compact lattice

  → 2 ID straights more than MAX II
- Retain tuning capability:
  - Pole-face strips in dipoles → tunes
  - Correction sextupoles → chromaticity
  - SC wiggler can be matched
- 4% MA → >10h overall lifetime

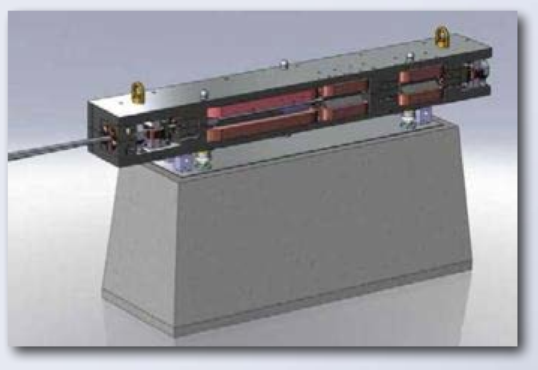
Energy [GeV]	1.5
Main radio frequency [MHz]	99.931
Harmonic number	32
Circulating current [mA]	500
Circumference [m]	96
Number of achromats	12
Length of straight section [m]	3.5
Betatron tunes (hor / ver)	11.22 / 3.14
Natural chromaticities (hor / ver)	−22.9 / −17.1
Corrected chromaticities (hor / ver)	+1.0 / +1.0
Momentum compaction factor	3.04×10^{-3}
Hor. emittance (bare lattice) [nm rad]	6.00
Radiated power (bare lattice) [keV/turn]	117.2
Natural energy spread (bare lattice)	7.51×10^{-4}
Req. dyn. acc. (hor / ver) [mm mrad]	61 / 6
Req. lattice mom. acceptance	±3.0%

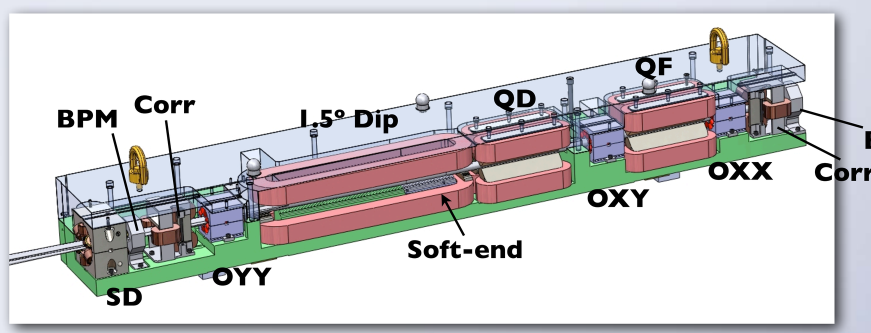


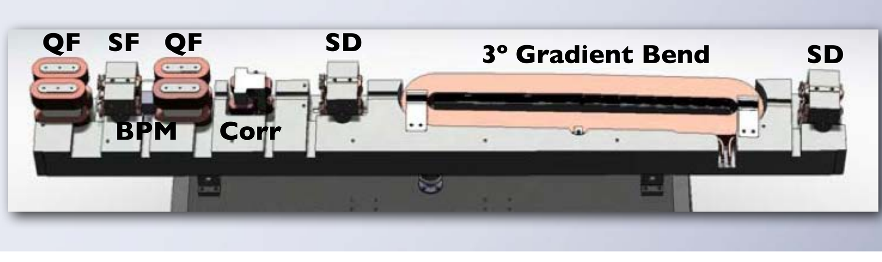


Magnets

- Magnets of each cell are machined into a solid iron block
  - 7 blocks per MBA in the 3 GeV ring
  - 1 block for the entire DBA in the 1.5 GeV ring
- Combined-function magnets for compact optics
  - Gradient dipoles in both rings
  - Quads with integr. sextupole in 1.5 GeV ring
- Highly-integrated magnet design
  → compact lattice
- Solid-iron magnet block → magnets = girder
  → excellent alignment
- Massive concrete supports with mounting plate
  → excellent stability (vibrational EF > 100 Hz)

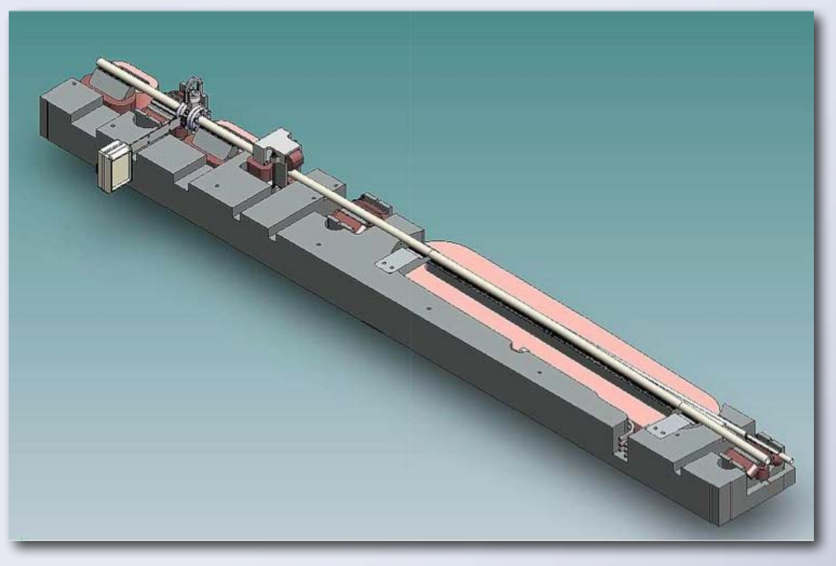


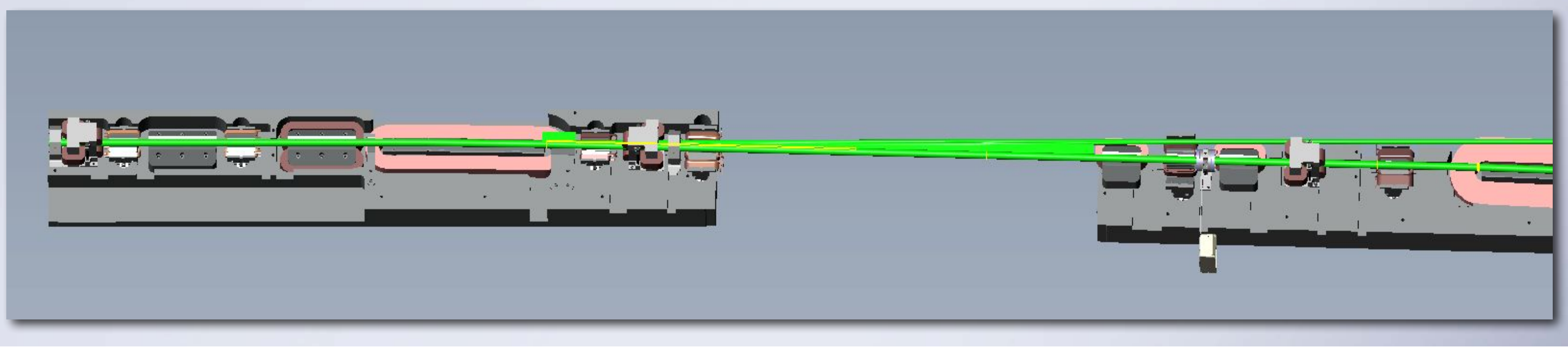




Vacuum System

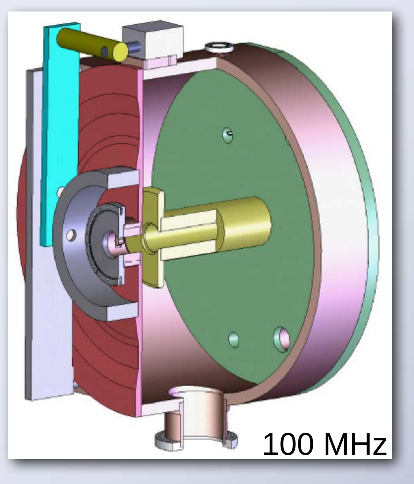
- NEG-coated Cu pipes → distributed pumping
- Cooling channel brazed to chamber @ dipoles
- No lumped absorbers, few pumps
- Excellent experience with prototype in MAX II [6]
- 3 GeV: circular, 24 mm ø
- 1.5 GeV: elliptical, 40x20 mm (extra dispersion)
- Bake large section in situ → few bellows and flanges
- BPM/corrector sections stainless steal (rigidity, Eddy currents)

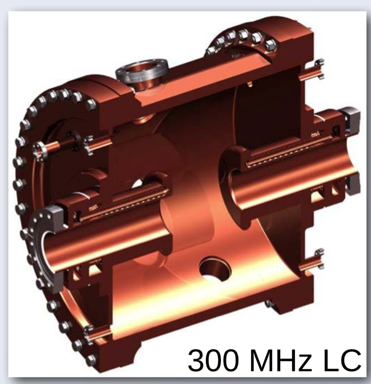




RF System

- Because of SPF storage rings don't have to be tailored to short bunches
- 100 MHz main RF system + 300 MHz Landau cavities (all n.c.)
- 100 MHz cavities similar to those used in MAX II and MAX III (→ EPAC'02, p.2118)
- 300 MHz Landau cavities are being designed in-house
- Long bunches (~ 50 mm)
  - increase Touschek lifetime
  - counteract instability (narrow chamber!)
    → run at low ξ → large MA
  - reduce ε blow-up from IBS


100 MHz


300 MHz LC

MAX IV Project → http://www.maxlab.lu.se/maxlab/max4

[1] MAX IV Detailed Design Report, http://www.maxlab.lu.se/maxlab/max4/index.html.
[2] S. Werin, S. Thorin, M. Eriksson, J. Larsson, Nucl. Instrum. Methods Phys. Res., Sect. A 601, 98 (2009).
[3] S.C. Leemann, Å. Andersson, M. Eriksson, L.-J. Lindgren, E. Wallén, J. Bengtsson, A. Streun, Phys. Rev. ST Accel. Beams, 12, 120701 (2009).
[4] S.C. Leemann, A. Streun, Phys. Rev. ST Accel. Beams, 14, 030701 (2011).
[5] E. Wallén, Insertion Devices for the MAX IV Light Source, WEPD038, IPAC'10, Kyoto, Japan.
[6] A. Hansson, E. Wallén, M. Berglubd, R. Kersevan, M. Hanh, J. Vac. Sci. Technol. A 28, 220 (2010).