The MAX IV 3 GeV Storage Ring
Multibend Achromats for Ultralow Emittance

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Where is MAX-lab? What is MAX-lab?

[Map showing the location of MAX-lab in Sweden]
Where is MAX-lab? What is MAX-lab?

MAX I: 550 MeV, 1986
MAX II: 1.5 GeV, 1996
MAX III: 700 MeV, 2007
MAX-FEL: 133 nm, 2009
MAX IV will become the new MAX-lab

- New site, replacement for present MAX-lab and MAX I, II, III rings
- Funding granted April 2009, construction starts mid 2010, commissioning of the 3 GeV storage ring in 2014, user operation 2015
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  ~ 300m
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- 1.5 GeV SR (IR/UV) 
  12 DBAs
  $\varepsilon_x = 6 \text{ nm rad}$
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- 3 GeV SR (X-ray)  
  20 MBAs  
  $\varepsilon_x < 0.3 \text{ nm rad}$
Multibend Achromats for Ultralow Emittance

- Originated in the damping ring community
  → simple (many unit cells, high periodicity)
  → robust (relaxed optics, error tolerance)

\[ \varepsilon_x = C \frac{E^2}{N_d^3} \]

TME MBA
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- Several iterations at MAX-lab
  - NIM A 508 (2003) 480 → 3 GeV (285 m), 12 MBAs, $\varepsilon_x = 1.2$ nm rad
    combined-function magnets, narrow apertures, integrated magnet design
  - PAC ’07 → 3.0/1.5 GeV rings stacked, 2x12 MBAs, $\varepsilon_x = 0.83 / 0.4$ nm rad
    replace MAX II with new ring, stacking possible because of magnet integration → CDR
  - PRST-AB 12 120701 (2009) → 3 GeV, 528 m, 20 MBAs, $\varepsilon_x < 0.3$ nm rad
    gradient dipoles, discrete sexts/octs, fully integrated magnet design, build new 1.5 GeV ring to replace MAX II and MAX III → re-evaluated, approved, and funded
MAX IV Multibend Achromat Lattice

- 20 MBAs → 19 ID straights
- 5 unit cells, 2 matching cells
- 5 m long straight sections
- 1.3m short straights (→RF)
- Gradient dipoles
  - 3° bends in UCs (~ 0.5 T)
  - 1.5° soft-end bends in MCs
- Quads, sextupoles, octupoles
- $\eta_{\text{max}} = 8 \text{ cm}$, $\sigma_y^* < 6 \mu\text{m}$
- $\nu_x = 42.20$, $\nu_y = 14.28$
- nat. $\xi_x = -50$, $\xi_y = -44$
Integrated Magnet Design

- Compact MBA optics $\rightarrow$ highly-integrated magnet design
- Each unit cell and matching cell is machined from two solid blocks of iron (demonstrated at MAX III $\rightarrow$ NIM A 601 (2009) 229)
- Machining precision $\rightarrow$ excellent alignment (small beam size $\rightarrow$ tolerances!)
Dynamic Aperture

- Octupoles → minimize ADTS (first-order effect!)
- Injection requirement: 8 mm (2.5 mm safety margin)
- Vertical: in-vacuum IDs, 4 mm full-gap height
Momentum Acceptance and Lifetime

- Sextupole chromatic correction + 100 MHz RF system
  - Small chromatic tune footprint
  - FMA: stop bands > 6%
  - 6D tracking: lattice MA > 4.5%
  - Excellent overall MA

- “Worst case” scenario:
  - Assume RF MA at 4%
  - Touschek lifetime 26h (low $\varepsilon$!)
  - Total lifetime >10h

- Further improve lifetime? → coupling control
  - Beam-based BPM calibration to sextupole centers
  - Corrector-based realignment of magnet cells as demonstrated at MAX III (NIMA 597 (2008) 170)
  - Secondary windings: aux. sextupoles, skew quadrupoles
  - Drive vertical dispersion bumps
Emittance and IBS

- MAX IV 3 GeV SR is IBS-limited!
- Damping wigglers reduce emittance (B = 2.22 T, λ = 80 mm, L = 2 m)
- DWs also increase energy spread → reduce IBS contribution to ε
- Landau Cavities → increase Touschek lifetime & reduce IBS contribution to ε