The MAX IV 3 GeV Storage Ring

Lattice & Technology

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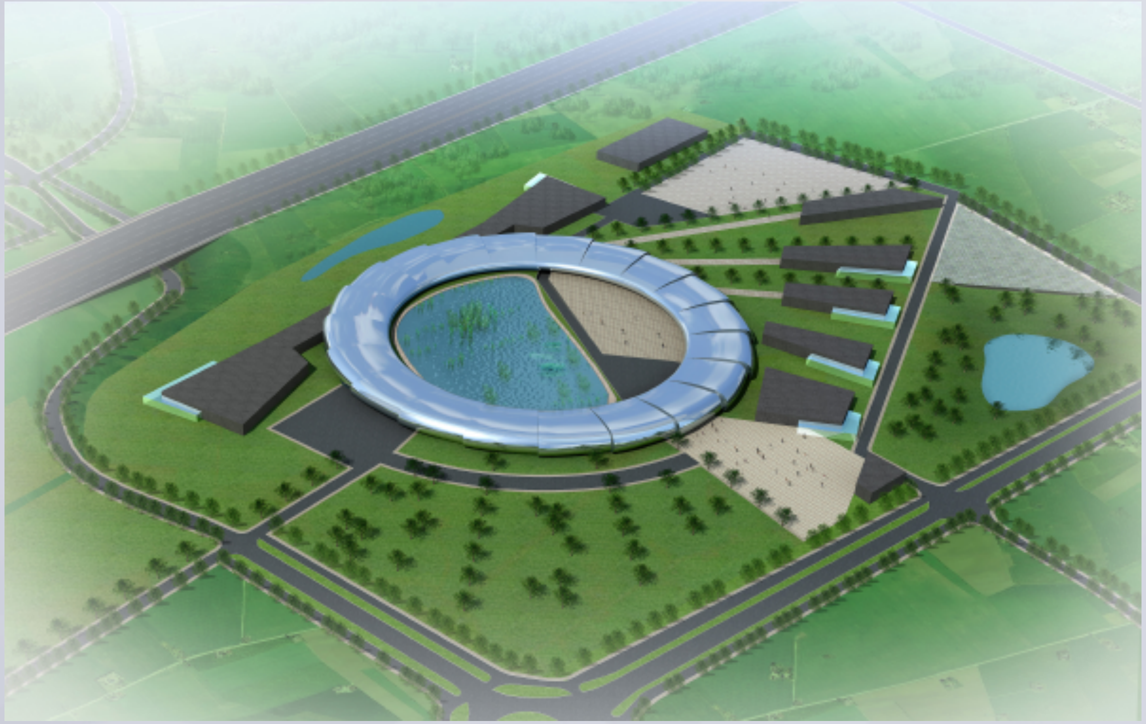
Outline

- Introduction
  - MAX-lab today
  - The MAX IV Project
- 3 GeV Storage Ring
  - Multibend Achromats
  - Lattice
  - Beam Dynamics (DA, MA, ε, IBS)
  - Performance Outlook
- Technology
  - Magnets & Girders
  - Vacuum System
  - RF System
  - Damping Wigglers



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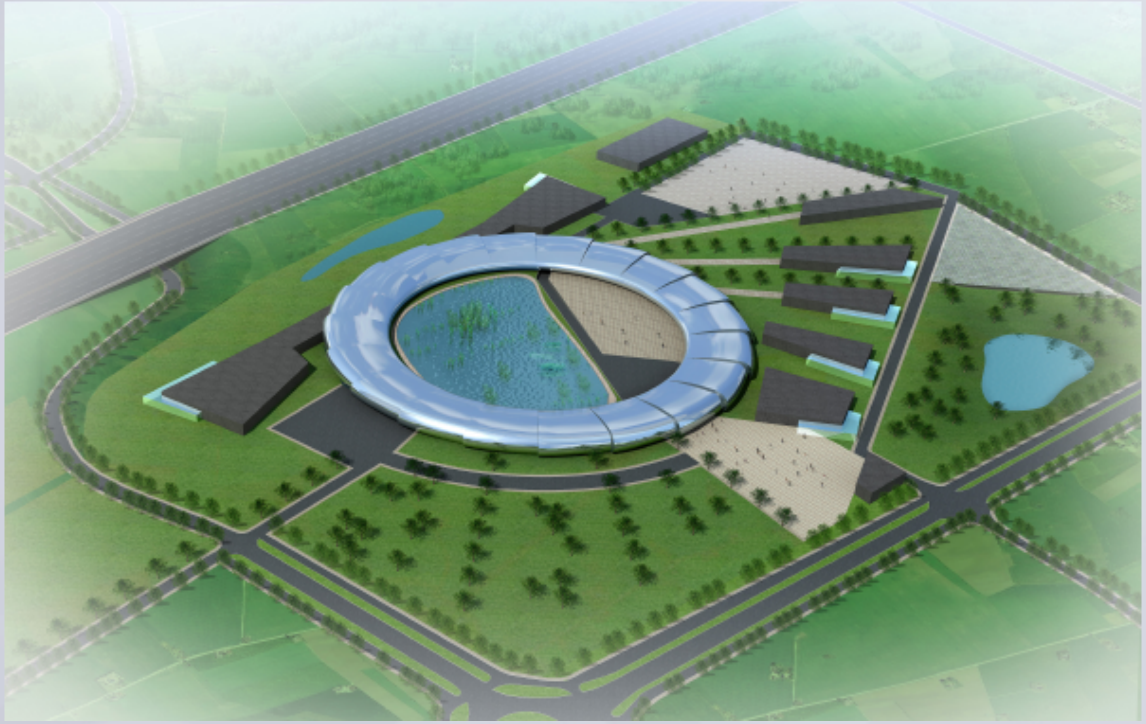
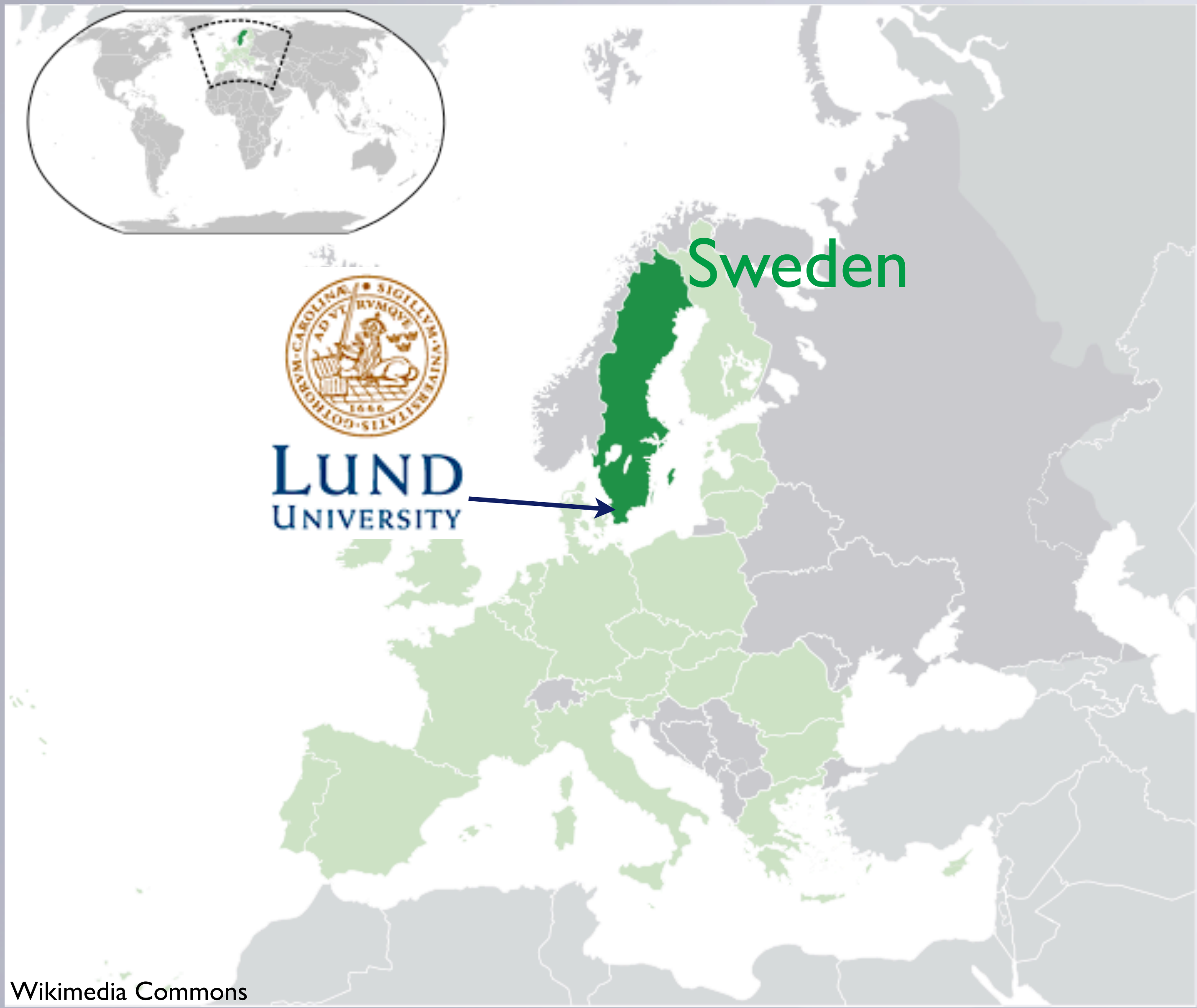


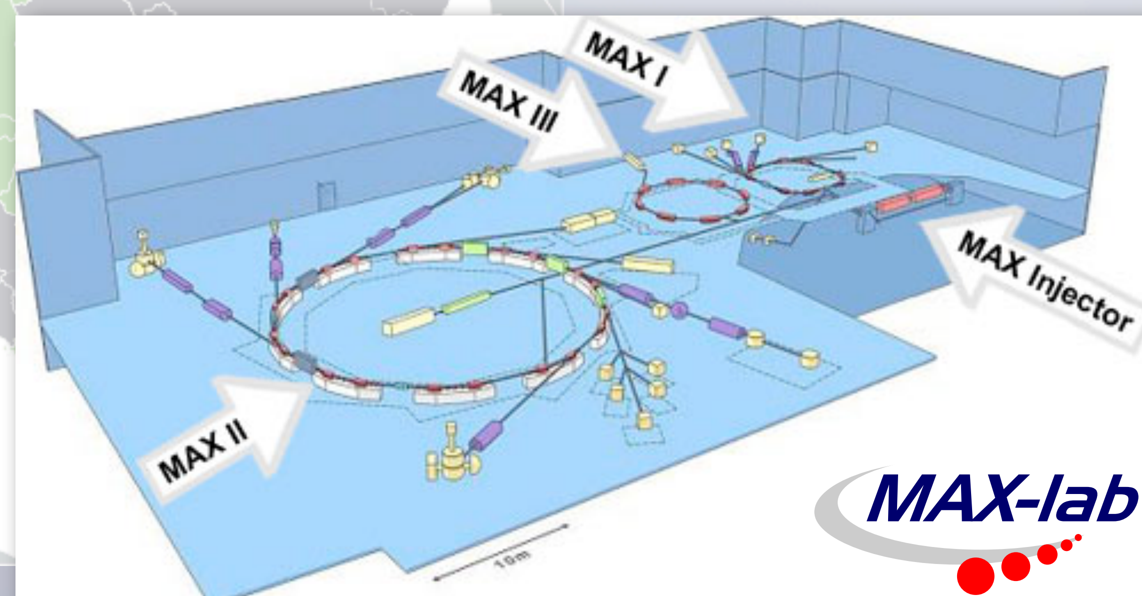
Where is MAX-lab? What is MAX-lab?



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

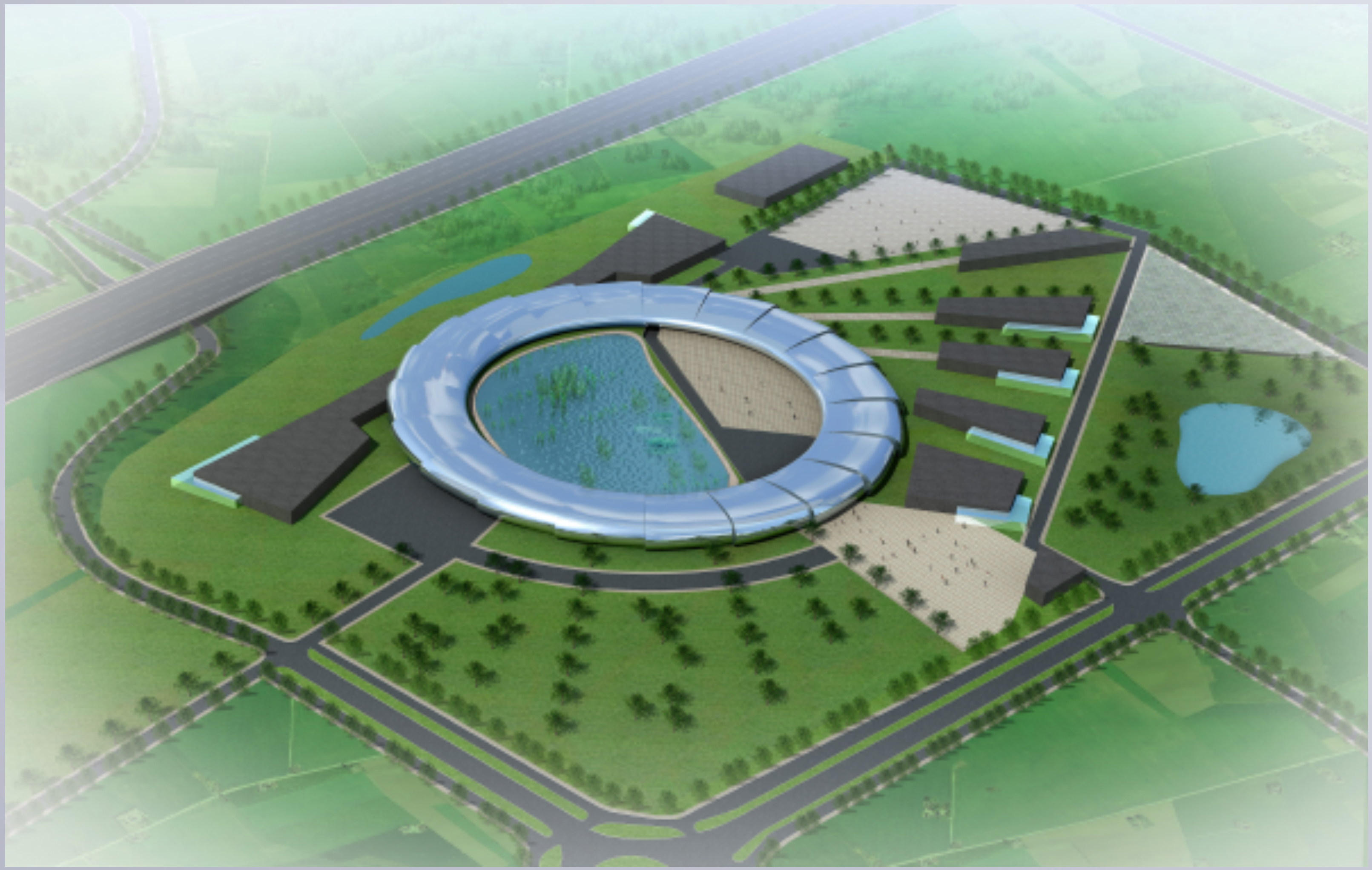
Wikimedia Commons

MAX I : 550 MeV, 1986
MAX II: 1.5 GeV, 1996
MAX III: 700 MeV, 2007
MAX-FEL: 133nm, 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 summer 2010, commissioning of the 3 GeV storage ring in 2014, user operation 2015



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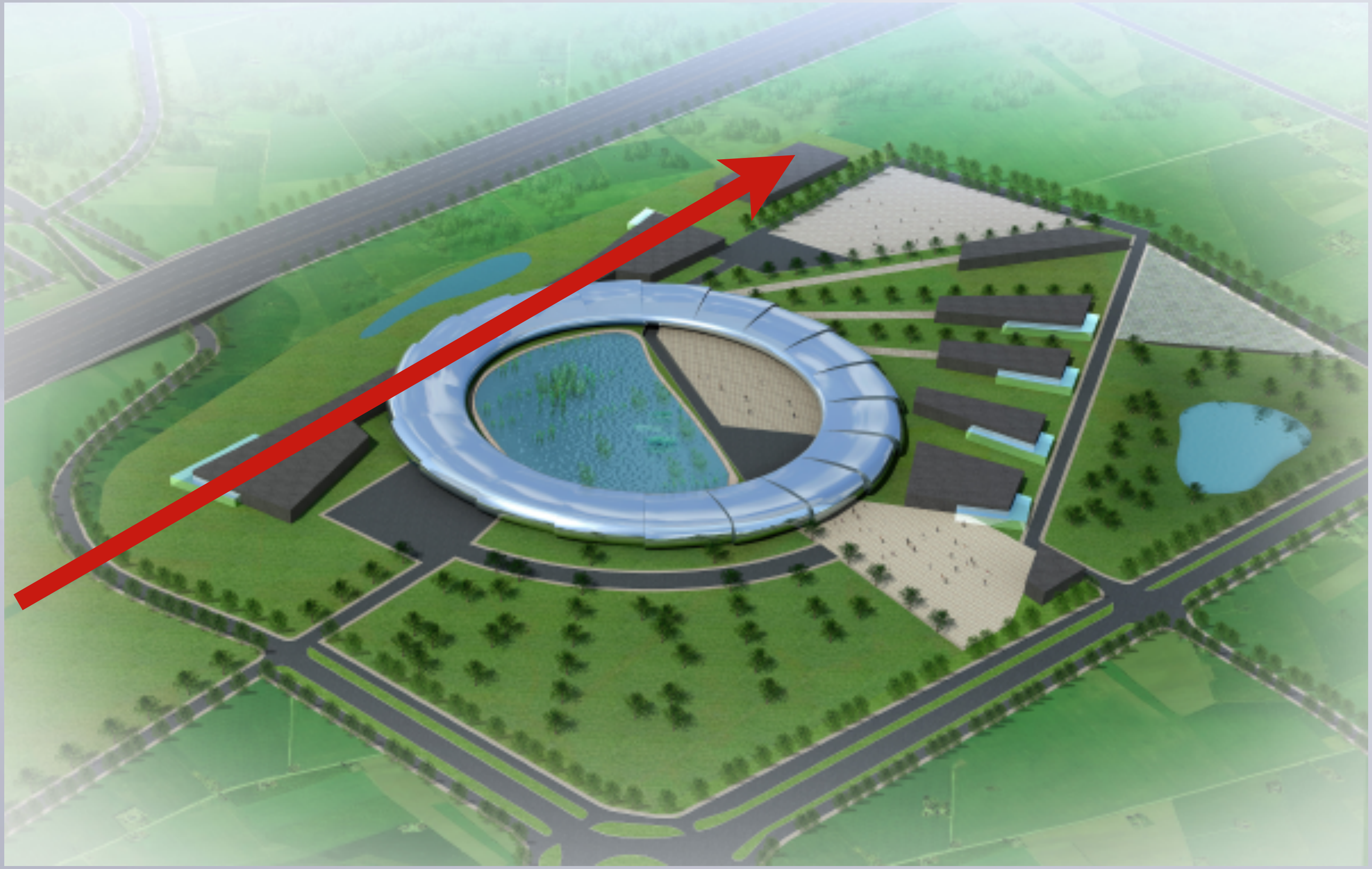

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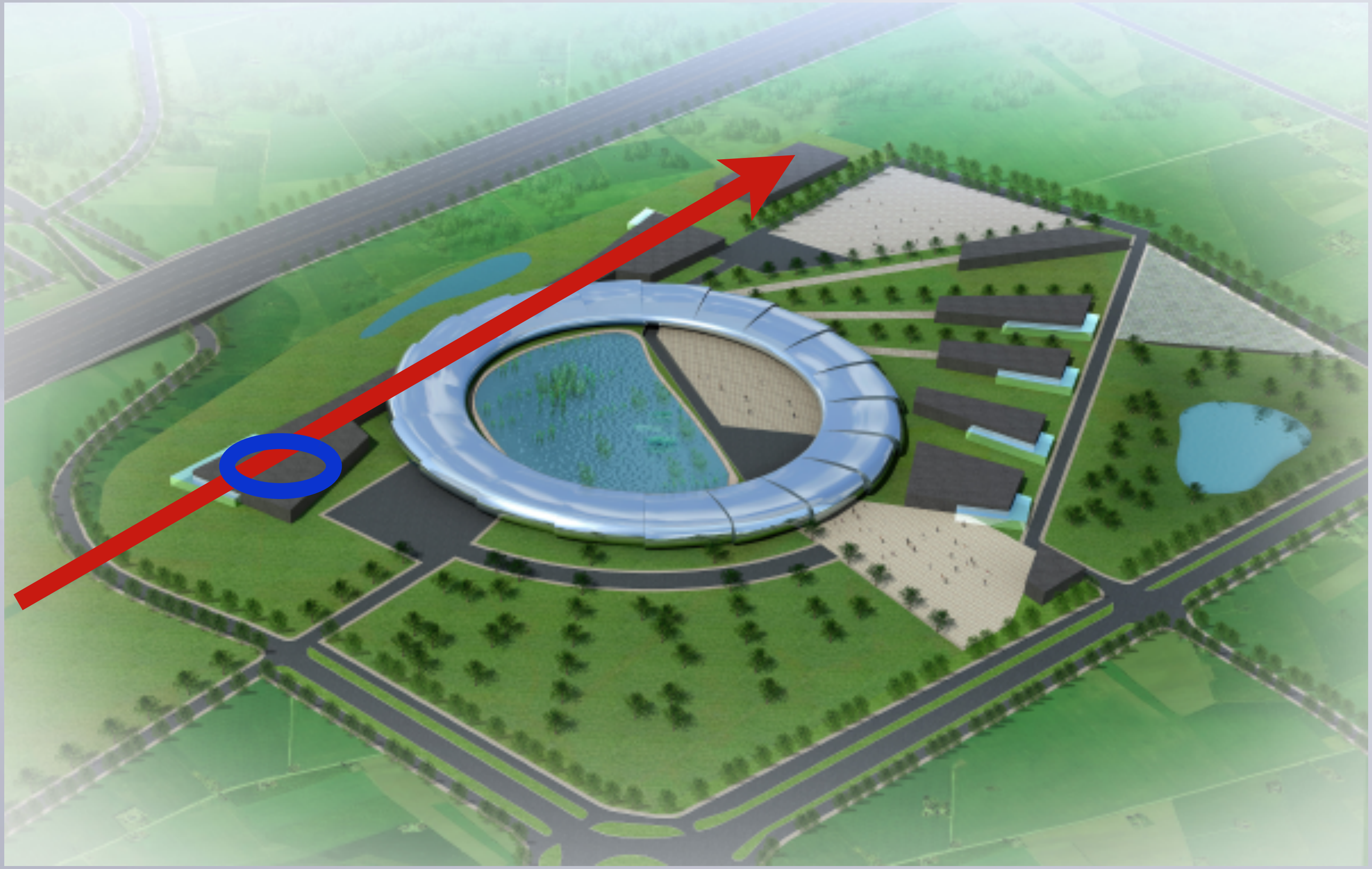
- 1.5 GeV SR (IR/UV) 12 DBAs ε_x = 6 nm rad



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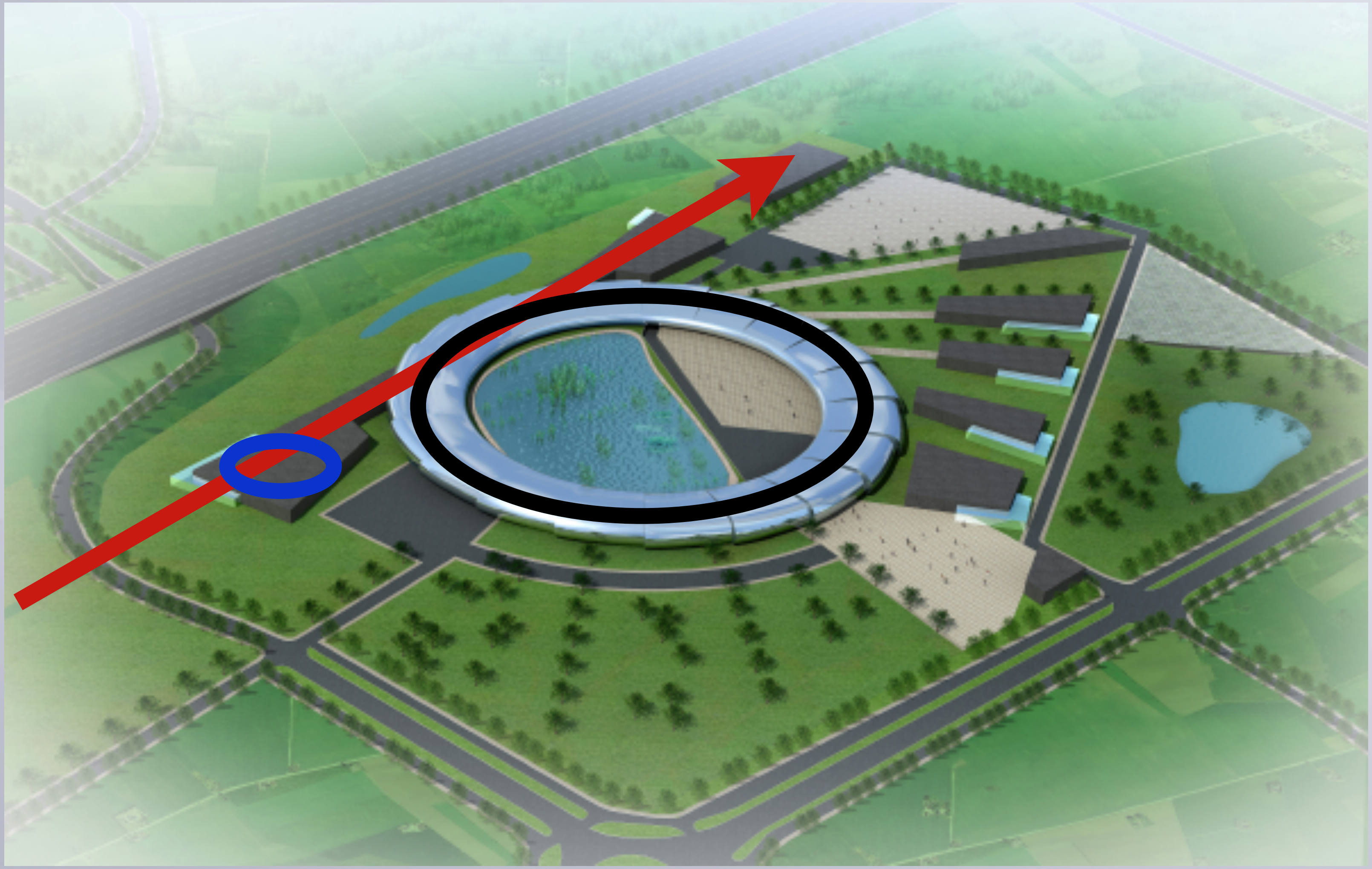
- 1.5 GeV SR (IR/UV) 12 DBAs $\varepsilon_x = 6$ nm rad
- 3 GeV SR (X-ray) 20 MBAs $\varepsilon_x < 0.3$ nm rad



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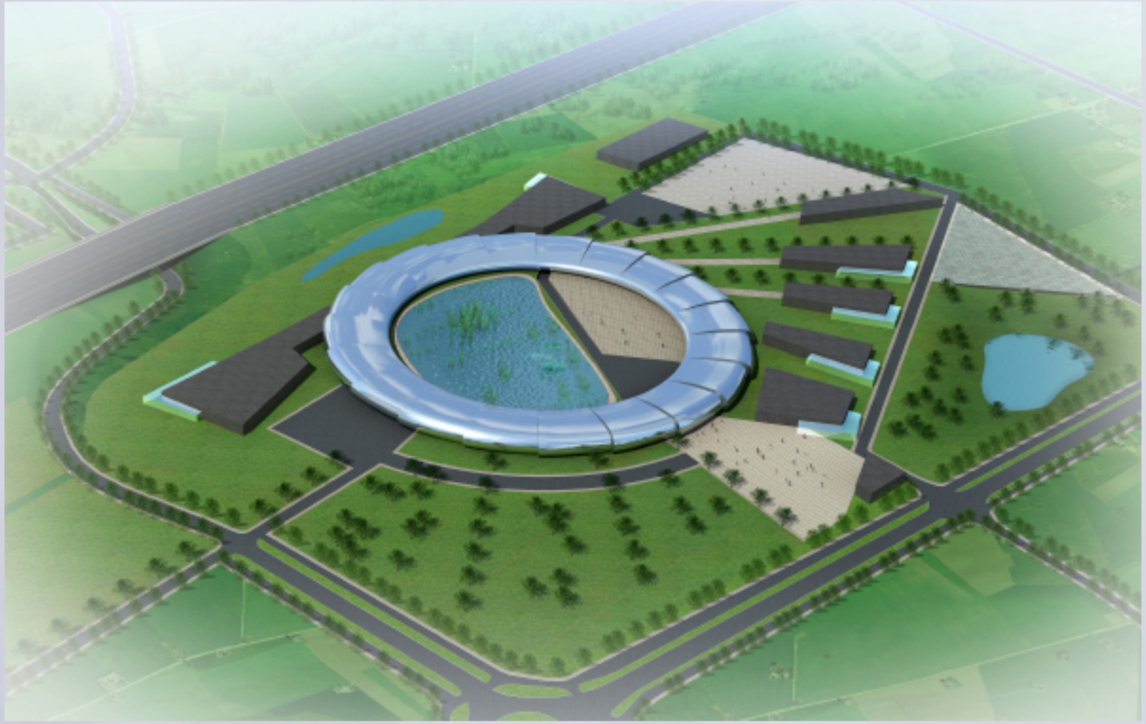

Multibend Achromats for Ultralow Emittance

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

$$\varepsilon_x = \underbrace{F\left(\nu_x, \mathrm{lat}\right)}_{\text{TME}} \frac{E^2}{J_x \underbrace{N_d^3}_{\text{MBA}}}$$

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- Considered at SLS (EPAC'94) and elsewhere (PAC'95: D. Einfeld et al., Design of a Diffraction Limited Light Source; PAC'95: D. Kaltchev et al., Lattice Studies for a High-brightness Light Source)

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TME — MBA

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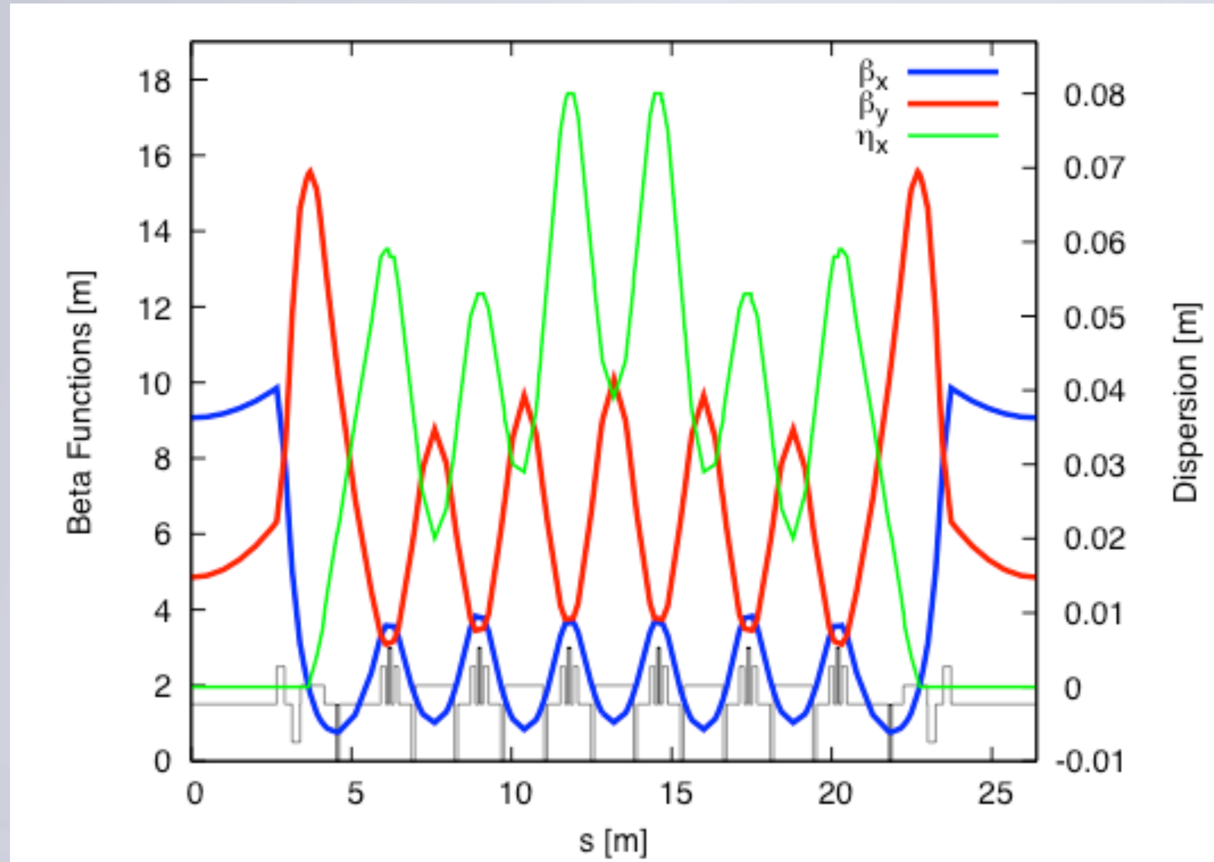
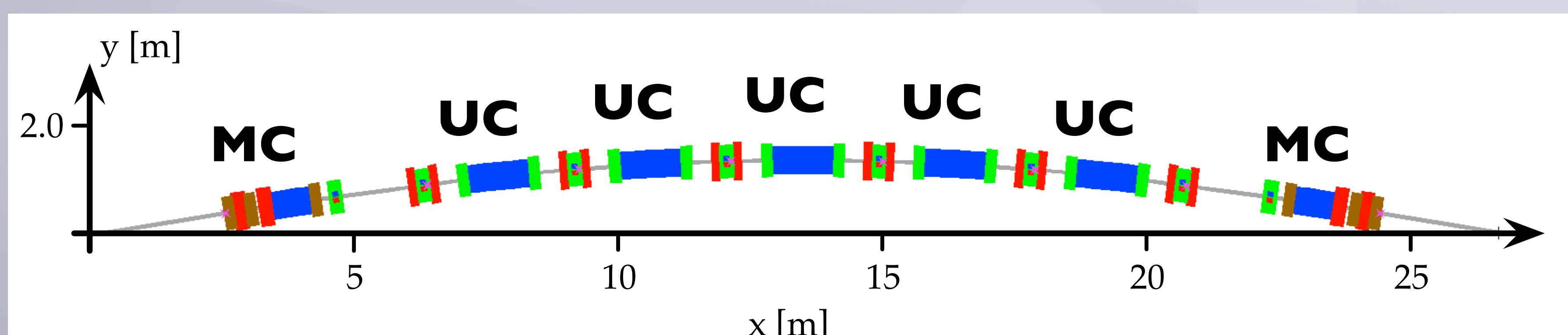
- Several iterations at MAX-lab
  - NIM A **508** (2003) 480 → 3 GeV (285 m), 12 MBAs, ε_x = 1.2 nm rad
    combined-function magnets, narrow apertures, integrated magnet design
  - PAC '07 → 3.0/1.5 GeV rings stacked, 2x12 MBAs, ε_x = 0.83 / 0.4 nm rad
    replace MAX II with new ring, stacking possible because of magnet integration → **CDR**
  - PRST-AB **12** 120701 (2009) → 3 GeV, 528 m, 20 MBAs, ε_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
- η_{max} = 8 cm, $\sigma_y^* < 6$ μm
- $\nu_x = 42.20$, $\nu_y = 14.28$
- nat. $\xi_x = -50$, $\xi_y = -44$

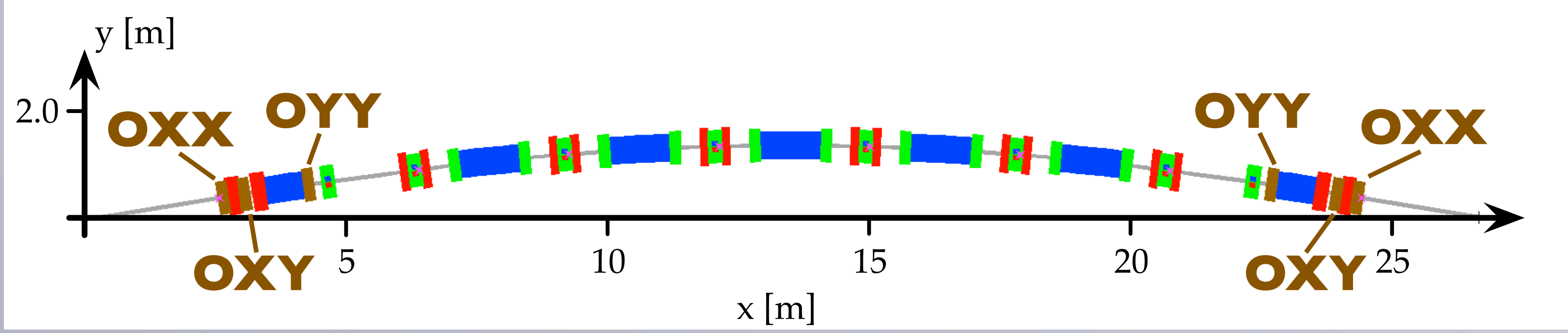




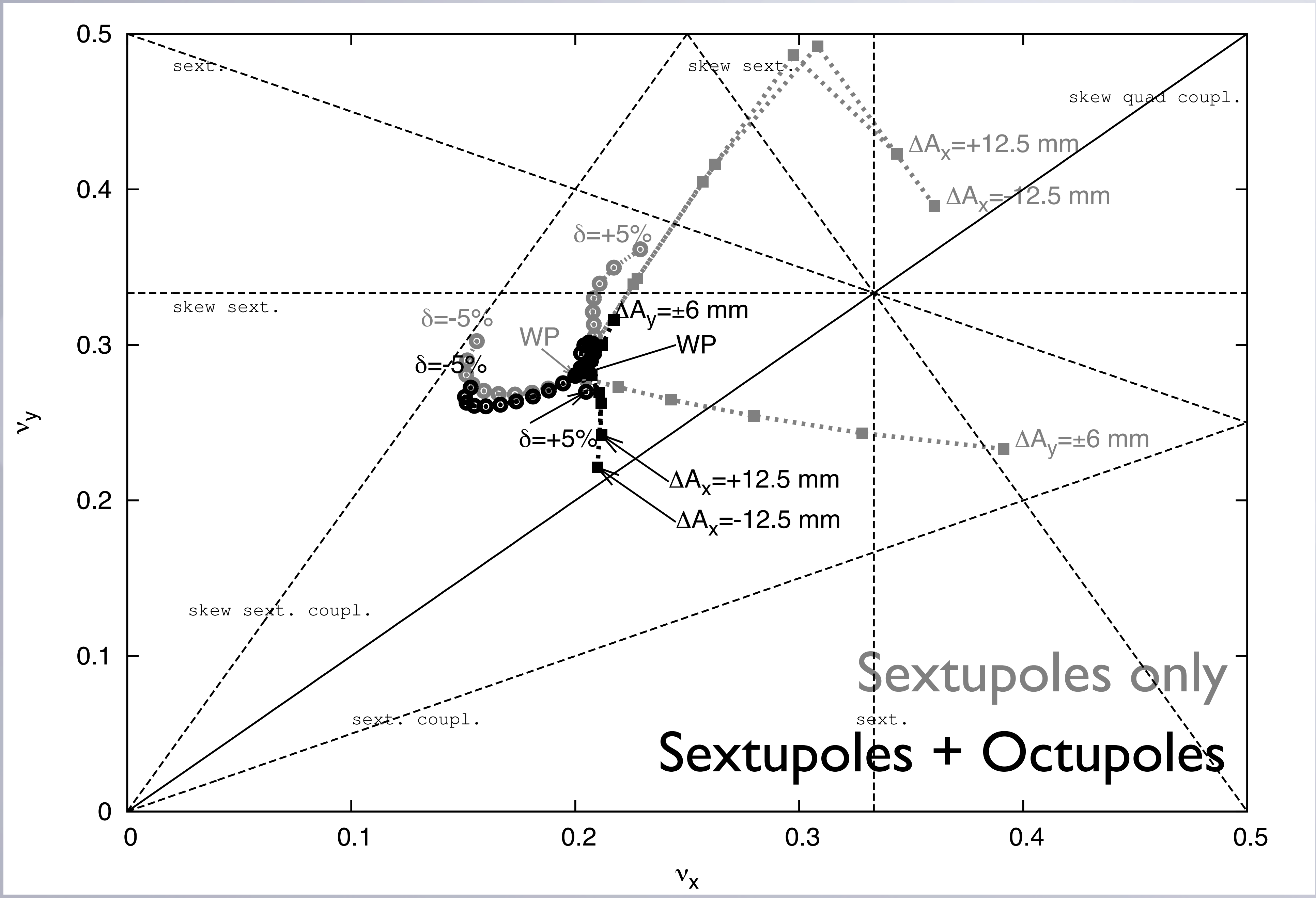
Why Octupoles?

- Large natural chromaticity + low dispersion → strong sextupoles
- Many first-order sextupole driving terms:
  - 2 linear chromaticities + 3 chromatic terms + 5 geometric terms
  - + second-order terms → ADTS, quadratic chromaticity, ... → **tune footprint**
- However, ADTS is second-order effect in sextupoles (→ weak correction)
- Our solution:
  - Use sextupoles to correct chromaticity and minimize first-order driving terms
  - Use octupoles to correct ADTS (in first order!)

    → compact tune footprint

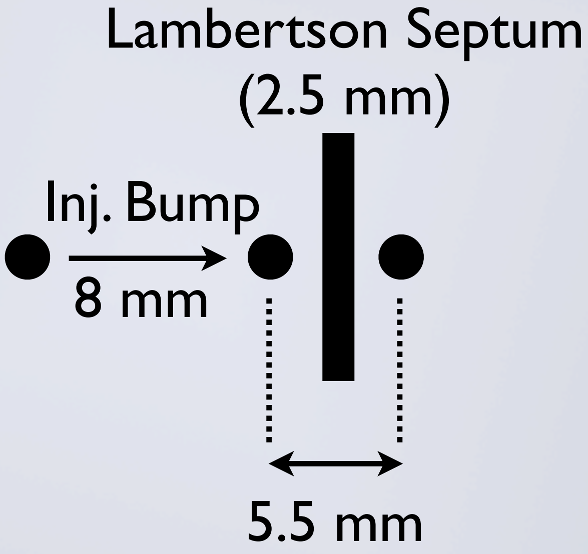


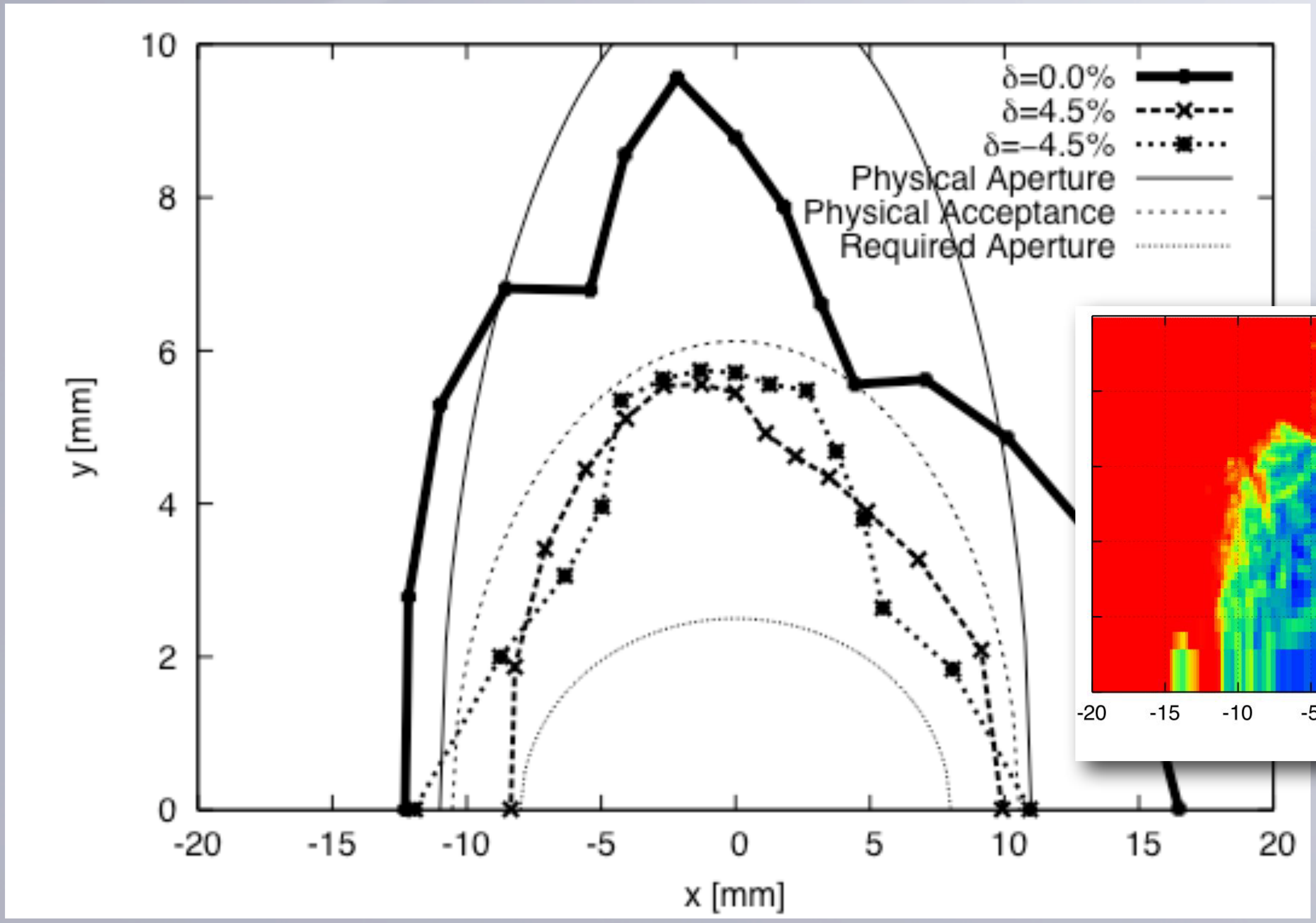
Tune Footprint with and without Octupoles

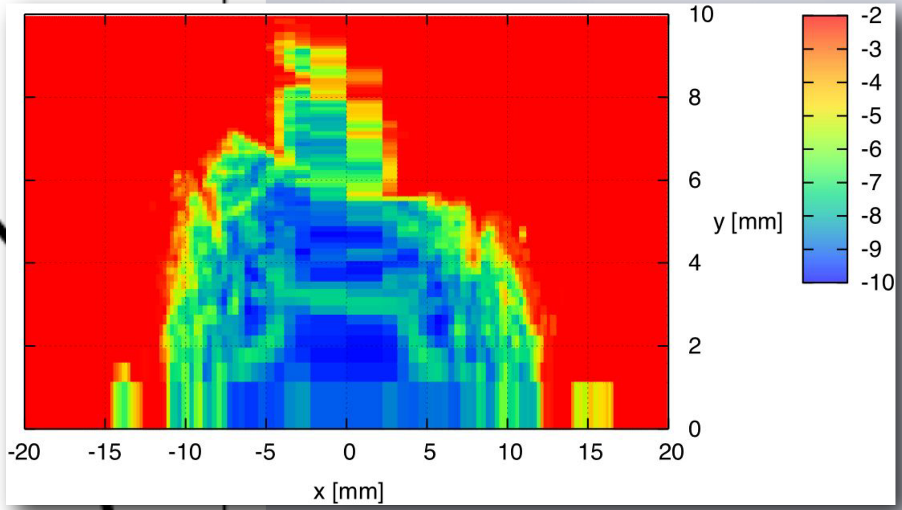


Dynamic Aperture

- Injection requirement: 8 mm (2.5 mm safety margin)
- Vertical: in-vacuum IDs, 4 mm full-gap height
- Shape DA with octupoles (commissioning!)

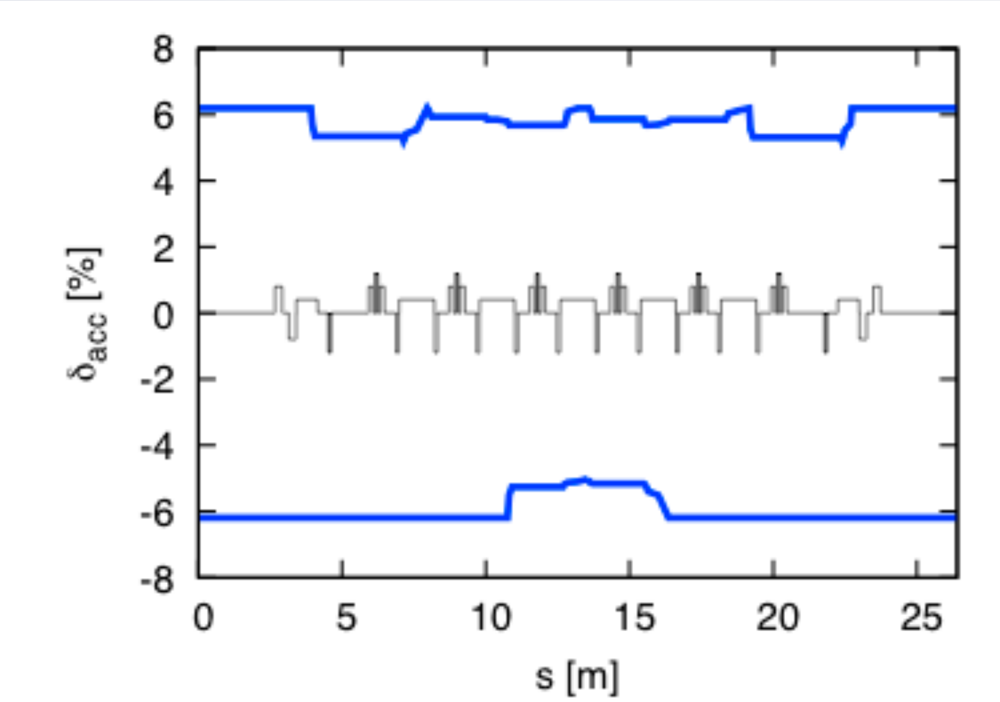






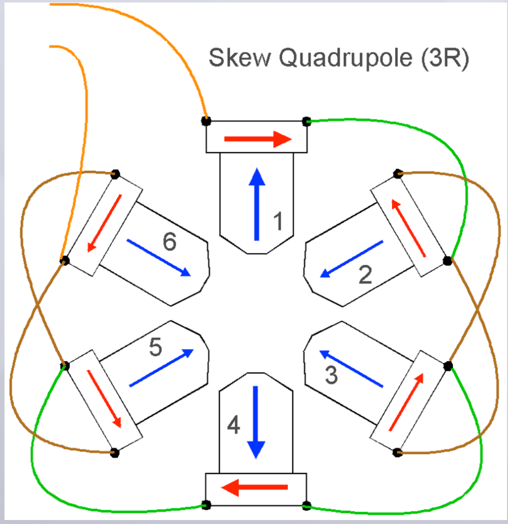
Momentum Acceptance and Lifetime

- 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 ε!)
  → 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 (NIM A **597** (2008) 170)
  - secondary windings: aux. sextupoles, skew quadrupoles
  → drive vertical dispersion bumps

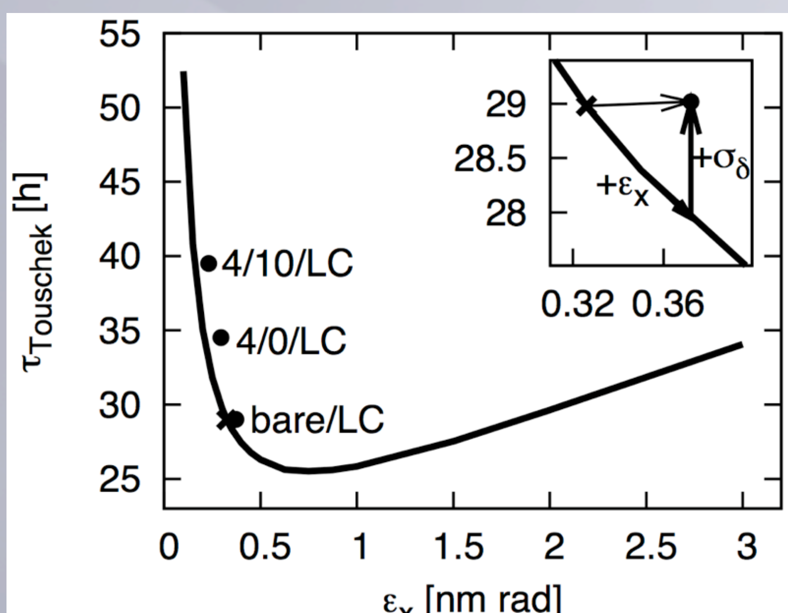


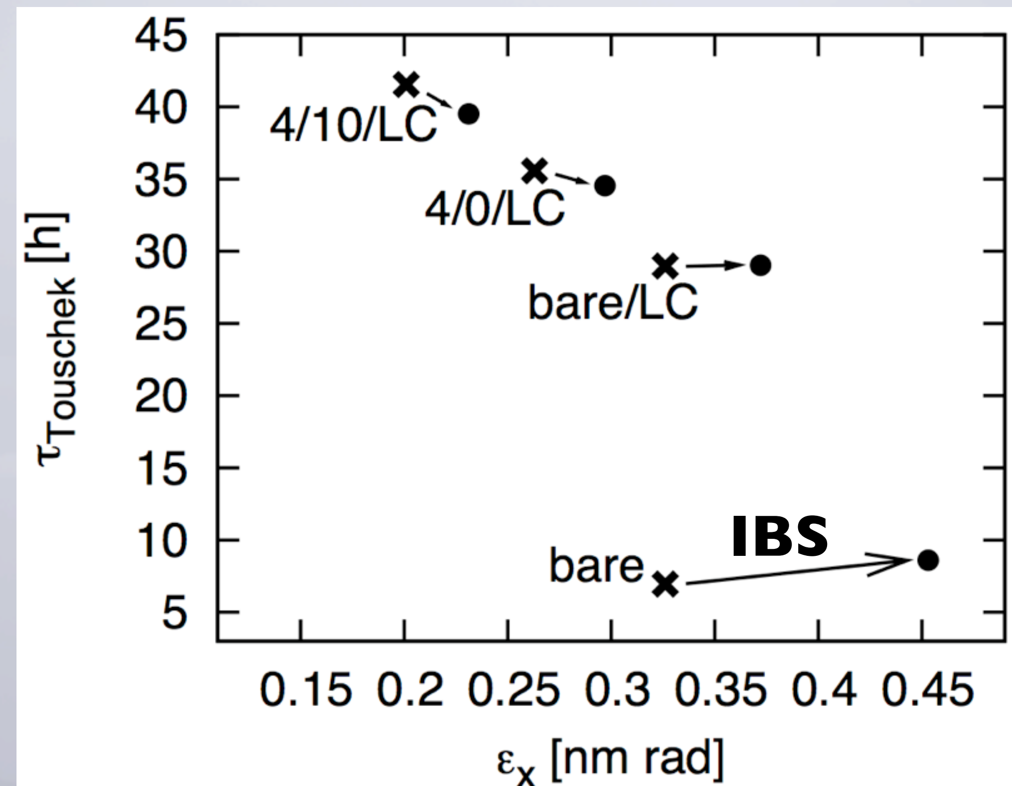
A. Streun (SLS)

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

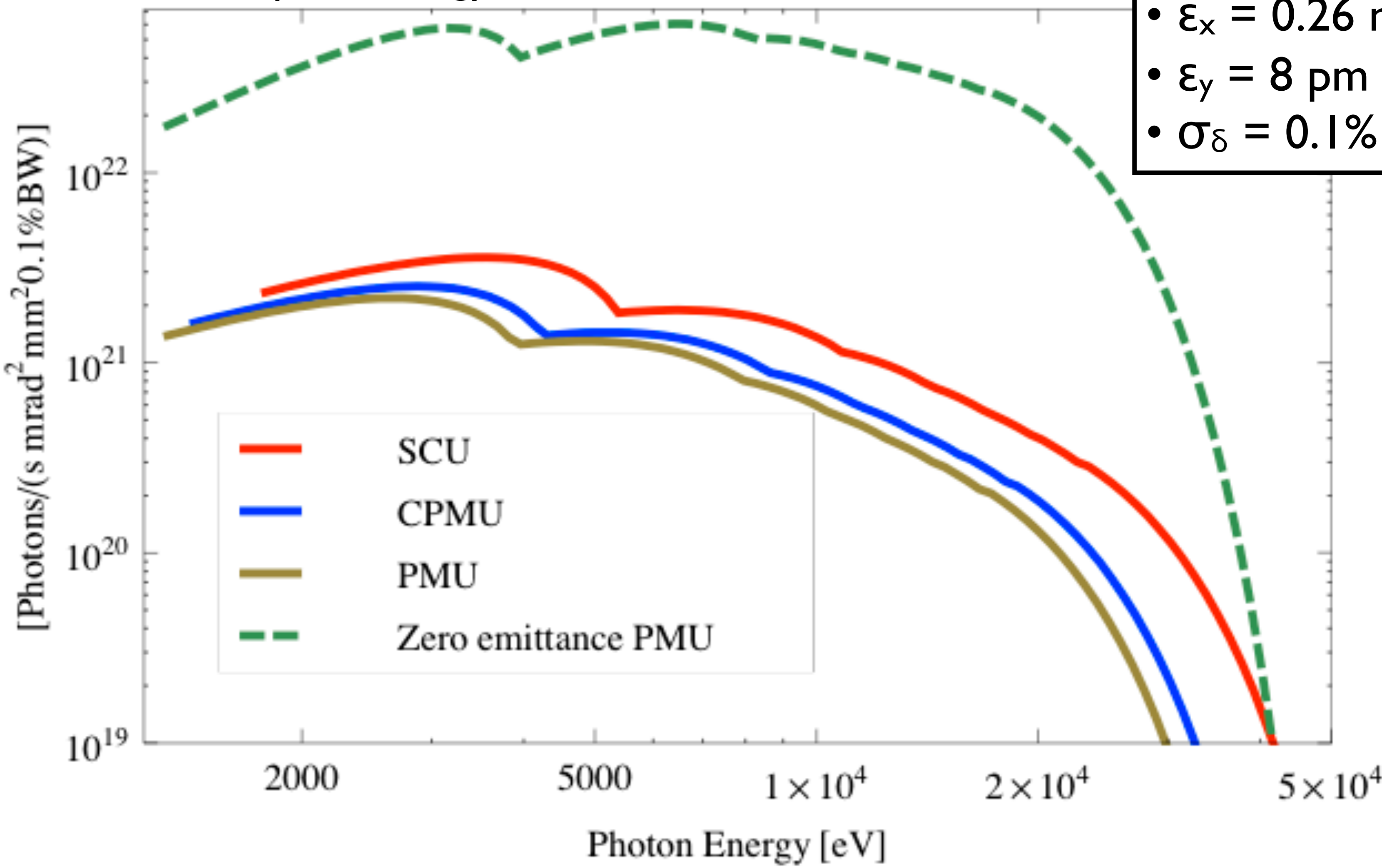
	ε_x [nm rad] Without IBS	ε_x [nm rad] With IBS
Bare lattice	0.326	0.453
Bare lattice with LC	0.326	0.372
Lattice with four PMDWs and LC	0.263	0.297
Lattice with four PMDWs, ten IVUs, and LC	0.201	0.231





Work on IDs has just started... → performance outlook

Brilliance @ ID peak energy



- 500 mA stored current
- ε_x = 0.26 nm rad
- ε_y = 8 pm rad
- σ_δ = 0.1%

http://www.maxlab.lu.se/maxlab/max4

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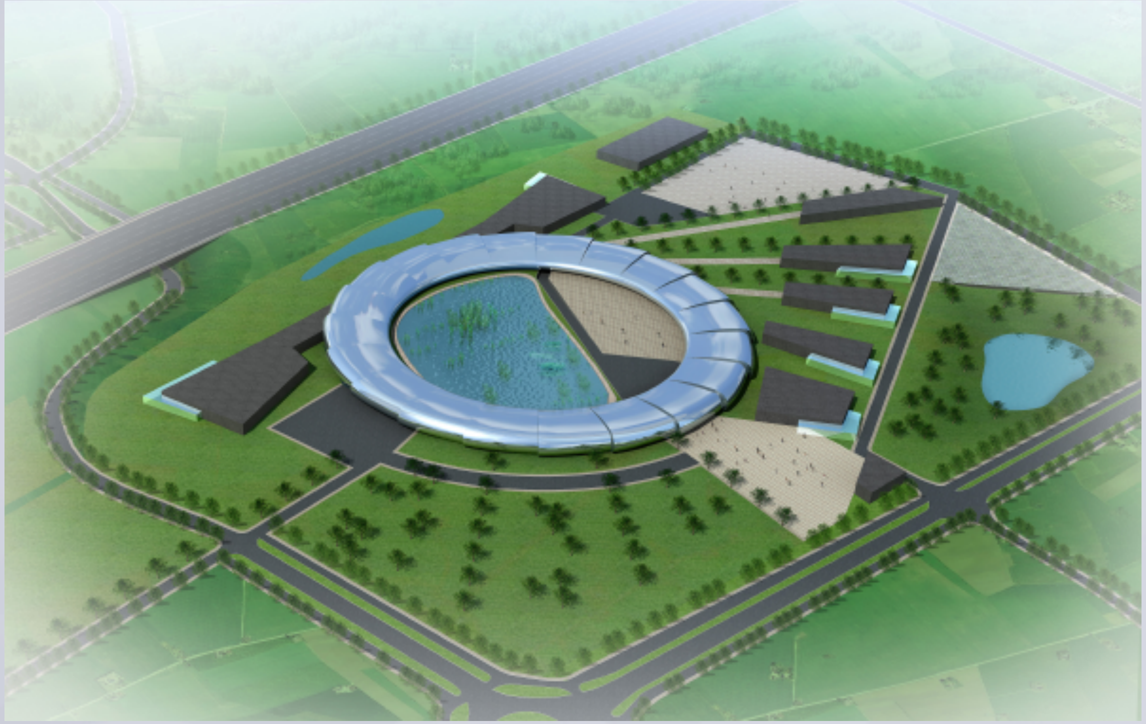
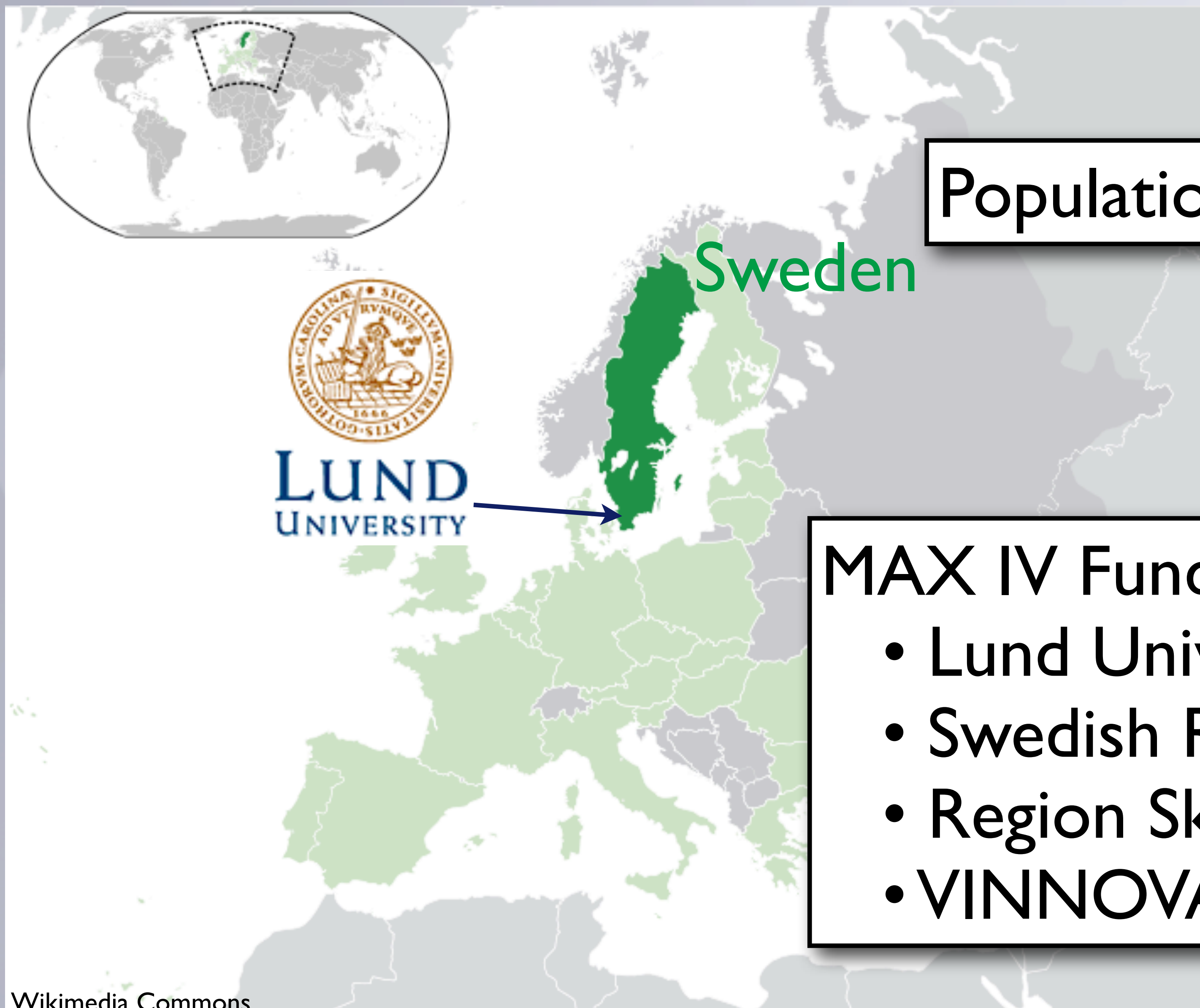


Technology Considerations

- Keep design simple and modular (like Ikea)
- Instead of building one machine “to fit all” build several specialized machines
- Small lab → make use of existing experience
- Use MAX II & MAX III for prototype testing
- Limited budget
  → use inexpensive technology
  → design for low operational cost

MAX-lab is a Swedish National Lab → Limited Budget



Population: 9,340,682 (2009)

MAX IV Funding:

- Lund University
- Swedish Research Council
- Region Skåne
- VINNOVA Foundation

Multibend Achromats → Magnet Technology

- Simple & robust method to reach ultralow ε_x
  → inexpensive (if ring remains compact!)

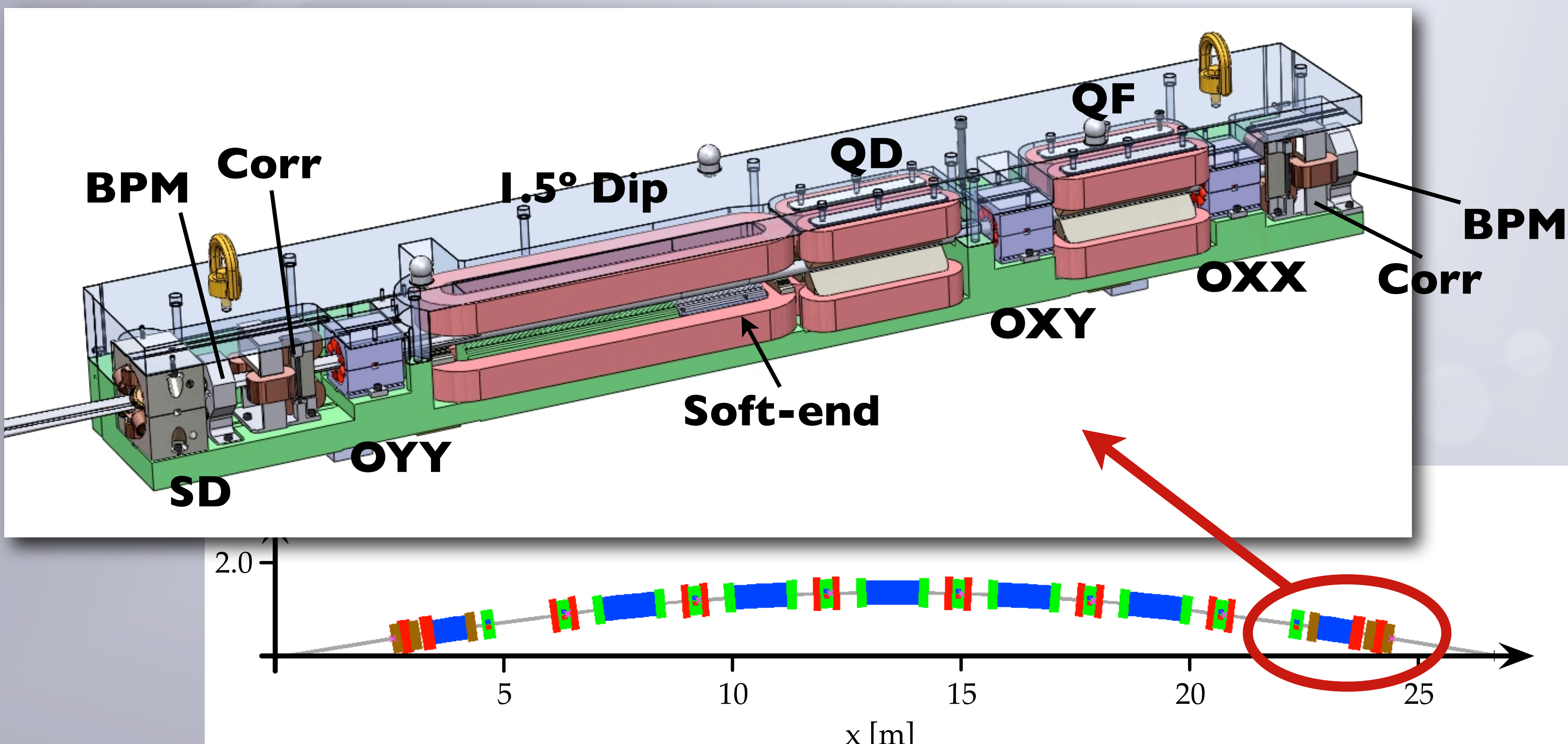
$$\varepsilon_x = F\left(\nu_x, \mathrm{lat}\right) \frac{E^2}{J_x\, N_d^3}$$

TME MBA

- Combined-function magnets and/or integrated magnet design
- Need strong quadrupoles and sextupoles
- Many (mechanically identical) small magnets → 25 mm magnet gap
  → less expensive to manufacture
  → reduce operational cost
- Power magnets in families; add floating power supplies where necessary
  → reduce cabling costs
  → reduce complexity

Integrated Magnet Design (3 GeV Storage Ring)

- Each unit cell and matching cell is machined from two solid blocks of iron (demonstrated at MAX III → NIM A **601** (2009) 229)
- Excellent in terms of alignment and comparably inexpensive to manufacture



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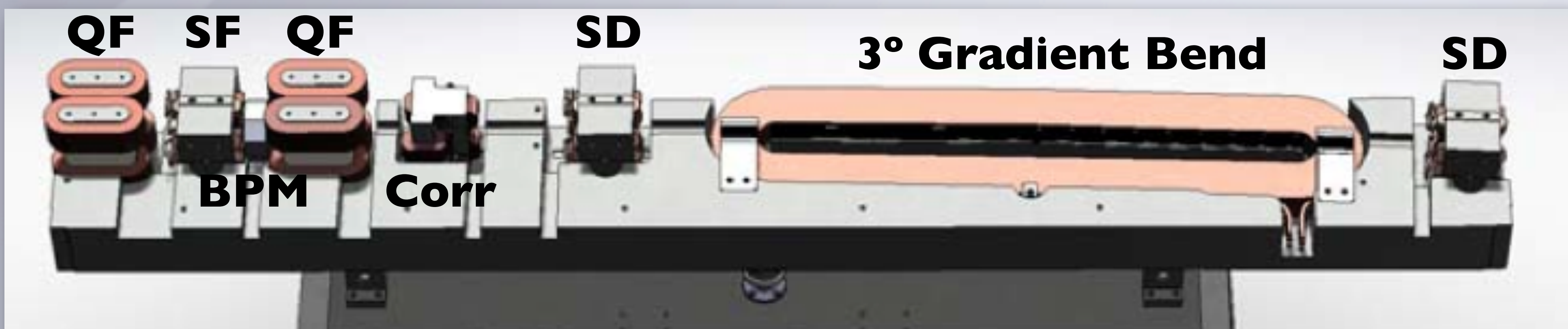
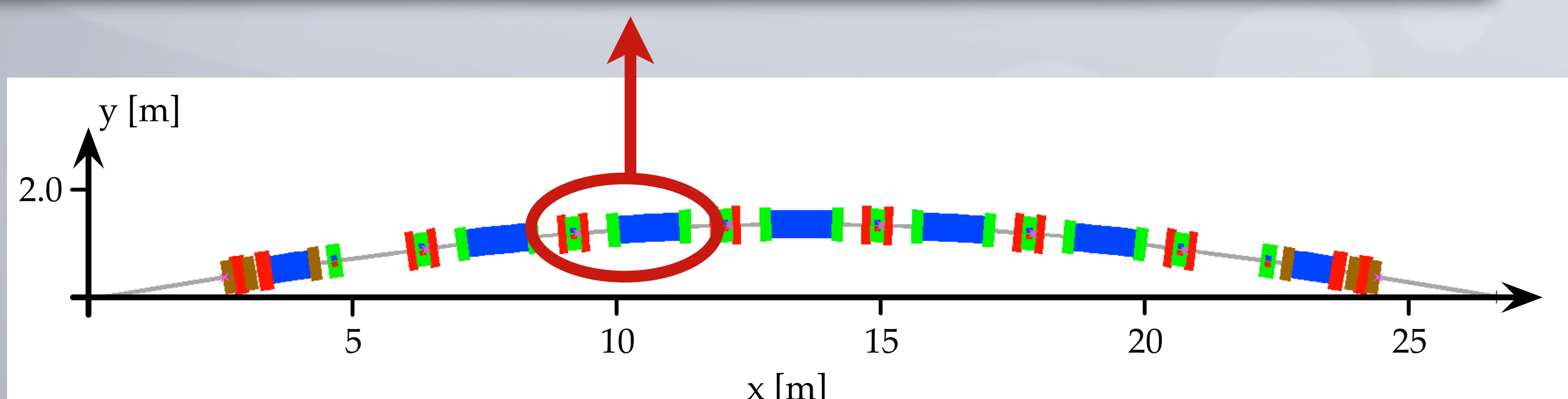
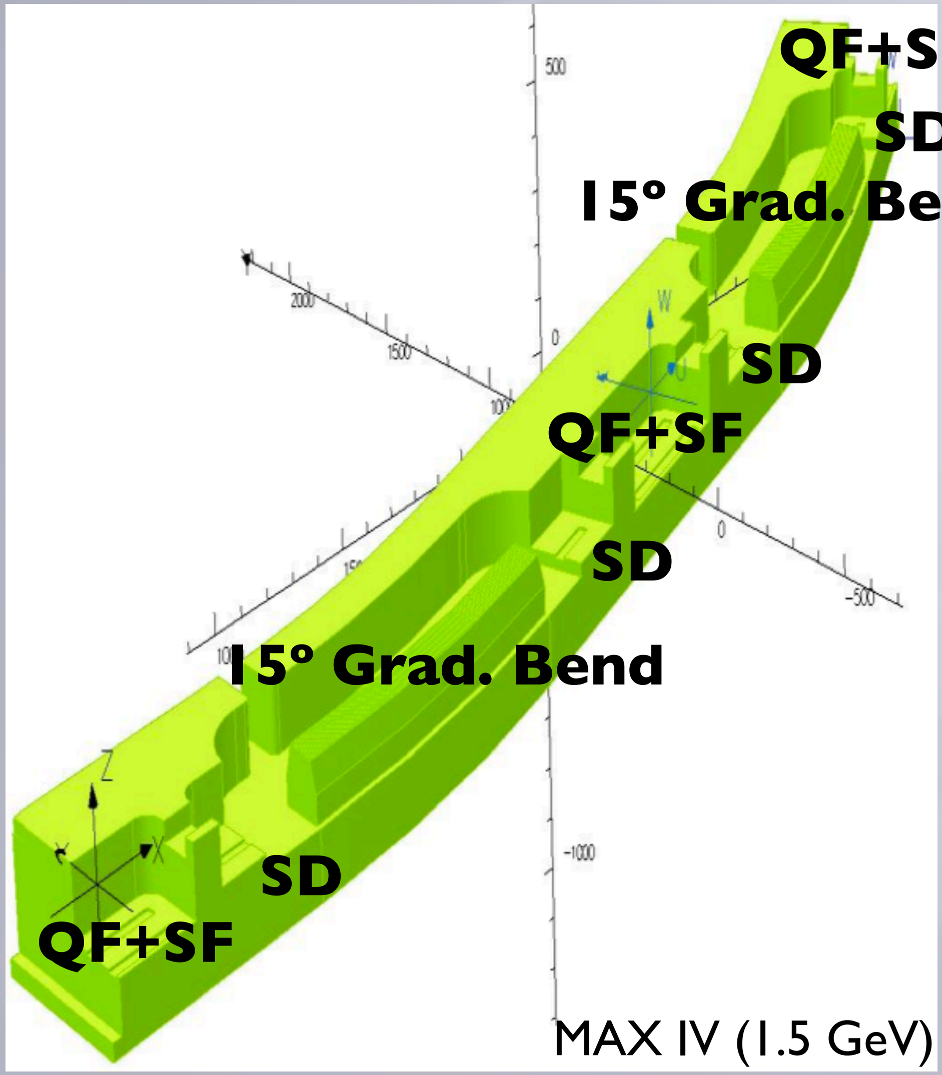
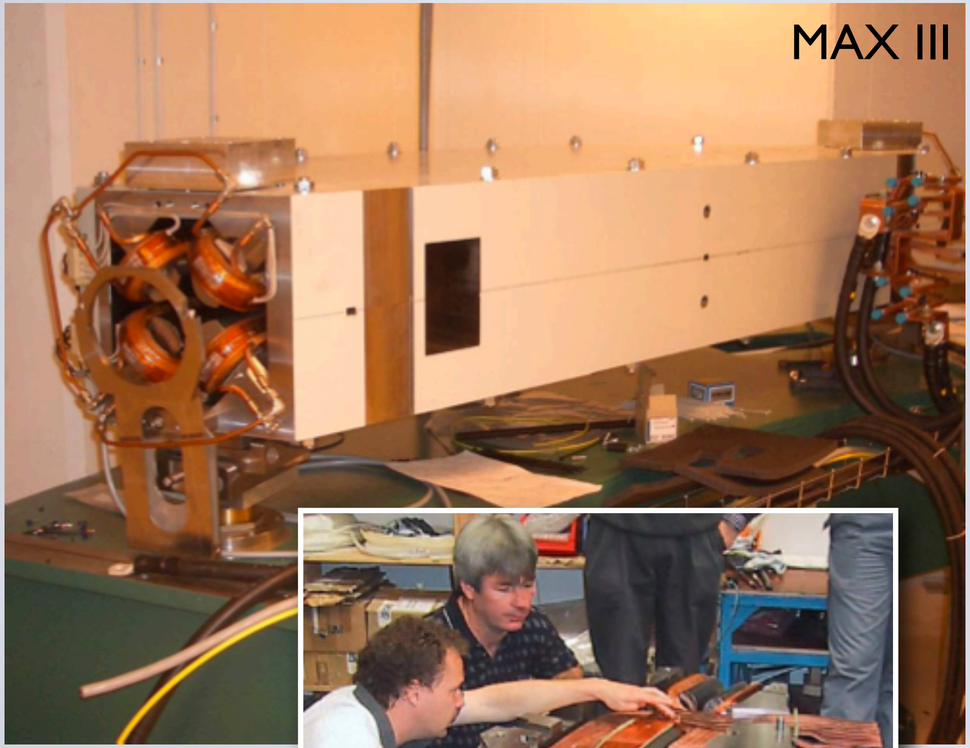




Integrated Magnet Design (1.5 GeV Storage Ring)

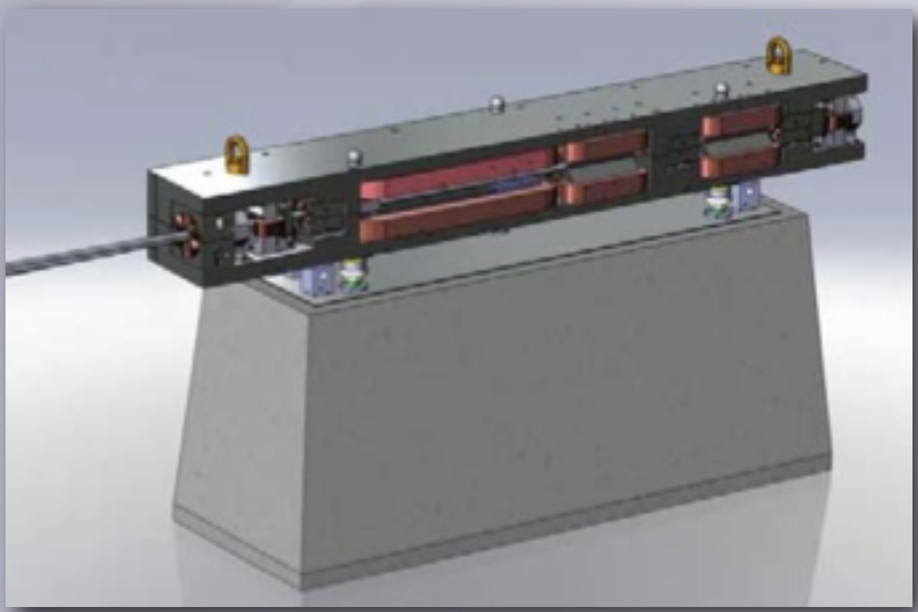
- Combined-function magnets
- Compact design →12 DBAs (to replace 10 DBAs in MAX II)





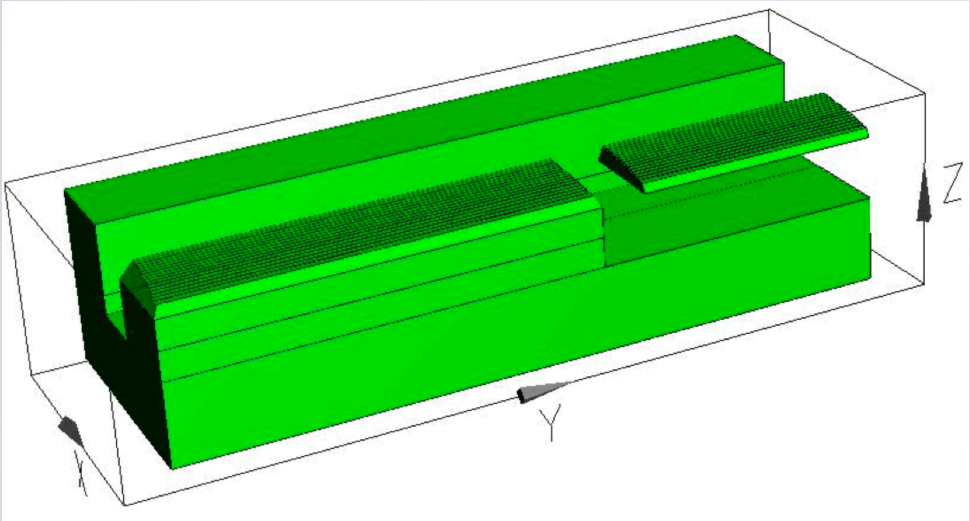
Supports

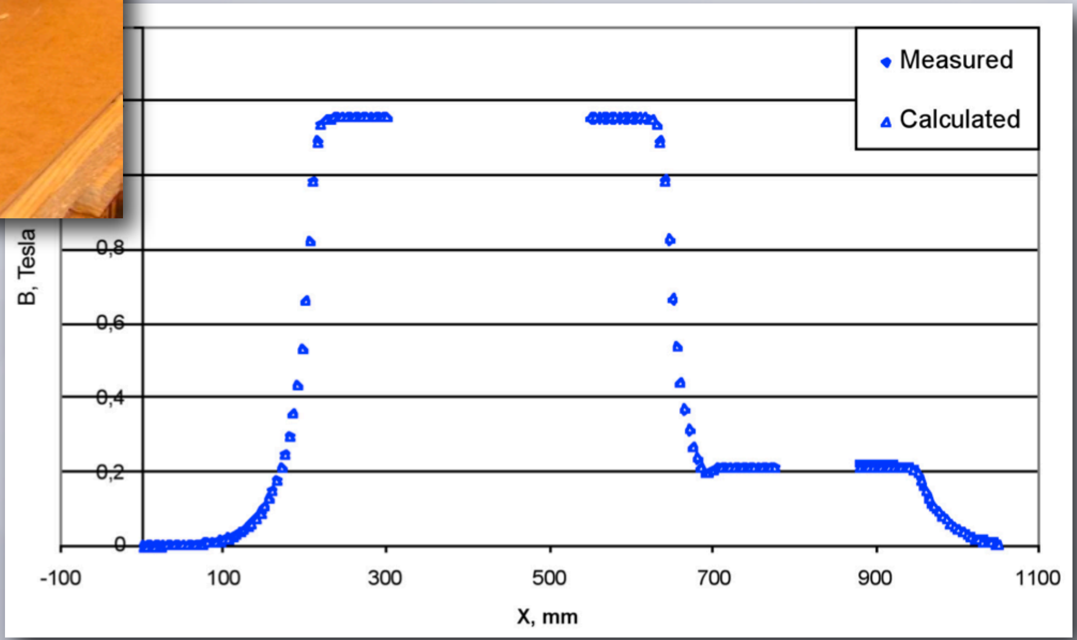
- Solid iron magnet blocks = "girders"
- Install on simple but massive concrete supports → inexpensive
- Vibrational eigenfrequencies pushed beyond 100 Hz → stability



Soft-end Dipoles → 2004 Prototype

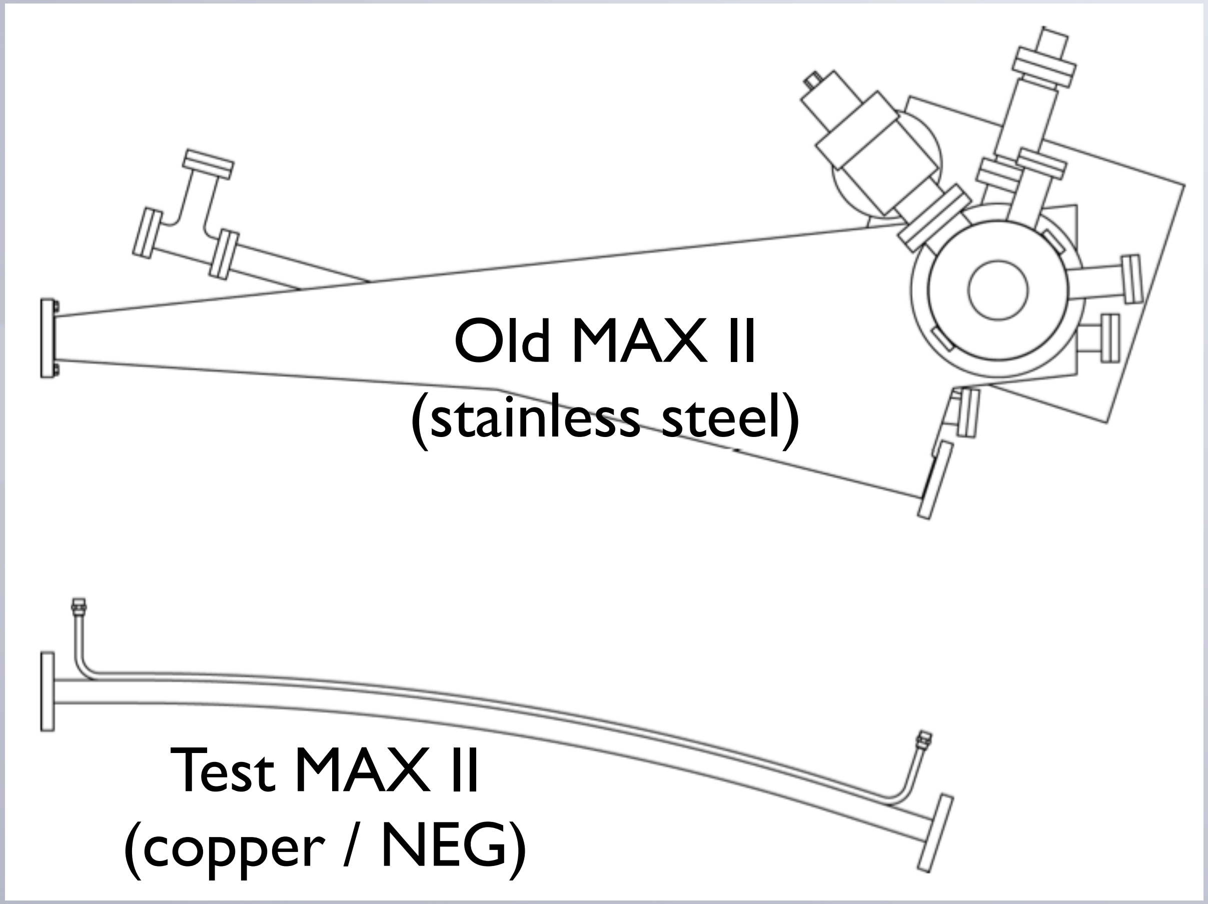
- Reduce radiation load on downstream ID cold bore → superconducting IDs





Vacuum System

- Problem: available apertures narrow, space for only few pumps
- Proposed solution: NEG-coated OFHC copper vacuum chamber
  → simple design, narrow apertures, no lumped absorbers, reduce no. of pumps
- Encouraging results @ MAX II → J. Vac. Sci. Technol. A **28**(2), Mar/Apr 2010



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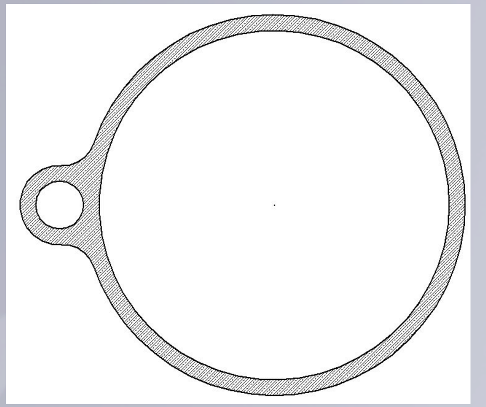
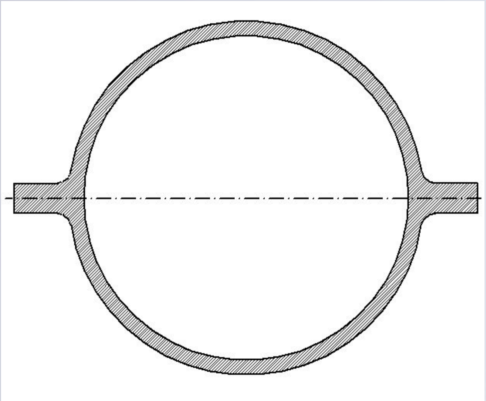
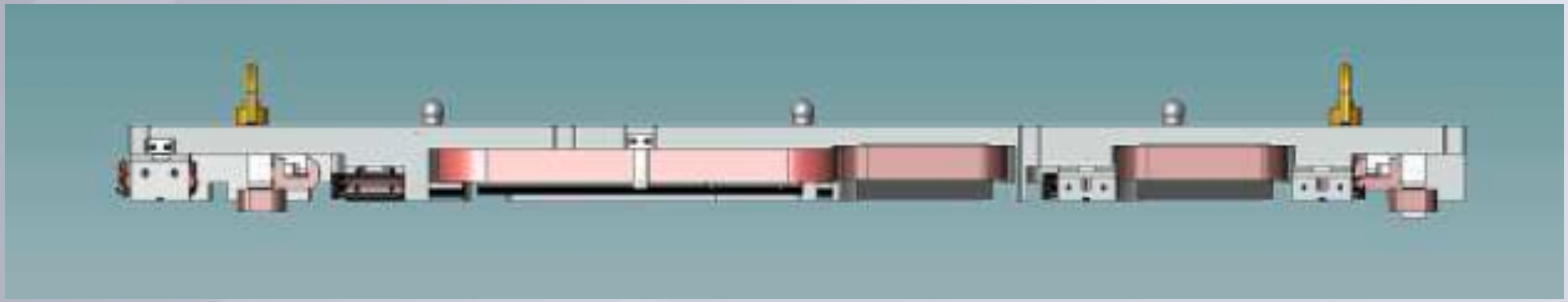
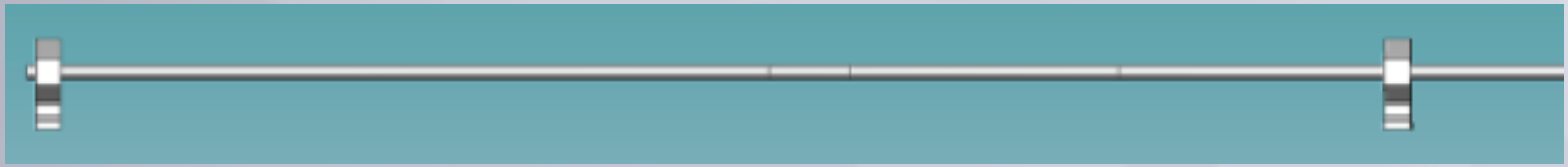




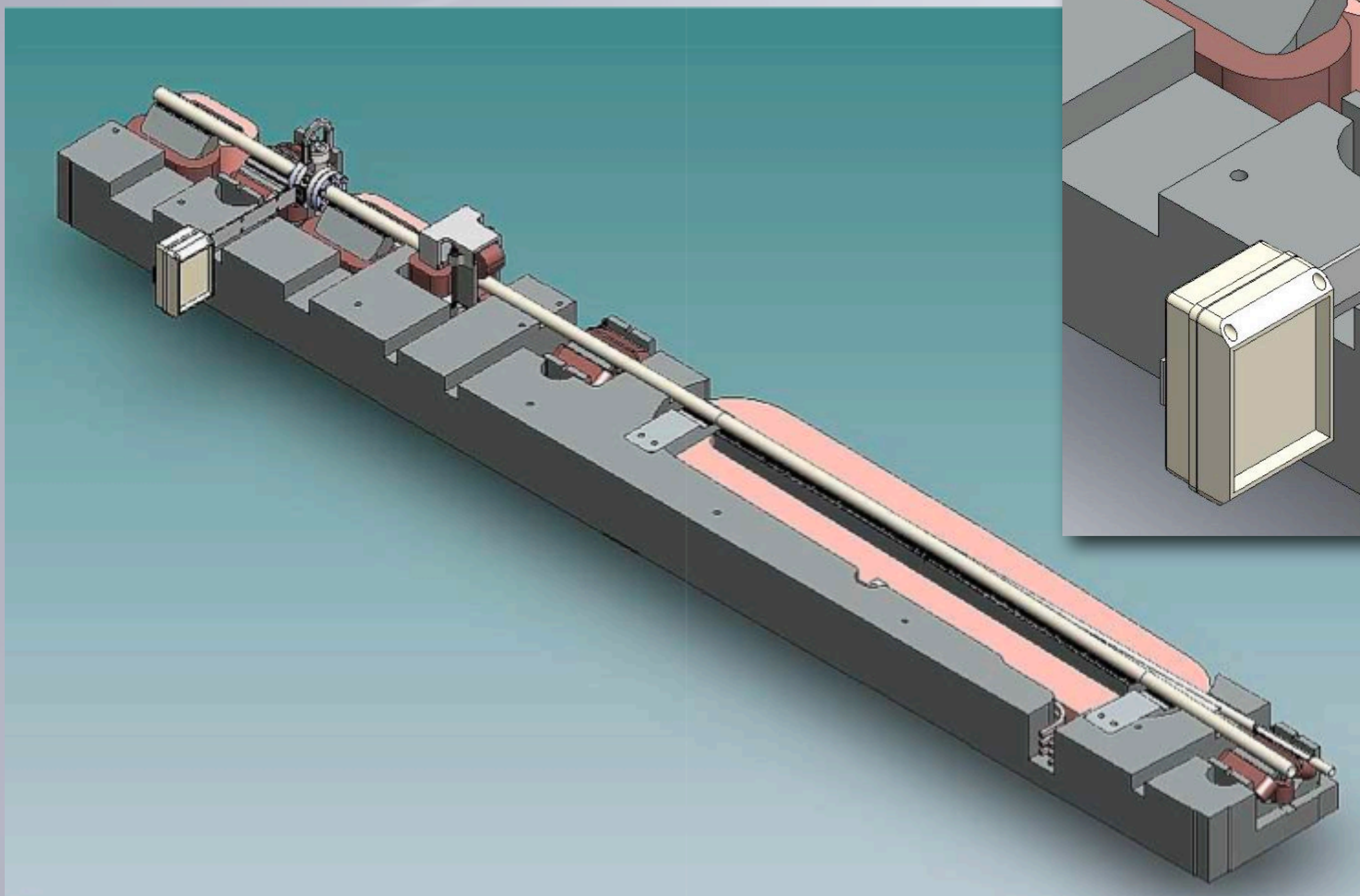
Ø 22 / 24 mm

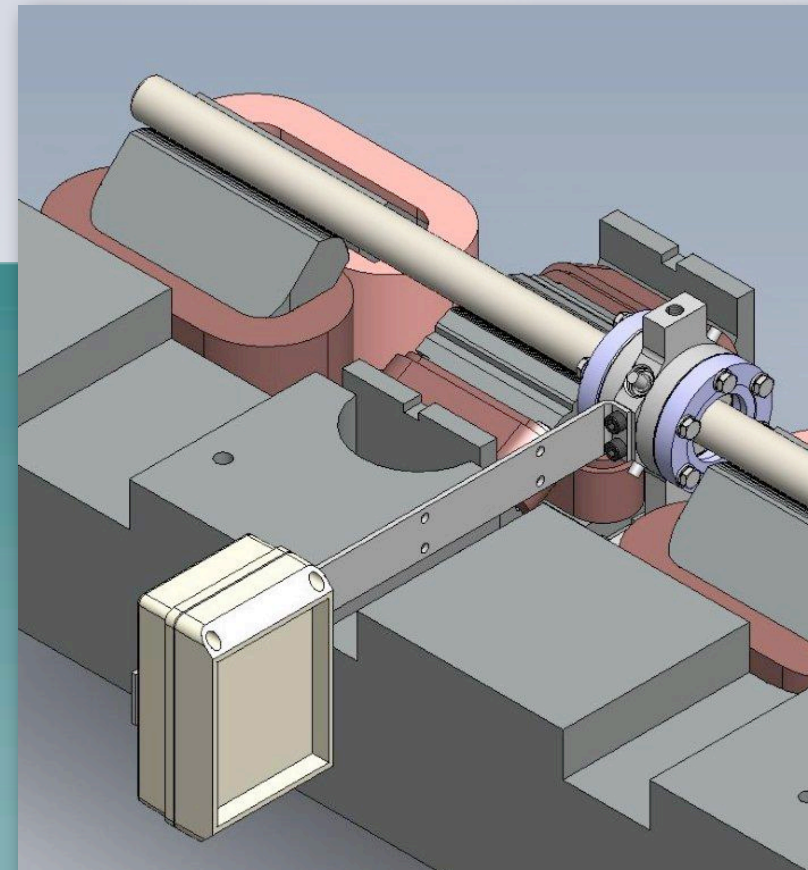




MAX IV
(copper / NEG)

Vacuum System





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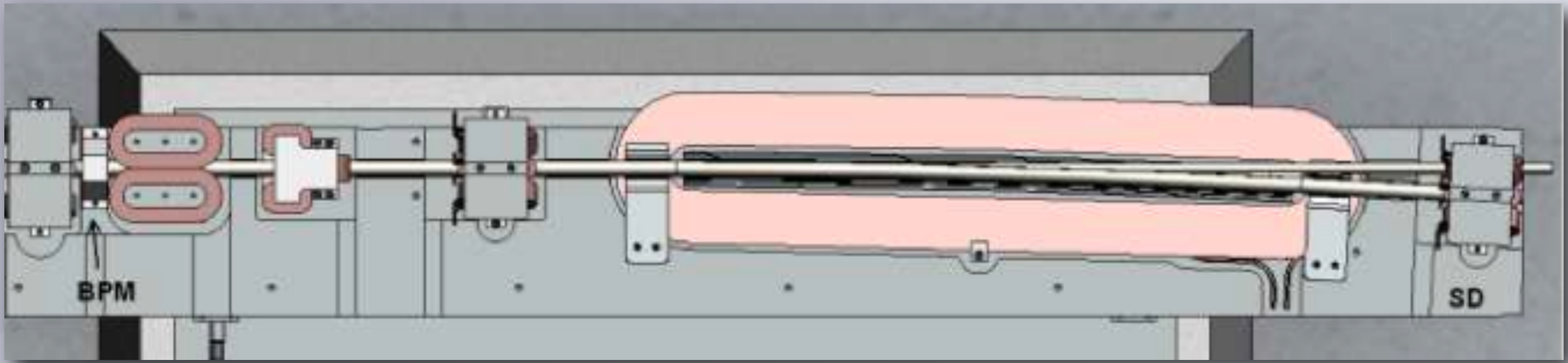
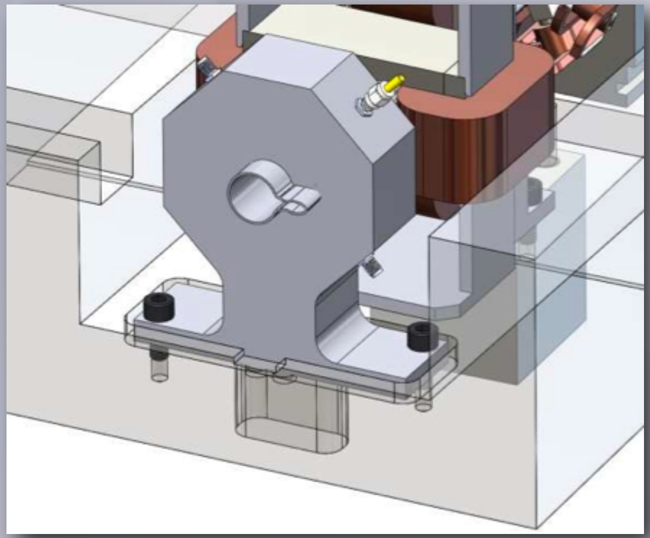
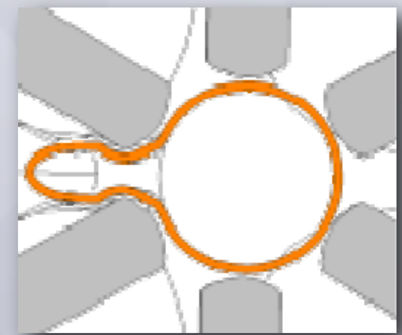
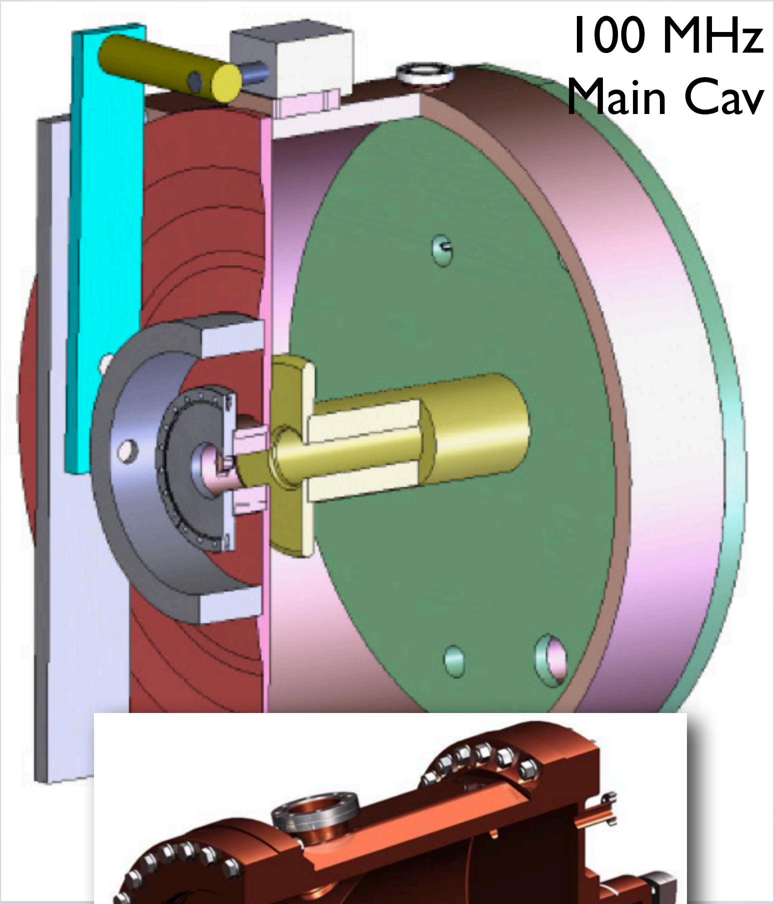




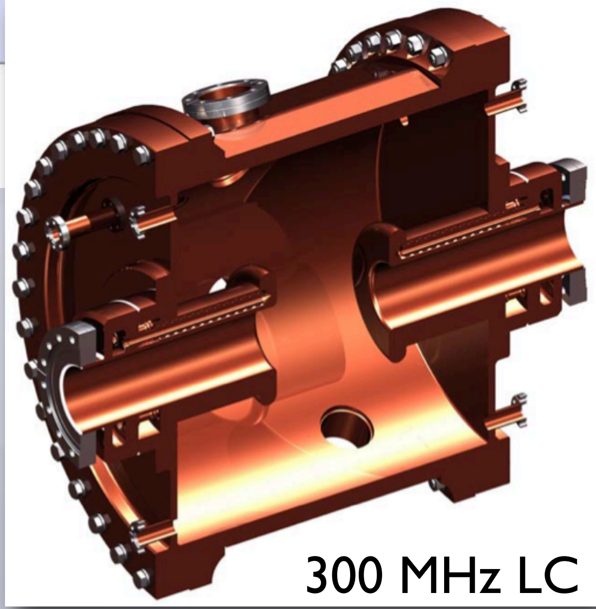


100 MHz RF System & Harmonic Landau Cavities

- 100 MHz RF system developed and implemented at MAX II and MAX III (→ EPAC'02, p.2118)
  → effectively suppresses HOMs in the accelerating cavities
- Inexpensive technology available (FM radio)
- Tetrode amplifiers are inexpensive and have low power consumption → low running cost



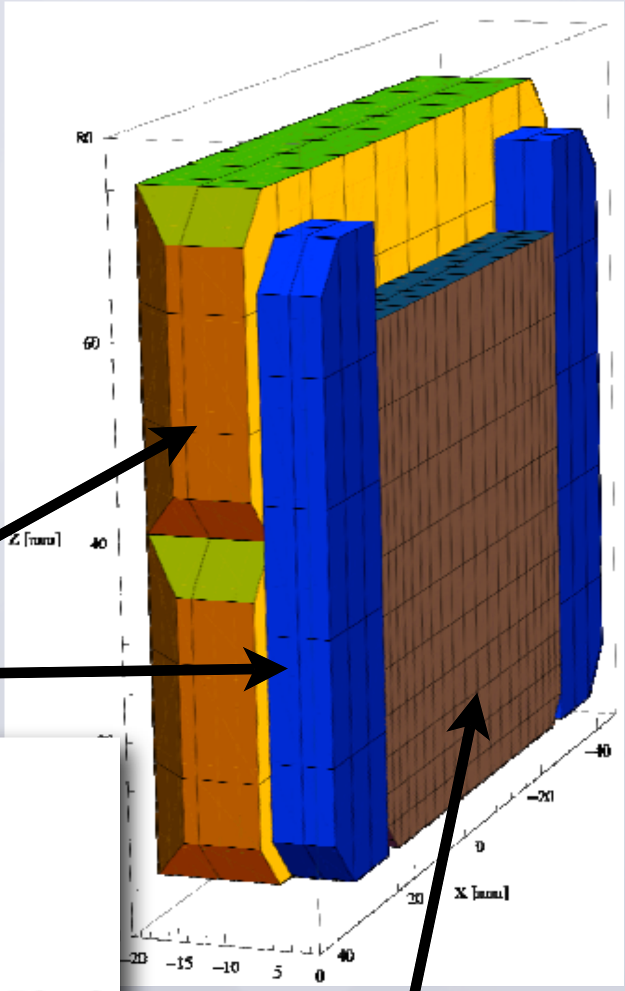
- Landau cavities @ 300 MHz: linearize RF
- Long bunches (~ 50 mm)
  → increase Touschek lifetime
  → counteract instability (narrow chamber!)
  → run at lower lin. $\xi_{x,y}$ → large MA
  → reduce ε blow-up from IBS



http://www.maxlab.lu.se/maxlab/max4

Damping Wigglers

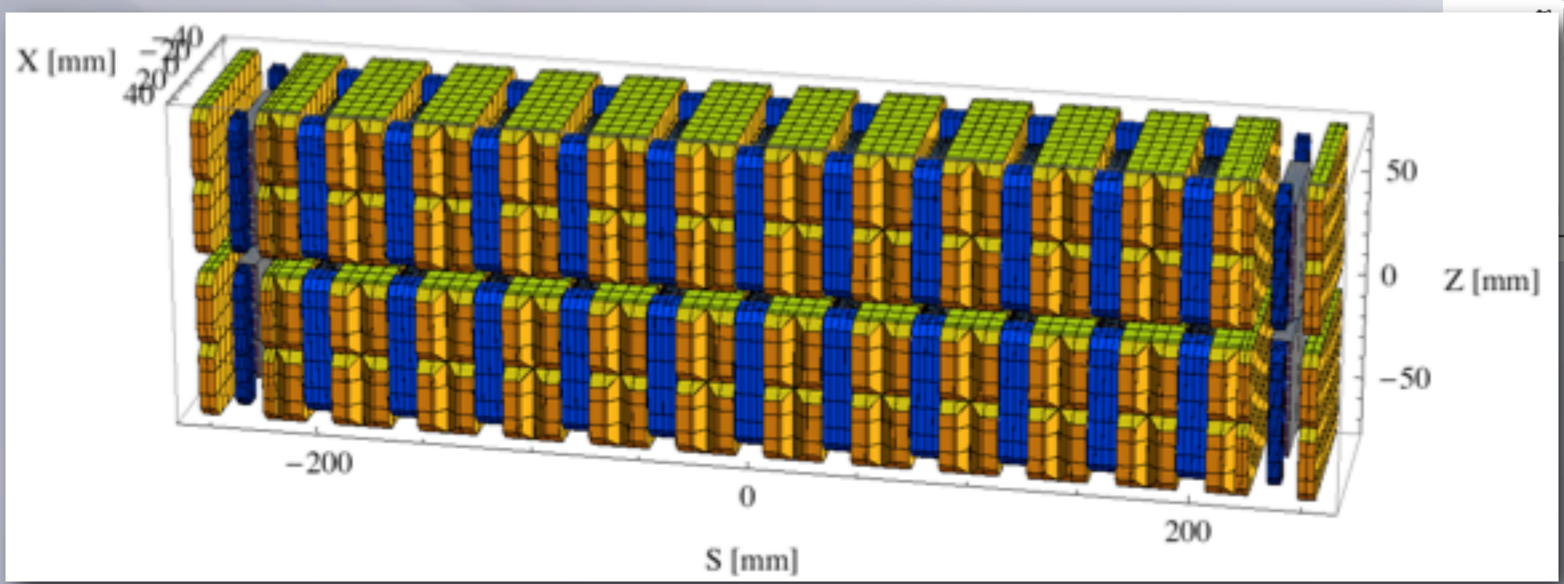
- Originally, considered superconducting DWs (lots of experience @ MAX-lab)
  NIM A **467** (2001) 118, NIM A **521** (2004) 530
- However, SCDWs come with high operational cost
  → Instead: Hybrid-type permanent-magnet DWs
- λ = 80 mm, 9 mm gap, B_{peak} = 2.2T, B_{eff} = 1.9T
- L = 2 / 4 m → P = 20 / 40 kW (@500mA)



NdFeB: Remanence 1.25 T, Intr. Coerc. 25 kOe

NdFeB: Remanence 1.28 T, Intr. Coerc. 21 kOe

Vanadium Permendur
(Fe: 49%, Co: 49%, V:2%)



Thanks for your attention!

http://www.maxlab.lu.se/maxlab/max4

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