MAX IV Lattice Design:
Multibend Achromats for Ultralow Emittance

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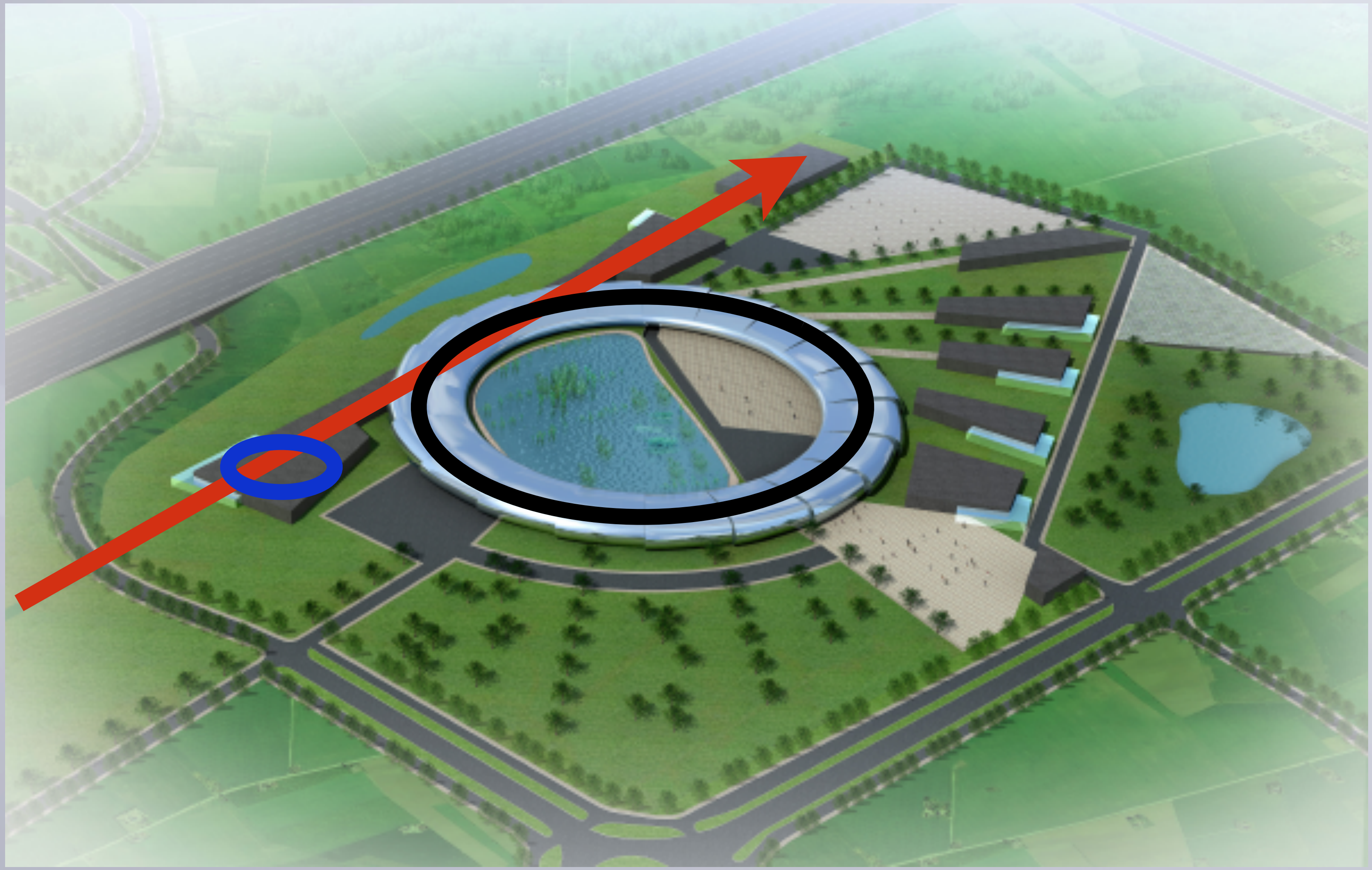
Brief Overview of the MAX IV Facility

- New site, replacement for present MAX-lab and MAX I, II, III rings
- Funding granted April 2009, construction starts in 2010, commissioning of the 3 GeV storage ring in 2014, user operation 2015

- 3 GeV linac (SPF, FEL) ~ 300m
- 1.5 GeV SR (IR/UV) 12 DBAs $\varepsilon = 6$ nm rad
- 3 GeV SR (X-ray) 20 MBAs $\varepsilon < 0.3$ nm rad



Multibend Achromats

- Damping ring community...
- EPAC '94: W. Joho et al., "Design of a Swiss Light Source"
- PAC '95: D. Einfeld et al., "Design of a Diffraction Limited Light Source (DIFL)"
- PAC '95: D. Kaltchev et al., "Lattice Studies for a High-brightness Light Source"

Design of a Swiss Light Source (SLS)

W. Joho, P. Marchand, L. Rivkin, A. Streun
Paul Scherrer Institute
CH-5232 Villigen-PSI, Switzerland

Abstract

Conceptual design of a synchrotron light source based on an electron storage ring with maximum energy of 2.1 GeV is presented. The lattice provides small emittance (3.2 nm at 2.1 GeV) with large dynamic aperture and flexible matching of the beam parameters to the insertion devices. This insures very bright VUV/XUV undulator radiation with a high degree of transverse coherence. Six achromatic

VUV photons of up to 100 eV (Figs. 1,5). The other long straight is reserved for future "bright ideas"!

2 SLS LAYOUT

The layout (Fig. 2) of the storage ring consists of six achromatic arcs, two very long (17 m) and four 7 m long straight sections.

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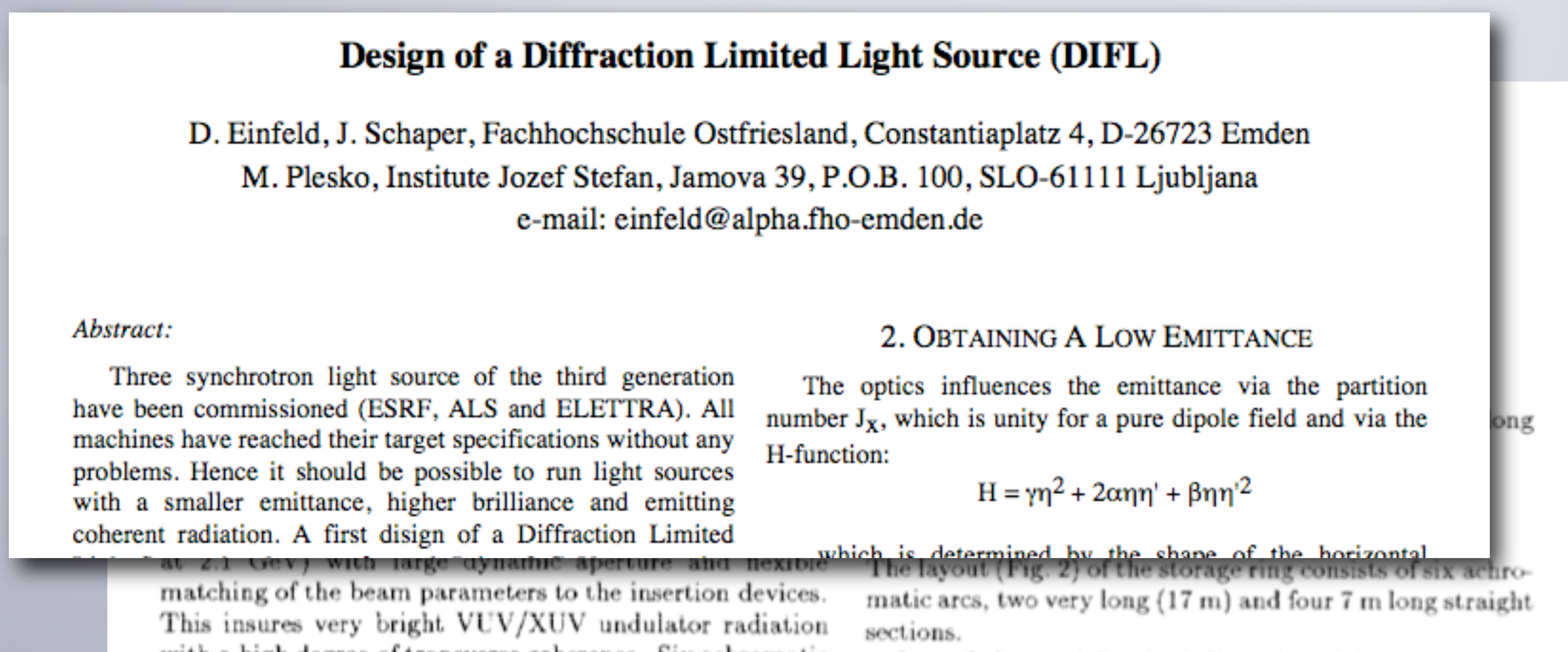

Design of a Diffraction Limited Light Source (DIFL)

D. Einfeld, J. Schaper, Fachhochschule Ostfriesland, Constantiaplatz 4, D-26723 Emden
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Abstract:

Three synchrotron light source of the third generation have been commissioned (ESRF, ALS and ELETTRA). All machines have reached their target specifications without any problems. Hence it should be possible to run light sources with a smaller emittance, higher brilliance and emitting coherent radiation. A first disign of a Diffraction Limited

matching of the beam parameters to the insertion devices. This insures very bright VUV/XUV undulator radiation with a high degree of transverse coherence. Six achromatic

2. OBTAINING A LOW EMITTANCE

The optics influences the emittance via the partition number J_x, which is unity for a pure dipole field and via the H-function:

$$H = \gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2$$

which is determined by the shape of the horizontal

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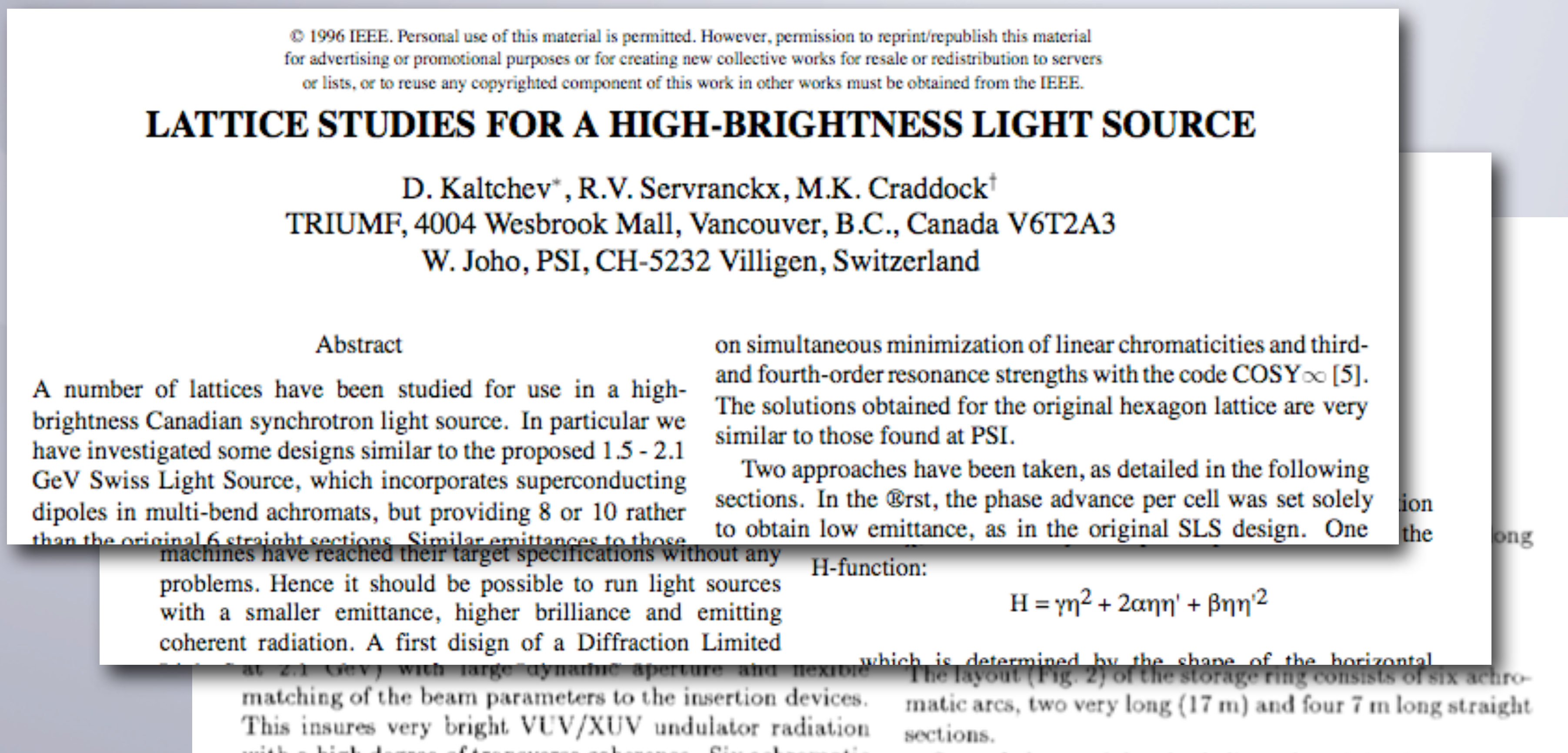

LATTICE STUDIES FOR A HIGH-BRIGHTNESS LIGHT SOURCE

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W. Joho, PSI, CH-5232 Villigen, Switzerland

Abstract

A number of lattices have been studied for use in a high-brightness Canadian synchrotron light source. In particular we have investigated some designs similar to the proposed 1.5 - 2.1 GeV Swiss Light Source, which incorporates superconducting dipoles in multi-bend achromats, but providing 8 or 10 rather than the original 6 straight sections. Similar emittances to those

on simultaneous minimization of linear chromaticities and third- and fourth-order resonance strengths with the code COSY∞ [5]. The solutions obtained for the original hexagon lattice are very similar to those found at PSI.

Two approaches have been taken, as detailed in the following sections. In the ®rst, the phase advance per cell was set solely to obtain low emittance, as in the original SLS design. One

machines have reached their target specifications without any problems. Hence it should be possible to run light sources with a smaller emittance, higher brilliance and emitting coherent radiation. A first disign of a Diffraction Limited

H-function:

$$H = \gamma\eta^2 + 2\alpha\eta\eta' + \beta\eta'^2$$

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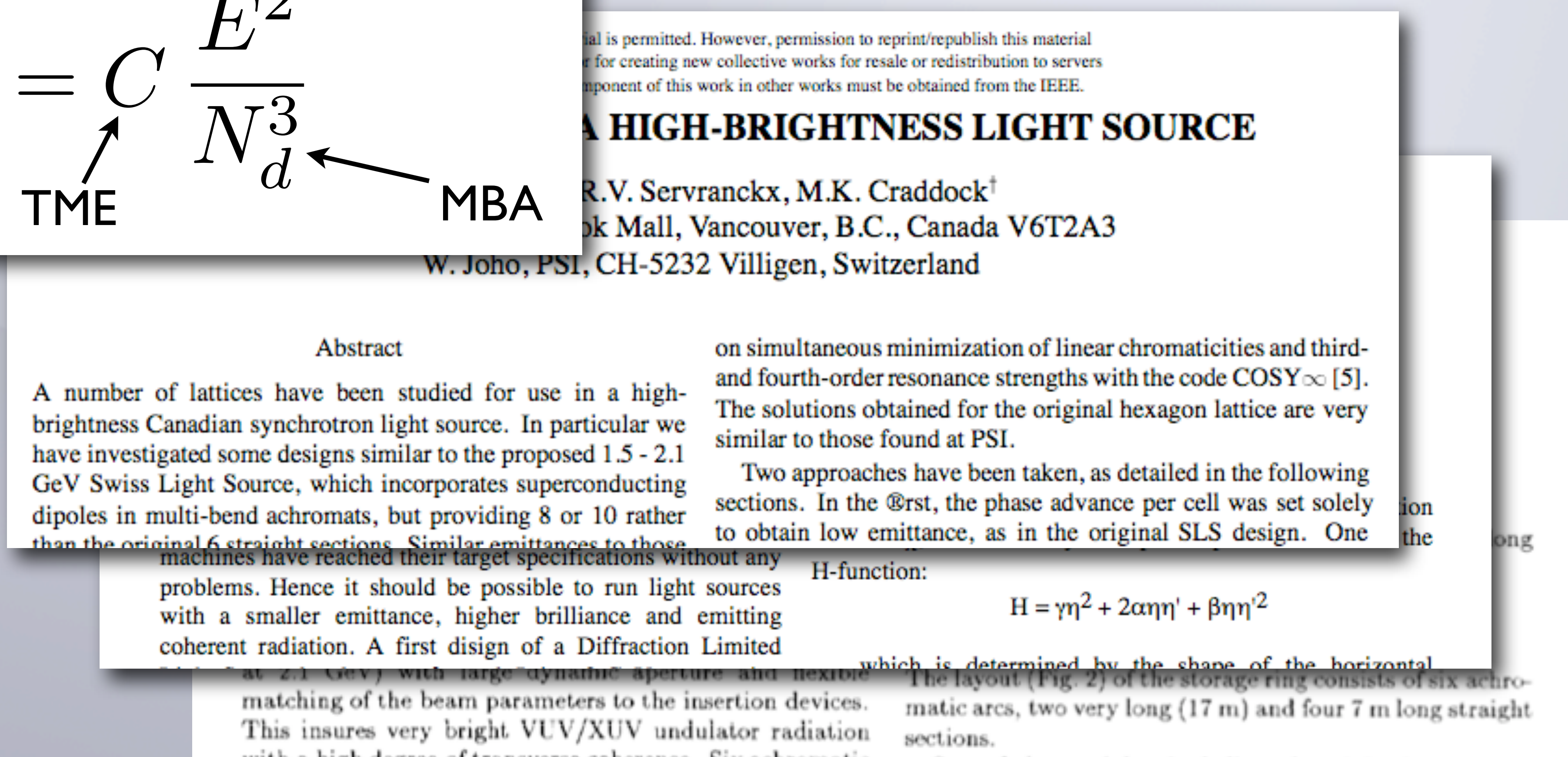
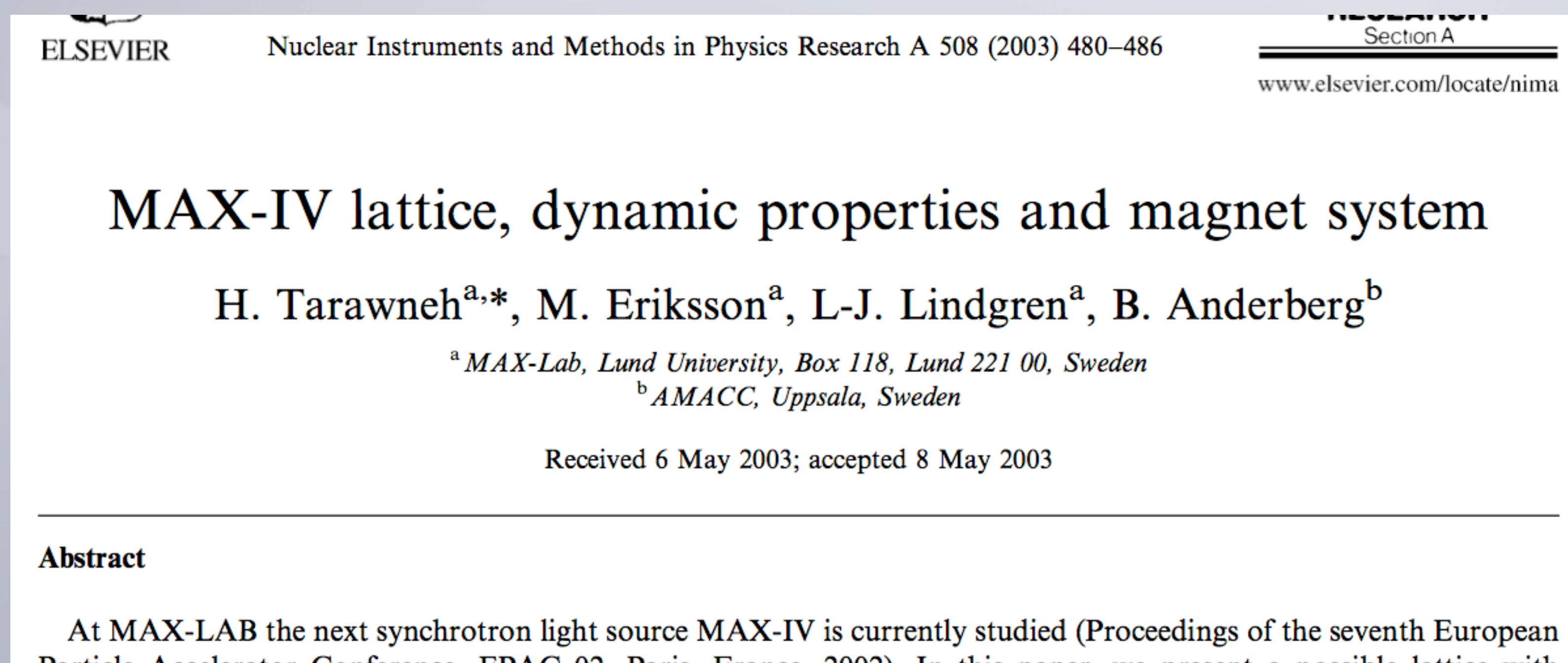
$$\varepsilon_x = C\,\frac{E^2}{N_d^3}$$

TME (→ C) MBA (→ N_d^3)



Evolution of the MAX IV 3 GeV Storage Ring

- MBA challenge: compact lattice → combined-function magnets, narrow apertures, ...
- Tarawneh et al., NIM A **508** (2003) 480 → 3 GeV (285 m), 12 MBAs, ε = 1.2 nm rad
- Eriksson et al. , PAC ’07 → 3.0/1.5 GeV rings stacked, ε = 0.83 / 0.4 nm rad
- Leemann at el., PRST-AB **12** 120701 (2009) → 3 GeV, 528 m, 20 MBAs, 5 m long straight sections, ε < 0.3 nm rad, gradient dipoles, discrete sextupoles & octupoles, fully integrated magnet design


ELSEVIER Nuclear Instruments and Methods in Physics Research A 508 (2003) 480–486

Section A

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MAX-IV lattice, dynamic properties and magnet system

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Received 6 May 2003; accepted 8 May 2003

Abstract

At MAX-LAB the next synchrotron light source MAX-IV is currently studied (Proceedings of the seventh European Particle Accelerator Conference, EPAC 02, Paris, France, 2002). In this paper, we present a possible lattice with

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MOZAAB02 Proceedings of PAC07, Albuquerque, New Mexico, USA

THE MAX-IV DESIGN: PUSHING THE ENVELOPE

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Hamed Tarawneh, Sesame, Amman, Jordan

Abstract

The proposed MAX IV facility is meant as a successor to the existing MAX-lab. The accelerator part will consist of three storage rings, two new ones operated at 3 and 1.5 GeV respectively and the existing 700 MeV MAX III ring. The two new rings have identical lattices and are placed on top of each other. Both these rings have a very short bunches for the generation of short pulses of spontaneous X-ray radiation and can also work as an electron source for Free Electron Lasers (FELs).

A more detailed description of the MAX IV facility can be found in ref. [1] and since the MAX III ring is described earlier [2], it will not be treated here.

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PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **12**, 120701 (2009)

Beam dynamics and expected performance of Sweden’s new storage-ring light source: MAX IV

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MAX-lab, Lund University, S-22363 Lund, Sweden

J. Bengtsson
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A. Streun
SLS, Paul Scherrer Institute, CH-5232 Villigen, Switzerland
(Received 4 August 2009; published 3 December 2009)

MAX IV will be Sweden’s next-generation high-performance synchrotron radiation source. The project has recently been granted funding and construction is scheduled to begin in 2010. User operation for a

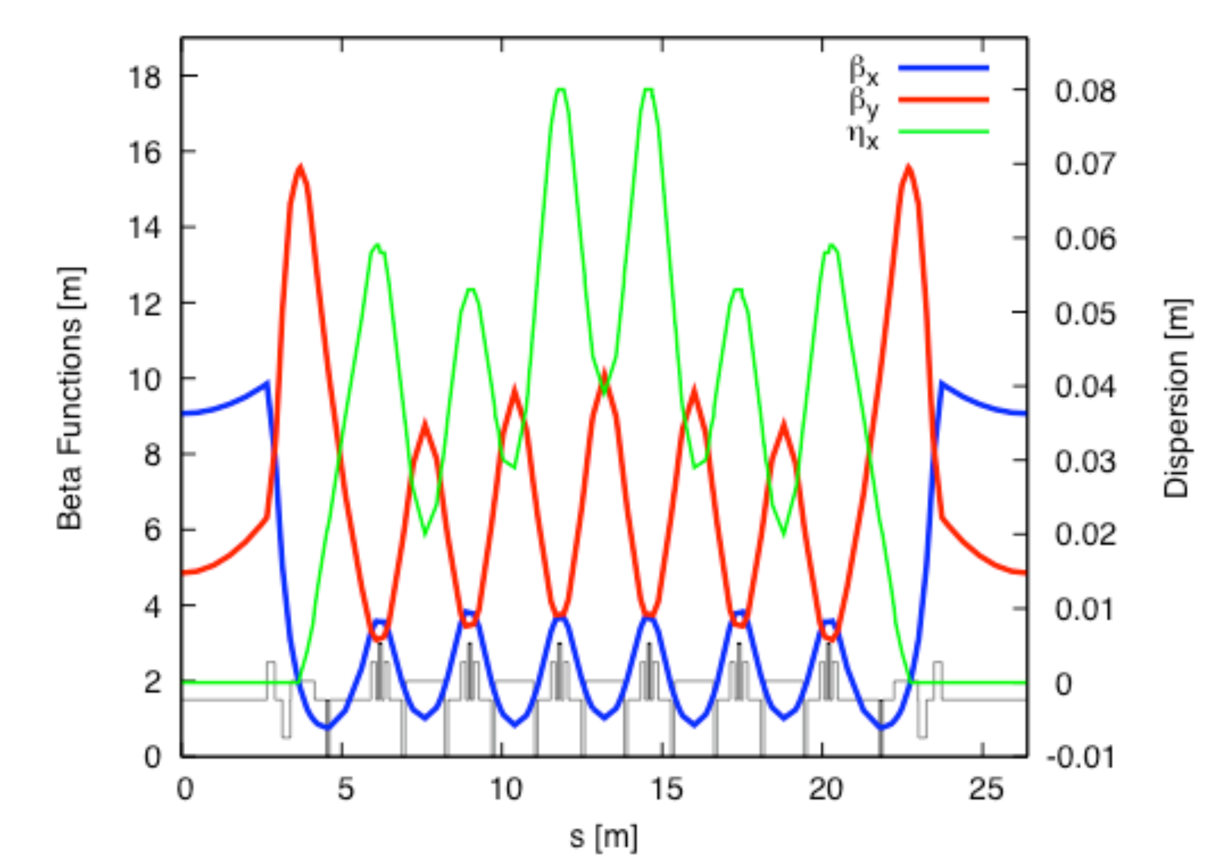
GeV respectively and the existing 700 MeV MAX III ring. The two new rings have identical lattices and are

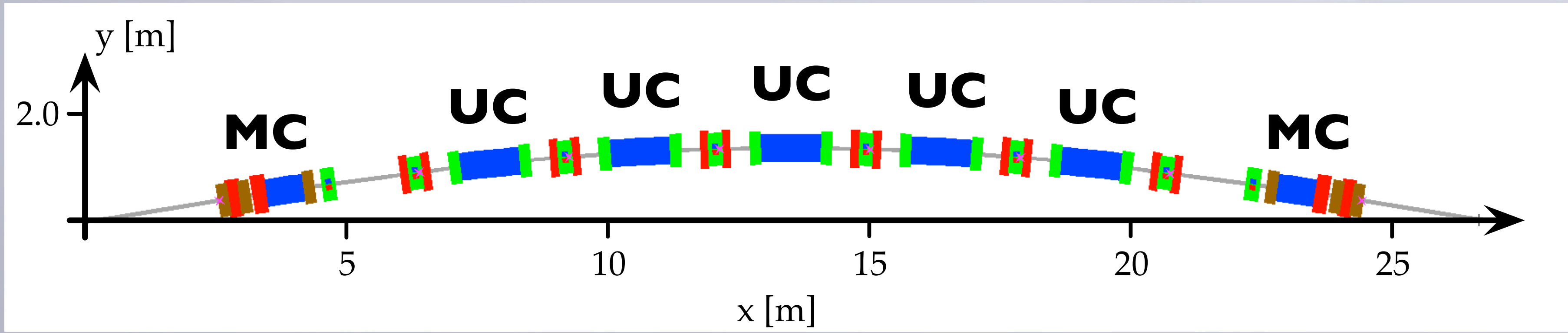
be found in ref. [1] and since the MAX III ring is described earlier [2], it will not be treated here.

At MAX-LAB the next synchrotron light source MAX-IV is currently studied (Proceedings of the seventh European Particle Accelerator Conference, EPAC 02, Paris, France, 2002). In this paper, we present a possible lattice with

MAX IV Multibend Achromat Lattice

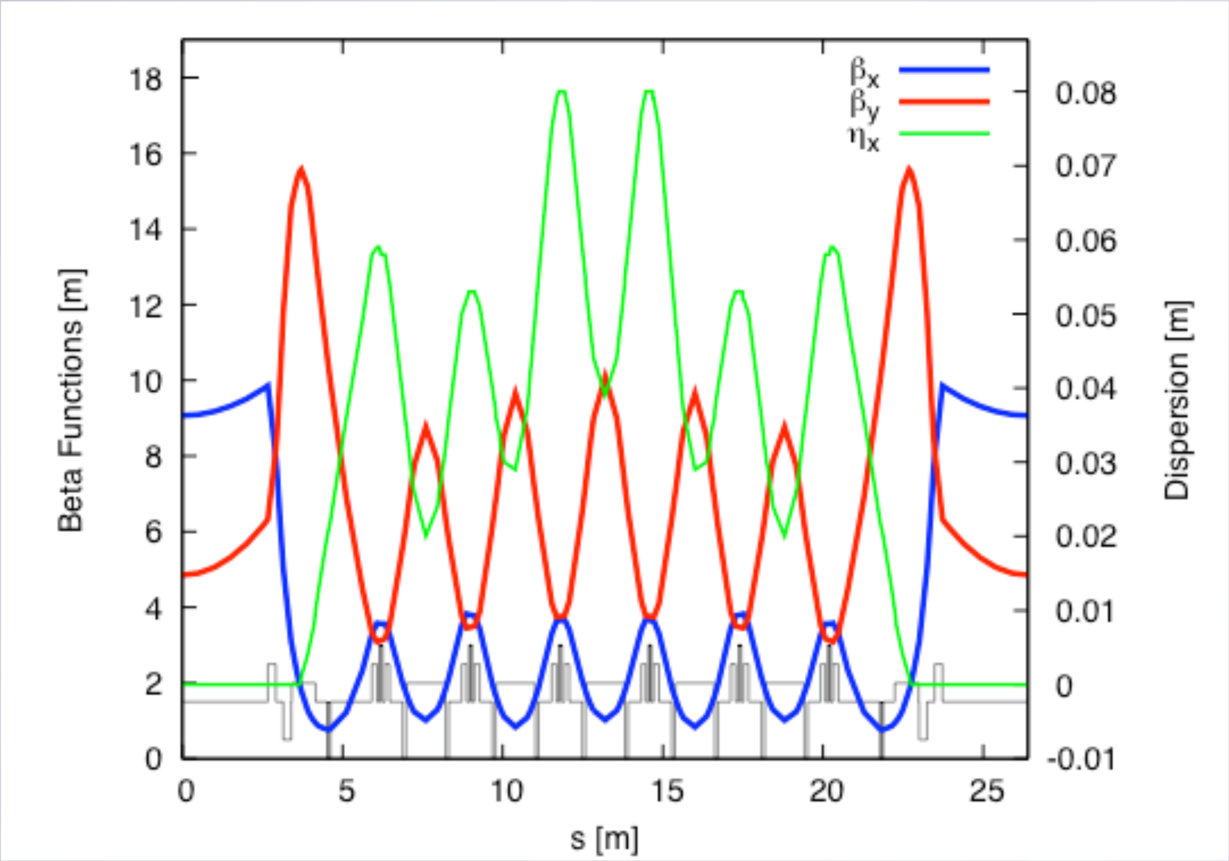
- 20 MBAs → 19 ID straights
- 5 unit cells, 2 matching cells
- 5 m long straight sections
- 1.3m short straights (→RF)
- ε_x = 0.3 nm rad
  (4 PMDWs, LCs, and IBS)
- Rad. power: 572 keV/turn
  (with 4 PMDWs)
- Energy spread: 0.096%
  (with 4 PMDWs)

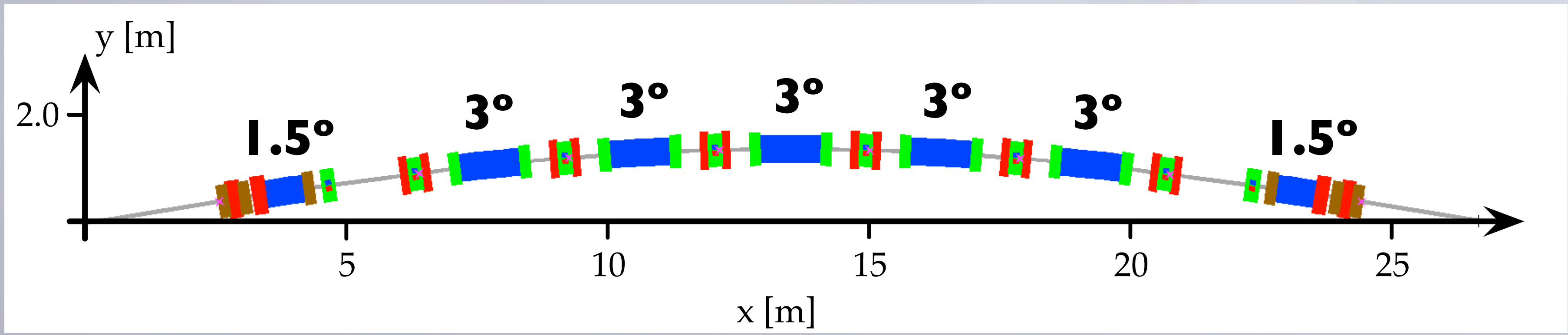




MAX IV Multibend Achromat Lattice

- 3° bends in unit cells (~0.5T)
- 1.5° soft-end bends in matching cells
- η_{max} = 8 cm, η^* = 0
- σ_y^* < 6 µm
- WP: ν_x = 42.20, ν_y = 14.28
- 2 QF families (~ 40 T/m)
- QD in dipoles (~ 9 T/m)
- Quad doublet in matching cell





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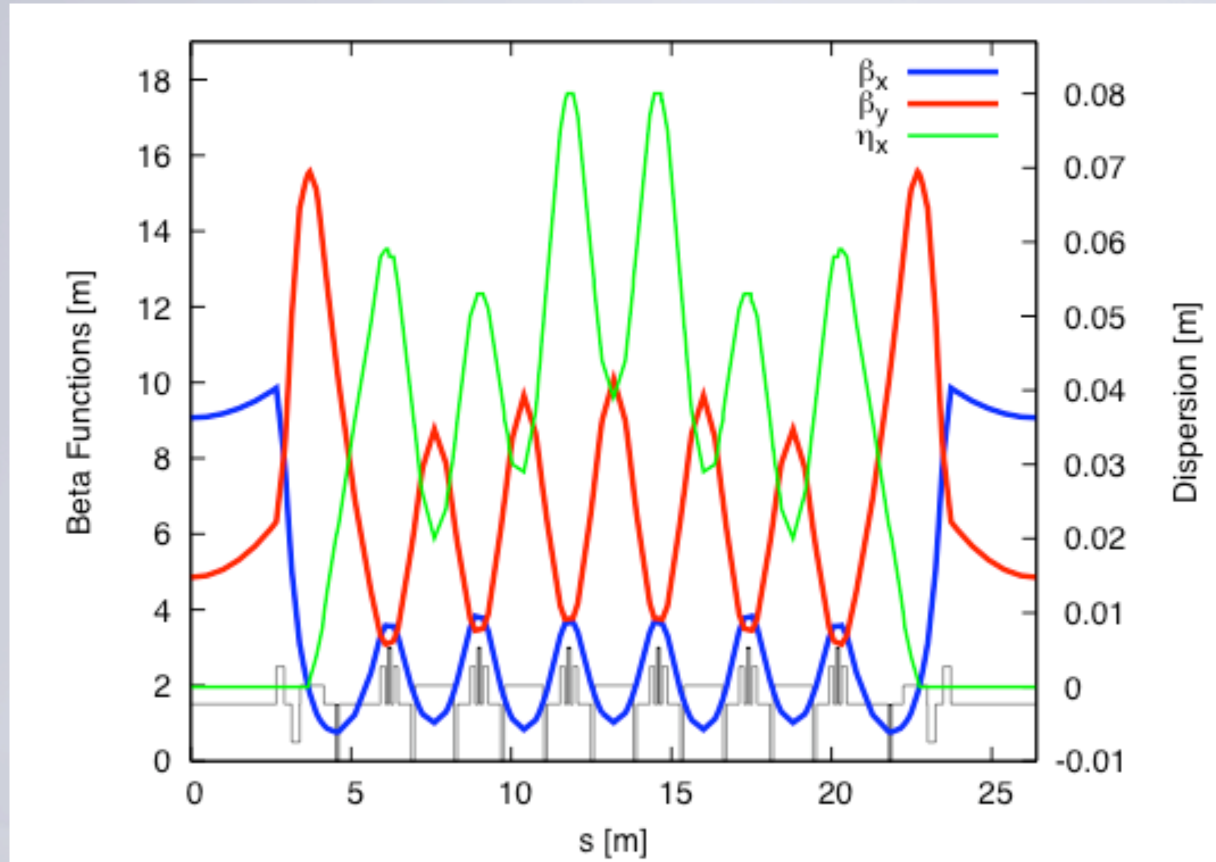

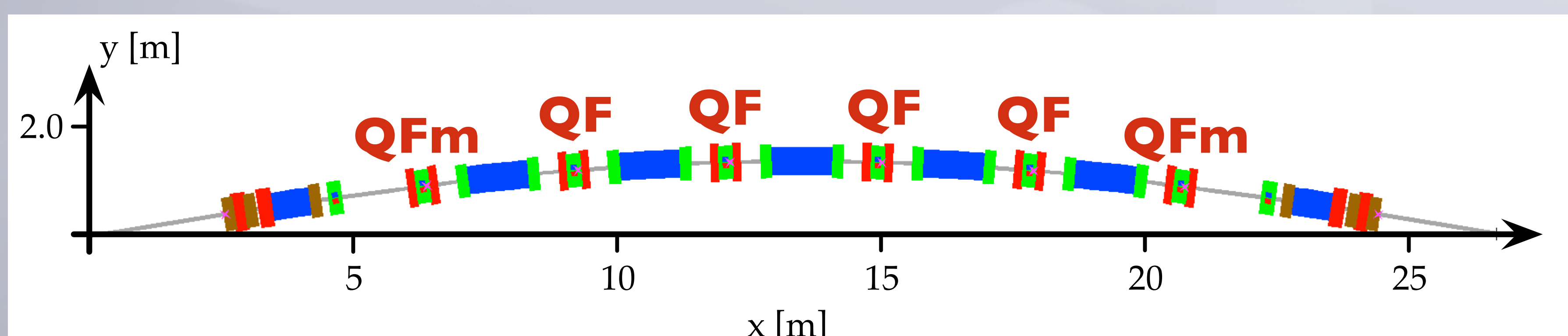

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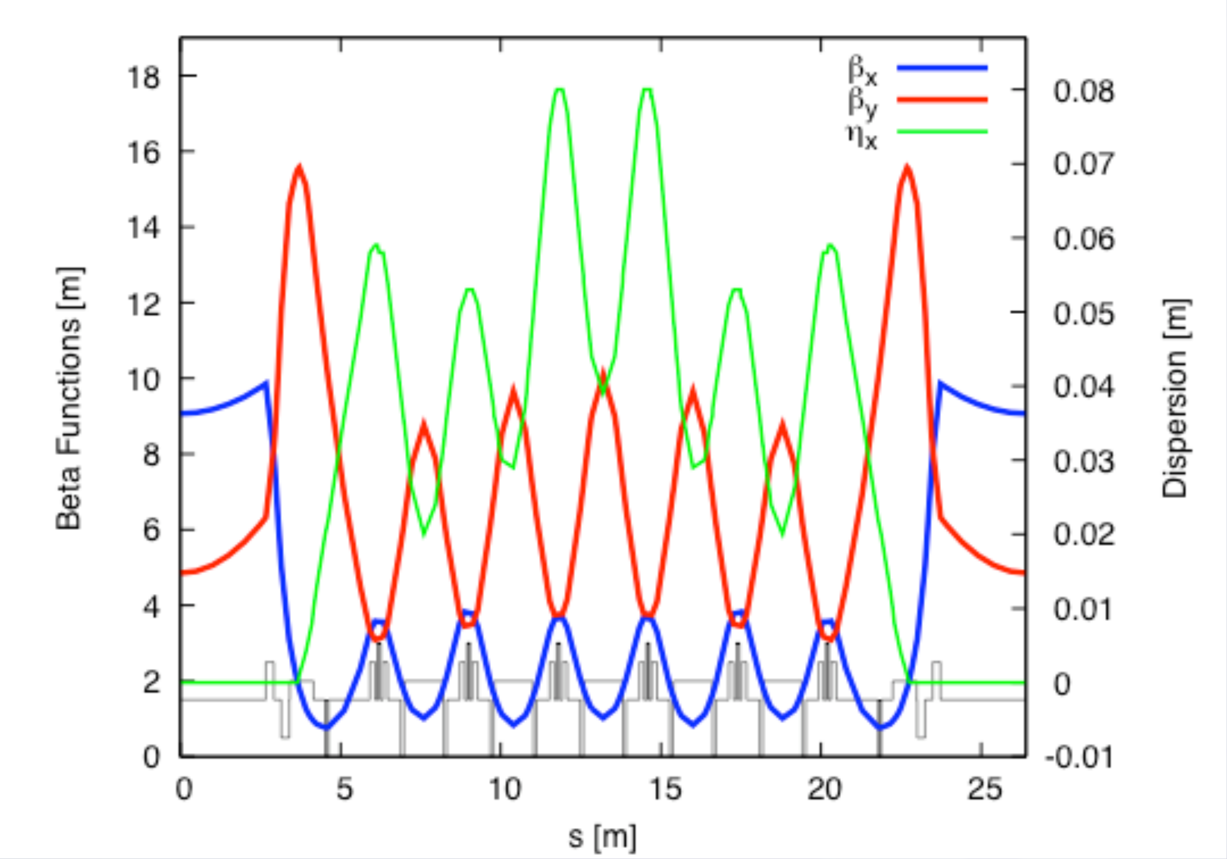

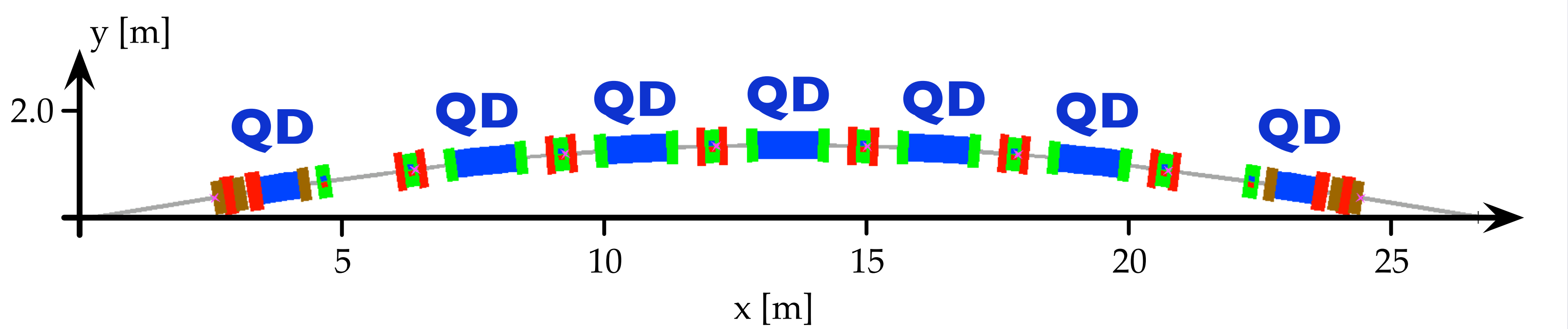

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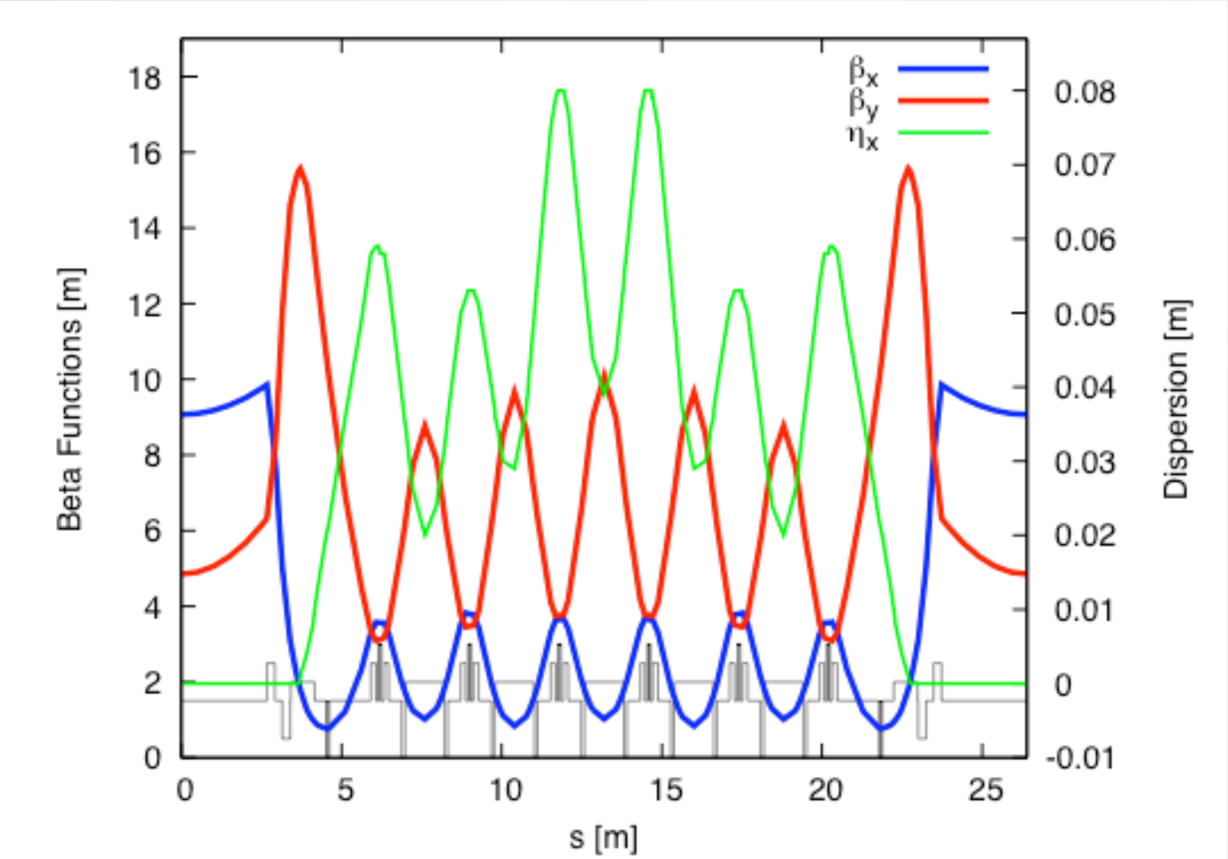
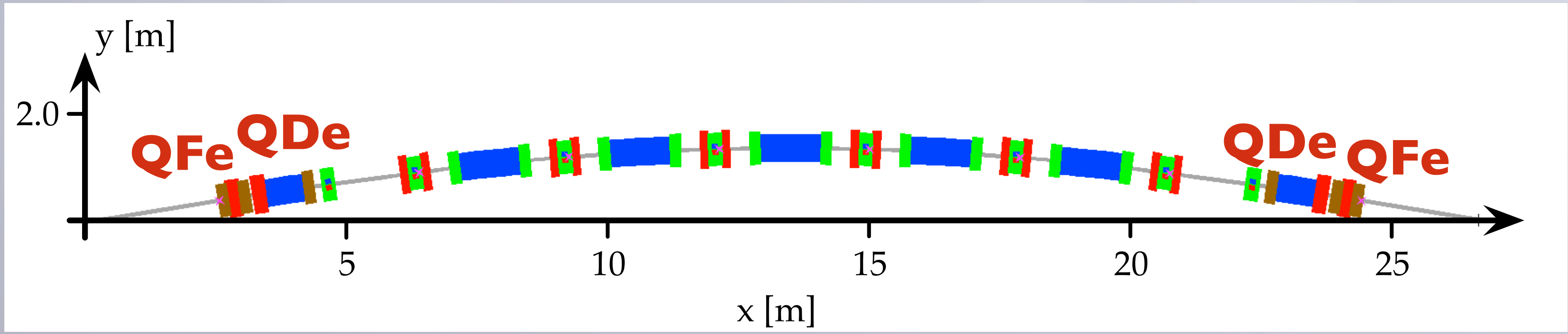
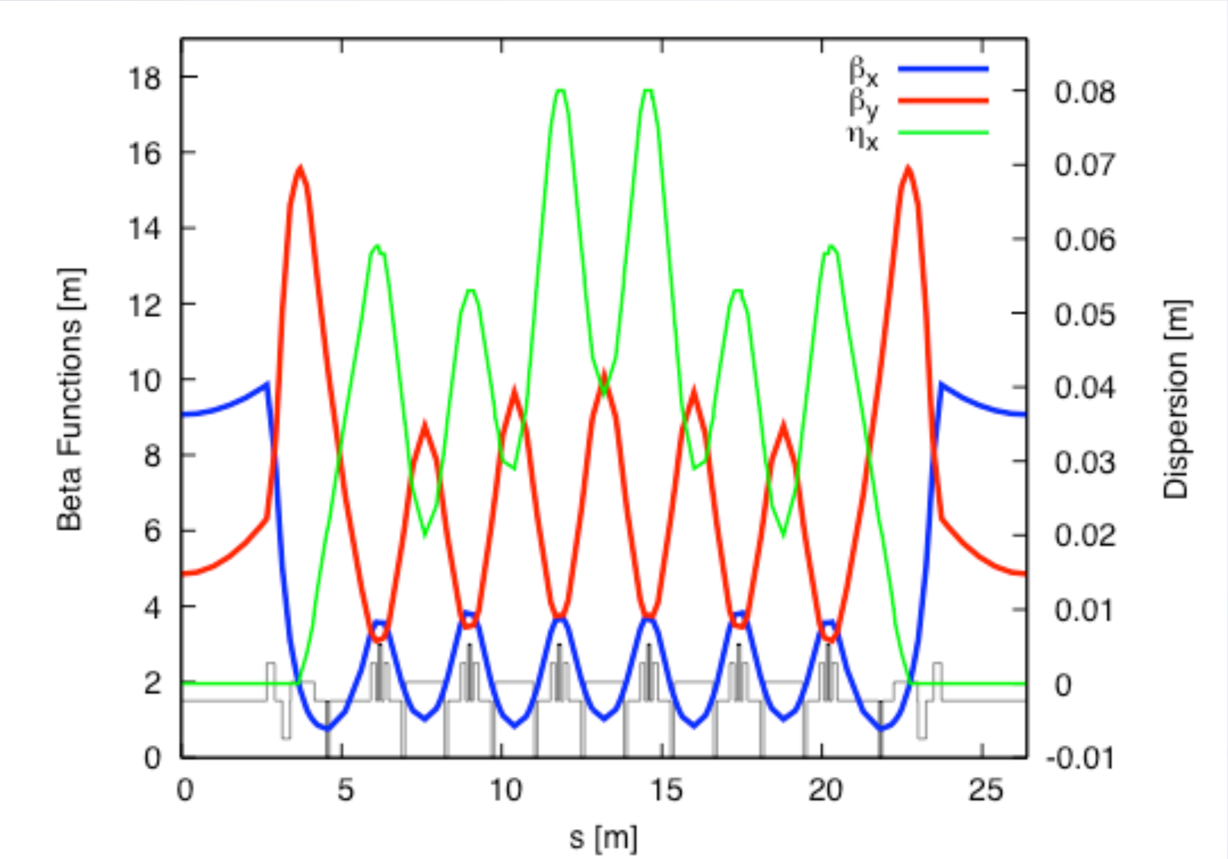
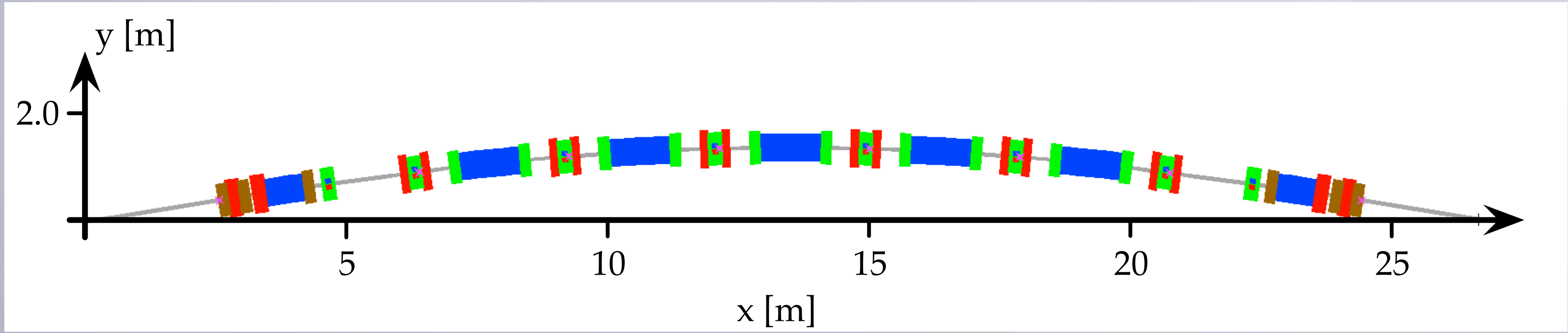




MAX IV Multibend Achromat Lattice

- nat. $\xi_x = -50$, $\xi_y = -44$
- 3 SF families ($< 2200\ T/m^2$)
- 2 SD families ($\sim 1200\ T/m^2$)
- 3 octupole families ($< 22000\ T/m3$)





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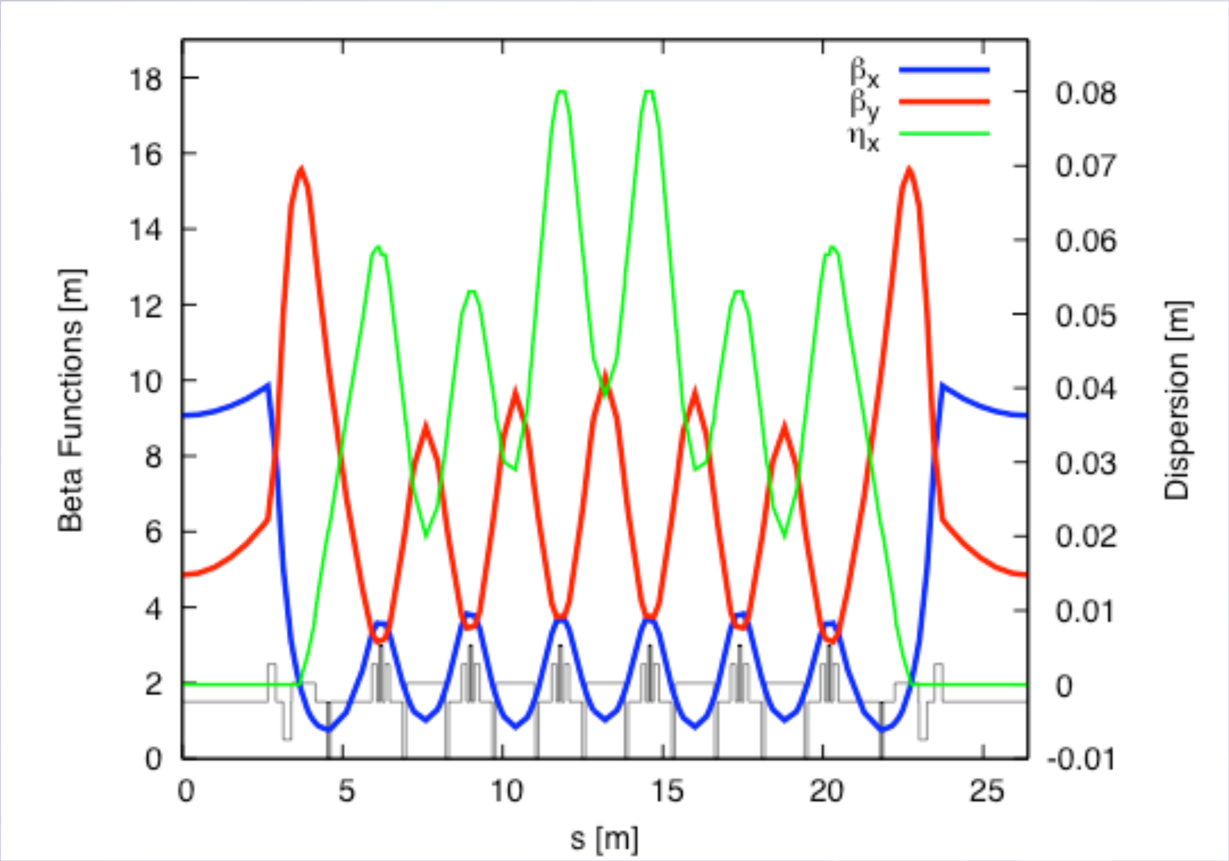

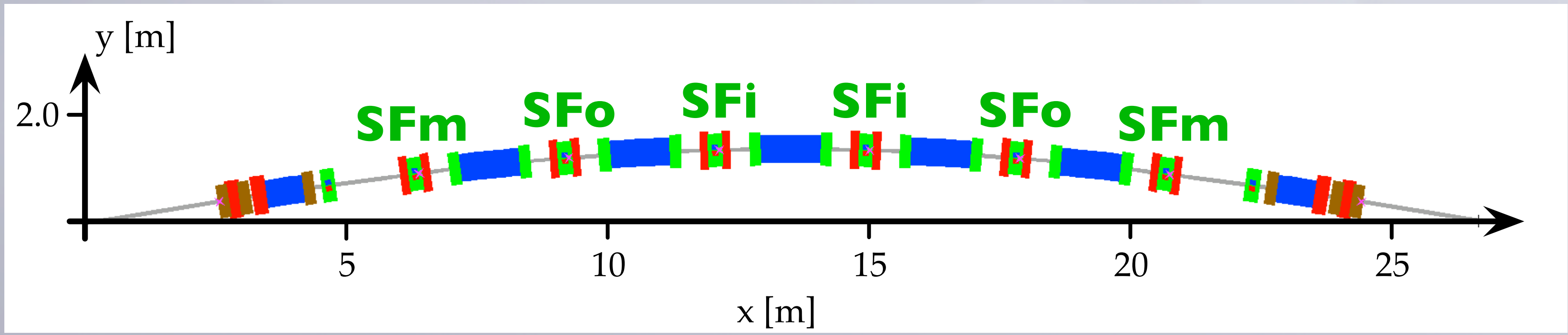

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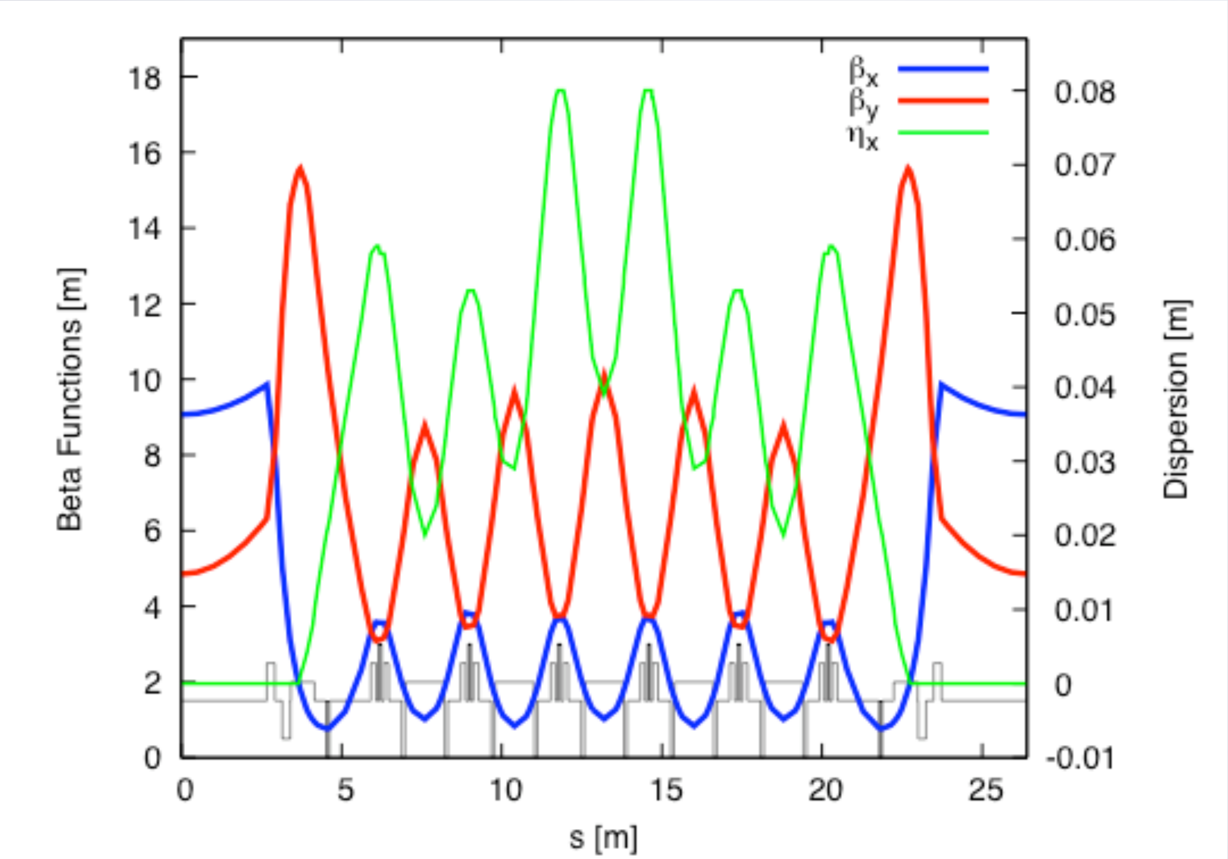

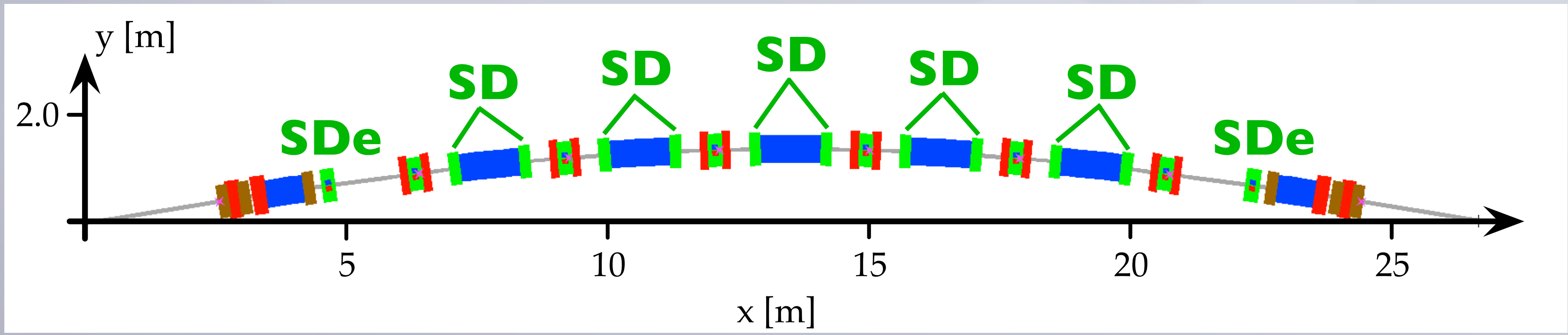

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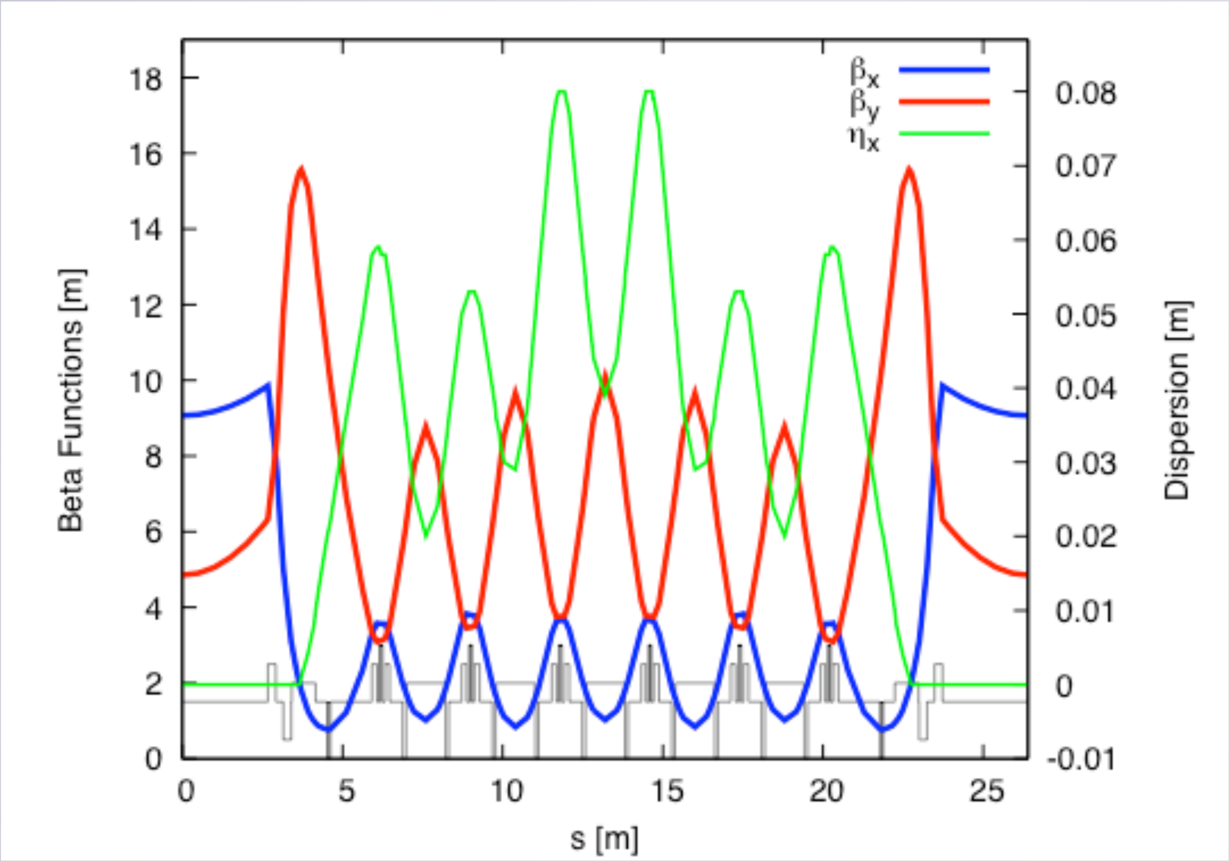
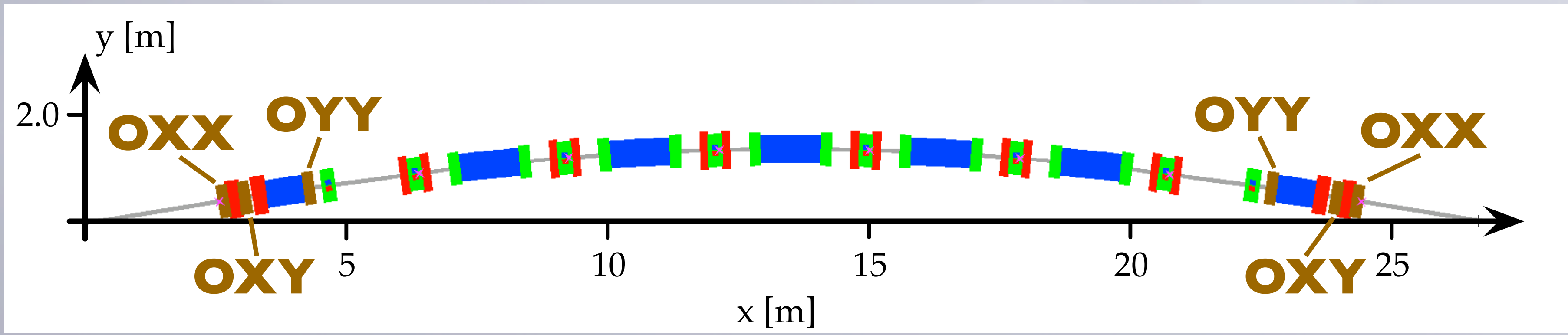
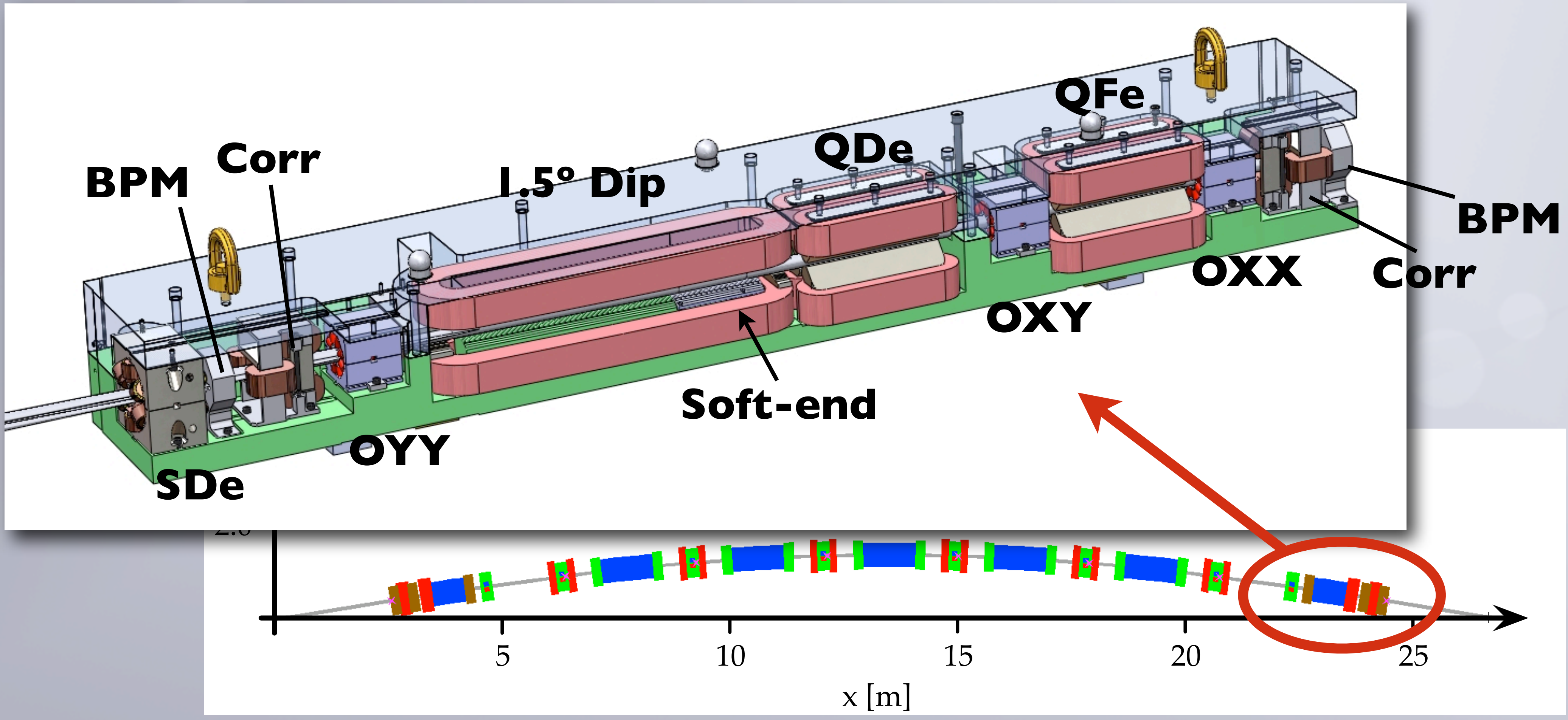




Integrated Magnet Design

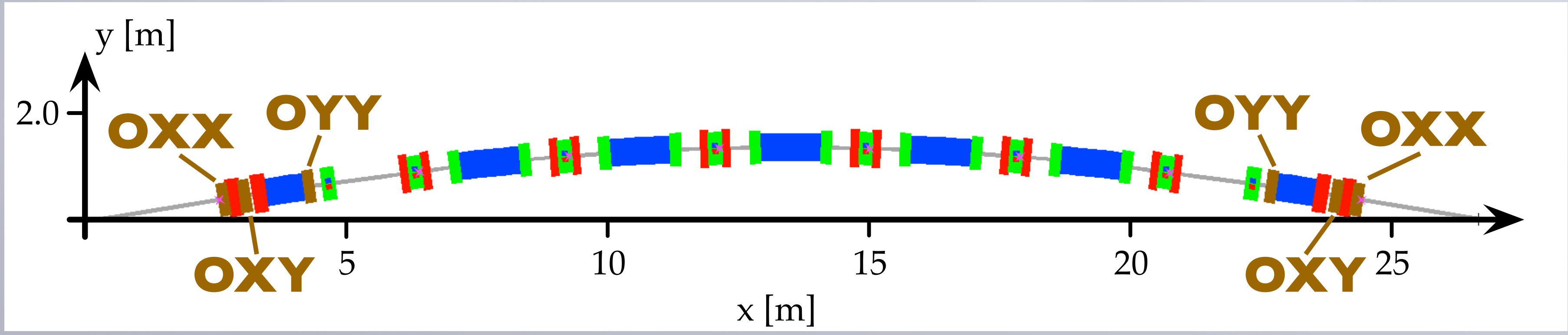
- Compact MBA optics → highly-integrated magnet design
- Each unit cell and matching cell is machined from two solid blocks of iron (demonstrated at MAX III → NIM A **601** (2009) 229)
- Machining precision → excellent alignment (small beam size → tolerances!)



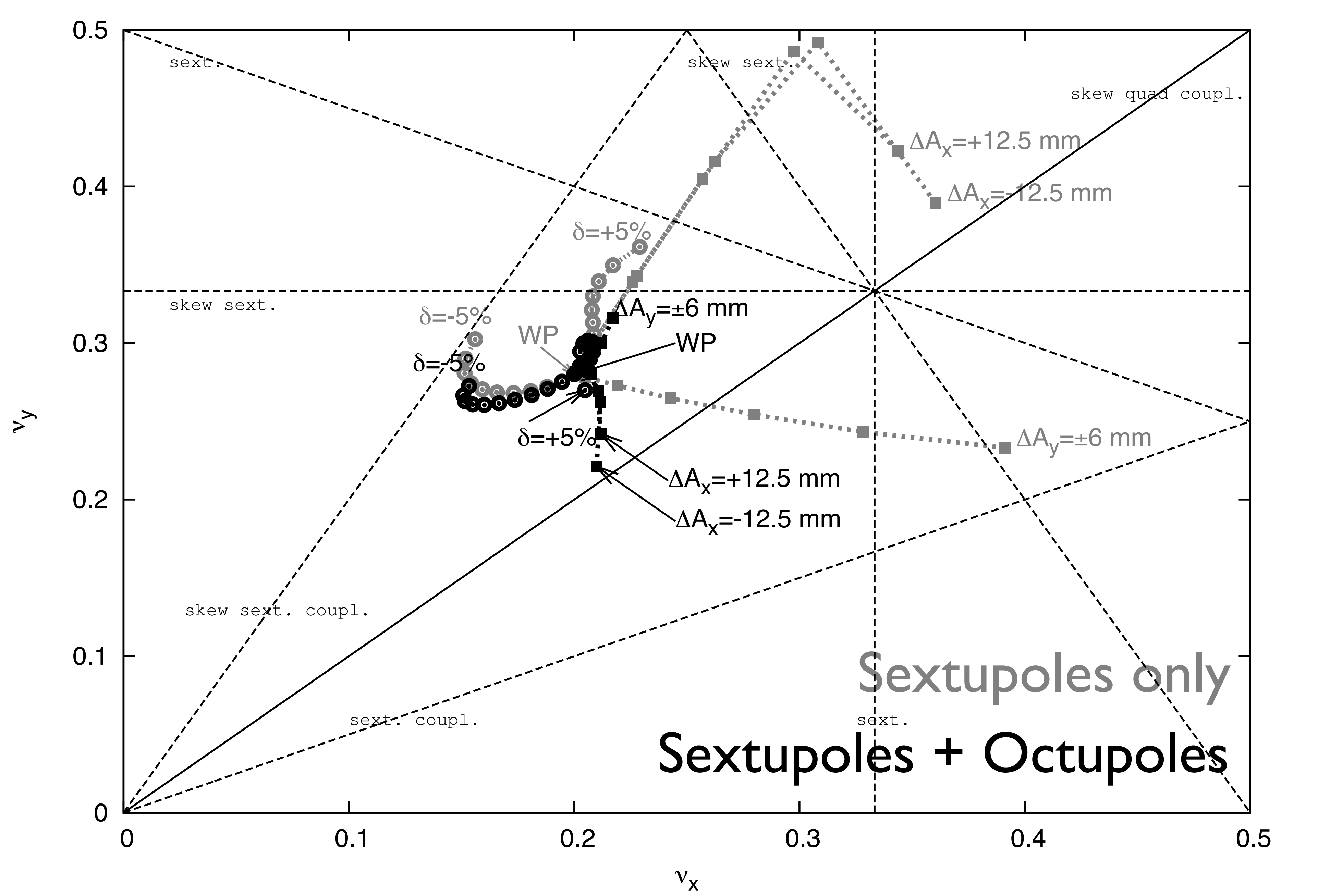
Octupole Strategy

- Large natural chromaticity + low dispersion → strong sextupoles
- Only 5 sextupole families, but many first-order sextupole driving terms
  - 2 linear chromaticities + 3 chromatic terms + 5 geometric terms
  - + second-order terms → ADTS, quadratic chromaticity, ... → tune footprint
- Not satisfied with DA and tune footprint even after extensive nonlin. optimization
- ADTS is second-order effect in sextupoles (→ weak correction)
- Instead:
  - Use sextupoles to minimize first-order driving terms and correct chromaticity
  - Use octupoles to correct ADTS (first-order effect!)

    → compact tune footprint

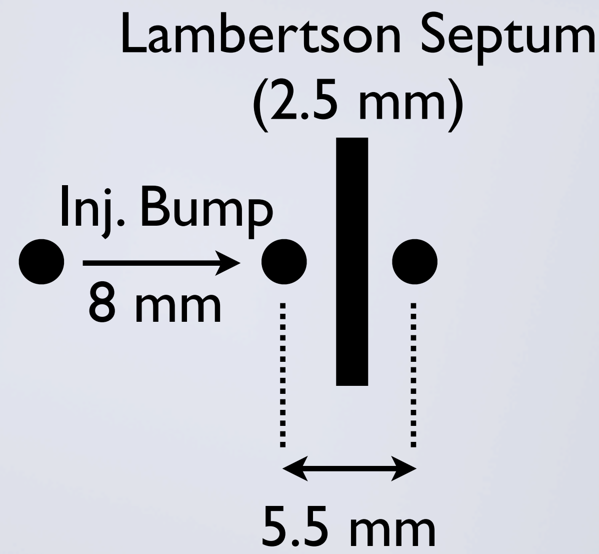


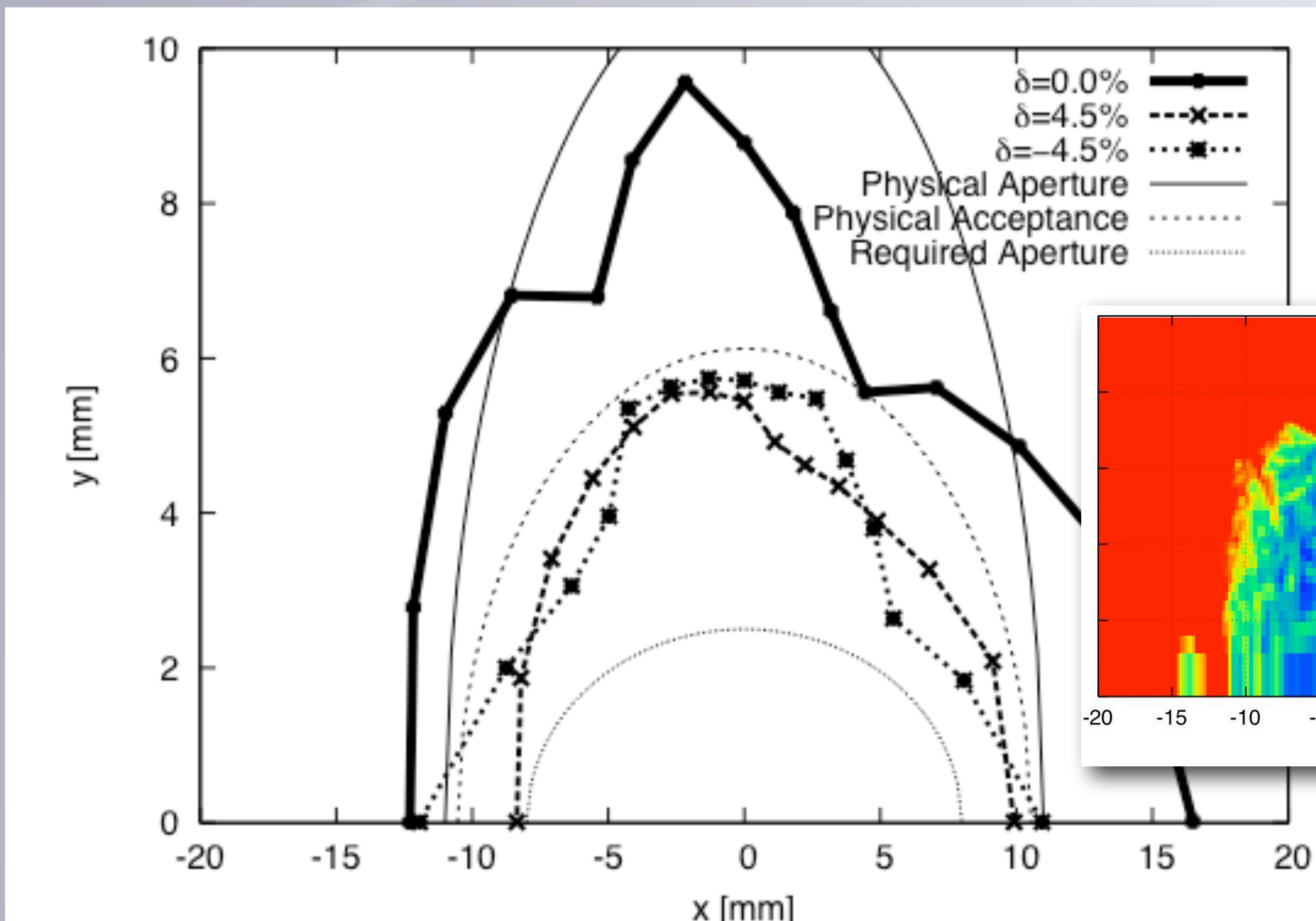
Tune Footprint with and without Octupoles

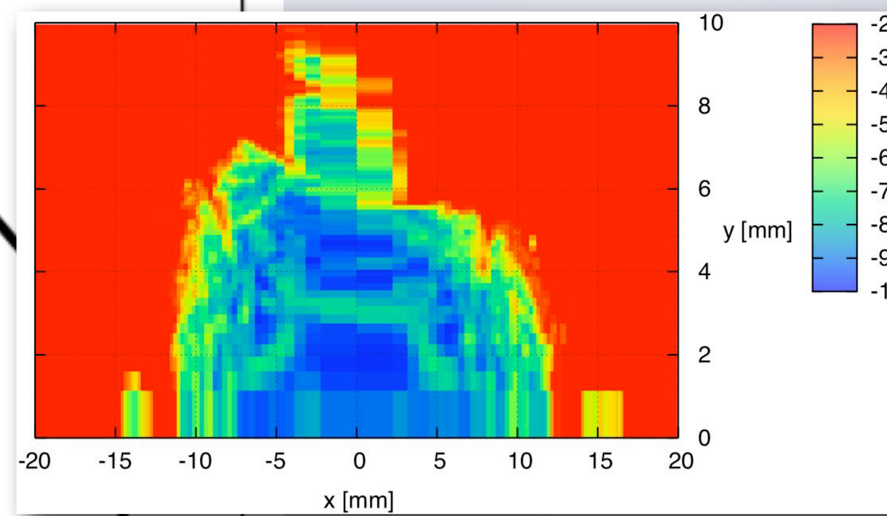


Dynamic Aperture

- Injection requirement: 8 mm (2.5 mm safety margin)
- Vertical: in-vac. IDs, 4 mm full-gap height
- Use octupoles to shape DA (commissioning!)



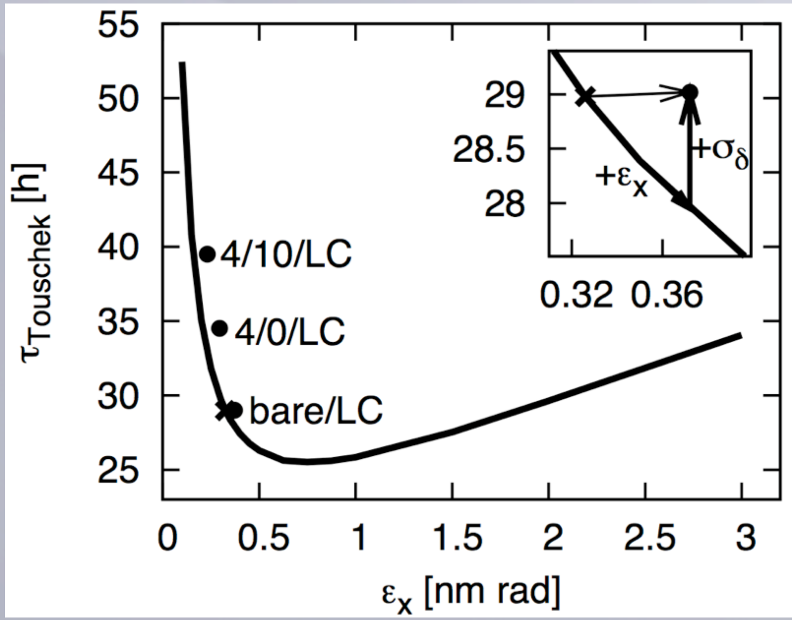


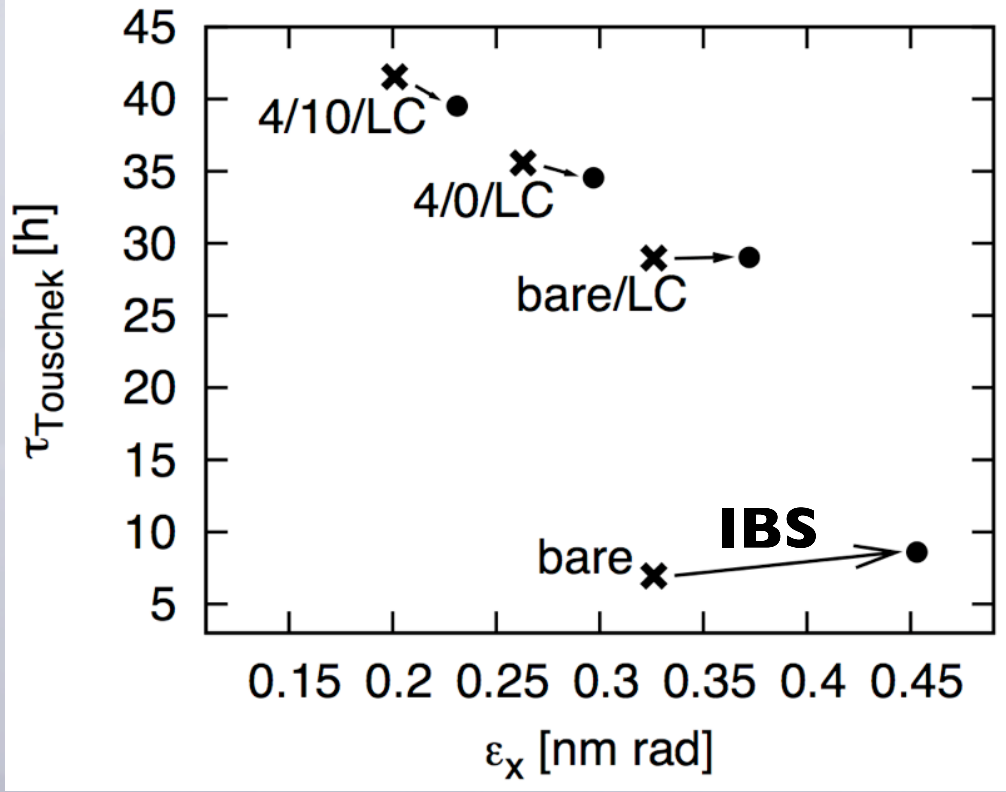


Emittance and IBS

- 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
- Landau Cavities → reduce effect of IBS & increase Touschek lifetime

	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





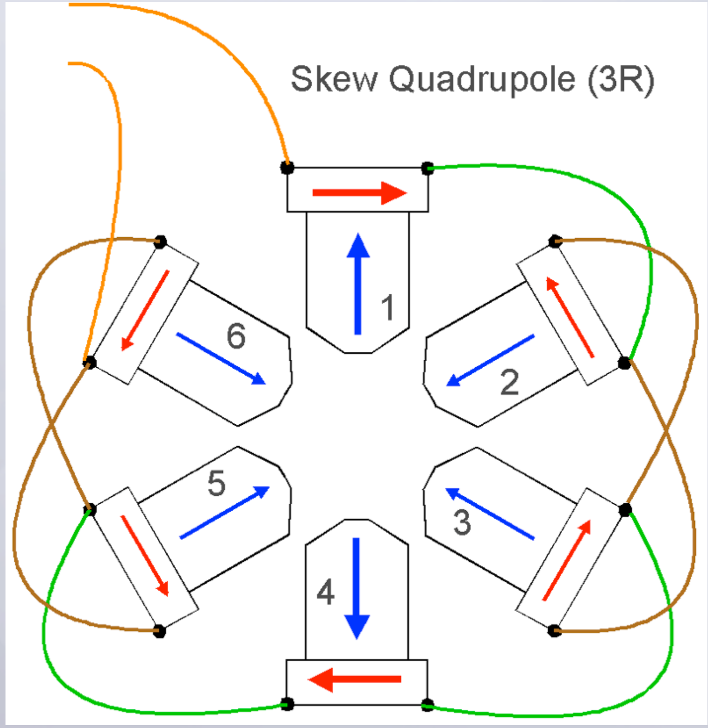
Coupling Control

- Diffraction limit 1Å → need ε_y = 8 pm rad → 2.7% coupling (feasible)
  - Beam-based BPM calibration to sextupole centers
  - Corrector-based realignment of magnet cells as demonstrated at MAX III (NIM A **597** (2008) 170)

    → minimize orbit offsets in sextupoles → low betatron coupling

- Reduce coupling even further → secondary windings on all sextupoles and octupoles
  - Nondispersive skew quads (on octupoles) to correct residual betatron coupling
  - Dispersive skew quads (on sextupoles) to drive vertical dispersion bumps within achromats

    → minimize vertical beam size in IDs without sacrificing lifetime



A. Streun (SLS)

- 0.2% coupling → ε_y = 0.6 pm rad → ≈ natural limit!