MAX IV 3 GeV Storage Ring

Accelerator Physics Issues

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Workshop on Diffraction Limited Storage Rings, SLAC, December 9-11, 2013

MAX IV

MAX IV Facility Overview

One size *does not* fit all! Instead, different sources to serve different users.

Short pulses:

- **3.5 GeV linac & SPF**
  100 Hz, ~30 fs,
  full-energy injector for rings
  FEL upgrade option

High average brightness:

- **1.5 GeV storage ring**
  DBA lattice, 6 nm rad,
  IR & UV users
- **3 GeV storage ring**
  MBA lattice, ~300 pm rad,
  x-ray users

MAX IV 3 GeV Storage Ring — Today vs. 2016

November 20, 2013

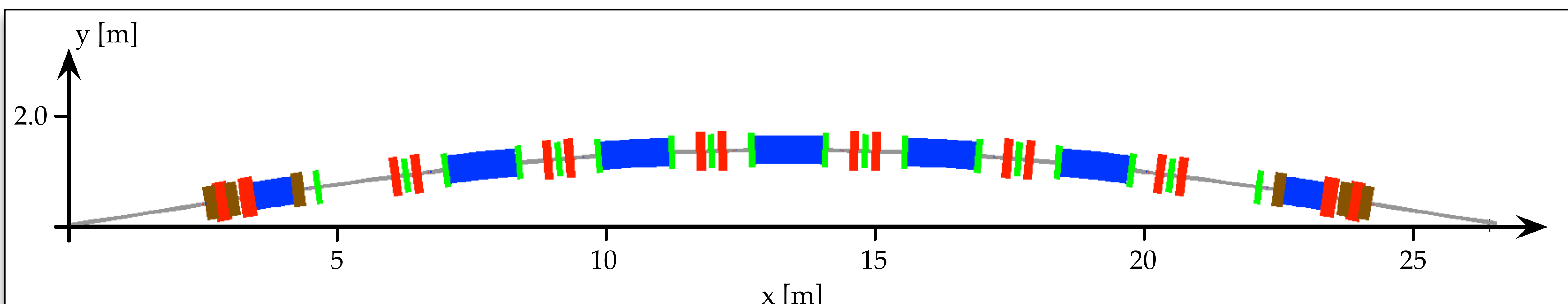
- Installation starts July 2014
- Commissioning starts July 2015
- Inauguration July 21, 2016, local noon

MAX IV 3 GeV Storage Ring is Based on a Multibend Achromat Lattice

- 3 GeV, 528 m circumference, 500 mA with top-up
- 20 achromats: 19 user straights (4.6 m), 40 short straights (1.3 m) for RF & diagnostics
- 7-bend achromat: 5 unit cells & 2 matching cells
- 320 pm rad bare lattice emittance (vertical emittance adjusted to 1 Å diffraction limit)

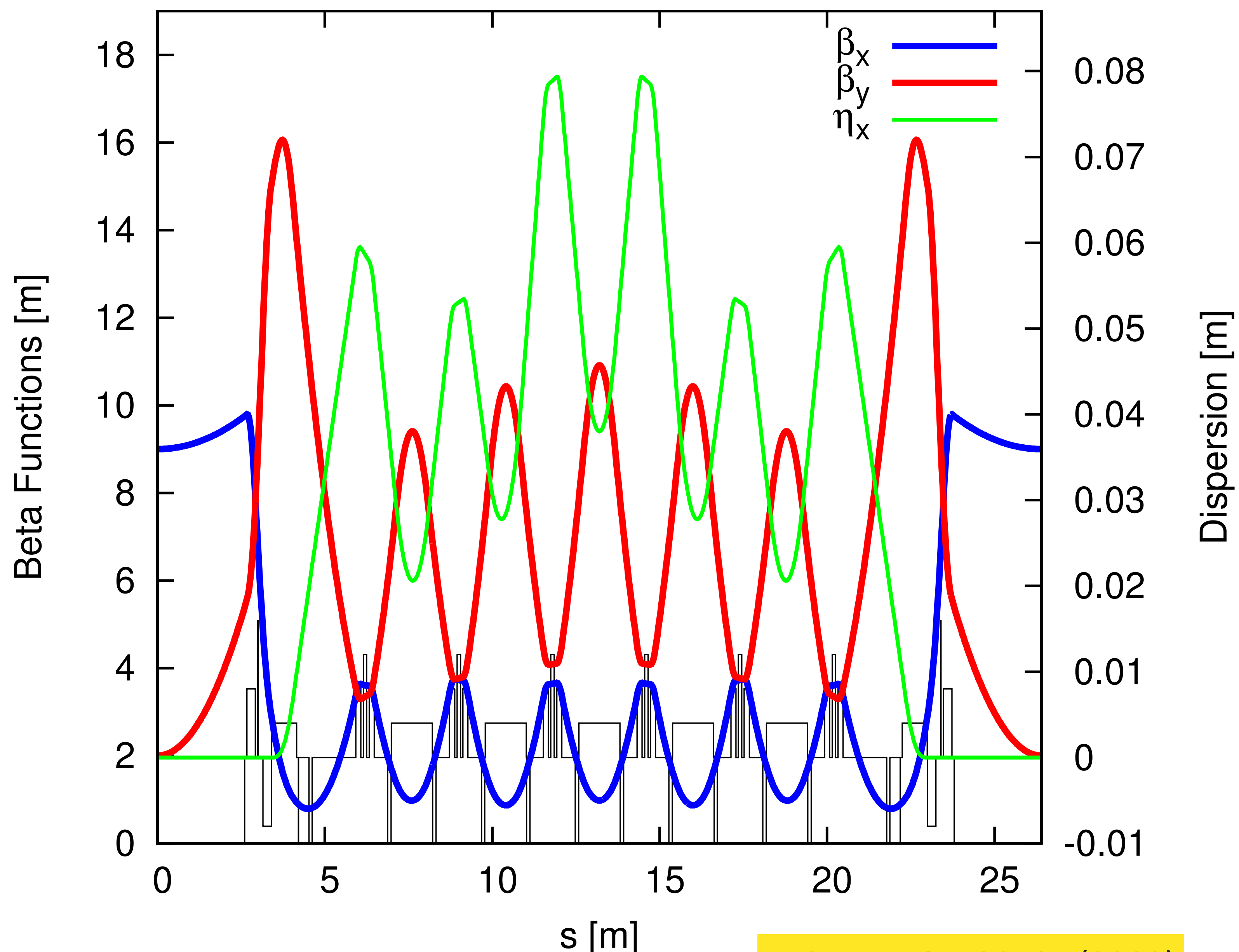
PRST-AB **12**, 120701 (2009)

IPAC'**11**, THPC059, p.3029



MAX IV 3 GeV Storage Ring is Based on a Multibend Achromat Lattice (cont.)

- Gradient dipoles flanked by sextupole pairs
- Sextupole insertions in focusing quadrupoles
- Dedicated octupoles
- 8 cm peak dispersion
- $\nu_x = 42.20$, $\nu_y = 16.28$
  $\beta_x^* = 9$ m, $\beta_y^* = 2$ m
- $\sigma_x^* = 54$ µm
  $\sigma_y^* = 2\text{-}4$ µm

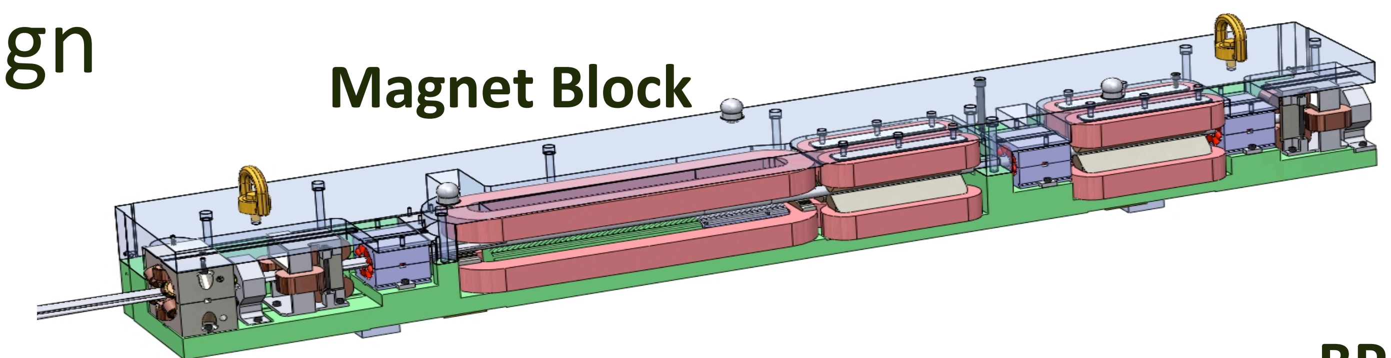


PRST-AB **12**, 120701 (2009)

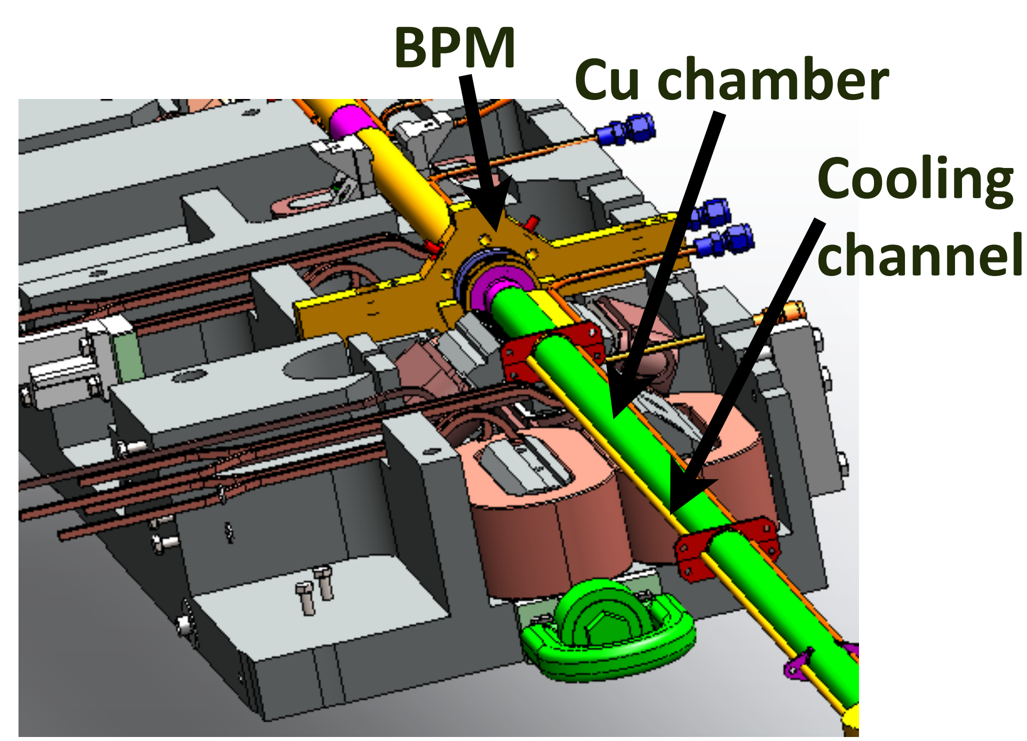
IPAC'**11**, THPC059, p.3029

Making a MBA lattice work

- Compact, strong focusing optics → tightly spaced short magnets with small bore → combined-function, integrated magnet design



- Small magnet bore, short gaps between magnets → narrow chambers without space for lumped absorbers → NEG-coated Cu with cooling channel



➡ See presentations on magnet and vacuum technology

Making a MBA lattice work (cont.)

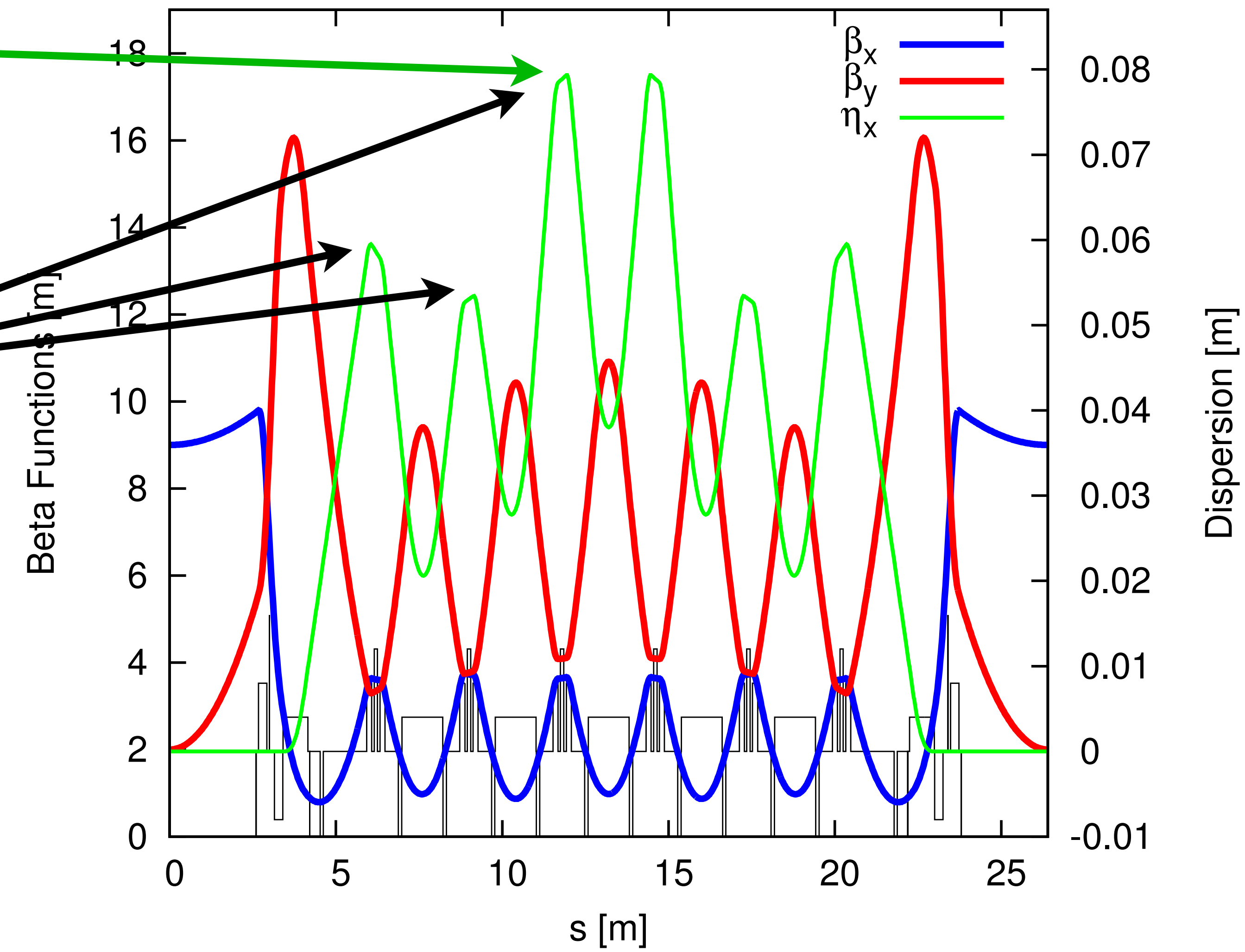
- Strong focusing & weak bends ➔ low dispersion ➔ strong chromatic sextupoles ➔ intricate nonlinear optics for large DA and MA (needs to remain stable under influence of IDs and errors!)

Peak dispersion 8 cm

Putting sextupoles here allows avoiding dispersion bump (would spoil MA or increase aperture requirements)

↓

Sextupole insertions in focusing quadrupoles

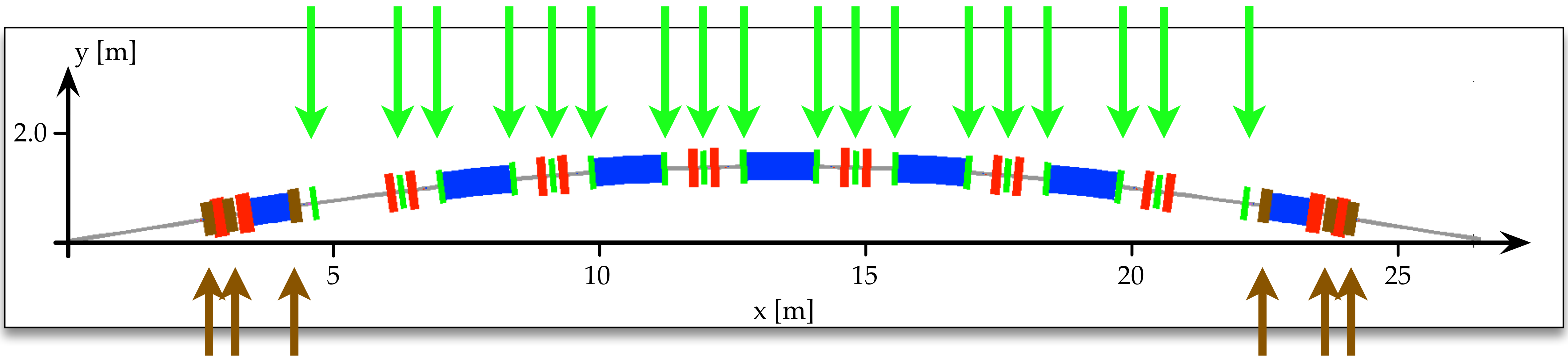


Making a MBA lattice work (cont.)

- Many strong chromatic sextupoles ➔ correct linear chromaticity and tailor its higher orders ➔ use additional sextupoles to minimize first-order RDTs (low because of choice of phase advance ≈ 2π×2, 2π×3/4)

PRST-AB **12**, 120701 (2009)

PRST-AB **14**, 030701 (2011)

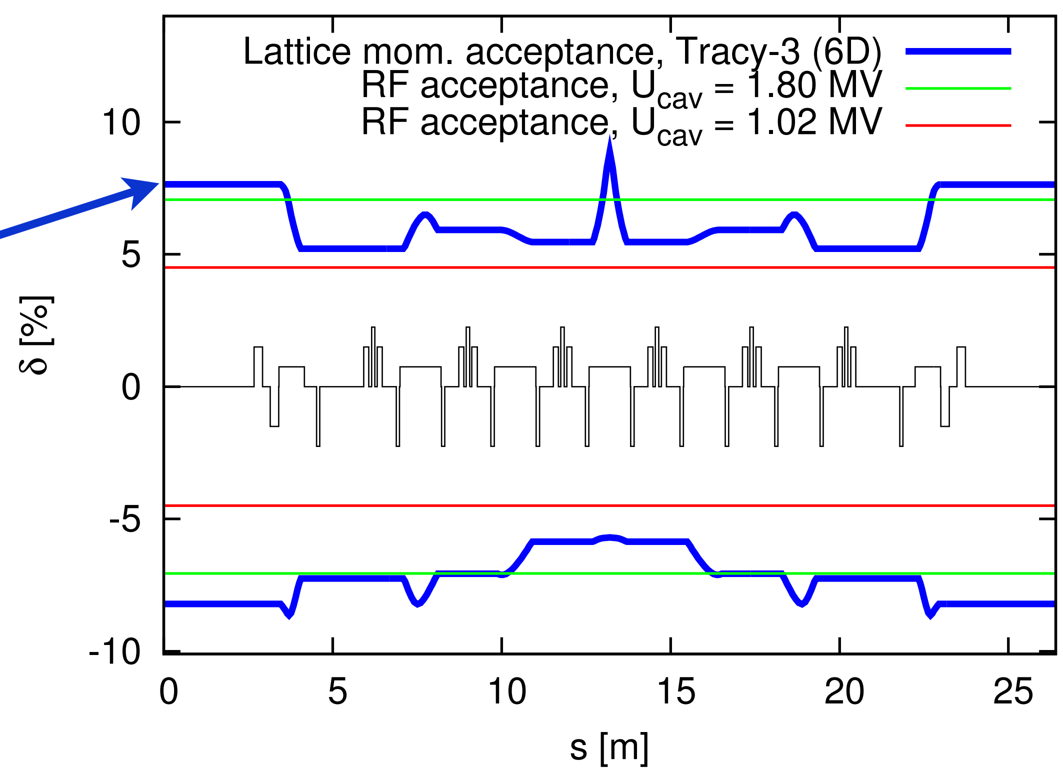


- Use achromatic octupoles to efficiently tailor ADTS to first order ➔ minimize tune footprint

Resulting Performance

- Overall tune footprint becomes very compact both on and off momentum
  - ➡ Large on-momentum DA ensures good injection efficiency (see presentation on injection)
  - ➡ Large off-momentum DA ensures good lattice MA
- MA and DA stable under influence of imperfections and ID’s

Lattice MA always beyond 5%

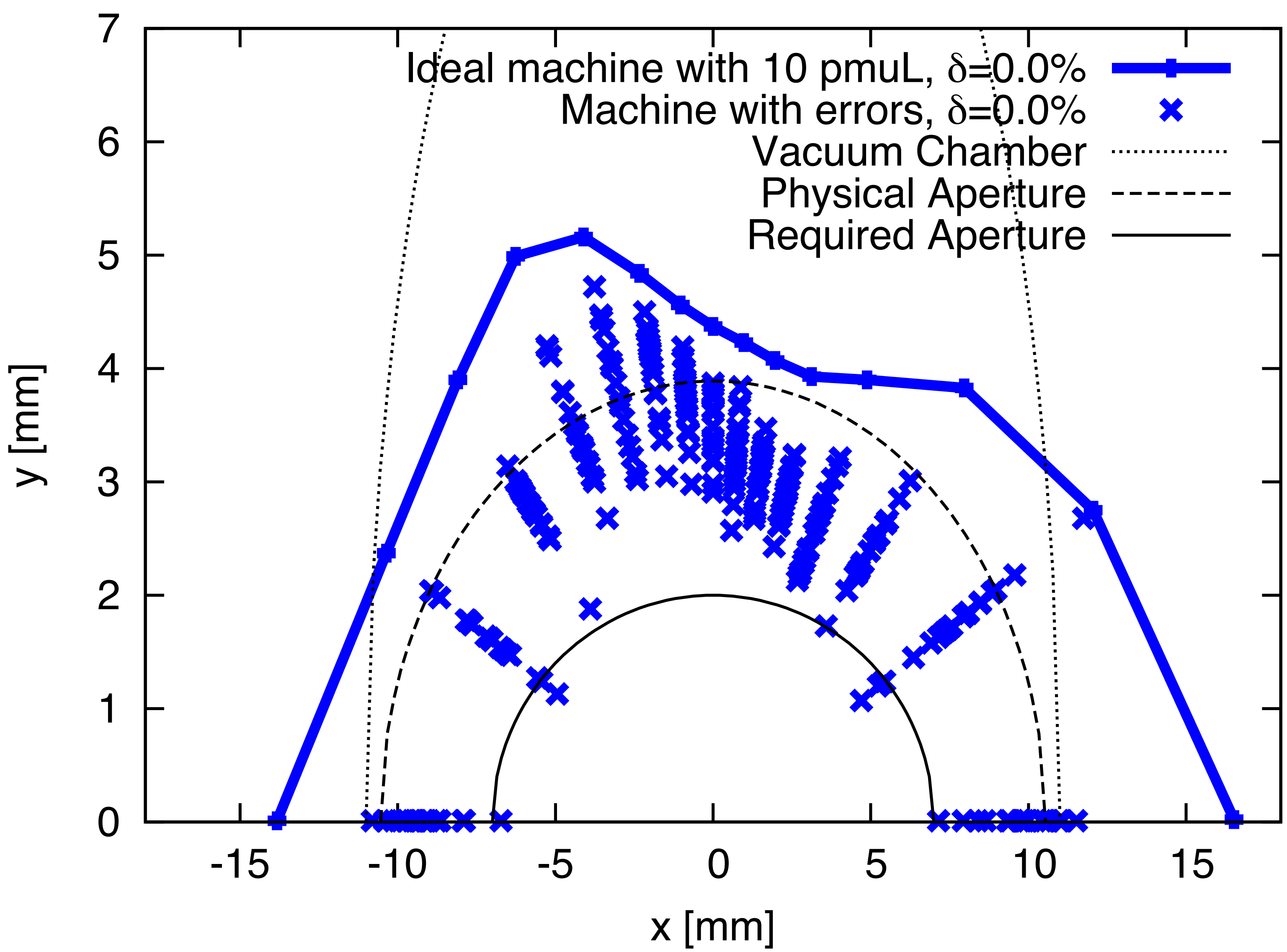


PRST-AB **12**, 120701 (2009)

PRST-AB **14**, 030701 (2011)

Resulting Performance (cont.)

- Example: 10 in-vac. undulators, gaps fully closed, ring optics matched, magnet and alignment errors included (20 seeds)



- IVU "pmuL": 3.7 m long, 1.1 T peak field, 18.5 mm period, 4.2 mm gap
- Misalignments:
  - 50 μm rms H/V, 0.2 mrad rms roll } for each magnet block
  - 25 μm rms H/V, 0.2 mrad rms roll } for all magnets within
- Field Errors: 0.05% rms within each family
- Multipole Errors: Upright and skew multipoles added

PAC'**11**, TUP235, p.1262

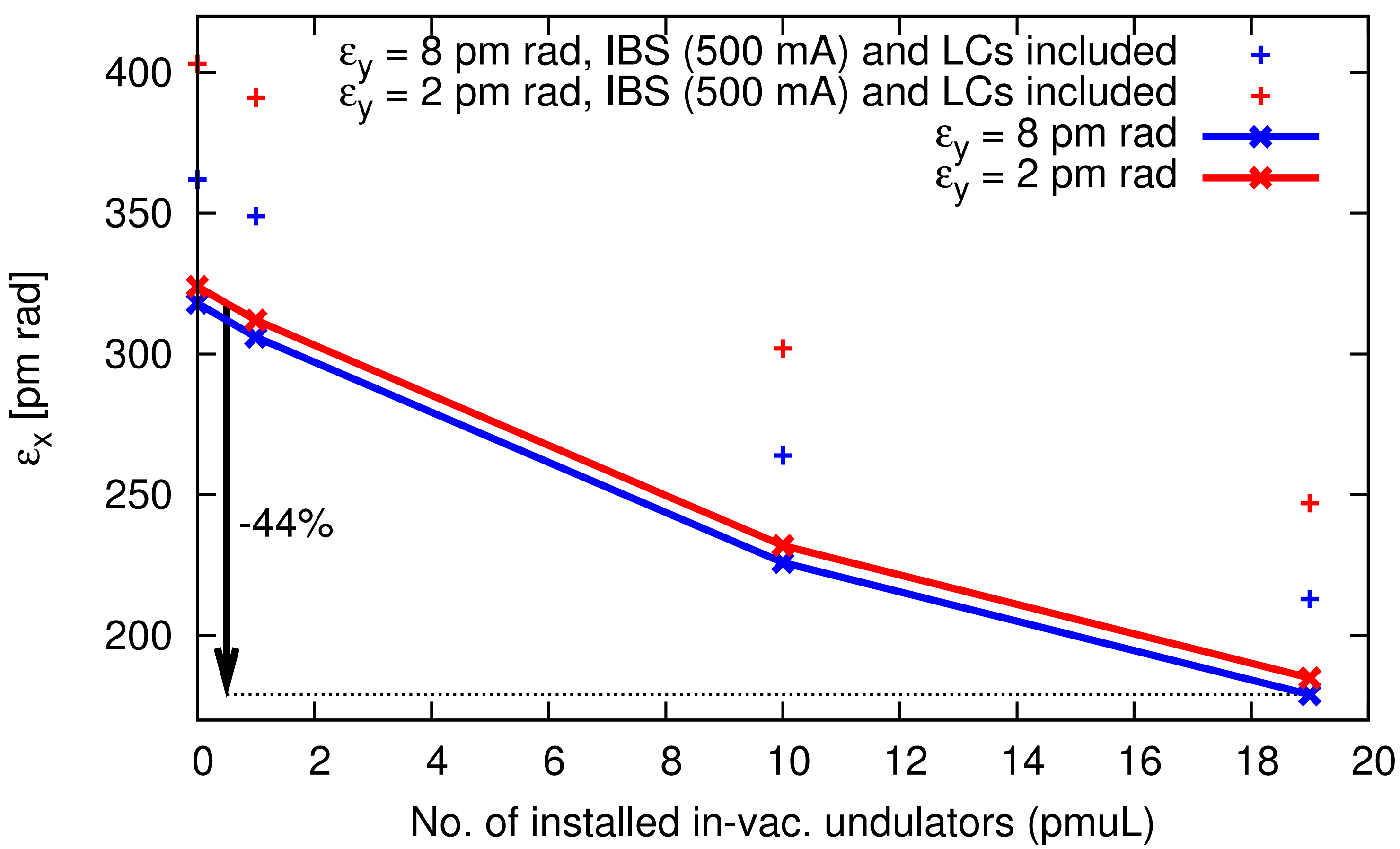
Resulting Performance (cont.)

- Together with 100 MHz RF system this ensures good beam lifetime
  - for 5% MA: 1.1 MV (100 MHz system) vs. 3.7 MV (500 MHz system) → significant reduction of Cu losses
  - 100 MHz system is inexpensive (don't need klystrons!)
  - 100 MHz system generates long bunches (11.3 mm vs. 2.7 mm) with large separation (3 m vs. 0.6 m) → mitigates collective effects
- Large MA and long bunches give excellent Touschek lifetime
  - LC's (3rd harm.) → $\sigma_s \approx 50$ mm → Touschek >25 h → >10 h overall
- Ample skew quadrupole windings allow brightness optimization via adjustment of emittance coupling

PAC'**13**, MOPHO05

A few interesting properties of ultralow-emittance rings

- Emittance varies during user operation
  - low radiated power from dipoles
  - equilibrium emittance determined by ID's and their gap settings
  - ➡ are damping wigglers required to hold emittance constant?

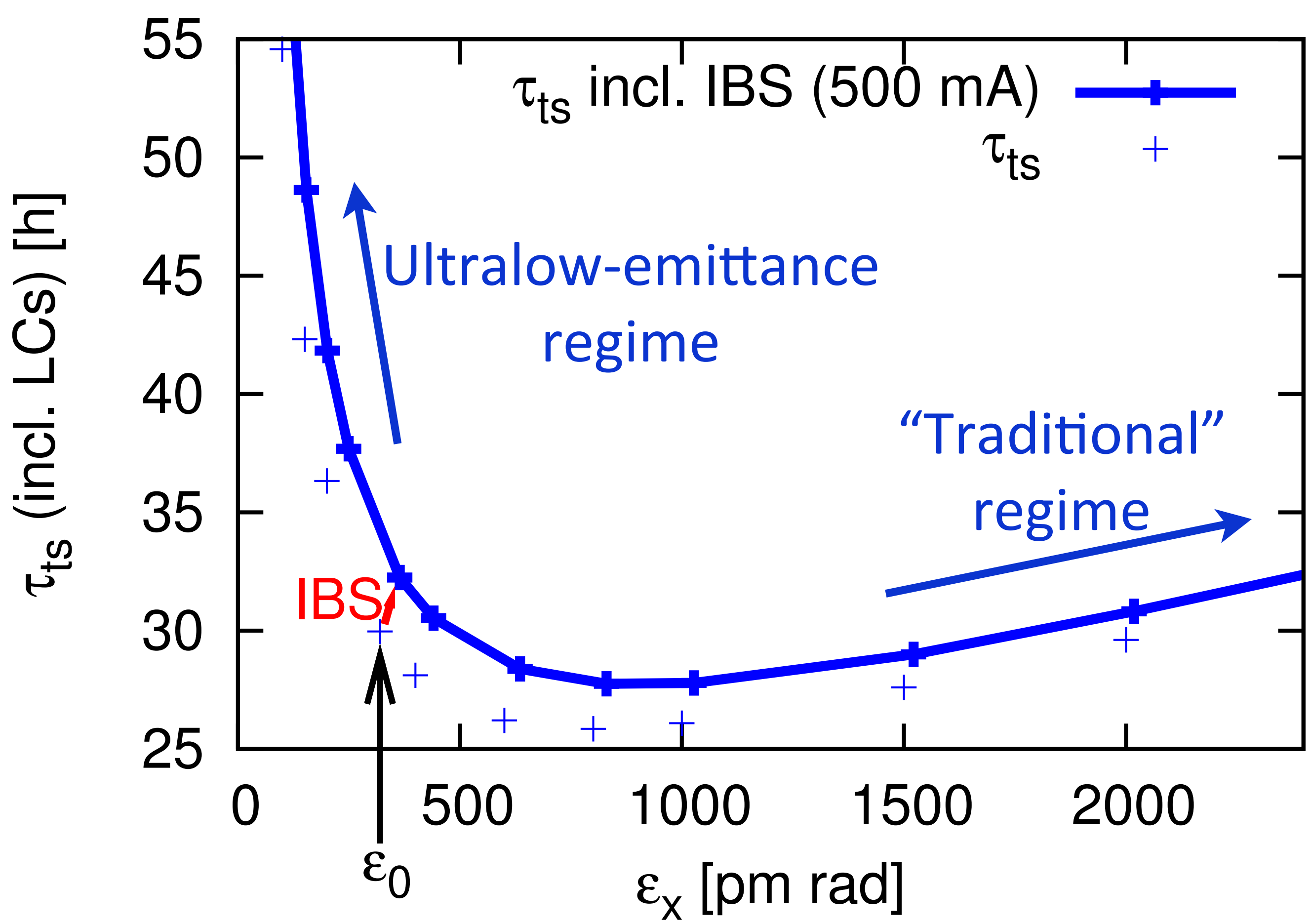


A few interesting properties of ultralow-emittance rings (cont.)

- Reducing the transverse emittance (DW's and/or user ID's) increases Touschek lifetime

➡ Add more DW's and ID's to get lower emittance and better lifetime?

  - Requires lots of RF power
  - Inefficient? Will overall photon brightness increase as energy spread increases with additional radiated power?



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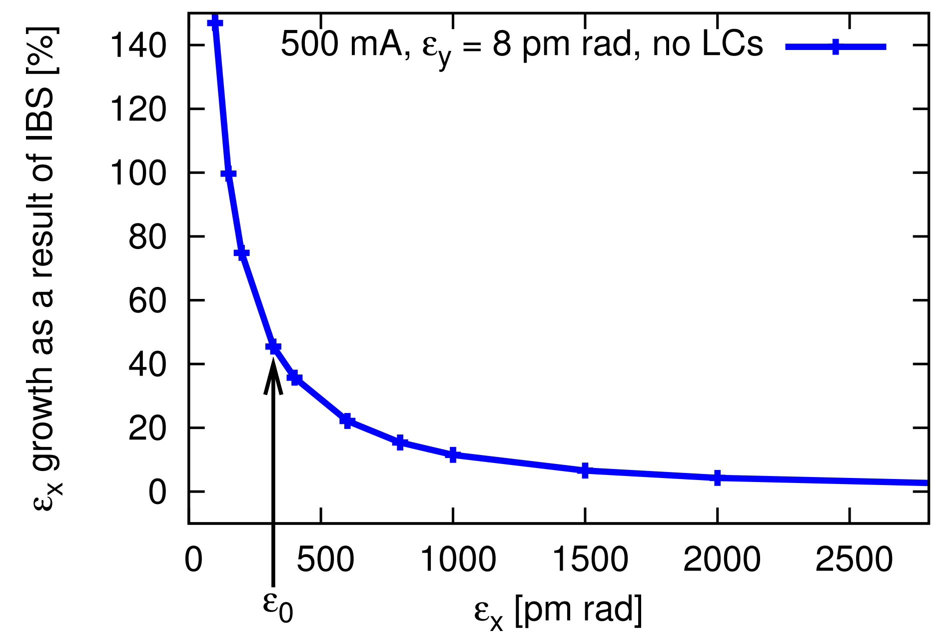

- IBS is very strong at high current
  - Raise energy?
    (6 GeV in ESRF Upgrade, SPring8-II, APS Upgrade)
  - IBS blows up beam's 6D emittance
    - good for lifetime, bad for brightness (transverse emittance, energy spread)
    - compounded by low emittance coupling ➔ round beams in DLSR's?
  - Trade-off: stored current vs. acceptable emittance increase

A few interesting properties of ultralow-emittance rings (cont.)

- IBS is very strong at high
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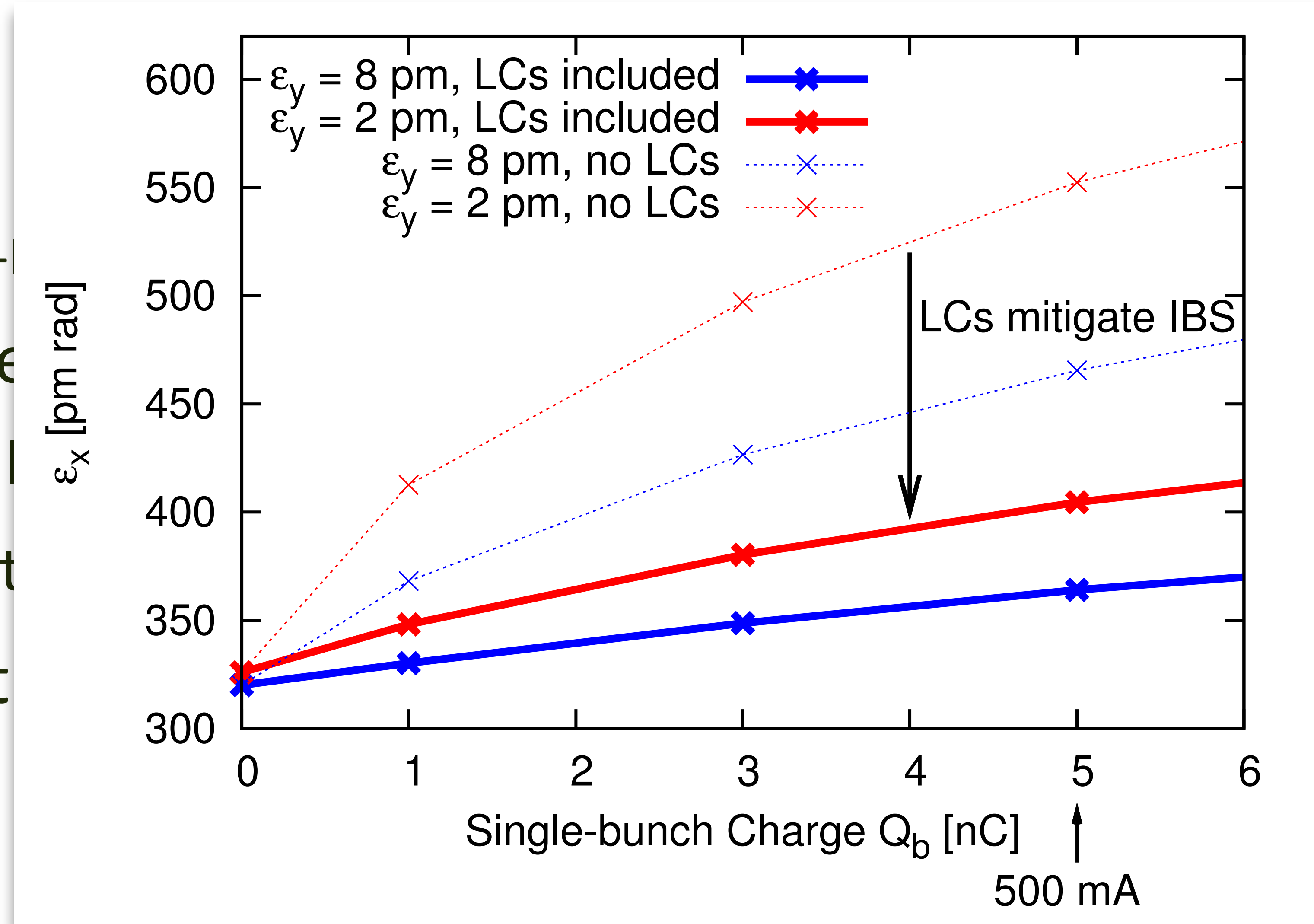
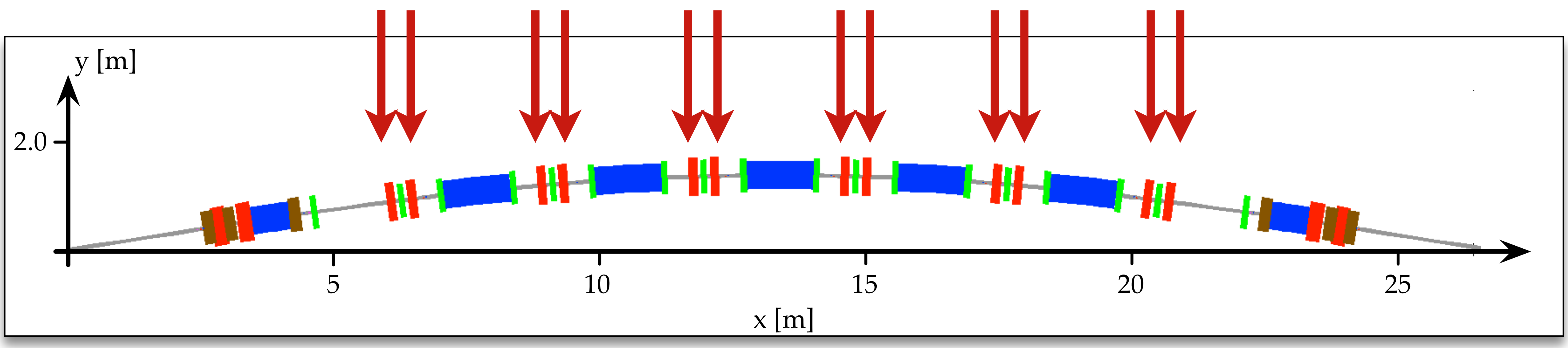


➡ Alternative: increase longitudinal emittance
  - DW's increase energy spread (brightness issue)
  - LC's increase bunch length → MAX IV choice (since we have dedicated SPF)

Latest Developments

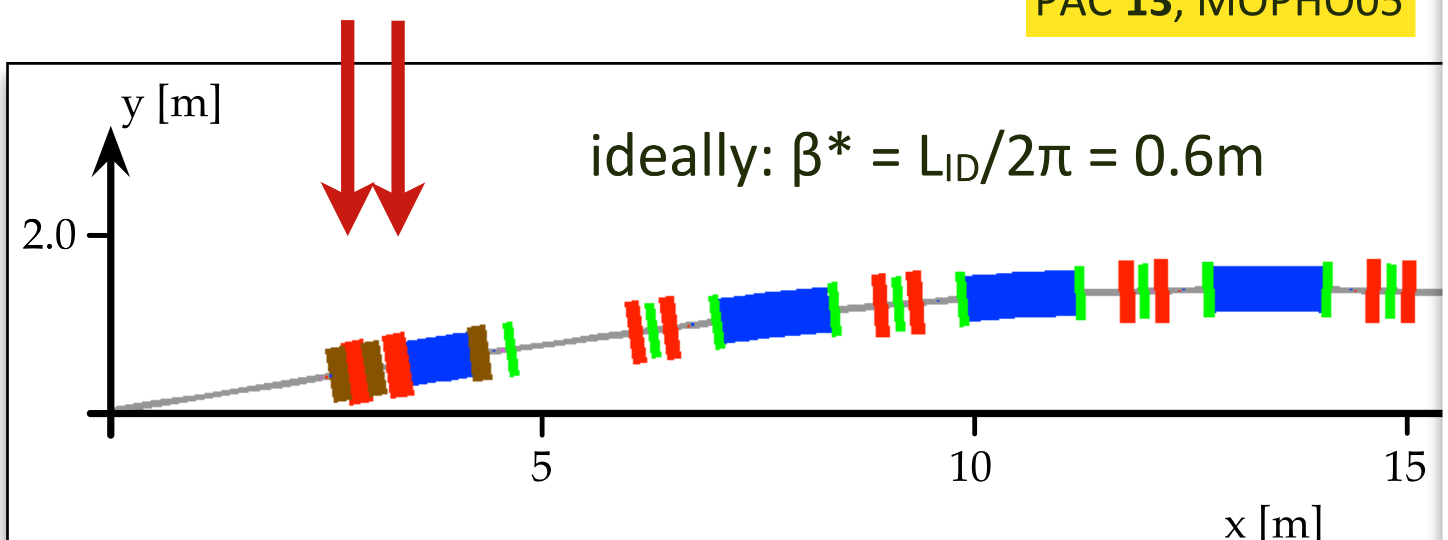
- Improve optics without requiring new magnets or PS's
- Adjust focusing quads in arc & doublets in straights
  - Increase horizontal focusing to lower emittance: 328 → 270 pm rad

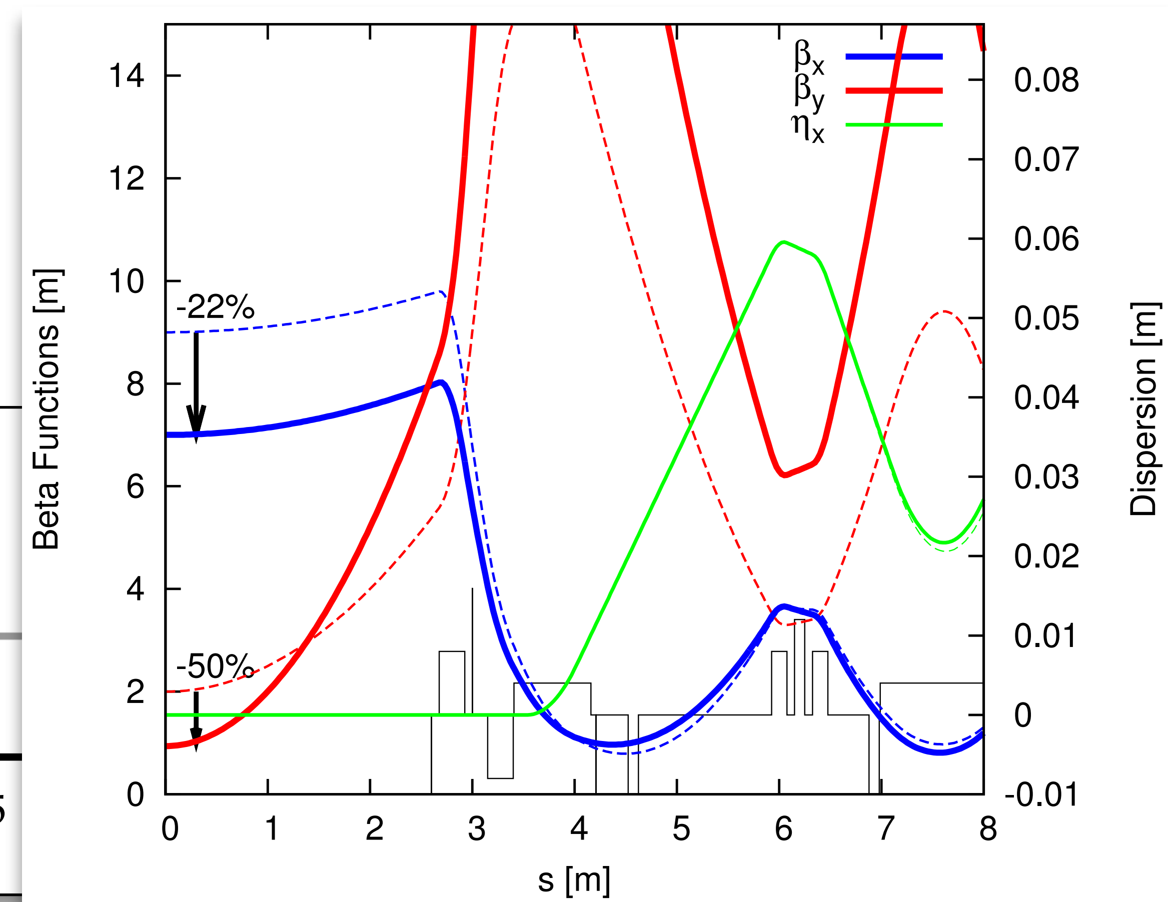


Latest Developments (cont.)

- Improve optics without requiring new magnets or PS's
- Adjust focusing quads in arc & doublets in straights
  - Increase horizontal focusing to lower emittance: 328 → 270 pm rad
  - Decrease $\beta_{x,y}$ in straights to better match intrinsic photon beam
    - ν_x = 42.2 → 44.2, ν_y = 16.28 → 14.28
    - β_y*= 2 m → 1 m, β_x*= 9 m → 7 m
      (should still be sufficient for injection)

PAC'**13**, MOPHO05





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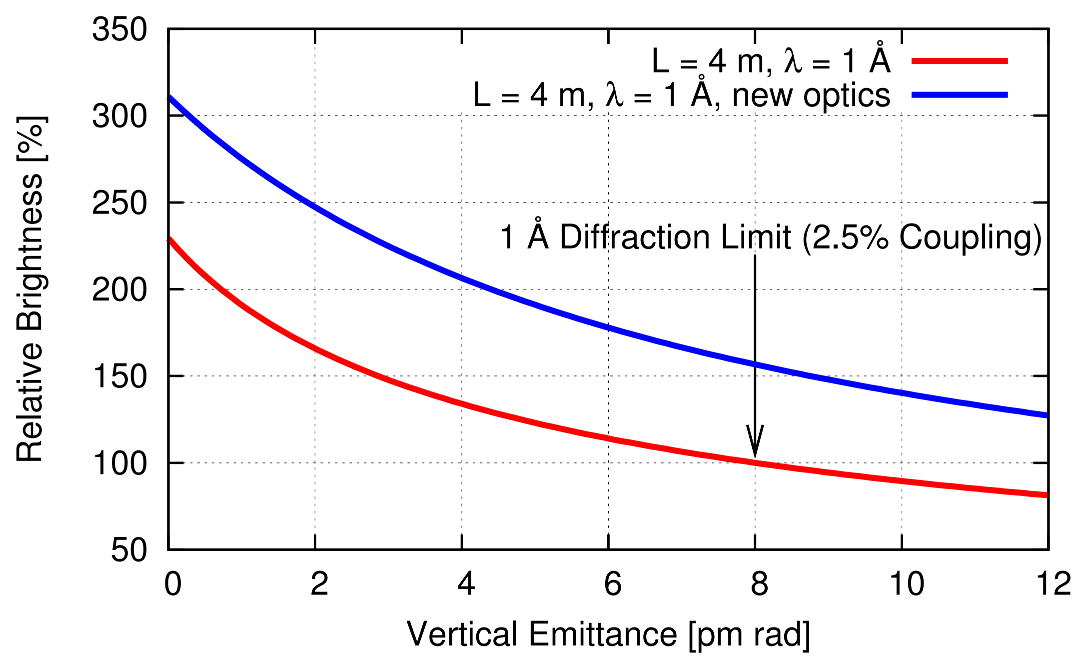

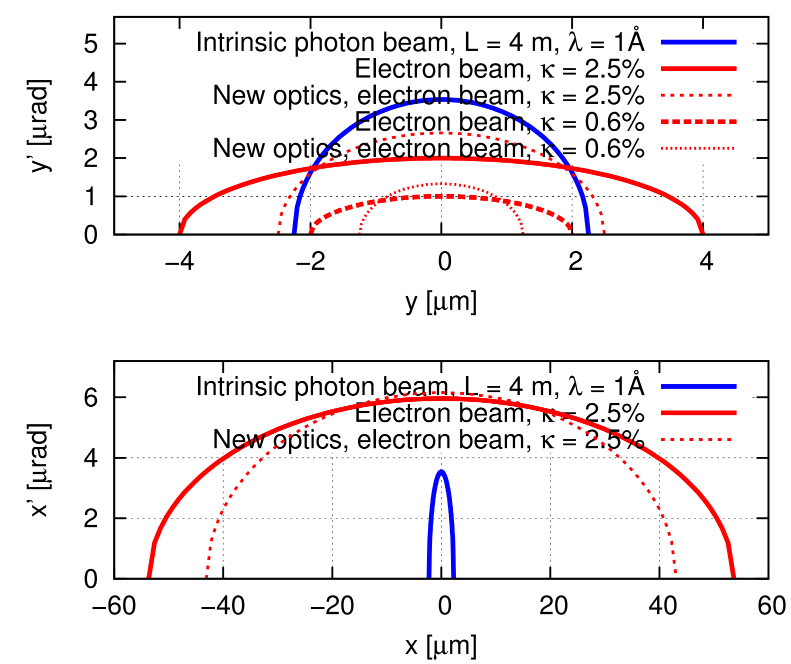

➡ Emittance reduced by ≈ 18% but brightness at 1 Å increases by ≈ 50% (because of improved matching)

Latest Developments (cont.)

- Under influence of DW's and/or user ID's emittance is expected to be lowered to
  - either ≈ 200 pm rad at 500 mA stored beam
  - or ≈ 150 pm rad by reducing stored beam current to 100 mA
- This should further increase brightness, but can we reach factor 2 overall compared to baseline design?
- Worry about energy spread increase when radiating lots of power in DW's or user ID's
  - Fortunately, IBS blows up longitudinal emittance
  - Can energy spread blow-up be mitigated via bunch lengthening? Ongoing work...