



# MAX IV 3 GeV Storage Ring

## Accelerator Physics Issues

# 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,  $\sim 30$  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,  $\sim 300$  pm rad,  
x-ray users

# MAX IV 3 GeV Storage Ring — Today vs. 2016

November 20, 2013



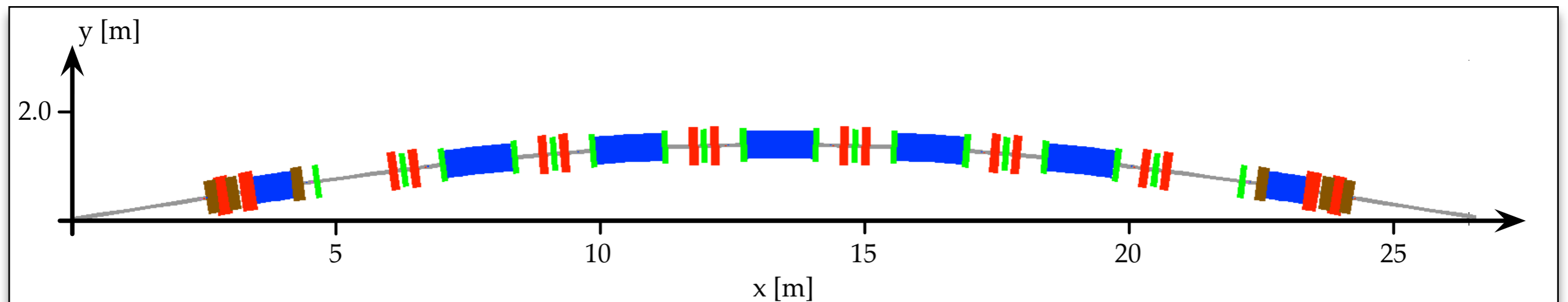
- Installation starts July 2014
- Commissioning starts July 2015
- Inauguration July 21, 2016, local noon

# 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)

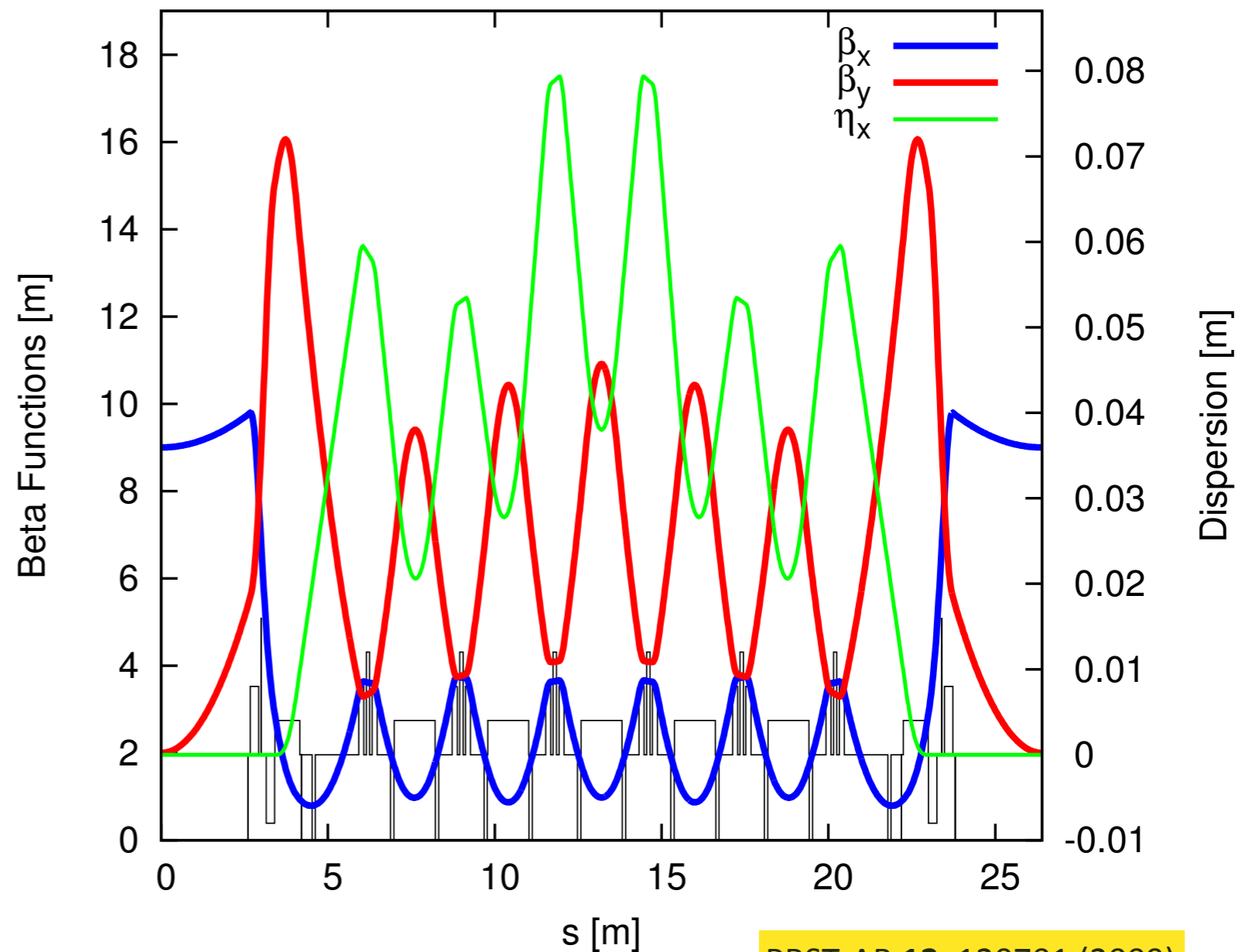
PRST-AB 12, 120701 (2009)

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
- $\sigma_x^* = 54$   $\mu\text{m}$   
 $\sigma_y^* = 2\text{-}4$   $\mu\text{m}$

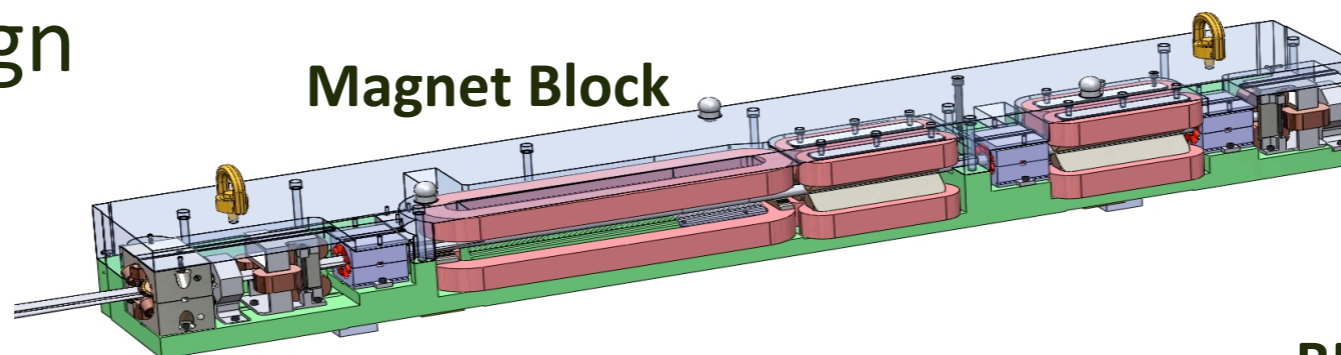


PRST-AB 12, 120701 (2009)

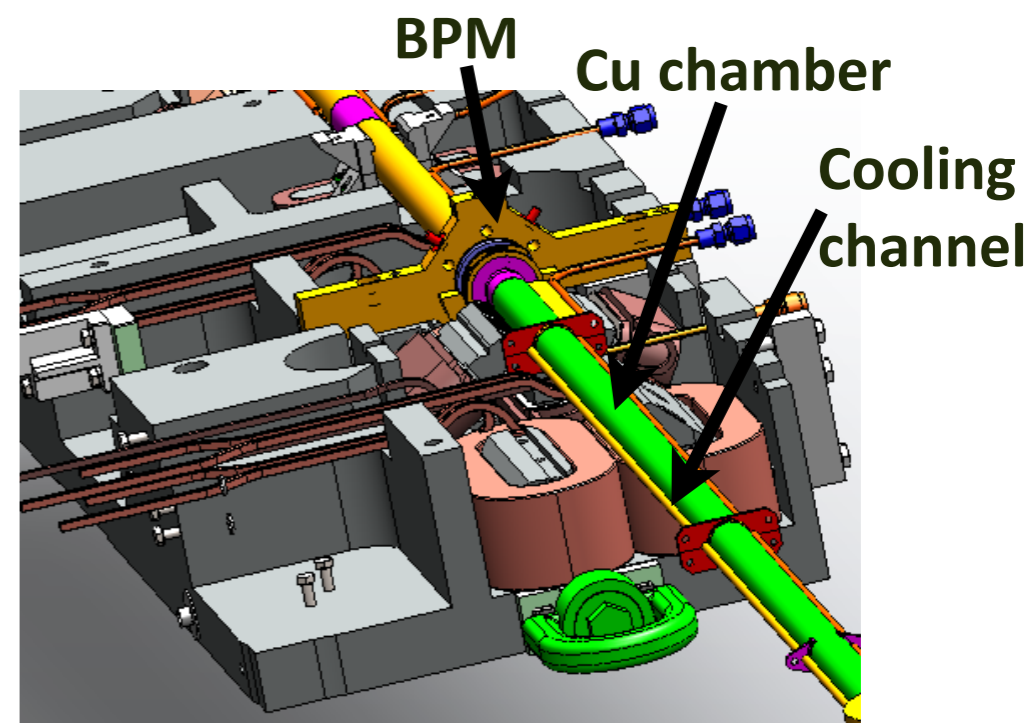
IPAC'11, THPC059, p.3029

# Making a MBA lattice work

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



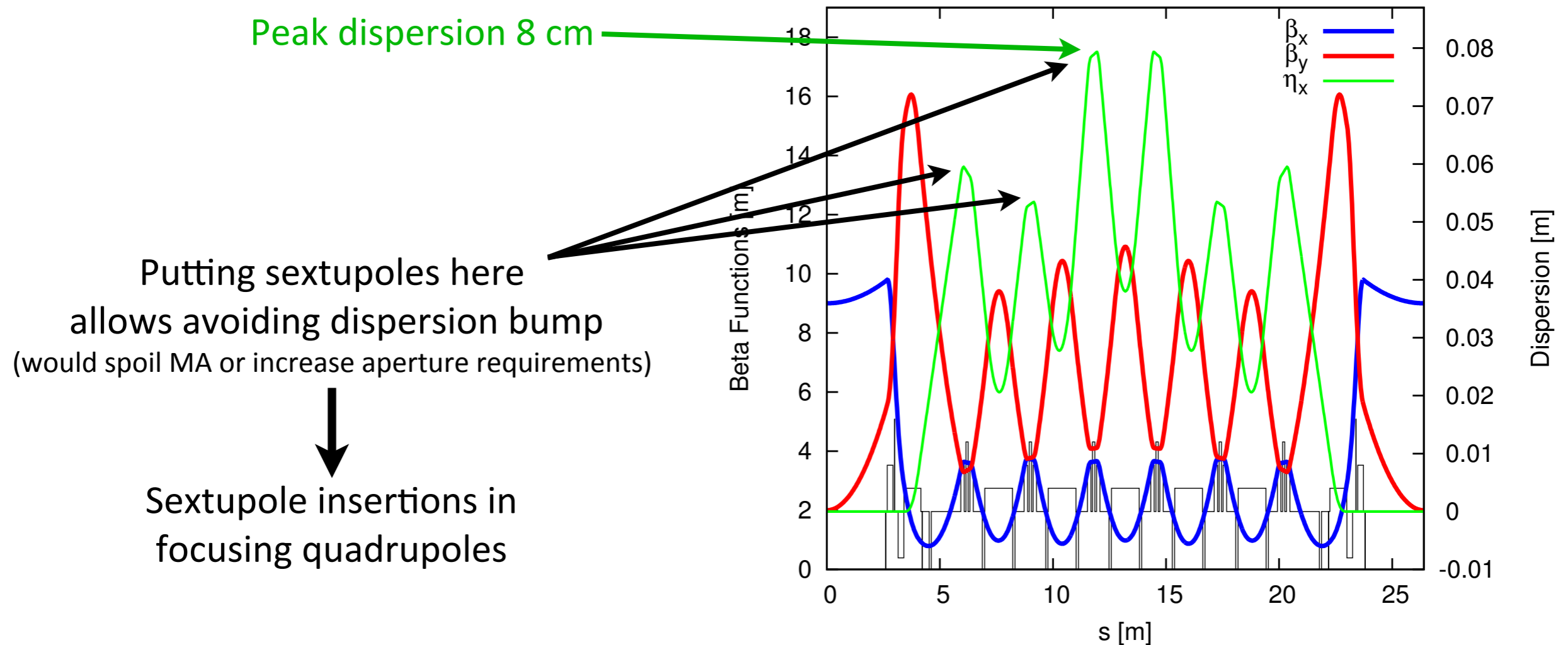
- Small magnet bore, short gaps between magnets → narrow chambers without space for lumped absorbers → NEG-coated Cu with cooling channel



➔ See presentations on magnet and vacuum technology

# Making a MBA lattice work (cont.)

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

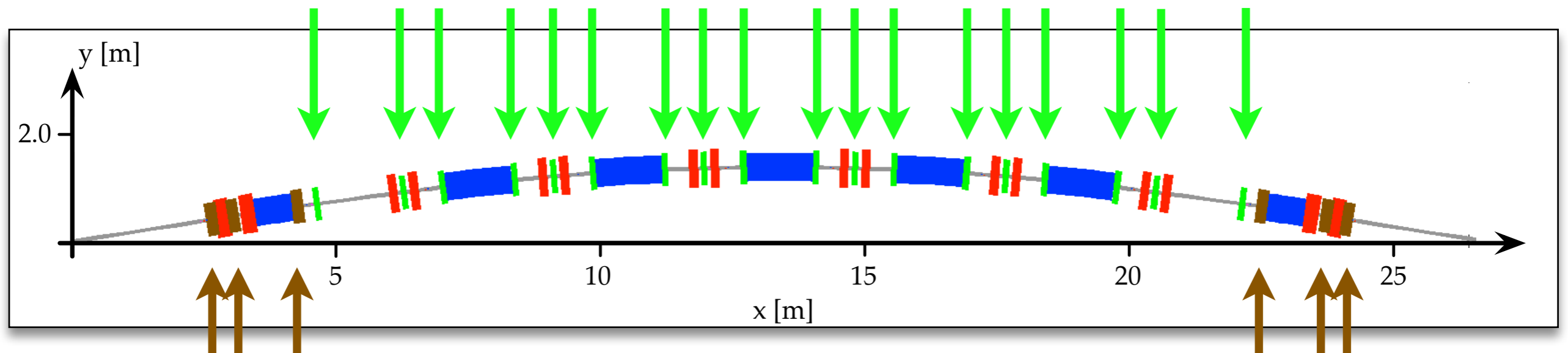


# Making a MBA lattice work (cont.)

- 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  $\approx 2\pi \times 2, 2\pi \times 3/4$ )

PRST-AB 12, 120701 (2009)

PRST-AB 14, 030701 (2011)

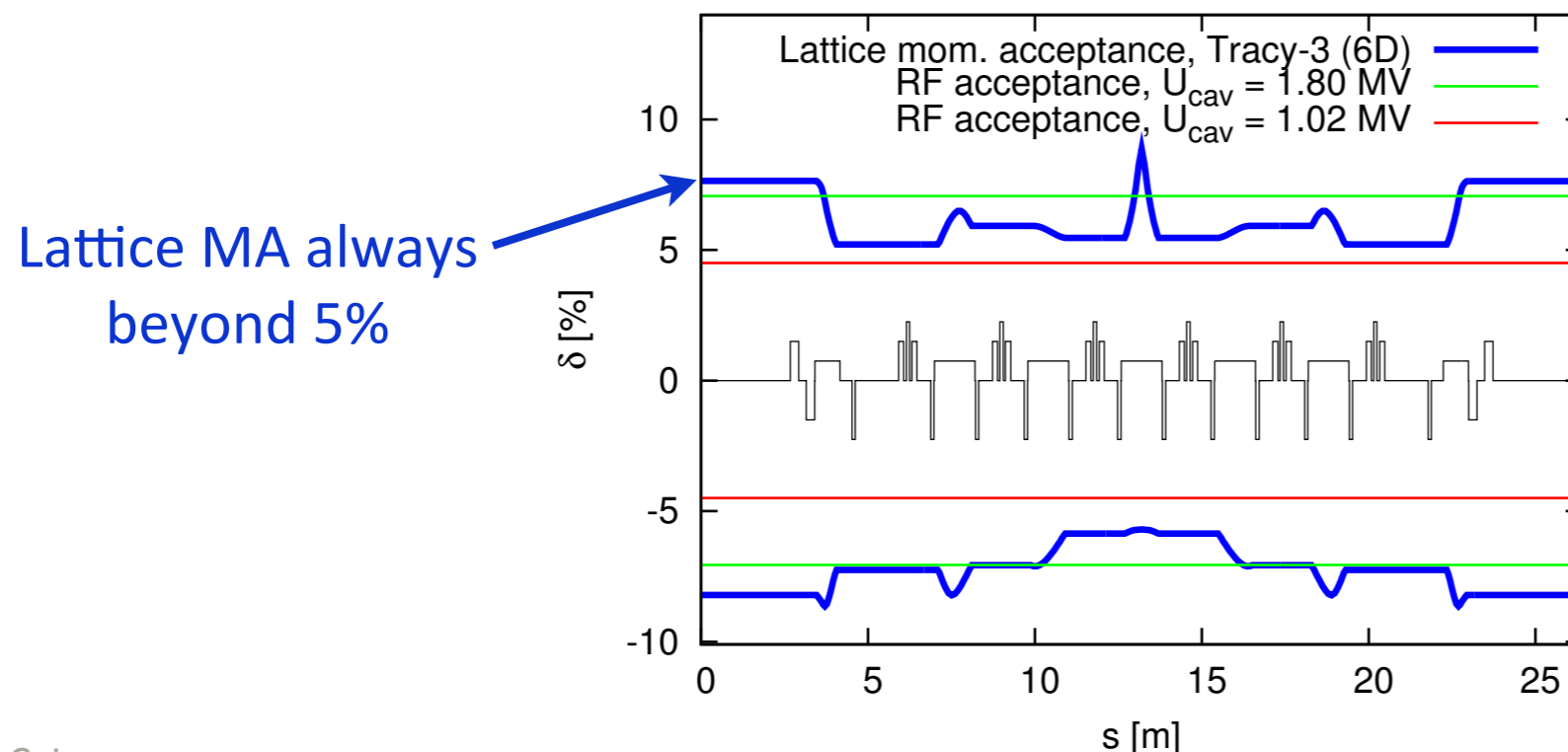


- Use **achromatic octupoles** to efficiently tailor ADTS to first order → minimize tune footprint



# 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

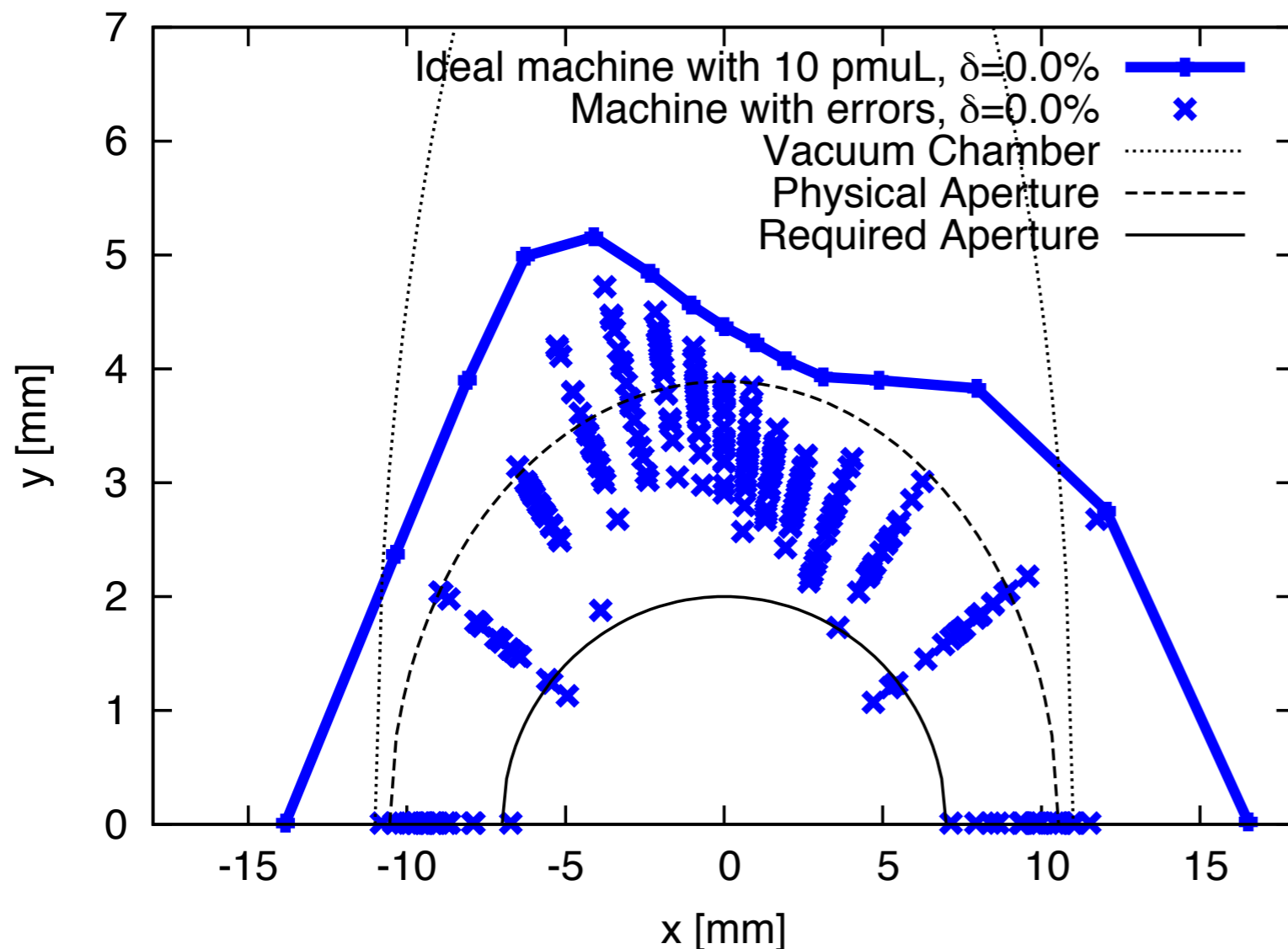


PRST-AB 12, 120701 (2009)

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  $\mu\text{m}$  rms H/V } for each magnet block  
0.2 mrad rms roll }  
25  $\mu\text{m}$  rms H/V } for all magnets within  
0.2 mrad rms roll }
- Field Errors:  
0.05% rms within each family
- Multipole Errors:  
Upright and skew multipoles added

PAC'11, TUP235, p.1262

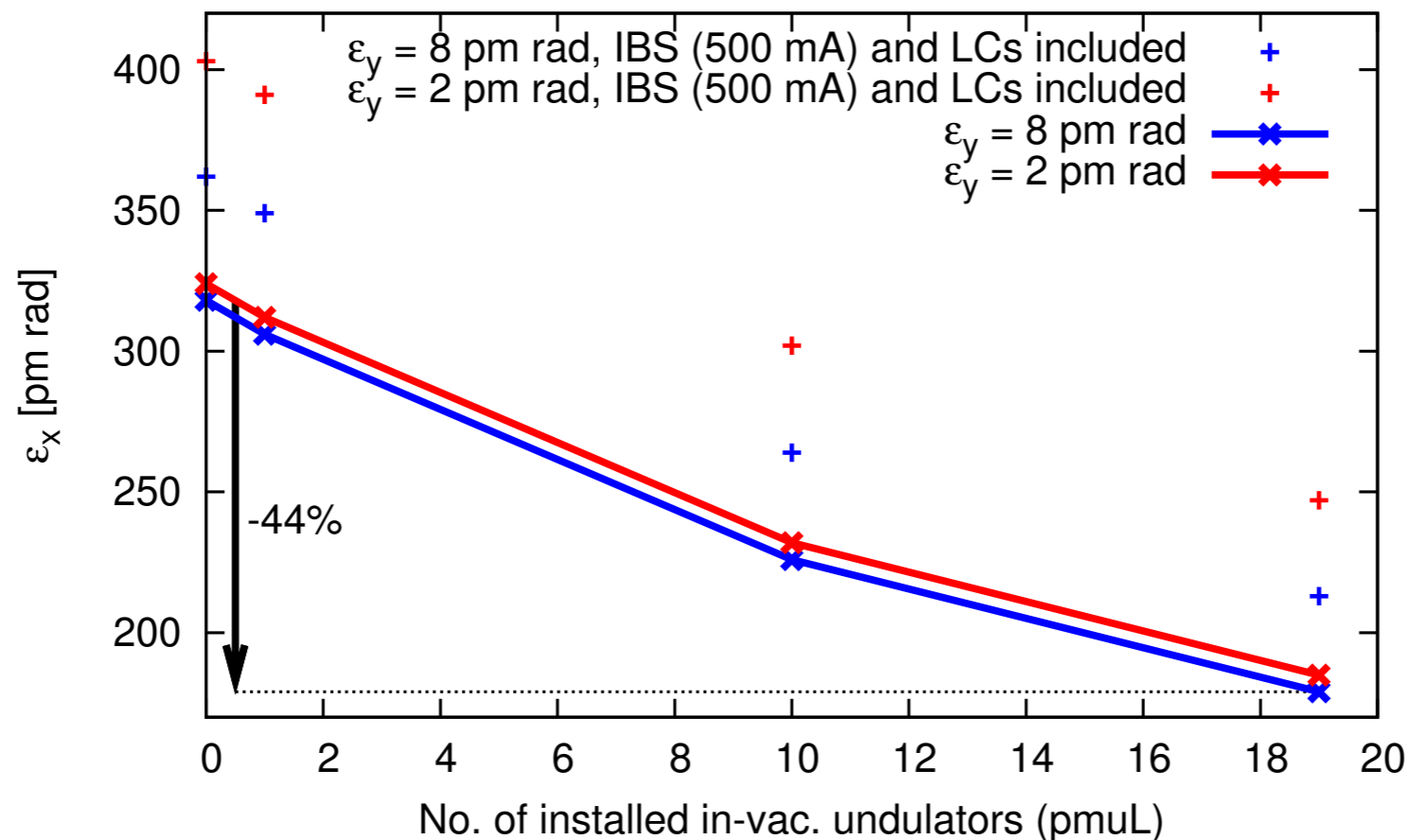
# Resulting Performance (cont.)

- 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

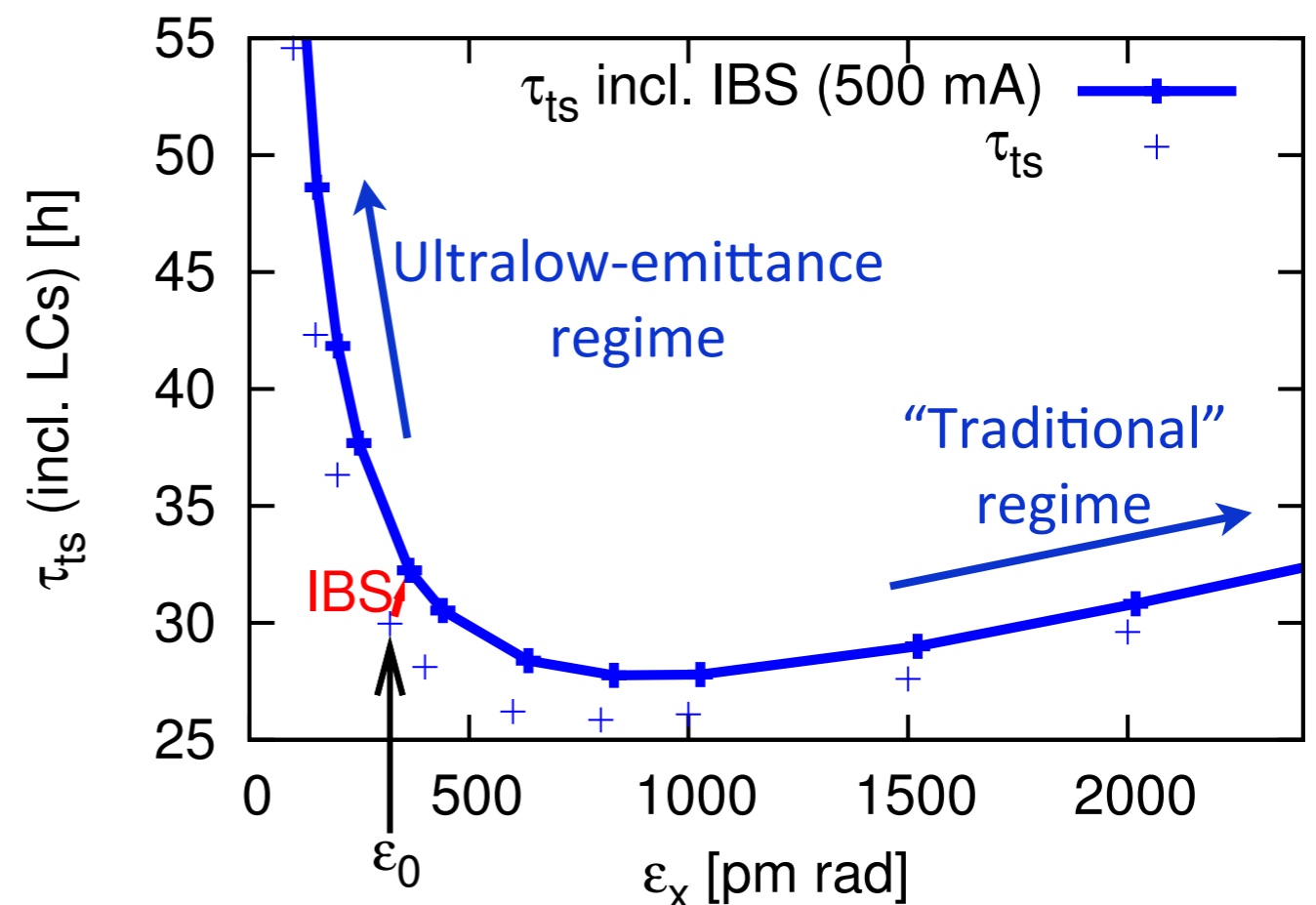
# A few interesting properties of ultralow-emittance rings

- 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?



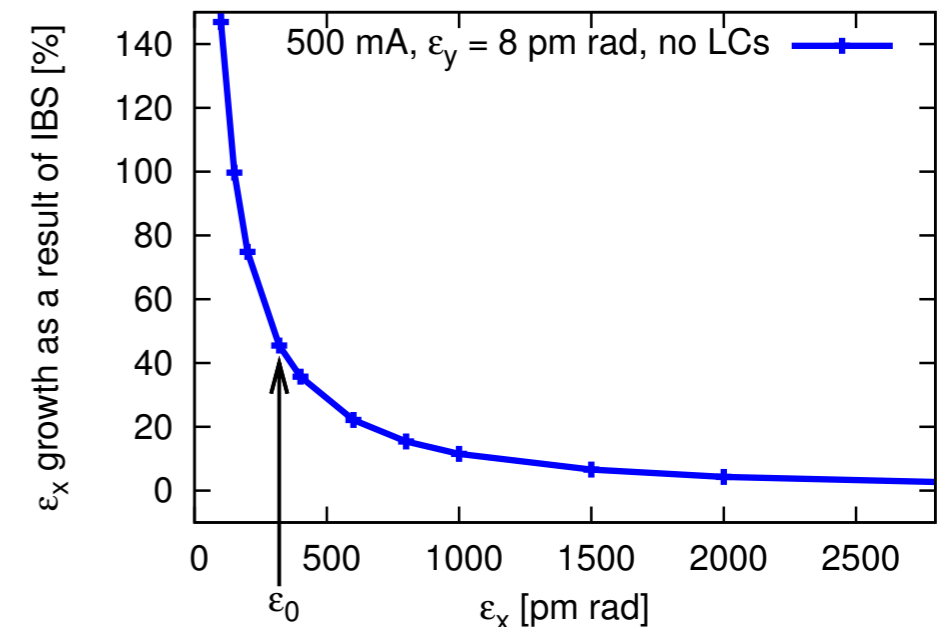
# A few interesting properties of ultralow-emittance rings (cont.)

- 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?



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

- 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  $\rightarrow$  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

- Raise energy?

- (6 GeV in ESRF Upgrade, SPring8-)

- IBS blows up beam's 6D  $\epsilon$

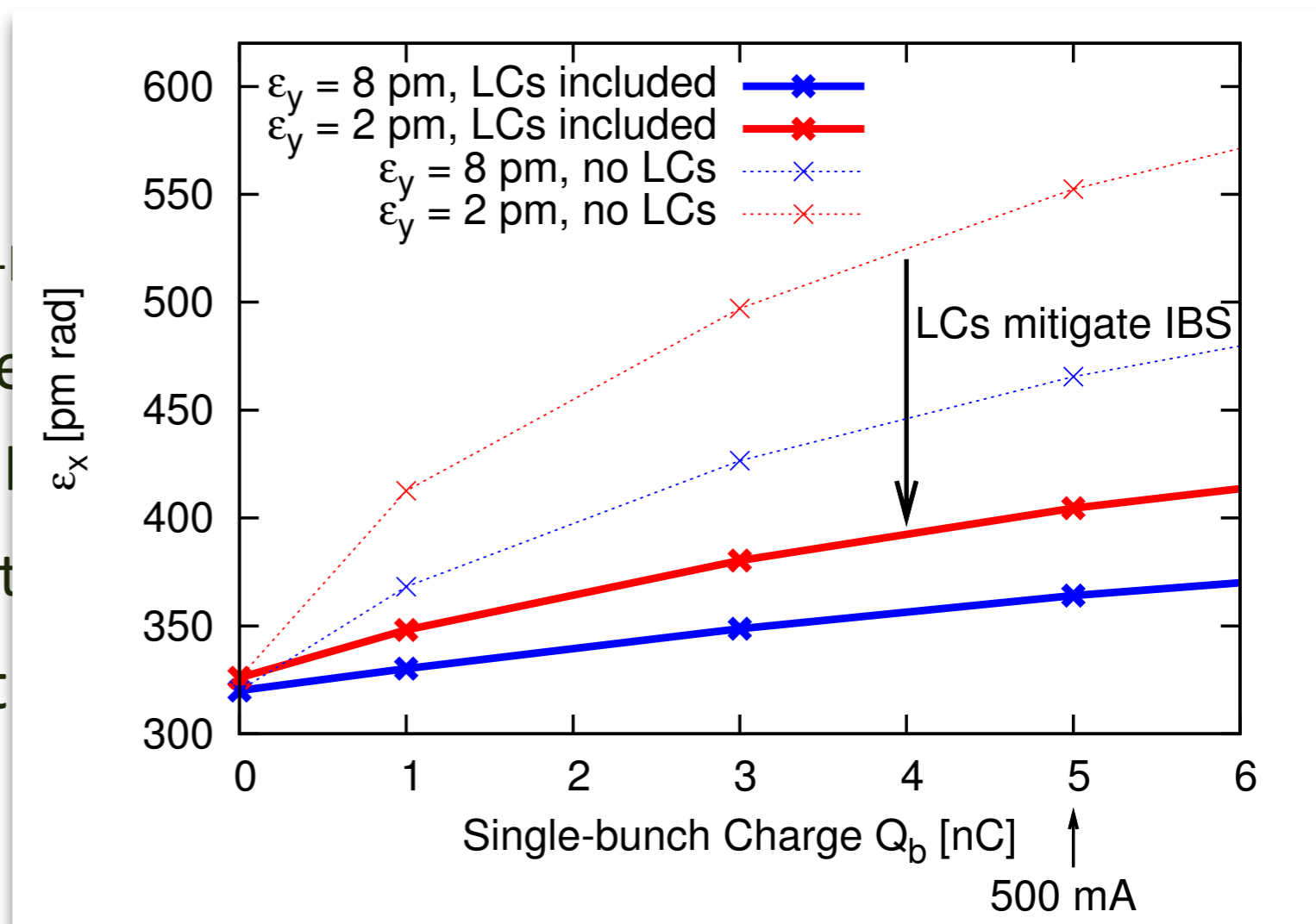
- good for lifetime, bad for IBS
    - compounded by low emittance

- Trade-off: stored current

➔ Alternative: increase longitudinal emittance

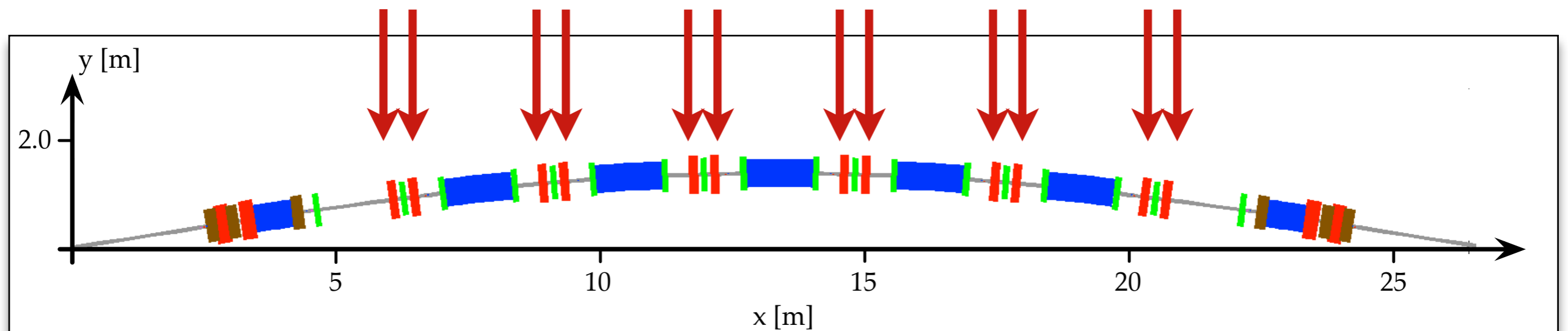
- DW's increase energy spread (brightness issue)

- 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.)

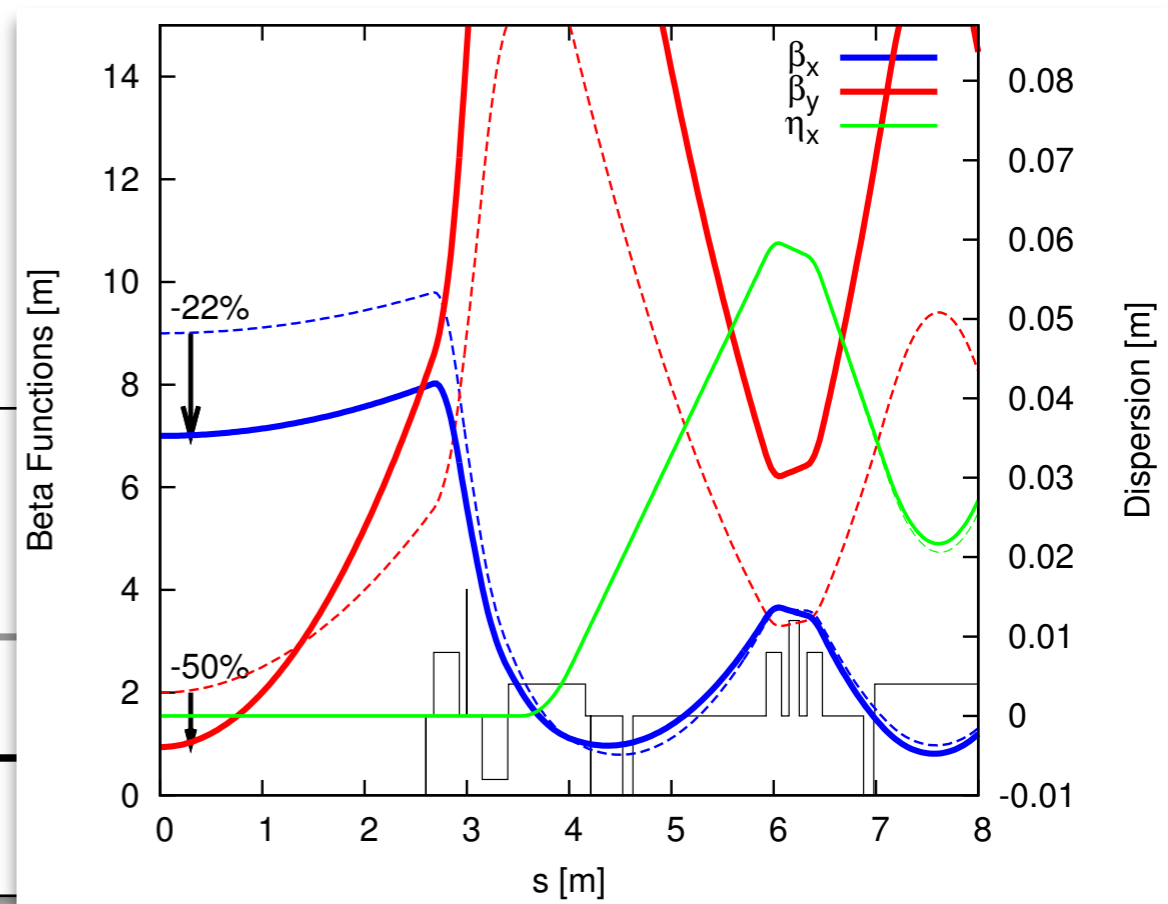
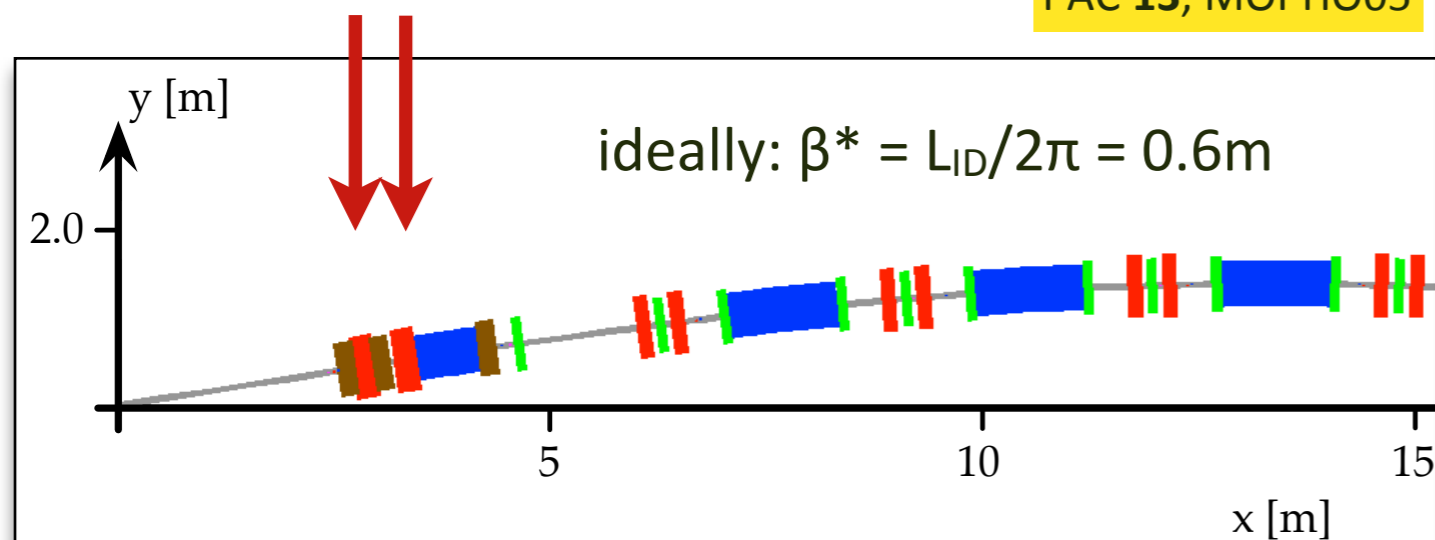
- Improve optics without requiring new magnets or PS's
- Adjust focusing quads in arc & **doublets in straights**
  - Increase horizontal focusing to lower emittance: 328 → 270 pm rad
  - **Decrease  $\beta_{x,y}$  in straights** to better match intrinsic photon beam

- $\nu_x = 42.2 \rightarrow 44.2$ ,  $\nu_y = 16.28 \rightarrow 14.28$

- $\beta_y^* = 2 \text{ m} \rightarrow 1 \text{ m}$ ,  $\beta_x^* = 9 \text{ m} \rightarrow 7 \text{ m}$

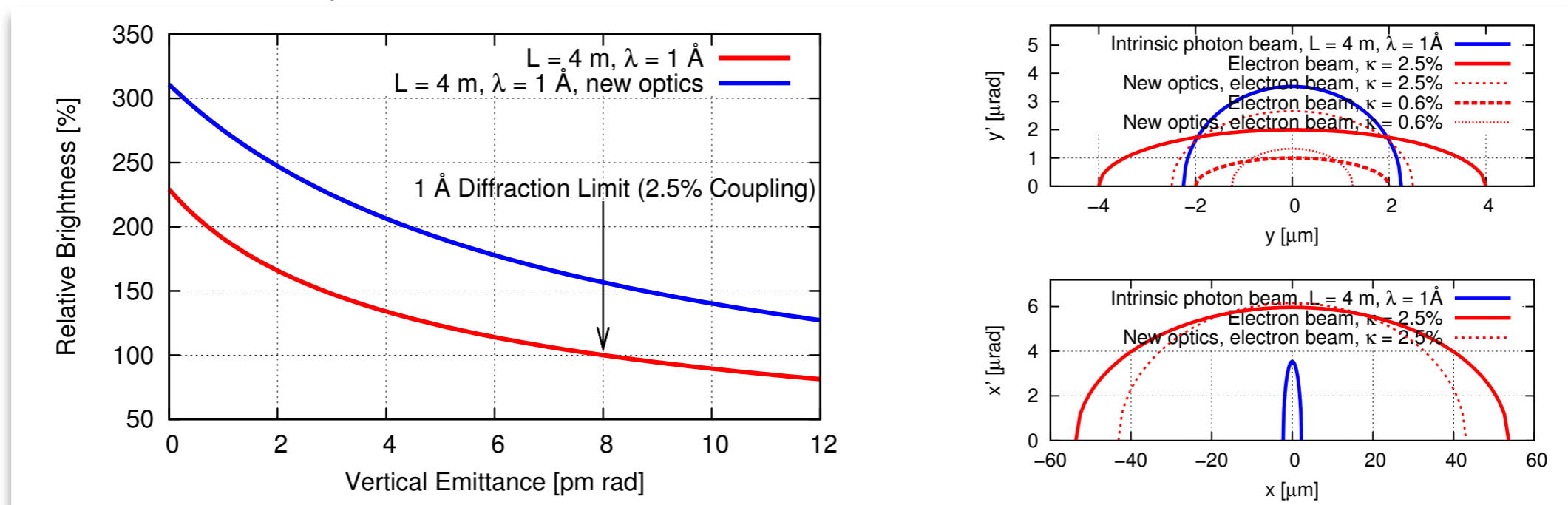
(should still be sufficient for injection)

PAC'13, MOPHO05



# 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



➔ Emittance reduced by  $\approx 18\%$  but brightness at 1 Å increases by  $\approx 50\%$  (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  $\approx 200$  pm rad at 500 mA stored beam
  - or  $\approx 150$  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...