Coupling and Brightness Considerations for the MAX IV 3 GeV Storage Ring

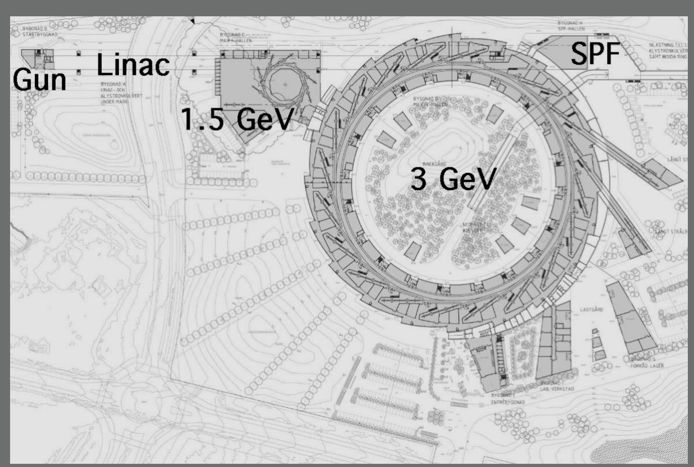
Simon C. Leemann*, Mikael Eriksson, MAX IV Laboratory, Lund University, SE-22100 Lund, SWEDEN

In a Nutshell

- MAX IV 3 GeV storage ring designed for hard x-rays, i.e. radiation around 1 Å.
- Previously, operation foreseen at the so-called "diffraction limit" 8 pm rad (corresponding to 2.5% coupling).
- An improved match between the phase space distributions of the intrinsic photon beam and the electron beam can significantly increase brightness and transverse coherence.
- By reducing vertical emittance to 2 pm rad (0.6% coupling) brightness & coherence are increased by roughly a factor 2. A total lifetime of 10 h can still be achieved.

MAX IV 3 GeV Storage Ring

- MAX IV facility consists of a 3 GeV linac (driving a short-pulse facility and eventually an FEL), a 1.5 GeV storage ring (IR, UV), and the MAX IV 3 GeV storage ring (x-rays).



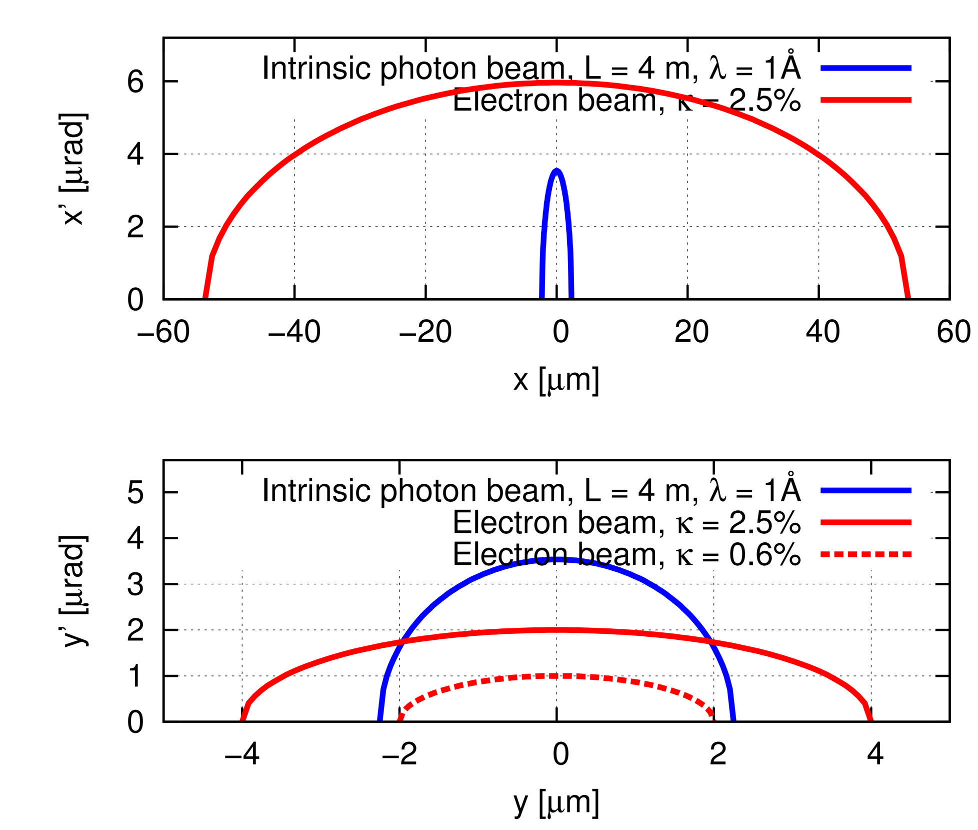
- Construction of the facility is progressing well. The 3 GeV storage ring hall is presently being completed. Installation 7/2014, commissioning 7/2015, operational by 5/2016.

Brightness & Coherence

Opt. Eng. Vol. **32**, No. 2, p. 342 (1995)

- Typical photon beam from in-vacuum undulator has diffraction-limited source size given by
$$\sigma_r = \frac{\sqrt{2L\lambda}}{4\pi}$$
and central cone has rms width
$$\sigma_{r'} = \sqrt{\frac{\lambda}{2L}}.$$
- This leads to often quoted "diffraction-limited emittance"
$$\varepsilon_r = \sigma_r \sigma_{r'} = \frac{\lambda}{4\pi}.$$
- In existing 3rd generation light sources
$$\varepsilon_0 = \varepsilon_x + \varepsilon_y, \quad \kappa = \frac{\varepsilon_y}{\varepsilon_y} \ll 1$$
so coupling usually adjusted so that
$$\varepsilon_y \approx \varepsilon_r.$$
- But this treatment neglects the actual radiation process in ID!
- Instead, brightness of emitted radiation needs to be calculated from resulting overlap between electron beam *and* intrinsic photon beam.
- The spatial overlap
$$\Sigma_{x,y} = \sqrt{\sigma_r^2 + \sigma_{x,y}^2} = \sqrt{\frac{2L\lambda}{(4\pi)^2} + \varepsilon_{x,y}\beta_{x,y}}$$
and the angular overlap
$$\Sigma_{x',y'} = \sqrt{\sigma_{r'}^2 + \sigma_{x',y'}^2} = \sqrt{\frac{\lambda}{2L} + \frac{\varepsilon_{x,y}}{\beta_{x,y}}}$$
together describe the effective emittance:
$$\mathcal{E}_{x,y} = \Sigma_{x,y}\Sigma_{x',y'}.$$
- The brightness of the emitted radiation is
$$\mathcal{B}(\lambda) = \frac{\mathcal{F}(\lambda)}{(2\pi)^2 \mathcal{E}_x \mathcal{E}_y},$$
where the spectral flux is
$$\mathcal{F}(\lambda) = \frac{\dot{N}}{0.1\% \times (\Delta\lambda/\lambda)}.$$
- The coherent fraction of emitted radiation is
$$f_c(\lambda) = \frac{\mathcal{B}(\lambda)\,(\lambda/2)^2}{\mathcal{F}(\lambda)} = \frac{(\lambda/4\pi)^2}{\mathcal{E}_x \mathcal{E}_y}.$$

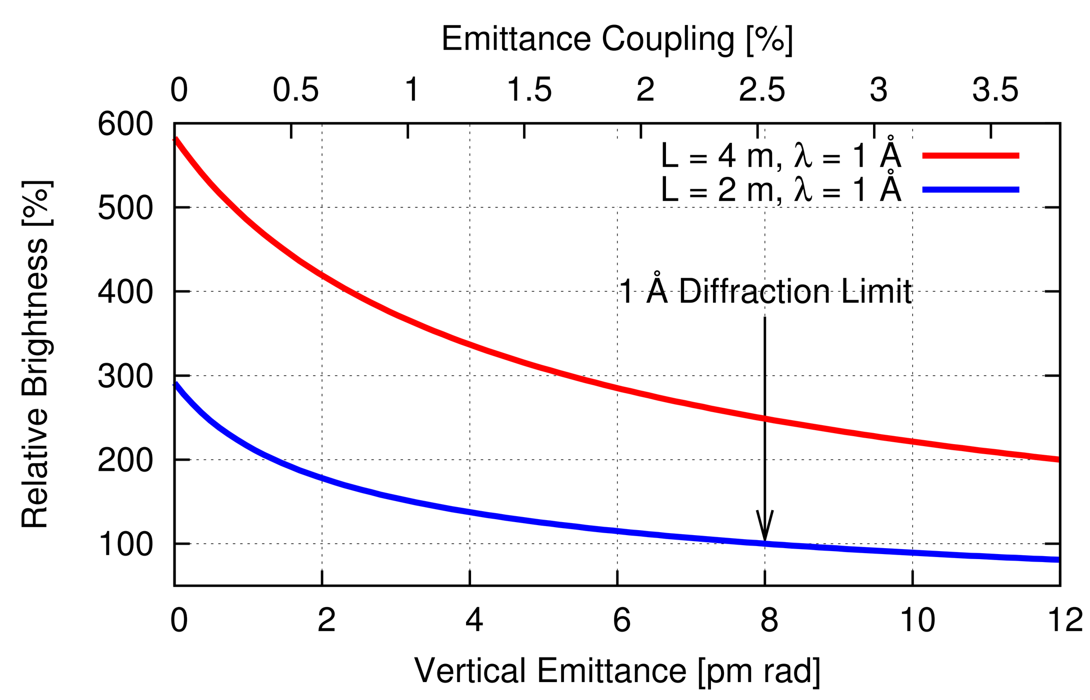
Optics Matching



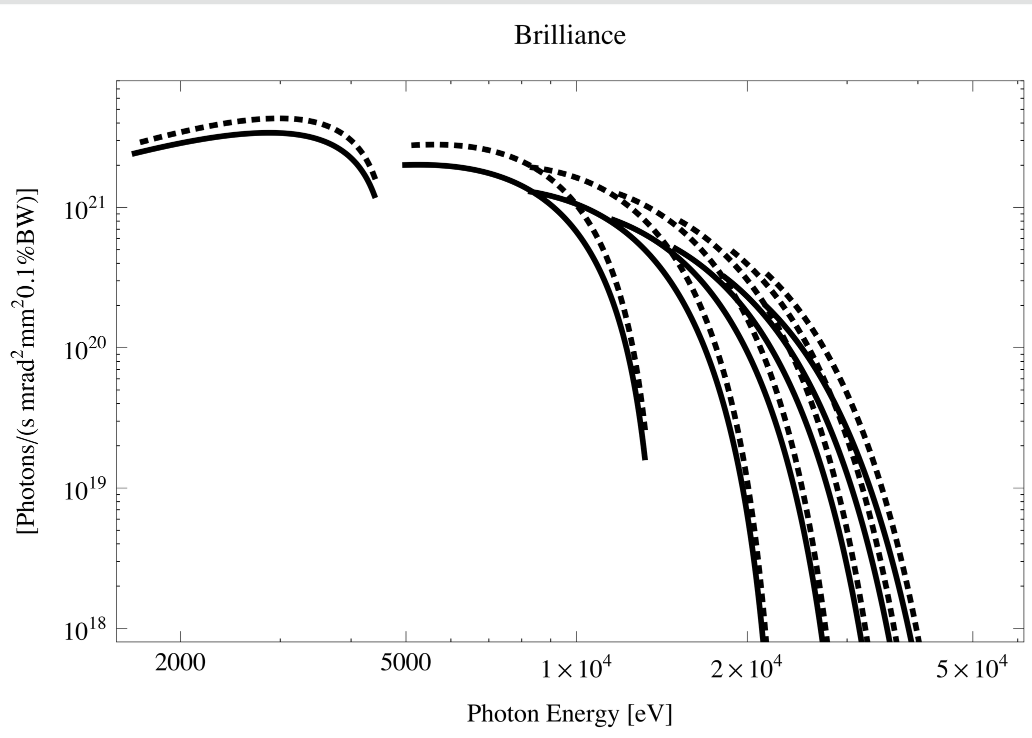
RMS beam size of the photon and electron beam assuming 1 Å radiation from a 4 m undulator in a long straight section of the MAX IV 3 GeV storage ring.

- Perfect optics matching calls for
$$\beta_y \stackrel{!}{=} \beta_r = \frac{\sigma_r}{\sigma_{r'}} = \frac{L}{2\pi}$$
but this often leads to acceptance & lifetime issues.
- Instead chose
$$\beta_y \stackrel{!}{=} \frac{L}{2}$$
for maximum acceptance.
- Then, optimize coupling to achieve better match of electron beam's phase space to the intrinsic photon beam's phase space.
- Sheet beam leads to horizontal mismatch but vertical overlap can be considerably improved by proper choice of coupling.

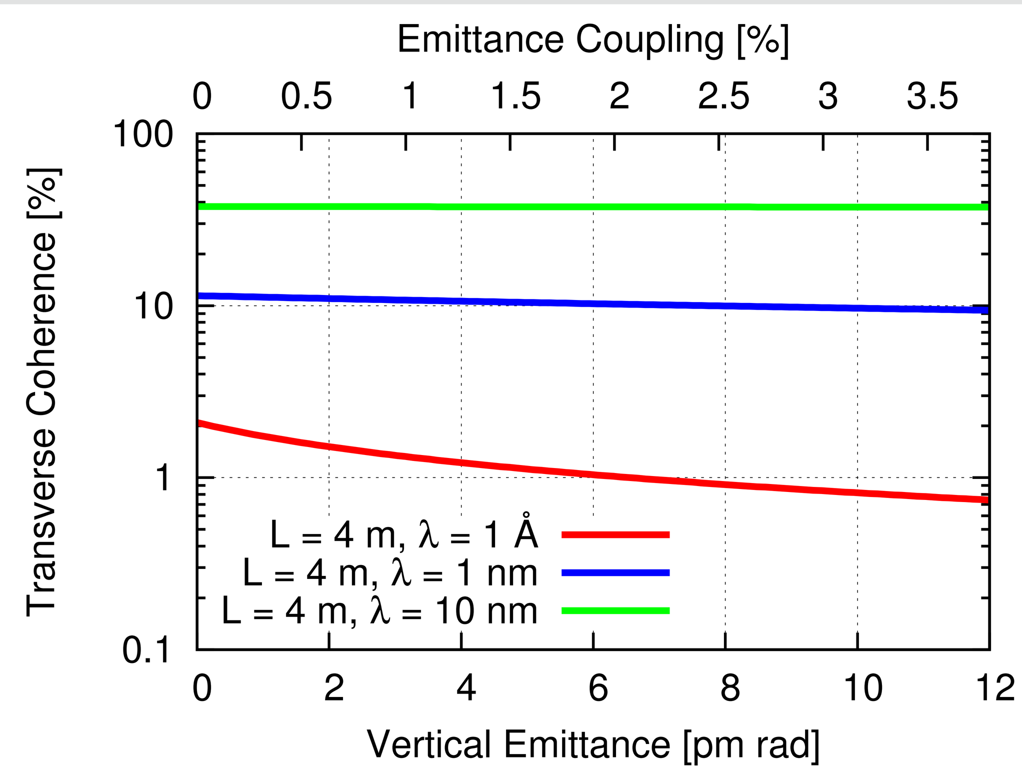
Maximizing Brightness & Coherence



Brightness increase as emittance coupling is reduced for two ID's tuned to 1 Å. Brightness values have been normalized to that of the short ID operated at 8 pm rad. IBS not included.



Spectral brightness at peak energy for a 3.3 m in-vacuum undulator installed in the MAX IV 3 GeV storage ring with 500 mA and coupling set to 8 pm rad (solid line) vs. 2 pm rad (dashed line).



Degree of transverse coherence as a function of emittance coupling for radiation emitted at different wavelengths from ID's installed in a long straight section of the MAX IV 3 GeV storage ring.

MAX IV Project → http://www.maxlab.lu.se/maxiv

*) simon.leemann@maxlab.lu.se

MOPHO05, NA-PAC'13, Pasadena, CA, USA, Sep 29 – Oct 4, 2013