STEADY-STATE MICROBUNCHING IN ELECTRON STORAGE RINGS WITH DISTRIBUTED ENERGY MODULATION*

S. Khan, Center for Synchrotron Radiation (DELTA), TU Dortmund University, 44227 Dortmund, Germany

Novel electron storage rings with steady-state microbunching (SSMB)

Properties [1-4]

- coherent emission with high intensity and ultrashort pulse duration
- high repetition rate and excellent stability

Replace radiofrequency (RF) by laser [5-7]

- laser-induced energy modulation in an undulator
- bucket size changes from RF (cm) to laser wavelength (μm)
- requires extreme isochronicity, e.g. bucket (1 μm) / circumference (100 m) = 10^{-8}

Isochronicity issues [8-9]

- electron optics with very small transfer matrix elements R_{51}, R_{52}, R_{56}
- random nature of synchrotron photon emission
- can be mitigated by distributed energy modulation

  single undulator → several undulators → dipole magnets

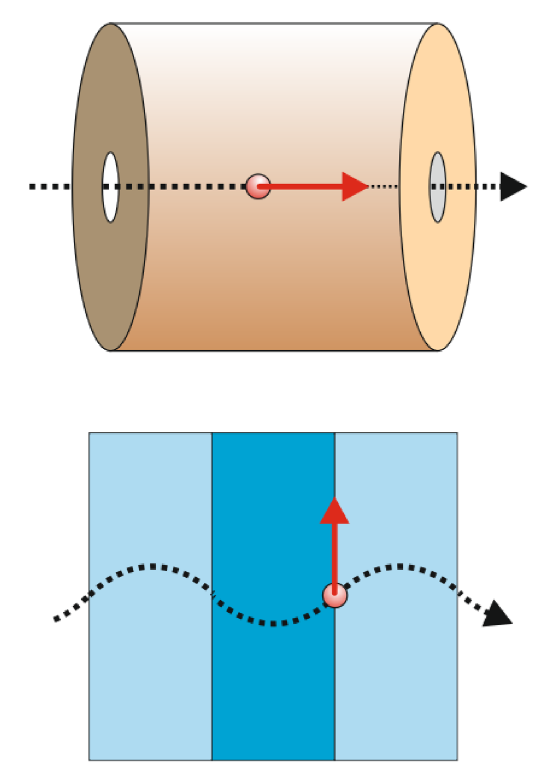
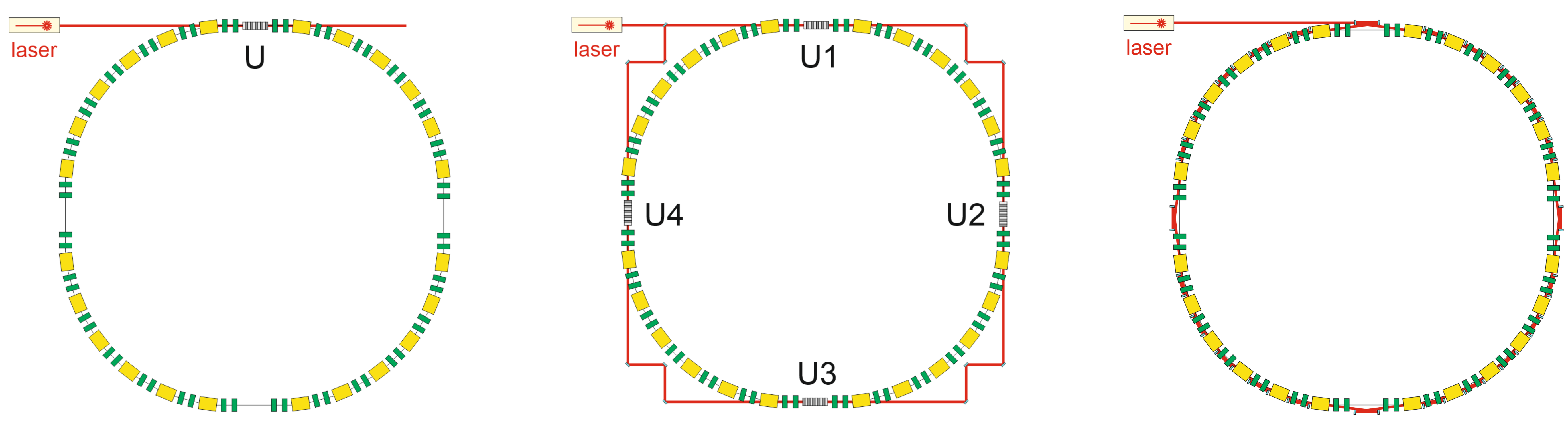


Figure: RF cavity (top) with longitudinal electric field and and undulator (bottom) with transverse electric laser field



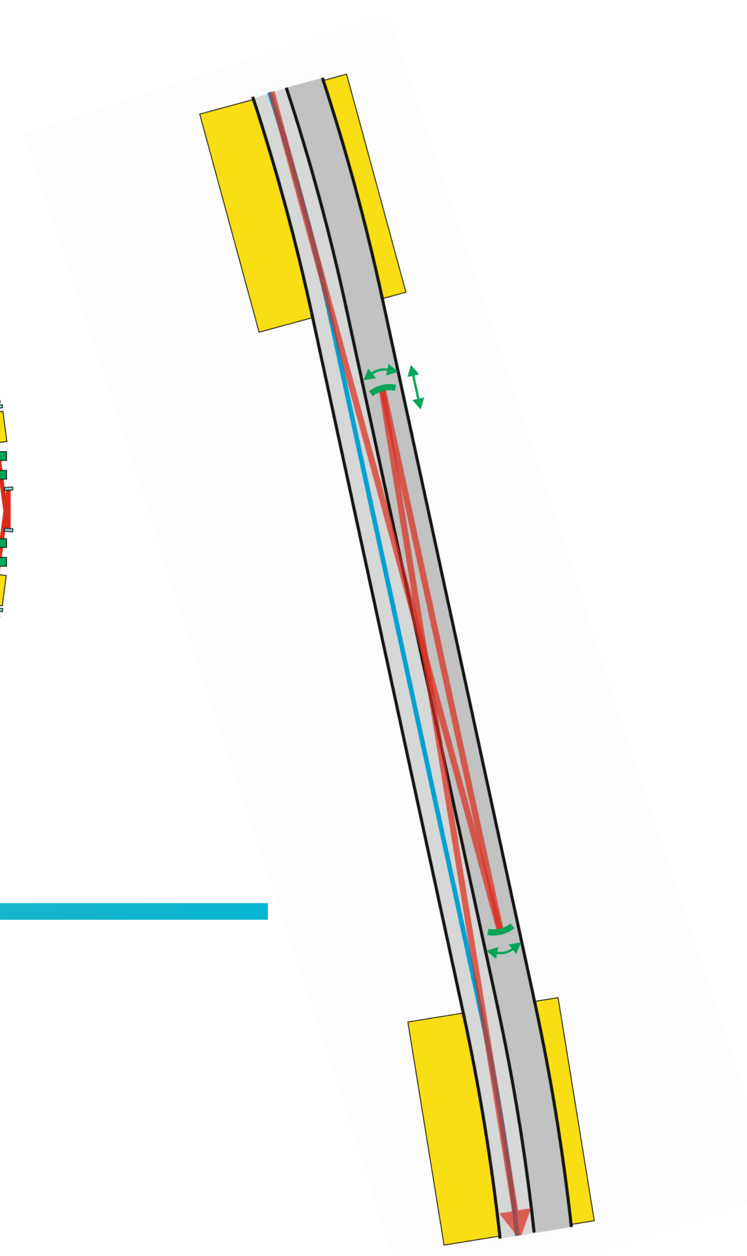


Figure: Laser guided from one dipole to the next by 2 mirrors controlling position, angle and laser phase (see arrows).

Distributed energy modulation in dipoles

Advantages

- no undulator and no dedicated straight section required
- requirements on isochronicity reduced, distance = circumference / number of dipoles
- many dipoles → low emittance

Drawbacks

- weak energy modulation per dipole
- phase tuning difficult

Technical layout

- ring-shaped laser cavity to guide and enhance laser beam
- two in-vacuum mirrors between dipoles for transverse position and phase
- conventional RF (X-band?) required for tuning phases between all dipoles
- extreme case: many off-axis quadrupoles instead of dipole magnets

Laser-electron interaction in dipoles

Predicted and experimentally verified [10-12]

- requires spectral/spatial overlap between laser and spontaneous emission
- energy gain/loss = force · displacement ~ electric field · angle
- limited overlap region along path s
- numerical simulation → figure

$$E_{\text{gain/loss}} = -e\int_s \mathcal{E}_{\text{L}} \cdot x' \cdot ds \qquad \mathcal{E}_{\text{L}} = \left(\frac{2I_{\text{L}}}{\varepsilon_0 c}\right)^{1/2}$$

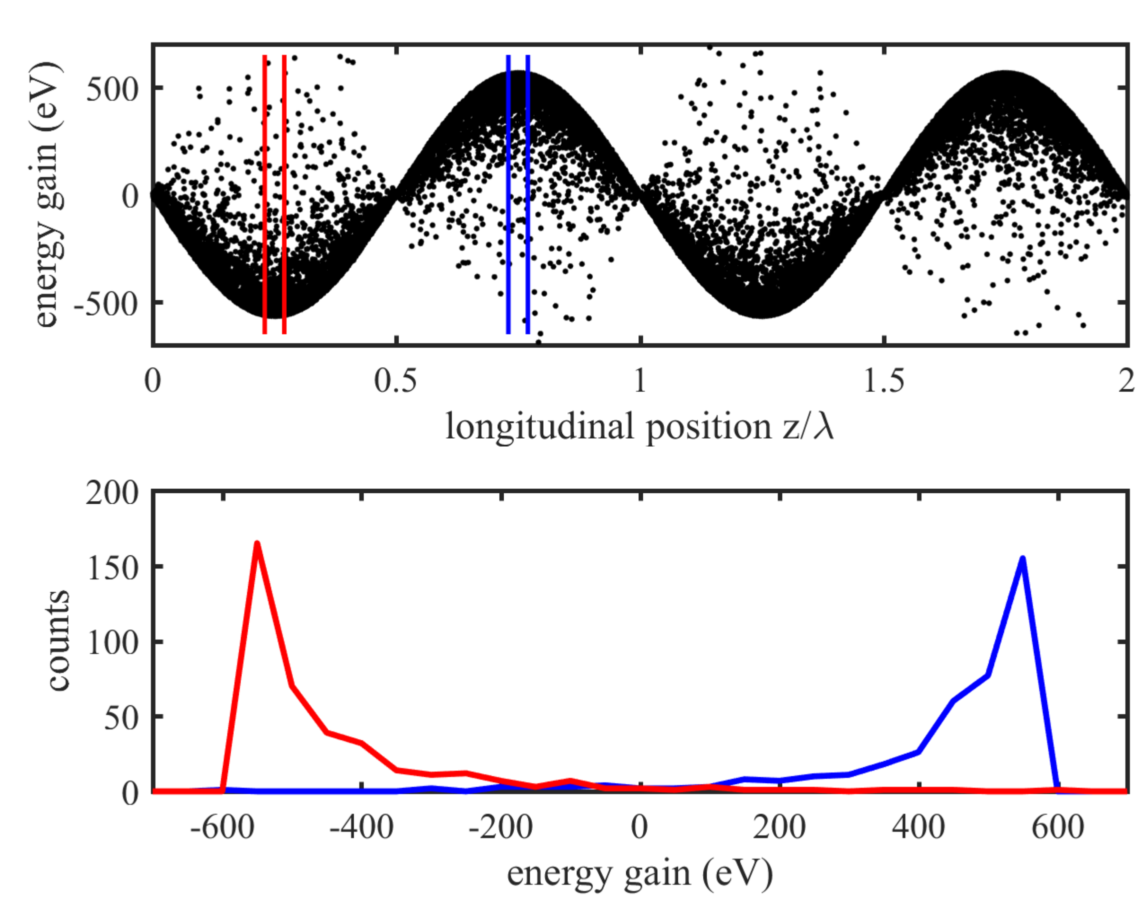


Figure: Laser-induced energy modulation in a dipole magnet. Top: energy versus position z/λ. Bottom: Marked distributions.

References

[1] D. Ratner, A. Chao, Phys. Rev. Lett. 105 (2010), 154801
[2] X. Deng et al., Proc. IPAC 2018, Vancouver, Canada, p. 4583
[3] Ch. Tang et al., Proc. FLS 2018, Shanghai, China, p. 166
[4] X. Deng et al., Nature 590 (2021), p. 576
[5] S. Khan, Nucl. Instr. Methods A 865 (2017), p. 95
[6] S. Khan, J. Phys.: Conf. Series 1596 (2020), 012025
[7] T. Rui et al., Proc. FLS 2018, Shanghai, China, p. 133
[8] Y. Shoji, Phys. Rev. ST Accel. Beams 7 (2004), 090703
[9] Y. Shoji et al., Phys. Rev. E54 (1996), R4556
[10] A. A. Zholents, K. Holldack, FEL 2006, Berlin, Germany, p. 725
[11] H. Deng et al., Nucl. Instr. Methods A 622 (2010), p. 508
[12] J. Yan et al., Adv. Photonics 3 (2021), 045003

* shaukat.khan@tu-dortmund.de

#126