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LASER-DRIVEN ELECTRON STORAGE RINGS*

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"Make storage rings great again" Properties of electron storage rings:

- high repetition rate (revolution frequency several MHz, typical bunch rate 500 MHz)
- high stability, same charge each turn, natural damping mechanisms, feedback systems
- high efficiency, only radiation losses fed back by radiofrequency (RF) system

"I have a dream" ... that storage rings could be driven by laser instead of RF wave:

- energy modulation in undulator instead of acceleration in RF cavity
- wavelengths:
  typical RF 60 cm, X band 3 cm (possible)
  IR FEL [1] 100 μm, CO_2 laser [2] 10 μm (demanding)
  vis. laser 500 nm, soft X-rays 1 nm (very difficult)
- main issue: electron path variation < wavelength

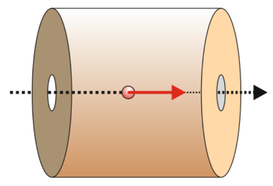
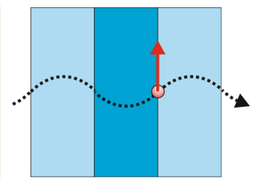


Figure: RF cavity (top) with longitudinal electric field and and undulator (bottom) with transverse electric laser field



"Turn, turn, turn" Steady-state microbunching [3-5] = density modulation at every turn, options:

- sustained microbunching ↔ modulation created and undone every turn
- continuous wave ↔ pulsed laser (several MHz)
- single laser-electron interaction ↔ multiple interactions
- single laser pass ↔ enhancement cavity

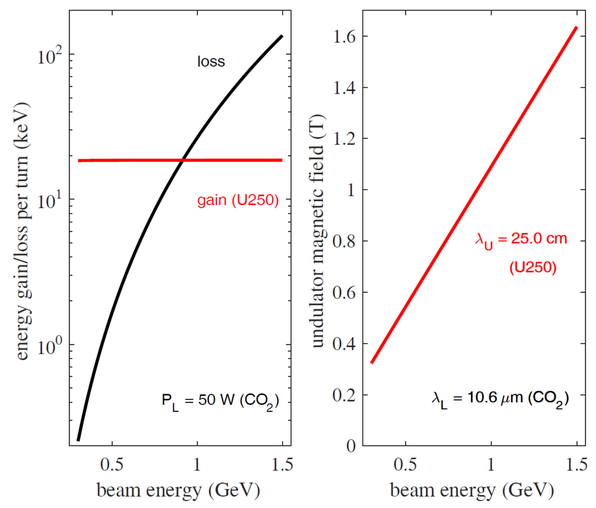
"Fascinating" Example with 50 W cw CO_2 laser:

- factor 60000 in wavelength and bunch rate compared to RF
- coherent emission at modulation wavelength and harmonics
- train of ultrashort bunches (fraction of ~15 fs bucket)
- single ultrashort bunches by removing adjacent bunches

Figure: Energy loss per turn and max. gain by laser interaction (left) and undulator magnetic field (right) as function of beam energy E using [6]:

$$E_{\text{loss}}[\text{keV}] = 88.5\frac{E^4}{R} \qquad E_{\text{gain}} = \int_{s=0}^{L_U} \varepsilon_L \cdot x' \cdot ds \qquad \varepsilon_L = \left(\frac{2I}{\varepsilon_0 c}\right)^{1/2} \qquad B[\text{T}] = \frac{K}{93.4 \cdot \lambda_U[\text{m}]} \qquad K = \left(\frac{4\gamma^2\lambda}{\lambda_U} - 2\right)^{1/2}$$

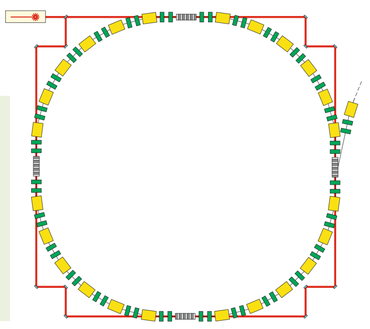
$R = 3.3$ m $\quad I = 50\ \text{W} / (16\varepsilon_x\beta_x\varepsilon_y\beta_y)^{1/2} \quad \beta_x = \beta_y = 5$ m $\quad \varepsilon_x = 10\varepsilon_y = 2\cdot10^{-8}$ radm $\quad \lambda_U = 0.25$ m



"Yes, we can" Required storage ring properties [7]:

- isochronous ring minimizing $\Delta z = \left(R_{51}^2 \cdot \sigma_x^2 + R_{52}^2 \cdot \sigma_{x'}^2 + R_{56}^2 \cdot \sigma_{\Delta E/E}^2\right)$
- control of higher-order momentum compaction and matrix elements
- minimize dispersion, e.g. multibend achromat lattice [8], reducing effects of matrix elements R_{51} and R_{52} [9], of stochastic photon emission [10]
- test experiment at MLS in Berlin [5], energy modulation with microbuncing after 1 turn
- next step: a demonstrator ring?

Figure: Sketch of a storage ring with 4 undulators for laser-driven energy modulation and laser beam in a ring cavity. Not shown: Space for injection, conventional RF, diagnostics, other insertion devices.



"A small step for mankind" ... but a novel type of "advanced" accelerator:

- storage ring driven by laser or RF+laser combination
- bunch length similar to linac or laser-plasma accelerator, but MHz bunch rate
- FEL-like coherent emission of radiation
- new parameter regime for storage ring physics: 10^7 bunches, 10^7 multibunch modes ...

References

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