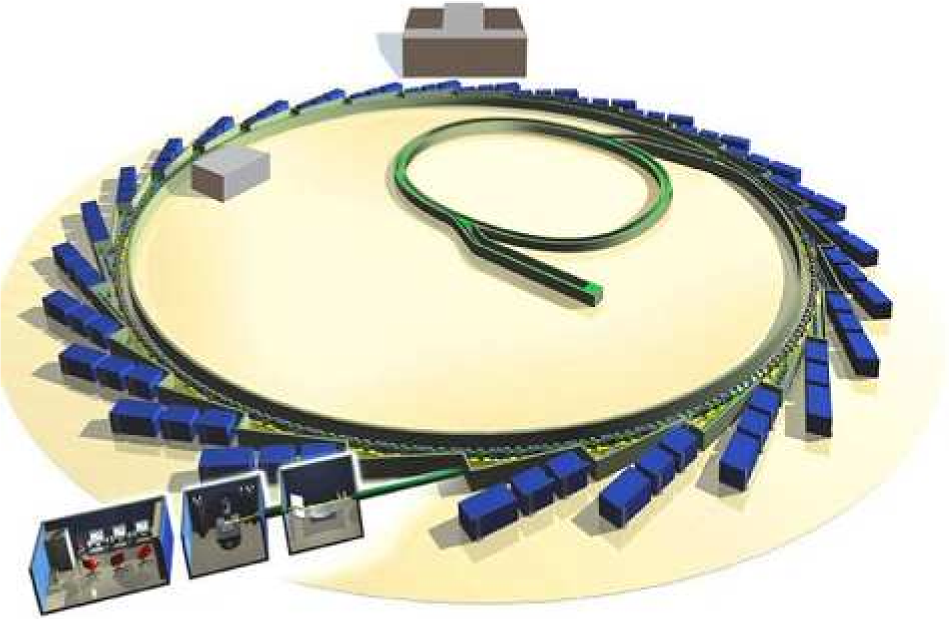
Workshop

Design of a dedicated synchrotron radiation source



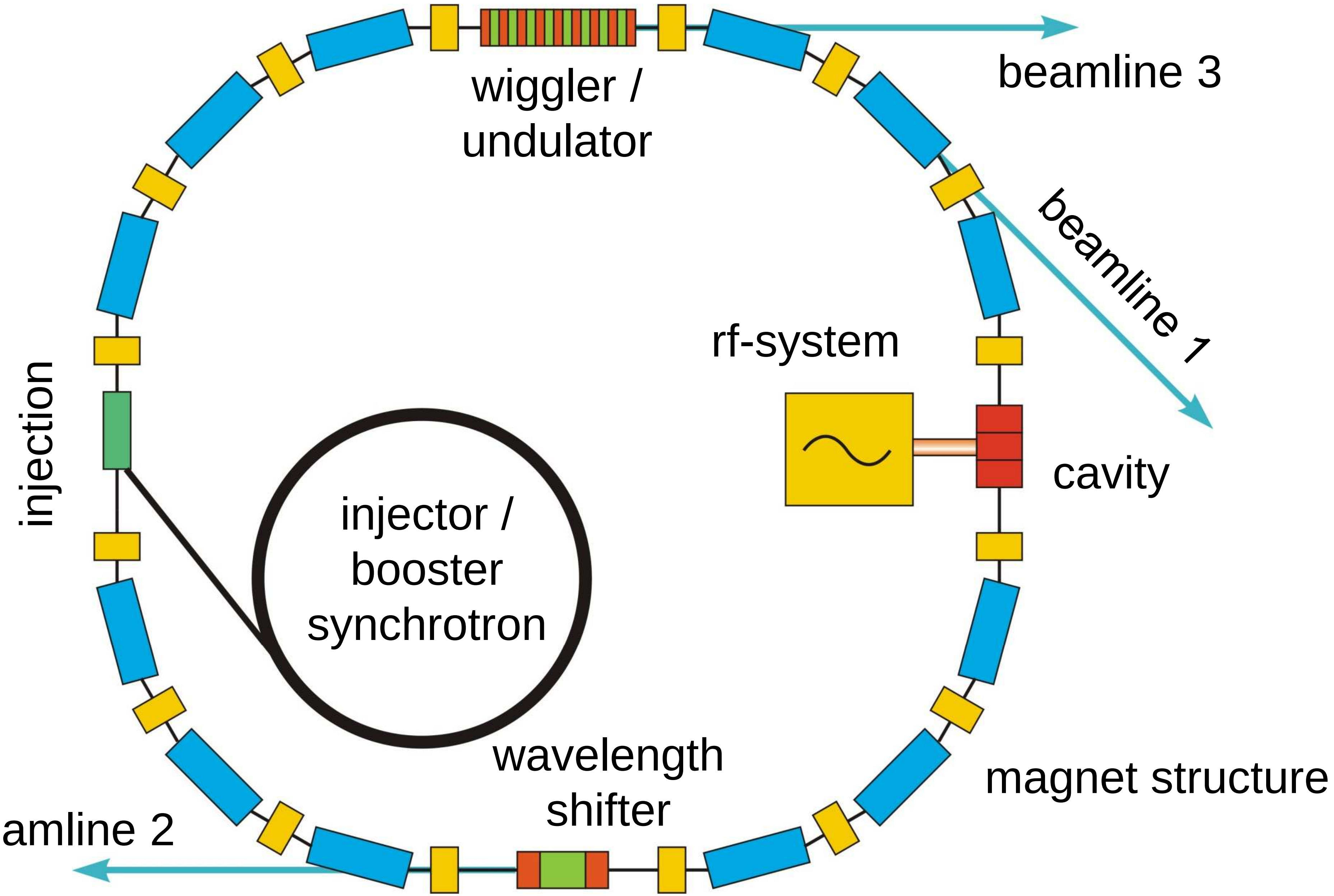
Aim of the workshop:

Design of an **electron storage ring** optimized to provide synchrotron radiation for material science etc.

Requirements of the machine

1. Sufficient high electron beam current
2. Low beam emittance
3. Special insertion devices as radiation sources
   - Normal bending magnet
   - Wafelength shifter (similar like a bending magnet, but higher magnetic field
   - Undulator magnet

The main elements of the SR-storage ring



1. Beamline requirements

Beamline 1 (bending magnet)

critical energy $E_c \geq 3.5\ \mathrm{keV}$

photon flux @ E_c $$\frac{d\dot{N}}{(d\varepsilon/\varepsilon)\,d\Theta} \geq 10^{12}\ \frac{\mathrm{photons}}{0.1\%\mathrm{BW}\cdot\mathrm{mrad}\cdot\mathrm{s}}$$

important formulas

radiated power $$P_0 = \frac{e\gamma^4 I_b}{3\varepsilon_0\rho}$$

critical frequency $$\omega_c = \frac{3c\gamma^3}{2\rho}$$

photon flux $$\frac{d\dot{N}}{d\varepsilon/\varepsilon} = \frac{P_0}{\omega_c\hbar} S\left(\frac{\omega}{\omega_c}\right)$$

spectral function $$S(\xi) = \frac{9\sqrt{3}}{8\pi}\xi\int_{\xi}^{\infty} K_{5/3}(t)\,dt$$

Beamline 2 (wavelength shifter)

critical energy $E_\mathrm{c} \geq 20\ \mathrm{keV}$

photon flux @ E_c $$\frac{d\dot{N}}{(d\varepsilon/\varepsilon)\,d\Theta} \geq 10^{12}\ \frac{\mathrm{photons}}{0.1\%\mathrm{BW}\cdot\mathrm{mrad}\cdot\mathrm{s}}$$

Beamline 3 (undulator)

photon wavelength $\lambda = 2 - 20\ \mathrm{nm}$

line width $\dfrac{\Delta\lambda}{\lambda} \leq 1\%$

important formulas

undulator field $$\tilde{B} = \frac{B_0}{\cosh(\pi g/\lambda_\mathrm{u})}$$

undulator parameter $$K = \frac{\lambda_\mathrm{u} e \tilde{B}}{2\pi m_\mathrm{e} c}$$

coherence condition $$\lambda = \frac{\lambda_\mathrm{u}}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\Theta^2\right)$$

2. General beam requirements

horizontal beam emittance $\varepsilon_x \le 1 \cdot 10^{-8}\,\mathrm{m\,rad}$

vertical beam emittance $\varepsilon_z \le 0.1 \cdot \varepsilon_x = 1 \cdot 10^{-9}\,\mathrm{m\,rad}$

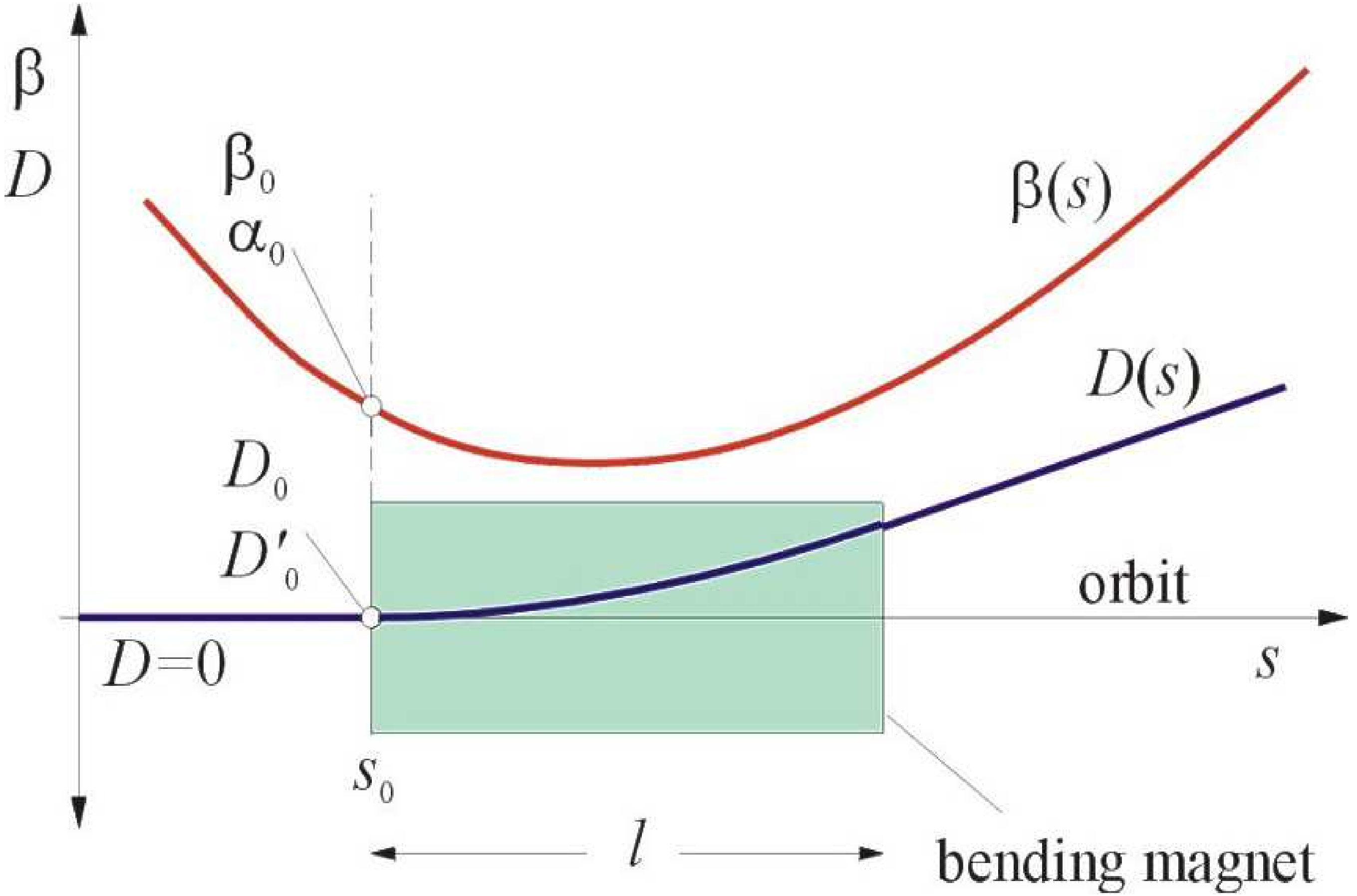
important formula

beam emittance $$\varepsilon_x = \frac{55}{32\sqrt{3}} \frac{\hbar}{m_e c} \gamma^2 \frac{\left\langle \frac{1}{\rho^3} H(s) \right\rangle}{J_x \left\langle \frac{1}{\rho^2} \right\rangle}$$

including the optics calculations of the storage ring

Optics

For the beam optics we coose a „Chassman-Green lattice“.



$$\varepsilon_x = C_\gamma \gamma^2 \Theta^3 \left(\frac{\gamma_0 l}{20} - \frac{\alpha_0}{4} + \frac{\beta_0}{3l} \right) < 1 \cdot 10^{-8}\,\mathrm{m\,rad}$$

$$C_\gamma = 3.832 \cdot 10^{-13}\,\mathrm{m}$$

For the minimum emittance the initial conditions are

$$\beta_0 = 2\sqrt{\frac{3}{5}}\,l = 1.549\ l$$

$$\alpha_0 = \sqrt{15} = 3.873$$

$$\gamma_0 = \frac{1+\alpha_0^2}{\beta_0} = \frac{10.329}{l}$$

This extreme slope α_0 is too high, it causes problems finding stable beam optics. Therefore, it is recommended not to exceed this value beond $\alpha_0 \approx 3,0$.

3. The machine

type: electron storage ring

beam energy $E_{\mathrm{b}} = ?$

beam current $I_0 = ?$

bending magnets

bending radius $\rho = ?$

magnet length $l = ?$

bending angle / magnet $\Delta\Theta = ?$

total number of magnets $N = ?$ $\left(N \cdot \Delta\Theta = 2\pi\right)$

beam optics (recommended: Cassman-Green lattice)

insertion optics

WLS	(strong magnet)
undulator	(weak magnet)

rf-system

rf-frequency $f_{\mathrm{rf}} = ?$

rf-power $P_{\mathrm{rf}} = ?$

cavity type: pillbox, 3-cell, 5 cell, superconductive etc.

injection

injection energy: $E_{\mathrm{inj}} = E_{\mathrm{b}}$

$E_{\mathrm{inj}} < E_{\mathrm{b}}$ (+ SR-ramping)

injection rate (maximum rate limited by radiaton damping)

damping constant $$a_{\mathrm{x}} = \frac{W_0}{2E_{\mathrm{b}}T_0}(1 - D)$$

generally: keep the design simple and cheep !