Design example of the dedicated SR source

1. Calculation of the required beam energy

We set the maximum bending magnet field: $\boldsymbol{B = 1.2\ \mathrm{T}}$

the required critical photon energy is $\boldsymbol{E_c \geq 3.5\ \mathrm{keV}}$

$$\left.\begin{aligned} E_c &= \hbar\omega_c = \frac{3\hbar c \gamma^3}{2\rho} \\ \frac{1}{\rho} &= \frac{e c B}{E_b} \\ E_b &= \gamma m_0 c^2 \end{aligned}\right\} \Rightarrow \quad \begin{aligned} \rho &= 5.8207\ \mathrm{m} \\ E_b &= 2.094\ \mathrm{GeV} \end{aligned}$$

2. Definition of the bending magnet parameters

We try a solution with $\boldsymbol{N = 24}$ identical bending magnets.

The length of the particle trajectory in each bend is

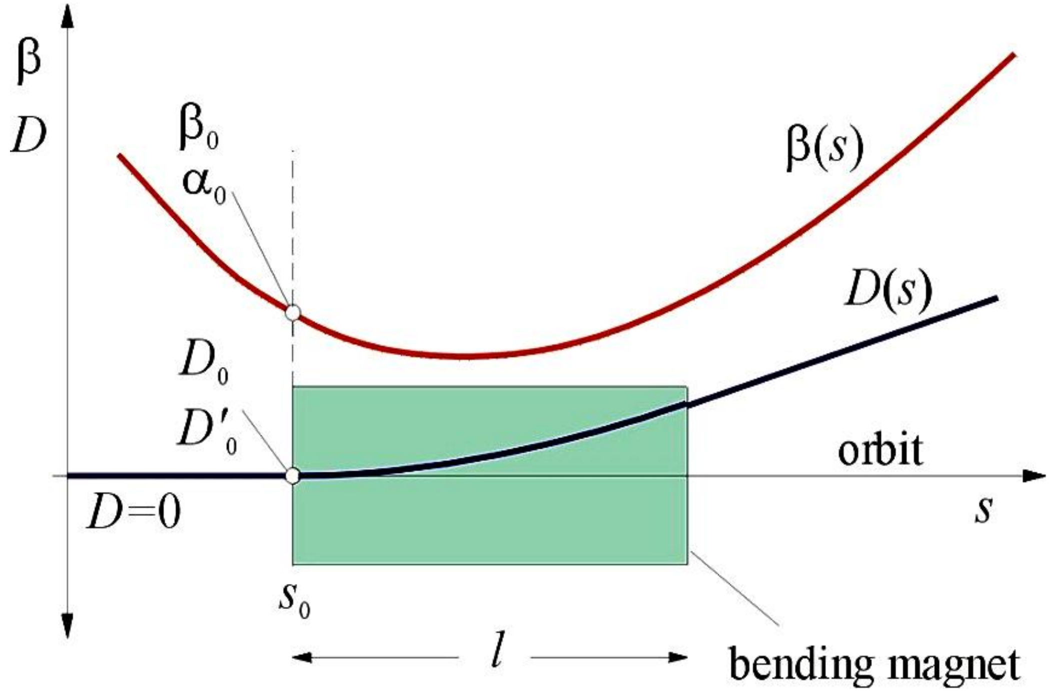
$$l_{\text{bend}} = \frac{2\pi\rho}{N} = 1.523856 \text{ m}$$

Initial values for a Chassman-Green lattice:

$$\beta_0 = 1{,}549 \cdot l_{\text{bend}} = 2.3605 \text{ m}$$

$$\alpha_0 = 3.873$$ too large because of optical reason

$$\alpha_0 \approx 3.0$$ reasonable limit



3. Calculation of the beam optics by use of a computer code

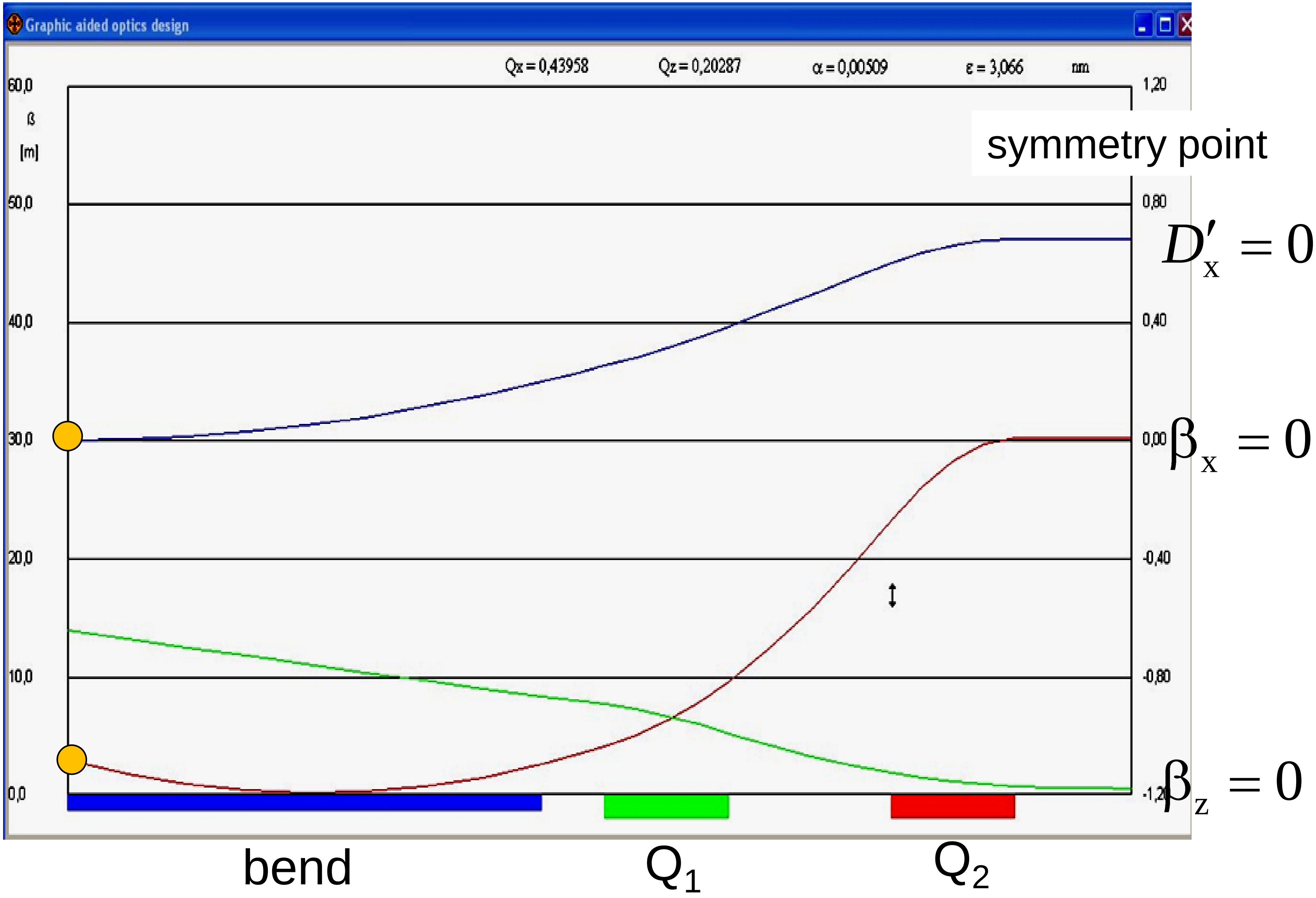
step 1

$D_x = 0$

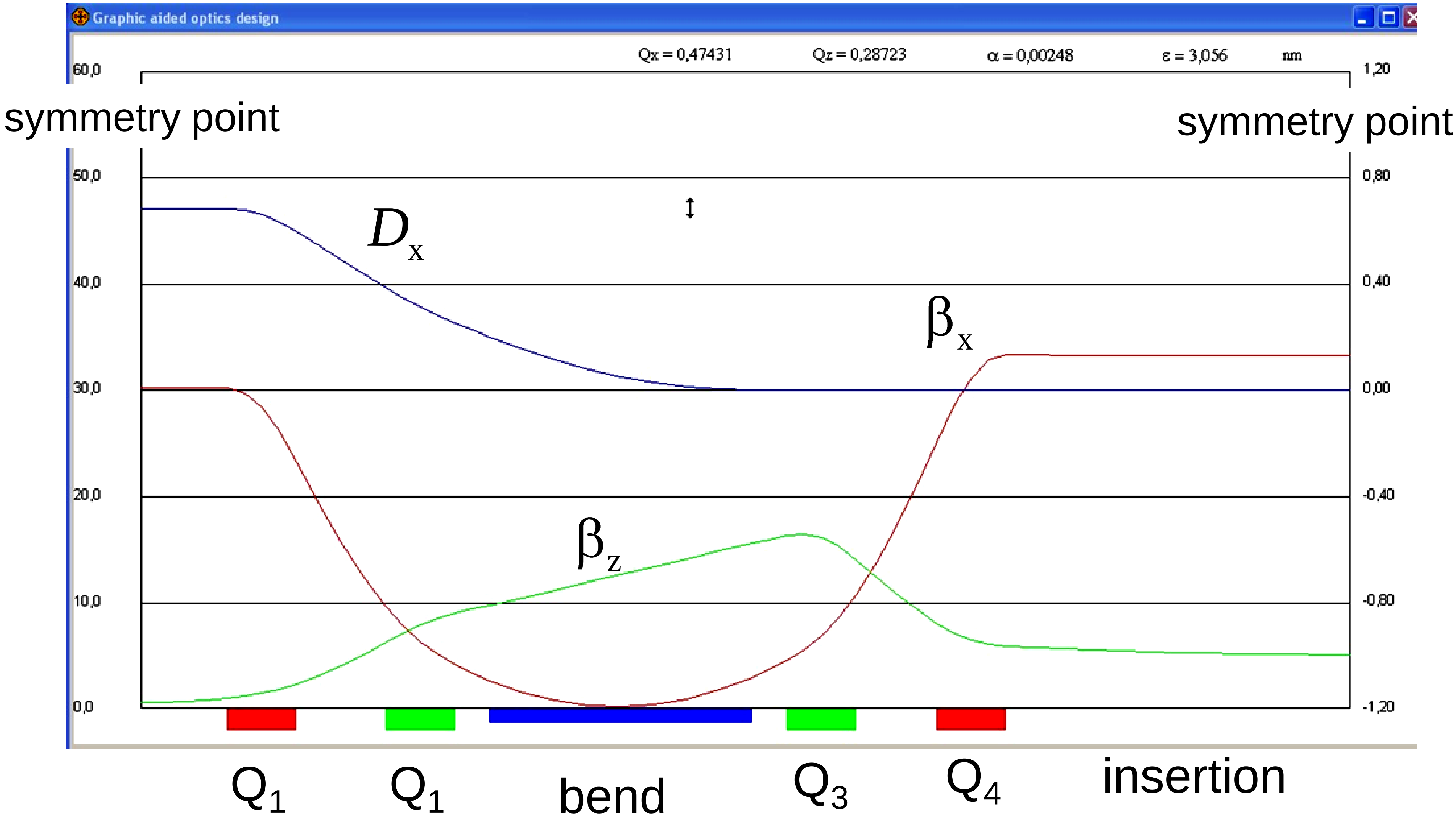
$D'_x = 0$

$\beta_x = 2.36\,\mathrm{m}$

$\alpha_x = 3.0$

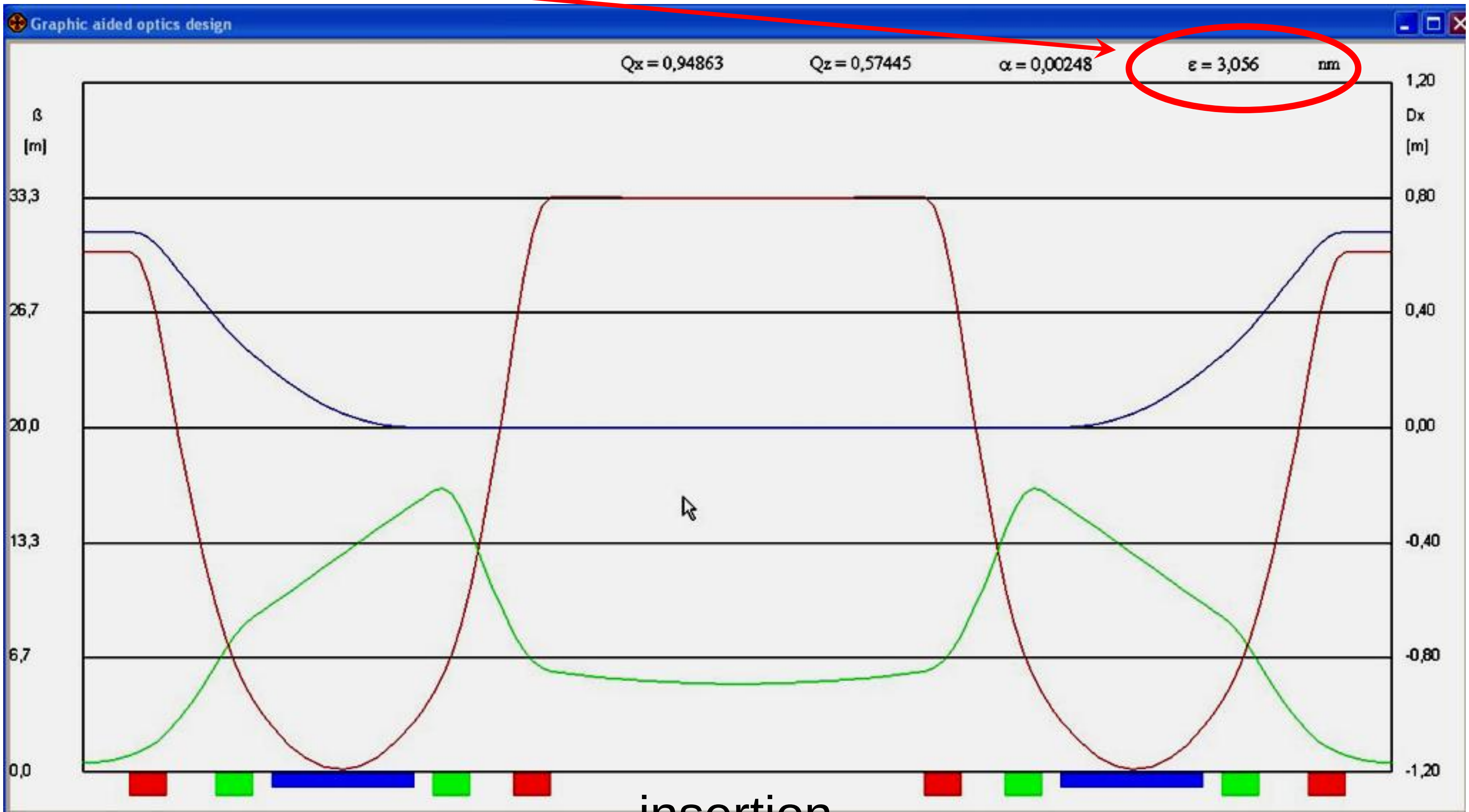


step 2: beam optics of one cell

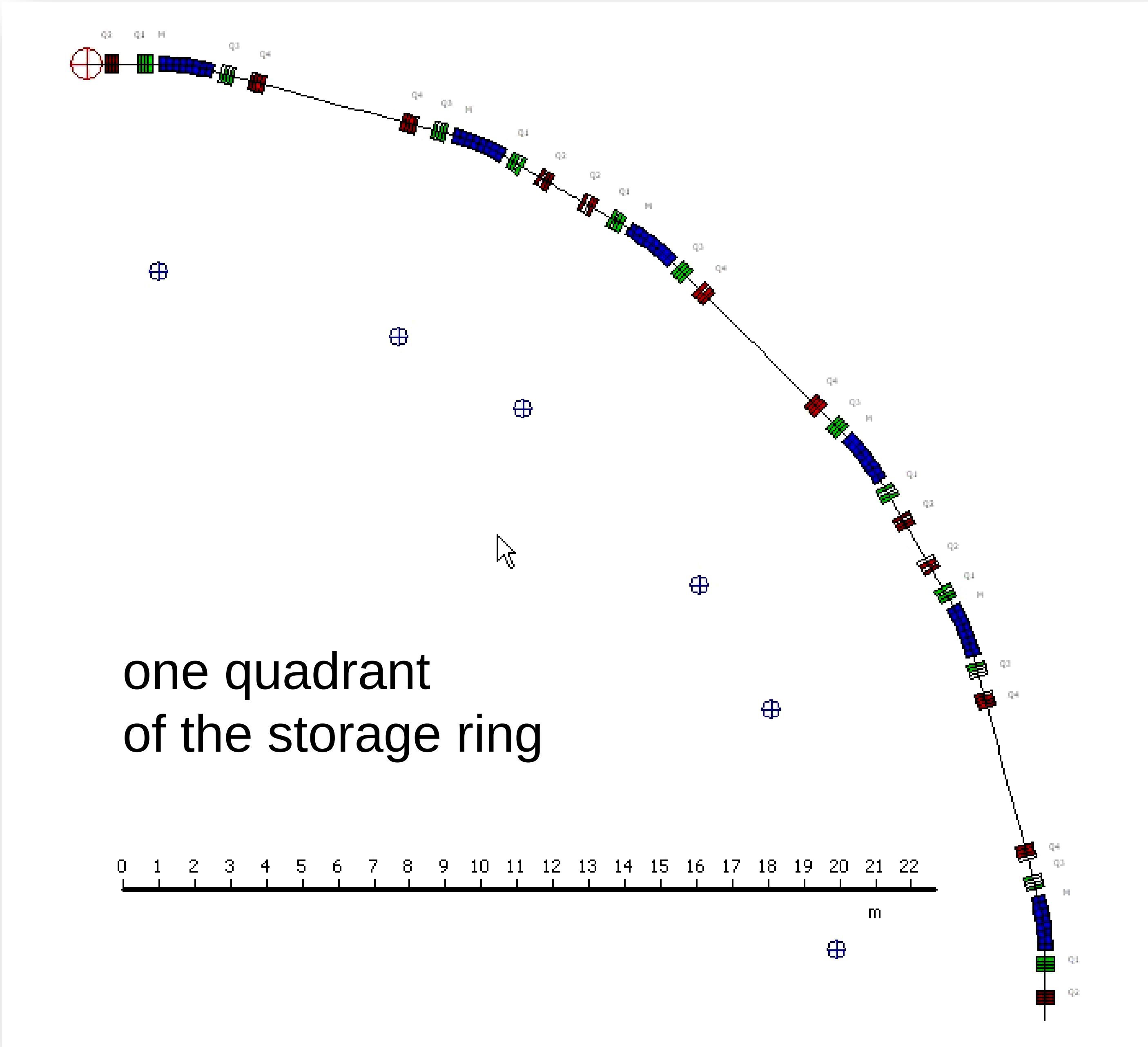


emittance calculated by the optics program:

$$\varepsilon_x = 3.06 \cdot 10^{-9}\,\mathrm{m\,rad} \quad @ \; 1\mathrm{GeV} \quad \Rightarrow \; \varepsilon_x = 1.34 \cdot 10^{-8}\,\mathrm{m\,rad} \; @ \; E_b$$



insertion



one quadrant
of the storage ring

4. Photon spectrum of the bending magnet radiation

The maximum beam current is set to $\boldsymbol{I_b = 100\ \mathrm{mA}}$

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

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

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

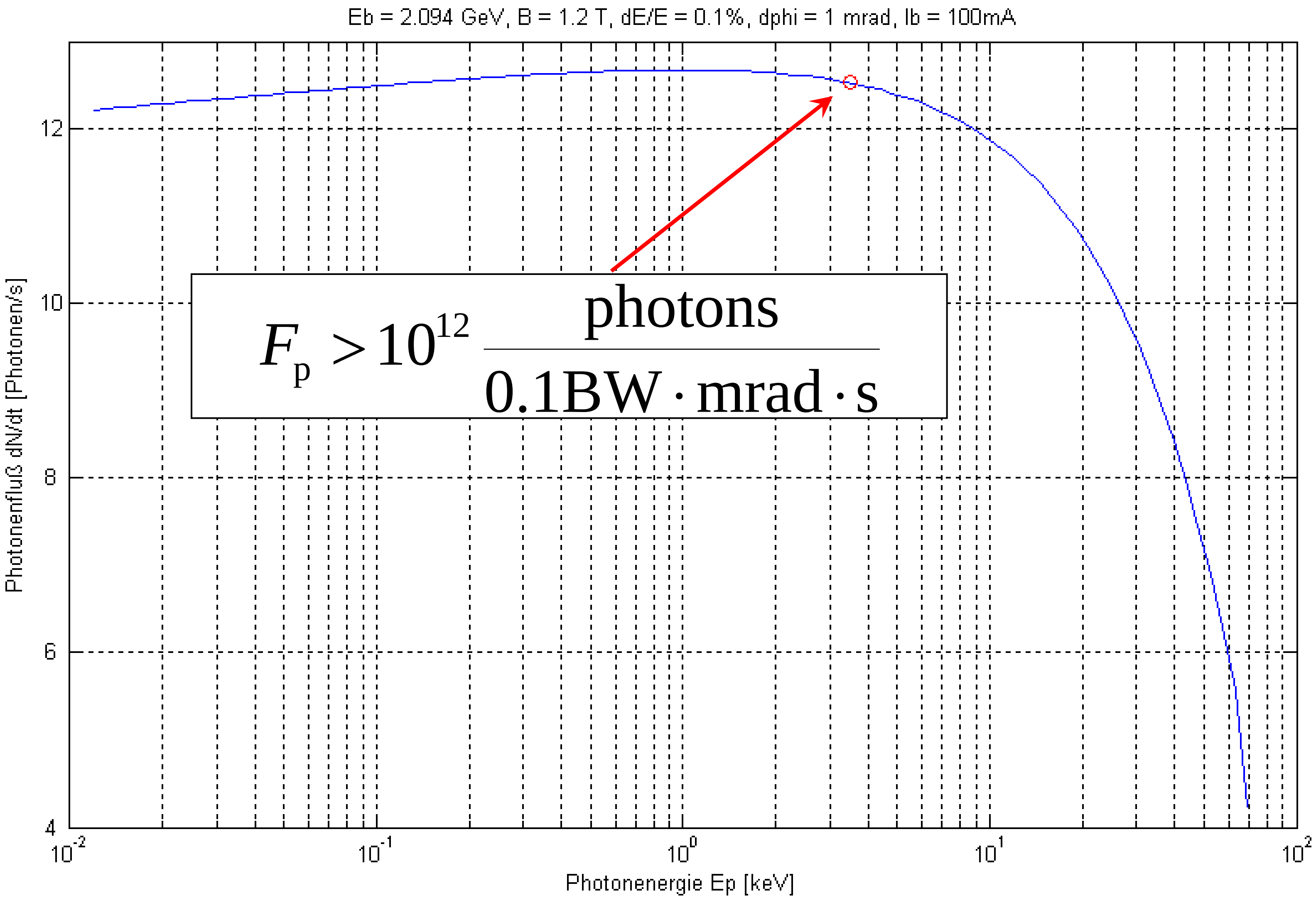
$$S(\xi) = \frac{9\sqrt{3}}{8\pi}\xi\int_\xi^\infty K_{5/3}(t)\,dt$$

The total emitted power is then

$$P_0 = 29.22\ \mathrm{kW}$$

The spectrum is calculated by a numerical computer code (i.e. MATLAB, SCILAB etc.

The spectrum of the bending magnet radiation



$$F_p > 10^{12} \frac{\text{photons}}{0.1\text{BW} \cdot \text{mrad} \cdot \text{s}}$$

4. Calculation of the wavelength shifter parameter

the required critical photon energy is $\mathbf{E_c \geq 20\ keV}$

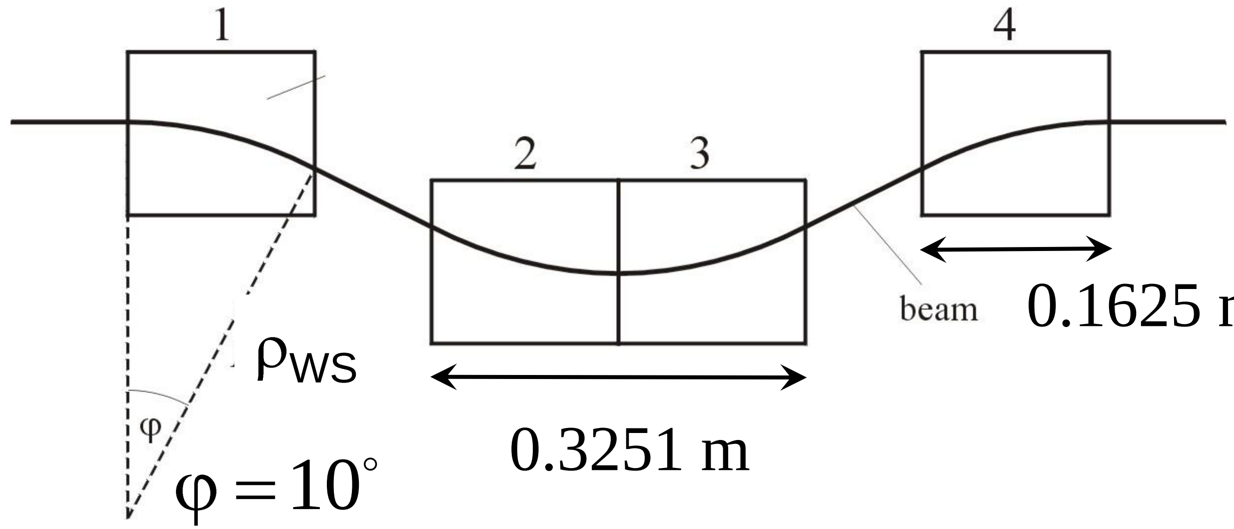
$$E_c = \hbar\omega_c = \frac{3\hbar c \gamma^3}{2\rho}$$

$$\frac{1}{\rho} = \frac{e c B}{E_b}$$

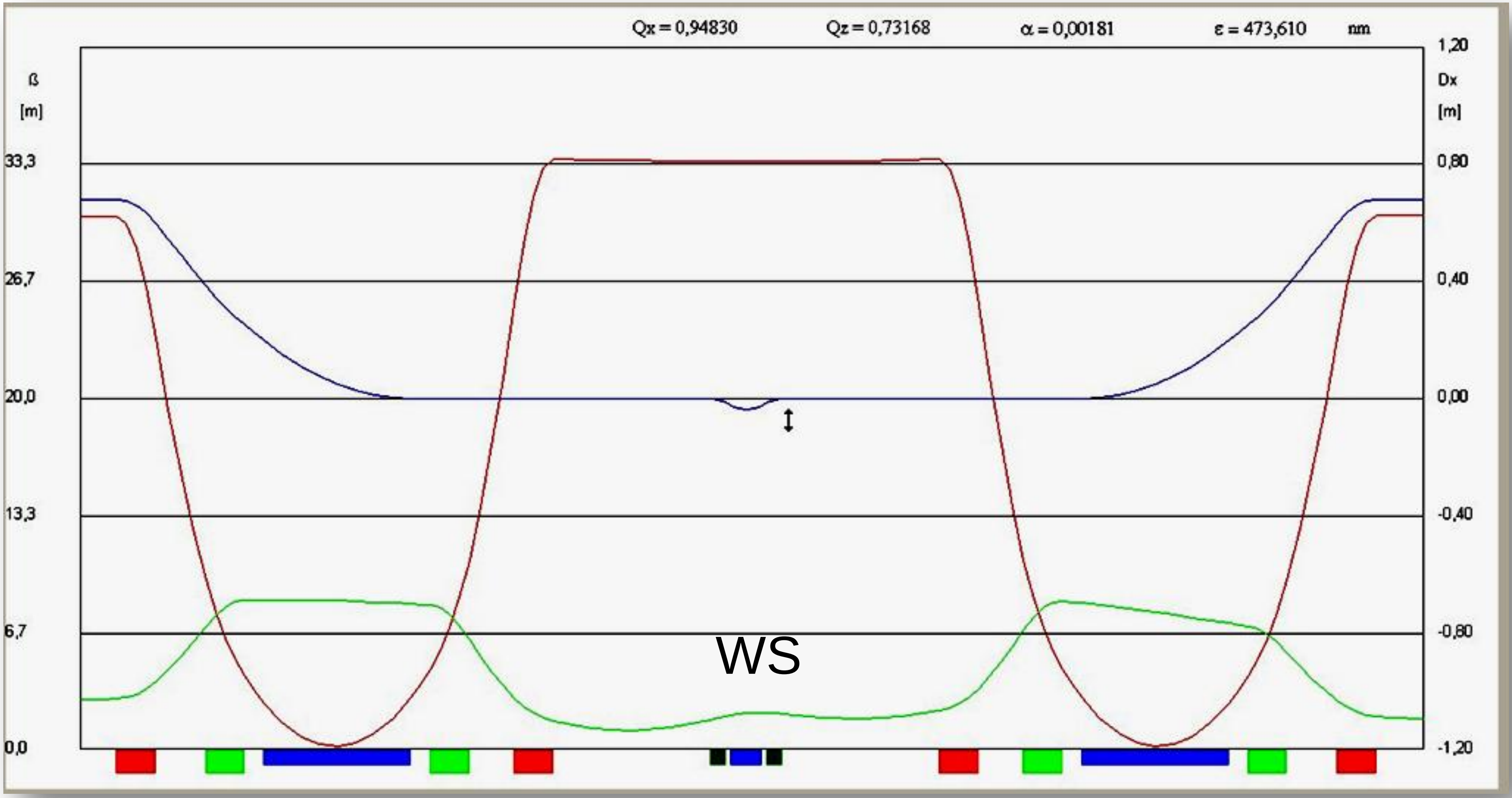
$B_{WS} = 7.5\,\mathrm{T}$ supercond.

$\rho_{WS} = 0.931311\ \mathrm{m}$

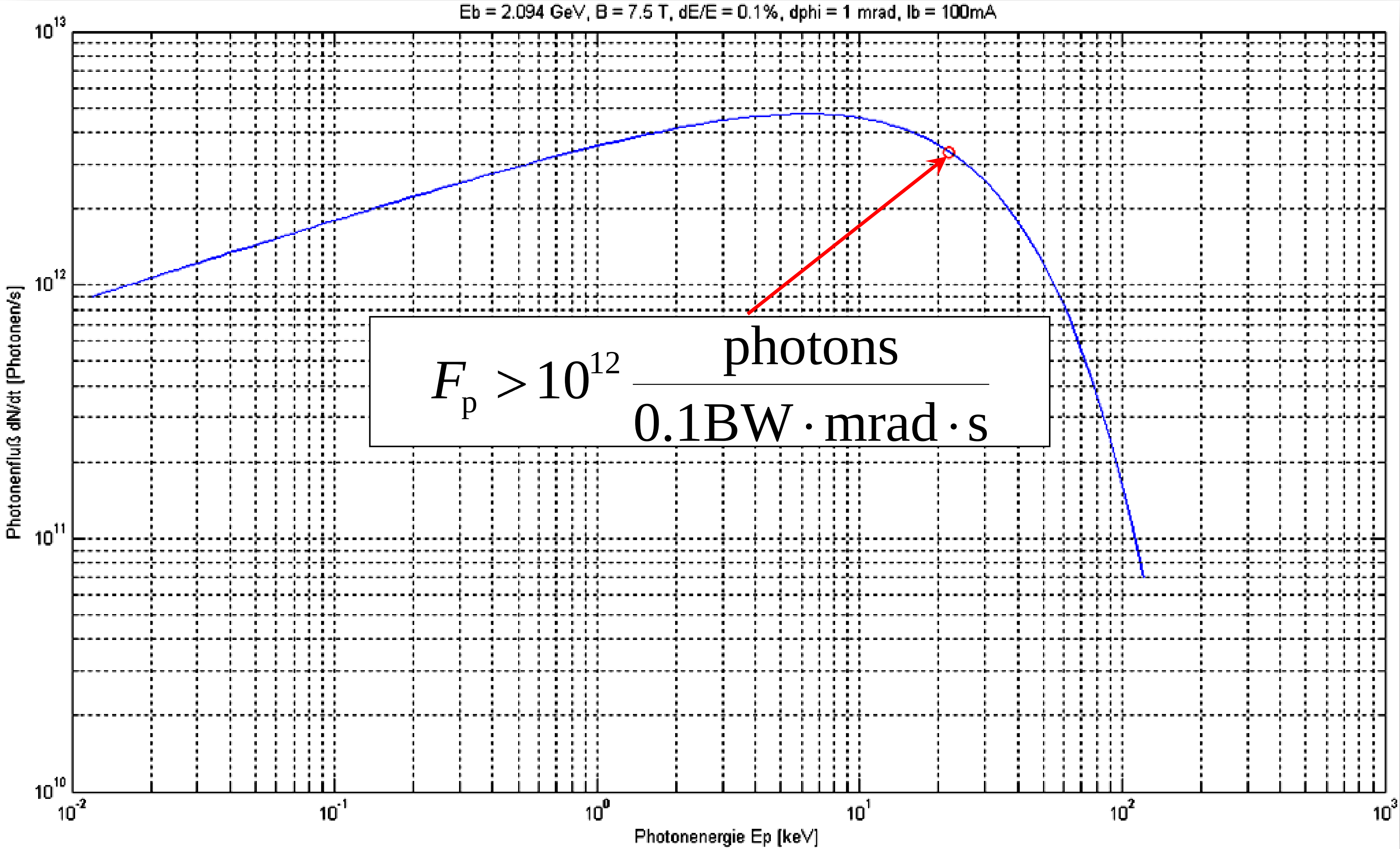
$E_c = 21.872\ \mathrm{keV}$



Beam optics with wavelenght shifter

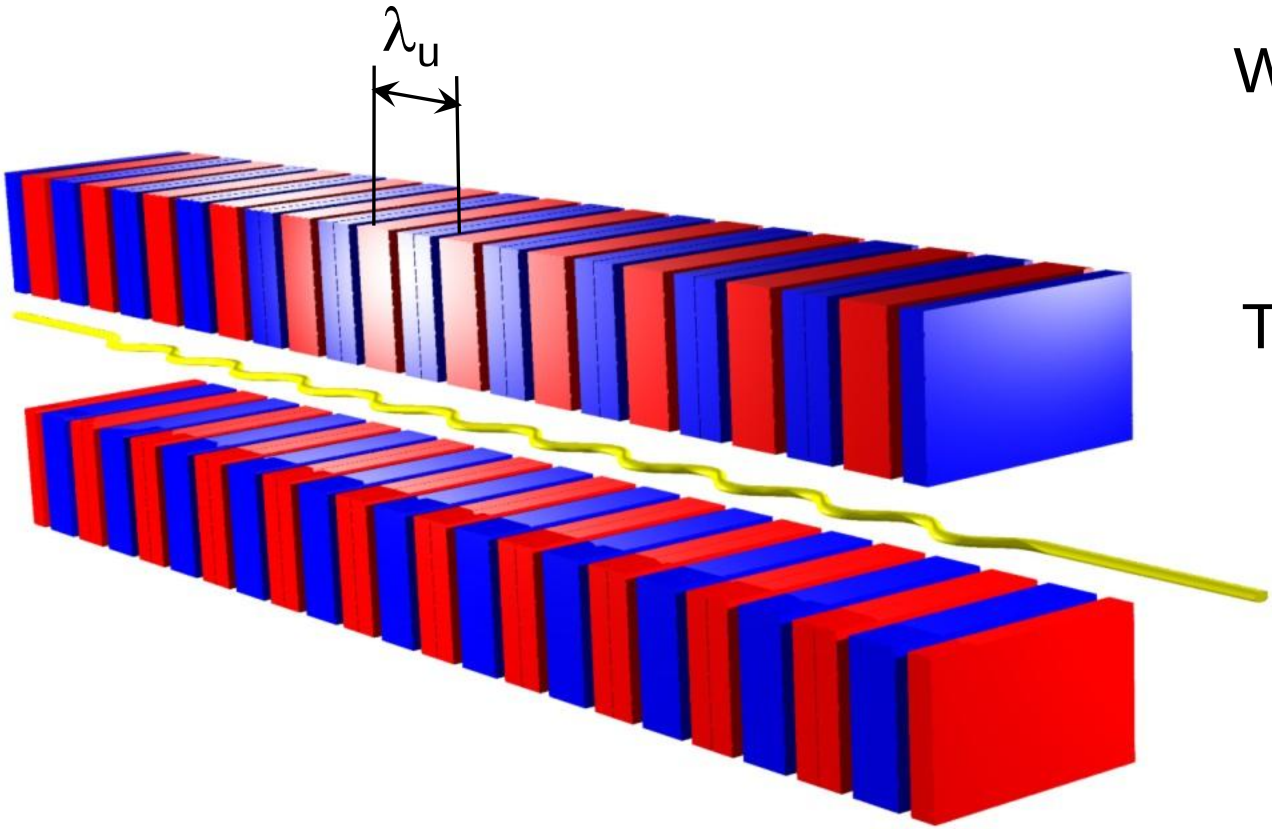


Specrum of the wavelength shifter



$$F_{\mathrm{p}} > 10^{12} \frac{\text{photons}}{0.1\mathrm{BW} \cdot \mathrm{mrad} \cdot \mathrm{s}}$$

5. Dimensions of the undulator



We try a periode length

$$\lambda_u = 0.05\ \mathrm{m}$$

The pole tip field is

$$B_0 = 1.2\ \mathrm{T}$$

gap height variation

$$g = 0.02 - 0.05\ \mathrm{m}$$

undulator peak field at the beam

$$\tilde{B} = \frac{B_0}{\cosh(\pi g/\lambda_u)} = 0.1035 - 0.6319\ \mathrm{T}$$

undulator parameter $$K = \frac{\lambda_u e \tilde{B}}{2\pi m_0 c} = 0.4833 - 2.9502$$

radiation wavelength $$\lambda = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\Theta^2\right)$$

$\Theta = 0$ $\lambda = 1.66 - 7.97 \text{ nm}$

$\Theta = 1\text{mrad}$ $\lambda = 26.66 \text{ - } 32.96 \text{ nm}$

required energy width

$$\frac{\Delta E_p}{E_p} = 0.01 \approx \frac{1}{N} \quad \Rightarrow \quad N \approx 100$$

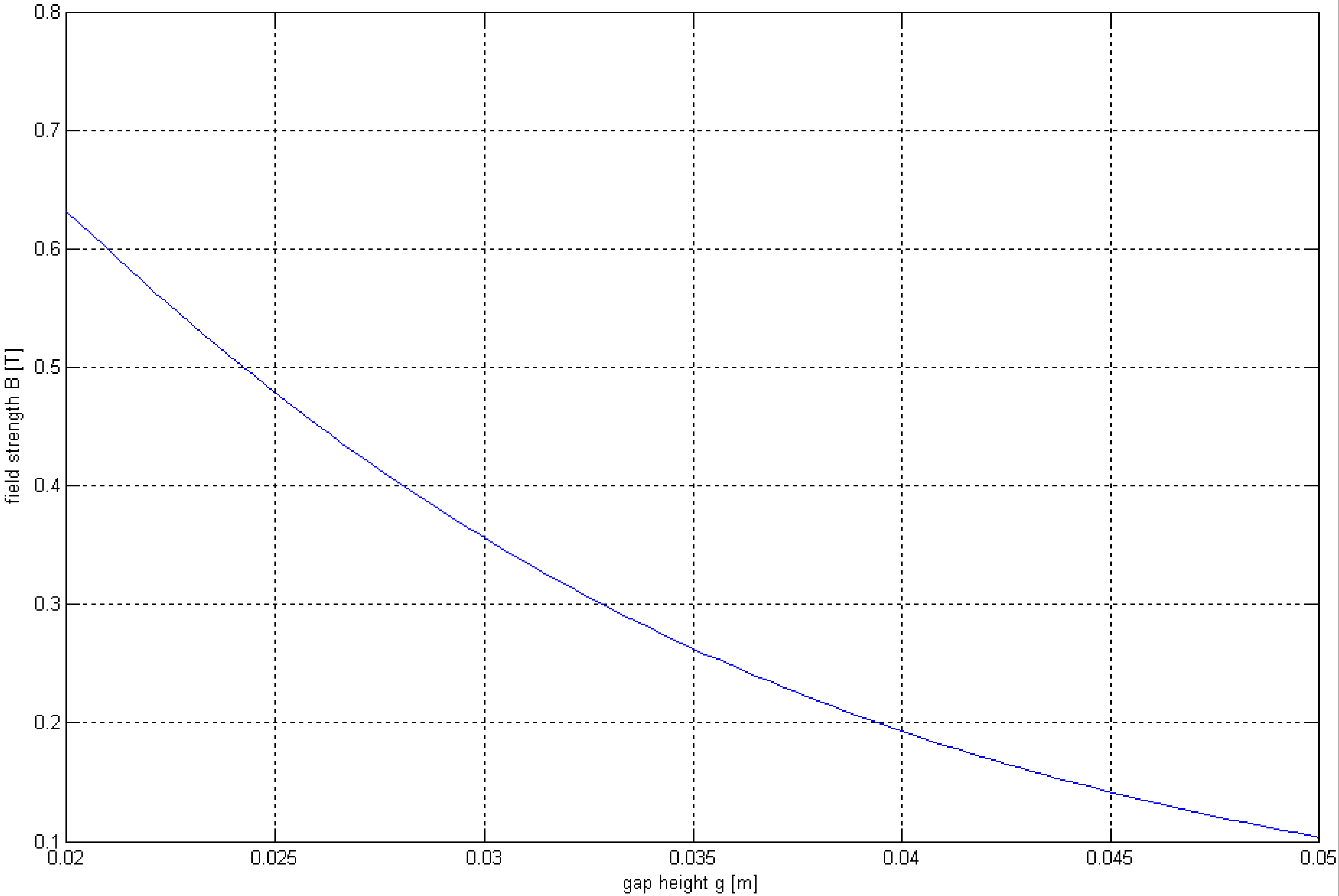
undulator length $$L_u = N\lambda_u = 5.0 \text{ m}$$

problem: the undulator is too long for the 4m-insertions

field strength as a function of the gap height

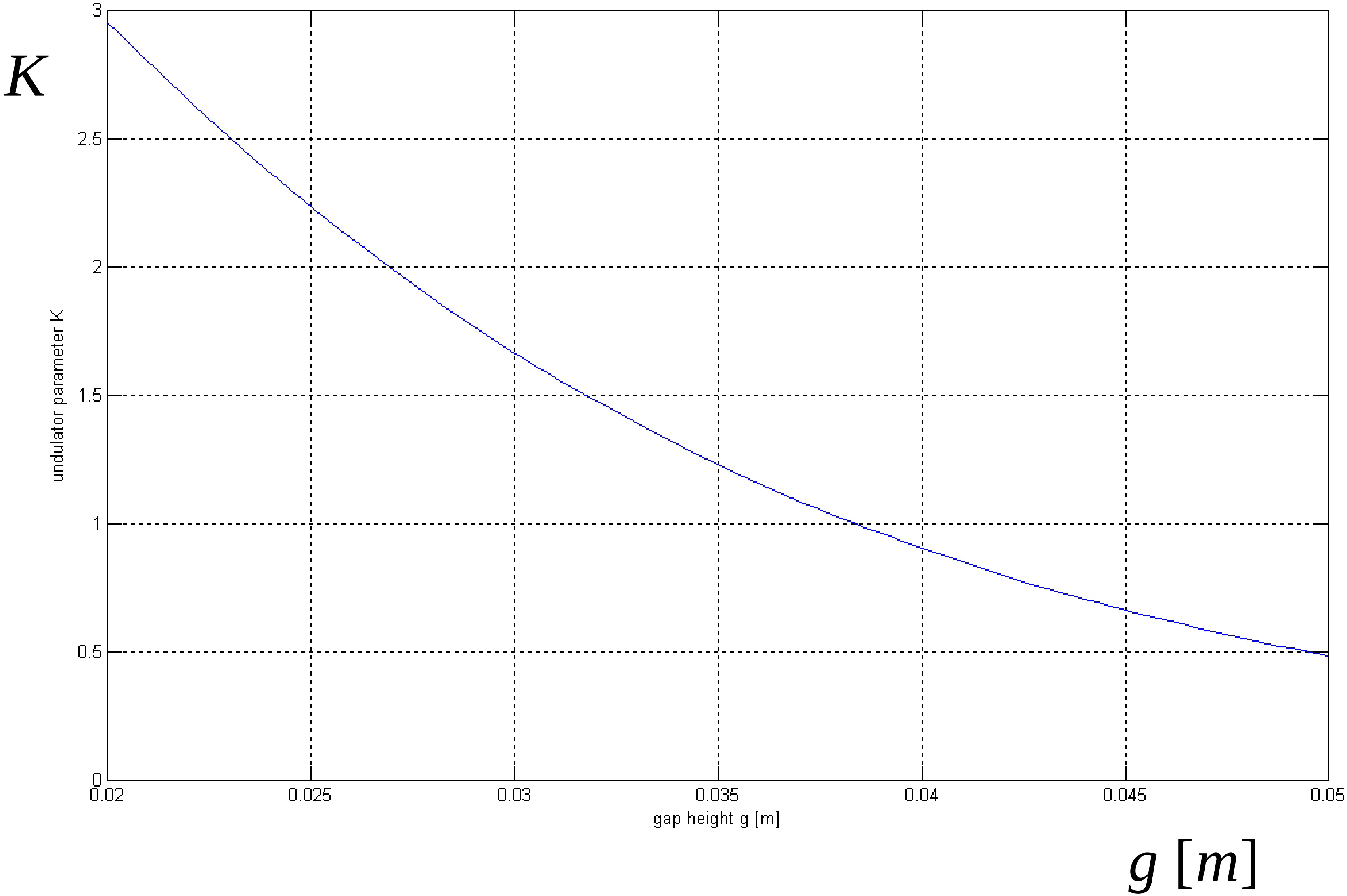
$\tilde{B}(g)$

[T]



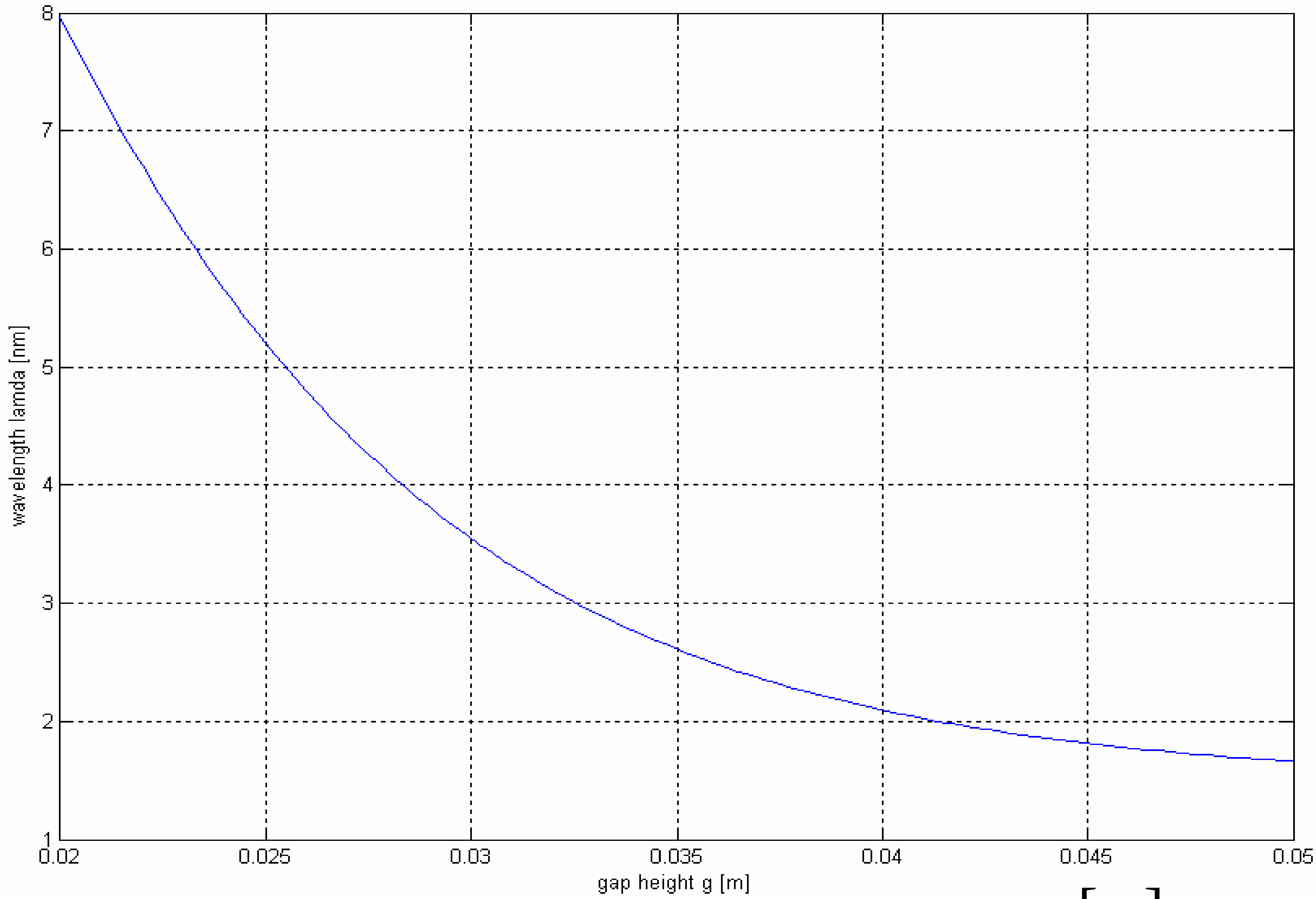
$g\ [m]$

undulator parameter as a function of the gap height



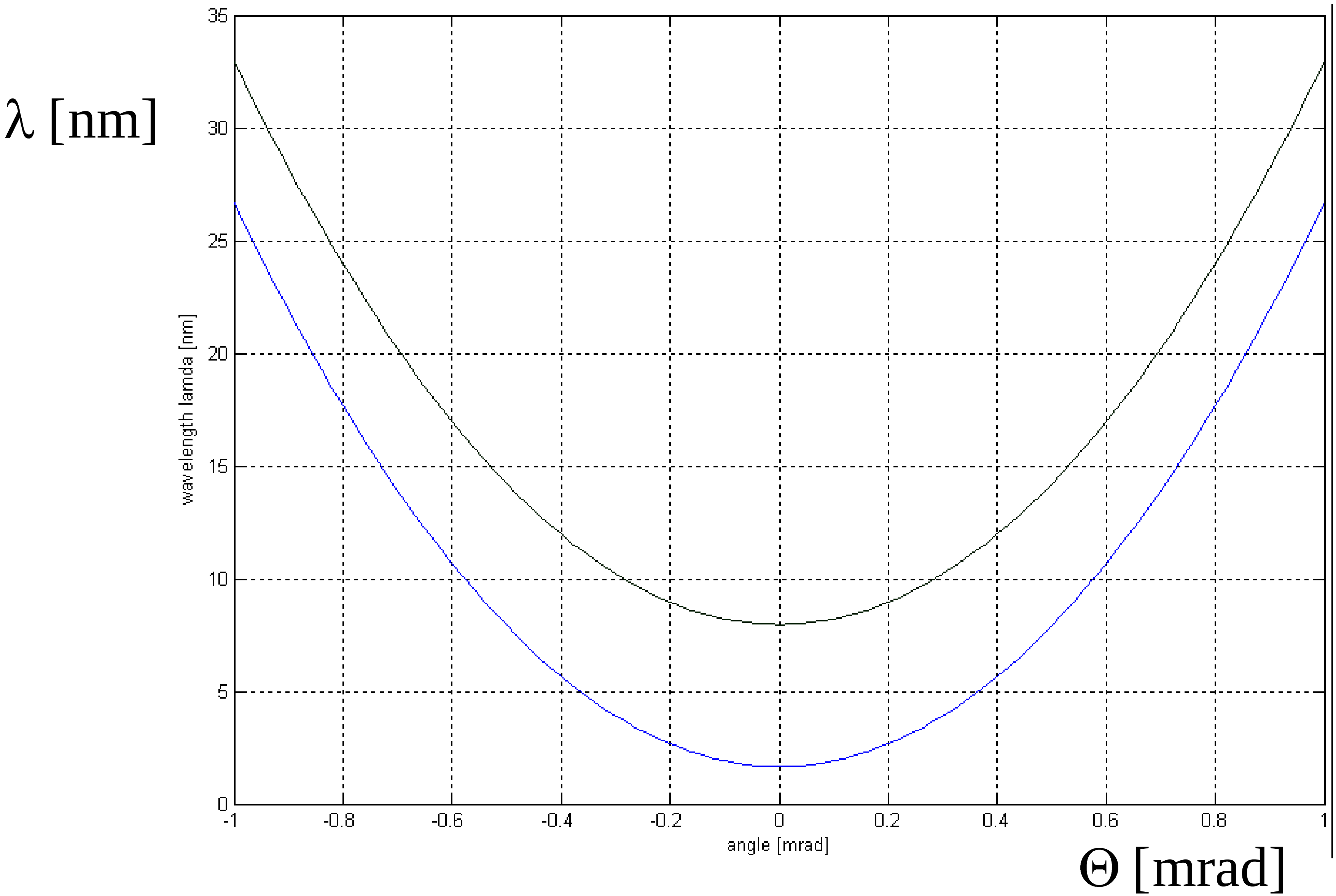
wavelength as a function of the gap height

λ [nm]



$g\ [m]$

wavelength as a function of the horizontal angle Θ



6. Calculation of the rf-system

we choose rf-wavelength:

$$f_{\mathrm{rf}} = 499.077\ \mathrm{Mhz} \quad \Rightarrow \quad \lambda_{\mathrm{rf}} = 0.6007\ \mathrm{m}$$

Circumference of the storage ring $L = 168.194\ \mathrm{m}$

The harmonic number is

$$q = \frac{L}{\lambda_{\mathrm{rf}}} = 280 = 2 \cdot 2 \cdot 2 \cdot 5 \cdot 7$$

The symmetry is sufficient.

Energy loss of the electrons per revolution

$$\Delta E\,[\mathrm{keV}] = 88.5\,\frac{E_{\mathrm{b}}^4}{\rho} \quad E_{\mathrm{b}}\ [\mathrm{GeV}], \quad \rho\ [\mathrm{m}]$$

1. energy loss caused by the bending magnets ($\varphi = 360°$)

$$\rho = 5.821\,\mathrm{m} \quad \Rightarrow \quad \Delta E = 88.5\frac{E_b^4}{\rho} = 292.32\ \mathrm{keV}$$

2. energy loss caused by wavelength shifter ($\varphi = 40°$)

$$\rho_{WS} = 0.93131\,\mathrm{m} \quad \Rightarrow \quad \Delta E_{WS} = 88.5\frac{E_b^4}{\rho_{WS}}\frac{\varphi_{WS}}{2\pi} = 203{,}0\ \mathrm{keV}$$

all other radiation is negligible. The total energy loss per turn is

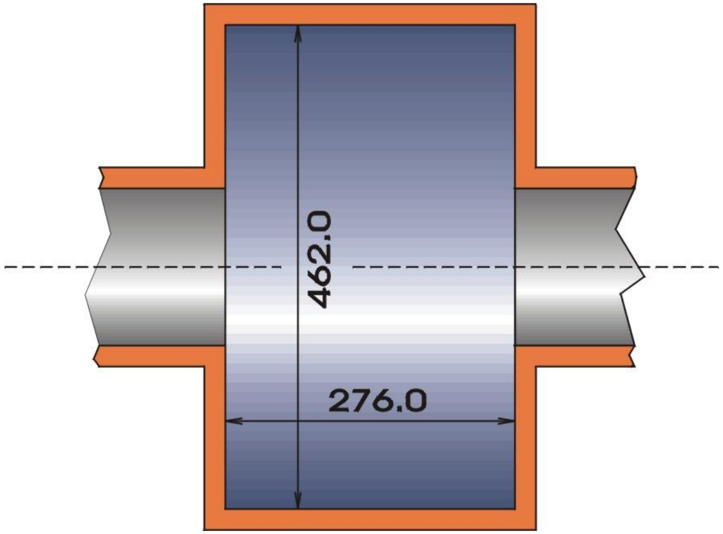
$$\Delta E_{tot} = \Delta E + \Delta E_{WL} = 495.33\ \mathrm{keV}$$

per revolution we need an accelerating voltage of

$$U_{acc} = 495.33\ \mathrm{kV}$$

The required beam current is $I_b = 0.1\ \mathrm{A}$ and the radiated power

$$P_{rad} = U_{acc} I_b = 49.533\ \mathrm{kW}$$



We use pilbox-cavities

typical values (DORIS-type)

$$R_s = 3.0\ \mathrm{M\Omega} \quad \Rightarrow \quad U_{cav} = \sqrt{2 P_{rf} R_s}$$

$$P_{max} = 50\,\mathrm{kW} \qquad U_{cav} = 548\,\mathrm{kV}$$

Using normal conductive cavities the total rf-power from the transmitter is splitt into the beam power and the cavity losses.

A good approximation is

$$P_{total} = P_{cavity} + P_{beam}\,, \qquad P_{cavity} \approx P_{beam}$$

Therefore we need 2 cavities and a total rf-power $P_{rf} \geq 100\ \mathrm{kW}$

7. Injection system

1. Full energy injector

This is the best solution, but the most expensive one.

At the maximum beam energy the betatron damping time is (optics program)

The time between two injection should

$$T_{\mathrm{inj}} \approx 5 \cdot \tau \approx 40\,\mathrm{ms} \quad \Rightarrow \quad \max\ f_{\mathrm{inj}} = 25\,\mathrm{Hz}$$

2. half energy injector $E_{\mathrm{inj}} = 1\,\mathrm{GeV}$

The damping time is $\tau = 74.6\ \mathrm{ms}$

The time between two injection is now

$$T_{\mathrm{inj}} \approx 5 \cdot \tau \approx 375\,\mathrm{ms} \quad \Rightarrow \quad \max\ f_{\mathrm{inj}} = 2.68\,\mathrm{Hz}$$

$\Rightarrow$ long injection time and in addition the time needed for energy ramping