Design progress on longitudinal strong focusing SSMB

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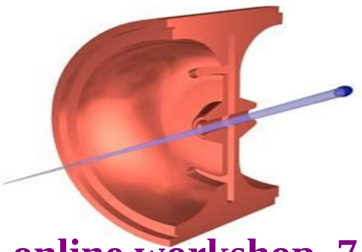
On behalf of Tsinghua SSMB Team

2020/12/08

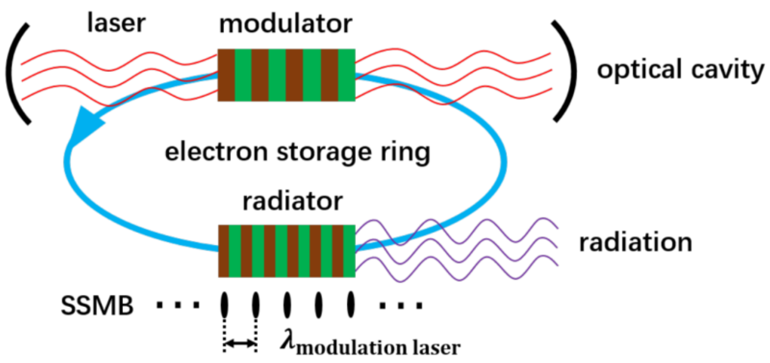


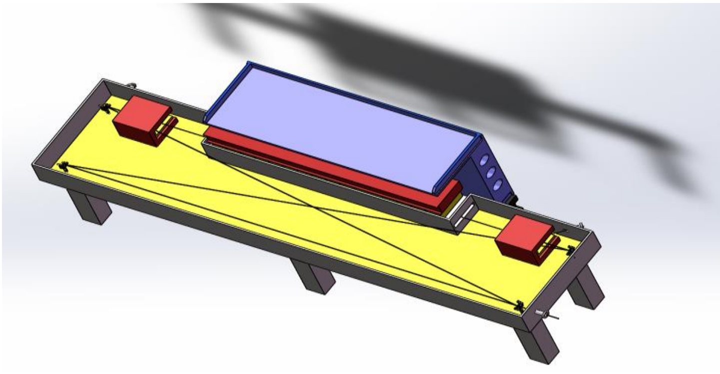
Accelerator Laboratory of Tsinghua University

contents

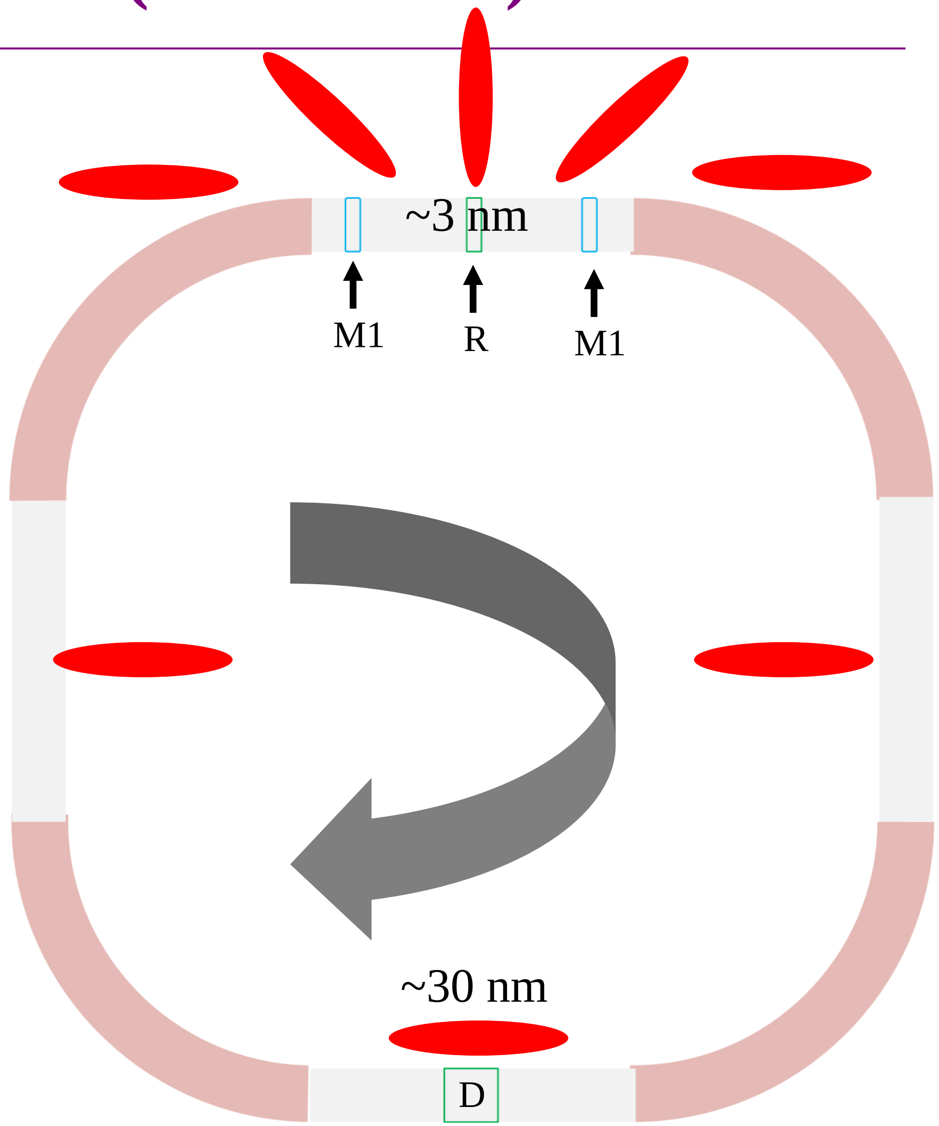
Longitudinal strong focusing SSMB (LSF SSMB)

- The longitudinal phase space is strongly rotated
- M1 is laser modulator, electron will get a energy chirp and bunched by laser wavelength here.



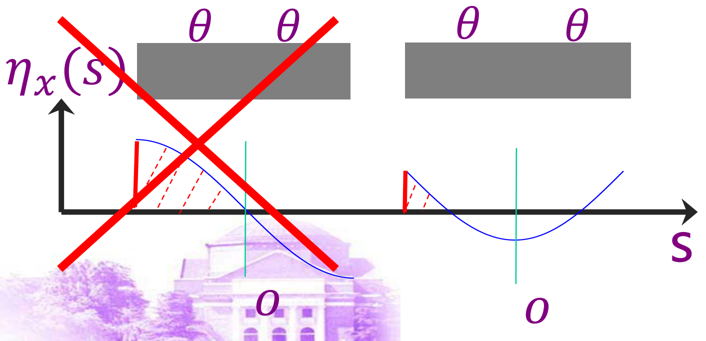


The laser wavelength will be ~1 μm,
hundreds of MW peak power is required.

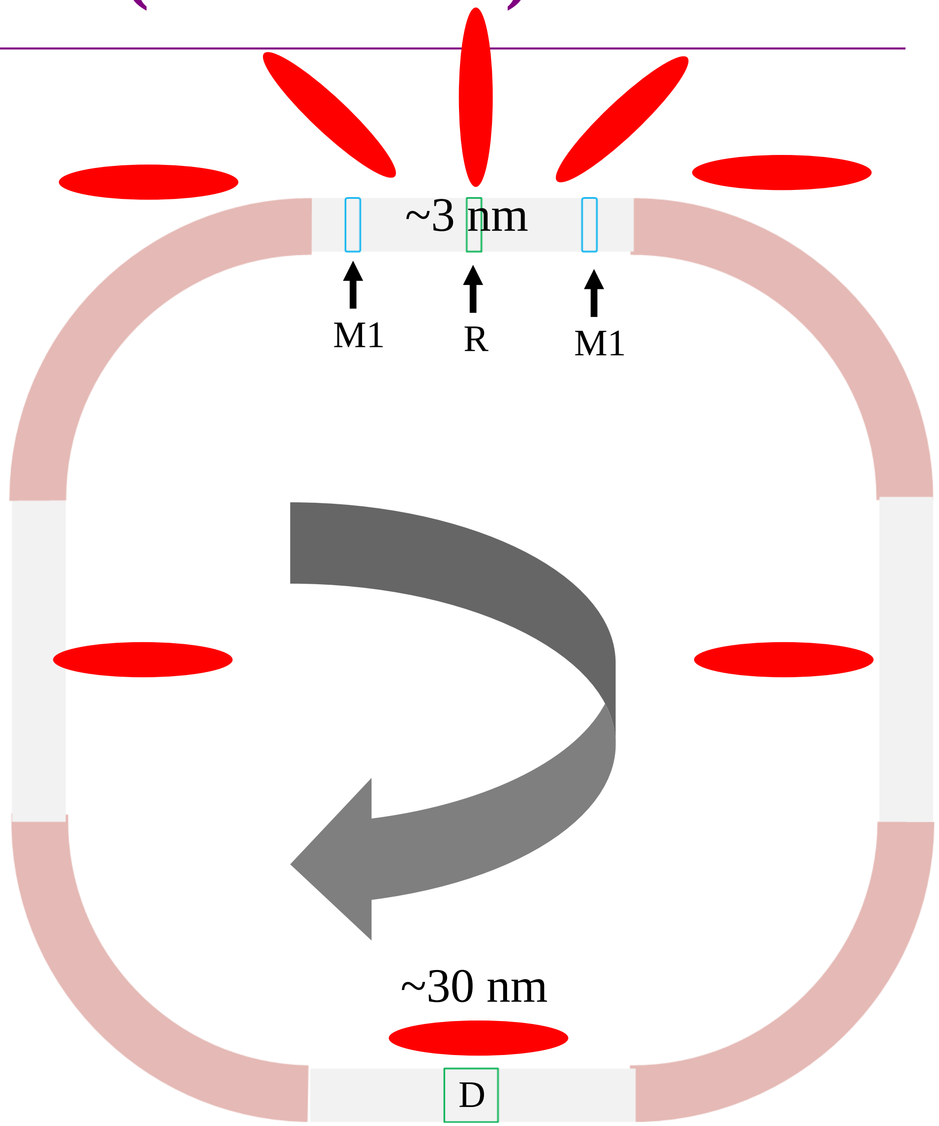


Longitudinal strong focusing SSMB (LSF SSMB)

- The electron is then compressed downstream and the bunch length should less than 3 nm at radiator.
- The bunch length at other dispersion free location will be less than 100 nm.
- The key point is to control longitudinal emittance in LSF SSMB.
- Horizontal emittance should be as large as possible to provide a reasonable Touschek lifetime.
- A special lattice is launched to minimize local momentum compaction factor as possible as we can.

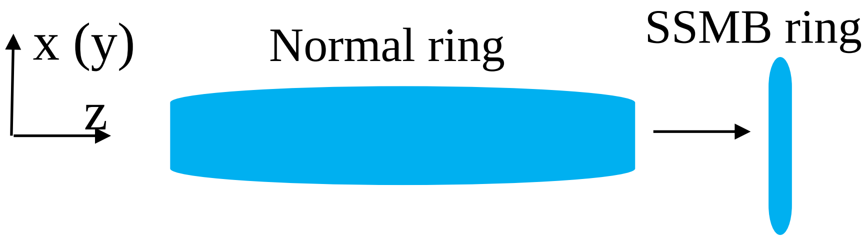


Control the dispersion function in dipoles precisely.



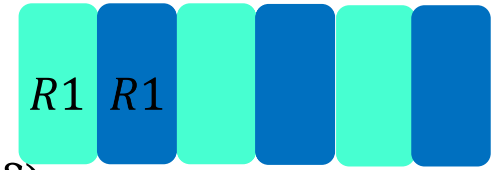
Design scheme

- **6D size optimization**



- **Bucket optimization**

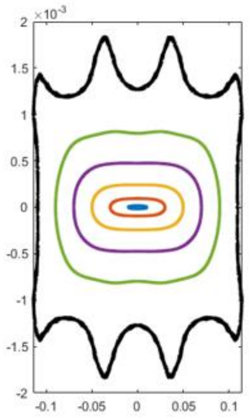
R56 of undulator



(z, δ)

$$R1 = \begin{bmatrix} 1 & R56 \\ 0 & 1 \end{bmatrix} \quad K1 = \begin{bmatrix} 1 & 0 \\ -\frac{V}{k}\sin(kz) & 1 \end{bmatrix}$$

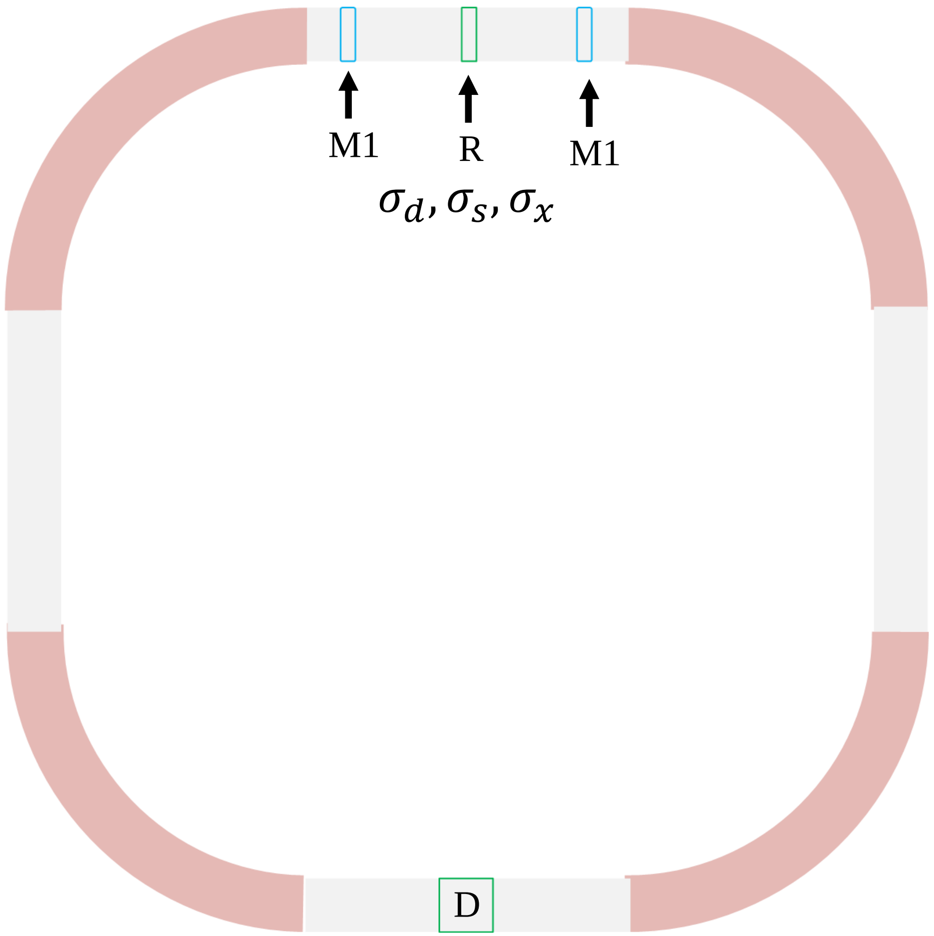
$$M = K1 * R1 * \cdots * K1 * R1$$



MOGA

- Variables: bending radius and angle; quadrupole strength; distance between dipoles; modulator parameters; radiator parameters.
- Dependent variables: longitudinal and transverse twiss functions; emittance; longitudinal bucket height
- Objectives: touschek lifetime; radiation power;
- Constrains: lattice matching; undulator and modulator period (also length); laser power; magnet length and strength;

Design scheme



• Objectives: radiation power

$$P_{\rm rad} = 2\pi^2 r_0 m_e c^3 F |B|^2 \frac{K^2}{2+K^2} [JJ]^2 \frac{N_u N_\mu^2}{\lambda_m^2} D$$

where $[JJ] = J_0(\chi) - J_1(\chi)$ with $\chi = \frac{K^2/2}{2+K^2}$, and

$$F = \frac{2}{\pi}\left[\tan^{-1}\left(\frac{1}{2S}\right) + S\ln\left(\frac{4S^2}{4S^2+1}\right)\right] \quad S = \frac{2\pi\sigma_x^2}{\lambda_r L_r}$$

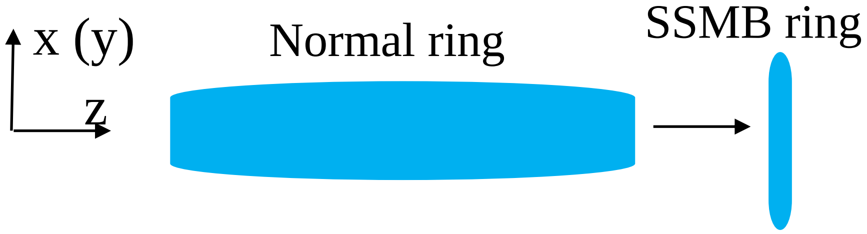
$$B^2 = e^{-(\frac{2\pi\sigma_s}{\lambda_r})^2}$$

$$D = \sqrt{\pi}\frac{\mathrm{erf}(\xi)}{\xi} + \frac{e^{-\xi^2}-1}{\xi^2} \quad \xi = 2\sqrt{2}\pi N_u \sigma_d$$

- Radiation power is strongly affected by the parameters of electron bunch at radiator: bunch length σ_s, energy spread σ_d, horizontal size σ_x. That is also 6D size.
- Radiation power is also affected by the parameters of undulator, by almost decoupling with the bunch parameters.

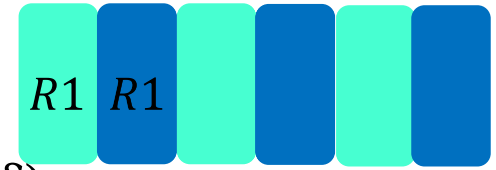
Design scheme

• 6D size optimization



• Bucket optimization

R56 of undulator



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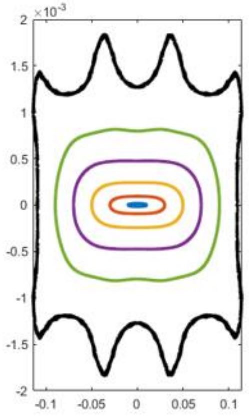


• Objectives: Touschek lifetime

$$\frac{1}{T_\ell} = \left\langle \frac{r_p^2 c N_p}{8\pi\gamma^2\sigma_s\sqrt{\sigma_x^2\sigma_z^2 - \sigma_p^4 D_x^2 D_z^2}\,\tau_m} F(\tau_m, B_1, B_2) \right\rangle$$

with

$$F(\tau_m, B_1, B_2) = \sqrt{\pi(B_1^2 - B_2^2)}\,\tau_m \int_{\tau_m}^{\infty} \left(\left(2+\frac{1}{\tau}\right)^2 \left(\frac{\tau/\tau_m}{1+\tau} - 1\right) + 1 - \frac{\sqrt{1+\tau}}{\sqrt{\tau/\tau_m}} - \frac{1}{2\tau}\left(4+\frac{1}{\tau}\right)\ln\frac{\tau/\tau_m}{1+\tau}\right) e^{-B_1\tau} I_o(B_2\tau)\frac{\sqrt{\tau}\,d\tau}{\sqrt{1+\tau}}$$

- Lifetime is affected by the 6D size and momentum acceptance all around the ring.
- What we need is very small size at radiator but large beam size elsewhere of the ring.

Design scheme

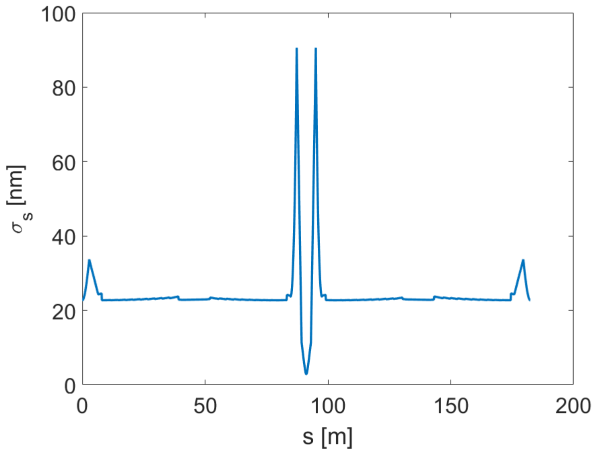
• Longitudinal emittance

$$\epsilon_L = \frac{55}{24\sqrt{3}} \frac{1}{\alpha_L} \oint ds\, \beta(s) \frac{\alpha_F {\lambda_e}^2 \gamma^5}{\rho^3(s)}$$

$$\alpha_L \approx \frac{2}{E_0}(U_0 + U_{0m} + U_{0r})$$

Calculate the contribution of modulator and radiator, damping wiggler

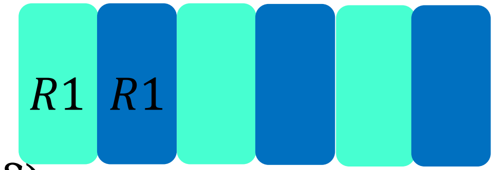
Control longitudinal twiss functions



There is no horizontal-longitudinal coupling in this figure.

• Bucket optimization

R56 of undulator



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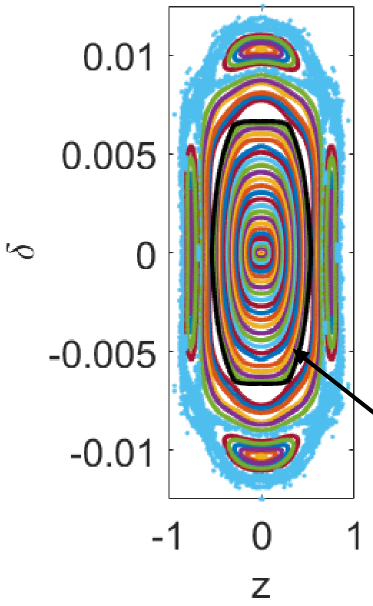
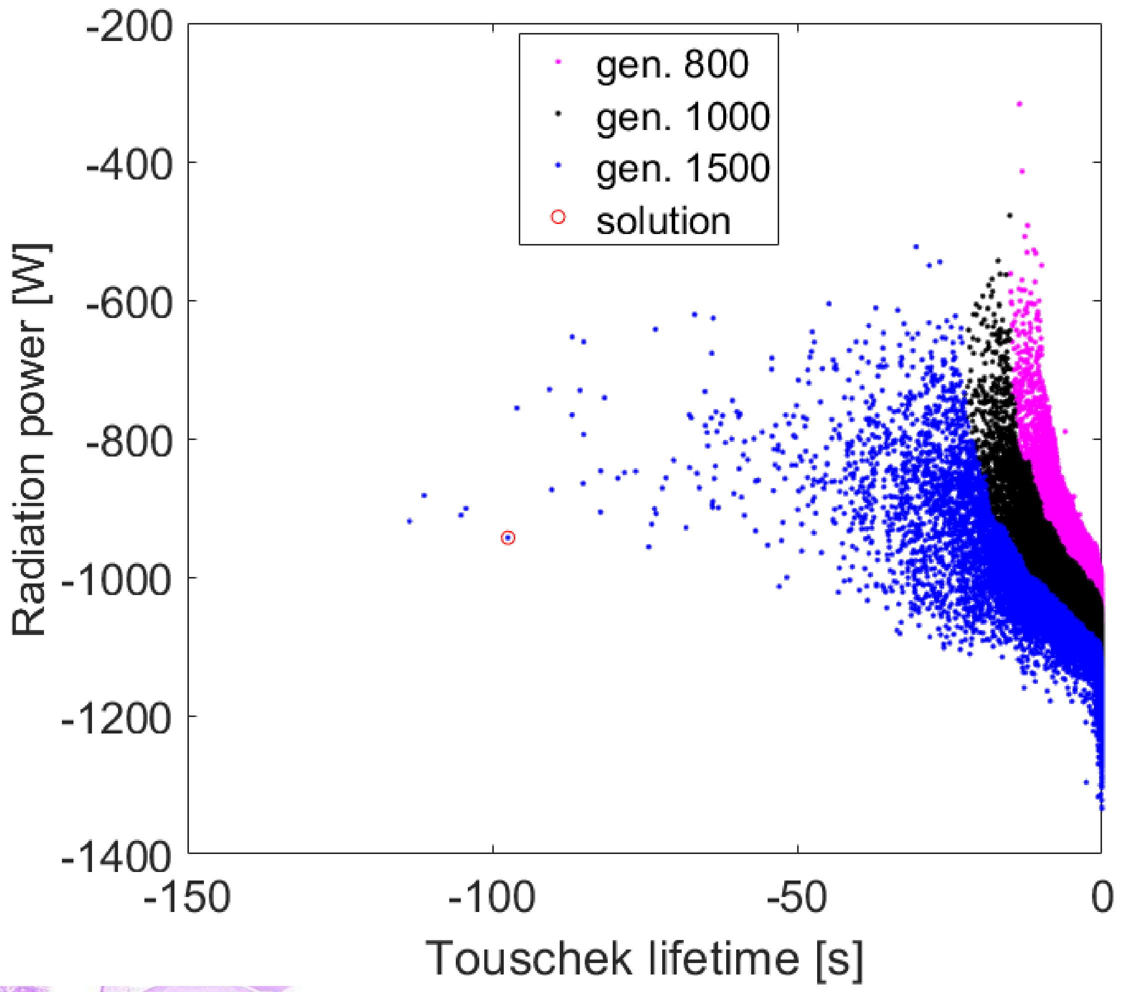


The bucket area we choose

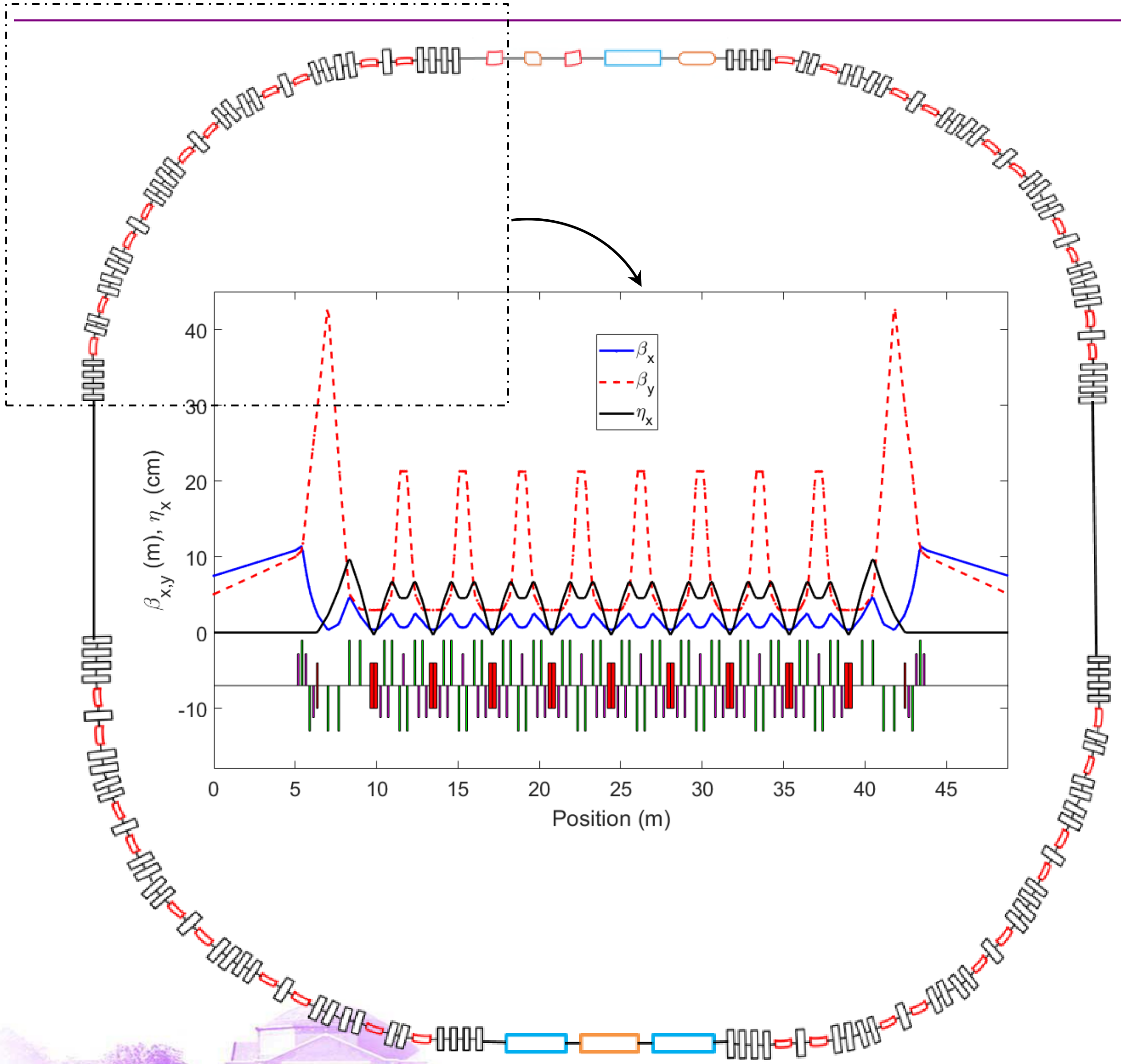
- ➢ Drop off bad bucket.
- ➢ Kick the resonance area out
- ➢ Inside the black line is area we can use
- ➢ No nonlinear of lattice has been considered.

Results



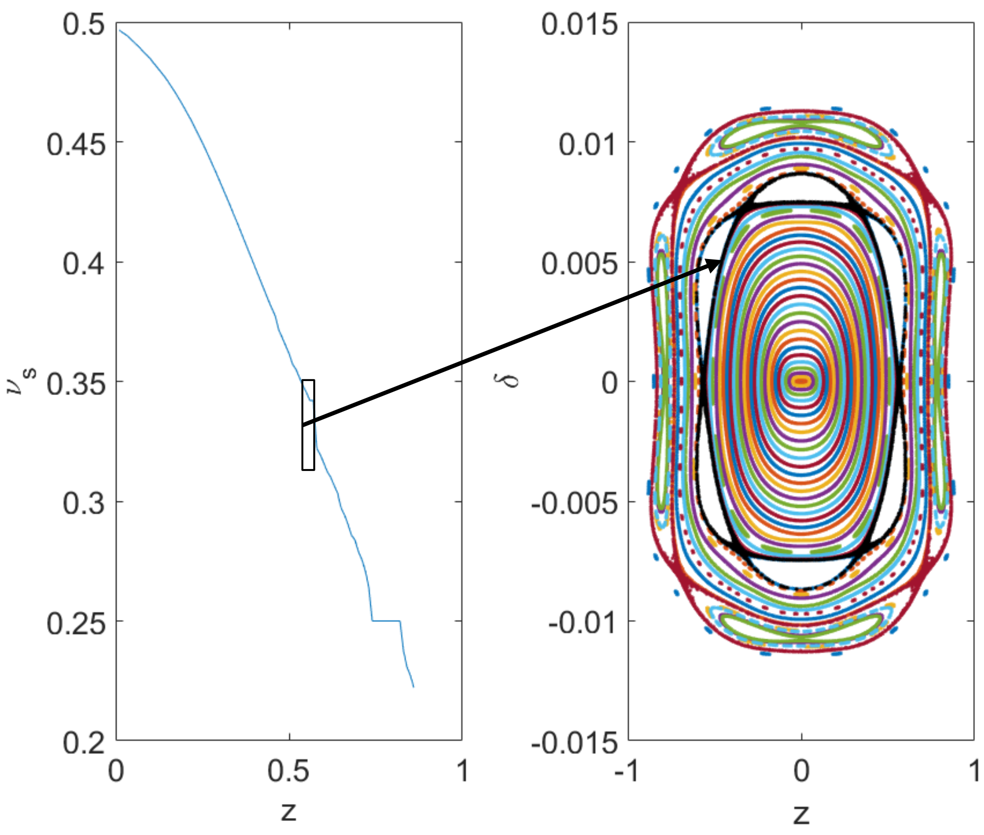
Population:10000
Generation: 1500
Laser peak power: 300 MW
Beam energy: 400 MeV
Beam current: ~1 A @coasting beam

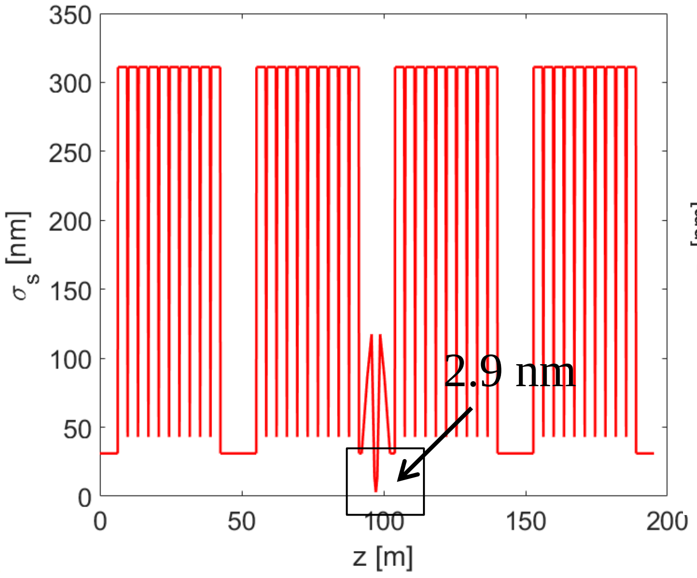
Results

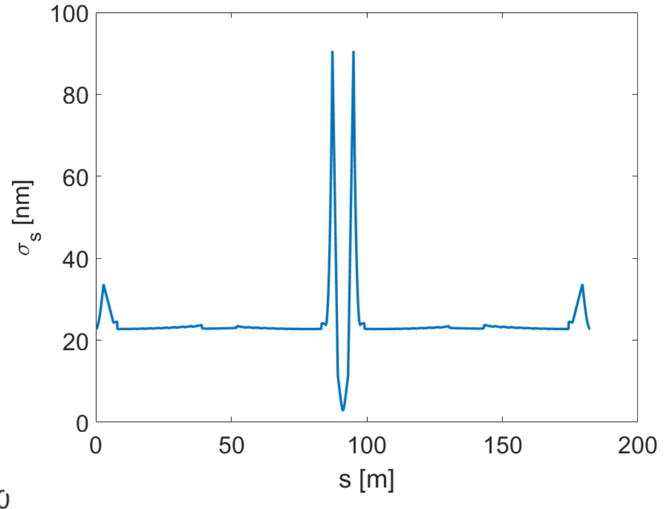


Parameters	Value
Circumference [m]	195.2
Tunes(x/y)	25.58/5.80
Chromaticity(x/y)	0.001/0.001
Beam energy [MeV]	400
Phase slippage factor η	1.0e-6
Second order Phase slippage factor η_2	6.0e-6
Energy spread	2.0e-4
Natural emittance [pm]	84.2
Energy loss per turn [keV]	1.5

Results







Touschek lifetime is about 100 s.

Bunch length is strongly affected by horizontal-longitudinal coupling.

Laser peak power: 300 MW

Bucket height: 0.7 %

Summary and discussions

- By 6D optimization, radiation power and Touschek lifetime is optimized simultaneously, the Touschek lifetime is ~100 s, radiation power is ~1 kW.
- There is still some matching need to do, for example the twiss functions around wigglers and undulator.
- The nonlinear dynamics is not included in present optimization, more study need to be done to include the nonlinear effects, such as longitudinal aperture and horizontal aperture.
- Implement a tracking tool for laser modulation is also important to confirm the optimization result.

Thanks for you attention!