トシェック散乱による ビームロスの計算結果修正*

*Beam Loss Due To Touschek Scattering. Simulation Results Corrections

2013年10月22日(火)14時00分
ビームダイナミクスWG打ち合わせ

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Outline

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  - Lattice & optics
  - Beam parameters
- Results
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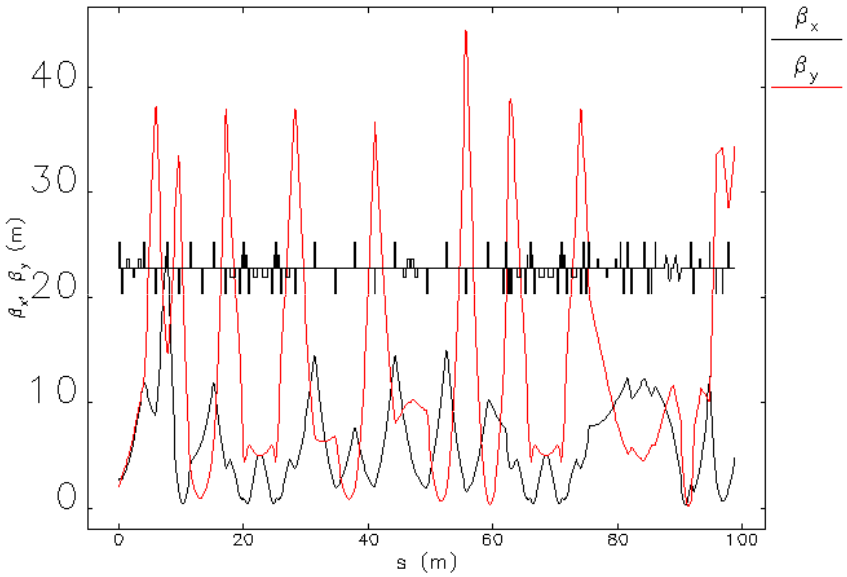
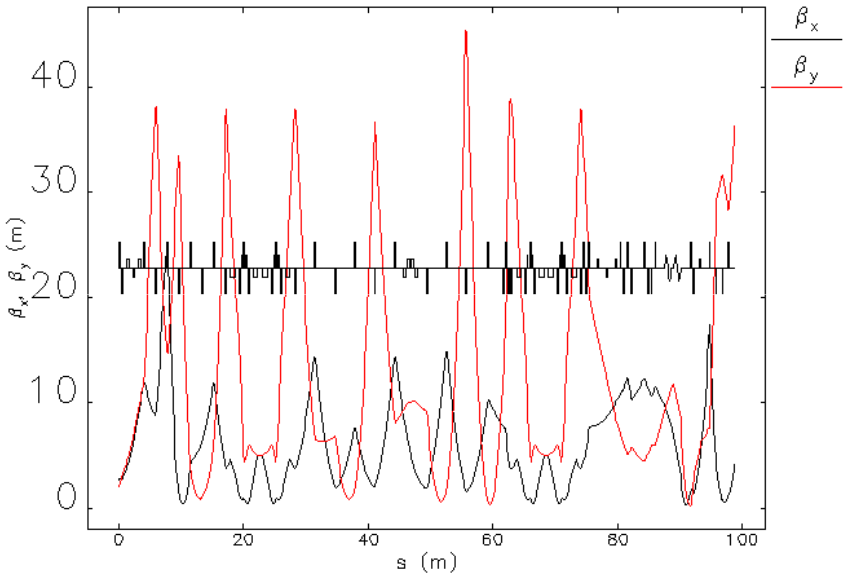
    - 35.5MeV vs 20MeV
    - Bunch length, momentum spread & normalized emittance influence
  - Piwinski's loss rate estimation
    - General equation
    - Theoretical estimation
- Summary

Input Data
Lattice & Optics

normal-20121122.new (Emax = 35.5MeV → Emax = 20MeV)





Maximum energy was modified →Twiss parameters had changed →
Beam loss position had changed

* 島田さんからのlatticeファイルを使用

see also: http://pfconrg07.kek.jp:8082/trac/cERL-Lattice/wiki

Input Data

Beam parameters

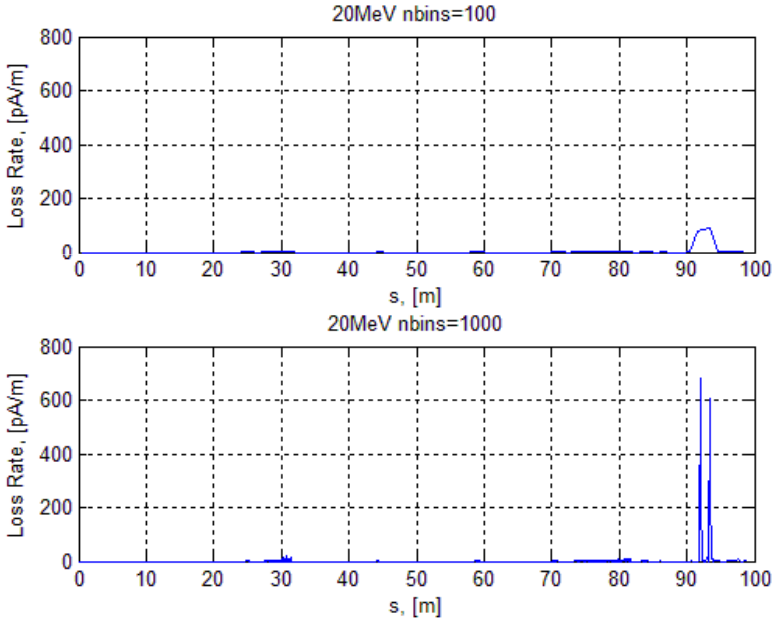
Main Parameters*	cERL	Simulation	
		Old	New
Maximum energy	20 MeV	35.5 MeV	20 MeV
Current	10 – 100 mA	10 mA	10 mA
Charge per bunch	7.7 – 77 pC	7.7 pC	7.7 pC
Repetition	1.3 GHz	1.3 GHz	1.3 GHz
Normalized emittance	0.1 – 1.0 mm-mrad	0.3 mm-mrad	1 mm-mrad
Momentum spread	< 3 x 10-4	3 x 10-4 eV	1 x 10-3 eV
Bunch length	1 – 3 ps	3 ps	2 ps

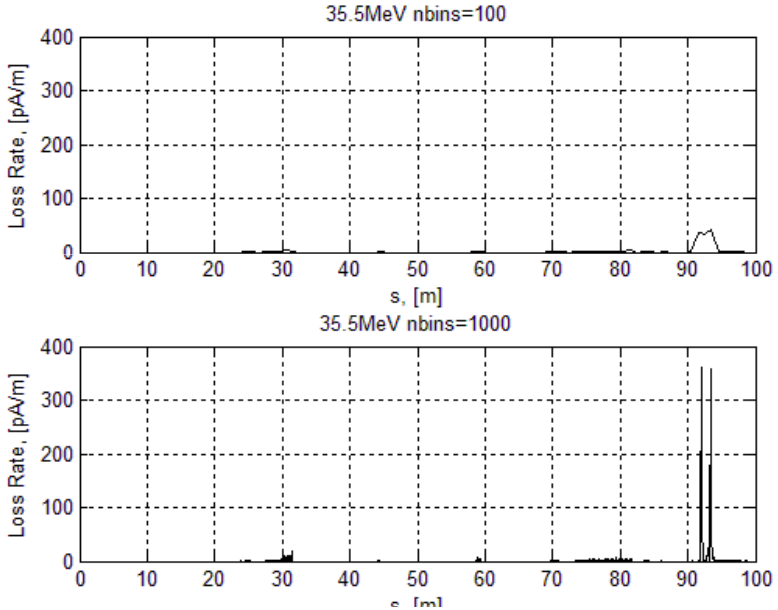
* K. Harada, M. Shimada, A. Ueda , Y. Kobayashi, T. Miyajima, R. Hajima , N. Nakamura / Lattice design of the compact ERL for first commissioning; Proceedings of the 7th Annual Meeting of Particle Accelerator Society of Japan (August 4-6, 2010, Himeji, Japan)

Results: Beam Loss Comparison

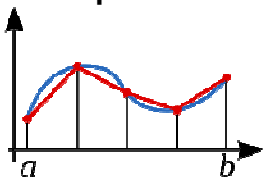
for Emax=35.5MeV and Emax=20MeV

20MeV+100bins	20MeV+1000bins	35.5MeV+100bins	35.5MeV+1000bins
∫ = 284.8597	∫ = 284.8323	∫ = 136.6370	∫ = 138.2992





Total volume of the beam losses is calculated with use of Trapezoidal rule



$$\int_a^b f(x)\,dx = \frac{f(a)+f(b)}{2}(b-a) + E(f), \qquad E(f) = -\frac{f''(\xi)}{12}(b-a)^3$$

Beam Loss Ratio (20MeV vs 35.5MeV) is 2.05953

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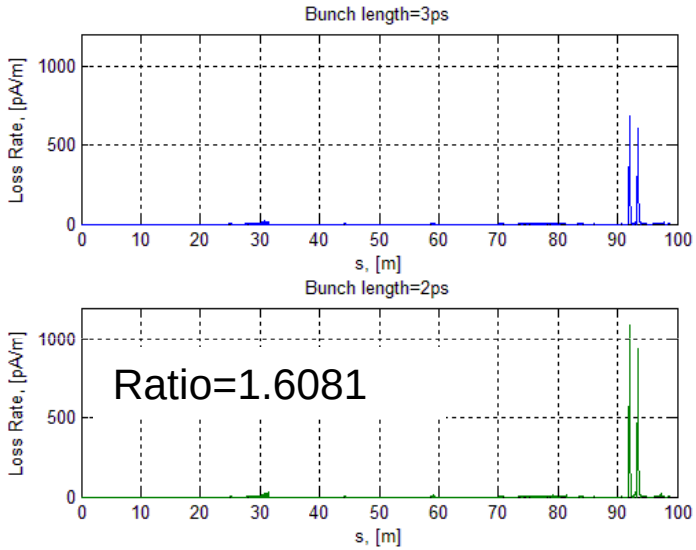
Results: Beam Loss Comparison

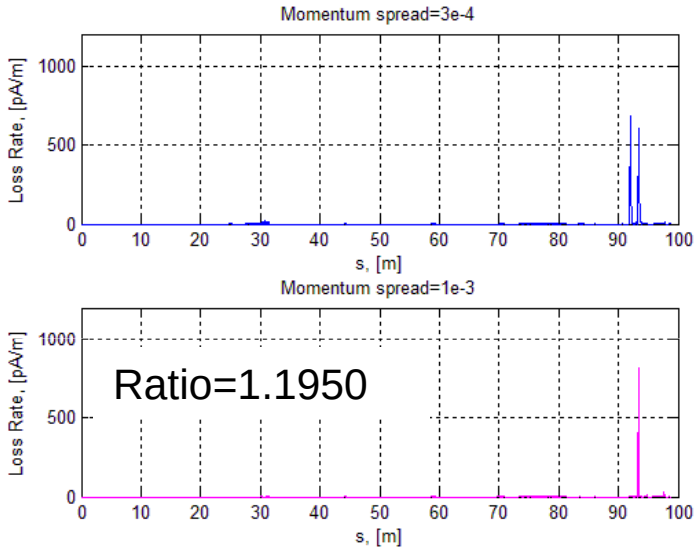
for Emax=20MeV and different beam parameters

Bunch length 3ps vs 2ps



- When the bunch density is growing the probability of Touschek scattering is increasing -> loss rate is growing

Momentum spread 3e-4 vs 1e-3

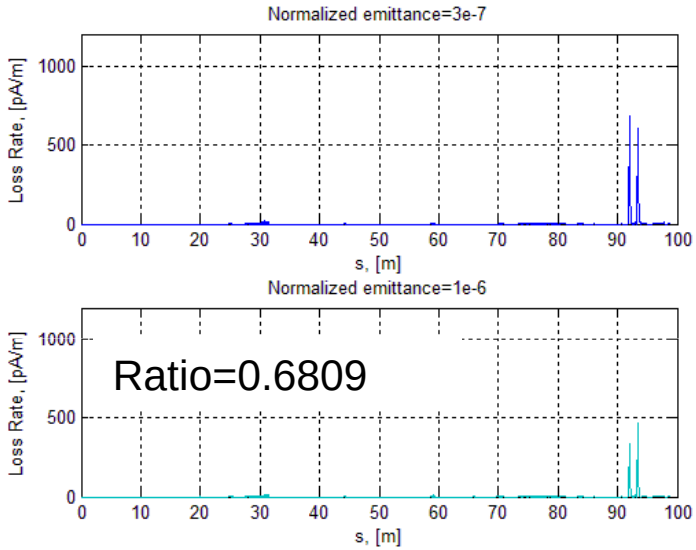


- When the momentum spread is growing the number of particles with momentum exceeding the momentum aperture is increasing -> loss rate is growing

Results: Beam Loss Comparison

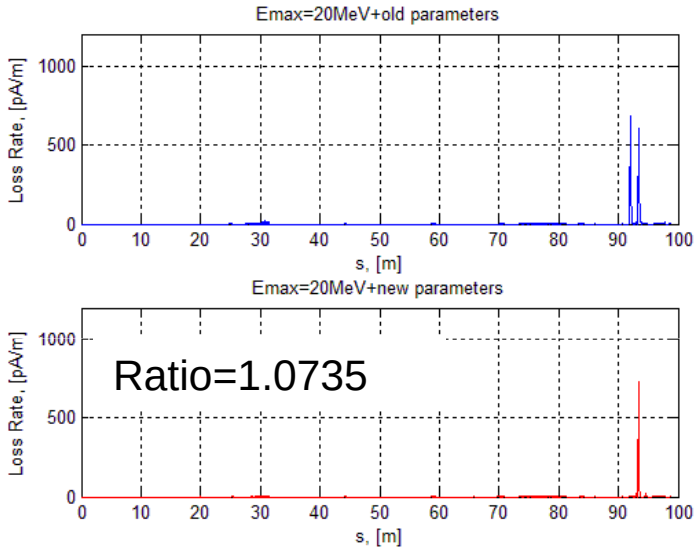
for Emax=20MeV and different beam parameters

Normalized emittance 3e-7 vs 1e-6



- When the normalized emittance is growing the bunch density is decreasing -> loss rate is decreasing

20MeV old param. vs new param.



- When the total influence of all 3 parameters (bunch length, momentum spread, normalized emittance) is summarized -> loss rate is slightly increasing

Results: Piwinski Loss Rate

General equation

Input parameters
rp=raduis of the particle=2.8179e-15 [m]
c=3e8 [m/sec]
βx,y=betatron function (from init.twi file)
Np=number of particles per bunch= =charge in bunch/electron charge
β=0.99967 (for Emax=20MeV)
γ=39.12894 (for Emax=20MeV)
me=0.511[MeV]
Dx,y=dispersion function (from init.twi file)
σxβ,σyβ=horizontal & vertical betatron width =√(βx,y*emitx,y)
emitx,y=normalized emittance=1e-6 [mm-mrad]
σs=rms bunch length=6e-4 [m]
σp=relative momentum spread=1e-3

$$R\left[particles/s\right]=\frac{r_p^2 c \beta_x \beta_y \sigma_h N_p^2}{8\sqrt{\pi}\,\beta^2\gamma^4\sigma_{x\beta}^2\sigma_{y\beta}^2\sigma_s\sigma_p}F\left(\tau_m, B_1, B_2\right)$$

Momentum Aperture:

$$\tau_m=\beta^2\delta_m^2=\beta^2\left(\frac{\Delta p_m}{p}\right)^2$$

$$\sigma_h=\frac{\sigma_{x\beta}\sigma_{y\beta}\sigma_p}{\sqrt{\tilde{\sigma}_x^2\sigma_{y\beta}^2+\tilde{\sigma}_y^2\sigma_{x\beta}^2-\sigma_{x\beta}^2\sigma_{y\beta}^2}}$$

$$F=\int_{\tau_m}^{\infty}\left(\left(2+\frac{1}{\tau}\right)^2\left(\frac{\tau/\tau_m}{1+\tau}-1\right)+1-\frac{\sqrt{(1+\tau)}}{\sqrt{\tau/\tau_m}}-\frac{1}{2\tau}\left(4+\frac{1}{\tau}\right)\ln\frac{\tau/\tau_m}{1+\tau}\right)e^{-B_1\tau}I_0\left(B_2\tau\right)\frac{\sqrt{\tau}\,d\tau}{\sqrt{1+\tau}}$$

$$B_1=\frac{\beta_x^2}{2\beta^2\gamma^2\sigma_{x\beta}^2}\left(1-\frac{\sigma_h^2\tilde{D}_x^2}{\sigma_{x\beta}^2}\right)+\frac{\beta_y^2}{2\beta^2\gamma^2\sigma_{y\beta}^2}\left(1-\frac{\sigma_h^2\tilde{D}_y^2}{\sigma_{y\beta}^2}\right)$$

$$\tilde{\sigma}_{x,y}^2=\sigma_{x\beta,y\beta}^2+\sigma_p^2\left(D_{x,y}^2+\tilde{D}_{x,y}^2\right)$$

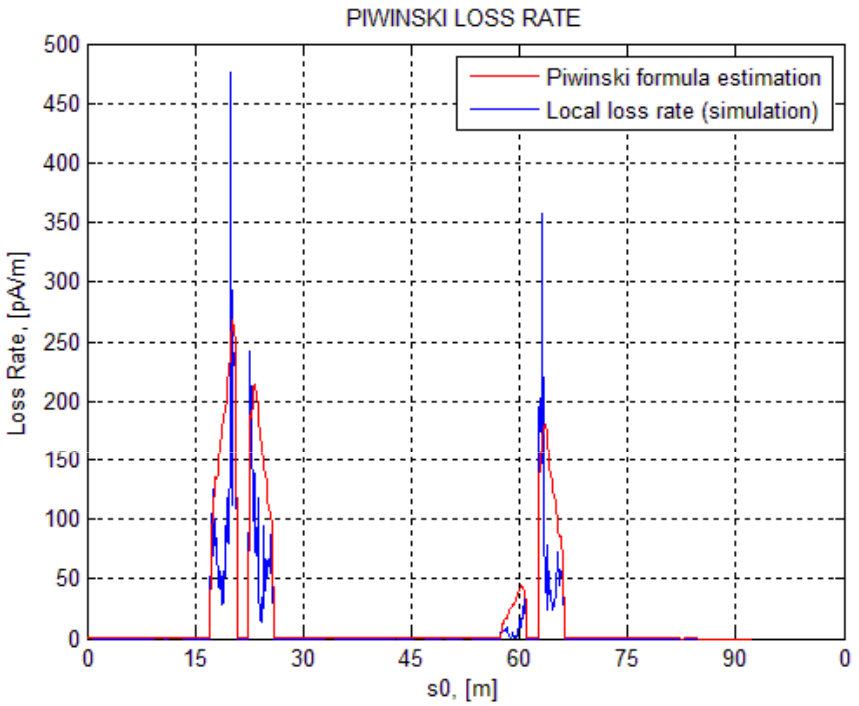
$$\tilde{D}_{x,y}=\alpha_{x,y}D_{x,y}+\beta_{x,y}D'_{x,y}$$

$$B_2^2=B_1^2-\frac{\beta_x^2\beta_y^2\sigma_h^2}{\beta^4\gamma^4\sigma_{x\beta}^4\sigma_{y\beta}^4\sigma_p^2}\left(\sigma_x^2\sigma_y^2-\sigma_p^4D_x^2D_y^2\right)$$

Results: Piwinski Loss Rate*

Estimation

Parameters obtained from MATLAB estimation (mean value)
σ_h=9.455387418879311e-04
Np=48125000
βx= 5.900141513614267
βy= 12.912173749594803
$\sigma_{x\beta}$=0.002264489534041
$\sigma_{y\beta}$=0.003288459226620
min(τ_m)=0.000020057
B1= 6.102909035031659e+03
B2= 3.210975722167509e+03



Good agreement with the local loss rate for Emax=20MeV+old parameters simulation

A. Piwinsiki, "The Touschek effect in strong focusing storage rings," DESY 98-179, Nov. 1998. p. 7 Eq. 22, p. 8 Eq. 28

Summary

- Because of the shift from Emax=35.5MeV to Emax=20MeV optics beam loss due to Touschek scattering increased significantly
- Toschek scattering rate depends on the bunch parameters in a very complicated way
  - Loss rate is growing due to decreasing the bunch length
  - Loss rate is growing due to increasing the momentum spread
  - Loss rate is growing due to decreasing normalized emittance
- Theoretical estimation by the Piwinski's formula for the beam loss rate is in a good agreement with simulation results -> comparison with experimental data