TOUSCHEK LIFETIME AT SCTF

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- Touschek lifetime calculation
- Simulation of Touschek scattering using ***Elegant*** (APS, M.Borland)
- Optimization of local momentum acceptance (LMA) to increase Touschek lifetime using "MOGA for rings" routine (*Elegant,* run on cluster)
- Impact of orbit error on dynamic aperture and LMA/Touschek lifetime – short study

Introduction

- Touschek effect – single Coulomb scattering effect which leads to the loss of the colliding particles from bunch.
- A. Piwinski “The Touschek effect in strong focusing storage rings” (DESY 98-179)

$$\frac{1}{T_{tl}} = \left\langle \frac{r_e^2 cN}{8\pi\gamma^2\sigma_s\sqrt{\sigma_x^2\sigma_y^2-\sigma_p^4 D_x^2 D_z^2 \tau_m}} F(\tau_m, B_1, B_2) \right\rangle, \tau_m = \beta^2\delta_m^2,$$

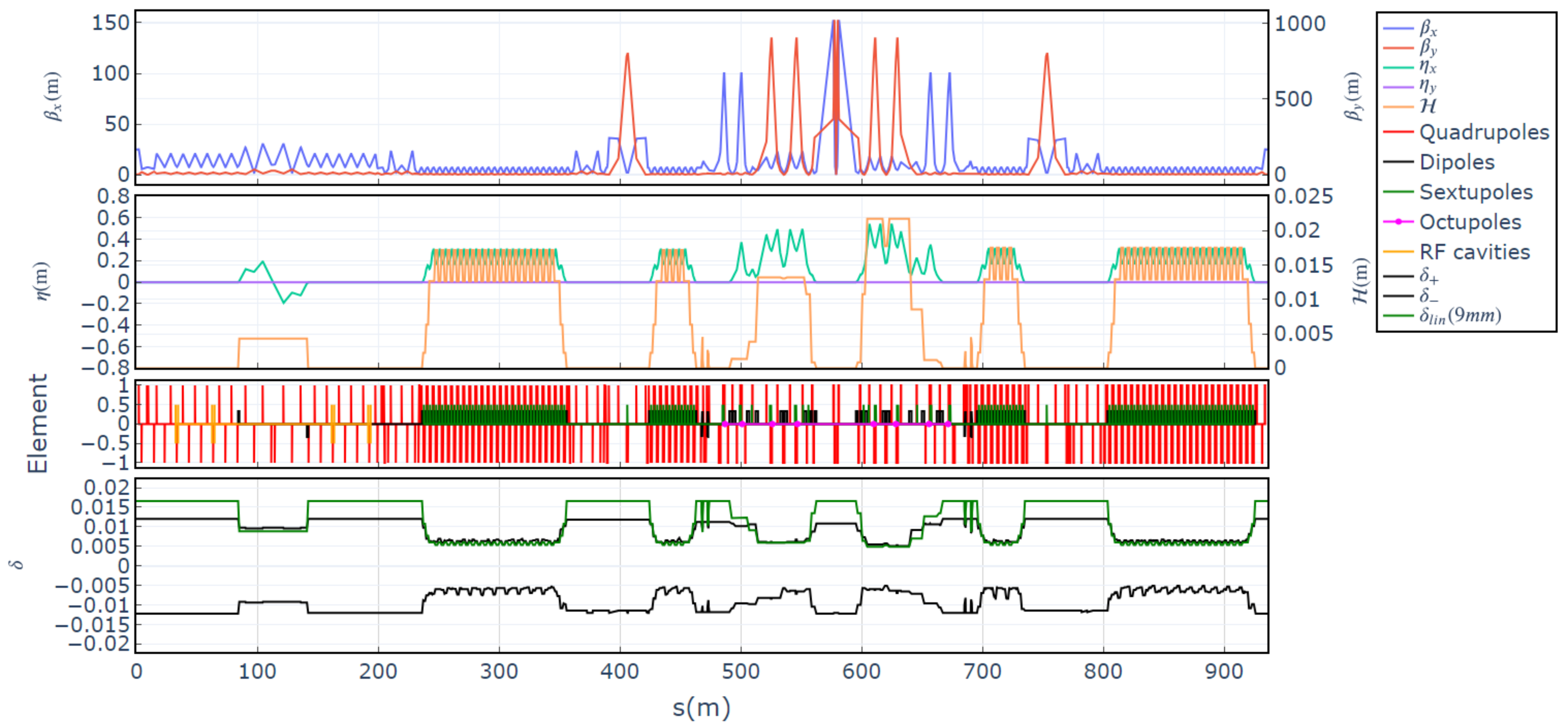
$$B_1(s) = f\left(\beta_{x,y}(s), D_{x,y}(s)\right), B_2(s) = g\left(\beta_{x,y}(s), D_{x,y}(s)\right)$$

δ_m - momentum acceptance

- Local momentum aperture (LMA) - $\delta_m(s)$, particle tracking required with $(x, x', y, y', \delta, s) = (\approx 0, \approx 0, \approx 0, \approx 0, \pm\delta, s)$
- Main limitation to total lifetime for SCTF

E(MeV)	1500 (test415)	1500 (test615)
Π(m)	935.874	
F_{RF}(MHz)	350	
2θ(mrad)	60	
β_x^*/β_y^* (mm)	100/1	
$\varepsilon_y/\varepsilon_x$(%)	0.5	
I(A) / N_b	2.9	0.65
$N_{e/bunch} \times 10^{-10}$	6	1.3
N_b / q	941/1093	983/1093
U_0(keV) / V_{RF}(kV)	91 / 1500	
ν_s	0.0153	
δ_{RF}(%)	1.98	
$\sigma_e \times 10^3$ (SR/IBS+WG)	0.27/1.1	0.27/0.9
σ_s(mm) (SR/IBS+WG)	3.6/14	3.6/12
ε_x(nm) (SR/IBS+WG)	2.0/6.4	2/3.9
$L_{HG} \times 10^{-35}(cm^{-2}s^{-1})$	1	0.075
ξ_x/ξ_y	0.005/0.12	0.001/0.04
$\tau_{Touschek}$ (s)	125	312
$\tau_{Luminosity}$ (s)	3500	10000

Optical functions and LMA of SCTF (ctau v68)



$$\delta(s) = \frac{R}{\eta(s) + \sqrt{\mathcal{H}(s)\beta(s)}}$$

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Monte Carlo simulation of Touschek effect

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(Received 29 April 2009; revised manuscript received 15 June 2010; published 30 July 2010)

- Scattering rate is computed using the Monte Carlo integration technique with N uniformly distributed random points in the n-dim volume V :

$$R = 2\int |v|\sigma\rho(\overrightarrow{x_1})\rho(\overrightarrow{x_2})dV \Rightarrow \int_V f(\vec{x})\,d\vec{x} \approx \frac{V}{N}\sum_{i=1}^{N} f(\overrightarrow{x_i})$$

- Average scattering rate for particles that result in energy deviation greater than a nominal value:

$$R_{MC}(|\delta| > \delta_m) = \frac{V}{N}\sum_{k=1}^{M}\left[\frac{v^*}{\gamma^2}\frac{d\sigma^*}{d\Omega^*}\sin\Theta^*\,\rho(\overrightarrow{x_1})\rho(\overrightarrow{x_2})\right]_k = \sum_{k=1}^{M} r_k$$

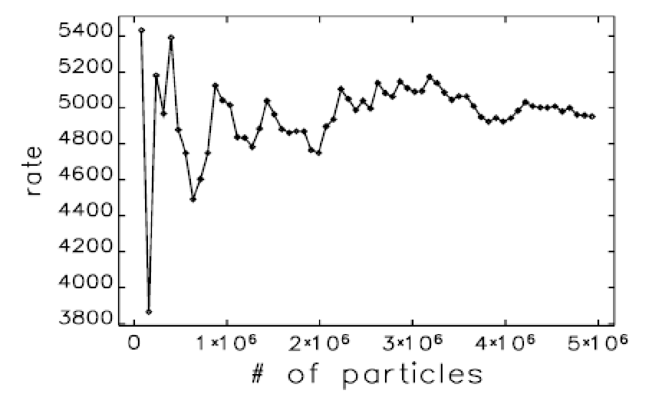
$N = 2 \times N_e$- number of scattered particles with N_e being the number of scattered events; V – total volume in the 11D space $\left(x, y, z, x'_1, y'_1, \Delta p_{1,}, x'_2, y'_2, \Delta p_2, \Theta^*, \Psi^*\right)$ from which the events are selected; M – total number of particles with energy deviation $|\delta| > \delta_m$; r_k - local scattering rate presented by each simulated scattered particle. Each particle represents many electrons with local scattering rate r_i

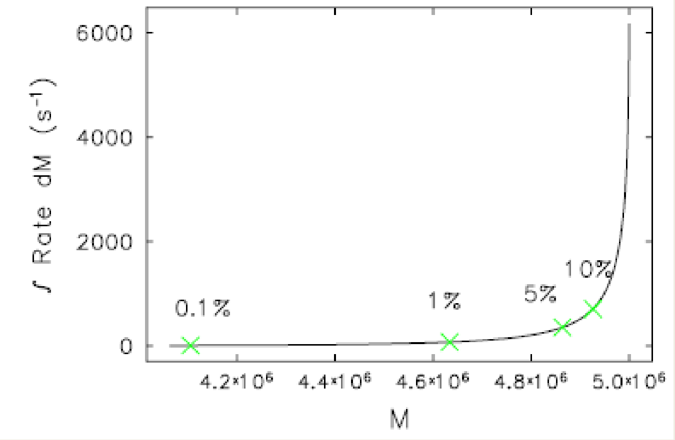
Steps of Touschek scattering simulation in *elegant*

- By default M=5e6. User can change this for better convergence of R_{MC} to Piwinski formula of R
- Beamline have to be divided into many small sections by inserting TSCATTER element at many locations
- LMA have to be calculated at every TSCATTER location. Results are scaled back to smaller value with a scaling factor (def.=0,85).
- Piwinski's formula is used to quickly determine the total scattering rate over each section. It's used to weight the local simulation results at the TSCATTER element. Each simulated particle having an associated local scattering rate r_i is assigned an associated total scattering rate

$$R_i = \frac{r_i}{\sum r_i} \frac{R_{MC}}{R_{Piwinski}} \times \int R_{Piwinski}$$

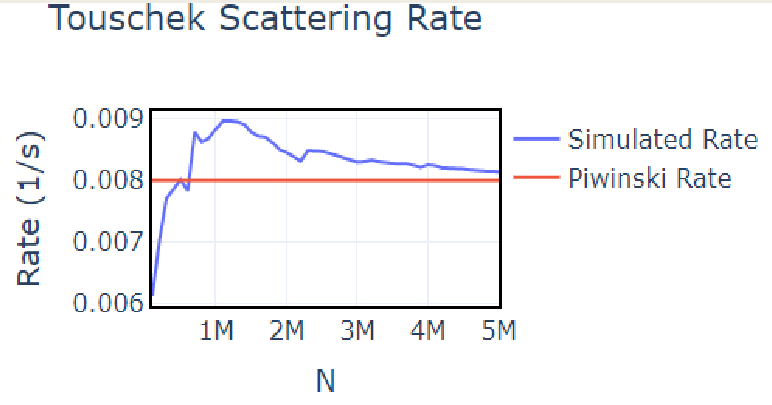
- The total loss rate will be the sum of R_i for all the particles lost at any location
- Some scattering events are much more probable than others. 99,9 % of scattering rate from example is represented by about 18% of generated particles. We can choose only most probable events to decrease simulation time.

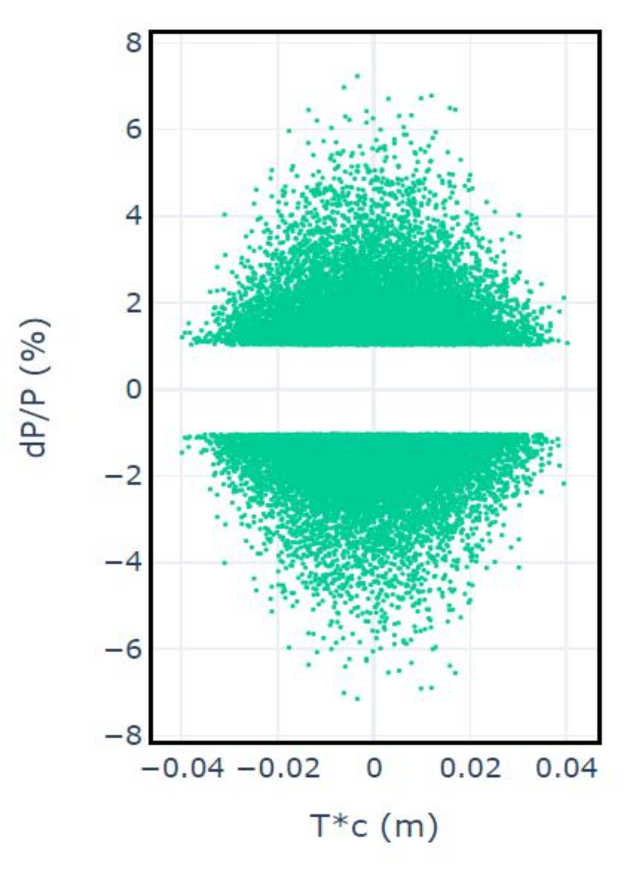




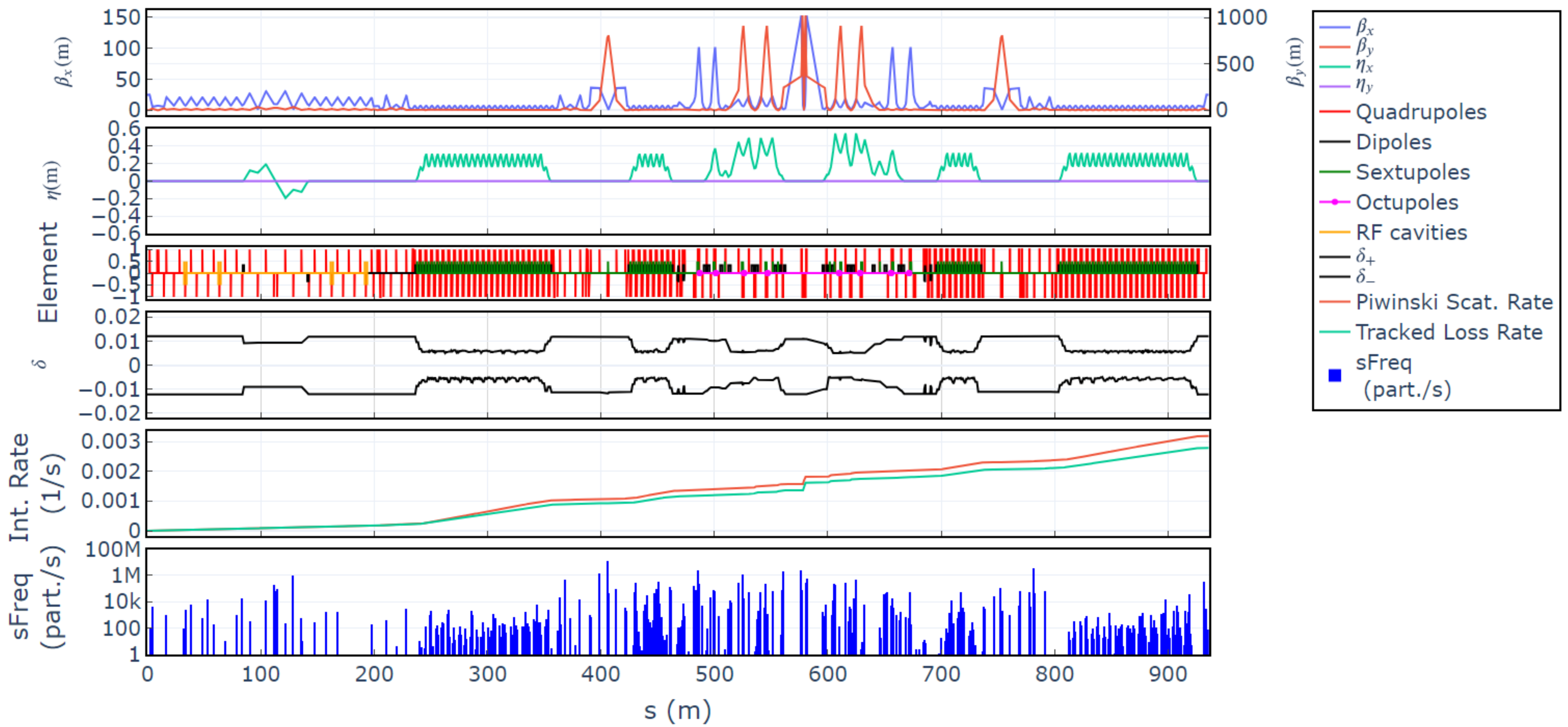
Setting up simulation of Touschek scattering *in SCTF*

- Lattice version ctau68-2022.10.08-19.03.53_1.0crab-1.5GeV
- Parameters – Test415 and Test615 (CRAB=1, IBS ON, RF ON, SR ON)
- 807 TSCATTER elements in lattice
- 4096 turns
- 5e6 of simulated particles in MC simulation, 0,05 – ignored portion of scattering rate in tracking
- Scale – 0,85 of LMA





Touschek scattering simulation results

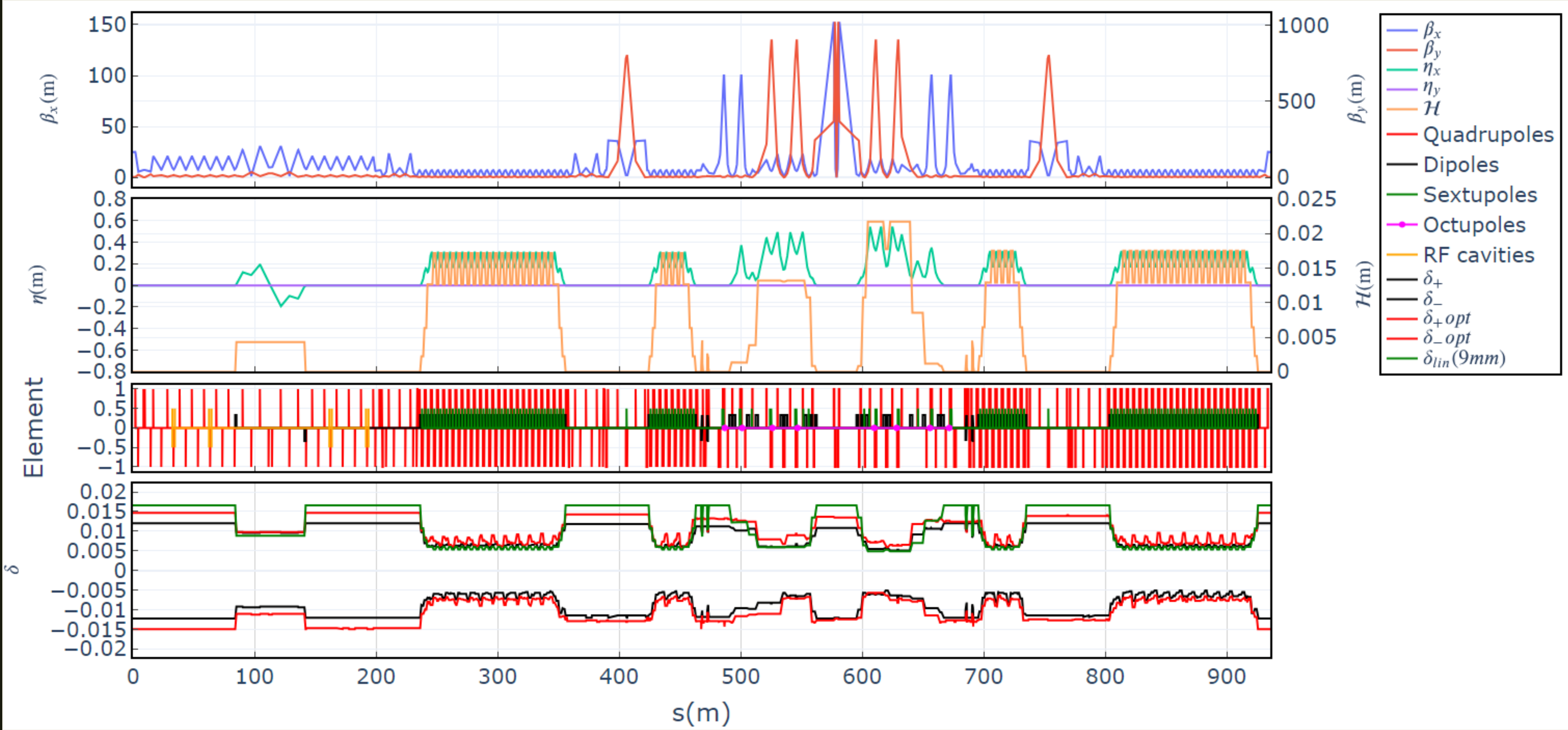


	Ctau68 Test415	Ctau68 Test615
Calculated lifetime (s)	128	314
Simulated lifetime (s)	141	359

Optimization of SCTF (ctau v.68) LMA

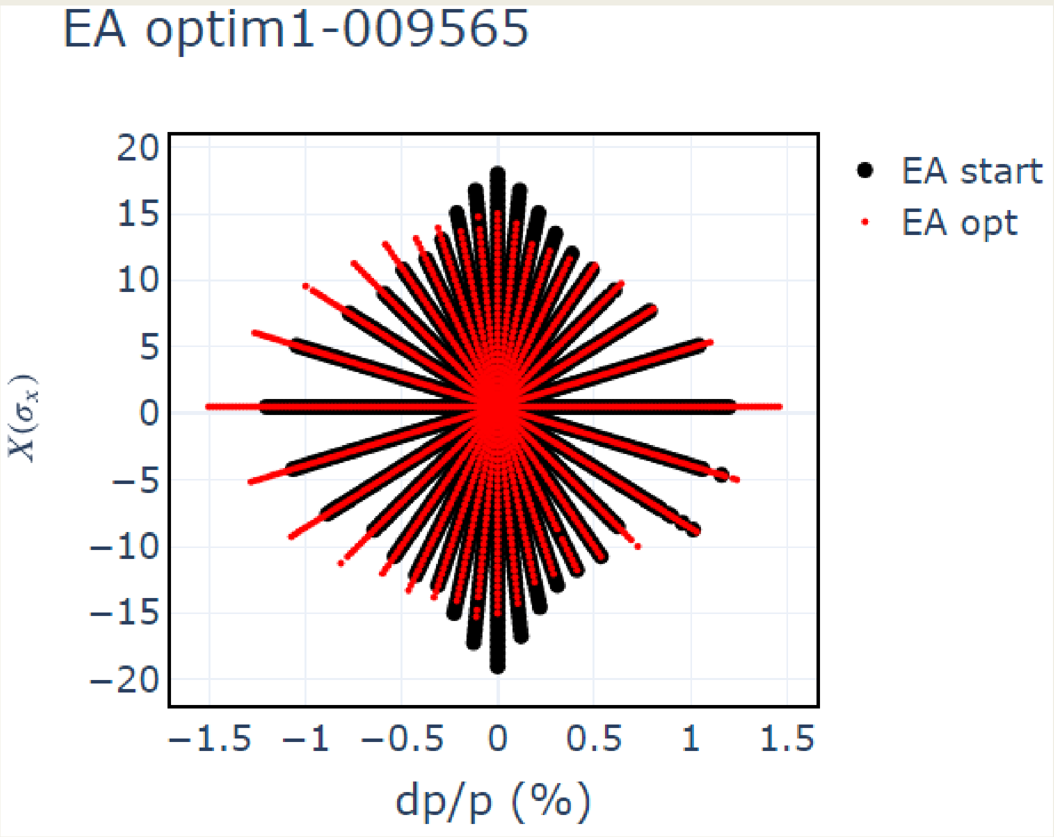
- MOGA optimizer for rings (M. Borland, V. Sajaev, L. Emery, A. Xiao – Multi-objective direct optimization of dynamic acceptance and lifetime for potential upgrades of the APS)
- Cluster with geneticOptimizer and elegant programs is required
- For efficiency – places for LMA search are chosen to be the places where H invariant value vary – entrance and exit of every dipole.
- Variables for optimizer – octupole and sextupole strengths (crab-sextupoles excluded) – elements in -I pairs have same variable

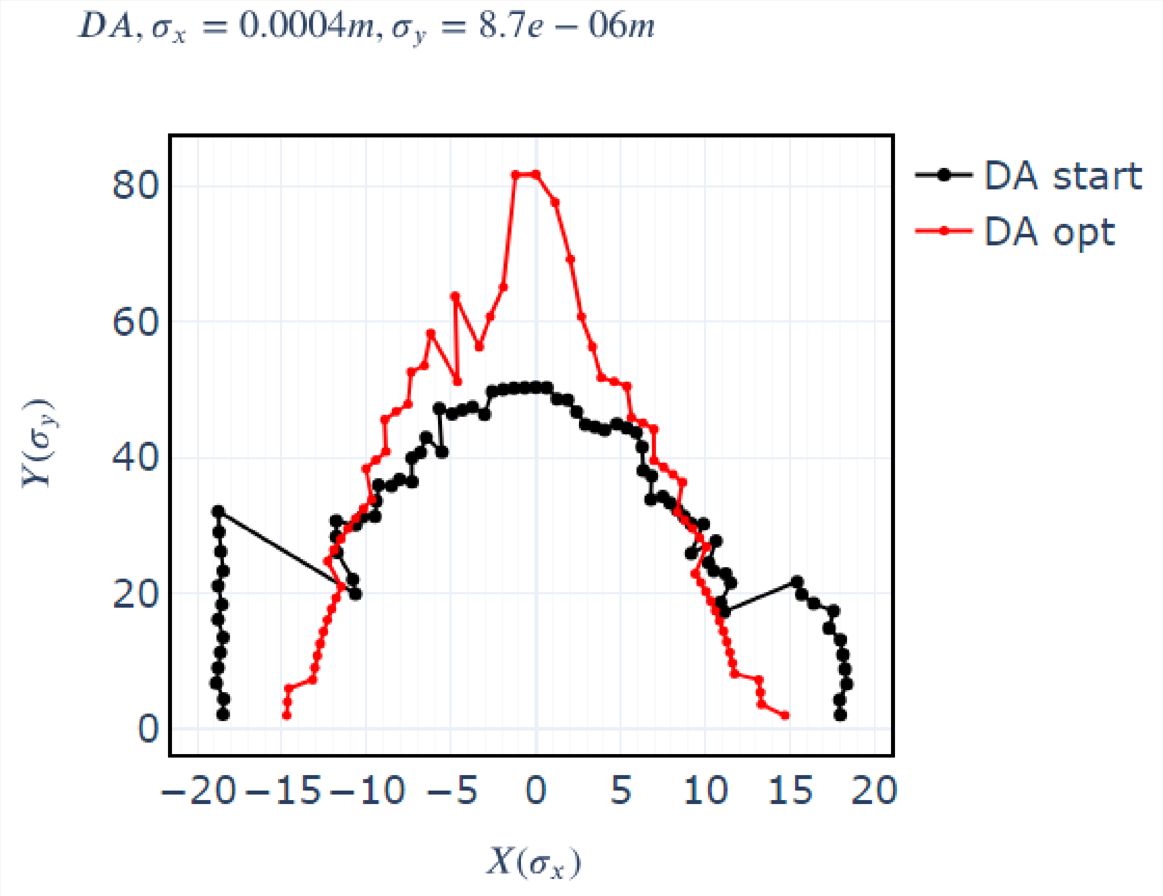
Optimization results for SCTF (ctau v68): optimized LMA



- TI_start = 145 sec
- TI_opt = 218 sec (+50%!!!)

SCTF (ctau v68): MA and DA optimization results

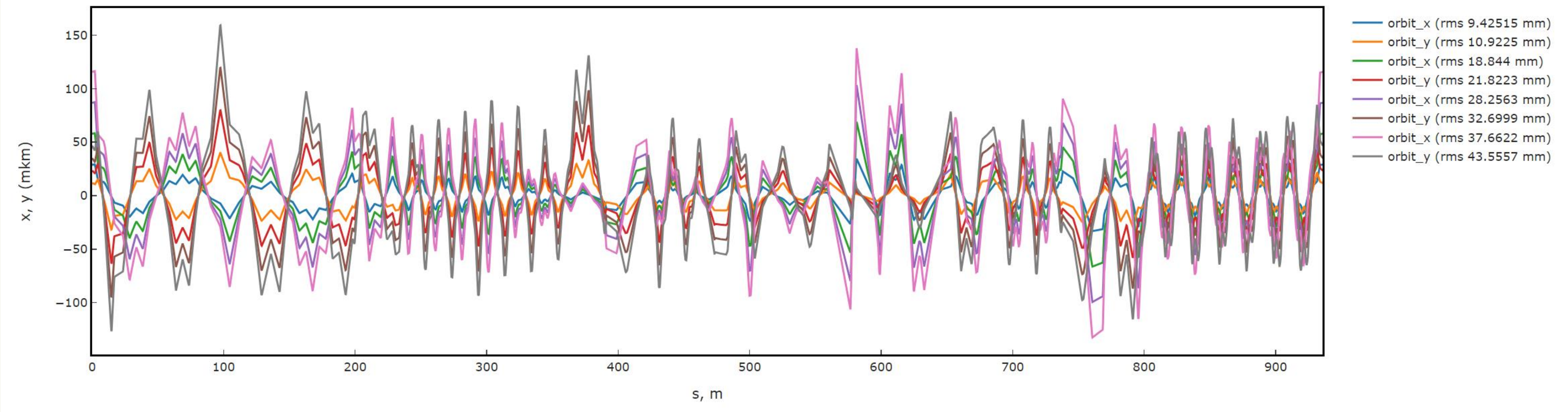


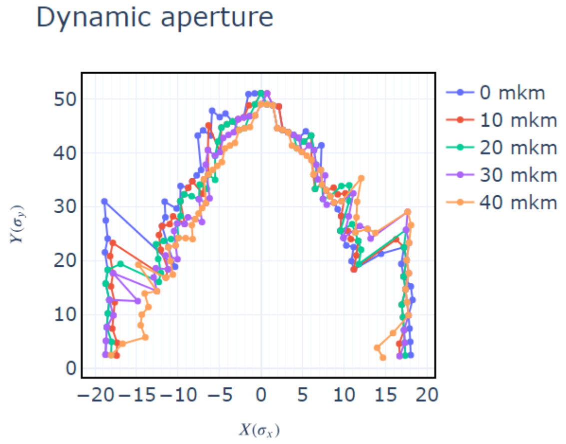


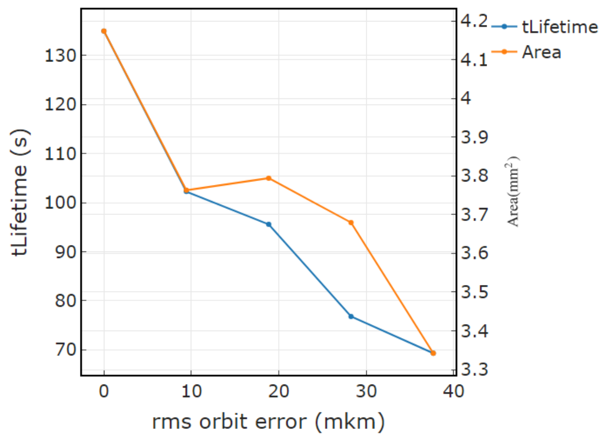
LMA optimization summary

- LMA optimization gave 50% Touschek lifetime increase
- LMA is increased at the expense of DA
- High number of variables required for optimization, works better for synchrotron light sources
- Optimization is time consuming
- X vs dP/P area optimization is faster
- Beam-beam simulations show beam blowup in IP which suggest incorrect use of variables (sextupole and octupole strengths) for optimization or a need of additional constrain for optimization

DA and Touschek lifetime with orbit error in SCTF







Thank you

Spare slide

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BENCHMARKING OF TOUSCHEK BEAM LIFETIME CALCULATIONS FOR THE ADVANCED PHOTON SOURCE*

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