Electron Beam Loss Mapping

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INTRODUCTION

- Electron beam losses in a storage ring can be due to random particle interactions, injection oscillations, lattice errors, RF decay (‘kill beam’)…

- Focus on random particle interactions (losses during beam delivery to users),

- Consequences are activation of machine elements, potentially radiation damage on insertion devices and electronics,

- Beam loss patterns would be very useful for both the running and the new machines to

  - ➢ *anticipate the degradation caused by radiation,*
  - ➢ *protect the sensitive elements,*
  - ➢ *optimize the shielding for radiation safety,*
  - ➢ *simulate the magnets’ activation for the dismantling study in view of the machine upgrade.*

OUTLINE

I. Sources of random beam losses

II. Touschek scattering simulation

III. Collimation scenario for the ESRF Upgrade

IV. Validation tests on the present ESRF

I. SOURCES OF RANDOM BEAM LOSSES

Elastic / inelastic scattering on residual gas nuclei

- Coulomb scattering → angle deviation,
  → particle loss on physical or dynamic aperture restriction,
- Bremstrahlung → energy loss due to photon emission,
  → particle loss because of energy acceptance limitation,
- Loss rate/pattern depend on the pressure profile and species constituting the residual gas.

Touschek scattering

- Elastic scattering between 2 electrons within the bunch → transfer of momentum from transverse to longitudinal direction,
- Loss rate/pattern depend on the emittance, the bunch distribution and the energy acceptance → varies along the ring,
- Dominant effect for high intensity and low emittance beam.

II. TOUSCHEK SCATTERING SIMULATION (1/2)

Function developed within the Matlab Accelerator Toolbox, done in two steps to limit the computation time:

1. Integrated scattering rate as a function of the lattice

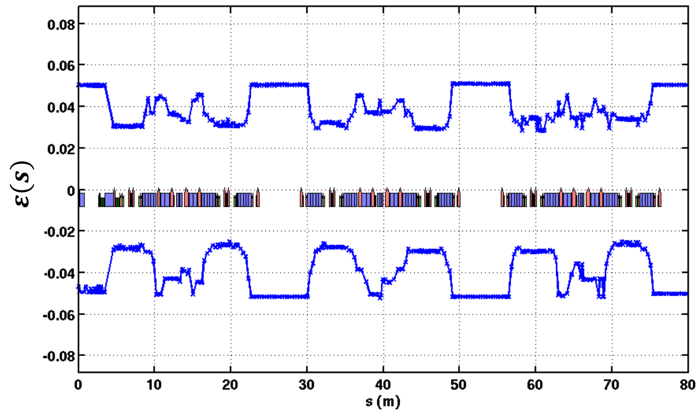
- Compute the momentum acceptance $\varepsilon(s)$ along the ring,

  Scanning of the energy deviation around the closed orbit to define the acceptance along the ring.

- Calculate the Touschek loss probability P at each step position using Piwinski's formula,

$$P(s) \sim \frac{N^2}{\sigma_x \sigma_y \sigma_z \gamma^2 \varepsilon^3} F(u) \quad \textit{with} \quad u = \left(\frac{\varepsilon}{\gamma \sigma_x'}\right)^2$$

Momentum acceptance of the ESRF Upgrade



- Deduce the number of scattering processes leading to particle losses at each position $N_{lost} = P * N_{part}$ (assuming $N_{lost} \ll N_{part}$ at each step)

II. TOUSCHEK SCATTERING SIMULATION (2/2)

2. Particles' generation and tracking

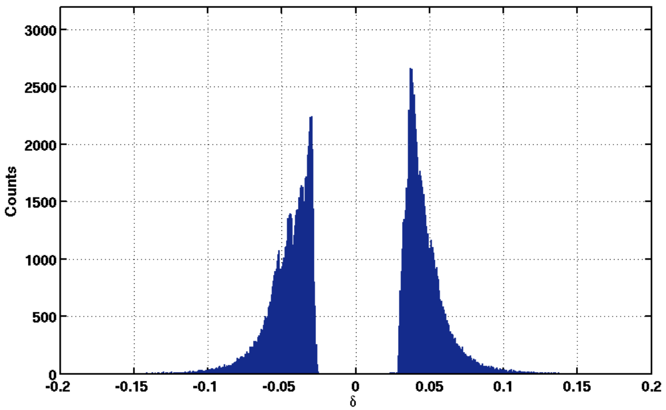
- Generate scattering pairs of particles until N_{lost} is reached at each longitudinal position:
  - $(x, x', y, y', z, \delta)_1$ *randomly generated in a 6D Gaussian distribution,*
  - *Imposing* (x, y, z)*, generate* $(x', y', \delta)_2$ *in the same bunch distribution,*
  - *Calculate the momentum offset of the two particles using the Touschek scattering differential cross section:*

$$\frac{d\sigma}{d(\cos\chi)} = \frac{8\pi r_0^2}{(v/c)^4}\frac{(\cos\chi)^2 - 2}{(\cos\chi)^3} \quad with \quad \begin{cases} v = x_1' - x_2' \\ \Delta\delta = \gamma\frac{v}{2}|\cos\chi| \end{cases}$$

and χ *is the scattering angle.*

- Track the particles until they are lost on the physical aperture, storing the number of turns, loss location, energy deviation and transverse coordinates.

Momentum distribution of tracked particles
(ESRF Upgrade)



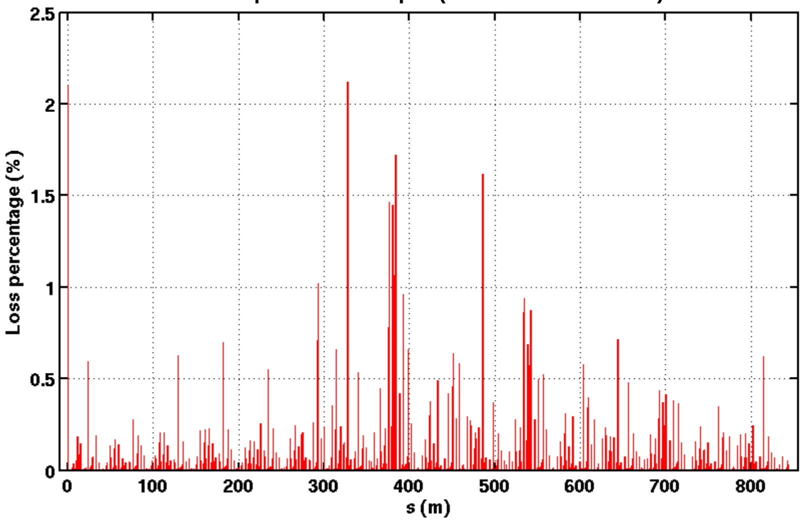
III. COLLIMATION SCENARIO FOR THE ESRF UPGRADE (1/2)

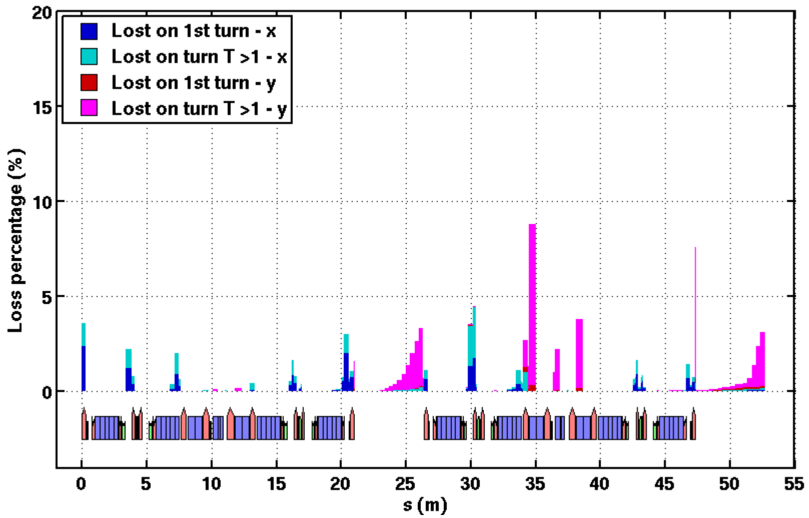
1. Motivations

- The Touschek loss rate will be strongly increased in the new machine,
- Concentrating the electron losses in a few places would help preserving the insertion devices and facilitate the radiation shielding.

Beam lifetime preliminary estimation for the ESRF Upgrade (uniform filling)

	ε_x (pm)	τ (h)
ESRF1	4000	70 h
ESRF2	150	15 h

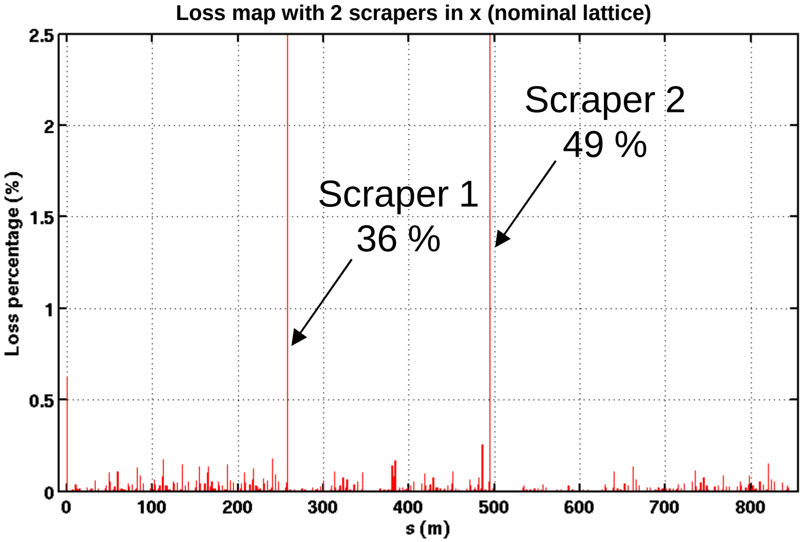


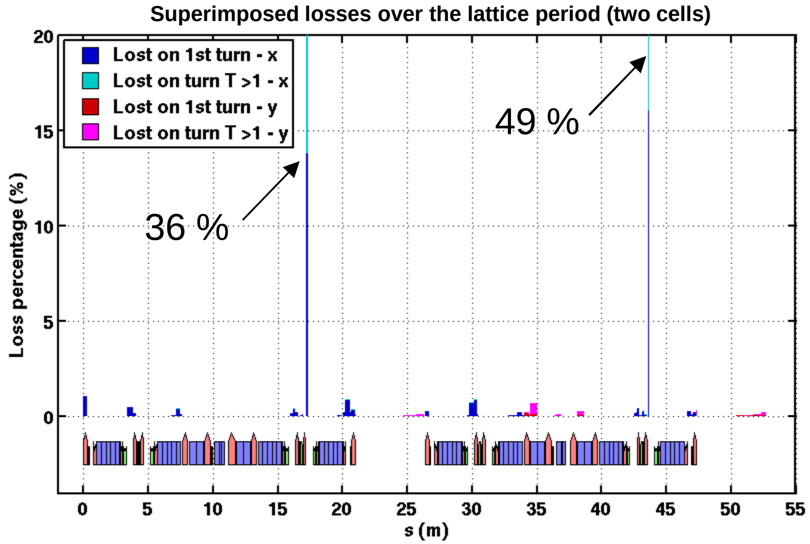


III. COLLIMATION SCENARIO FOR THE ESRF UPGRADE (2/2)

2. Simulation results

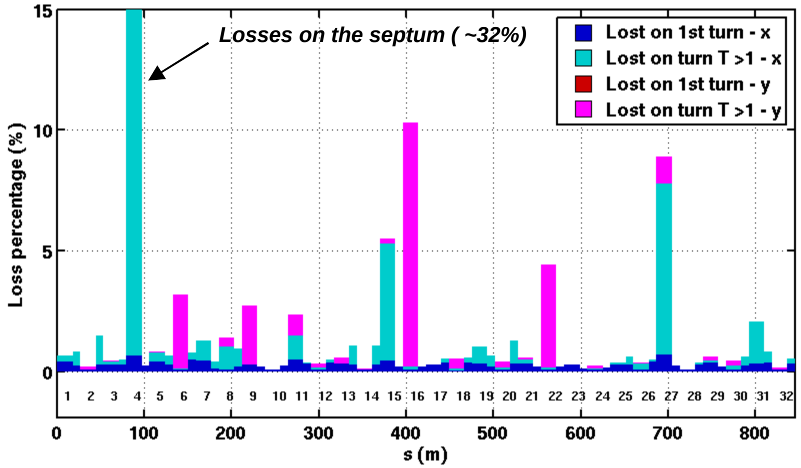
- More than 80 % of the losses could be relocated using two scrapers in the horizontal plane (4 jaws) even if losses are mainly on the vertical aperture in the straight sections,
- The lifetime is reduced by ~6%,
- Impacts' position on the scrapers are available to serve as input for radiation calculations.



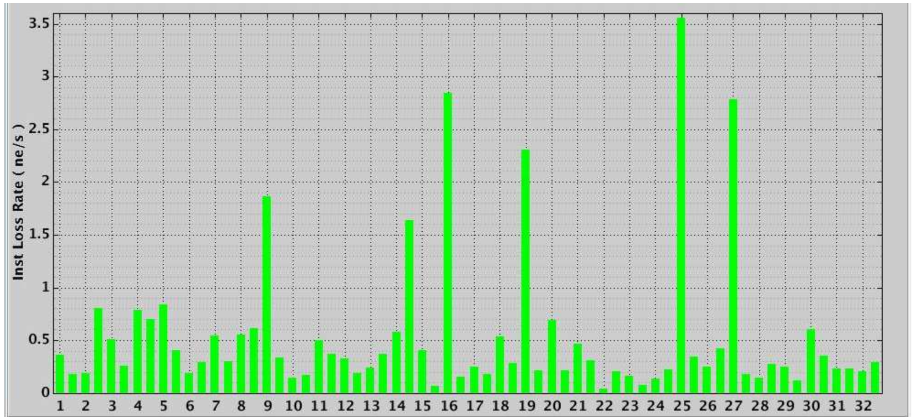


IV. VALIDATION TESTS ON THE PRESENT ESRF

Touschek loss map for ESRF1 with errors (preliminary)



Beam loss detectors' signal in uniform mode
(during beam delivery to users)



- Cross check of simulation results with experimental data are foreseen for ESRF1,
- Requires a detailed aperture description in the straight sections (under implementation),
- Experimental tests must be performed with high intensity per bunch and low vertical emittance for the losses to be Touschek dominated (I_b ~ 4 mA and ε_y ~ 5 pm·rad),
- Possibility to monitor the losses while scanning scrapers and/or in-vacuum IDs' gap positions.

SUMMARY AND OUTLOOK

- Given the decrease of beam lifetime in the new machine design, beam losses have to be studied in order to optimize the machine shielding and to protect the various equipment,
- A tool to simulate the Touschek scattering process has been developed to track lost particles,
- First results show that concentrating the losses in two locations far from the insertion devices should be feasible with horizontal scrapers.

- Application to the current machine is under study to validate the model (also useful for activation studies before dismantling),
- Tests of loss re-location using scrapers and comparison with predictions for loss patterns require a detailed aperture description of the straight sections,

- Inclusion in the model of losses due to interactions with residual gas particles is on-going,
- Loss distribution during beam injection and kill beam will be studied.