LER2016

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Electron Beam Losses and Collimation at ESRF-EBS

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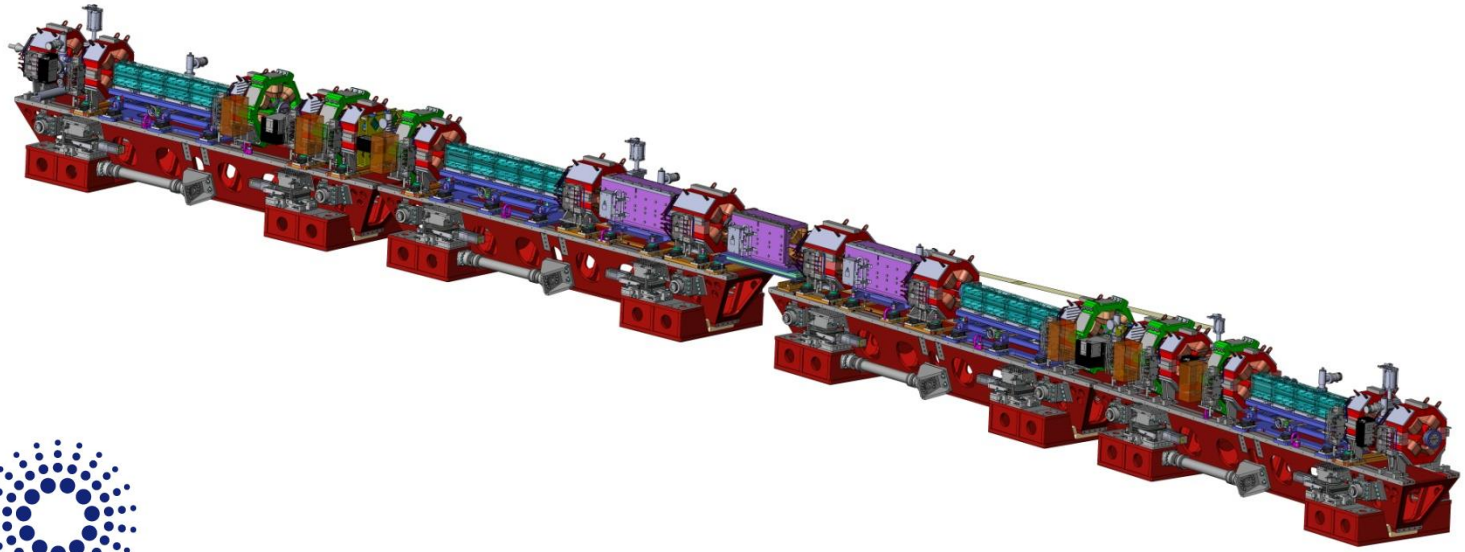
On behalf of the ESRF-EBS Accelerator Project Team



ESRF | The European Synchrotron

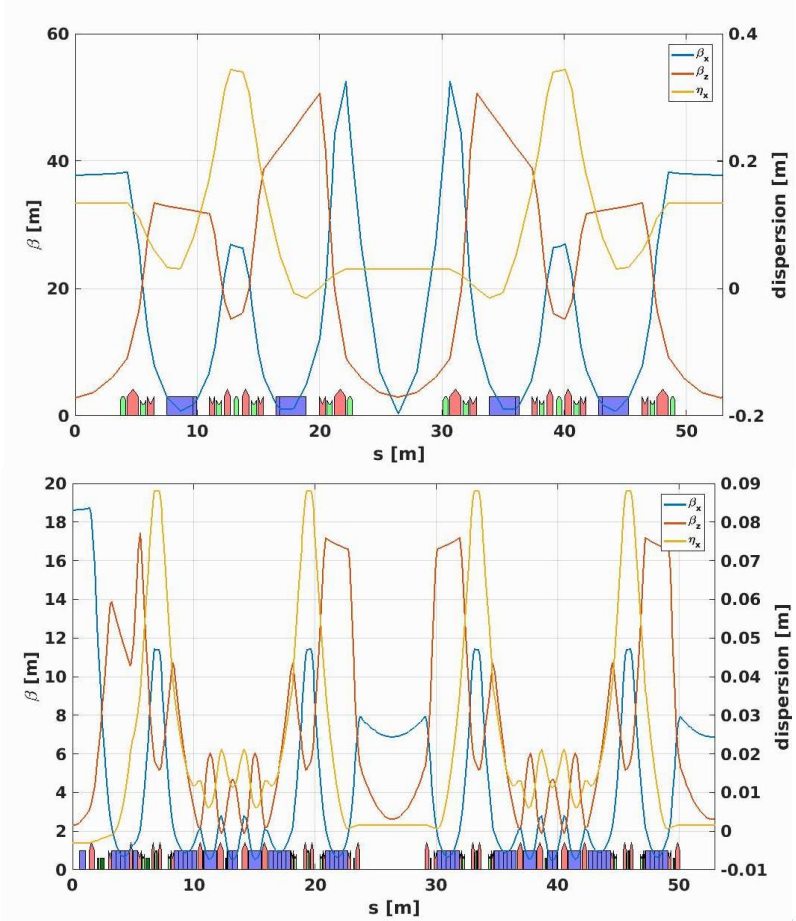
OUTLINE

I. Introduction to ESRF-EBS
II. Simulation of Touschek losses for ESRF-EBS
III. Collimation scheme for ESRF-EBS
IV. Collimation tests at ESRF
V. Vacuum losses and vacuum conditioning at ESRF-EBS

I. INTRODUCTION TO ESRF-EBS

The ESRF-EBS lattice is a Hybrid Multi-Bend lattice which will allow to reduce the horizontal emittance by a factor 30 compared to the present ESRF lattice (Double Bend Achromat).

	ESRF-1	ESRF-EBS
Energy (GeV)	6	6
$I_{b,multibunch}$ (mA)	0.23	0.23
RF Voltage (MV)	9	6.5
$\varepsilon_x/\varepsilon_y$ (pm)	4000/5	134/5
σ_z (mm)	6	4.6
$\tau_{multibunch}$ (h)	45	19
β_x/β_y(ID) (m)	High β: 37.8/2.9 Low β: 0.35/2.9	6.9/2.6



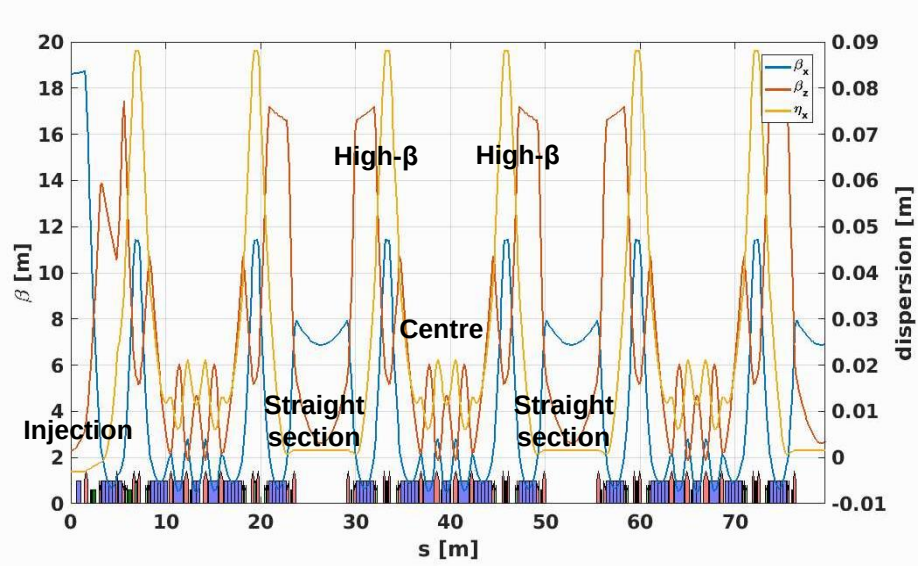
I. INTRODUCTION TO ESRF-EBS

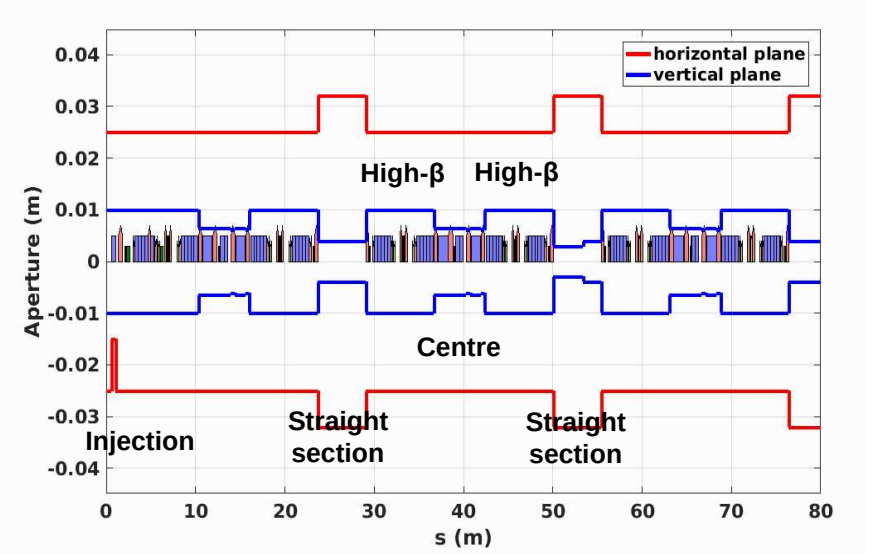
The standard cells are made of four regions:

→ two high-β (and high dispersion) sections,

→ a central region with ±6.5 mm vertical aperture,

→ a 5m-straight section with ±4 mm vertical aperture chamber and/or in-vacuum undulators with ±3 mm vertical gaps.





I. INTRODUCTION TO ESRF-EBS

- Electron losses during beam decay are caused by random collisions with atoms of the residual gas particle and collisions within the bunches :

  → elastic scattering with residual gas atoms (Coulomb scattering),
  → inelastic scattering with residual gas atoms (bremsstrahlung),
  → Touschek scattering (e^--e^- elastic scattering),

- Touschek scattering represents ~ 90 % of the losses in nominal vacuum conditions and multi-bunch delivery mode,
- The loss probability depend strongly on the physical aperture and on the bunch density,
- The foreseen reduced beam lifetime imposes top-up operation which implies higher average current,

⇒ Mapping of electron losses has become a major concern of the ESRF upgrade design to anticipate a collimation scenario and/or an appropriated shielding in order to :

- maintain a radiation-free zone in the experimental hall,
- preserve the insertion devices from radiation damage.

OUTLINE

II. Simulation of Touschek losses for ESRF-EBS

II. SIMULATION OF TOUSCHEK LOSSES FOR ESRF-EBS

- Computation of the local momentum acceptance along the lattice,
- Random generation of momentum deviations according to
  - the probability of interaction (Piwinski formula, depending on the 6D Gaussian beam distribution along the ring),

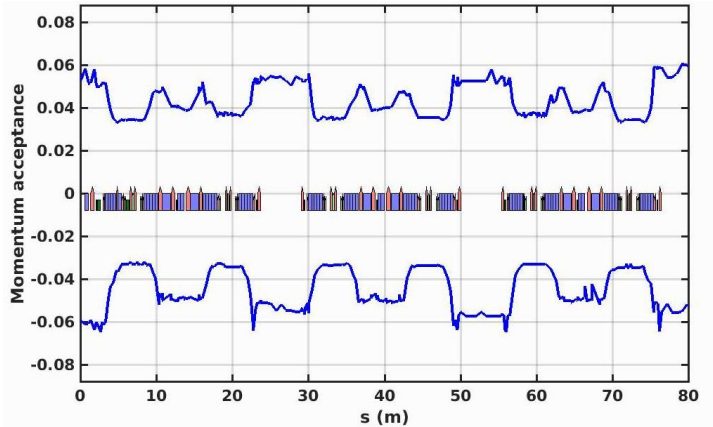
$$P(s) \sim \frac{N^2}{\sigma_x \sigma_y \sigma_z \gamma^2 \varepsilon^3} F(u) \quad \textit{with} \quad u = \left(\frac{\varepsilon}{\gamma \sigma_x'}\right)^2$$

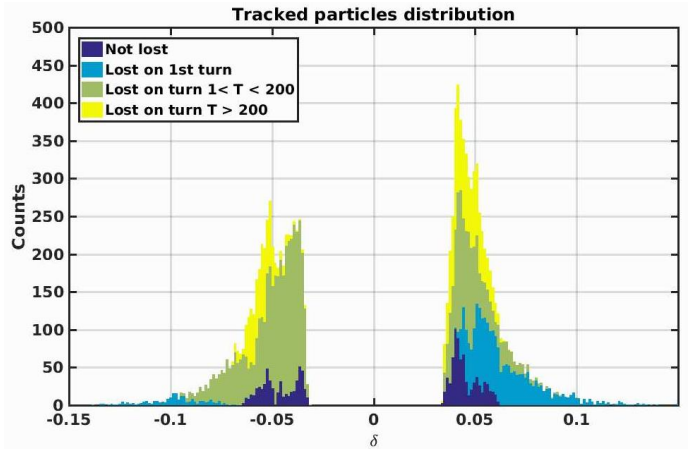
  - the Møller differential cross section,

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

and χ is the scattering angle.

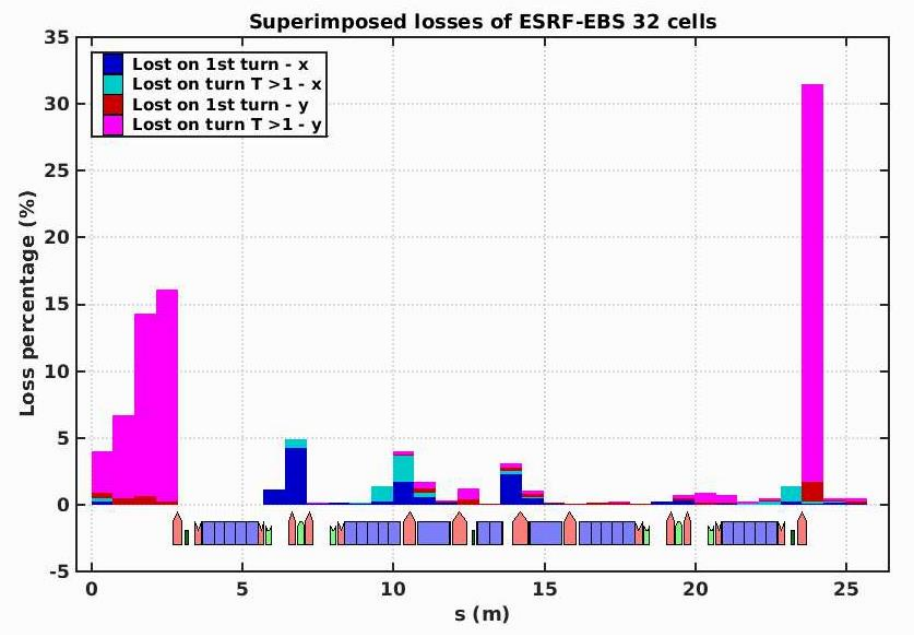
- Tracking of the scattered particles until they hit the physical aperture.





II. SIMULATION OF TOUSCHEK LOSSES FOR ESRF-EBS

- Inside the cells, losses are mainly in the horizontal plane: largest energy kicks leading to losses within the first turn after the collision,
- In the straight sections, losses are in the vertical plane: coupling transfers horizontal oscillations to the vertical plane leading to losses on the small aperture after several turns,



→ A collimation system can be efficient relocating the losses observed in the straight sections, but the small fraction lost within one turn inside the cells are unavoidable.

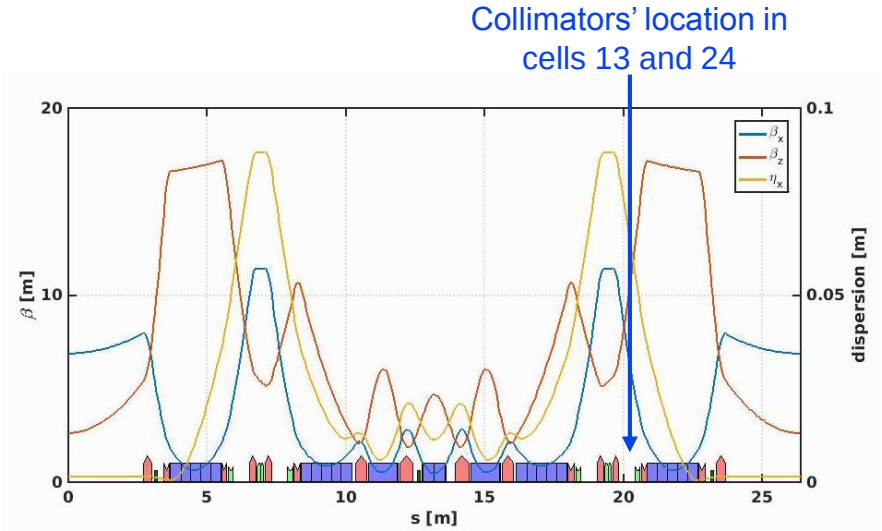
OUTLINE

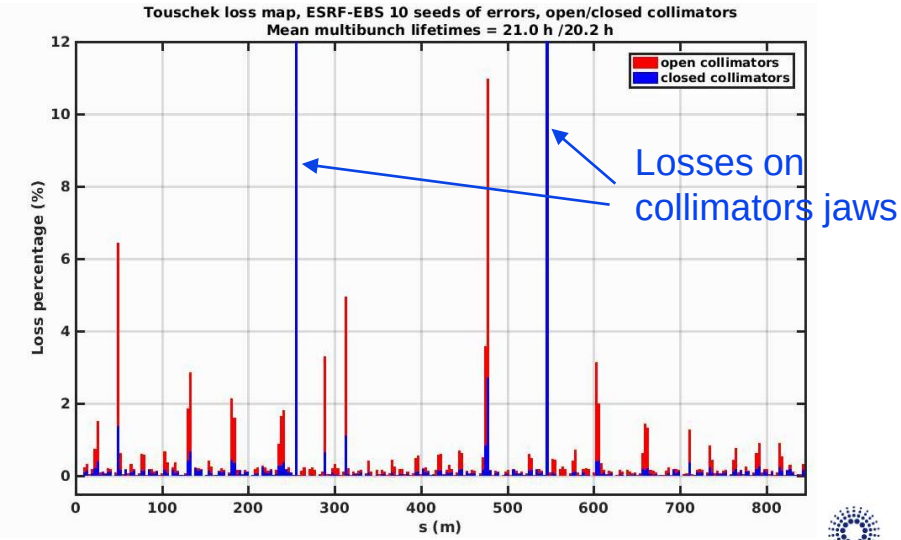
III. Collimation scheme for ESRF-EBS

III. COLLIMATION SCHEME FOR ESRF-EBS – SCENARIO

- We take advantage of the high dispersive and high-beta regions to intercept large amplitude horizontal motion before it generates vertical oscillations,
- Criterion: ~ 80 % of the losses must be concentrated on two horizontal collimators, while the impact on the lifetime is kept lower than 10 %,

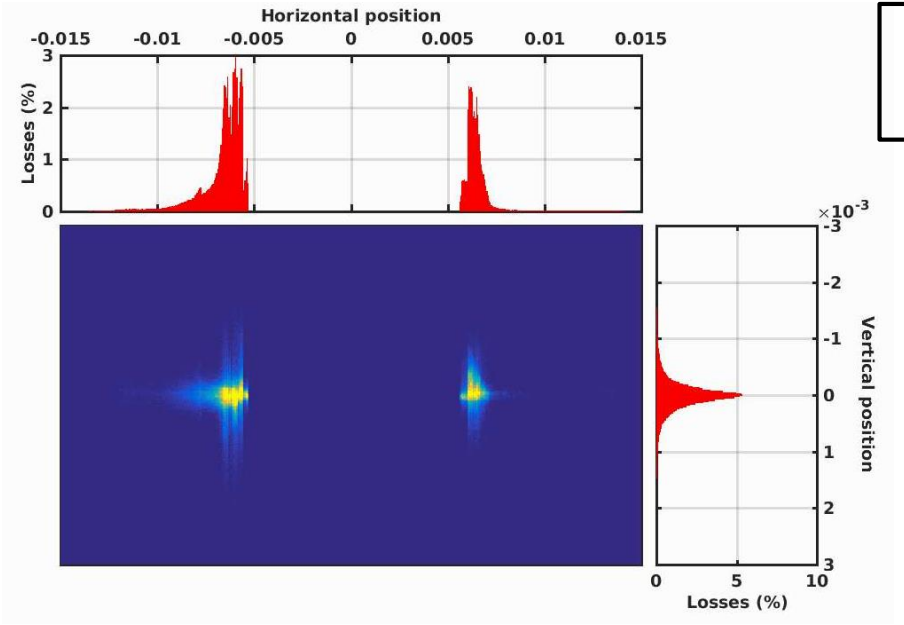
→ Result: on average over 10 machines with random errors, 75% of the losses are concentrated in two locations for 4% reduction of lifetime:

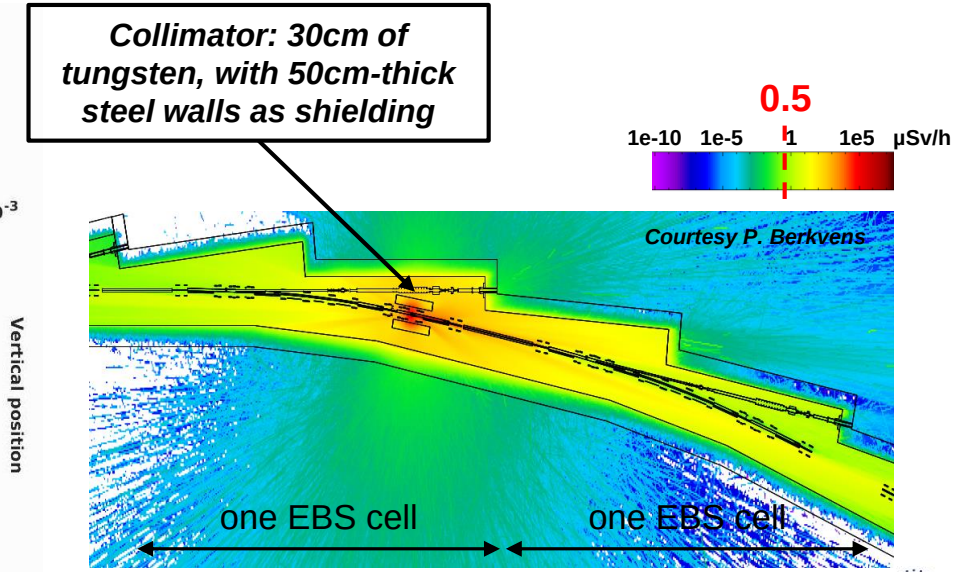




III. COLLIMATION SCHEME FOR ESRF-EBS – COLLIMATORS SPECIFICATIONS

- Tracking provide 6D phase space distributions of particles hitting the collimators,
- It serves as input for the optimization of the collimators' jaw material (Cu or W) and geometry (thickness, taper, vertical beam stop) and for the optimization of the external shielding,
- The goal is to get less than 0.5 µSv/h radiation level for emitted photons and neutrons outside the tunnel in order to insure the free access zone.

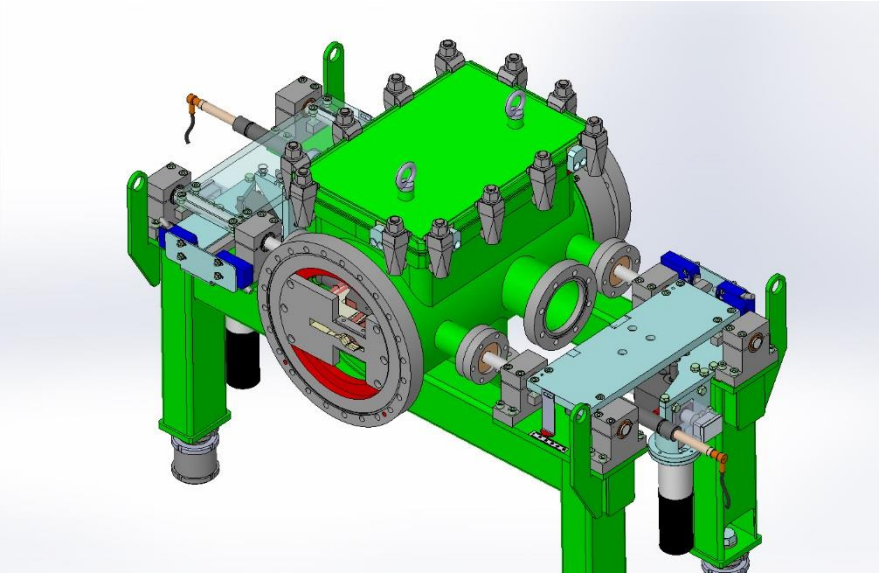


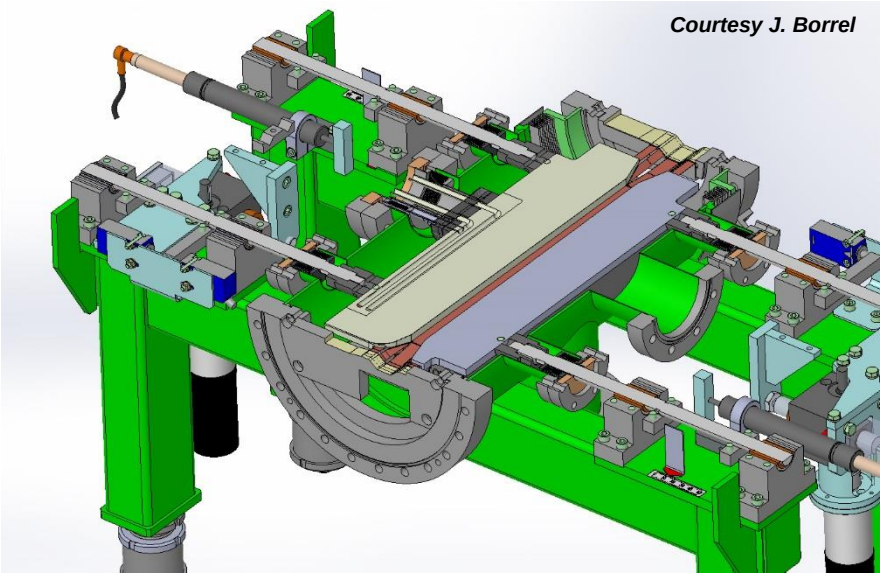


III. COLLIMATION SCHEME FOR ESRF-EBS – COLLIMATORS DESIGN

The main challenges for the collimators design concern

- the photon absorber required on the outside jaw (with its cooling system),
- the RF-fingers and tapers at entrance and exit for the chamber transitions,
- the short allocated space (~ 50cm), and the activated environment.





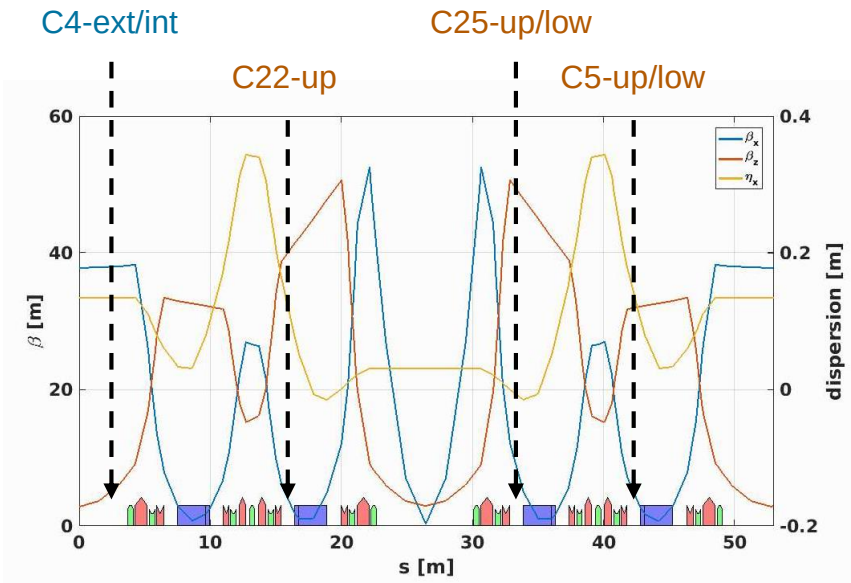
OUTLINE

IV. Collimation tests at ESRF

IV. COLLIMATION TESTS AT ESRF

- Recent top up operation in high intensity per bunch mode allows not to blow the vertical emittance up to 40pm, implying
  - 4 times more injected current per day,
  - ~35% lifetime reduction,

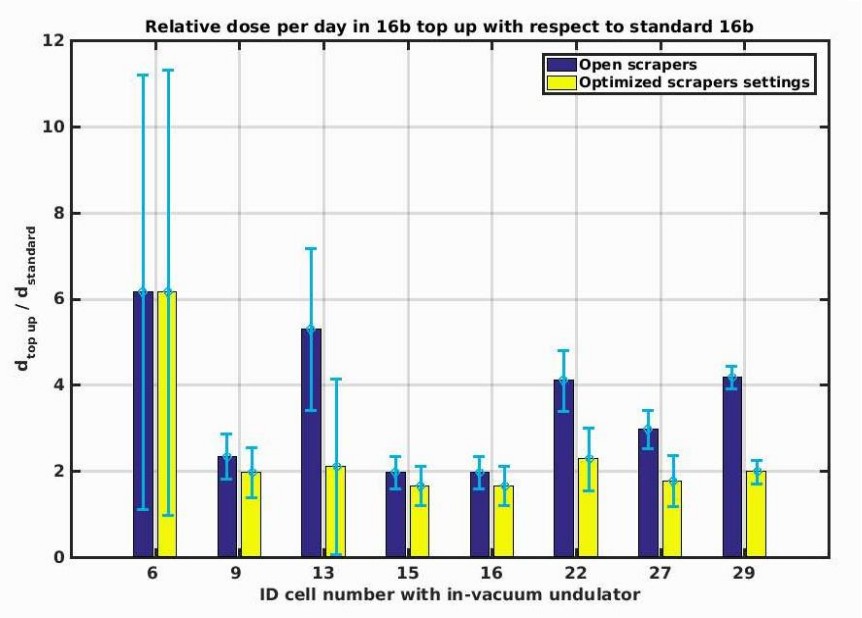
- Only one scraper available in the horizontal plane (C4, not at maximum dispersion),
- Simulations show that up to 80% of injection losses, and up to 50% of the losses coming from the decay could be concentrated on two scrapers (C4/C25),
- The scheme was tested and adopted to protect the IDs and to limit as much as possible the activation before the machine dismantling.



IV. COLLIMATION TESTS AT ESRF

Total dose in the straight sections, blown up emittance versus top up operation

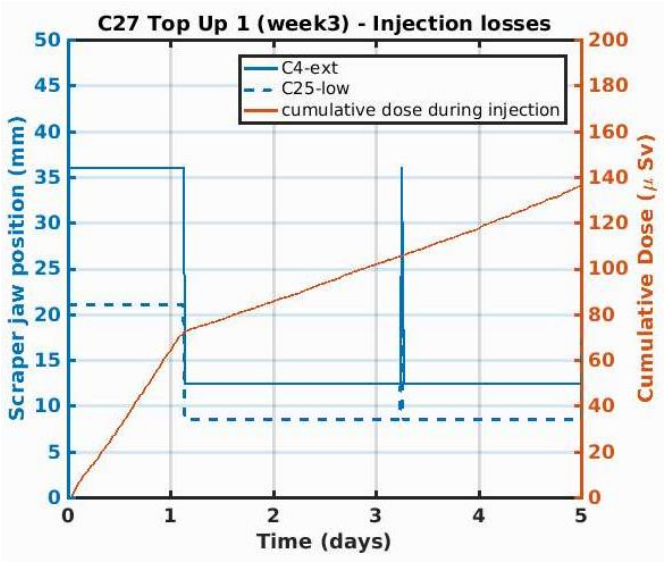
- Criterion for scrapers' settings optimization: reduce as much as possible the losses in the straight sections, keeping the impact on injection efficiency and beam lifetime below 10%,
- The influence on the dose is clear but varies depending on the straight sections,
- The total dose of previous runs with larger emittance remains lower.

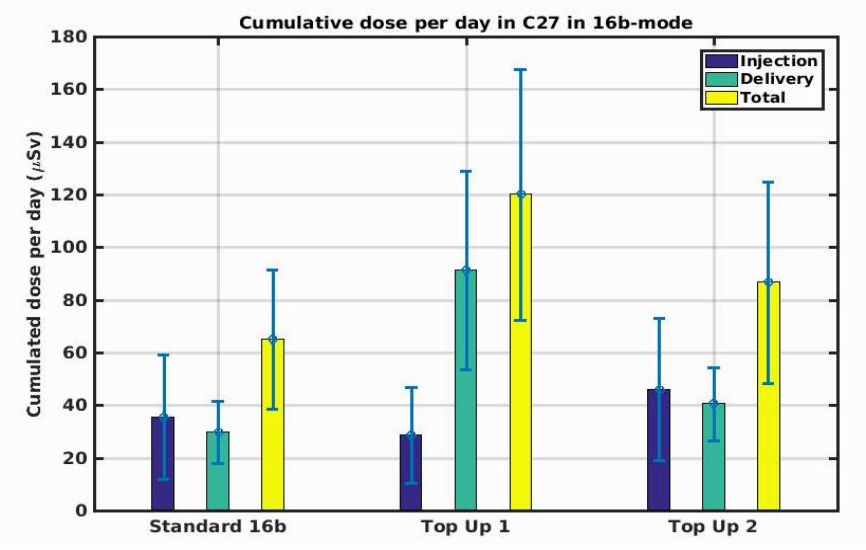


Run	Refill frequency	ε_y
Standard 16 b (12/2015)	6 h	40 pm
Top up 1 (04/2016) **Top up 2 (09/2016)**	20 min	6 pm

Injection losses and losses from beam decay – Example in cell 27

- Thanks to the scrapers optimization the radiation level due to injection is kept within the same order of magnitude than before topping up,
- Losses from Touschek scattering (during beam delivery) remain higher but are reduced by more than 50% with the scrapers.





Open scrapers

Scrapers optimized only at injection

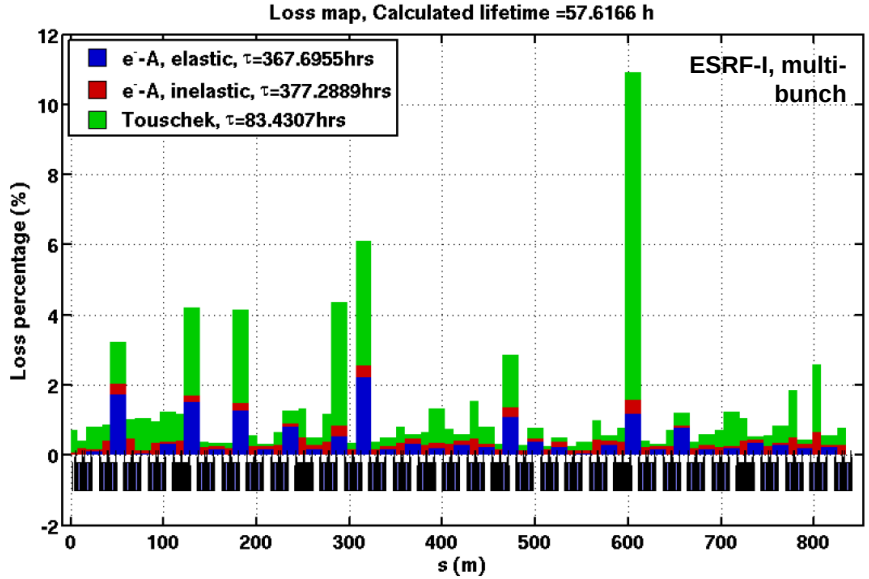
Scrapers optimized both at injection and during delivery

OUTLINE

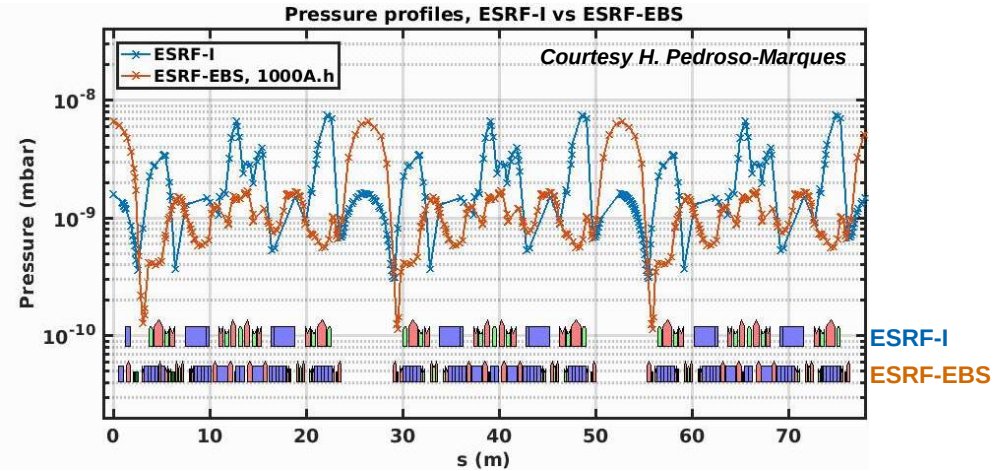
V. Vacuum losses and vacuum conditioning at ESRF-EBS

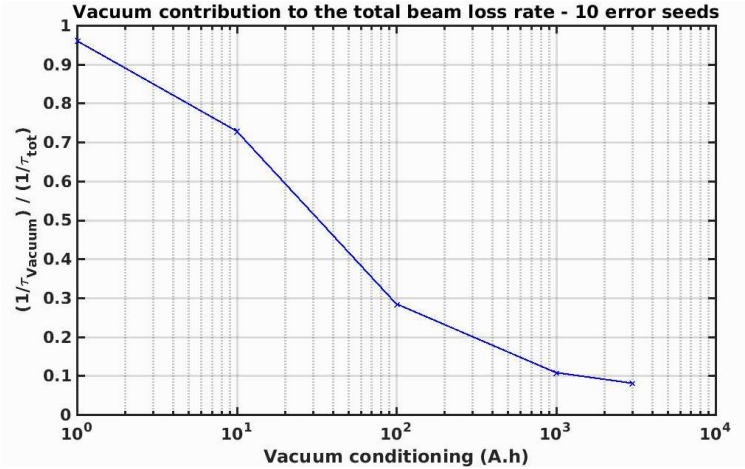
V. VACUUM LOSSES AND CONDITIONING

- Vacuum losses will be dominant over Touschek losses during the commissioning and conditioning of the new machine,
- Following a similar method as for Touschek scattering, scattered electrons can be generated and tracked after colliding with residual gas atoms,
- It includes a detailed pressure profile along the ring, as well as a custom gas composition,
- The losses are determined by
  - the vertical angle acceptance for elastic collisions,
  - by the negative side of the momentum acceptance for the inelastic collisions.



V. VACUUM LOSSES AND CONDITIONING





- ESRF-EBS and ESRF-I pressure are expected to be comparable except for the straight sections where the higher level of radiation generates more photodesorption in the vacuum chamber,
- Collision rates are estimated along the lattice for 10 machines with random sets of errors,
- Assuming an optimized Touschek lifetime (~20h), 200mA stored current, and no pre-conditioning of the chambers, 1000 A.h conditioning time would be needed to reach 10 % vacuum lifetime contribution to the total beam lifetime.

CONCLUSIONS

Summary

- Simulation tools have been developed for mapping beam losses from random collisions processes along the lattice,
- It allows to generate detailed phase space coordinates of lost particles useful for radiation and activation calculations,
- A collimation scheme was studied and collimators are in a design phase for ESRF-EBS,
- Calculations were applied to ESRF-I, concentrating the losses on two scrapers proved to be efficient to reduce the activation in view of the machine dismantling, it is kept in operation,
- Simulation of vacuum losses could help estimating the time needed for conditioning depending on pressure profiles predictions.

CONCLUSIONS

Outline

- Detailed vacuum losses during the commissioning / conditioning period of the new machine,
- Influence of machine mistuning,
- Injection losses and collimators' settings,
- ID gaps and collimators' settings,
- Installation of new EBS beam loss detectors in the running machine (4 per cell), optimization of their location and monitoring of their signal to built reference data for the new machine.

MANY THANKS FOR YOUR ATTENTION