# TOUSCHEK BACKGROUND AND LIFETIME STUDIES FOR THE SuperB FACTORY

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*Abstract*

The novel crab waist collision scheme under test at the DAΦNE Frascati Φ-factory finds its natural application to the SuperB project, the asymmetric $e^+e^-$ flavour factory at very high luminosity with relatively low beam currents and reduced backgrounds.

The SuperB accelerator design requires a careful choice of beam parameters to reach a good trade-off between different effects. We present here simulation results for the Touschek backgrounds and lifetime obtained for both the low and high energy rings for different machine designs. A first set of horizontal collimators has been studied to stop Touschek particles. A study of the distributions of the Touschek particle losses at the interaction region into the detectors for further investigations is underway.

## INTRODUCTION

The Touschek effect [1], due to the dense beams in the crab waist (CW) scheme [2], has a strong impact on both the low and high energy SuperB [3] rings, LER and HER. In fact, Touschek lifetime scales, defined as the relative loss rate at the nominal current, linearly with the bunch dimensions: $\tau_{Tou} \propto \sigma_z\, \sigma_x \sigma_y$. For this reason Touschek lifetime and backgrounds need dedicated simulation studies for handling efficiently this effect. It consists of a single Coulomb scattering which leads to an immediate loss of the two colliding particles due to the energy transfer from the transverse to the longitudinal direction with the relativistic effect of momentum change amplification. Off-momentum particles can exceed the momentum acceptance given by the radio-frequency (RF) bucket, or may hit the aperture when displaced by dispersion.

In the first section there is a brief description of the simulation code used for our studies. In the second section Touschek lifetime and backgrounds estimates for the SuperB LER and HER are presented. The joint effort with the backgrounds detector team to track particle losses into the detector is in progress. To conclude, Touschek lifetime measurements recently performed at DAΦNE-CW [4] are compared to simulation results, giving a feeling on the reliability of the tracking code.

## SIMULATION TOOL

The Touschek simulation code is based on the Monte Carlo technique and it has been developed for handling DAΦNE lifetime and particle losses, resulting very useful for understanding the critical beam parameters and optics knobs [5-6]. An accurate analysis of the critical positions where Touschek particles are generated –mainly dispersive regions- can be performed, together with the optimization of collimators, both for finding the optimal longitudinal position along the ring and the optimal radial jaw position. IR losses can be studied in detail, like transverse phase space and energy deviation of these off-energy particle losses as a function of different beam parameters, of different optics and for different sets of movable collimators. The Touschek lifetime can be evaluated directly from the ratio between the initial number of particles per bunch N and the particle loss rate, i.e. $\tau = N/\dot{N}$. A realistic tracking of the off-energy particles includes the main non-linear terms present in the magnetic lattice.

## TOUSCHEK EFFECT AT THE SUPERB

Touschek background and lifetime simulations have been performed for both LER and HER, following quite directly the lattice design evolution. Table 1 reports beam parameters relevant to Touschek estimates for the different lattices used for our investigations.

Table 1: SuperB Parameters for Different Lattices Relevant for the Touschek Background and Lifetime

| **LER/HER** | ***Unit*** | ***June'08 lattice*** | ***Jan.'09 lattice*** | ***April'09 lattice*** |
|---|---|---|---|---|
| $e^+/e$ | GeV | 4/7 | 4/7 | 4/7 |
| L | $cm^{-2}s^{-1}$ | $1\cdot10^{36}$ | $1\cdot10^{36}$ | $1\cdot10^{36}$ |
| $I^+/I^-$ | A | 1.85/1.85 | 2.00/2.00 | 2.70/2.70 |
| $N_{part}$/bunch | $10^{10}$ | 5.52· | 6/6· | 4.53/4.53 |
| $I_{bunch}$ | mA | 1.48 | 1.6 | 1.6 |
| $N_{bunches}$ | | 1250 | 1250 | 1740 |
| $\beta_x$* | mm | 35/20 | 35/20 | 35/20 |
| $\beta_y$* | mm | 0.22/0.39 | 0.21/0.37 | 0.21/0.37 |
| $\varepsilon_x$ | nm | 2.8/1.6 | 2.8/1.6 | 2.8/1.6 |
| $\varepsilon_y$ | pm | 7/4 | 7/4 | 7/4 |
| C | m | 1800 | 1800 | 1400 |

### *LER Lifetime and Backgrounds*

After the CDR [7] completion SuperB beam parameters have been optimized to decrease the vertical tune shift; also the horizontal emittance has been increased and number of particles per bunch have been slightly decreased in the LER. This new configuration is reported in the first column of Table 1.

Table 2: Summary of LER Touschek Lifetime Simulations

| LER lattice | $\tau_{Tou}$(min) | Coll. pos.(m) from IP/ n$\sigma_x$ | IR losses(Hz) |
|---|---|---|---|
| June08 | 24 | out | $1.7 \cdot 10^6$ |
| | 20 | -8.5 / 20 $\sigma_x$ | ~ $10^3$ |
| Jan.09 | 13 | out | $1.8 \cdot 10^6$ |
| | 12 | -59.9 / 31 $\sigma_x$ -34.4 / 27 $\sigma_x$ - 8.5 / 20 $\sigma_x$ | ~ $10^3$ |

A new lattice with this new set of parameters, named *June '08* [8], has been designed. Optimization of the dynamic aperture (DA) of the off-energy particles, an important issue for controlling this effect, has also been performed.

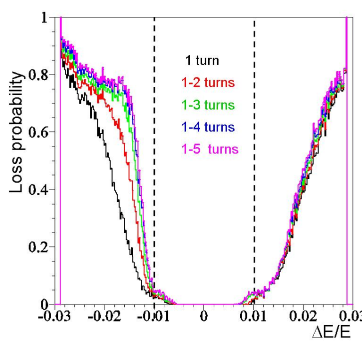


Figure 1: LER energy acceptance from Touschek simulations for the June08 *lattice* for the first five machine turns.

A plot showing the Touschek loss probability as a function of the energy deviation is shown in Fig. 1. In the first machine turn particle losses have larger energy acceptance (black curve), then the loss probability increases as a function of ΔE/E when tracking for a few turns. A longer Touschek lifetime of about 24 min, as summarized in first row of Table 2, was found, with IR losses of the order of 1.7 MHz. A horizontal collimator has been placed at 8 mm from the center of the beam pipe. This distance corresponds to 20 standard deviations of a gaussian beam distribution with an horizontal emittance of $\varepsilon_x$=2.8nm. The collimator therefore does not intercepts beam particles but is cutting into the wider horizontal distribution of off-momentum particles. It is symmetrical from the beam pipe and placed at -8.5 m upstream the IP to reduce IR particle losses. In this case $\tau_{Tou}$ reduces to about 20 min but a strong reduction of the IR losses (second row of Table 2) was obtained.

New simulations have been performed with a more accurate IR design [9], in terms of low-β quads position and strength for the minimization of the IR synchrotron radiation and in terms of beam stay clear (BSC). The lattice that includes this IR design has been named *Jan. '09 lattice*. For our interest, there is a small increase of the single bunch current from 1.48 to 1.6 mA to further reduce the y tune shift. A small increase of the Touschek lifetime was expected for this lattice. In fact, as particle losses are concentrated mostly at the IR where the BSC is smaller, an accurate design of the IR physical aperture in terms of BSC is an essential issue for a long lifetime as well. However, for this lattice a DA optimization for off-energy particles has not been undertaken yet. So a shorter lifetime is found due to the worse off-energy DA; the IR losses are instead more or less unchanged, essentially due to the better IR design. Fig. 2 shows some Touschek trajectories with three horizontal collimators inserted at a distance corresponding to more than 20 $\sigma_x$ from the central beam axis showing their effectiveness. The last two rows of Table 2 summarize results for the *Jan.'09 lattice*.

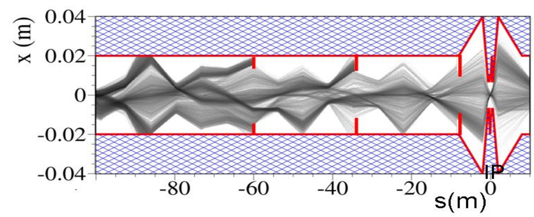


Figure 2: LER Touschek particles trajectories for the *Jan.'09 lattice* with three collimators rejecting particle losses.

### *HER Lifetime and Backgrounds*

Touschek simulations have been performed for the HER as well, as the dense beam induces a strong scattering within bunches, even if the beam energy is higher. However, as expected, HER Touschek lifetime results somewhat longer than the LER one.

Touschek lifetime estimated for the *June'08 lattice* is about 40 min; with an upstream IR collimator it is reduced to ~32 min and IR losses are strongly reduced. The first two rows of Table 3 summarize these results.

Table 3: Summary of HER Touschek Lifetime Simulations

| HER lattice | $\tau_{Tou}$(min) | $I_b$(mA) | Coll. pos.(m) from IP/ n$\sigma_x$ | IR losses(Hz) |
|---|---|---|---|---|
| June08 | 40 | 1.49 | out | $4.2 \cdot 10^6$ |
| | 32 | 1.49 | -8.5 / 20 $\sigma_x$ | ~ $10^3$ |
| April'09 lattice | 35 | 1.49 | out | ~ $10^3$ |
| | 32 | 1.6 | | Only downstream |

A further evolution is the *April'09 lattice*, a shorter machine (parameters listed in last column of Table 1) with a good DA for off-energy particles, comparable to the *June'08 lattice*. Particularly good seems the energy acceptance at ΔE/E<0.01, corresponding to a low loss probability below this energy deviation. For this lattice design Touschek lifetime is more or less unchanged, thanks to this accurate DA correction. IR losses are greatly decreased and, in addition, simulation predicts losses only downstream the IP. Fig. 3 shows trajectories of particles eventually lost at the IR without any collimator inserted in the simulation; in red are drawn two proposed positions.

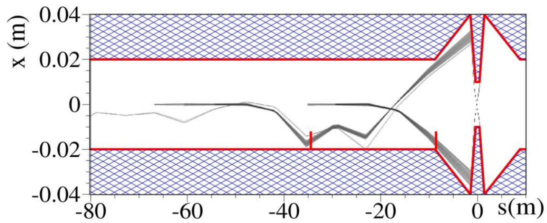


Figure 3: HER Touschek trajectories of the IR particle losses for the *April'09 lattice;* no collimators were inserted in the simulation, superimposed in red is a possible position.

## TOUSCHEK EFFECT AT DAFNE CW

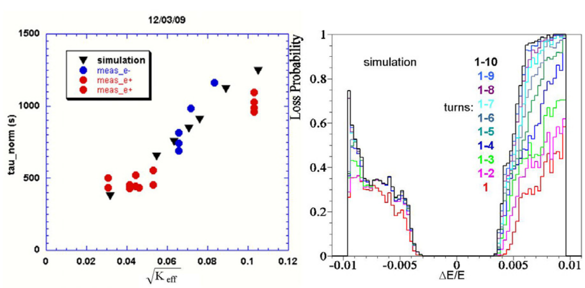


Figure 4: Left: calculated (black markers) and measured normalized lifetime for $e^+$ (red dots) and $e^-$ (blue dots) beams versus the square root of coupling. Right: simulated Touschek energy acceptance for ten turns.

As already discussed for the SuperB design, the important features of the new CW lattice affecting the Touschek effect are the smaller emittances and beam sizes, especially at the IP with respect to the standard collision scheme. For the DAΦNE upgrade from the standard to the CW collision scheme, $\sigma_x$* has been decreased from 700 to 200 μm, $\sigma_y$* from 15 to 2.4 μm, $\sigma_z$ from 2.5 to 2.0 cm and $\varepsilon_x$. from 0.3 to 0.26 mm-mrad.

Touschek measured lifetime is now shorter than it was with the standard collision scheme, as confirmed also by simulations [10]. The resulting simulated Touschek lifetime is as short as $\tau \cong 840$ s for a 0.5% beam coupling. This result is in agreement with measurements, as appears from the left plot of Fig. 4, that shows the normalized measured lifetime for both beams and the calculated one as a function of the square root of the effective beam coupling. Black markers refer to simulation while blue and red ones to electrons and positrons measured lifetimes, respectively. The plotted lifetime is normalized to the total current: $\tau_{norm}=\tau_{mis}(I/I_{tot})^{2/3}$, according to the scaling law $\tau \propto \sigma_z\sigma_x\sigma_y/I$ where $\sigma_z$ is the current dependent bunch length $\sigma_z \propto I^{1/3}$. Beam coupling is evaluated at the synchrotron light monitor from the measured transverse sizes and from the ratio $\beta_y/\beta_x$=2.25, as indicated by the MAD optical model. The effective vertical beam size used for the evaluation of the effective coupling $K_{eff}$ takes into account its measurement resolution of 80 μm [11]. The total beam current during measurements was $I_{tot} \cong 100$ mA with 10 bunches. The right plot of Fig. 1 shows the simulated energy acceptance of the Touschek particles tracked for ten turns for the corresponding lifetime plotted by the black markers on the left plot. With the present DAΦNE-CW lattice tracking simulation takes into account the decapole and dodecapole term present in wigglers poles, as obtained by fitting the wigglers magnetic measurements [12].

## CONCLUSIONS

LER and HER Touschek studies have been performed following the lattice evolution, finding simulation results consistent with lattice and parameters changes. The main differences are due to different IR design, to different levels of DA optimization, but also on how stringent machine parameters are for the Touschek effect.

Simulations will be repeated with a model including the detector solenoidal field, the optimization of the dynamic aperture (DA) of the off-energy particles calculated with dedicated codes and -for the HER- the spin rotator for e-beam polarization.

A first collimators set has been found, reducing very efficiently IR particle losses. Nevertheless, IR particle losses will be tracked into the detector with GEANT4 for further investigations. Background rates seen by the detectors are evaluated tracking the secondaries particles produced by the interaction of the primaries lost particle with the material of the machine and of the detector. The secondaries are generated by feeding primaries losses into a full Monte Carlo simulation code based on Geant4 that incorporates a detailed model of the SuperB detector and IR. Present detector technologies are adequate to cope with the predicted Touscheck backgrounds using the proposed set of collimators.

The Touschek simulation code results have been found in good agreement with the DAΦNE-CW measurements.

## REFERENCES

[1] C. Bernardini, et al., Phys. Rev. Lett., vol. 10, 1963, p. 407.
[2] P. Raimondi, 2nd SuperB Workshop, LNF, (2006) and physics/0702033.
[3] M.E. Biagini, this Conference.
[4] C. Milardi, this Conference.
[5] M. Boscolo et al., Proc. of the 2001 IEEE PAC, USA (2001), p.2032.
[6] M. Boscolo et al., Proc.of the 8th EPAC Paris, France, (2002), p.1238.
[7] SuperB CDR, arXiv:0709.0451 (2007) 480 pp.
[8] M.E. Biagini et al., in Proc. of EPAC08, Genoa (2008) p. 2608.
[9] M. Sullivan, this Conference.
[10] M. Boscolo, ICFA BD Newsletter, N. 48, April (2009)
[11] DAΦNE operation logbook 2/4/2008 p.58.
[12] DAΦNE Technical Note MM-34, January 2004.