DAΦNE TECHNICAL NOTE

INFN - LNF, Accelerator Division

Frascati, June 15, 1994

Note: **IR-5**

Background in the KLOE IR due to Touschek scattering

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1. Introduction

In ref.[1] the single beam lifetime has been calculated for DAΦNE taking into account the actual shape of the vacuum pipe. In this note we evaluate the number of particles which hit the pipe of the IR and the effectiveness of beam scrapers in reducing the background for the experiments.

In DAΦNE the maximum number of particles per bunch is:

$$N = 8.9\ 10^{10}\ \text{particles/bunch},$$

and the various contributions to the beam lifetime, calculated for the design parameters, are:

$\tau_{Touschek} = 340$ min
$\tau_{scattering} = 1440$ min
$\tau_{bremsstrahlung} = 2350$ min

corresponding to a total lifetime:

$\tau_{total} = 240$ min.

For background evaluation only Touschek scattering, which is the dominant loss effect, is considered in the following.

2. Background from Touschek scattering

Each ring is divided into two regions: straight sections, where the dispersion function is vanishing, and arcs, where it is non zero.

Particles which undergo an energy change exceeding RF acceptance, due to a Touschek scattering in the straight sections, are lost in the arcs and do not contribute to the background in the KLOE detector.

Instead the particles that change energy in the arcs gain a large betatron amplitude in the horizontal plane and could be lost in the IR; therefore we are interested in estimating the number of the lost particles as well as the location where they are lost.

We assume that only the particles scattered in the arc upstream (LONG arc) could reach the KLOE IR, since the particles scattered in the other three arcs can be intercepted elsewhere in the ring.

At the maximum current, the number of particles per bunch lost by Touschek scattering per second all over the ring is:

$$\Delta N_{Tou} = \frac{N}{\tau_{Tou}} = \frac{8.9 \cdot 10^{10}}{340 \cdot 60} s^{-1}/bunch = 4.4 \cdot 10^{6}\, s^{-1}/bunch$$

The contribution to the Touschek beam lifetime of the particles which are scattered in the arc upstream the KLOE IR is nearly 20% of the total. We want to evaluate how many of these particles hit the vacuum chamber inside the KLOE detector.

3. Trajectories in the KLOE IR

A particle with a relative energy change $\pm\varepsilon$, due to a Touschek scattering at an azimuth s_i with dispersion D_i , starts to oscillate around an orbit displaced by εD_i with respect to the reference orbit, with a maximum betatron amplitude:

$$\hat{x}_\beta(s) = \sqrt{\varepsilon^2 H_i \beta(s)}$$

where:

$$H_i = \gamma_i D_i^2 + 2\alpha_i D_i D_i' + \beta_i D_i'^2 .$$

In a region between two bending magnets, *H* is constant and therefore all the trajectories originated inside the arc have an amplitude proportional to ε.

Moreover the trajectory of a particle, which changes energy inside the arc, remains unchanged until it reaches the bending magnet, since the betatron and synchrotron part cancel each other, so the trajectories of the particles Touschek-scattered inside the arc have all the same phase and are proportional to the relative energy change ε.

This is not exactly true in the wiggler, where the quantity *H* oscillates. The amplitude of the trajectories , originated inside the wiggler, varies by plus or minus a few percent with respect to the rest of the arc, while the phase is the same.

In order to see where the particles are lost, we consider only one trajectory originated inside the arc, in particular the trajectory for ε=.0065, which is at the limit of the vacuum chamber aperture.

Figure 1 shows the horizontal and vertical trajectories, from the bending upstream to the end of the KLOE IR, of a particle which has gained an energy ε=.0065 in the arc (LONG arc). The vertical orbit is due to the coupling in the solenoid.

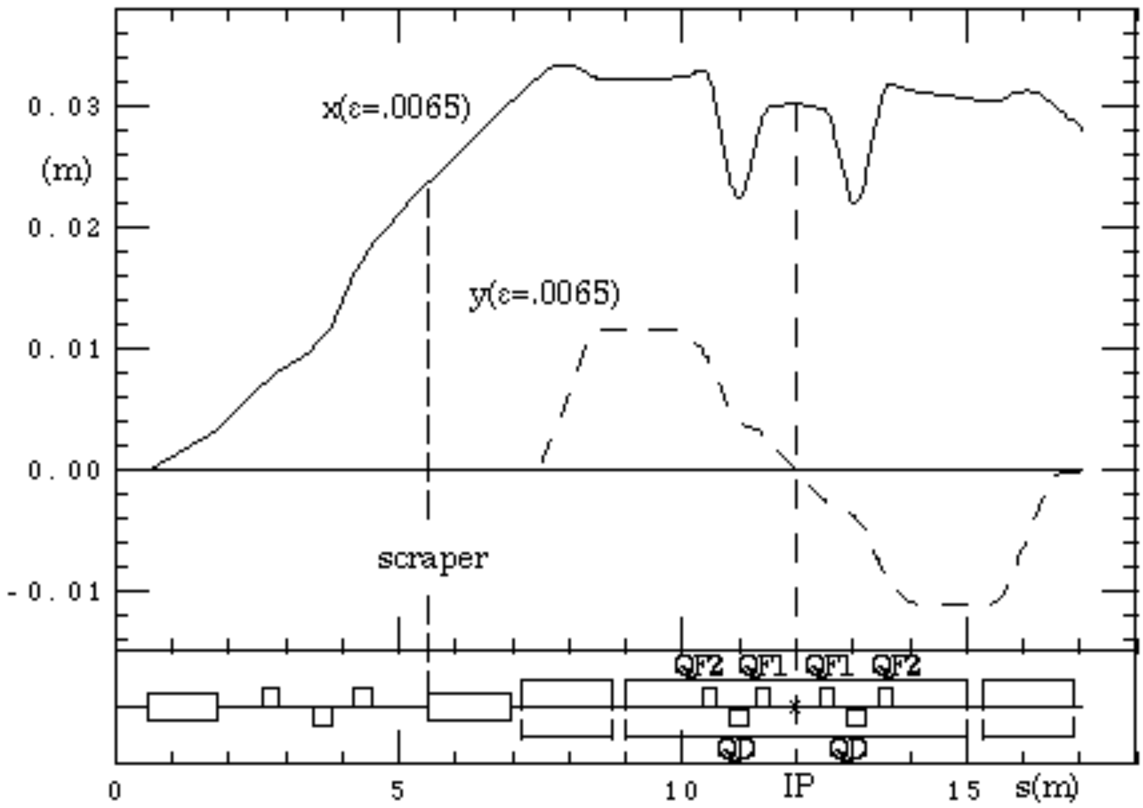

***Fig. 1** - **x** and **y** from the bending upstream KLOE to the end of the KLOE IR for ε =.0065.*

In the third quadrupole from the IP (QF2) the trajectory has a maximum which is at the limit of the vacuum chamber aperture. If we do not insert any scraper, most of the particles will be lost inside the KLOE detector.

Due to the crossing angle the reference trajectory in the IR is displaced with respect to the quadrupole axis, the displacement is the half separation between the two beams ($\Delta \mathbf{x}$ and $\Delta \mathbf{y}$).

Figure 2 shows the sum of the trajectory for ε =.0065 plus the half-separation between the two beams, for a half crossing angle θ = 12.5 mrad both in the horizontal and vertical planes, together with the radius $\mathbf{r} = \sqrt{(\mathbf{x}+\Delta\mathbf{x})^2 + (\mathbf{y}+\Delta\mathbf{y})^2}$. In this figure is adopted a reference system centered on the quadrupole axis, which has a discontinuity at the beginning of the IR; the aperture of the low beta quadrupoles is also shown in the figure.

In **Fig. 3** the same quantities are shown for ε = -.0065.

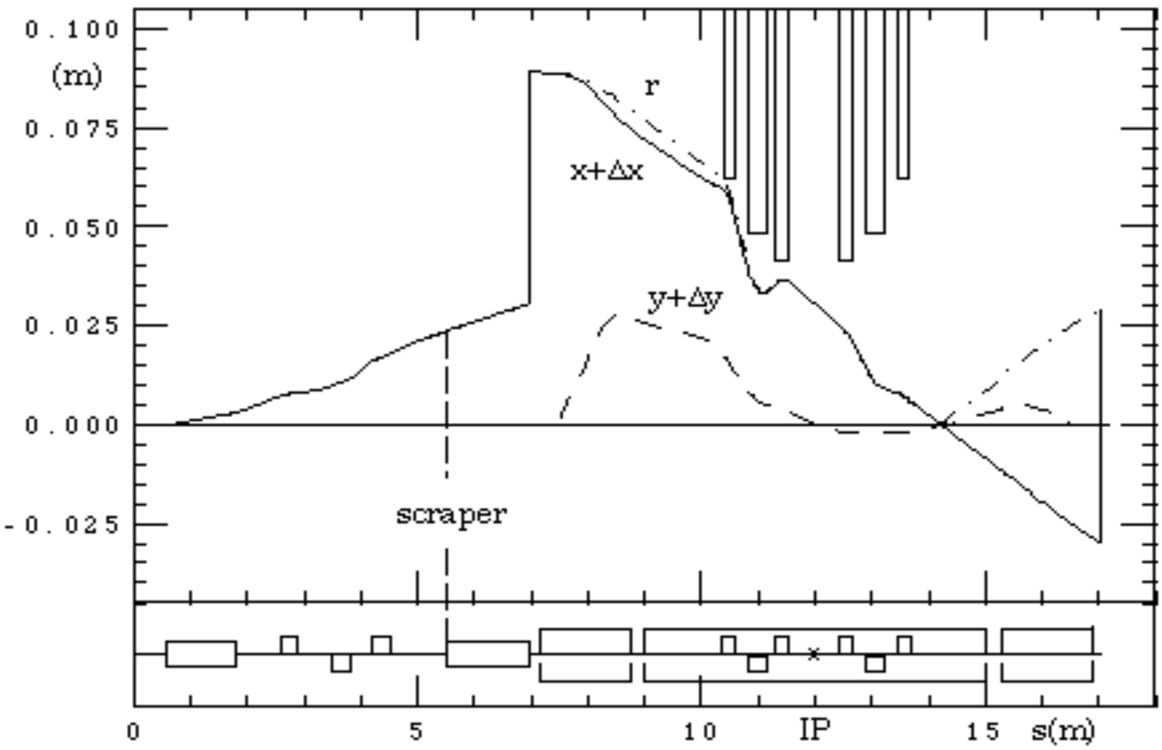

Fig. 2 *- **x+Δx** , **y+Δy** and **r** from the bending upstream KLOE to the end of the KLOE IR, for ε =.0065 andθ=12.5mrad.*

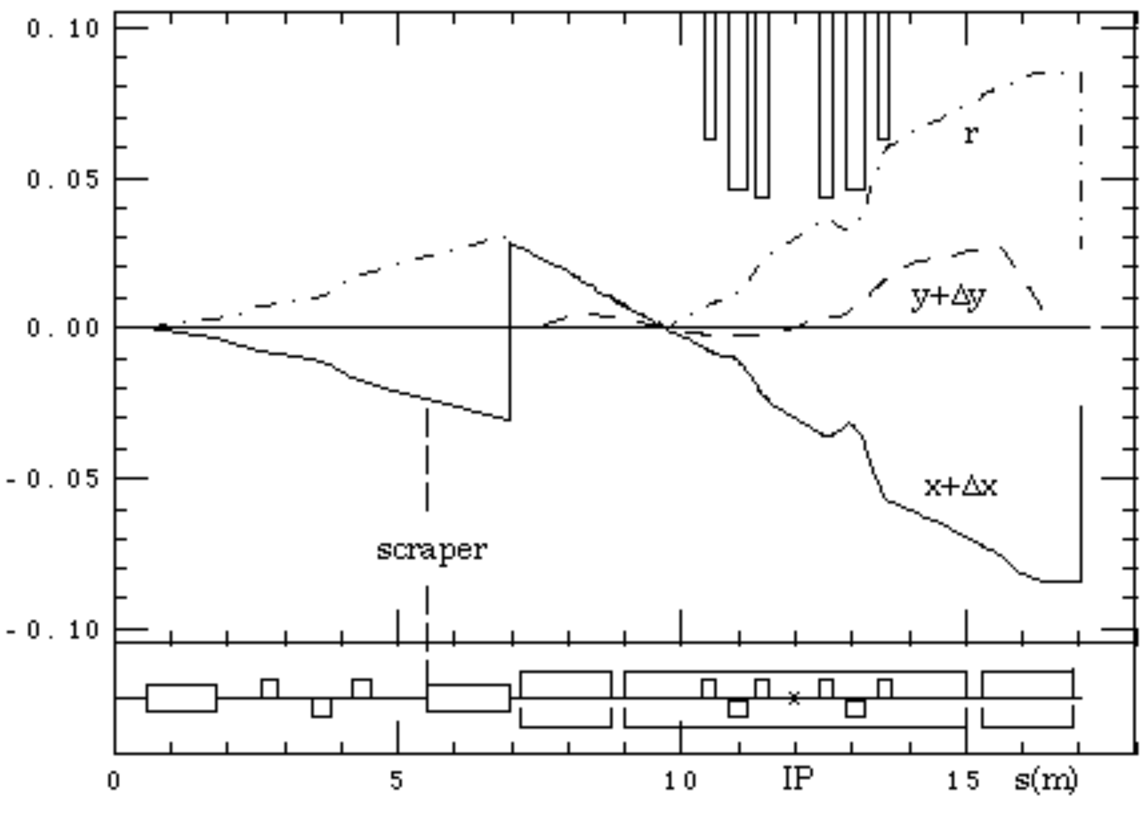

Fig. 3 *- **x+Δx** , **y+Δy** and **r** from the bending upstream KLOE to the end of the KLOE IR, for ε =-.0065 and θ=12.5mrad.*

4. Scrapers position

In order to reduce the background for the KLOE experiment, we suggest to install in each ring a first beam scraper, in the horizontal plane, upstream the splitter magnet.

An advantage of this choice is that the bending angle of the splitter helps in reducing the background. In fact the electrons of the electromagnetic shower produced in the scraper are bent away by the splitter magnet and most of the photons are in the line of flight of the electrons before the splitter, which does not intersect the detector.

The drawback of this solution is that the amplitude of the trajectory at the splitter entrance is considerably smaller than that at the quadrupole (see Fig. 1). Therefore the scraper must be inserted very near the beam axis to cut all the particles which would be lost on the quadrupole, producing a non-negligible reduction of the beam lifetime.

The scraper's target has to be thick ($\geq$ 10 r. l., corresponding to 3.5 cm for W and 14.3 cm for Cu) in order to stop almost all of the electromagnetic shower produced by 500 MeV electrons.

The shape of the target has to be tapered in order to minimize the discontinuity in the vacuum chamber which is a possible source of beam instability.

It is important to have independent movements on both sides of the beam axis because the closed orbit is displaced from the center of the chamber when the crossing angle is changed and, due to the sextupoles, the trajectories are not symmetric.

During the operation of DAΦNE the position of the scraper can be varied in order to find a compromise between a good beam lifetime and an acceptable background on the detector. At injection the scraper to be open in order to exploit the whole available aperture.

To further reduce the background in the KLOE IR it is useful to insert a second scraper in each ring in order to intercept the particles scattered in the arc upstream KLOE after the first passage in the IR and the particles scattered in the other three arcs. A discussion of the location and the effectiveness of this scraper is given in **Appendix A**.

The background evaluation for FI.NU.DA. has not yet been carried out since the design of the low-β quadrupoles is still in progress. Anyway the apertures of this quadrupoles should be chosen large enough to obtain a low background level with the insertion of a scraper in the equivalent location with respect to the KLOE one (upstream the splitter magnet of the SHORT arc in both rings).

The location of the scrapers in the rings is shown in **Fig. 4**.

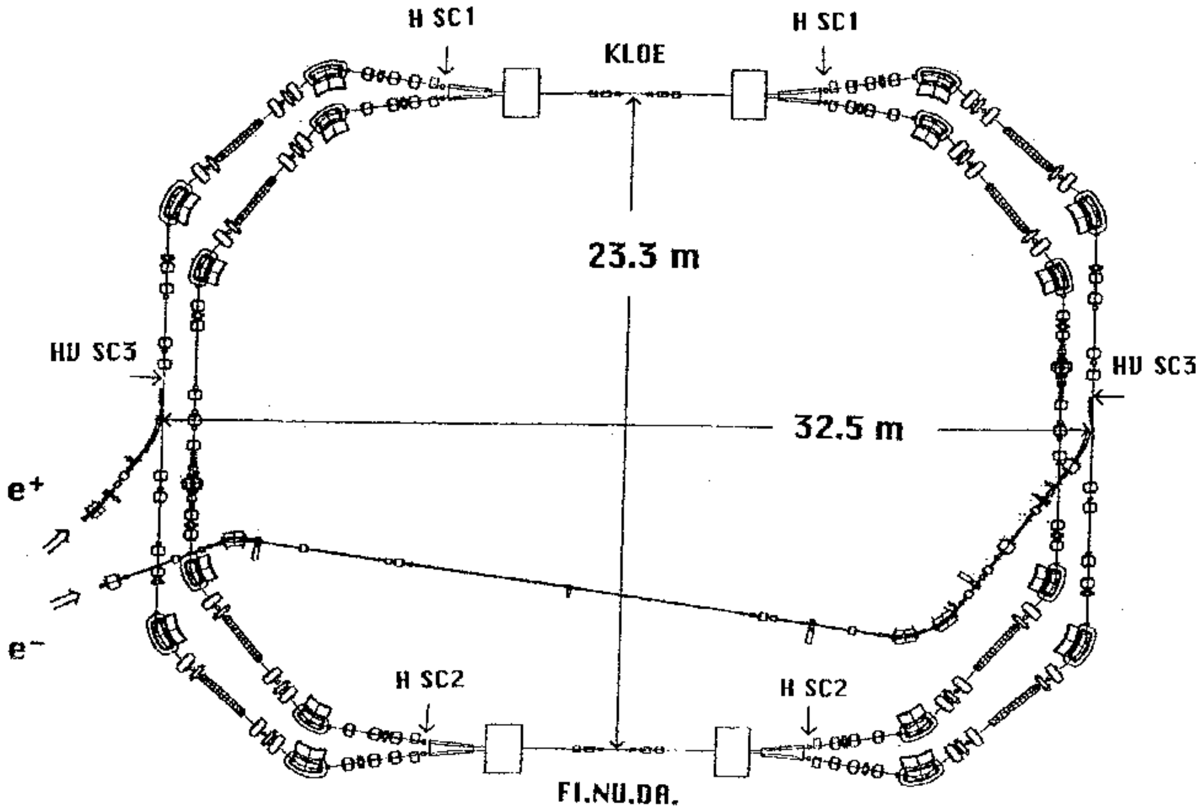

Fig. 4 - *Location of the scrapers in the two rings.*

5. Beam lifetime and background evaluation

In **Table I** we give an estimate of the various contribution to the beam lifetime, for the KLOE lattice, as a function of the aperture $\mathbf{A_{sc}}$ of the scraper at the splitter entrance. The calculation is done assuming the design parameters for the maximum luminosity, in particular the maximum bunch current and a coupling factor κ=.01.

The gas bremsstrahlung beam lifetime is calculated taking into account only the RF energy acceptance and is τ_{br} = 2350 min independent of aperture.

Table I

A_{sc} (mm)	A_{sc}/σ_x	$\tau_{quantum}$ (min)	τ_{sc} (min)	τ_{Tou} (min)	τ_{tot} (min)
16.	5.5	**46.**	742	98.	30
17.5	6.	548.	823	119	84
20.5	7.	$2.0\ 10^5$	970	165	133
23.5	8.	$2.1\ 10^8$	1097	217	168
26.5	9.	$5.8\ 10^{11}$	1205	263	198
29.	10.	$4.2\ 10^{15}$	1297	323	233

The dependence of the total beam lifetime on the scraper position is nearly linear in the interval $6\div10\sigma_x$, while below $6\sigma_x$ the exponential behaviour of the quantum lifetime becomes dominant and τ_{tot} drops rapidly.

A Montecarlo program has been written to evaluate the fraction of the circulating particles which hit the scraper or the low-β quadrupole QF2.

Particle coordinates are extracted with a gaussian distribution, weighted with the probability of having a Touschek scattering of energy ε in a proper energy interval, and tracked from the bending upstream KLOE up to the end of the KLOE IR. A check on the aperture is done at the scraper (horizontal aperture limit) and at the two QF2 quadrupoles (circular aperture in the xy plane) on both sides of the IP.

The calculation is performed considering only the first passage through the IR, since this is case which presents the worst phase of the off energy trajectory for loosing particles in the IR, i.e. a maximum at the IP. Moreover it is assumed that a second scraper is inserted in the ring to reduce the particles lost on successive passages.

In **Table II** the beam lifetime and the fraction of particles (η_Q, η_{sc}) lost per second on the scraper and on QF2, respectively, is given as a function of the scraper aperture for the design value of the half crossing angle θ = 12.5 mrad. In the same table also the number of particles $\mathbf{N_Q}$ lost per second and per bunch on QF2 for a number of circulating particles $\mathbf{8.9 \cdot 10^{10}}$**/bunch**, the maximum design value, is shown.

Table II - θ = 12.5 mrad

A_{sc} (mm)	η_Q (s^{-1})	η_{sc} (s^{-1})	N_Q (part./s/bunch)	τ_{tot} (min)
20.5	$4.5\ 10^{-11}$	$6.33\ 10^{-6}$	4.	133
22.	$2.59\ 10^{-9}$	$5.37\ 10^{-6}$	231	150
23.5	$8.82\ 10^{-8}$	$4.54\ 10^{-6}$	$7.85\ 10^{3}$	168
25.	$3.88\ 10^{-7}$	$3.90\ 10^{-6}$	$3.45\ 10^{4}$	184
26.5	$8.01\ 10^{-7}$	$3.38\ 10^{-6}$	$7.13\ 10^{4}$	198
29.	$1.42\ 10^{-6}$	$2.73\ 10^{-6}$	$1.26\ 10^{5}$	233

The number of particles lost on QF2 and the total beam lifetime as a function of the scraper position are also shown in **Fig. 5**.

From the inspection of Table II one can see that, in order to reduce the background in the detector to an acceptable level (less than 1 KHz per bunch, per beam), we loose a factor 1.5 on the beam lifetime.

The only solution to obtain the same background level with a larger beam lifetime is to increase the aperture of the low-β quadrupoles. As it is shown in Figs. 2 and 3 the limiting aperture is that of QF2, on the aperture of QF1, and QD! there is a little margin.

The aperture of QF2, which is already quite large due to the beam separation, is essentially a matter of cost and not of space, while the aperture of QF1 can be increased only at the expense of the free solid angle available for the experiment.

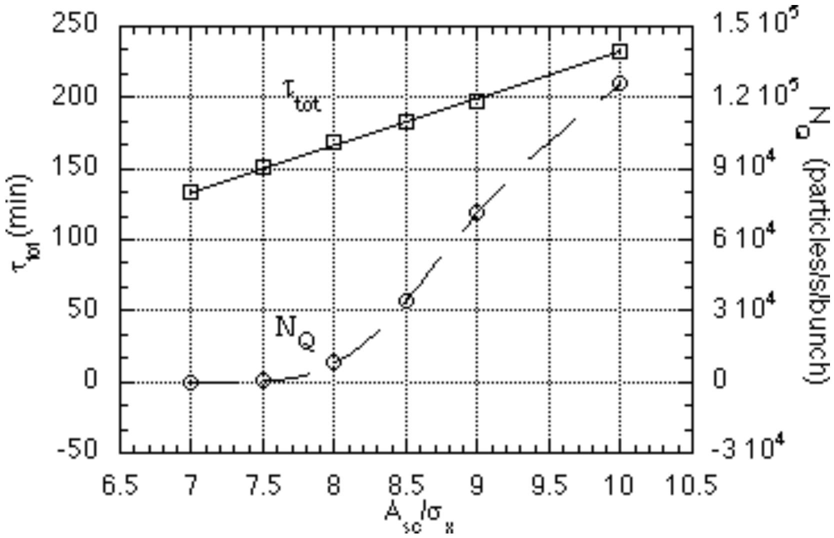

***Fig. 5** - τ_{tot} and N_Q versus the scraper half aperture (in units of σ_x at the scraper).*

The solution we propose is to increase the aperture of QF2 up to the limit where particles get lost on QF1. **Table III** shows the values of N_Q as a function of the scraper aperture for different apertures of the quadrupole QF2. **In Fig. 6** N_Q is plotted as a function of the aperture of QF2 for two different values of the scraper aperture.

Table III - θ = 12.5 mrad

A_{sc} (mm)	N_Q (part./s/bunch)			τ_{tot} (min)
	A_{QF2}=62.5mm	A_{QF2}=67.5mm	A_{QF2}=72.5mm	
23.5	$7.85\ 10^3$	0.	0.	168
26.5	$7.13\ 10^4$	$1.24\ 10^3$	46.	198
29.	$1.26\ 10^5$	$2.71\ 10^4$	$5.31\ 10^3$	233

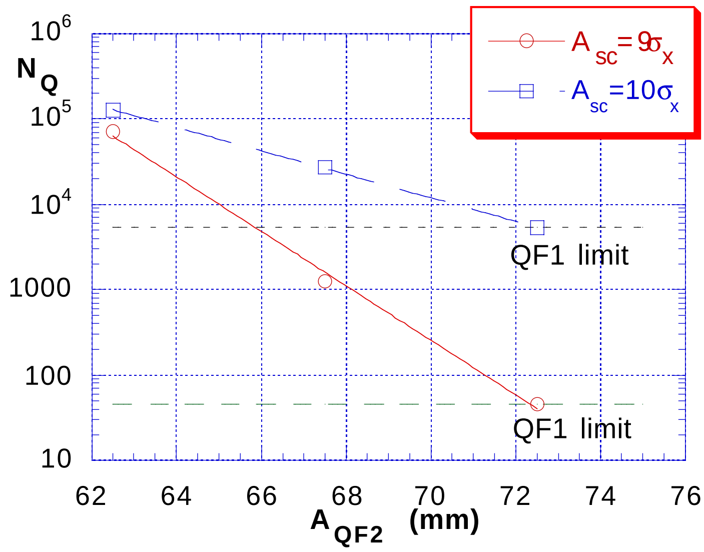

***Fig. 6** - N_Q as a function of the aperture of QF2 for two values of A_{sc} and θ=12.5mrad.*

The design aperture for QF2 is 62.5 mm, it can be increased up to 72.5 mm before QF1 begins to intercept the particles. With this aperture we have a very low background level with a beam lifetime larger than three hours.

In DAΦNE the half crossing angle θ can be varied around the nominal value in order to reduce the beam-beam effect at the parasitic crossing points.

By changing θ, the available aperture of the low-β quadrupoles is reduced or increased. Therefore, in order to keep the same background level, the scraper aperture has to be varied, producing a longer beam lifetime for smaller values of the crossing angle and viceversa.

The results for $\theta = 10$ and 15 mrad are presented in **Appendix B**.

6. Conclusions

Due to the high value of the circulating current foreseen to get the maximum luminosity in DAΦNE, the background level in the detector is of concern for KLOE.

The dominant loss effect in DAΦNE is Touschek scattering; in this note the background due to particles which undergo a Touschek scattering in the arc and are lost in the KLOE IR is evaluated.

In order to stop the particles which would reach the KLOE IR, it is proposed to install, for each ring, a beam scraper upstream the splitter magnet of the LONG arc and one in the injection straight section. For the FI.NU.DA. IR other two scrapers, upstream the splitter magnet of the SHORT arc, are foreseen.

With this configuration, in order to reduce the background to the low level required for the KLOE experiment, the scrapers aperture reduces the beam lifetime by a factor 1.5.

To avoid this beam lifetime reduction we propose to increase the aperture of the low-β quadrupoles QF2 by 1 cm.

With this solution a very low background level (less than 1 KHz per bunch, per beam) with a beam lifetime larger than three hours is obtained.

References

[1] S. Guiducci: "Beam lifetime in DAΦNE ", Technical note L-12 .

[2] M.E. Biagini: "KLOE interaction region update ", Technical note L-13.

[3] M.E. Biagini, C. Biscari, S. Guiducci, M.R. Masullo, G. Vignola: "Review of DAΦNE lattices", Technical note L-9.

Appendix A

A good position for the second scraper is in the LONG straight section, upstream the injection septum, where the phase advance distance from the KLOE scraper is ~90°, which assures the maximum efficiency on the multiturn background reduction.

This scraper can be as thin as 2÷3 radiation lengths (i.e. ~ 1 cm of W) because it is far from the two IRs.

In **Figs. A1, A2, A3** the trajectory in the horizontal plane for ε=.0065 is shown for particles Touschek scattered in the three arcs not yet considered. These plots are done for the DAY-ONE lattice, which is simpler than the KLOE one since it has no solenoids, and is equivalent for our purpose, due to the transparency criterion[3] (the two IRs have nearly the same transfer matrix).

The scraper in the injection straight section is in the maximum of the trajectory for orbits originating in the two arcs upstream (see Figs. A1, A2), and therefore has the maximum effectiveness for them.

The particles scattered in the SHORT arc upstream the SHORT straight section are cut with good efficiency at the first passage in the KLOE scraper without increasing the background in the IR (see Fig. A3).

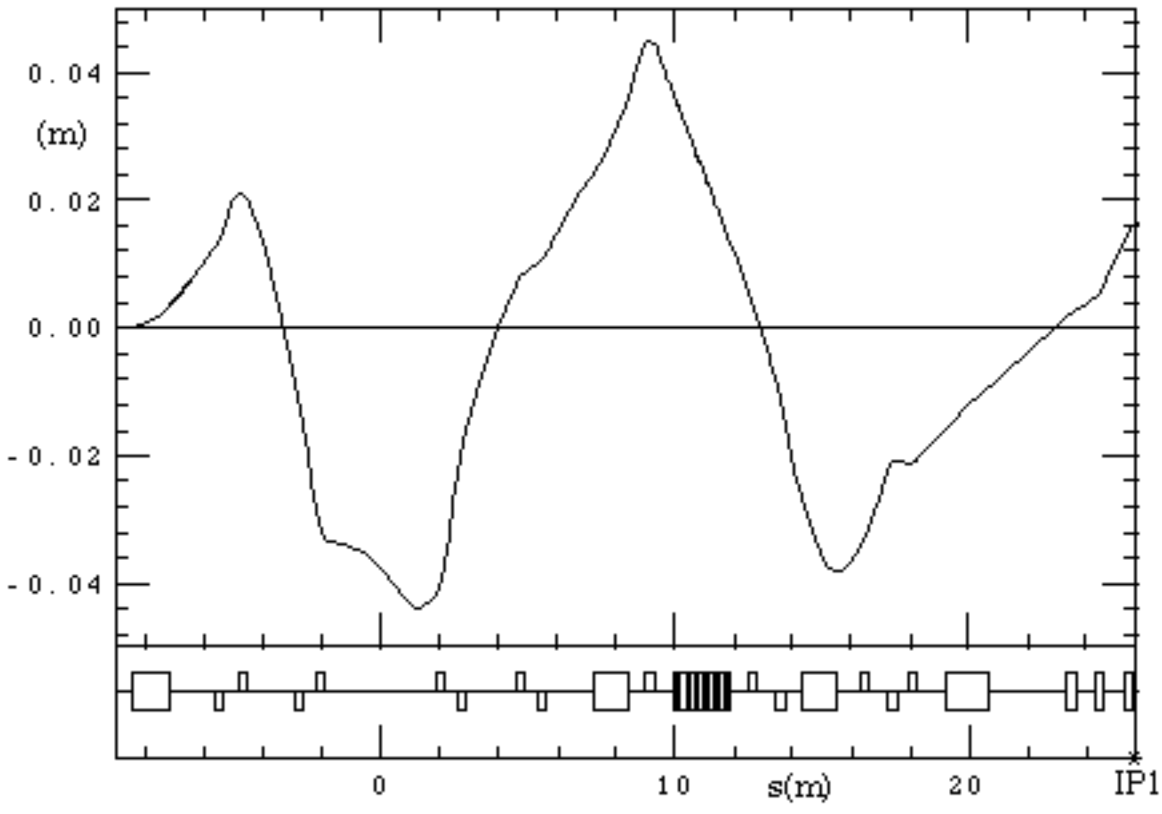

Fig. A1 - *x(ε=.0065) from the bending upstream the LONG straight section to the KLOE IP.*

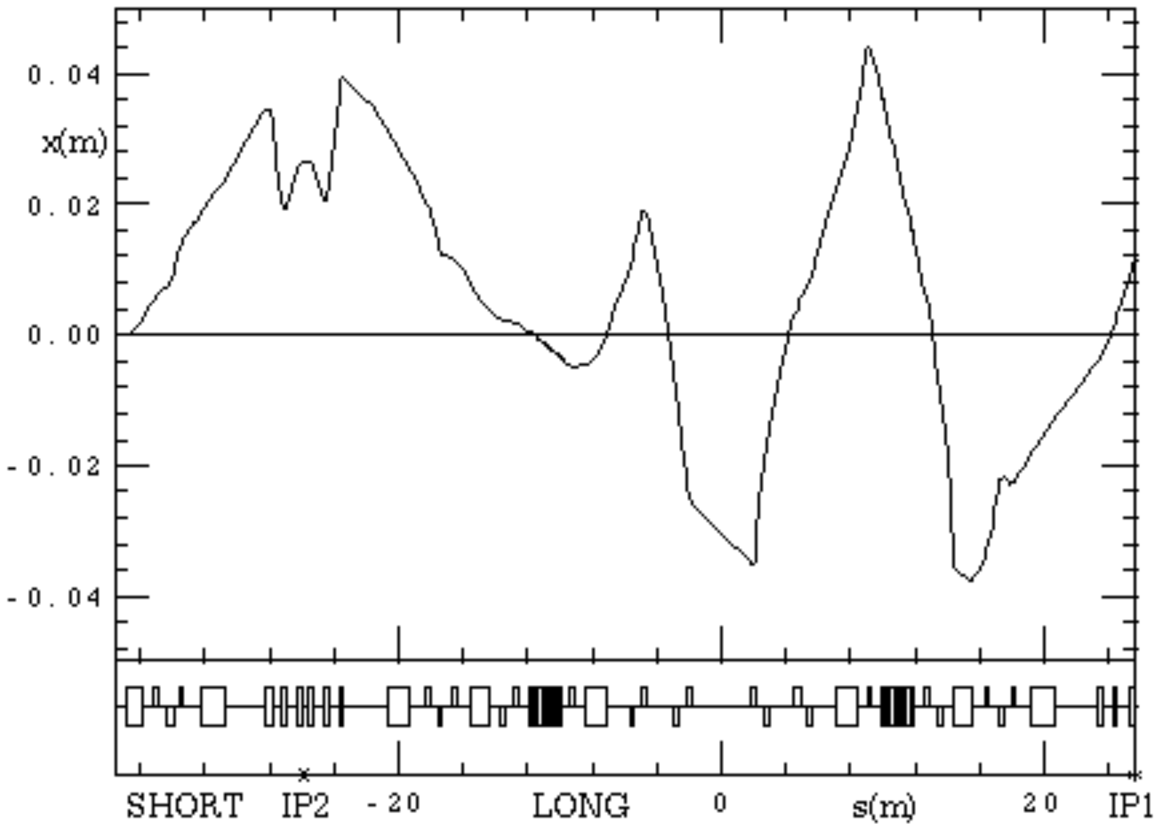

Fig. A2 *- x(ε=.0065) from the bending upstream the FINUDA IR to the KLOE IP.*

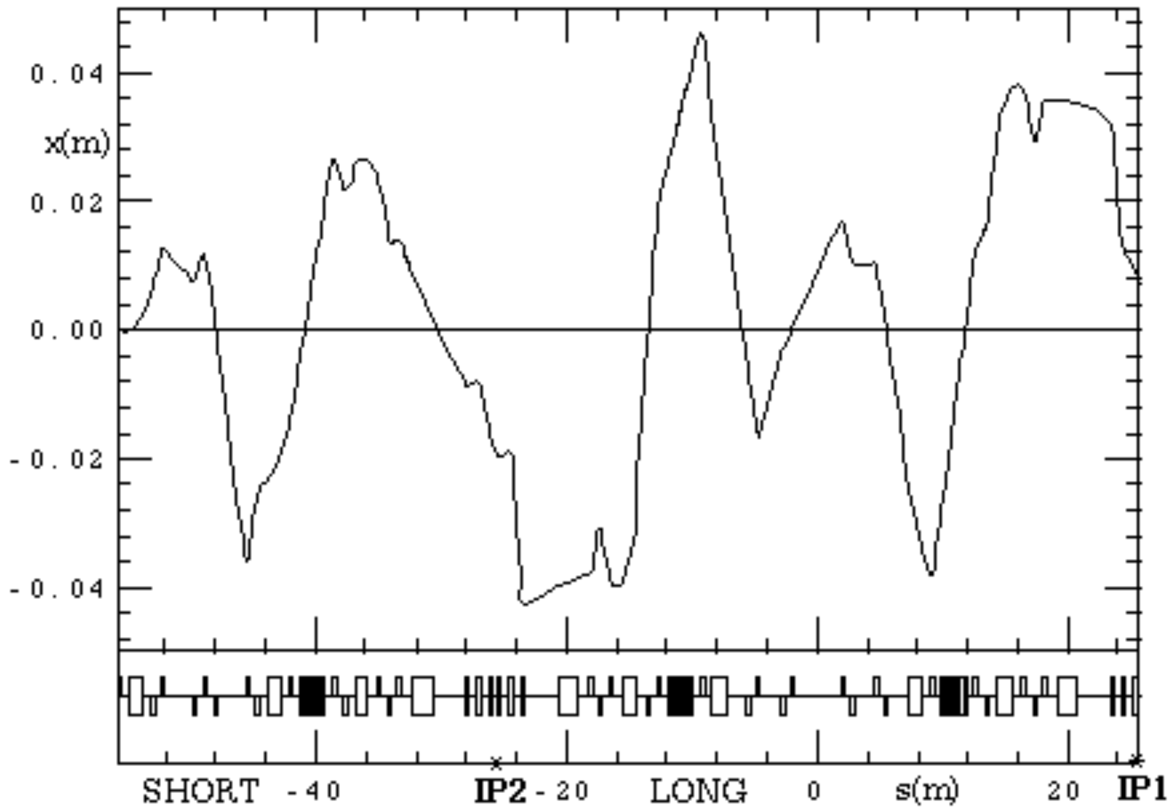

Fig. A3 *- x(ε=.0065) from the bending upstream the SHORT straight section to the KLOE IP.*

Appendix B

In DAΦNE the half crossing angle θ can be varied from 10 to 15 mrad in order to reduce the beam-beam effect at the parasitic crossing points.

When increasing θ the available aperture of the low-β quadrupoles is reduced and the number of particles lost there increases. In order to keep the same background level the scraper aperture has to be decreased, with a reduction of the beam lifetime. Viceversa happens when operating with a smaller θ.

The values of η_Q,N_Q and the corresponding beam lifetime are shown in **Table I** for the two extreme values of the crossing angle and the largest aperture for QF2.

Table I - A_{QF2}= 72.5 mm

	A_{sc} (mm)	η_Q (s^{-1})	N_Q (part./s/bunch)	τ_{tot} (min)
θ = **15mrad**	23.5	0.	0.	168.
	26.5	$4.07\ 10^{-8}$	$3.62\ 10^{3}$	198.
	29.	$4.16\ 10^{-7}$	$3.70\ 10^{4}$	233.
θ = **10mrad**	29.	$6.36\ 10^{-9}$	566.	233.