Touschek effect: DAFNE, DAFNE crab waist and SuperB

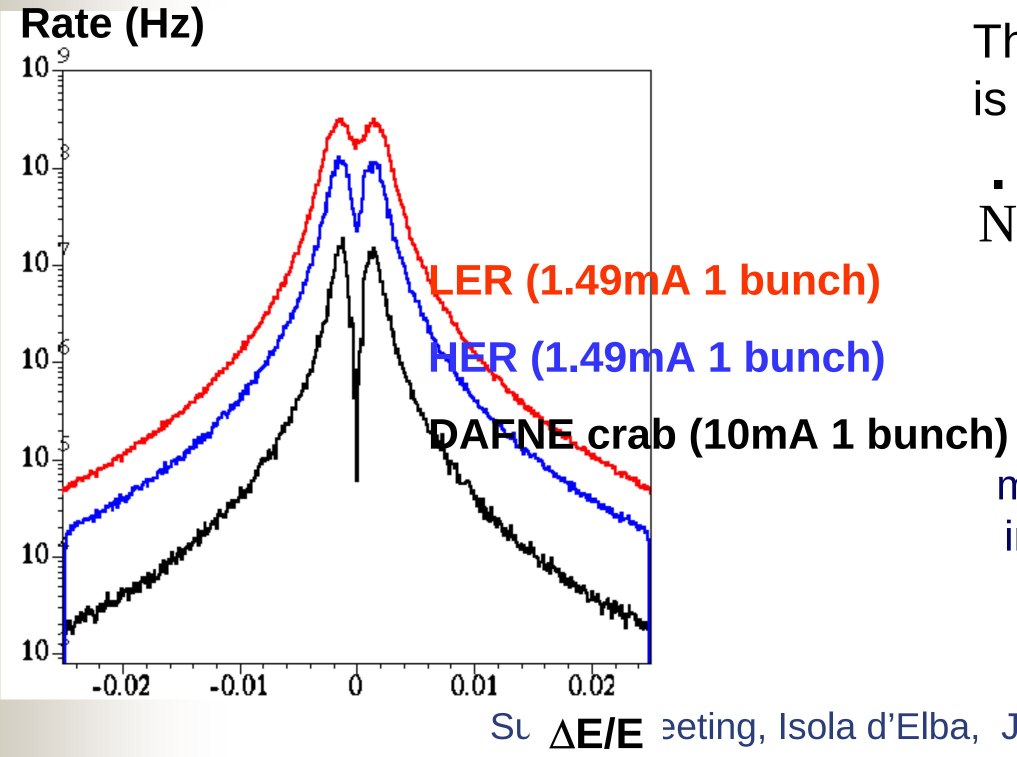
Manuela Boscolo

SuperB meeting, Isola d'Elba, June 1st 2008

DAΦNE background and beam lifetime are dominated by **Touschek scattering**, as typically happens in low energy rings

At the **SuperB** energy is higher but beam sizes are very small, so Touschek effect is important regarding both lifetime and IR particle losses

Rate of particles (Hz) undergoing Touschek scattering versus ΔE/E



The Touschek particle loss rate is approximately

$$\dot{N} \propto \frac{N^2}{\gamma^3 \varepsilon^2 V}$$

N particles/bunch
V bunch volume
ε momentum acceptance

Touschek effect is determined by momentum acceptance and bunch density integrated over the lattice structure and by (beam energy)^3

Touschek effect:

elastic Coulomb scattering of pairs of particles within a bunch

The two emerging particles have the same momentum deviation $\Delta p/p$:

one gains and the other loses it.

Off-momentum particles can exceed the momentum acceptance given by the RF bucket, or may hit the physical aperture.

A betatron oscillation is excited if the momentum change happens in a dispersive region with:

$$x_\beta = \frac{\Delta p}{p}\sqrt{H\beta(s)}$$

where $$H = \gamma_x D_x^2 + 2\alpha_x D_x D_x' + \beta_x D_x'^2$$

Background Handling

- Tracking studies/measurements useful to reduce backgrounds rates
- **collimators:** positions and shape – need long time of beam conditioning to be efficient
- **Optics:** Low-β quads
- **Shielding:** between pipe and low-β quads, fill all possible holes
- **Optics Adjustments:**
  - orbit optimization,
  - Sextupoles Optimization
  - Octupoles Optimization
  - Improved linear and non-linear knowledge of the machine
  - Increased Dynamic aperture with better βs on Sexts

Program Flow Touschek simulation

Optics check

(nonlinearities included)

Beam parameters calculation (betatron tunes, emittance, synchrotron integrals, natural energy spread, bunch dimensions, optical functions and Twiss parameters all along the ring)

Calculation of **Touschek energy spectra** all along the ring averaging Tousc. probability density function over 3 magnetic elements

Tracking of Touschek particles:

Start with transverse gaussian distribution and proper energy spectra every 3 elements: track over many turns or until they are lost

- Estimation of **IR and total** Touschek particle **losses** (rates and longitudinal position)
- Estimation of Touschek **lifetime**

Calculation of energy spectra

Starting formula:

Integrated Touschek probability

$$\frac{1}{\tau} = \frac{\sqrt{\pi} r_e^2 c N}{\gamma^3 (4\pi)^{3/2} V \sigma'_x \varepsilon^2} C(u_{\min})$$

$$\frac{1}{\tau} = \int_{\varepsilon}^{\infty} P_{Tou}(E) dE$$

$$\varepsilon = \frac{\Delta E}{E} \qquad u_{\min} = \left(\frac{\varepsilon}{\gamma \sigma'_x}\right)^2$$

$$\sigma'_x = \sqrt{\frac{\varepsilon_x}{\beta} + \sigma_p^2 \left(D'_x + D_x \frac{\alpha_x}{\beta_x}\right)^2}$$

V = bunch volume= $\sigma_x \cdot \sigma_y \cdot \sigma_l$

C(umin) accounts for Moller x-section (polarization is included) and momentum distribution

For a chosen machine section the Touschek probability is evaluated in small steps (9/element) to account for the beam parameters evolution for 100 ε values.

Use an interpolation between the calculated ε values according to the Touschek scaling law: $A_1 \cdot \varepsilon^{-A_2}$

DAFNE Detectors Sensitivity to Backgrounds

- KLOE suffered from ‘high’ energy particles (E> 10 MeV) – seen in overlap with physics (accidentals)

  also important higher energy products with E>150MeV (endcap trigger threshold)

  4π acceptance- difficult shielding

- DEAR suffered from low energy photons (O(100) keV)-

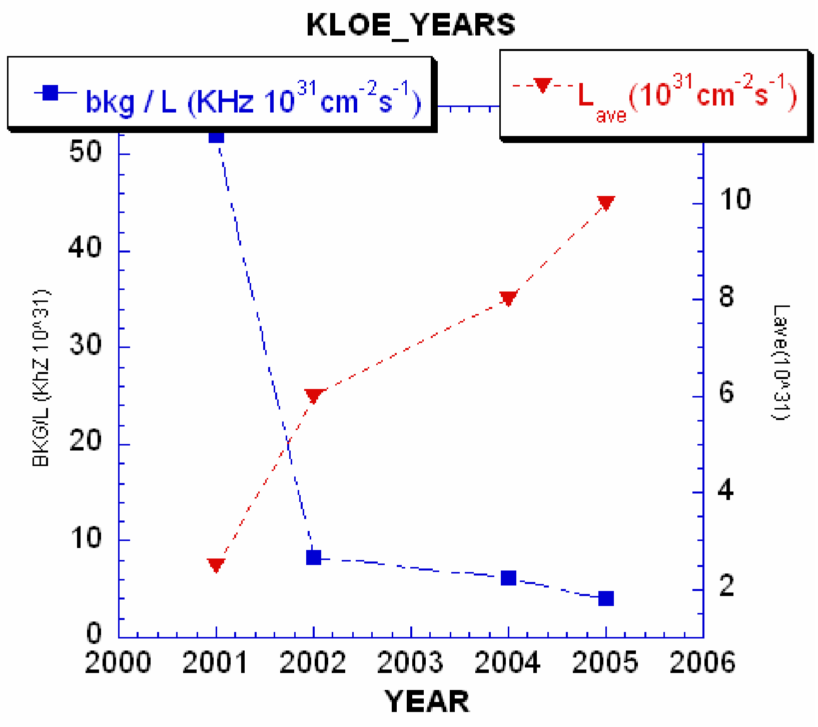
  no trigger, but small gas target detector could be shielded by lead all around

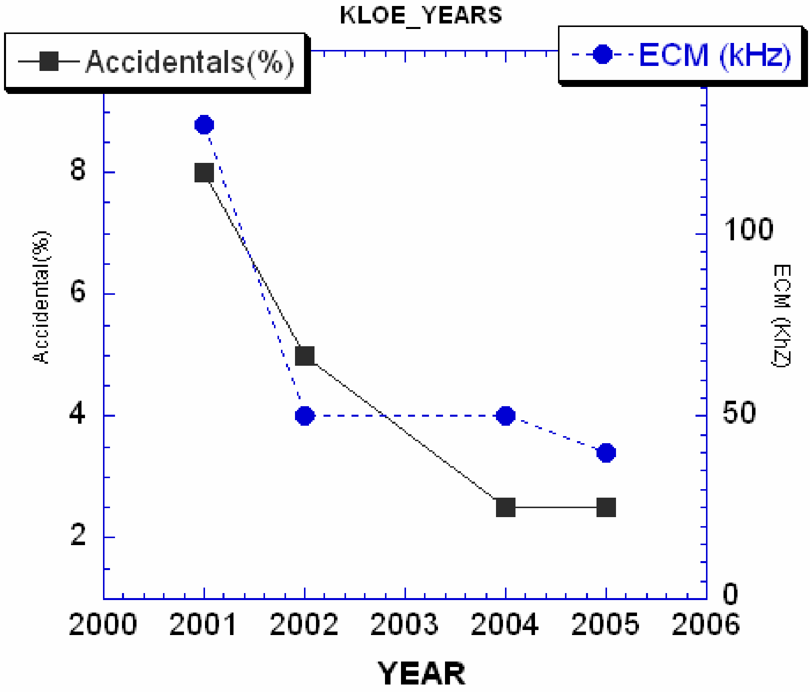
•SIDDHARTA is a gas target detector with trigger, many shieldings have been tested to optimize S/N

now- CRAB TEST

At the beginning of data taking, all these experiments suffered from large background.

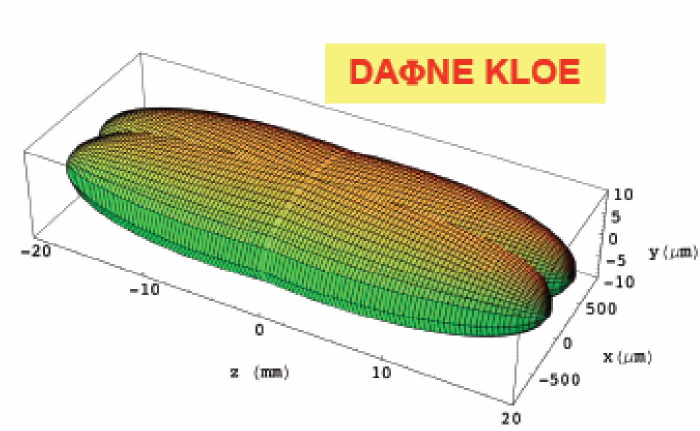
Backgrounds and Luminosity
versus years of **KLO**E data taking





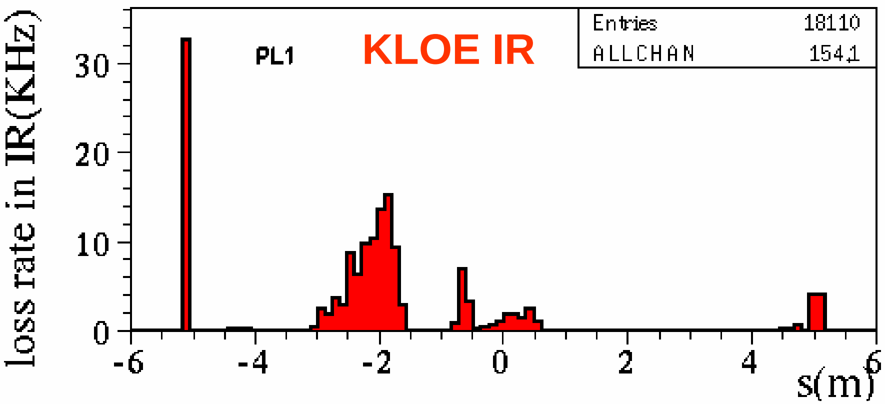
	L_{ave} (10^{31} cm^{-2}s^{-1})	Bkg_{ave} (kHz)	Bkg/L (kHz 10^{31} cm^{2}s^{1})	Accidental probability
2001	2.5	130	50	8%
2002	6	50	8.3	5%
2004	8	50	6.25	2.5%
2005	10	40	4	2.5%

DAFNE experience



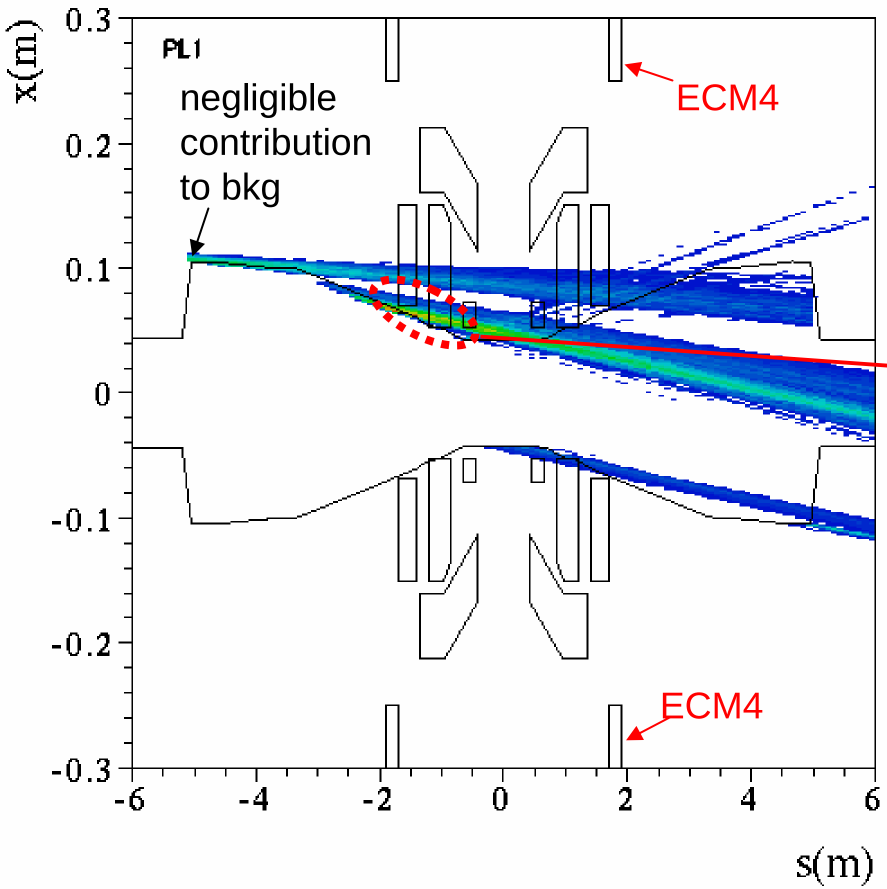
- Added collimators in dispersive regions, optimized shape: at the end of the KLOE run they were very efficient, reducing ECM rates by a large factor

  (~20 for e^- and 50 for e^+)
- Optimized IR optics
- Adiabatic beam tuning
- Simulation tool improved, non-linear terms included, Touschek scattering simulated at each longitudinal position, also lifetime can be evaluated

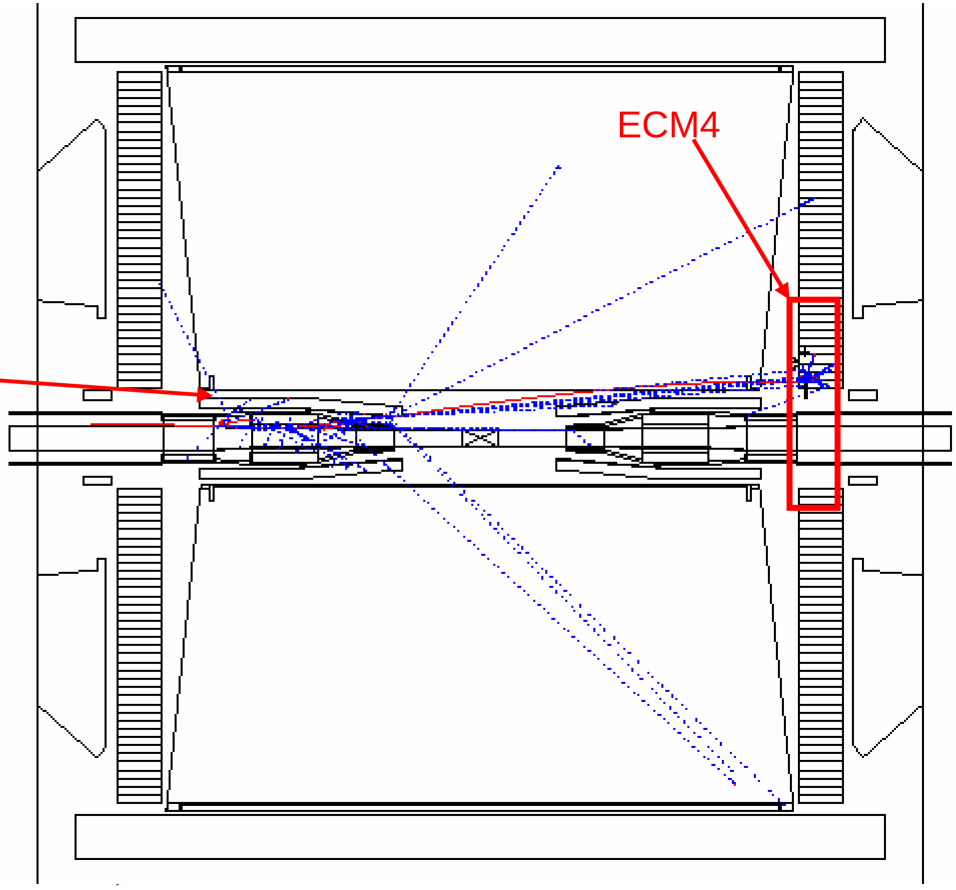


evaluation of detector acceptance is essential for a comparison between measured and simulated background rates

agreement with measurements within 30% on calorimeter rates



negligible contribution to bkg

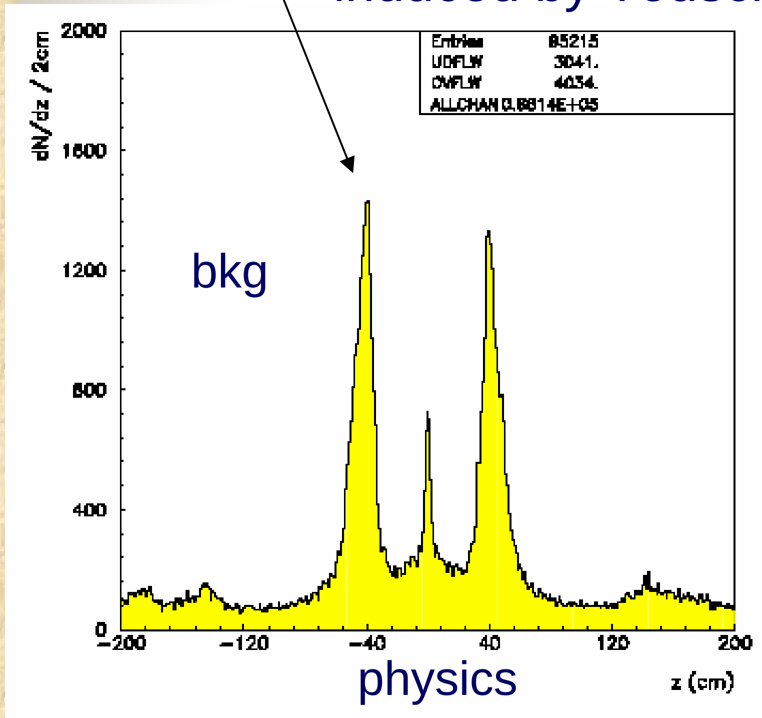


Touschek Backgrounds view from the experiments- an example

high rate 200 Hz of localized 1-track (protons) in KLOE until 2001

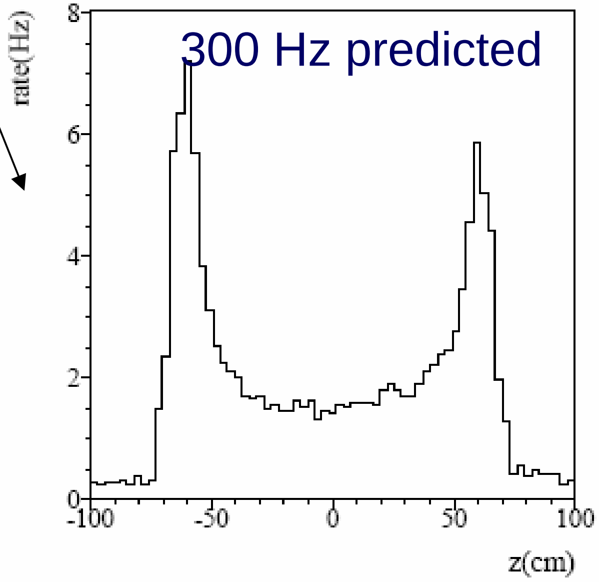
understood as photoproduction (ep(n)$\rightarrow\Lambda$e $\rightarrow$ pπ^0(π^-)e)

induced by Touschek particles hitting beam pipe support



bkg

physics



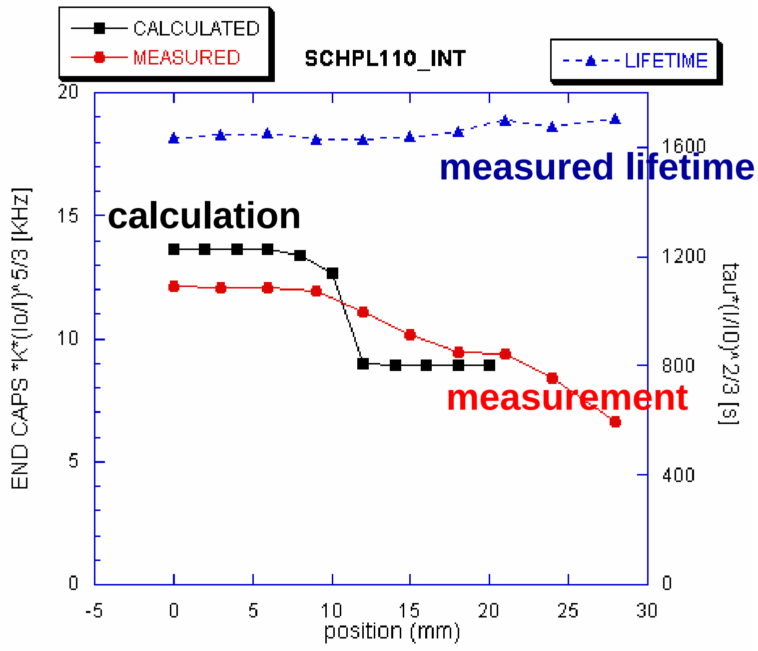
300 Hz predicted

Comparison between measured and calculated effectiveness of collimators

The calculated rate is evaluated by tracking Touschek scattered particles from their loss point in the pipe into the KLOE detector. The endcap acceptance has been taken into account by means of full detector simulation including the geometrical details of the IR.

The MC reproduces behaviour of background vs collimator position

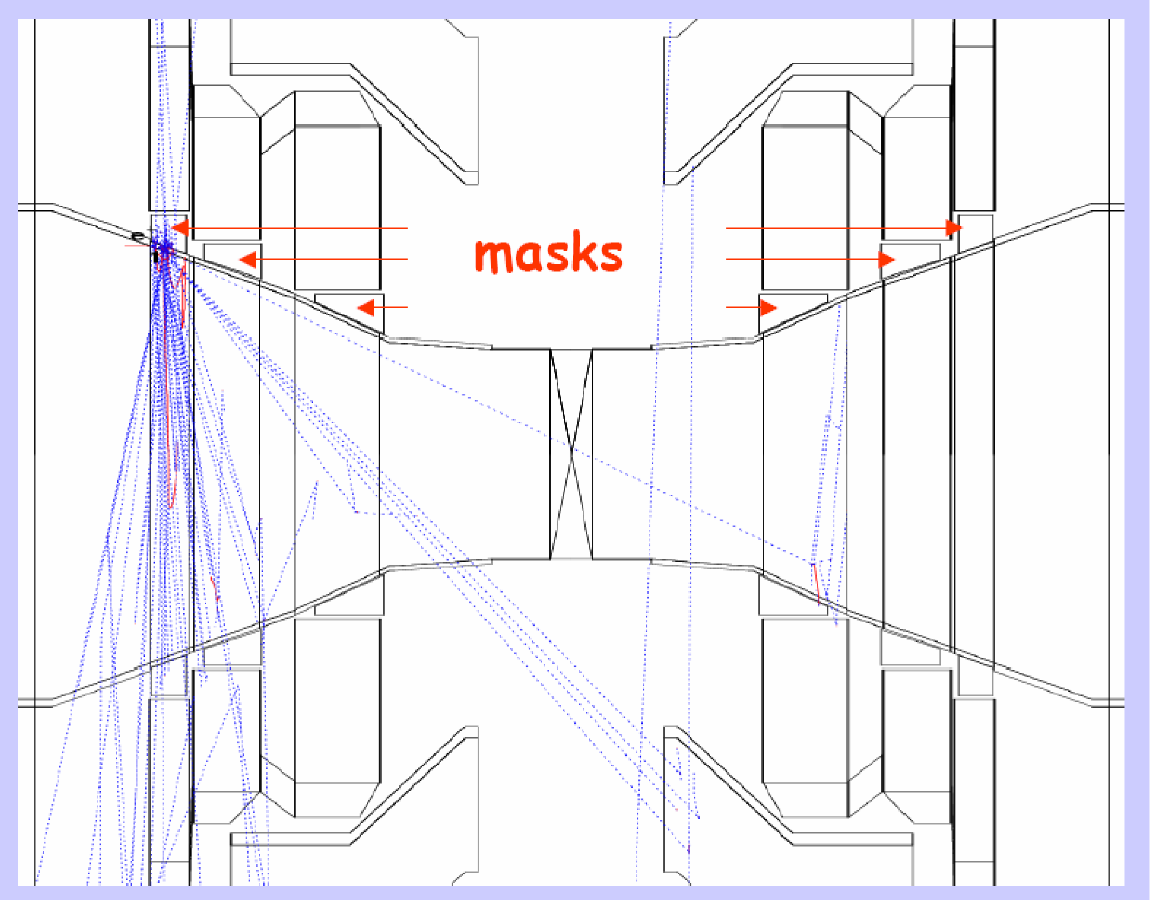
absolute normalization



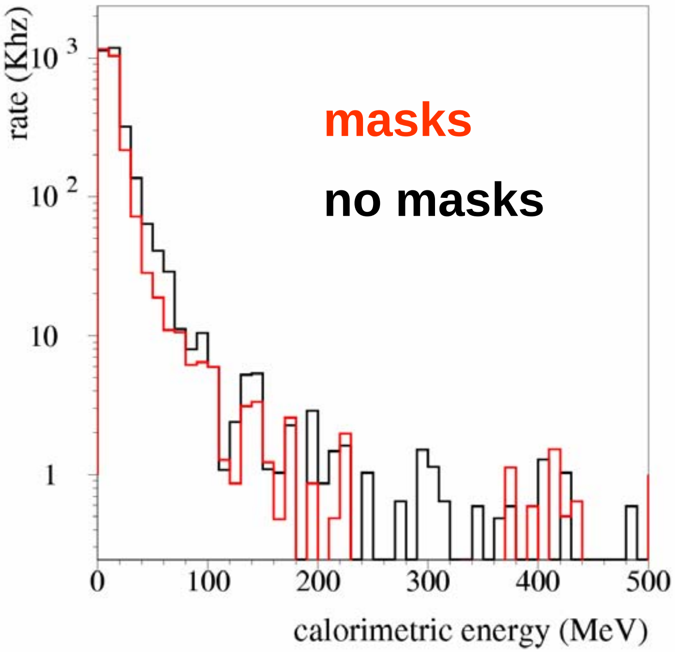
Scan of the background rate in the KLOE forward calorimeter versus position of the internal jaw of a collimator: The collimator opening is measured from the beam pipe edge.

Masks added between pipe and low-β quads

IR layout + background event x-s view



Masks effectiveness



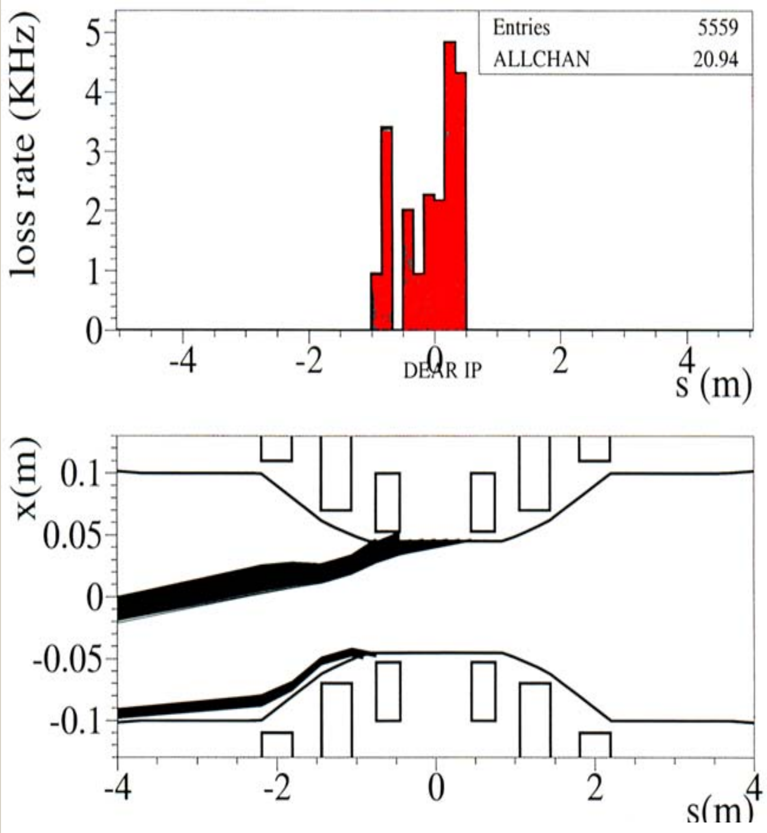
masks

no masks

Touschek particles trajectories at DEAR IR

calculated background

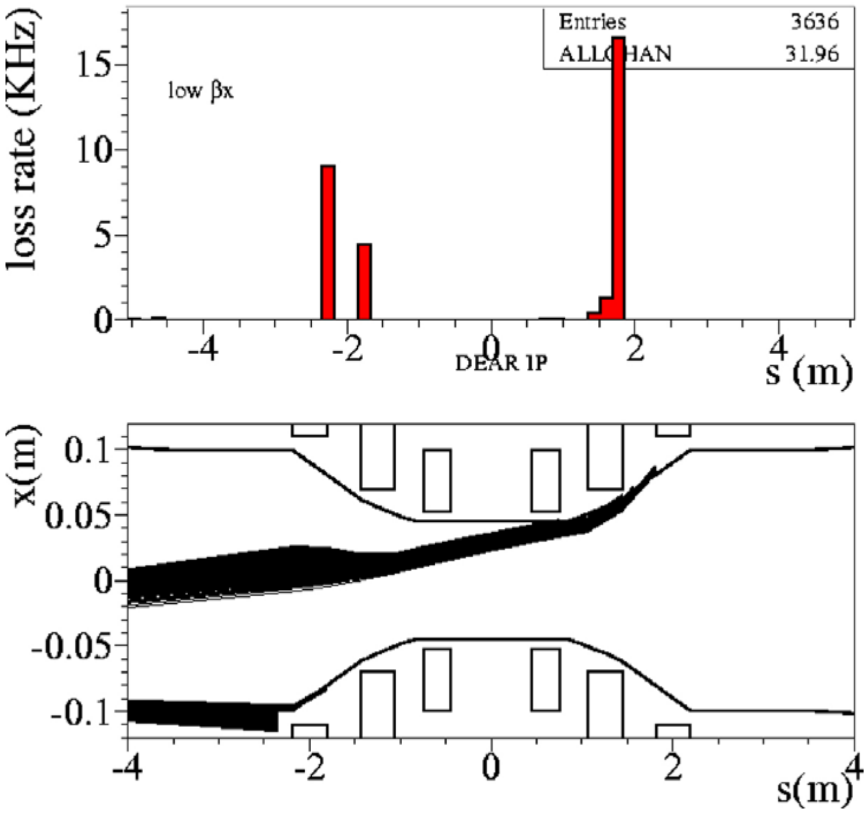
With last December 2001 optics



calculated background

with April 2002 optics

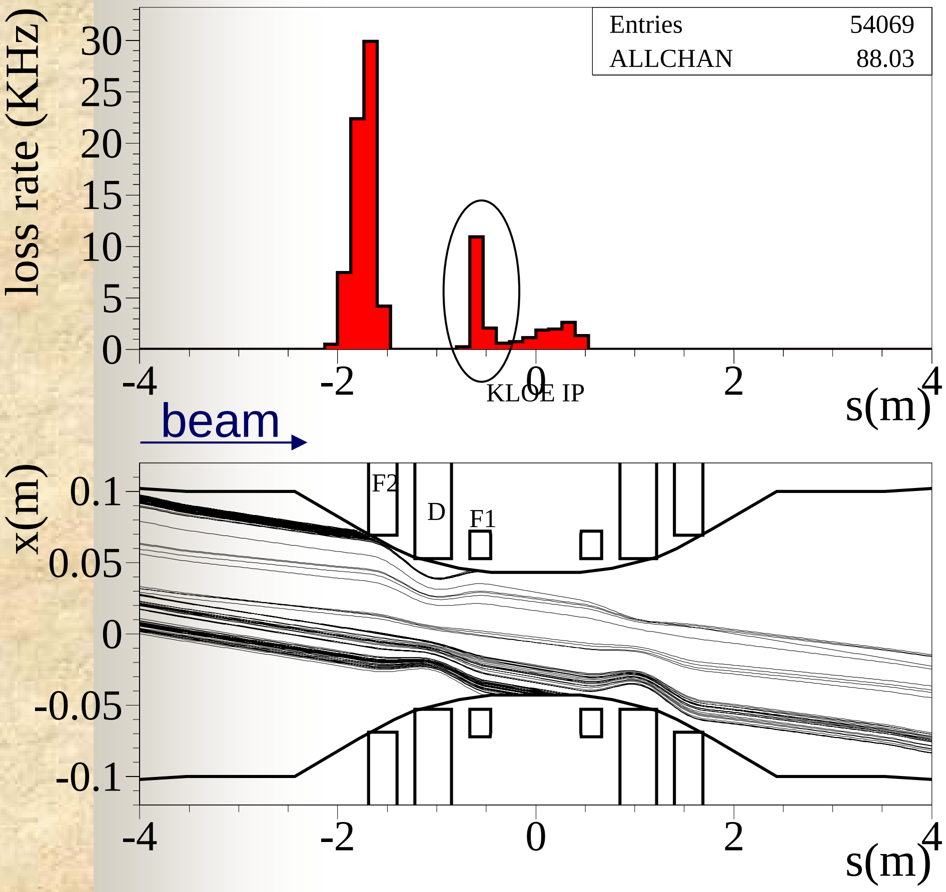
(low-β_x at IP and at first quad-F)



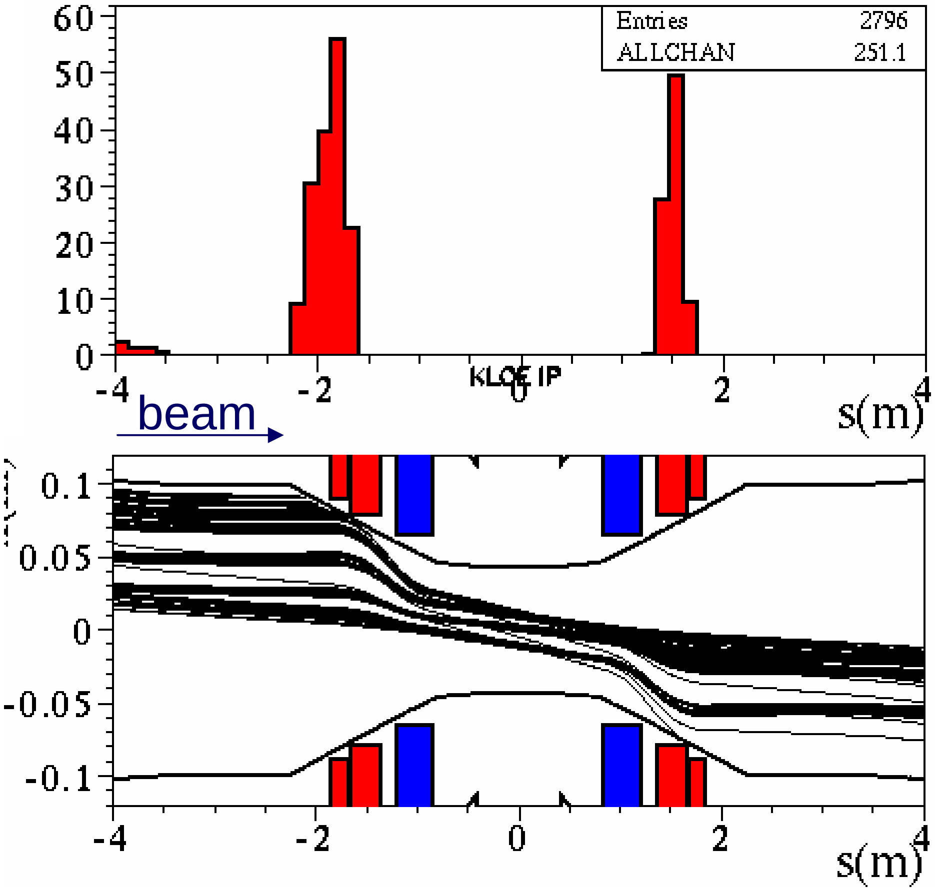
Studying the particles distribution at DEAR IR improved background rates both by the indication of lowering σ_x^* by lowering the β_x^* and by indication of position for shielding

Touschek particles trajectories at KLOE IR

triplet FDF low-β quads

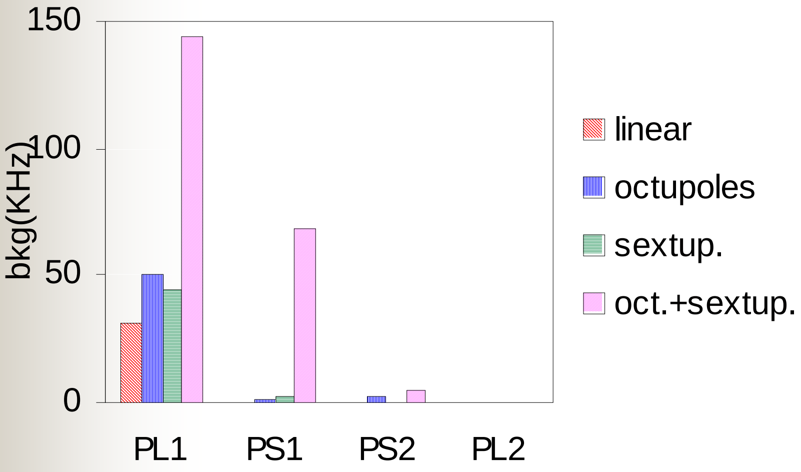


doublet low-β quads

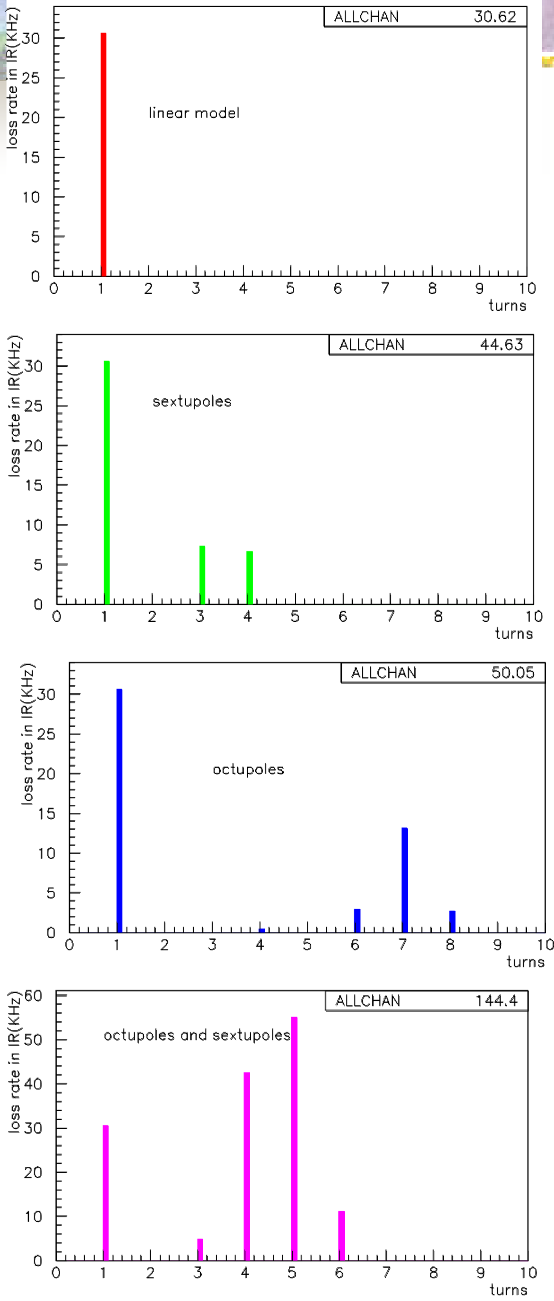


Effects of non linearities on Touschek particle losses

Tracking includes non linearities: sextupoles and octupoles relevant to account for the correct dynamical aperture

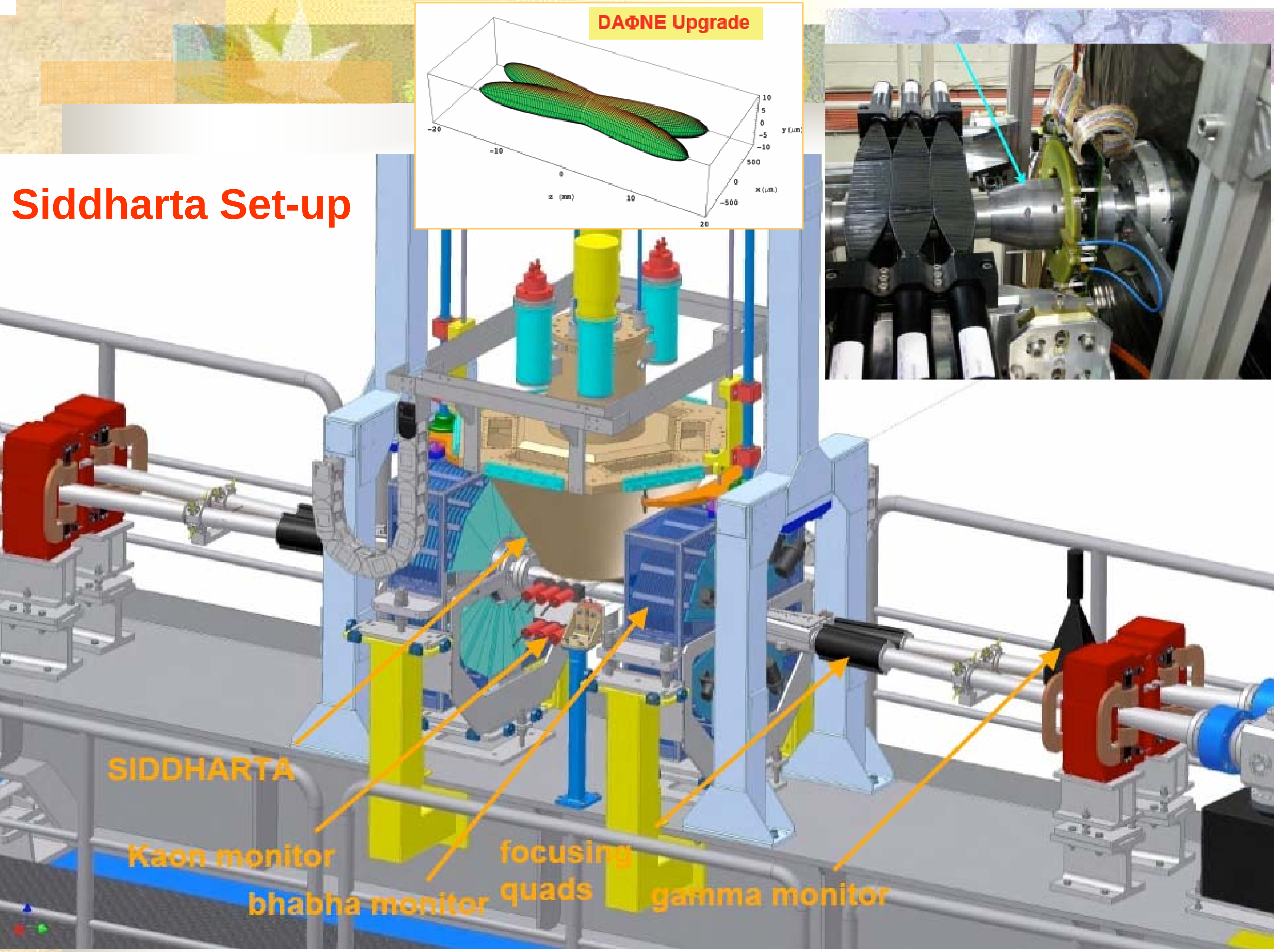


Expected beam losses at the KLOE IR for one bunch of 10 mA: contributions change when nonlinearities are taken into account

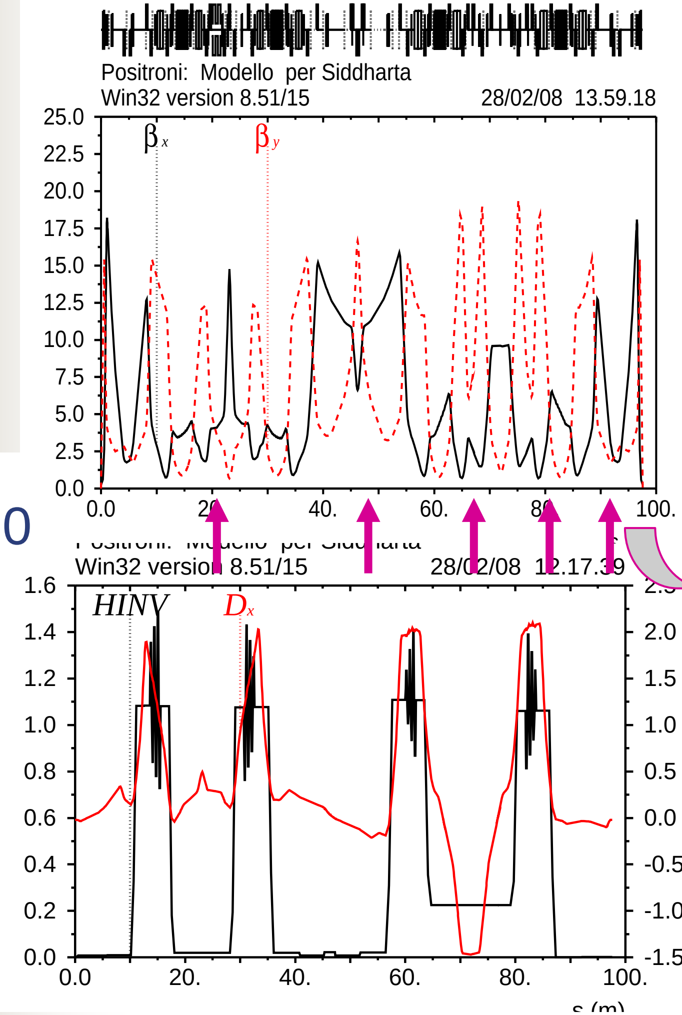


Distribution of particles scattered in the high dispersive region before IR and lost at the KLOE IR versus the machine turns

Siddharta Set-up



β_x, β_y, H and dispersion functions for the DAFNE crab waist configuration



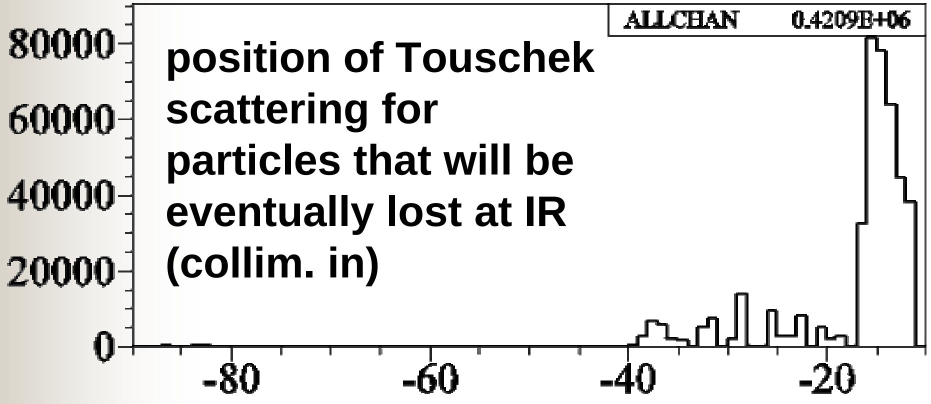
IP at s=0

2 collimators have been moved during the upgrade shutdown to account for the new lattice

Collimators

Touschek particles that get lost are scattered in high dispersive regions

Touschek particles lost at the IR



position of Touschek scattering for particles that will be eventually lost at IR (collim. in)

when all collimators are inserted only Touschek particles scattered in the closest arc before the IP are lost at the IR

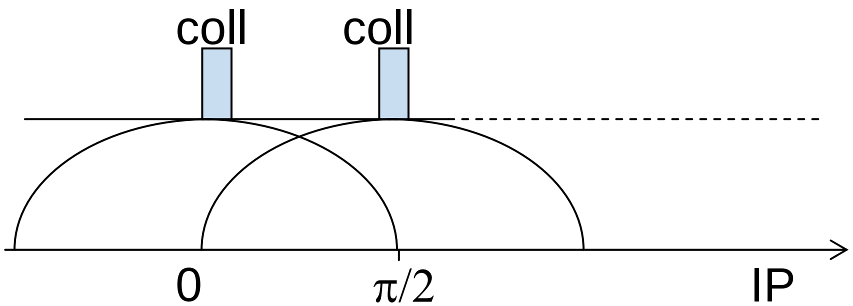
In DAFNE IP very close to last high dispersive region, about 10 m

collimators needed close to the IP

careful study of collimator shape to avoid background generation

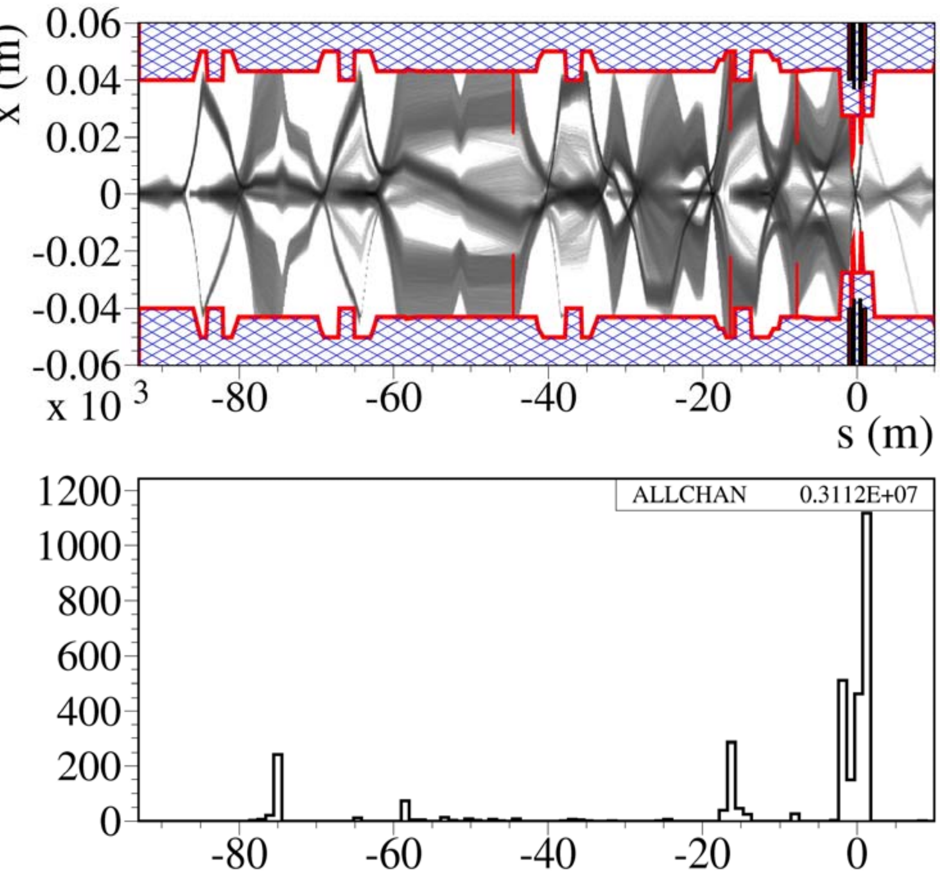
phase advance between collimators and IR

in order to stop particles that get lost at IR, phase advance between collimator and QF should be ~ $\pi/2$



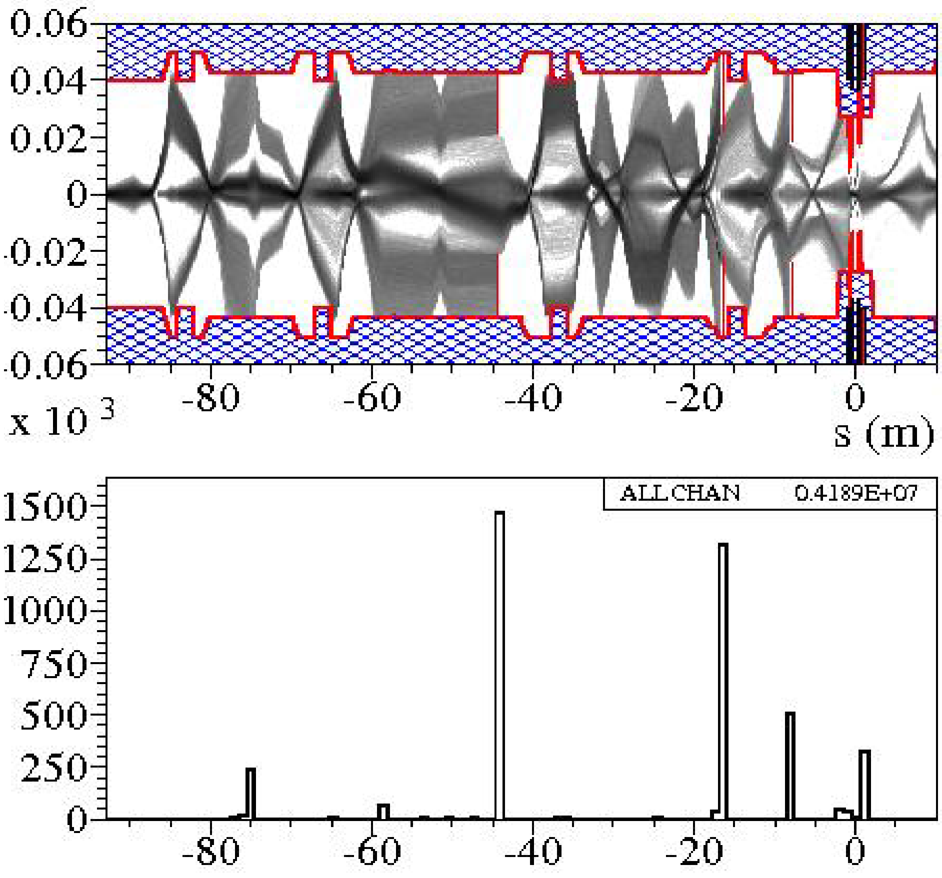
DAFNE crab waist optics

no collimators
inserted in simulation



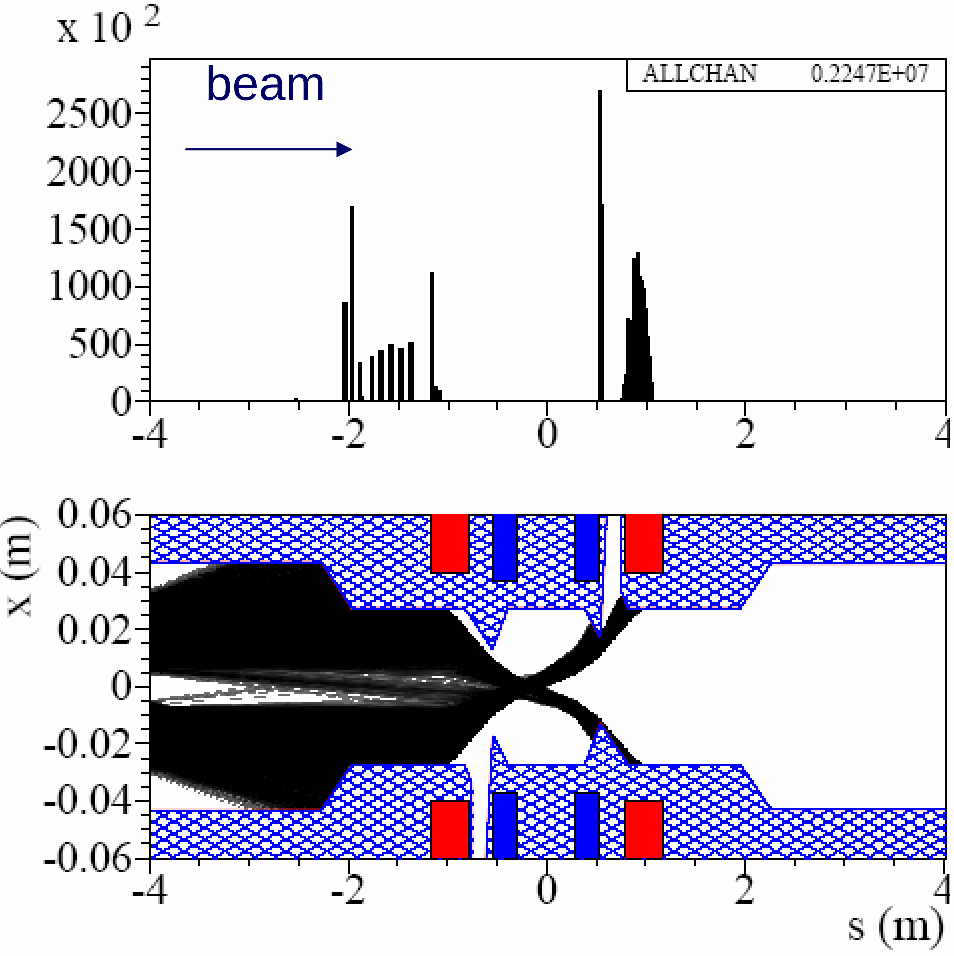
IR

with collimators
inserted in simulation

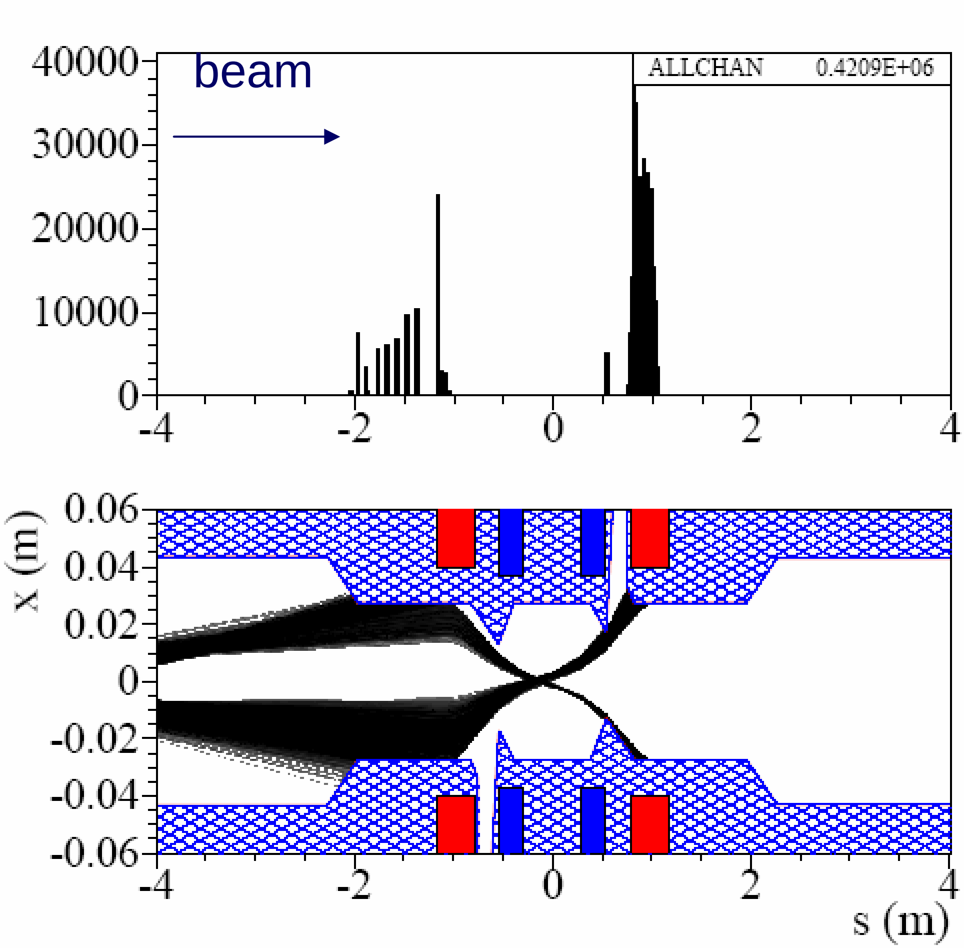


zoom at IR losses

no collimators
inserted in simulation

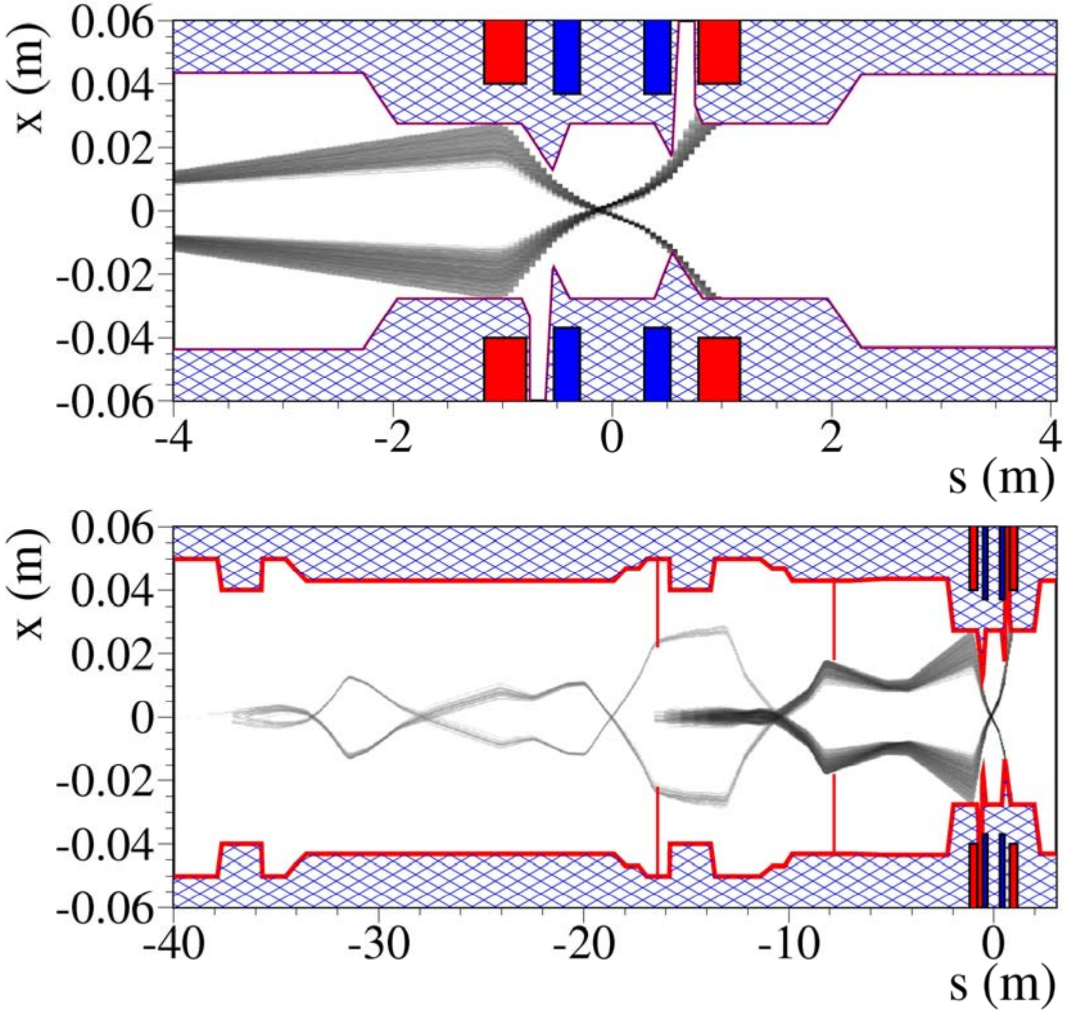


with collimators
inserted in simulation



about a factor 5 with collimators inserted at present machine set, in agreement with measurements

Investigation of losses downstream the IP



particles lost downstream the IP, at the QF0, are Touschek scattered in the closest arc before the IP and cannot be stopped by IR collimator

these particles, as well as upstream ones can produce high showers in the close-by calorimeter, lead shielding has been put to protect calorimeter and SIDDHARTA detector

Simulation/measurements comparison with DAFNE crab configuration

Full simulation of Touschek particles into the calorimeter

in close collaboration with the DAFNE upgrade working group

(Benoit Viaud)

It is a work in progress, but first attempt of comparison shows that

first full simulation of Touschek particles into the calorimeter is in **good agreement** to observation, in fact

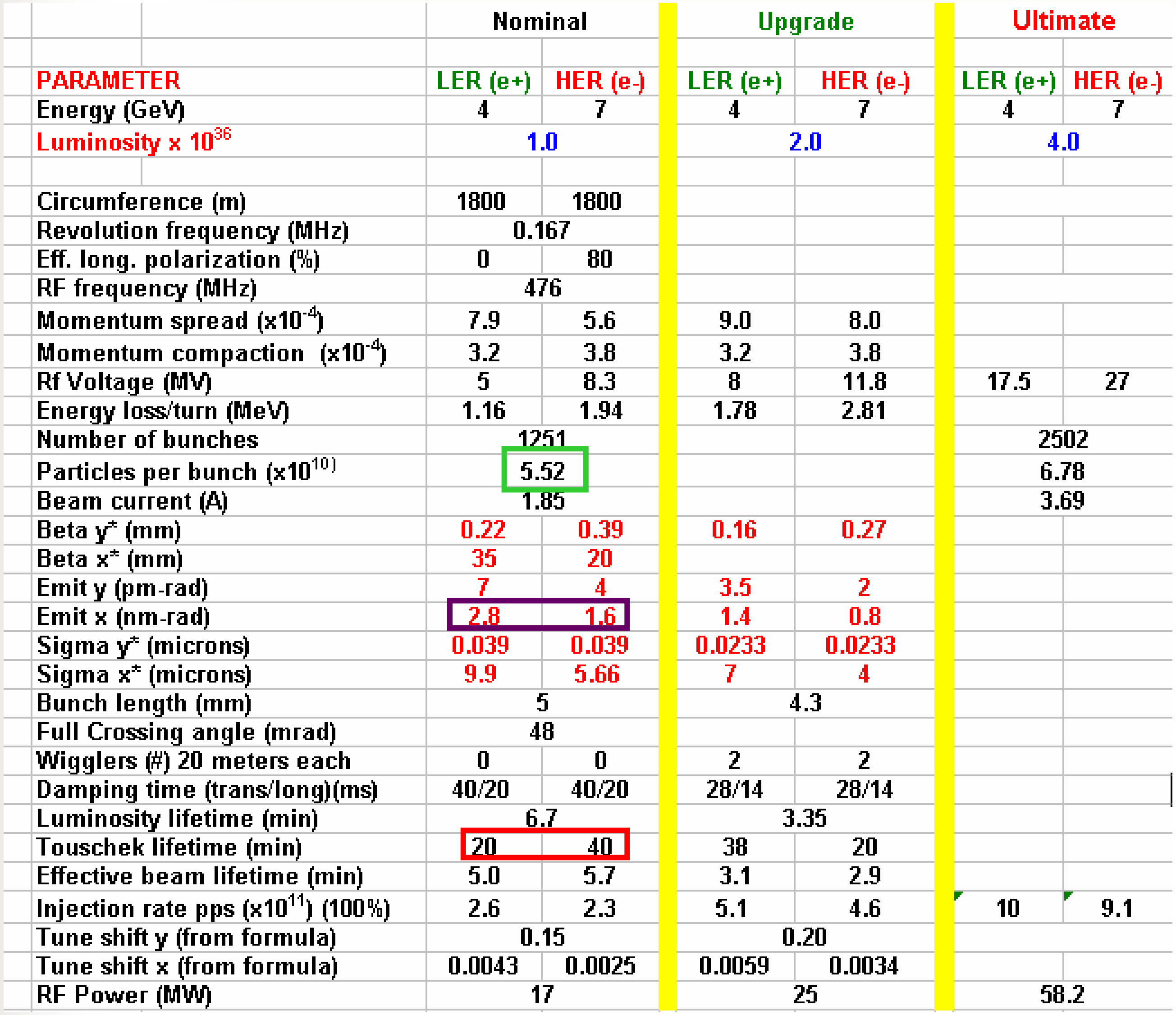
we expect from simulations no background with energies higher than about 380 MeV at the calorimeter coming from Touschek losses ,

consistently with the measured background of about 5% with a threshold of about 480 MeV

Touschek Background at the SUPERB Factory

SuperB meeting, Isola d’Elba, June 1st 2008

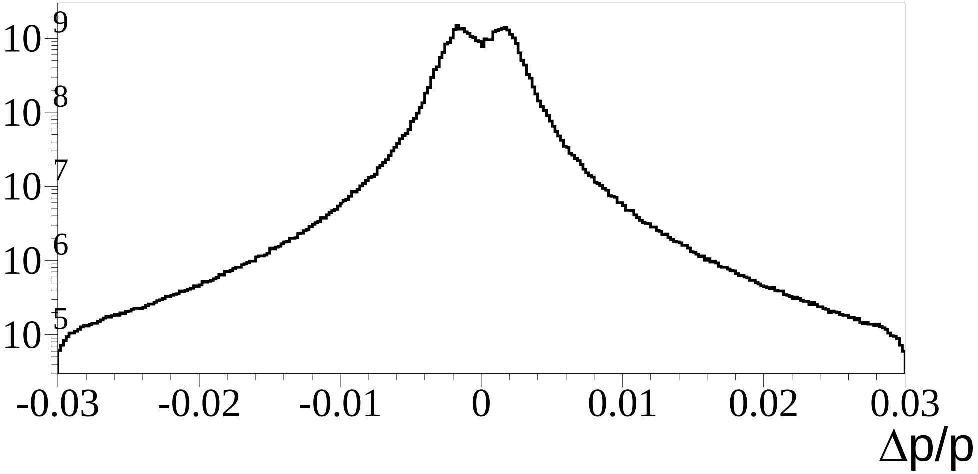
SuperB New Parameters



	Nominal		Upgrade		Ultimate	
PARAMETER	LER (e+)	HER (e-)	LER (e+)	HER (e-)	LER (e+)	HER (e-)
Energy (GeV)	4	7	4	7	4	7
Luminosity x 10^{36}	1.0		2.0		4.0	
Circumference (m)	1800	1800				
Revolution frequency (MHz)	0.167					
Eff. long. polarization (%)	0	80				
RF frequency (MHz)	476					
Momentum spread ($x10^{-4}$)	7.9	5.6	9.0	8.0		
Momentum compaction ($x10^{-4}$)	3.2	3.8	3.2	3.8		
Rf Voltage (MV)	5	8.3	8	11.8	17.5	27
Energy loss/turn (MeV)	1.16	1.94	1.78	2.81		
Number of bunches	1251				2502	
Particles per bunch ($x10^{10}$)	5.52				6.78	
Beam current (A)	1.85				3.69	
Beta y* (mm)	0.22	0.39	0.16	0.27		
Beta x* (mm)	35	20				
Emit y (pm-rad)	7	4	3.5	2		
Emit x (nm-rad)	2.8	1.6	1.4	0.8		
Sigma y* (microns)	0.039	0.039	0.0233	0.0233		
Sigma x* (microns)	9.9	5.66	7	4		
Bunch length (mm)	5		4.3			
Full Crossing angle (mrad)	48					
Wigglers (#) 20 meters each	0	0	2	2		
Damping time (trans/long)(ms)	40/20	40/20	28/14	28/14		
Luminosity lifetime (min)	6.7		3.35			
Touschek lifetime (min)	20	40	38	20		
Effective beam lifetime (min)	5.0	5.7	3.1	2.9		
Injection rate pps ($x10^{11}$) (100%)	2.6	2.3	5.1	4.6	10	9.1
Tune shift y (from formula)	0.15		0.20			
Tune shift x (from formula)	0.0043	0.0025	0.0059	0.0034		
RF Power (MW)	17		25		58.2	

Comparison between lifetime estimate from formula and calculation from tracking

generated Touschek particles per second all over the ring



Reference:

τ(CDR)=330 s (Wienands)

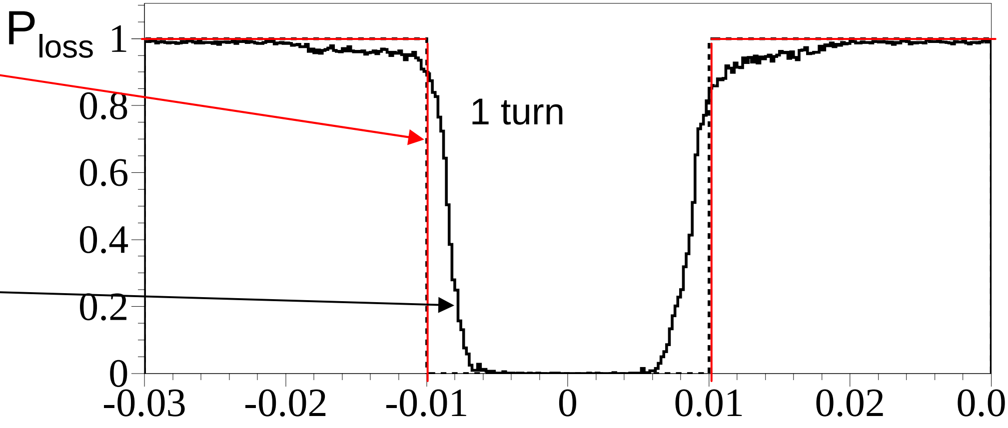
assuming that particles with $|\Delta p/p|>1\%$ are lost (like CDR):

τ = 308 s

good agreement with CDR

efficiency calculated from tracking

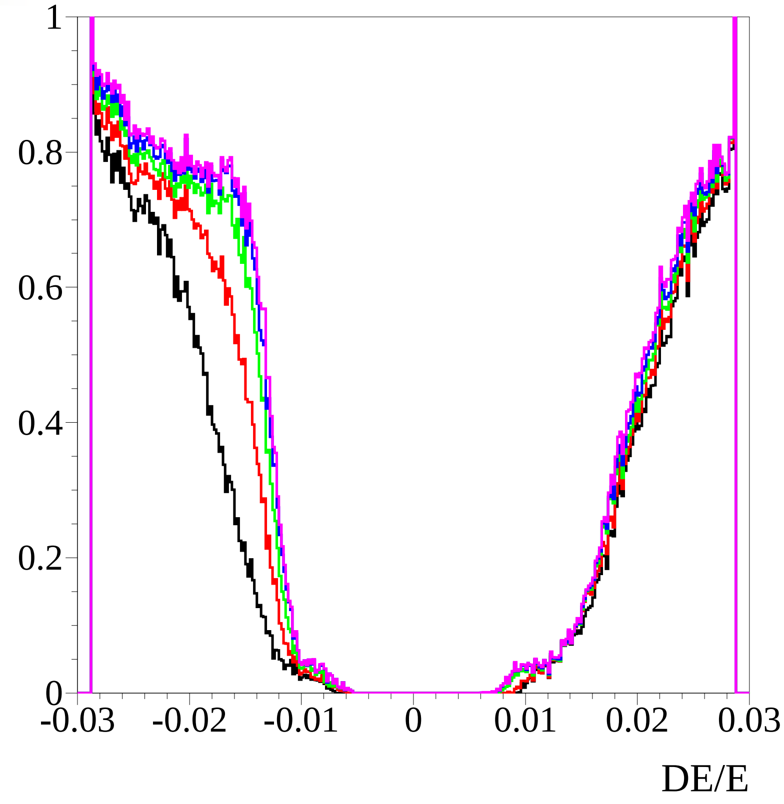
τ = 200 s



tracked particles with $\Delta p/p$= 0.6%-0.8% are lost, with some efficiency. These have very large weight, this induces difference in lifetime estimation (Touschek function very non linear)

Energy acceptance with the latest LER lattice

energy acceptance higher than the previous lattice



1 machine turn

2 machine turns

3 machine turns

4 machine turns

5 machine turns

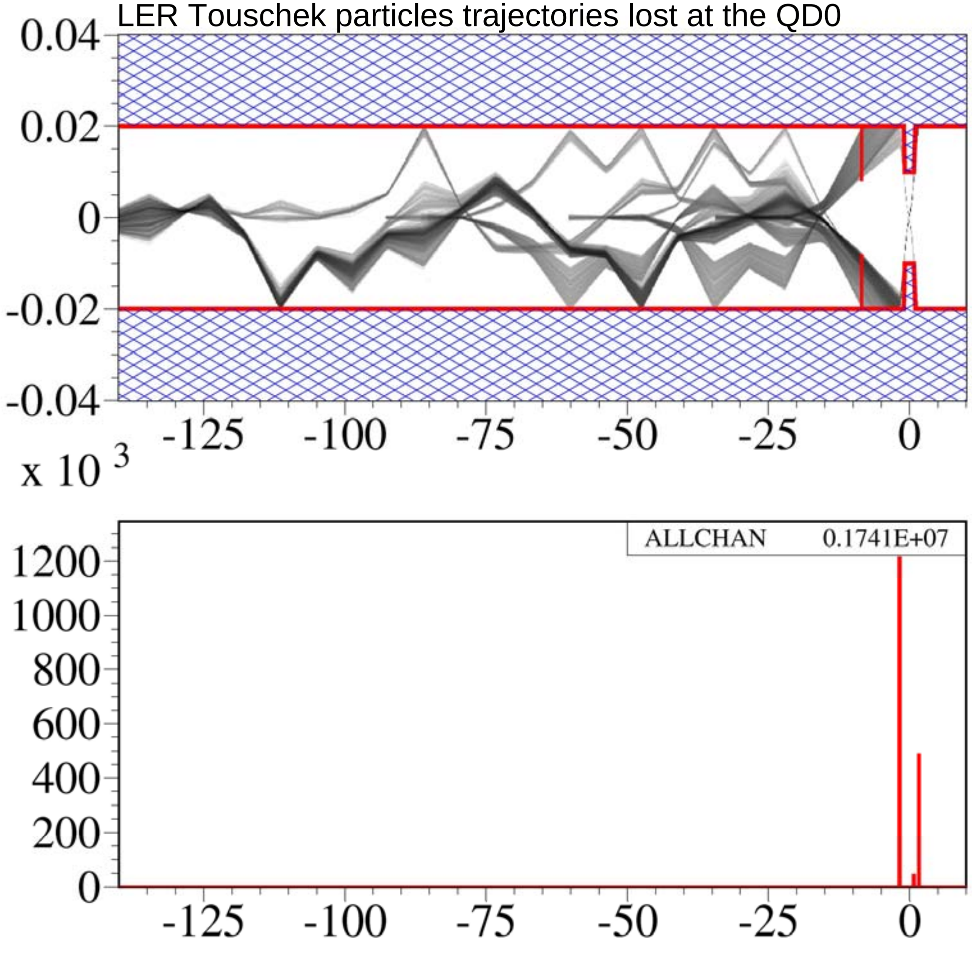
no collimators

LER Touschek particles lost at IR

NO COLLIMATORS inserted

Touschek lifetime ≈ 24 min

example of
LER Touschek particles trajectories lost at the QD0



$\Delta E/E$ = 0.1% - 4%

rf accept. =2.9 %

machine turns = 5

K=0.25%

ε_x=2.8 nm ; σ_z=5 mm

IR Losses (|S|<2m)= 1.7 MHz

for 1 bunch with I_{bunch} =1.49 mA

IR Losses (|S|<2m)= 2.1 GHz

at full current

LER Touschek particles lost at IR

IR COLLIMATOR inserted s = -8.5 m far from IP

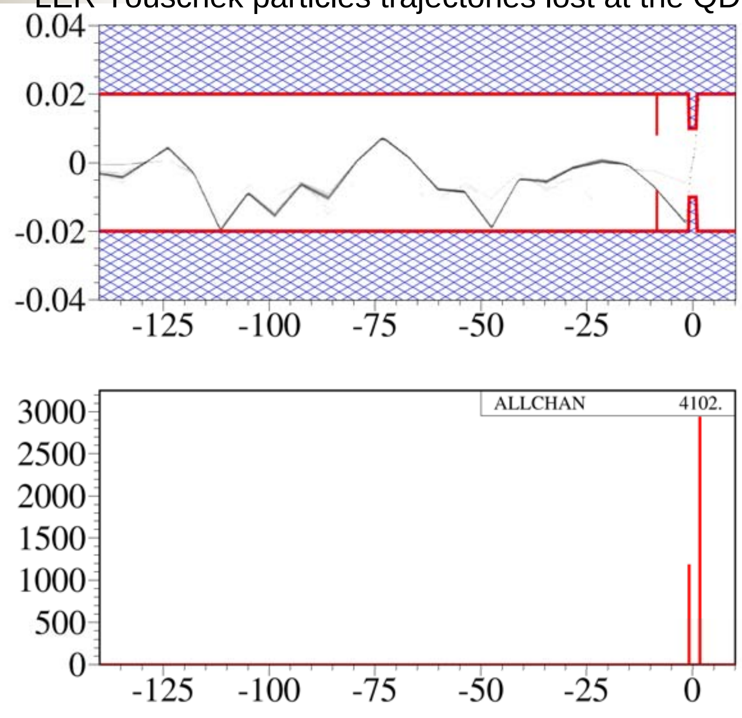
Touschek lifetime ≈ 20 min

IR Losses (|S|<2m)= 4.1 kHz
for 1 bunch with I_{bunch} =1.49 mA

IR Losses (|S|<2m)= 5.1 MHz

at full current

example of
LER Touschek particles trajectories lost at the QD0



These particle losses close to QD0 are being fully simulated into the detector

(see Paoloni and Rama's talks)

IR collimator modeled as perfectly absorbing and no width.

Care must be paid in this collimator close to IP: full tracking simulation is foreseen

HER Touschek particles lost at IR

NO COLLIMATORS inserted

Touschek lifetime ≈ 40 min

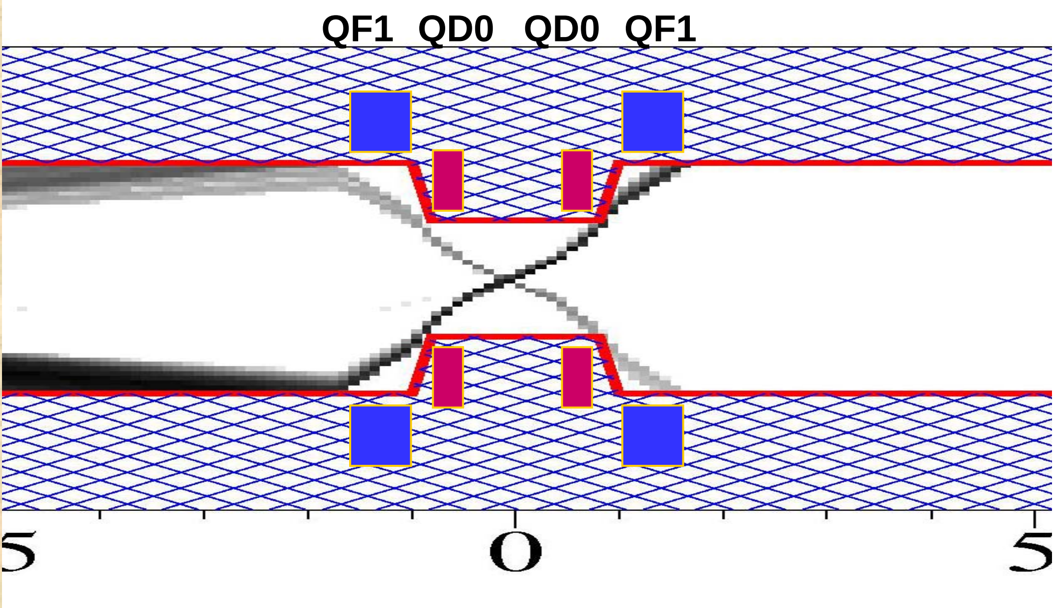
$\Delta E/E$ = 0.1% - 4%

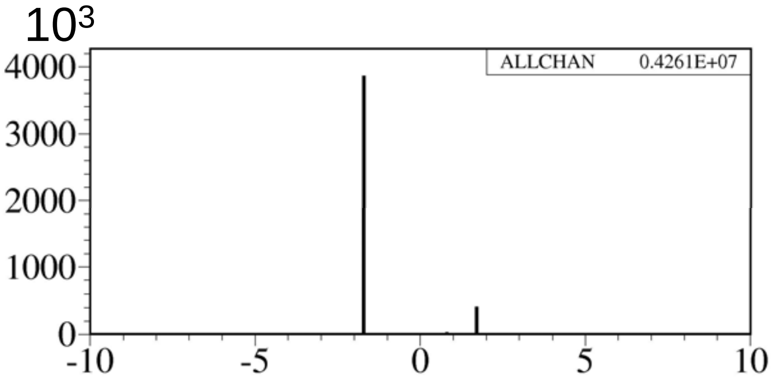
rf accept. =2.9 %

machine turns = 5

K=0.25%

ε_x=1.8 nm ; σ_z=5 mm





IR Losses (|S|<2m)= 4.2 MHz

for 1 bunch with I_{bunch} =1.49 mA

IR Losses (|S|<2m)= 5.2 GHz for nominal full current

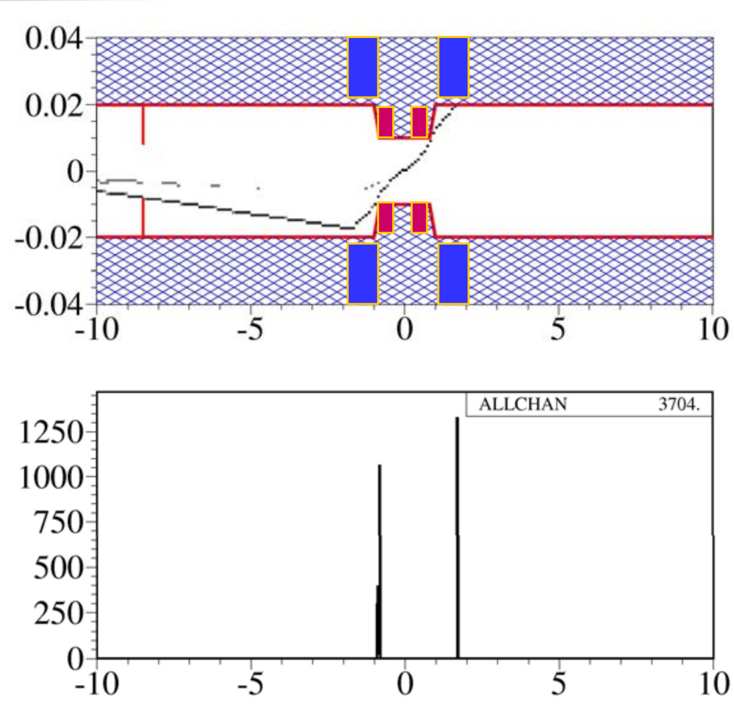
IR collimator modeled as perfectly absorbing and no width.

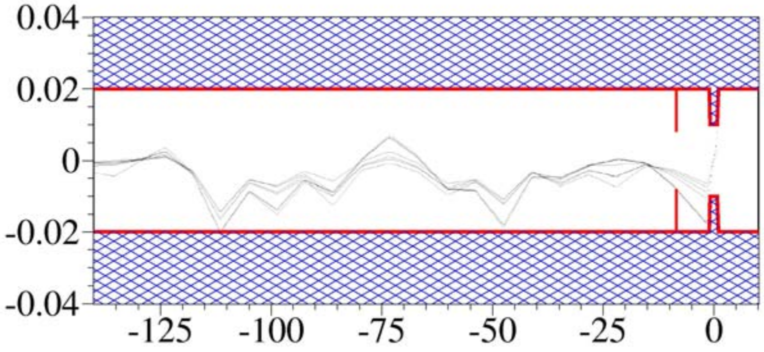
Care must be paid in this collimator close to IP: full tracking simulation is foreseen

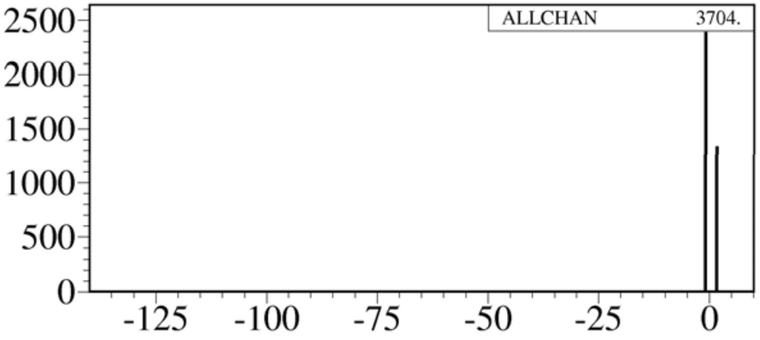
HER Touschek particles lost at IR

IR COLLIMATOR inserted S=-8.5 m far from IP

Touschek lifetime ≈ 32 min







IR Losses (|S|<2m) ~4 kHz for 1 bunch with I_{bunch} =1.49 mA

IR Losses (|S|<2m) ~ **4.6 MHz** at nominal full current

Conclusions

In DAFNE a lot of effort has been put in the Touschek backgrounds minimization, extremely high at the beginning of each run.

- **Collimators**: position and shape crucial
- **Shieldings**: very useful for small experiments
- **Optics**: IR design critical, small β_x required (synergy with L), nonlinearities and dynamic aperture optimization, as well as fine tuning of orbit at the IR

Same approach can be used for studies at SUPERB LER/ HER:

- Collimators
- Shieldings
- Optics