Single beam backgrounds

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for the SuperB background team

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Dominant effects on backgrounds and lifetime

Two colliding beams

- **Radiative Bhabha** → dominant effect on lifetime
- **Pairs Production** → only ~ 3% contribution to rad. bhabha lifetime but important source of background in SVT

Single beam

- **Synchrotron Radiation** -strictly connected to IR design
- **Touschek** → important effect especially for LER
- **Beam-gas** → pressure as low as possible especially close to IR - simulations foreseen
- **Intra-beam scattering** → foreseen an update on simulation for present lattice (mostly for lifetime)

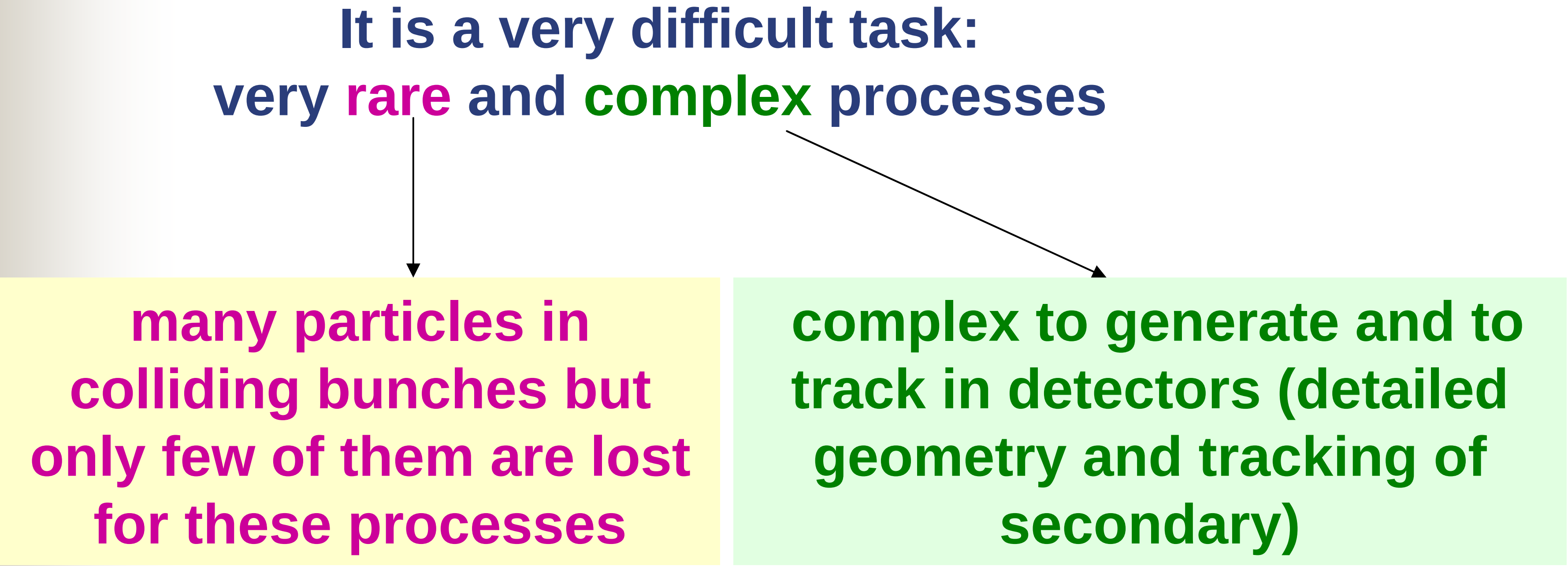
Background reduction: multiple step process

- Simulation of main different background sources
- Propagation of background generated particles into the detector region → simulation of interactions and showers in and nearby the detectors with MC
- Shieldings optimization: Masks + collimators

If detector background budget not satisfactory, readjustments of

- critical beam parameters
- IR design

Backgrounds simulation



It is a very difficult task:
very rare and complex processes

many particles in colliding bunches but only few of them are lost for these processes

complex to generate and to track in detectors (detailed geometry and tracking of secondary)

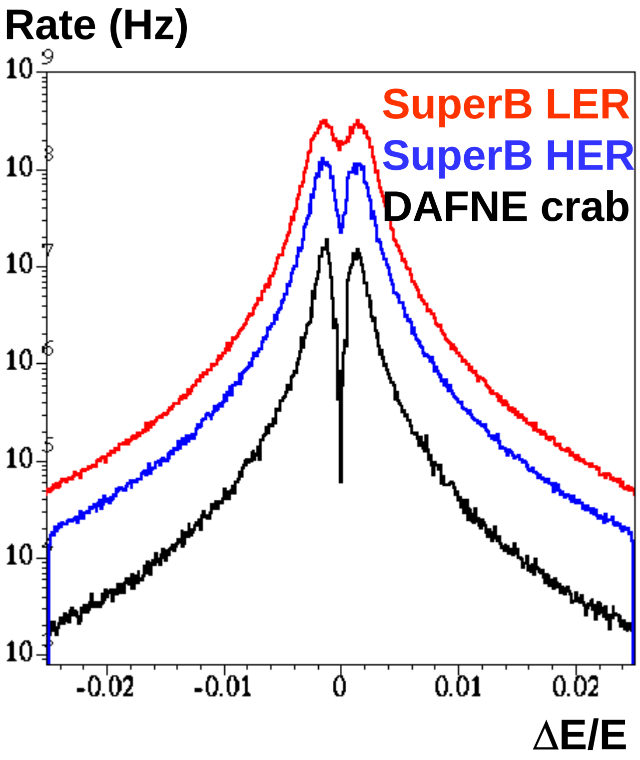
hard to predict what detectors will see

Simulation of very rare processes

many particles in colliding bunches but only few of them are lost for these processes

example:

probability for Touschek effect



Coulomb scattering of charged particles travelling together causes an exchange of momentum between the tranverse and longitudinal directions.

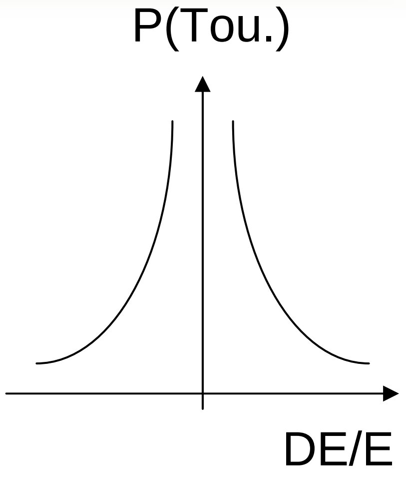
Due to relativistic effects, the momentum transferred from the tranverse to the longitudinal direction is enhanced by γ.

particles are lost if their ΔE/E
1) exceeds the rf bucket
2) exceeds the momentum aperture determined by the lattice.
loss probabilty increases with ΔE/E

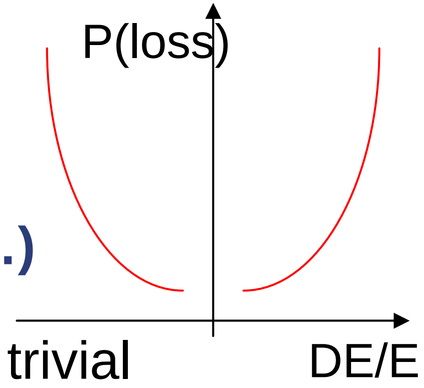
Touschek energy spectra related mostly to beam parameters (i.e. bunch volume, ε, σ_p, bunch current…)

With a given energy spectrum P(E) (see next slide) one can:

1. extract according to P(E) or
2. Use a uniform extraction and use P(E) as a weight



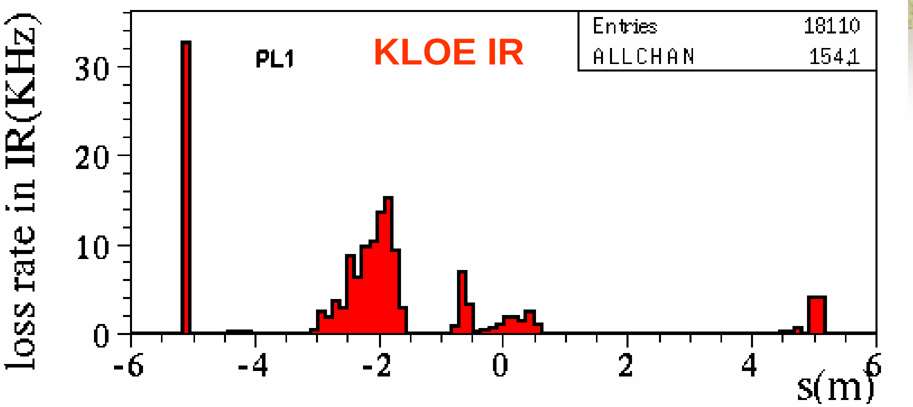
Particle losses related mostly to machine parameters/optics (i.e. physical aperture, phase advance, dispersion, …)



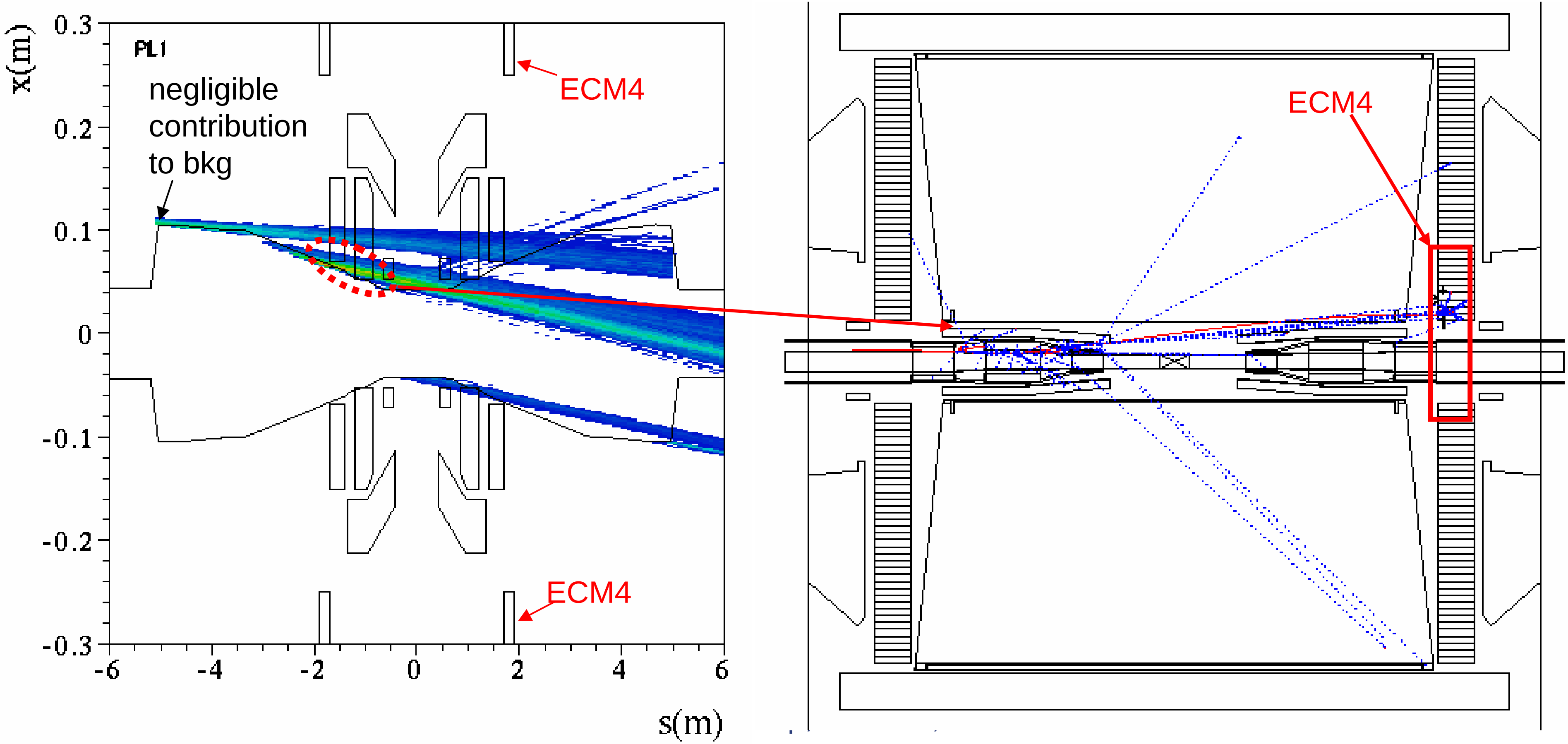
We use 2. to cope with tails of both distributions (non trivial statistical errors with large weights)

O(10^{-2}) s per particle for 5 turns on 3 a Ghz Xeon cpu

complicated prediction on detector



complex to generate and to track in detectors (detailed geometry and tracking of secondary)



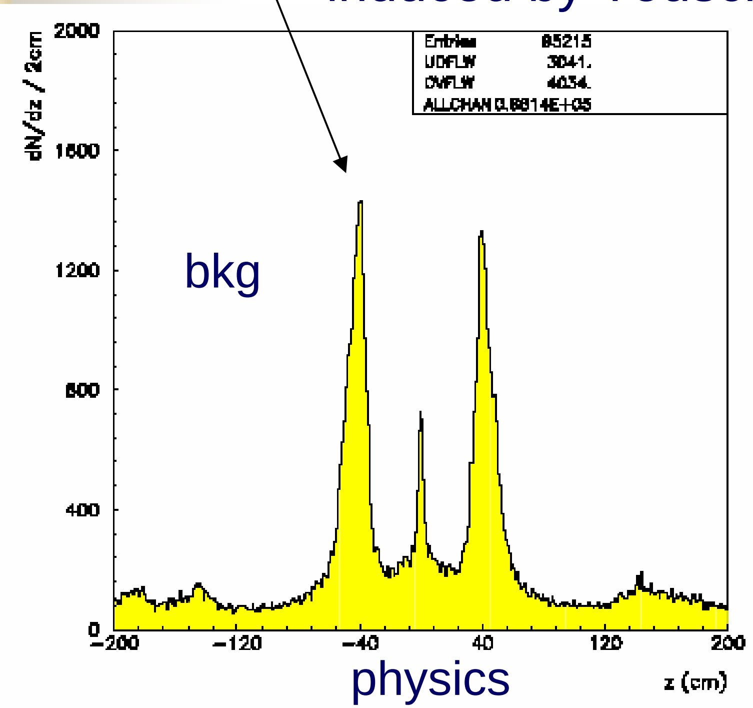
to test predictions clean events are needed

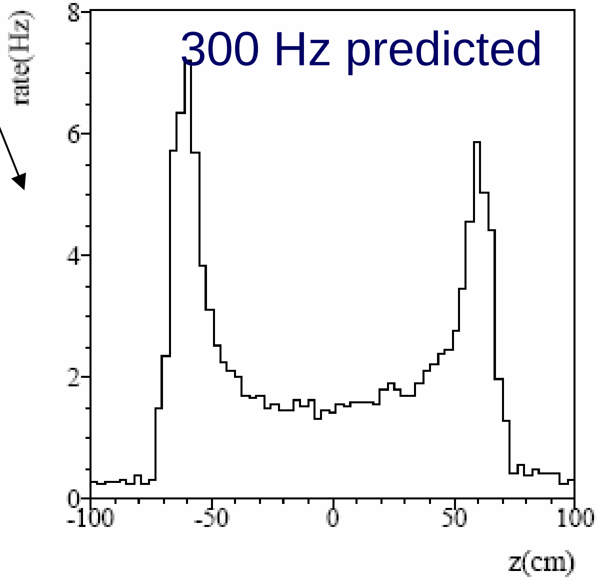
Since the very first data taking KLOE suffered from large rates of mono-tracks background

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)

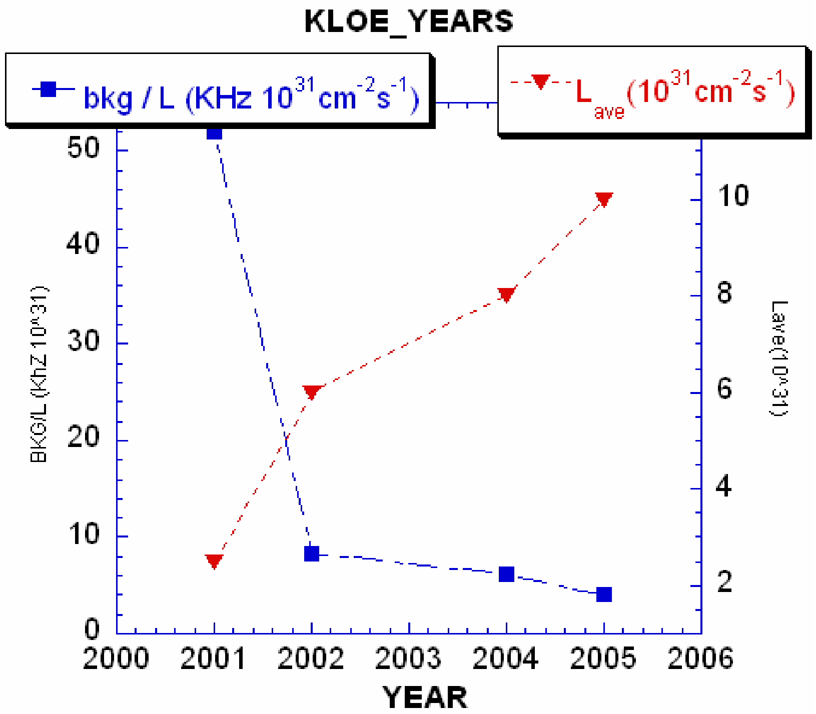
induced by Touschek particles hitting beam pipe support

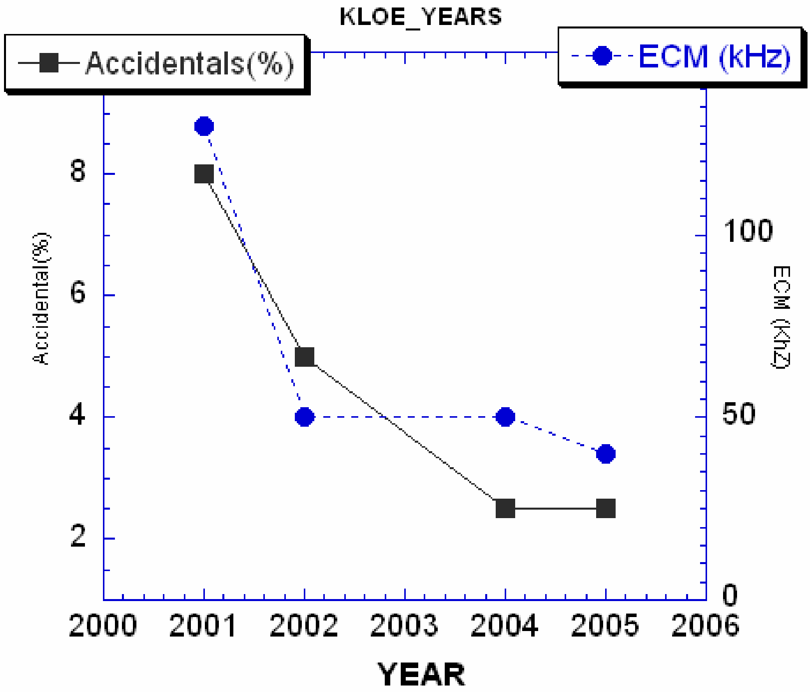




300 Hz predicted

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



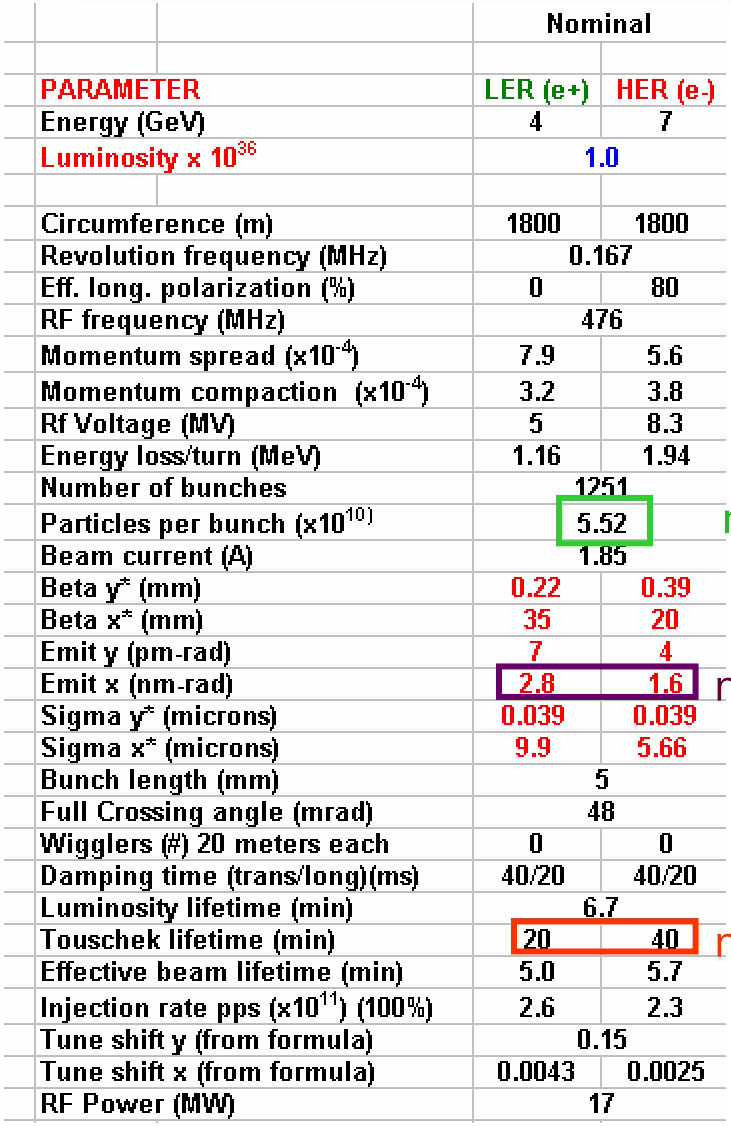


	L_{ave} (10^{31} cm^{-2}s^{-1})	Bkg_{ave} (kHz)	Bkg/L (kHz 10^{31} cm^{2}s^{1})	Accidental probability
2001	2.5	130	50	8%
2002	6	50	8.3	5%
2004	8	50	6.25	2.5%
2005	10	40	4	2.5%

Touschek effect at SuperB

SuperB Parameters (June 2008)

nominal CDR lattice:



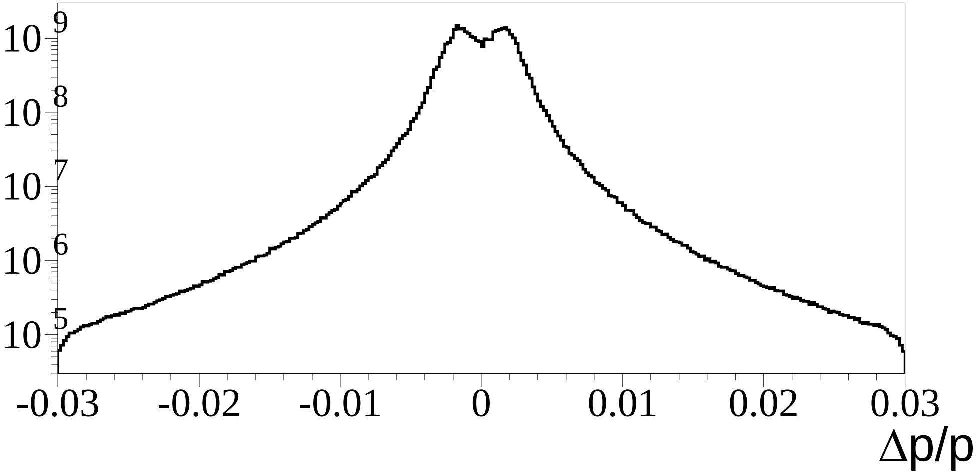
	Nominal	
PARAMETER	**LER (e+)**	**HER (e-)**
Energy (GeV)	4	7
Luminosity x 10^{36}	1.0	
Circumference (m)	1800	1800
Revolution frequency (MHz)	0.167	
Eff. long. polarization (%)	0	80
RF frequency (MHz)	476	
Momentum spread ($x10^{-4}$)	7.9	5.6
Momentum compaction ($x10^{-4}$)	3.2	3.8
Rf Voltage (MV)	5	8.3
Energy loss/turn (MeV)	1.16	1.94
Number of bunches	1251	
Particles per bunch ($x10^{10}$)	5.52	
Beam current (A)	1.85	
Beta y* (mm)	0.22	0.39
Beta x* (mm)	35	20
Emit y (pm-rad)	7	4
Emit x (nm-rad)	2.8	1.6
Sigma y* (microns)	0.039	0.039
Sigma x* (microns)	9.9	5.66
Bunch length (mm)	5	
Full Crossing angle (mrad)	48	
Wigglers (#) 20 meters each	0	0
Damping time (trans/long)(ms)	40/20	40/20
Luminosity lifetime (min)	6.7	
Touschek lifetime (min)	20	40
Effective beam lifetime (min)	5.0	5.7
Injection rate pps ($x10^{11}$) (100%)	2.6	2.3
Tune shift y (from formula)	0.15	
Tune shift x (from formula)	0.0043	0.0025
RF Power (MW)	17	

now N_b slightly lower
(LER/HER 6.16/3.52)

now higher LER horiz. emitt.
(LER/ HER 1.6/1.6)

now higher Tou. lifetime
(LER/ HER 3.6/5.1)

SuperB: Comparison between lifetime estimate from formula and calculation from tracking (CDR lattice)



generated Touschek particles per second all over the ring

Reference:

τ(CDR)=330 s (Wienands)

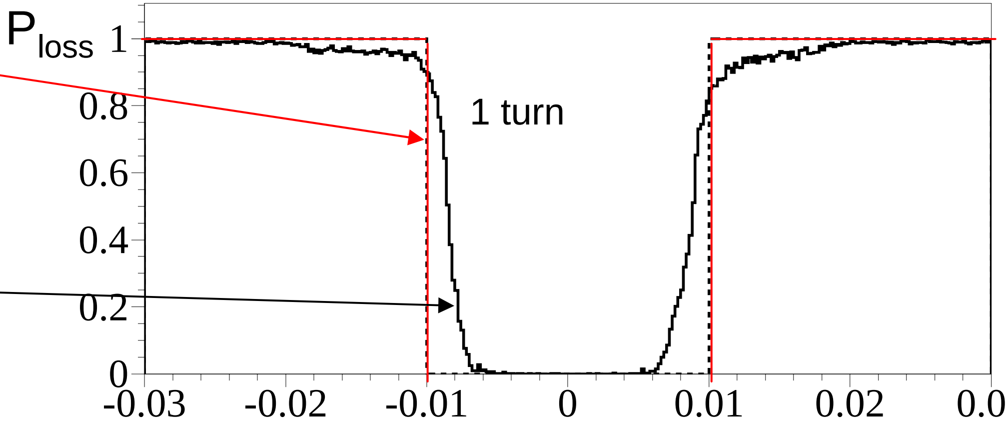
assuming that particles with |Δp/p|>1% are lost (like CDR):

τ = 308 s

good agreement with CDR

efficiency calculated from tracking

τ = 200 s

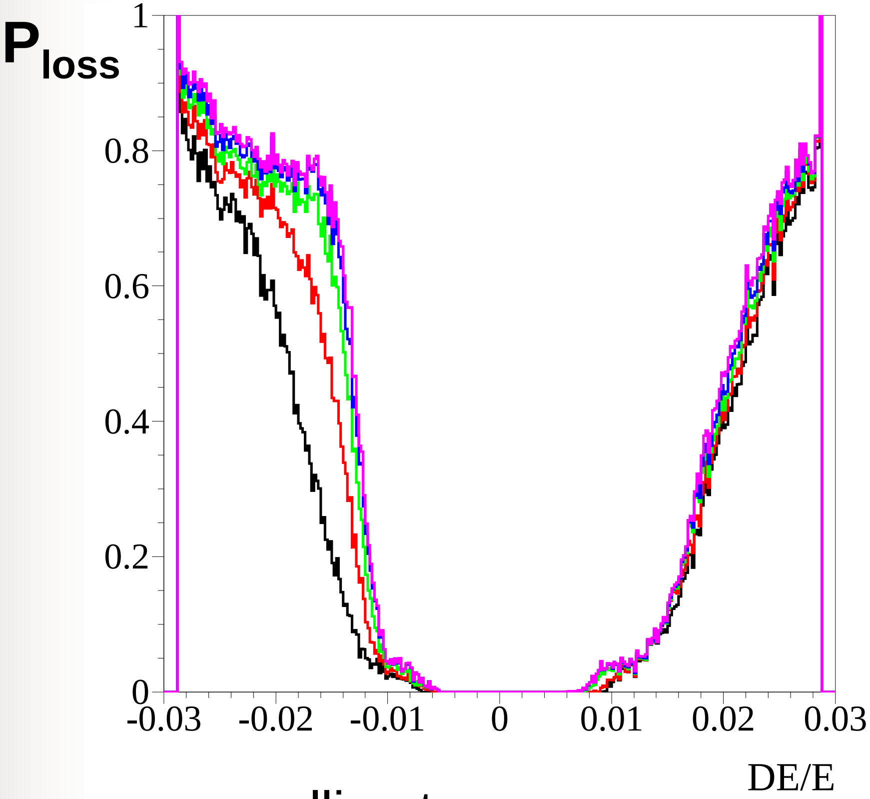


tracked particles with Δp/p= 0.6%-0.8% are lost, with some efficiency. These have very large weight, this induces difference in lifetime estimation

(Touschek function very non linear)

Energy acceptance with the present **LER** lattice

energy acceptance higher than the previous lattice



1 machine turn

2 machine turns

3 machine turns

4 machine turns

5 machine turns

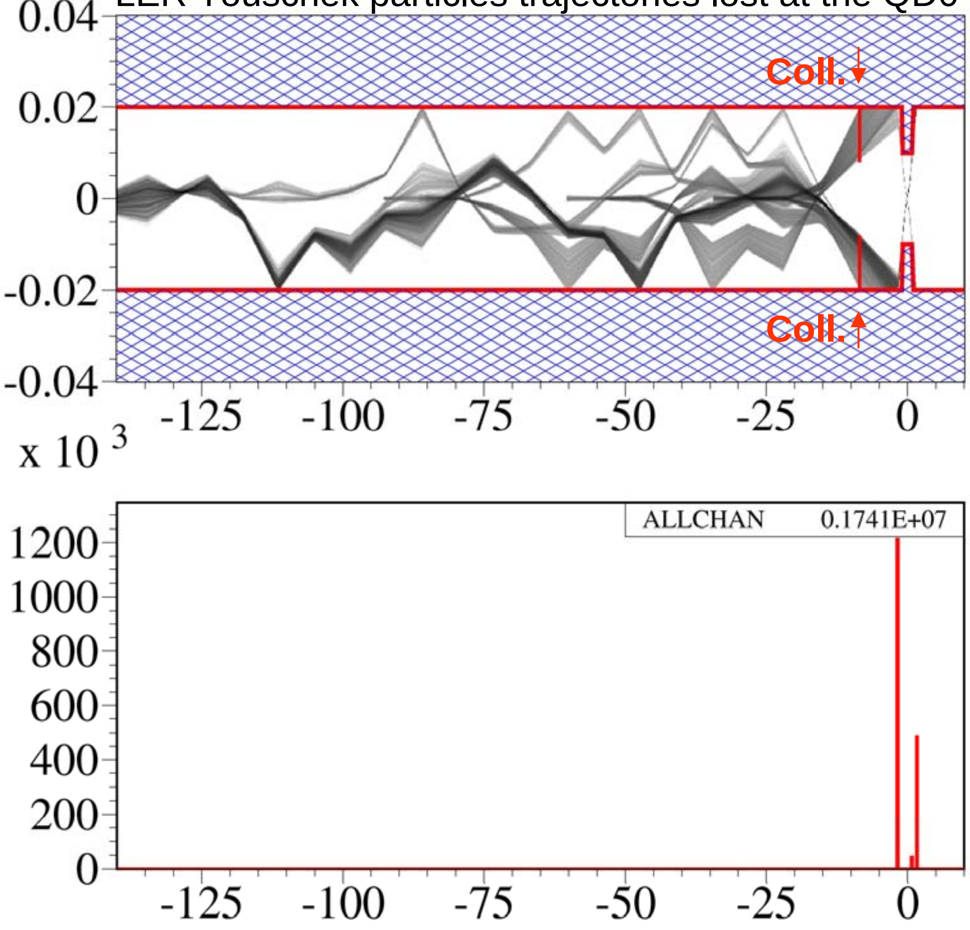
no collimators

LER Touschek particles lost at IR

<u>NO</u> COLLIMATORS inserted

Touschek lifetime ≈ 24 min

example of
LER Touschek particles trajectories lost at the QD0



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

<u>parameters for simulations</u>

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

rf accept. =2.9 %

machine turns = 5

K=0.25%

ε_x=2.8 nm ; σ_z=5 mm

LER Touschek particles lost at IR

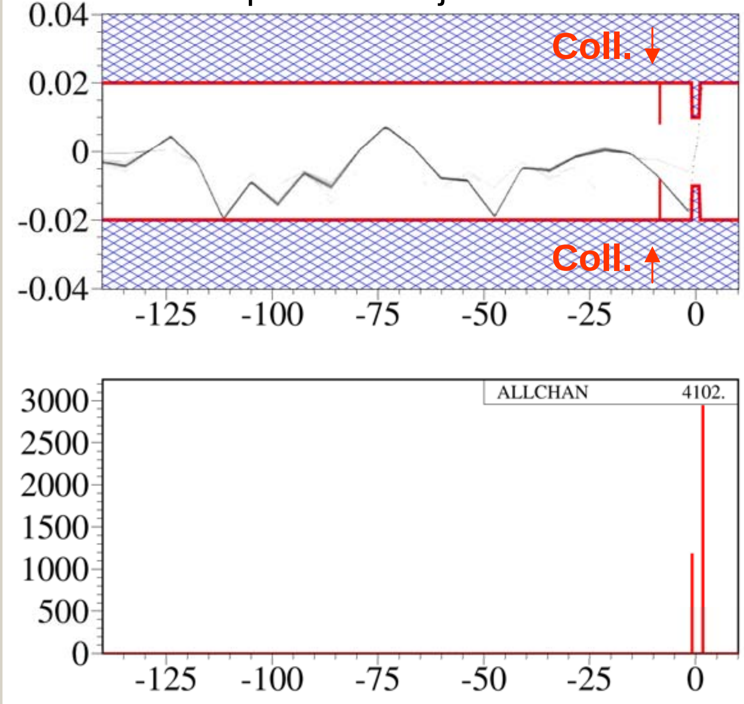
Touschek lifetime ≈ 20 min

with IR COLLIMATOR inserted s = -8.5 m far from IP at about 20 σ_x

IR collimator modeled as perfectly absorbing and no width.

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

example of
LER Touschek particles trajectories lost at the QD0



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

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

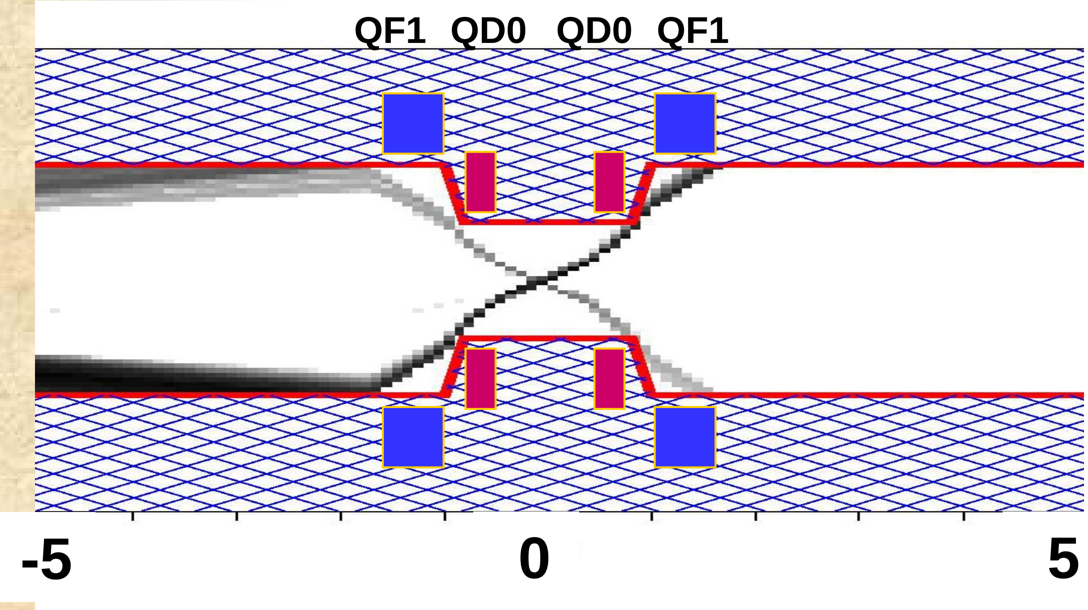
at full current

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

HER Touschek particles lost at IR

NO COLLIMATORS inserted

Touschek lifetime ≈ 40 min

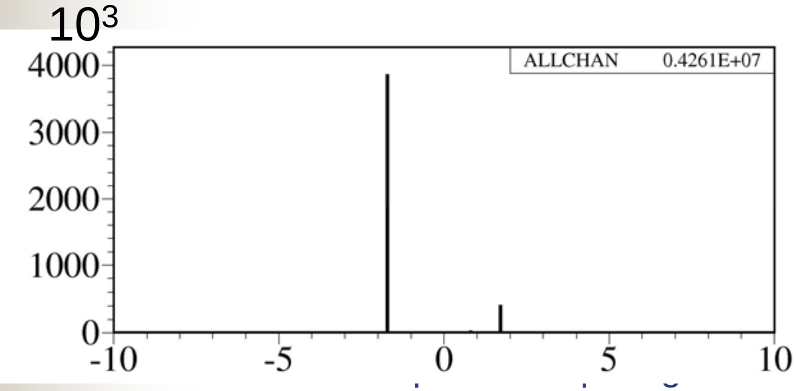


IR Losses (|S|<2m)= 4.2 MHz

for 1 bunch with I_{bunch} =1.49 mA

IR Losses (|S|<2m)= 5.2 GHz

for nominal full current



parameters for simulations

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

rf accept. =2.9 %

machine turns = 5

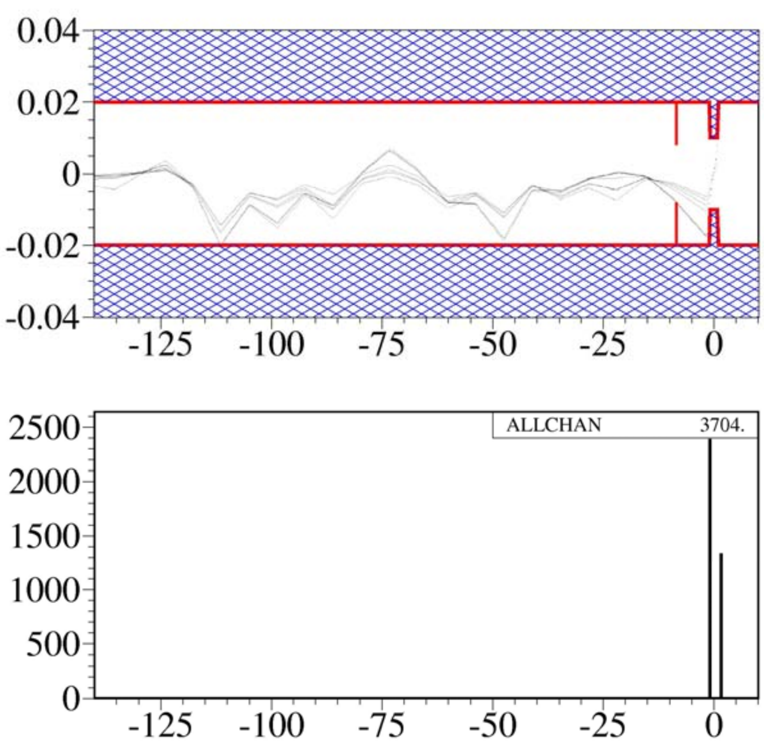
K=0.25%

ε_x=1.8 nm ; σ_z=5 mm

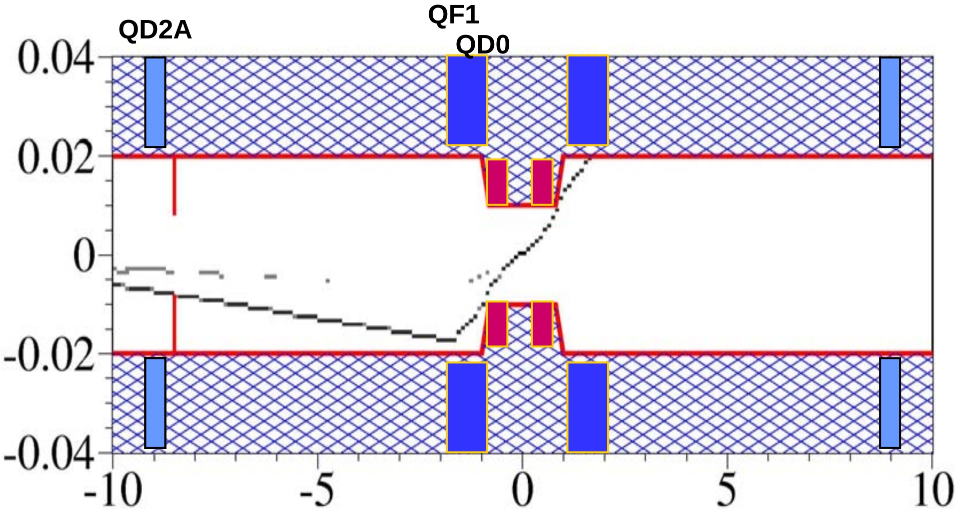
HER Touschek particles lost at IR

Touschek lifetime ≈ 32 min

<u>with</u> IR COLLIMATOR inserted S=-8.5 m far from IP at about 20 σ_x



zoomed view



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

IR Losses (|S|<2m) ~ 4.6 MHz

for nominal full current

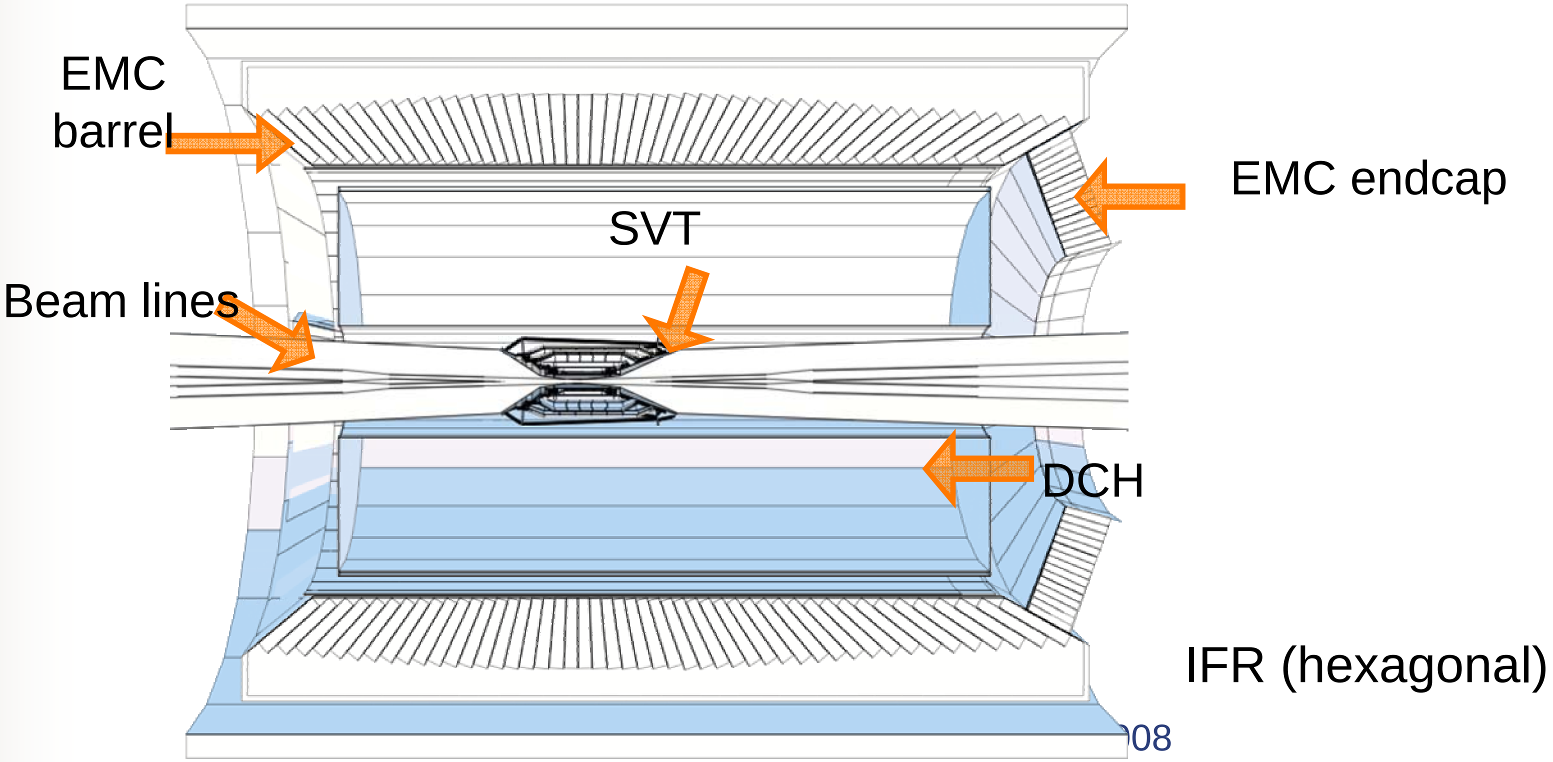
IR collimator modeled as perfectly absorbing and no width.

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

Background Impact on detectors

Geant4 simulations
from the bkg sources: radiative Bhabha, pairs prod., Touschek

- **SVT**
- **DCH**
- **EMC**
- **IFR**



Beam-gas effect at SuperB

Beam-gas scattering

- **Elastic scattering-**
  loss at physical or dynamic aperture

  stored beam particle is deflected when scattered by a nucleus of the residual gas atom (classical Rutherford cross section)

- **Inelastic scattering-**
  loss at RF acceptance limit or off-momentum (phys. or dynamic like Touschek)
  - Bremsstrahlung: photon emission by a stored electron deflected by the nucleus
  - Energy transfer from the stored electron to the atom of the residual gas

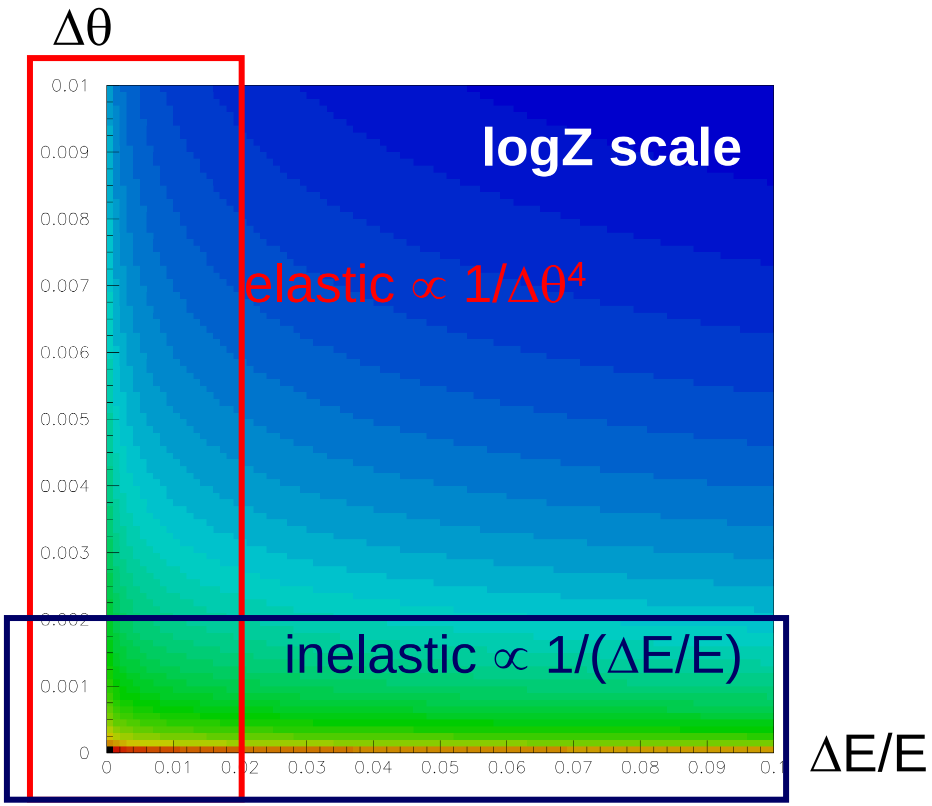
  Secondaries can be background source themselves- important near the IR (simulate with DECAY-TURTLE or directly with GEANT)

Beam-gas scattering

The two components actually belong to the same physics process. They need to be treated separately for practical purposes

they can be treated easily “a la” Touschek

Probability of beam-gas scattering



Elastic beam-gas scattering

Giving a circulating electron a kick θ results is an oscillation

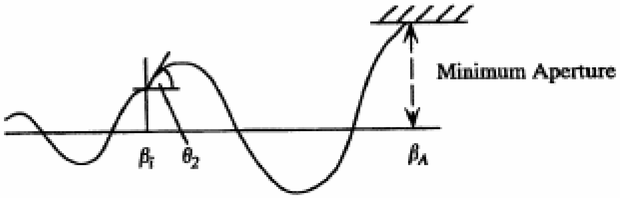
$$u(s) = \theta_i \sqrt{\beta(s)\beta_i}\ \sin(\varphi(s) - \varphi_i)$$

The maximum amplitude is

$$Max\,|u(s)| = A = \theta_i \sqrt{\beta_A \beta_i}$$

If A exceeds the physical or dynamic aperture the particle is lost

$$\theta_i \geq \sqrt{\frac{1}{\beta_i}\left(\frac{A^2}{\beta_A}\right)_{\min}} = \sqrt{\frac{H}{\beta_i}}$$



Where H is the machine acceptance

Loss of electrons - Calculate collision cross-section that leads to a deflection angle greater than a maximum θ_{max} defined by the acceptance of the ring. Integrating dσ from θ_{max} to π:

$$\sigma_{loss} = 2\pi \int_{\theta_{\max}}^{\pi} \frac{d\sigma}{d\Omega} \cdot d\Omega = \frac{\pi}{2}\left(\frac{Z r_0}{\gamma}\right)^2 \cot^2\left(\frac{\theta_{\max}}{2}\right)$$

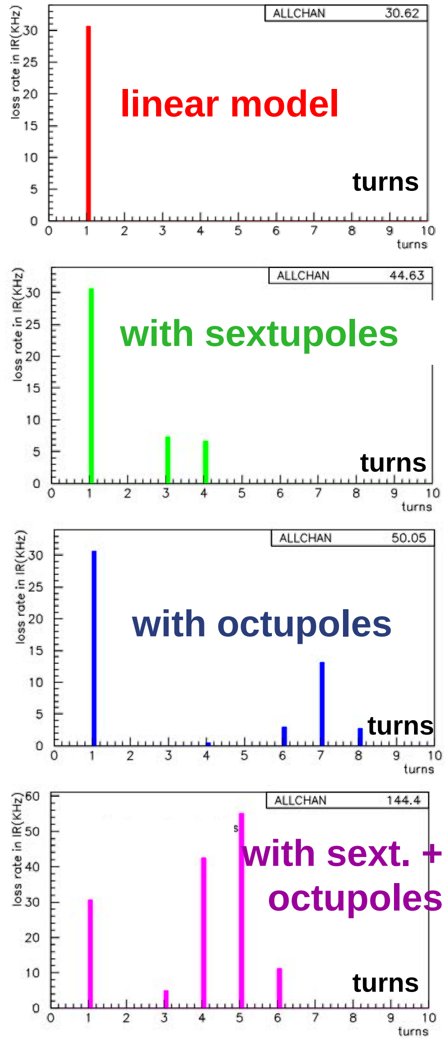
$\theta_{max} = \sqrt{H/\beta_i}$ is a small angle & approximating tan θ_{max} ~ θ_{max}

$$\sigma_{loss} = \frac{2\pi Z^2 r_o^2}{\gamma^2} \cdot \frac{1}{\theta^2_{\max}} = \frac{2\pi Z^2 r_o^2}{\gamma^2}\,\frac{\beta_i}{H}$$

Averaging over the ring $\sigma_{loss} = \dfrac{2\pi Z^2 r_0^2}{\gamma^2} \cdot \dfrac{\langle\beta\rangle}{H}$

need to track for many turns

Touschek particle losses vs machine turns



Beam-gas Inelastic scattering

- differential cross section for energy loss from photon emission at the nucleus (Bremsstrahlung):

$$\left(\frac{d\sigma}{d\varepsilon}\right)_N = \alpha \frac{4Z^2 r_0^2}{\varepsilon} \left\{ \left[\frac{4}{3}\left(1-\frac{\varepsilon}{E}\right) + \frac{\varepsilon^2}{E^2} \right] \left[183 - \frac{1}{3} \ell n Z \right] + \left[\frac{1}{9}\left(1-\frac{\varepsilon}{E}\right) \right] \right\}$$

- ionization of residual gas, lower cross section

$$\left(\frac{d\sigma}{d\varepsilon}\right)_e = \alpha \frac{4Z r_0^2}{\varepsilon} \left\{ \left[\frac{4}{3}\left(1-\frac{\varepsilon}{E}\right) + \frac{\varepsilon^2}{E^2} \right] \left[1194 - \frac{2}{3} \ell n Z \right] + \left[\frac{1}{9}\left(1-\frac{\varepsilon}{E}\right) \right] \right\}$$

like Touschek with ΔE/E<0 for primary electrons

Single beam backgrounds

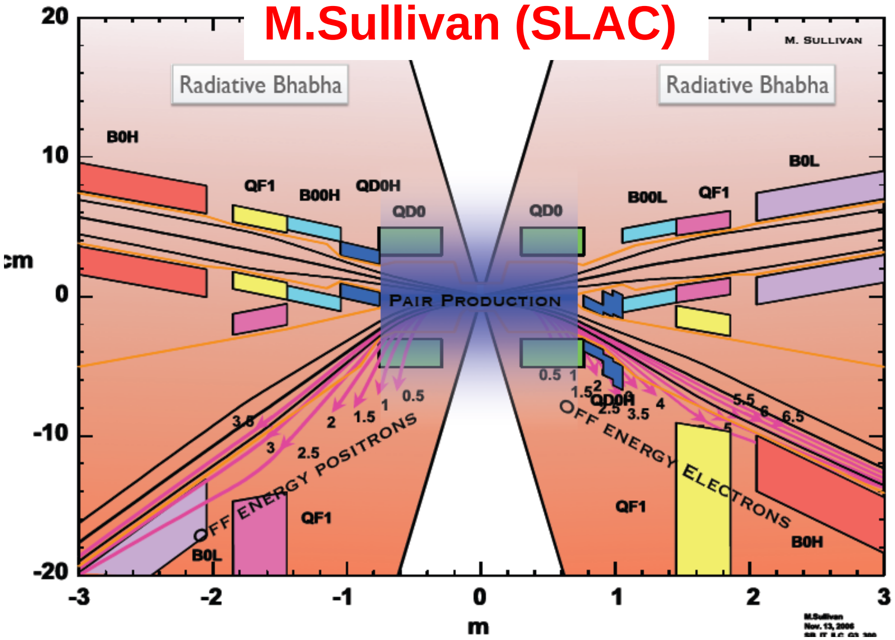
- **Synchrotron radiation backgrounds**

bends and quads near the IP are the main sources of SR that cause background problems

Masks shield the IP beampipe from direct SR as well as from scattered SR.

A perfectly black mask does not exist, i.e. every photon hitting a mask has some probability of reradiation (depending on E, angle, material and geometry)

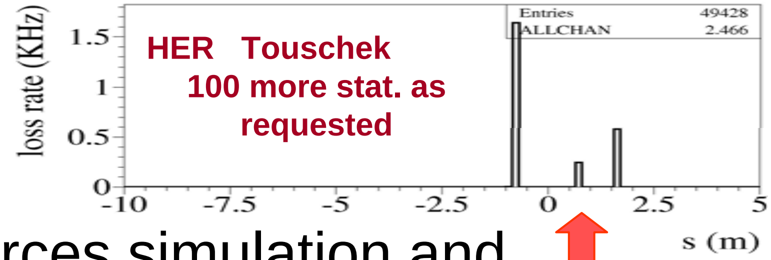
IR layout


M.Sullivan (SLAC)

Conclusions

Background sources simulations:

- Touschek: some more checks on non-linear tracking, repeat calculations with optimized sextupoles and repeat simulations with latest IR design from M. Sullivan
- pairs production: careful study on the beam pipe design
- Beam-gas: simulations soon



HER Touschek
100 more stat. as requested

DONE

Detector bkg simulations:

- produce more statistics with bkg sources simulation and further check expected rates
- optimize shape and dimension of shieldings
- track into detectors possible showers from collimators (inserted for stopping Touschek particles)

Back-up slides

Approximations in single beam background simulation

- Approximations in calculating a particular background process
- Approximations in deciding which are the dominant processes

Comparison with actual experience

It is valuable and possibly essential for a successful design to compare our calculational techniques and procedures with data from a real detector at a real storage ring

Acceptable agreement does not assure success, of course, because scaling from one machine to another is not so direct…but it would be a good start.

Possible scenarios for 10^{36} (LER/HER)

	Unit	CDR 2007	June 2008	ε_y X 2	ε_y X 4	ε_y & β_y^* higher	β_y^* higher	σ_z longer	σ_z shorter	ξ_y 0.085
I^+/I^-	Amp	2.28 /1.30	1.85 /1.85	2.28 /1.30	2.28 /1.30	4.56 /2.60	3.42 /1.95	2.28 /1.30	2.28 /1.30	4.56 /2.60
N_{part}	$x10^{10}$	6.16 /3.52	5.52 /5.52	8.71 /4.98	12.4 /7.0	6.16 /3.52	5.0 /2.87	12.4 /7.0	3.1 /1.26	6.16 /3.52
N_{bun}		1250	1250	884	625	2500	2296	625	2500	2500
β_y^*	mm	0.3 /0.3	0.22 /0.39	0.3 /0.3	0.3 /0.3	0.6 /0.6	0.45 /0.45	0.3 /0.3	0.3 /0.3	0.3 /0.3
ε_y	pm	4/4	7/4	8/8	16/16	8/8	4/4	4/4	4/4	16/16
σ_y	nm	35/35	39/39	49/49	70/70	70/70	42/42	35/35	35/35	70/70
ξ_y	Tune shift	0.17 /0.17	0.15 /0.15	0.17 /0.17	0.17 /0.17	0.17 /0.17	0.17 /0.17	0.17 /0.17	0.17 /0.17	0.085 /0.085
σ_z	mm	6/6	6/6	6/6	6/6	6/6	6/6	12/12	3/3	6/6

↑ Lower ξ_y

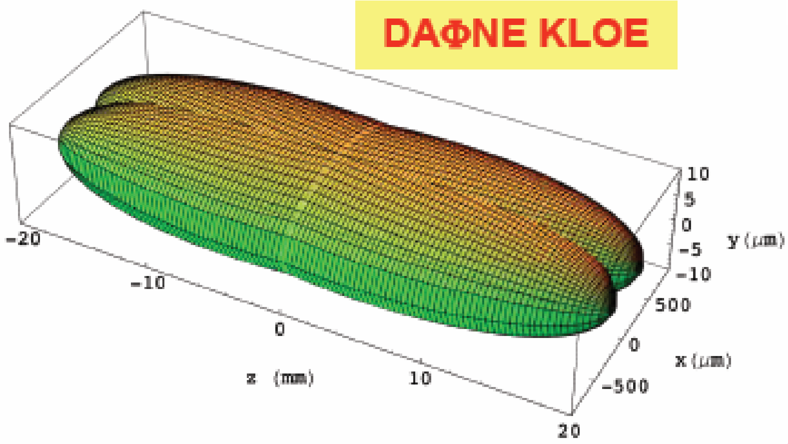
Several parameter sets allow to reach10^{36}.
No scenario has all parameters pushed to limit

J. Seeman, MiniMac, LNF, July 2008

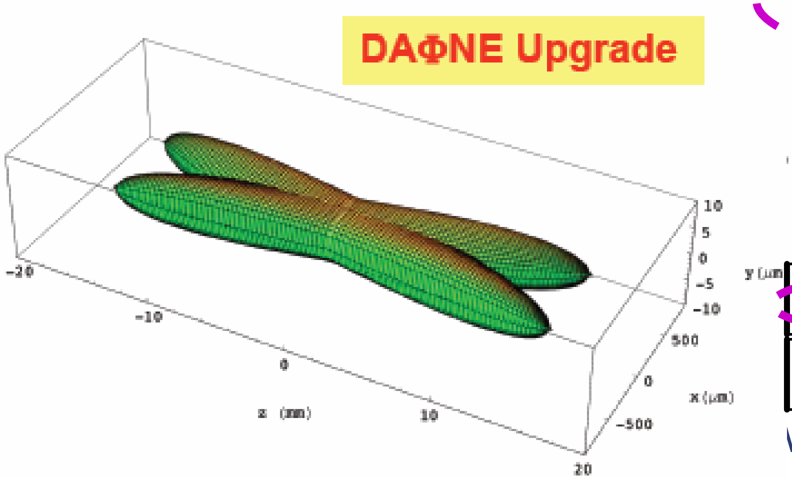
Touschek Backgrounds for the Crab waist scheme at DAFNE

Energy deviat.	0.003 -0.02
σ_p/p	4 e-4
ε_x(m rad)	$0.2\cdot10^{-6}$
coupling	0.005
N_p	$2\cdot10^{10}$
I_{bunch}(mA)	10

BEAM DISTRIBUTION AT IP



DAΦNE KLOE



DAΦNE Upgrade

	DAΦNE KLOE	DAΦNE Upgrade
I_{bunch} (mA)	13	13
N_{bunch}	110	110
β_y* (cm)	1.7	0.65
β_x* (cm)	170	20
σ_y* (μm)	7	2.6
σ_x* (mm)	0.7	0.2
σ_z (mm)	25	20
$\theta_{cross}/2$ (mrad)	12.5	25
$\Phi_{Piwinski}$	0.45	2.5
ε_x(mm mrad)	0.34	0.26
$L(cm^{-2}s^{-1})\cdot10^{32}$	1.6	5

smaller transv. beam size and emittance

⇩

Touschek more important

SCALING of Touschek loss rate dN/dt and lifetime τ with beam parameters

$$\frac{1}{\tau} = \frac{1}{N}\frac{dN}{dt}$$

The Touschek part. 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.

Lifetime $\tau \propto \frac{\sigma_x \sigma_y \sigma_z}{I}$ where $\sigma_z \propto I^{1/3}$

$\tau \propto I^{-2/3}$

$dN/dt \propto I/\tau \propto I^{5/3}$

$\frac{dN}{dt} \propto 1\Big/\sqrt{\kappa}$ $\kappa = \varepsilon_y \big/ \varepsilon_x$

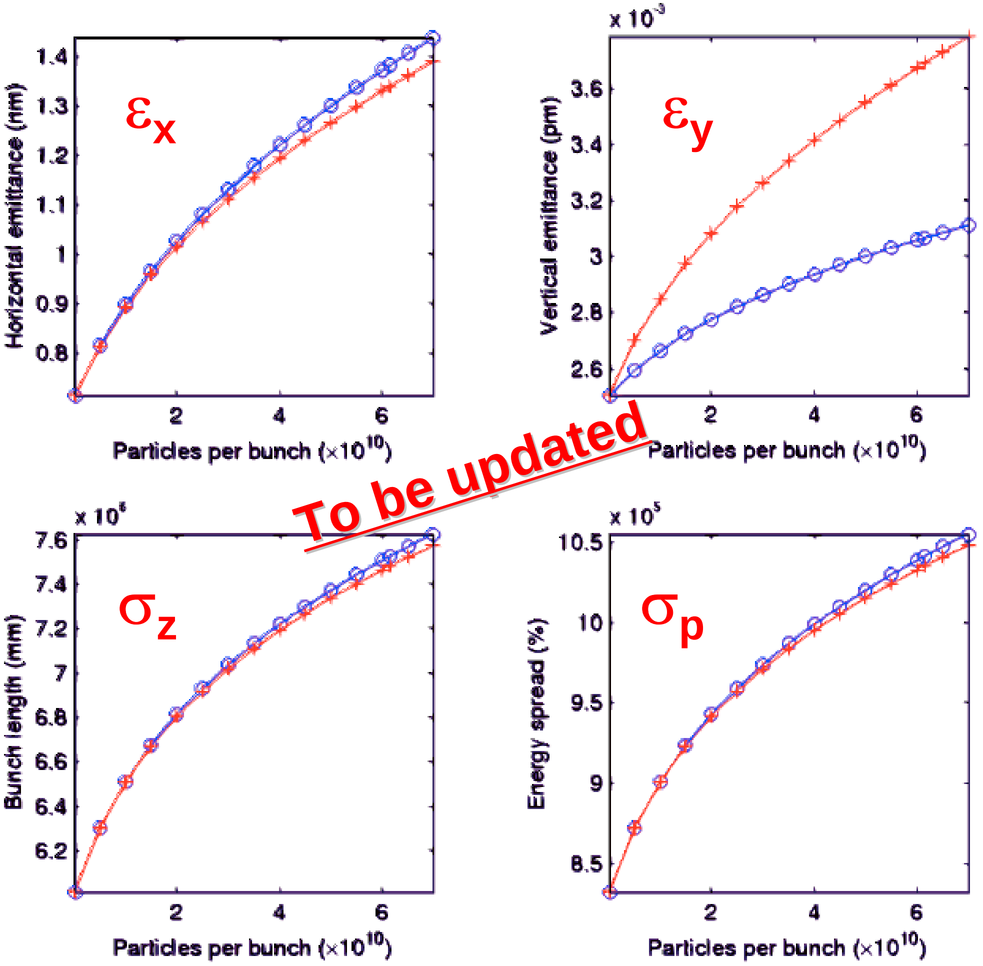
Intra Beam Scattering

SuperB LER from CDR (A. Wolski, LU)

- IBS is associated with Touschek effect: while single large-angle scattering between particles in a bunch leads to loss of particles (Touschek lifetime), multiple small-angle scattering leads to emittance growth.
- Usually IBS has long growth rates, but for machines that operate with high N_{part} and very low ε_y the IBS growth rates can be large enough that significant emittance increase can be observed.
- IBS growth rates decrease rapidly with increasing energy → LER problem only.
- Should be better with updated LER parameters

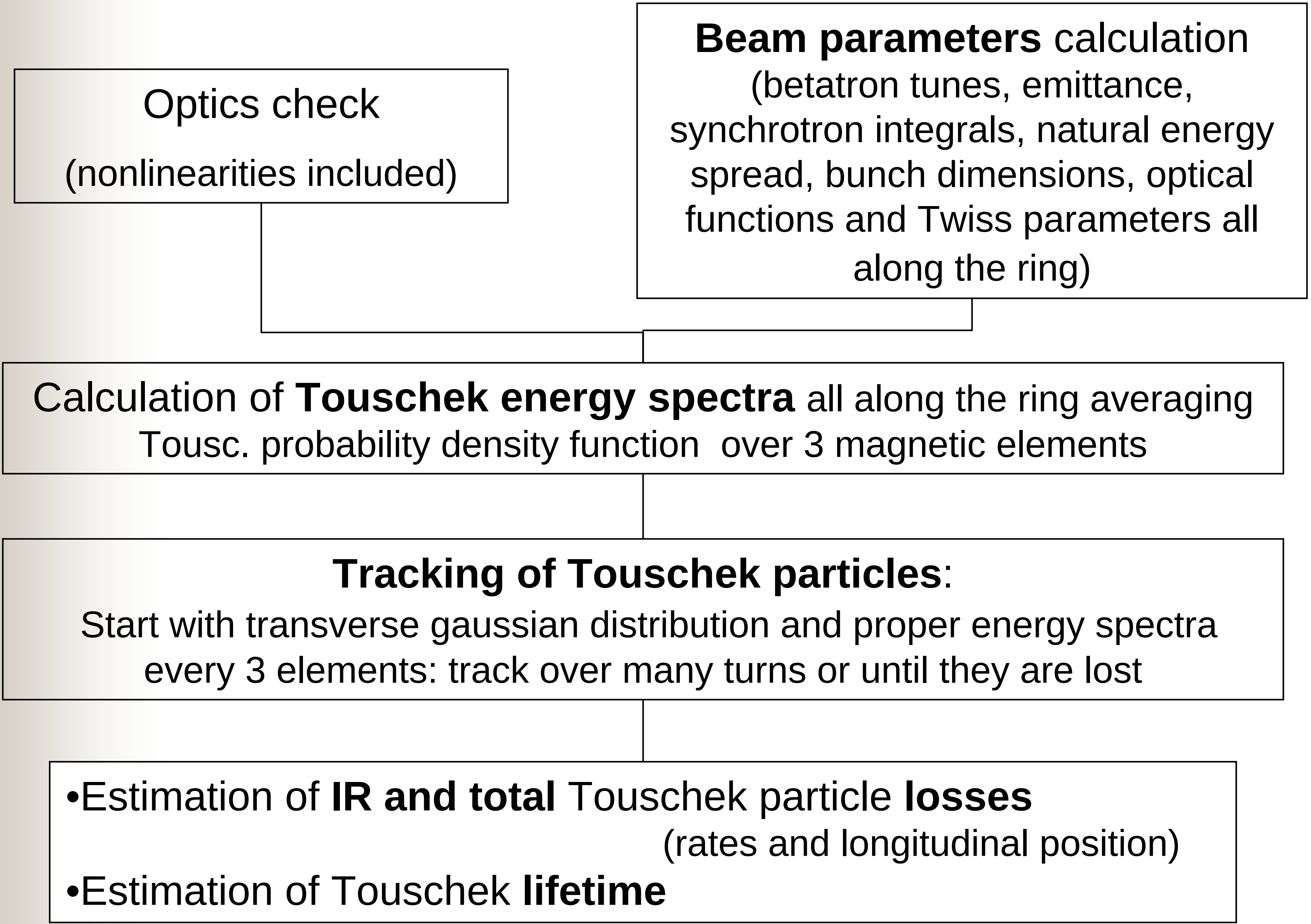
Blue: β-tron coupling makes a 10% contribution to ε_y, with η_y contributing 50%.

Red: β-tron coupling and η_y make equal contributions.



To be updated

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)

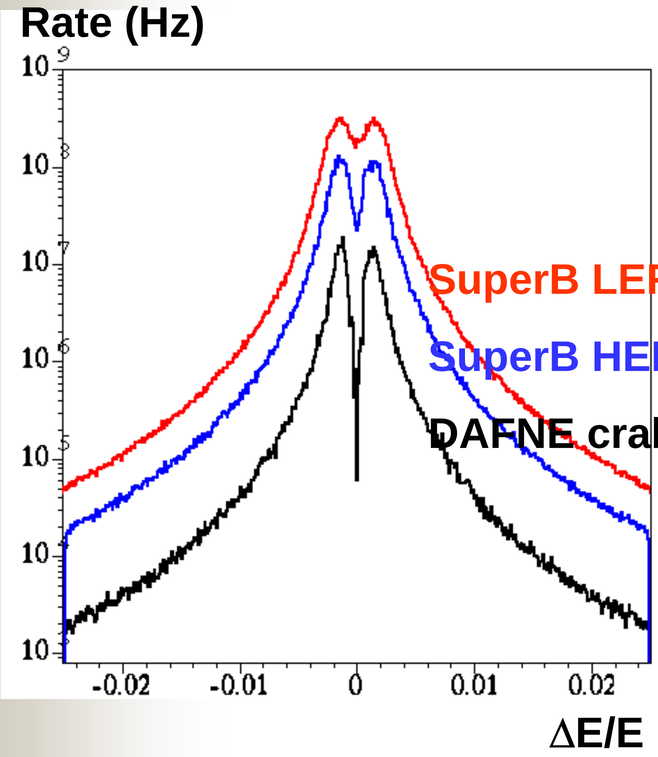
Calculation of **Touschek energy spectra** all along the ring averaging Tousc. probability density function over 3 magnetic elements

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**

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

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

Calculation of energy spectra

Starting formula:

Integrated Touschek probability

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

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

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

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

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: $A_1 \cdot \varepsilon^{-A_2}$