Istituto Nazionale di Fisica Nucleare

Background Issues at DAFNE
with the Crab Waist scheme

Manuela Boscolo

for the DAFNE Team

Japan-Italy collaboration meeting, Frascati, Dec. 10th 2008

Outline

- Experimental knobs used to control backgrounds in the detectors
- Simulation Studies - Touschek effect -
- Comparison between simulation and measurements – KLOE run
- Studies with the crab waist scheme

DAΦNE backgrounds and beam lifetime are dominated by Touschek scattering, as for all lepton storage rings of low emittance (i.e. high bunch density) and low or moderate beam energy

Touschek effect

Coulomb scattering of charged particles traveling 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 the factor γ.

For stored beam, particles are lost if their longitudinal momentum deviation exceeds the rf bucket or the momentum aperture determined by the lattice.

Questions need to be answered:

- What are the loss rates?
- Where are the scattered particles lost?
- Do we provide enough radiation shielding?

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

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

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

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

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

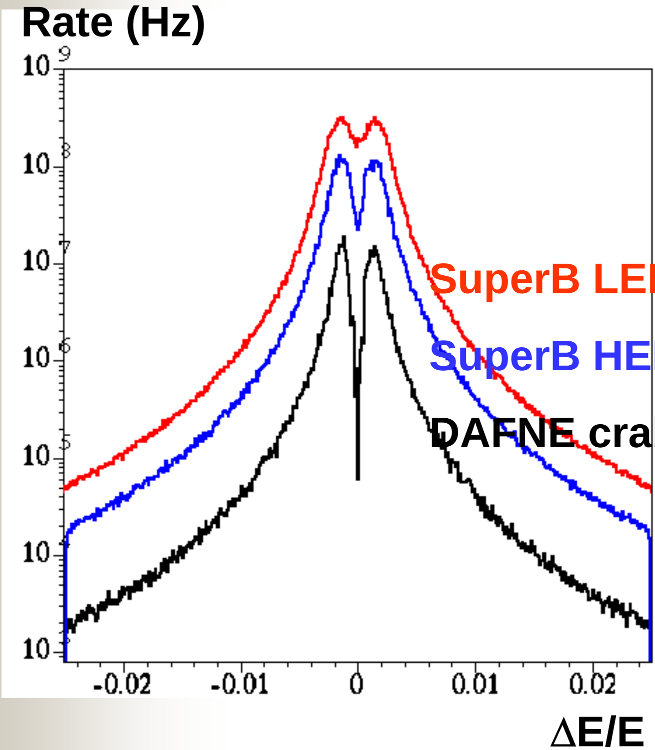
V = bunch volume= $\sigma_x \cdot \sigma_y \cdot \sigma_l$

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

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

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)-

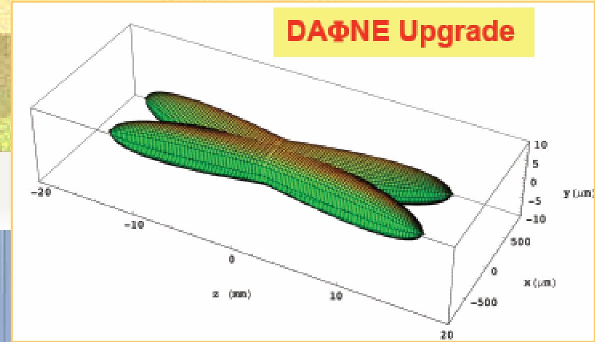
  no trigger, but small gas target detector could be shielded by lead all around

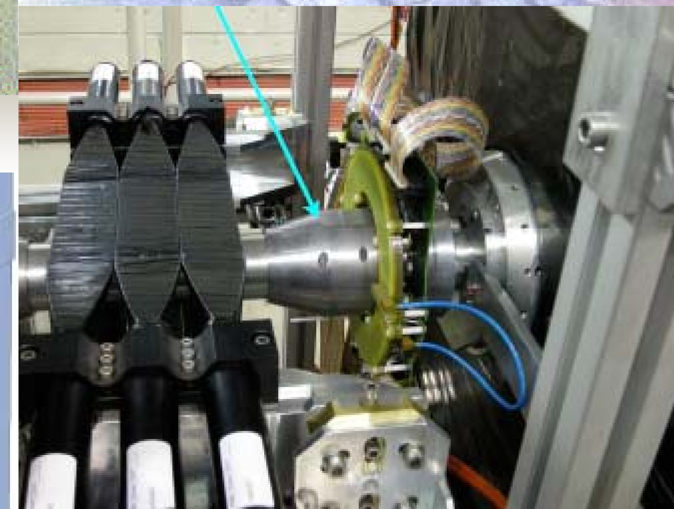
- SIDDHARTA is a gas target detector with trigger, many shieldings have been tested to optimize S/N

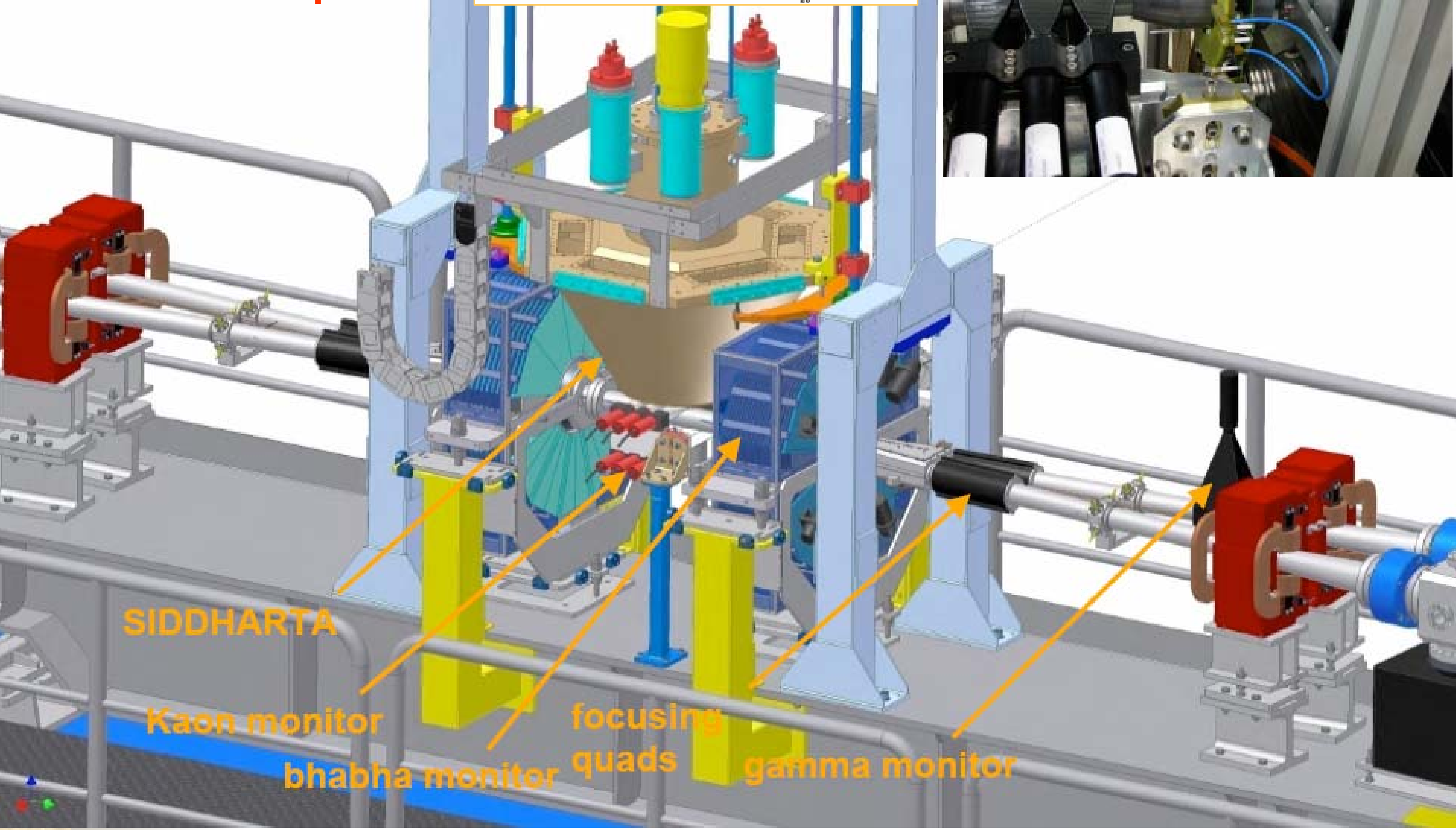
now- CRAB TEST

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

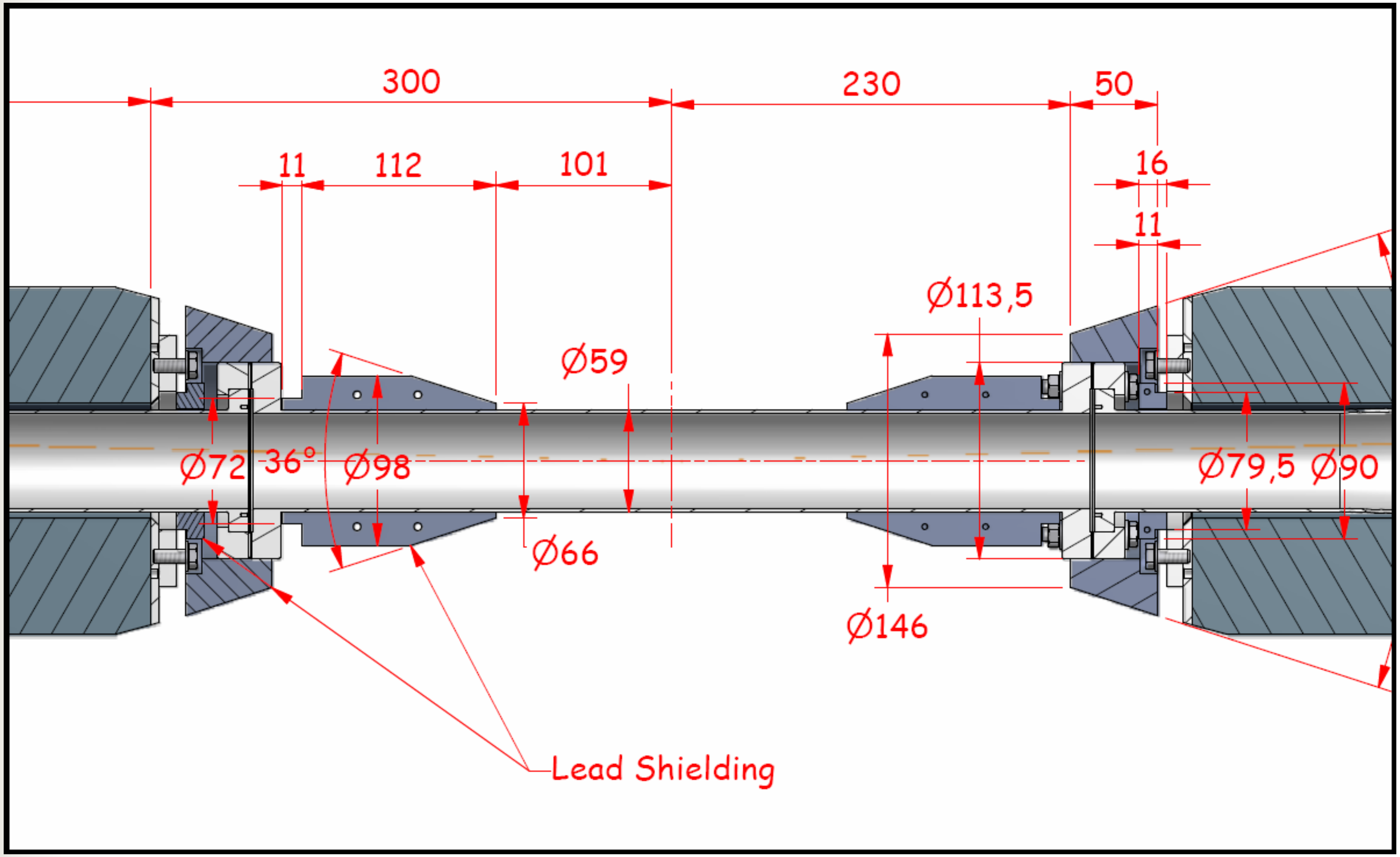
Siddharta Set-up







soyuz



300
230
50
11
112
101
16
11
Ø113,5
Ø59
Ø72
36°
Ø98
Ø79,5
Ø90
Ø66
Ø146
Lead Shielding

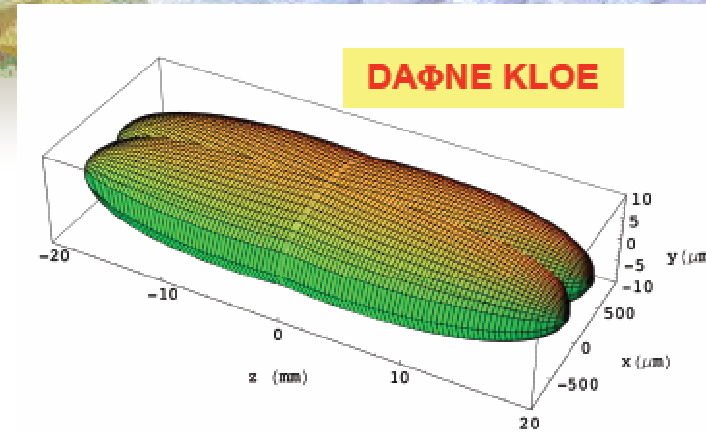
Background studies: multiple step process

- Simulation of main different background sources (i.e. Touschek)
- 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

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

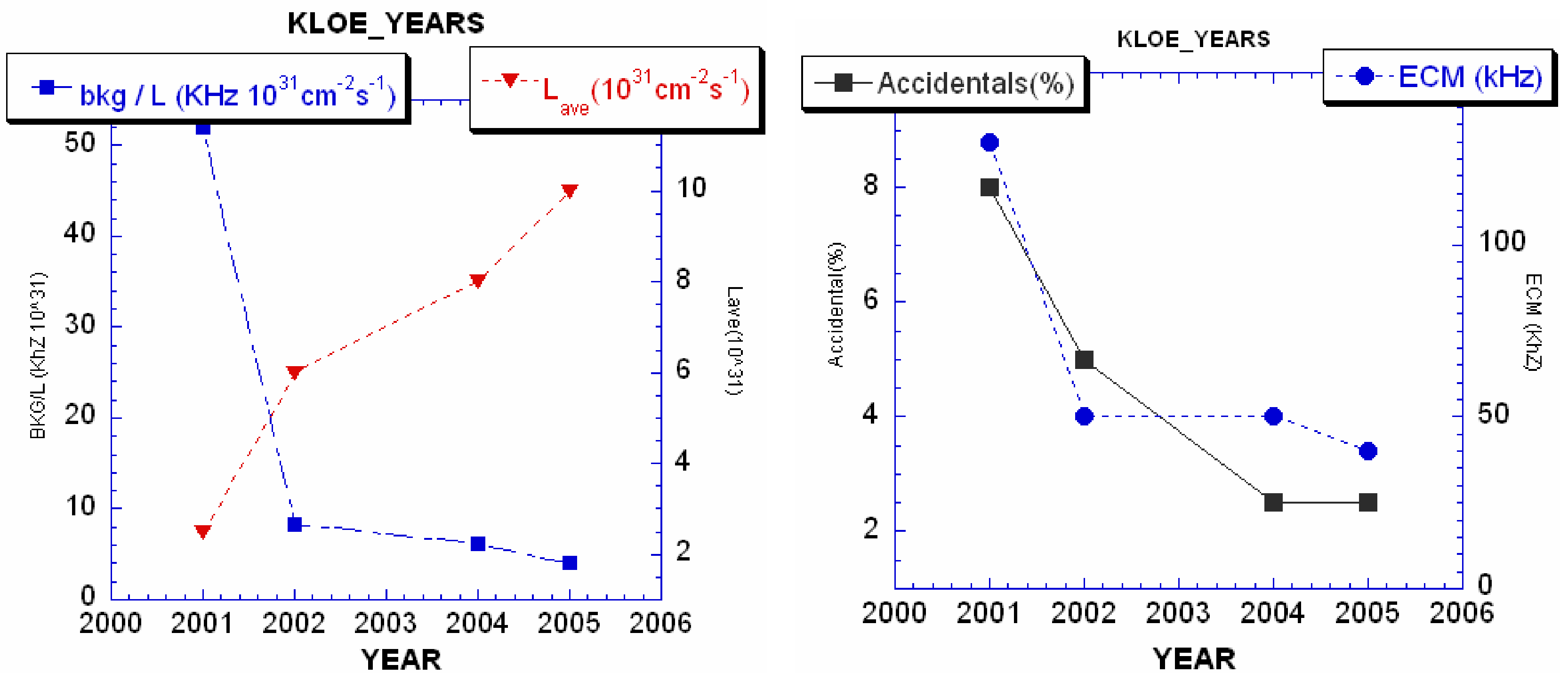
  (~20 for e^- and 50 for e^+)

collimators also with crab waist scheme now reduce loss rates by about same order than for KLOE

- Optimized IR optics
- Adiabatic beam tuning
- Simulation tool improved, non-linear terms included,

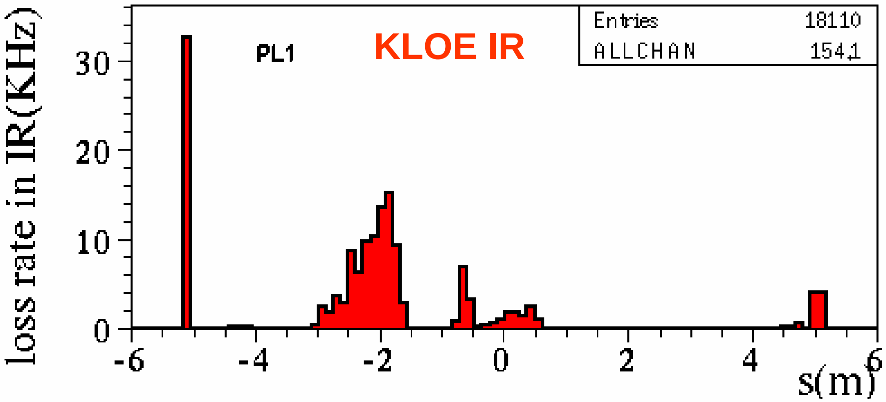
  Touschek scattering simulated at each longitudinal position, also lifetime can be evaluated

Backgrounds and Luminosity versus years of KLOE data taking



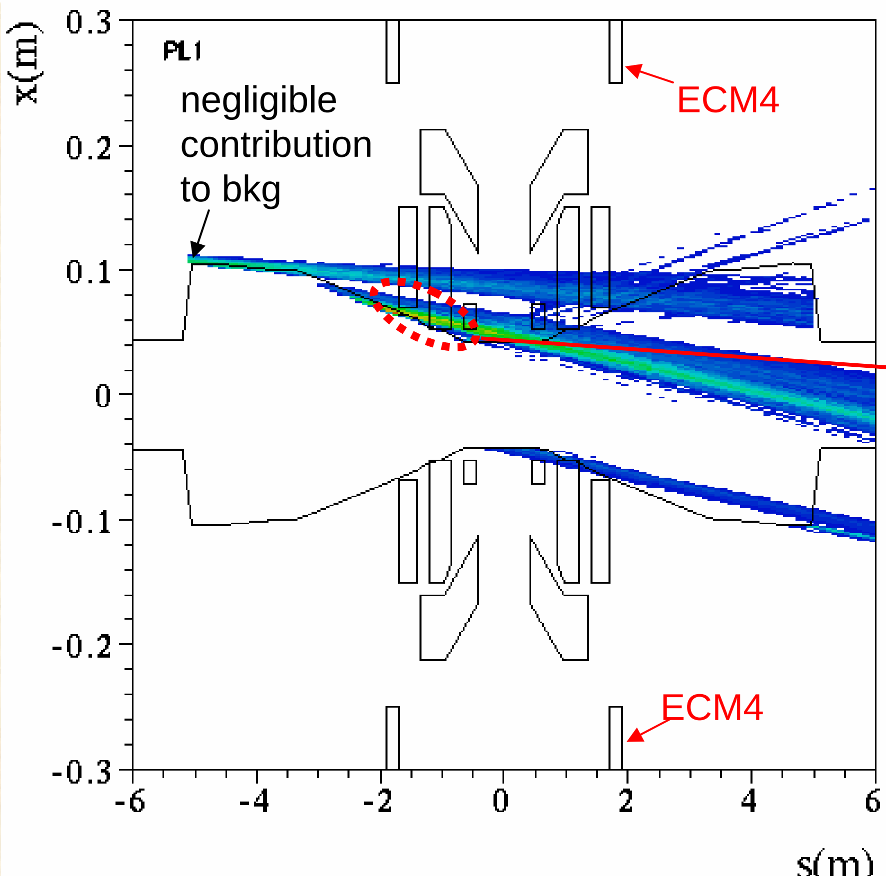
	L_{ave} (10^{31} cm^{-2}s^{-1})	Bkg_{ave} (kHz)	Bkg/L (kHz 10^{31} cm^{2}s^{1})	Accidental probability
2001	2.5	130	50	8%
2002	6	50	8.3	5%
2004	8	50	6.25	2.5%
2005	10	40	4	2.5%

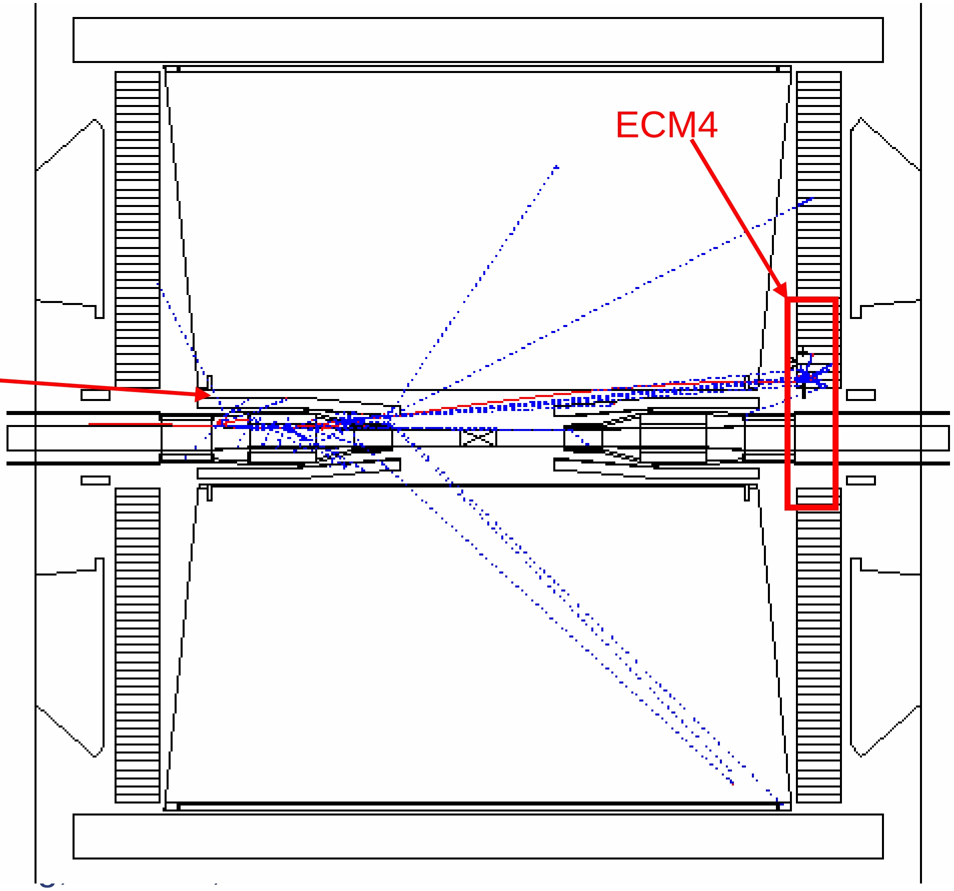
It is not easy to quantify reduction factor of the different actions



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

agreement with measurements within 30% on calorimeter rates

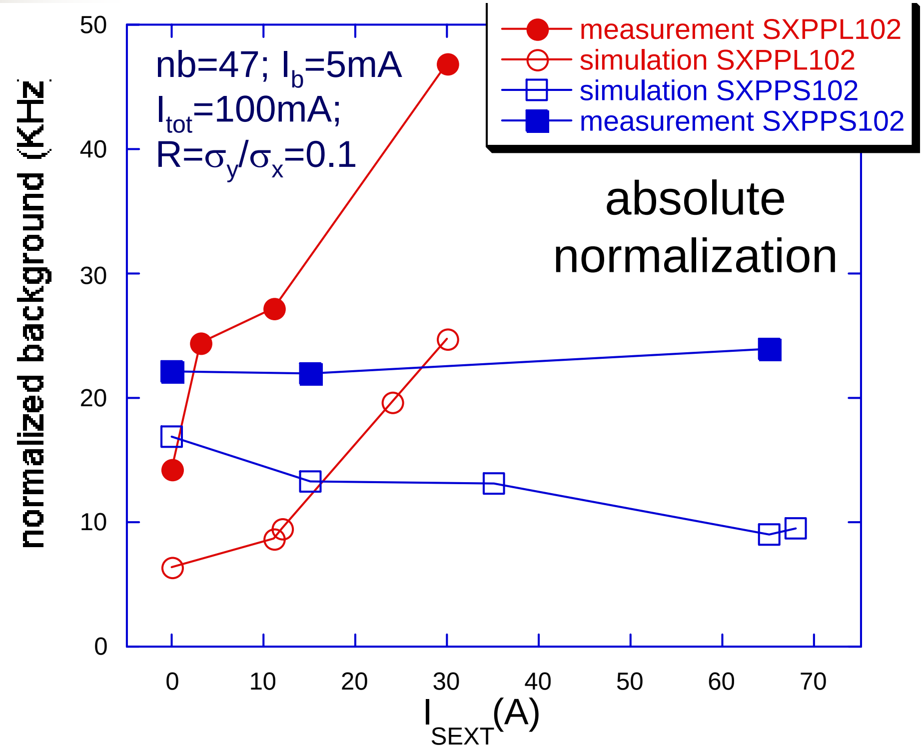




DAFNE experience: Effects of non linearities on Touschek particle losses

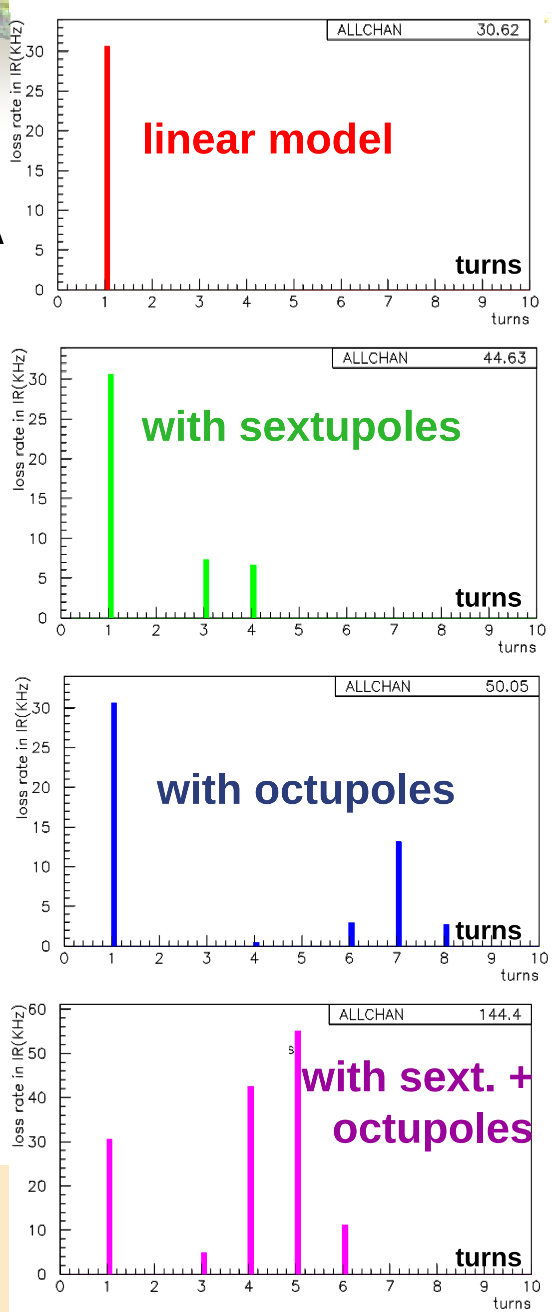
sextupoles and octupoles essential to account for the correct DA

Comparison between expected and measured bkg rates at the KLOE ECM vs sextupoles strengths



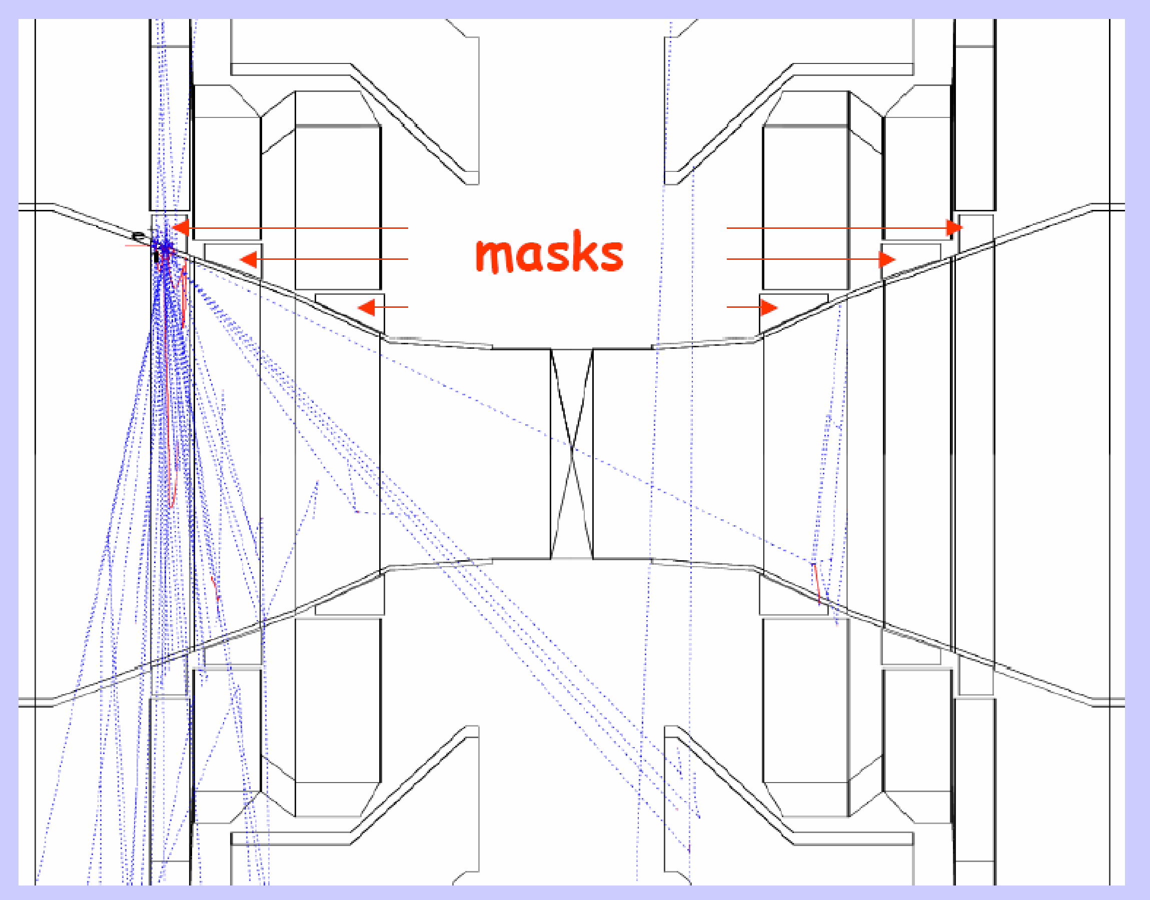
The MC reproduces actual behaviour of Touschek background vs sextupoles strengths

Touschek particle losses vs machine turns

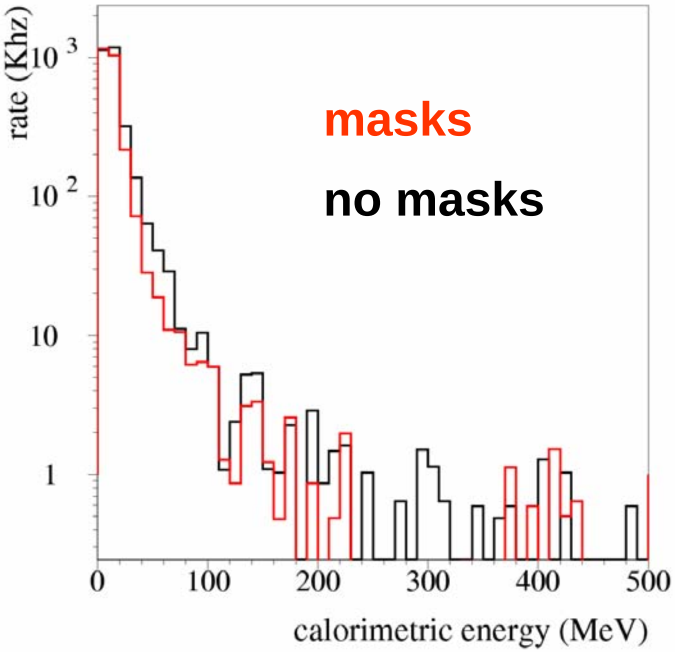


Masks added between pipe and low-β quads

IR layout + background event x-s view



Masks effectiveness

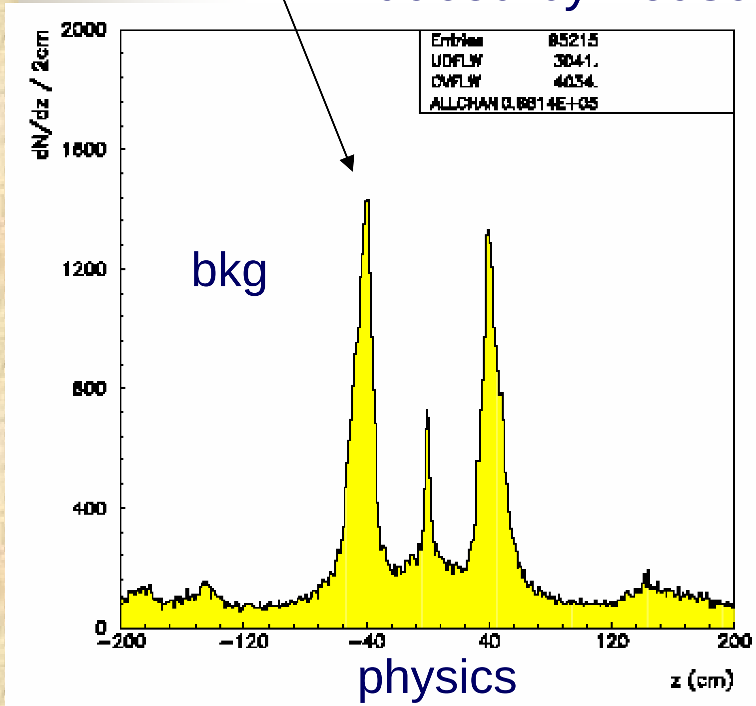


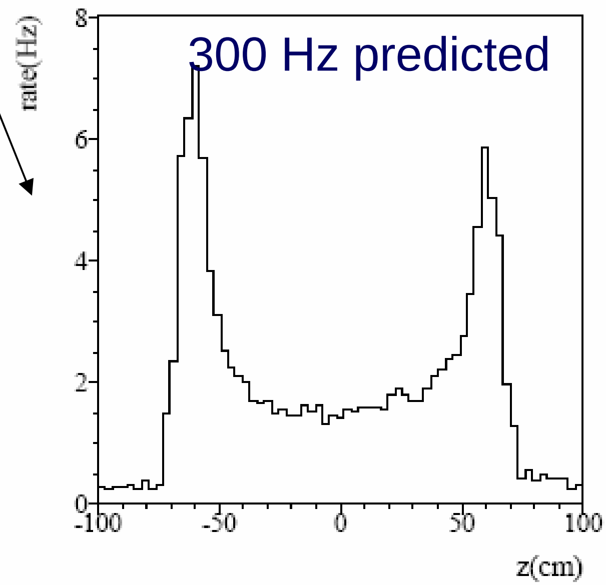
DAFNE experience: Touschek simulation tool validated by comparison with real data

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

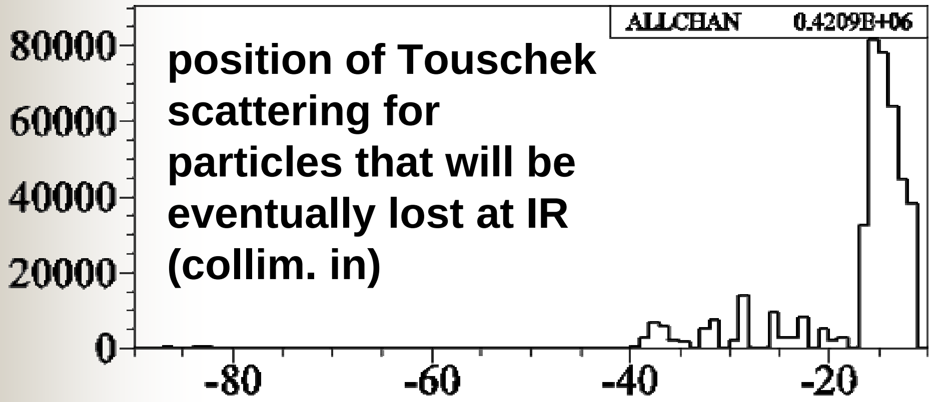
understood as photoproduction (ep(n)$\rightarrow\Lambda$e $\rightarrow$ pπ^0(π^-)e)

induced by Touschek particles hitting beam pipe support





Touschek particles lost at the IR



when all collimators are inserted only 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

right phase advance between collimators and IR

Collimators Modeling

- Perfectly absorbing collimators
- No width

collimators assumed perfectly absorbing and infinitely thin

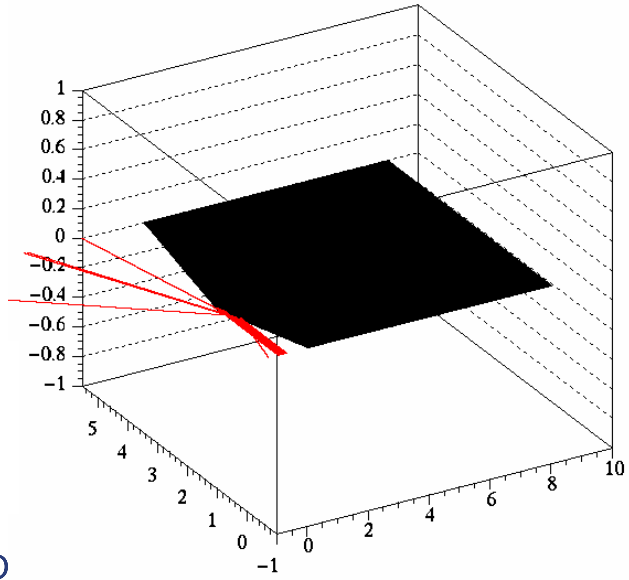
actual behaviour is reproduced but

Edge effect is missing

It has been found that most of the particles are scattered by the collimator edge, instead of being absorbed, thereby producing additional background to the experiments.

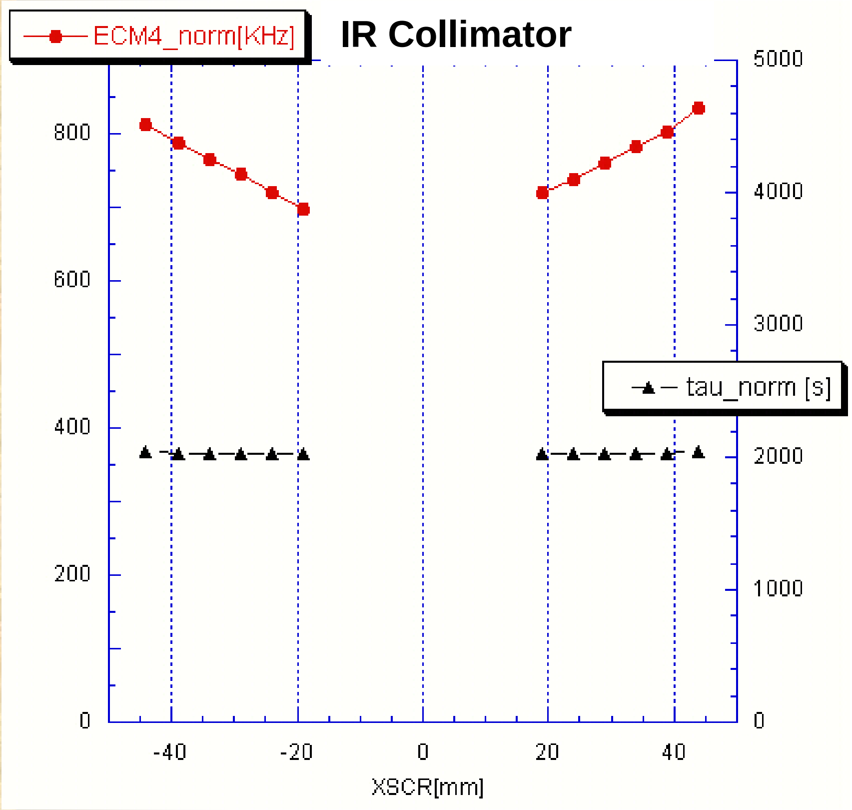
real collimator shape included in simulation

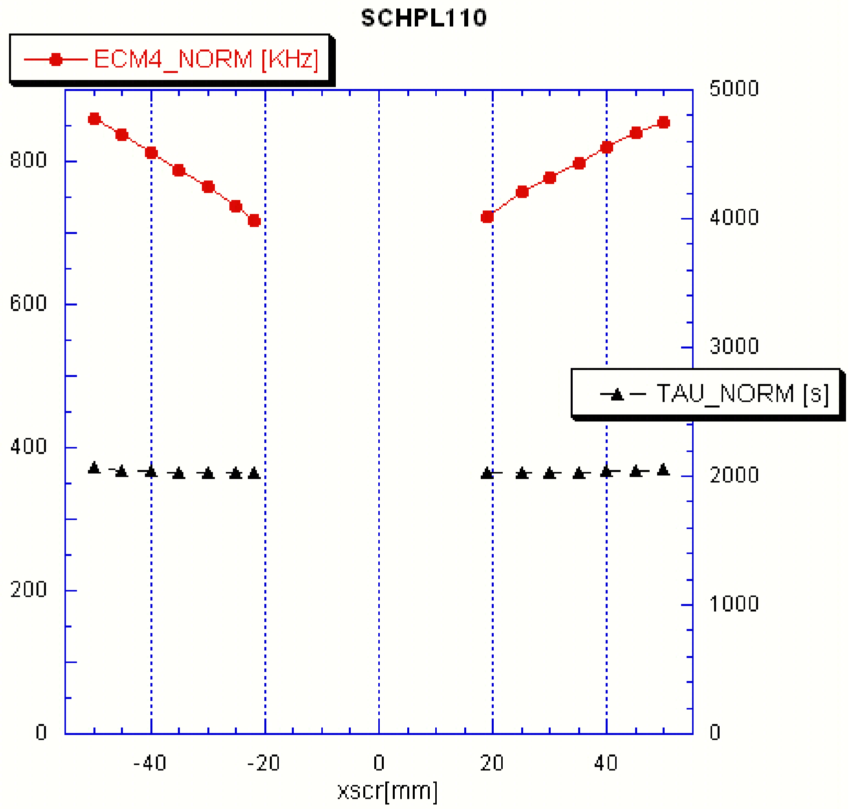
and edge effect has been simulated



Electron interaction: Multiple scattering, Bremsstrahlung, de/dx simulated by a MC

Collimator efficiency measurement at the end of the KLOE run (e+)





Collimators very efficient

Collimator need to be VERY clean in order to be efficient- very slow process;

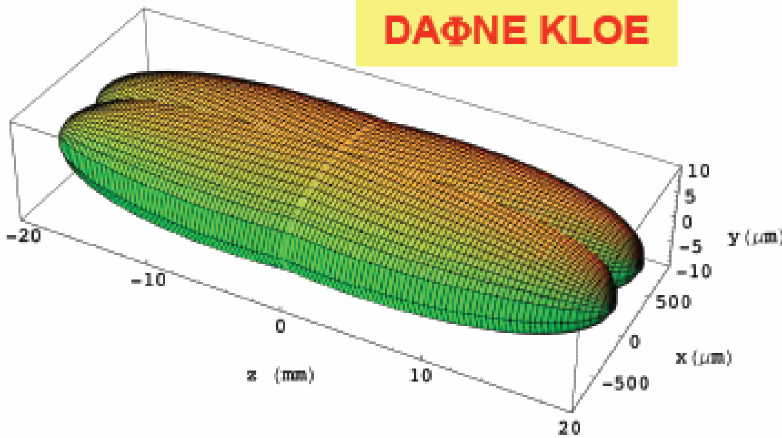
Copper tapering has been removed from borders of collimators

Touschek Backgrounds for the Crab waist scheme at DAFNE

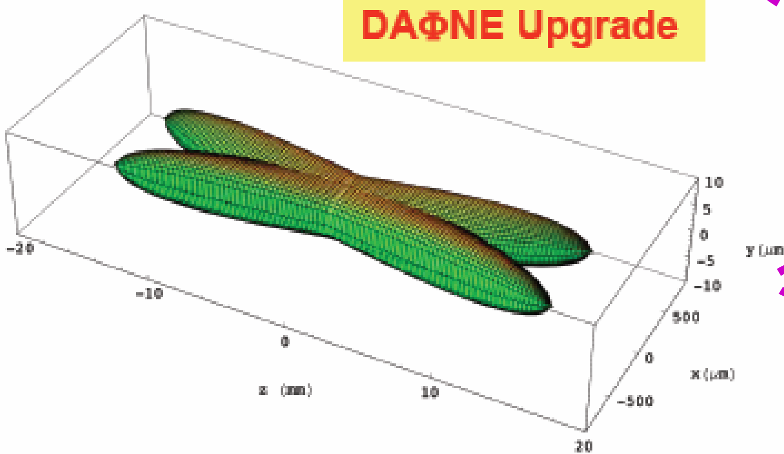
Energy deviat.	0.003 -0.02
σ_p/p	4 e-4
ε_x(m rad)	$0.2\cdot10^{-6}$
coupling	0.005
N_p	$2\cdot10^{10}$
I_{bunch}(mA)	10

BEAM DISTRIBUTION AT IP

DAΦNE KLOE



DAΦNE Upgrade



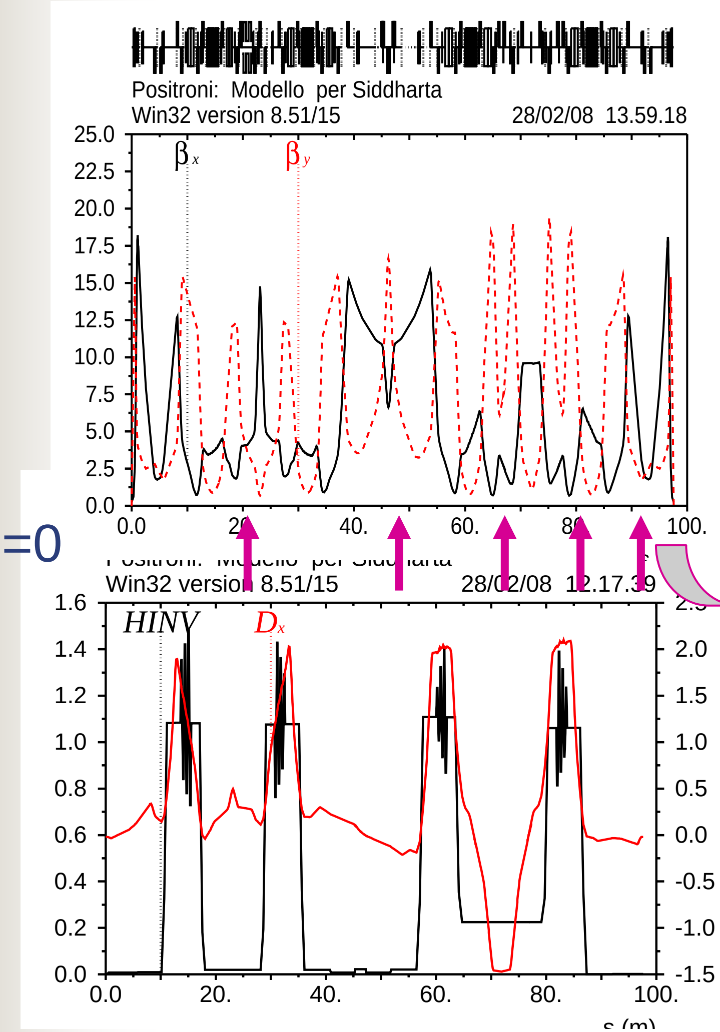
	DAΦNE KLOE	DAΦNE Upgrade
I_{bunch} (mA)	13	13
N_{bunch}	110	110
β_y^* (cm)	1.7	0.65
β_x^* (cm)	170	20
σ_y^* (μm)	7	2.6
σ_x^* (mm)	0.7	0.2
σ_z (mm)	25	20
$\theta_{cross}/2$ (mrad)	12.5	25
$\Phi_{Piwinski}$	0.45	2.5
ε_x(mm mrad)	0.34	0.26
$L(cm^{-2}s^{-1})\cdot10^{32}$	1.6	5

smaller transv. beam size and emittance

⇩

Touschek more important

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



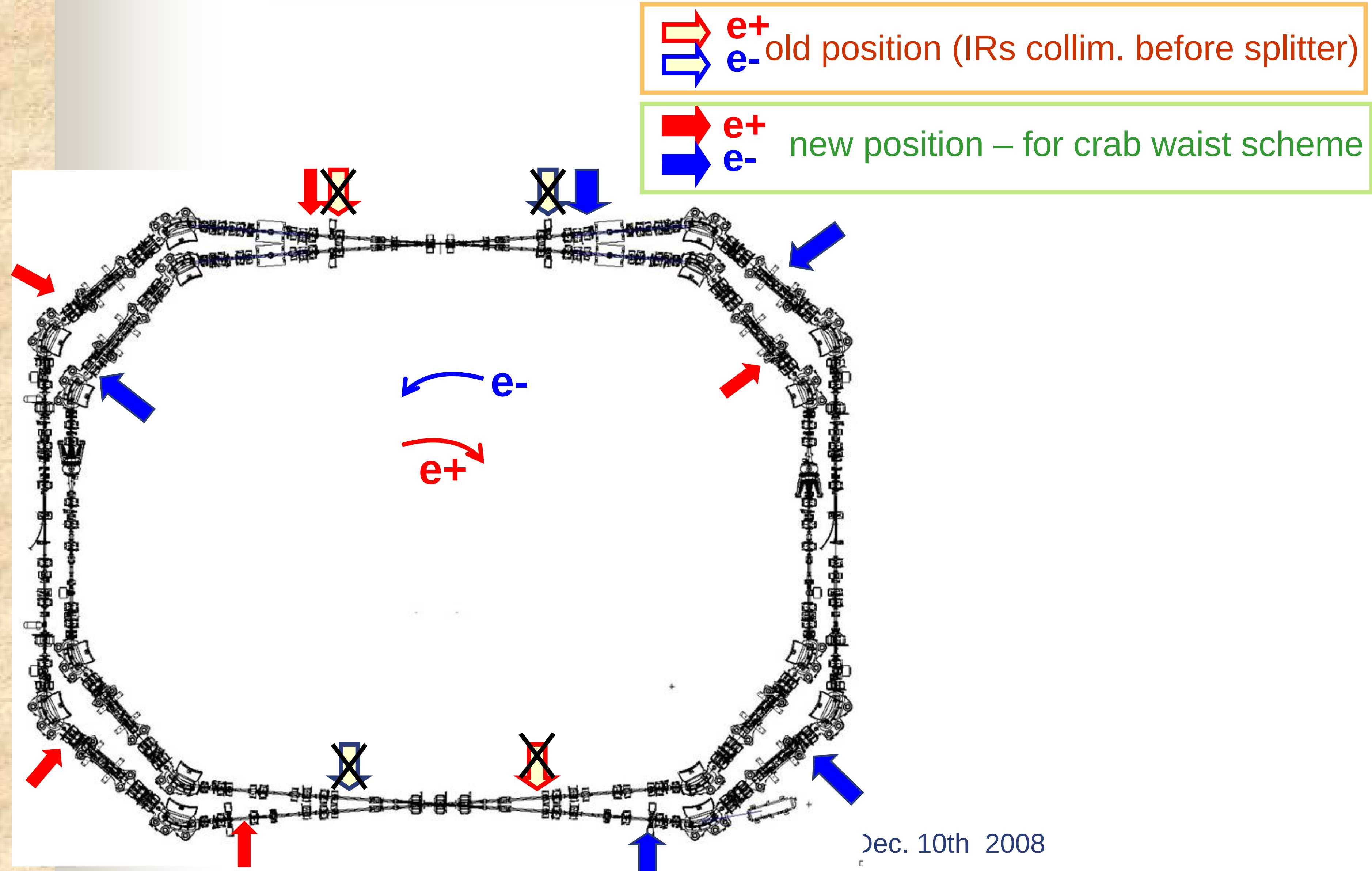
IP at s=0

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

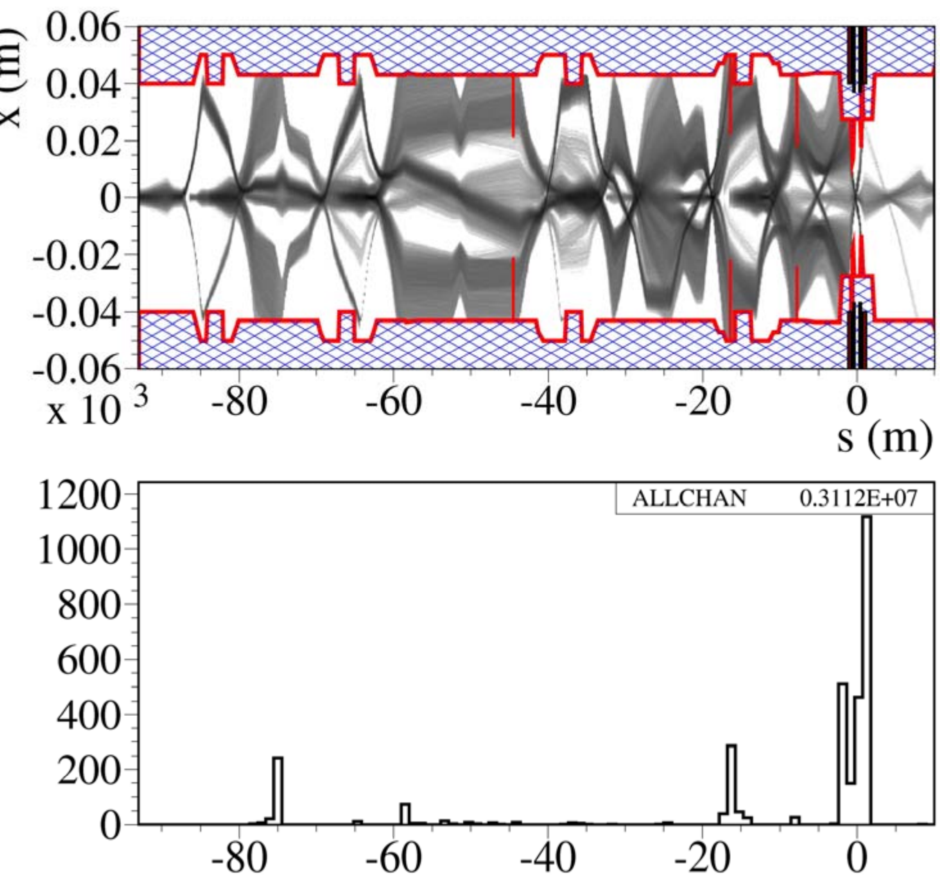
Position of collimators along rings

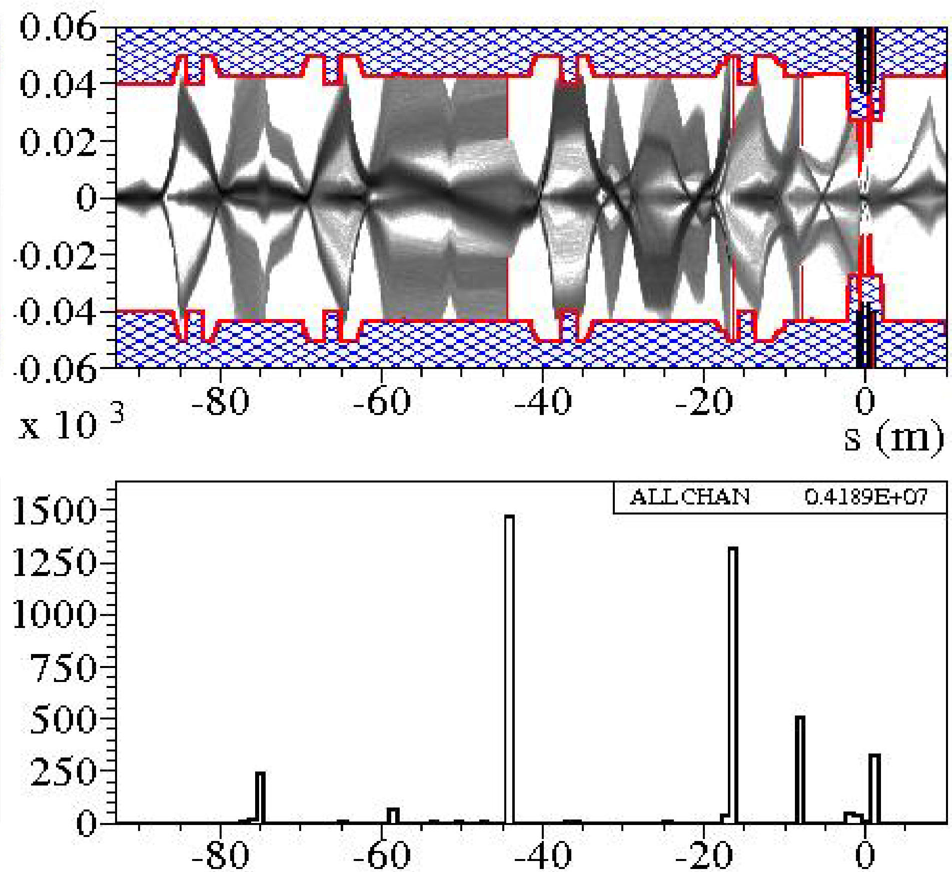


DAFNE crab waist optics linear optics model

no collimators
inserted in simulation

with collimators
inserted in simulation

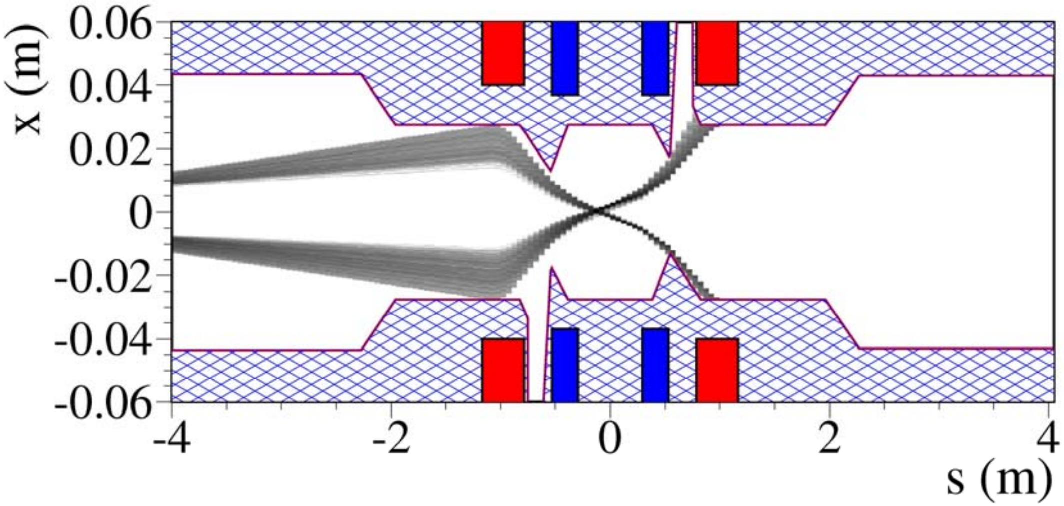




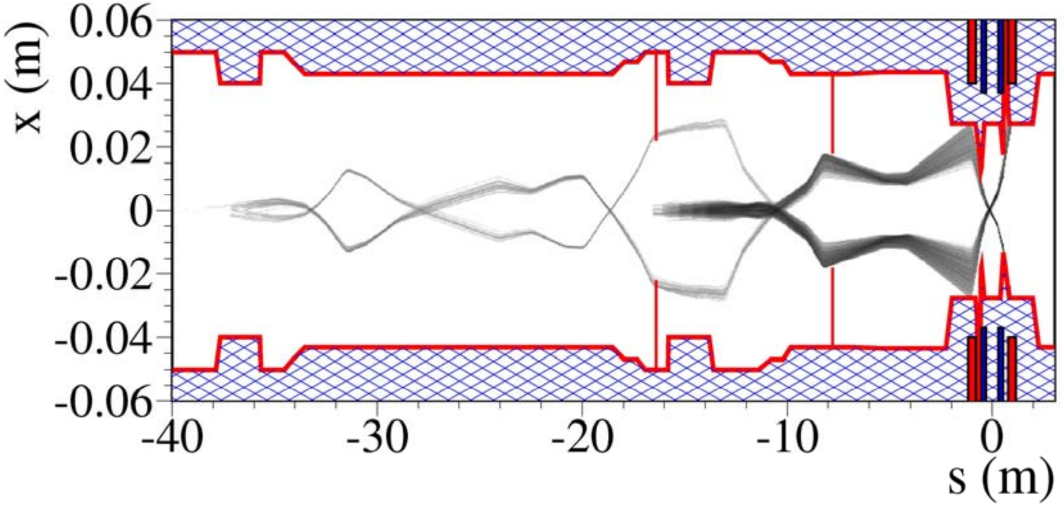
IR

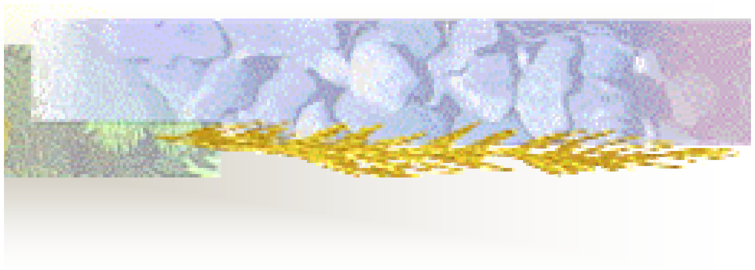
tracking used to find best position of collimators for the new optics

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

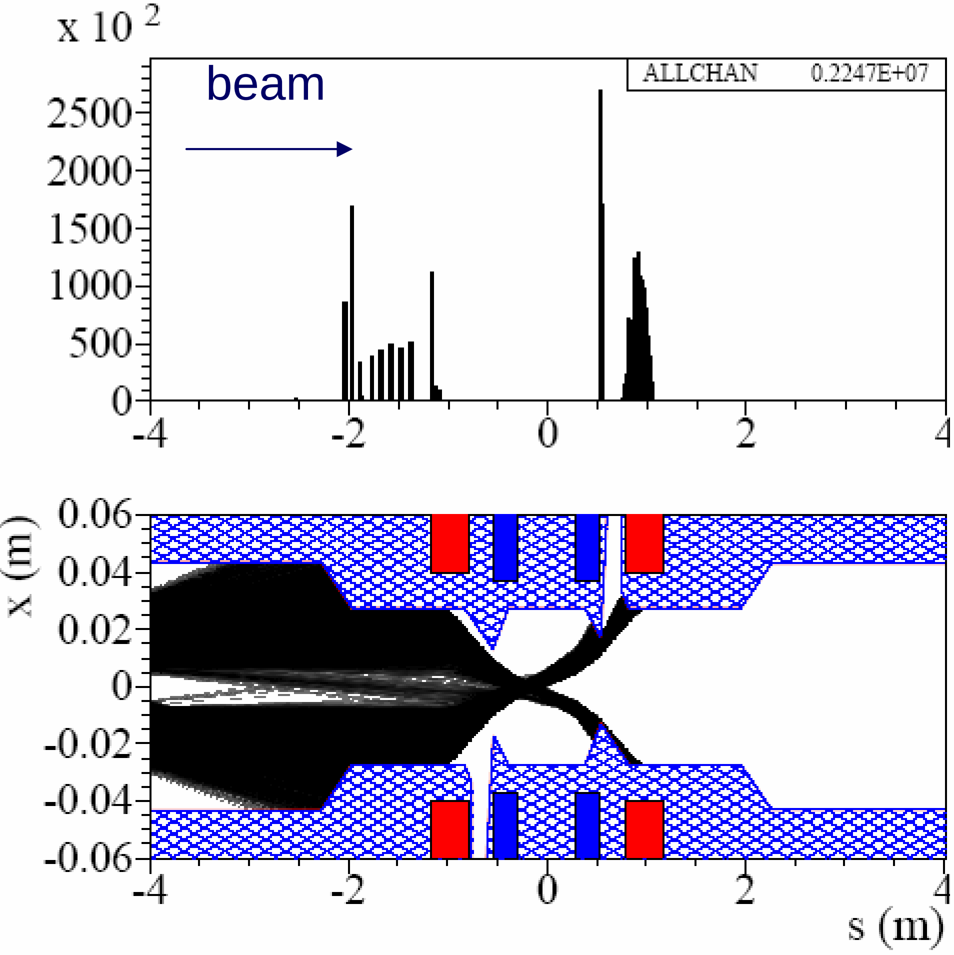




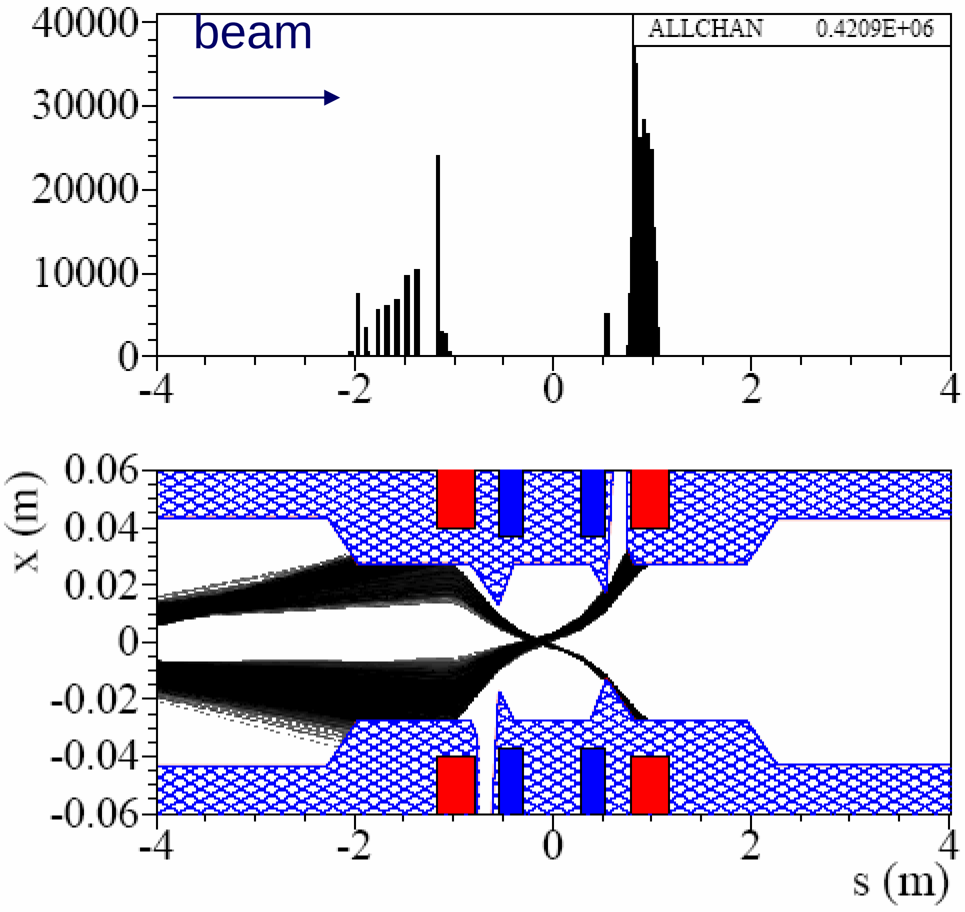
these particles, as well as upstream ones can produce high showers in the close-by calorimeter, lead shielding has been put to protect calorimeter and SIDDHARTA detector

zoom at IR losses

no collimators
inserted in simulation



with collimators
inserted in simulation



linear optics model

Simulation/measurements comparison with DAFNE crab configuration

Full simulation of Touschek particles into the calorimeter
in collaboration with the DAFNE luminometer working group

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

dedicated meas. foreseen

dedicated measurements for **collimators efficiency** and lifetime have not been repeated recently, however collimators now (conditioned during months running after the upgrade shut-down) reduce loss rates by about same order than for KLOE

lifetime is shorter than previous optics, as expected, due to smaller transv. beam sizes, however same L is reached with much lower currents

Conclusions

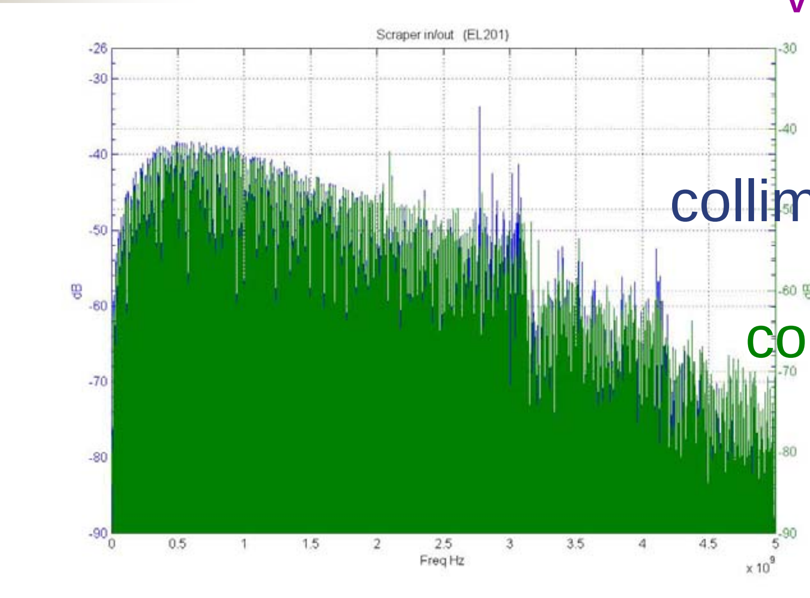
In DAFNE a lot of effort has been put in the Touschek backgrounds minimization, extremely high at the beginning of each run.

- **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

Back-up slides

BPM spectrum versus collimator position

BPM spectra are sensitive to wake field variation along the ring vacuum chamber



collimator jaws IN (blue)

collimator jaws OUT (green)

We see contribution of collimators to impedance, they induce some longitudinal instability at high currents when jaws inserted inside the pipe

modification of present collimators under study

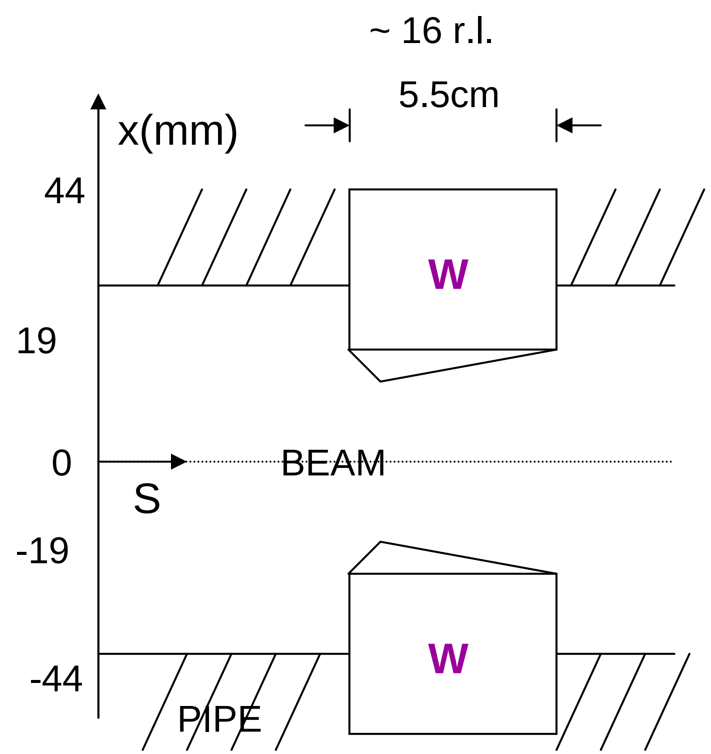
Collimators

The inner surface of the modified collimator blocks has been divided into two flat parts.

A first 1 cm long section has a slope of 100 mrad towards the beam, in order to **increase the impinging angle** into the block for most particles.
This is followed by a second section of 4.5 cm length with a slope of 10 mrad in the opposite direction to **avoid foreward scattering** of electrons back into the beam pipe.

The total scraper thickness of now 5.5 cm (about 16 r.l.) is reducing the punch through probability of 500 MeV electrons to below 10^{-6}.

In order to protect the detectors of the experiments from off-momentum particles remote controlled collimators have been installed for the incoming beams on either side of each experiment. They were placed before the splitter magnets, about 7.0m from the IP



Two horizontal jaws external and internal, are used to intercept the two off-energy particle families.

SuperB New Parameters

(Biagini)

nominal CDR lattice:

PARAMETER	Nominal LER (e+)	Nominal 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 ($\times 10^{-4}$)	7.9	5.6
Momentum compaction ($\times 10^{-4}$)	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 ($\times 10^{10}$)	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 ($\times 10^{11}$) (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)

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

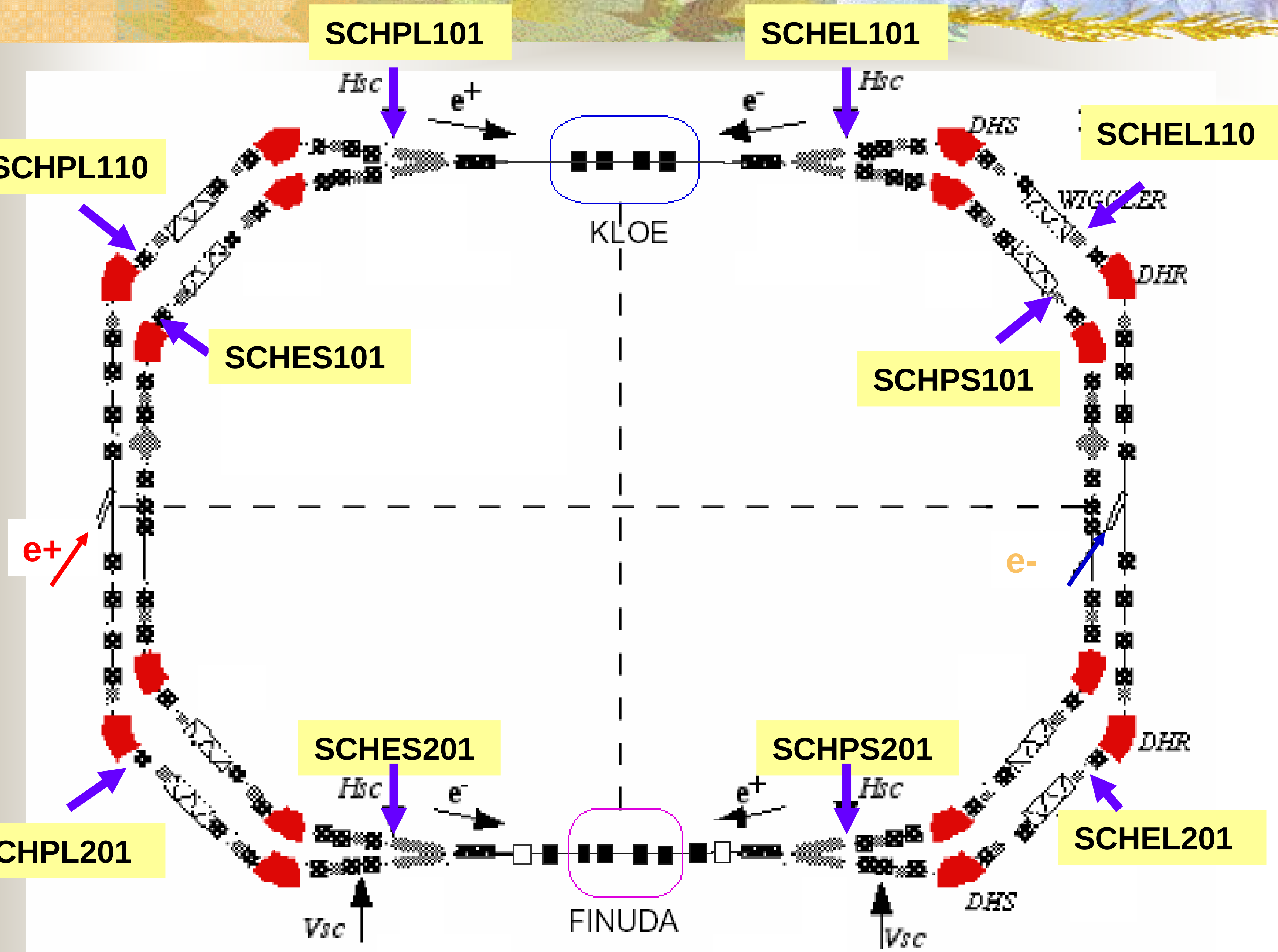
Touschek effect is determined by momentum acceptance and bunch density integrated over the lattice structure.

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

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

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

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


SCHPL101
SCHEL101
SCHPL110
SCHEL110
Hsc
e+
e-
DHS
WIGGLER
DHR
KLOE
SCHES101
SCHPS101
e+
e-
SCHES201
SCHPS201
SCHPL201
SCHEL201
Vsc
FINUDA

Touschek energy spectra

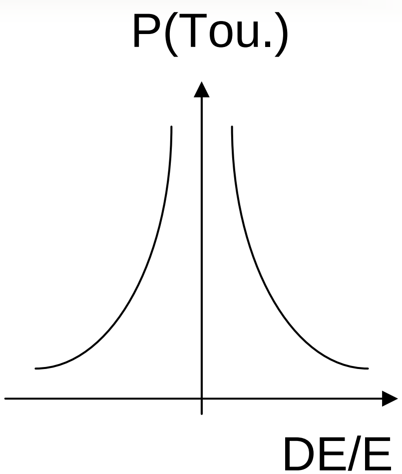
related mostly to beam parameters

(i.e. bunch volume, ε, σ_p, bunch current…)

With a given energy spectrum P(E)

(see next slide) one can:

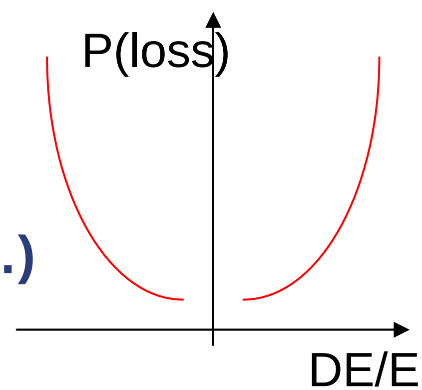
1. extract according to P(E) or
2. Use a uniform extraction and use P(E) as a weight



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