SuperB Touschek and beam-gas background

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Vienna, Austria
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Outline

- Introduction

- Touschek generator
- Collimation system (horizontal)
- Touschek simulation results for LER & HER

- Beam-gas generator
- Collimation system (vertical)
- Beam-gas simulation results for LER & HER

Introduction

- The main sources of loss rates are under control and secondaries tracked into sub-detectors and their effects evaluated

- In the next months we will freeze lattice design:

  if needed, we'll update backgrounds simulations,

  some minor changes are expected

- **Present Status on Touschek and beam-gas lifetime & loss rates estimates for**

  V12 lattice with *realistic* IR layout from M. Sullivan

  (optics with the whole ring rematched, PAC11)

Approximations in single beam background simulation

- Approximations in calculating a particular background process are unavoidable

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.

Simulation tool used for Superb tested at DAFNE: Touschek lifetime measurements vs MC

[M. Boscolo, P. Raimondi, e. Paoloni and A. Perez, IPAC11]

Please refer to paper for more details

- a **good agreement** between measured and calculated lifetime **with scrapers** inserted
- the comparison **without scrapers** shows a **disagreement of within a factor 2**,

which might be explained by a misalignment of the on-energy beam orbit that induced beam scraping in the IP2 section, as found after these measurements.

We remark that in the simulation the beam is assumed perfectly aligned and centered along the beam vacuum pipe.

In addition, dynamic aperture was not optimized in the machine as well as in the MAD lattice used for calculation.

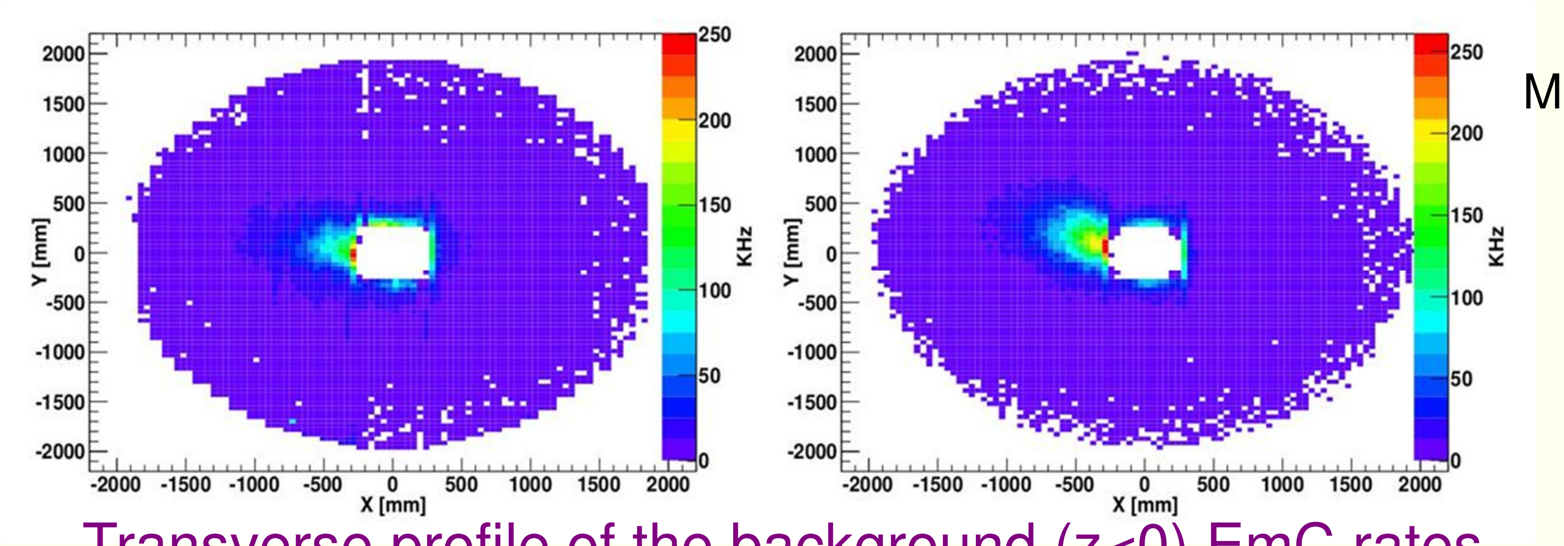
Simulation tool used for Superb tested at DAFNE: Touschek bkg measurements vs MC

- The **data/MC background rates are in agreement within a factor of two** in the different regions of the KLOE EmC

EmC Region	Data rates (MHz)	MC rates (MHz)	Data/MC (MHz)
Barrel	24.7	33.3	0.74
Forward	3.0	1.6	1.87
Backward	37.4	78.0	0.48

- The main features of the **shapes** are well **reproduced**

data



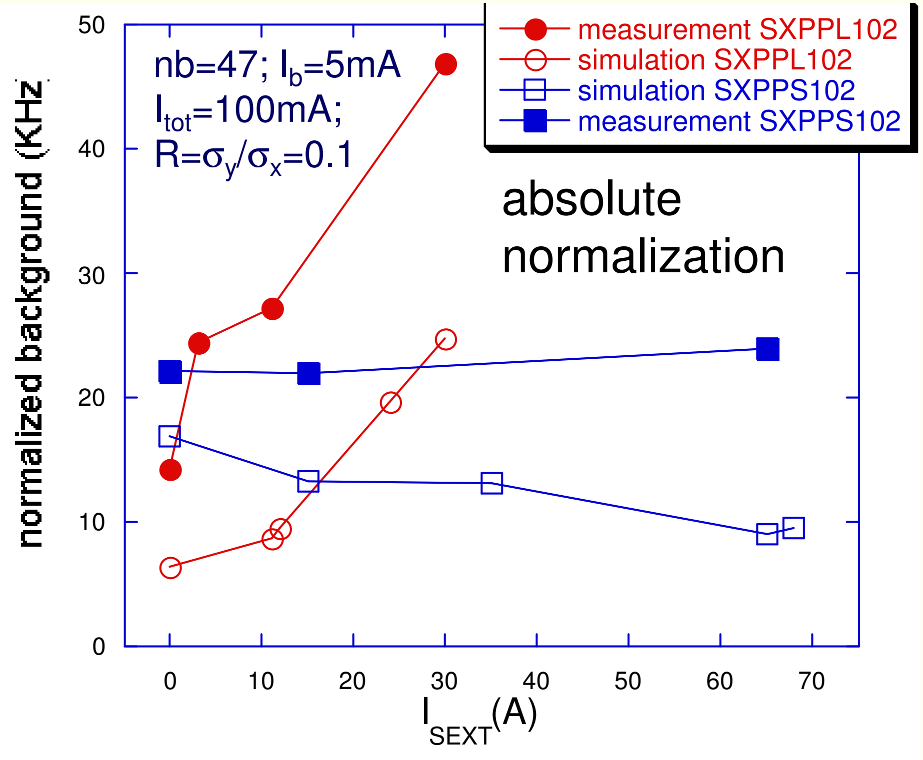
Monte Carlc

Transverse profile of the background (z<0) EmC rates

DAFNE experience (first KLOE run): Effects of non linearities on Touschek particle losses

sextupoles and octupoles relevant to account for the correct DA

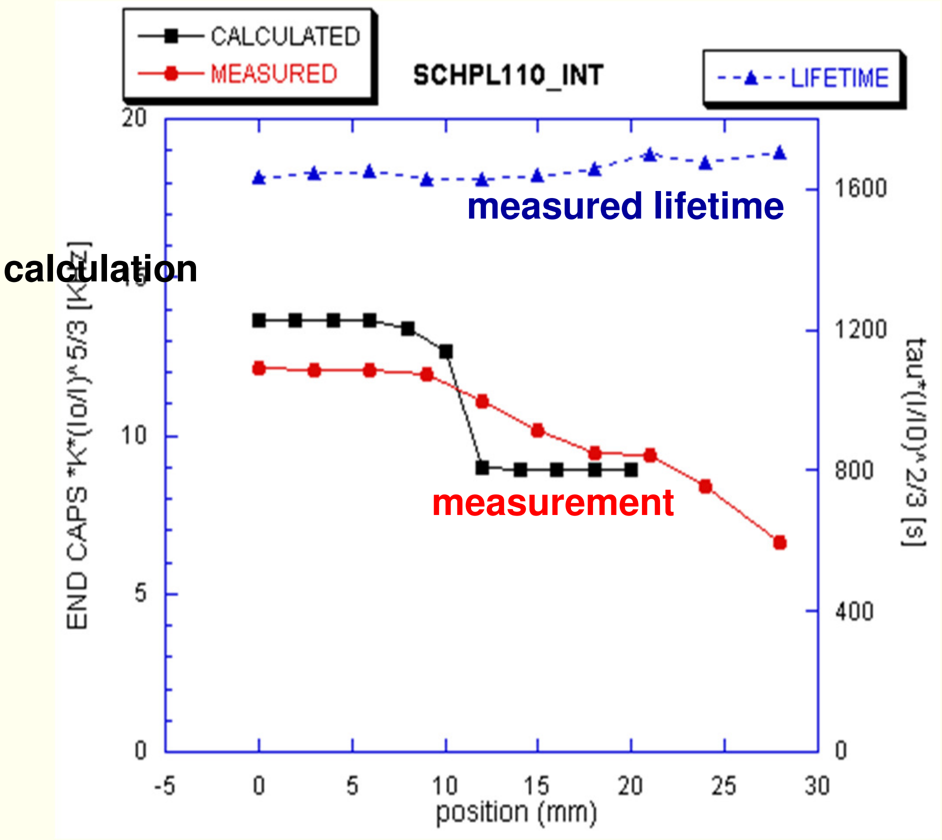
Comparison between expected and measured bkg rates at the KLOE ECM vs sextupoles strengths



The MC reproduces actual behaviour of Touschek background vs sextupoles strengths

DAFNE experience (first KLOE run): Comparison between measured and calculated effectiveness of collimators

The MC reproduces behaviour of background vs collimator position



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.

Touschek energy spectra

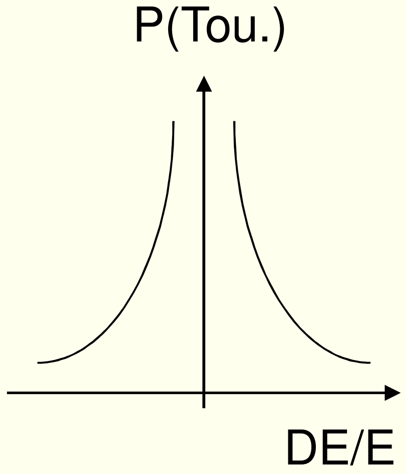
related mostly to beam parameters

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

With a given energy spectrum P(E)

we use a uniform extraction in energy
and use P(E) as a weight

(other possibility is to extract according to P(E))



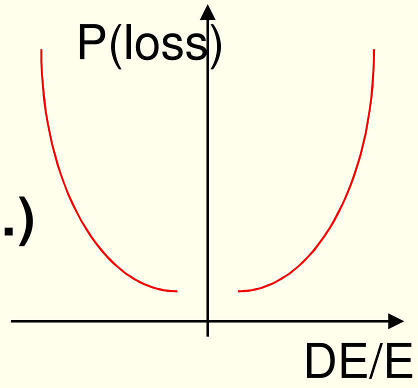
Particle losses related mostly to

machine parameters/optics

(i.e. physical aperture, phase advance, dispersion, …)

We cope with tails of both distributions

(non trivial statistical errors with large weights)



Program Flow Touschek simulation

Optics check

(read MAD output)

(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

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

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

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

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

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

C(umin) accounts for Moller x-section

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 e values according to the Touschek scaling law: $A_1 \cdot \varepsilon^{-A_2}$

Collimators Modeling

- Perfectly absorbing collimators
- No width

↓ collimators assumed perfectly absorbing and infinitely thin

actual behaviour is reproduced but

Edge effect is missing

This is a first order approximation,
good for Superb, as closest collimator upstream IP is at -20 m.

For DAFNE, short machine, approximation works less well,
closest collimator upstream IP is at about -8 m .
Refinement to perfectly absorbing model was needed

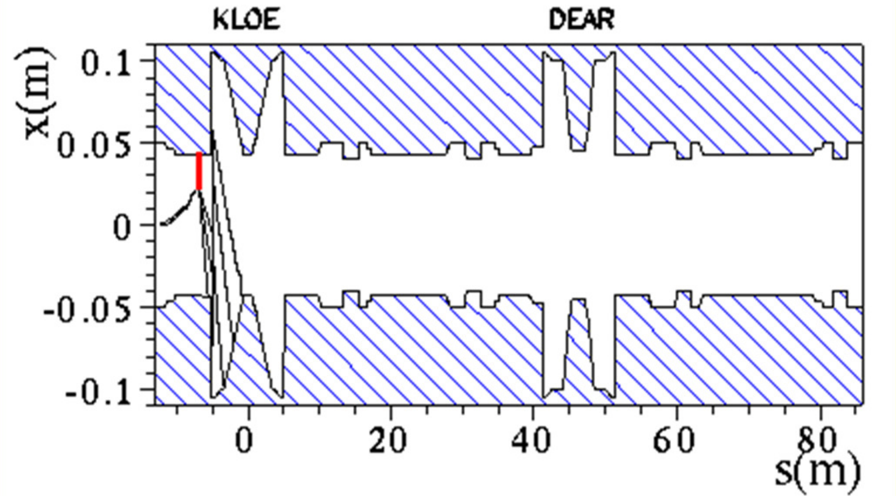
For DAFNE more realistic collimators modeled

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.

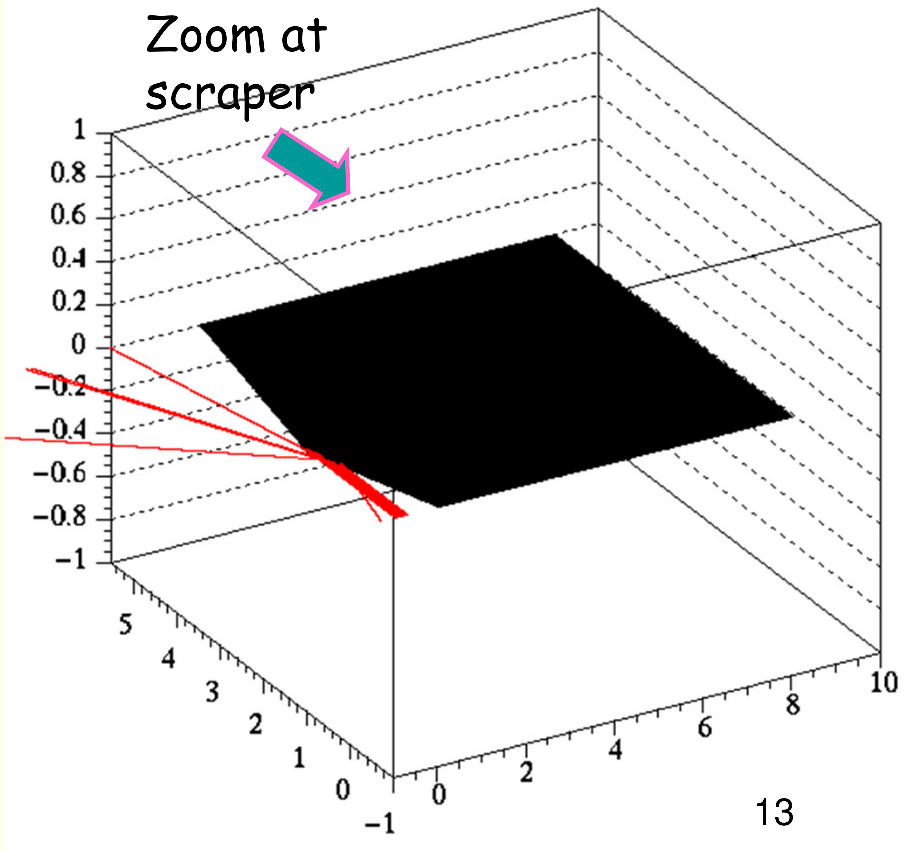
Electron interaction: Multiple scattering, Bremsstrahlung, de/dx simulated by a toy MC

real collimator shape included in simulation and edge effect has been simulated

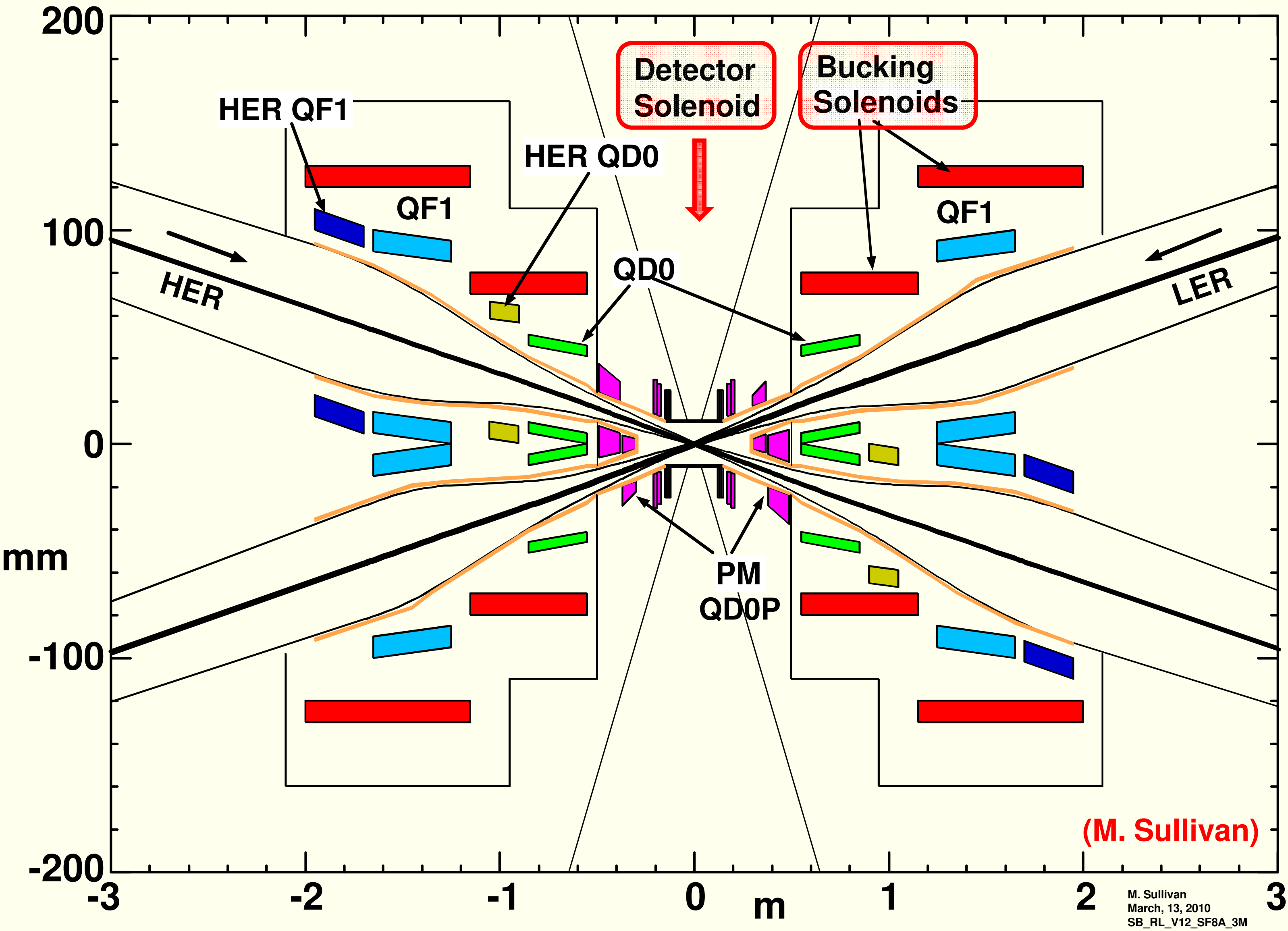
Electron interactions at collimator edge



Only additional background to KLOE IR from edge effect displayed


Zoom at scraper

IP region
Air core "Italian" QD0, QF1



About Touschek Simulation

- Calculated lifetime and rates are dependent on the:
    - *Lattice* energy acceptance
    - physical aperture -elliptical shape
    - Dynamical aperture accounted for with non-linear elements in tracking

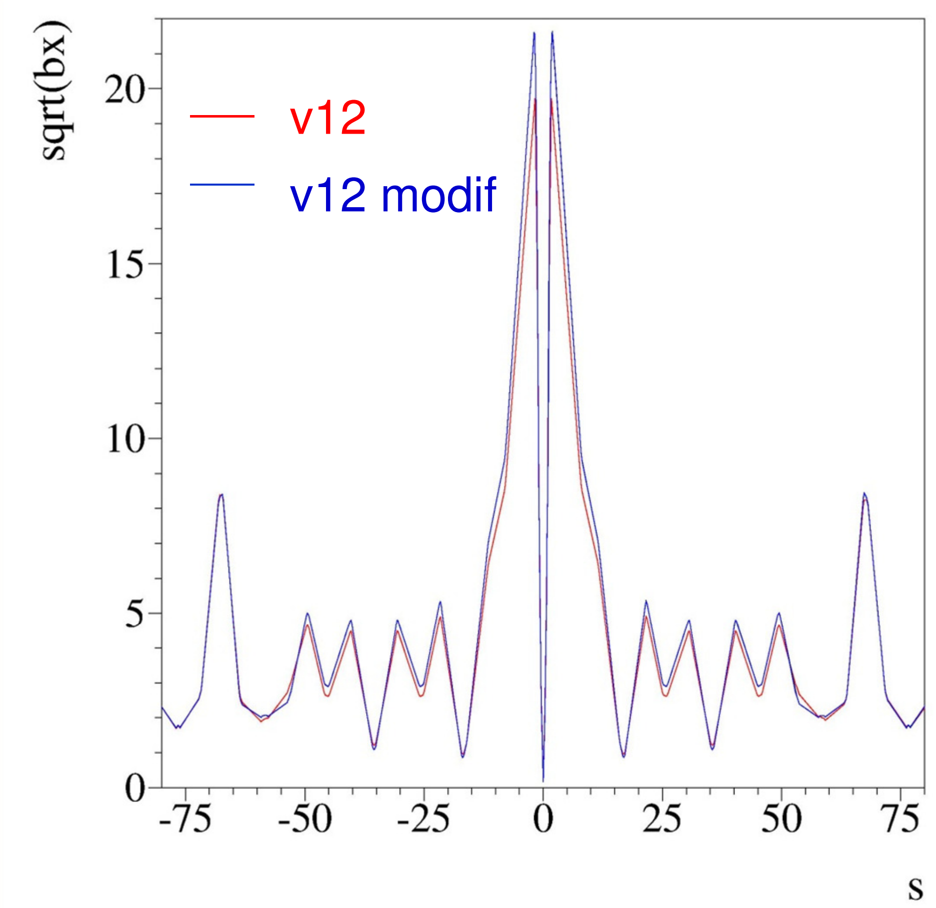
- stable results with few (~5) machine turns
- stable results with about 10^6 macroparticles
    - 500particles x 2 (DE/E>0, DE/E<0) every 3elements out of 2300 (≈0.8e6 tracked)

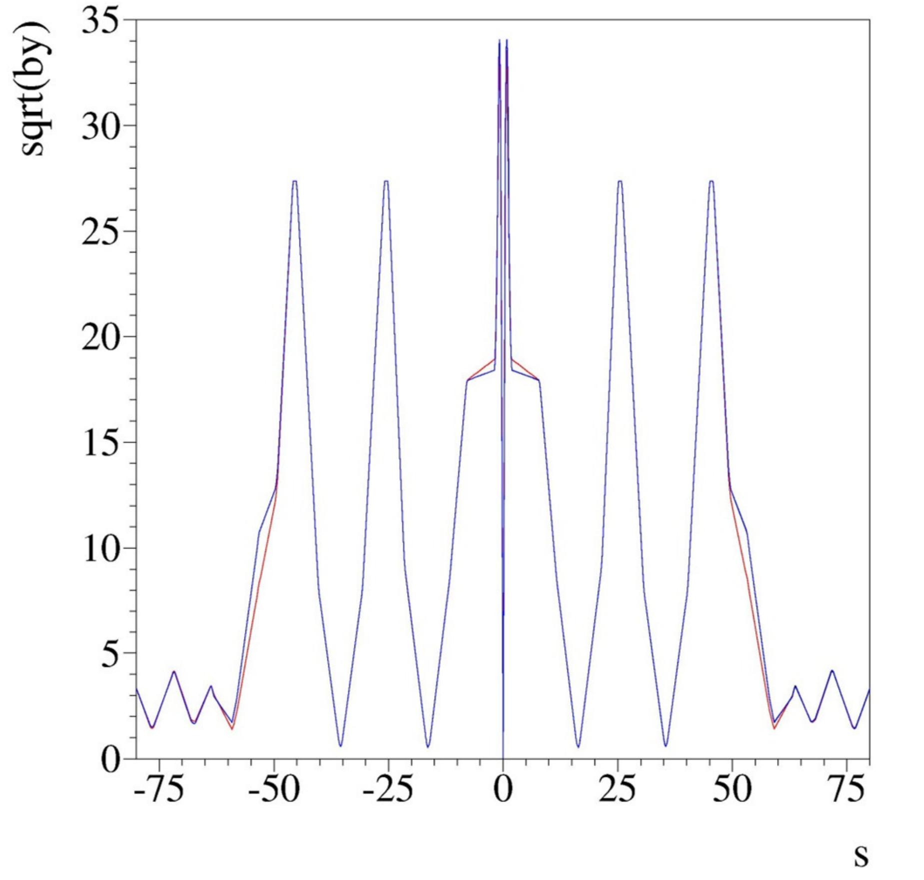
Parameters used in the IR designs

(Mike Sullivan, Dec. 11)

Parameter	HER	LER	
Energy (GeV)	6.70	4.18	
Current (A)	1.89	2.45	
Beta X* (mm)	26	32	(26)
Beta Y* (mm)	0.253	0.205	(0.274)
Emittance X (nm-rad)	2.00	2.46	
Emittance Y (pm-rad)	5.0	6.15	
Sigma X (μm)	7.21	8.87	
Sigma Y (nm)	36	36	
Crossing angle (mrad)	+/- 30		

HER Optics: zoom of Final Focus

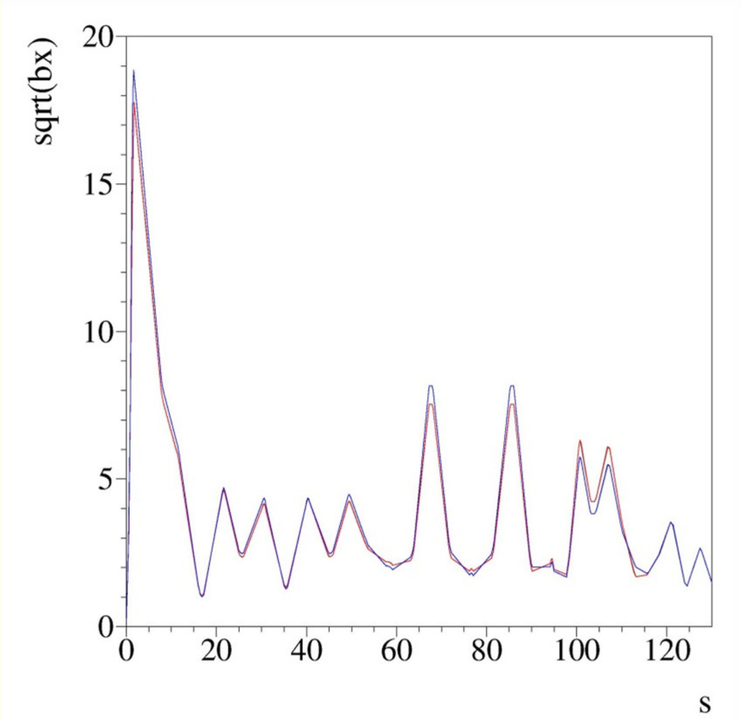


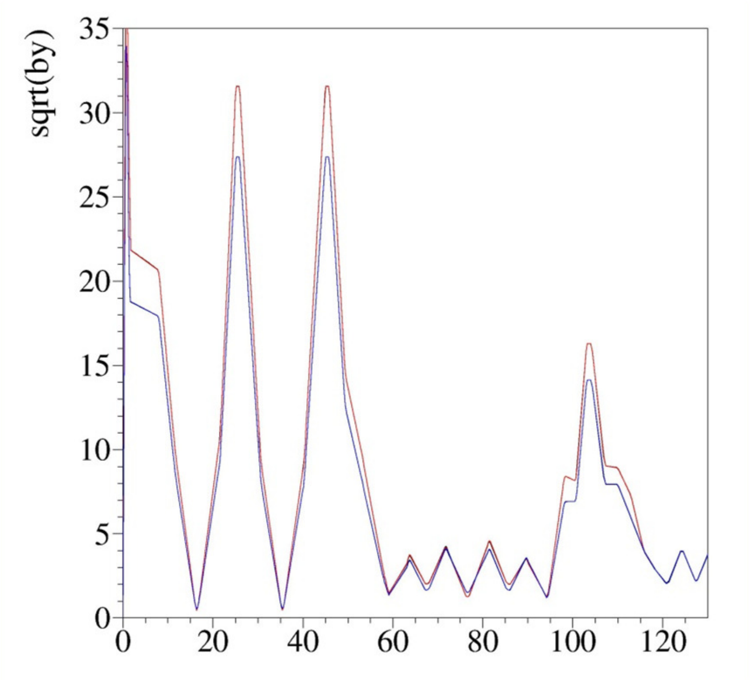


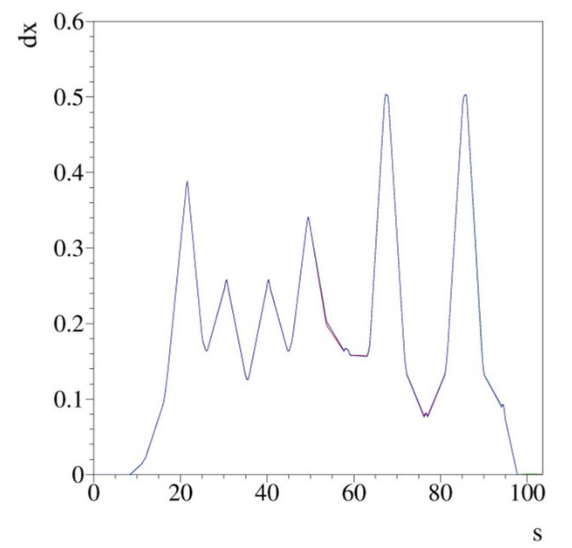
beta_x* = 2.6cm
beta_y* = 0.27mm

beta_x* = 2.6cm
beta_y* = 0.27mm

LER Optics: Final Focus





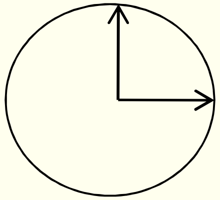


v12 — beta_x* = 3.2cm
beta_y* = 0.206mm
Nominal values

v12 modif — beta_x* = 2.6cm
beta_y* = 0.274mm

Physical aperture

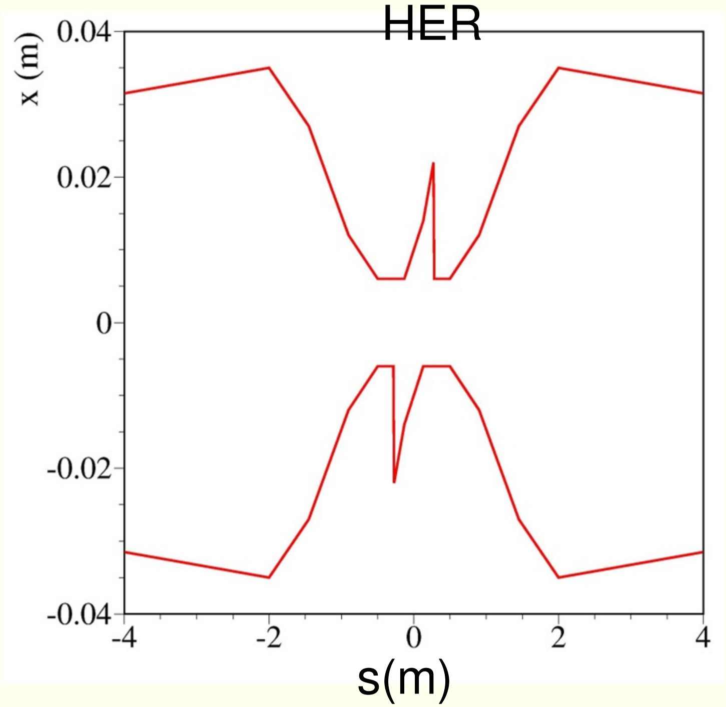
- circular pipe everywhere but at IR

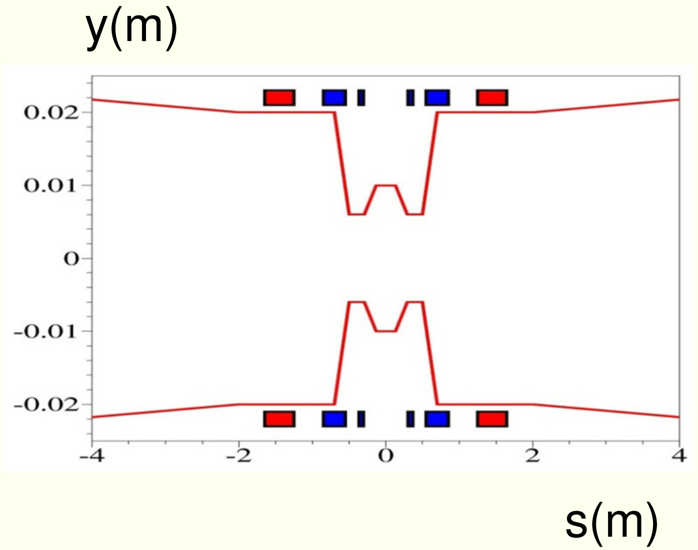


apy=2.5 cm

apx=2.5 cm

- At IR elliptical pipe:
- **horizontal** **vertical**

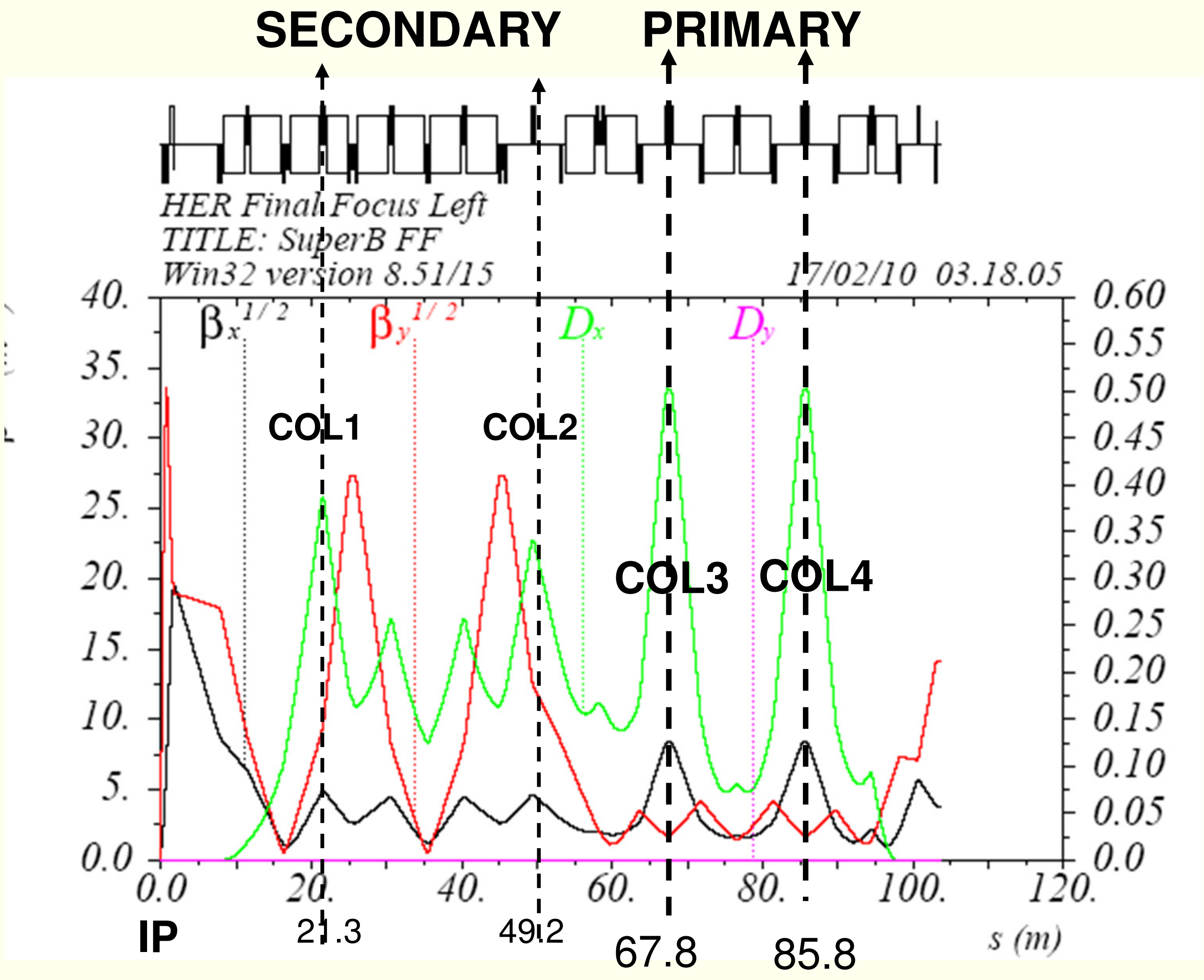




(From Mike)

HER / LER   Final Focus collimation system

Collimators are located where βx and Dx are large



Collimators – basic idea

- The technical design is not required at this stage of the project

  we will address this point in the near future

However, our plan is that they should:

Intercept the Touschek particles
in the final focus upstream the IR
that otherwise would be lost at the QF1

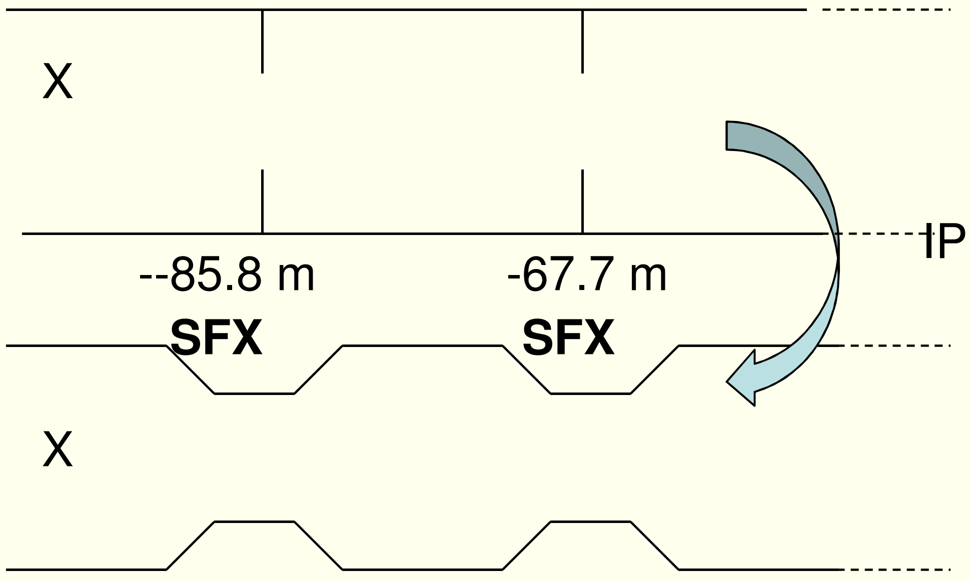
So, in principle, the good collimators set corresponds to the same Beam Stay Clear , in sigmax units, that we have in the IR

Collimator jaw insertion = 0.9* phys. aperture(QF1)$\cdot\sigma_{COL}/\sigma_{QF1}$

in the simulations an optimal position close to this value has been set

Collimators design

- The proposed **horizontal collimation system** results **very efficient** from simulations.
- Idea is **to model the beam pipe at the longitudinal positions of the primary horizontal collimators** (two hor. Sextupoles) with a horiz. physical aperture corresponding to the one needed for the jaws to efficiently intercept the scattered particles that would be lost at the QF1, **and add two movable jaws as a further knob to tune IR backgrounds.**



This design has been implemented in DAFNE recently for the two most effective scrapers

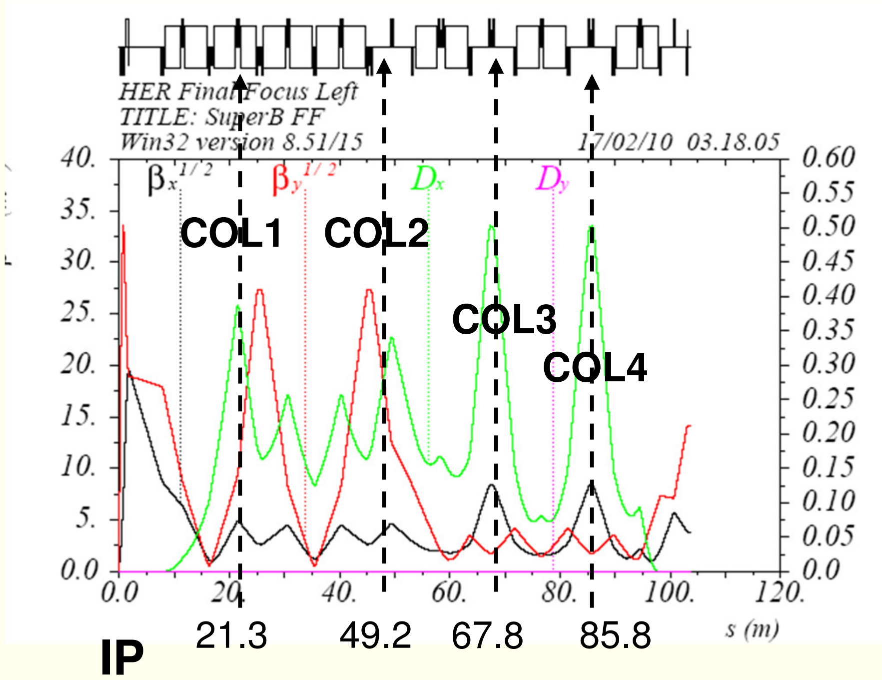
Touschek IR background rates

|s|< 2 m

HER (e+):

no collimators = 2.5 MHz × 978 bunches = 2.4 GHz/beam

with collimators = 6.95 kHz × 978 bunches = 6.8 MHz/beam



Collimator set: (mm)

	internal / external
Col1	-9 / +12
Col2	-9 / +25(out)
Col3	-18 / +12
Col4	-12 / +18

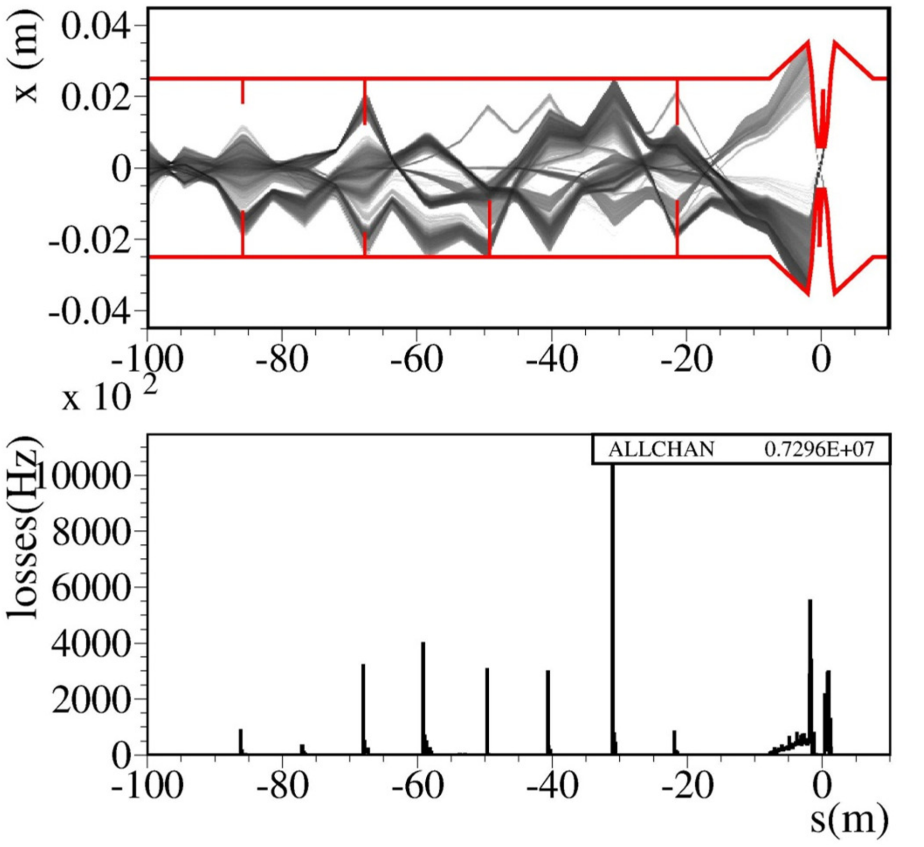
(pipe is -25 /+25 mm)

no collimators τ_{TOU} = 26 minutes

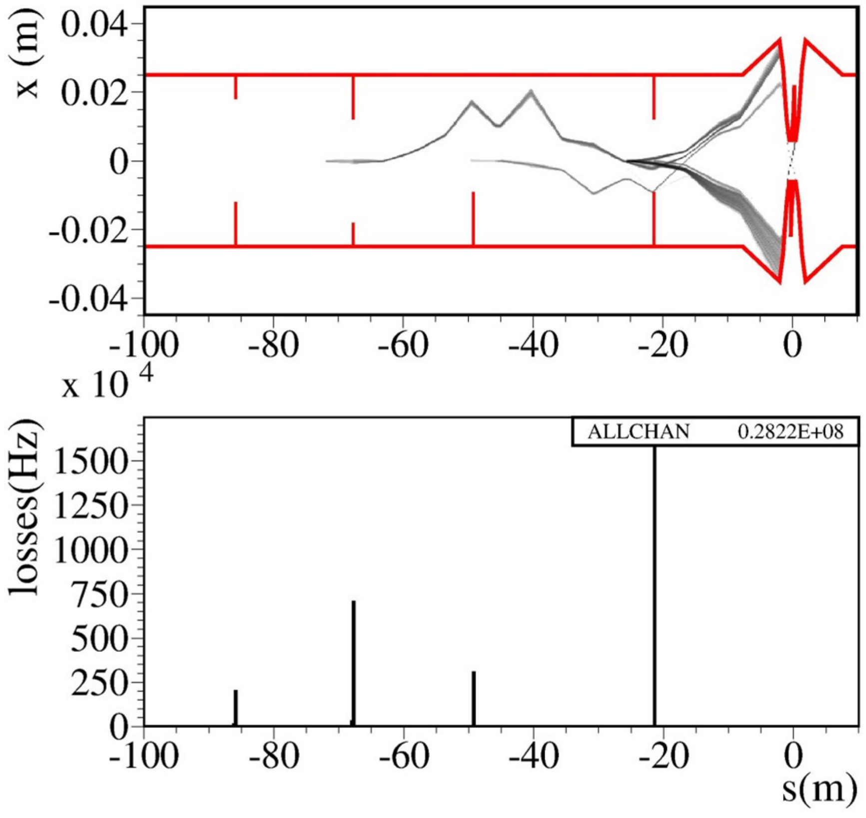
with collimators τ_{TOU} = 22 minutes

HER v12modif Touschek Trajectories

No collimators



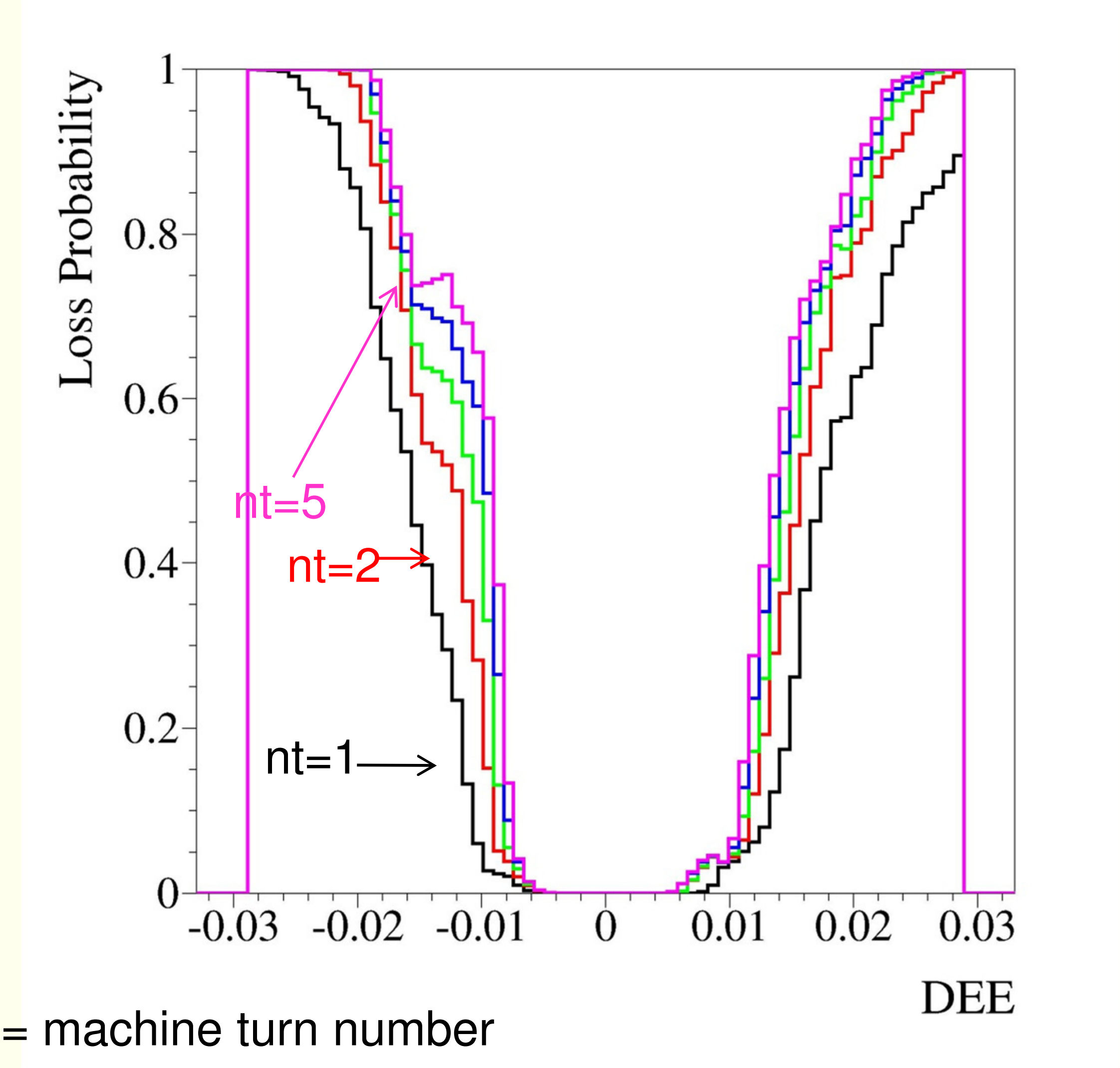
with collimators



found by minimizing IR rates and maximizing lifetime

real set will be found experimentally

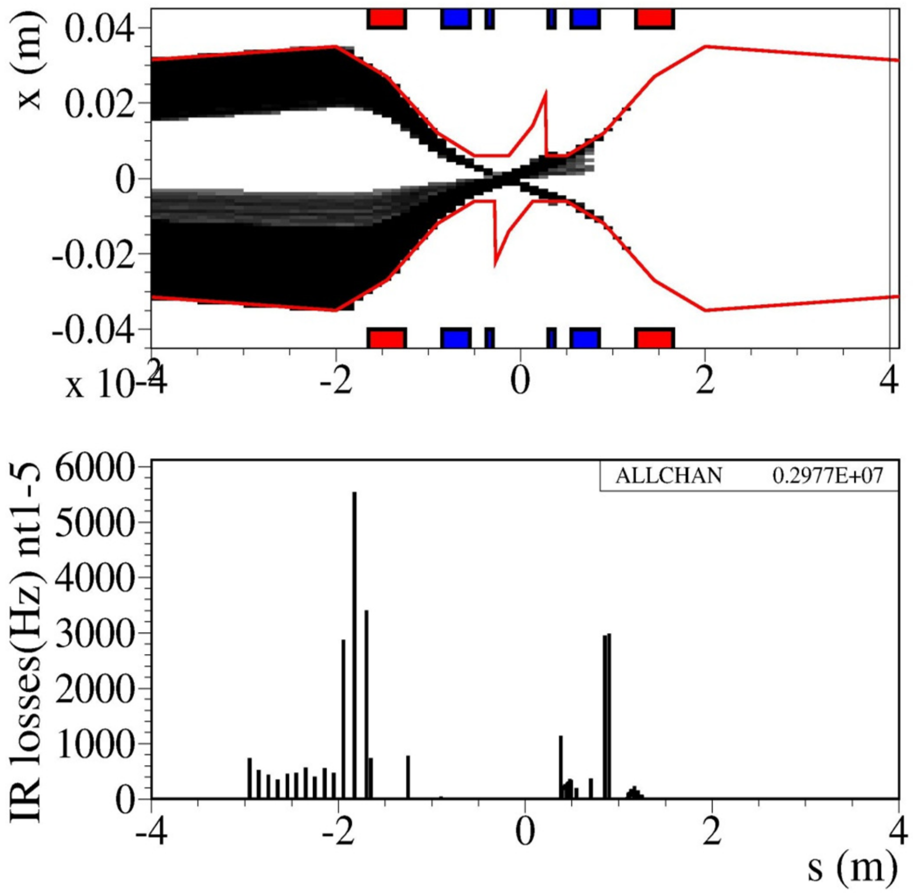
Loss probability of HER Touschek particles as a function on ΔE/E



nt= machine turn number

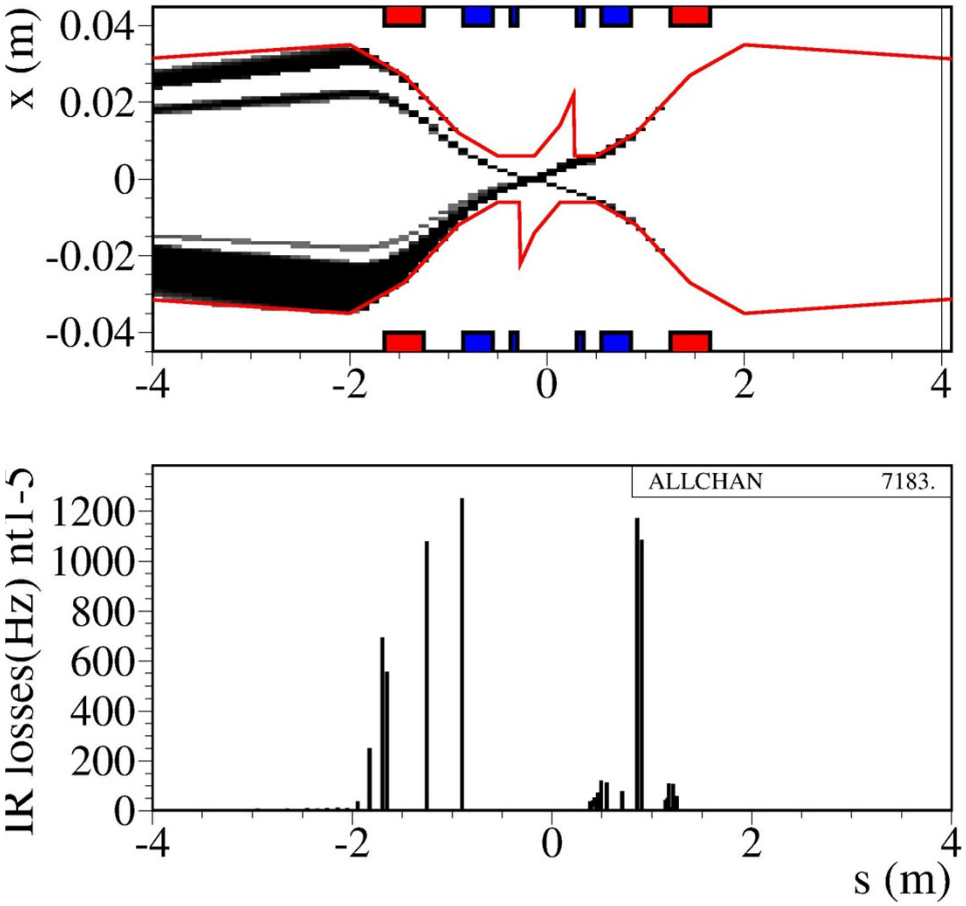
HER IR losses (|s|< 2 m)

NO collimators



IP

with collimators



IP

Collimators greatly reduce loss rates

IR rates for the LER

I_b =2.5 mA

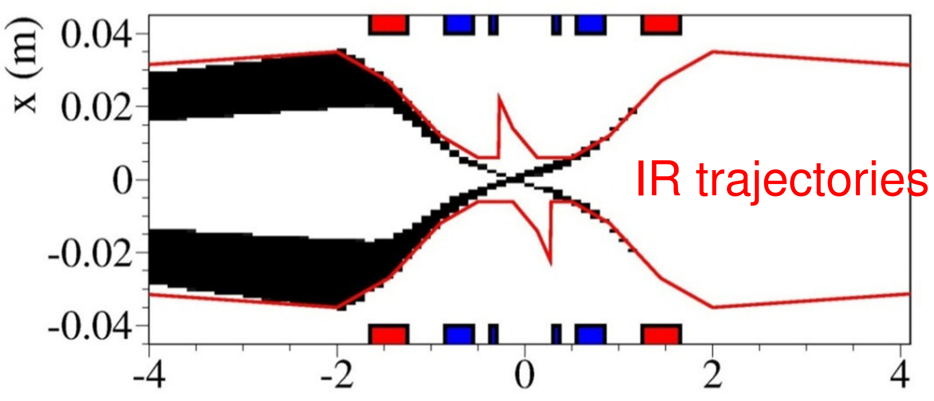
ε_x =2.4 nm

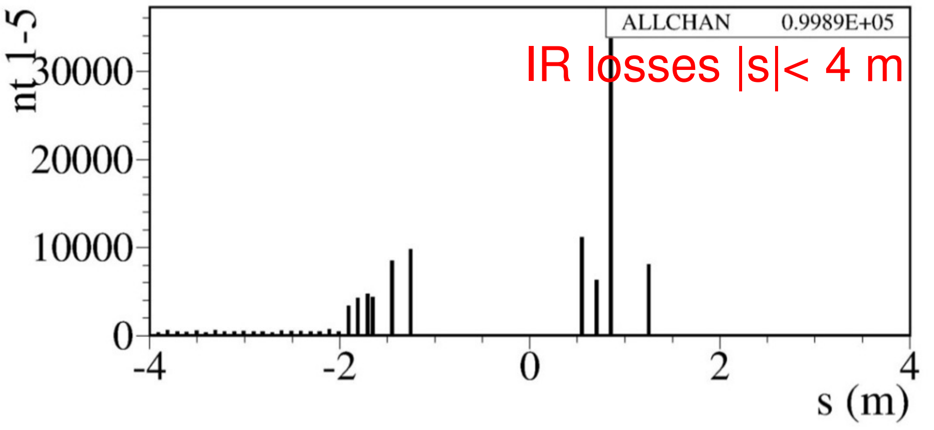
no collimators = 17.2 MHz × 978 bunches = 16.8 GHz/beam

with collimators = 93 kHz × 978 bunches = 90 MHz/beam

no collimators τ_{TOU} = 610 s (10.1 minutes)

with collimators τ_{TOU} = 470 s (7.9 minutes)

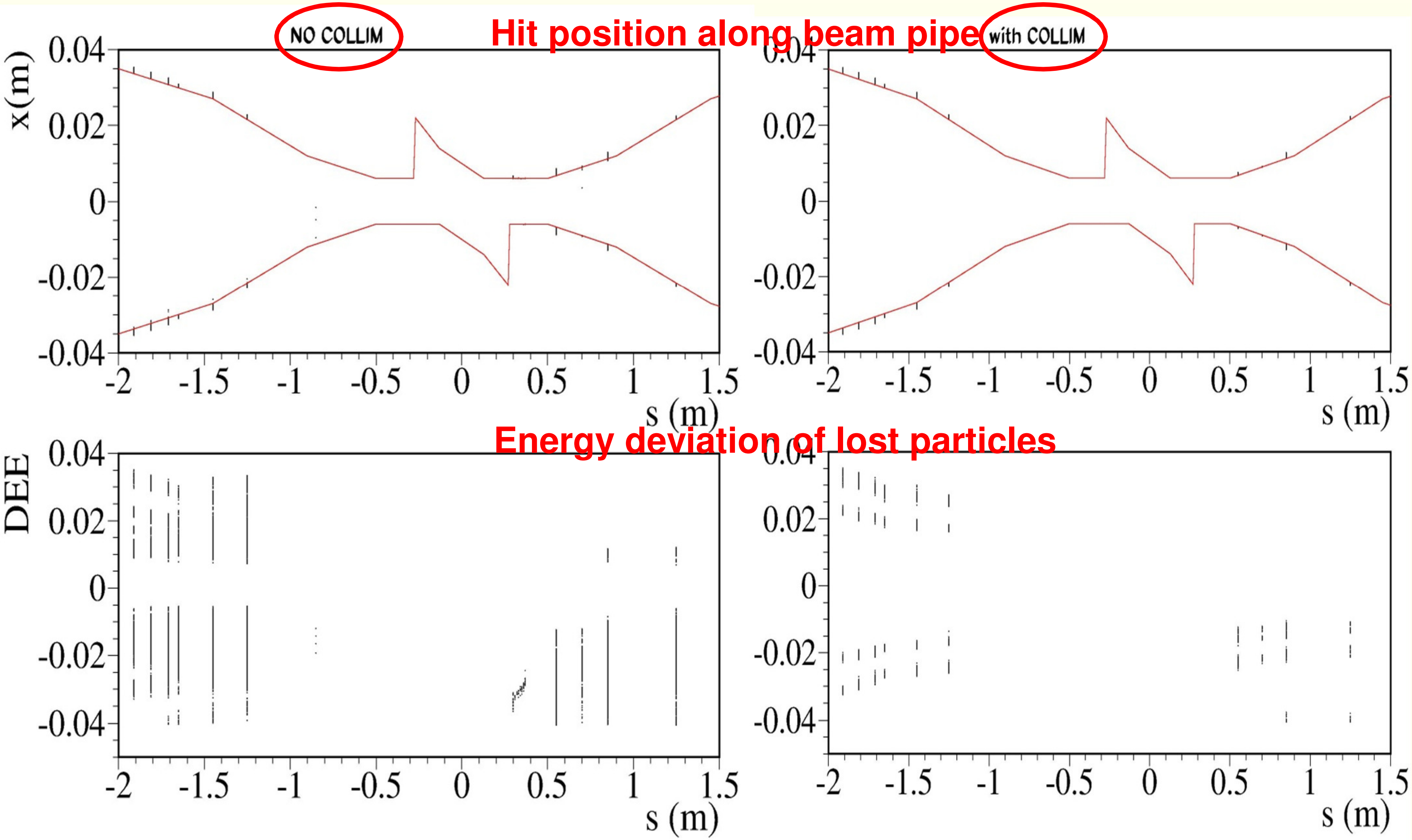




Collimator set: (mm)	internal	/	external
Col1	-10	/	+14
Col2	-10	/	+18
Col3	(out)-25	/	+12
Col4	-12	/	+16

careful study of secondaries into sub-detectors indicated these rates were a bit too high

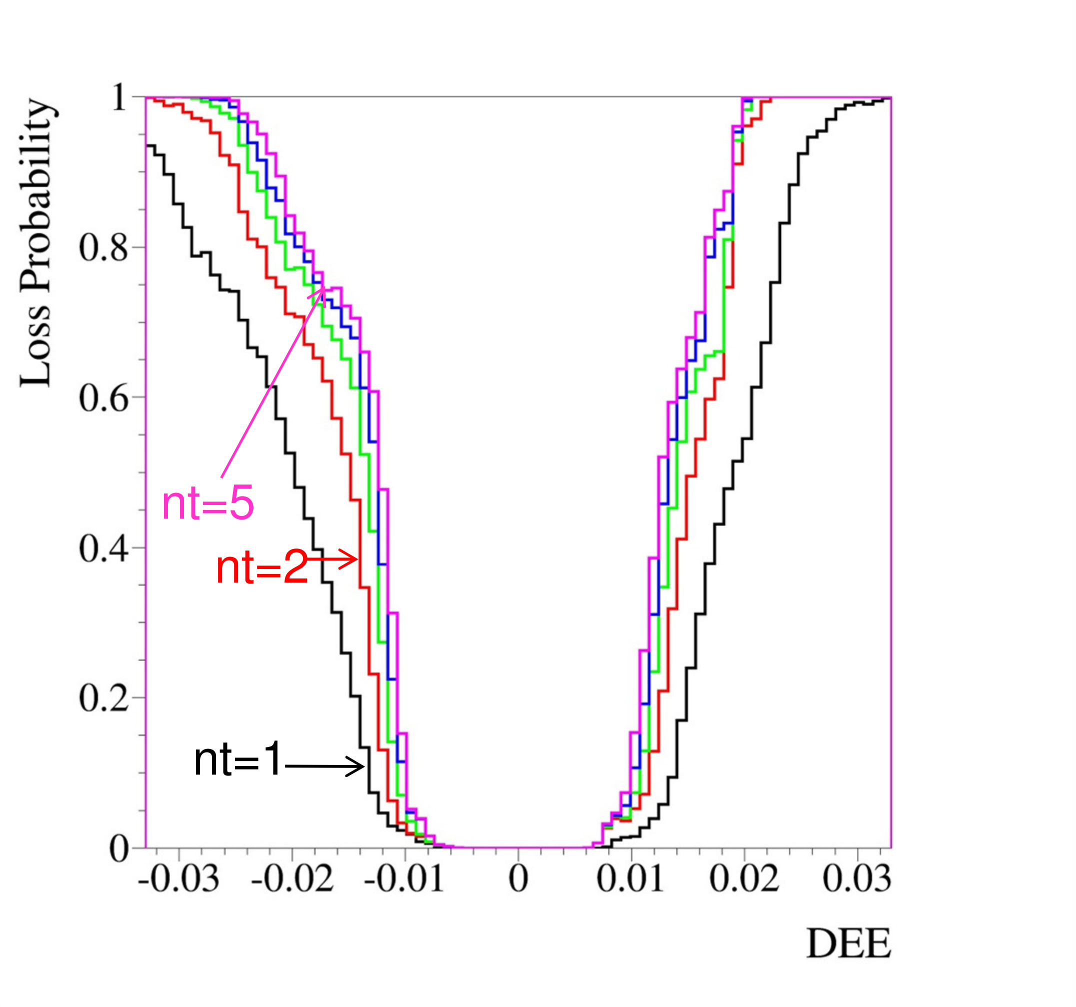
IR lost particles of the LER



Hit position along beam pipe

Energy deviation of lost particles

Loss probability of **LER** Touschek particles as a function on ΔE/E



nt= machine turn number

LER Touschek IR background rates

I_b =2.5 mA

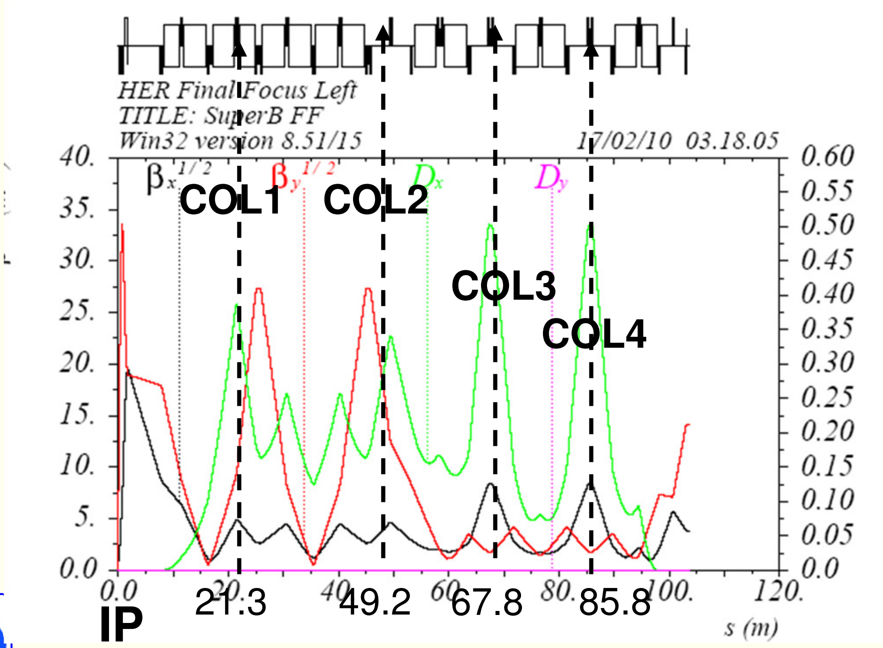
|s|< 2 m

With IBS: ε_x =2.4 nm

Collimators inserted further
With a 1.3 IR rates reduction

with collimators = 73.3 kHz/bunch × 978 bunches =72 MHz/bea

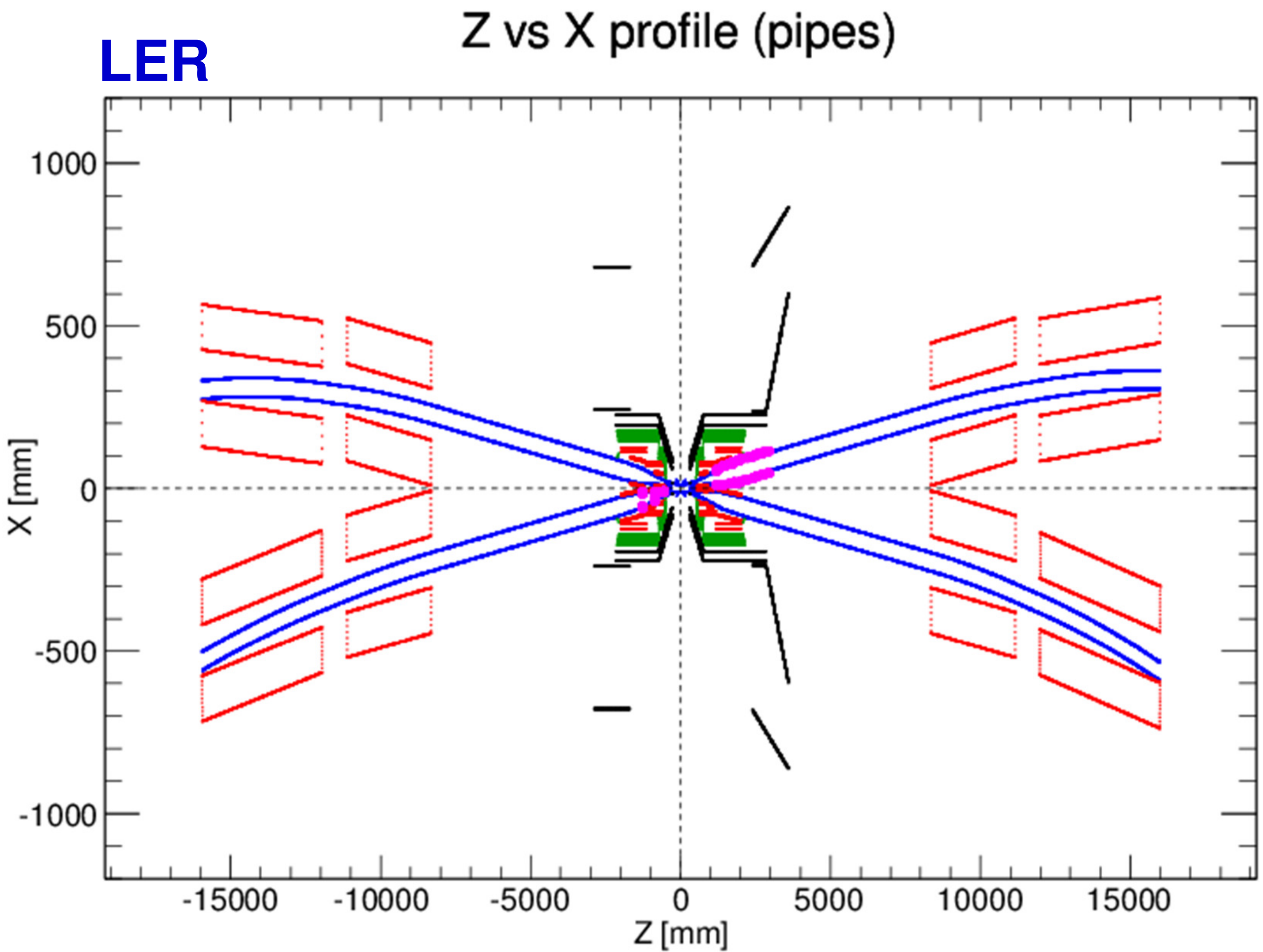
with collimators τ_{TOU} = 420 s (7 minutes)



Collimator set: (mm)

	internal / external
Col1	-9 / +12
Col2	-10 / +18
Col3	(out)-25 / +12
Col4	-12 / +16

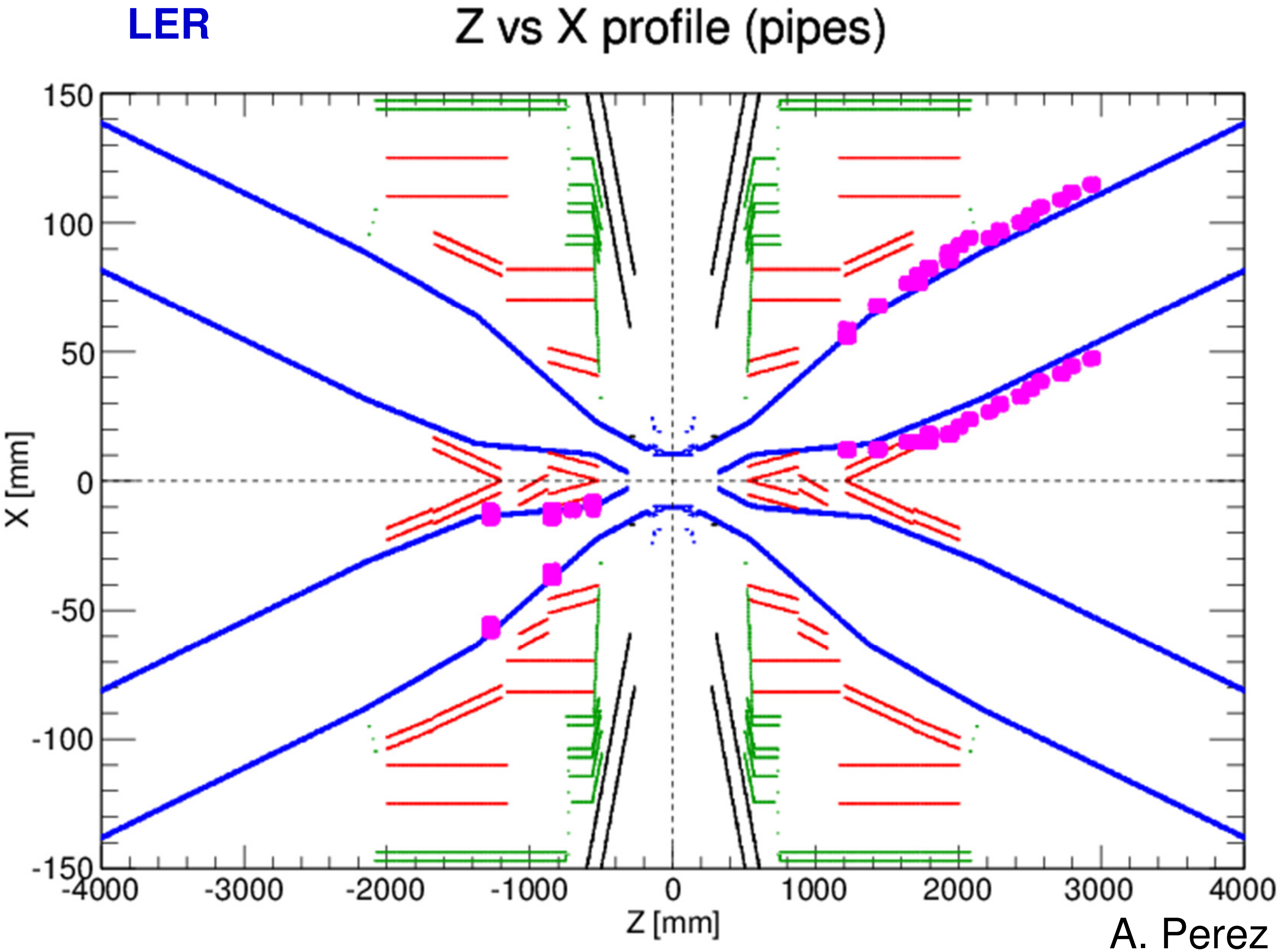
Touschek particles hitting the pipe: full geometry before tracking



A. Perez

Touschek particles hitting the pipe: full geometry before tracking

Zoom within 4 m

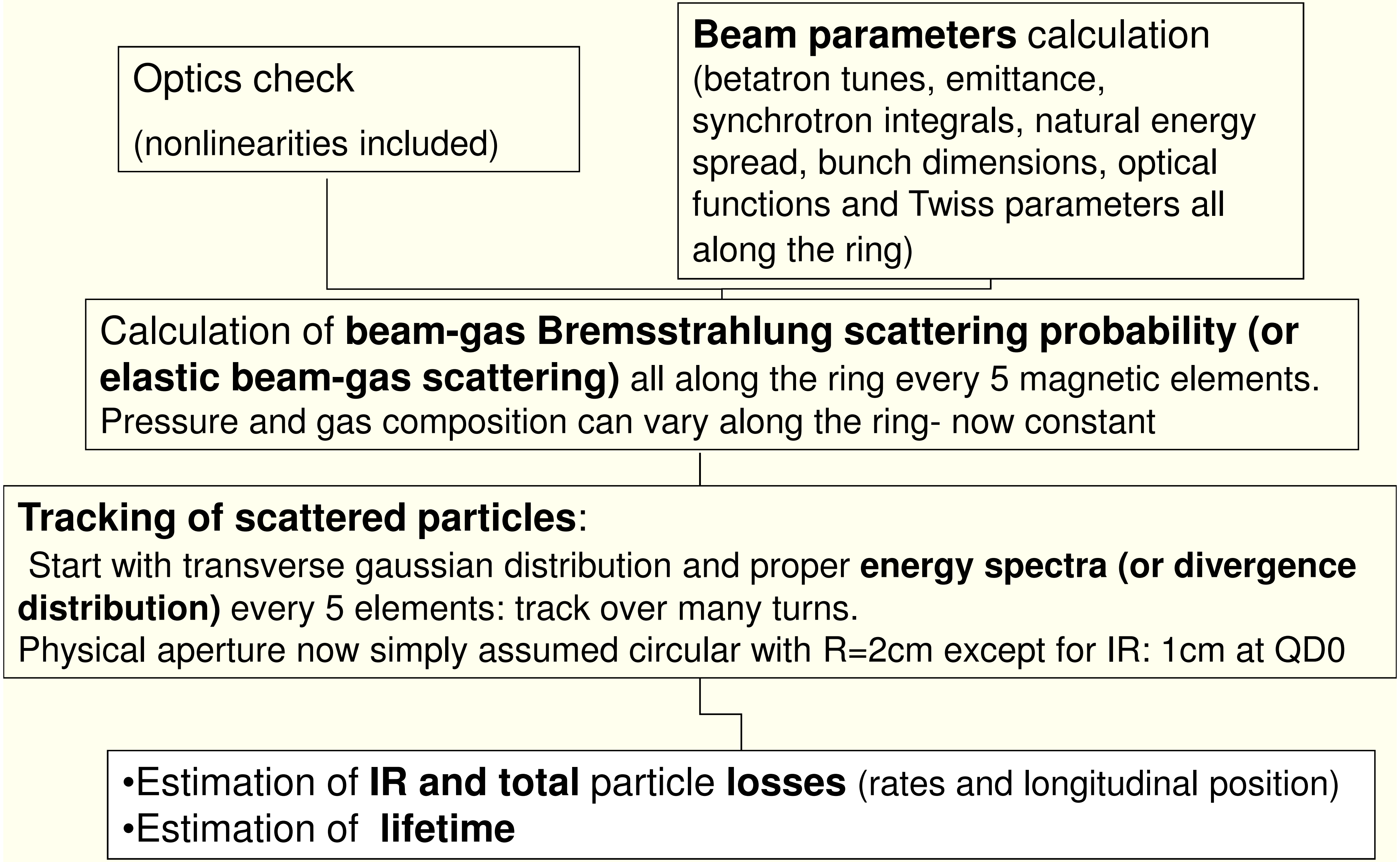


A. Perez

Beam-gas scattering

The same MonteCarlo approach as for Touschek simulation is used by substituting the elastic/ inelastic differential cross-section to the Touschek cross-section

Program Flow Beam-gas 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 **beam-gas Bremsstrahlung scattering probability (or elastic beam-gas scattering)** all along the ring every 5 magnetic elements. Pressure and gas composition can vary along the ring- now constant

Tracking of scattered particles:

Start with transverse gaussian distribution and proper **energy spectra (or divergence distribution)** every 5 elements: track over many turns.

Physical aperture now simply assumed circular with R=2cm except for IR: 1cm at QD0

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

Beam-gas inelastic scattering

usually the gas Bremsstrahlung lifetime is estimated from the integrated cross section

$$\boxed{\frac{1}{\tau_{\mathrm{Brems}}} = \rho\,\sigma_{\mathrm{inel}}^{\mathrm{N}}\,c}$$ with

$$\sigma_{\mathrm{inel}}^{\mathrm{N}} = 4r_e^2 Z^2 \alpha \frac{4}{3}\left(\ln\frac{183}{Z^{1/3}}\right)\left(\ln\frac{1}{\varepsilon_{\mathrm{RF}}} - \frac{5}{8}\right)$$

$\rho\ [\mathrm{m}^{-3}] = 3.217\times10^{22} P\ [\mathrm{Torr}]$ atoms/cm^3

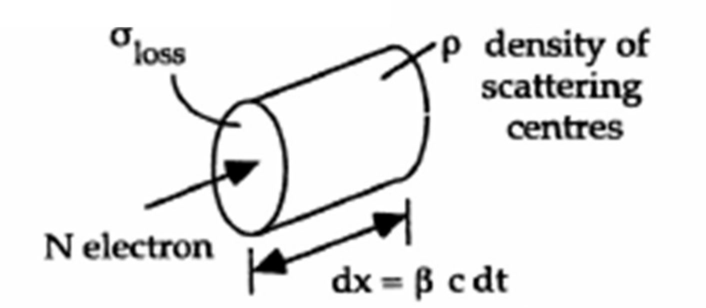
c speed light

The number of particles lost dN per unit time is proportional to the cross-section, the number of scattering centres and the number of incident particles.

$$dN = -N\rho\sigma_{loss}dx$$

$$\frac{1}{N}\frac{dN}{dt} = -\rho\sigma_{loss}\beta c$$

$$\left(N = N_0\,e^{-t/\tau}\right)$$



I compared the simulation results to the gas Bremss. lifetime estimated from this integrated cross section

Beam-gas Bremsstrahlung scattering- MC technique

$$\frac{1}{\tau} = \rho \left(\frac{d\sigma}{du} \right) c$$

frequency of a beam-gas scattering

u=Δp/p

$\frac{d\sigma}{du}$ differential cross section

$$\frac{1}{\tau} = \rho c \sum_{L} \underbrace{\left(\int_{u_{min}}^{u_{max}} \frac{d\sigma}{du} du \frac{\Delta L}{L} \right)}$$

frequency of a beam-gas scattering for a tracked particle

MC technique: uniform extraction of N_{MC} between u_{min} and u_{max} weighted with the cross section

$$\sum_{1}^{N_{MC}} \frac{d\sigma}{du} (u_{max} - u_{min}) / N_{MC}$$

$$\dot{N}(Hz) = \frac{1}{\tau_{ine}} N$$

rate of losses due to beam-gas scattering for N (particles/bunch)

τ_{ine} is the calculated beam-gas Bremsstrahlung lifetime

Beam-gas Inelastic scattering

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

we consider both nuclear and electrons interactions

$$\frac{d\sigma}{du} = 4\alpha\, r_e^2\, Z\,(Z+1)\,\frac{4}{3u}(1-u+.75u^2)\ell n\left(\frac{183}{Z^{1/3}}\right) \quad (4.1)$$

$$u = \frac{k}{E}\,. \quad (4.1a)$$

[A. Chao and Tigner Handbook]

[H. DeStaebler]

like Touschek with $\Delta E/E<0$ for primary electrons

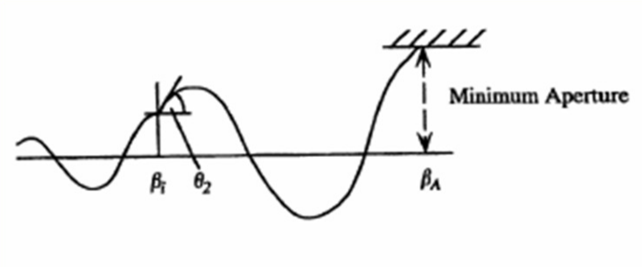
particles undergoing inelastic scattering are lost either for physical/dynamic aperture or for exceeding RF bucket

Beam-gas elastic scattering- MC technique

frequency of a beam-gas scattering

$$\frac{1}{\tau} = \rho \left(\frac{d\sigma}{d\Omega} \right) c$$

multiturn effect, as expected



betatron oscillation excitation

Nuclear Coulomb differential cross section

$$\frac{1}{\tau} = \frac{1}{L} \rho \, c \sum_{L} \left(\int_{\vartheta_{\min}}^{\vartheta_{\max}} \frac{d\sigma}{d\Omega} \right) dL$$

frequency of a beam-gas scattering for a tracked particle

$$\dot{N}(\mathrm{Hz}) = \frac{1}{\tau_{ela}} N$$

rate of losses due to beam-gas scattering for N (particles/bunch)

τ_{ela} is the calculated beam-gas elastic lifetime

Elastic beam-gas scattering

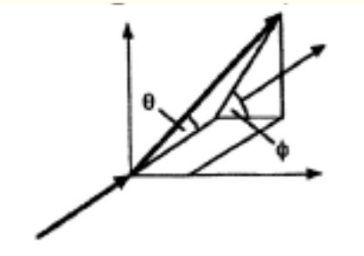
differential cross section

$$\frac{d\sigma}{d\Omega} = 4r_e^2\, Z^2 \frac{\left(\frac{m}{p}\right)^2}{(\theta^2+\theta_1^2)^2} ,$$

$$\theta_1 = \alpha Z^{1/3} \left(\frac{m}{p}\right) .$$

[A. Chao and Tigner Handbook]

[H. DeStaebler]



$$d\Omega = \sin\theta\, d\theta\, d\phi$$

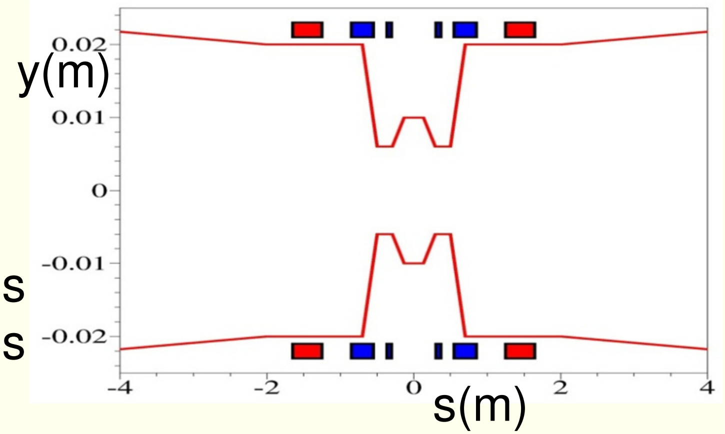
The screening of the atomic electrons is accounted for by the angle θ_1. Any nuclear form factor effects are neglected, which requires $q \approx E\theta < q_{\max} = 137\ \mathrm{m}/A^{1/3}$. The energy lost by the beam particle is $q^2/2A$ which can safely be neglected.

Beam-gas bkg –general considerations

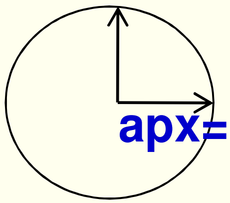
- Particle losses expected vertically, at the QD0

  beam pipe is assumed circular all along the ring

  But at the IR:



plot from M. Sullivan's stay-clear evaluations



apy=2.5 cm

apx=2.5 cm

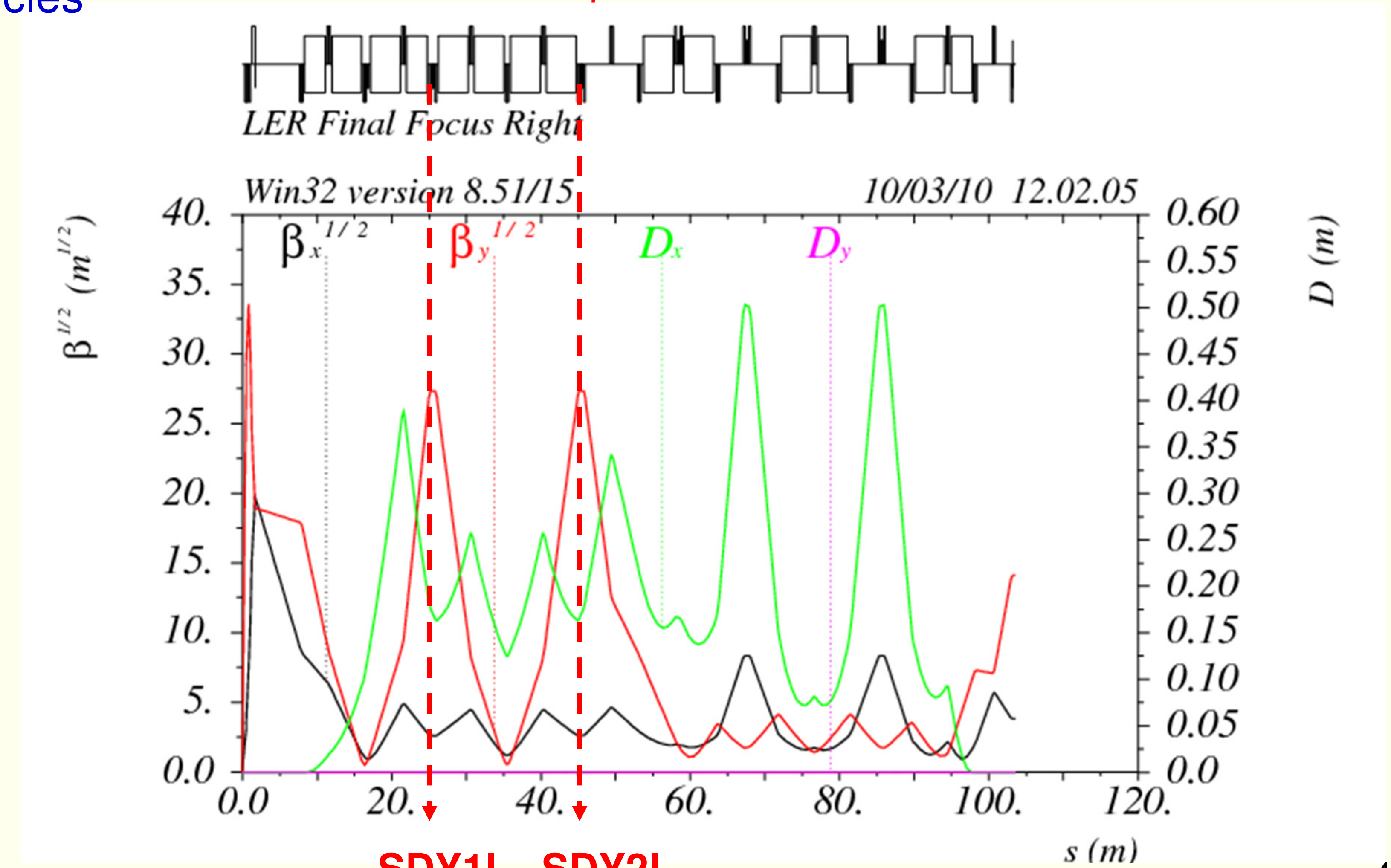
- Beam-gas is very much dependent on how good vacuum is:

  P=1nTorr constant up to now,

  different pressures along ring, especially at IR, planned

Vertical COLLIMATORS in the Final Focus

To be added to the Horizontal ones, placed to intercept Touschek scattered particles



SDY1L **SDY2L**

Following the same criteria used for horizontal collimators:

Vertical Collimators upstream the IR

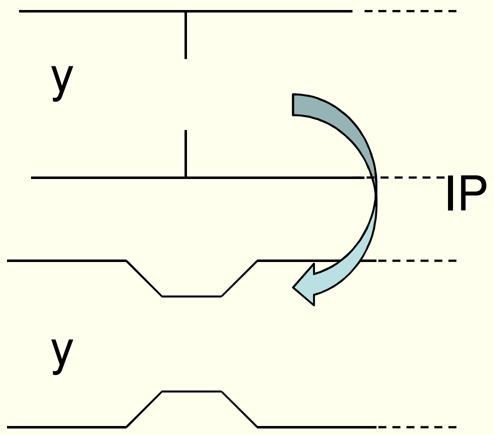
Intercept the scattered particles
in the final focus upstream the IR
that otherwise would be lost at the QD0

Collimator jaw insertion = 0.9* phys. aperture(QD0)$\cdot\sigma_{COL}/\sigma_{QD0}$

IR losses are greatly reduced by these Vertical collimators placed with this criteria

Reshaping of Beam pipe as collimators

A vertical beam pipe at the longitudinal position where the vertical Collimator should be placed (Vertical Sextupoles) could be modeled by the same aperture needed to collimate particles that would be lost at the QD0, **and add two movable jaws as a further knob to tune IR backgrounds.**



HER Beam-gas Coulomb scattering

P = 1 nTorr constant along ring, Z = 8

HER	**τ (s)**	IR losses/beam
no collimators	4590	10.5 GHz
with vertical Collimators	**3040**	**3.7 MHz**

↓ About a factor 950 in IR losses reduction

no collimators =10.8 MHz/bunch × 978 bunches=10.5GHz/beam

with collimators = 3.8 kHz/bunch × 978 bunches= 3.7 MHz/beam

Collimator set: (mm)

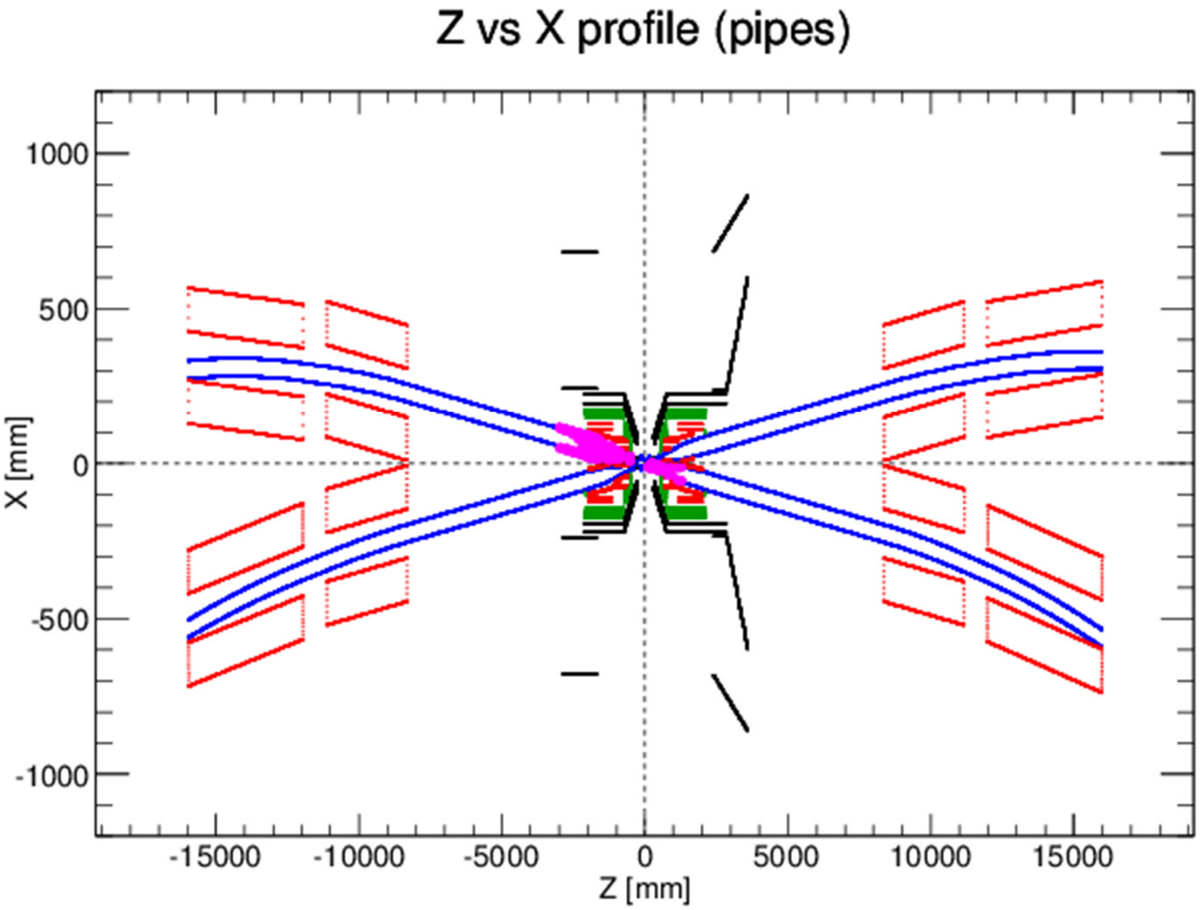
	internal / external
HCol1	-9 / +12
HCol2	-9 / +25(out)
HCol3	-18 / +12
HCol4	-12 / +18
VCol1	**-4.5 / +4.5**
VCol2	**-4.5 / +4.5**

Set of values optimized for Touschek

Coulomb particles hitting the pipe: full geometry before tracking

HER

IR within 15 m

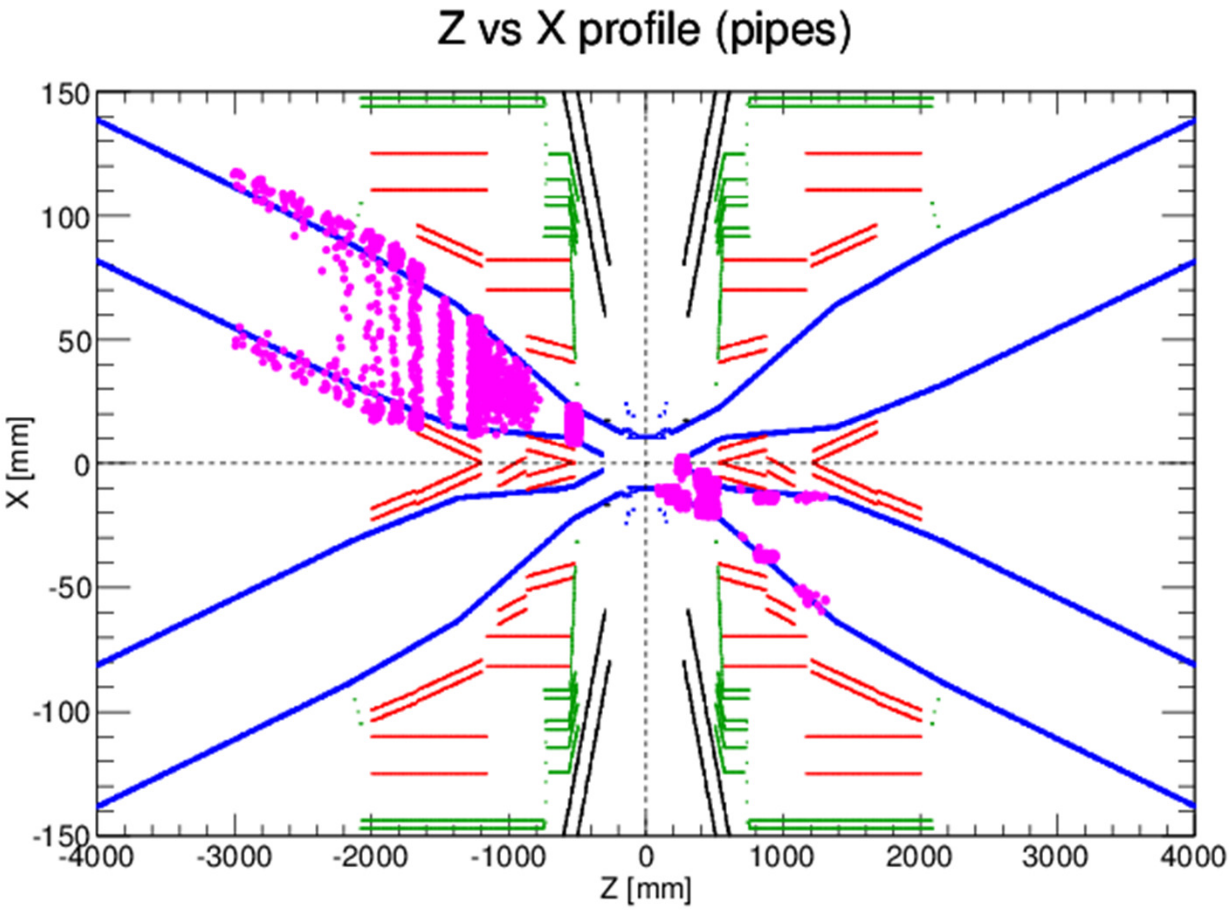


[A. Perez]

Coulomb particles hitting the pipe: full geometry before tracking

HER

Zoom: IR within 4 m



[A. Perez]

LER Beam-gas Coulomb scattering

P = 1 nTorr constant along ring, Z = 8

LER	**τ (s)**	IR losses/beam
no collimators	2520	25 GHz
with vertical Collimators	2350	**36 MHz**

↓

About a factor 700 in IR losses reduction

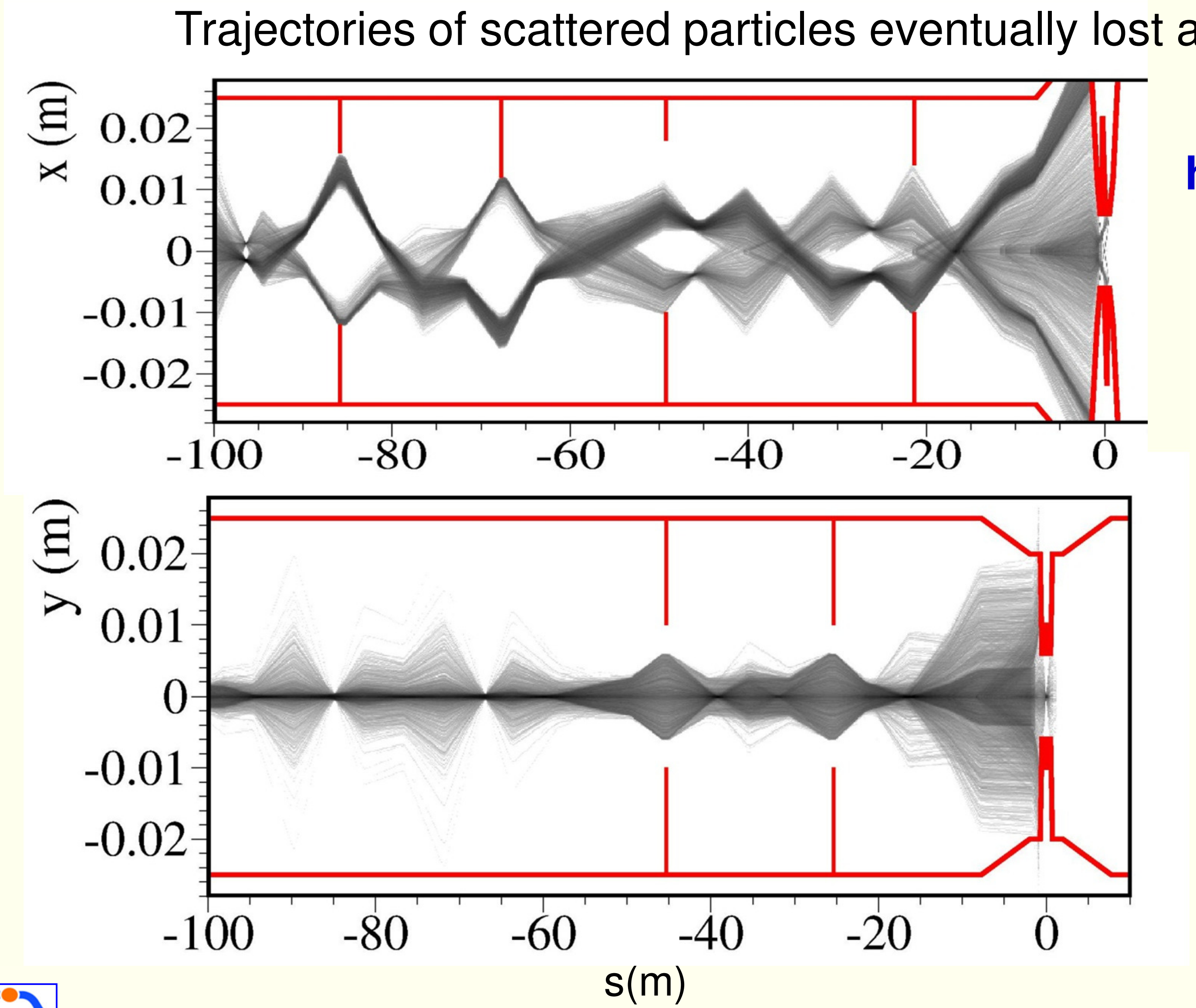
no collimators = 26 MHz/bunch × 978 bunches =25.4 GHz/beam

with collimators = 36.7 kHz/bunch × 978 bunches=36 MHz/beam

Collimator set: (mm)	internal / external
HCol1	-10 / +14
HCol2	-10 / +18
HCol3	(out)-25 / +12
HCol4	-12 / +16
VCol1	**-6 / +6**
VCol2	**-6 / +6**

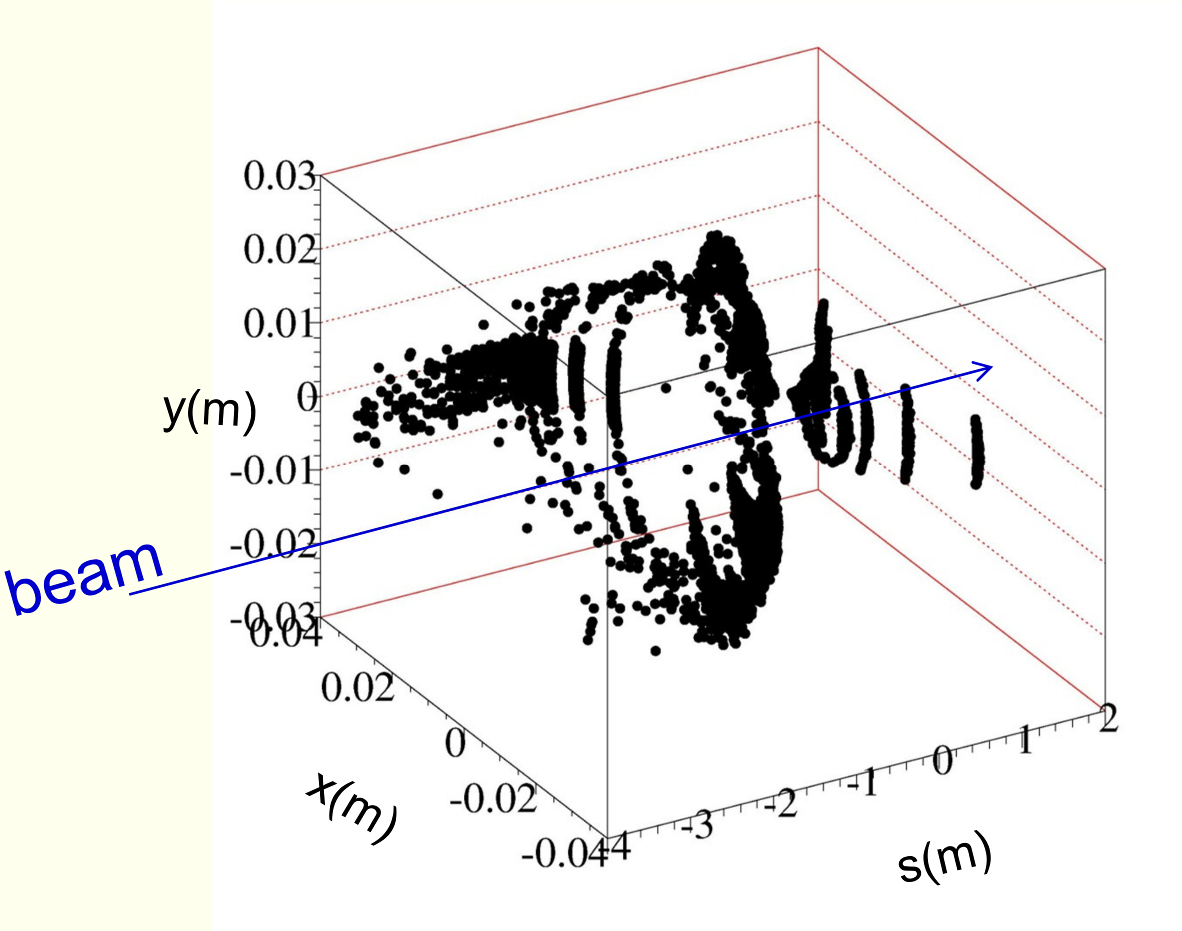
There is margin of further IR rate reduction, As for the HER, Vcol set may be re-checked if secondaries not satisfactory (we still have margin in lifetime)

Coulomb scattered particles lost at IR



Coulomb beam-gas scattering

3D plot: scattered particles hitting the pipe



Lifetime summary

	HER	LER
Touschek lifetime	τ_{TOU} (min)	τ_{TOU} (min)
No collimators, nominal ε_x (no IBS)	26	7.4
No collimators, ε_x with IBS	26	10.2
With Collimators, ε_x with IBS	22	7

Coulomb	50 min	39 min
Bremsstrahlung	72 hrs	77 hrs

IR rates summary

|s|<2 m

Touschek	**HER**	**LER**
No collimators, ε_x with IBS	2.4 GHz	17 GHz
With Collimators, ε_x with IBS	**6.8 MHz**	**72 MHz**

Coulomb No collimators, ε_x with IBS	10.5 GHz	25 GHz
Coulomb **with collimators, ε_x with IBS**	**3.7MHz**	**36 MHz**
Bremsstrahlung with coll	130KHz	450KHz

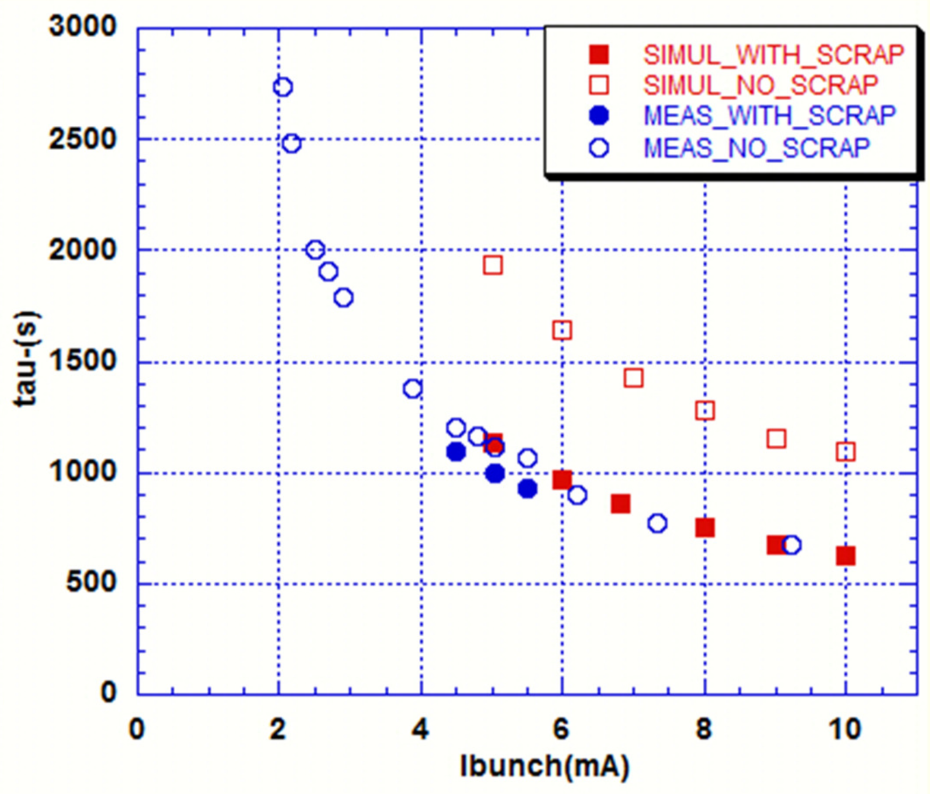
Conclusions

- Monte Carlo for Touschek lifetime and backgrounds is a solid simulation tool
- Background rates at IR are under control with an efficient Horiz & vert. Collimation system in the Final Focus
- More beam-gas simulation studies under variable pressure along ring are on the way
- Technical Design of realistic collimators is planned

back-up

Dafne lifetime measurements

IPAC11



Red: SIMULATION

Blue: Measurement

Measured (blue dots) and predicted (red squares) electron beam lifetime vs bunch current, with K=0.4%.

Modif. V12 HER Touschek Lifetime

V12 lattice+ more realistic aperture	τ_{TOU} (min)
No collimators	**26**
Optimal set of horizontal Collimators	**22**

~1.2 lifetime reduction
to greatly reduce IR losses

Modif. V12 LER Touschek Lifetime

collimators setting	ε_x (m rad)	τ_{TOU} (s)	τ_{TOU} (min)
No collimators	1.8e-9 , no IBS	**447**	**7.4**
No collimators	2.4e-9, with IBS	**611**	**10.2**
With collimators	2.4e-9, with IBS	**420**	**7**

~ 1.45 lifetime reduction
to greatly reduce IR losses

CDR and CDR2

CDR

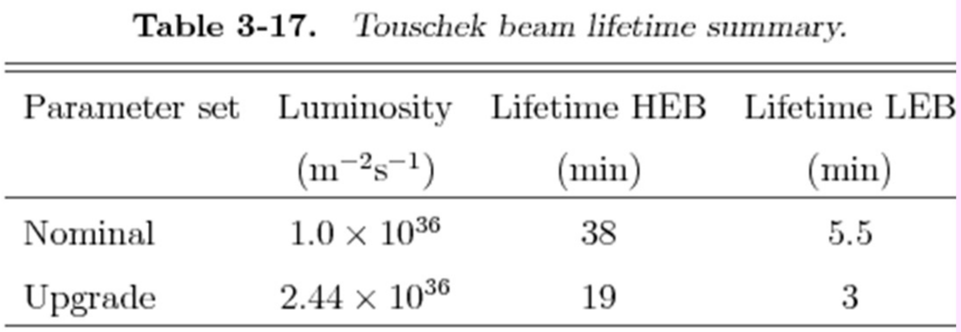


Table 3-17. *Touschek beam lifetime summary.*

Parameter set	Luminosity ($m^{-2}s^{-1}$)	Lifetime HEB (min)	Lifetime LEB (min)
Nominal	1.0×10^{36}	38	5.5
Upgrade	2.44×10^{36}	19	3

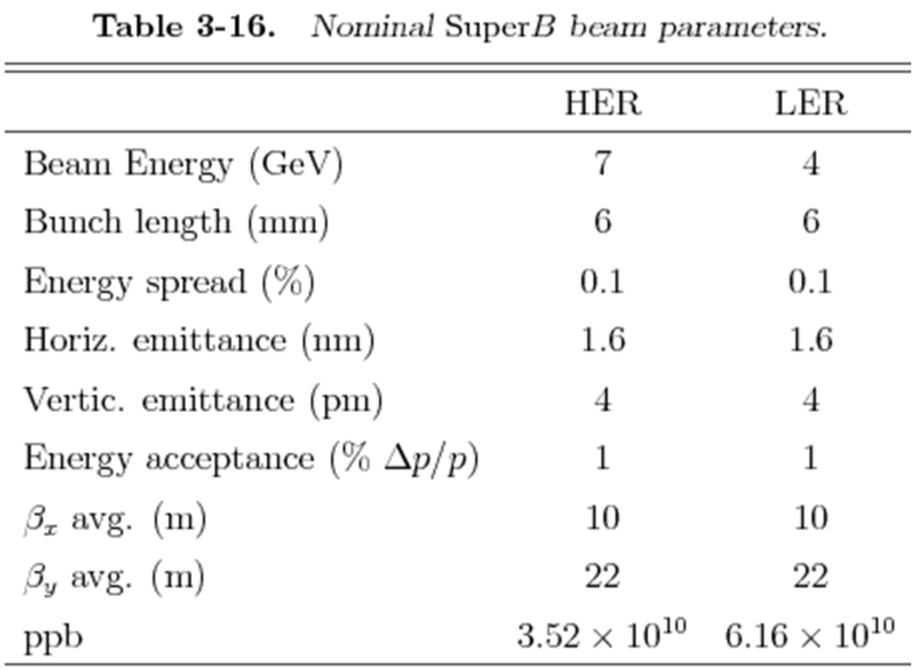


Table 3-16. *Nominal* Super*B* *beam parameters.*

	HER	LER
Beam Energy (GeV)	7	4
Bunch length (mm)	6	6
Energy spread (%)	0.1	0.1
Horiz. emittance (nm)	1.6	1.6
Vertic. emittance (pm)	4	4
Energy acceptance (% $\Delta p/p$)	1	1
β_x avg. (m)	10	10
β_y avg. (m)	22	22
ppb	3.52×10^{10}	6.16×10^{10}

CDR2

Touschek lifetime [min]	HER	LER
No collimators, ε_x including IBS	40.0	7.8
No collimators, nominal ε_x (no IBS)	39.8	5.9
Optimal set of Collimators, ε_x including IBS	33.2	6.6

V12 parameters	HER	LER
Beam Energy (GeV)	6.7	4.18
Bunch length (mm)	5	5
Nominal horizontal emittance (nm)	1.97	1.80
Horiz. emittance (nm) including IBS	2.00	2.46
Coupling (%)	0.25	0.25
Particles/bunch	5.08×10^{10}	6.56×10^{10}