Beam lifetime and backgrounds simulation studies at SuperB

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Dominant effects on backgrounds and lifetime

Two colliding beams

- Radiative Bhabha $\rightarrow$ dominant effect on lifetime
- Pairs Production

Single beam

- Synchrotron Radiation
- **Touschek**
- **Beam-gas**
- Intra-beam scattering

Outline

V12 lattice **LER & HER**

Touschek

- **Lifetime**
- **Loss rates at Interaction Region**
- **Horizontal collimators system**

Beam- gas: Coulomb and Bremsstrahlung

- **Lifetime**
- **Loss rates at Interaction Region**
- **Vertical collimators system**

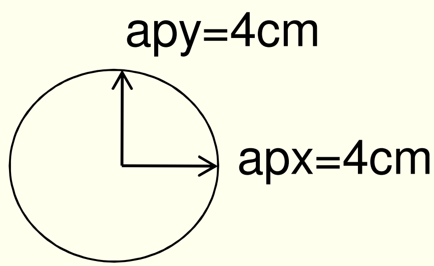
Beam Parameters V12 lattice

	units	HER (e+)	LER (e-)
Beam Energy	GeV	6.7	4.18
Particles/bunch		5.08×10^{10}	6.56×10^{10}
Nominal horiz. emitt. no IBS	m rad	1.97e-9	1.80e-9
Horiz. emittance with IBS	m rad	2.00e-9	2.46e-9
Coupling (full current)	%	0.25	0.25
Bunch length (full current)	mm	5	5
RF acceptance	%	0.03	0.04

Simulation results

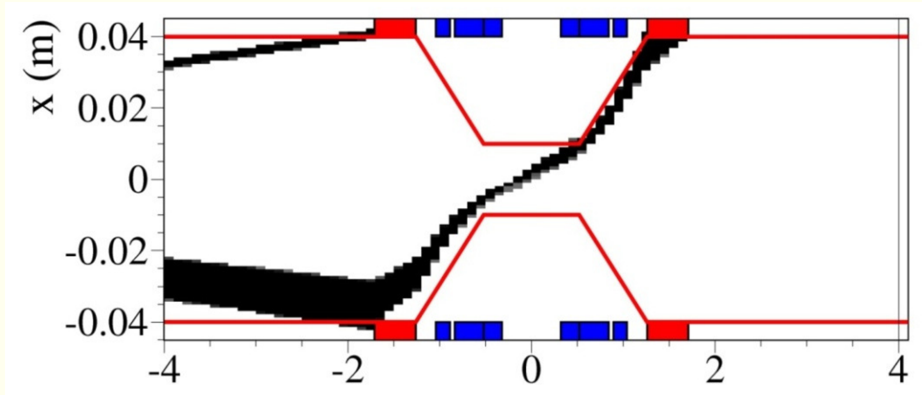
stable results with
machine turns= 5
macropart. 10^6= 500x2 every 3 out of 2300 elements

- Calculated lifetime and rates are dependent on the:
  - *lattice* energy acceptance
  - physical aperture -elliptical shape

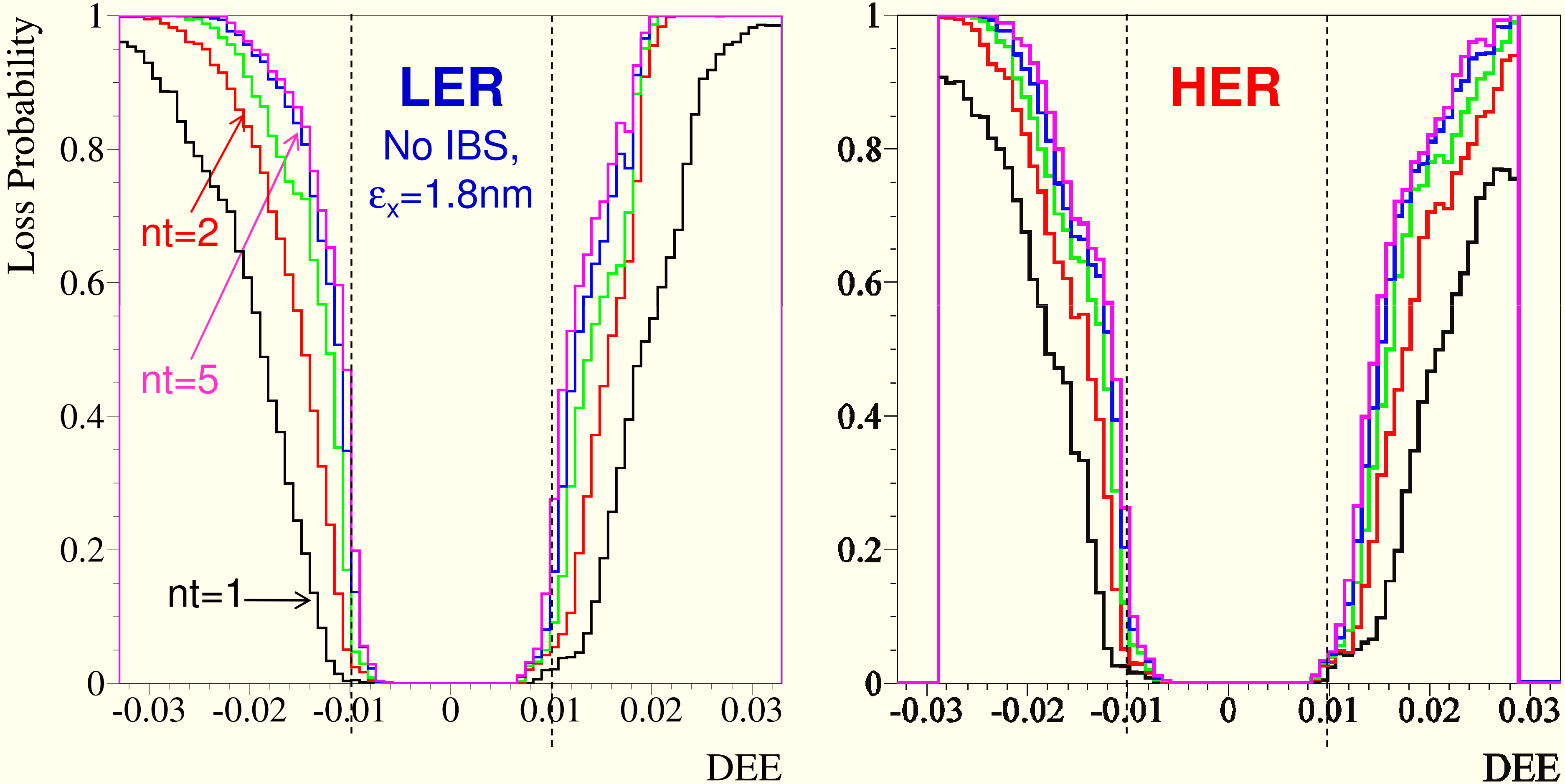


- Half vertical aperture = 4 cm everywhere
- Half horizontal aperture = 4 cm everywhere but at the IR
  - at QF1 BSC >~ 30 σ_x
  - at QD0 BSC >~ 30 σ_x at full coupling

Simulation results need to be updated together with IR design



Lattice Energy Acceptance



nt= machine turn number

HER Touschek Lifetime

V12 lattice	τ_{TOU} (min)
No collimators	**40**
Optimal set of horizontal Collimators	**33**

~15% lifetime reduction
to greatly reduce IR losses

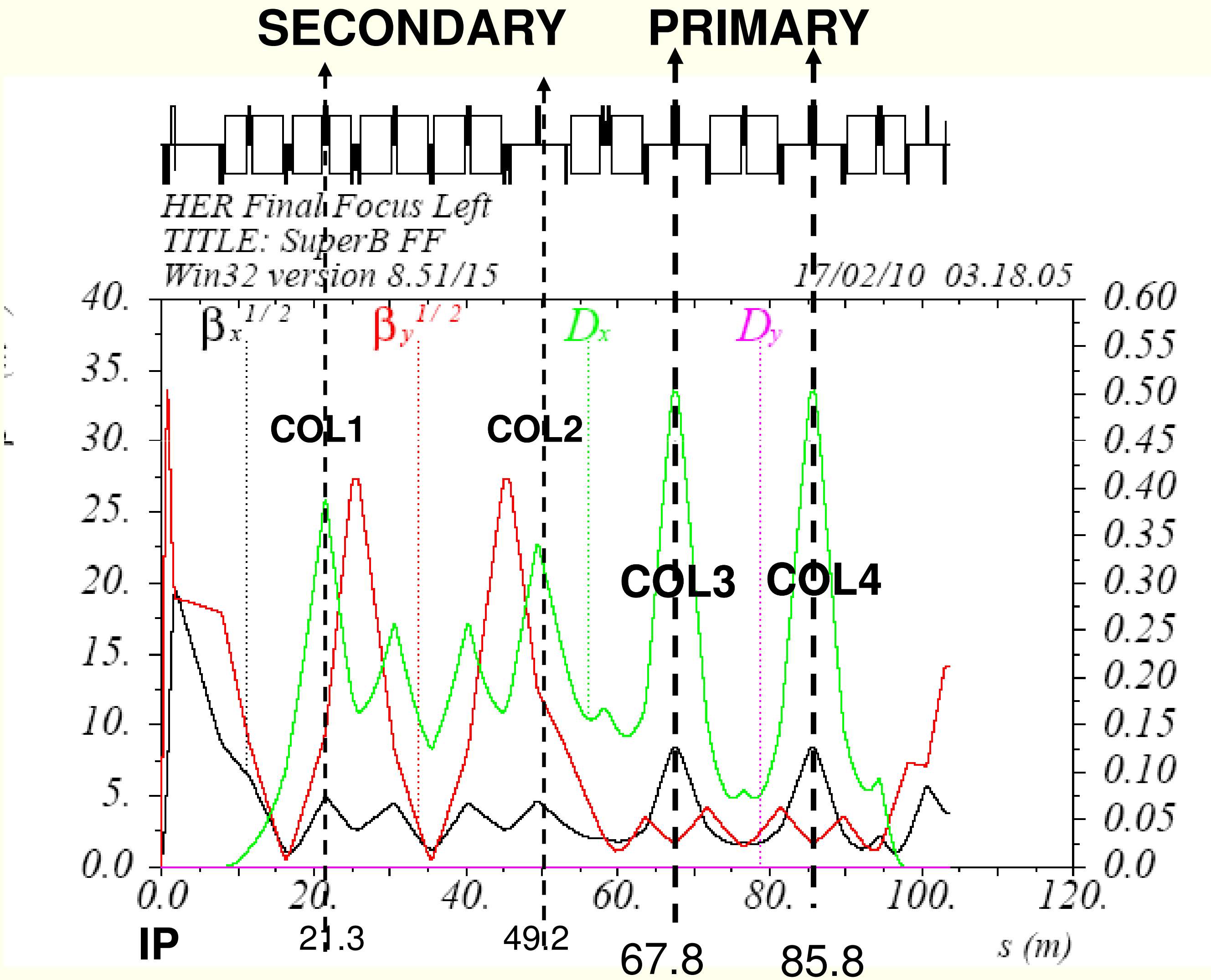
LER Touschek Lifetime

collimators setting	ε_x (m rad)	τ_{TOU} (s)	τ_{TOU} (min)
No collimators	1.8e-9 , no IBS	**350**	**5.9**
No collimators	2.4e-9, with IBS	**460**	**7.8**
With collimators	2.4e-9, with IBS	**400**	**6.6**

~ 15% lifetime reduction
to greatly reduce IR losses

Short Touschek lifetime, but not the limiting effect-however it needs special care, especially because most of particle losses tend to be at the IR

HER / LER Final Focus collimation system



Horizontal Collimators upstream the IR

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

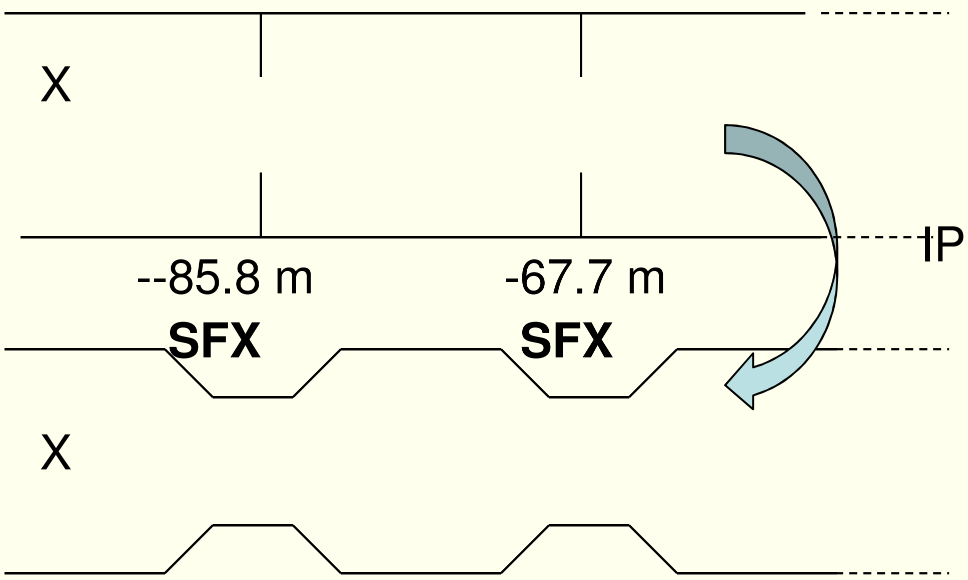
Collimator jaw insertion = 0.9* phys. aperture(QF1)$\cdot\sigma_{COL}/\ \sigma_{QF1}$

For example: HER: primary collimators = 1.5 cm

This has been the initial jaw opening, the optimal position has been found in the simulations

Proposal: fixed collimators

- The proposed **horizontal collimation system** results **very efficient** from simulations.
- It is almost straightforward **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.

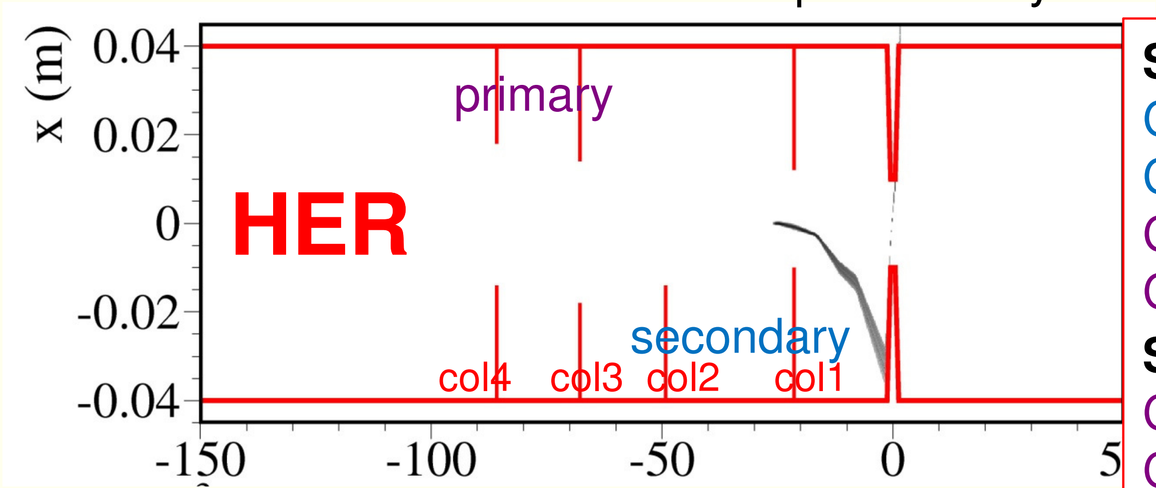


A symmetrically shaped pipe is a better solution from wakefields and HOM point of view instead of collimators

Dedicated discussion foreseen

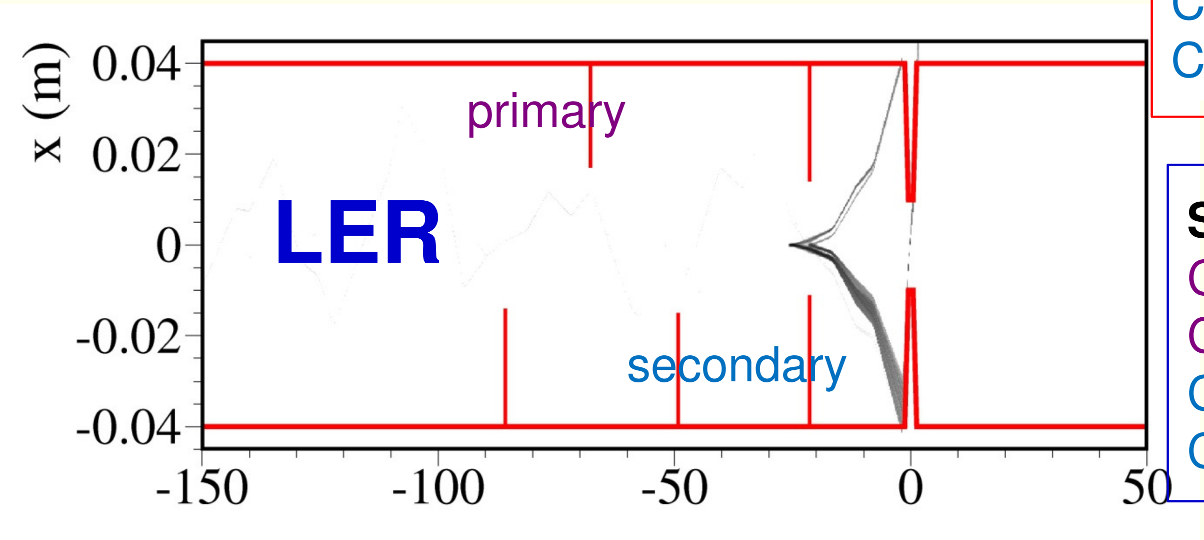
Collimators Final set from the simulation

found by minimizing IR rates and maximizing lifetime
real set will be found experimentally



SET (σ_x units):
Col1= -26 /+31 σx
Col2= -26 σx
Col3= -36/ +28 σx
Col4= -28/ 36 σx

SET (cm):
Col1= -1.2 / +1.2
Col2= -1.
Col3= -1.8 / +1.4
Col4= -1.4 / 1.8

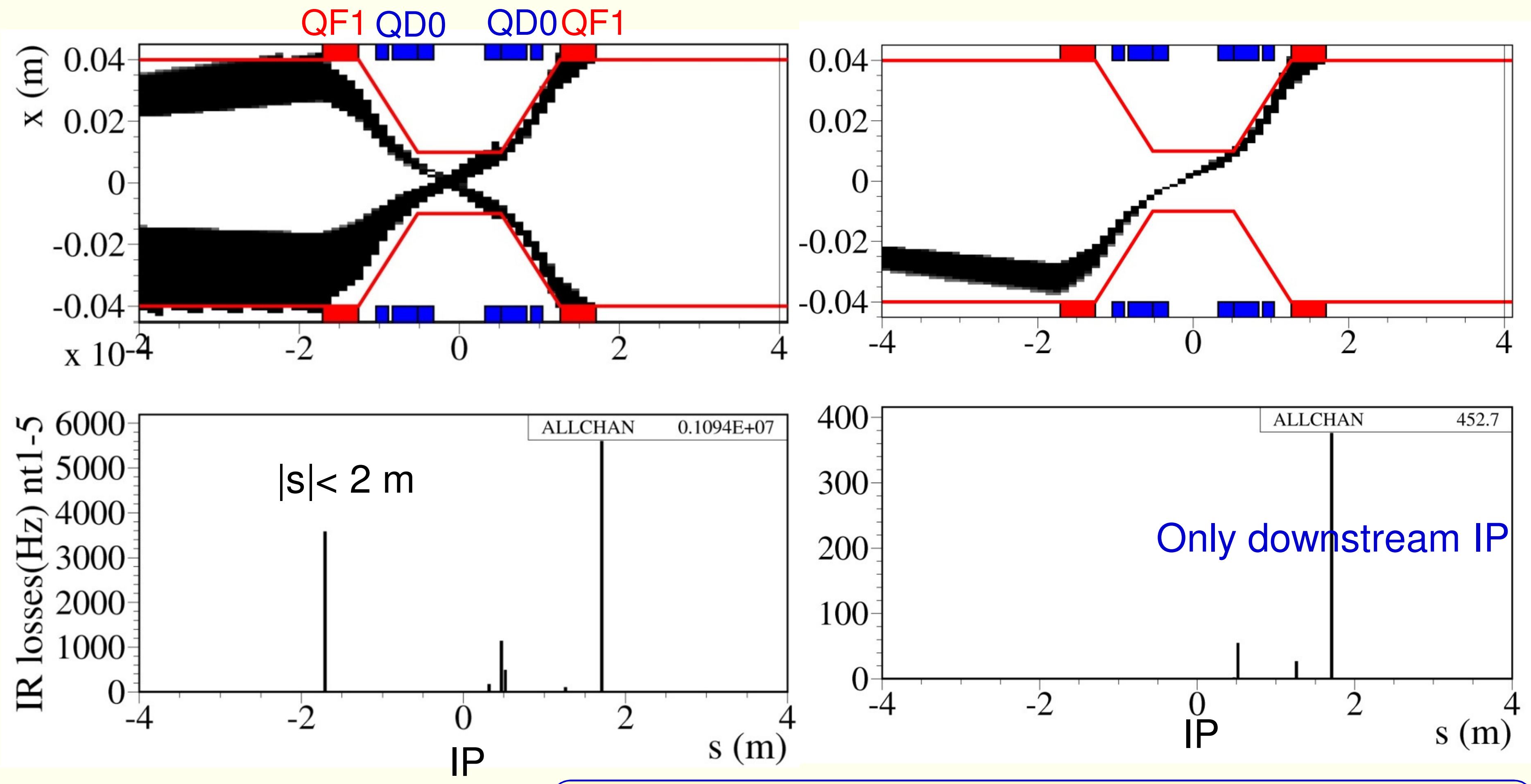


SET (σ_x units):
Col1= -28 /+35 σx
Col2= -35 σx
Col3= +29 σx
Col4= -25 σx

HER IR losses (|s|< 2 m)

NO collimators = 1.1·10^6 Hz/bunch

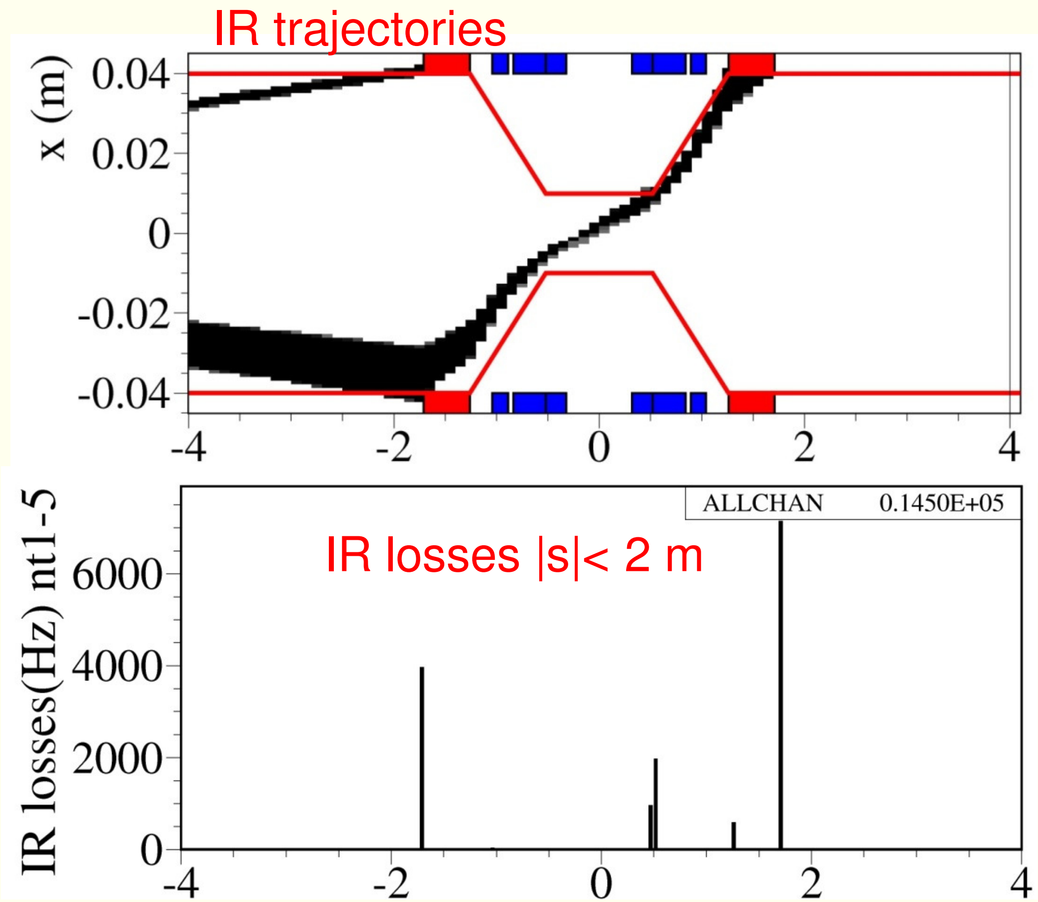
with collimators = 4.5·10^2 Hz/bunch



with collimators=4.4·10^5 Hz/**beam** at full current

bunches 978

LER final collimators set ε_x =2.4 nm



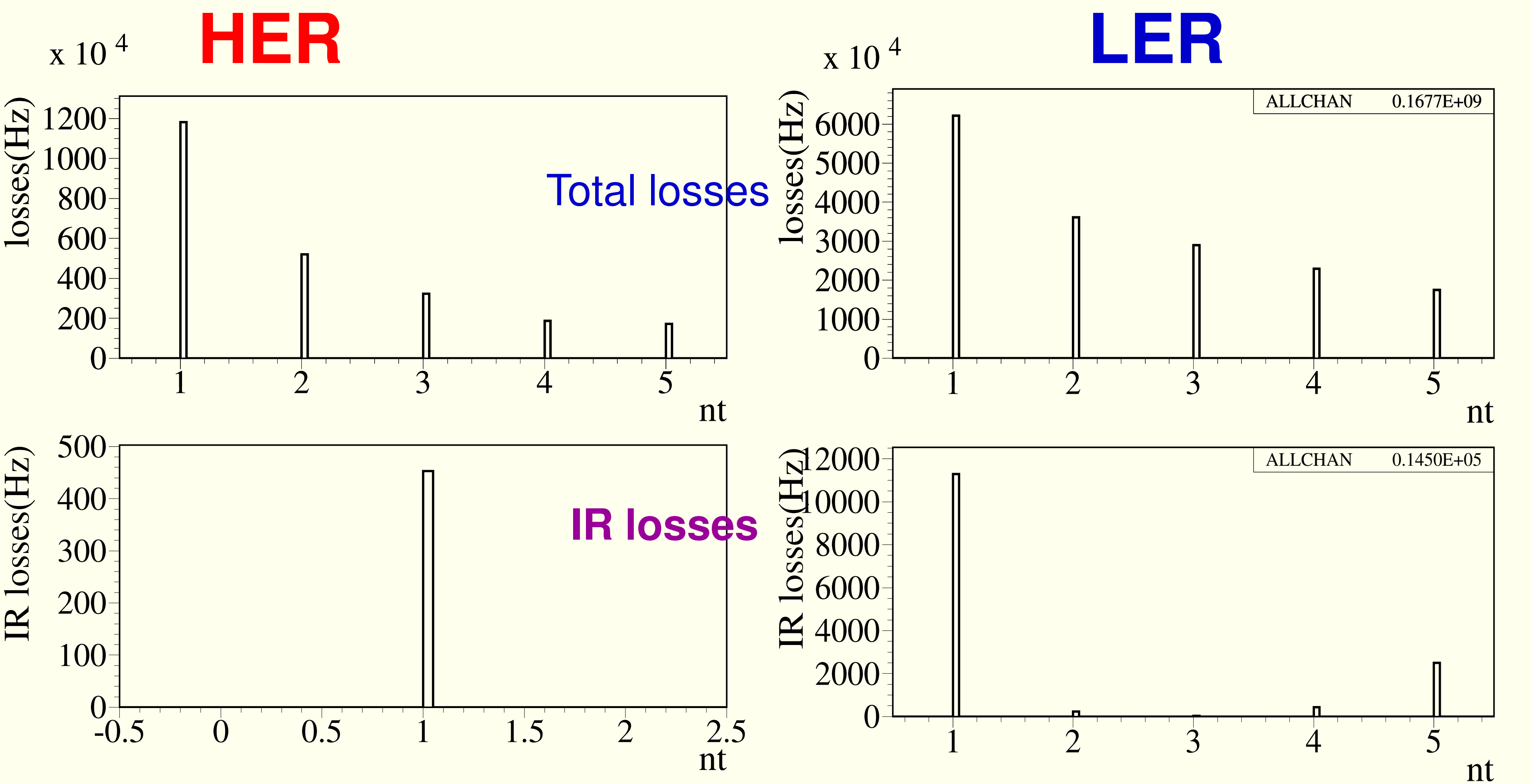
NO collimators
IR losses = 6.510^6 Hz/bunch

with collimators
IR losses = 1.4 10^4 Hz/bunch

careful study of secondaries into sub-detectors are needed to design adequate shieldings (experience at DAΦNE)

with collimators= 1.37 10^7 Hz/**beam** at full current
\# bunches 978

Touschek particle losses vs #machine turns
with collimators



Beam-gas scattering

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

Beam-gas Coulomb scattering

P = 1 nTorr, Z = 8

LER	**τ (s)**	IR losses (Hz/bunch)
no collimators	1800	$6.4 \cdot 10^6$
with vertical Collimators	**1800**	**$9.1 \cdot 10^3$**

a factor 1000 in IR losses reduction

HER	**τ (s)**	IR losses (Hz/bunch)
no collimators	7100	$1.1 \cdot 10^6$
with vertical Collimators	**7100**	**$4.4 \cdot 10^4$**

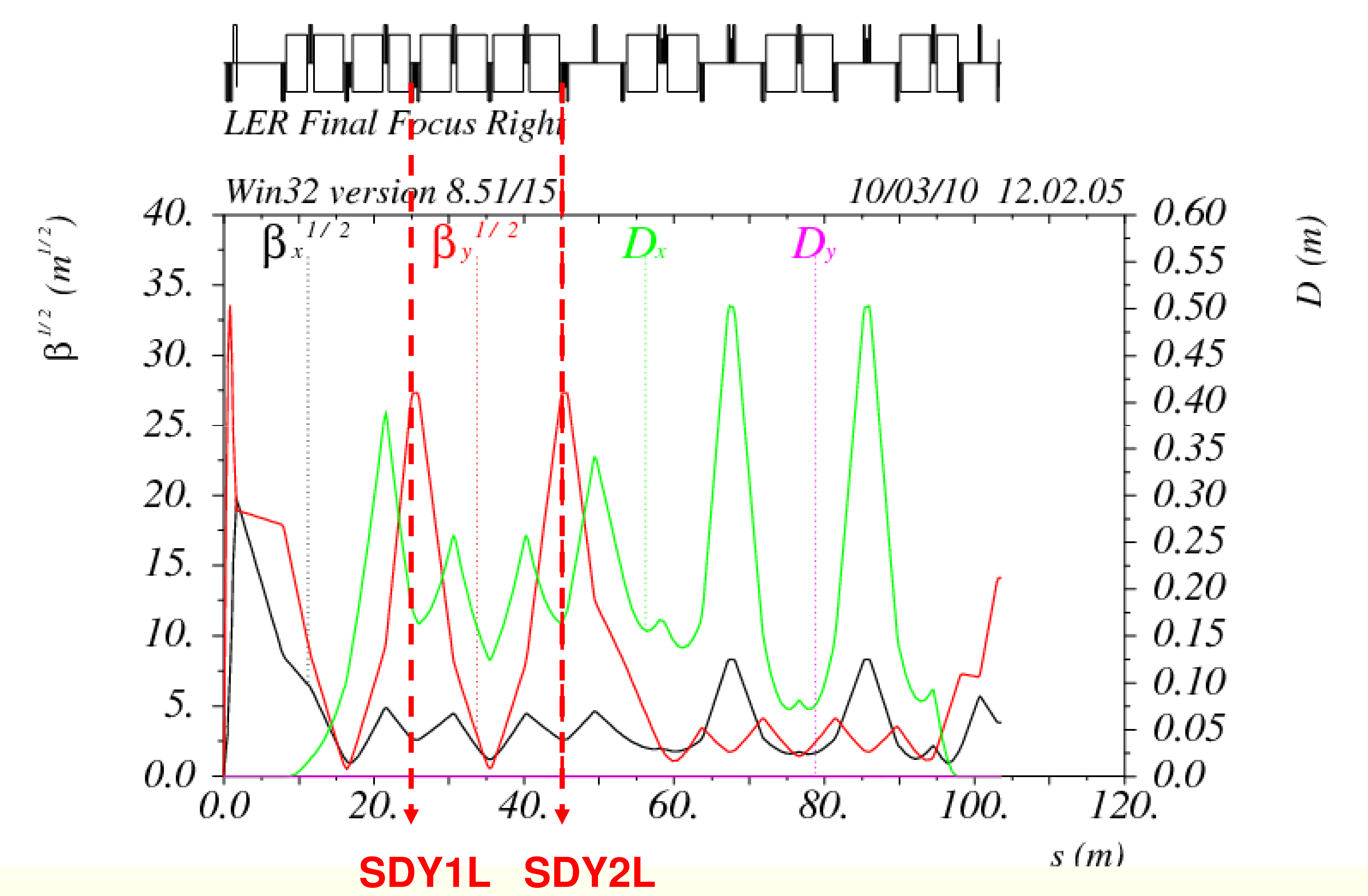
a factor 25 in IR losses reduction

LER $\tau_{integrated} \approx$ **13 hr**

HER $\tau_{integrated} \approx$ **45 hr**

Very different results between integrated formula and Monte Carlo (differential cross-section)

VERTICAL COLLIMATORS



Vertical Collimators upstream the IR

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

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

vertical half-physical aperture = 4cm

LER β_y(QD0)=1490 m

β_y(VCOL1, VCOL2)=996 m

collimator opening=2.9 cm

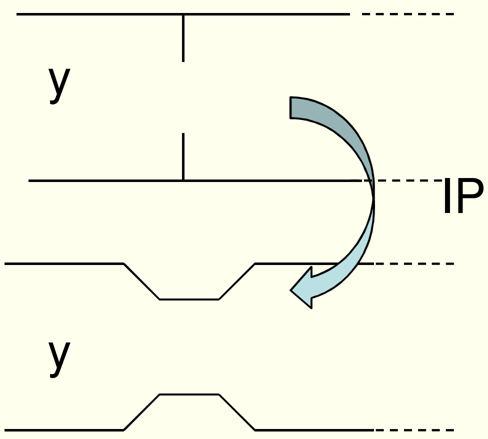
at full coupling≈26 σ_y

↓

With this value IR losses are reduced by a factor 1000
and NO lifetime reduction

Reshaping of Beam pipe as collimators

A vertical beam pipe at the longitudinal position where the vertical Collimator should be placed (V. Sextup.) could be modeled by the same aperture needed to collimate particles that would be lost at the QD0



A symmetrically shaped pipe is a better solution from wakefields and HOM point of view instead of collimators

Dedicated discussion foreseen

Coulomb beam-gas scattering

LER v12 lattice

$\tau_{Coul} \approx 1800$ s

P = 1 nTorr, Z = 8

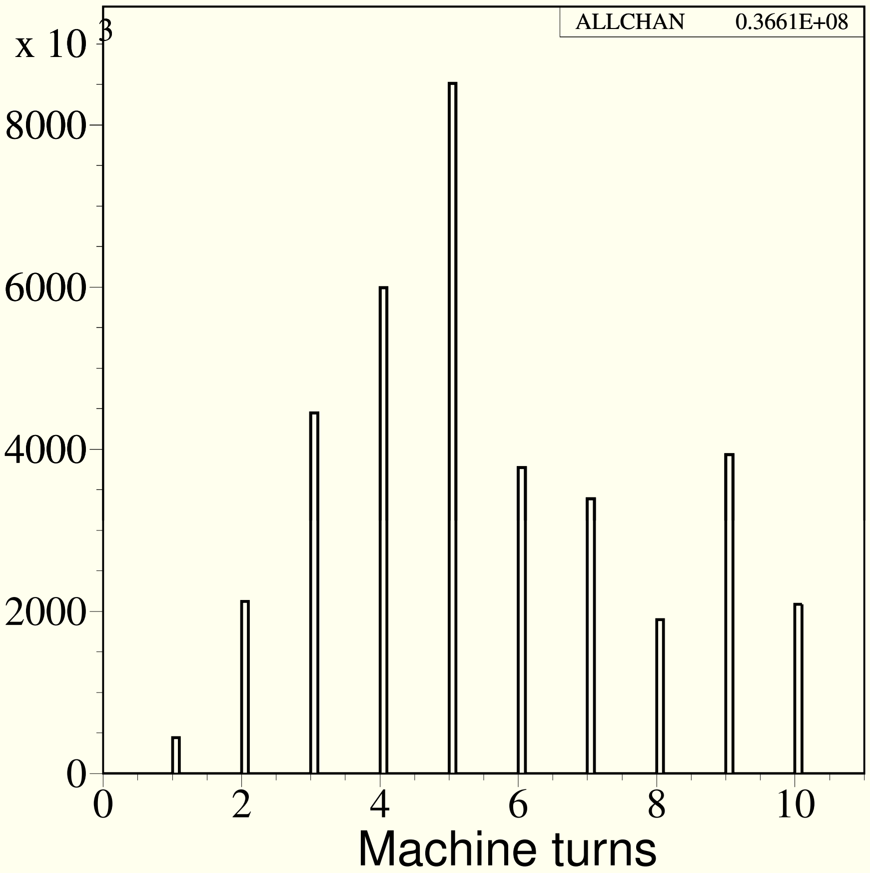
I_{bunch}= 2.5 mA

ε_x (IBS) = 2.4 nm

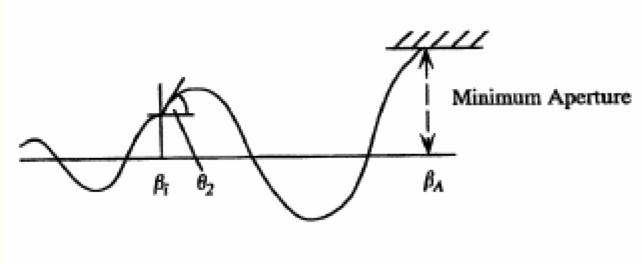
(for 1 bunch at 2.5 mA)

Tot. Losses = 36.6 MHz

IR Losses = 6.4 MHz



multiturn effect, as expected

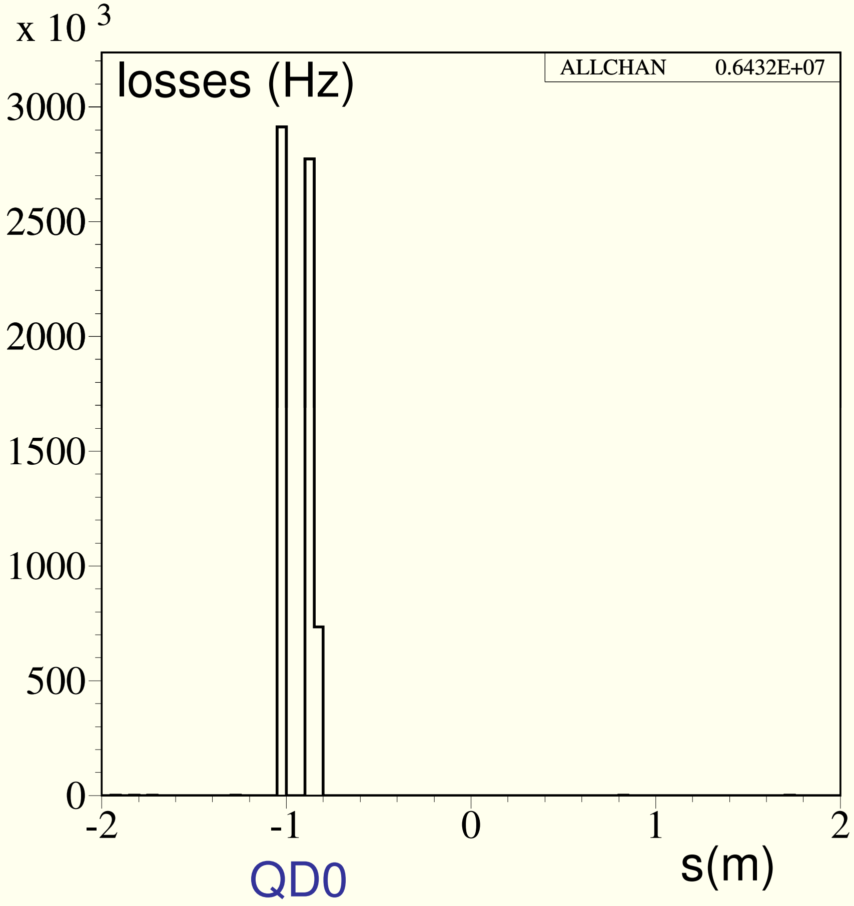


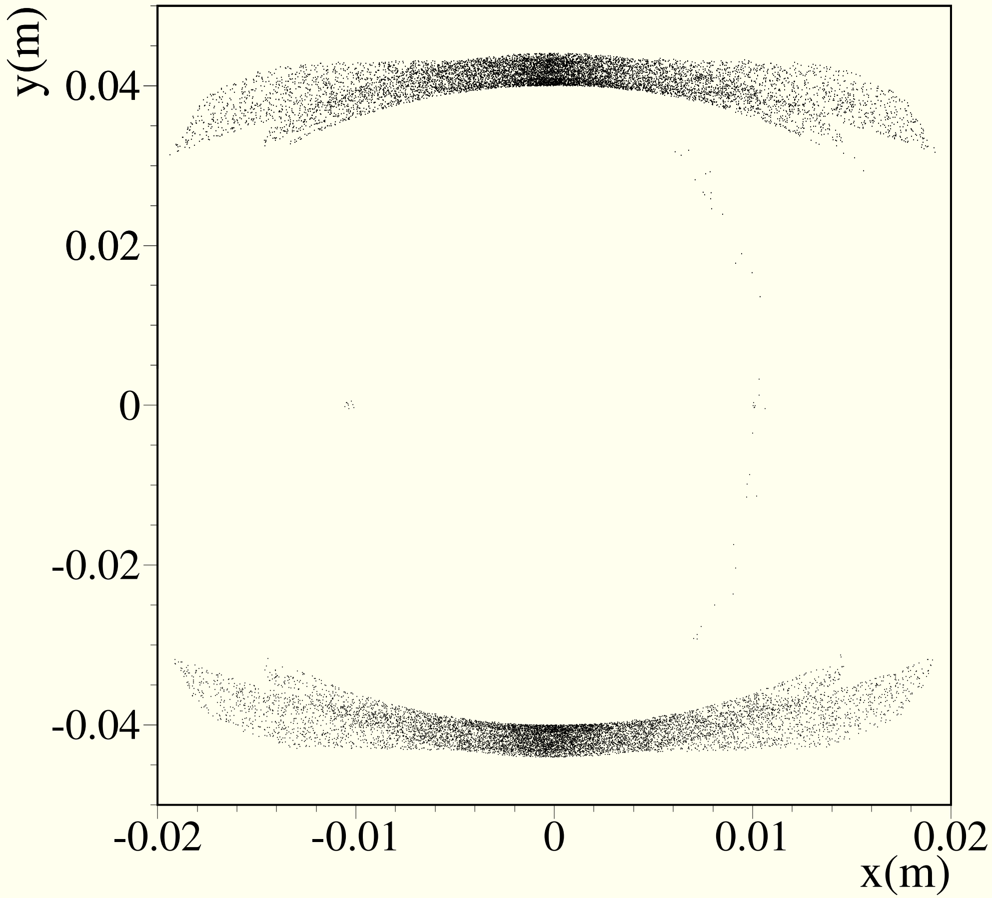
betatron oscillation excitation

Coulomb scattering

LER v12lattice

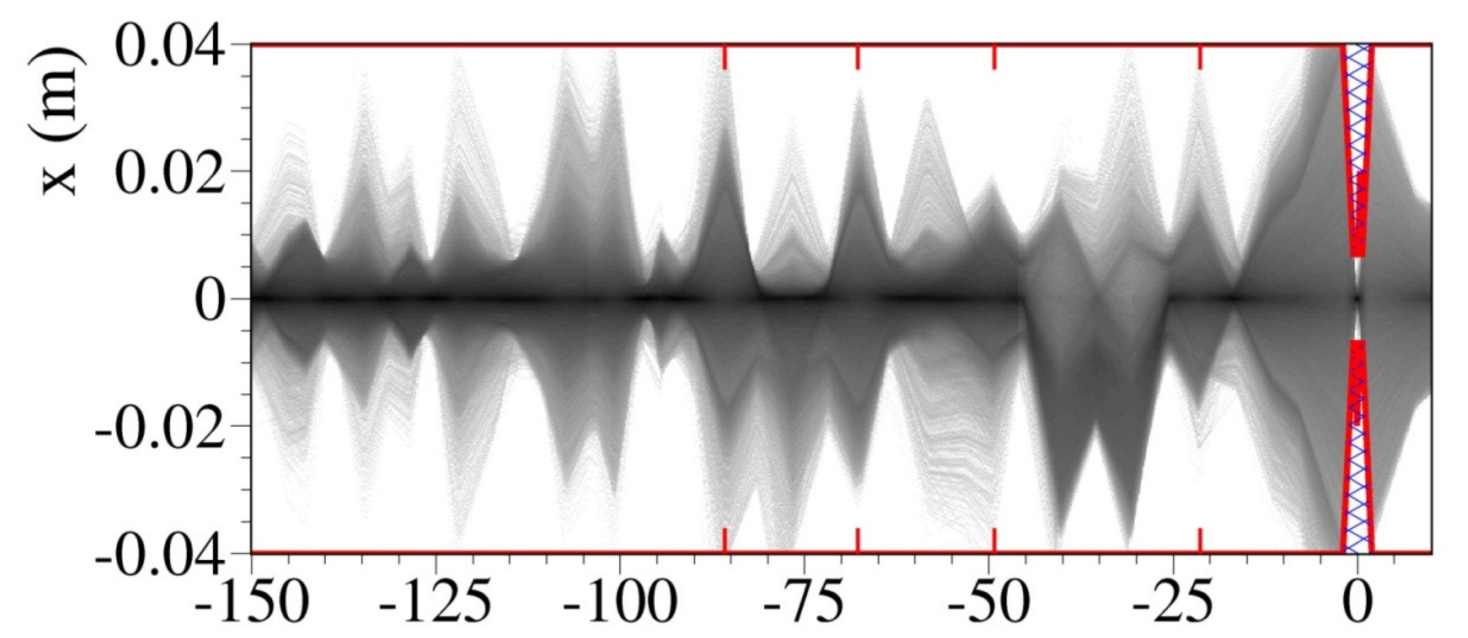
In the simulation cylindrical aperture, vertical physical aperture= 4 cm





Coulomb scattering

LER v12lattice



All horizontal trajectories of Coulomb scattered particles

LER Beam-gas Bremsstrahlung

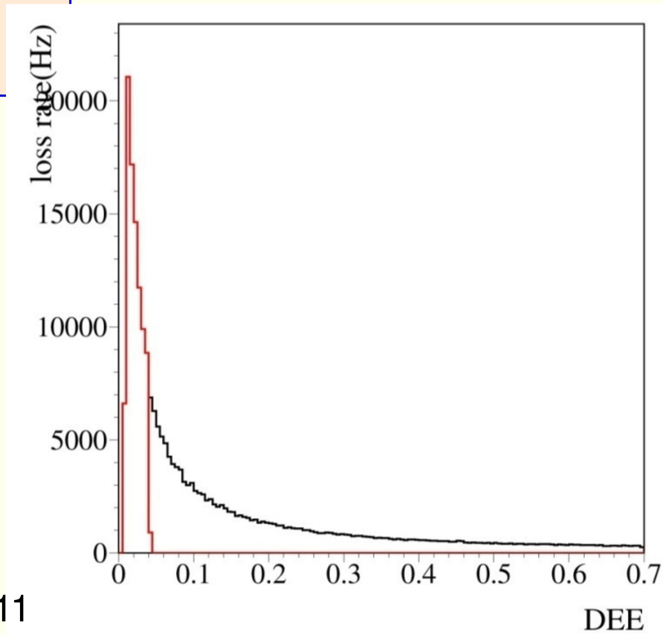
P = 1 nTorr, Z = 8

integrated formula	$\tau_{Brems} = 3.8 \cdot 10^5$ s ≈ 107 hrs; tot. losses=175 kHz
MC with NTurn=1, no aperture check	$\tau_{Brems} = 3.8 \cdot 10^5$ s ≈ 107 hrs

MC with NTurn=**10**, aperture check	$\boldsymbol{\tau_{Brems} = 2.8 \cdot 10^5}$ **s ≈ 77 hrs** IR Losses = 600 Hz/bunch tot losses= 233 kHz/bunch

losses for exceeding physical aperture

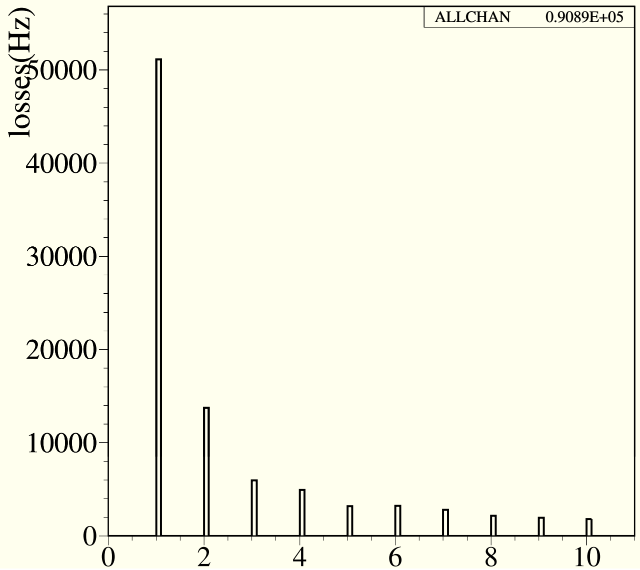
62% of total losses

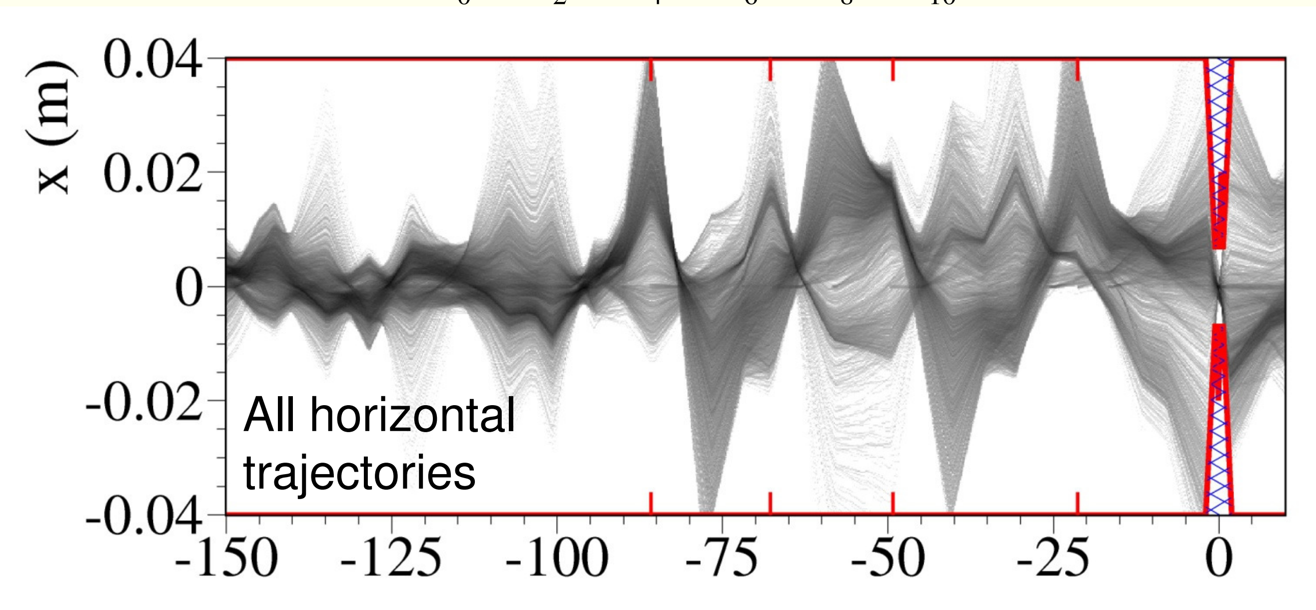


these are losses not taken into account with integrated cross section (enters only the RF acceptance)

LER Beam-gas Bremsstrahlung

V12 lattice





Conclusions (1): Lifetime summary

	HER	**LER**
Touschek lifetime	τ_{TOU} (min)	τ_{TOU} (min)
No collimators, nominal ε_x (no IBS)	39.8	5.9
No collimators, ε_x with IBS	40.0	7.8
With Collimators, ε_x with IBS	33.2	6.6

Coulomb	2 hrs	30 min
Bremsstrahlung	83 hrs	77 hrs

Conclusions (2): IR rates summary

	HER	LER
Touschek	Hz/bunch	Hz/bunch
No collimators, ε_x with IBS	$1.1 \cdot 10^6$	6.510^6
With Collimators, ε_x with IBS	$4.5 \cdot 10^2$	$1.4\ 10^4$

Coulomb No collimators, ε_x with IBS	$1.1 \cdot 10^6$	$6.4 \cdot 10^6$
Coulomb with collimators, ε_x with IBS	$4.4 \cdot 10^4$	$9.1 \cdot 10^3$
Bremsstrahlung	400	600

back-up

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 SuperB 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}

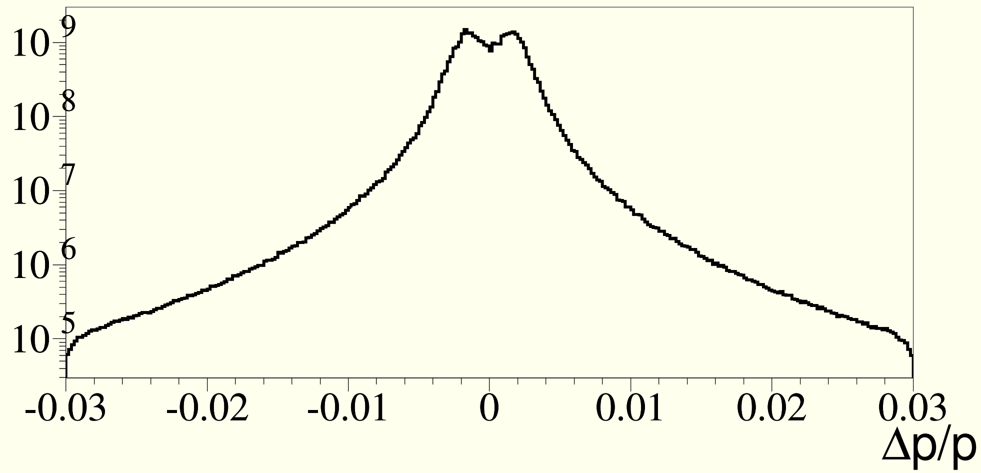
CDR2

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}

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)

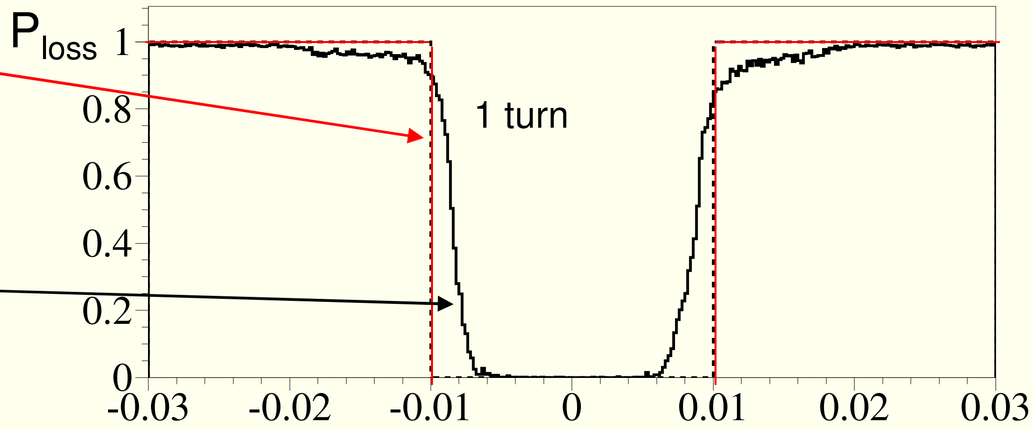
assuming that particles with |Δp/p|>1% are lost (like CDR):

τ = 308 s

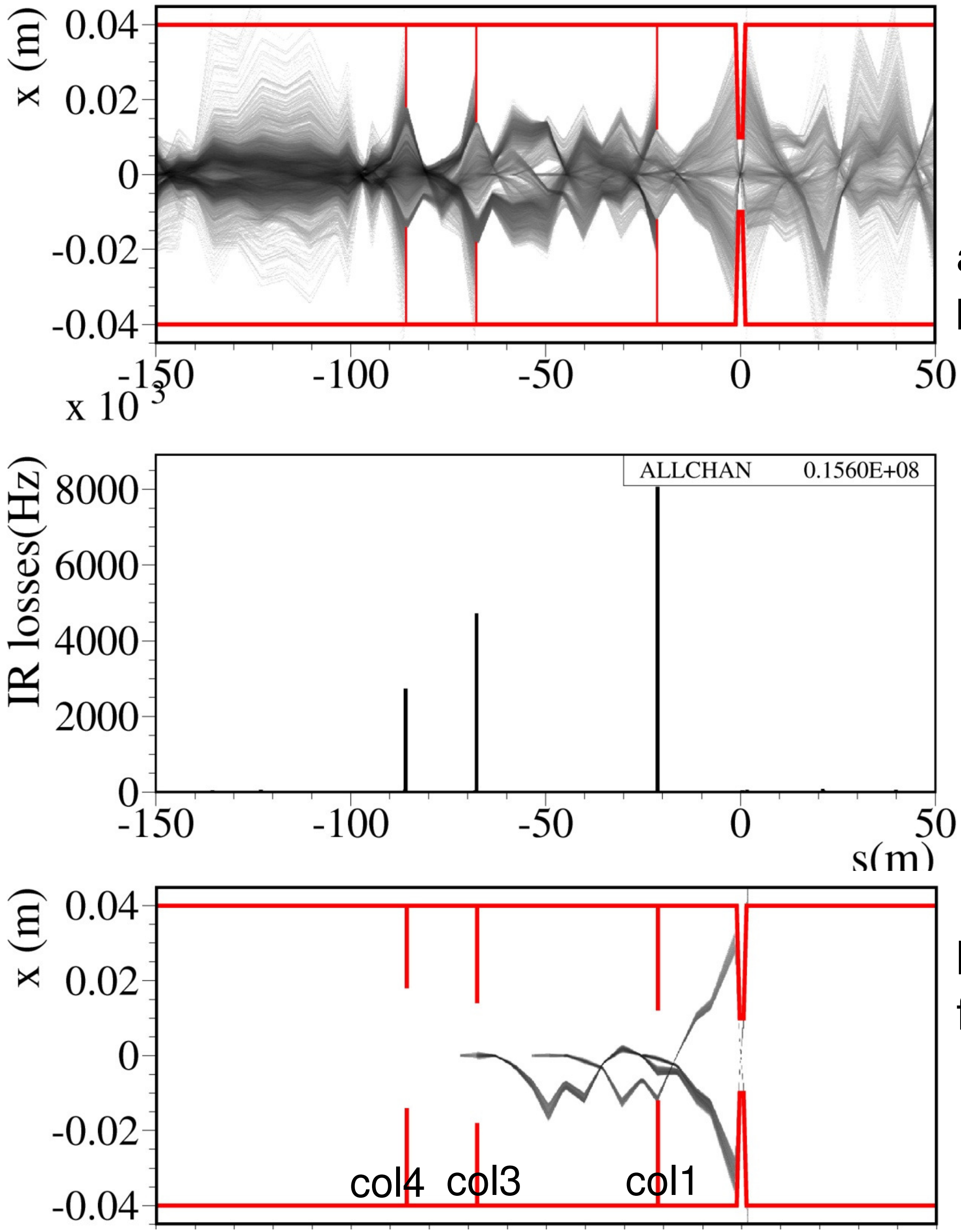
good agreement with CDR

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)



all Touschek particles

Partial insertion of collimators

Col3 = 1.6, -1.8 cm
Col4 = -1.6, 1.8 cm
Col1 = -1.2, 1.2 cm

tau=2185 s (36.4min)
(about 8% reduction)

IR losses reduced a factor 100:
from 0.22e7Hz to 0.207e5Hz

Present parameters Table

(Bold: computed values)		Base Line	
Parameter	Units	HER (e+)	LER (e-)
LUMINOSITY	$cm^{-2}\ s^{-1}$	1.00E+36	
Energy	GeV	6.7	4.18
Circumference	m	1258.4	
X-Angle (full)	mrad	66	
β_x @ IP	cm	2.6	3.2
β_y @ IP	cm	0.0253	0.0205
Coupling (high current)	%	0.25	0.25
Emittance x (without IBS)	nm	1.97	1.82
Emittance x (with IBS)	nm	2.00	2.46
Emittance y	pm	**5**	**6.15**
Bunch length (zero current)	mm	4.69	4.29
Bunch length (full current)	mm	5	5
Beam current	mA	1892	2447
Buckets distance	#	2	
Ion gap	%	2	
RF frequency	Hz	4.76E+08	
Revolution frequency	Hz	**2.38E+05**	
Harmonic number	#	**1998**	
Number of bunches	#	**978**	
N. Particle/bunch	#	**5.08E+10**	**6.56E+10**
σ_x @ IP	microns	**7.211**	**8.872**
σ_y @ IP	microns	**0.036**	**0.036**
$\sigma_{x'}$ @ IP	microrad	**277.4**	**277.3**
$\sigma_{y'}$ @ IP	microrad	**140.6**	**173.2**
Piwinski angle	rad	**22.88**	**18.60**
σ_x effective	microns	**165.22**	**165.30**
Σ_x	microns	**11.433**	
Σ_y	microns	**0.050**	
Σ_x effective	microns	**233.35**	
Hourglass reduction factor		0.950	
Tune shift x		**0.0021**	**0.0033**
Tune shift y		**0.0970**	**0.0971**
Longitudinal damping time	msec	13.4	20.3
Energy Loss/turn	MeV	2.11	0.865

Momentum compaction		4.36E-04	4.05E-04
Energy spread (zero current)	dE/E	6.31E-04	6.68E-04
Energy spread (full current)	dE/E	6.43E-04	7.34E-04
CM energy spread	dE/E	**5.00E-04**	
Energy acceptance	dE/E	0.01	0.01
SR power loss	MW	**3.99**	**2.12**
Touschek lifetime	min	35	16
Luminosity lifetime	min	**4.81**	**6.23**
Total lifetime	min	**4.23**	**4.48**
RF Wall Plug Power (SR only)	MW	**12.22**	
Total RF Wall Plug Power	MW	17.08	

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

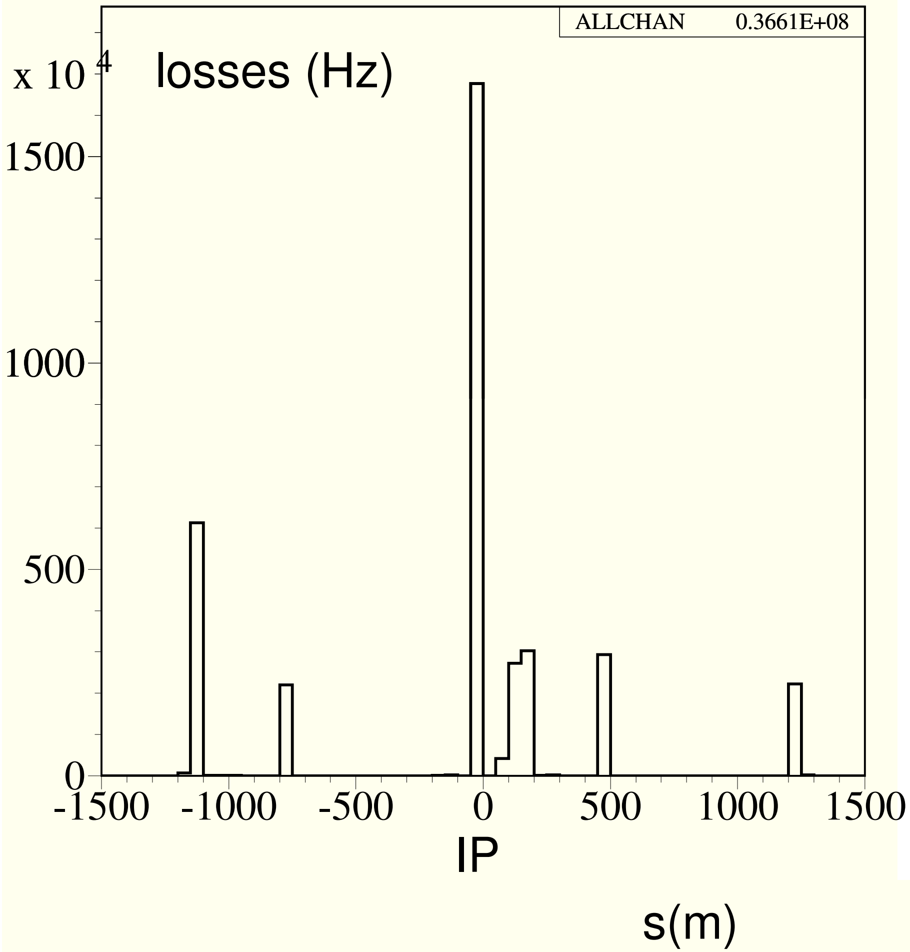
Tracking of Touschek particles:
Start with transverse gaussian distribution and proper energy spectra every 3 elements: track over many turns or until they are lost

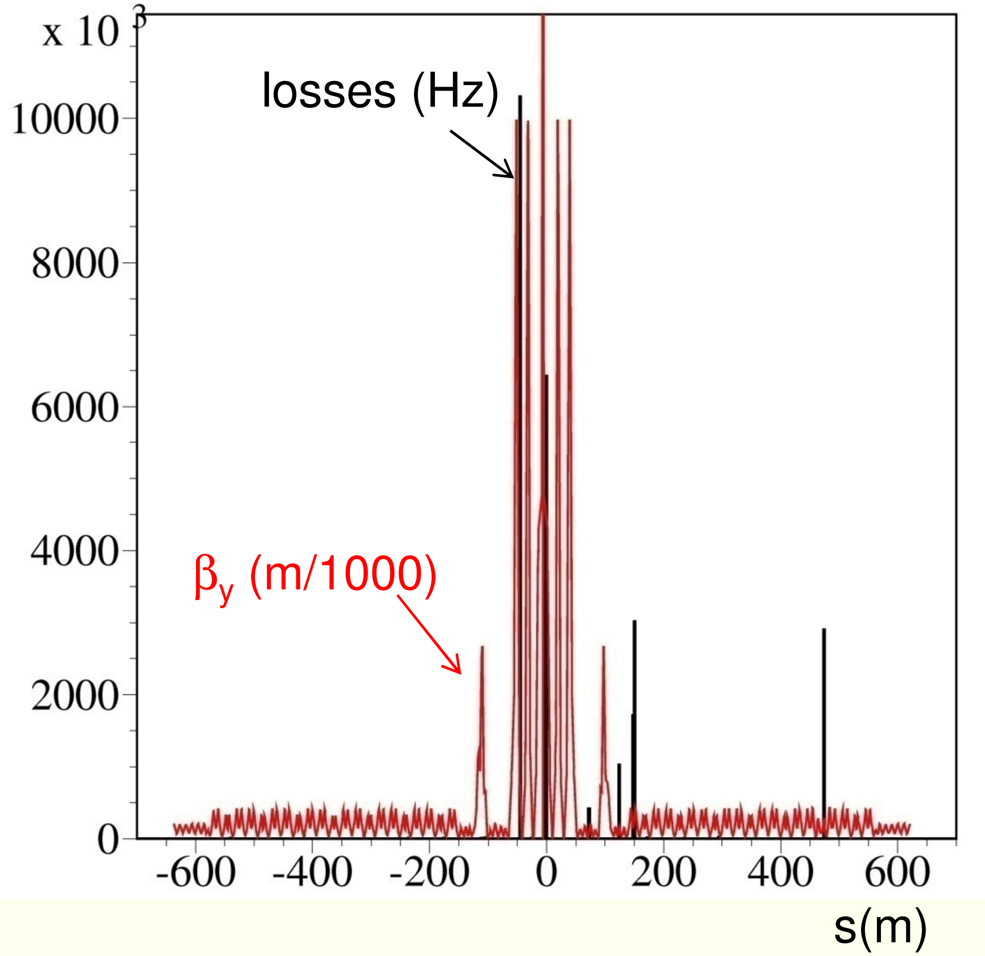
- Estimation of IR and total Touschek particle losses (rates and longitudinal position)
- Estimation of Touschek lifetime

Coulomb scattering

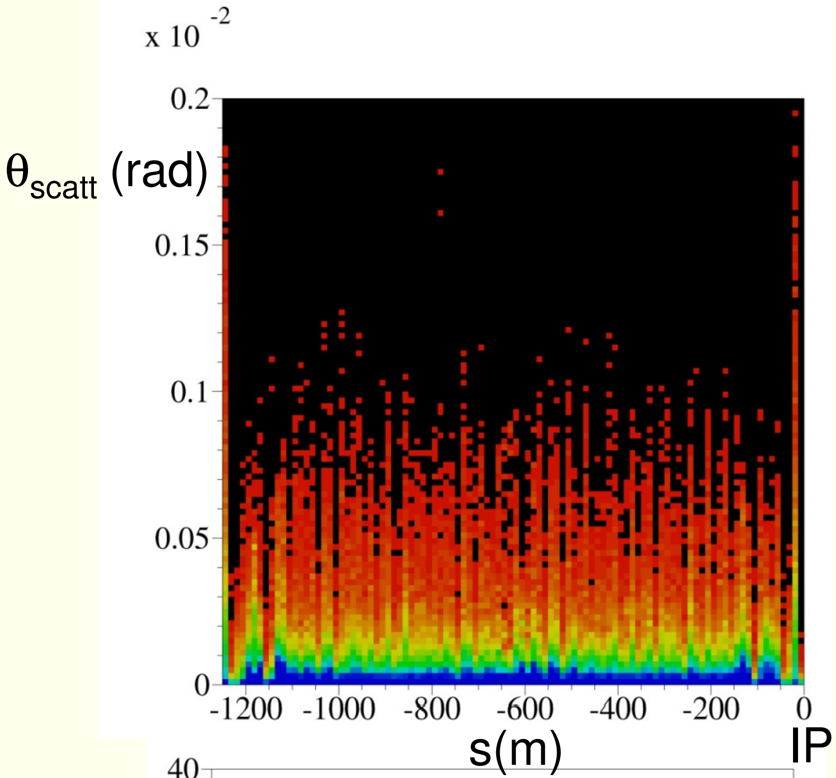
LER v12lattice

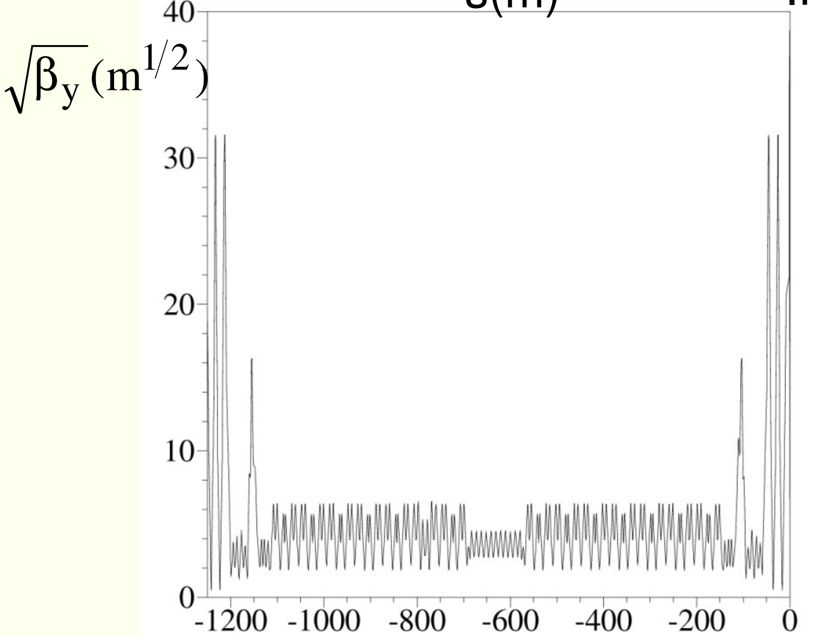
Mostly vertical losses





Coulomb scattering





Scattering angle as a function of the longitudinal position

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Scattering angle sums up to vertical beam size