SuperB IR:
backgrounds overview

from the machine side

M. Boscolo (INFN-LNF)

Luminometry and IP beam monitors for high luminosity
Flavour Factories: techniques and detectors
Napoli, November 22nd-23rd 2012

Outline

- Introduction
- Dominant effects on backgrounds and lifetime
- Evaluation procedure and rates of primary losses
  - Touschek
  - Beam-gas
  - Radiative Bhabha
  - Syncrotron radiation
- Collimation system in the final focus
- Conclusions

Machine Backgrounds

Key issue of the SuperB project

Each subsystem of the detector must be able to sustain the expected backgrounds hits, and avoid deterioration due to radiation damage

Detector's subsystems:

- SVT
- DCH
- PID
- EMC
- IFR
- ETD

Each subsystem is challenging and needed some R&D
Dedicated studies in each subsystem to define
sustainability of expected backgrounds

Expected change on backgrounds from B-factories (PEPII) to Super-B factories

- Higher luminosity (factor 80)

  → Radiative Bhabha/2-photon scattering rate increases drastically

- Smaller beam size (LER ~ factor 20 hor.)
- Smaller emittance

  →Touschek scattering rate increases drastically

- Smaller IR beam pipe aperture

  → scattered particles are more likely to be lost in IR, not in the ring

Backgrounds studies

- Studies have been finalized to
  - estimate rate of each background source
  - Develop counter-actions so that these rates are tolerable for each sub-detector

Counter-actions:

- First of all during design: find the right trade-off between different machine parameters
  (essentially emittance, bunch current, bunch length)
- IR beam-stay-clear as large as possible (trade-off with experiment)
- Efficient Collimators system (horizontal + vertical)
- Efficient detector shieldings

Dominant effects on backgrounds and lifetime

Two colliding beams

- **Radiative Bhabha** → dominant effect on lifetime
- Pairs Production → important source of bkg in L0 of the SVT

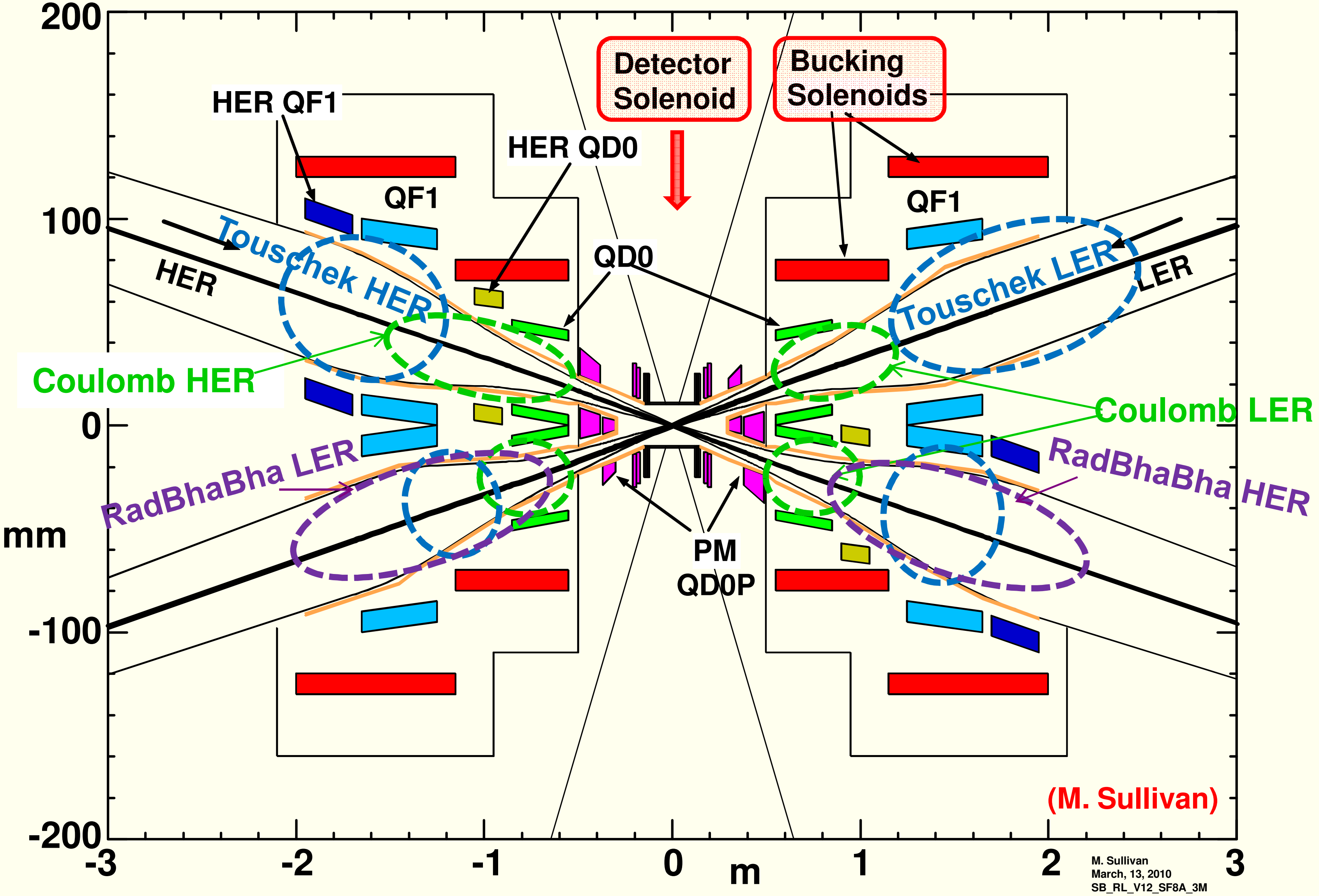
Main effect from direct bkg studied with standard MC generators (BBBrem, GP++,...)
Multiturn effect for RBB sudied with full machine simulation

Single beam

- Synchrotron Radiation
- Single Touschek effect → important especially for LER
- Coulomb Beam-gas
- Bremsstrahlung

Main effect studied with full machine simulation

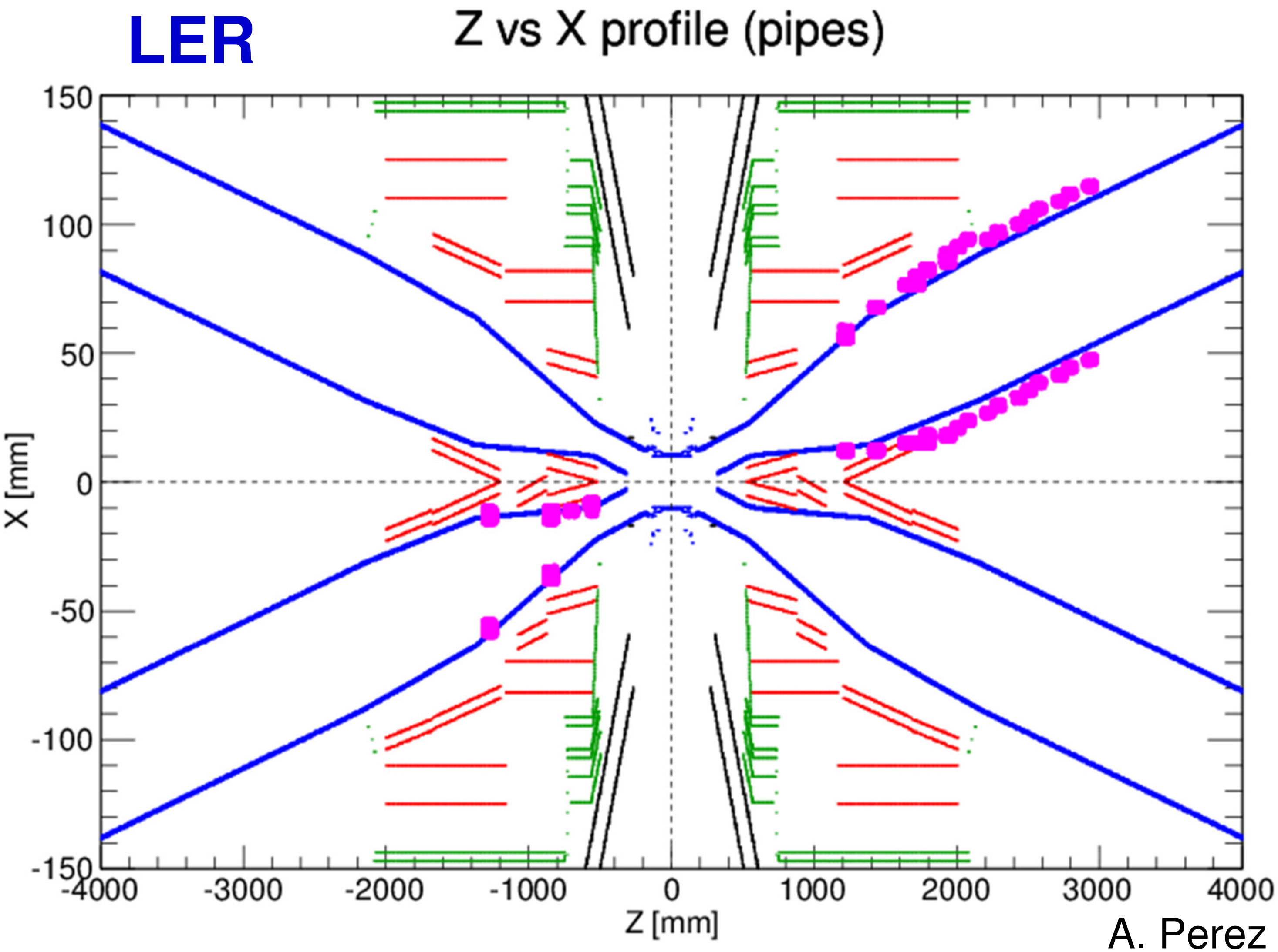
IP region with backgrounds hot spots



M. Boscolo, LFF Workshop, Nov. 22-23 2012

Touschek particles hitting the pipe: full geometry before tracking

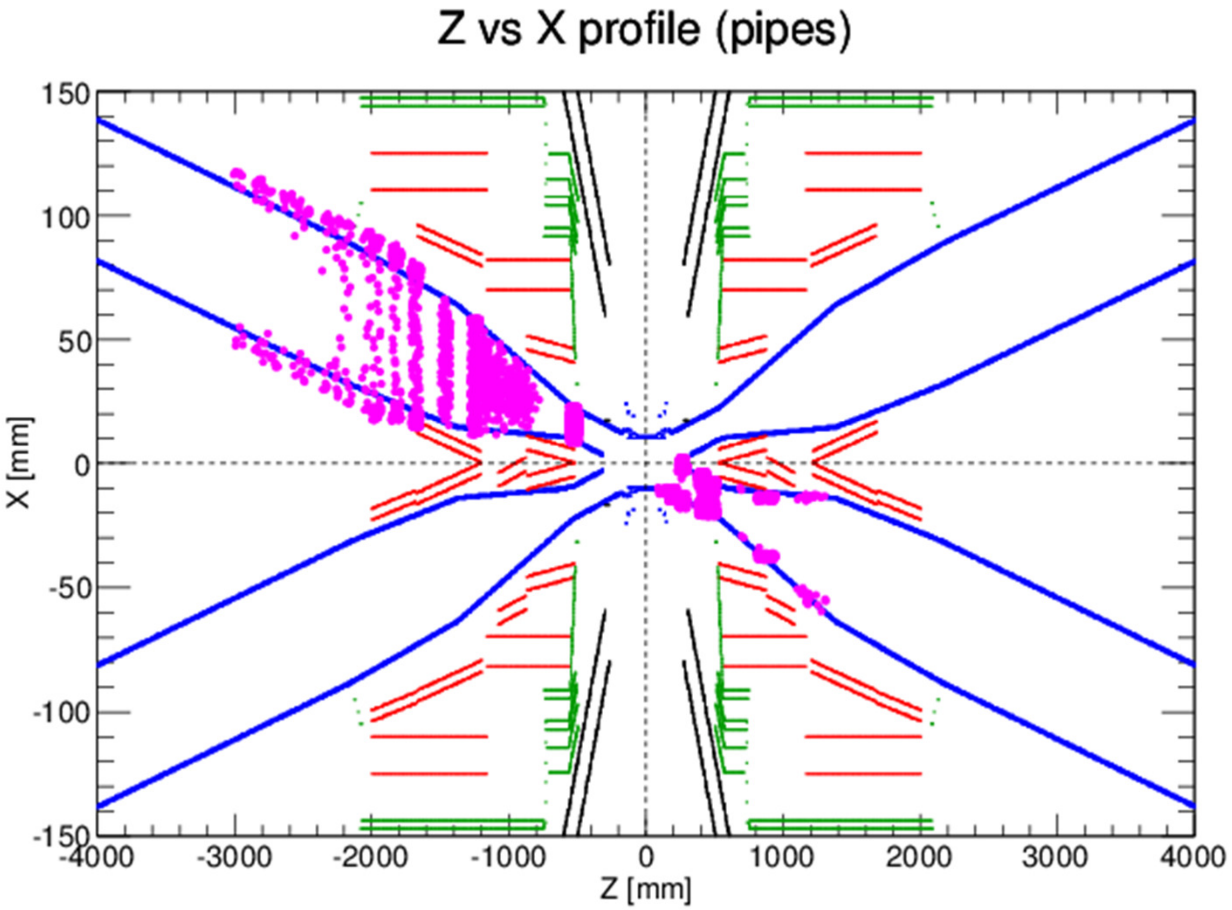
LER



A. Perez

Coulomb particles hitting the pipe: full geometry before tracking

HER



[A. Perez]

Beam Lifetime

- Dominated by luminosity itself- all other contributions are much smaller but for the Touschek effect in the LER.
- Dynamic aperture and momentum acceptance are crucial for the Touschek lifetime
- dedicated Monte Carlo simulation (for all the effects contributing to particle losses) necessary for:
  - lifetime evaluation
  - careful study of backgrounds, horizontal/vertical collimation system design and shieldings

Lifetime (seconds)	**HER**	**LER**
Radiative Bhabha	290* / 280^{+}	380* / 420^{+}
Touschek	1320	420
Coulomb Beam-gas	3040	1420
Bremsstrahlung	72 hrs	77 hrs

with collimators inserted and IBS included
(momentum acceptance calculated with tracking)

* 1% momentum acceptance assumed
$^{+}$ momentum acceptance calculated with tracking

Total Lifetime	**220 s** (3.7 min)	**180 s** (3.0 min)

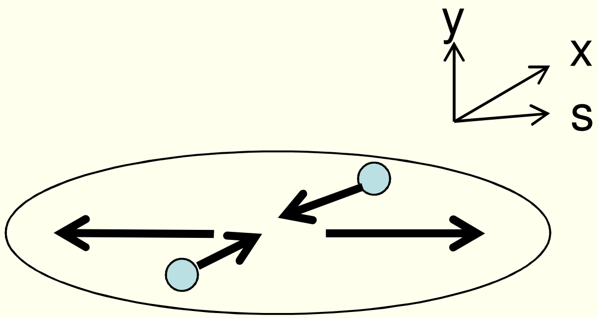
Single beam backgrounds IR rates summary

|s|<2 m

Touschek	**HER**	**LER**
Touschek No collimators, ε_x with IBS	2.4 GHz/4m	17 GHz/4m
Touschek with Collim., ε_x with IBS	**6.8 MHz** /4m	**72 MHz**/4m

Coulomb No collimators, ε_x with IBS	10.5 GHz/4m	25 GHz/4m
Coulomb with collim ε_x with IBS	**3.7MHz/4m**	**20 MHz/4m**
Bremsstrahlung with coll	130KHz/4m	450KHz/4m

Touschek Background source



Scattering rate $\propto$ 1/ (beam sizes), $1/\gamma^3$, N_{part}

The Coulomb scattering between particles in a stored bunch induces an energy exchange between transverse and longitudinal motions.

In this process small transverse momentum fluctuations are transformed into magnified longitudinal fluctuations due to the relativistic Lorentz factor in the transformation.

Off-momentum particles can exceed the rf momentum acceptance, or they may hit the aperture when displaced by dispersion. In both cases they get lost.

This process results in a finite lifetime of a bunched beam.

Touschek effect calculation

- **There are different ways to calculate Touschek lifetime:**
    - Give the machine momentum acceptance as input, and calculate the formula of the Touschek lifetime averaging on the whole lattice
    - Calculate the local momentum acceptance through the lattice elements and calculate the formula for each small section of the lattice and then sum up
    - Perform tracking of macroparticles with non-linear kicks included, so the momentum acceptance is calculated for each macroparticle, dynamic aperture calculated intrinsically

⇩

- **Most accurate estimate is with a macroparticle tracking code with the Monte Carlo technique**
    - *S. Khan, Proc. of EPAC 1994 – Bessy II*
    - *A. Xiao and M. Borland,* Phys.Rev.ST-AB 13 074201 (2010) pp10
    - *M.Boscolo and P. Raimondi,* Phys.Rev.ST-AB 15 104201 (2012) pp11 and ref. therein

LNF Tracking code Monte Carlo

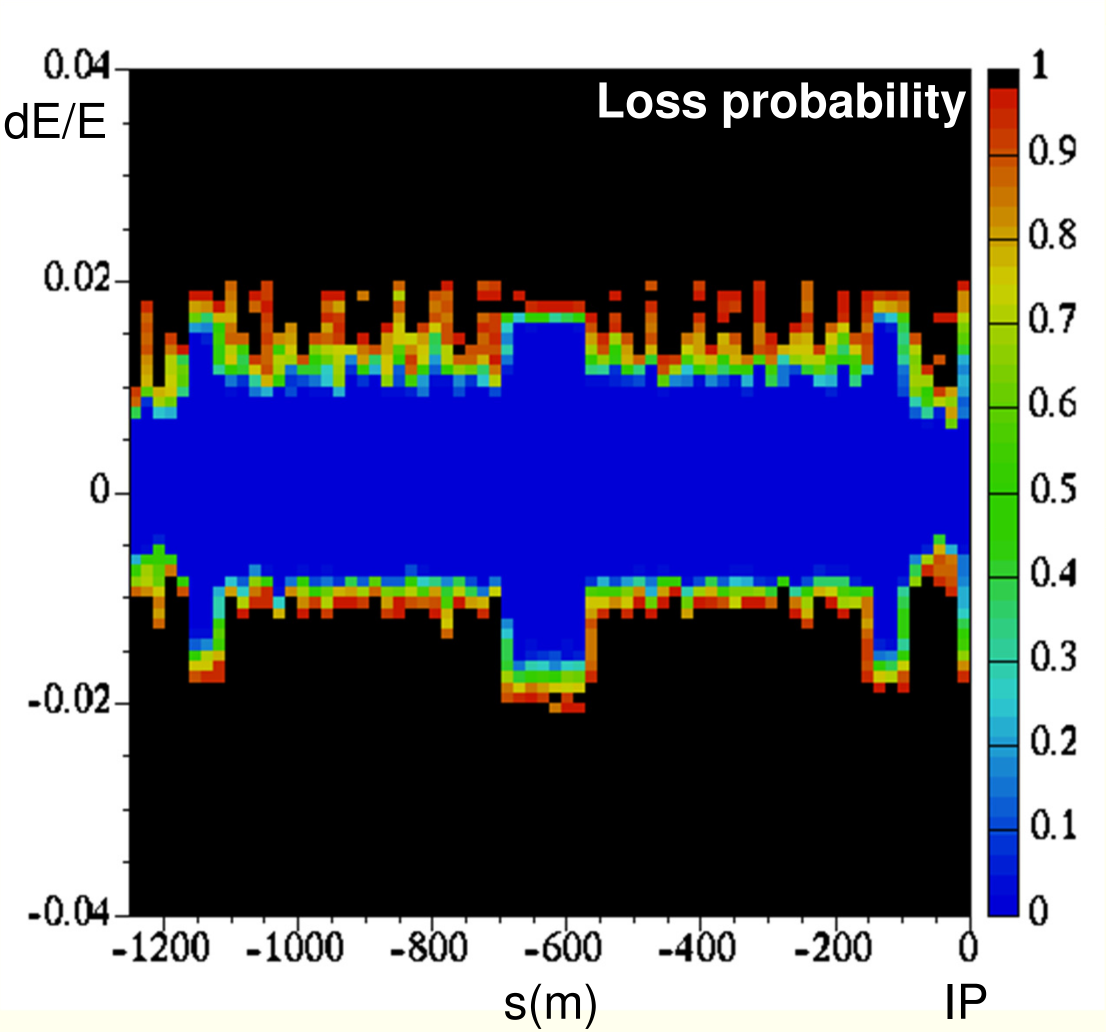
- The lattice is imported from MAD8
- At each element in the ring a set of macroparticles (usually 500) is extracted from a Gaussian distribution in the transverse planes and with a proper energy off-set -given by very nonlinear dependence of the Touschek scattering probability to the energy $1/\tau = a\,|E|^{b}$ (*a* and *b* depend locally on the lattice) [C. Bernardini *et al.* PRL 10 (1963)].
- The macroparticles have a weight proportional to the Touschek scattering probability: $\frac{1}{\tau} = \frac{\sqrt{\pi} r_e^2 cN}{\gamma^3 (4\pi)^{3/2} V \sigma_x' \delta_\varepsilon^2} C(u_{\min})$

$$\delta_\varepsilon = \frac{\Delta E}{E} \qquad u_{\min} = \left(\frac{\delta_\varepsilon}{\gamma \sigma_x'}\right)^2 \qquad \sigma_x' = \sqrt{\frac{\varepsilon_x}{\beta} + \sigma_p^2 \left(D_x' + D_x \frac{\alpha_x}{\beta_x}\right)^2}$$

$$C(u_{min}) = \int_{u_{min}}^{\infty} \frac{1}{u^2} \left[u - u_{min} - \frac{1}{2} \ln\left(\frac{u}{u_{min}}\right)\right] e^{-u} du$$

- 4-D tracking in the transverse dimensions; once per turn the macroparticle’s energy deviation is compared to rf acceptance. Loss location not determined, not need to track for few damping times
- >10^6 macroparticles tracked for few machine turns or until they are lost
- Benchmarked with DAFNE measured data, showing good agreement
- Detailed loss particles analysis useful for background studies in colliders

Momentum aperture



Not simply an s dependent momentum aperture

A.Xiao,M.Borland, PAC07 p.3457

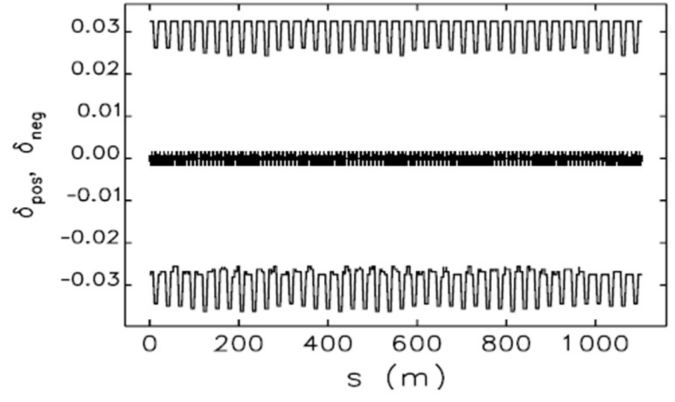
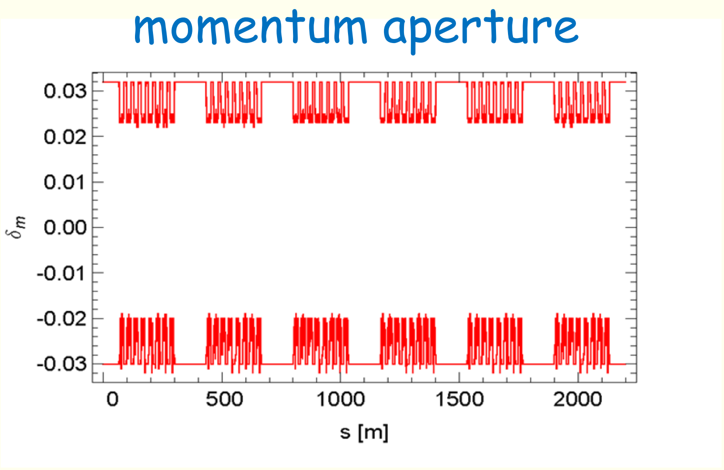


Figure 1: Momentum aperture of the APS.



PEP-X Y. Cai, SLAC
FLS-2012, March 2012

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**,

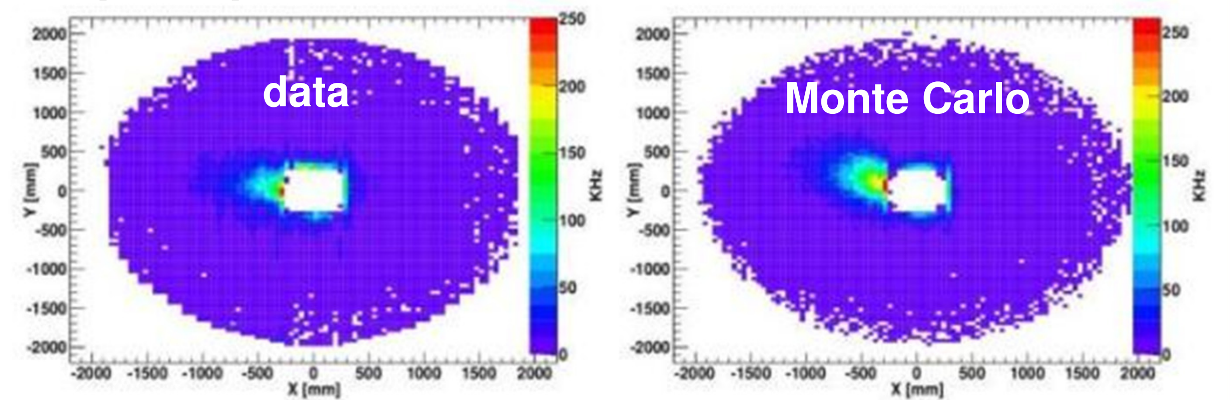
which might be explained by a misalignment of the on-energy beam orbit that induced beam scraping in the IP2 section, as found after these measurements.

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

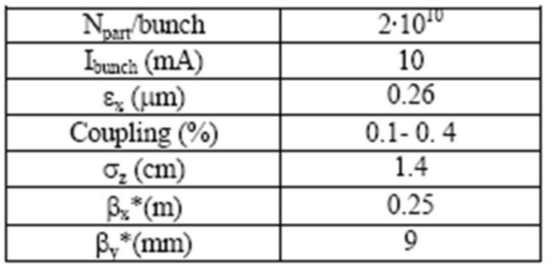
In addition, dynamic aperture was not optimized in the machine as well as in the MAD lattice used for calculation.

Benchmark with DAFNE real data

[IPAC11]



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



N_{part}/bunch	$2\cdot10^{10}$
I_{bunch} (mA)	10
ε_x (μm)	0.26
Coupling (%)	0.1- 0. 4
σ_z (cm)	1.4
β_x*(m)	0.25
β_y*(mm)	9

See also

- M. Boscolo et al. PAC01 P.2032
- M. Boscolo, M. Antonelli and S. Guiducci, EPAC02 p.1238
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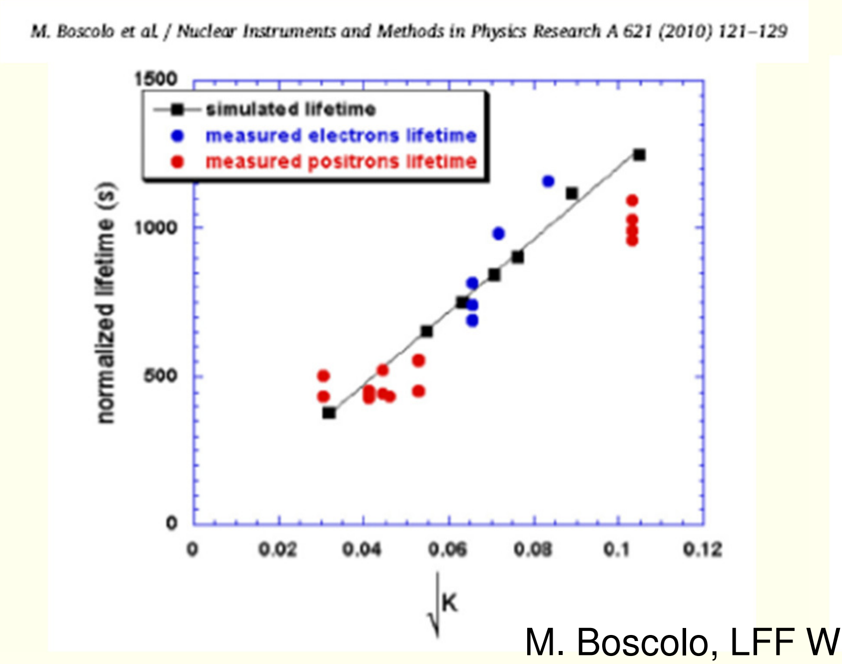
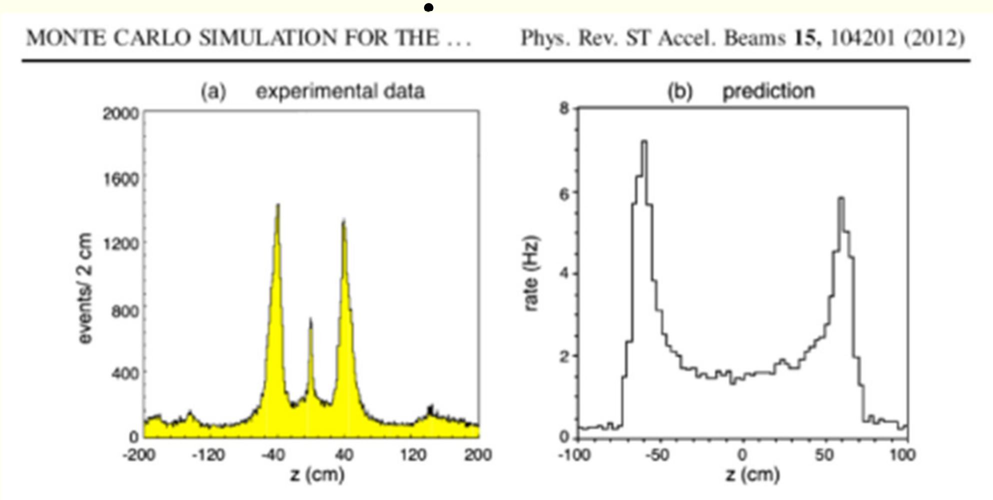


M. Boscolo et al. / Nuclear Instruments and Methods in Physics Research A 621 (2010) 121–129



MONTE CARLO SIMULATION FOR THE … Phys. Rev. ST Accel. Beams 15, 104201 (2012)

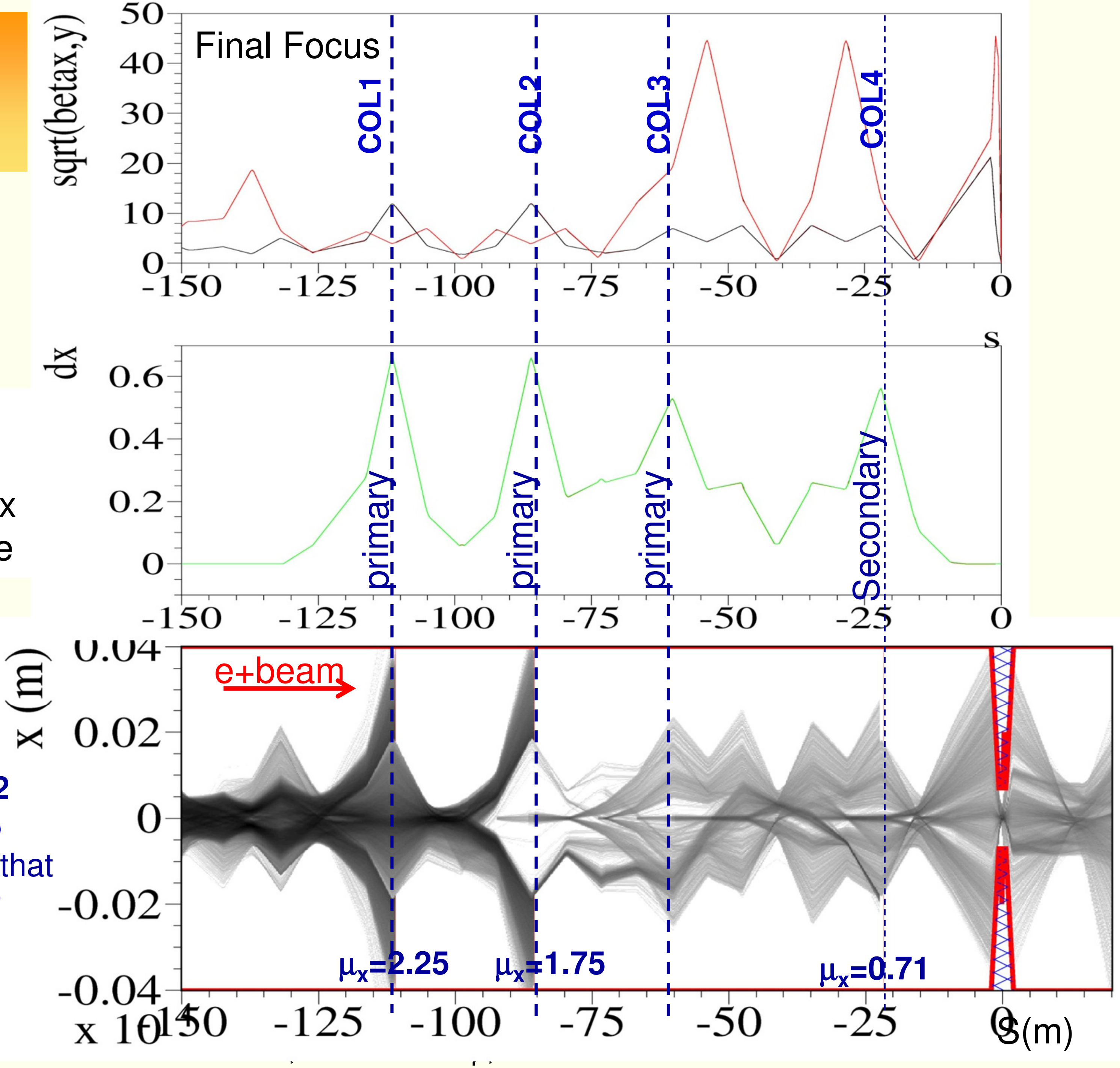
FIG. 12. (a) High rate of localized monotracks (protons) in KLOE until 2001 understood as photoproduction $ep(n) \rightarrow \Lambda e \rightarrow p\pi^0(\pi^-)e$, induced by Touschek particles hitting the beam pipe support; (b) prediction from full simulation of Touschek particles into detector.

Collimators optimization

HER SuperB

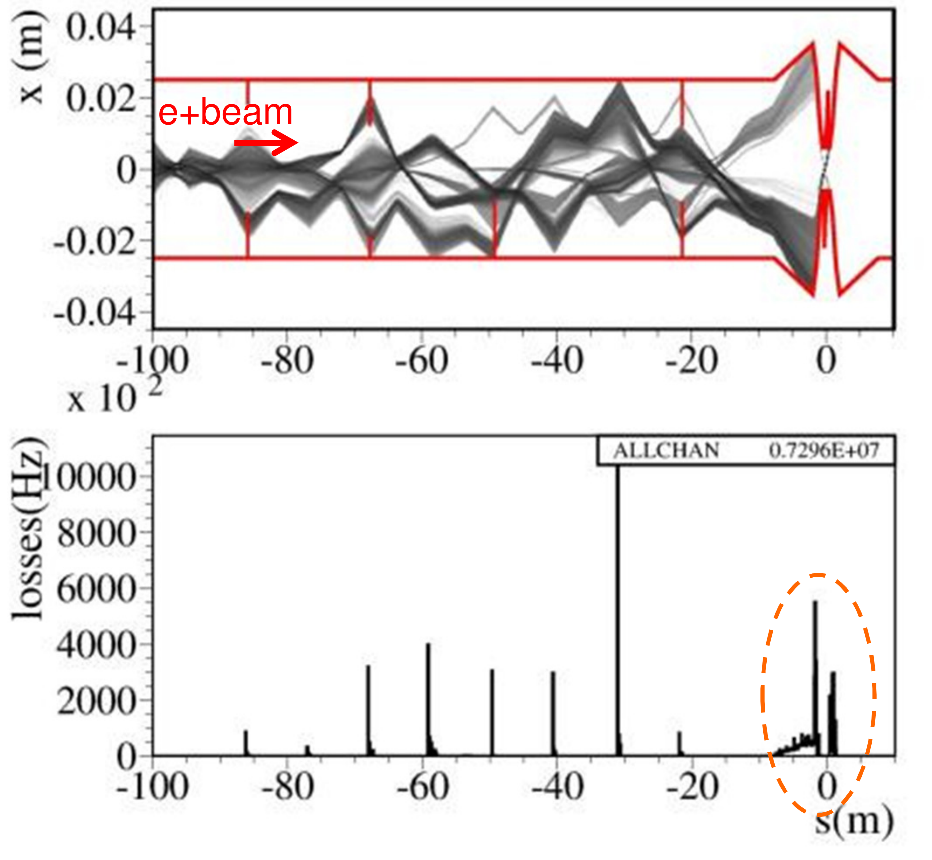
Horizontal Collimators are located where βx and Dx are large

collimators at **n·π/2** upstream the IP to intercept particles that would be lost at IP

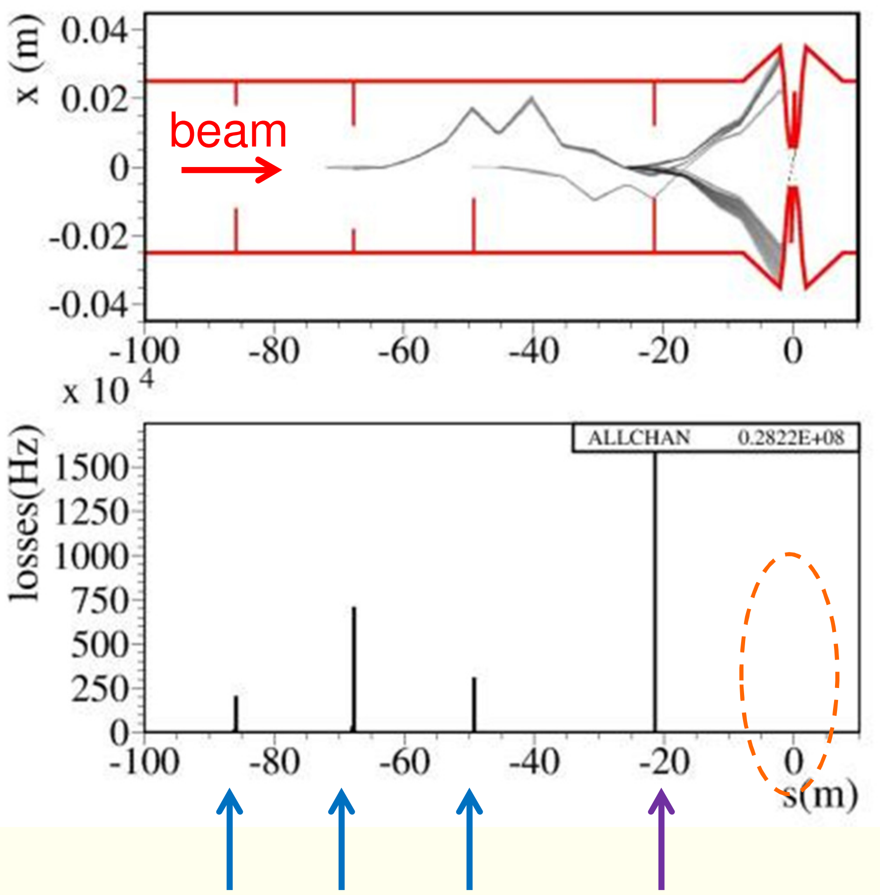


HER Touschek Trajectories

No collimators



with collimators

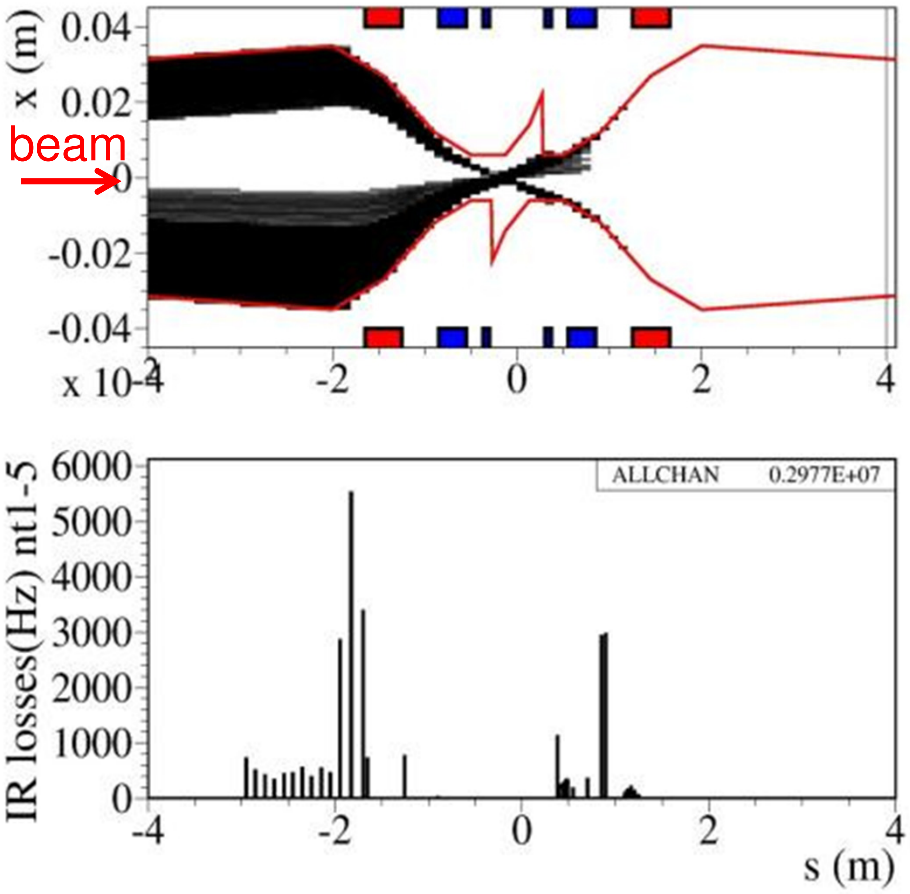


found by minimizing IR rates and maximizing lifetime

real set will be found experimentally

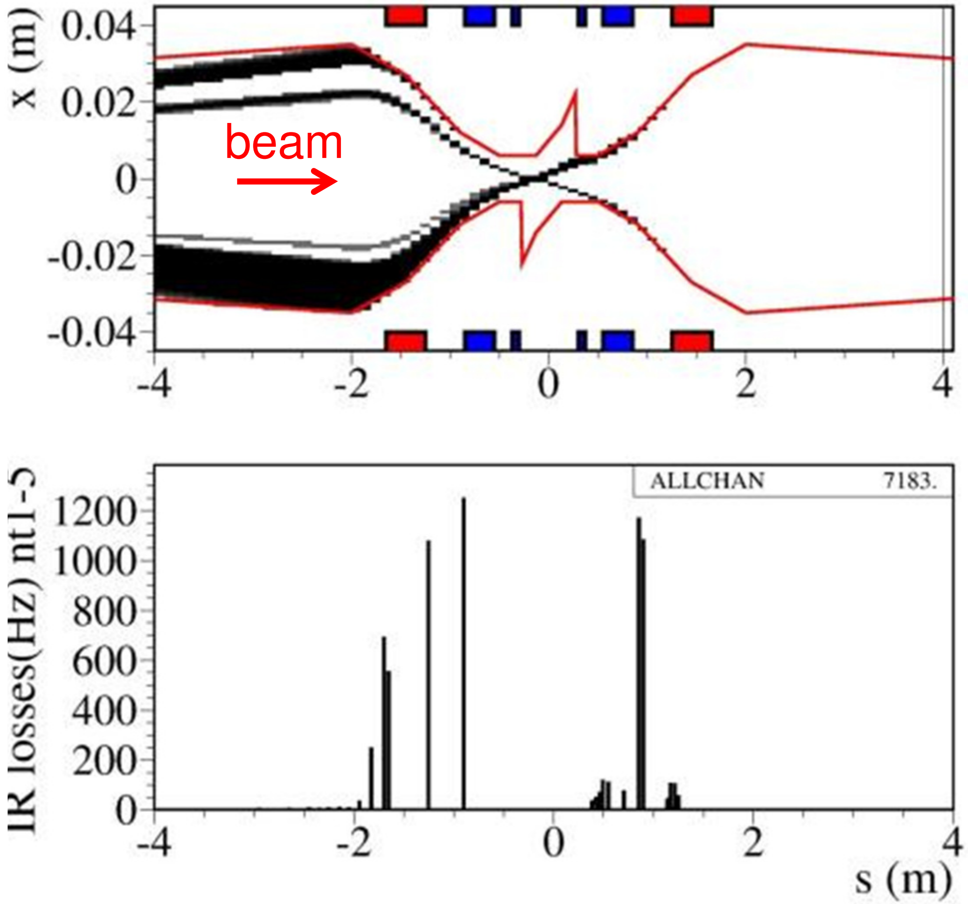
HER IR losses (|s|< 2 m)

NO collimators



IP

with collimators

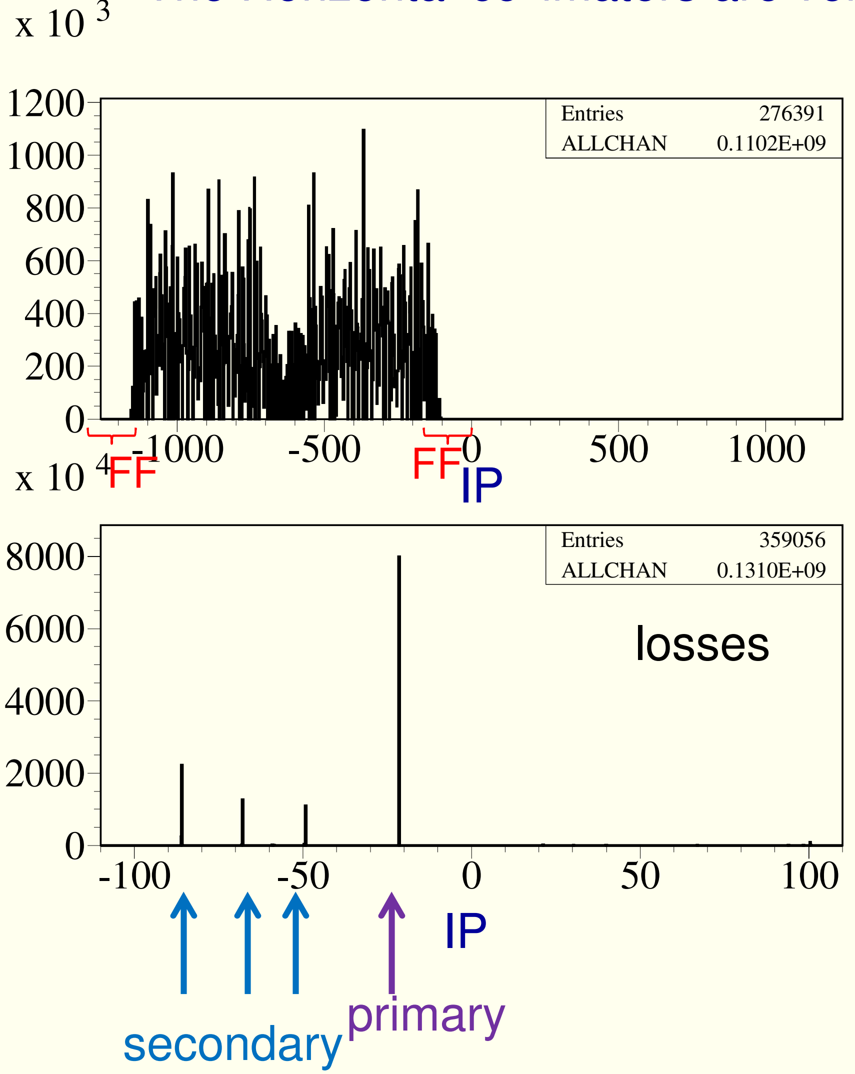


IP

Collimators greatly reduce loss rates

LER Horizontal collimators efficiency

The Horizontal collimators are very efficient



Touschek scattering points through ring except final focus

LER Touschek IR background rates

I_b =2.5 mA

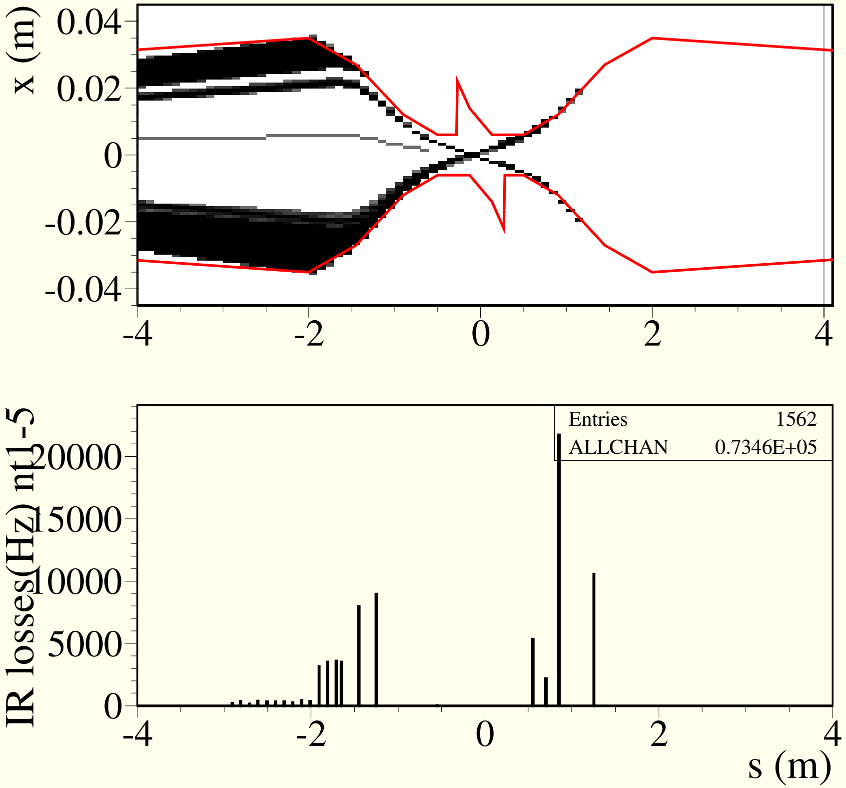
|s|< 2 m

With IBS: ε_x =2.4 nm

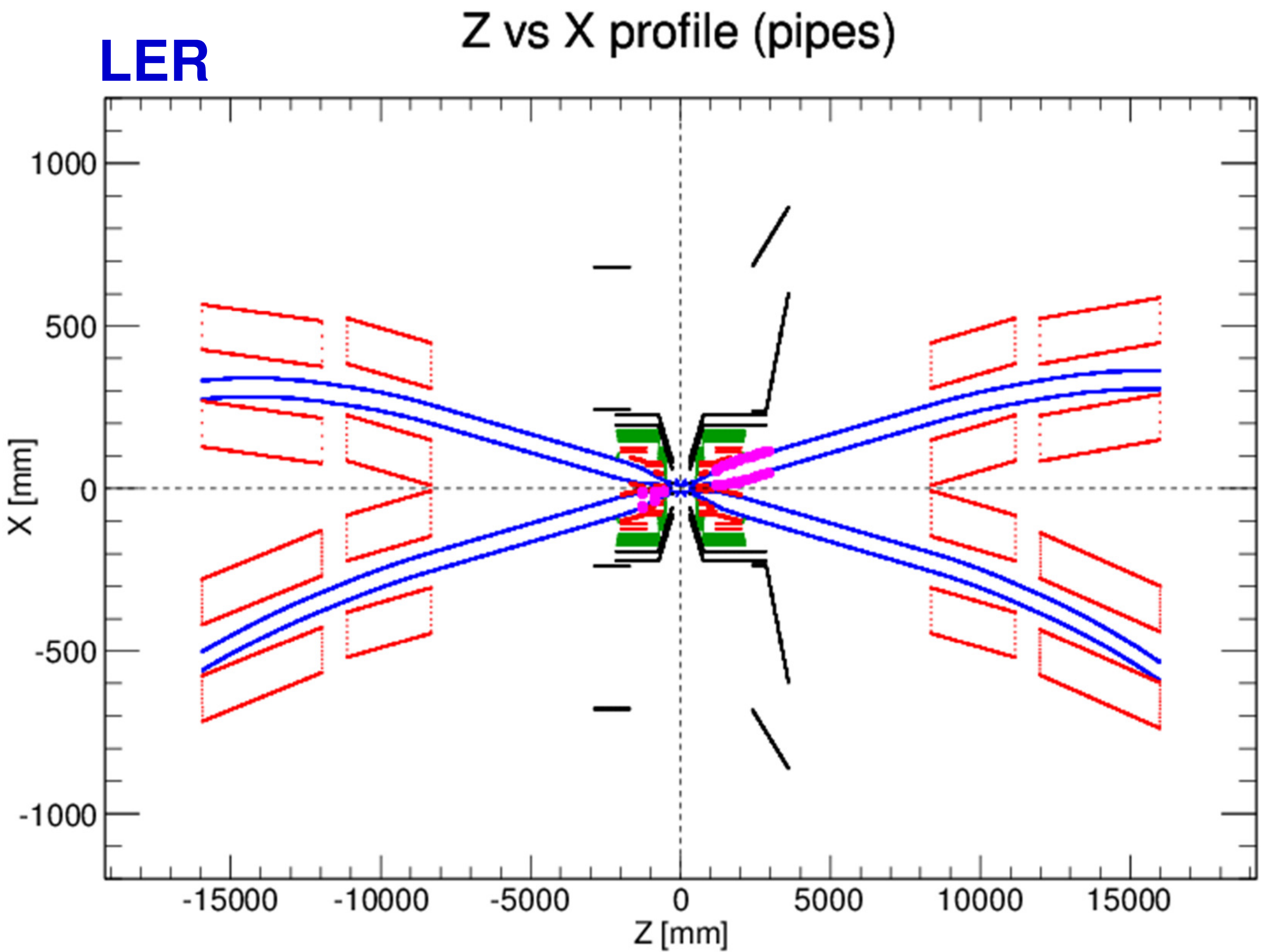
Collimators inserted further
With a 1.3 IR rates reduction

with collimators= 73.3 kHz/bunch × 978 bunches =72 MHz/beam/4m

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



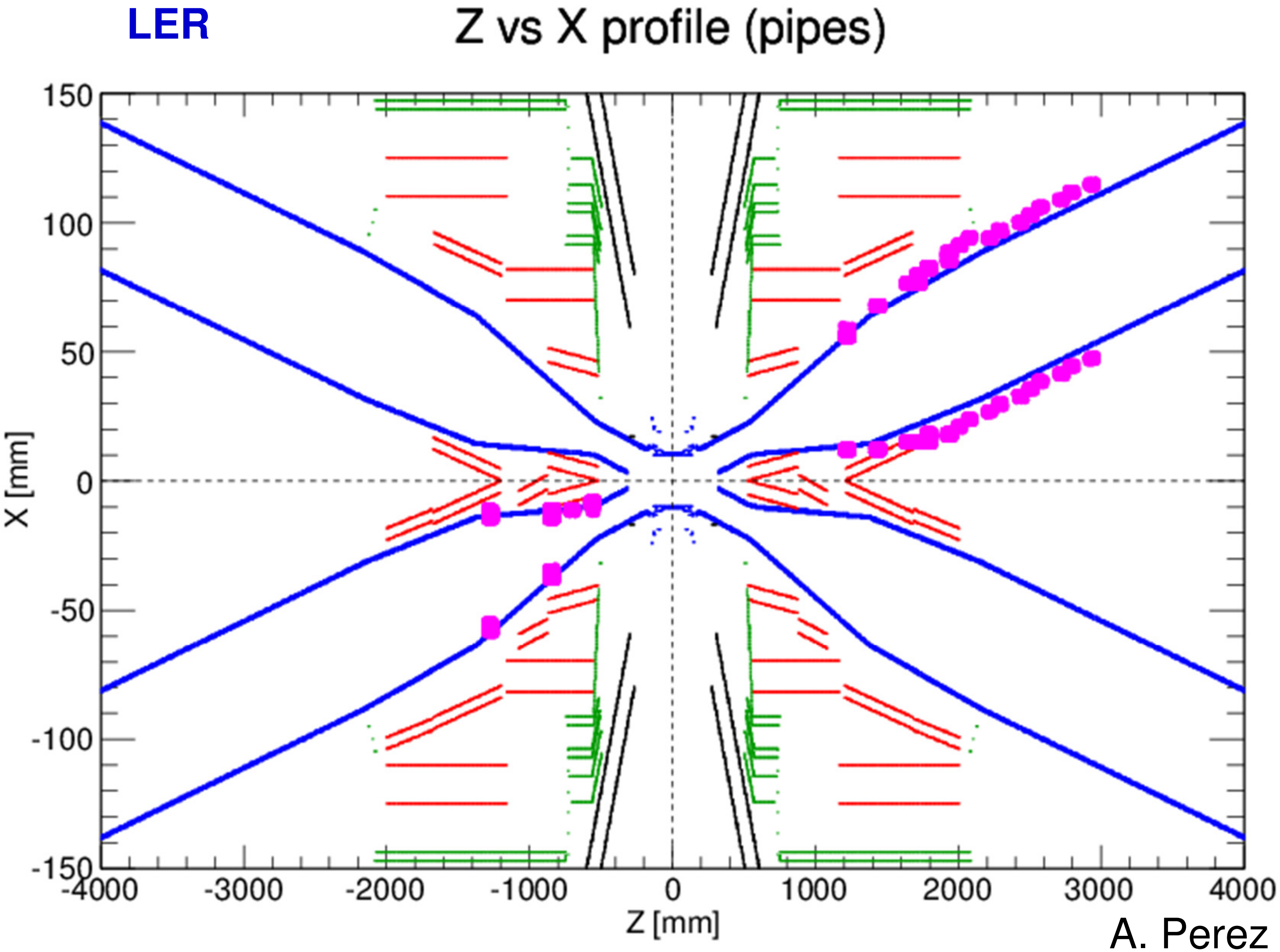
Touschek particles hitting the pipe: full geometry before tracking



A. Perez

Touschek particles hitting the pipe: full geometry before tracking

Zoom within 4 m



A. Perez

Collimators – basic idea

They should intercept the Touschek particles
in the final focus upstream the IR
that otherwise would be lost at the QF1

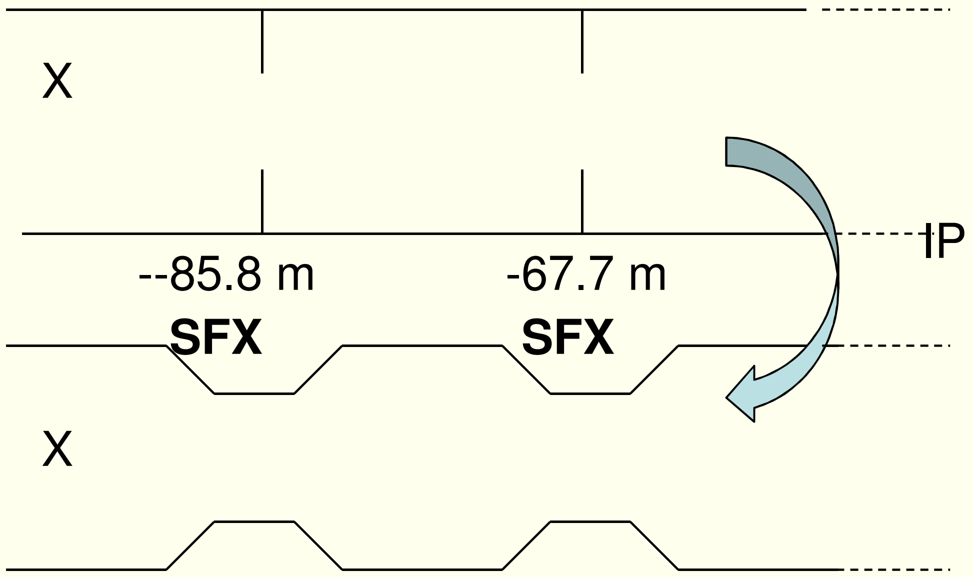
So, in principle, the good collimators set corresponds to the same Beam Stay Clear , in sigmax units, that we have in the IR

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

- 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.**



Beam-gas scattering

Coulomb>> Bremsstrahlung

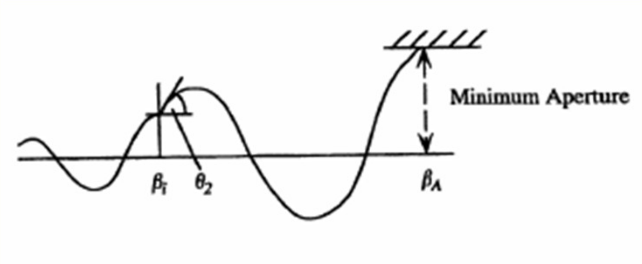
Coulomb beam-gas scattering is proportional to P x I
Also depends on beta function and IR physical aperture.

P = 1nTorr is assumed

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

Beam-gas Coulomb lifetime

multiturn effect, as expected



betatron oscillation excitation

Beam lifetime τ_{Coul} is proportional to θ_c^2

$$\frac{1}{\tau_{Coul}} = cn_G \langle \sigma_R \rangle = cn_G \frac{4\pi \sum Z^2 r_e^2}{\gamma^2} \boxed{\left\langle \frac{1}{\theta_c^2} \right\rangle}$$

Rate ∝ P · I · <β>

The minimum scattering angle θ_c to hit QD0 beam pipe

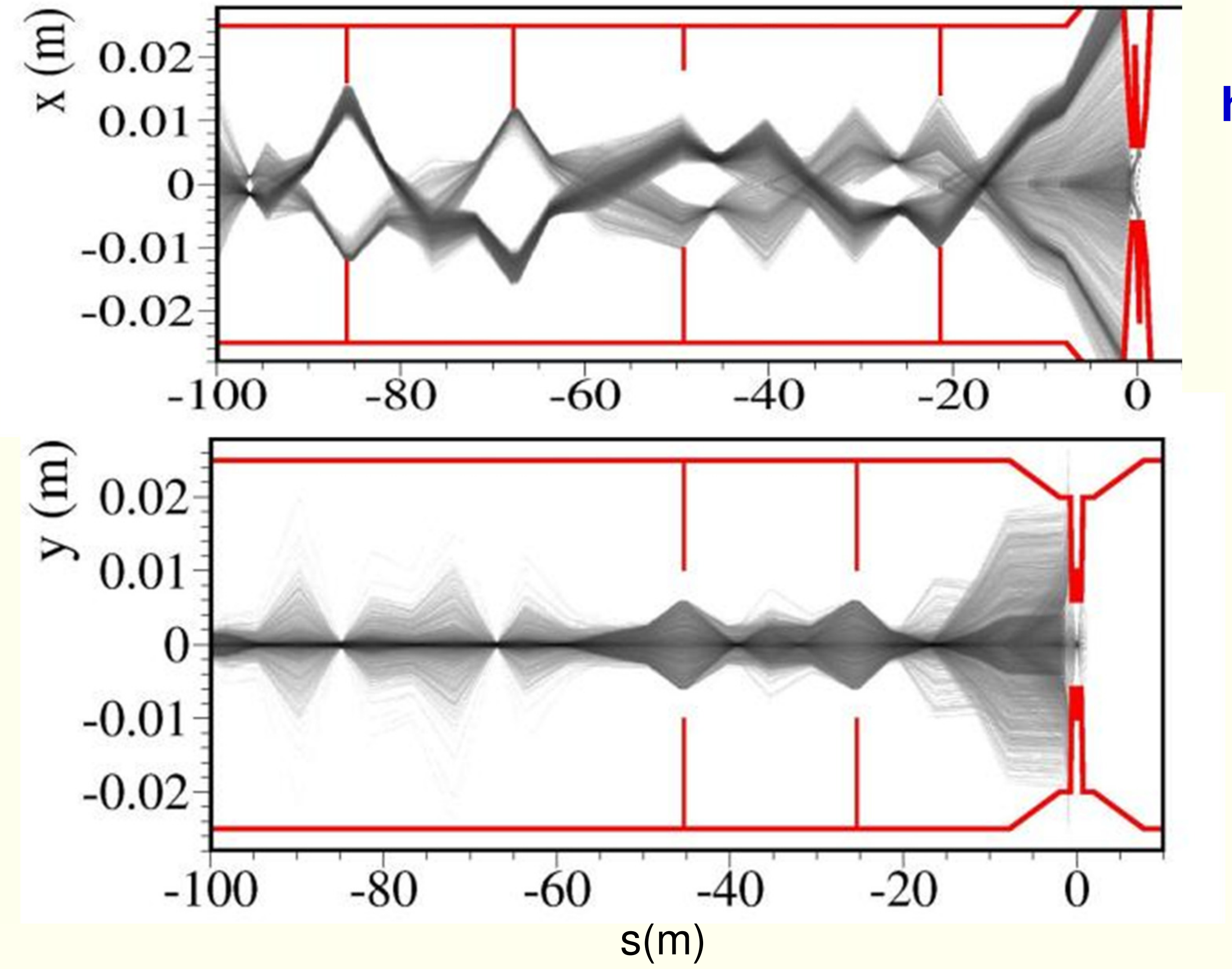
$$\theta_c = y_{QD0} / \sqrt{\langle \beta_y \rangle \cdot \beta_{yD0}}$$

	KEKB LER	**SuperB LER**
QD0 vert beam pipe :	35mm	6 mm
Max. beta y ($\beta_{y,}$@QD0)	600m	1497 m
<β_y>	23m	47m
Coulomb lifetime	>10 hrs	1420s

Beam-gas lifetime is smaller by about 1/100, due to larger vertical beta in QD0 and smaller physical aperture

Coulomb scattered particles lost at IR

Trajectories of scattered particles eventually lost at IR

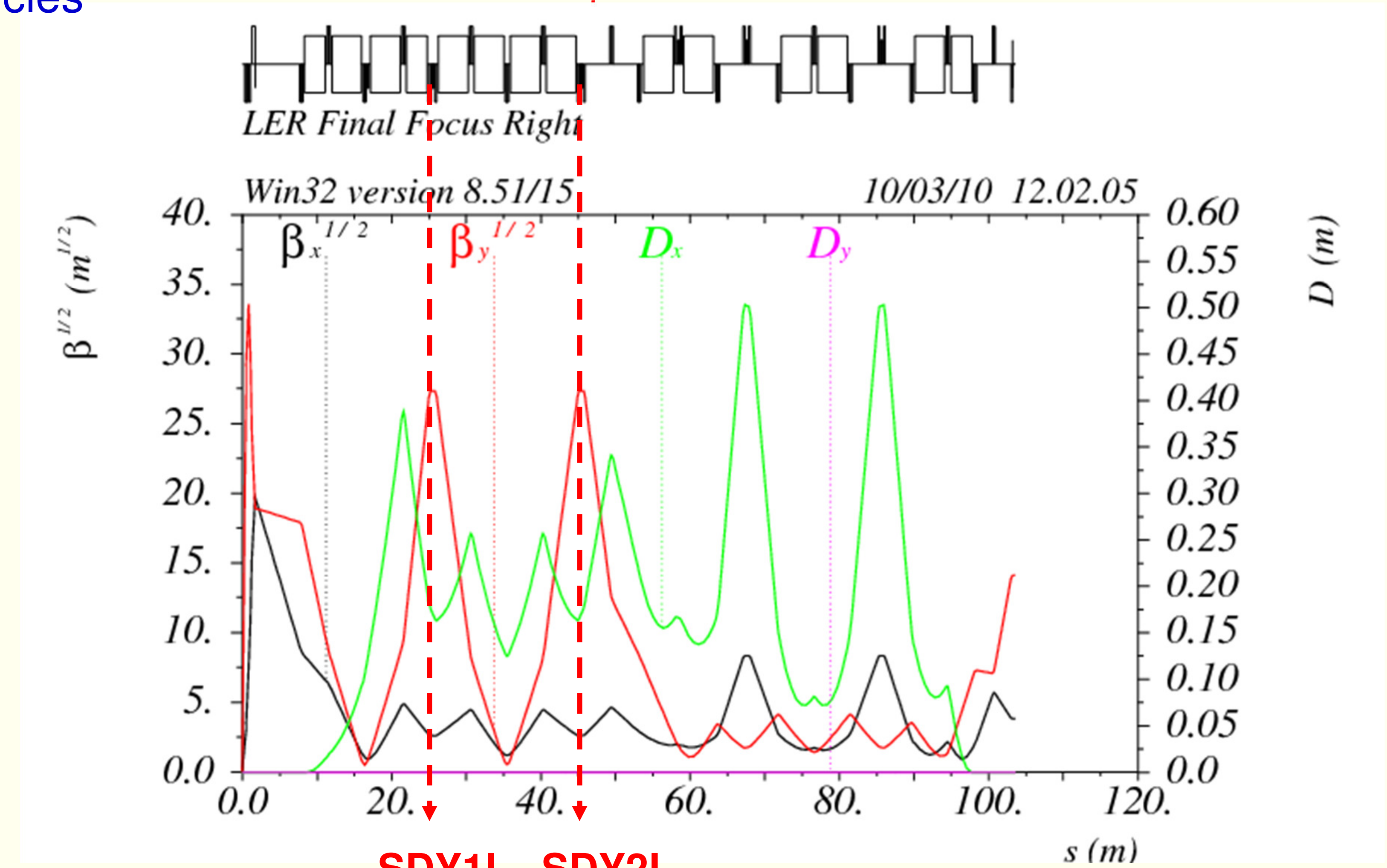


horizontal

vertical

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

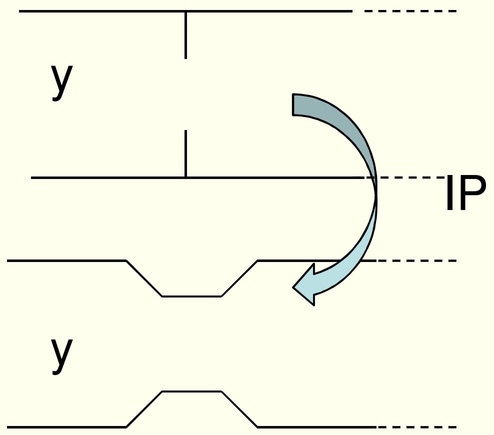
Intercept the scattered particles
in the final focus upstream the IR
that otherwise would be lost at the QD0

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.**



Single beam backgrounds IR rates summary

|s|<2 m

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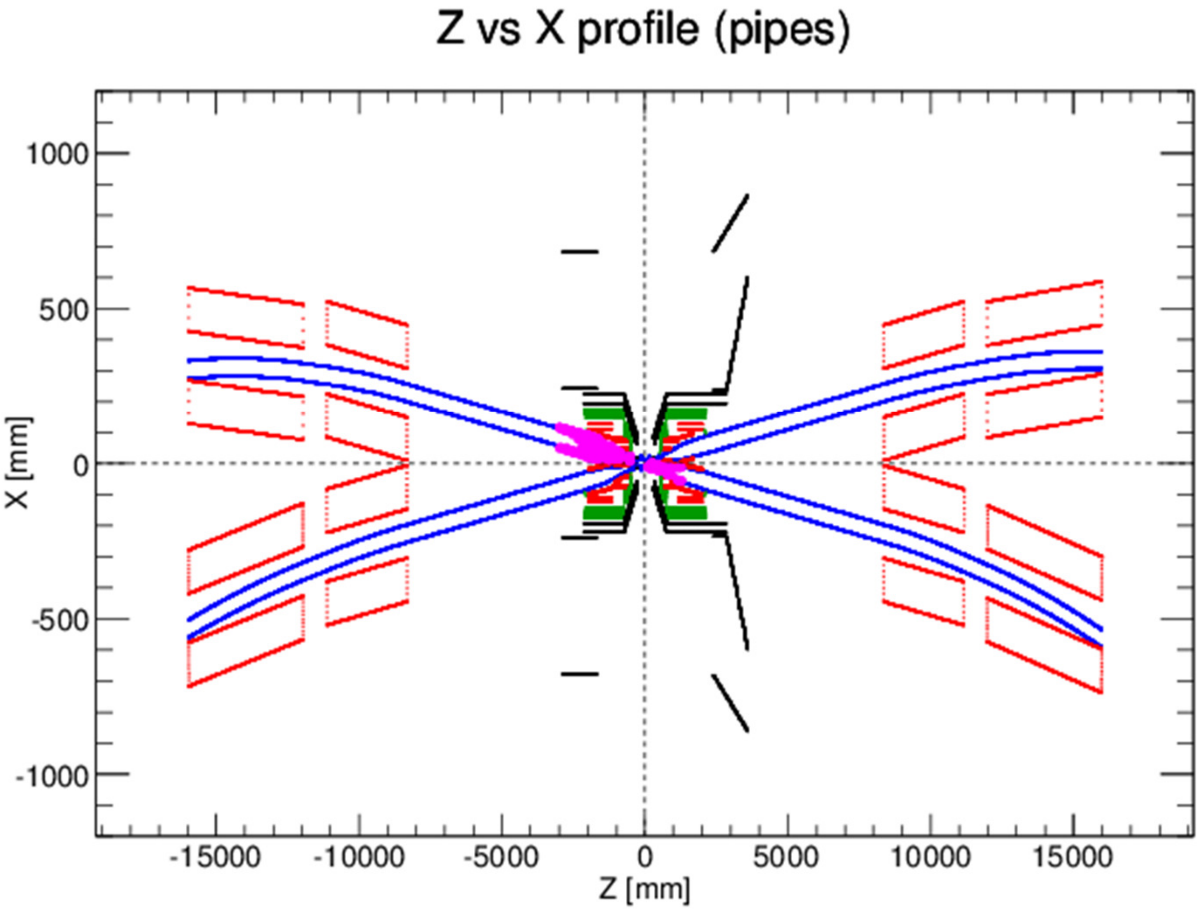
M. Boscolo, LFF Workshop, Nov. 22-23 2012

Coulomb particles hitting the pipe: full geometry before tracking

HER

IR within 15 m

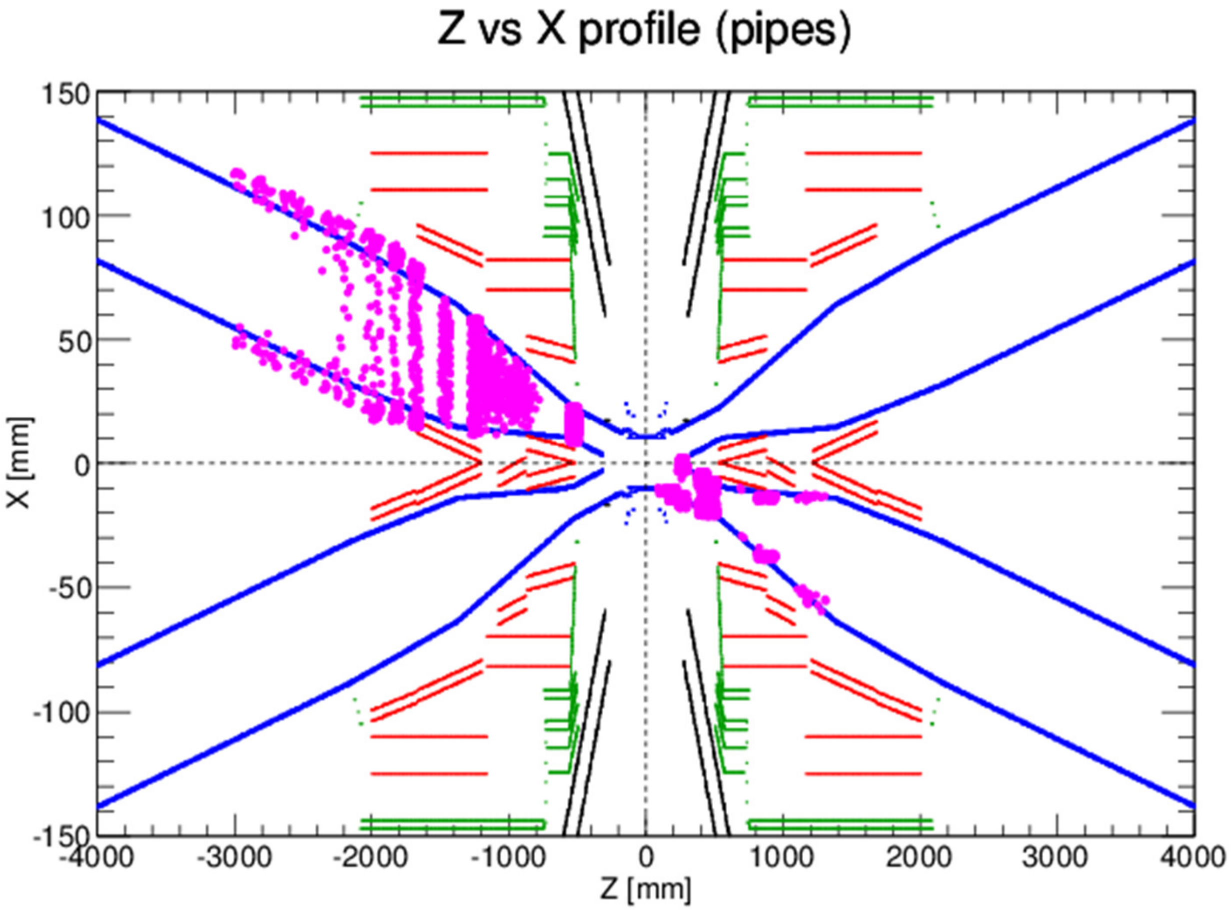


[A. Perez]

Coulomb particles hitting the pipe: full geometry before tracking

Zoom: IR within 4 m

HER



[A. Perez]

Radiative Bhabha: dominant effect

It takes place only at IP, of course, with two possibilities:

- Bhabha final states particles have **large energy deviation** => are lost immediately inside the detector

easily simulated (BBBREM) and tracked with GEANT4 into detector.

Strongly correlated with lumi observable

Almost independent on machine lattice (but FF)

- Bhabha final states particles have **small energy deviation** => may be lost after few machine turns

Same Monte Carlo approach as for Touschek and beam-gas

Extensively studied:
Two complementary methods used

Small DE/E: multiturn effect

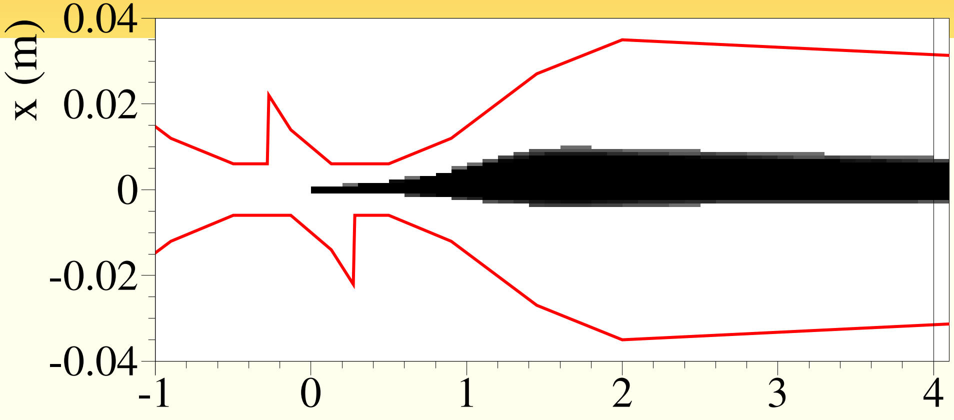
- Same set of collimators used for Touschek and beam-gas:

Radiative Bhabha particles are stopped by horizontal collimators, as they have the same horizontal phase advance as Touschek particles

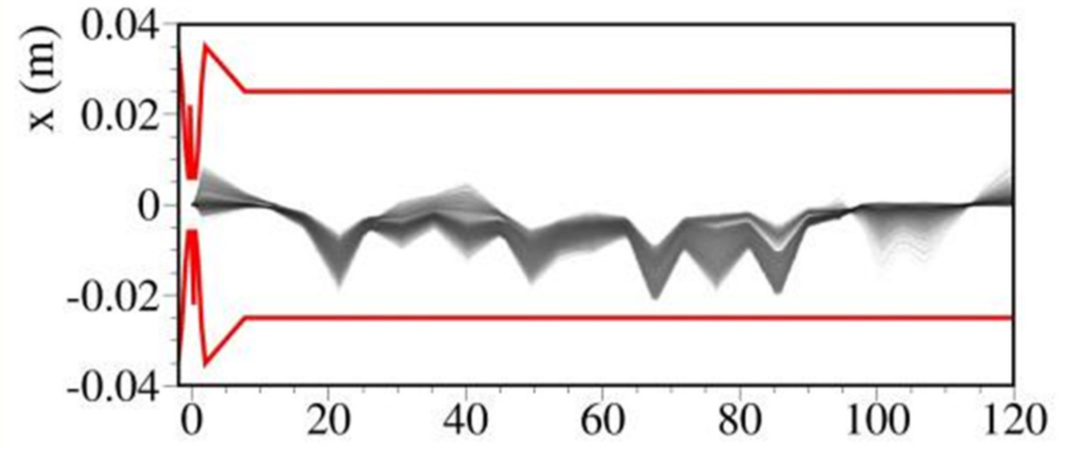
- Collimators do not reduce lifetime
- Not a big effect at first look

LER with collimators

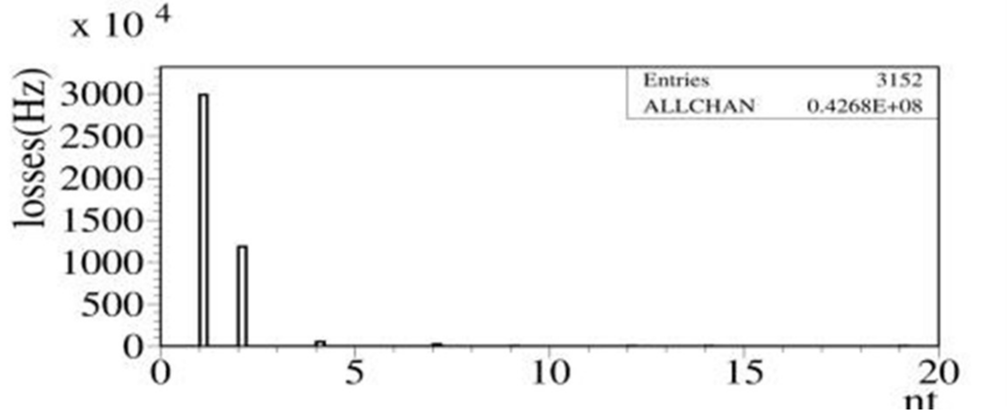
IR: Trajectories final state radiative Bhabha particles from IP



Trajectories in the Final Focus of final state radiative Bhabha particles from IP



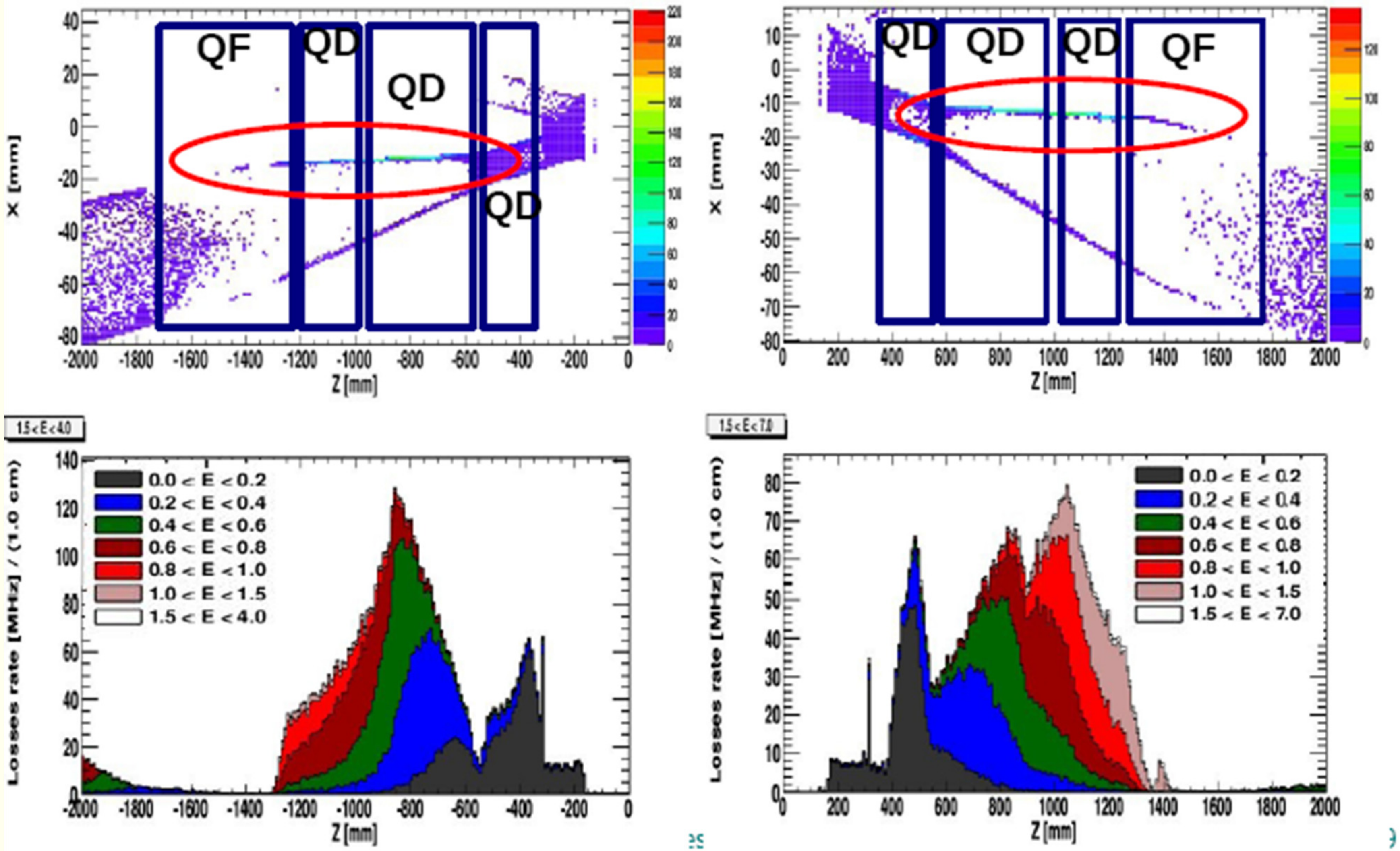
Total losses vs Machine turns



A. Perez

Losses rates: results v12-sf11 (leptons)

- V12-sf11 layout: HER = e^+ (6.69 GeV) and LER = e^- (4.18 GeV)

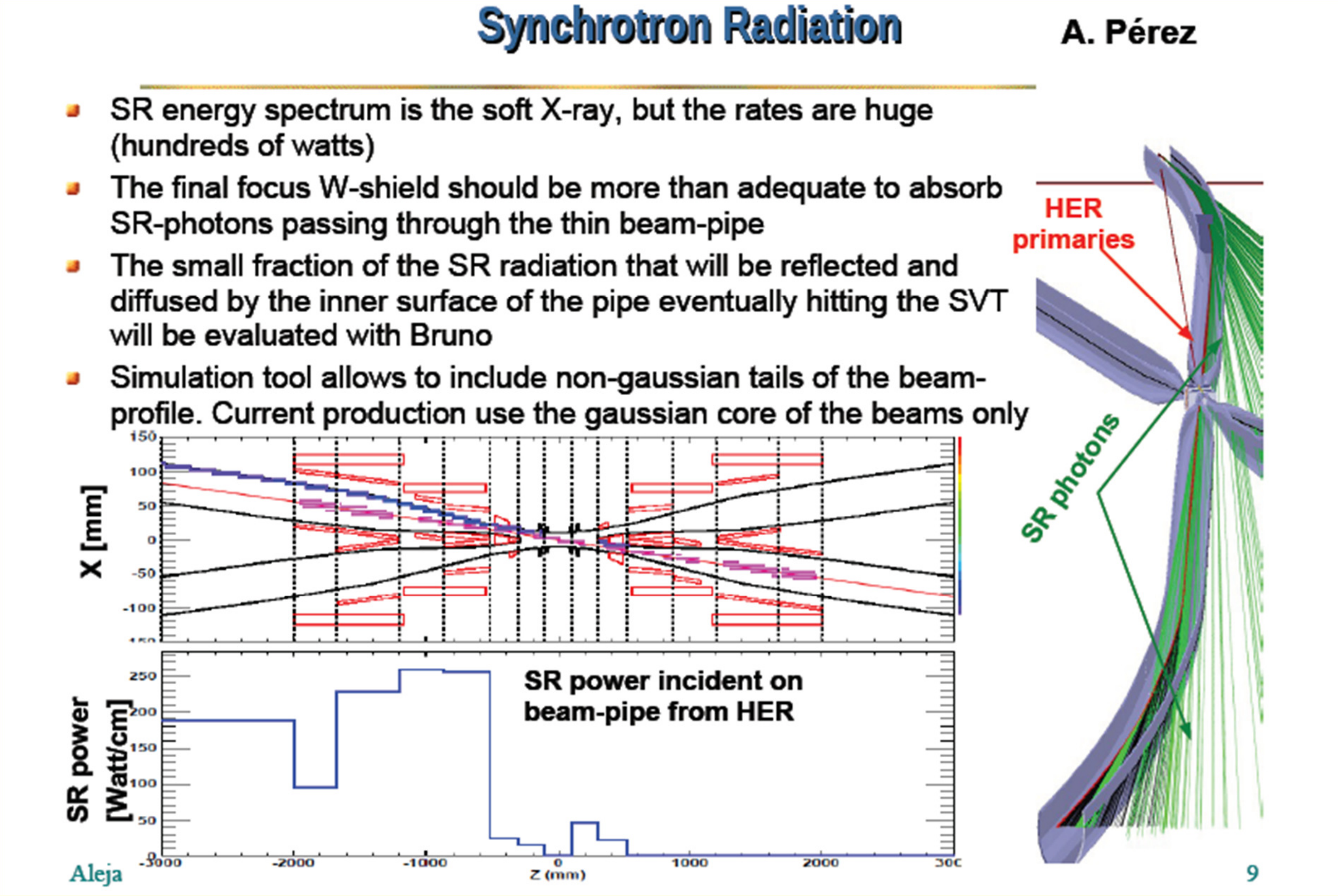


Lifetime Radiative Bhabha

- radiative Bhabha **lifetime** estimated assuming 1% energy acceptance:

$$\dot{N} = \sigma(dE/E > 1\%) \cdot \mathrm{L}$$

Used in CDR to evaluate RBB lifetime contribution
HER lifetime = 4.6 minutes
LER lifetime = 3.3 minutes



Synchrotron Radiation

A. Pérez

- SR energy spectrum is the soft X-ray, but the rates are huge (hundreds of watts)
- The final focus W-shield should be more than adequate to absorb SR-photons passing through the thin beam-pipe
- The small fraction of the SR radiation that will be reflected and diffused by the inner surface of the pipe eventually hitting the SVT will be evaluated with Bruno
- Simulation tool allows to include non-gaussian tails of the beam-profile. Current production use the gaussian core of the beams only

Aleja

Sept. 2012 SuperB General meeting

SR Summary

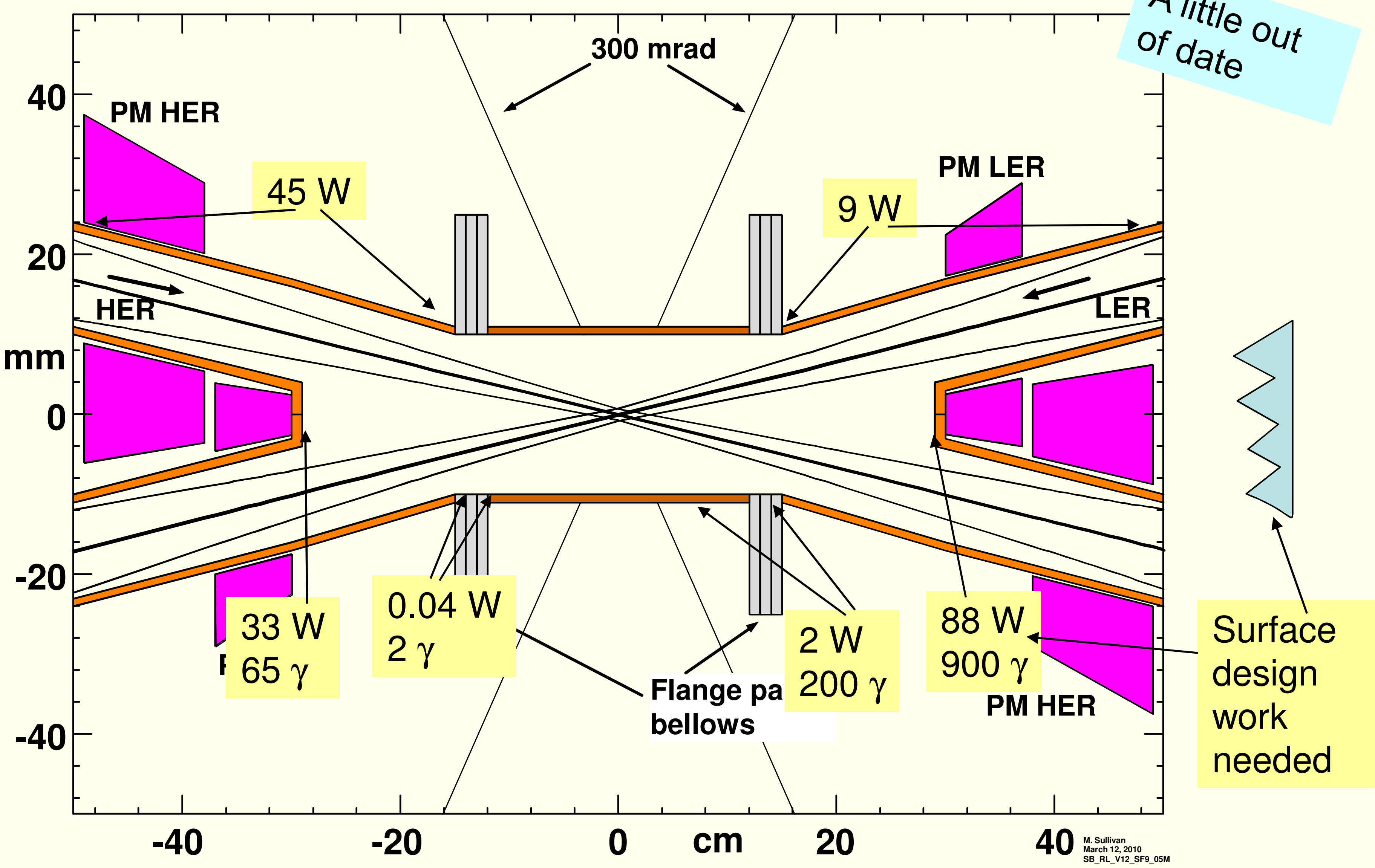
M. Sullivan

- The SR backgrounds have been studied fairly carefully and backgrounds look to be under control. Studies need to be continued.

Beam pipe close up

M. Sullivan

A little out of date



Surface design work needed

Conclusions

- We have developed solid simulation tools for all the effects that induce backgrounds and determine lifetime
- Background rates at IR are under control with an efficient Horiz & vert. Collimation system in the Final Focus
- Simulations with realistic collimators planned, especially for the closest one to the IP
- However, a lot of work still on-going for the TDR

Back-up

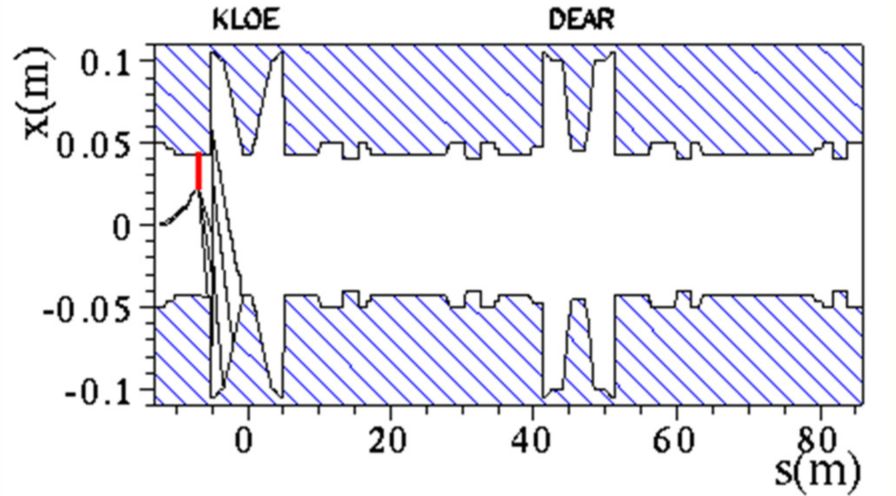
For DAFNE more realistic collimators modeled

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.

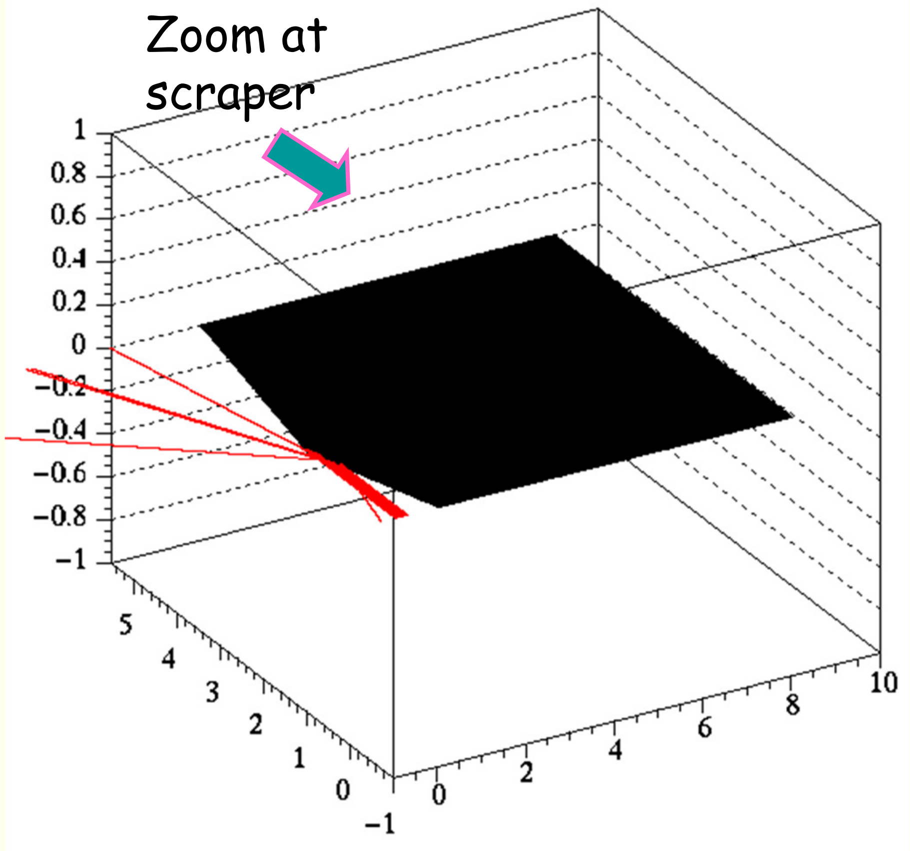
real collimator shape included in simulation and edge effect has been simulated

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

Electron interactions at collimator edge

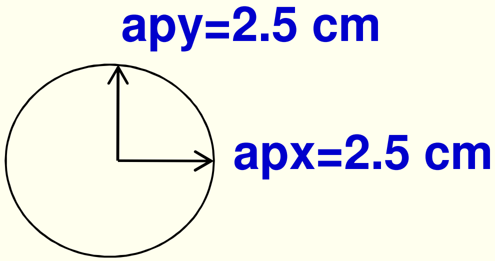


Only additional background to KLOE IR from edge effect displayed



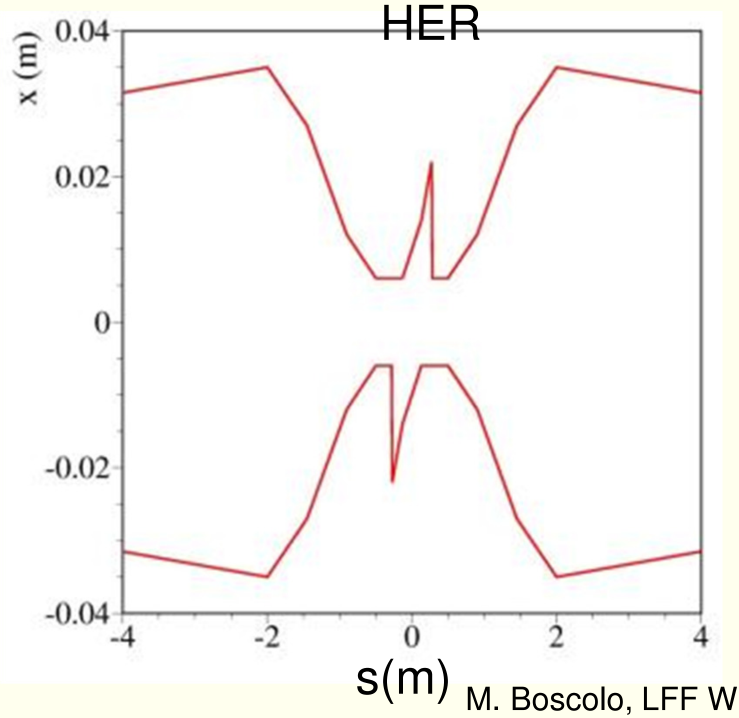
Physical aperture

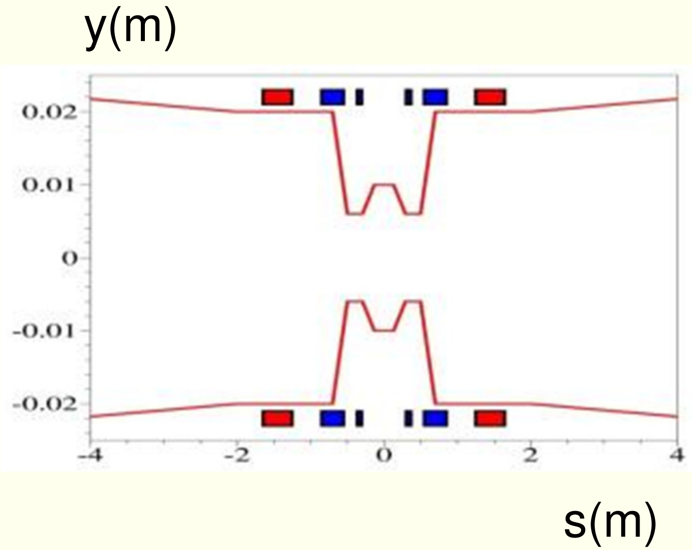
- circular pipe



everywhere but at IR

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





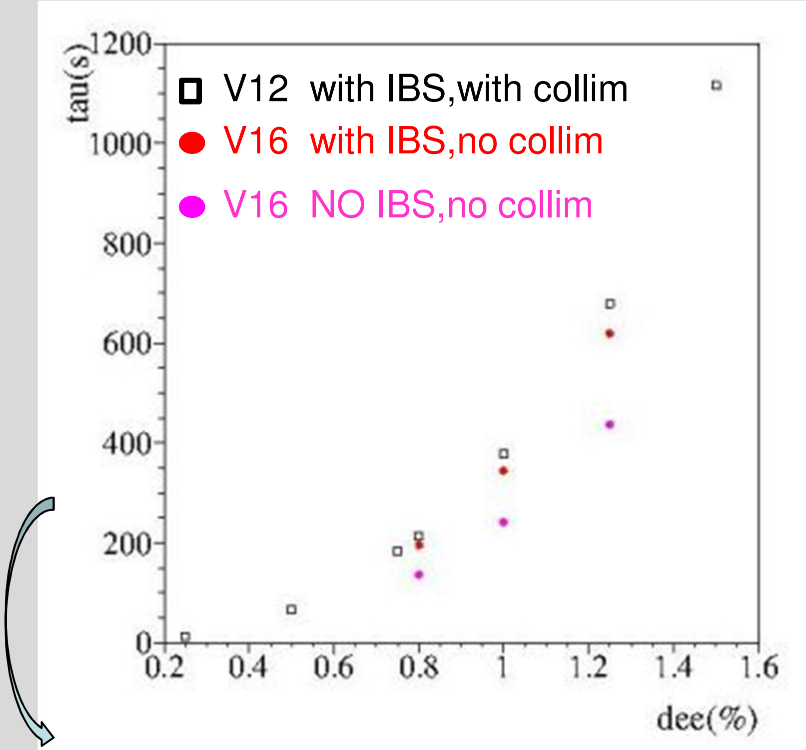
(From Mike)

Parameters used in the IR designs

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		

SuperB-LER Touschek lifetime vs ΔE/E

No tracking mode: quick estimate of Touschek lifetime for a given momentum aperture → useful to find the required momentum aperture

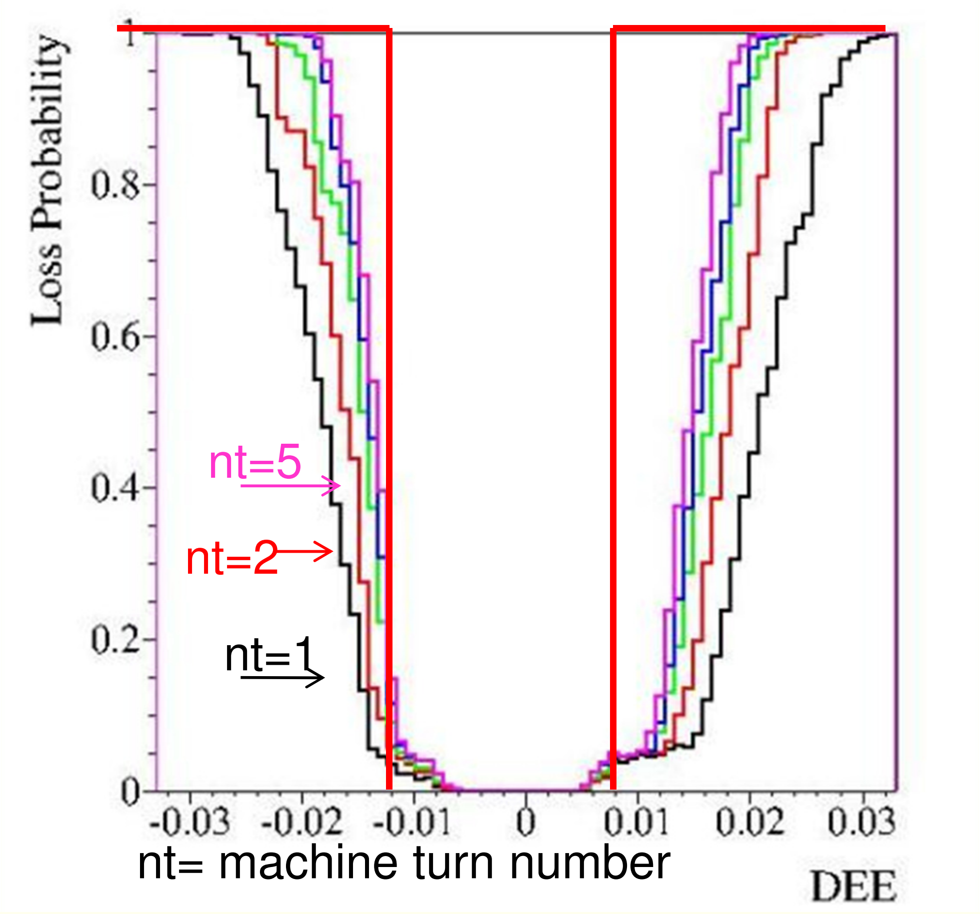


τ_{Tou} > 5min if mom. Acc.>0.9-1%

V16
(Pantaleo)

I_b =2.45 mA
$\varepsilon_{x\ (nat)}$=1.7 nm

efficiency is calculated from tracking- more realistic description of nonlinear dynamics than assume that particles with |Δp/p|>1% are lost



nt= machine turn number

SuperB Parameter list

		Base Line		Low Emittance		High Current		τ/charm	
Parameter	Units	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)	HER (e+)	LER (e-)
LUMINOSITY (10^{36})	$cm^{-2}\ s^{-1}$	1		1		1		1	
Energy	GeV	6,7	4,18	6,7	4,18	6,7	4,18	2,58	1,61
Circumference	m	1195		1195		1195		1195	
X-Angle (full)	mrad	60		60		60		60	
Piwinski angle	rad	20,11	17,25	29,42	23,91	13,12	10,67	8,00	6,50
β_x @ IP	cm	2,6	3,2	2,6	3,2	5,06	6,22	6,76	8,32
β_y @ IP	cm	0,0253	0,0205	0,0179	0,0145	0,0292	0,0237	0,0658	0,0533
Coupling (full current)	%	0,25	0,25	0,25	0,25	0,5	0,5	0,25	0,25
ε_x (without IBS)	nm	2,00	1,7	1,00	0,91	1,97	1,82	1,97	1,82
ε_x (with IBS)	nm	2,14	2,363	1,00	1,23	2,00	2,46	5,20	6,4
ε_y	pm	5,35	5,9075	2,5	3,075	10	12,3	13	16
σ_x @ IP	μm	7,459	8,696	5,099	6,274	10,060	12,370	18,749	23,076
σ_y @ IP	μm	0,037	0,035	0,021	0,021	0,054	0,054	0,092	0,092
Σ_x	μm	11,457		8,085		15,944		29,732	
Σ_y	μm	0,051		0,030		0,076		0,131	
σ_L (0 current)	mm	4,69	4,29	4,73	4,34	4,03	3,65	4,75	4,36
σ_L (full current)	mm	5	5	5	5	4,4	4,4	5	5
Beam current	mA	1892	2447	1460	1888	3094	4000	1365	1766
Buckets distance	#	2		2		1		1	
Buckets distance	ns	4,20		4,20		2,10		2,10	
Ion gap	%	2		2		2		2	
RF frequency	MHz	476		476		476		476	
Harmonic number		1998		1998		1998		1998	
Number of bunches		442		442		884		884	
N. Particle/bunch (10^{10})		5,08	6,56	3,92	5,06	4,15	5,36	1,83	2,37
Tune shift x		0,0026	0,0040	0,0020	0,0031	0,0053	0,0081	0,0063	0,0096
Tune shift y		0,1089	0,1033	0,0980	0,0981	0,0752	0,0755	0,1000	0,1001
Long. damping time	msec	13	18,0	13,4	20,3	13,4	20,3	26,8	40,6
Energy Loss/turn	MeV	2,11	0,865	2,11	0,865	2,11	0,865	0,4	0,166
σ_E (zero current)	δE/E	6,10E-04	7,00E-04	6,43E-04	7,34E-04	6,43E-04	7,34E-04	6,94E-04	7,34E-04
σ_E (with IBS)	δE/E	6,28E-04	7,91E-04						
CM σ_E	δE/E	4,75E-04		5,00E-04		5,00E-04		5,26E-04	
Total lifetime	min	4,23	4,48	3,05	3,00	7,08	7,73	11,41	6,79
Total RF Power	MW	16,38		12,37		28,83		2,81	

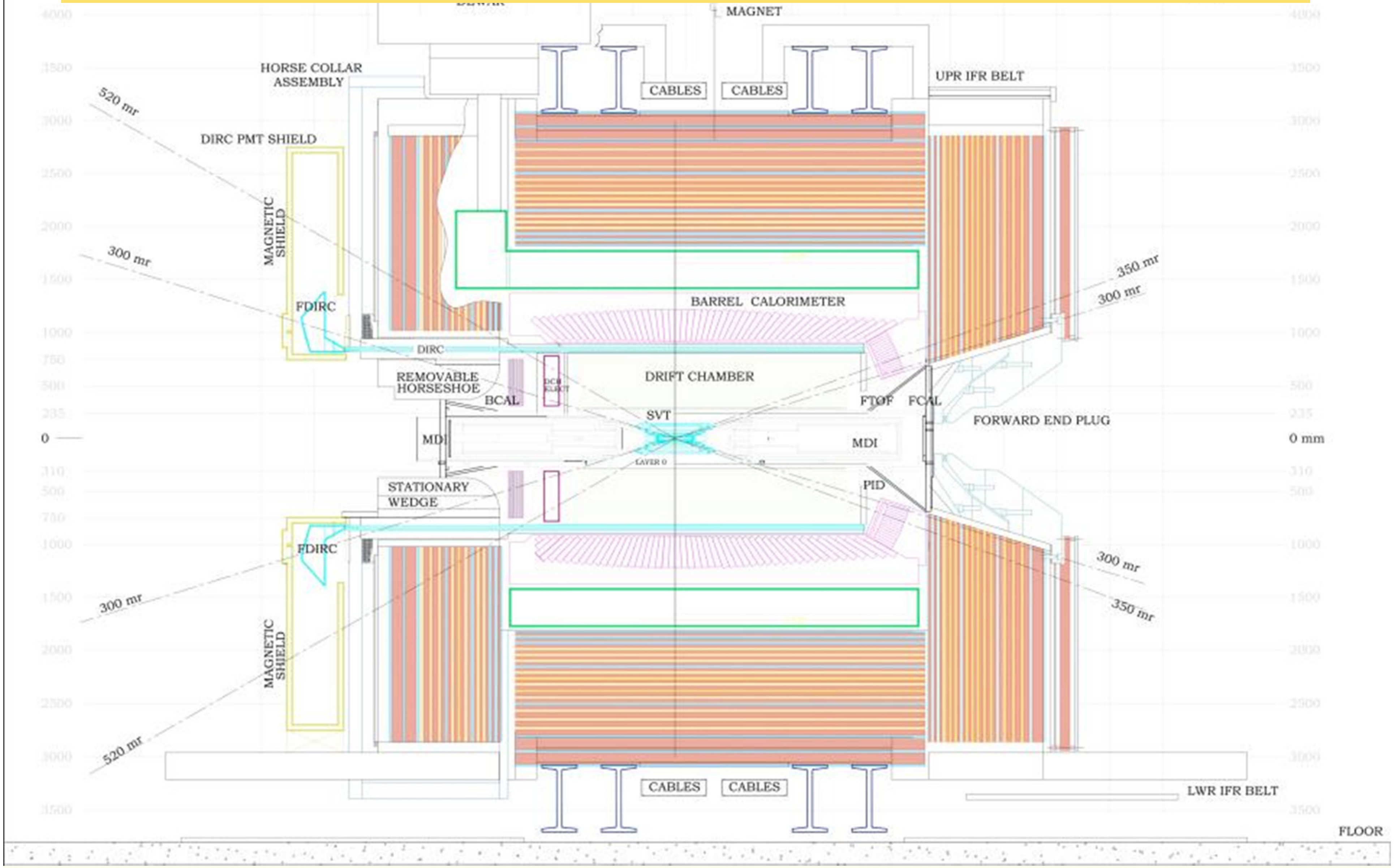
Baseline + other 2 options:
- **Lower y-emittance**
- **Higher currents (twice bunches)**

Baseline:
- **Higher emittance due to IBS**
- **Asymmetric beam currents**

RF power includes SR and HOM

Tau/charm threshold

Detector layout



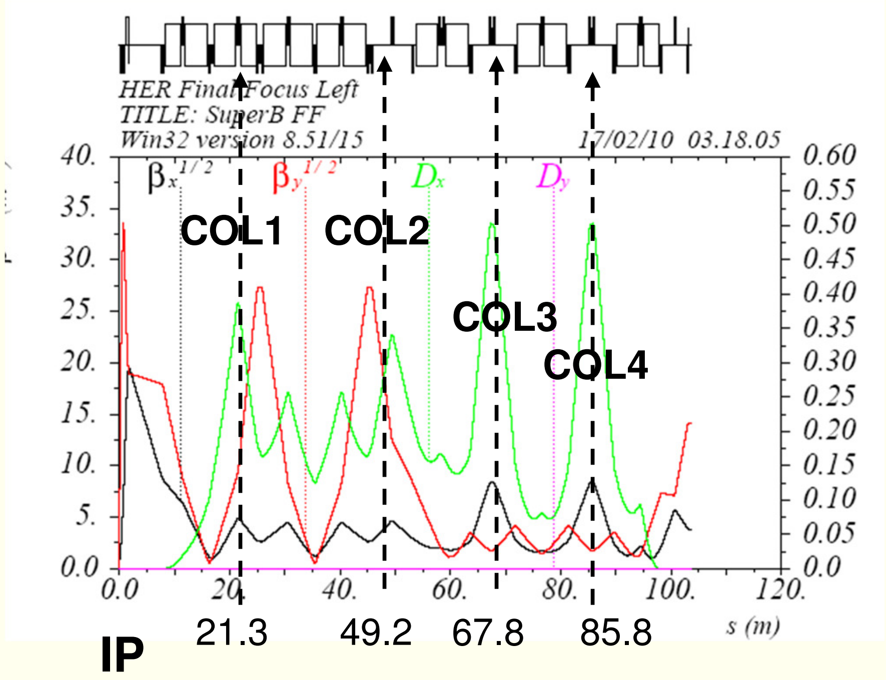
Touschek IR background rates

|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

(beam pipe is -25 /+25 mm)

no collimators τ_{TOU} = 26 minutes

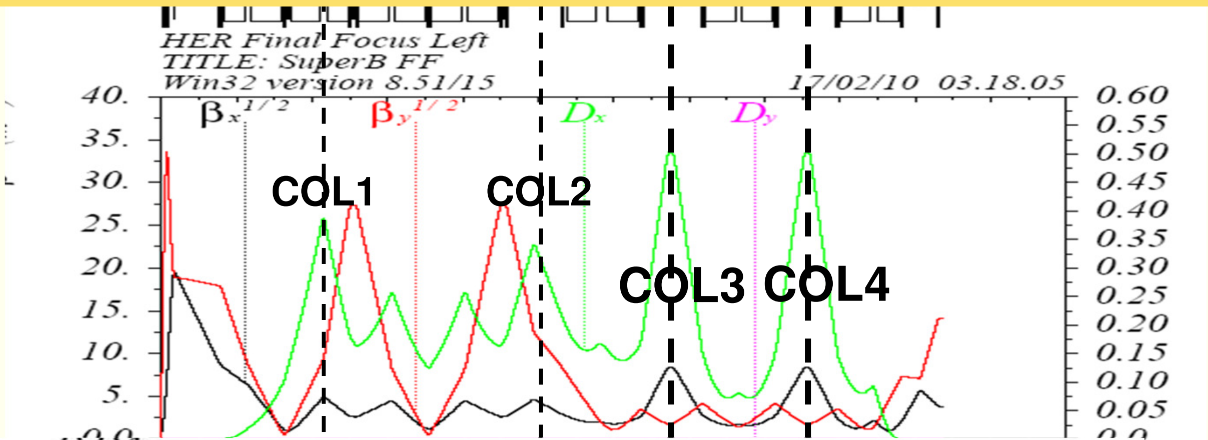
with collimators τ_{TOU} = 22 minutes

Trajectories Bhabha final states particles

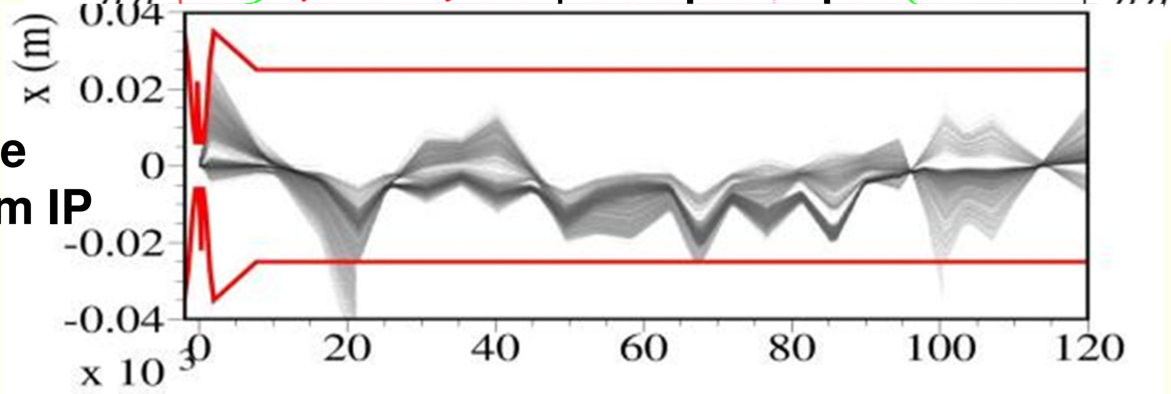
LER

No collimators

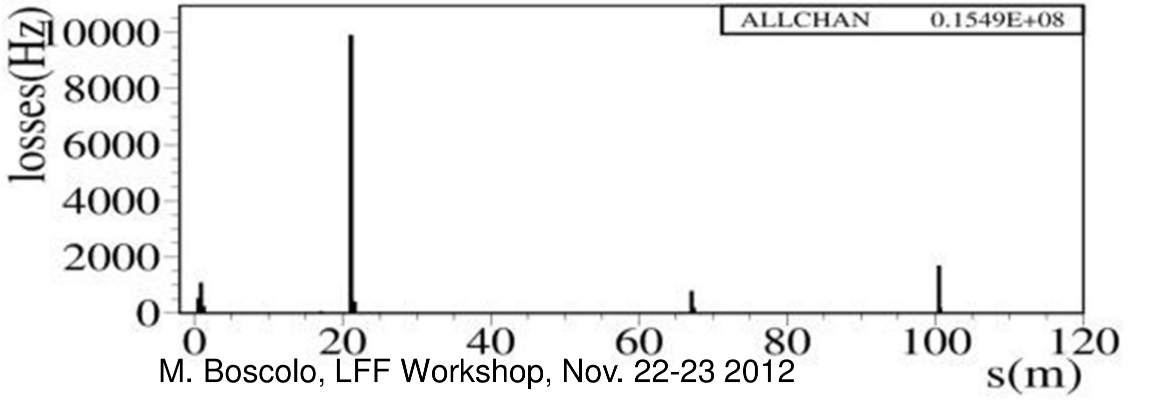
Optical functions in the Final Focus



Trajectories final state radiative Bhabha particles from IP



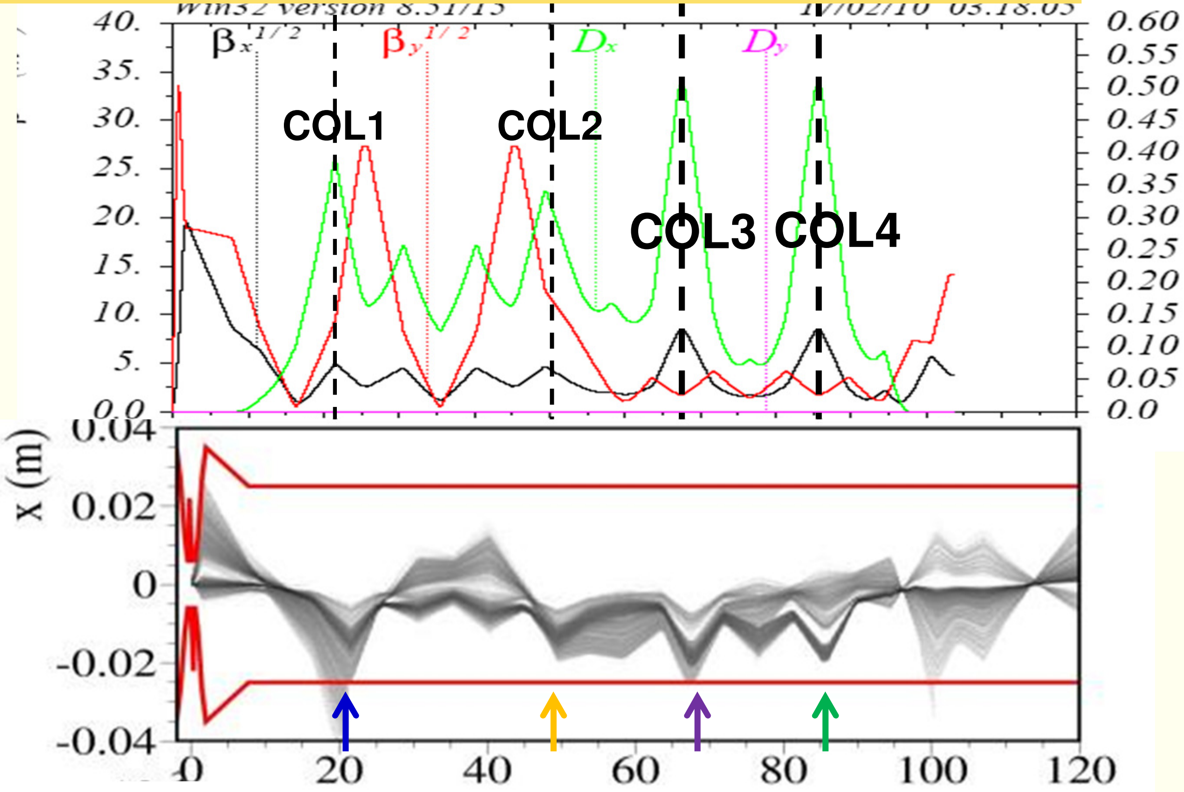
Loss points in the Final Focus



Trajectories Bhabha final states particles

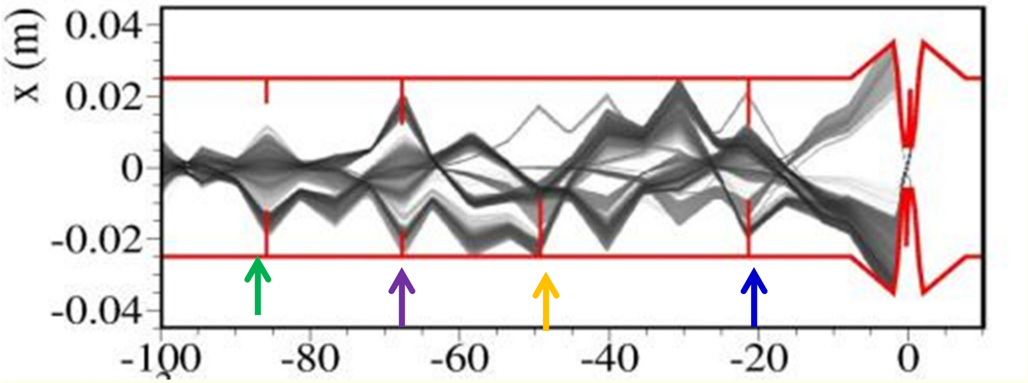
LER

No collimators



Trajectories final state radiative Bhabha particles from IP

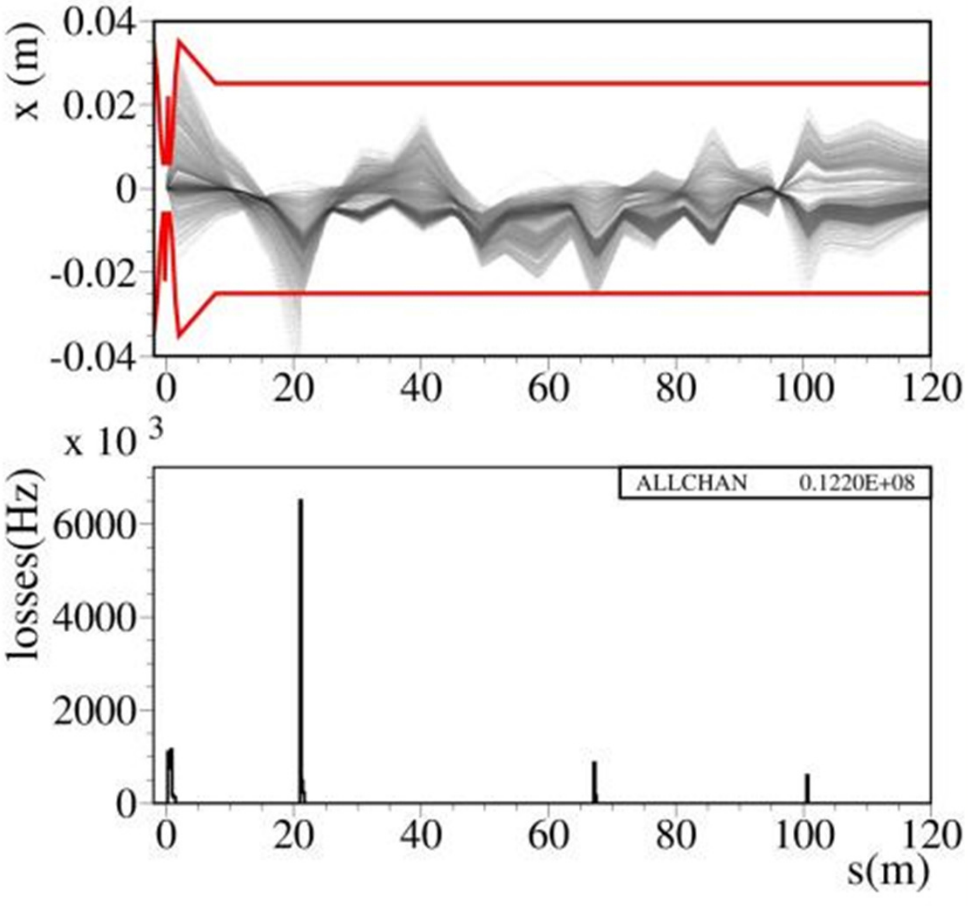
Same phase advance as Touschek particles!



Trajectories of particles after Touschek scattering upstream IP

HER losses from rad Bhabha process

HER no collimators



HER with collimators
(same set of Touschek &beam-gas)