Beam Loss Simulation at SuperKEKB

Y. Funakoshi

KEKB Review

2013. 03. 05

Beam Loss Simulation

- Needs of simulation on loss distribution around the ring
  - Estimation of detector beam background (Y. Nakayama)
  - Design of radiation shield
  - Design of beam loss monitor
- Simulation
  - Touschek: Y. Ohnishi
  - Beam-gas Coulomb: Y. Funakoshi
  - Radiative Bhabbha: Y. Funakoshi

Comparison of beam loss

	KEKB (design)		KEKB (achieved)		SuperKEKB	
	LER	HER	LER	HER	LER	HER
Radiative Bhabha	21.3h	9.0h	6.6h	4.5h	28min.	20min.
Beam-gas	45h[a)]	45h[a)]			24.5min.[b)]	46min. [b)]
Touschek	10h	-			10min.	10min.
Total	5.9h	7.4h	~133min.	~200min.	6min.	6min.
Beam current	2.6A	1.1A	1.6A	1.1A	3.6A	2.6A
Loss Rate	0.12mA/s	0.04mA/s	0.23mA/s	0.11mA/s	10mA/s	7.2mA/s

a) Bremsstrahlung
b) Coulomb scattering, sensitive to mask setting

Beam loss accompanied with the beam injection should be added.

Beam-gas Coulomb simulation

Cross section of Beam-Gas scattering (Coulomb scattering)

- Differential cross section
  - Scattering angle: θ
  - Azimuthal angle: ϕ

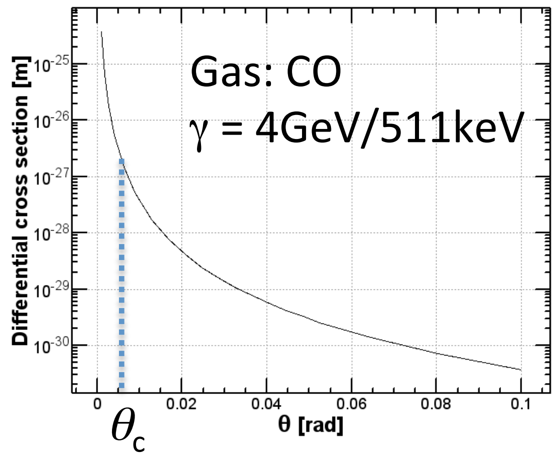
+1 comes from Mϕller scattering.
No energy loss is considered.

$$d\sigma_G = \frac{1}{2}\frac{\sum_{gas} Z_i(Z_i+1)r_e^2}{\gamma^2}\cot^3\frac{\theta}{2}d\theta d\phi \rightarrow d\sigma_G = \pi\frac{\sum_{gas} Z_i(Z_i+1)r_e^2}{\gamma^2}\cot^3\frac{\theta}{2}d\theta$$

- Total cross section
  - $\theta > \theta_c$

$$\sigma_G = \int_{\theta_c}^{\pi}\frac{d\sigma_G}{d\theta}d\theta = 2\pi\frac{\sum_{gas} Z_i(Z_i+1)r_e^2}{\gamma^2}\left(\frac{1}{2}\cot^2\frac{\theta_c}{2} + \ln\left|\sin\frac{\theta_c}{2}\right|\right)$$

$$\sigma_G \propto \frac{1}{\theta_c^2} = \frac{\beta_y}{A_c}$$



Beam Lifetime from Coulomb scattering against residual gas

- Parameters (LER)
  - Gas: CO
  - Pressure: 1 x 10^{-7} Pa
  - Temperature: 300°K
  - Acceptance
    - Vertical: QC1: 13.5mm (β_{ym} ~ 2888m)
    - Horizontal: 20 σ_x

Lifetime ~ 1468 sec
vertical mask: 2.0mm (β_{ym} ~ 104.57m)

$$\langle \beta_y \rangle \cong 47.9\mathrm{m}$$

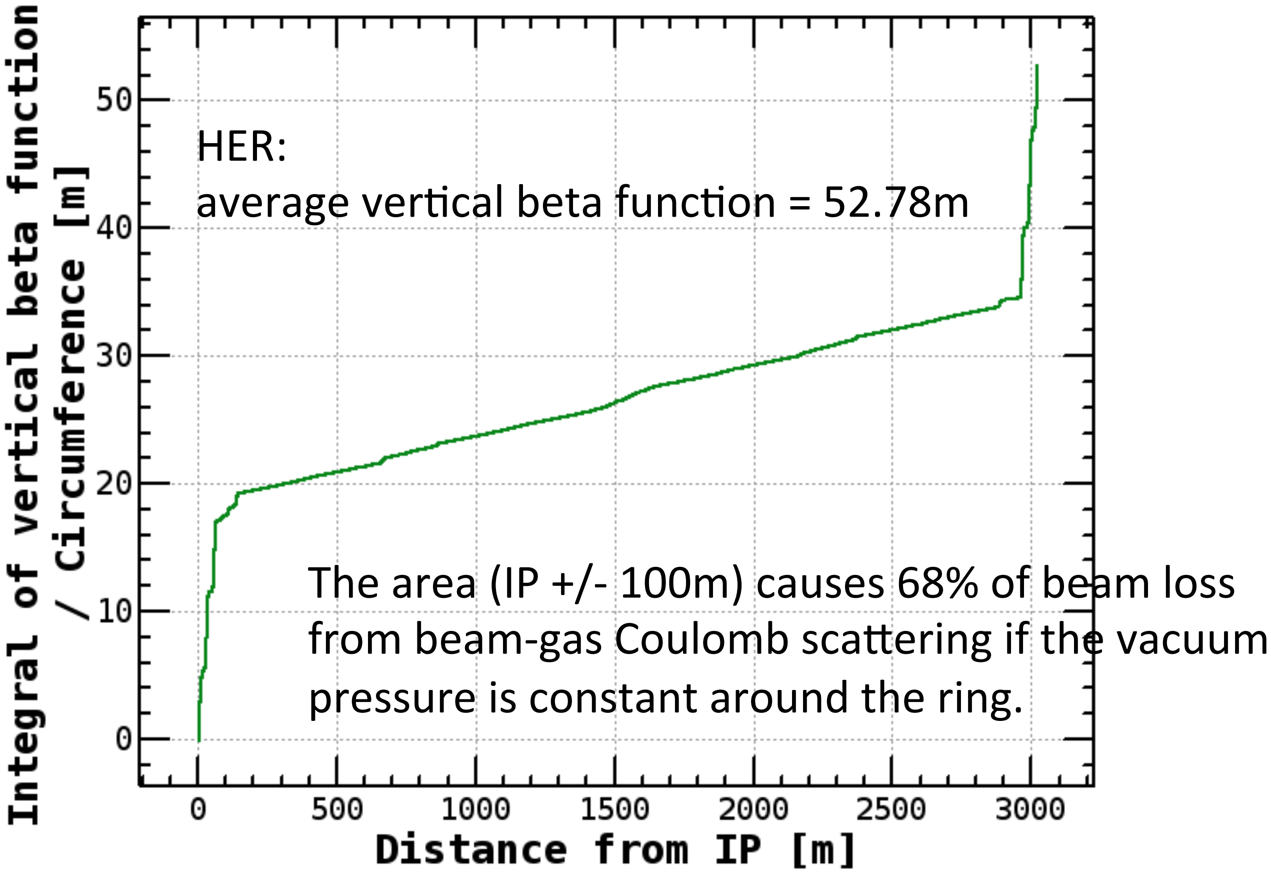
- Lifetime

$$\frac{1}{\tau_C} = c n_G \frac{4\pi r_e^2 \sum_{gas} Z(Z+1)}{\gamma^2} \left\langle \frac{1}{\vartheta_c(s)^2} \right\rangle$$

$$\left\langle \frac{1}{\vartheta_c(s)^2} \right\rangle = \frac{\langle \beta_x \rangle \beta_{xm}}{2a_{xm}^2} + \frac{\langle \beta_y \rangle \beta_{ym}}{2a_{ym}^2}$$

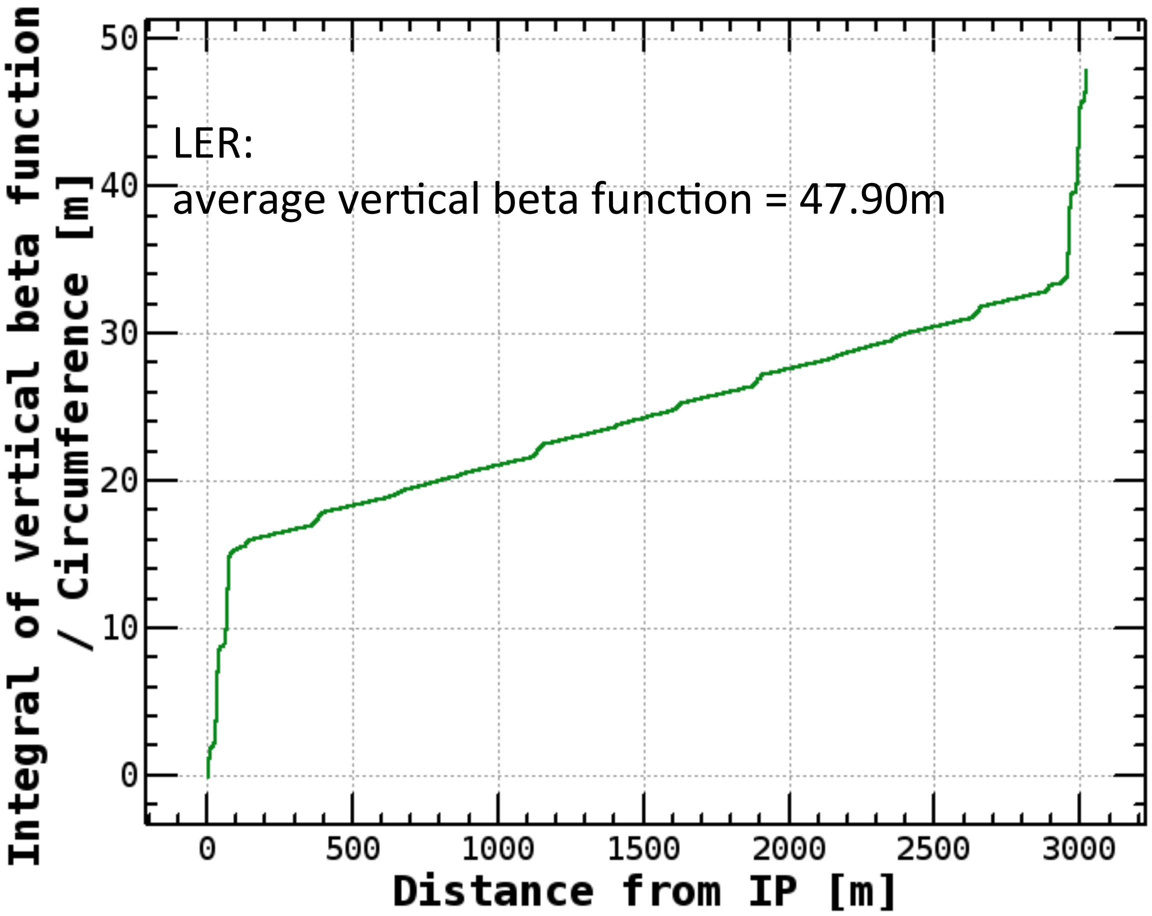
  - Lifetime calculated = 1961 sec (@$QC1_{ap}$=13.5mm), 1186 sec (@$QC1_{ap}$=10.5mm)

HER integral of vertical beta function



The area (IP +/- 4m) causes ~7% beam loss. If the vacuum pressure in this region gets worse by a factor 10, the beam loss increases by about 63%.

LER integral of vertical beta function



Tracking

- Starting points: each SAD element (minimum distance: 50cm)
- # of turns: 3~10 turns (tracking of 30 turns is under way)
- Minimum scattering angle (θ_c) depends on ring position

$$\theta_c = \frac{A_p}{\sqrt{\beta_{ys}\beta_{yAp}}} - 3\sigma'_y \quad \sigma'_y = \sqrt{\frac{\varepsilon_y}{\beta_y}}$$

  - Azimuthal angle ϕ : uniform distribution
- # of particles
  - ~0.2 ~ 2 x 10^6 particles in the ring
- Consider beam size distribution
- Mask setting
  - Optimized for Touschek background

Setting values for masks

Y. Ohnishi

LER: Touschek Background

sler_1672_5

LER_2012_06_22_11:26

D06H1	-16.0/+17.0	D03H1	-21.0/+20.0	D02H1	-10.6/+12.0
D06H2	-16.0/+16.0	D03H2	-18.0/+20.0	D02H2	-16.0/+20.0
D06H3	-16.0/+15.0	D03V1	-9.0/+9.0	D02H3	-18.0/+21.0
D06H4	-13.0/+13.0	D03V2	-9.0/+9.0	D02H4	-13.0/+9.0
	(mm)		(mm)	D02V1	-2.0/+2.0

HER: Touschek Background

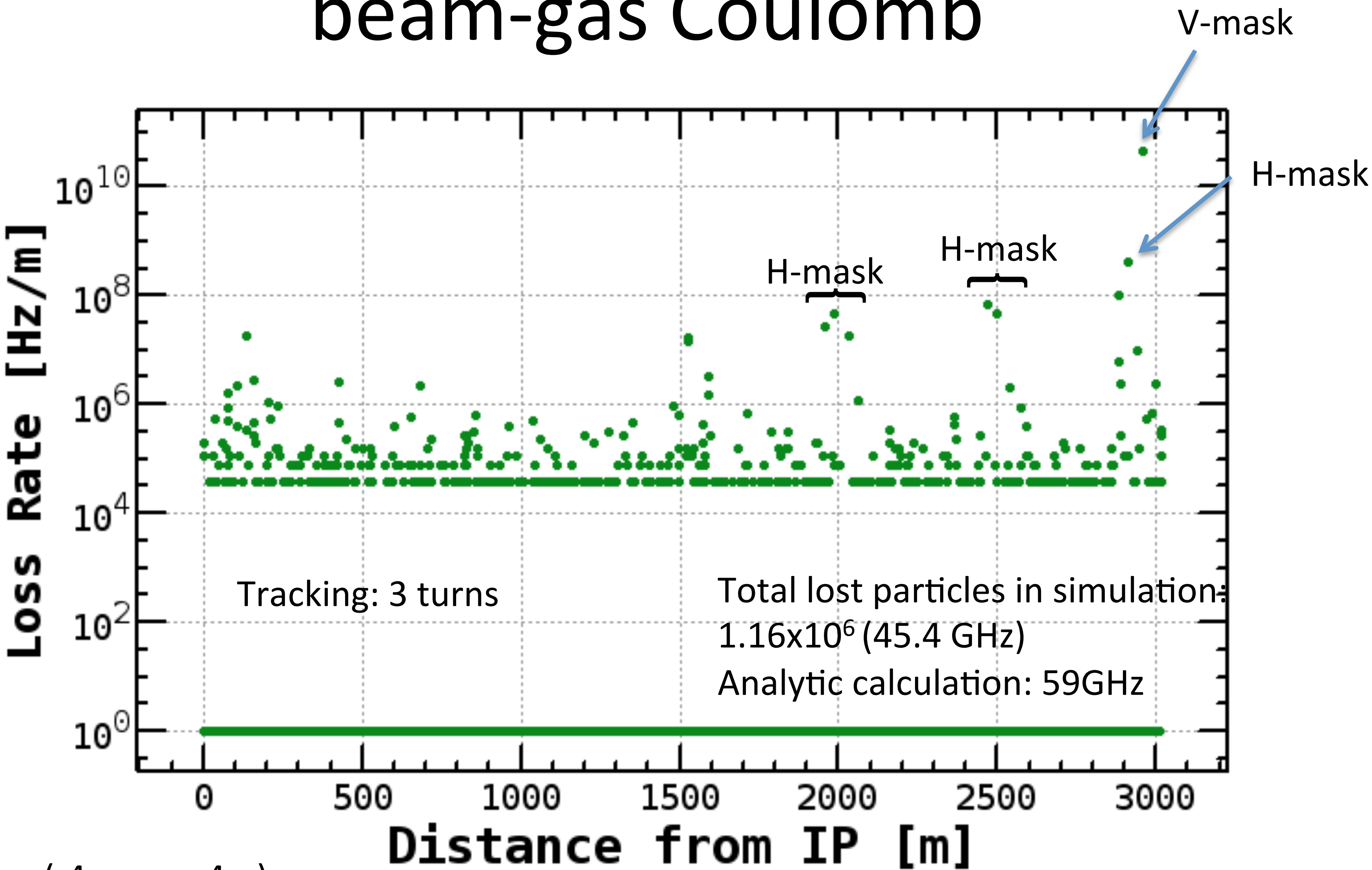
sher_5745_1

HER_2012_07_06_10:17

D09H1	-22.0/+14.0	D12H1	-10.0/+20.0	D01H1	-6.5/+7.0
D09H2	-22.0/+11.0	D12H2	-10.0/+17.0	D01H2	-11.0/+9.5
D09H3	-13.0/+16.0	D12H3	-20.0/+21.0	D01H3	-9.0/+5.5
D09H4	-16.0/+15.0	D12H4	-18.0/+21.0	D01H4	-12.5/+15.0
				D01H5	-10.0/+10.0
	(mm)		(mm)	D01V1	-2.2/+2.2

sher_5753

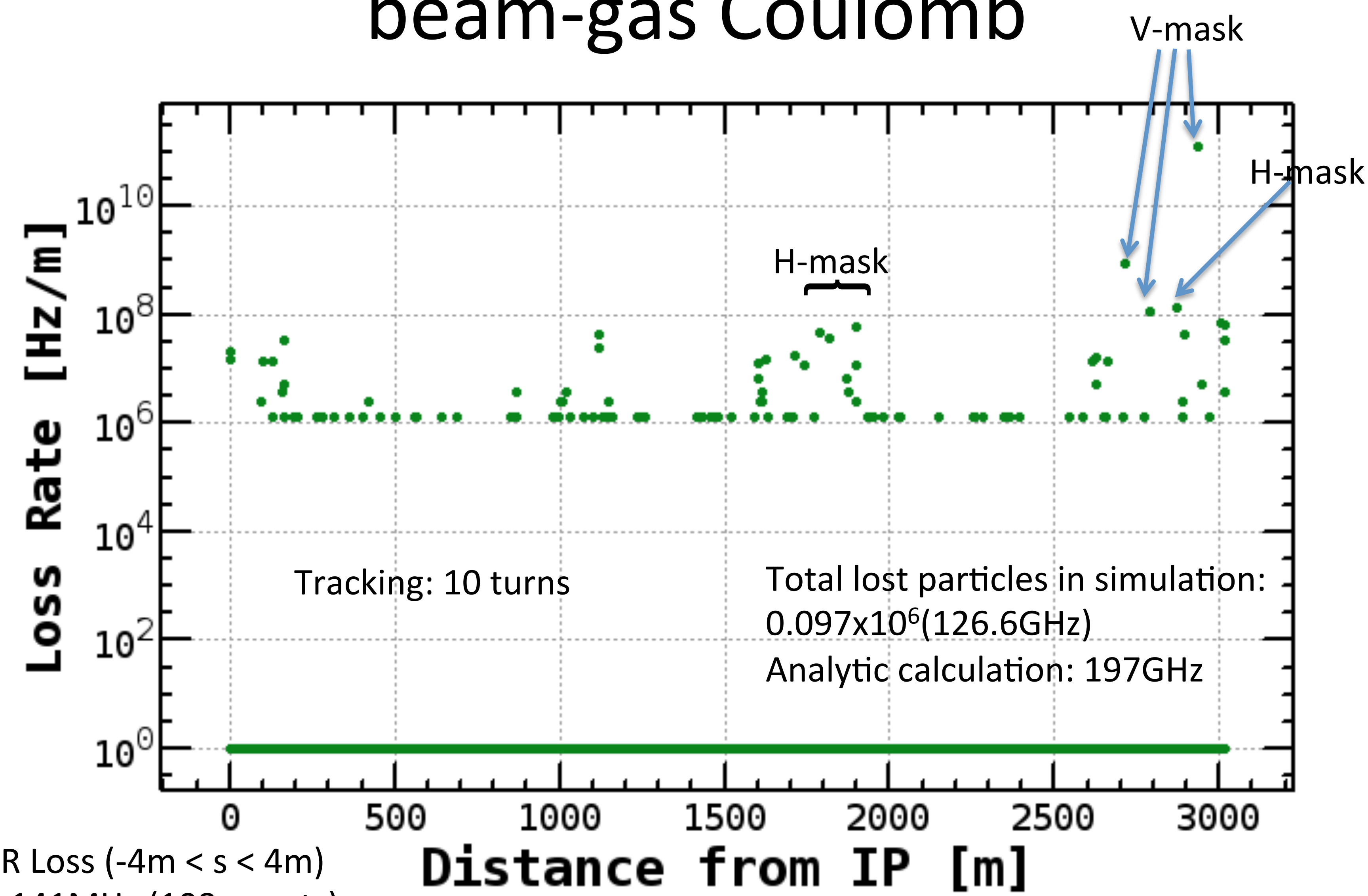
Loss distribution HER beam-gas Coulomb



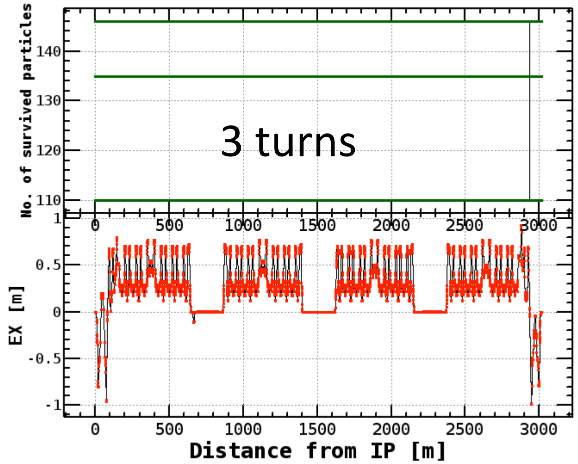
IR Loss (-4m < s < 4m)
~1.09MHz (28 events)

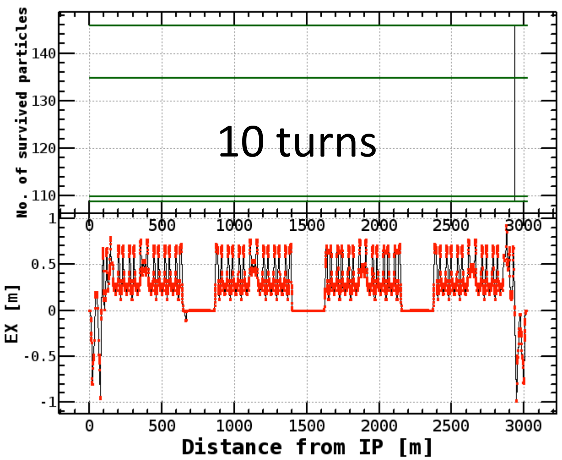
sler_1684

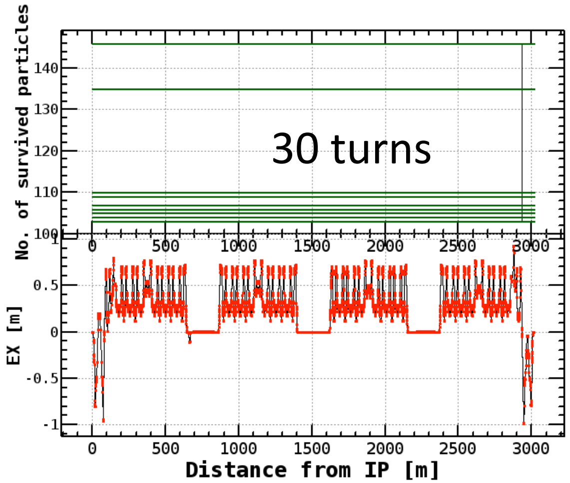
Loss distribution LER beam-gas Coulomb

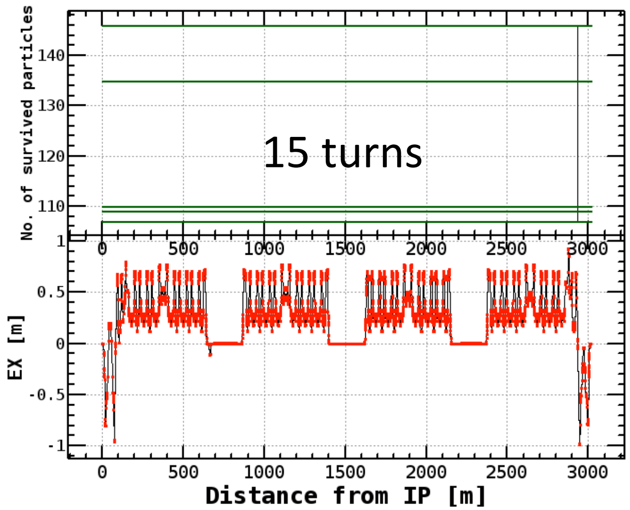


IR Loss (-4m < s < 4m)
~141MHz (108 events)





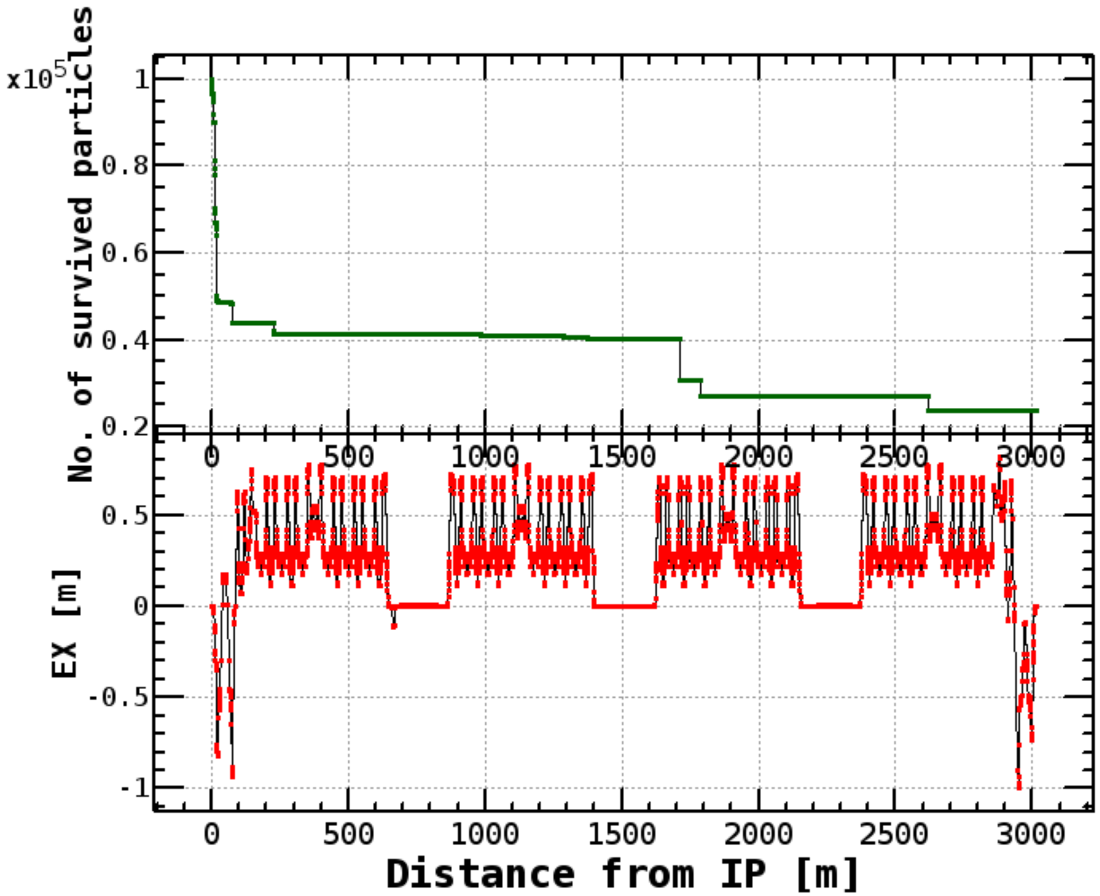




Element name: APT.6002
S [m] = 2934.3069853702323
BX = 16.68318748342323
BY = 142.88788115847524
sigmax = .00023463699345008804
sigmapx = 1.4064278405024721e-05
sigmay = 4.3429483433398944e-05
sigmapy = 3.0394098562656846e-07
sigmaz = .006
sigmae = .000809
Theta_c = 1.8337874570821454e-05
Length which element represent for [m] =
5.098814615590072
Number of particles = 146

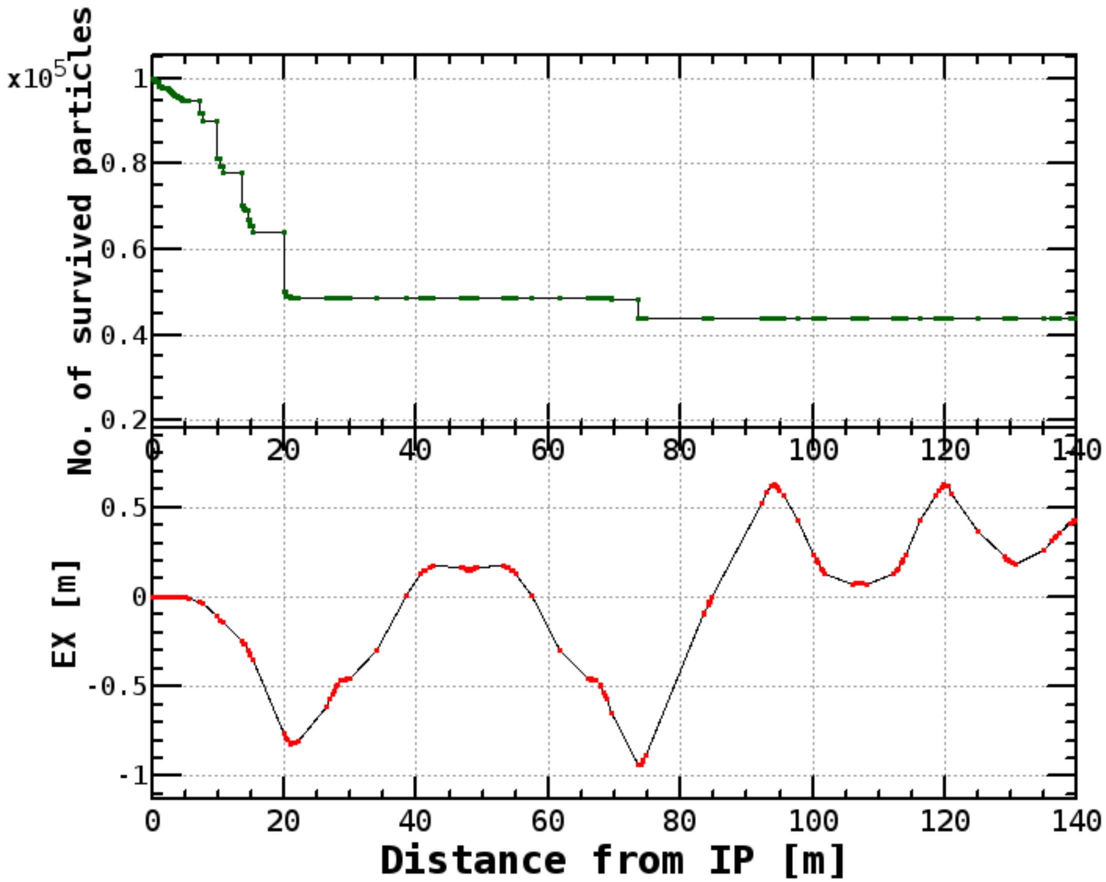
Radiative Bhabha simulation

Radiative Bhabha (LER)



0.5% < ΔE < 100%: using analytic formula

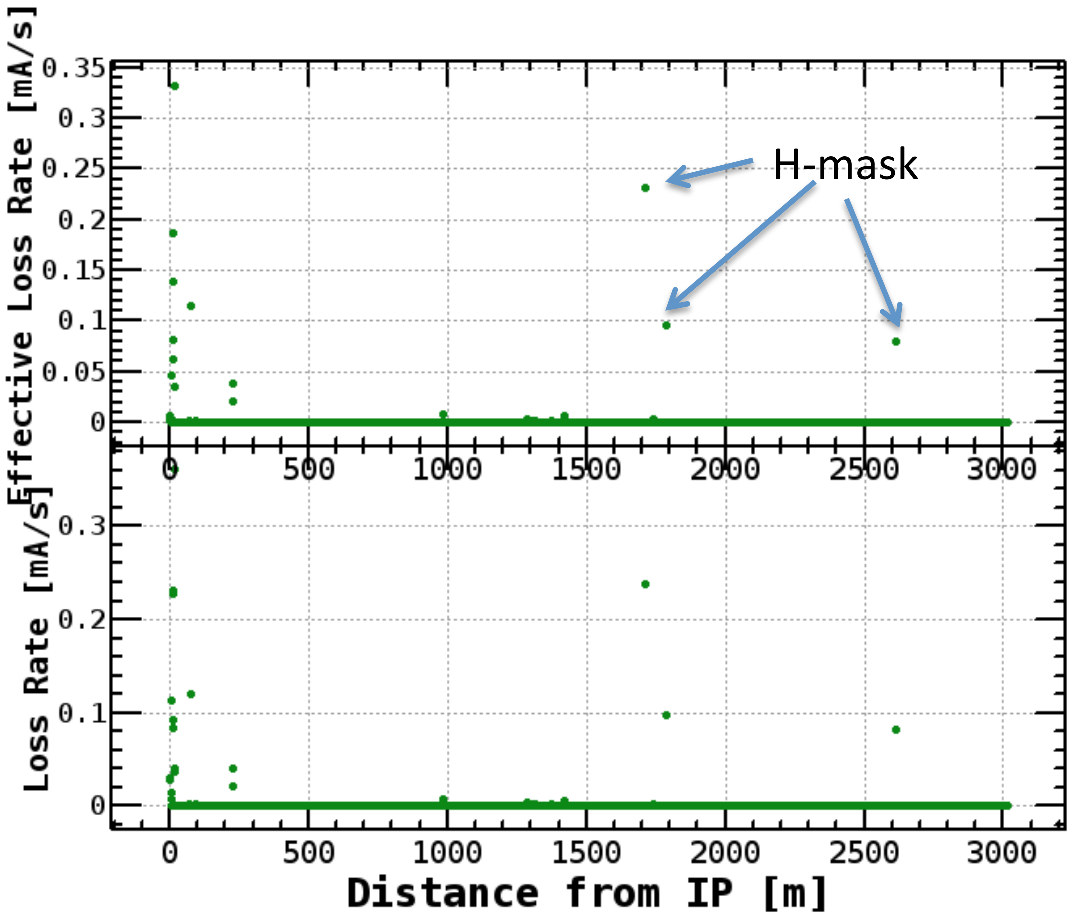
1 turn tracking
Multi-turn effects are small.



x10^5
No. of survived particles
1
0.8
0.6
0.4
0.2
0
20
40
60
80
100
120
140
EX [m]
0.5
0
-0.5
-1
Distance from IP [m]

sler_1684

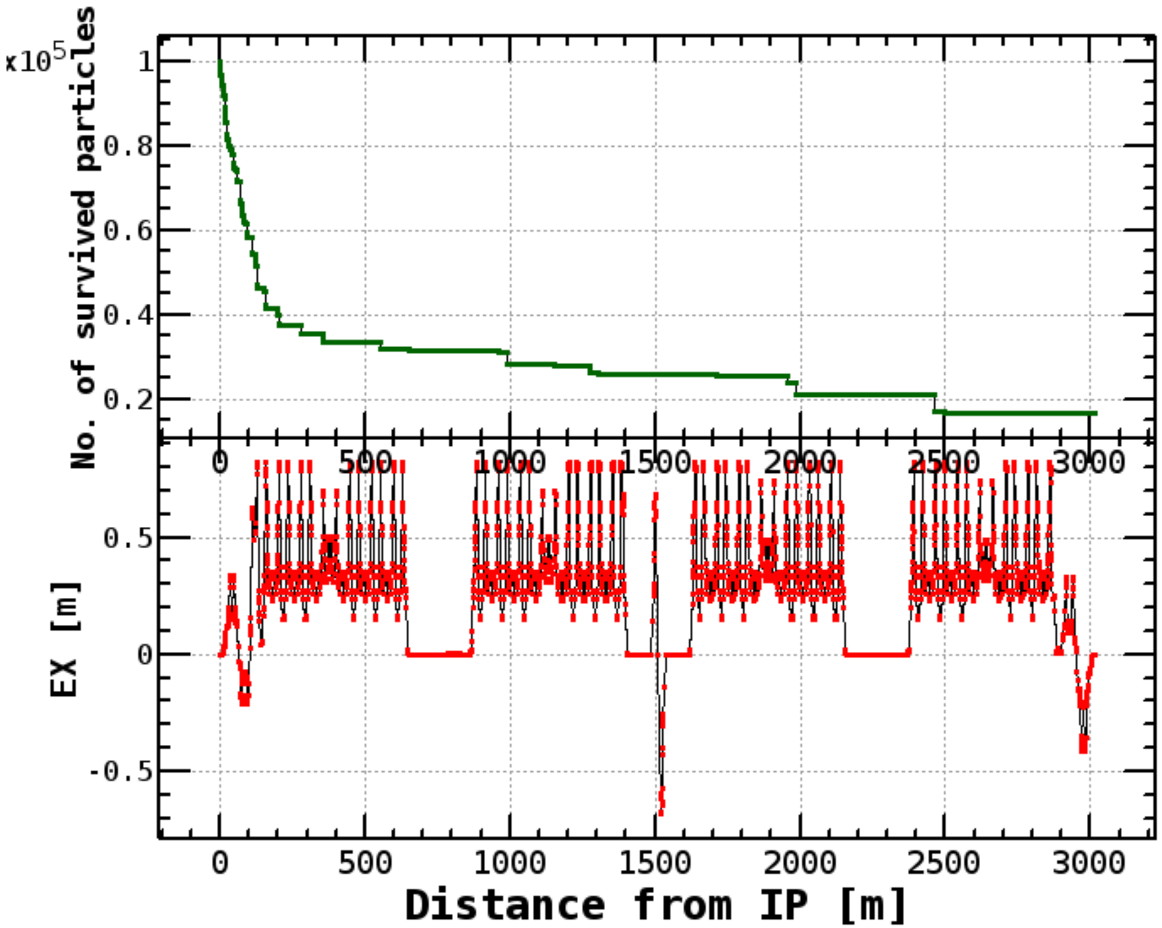
Radiative Bhabha (LER) beam loss rate per m

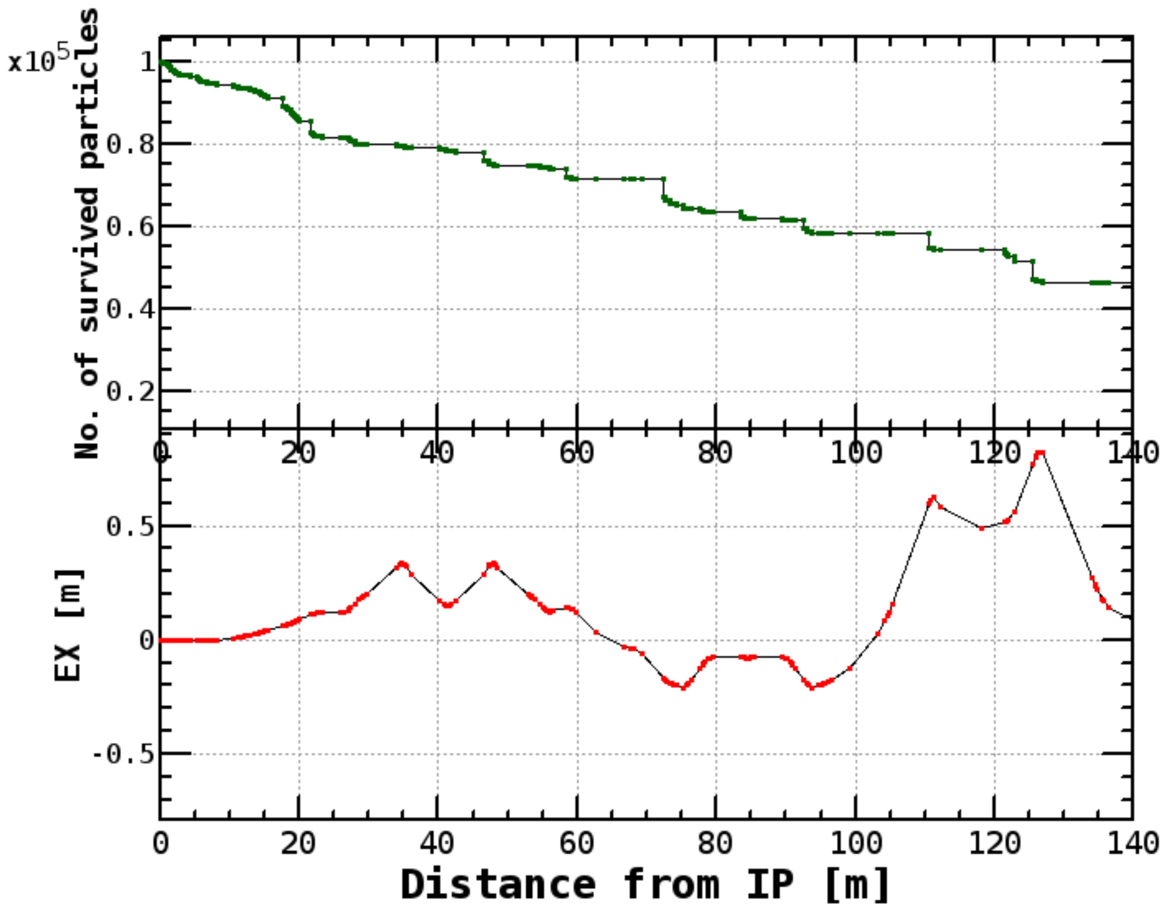


CoordinateBeamLoss2013_3_5_1_18_32.dat

Loss rate = 2.04mA/s -> τ = 29.4min. (3.6A)

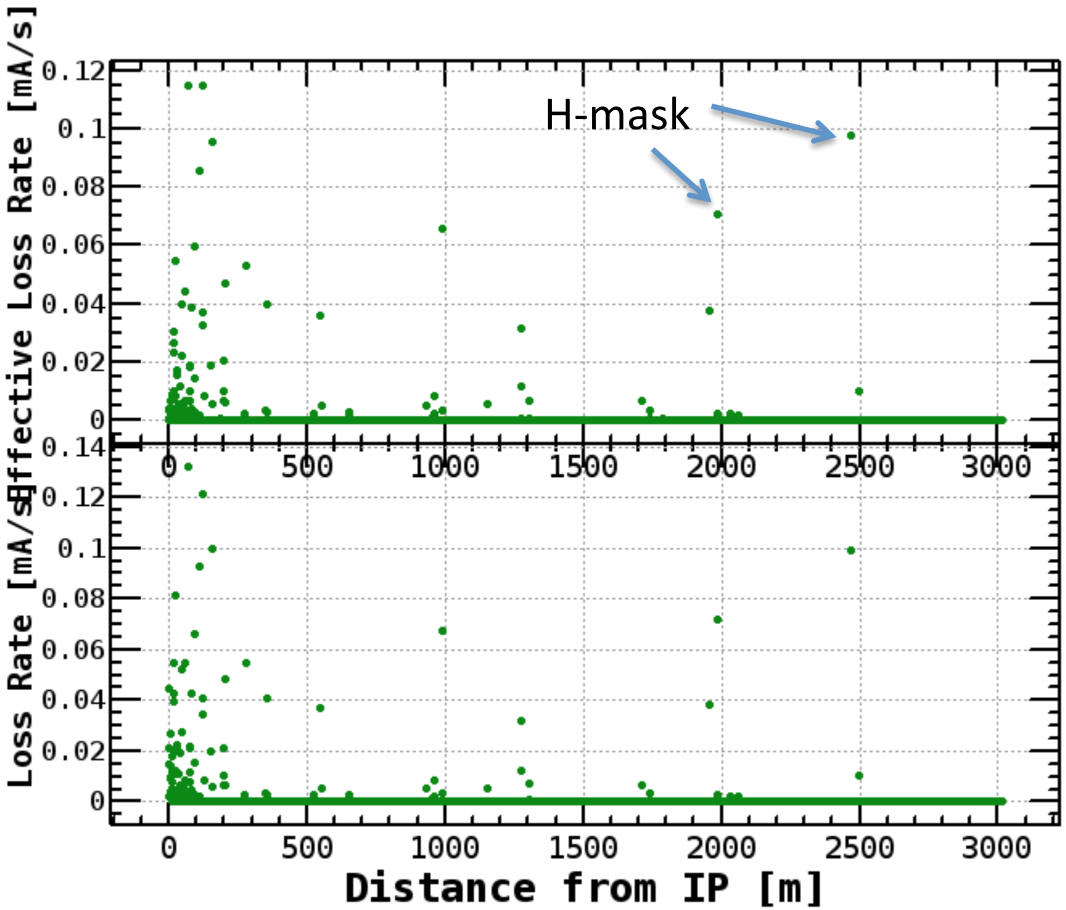
Radiative Bhabha (HER)




x10^5
No. of survived particles
1
0.8
0.6
0.4
0.2
EX [m]
0.5
0
-0.5
0
20
40
60
80
100
120
140
Distance from IP [m]

sher_5753

Radiative Bhabha (HER) beam loss rate per m

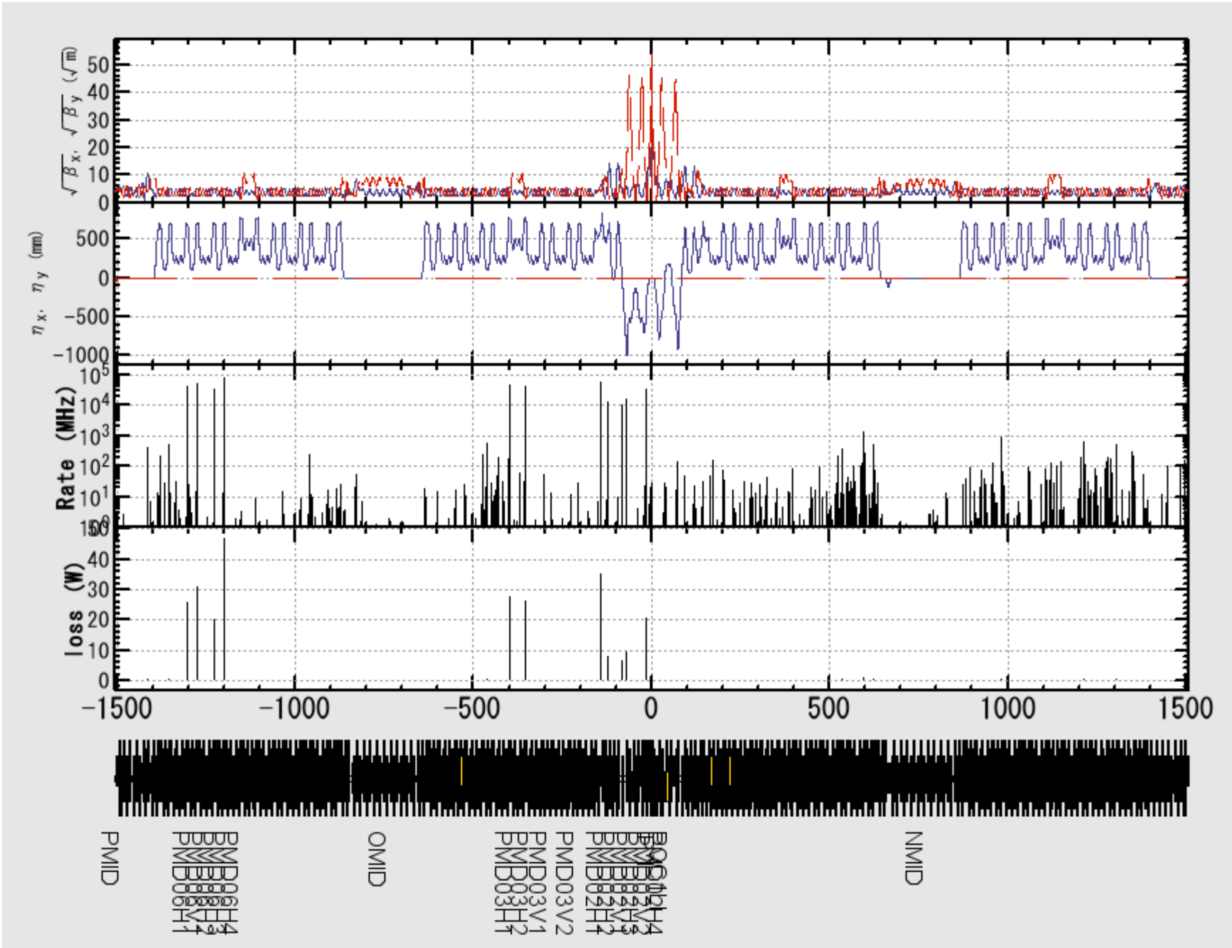


CoordinateBeamLoss2013_3_5_0_28_36.dat

Loss rate = 2.14mA/s -> τ = 20.2min. (2.6A)

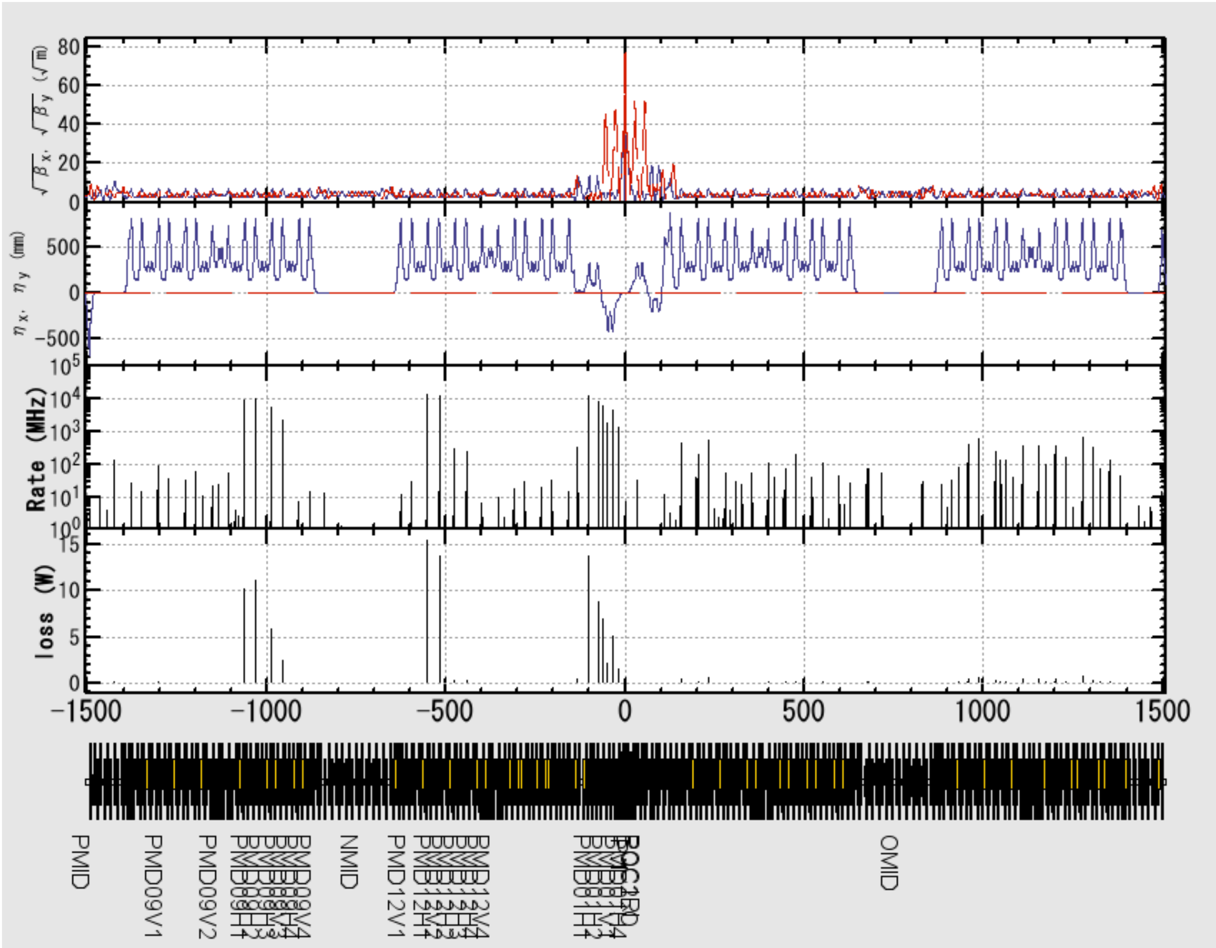
Touschek Beam Loss
Y. Ohnishi

sler_1672_5 loss distribution



Y. Ohnishi

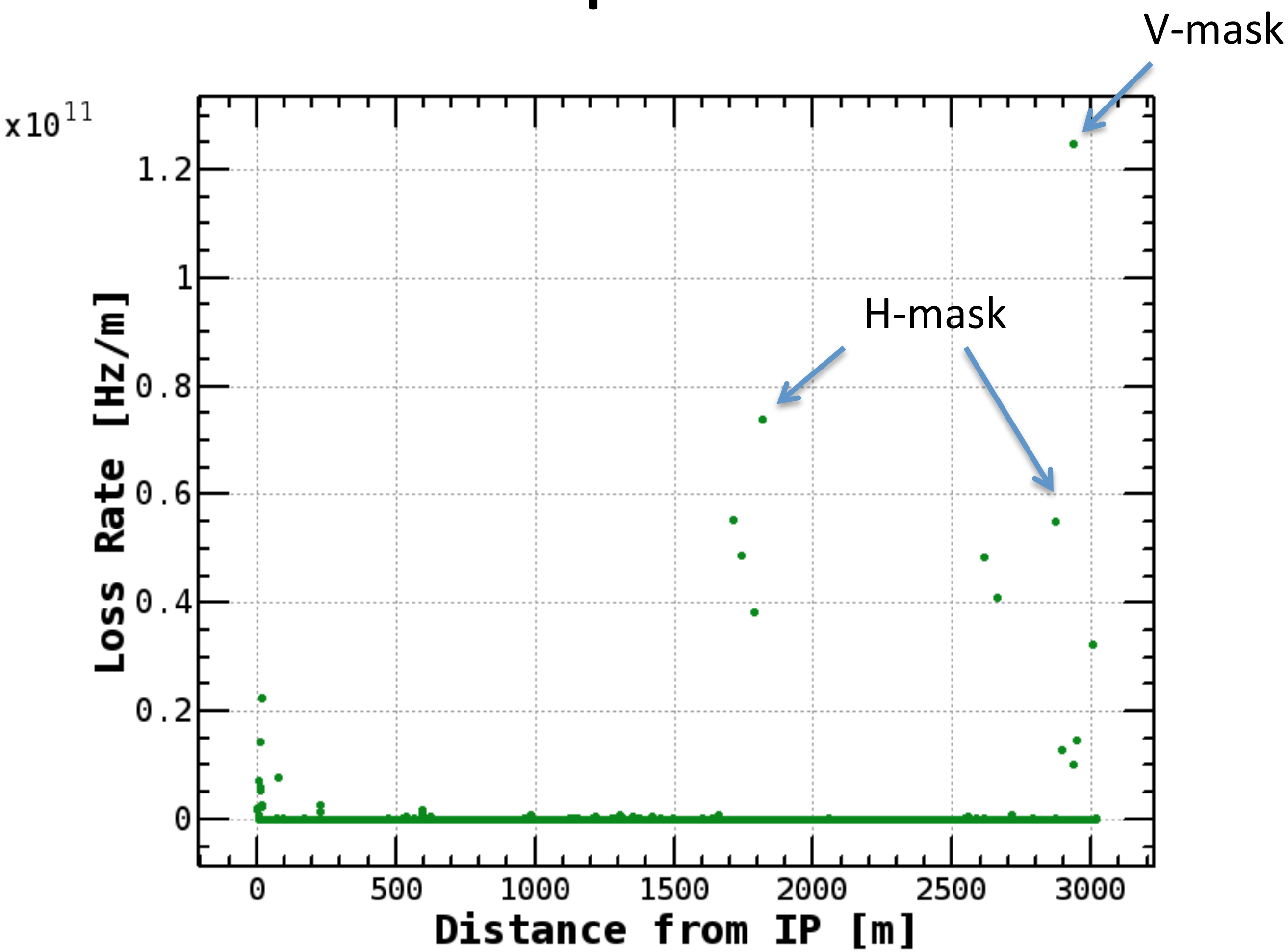
sher_5745_1 loss distribution



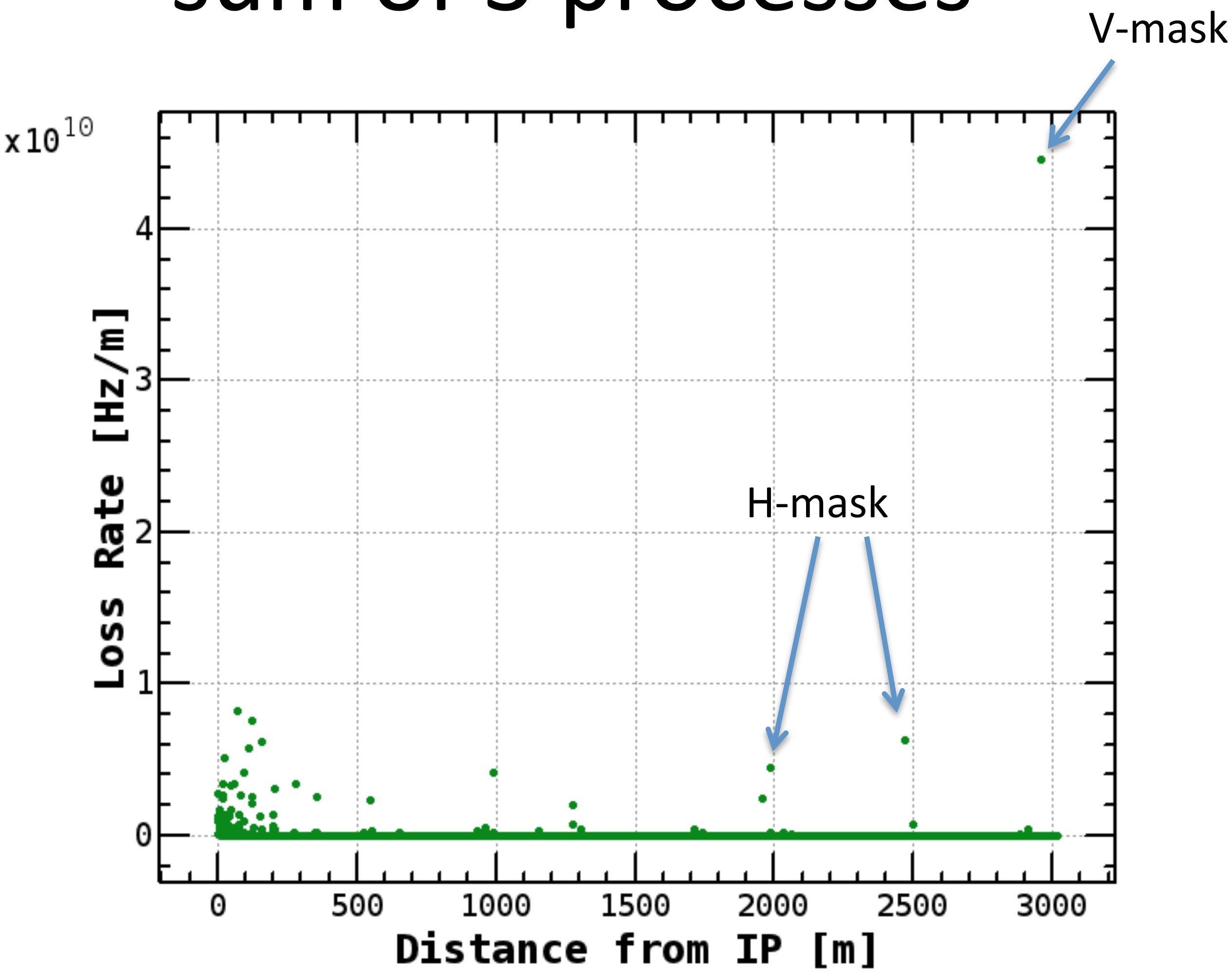
Y. Ohnishi

Sum of 3 processes

Beam loss rate (LER) sum of 3 processes



Beam loss rate (HER)
sum of 3 processes



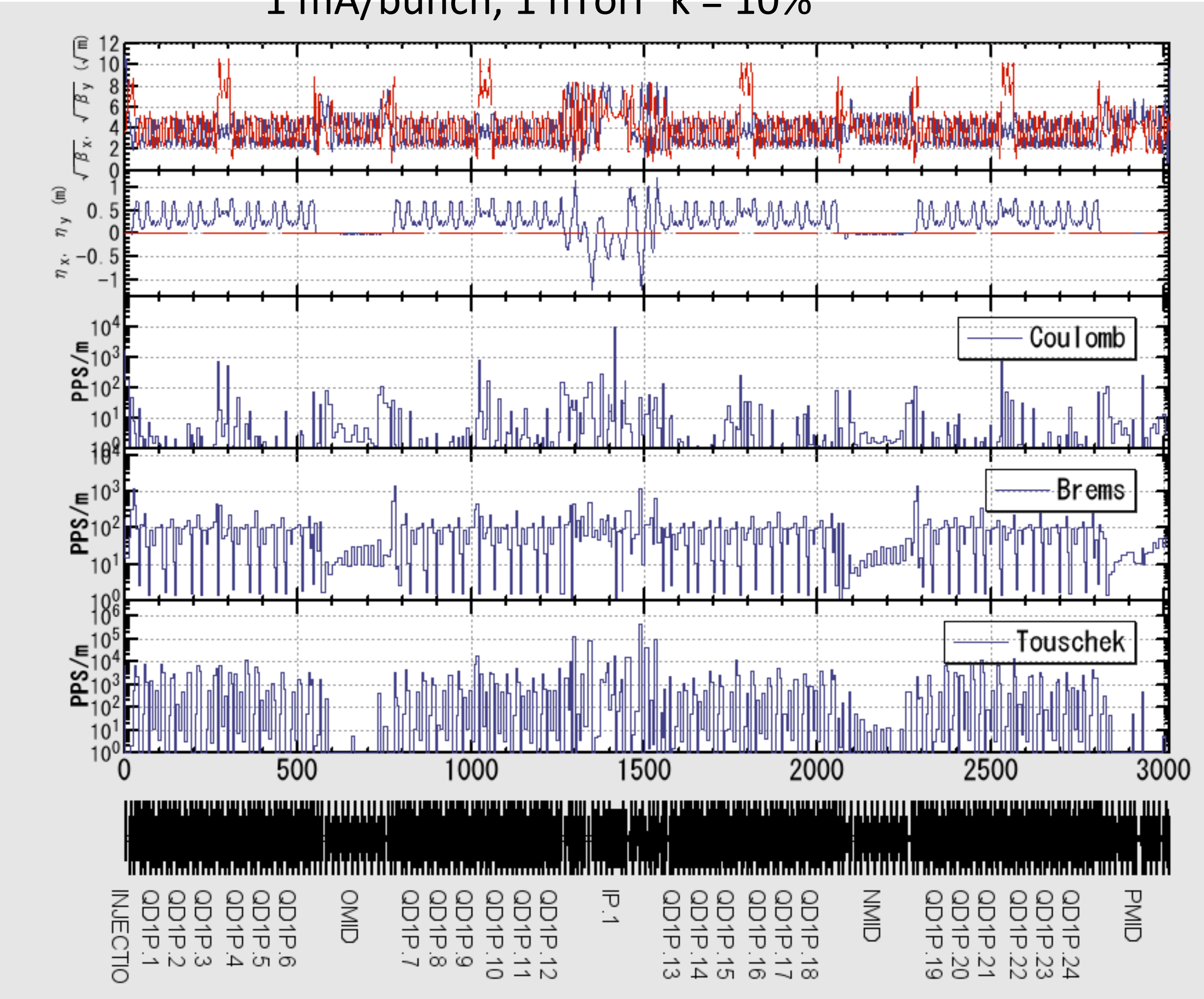
How to use the simulation results

- IR loss
  - Touschek, Radiative Bhabha -> already Nakayama san uses data for Belle II background estimation
  - Beam-gas Coulomb -> to be sent to Nakayama san
- Other loss
  - I already passed a preliminary results of LER to radiation safety section. They started an estimation. After finishing the beam-gas simulation under way, I will send them the results.

Phase-1 LER

Y. Ohnishi

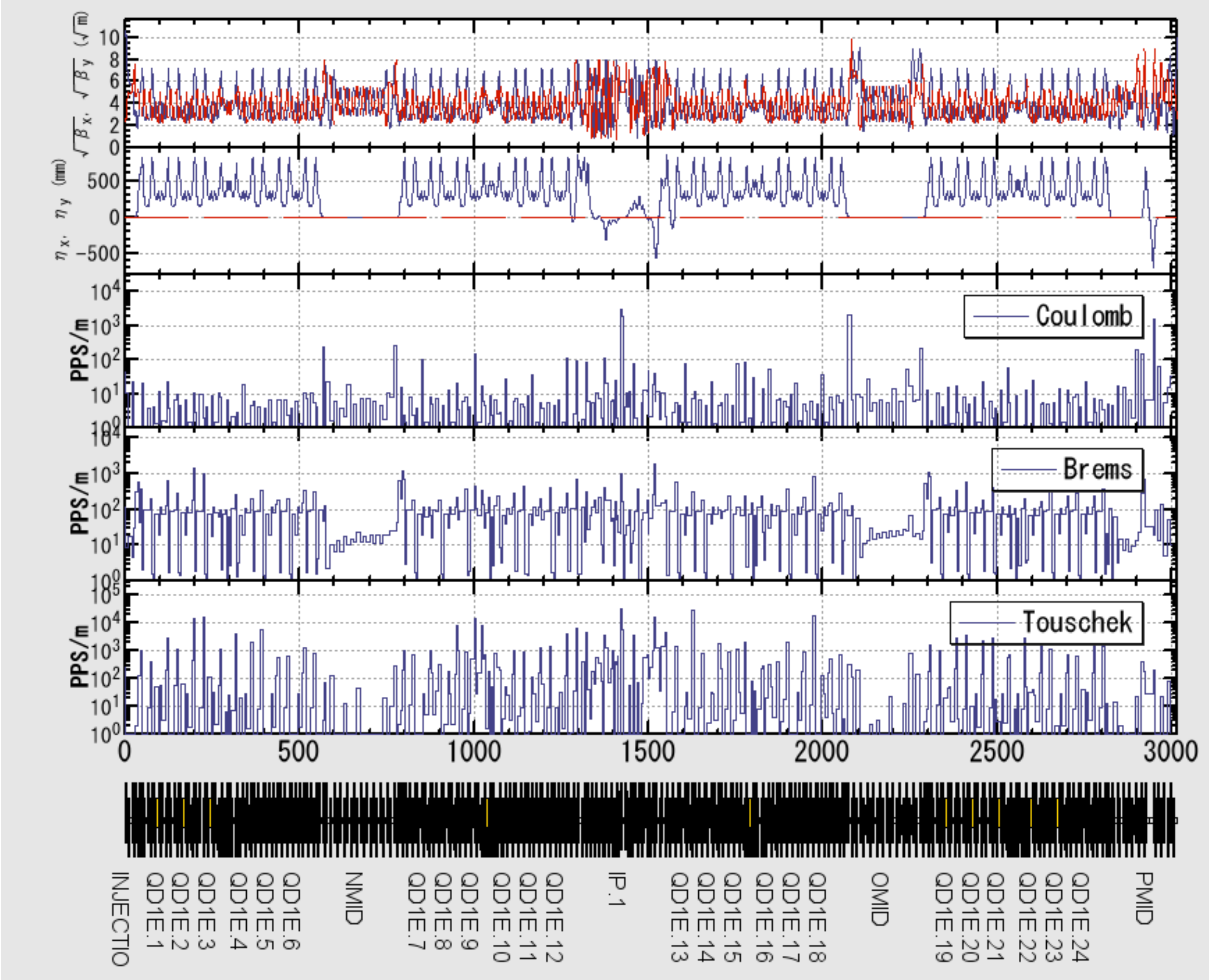
1 mA/bunch, 1 nTorr k = 10%



Phase-1 HER

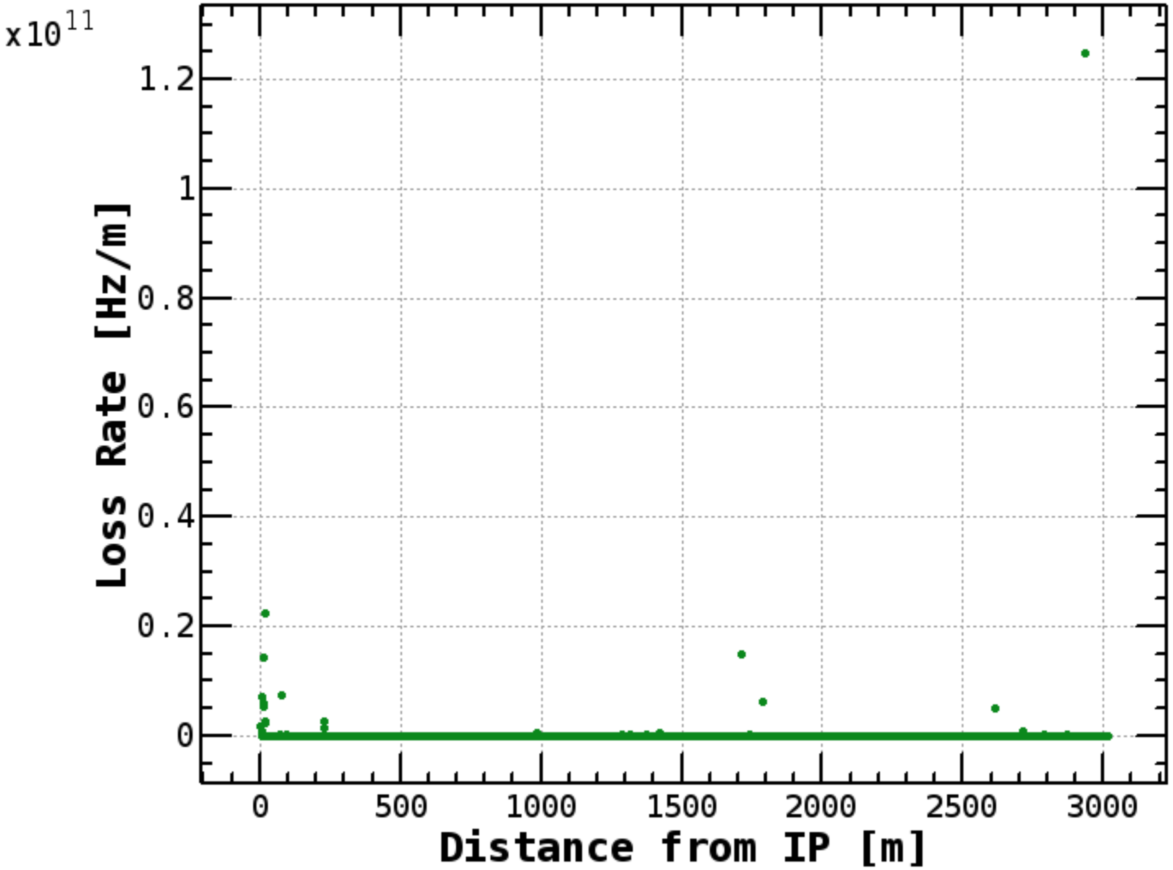
Y. Ohnishi

1 mA/bunch, 1 nTorr k = 10%



Backup

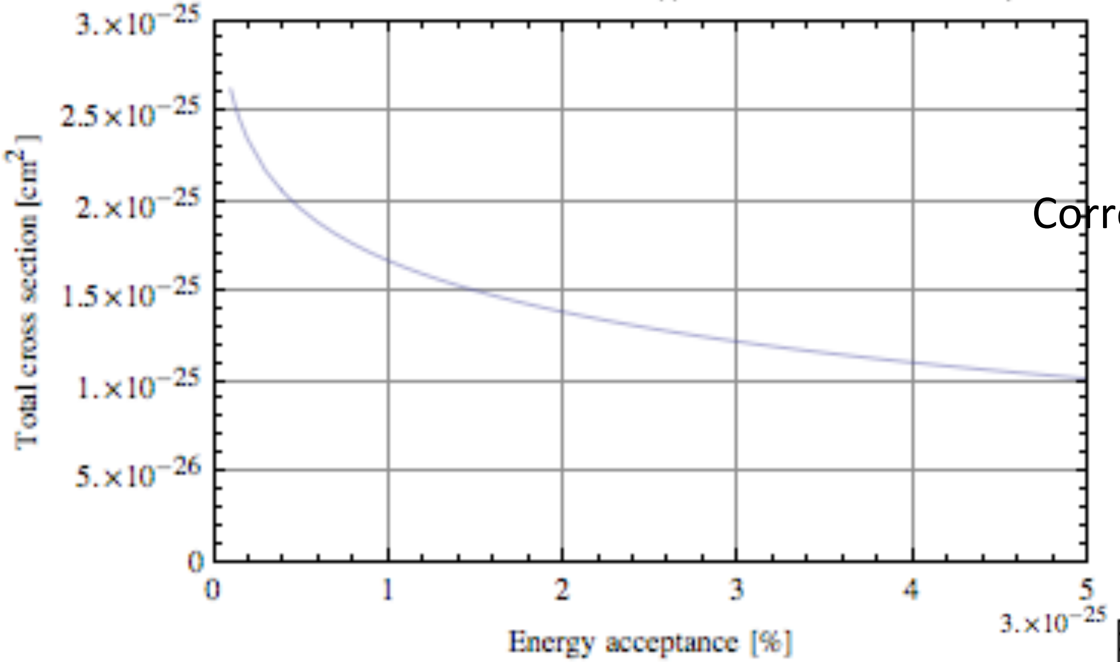
Beam loss power (LER)
sum of 2 processes (beam-gas, radiative Bhabah)

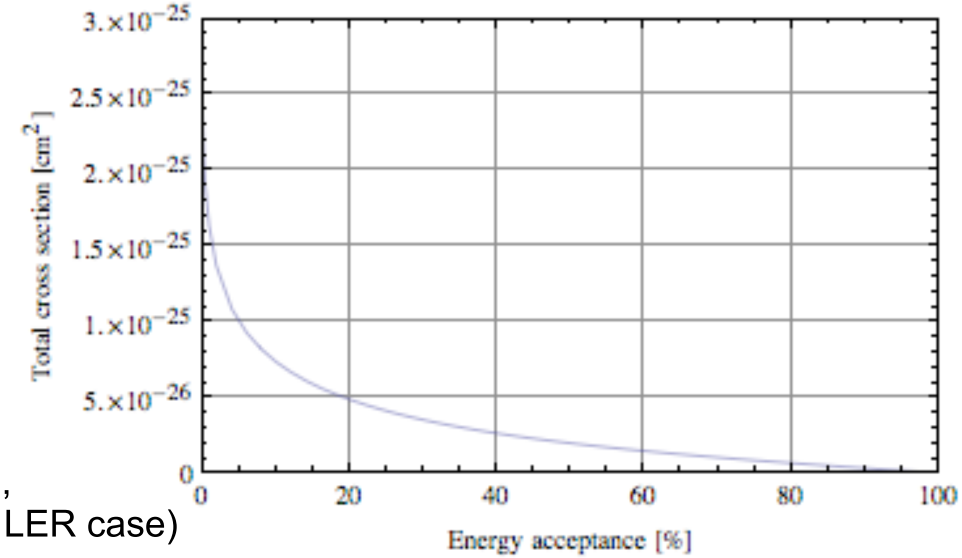


Total cross section

$$\sigma[\epsilon, a] = \frac{16}{3}\alpha r_e^2\left(\left(-\frac{3\epsilon^2}{8}+\epsilon+\log\left(\frac{1}{\epsilon}\right)-\frac{5}{8}\right)\left(\log\left(\sqrt{2}\,a\,m_e\right)+\frac{\gamma_\epsilon}{2}\right)+\frac{1}{4}\left(-\frac{2\epsilon^2}{3}+\frac{13\epsilon}{3}+\frac{13}{3}\log\left(\frac{1}{\epsilon}\right)-\frac{17}{6}\right)\right)$$

Correction for finite beam size is included.

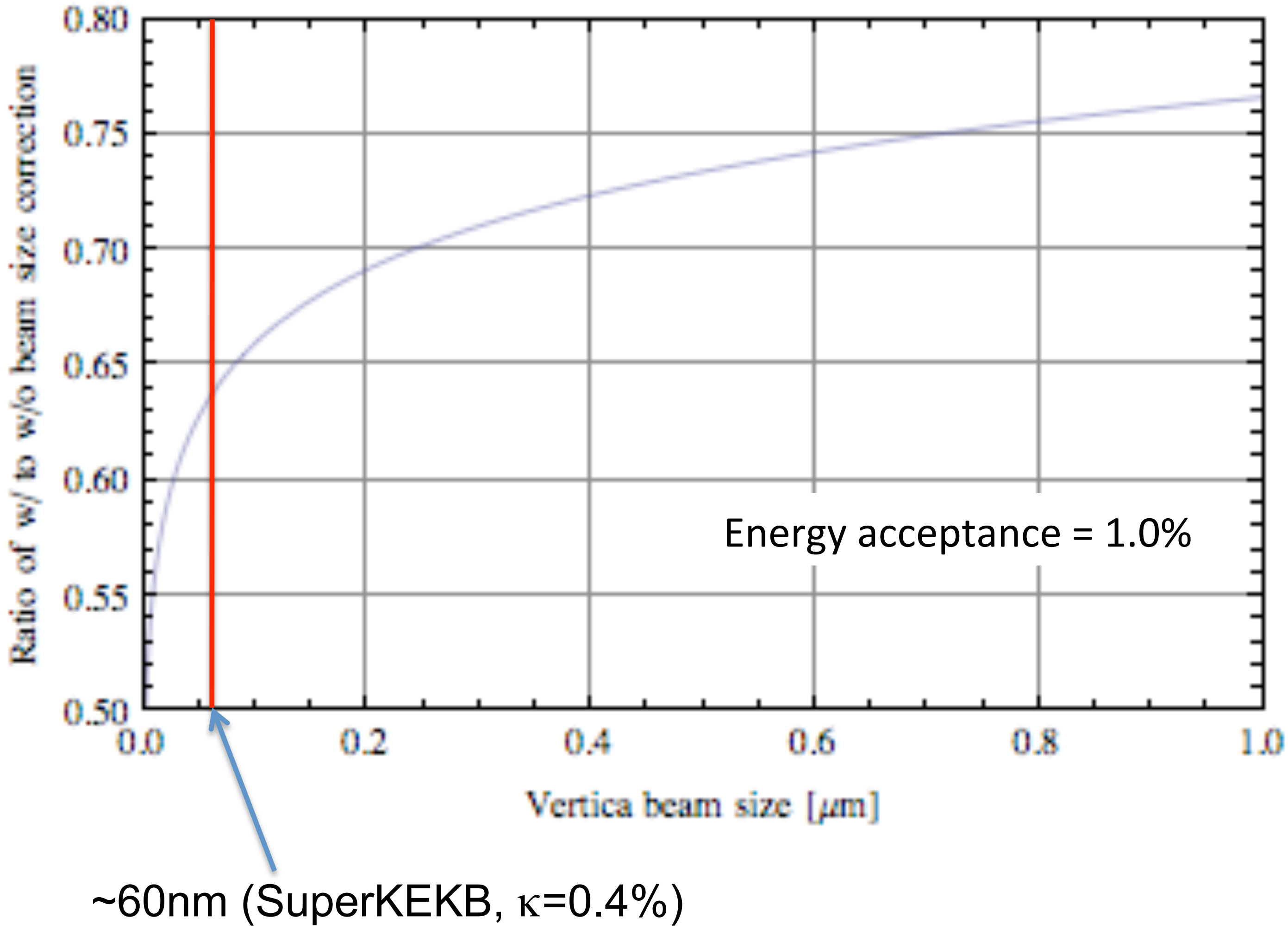




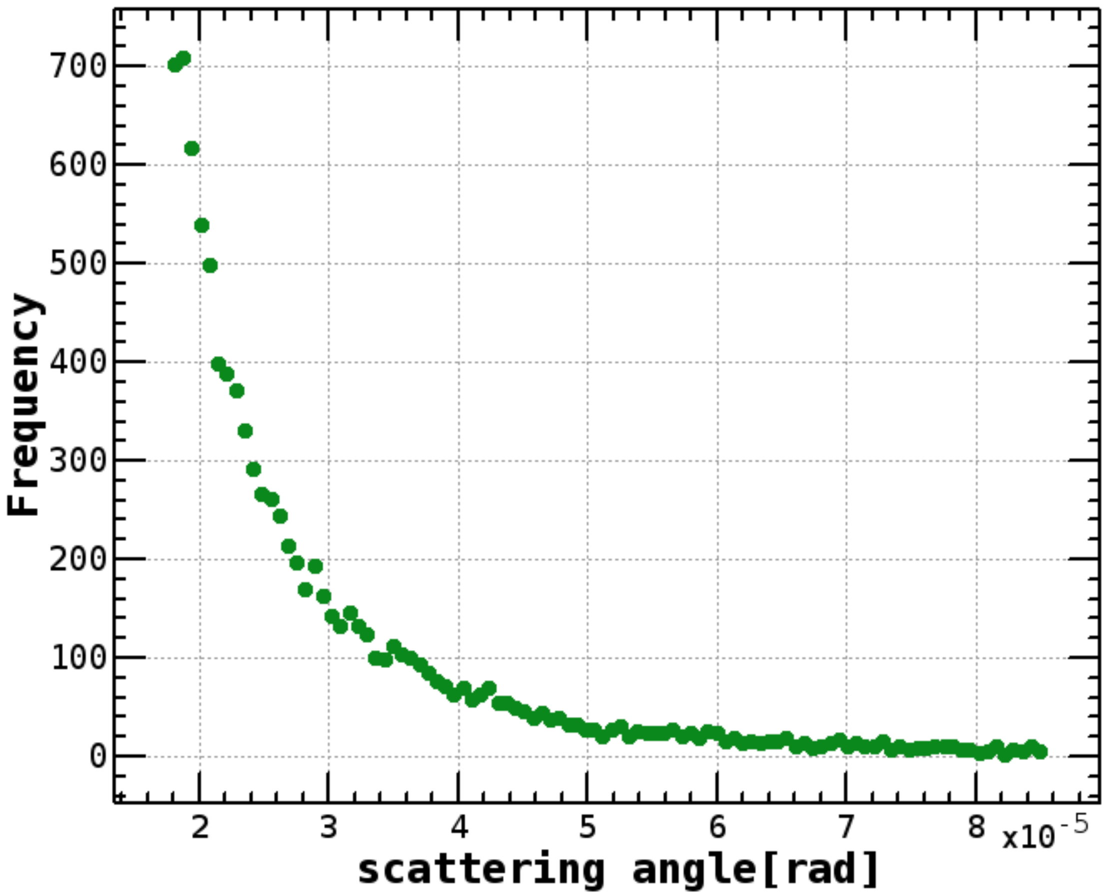
$\sigma(\varepsilon>1.5\%) = 1.55 \times 10^{-25}\ cm^2$
$\sigma(\varepsilon>5.0\%) = 1.05 \times 10^{-25}\ cm^2$
$\sigma(\varepsilon>20\%) = 0.51 \times 10^{-25}\ cm^2$
$\sigma(\varepsilon>50\%) = 0.20 \times 10^{-25}\ cm^2$

Assuming particles are lost with energy loss of $\varepsilon>1.5\%$,
Beam lifetime = 30.15 min. ($L=8\times10^{35}$ /cm^2/s, Ib=3.6A, LER case)
Loss rate 1.99mA/s

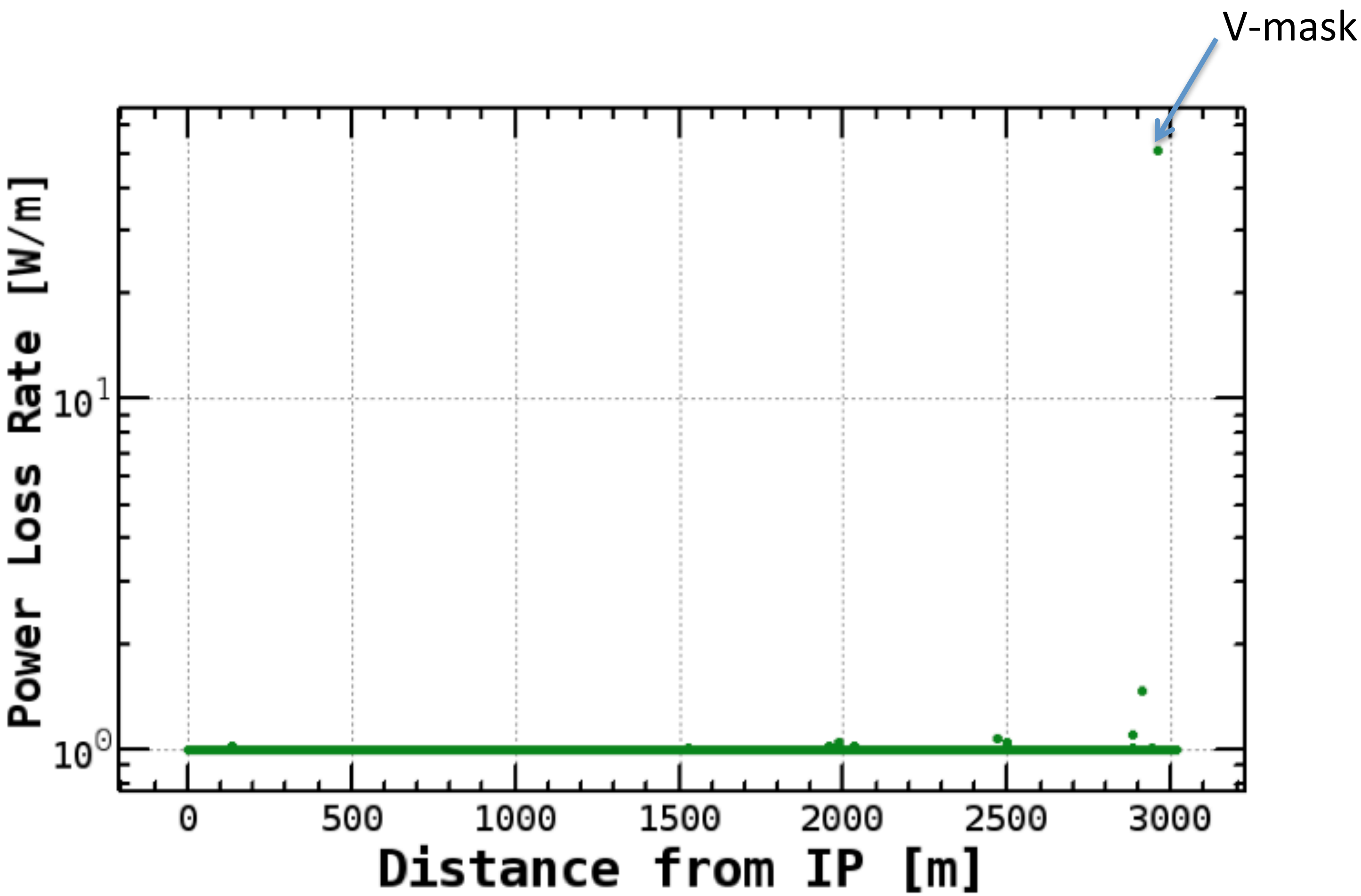
Correction for cross section due to finite beam size



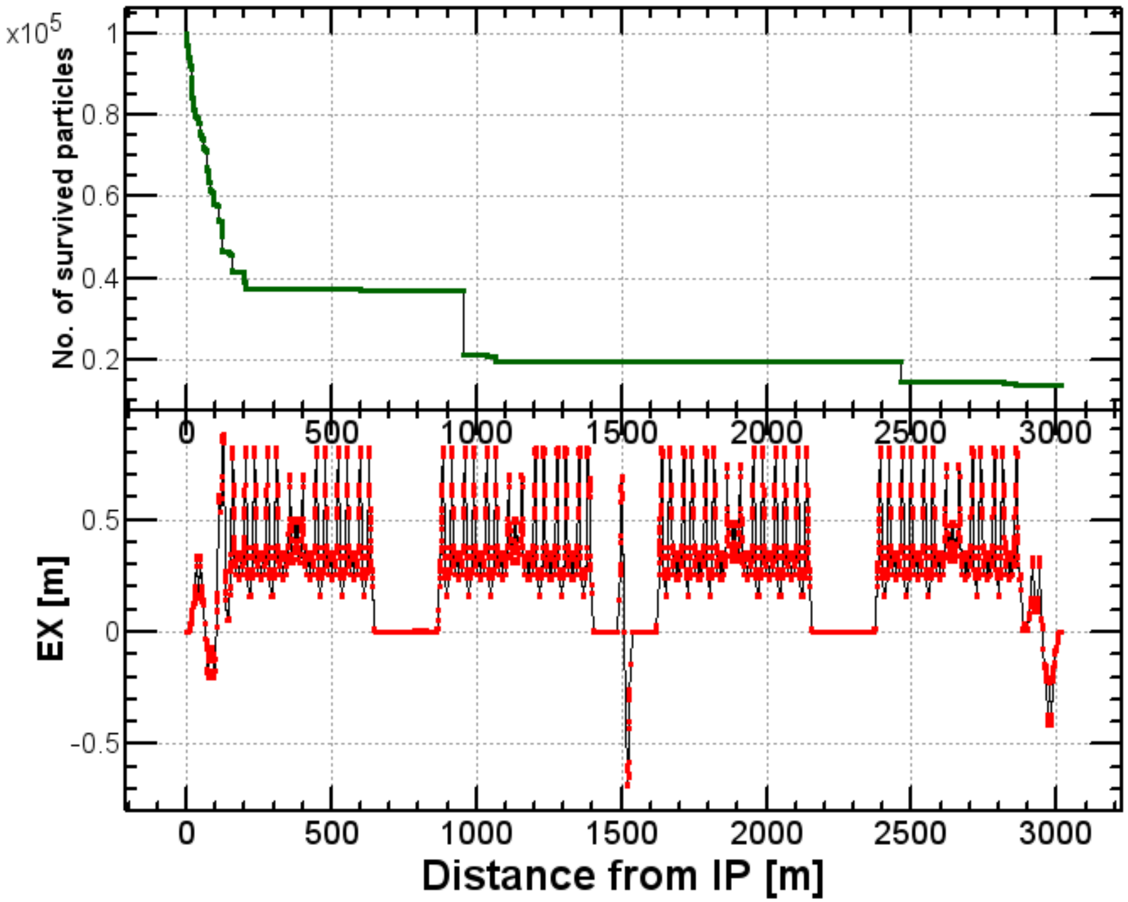
Created distribution of Coulomb scattering angles



Loss distribution (power) HER beam-gas Coulomb

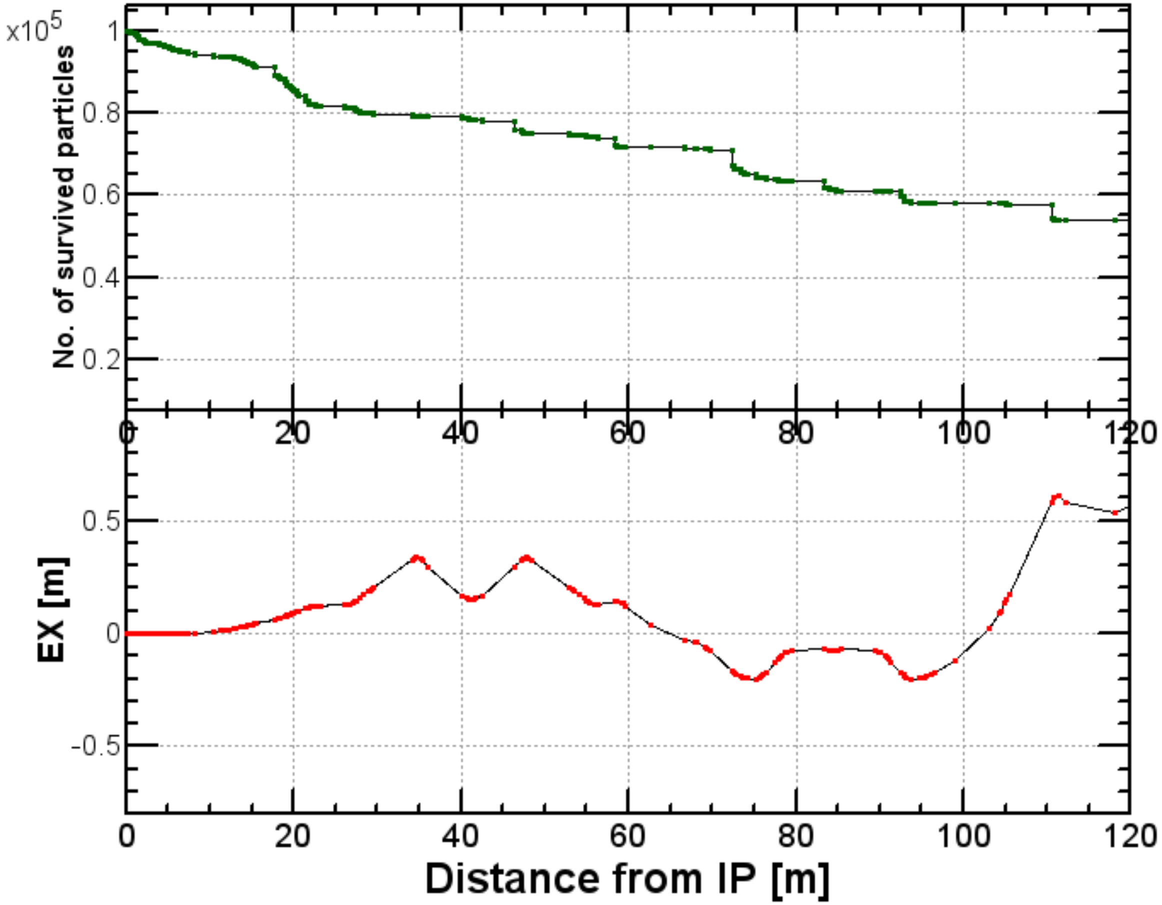


Radiative Bhabha (HER)

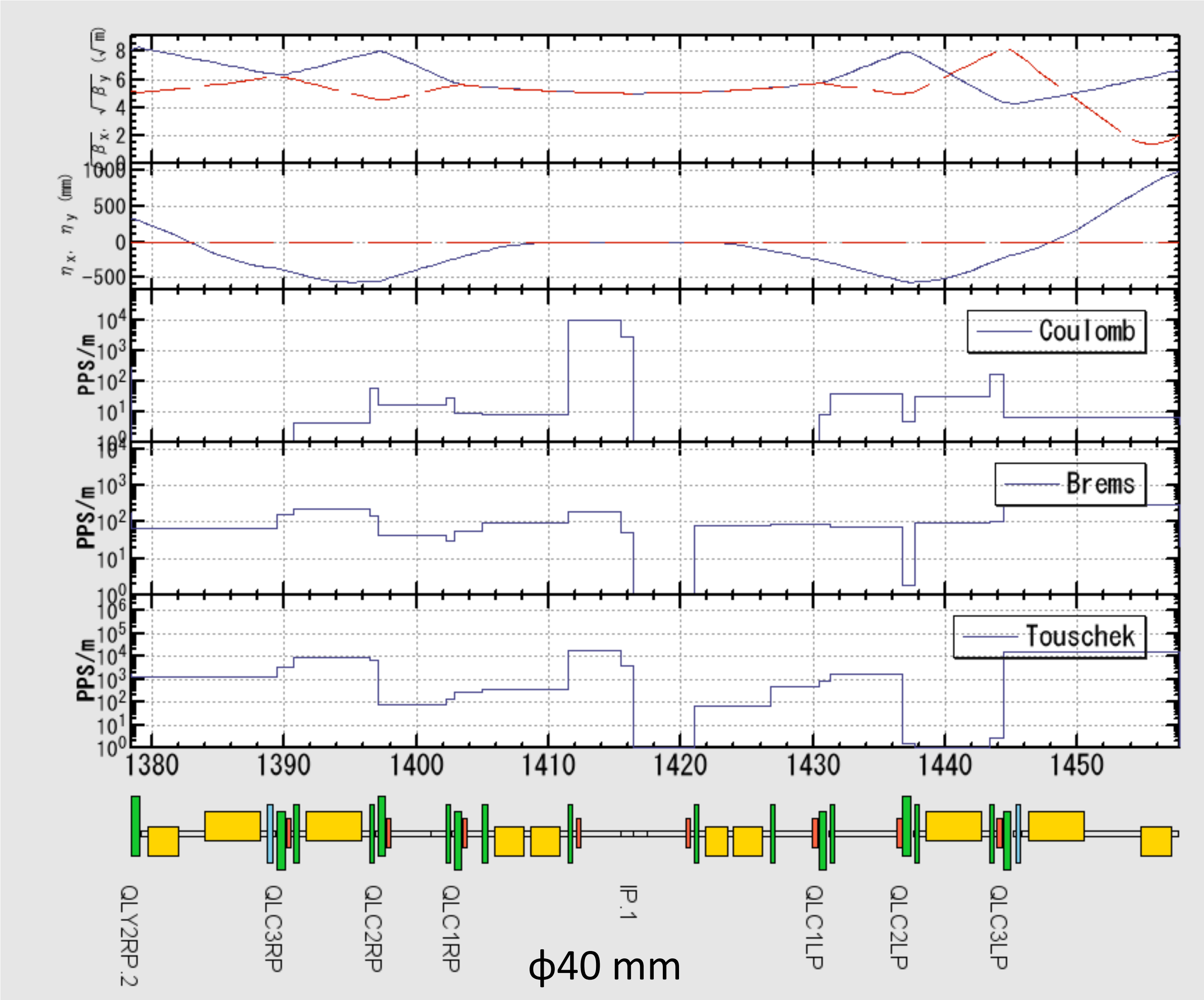


0.5% < ΔE < 100%: using analytic formula

1 turn tracking
Multi-turn effects are small.

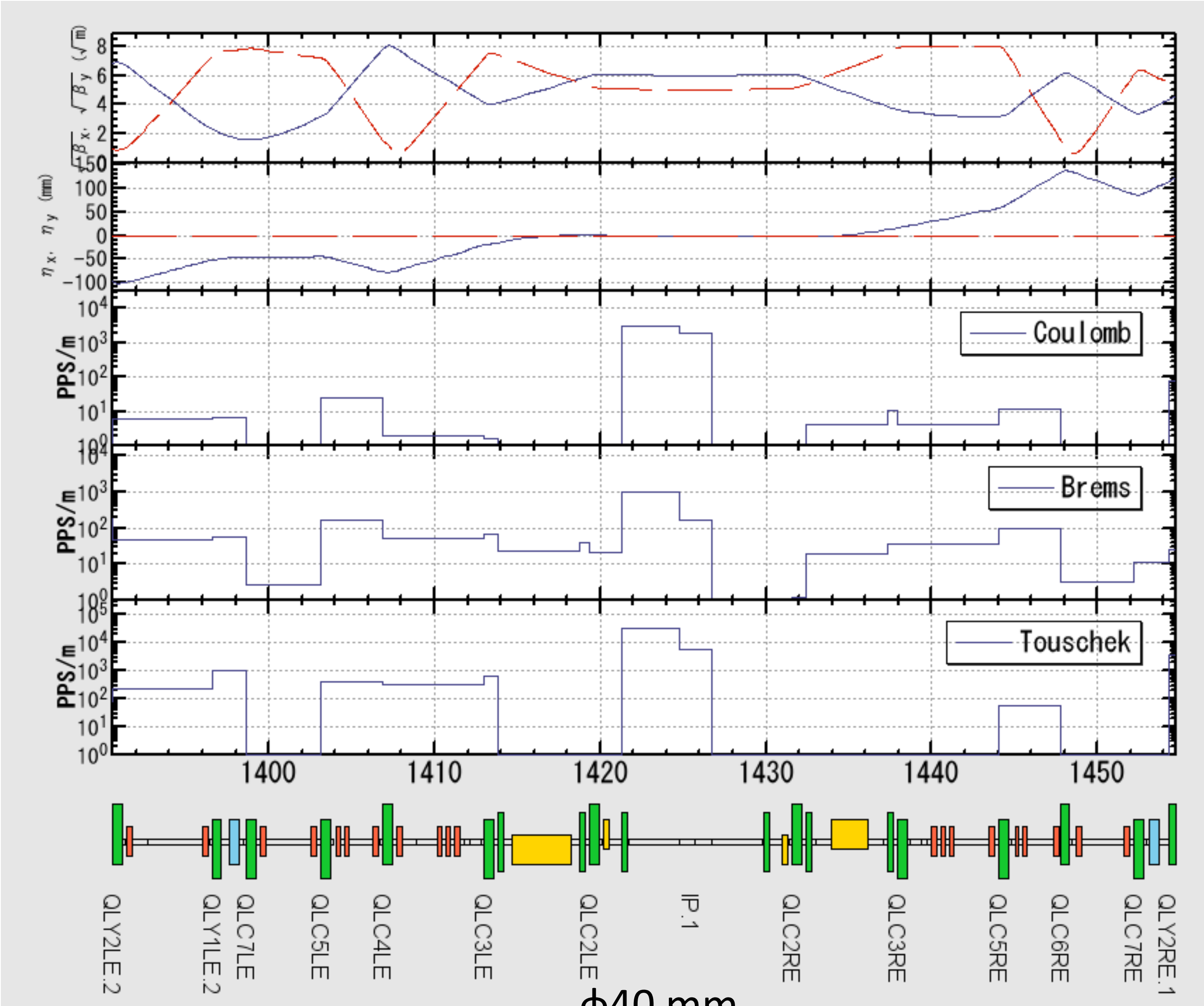

x10^5
No. of survived particles
1
0.8
0.6
0.4
0.2
0
20
40
60
80
100
120
EX [m]
0.5
0
-0.5
Distance from IP [m]

Phase-1 LER



Coulomb
Brems
Touschek
PPS/m
1380
1390
1400
1410
1420
1430
1440
1450
QLY2RP.2
QLC3RP
QLC2RP
QLC1RP
IP.1
QLC1LP
QLC2LP
QLC3LP
ϕ40 mm

Phase-1 HER



ϕ40 mm

Summary

Total beam loss / bunch

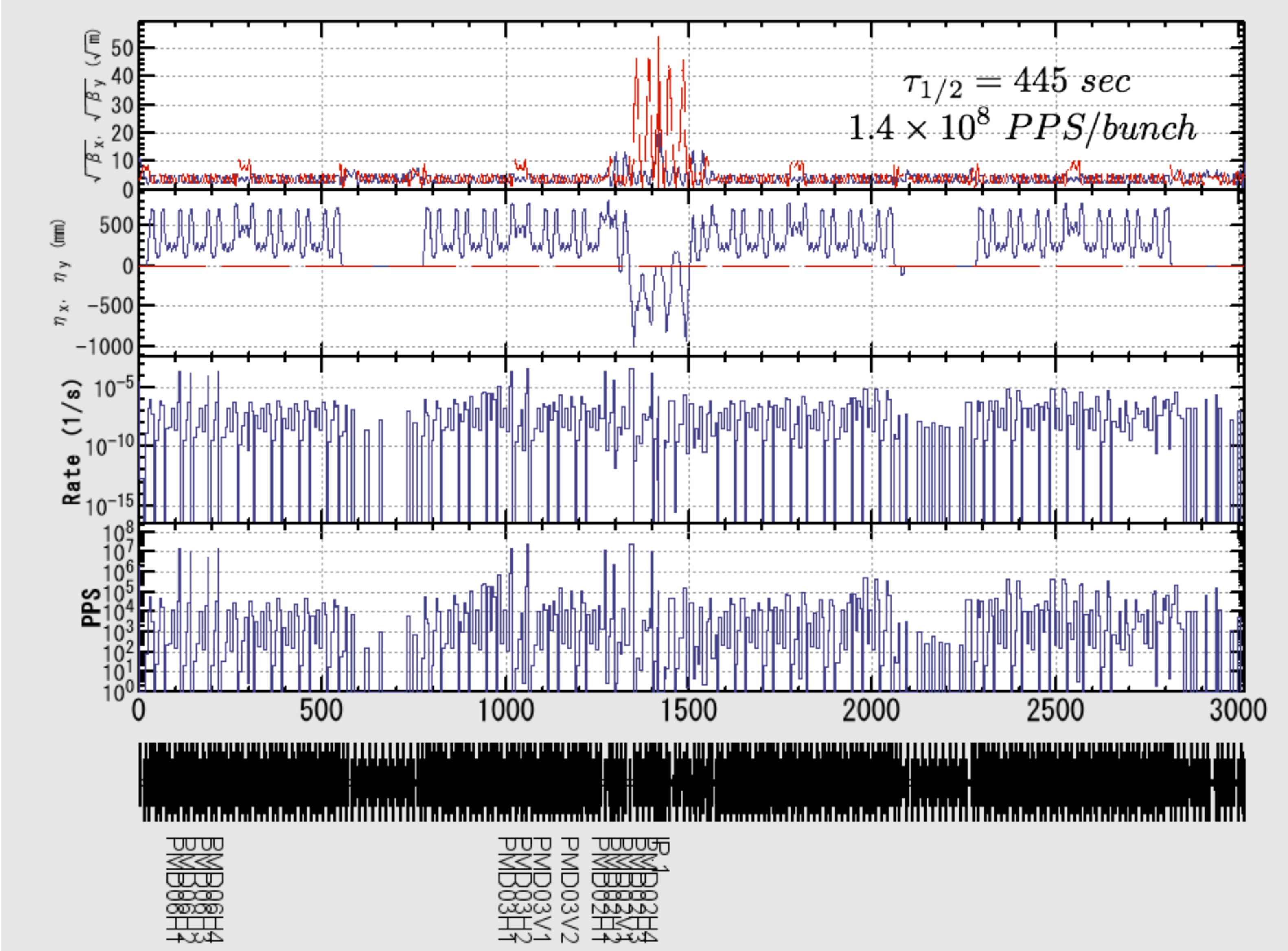
Phase 1	N_b	Touschek PPS	Coulomb PPS	Brems. PPS	Total PPS
HER	6.28×10^{10}	1.41×10^{6}	6.17×10^{4}	2.94×10^{5}	1.76×10^{6}
LER	6.28×10^{10}	8.74×10^{6}	9.95×10^{4}	2.72×10^{5}	9.11×10^{6}
condition	1 mA/bunch	10 % coupling	P_{ave}= 1 nTorr		1.09×10^{7}

w/o movable masks
#bunches = 1000 - 2000
P_{ave} = 1 nTorr - 10 nTorr

sher_5755_beast
sler_1684_beast

Phase-2 LER

Touschek loss



Phase-2 HER

Touschek loss