Touschek Background Simulation

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Joint Belle II & SuperB Background Meeting

Vienna, Austria 9-10 February 2012

Piwinski's Formula

A. Piwinski, DESY 98-179, 1998

- Local loss rate:

$$r(\epsilon_a, B1, B2) = \frac{r_e c N^2}{4\sqrt{\pi}\gamma^2\sigma_z\sqrt{\sigma_x^2\sigma_y^2 - \sigma_\delta^4\eta_x^2\eta_y^2}} G(\epsilon_a, B_1, B_2)$$

$$G(\epsilon_a, B_1, B_2) = \sqrt{B_1^2 - B_2^2}\int_{k_a}^{\pi/2}\left\{\frac{(2\epsilon+1)^2}{\epsilon}\left(\frac{\epsilon/\epsilon_a}{1+\epsilon} - 1\right) + \epsilon - \sqrt{\epsilon\epsilon_a(1+\epsilon)} - \left(2 + \frac{1}{2\epsilon}\right)\ln\frac{\epsilon/\epsilon_a}{1+\epsilon}\right\} e^{-B_1\epsilon} I_0(B_2\epsilon)\sqrt{1+\epsilon}\,dk$$

$$\epsilon = (\beta\delta)^2 \quad k \equiv \tan^{-1}\sqrt{\epsilon} \qquad \delta = \frac{\Delta p}{p_0}$$

$$B_1 = B_1(\varepsilon_x, \varepsilon_y, \beta_x, \beta_y, \eta_x, \eta_y, \sigma_\delta)$$
$$B_2 = B_2(\varepsilon_x, \varepsilon_y, \beta_x, \beta_y, \eta_x, \eta_y, \sigma_\delta)$$

- Loss rate:

$$R(\epsilon_a) = \frac{1}{L_{circ}}\oint r(\epsilon_a, B_1, B_2)\,ds \qquad \frac{dN}{d\tau} = -\frac{N}{\tau} = -R(\epsilon_a)$$

- Momentum dependence:

$$\frac{\partial r(\epsilon_a, B_1, B_2)}{\partial\delta_a} = \frac{\partial r(\epsilon_a, B_1, B_2)}{\partial\epsilon_a}\frac{\partial\epsilon_a}{\partial\delta_a} \qquad \epsilon_a \sim \delta_a^2$$ = (momentum aperture)^2

Bruck's Formula

- Non-relativistic and flat-beam approximation for Piwinski's formula is consistent with Bruck's formula.

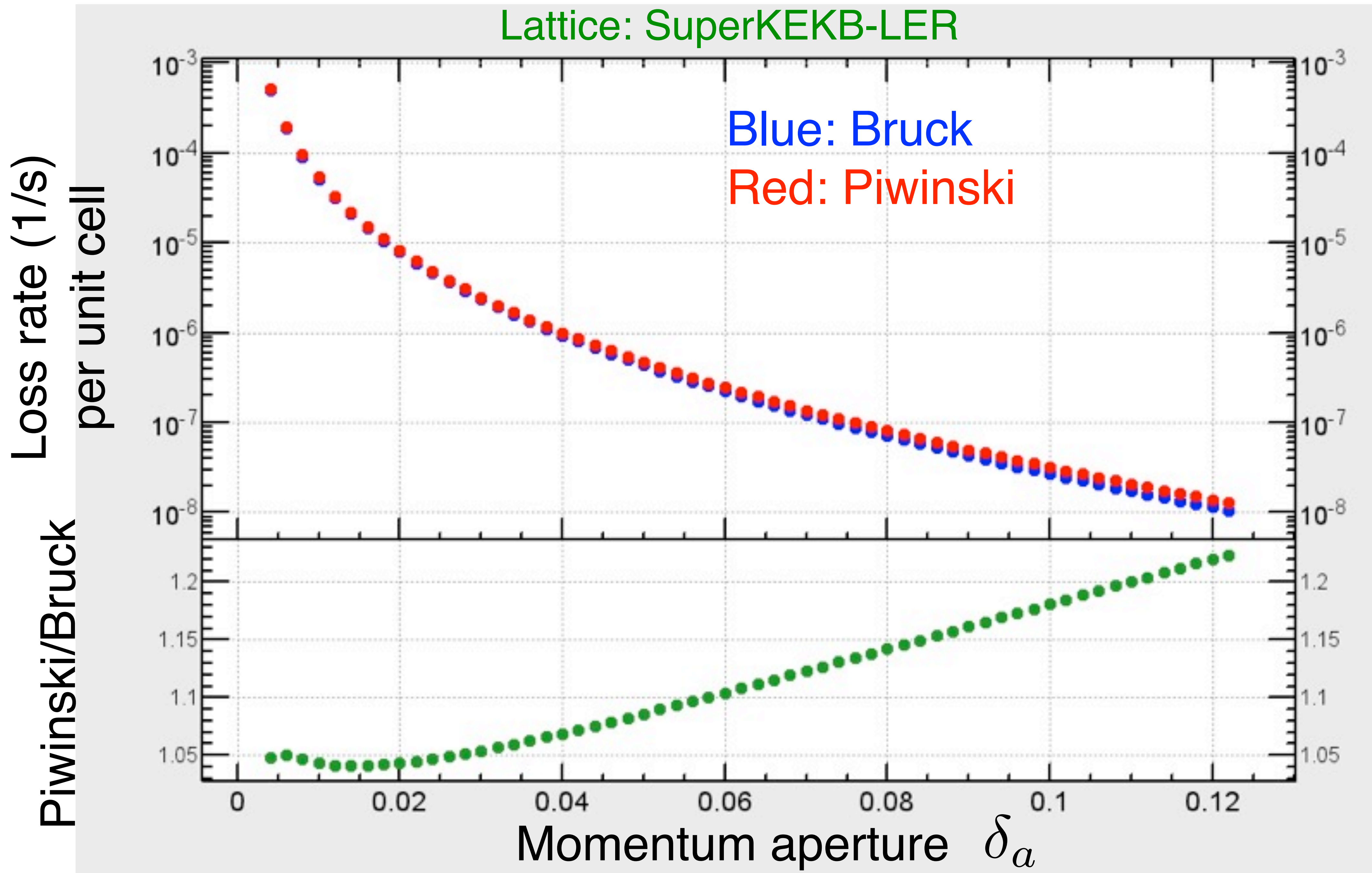
$$r(u_a, \varepsilon_x, \beta_x, \eta_x, \varepsilon_y, \beta_y) = \frac{r_e^2 c \beta_x N^2}{8\pi\gamma^3 \beta \sigma_{x\beta} \sigma_{y\beta} \sigma_z \sigma_x u_a} C(u_a)$$

$$C(u_a) = -\frac{3}{2} e^{-u_a} + \int_{u_a}^{\infty} \left(1 + \frac{3}{2} u_a + \frac{u_a}{2} \ln \frac{u}{u_a}\right) e^{-u} \frac{du}{u}$$

$$u_a = \left(\frac{\delta_a \beta_x}{\gamma \sigma_{x\beta}}\right)^2$$

Comparisons

- Bruck's and Piwinski's formula



Good agreement within ~20 % for δ_a < 12 %

Tracking Simulation + Analytic Formula

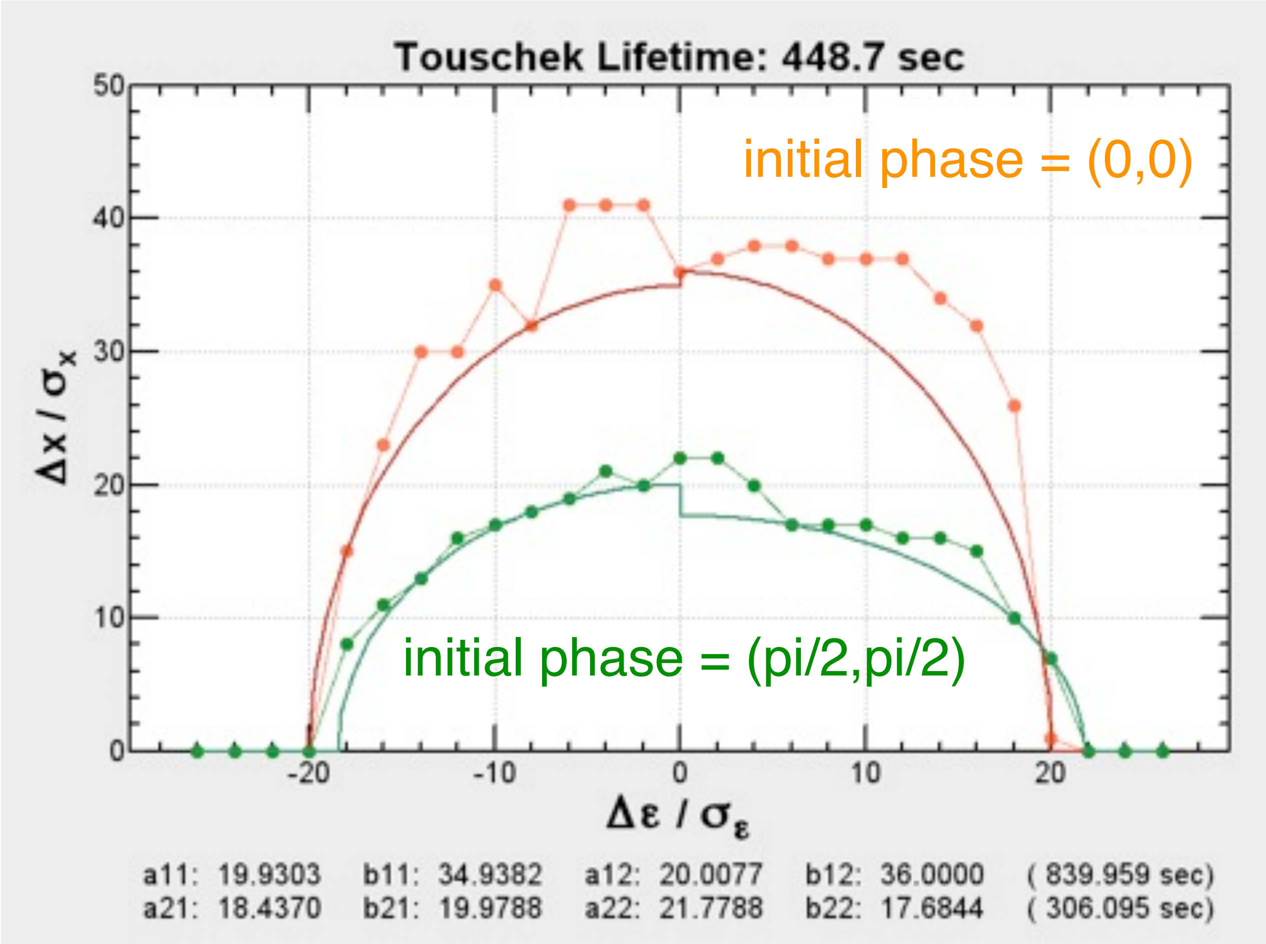
- Macro particles for $\delta_i = \sigma_\delta n_z$ $(n_z = -100,-99,-98,..,0,..,+99,+100)$
- initial orbit : $x = 0$, $p_x = 0$, $y = 0$, $p_y = 0$, $z = 0$ for all macro particles : $(x, p_x, y, p_y, z, \delta)$ for particle tracking in *SAD*
- Scattered position is an entrance of the component in the ring. We change the scattered position one by one in the whole ring, then we check the particle orbit whether within the aperture or not.
- Tracking is performed within 5 turns (to save computing time).
- The scattered probability is calculated by Bruck's formula.
- Loss at each position is obtained by integration of the tracking result multiplies the loss rate based on the scattered probability.
- Lattice error is included as sextupole misalignments to generate reasonable XY couplings. No DA optimization with error.

Lifetime Estimation

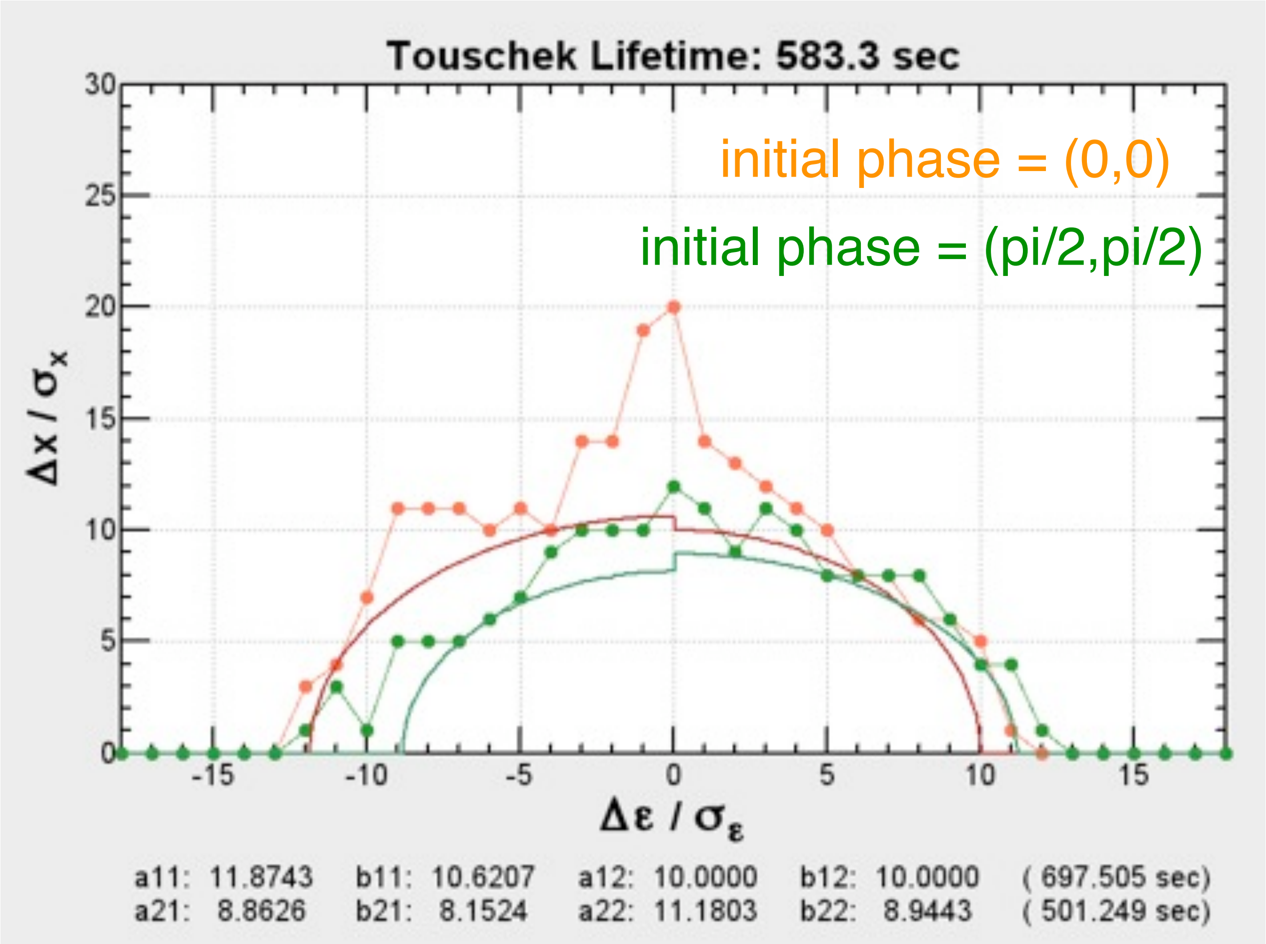
- Estimation of Touschek lifetime based on the dynamic aperture

Starting point of the tracking is IP.
No physical aperture except for the final focus magnets

LER



HER



The shape of the phase space is not a circle.

Lifetime depends on the lattice optimization.

Horizontal Mask

- Mask aperture:

$$d_x(s) = \max\left(\sqrt{\frac{\beta_x(s)}{\beta_{x,QC}}}a_{x,QC}, \eta_x(s)\delta_a, n_{x,max}\sqrt{\varepsilon_x\beta_x(s)}\right)$$
$$d_y(s) = \max\left(\sqrt{\frac{\beta_y(s)}{\beta_{y,QC}}}a_{y,QC}, \eta_y(s)\delta_a, n_{x,max}\sqrt{\kappa\varepsilon_x\beta_y(s)}\right)$$
$$\delta_a = n_{z,max}\sigma_\delta$$

a_x = Radius of QC2 (second final focus
a_y = Radius of QC1 (first final focus)

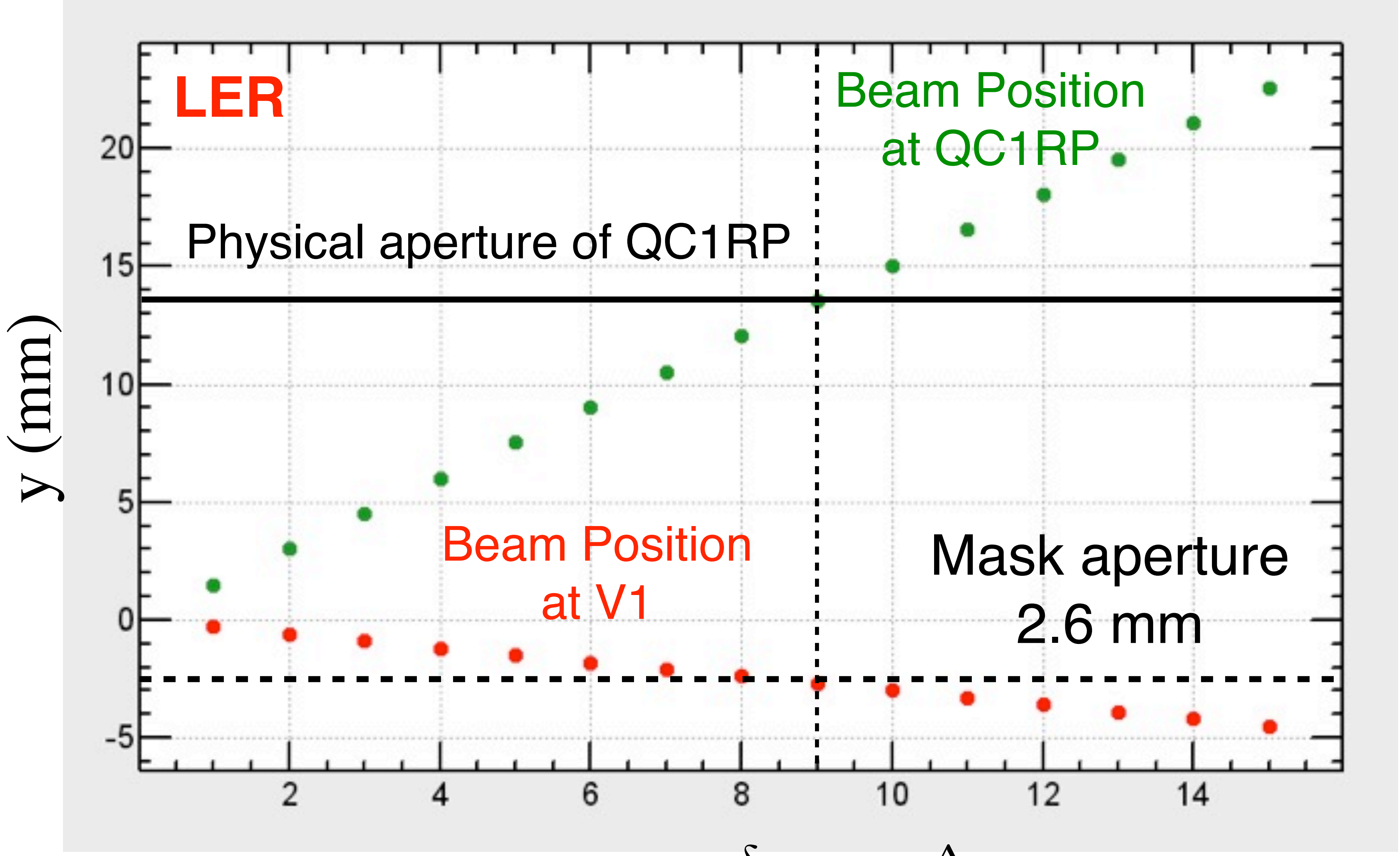
	LER	HER
$n_{z,max}$	22	15
$n_{x,max}$	30	22

Vertical Mask

- Mask position is determined by the smallest aperture (final focus magnet). The betatron oscillation is induced by:

$$y_\beta(s) = m_{11}\eta_y(s_0)\delta + m_{12}\eta_{py}(s_0)\delta$$

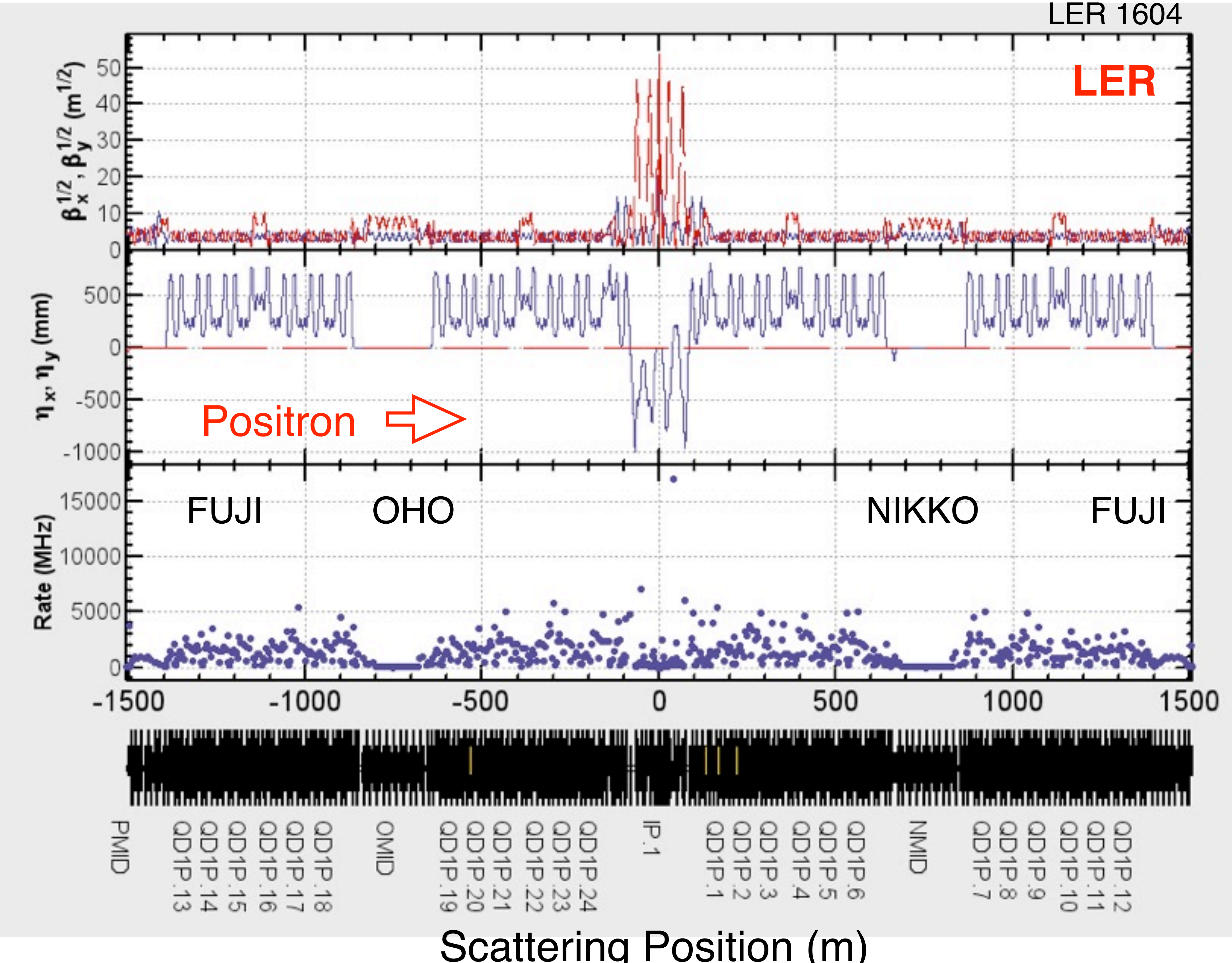
s_0: source point
η: dispersion



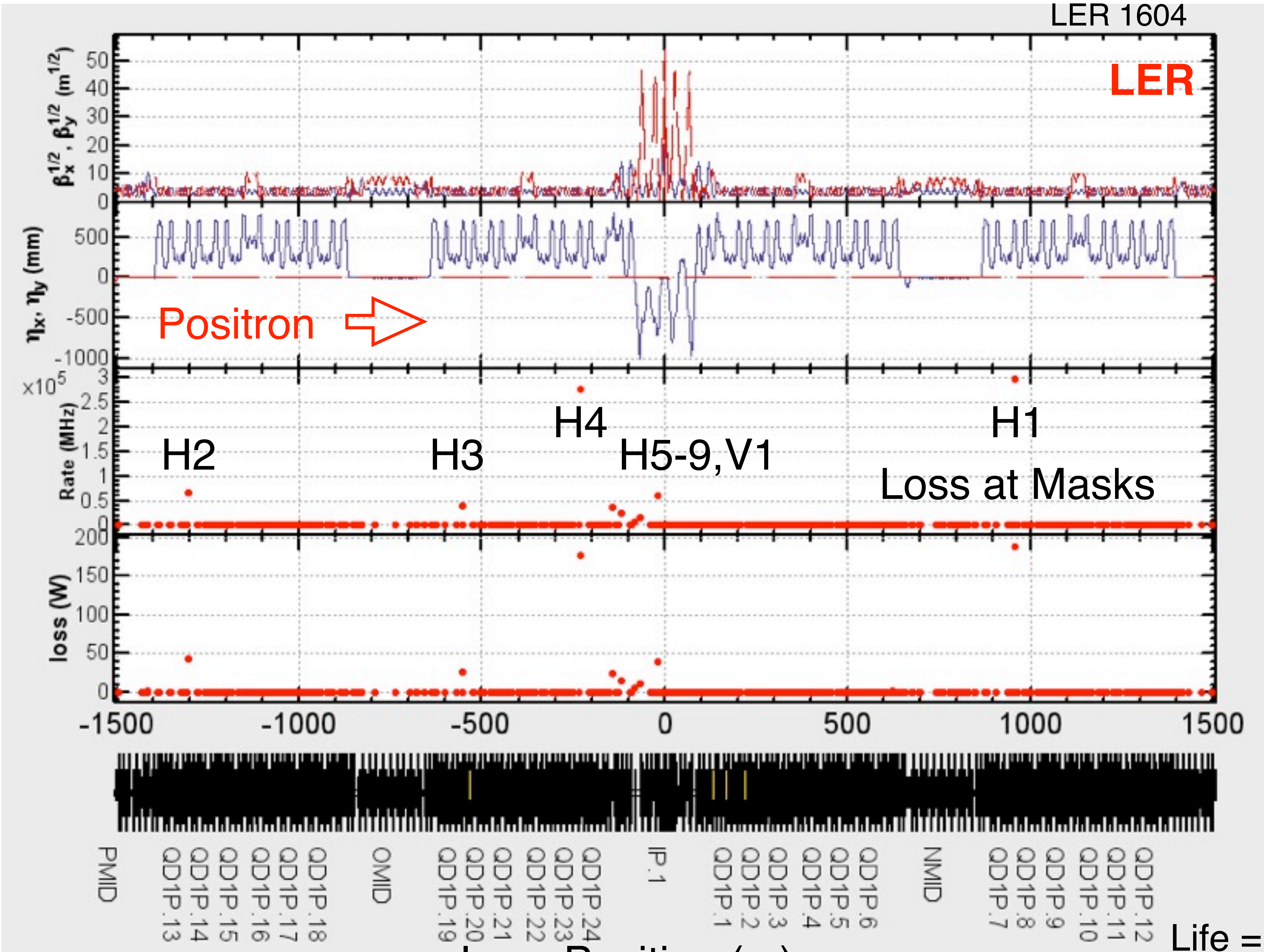
$$n_z = \frac{\delta}{\sigma_\delta} \quad \delta = \frac{\Delta p}{p_0}$$

LER

Loss Rate in LER

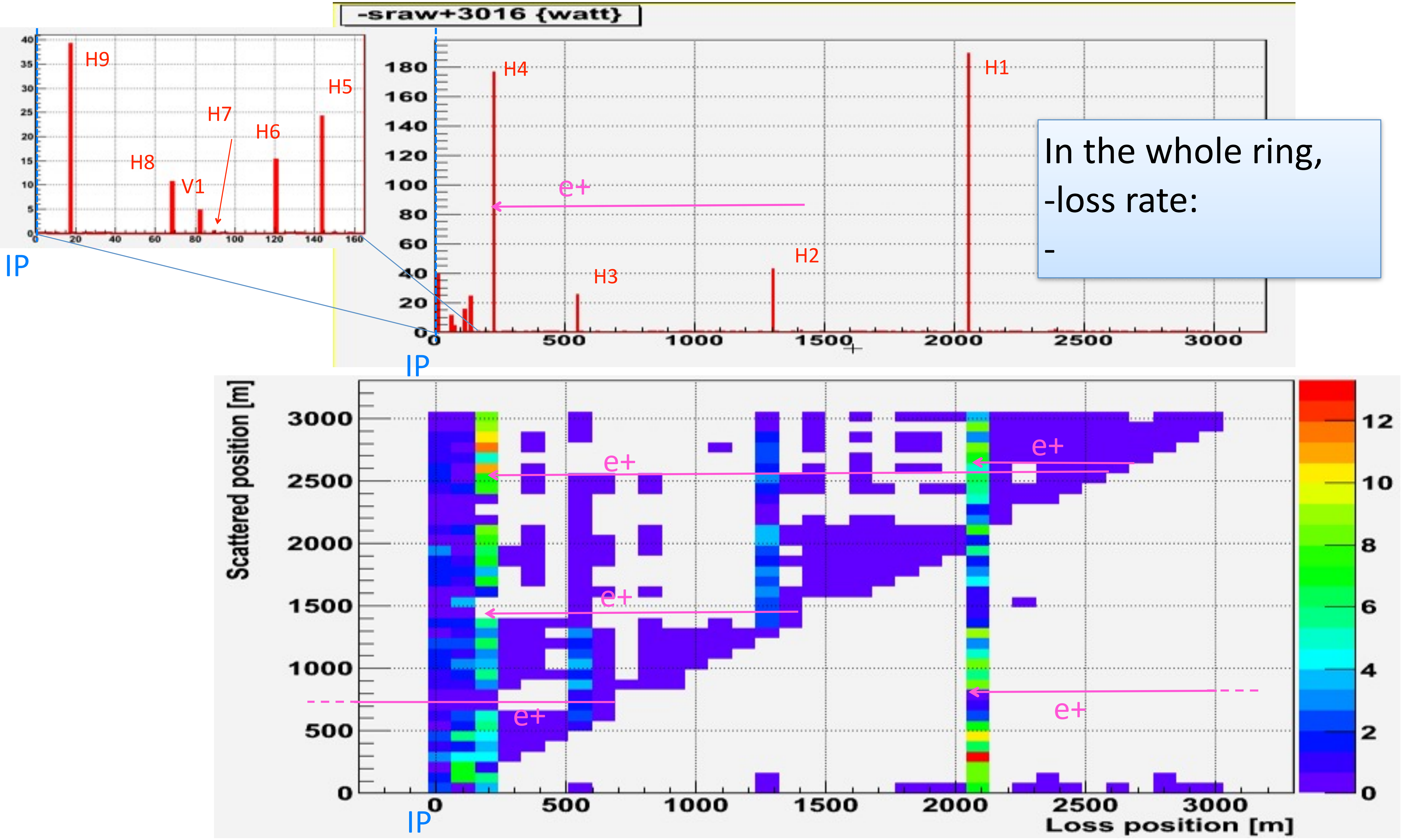


Loss in LER



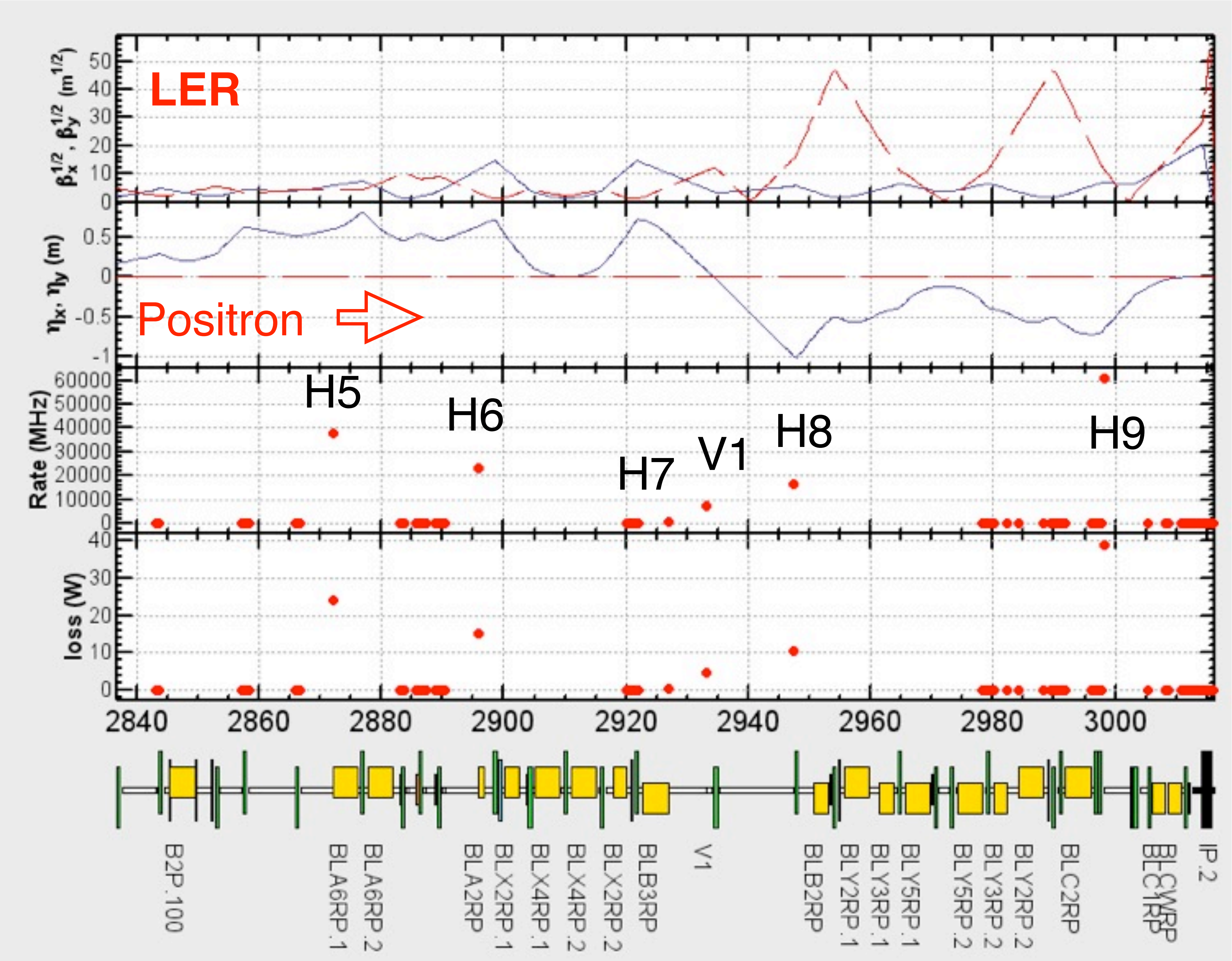
Life = 265 sec
(544 W)

LER Touschek (total ring)



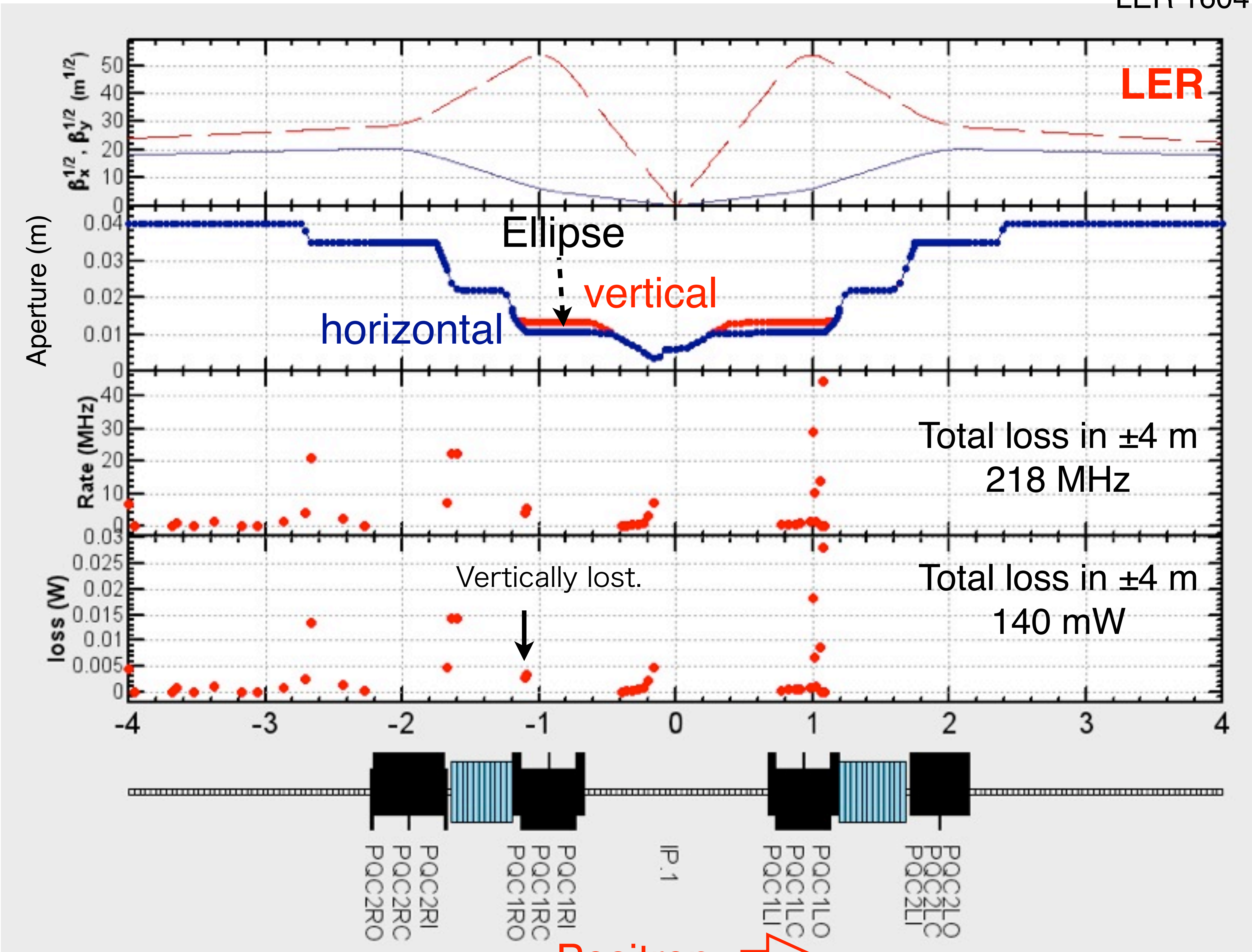
In the whole ring,
-loss rate:
-

Movable Masks

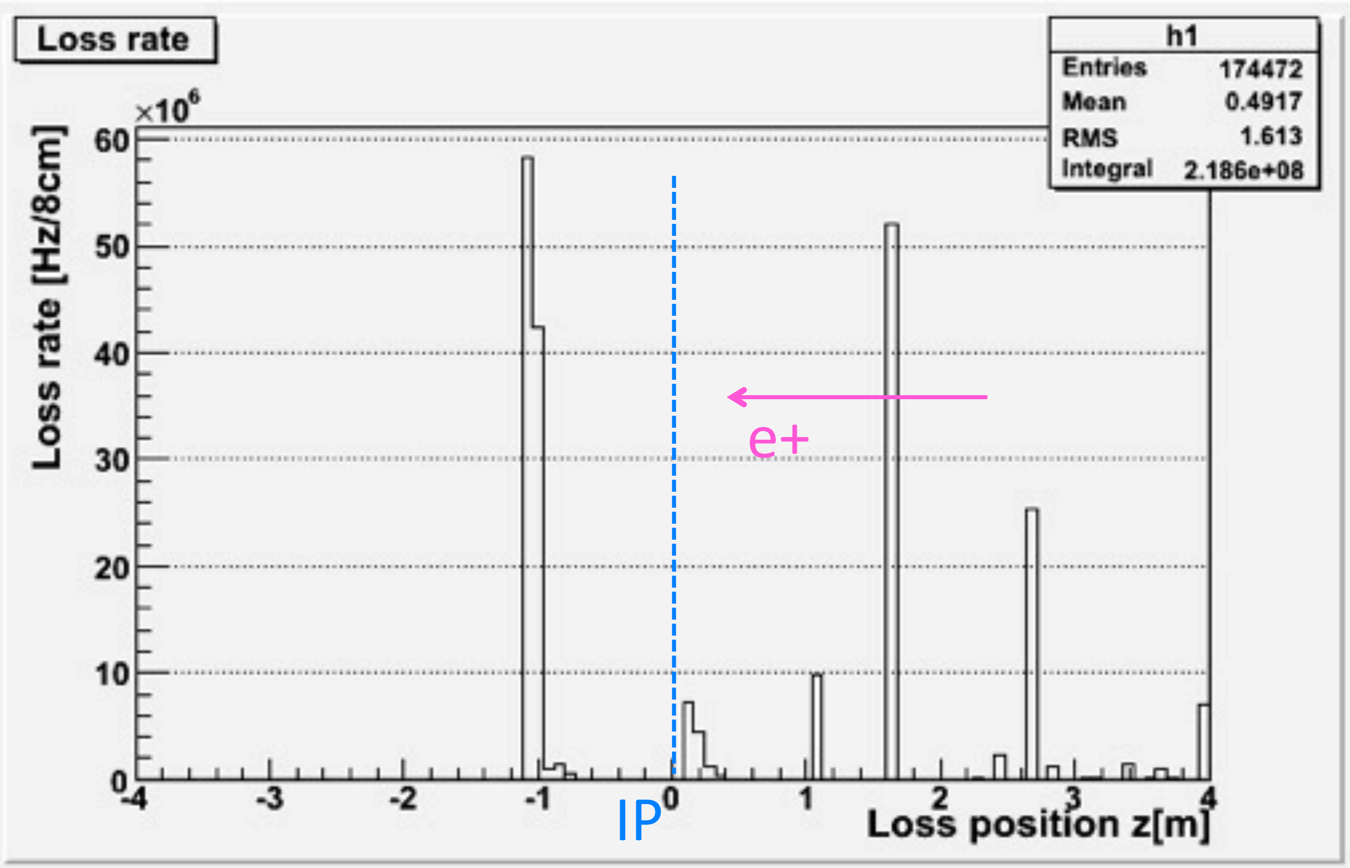


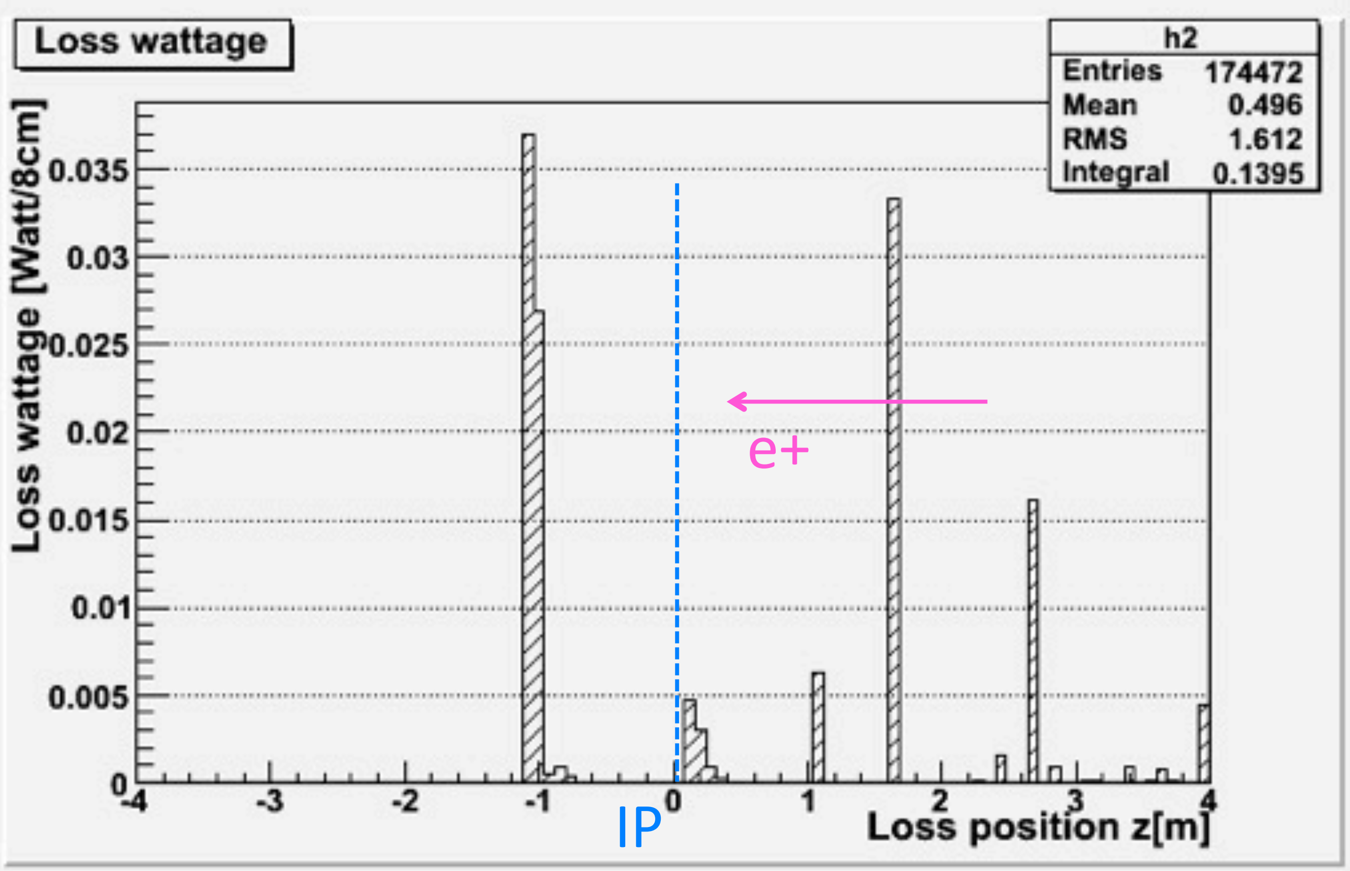
Loss at IR (LER)

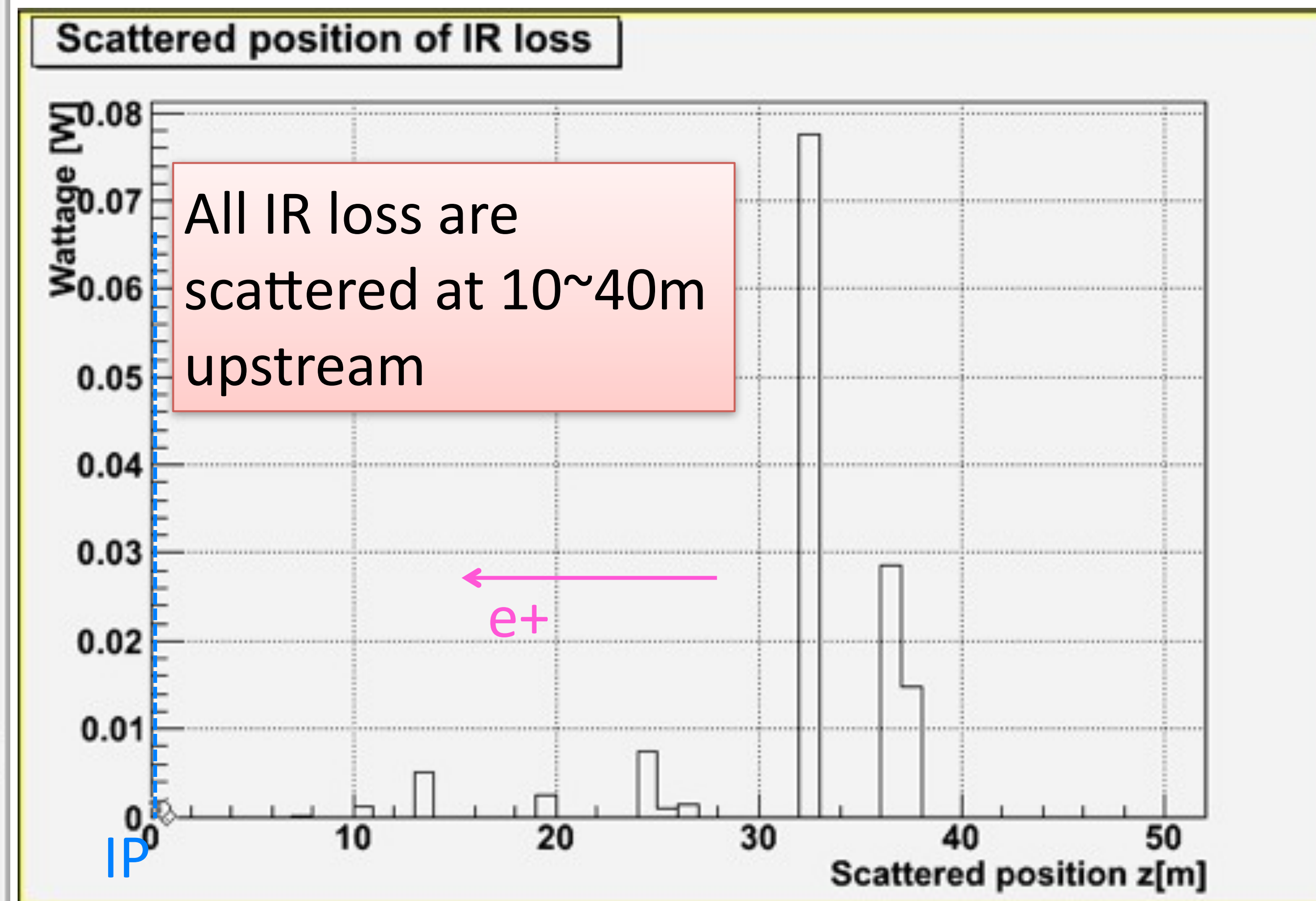
LER 1604



LER Touschek



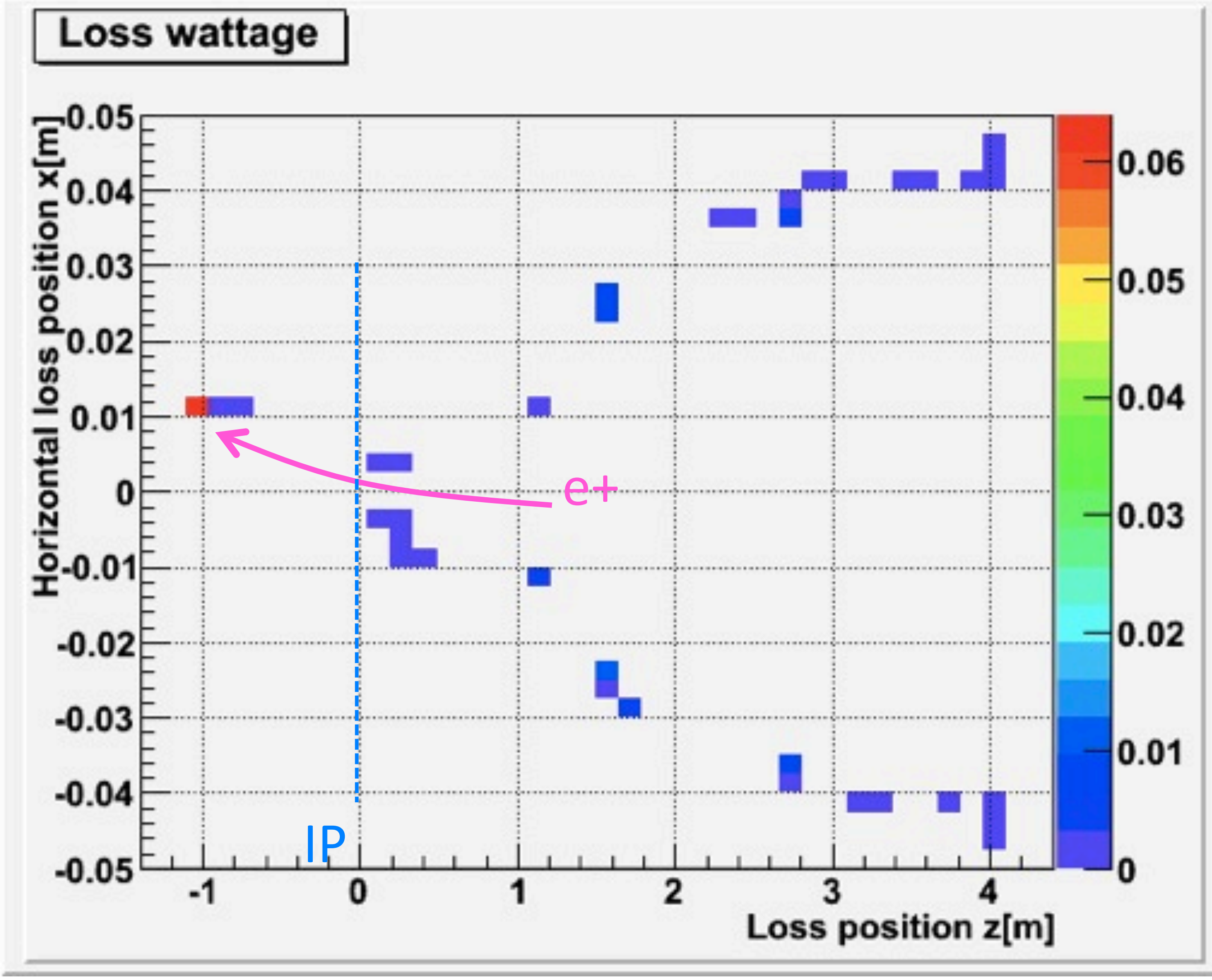


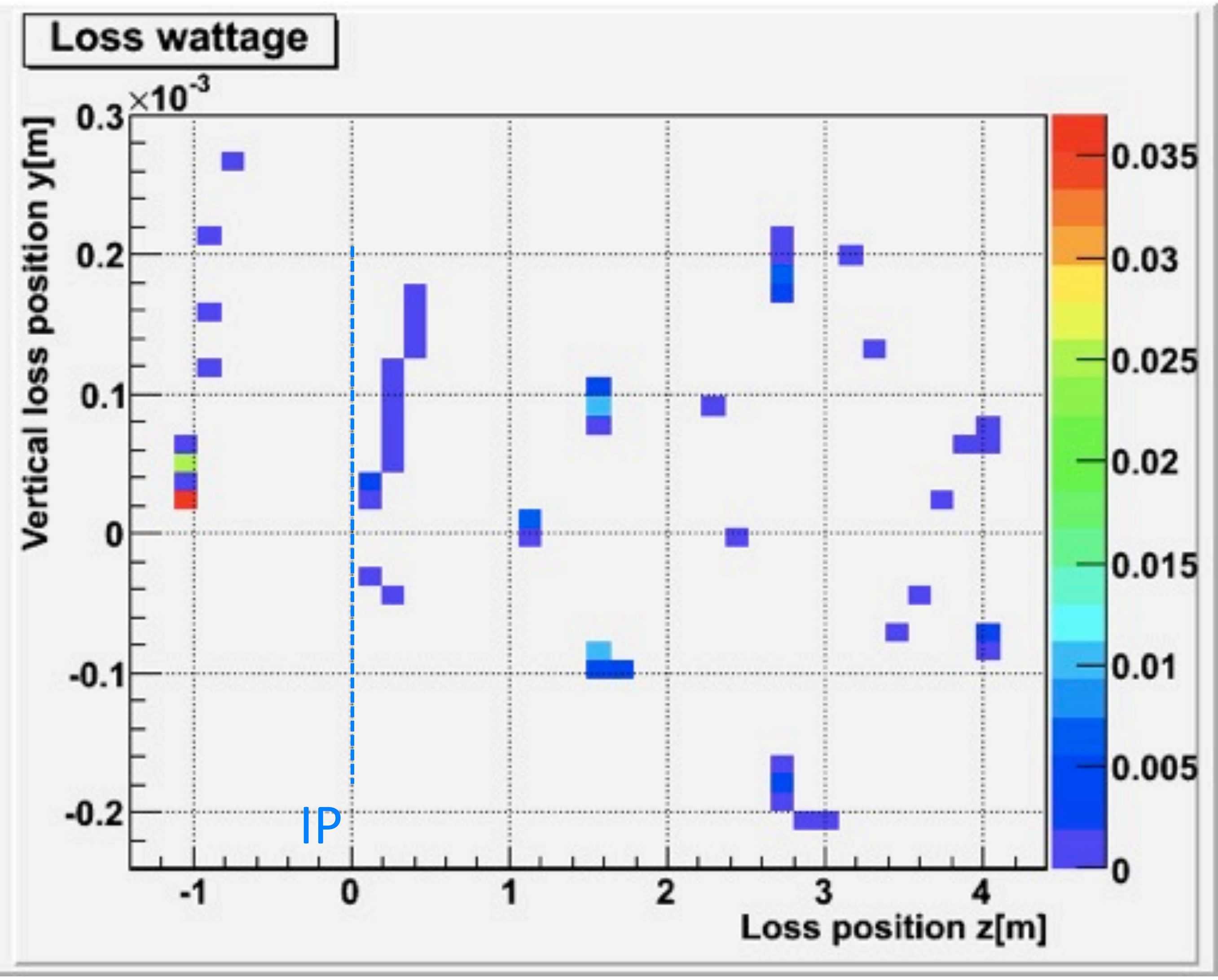


Within |z|<4m,
- loss rate: 0.22 GHz
- loss wattage: 0.14 W

Loss wattage: we assume all energy of beam particle is deposited at the loss position.

LER Touschek (contd.)



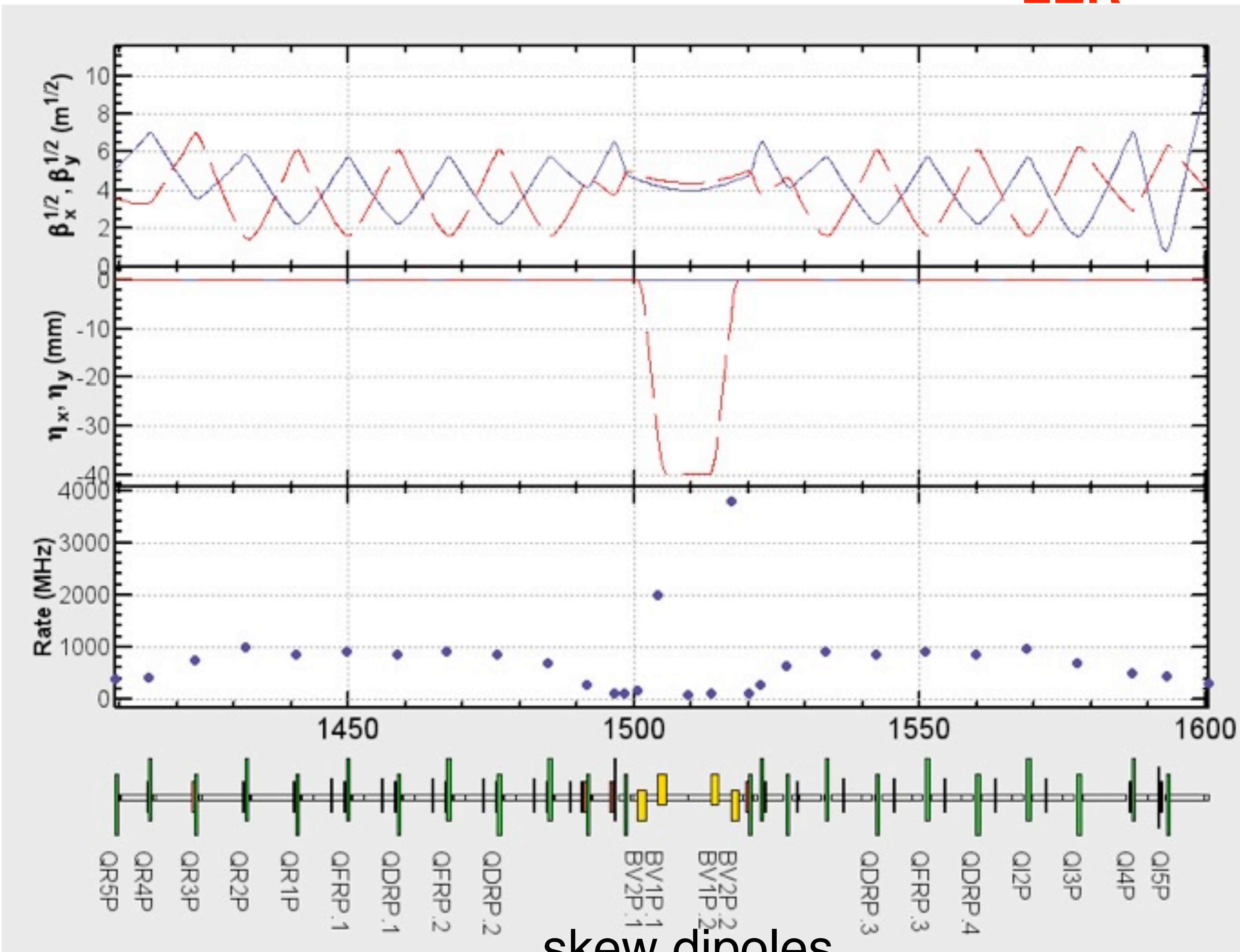


Vertically lost at z=-1m

Source of Loss Particles for Vertical Direction

FUJI (opposite of IP)

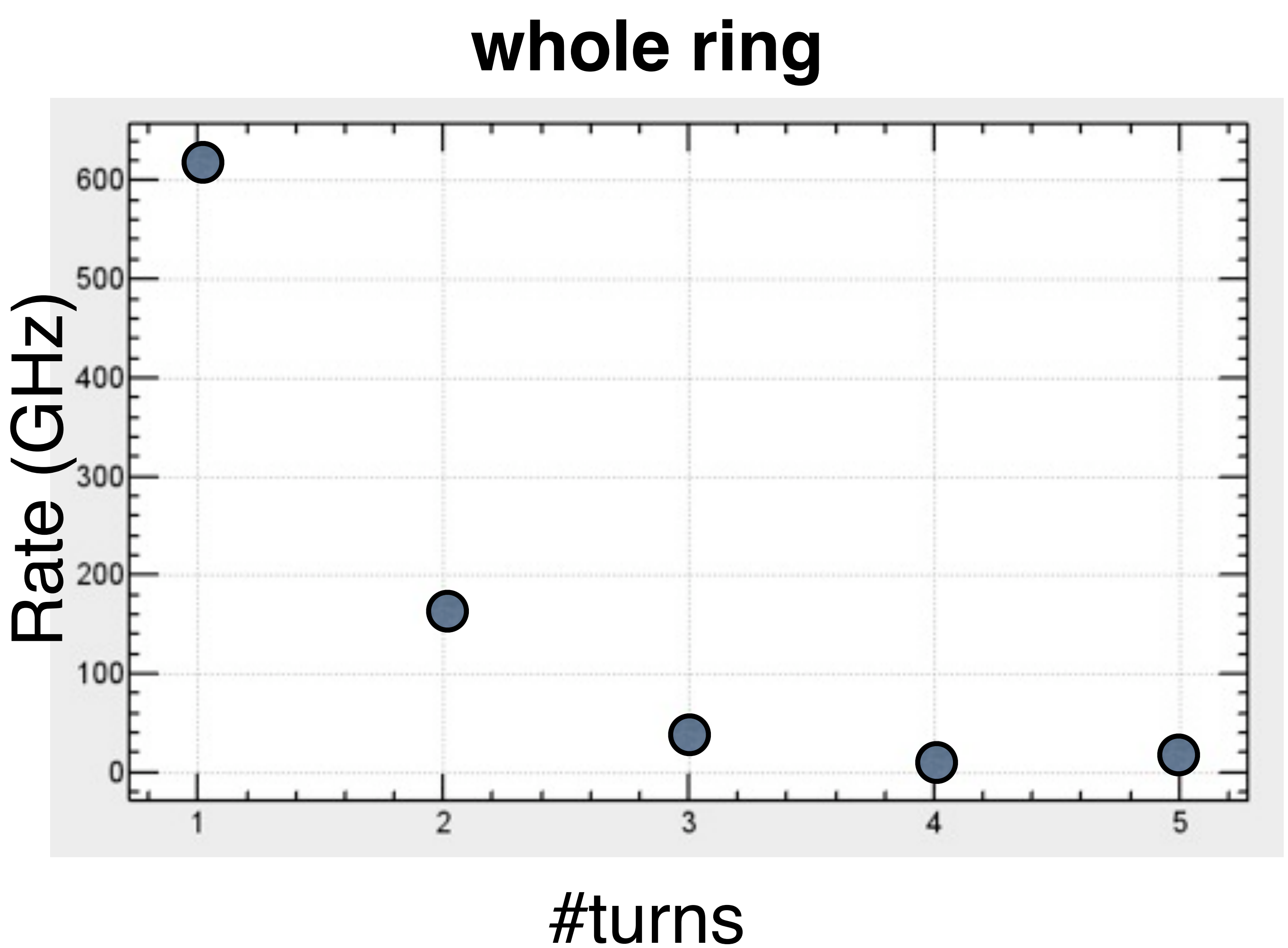
LER

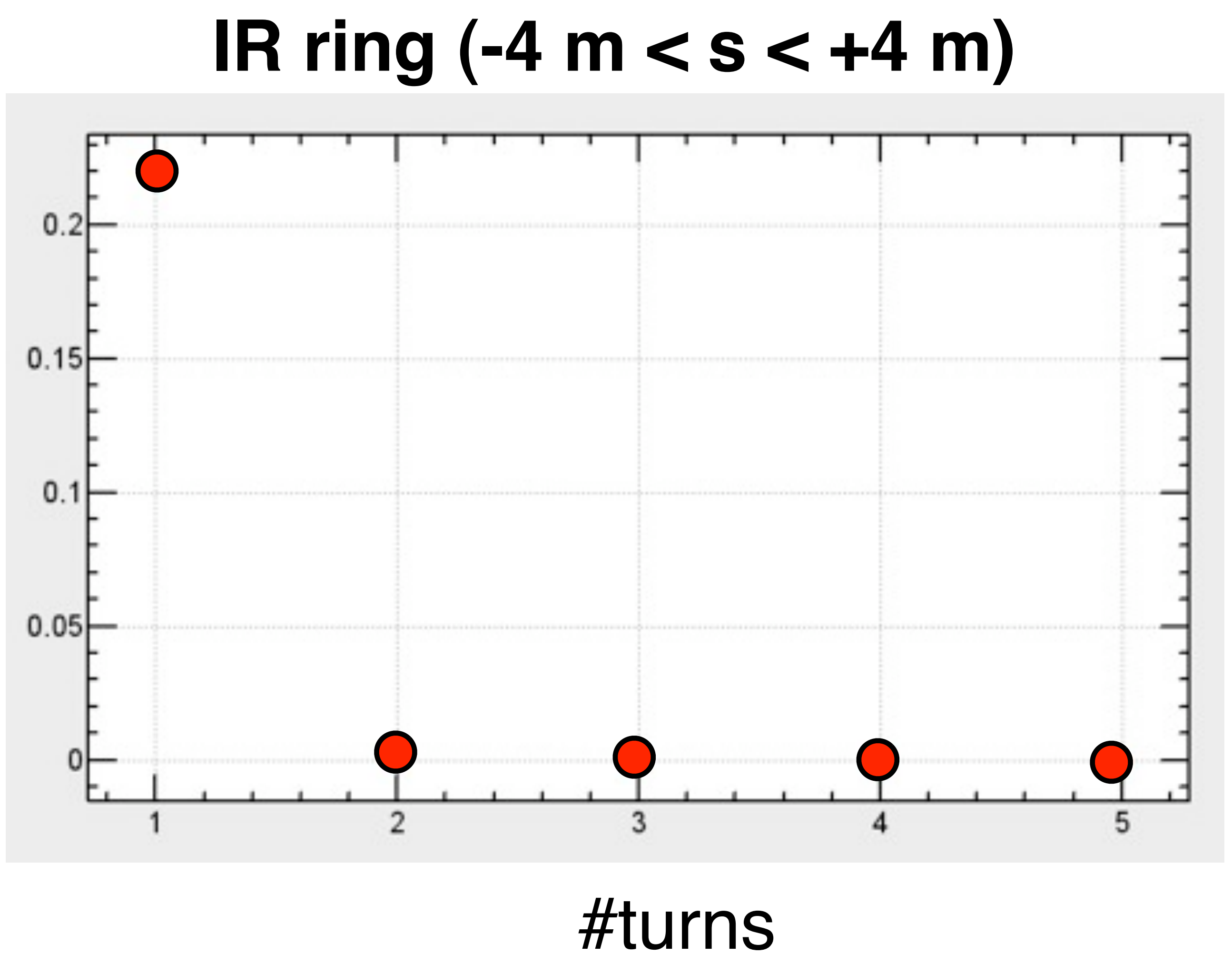


skew dipoles

If QC1 is a narrow aperture, these particles are lost at QC1.

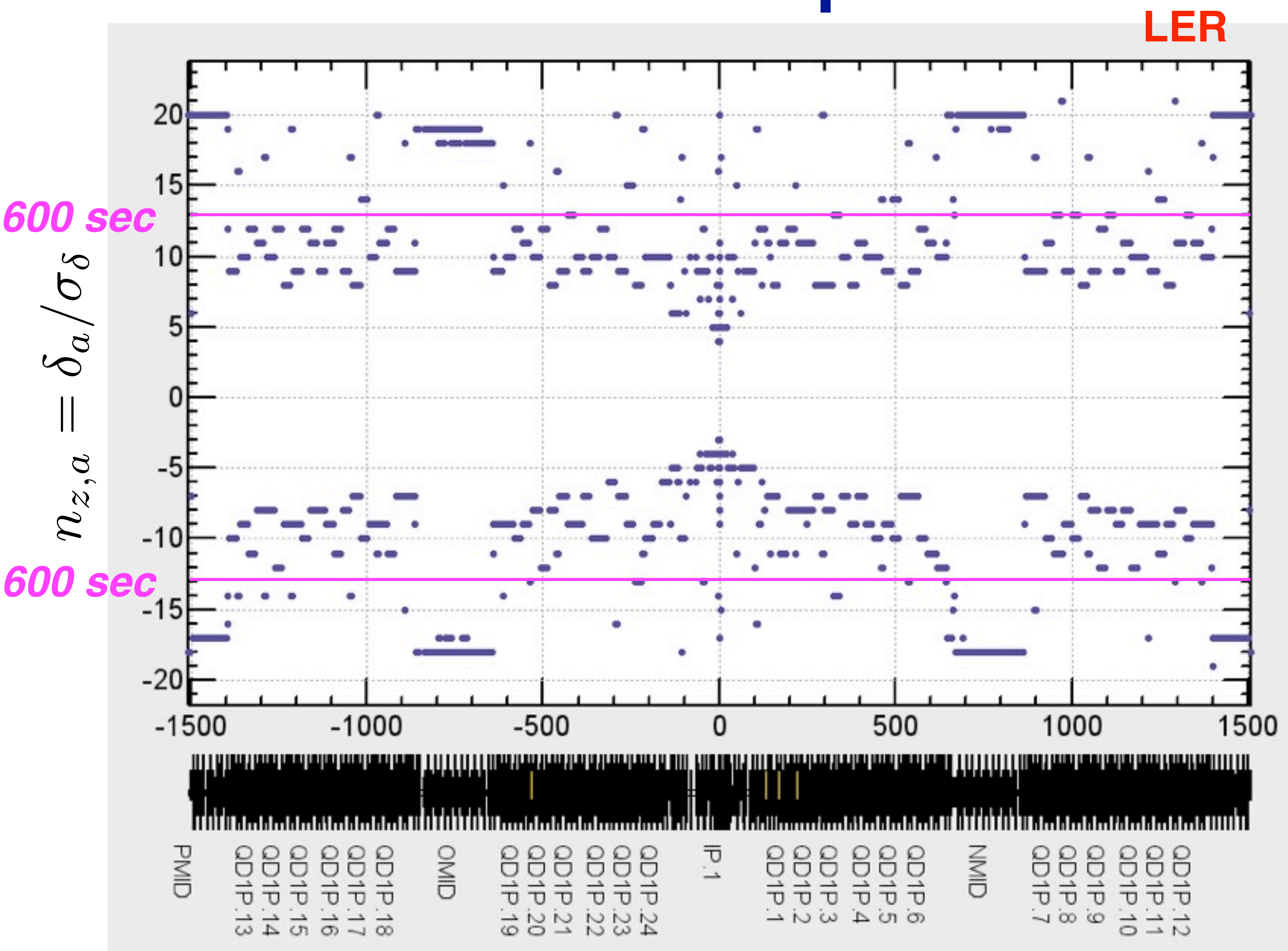
Touschek Effect in LER

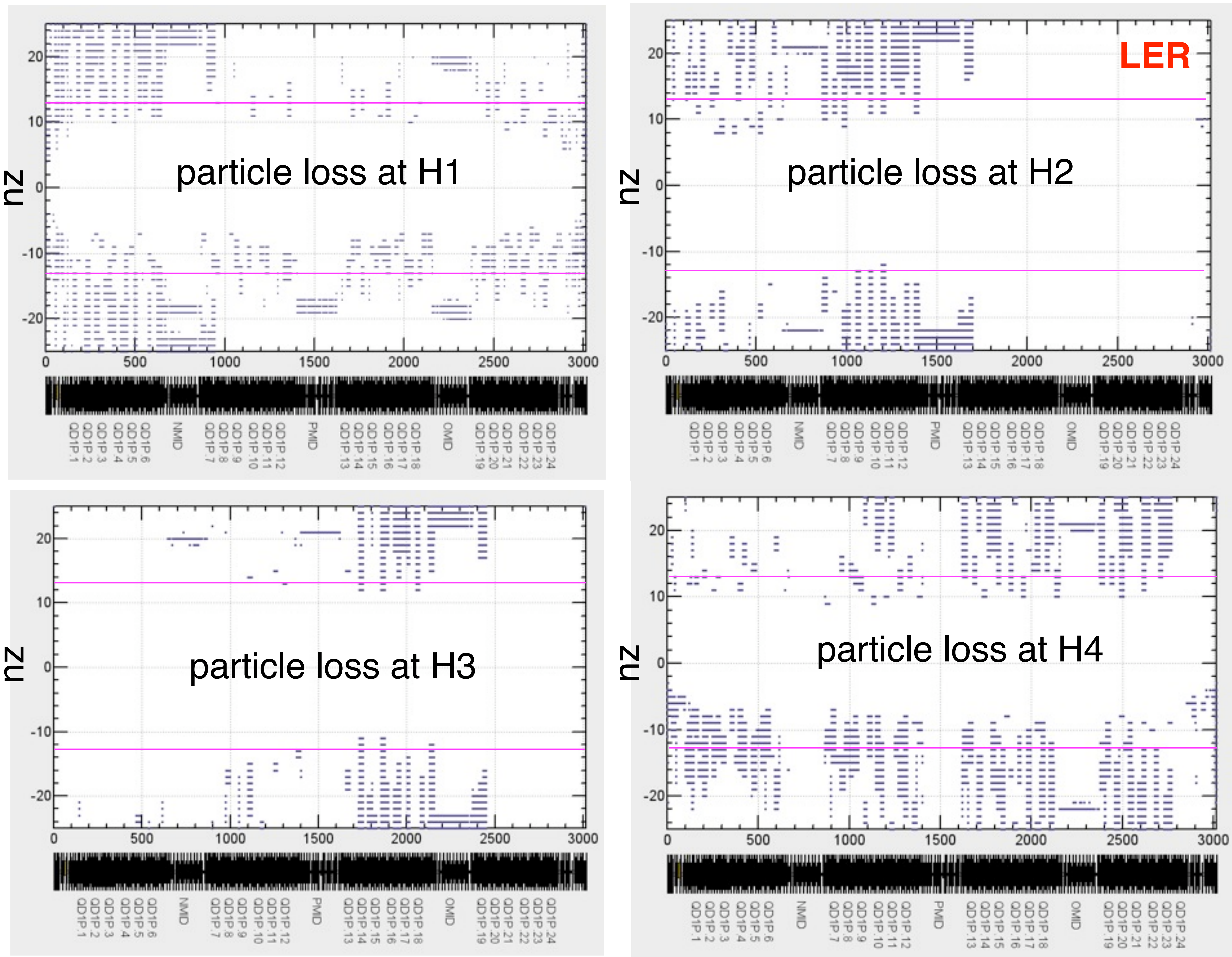


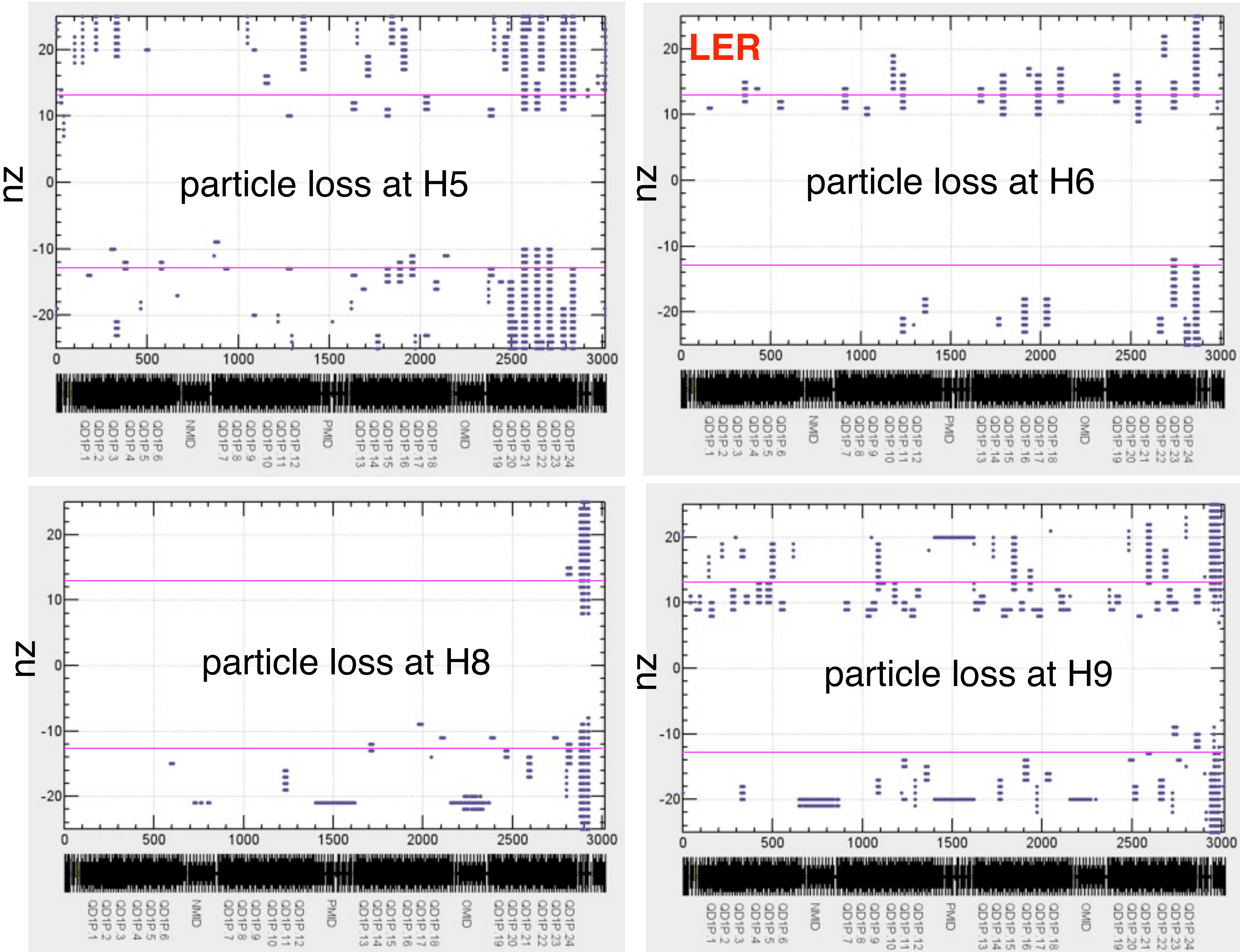


IR loss is single-pass.

Momentum Aperture




LER
particle loss at H1
particle loss at H2
particle loss at H3
particle loss at H4
nz
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
QD1P.1
QD1P.2
QD1P.3
QD1P.4
QD1P.5
QD1P.6
NMID
QD1P.7
QD1P.8
QD1P.9
QD1P.10
QD1P.11
QD1P.12
PMID
QD1P.13
QD1P.14
QD1P.15
QD1P.16
QD1P.17
QD1P.18
OMID
QD1P.19
QD1P.20
QD1P.21
QD1P.22
QD1P.23
QD1P.24


LER
particle loss at H5
particle loss at H6
particle loss at H8
particle loss at H9
nz
20
10
0
-10
-20
0
500
1000
1500
2000
2500
3000
QD1P.1
QD1P.2
QD1P.3
QD1P.4
QD1P.5
QD1P.6
NMID
QD1P.7
QD1P.8
QD1P.9
QD1P.10
QD1P.11
QD1P.12
PMID
QD1P.13
QD1P.14
QD1P.15
QD1P.16
QD1P.17
QD1P.18
OMID
QD1P.19
QD1P.20
QD1P.21
QD1P.22
QD1P.23
QD1P.24

mask aperture	$n_{z,max}$ = 22 $n_{x,amx}$ = 30	$n_{z,max}$ = 24 $n_{x,amx}$ = 30	$n_{z,max}$ = 22 $n_{x,amx}$ = 40	
H1	12.449	13.581	12.449	mm
H2	12.421	13.550	12.421	mm
H3	12.449	13.581	12.449	mm
H4	12.391	13.518	12.391	mm
H5	10.630	11.597	13.328	mm
H6	20.284	20.284	26.102	mm
H7	17.925	17.925	23.067	mm
H8	17.538	19.133	17.538	mm
H9	11.898	12.520	15.311	mm
V1	2.600	2.600	2.600	mm
Rate in IR	0.218	1.566	5.014	GHz
IR loss (W)	0.140	0.996	3.186	W
lifetime	265	312	269	sec

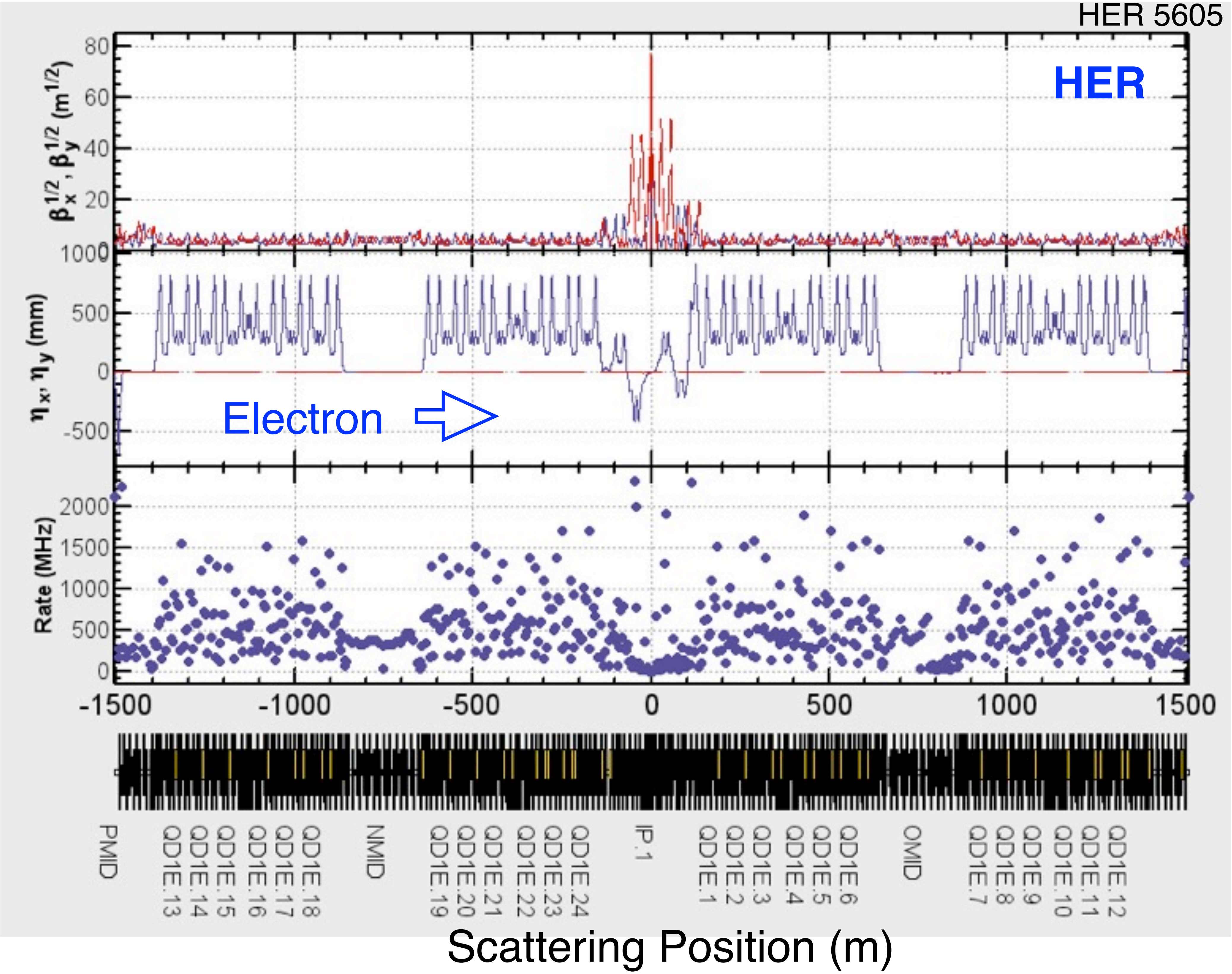
lifetime sensitive (H1–H4)

BG sensitive (H9)

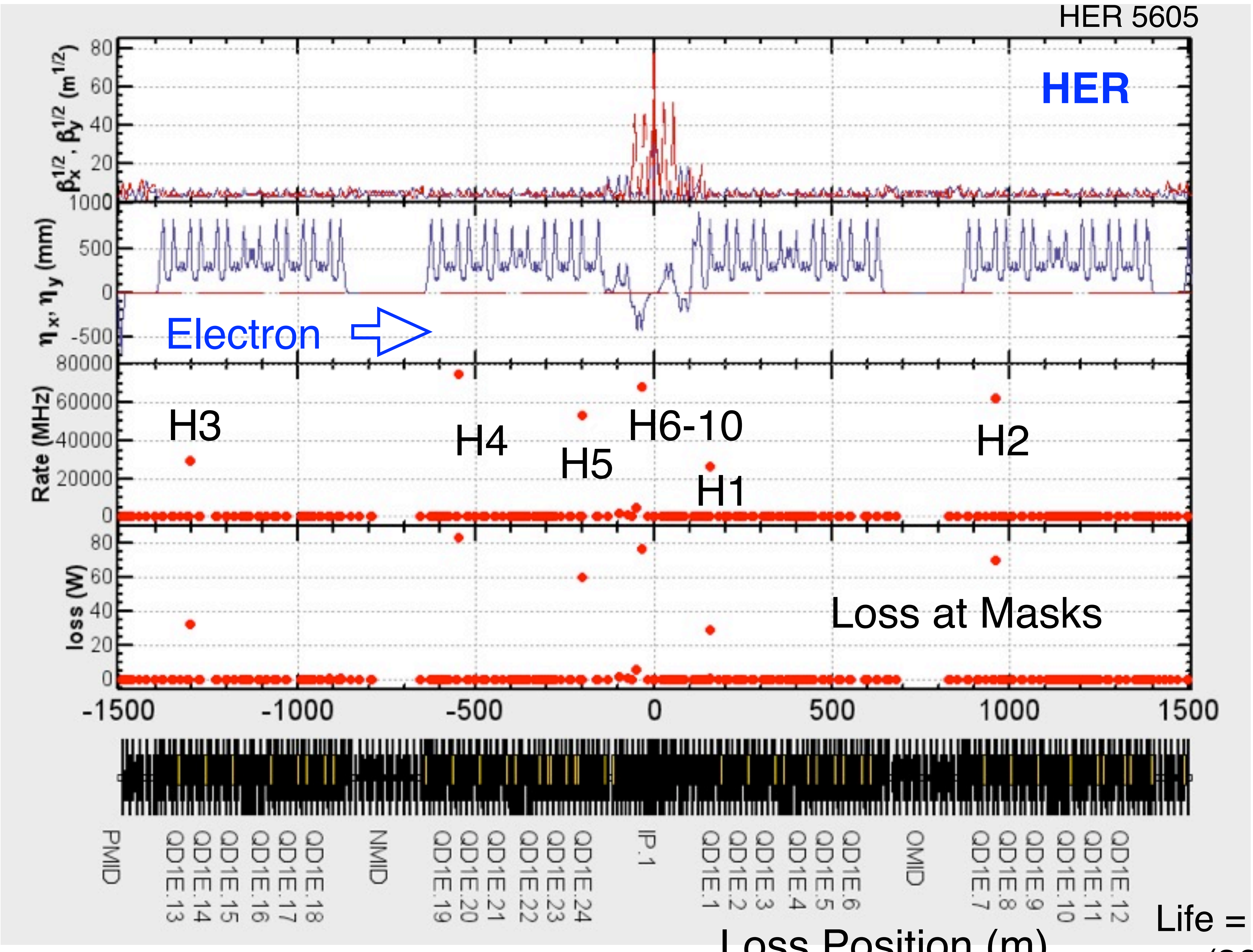
IR means -4 m < s < 4 m.

HER

Loss Rate in HER

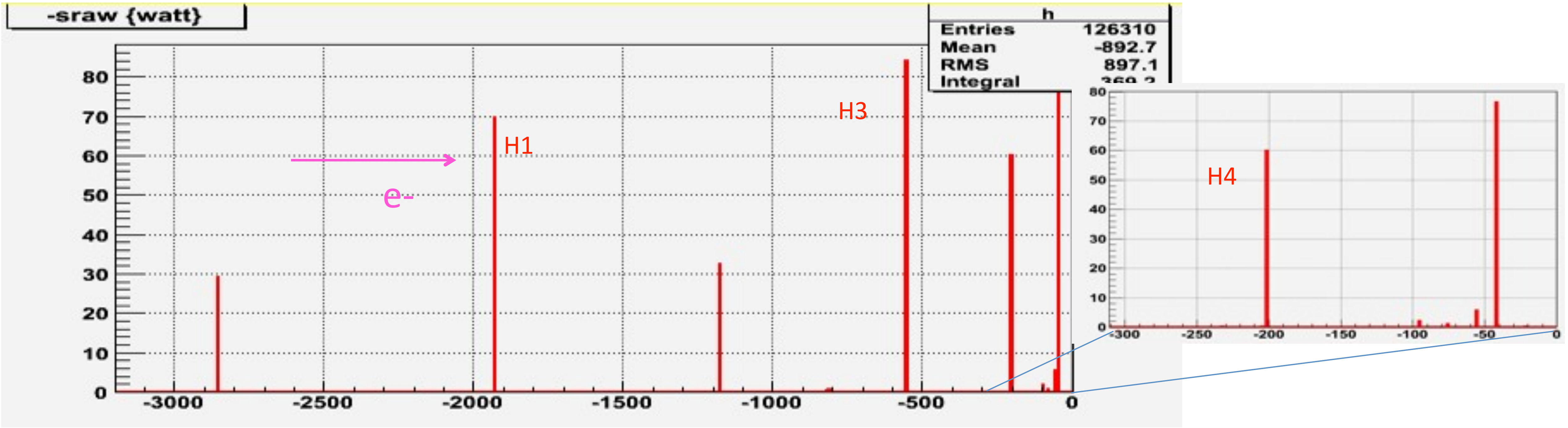


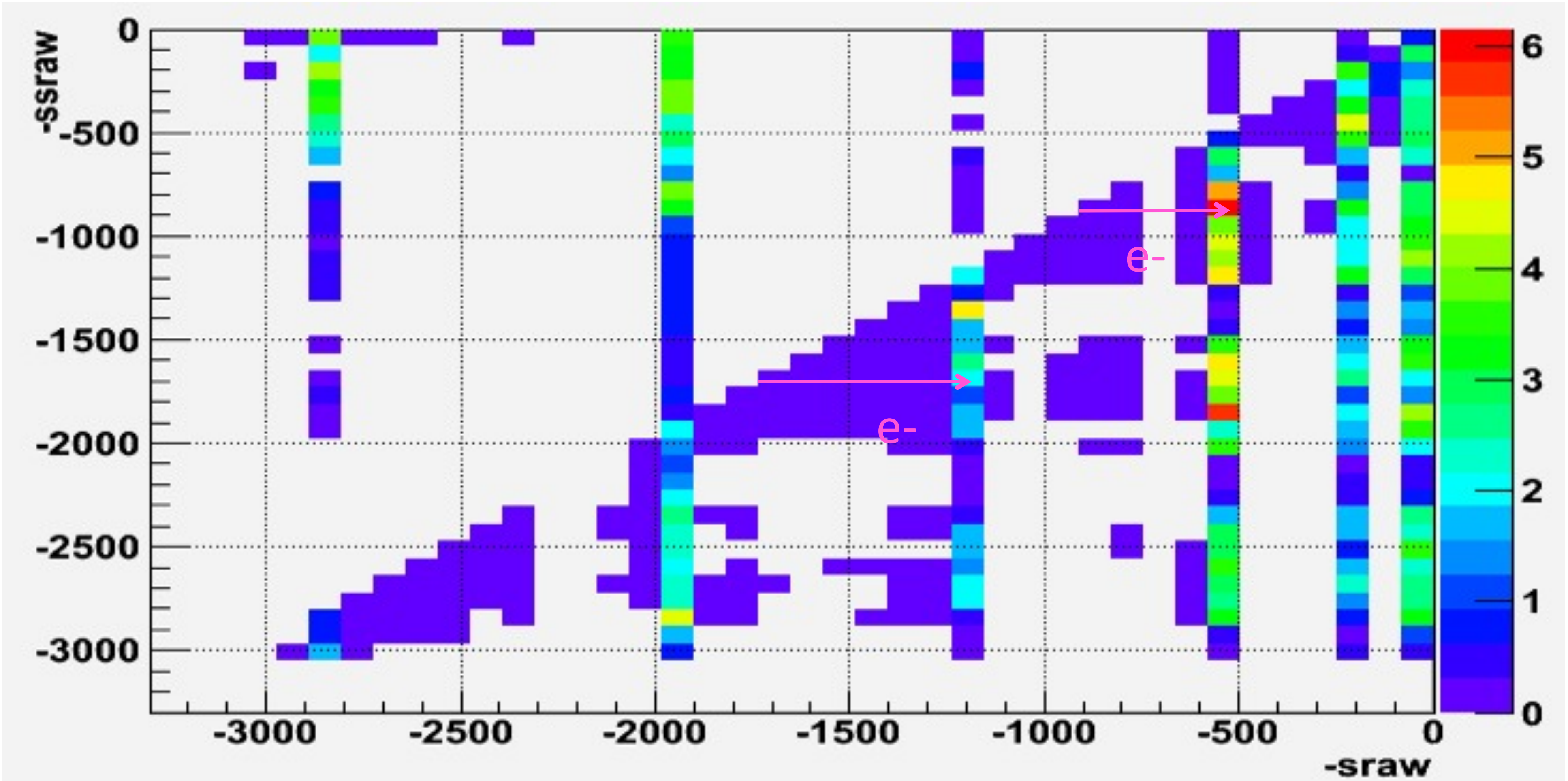
Loss in HER



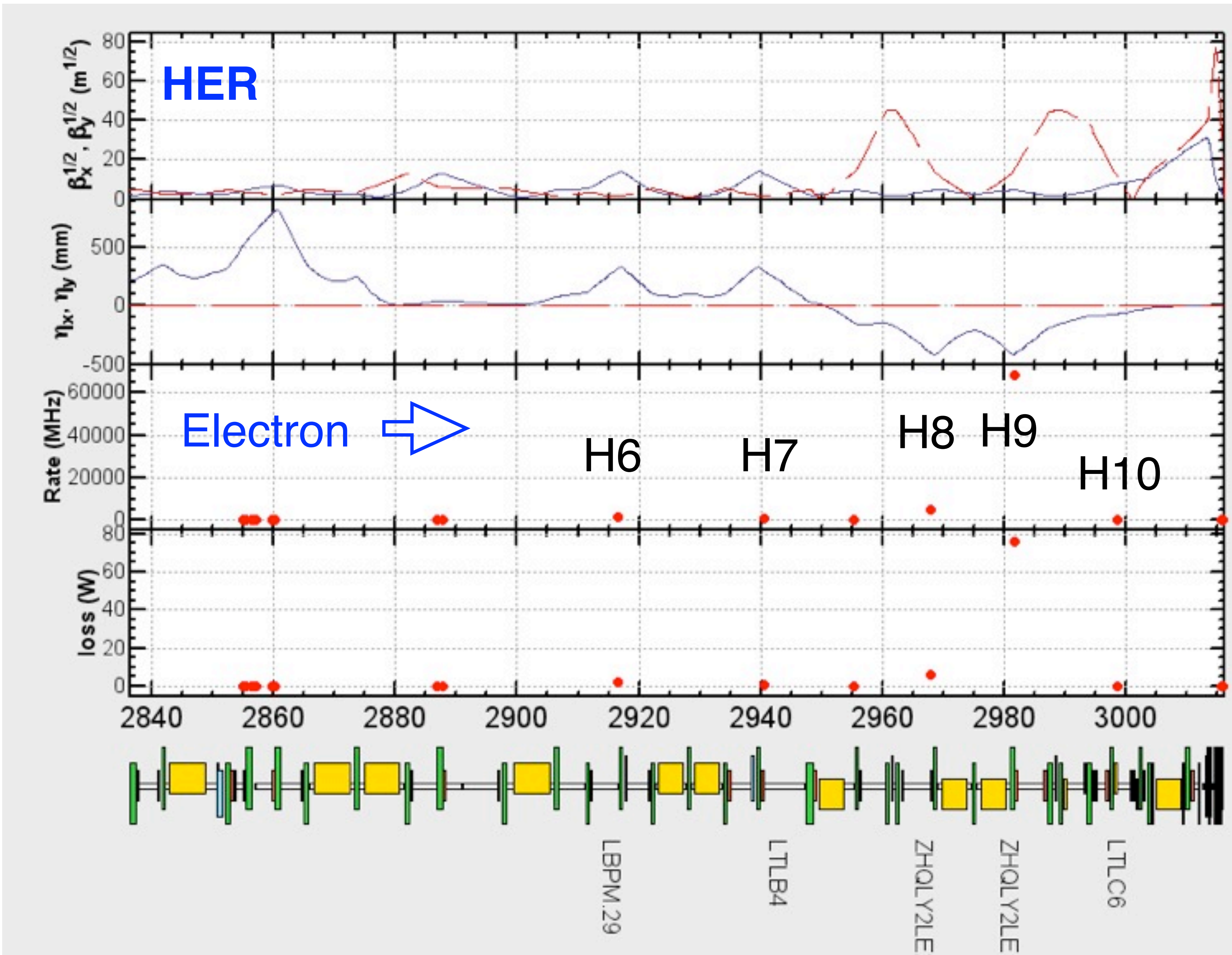
Life = 496 sec
(369 W)

HER Touschek (total ring)



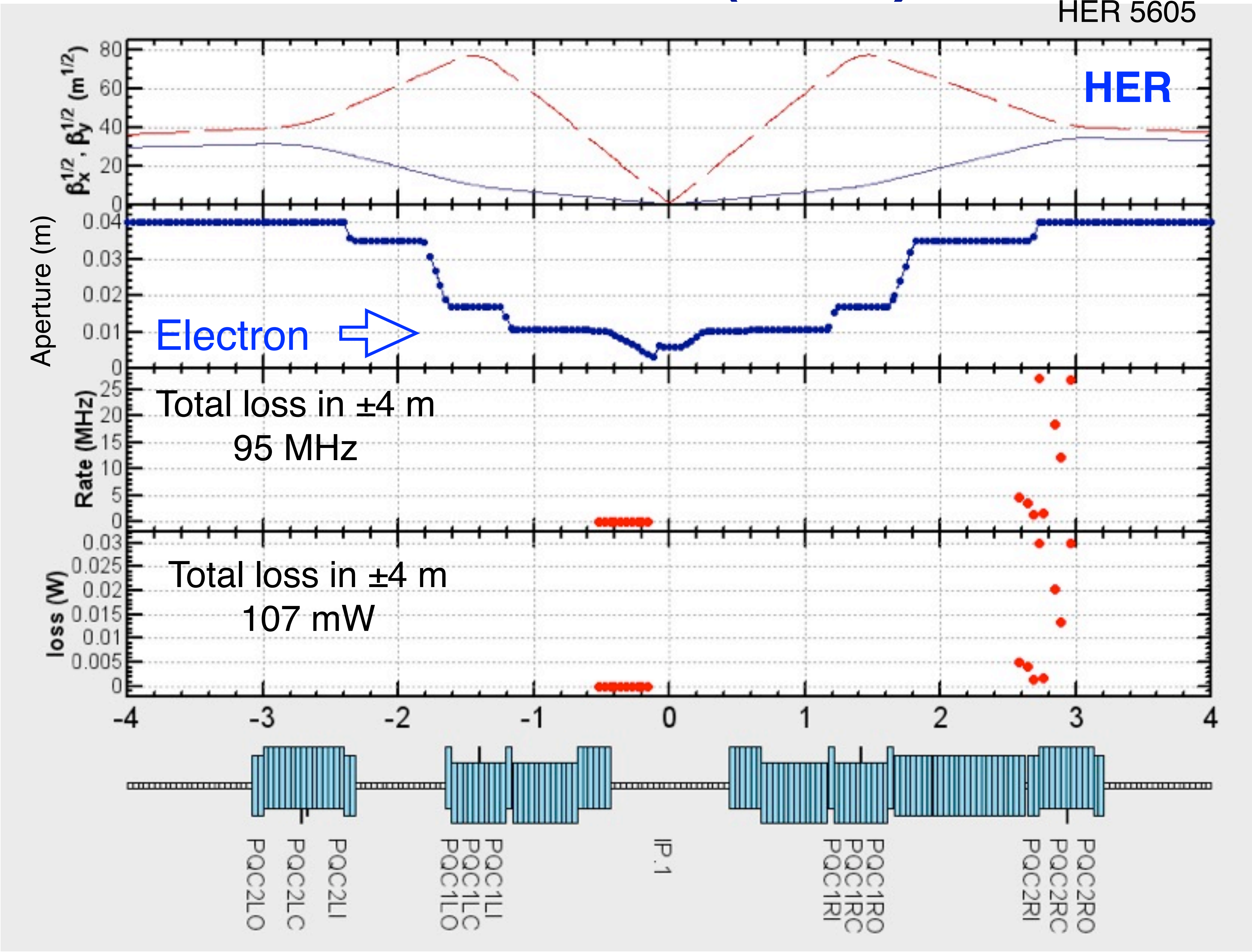


Movable Masks

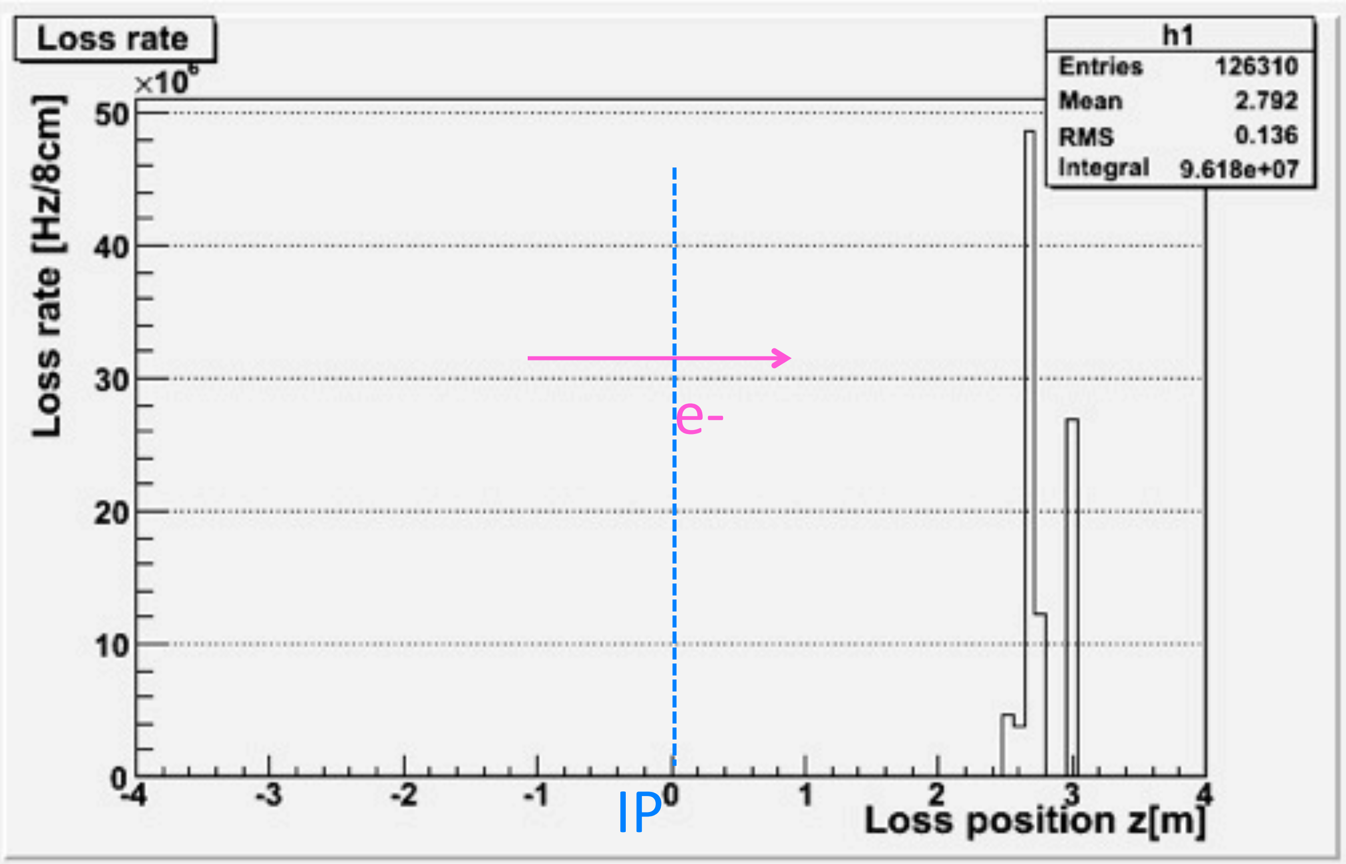


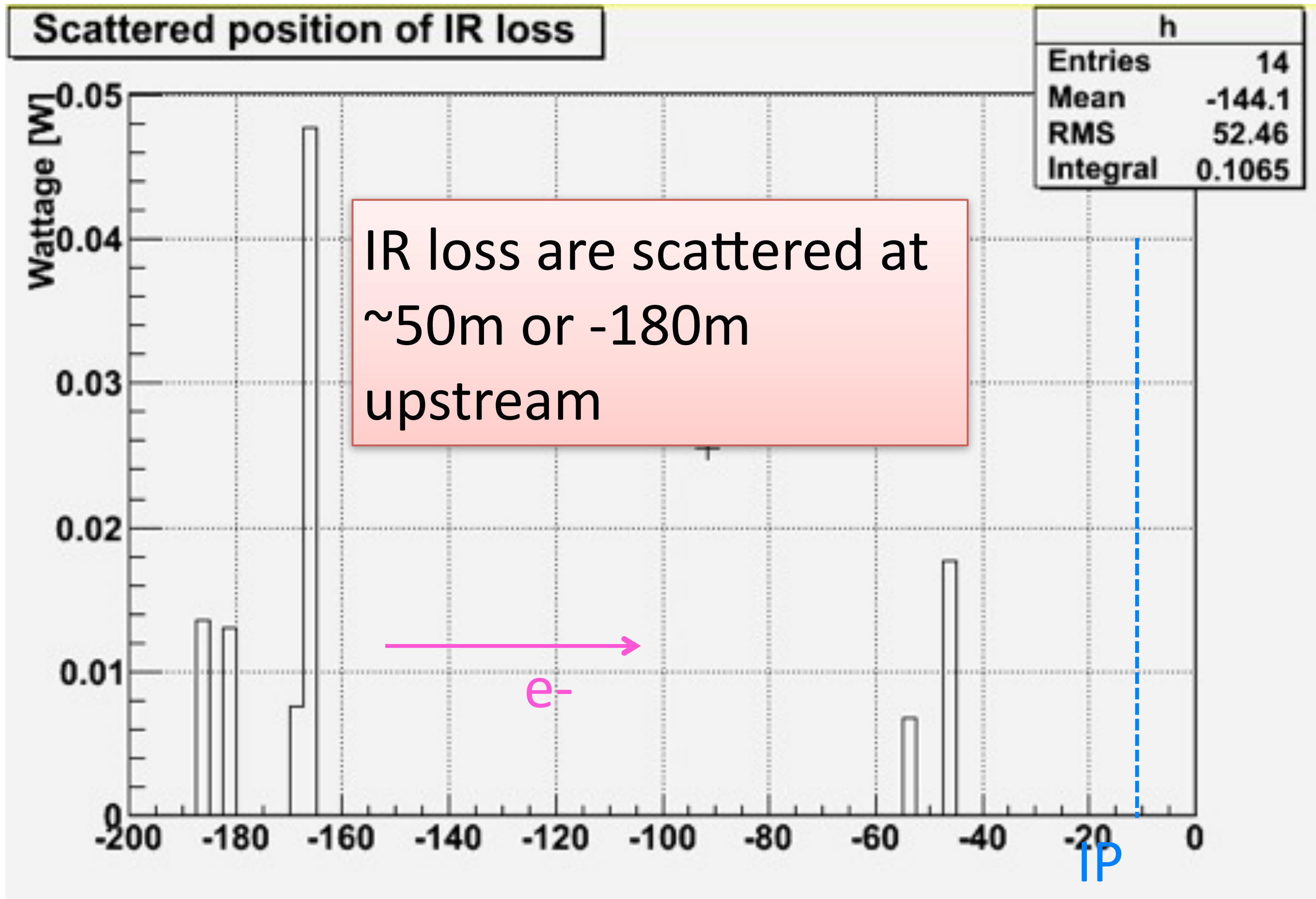
Only H9 mask is effective.

Loss at IR (HER)

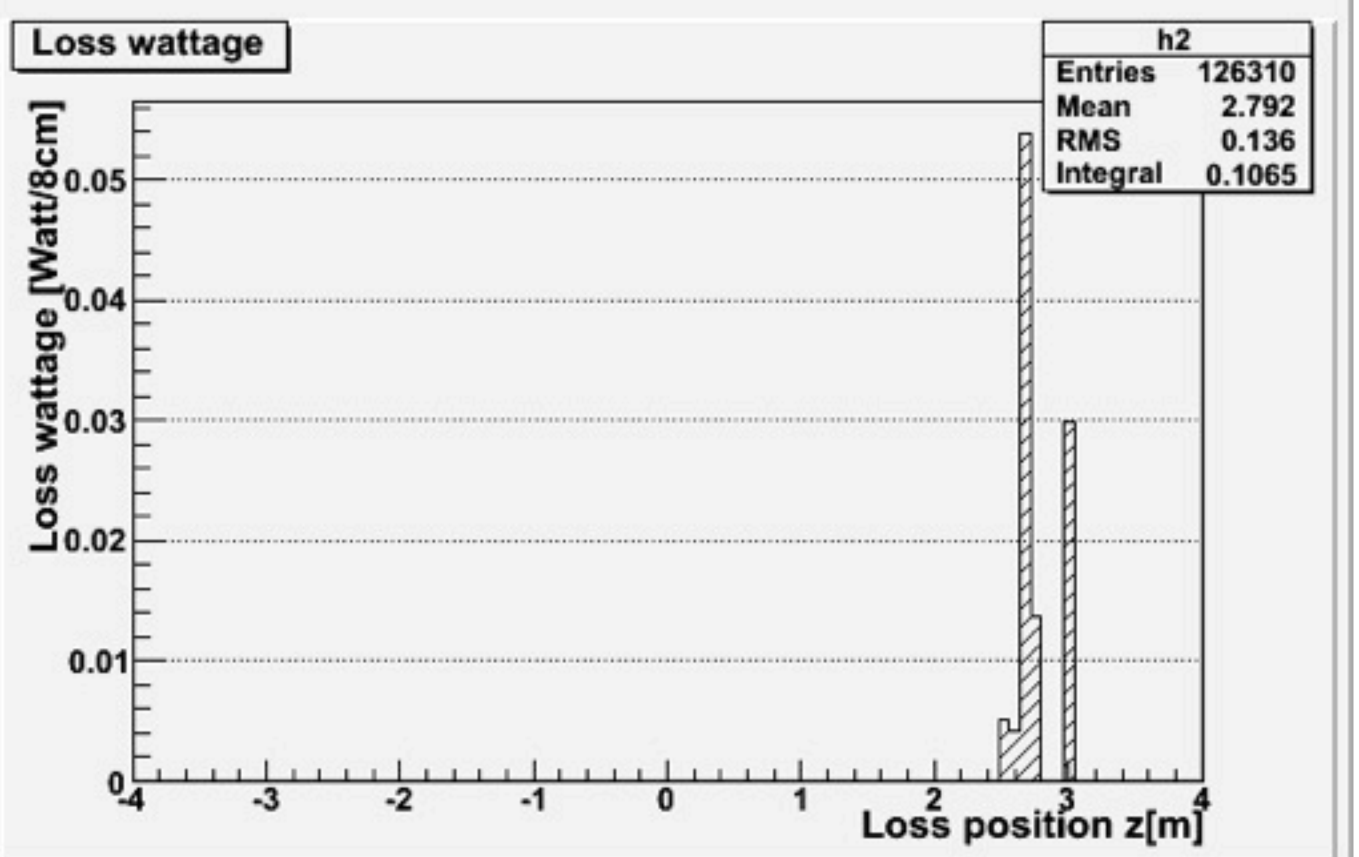


HER Touschek





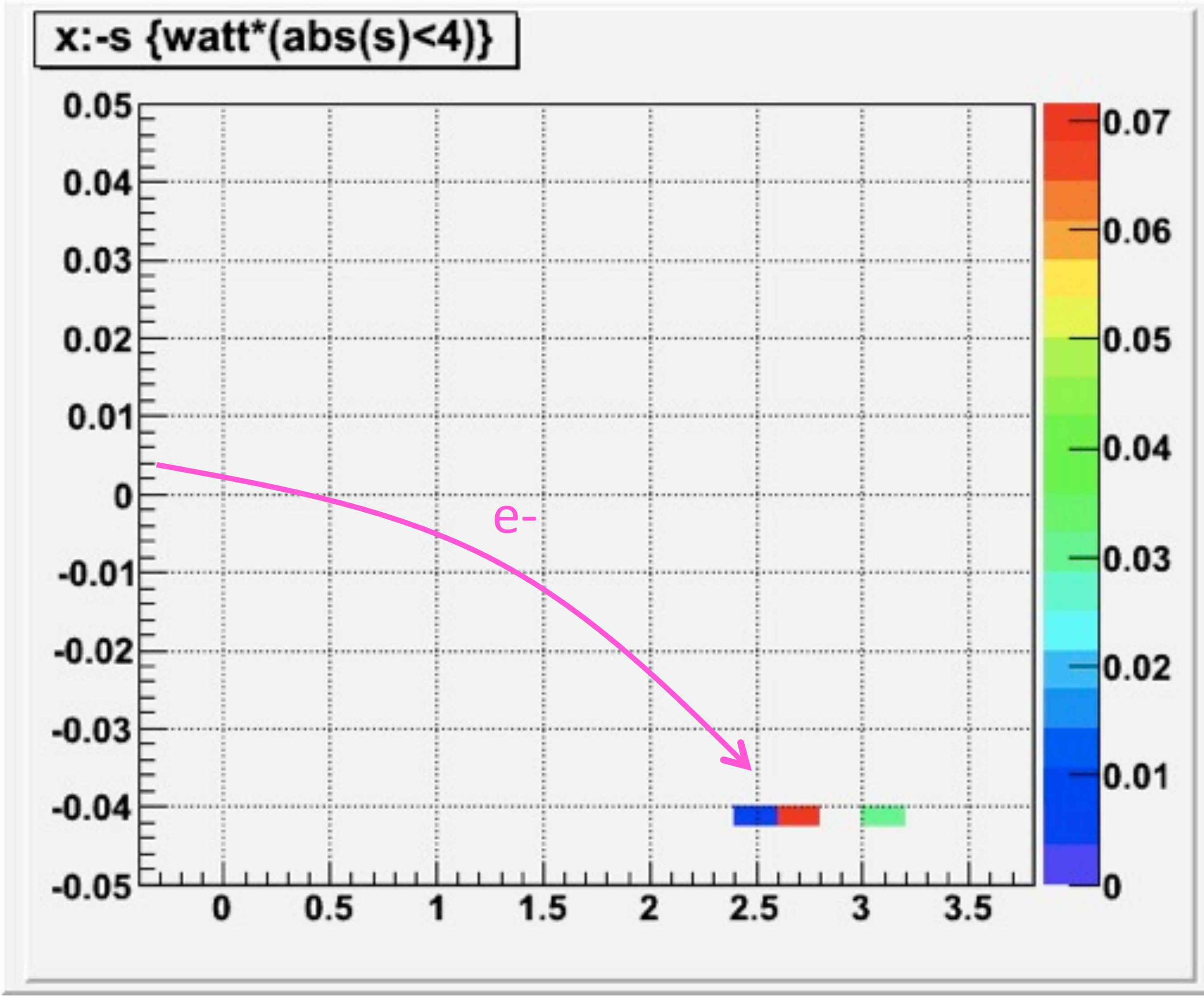
IR loss are scattered at ~50m or -180m upstream

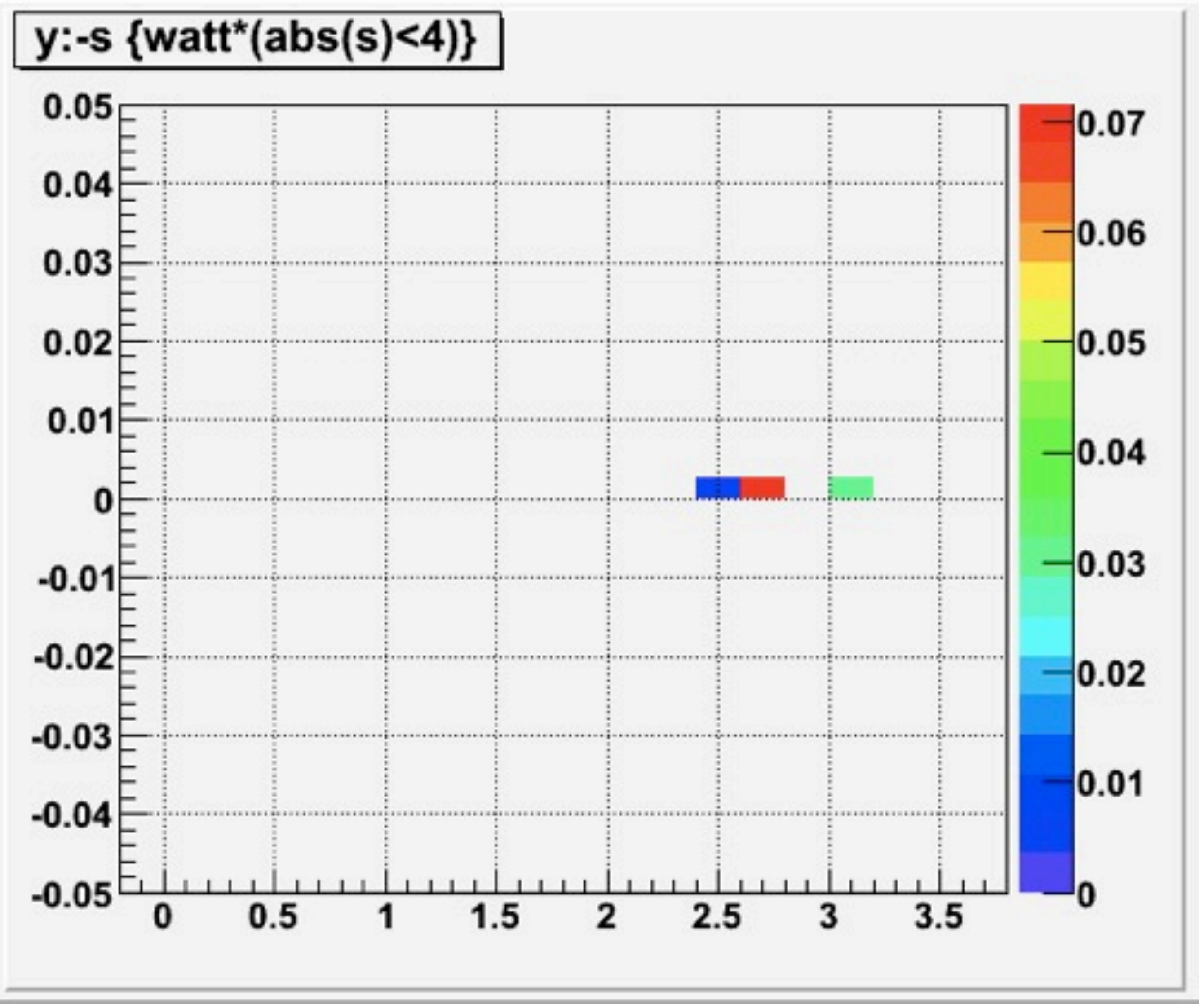


Within |z|<4m,
- loss rate: 0.10 GHz
- loss wattage: 0.10 W

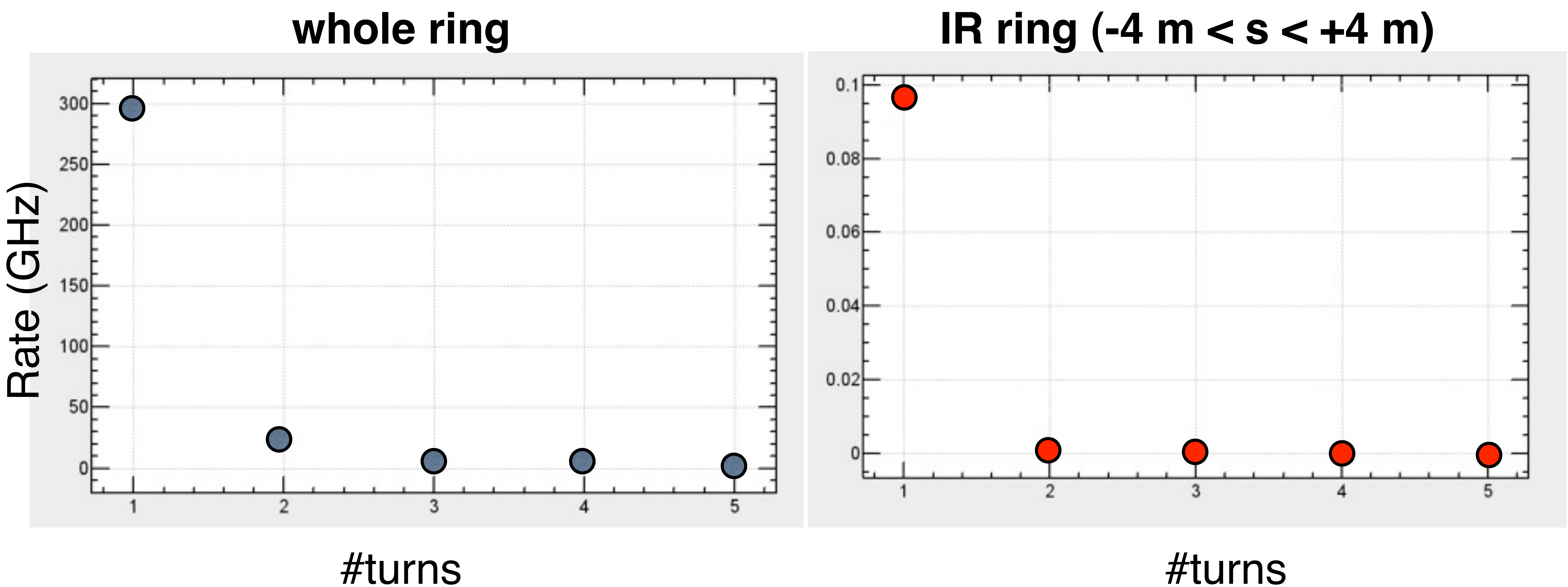
Loss wattage: we assume all energy of beam particle is deposited at the loss position.

HER Touschek (contd.)





Touschek Effect in HER

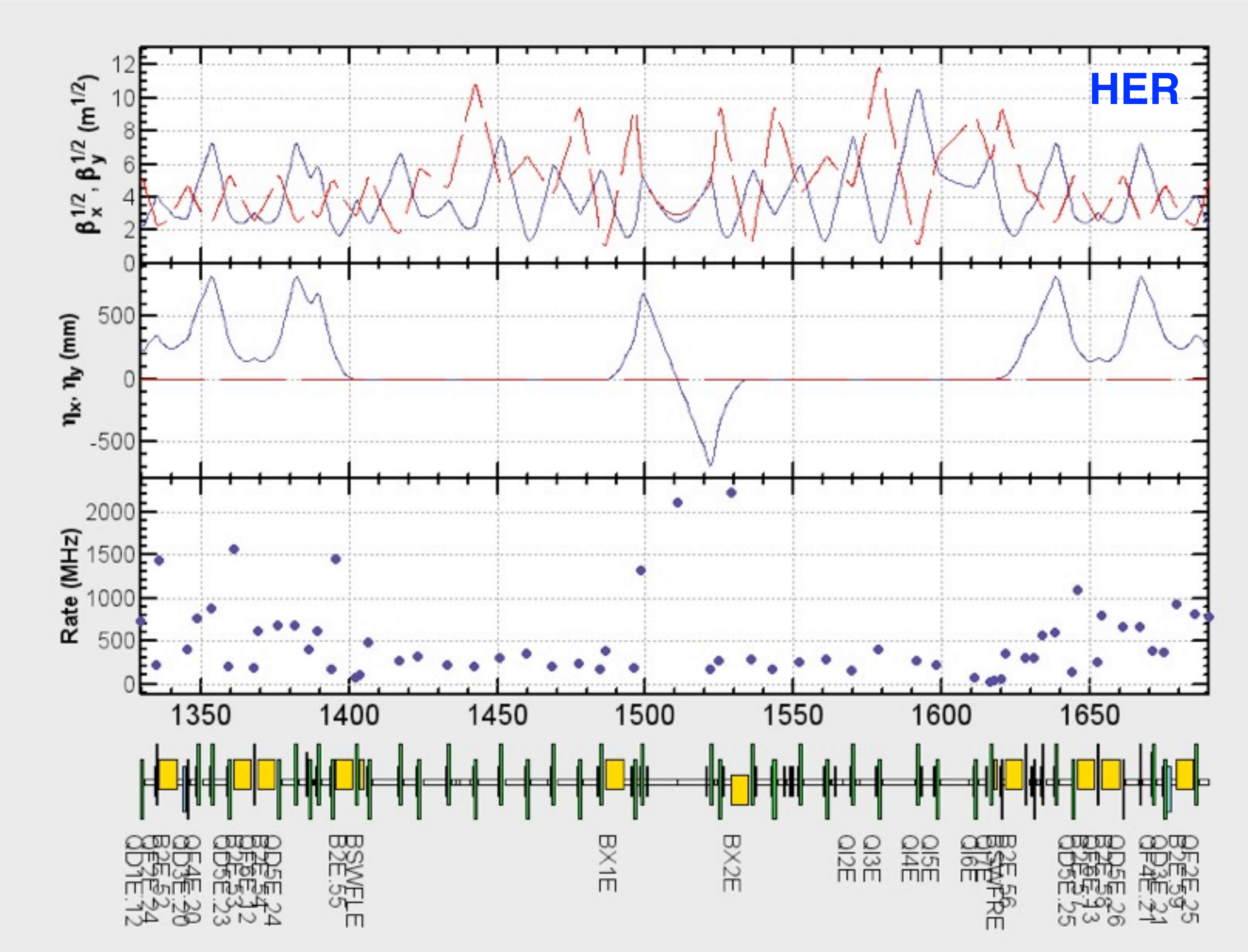


IR loss is single-pass.

Summary

- Comparison between Piwinski's and Bruck's formula
  - Consistent within ~20 % for the practical region
- Vertical mask is necessary in LER.
  - There is a vertical dispersive region in opposite of IP
  - Otherwise, the loss rate in IR will be more than a few GHz.
- Mask aperture affects both lifetime and IR loss.
  - Still need to optimize aperture for each mask.
  - H1 & H4 might be narrow in LER (in this study).
  - Even though the simulation, the mask tuning has a similar difficulty to that at a real physics run. Not simple !

Opposite of IP in HER



Bjorken-Mtingwa Formula

J.D. Bjorken, K. Mtingwa, FERMILAB-Pub-82/47-THY, 1982
K. Kubo, K. Oide, PRST-AB. Vol4, 124401, 2001

- Ready for generalizing for coupled beams between xy, yz, and zx coordinates

- Numerical calculations such as emittance growth by using the beam-envelope method are applicable.

- A rate of M∅ller scattering between (p_1,p_2)->(p_1',p_2'):

$$\frac{dN}{dt} = \frac{1}{2}\int d^3x\rho(x,p_1)\rho(x,p_2)\int\frac{md^3pp_1'}{(2\pi)^2E_1'}\int\frac{md^3p_2'}{(2\pi)^2E_2'}\frac{m^2}{E_1E_2}|M|^2(2\pi)^4\delta^4(p_1'+p_2'-p_1-p_2)$$

$$|M|^2 \sim (4\pi\alpha)^2\left\{\frac{1}{q^4}-\frac{3}{4q^2(p_1-p_2)^2}\right\} \sim (4\pi\alpha)^2\frac{1}{q^4}$$

non-relativistic scattering
small scattering angle

- Emittance growth can be calculated by this equation.