Background estimation

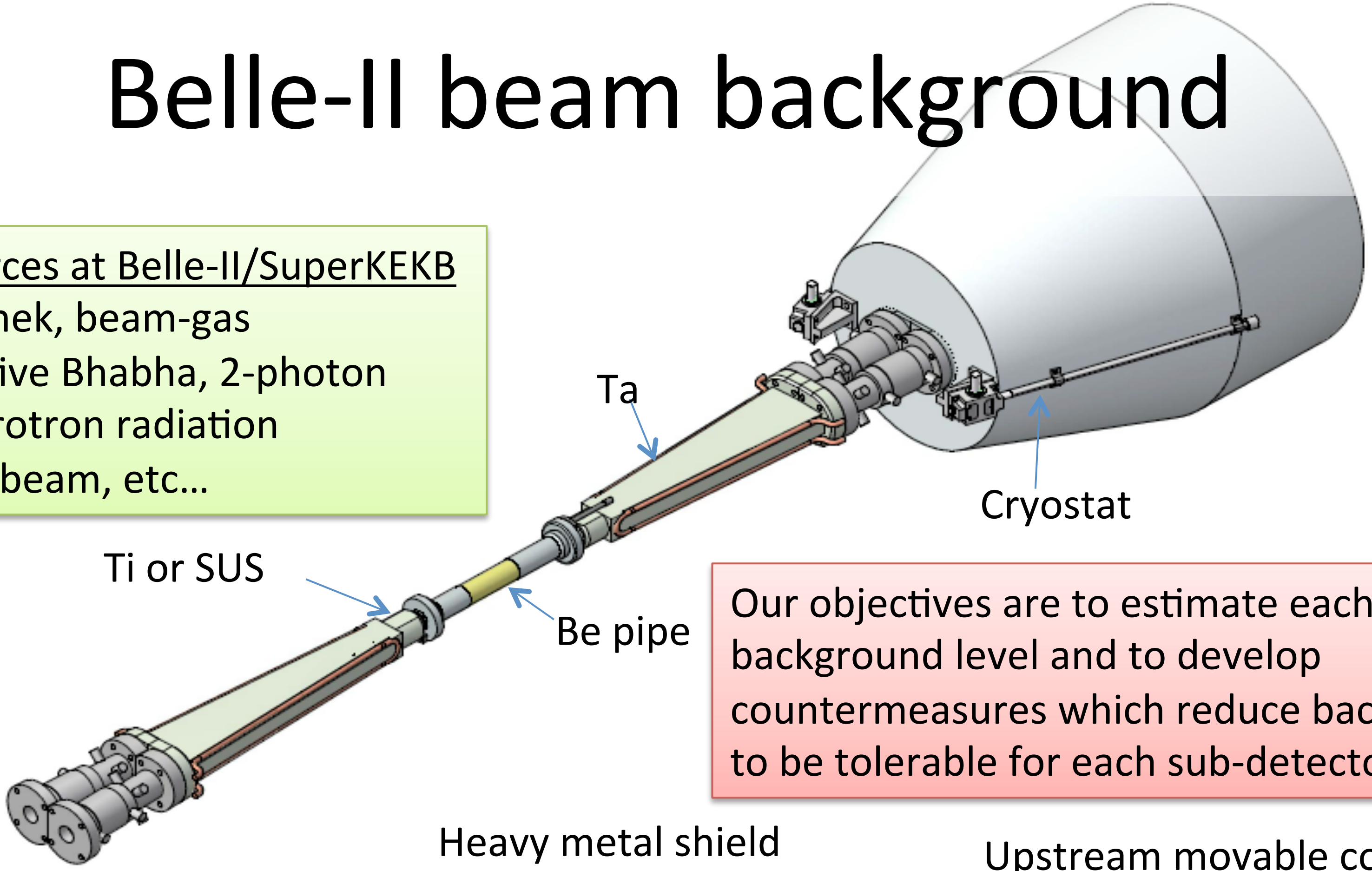
- Touschek BG, beam-gas BG
  - Vertical collimators and beam instability
- Radiative Bhabha BG
- Synchrotron radiation BG
- 2-photon BG
- Full-detector GEANT4 simulation

Hiroyuki NAKAYAMA (KEK)

KEKB ARC(Feb. 20, 2012)

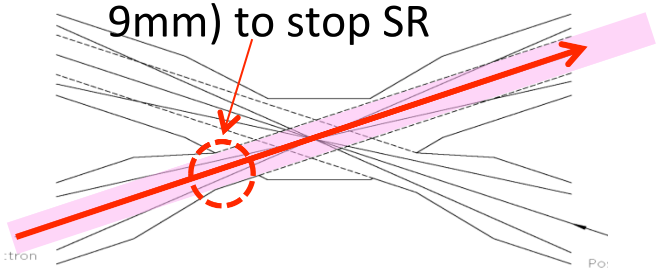
Belle-II beam background

<u>BG sources at Belle-II/SuperKEKB</u>
- Touschek, beam-gas
- Radiative Bhabha, 2-photon
- Synchrotron radiation
- beam-beam, etc…

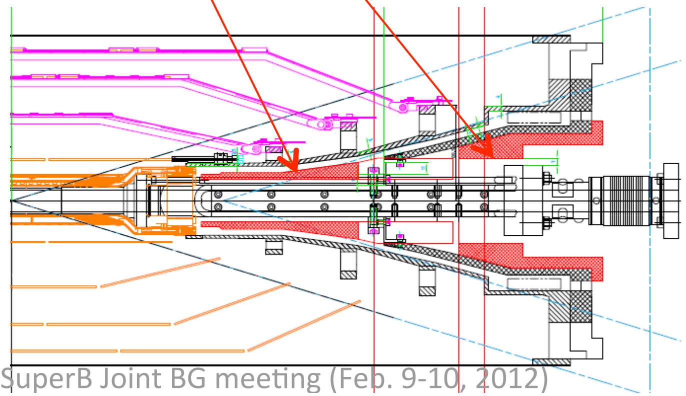


Our objectives are to estimate each background level and to develop countermeasures which reduce background to be tolerable for each sub-detectors.

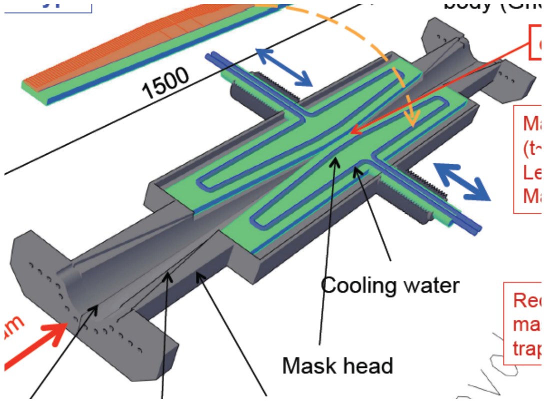
Collimation (20mm->9mm) to stop SR



Heavy metal shield to stop BG showers



Upstream movable collimators



Expected change on BG from KEKB to SuperKEKB

- x20 smaller beam size

  → Touschek scattering rate increases drastically. Need special care.

- x2 more beam current

  → Touschek/Beam-gas scattering rate increases.

- x40 higher luminosity

  → Radiative Bhabha/2-photon scattering rate increases drastically.

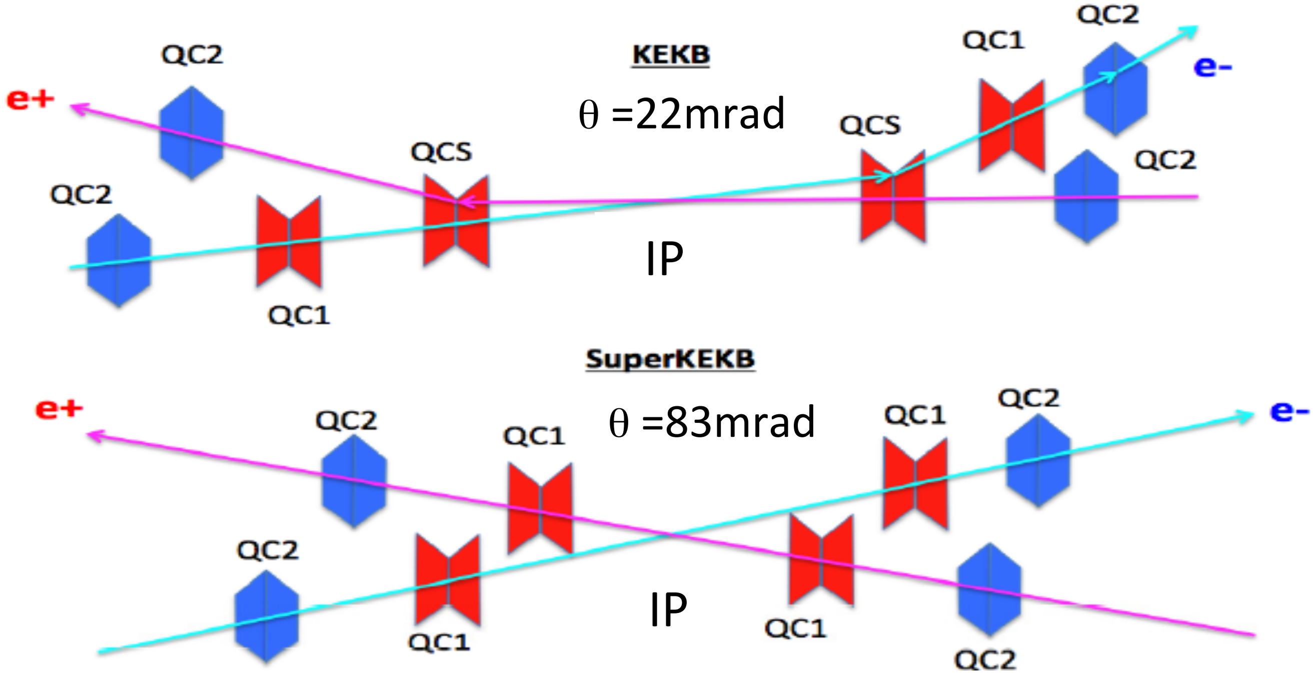
- Smaller IR beam pipe aperture

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

- Final focusing scheme

  → Back-scattering SR and over-bent radiative Bhabha can benefit from it

Final focusing scheme

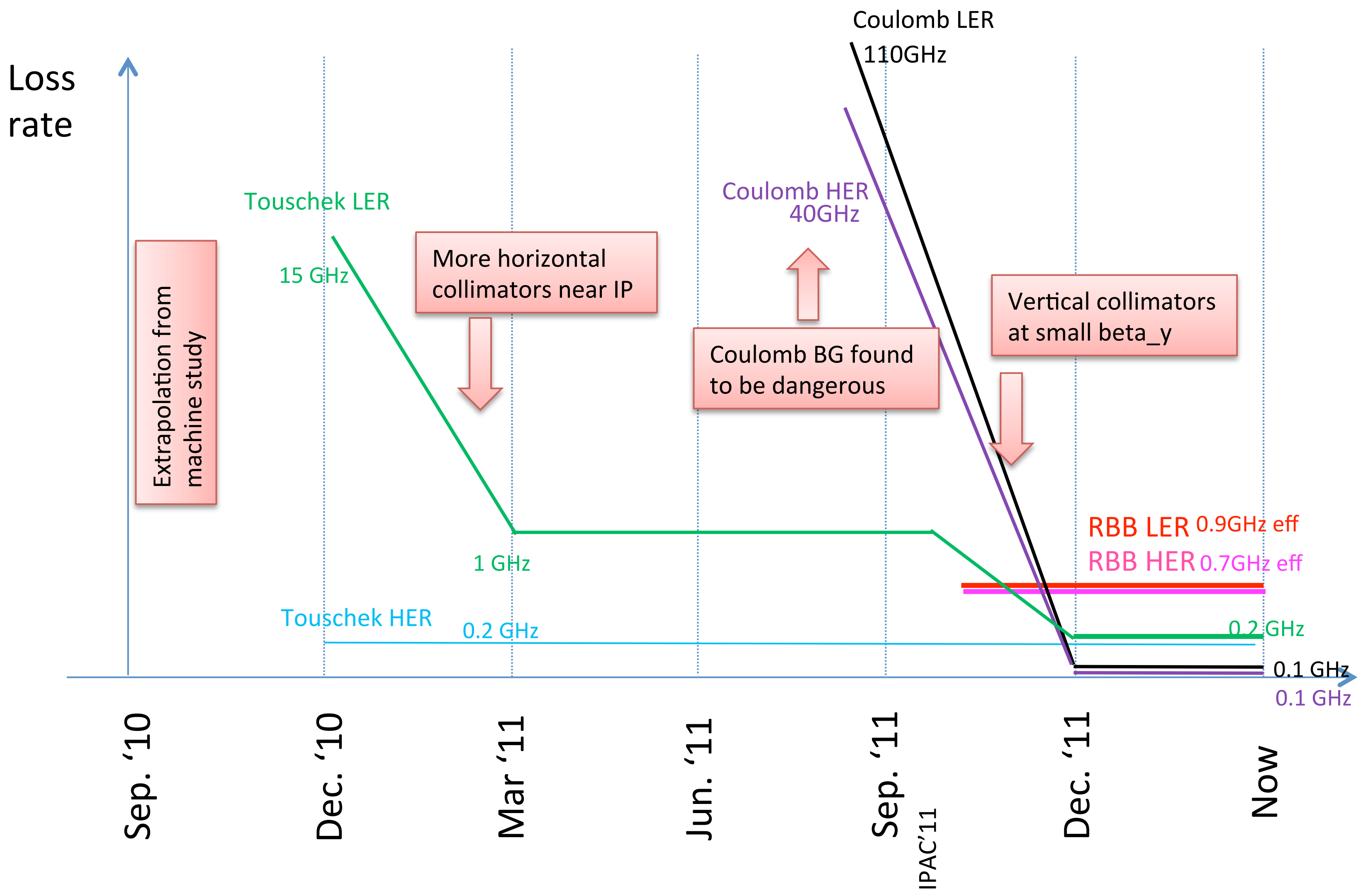


In Belle-II, thanks to the independent final Q magnets for each ring, downstream orbits pass through the center of Q magnets, which results in less dispersion and therefore less back-scattering SR BG and less over-bent radiative Bhabha background.

Estimation status of each BG

- **Touschek BG**
  - Reduced down to ~0.2GHz(LER/HER) thanks to horizontal/vertical collimators (Apr. 2011)
- **Beam-gas BG**
  - Reduced down to ~0.1GHz(LER/HER) thanks to vertical collimators. (Nov. 2011)
- **Synchrotron BG**
  - Reduced down to few order smaller than PXD requirement thanks to collimation on incoming beam pipe (Jul. 2010, toy study) Full detector simulation has just started. . (Jan. 2012)
- **Radiative Bhabha**
  - Most of spent electrons/positrons are lost outside detector thanks to independent final Q magnet (Aug. 2010). But few GHz are still lost in $|s|<4$m (Nov. 2011).
- **2-photon process**
  - Small enough according to KoralW simulation, which is confirmed with BELLE-I machine study (Nov. 2010).
- (Beam-beam)
  - Computational study ongoing by accelerator group

History

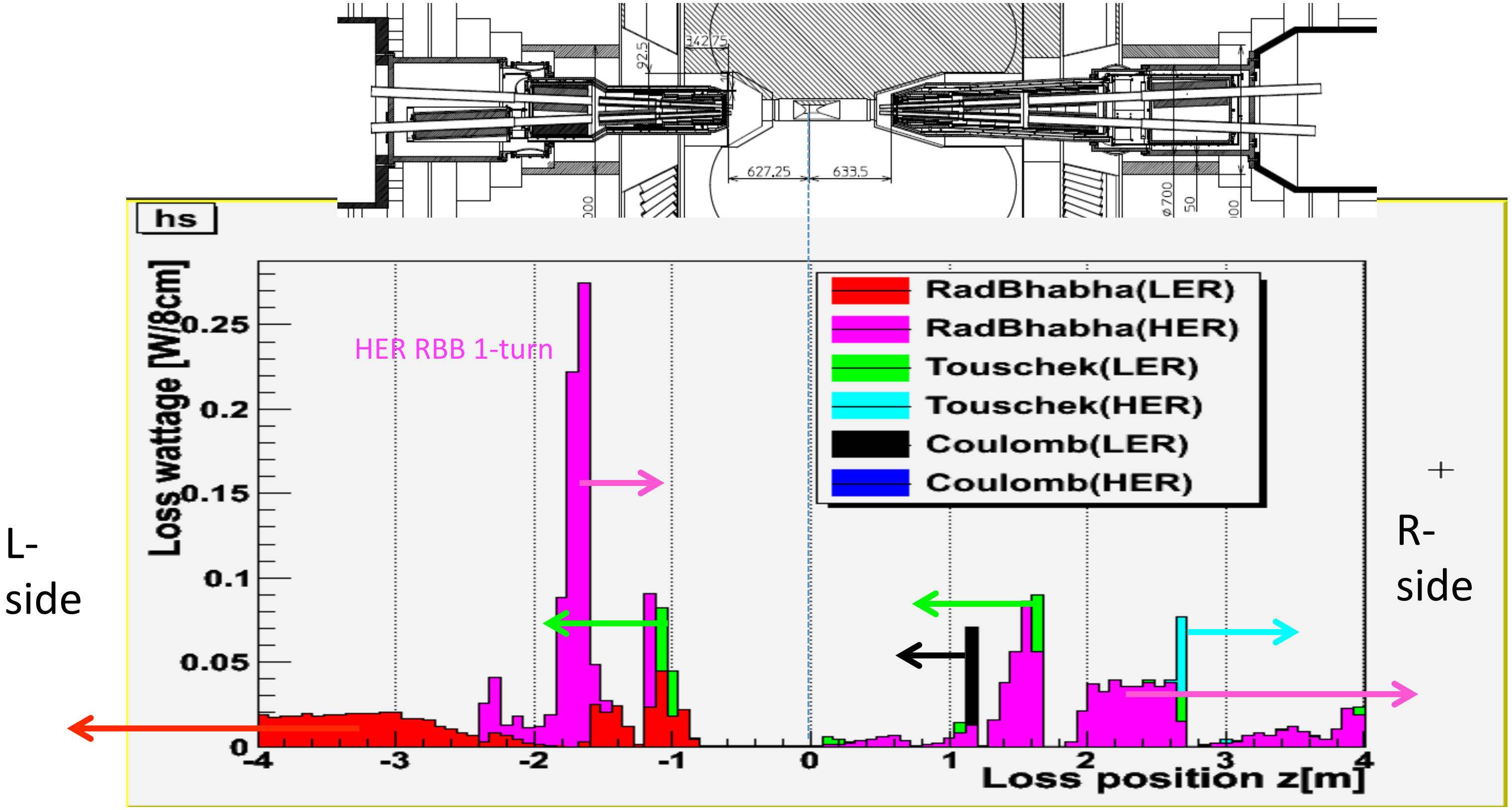


Loss rate
Extrapolation from machine study
Touschek LER
15 GHz
More horizontal collimators near IP
1 GHz
Touschek HER
0.2 GHz
Coulomb LER
110GHz
Coulomb HER
40GHz
Coulomb BG found to be dangerous
Vertical collimators at small beta_y
RBB LER 0.9GHz eff
RBB HER 0.7GHz eff
0.2 GHz
0.1 GHz
0.1 GHz
Sep. '10
Dec. '10
Mar '11
Jun. '11
Sep. '11
IPAC'11
Dec. '11
Now

Ver. 2012.2.20

Total BG

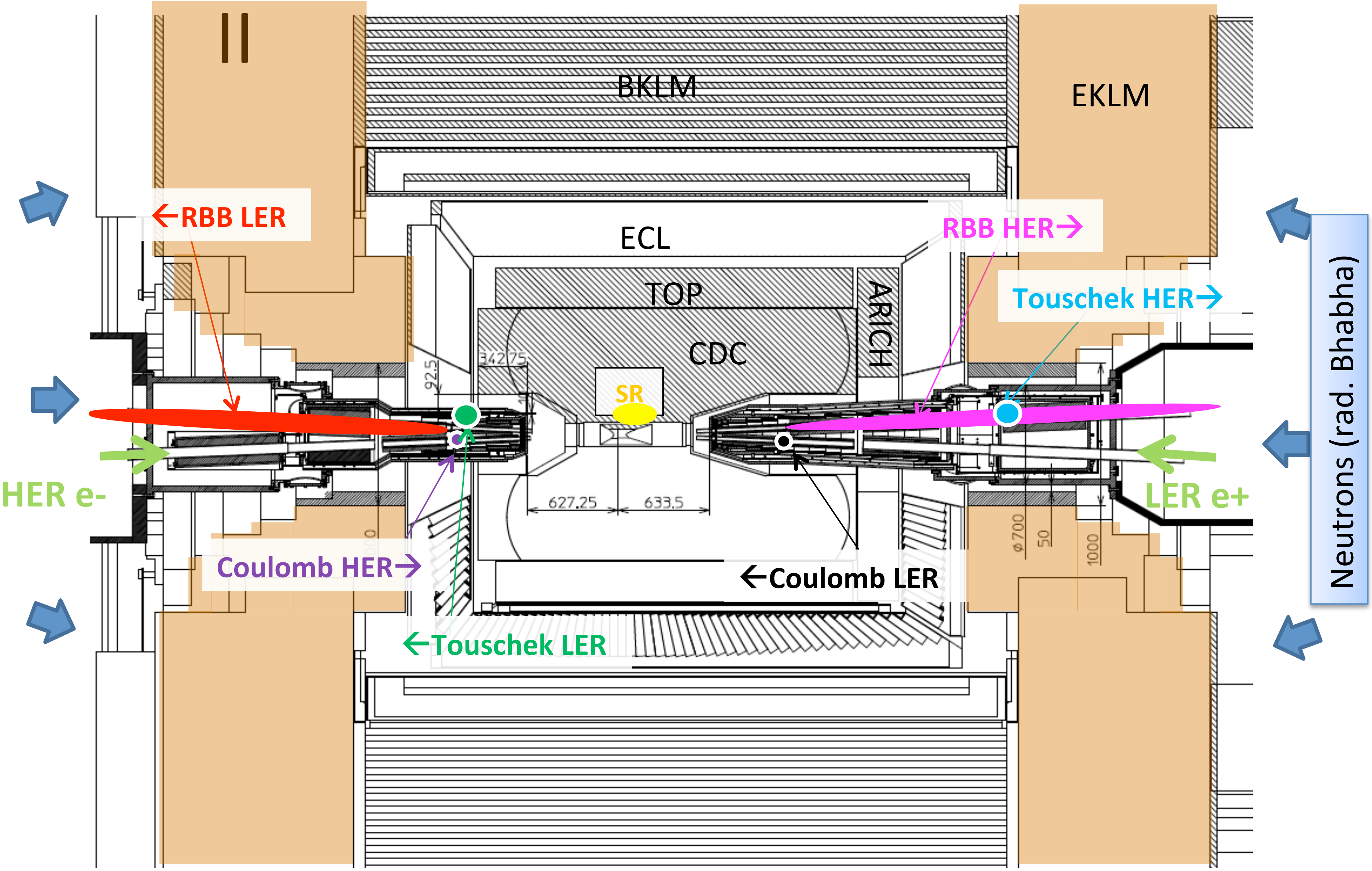
w/o SR, 2-photon



	LER (4GeV e+)	HER (7GeV e-)
Rad. Bhabha	0.55 W (eff. 0.9GHz)	0.76W (eff. 0.68GHz)
Touschek	0.14 W (0.22GHz)	0.10 W (0.09GHz)
Coulomb	0.06 W (0.09GHz)	0.001W (0.001GHz)

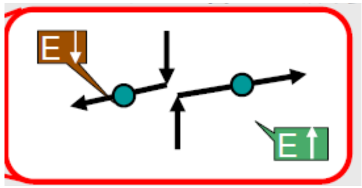
1GeV ,1GHz
= 0.16W

Background picture at Belle-II



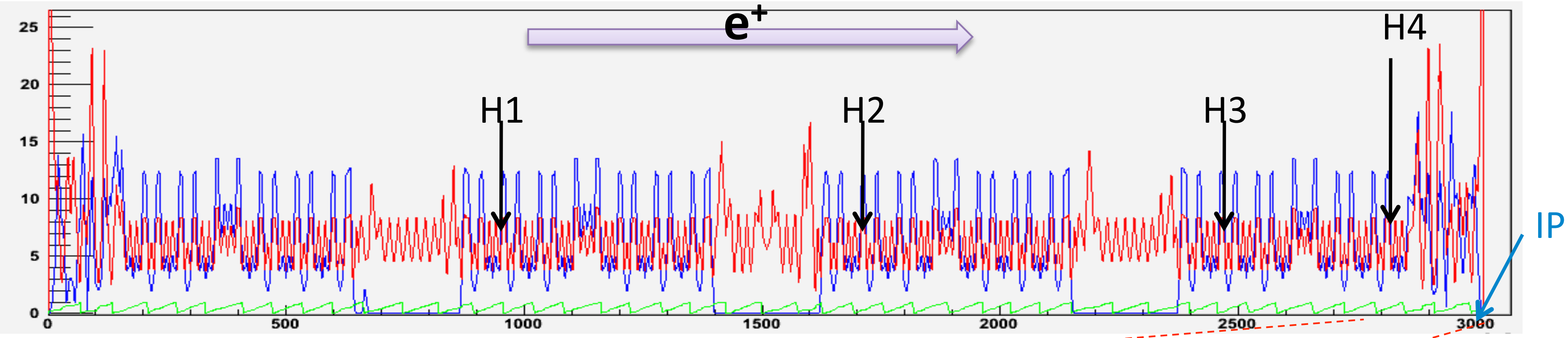
Y. Ohnishi
H. Nakayama

Touschek background

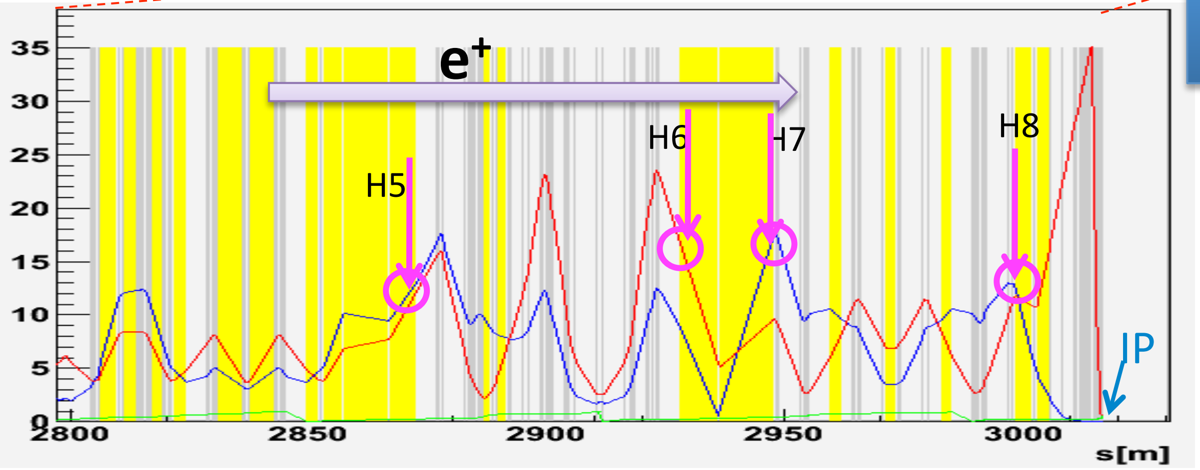


Intra-bunch scattering, Rate $\propto$ (beam size)$^{-1}$,(E$_{beam}$)$^{-3}$
More dangerous in LER

LER horizontal collimators



β_x or η_x converted to collimator width (mm)



Collimator width: 10~15mm

$$d_x = Max[d_{x\beta}, d_{x\eta}, d'_{x\beta}]$$

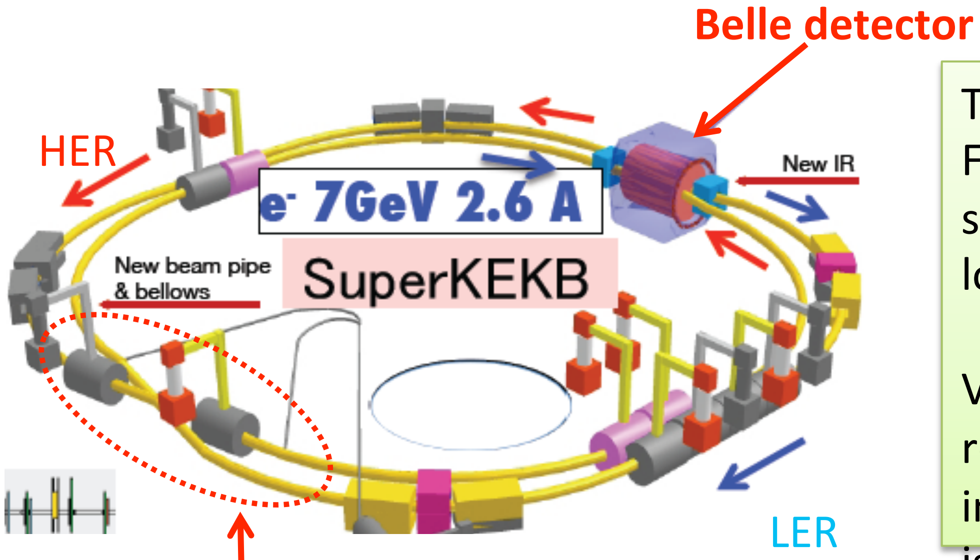
$$d_{x\beta} = n_x\sqrt{\varepsilon_x\beta_x}$$

$$d_{x\eta} = \eta_x(n_z\sigma_\delta)$$

$$d'_{x\beta} = \sqrt{\frac{\beta_{x,\mathrm{mask}}}{\beta_{x,\mathrm{QC2}}}}r_{\mathrm{QC2}}$$

Compared to KEKB, we add more collimators (H5-H8) just before IP (-200m~-18m).
Collimators are located where beta function or dispersion is large.

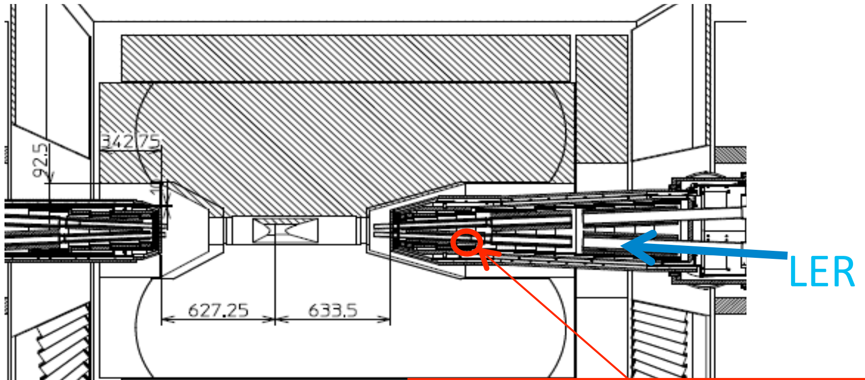
Vertically oscillating Touschek BG



In Fuji area, LER ring bends vertically , to pass under HER ring

Touschek scattered particles scattered at Fuji-area (where vertical dispersion exists) start vertical oscillation and are eventually lost in IR QC1 where βy is large.

Vertical collimator narrower than QC1 can reduce such Touschek loss. Beam instability caused by such collimator is an issue.

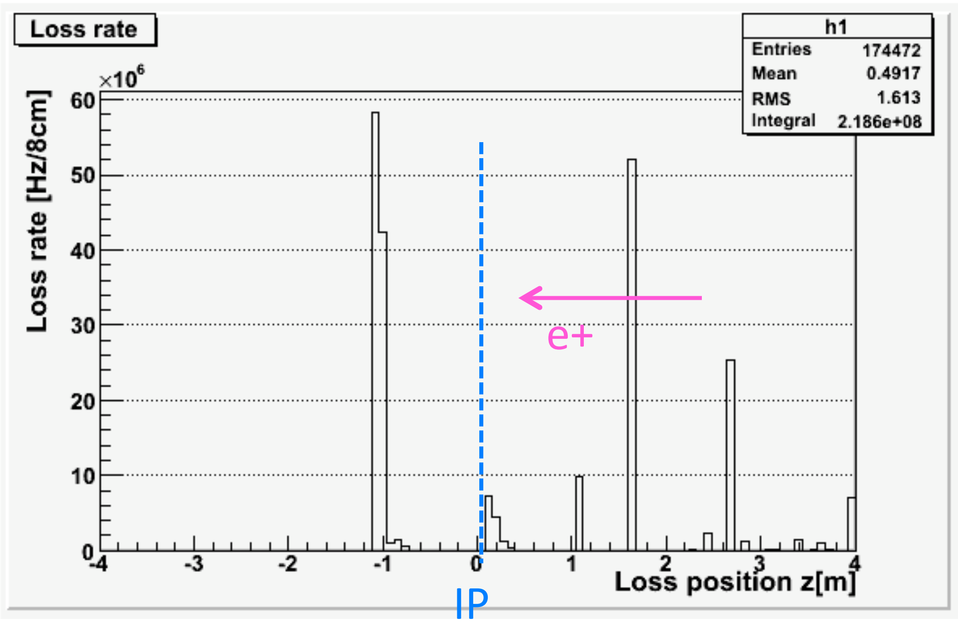


Vertical collimator width: few mm

Few GHz e+ loss w/o vertical collimator

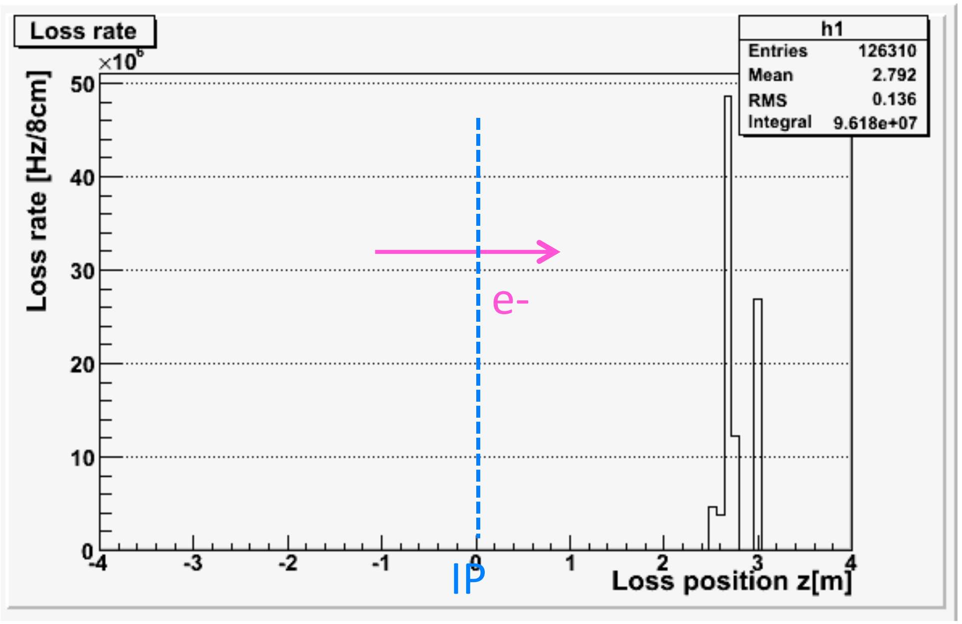
Final Touschek loss in IR

LER



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

HER



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

H. Nakayama
K. Kanazawa
Y. Funakoshi

Beam-gas background

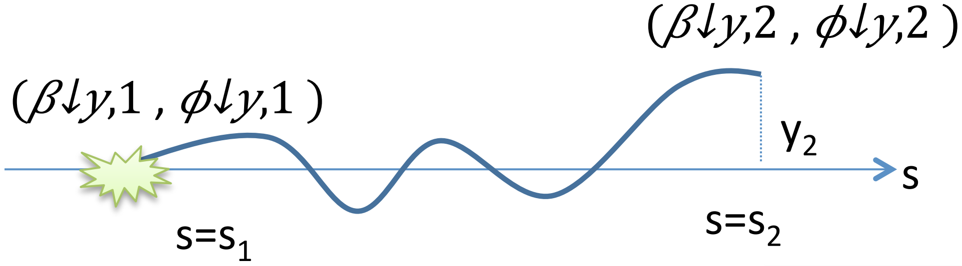
Coulomb>> bremsstrahlung

Coulomb BG is naively proportional to P x I.
Also depends on beta function over the ring
and IR physical aperture.

P = 10^{-7}Pa is assumed

H. Nakano
K. Kanazawa

Beam-gas Coulomb lifetime



θ: Scattering angle

$$y_2 = \theta\sqrt{\beta_{y,1}\cdot\beta_{y,2}}\ \sin(\phi_{y,2}-\phi_{y,1})$$

The minimum scattering angle θ_c to hit QC1 beam pipe

$$\theta_c = r_{QC1}/\sqrt{\langle\beta_y\rangle\cdot\beta_{y,QC1}}$$

Beam lifetime τ_R is proportional to θ_c^2

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

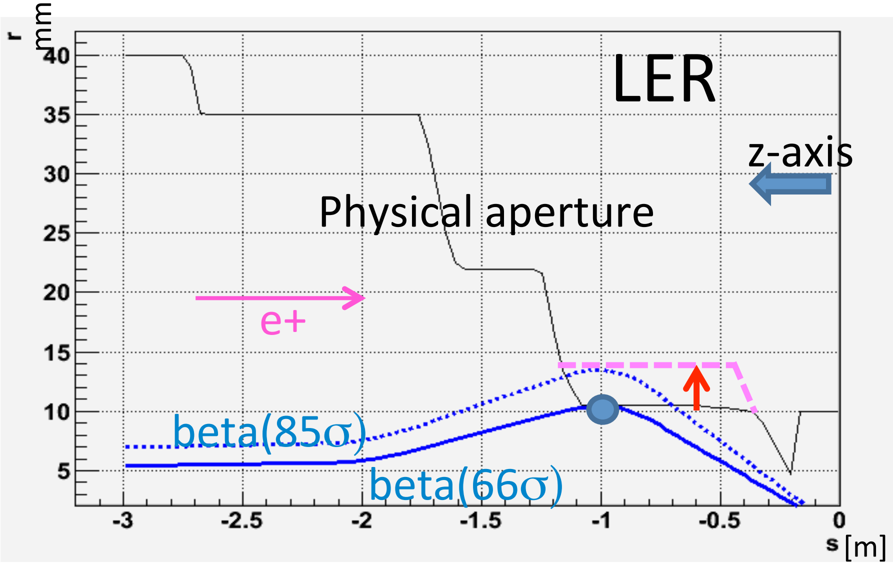
	KEKB LER	SuperKEKB LER
QC1 beam pipe radius: r_{QC1}	35mm	13.5mm
Max. vertical beta (in QC1): $\beta_{y,QC1}$	600m	2900m
Averaged vertical beta: $\langle\beta_y\rangle$	23m	48m
Min. scattering angle: θ_c	0.3mrad	0.036mrad
Beam-gas Coulomb lifetime	>10 hours	2200sec

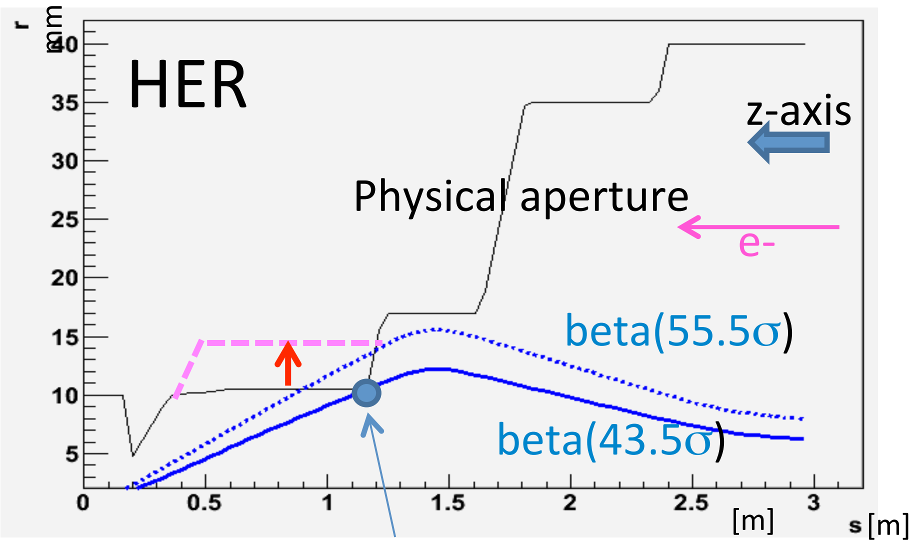
Rate $\propto$ P x I x $\langle\beta\rangle$
x β_{QC1} / r_{QC1}^2

Beam-gas lifetime is only x1/100 of KEKB, due to larger vertical beta in QC1 and narrower QC1 physical aperture

Strategy to reduce Coulomb BG

- Larger QC1 physical aperture (r=10.5mm→13.5mm)





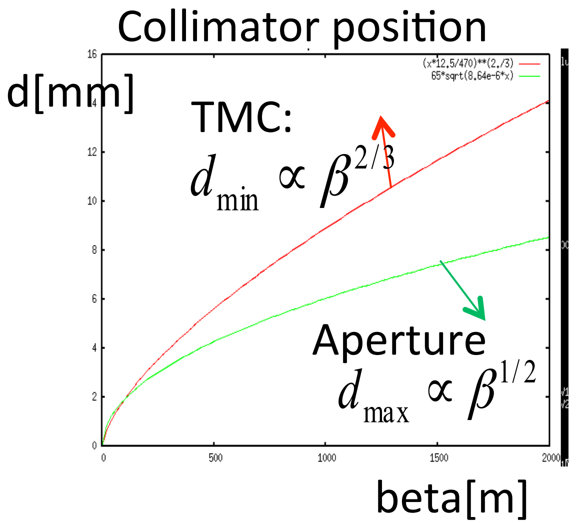
We widened QC1 aperture without major change in QCS design.
Coulomb lifetime improved (LER: 1360→2240sec, HER: 2100→3260sec)

- Vertical collimators!
  - QC1 aperture should not be narrowest over the ring
  - – Collimator aperture should be narrower than QC1 aperture
  - – Beam instability? (collimators should be very close(few mm) to the beam)

Where we should put vertical collimator?

Collimator <u>aperture</u> should be narrower than QC1 aperture.

$$d/\sqrt{\varepsilon\beta} < r_{QC1}/\sqrt{\varepsilon\beta_{QC1}} \Rightarrow \boxed{d_{\max} \propto \beta^{1/2}}$$


Collimator position

<u>TMC instability</u> should be avoided.

<u>Assuming following two formulae</u>:

$$I_{thresh} = \frac{C_1 f_s E/e}{\sum_i \beta_i k_{\perp i}(\sigma_z)} > 1.44 \text{ mA/bunch (LER)}$$

taken from "Handbook of accelerator physics and engineering, p.121"

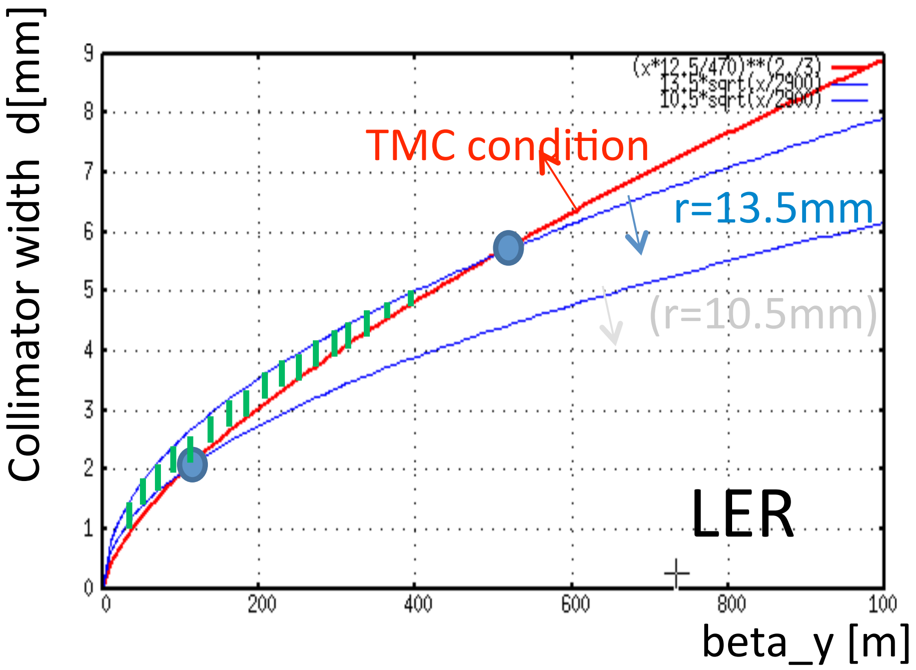
$$\Rightarrow \boxed{d_{\min} \propto \beta^{2/3}}$$

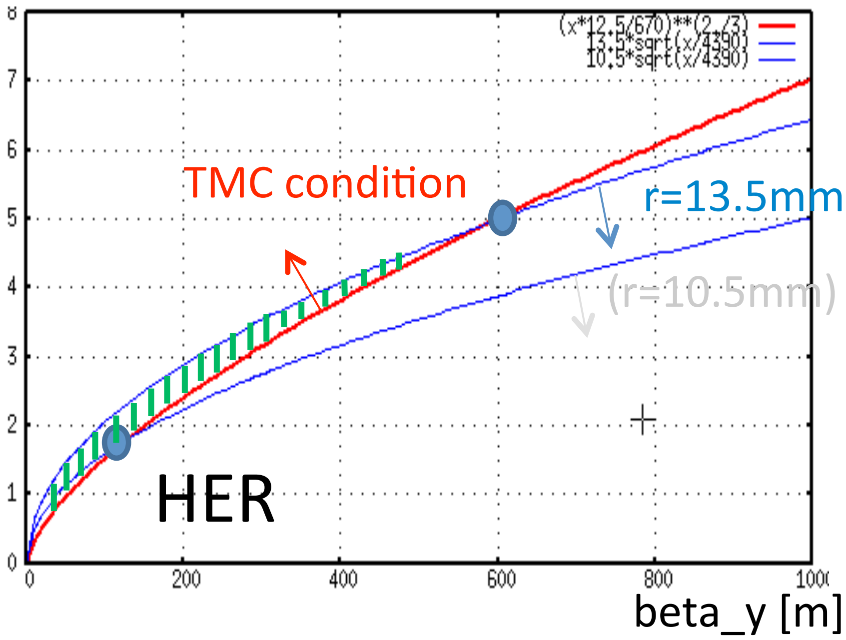
Kick factor $k_\perp = 0.215 A Z_0 c \sqrt{\frac{\theta}{\sigma_z d^3}}$

(in case of rectangular collimator window)

We should put collimator where beta_y is <u>SMALL!</u>

Candidate collimator locations





lerfqlc_1604

V1 collimator @ LLB3R (downstream)
(s=-90→-82m, βy=30→146m)
βy=125m, 2.23mm<d<2.81mm

herfqlc5605

V1 collimator @ LTLB2 (downstream)
(s=-63→-61m, βy=81→187m)
βy=123m, 1.74mm<d<2.26mm

Collimator position should satisfy beta_y condition above,
need space(at least 1.5m), and the phase should be close to IP

Vertical collimator width vs. Coulomb loss rate, Coulomb life time

ler1604, V1=LLB3R downstream

V1 width[mm]	IR loss [GHz]	Total loss[GHz]	Coulomb life[sec]
2.40	0.04	149.5	1513.3
2.50	0.05	137.8	1642.0
2.60	0.09	127.4	1776.0
2.70	0.24	118.1	1915.2
2.80	0.81	110.0	2057.2
2.90	8.48	109.3	2069.6
3.00	18.98	109.3	2069.6

Based on element-by-element simulation considering causality the phase difference (by Nakayama)

her5365,V1=LTLB2 downstream

V1 width[mm]	IR loss [GHz]	Total loss[GHz]	Coulomb life[sec]
2.10	0.001	48.4	3379.4
2.20	0.001	44.1	3709.0
2.30	0.357	40.0	4053.8
2.40	6.862	33.0	4099.1
2.50	12.004	27.9	4099.1

IR loss rate is VERY sensitive to the vertical collimator width.
(Once V1 aperture>QC1 aperture, all beam loss goes from V1 to IR

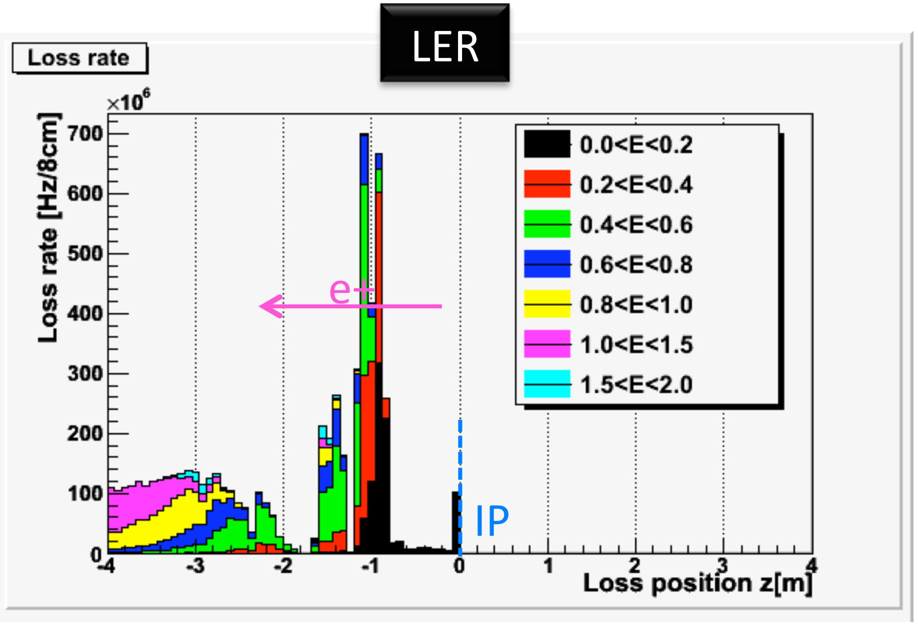
Typical orbit deviation at V1 : +-0.12mm (by iBump V-angle: +-0.5mrad@IP)

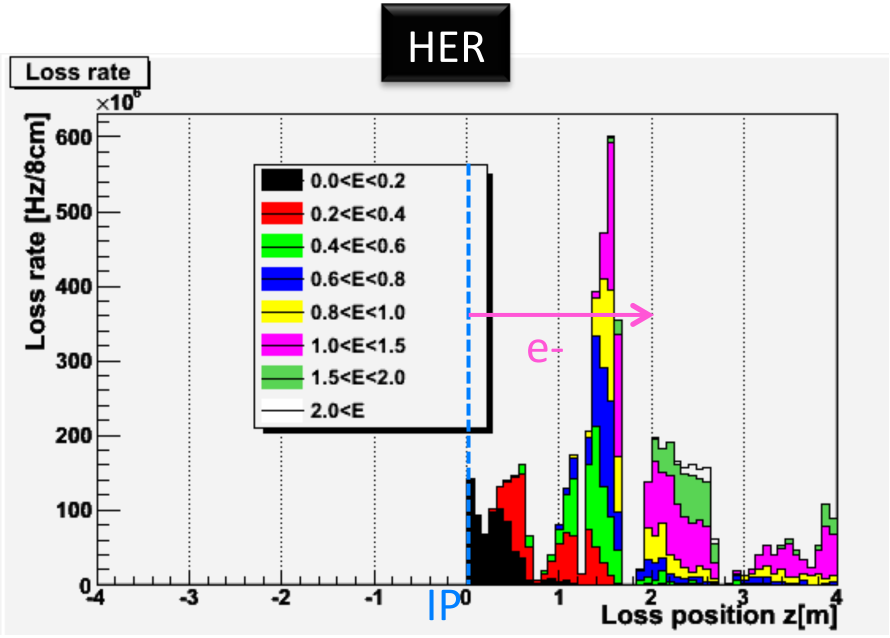
Y. Funakoshi

Radiative Bhabha background

- Spent e+/e- loss in downstream
  Dominant loss position is very far (~10m) from IP, but little fraction with large ΔE (still dangerous with Lx40) can be lost inside detector.
- Gamma emitted from IP
  They hit downstream (~10m) beam pipe/magnet and generate neutrons by giant dipole resonance. Neutron shielding inside tunnel will be increased

Radiative Bhabha BG

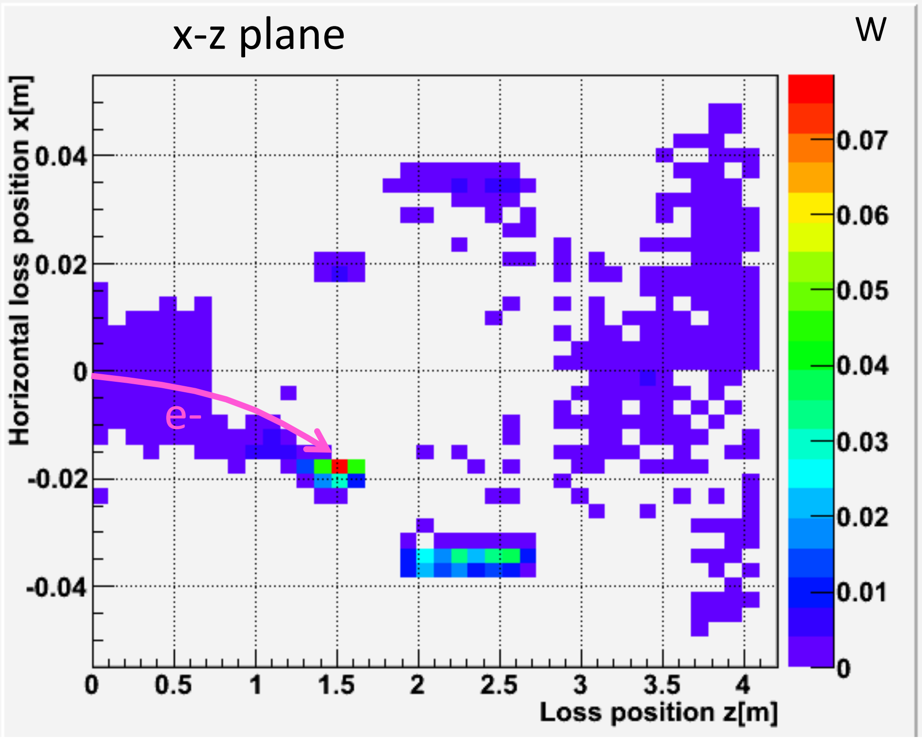


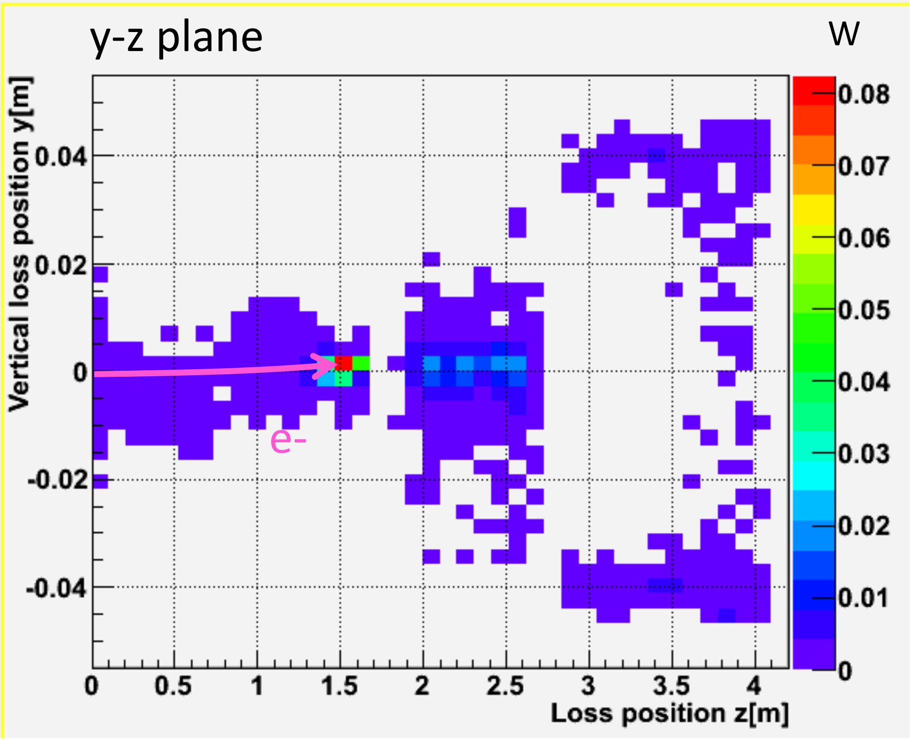


Within |z|<4m,
loss rate: 6.8 GHz(0~1.4GeV)
loss wattage: 0.55 W
(Equivalent to 0.86GHz of 4GeV e-)

Within |z|<4m,
loss rate: 5.8 GHz(0~2GeV)
loss wattage: 0.75 W
(Equivalent to 0.68GHz of 7GeV e-)

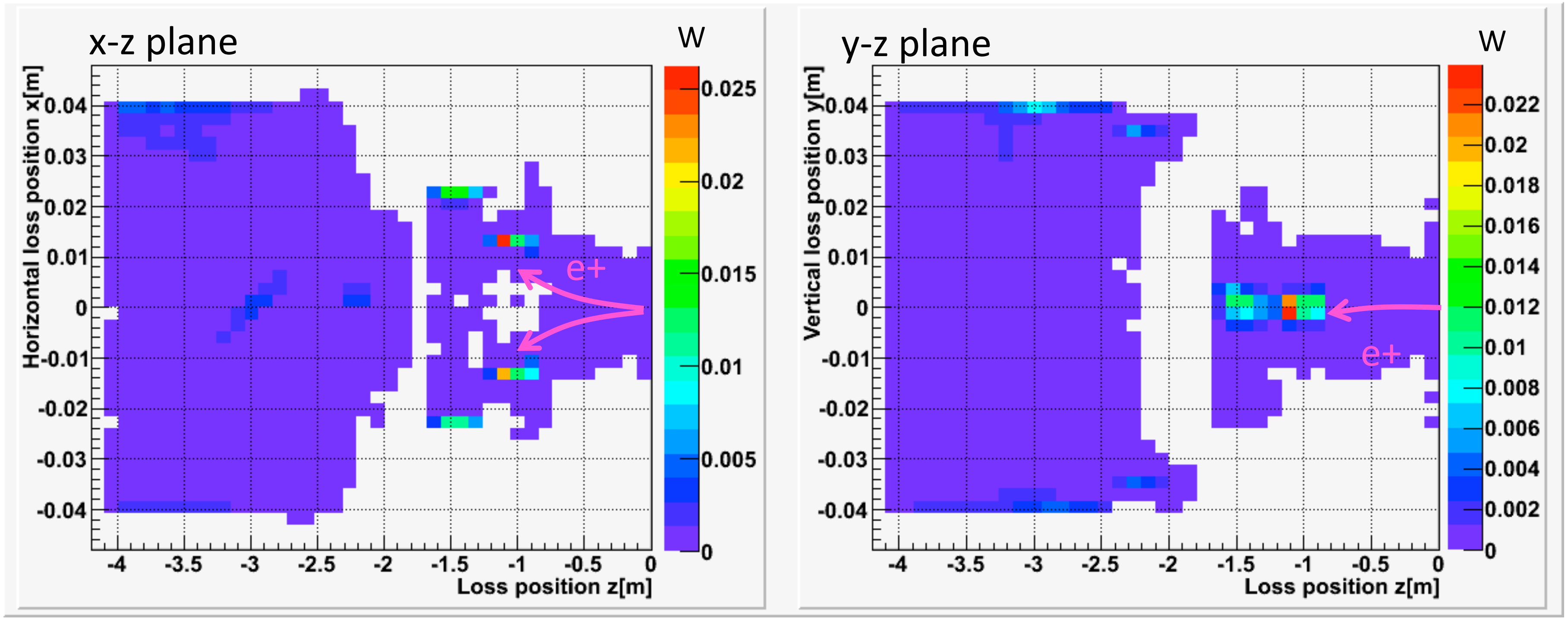
Radiative Bhabha HER (contd.)





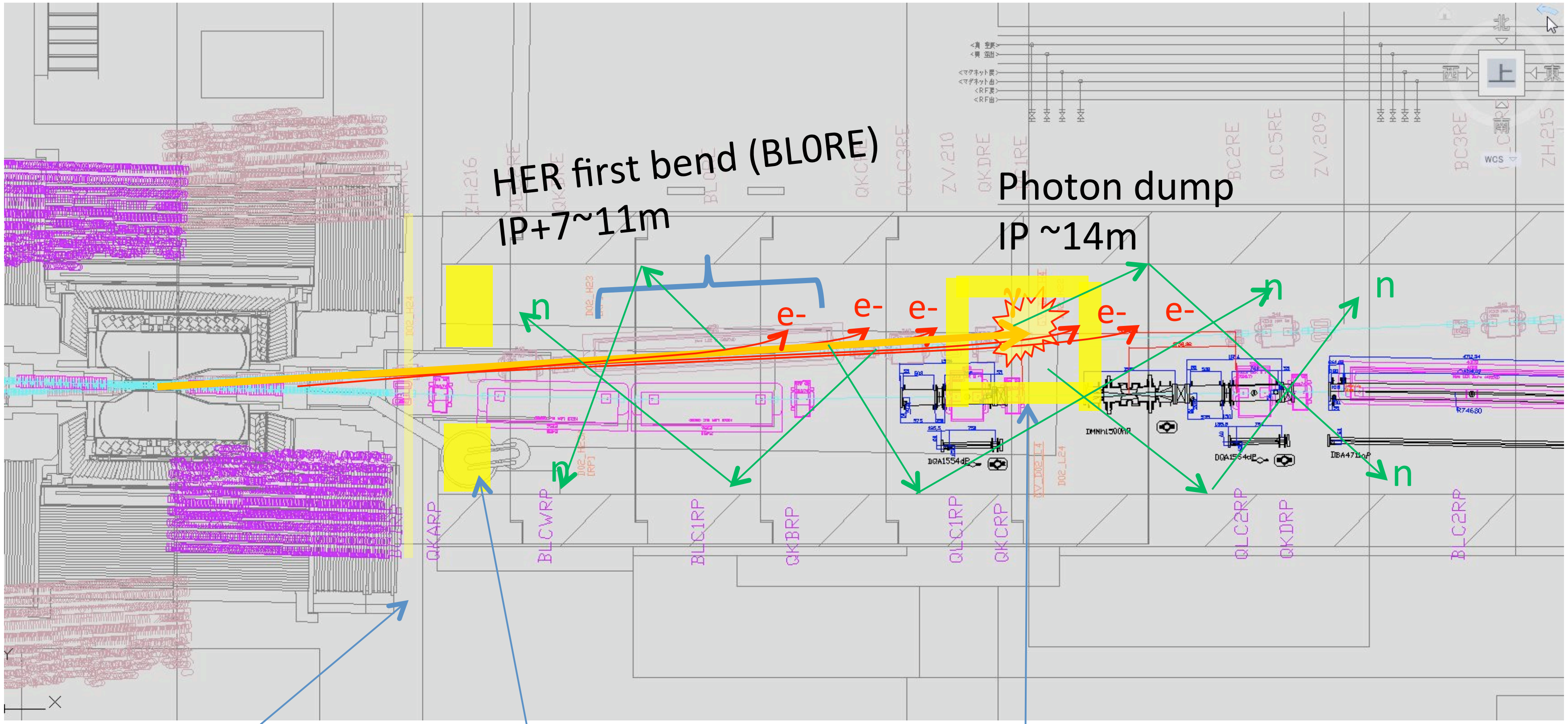
Horizontally lost at z=1.5m

Radiative Bhabha LER (contd.)



Horizontally lost at z=-1m

Additional shields in tunnel

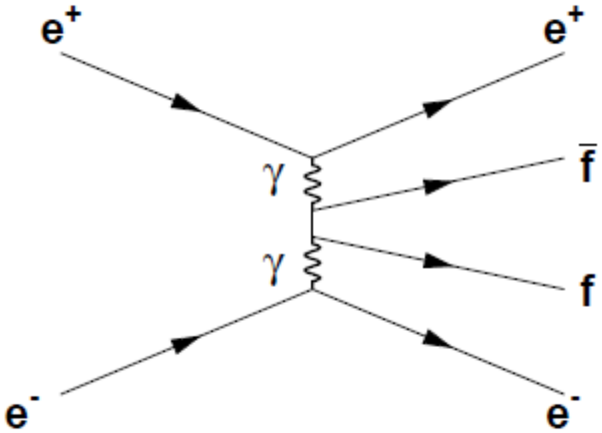


Polyethylene shield (10cm) at KEKB

Additional concrete shield at tunnel exit

Additional neutron shield around gamma dump

2-photon BG



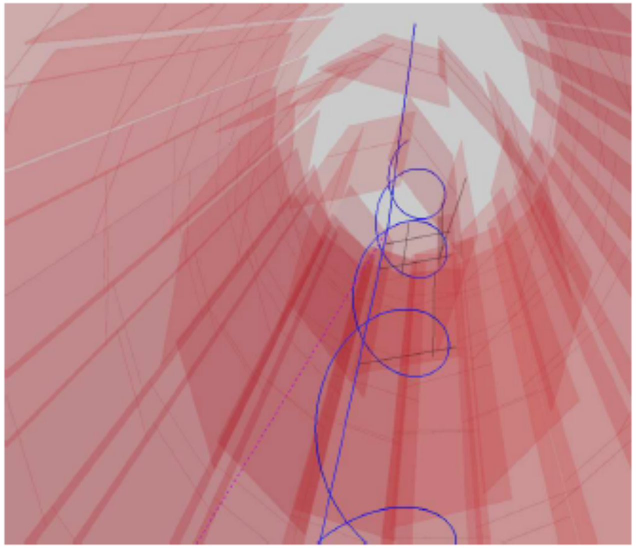


Figure 6.3: Event display of the two-photon KoralW events in the SVD

2-photon BG

C. Kiesling, S. Koblitz
E. Nedelkovska

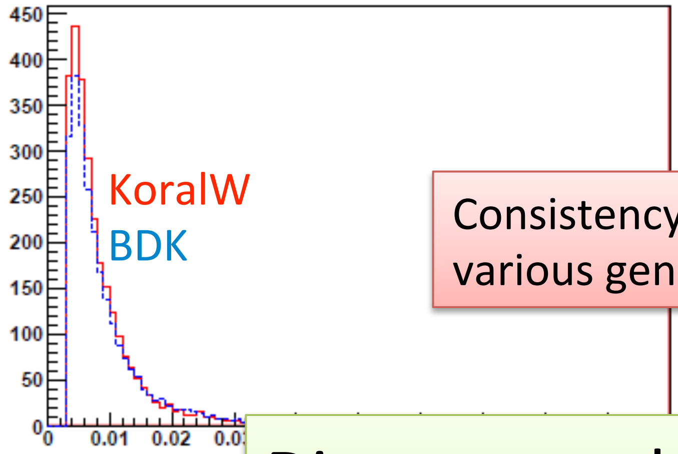
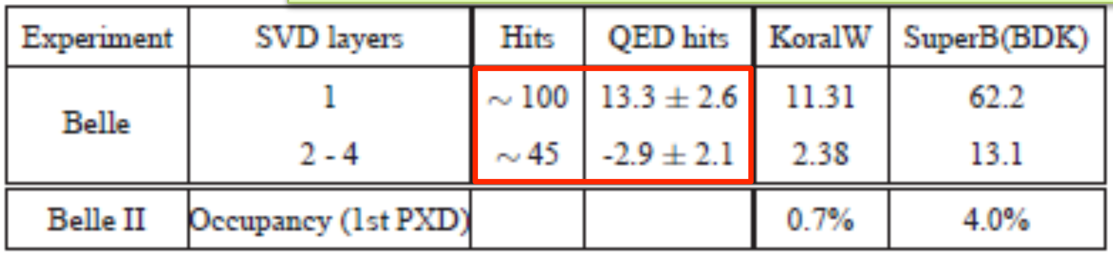


Figure 2.4: KoralW(

Consistency among the various generator s

Discrepancy between SuperB numbers and ours disappeared now.

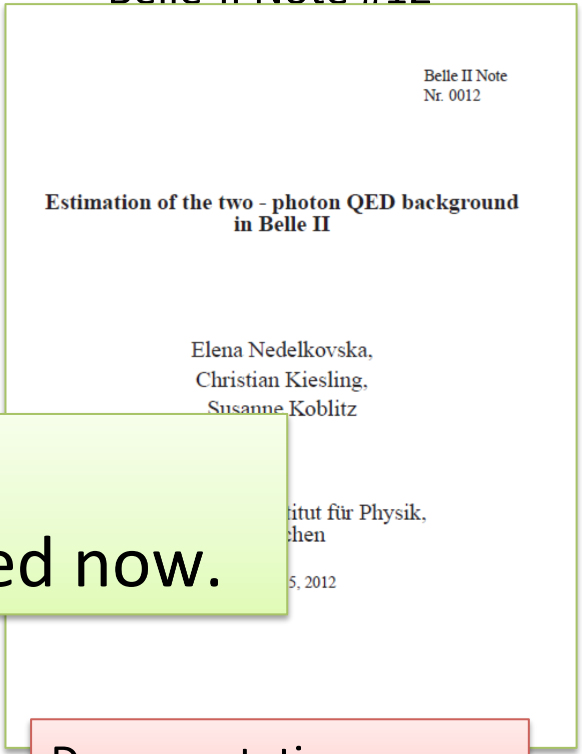


Experiment	SVD layers	Hits	QED hits	KoralW	SuperB(BDK)
Belle	1	~ 100	13.3 ± 2.6	11.31	62.2
	2 - 4	~ 45	-2.9 ± 2.1	2.38	13.1
Belle II	Occupancy (1st PXD)			0.7%	4.0%

Table 6.1: Comparison between data and Monte Carlo

KEKB machine study in 2010 is consistent with our generator, and inconsistent with SuperB numbers

Belle-II Note #12



Belle II Note
Nr. 0012

Estimation of the two - photon QED background in Belle II

Elena Nedelkovska,
Christian Kiesling,
Susanne Koblitz

itut für Physik,
chen

5, 2012

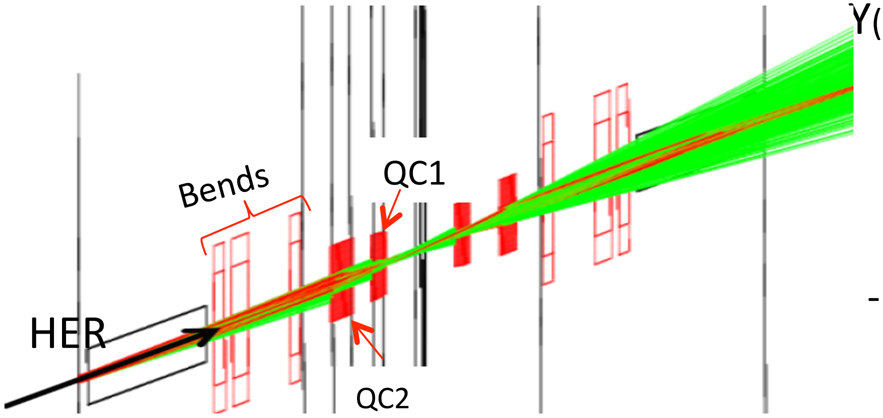
Documentation now available

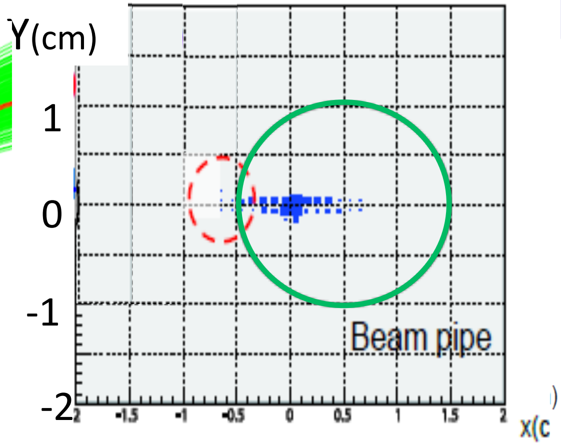
Synchrotron BG

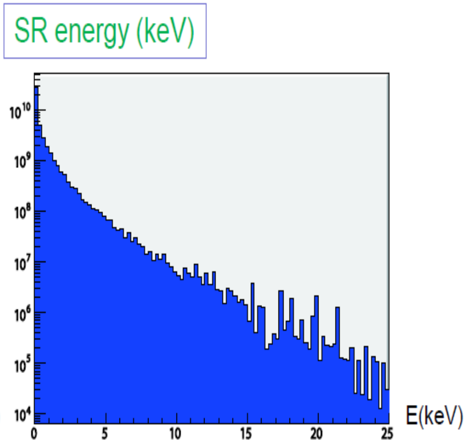
mainly from HER

M.Iwasaki

SR simulation results in 2010

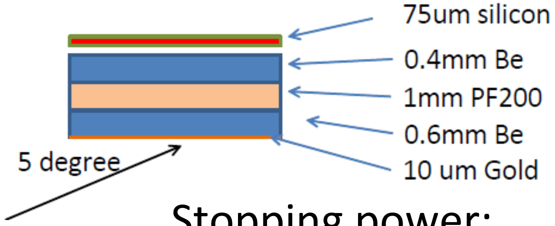






- Simplified geometry, no SR scattering/reflection considered
- Bending magnets, solenoids, Q magnets, Q leak field implemented
- Gaussian beam with tail cutoff of 20σ

~200/bunch (>5keV) photons hit straight part of beam pipe, which is 3-4 order below PXD requirements.

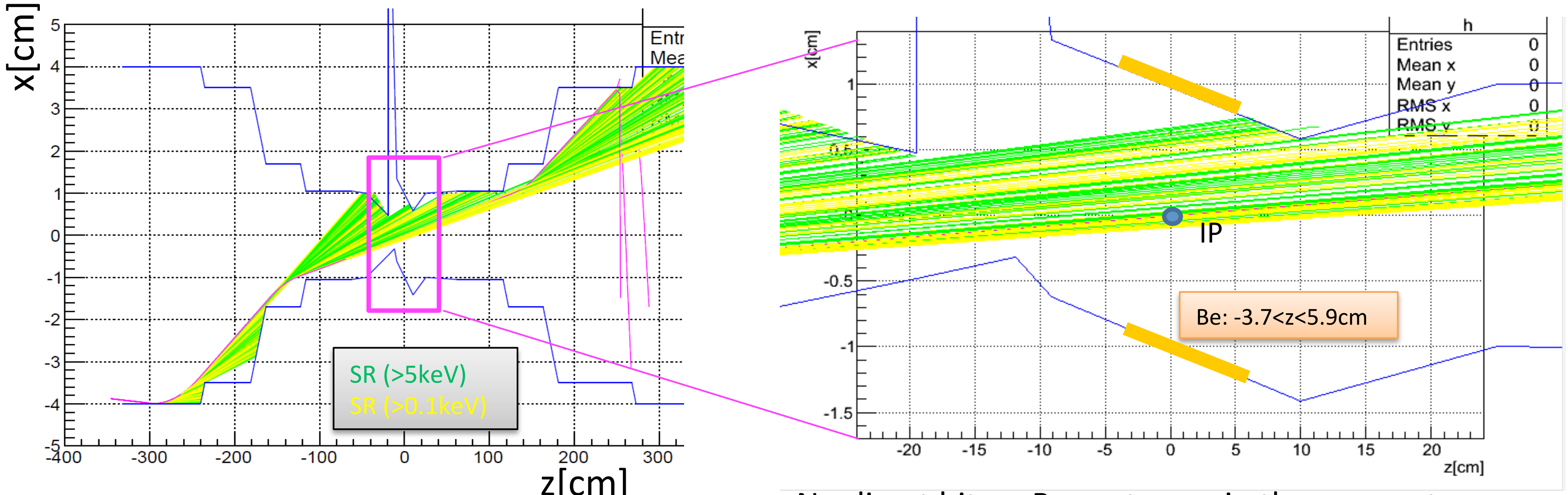


Stopping power: O(~10^{-6}) for <20KeV

H. Nakayama
K. Itagaki

Detailed SR simulation

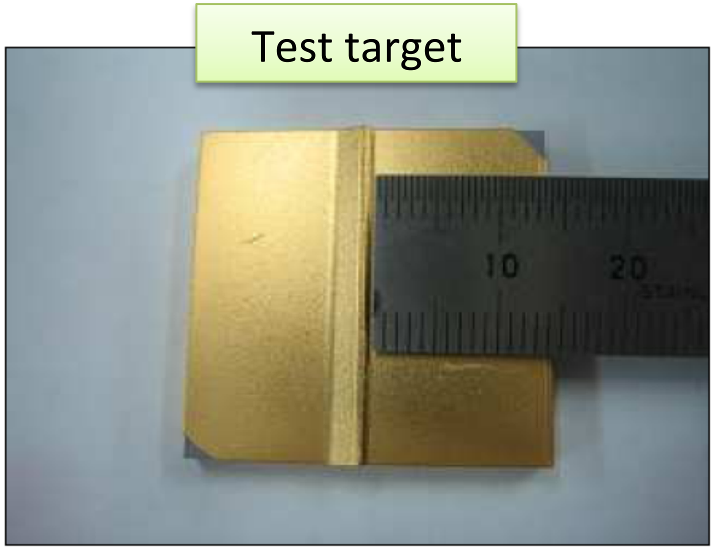
- Detailed beam pipe geometry implemented.
- Only QC1/2 included so far, missing bending magnets upstream
- Currently using 2D “cylindrical” solenoid field, need to be updated with 3D
- Reflection/scattering on Au coating of beam pipe will be considered
- Test-beam study to implement home-made “tip-scattering” model

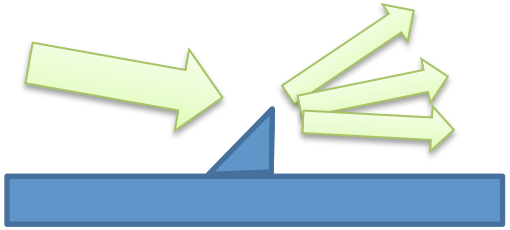


No direct hit on Be part even in the severest case

J. Murakami
S. Tanaka

X-ray beam test



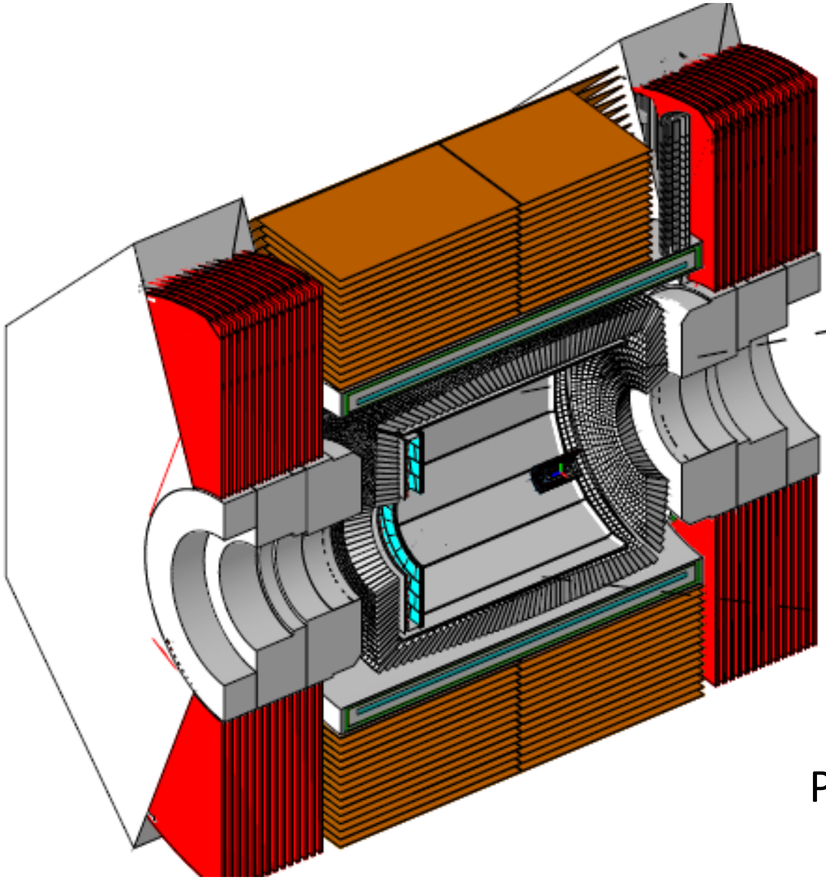


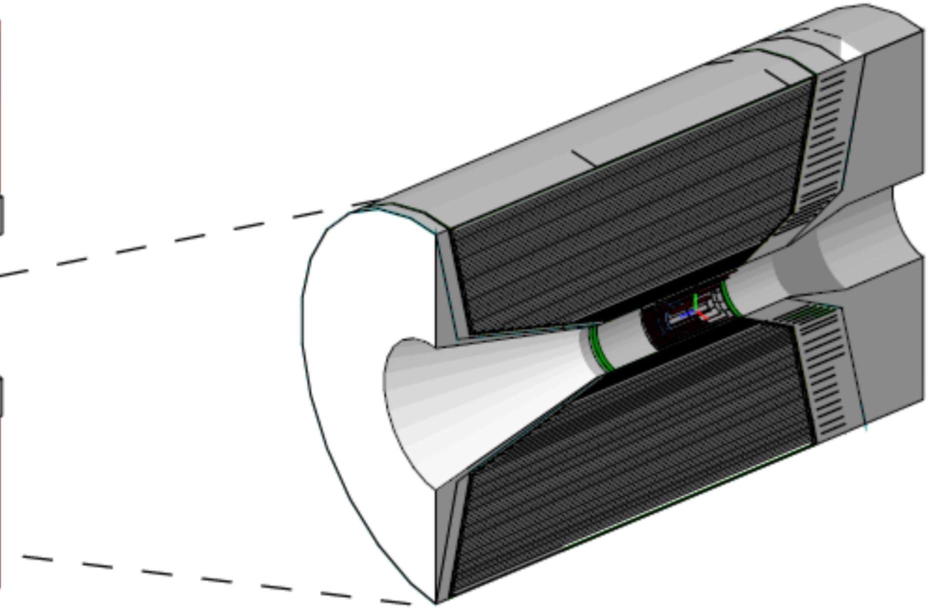
Measure scattering angle distribution

Irradiate X-rays onto Ta tip plated with gold and measure angle distribution of scattered flux.

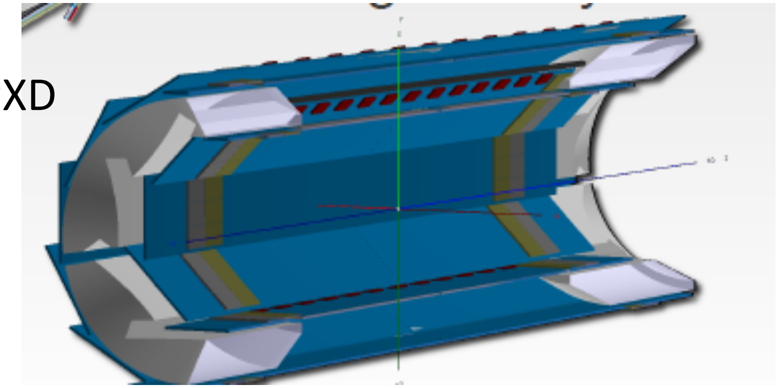
Analysis ongoing

Whole geometry ready in GEANT4





PXD

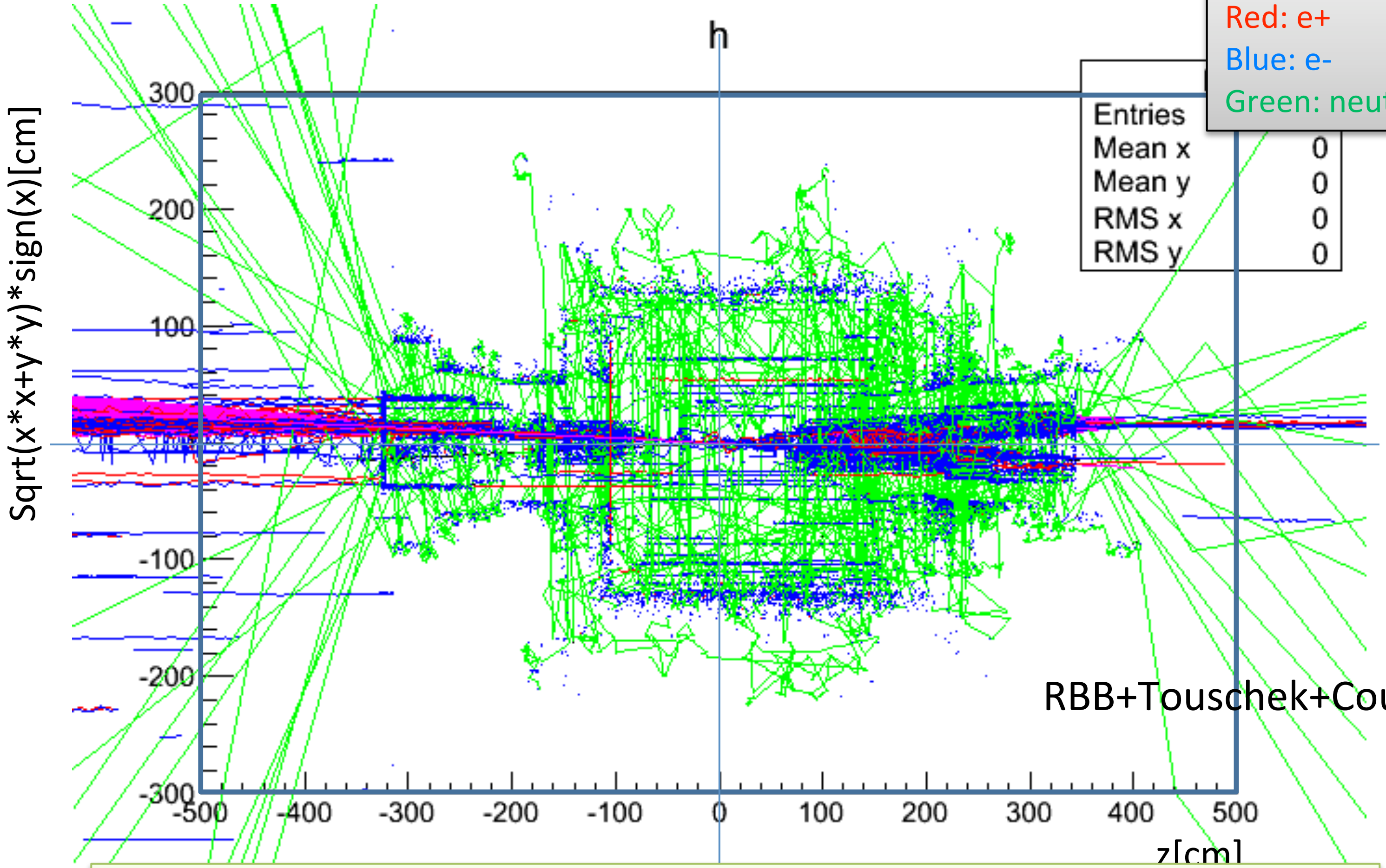


Elements outside detector (|s|>4m) are not yet implemented (bending magnets, concrete shield etc…)

Event display

Draw trajectories of particle with E>1MeV

Magenta: primary particle
Red: e+
Blue: e-
Green: neutron



RBB+Touschek+Coulomb

-True event signals are not hidden by fake background hits?

-Our detectors are not severely damaged by radiation?

Full simulation campaign

- 1st campaign in Dec. 2011
  - 0.9GHz Touschek LER / 2photon
- 2nd campaign in Feb. 2012 (for BPAC)
  - Latest Touschek/Beam-gas/Rad. Bhabha/ 2photon

- Results of 1st campaign
  - Neutron flux, radiation dose are OK for most of sub-detectors
- Preliminary results of 2nd campaign
  - PXD: OK (Touschek/2-photon dominates)
  - TOP: photo-cathode aging seems problematic
  - ARICH: OK
  - ECL: OK
  - Results from other detector are coming soon

Summary

- Touschek BG is effectively reduced by horizontal and vertical collimators
- Beam-gas Coulomb BG can be reduced by vertical collimators (but very sensitive to the collimator width)
- Small β_y collimation is essential to avoid beam instability
- Radiative Bhabha is dominant BG now
- 2-photon BG is confirmed to be safe
- No direct SR hits on Be part of beam pipe found
- Full-detector simulation is ongoing

To do

- Simulation on 3D solenoid magnetic field
- Secondary shower study from collimators
- Collimator R&D which can survive ~100GHz particle hits
- Background simulation “at day 1” or “during injection”
- Include beam-beam effect

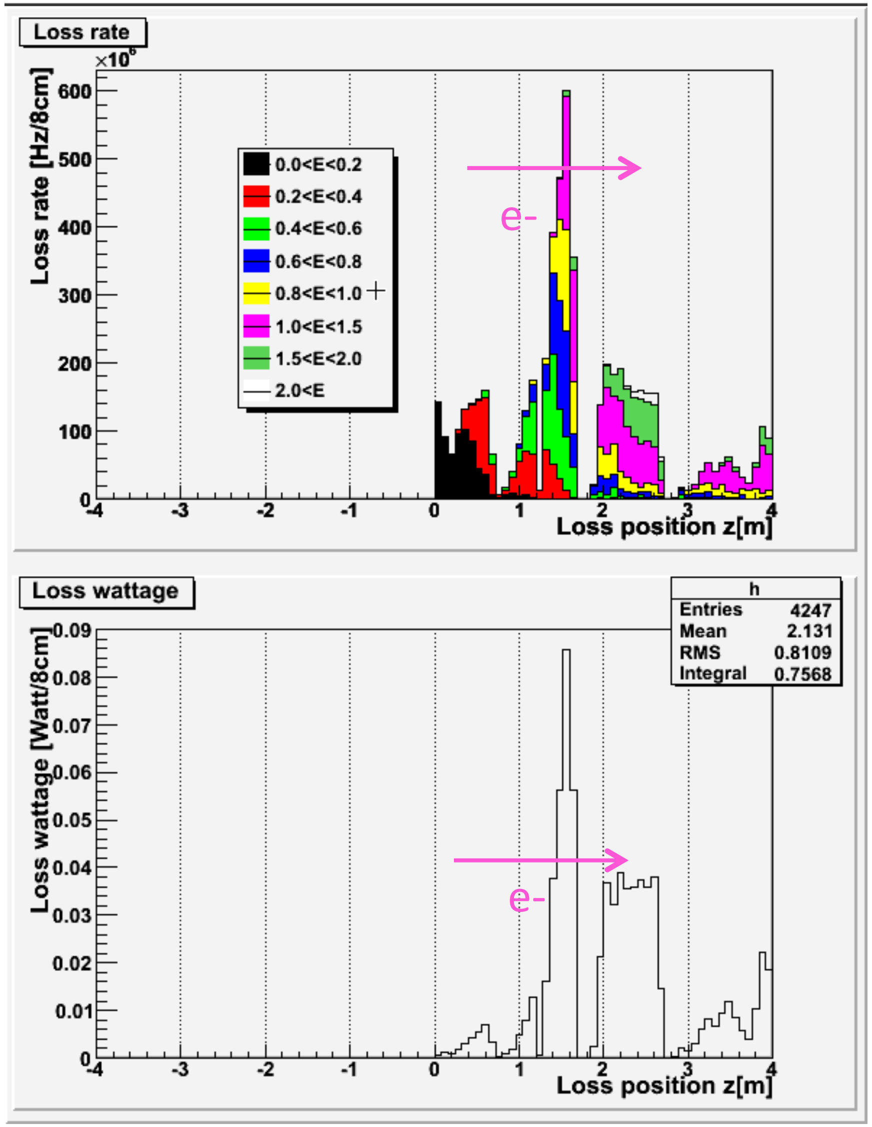
backup

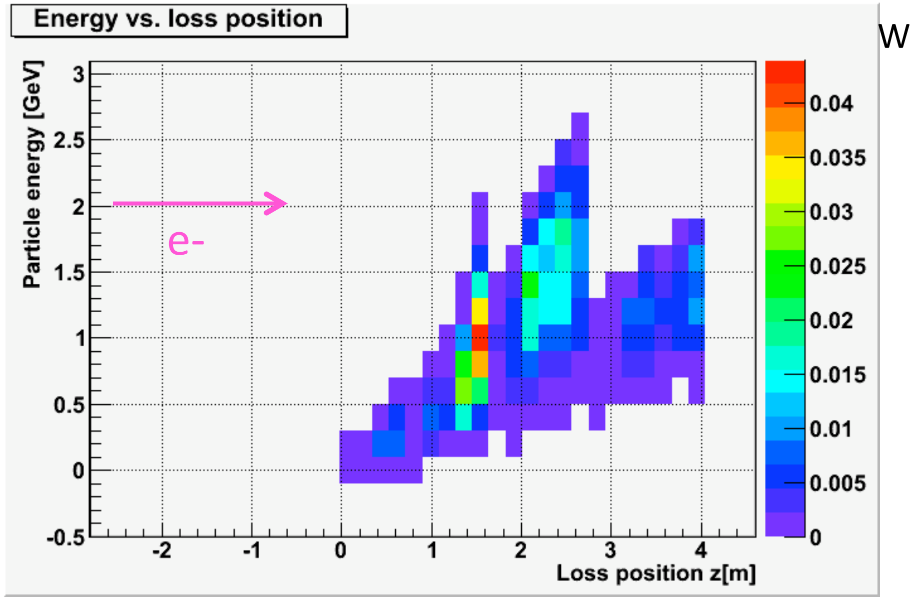
Y. Funakoshi

Radiative Bhabha background

- Spent e+/e- loss in downstream
  Dominant loss position is very far (~10m) from IP, but little fraction with large ΔE (still dangerous with Lx40) can be lost inside detector.
- Gamma emitted from IP
  They hit downstream (~10m) beam pipe/magnet and generate neutrons by giant dipole resonance. Neutron shielding inside tunnel will be increased

Radiative Bhabha HER





Within |z|<4m,

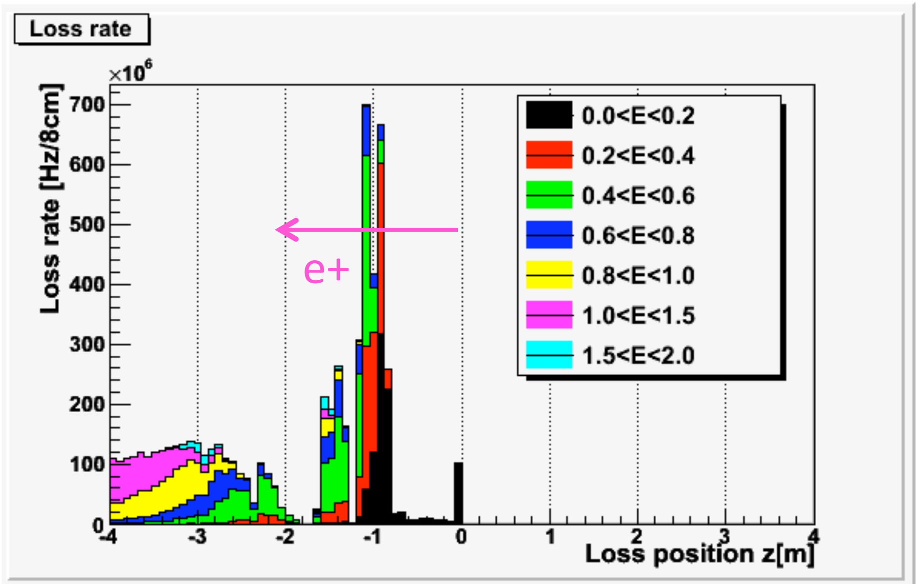
loss rate: 5.8 GHz(0~2GeV)

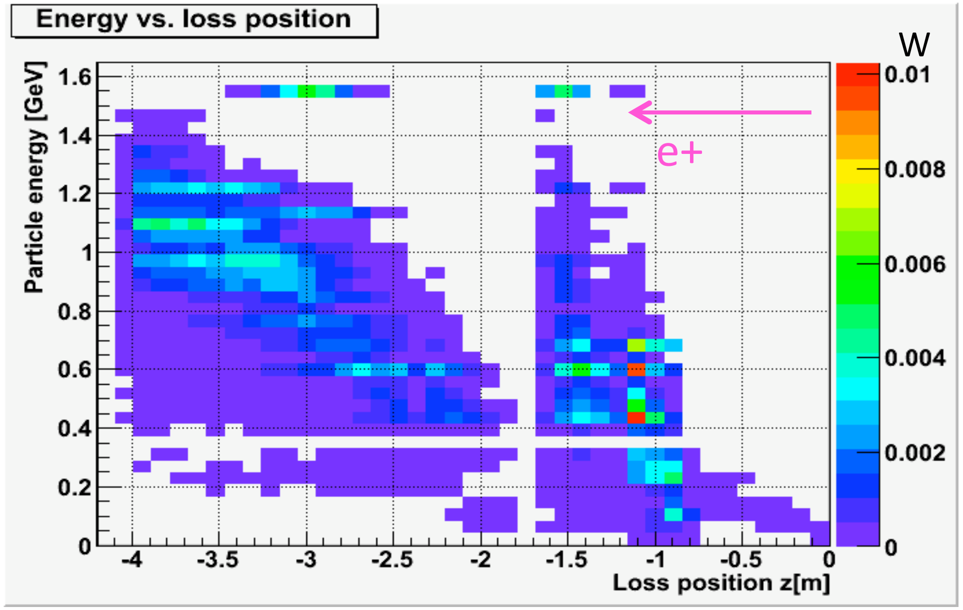
loss wattage: 0.76 W

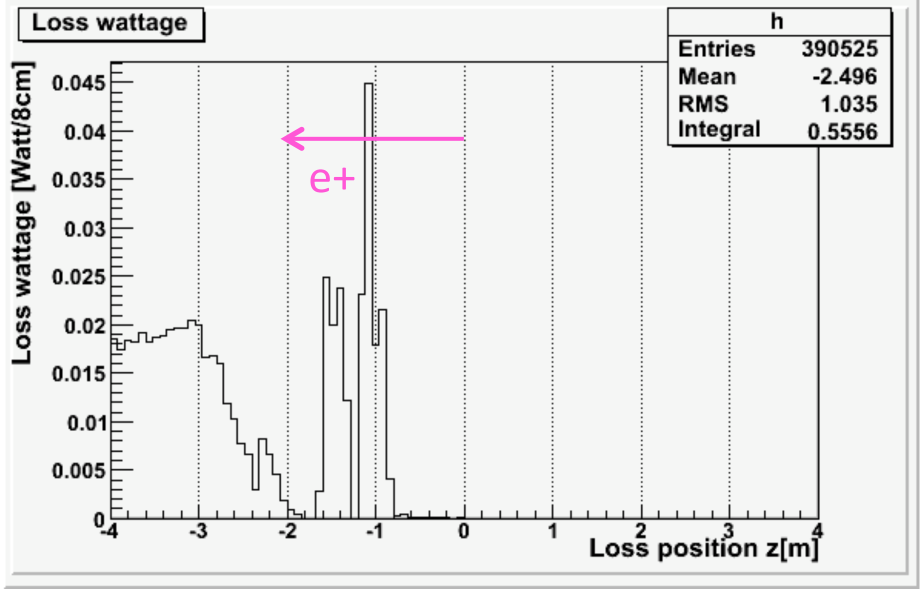
(Equivalent to 0.68GHz of 7GeV e-)

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

Radiative Bhabha LER







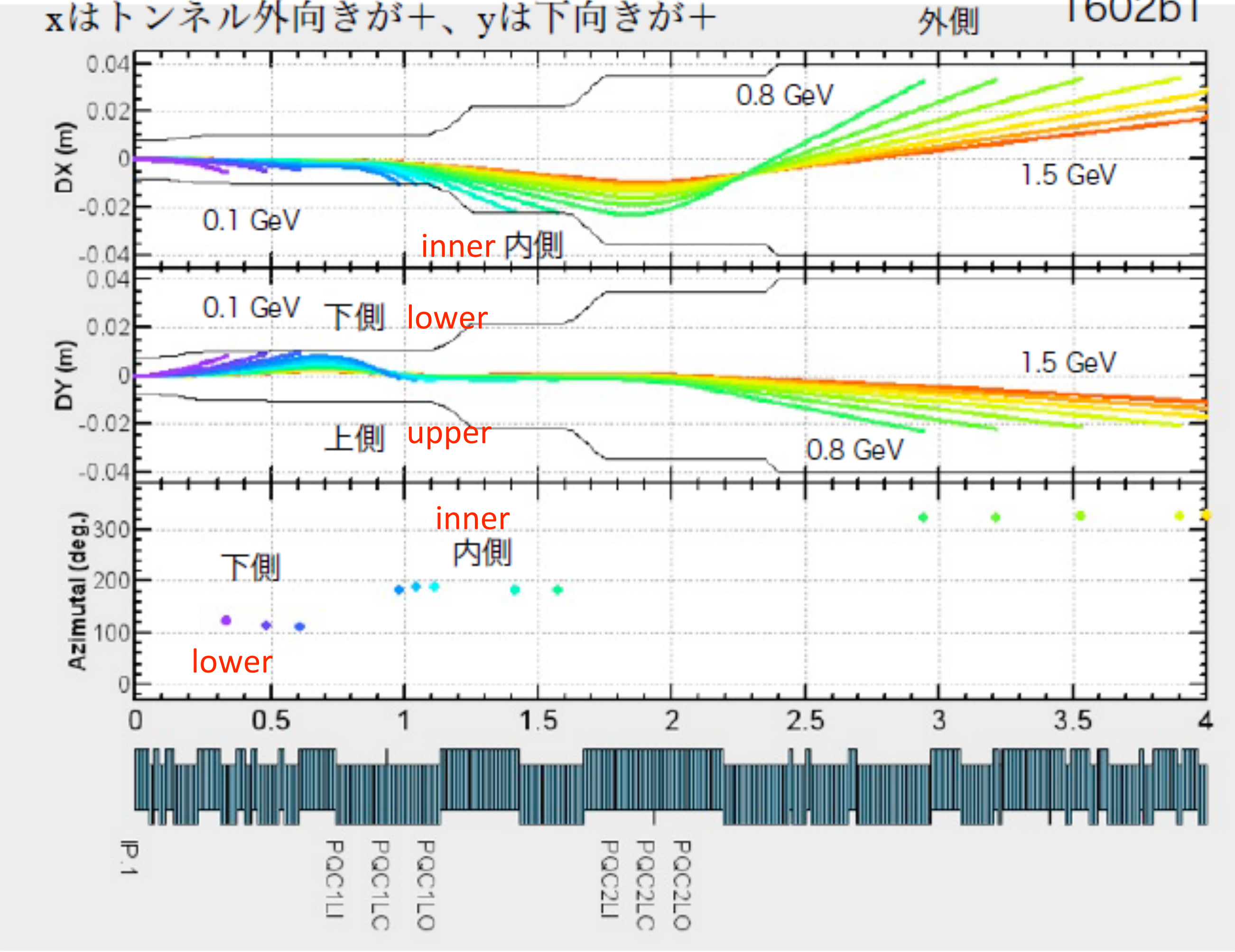
Within |z|<4m,
loss rate: 6.0 GHz(0~1.4GeV)
loss wattage: 0.55 W
(Equivalent to 0.86GHz of 4GeV e-)

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

LER

x : positive=ring outer, y: positive=downward

xはトンネル外向きが+、yは下向きが+



4

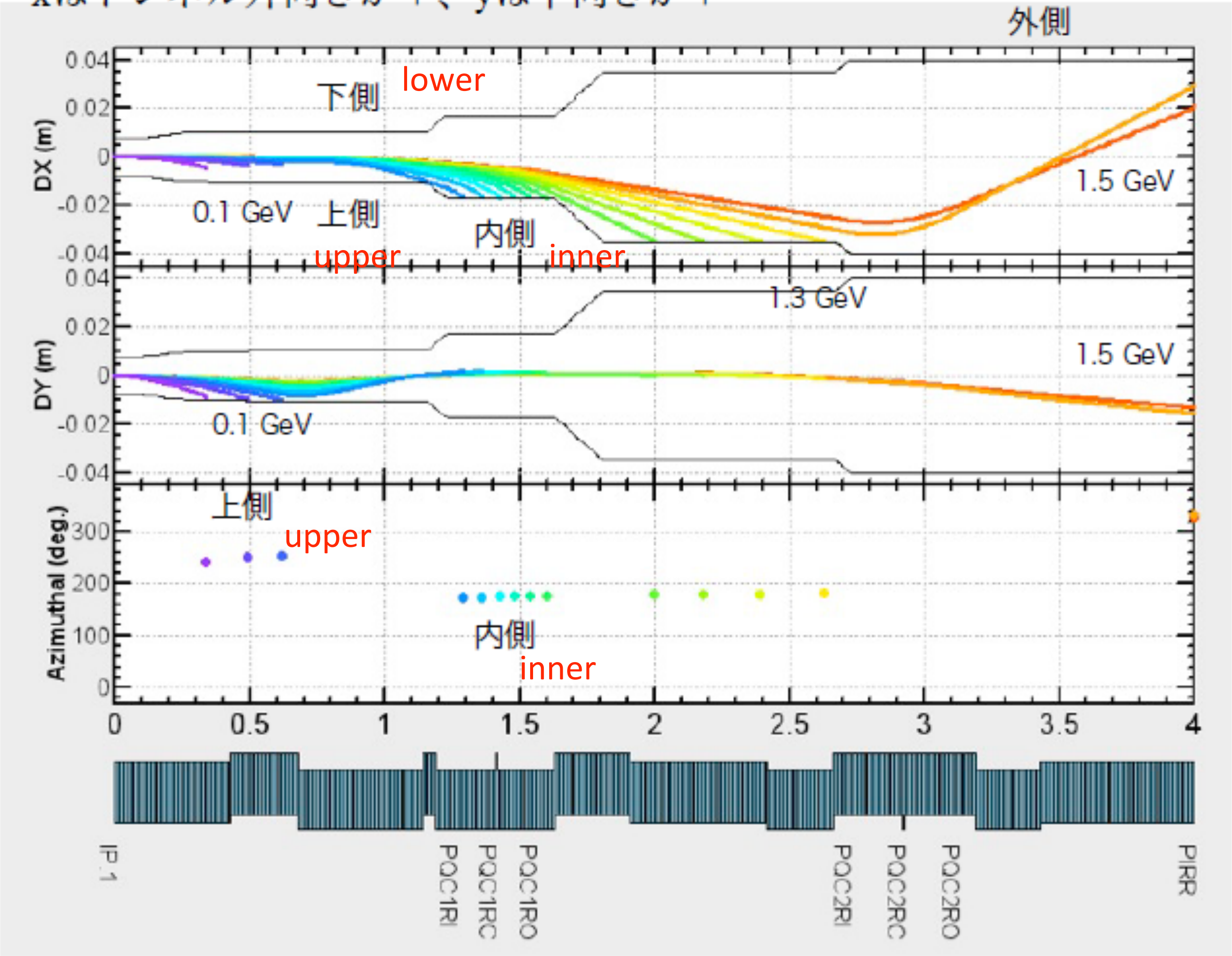
2011年10月26日水曜日

HER

x : positive=ring outer, y: positive=downward

xはトンネル外向きが+、yは下向きが+

5710c(ビームライン裏返し)



5

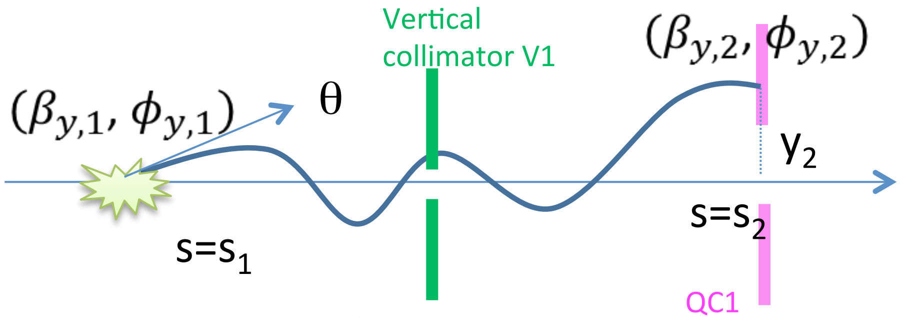
2011年10月26日水曜日

How to reduce RBB background?

- Shield leak field
  - Leak field (dipole component) from LER QC1 into HER beam pipe is difficult to shield. If we shield dipole component, Filed inside LER is affected and LER dynamic aperture is degraded.
- Add Tungsten shield around QCS?
  - Space btw QCS and CDC is very limited and many cables and pipes should sit there. Need further investigation for the space left for the shield (up to 2cm or less).

Nakayama

Element-by-element simulation



θ: Scattering angle

$$y_2 = \theta \sqrt{\beta_{y,1} \cdot \beta_{y,2}} \, \sin(\phi_{y,2} - \phi_{y,1})$$

θ_c: critical angle

$$\theta_c(s_1 \to \mathrm{QC1}) = r_{\mathrm{QC1}} / \sqrt{\beta_{y,s_1} \cdot \beta_{y,\mathrm{QC1}}} \, / \sin(\Delta\phi_{s_1 \to \mathrm{QC1}})$$

$$\theta_c(s_1 \to V_1) = r_{V_1} / \sqrt{\beta_{y,s_1} \cdot \beta_{y,V_1}} \, / \sin(\Delta\phi_{s_1 \to V_1})$$

Taking into causality, hit rate on QC1 from element s_1 can be calculated by

$$\frac{I_{beam} L_{s_1} n_G}{e} \langle \sigma_R \rangle = \frac{I_{beam} L_{s_1} n_G}{e} \cdot \frac{4\pi \sum Z^2 r_e^2}{\gamma^2} \Delta\left(1/\theta_c^2\right)$$

$$\Delta(1/\theta_c^2) = 1/\theta_c(s_1 \to \mathrm{QC1})^2 - 1/\theta_c(s_1 \to V_1)^2$$

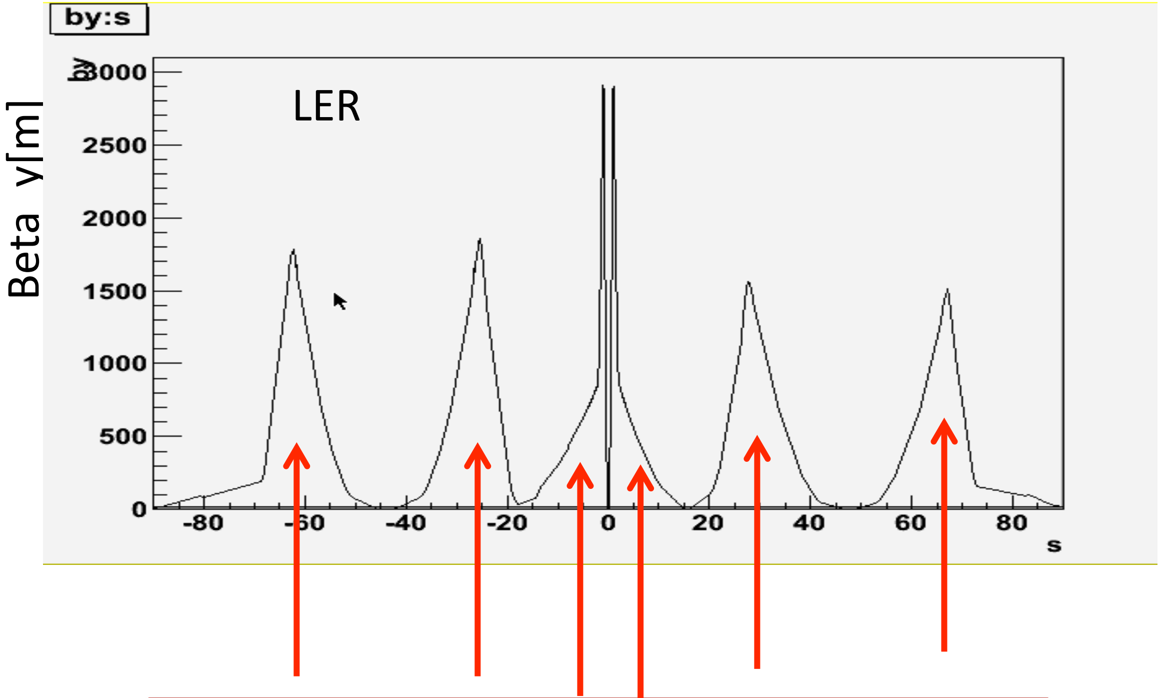
Sum up for all element s_1 over the ring to obtain total hit rate on QC1.

Multi-turn loss is also simulated in similar way ($\Delta\phi$+= N_{turn}*$\Delta\phi_{turn}$), also taking in account the causality

Beta_y and vacuum level

$$\tau_R \propto \left\langle \frac{\beta_y}{P} \right\rangle \cdot \beta_{y,\mathrm{QC1}} / r_{\mathrm{QC1}}{}^2$$

- Vacuum level at large beta_y determines Coulomb lifetime



s	βy	ν_y	
-82m	-	-1.75	V1
-62m	1783m	-1.25	
-25m	1854m	-0.75	
-1m	2905m	-0.25	QC1
+1m	2902m	0.25	
+28m	1564m	0.75	
+67m	1513m	1.25	

Very important to achieve good vacuum level in these regions

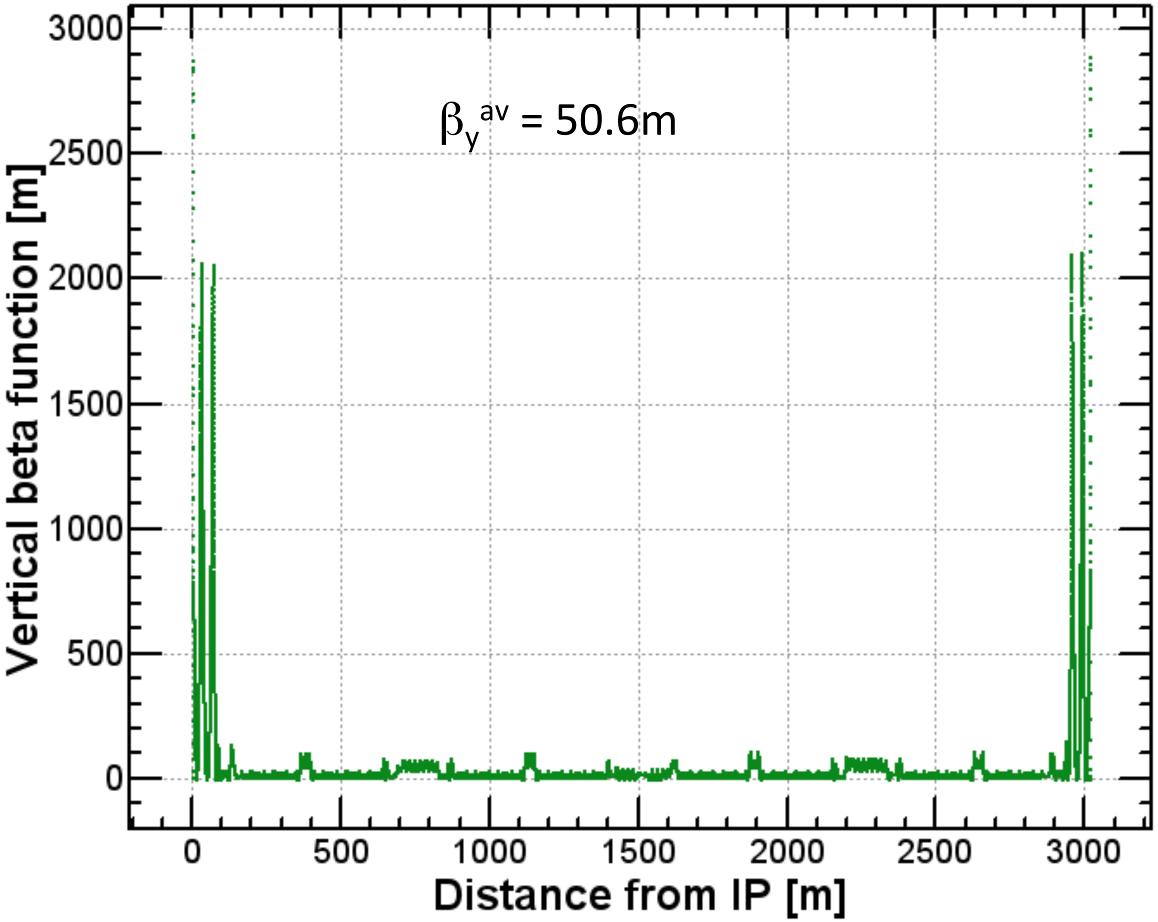
ν_y(1 turn)=44.57

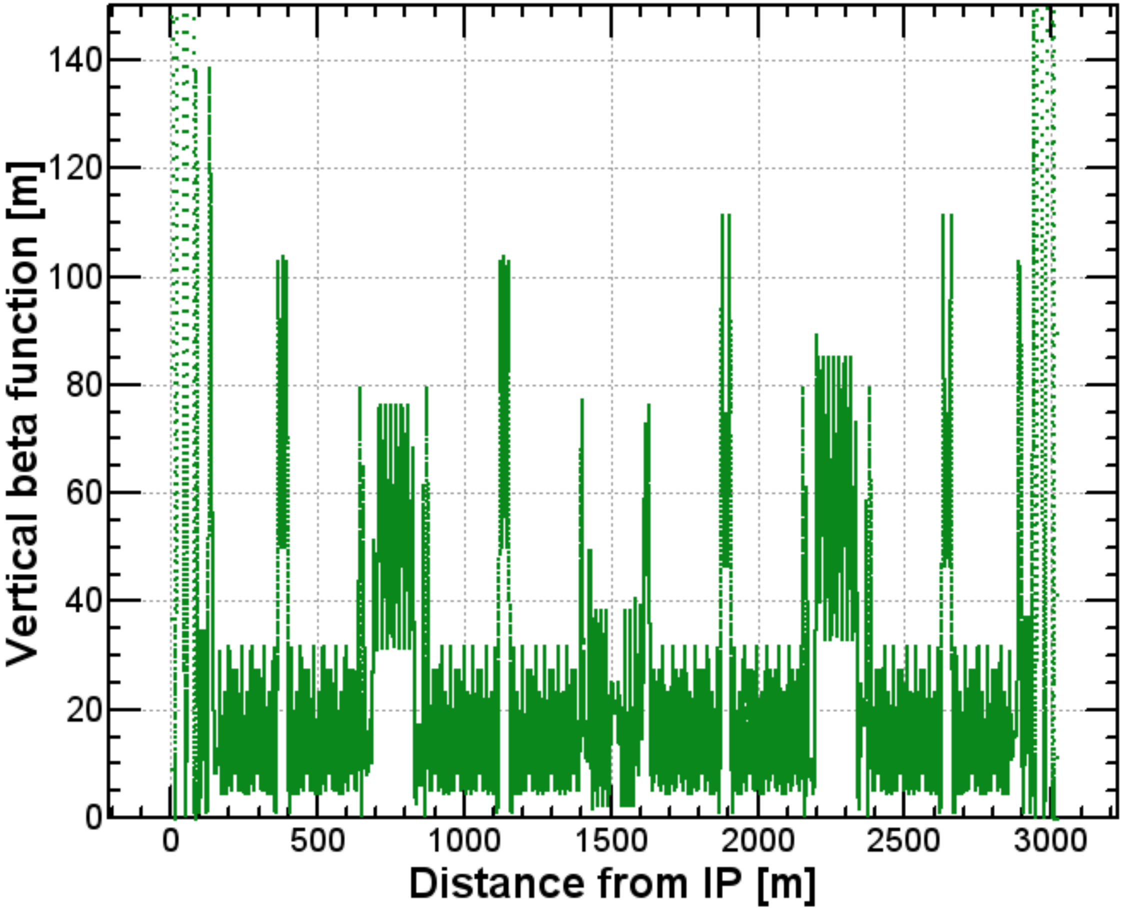
Turn-by-turn loss

ler1604, V1=LLB3R downstream, d_V1=2.6mm

#turn	Loss @ V1	Loss @ QC1
1	32.760	0.090
2	34.220	0.000
3	36.100	0.000
4	17.450	0.000
5	3.720	0.000
6	2.300	0.000
7	0.660	0.000
8	0.040	0.000
9	0.030	0.000
10	0.050	0.000
11	0.320	0.000
12	0.330	0.000
13	0.060	0.000
14	0.060	0.000
15	0.030	0.000
16	0.020	0.000
17	0.030	0.000
18	0.750	0.000
19	0.700	0.000
20	0.030	0.000
21	0.040	0.000
22	0.020	0.000
23	0.010	0.000
24	0.020	0.000
25	0.470	0.000
26	0.410	0.000
27	0.010	0.000
28	0.020	0.000
29	0.010	0.000
30	0.010	0.000
31	0.010	0.000
32	0.140	0.000
33	0.120	0.000
34	0.010	0.000
35	0.010	0.000
36	0.010	0.000
37	0.000	0.000
38	0.010	0.000
39	0.010	0.000
40	0.010	0.000

No loss at nturn>40


β_y^{av} = 50.6m
Vertical beta function [m]
3000
2500
2000
1500
1000
500
0
0
500
1000
1500
2000
2500
3000
Distance from IP [m]



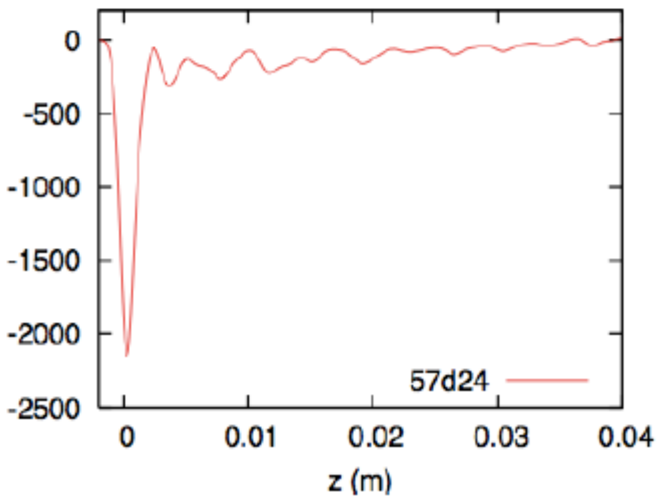
Vertical beta function [m]
0
20
40
60
80
100
120
140
0
500
1000
1500
2000
2500
3000
Distance from IP [m]

Confirmation of TMC conditions with realistic model

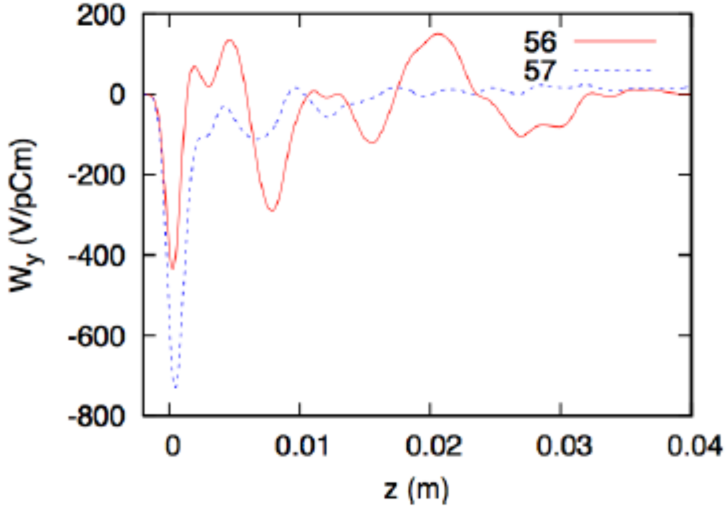
K. Ohmi (KEKB)

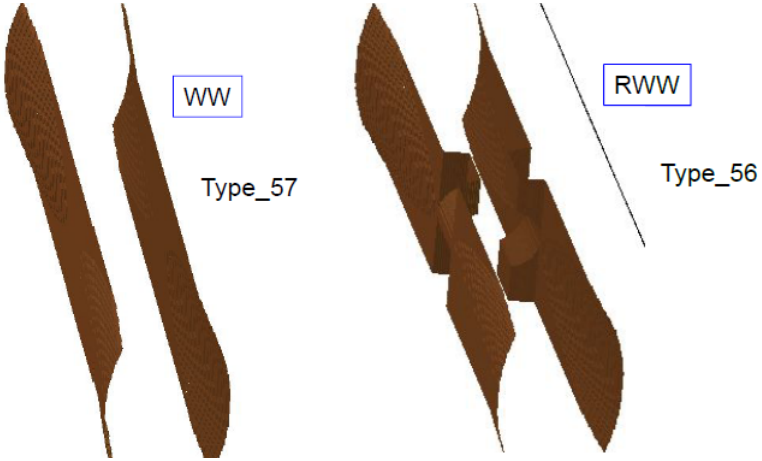
Impedance of realistic collimator

d=2.4mm mask for LER



d=5mm mask for HER





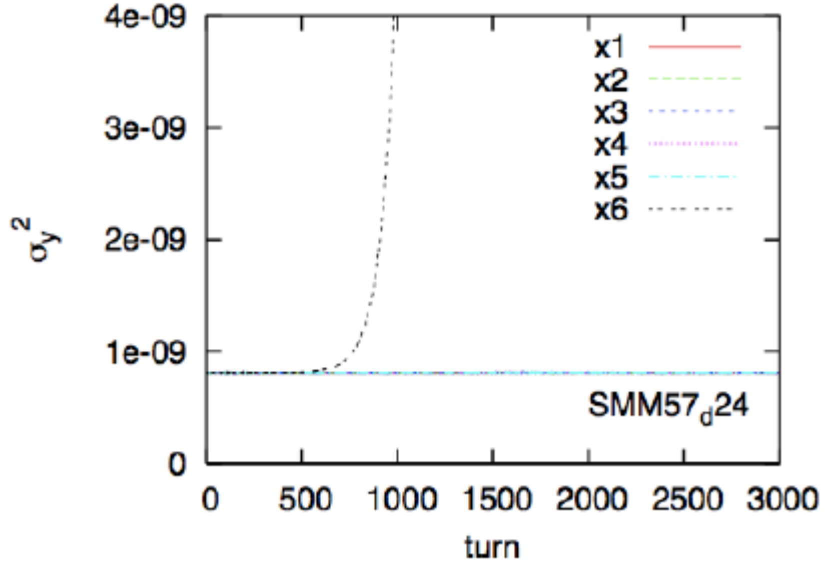
Dedicated collimator design for small impedance

- Round-shape of collimator head
- d=5mm(H), d=2mm(V)

Y. Suetsugu
(KEKB)

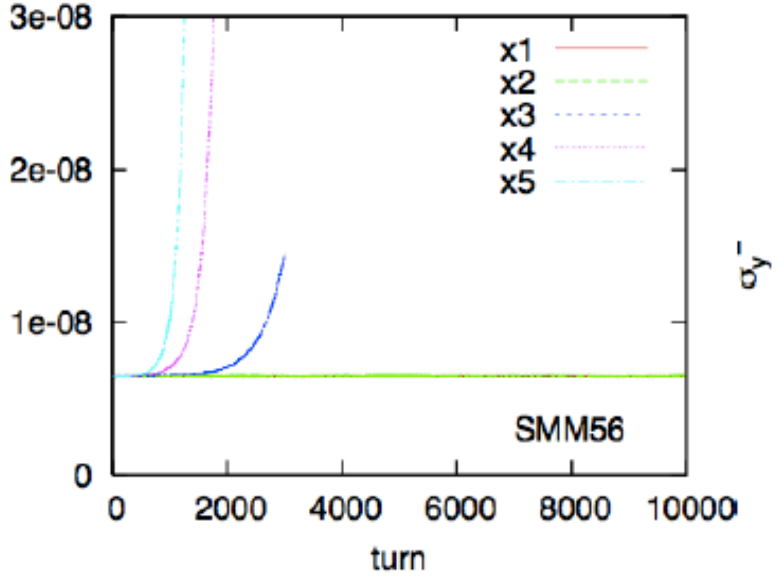
I_{th} calculated by tracking simulation

LER σ_z = 6mm



I_{th}=1.44mAx5~6=7.2~8.6mA

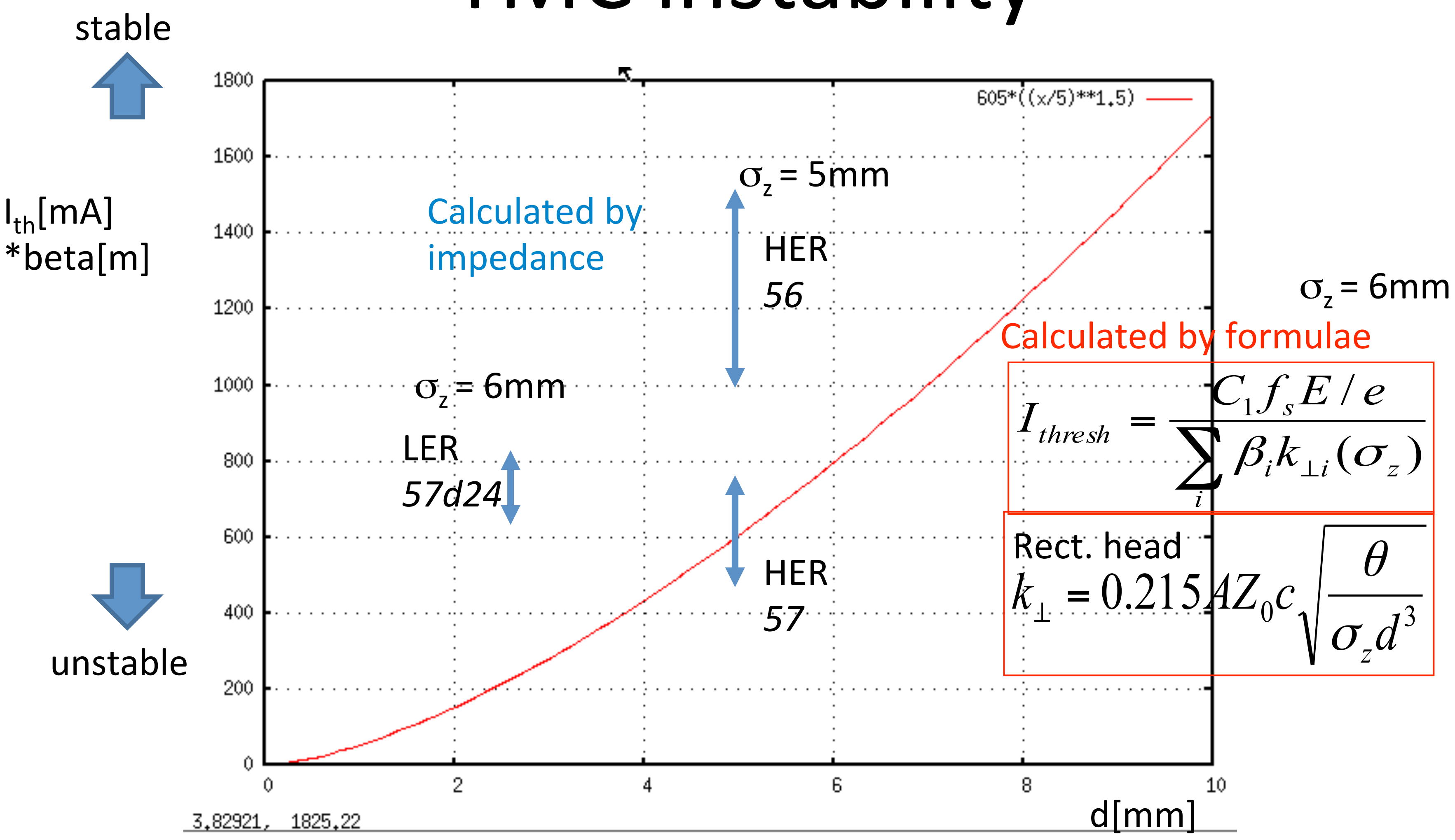
HER σ_z = 5mm



I_{th}=1.04mAx2~3=2~3mA

TMC instability caused by the LER/HER vertical collimators are tolerable.

TMC instability



Calculated by formulae

$$I_{thresh} = \frac{C_1 f_s E / e}{\sum_i \beta_i k_{\perp i}(\sigma_z)}$$

Rect. head

$$k_\perp = 0.215 A Z_0 c \sqrt{\frac{\theta}{\sigma_z d^3}}$$

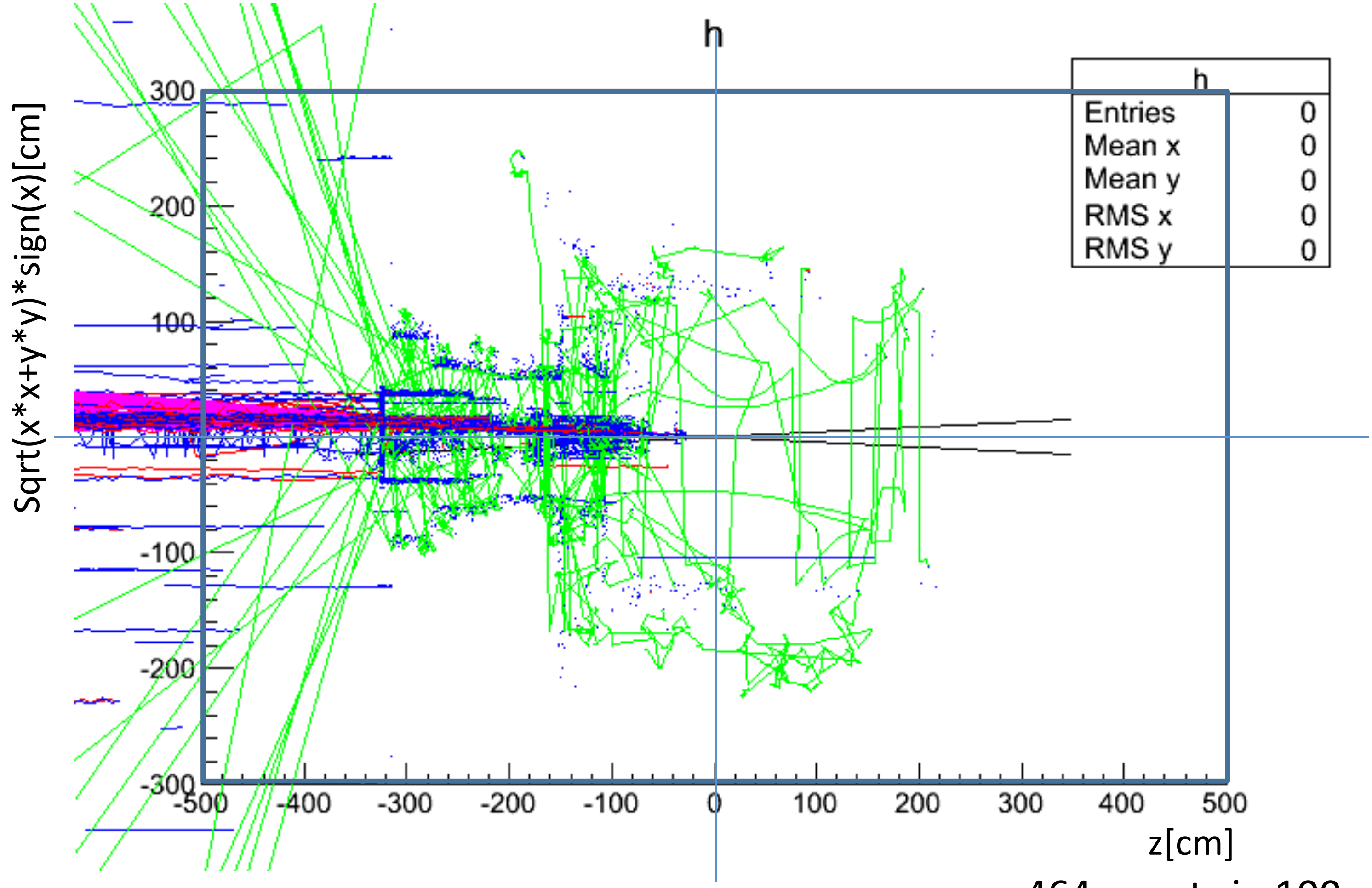
Beam-gas summary

- Coulomb >> bremsstrahlung
- Larger <β_y> and narrower IR aperture make Coulomb BG much severer at SuperKEKB than at KEKB
- Vertical collimators , placed at small beta_y, can reduce beam-gas BG down to ~0.1GHz for LER/HER.
- Beam instability for such collimators is confirmed to be tolerable, performing tracking simulation with realistic collimator shape
- Vacuum level at large beta_y affects beam-gas lifetime.
- Simulation using "SAD" is in preparation
- R&D ongoing for collimator which can resist ~100GHz loss

Rad. Bhabha LER

Magenta: primary particle
Red: e+
Blue: e-
Yellow: gamma
Green: neutron

Show particles with E>1MeV

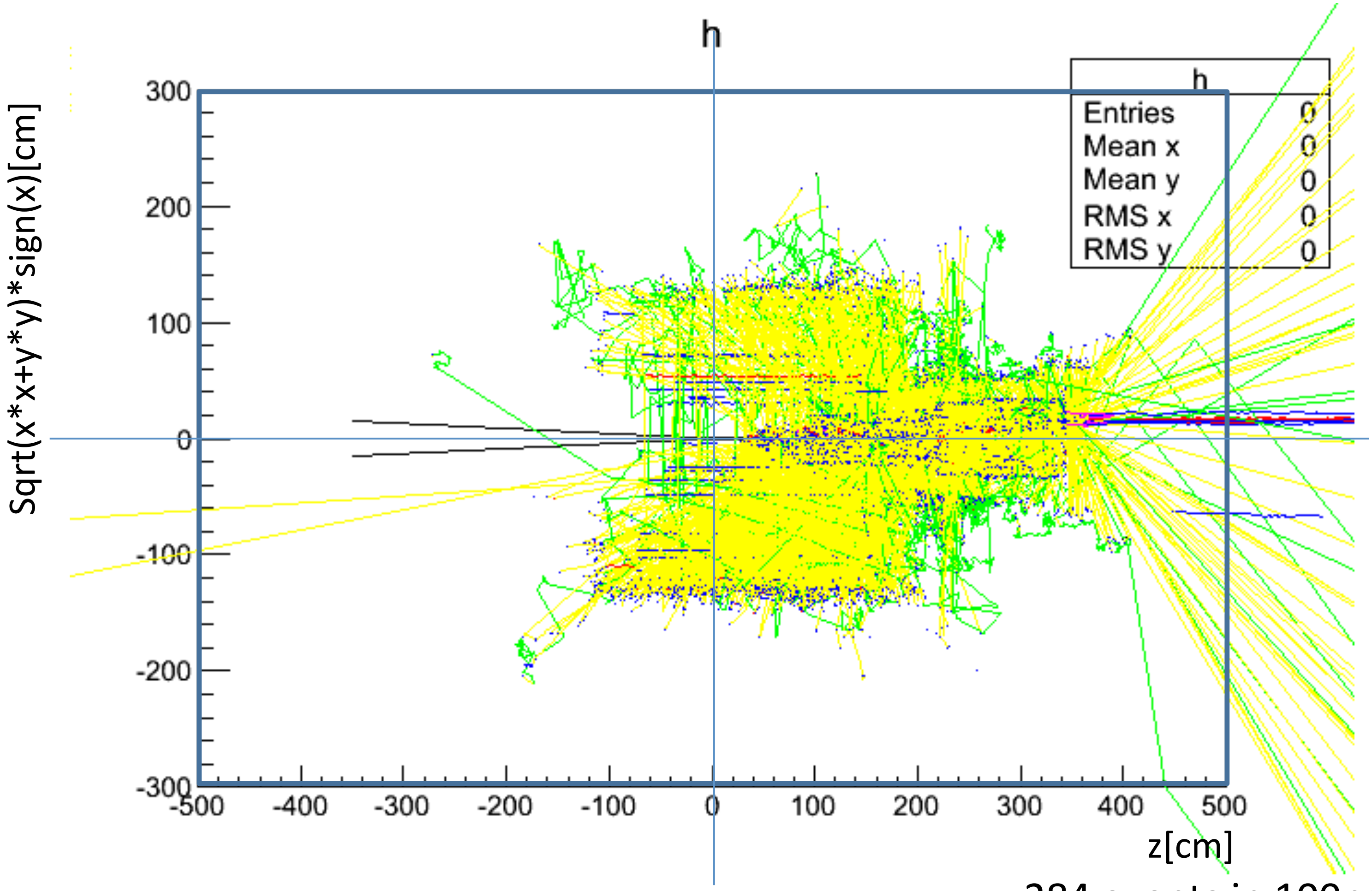


464 events in 100ns

Rad. Bhabha HER

Magenta: primary particle
Red: e+
Blue: e-
Yellow: gamma
Green: neutron

Show particles with E>1MeV

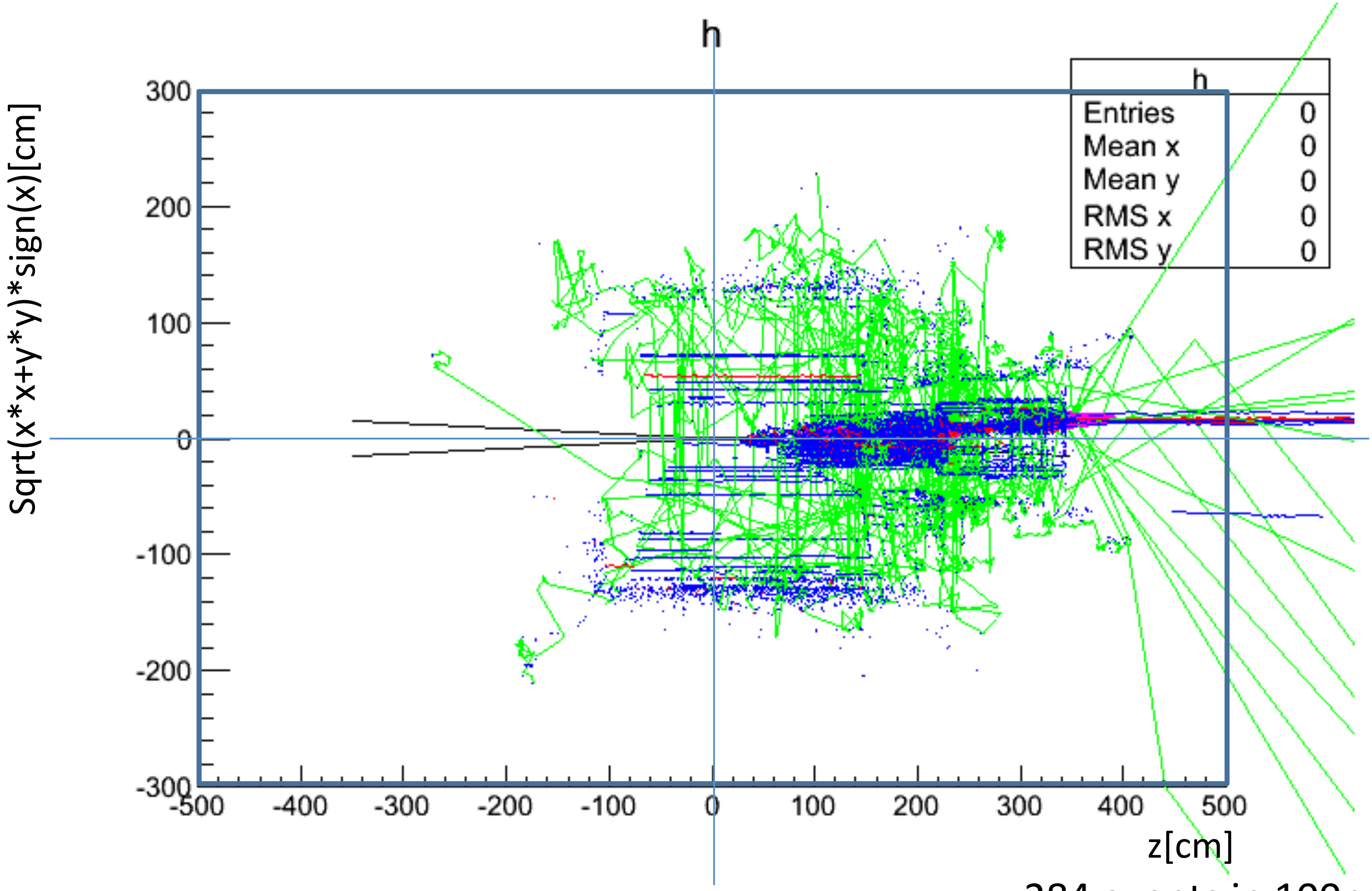


284 events in 100ns

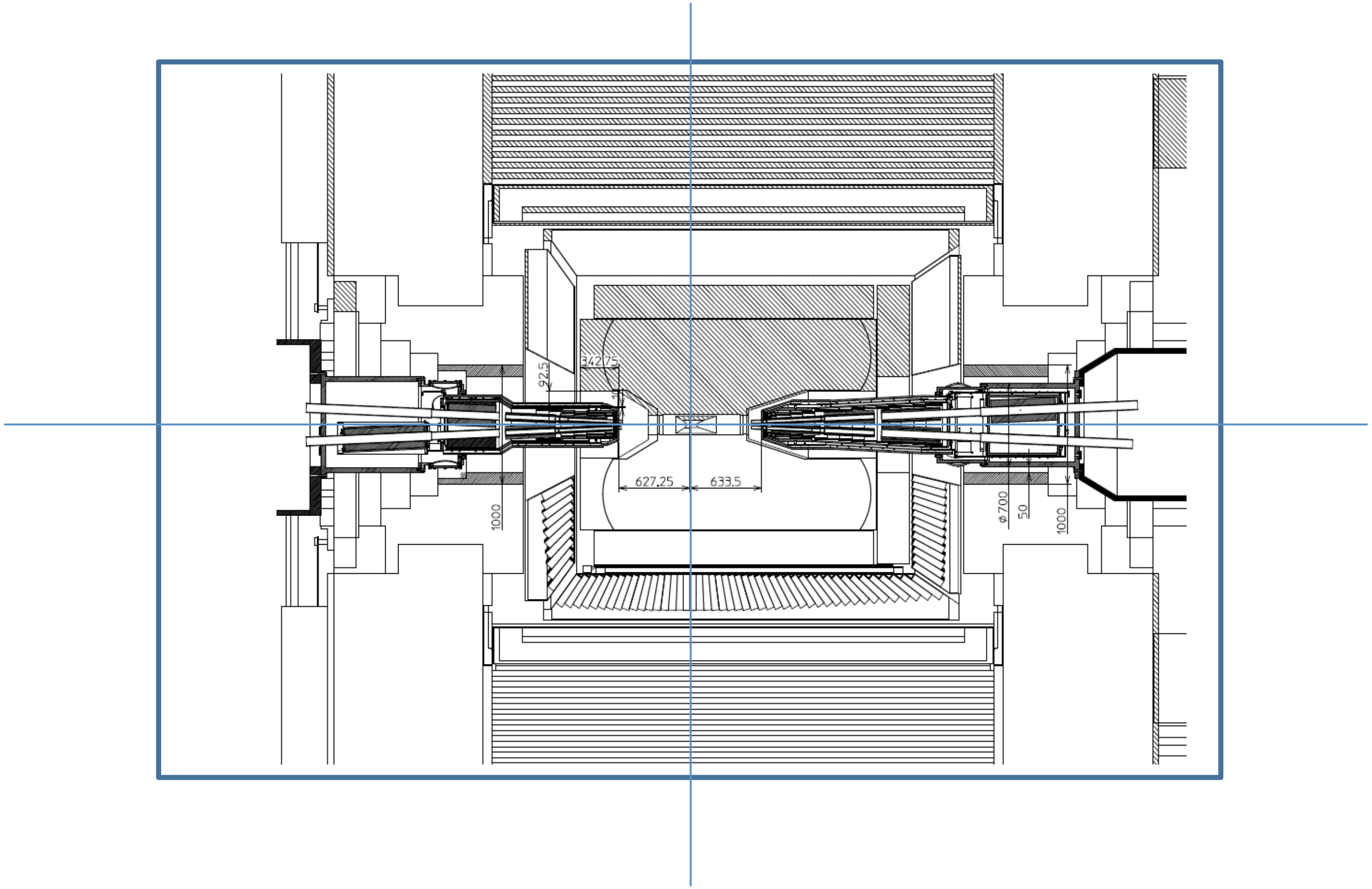
Rad. Bhabha HER

Magenta: primary particle
Red: e+
Blue: e-
Yellow: gamma
Green: neutron

Show particles with E>1MeV

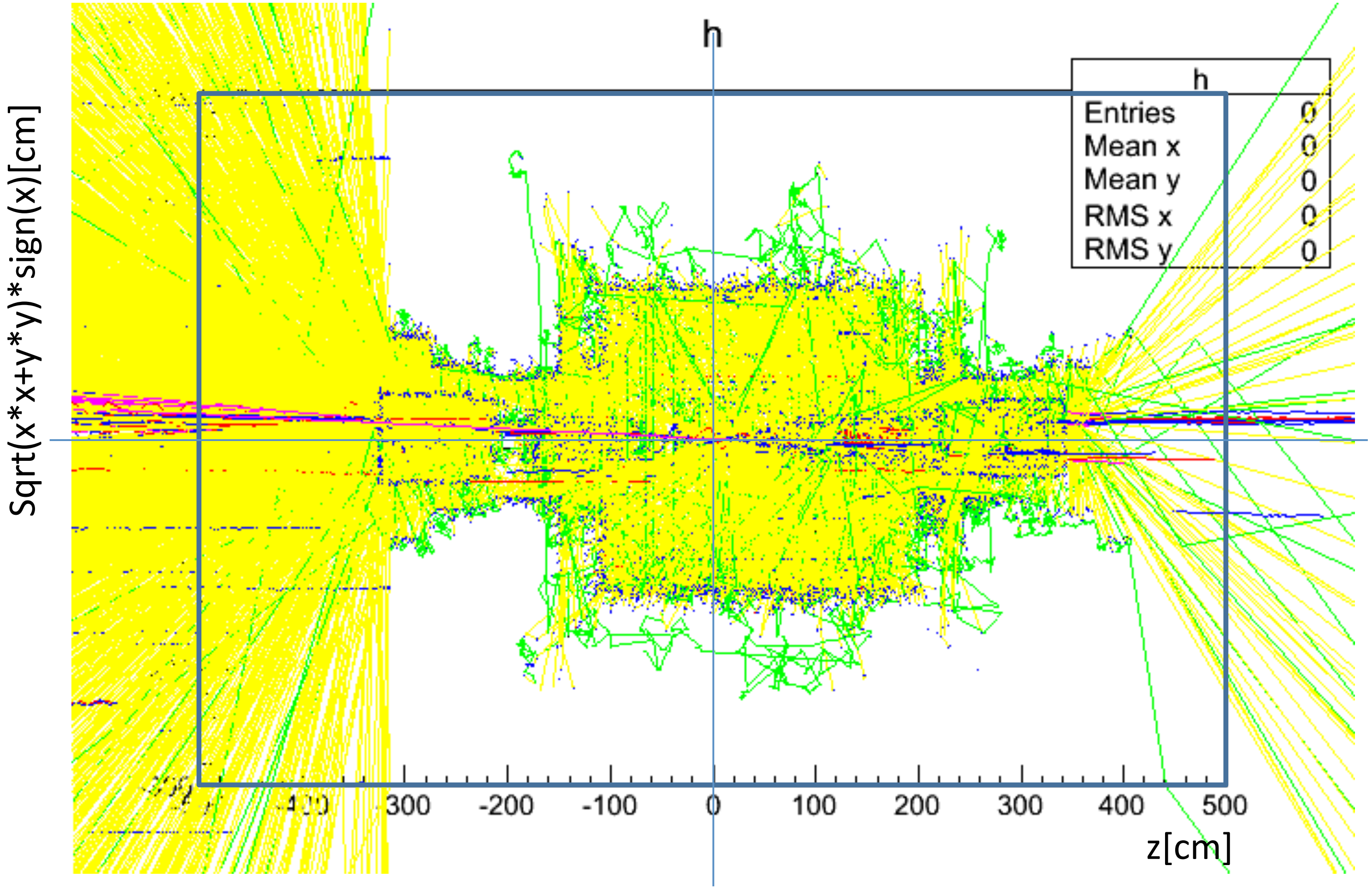


284 events in 100ns


342.75
92.5
627.25
633.5
1000
ø700
50
1000

Total (w/o SR, 2-photon)

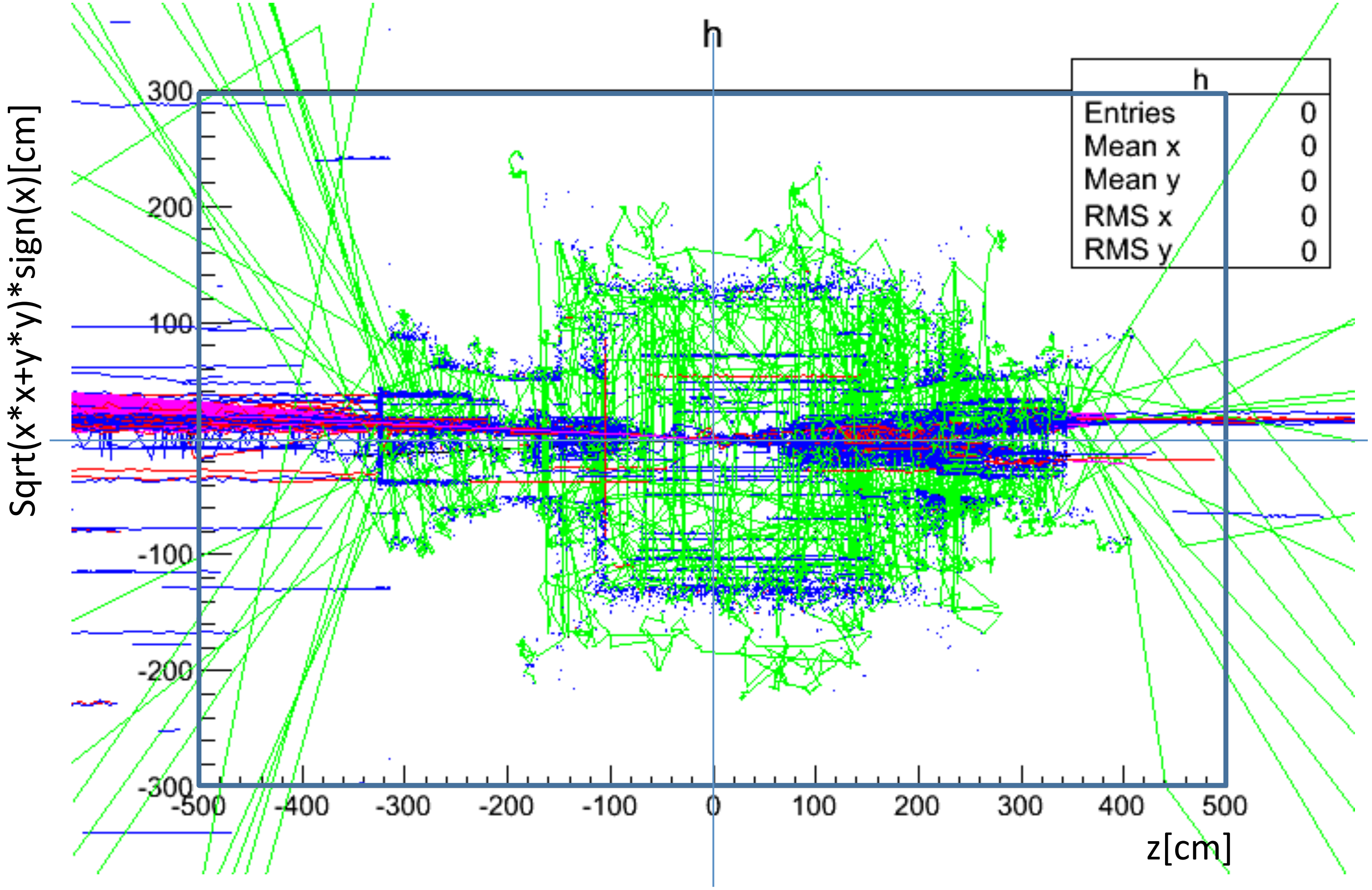
Show particles with E>1MeV



in 100ns

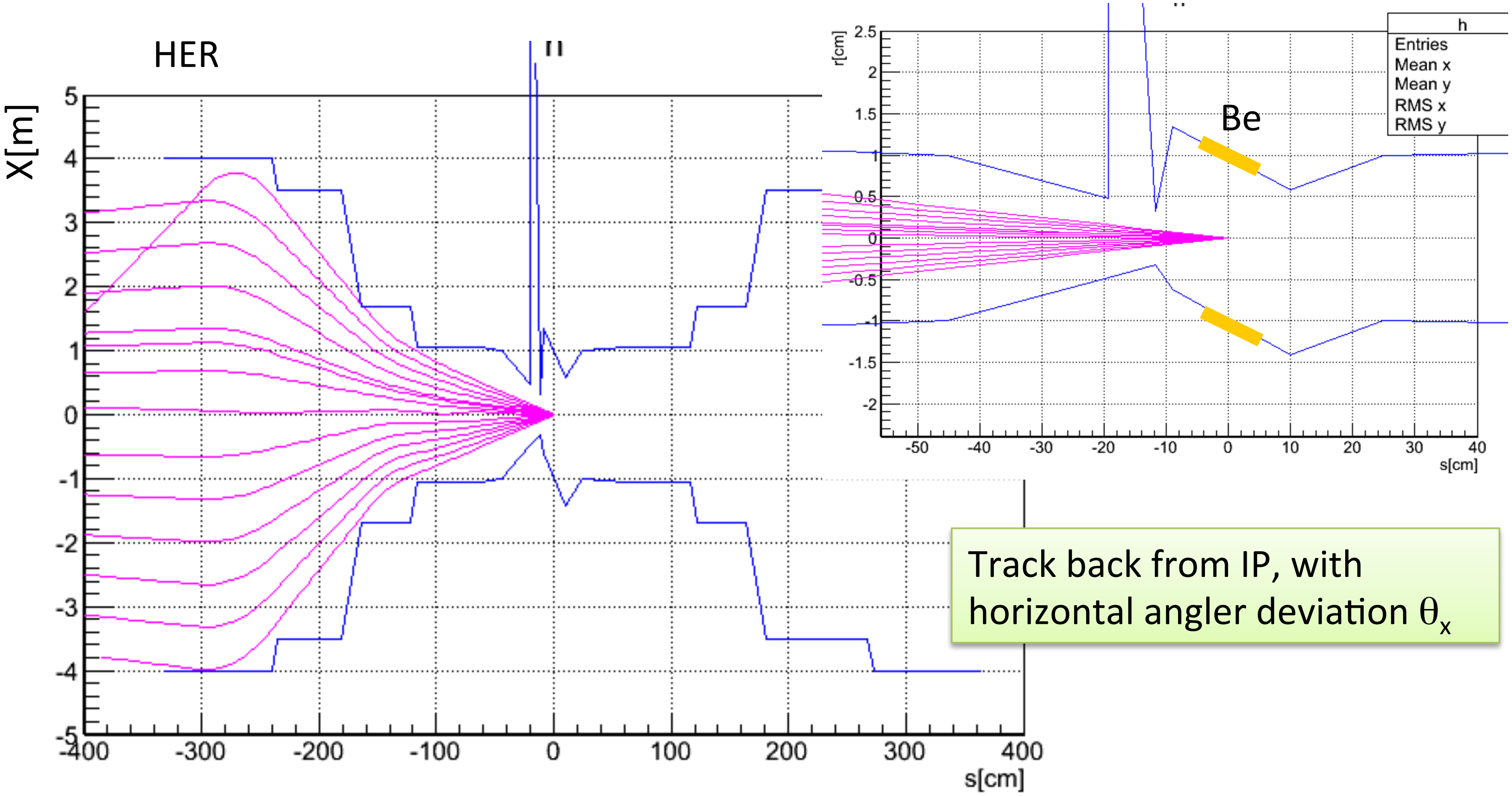
Total (w/o SR, 2-photon)

Show particles with E>1MeV



in 100ns

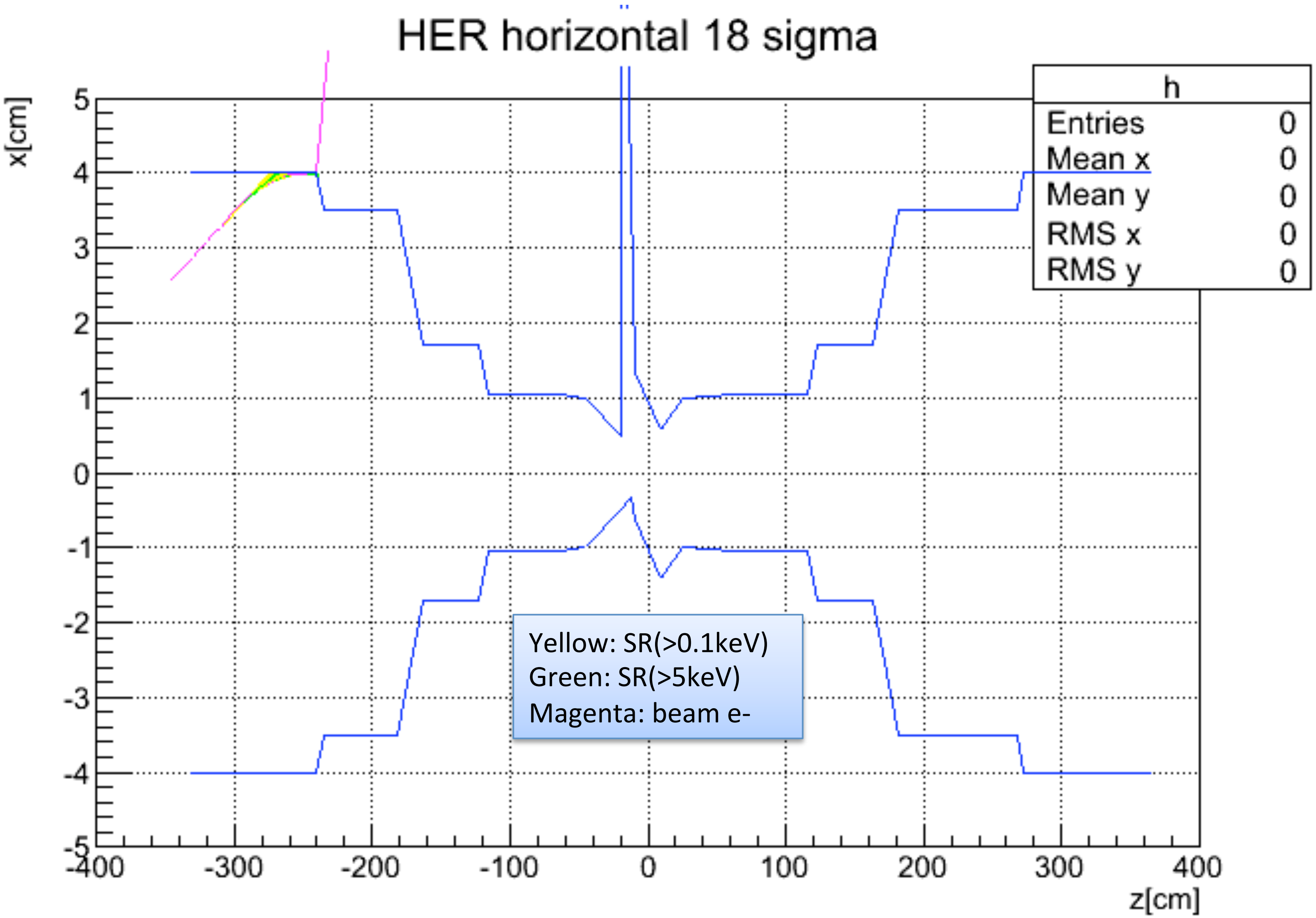
Orbit deviation



Track back from IP, with horizontal angler deviation θ_x

Orbit entering IP with θ_x/σ'^*_x = 0, +-3,+-6, +-9, +-12, +-15, +-18

σ'^*_x= 0.45mrad

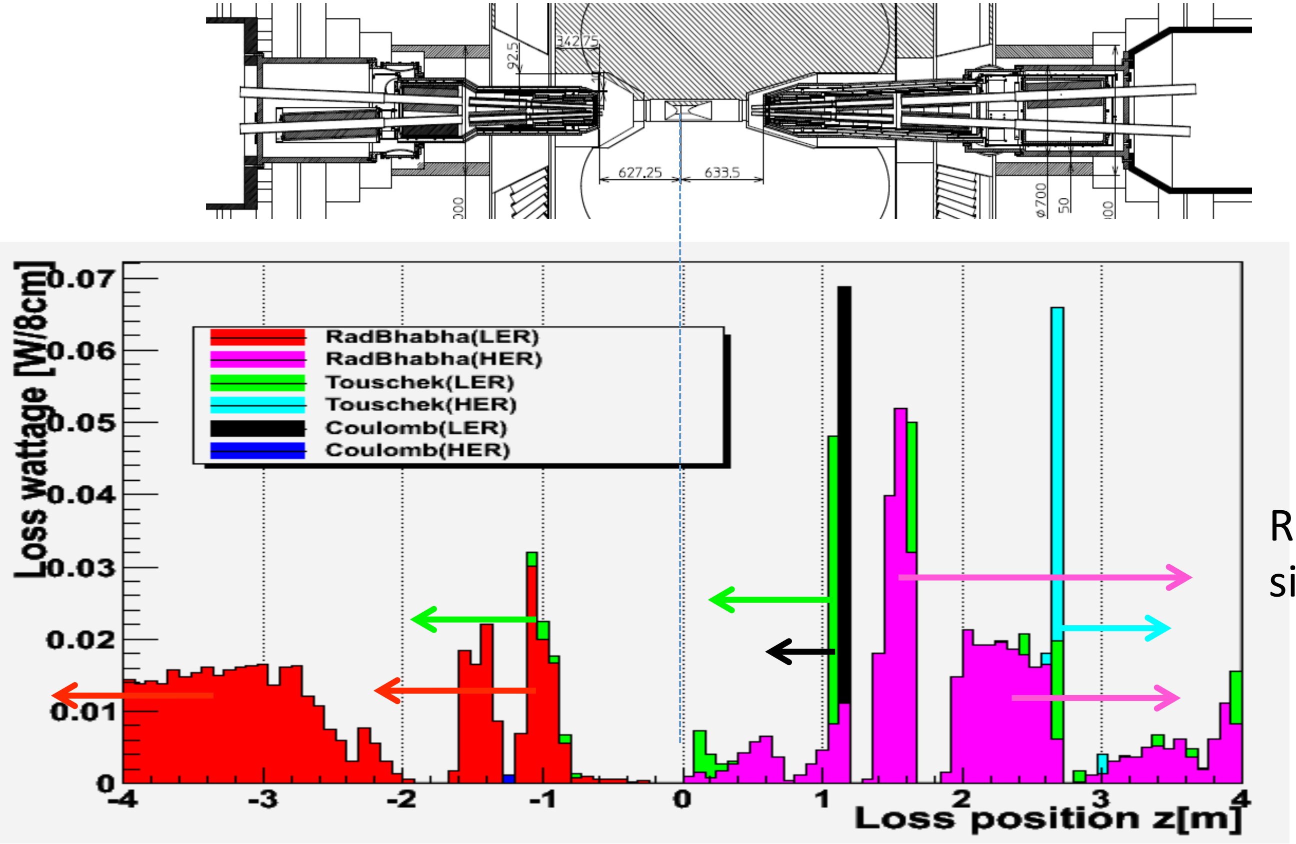


Yellow: SR(>0.1keV)
Green: SR(>5keV)
Magenta: beam e-

Ver. 2012.2.2

Total BG (for full simulation campaign)

L-side



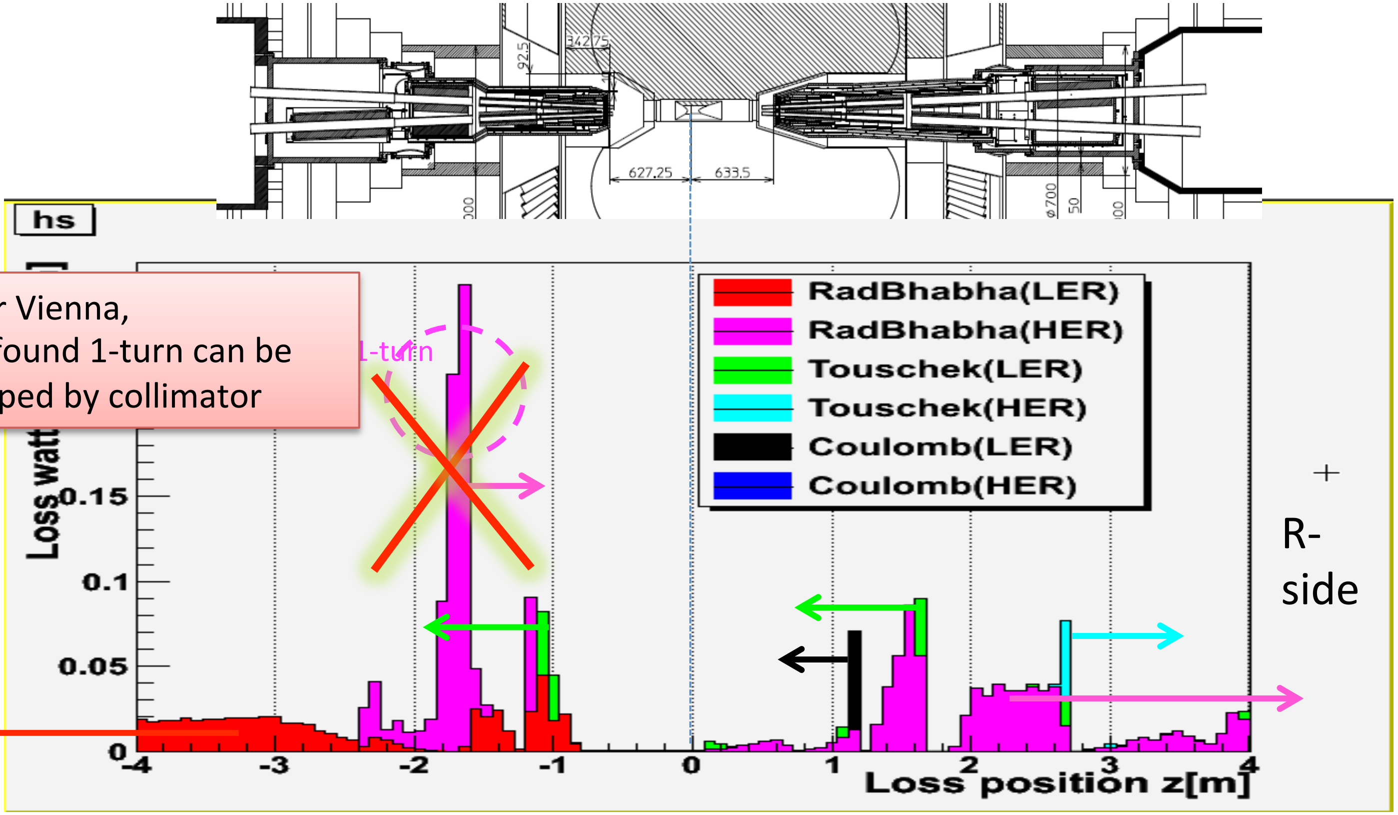
R-side

	LER (4GeV e+)	HER (7GeV e-)
Rad. Bhabha	0.45 W (eff. 0.7GHz)	0.44W (eff. 0.40GHz)
Touschek	0.10 W (0.16GHz)	0.05 W (0.04GHz)
Coulomb	0.06 W (0.09GHz)	0.001W (0.001GHz)

1GeV ,1GHz
= 0.16W

Ver. 2012.2.9

Total BG (shown at Vienna)



After Vienna,
We found 1-turn can be stopped by collimator

L-side

R-side

	LER (4GeV e+)	HER (7GeV e-)
Rad. Bhabha	0.55 W (eff. 0.9GHz)	~~1.60W (eff. 1.4GHz)~~ 0.75W(eff.0.68GHz)
Touschek	0.14 W (0.22GHz)	0.10 W (0.09GHz)
Coulomb	0.06 W (0.09GHz)	0.001W (0.001GHz)

1GeV ,1GHz
= 0.16W