Evaluation of Detector Background

2009/2/10

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for the s-Belle MDI group
(KEK / Tohoku Univ. / Univ. of Tokyo)

Introduction

Super-KEKB → High luminosity experiment

Remarkable features of Super-KEKB

- **High beam current**
- **Strong dynamic-beam effect**

  … squeezes the beam at IP and increases the emittance

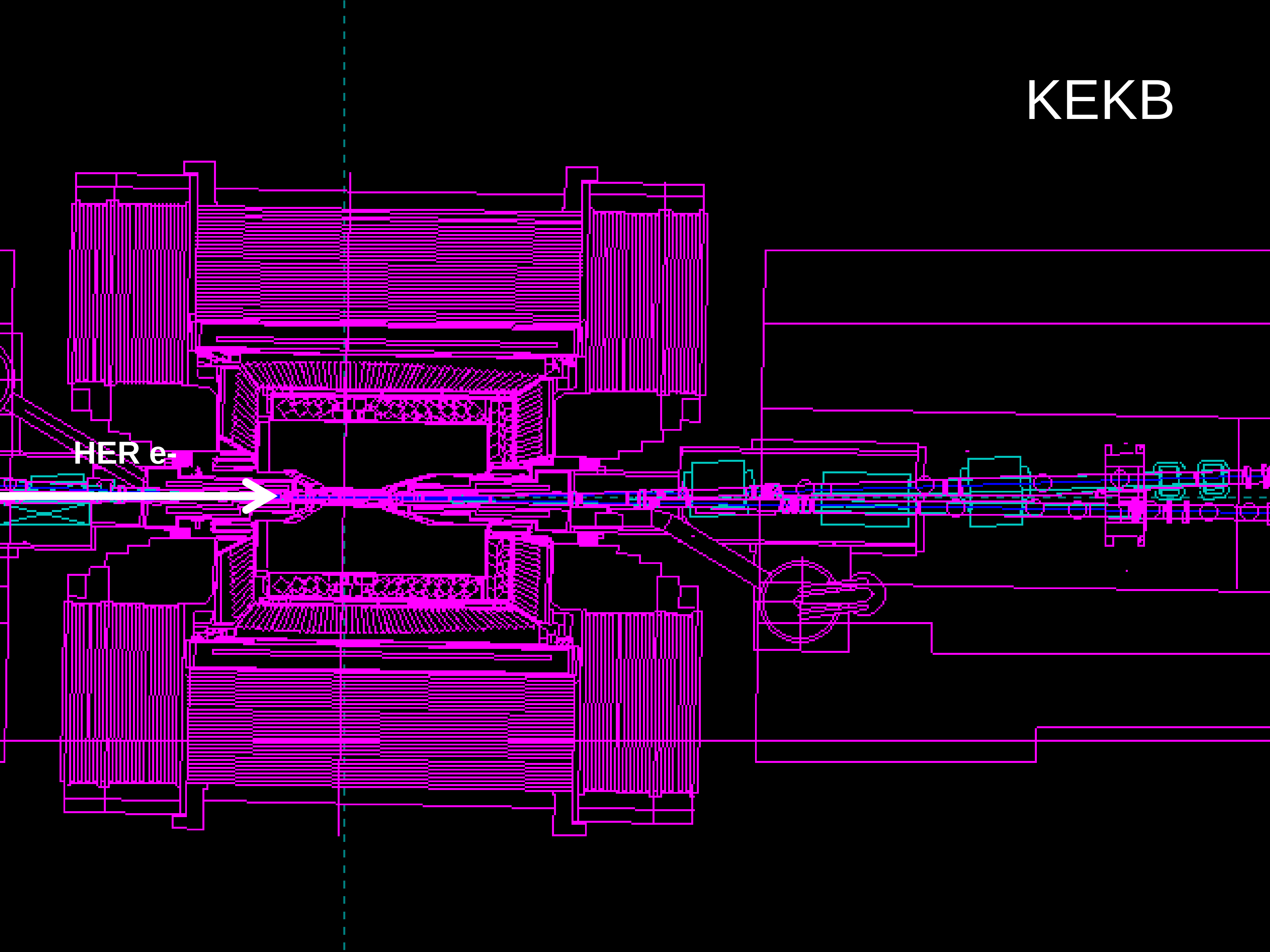
(To take care of the dynamic-beam effect, IR design has been changed)

- **Large beam size** at final Q → **High power SR** emission
- Place **final Q-magnets closer to IP**

→ **These features directly related to the detector beam BG**

To assure the stable detector operation,
IR design based on the beam BG study is important

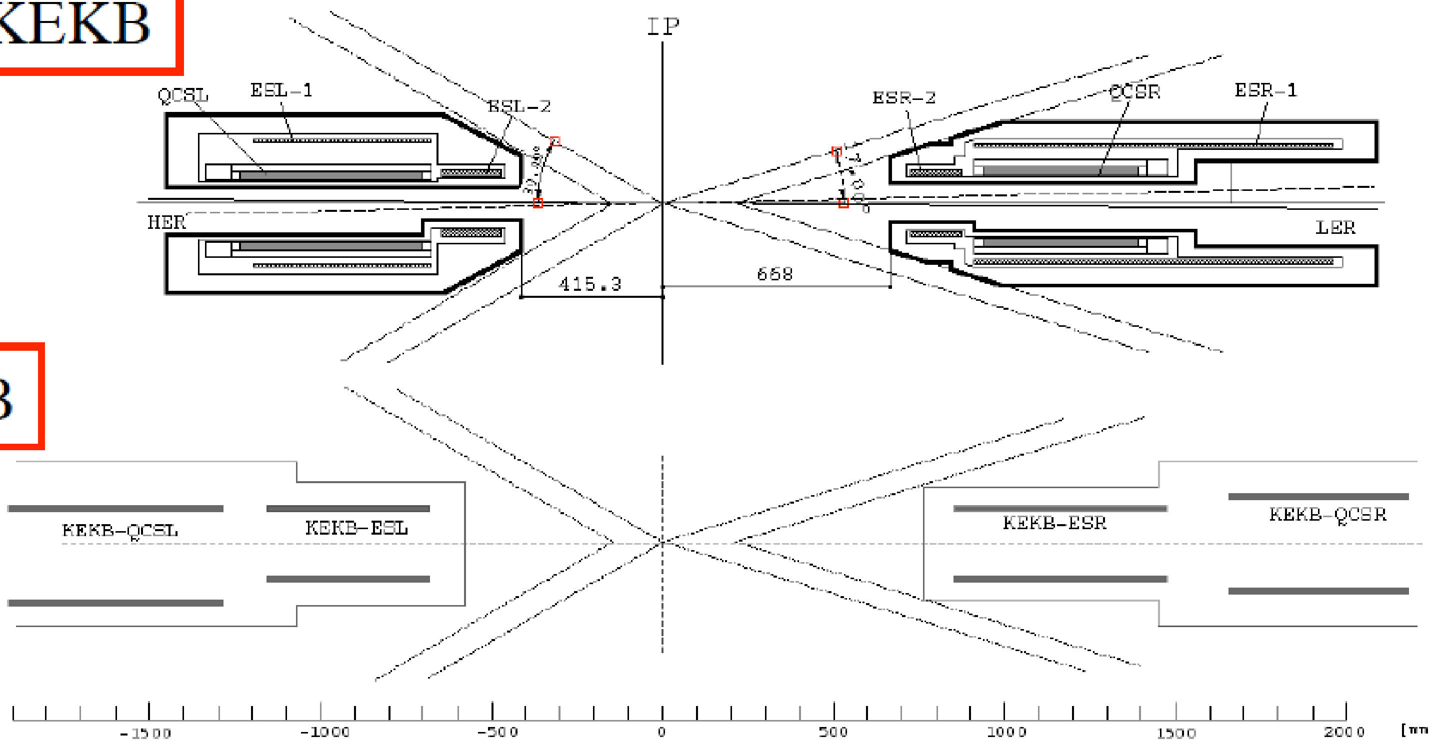
KEKB



Place QCS magnets closer to IP

SuperKEKB

KEKB



The boundary between KEKB and Belle is the same.
ESL and ESR will be divided into two parts (to reduce E.M. force).
QCSL (QCSR) will be overlaid with (the one part of) ESL(ESR).

Current status of the MDI group

- SR BG simulation studies (Tokyo / KEK)

With the Super-KEKB design, much higher SR BG is expected

Critical energy is 14keV

SR size at IP is 3-7mm for 5σ size beam

(KEKB : 2keV and <5mm for 10σ size beam)

→ Then we estimate the SR BG first

- Other BG sources

Beam-gas, radiative BhaBha, Touschek, … Not yet

- HOM / mirror current heating studies (Tohoku / KEK)

Just started!

Based on these studies, we'll design the IP region

SR BG studies

- In this talk, we show
  1. Upstream SR
     1-1. Design of IP beam-pipe to avoid SR hits from HER
     1-2. Study of the energy deposit to the IP beam-pipe
  2. Backscattered SR
     Estimate # of SR hit in the IR region

- For the SR BG study,
  we construct the beam line simulation based on GEANT4.

Upstream SR
  Simple beam pipe + 1st layer SVD + B-field of Q-magnets

Backscattered SR
  Realistic beam pipe + SR data

1. Upstream SR BG study

1-1. Design of the IP beam-pipe to avoid SR direct hit

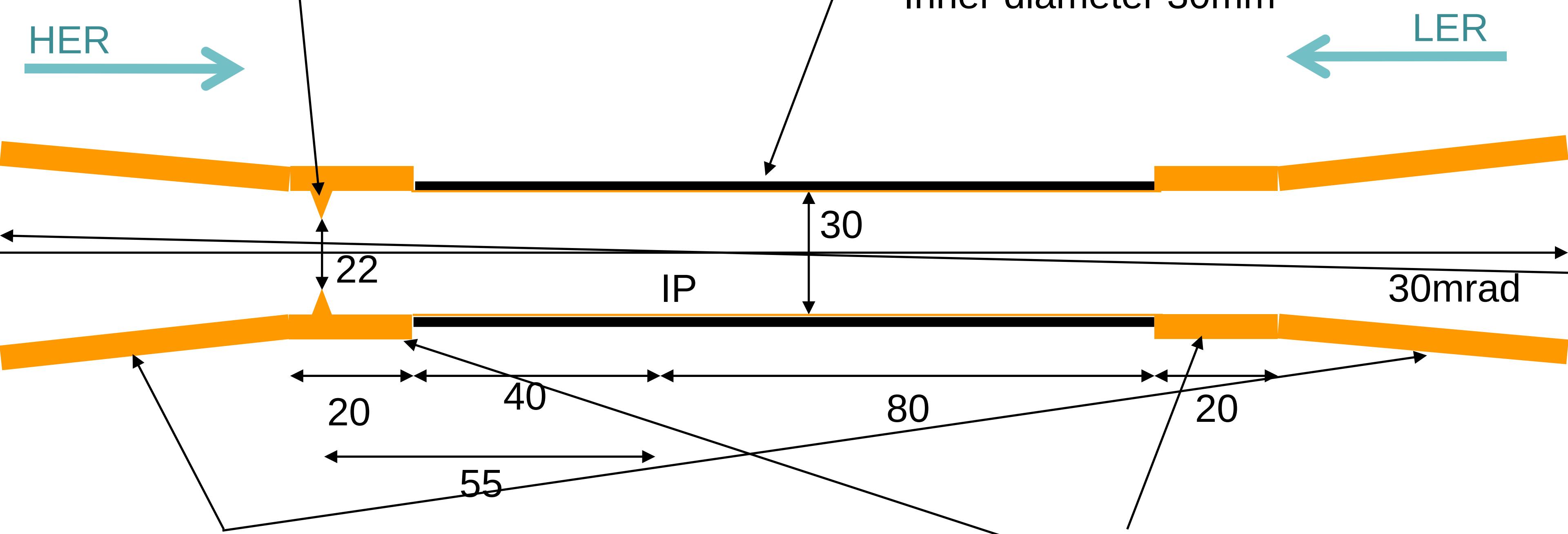
Beam pipe design

S.Uno

We put the beam pipe in our simulation

SR Mask
Au
Base length 4mm
Height 4mm
Inner diameter 22mm

Be part
Au 10μm^t
Be 2mm^t
Inner diameter 30mm

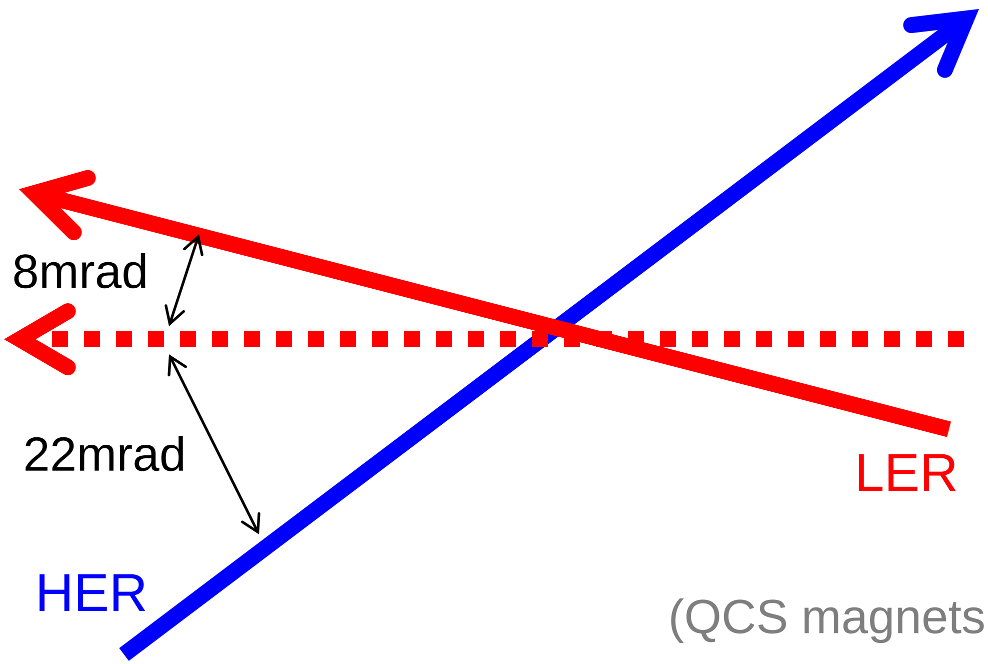


Au Taper part
Au 5mmt
30mrad taper
Length 500mm

Au straight part
Au 5mm^t
Inner diameter 30mm
Length 20mm

Relationship between s-Belle and Super-KEKB

In Super-KEKB, crossing angle will be increased : 22mrad → 30mrad



e^- KEKB / Super-KEKB
HER(e^-) axis will not change

e^+ KEKB, Belle solenoid
Belle solenoid will not change

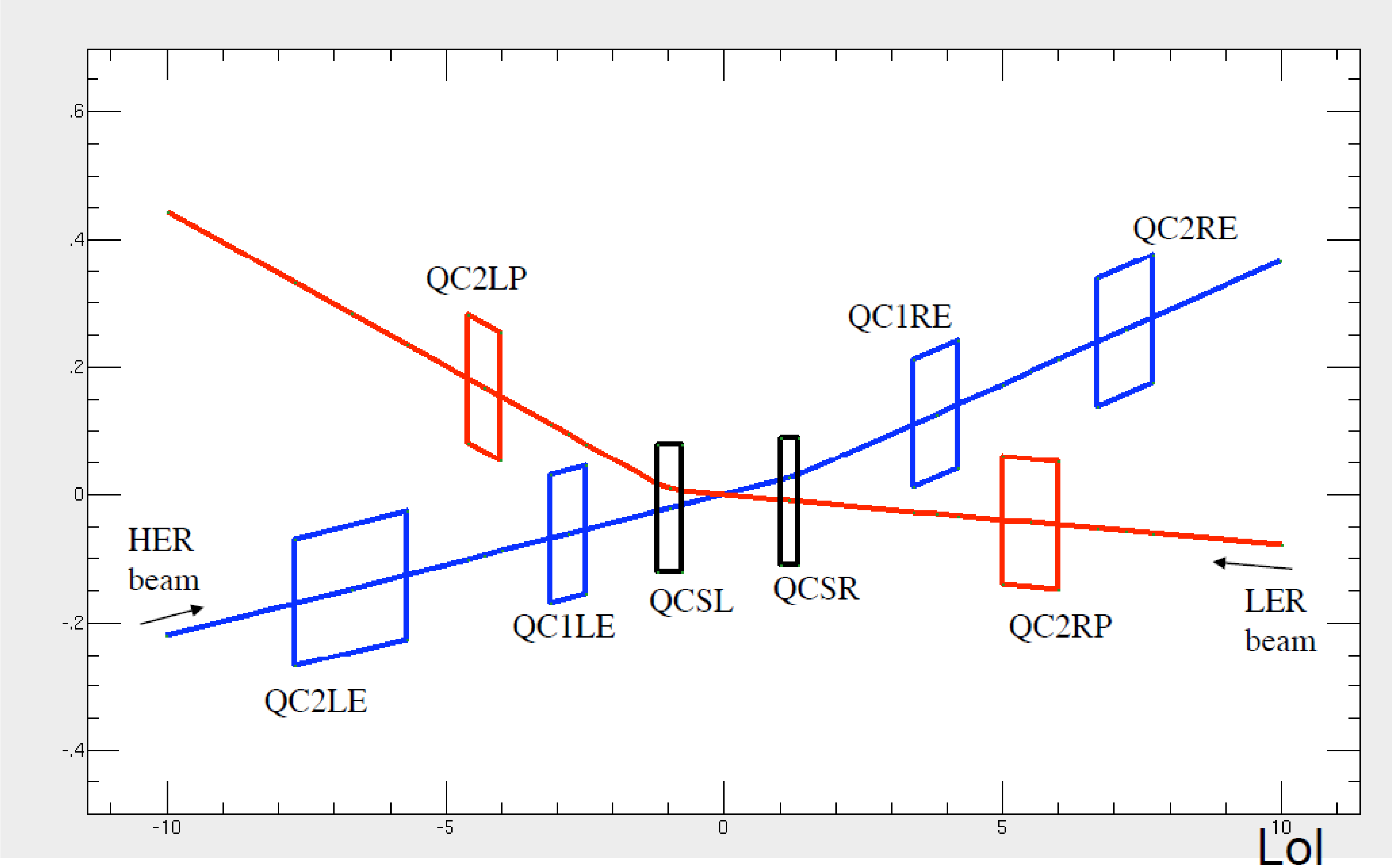
e^+ Super KEKB
LER(e^+) axis will rotate by 8mrad

(QCS magnets will be set parallel to Belle solenoid)

Belle beam pipe (and SVD??) axis at Super-KEKB

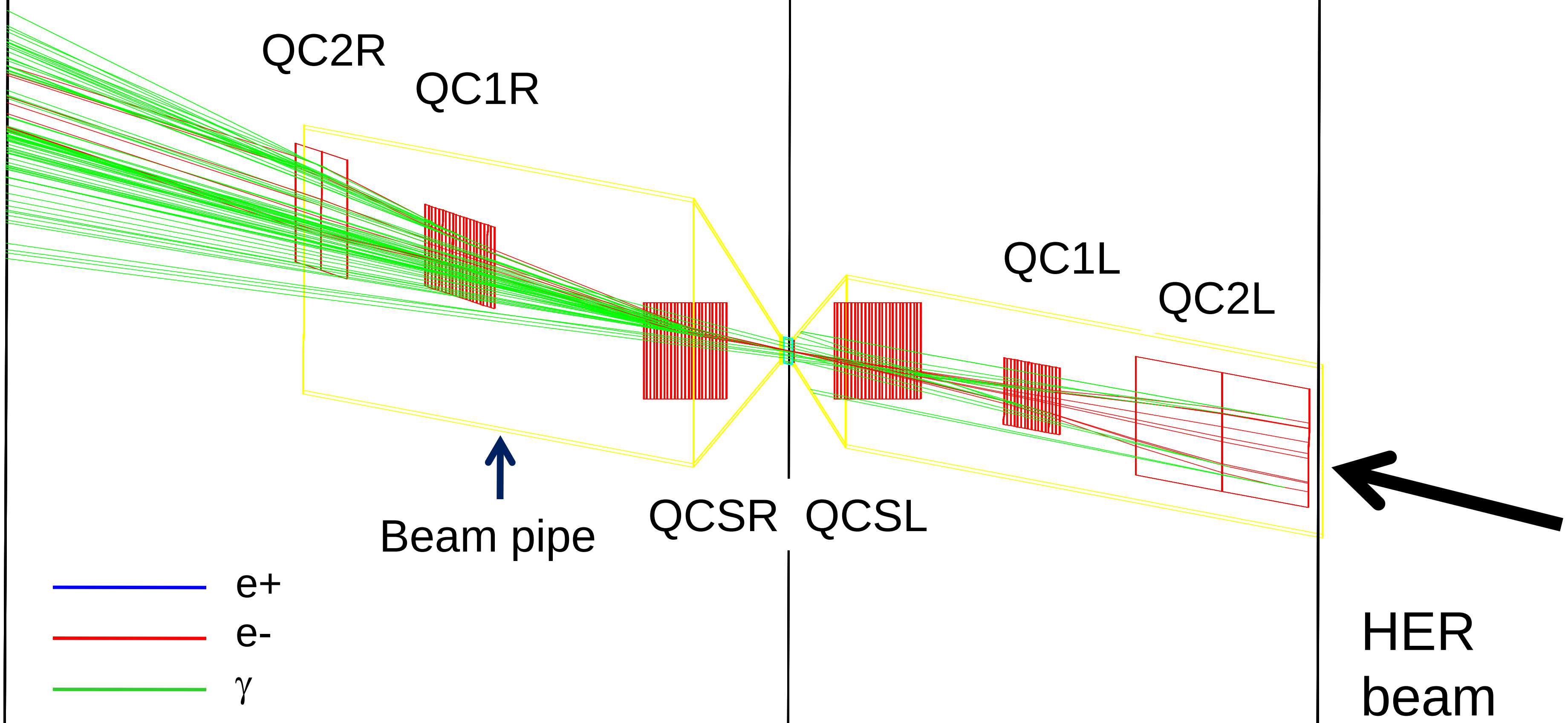
- Belle solenoid
- Center of the LER and HER (7mrad from Belle solenoid)
- <u>HER axis (22mrad from Belle solenoid)</u>

IR magnet layout



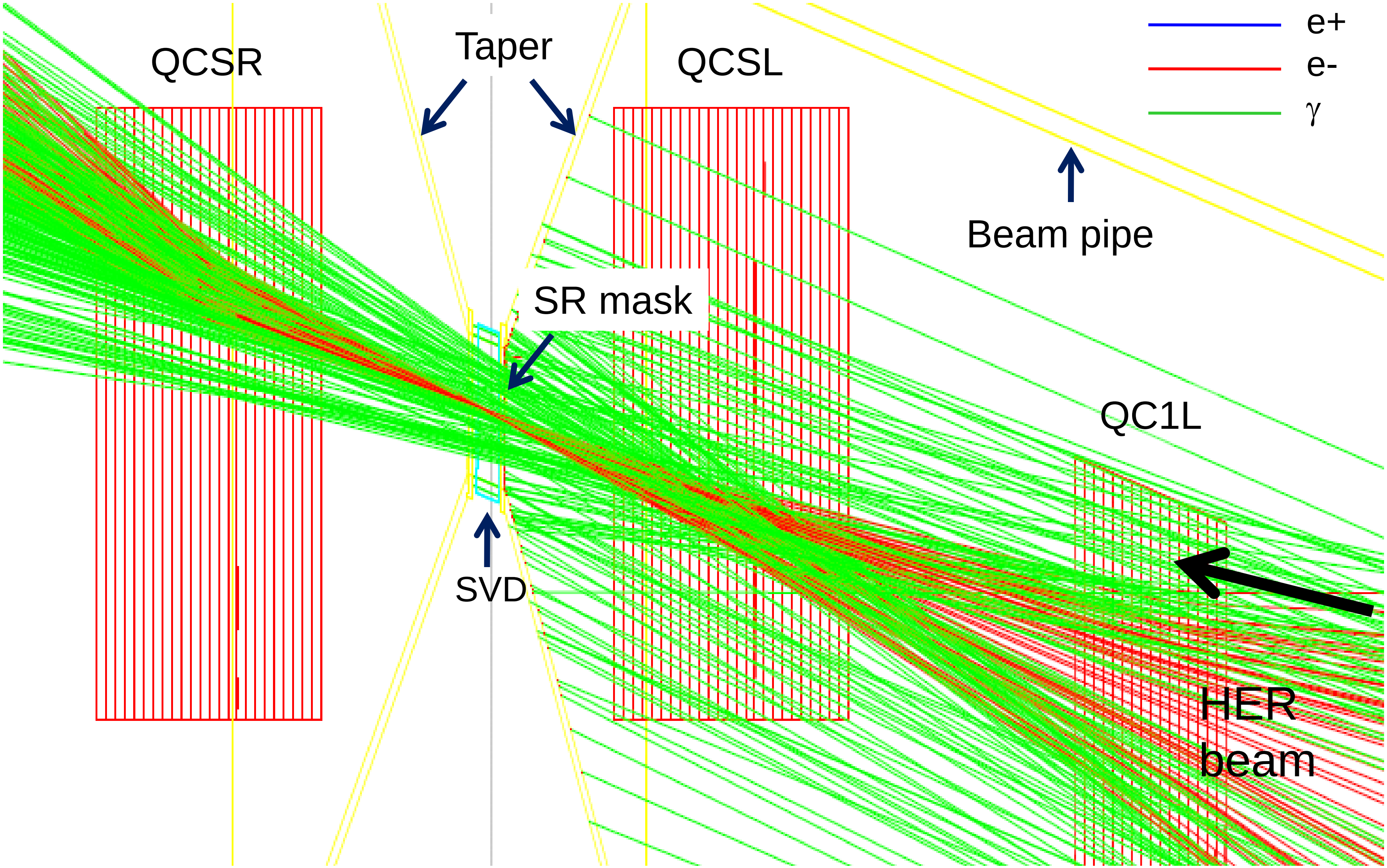
HER beam line simulation

HER simulation with LCBDS
5σ beam / physics process on



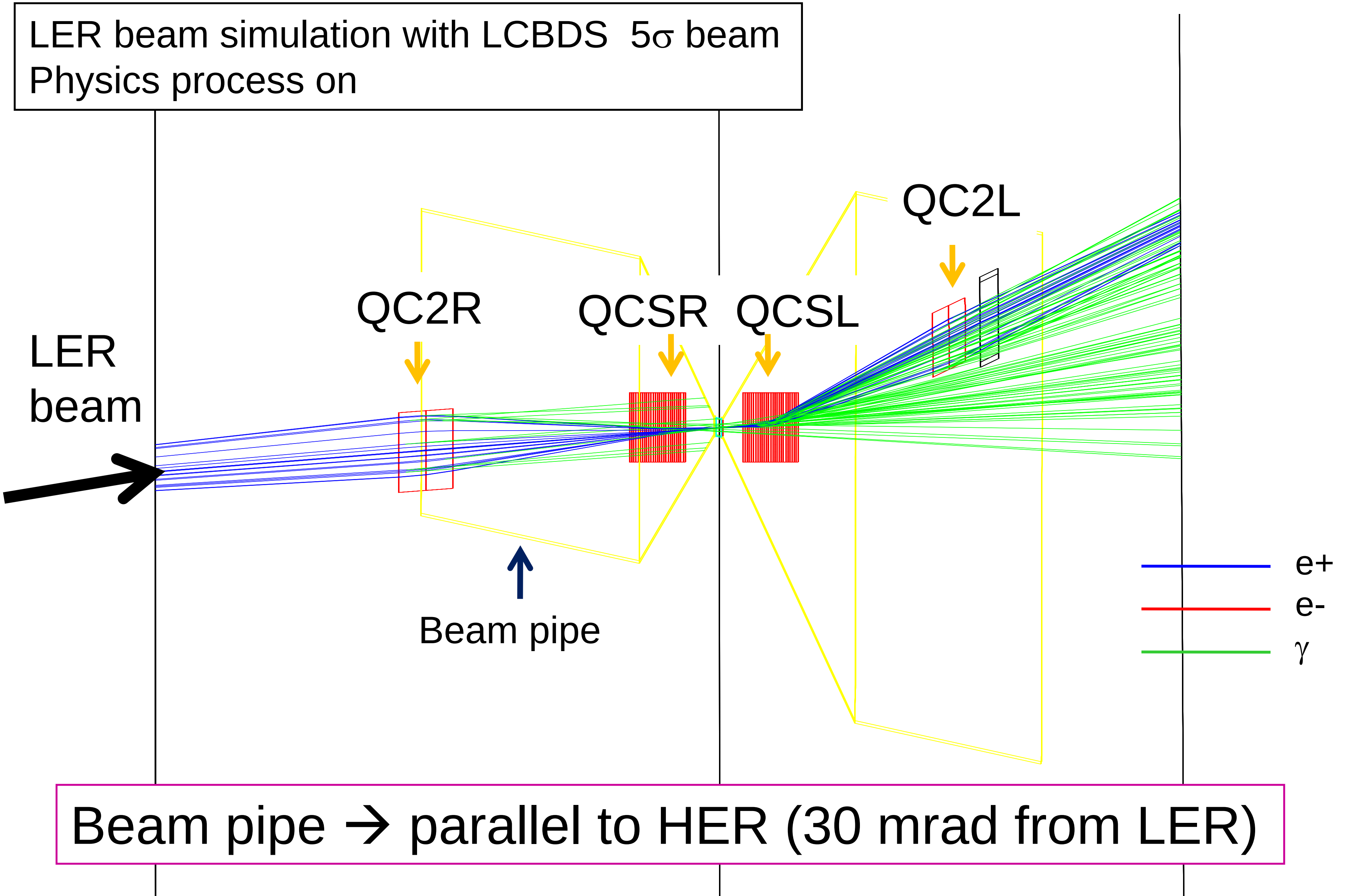
Beam pipe → parallel to HER

HER simulation



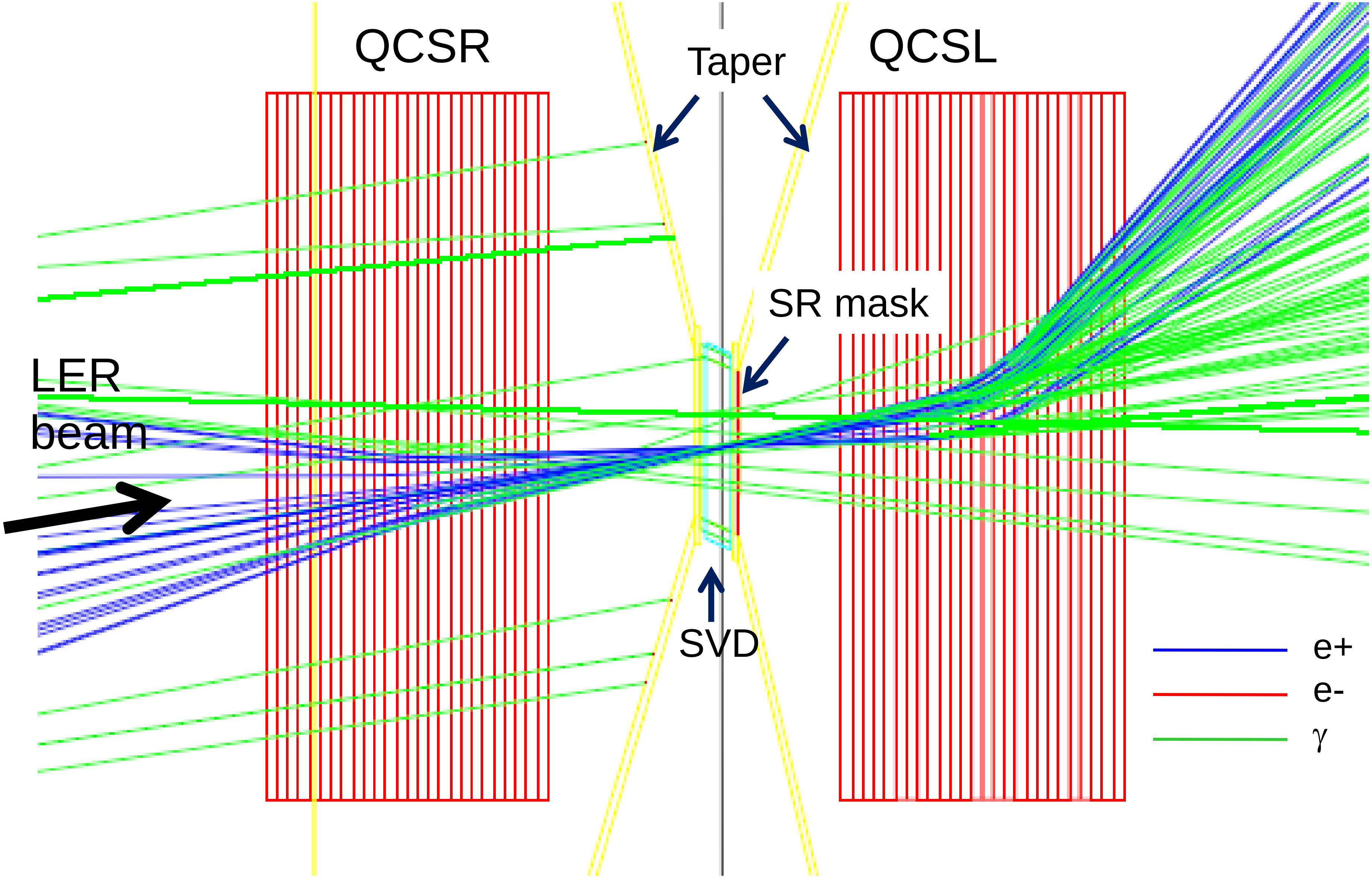
LER beam-line simulation

LER beam simulation with LCBDS 5σ beam
Physics process on



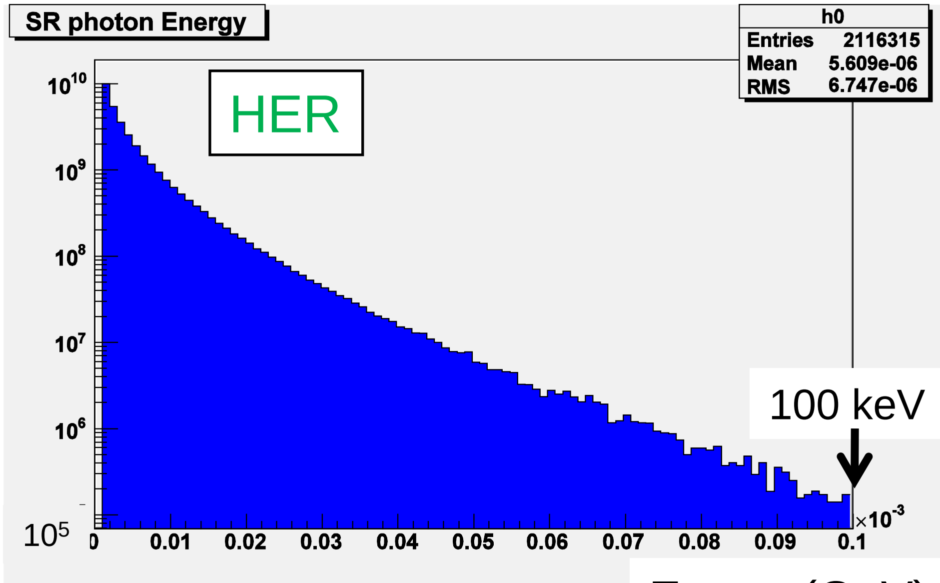
Beam pipe → parallel to HER (30 mrad from LER)

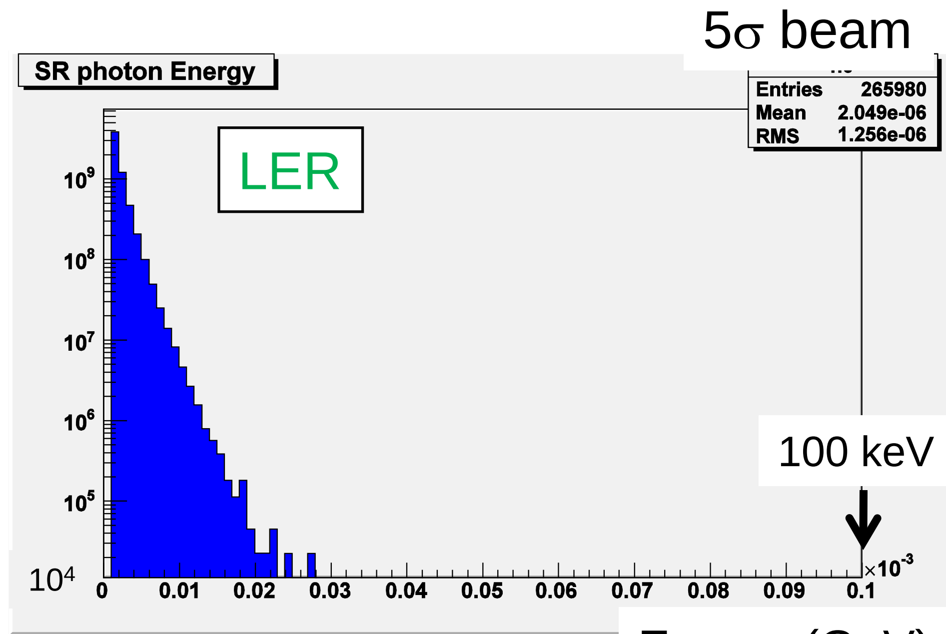
LER simulation



Upstream SR energy

SR energy (at IP)





(Vertical scale: Scaled for 1-bunch beam)

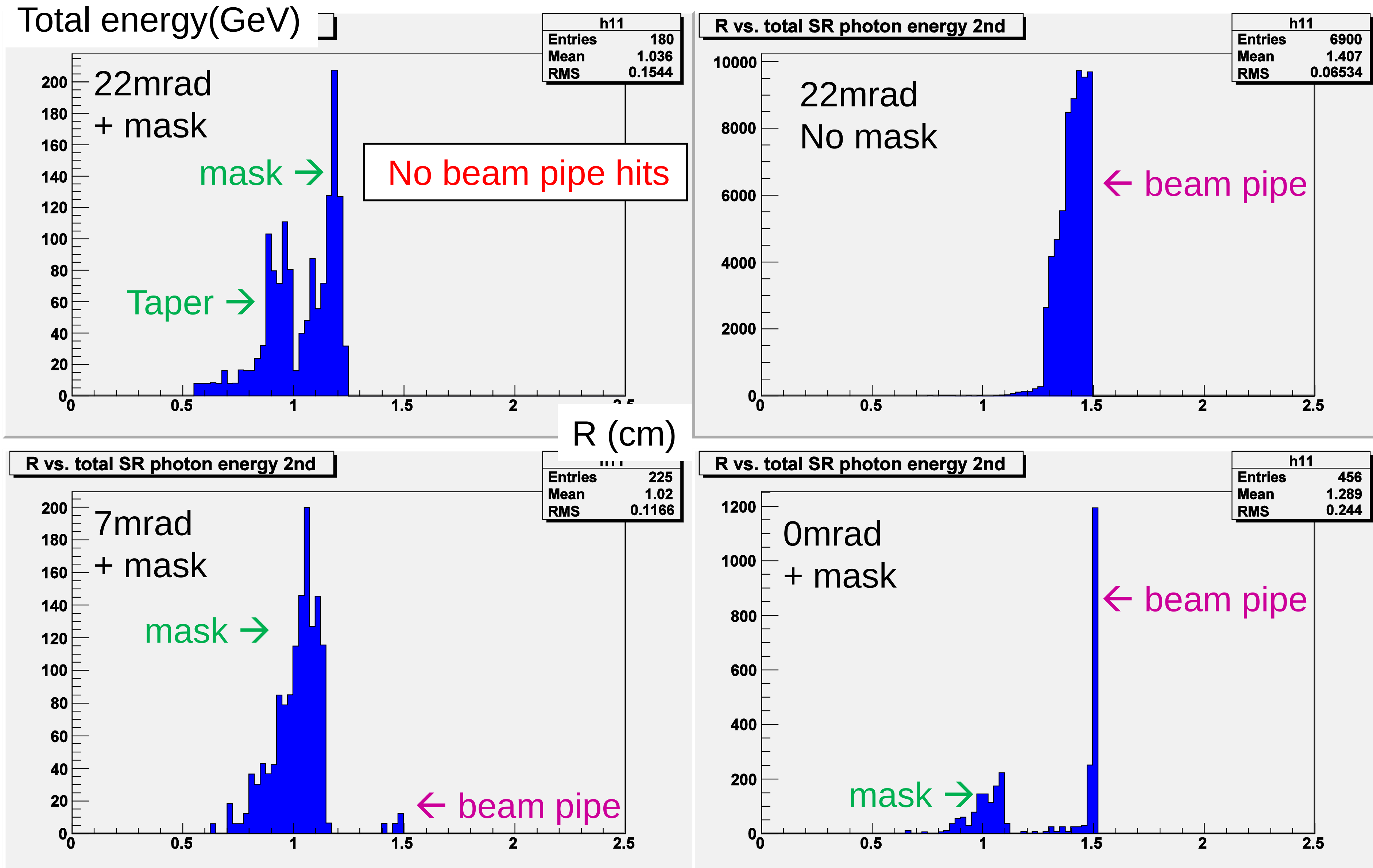
The SR energy from HER is very high (< ~100keV)

→ We don't want the direct hits from HER SR at first

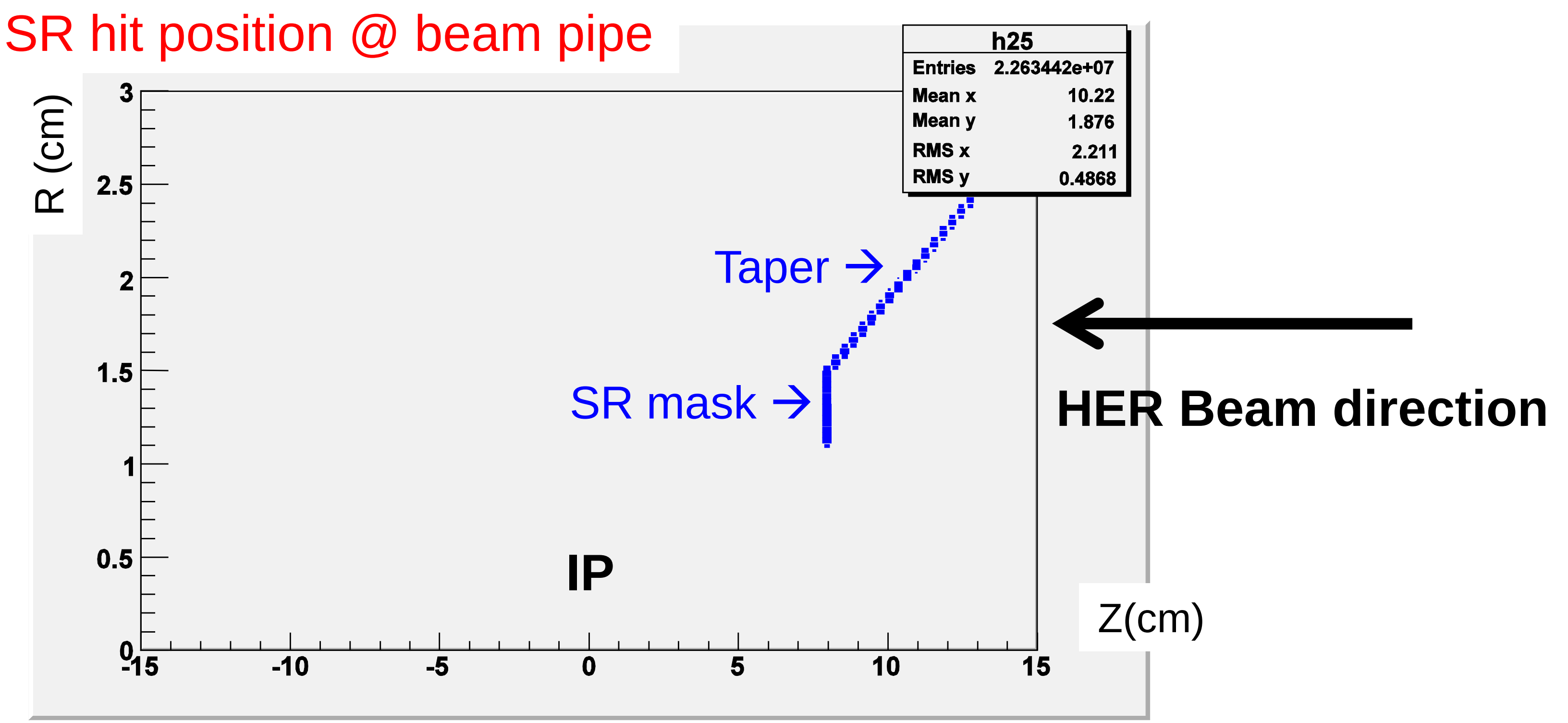
HER beam line simulation

2ndary particle production position @ IP

5σ beam



HER beam line simulation



If we locate the beam pipe parallel to HER (22 mrad from solenoid) and put a 4mm SR mask, we can avoid direct SR hit from HER

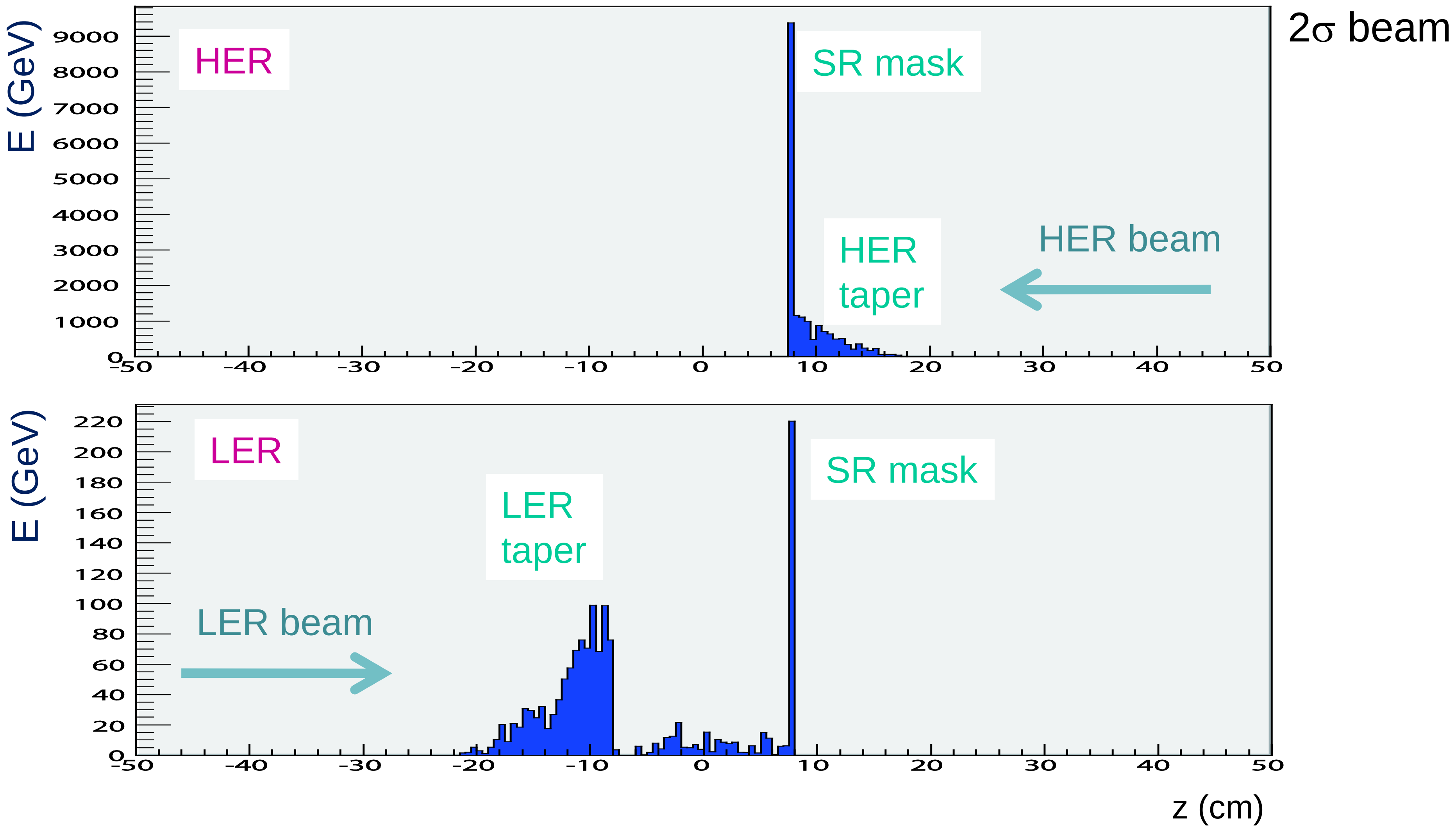
We cannot avoid the SR direct hit if:

- Without HER side SR mask,
- Put the beampipe parallel to Belle solenoid (0mrad) , nor
- Put the beampipe center of the LER and HER (7mrad)

1. Upstream SR BG study

1-2. Study of the energy deposit to the IP beam pipe

Energy deposit from upstream SR



Total E deposit to the IP beam pipe

HER ~18000GeV/bunch → 1.4kW

LER ~1400GeV/bunch → 110W

Energy deposit from SR

2σ beam

HER

SR Mask 0.73kW HER taper 0.69kW

LER

SR Mask 20W LER taper 75W IP beam-pipe 15W

We have ~1kW Energy deposit at 4mm height SR mask...

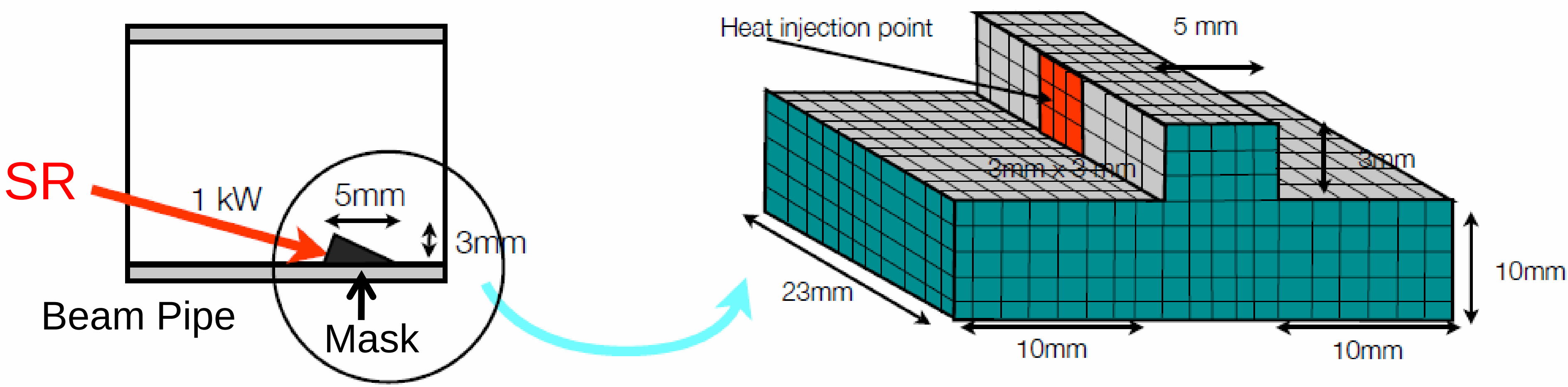
(Max. limit to cool : 10~100(?)W / mm^2)

→ SR mask may melt??

Heat at the synchrotron light mask

T.Tsuboyama (KEK)

- The heat differential equation is solved by a 3D discrete finite difference method.
- The following model was made and calculated.
- The bottom surfaces are connected to a heat sink (0 °C)
- The other surfaces are heat insulated.
- Calculation was done with equal mesh size: 1 mm in x,y,z direction.

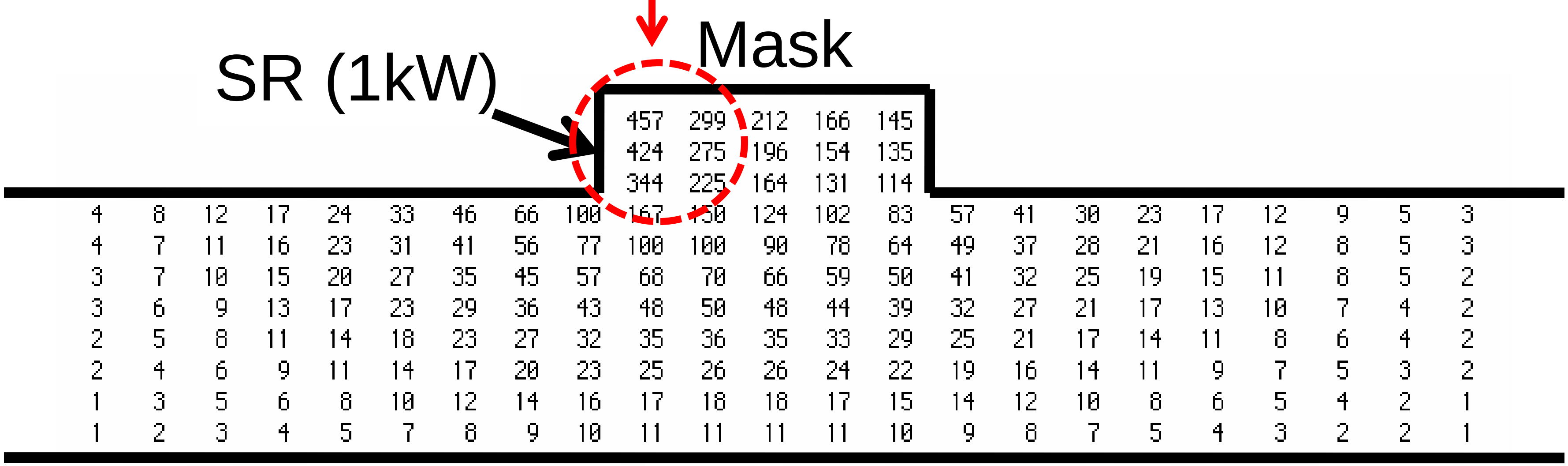


Material : copper is assumed (because of its good thermal conductivity)

Heat at the synchrotron light mask

T.Tsuboyama (KEK)

- The temperature distribution Δt for the center slice after equilibration (in one second) is shown below.
- The temperature goes up to Δt = ~450 degree.
- The heat dissipation to the mask should be of order 100W.
- Next step: reliable calculation by ANSYS or a similar tool.



									457	299	212	166	145									
									424	275	196	154	135									
									344	225	164	131	114									
4	8	12	17	24	33	46	66	100	167	150	124	102	83	57	41	30	23	17	12	9	5	3
4	7	11	16	23	31	41	56	77	100	100	90	78	64	49	37	28	21	16	12	8	5	3
3	7	10	15	20	27	35	45	57	68	70	66	59	50	41	32	25	19	15	11	8	5	2
3	6	9	13	17	23	29	36	43	48	50	48	44	39	32	27	21	17	13	10	7	4	2
2	5	8	11	14	18	23	27	32	35	36	35	33	29	25	21	17	14	11	8	6	4	2
2	4	6	9	11	14	17	20	23	25	26	26	24	22	19	16	14	11	9	7	5	3	2
1	3	5	6	8	10	12	14	16	17	18	18	17	15	14	12	10	8	6	5	4	2	1
1	2	3	4	5	7	8	9	10	11	11	11	11	10	9	8	7	5	4	3	2	2	1

Energy deposit from HER SR

Why do we have so high energy deposit?

1. Increase the beam current — effect : x3

2. Change beam optics (QC2L)
   - x3 Beam size at the Q-magnet ↑
   - x7 B-field of the Q-magnet ↑
   - Same magnet length
   - No-bending component ↓

Critical Energy @ QC2L : 2keV for 10σ beam (KEKB)

56keV for 10σ beam (super-KEKB) effect : x28

→ We have 3x28 ~ 100 times higher E deposit at super-KEKB

Current super-KEKB beam optics produces huge power SR

Total SR power produced at Q-magnet

- To check our simulation results,
  we compare the total SR power at the QC2 magnet

1. GEANT4 simulation
   (For 2σ beam :corresponds to nominal Gaussian beam core)
   Total power = 3.3kW
2. Hand calculation (by Y.Funakoshi-san)
   Total power = 2.9kW

- We also check that SR power produced at QC2 in our current KEKB is about 1/100 of super-KEKB, in GEANT4 simulation

2. Backscattered SR study

- **SR hit to the beam pipe**

Back scattered SR simulation

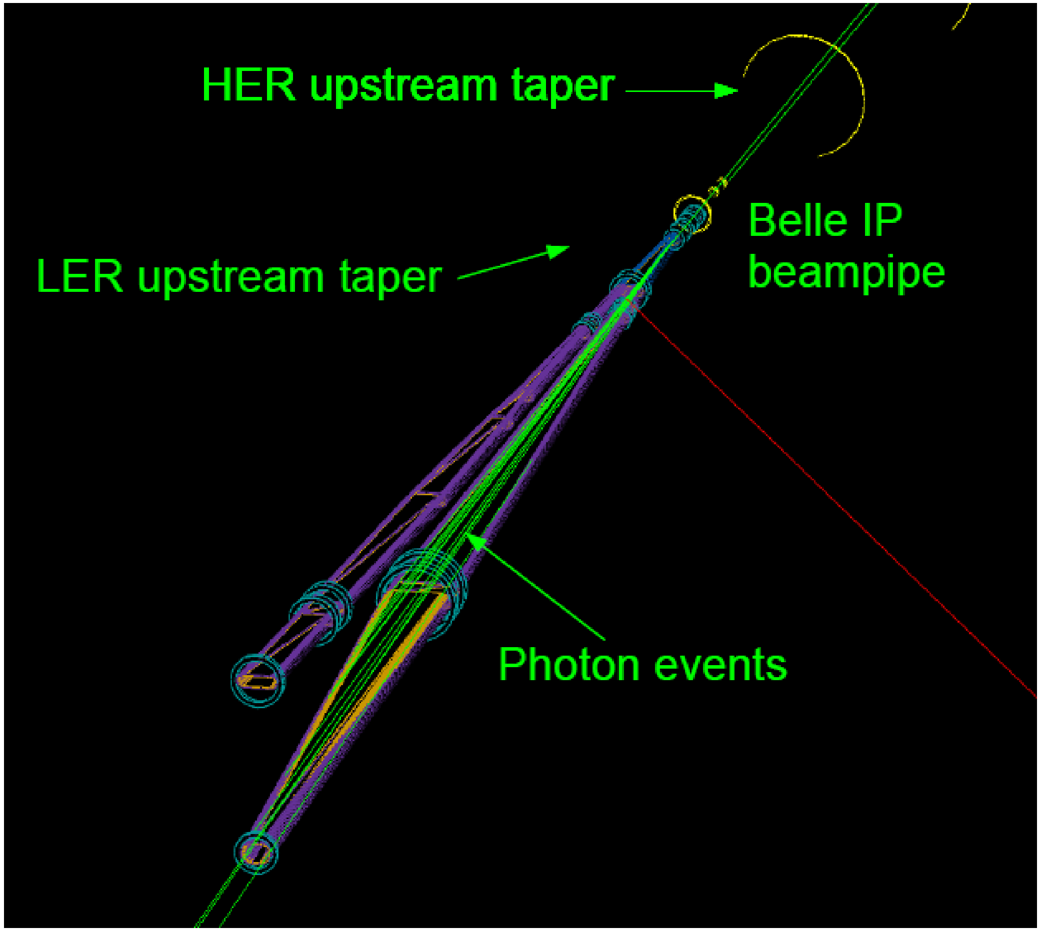
Clement Ng (U. Tokyo)

By constructing the realistic beam pipe in our simulation,
we have studied the back scattered SR BG effect.

- Beam Pipe material
  6mm Cu + 10um Au

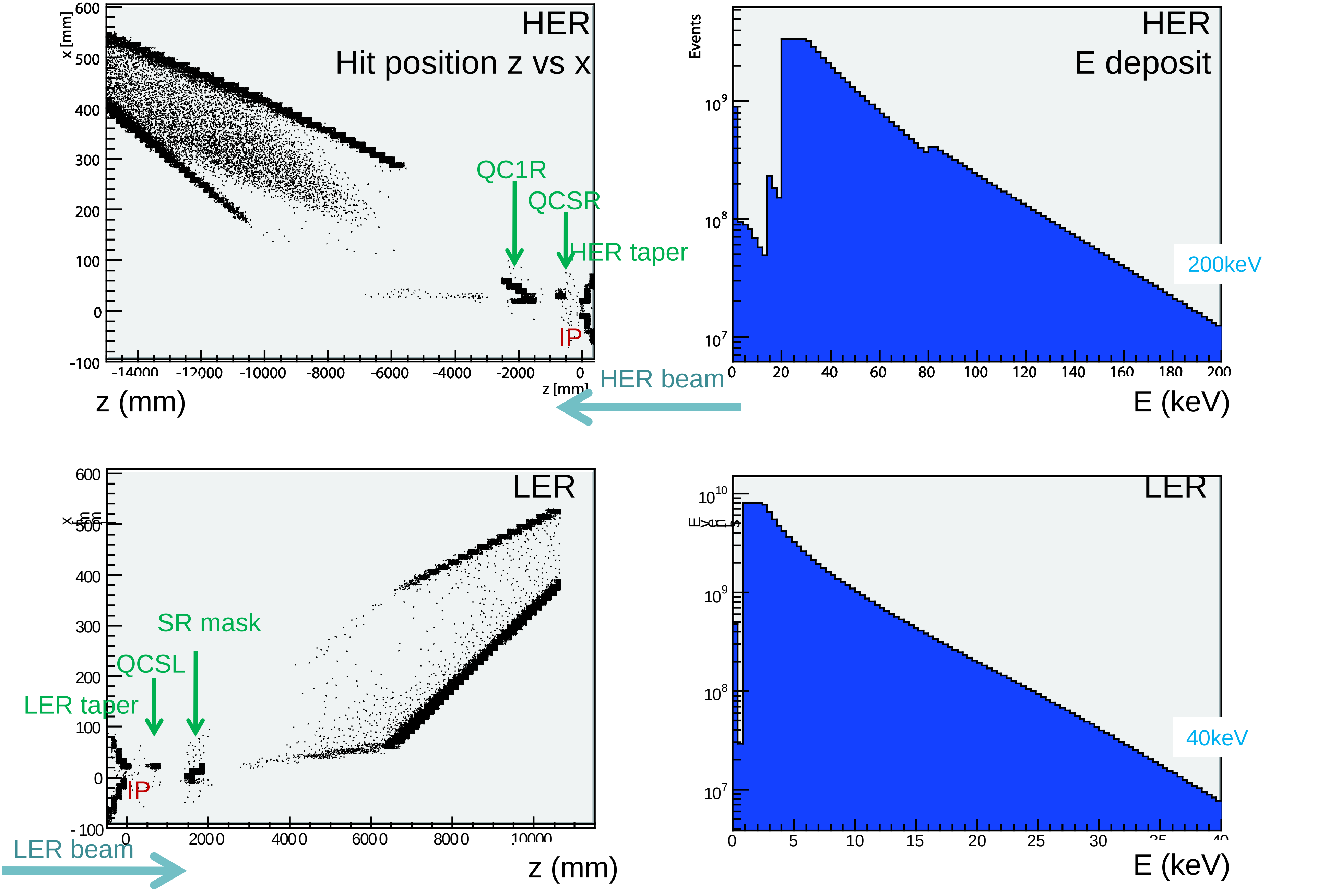
- Construct ±10m from IP

- Input SR data generated
  in the upstream SR studies



HER/LER SR simulation

C.Ng (Tokyo)

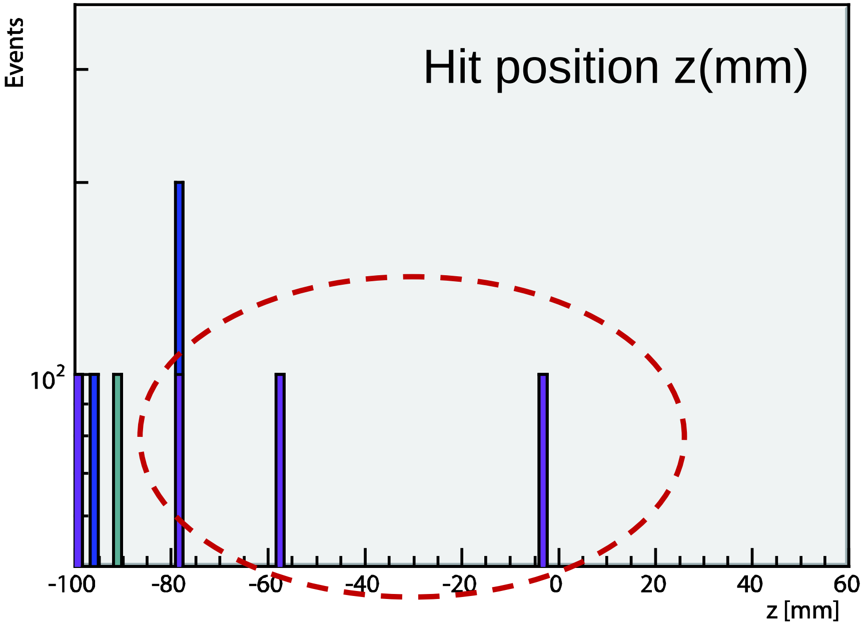


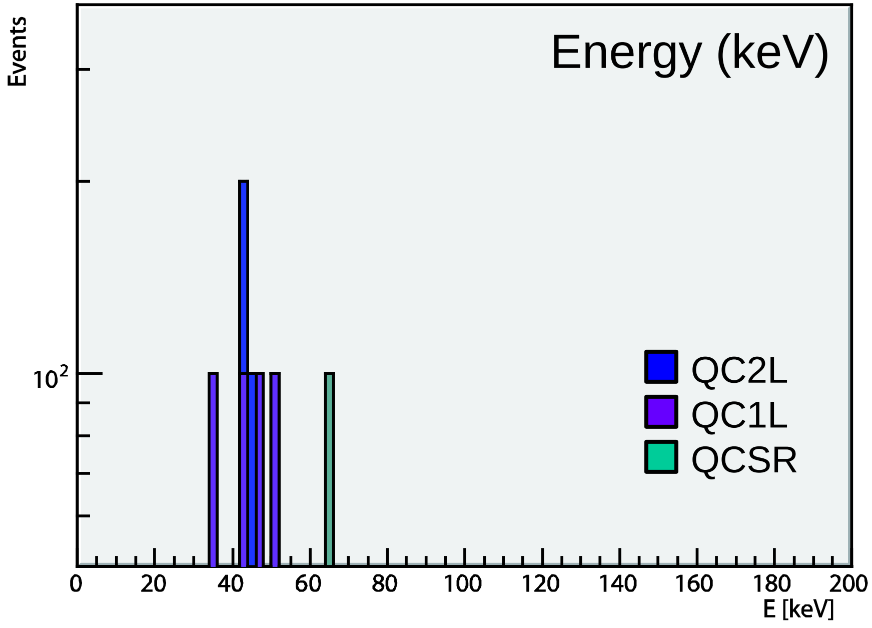
Back scattered photons at IP

C.Ng (Tokyo)

HER IP region (E_{SR}>20keV)

Vertical scale is scaled for 1-bunch beam, Scale factor = 100





There are 4 entries which may enter to the detector region (energy ~50keV)
These are caused by SR photons produced at QC1/2L

We cannot evaluate the SVD occupancy because MC statistics is too small.
After increasing the statistics, we'll study the SVD occupancy

Conclusion

Based on the GEANT4 simulation, SR BG has been studied

1. Upstream SR

- Design of the IP beam-pipe to avoid SR from HER

To avoid the SR direct hit, we should

Locate the beam pipe parallel to HER (22mrad from Belle solenoid), and

Put a 4mm height SR mask

- Study of the energy deposit to the IP beam-pipe

The energy deposit from HER SR will be ~1kW (SR mask) ~1kW (taper)

1kW deposit to the 4mm mask makes ~500 degree temperature rise

→ It is very hard to cool the beam pipe…

2. Backscattered SR

We need more MC statistics to study in detail.

We try to minimize the BG effect in our beam-pipe design, but SR power is so high that we cannot cool the beam-pipe

New super-KEKB machine parameters with lower SR power are highly appreciated

→ See the next slide..

New super-KEKB optics

New super-KEKB optics has just been delivered

- **Beam size at the Q-magnet**
  QC1L / QC2L : ½ of the current one
- **B-field of the Q-magnet**
  QC1L : x1.6 of the current one
  QC2L : same
- **Same magnet length**

In total, SR power is reduced to

80% (QC1L) or 25% (QC2L) of the current one

We'll re-estimate the SR BG based on the new optics

Back up

Beam line simulation

Based on the following programs, we construct
the Super-KEKB beam-line simulation

- SAD

To get the geometry / element definition / Twiss parameters.
SAD file with dynamic beam-beam effect from Funakoshi-san
(Dynamic effect → 5 times higher ε, 10 times smaller β in x)

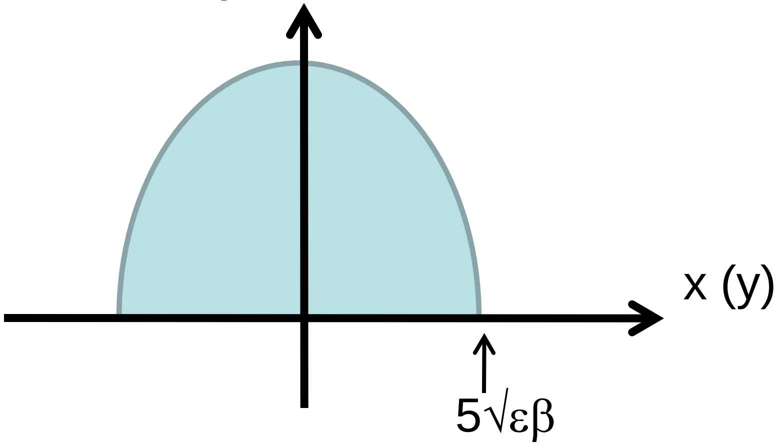
- LCBDS

Beam line simulation <u>based on GEANT4</u>
developed by K.Tanabe and T.Abe of U.Tokyo (for ILC/T2K)

At first, we just align the beam line components, beam pipe,
and 1st layer SVD in the simulation

Beam line simulation setup

- Aperture of the Q-magnets ~ 5σ (= $5\sqrt{\varepsilon\beta}$)
- Beam size 5σ (max = 5σ) or 2σ (max = 2σ)
- Beam shape : sqrt(x) shape



- The number of particles in a bunch

HER : 4.1A / (1.6*10^-19)/(100kHz)/5000 = 0.5 $*10^{11}$

LER : 9.4A / (1.6*10^-19)/(100kHz)/5000 = 1.2 $*10^{11}$

Beam size @ IR Q-magnets

IP

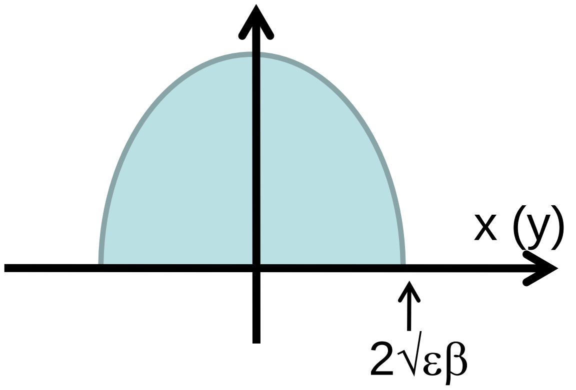
HER Beam →

HER	QC2L	QC1L	QCSL	QCSR	QC1R	QC2R
OLD	75.2mm ($5\sigma_x$)	31.1	11.0	4.4	30.3	74.5
New	35.4	16.5	14.4	6.3	30.1	69.0

← LER Beam

LER	QC2L	QC1L	QCSL	QCSR	QC1R	QC2R
OLD	52.1mm ($5\sigma_x$)	29.0	2.9	15.1	52.2	63.9
New	34.4	---	2.9	10.7	---	66.3

Energy deposit from SR



- 2σ sqrt-shape beam

HER: SR Mask 0.73kW   HER taper 0.69kW

QC1 0.30kW   QC1 0.02kW

QC2 0.44kW   QC2 0.67kW

LER: SR Mask 20W   LER taper 75W   IP beam-pipe 15W

- Gaussian beam (2σ tail cut)

HER: SR Mask 0.52kW   HER taper 0.43kW

QC1 0.15kW   QC1 0.01kW

QC2 0.37kW   QC2 0.42kW

- Gaussian beam (5σ tail cut)

HER: SR Mask 0.68kW   HER taper 1.18kW

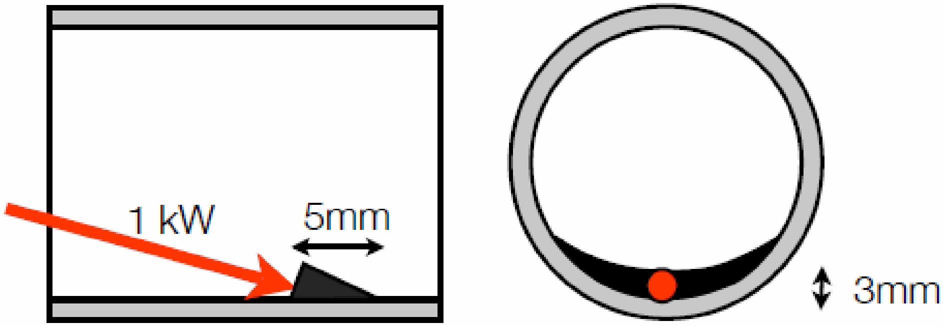
QC1 0.32kW   QC1 0.17kW

QC2 0.36kW   QC2 1.01kW

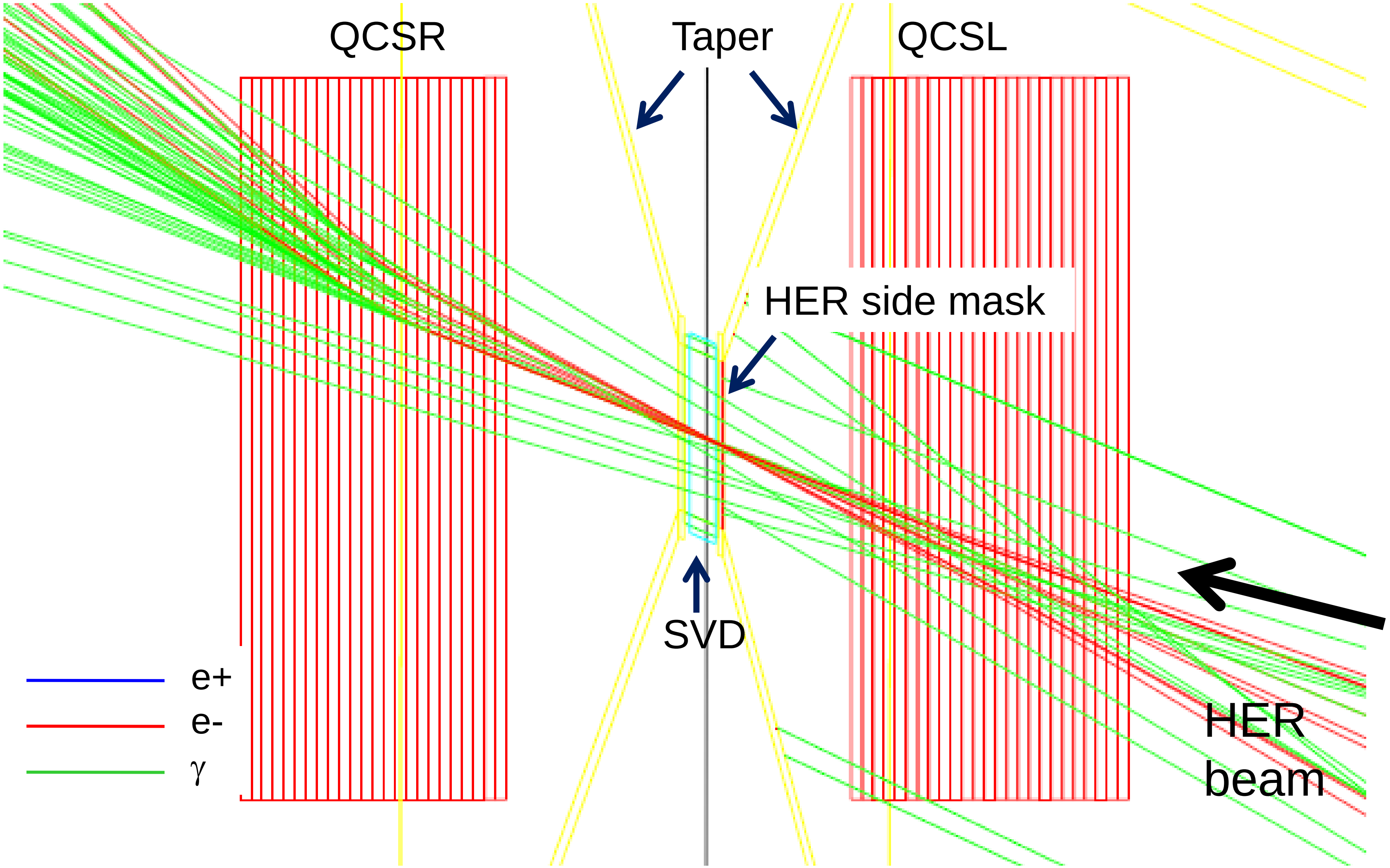
Heat at the synchrotron light mask

T.Tsuboyama (KEK)

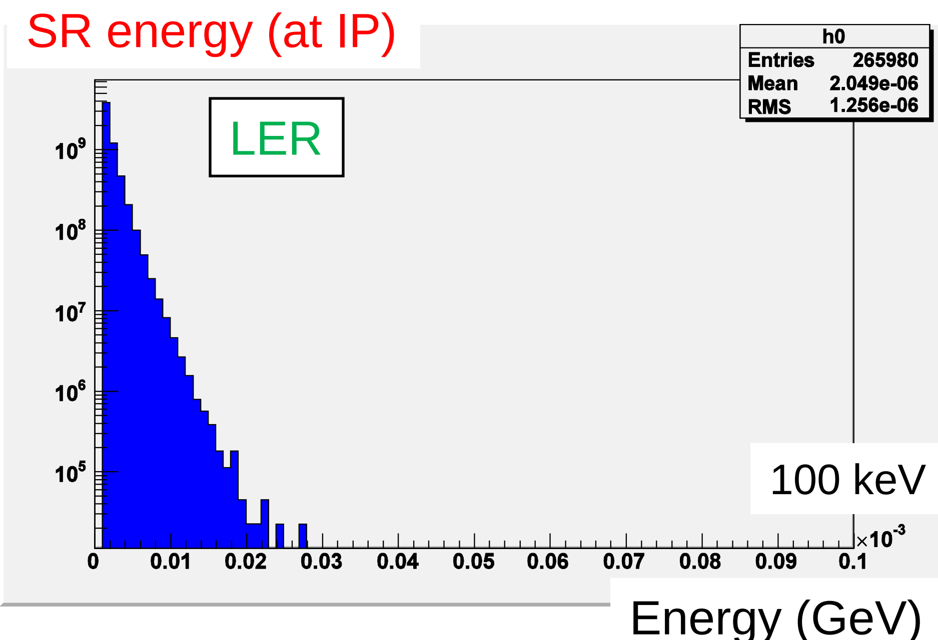
- Simplest calculation: 1 Dim. model.
- Temperature increase is $\Delta T = P \cdot L / S / \sigma$, where P: power, L: length, S: area and σ: heat conductivity.
- Assumption: P=1 kW heat lost at the 3 mm diameter spot. $S = \pi r^2 = 0.07$ cm^2. L = 0.3 cm (being half of the maximum length).
- Copper: σ=4.0 W/°C/cm, Tungsten: σ=1.7 J/°C/cm.
- Consequently, ΔT=1000*0.3/0.07/4 ~ 1200 °C for Cu and ΔT= 1000*0.3/0.07/1.7 ~ 2500 °C for W.
- 1 KW power dissipation at a 3 mm diameter heat spot is out of question.

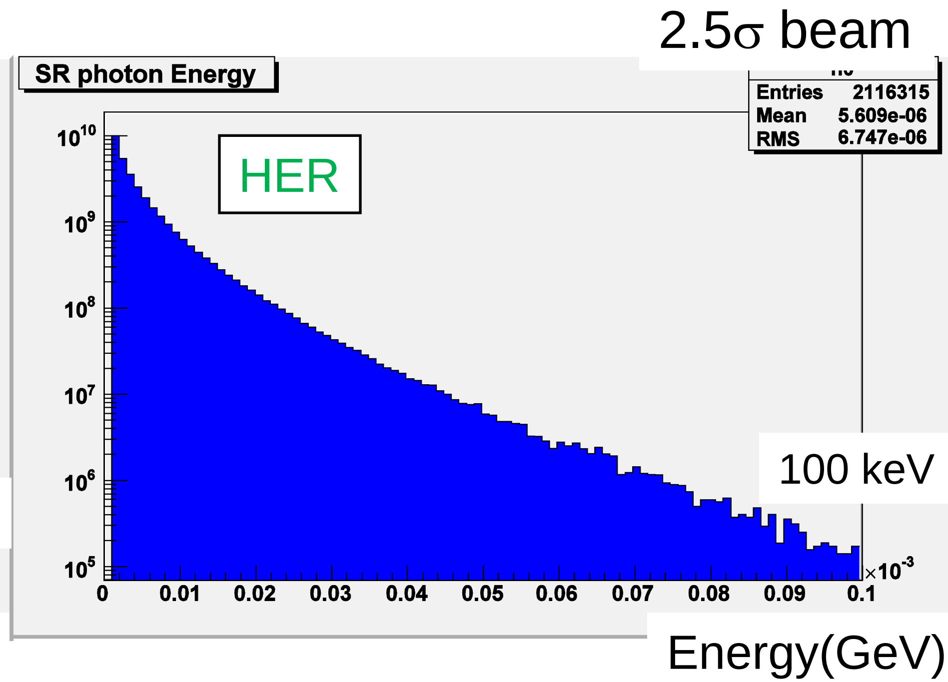


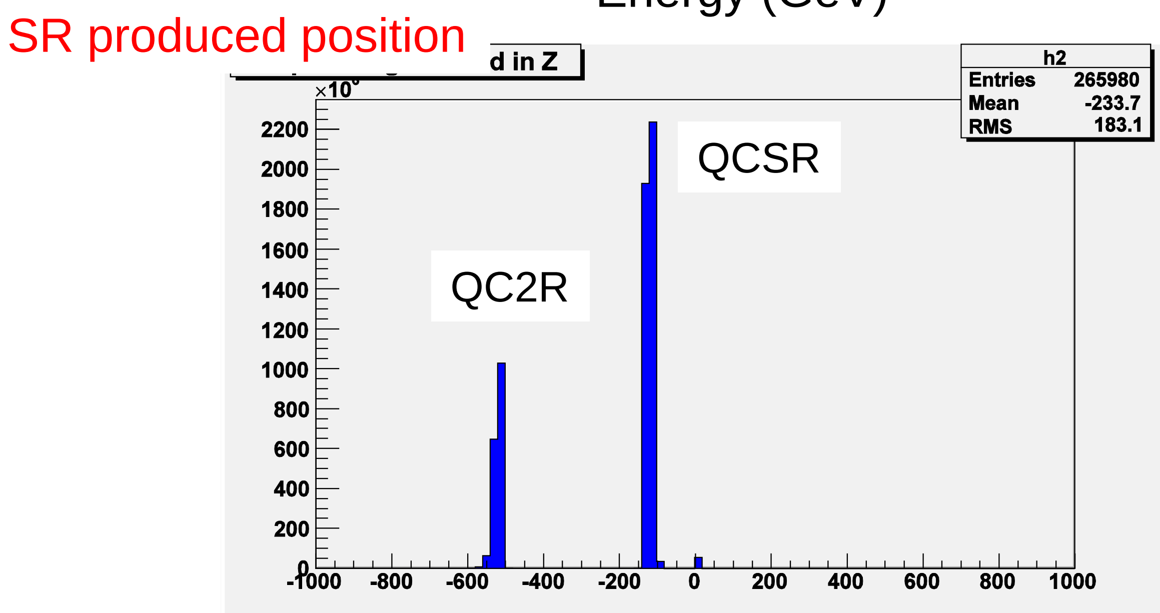
HER simulation



LER beamline simulation







(Vertical scale:
Scaled for 1-bunch beam)

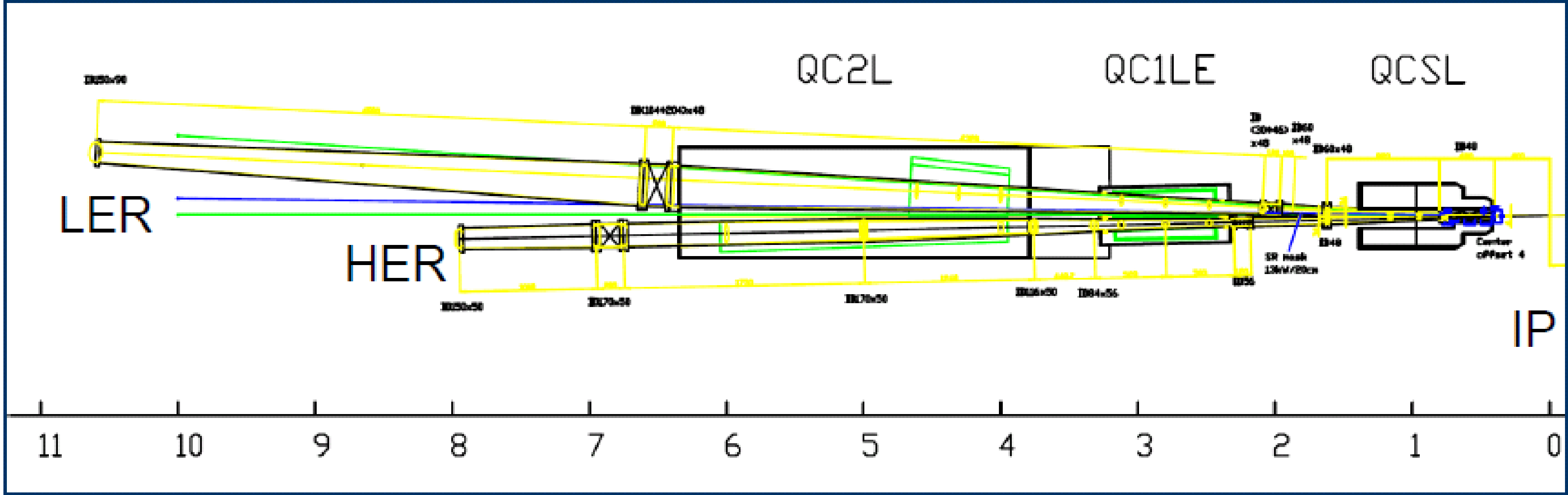
Progress to date

Geant4 Beampipe Geometry Modelling

- SuperKEKB LER Downstream IR Beampipe
  - Written according to AutoCAD design plan by Kanazawa-san

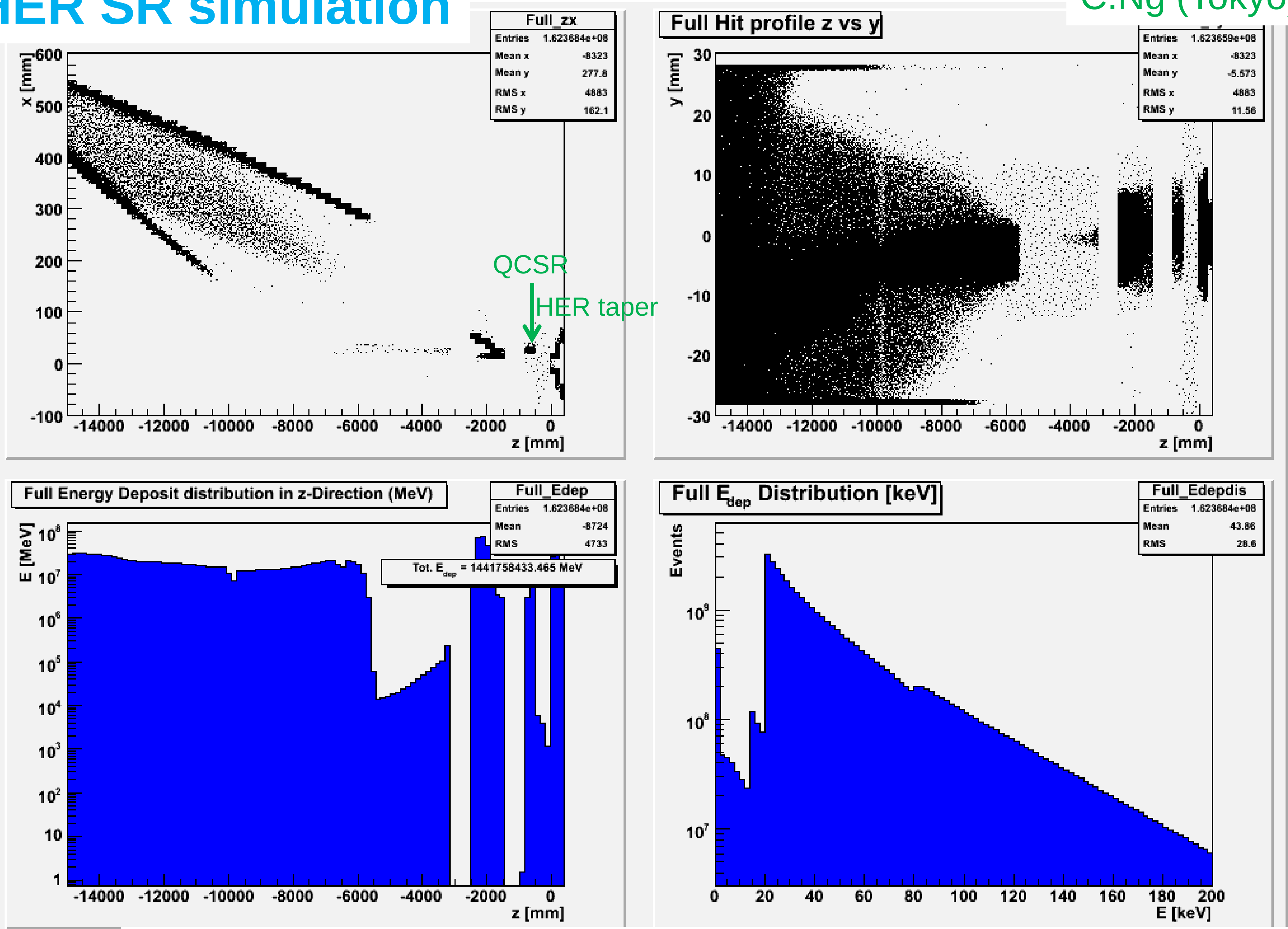
Synchrotron backscattering simulation - underway

- Merged with IP beampipe and synchrotron beam data constructed by Iwasaki-san



HER SR simulation

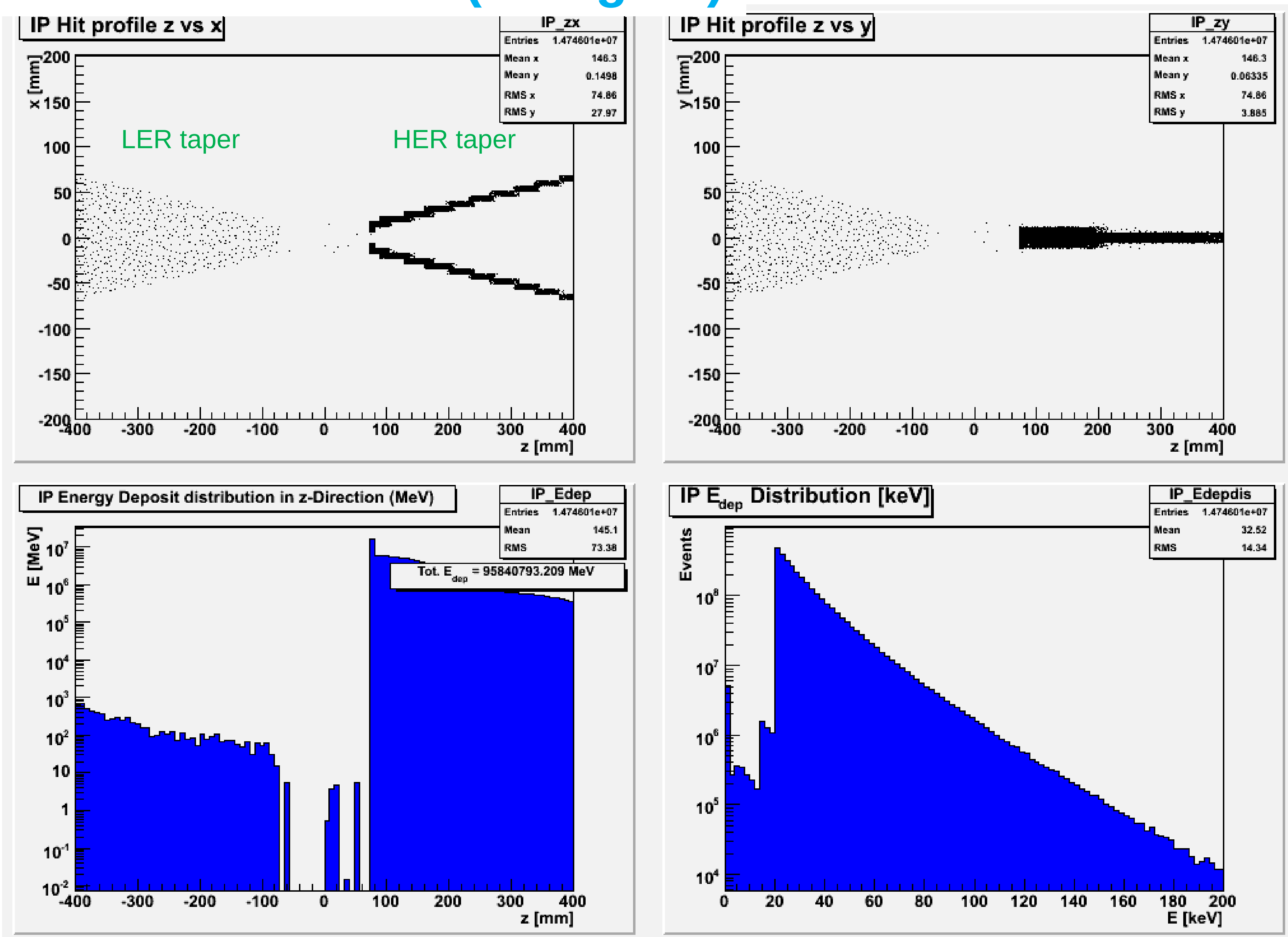
C.Ng (Tokyo)



event for the simulation ~10^8 event → We need to scale $2*10^2$ for a bunch

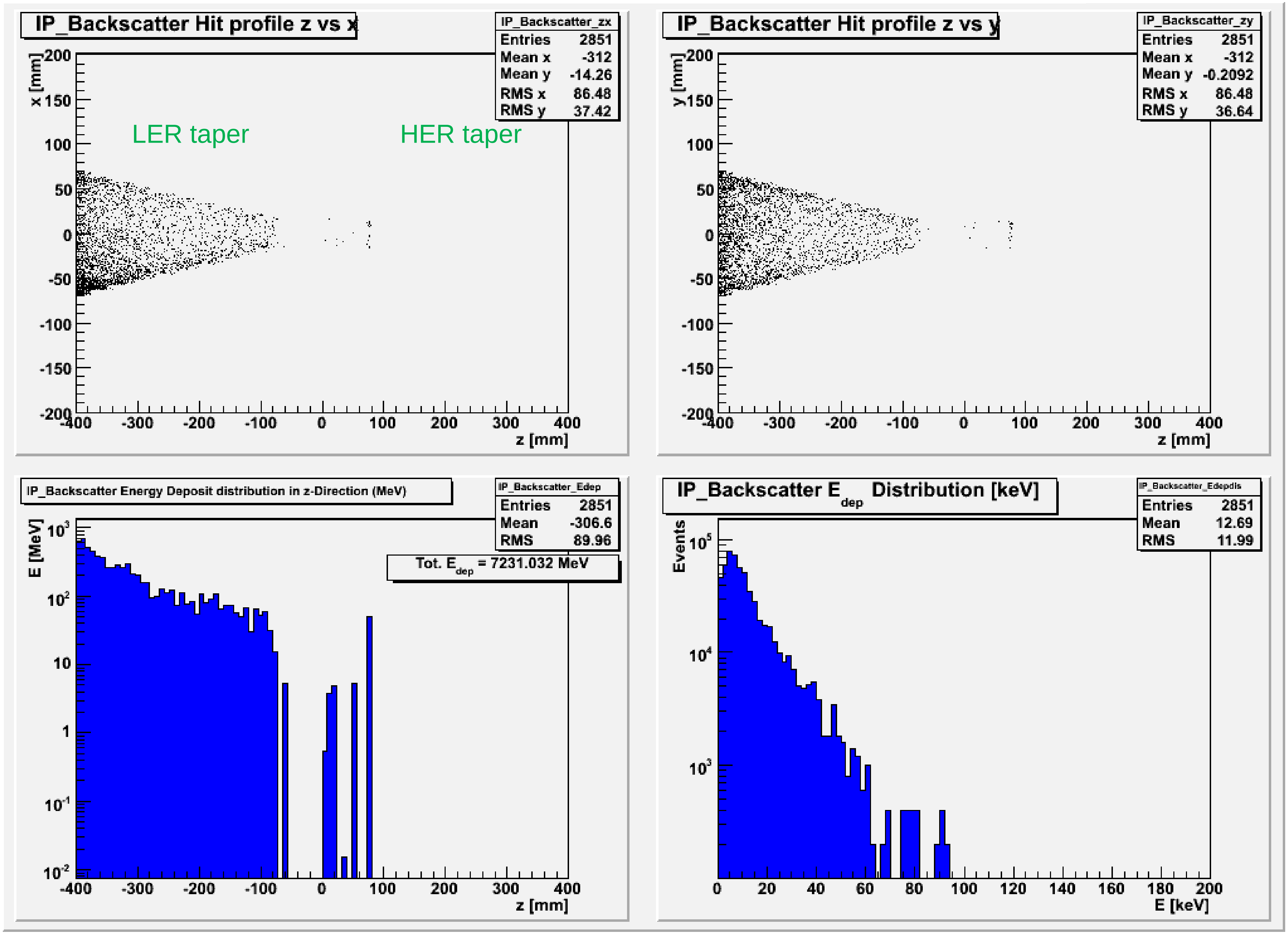
HER SR simulation (IP region)

C.Ng (Tokyo)



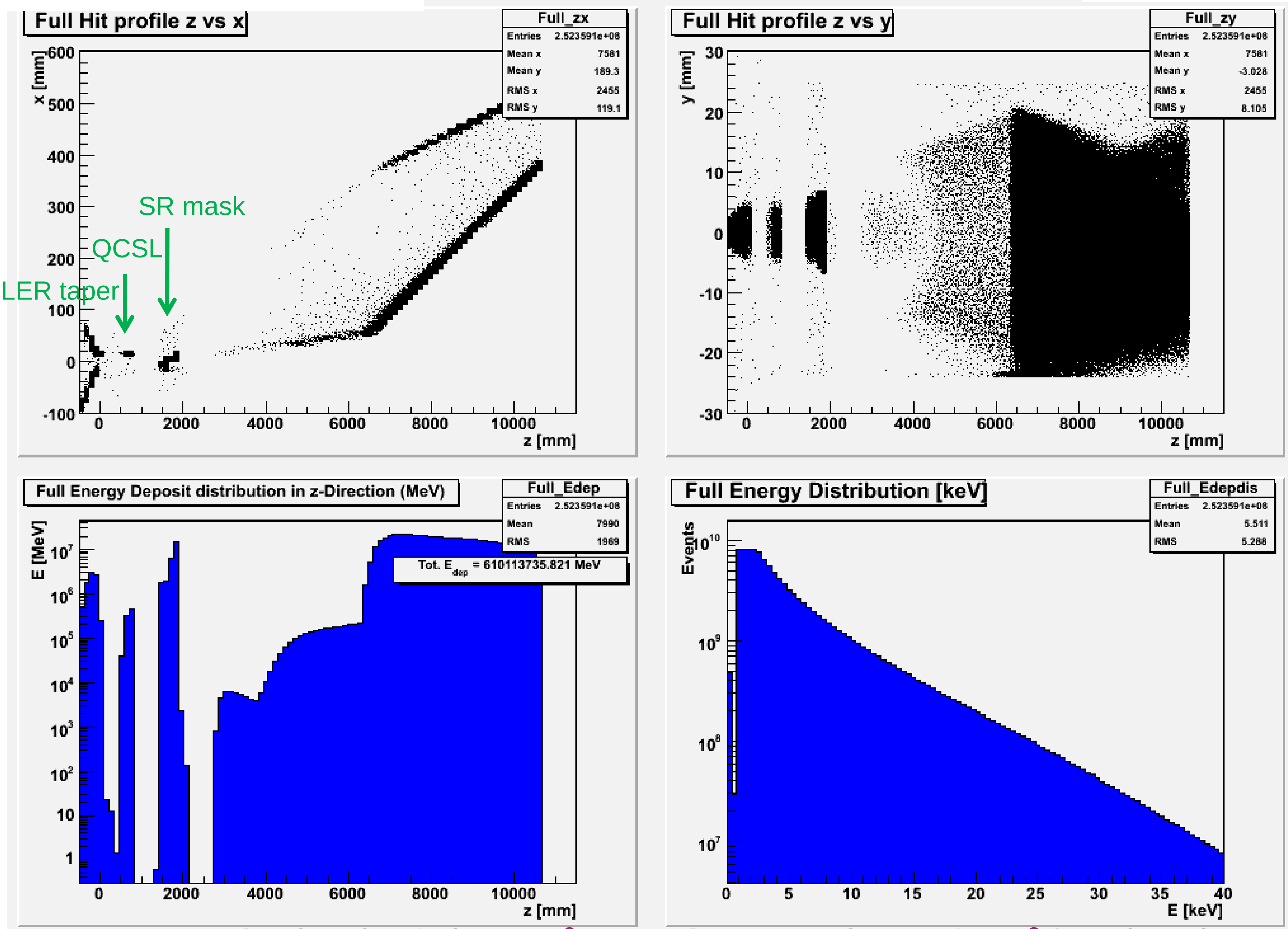
HER SR simulation (IP region:Back-scattered only)

C.Ng (Tokyo)



LER SR simulation

C.Ng (Tokyo)

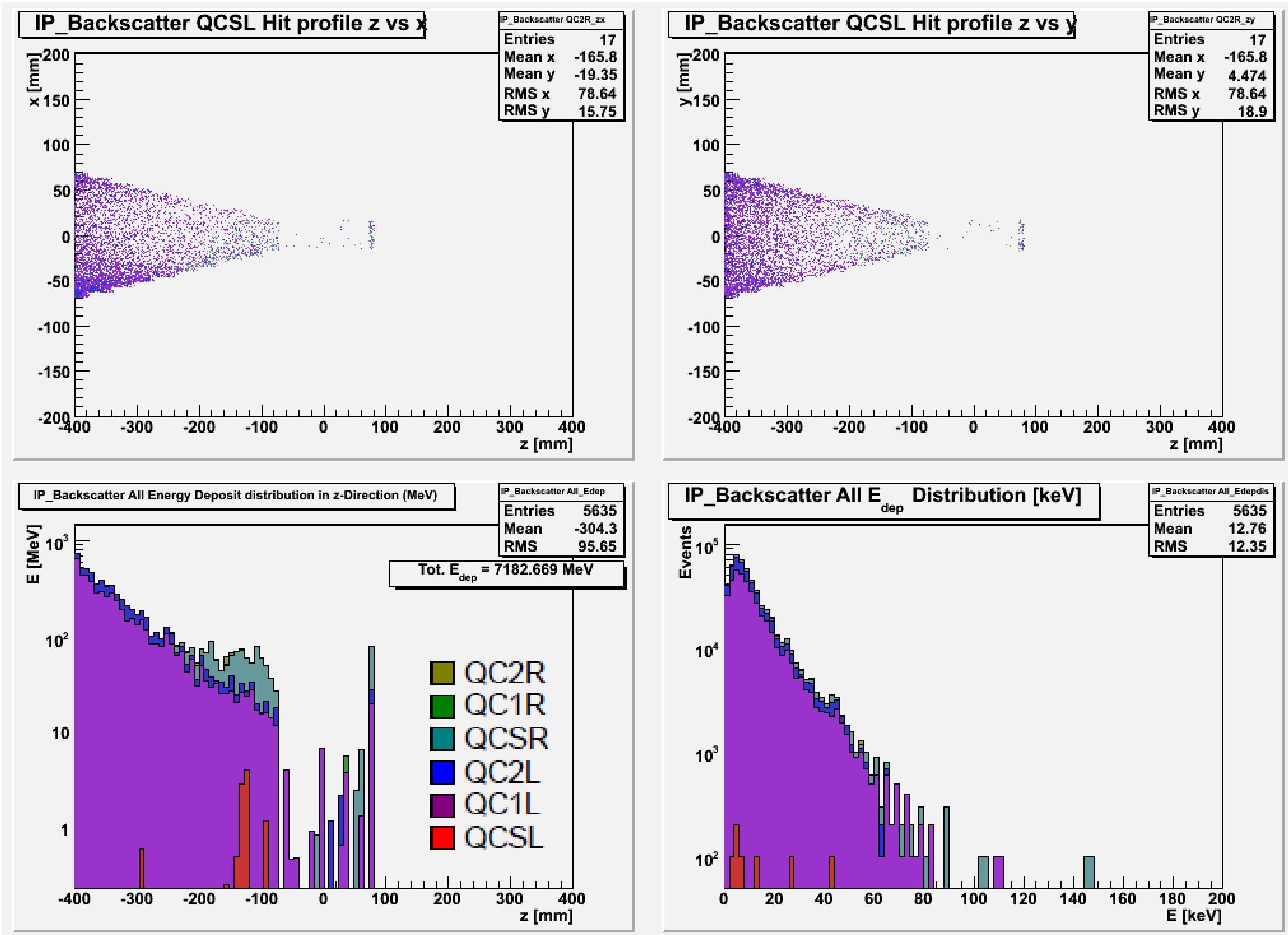


event for the simulation ~10^8 event → We need to scale 10^3 for a bunch

Back scattered particles

HER IP+Taper (E_{SR}>20keV)

C.Ng (Tokyo)



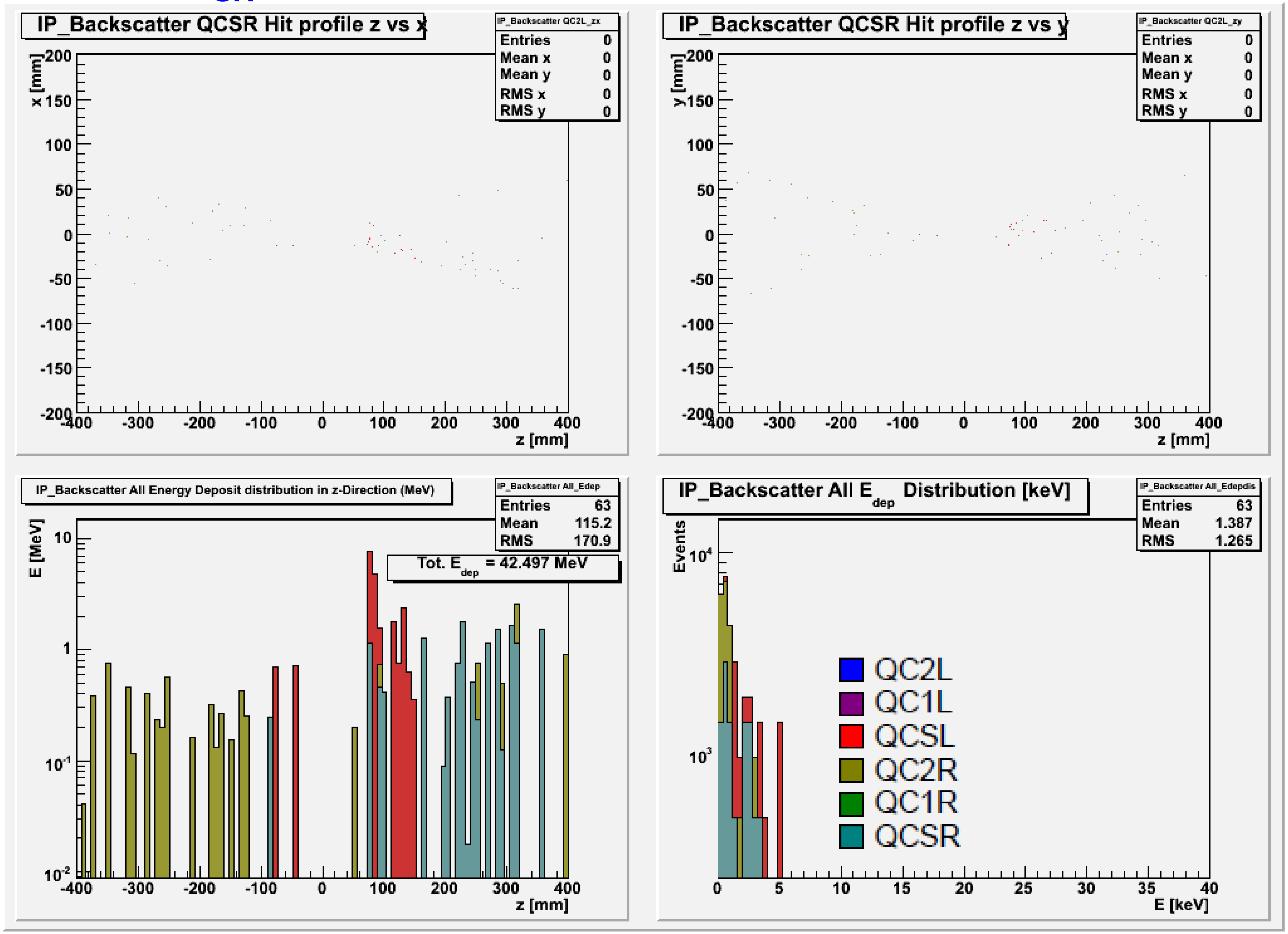
Back scattered particles in IR are caused by SR produced at QC1L & QCSR

~2000 particles in IP region Mainly (97%) charged particle ← can ignore them?!

Back scattered particles

LER IP+Taper (E_{SR}>1keV)

C.Ng (Tokyo)



Back scattered particles in IR are caused by SR produced at QCSL

Energy of back scattered particles is low

Dynamic beam-beam effect

Parameter search for smaller beam size

Y.Funakoshi

	no b-b	nominal			higher emittance			higher βx*			even higher βx*		
ν_{x0}		.503	.505	.510	.503	.505	.510	.503	.505	.510	.503	.505	.510
ε_{x0} [nm]								[illegible]	12	12	12	12	12
β_{x0}^* [cm]	20	20	20	20	20	20	20	40	40	40			
ξ_{x0}	0	.270	.270	.270	.135	.135	.135	.272	.272	.272	.273	.273	.273
ε_x [nm]		81.9						[illegible]	64.3	46.7	82.3	64.4	46.8
β_x^* [cm]		1.50	1.93	2.77	2.1	2.7	3.8	2.99	3.87	[illegible]			
σ_x@QC2RE [mm]	4.0	39.5	30.9										
No[illegible]													

Emittance ε (wo dynamic effect)

β (wo dynamic effect)

ε (with dynamic effect)

β (with dynamic effect)

5 times higher ε, 10 times smaller β in x

Dynamic effect at Super-KEKB is very strong

Beam size @ IR Q-magnets

ν_x =.505
(): 5 σ_x

	QC1LE	QC2LE	QC1RE	QC2RE	QC2LP	QC2RP
β_x^*=20cm QC2RE:元	8.2 (41)	26.9 (134.5)	11.6 (58)	28.8 (144)	14.7 (73.5)	18.6 (93)
β_x^*=20cm QC2RE->IP	8.4 (42)	19.0 (95)	12.0 (60)	20.7 (103.5)		
β_x^*=40cm QC2RE->IP	5.9 (29.5)	13.4 (67)	8.5 (42.5)	14.6 (73)	9.8 (49)	12.3 (61.5)

			QC1LE	QC2LE	QC1RE	QC2RE	QC2LP	QC2RP
	Field gradient	T/m	15.5	3.4	12.0	8.8	6.7	3.4
	Pole length	m	0.64	2.0	0.75	0.8	0.6	1.0
b	bore radius	mm	25	50	48	90	80	40
	Current	AT	3920	3400	11050	28400	17100	1980
	coil turns	/pole	3	8	3	16	15	3
	Current density of Septum conductor	A/mm^2	30	10	70	24	31	15
	Field in the area for couter-circulating beam	Gauss	0~-0.65	0~-0.4	0~-1.1	0~-0.35	0~-0.85	0~-0.35

Table 3.3: Parameters of special quadrupole magnets

SR BG studies

- SR BG may affect to

  Increase the vertex detector occupancy

  To keep ~1% occupancy for pixel (readout 10μsec) or

  ~10% occupancy for strip (readout 150nsec)

  # of SR hits (E>50keV) < ~100hits/bunch

  Heat the IP beam pipe

- In this talk, we show

  1. Upstream SR

     1-1. Design of IP beam-pipe to avoid SR hits from HER

     1-2. Study of the energy deposit to the IP beam-pipe

  2. Backscattered SR

     Estimate # of SR hit in the IR region

- For SR BG study,

  beam line simulation based on GEANT4 is constructed

Upstream SR — Simple beam pipe + 1st layer SVD + B-field of Q-magnets

Backscattered SR — Realistic beam pipe + SR data