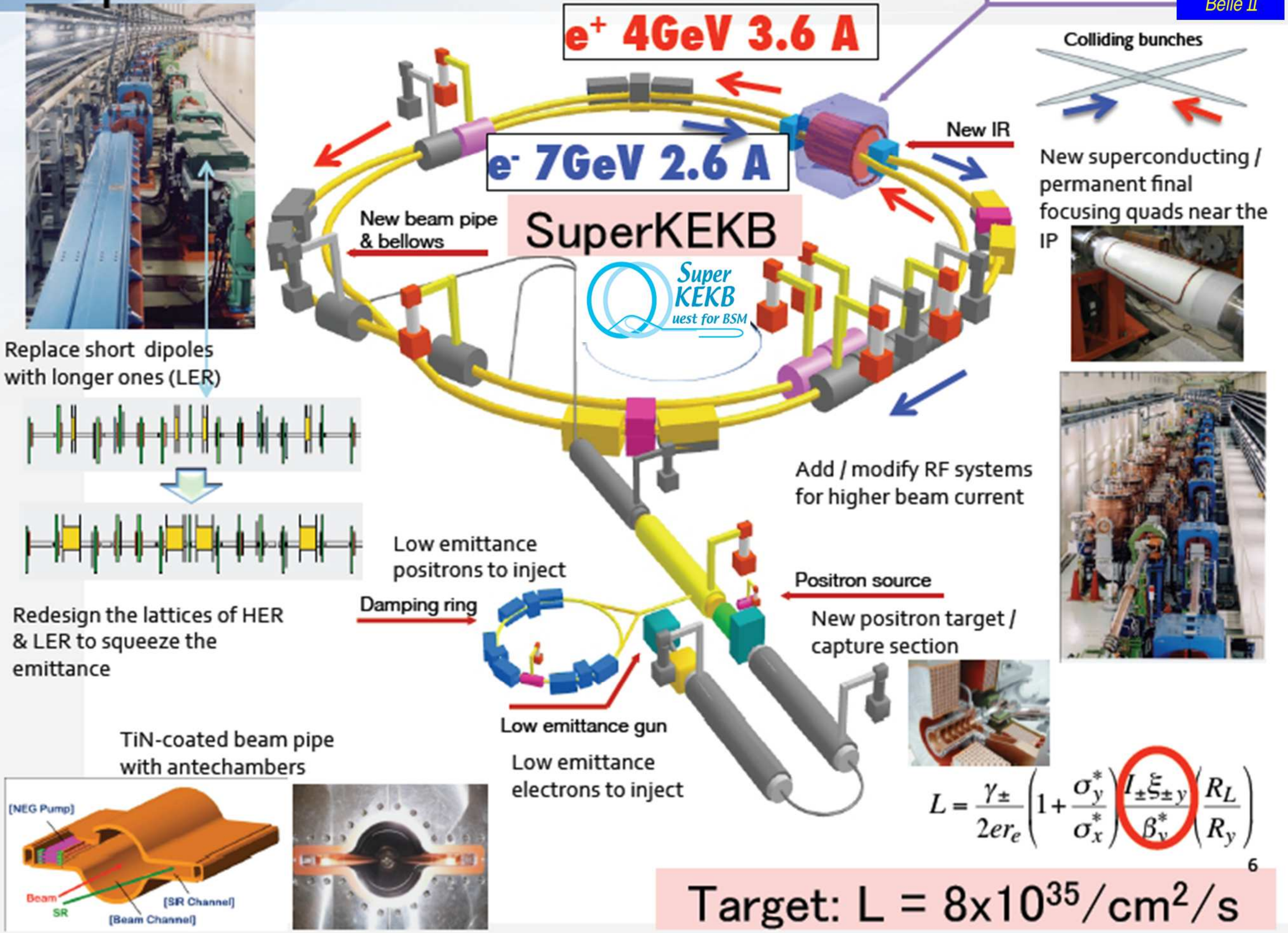
Beam Background at SuperKEKB/Belle-II

Shoji Uno, Hiroyuki Nakayama (KEK)

SuperKEKB and Belle II



$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

Target: L = $8\times10^{35}/cm^2/s$

Accelerator upgrade

At SuperKEKB, we increase the luminosity based on "Nano-Beam" scheme, which was originally proposed for SuperB by P. Raimondi.

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\left(\frac{R_L}{R_y}\right)$$

- Vertical β function at IP:

  5.9 mm → 0.27/0.30 mm (x20)

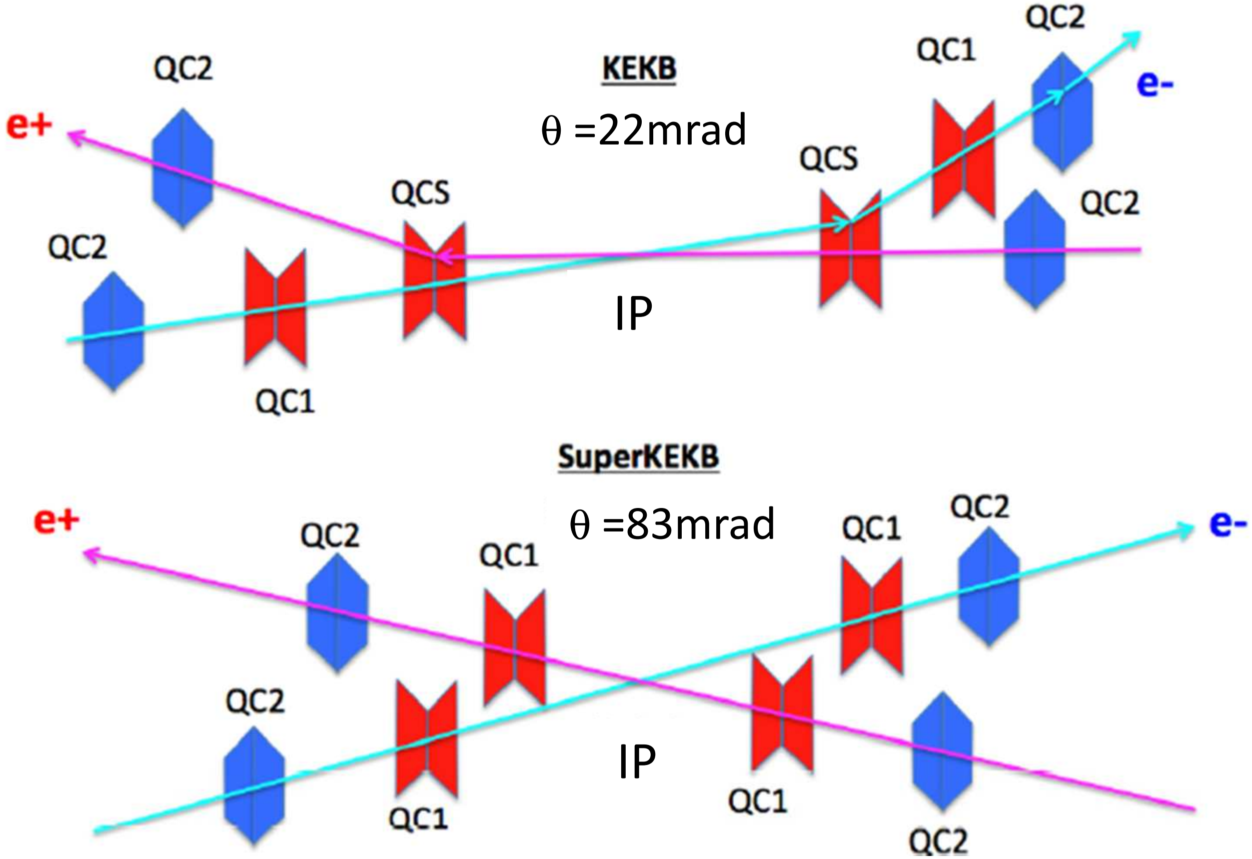
- Beam current:

  1.7/1.4 A → 3.6/2.6 A (x2)

Luminosity Gain

→ L = 2×10^{34} → ***8×10^{35} cm^{-2}s^{-1}*** (x40)

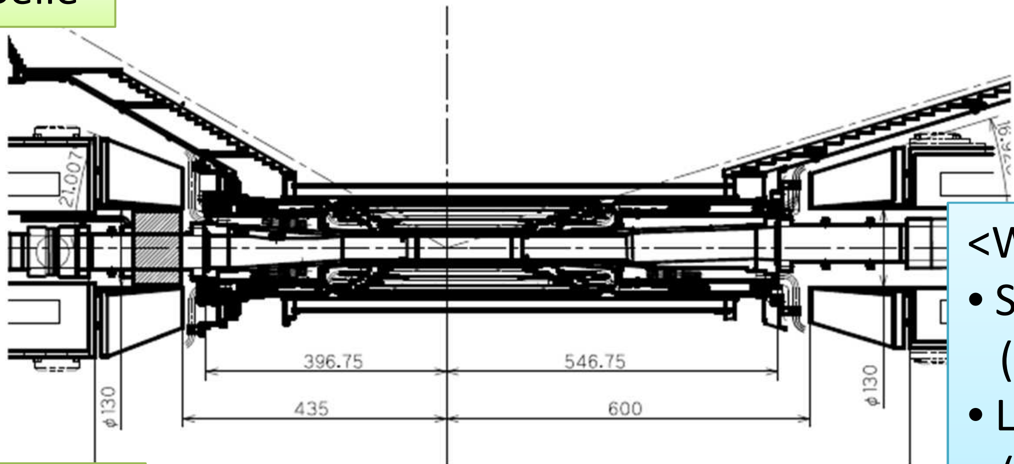
Beam crossing angle and final focusing magnets



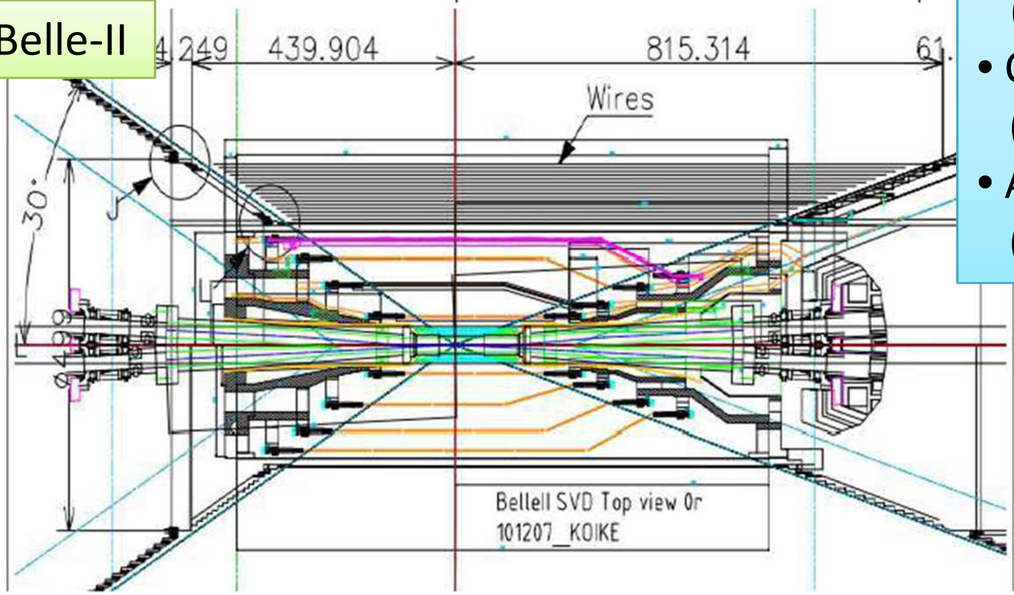
- Larger crossing angle: 22mrad→83mrad
- Final Q for each ring→ more flexible optics design
- No bend near IP→ less emittance, less background

Interaction region design

Belle



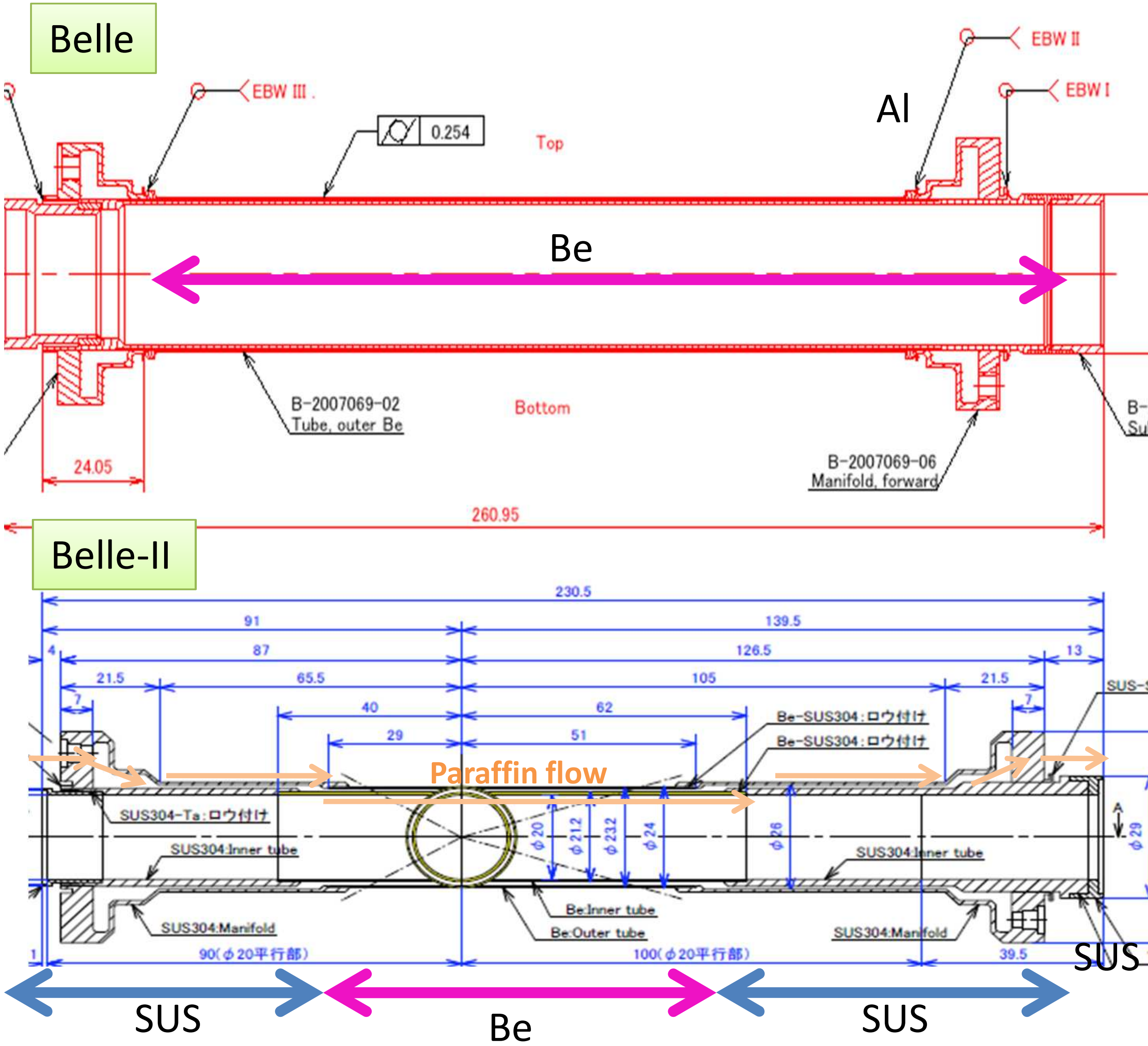
Belle-II



<What's new>

- Smaller beam pipe radius (r=15mm⇒10mm)
- Larger beam crossing angle (22mrad⇒83mrad)
- Crotch starts closer to IP (complicated IP beam pipe design)
- Additional innermost detector (PXD) (more cables, cooling pipes to go out)

IP beam pipe design



- Use shorter Be part (within acceptance)
- Gold plating (10um) to stop Synchrotron radiation
- Coolant (Paraffin, n=10) flow for wall current heat
- Allow Paraffin and vacuum to touch both side of welding
→ shorter and simpler Be shape (less expensive)

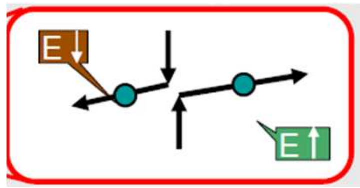
Background sources at SuperKEKB

- Background from scattered beam particles
- Background from physics processes
- Background from synchrotron radiation
- etc..

Background sources
~1. **Scattered beam particles**~

Touschek scattering

– Intra-bunch scattering, Rate$\propto$(beam size)$^{-1}$,$(E_{beam})^{-3}$

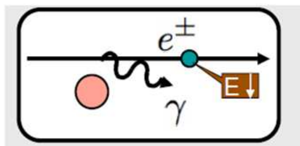


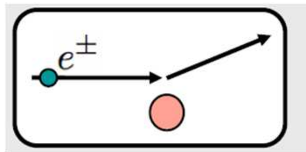
– Most dangerous background at SuperKEKB,
since beam size is x20 smaller ("Nano-beam scheme")

Beam-gas scattering

– Scattering by remaining gas, Rate $\propto$IxP

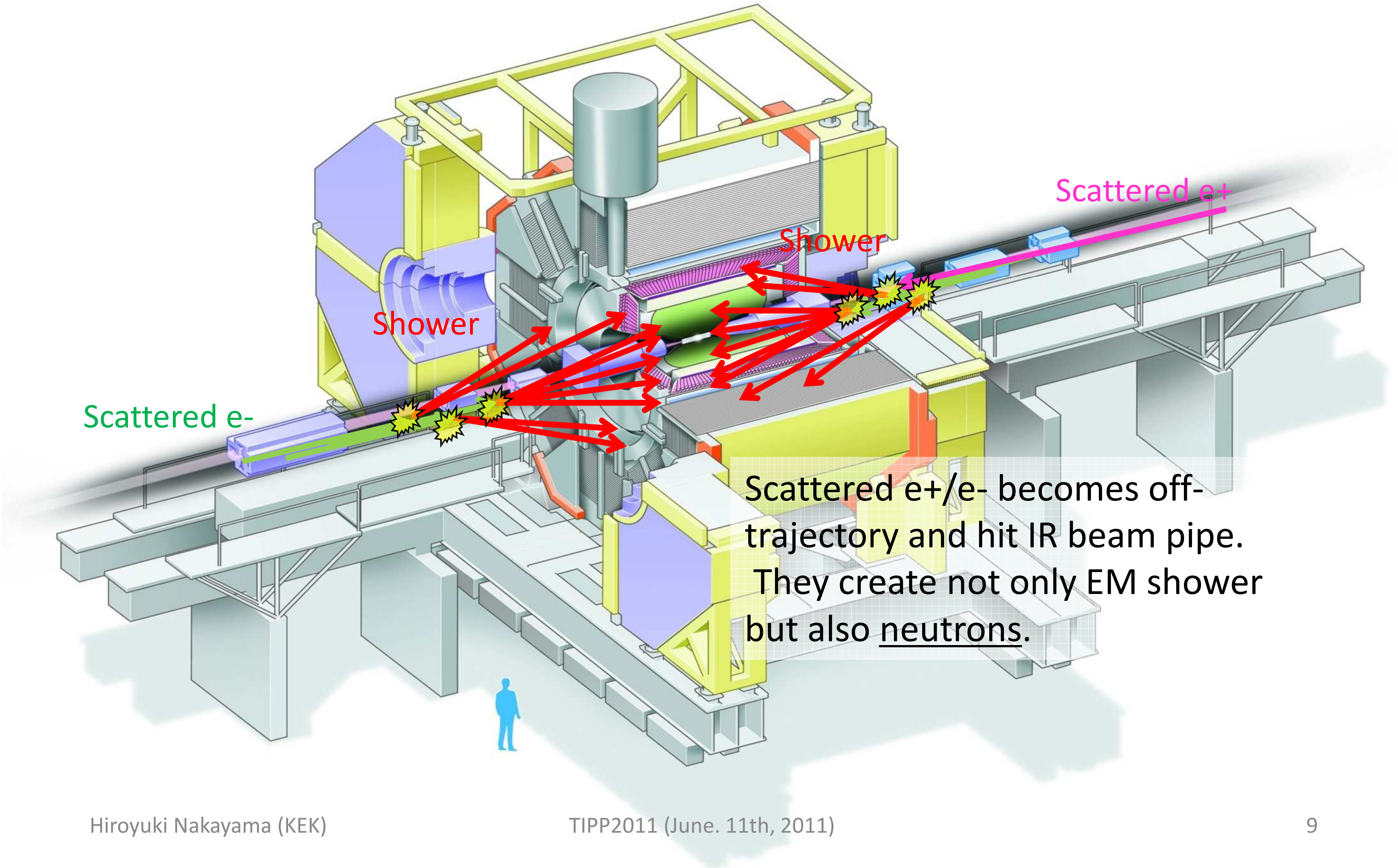
– Vacuum level at SuperKEKB will be similar to KEKB,
so less dangerous compared to Touschek scattering





– Vacuum level in IR region could be worse than KEKB, but particles scattered in IR region will be lost far downstream IP and will not be dangerous for the detector

Touschek/beam-gas background

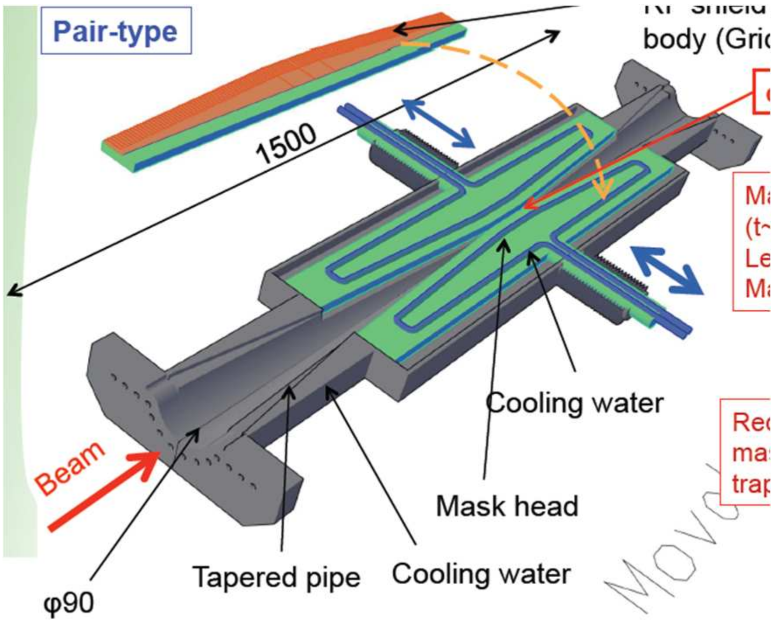


Scattered e+/e- becomes off-trajectory and hit IR beam pipe.
They create not only EM shower but also <u>neutrons</u>.

Countermeasures

Collimators in the ring

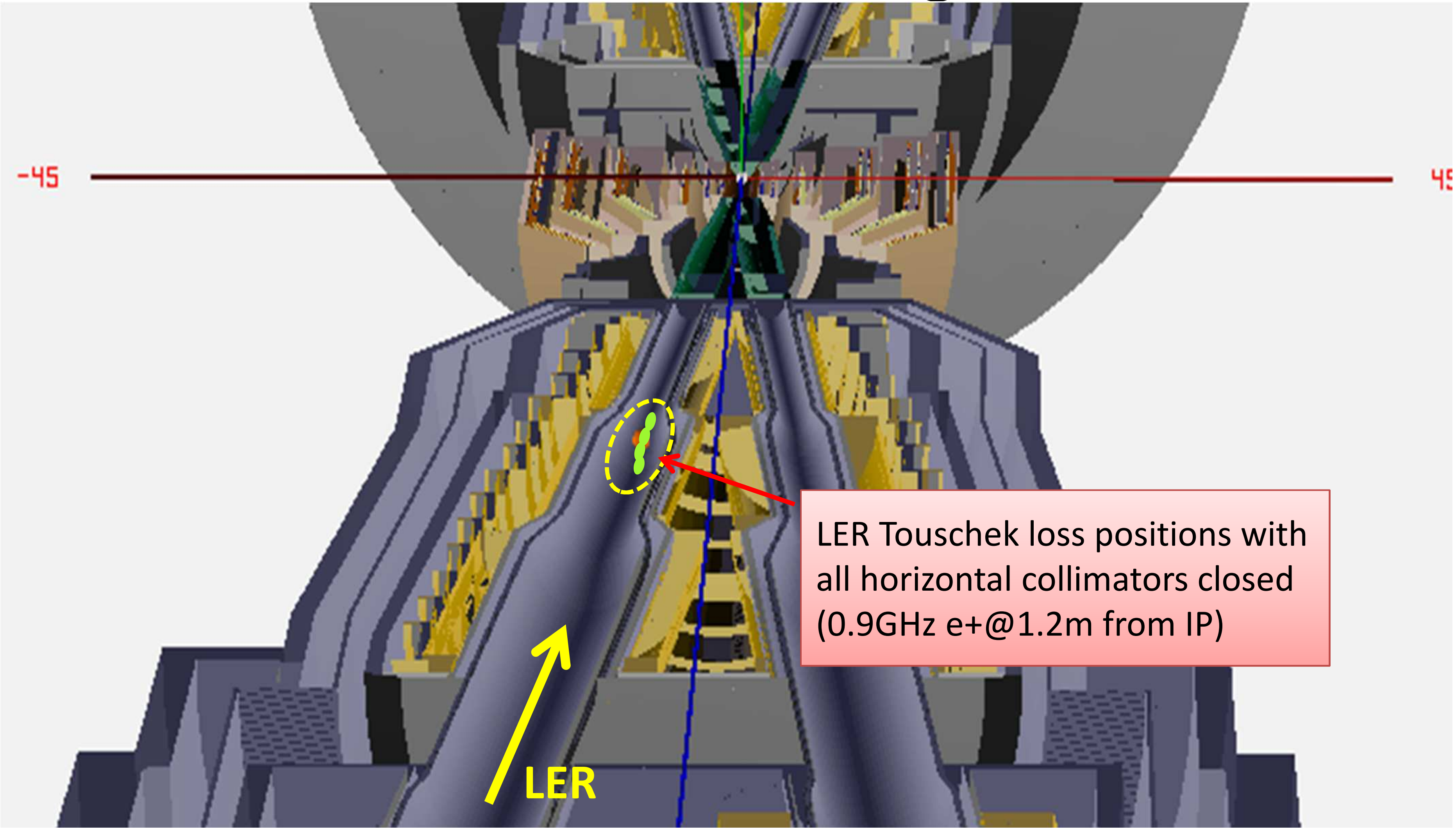
- Horizontal collimation from both inner/outer sides (+- ~12mm)
- Stop off-momentum e+/e- before reaching interaction region



Heavy-metal shield

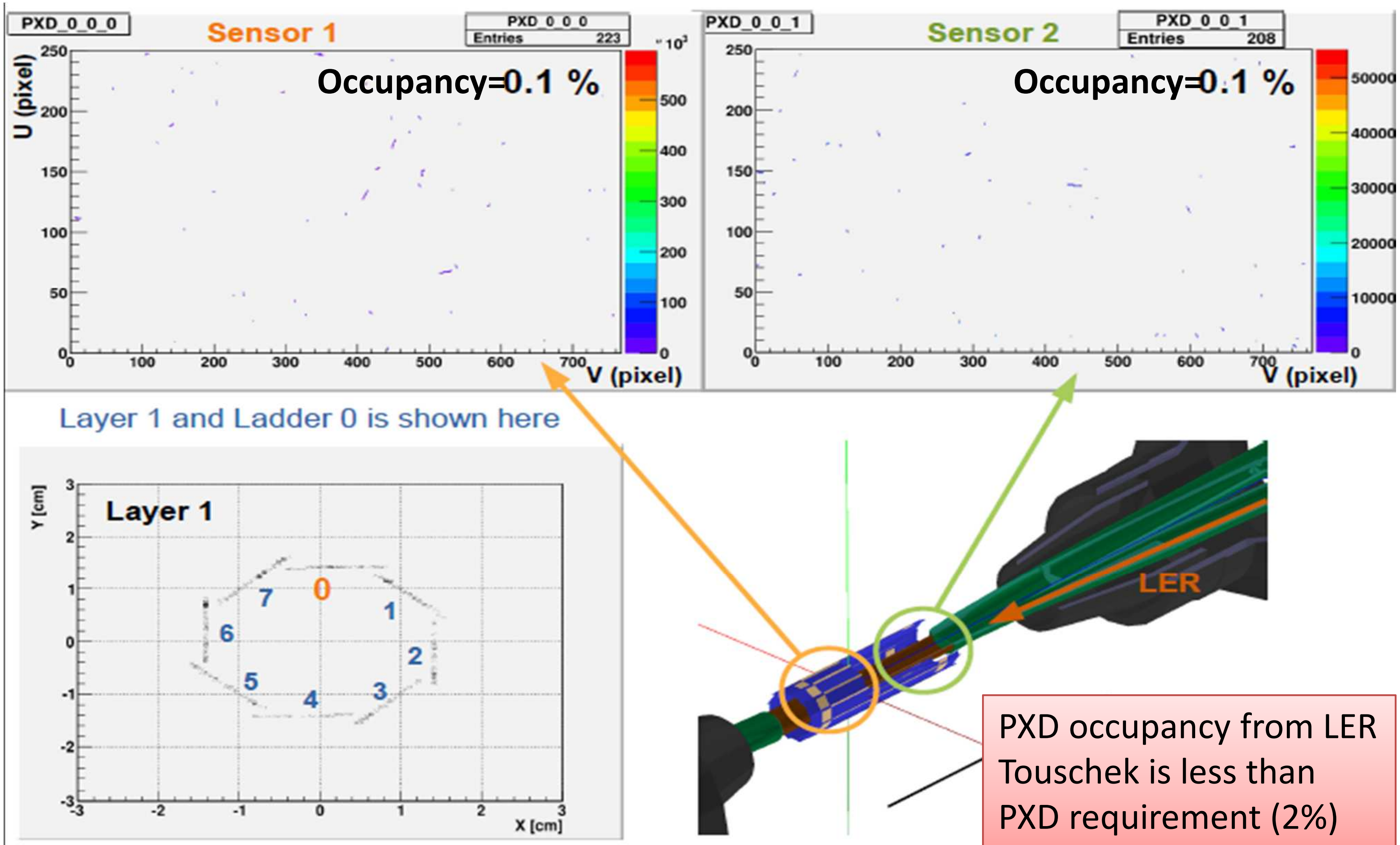
- Placed outside IR beam pipe
- Protect inner detector from EM shower created by loss particle

Loss position of LER Touschek background



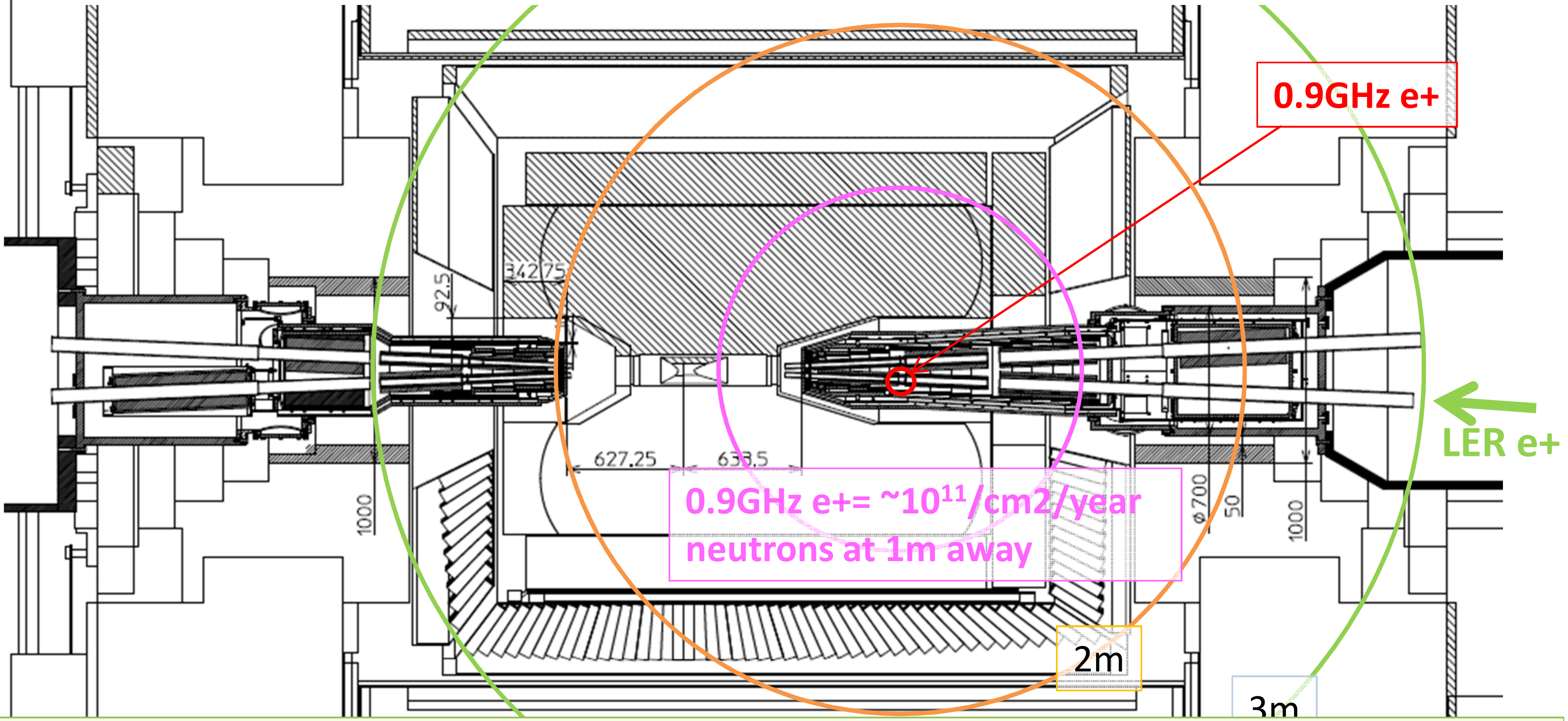
LER Touschek loss positions with all horizontal collimators closed (0.9GHz e+@1.2m from IP)

Simulated background hits on PXD



PXD occupancy from LER Touschek is less than PXD requirement (2%)

Neutron flux from LER Touschek



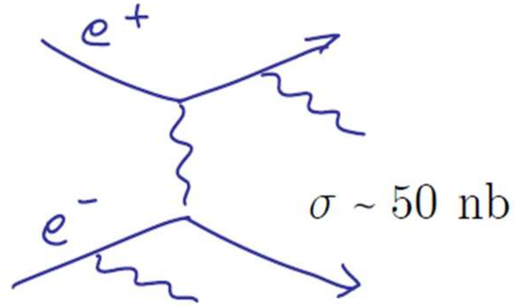
- γs in showers hit nuclei and generate 1~2 neutrons per e+ via "Giant Dipole Resonance".
- e+ hitting point is INSIDE detector. Almost no space to put neutron shield.
- <u>0.9GHz e+ = few*10^{11}/cm2/year neutrons </u>(1MeV equiv.):

  → comparable to our assumption for detector R&D

Background sources (cntd.)
~2. Luminosity dependent~

Radiative Bhabha

- Rate∝Luminosity (KEKBx40)
- EM shower from spent e+/e-:
  hit position is very far (~10m) from IP,
- Neutrons from emitted γ (hitting downstream magnet)
  Need to increase neutron shields in the tunnel

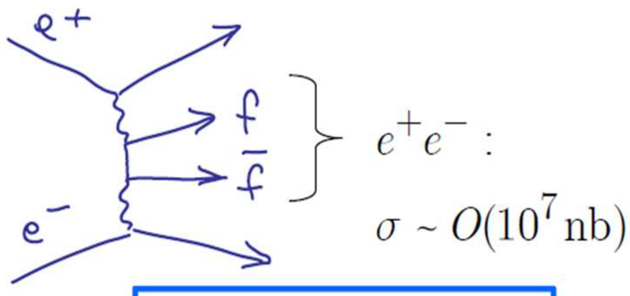


Bhabha scattering

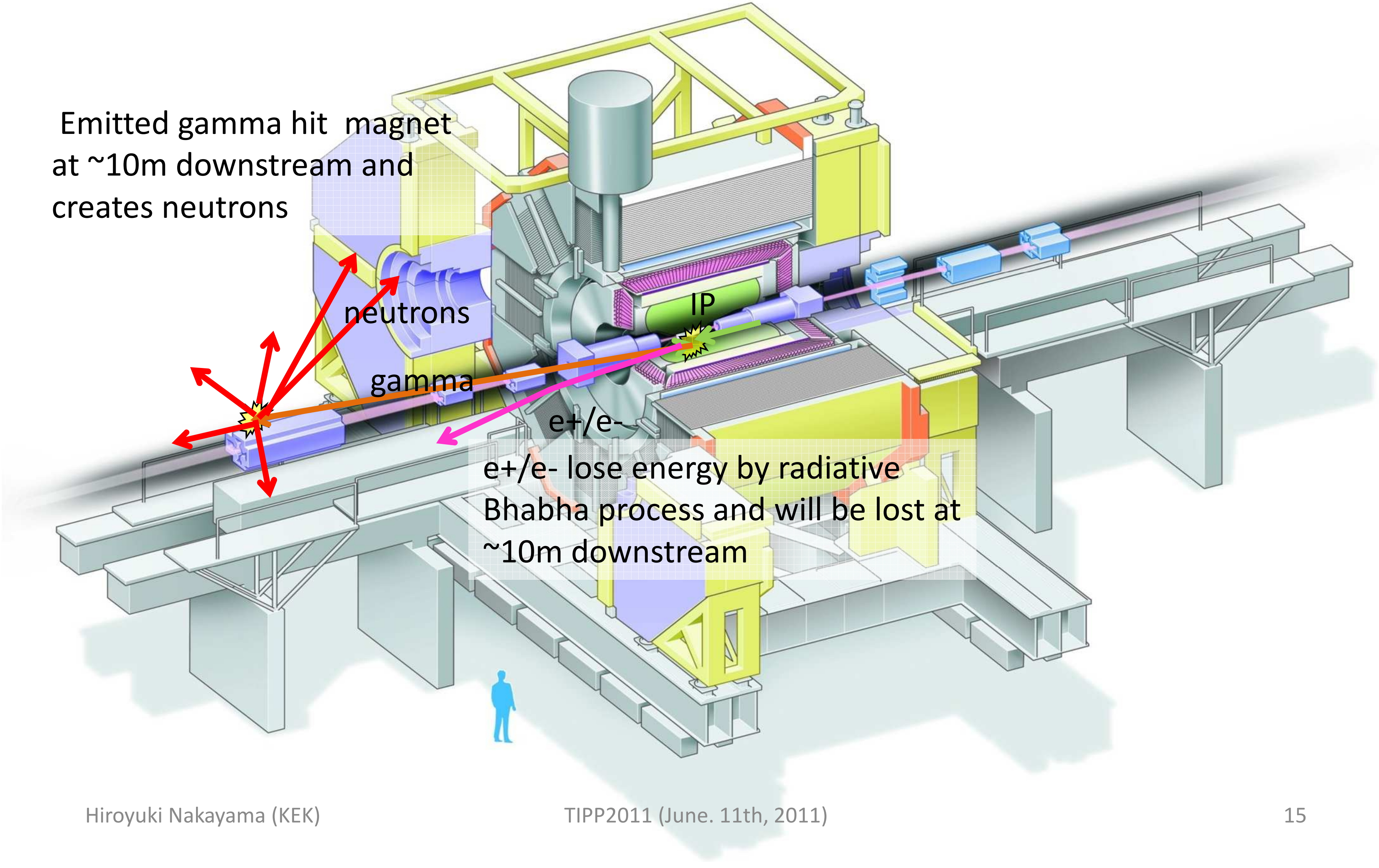
2-photon process

- Generated e+e- pair might hit PXD
- Confirms to be OK, according to KoralW simulation and KEKB machine study

"0.2%(<<2%) occupancy on PXD"

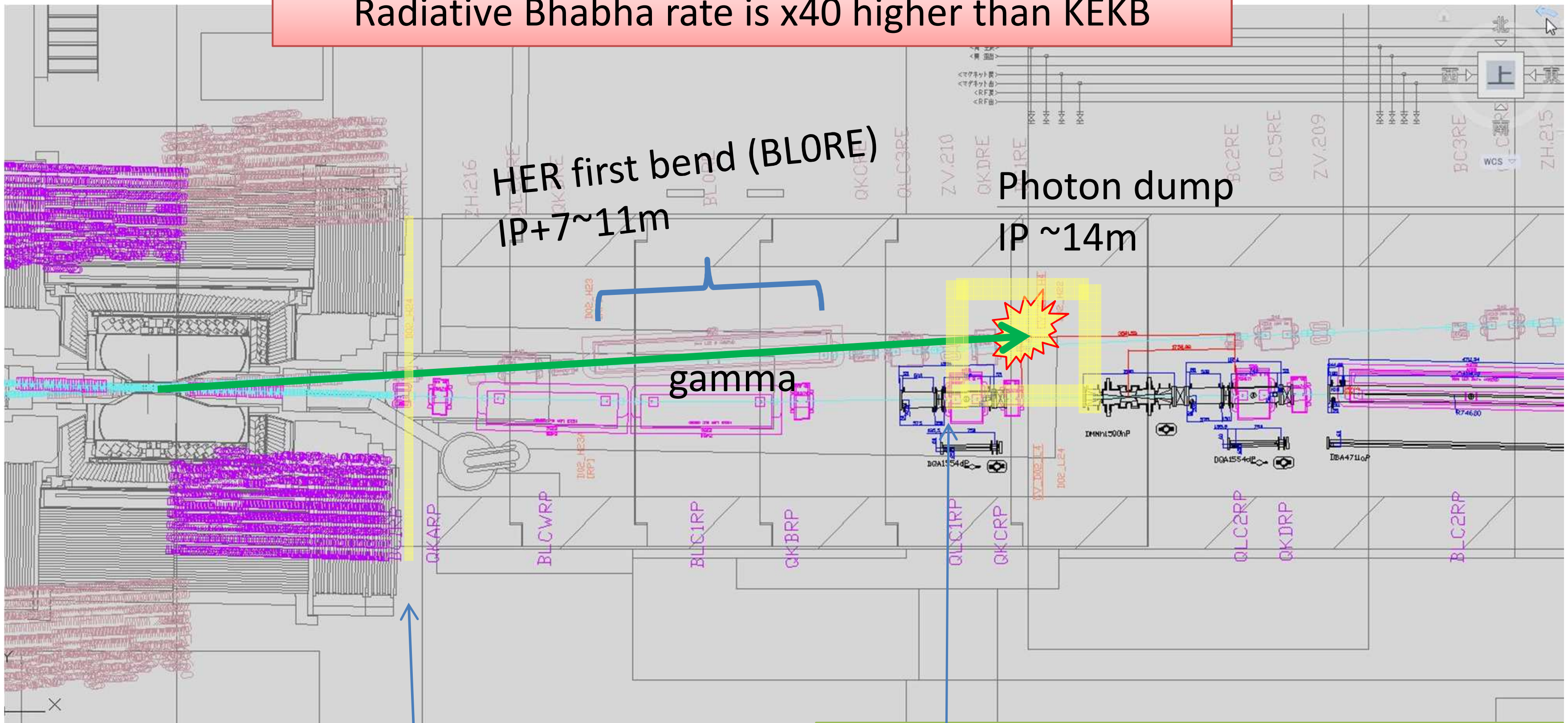


Radiative Bhabha



Additional neutron shield around radiative Bhabha photon dump

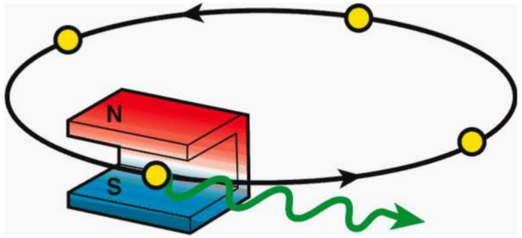
Radiative Bhabha rate is x40 higher than KEKB



Polyethylene shield (10cm) at KEKB

Additional neutron shield around photon dump is necessary

Background sources (cntd.)
~3. Synchrotron radiation~



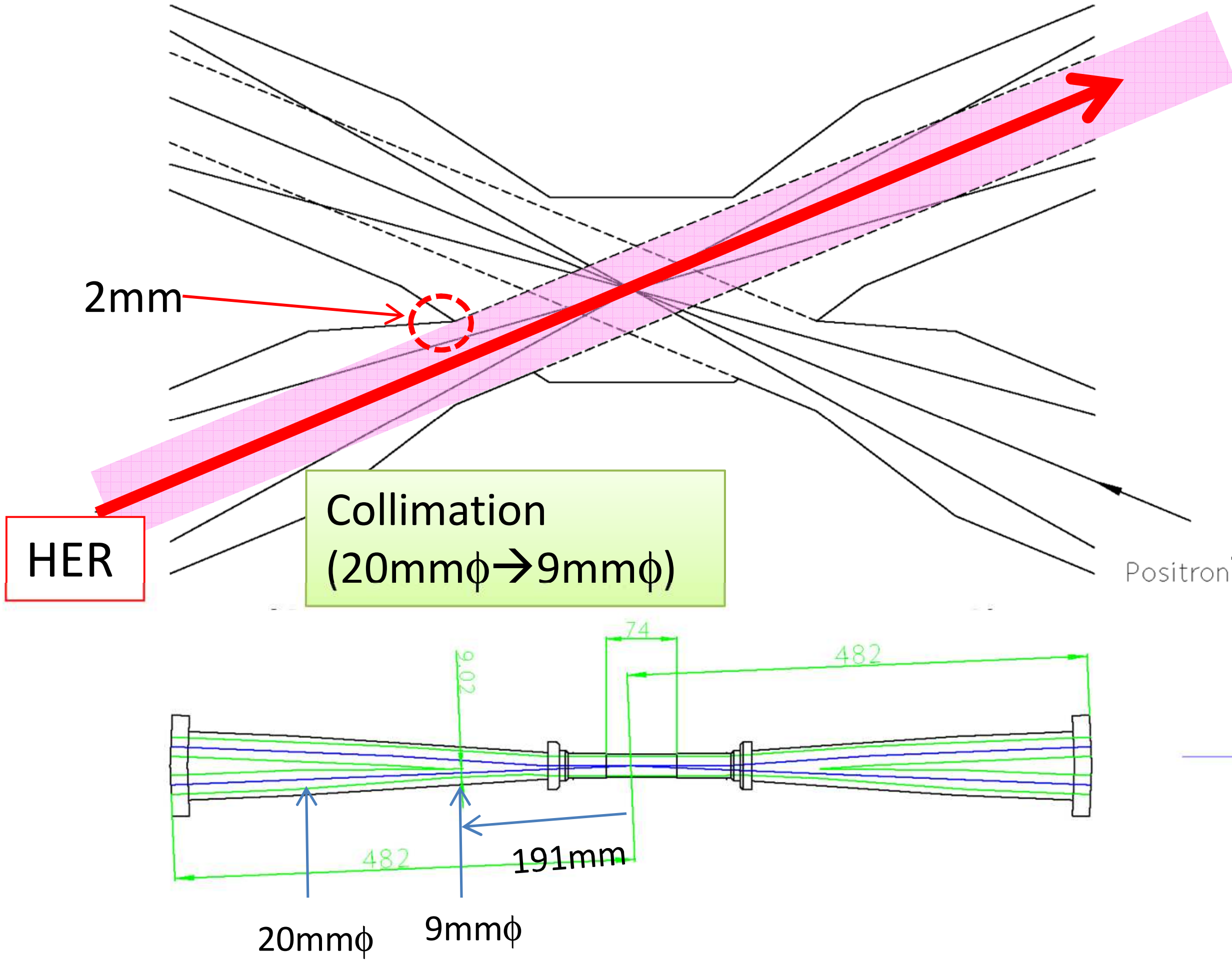
Synchrotron radiation

- Rate ∝ E^2B^2: mainly from HER
- Photons are emitted inside upstream final focusing magnet
  → hit IP beam pipe (Be) and penetrate → reach PXD/SVD

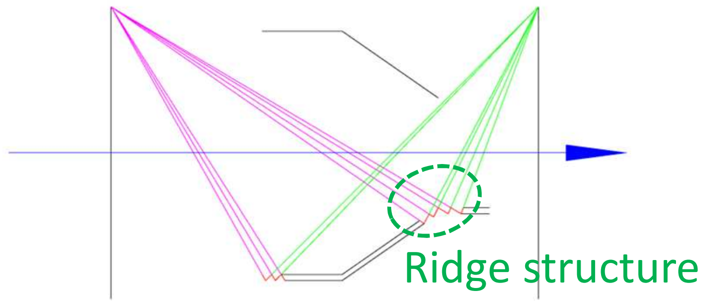
Back-scattering synchrotron radiation

- At Belle, e+/e- are strongly bent by downstream magnet and emit SR. These photons hit downstream beam pipe and scattered back to detector.
- At Belle-II, such strong bend does not exist. We don't have to worry about this background.

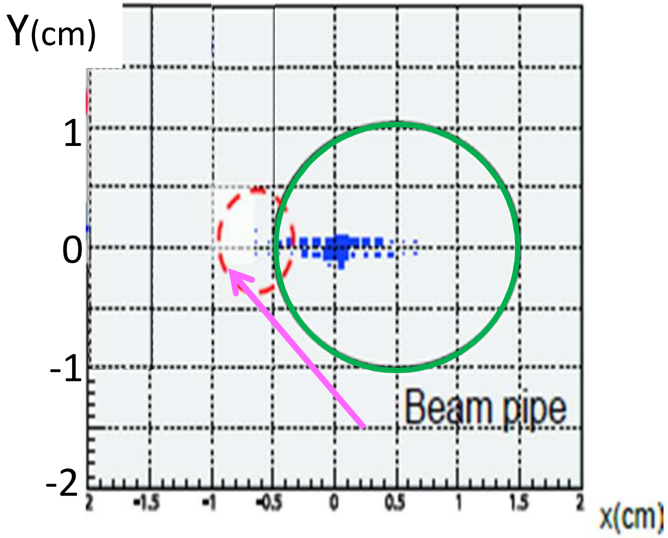
Beam pipe design



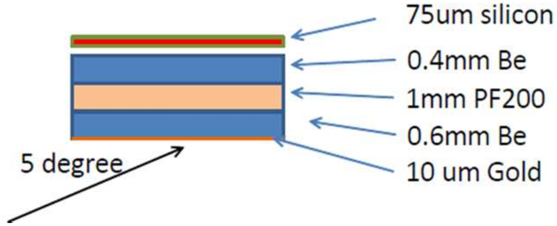
- Collimation part of incoming pipe stops most of SR.
- The minimum distance of the duct wall from the beam stay clear is 2 mm.
- HOM can escape through the pipes for the outgoing beam.
- "Ridge (saw-tooth)" structure on inner surface of collimation part to hide Be pipe from reflected/scattered SR.



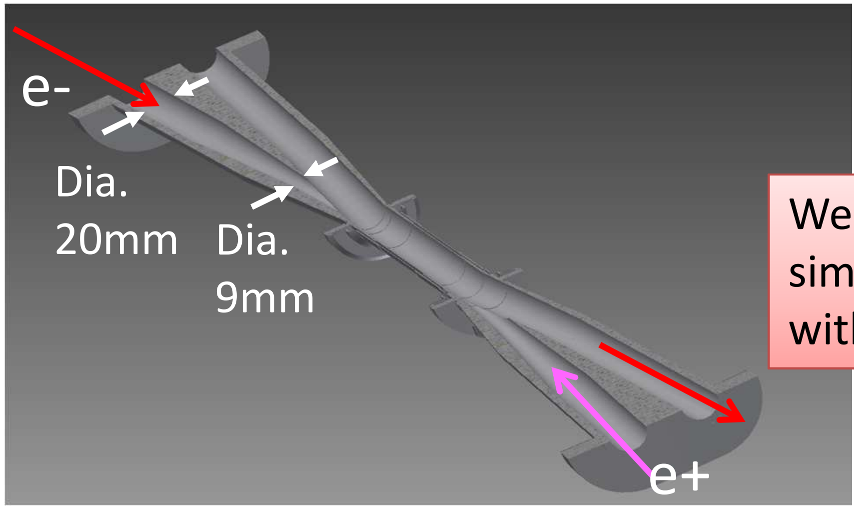
Simulation status



Stand-alone simulation with simple geometry shows ~200/bunch (>5keV) photons hit straight part of beam pipe, which is far below PXD requirements.



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



We will simulate again in our full-detector simulation framework with exact geometry, with the leak magnetic field.

Summary

- Touschek scattering is most dangerous background source for Belle-II/SuperKEKB. Both EM shower and neutrons from Touschek loss particle should be carefully examined.
- Preliminary study shows Synchrotron radiation is safe. This will be updated taken into account the leak field , mis-alignment, and tip-scattering.
- Radiative Bhabha, 2-photon process might not be a big problem.

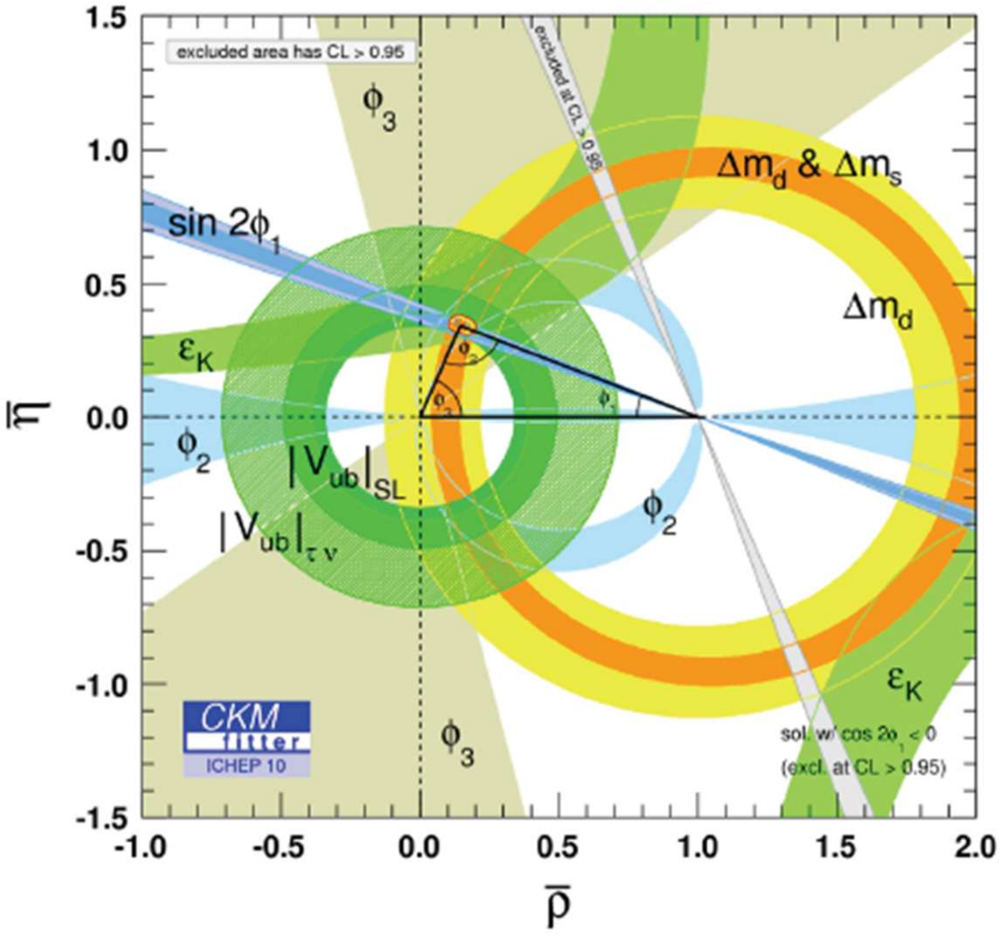
Simulation status summary

Source	Comment
Touschek	0.9GHz loss from LER in IR region. This is tolerable for PXD/SVD. Impact on outer detector is being simulated. Rate from HER is also being simulated.
Neutrons from Touschek loss	~2GHz from LER: Comparable to detector assumption (~10^{11}/cm2/year at 1m away from source point). Very difficult to shield. Rate from HER is under simulation.
Beam-gas	KEKBx2: OK. Much less than Touschek
e+/e- from rad. Bhabha	OK: Loss position is far enough(~10m downstream), thanks to individual final Q magnet.
Neutrons from rad. Bhabha	KEKBx40: Generated at ~10m downstream. We should increase neutron shields in the beam tunnel.
2-photon process	OK: Simulated PXD occupancy is small enough: 0.2%(<<2%) (using BDK/KoralW). Simulation is confirmed by KEKB machine study.
SR	OK: Simple simulation has already shown it's OK. Leak field impact should be updated. Tip-scattering beam test is planned.
Beam-beam	Accelerator group are now investigating.

backup

Primary Target of KEKB/Belle

... was to confirm Kobayashi-Maskawa mechanism.



... and was so successful.

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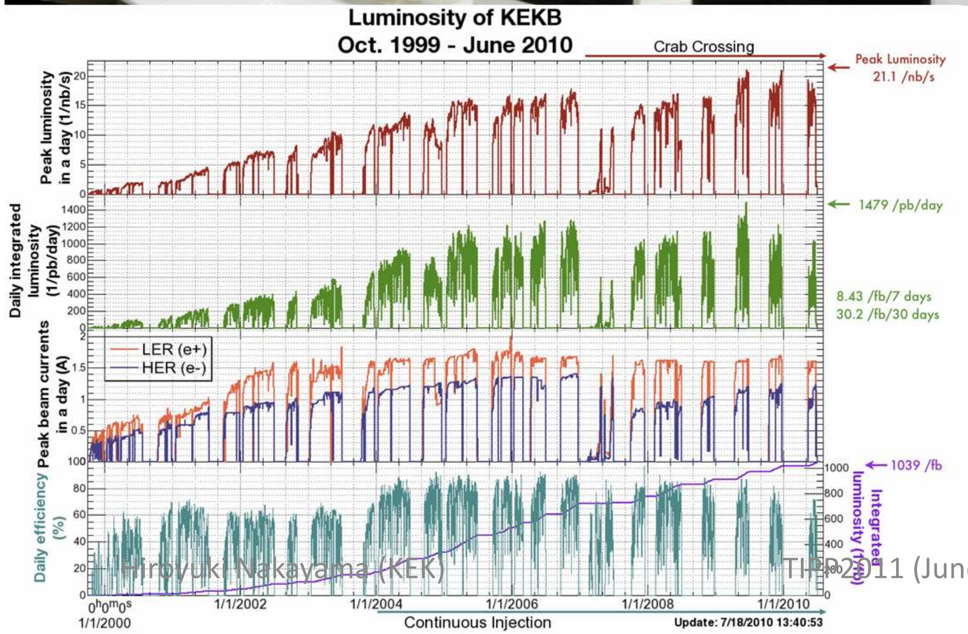
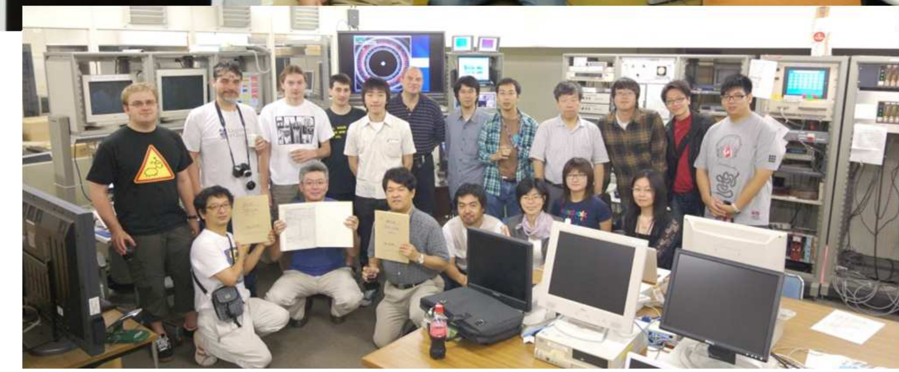
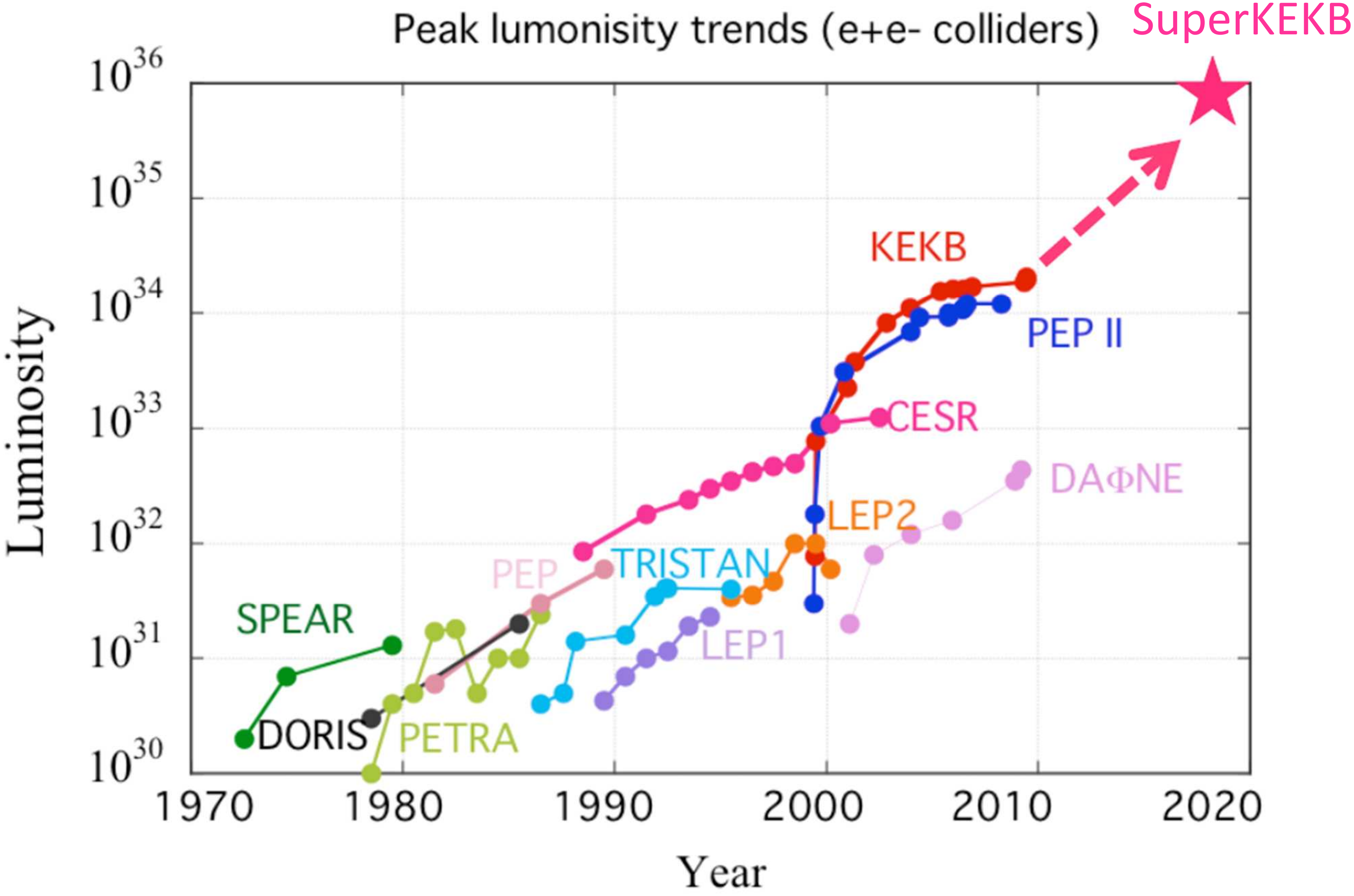
The last beam abort of KEKB on June 30, 2010





First physics run on June 2, 1999
Last physics run on June 30, 2010
L_{peak} = $2.1 \times 10^{34}/cm^2/s$
L > $1 ab^{-1}$

SuperKEKB Luminosity



Simulation framework

- Touschek/beam-gas generator: SAD or TURTLE
- Radiative Bhabha generator: BHWide, BBBrem
- 2-photon process generator: BDK or KoralW
- Synchrotron radiation generator: GEANT4

- Detector responses full simulation: GEANT4

Collimator width

How narrow we can collimate the beam without losing lifetime?
The minimum width dx is given by:

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

$$d_{x\beta} = n_x\sqrt{\varepsilon_x\beta_x},\ \ d_{x\eta} = \eta_x(n_z\sigma_\delta)$$

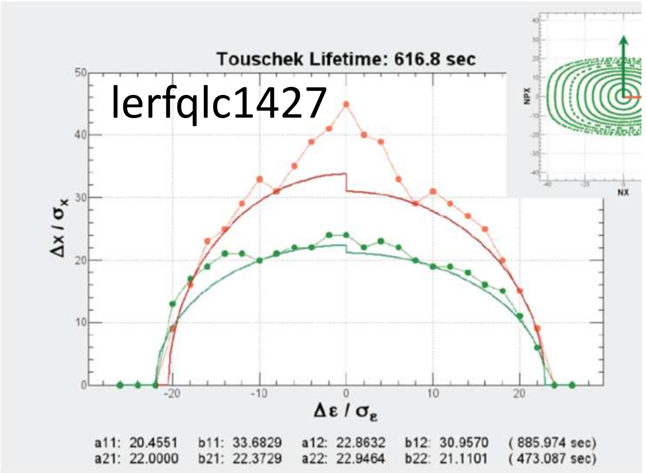
Or, use this value to be conservative

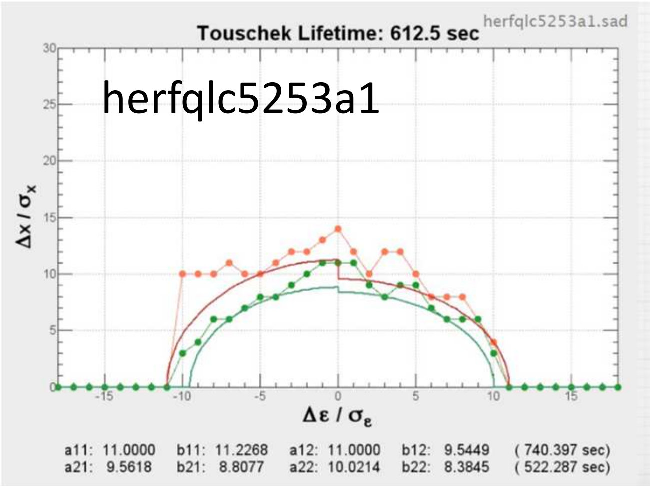
$$d'_{x\beta} = \sqrt{\frac{\beta_{x,\mathrm{mask}}}{\beta_{x,\mathrm{QC2}}}}r_{\mathrm{QC2}}$$

QC2 beam-pipe equivalent radius at mask position

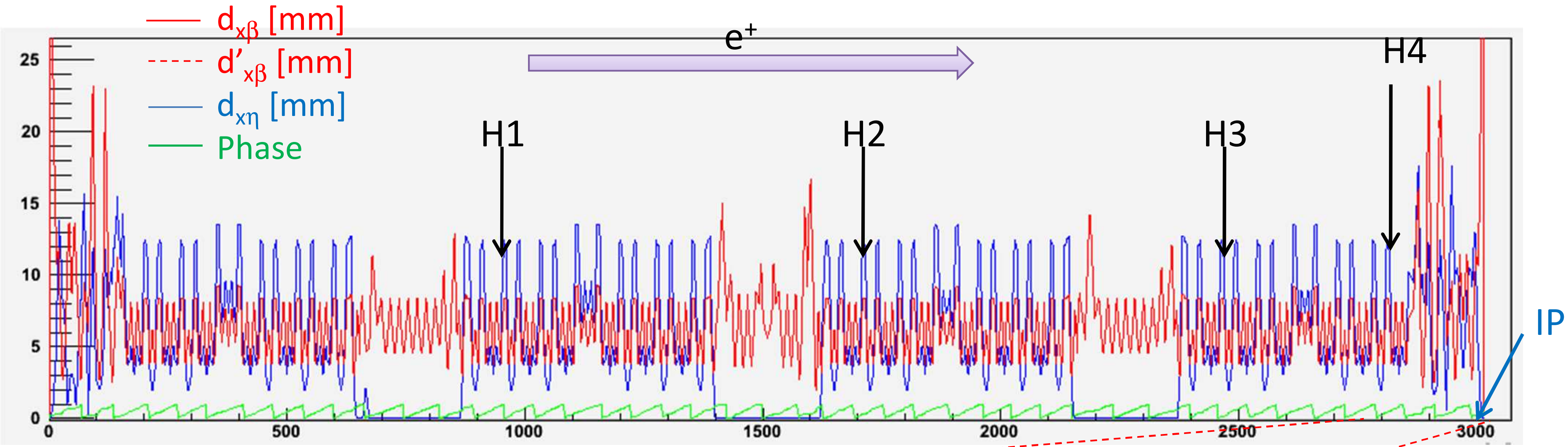
For SuperKEKB LER,
n_x = 30, n_z = 22, ε_x = 3.2 nm, σ_δ = 0.00080
r_{QC2} = 35 mm, $\beta_{x,QC2}$ = 424 m (at QC2RP2216)

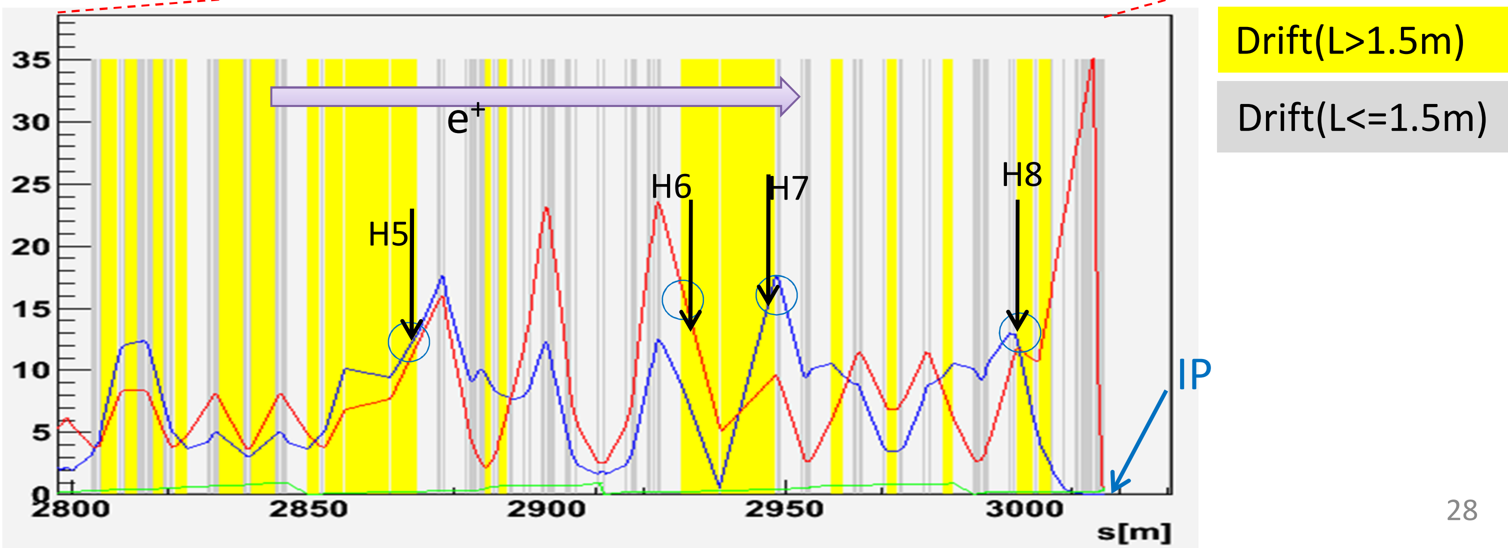
For SuperKEKB HER,
n_x = 15, n_z = 14, ε_x = 4.3 nm, σ_δ = 0.00066
r_{QC2} = 40 mm, $\beta_{x,QC2}$ = 974 m (at QC2LE3060)



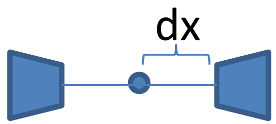


LER collimators





LER collimators



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

$$d_{x\beta} = n_x\sqrt{\varepsilon_x\beta_x}, \quad d'_{x\beta} = \sqrt{\frac{\beta_{x,\mathrm{mask}}}{\beta_{x,\mathrm{QC2}}}}\, r_{\mathrm{QC2}}$$

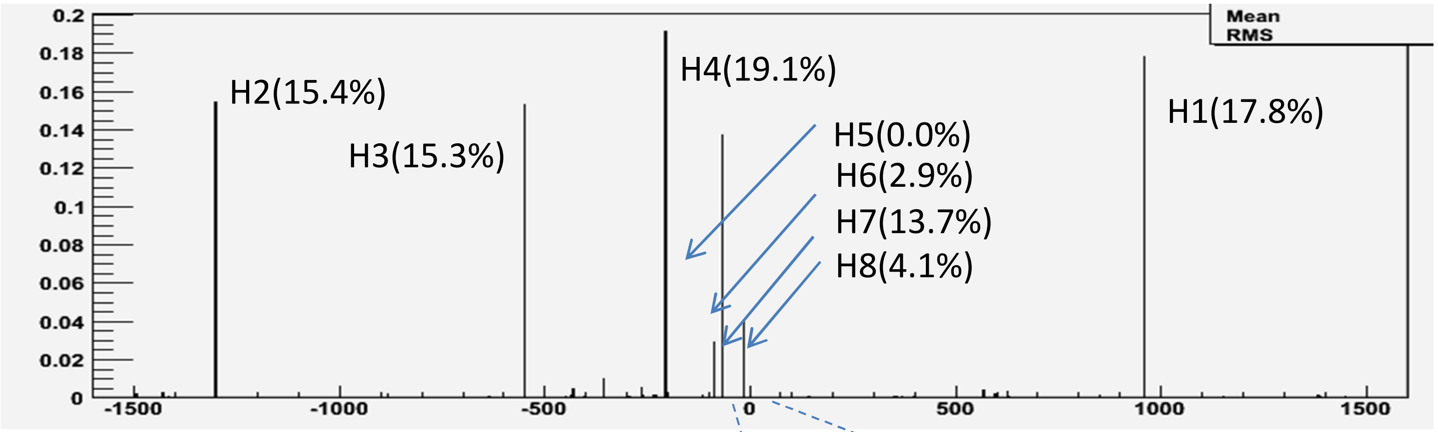
$$d_{x\eta} = \eta_x(n_z\sigma_\delta)$$

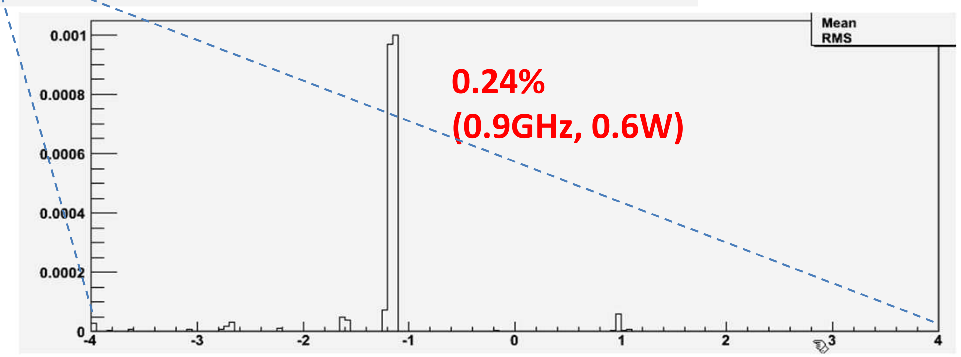
Based on lerfqlc1427

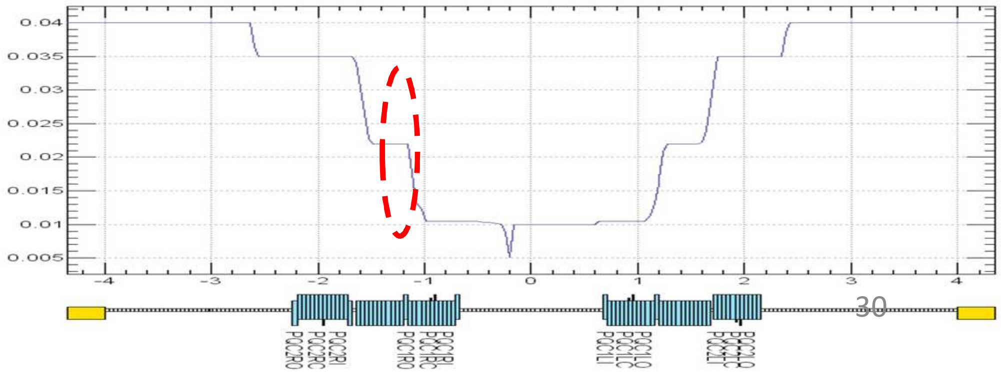
			Element				s[m]	L[m]	betax[m]	etax[m]	phase	dxb[mm]	dxh[mm]	d'xb[mm]
H1	upstream	of	**L8P.13**	(near	SF4NLP.1	)	956.17	**3.20**	24.37	0.70	14.00	8.38	**12.34**	8.39
H2	upstream	of	**L8PMH1.1**	(near	PMD06H1	)	1710.94	**2.87**	24.33	0.70	25.29	8.37	**12.31**	8.38
H3	upstream	of	**L8P.32**	(near	SF4OLP.1	)	2463.72	**3.20**	24.37	0.70	36.11	8.38	**12.34**	8.39
H4	downstream	of	**-L8PMHD3.4**	(near	-PMD03H4	)	2813.88	**2.53**	24.30	0.70	41.45	8.37	**12.28**	8.38
H5	downstream	of	**LLA8R**	(near	-BLA6RP.1	)	2872.80	**5.57**	51.94	0.74	42.29	12.23	**12.98**	12.25
H6	upstream	of	**LLB3R**	(near	BLB3RP	)	2927.91	**7.91**	96.47	0.50	43.26	16.67	8.83	**16.70**
H7	downstream	of	**LLB2R**	(near	QLB2RP	)	2947.61	**11.20**	31.98	-1.00	43.42	9.60	**17.60**	9.61
H8	upstream	of	**LLC2R**	(near	PQLC2RC	)	2998.47	**3.52**	47.82	-0.70	44.25	11.74	**12.34**	11.75

H5 might be removed, since it stops almost nothing.

LER Touschek loss positions







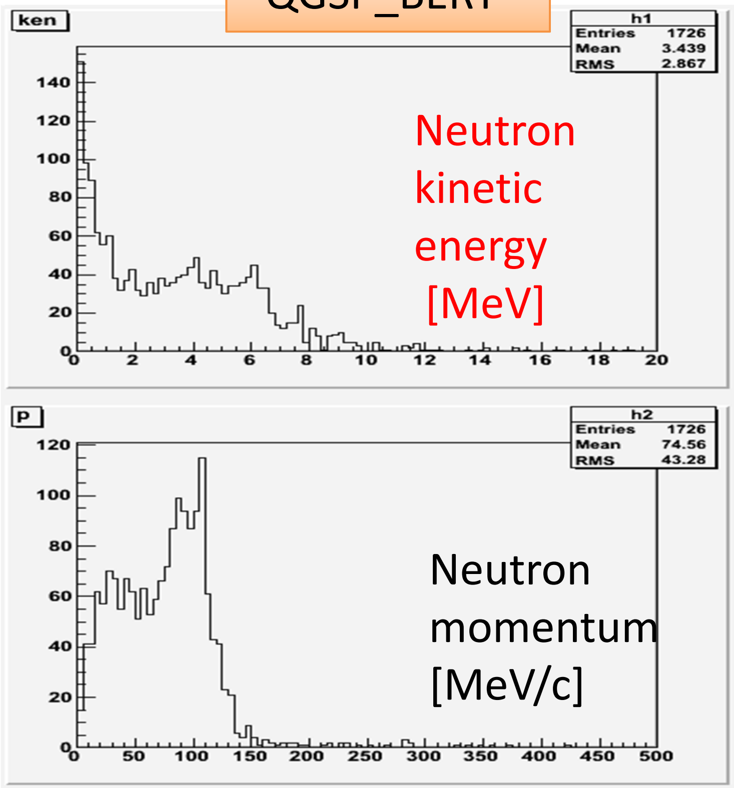
By adding 4 collimators H5-H8,

Collimator loss (H1-H4)	81.2% →67.7%
Collimator loss (H5-H8)	0.0% →20.7%
Arc loss	14.8% →11.3%
IR loss(|s|<6m)	3.9% → 0.24%!!

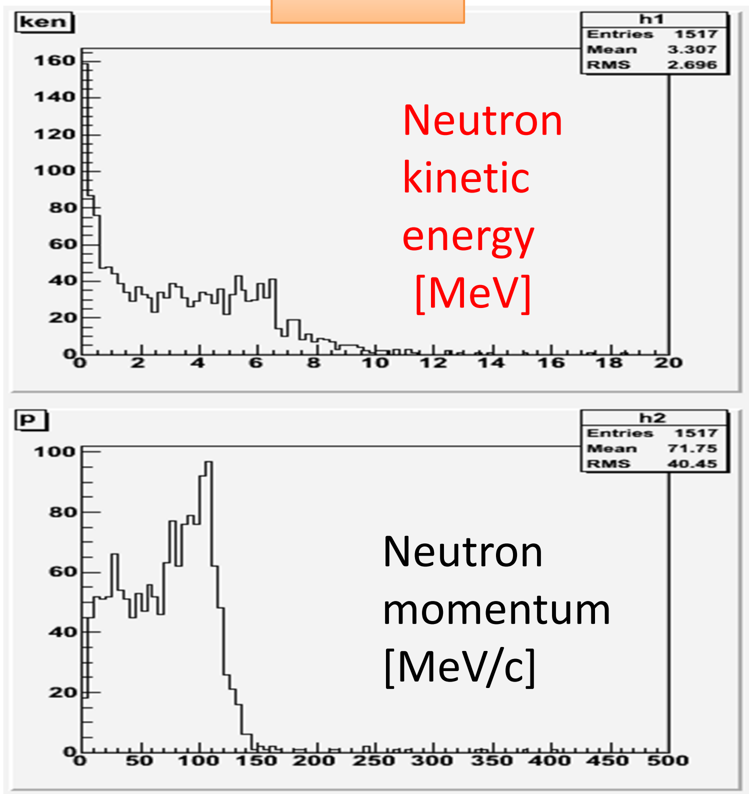
100%=375GHz=240W

Neutron energy spectrum (at generated point)

"QGSP_BERT"



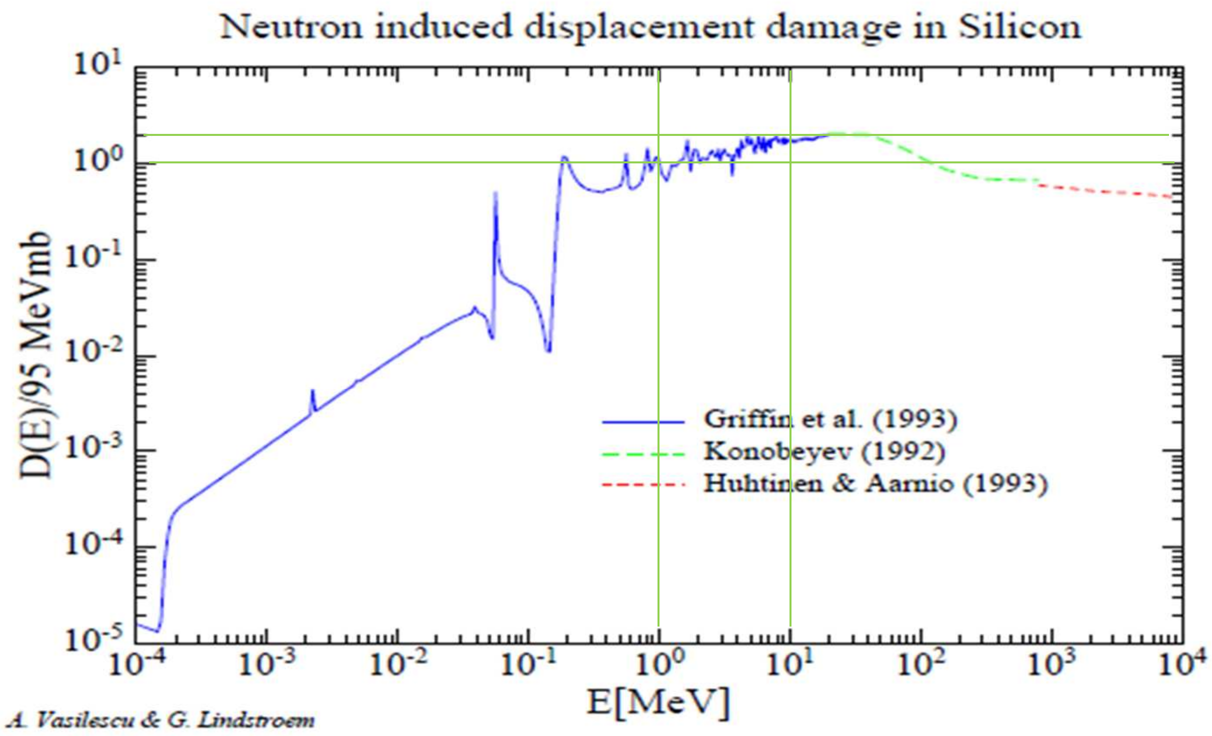
"HLEP"



Neutron kinematic energy is **~5MeV.**

(Neutron momentum is ~100MeV/c)

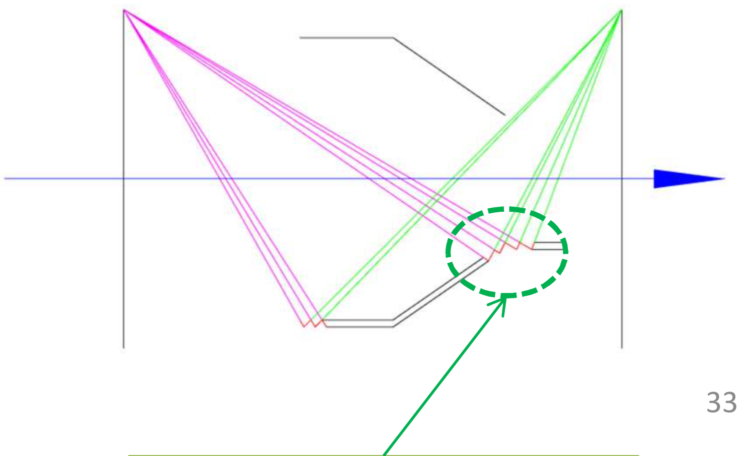
Neutron displacement damage on Si



Displacement damage on Silicon by few MeV neutron is about **twice larger** than the damage by 1MeV neutron

Beam test for tip-scattering SR

Ridge (saw-tooth) structure avoid reflected X-ray to hit the straight part of beam pipe, but "tip-scattered" X-rays might create additional hits.



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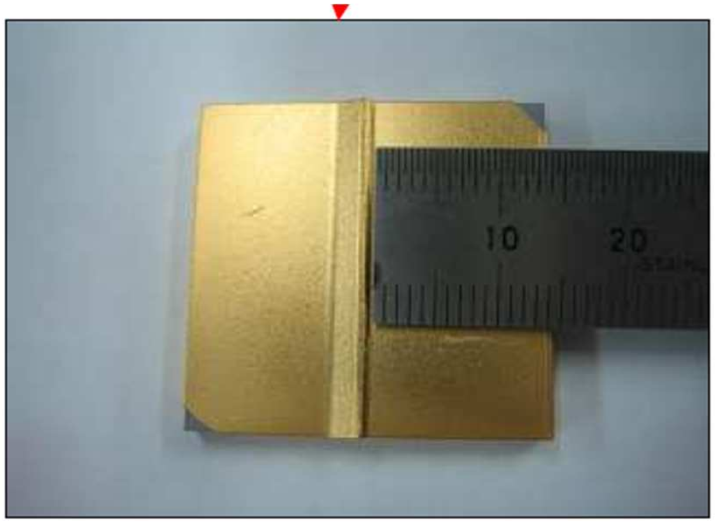
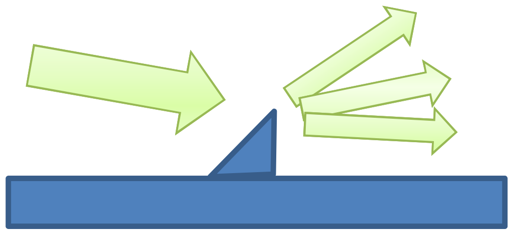
Ridge (saw-tooth) structure avoid reflected SR to hit IP beam pipe



gamma



Measure scattering angle distribution

Beam test scheduled in 2011 summer

Gamma from radiative Bhabha

Measured at KEKB. At SuperKEKB, 40 times severer.

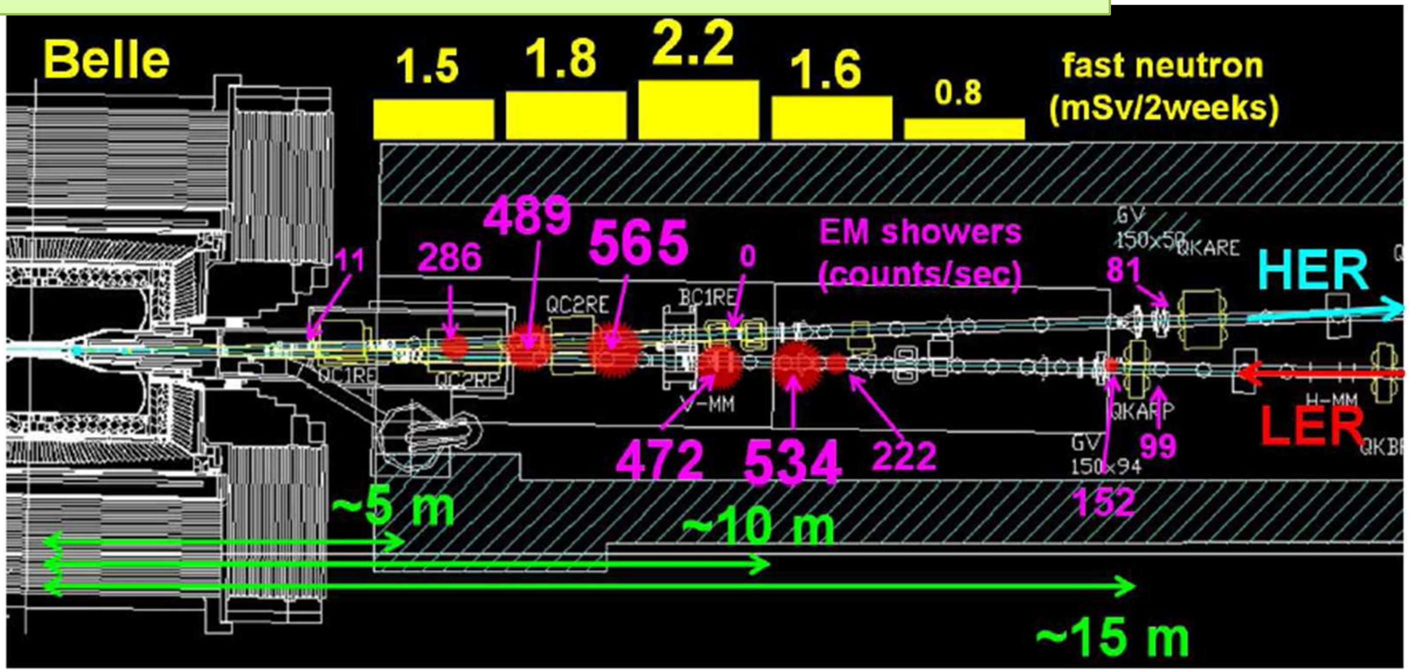


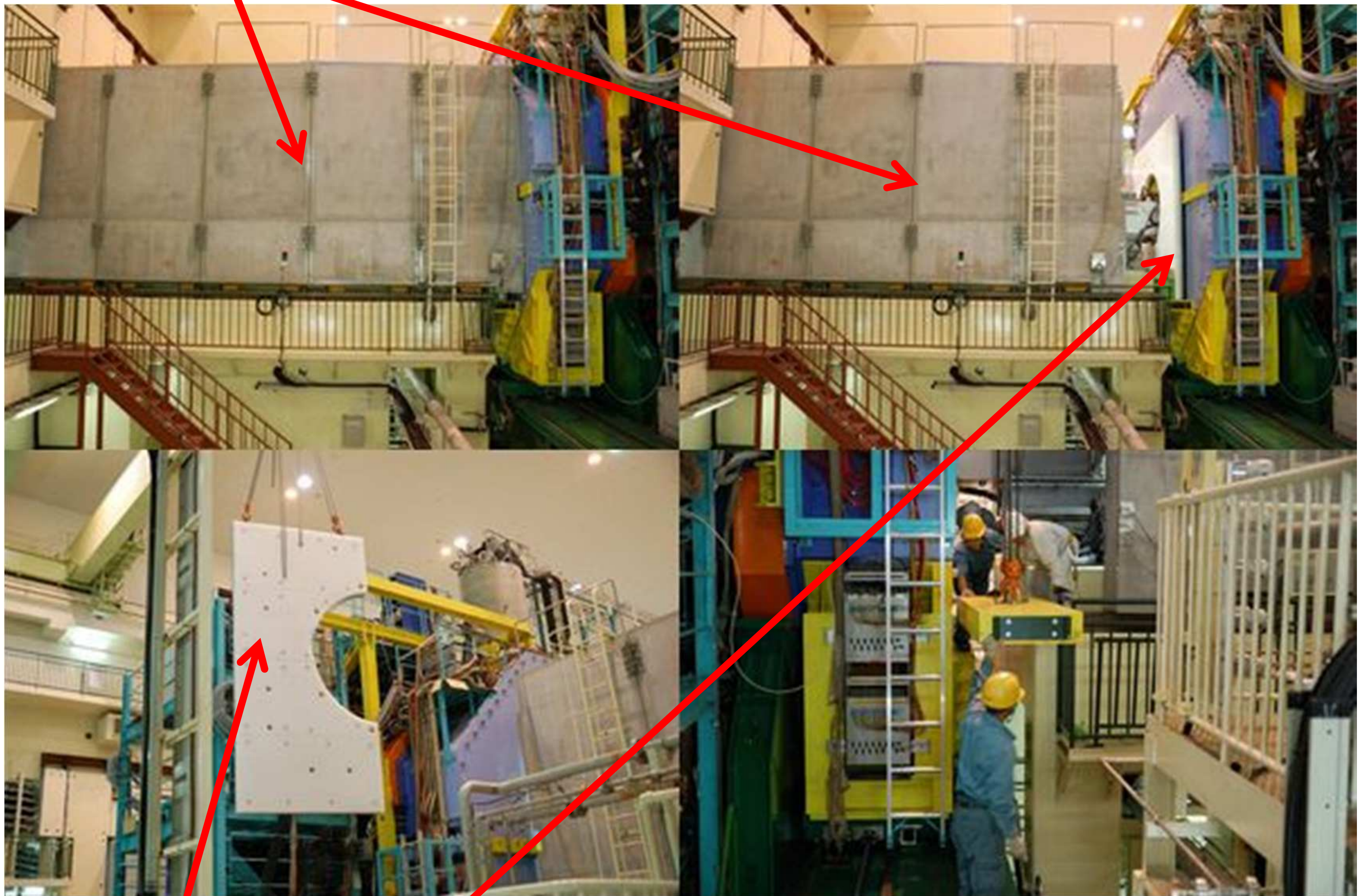
FIG. 1: Measured radiation levels around the beam lines in the HER downstream of the Belle detector. Neutron dose rates were measured outside of the concrete shield in 2003. The electromagnetic (EM) shower rates were measured with a scintillation counter in the same year. The position resolution of a movable EM shower counter is a 150 mm diameter circle along the beam lines; the counter is surrounded by a 200 mm thick lead shield and has a window diameter of 20 mm.

1Gy=1J/kg

1Sv=1Gv x 5x0.1

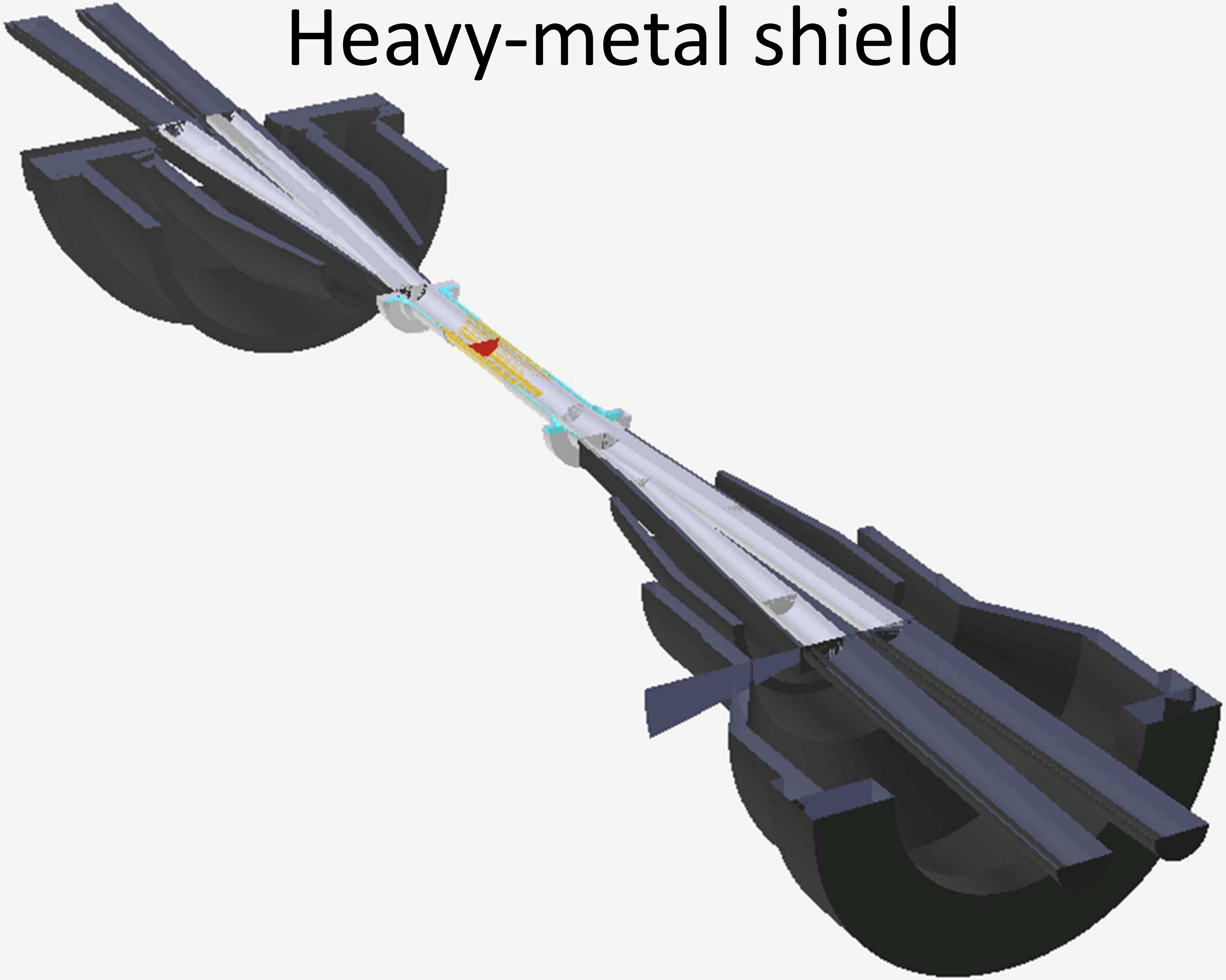
Neutron shield @ KEKB

Concrete wall



Polyethylene shield

Heavy-metal shield



Background sources (cntd.)
~4. beam-beam interaction~

<u>Beam-beam interaction</u>

- Scattered at IP, by field of the other beam
- Beam shape has non-Gaussian tail → might increase SR background
- Multi-body effect, not easy to calculate analytically
- Being simulated by accelerator group