Beam Background at SuperKEKB during Phase 2 operations

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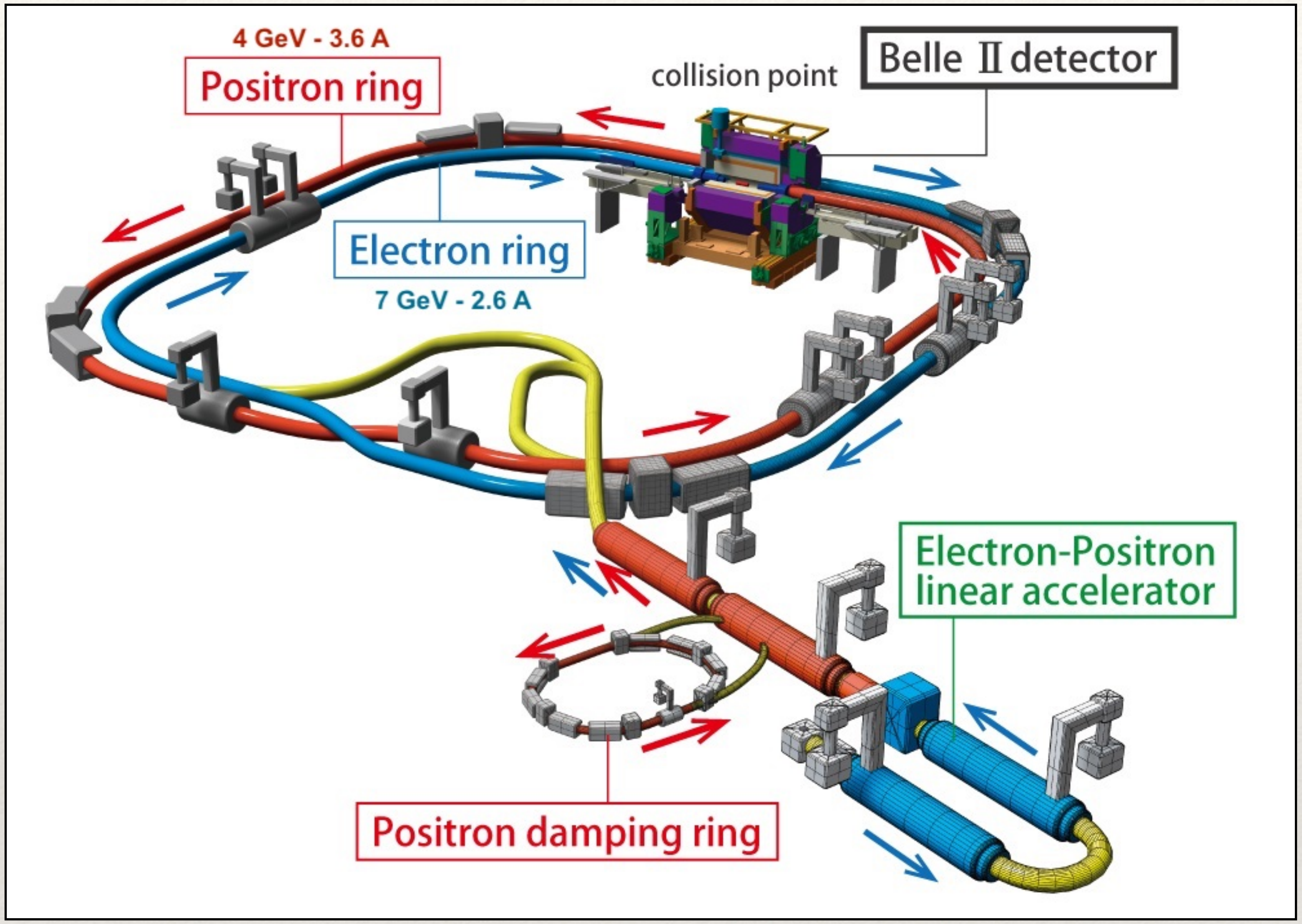
SuperKEKB



The SuperKEKB accelerator is located in Tsukuba, Japan.

It is an asymmetric electron-positron collider that aims to reach the unprecedented instantaneous luminosity of 8 x 10^{35} cm^{-2} s^{-1}.

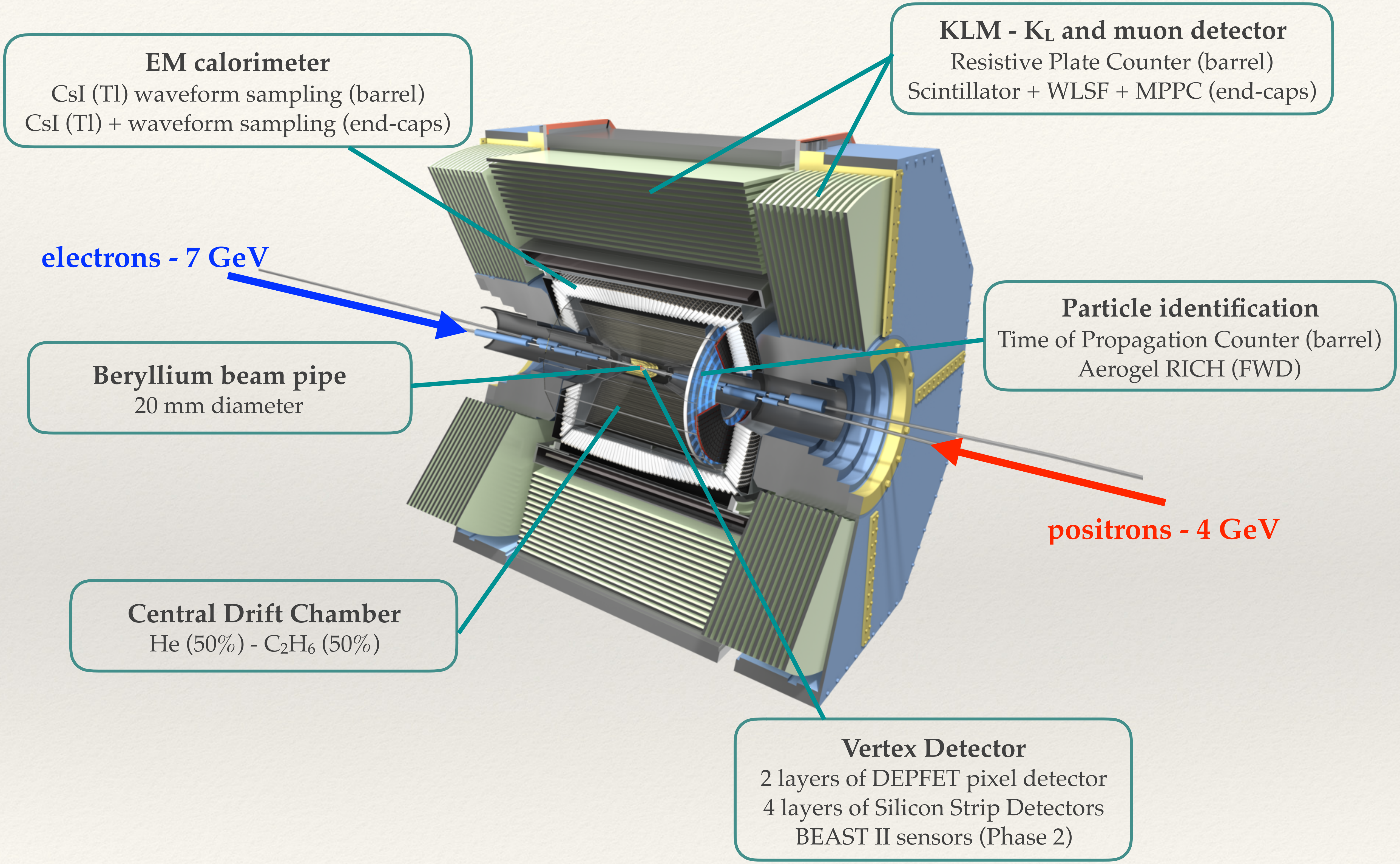
The Belle II experiment targets a total integrated luminosity of about 50 ab^{-1} in ten years of data taking.

- E_{CM} = 10.58 GeV, Υ(4S)

3 commissioning phases:

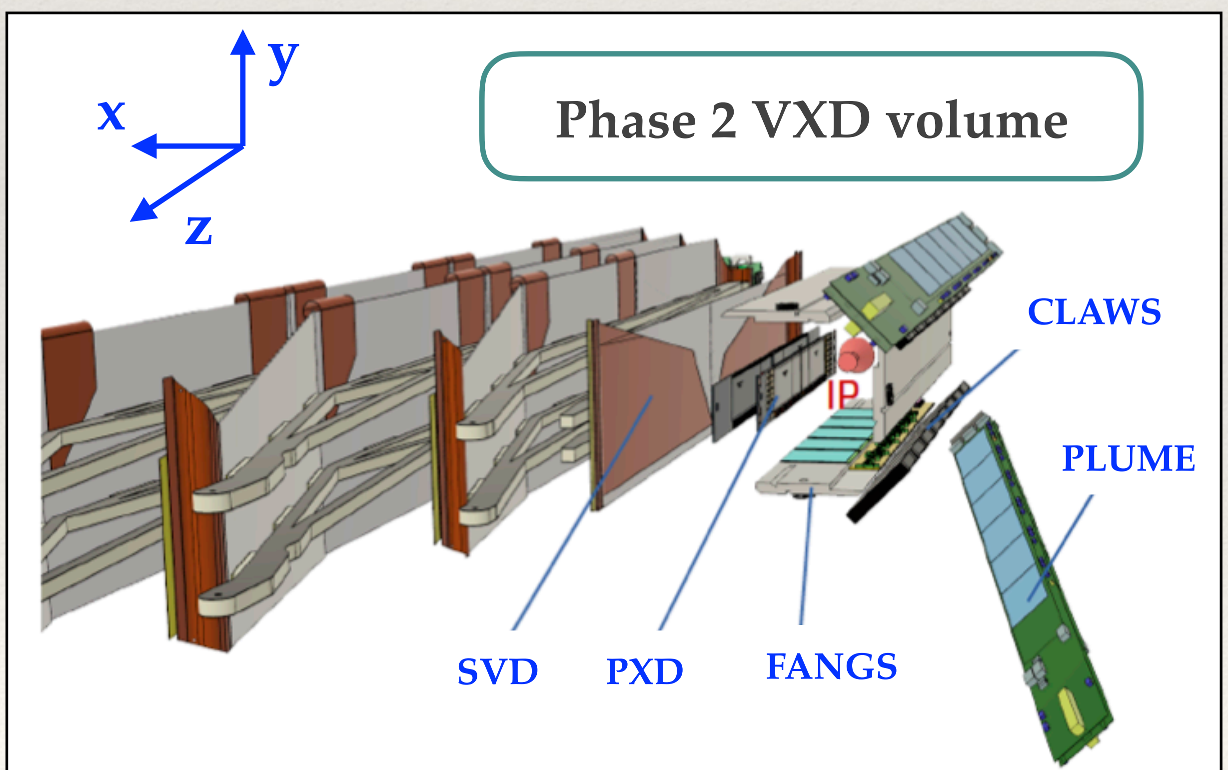
- Phase 1: no Belle II detector, no Final Focus system, no collisions.
- Phase 2: Belle II detector in its final position, Final Focus system in place and collisions, VXD volume with BEAST II detectors.
- Phase 3: full Belle II detector, physics runs.

The Belle II detector



BEAST II detectors

- FANGS - hybrid silicon pixel detectors.
- CLAWS - plastic scintillators with SiPM readout.
- PLUME - double sided CMOS pixel sensors.
- Diamond sensors for ionizing radiation dose monitoring in the IR.
- PIN diodes for ionizing radiation dose monitoring around Superconducting magnets of the Final Focus system (QCS).
- ^{3}He detectors for thermal neutron flux measurements.
- TPC detectors for fast neutron flux and direction measurements.



Goal for Phase 2: separate each background component, in order to validate the simulation and reliably extrapolate background levels to Phase 3.

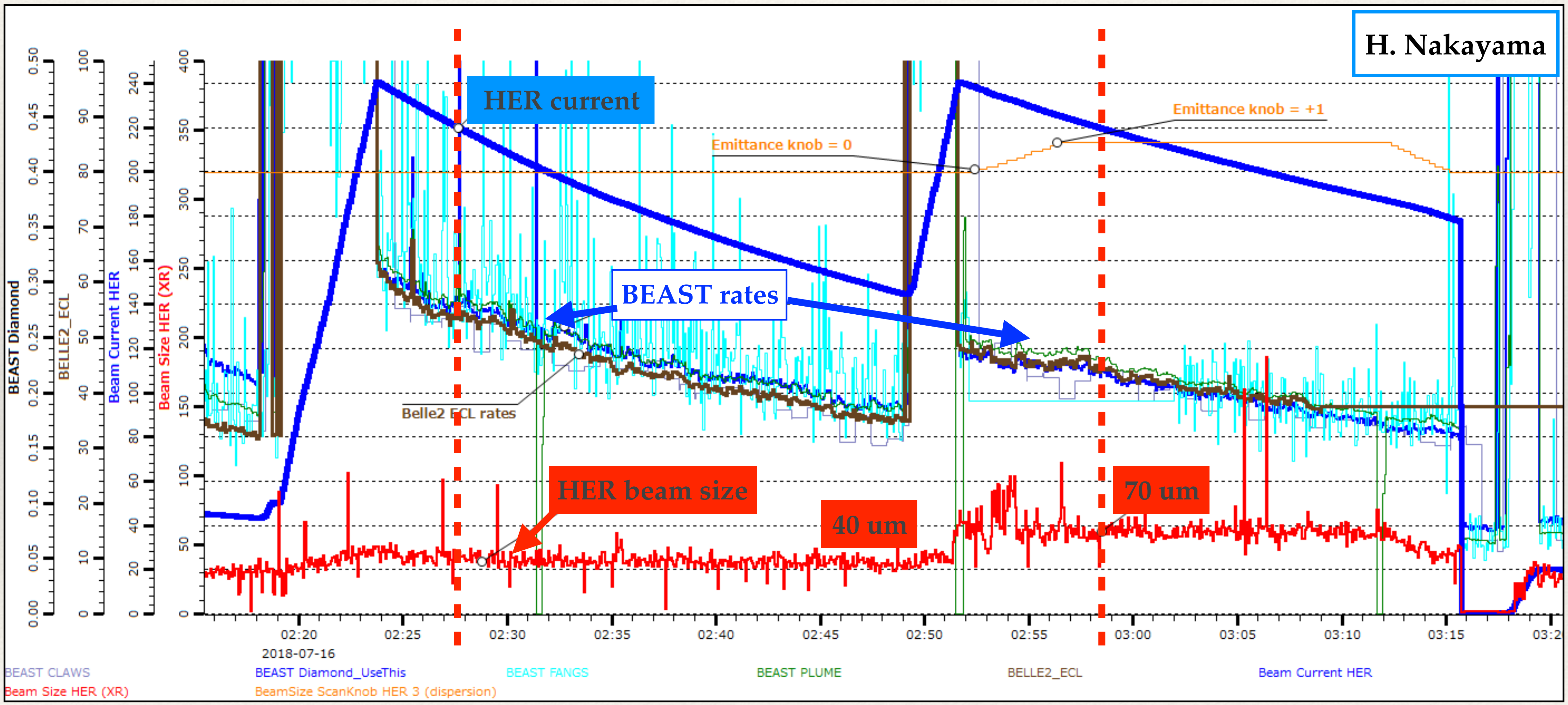
Background sources

Touschek scattering: single Coulomb scattering event. Phase 1: measured, consistent with simulation.	$R_{Tou} \propto \frac{1}{\sigma} E^3 n_b I_{beam}^2$
Beam-gas scattering: Coulomb scattering with residual gas atoms and bremsstrahlung. Phase 1: measured, more than predicted in simulation but	$R_{bg} \propto IP$
Synchrotron Radiation (SR): photon emission from beam particles. Phase 1: not measured.	$R_{SR} \propto E^2 B^2$
Radiative Bhabha: neutron production from emitted photons; particle loss because of too much ΔE wrt nominal energy. Phase 1: not measured.	$R_{RB} \propto L$
Two photons process: low momentum e^+e^- pairs hitting VXD. Phase 1: not measured.	$R_{tp} \propto L$
Injection background: injected bunch is perturbed, resulting in particle losses. Phase 1: measured (time structure and energy of radiation produced)	

Touschek background - beam size studies

Single Coulomb scattering events where a small fraction of transverse momentum is transformed into a large longitudinal momentum, resulting in loss of both particles.

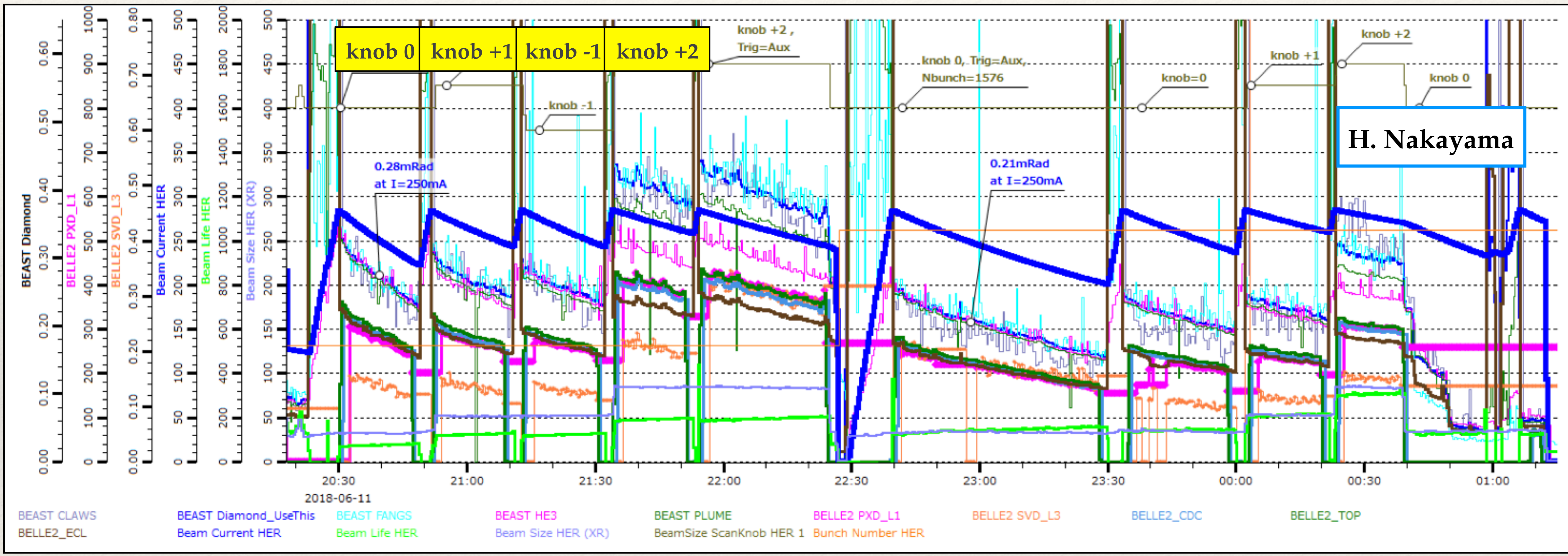
- Studies done with single beams, for both LER and HER, changing vertical beam size and observing the change in the background levels.



As expected, background decreases as beam size increases.

Touschek background - beam size studies

- In a previous study done in June for the HER, same results obtained for knob ±1, but for even larger beam size an increase in background was observed, which is the opposite of the expectations for Touschek effect. Possible beam “scraping”, but not confirmed.



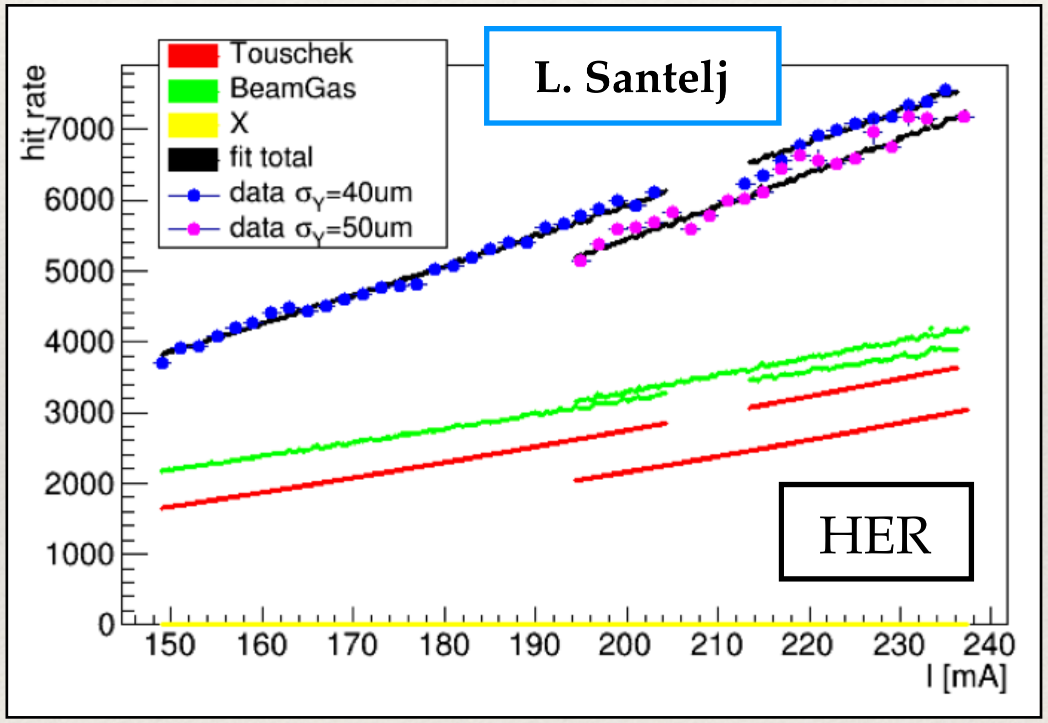
- For diamonds good agreement between data and simulation, for SVD there is discrepancy, other detectors are still performing analysis.

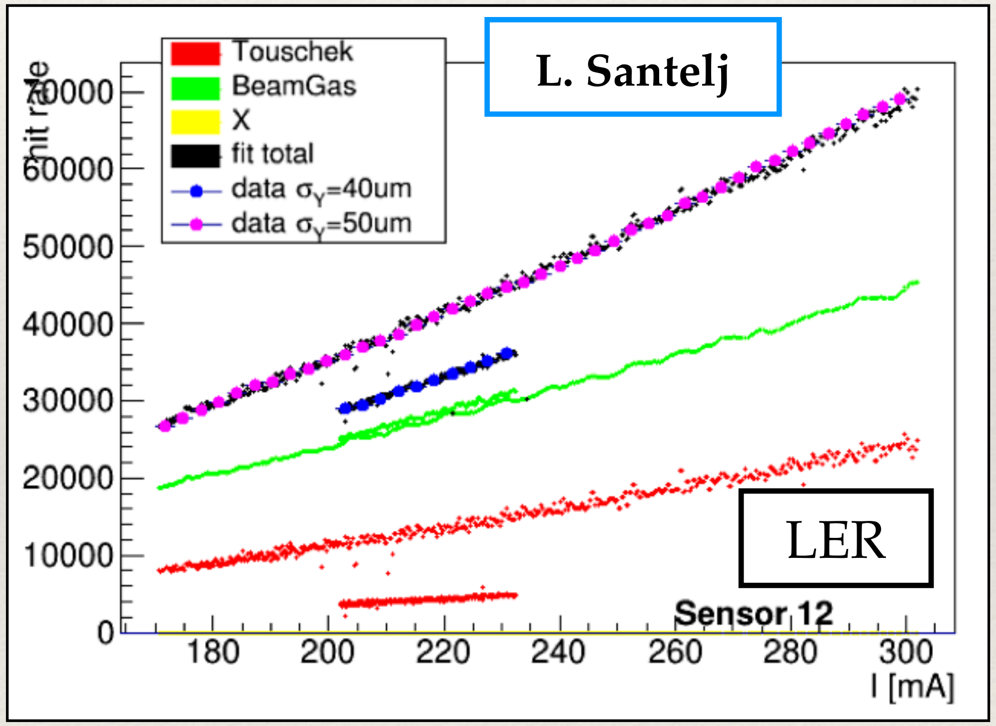
Beam-gas scattering

Interaction between beam particles and residual gas atoms in the beam pipe. Coulomb scattering changes particle trajectory, Bremsstrahlung decreases particle energy.

- In the IR, Touschek and beam-gas backgrounds have similar contributions. Fraction depends on the sensor, but background is of the same order.

Function used for the fit: $$P = T\frac{I^2}{\sigma_y n_b} + BIp$$





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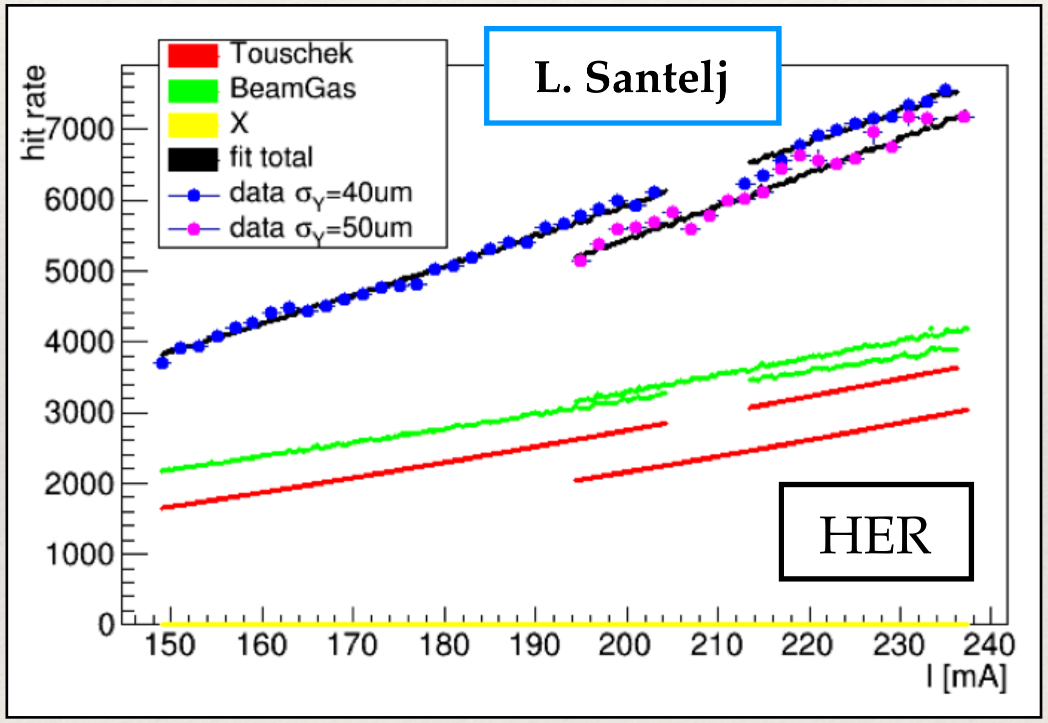
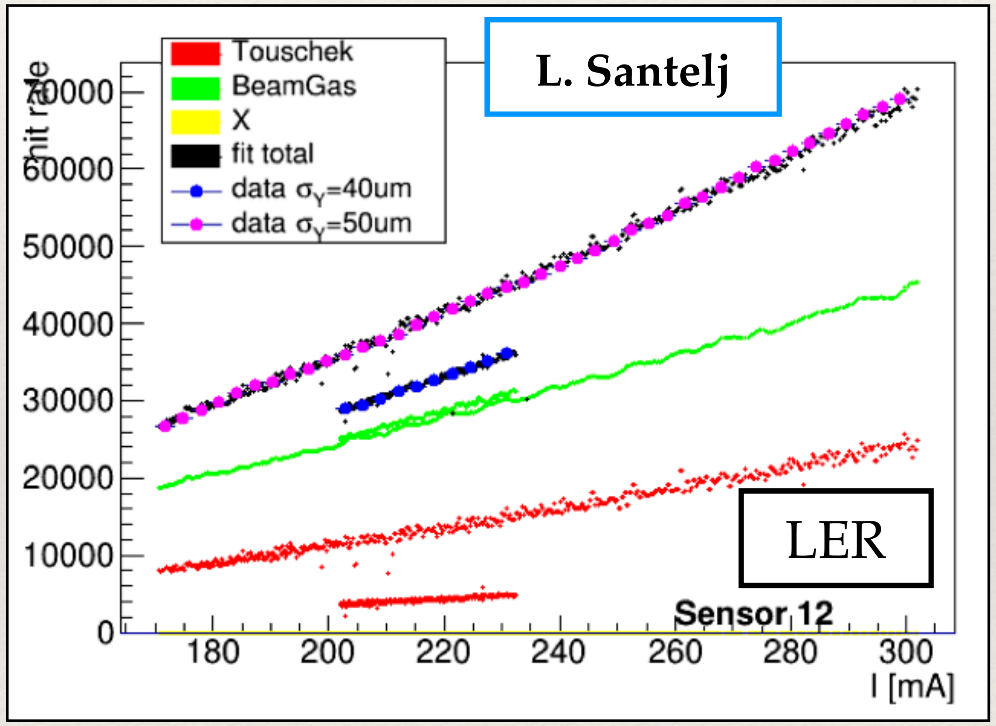
Function used for the fit: $P = T\frac{I^2}{\sigma_y n_b} + BIp + XI^2\sigma_y^{n/2}$ → Only for HER and large beam size

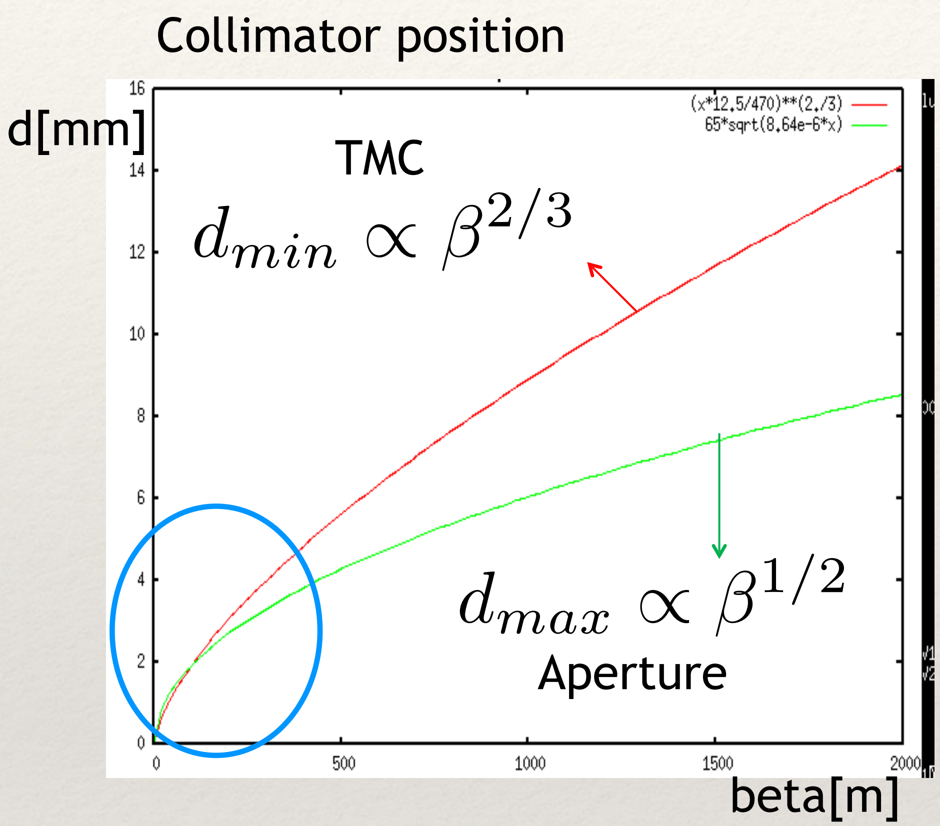




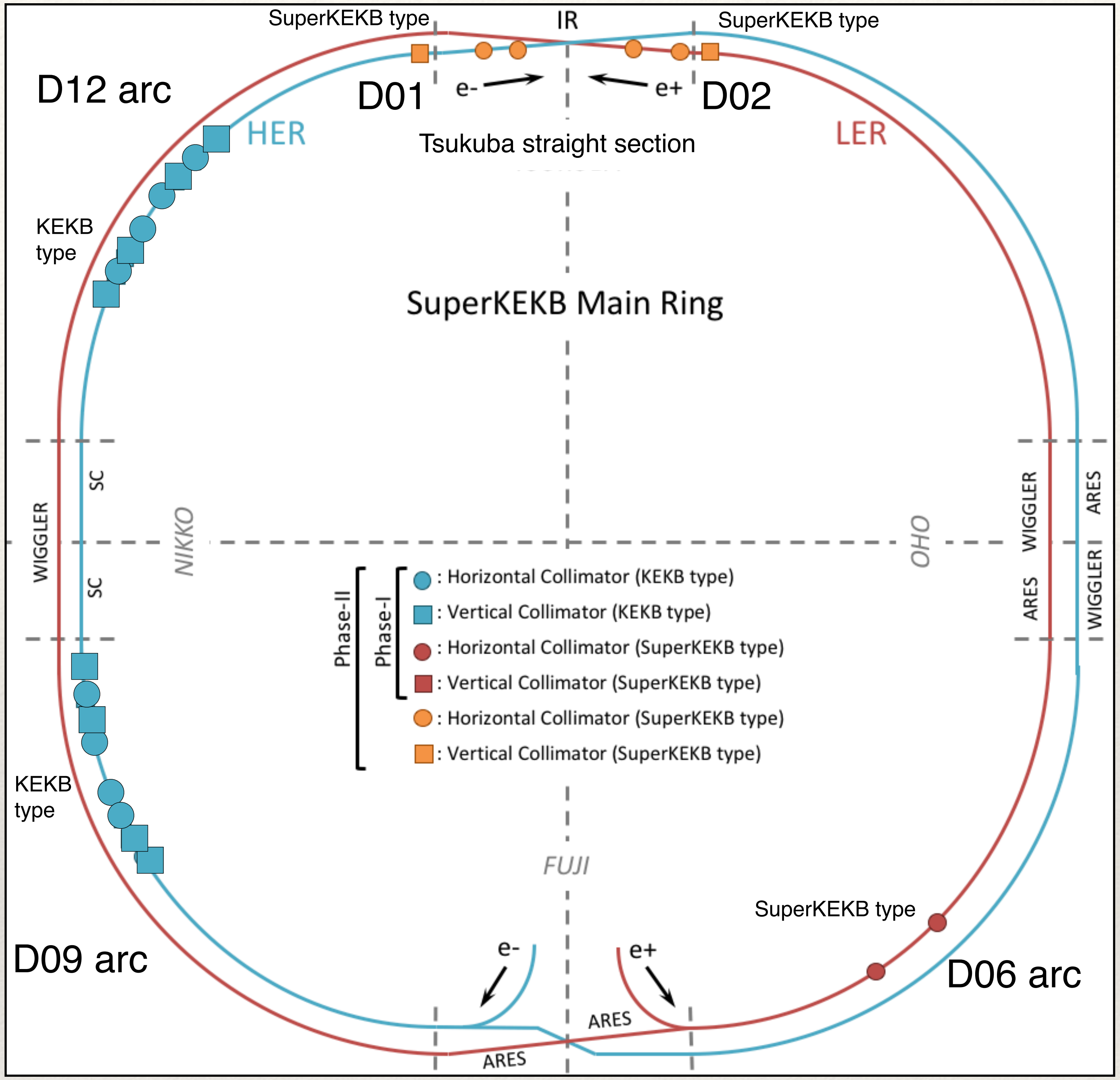
- In Phase 3 β_y inside the final focus system will be 10 times higher than the end of Phase 2. Therefore beam-gas Coulomb lifetime will be shorter and the background level will be very high without a proper vertical collimation.

Background reduction - collimators

- IR Touschek and Beam-gas backgrounds can be reduced with horizontal and vertical collimators.



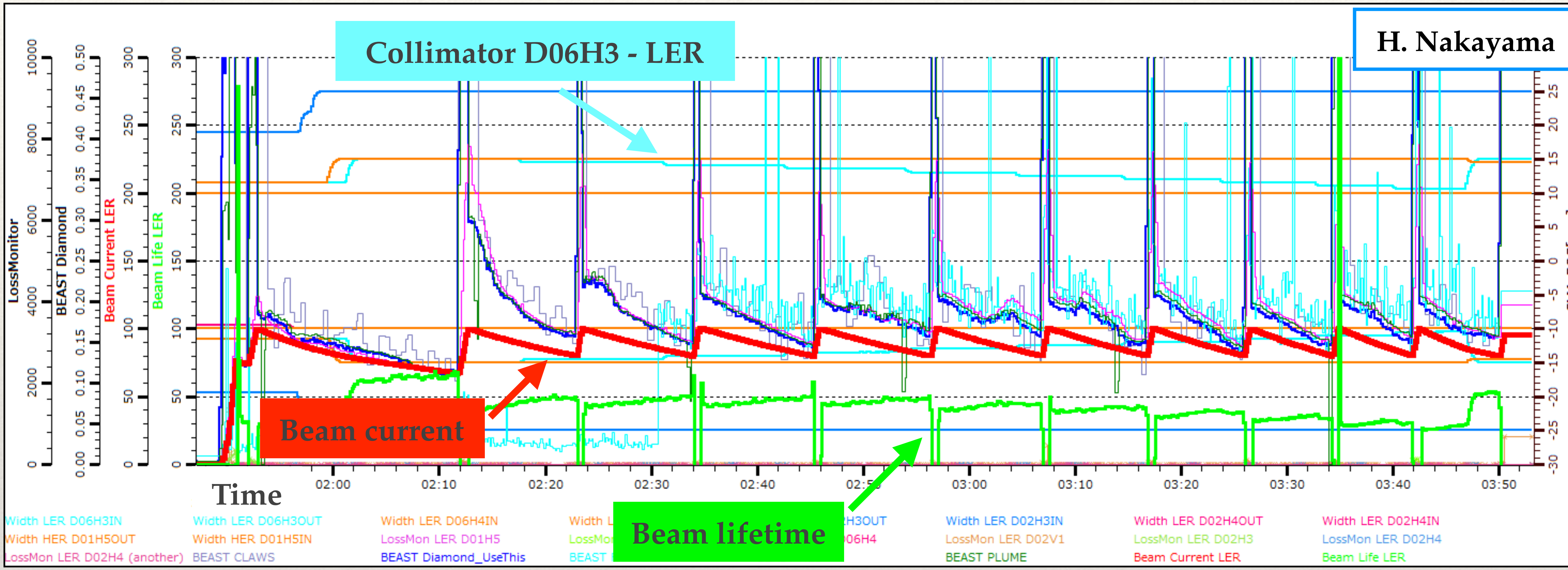
See: H. Nakayama et al., "Small-Beta Collimation at SuperKEKB to Stop Beam-Gas Scattered Particles and to Avoid Transverse Mode Coupling Instability," Conf. Proc. C **1205201**, 1104 (2012).



- Horizontal collimators are positioned where β_x is large, as in other accelerators. The ones installed in Tsukuba straight section are crucial to reduce Touschek background.
- Vertical collimators position, instead, is determined by local beam size and Transverse Mode Coupling (TMC) instability conditions, therefore they are positioned at small β_y.

Background reduction - collimators study

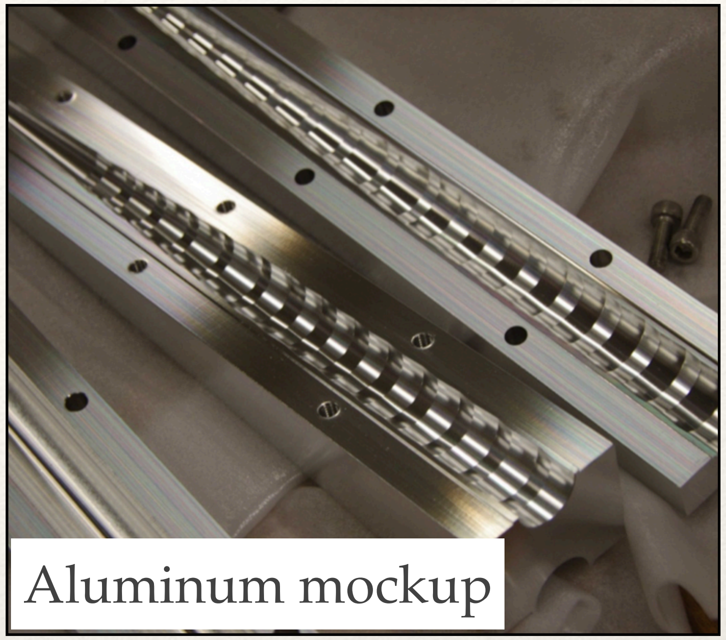
- Collimators studies performed with simulations and during Phase 2 operation.



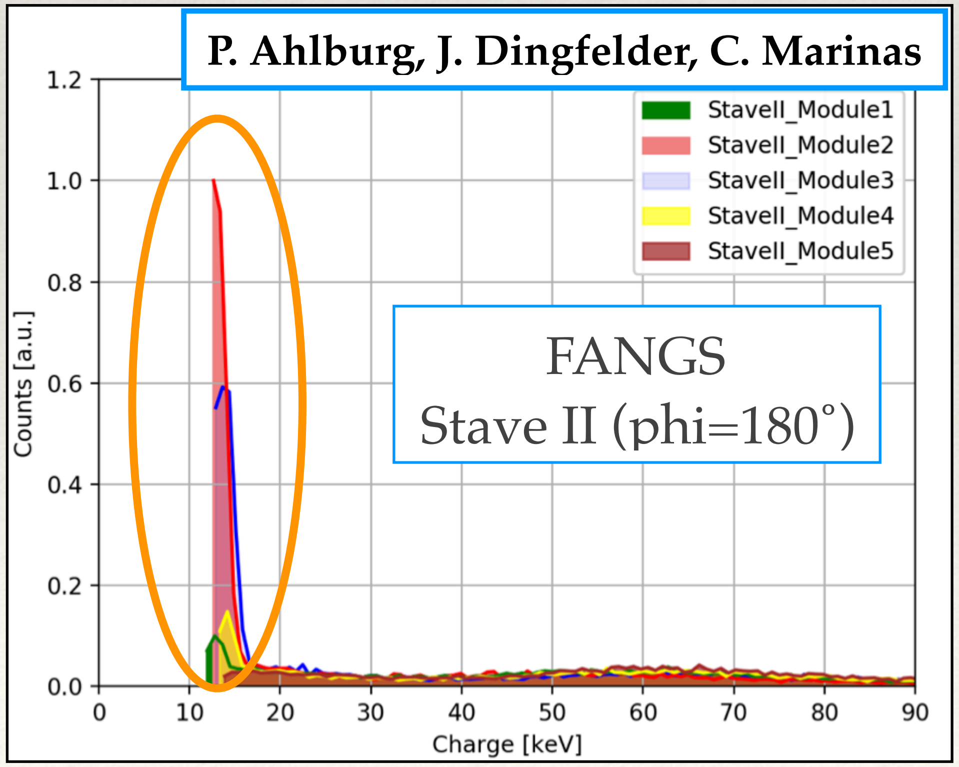
- From an "open" collimators configuration, gradually close each collimator individually to find the best compromise between background level and beam lifetime.
- After closing collimators individually, all collimators were closed at the same time to their optimised aperture —> reduction in IR background clearly visible.
- Same study performed on HER with similar results.

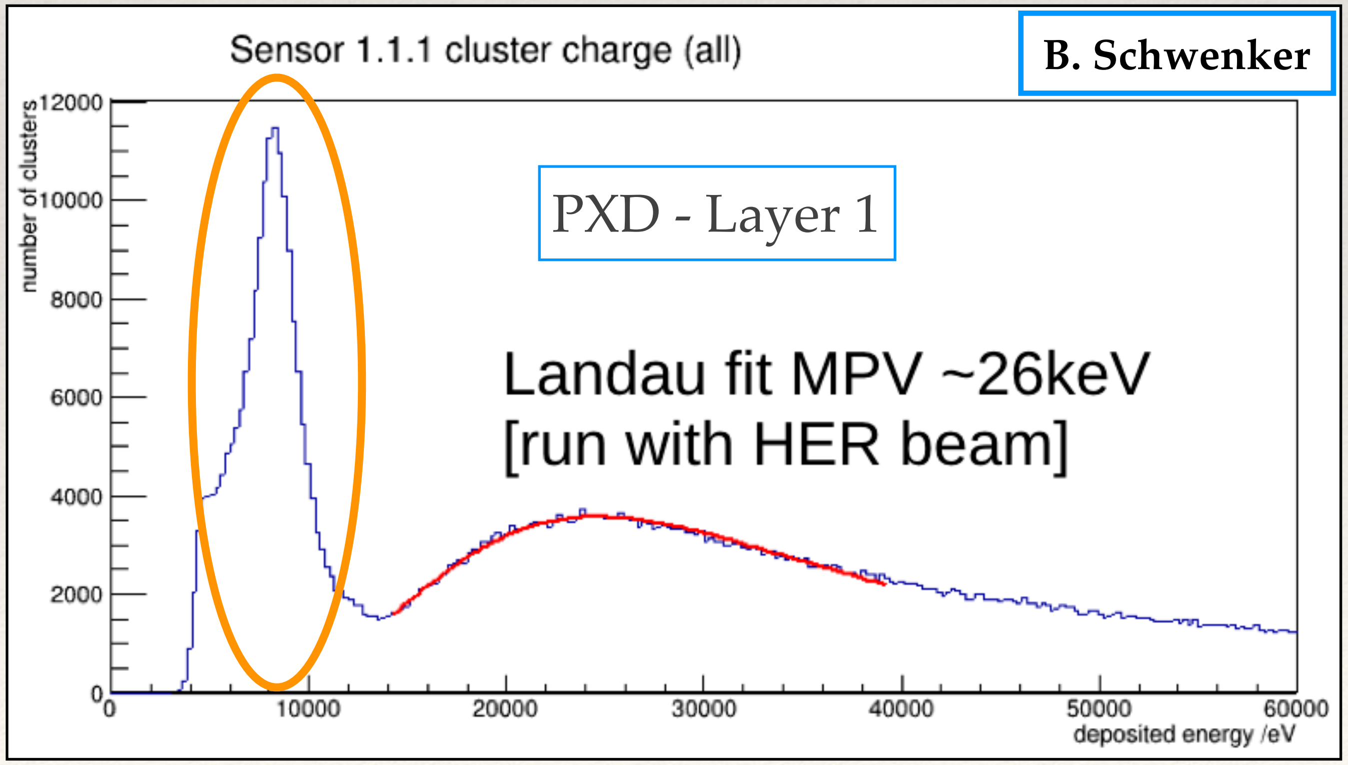
Synchrotron radiation

- $R_{SR} \propto E^2 B^2$ —> bigger contribution expected from HER.
- SR observation not expected in Phase 2.
- Energy of SR photon expected from a few keV to tens of keV.
- Inner surface of beryllium pipe coated with Au layer to absorb SR photons.
- Ridge structures of incoming pipes to avoid hits from forward reflected SR photons to IR beam pipe.
- Direct hits stopped by tapered shape of incoming beam pipes.



- PXD (ring outer side) and FANGS (ring inner side) observed SR peaks around 8-10 keV.
- Longitudinal distributions for HER and LER suggest same mechanism of SR generation.

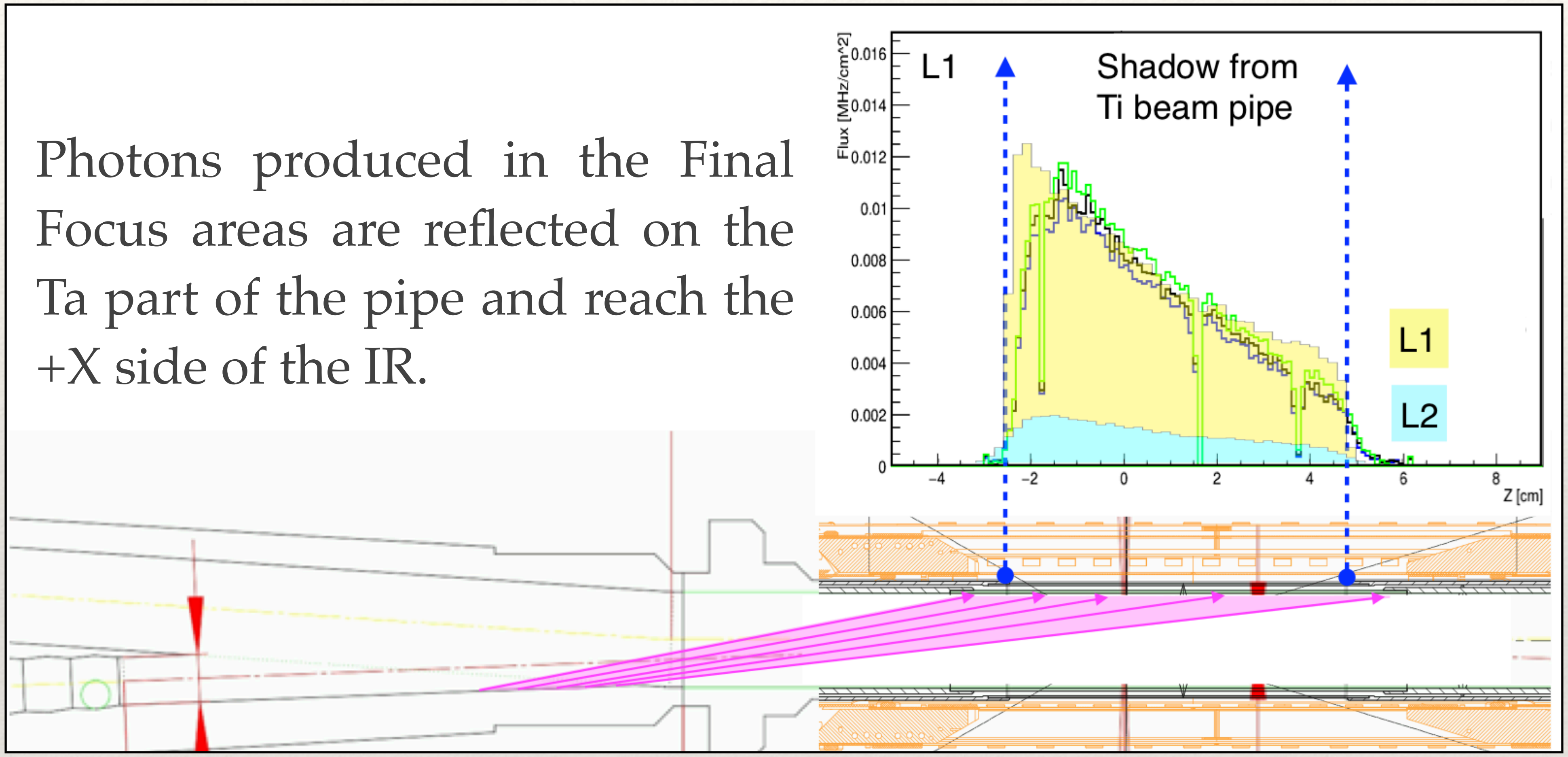




Synchrotron radiation

- It's unlikely to have direct hits from SR. The most probable mechanism is reflection of photons generated in the Final Focus sections.

Photons produced in the Final Focus areas are reflected on the Ta part of the pipe and reach the +X side of the IR.



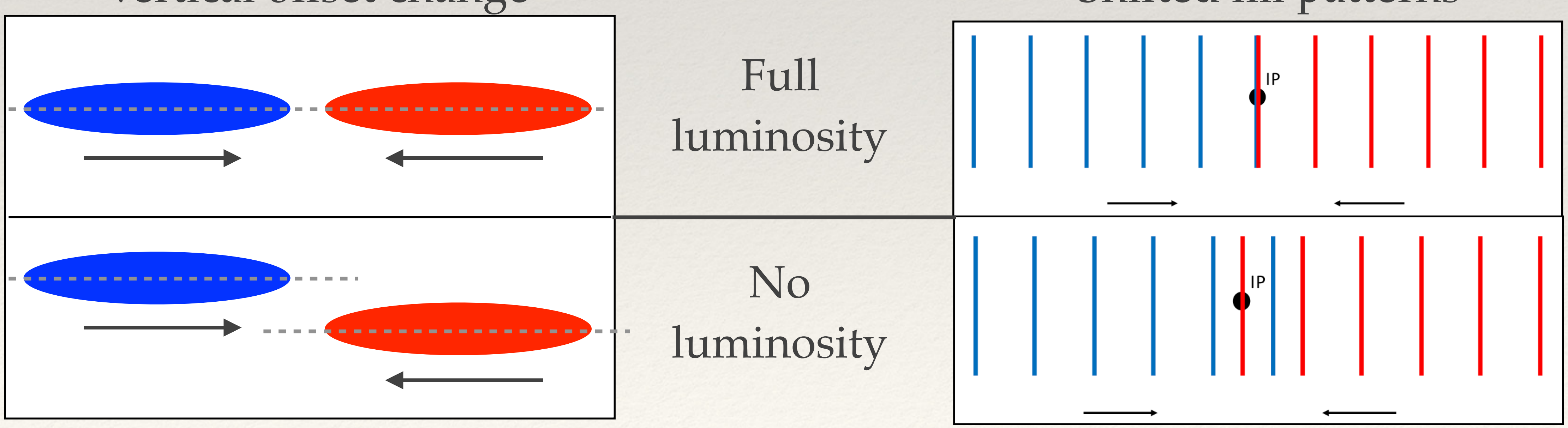
- Au layer in Phase 2: 6.6 μm
  Au layer in Phase 3: 10.0 μm
- The most recent simulations for SR can reproduce qualitatively the data, with still a few differences in the rate ratio between layer 1 and layer 2 of the PXD.

Luminosity background

1. After losing energy through photon emission, particles could be over-bent by Final Focus magnets, hit beam pipe walls and produce EM showers.
   - In SuperKEKB separate QC magnets are used for incoming and outgoing beams, but still this remains the actual dominant component of background.
2. Photons from Radiative Bhabha interact with iron in the magnets and produce neutrons.
   - Additional shielding to stop neutrons from hitting outermost sub-detectors.
3. In the two-photons process *e e —> e e e e* low momentum e^+e^- pairs can hit tracking detectors and affect their performance.

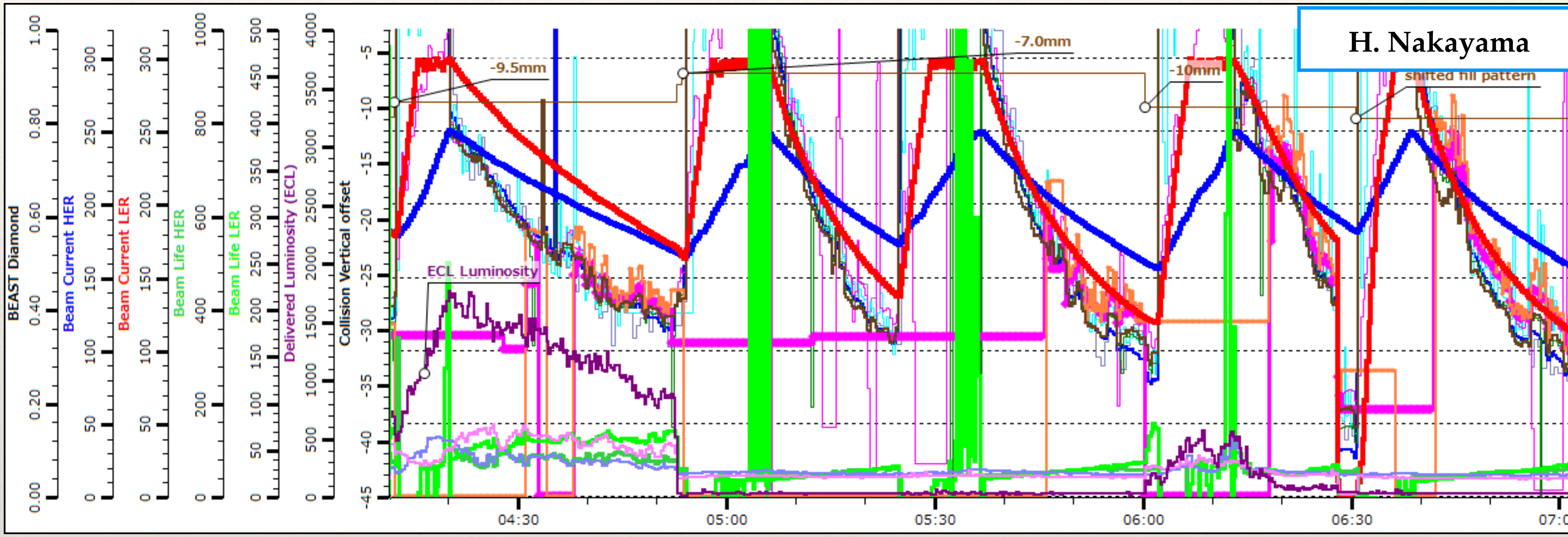
- These contributions depend on luminosity and should go to zero with no luminosity.
- Studies of luminosity background done in two ways:

Vertical offset change | Shifted fill patterns



Luminosity background

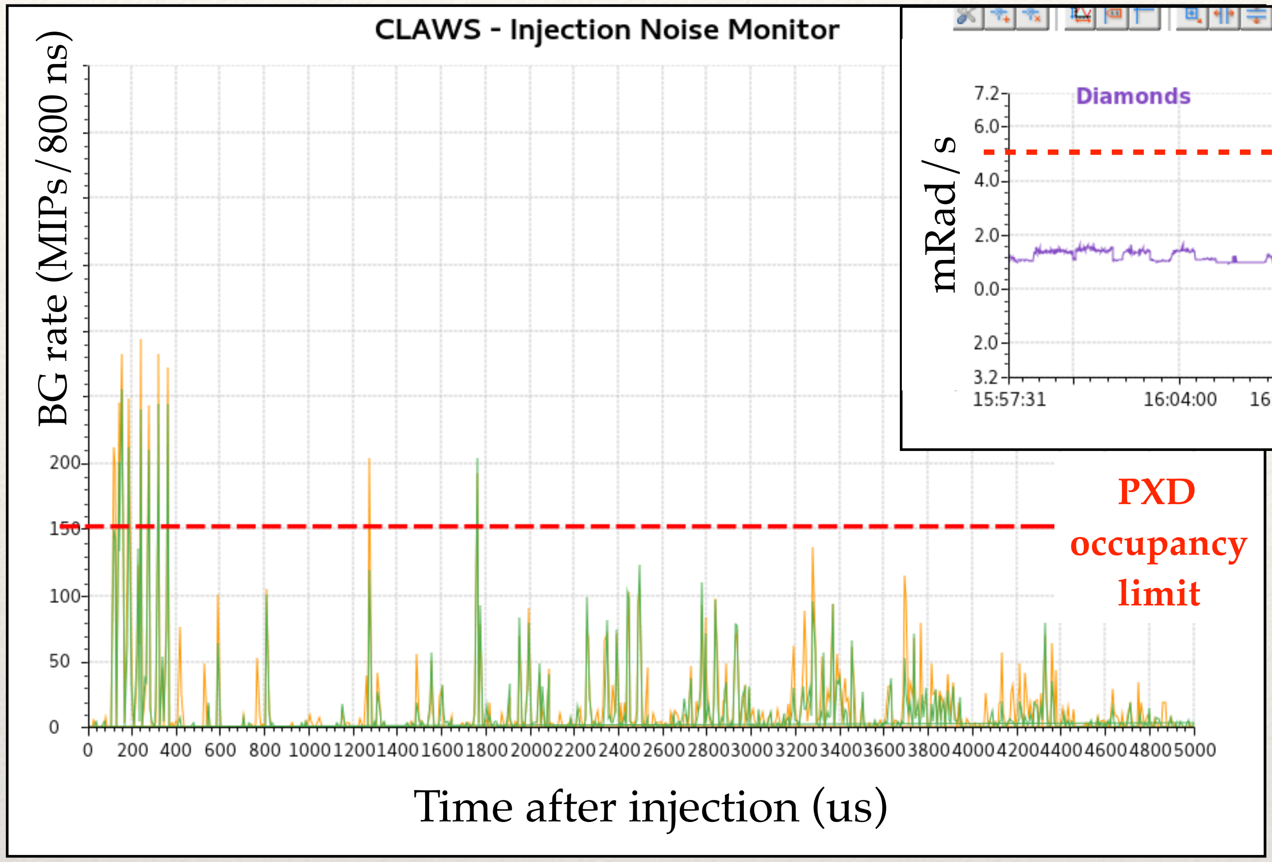
The observation was that when luminosity goes to zero changing vertical offset, PXD and SVD background rates increase.

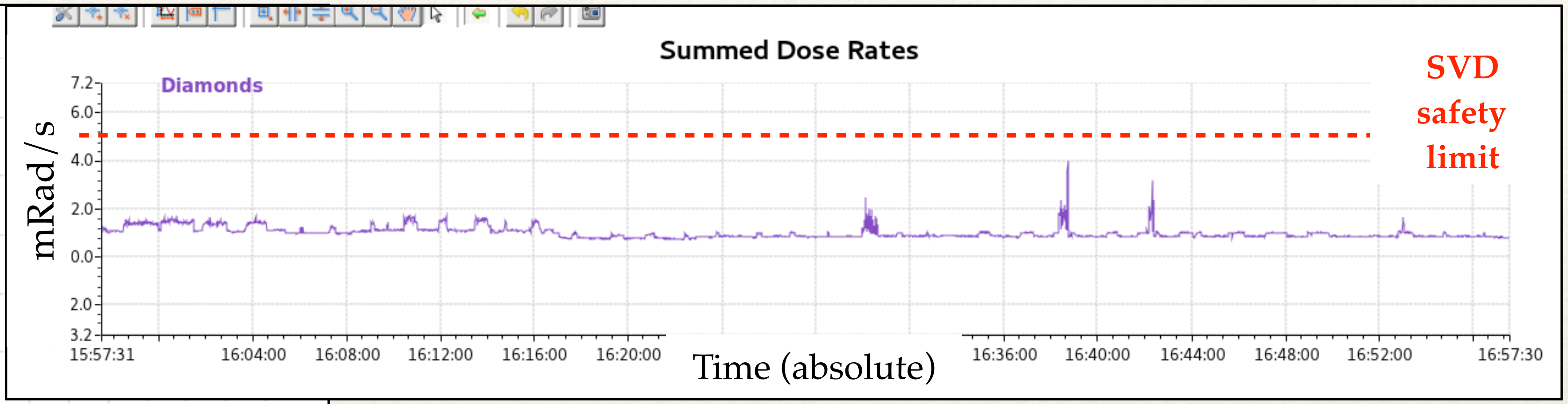


- We expect backgrounds to be smaller if luminosity background (two-photon process in particular) is the main source and no collisions occur.
- To be further investigated. Challenging analysis due to low luminosity and to changing BG conditions between single beam BG studies and luminosity studies: makes difficult to disentangle Touschek and beam-gas backgrounds and extract luminosity background component.

Injection background

- Injection background is monitored using Diamond sensors and CLAWS (BEAST II).



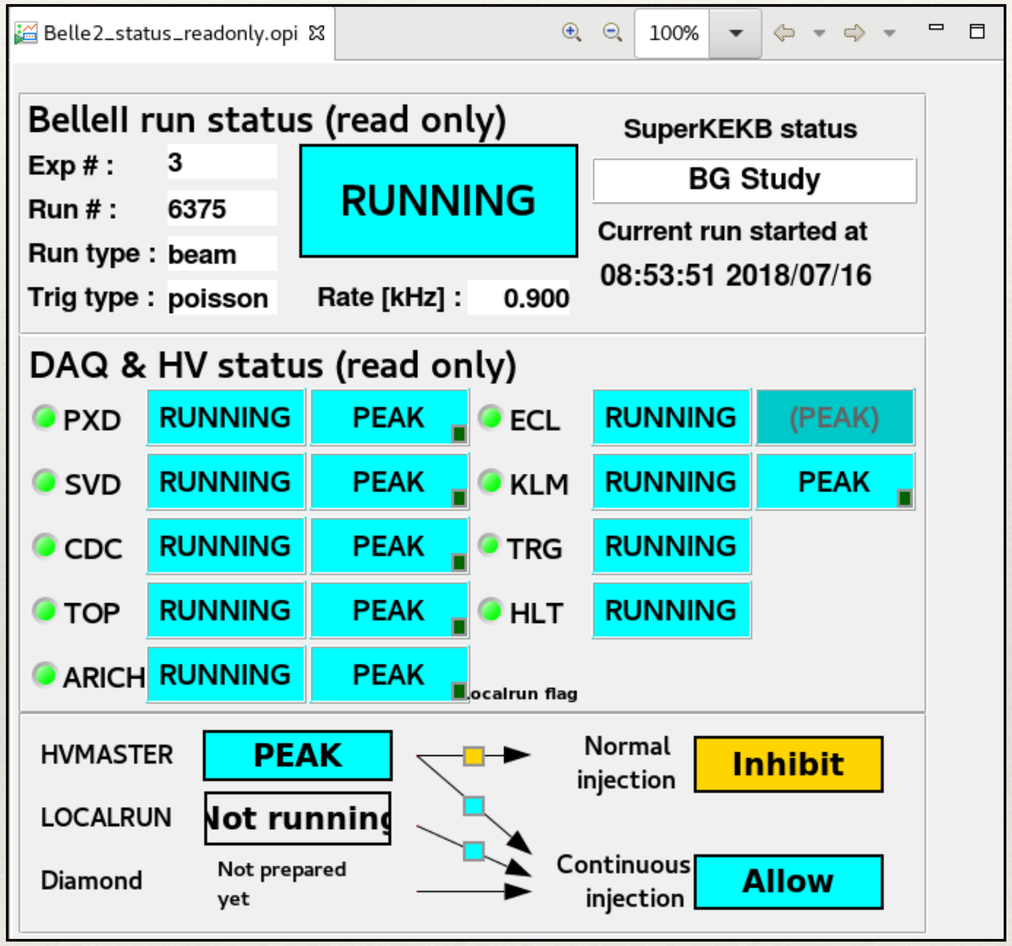


Example of good injection:
- Spikes in CLAWS less then PXD occupancy limit after 1 ms.
- Diamonds spikes less than 5 mRad/s, below the SVD safety limit.

- Belle II detector uses trigger VETO for high-background period during injection, so this period must be as short as possible.
- Too high injection background could induce quenches of Final Focus magnets.
- Injection background highly dependent on optics change: tuning injector parameters and collimator settings required for every new optics.
- Positron Damping Ring commissioned and used during Phase 2.
- Injection background was always higher for HER.

Other MDI topics

- Diamond sensors used to protect Final Focus magnets from quenches: two thresholds were set, when background level increased above one of the thresholds, a beam abort was issued.
  98 “beam abort” signals were issued during Phase 2.



- Injection inhibit: reading the status of each sub-detector, normal injection is inhibited if HV is ON or ramping up in at least one sub-detector.

- BCG (Belle II Commissioning Group) shifters always in SuperKEKB control room to assure active and prompt MD interaction.

Conclusions

- BEAST II and Belle II detectors were successfully used to evaluate beam background components during Phase 2.
- Touschek and beam-gas BG components evaluated for Phase 2, revised projections for Phase 3 are under development.
- Synchrotron radiation was not expected in Phase 2, but was observed and the most recent simulation can predict it.
- More Luminosity BG results for Phase 2 yet to come from other sub-detectors; to be further studied at the beginning of Phase 3.
- Injection background can be kept under control and within the limits given by inner sub-detectors and QCS.
- Additional collimators will be installed for Phase 3 to allow better BG reduction in the IR.
- Overall, the background levels during Phase 2 look higher than expected, more time should be dedicated at the beginning of Phase 3 to improve background reduction.


Thank you!

Backup slides

Machine parameters - SuperKEKB

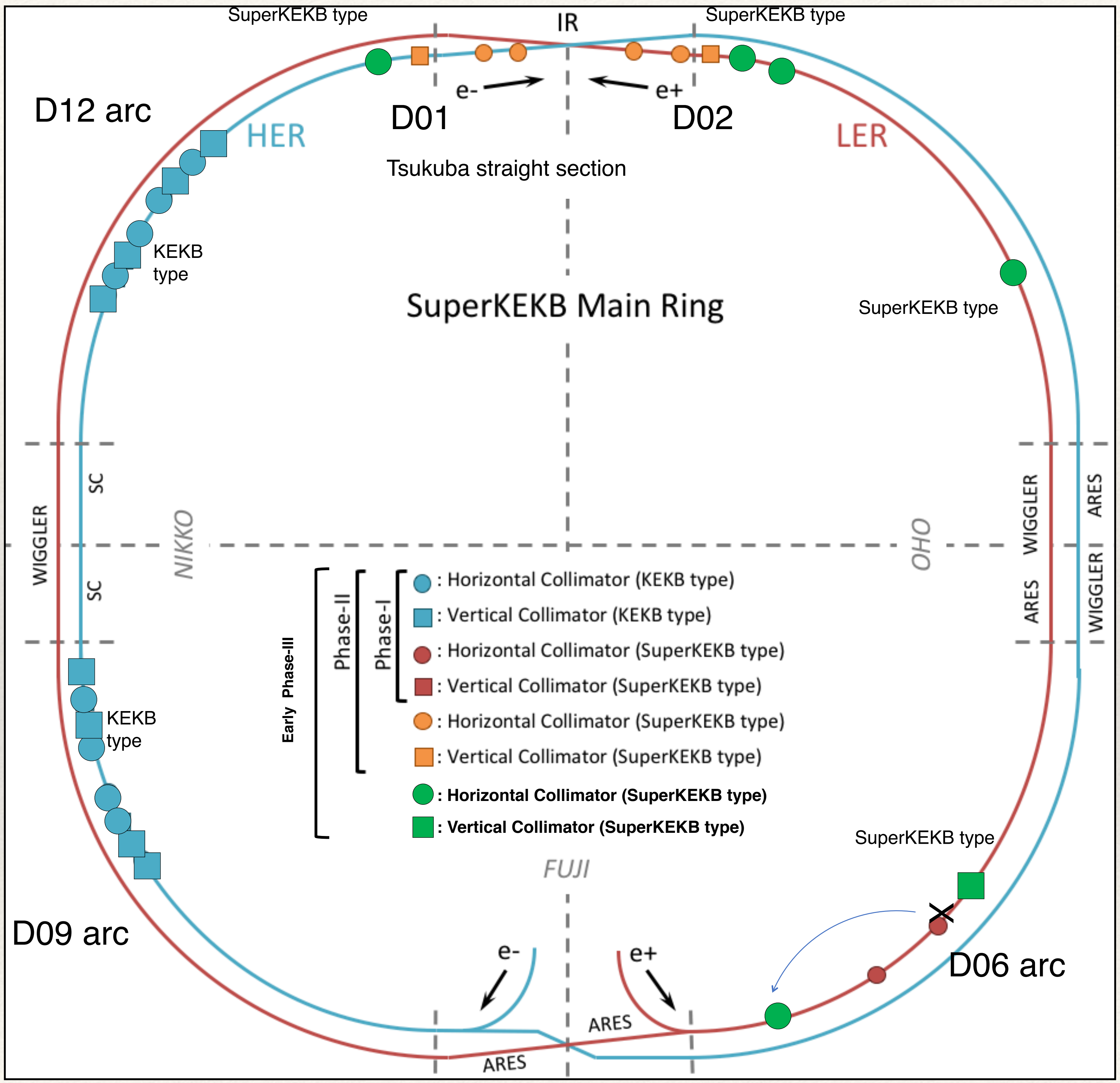
2017/September/1	LER	HER	unit	
E	4.000	7.007	GeV	
I	3.6	2.6	A	
Number of bunches	2,500			
Bunch Current	1.44	1.04	mA	
Circumference	3,016.315		m	
$\varepsilon_x/\varepsilon_y$	3.2(1.9)/8.64(2.8)	4.6(4.4)/12.9(1.5)	nm/pm	():zero current
Coupling	0.27	0.28		includes beam-beam
β_x^*/β_y^*	32/0.27	25/0.30	mm	
Crossing angle	83		mrad	
α_p	$3.20\text{x}10^{-4}$	$4.55\text{x}10^{-4}$		
σ_δ	$7.92(7.53)\text{x}10^{-4}$	$6.37(6.30)\text{x}10^{-4}$		():zero current
V_c	9.4	15.0	MV	
σ_z	6(4.7)	5(4.9)	mm	():zero current
ν_s	-0.0245	-0.0280		
ν_x/ν_y	44.53/46.57	45.53/43.57		
U_0	1.76	2.43	MeV	
$\tau_{x,y}/\tau_s$	45.7/22.8	58.0/29.0	msec	
ξ_x/ξ_y	0.0028/0.0881	0.0012/0.0807		
Luminosity	$8\text{x}10^{35}$		$cm^{-2}s^{-1}$	

Machine parameters - KEKB/SuperKEKB

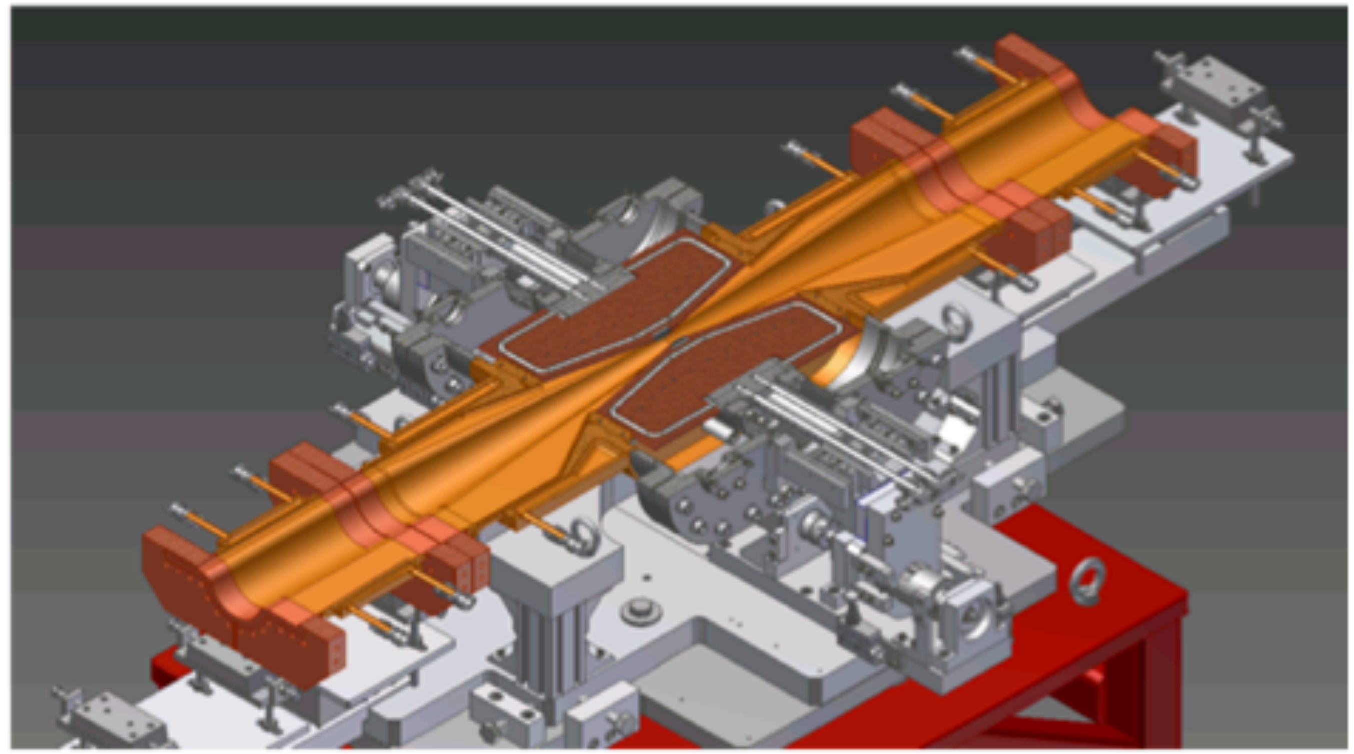
Machine Design Parameters

parameters		KEKB		SuperKEKB		units
		LER	HER	LER	HER	
Beam energy	E_b	3.5	8	4	7.007	GeV
Half crossing angle	ϕ	11		41.5		mrad
# of Bunches	N	1584		2500		
Horizontal emittance	ε_x	18	24	3.2	4.6	nm
Emittance ratio	κ	0.88	0.66	0.27	0.25	%
Beta functions at IP	β_x^*/β_y^*	1200/5.9		32/0.27	25/0.30	mm
Beam currents	I_b	1.64	1.19	3.6	2.6	A
beam-beam param.	ξ_y	0.129	0.090	0.088	0.081	
Bunch Length	σ_z	6.0	6.0	6.0	5.0	mm
Horizontal Beam Size	σ_x^*	150	150	10	11	μm
Vertical Beam Size	σ_y^*	0.94		48	62	nm
Luminosity	L	2.1×10^{34}		8×10^{35}		$cm^{-2}s^{-1}$

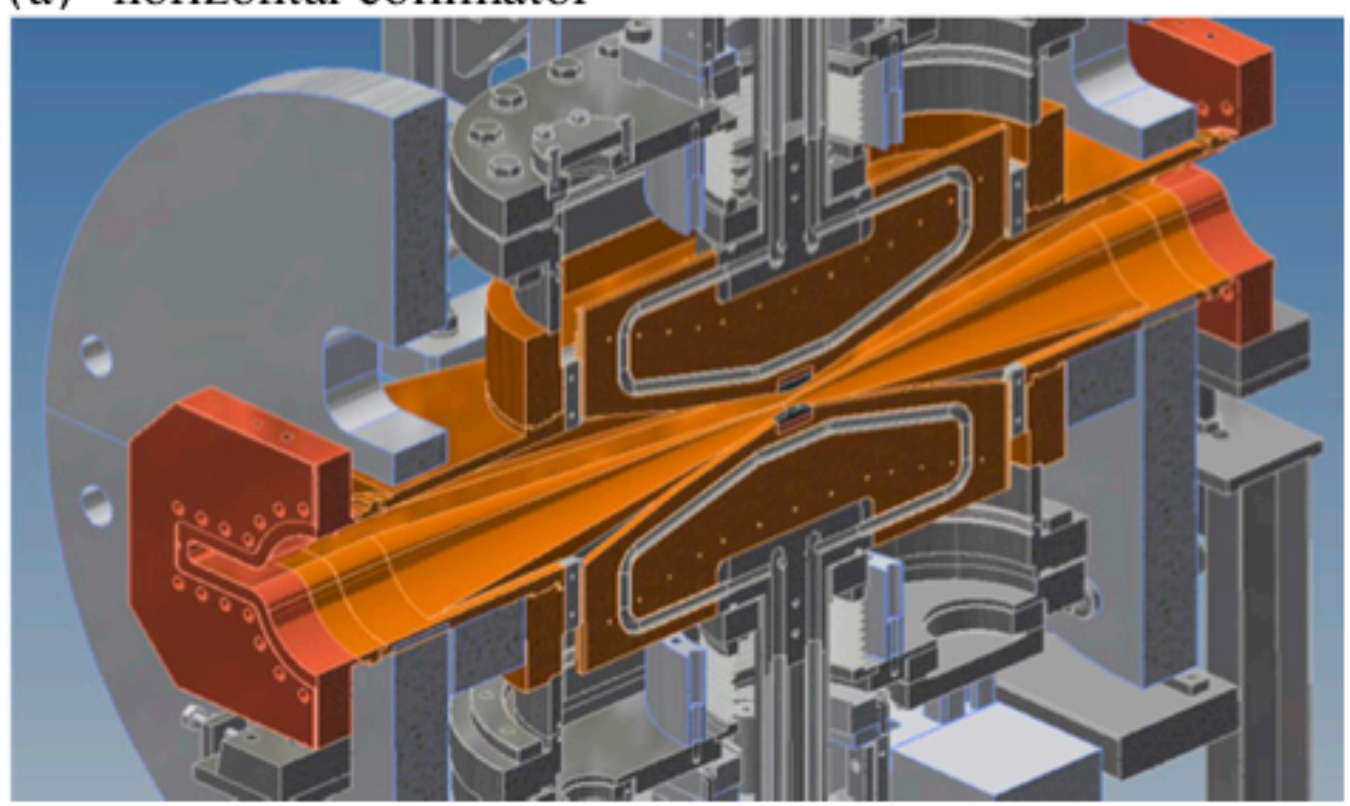
Collimators location - early Phase 3



Vertical and horizontal collimators

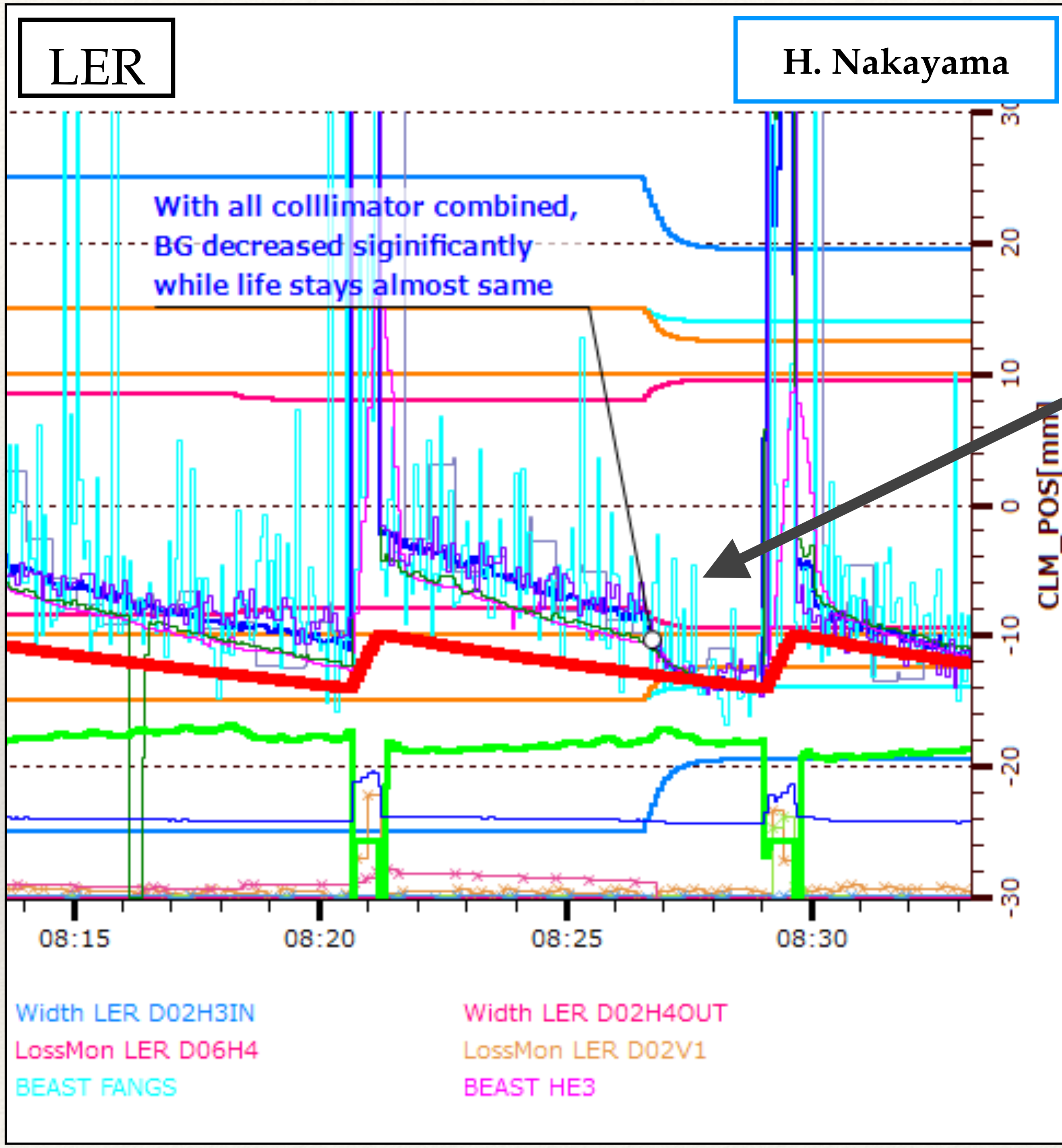


(a) horizontal collimator



(b) vertical collimator

BG reduction after collimator study



At the end of a collimator study, all collimators were opened as in the initial configuration, and then closed all together to their optimised aperture. A reduction in the background level is observed.

Background reduction - collimators

- To adjust collimators, the physical aperture of QC1 and QC2 in terms of number of σ_x has to be considered:
  - Collimators with larger $N\sigma_x$ than QC1/QC2 can be closed without loosing lifetime.
  - Closing collimators at same (or more) $N\sigma_x$ as QC1/QC2 helps avoiding QCS quenches

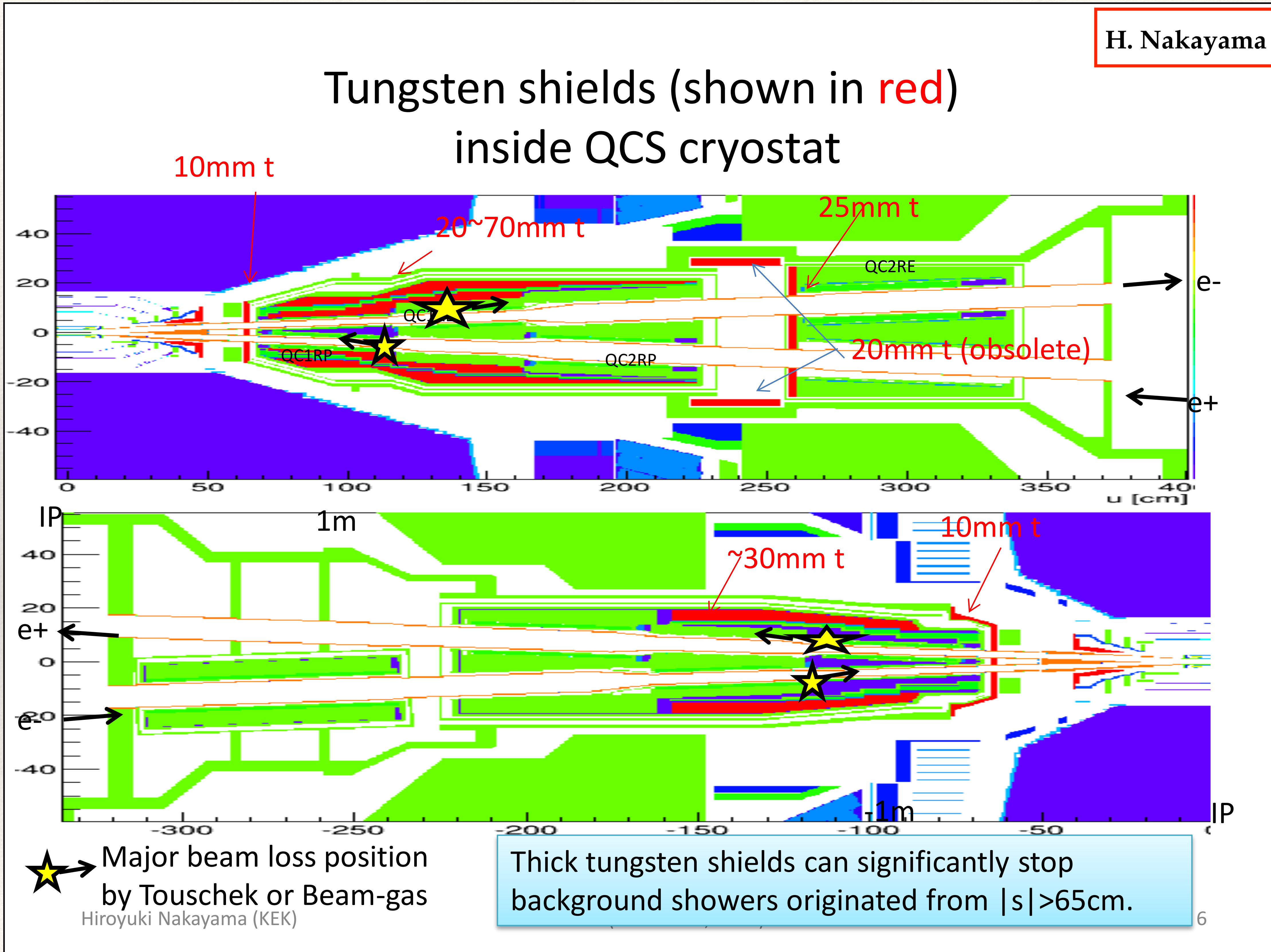
HER	SetPos [mm]	beta_x [m]	nu_x	Nsigma
D09H1	-10.00	39.7	15.98	**23.4**
D09H2	-11.00	39.7	15.49	**25.7**
D09H3	-13.00	39.7	14.83	**30.4**
D09H4	-13.00	39.7	14.34	**30.4**
D12H1	-12.50	39.7	8.73	**29.2**
D12H2	-12.50	39.7	8.24	**29.2**
D12H3	-13.00	39.7	7.58	**30.4**
D12H4	-15.00	39.7	7.09	**35.1**
D01H4OUT	18.00	27.6	0.51	**50.5**
D01H4IN	-18.00	27.6	0.51	**50.5**
D01H5OUT	9.50	19.3	0.29	**31.9**
D01H5IN	-9.50	19.3	0.29	**31.9**
QC2 (-2.9m)	35.0	249.6	0.24	**32.7**

Cannot be reduced more because of too much losses during injection

LER	SetPos [mm]	beta_x [m]	nu_x	Nsigma
D06H3OUT	14.00	24.2	26.22	**62.0**
D06H3IN	-14.00	24.2	26.22	**62.0**
D06H4OUT	12.50	24.2	26.70	**55.4**
D06H4IN	-12.50	24.2	26.70	**55.4**
D02H3OUT	19.50	120.6	43.54	**38.7**
D02H3IN	-19.50	120.6	43.54	**38.7**
D02H4OUT	9.50	10.5	44.23	**64.1**
D02H4IN	-9.50	10.5	44.23	**64.1**
QC1 (1.18m)	10.5	12.9	44.34	**63.8**

β_x large during Phase 2, even with collimator fully open $N\sigma_x$ is smaller than QC1

Shielding inside QCS cryostat



Shielding outside QCS cryostat