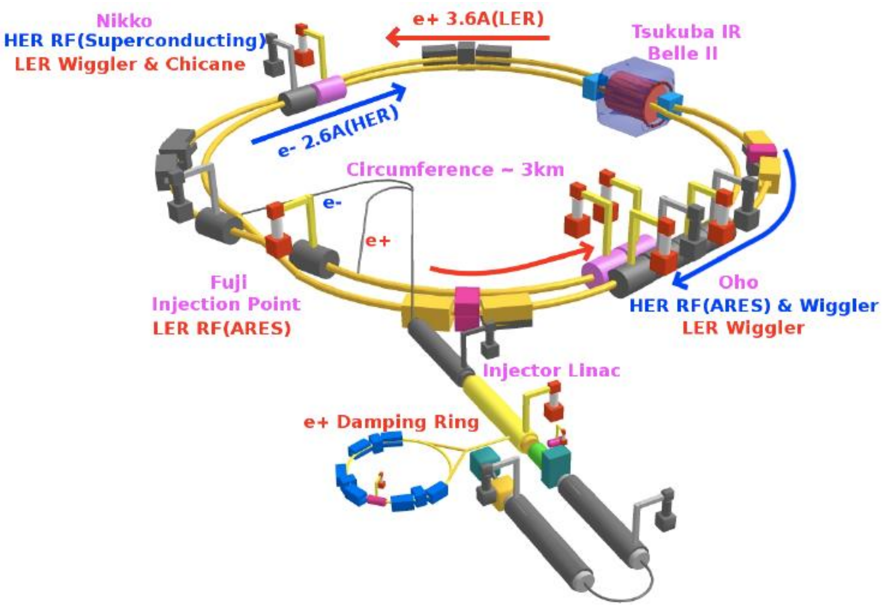
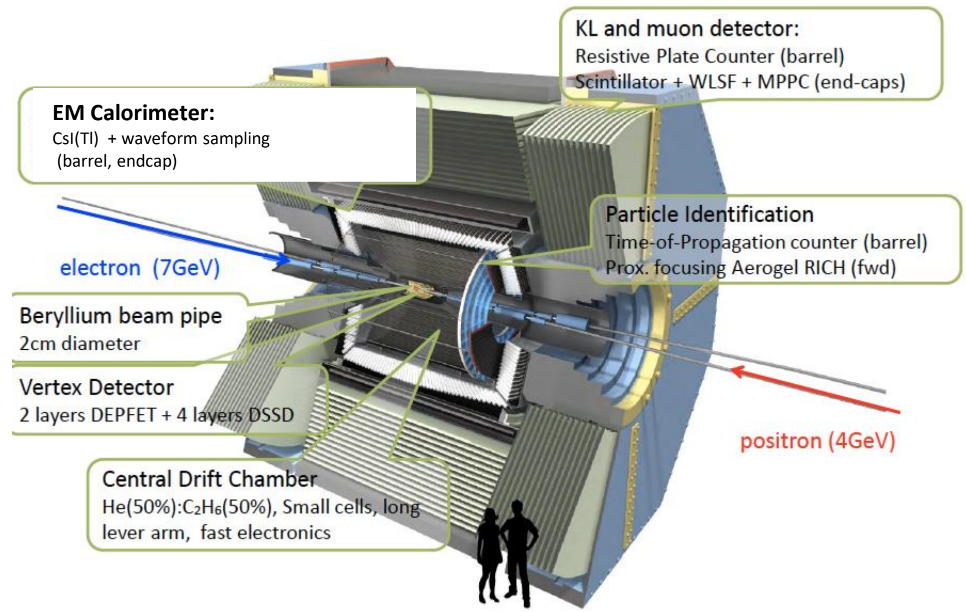
7GeV(e-), 4GeV(e-)





Latest beam background measurements at Belle II and future prospects

Hiroyuki Nakayama (KEK), on behalf of SuperKEKB/Belle II collaboration

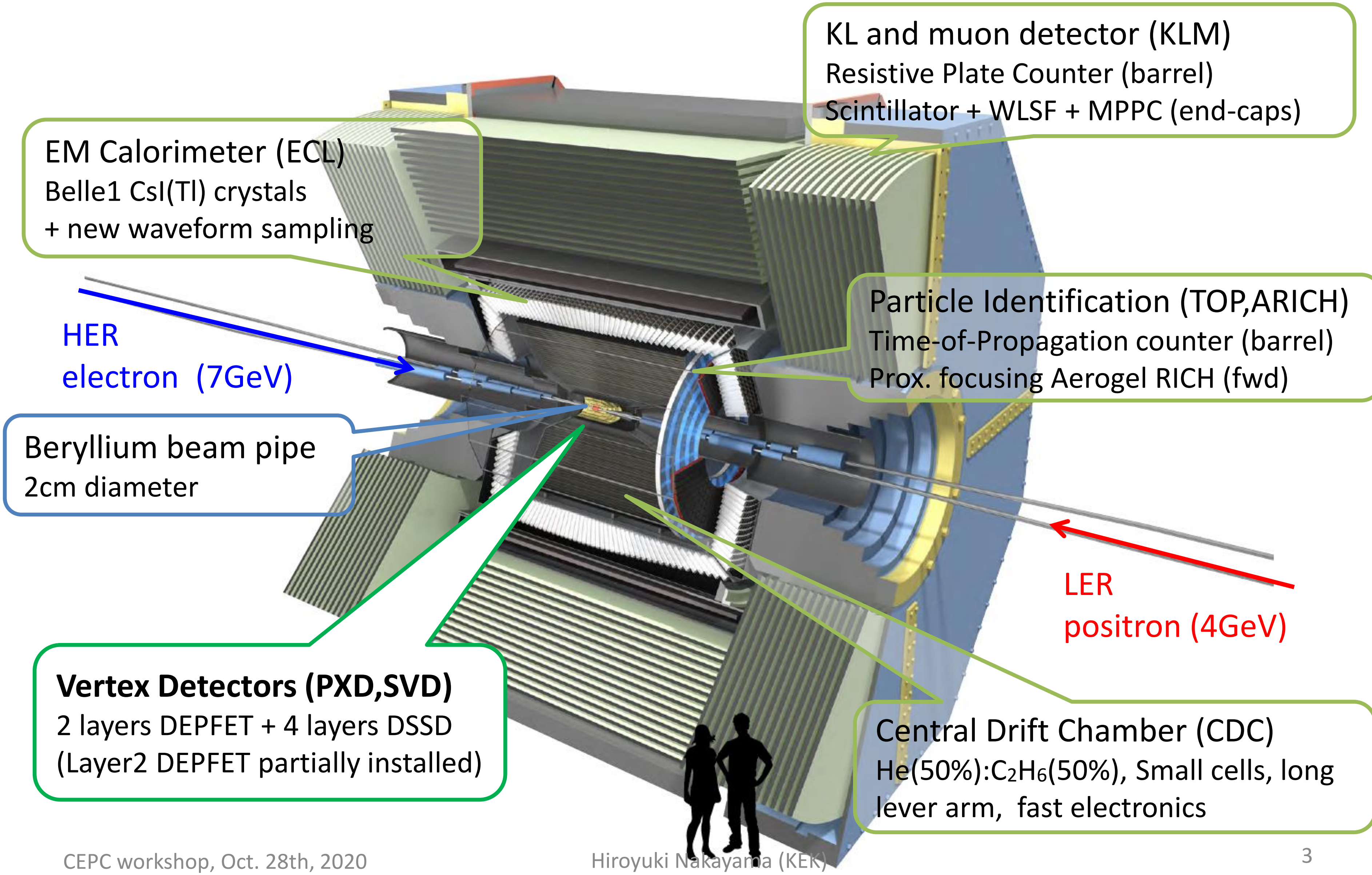
hiroyuki.nakayama@kek.jp

Today’s Contents

- **Beam background sources at SuperKEKB/Belle II**
  - Touschek scattering/Beam-gas scattering
    - Countermeasures: collimators and shield structures
  - Synchrotron radiation
  - Luminosity-dependent BG (radiative Bhabha, 2-photon process)
  - Background simulation tools
  - Simulated BG rates at full luminosity
- **Recent Background measurement at SuperKEKB**
  - Single-beam BG study
    - To measure Touschek and Beam-gas separately
  - Luminosity BG study
  - Data/MC ratio measured by BG studies, extrapolation for future
  - Mitigation plans
- **Summary**

Andrii Natochii’s talk on simulation details in Tuesday MDI session

Belle II Detector



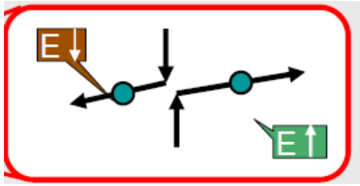
Beam background

- Beam-induced background at SuperKEKB accelerator can be dangerous for Belle II detector
- Beam BG determines survival time of Belle II sensor components and might lead to severe instantaneous damage
- Also increases sensor occupancy and irreducible analysis BG

SuperKEKB Beam BG sources

- *Single-beam BG:* Touschek, Beam-gas Coulomb/Brems, Synchrotron radiation, injection BG
- *Luminosity BG:* Radiative Bhabha, two-photon BG, etc..

1.Touschek scattering

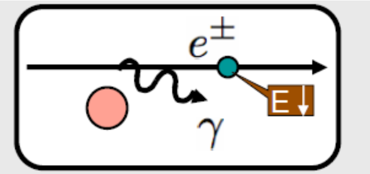


- Intra-bunch scattering : Rate∝(beam size)$^{-1}$,(E_{beam})$^{-3}$
- Touschek lifetime: should be >600sec (required by injector ability)

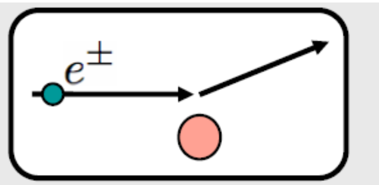
  → ring total beam loss: ~375GHz (LER), ~270GHz(HER)
- Horizontal collimators to reduce loss inside Belle II (|s|<4m)
  - collimators added at 0~200m upstream IP are very effective
- Collimator width optimization
  - Initial values: $d_x = Max[d_{x\beta}, d_{x\eta}], \quad d_{x\beta} = n_x\sqrt{\varepsilon_x \beta_x}, \; d_{x\eta} = \eta_x(n_z\sigma_\delta)$
  - Further optimization to balance IR loss and beam lifetime
  - Smaller loss rate on the last collimators (~20m upstream IP) is preferred
- After careful optimization of collimators, simulated beam loss in the detector can be mitigated to few hundred Hz level
  - 3 orders of magnitude smaller than the loss without any collimators

2.Beam-gas scattering

Brems



Coulomb



- Scattering by remaining gas, Rate ∝ IxP
- Due to smaller beam pipe aperture and larger maximum βy at SuperKEKB, beam-gas Coulomb scattering could be more dangerous than in KEKB

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

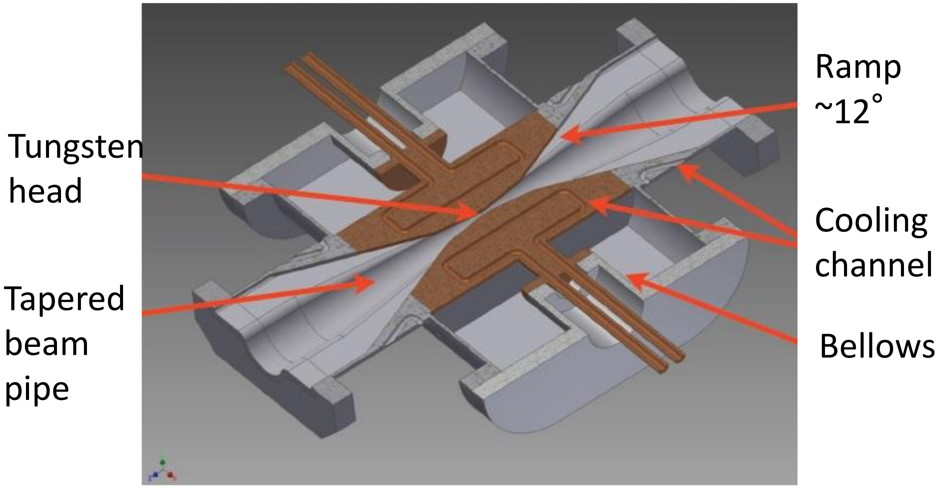
σ_R: cross section of the scattering
Z: atomic number of gas nucleus
n_G: $=2P/k_B/T$

	KEKB LER	SuperKEKB LER
QC1 beam pipe radius: $\mathbf{r_{QC1}}$	35mm	***13.5mm***
Max. vertical beta (in QC1): $\beta_{y,QC1}$	600m	2900m
Averaged vertical beta: $\langle\beta_y\rangle$	23m	50m
Min. scattering angle: θ_c	0.3mrad	0.036mrad
Beam-gas Coulomb lifetime: τ_R	>10 hours	35 min

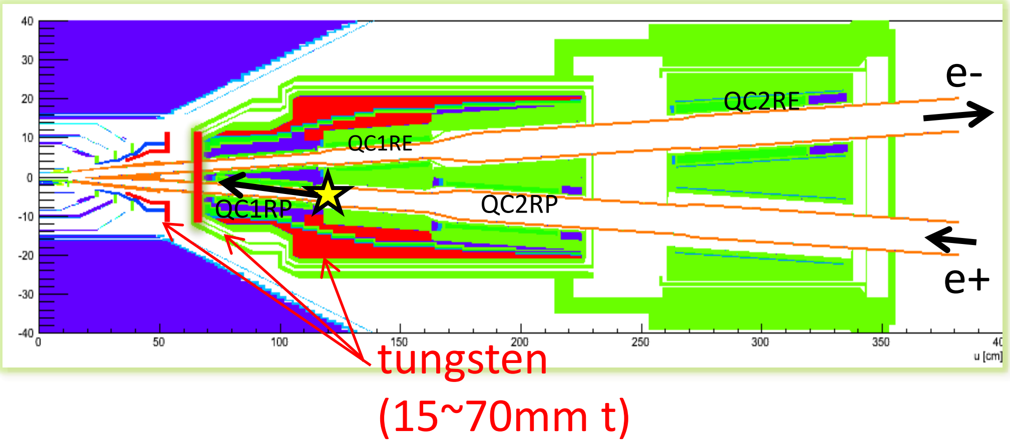
How to cope with beam BG?

- Movable collimators
  - Arc collimators and horizontal collimators near IP
  - Very narrow (~<2mm half width) vertical collimators
- Shielding structures
  - Thick tungsten structures inside final focus cryostat and vertex detector volume
  - Stops showers from beam loss "hot spot" ☆ at ~1m upstream from IP (maximum beta_y)
  - Polyethylene shields for neutrons

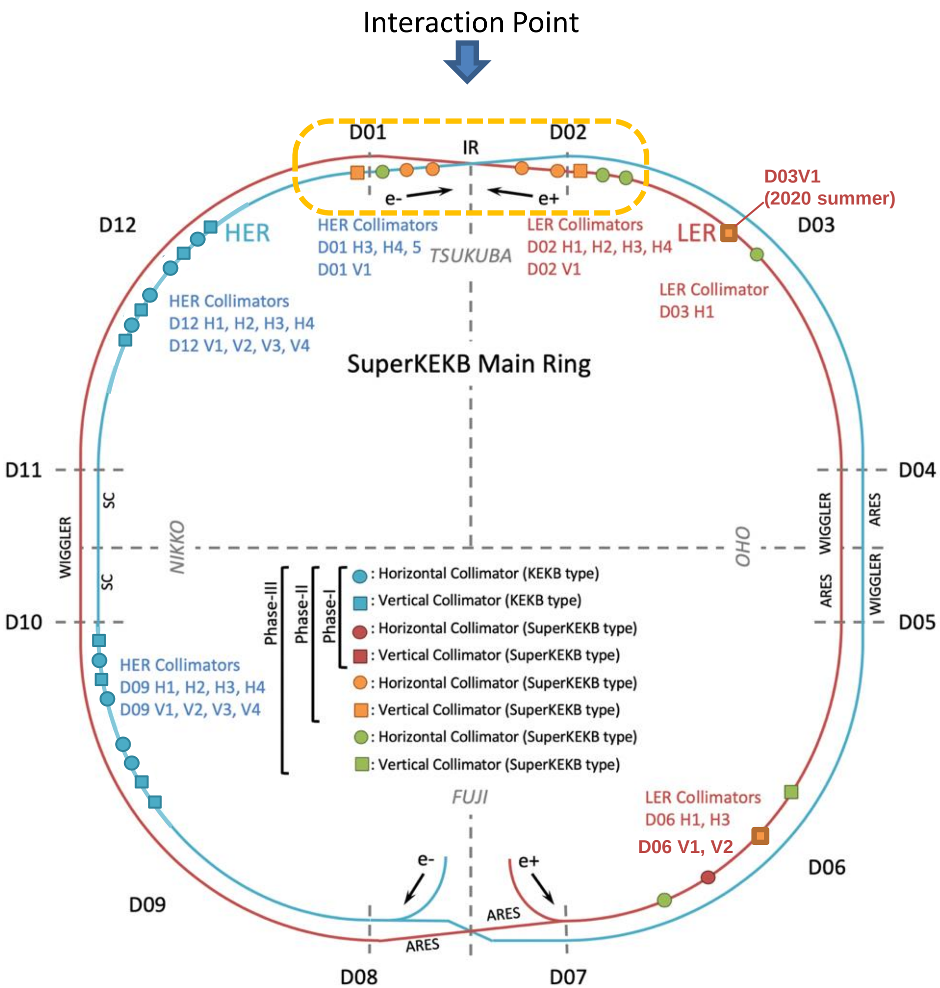
SuperKEKB horizontal collimator



Final focus magnet cryostat, R-side



SuperKEKB Collimators



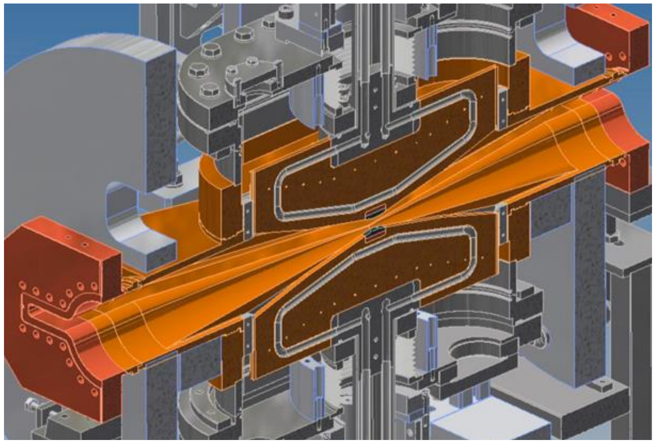
As of 2020 autumn,

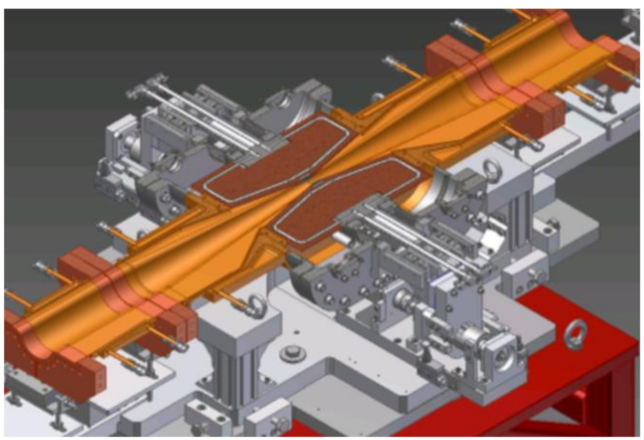
31 movable collimators installed

LER(11):
- 7 horizontal, 4 vertical "SuperKEKB type" collimators
  - horizontal: D06H1, D06H3, D03H1
    D02H1, D02H2, D02H3, D02H4
  - vertical: D06V1, D06V2, D03V1, D02V1

HER(20):
- 3 horizontal, 1 vertical "SuperKEKB type" collimators
  - horizontal: D01H3, D01H4, D1H5
  - vertical: D01V1
- 8 horizontal, 8 vertical "KEKB type" collimators
  - horizontal: D12{H1,H2,H3,H4},D09{H1,H2,H3,H4}
  - vertical: D12{V1, V2, V3, V4},D09{V1,V2,V3,V4}

Vertical Collimators



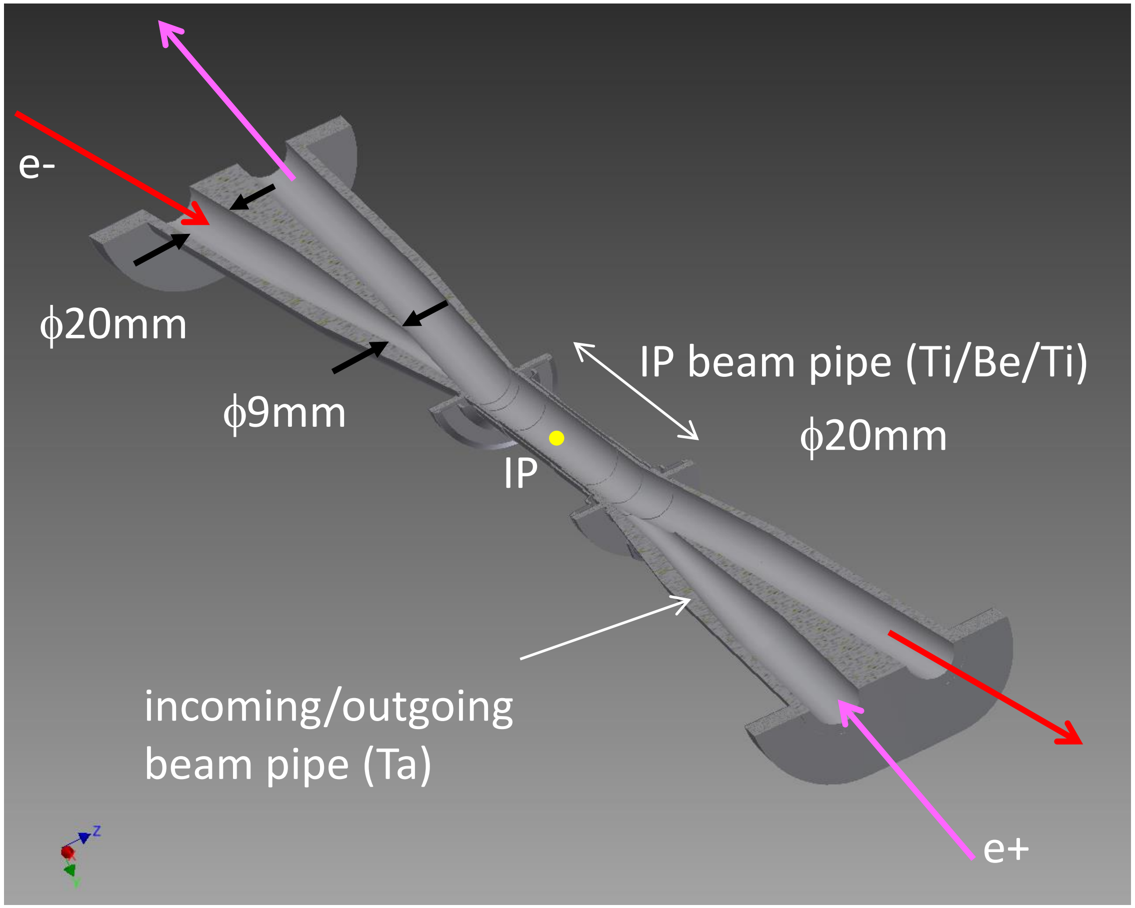


- To reduce beam-gas Coulomb IR loss, we need very narrow (<~2mm half width) vertical collimators
- TMC instability is an issue: low-impedance collimator head design is important, and collimators should be installed where beta_y is rather small (*)

- Precise control (Δd~50um) of collimator head is required, since IR loss is quite sensitive to the collimator width
- Collimator head should survive ~100GHz beam loss → tungsten is used, but we also try carbon for far upstream collimators
- Secondary shower (tip-scattering) effect should be carefully examined

(*) "Small-Beta Collimation at SuperKEKB to Stop Beam-Gas Scattered Particles and to Avoid Transverse Mode Coupling Instability", H, Nakayama et al, *Conf.Proc.C* 1205201 (2012) 1104-1106

3. Synchrotron radiation

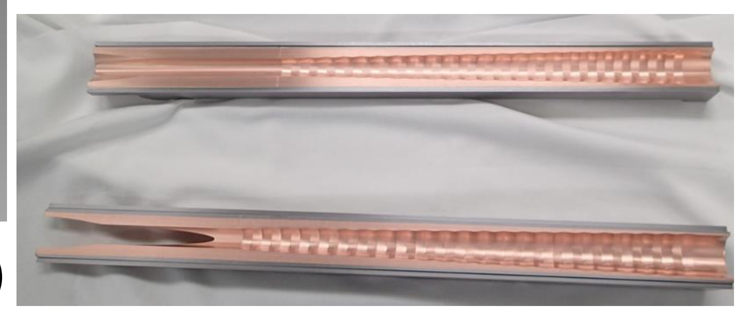


Inner surface of Be pipe are coated with Au layer (10um)

- ϕ20mm→ϕ9mm collimation on incoming beam pipes (no collimation on outgoing pipes, HOM can escape from outgoing beam pipe)

- Most of SR photons are stopped by the collimation on incoming pipe.
- Direct hits on IP beam pipe is negligible

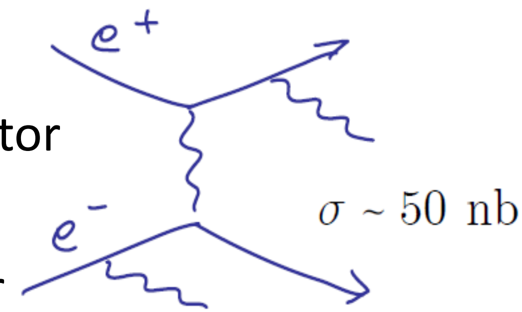
- To hide IP beam pipe from reflected SR, "ridge" structure on inner surface of collimation part.



4. Luminosity-dependent background

Radiative Bhabha scattering

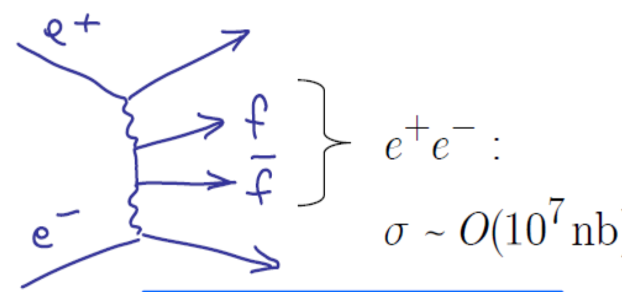
- Rate ∝ Luminosity (KEKBx40)
- Spent e+/e- with large ΔE could be lost inside detector (see next page)
- Emitted γ hit downstream magnet outside detector and generate neutrons via giant-dipole resonance



Bhabha scattering

2-photon process

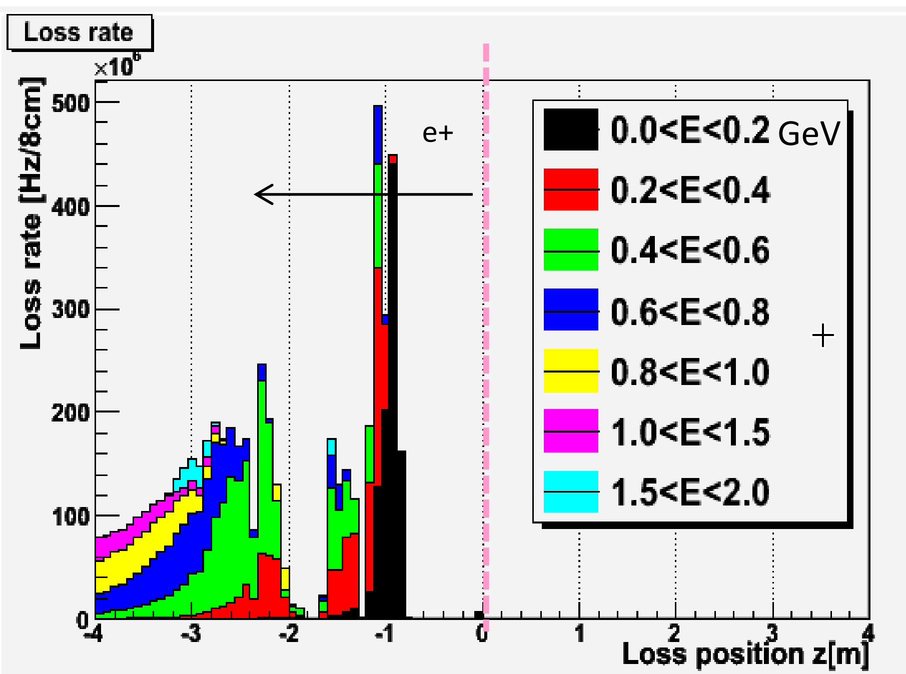
- Rate ∝ Luminosity (KEKBx40)
- e+ e- → e+ e- e+ e-
- Emitted e+e- pair curls by solenoid and might hit inner detectors multiple times



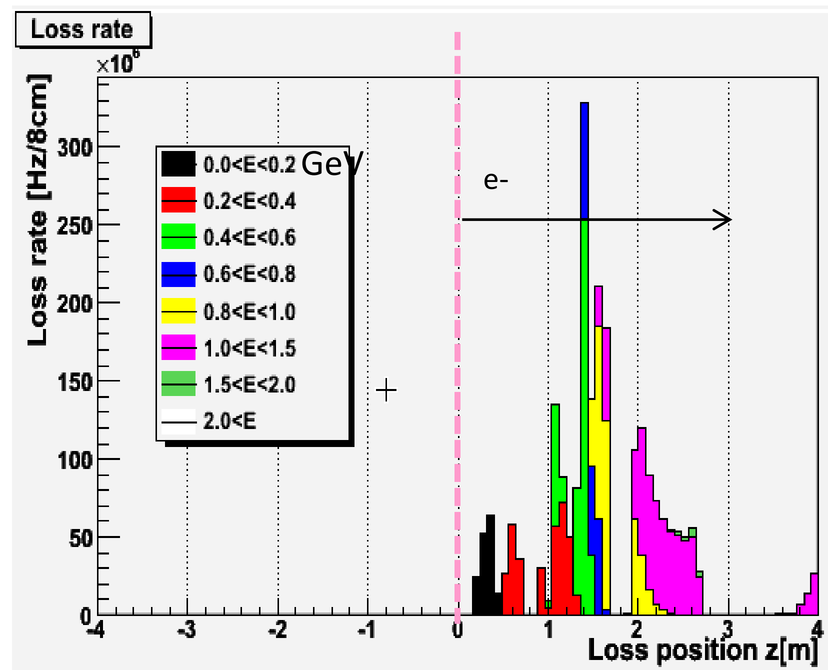
2-photon-processes

Spent e+/e- loss position after RBB scattering

LER(orig. 4GeV)



HER(orig. 7GeV)



If ΔE is large and e+/e- energy becomes less than 2GeV, they can be lost inside the detector (<4m from IP), due to kick by the 1.5T detector solenoid with large crossing angle(41.5mrad)

Background simulation tools

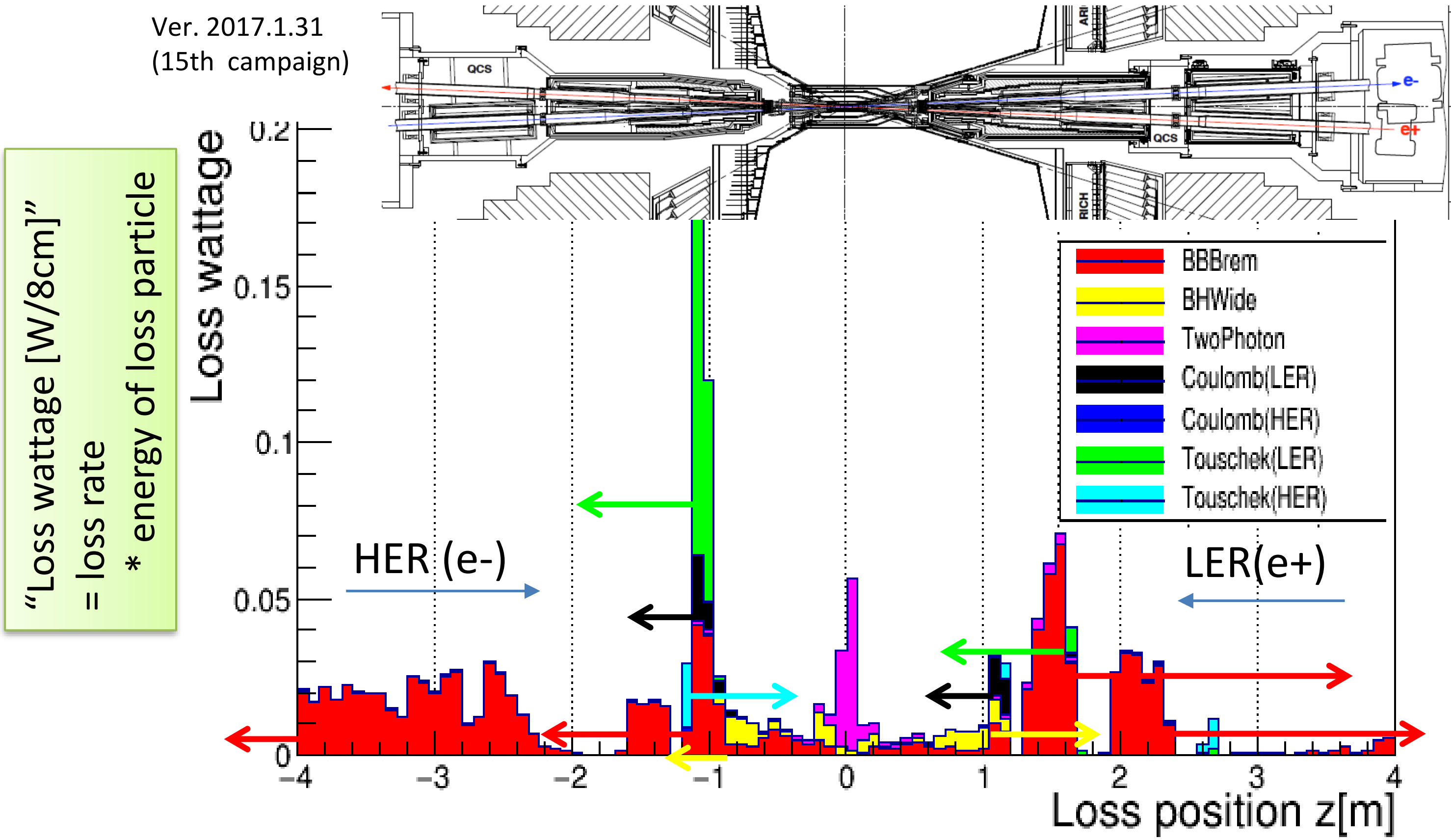
- Use SAD for multi-turn tracking in the entire rings
- Use GEANT4 for single-turn tracking within detector and full simulation

BG type	BG generator	Tracking (till hitting beam pipe)	Detector full simulation
Touschek/Beam-gas	Theoretical formulae [1]	SAD [2] (up to ~1000 turns)	GEANT4
Radiative Bhabha	BBBREM/BHWIDE	GEANT4 (multi-turn loss is small)	GEANT4
2-photon	AAFH	GEANT4 (multi-turn loss is small)	GEANT4
Synchrotron radiation	Physics model in GEANT4 (SynRad)	GEANT4	GEANT4

[1] Y. Ohnishi et al., PTEP **2013**, 03A011 (2013).
[2] SAD is a “Home-brew” tracking code by KEKB group, http://acc-physics.kek.jp/SAD/

Simulated BG loss distribution (design luminosity)

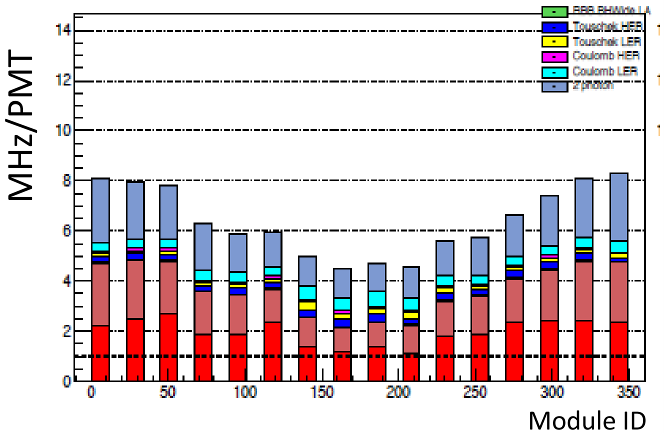
Ver. 2017.1.31
(15th campaign)



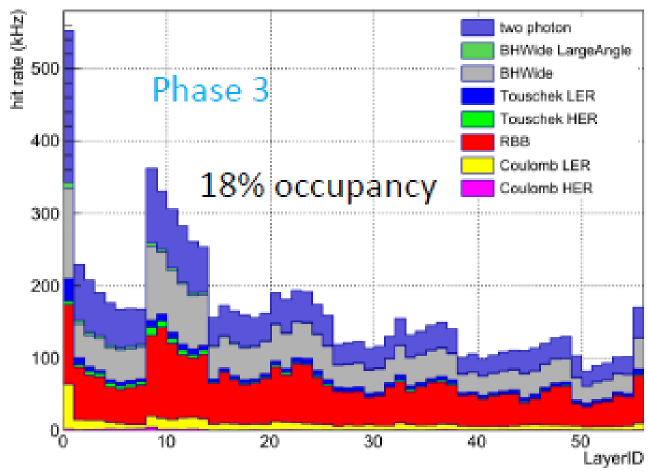
	LER (4GeV e+)	HER (7GeV e-)
Lumi-dependent BG	BBBrem: **1.08 W** (0.06 W in |z|<65cm) BHWide: 0.11 W (0.04 W), 2photon: 0.14 W(0.11W)	
Touschek	0.27 W (0.42GHz)	0.04 W (0.03GHz)
Coulomb	0.06 W (0. 10Hz)	0.00 W (0.002GHz)

Simulated Sub-Detector BG rates

TOP PMT rate



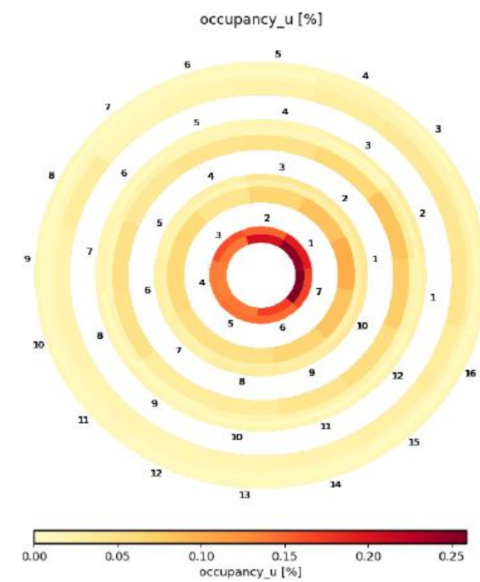
CDC wire rate



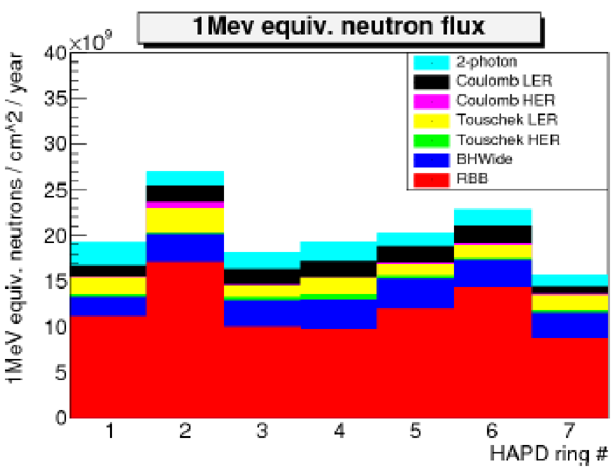
PXD occupancy

Layer #1
0.84 % occupancy
from 2-photon

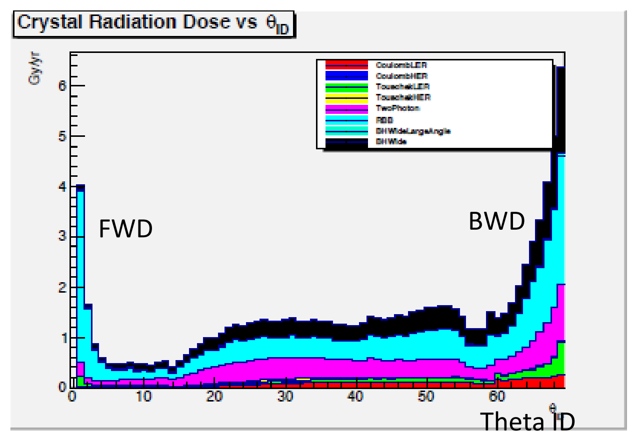
SVD occupancy



ARICH neutrons



ECL crystal dose



Simulation shows that sub-detectors will survive ~10 years at full luminosity (except TOP PMTs, which will be replaced in few years)

data/MC ratio is not applied here

BG simulation summary

- Collimators/shields are installed to mitigate Touschek/Beam-gas BG
- Radiative Bhabha spent e+/e- are dominant BG source at full design luminosity

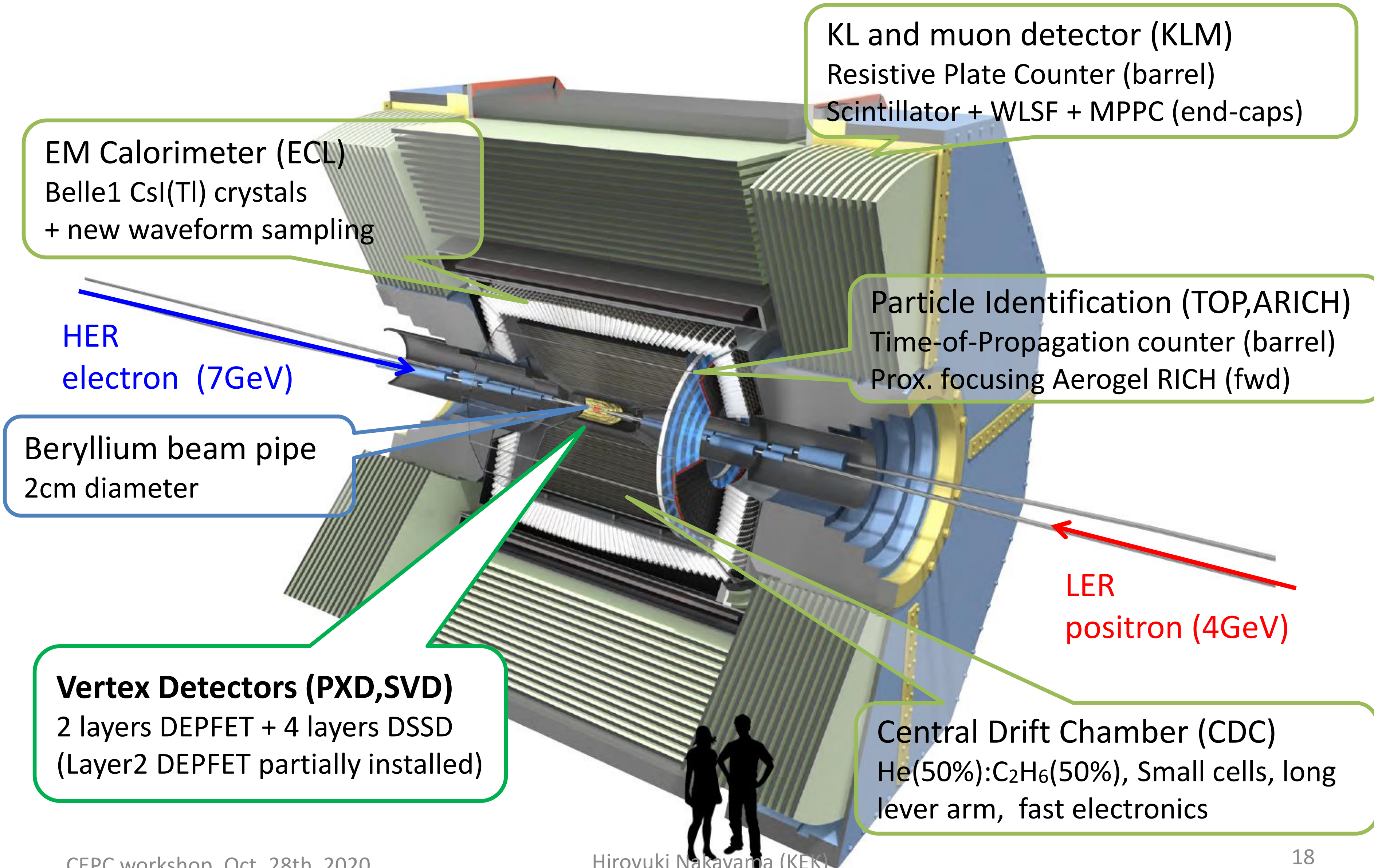
- Simulated BG rates on subdetectors at full luminosity seems acceptable, but safety margins are small
  - Exception: 1/3 of TOP PMTs need replacement after few years of operation

- BUT…
  - **BG in a real machine can be larger than simulation**
  - We need to measure BG by machine studies and verify simulation

Beam background measurement during SuperKEKB 2020 runs

~ hot from the oven ~

Belle II Detector



3-phase SuperKEKB commissioning

Phase1 (2016 Feb-June)

DONE

- No final focus, no Belle II
- Vacuum baking, beam tuning

"First Measurements of Beam Backgrounds at SuperKEKB"
Nucl.Instrum.Meth. A914 (2019) 69-144

Phase2 (2018 Mar-July)

DONE

- Final focus and Belle II installed (partial inner detector)
- Collision tuning + early physics samples

Paper in preparation

Phase3 (2019, 2020, 2021, …)

- All Belle II sensors installed -- "in full swing"
- Aim for higher luminosity with further focused beams

Background "big picture" in 2020 runs

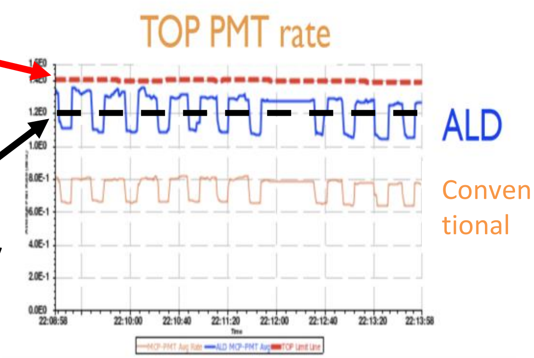
Luminosity world record !

- L_{peak}=2.402 x 10^{34}/cm2/s achieved on June 21st
  - with LER 720mA, HER 610mA, continuous injection
  - beta*y = 1.0mm, 978 bunches

- TOP is the detector currently most vulnerable to beam backgrounds
  - Finite PMT lifetime + new SuperKEKB run plan dictates: PMT rate from all bkg components except luminosity needs be <1.2MHZ

Limit, all bkg

Limit, all bkg but luminosity

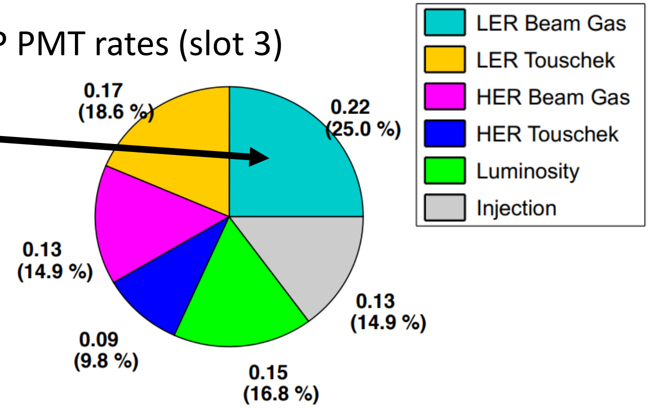


Kojima

- Latest BG composition
  - LER BG (especially LER beam-gas) dominates
  - LER beam-gas BG was reduced substantially since 2019

- Further reduction of TOP single-beam BG required for higher beam currents in 2021 and later

TOP PMT rates (slot 3)



Good news: Background reduction, 2019 to 2020

- Previously dominant LER beam-gas significantly reduced, by factors of approx.
  - SVD: 2.3
  - PXD: 5
  - CDC: 3
  - TOP: 2.4*

*dynamic pressure component

- Combined result of D6V1 collimator (installed in Jan. 2020), moving other collimators, vacuum scrubbing
- Matches our prediction (factor 2.5 expected)
- New: We now separate beam-gas into dynamic and base
  - Both in simulation analysis
  - Main reduction seen in <u>dynamic component</u>. Base component not always reduced.
  - Important to understand evolution for future BG predictions.

SVD

Tanigawa

(May 2020)/(Dec 2019) SVD L3 strip occupancy	
HER Beam-gas	1.1
LER Beam-gas	0.43
HER Touschek	1.0
LER Touschek	1.1

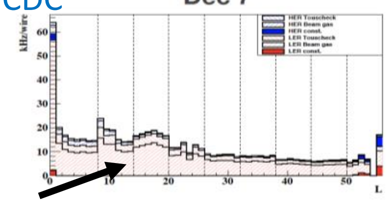
PXD

Stefkova

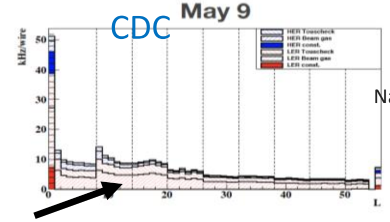
▹ Comparison based on fitted sensitivities

Sensitivity/Period	07/12/2019	09/05/2020	Ratio (May/December)
B_0 (L1)	1.9×10^{-7}	1.9×10^{-7}	↑ 1.02
B_0 (L2)	9.9×10^{-8}	8.2×10^{-8}	↓ 0.83
B_1 (L1)	8.4×10^{-10}	1.8×10^{-10}	↓ 0.21
B_1 (L2)	4.2×10^{-10}	0.9×10^{-10}	↓ 0.21
T (L1)	2.5×10^{-5}	2.8×10^{-5}	↑ 1.14
T (L2)	1.1×10^{-5}	1.1×10^{-5}	≈ 1.0

CDC



CDC



Nakagiri

Kojima

TOP

■ Ratios of Fit Parameters for slot01

		Dec. 7th	May 9th	Ratio
HER	T	0.63×10^{-2}	1.1×10^{-2}	1.7
	B_0	1.3×10^{-4}	1.9×10^{-4}	1.5
	B_1	0.32×10^{-6}	0.18×10^{-6}	0.6
LER	T	2.6×10^{-2}	3.0×10^{-2}	1.2
	B_0	4.7×10^{-4}	2.4×10^{-4}	0.5
	B_1	2.2×10^{-6}	0.91×10^{-6}	0.4

* T: Touschek, B_0: Beam gas base, B_1: Beam gas dynamic

Background rates from beam gas components are decreased.

Single-beam BG study

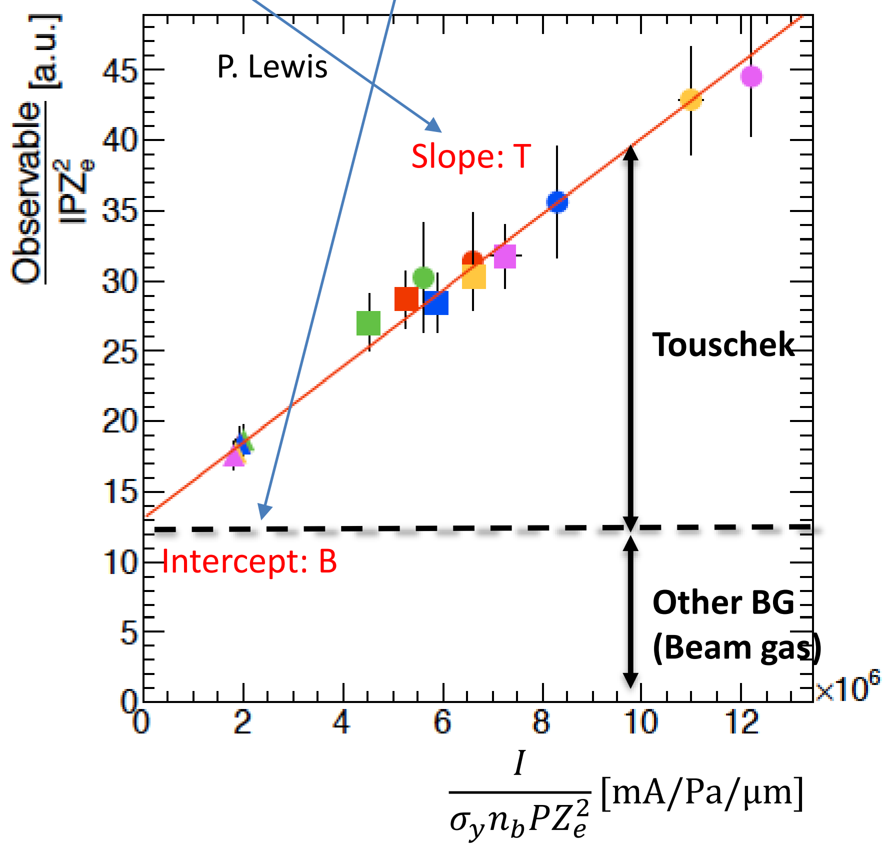
for measuring Touschek and Beam-gas component separately

$$P = P_0 + cI$$

$$Rate = T\frac{I^2}{\sigma_y n_b} + BZ_e^2 IP \longrightarrow Rate/Z_e^2 IP = T\frac{I}{\sigma_y n_b P Z_e^2} + B$$

Linear function

T, B: Touschek/Beam-gas coefficient
σ_y: vertical beam size, n_b: number of bunches
P: pressure, I: beam current
Z_e: effective atomic number of residual gas



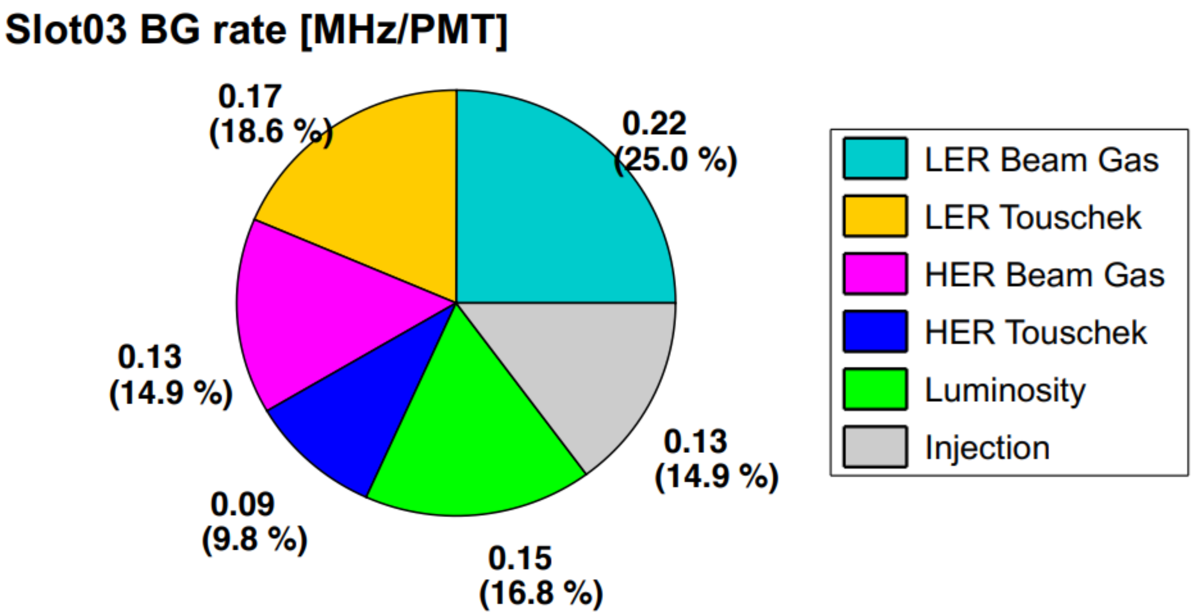
Strategy:

- **Single-beam (no collision)**
- **Assume Touschek + Beam-gas and no other BG component**
- **Vary number of bunches (or beam size), which should affect Touschek component only**
- **Fit for T and B coefficients and compare them against estimation by MC**
- **Use measured data/MC ratio for scaling BG simulation at future optics**
- **Lumi-BG = "total BG in collision runs" – "single-beam BG" – "injection BG"**

TOP background breakdown during recent physics runs

beta*y = 0.8mm

Kojima



Input values
to calculate background rate.

$$I^{\mathrm{HER}} = 500 \text{ mA}$$
$$\sigma_y^{\mathrm{HER}} = 34 \ \mu\mathrm{m}$$
$$N_b^{\mathrm{HER}} = 978$$
$$I^{\mathrm{LER}} = 480 \text{ mA}$$
$$\sigma_y^{\mathrm{LER}} = 66 \ \mu\mathrm{m}$$
$$N_b^{\mathrm{LER}} = 978$$
$$\mathcal{L} = 1.5 \times 10^{34} \ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

- In these plots, BG rates measured by single-beam studies are scaled to the physics run parameters (larger beam sizes due to collision, etc..)
- LER Beam-gas is the largest component
- Measured lumi-BG is still small and consistent with prediction (will dominate at full luminosity)

Andrii Natochii's talk on Tuesday MDI session

Recent Improvement in data/MC agreement

- Due to the improved collimator simulation, order 1000 increase in predicted HER Touschek rates
- Appears to largely resolve the long-standing HER simulation problem
- SVD, CDC shown here, but also holds for TOP, PXD
- Measured luminosity bkg agrees with simulation at the ~10% level in TOP, PXD. Also agrees between continuous injection and decay data (SVD see problem and more work needed)

- For the first time, data and MC agree within one order of magnitude for all five leading background components

LER Beam-gas, LER Touschek, HER Beam-gas, HER Touschek, Lumi-BG

36th B2GM, June 2020

CDC data/MC ratio

Nakagiri

BG sources	Old simulation	New simulation*
HER beam-gas (base)	x30-130	x6-22
HER beam-gas (dynamic)	x20-50	x4-12
HER Touschek	x30-80	x0.6-1.2

SVD data/MC ratio

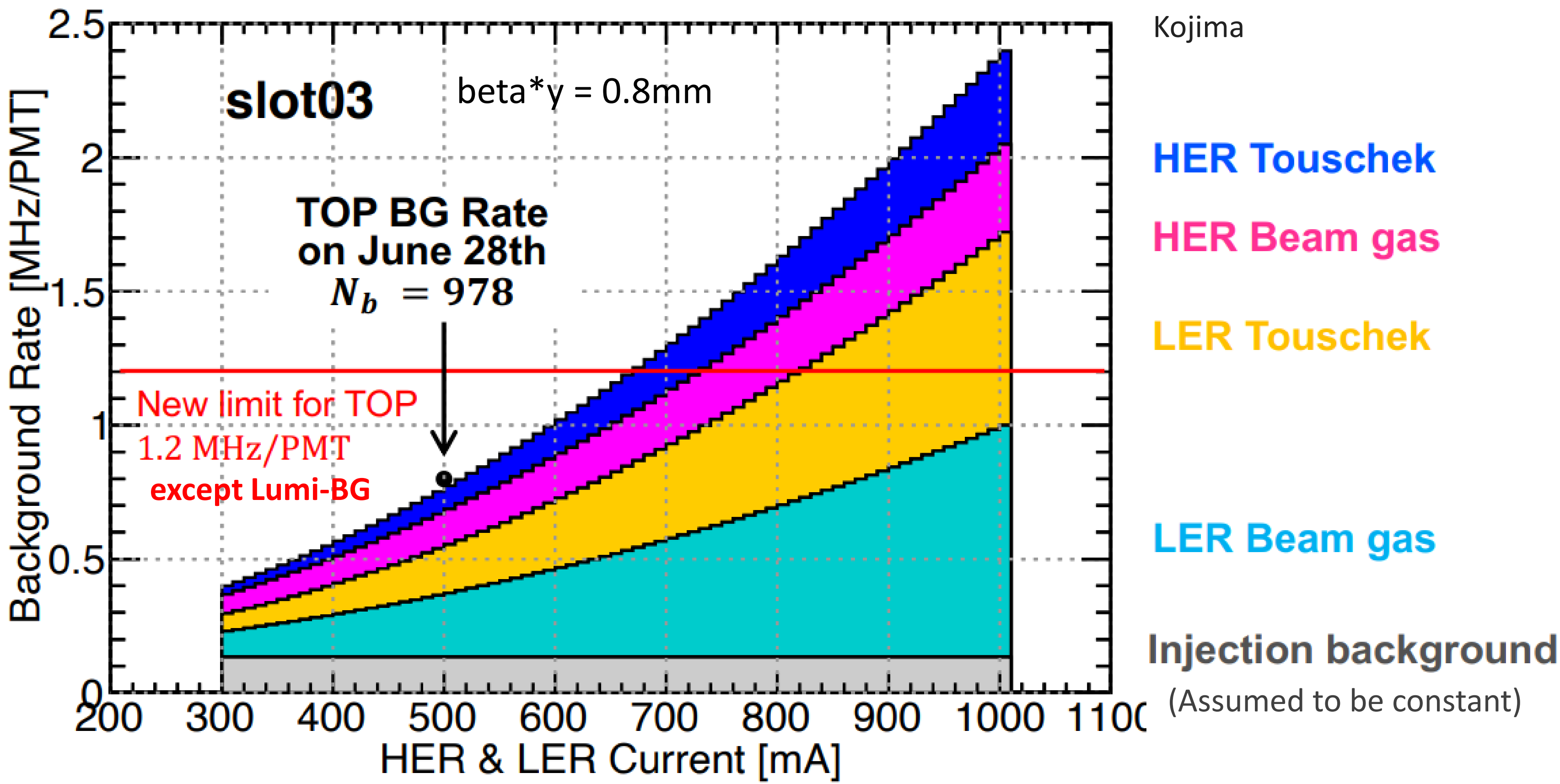
Tanigawa

BG sources	Old simulation	New simulation*
HER beam-gas (base)	x11	x3.4
HER beam-gas (dynamic)	x15	x6.3
HER Touschek	x130	x0.24

- New simulation includes realistic collimator shape and tip-scattering (details in backup p.34)

TOP BG extrapolation

Naïve extrapolation, assuming no bkg mitigation



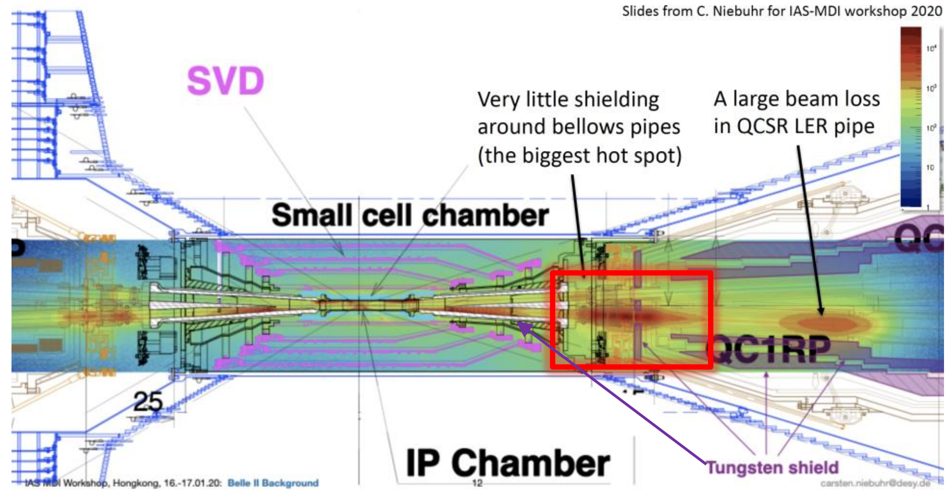
TOP PMT rate will hit the limit at LER~700mA (design: 2.8A)

NEED FURTHER BKG MITIGATION!

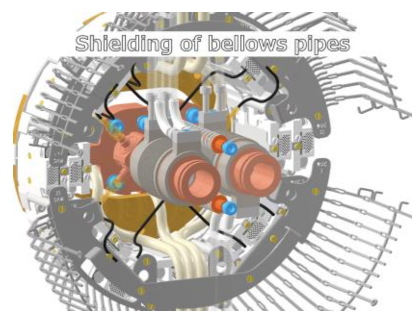
Mitigation ideas: Bellows shielding

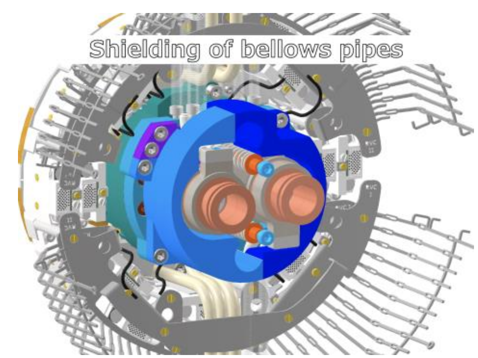
- To reach design luminosity, we need further background mitigation.
- One of ongoing project is an <u>additional shield</u> around bellows pipe where we see “hot spot” in data (also seen in simulation).
- Showers generated at z=1m leak out to the detector from the bellows part, where we cannot put enough shielding due to inner detector cables
- Shield design is ongoing. The beam loss simulation predicts LER coulomb bkg can be reduced by 53% (CDC), 28% (TOP) with this shield.

Hot Spots around IR from V0 analysis



V0 vertex distribution for Inv-M>550MeV

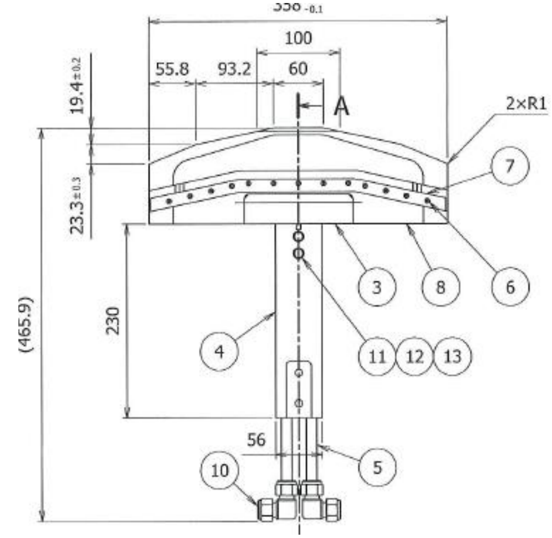




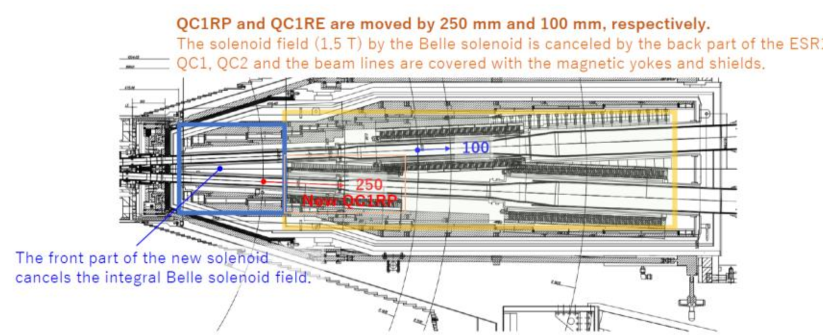
Further improvements

- Vacuum scrubbing
  - beam-gas background will be gradually improved
- Collimators
  - 2020 summer: install LER D3V1 collimator, replace D6V1 with carbon head to avoid sever damage
  - Optimize collimators as beta*y becomes smaller (add new ones and/or move current ones to different places in the ring)
- Additional shield around QCS bellows (2022)
  - Further BG reduction for TOP/CDC
- QCS modification (2026?)
  - Less overlap of solenoid and quads → suppress beam-beam blowup
  - Wider beam pipe aperture→ less beam loss

Carbon collimator head for D6V1



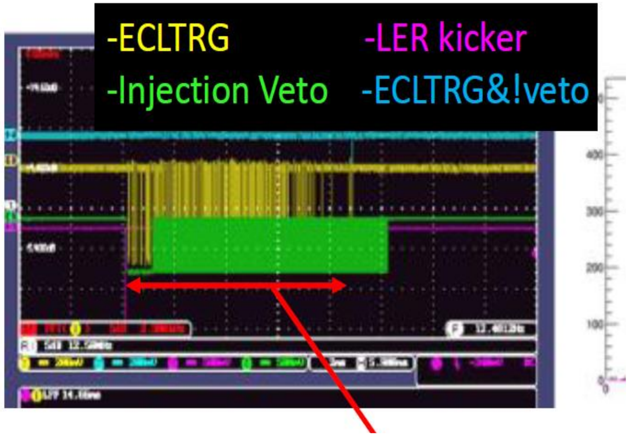
QCS remodeling

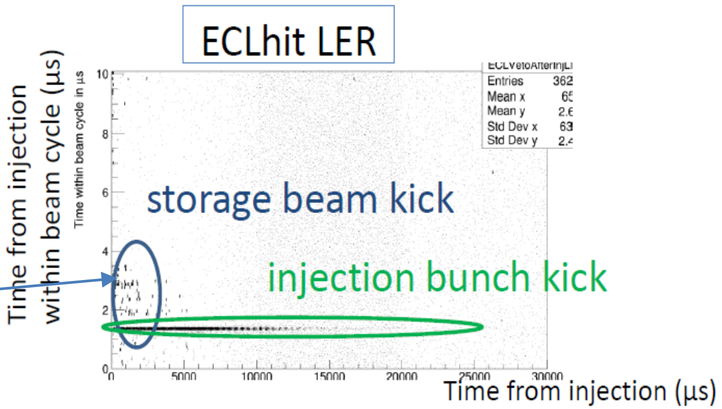


Other Issues: Injection BG duration

T. Koga

- Top-up injection is essential to compensate short beam life of SuperKEKB
- Belle II needs trigger veto after each injection
  - longer veto window -> less integrated luminosity
- Typical duration: LER: 6~12ms, HER:1~6ms
  - Corresponds to 7~8% deadtime
- Dedicated machine study in 2020 shows:
  - Single beam: BG duration∝bunch current
  - Colliding beams: BG duration longer than single-beam
    - beam-beam effect
    - However, luminosity scan w/ v-offset didn't change BG duration...
  - beta*y squeeze: BG duration longer with small beta*y
- Not only the injected bunch, but also later bunches are lost
  - However, "blank-shot" injections don't give any BG duration → coupling btw an injected bunch and later bunches?





"blank-shot" injection: kickers are fired but no charge is injected

Summary of BG measurement

- BG studies in 2020 spring run shows:
  - Beam BG is still dominated by LER beam-gas
  - Data/MC ratio is now within O(10) for all BG components
    - HER Touschek discrepancy finally solved
  - Measured Lumi-BG consistent with prediction

2020 spring run has finished!
- beta_y*: 1mm (achieved L_{peak} world record)→ 0.8mm
- Collimators and vacuum scrubbing progress contributes to BG reduction
- Injection BG should be carefully monitored to reduce dead time and beam aborts

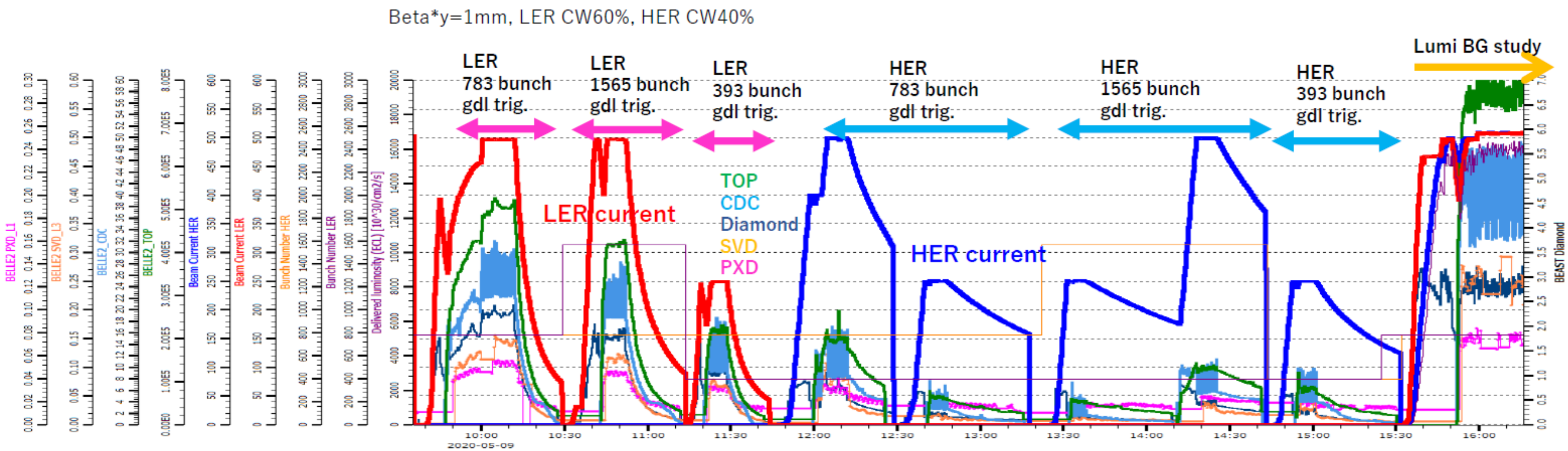
Overall summary

- Beam background at SuperKEKB can be dangerous and many countermeasures have been applied
- BG simulation predicts the impact on Belle II detectors
- BG measurements by dedicated machine studies can provide scaling factors between data and MC, which can be used for future extrapolation
- We still need further mitigation to cope with beam background at the design luminosity

backup

A snapshot from a single-beam BG study

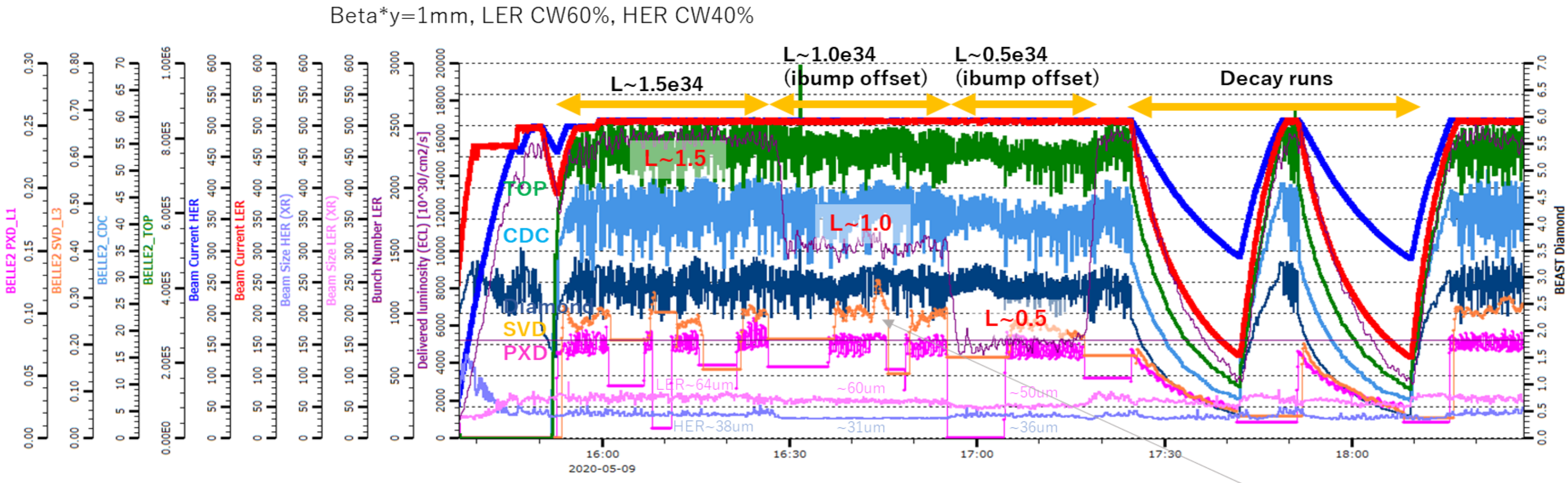
Example: LER/HER single-beam study on May 9th, 2020



- Number of bunches: Nb=783/1565/393.
- As we increase number of bunches, Belle II BG rates at the same beam current becomes smaller (due to decrease in Touschek BG)
- Beam size scan is not used recently, since unexpected BG increase was observed at larger beam size.

- <u>Observed dependency are consistent with the “Touschek+ Beam-gas” model (no significant indication of other BG sources)</u>

A snapshot from a Lumi-BG study



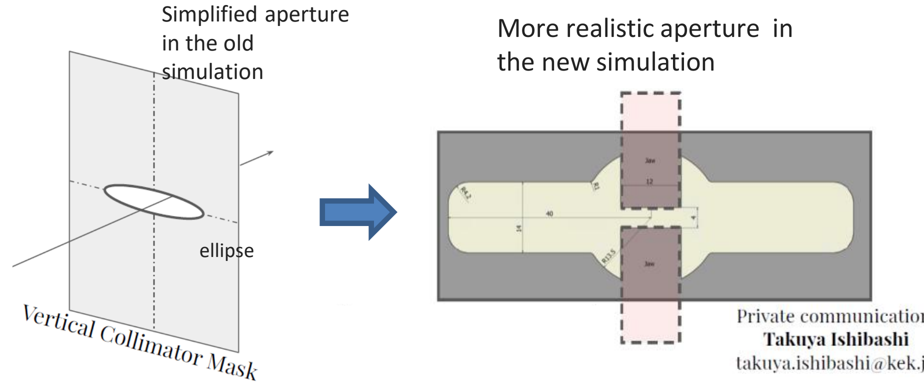
- “Continuous injection” runs
  - L=1.5→1.0→0.5e34, by vertically displacing two beams (“ibump V-offset”)
  - Beam sizes slightly changes as luminosity changes
- “Beam decay” runs (no injections)
  - Measurement not affected by injection BG
- Measure lumi-BG component by subtracting single-beam BG components scaled with current, beam size, etc..

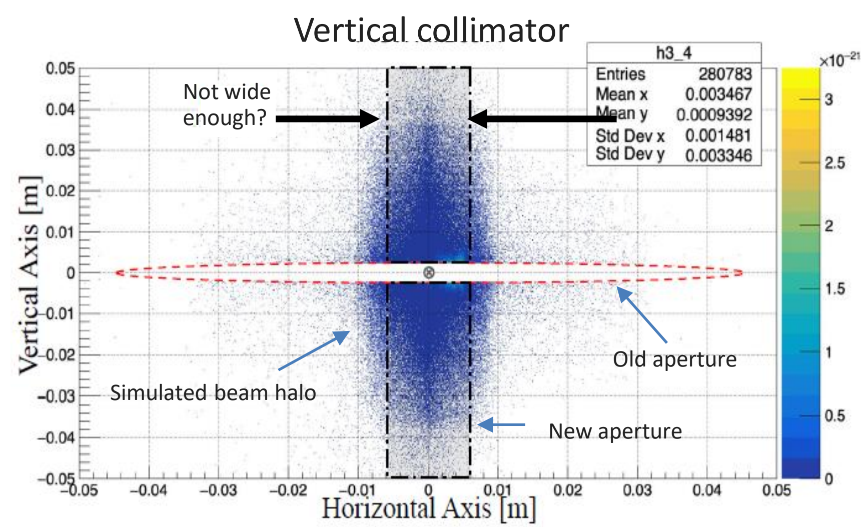
- Measured Lumi-BG agrees with simulation at the ~10% level in TOP, PXD !!
  - Also agrees between “continuous injection” and “beam decay” data

Recent improvements to simulation

A. Natochii

- Andrii Natochii implemented an improved framework for beam-particle tracking in SuperKEKB
  - New features: apply collimation after particle tracking, pressure-weighted beam-gas simulation, custom beam pipe aperture shapes, etc..
- Largest impact: implementation of correct SuperKEKB collimator shape + tip scattering
  - Particles previously stopped by the collimators can now reach the IP
- Up to factor 1000(!) increase in simulated Belle II detector rates, resolving a longstanding HER data/MC discrepancy
- Surprisingly, largest effect from collimator shape change transverse to beam axis
  - This may imply we could benefit from wider collimator heads for HER D1V1, in plane transverse to beam → should be studied (kick factor, etc.)

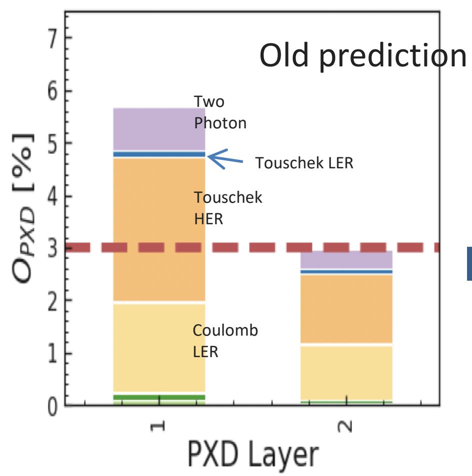




Implications for design luminosity

- Once we correct design-luminosity rates by measured data/MC, the new rates predictions are slightly lower than before (PXD)
- Despite previous corrections factors of order 1000, our Phase 3 rate predictions seem to have been correct to factor ~3
- Goal is to get to ~25% accuracy for single beam background, ~5% for luminosity backgrounds.

PXD



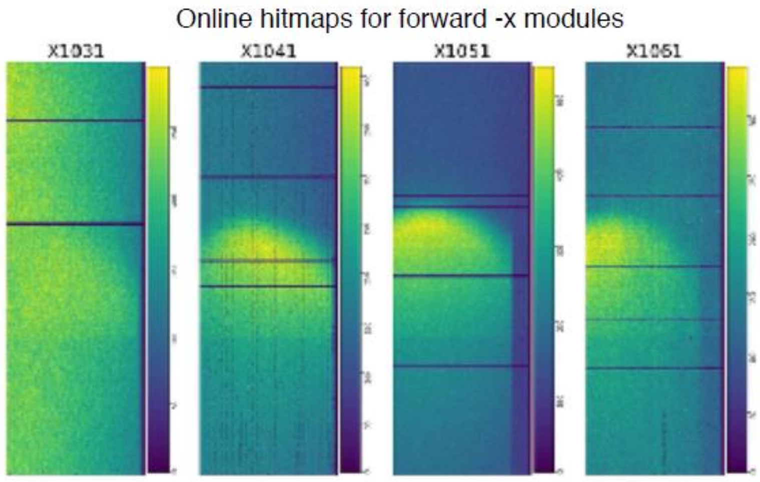
Stefkova

New prediction

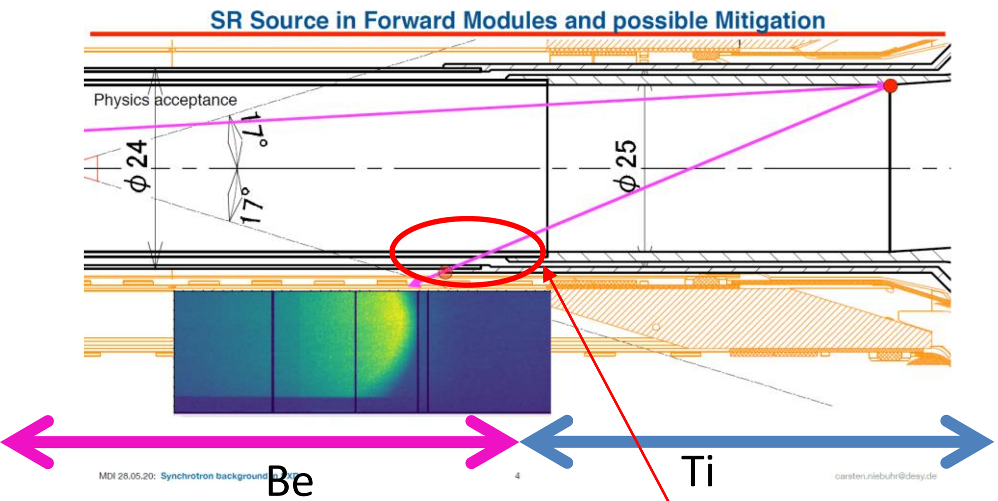
- Difference between BG 17/18 MC samples: corrected IR beam-pipe aperture, real collimator shape for SuperKEKB-type collimators, tip-scattering for SuperKEKB-type collimators, new data/MC ratios, the latest basf2/Geant4 geometry of the Belle II

Issues: PXD SR during HER injection

Carsten



- SR hit pattern on PXD forward -X modules
- Became stronger when HER beta*_x was squeezed
- Only visible during HER injection
  - not observed with “blank-shot” HER injections



We plan to add gold layer here for the new beam pipe (2022)

- HER horizontal tune adjustment shows no significant improvement within acceptable tune range
- HER D01H collimator adjustment didn’t improve SR

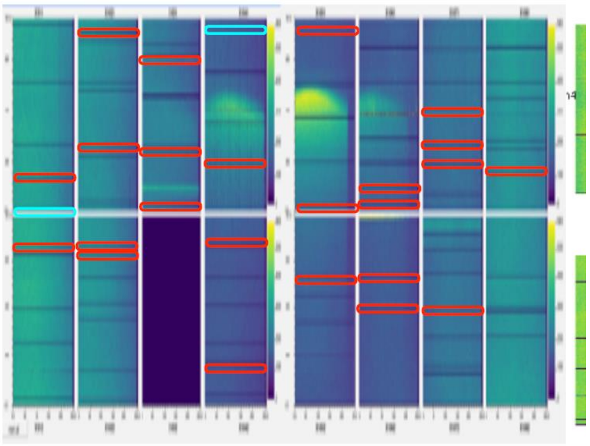
PXD SR is not critical right now, but we need to keep our eyes on it.

Issues: QCS quench on May 27th, 2020

What happened?

- LER was aborted first. Diamond abort was not issued.
- Diamond system received the abort acknowledge signal and started the data dump.
- Diamond was blind during this data dump, while still HER is circulating the ring.
- ~0.7 sec later, iBump fast FB strongly kicked HER beam and caused HER beam loss.
- It resulted in QCS quench and damage on PXD.

PXD after QCS quench in May 27th



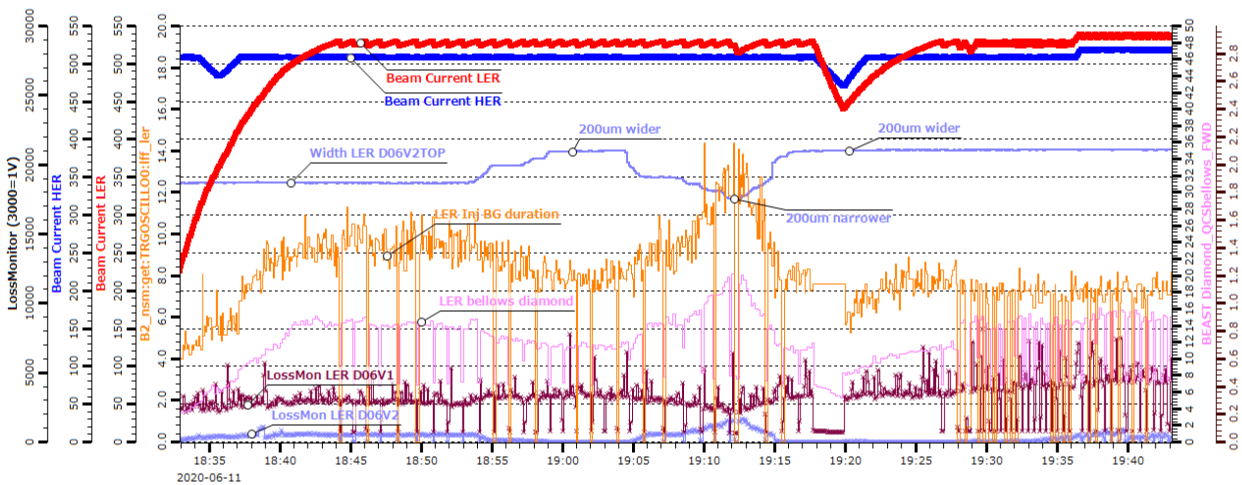
New inefficient gates after QCS quench

Solutions

- Diamond system is modified.
  - Dump the data only when both beams are aborted.
- iBump fast FB is also modified
  - Add the limiter on the FB power supply controller

Another QCS quench occurred on June 20th. Diamond abort was issued. Caused by small LER vacuum burst?

Issues: LER D6V2 “mystery”



	DIF_POS [mm]	beta_y [m]	nu_y	Nsigma (beta)
D06V1TOP	2.30	67.3	28.86	61.3
D06V1BTM	-2.33	67.3	28.86	62.0
	0.33			
D06V2TOP	2.06	20.6	30.50	99.2
D06V2BTM	-2.11	20.6	30.50	101.3
	0.21			
D02V1TOP	1.28	13.9	44.87	74.6
D02V1BTM	-1.35	13.9	44.87	78.8
	0.16			
QC1 (1.12m)	13.5	782.2	46.34	105.3
				11.1

- When we opened D6V2, injection BG duration (and injection BG on diamonds) improved.
- Now we use ~400um wider D6V2 settings.

<u>Why?</u>

- Tip-scattering of injection charge? → seems unlikely to reach IR from D6 or affect BG duration.
- Collimator impedance issue? (why only in D6V2?)

Issues: activation of collimators

Tanaka, Terui

- LER survey (June 2020)

  D06H3 : 400 uSv/h
  D06V1 : 400 uSv/h
  D06V2 : 260 uSv/h
  D02V1: 130 uSv/h
  D02H3: 950 uSv/h

- D6V1: “primary” (=narrowest) LER vertical collimator
- D2V1: Low activation is thanks to D6V1

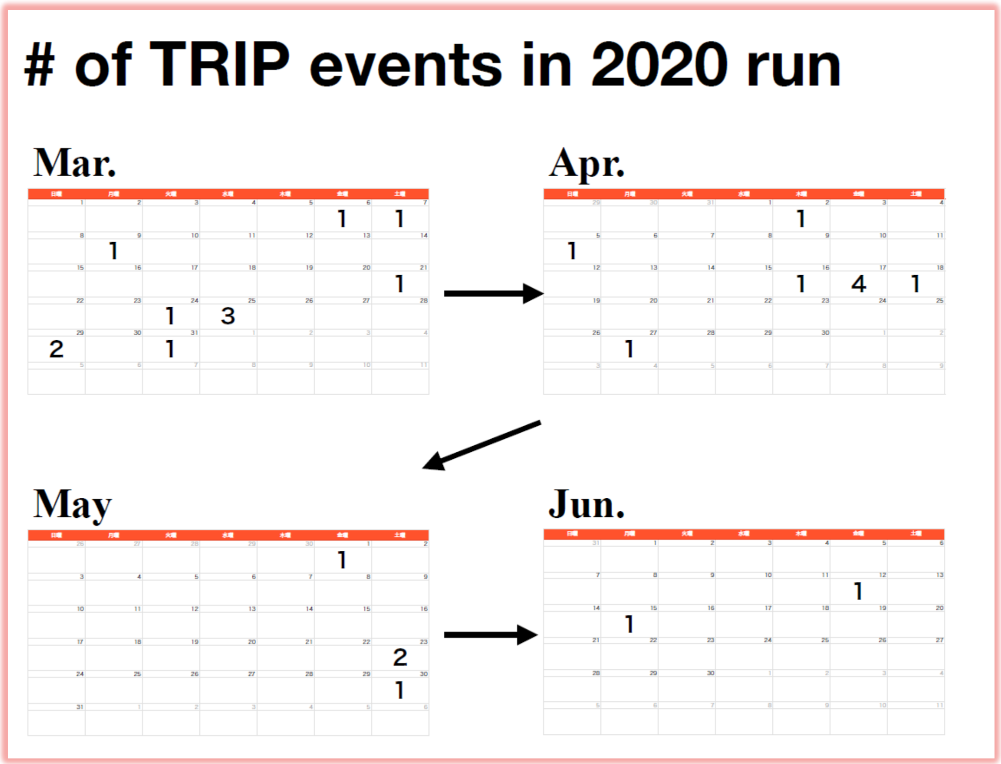
	DIF_POS [mm]	beta_y [m]	nu_y	Nsigma (beta)	LM
D06V1TOP	2.60	67.3	28.85	69.3	0.07
D06V1BTM	-2.61	67.3	28.85	69.6	
	0.33				
D06V2TOP	1.79	20.6	30.49	85.8	1.28
D06V2BTM	-1.83	20.6	30.49	88.2	1.35
	0.19				
D02V1TOP	1.32	13.9	44.86	77.1	0.00
D02V1BTM	-1.33	13.9	44.86	77.7	
	0.17				
QC1 (1.12m)	13.5	782.2	46.33	105.3	
				10.8 Dia QCSFW	

- HER survey (Apr. 2020)

D09V4 :	80µSv/h	D12V1	200µSv/h
D09H4 :	60µSv/h	D12H1	15µSv/h
D09V3 :	40µSv/h	D12V2	35µSv/h
D09H3 :	9µSv/h	D12H2	20µSv/h
D09V1 :	380µSv/h	D12H3	65µSv/h
D09V2 :	15µSv/h	D12V3	350µSv/h
D09H1 :	25µSv/h	D12H4	45µSv/h
D09H2 :	75µSv/h	D12V4	2µSv/h

- HER D09V1(and D12V1,3) show large activation, but the loss monitors at those collimators show small values
- Several collimators are opened, especially ones with higher activation, by carefully looking at injection BG

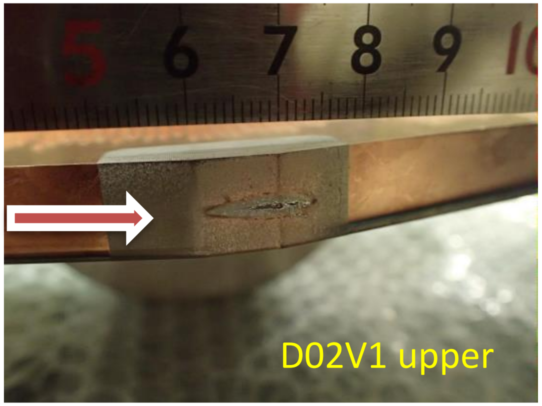
CDC HV trips – much less frequent in 2020a,b



- Only few CDC HV trips in 2020ab (using higher trip thresholds)
- Inner layers(∈SL0) were tripped
- Mostly caused by HER injections
- Trip frequency seems to be decreasing over time, although
  the beam currents gets higher
- Still acceptable trip rates at higher beam currents?

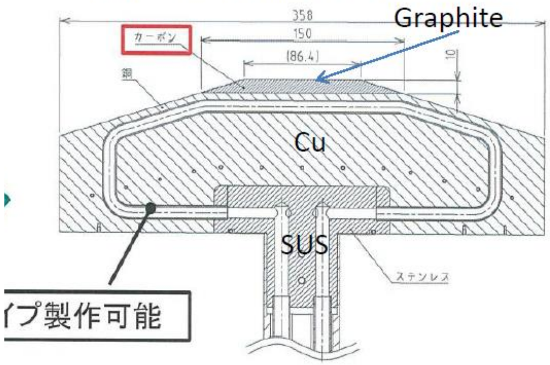
Low-Z collimator head option

- D02V1 collimator head was severely damaged by beam loss due to “beam-dust” event.
- D02V1 will be protected by adding D06V1, but then D06V1 could be damaged
- If D06 collimator head can be made with low-z material, loss is not localised and it could survive “beam-dust” event



S. Terui

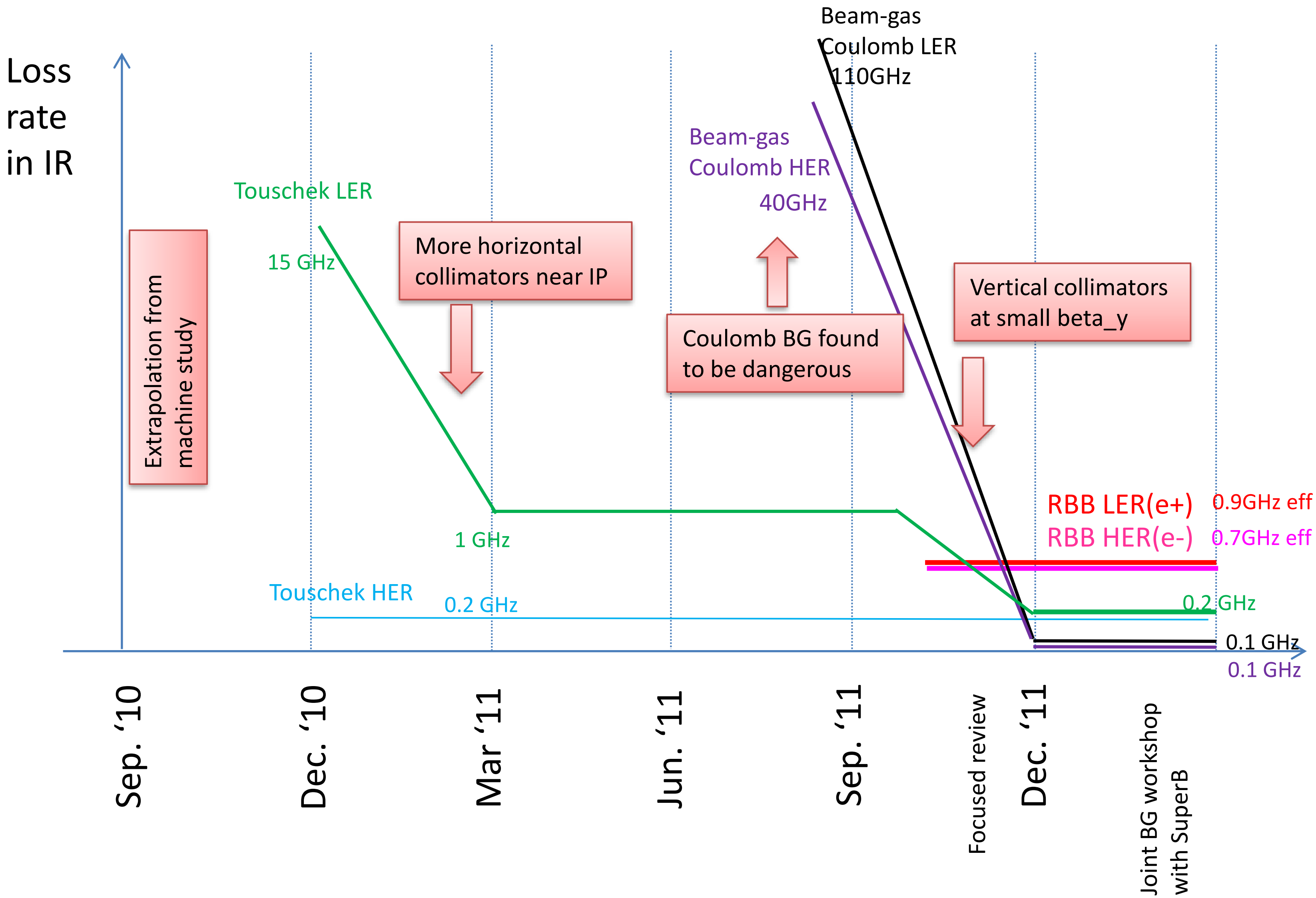
Graphite head (not final design)



- Material choice: Graphite? Ti ?
- Simulation shows particles losing >2% energy at low-Z collimator will be lost downstream and will not reach IR
- Aiming for install in 2020 fall/winter
- Activity lead by SKB vacuum group

SuperKEKB beam backgrounds

Background reduction history



Where we should put the vertical collimators?

Collimator aperture should be narrower than QC1 aperture.

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

TMC instability should be avoided.

Transverse Mode Coupling instability

Assuming following two formulae:

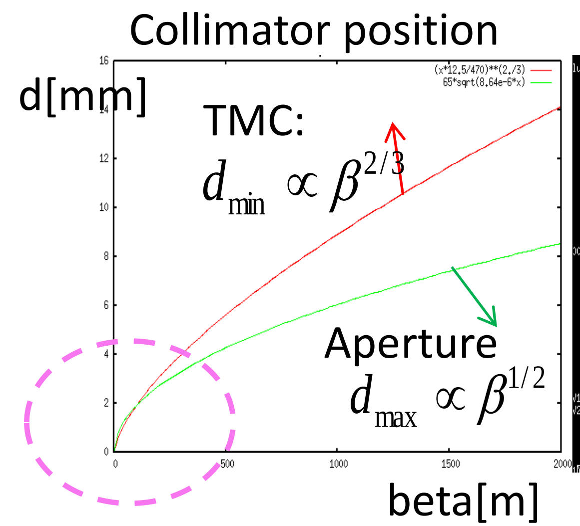
$$I_{thresh} = \frac{C_1 f_s E/e}{\sum_i \beta_i k_{\perp i}(\sigma_z)} > 1.44 \text{ mA/bunch (LER)}$$

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

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

(in case of rectangular collimator window)

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



We should put collimator where beta_y is rather SMALL!

For more details, please check out following paper:
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)

IR loss is quite sensitive to vertical collimator width

ler1604, V1=LLB3R downstream

V1 width[mm]	IR loss [GHz]	Total loss[GHz]	Coulomb life[sec]
2.40	**0.04**	153.9	1469.8
2.50	**0.05**	141.8	1594.8
2.60	**0.09**	131.0	1724.9
2.70	**0.24**	121.4	1860.2
2.80	**1.65**	111.4	2000.5
2.90	**11.48**	100.8	2014.3
3.00	**21.98**	90.3	2014.3

her5365,V1=LTLB2 downstream

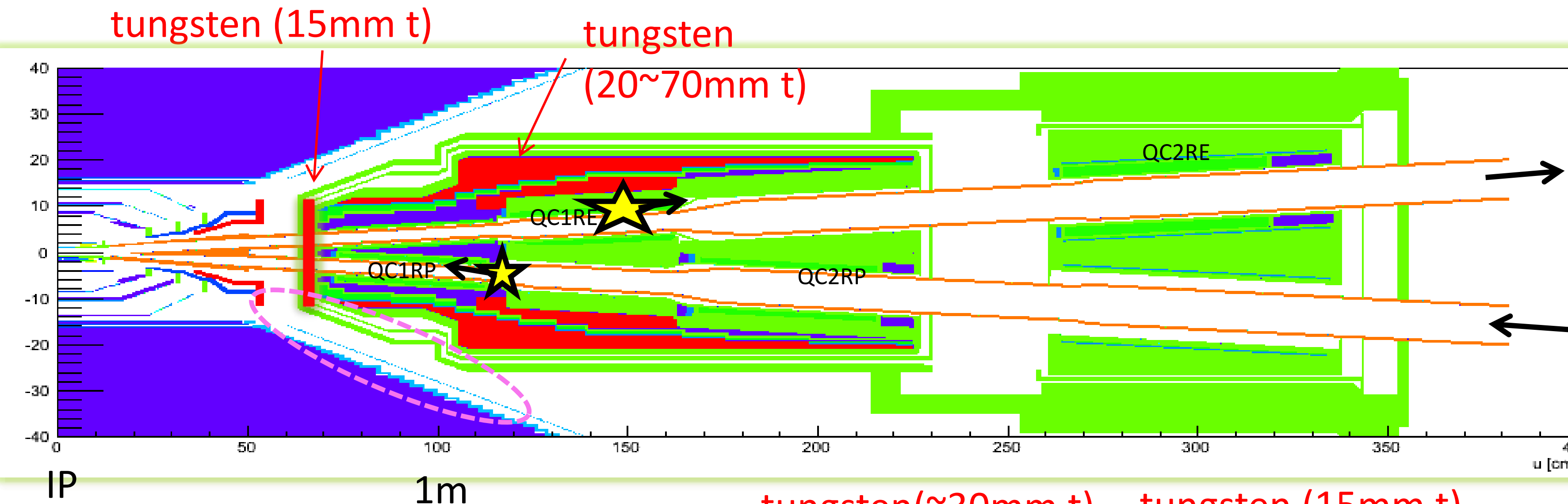
V1 width[mm]	IR loss [GHz]	Total loss[GHz]	Coulomb life[sec]
2.10	**0.0007**	49.6	3294.0
2.20	**0.001**	45.2	3615.2
2.30	**0.357**	41.0	3951.3
2.40	**7.99**	33.0	3985.9
2.50	**13.1**	27.9	3985.9

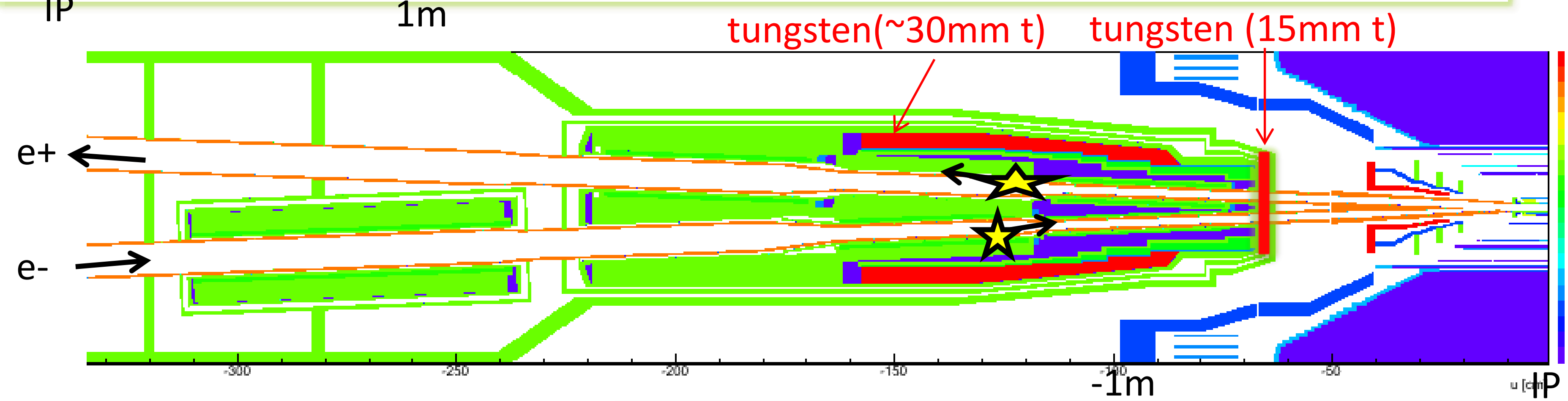
Based on element-by-element simulation, taking into account the causality and the phase difference, up to 100 turns (Nakayama)

Just a few hundreds micron wider setting of vertical collimator width can lead to significant increase on IR loss. Quite dangerous!

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

Tungsten shields inside Final Focus cryostat

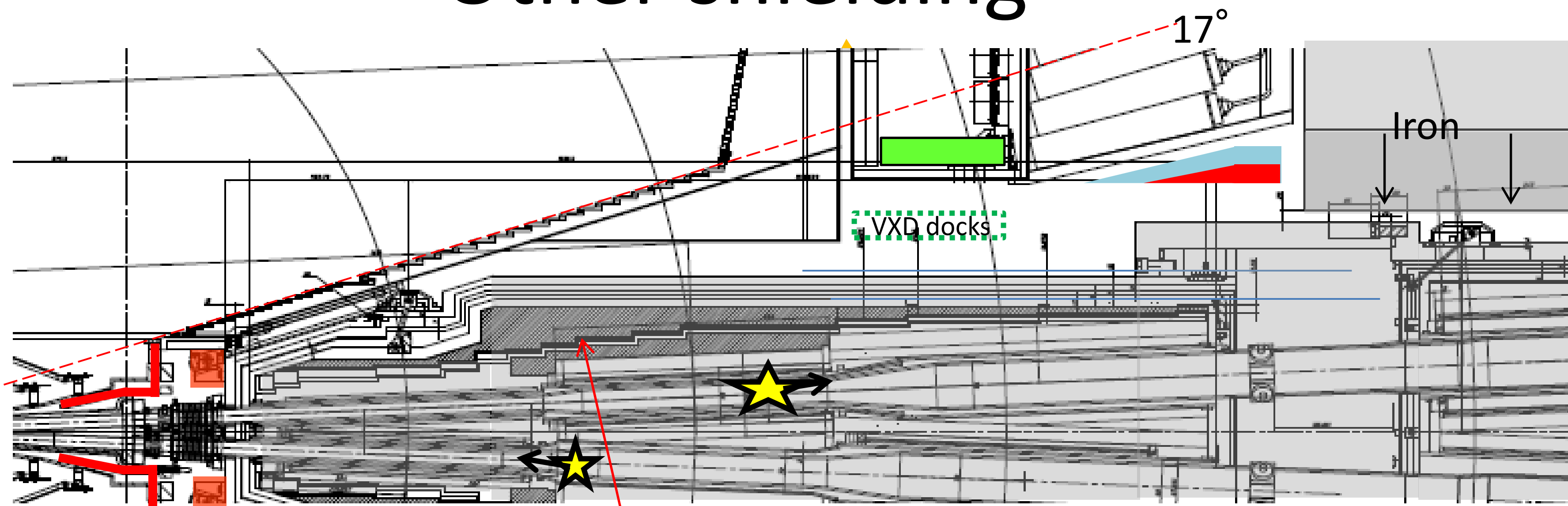




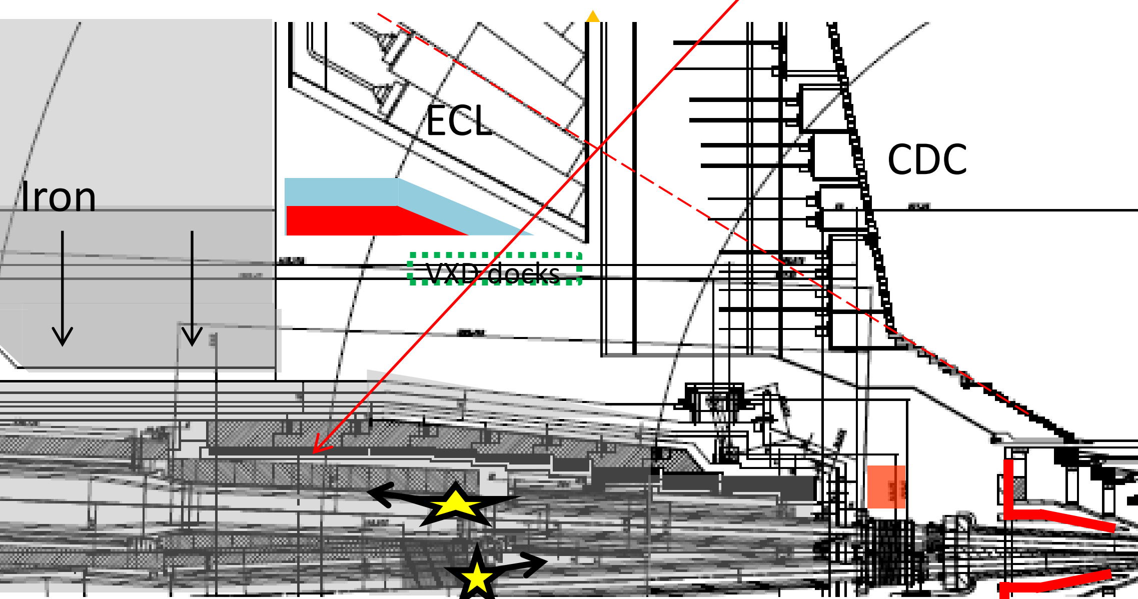
Major beam loss position by Touschek or Beam-gas

Thick tungsten shields can significantly stop background showers originated from |s|>65cm.

Other shielding



Thick tungsten layers inside cryostat



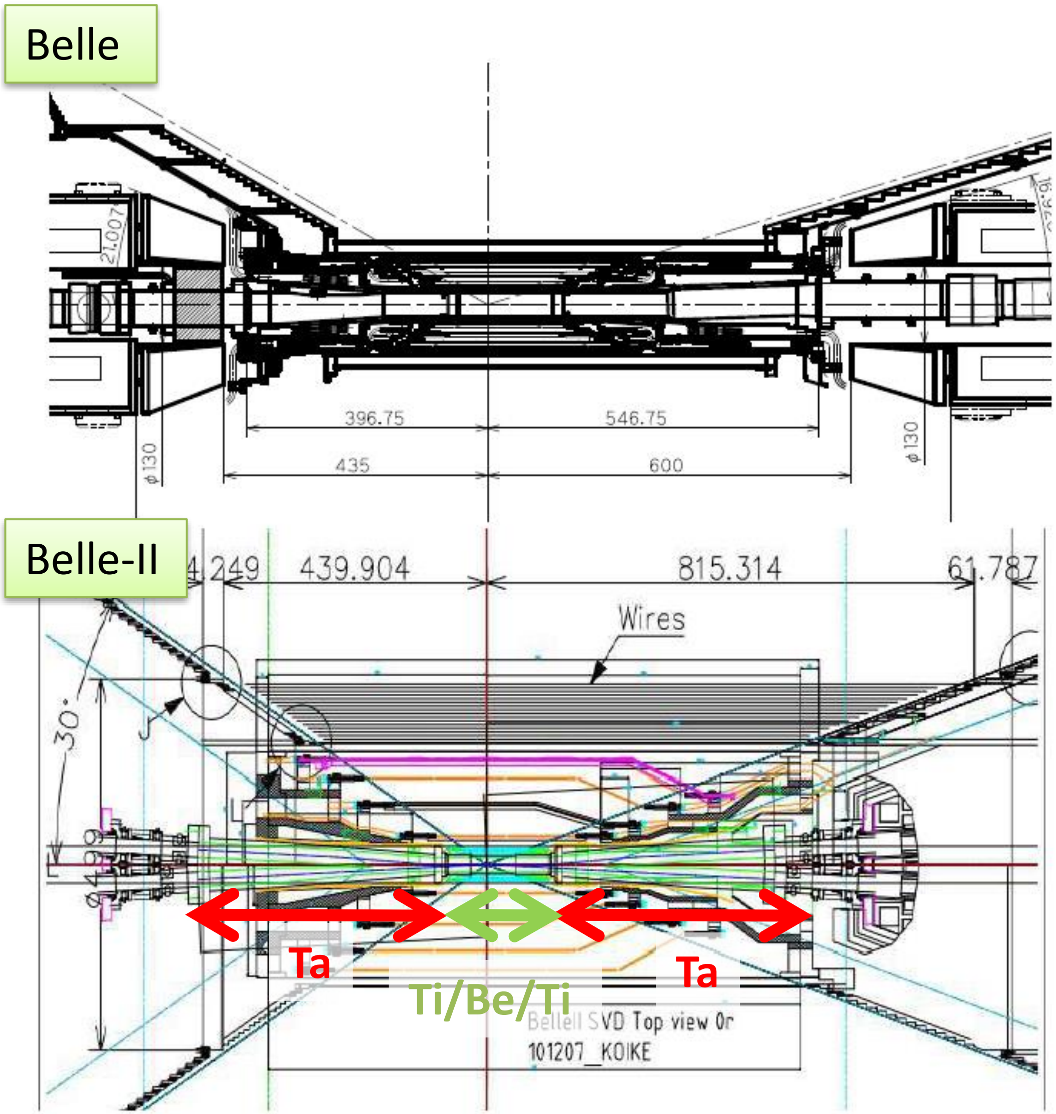
Heavy metal shields to protect VXD from showers generated in cryostat

Neutron shield to protect HAPDs in ARICH (Boron-doped Polyethylene)

ECL shield, for included for (Lead + Polyethylene)

Remote Vacuum Connection structure in front of QCS reduces showers from RBB loss at |s|~60cm (6cm-thick SUS)

Interaction region

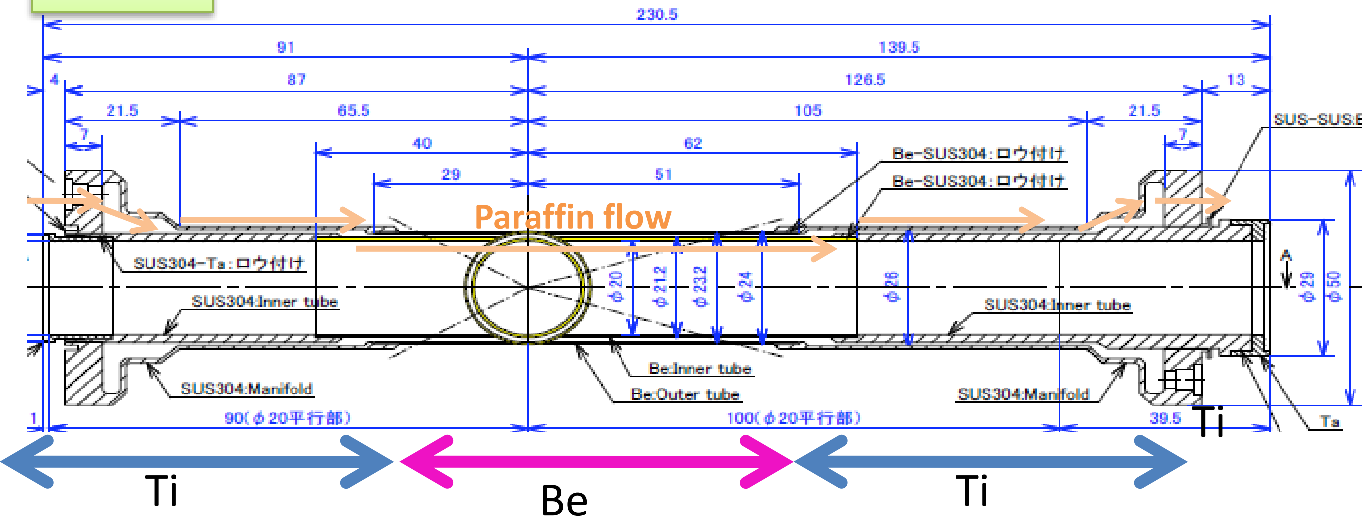


<Belle-II>

- Smaller IP beam pipe radius (r=15mm⇒10mm)
- Wider beam crossing angle (22mrad⇒83mrad)
- Crotch part: Ta pipe
- Pipe crotch starts from closer to IP, complicated structure
- New detector: PXD (more cables should go out)

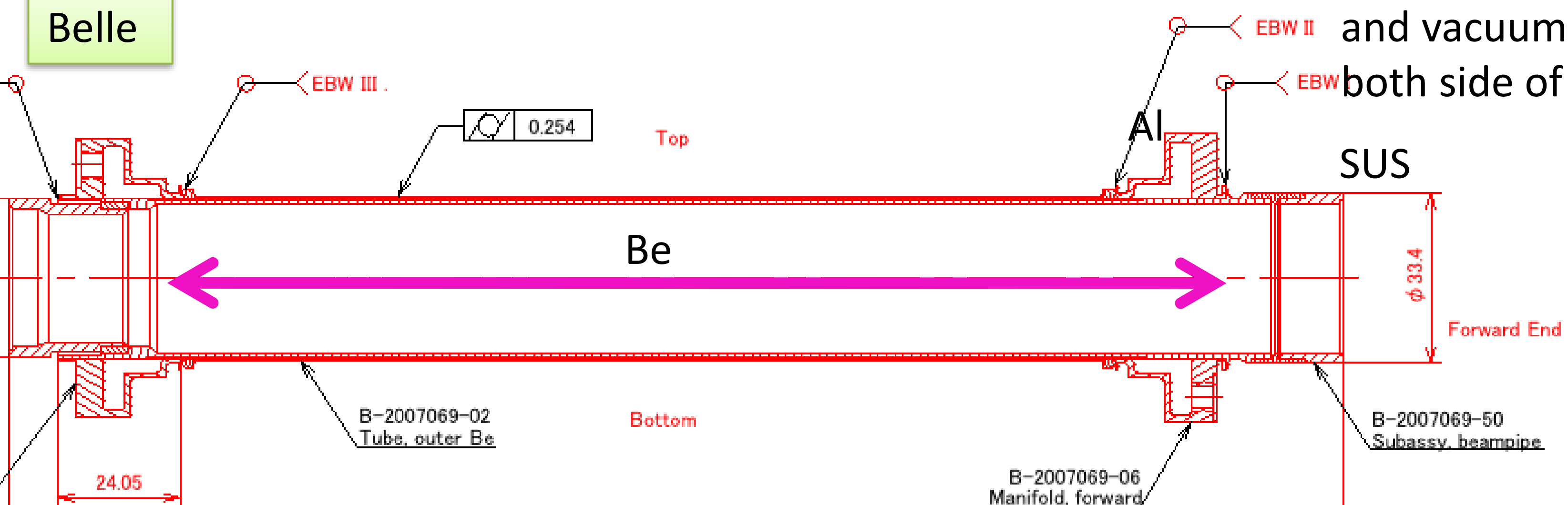
IP beam pipe

Belle-II

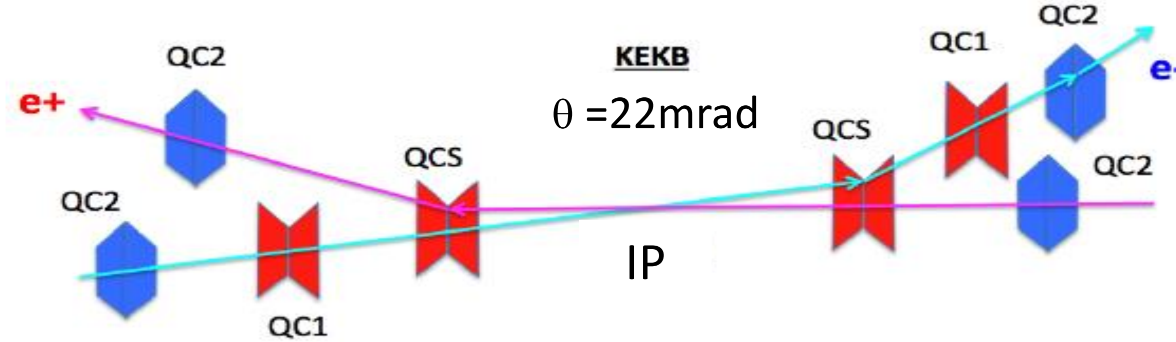


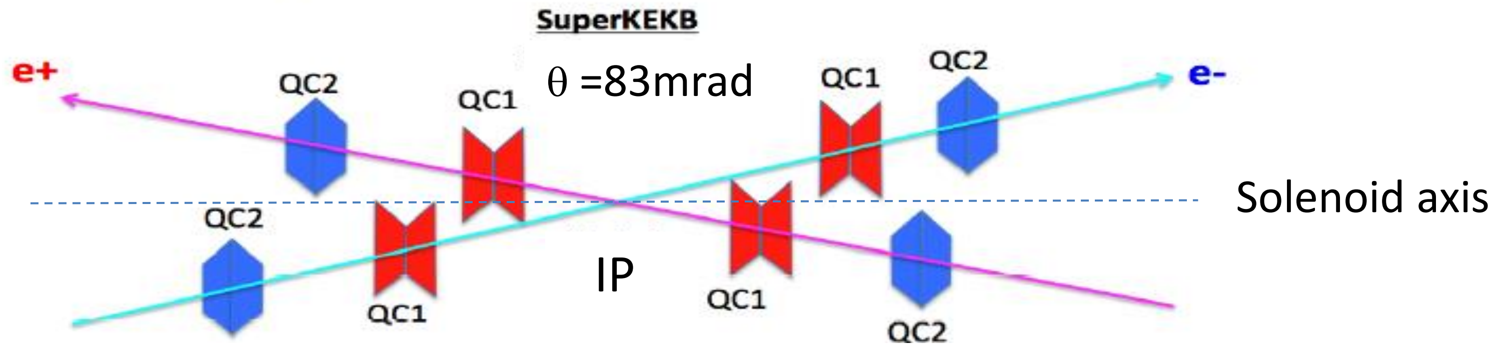
- Light material (Be) inside detector acceptance
- Paraffin ($C_{10}H_{22}$)flow to remove heat from mirror current (~80W)
- Gold plating (~10um) on inner wall to stop SR
- Much simpler Be shape (also much cheaper) since we allow Paraffin and vacuum to attach both side of welding

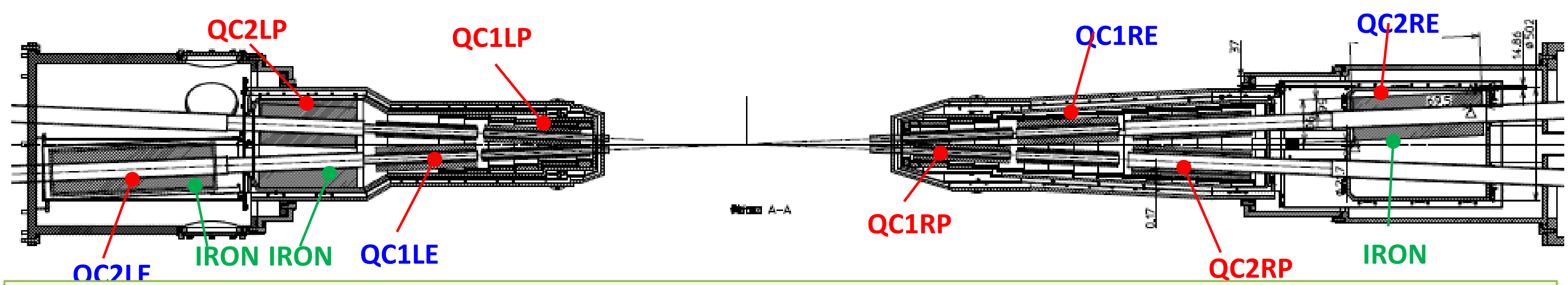
Belle



Final focusing magnets

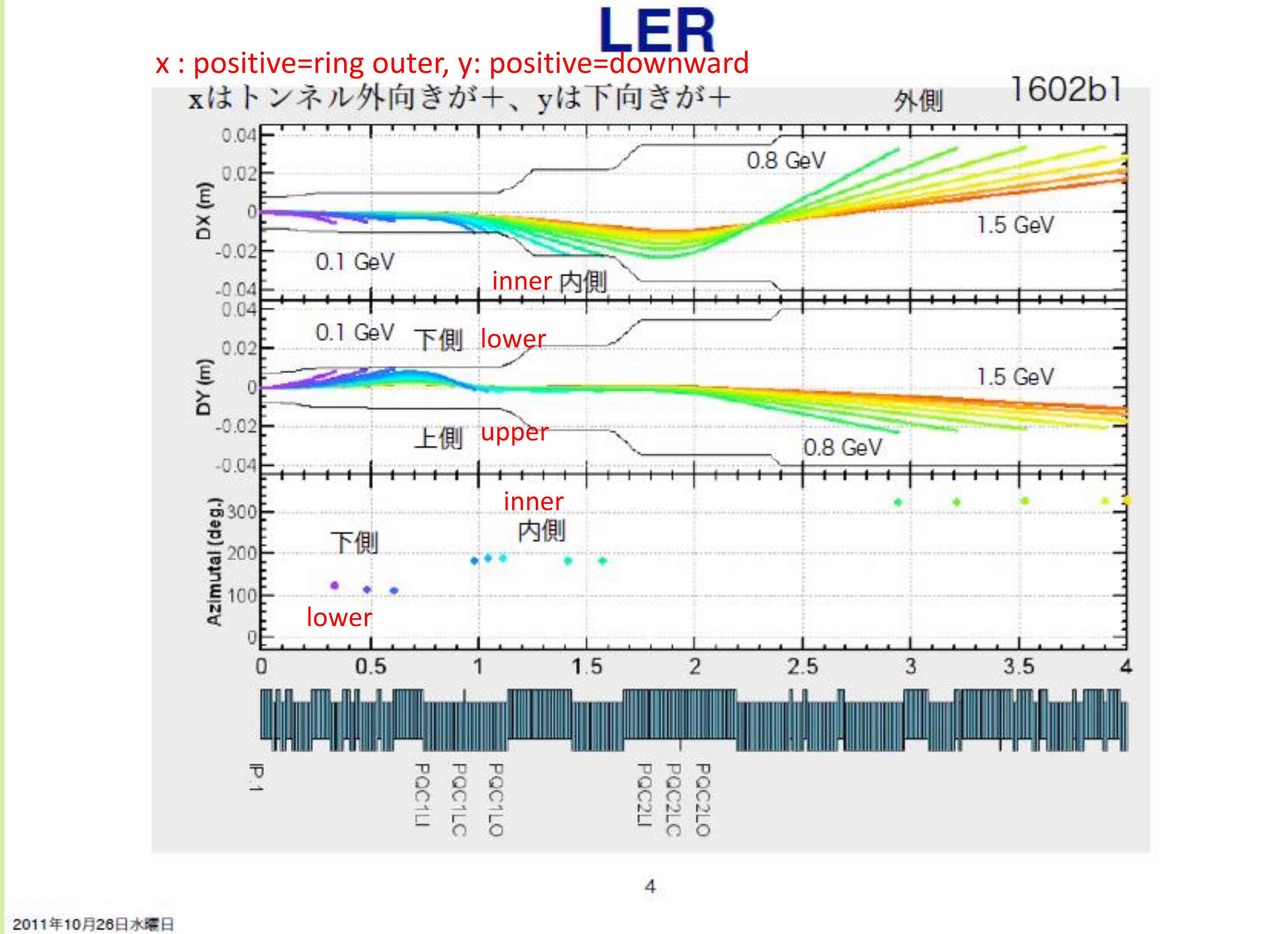






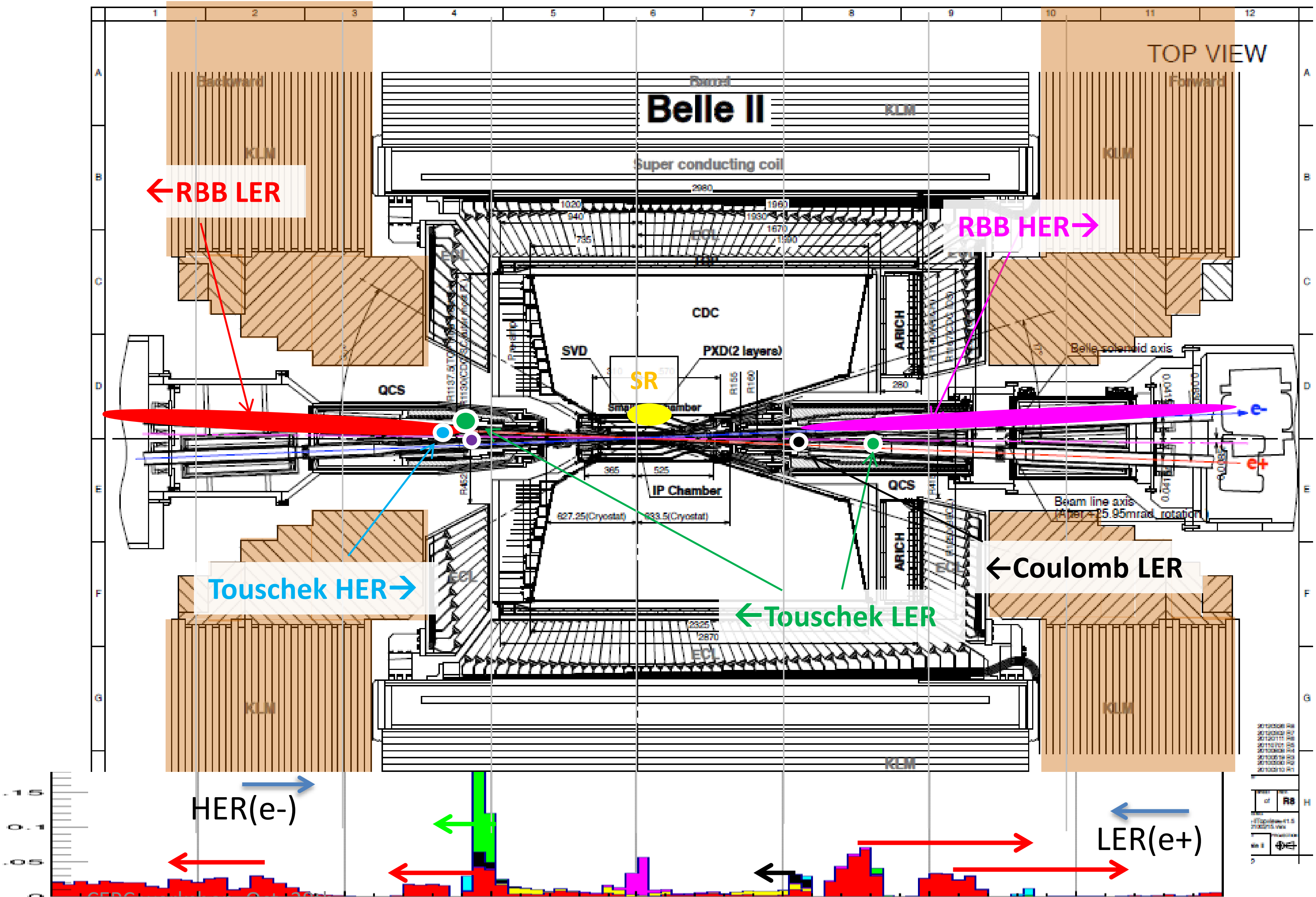
- Larger crossing angle θ than KEKB
- Final Q for each ring→ more flexible optics design
- No bend near IP→ less emittance, less background from spent particles

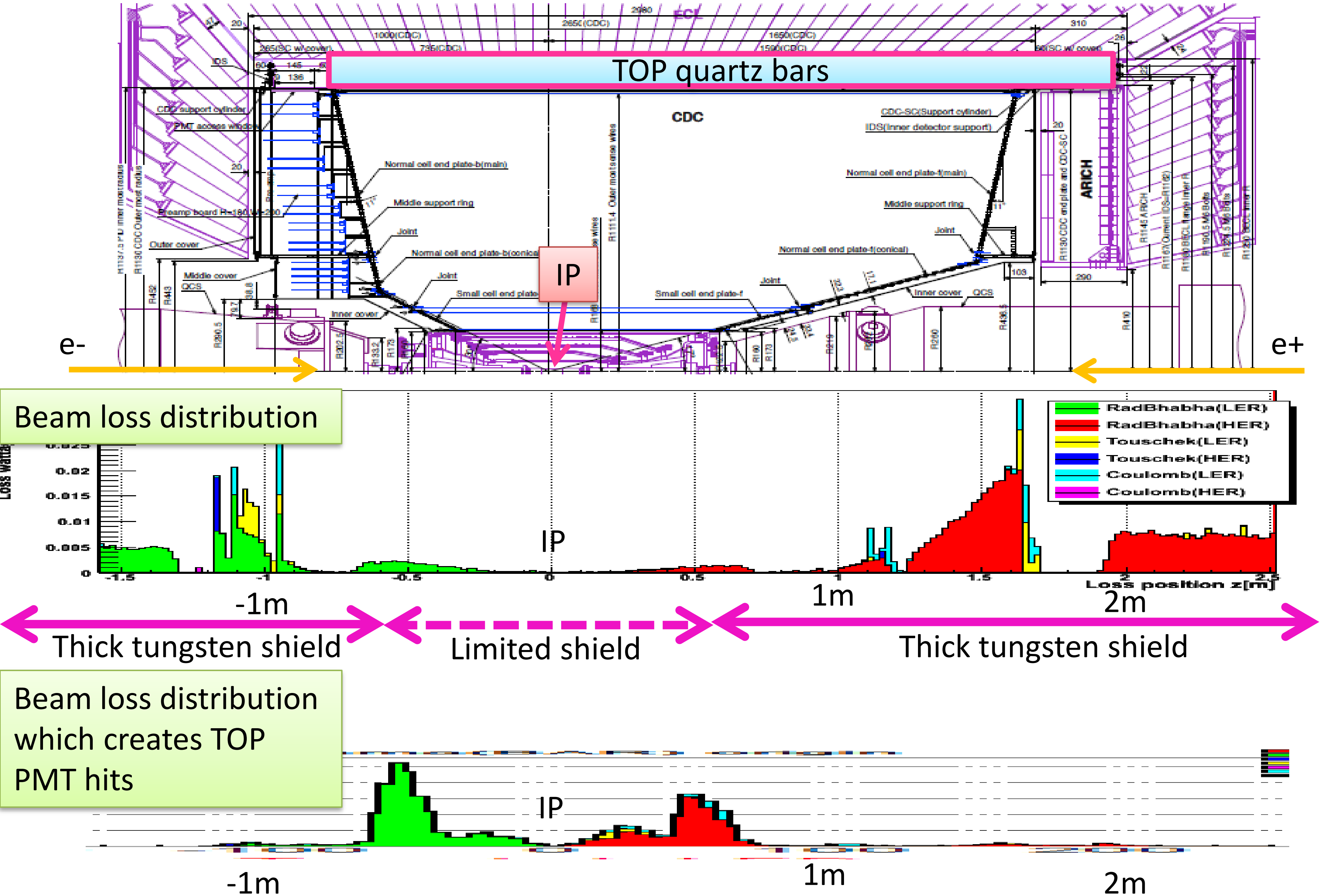
Beam orbit after RBB scattering



Background Global picture

Ver. 2017.1.31





TOP quartz bars
CDC
ECL
ARICH
IP
e-
e+
Beam loss distribution
RadBhabha(LER)
RadBhabha(HER)
Touschek(LER)
Touschek(HER)
Coulomb(LER)
Coulomb(HER)
Loss position z[m]
-1m
1m
2m
Thick tungsten shield
Limited shield
Thick tungsten shield
Beam loss distribution which creates TOP PMT hits
IP
-1m
1m
2m