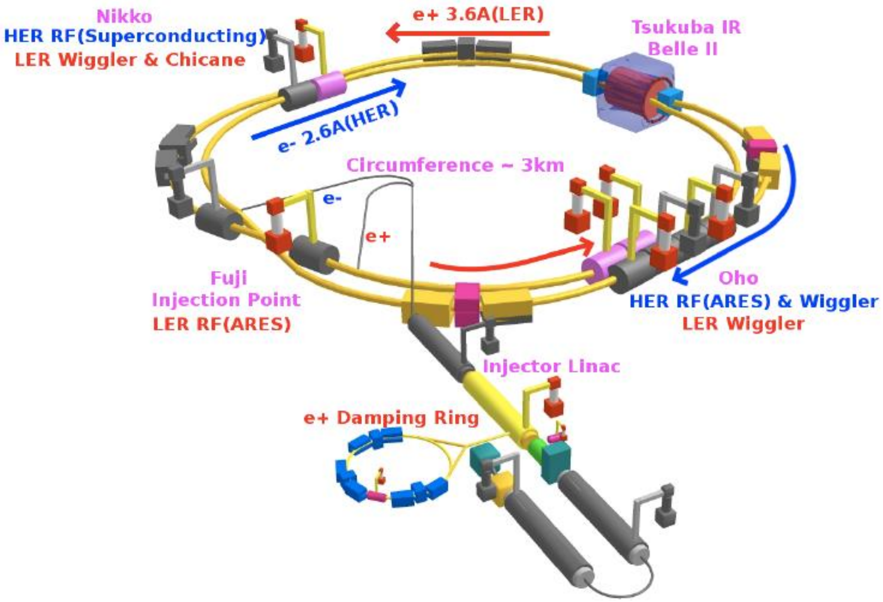
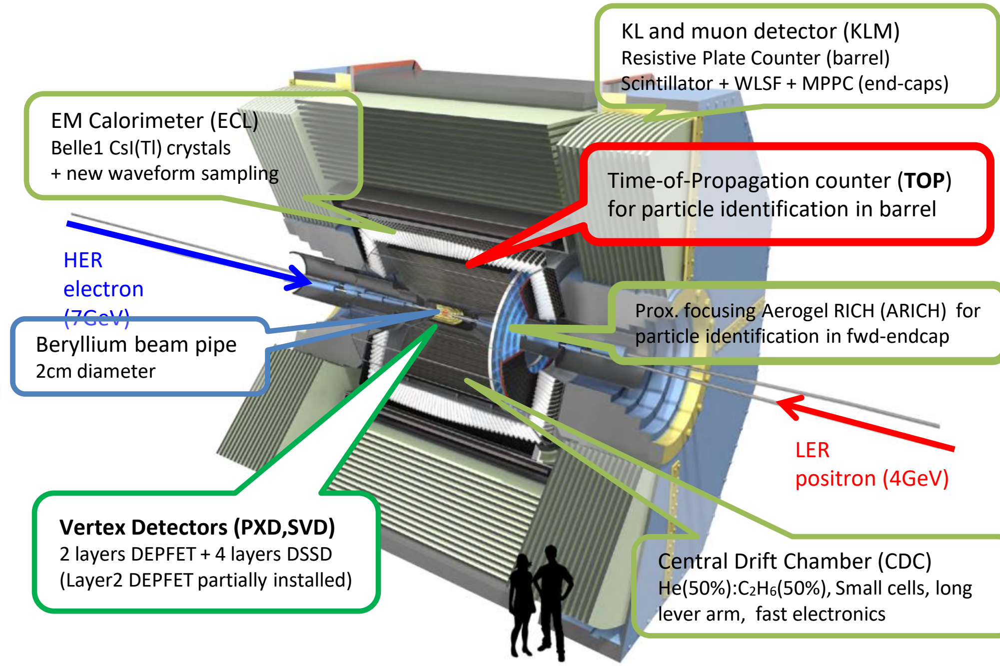
e-(7GeV,HER), e+(4GeV,LER)





SuperKEKB experience on MDI design and beam background

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

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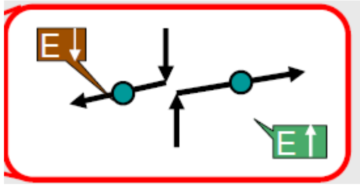
Beam background at SuperKEKB

- Beam-induced background at SuperKEKB can be dangerous for Belle II
- 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 $\propto$ (beam size)$^{-1}$,(E_{beam})$^{-3}$
- Touschek lifetime: should be >600sec (required by injector ability)

→ ring total beam loss: ~375GHz (LER), ~270GHz(HER)

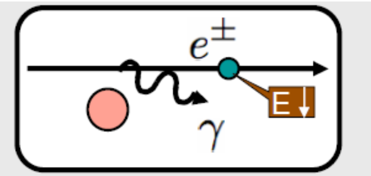
- **Countermeasure: horizontal collimators in the ring**
  - collimators added at 0~200m upstream IP are very effective
  - only O(100MHz) loss inside Belle II detector

- Horizontal collimators are installed where beta_x or eta_x is large

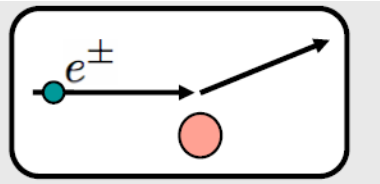
$$d_x = Max[d_{x\beta}, d_{x\eta}], \quad d_{x\beta} = n_x\sqrt{\varepsilon_x \beta_x}, \; d_{x\eta} = \eta_x(n_z \sigma_\delta)$$

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

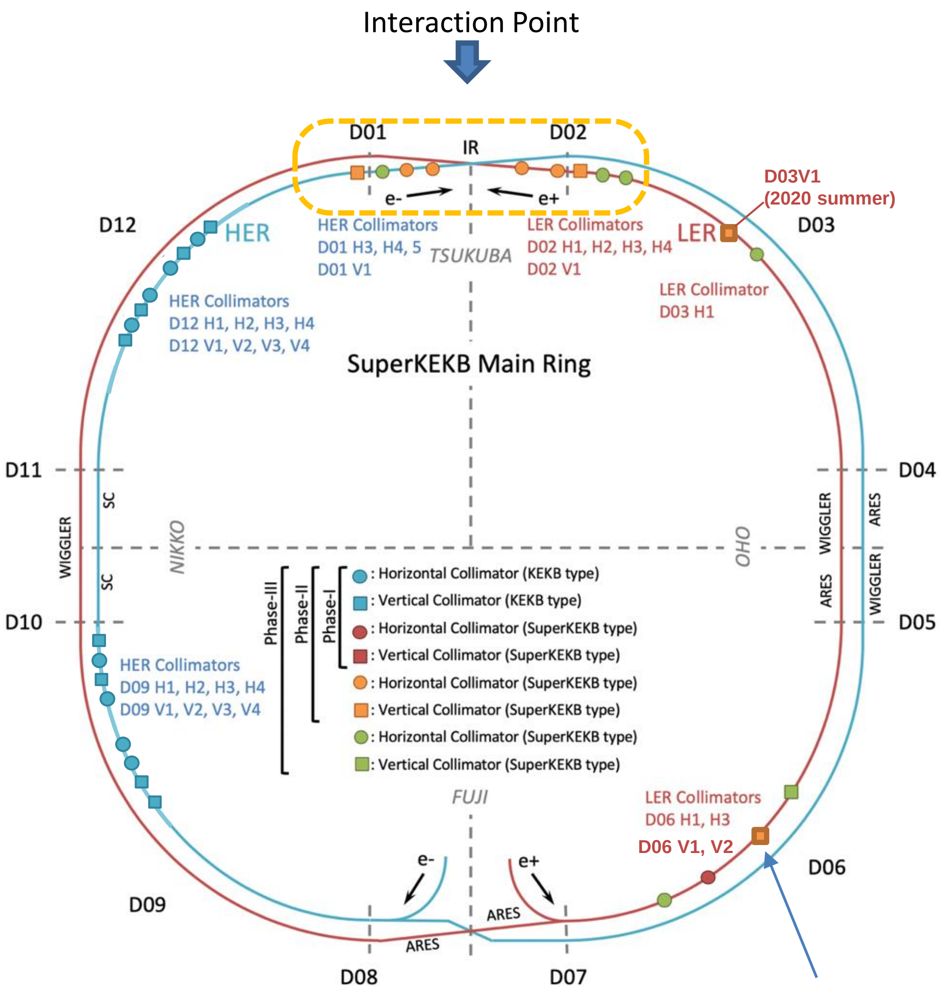
$$\frac{1}{\tau_R} = c n_G \langle \sigma_R \rangle = c n_G \frac{4\pi \sum Z^2 {r_e}^2}{\gamma^2} \left\langle \frac{1}{{\theta_c}^2} \right\rangle$$

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

- <u>Countermeasures: Vertical collimators in the ring</u>
  - very narrow (<~2mm) collimators
  - TMC instability issue at high current
  - Need to install where beta_y is rather small

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

SuperKEKB Collimators



As of 2020 autumn,

31 movable collimators installed

LER(11):

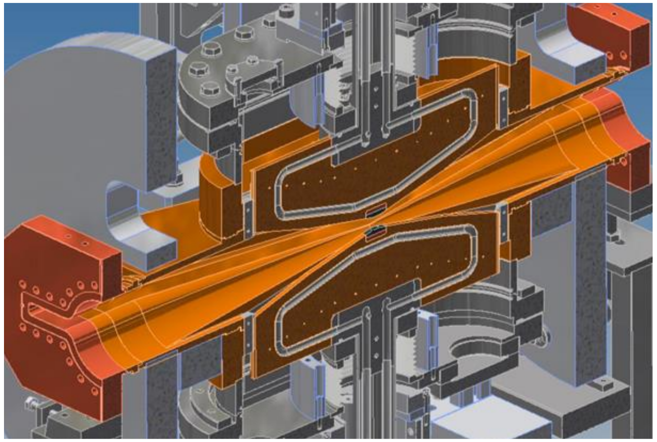
- 7 horizontal, 4 vertical "SuperKEKB type" collimators
  - horizontal: D06H1, D06H3, D03H1
    D02H1, D02H2, D02H3, D02H4
  - vertical: D06V1, D06V2, D03V1, D02V1

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}

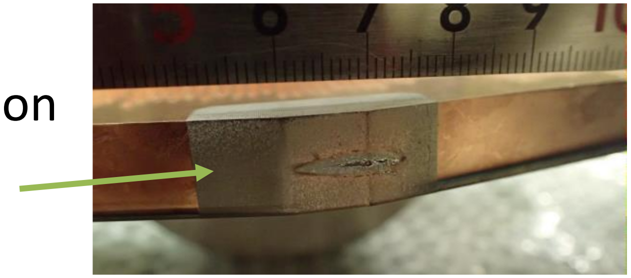
D6V1 collimator head is replaced with carbon in 2020 summer shutdown, to prevent severe damage from "burst" events

Vertical Collimators: very narrow



- To reduce beam-gas Coulomb IR loss, we need very narrow (<~2mm half width) vertical collimators
- TMC instability is an issue: low-impedance head design is important, and collimators should be installed where beta_y is rather small (*)
- Precise head control (Δd~50um) is required, (IR loss is quite sensitive to the collimator width)
- Collimator head should survive severe beam loss → tungsten is used for head tip, but we also try carbon for far upstream collimators
- Secondary shower (tip-scattering) effect should be carefully examined

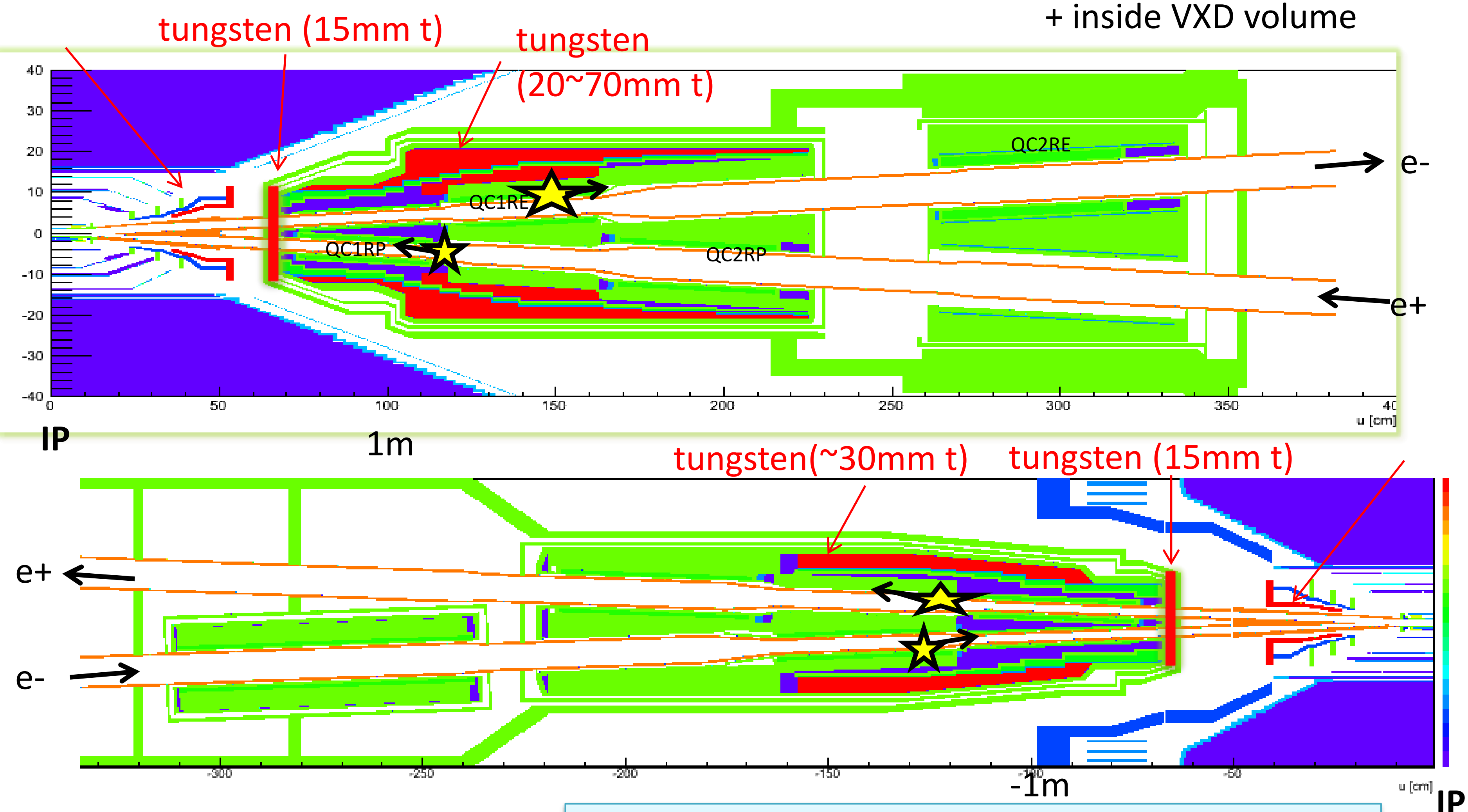
Damaged collimator head

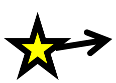


(*) "Small-Beta Collimation at SuperKEKB to Stop Beam-Gas Scattered Particles and to Avoid Transverse Mode Coupling Instability", H, Nakayama et al, *Conf.Proc.C* 1205201 (2012) 1104-1106

Tungsten shields inside final focus cryostat

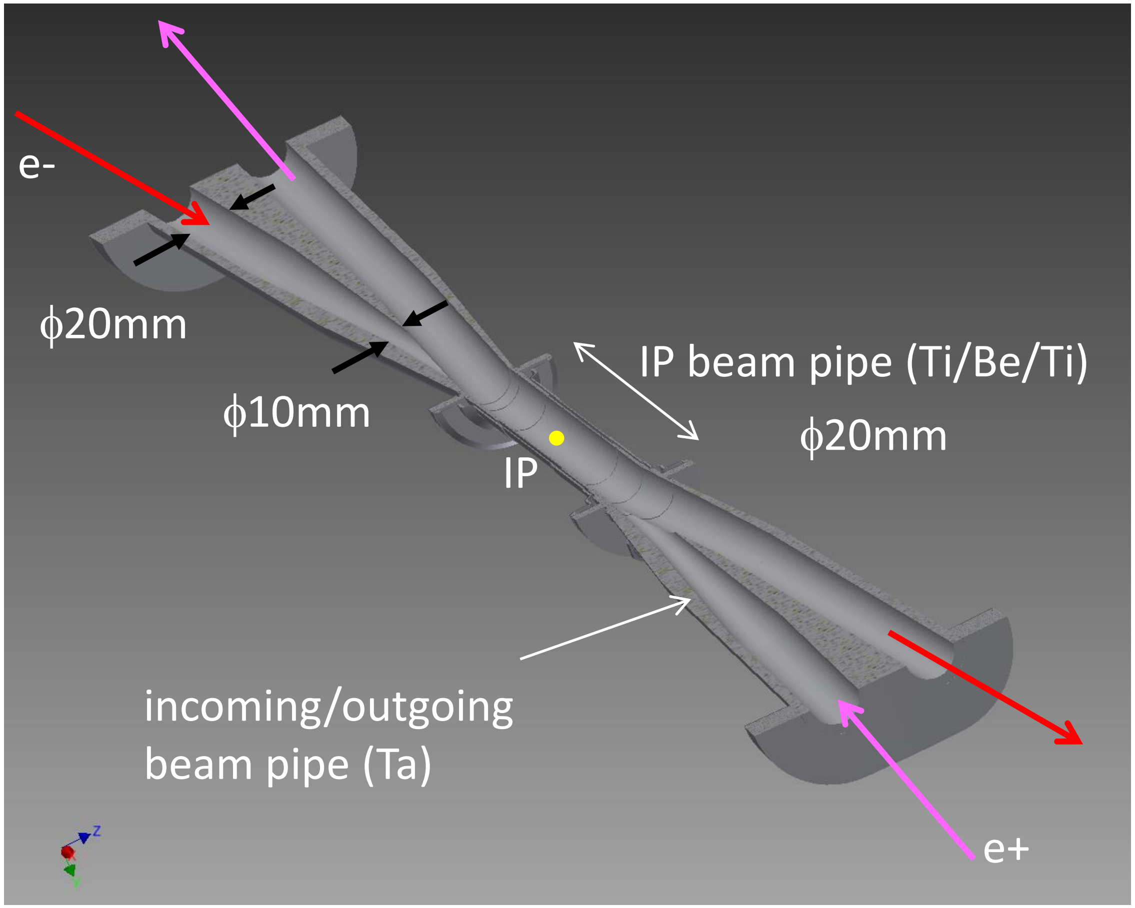
+ inside VXD volume




Major beam loss position by Touschek or Beam-gas

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

3. Synchrotron radiation

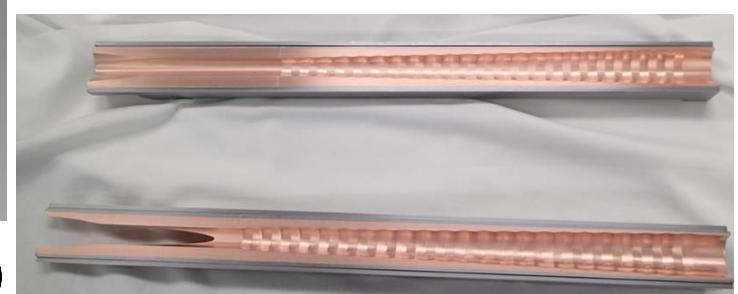


Inner surface of Be pipe are coated with Au layer (10um)

- ϕ20mm→ϕ10mm 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

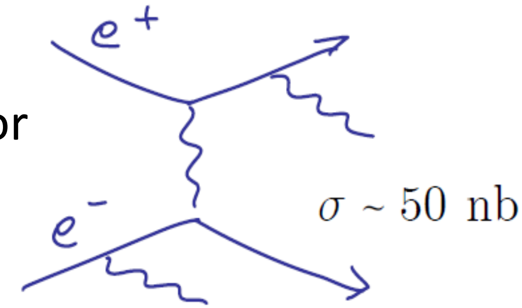
- To hide IP beam pipe from reflected SR, "ridge" structure on inner surface of collimation part.



4. Luminosity-dependent background

<u>Radiative Bhabha scattering</u>

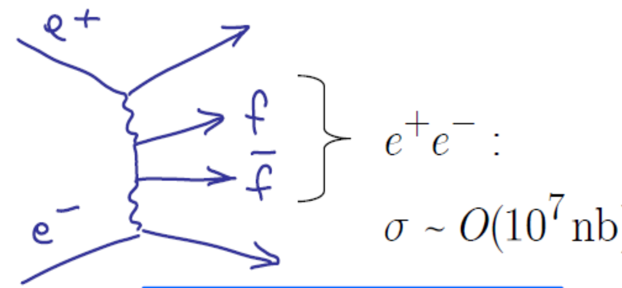
- Rate∝Luminosity (KEKBx40)
- Spent e+/e- with large ΔE could be lost inside detector due to due to kick from detector solenoid kick (even with separate final focus magnets for each ring)
- Emitted γ hit downstream magnet outside detector and generate neutrons via giant-dipole resonance



Bhabha scattering

<u>2-photon process</u>

- 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

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

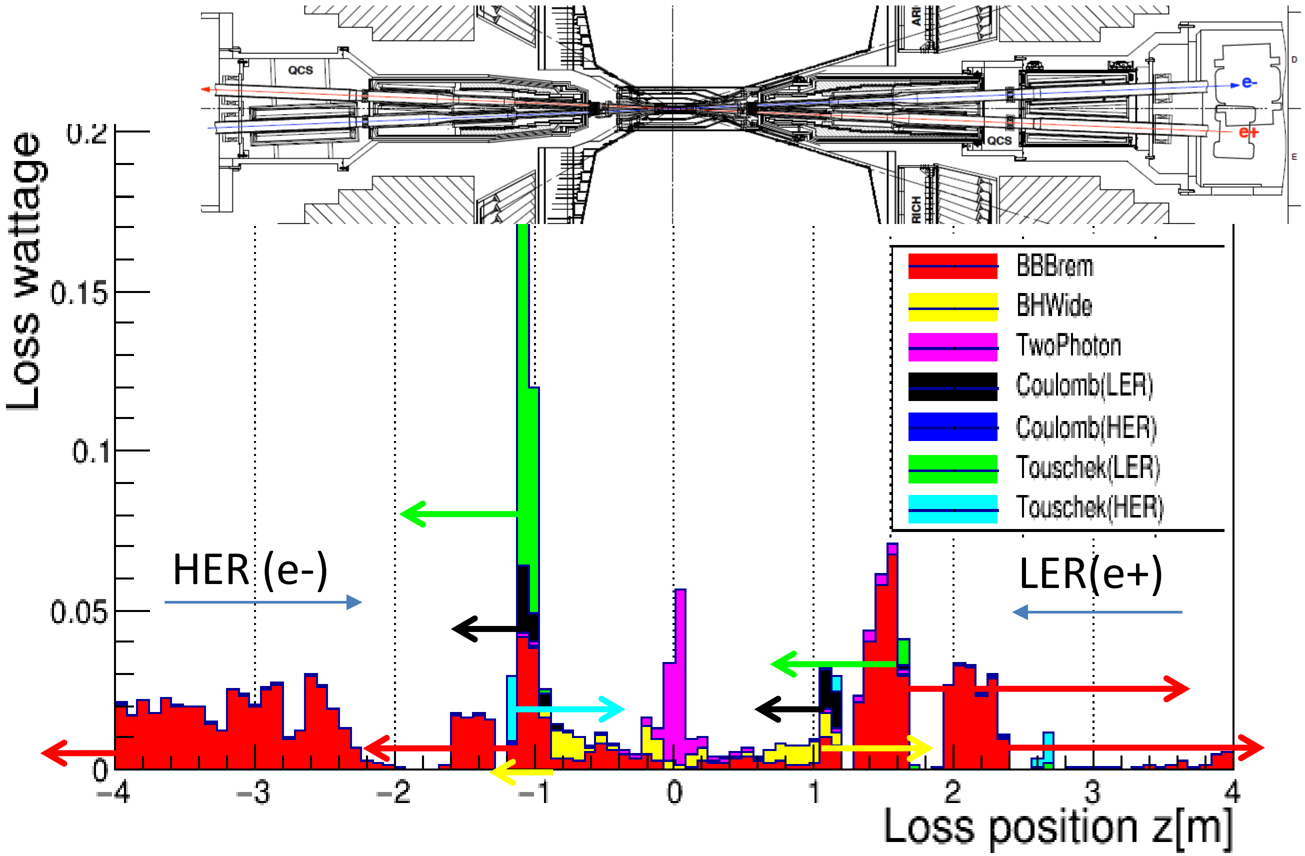
[1] Y. Ohnishi et al., PTEP **2013**, 03A011 (2013).
[2] SAD is a "Home-brew" tracking code by KEKB group, http://acc-physics.kek.jp/SAD/

Injection BG: difficult to simulate

Simulated IR beam loss distribution (design luminosity)

15th campaign (2017)

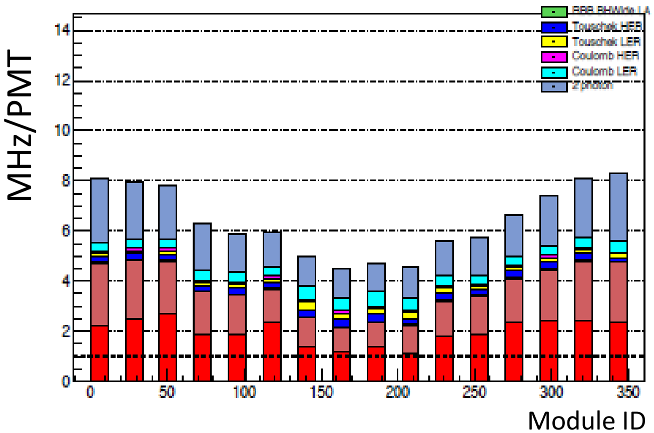
"Loss wattage [W/8cm]"
= loss rate
* energy of loss particle



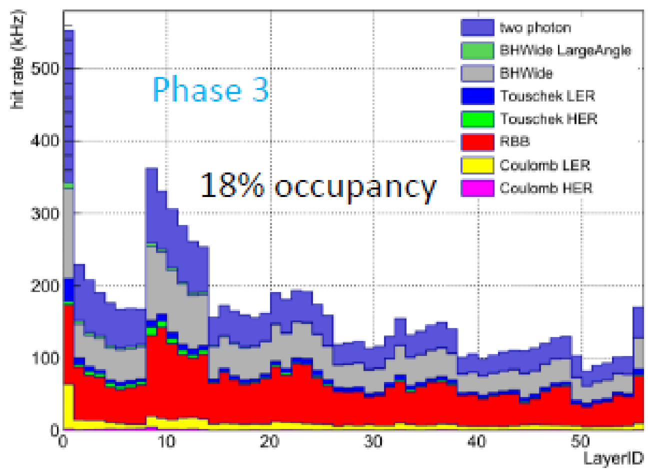
	LER (4GeV e+)	HER (7GeV e-)
Lumi-dependent BG	BBBrem: **1.08 W** (0.06 W in |z|<65cm) BHWide: 0.11 W (0.04 W), 2photon: 0.14 W(0.11W)	
Touschek	0.27 W (0.42GHz)	0.04 W (0.03GHz)
Coulomb	0.06 W (0. 10Hz)	0.00 W (0.002GHz)

Simulated Sub-Detector BG rates

TOP PMT rate



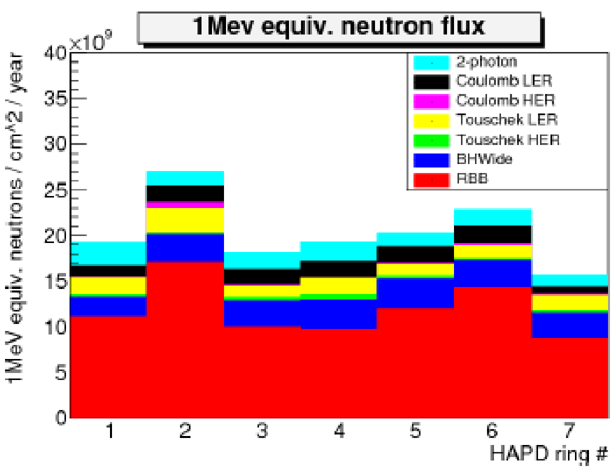
CDC wire rate



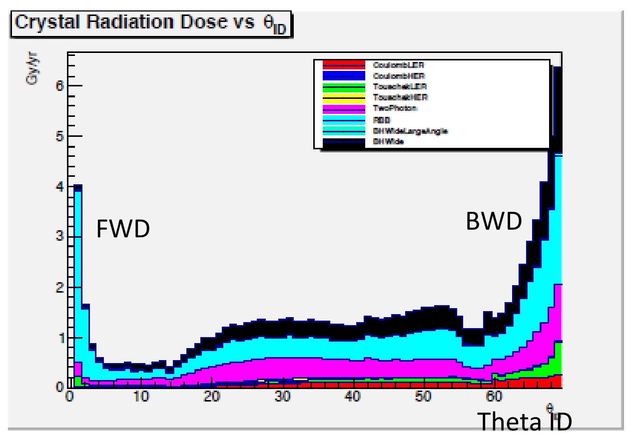
PXD occupancy

Layer #1
0.84 % occupancy
from 2-photon

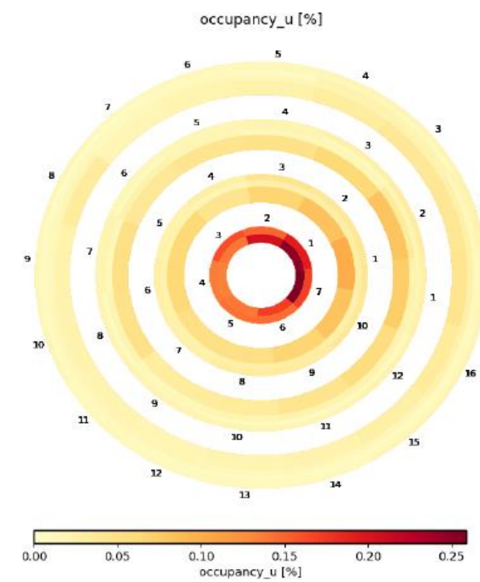
ARICH neutrons



ECL crystal dose



SVD occupancy



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

data/MC ratio is not applied here

BG simulation summary

- IR beam pipes and final focus cryostat are carefully designed to mitigate beam BG
- Collimators can significantly suppress single-beam BG, but vertical ones are challenging

- Radiative Bhabha BG from spent e+/e- will dominate at the full design luminosity
- Simulated BG rates on subdetectors seemed acceptable, but **BG in a real machine can be larger than simulation**
- We need to measure BG by machine studies and verify our simulation. If needed, we should apply data/MC factor for the future estimation

Beam background measurement during SuperKEKB 2020 runs

~ hot from the oven ~

- Phase1 (2016) : no Belle II, no collision
- Phase2 (2017) : partial Belle II installed
- Phase3 (2019,2020,…) : “in full swing”

Phase1 beam background measurement paper:
“First Measurements of Beam Backgrounds at SuperKEKB”,
Nucl.Instrum.Meth. A914 (2019) 69-144

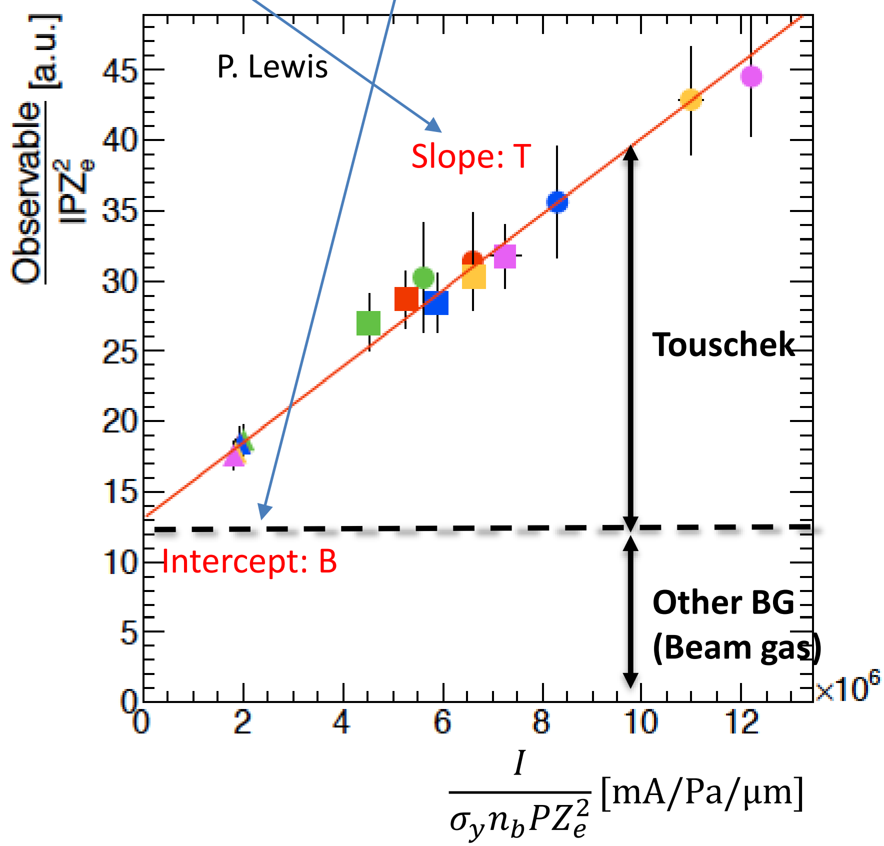
Single-beam BG study

for measuring Touschek and Beam-gas component separately

$$Rate = T\frac{I^2}{\sigma_y n_b} + BZ_e^2 IP \xrightarrow{P = P_0 + cI} Rate/Z_e^2 IP = T\frac{I}{\sigma_y n_b P Z_e^2} + B$$

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 of collision runs" – "single-beam BG" – "injection BG"

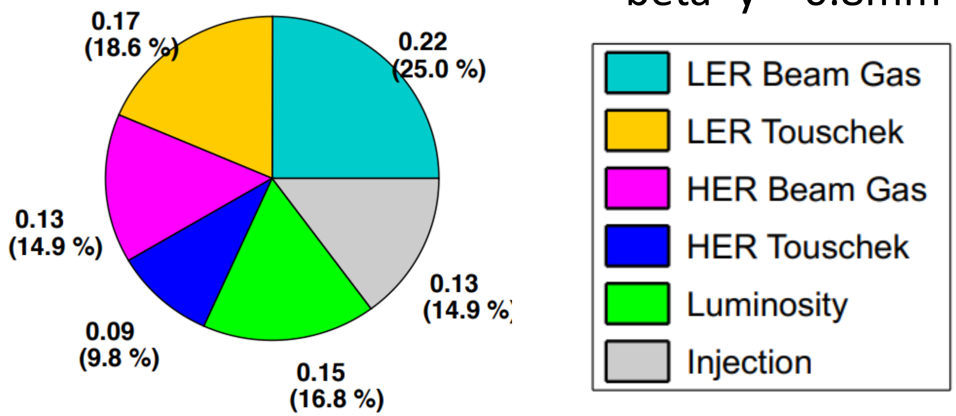
BG measurement in 2020 spring run

TOP background breakdown
during recent physics runs

June 28, 2020
beta*y = 0.8mm

Kojima

Slot 3
rate
[MHz]



Input values
to calculate background rate.

$I^{\mathrm{HER}} = 500\ \mathrm{mA}$
$\sigma_y^{\mathrm{HER}} = 34\ \mu\mathrm{m}$
$N_b^{\mathrm{HER}} = 978$

$I^{\mathrm{LER}} = 480\ \mathrm{mA}$
$\sigma_y^{\mathrm{LER}} = 66\ \mu\mathrm{m}$
$N_b^{\mathrm{LER}} = 978$

$\mathcal{L} = 1.5 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

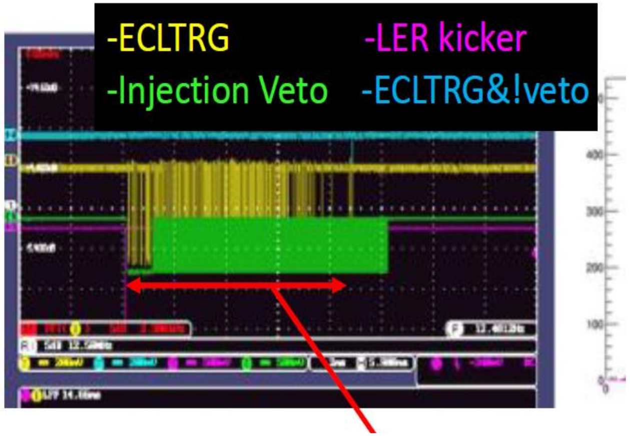
<u>BG studies in 2020 spring run shows:</u>

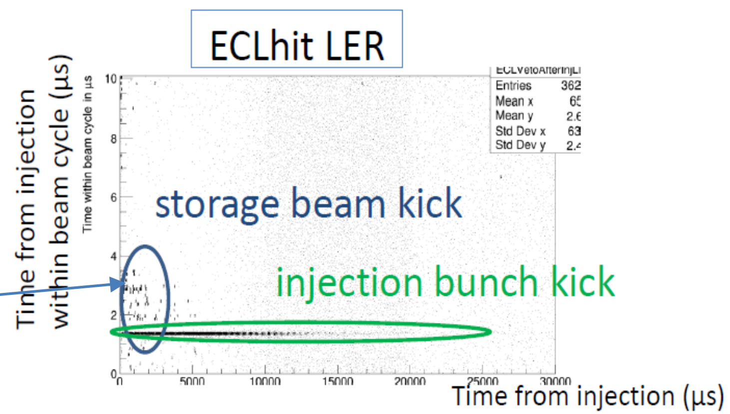
- LER beam-gas BG has reduced since 2019, but still the largest component
- Data/MC ratio is now within O(10) for all BG components
  - Long-lasting HER Touschek discrepancy finally solved by simulation improvement taking into collimator scattering
  - Measured lumi-BG stays consistent with prediction (will dominate at full luminosity)

Issues: Injection BG duration

T. Koga

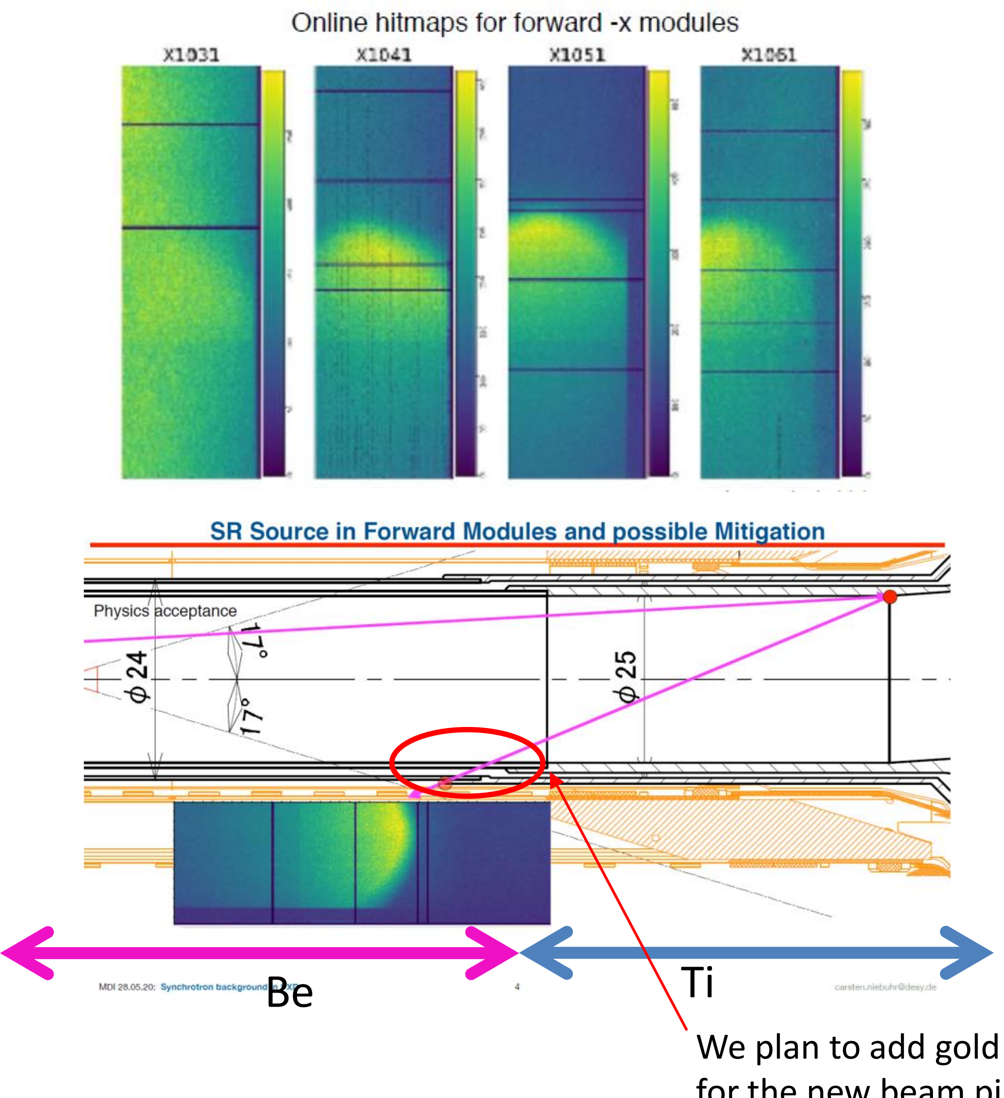
- Top-up injection is essential to compensate short beam life of SuperKEKB
- Belle II needs trigger veto after each injection
  - longer veto window -> less integrated luminosity
- Typical duration: LER: 6~12ms, HER:1~6ms
  - Corresponds to 7~8% deadtime
- Dedicated machine study in 2020 shows:
  - Single 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

Issues: PXD SR during HER injection



Carsten

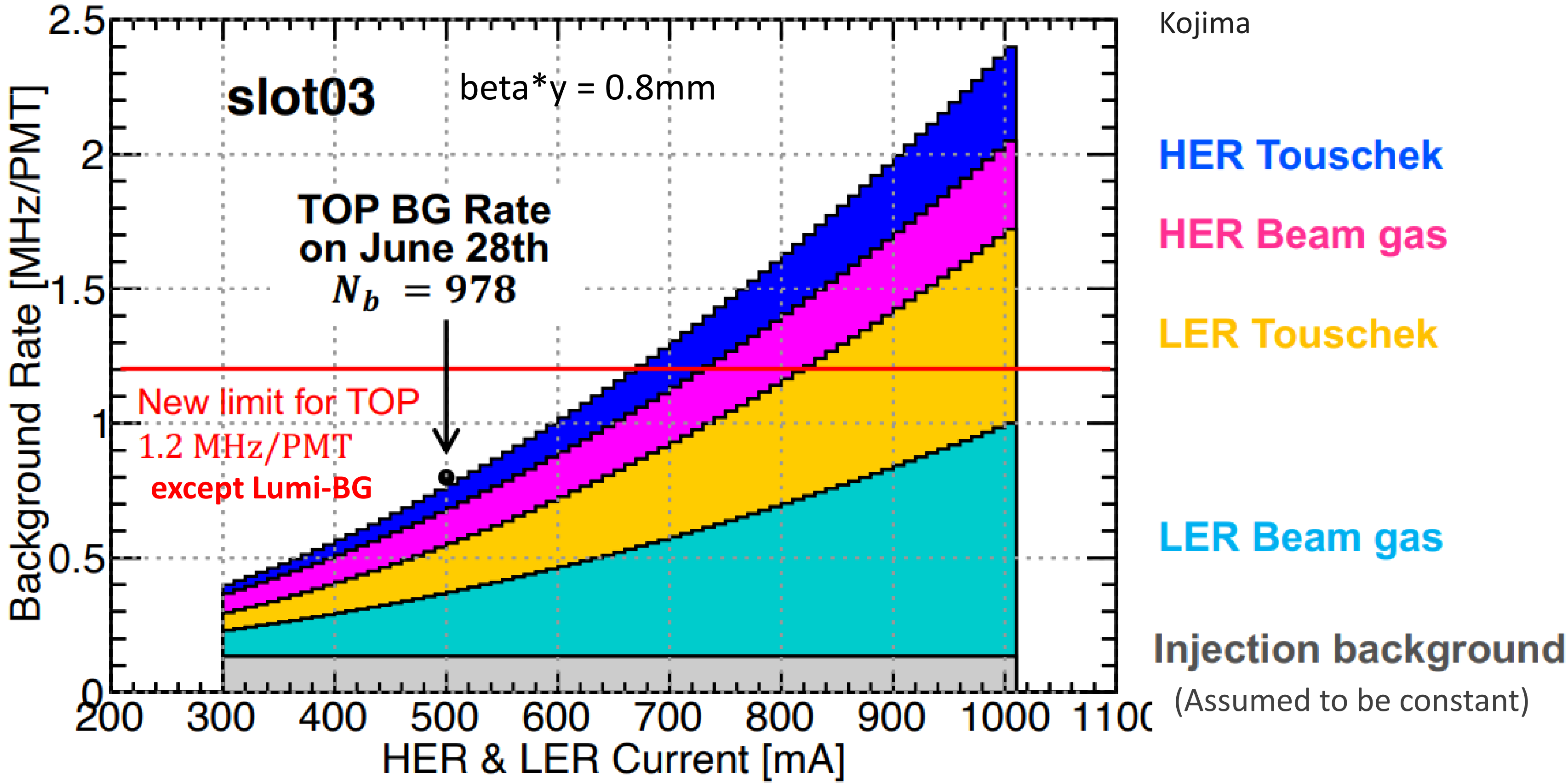
- SR hit pattern on PXD forward -X modules
- Became stronger when HER beta*_x was squeezed
- Only visible during HER injection
  - not observed with "blank-shot" HER injections
- HER horizontal tune adjustment shows no significant improvement within acceptable tune range
- HER D01H collimator adjustment didn't improve SR

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

TOP BG extrapolation

Naïve extrapolation, assuming no bkg mitigation

Kojima



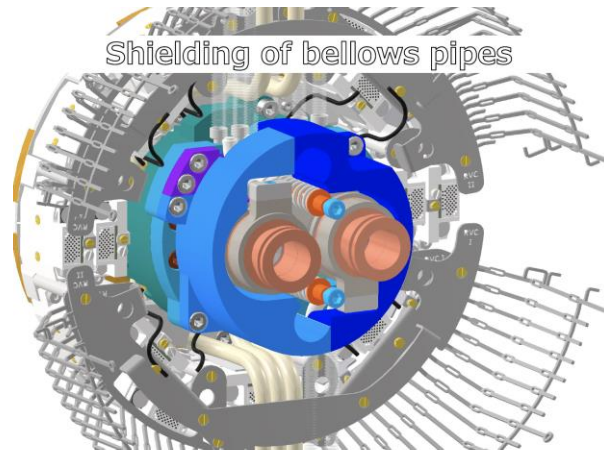
TOP PMT rate will hit the limit at LER~700mA (design: 2.8A)

NEED FURTHER BKG MITIGATION!

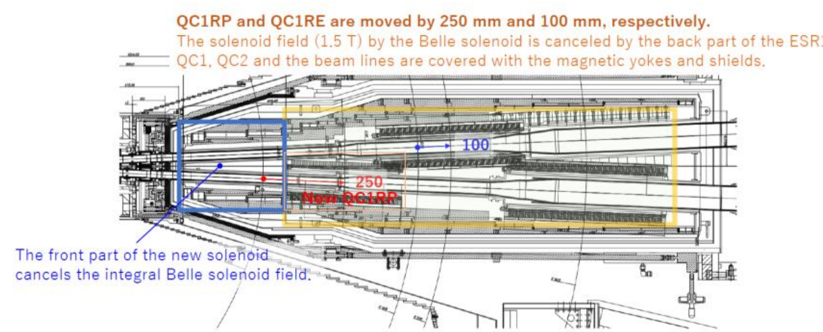
Further BG mitigation Ideas

- Vacuum scrubbing
  - beam-gas background will be gradually improved as baking proceeds
- Collimators
  - Optimize collimators as beta*y becomes smaller (add new ones and/or move current ones to different places in the ring)
  - As injection gets more stable and cleaner, we can further squeeze collimators to reduce storage BG
- Additional shield around QCS bellows (2022)
  - Cover the bellows pipe area where showers leak out
  - small space left for the shield, occupied by cables
  - Further BG reduction for TOP/CDC
- QCS modification (2026?)
  - Less overlap of solenoid and quads → suppres beam-beam blowup
  - Wider beam pipe aperture→ less beam loss

Additional shield around QCS bellows



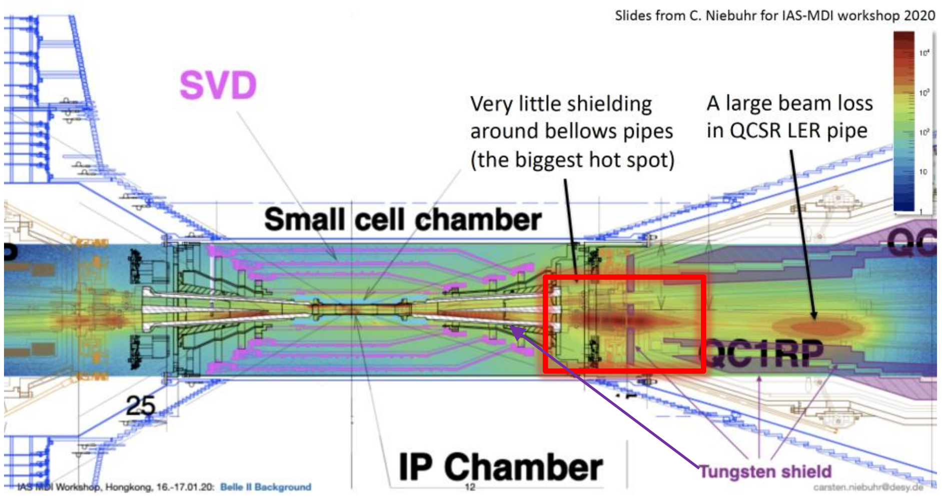
QCS remodeling



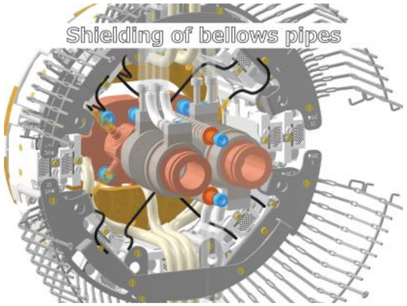
Mitigation ideas: Bellows shielding

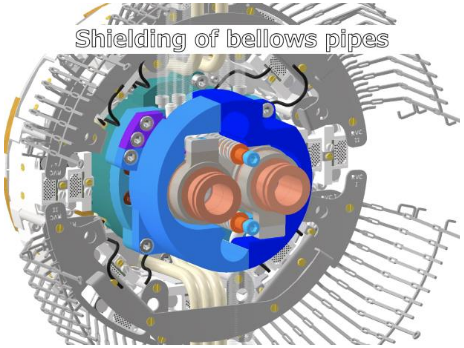
- To reach design luminosity, we need further background mitigation.
- One of ongoing project is an additional shield around bellows pipe where we see "hot spot" in data (also seen in simulation).
- Showers generated at z=1m leak out to the detector from the bellows part, where we cannot put enough shielding 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. Also effective to suppress Lumi-BG.

Hot Spots around IR from V0 analysis



V0 vertex distribution for Inv-M>550MeV





Overall summary

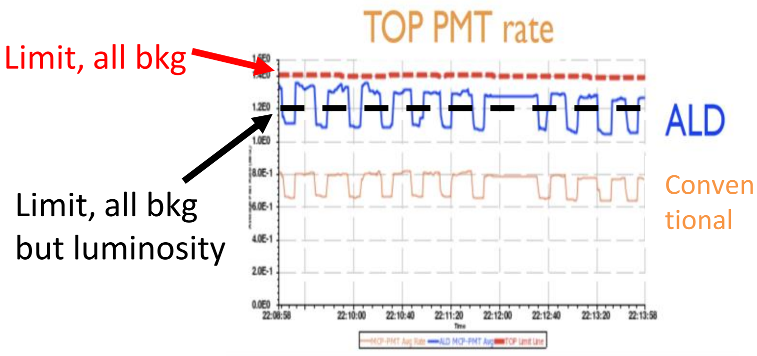
- Beam background at SuperKEKB can be dangerous and many countermeasures have been applied
- BG simulation predicts the impact on Belle II detectors
- BG measurements by dedicated machine studies can provide scaling factors between data and MC, which can be used for future extrapolation
- We still need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

backup

Background "big picture" in 2020 runs

Luminosity world record !

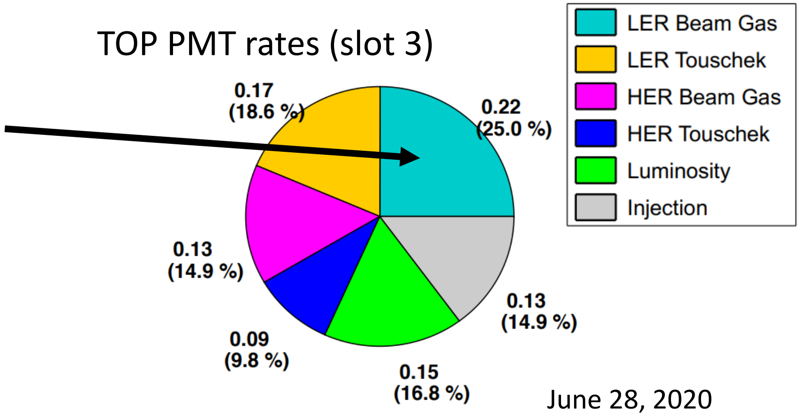
- L_{peak}=2.402 x 10^{34}/cm2/s achieved on June 21st
  - with LER 720mA, HER 610mA, continuous injection
  - beta*y = 1.0mm, 978 bunches



Kojima

- 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

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

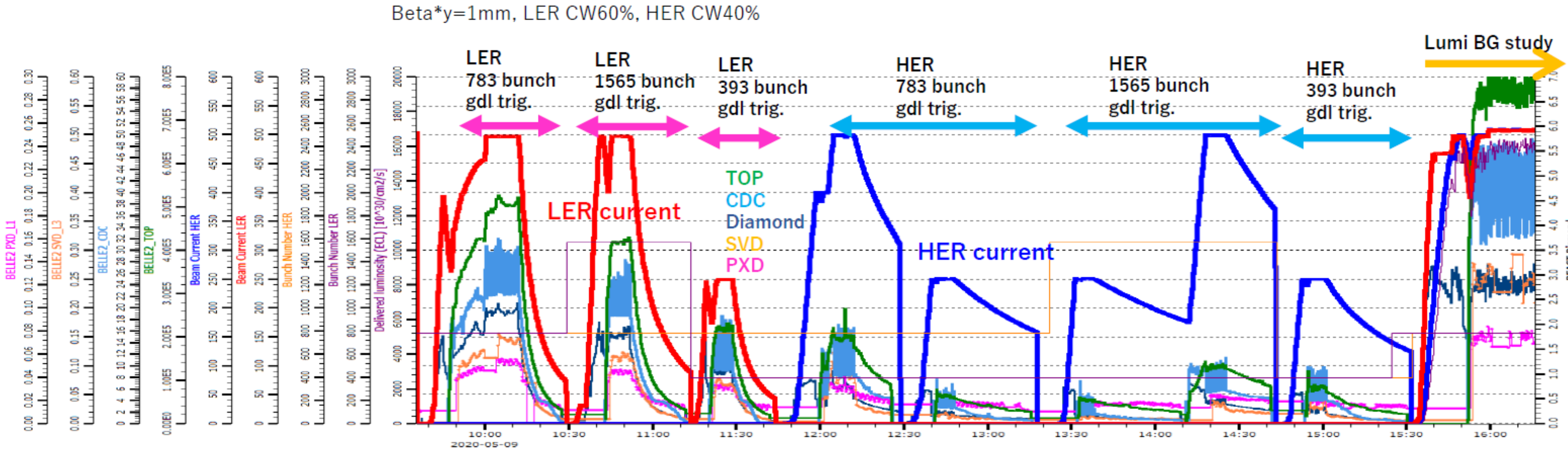


June 28, 2020

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

A snapshot from a single-beam BG study

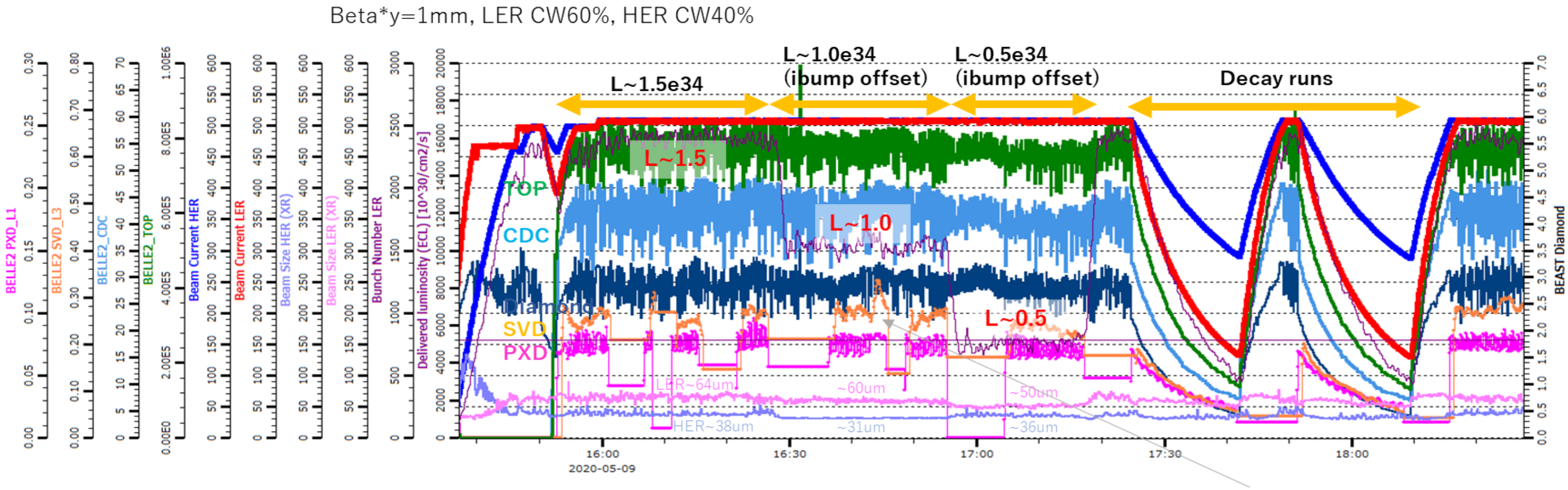
Example: LER/HER single-beam study on May 9th, 2020



- 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>

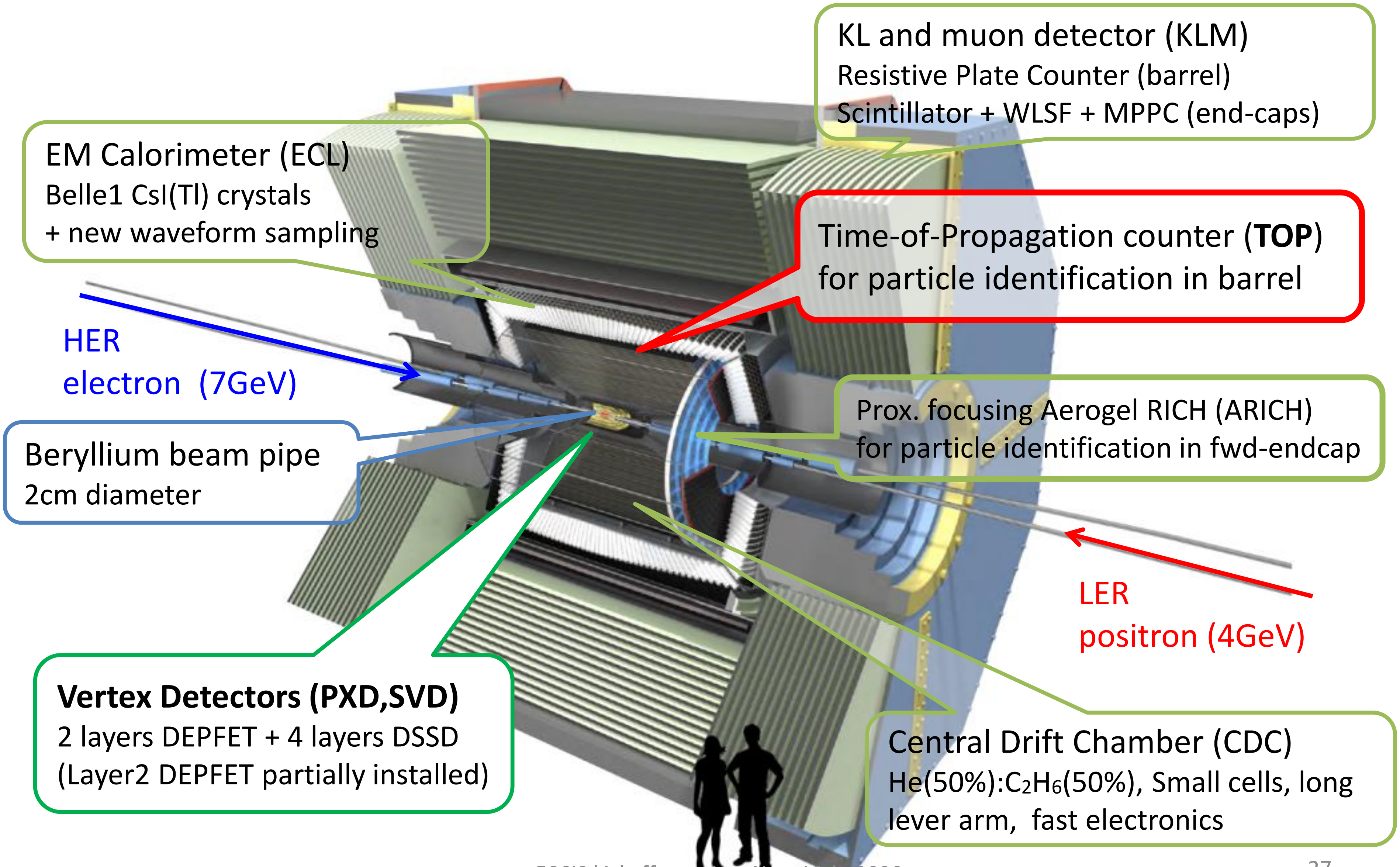
A snapshot from a Lumi-BG study



- “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

Where's "TOP" in Belle II Detector



SuperKEKB beam backgrounds

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

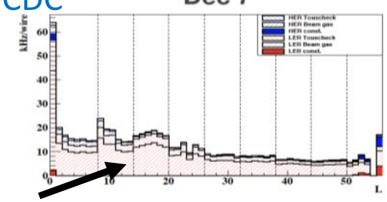
Stefkova

▷ 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

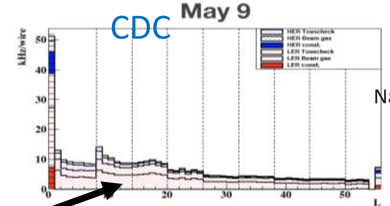
CDC

Dec 7



CDC

May 9



Nakagiri

TOP

Kojima

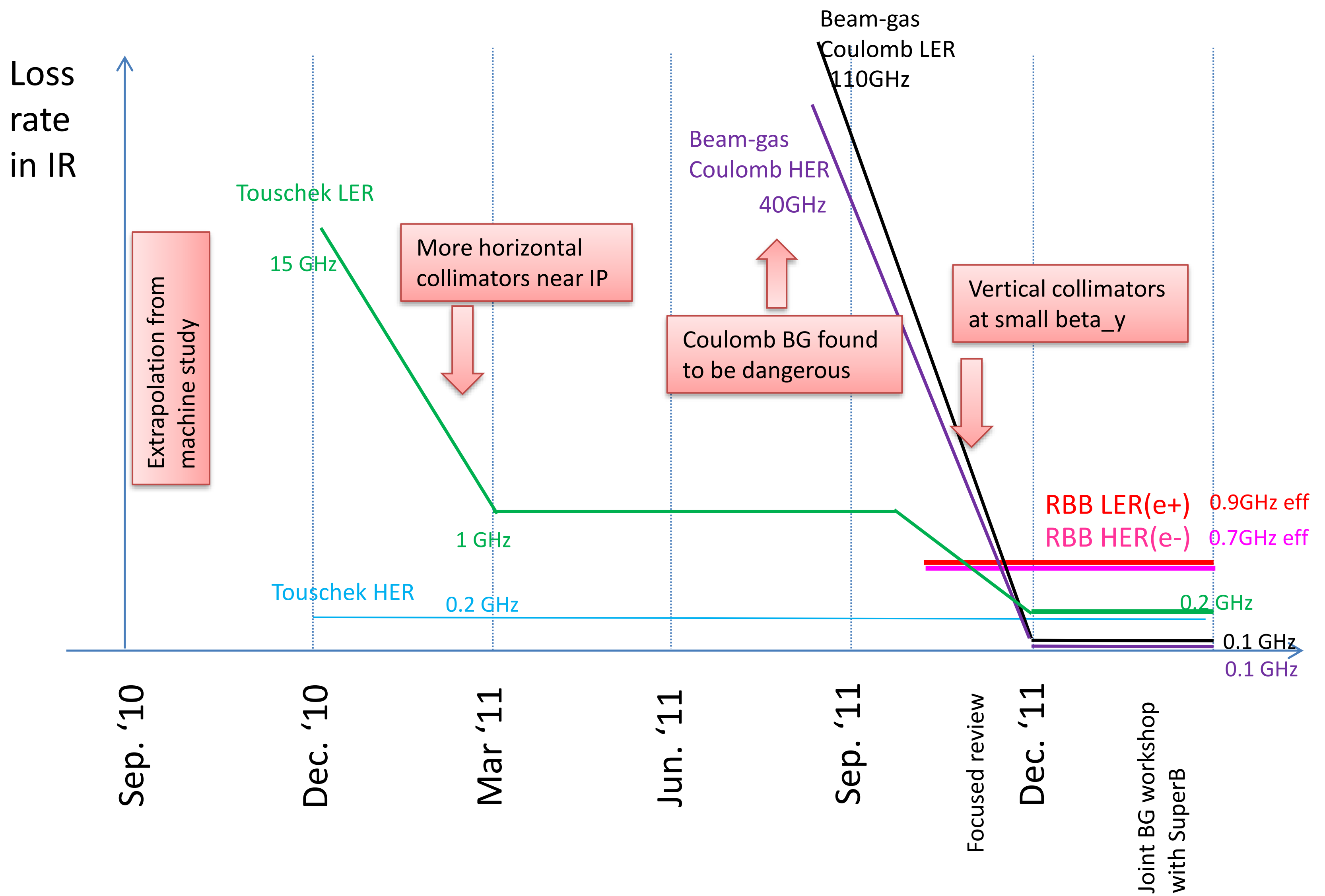
■ Ratios of Fit Parameters for slot01

		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.

Background reduction history

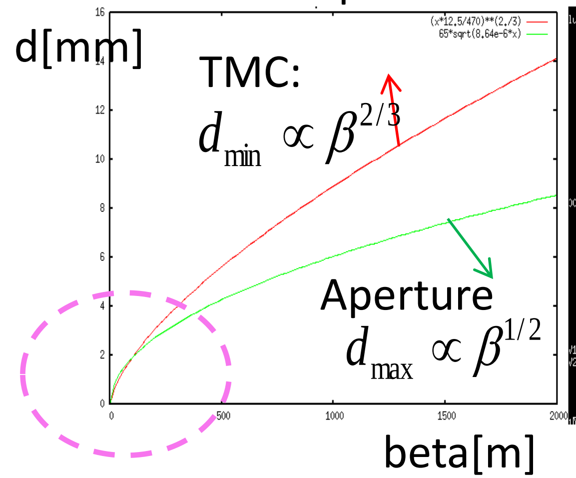


Where we should put the vertical collimators?

Collimator aperture should be narrower than QC1 aperture.

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

Collimator position



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)

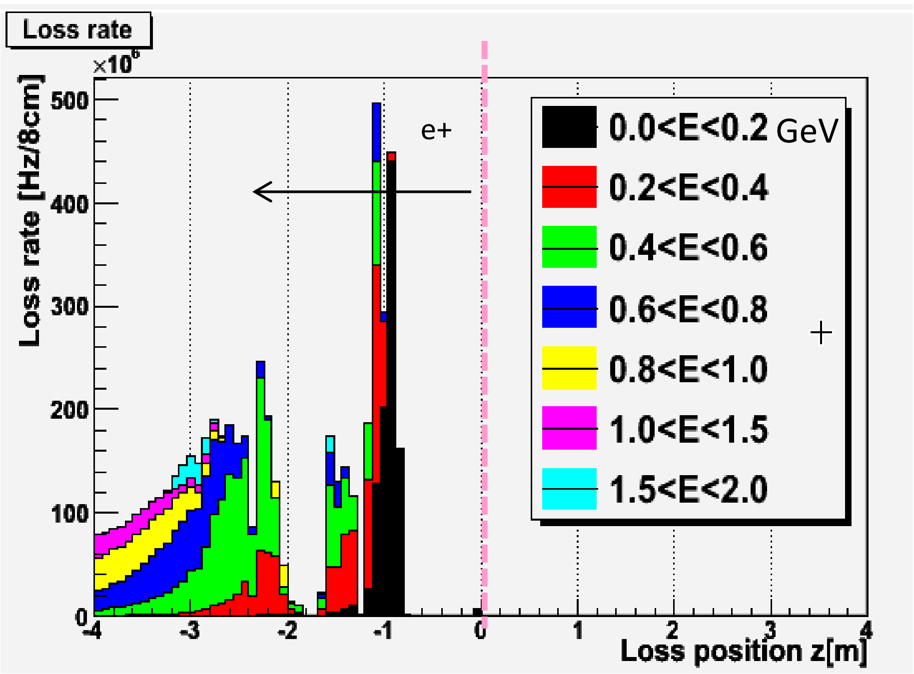
$$\Rightarrow d_{min} \propto \beta^{2/3}$$

We should put collimator where beta_y is rather SMALL!

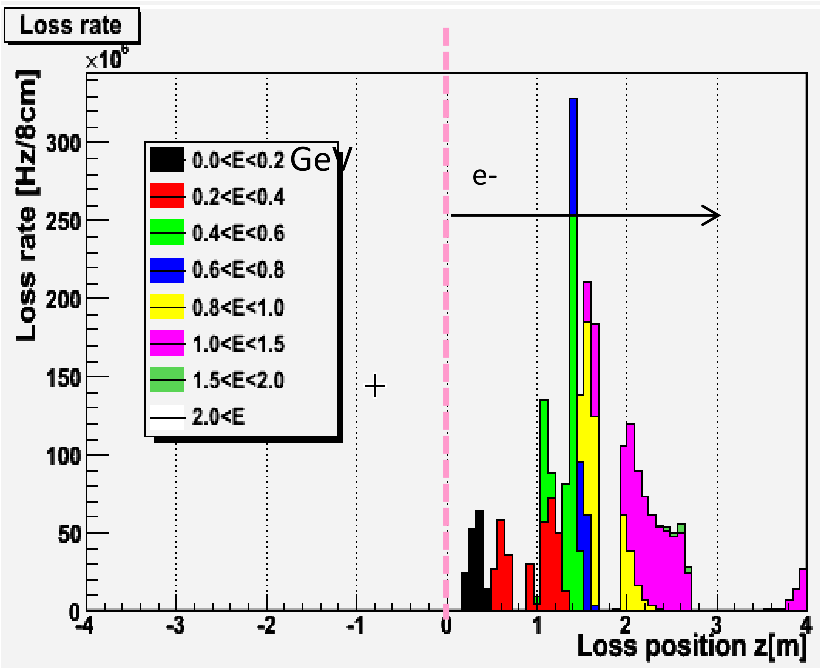
For more details, please check out following paper:
H. Nakayama et al, "Small-Beta Collimation at SuperKEKB to Stop Beam-Gas Scattered Particles and to Avoid Transverse Mode Coupling Instability", Conf. Proc. C **1205201**, 1104 (2012)

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)

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

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

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

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

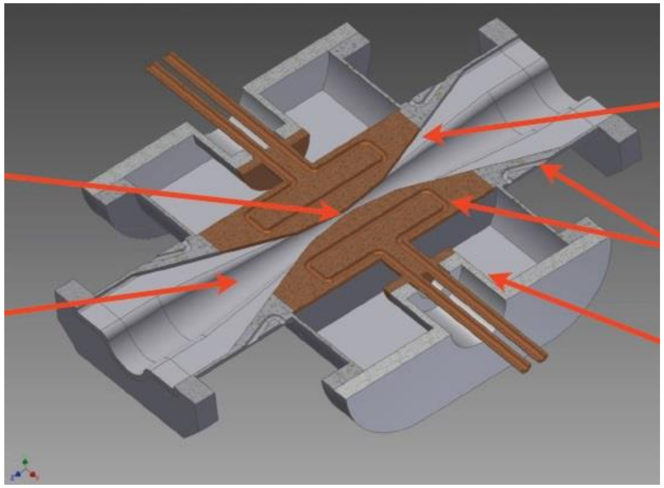
Typical orbit deviation at V1 : +-0.12mm (by iBump V-angle: +-0.5mrad@IP)

MDI design

How to cope with those beam BG?

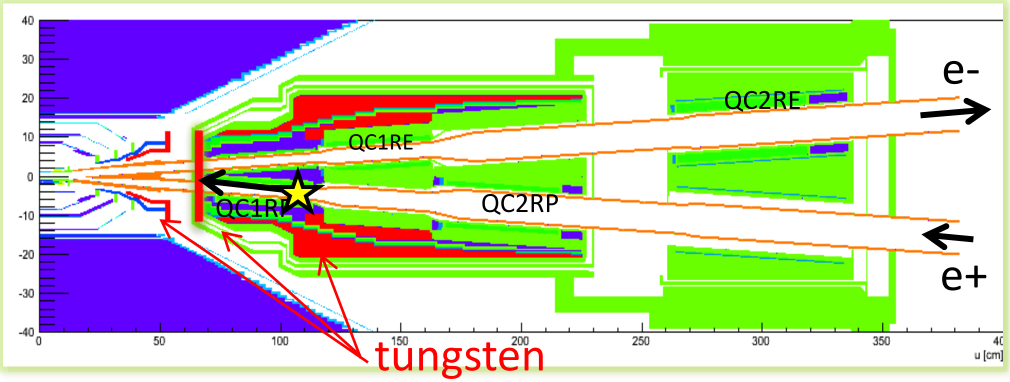
- Movable collimators
  – Horizontal collimators at arc sections and the straight section near IP for <u>Touschek BG</u>
  – Very narrow (~<2mm half width) vertical collimators for <u>Beam-gas BG</u>

SuperKEKB horizontal collimator

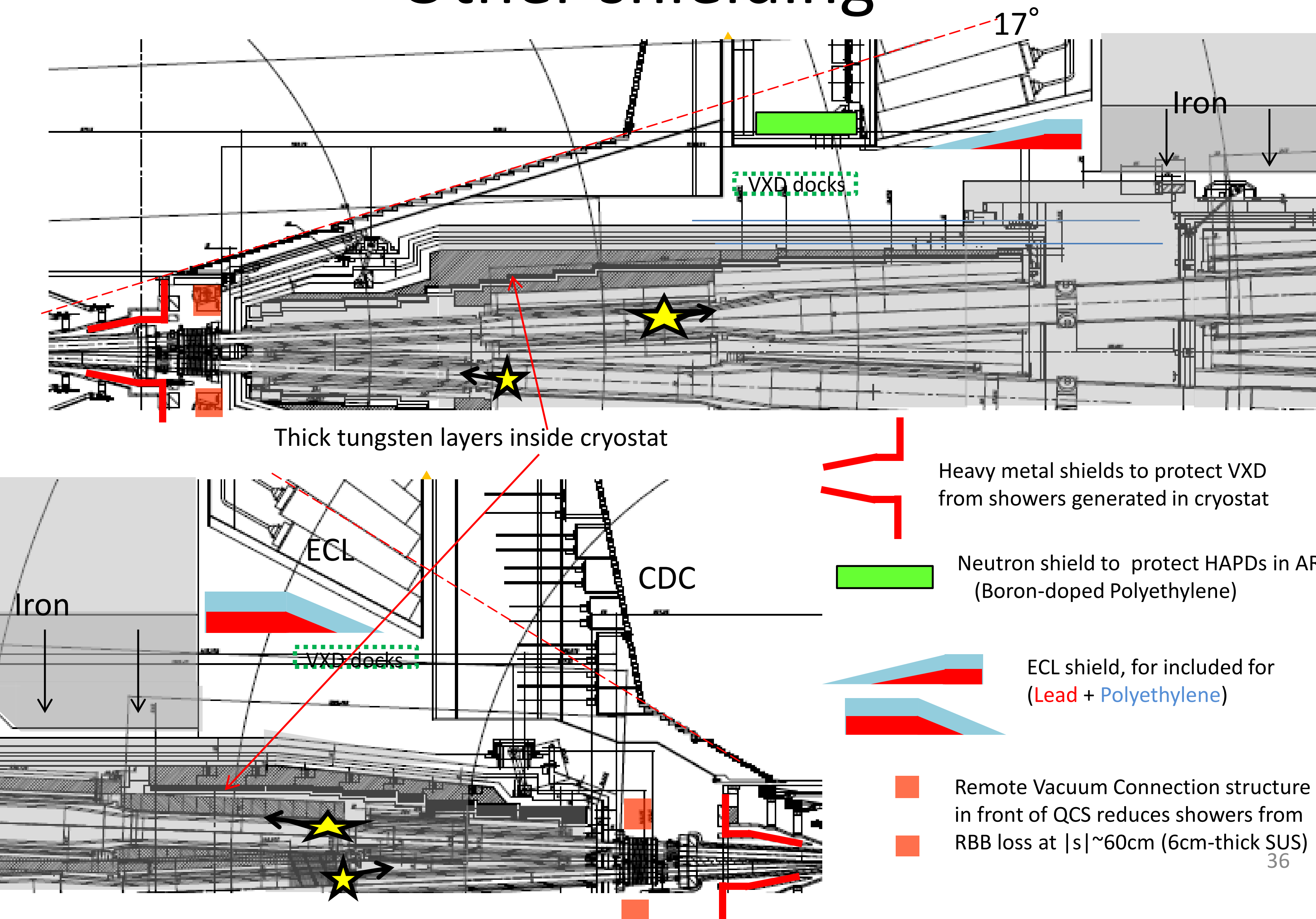


- Shielding structures
  – Thick tungsten structures inside final focus cryostat and vertex detector volume
  – Stops showers from beam loss “hot spot” ☆ at ~1m upstream from IP (maximum beta_y)
  – Polyethylene shields for neutrons

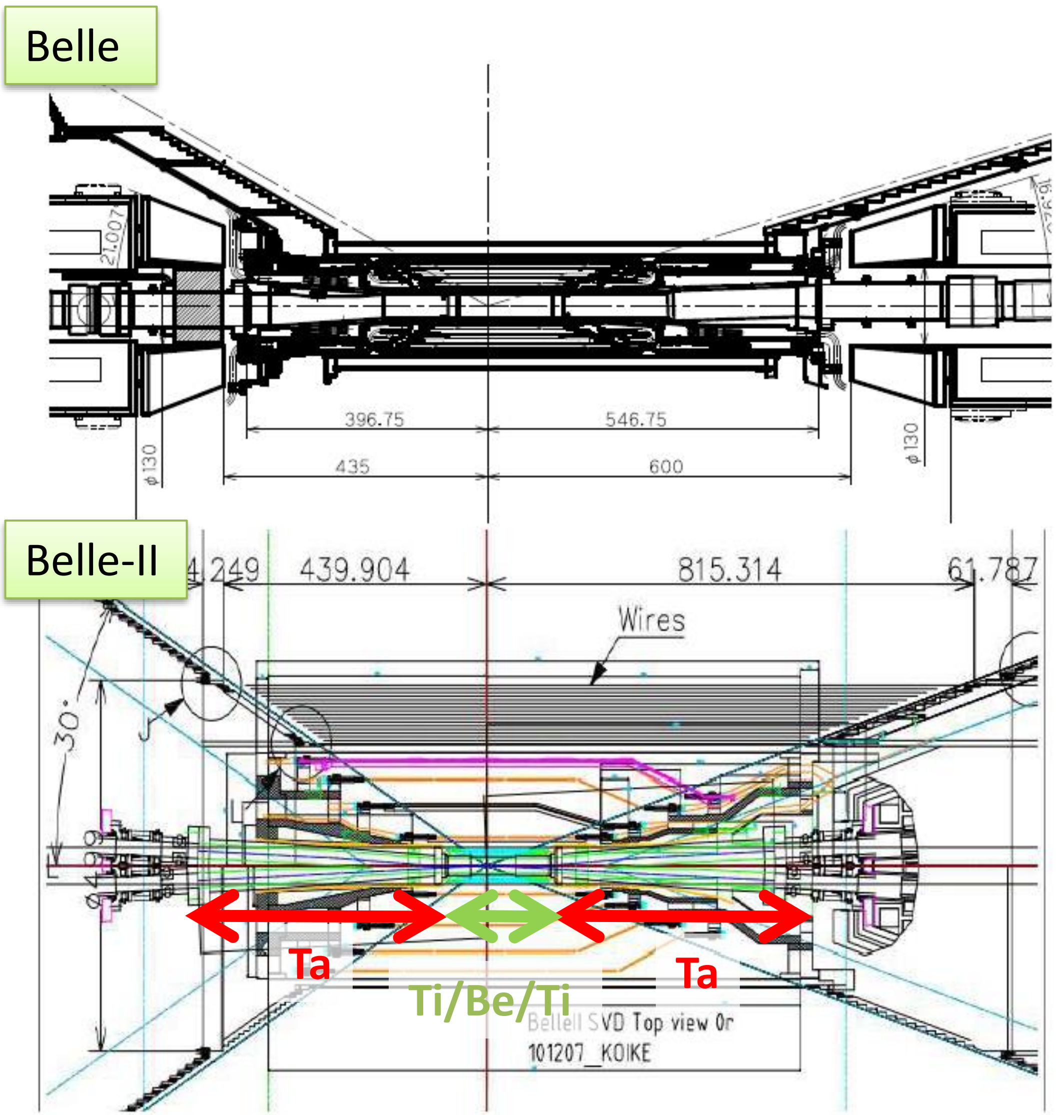
Final focus magnet cryostat, R-side



Other shielding



Interaction region

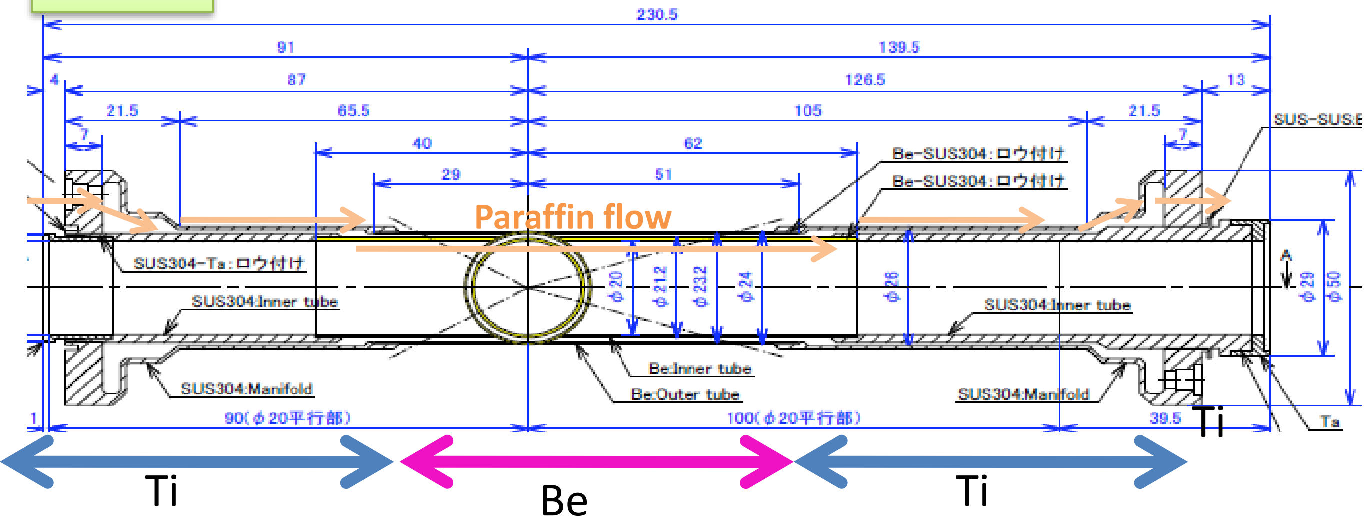


<Belle-II>

- 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)

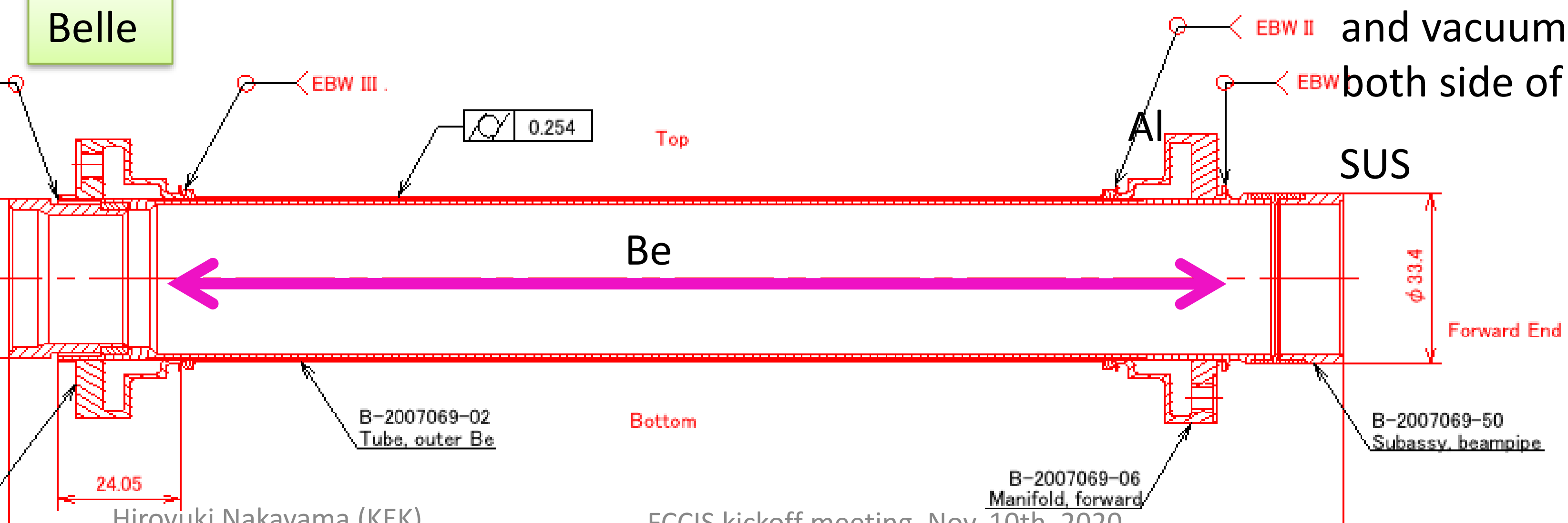
IP beam pipe

Belle-II

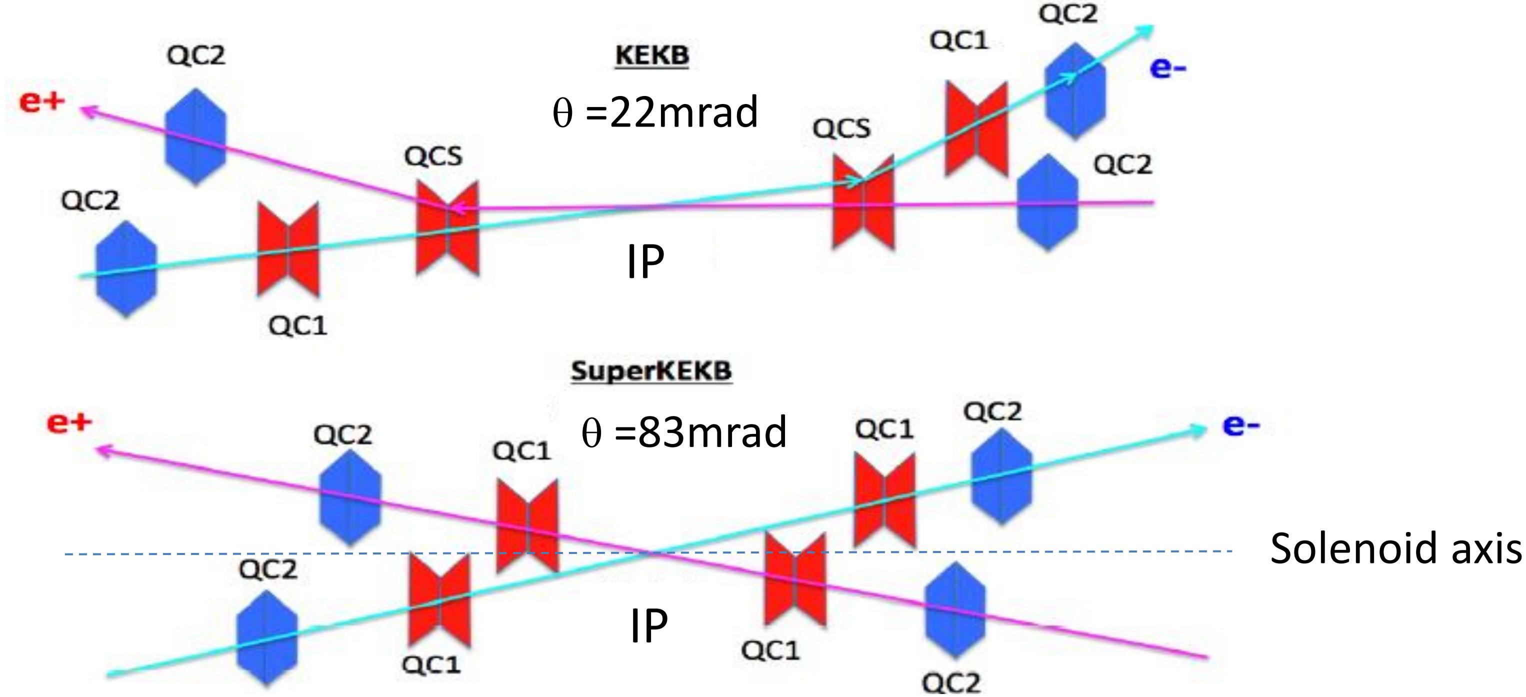


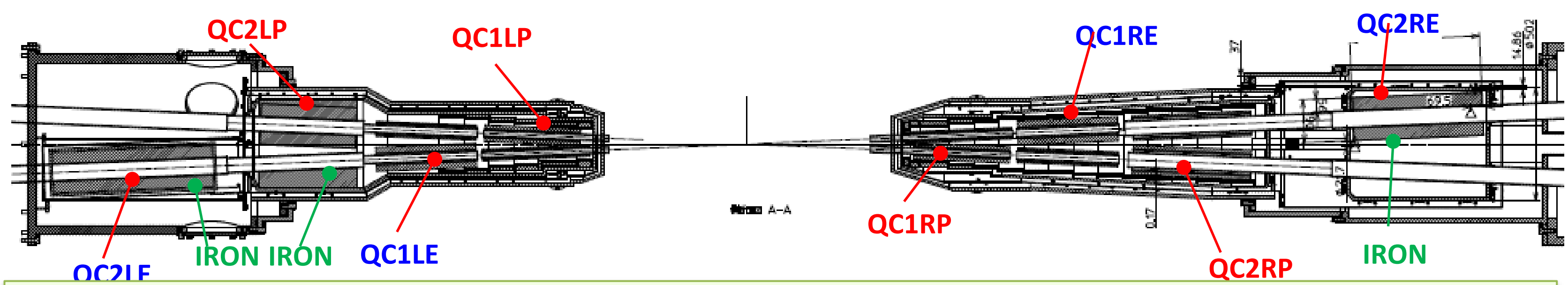
- Light material (Be) inside detector acceptance
- Paraffin ($C_{10}H_{22}$)flow to remove heat from mirror current (~80W)
- Gold plating (~10um) on inner wall to stop SR
- Much simpler Be shape (also much cheaper) since we allow Paraffin and vacuum to attach both side of welding

Belle



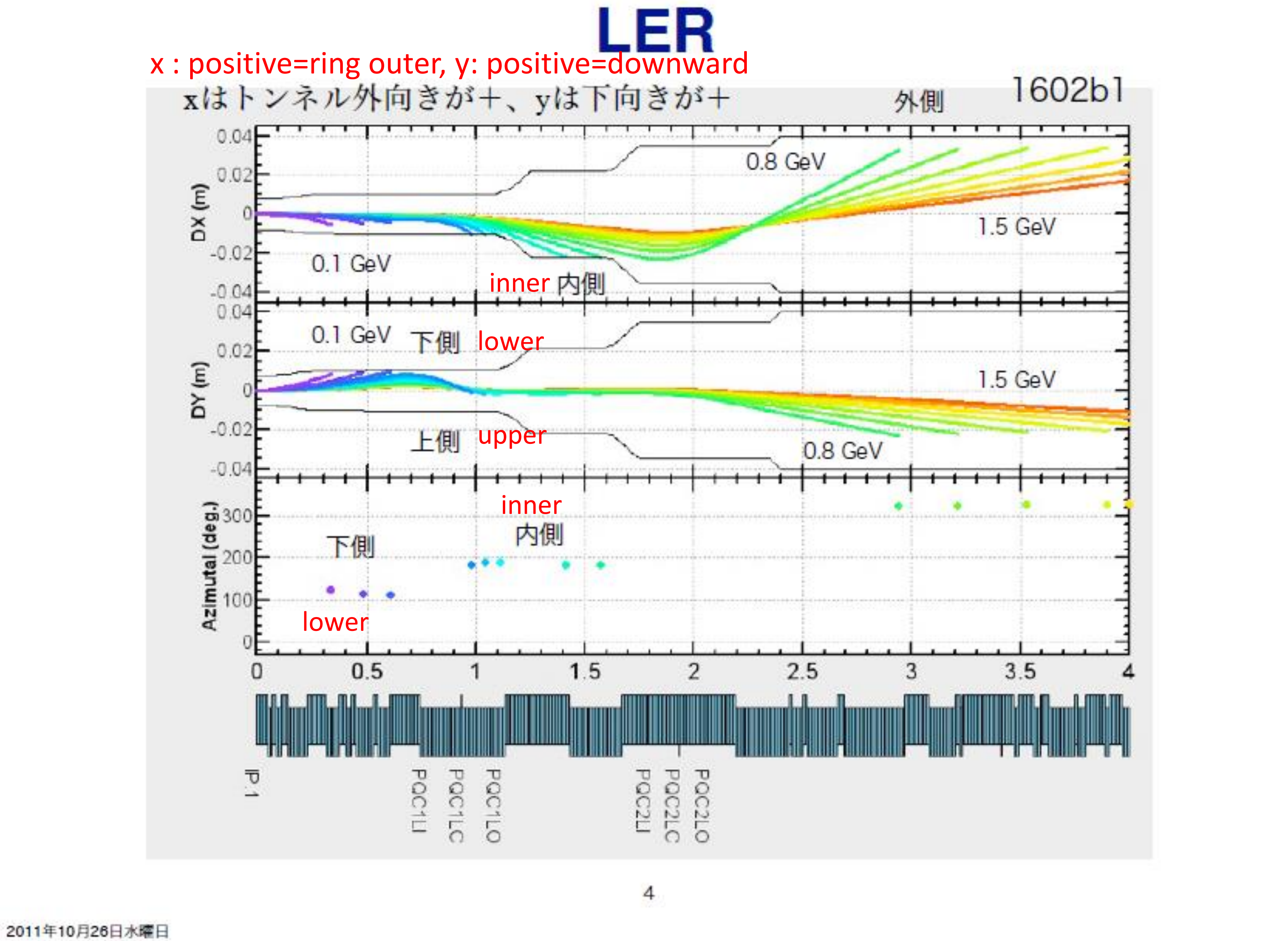
Final focusing magnets





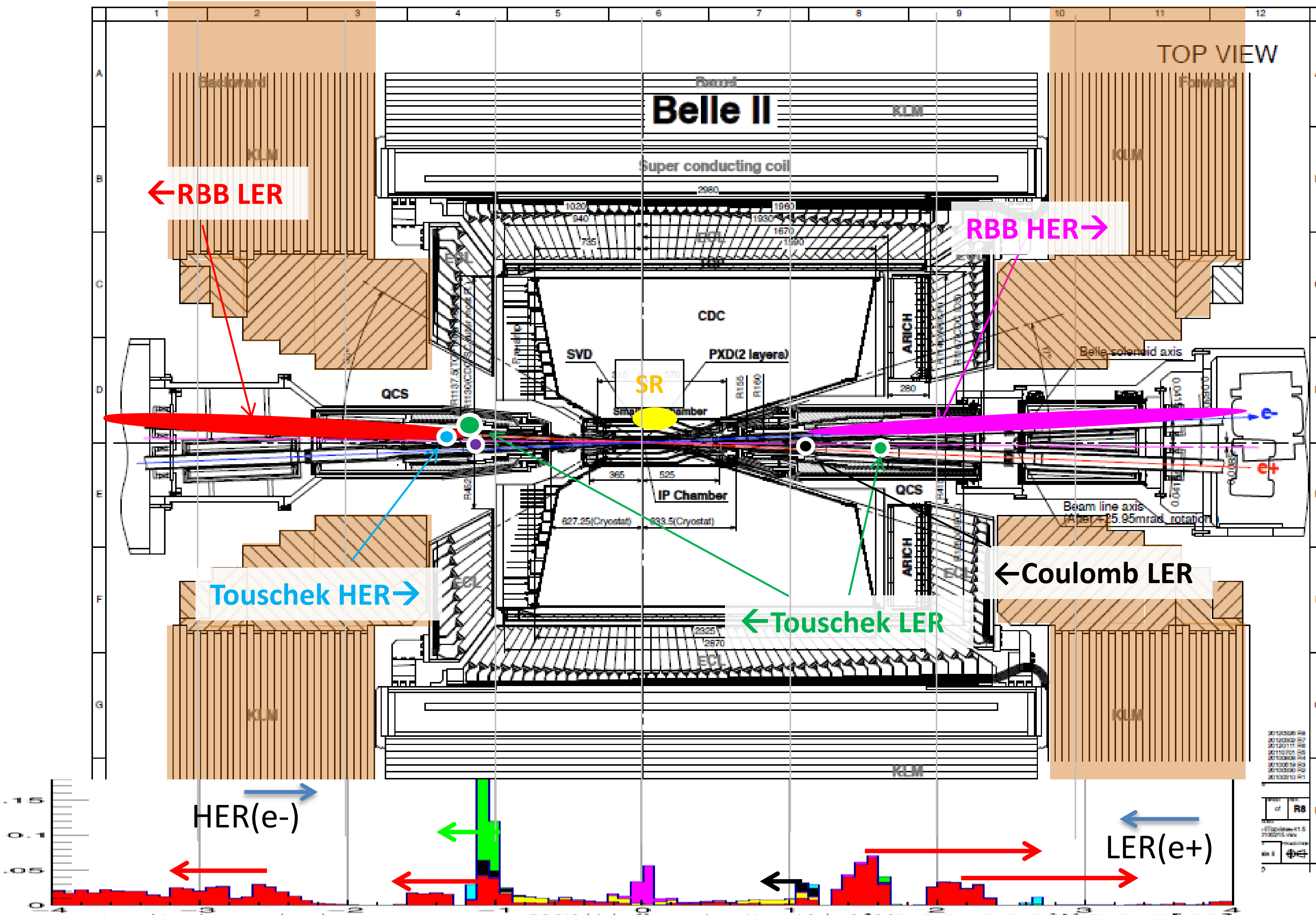
- Larger crossing angle θ than KEKB
- Final Q for each ring→ more flexible optics design
- No bend near IP→ less emittance, less background from spent particles

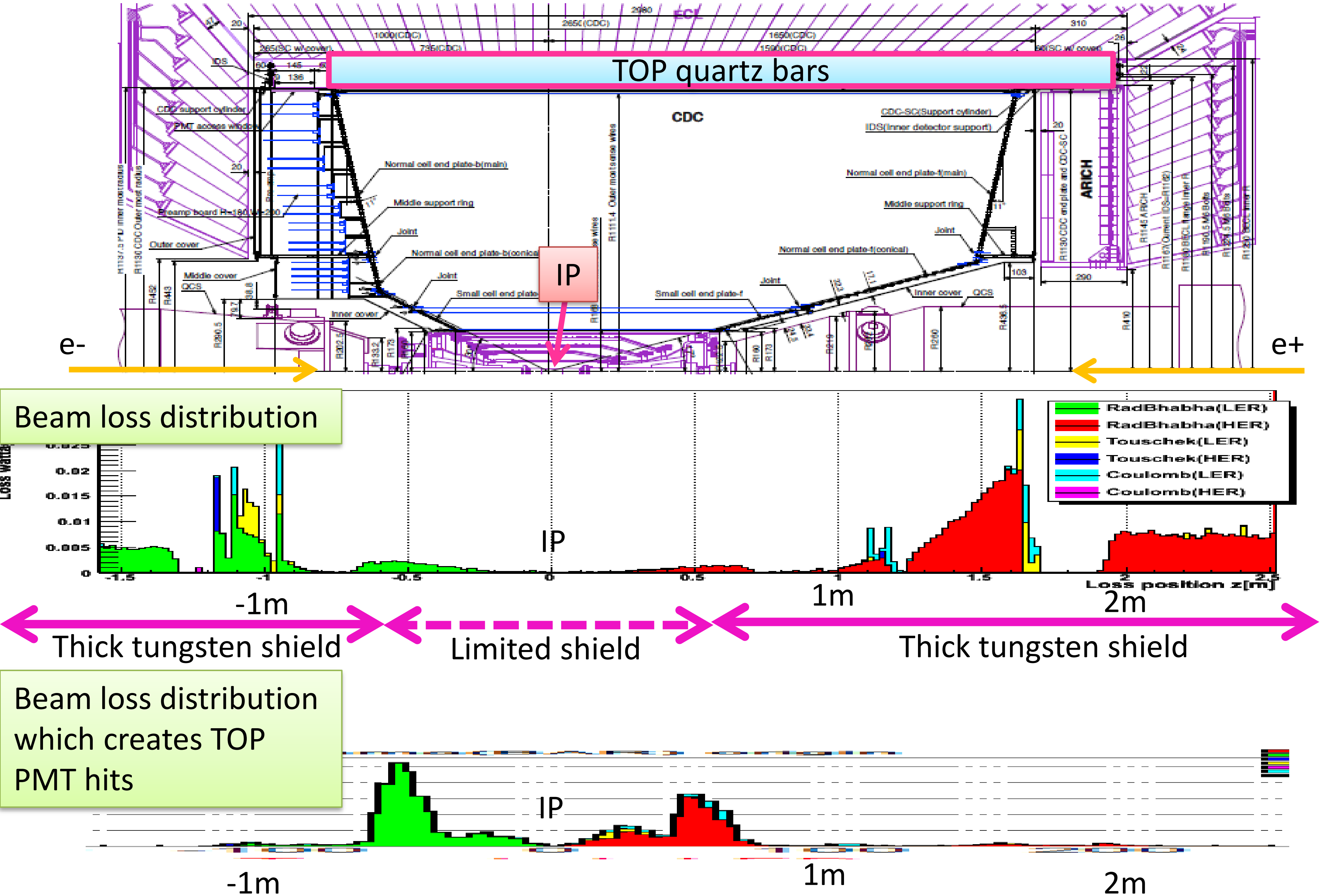
Beam orbit after RBB scattering



Ver. 2017.1.31

Background Global picture



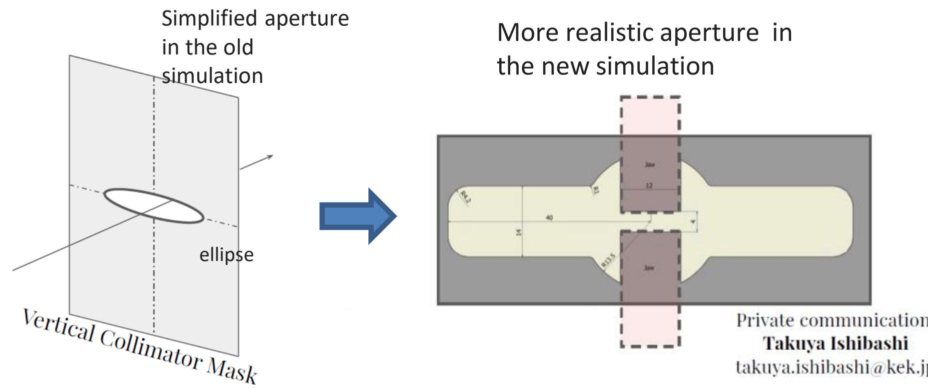

TOP quartz bars
CDC
ARICH
ECL
IP
e-
e+
Beam loss distribution
RadBhabha(LER)
RadBhabha(HER)
Touschek(LER)
Touschek(HER)
Coulomb(LER)
Coulomb(HER)
Loss position z[m]
-1m
1m
2m
Thick tungsten shield
Limited shield
Thick tungsten shield
Beam loss distribution which creates TOP PMT hits
IP
-1m
1m
2m

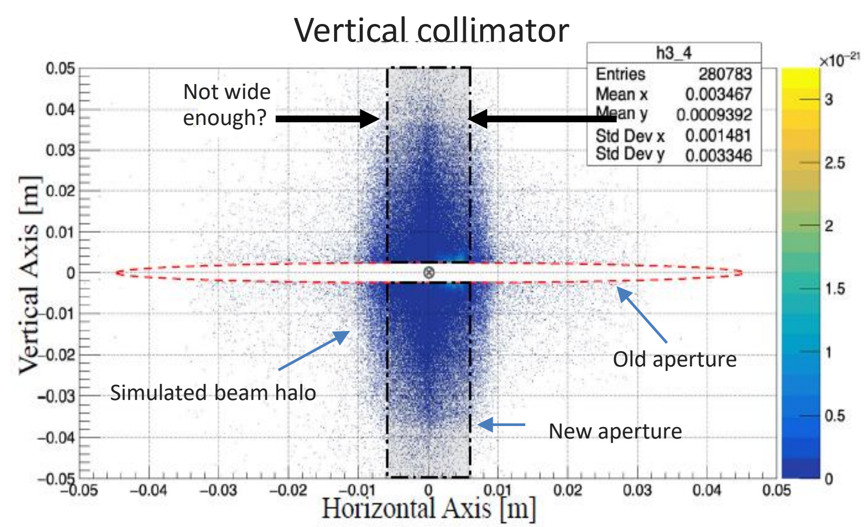
BG measurement in 2020

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.)





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

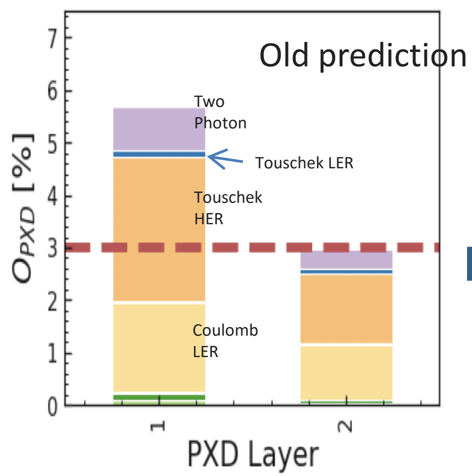
BG sources	Old simulation	New simulation*
HER beam-gas (base)	x11	x3.4
HER beam-gas (dynamic)	x15	x6.3
HER Touschek	x130	x0.24

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

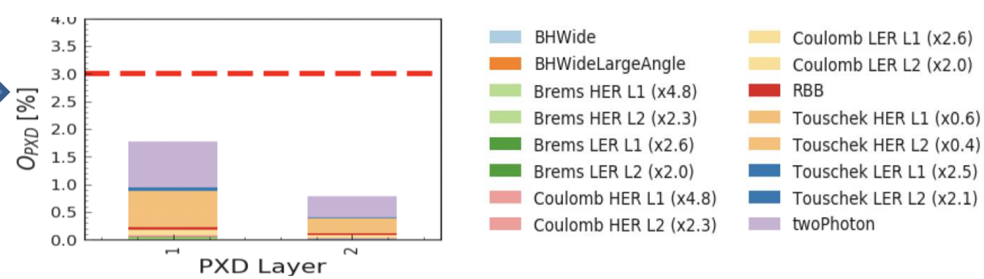
Implications for design luminosity

- 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



- 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: QCS quench on May 27th, 2020

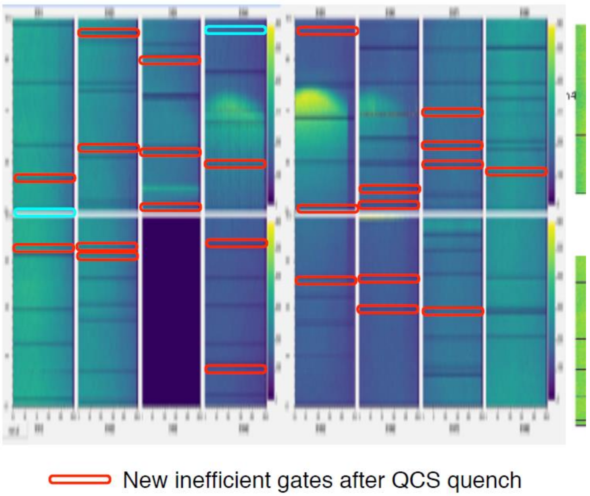
<u>What happened?</u>

- 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.

<u>Solutions</u>

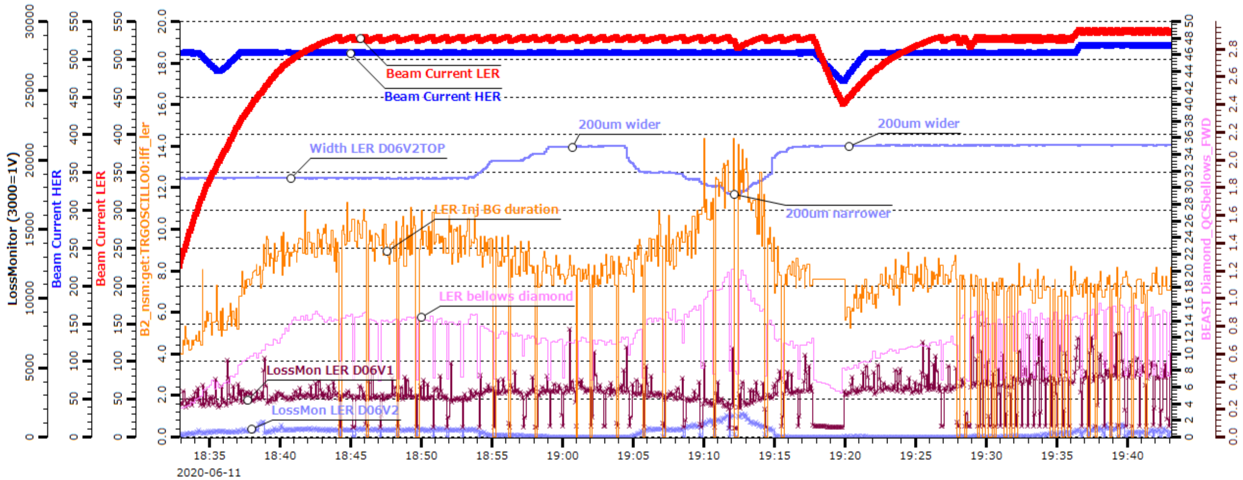
- Diamond system is modified.
  - Dump the data only when <u>both beams</u> are aborted.
- iBump fast FB is also modified
  - Add the limiter on the FB power supply controller

PXD after QCS quench in May 27th



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.

Why?

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

Hiroyuki Nakayama (KEK)

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

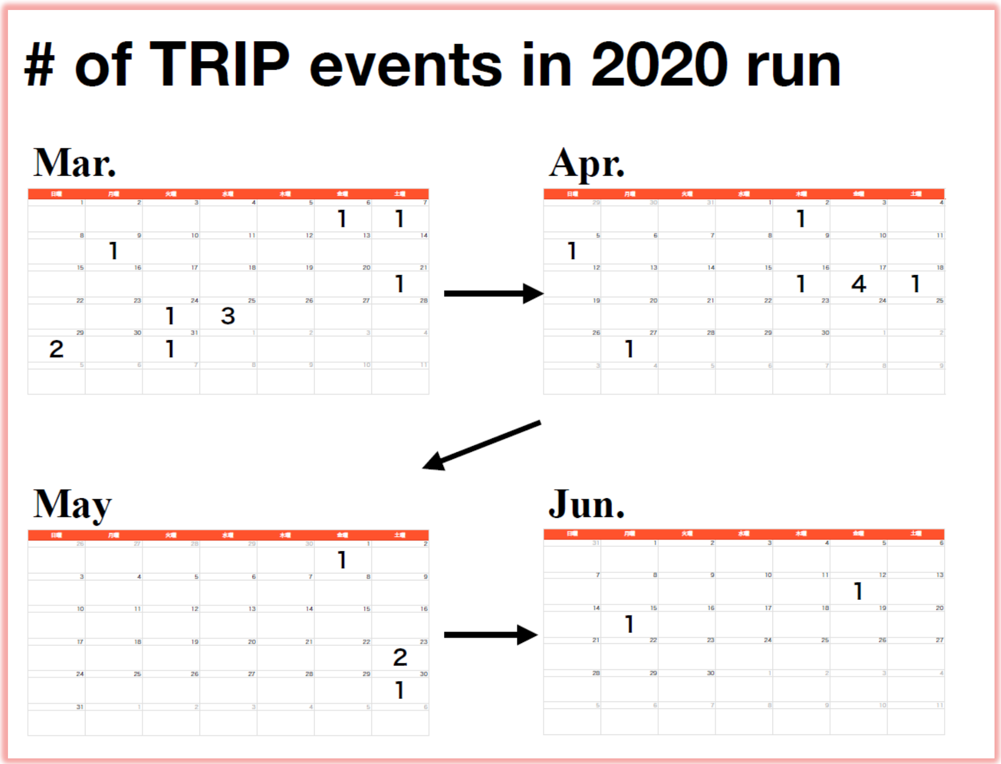
	DIF_POS [mm]	beta_y [m]	nu_y	Nsigma (beta)	LM
D06V1TOP	2.60	67.3	28.85	69.3	0.07
D06V1BTM	-2.61	67.3	28.85	69.6	
	0.33				
D06V2TOP	1.79	20.6	30.49	85.8	1.28
D06V2BTM	-1.83	20.6	30.49	88.2	1.35
	0.19				
D02V1TOP	1.32	13.9	44.86	77.1	0.00
D02V1BTM	-1.33	13.9	44.86	77.7	
	0.17				
QC1 (1.12m)	13.5	782.2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

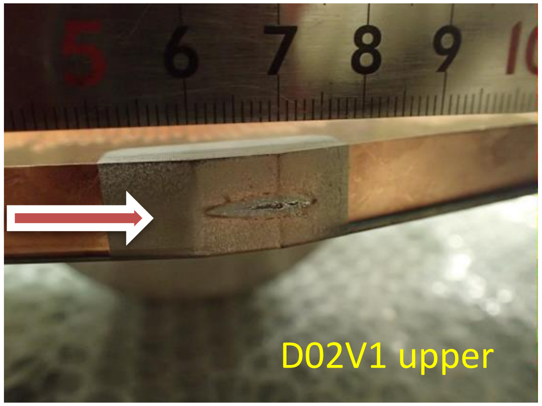
CDC HV trips – much less frequent in 2020a,b



- 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?

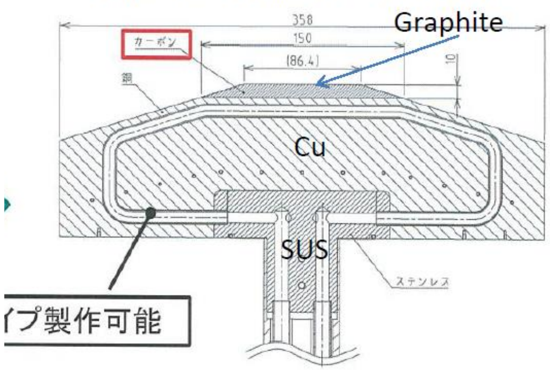
Low-Z collimator head option

- 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