Beam background/MDI report

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S. Vahsen (Hawaii)

Contents:

- Latest background/MDI status
- Improvements to background simulation
- Improved data/MC agreement
- Further background mitigation
- MDI-related issues during 2020b

Background Status in 2020a,b Run

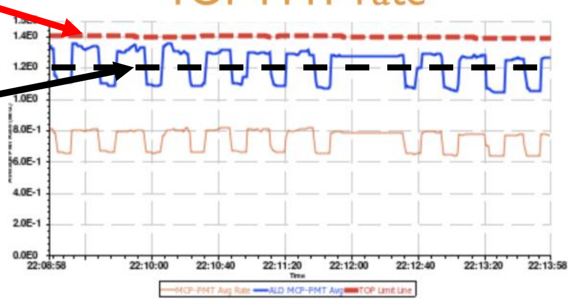
- L_{peak}=2.402 x 10^{34}/cm2/s on June 21st, 2020
  - Achieved with LER 720mA, HER 610mA
  - beta*y = 1.0mm, 978 bunches
- TOP is the detector currently most vulnerable to beam backgrounds
  - close to or at the rate limit in recent runs
- Finite PMT lifetime + new SuperKEKB run plan dictates: PMT rate from all bkg components except luminosity needs be <1.2MHZ
- Current composition, measured May 9
  - LER beam-gas is the dominant component, approx. 50% of total
  - Reduced substantially since 2019c
- Further reduction of TOP single-beam BG required for higher beam currents in 2020c

Iijima San's talk

Luminosity world record !

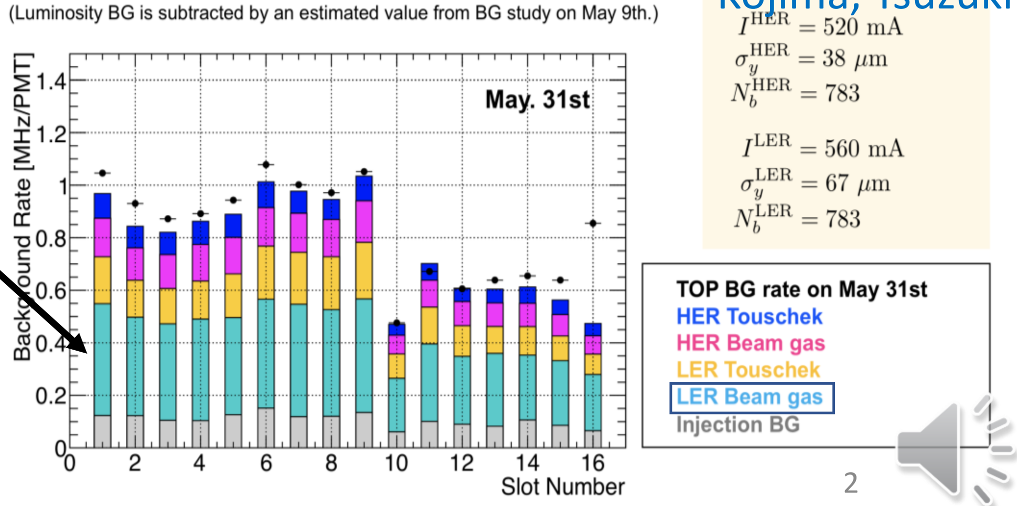
Belle II background lower than the limit, thanks to many many efforts

TOP PMT rate

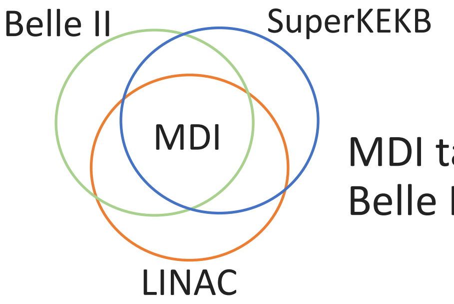


Kojima, Tsuzuki

(Luminosity BG is subtracted by an estimated value from BG study on May 9th.)



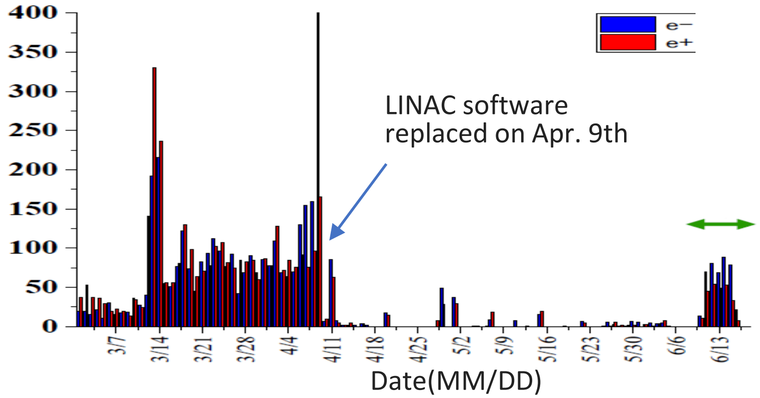
MDI Status in 2020a,b Run



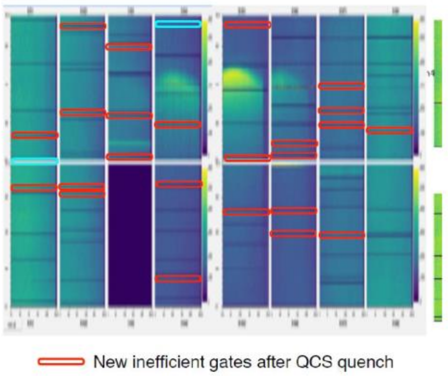
MDI taskforce unites
Belle II, SuperKEKB and LINAC

- New LER V collimator (D6V1)
  - Used D6V1 as "primary" (=narrowest) collimator to protect D2V1 near IP
  - Effectively suppress LER Beam-gas Coulomb (see next slide)
  - Plan to replace D6V1 head with Carbon in this summer
- Beam aborts due to bad injections: less frequent
  - Less machine downtime → more integrated luminosity
  - LINAC pulsed magnet misfire problem is solved on Apr. 9th
  - LINAC/BT orbit monitoring significantly improved
- Injection BG duration
  - Shorter veto window → less dead time
  - Many studies in 2020a,b, with newly developed monitoring tools
- 2-bunch injections
  - Essential to achieve higher beam currents
  - HER 2-bunch injection is successful and now set as default (LER needs more work)
- Others
  - Faster Diamond abort cycle 2.5 us in 2020 a+b (10 us before) ensuring safer operation
  - Two QCS quench events (May 27th, June 20th)
  - PXD SR by HER injections: not critical right now, but need careful watching
  - CDC HV trip is much less frequent in 2020a,b
  - Collimator activations, collimator impedance

Daily count of pulse magnet failures



PXD damage/QCS quench by beam loss on May 27th



Good news: Background reduction, 2019c to 2020b

- 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, moving other collimators, vacuum scrubbing
- Similar to our prediction (factor 2.5) by adding D6V1
- New: We now separate beam-gas into dynamic and base
  - Both in simulation analysis
  - Main reduction seen in dynamic component. Base component not always reduced.
  - Important to understand evolution for future BG predictions.

SVD   Tanigawa

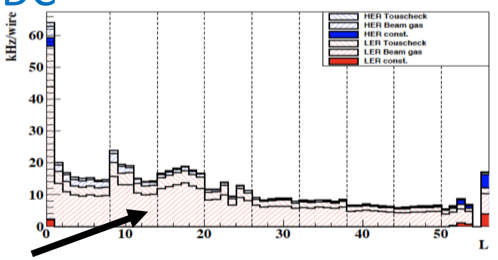
(May 2020)/(Dec 2019) SVD L3 strip occupancy	
HER Beam-gas	1.1
LER Beam-gas	0.43
HER Touschek	1.0
LER Touschek	1.1

PXD   Stefkova

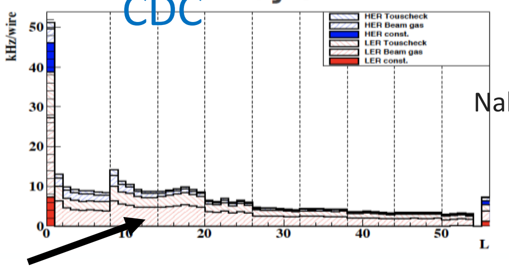
▷ Comparison based on fitted sensitivities

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



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.

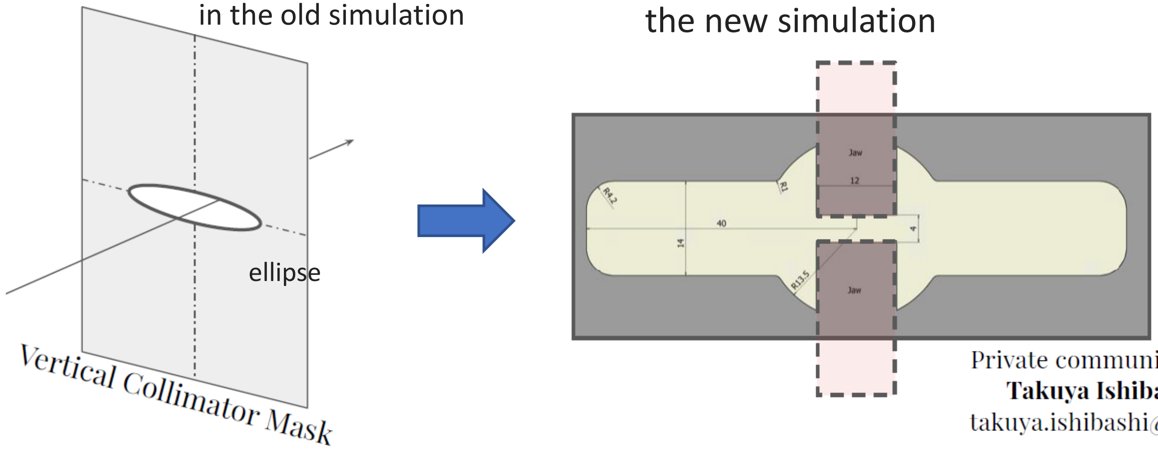
Recent improvements to simulation

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.)

Simplified aperture in the old simulation

More realistic aperture in the new simulation



Private communication:
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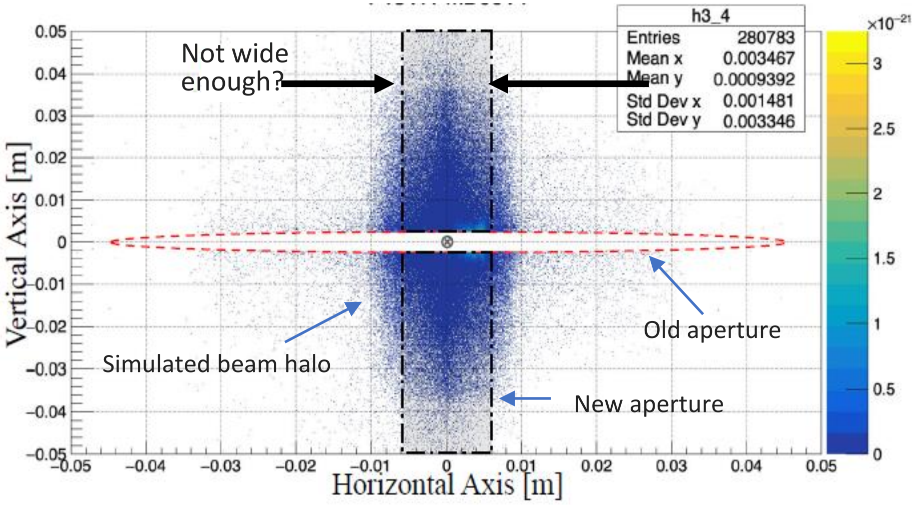
Vertical collimator



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

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

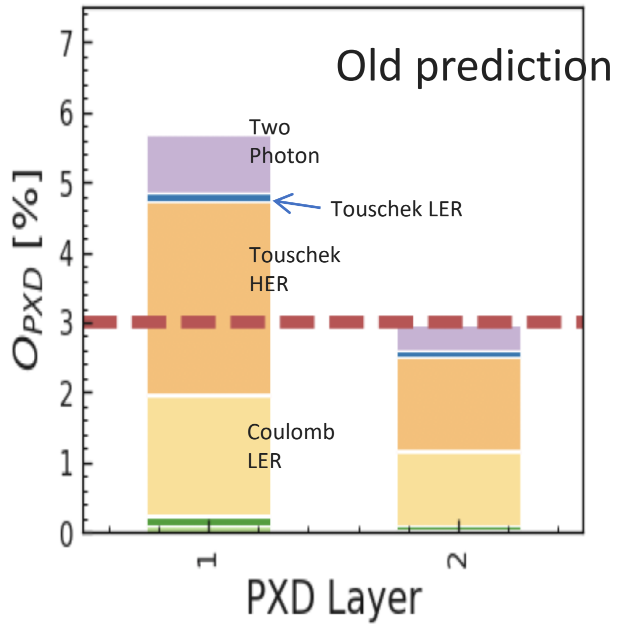
BG sources	Old simulation	New simulation*
HER beam-gas (base)	x11	x3.4
HER beam-gas (dynamic)	x15	x6.3
HER Touschek	x130 →	x0.24

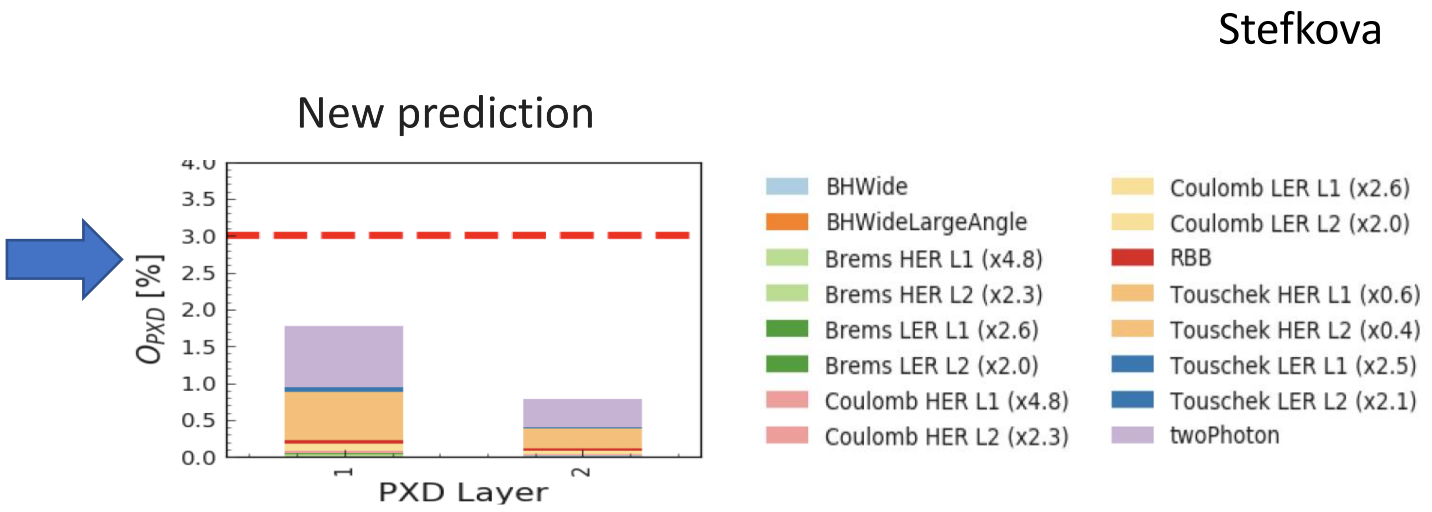
* New simulation includes realistic collimator shape and tip-scattering

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. This will require more hard work, but now seems achievable.
  - need gas injection study for better understanding of beam-gas background (Z_{eff}=7 or 2.2 or ?)

PXD





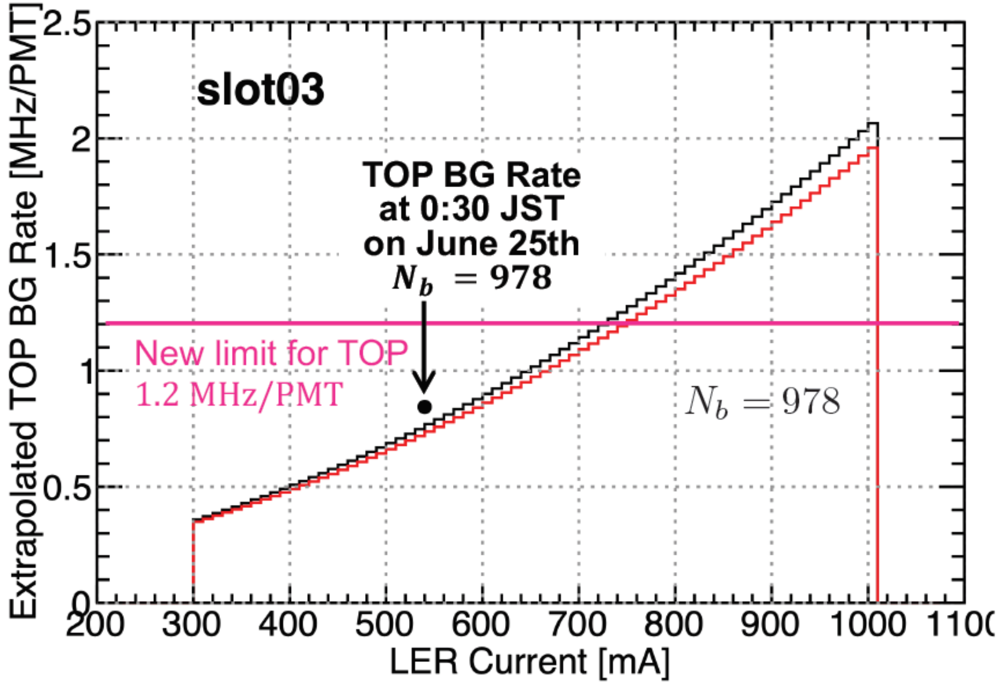
- Difference between BG 17/18 MC samples: corrected IR beam-pipe aperture, real collimator shape for SuperKEKB-type collimators, tip-scattering for SuperKEKB-type collimators, new data/MC ratios, the latest basf2/Geant4 geometry of the Belle II

TOP BG extrapolation toward higher current

Kojima

Background Extrapolation

The fit parameters are taken from the data of single beam background study on May 9th.
→ Luminosity and injection BG is also estimated from the condition on May 9th.



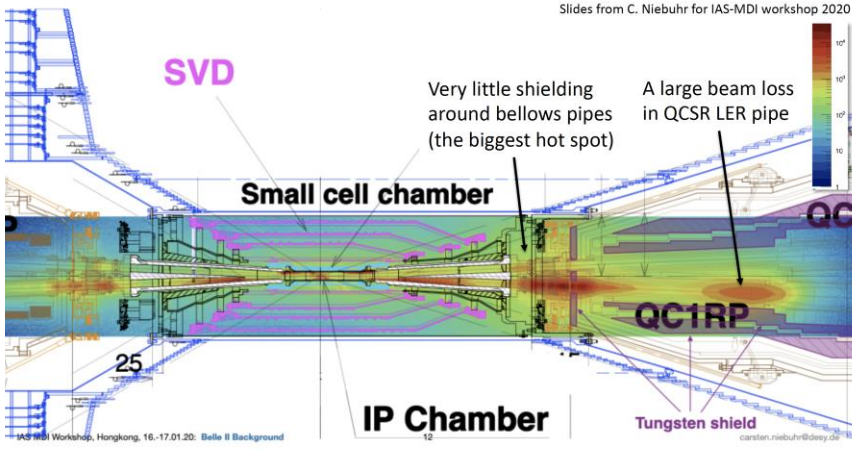
2020/6/25 K. Kojima / Background Extrapolation 1 / 9

Without further mitigation, TOP PMT rate will hit the limit at LER~750mA (design current : 3.6A)

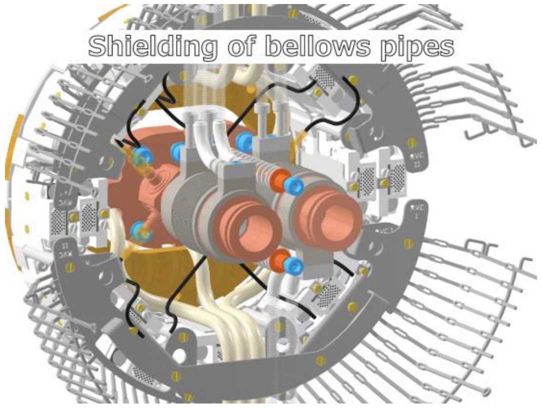
Mitigation idea example: Bellows shielding

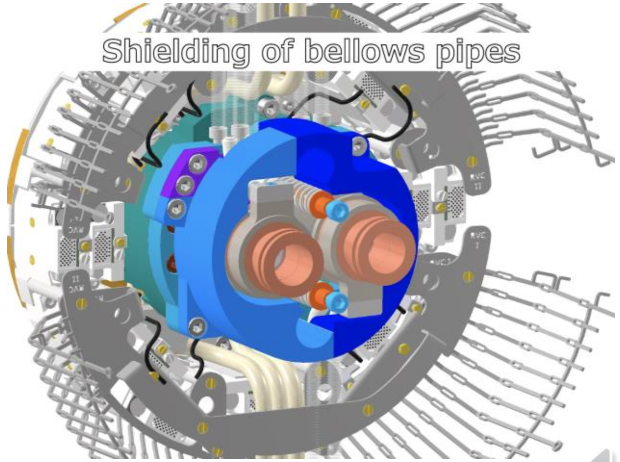
- To reach design luminosity, we need further background mitigation.
- One of ongoing project is to add a shield around bellows pipe btw VXD and QCS, where we see “hot spot” in data (also seen in simulation).
- Remaining space is quite limited there, so mechanical design is challenging.
- Katsuro Nakamura prepared a CAD design of the shield and run beam loss simulation. He estimates LER coulomb bkg can be reduced by 53% (CDC), 28% (TOP)
- Aiming for installation in 2022

Hot Spots around IR from V0 analysis



V0 vertex distribution for Inv-M>550MeV





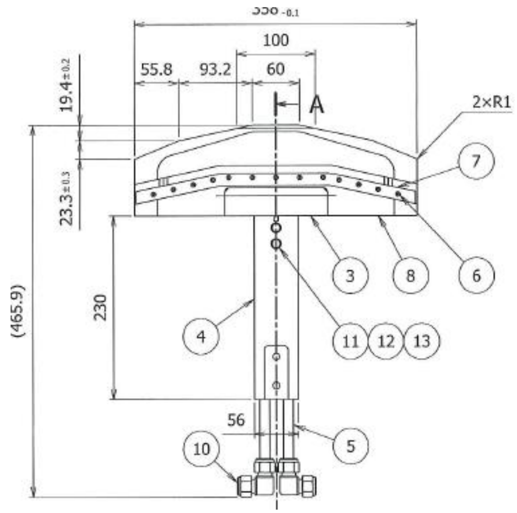
Further background improvements

- Collimator work in mid-September 2020
  - Replace D6V1 with carbon head, install LER D3V1 collimator
  - Simulation study including tip-scattering is ongoing
- Additional shield around QCS bellows (2022)
  - Shown in the previous slide
  - Further BG reduction for TOP/CDC
- QCS modification (2026)
  - Less overlap of solenoid and quads → suppress beam-beam blowup
  - Wider beam pipe aperture→ less BG

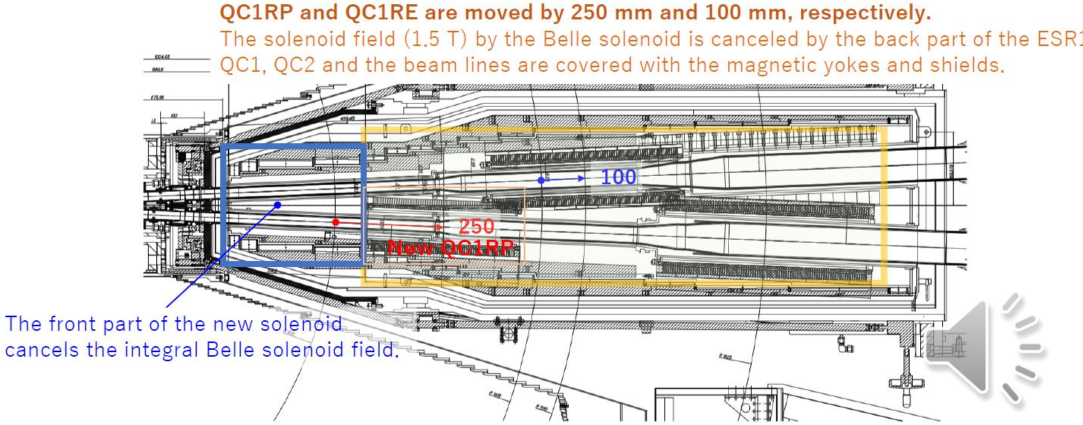
=============

- LINAC work aiming for <u>higher beam currents</u>
  - Stable LER 2-bunch injections
  - Increase injection charge while keeping good emittance
- VXD diamond & beam abort system upgrade
  - Radiation Monitor & Beam Abort (RMBA) task force

Carbon collimator head for D6V1



QCS remodeling

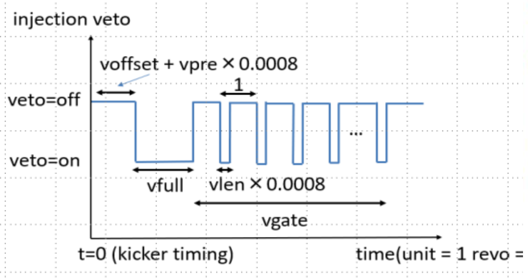


MDI-related issues found in 2020b run

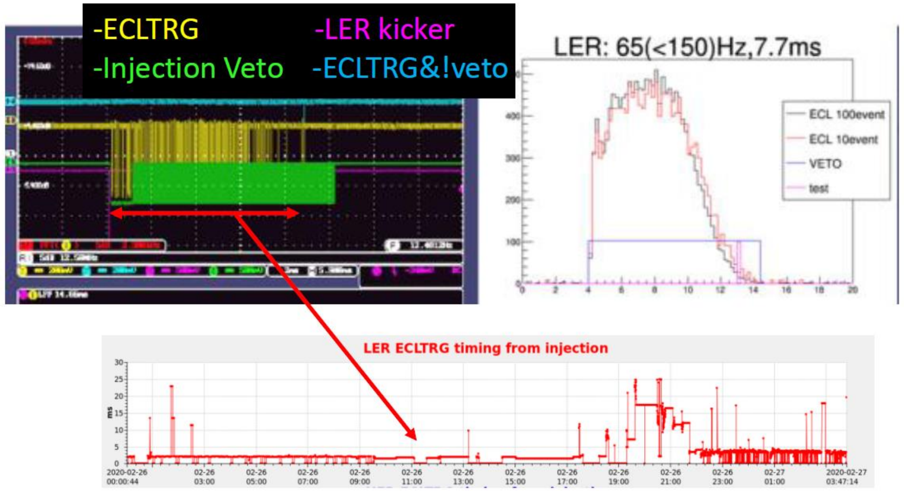
T. Koga

Issues: Injection BG duration

- Injection BG continues after injections
  - We apply trigger veto after each injection
  - Longer veto window
    -> more DAQ deadtime

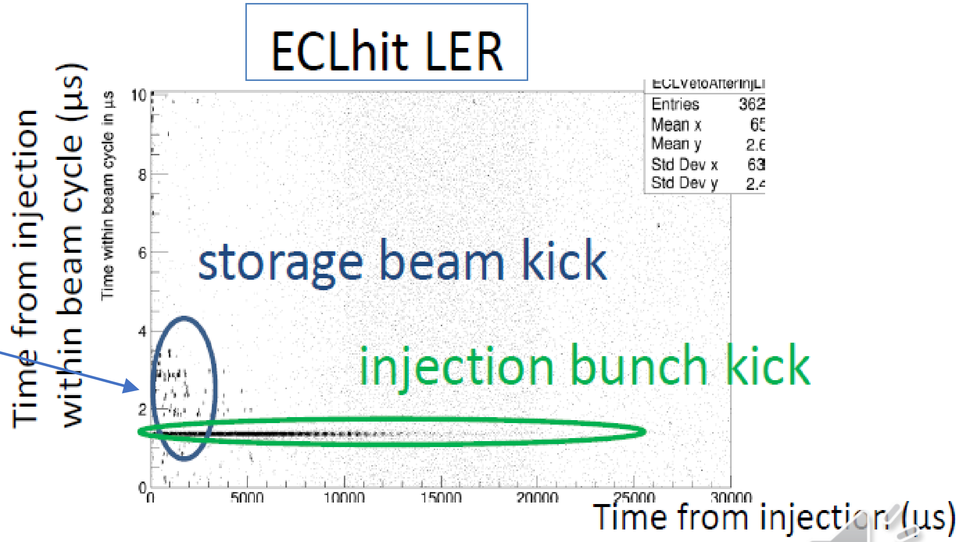


ECLTRG (#cluster>6)



- Typical duration: LER: 6~12ms, HER:1~6ms
  - Single beam: BG duration∝bunch current
  - Colliding beams: BG duration longer than single-beam
  - Crab waist strength: no clear dependence
  - beta*y squeeze: BG duration longer with small beta*y

ECLhit LER



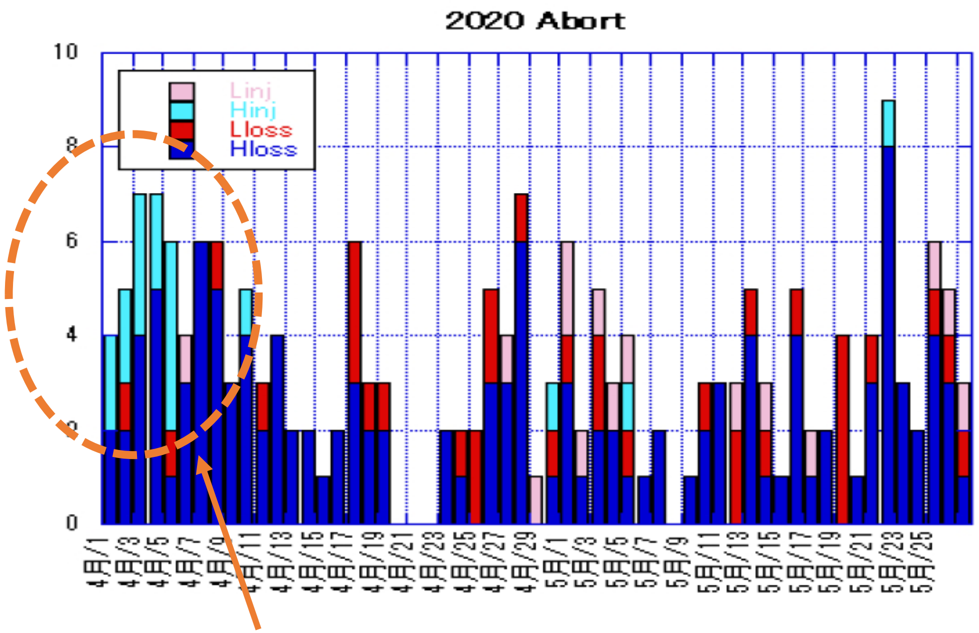
- Dedicated machine study shows:
  - Not only the injected bunch, but also later bunches are lost
  - However, “blank-shot” injections don’t give any BG duration
    → coupling btw an injected bunch and later bunches?

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

H. Ikeda

Issues: Beam aborts

- “Beam abort” taskforce, led by Hitomi Ikeda, to investigate the possible cause of beam aborts and improve integrated luminosity by reducing machine downtime



HER aborts by bad injections have disappeared since Apr. 9th

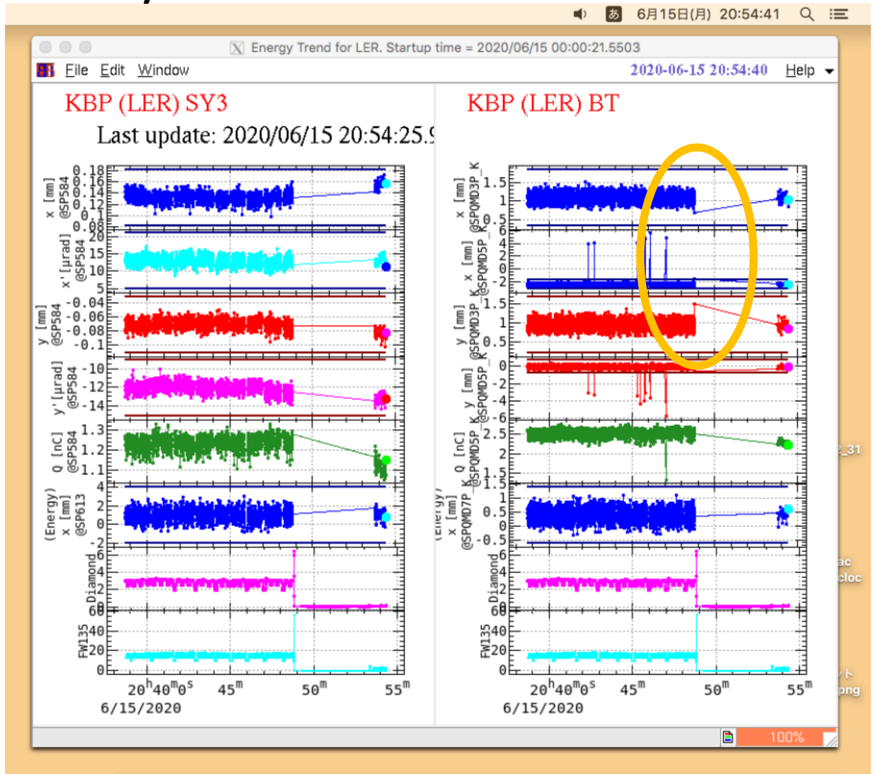
- Beam aborts in-sync with injection has significantly decreased thanks to LINAC group’s effort
- HER beam loss aborts not-in-sync with injections are dominant now.
  - No clear correlation with injection timing
    → Not caused by “delayed” injection losses
  - Small vacuum bursts? Or any unknown causes?

Improvements: LINAC/BT monitoring

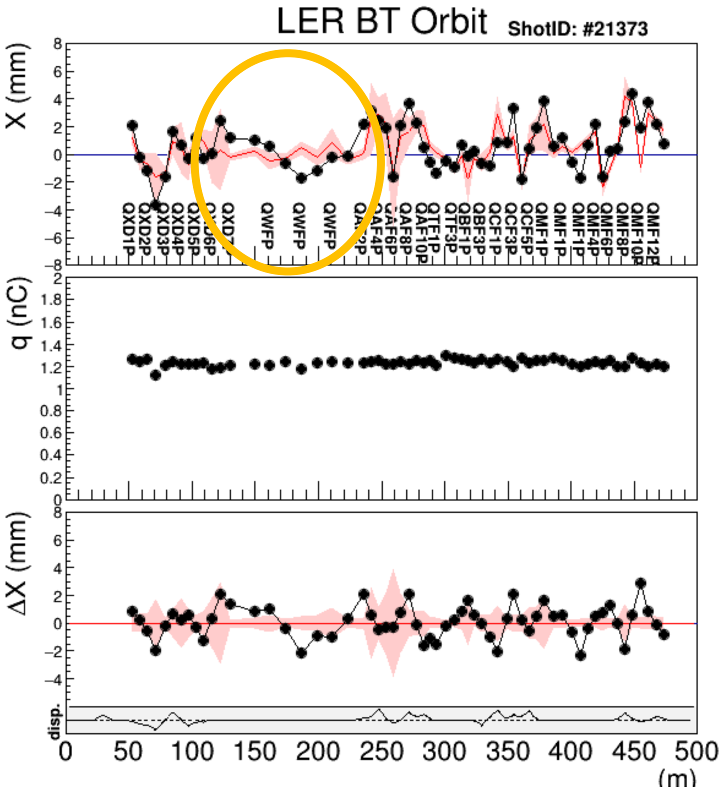
Miyahara,Mori,
Seimiya, Kaji,
etc..

LINAC/BT orbit trend

2020/06/15 20:48
Diamond abort
Pulse Magnet failure
(PC_6,181)



BT orbit web



These new monitors allows us to easiy detect injector problems when bad injections happens. → Effectively worked to reduce injection-related beam aborts

Weekly beam abort counts

Nakayama

HER aborts in-sync with injections due to LINAC pulse magnet misfires (till April 9th)

LER aborts in-sync with injection due to LINAC Klystron down or other unknown reasons

List of beam aborts @ large currents (both beams >60mA)

	HER loss no inj.	HER loss inj.	LER loss no inj.	LER loss inj.	RF	CCG	EQ	Others	Total	
4/1~7	26	7	3	0	0	3	0	1	40	
4/8~15	19	0	3	0	0	0	0	3	25	
4/16~23	9	0	3	0	0	2	1	2	17	
4/24-30	13	0	8	1	8	0	6	3	39	4/24~ HER CW start
5/1-7	12	0	3	5	3	2	5	1	31	
5/8-14	11	0	5	2	0	2	1	0	21	5/11~14 off resonance
5/15-20	8	0	7	0	1	1	2	1	20	5/14~31 HER angle
5/21-27	18	0	5	2	1	0	0	6	32	5/21~ LER high εx
5/28-6/3	10	0	5	1	0	7	0	1	24	
6/4-11	9	0	8	0	0	0	1	2	20	6/11 D6V2 open
6/12-17	10	0	15	8	0	2	2	2	39	6/10~16 off resonance

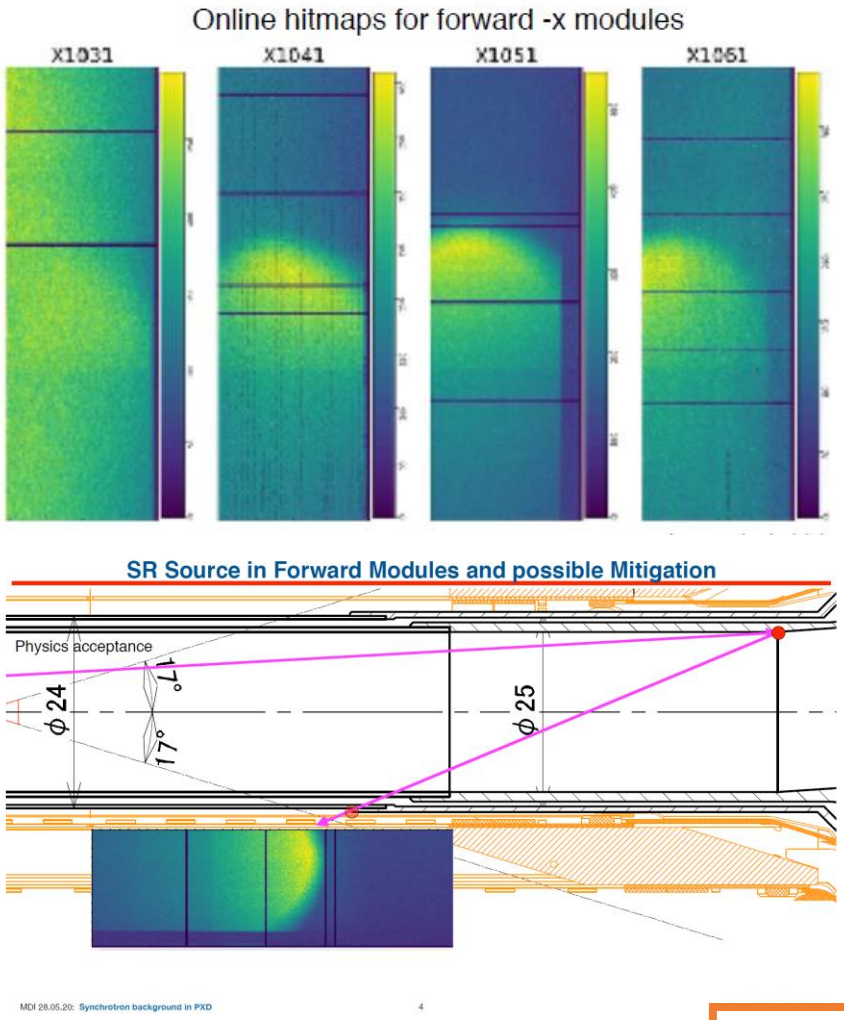
What is the cause of those HER aborts **not** in-sync with injections?

Due to higher beam currents? or D6V2 open on 6/11?

LINAC pulse magnet misfires appeared again (June 11-)

Carsten

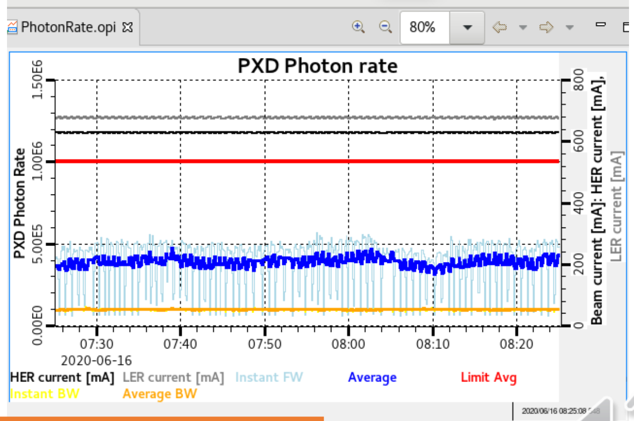
Issues: PXD SR during HER injection



- SR hit pattern on PXD forward –X modules
- Becomes stronger when HER beta*_x was squeezed
- Only visible during HER injections
  - SR 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
- SR increased with the smaller HER IR orbit horitontal angle (May 15-31), so we went back to the original angle

- SR rate PV is now available.
- BCG/PXD experts monitors it.



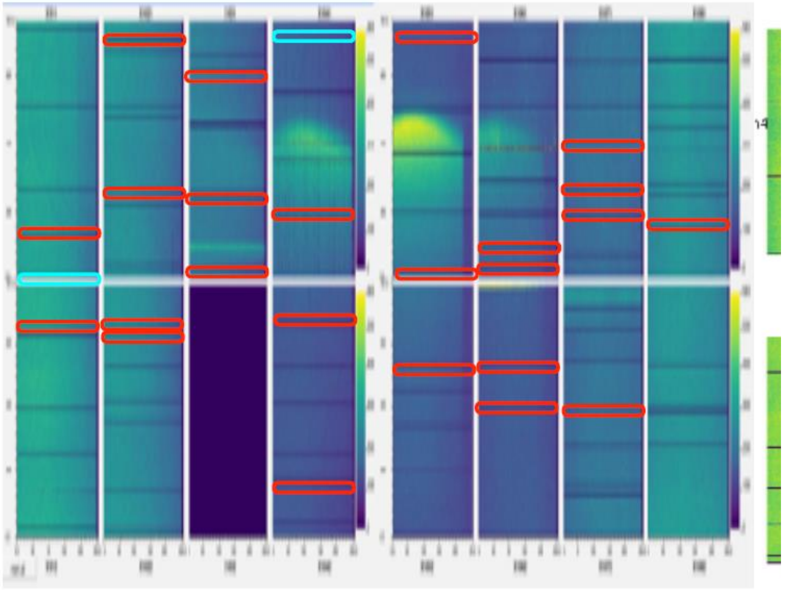
PXD SR is not critical right now, but we need to keep our eyes on it.

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. Diamond abort was not issued.
- It resulted in QCS quench and damage on PXD/diamond readout.

PXD after QCS quench in May 27th



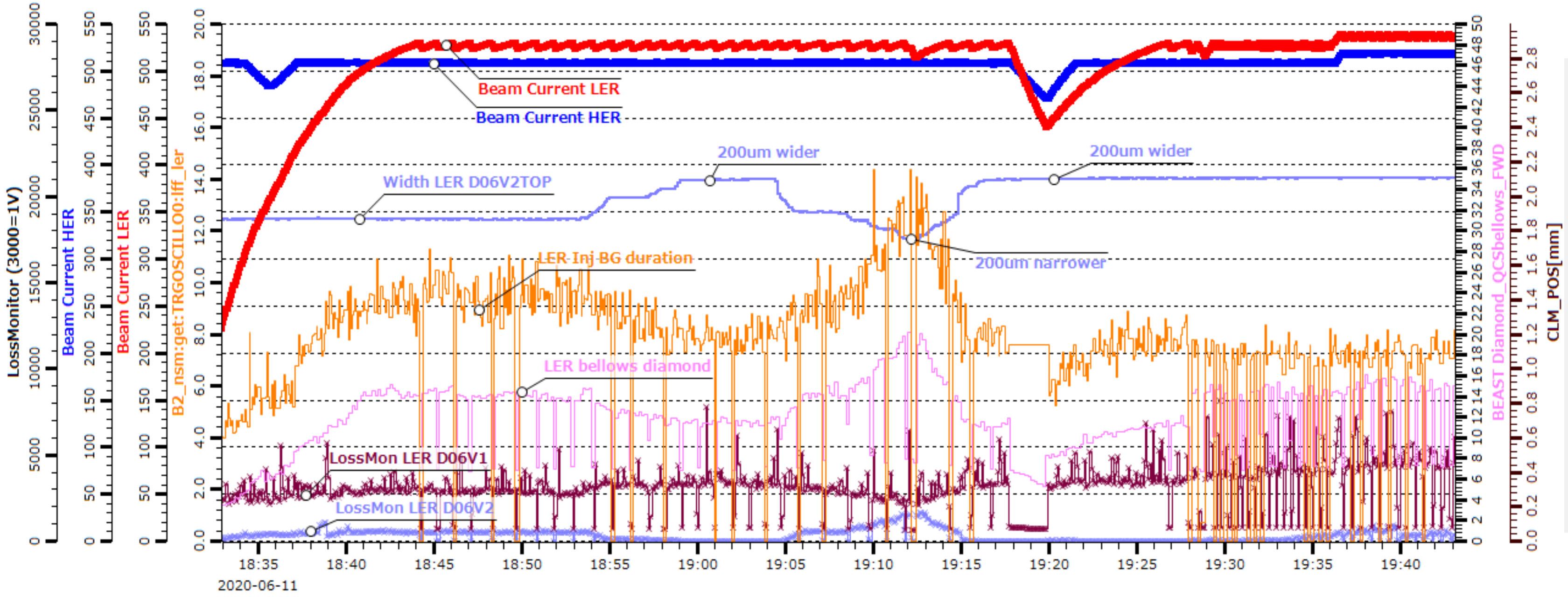
New inefficient gates after QCS quench

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.

Why?

- Tip-scattering of injection charge? → seems unlikely to reach IR from D6 or affect BG duration.
- We start to see collimator impedance issue ?

Summary

- Beam backgrounds in 2020ab is significantly improved than 2019c
  - New LER V collimator, tighter collimators (thanks to stable injection), and vacuum scrubbing progress
  - Enables us to go higher beam currents and achieve peak luminosity record
  - Stable injections lead to less beam aborts/CDC HV trips → less downtime, more integrated luminosity
- For the first time, data and MC agree within one order of magnitude
  - Simulation now handles true SuperKEKB collimator shapes and tip-scattering
  - The longstanding HER simulation problem has been resolved
  - Luminosity background in PXD, TOP agrees well with simulation (~10% level)
  - ~25% accuracy for single beam background, ~5% for luminosity is our goal
- To reach design luminosity with acceptable background, further background mitigation is needed.
  - More LER collimators, bellows shield, QCS modification, etc..
- For more integrated luminosity and stable operation in 2020c and future runs, we need to
  - Achieve stable LER 2-bunch injection and larger injection charges with good emittance
  - Minimize injection BG duration to reduce DAQ deadtime
  - Understand the cause of beam aborts (not related to injections)
  - Control SR background on PXD
  - etc…

backup

KEKB review report 2019

3. Belle II status

The Belle II detector collaboration has worked very hard to get the detector ready for data taking. Over the last summer and fall the temporary detectors (Beast 2) have been removed from the central region. The SVD and part of the PXD have been installed and are now working. Only one of two layers of the PXD was ready at this time. Several problems in various subsystems were uncovered during the Phase 2 running and these have been addressed with a much more robust and improved efficiency for the overall performance. There is still much to do and more data will help to shake down the detector into a high performance mode.

The backgrounds in the detector are still higher than expected and at the highest currents and highest luminosity the backgrounds were too high by about a factor of 3 for the detector to take data. It should be noted that the high luminosity reached near the end of the run was with a collimator-setting configuration not optimized for minimizing the backgrounds.

In addition, part of the PXD has been damaged by a very short, sharp radiation burst which also quenched the QCS magnets. These events are so fast that the current abort system is unable to dump the beam in time to prevent either QCS quenches or high radiation bursts going into the detector. The high background levels and the possibility of these intense radiation bursts have made it more difficult to make progress toward improving the accelerator

Frequent injection background bursts, that are not catastrophic, but trip the CDC and make large backgrounds in the outer detector (TOP, ECL), seem to be due to "rogue pulses" in the linac/BT. These injection background bursts are limiting the present Belle II operation to a greater extent than the steady state (DC) backgrounds, which are mostly from LER beam gas scattering.

Recommendations:

R3.1: Continue to maintain close relations with the accelerator team. We strongly encourage the continuation of a background liaison shifter in the control room.

R3.2: Assist the accelerator team in looking for ways of either creating an earlier signal to abort the beam and in coming up with a collimator configuration that can protect the detector and QCS magnets.

R3.3: The accelerator team should closely cooperate with Belle II to develop countermeasures against injection background bursts (e.g. additional BT collimators, injection phase control, energy feedback, optics and orbit stabilization, etc.).

CDC trips are much less frequent in 2020 thanks to stable injections and higher CDC trip threshold.

Unfortunately, from 2020b, we had to move the BCG shifter booth to another building amid this COVID-19 situation. However, communication between machine operators and BCG was basically smooth.

Belle II diamond abort cycle in 2020 runs is 2.5 us, faster than 2019(10us). It can detect a surge in dose and issue a beam abort faster.

Details in Iida-san's report. We made a significant progress in 2020 runs.

SuperKEKB collimators

Andrii Natochii

Collimation system

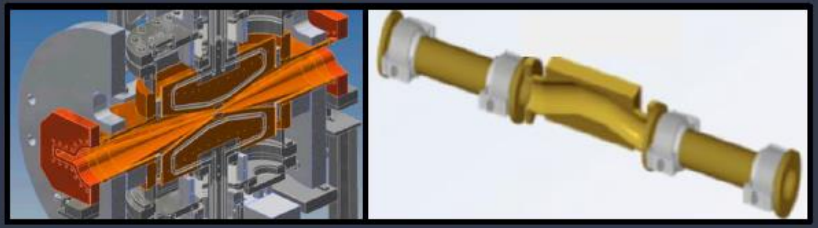
LER » 10 collimators:

- 7 horizontal: D06{H1,H3}, D03H1, D02H1, D02{H2,H3,H4} — *Two-sides*
- 3 vertical: D06{V1,V2}, D02V1 — *Two-sides*

HER » 20 collimators:

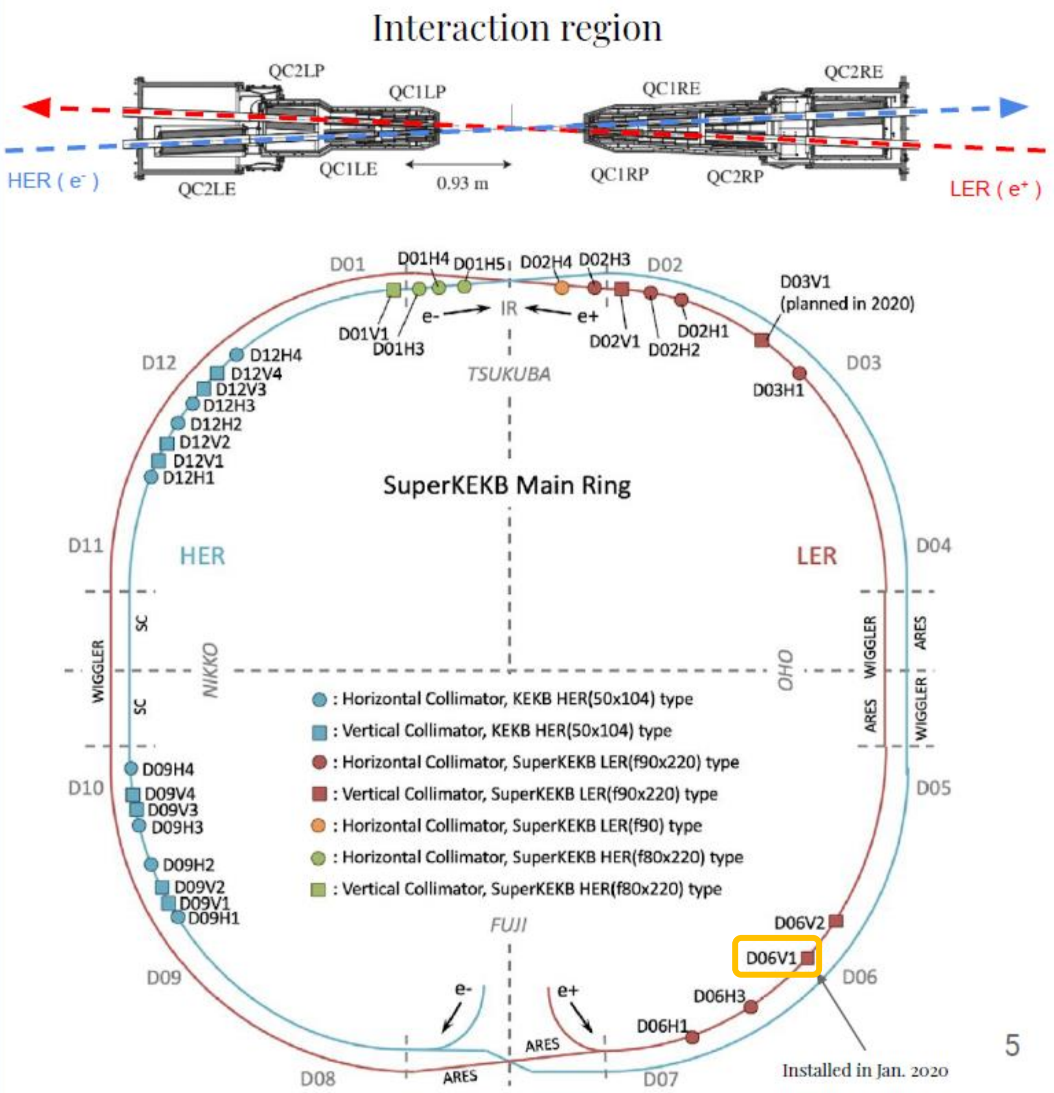
- 11 horizontal: D01{H3,H4, H5} — *Two-sides*; D12{H1,H2,H3,H4}, D09{H1,H2,H3,H4} — *One-side*
- 9 vertical: D01V1 — *Two-sides*; D12{V1,V2,V3,V4}, D09{V1,V2,V3,V4} — *One-side*

Have to be optimized to mitigate beam-induced BG



Two-sides collimator ***SuperKEKB**-type*

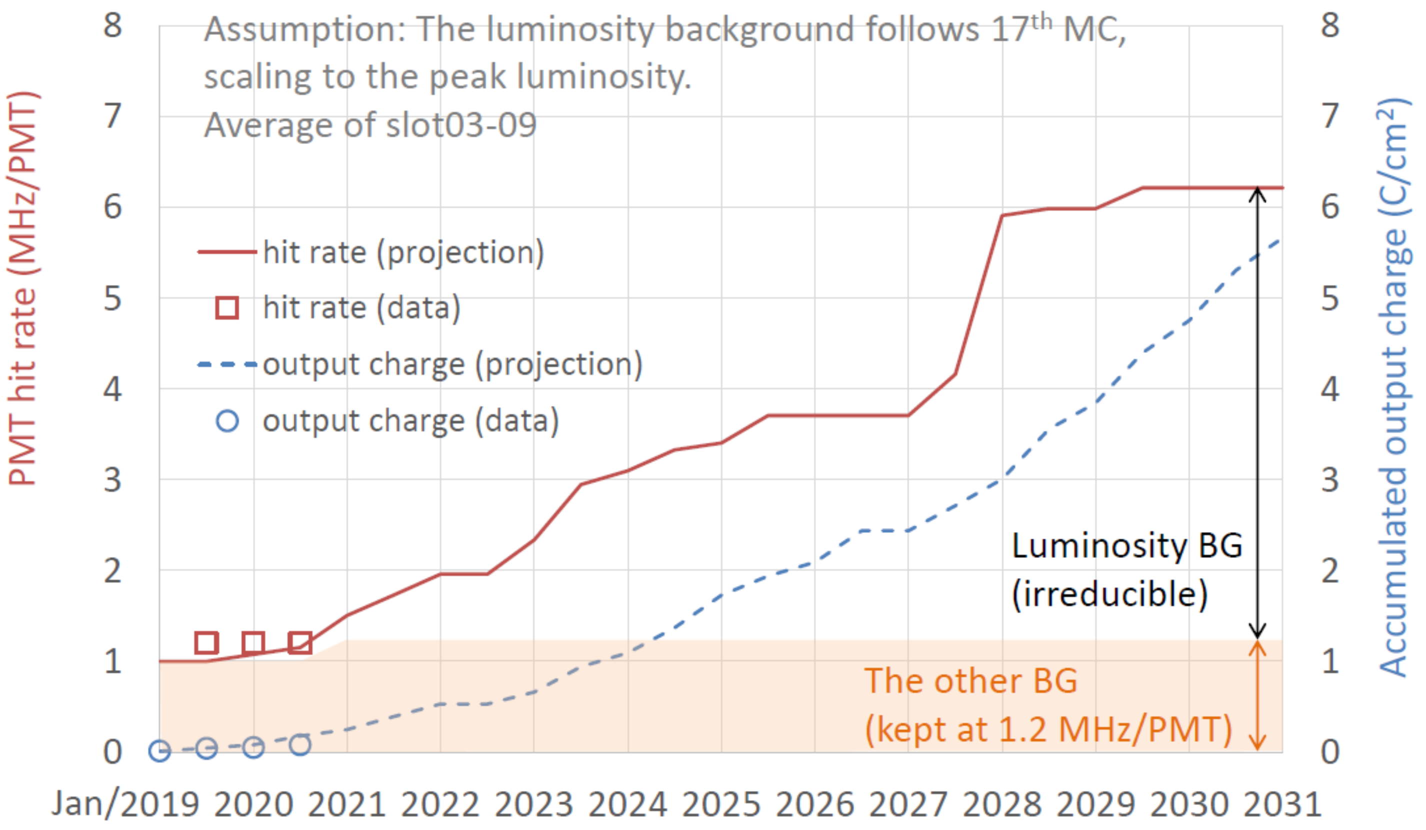
One-side collimator ***KEKB**-type*



5

Projection of TOP PMT hit rate and charge

Based on the updated luminosity projection (MEXT roadmap 2020)



Single-beam BG study

for measuring Touschek and Beam-gas component separately

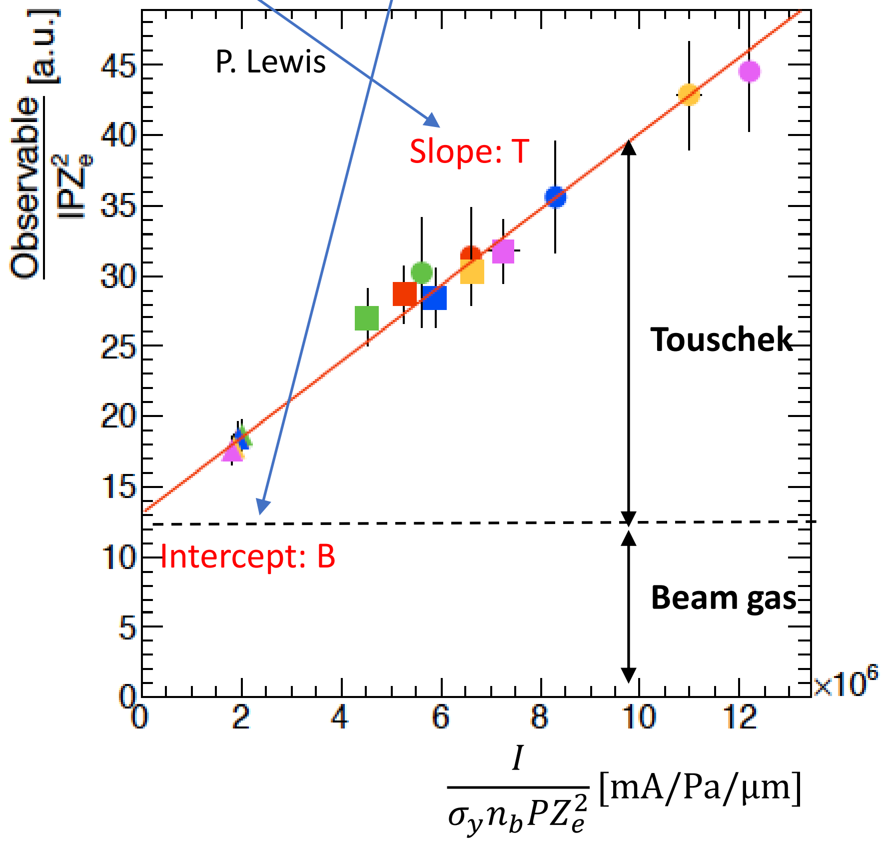
$$Rate = T\frac{I^2}{\sigma_y n_b} + BZ_e^2 IP \longrightarrow Rate/Z_e^2 IP = T\frac{I}{\sigma_y n_b P Z_e^2} + B$$

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

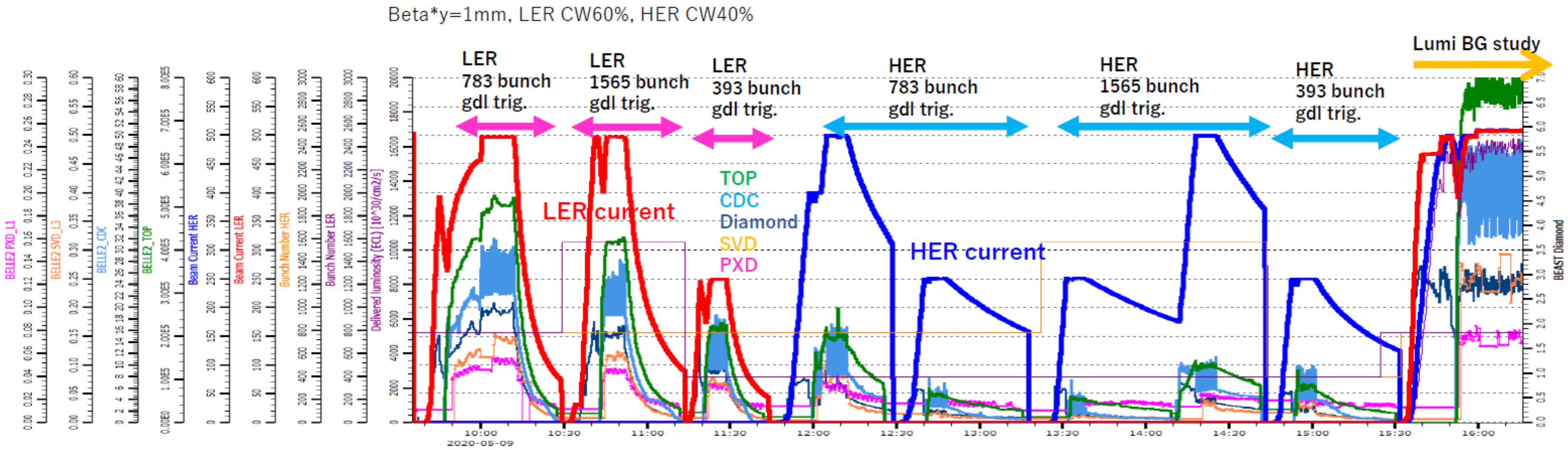
Strategy:

- **Single-beam**
- **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**



A snapshot from a single-beam BG study

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

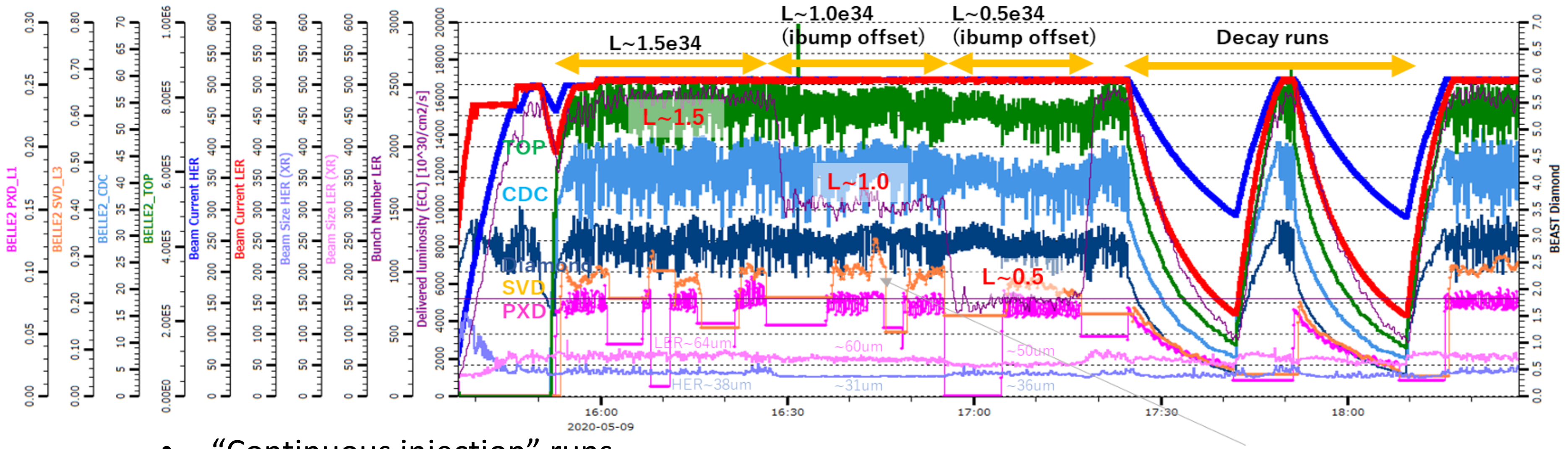


- Number of bunches: Nb=783/1565/393.
- As we increase number of bunches, Belle II BG rates at the same beam current becomes smaller (due to decrease in Touschek BG)
- Beam size scan is not used recently, since unexpected BG increase was observed at larger beam size.

- <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

Beta*y=1mm, LER CW60%, HER CW40%



- "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 BG measurement and analysis

$$R^{\mathrm{Data}} = T\cdot\frac{I^2}{n_b\sigma_y} + B\cdot PI + C \qquad P = P_0 + kI$$

$$= T\cdot\frac{I^2}{n_b\sigma_y} + P_0B\cdot I + kB\cdot I^2 + C$$

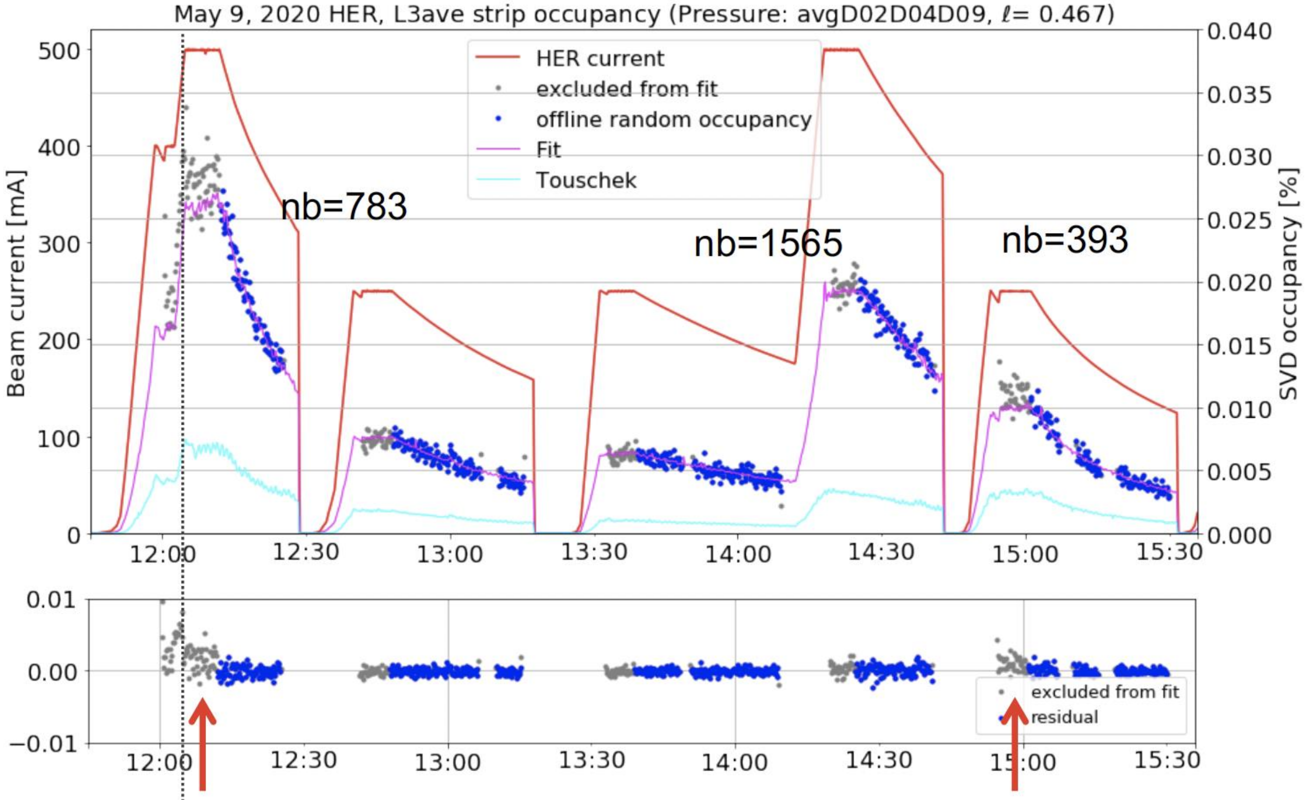
base-pressure component

dynamic-pressure component

- To reduce systematics from different pressure conditions during continuous injection, perform more extensive beam studies
  - Single beams, cont. injection
  - Single beam, decaying
  - Colliding beams w/ continuous injection
  - Colling beam, decaying
- We use three fill-patterns to vary Touschek bkg, rather than emittance control knob
- We now account static and dynamic pressure separately in fit
- Tanigawa San (SVD) found that bunch-length correction can improve background even model further→fit model matches all data at 0.5% level

$$O(I,\sigma_y,n_b,P_{meas}) = T\cdot\frac{I^2}{\sigma_y n_b(1+\ell I_b)} + B_2\cdot P_{meas}I - B_3\cdot I$$

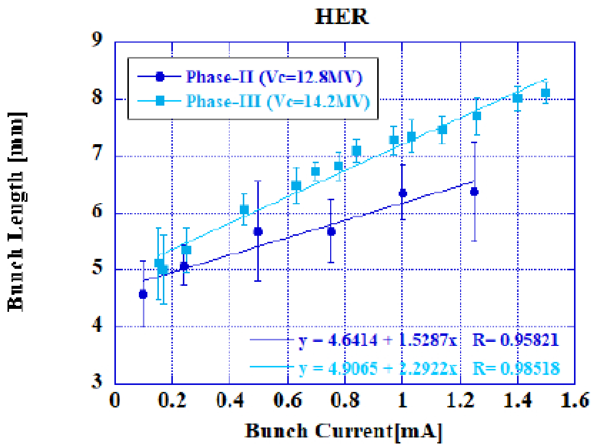
- bunch lengthening, measured pressure
- P_{meas} = avg of D02, 04, 09 sectional pressures



Bunch lengthening correction

Bunch length increases with bunch current.

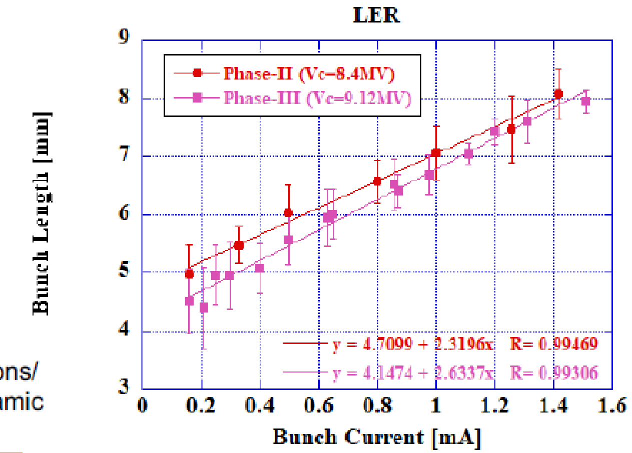
- $\sigma_z = \sigma^0{}_z + \frac{d\sigma_z}{dI_b} I_b = \sigma^0{}_z (1 + \ell I_b)$
- We reached Ib > 0.6mA on May 9th.
  -> Bunch length might have been changing by **20-30%** during the scan.
- less beam density should reduce Touschek effect



Consider this in the Touschek model.

$$\mathcal{O}(I, \sigma_y, n_b, P_{meas}) = T \cdot \frac{I^2}{\sigma_y n_b (1+\ell I_b)} + B_2 \cdot P_{meas} I - B_3 \cdot I$$

- bunch length correction factor ℓ is determined by an independent measurement.
- No degree of freedom is added for the new parametrization.
- $\ell = 0.635(LER), 0.467(HER)$
- (Should confirm if the measurement is appropriate for this analysis.)



https://kds.kek.jp/indico/event/31793/contributions/119373/attachments/93152/110877/BeamDynamicsOverviewStrategy2019_07_17.pdf

Data/MC agreement: full tables

SVD

Data/MC of SVD L3 strip occupancy
(Pressure reweighted MC)

Date →		Dec 7	Apr 1	May 9
LER Beam-gas	base	5.2	4.9	10
	dynamic	1.5	1.3	3.4
	total*	1.9	1.8	4.4
LER Touschek		1.0	1.2	1.9
HER Beam-gas	base	12	20	11
	dynamic	4.3	6.2	15
	total*	6.2	9.4	15
HER Touschek		150	490	130

*I = 0.4 A for Dec & Apr, 0.5 A for May
Fit model
- Dec, Apr: w/o measured pressure
- May: w/ measured pressure, bunch lengthening

2020/6/22 HIKARU TANIGAWA 8

Data/MC of SVD L3 strip occupancy
(Pressure reweighted MC,
real shape + tip scattering for SKB collimators)

Date →		May 9
LER Beam-gas	base	11
	dynamic	3.5
	total*	4.6
LER Touschek		2.0
HER Beam-gas	base	3.4
	dynamic	6.3
	total*	5.5
HER Touschek		0.24

CDC

May 9th, Data/MC

(a): re-weighted gas pressure
(b): re-weighted gas pressure + real collimator shape
(c): re-weighted gas pressure + real collimator shape + tip-scattering

		MC (a)	MC (b)	MC (c)
HER	T	×30-80	×0.2-0.4	×0.6-1.2
	P0B	×30-130	×2-8	×6-22
	kB	×20-50	×1.5-4	×4-12
LER	T	×1.5-4.5	×2-4.5	×1.5-4
	P0B	×10-23	×10-23	×10-23
	kB	×2-5.5	×2-5.5	×2-5.5

update of the collimator shape improve the HER Data/MC agreement
tip-scattering improve the HER Touschek, but not Beam-gas

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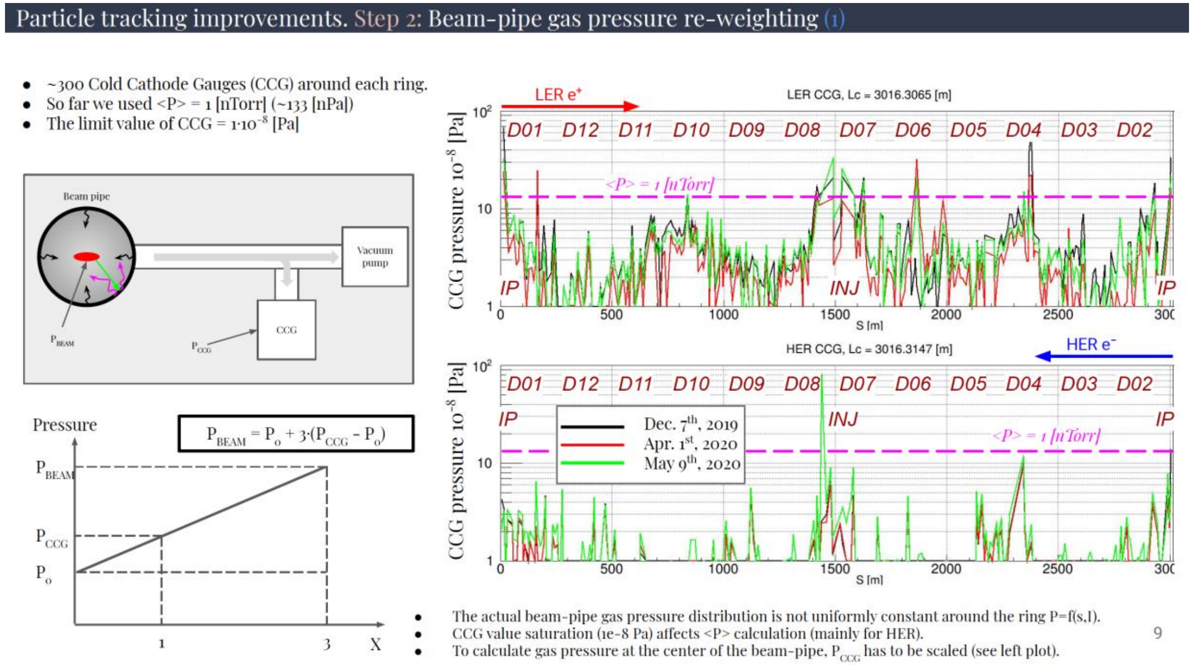
Recent improvements to simulation

- Andrii Natochii implemented an improved framework for beam-particle tracking in SuperKEKB: SAD+G4+C++ → SAD++
- This allows applying collimation after particle tracking, custom beam pipe aperture shapes, and more
- This and related work has led to multiple crucial simulation improvements
  - More CPU-efficient collimation system optimization
  - Re-weighting of beam-gas background with position-dependent (CCG) pressure measurement → improved LER beam-gas simulation
  - IR beam-pipe aperture correction
  - **Realistic collimator mask profile** → improved HER simulation
  - **Collimator tip-scattering** → improved HER simulation



Luminosity background

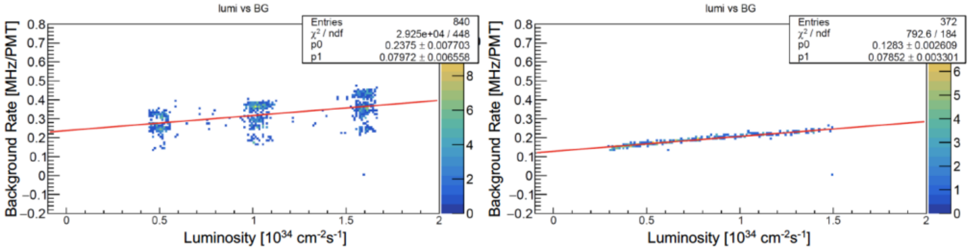
- Measured lumin. bkg agrees with simulation at the few-% level in TOP, PXD
- Agrees between continuous injection and decay data
- Highly encouraging!
- However, SVD, which has the most detailed bkg model, sees a problem. More work needed.

Luminosity and Injection Background Fit

Fitting linear functions of luminosity to the luminosity BG study data both with and without injection.

$$BG_{\text{decay}} = p_0^{\text{decay}} + p_1^{\text{decay}} \cdot L$$

■ Continuous injection ■ Decay beam

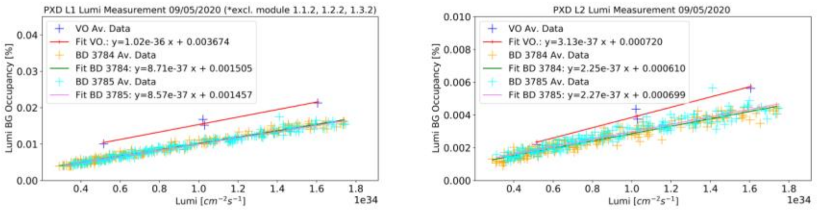


Luminosity measurement 09.05.2020

- **Very good agreement** between simulation and measurement for both L1 and L2 in beam decay runs

Layer	MC $@\mathcal{L} = 8 \times 10^{35}$ $cm^{-2}s^{-1}$	MC $@\mathcal{L} = 1 \times 10^{34}$ $cm^{-2}s^{-1}$	Meas. 3784 $@\mathcal{L} = 1 \times 10^{34}$ $cm^{-2}s^{-1}$	Meas. 3785 $@\mathcal{L} = 1 \times 10^{34}$ $cm^{-2}s^{-1}$
L1	0.89%	0.011%	**0.0102%**	**0.0100%**
L2	0.25%	0.0031%	**0.0028%**	**0.0029%**

- Difference between vertical offset scans and beam decay scans is present (needs detailed investigation, SR in HER accounted for in different way compared to Dec 2019)
- L2 does not exhibit the same difference



Neutrons

- In KLM, data/MC agreement is still quite poor.
- My suspicion is that this is due to cavern neutrons, which are not yet simulated
- Such neutrons may be delayed w.r.t. accelerator parameters when they reach KLM, hence also defy our usual analysis procedure
- We are now starting a neutron-campaign to accurately measure and simulate this component

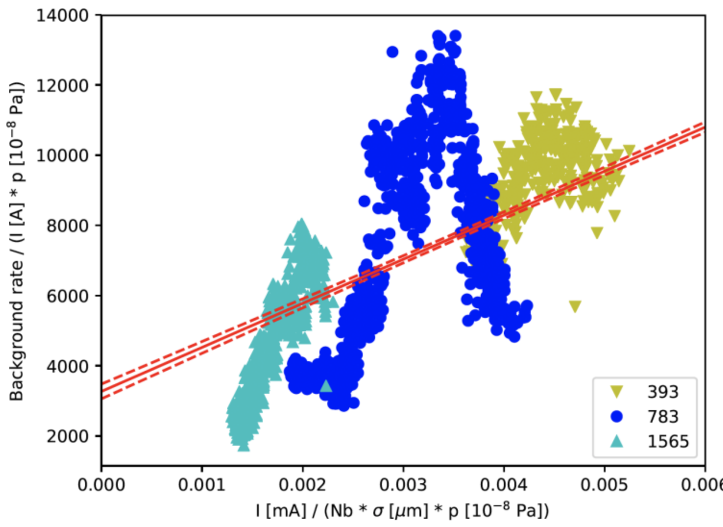
Data / MC ratios

HER		Touschek	Beam Gas
BWD	inner-most layer	11	-
	middle layer	-	-
	outer-most layer	2300	7500
FWD	inner-most layer	4.4	388
	middle layer	-	-
	outer-most layer	9.5	-

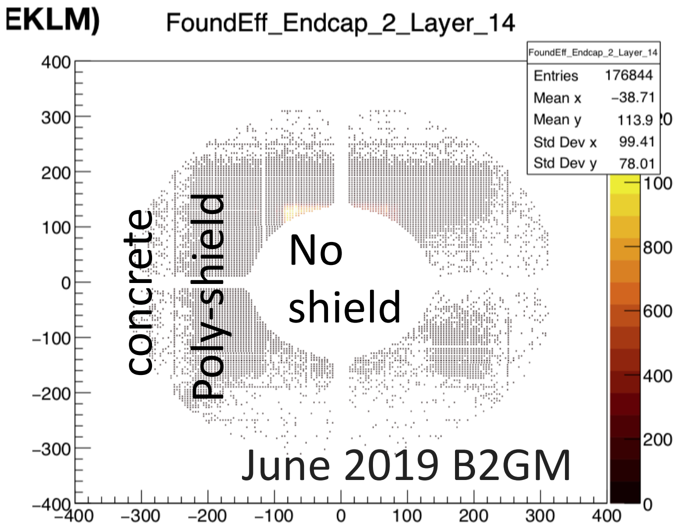
LER		Touschek	Beam Gas
BWD	inner-most layer	125	428
	middle layer	-	989
	outer-most layer	205	1813
FWD	inner-most layer	289	416
	middle layer	6800	5900
	outer-most layer	-	-

- all ratios large or extremely large
- increased background rate in MC for new setting goes in right direction
- uncertainties large

LER FWD outer-most layer



Origin of cavern neutrons? TPCs and He-3



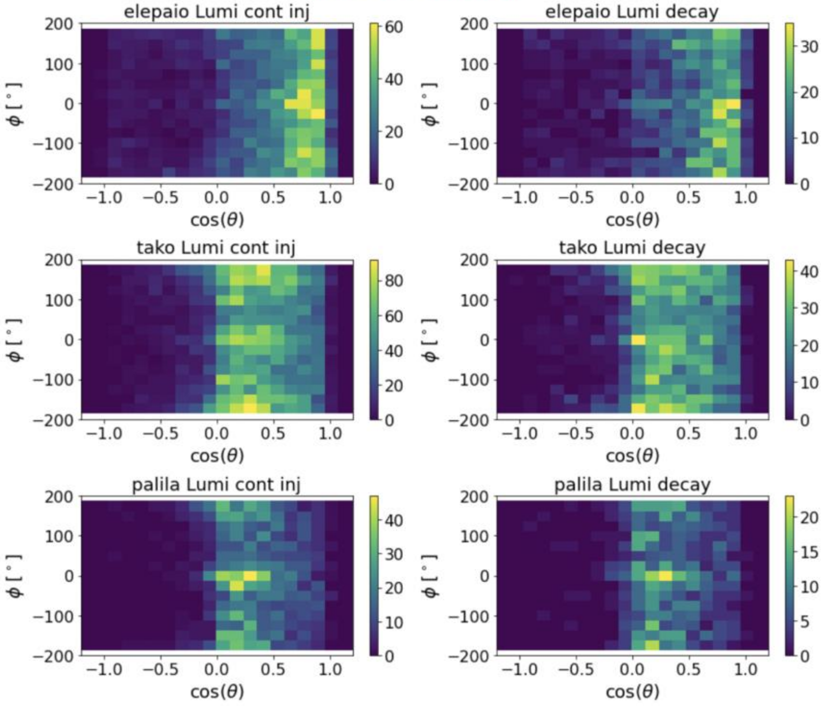
FWD

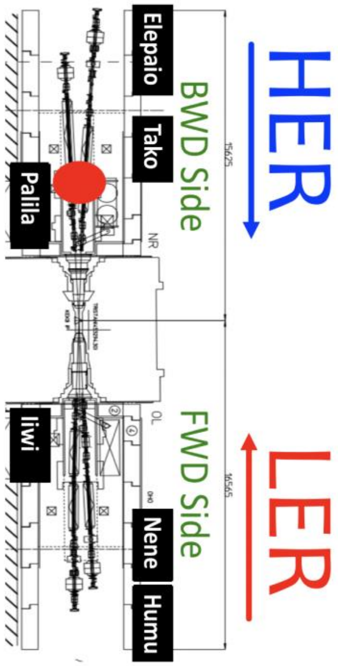
BWD

Schueler

Black rectangles: positions of TPC directional neutron detectors

Preliminary





TPC analysis by Schueler is measuring neutron (recoil) energy spectra and directional distribution (identifying hot spots). Miller has moved spare He-3 tube far into tunnel for more information. Cavern neutron BKG component is not included in the simulation. New simulation effort started (Natochii, Liventsev). Liventsev has already updated geometry.

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 t D6V1

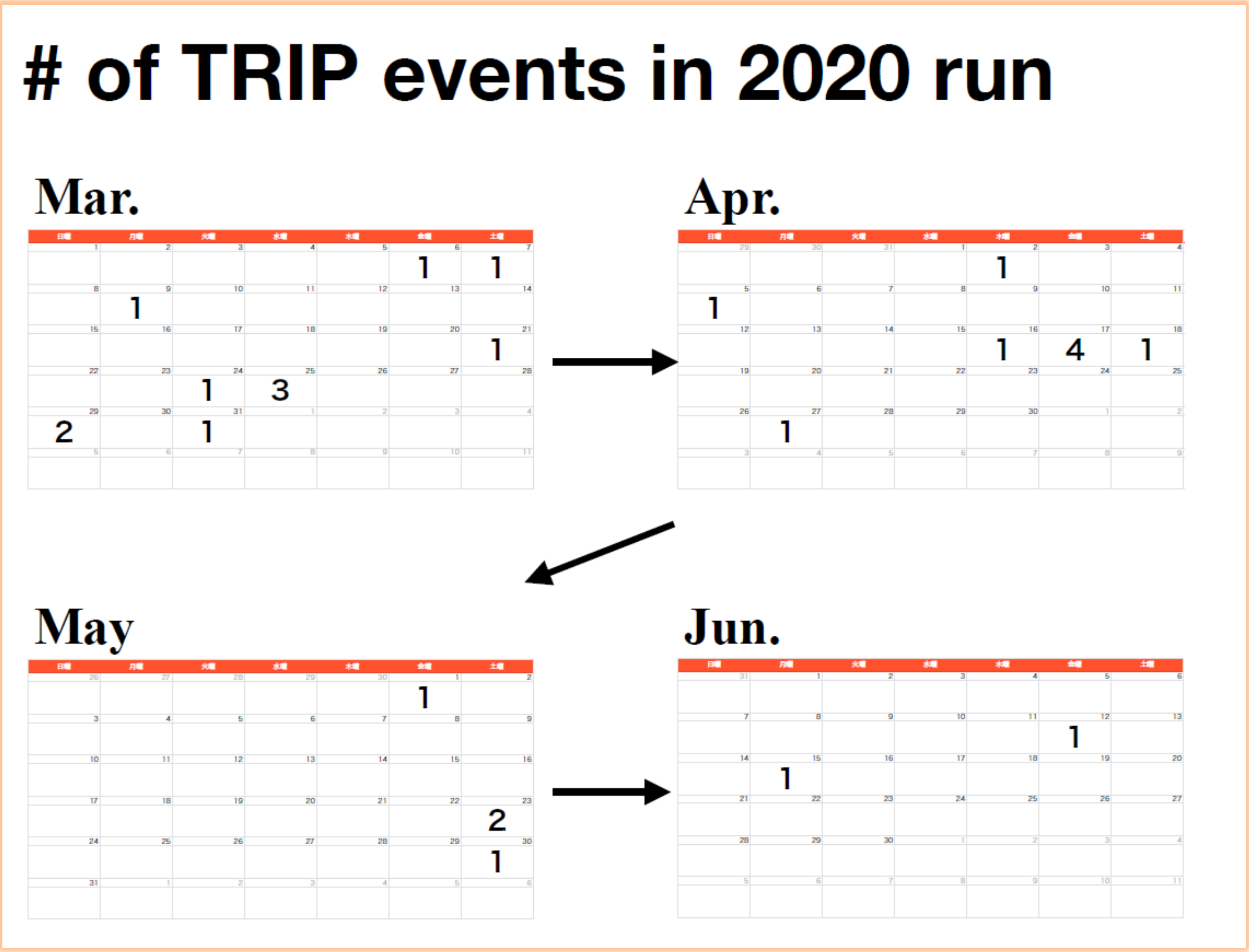
	DIF_POS [mm]	beta_y [m]	nu_y	Nsigma (beta)	LM
D06V1TOP	2.60	67.3	28.85	69.3	0.07
D06V1BTM	-2.61	67.3	28.85	69.6	
	0.33				
D06V2TOP	1.79	20.6	30.49	85.8	1.28
D06V2BTM	-1.83	20.6	30.49	88.2	1.35
	0.19				
D02V1TOP	1.32	13.9	44.86	77.1	0.00
D02V1BTM	-1.33	13.9	44.86	77.7	
	0.17				
QC1 (1.12m)	13.5	782.2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

BPAC reviewer's comments in 2020 Feb

3.3 Recommendations

- The committee strongly encourages close collaboration with the accelerator team to study the 'bad' injection bunches. The ability of the detector to identify exactly which injected bunch causes high backgrounds should greatly help in the effort to improve this issue.
- The committee encourages further efforts to make the beam abort as fast as possible. This includes placing "bad beam" sensors near the abort system as well as decreasing further the response time of the current beam monitors or deploying other abort signals.
- The plan to implement the crab-waist in the next run, first in the LER then possibly in the HER later, seems very attractive to suppress the beam blowup both for the core and the tail of the beam. Simulations indicate positive effects, at least for the $\beta_y^* = 1$ mm configuration, in producing a higher luminosity and a smaller beam tail from the beam-beam interactions. The committee encourages the use of the crab waist scheme as the main strategy for an intermediate luminosity step up to around 10^{35} cm^{-2}s^{-1}.
- Establish a clear collimator strategy, such as in the LHC, by defining the role of each collimator. The D06 vertical collimators may work as the primary collimators if the phases between them are chosen properly. Then it is not clear if the D02 collimator still works as a secondary collimator. Perhaps the collimator optimisation code can shed light on this issue.
- The committee also encourages further studies of collimators using a low-Z material for the tip. This type of collimator could perhaps also be connected to the fast beam-abort signal.
- The committee was very pleased to hear that a background signal that looks to be luminosity related has been found and encourages further effort to dig this signal out of the general background information. This is the first time the background team has uncovered a signal that appears to be correlated to the luminosity. If the signal is coming from radiative Bhabha scatterings, as is expected, then they should try to benchmark this signal against expected background levels in various detector sub-systems using the current performance level of the accelerator.

We prepared a scheme to obtain the "shotID" of bad injection causing beam abort, using the abort timestamp. It makes the injector diagnosis much easier.

We implement faster Diamond abort cycle 2.5 us in 2020 a+b (10 us before) ensuring safer operation. We also plan to send beam aborts using the plastic scintillators installed on the surface of QCS cryostat (see CLAWS++ report in MDI session). Preliminary study indicates the possibility to send aborts earlier than diamonds.

LER crab waist strength is now LER 80% and HER 40%. It seems crab waist well suppresses beam-beam blowup, and we reach higher bunch current.

We added D6V1 in LER and use it as a "primary" (=narrowest) vertical collimator, to protect D2V1 near IP, which was damaged in the past.

To ease a load on D6V1, we will replace with Carbon-type head during the 2020 summer shutdown.

The luminosity BG study on May 9th was conducted at a high luminosity (L~1.5e34) and matches simulation very well. We will repeat the studies at higher luminosities.