Collimators and TMCI

15th annual Belle PAC Review meeting

Machine, MDI, Beam background, Operation plan

T. Ishibashi

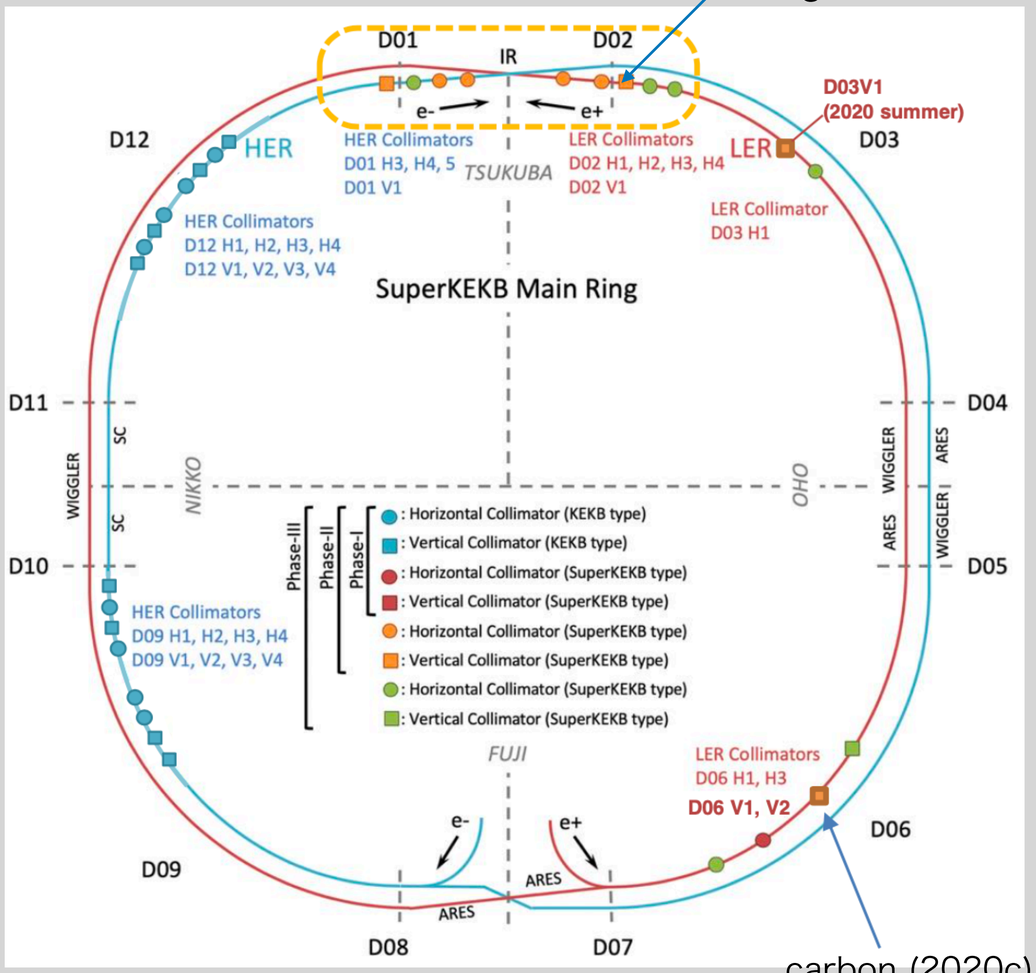
Table of Contents

Introduction: Beam collimators in SuperKEKB main ring

- LER: 4 vertical（D06V1, D06V2, D03V1, D02V1） and 7 horizontal（D06H1, D06H3, D03H1, D02H1, D02H2-H4）
- HER: 9 vertical（D01V1, D12V1-V4, D09V1-V4） and 11 horizontal（D01H3-H5, D12H1-H4, D09H1-H4）

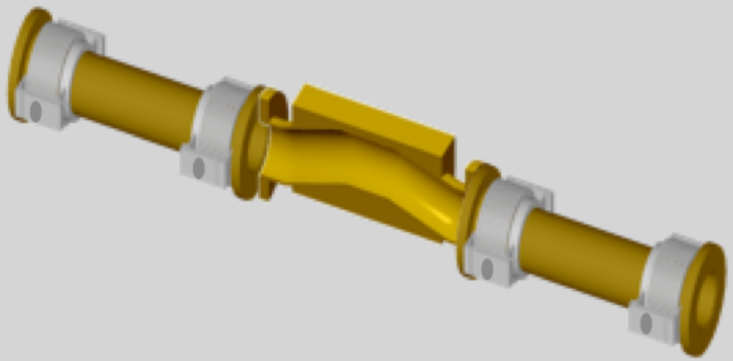
blue：SuperKEKB type
red：KEKB type

damage and vacuum leak (2020c)



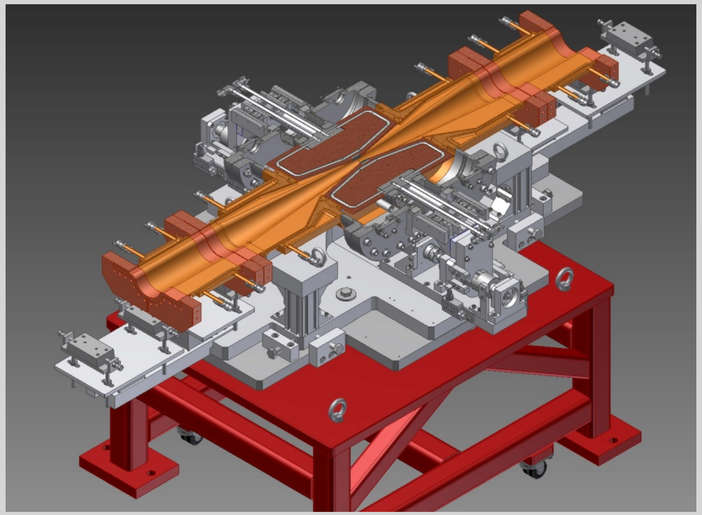
carbon (2020c)
tantalum (2021ab)

- Featured collimators in 2020c
  - D06V1：carbon jaws (installed during 2020 summer shutdown)
  - D02V1：damaged and replacement work during 2020c. vacuum leak.
  - D03V1：new collimator (installed during 2020 summer shutdown)
- Featured collimators in 2021ab
  - D06V1：changed to tantalum jaws



KEKB type

[Y. Suetsugu et al., NIM A **513**, 465 (2003)]



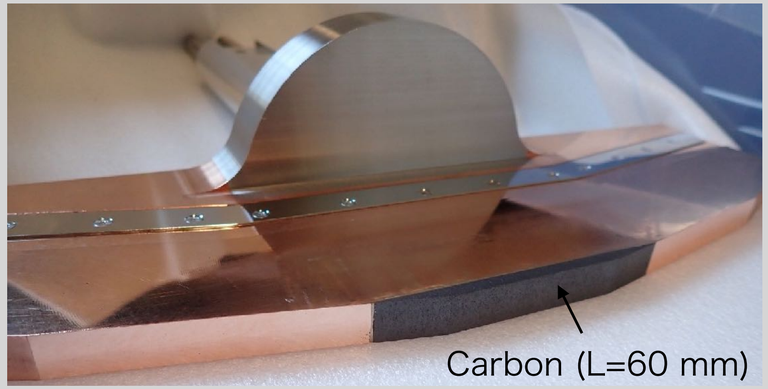
SuperKEKB type

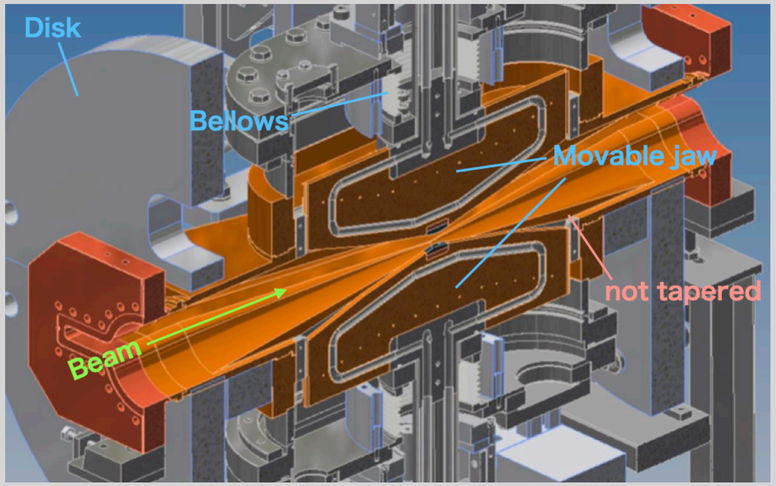
[T. Ishibashi et al., PRAB **23**, 053501 (2020)]

Topics: Low-Z (Carbon) collimator in D06V1 collimator

- Materials with a short radiation length is very effective as a beam tail shield, however the beam loss is localized and the temperature of that exceeds the melting point.
- In order to protect the collimators for BG suppression from abnormal beams, we developed a collimator with carbon* and installed it in D06V1 during 2020 summer shutdown.
- In 2020c, no abnormal pressure rise and heating are observed, however its impedance lower the bunch current threshold.

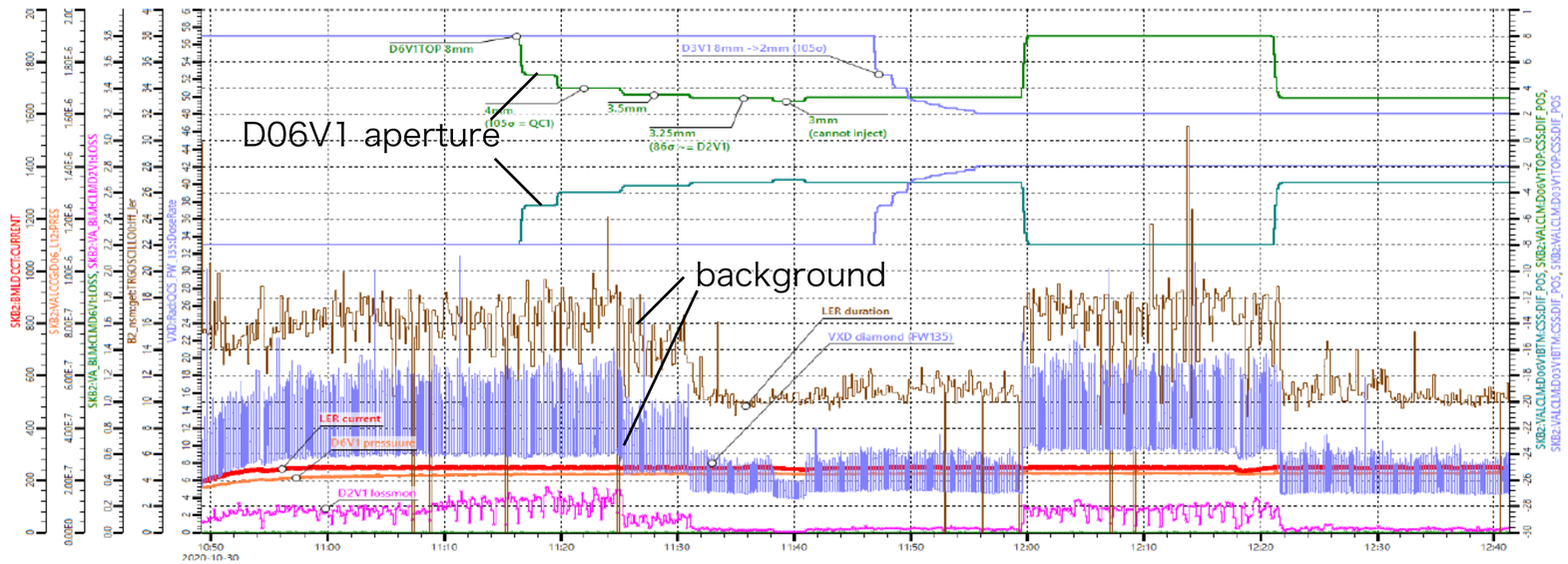
* Glass like carbon coated and impregnated C/C composite (CX-2002U_GP2B, Toyo Tanso Co.,Ltd.).





D6V1 vs. diamond, duration

H. Nakayama

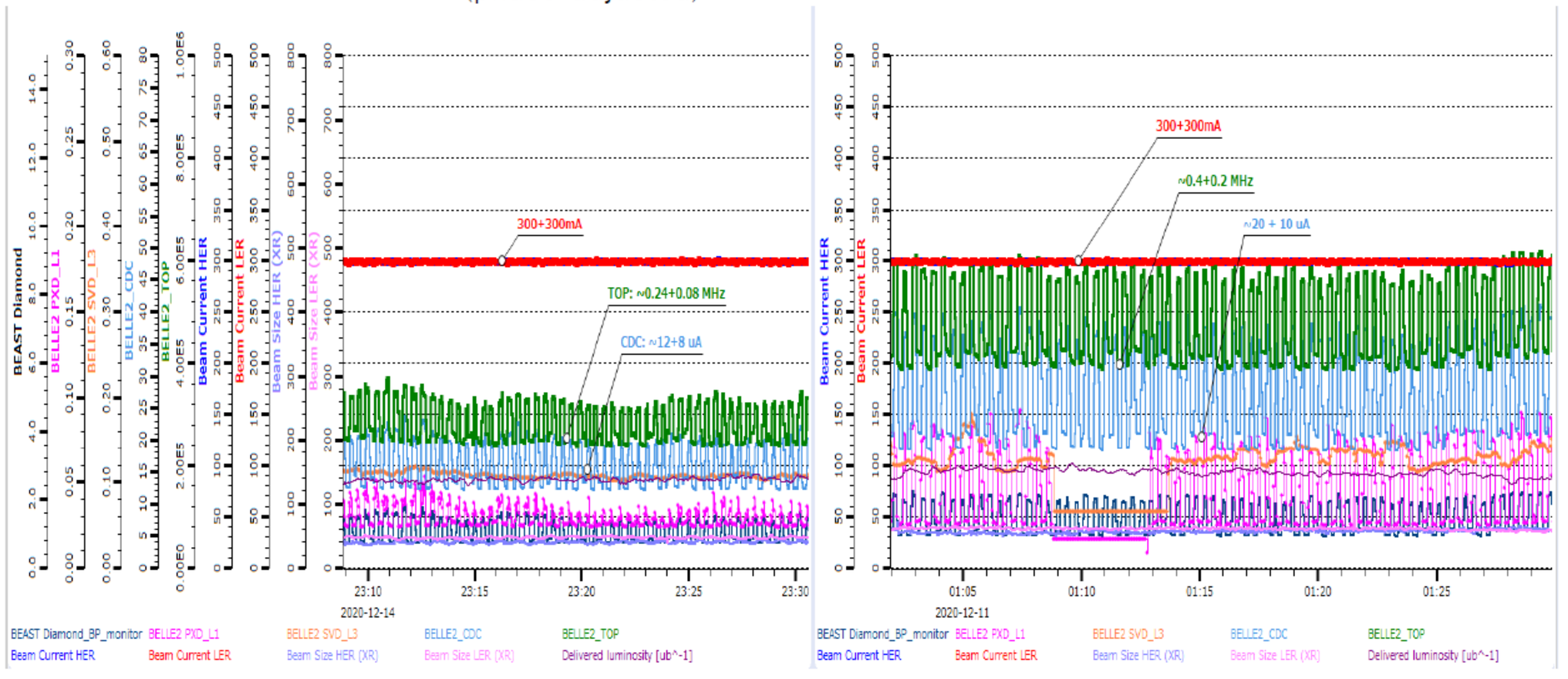


1) We closed D6V1 down to 3mm at I=250mA and didn't observe pressure increase around D6V1. The collimator is well baked now ☺
2) The background changes as expected against D6V1 width:
 - When D6V1 became narrower than QC1, **diamond injection/storage loss** and **injection duration** significantly improved. D2V1 loss also became smaller.
 - When D6V1 became narrower than D2V1, injection efficiency dropped significantly, so we stopped there.
3) We also closed D3V1 down to 2mm and didn't observe any significant improvement in BG, as expected for b*y=1mm optics.

Topics: Trial of phase matched optics between collimators in LER

- In its final stage (Dec. 14th), LER optics was changed to one where the phase advance between D02V1-D03V1 and D02V1-D06V1 are 3.5 and 16, respectively.
  - Protecting D02V1 by the two collimators.
- By closing the D03V1 aperture to ±1 mm、the storage BG in TOP was decreased by 30-40%. However, injection BG in VXD was increased and the effect of collimators' impedance became prominent (talk later).

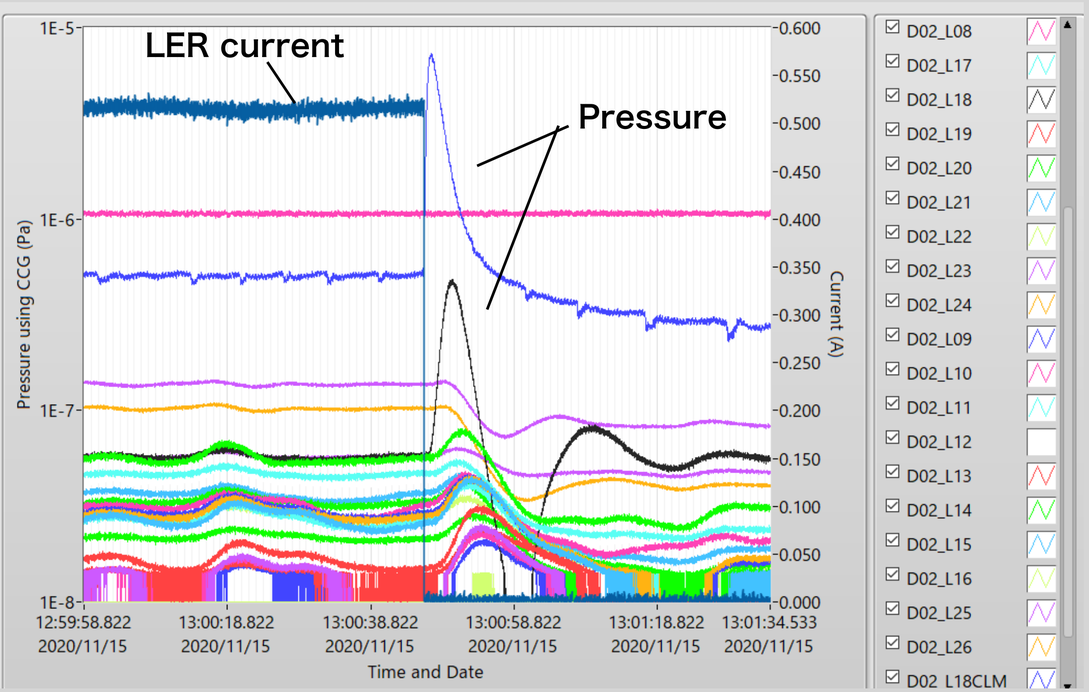
Hit rates of TOP and CDC Dec. 14, 2020 (phase-adjusted) Dec. 11, 2020 **H. Nakayama**

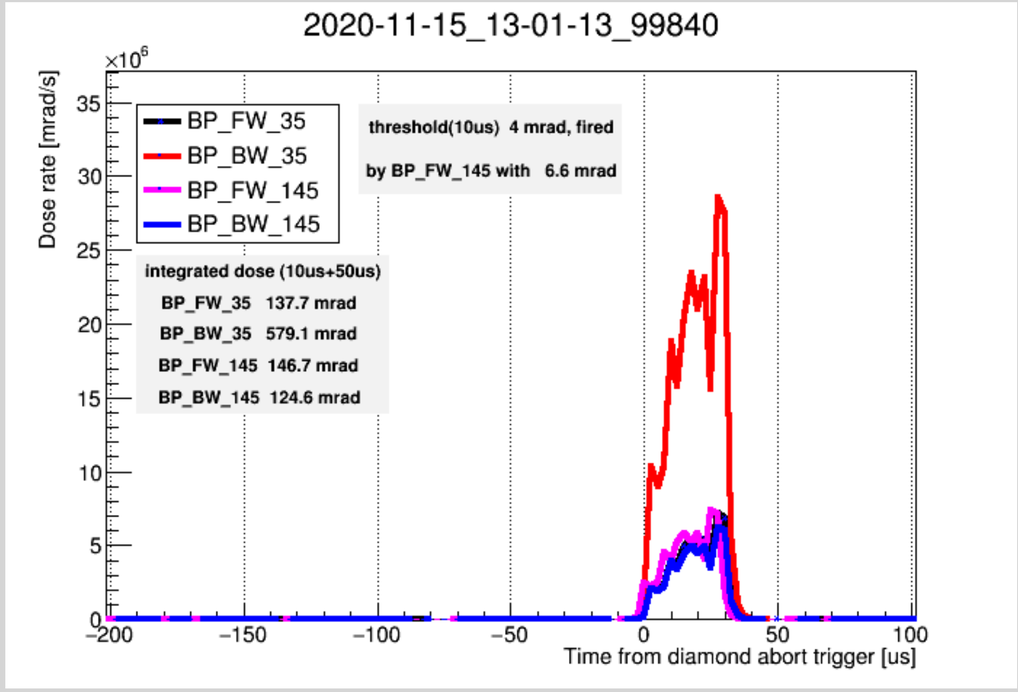


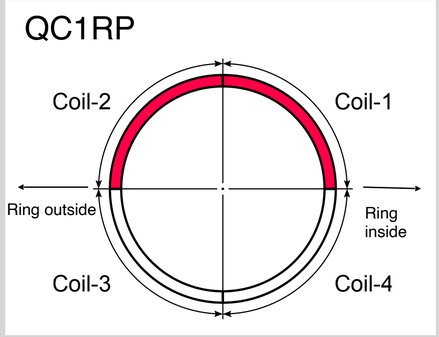
Troubles: Damage of D02V1 collimator's jaws

2020-11-15 13:01:13, beam abort with QCS quench

- LER: 509 mA, HER: 469.6 mA
- Pressure burst was observed in D02V1. The other pressure burst in D05 section was also observed (dust event?).
- After that, the BG levels were higher by a factor of 2 and limited the beam currents .
  * D02V1 was shifted ~3.5 mm to outside of the ring to avoid scars, but the BG level was still high.
  * Horizontal oscillation related to the injection seems larger than expected.
- The damaged jaws were replaced to spears from Nov. 18th to 21st.







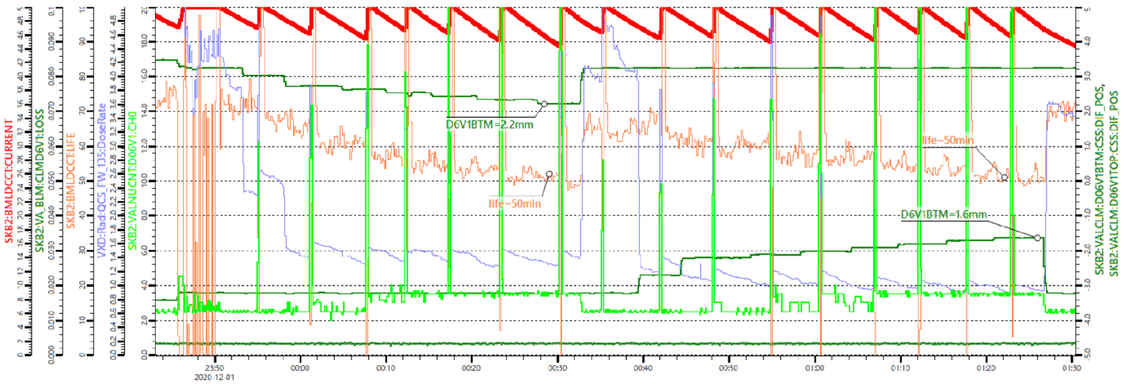
Troubles: Damage of D02V1 collimator's jaws

- Why D06V1 was not able to protect D02V1?
  - D06V1 had a vertical offset of ~ -300 μm to the beam. If D02V1 also had a vertical offset of +200 μm, D06V1 could be wider than D02V1.
    - The offset study for D02V1 on Dec. 15th shows that it has almost no offset, however this was after the jaw's replacement work.
  - If the dust event in the D05 section between D02V1 and D06V1 happened, the strayed beam hits D02V1? D03V1 had been wider than D02V1.

LER D6V1 collimator offset study on 2020.12.01

H. Nakayama

b*y=1mm, I=50mA



D6V1TOP: 85→59sigma (DelPos: 3.2→2.2mm), LER life: 70→50min.
D6V1BTM: 85→44sigma (DelPos: -3.2→-1.6mm), LER life: 70→50min.

➔ D6V1 collimator center is shifted by ~300um downward from the BPM center

(*) Just before the study, D6V1 BPM offset was corrected for +160um.
Before this correction, D6V1 center was shifted by ~460um upward from the BPM center.
-- consistent with Nov. 22 study (at least 200um downward) and Oct. 30 study (at least few 100 um downward)

9

Collimator setting (Nov. 15th)

Collimator	β_y [m]	ν_y	aperture [mm] (jaw_pos - BPMy)	# of σ_y
D06V1TOP	67.3	28.86	2.21	58.8
D06V1BTM	67.3	28.86	-2.99	79.5
D03V1TOP	17	41.44	2.34	123.9
D03V1BTM	17	41.44	-1.66	87.86
D02V1TOP	13.9	44.88	1.54	90.13
D02V1BTM	13.9	44.88	-1.16	67.9

Optics: sler_1706_80_1.sad
Assuming ε_y = 21 pm

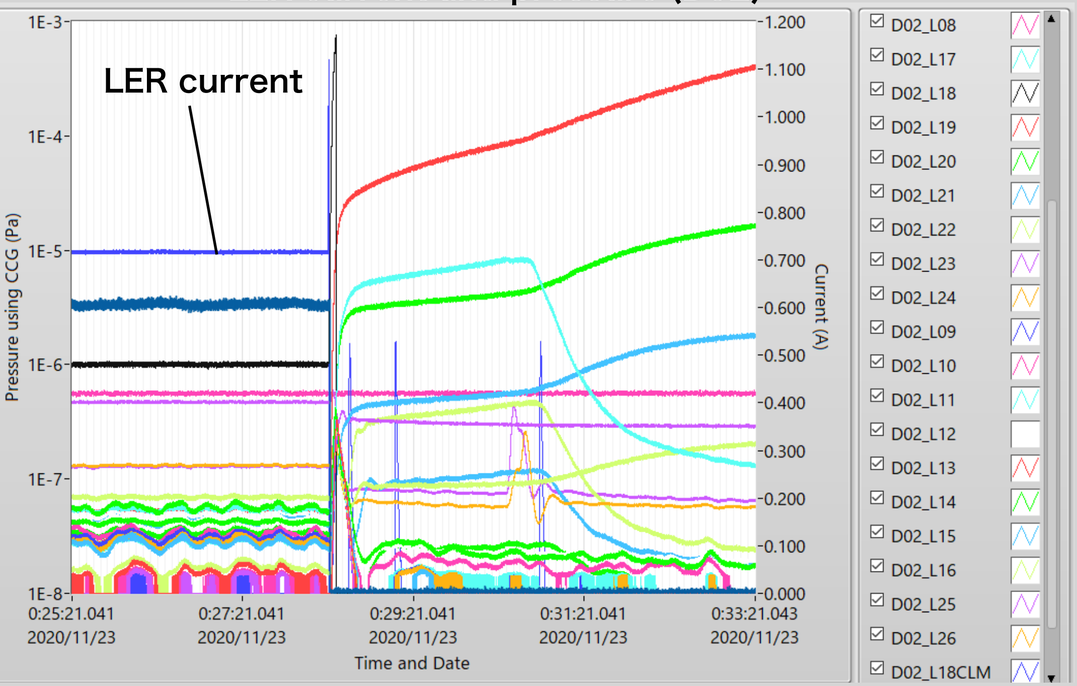
Taking vertical offsets into consideration. →

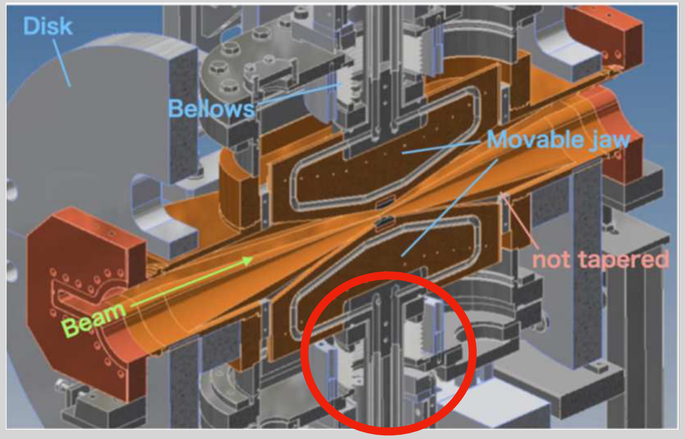
V-offset [mm]
D06V1: -0.3
D03V1: 0.4
D02V1: 0.2

Troubles: Vacuum leak in D02V1 collimator

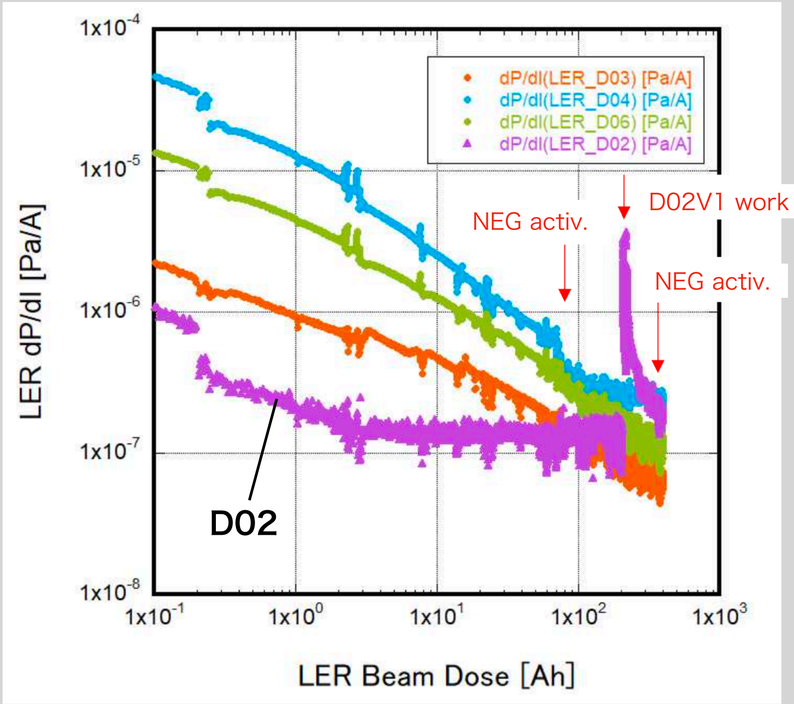
- On Nov. 23rd 0:28 (LER: 599.7 mA), a pressure burst happened in D02V1, and beam was aborted by it.
- Vacuum leakage was detected at the bottom side flange. A scar on the seal surface was found.
  → replaced to the spare one.
- On Nov. 24th, replacement work done and vacuum scrubbing resumed.
- On Nov. 27th, physics run resumed (LER β_y^* = 2 mm).
- The outgassing from the spare flange had been high, thus we baked-out D02V1 in-situ during this winter shutdown.

LER current and pressure (D02)





dP/dl in LER



Issue: TMCI in LER derived from collimators' impedance

D06V1 (C, 60 mm) survey (2020-12-02)

The maximum bunch current was ~1.04 mA/bunch limited by an instability in the collimator settings.

$$I_{\mathrm{b,th}} = \frac{C_1 f_s E/e}{\sum_i \beta_i k_{\mathrm{T},i}(\sigma_z)}$$

[Handbook of Accelerator Physics and Engineering 3rd Printing (2009)]

$C_1 \approx 8,\ f_s = 2.13\,[\mathrm{kHz}],\ E/e = 4\,[\mathrm{GV}]$

Collimator	β_y [m]	aperture [mm]	k_T [V/pC/m] a)
D06V1	67.3	±2.0	841 b) ← 552 c)
D06V2	20.6	±3	237
D03V1	17	±3	237
D02V1	13.9	±3	237

$I_{\mathrm{b,th}} \approx 0.99$ mA/bunch ← (1.49 mA/bunch)

a) Kick factors are calculated by GdfidL（σ_z: 6 mm）.
b) including lossy metal (GdfidL 2020-07-23, T. Ishibashi).
c) loss-free (GdfidL 2013-10-15, T. Ishibashi)

This study is conducted taking the beam orbit and the D06V1, D03V1 vertical offset into consideration.

B-PosY [mm]	V-offset [mm]
D06V1: 0.44	D06V1: -0.3
D06V2: 0.22	D06V2: 0
D03V1: 0.04	D03V1: 0.4
D02V1: 0.16	D02V1: 0

D06V2 (Ta, 10 mm) survey (2020-12-04)

We were able to accumulate ~1.5 mA/bunch at least.

However, we were not able to measure the vertical tune accurately because the main peak and side band were coupled.

Collimator	β_y [m]	aperture [mm]	k_T [V/pC/m] a)
D06V1	67.3	±4.0	249 b) ← 205 c)
D06V2	20.6	±1.8	490
D03V1	17	±2.0	430
D02V1	13.9	±1.0	1287

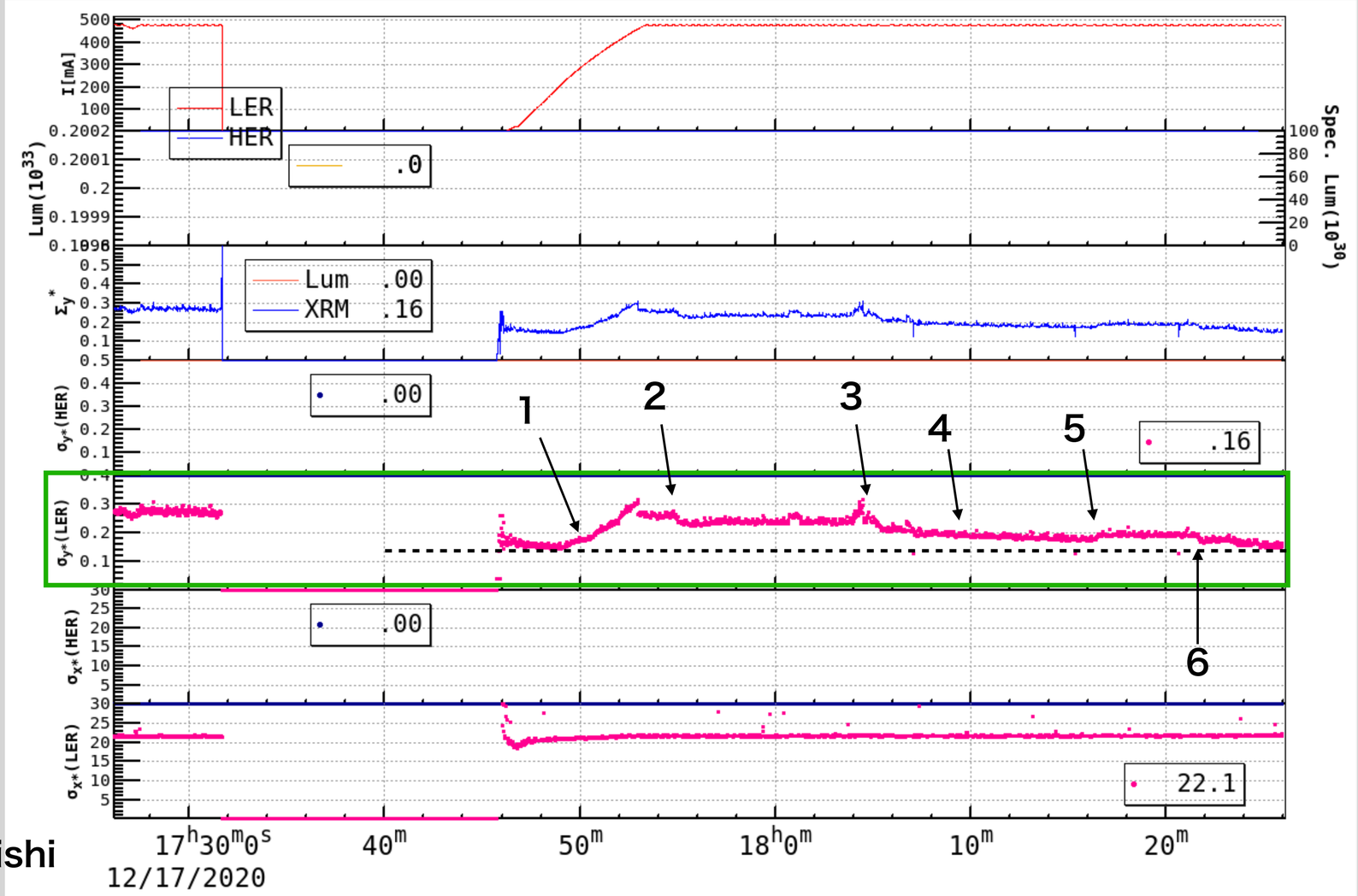
$I_{\mathrm{b,th}} \approx 1.31$ mA/bunch

- In this study, we were not able to measure the beam size because of the single-bunch operation.
- After this study, a vertical beam size blowup due to a dipole mode was observed for the multi-bunch operation, and the threshold is 0.7-0.8 mA/bunch (lower than the calculated values).

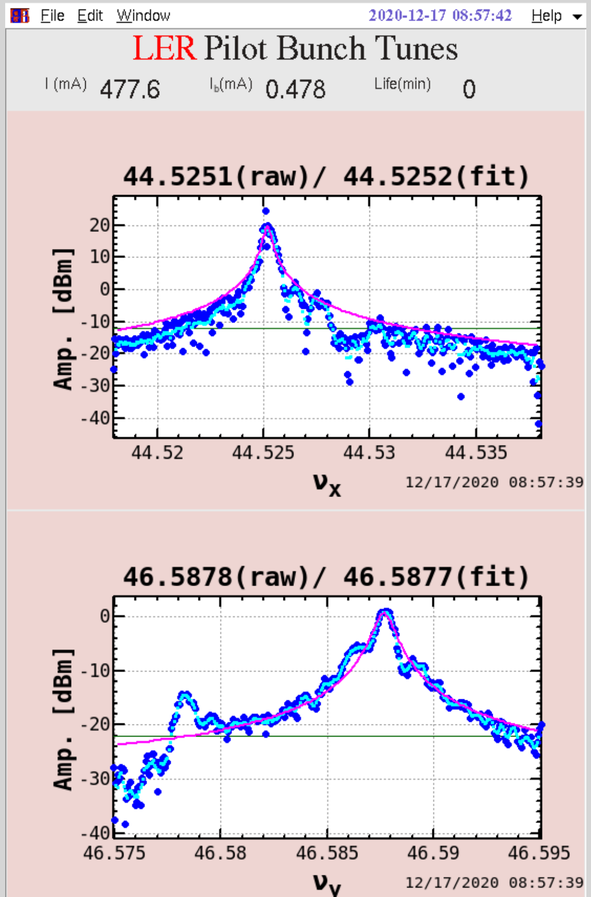
Issue: TMCI in LER derived from collimators' impedance

- The impedance of D06V1 is larger than that of D03V1.
  - The kick factor of D06V1 (carbon, L=60 mm) is about twice larger than that of D03V1 (tantalum, L=10 mm) by GdfidL.

1. vertical beam size blowup with increasing bunch current
2. changed vertical tune
3. adjusted BxB FB gain
4. D03V1 open (18:09-18:14, ±1mm → ± 2 mm)
5. D03V1 close (18:16, ±2 mm → ±1mm)
6. D06V1 open (18:22, ±1.95 mm → ±2.25mm)



Tune spectrum (12/17, LER 0.478 mA/bunch)

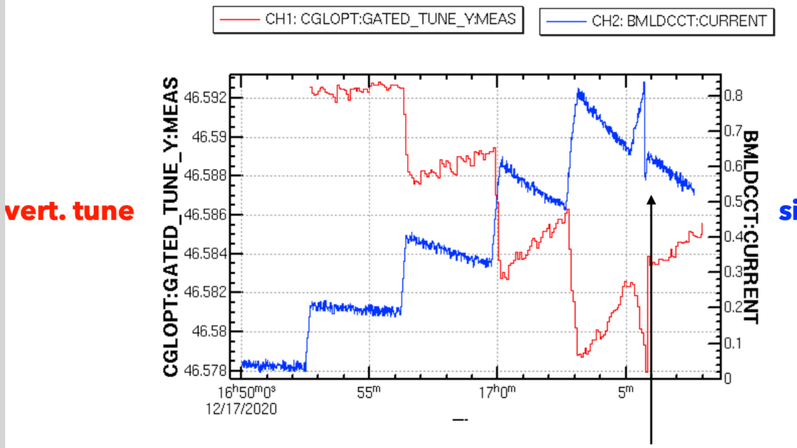


Y. Ohnishi

Issue: TMCI in LER derived from collimators' impedance

- Vertical tune shift was large. -0.0229 mA^{-1} (2020-12-17), -0.0131 mA^{-1} (2020-11-5).
- In terms of the bunch current, it's necessary to manage the collimators' aperture limiting with the tune shift.
  - For example, if we try to suppress it ~0.012 mA^{-1}, the collimator setting is on June, 2020 (The BG was about twice larger than that in Dec., 2020).
- Carbon jaws had contributed on the impedance in LER, we decided to replace it with tantalum jaws with 5 mm length during this winter shutdown.

Y. Ohnishi

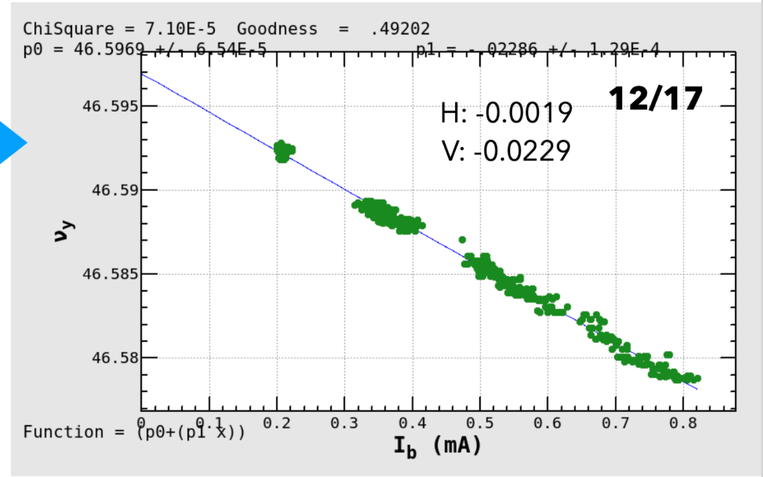


vert. tune

single bunch current

Tune shift is same as synchrotron tune

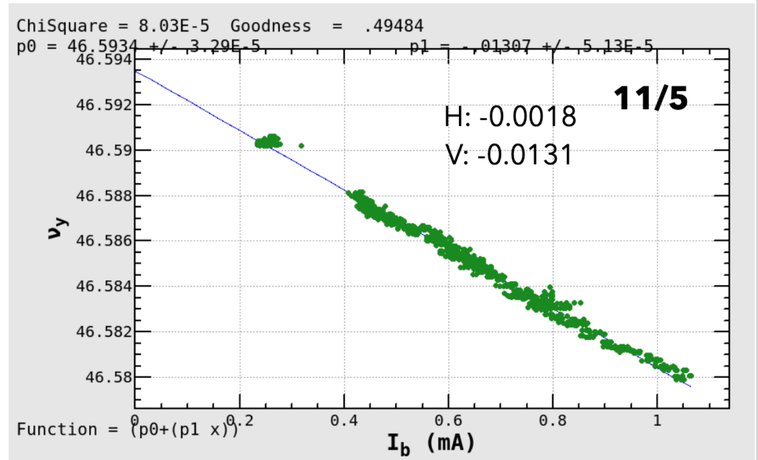
$\nu_s = -0.0235$



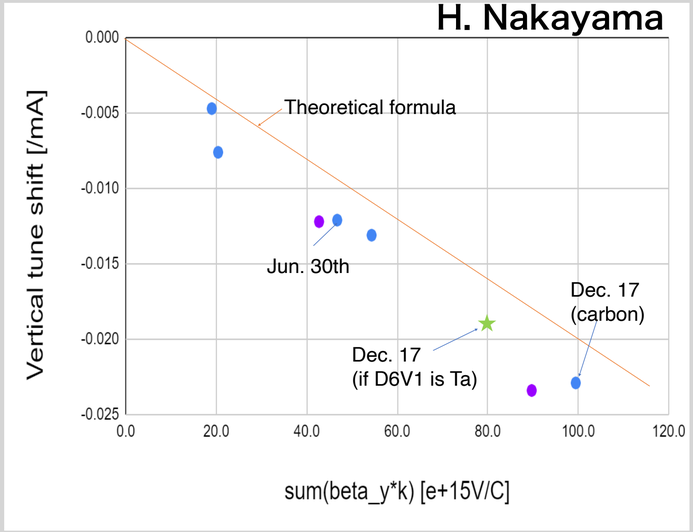
Beam current can not be stored larger than 0.8 mA/bunch.

	11/5	12/17
D02V1 (mm)	1.52 / 1.2 (1.36)	1.68 / 1.2 (1.44)
D03V1 (mm)	2.0 / 1.98 (1.99)	0.68 / 1.38 (1.03)
D06V1 (mm)	3.2 / 3.2 (3.2)	2.7 / 1.2 (1.95)
D06V2 (mm)	2.2 / 1.9 (2.05)	2.28 / 1.85 (2.07)

← carbon head



H. Nakayama

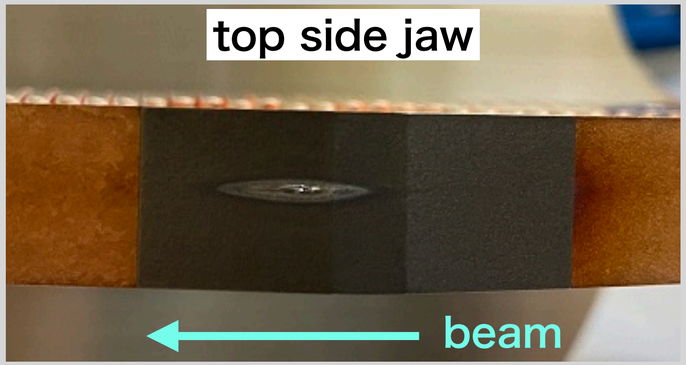


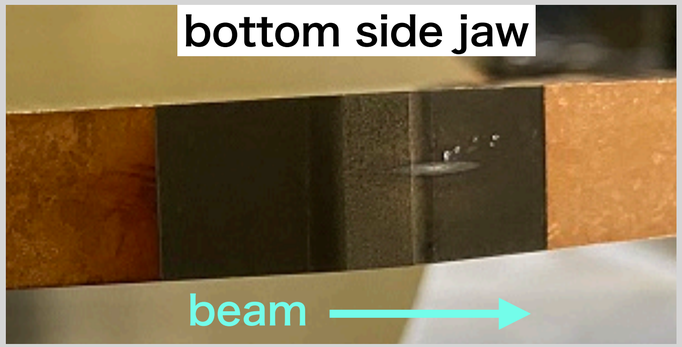
Issue: TMCI in LER derived from collimators' impedance

Reuse damaged tantalum jaws with short tip in D06V1 for 2021ab

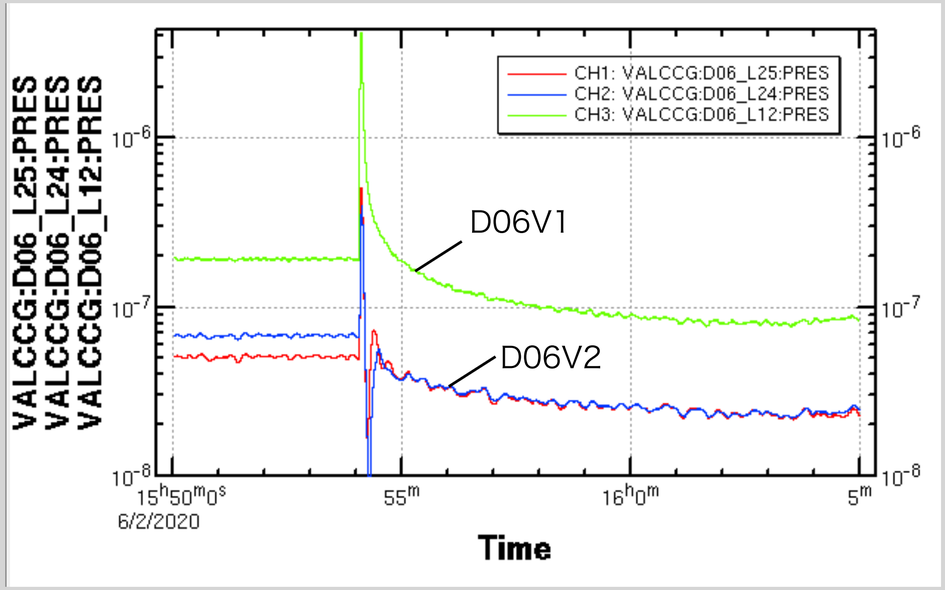
- We found the damage when we opened the collimator chamber for a carbon jaws' installation work in 2020 summer.
- There's a possibility that the jaws was damaged on 2020-06-02 15:54 (2020b).
  - Beam abort with pressure burst near D06V1 (LER: 546.8 mA, ~4×10^{-6} Pa).
  - Small pressure burst happened in D02V1 (~1.7×10^{-7} Pa) and D06V2 (~5×10^{-7} Pa).
  - VXD dose: ~119 mRad

Tantalum jaw with 5 mm length

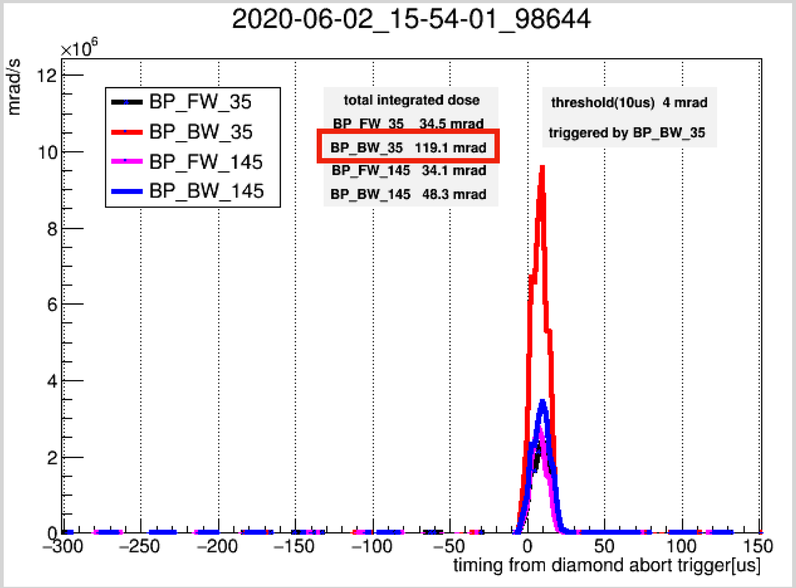




Pressure



VXD dose



Collimators during 2021ab

LER

- Carbon jaws in D06V1 collimator were replaced with tantalum to reduce the impedance.
- In situ baking of D02V1 and D06V1 collimators to reduce the base pressure.

HER

- Damaged jaw in D09V3 has been replaced with new one, which is copper coated titanium.
- Drive mechanism of D12V1 has been replaced with new one for precise positioning.

Others

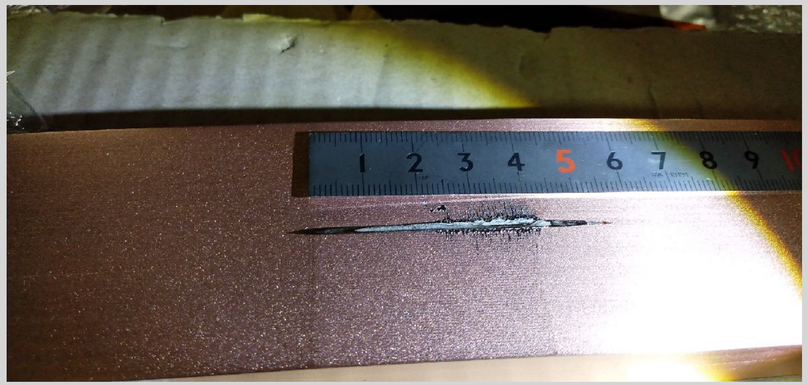
- Prepared PVs to interactively monitor the kick factors and $\sum_i \beta_i k_{\mathrm{T},i}$. (H. Nakayama, Y. Ohnishi)

LER D02V1 in-situ baking

HER: D12V1 and drive mechanism - before

after

HER: Removed jaw from D09V3



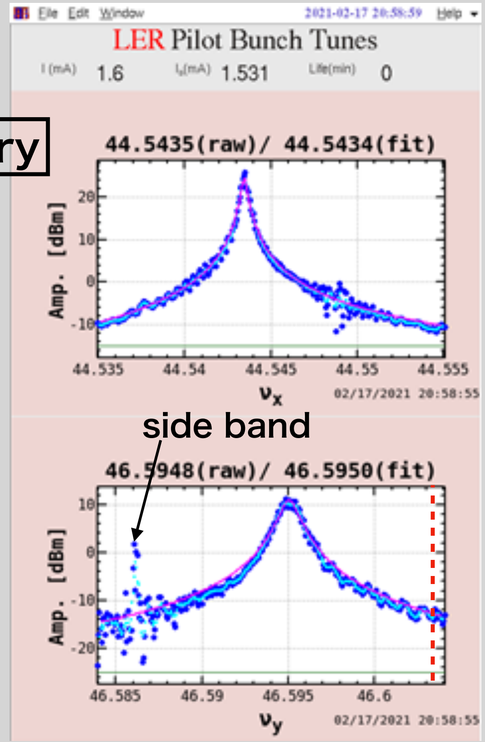
Study Plans

Machine studies in LER during 2021ab

- Tune shift measurement (see figure on lower left)
- High bunch current study (see figure on lower right)
  - remeasure them in the current situation (D06V1: Ta-5 mm)
- Chromaticity scan study [K. Ohmi]
  - measure the beam size and the threshold of the blowup with changing the chromaticity
  - ESRF, SOLEIL, NSLS-II operate with large positive chromaticity (ξ>~5) and result in higher threshold (1 mA→ >10 mA) after 2000.

and so on (studies related to the injection)

Preliminary



Tune shift: 0.008 mA^{-1}

We were not able to inject up to ~1.7 mA/bunch.

TMCI threshold (calc.): ~1.77 mA/bunch

Design: 1.44 mA/bunch

βy* = 8 mm, single-bunch operation

D02V1: 2.17 mm, -1.8 mm, D03V1: ±9 mm,

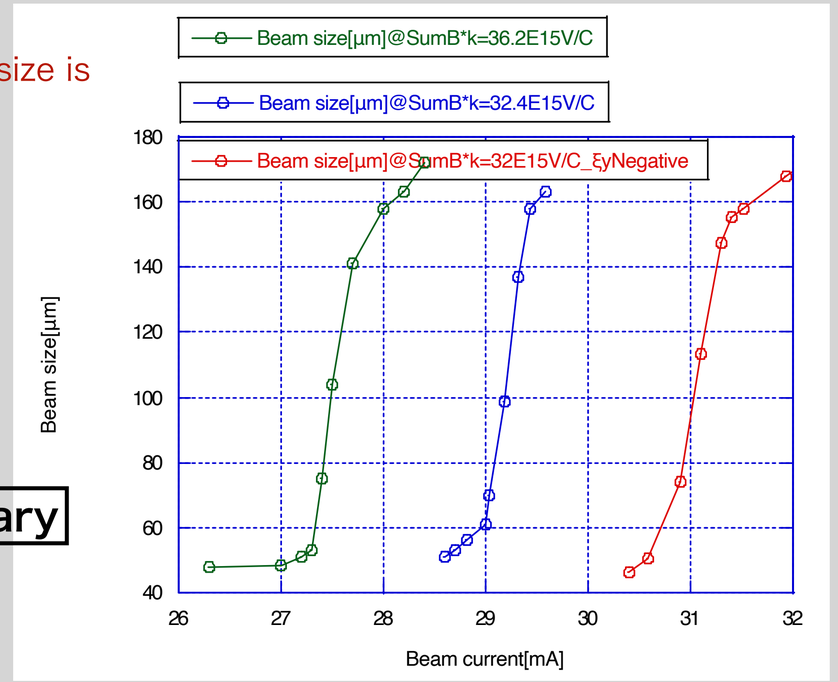
D06V1: ±2 mm, D06V2: ±9 mm

Threshold of the beam size is ~1 mA/bunch.

βy* = 2 mm, 30-bunch operation

S. Terui

Preliminary

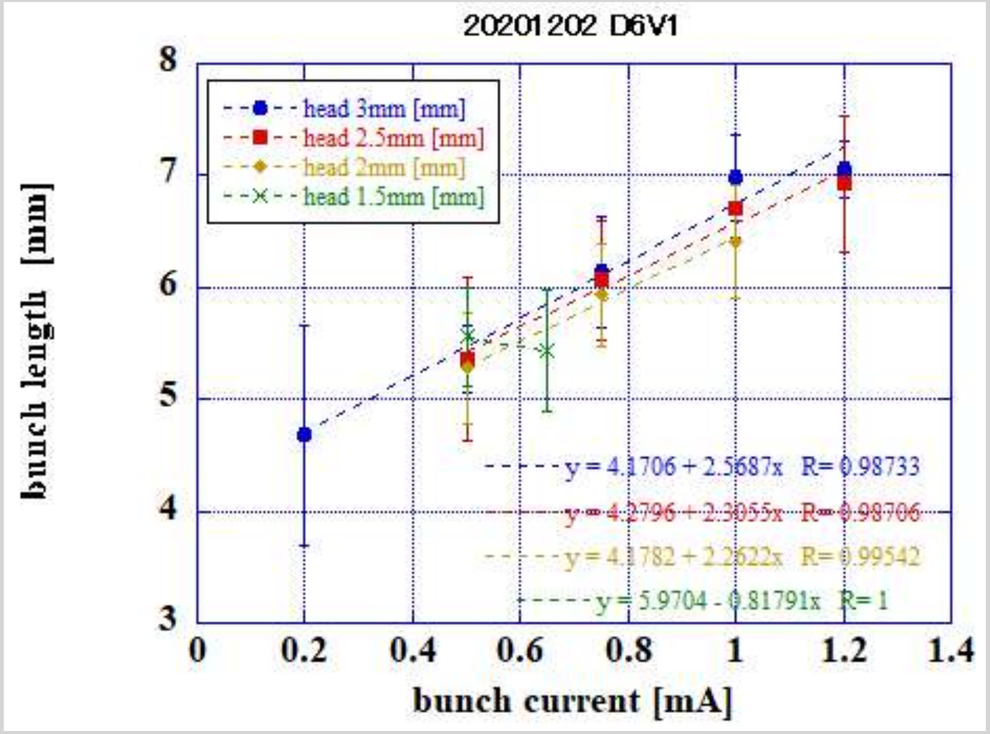


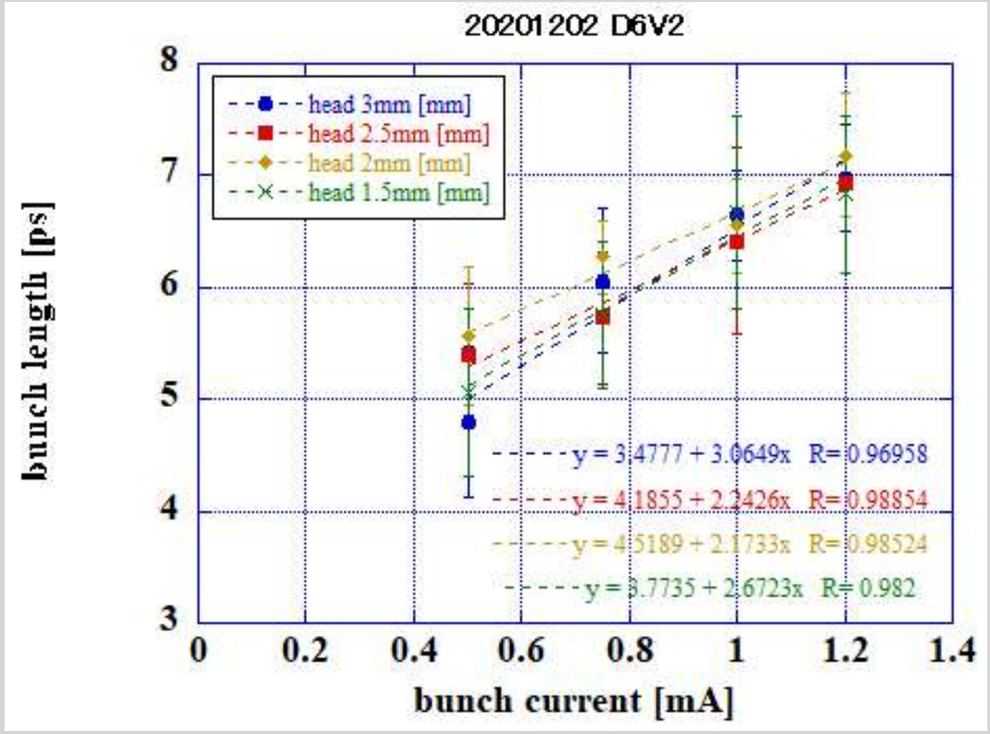
backup

Topics: Bunch length measurements for collimator apertures

- We measured the bunch length in LER in the collimators' impedance study simultaneously.
- No correlation for the collimators' apertures.
- However, it's longer than expected.

H. Ikeda



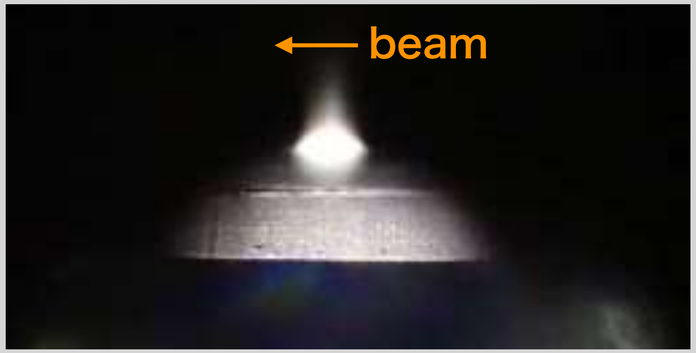


Topics: Damage of D06V2 (found after 2020c)

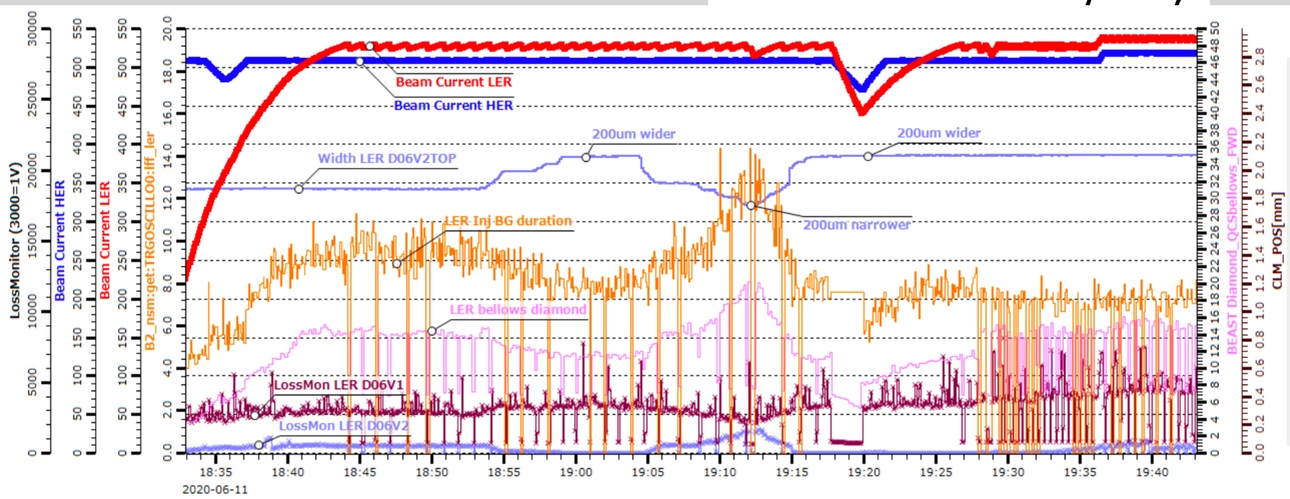
- After 2020c, a damage of D06V2 (Ta, L: 10 mm) was found.
- There's a possibility that the jaws was damaged on 2020-06-08 15:01(2020b).
  - Beam abort with pressure burst near D06V2 (LER: 580 mA, ~7×10^{-7} Pa).
  - Pressure bursts except for D06V2 were not observed.
  - VXD dose: ~225 mrad.
- This damage is probably an answer for a mystery of the strange response on BG in D06V2.

D06V2 TOP

D06V2 Bottom



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.

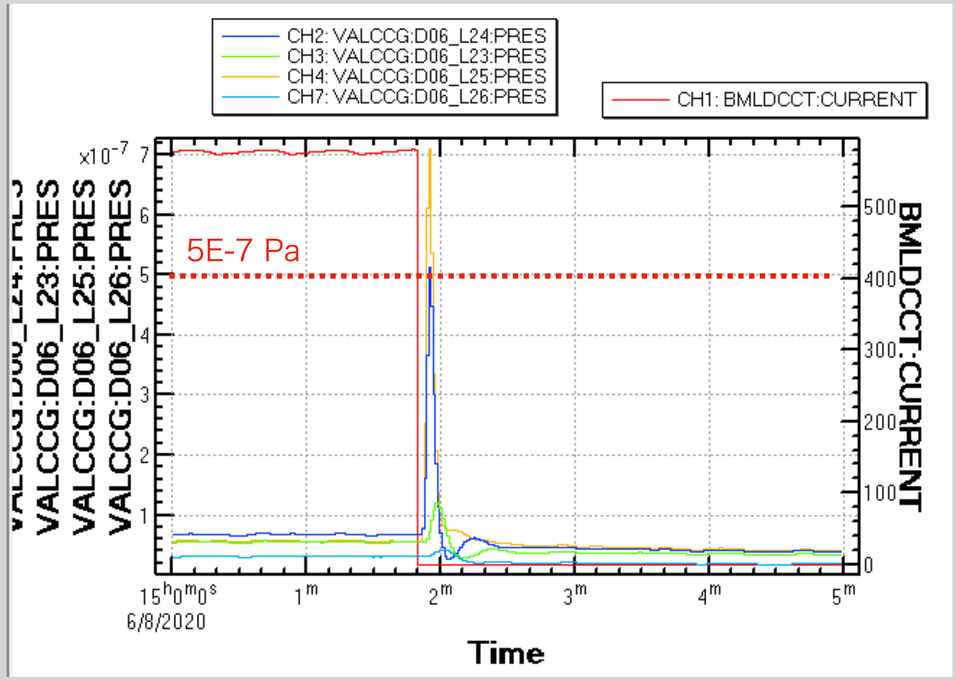
Why?

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

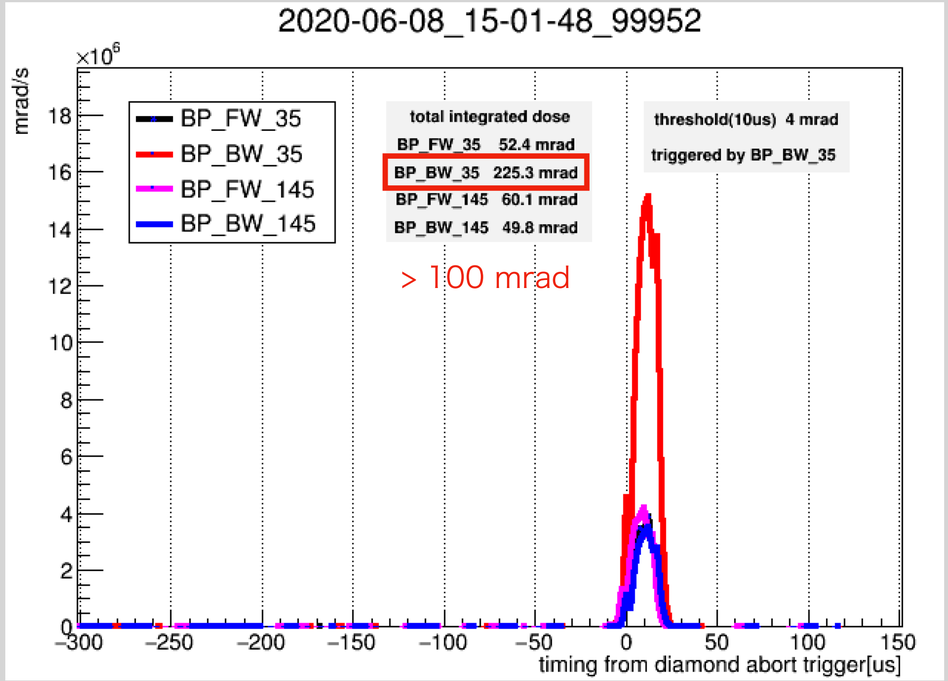
Topics: Damage of D06V2 (found after 2020c)

- We've prepared records that inform the operators to have doubts about the damage.
  - Example: VAHCCG:D01_H03:WORRY_CLM
    (D01_H03 is a name of a CCG near D01H5 collimator)
  - The records issue the alarm when a pressure near collimators is larger than 5×10^{-7} Pa for a moment and VXD:Rad:MaxDoseLastAbort is larger than 100 mrad within 5 min after the pressure burst.
- It was decided that D06V2 jaws were not replaced during this winter shutdown as a result of discussions.
  - We have only two sets of spare jaws for the vertical collimators. These should be kept for 2021ab.
  - D06V2 has not much contributed to reduce BG .

Pressure bursts on 2020-06-08 15:01

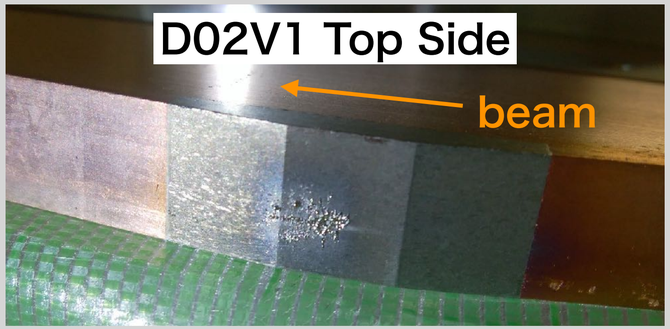


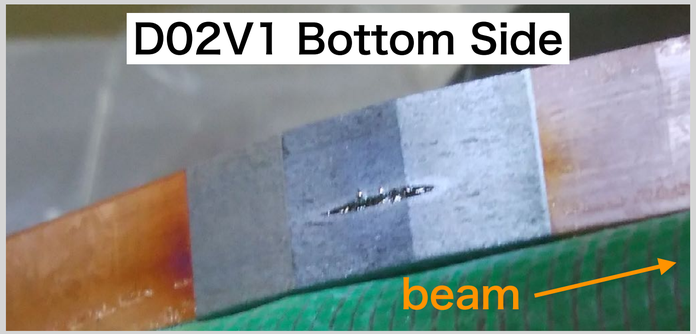
VXD dose



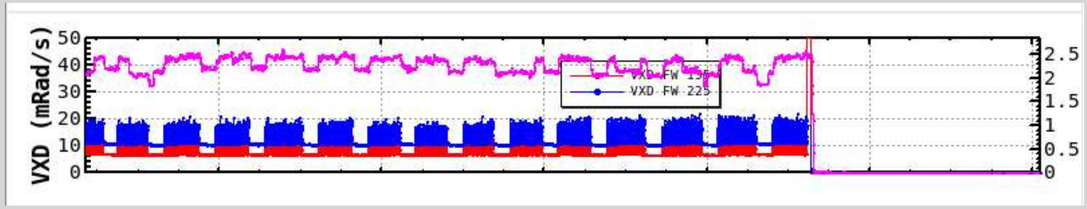
Issues: Horizontal oscillation related to injection in LER

- After D02V1 had been damaged in 2020c, we shifted it ~3.5 mm to outside of the ring to avoid scars, but the injection BG level was still high.
- Why was the BG level high?
  - The scar or the protrusions are widely spread? → These are localized when we observed the removed jaws.
  - Horizontal oscillation related to injection is large and particles went through the jaws?

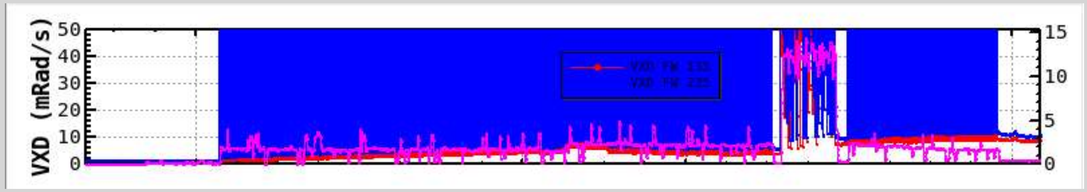




before damage



after damage



Issues: Horizontal oscillation related to injection in LER

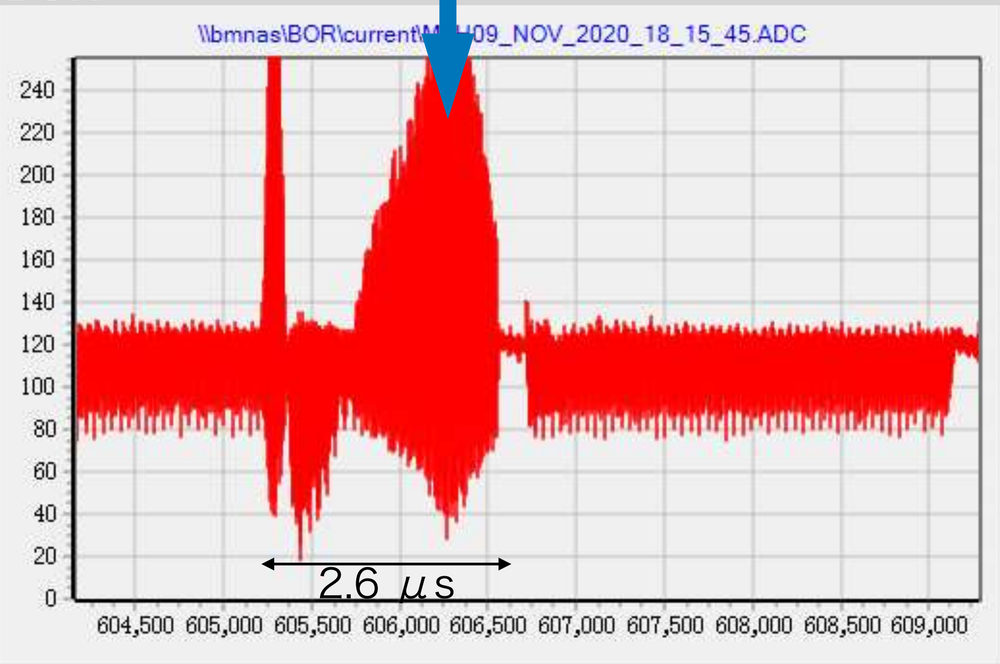
- We observed horizontal oscillations for the injected beams and for storage beams, which is caused by an imperfection of a cancellation between the injection kickers (and mis-match between MR and BT?).
  - Adjusted the kickers' timing and monitored the oscillation using turn by turn monitors.
- The horizontal oscillation for the injection beam at D02V1 is ~8.8 mm (peak-peak, ideally 4.3).
- The horizontal oscillation for the storage beam at D02V1 is ~4.3 mm (peak-peak, ideally 0 mm).
- There is a possibility that particles go through the jaws by the horizontal oscillations.
  - Jaw's full width: 12 mm

S. Terui, G. Mitsuka

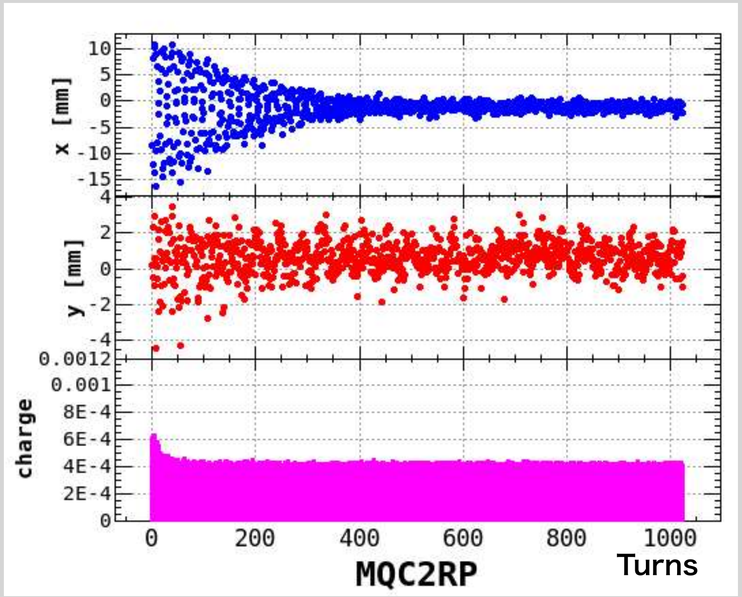
568th bucket from the injected bucket

(imperfection of the cancellation between kickers)

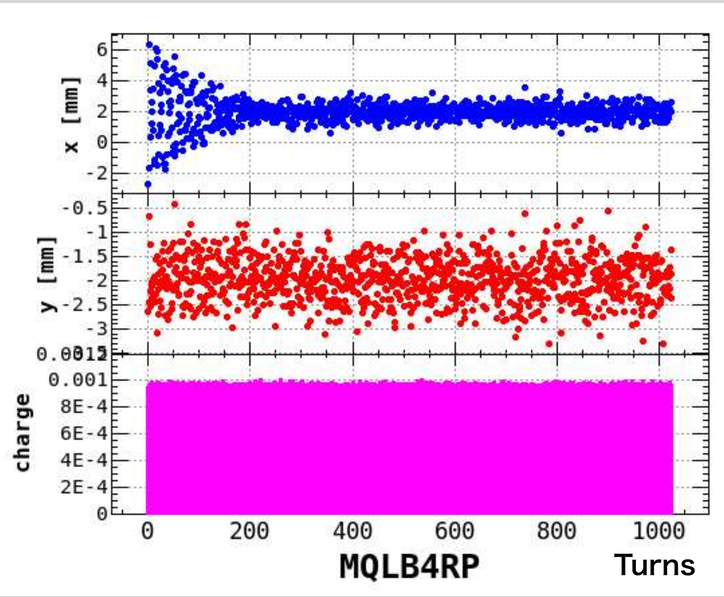
BOR



Injection beam oscillation@QC2

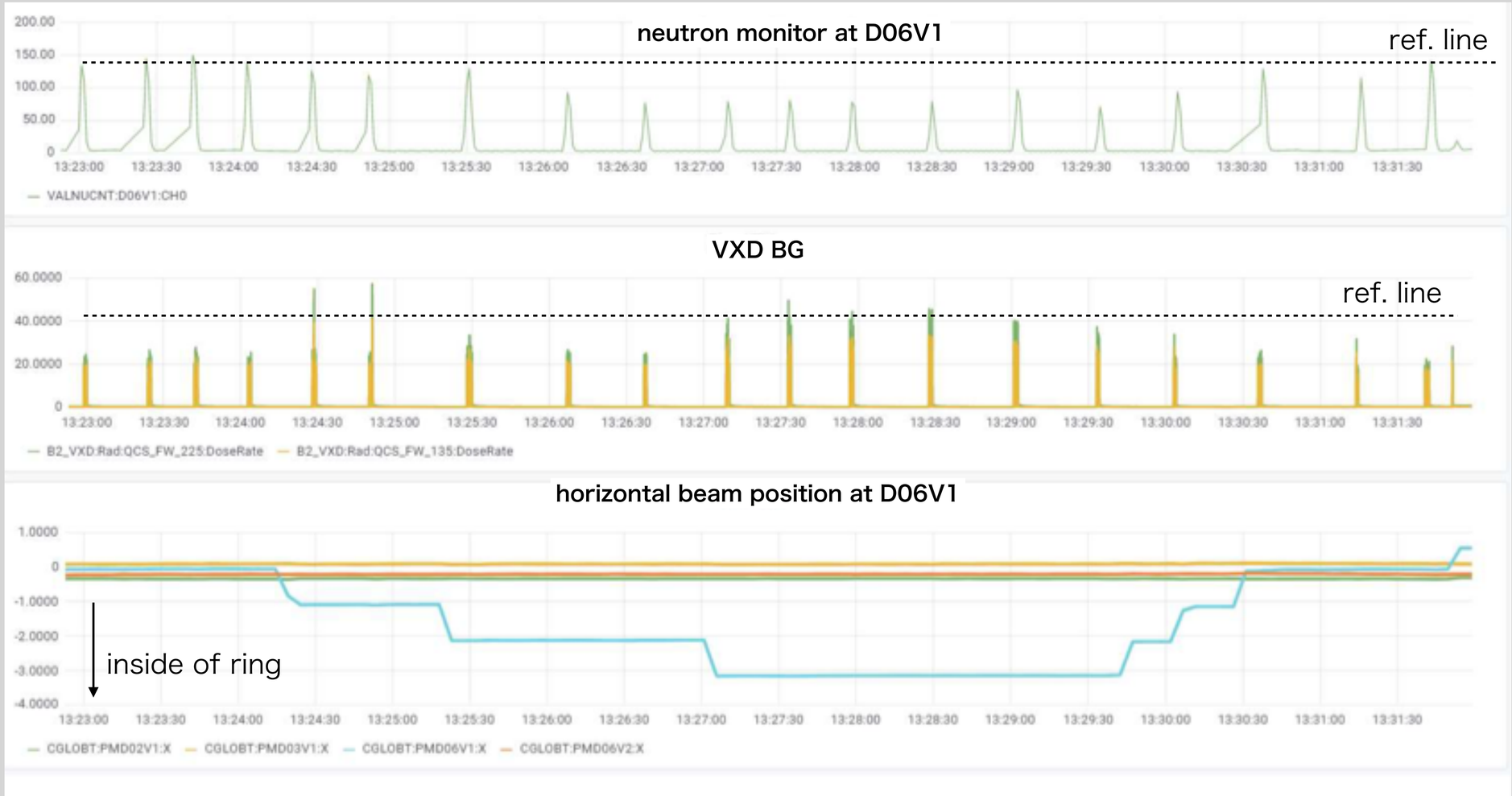


Storage beam oscillation by the imperfection near D02V1



Issues: Horizontal oscillation related to injection in LER

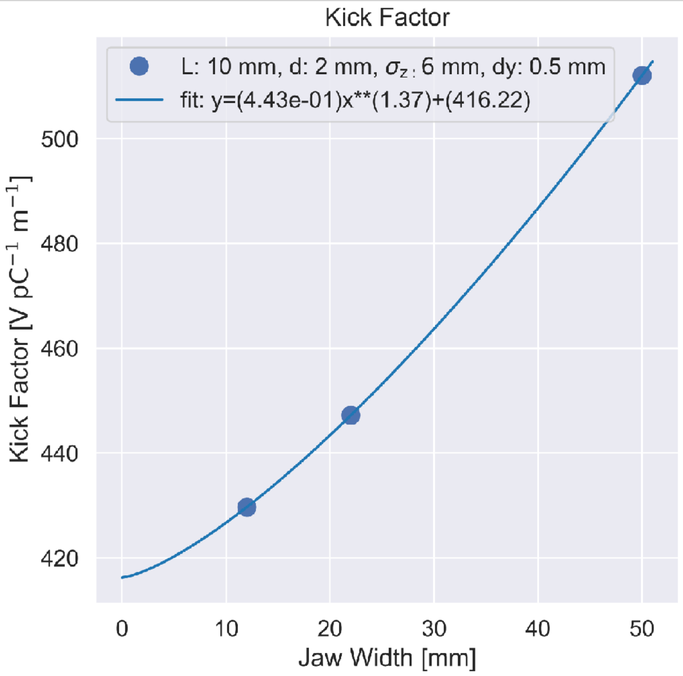
- We also checked an effect on the BG using a horizontal orbit bump at the vertical collimators.
  - When the beam orbit had been shifted to the inside of the ring, the loss at D06V1 had been decreased. The VXD BG had been increased.
  - Particles can go through the jaws because of the horizontal oscillation.



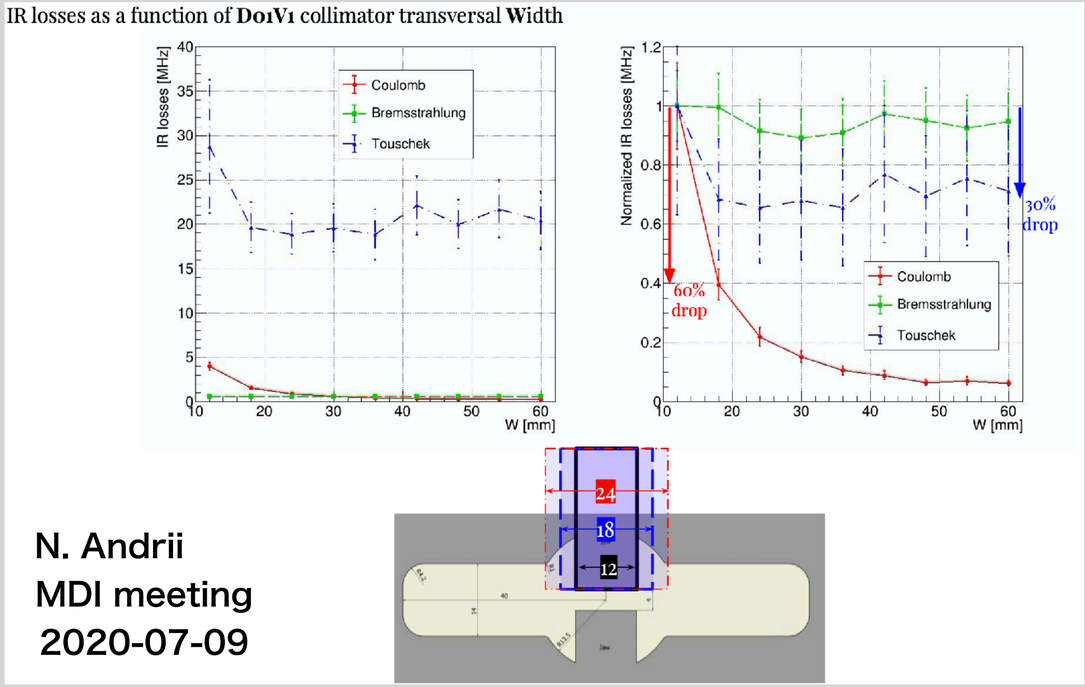
S. Terui, H. Koiso

Issues: Horizontal oscillation related to injection in LER

- Countermeasures for the horizontal oscillation
  - Develop a vertical collimator with wider jaws.
    * increase the impedance
    * can secure a space for the horizontal shift of the collimator when the jaws are damaged.
    * can be useful to reduce HER storage BG by adopting this structure on D01V1.
  - Perfectly cancel the waves between kickers using new kicker correctors(?) [T. Mimashi].
  - Correct the mis-match in the injection region(?).
- If we can reduce the injection BG without using the collimators, we can open the apertures.
  → longer beam life time, higher (bunch) current



L: longitudinal tip length of jaws
d: half aperture
σ_z : bunch length
dy: vertical beam offset

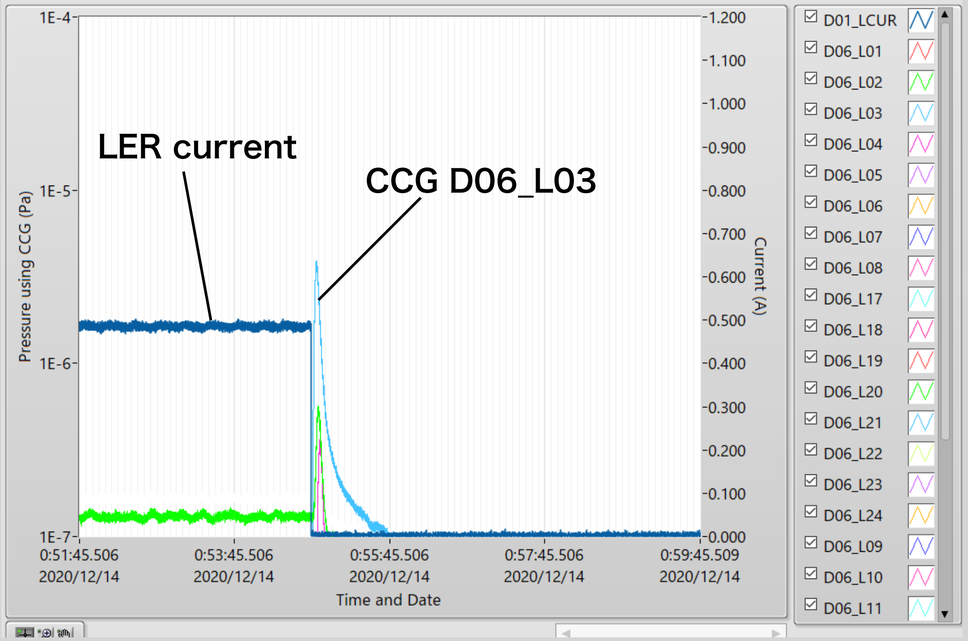


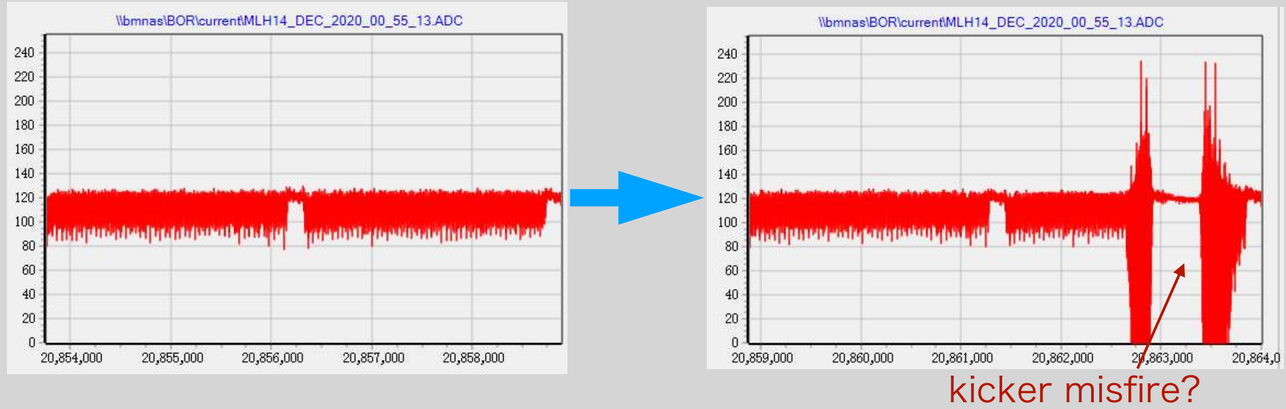
N. Andrii
MDI meeting
2020-07-09

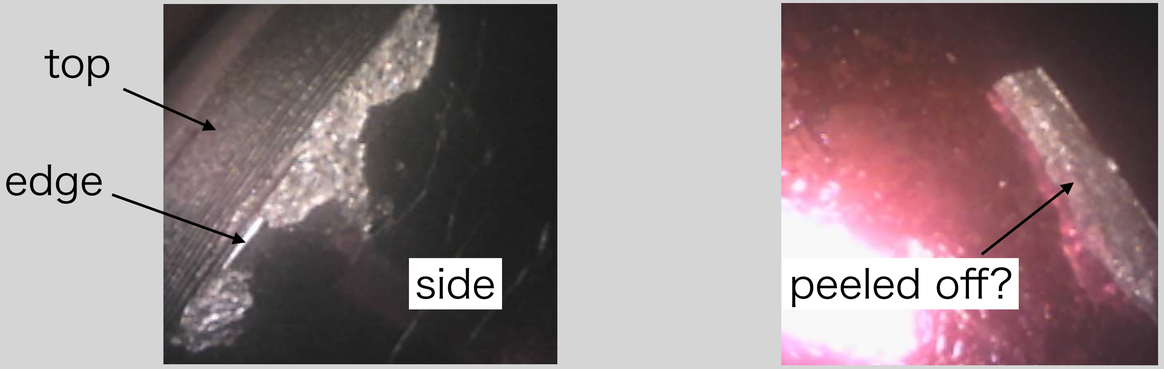
Others

- 2020-12-14 0:55, beam abort (VXD diamond) with pressure burst at D06H3.
  - LER: 480 mA, HER: 449.9 mA
  - A part of the bunches was suddenly kicked (caused by a misfire in a kicker?)
  - There are no scars on the tip of D06H3 (tungsten) using a fiber scope after 2020c, but a part of the tip at the edge seems to be peeled off.

S. Terui







- We have 2 sets of spear jaws (Ta, 10 mm) for the vertical collimators.
- We try to machining the damaged tip to fix the scar or protrusions under a supervision of KEK Radiation Science Center.

Future plans (personal opinion)

LER

- In the near future (next 1-2 years), what should we update the collimators in LER?
  - Observed bunch current limit derived from the collimators' impedance.
  - Damages of jaws.

  → adopt jaws with short length at the tip to reduce impedance with avoiding the damage by beam hit.

Name	Jaw's type	Others
D02V1	standard (Ta, L=10 mm)	Ta (L=10 mm) is currently installed. Option：wider jaw, short length tip etc.
D03V1	short length tip (Ta, L=1.5-2 mm)	Ta (L=10 mm) is currently installed. Option：[wider jaw+short length tip] etc.
D06V2	short length tip (Ta, L=1.5-2 mm)	Ta (L=10 mm) is currently installed. Option：[wider jaw+short length tip] etc.
D06V1	short length tip (Ta, L=1.5-2 mm)	Damaged Ta (L=5 mm) is currently installed. Option：[wider jaw+short length tip] etc.

HER

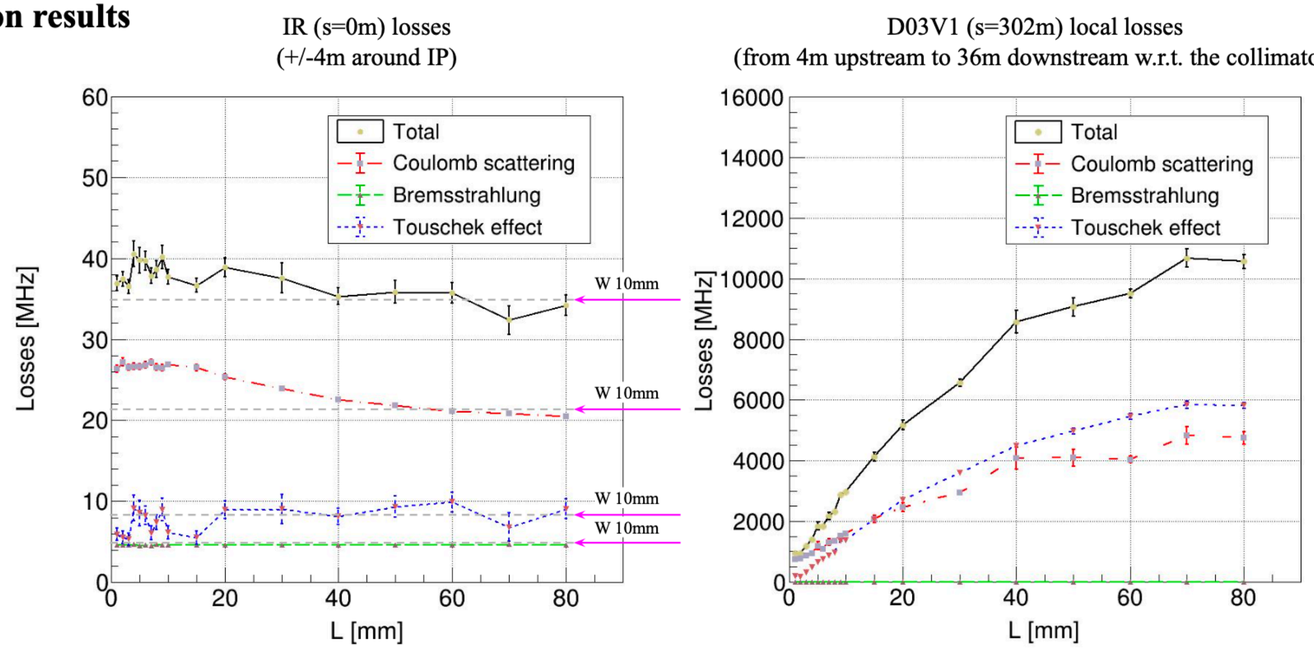
- In the near future (next 2-3 years), what should we update the collimators in HER?
  - The impedance can also limit the bunch current in HER in the future (see page. 24).

Name	Jaw's type	Others
D01V1	wider jaw (Ta, L=10 mm, width=22 mm)	We don't need re-design the collimator chamber until the width is 22 mm. The β_x at D01V1 decreases with β_y^* squeezing. Option：[wider+short length tip] etc
KEKB type V	SuperKEKB type with short tip jaw (Ta, L=4 mm(？))	Need re-design the collimator and the bellows and beam pipes beside it. KEKB type jaws are made of Ti with 40 mm (1.12 R.L.) + Cu coating Integrate two KEKB types with phase advance ~π to a SuperKEKB type. (D09V1-D09V3, D12V3-D12V4 etc)

Short tip jaw - How shorten the length?

- Carbon with 60 mm length has almost same performance for the BG reduction as tungsten with 10 mm length.
- Carbon with 60 mm (~0.31 R.L.) is equivalent to tantalum with ~1.3 mm by the scaling.
- Is tantalum with 1.5-2 mm (0.36-0.5 R.L.) sufficient to reduce the BG? → need simulations

SAD simulation results



- We expect the same IR BG level with L_Z = 60mm for graphite head compared to tungsten with L_Z = 10mm (see ←).
- Changing the length of the tip-part of the collimator head:
  - Small reduction of IR losses:
    - 50mm < L_Z < 80mm - flat Beam-gas losses behaviour.
    - 10mm < L_Z < 50mm - almost linear dependence of Coulomb IR losses.
  - Increase of the local beam losses due to the absorption/collimation of stray particles and tip-scattering.
- Graphite radiation length (*RL*) = 19.32 cm

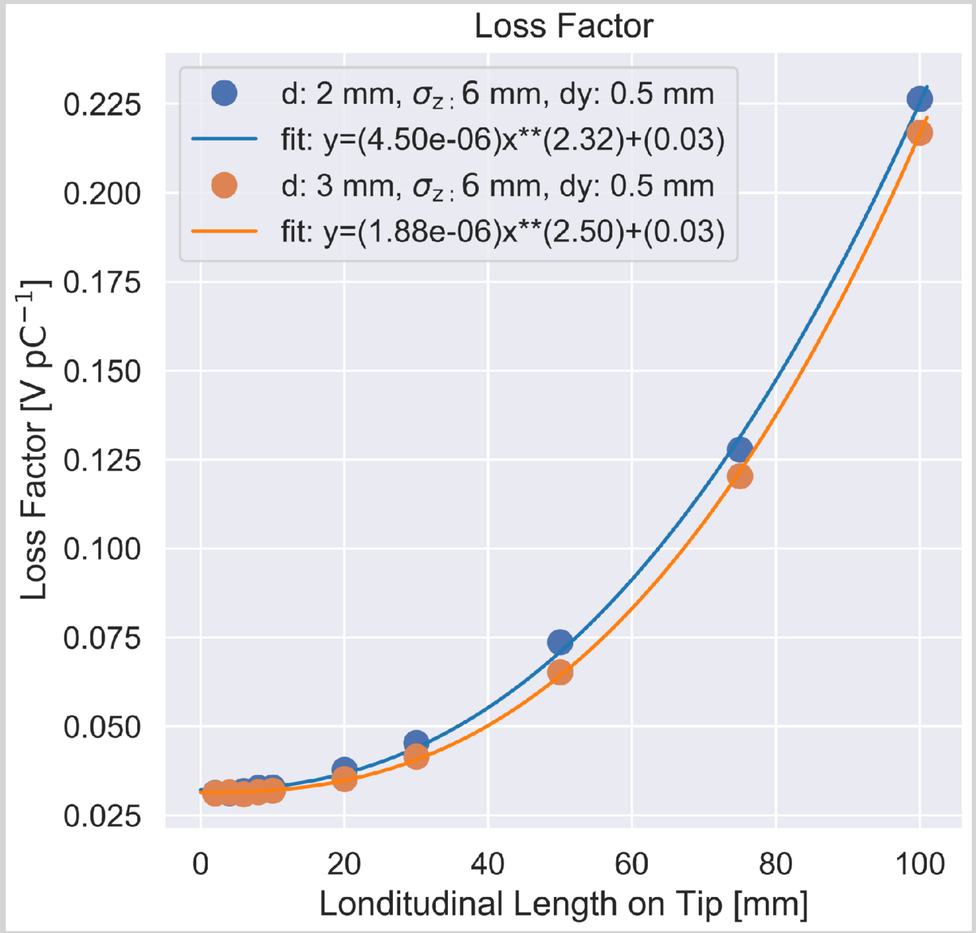
6

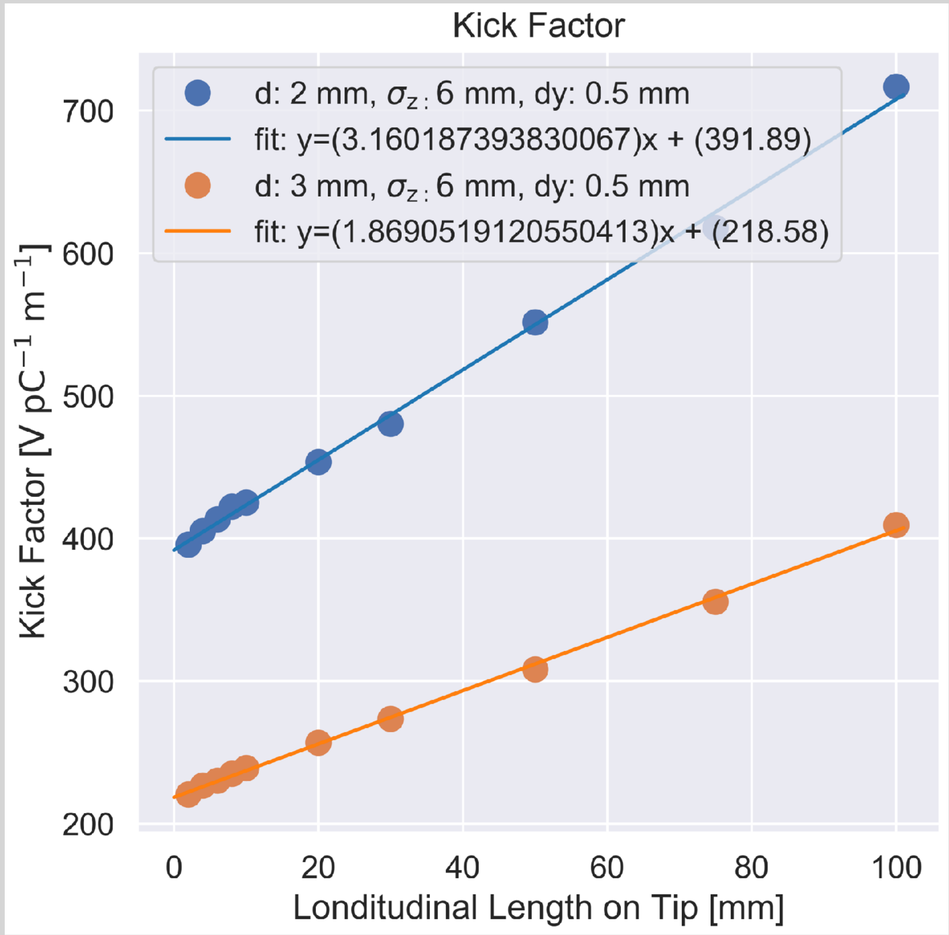
MDI meeting
2020-12-03
N. Andrii

(C: 1R.L. = 193.2 mm)
(Ta: 1R.L. = 4.094 mm)

Short tip jaw - kick factor

- The kick factor of the 2 mm tip is ~7% smaller than that of the 10 mm tip.
- The kick factor of the 2 mm tip is ~30% smaller than that of the 50 mm tip.





TMCI rough estimation

LER (Design: 1.44 mA/bunch)

$I_{\mathrm{b,th}} \approx 0.59$ mA/bunch

Collimator	β_y [m]	aperture [mm]	# of σ_y	k_T [V/pC/m]a)
D06V1	61.44	±1.4	61	706
D06V2	19.24	±1.3	101	764
D03V1	16.96	±1.0	83	1294
D02V1	111.75	±2.4	77	310
QC1(1.12 m)	2686	13.5	89	

Optics: sler_1704 (β_y^* = 0.27 mm, ε_y = 8.64 pm)
sher_5780 (β_y^* = 0.30 mm, ε_y = 12.9 pm)

a) Kick factors were calculated with GdfidL (σ_z = 6 mm).
Collimator model:
D06V1-V2, D03V1, D02V1, D01V1:
SuperKEKB type (L: 5 mm, W: 12)
D09V1-V4, D12V1-V4:
KEKB type (L: 40 mm, W: 50 mm)

HER (Design: 1.04 mA/bunch)

$I_{\mathrm{b,th}} \approx 0.76$ mA/bunch

Collimator	β_y [m]	aperture [mm]	# of σ_y	k_T [V/pC/m]a)
D09V1	15.47	-0.8	57	1670
D09V2	19.44	-1.5	95	826
D09V3	15.47	-0.9	64	1463
D09V4	16.74	-1.7	116	718
D12V1	16.74	2.0	136	598
D12V2	15.47	-1.1	78	1168
D12V3	15.47	0.9	64	1463
D12V4	19.44	-1.5	95	826
D01V1	153.19	±2.0	45	412
QC1(-1.16 m)	4390	13.5	57	

Note that the design bunch length in HER is not 6 mm but 5 mm.

$$k_{\mathrm{T}}(0.005)/k_{\mathrm{T}}(0.006) \approx 1.2$$
$$\longrightarrow \quad I_{\mathrm{b,th}} \approx 0.63 \text{ mA/bunch}$$

$$I_{\mathrm{b,th}} = \frac{C_1 f_{\mathrm{s}} E/e}{\sum_i \beta_i k_{\mathrm{T},i}(\sigma_z)}$$

[Handbook of Accelerator Physics and Engineering 3rd Printing (2009)]

LER: $C_1 \approx 8$, $f_{\mathrm{s}} = 2.13$ [kHz], $E/e = 4$ [GV]
HER: $C_1 \approx 8$, $f_{\mathrm{s}} = 2.8$ [kHz], $E/e = 7$ [GV]