Beam collimators and transverse mode coupling instability

2021 EIC Accelerator Partnership Workshop

2021-10-27

KEKB: Lessons from SuperKEKB

Takuya Ishibashi and Michael Blaskiewicz

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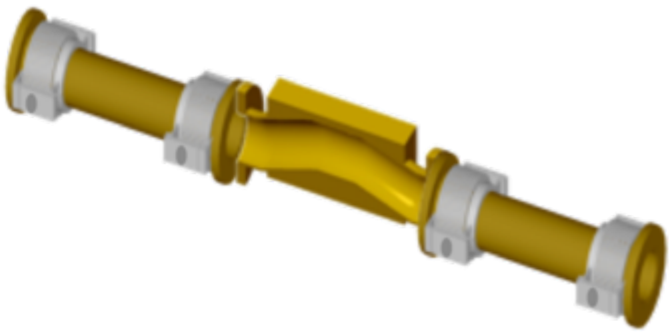
  - Non-linear collimator at LER OHO section (during Long Shutdown-1 in 2022)
- Synchro-betatron instabilites in the LER [Michael Blaskiewicz]
- Summary

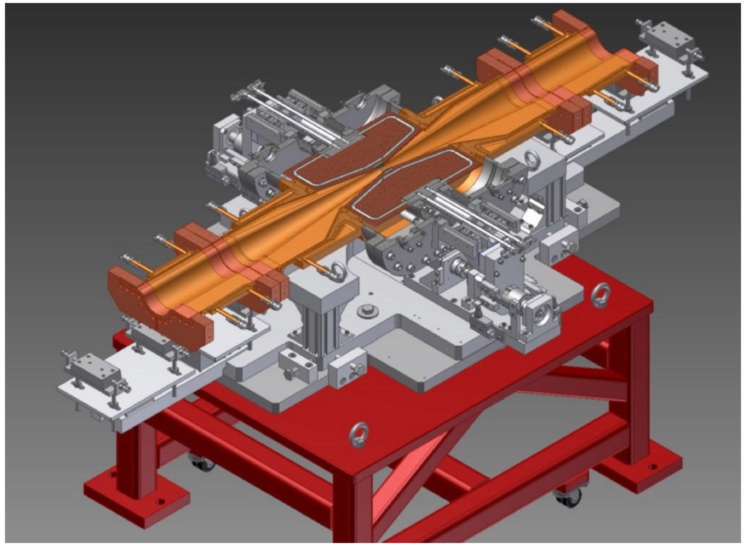
Beam collimators in SuperKEKB

- There are two types of collimators in SuperKEKB MR.
  - KEKB type: Tapered chamber itself approaches the beam. The tip is made of Cu coated titanium.
  - SuperKEKB type: A chamber has two movable jaws, and they approaches the beam.
- In HER, 8 horizontal and 8 vertical KEKB type collimators have been reused at the same location as KEKB era. 3 horizontal and 1 vertical SuperKEKB type collimators have been installed in Tsukuba straight section.
- In LER, 7 horizontal and 4 vertical SuperKEKB type collimators have been installed.



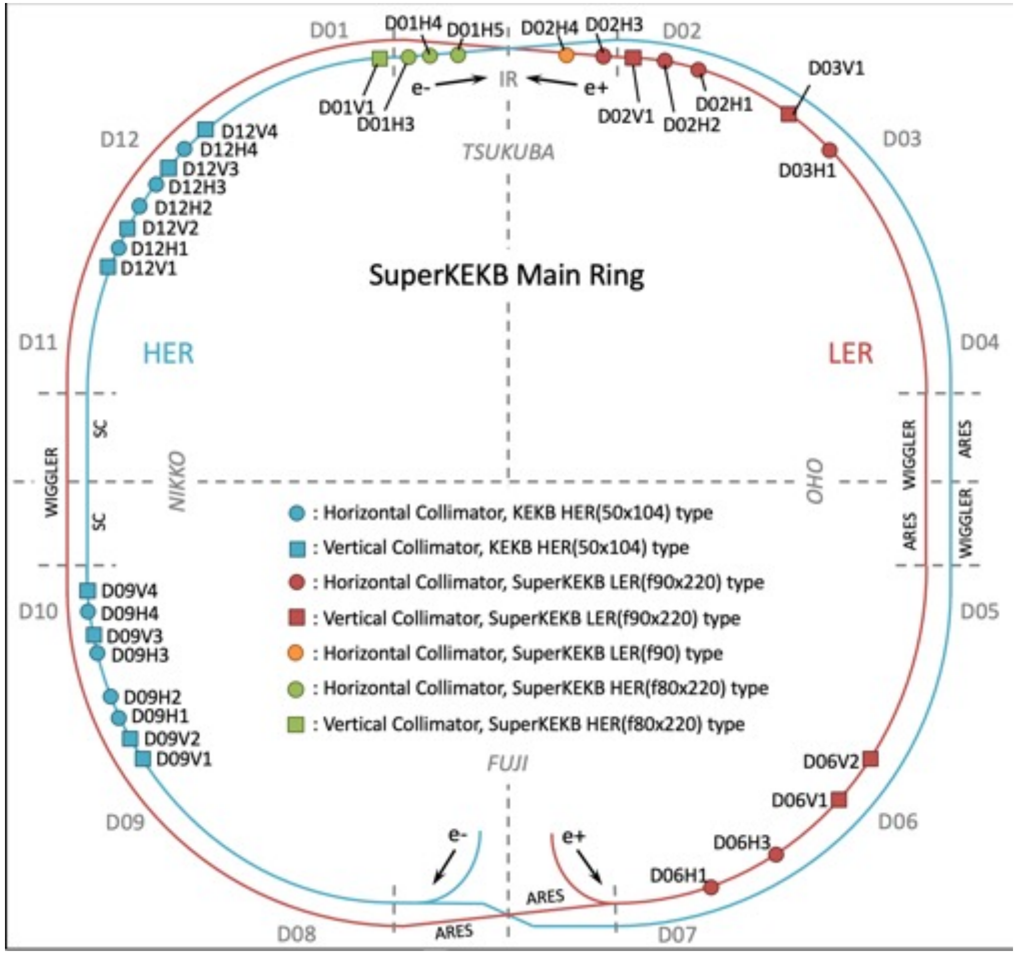
KEKB type

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



SuperKEKB type

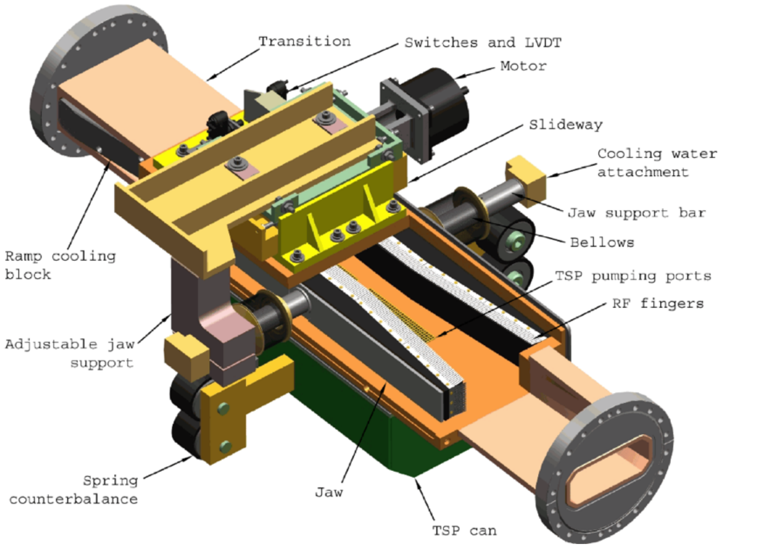
[T. Ishibashi et al., PRAB 23, 053501 (2020)]



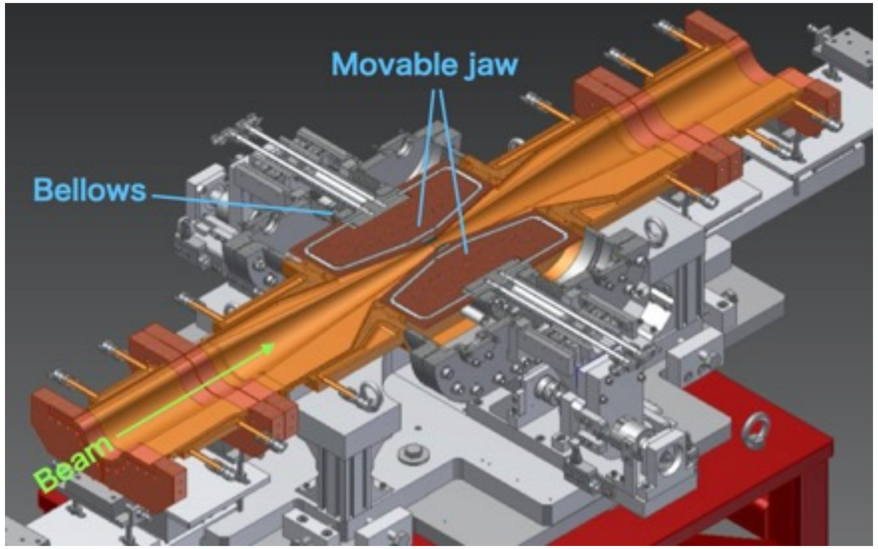
Location of collimators in MR

Design

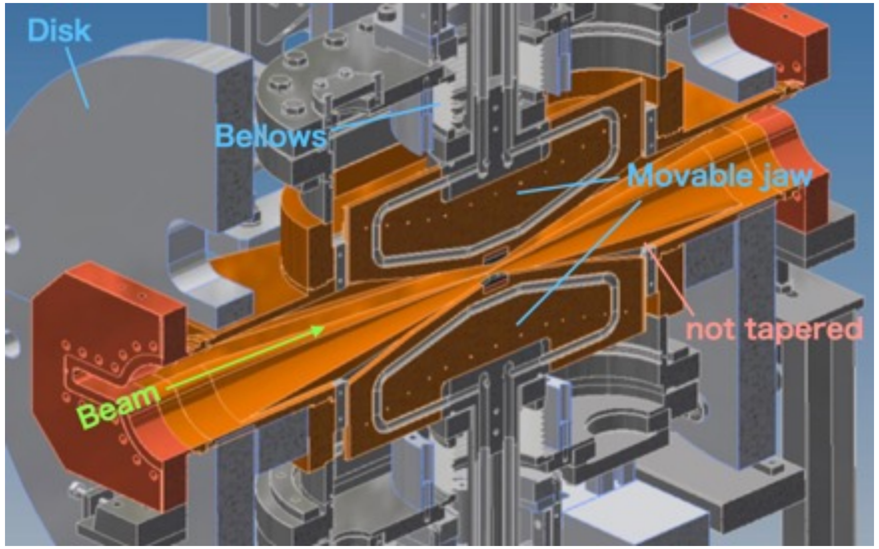
- We referenced movable collimators for PEP-II in SLAC for the basic design of the SuperKEKB type.
- A collimator chamber has two movable jaws, which are placed the horizontal/vertical direction.
- Part of the movable jaws is hidden inside the antechambers to avoid a trapped mode in gaps between the movable jaw and the chamber.
- The chamber is tapered to the center of the collimator in order to avoid excitation of trapped-modes.
- Materials at the tip of the jaws are tungsten (1st ver.), tantalum (2nd ver.), and carbon (low-Z, special ver.).



Collimator in PEP-II
[S. DeBarger et al., SLAC-PUB-11752]



Horizontal direction



Vertical direction

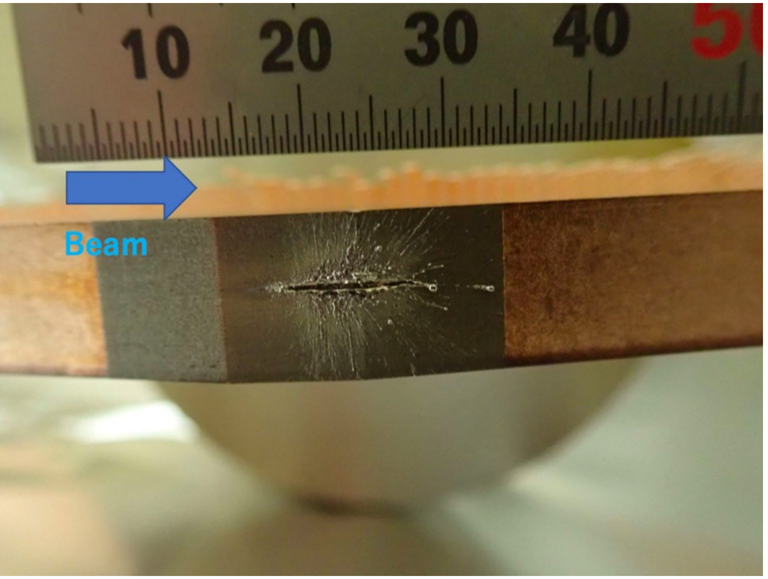
SuperKEKB type collimator

Issue – Damage

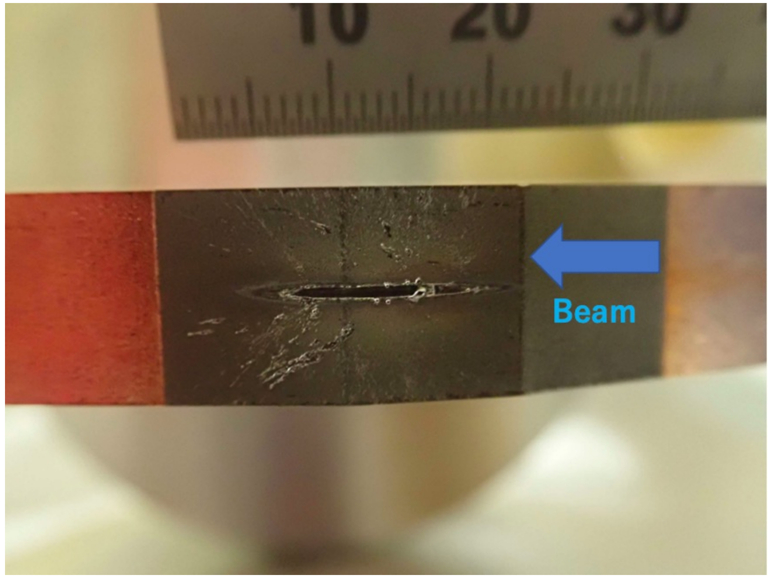
* short tantalum tip which has 5 mm.

- Jaws of the collimators were damaged by beam hit.
  - LER: D02V1 (2021ab), D06V1(2021ab)*, D06V1 (2020ab)*, D06V2 (2019c), D02V1 (2019ab), D02V1 (Phase-2)
  - HER: D01V1 (Phase-2)
- A huge beam loss and pressure burst has happened near them with a QCS quench .
- The damaged tungsten tip has embrittled. For the tantalum tip, it did not embrittle.
- The cause is unknown. A candidate is an interaction between the beam and a dust in the beam pipes.
- The damaged jaws of D02V1 were replaced once during 2020c and 2021b because of the high BG level.

[S. Terui]



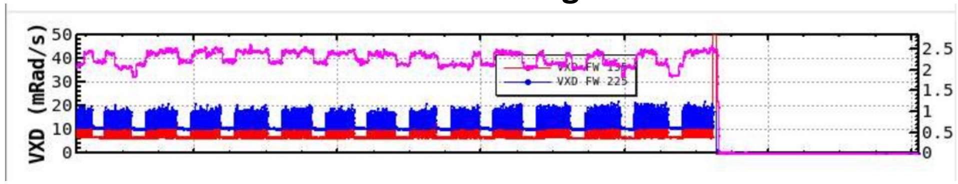
D02V1 bottom side (38 µSv/h)



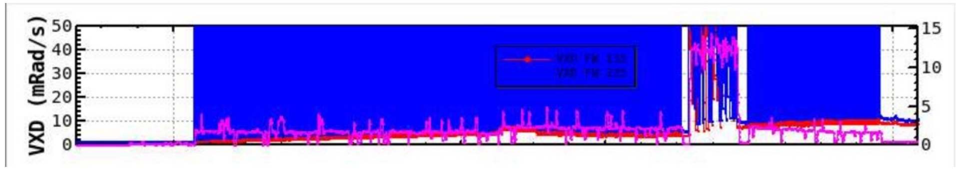
D02V1 top side (95 µSv/h)

taken on 2021-06-08

Before damage



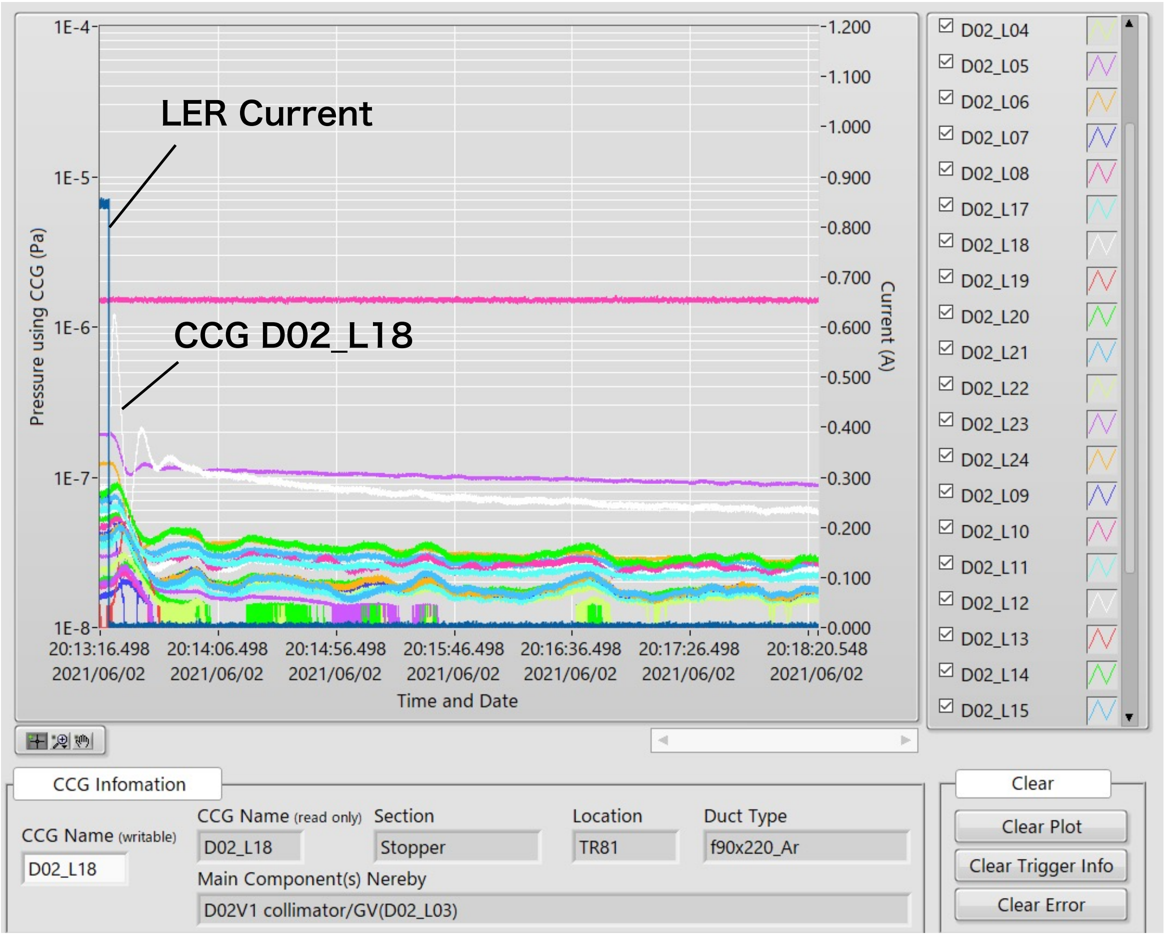
After damage



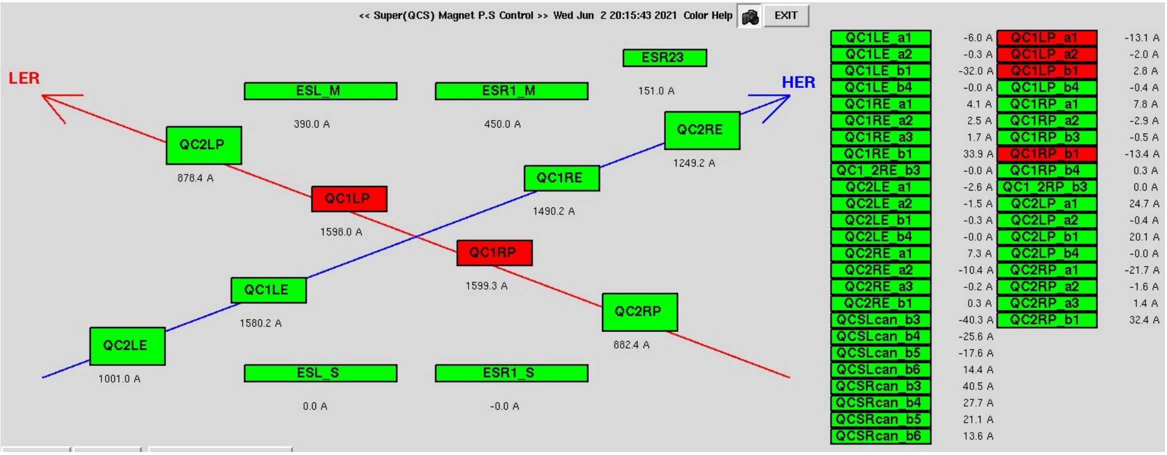
Issue – Damage

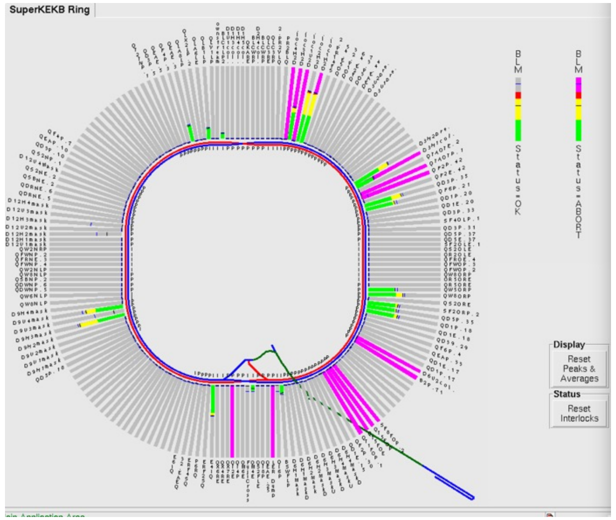
- In case of a damaged event in 2021-06-02 20:13 (2021b run).
- Pressure near CCG D02_L18 and D06_L12, which are placed near D02V1 and D06V1 collimator respectively, was increased instantaneously (beam hit the jaws probably).
- QCS quench happened (QC1LP, QC1RP in LER).

Pressure and beam current



Status of QCS

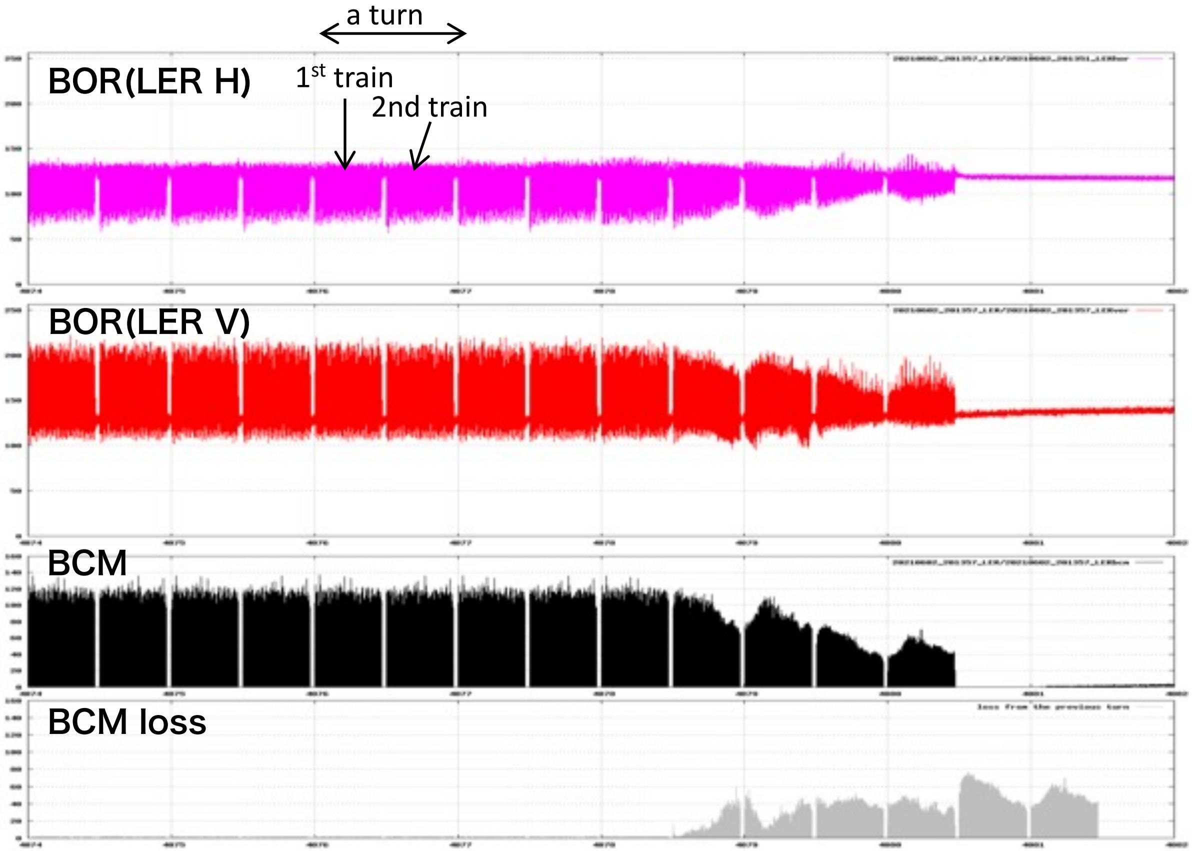




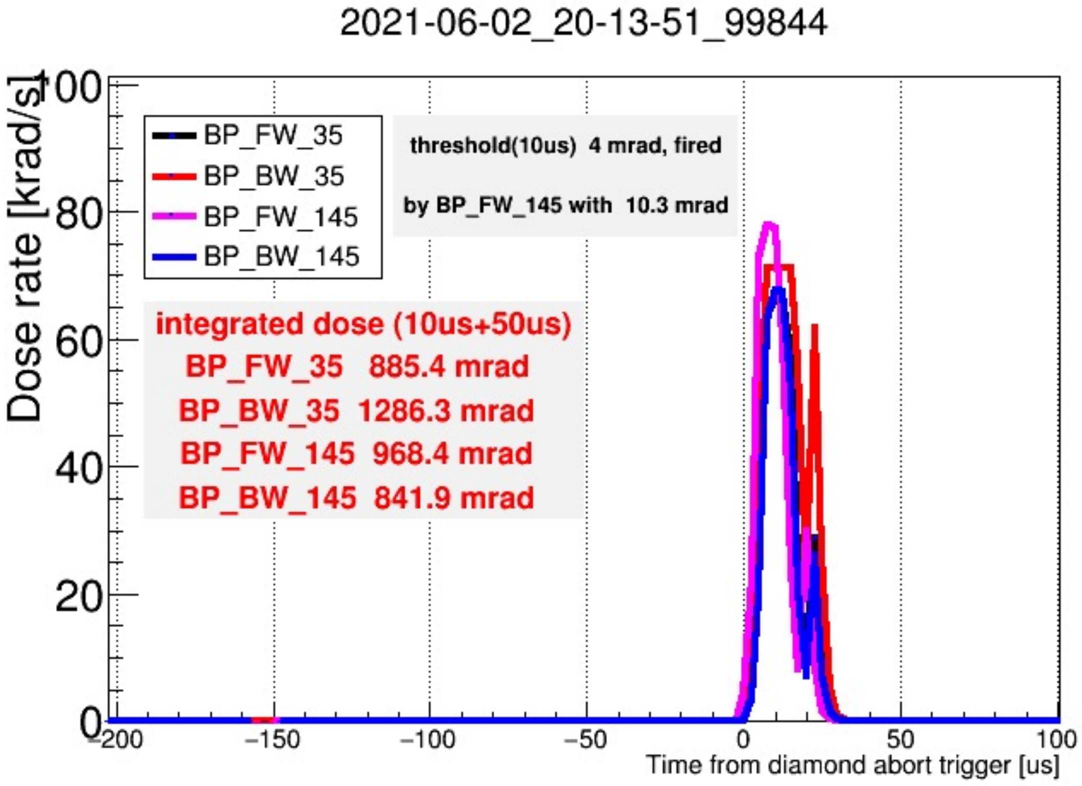
Loss monitors in the rings

Issue – Damage

- Sudden beam loss happened within 2-turn before the beam abort.
- Dose on VXD diamond sensors of Belle II were extremely high and the signal saturated (usual beam loss abort: ~50 mRad or less).
- The cause of the huge beam loss is unknown so far. One of the candidates is the interaction between the beam and a dust in the beam pipe.
    - Results of simulations indicate that the beam loses at not the vertical collimators but the horizontal collimators mainly [Y. Funakoshi].



Bunch oscillation recorder (BOR) and bunch current monitor (BCM), BOR signal is proportional to (bunch displacement)×(bunch intensity).



Dose in VXD diamond sensors of Belle II

Issue – Beam size blowup in LER (TMCI)

- We've observed beam size blowup in LER at low bunch current (~1.0 mA/bunch).

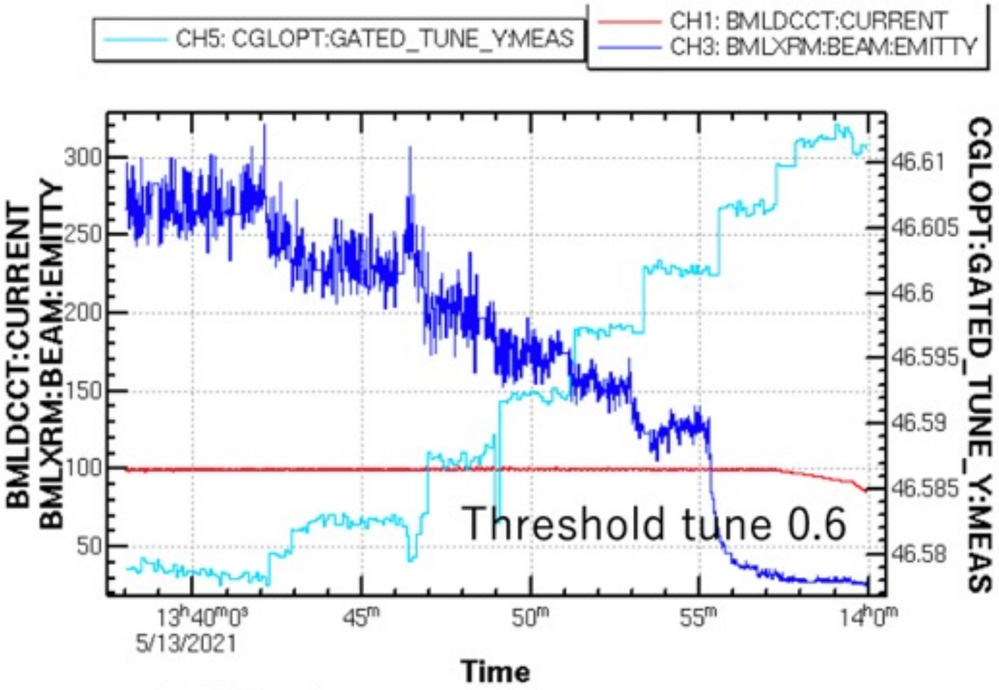
LER measurement at May 13

[K. Ohmi et al.]

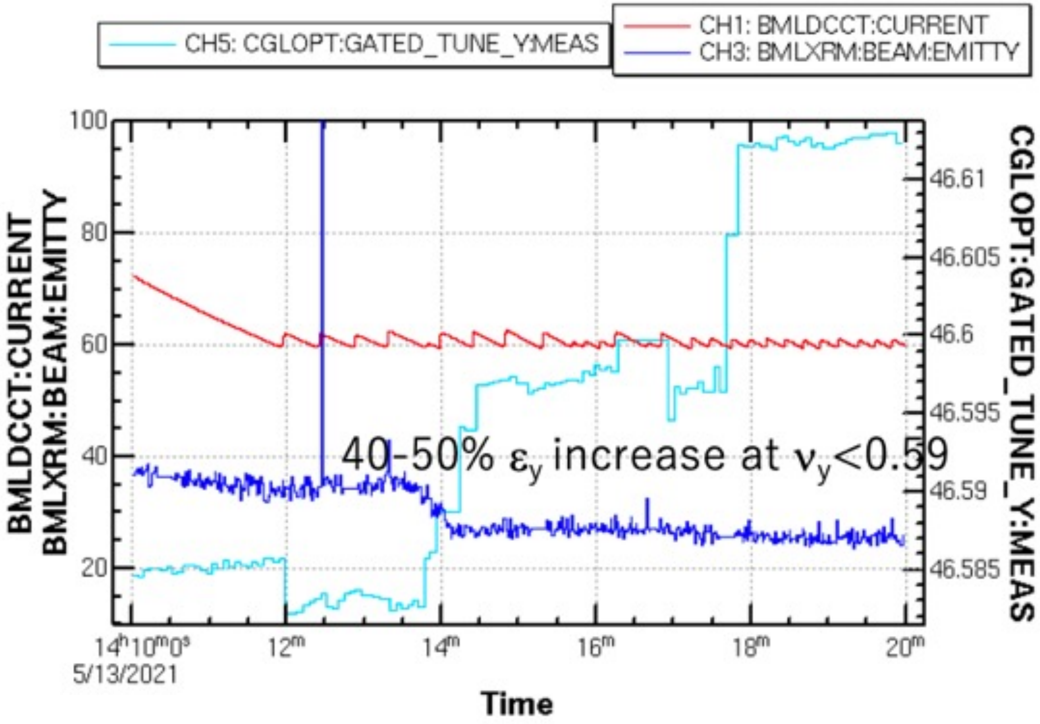
$d\nu_y/dI = 0.008/\mathrm{mA}$

- 97 bunches
- Keep current scan V-tune 0.570-0.610

100mA



60mA



BOR data taking

Emittance blow up was seen at 1mA/bunch.

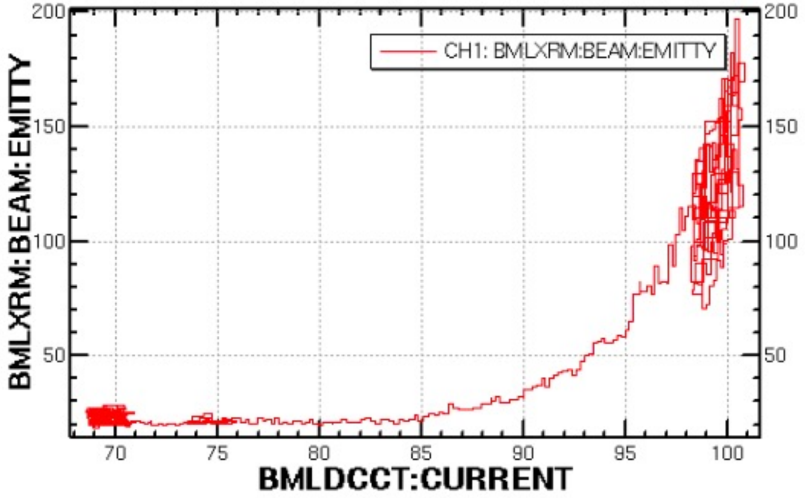
Issue – Beam size blowup in LER (TMCI)

[K. Ohmi et al.]

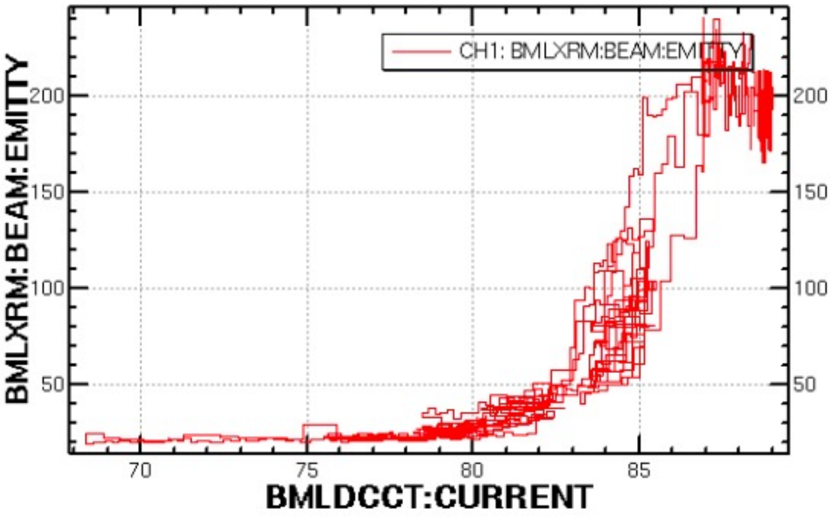
Threshold change for Collimator gap

ν_y=0.59

Kβ=36x10[15] V/c



Kβ=41.6x10[15] V/c

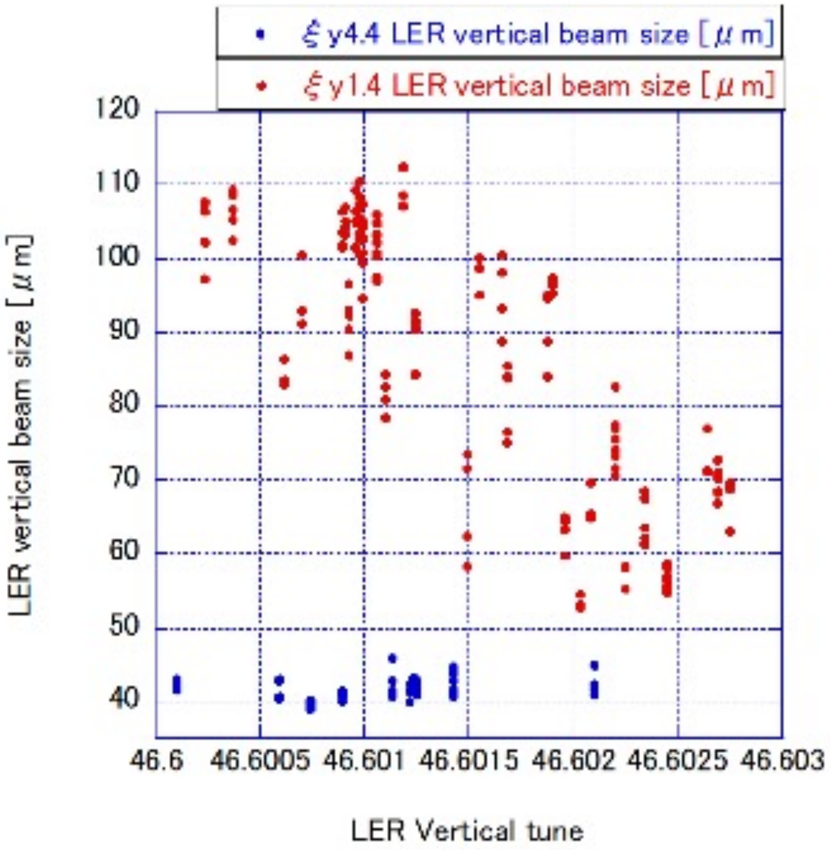


- The threshold almost scales to KβI.
- The emittance growth seems to be due to TMCI, though not ordinary TMCI.

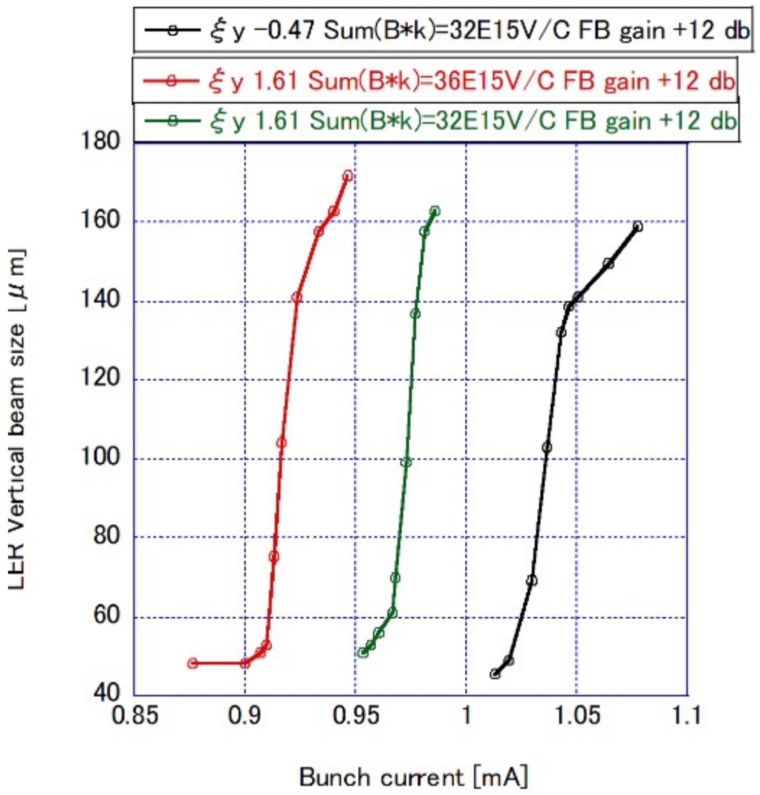
Issue – Beam size blowup in LER (TMCI)

[S. Terui et al.]

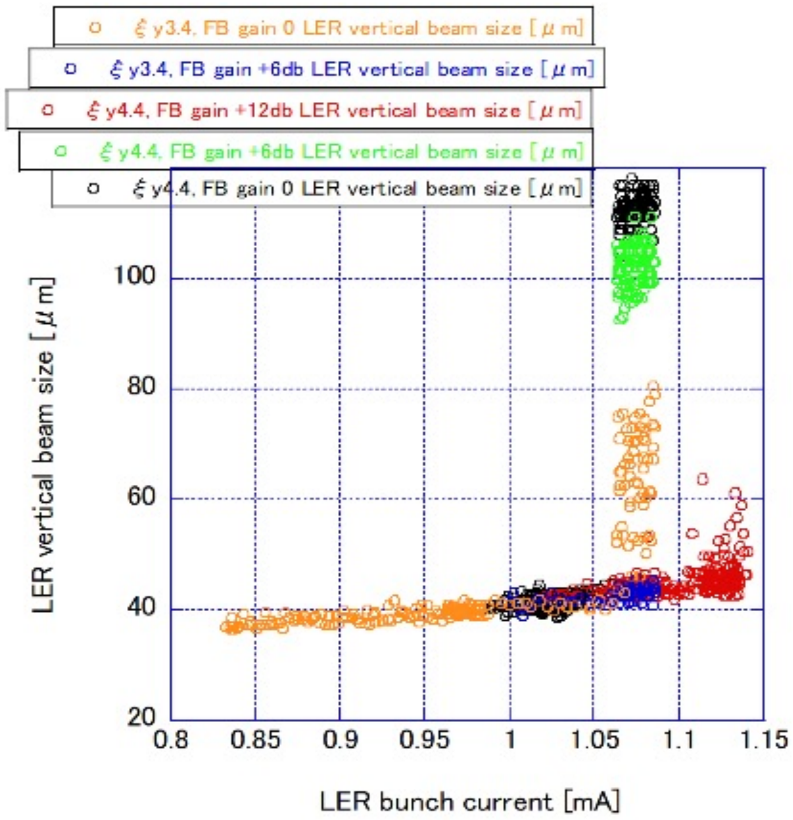
Change chromaticity



Change chromaticity and collimator's aperture



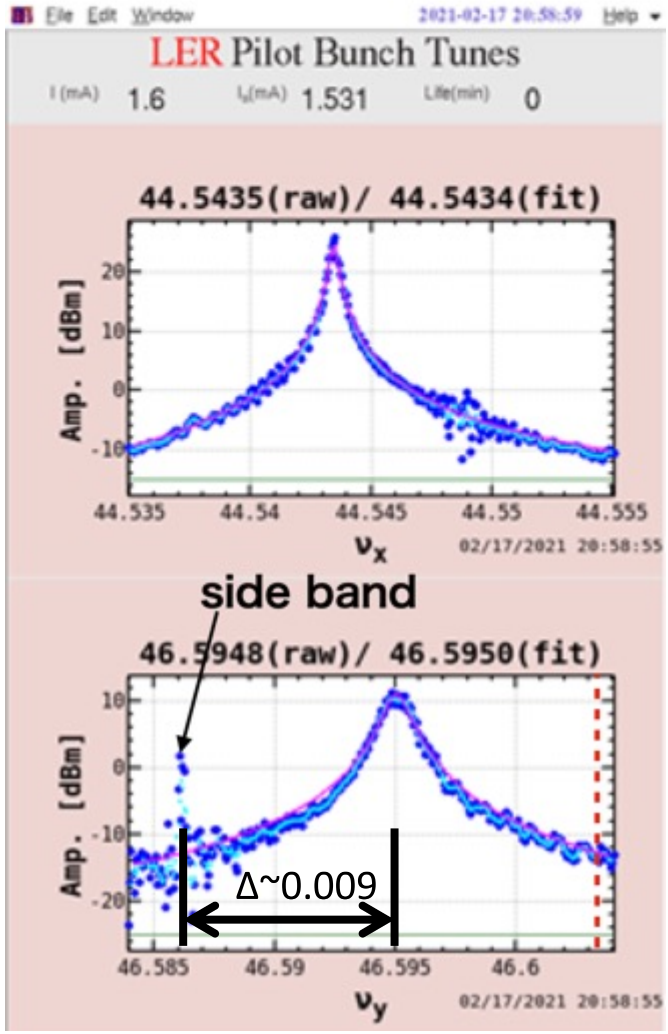
Change chromaticity and FB gain



- The beam size blowup can be suppressed by increasing the vertical chromaticity.
- The threshold of the blowup increases with the negative chromaticity.
- The blowup can be suppressed by increasing the feedback gain.

Issue – Beam size blowup in LER (TMCI)

- We can accumulate ~1.5 mA/bunch at least.
- We‘ve not observed the coupling of the modes 0 and -1 yet.
- We‘ve observed the vertical beam size blowup before the coupling.



2021-02-17
βy* = 8 mm, single-bunch operation

Tune shift: ~0.008 mA^{-1}
ν_y ~ 0.595 @ 1.6 mA/bunch

We were not able to inject up to ~1.7 mA/bunch (rep. rate 1 Hz).
TMCI threshold (calc.): ~1.77 mA/bunch

D02V1: 2.17 mm, -1.8 mm, D03V1: ±9 mm,
D06V1: ±2 mm, D06V2: ±9 mm

Issue – Beam size blowup in LER (TMCI)

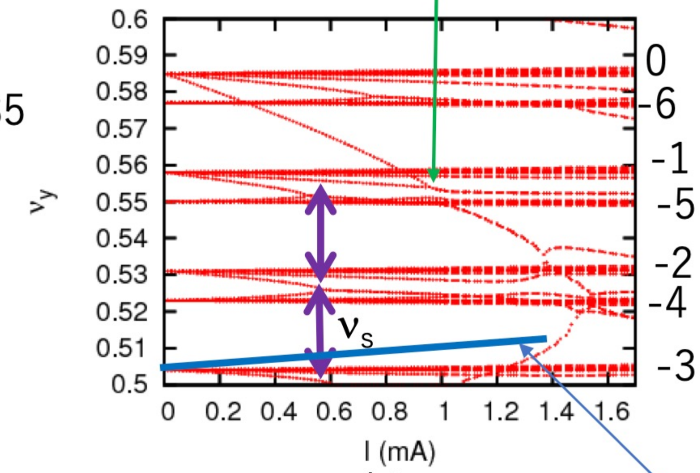
[K. Ohmi]

Mode coupling for localized wake

- In ordinary mode coupling, the betatron tune does not have meaning, but only tune different between sidebands, ns has meaning.
- In mode coupling due to a localized wake, the betatron tune has meaning. Sideband modes wrapped at 0.5.

Broad band resonator wake 50GHz, Q=1, no x-y coupling

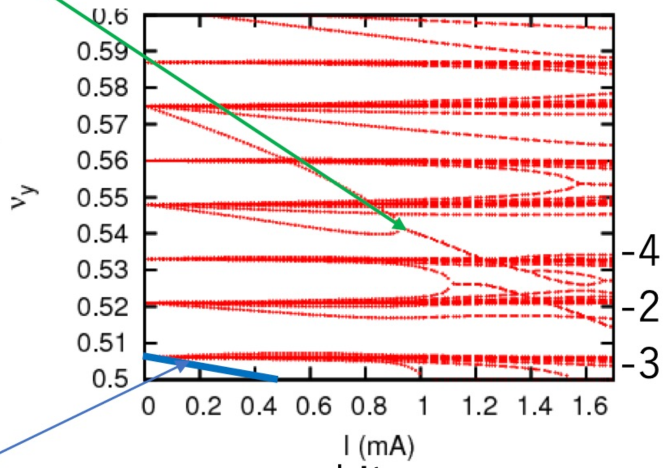
ν_y=0.585



arbitrary

$2\nu_y$-$6\nu_s$ resonance

ν_y=0.575



arbitrary

Experiments showed lower ν_y was worse.

This wake induces negative tune shift for -3 mode.
Positive tune shift is preferred to explain experimental results

Issue – Beam size blowup in LER (TMCI)

- Summary of TMCI in LER
  - We can accumulate the bunch current up to calculated value using a broad impedance model, however we've observed the vertical beam size blowup around ~60% of the calculated values.
  - The bunch current threshold about the beam size blowup depends on the tune and the chromaticity.
    - Proper vertical tune and/or higher chromaticity can increase the threshold.
    - Since the threshold in the ordinary TMCI doesn't depend on the tune, the beam size blowup can be caused by the localized wake in the vertical collimators.
    - We've not observed the coupling of the modes 0 and -1, so K. Ohmi has suggested that we should observe this, which is the ordinary TMCI, in a higher vertical tune ($\nu_y > 0.6$).
  - The beam size blowup has been observed for the single-beam operation (no collision). We've observed a beam size blowup in LER with the collision, and it has been caused by the beam-beam because the beam size depends on not the collimators' aperture but the current balance between LER and HER. We've not been able to accumulate the bunch current till the TMCI threshold with the collision so far.
  - The threshold of the blowup may increase at least up to ~0.9-1.0 mA with present collimator setting by choosing the vertical tune and/or the vertical chromaticity.
  - For higher beam current operation assuming $L=1\times10^{35}$ cm^{-2} s^{-1}, a bunch current more than 1.0 mA will be needed for LER, so this beam size blowup by TMCI may be more serious.
  - There is a possibility that the tune to avoid the blowup is not good for the luminosity performance.
    - D. Zhou's strong-strong beam-beam simulation has predicted that the luminosity will increase by 10% by moving from the present tune to the designed tune $(\nu_x, \nu_y)=(.53, .57)$.

EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH

CERN-LEP-TH/84-21

TRANSVERSE MODE COUPLING INSTABILITY DUE TO LOCALIZED STRUCTURES

F. Ruggiero

Geneva, November 1984

ABSTRACT

A relativistic charged particle passing through localized structures of a storage ring, like RF-cavities, induces electromagnetic wakefields which react on the following particles. If the beam current is increased beyond a threshold value, this phenomenon leads to a fast single bunch instability generally described in terms of transverse mode coupling.

Starting from the Vlasov equation for a simplified model of electron-positron machine, we show the existence of instability stop-bands at currents below threshold, which are due to the coupling between high order and low order dipole modes. Since the global effect of wakefields is represented by a transverse kick localized at a single point of the machine, the stop-band pattern repeats periodically every half-integer in the betatron tune ν_z. Denoting the synchrotron tune by ν_s and for ν_z in the range [0, 1/2], the bunch may become unstable at very low currents when ν_z approaches the resonant values $\nu_z = n\,\nu_s$ or $\nu_z = 1/2 - n\,\nu_s$.

Issue – Beam size blowup in LER (TMCI)

- (Example) parameter sets for L=1×10^{35} cm^{-2} s^{-1}.

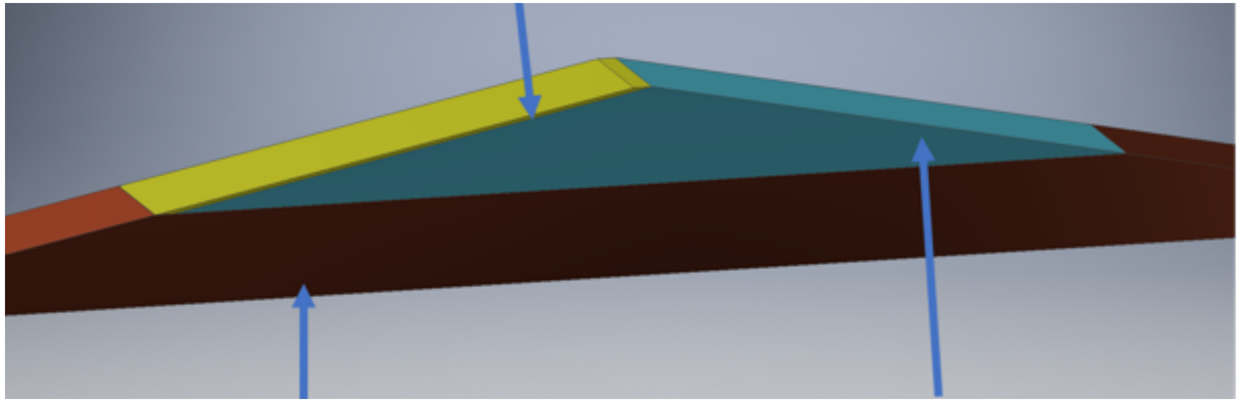
[Y. Funakoshi]

	LER	HER	LER	HER
# of bunches	1564+1		2345+1	
Luminosity	4.79 x 10^{34} $cm^{-2}s^{-1}$		1.0 x 10^{35} $cm^{-2}s^{-1}$	
I_{total}	1.41 A	0.986 A	2.35 A	1.64 A
I_{bunch}	0.898 mA	0.630 mA	1.0 mA	0.7 mA
βy*	1 mm	1 mm	0.8 mm	0.8 mm

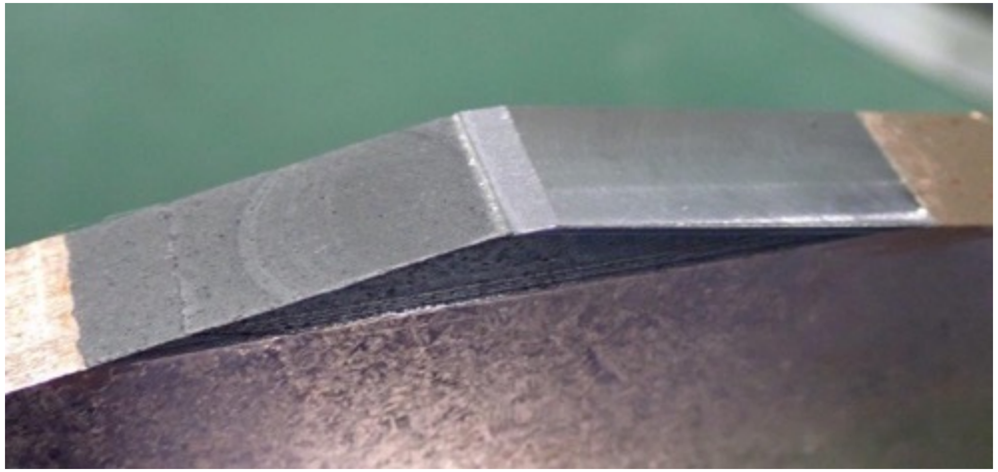
Plan – R&D of durable jaws (hybrid jaw)

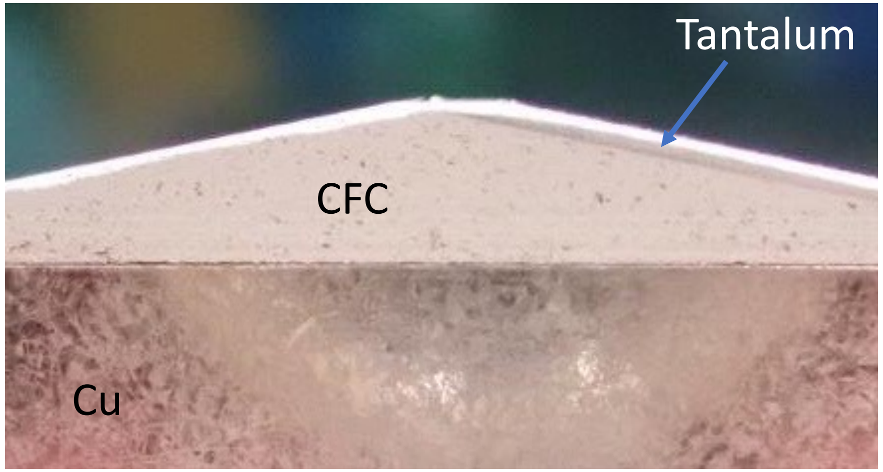
- We installed hybrid type jaws in D06V2 during this summer shutdown for the test purpose. The tip is made from carbon and tantalum in order to improve the robustness regarding to the beam hit.
- It could be difficult to form the protrusions on the tip.

Model

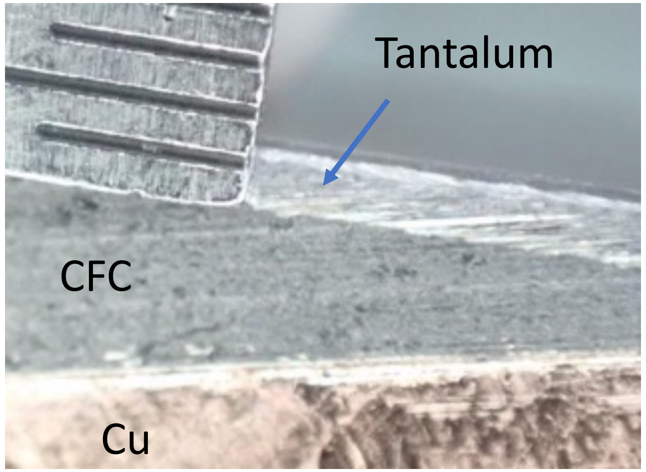


Actual





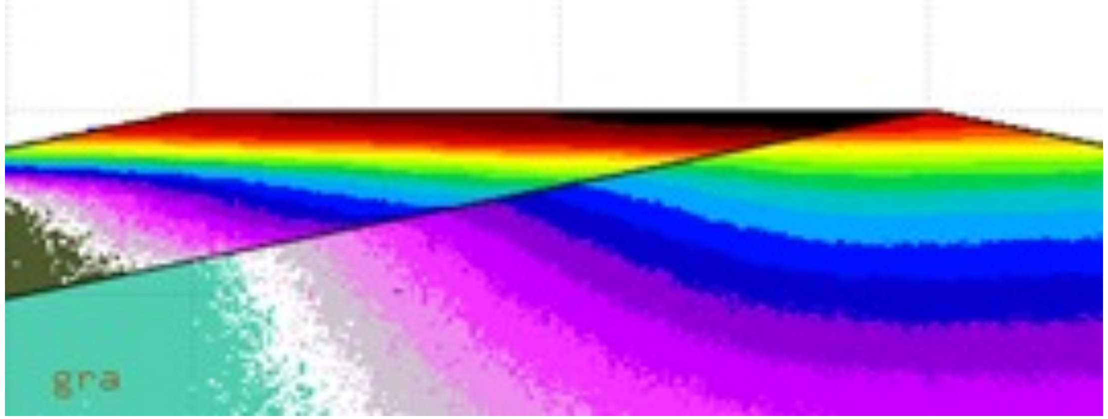
Cu plate



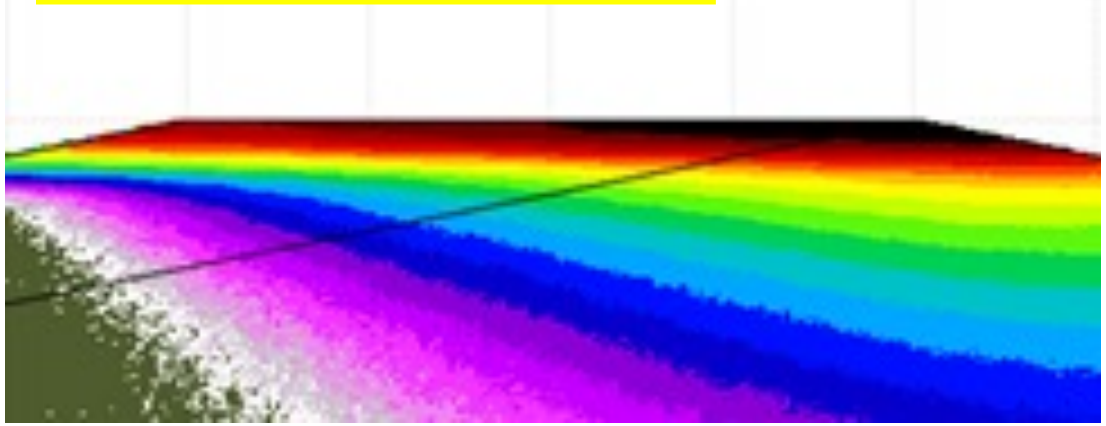
Plan – R&D of durable jaws (hybrid jaw)

[Y. Morikawa, S. Terui]

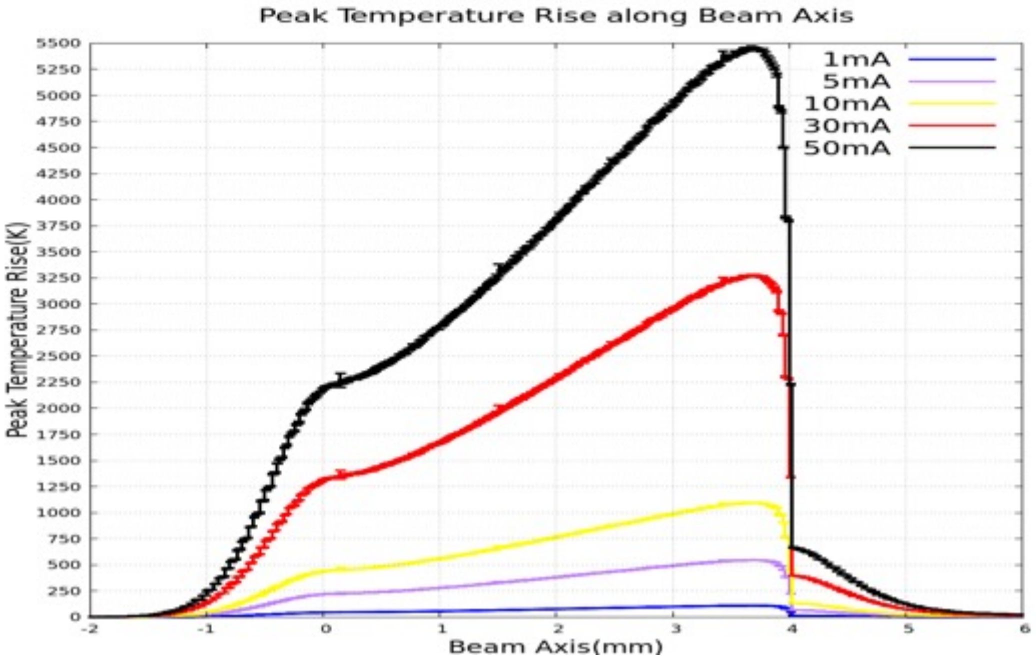
Temperature Rise(1mA)-Hybrid type

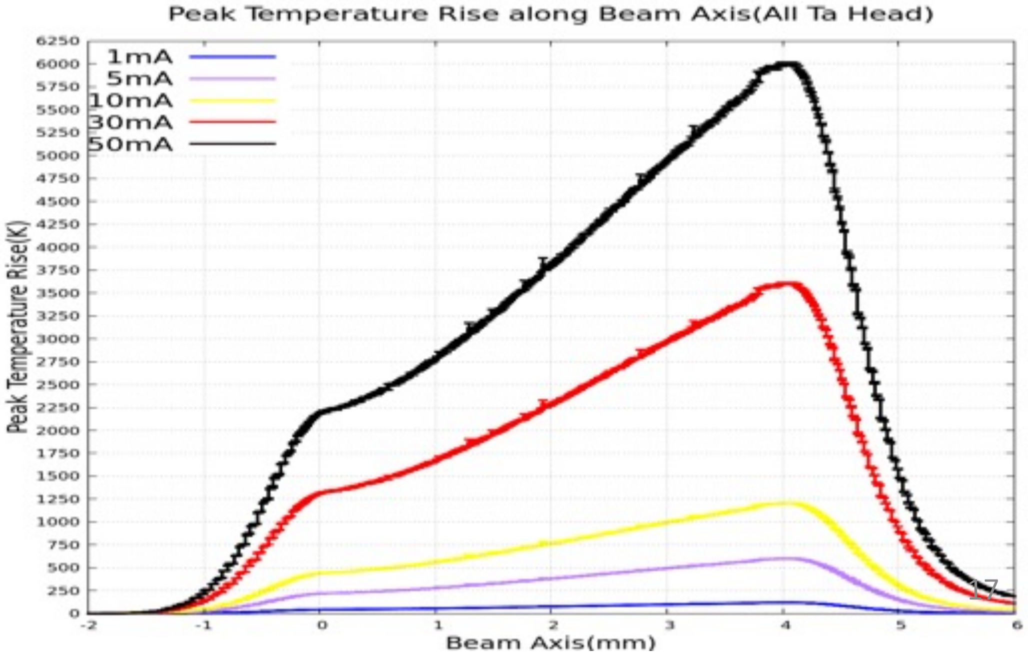


Temperature Rise(1mA)-All Ta



When 30 mA beam hits the jaw, the volume of the melting tantalum is 68 % less compared to the standard jaw. This might relax the bad effect on the background (durable jaw?).





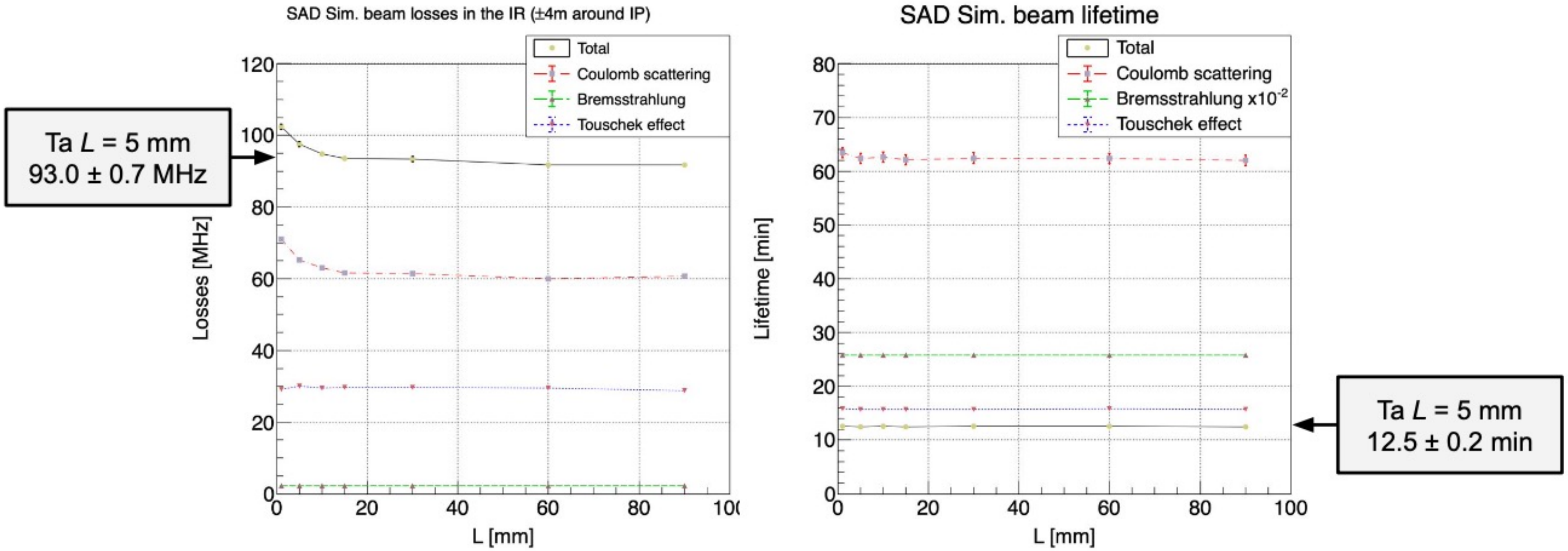
Plan – R&D of durable jaws (titanium jaw)

- High-Z (Ta/W)
  - The radiation length is short (Ta: 0.41 cm, W: 0.35 cm), and we can decrease the length at the tip of the jaw to a few mm.
  - The electric conductivity is acceptable (Ta: 7.61e6 S/m, W: 18.9e6 S/m). [Ref. Cu: 59.6e6 S/m]
  - Easy to damage.
  - Large effect to raise the IR background when it's damaged (This is derived from the mass density of the protrusions on the tip surface?)
  - Generate radioactive dusts when it's damaged. Radiation Science Center has commented that the half-life time of the Ta may be longer compared to that of W. However, it's very easy to generate the dusts for W when it's damaged…
  - In the future, the radioactivity can limit the replacement work. We may have to wait the decay of the radioactivity and be not able to replace during runs.
- Low-Z (Carbon)
  - The radiation length is long (C: 19.32 cm) . We need longer tip (>60 mm) to shield the halo, and this raise the geometrical impedance.
  - The electric conductivity is very low (C: 3e5 S/m), and the resistive wall also raises the impedance. However, we can avoid this by adopting Cu plate on the carbon.
  - The melting point is high.
  - Very difficult to damage.
- Mid-Z (Ti)
  - The radiation length is intermediate (Ti: 3.56 cm), and we can adopt a dozen mm for the tip length.
  - The electric conductivity is acceptable (Ti: 2.38e6 S/m). If we need Cu plating, we can do it as with the jaws of KEKB type collimators.
  - Easy to damage from the experiences of KEKB type collimators in HER.
  - Nevertheless, we've used damaged Ti jaws in HER without major impact on the IR backgrounds. (This is derived from the mass density?)

  (→ Titanium jaws may have good balance in terms of the durability and the impedance.)
  - Difficult to generate the radioactive dusts when it's damaged from the experiences of KEKB type collimators in HER.

D06V1 titanium head study by A. Natochii

LER D06V1 SAD sim. results



We expect the same IR BG level and beam lifetime for *L* = 10 mm of titanium D06V1 head compared to *L* = 5 mm of tantalum.

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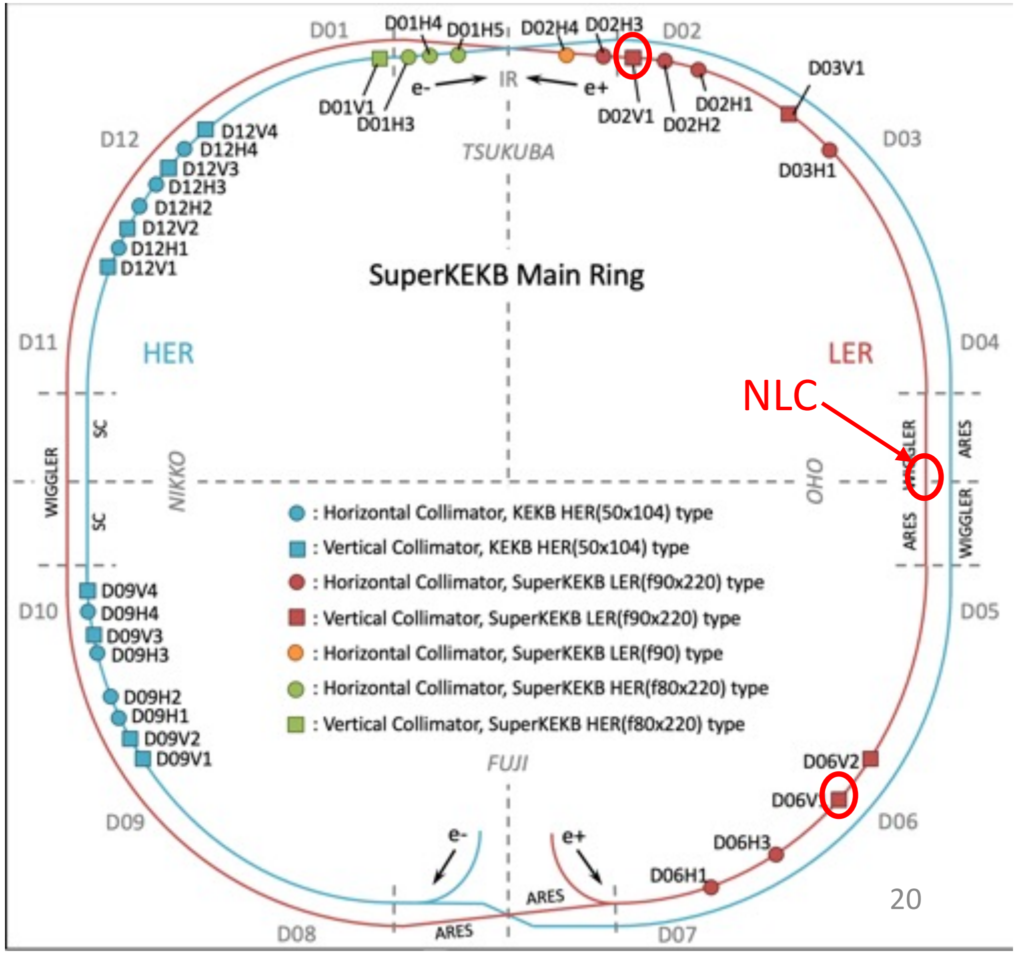
- We could also use the Ti-10 mm jaw in the non-linear collimator by A. Natochii's simulations.

Plan – Non-linear collimator at LER OHO section

- Present collimator setting (2021ab)
  - D06V1: primary collimator: most tightly closed and suppresses the injection BG.
  - D02V1: second collimator: closest vertical collimator to IP and very important to suppress BG
  - D06V2, D03V1: backup: not so tightly closed. D03V1 can be used for a backup of D02V1.

- If we can replace D06V1 collimator with non-linear collimator (NLC) for example, the $\Sigma\beta_y k_y$ dramatically decreases.

  (βy: vertical beta function, ky: vertical kick factor)



Plan – Non-linear collimator at LER OHO section

- Collimator setting (half-aperture) during physics run in 2021b (βy*=1 mm)

	β_y [m]	2021-06-30 [mm]	2021-07-02 [mm]
D06V1 top	67.3	3.06	3.84
D06V1 bottom		-2.65	-2.65
D06V2 top	20.6	2.27	2.25
D06V2 bottom		-2.26	-2.24
D03V1 top	17.0	8.00	7.99
D03V1 bottom		-8.00	-7.99
D02V1 top	13.9	1.30	1.71
D02V1 bottom		-1.14	-1.35
NLC@OHO	2.9	5.7	5.7

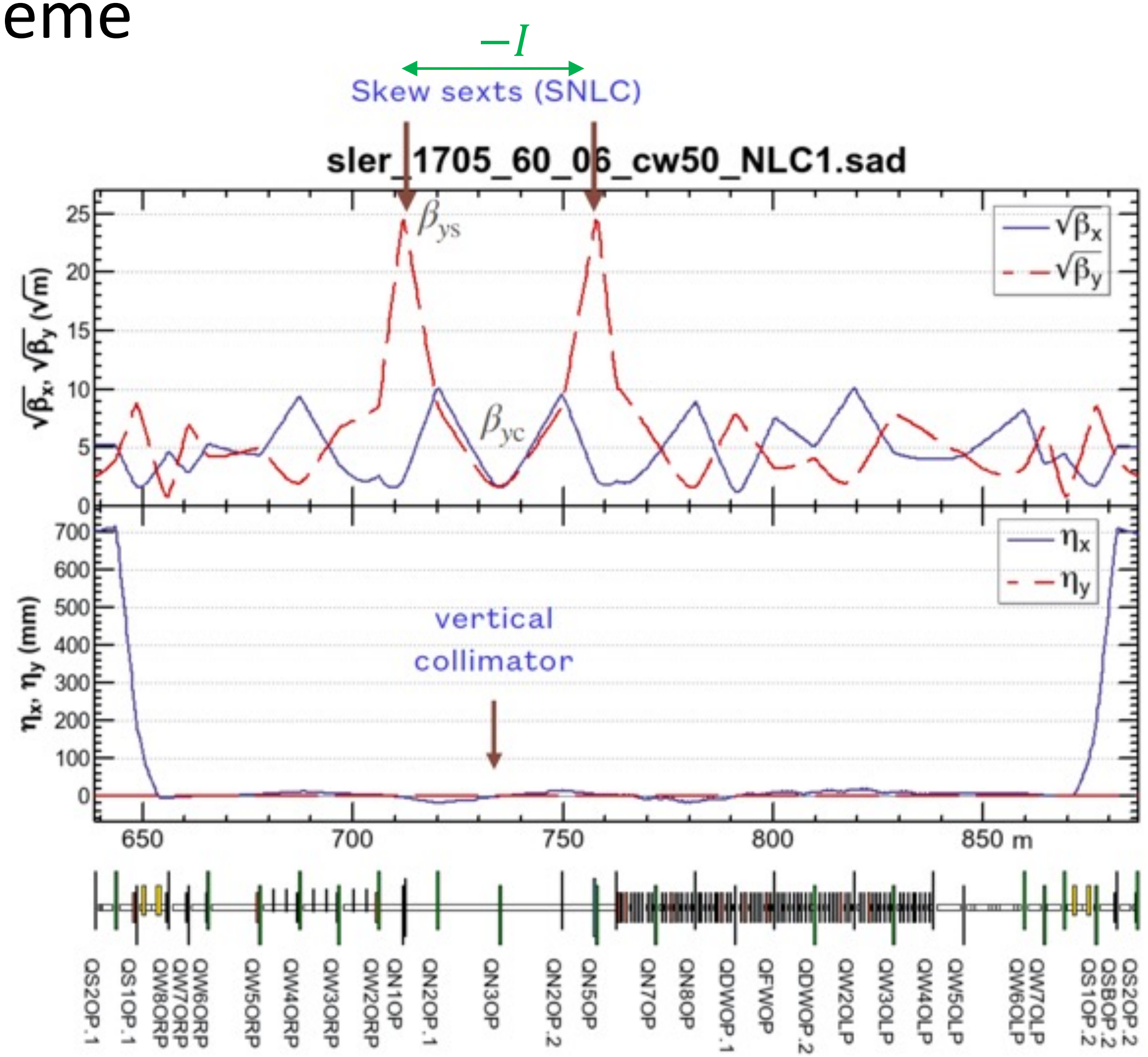
- The β_y at the D06V1 is large, and the aperture is narrow.
- The β_y at the NLC is small, and the aperture is wide.

→ can dramatically decrease the $\Sigma\beta_y k_y$ if we can replace D06V1 with NLC.

Plan – Non-linear collimator at LER OHO section

- Scheme

[K. Oide]



L_{sc}

$\Delta\mu_y = \frac{\pi}{2}$

Requirements for the NLC optics:

- Large $\beta_y = \beta_{ys}$ at the (skew) sextupole.
  - $\beta_y = \beta_{yc}$ at the collimator: $\sqrt{\beta_{yc}\beta_{ys}} \approx 1.7 \times L_{sc}$
- A (skew) sextupole pair connected by a $-I$ transformation.
- No dispersion at the sextupoles and the collimator.
- ≈ 0.25 vertical phase advance between the sexts and the IP.

Five sections of wigglers are removed!

Here the collimator is placed right before the center quad (QN3OP).
If the quad is split into two pieces, the collimator can be placed in the middle of them.

June 17, 2021 K. Oide

Plan – Non-linear collimator at LER OHO section

[K. Oide]

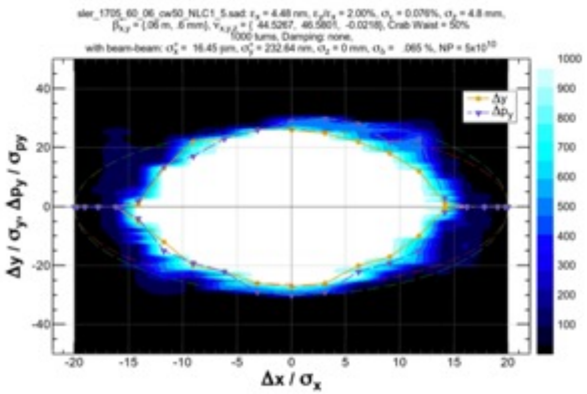
LER optics for (60,0.6) mm

CW = 50%

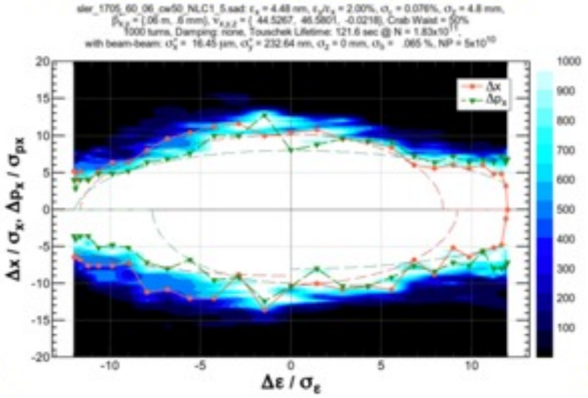
Requirements on the collimation

SuperKEKB

Dynamic aperture (X-Y) with NLC



Dynamic aperture (Z-X) with NLC



- Consider a collimation at a vertical amplitude y_q, which is equal to the *dynamic aperture*.
  - For the (60,0.6) mm optics, $y_q = 10.0\,\mathrm{mm}$ at QC1 ($30\sigma_y$ with $\varepsilon_y/\varepsilon_x = 2\%$).
- It is equivalent to $y_s = y_q\sqrt{\beta_{ys}/\beta_{yq}} = 6.8\,\mathrm{mm}$ at the NLC skew sextupole SNLC.
- The sextupole kicks the beam vertically by

$$\Delta p_{ys} = \frac{s'}{2}(y_s^2 - x_s^2)\,, \tag{1}$$

$$s' \equiv \frac{L_s}{B\rho}\frac{\partial^2 B_x}{\partial y^2}\,. \tag{2}$$

  - For instance, $s' = 6.0/\mathrm{m}^2$, $\Delta p_{ys} = 0.14\,\mathrm{mrad}$, with $|y_s| \gg |x_s|$.
- Then the kick makes a vertical displacement at the collimator:

$$\Delta y_c = R_{34}\Delta p_{ys} = 5.7\,\mathrm{mm} \tag{3}$$

$$R_{34} \approx \sqrt{\beta_{yc}\beta_{ys}} = 40.8\,\mathrm{m} \tag{4}$$

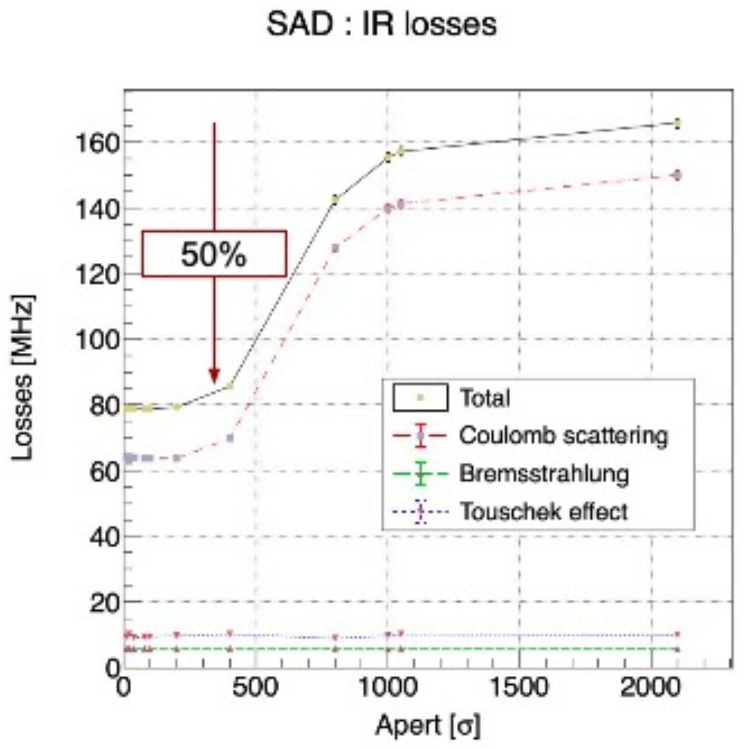
- This example optics: $\beta_{ys} = 570\,\mathrm{m}$, $\beta_{yc} = 2.9\ \mathrm{m}$.

Plan – Non-linear collimator at LER OHO section

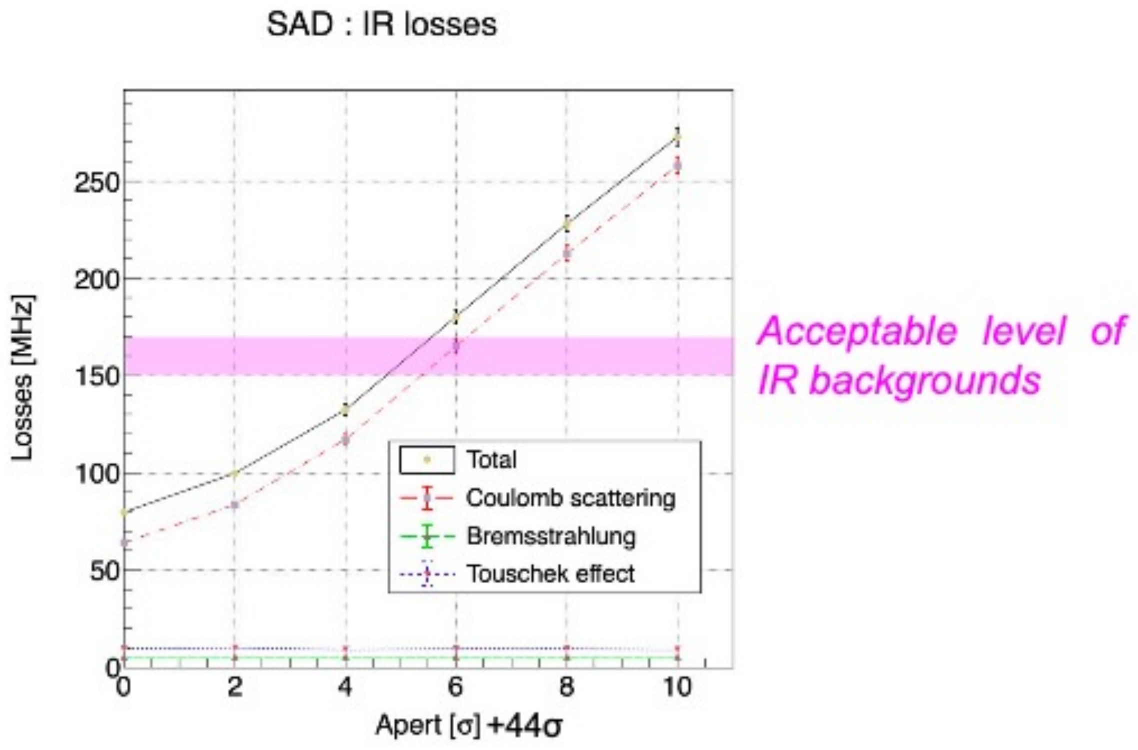
[A. Natochii]

Storage background impact

- For β^*_Y = 1mm and ε_y = 80pm in LER, **NLC can significantly reduce IR storage backgrounds** at ~300σ (±5.7mm), which corresponds to ~40σ at skew sextupoles, while QC1 is at ~50σ
- **D06V1 can be fully opened** with no harm to the IR
- **D02V1 can be opened** up to the acceptable level of beam-induced backgrounds in the IR



NLC aperture scan



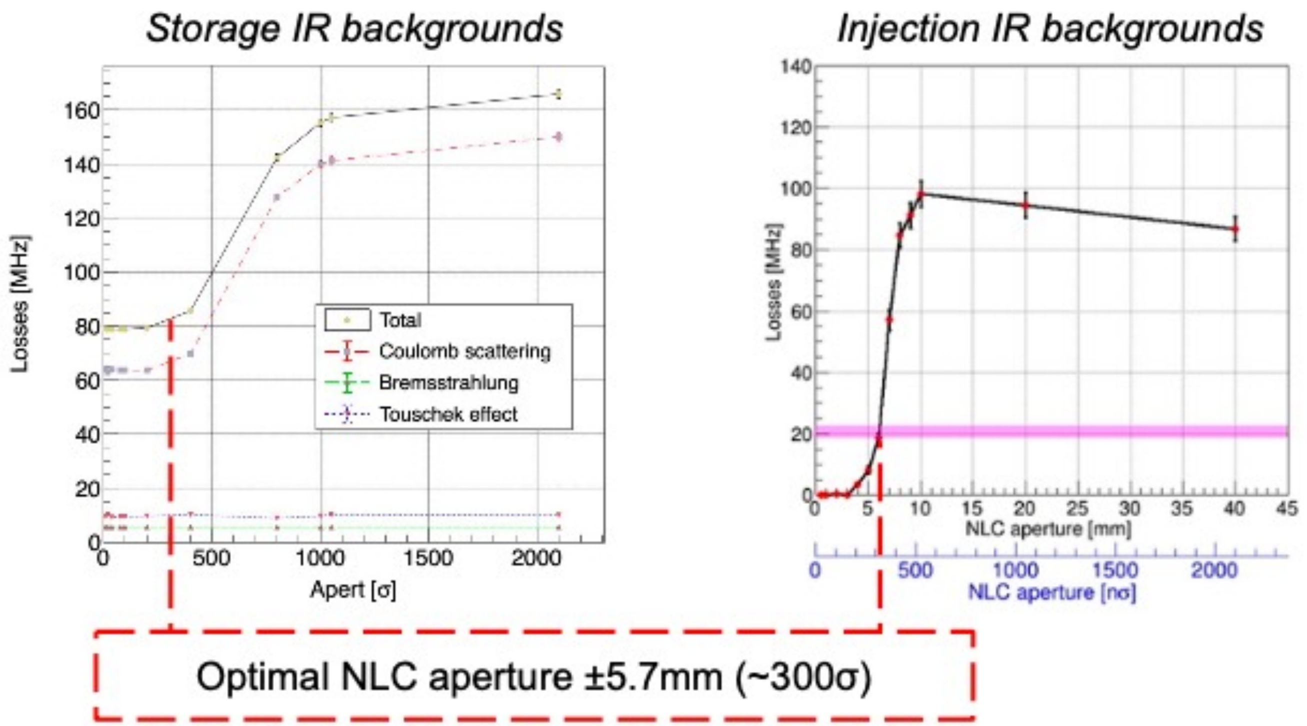
D02V1 aperture scan while NLC is closed

Plan – Non-linear collimator at LER OHO section

[A. Natochii]

Conclusion

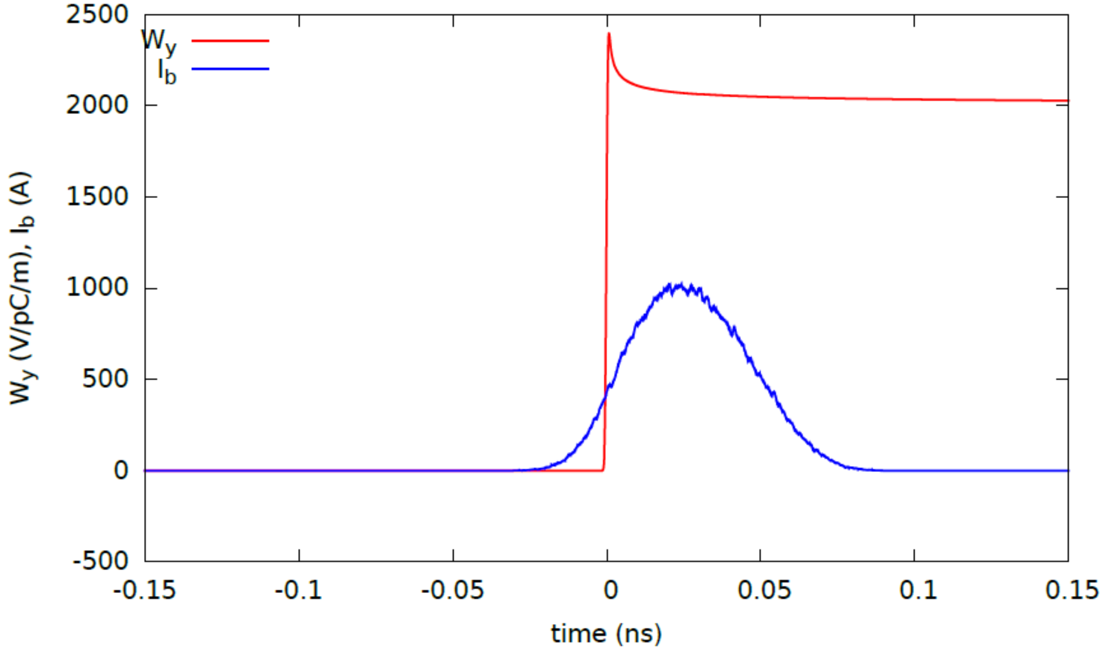
- The optimal NLC aperture for storage and injection backgrounds mitigation is ±5.7mm which is about 300σ at the NLC and 40σ at skew sextupoles
- D06V1 can be fully opened with no harm to the IR while using NLC
- Closing NLC, opening D06V1, and keeping D02V1 & D06V2 collimators at the QC1 aperture increases the TMCI bunch current threshold from 1.6mA up to 4.2mA
- For more simulation and analysis details use this *link*



Synchrobetatron Instabilites in the LER

[Michael Blaskiewicz]

- A preliminary study of transverse stability was made using TRANFT. (M. Blaskiewicz, “The TRANFT User’s Manual” BNL-77074-2006-IR)
- Only resistive wall and a smallish step function wake were used.
- Took a bunch charge of 50 nC (large) at β_y=10.4 m.

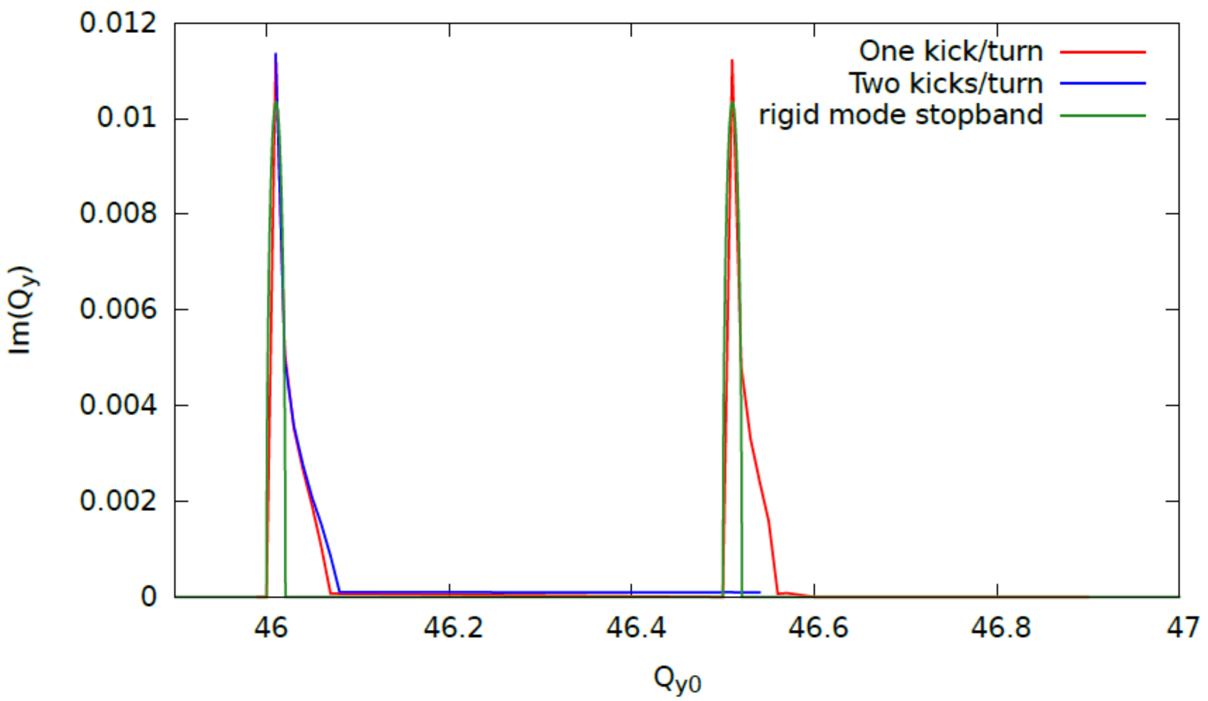


- The tune shift of the rigid mode is ΔQ_{y0}=-0.01, less than Q_s=0.025.
- Other parameters are close to the LER

Results

[Michael Blaskiewicz]

- Calculated growth rates with all the wake either in one location or split evenly between two locations on opposite sides of the ring.
- For one kick per turn the beam was strongly unstable just above the integer and half integer. For two kicks per turn the beam was unstable just above the integer. The green line shows the imaginary part of the tune driven by a single thin lens with a strength k that satisfies $\beta k=4\pi\Delta Q_y=-0.13$, which was the rigid mode kick strength in the simulations.
- For a half integer tune, 2 thin lenses at symmetric locations are stable. Hence, the behavior for 2 kicks per turn is reasonable.



Electron-Ion Collider

Comments

[Michael Blaskiewicz]

- The instability simulations were done with a tune step of 0.01, it is possible a finer structure will emerge with smaller step size.
- This effect is discussed in
  F. Ruggerio "TRANSVERSE MODE COUPLING INSTABILITY DUE TO LOCALIZED STRUCTURES" Particle Accelerators 20, p45, (1986).
- Figure 1 from that paper shows threshold current versus Q_{y0} for Q_s=0.10.
- I have not looked hard enough to comment on the narrow stable regions.

The details in the plot probably depend on detailed input, but the general characteristic of reduced threshold current just above the integer agrees with simulations.

Note that short range wakes always defocus, hence above or below the integer matters.

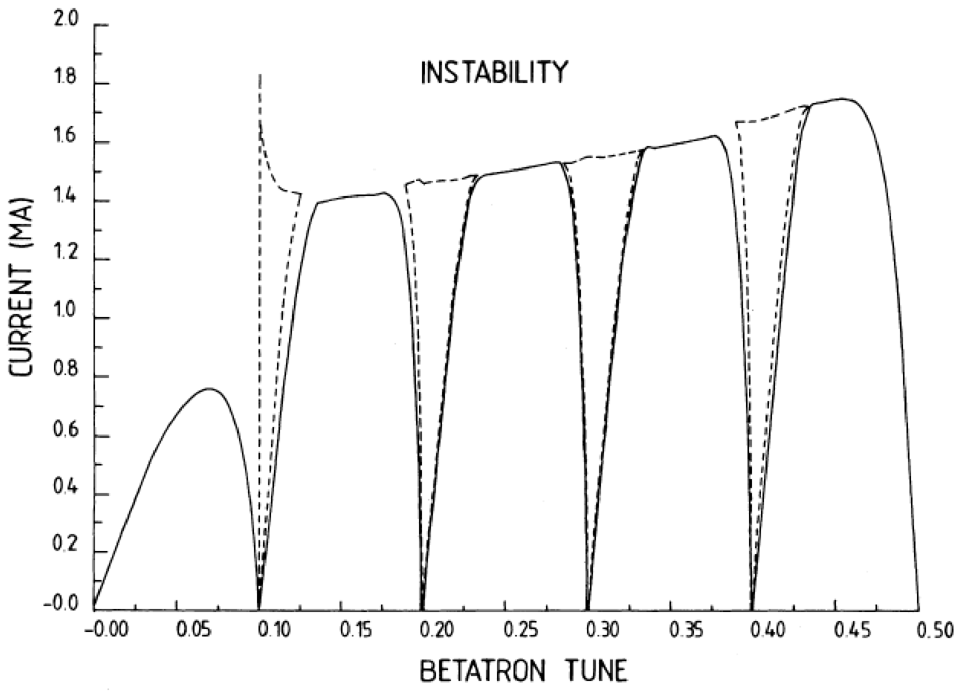


FIGURE 1 Stop-band pattern for a synchrotron tune $\nu_s = 1/10$. The regions delimited by solid or dashed lines correspond to bunch stability.

Summary

- Collimators are an indispensable sub-system in SuperKEKB MR to reduce the detector BG and avoid the QCS quench. However, there are serious issues:
  - Beam induced damage
  - TMCI in LER caused by localized wake in vertical collimators
- Non-linear collimator at LER OHO section could relax the TMCI. We have plans to construct this during Long Shutdown-1 (LS1), 2022.

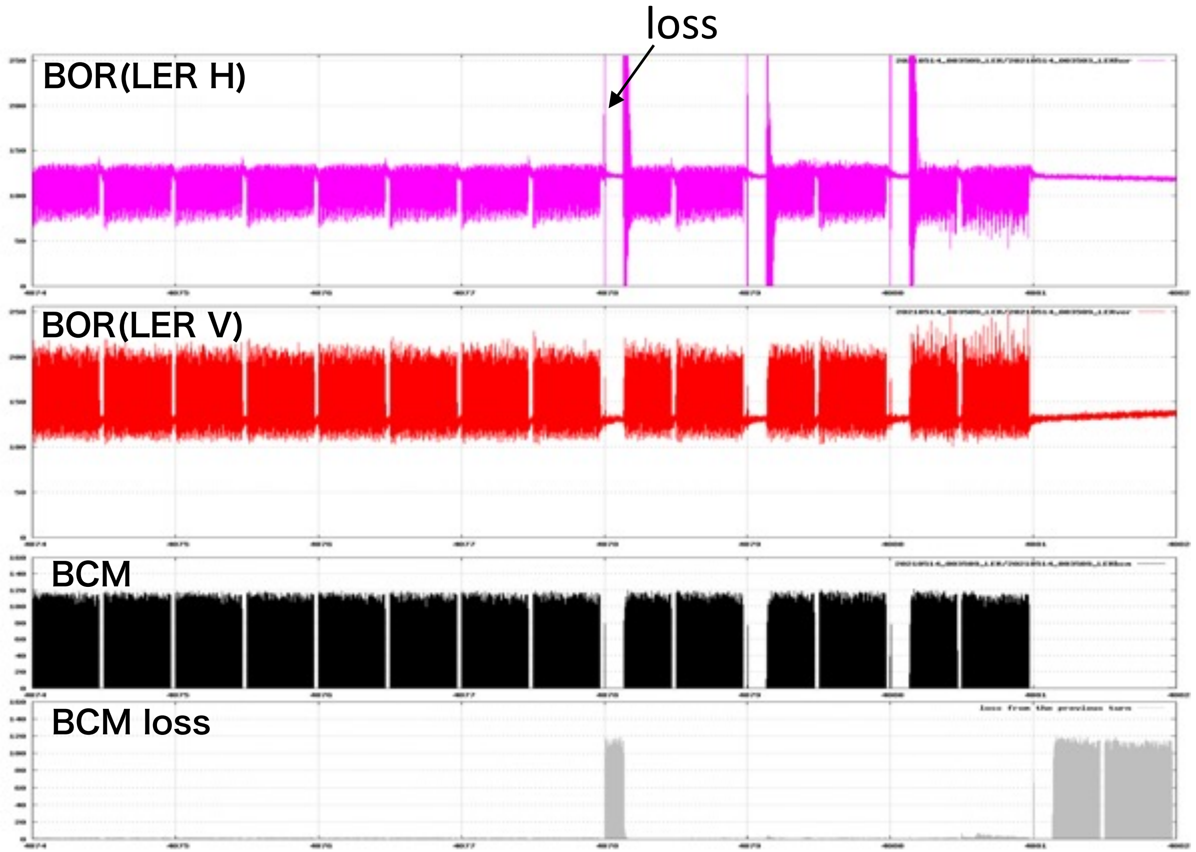
- We're also working to understand the observed transverse blow-up through machine studies, building a machine impedance model able to reproduce the instability in a TMCI working group of SuperKEKB International Task Force.
  - Contact person: Mauro Migliorati (SAPIENZA - Università di Roma)
  - Sub-contact person: Takuya Ishibashi (KEK)

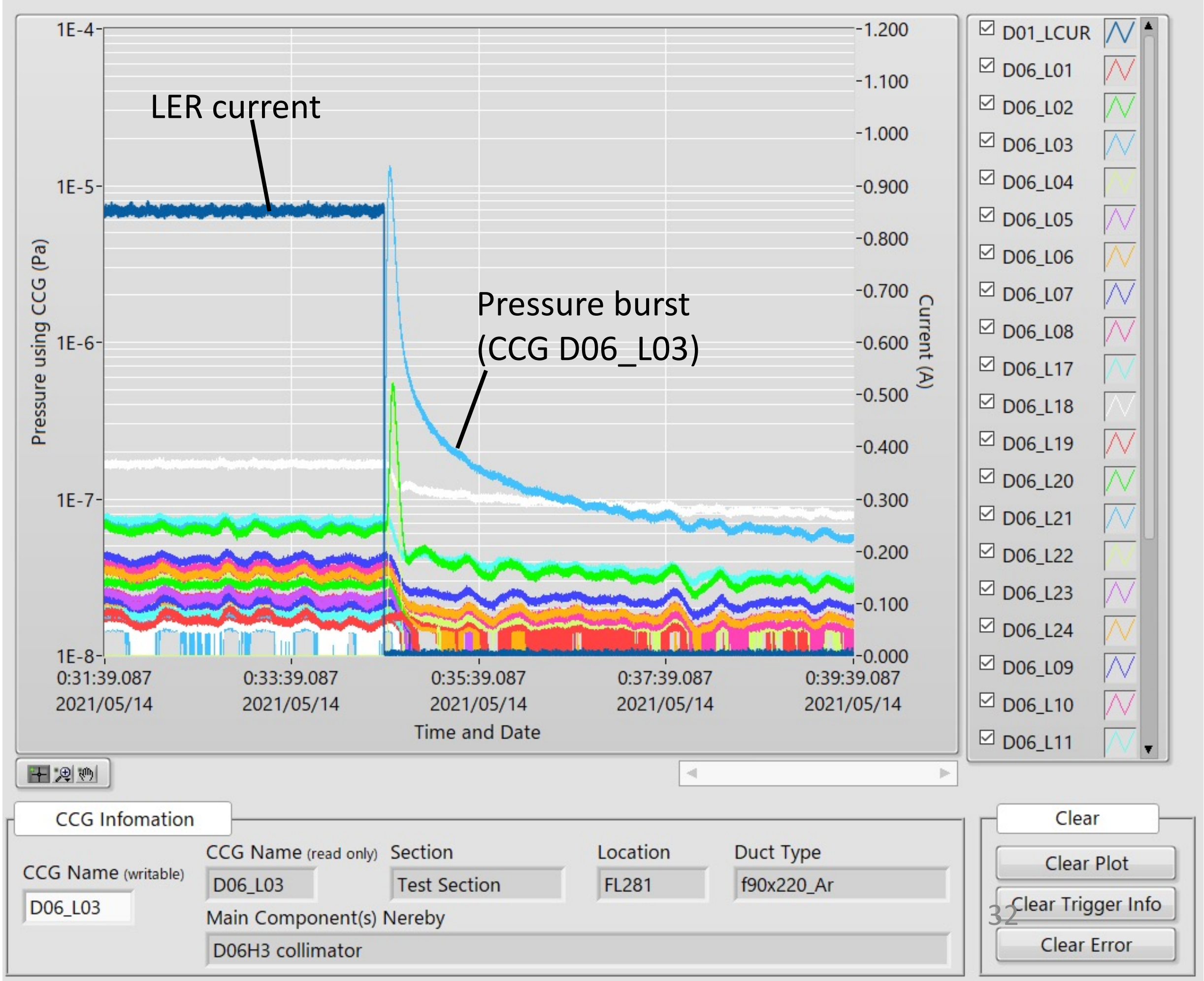
Thank you for your attention.

backup

Issue – Accidental firing of injection kickers

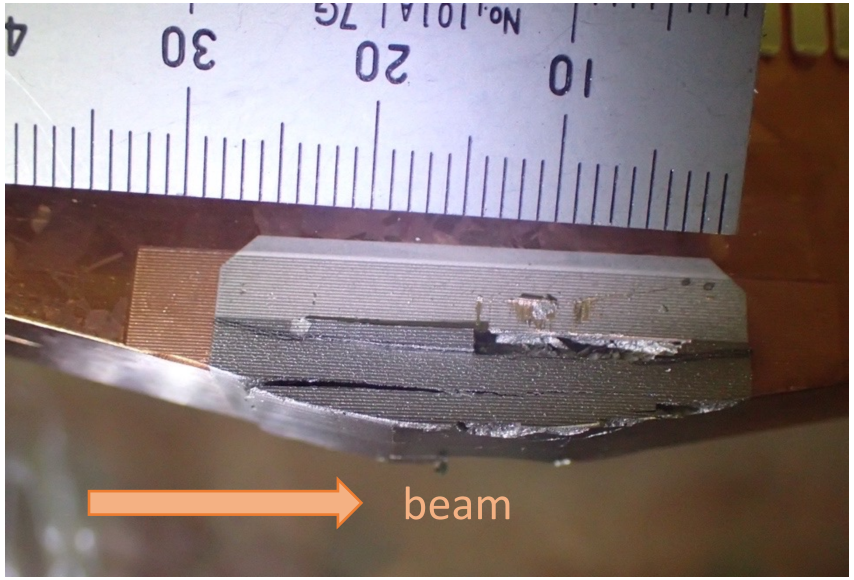
- Accidental firing of injection kickers in LER has happened.
- Example:
  - On 2021-05-14 00:35, a both ring abort happened.
  - QCS quench (QC1RP a1, a2, b1).
  - A pressure burst at D06H3 collimator was observed.



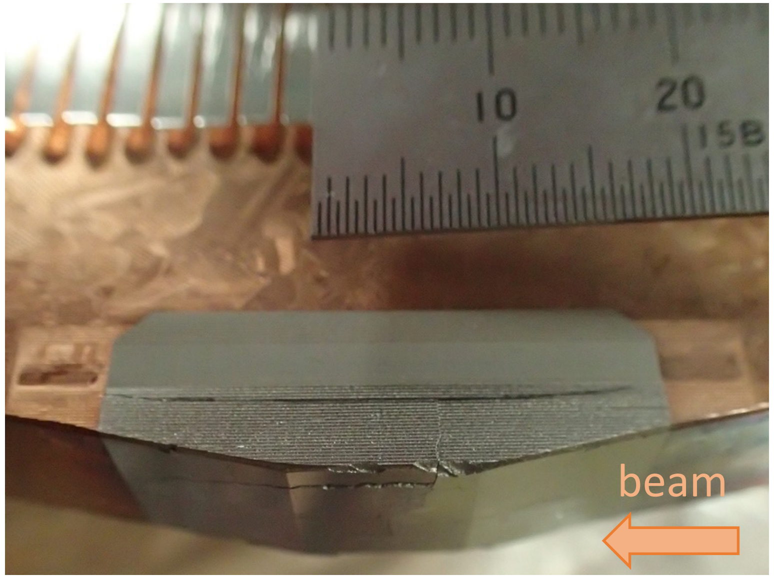


Issue – Accidental firing of injection kickers

- D06H3 collimator has used for the protection from the accidental firing, and it was severely damaged.
- We replaced them with healthy ones during this summer shutdown.
  - We don't have the spare jaws for D06H3 collimator. Thus, we removed jaws of D06H1 and installed them into D06H3.
  - We installed new jaws into D06H1 instead, however the length of the jaws is short for this collimator. The minimum aperture of D06H1 is ±14 mm.
  - We're staring to manufacture the spare jaws made of tantalum, and it'll be delivered till the beginning of next Jan.
- All the thyratrons have been replaced with ones which have a higher breakdown voltage, during this summer shutdown [T. Mimashi]. However, the accidental firings had occurred during 2021c, and this could be caused by noise in the trigger system. An additional system has been installed to guarantee the coincidence of the trigger in a hurry.

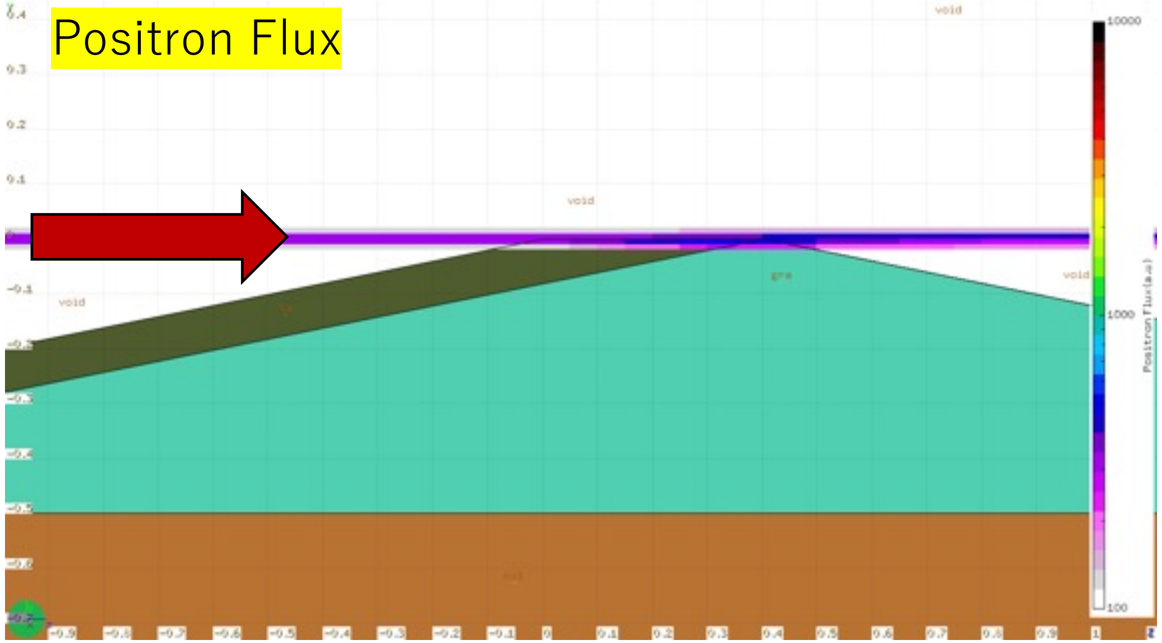


D06H3 IN (~700 μSv/h)



D06H3 OUT (~320 μSv/h)

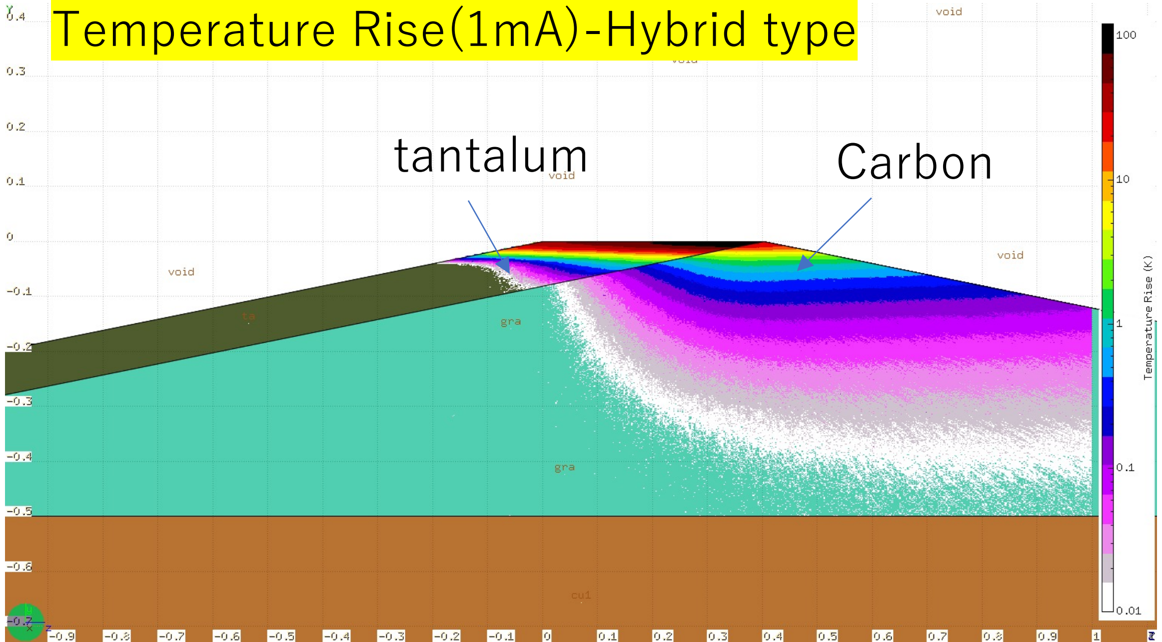
Plan – R&D of durable jaws (hybrid jaw)

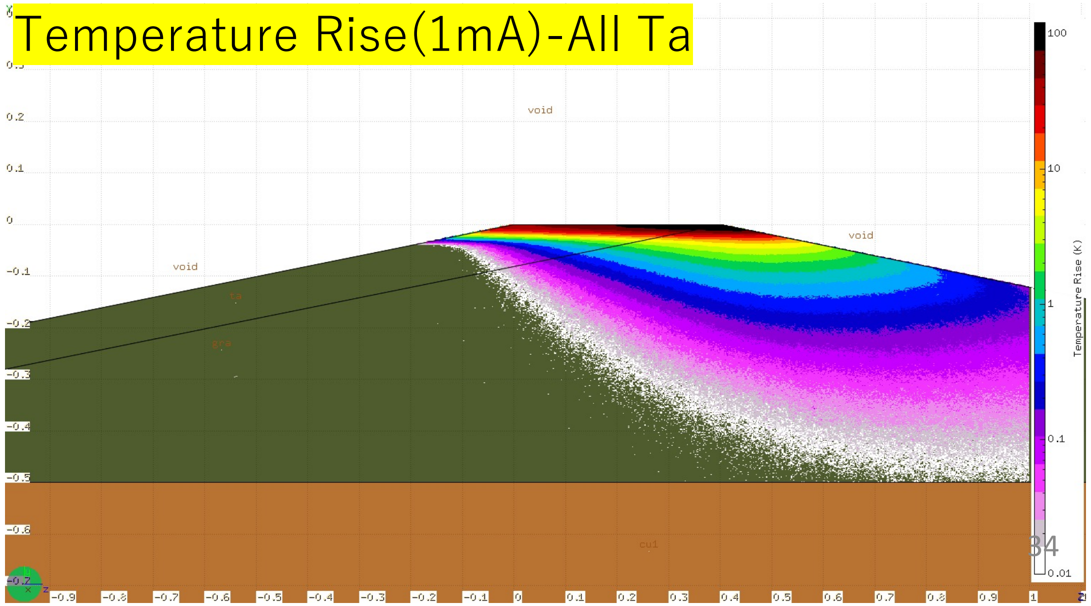


[Positron Beam]

- Beam Size : $\sigma y = 100um$, $\sigma x = 300u$ property
- Beam Energy : 4 GeV
- No energy spread
- Lower half of the beam hit the jaw
- Beam current (assuming 99.4kHz) :
  1 mA, 5 mA, 10 mA, 30 mA, 50 mA

[Y. Morikawa, S. Terui]

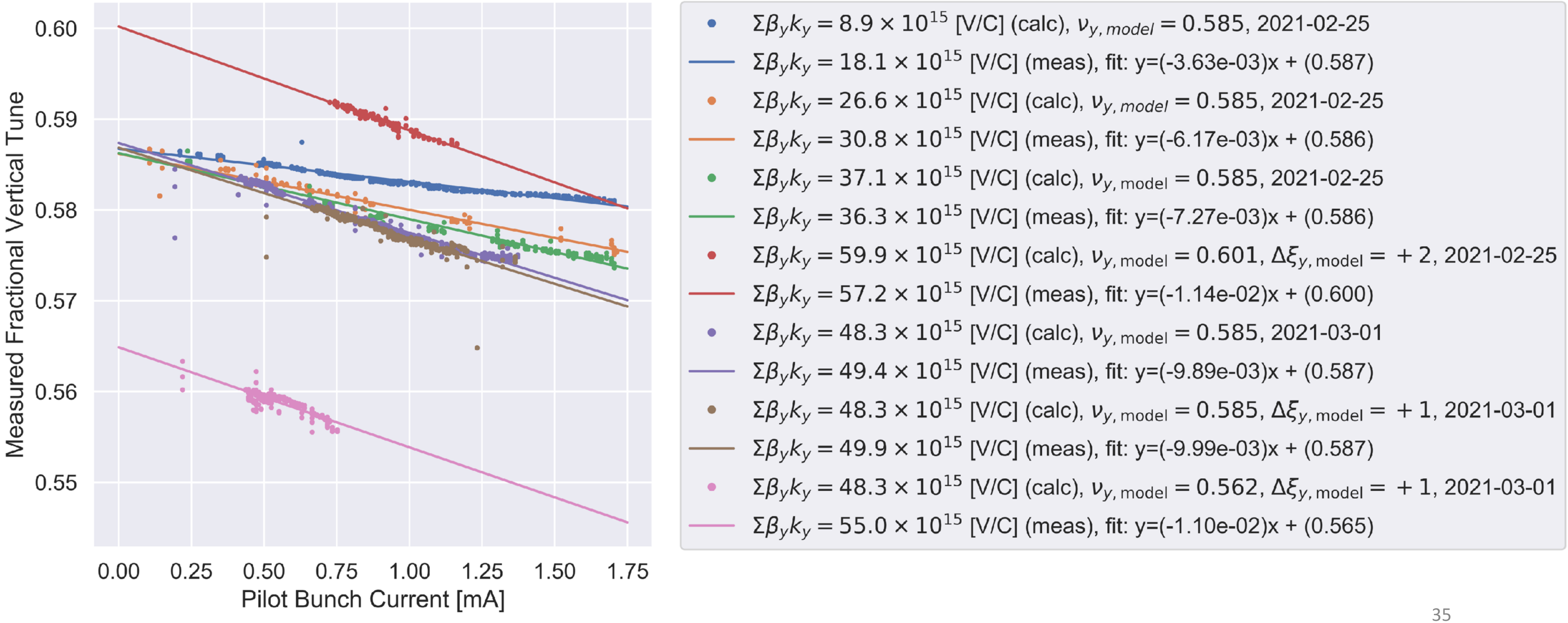




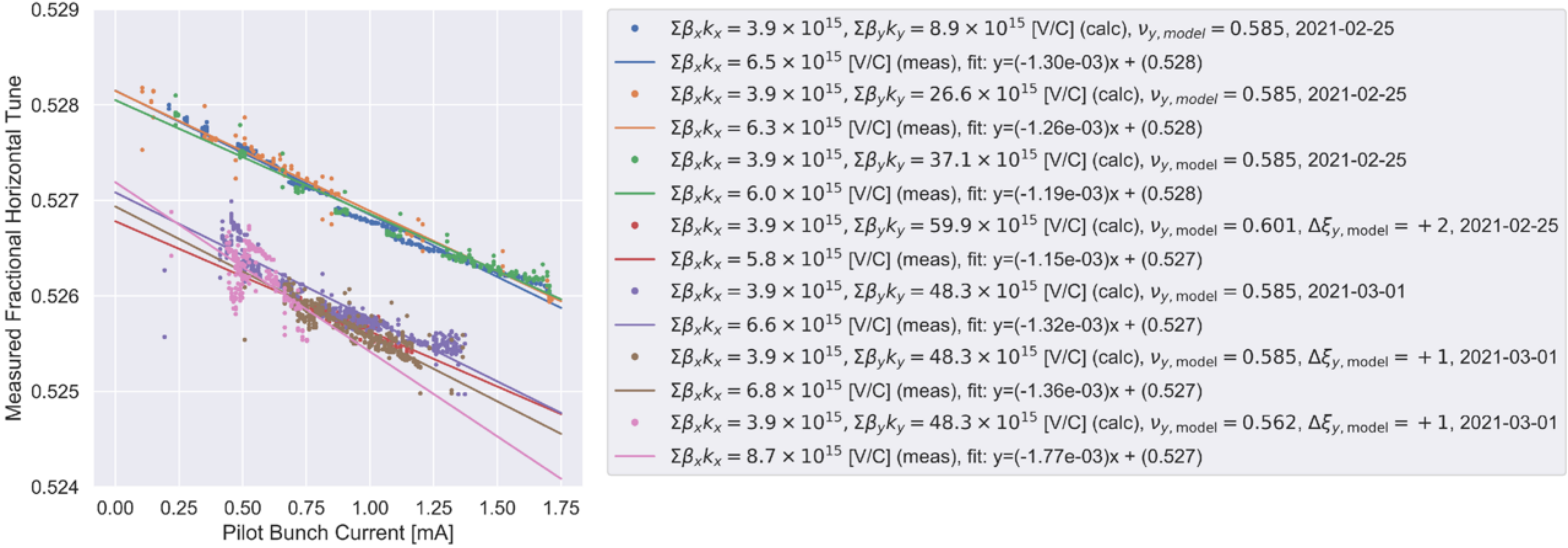
Vertical tune shift

$$\Delta\nu_{x/y} = \frac{I_b T_0}{4\pi(E/e)} \Sigma\beta_{x/y} k_{x/y}$$

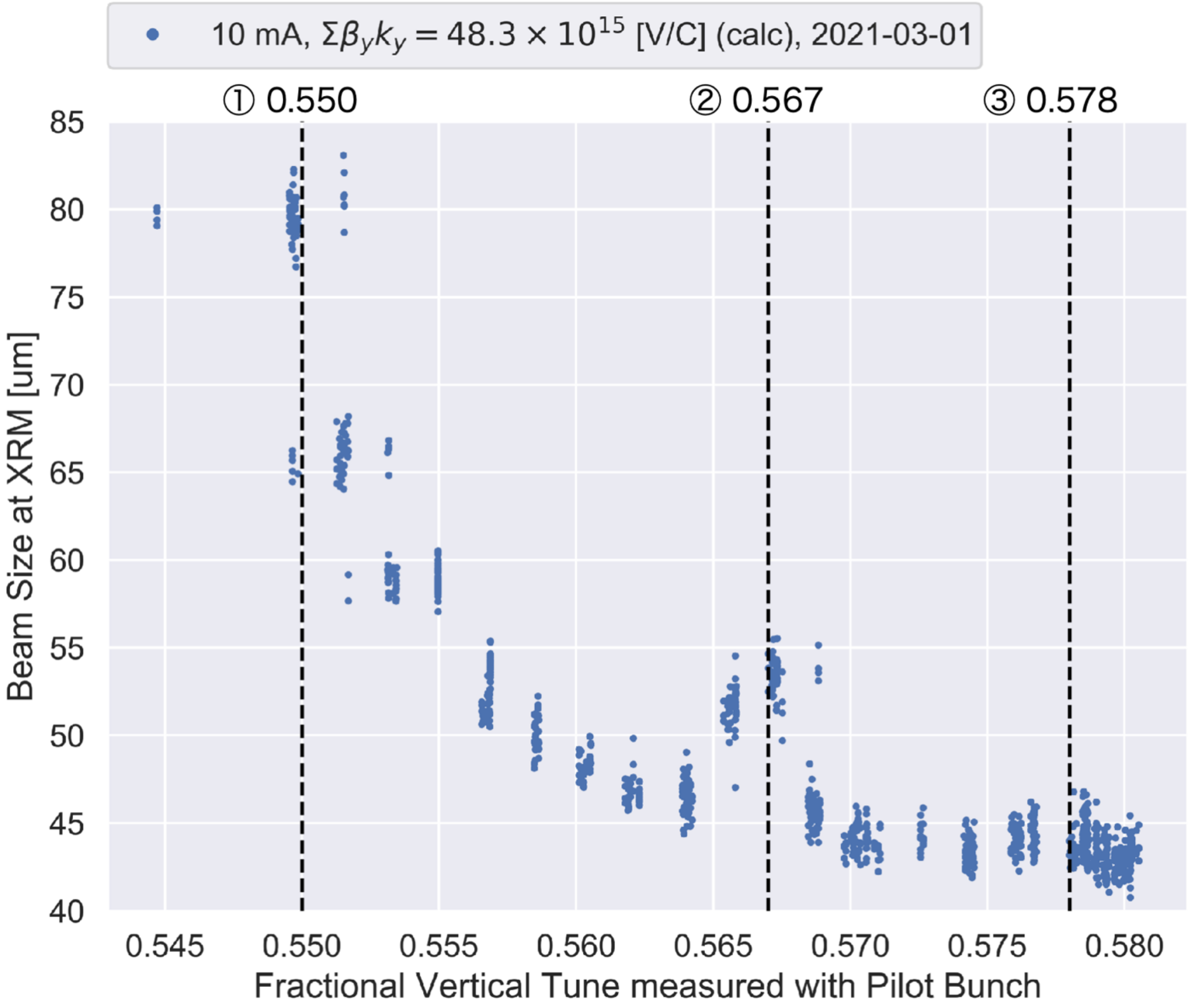
T_0 = circ./c ~1e-5 s
E/e = 4 GV

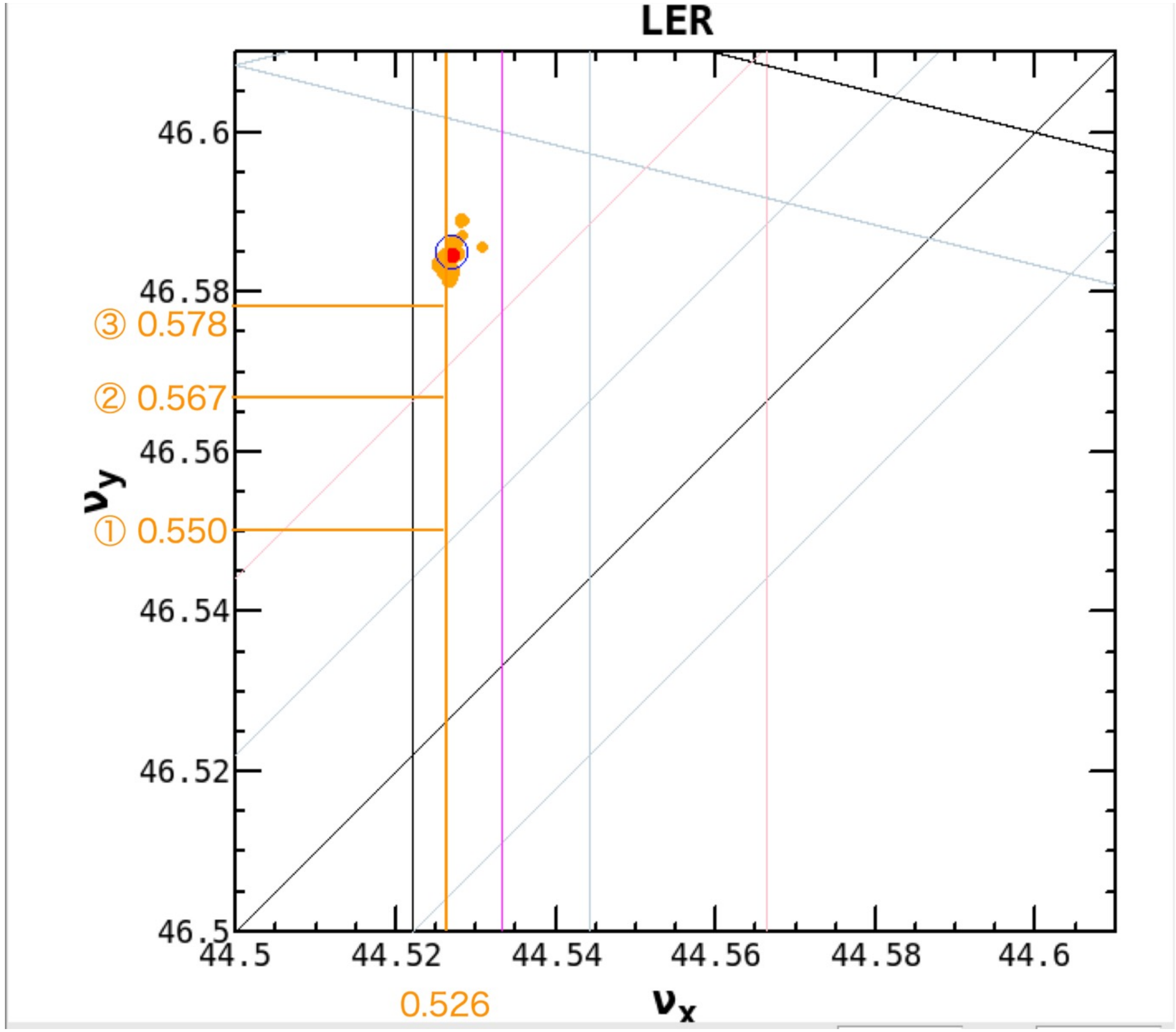


Horizontal tune shift

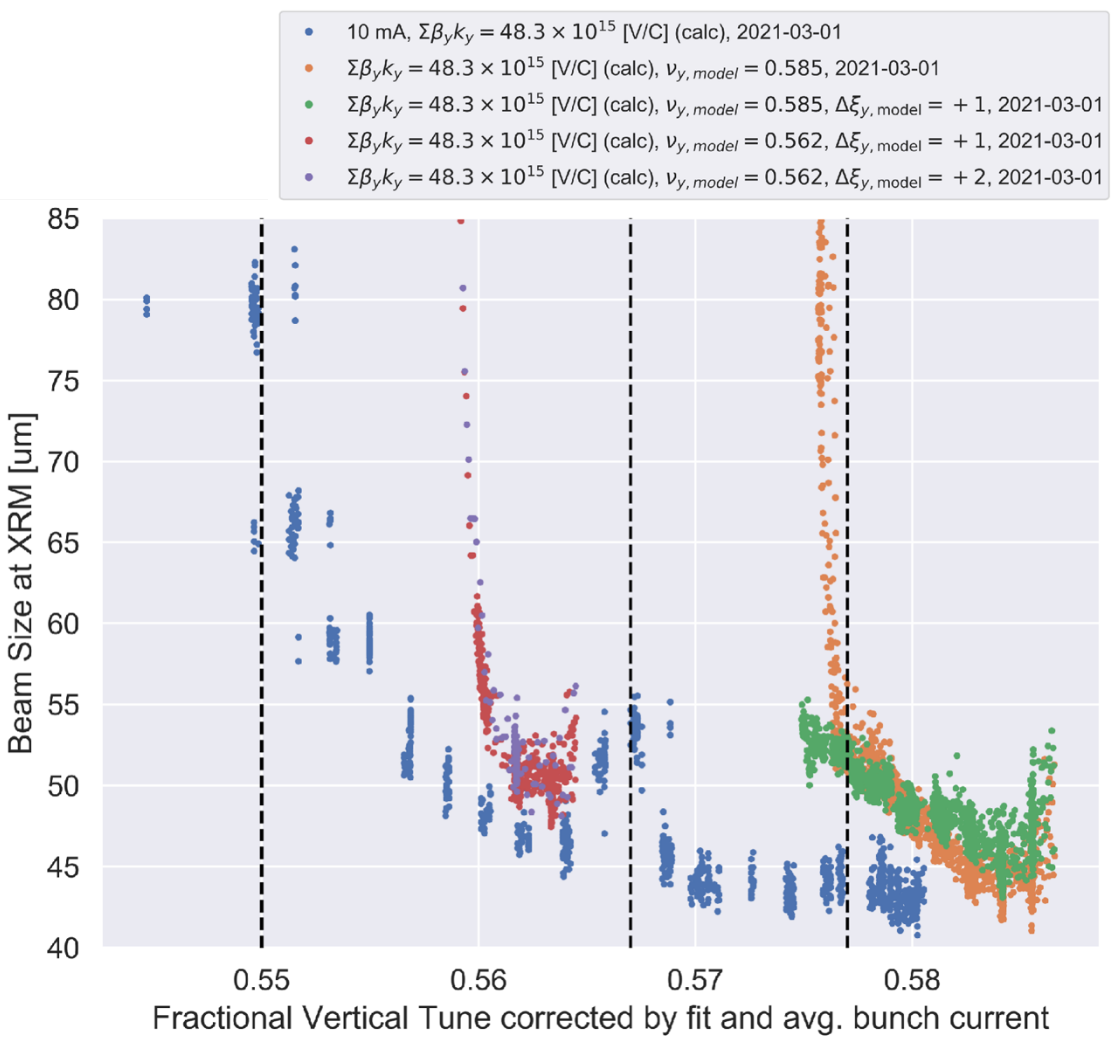


Vertical tune scan

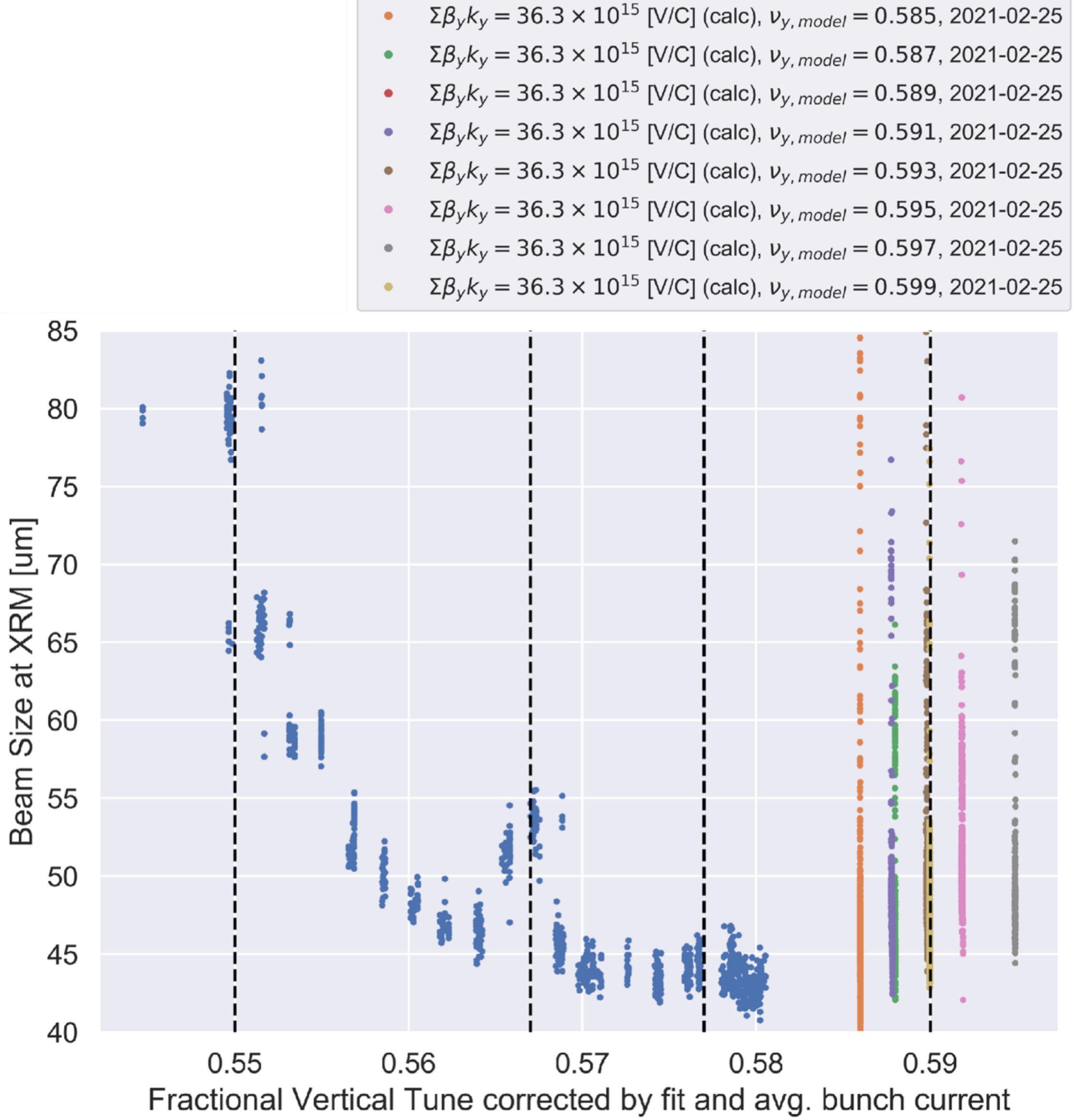




Beam size blowup

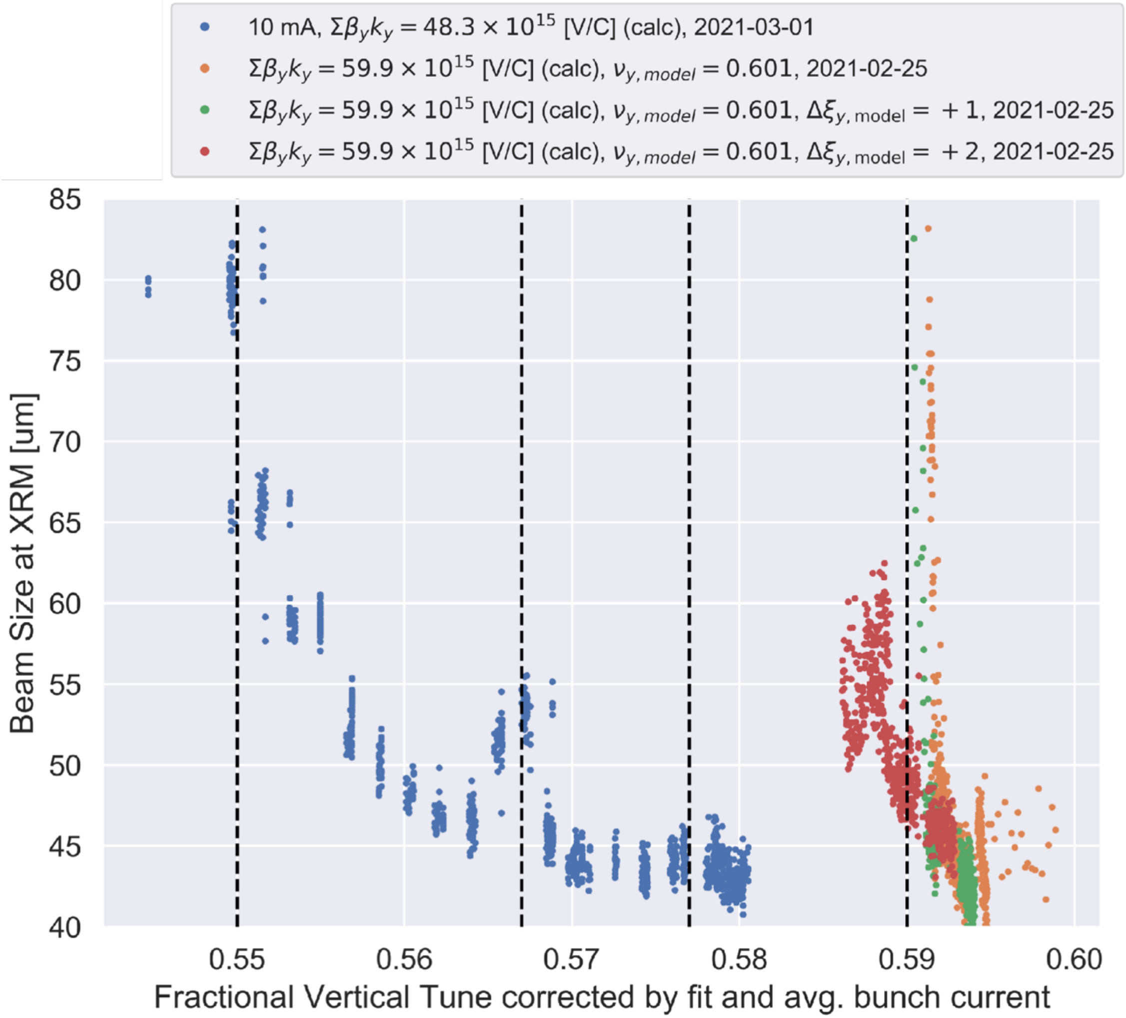


Tune scan

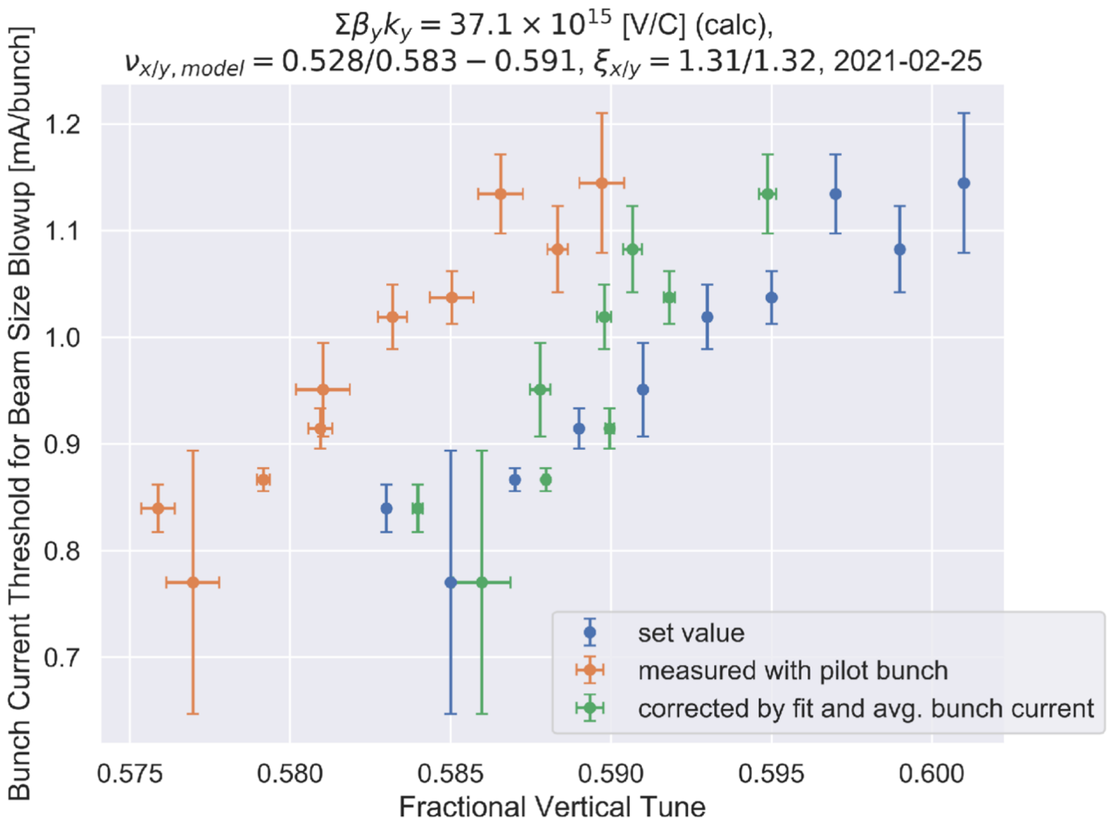


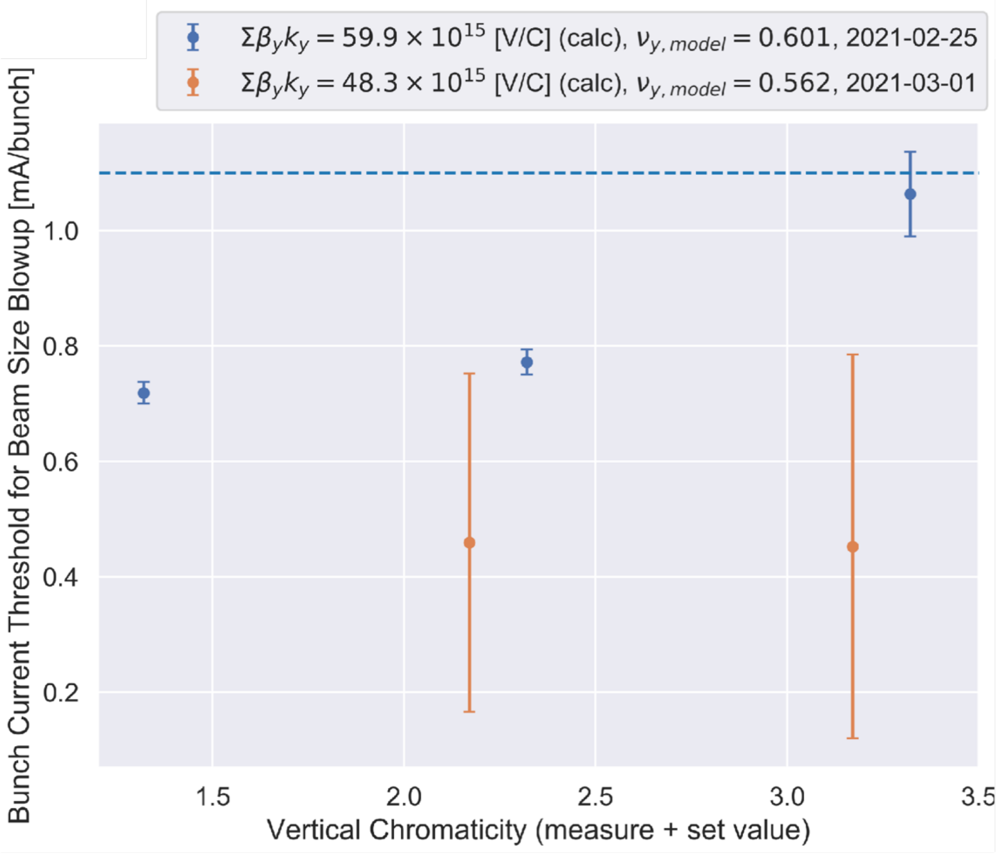
Beam size blowup

Chromaticity scan



Beam size blowup





TMCI threshold (calc): ~1.6 mA/bunch
Reference sigma_y at XRM: 45.5 μm
Judgement value of beam size blowup: 54.6 ± 2.9 μm

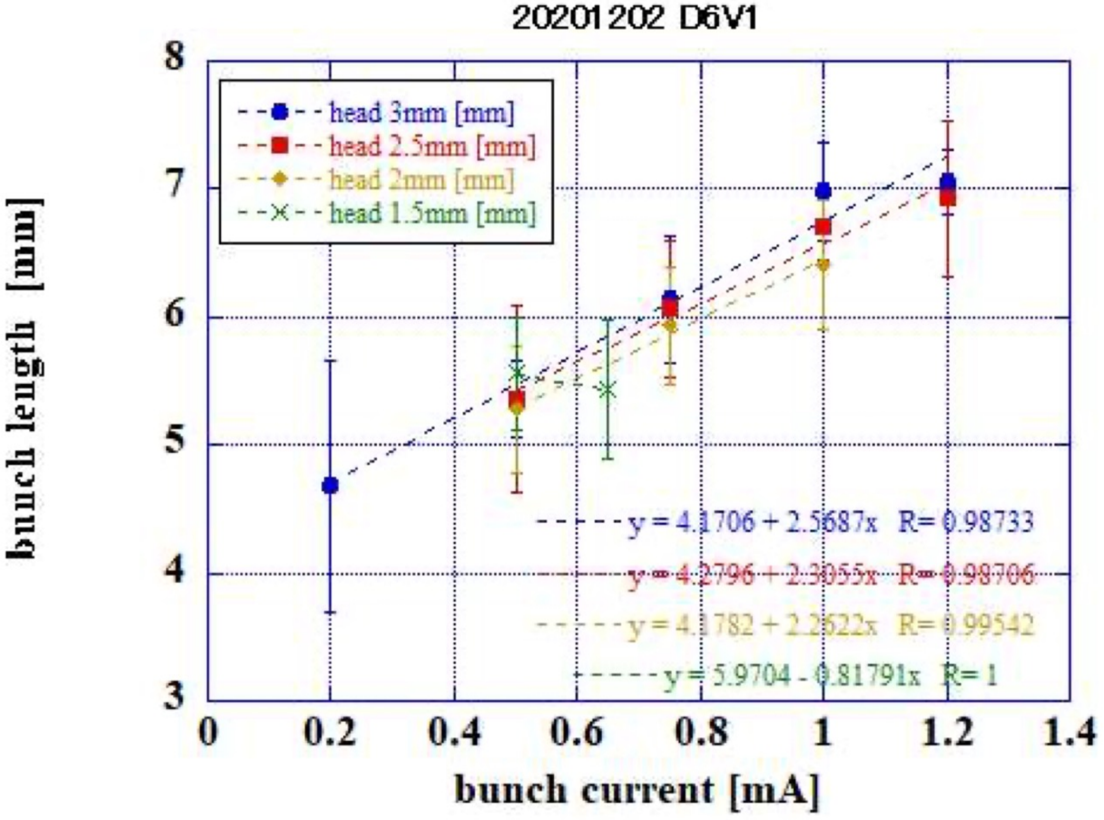
Defining the beam size blowup as (reference sigma_y)*1.2 ± (std).
(reference sigma_y) is averaged sigma_y at XRM in low current.
(std) is the standard deviation of the sigma_y at XRM in low current.
Low current is defined from 9 mA to 11 mA in total current here.

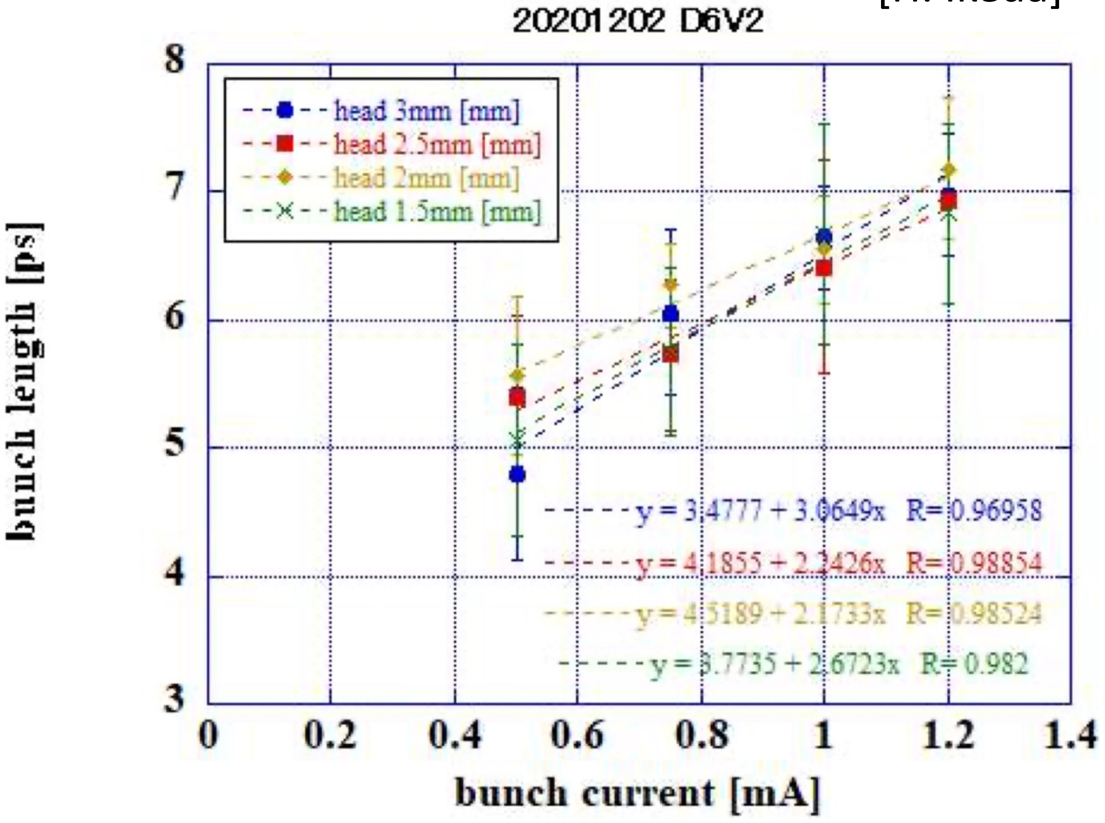
TMCI threshold (calc): ~1.1 mA/bunch ($\Sigma\beta_y k_y$ = 59.9×10[15] V/C, Feb. 25th)
Reference sigma_y at XRM: ~44.2 μm (Feb. 25th), ~51.6 μm (Mar. 1st),
Judgement value of beam size blowup: ~53.0 ± 2.1 μm (Feb. 25th), ~62 ± 2.8 μm (Mar. 1st),

Defining the beam size blowup as (reference sigma_y)*1.2 ± (std).
(reference sigma_y) is averaged sigma_y at XRM in low current.
(std) is the standard deviation of the sigma_y at XRM in low current.
Low current is defined from 9 mA to 11 mA in total current here.

Beam length measurements for collimator apertures

[H. Ikeda]





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.