SuperKEKB Accelerators current status and challenges

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KEK Accelerator Laboratory, BNL

EIC Accelerator Partnership Workshop 2021

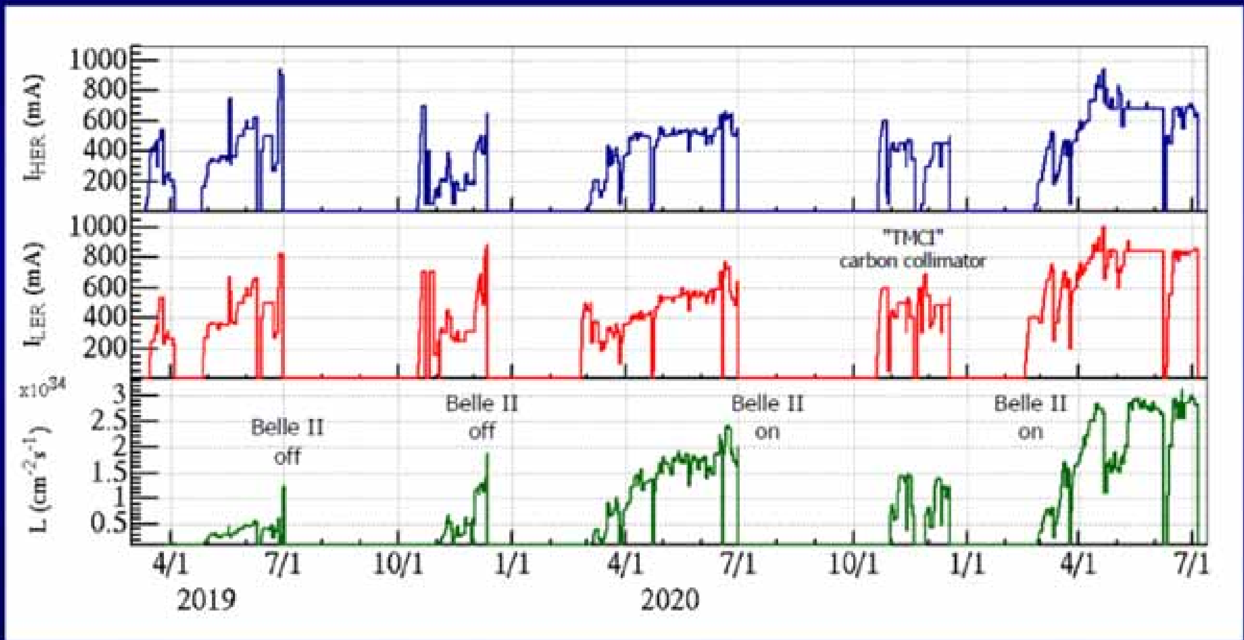
SuperKEKB Operation Summary

Peak Luminosity : 3.12 x 10^{34} $cm^{-2}s^{-1}$

a: February - March
b: April - July
c: October - December

Operation time
6 - 7 months per year

2019a/b 2019c 2020a/b 2020c 2021a/b



β_y^* 3 → 2 mm
β_y^* 2 → 1 mm
β_y^* 1 → 0.8 mm
β_y^* 1 mm
β_y^* 1 mm

	int. L recorded	int. L delivered
Shift	747.2 pb^{-1} May 18 swing	797.6 pb^{-1} June 22 day
Day	1.964 fb^{-1} May 18	2.233 fb^{-1} May 22
7 days May 14 - 20	12.141 fb^{-1}	13.482 fb^{-1}
30 days May 18 - June 23	42.319 fb^{-1}	47.370 fb^{-1}
2021ab 140 days	123.2 fb^{-1}	138.6 fb^{-1}
total	213.5 fb^{-1}	

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Machine Parameters (2020b and 2021b)

	2020b : June 21, 2020		2021b : June 22, 2021		Unit
Ring	LER	HER	LER	HER	
Emittance	4.0	4.6	4.0	4.6	nm
Beam Current	712	607	790	687	mA
Number of bunches	978		1174		
Bunch current	0.728	0.621	0.673	0.585	mA
Lifetime	760	1270	540	1320	sec
Horizontal size σ_x^*	17.9	16.6	17.9	16.6	μm
Vertical cap sigma Σ_y^*	0.403		0.324		μm*1
Vertical size σ_y^*	0.285		0.229		μm*2
Betatron tunes ν_x / ν_y	45.523 / 43.581	44.531 / 41.577	44.524 / 46.596	45.532 / 43.581	
β_x^* / β_y^*	80 / 1.0	60 / 1.0	80 / 1.0	60 / 1.0	mm
Piwinski angle	10.7	12.7	10.7	12.7	
Crab Waist Ratio	80	40	80	40	%
Beam-Beam parameter ξ_y	0.039	0.026	0.046	0.030	
Specific luminosity	5.43×10^{31}		6.76×10^{31}		$cm^{-2}s^{-1}/mA^2$
Luminosity	2.40×10^{34}		3.12×10^{34}		$cm^{-2}s^{-1}$

*1) estimated by luminosity with assuming design bunch length
*2) divide *1 by √2

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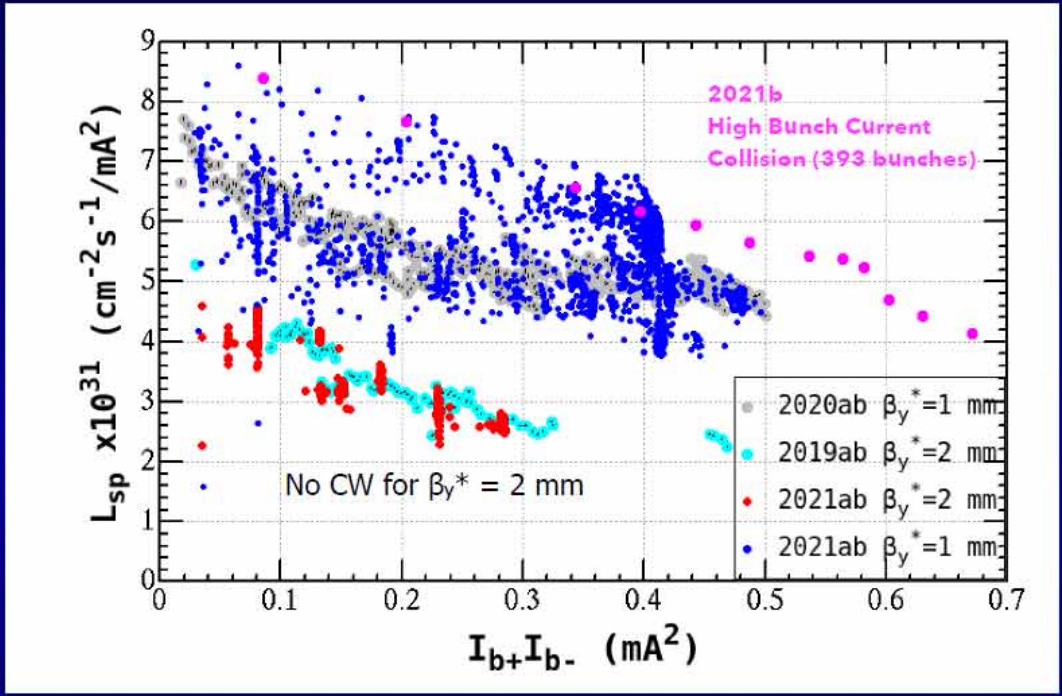
Definition of specific luminosity

$$L_{sp} = \frac{L}{n_b I_{b+} I_{b-}}$$



- Specific luminosity for β_y^* = 1 mm is improved compared to that of 2020ab.
- X-Y couplings at IP are improved by using local correctors with luminosity optimization.
- We also use chromatic X-Y coupling correctors.
- Bunch current product is achieved larger than 0.5 mA^2 with crab waist scheme.

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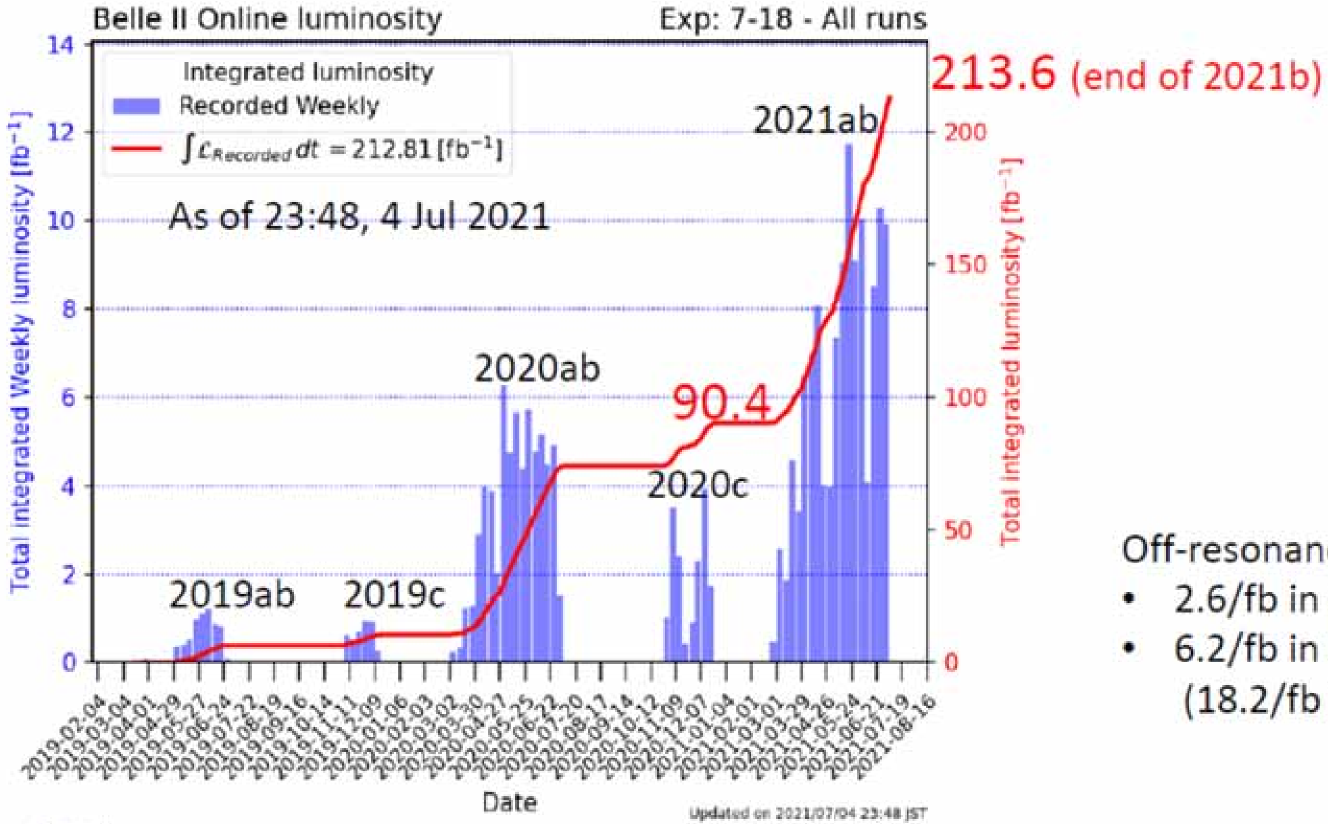
Online recorded luminosity



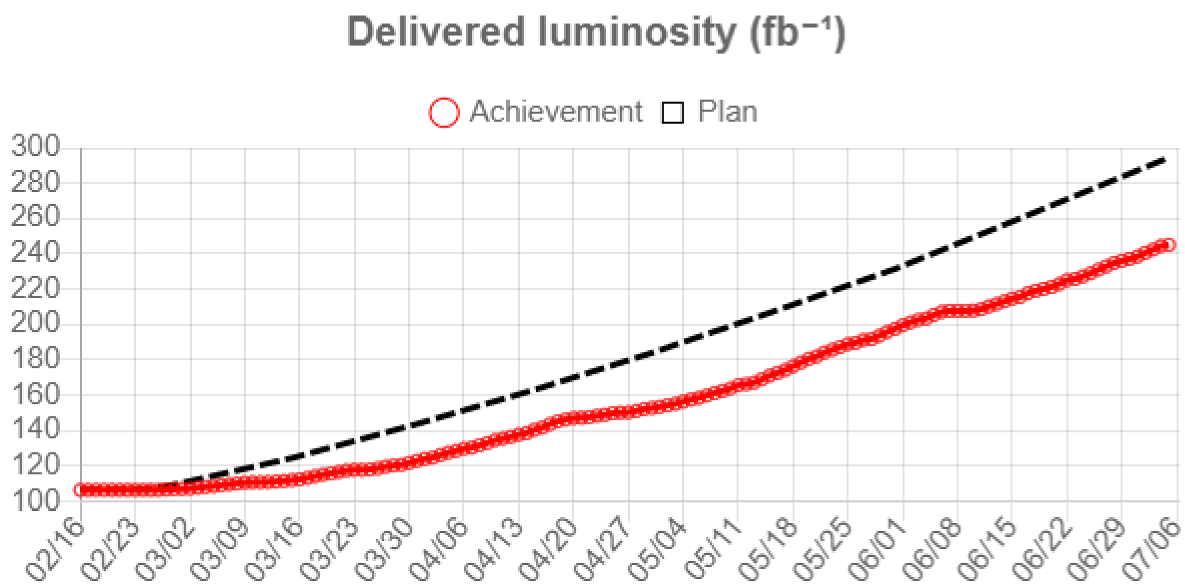
Caveat:
Online luminosity plots in the Confluence page are not exactly correct because they use the data in Run Registry, which are sometimes wrong for unknown reasons.

Off-resonance runs:

- 2.6/fb in Apr
- 6.2/fb in Jun
  (18.2/fb in total)

K. Matsuoka

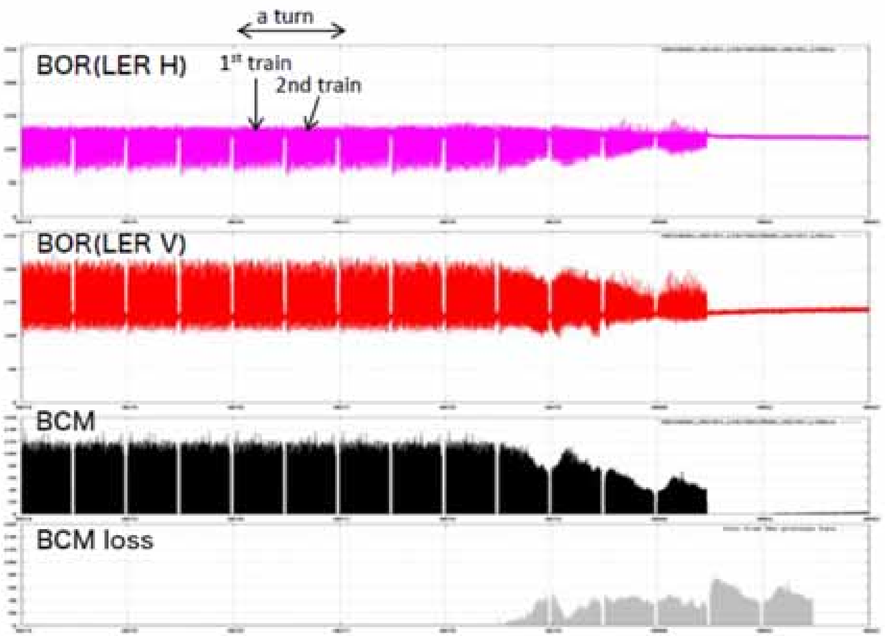
Lower than expected



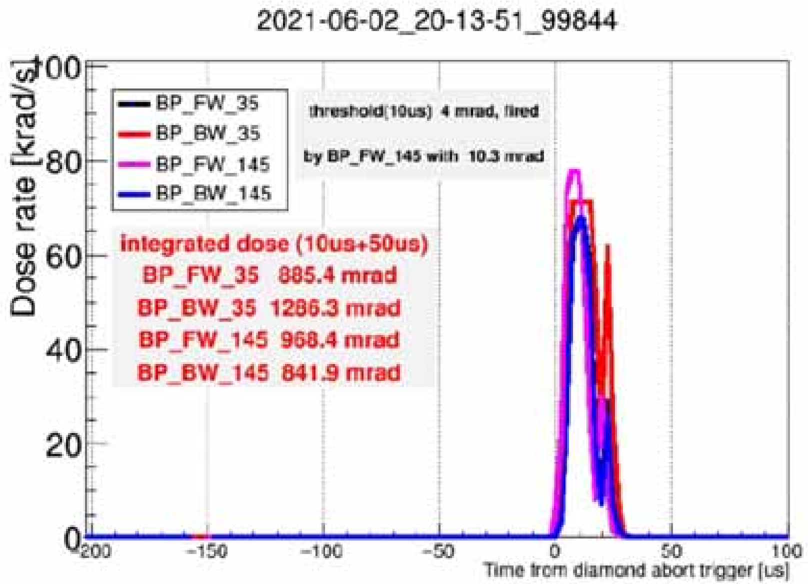
[Delivered $\int L$ (plan)] = Σ [Delivered L_{peak} (plan)] × [Period (14 days / 0.5 month)] × 0.65

Challenges (1)

- **Beam background and beam aborts due to (extremely fast) beam loss.**
  - **Serious radiation does at collimators, severe damage at collimators, damage on Belle II detector.**
  - **Large risks for increasing beam currents (to achieve higher luminosity).**



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

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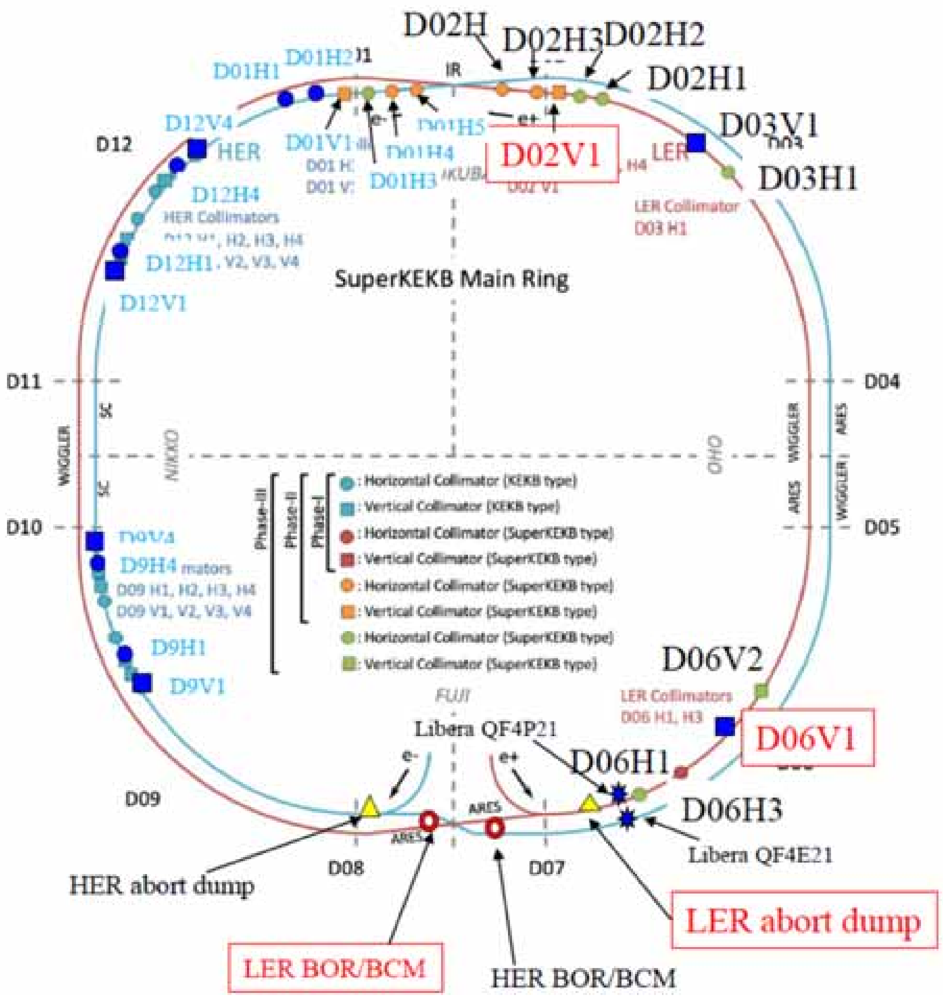
Location of BOR/BCM

BOR = Beam Orbit Recorder
BCM = Bunch Current Monitor

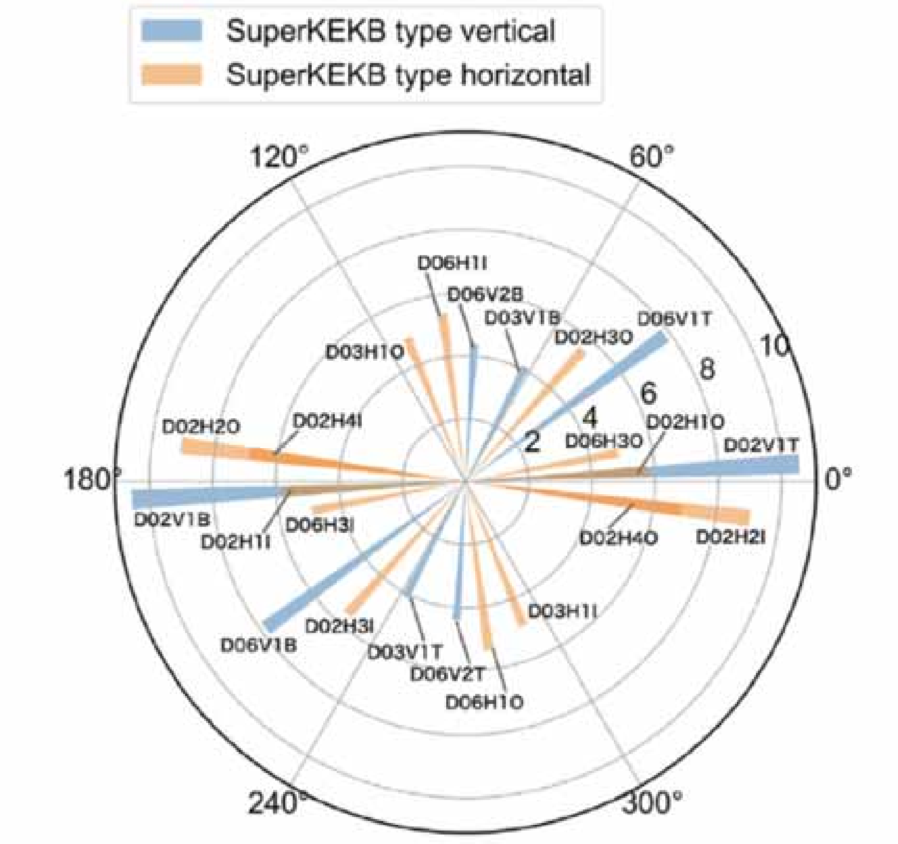
https://www.pasj.jp/web_publish/pasj2016/proceedings/PDF/TUOM/TUOM06.pdf



Two fast beam monitors in the ring

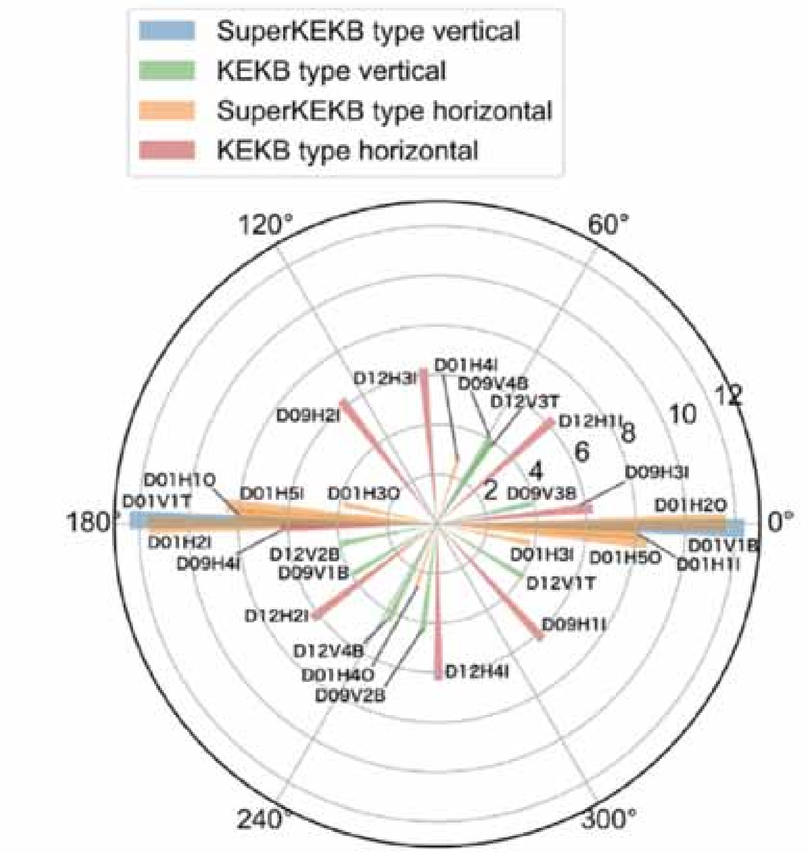
- VXD diamond at IP
- BOR/BCM at Fuji

By H. Nakayama (MDI meeting)



SuperKEKB type vertical
SuperKEKB type horizontal
120°
60°
180°
0°
240°
300°
2
4
6
8
10
D06H1I
D06V2B
D03V1B
D06V1T
D02H3O
D03H1O
D02H2O
D02H4I
D02H1O
D06H3O
D02V1T
D02V1B
D02H1I
D06H3I
D02H4O
D02H2I
D03H1I
D02H3I
D06V1B
D03V1T
D06V2T
D06H1O

(a)



SuperKEKB type vertical
KEKB type vertical
SuperKEKB type horizontal
KEKB type horizontal
120°
60°
180°
0°
240°
300°
2
4
6
8
10
12
D01H4I
D12H3I
D09V4B
D12V3T
D09H2I
D12H1I
D09H3I
D01H1O
D01V1T
D01H5I
D01H3O
D09V3B
D01H2O
D01H2I
D09H4I
D12V2B
D09V1B
D01H3I
D01H5O
D01V1B
D01H1I
D12V1T
D12H2I
D09H1I
D12V4B
D01H4O
D09V2B
D12H4I

(b)

LER

HER

Collimator_Nsigma_offset.opi | TPC_rates_monitor.opi

HER (INJ)

	DIF_POS [mm]	beta_x [m]	nu_x	eta_x [m]	Nsigma (BSC)	Nsigma (beta)	Nsigma (eta)	LM
D09H1	-9.09	39.7	15.98	0.7	14.6	21.3	20.0	1.16
D09H2	-9.03	39.7	15.49	0.7	14.5	21.1	19.9	0.51
D09H3	-9.72	39.7	14.83	0.7	15.6	22.7	21.4	0.87*
D09H4	-8.81	39.7	14.34	0.7	14.1	20.6	19.4	0.95*
D12H1	-9.07	39.7	8.73	0.7	14.5	21.2	19.9	0.21
D12H2	-8.89	39.7	8.24	0.7	14.3	20.8	19.6	0.15
D12H3	-9.02	39.7	7.58	0.7	14.5	21.1	19.8	0.59*
D12H4	-12.50	39.7	7.09	0.7	20.0	29.3	27.5	-0.10*
D01H3OUT	8.80	7.0	0.82	-0.3	31.0	48.9	40.0	0.00
D01H3IN	-9.15	7.0	0.82	-0.3	32.2	50.8	41.6	
D01H4OUT	15.12	16.7	0.52	-0.3	46.5	54.5	89.2	0.00
D01H4IN	-14.81	16.7	0.52	-0.3	45.6	53.4	87.4	
D01H5OUT	8.77	30.9	0.27	-0.1	23.1	23.2	244.6	0.00
D01H5IN	-10.41	30.9	0.27	-0.1	27.5	27.6	290.6	
QC2 (-2.9m)	35.0	415.2	0.24			25.3		

*10=Abort; >7.00; >3.00; >0.70

D1V1

Dia QCSBW: >50.0; >25.0; >10.0

	DIF_POS [mm]	beta_y [m]	nu_y	Nsigma (beta)	LM
D09V1	-1.56	15.5	18.74	58.2	1.24 *
D09V2	-2.90	19.4	16.60	96.9	1.11 *
D09V3	-1.51	15.5	14.29	56.7	0.75 *
D09V4	-3.40	16.7	13.17	122.6	1.20 *
D12V1	3.89	16.7	9.91	140.3	0.26
D12V2	-2.21	15.5	8.79	82.7	0.02
D12V3	1.36	15.5	7.67	51.1	0.14
D12V4	-3.03	19.4	6.65	101.3	0.01
D01V1TOP	2.68	46.5	1.26	57.9	0.00
D01V1BTM	-1.81	46.5	1.26	39.1	
QC1 (-1.16m)	13.5	1295.2	0.25	55.3	

0.02

Dia QCSBW

40 %

beta_y*[mm]	beta_x* [mm]
1.0	60.0

20200505_1x60CW40_1x80 CW60_sher_2020-05

emit_x [nm]	4.60
emit_y [nm]	0.046
emit_y [nm] by XRM	0.060
Sigmay by XRM [um]	41.0
current [mA]	150

Collimator offset

D1V1 offset[mm]	DIF_POS'	Nsigma'
-0.450	2.23	48.2
	-2.26	48.8

LER (INJ)

	DIF_POS [mm]	beta_x [m]	nu_x	eta_x [m]	Nsigma (BSC)	Nsigma (beta)	Nsigma (eta)	LM
D06H1OUT	8.96	24.2	25.01	0.7	15.6	39.7	17.0	0.14
D06H1IN	-9.04	24.2	25.01	0.7	15.8	40.1	17.1	
D06H3OUT	8.74	24.2	26.23	0.7	15.2	38.7	16.6	0.00
D06H3IN	-8.66	24.2	26.23	0.7	15.1	38.4	16.4	
D03H1OUT	11.85	29.0	38.44	0.8	18.8	48.0	20.4	0.01
D03H1IN	-12.22	29.0	38.44	0.8	19.3	49.5	21.0	
D02H1OUT	7.91	20.8	42.26	0.2	31.1	37.8	54.9	0.01
D02H1IN	-8.06	20.8	42.26	0.2	31.7	38.5	55.9	
D02H2OUT	10.09	36.5	42.74	0.6	18.8	36.5	22.0	0.02
D02H2IN	-10.06	36.5	42.74	0.6	18.8	36.3	21.9	
D02H3OUT	12.82	50.8	43.47	-0.9	17.1	39.3	19.0	0.02
D02H3IN	-13.14	50.8	43.47	-0.9	17.5	40.2	19.5	
D02H4OUT	7.96	20.4	44.23	-0.4	20.2	38.4	23.7	0.02
D02H4IN	-8.09	20.4	44.23	-0.4	20.5	39.1	24.1	
QC1(1.18m)	10.5	31.4	44.29			40.9		

4=Abort; >3.00; >1.50; >0.70

D6V1 neutron: 0.00

Dia QCSFW

	DIF_POS [mm]	beta_y [m]	nu_y	Nsigma (beta)	LM
D06V1TOP	2.47	67.3	28.86	65.8	0.00
D06V1BTM	-3.24	67.3	28.86	86.1	
	0.58				
D06V2TOP	2.14	20.6	30.50	102.9	0.14 0.28
D06V2BTM	-2.41	20.6	30.50	115.8	
	0.14				
D03V1TOP	7.99	17.0	41.43	423.2	0.00
D03V1BTM	-8.01	17.0	41.43	424.4	
	0.01				
D02V1TOP	1.09	13.9	44.87	63.6	0.02
D02V1BTM	-1.37	13.9	44.87	80.3	
	0.23				
QC1 (1.12m)	13.5	782.2	46.34	105.3	

Dia QCSFW

80 %

beta_y*[mm]	beta_x* [mm]
1.0	80.0

20200601_1x60CW40_1x80 CW80_sler_2020-06

emit_x [nm]	2.10
emit_y [nm]	0.021
emit_y [nm] by XRM	0.029
Sigmay by XRM [um]	45.1
current [mA]	458

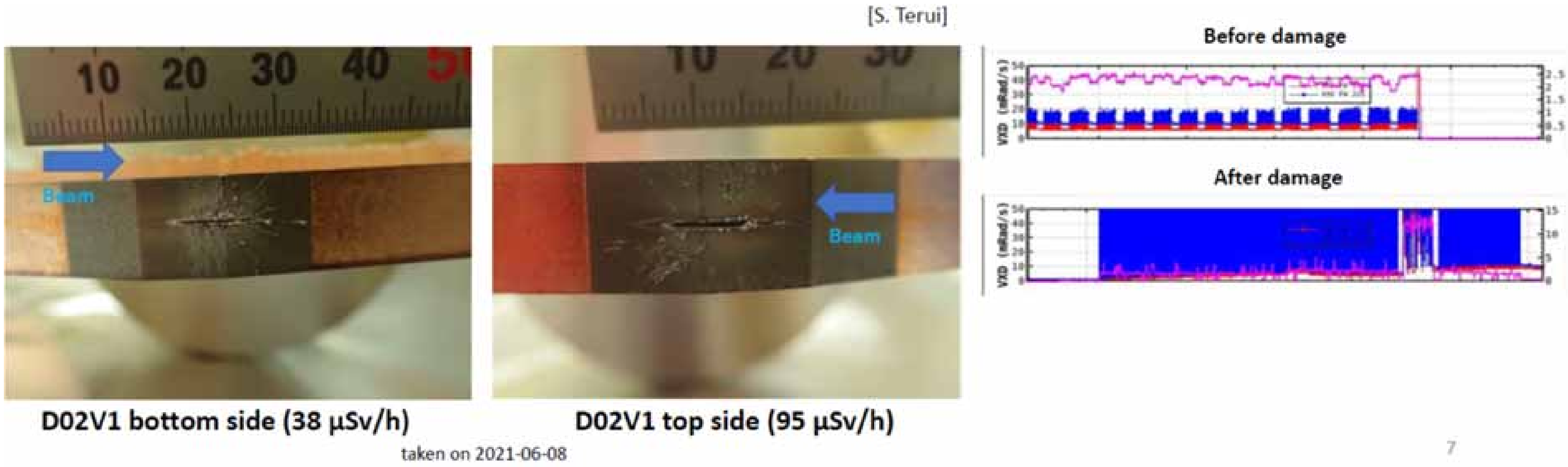
Collimator offset

	offset[mm]	DIF_POS'	Nsigma'
D6V1	0.000	2.47	65.8
		-3.24	86.1
D3V1	0.400	8.39	444.4
		-7.61	403.2
D2V1	0.100	1.19	69.4
		-1.27	74.5

- For Nsigma calculation, emittance values are given by hand (1% coupling). XRM measurements are NOT used.
  - LER XRM measuremet shows much larger coupling than 1%.
- If nu_x (collimator) - nu_x(QC1) is close to half integer, that collimator can effectively suppress BG.
- Nsigma(collimator) should be similar to Nsigma(QC1) in terms of beam lifetime and BG suppression.
  - If Delta(nu) is far from half integer, the collimator need to be further closed to suppress BG but beam life gets shor

Collimator movement ongoing
HER LER
2021/06/29 22:19:45.074

Collimator damage



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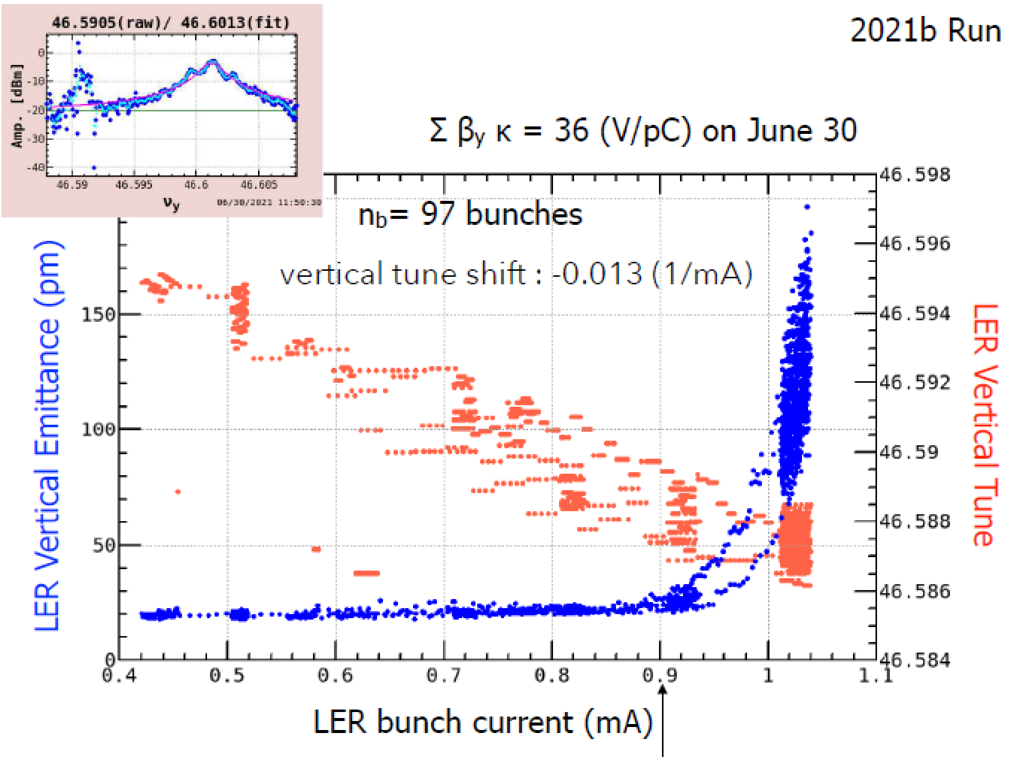
Detail will be shown in the “Beam background and MDI” session

Challenges (2)

■ Collimator transverse impedance (TMCI threshold)

- **Fairly narrow aperture to reduce beam background to Belle II detector.**
  - **Shorter beam lifetime (especially in LER)**
  - **Limit the maximum bunch current due to lower TMCI threshold**
  - **Increasing risks to damage the beam collimators (including residual radiation).**



Details will be shown in the talk of “Beam collimators and transverse mode coupling instability”

Challenges (3)

- **Beam-beam blowup (in vertical plane)**
  - Source of the blowup : Chromatic X-Y coupling?? or other?
  - Single bunch blowup or multi bunch effect?
  - Contribution from (broadband noise in) transverse bunch-by-bunch feedback?
  - Beam-beam head-tail instability?
  - Could be cured by the optimization of crab waist?

  - Detail will be discussed in the talk of “Beam-beam simulation”

Challenges (4)

■ Quality and amount of the injection beam from Linac

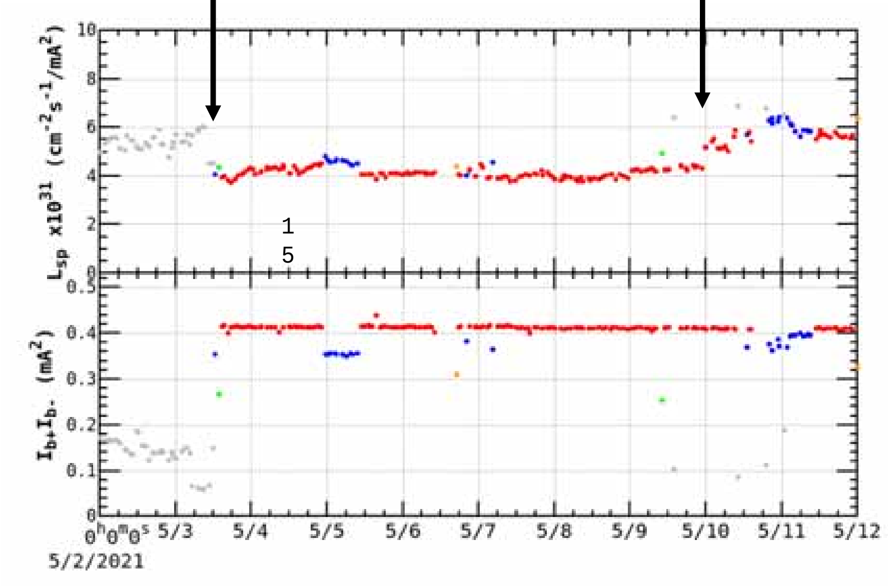
- Larger emittance than expected
- Emittance blowup in the beam transport line (due to CSR??)
- Stability of the injector Linac
  - Orbit fluctuation
  - Change of energy spread

Challenges (5)

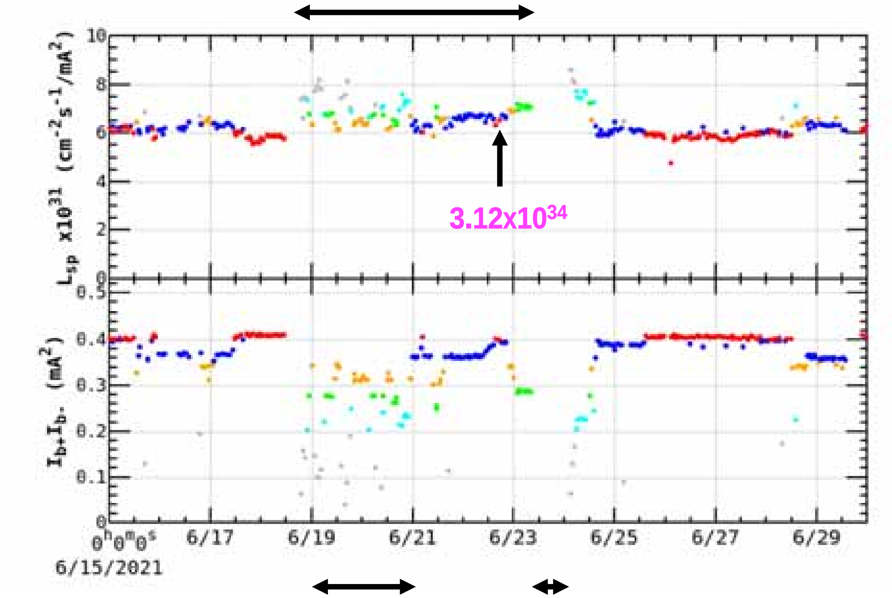
- **Feedback gain of bunch feedback system to suppress coupled-bunch instabilities.**
  - **Larger feedback gain will also inject larger noise related to the bunch feedback system to the beam which might cause (unexpected) dipole motion of the beam**

HER
change ν_y
43.572 → 43.578

HER BxB Feedback gain (vertical) decreased.
Swing shift on May 9



off-resonance (-60 MeV)



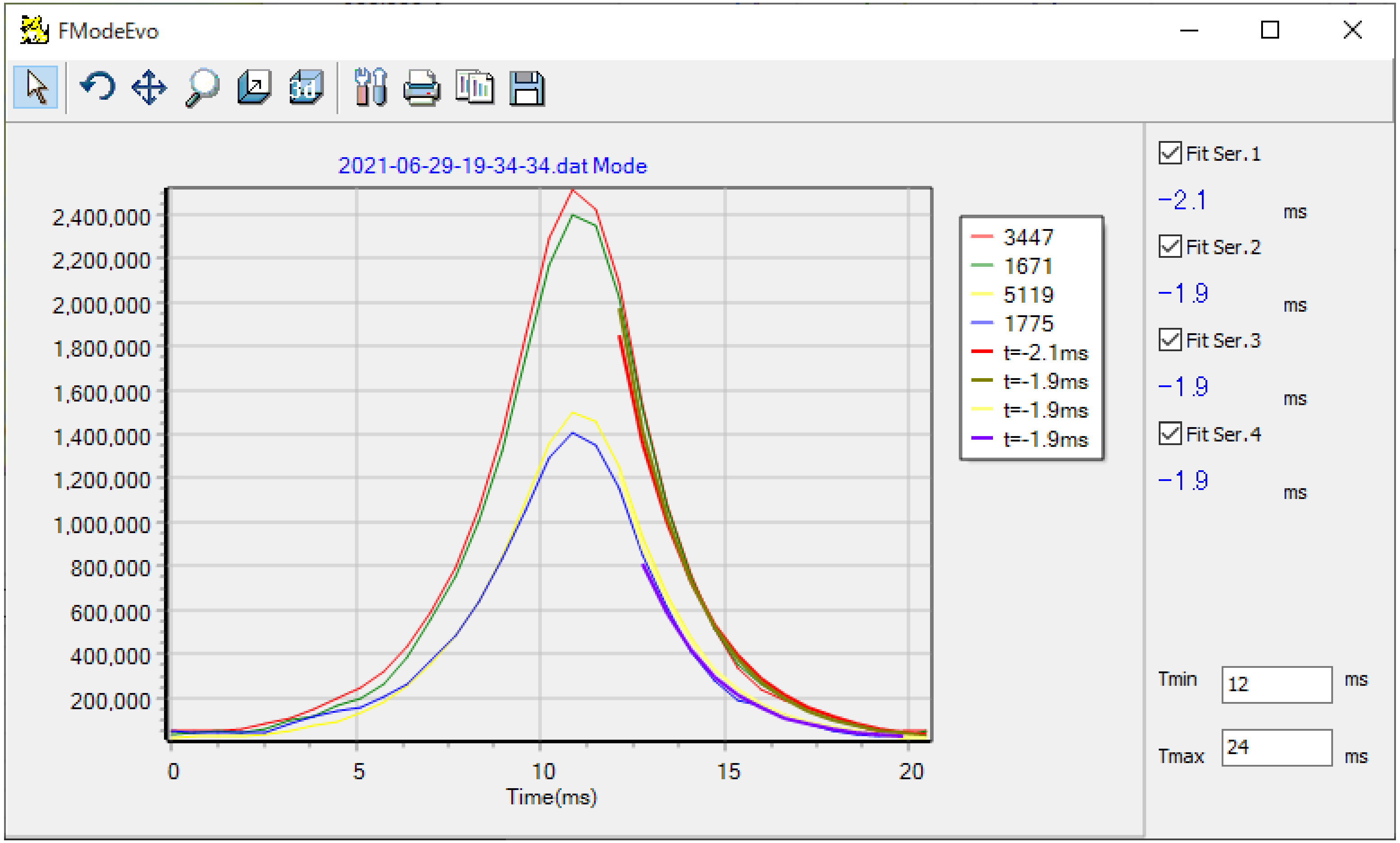
Linac energy FB trouble

maintenance

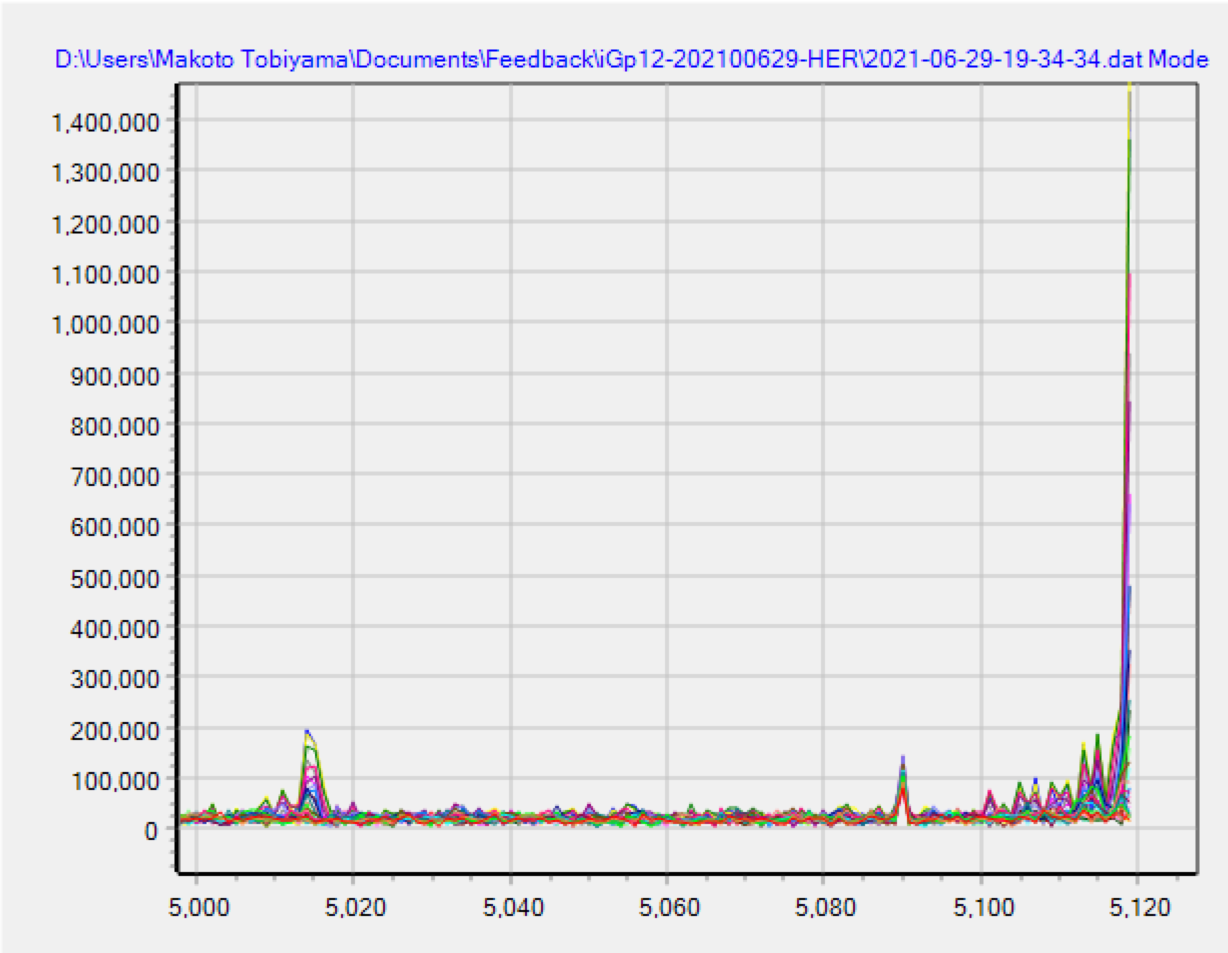
HER vertical FB situation

- Measurement of instability growth rate and feedback damping rate using transient domain analysis with iGp12 digital filters.
  - turn off FB (10ms – 15ms) and turn-on again, record 12MB data
- by*=8mm (200mA, 370mA), by*=1mm (200mA, 400mA, 600mA) with normal filling pattern of current runs.
- Mode -1 is the strongest mode, which is suspected to be caused by the resistive wall impedance.
  - Unstable mode measurement at SuperKEKB Phase 1 has shown the ion-like unstable modes (and behaviors).
  - Recent measurement shows much weaker ion-like unstable modes.

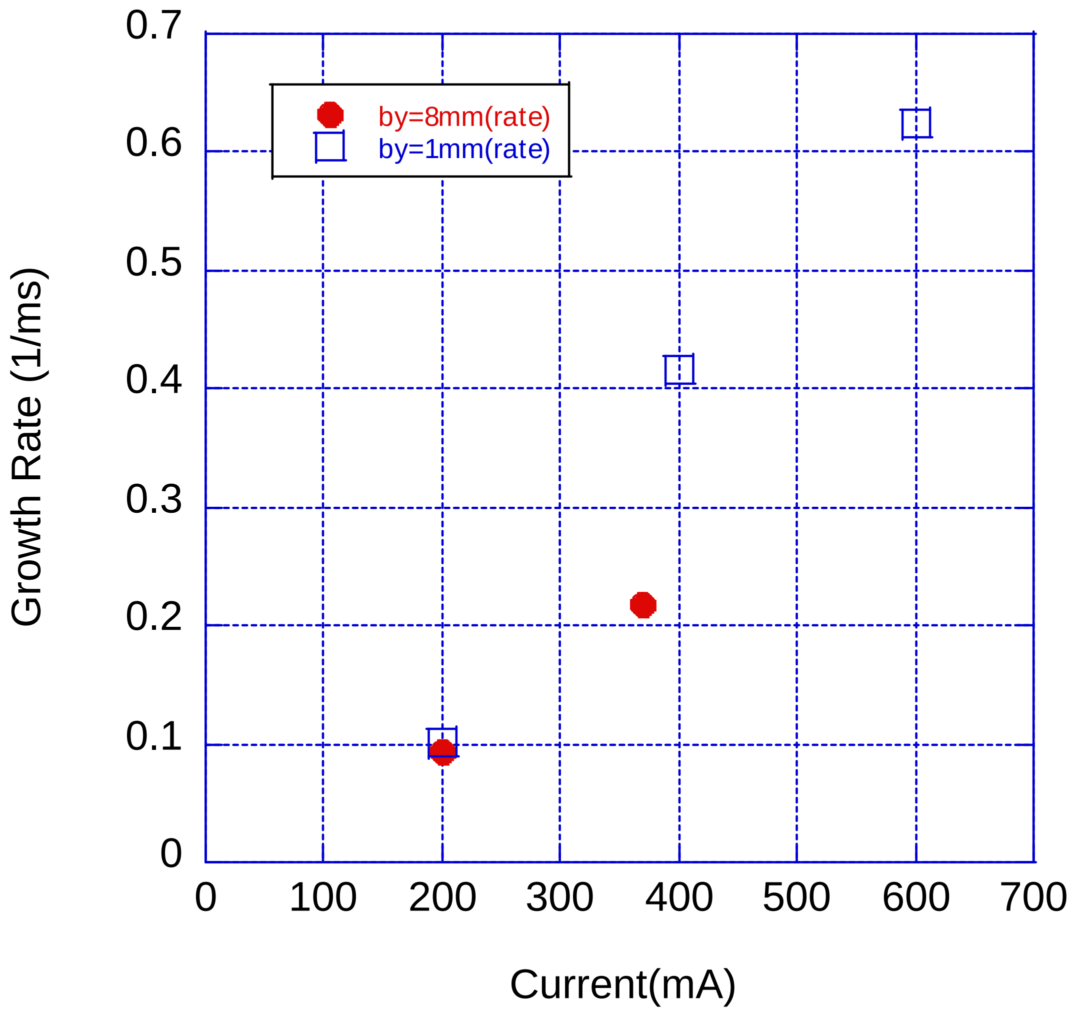
Growth and damp of unstable modes



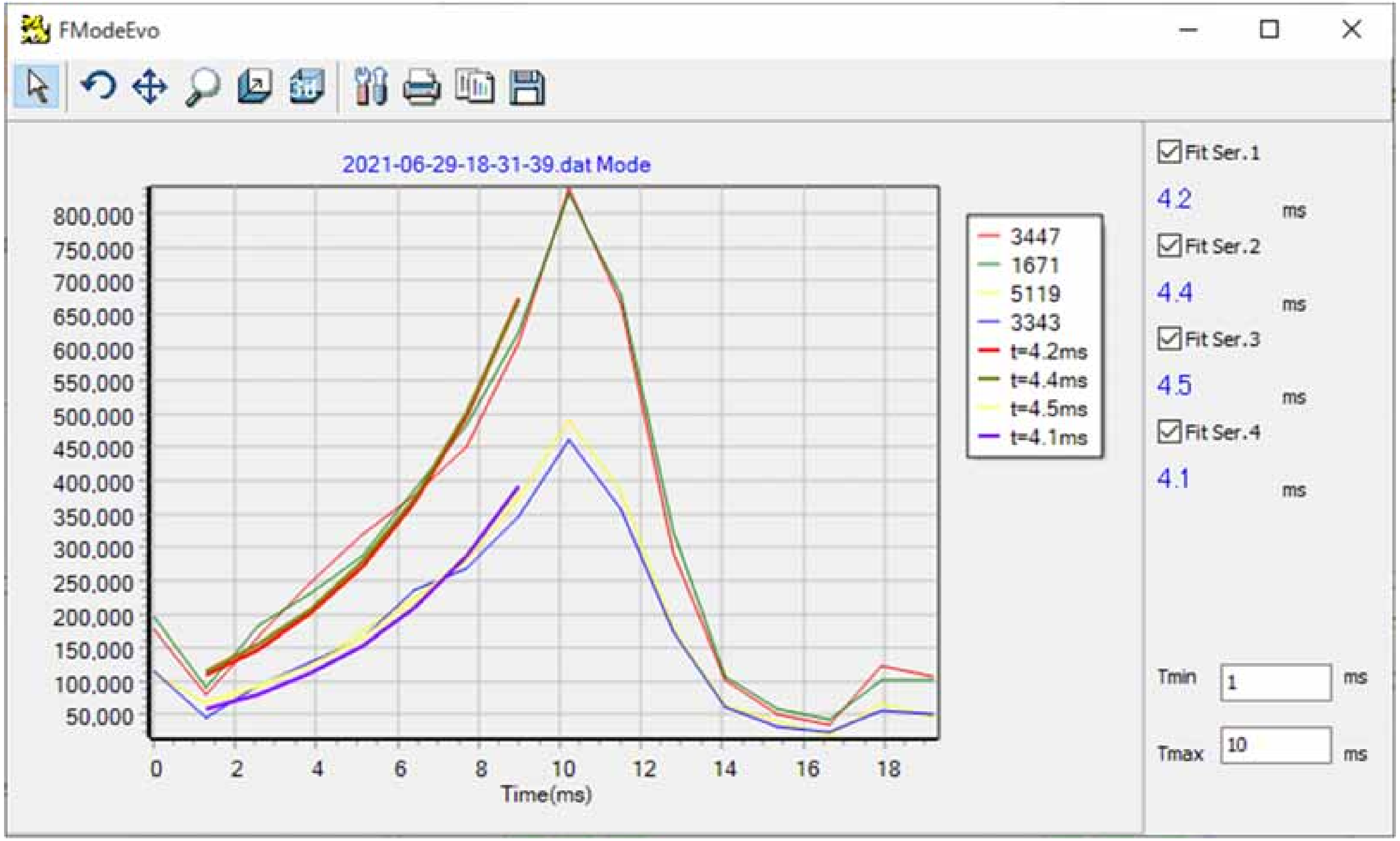
-1 mode dominant



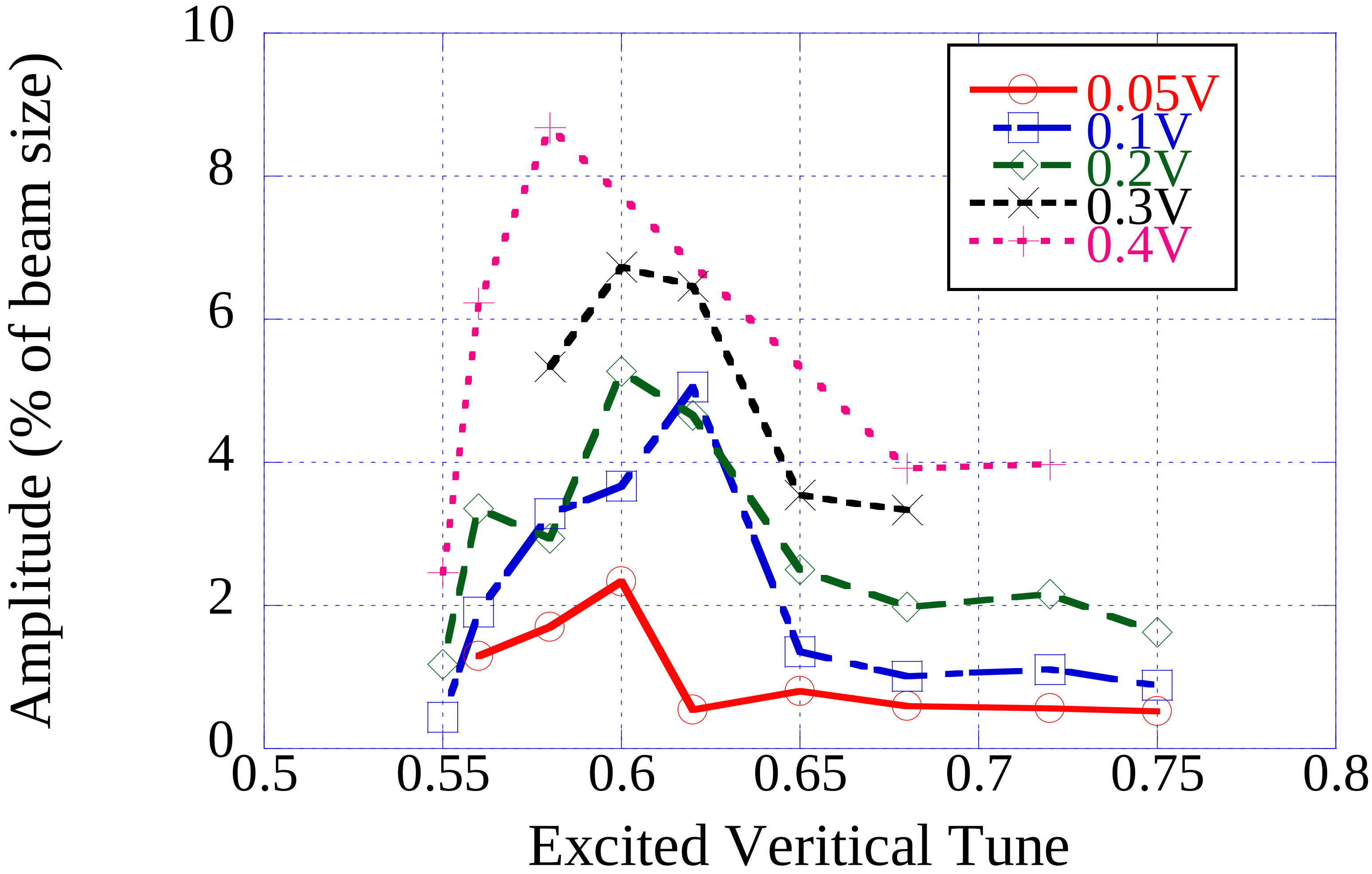
Growth rate of (-1) mode



During collision (by*=1mm, 670mA)



Noise effect study at KEKB LER



Many challenges remains

- Optimization of crab waist
- Impedance (bunch lengthening: longitudinal and transverse)
- Machine stability (mechanical, power supplies)
- Machine protection
- RF beam loading, HOM
- Aging of the infrastructures, including buldindgs.

Corrosion of cooling fan for RF system

Water leak of MR power supply building

BT

International Task force for SuperKEKB upgrade

■ Members

- ARC members prepared a list of possible candidates in June, 2021
- Initial members have been identified. More members who have required expertise and strong interest are welcome.
- Should work in close collaboration with KEKB commissioning team.

International Task Force members

2021/7/27

International members

Maria Enrica Biagini	INFN
Georg Hoffstaetter	Cornell
Evgeny Levichev	BINP
Mark Palmer	BNL
Yunhai Cai	SLAC
Rogelio Tomas	CERN
Pantaleo Raimondi	ESRF
Katsunobu Oide	CERN/KEK

KEK ACCL members

Mika Maszawa (Chair)	SKEKB
Yukiyoshi Ohnishi	SKEKB
Akio Morita	SKEKB
Hiroshi Sugimoto	SKEKB
Renjun Yang	SKEKB
Haruyo Koiso	SKEKB
Yoshihiro Funakoshi	SKEKB
Tsukasa Miyajima	SKEKB
Kazuhito Ohmi	SKEKB
Demin Zhou	SKEKB
Kentaro Harada	KEK-PF

Belle II members

Hiroyuki Nakayama	Belle II
Francesco Forti	Belle II

BPO members

Masanori Yamauchi	KEK		
Tadashi Koseki	ACCL	Naohito Saito	IPNS
Makoto Tobiyama	SKEKB	Shoji Uno	Belle II
Kazuro Furukawa	SKEKB	Yutaka Ushiroda	Belle II
Kyo Shibata	SKEKB	Toru Iijima	Belle II
Yusuke Suetsugu	SKEKB	Kodai Matsuoka	Belle II

International Task Force

Charges

- Consider effective ideas to realize luminosity of ~6×10^{35} cm^{-2} s^{-1} as a result of an intermediate upgrade around 2026, which could include modifications of IR, final focus systems, injectors, but without changing the boundary to the Belle II detectors.
- Find a realistic way before long shutdown 1 (LS1) scheduled to start Jul/2022 in order to achieve luminosity of the order of 10^{35} cm^{-2} s^{-1} without large modification of accelerator components.
- Consider longer-term alternative idea to achieve ~6×10^{35} cm^{-2} s^{-1} or more, even by largely modifying the IR and the Belle II detector

Four working groups (sub-groups) organized and their indico sites created

- Optics (contact person: Akio Morita)
- Beam-beam (contact person: Demin Zhou)
- TMCI (contact person: Mauro Migiliorati)
- Linac (contact person: Masanori Satoh)

Please join the sub-group

- Anyone can join the group-mail-list by sending an email to {group-name}-request AT ml.post.kek.jp with a subject of "subscribe"
- Sub-group
  - skb-itf-bb AT ml.post.kek.jp: for Beam-beam
  - skb-itf-opt AT ml.post.kek.jp: for Optics
  - skb-itf-tmci AT ml.post.kek.jp: for TMCI
  - skb-itf-linac AT ml.post.kek.jp: for Injector Linac
- We look forward to your participation!