Sudden Beam Loss (SBL)/MDI

Kenta Uno (KEK)

BPAC

September 16th, 2024

Machine Detector Interface (MDI)

MDI group structure

Nakayama-san's slide

MDI group

Leader: Hiro Nakayama

MDI group includes not only Belle II collaborators but also several experts from SuperKEKB vacuum, monitor, control, commissioning, injection, RF groups, as well as from LINAC group.

Beam background subgroup

Leader: Andrii Natochii
(10 staff, 7 postdoc, 7 students)

- **BKG simulation**
  - simulate storage and injection background
  - Find optimal collimator settings
- **BKG machine studies**
  - validate BKG simulation based on machine study data
  - understand and improve injection BG duration which causes DAQ deadtime
- **etc..**

Beam loss monitor subgroup

Leader: Kenta Uno
(8 staff, 3 postdoc, 7 students)

- **Sudden beam loss (SBL)**
  - beam loss monitors with fast readout
  - acoustic sensors
  - post-mortem abort timing analysis
  - BOR timing analysis
- **Faster Abort delivery**
  - NLC CLAWS as a new abort source
  - Abort delivery using laser transmission in air
- **etc..**

Other efforts which are directly reported to the MDI meetings

There also exist other MDI-related topics which are not covered by these two subgroups, such as machine-learning application to accelerator tuning (*), **beam injection, collimator R&D, diamond abort system, etc…**

Smaller beam BKG | Longer beam life | Larger beam currents | Better injection performance

Higher luminosity

KEK's new M&O MDI postdoc, TakShun Lau, is expected to contribute to Beam loss monitor group and machine learning taskforce

(*)Recently, B2/SKB/LINAC management has agreed to promote our further collaborations on "machine-learning application to accelerator tuning". Kickoff seminars are being held to recruit (remote) Belle II collaborators.

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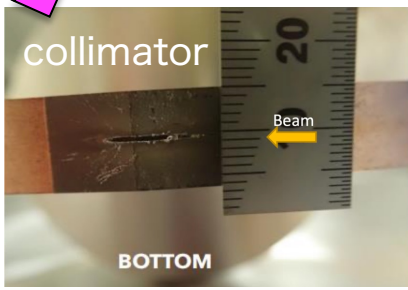
(4 staff, 1 postdoc, 2 students)

Today, I focus on Sudden Beam Loss

Sudden Beam Loss (SBL)

Cause the beam to lose most of its particles within a few turns

- Mechanism of SBL is not fully understood yet



Damaged Belle II detector and accelerator equipment

- Temporary PXD off since May 7 to avoid further damage

Covered by K. Nakamura-san and Bjoern's talk

The radiation dose and frequency seem to be proportional to beam current

→ We have to be cautious about increasing the current

Understanding SBL and making countermeasures are crucial to achieve high luminosity

Countermeasures in LS1

LS1: July, 2022 – Jan, 2024

H. Ikeda-san's slide, The 27th KEKB Accelerator Review Committee

Work during LS1

For preventing SBL

- Replacing damaged collimator head.
- Copper coating of collimator heads (D6H3, D6V1, D5V1, D2V1). （Cover material with a high sublimation point, which could be the seed of a fireball, with material with a low sublimation point.)
- Installation of permanent magnets in all SuperKEKB-type horizontal collimators. （In order to reduce the electron cloud effect…）
  - LER D02H4, D02H3, D02H2, D02H1, D03H1, D06H3, D06H4
  - HER D01H3, D01H4, D01H5

For investigation the cause of SBL

- Add BOR to investigate beam orbit change in locations that may be the cause of SBL.
  - Measure the orbit at two different locations with phase differences. ：Existing BOR
  - Add a simplified version to measure in phase with the collimator, although with less accuracy. ：New BOR
- Add loss monitor for timing measurement
- Install acoustic sensors to observe the sound when the Fireball occurs.(D2V1:minimum physical aperture, D5V1:new collimator, QCS, D6V2)

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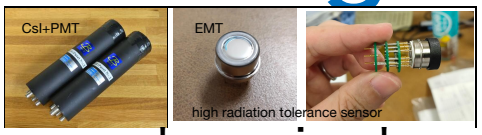
Belle II contributed to these important tasks with SuperKEKB

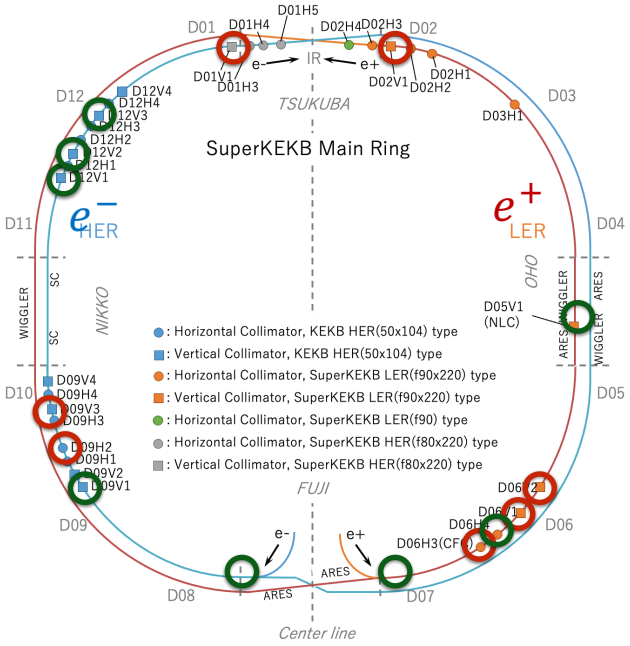
Timing analysis using Loss Monitor

Where beam loss starts?

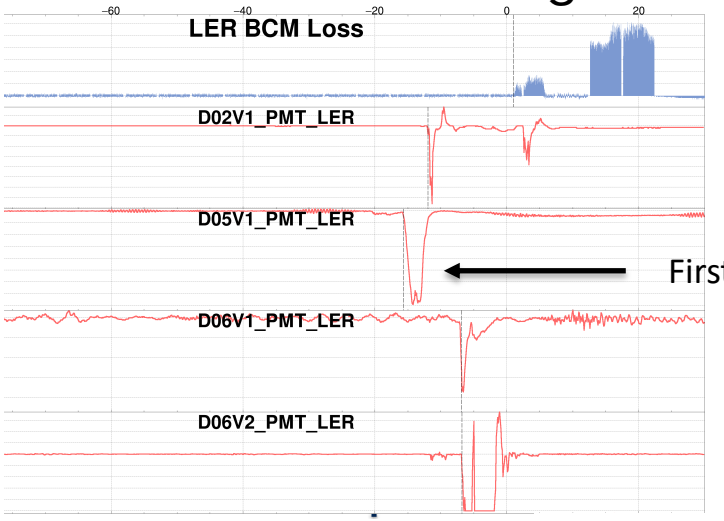


- Install fast loss monitors to record precise beam loss timing of SBLs
  - Provide chronological order of beam loss along the rings

White Rabbit developed by CERN has been introduced as time sync system

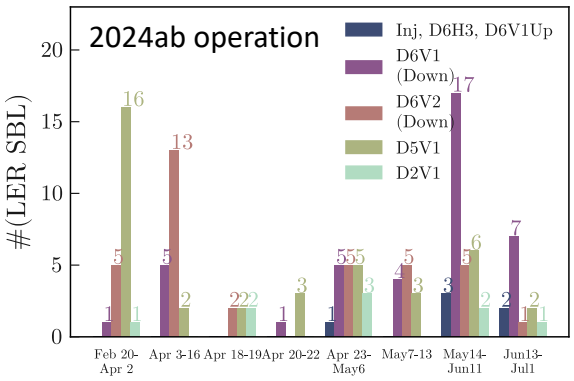


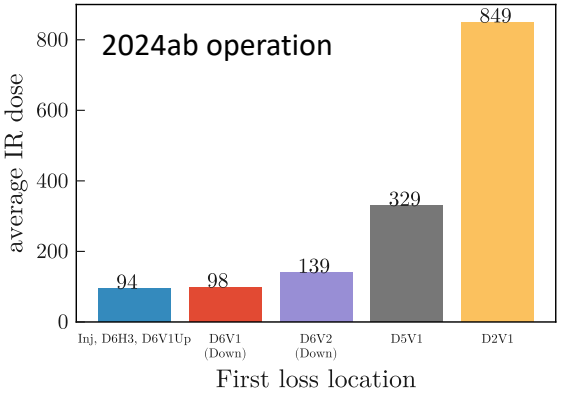
Installation in LS1
Installation before LS1



SBL on March 24th

First beam loss is D05V1





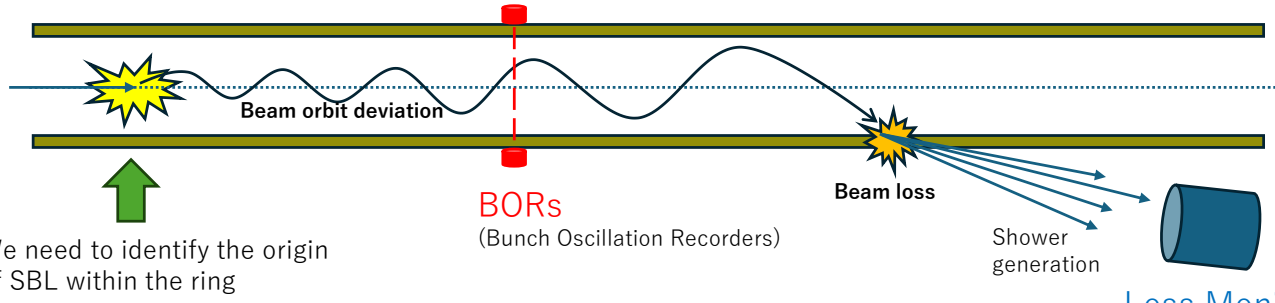
The initial loss mostly appeared on D05V1 or D06V1
IR dose tends to be high in case the first loss location is D2V1

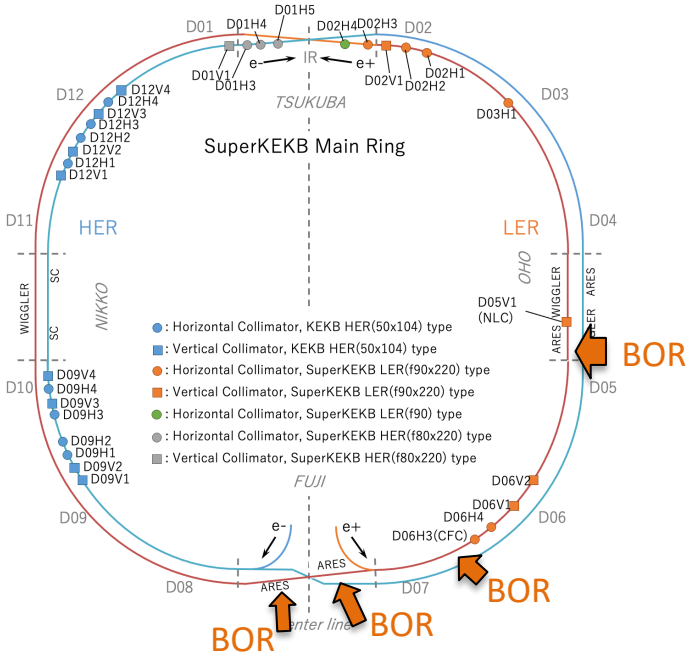
Bunch Oscillation Recorder (BOR)

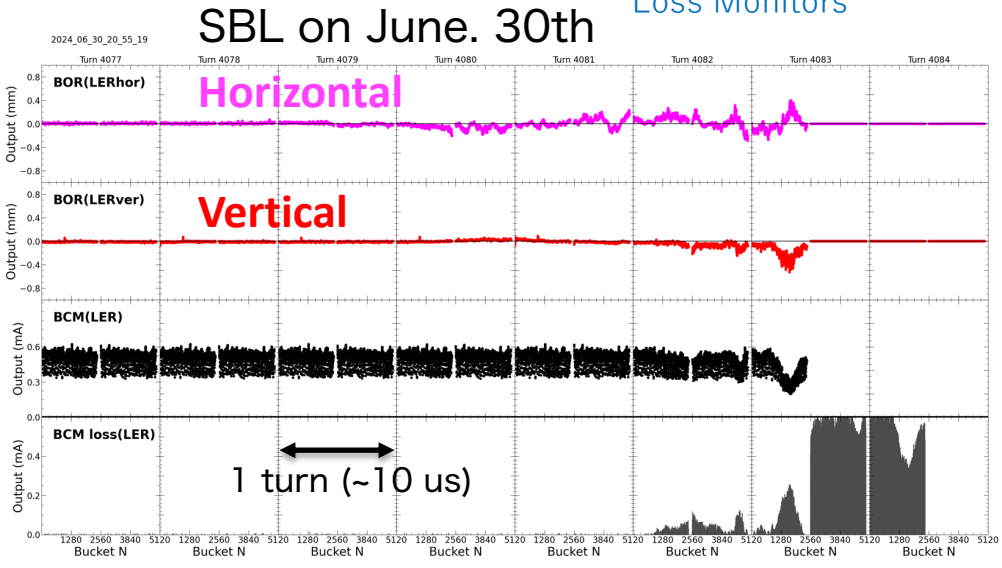
Is there any abnormal behavior of beam orbit?

(prior to the beam loss)

- Installed BORs to observe earlier stage of beam orbit deviation







More study is ongoing

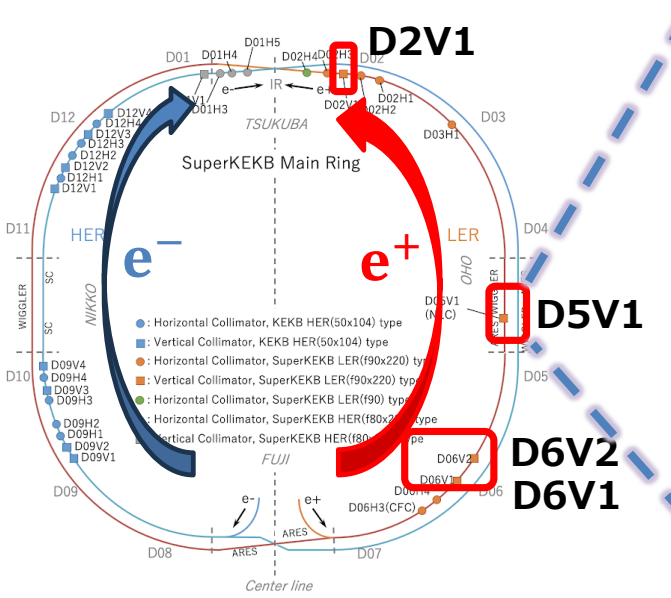
In most cases, beam orbit deviations were observed, but the source was not identified..

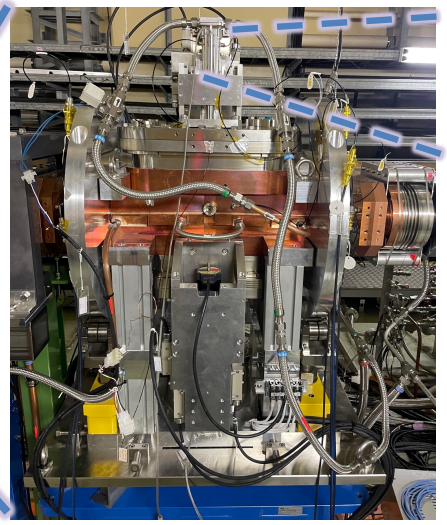
Acoustic Emission sensors

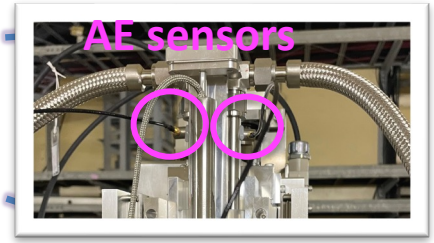
Possible candidate of SBL: electric discharge

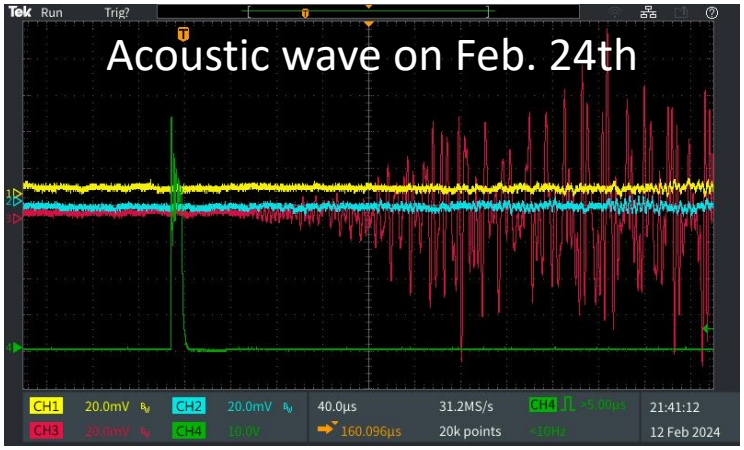
- Electric discharge may happen on collimators (eg. fire-ball hypothesis)

→ Install acoustic emission sensors (AE sensors) around collimators









In total, 34 AE sensors are attached.

No clear indication of electric discharge in 2024ab operation

→ No discharge around happened around collimators

(fire-ball hypothesis is disfavored)

2024ab operation: SBL

Suffered from several SBLs: HER ~20 times, LER~140 times

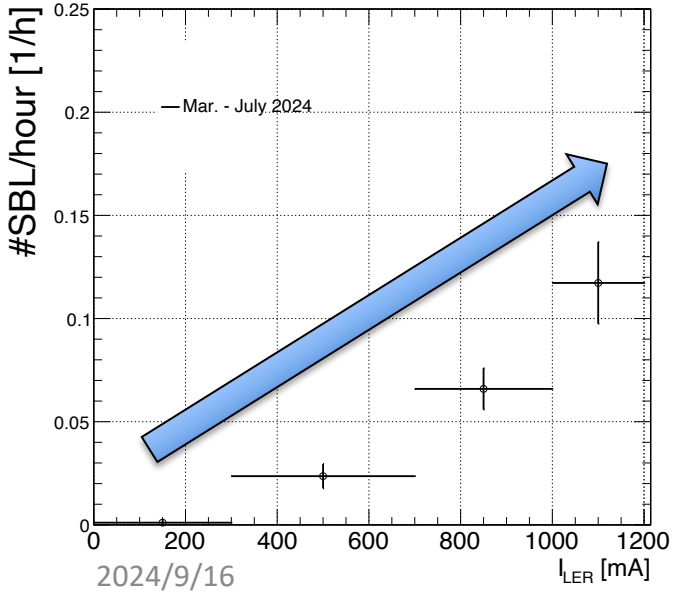
※ SBL in 2022: ~50 for LER, ~20 for HER

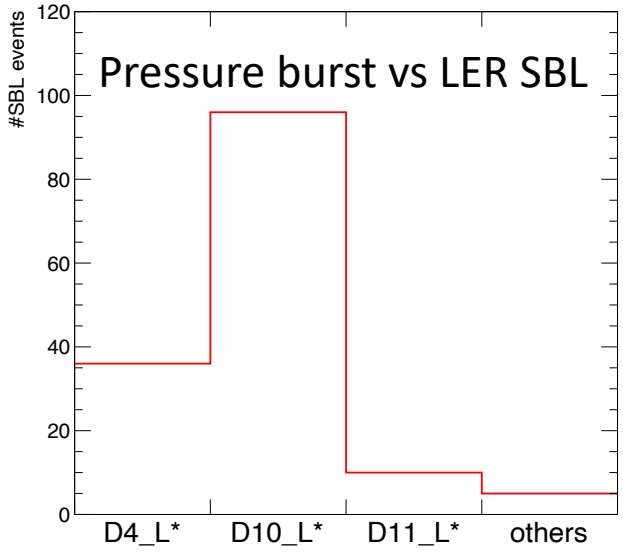
- LERSBL frequently occurred.. Collision and optics (β_y^*) do not matter ☹
- Excluded some hypothesis. Obtained a good knowledge by monitors ☺

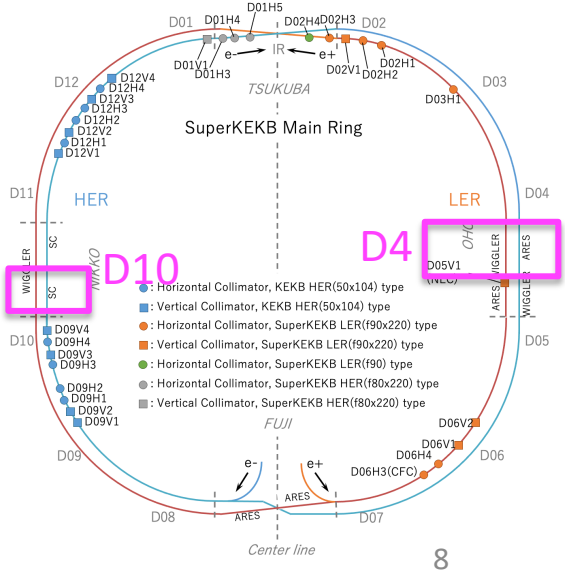
Belle II/SuperKEKB analyzed SBL events and found some features

- Frequency (#SBL/hour) strongly depends on beam current
- Pressure burst is mostly observed in LER SBL: D04/D10 wiggler section
- vertical beam size blow-up is observed for some SBL events

→ The source of LER SBL is dust in D04 or D10 wiggler section?



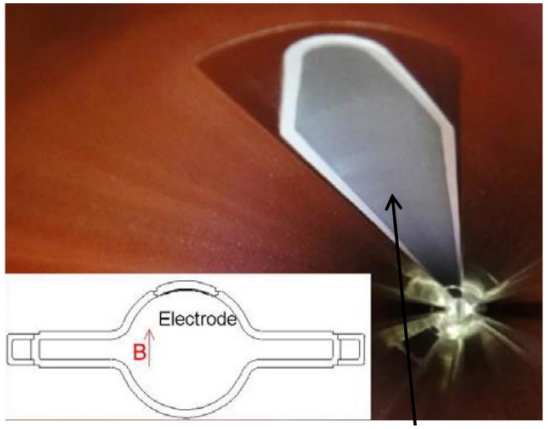




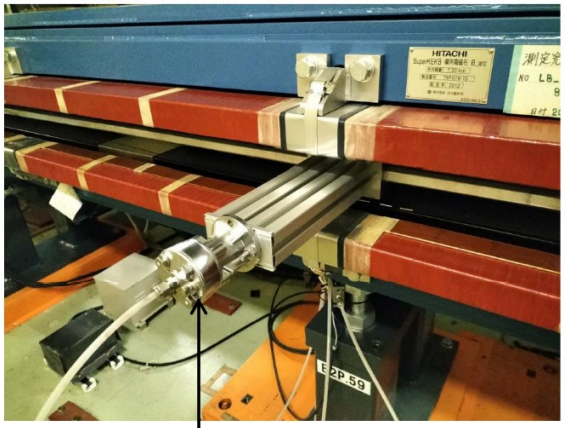
Knocker study

with beams (600 mA – 1000 mA)

Knocked beam pipes on D10 wiggler with clearing electrode



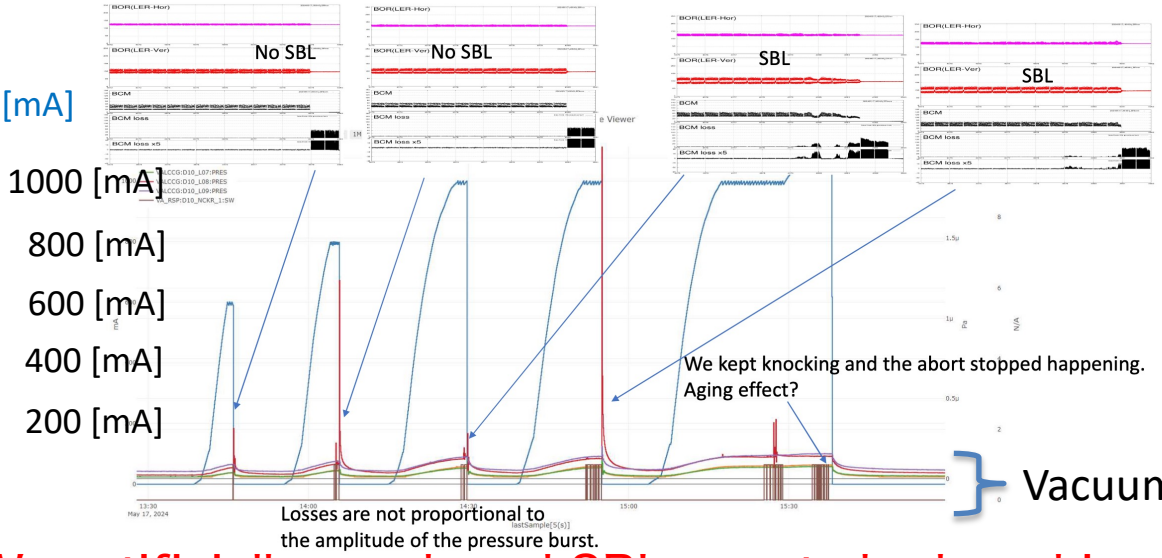
Clearing electrode



Knocker machine

Beam pipe with clearing electrode in D10 Nikko Wiggler section

H. Ikeda-san's slide



We artificially produced SBL events by knocking beam pipes!

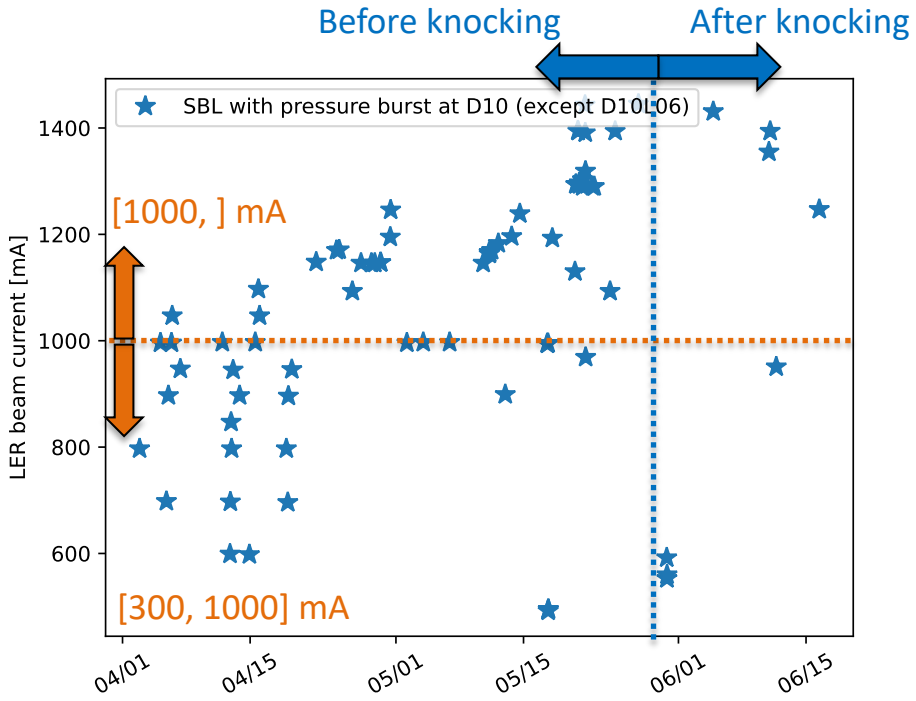
Another observation: knocking effect

Knocked beam pipes at D10 several times (w/o beams)

→ Checked the frequency of LER SBL before/after knocking

Count #SBL with pressure burst with D10

- Before knocking: 4/1 – 5/29, After knocking: 5/31 – 6/17



I_{LER} [mA]		[300, 1000]	[1000,]
Before knocking	#SBL	24	42
	Operation-time [h]	633.77	350.32
	#SBL/time [1/h]	0.038 ± 0.008	0.12 ± 0.02
After knocking	#SBL	4	4
	Operation-time [h]	98.5	162.3
	#SBL/time [1/h]	0.041 ± 0.020	0.025 ± 0.012

The frequency at $I_{\mathrm{LER}} \geq 1$ A is reduced: $0.12 \pm 0.02 \rightarrow 0.025 \pm 0.012$

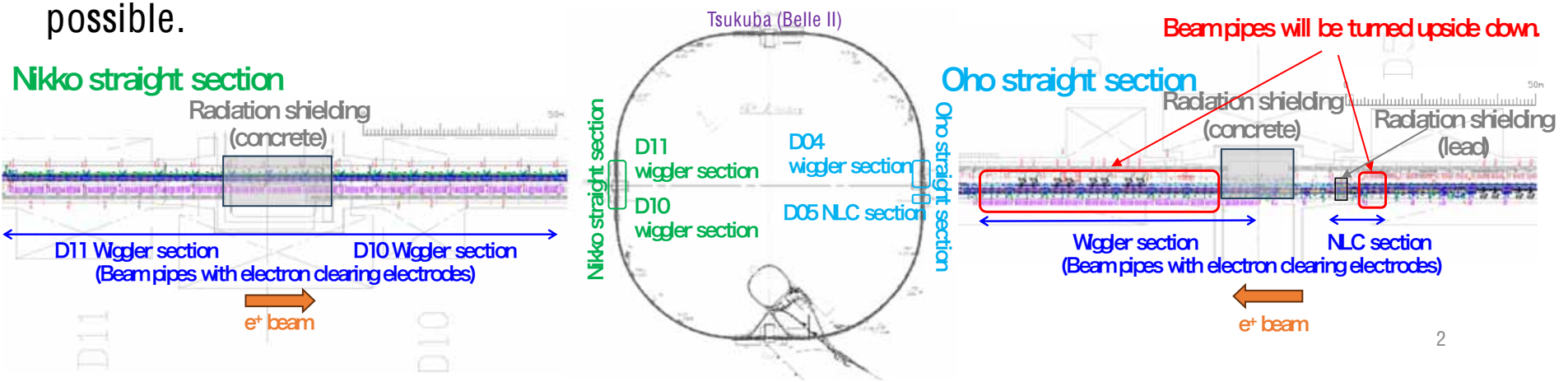
"Knocking effect" is seen.

Countermeasures in this summer

M. Tobiyama-san, K. Shibata-san' slide

Countermeasure against SBL

- Turning beam pipes with electron clearing electrode upside down
  - 15/50 beam pipes will be turned upside down. (56 m/185 m = 30 %)
  - Oho straight section : 13/16 beam pipes (D04 wiggler section) and 2/4 beam pipes (D05 NLC section) will be turned upside down.
    - D05 NLC section (2/4) : Done
    - D04 wiggler section (13/16) : In progress now (until the end of September)
  - Nikko straight section : 30 beam pipes at Nikko wiggler section will not be turned upside down.
- Visual check and dust cleaning of beam pipes which will not be turned upside down.
- Knocking as many beam pipes (with electron clearing electron or groove structure) as possible.



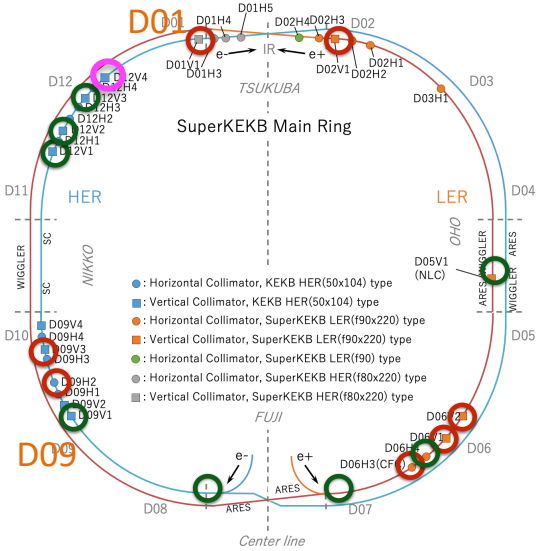
Source of HER SBL

HER SBL is not still understood yet (no clearing electrode in HER)

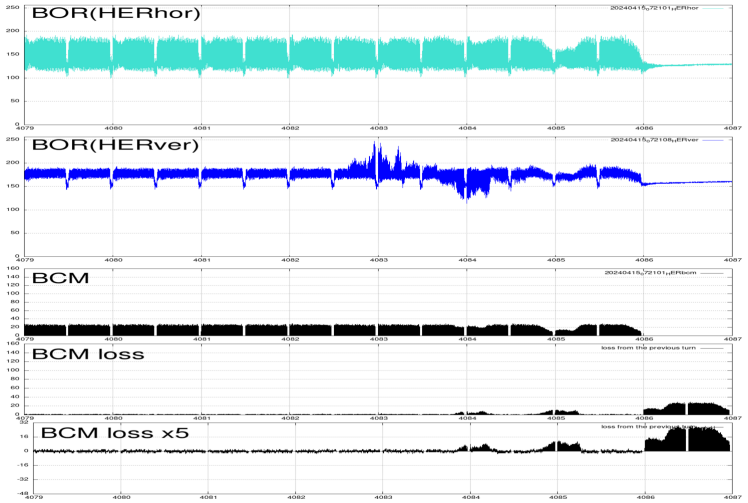
- Need fast beam abort to protect our system against HER SBLs
  - **Result of loss monitors: initial loss on all HER SBL is D9V1/D9V3**

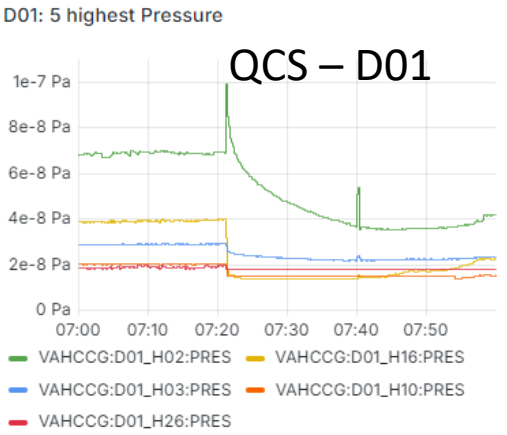
  → Install optical fiber around the collimators for beam aborts this summer

  Expectation ~5 us earlier
- Add Loss Monitors to understand HER SBLs
  - AE sensors around collimators/QCS where pressure burst was seen
  - PMT(CsI) in D12V4 collimator with high radiation in 2024ab
- Continue analyzing HER SBLs by combining info of all monitors



Installation in LS1
Installation before LS1





Summary and Prospect

SBL is one of the most critical issues in our operation

- Mostly understood source of LER SBL by analyzing SBL events
  - Major source is a clearing electrode at D04/D10 wiggler section

→ This was identified by effort from both Belle II and SuperKEKB

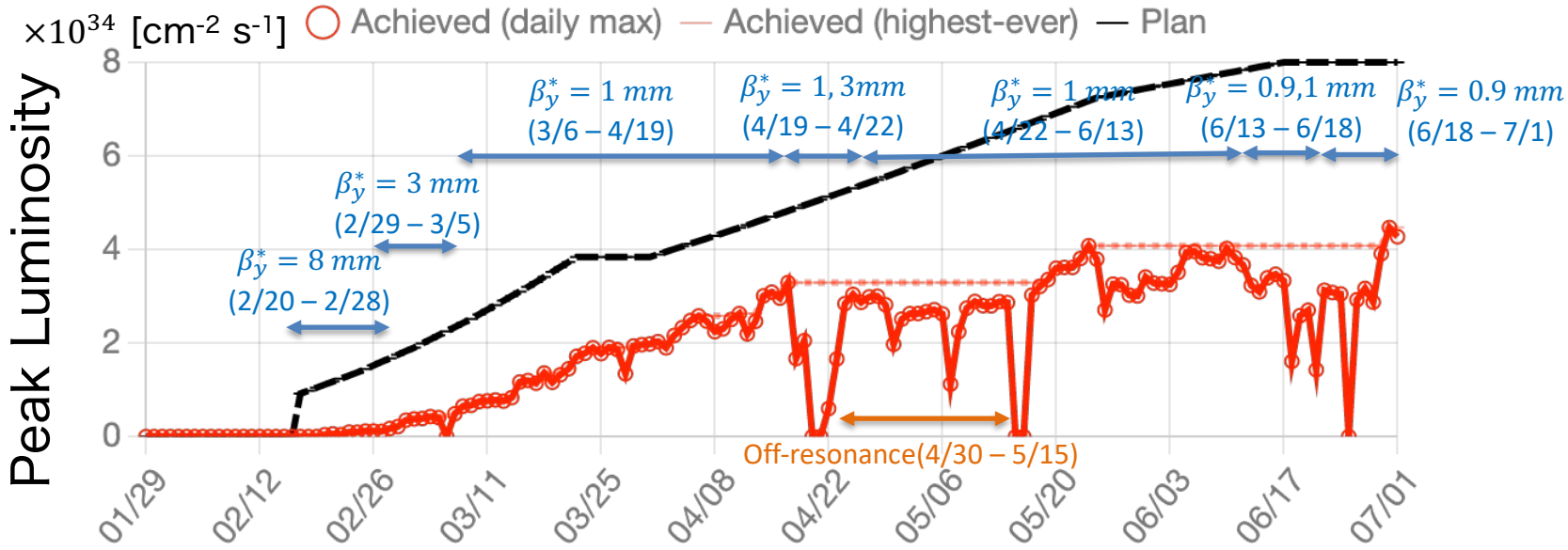
- 15 beam pipes with clearing electrode will be flipped (~30%)
  - Verify the countermeasures work in autumn run

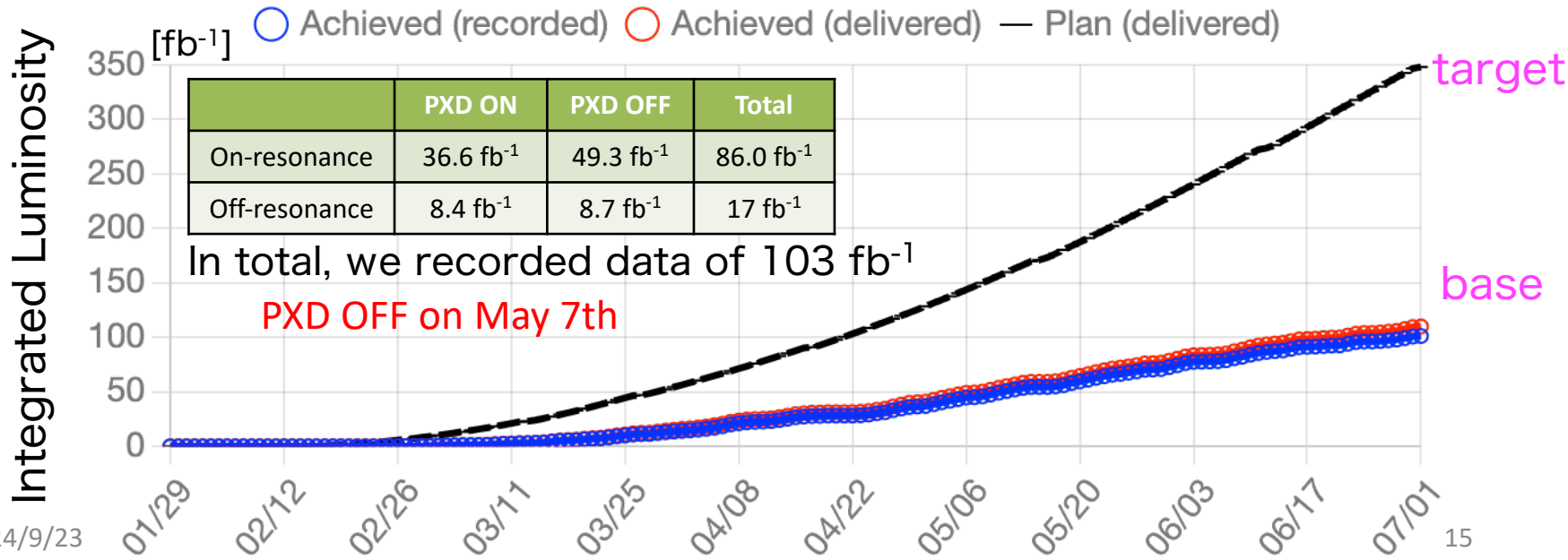
Next mission is to understand source of HER SBL

- Reinforce abort system and loss monitors in HER
  - Install optical fiber, add AE sensors and loss monitors
- Utilize BOR information for better understanding of SBL events
  - Discussion of suitable location is ongoing

Backup

Reminder: 2024ab operation





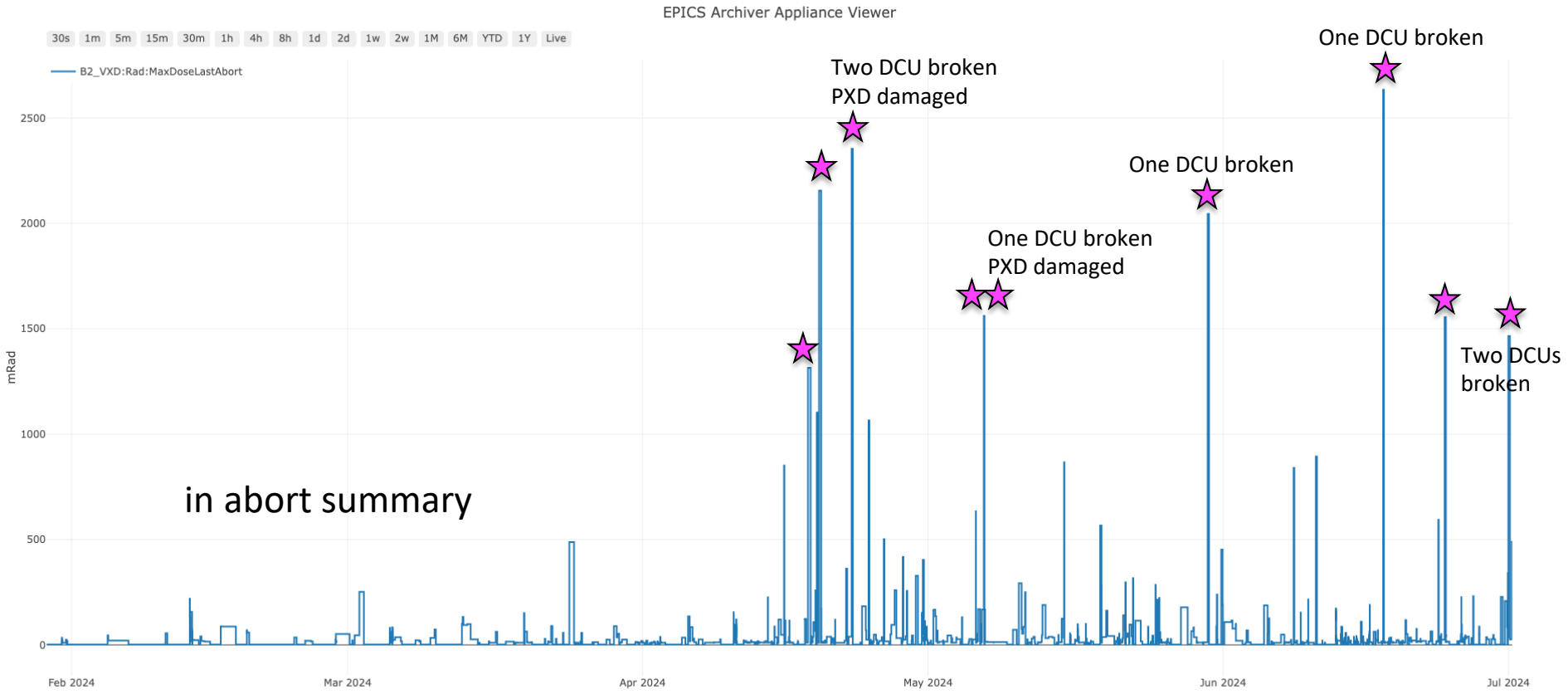
	PXD ON	PXD OFF	Total
On-resonance	36.6 fb^{-1}	49.3 fb^{-1}	86.0 fb^{-1}
Off-resonance	8.4 fb^{-1}	8.7 fb^{-1}	17 fb^{-1}

In total, we recorded data of 103 fb^{-1}

PXD OFF on May 7th

IR loss at beam abort

★ QCS quench



#aborts w/ VXD

Raw Data[0(s)]

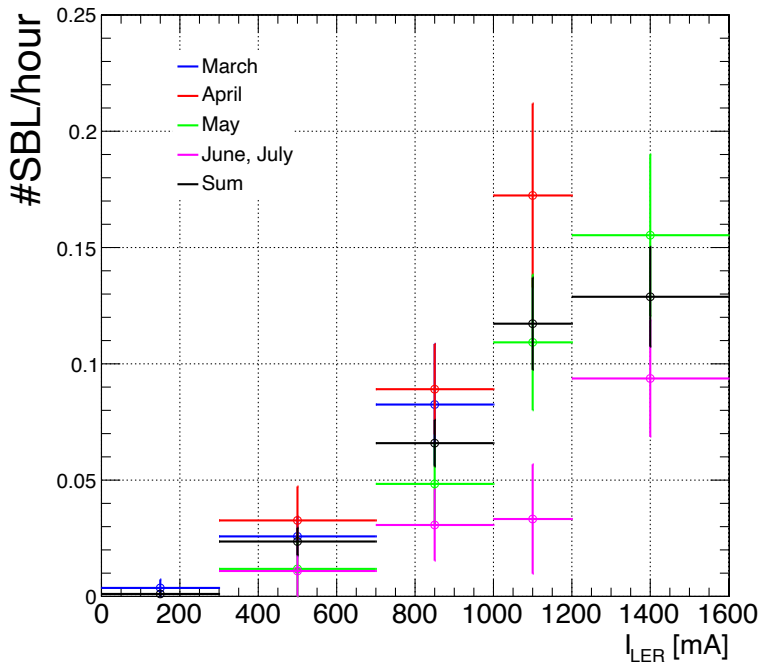
※ number in Run1 multiplied by 2.2 for the comparison

IR loss [mRad]	[0, 300] mRad	[300, 1000] mRad	[1000,] mRad	Total
2/1 – 7/1 (2024)	1399	18	11	1429
2/21 – 6/22 (2022)	615	18	13	646

- 953/1399: injection related aborts (VXD)..
- Several SBLs……

Frequency of LER SBL

March.1st - July. 1st



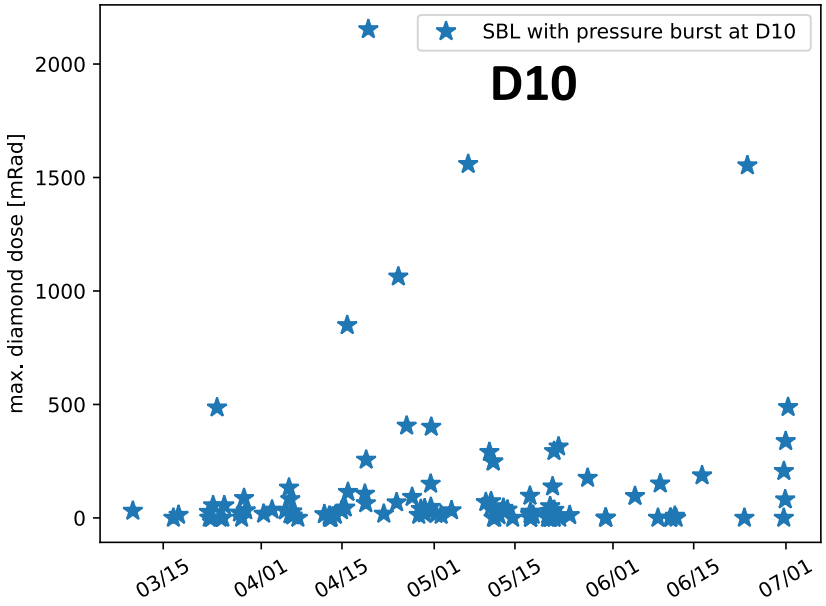
I_{LER} [mA]		[300, 700]	[700, 1000]	[1000, 1200]	[1200,]
March	#LER SBL	9	10	0	0
	Operation time [hour]	348	121	0	0
	#SBL/hour	0.026 ± 0.009	0.082 ± 0.026	–	–
April		5	21	19	2
		153	236	110	1.3
		0.032 ± 0.014	0.089 ± 0.02	0.17 ± 0.04	1.6 ± 1.1
May		1	8	14	20
		85	165	128	129
		0.012 ± 0.011	0.048 ± 0.02	0.11 ± 0.03	0.16 ± 0.03
June		1	4	2	14
		92	130	60	149
		0.011 ± 0.01	0.031 ± 0.02	0.033 ± 0.02	0.09 ± 0.03

Exclude SBL on May17, 30 and June 18, 25 (knocker study)

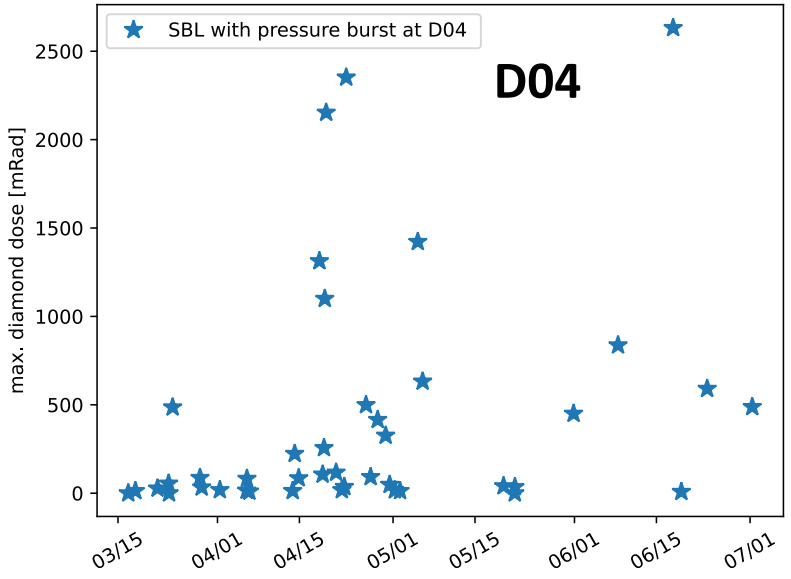
- Frequency (#SBL/hour) depends on I_{LER}
- The frequency (#SBL/hour) in June decreased
  - Knocking effect performed on May 29th seems effective

IR dose vs LER SBL

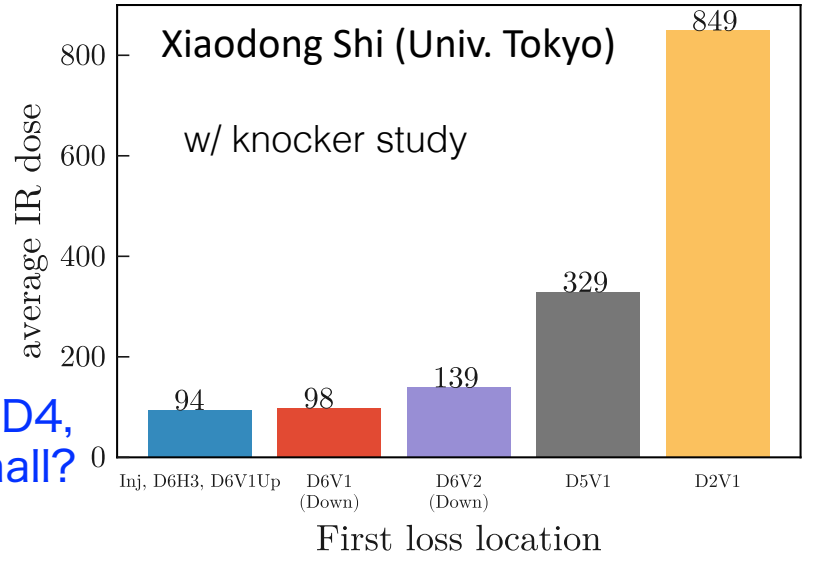
> 500 mRad: 5/112



> 500 mRad: 9/42



- For first loss at D2V1, all are w/ pressure bust at D4
- But not all D4's pressure burst will cause first loss at D2



If we can reduce SBLs with pressure burst at D4, the risk of damage on the Belle II would be small?

Loss Monitors

Timing analysis using Loss Monitors

high radiation dose in 2024ab

- Added monitors around the collimators, D03H1 and D12V4

AE sensors

- Added AE sensors in HER (D1V1, QCS-R) where pressure burst was seen

BOR

- Will add two BORs on November
  - Discussion of a suitable location is ongoing

Loss Monitor for beam aborts

- Installed optical fiber around the collimators, D9V1, D9V3 (HER)
- Install CLAWS around the collimator, D6V1 (LER) on October 1st