Sudden Beam Loss (SBL)

2024/6/3 B2GM H. Ikeda

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Contents

What is “Sudden Beam Loss” ?

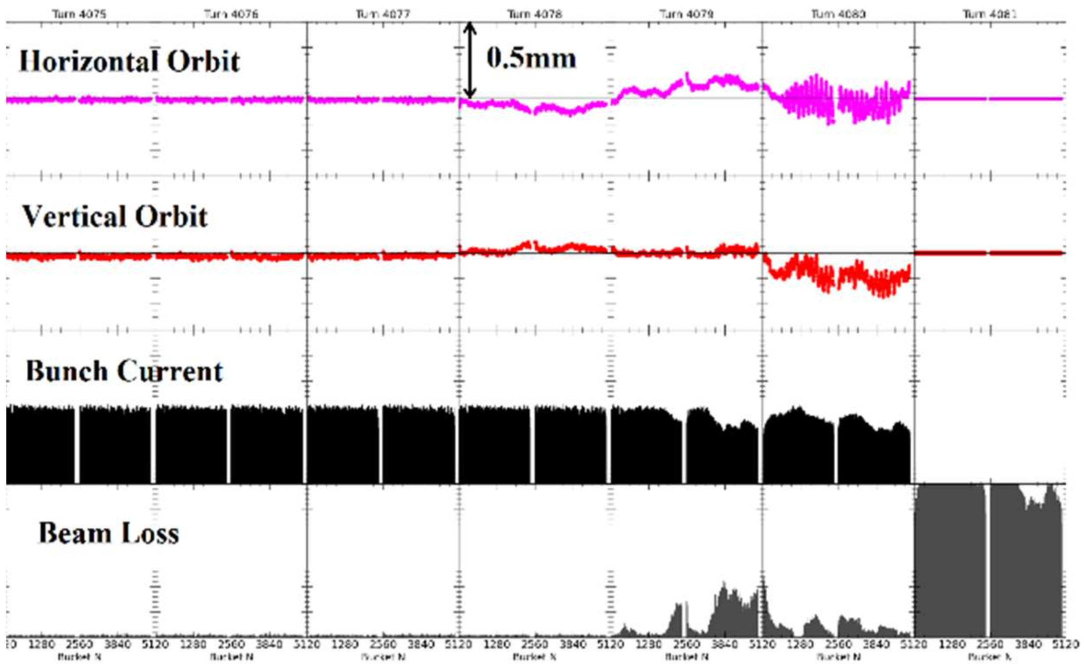
Beam loss that occurs suddenly within 1 turn (10μs) without precursory phenomena. ＝ Sudden Beam Loss（SBL）

- The cause of SBL has been unknown.
- A significant percentage of the beam is before the abort trigger is issued and stored beam is dumped

→ Harmful effects of SBL;

- Damage to collimators and other accelerator components,
- Quench of the final focusing superconducting magnets (QCS),
- Large backgrounds to the Belle-II detector,
- Inability to store high current due to beam abort.

Beam signal measured by
Bunch Oscillation Recorder(BOR) & Bunch Current Monitor(BCM)



Observations (Run1)

- A large fraction of the stored beam is **suddenly** lost before the abort.
- **Beam loss occurs in both HER and LER**, but the damage to the hardware is particularly large when the loss occurs in LER.
- We don't know if it will happen even with a single beam or low current beam because we haven't operated for a long time under such a conditions.
- The starting point of beam loss depends on the collimator setting and is not limited to a specific location.
- Just before the beam loss begins, the orbit appears to move, but the displacement is small～ O(0.1 mm).
- **After the start of the beam loss, orbit displacement is <O(1mm).**
- **No oscillations** that could be precursors to beam loss are observed.
- **Pressure bursts have been observed** all over the place and rarely occur in the same place except at the collimator sections.
- At D06H3 and D06H1 collimators, we observed rapid and nonlinear pressure increase as we stored more beam current.

Works during LS1

To Mitigate SBL

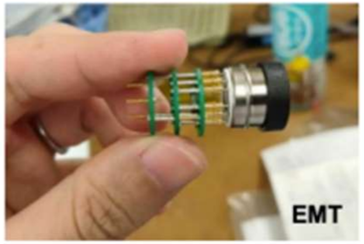
- Replaced damaged collimator heads.
- Copper coating of collimator heads (D6H3, D6V1, D5V1, D2V1).（Cover material with a high sublimation point, which could be the seed of a fireball, with material with a low sublimation point.)
- Installed permanent magnets in all SuperKEKB-type horizontal collimators.（In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

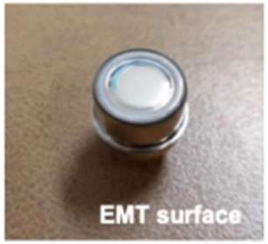
To Investigate the cause of SBL

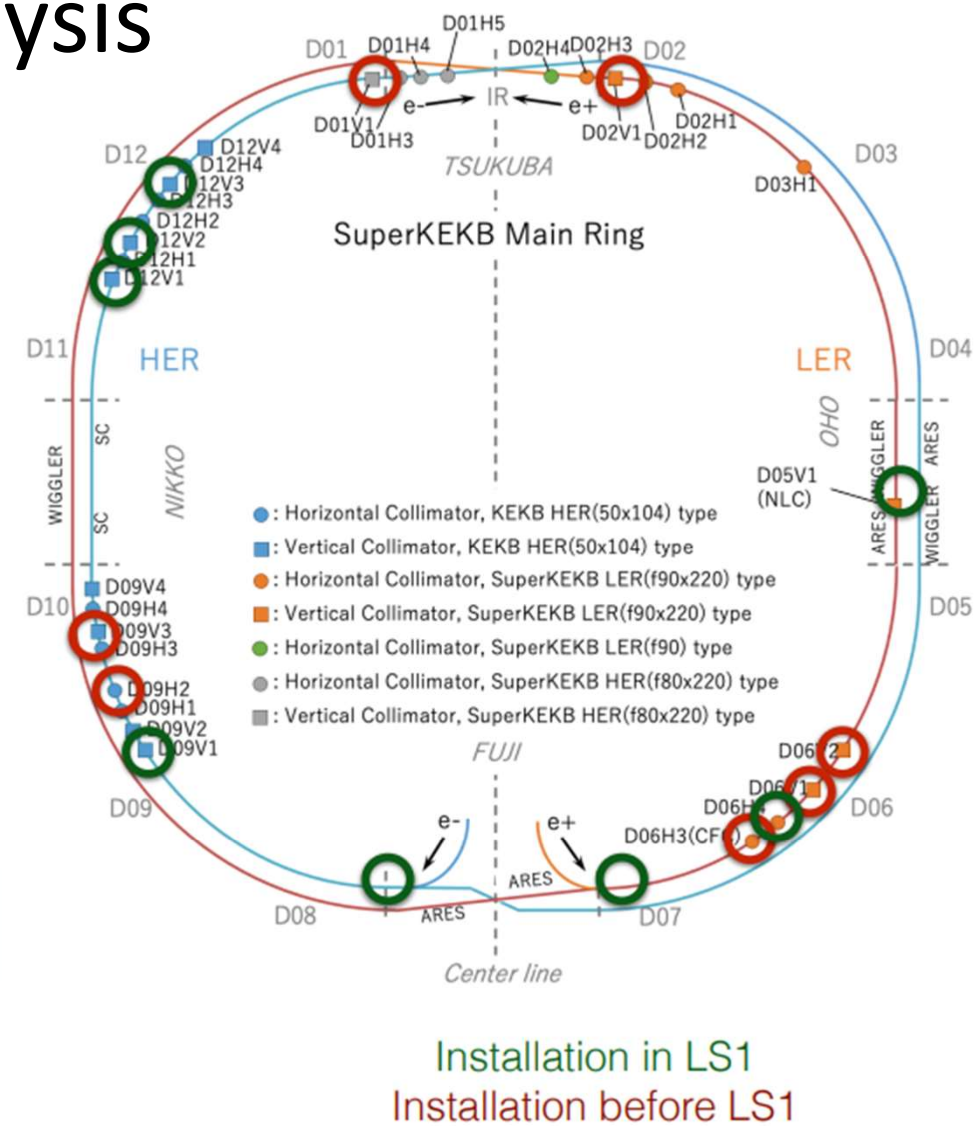
- Installed more loss monitors for timing analysis.
- Added BORs (Bunch Oscillation Recorders) to investigate beam orbit change in locations that may be the cause of SBL.
  - Measure the orbit at two different locations with phase differences. ：Existing BOR
  - Add a simplified version to measure in phase with the collimator, although with less accuracy. ：New BOR
- Installed acoustic sensors to detect acoustic waves due to thermal shock generated by vacuum arc for investigation the cause of LER SBL.(D2V1:minimum physical aperture, D5V1:new collimator, QCS, D6V2 and D6V1 after starting run2)

Loss Monitor for Timing analysis

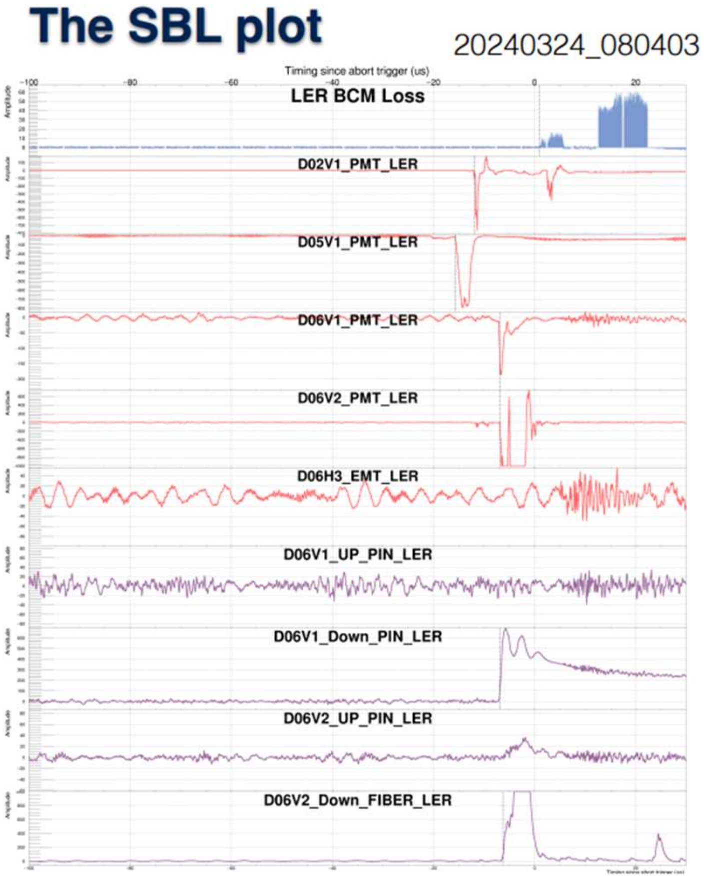
- To gain more information about beam aborts, especially SBL, some PMT/EMT are installed during LS1.
- We shall analysis the waveform of each sensors to determine the signal time and synchronize all the sensors.



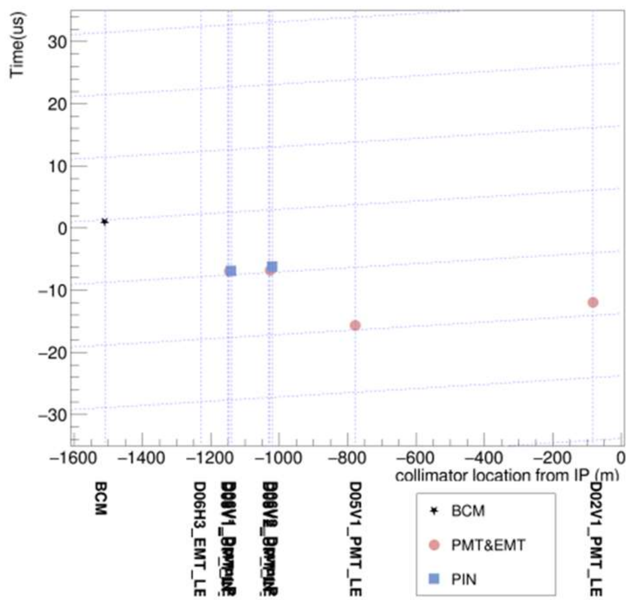




Example of loss monitor timing analysis

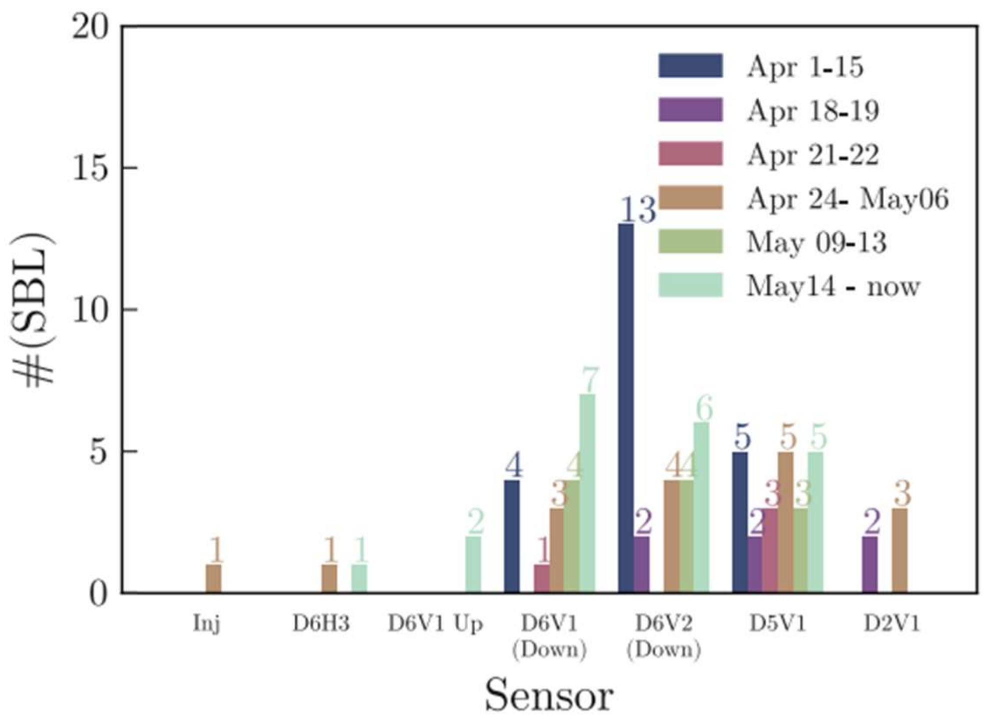


- For every abort, 2 plots are shown. The second one shows time of every turn.



- The vertical dash line is the signal time determined by 'bi-threshold' .
- For this abort, first signal is seen on D5V1. Then in same turn, signal is seen in D2V1. Then IR has huge dose.
- The collimators in the upstream of D5 won't help for this abort.
- The D5V1 was fully opened. (Was closed to 5mm at 3/26.

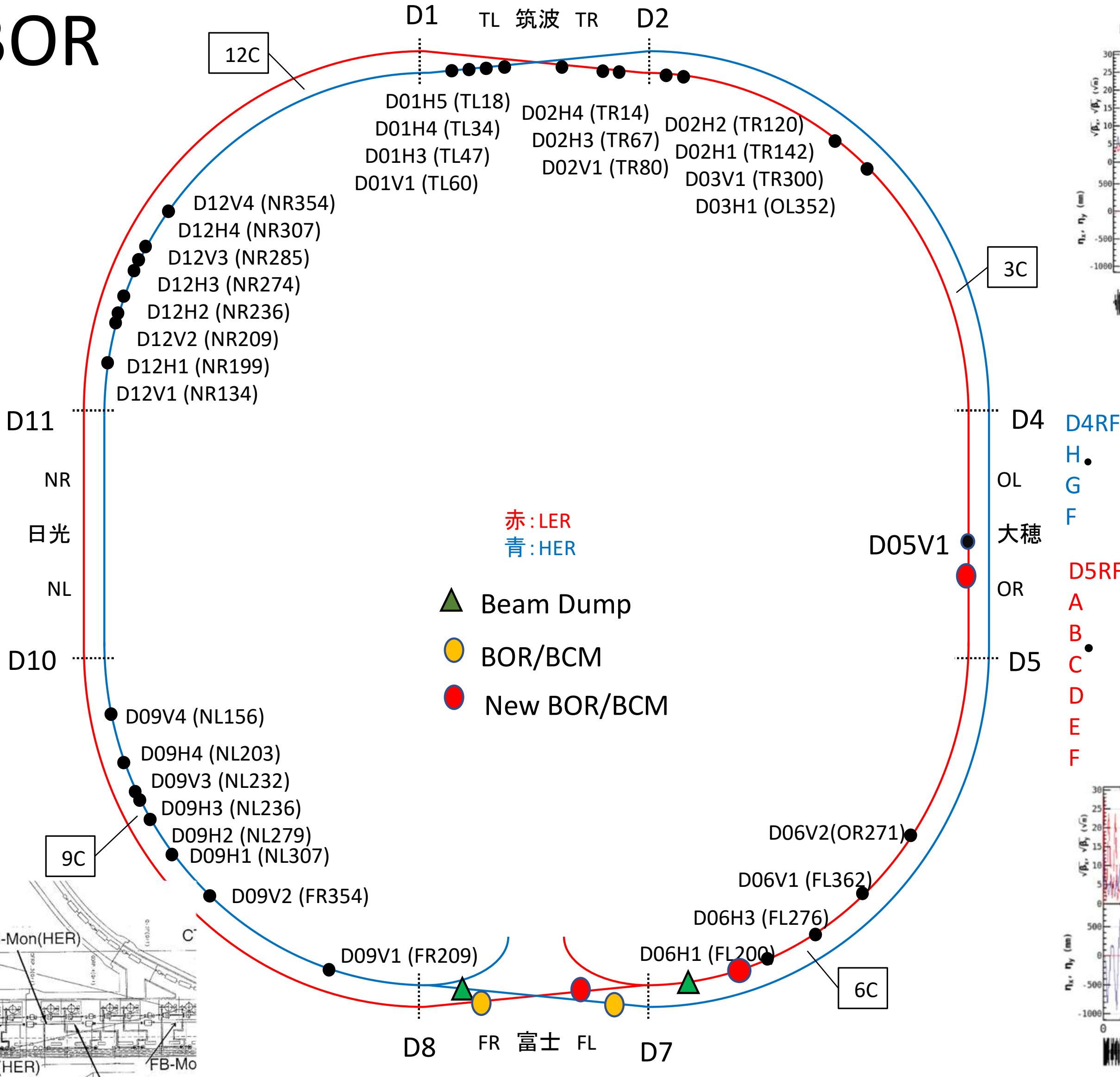
(X. Shi)

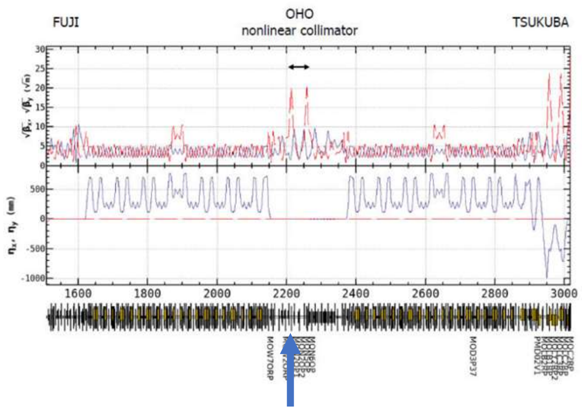


- For the 5 aborts start D2V1, average IR dose is 726 mRad (including one QCS quench).
- For aborts start D6V1, average IR dose is 64 mRad, thanks to the collimators btw IR and D6V1.
- Maybe there are multi-sources of SBL? As the initial position is not always in same region

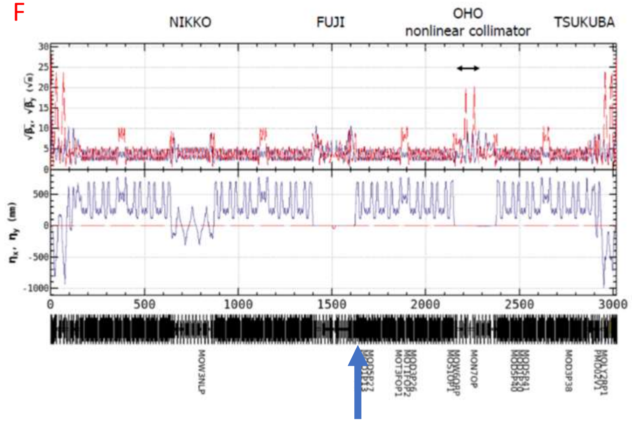
(X. Shi)

Location of BOR

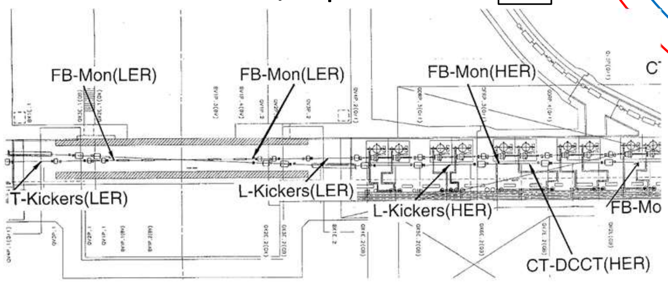




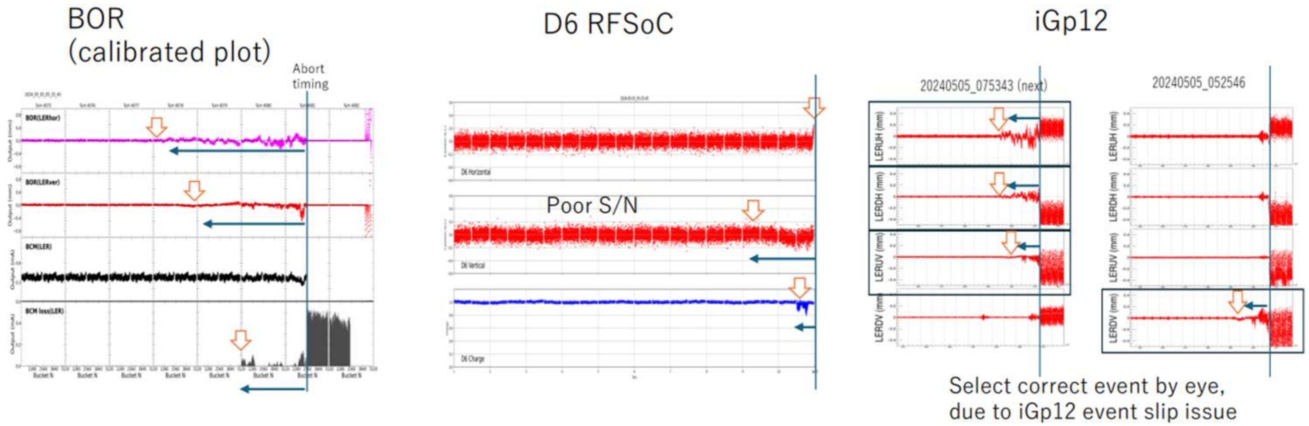
- Use BPM that is upstream of the collimator in phase with the collimator head.
  - Same vertical betatron phase as D2V1 : MQN1OP D5 BM2 66.7m
  - Same vertical betatron phase as D6V1 : MQD5P26 D7 BM3 144.4
- Readout: oscilloscope → RFSoC



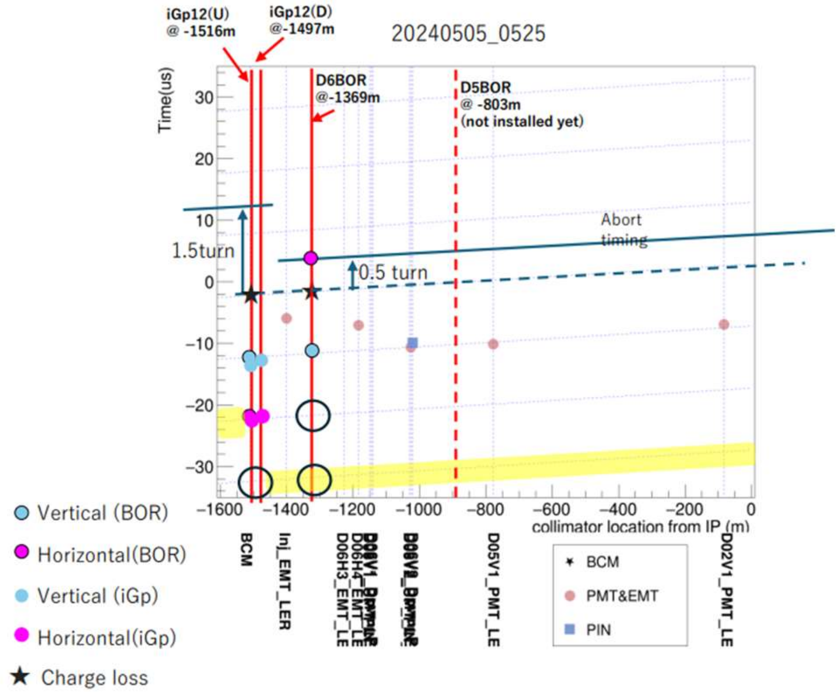
- Use original FB monitor (upstream and downstream).
- Readout:BOR/iGp12



BOR timing analysis (May 5th, QCS quench event)



Find the start timing of horizontal/vertical beam orbit deviation (w.r.t. the abort timing)



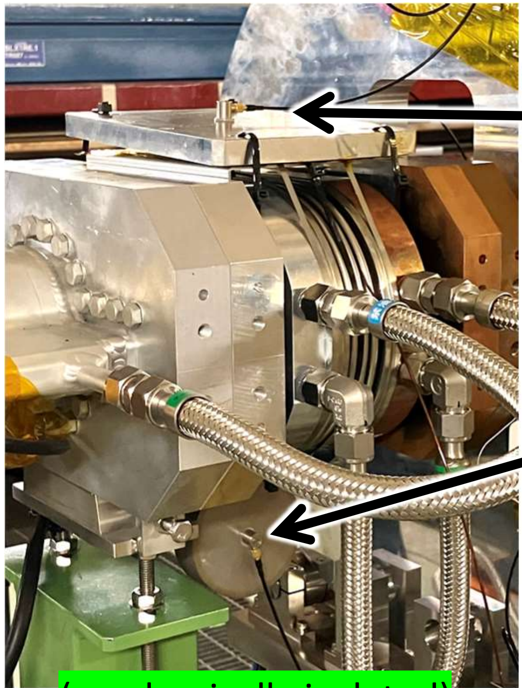
- Beam orbit deviation timings found in BOR plots are overlayed on the loss monitor timing diagram
- BOR/iGp12: Horizontal orbit deviation started 3.5turns before abort. Vertical orbit deviation and beam loss at collimators started in the next turn.
- RFSoC: Horizontal orbit deviation was not seen in the first turn. This gives implication for the phase of oscillation.
- Since the oscillation was not observed at D6 in the first turn, we cannot select the ring section for SBL origin.

(H. Nakayama)

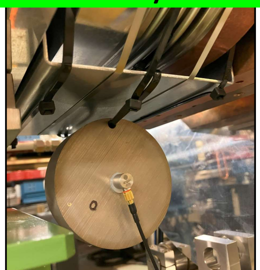
Acoustic-Emission Sensors for D02V1 collimator

I. Okada,
K. Uno, and
T. Abe

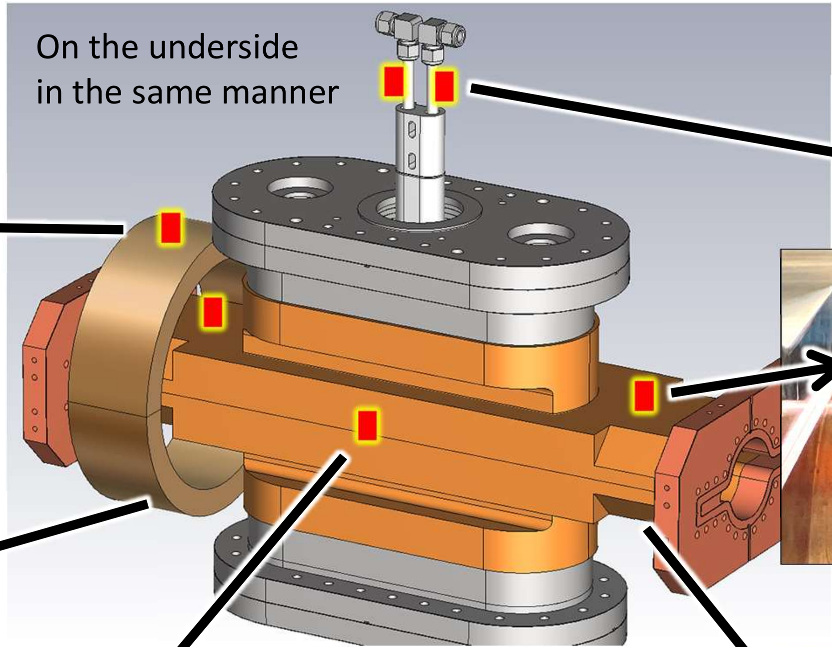
Acoustic loss monitor

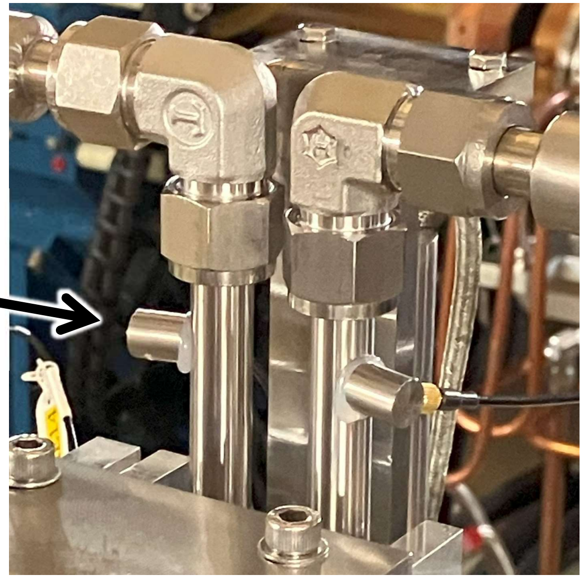


(mechanically isolated)

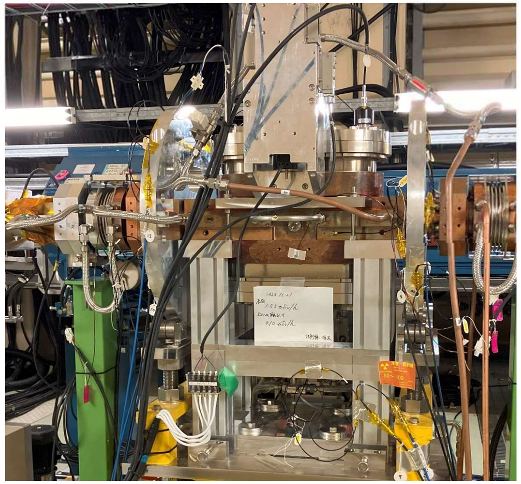


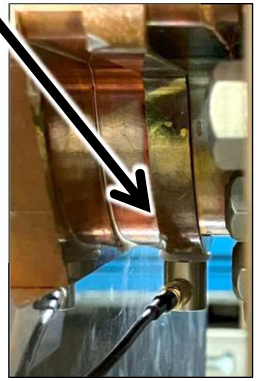
Can hear particle showers

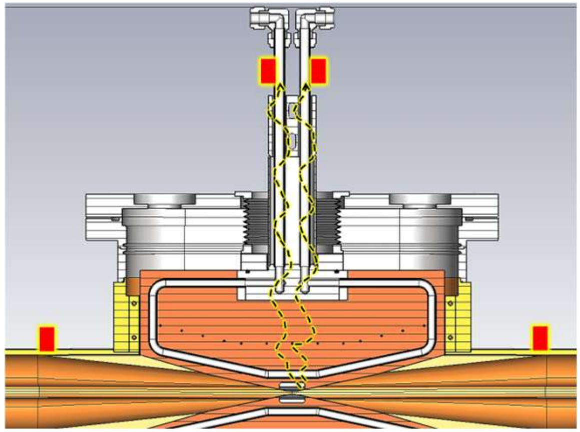




Can hear AE around the head.



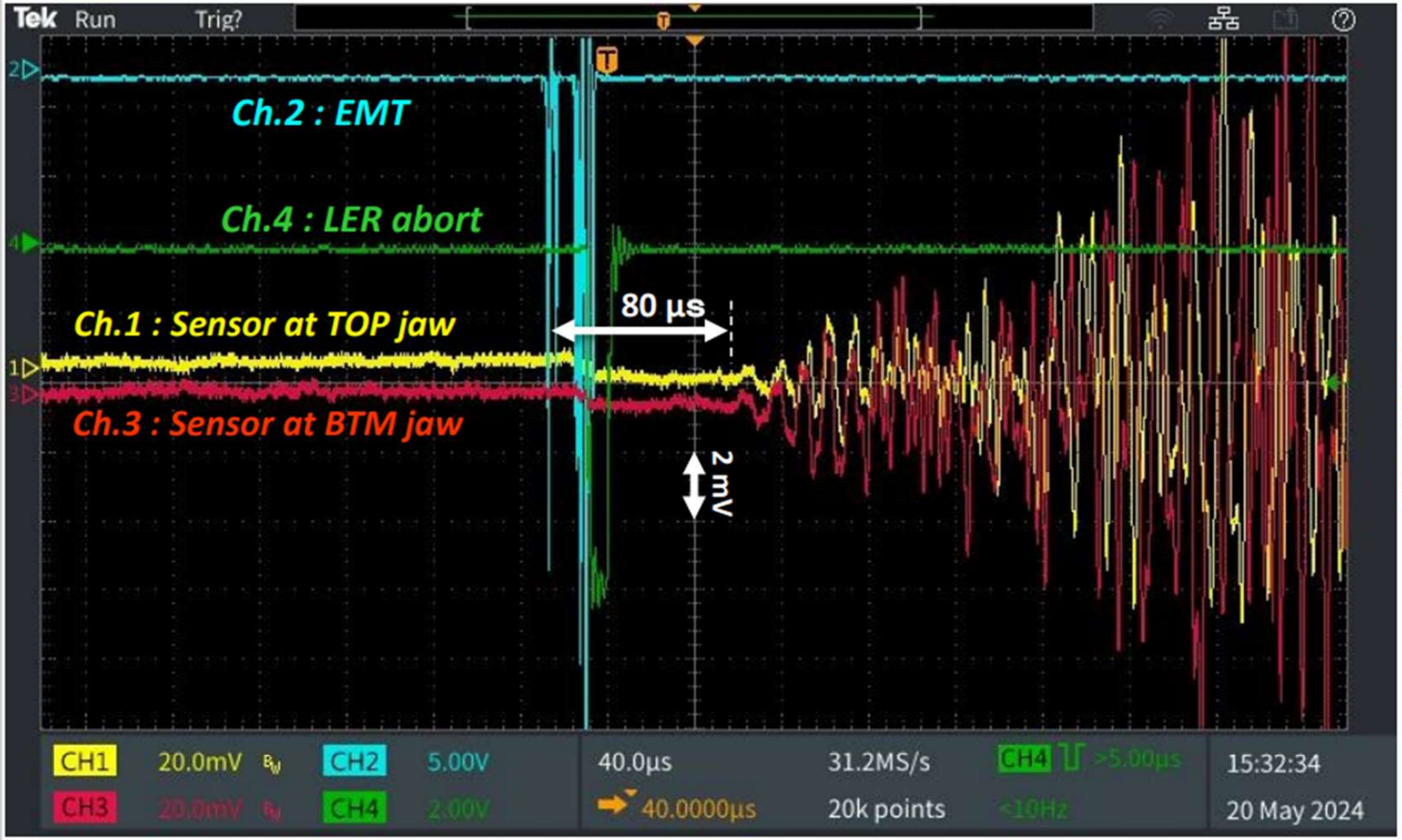


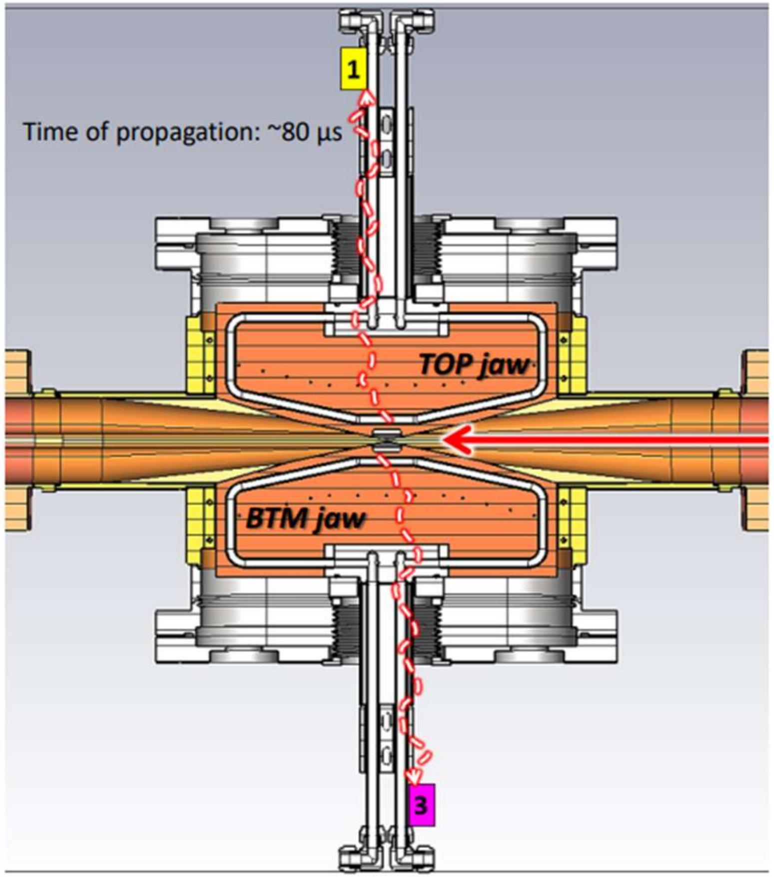


In the same manner for D05V1 collimator (NCL)

At **D06V2**, LER SBL at 2024-05-20 15:32

Example of typical acoustic waves (1/2)





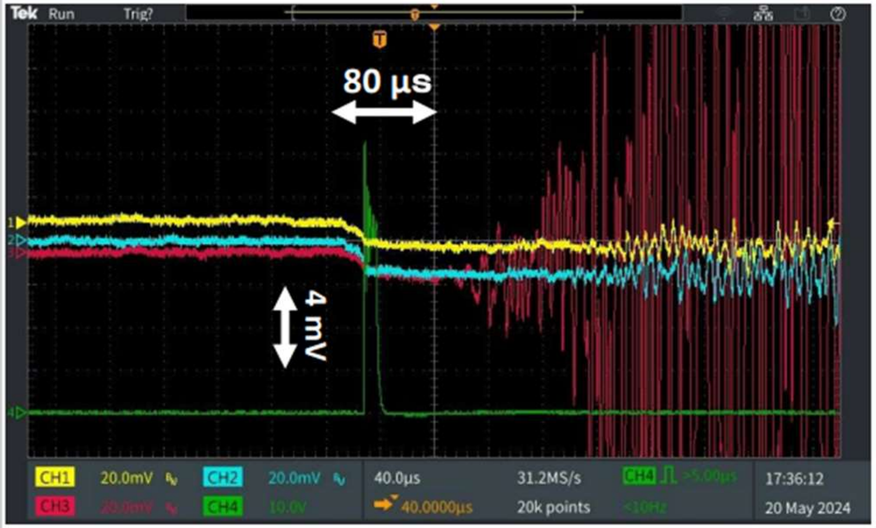
- ✓ The start of the acoustic-wave detection is consistent with the time of propagation (~80µs), where the acoustic-wave generation is understood to be caused by **LER beam particles impacting the head**
- ✓ The simultaneous start of waves at both the TOP and BTM means that the beam was **vertically spreaded**.

(D06V2 TOP: +1.94 mm, BTM: -2.72 mm at 2024-05-20 15:32)

(T. Abe)

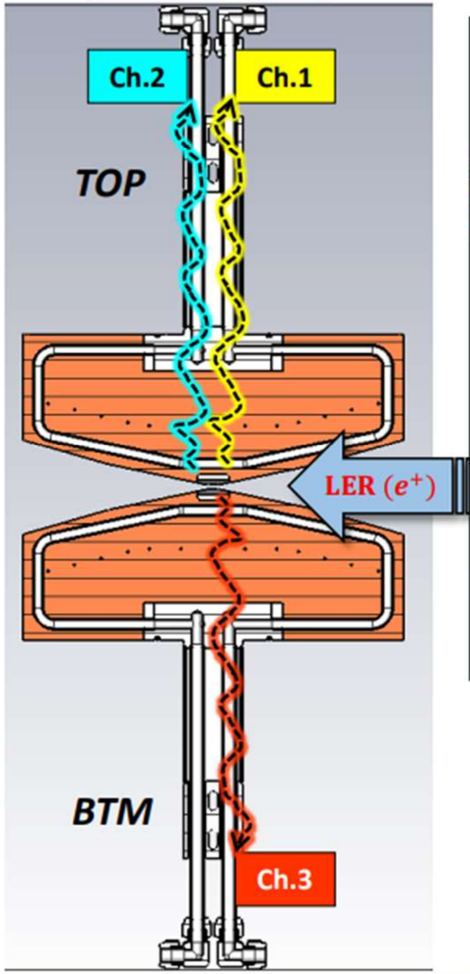
Example of typical acoustic waves (2/2)

LER SBL at 2024-05-20 17:35
(D05V1 TOP: +10 mm, BTM: -4.54 mm)

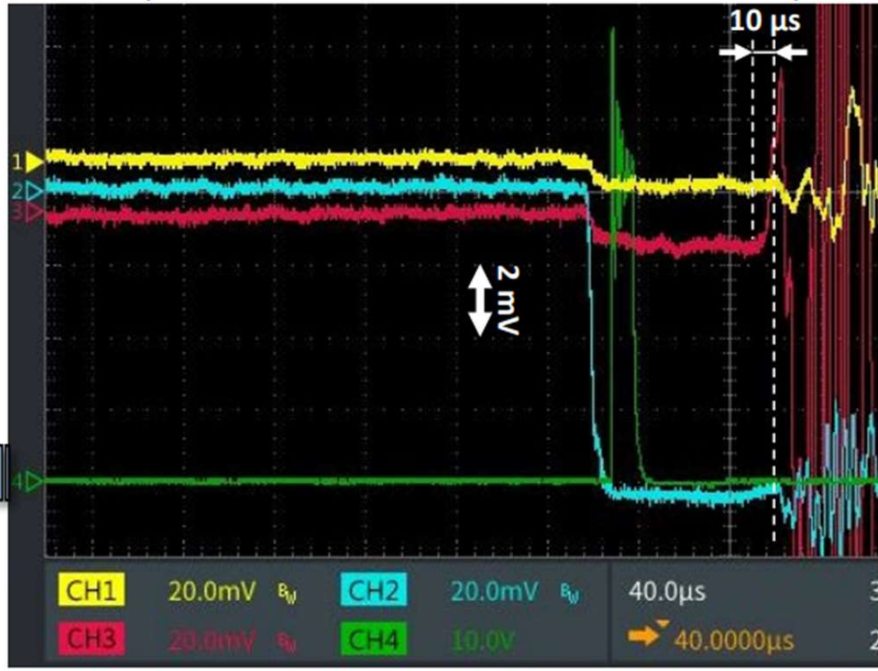


Significant wave only from BTM,
which means the beam was **vertically spreaded**,
then dumped by the LER beam abort system

D05V1 (NLC)



LER SBL at 2024-05-21 18:38
(D05V1 TOP: +10 mm, BTM: -4.78 mm)



Significant wave from BTM,
followed by one from TOP after 10 µs,
which means the beam was **vertically spreaded**,
then **horizontally spreaded** in the next turn
before dumped by the LER beam abort system

We can know the beam status from the acoustic observation.

(T. Abe)

Observation (Run2)

- We are investigating the beam conditions and information from various sensors when an SBL abort occurs.

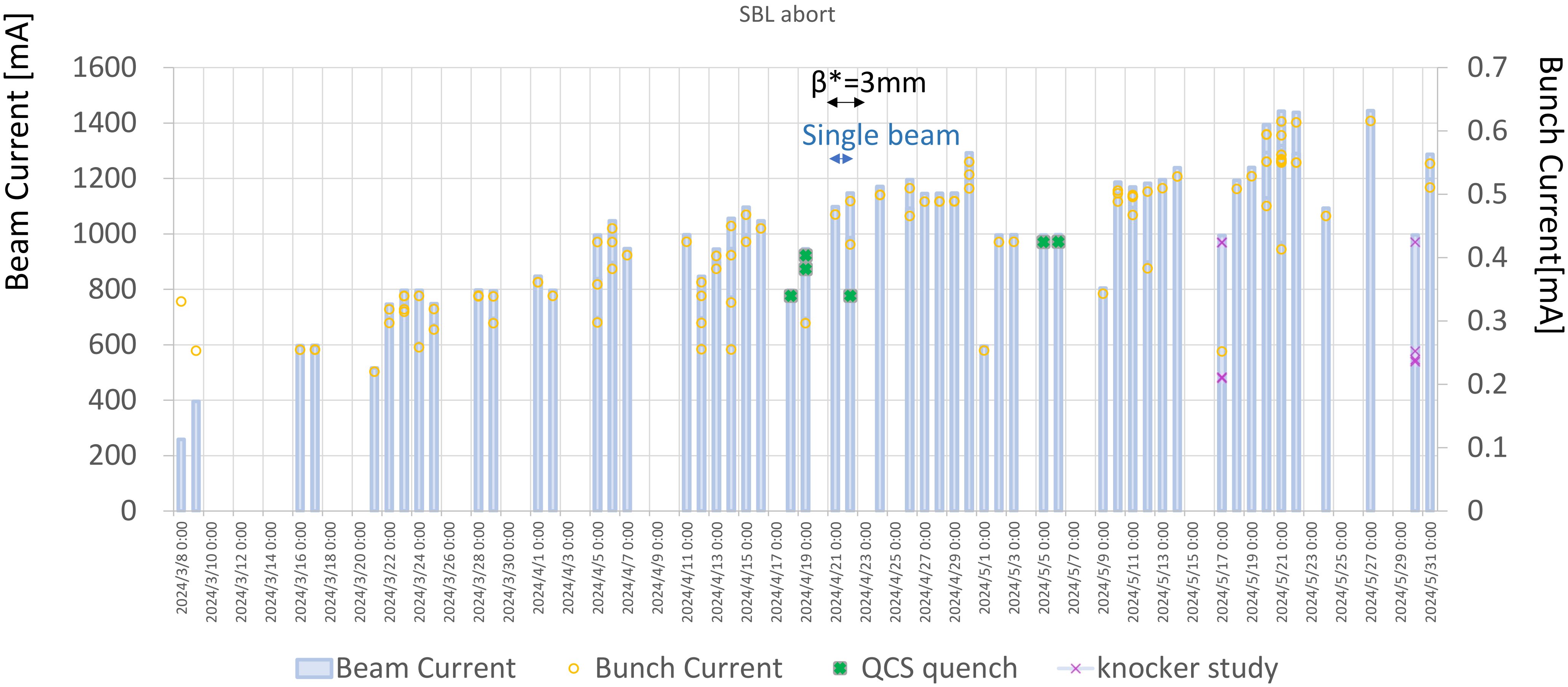
↓

- For the aborts until 05/29, most of them start in in region of [D6V1, D5V1]. If beam loss happens in D6V1, less IR does.
- Horizontal oscillations are often initially invoked.
- So far, no acoustic observation clearly considered a vacuum arc at any collimator of D02V1, D05V1, (D06V2, or D06V1) when SBL occurred. Further analysis on-going.

- SBL can occur with both single beam and collision beam.
- SBL occurs both at β^*=1mm or 3mm.
- Vertical Beam Size increases when SBL occurs compared to other abort.
- The vacuum pressure spiked at D04 or D10 in the most cases when LER beam aborts of unknown cause happened.
- Aging effect might be seen.

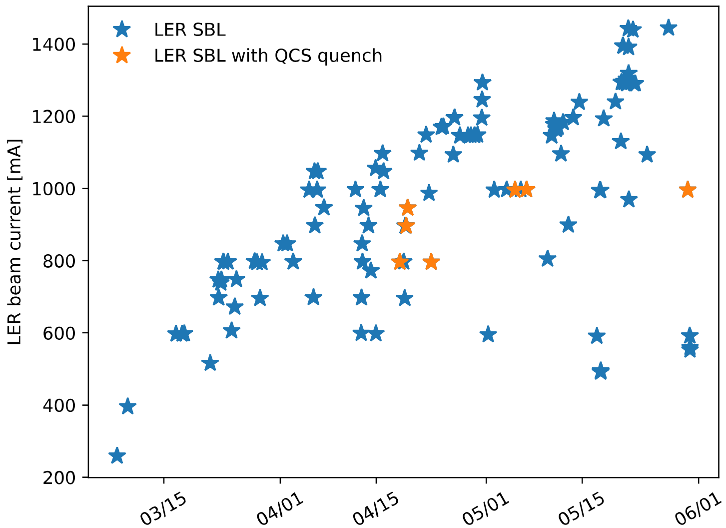
SBL statistics

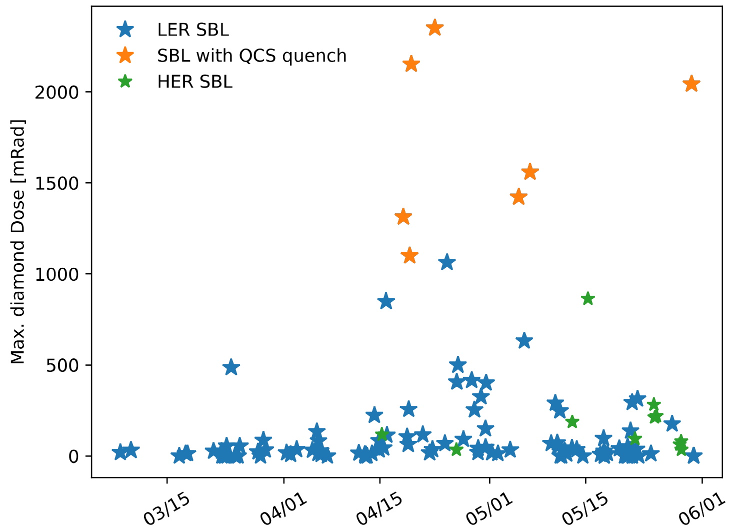
The beam current which SBL occurs looks increasing.



SBL: Mar.1st – June. 2nd

118 LER SBLs (incl. SBL with QCS quench) + 11 HER SBLs



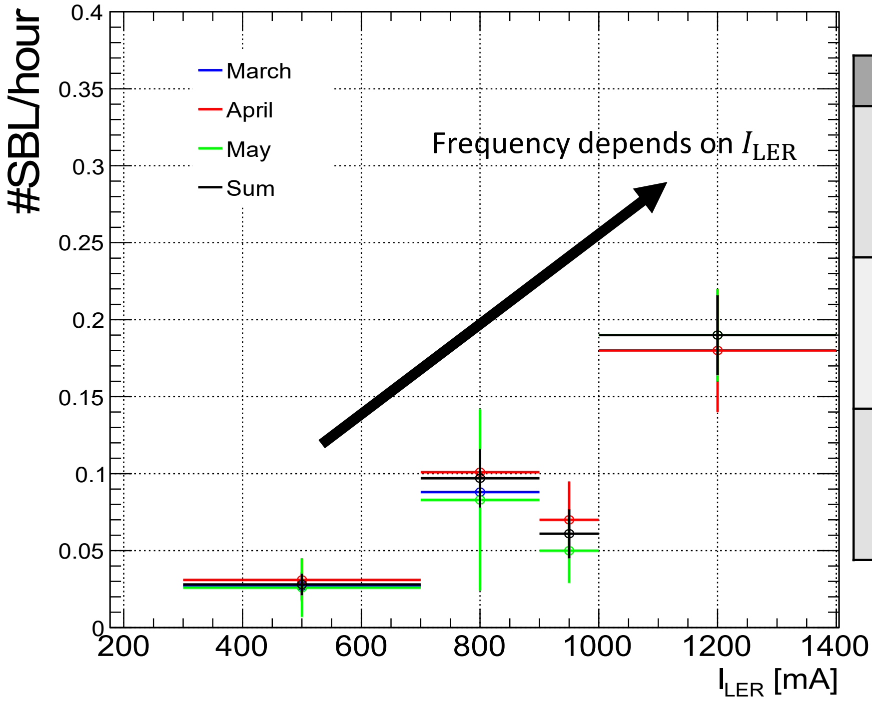


I_{LER} [mA]	#LER SBL
[0.0, 300]	1
[300,500]	4
[500,800]	34 (incl. 2 quench)
[800,1000]	27 (incl. 5 quench)
[1000, 1200]	31
[1200,]	21

Max. Dose [mRad]	#LER SBL	May.9th※ -
[0.0, 100]	87	38
[100,300]	14	6
[300,500]	7	1
[500,800]	1	0
[800, 1000]	1	0
[1000,]	8	1 ← Knocker study

※ Closed LER horizontal collimators on May 9th

Beam current dependency



Mar.1st - May. 22 at 19:00

I_{LER} [mA]		[300, 700]	[700, 900]	[900, 1000]	[1000,]
March	#LER SBL	9	10	0	0
	Operation time [hour]	331	114	0	0
	#SBL/hour	0.027 ± 0.009	0.088 ± 0.028	–	–
April	#LER SBL	5	13	8	20
	Operation time [hour]	159	120	114	110
	#SBL/hour	0.031 ± 0.014	0.101 ± 0.003	0.07 ± 0.025	0.18 ± 0.04
May	#LER SBL	2	2	6	30
	Operation time [hour]	76	24	115	159
	#SBL/hour	0.026 ± 0.019	0.083 ± 0.059	0.05 ± 0.021	0.19 ± 0.03

- Frequency (#SBL/hour) depends on the LER beam current
- It seems no aging effect.. (hard to say something about it)

Beam size measurement @SBL

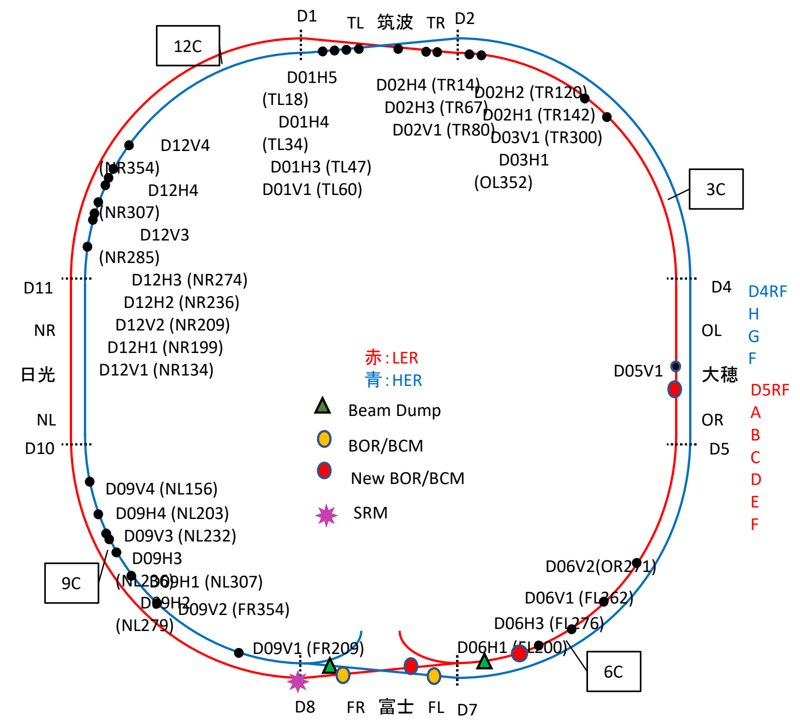
- A beam image at the abort timing was measured using a D8 SRM gated camera.
- trigger：Abort trigger
- Gate width：10us
- When the Abort trigger is sent to the kicker, a signal is also sent to D8.
- The beam goes in the order of D8 → BOR → Abort kicker, so we should be able to see the image of the last turn.

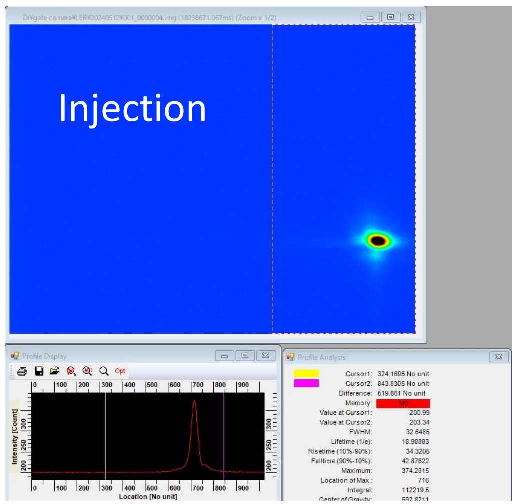
↓

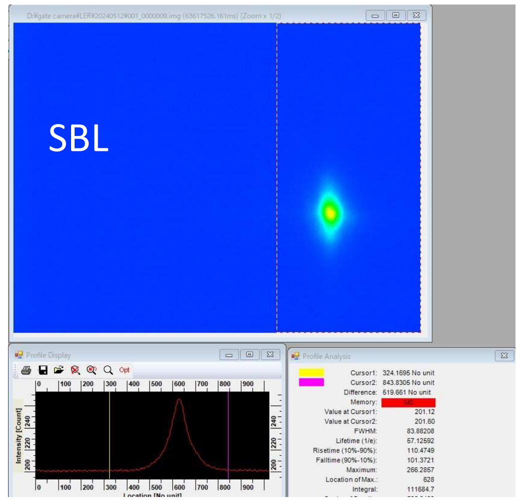
- Vertical Beam Size increases when SBL occurs compared to other abort.

Reason:

- due to beam loss? (Loss amount is relatively small)
- Beam size increase due to some kind of kick (collision with dust? discharge?), resulting in beam loss at the collimator?







Pressure Burst

- D05V1 has a burst near 1200mA. Previously, it occurred at a lower beam current. It looks aging effect.
- Aging effect at D6H3&H4 also appears.

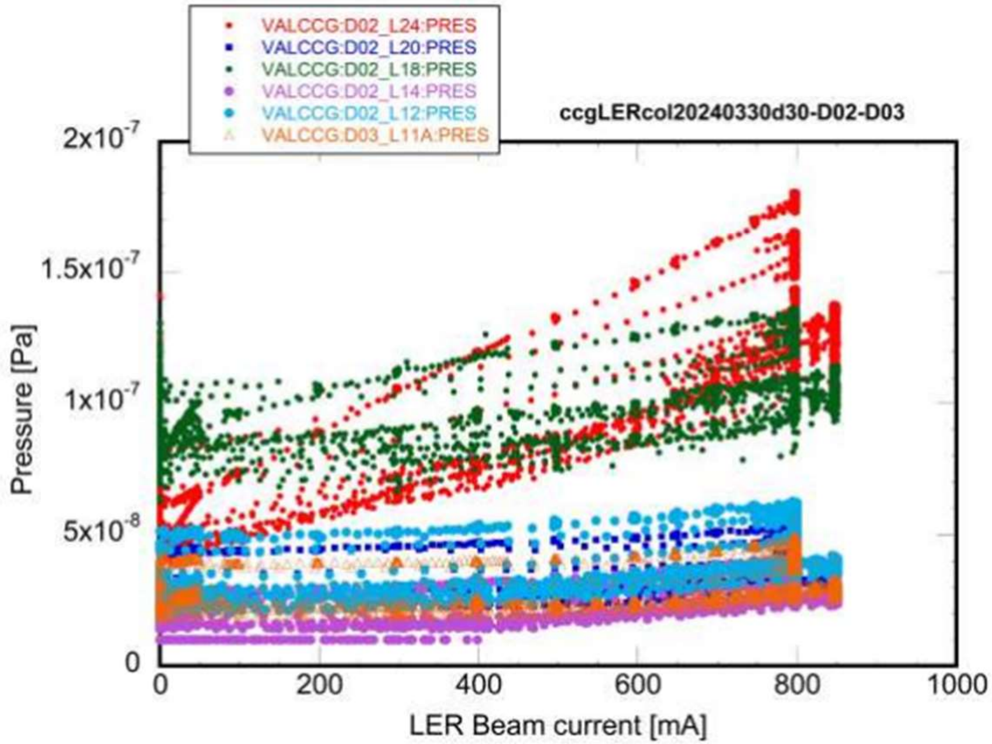
- There are many vacuum bursts in the Wiggler(D10/D4) section, but they also occur when SBL is not occurring.
- LM(PIN) were installed downstream of the Wiggler section, but no beam loss was observed.

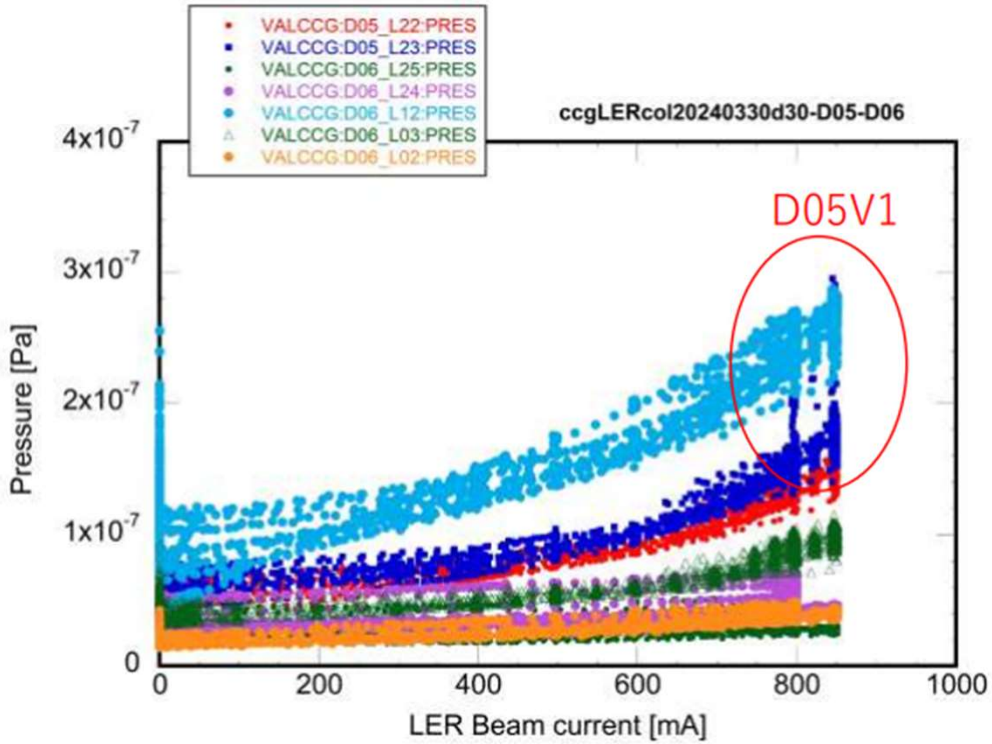
- Anomaly detection to investigate the cause of sudden beam loss (K. Matsuoka)
  - The vacuum pressure spiked at D04 or D10 in the most cases (145/161) when LER beam aborts of unknown cause happened.
  - The spike never coincided in D04 and D10.
  - The spike never coincided at different locations within D04 or D10.

LER

2024/3/28-3/30

CCG	Collimator	CCG	Collimator
D02_L24	D02H4	D05_L22, L23	D05V1
D02_L20	D02H3	D06_L25, L24	D06V2
D02_L18	D02V1	D06_L12	D06V1
D02_L14	D02H2	D06_L03	D06H4
D02_L12	D02H1	D06_L02	D06H3
D03_L11A	D03H1		





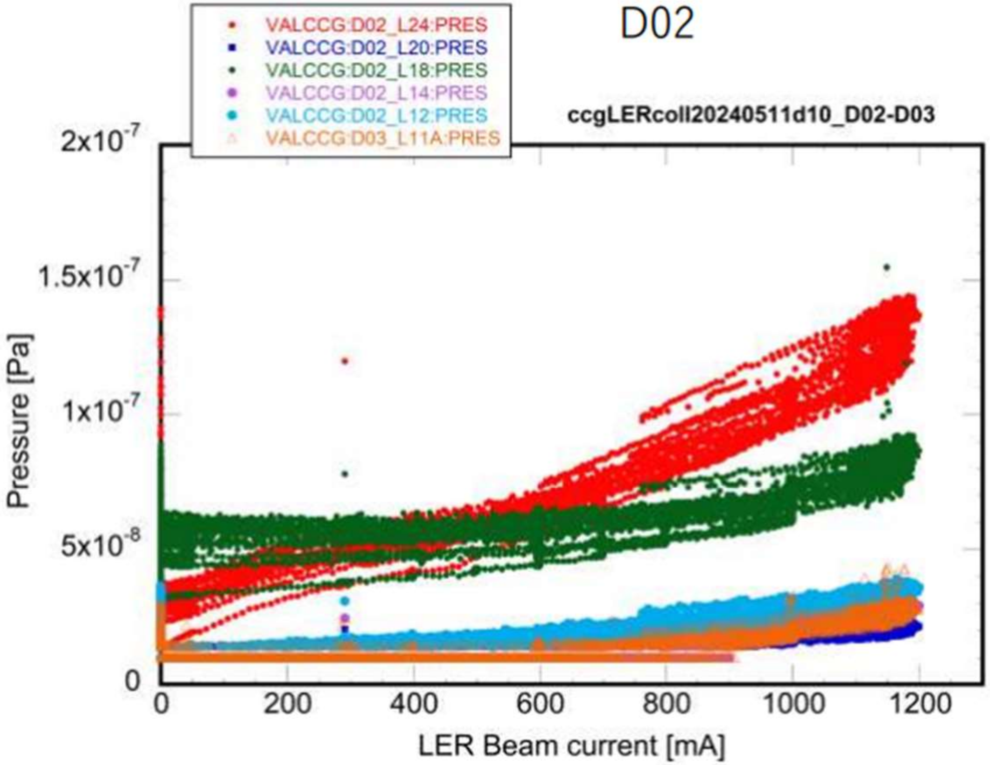
(Y. Suetsugu)

LER

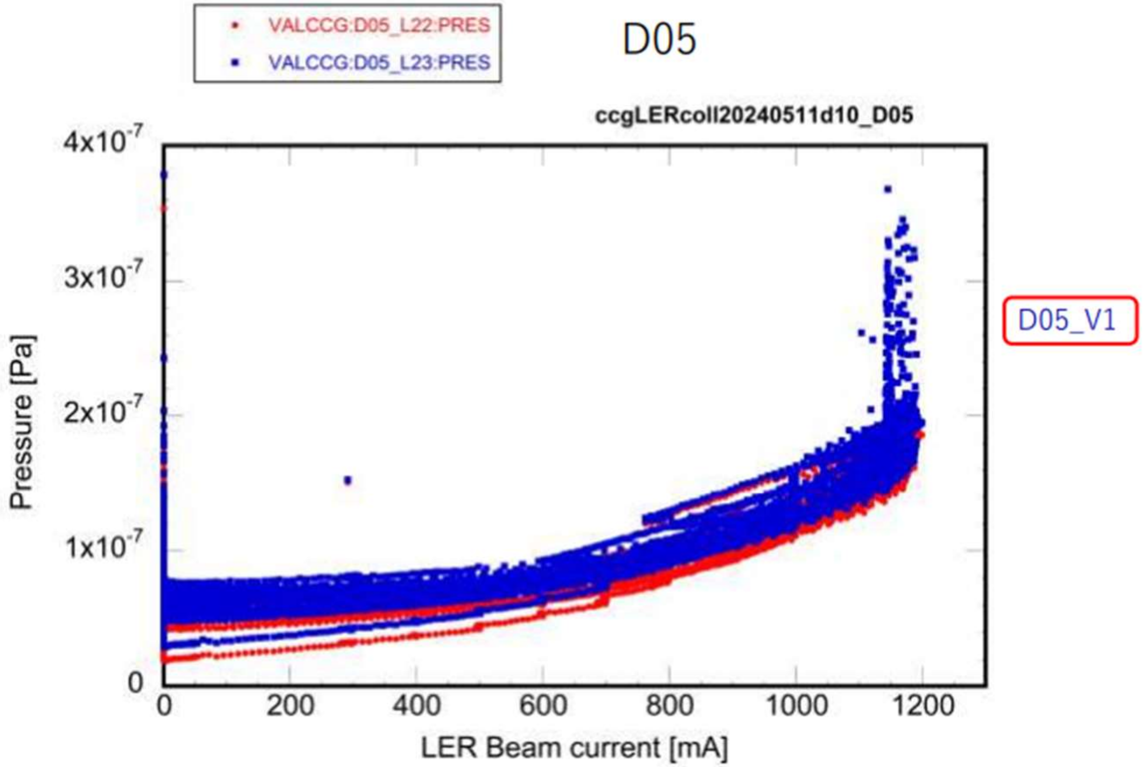
2024/5/8-5/11
Nb = 2346

CCG	Collimator	CCG	Collimator
D02_L24	D02H4	D05_L22, L23	D05V1
D02_L20	D02H3	D06_L25, L24	D06V2
D02_L18	D02V1	D06_L12	D06V1
D02_L14	D02H2	D06_L06	D06H4
D02_L12	D02H1	D06_L03	D06H3
D03_L11A	D03H1		

D02



D05



(Y. Suetsugu)

LER

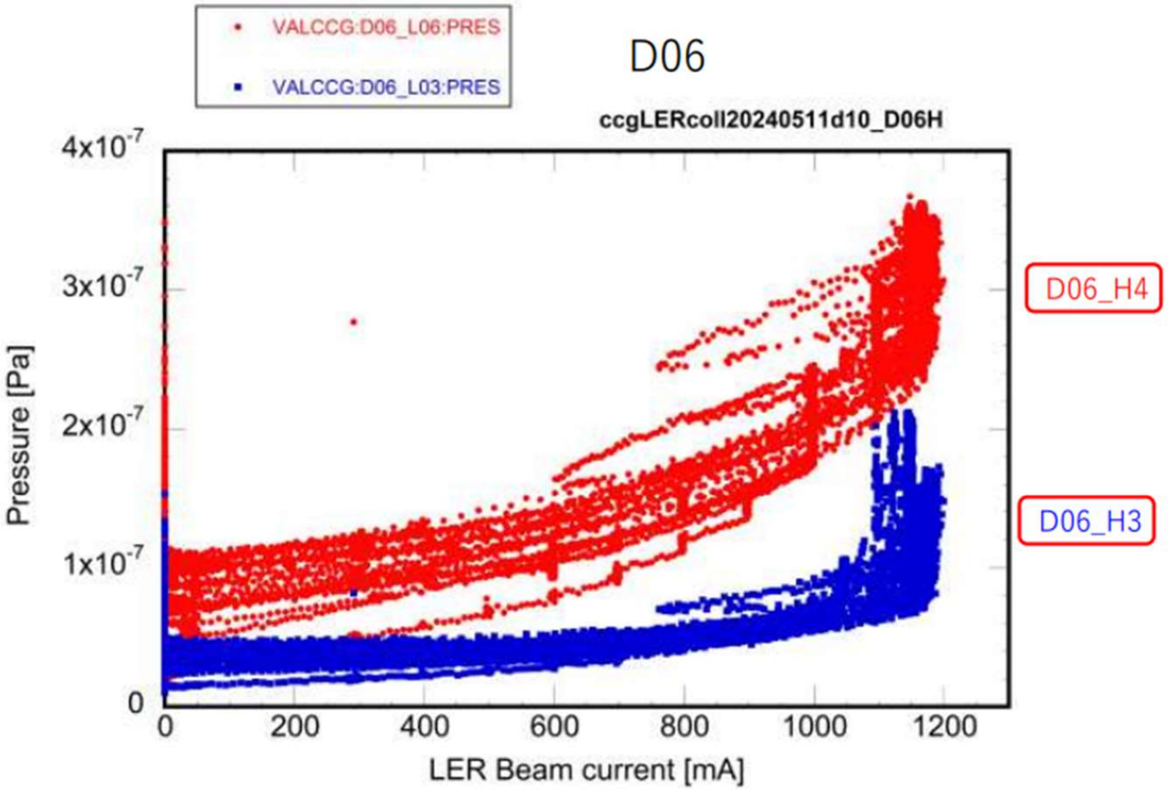
2024/5/13-5/15
Nb = 2346

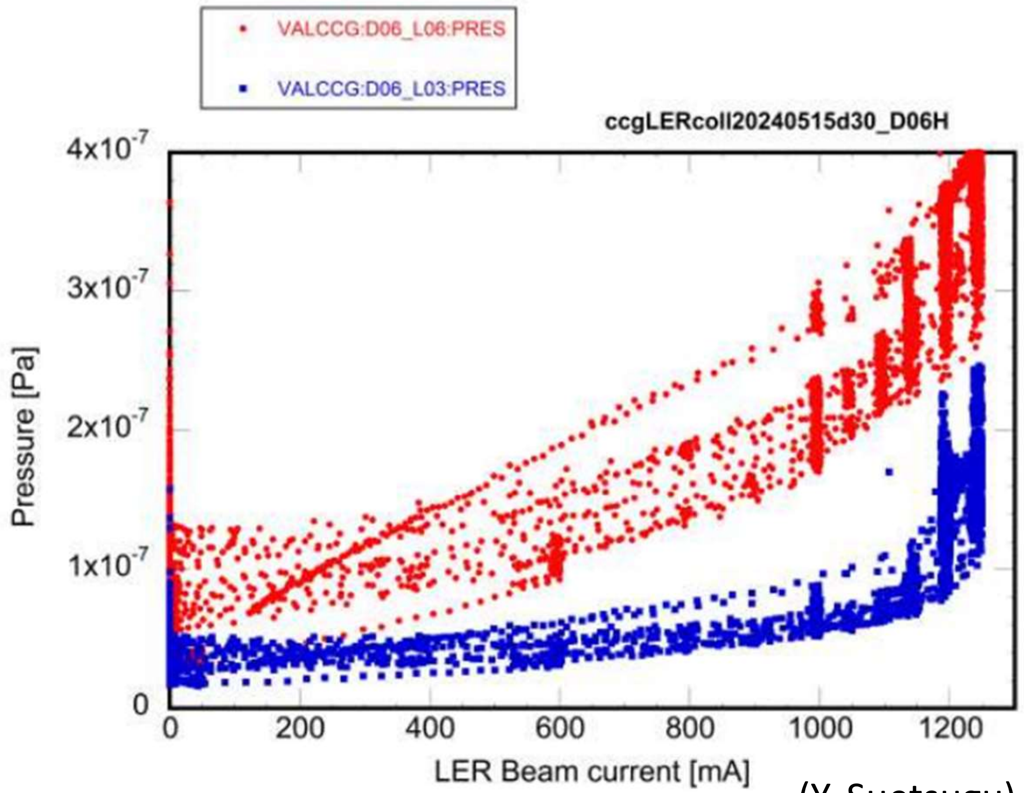
D06_H3はまだエージングが進んでいるよう

CCG	Collimator	CCG	Collimator
D02_L24	D02H4	D05_L22, L23	D05V1
D02_L20	D02H3	D06_L25, L24	D06V2
D02_L18	D02V1	D06_L12	D06V1
D02_L14	D02H2	D06_L06	D06H4
D02_L12	D02H1	D06_L03	D06H3
D03_L11A	D03H1		

前回のプロット

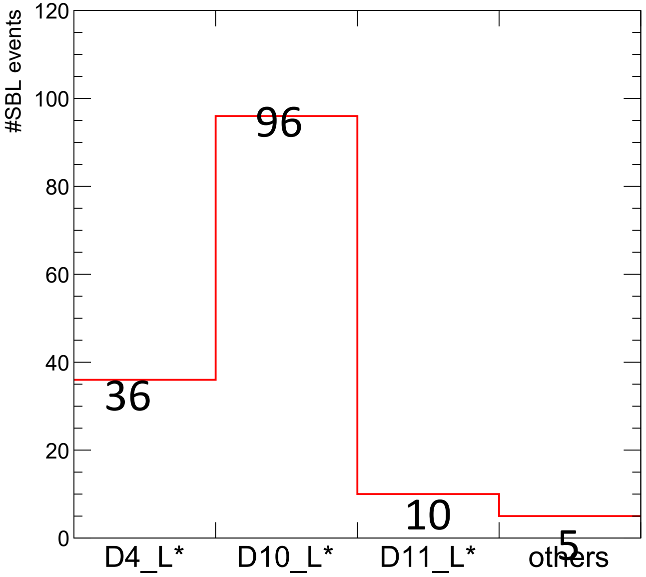
D06

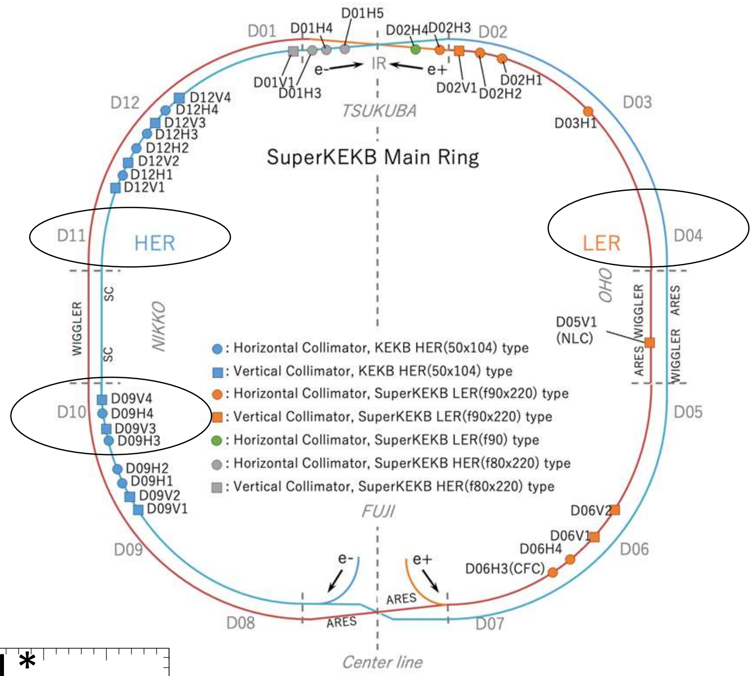


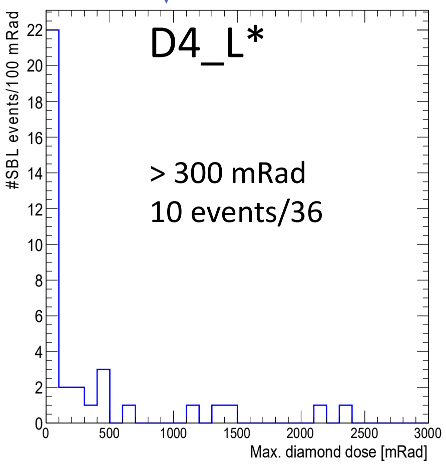


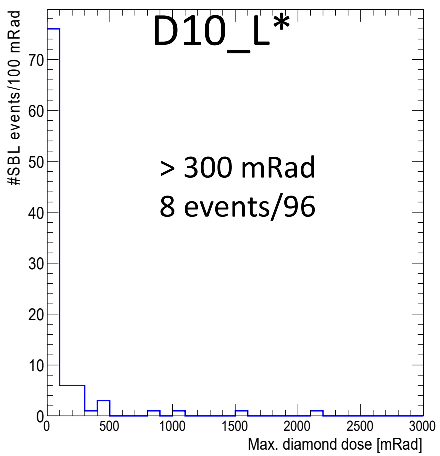
(Y. Suetsugu)

LER SBL vs Pressure burst





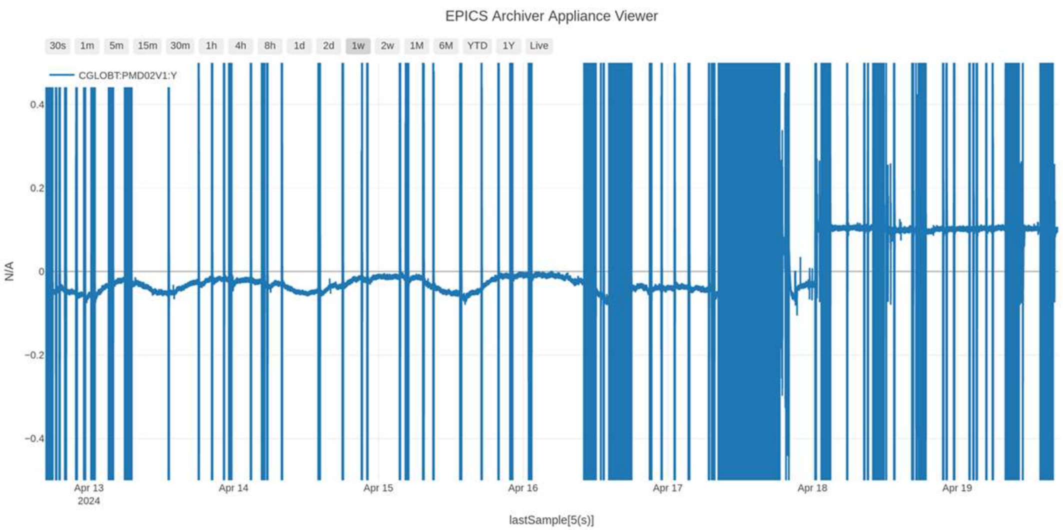




SBL events with QCS Quench/Belle II damage

- 2024-04-18 10:00:12 (796mAx6.0%) orbit of D2V1 was off by ~100um.
- 2024-04-19 07:58:25 (896mAx12%) orbit of D2V1 was off by ~100um.
- 2024-04-19 13:45:10 (946x19.4%) orbit of D2V1 was off by ~100um.
- 2024-04-22 23:55:08 (796x13.9%) β^*_y=3mm(LER)/1mm(HER),
- 2024-05-05 05:25:45 (996x4.7%)
- 2024-05-06 21:25:11 (997x5.8%)

QCS quench:
4/18, 4/19 quench case

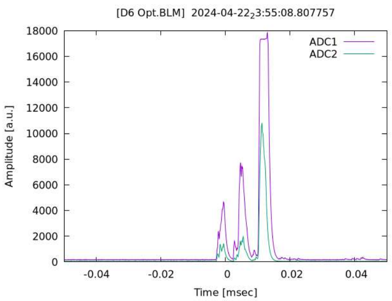


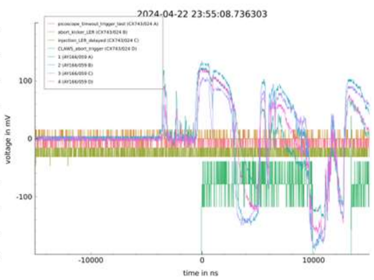
- Optics correction after maintenance revealed that the orbit of D2V1 was off by ~100um.
- Because of that, D2V1's Aperture was narrowest condition.
- It was a normal SBL, but an unstable beam hit D2V1 and was scattered in the IR direction, causing a QCS quench.
- After that, we adjusted the collimator to match the orbit, so the quench doesn't seem to occur.

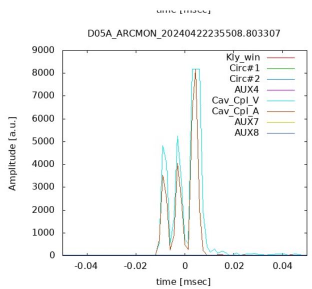
2024-04-22 23:55:08 (796mA) Case;

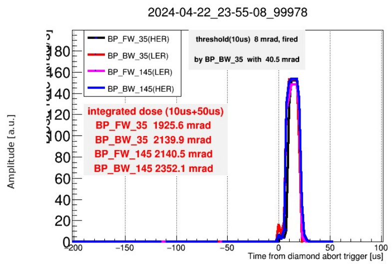
CLAWS D05V1→LM D6 (Optical Fiber)→Belle2 CLAWS→LM(D6V1V2collimator)

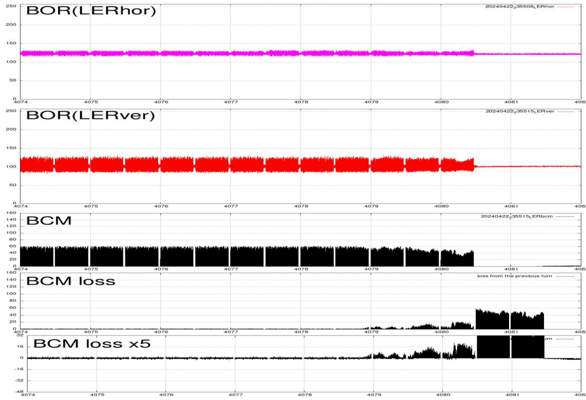
SBL/QCS quench

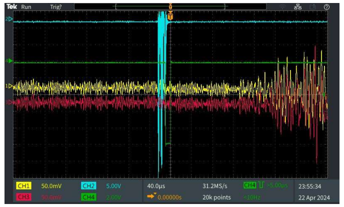


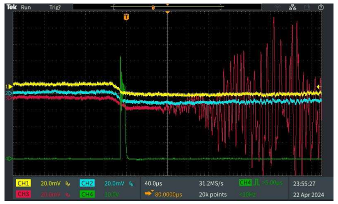


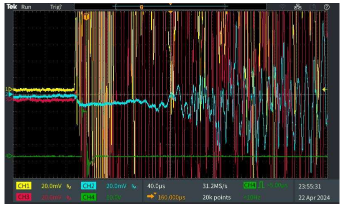


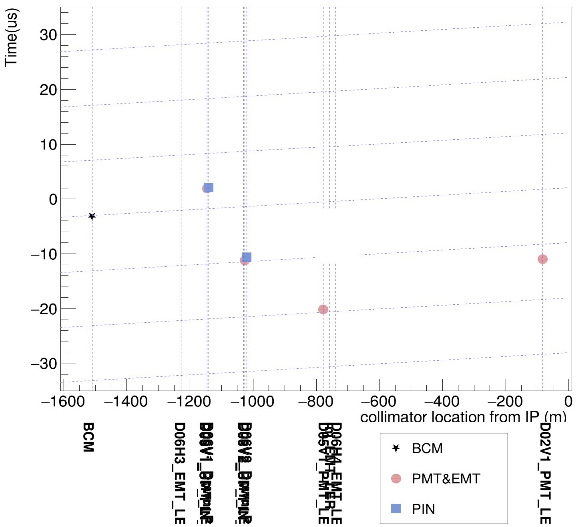


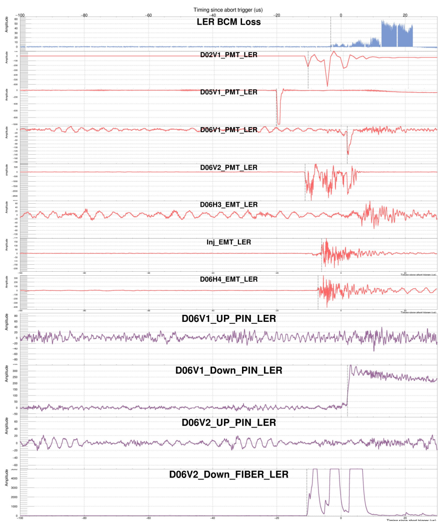












QCS quench:
4/22,5/5,6 quench case

2024-04-22 23:55:08

- D6V1/V2 had a narrower aperture, but the beam passed through it and hit D2V1, causing a large dose and QCS quench.
- Based on this experience, we decided to close the D5V1 collimator as much as possible and operate in a way that the unstable beam would not cause loss at D2V1.

2024-05-05 05:25:45

2024-05-06 21:25:11

- Beam loss at D2V1 was small, but…
- After passing through the vertical collimator, the horizontal oscillation was coupled to the vertical vibration.?
- We closed horizontal collimator's after these events.

SBL with large doses due to LER did not occur after PXD OFF, D6V1close,D6V2open, D5V1close(bottom), Horizontal collimator close.

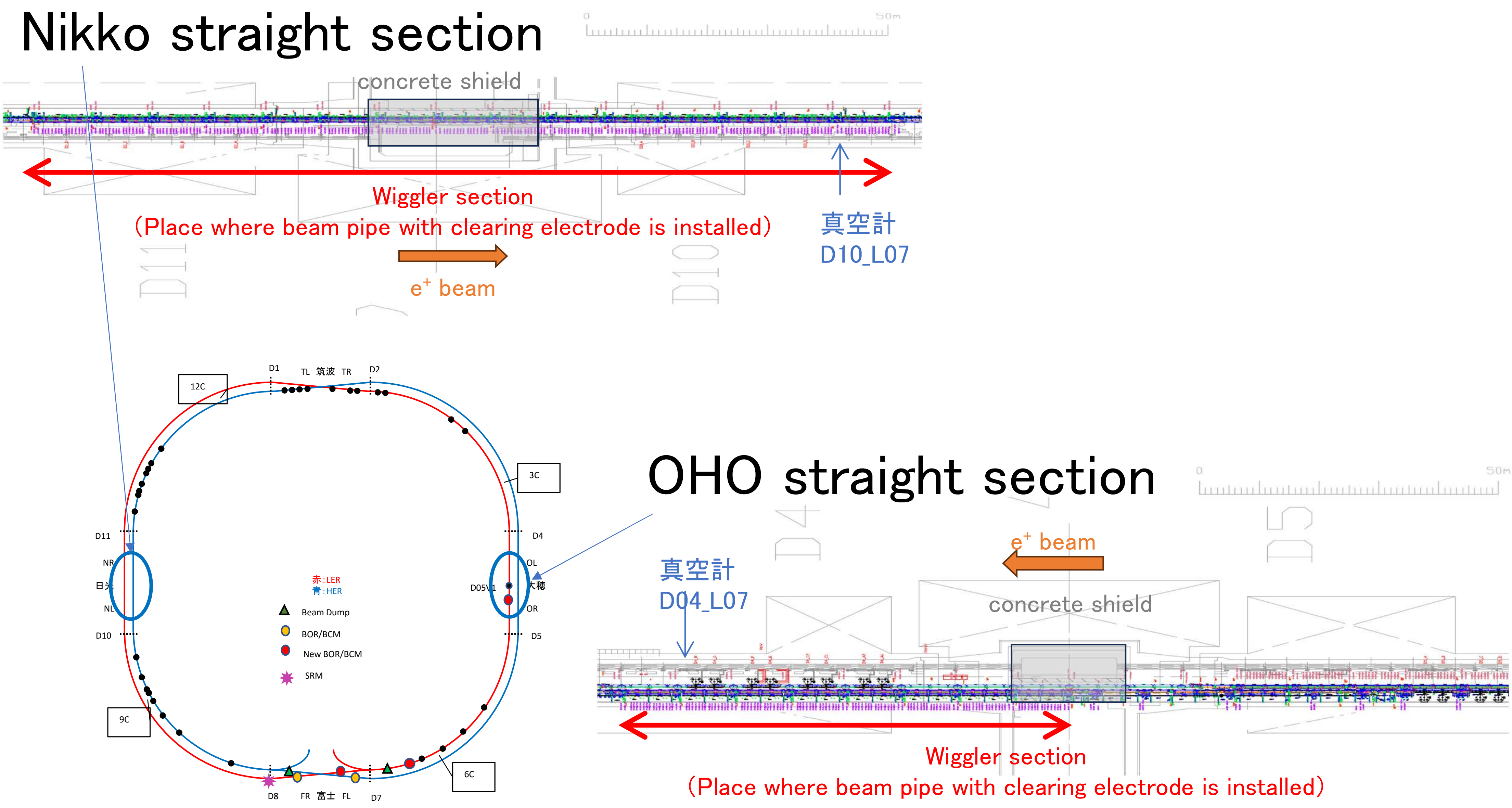
Causes of SBL from observation

- No. of SBL depend on LER current.
- Aging effect might be seen.
- The vacuum pressure spiked at D04 or D10 (Wiggler section) were happened for most of SBL events.
- Vertical Beam Size increases when SBL occurs compared to other abort.

↓

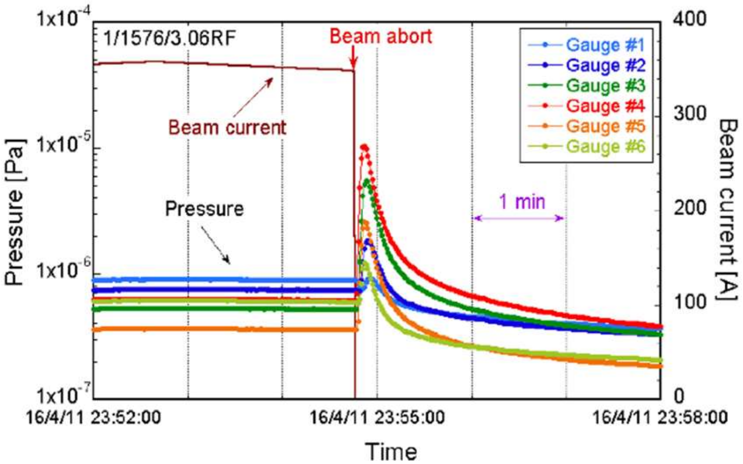
What does this mean?

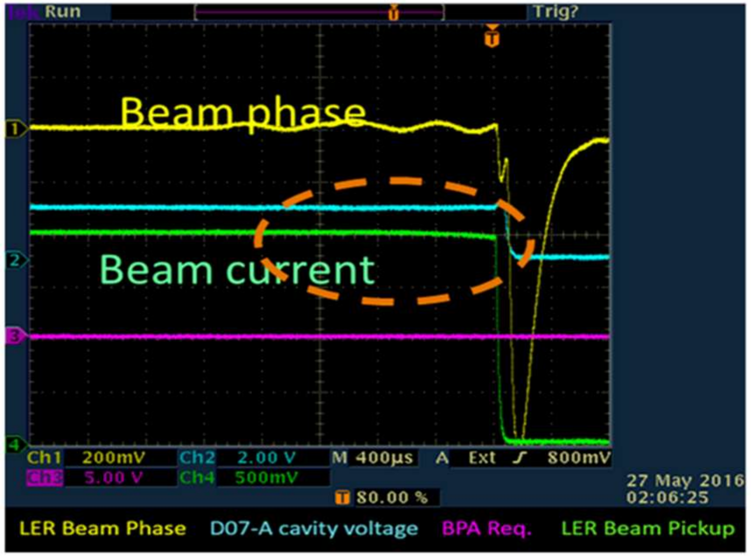
- We're back to the possibilities of dust.

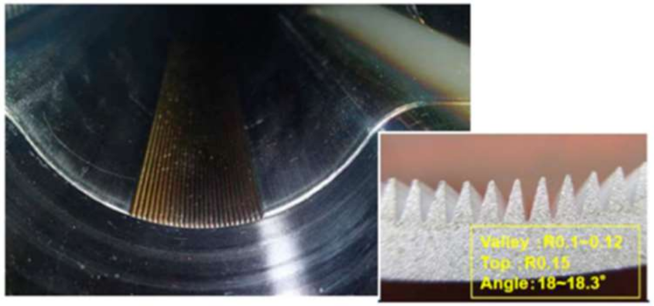

Nikko straight section
0
50m
concrete shield
Wiggler section
(Place where beam pipe with clearing electrode is installed)
真空計
D10_L07
e+ beam
D1
TL 筑波 TR
D2
12C
3C
D11
NR
日光
NL
D10
D4
OL
D05V1
大穂
OR
D5
赤 : LER
青 : HER
Beam Dump
BOR/BCM
New BOR/BCM
SRM
9C
6C
D8
FR 富士 FL
D7
OHO straight section
0
50m
e+ beam
真空計
D04_L07
concrete shield
Wiggler section
(Place where beam pipe with clearing electrode is installed)

Dust event (reminder)

- At the Phase-1, pressure bursts with beam loss were frequently observed in the LER, which was an obstacle to beam current increase.
  - ➢ When a loss monitor was triggered and issued abort, the pressure momentarily jumps to the 10^{-7}-10^{-6} Pa range in some parts of the ring at the same time.
  - ➢ The beam was lost over several 100 μs, and oscillations in the beam phase were observed.
- Estimating the location of pressure bursts from the CCG indications, most of the pressure bursts occurred in the vicinity of the grooved aluminum beam pipes in the bending magnets.
- The beam current at which pressure bursts occurred increased with the maximum beam current at that time. The frequency of pressure bursts tended to decrease after a while of operation at the same maximum beam current (aging effect).



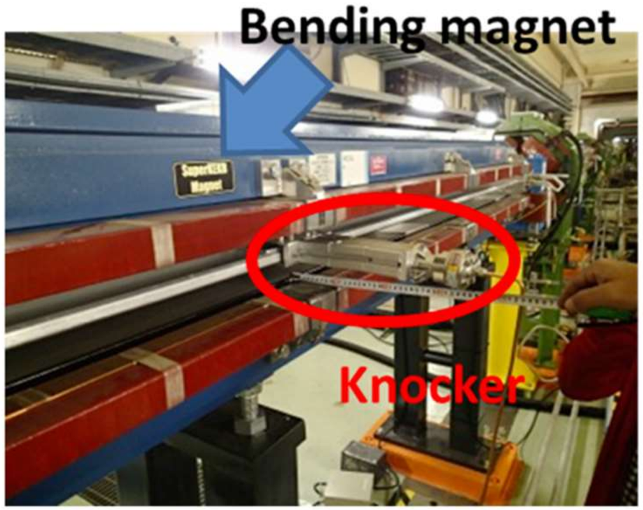


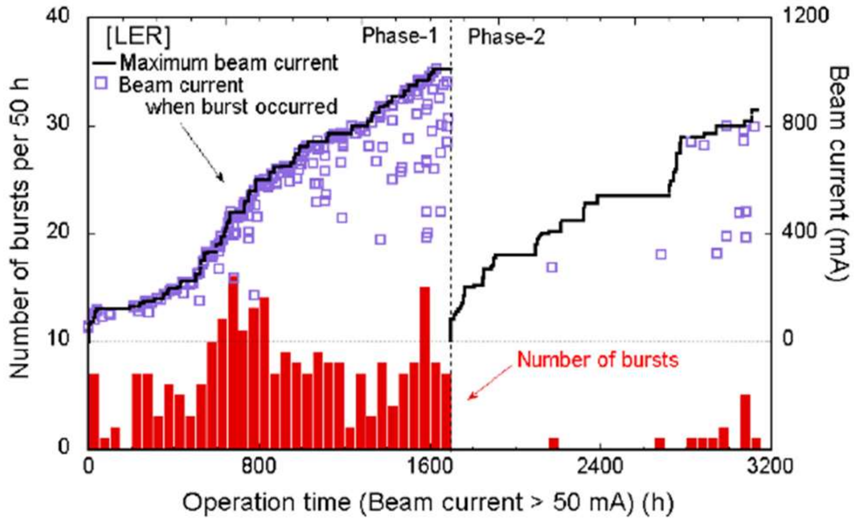


(T. Ishibashi)

Dust event (reminder)

- We speculated that this phenomenon was caused by dusts trapped in groove structures falling into the beam. To verify this, a knocker was installed in the LER beam pipe.
- When this knocker was operated during beam operation and the beam pipe was struck, the above phenomenon was reproduced.
- As a countermeasure for Phase-2 operation, the grooved aluminum beam pipe was knocked around with a knocker during the shutdown period. As a result, the frequency of pressure bursts with beam loss was dramatically reduced.
- **However, the frequency of occurrence has not been reduced to zero. Then, sometimes dust events occur even at low beam currents.**





（T. Ishibashi）

Similarities between SBL and dust event

- The frequency of SBL (Sudden Beam Loss) in LER increased after LS1(?)
  - During LS1, there was vacuum work in about 2/3 of the LER, and dusts may have moved significantly through the beam pipe in that section due to nitrogen purging and pumping, etc. (groove structure re-traps dusts?) .
- Pressure bursts are sometimes observed along with SBLs.
  - ✓ Similar to dust events
- The beam current that SBL occurs is gradually increasing(?)
  - ✓ Aging effect, similar to dust events.

- **However, in the case of dust events, slow beam loss and aborts with oscillations in the beam phase were observed, but no such phenomena were observed in the SBL.**

- However, at some point (Phase-3?), the abort itself with slow beam loss and oscillations in the beam phase did not occur at all.
- Since there is still a myriad of dusts in the beam pipe, it is also unnatural that no dust events have occurred at all.
  - Are some of the unexplained aborts now due to dust events? Are some of the unexplained aborts occurring now due to dust events?
  - Is it possible that the SBLs is caused by dusts, and that squeezing the β_y^* has changed the way we see dust events?

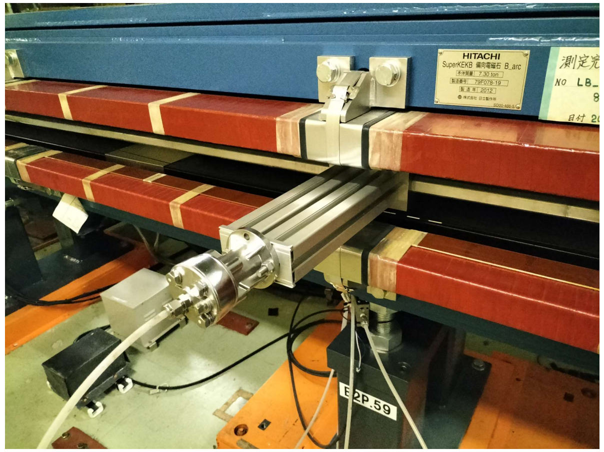
（T. Ishibashi）

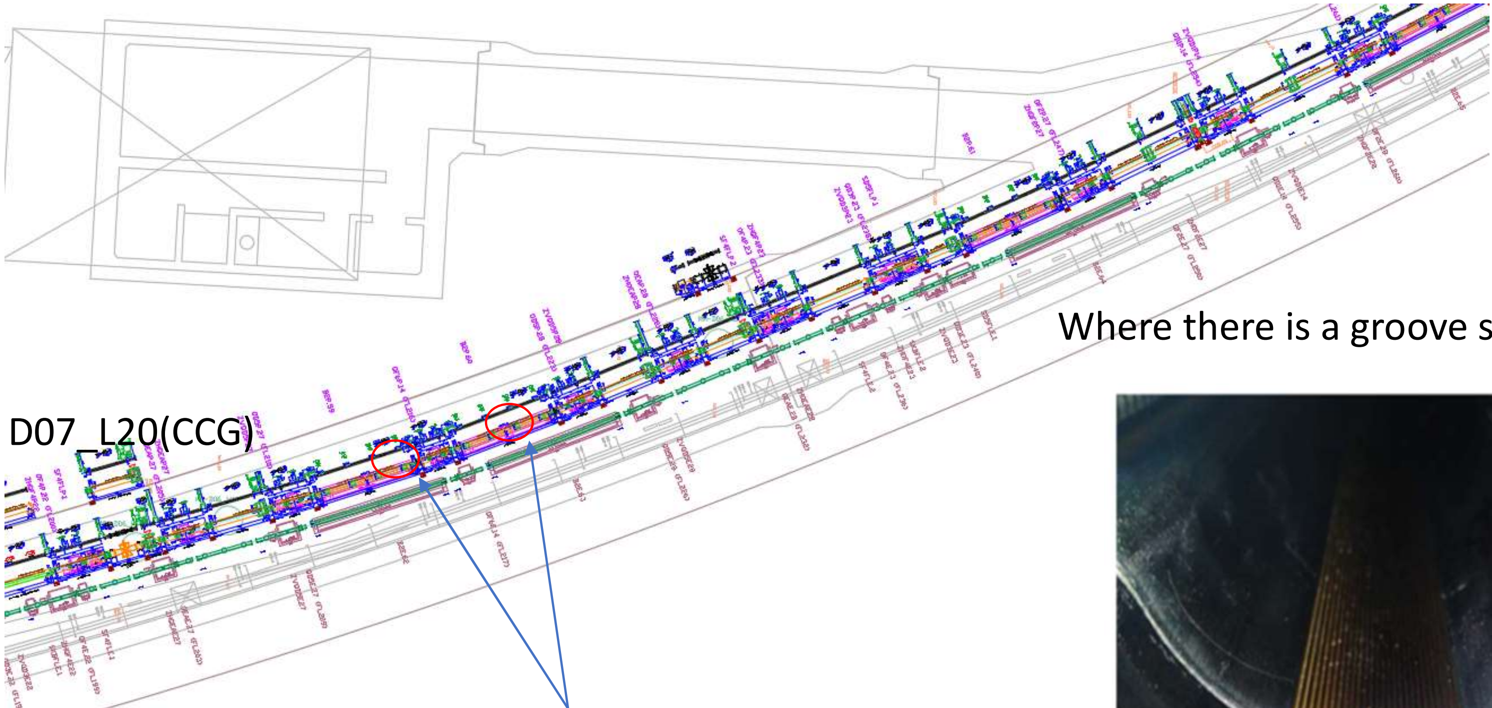
Knocker study

- We would like to reinstall the knocker to the beam pipe and see how the abort due to the current dust event is observed.
  - ➢ It may be possible to determine some of the many non-SBL aborts as dust events even if they are not observed as SBLs.

- Knocker installation locations
  - Where there is vacuum work during LS1 and dusts are likely to be re-trapped in the grooves. And where the collimator passes from the Belle II and QCS safety point of dust generation to the IP.
    - ✓ **Aluminum beam pipe with grooves in bending magnet in D06 arc section**
  - A location where pressure often jumps and is suspicious when SBL occurs. And where the collimator passes from the Belle II and QCS dust generation point to the IP for safety reasons.
    - ✓ **Beam pipe with clearing electrode in D10 Nikko Wiggler section** : Electrodes are formed by spraying alumina and tungsten onto copper beam pipes (electrodes are on top of the beam) .

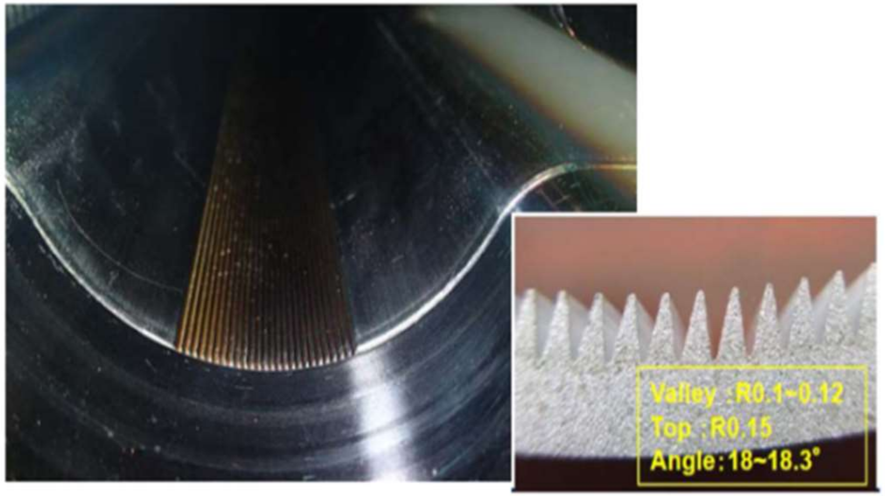
Detailed location of knocker installation D06



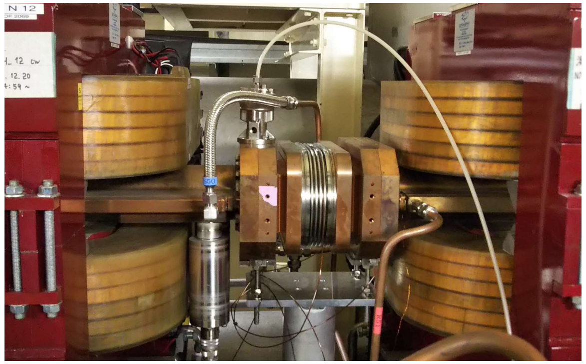


B2P59 and 60

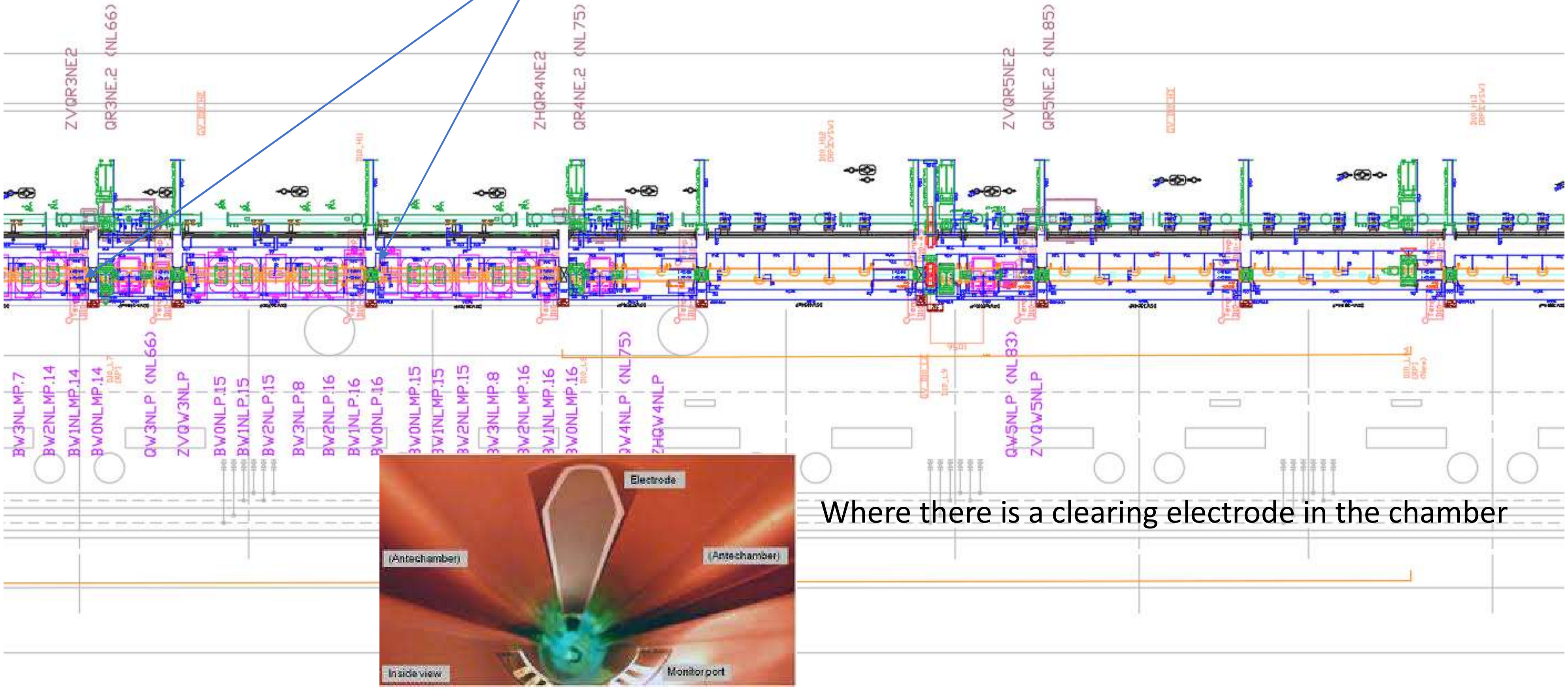
Where there is a groove structure in the chamber



Detailed location of knocker installation D10



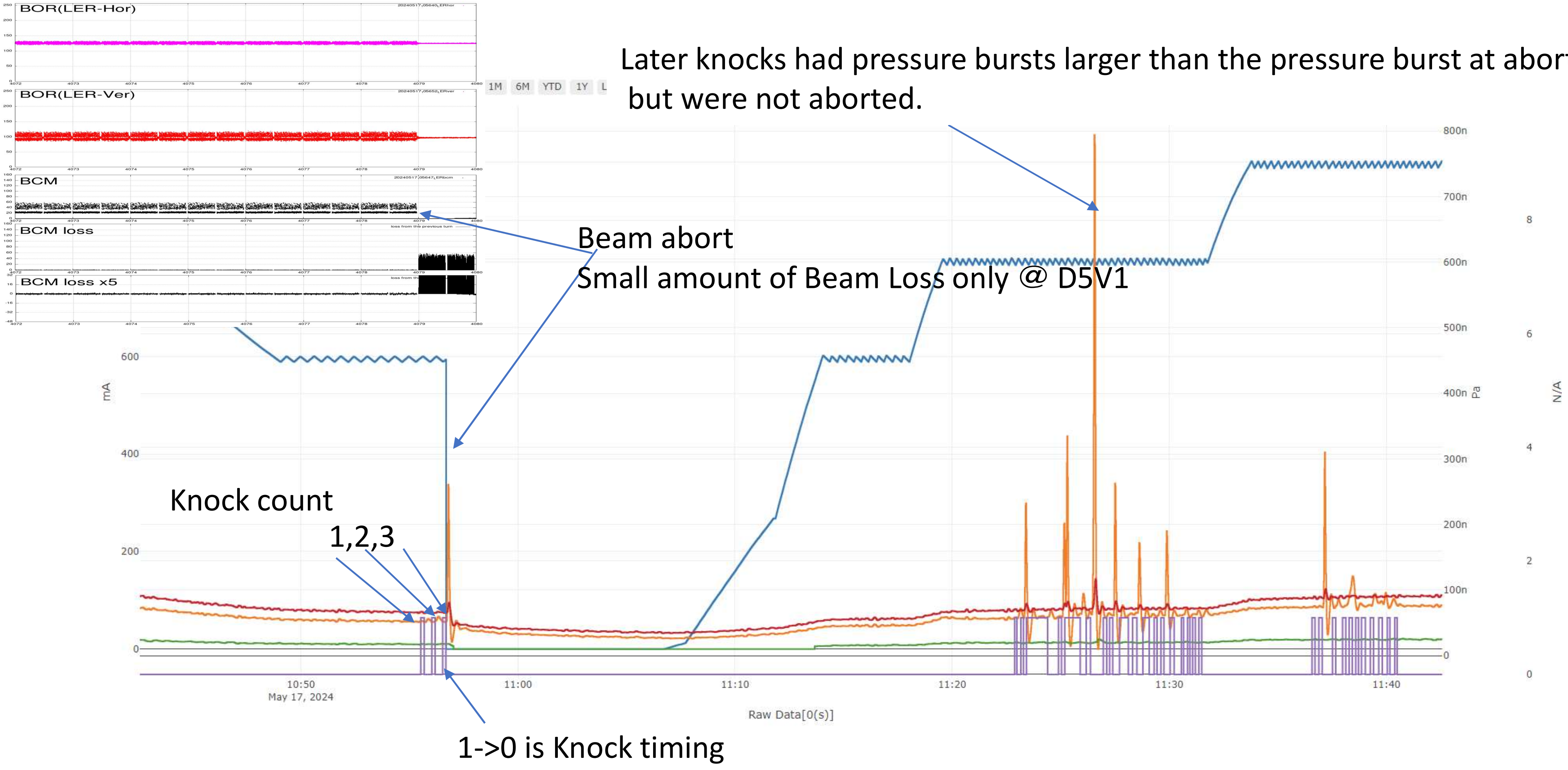
BW0NNLP.16 and BW0NLMP.14



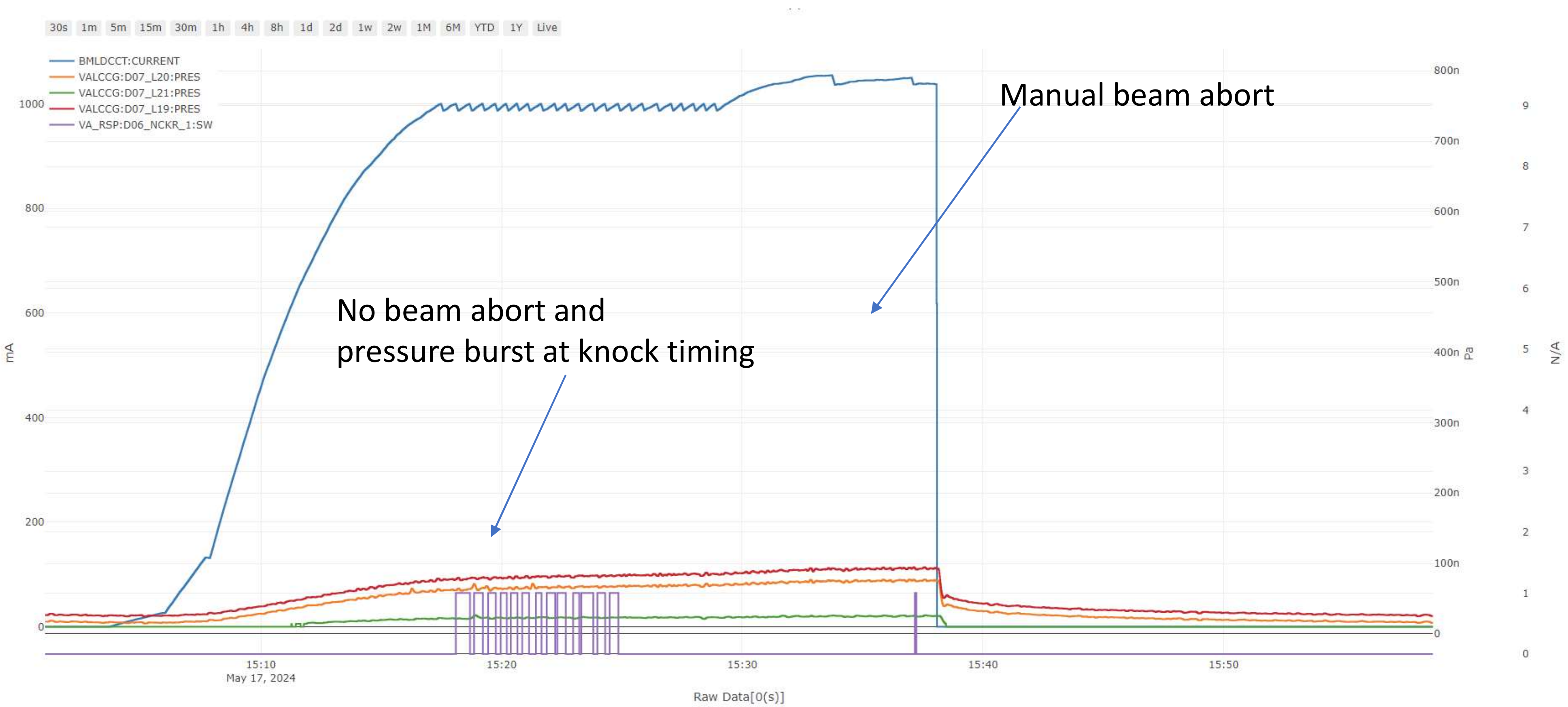
Where there is a clearing electrode in the chamber

D06:B2P.59 groove point

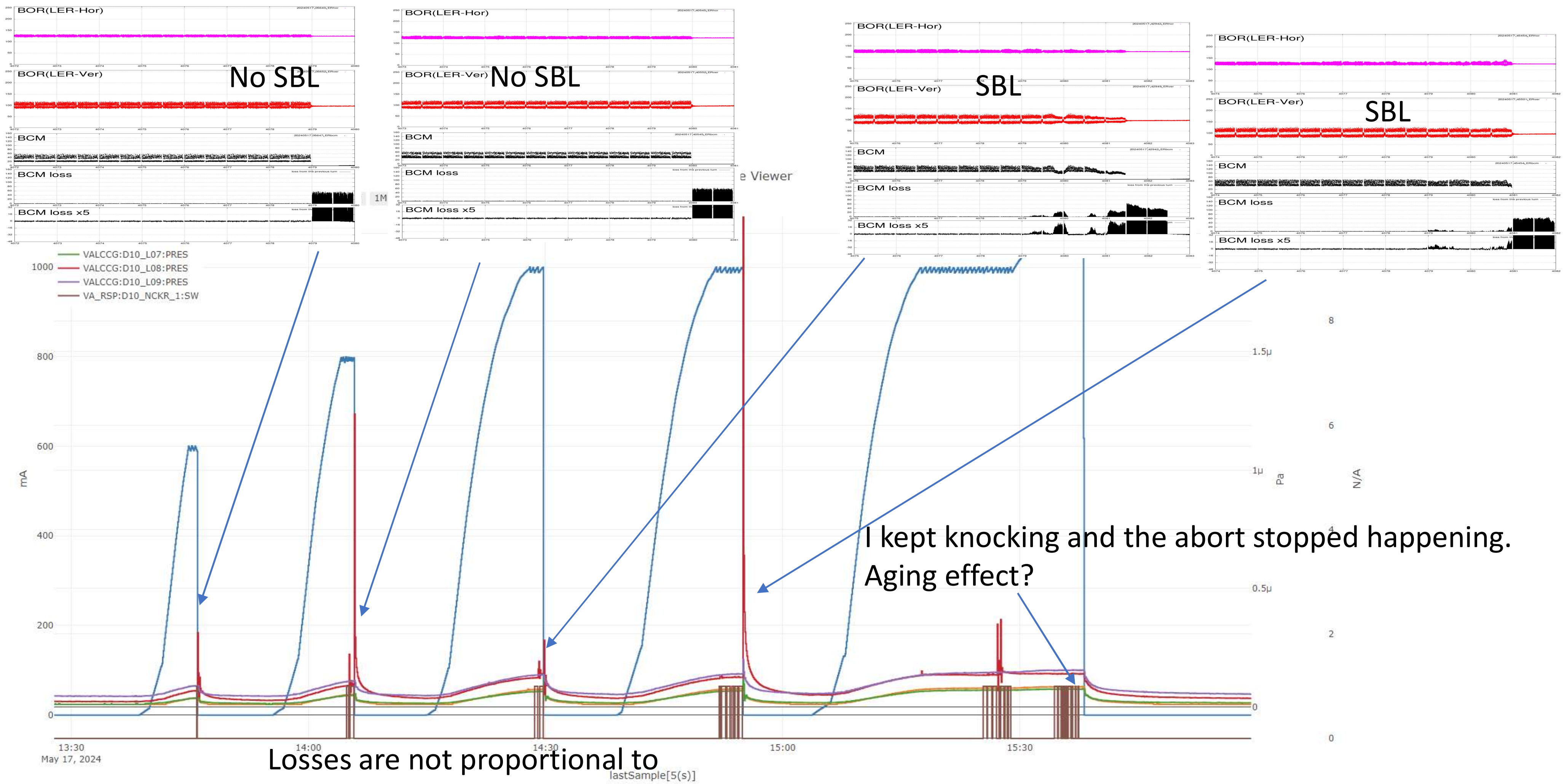
B2P.59 aborted on the knock count =3.
However, it was not an SBL.
Pressure burst observed.



D06:B2P.60 groove point

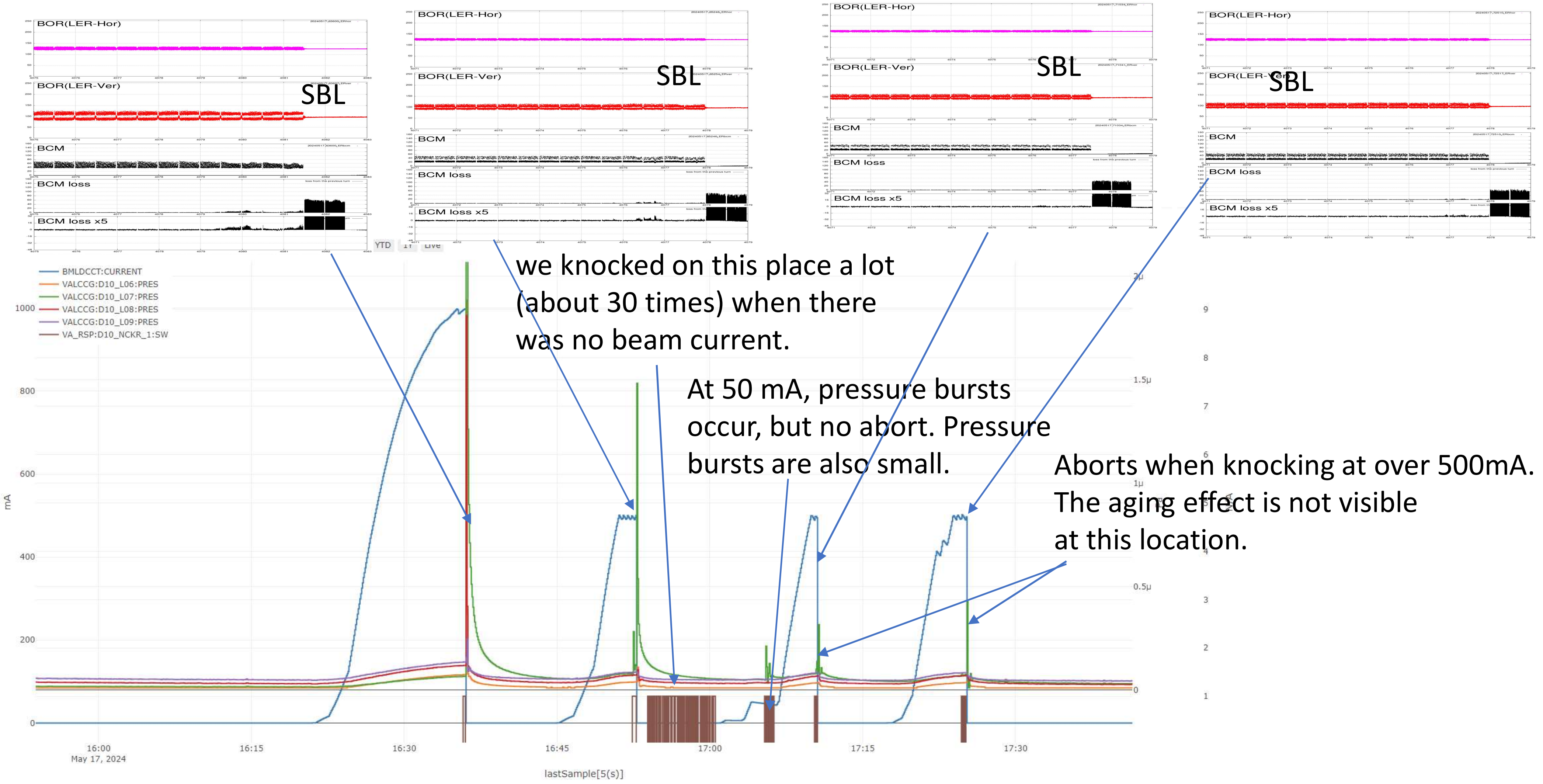


D10: BW0NNLP.16 clearing electrode point



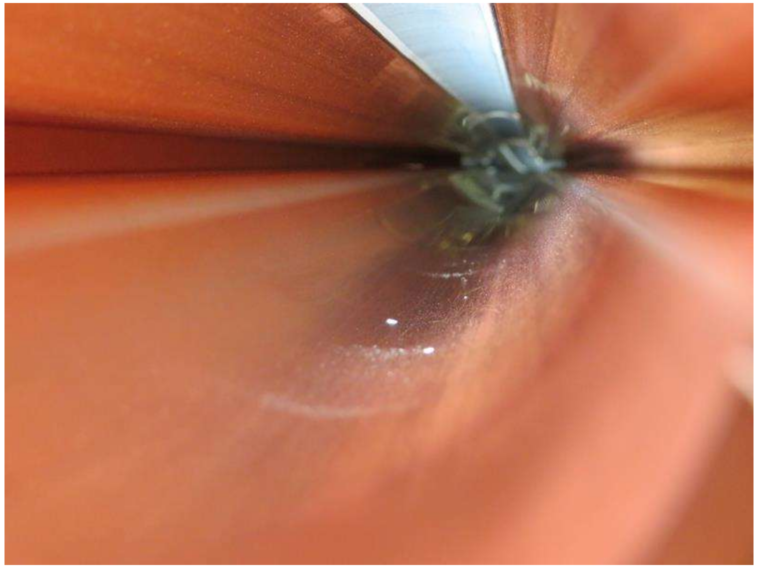
Losses are not proportional to the amplitude of the pressure burst.

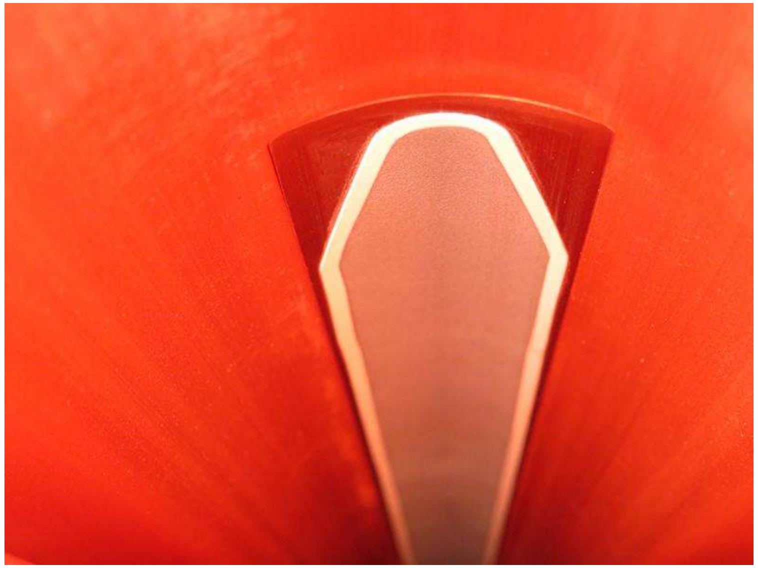
D10: BW0NLMP.14 clearing electrode point



- 2024/5/17 Knocker study was performed.
- Aluminum beam pipe with grooves in bending magnet in D06 arc section：Abort x1
  - Beam Loss is small only in D5V1.
  - Then only vacuum bursts occurred, but stopped as the knocking continued.
  - No beam abort and pressure burst at knock timing @another beam pipe.
- Beam pipe with clearing electrode in D10 Nikko Wiggler section
  - Up to 800mA, small amount of Beam Loss Abort at D6V2/D5V1.
  - SBL Abort occurred with beam loss at all around in the ring by increasing to 1000mA.
  - After that, the amount of Loss decreased and eventually vacuum bursts no longer occurred.
  - When the Chamber was changed, SBL Abort occurred even at 500 mA, and then knocked several tens of times, but no aging effect was observed. However, at 50 mA, vacuum bursts were seen but not abort.
- In both cases, the magnitude of the vacuum burst is not particularly proportional to the magnitude of Beam Loss.

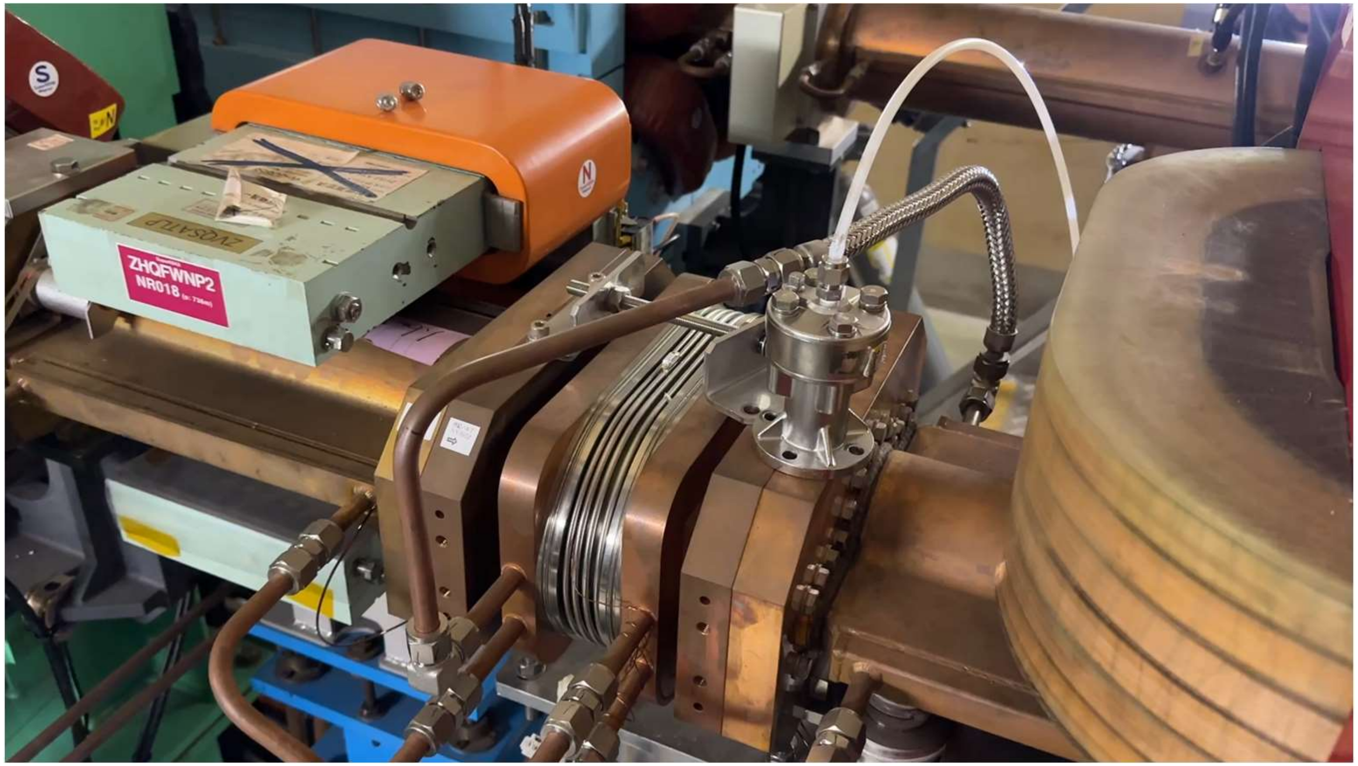
There seems to be a problem with the beam pipe with clearing electrode, so the vacuum group investigated in the experimental room with test-chamber（Chamber with electrodes taken out for D5V1 collimator installation) and came up with a countermeasure.
*It was sent for chemical analysis, but no alumina or tungsten was detected in the dust.





5/29 Maintenance

- We knocked the D10（almost）/D11(3)   wigller chamber with a knocker (about 100 times each).



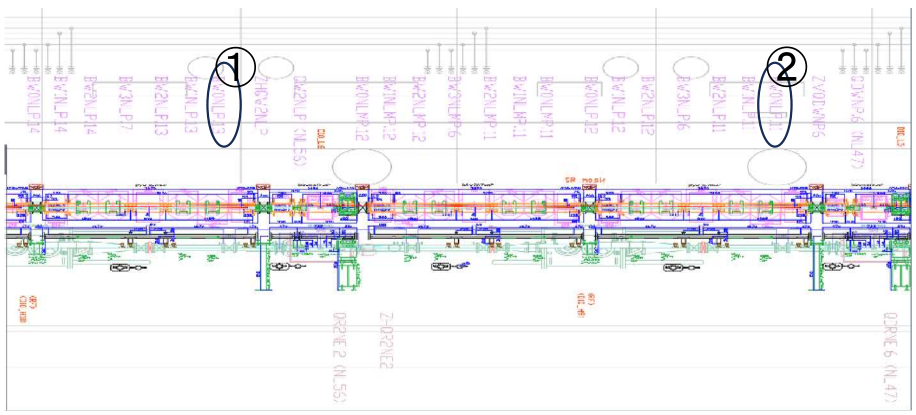
2024/5/30 : knocker study

- knocked the chamber upstream of D11 (to see the effect).
  - where there is less vacuum burst (&SBL) at lower current, but bursts can be seen when the beam current is high
- saw the current dependence by knocking D10 chamber.
- applied voltage to the electrode.

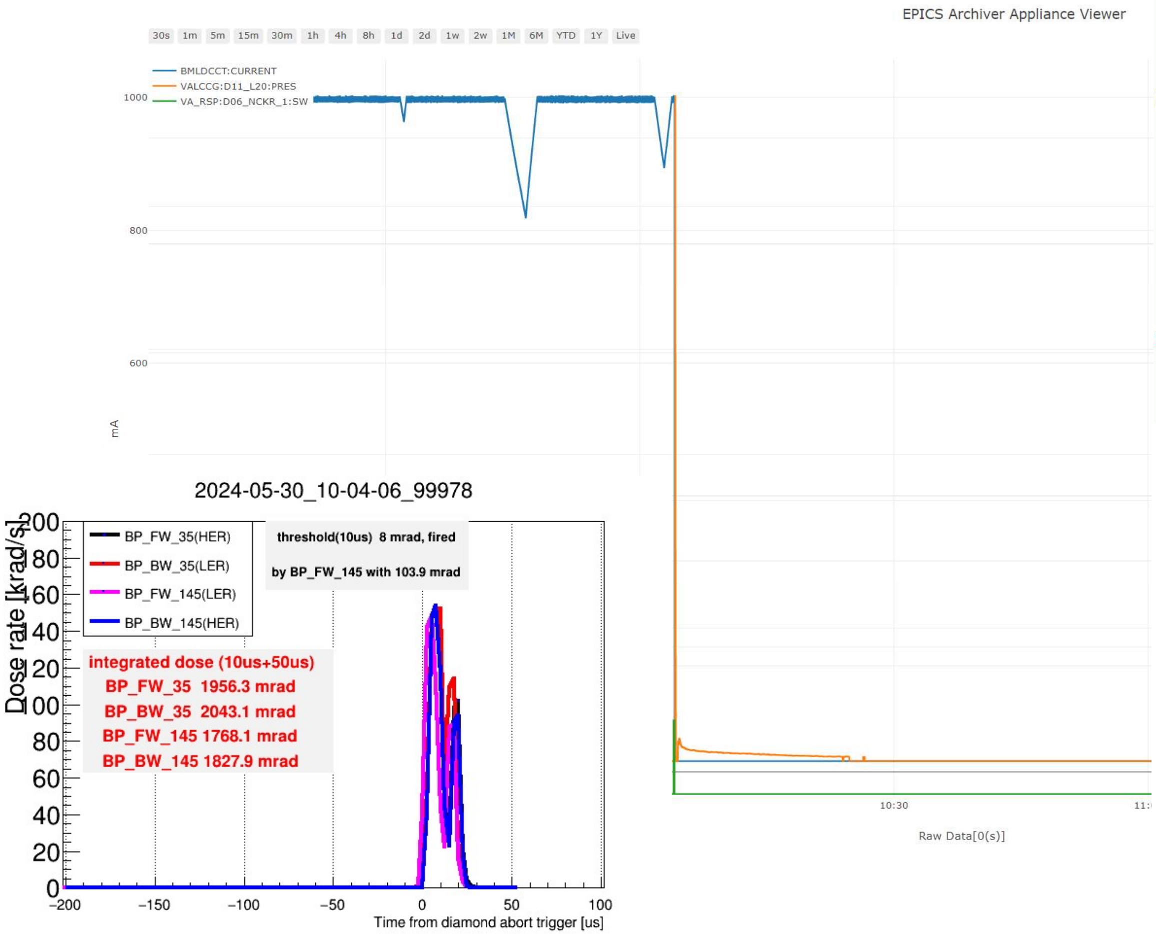
*Fill pattern is changed for each current to keep the bunch current constant.

D11

D10

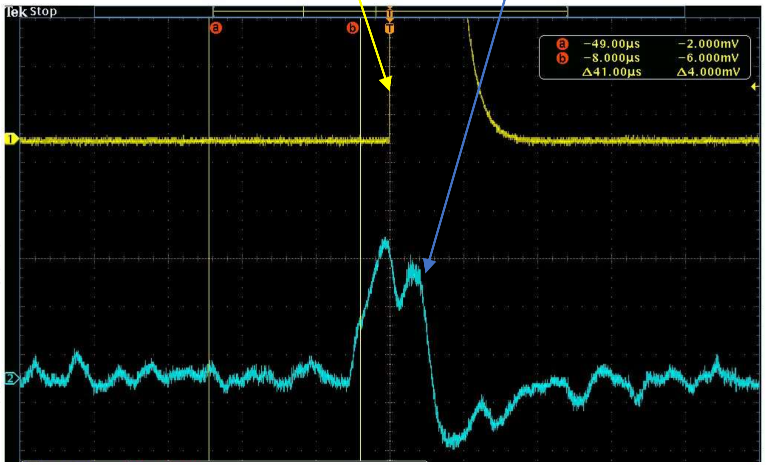


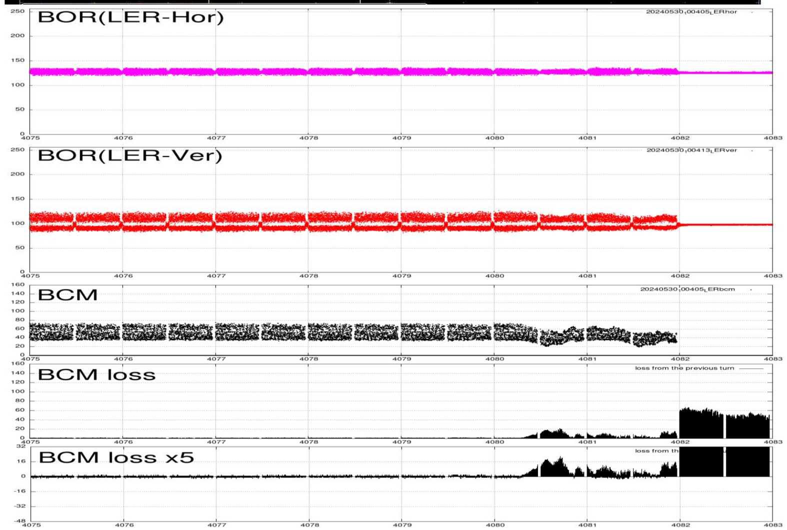
QCS quench BW0NRP3 （D11①）



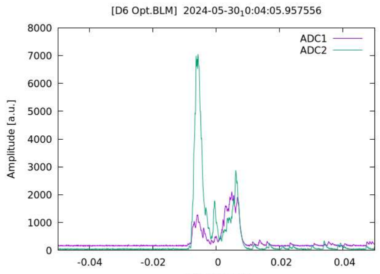
Abort signal

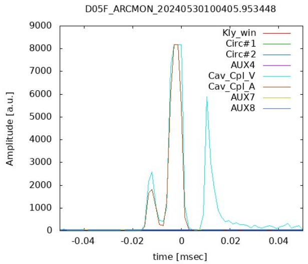
Loss monitor

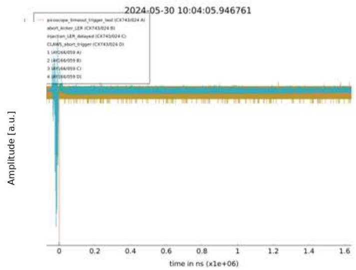


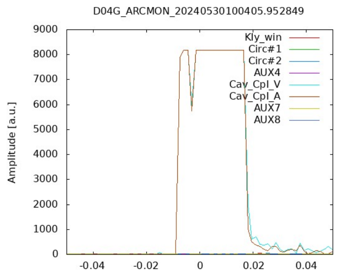


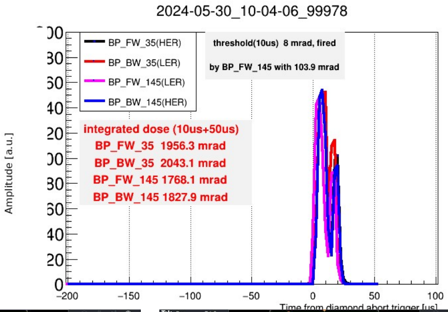
QCS quench BW0NRP3 (2024/5/30)
Abort : RF D04H(HER)→Belle2 CLAWS→ LM(D5V1 collimator)→

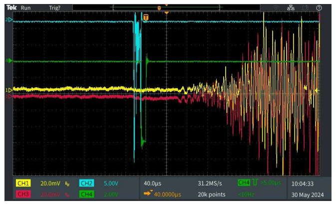


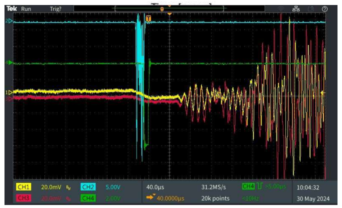


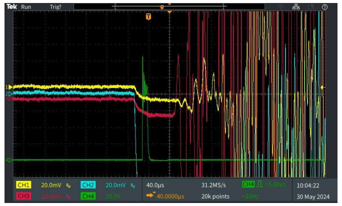


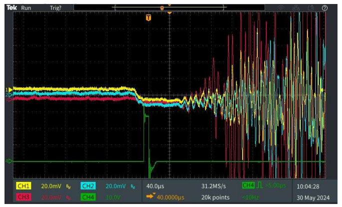


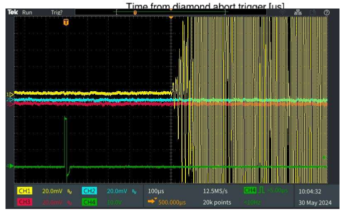


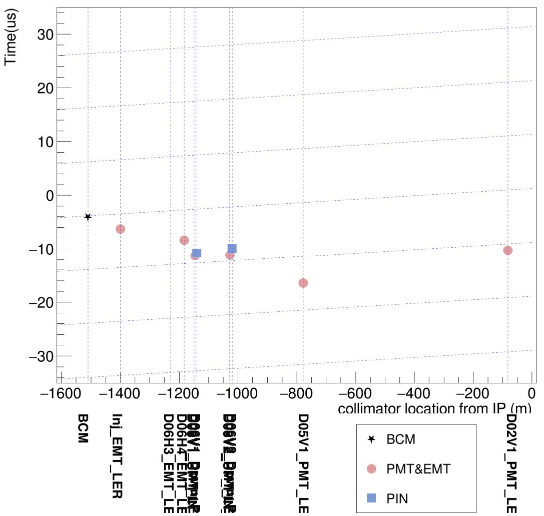


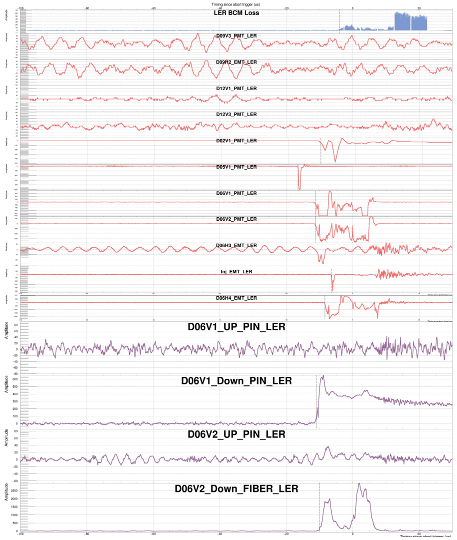


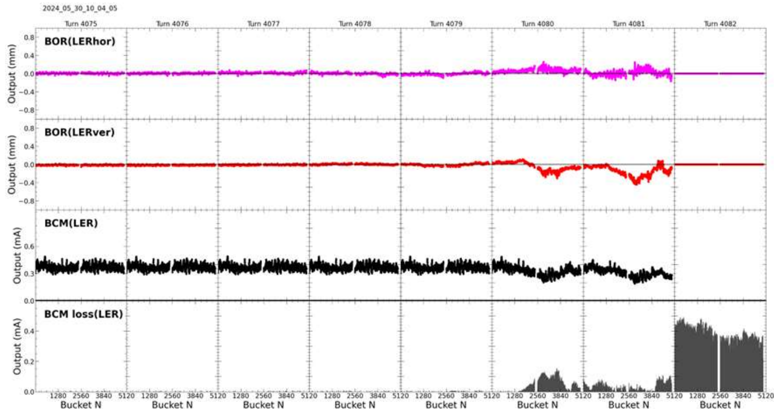




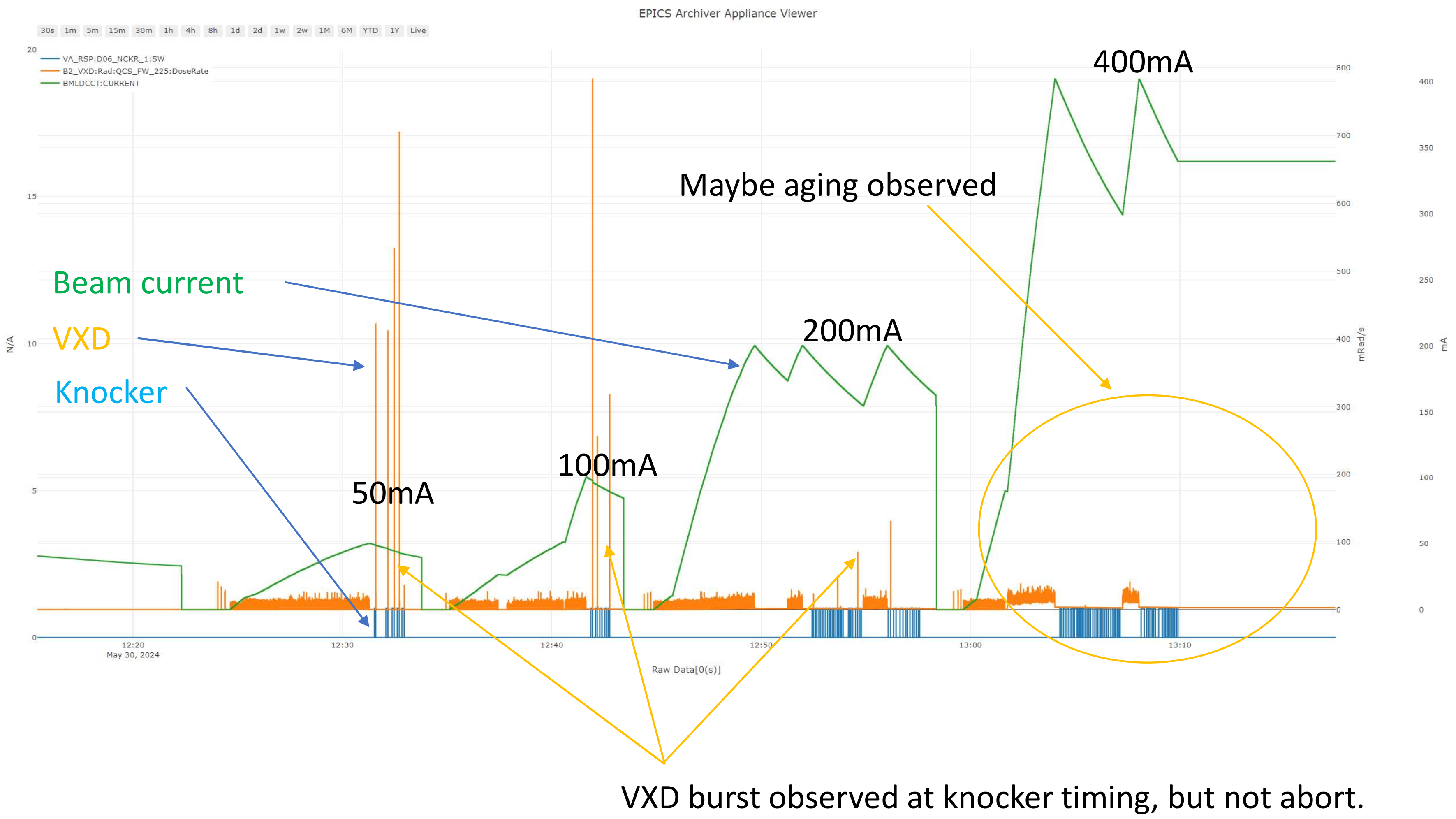




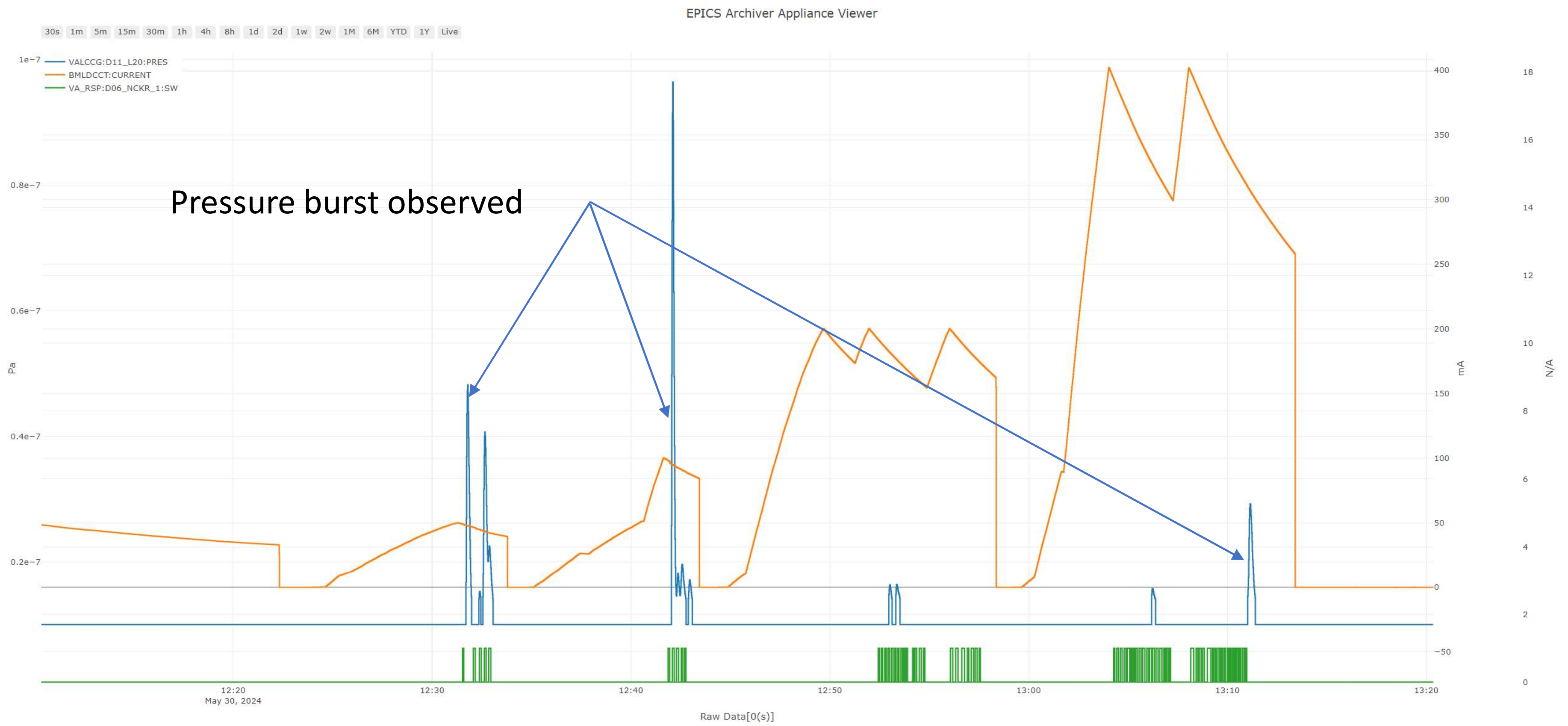




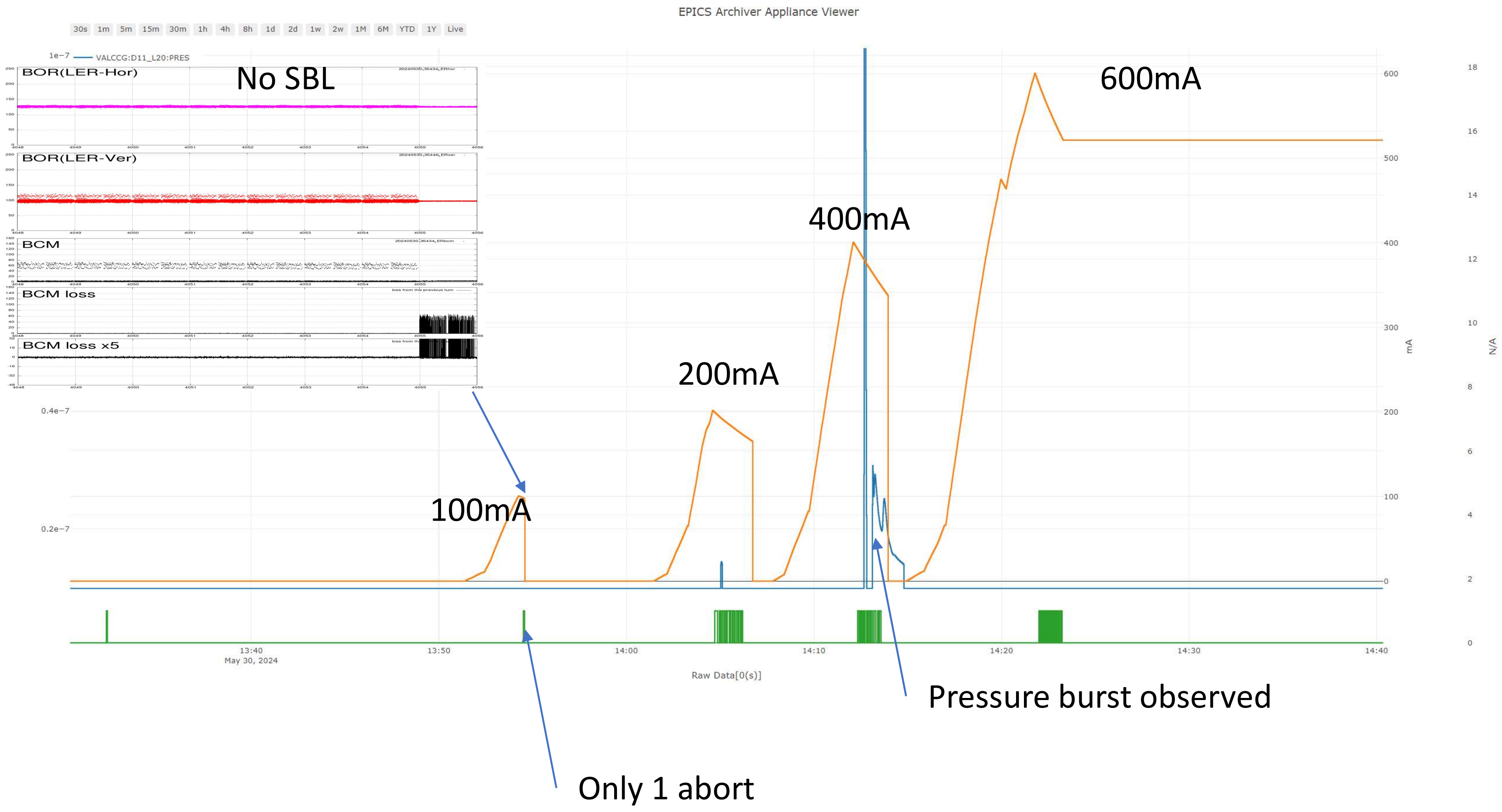
Beam current dependent BW0NRP3（D11①）



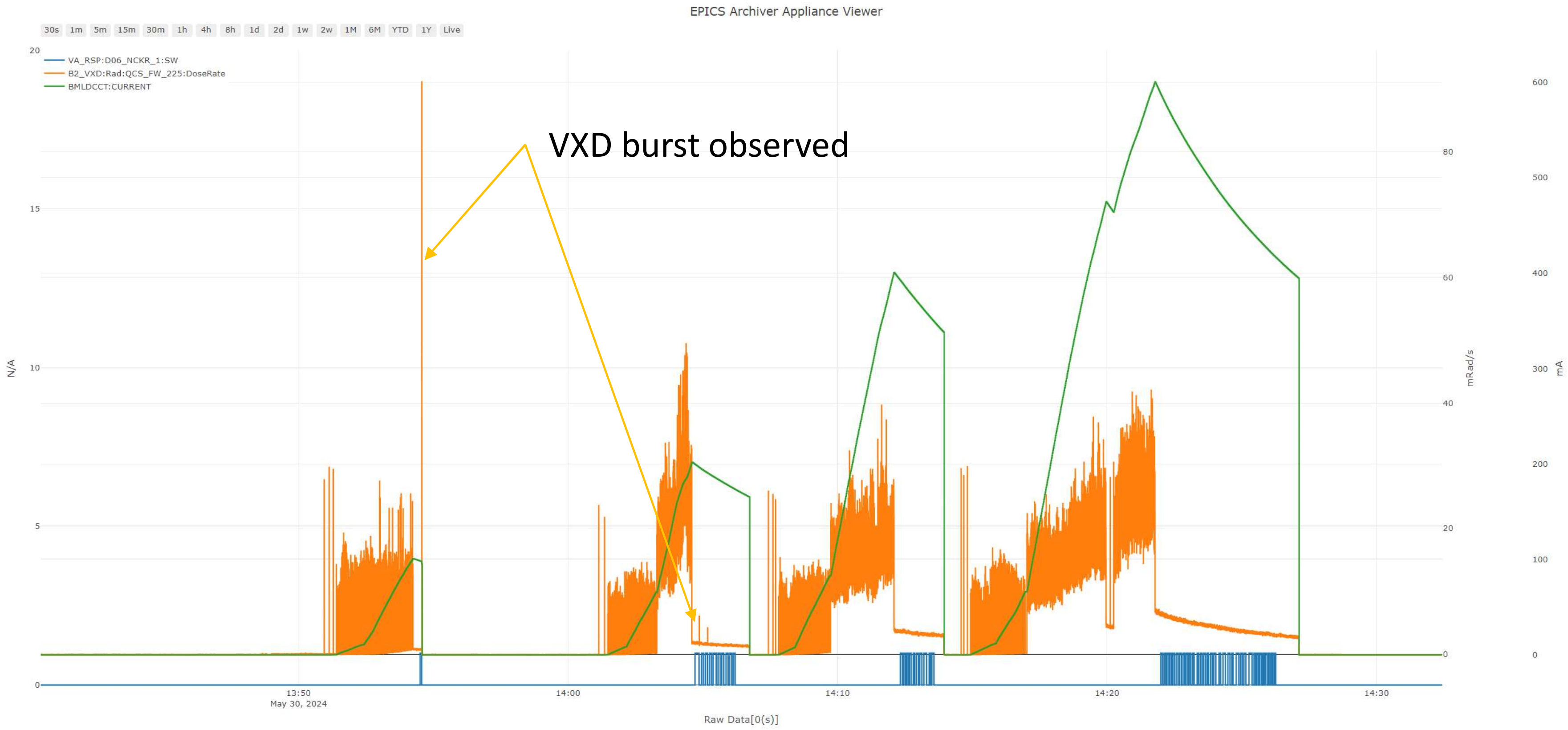
Beam current dependent BW0NRP3（D11①）



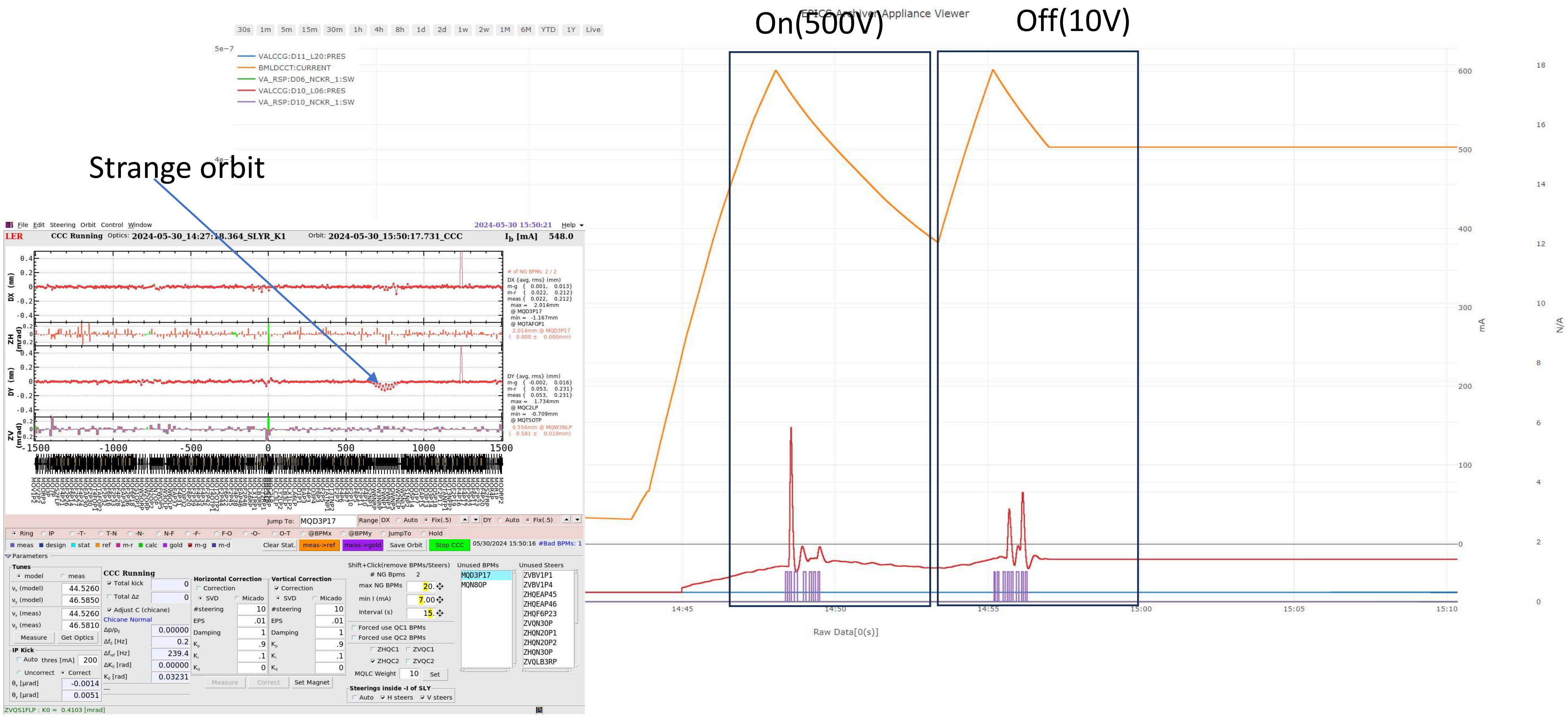
Beam current dependent BW0NRMP2（D11②）



Beam current dependent BW0NRMP2（D11②）

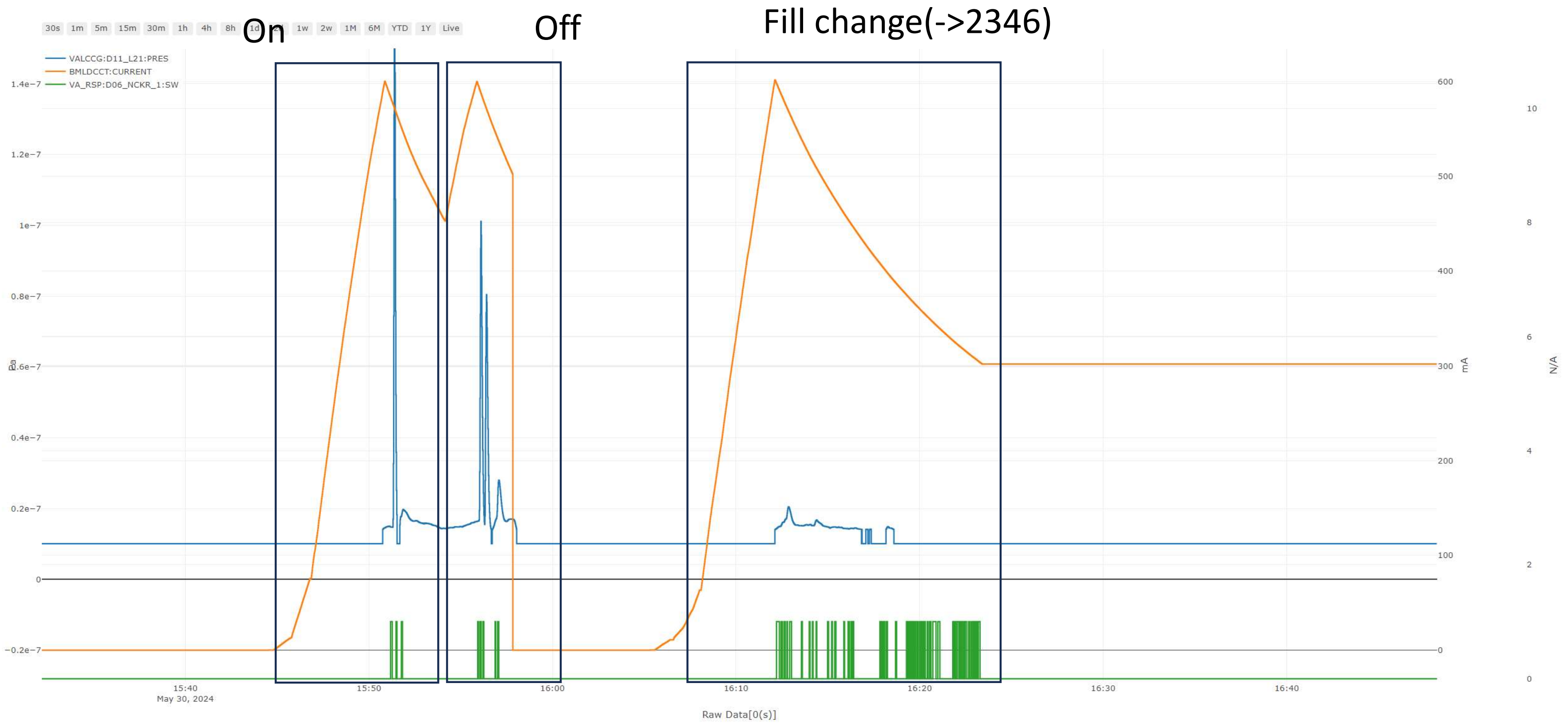


Clearing electrode On/Off dependent BW0NLP13(D10①)

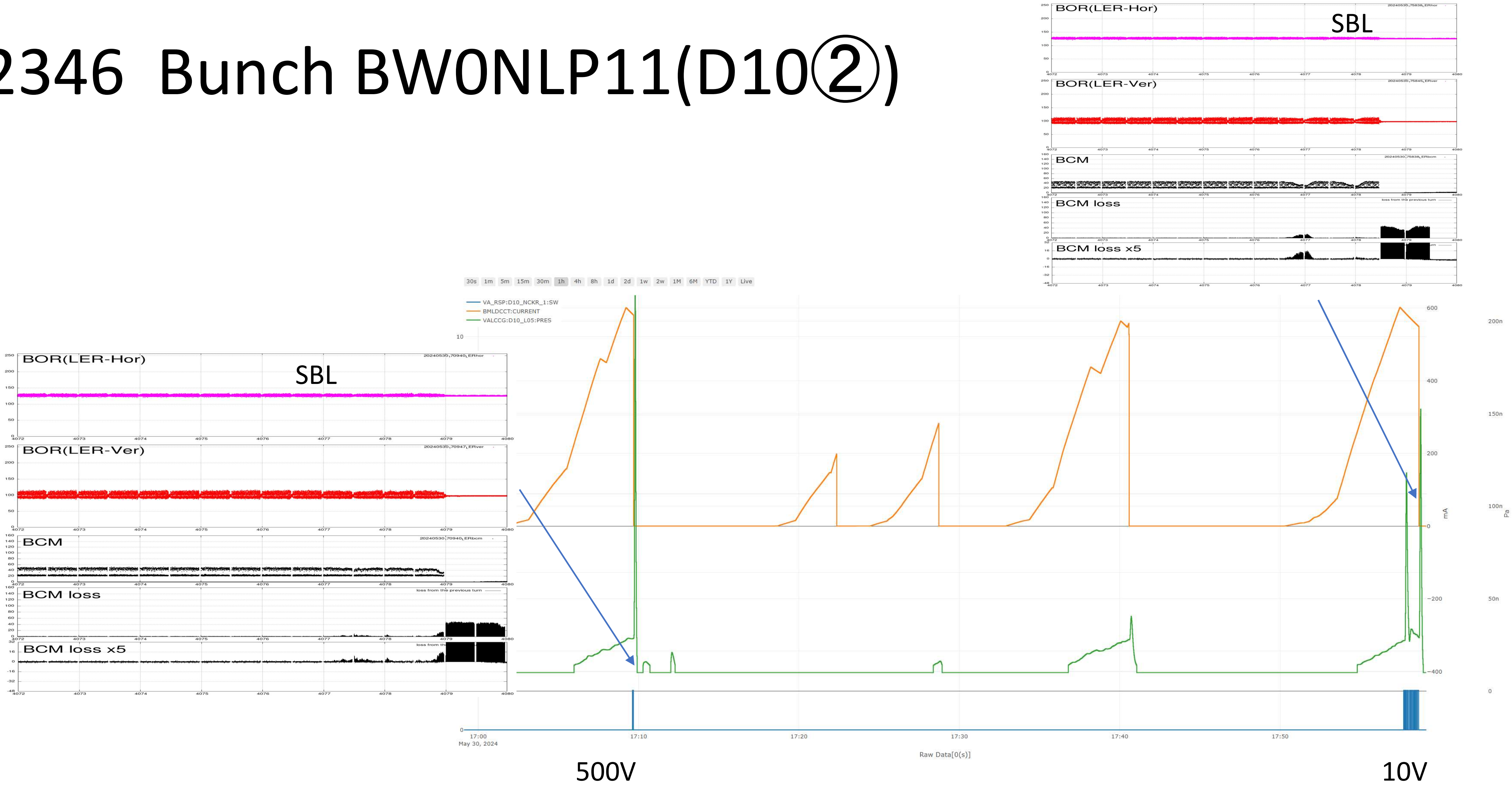


Clearing electrode On/Off dependent BW0NLP13(D10①)

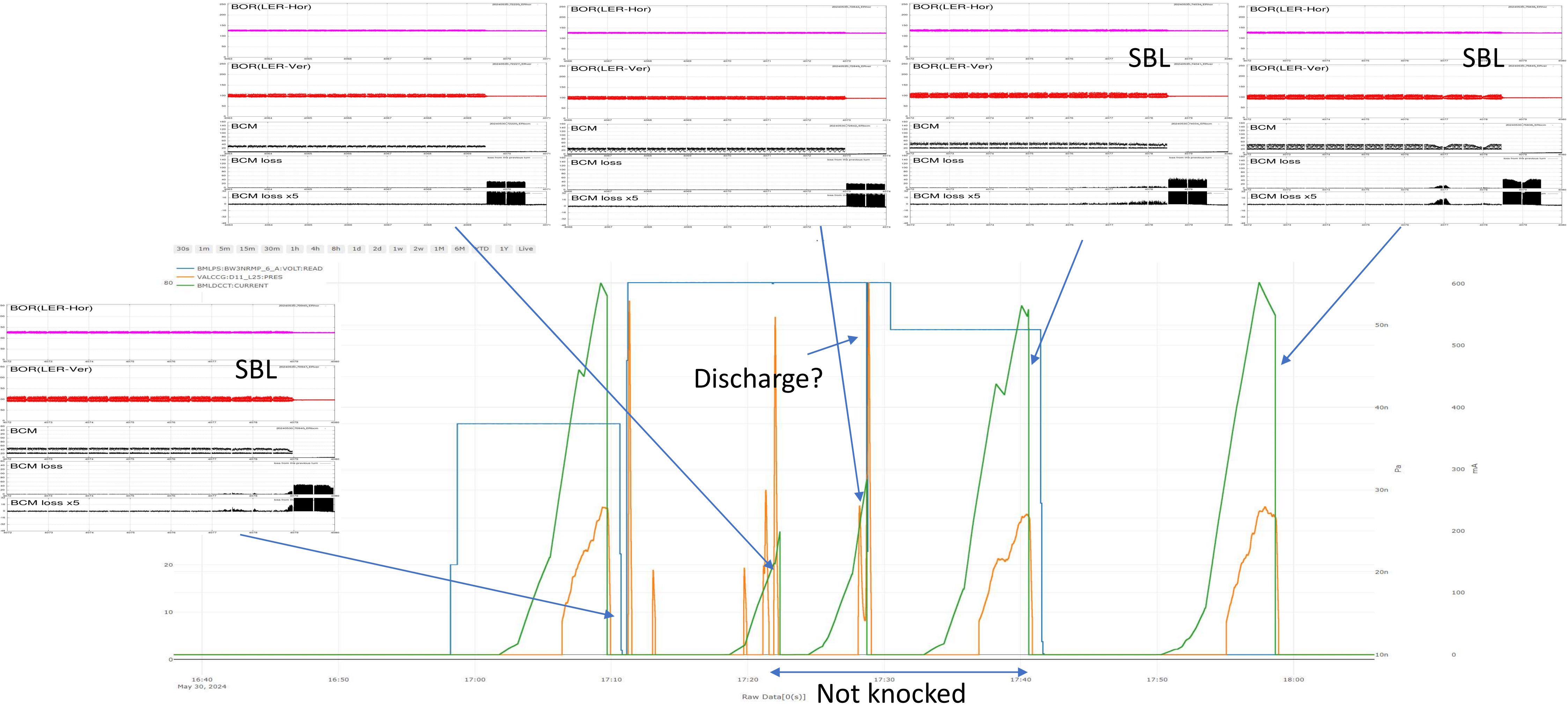
Clearing electrode On/Off dependent BW0NRP5(D11③)



2346 Bunch BW0NLP11(D10②)



Clearing electrode voltage change(D10②)



- D11-①
  - Knocked D11 chamber which is less Pressure burst →QCS quench @1A
  - Check the current dependence（50,100,200,400mA）
    - VXD burst observed at knocker timing, but not abort.
    - Pressure burst was observed at any current.
- D11-② （100,200,400,600mA）
  - Abort（not SBL）＠100mA
  - Pressure burst @ 400mA, After that, the pressure burst disappeared？
- D10-①：Clearing electrode On/Off dependent
  - No difference was seen between ON (500V)/OFF (10V) (both without Abort)
- D11-③Clearing electrode On/Off dependent
  - No difference was seen between ON (500V)/OFF (10V) (both without Abort)
  - changed the Fill Pattern, but it already disappeared?
- D10-②Clearing electrode On/Off dependent
  - **No difference was seen between ON/OFF** (both SBL Abort)
  - When the voltage is increased to 800V, Abort occurs without knocking.
    - There was also an Abort where a phenomenon similar to discharge was observed.

- **At low currents, even if an Abort occurs, it did not reach SBL**.

Further investigation

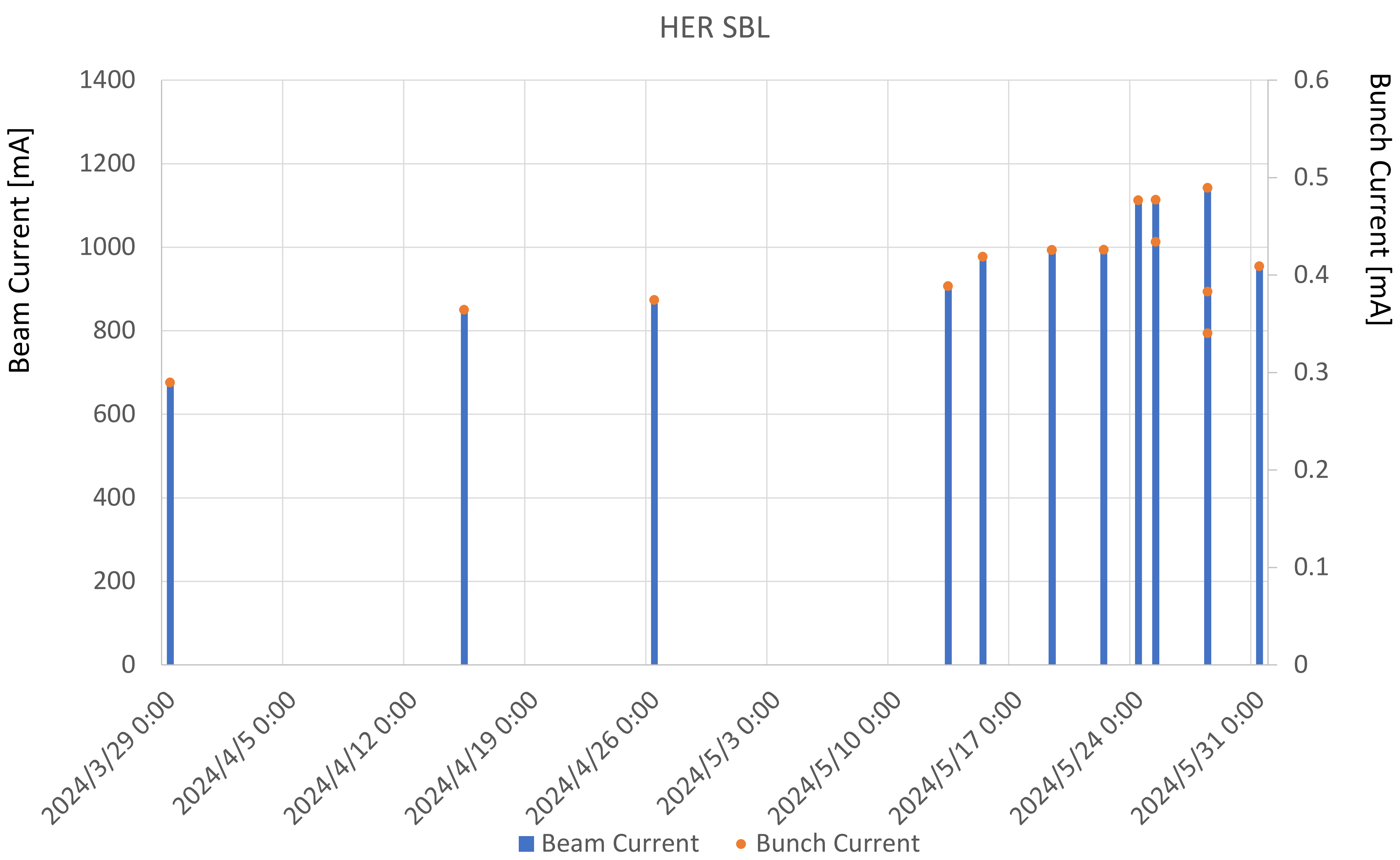
- There seems to be a problem with the beam pipe with clearing electrode, so the vacuum group continues to perform measurements using particle counter, etc. in the experimental room with test-chamber（Chamber with electrodes taken out for D5V1 collimator installation) and come up with a countermeasure.
- On the maintenance day on May 29th, we reinstalled the knocker in the D10 section and knocked almost all chambers with electrodes.

  →If it works and we get less serious SBL, we may knock on other places too.
- Since the mechanism by which dust falls and interacts with the beam is not clear, turning the beam pipe upside down may not be very effective, so we are carefully considering it.

Summary

- We had been suffering from SBL before LS1, and were working hard to find out the cause.
- Although there are signs of a causal relationship between dust and SBL, the mechanism is still unclear.
- The observed event depends on the type of dust, the location where it falls, and the beam current.
- There seems to be a problem with the beam pipe with clearing electrode, so the Vacuum group investigation underway.

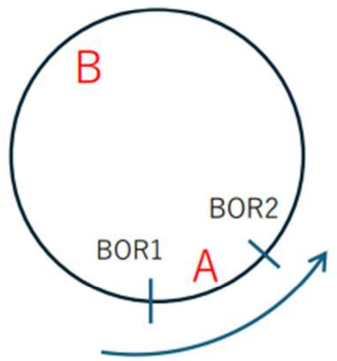
backup


HER SBL
Beam Current [mA]
Bunch Current [mA]
1400
1200
1000
800
600
400
200
0
0.6
0.5
0.4
0.3
0.2
0.1
0
2024/3/29 0:00
2024/4/5 0:00
2024/4/12 0:00
2024/4/19 0:00
2024/4/26 0:00
2024/5/3 0:00
2024/5/10 0:00
2024/5/17 0:00
2024/5/24 0:00
2024/5/31 0:00
Beam Current
Bunch Current

What can be derived from BOR measurements?

Timing→ Location

- BORs reveals **the ring section which includes the location of SBL origin.** With three BORs installed, we can divide the ring into 3 potential sections.

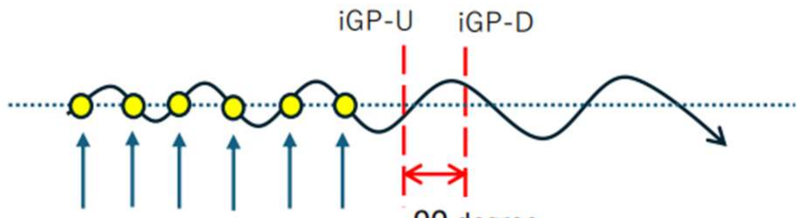


If BOR2 saw oscillation in the first turn but BOR1 didn't, the location of SBL origin should be included in the ring section A, not B.

Caveat:
BOR could overlook the oscillation if the amplitude is too small due to its betatron phase and/or poor S/N

Betatron phase

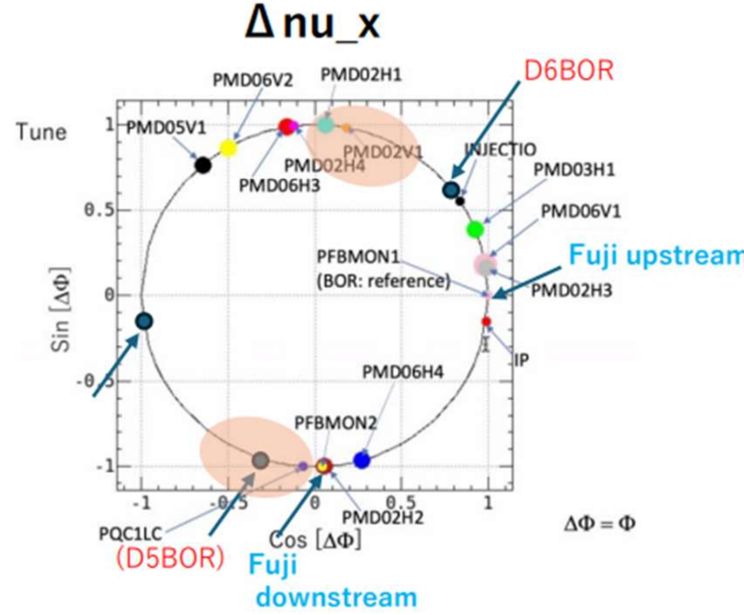
- Comparing the size of deviation of BORs (iGp12 sensors) at Fuji upstream and downstream, with 90 degree phase difference, **the betatron phase of the location of SBL origin** can be estimated
  - 1 revolution = ~45 rotations of phase
    = ~90 candidate locations

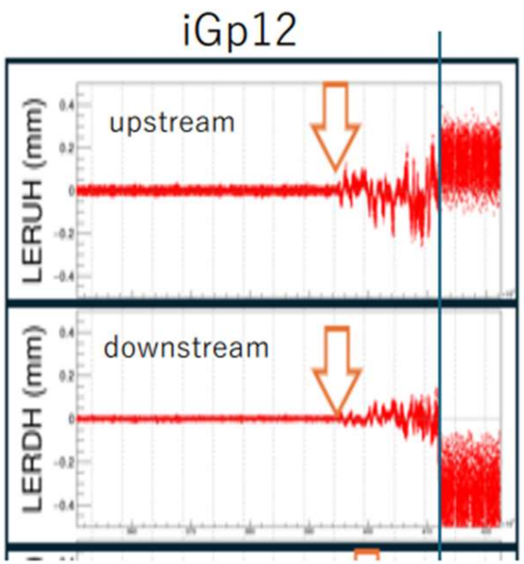


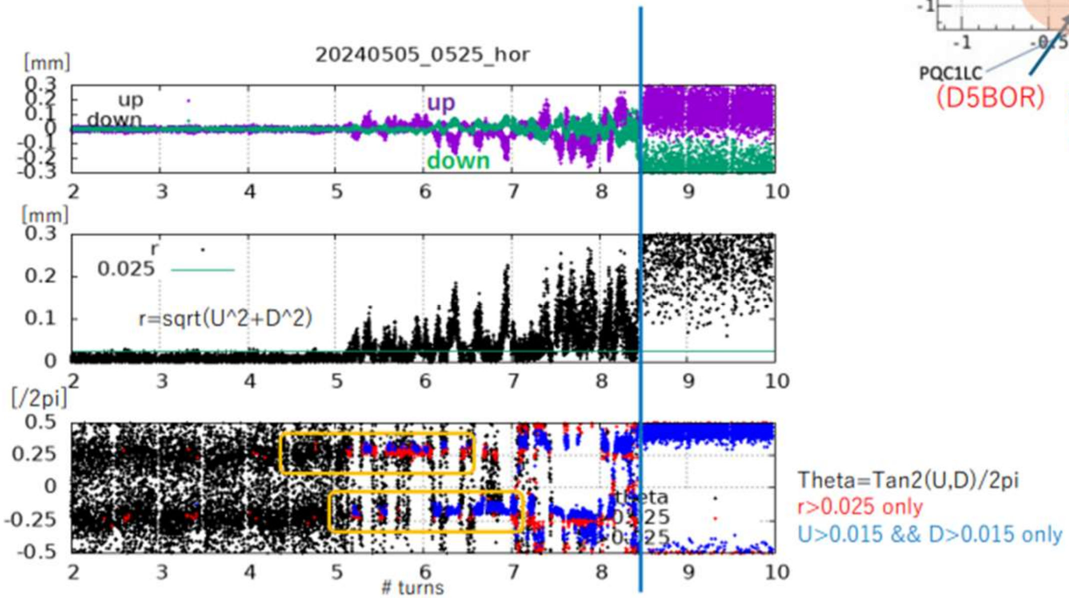
Candidate locations for SBL origin
(the phase should be 0 or pi)

BOR phase analysis (May 5th, QCS quench event)

- Fuji upstream iGp12 saw larger oscillation than downstream iGp12.
- The initial horizontal oscillation was observed at Fuji, but not in D6 RFSoC in the same turn (too small to be seen due to high noise level at D6)
- According to those observations, possible starting point of the initial horizontal oscillation seems to be **upper-right** or **lower-left** of the nu_x phase diagram
- Further detailed analysis on iGp12-U/D data shows that theta (= phase advance from the SBL origin to iGp12-U) is expected to be ~ **0.3 or -0.2**

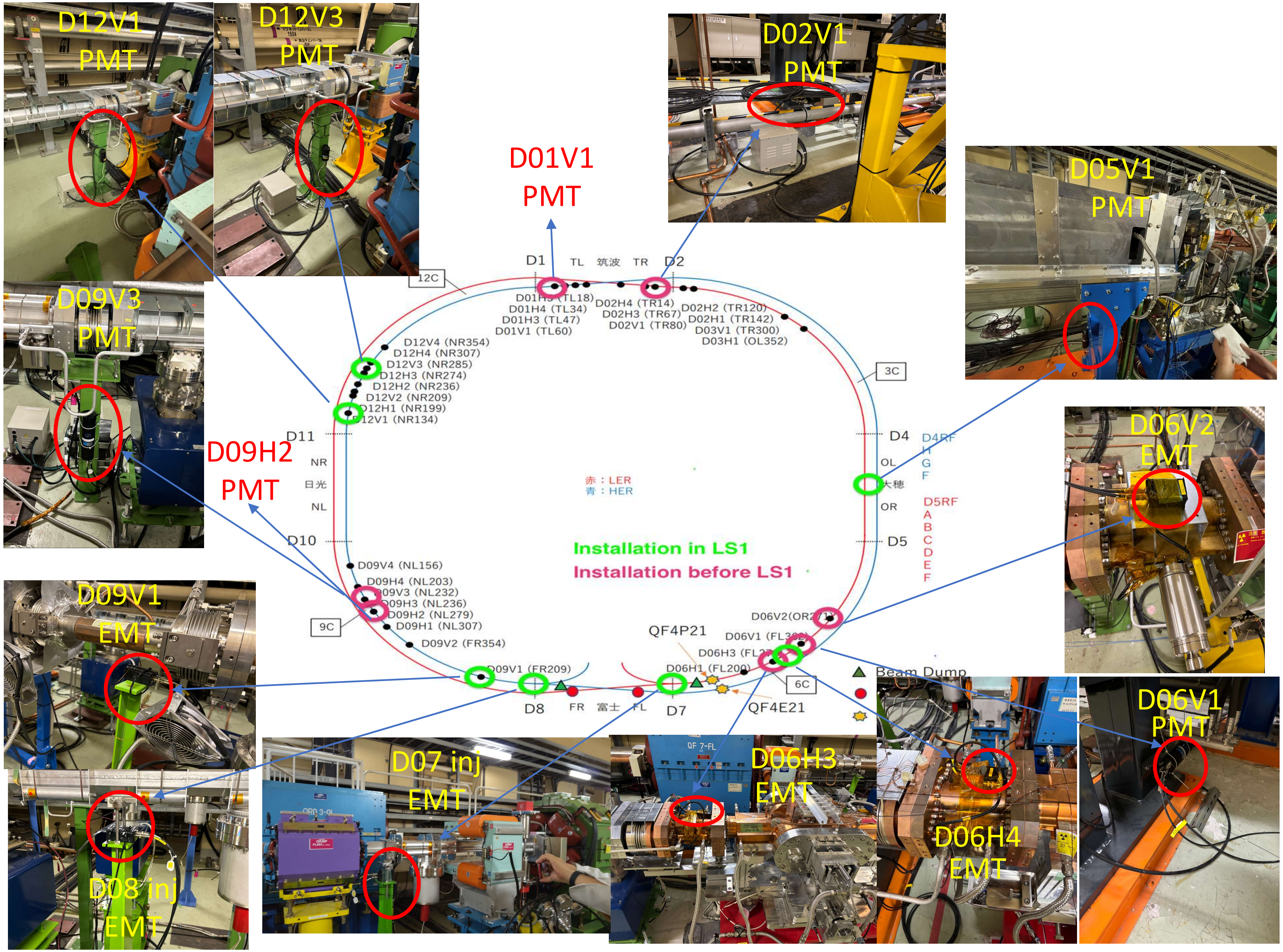






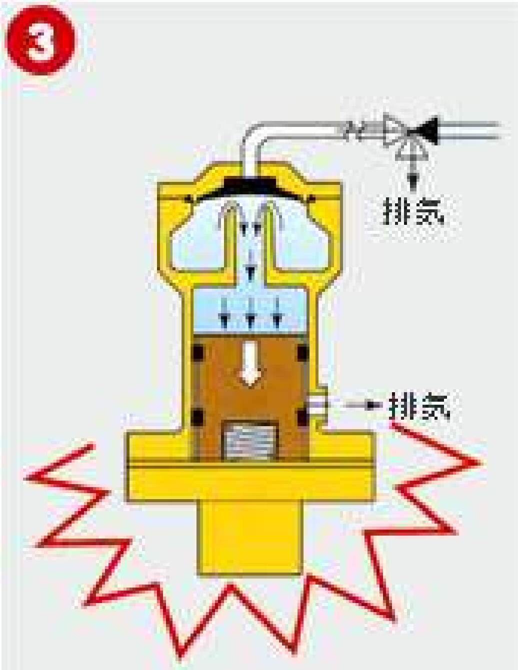
(H. Nakayama)

LM

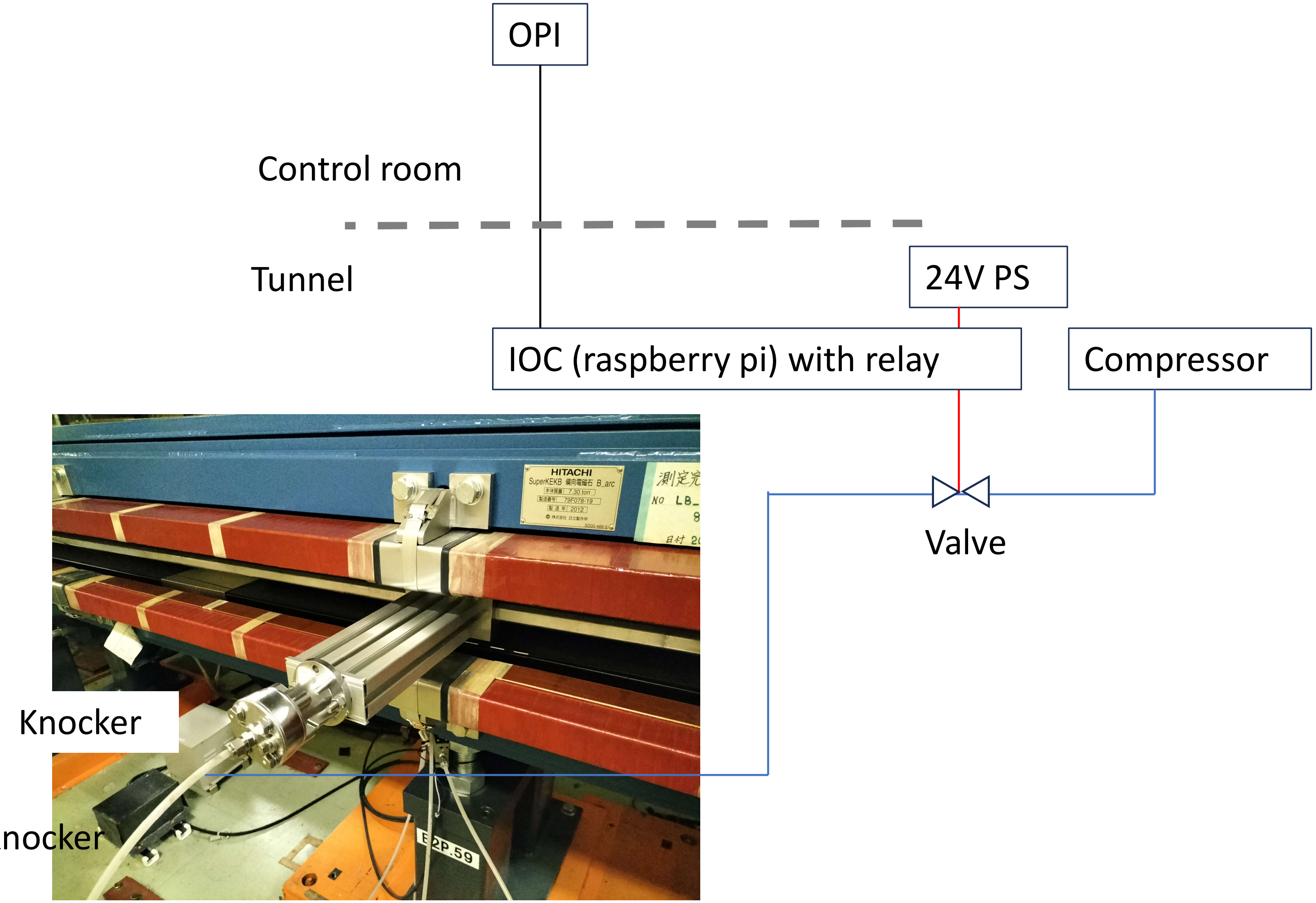

D12V1 PMT
D12V3 PMT
D01V1 PMT
D02V1 PMT
D05V1 PMT
D09V3 PMT
D09H2 PMT
D06V2 EMT
D09V1 EMT
D08 inj EMT
D07 inj EMT
D06H3 EMT
D06H4 EMT
D06V1 PMT
Installation in LS1
Installation before LS1
赤：LER
青：HER
D1
D2
D4
D5
D7
D8
D10
D11
TL
筑波
TR
NR
日光
NL
OL
大穂
OR
FR
富士
FL
12C
3C
6C
9C
D4RF
D5RF
QF4P21
QF4E21
Beam Dump
D12V4 (NR354)
D12H4 (NR307)
D12V3 (NR285)
D12H3 (NR274)
D12H2 (NR236)
D12V2 (NR209)
D12H1 (NR199)
D12V1 (NR134)
D01H4 (TL34)
D01H3 (TL47)
D01V1 (TL60)
D02H4 (TR14)
D02H3 (TR67)
D02V1 (TR80)
D02H2 (TR120)
D02H1 (TR142)
D03V1 (TR300)
D03H1 (OL352)
D09V4 (NL156)
D09H4 (NL203)
D09H3 (NL236)
D09H2 (NL279)
D09H1 (NL307)
D09V2 (FR354)
D09V1 (FR209)
D06H1 (FL200)

(K. Uno et al.)

Knocker study



https://www.technos-serve.com/mgk-knocker



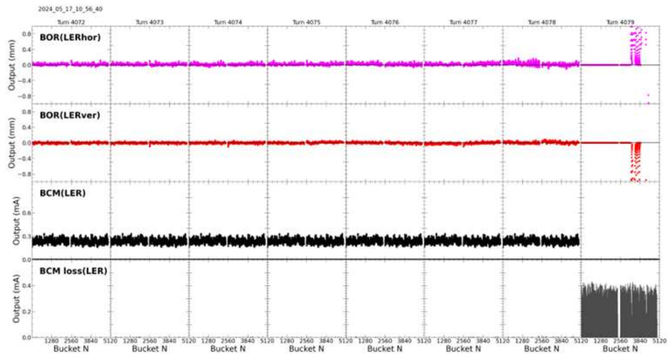
日時	knock	Current[mA]	Abort	SBL	D05 CLAWS
2024-05-17 10:56:40	D6	594	LM(D5V1 collimator)→RF D04G		ON
2024-05-17 13:45:56	D10-①	598	CLAWS D05V1→LM(D5V1 collimator)		ON
2024-05-17 14:05:45	D10-①	792	CLAWS D05V1		ON
2024-05-17 14:29:42	D10-①	995	RF D04G→Belle2 CLAWS→LM(D5V1 collimator)	✓大	OFF
2024-05-17 14:54:54	D10-①	994	LM（D6V1V2collimator）→RF D04G→Belle2 CLAWS→	✓	OFF
2024-05-17 16:36:00	D10-②	995	LM D6 (Optical Fiber)→RF D04G→Belle2 CLAWS→	✓	OFF
2024-05-17 16:52:46	D10-②	492	LM（D6V1V2collimator）→RF D04G→LM(D5V1 collimator)→	✓	OFF
		50	--------		OFF
2024-05-17 17:10:34	D10-②	495	LM（D6V1V2collimator）	✓	OFF
2024-05-17 17:25:10	D10-②	495	CLAWS D05V1→LM（D6V1V2collimator）	✓	ON

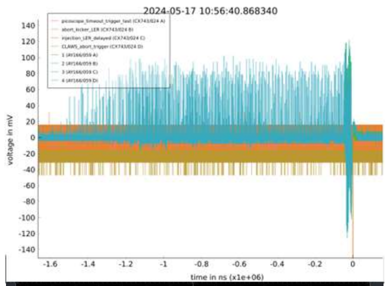
Possible Reasons for SBL

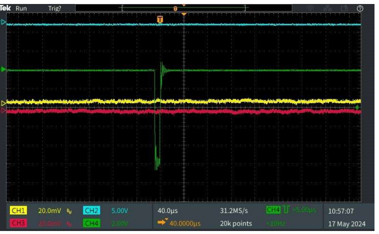
- Damage of vacuum component (RF Finger) @KEKB & PEP-II
  - Beam phase changes (beam energy losses) observed ms to several hundred μs before aborts.

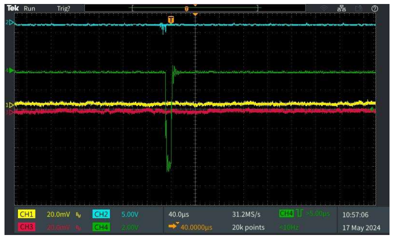
  → The time scale differs from that of SBL.
  - Abnormal temperature rise at bellows chambers had been observed and the catastrophic damages in the RF-finger had been confirmed. → We could not find that damage.
- Interaction with Dust : Early stage @ SuperKEKB
  - Beam aborts accompanied by local pressure bursts. → not observed the burst that causes it in SBL
  - Beam loss lasted a few ms before the beam abort. → time scale is different
  - Vacuum chambers were cleaned or tapped to remove as much dust as possible and fixed the problem.
- Vertical abort kicker misfire
  - We are using the same thyratron for horizontal kicker.
- FB kicker trouble or lack of power : measured @ BEPC II
  - Sinch the growth time of coupled bunch instability might be O(～several 10 turns), our sbl was not caused by FB system problem.

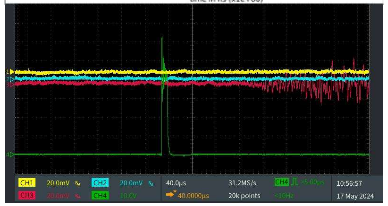
2024-05-17 10:56:40 594mA
LM(D5V1 collimator)→RF D04G
D6 knock
Small amount of Beam Loss only @ D5V1

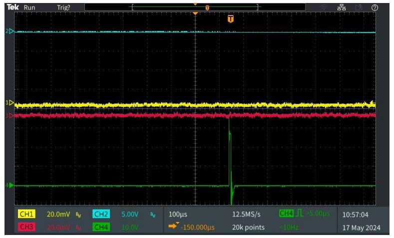


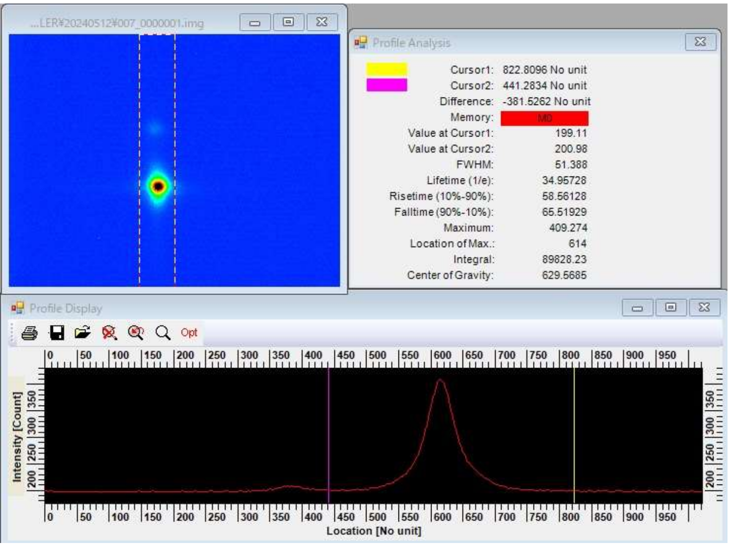


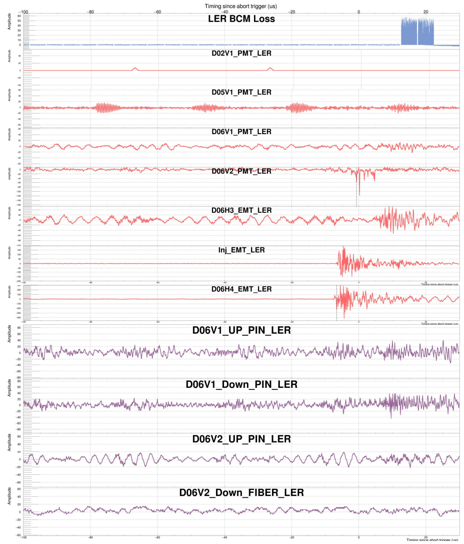


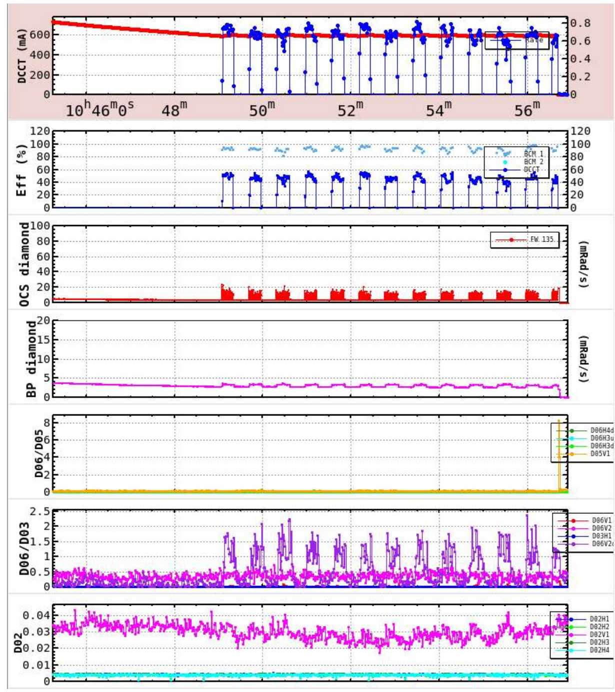




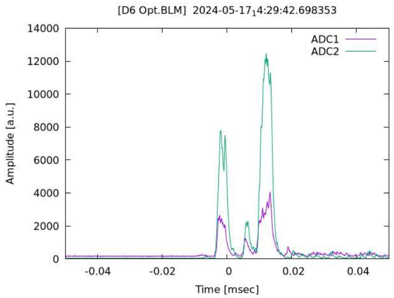


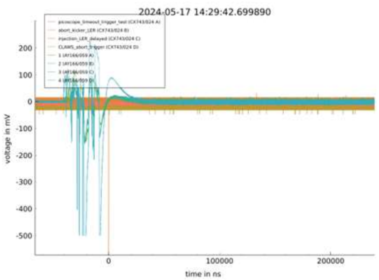


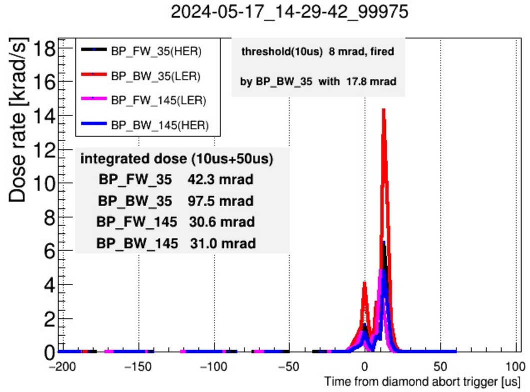


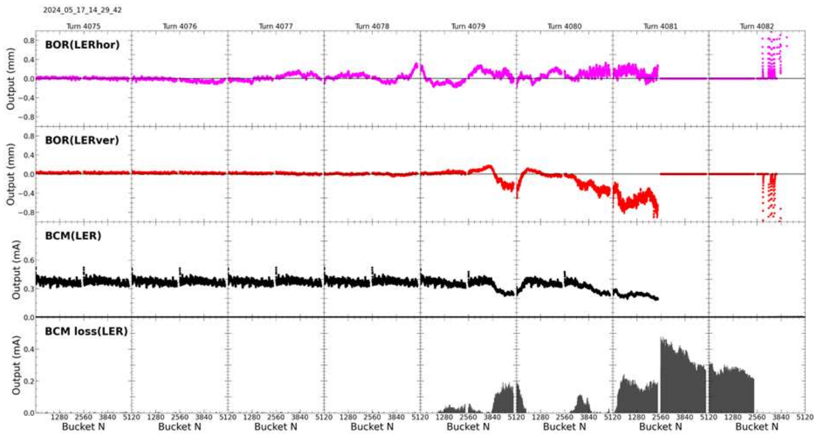


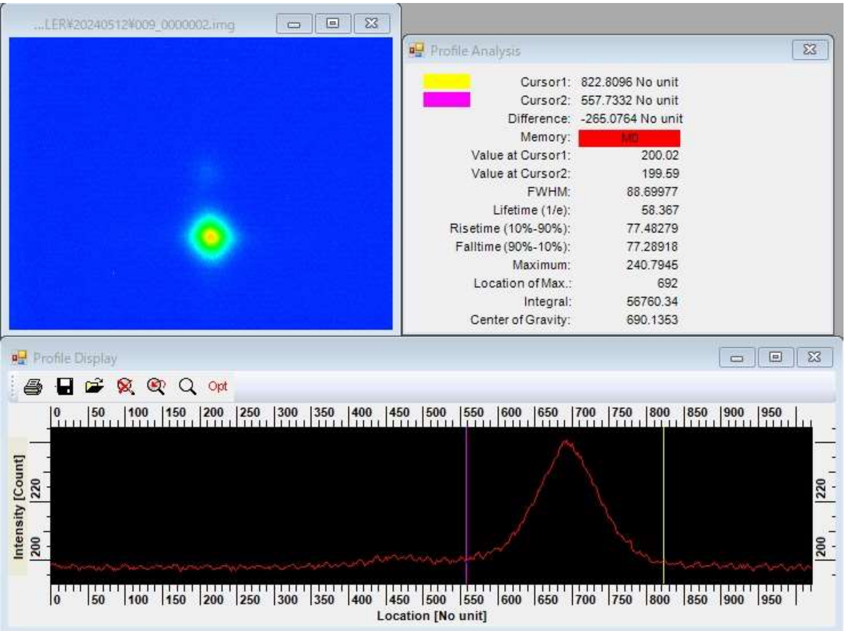
2024-05-17 14:29:42 995mA
RF D04G→Belle2 CLAWS→LM(D5V1 collimator)
D10-①
SBL　全周でLoss

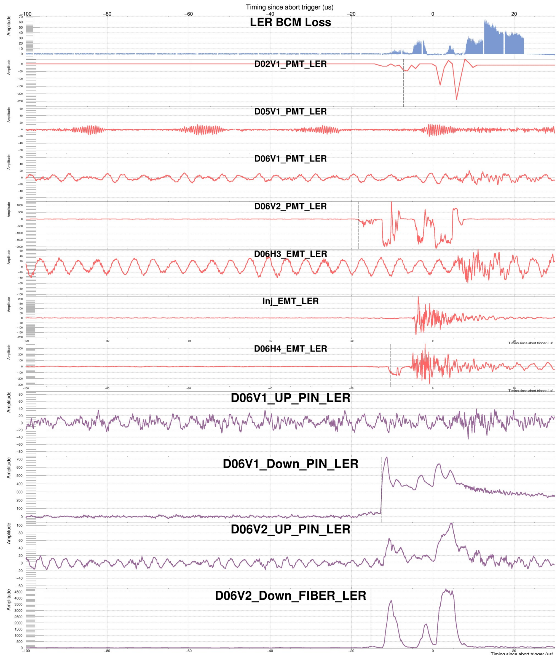


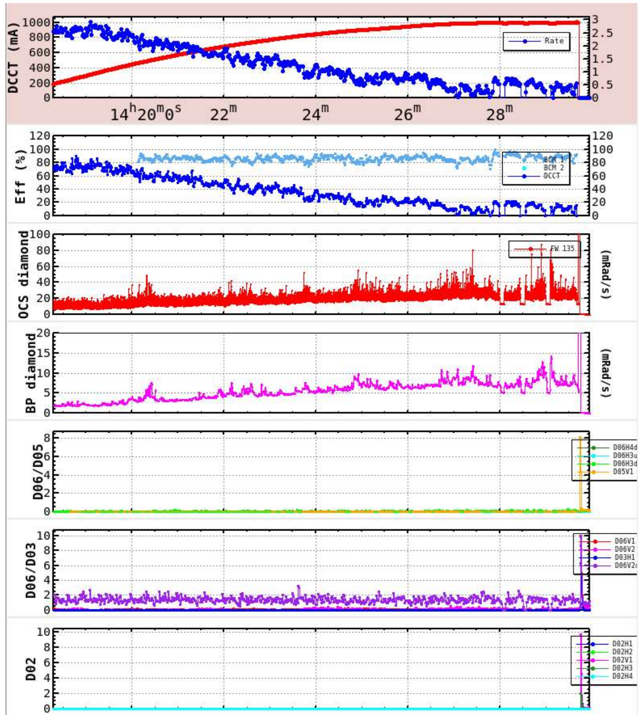








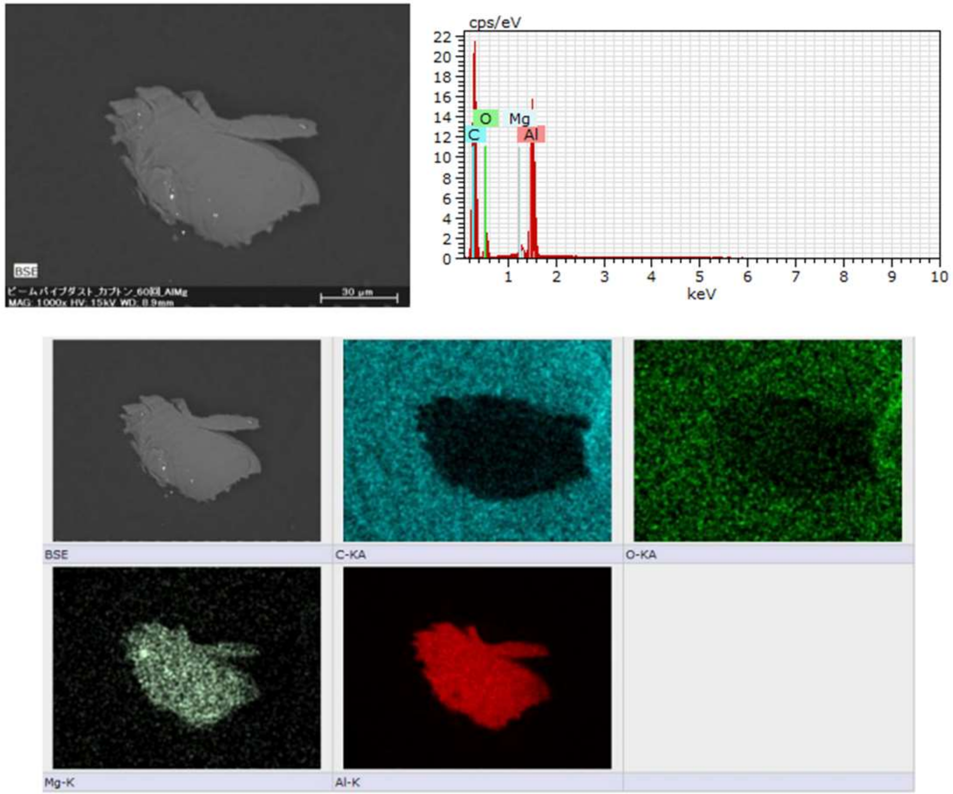




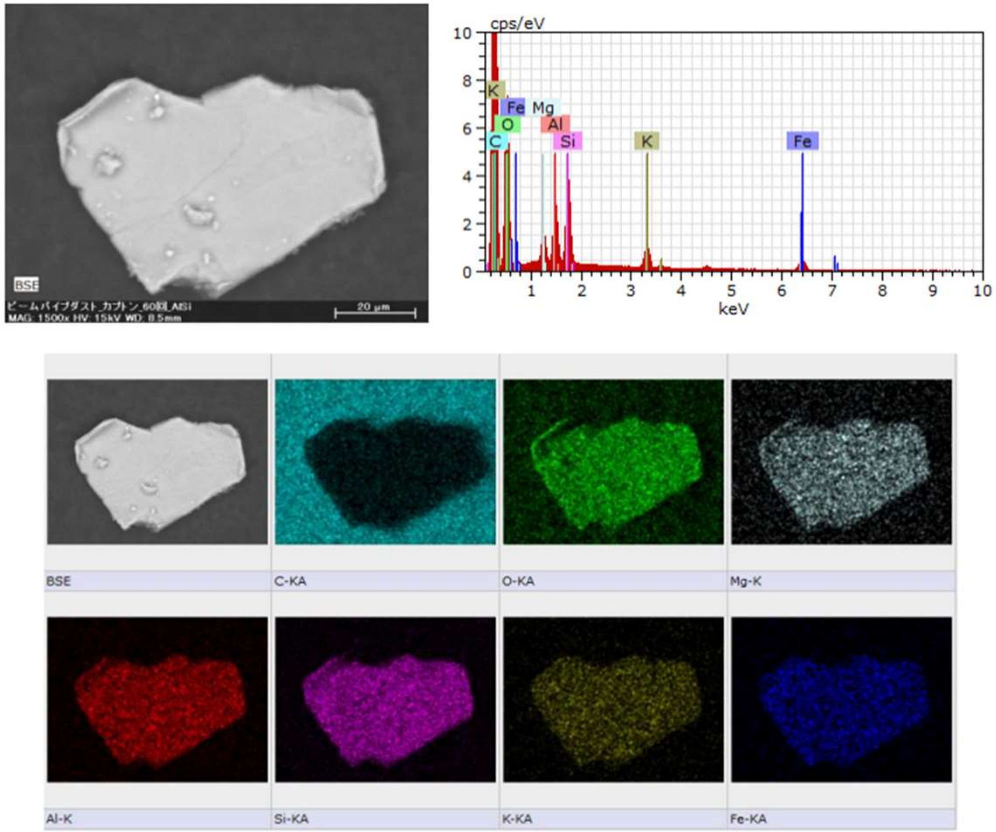
NLC建設のためのビームパイプ撤去作業の様子

NLC建設のためのビームパイプ撤去作業の様子

Component analysis of collected dust



図第 1 号：固体①（Al を含む固体を複数個確認）



図第 2 号：固体②（Si を含む固体を複数個確認）

Possible Reasons for SBL

- Equilibrium of tuners, piezo's parameter, LLRF, noise from transmitter, 50Hz filter of RF system could cause sudden beam loss. : measured @ BEPC II, DAFNE
  - RF system are monitored at each abort, and were not seen abnormal signal.
- Electron Cloud
  - SBL should be measured only in LER.→ SBL is also measured in the HER beam.
  - Curious behavior of the pressure in D06H3 collimator may suggest the formation of a discharge or electron cloud.
  - Simulations show that the electron density distribution changes with time and a maximum electron density is on the order of 1E13/m^3 to 1E14/m^3 → How this relates to SBL?
- Fireball : Measured @ RF cavity
  - The vacuum chamber is made of copper with low sublimation point and collimator head is made of tungsten or tantalum with high sublimation point.
  - → The situation has the potential for a fireball to be formed.
  - This fireball hypothesis could explain SBL (~μs) due to the fast plasma evolution (~100 ns at the fastest).

Candidate Reasons for SBL : Damage of vacuum component

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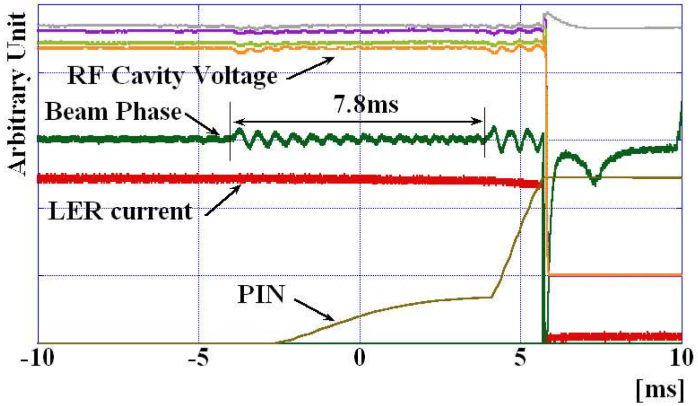
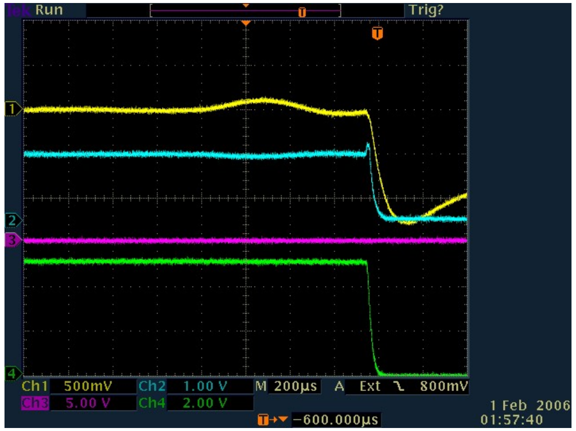
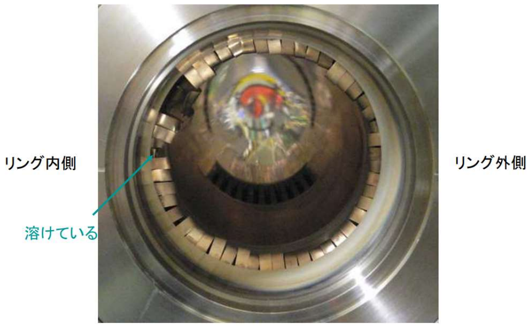
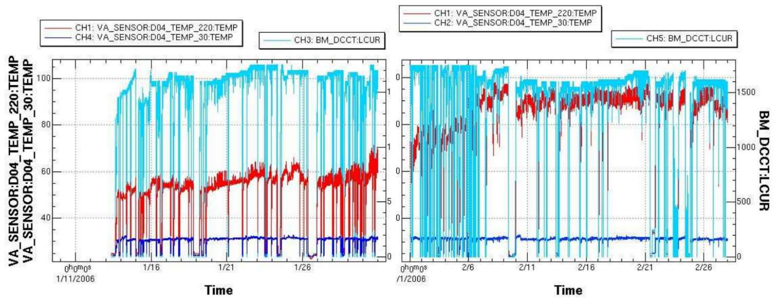




LERD04シケイン部ベローズ（内側）





(Y.Suetsugu)

Candidate Reasons for SBL : Interaction with Dust

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  - Beam aborts accompanied by local pressure bursts. → not observed the burst that causes it in SBL
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  - We are using the same thyratron for horizontal kicker. X
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  - Sinch the growth time of coupled bunch instability might be O(〜several 10 turns), our sbl was not caused by FB system problem. X
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