Sudden Beam Loss

The 26th KEKB Accelerator Review Committee

2022/12/14 H.Ikeda

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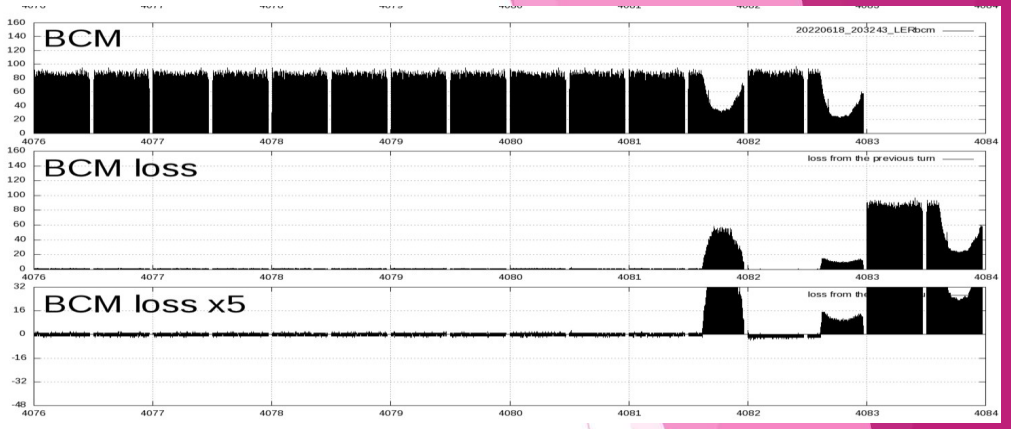
Motivation



The biggest goal of SuperKEKB is to increase luminosity, but one of the obstacles is sudden beam loss.

The cause of the sudden large beam loss is unclear.

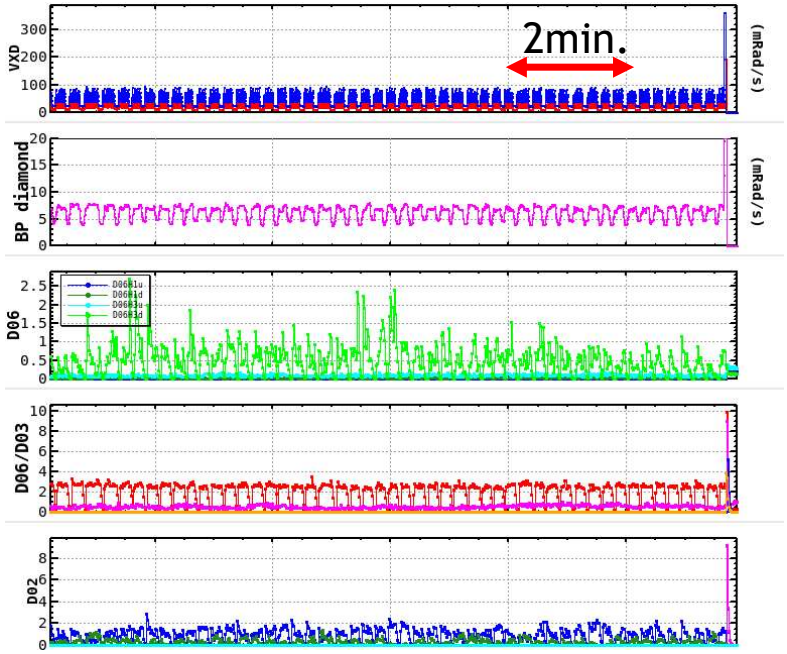
- Causes collimator (and other component)damage, QCS quench, Large B.G. to Belle-II.
- Cannot storage a large current since it causes beam abort.

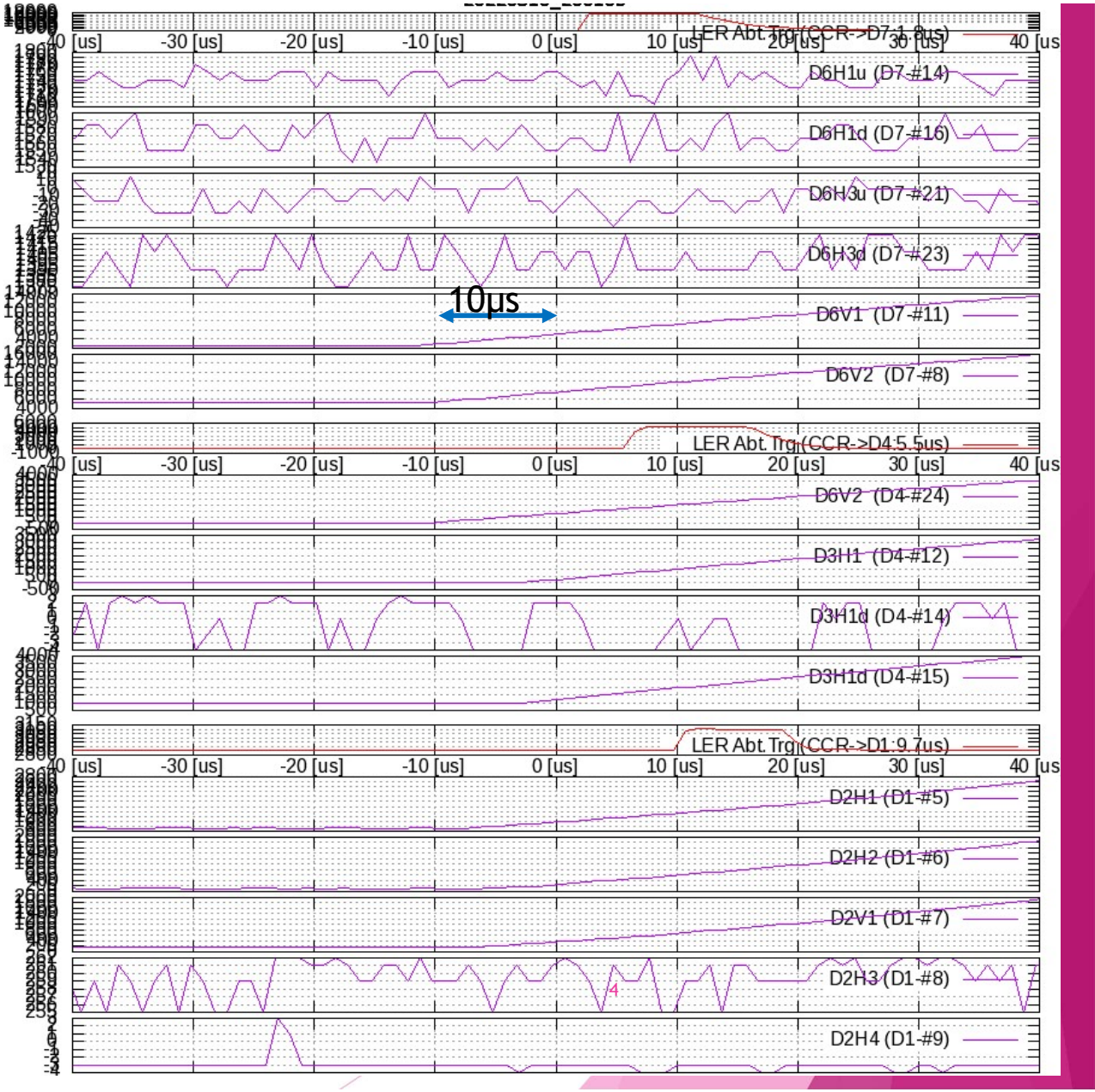
↓

Start the task force to investigate and resolve the cause of the sudden beam loss.

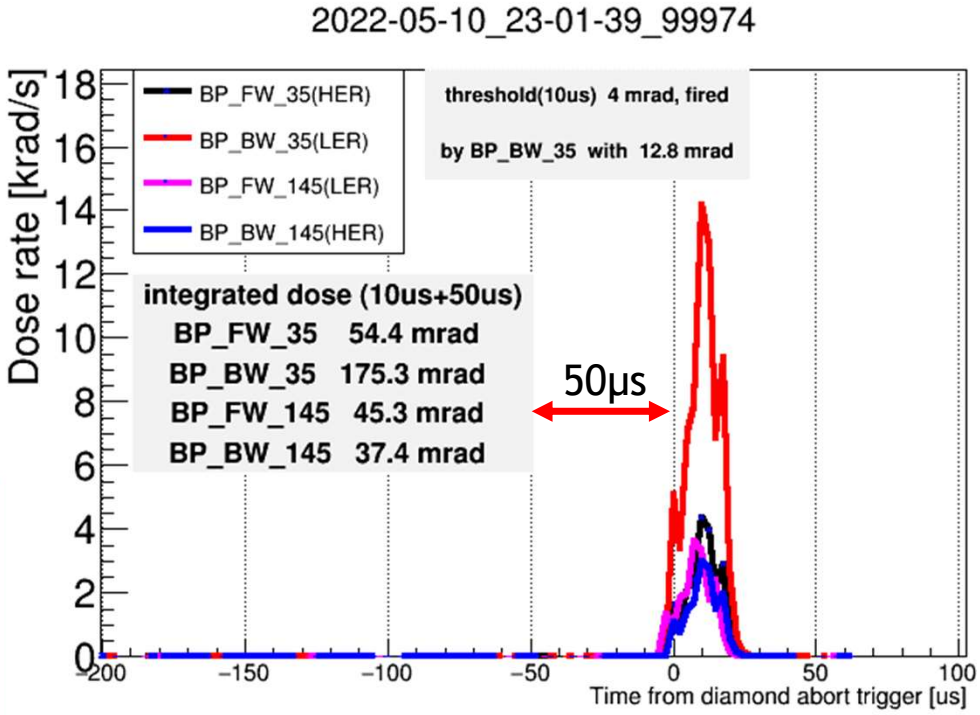
Observations : LM

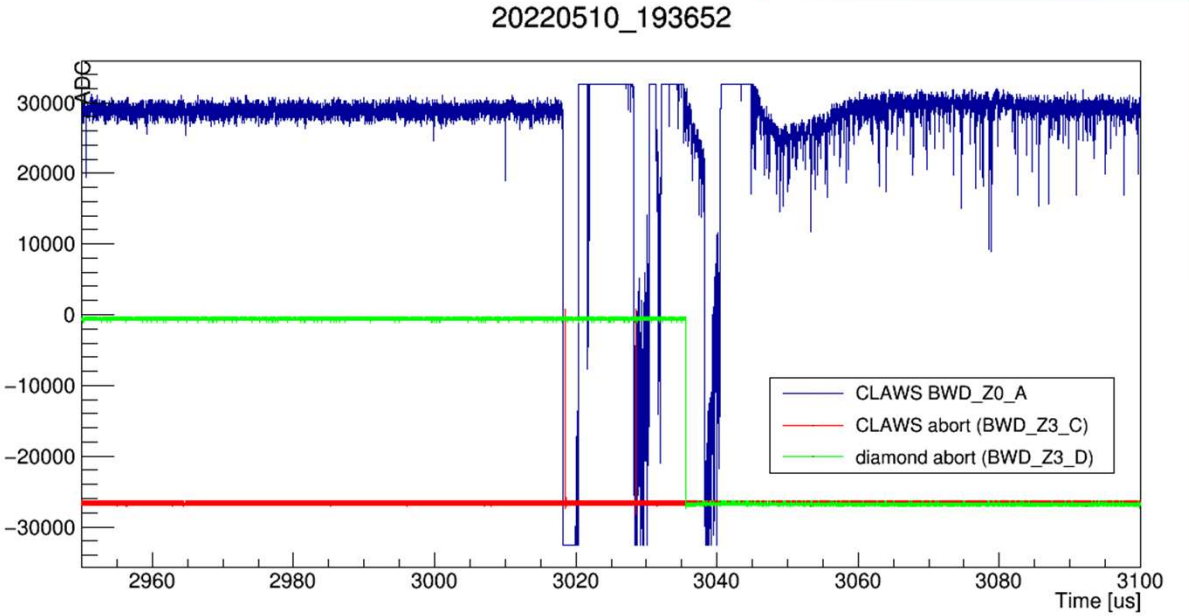
When we looked at the loss monitor when the abort occurred, which was thought to be caused by beam loss, beam loss looks started within one turn at the whole ring collimator part and Belle-II detector.





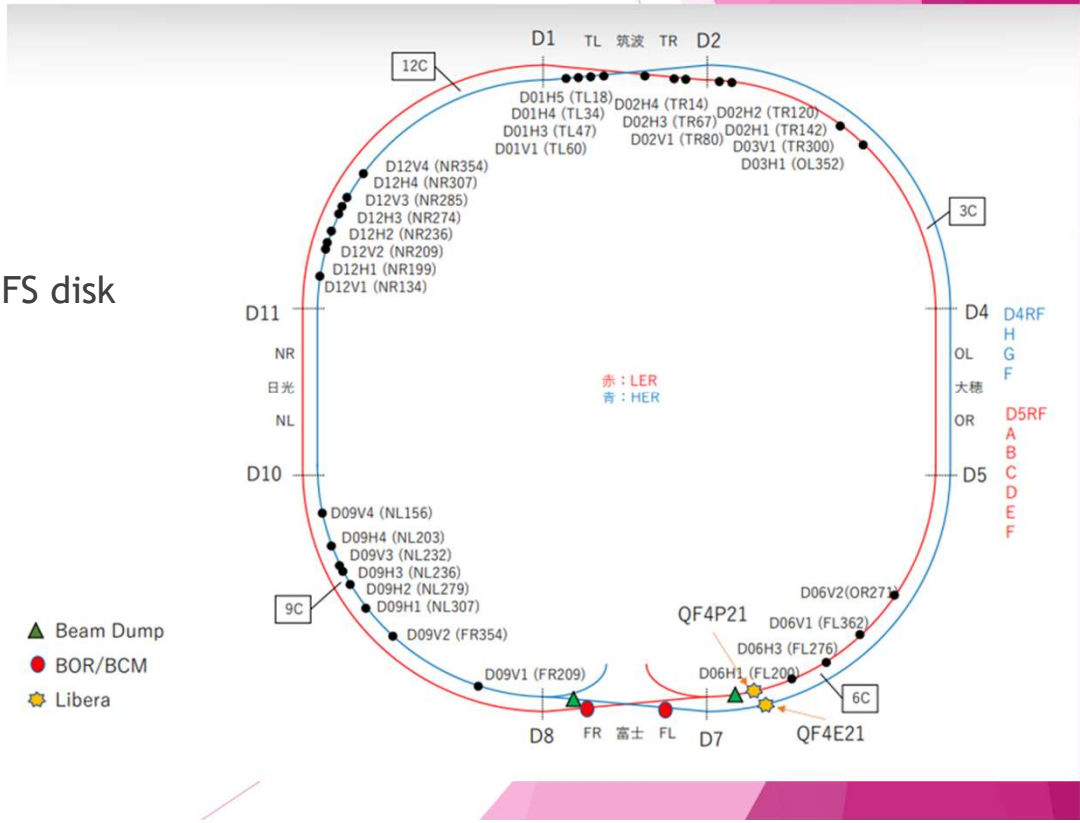
Observation : Belle dose





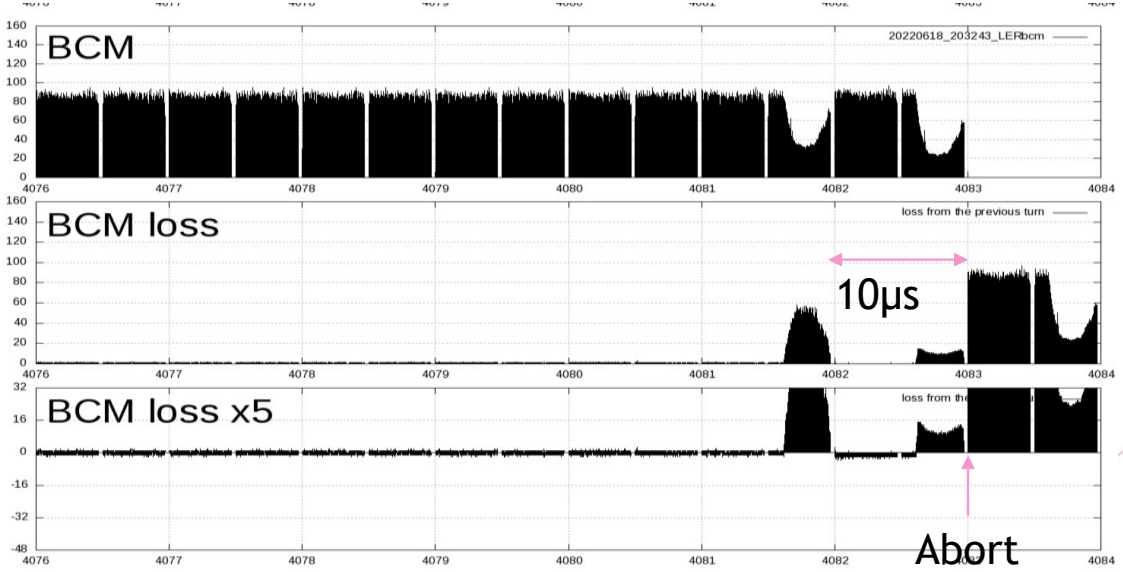
Observations：Bunch Oscillation Recorder (BOR)
Bunch Current Monitor (BCM)

- 18K10 ADC board
  - VME 2W form factor with BLT data transfer function
  - 8 bits resolution (MAX108 ADC)+Spartan6 FPGA card
  - 5120x4096 turns of ring memory, or 5120x1 (BCM)
  - 4.6s from 18k10（20M) to VME CPU, 1.4s from VME to NFS disk
  - stop acquisition with (quick) beam loss event (DCCT)
  - LER Horizontal Vertical Longitudinal
  - HER Horizontal Vertical Longitudinal
  - BCM HER LER (shared memory)
  - Long BCM HER LER(5120x4096)



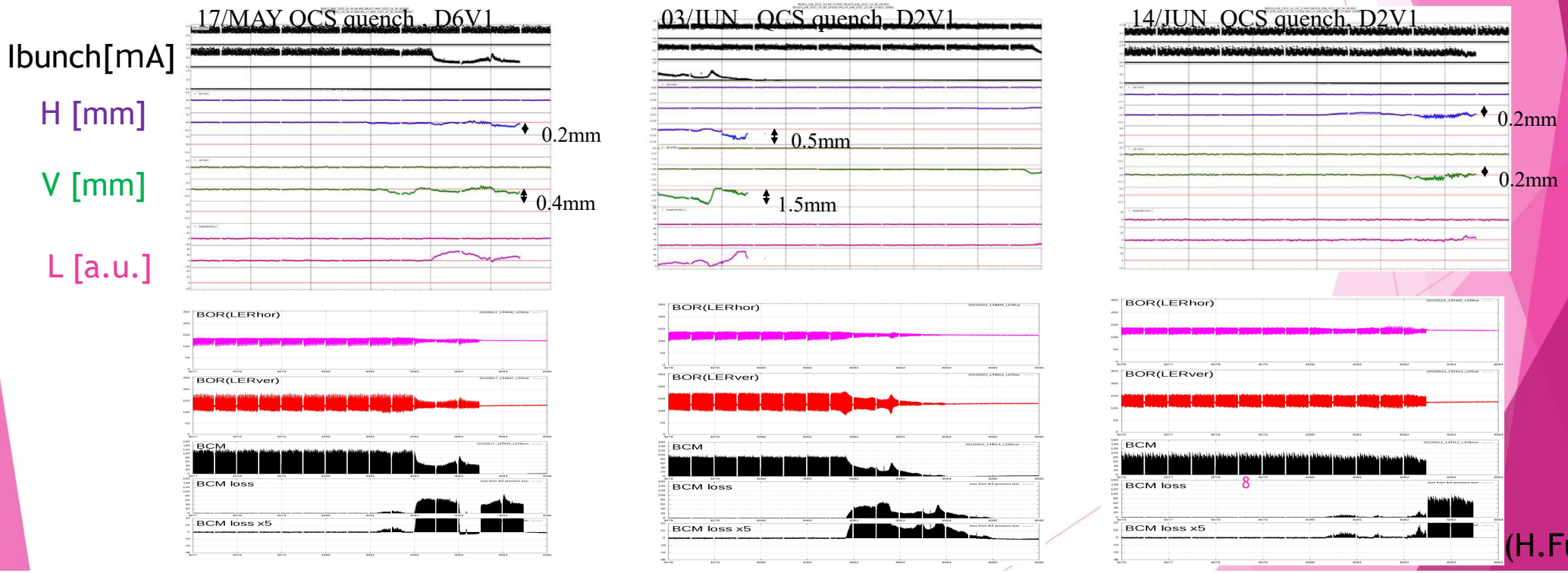
Observations : Bunch Current Monitor

- In order to investigate where in the train the beam loss started at the moment of beam loss, we recorded the bunch current 4096 turns before the abort trigger using feedback processors .
- The beam loss measured by the bunch current monitor (BCM) occurs suddenly at a certain turn.

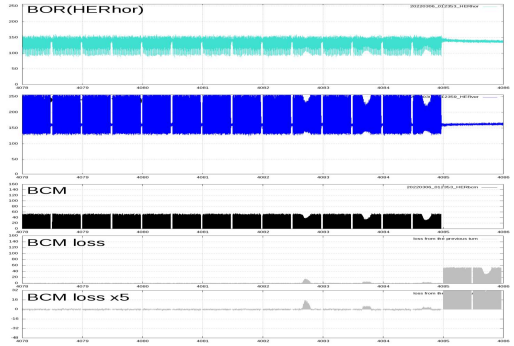


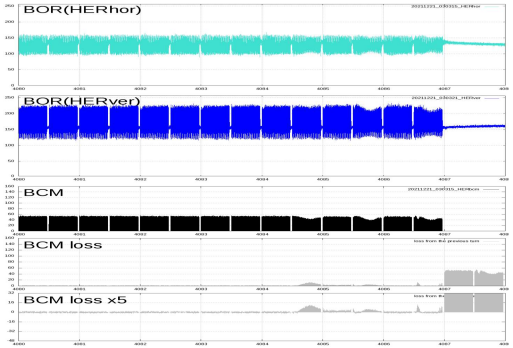
Observations : Bunch Oscillation Recorder

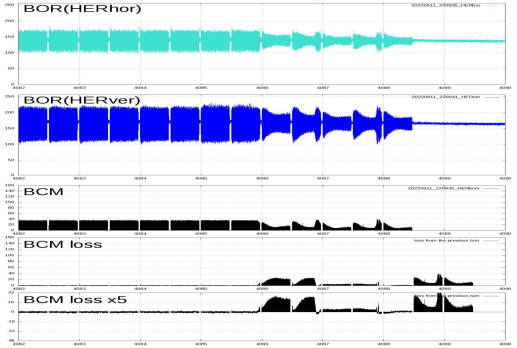
- The Bunch oscillation is measured 4096 turns before the abort and the orbit is calculated from the data.
  - The orbit changed small ～1mm@FB position

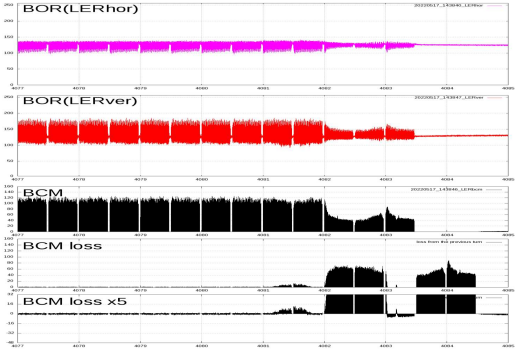


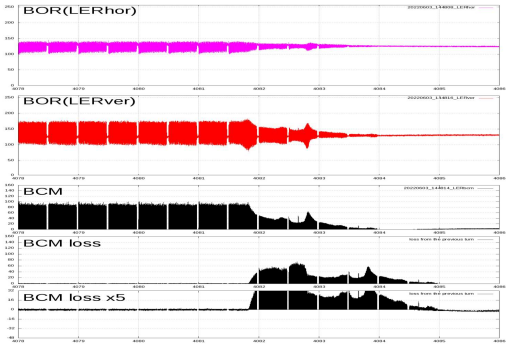
(H.Fukuma)

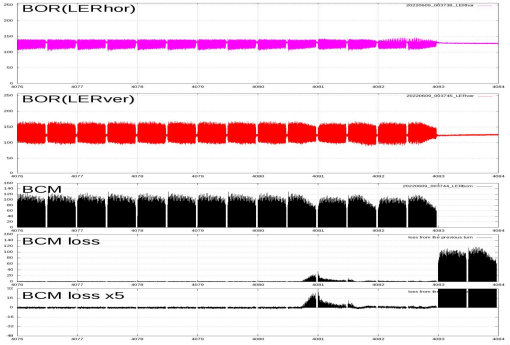








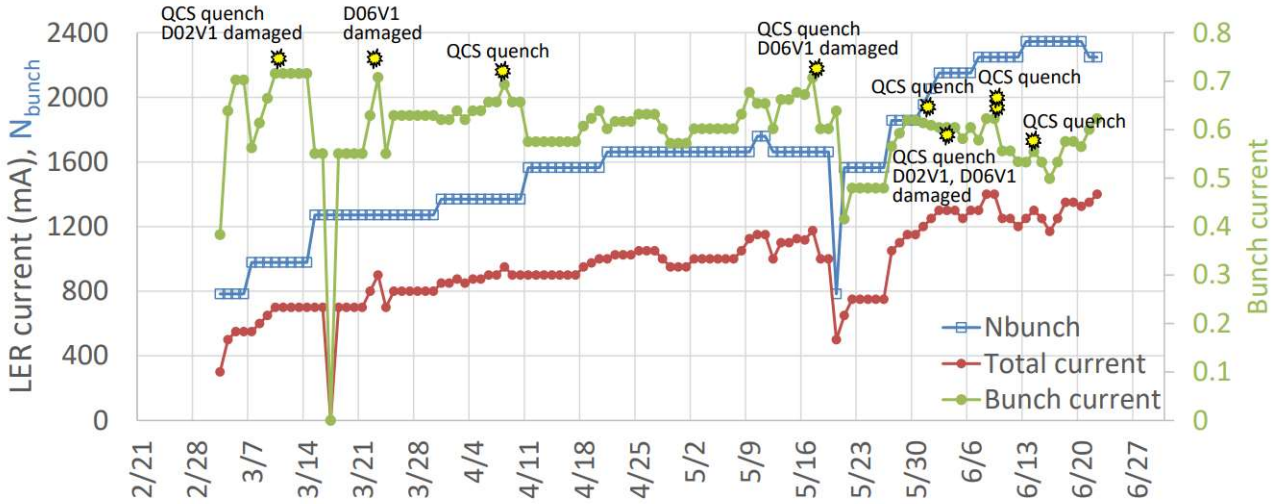




- Beam loss occurs in both HER and LER, but the damage to the hardware is particularly large when loss occurs in LER.
- We don't know if it will happen even with a single beam operation, low current beam because we haven't operated for a long time.

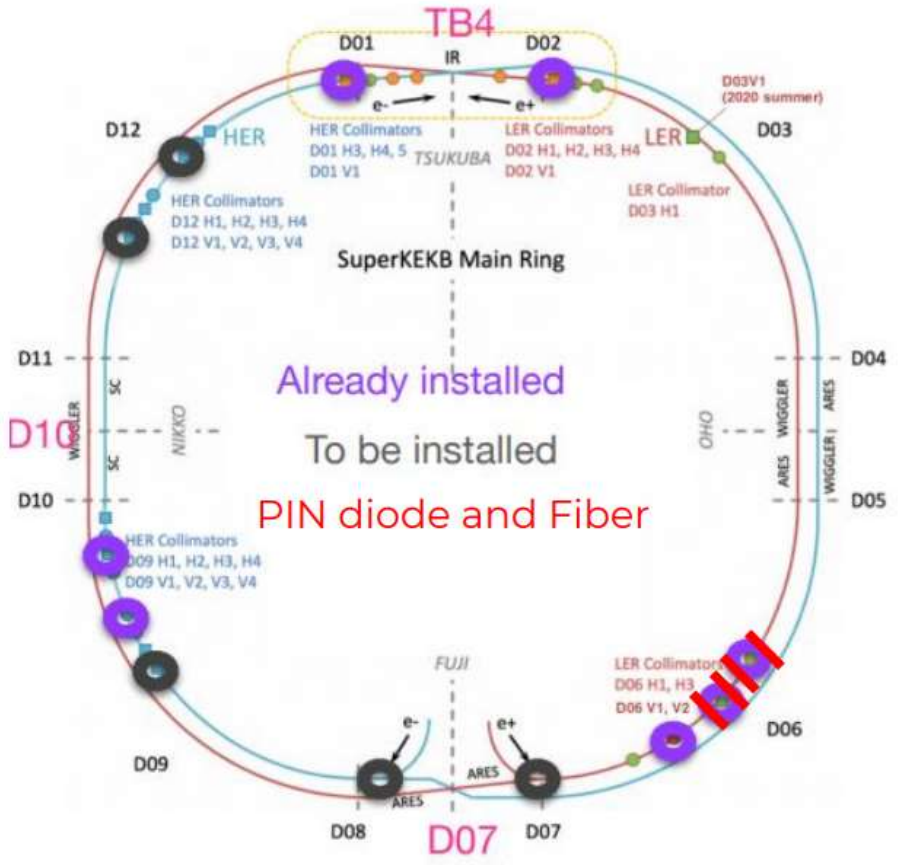
Observations : Bunch Current of Operation

- It is likely to occur when a certain bunch current is exceeded.
  - The first four accidents of LER beam loss in 2022 happened at $Ib \gtrsim 0.7$ mA/bunch within a day after increasing the beam current at each different Nbunch.
  - The threshold became somehow lower after the D06V1 damage on May 17.
  - It might be due to the D06V1 damage, different collimator configuration than usual to mitigate the beam background, or something else.



(K.Matsuoka)

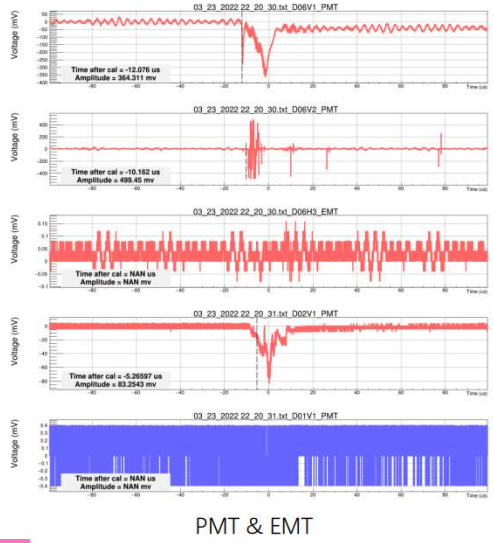
Observations : Beam Loss Timing

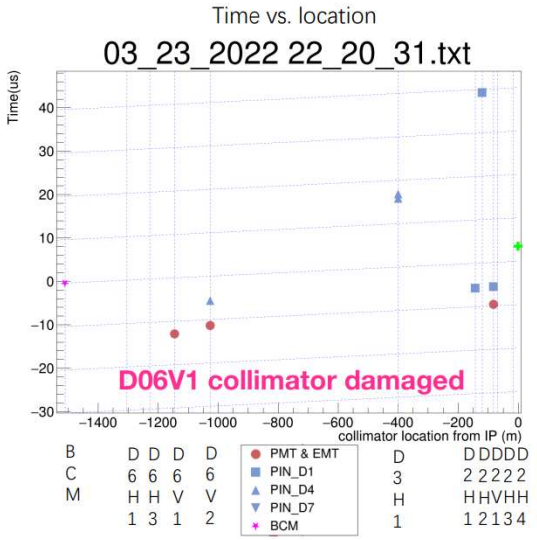


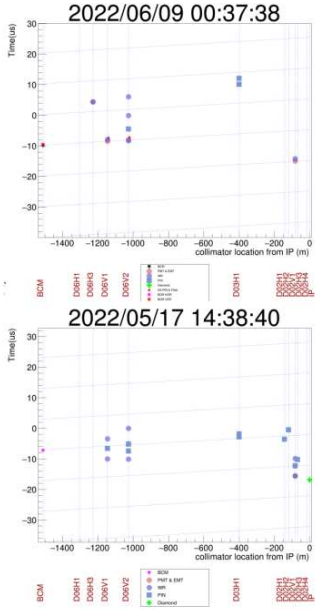
- In order to find out where in the ring the beam loss first started, we installed a loss monitor specialized for timing measurement inside the ring.
  - 7 beam loss sensors (CSI+PMT, EMT) installed near collimators
  - Data aquisition
    - WhiteRabbit (WR) : Distributed TDC system synchronized to GPS
    - Picoscope : ±1ms of abort trigger

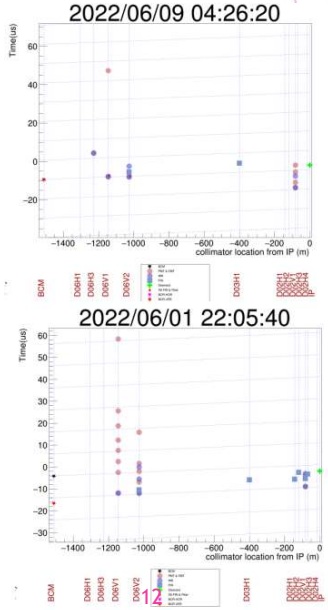
Observations : Beam Loss Timing

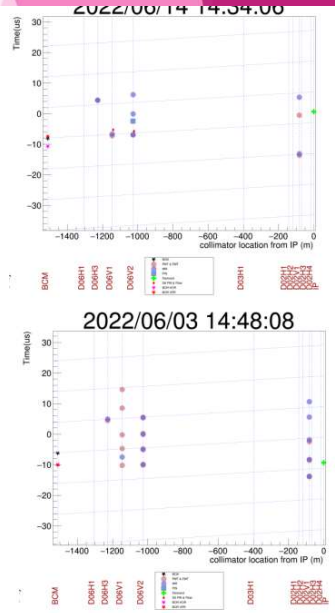
- Beam loss occurs in collimator & IR, and where it occurs first depends on collimator tuning .







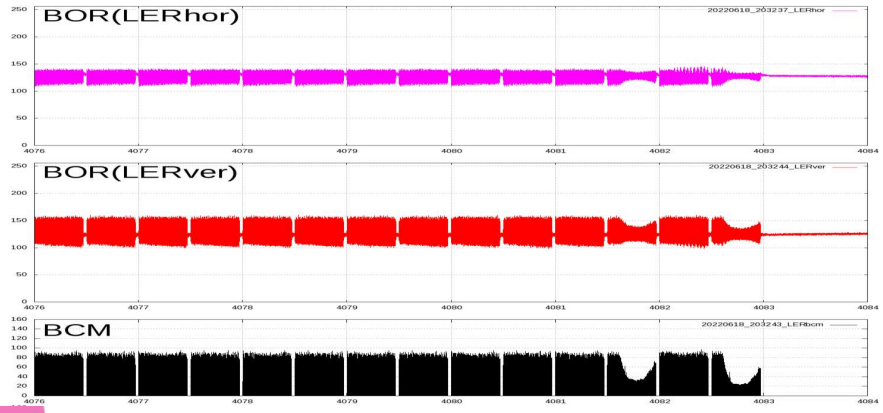


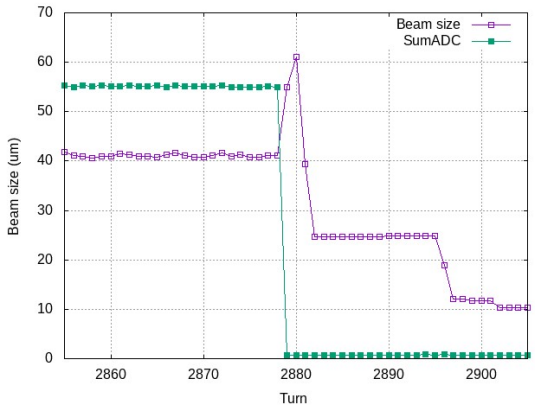


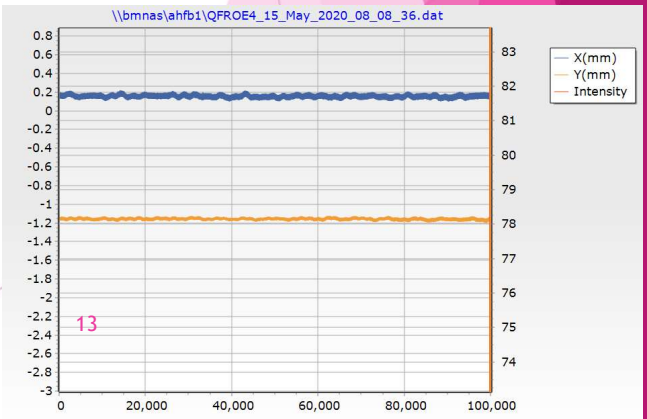
(Y.Liu)

Observations

- There are no signs before beam loss starting.
  - No small beam loss (beam loss monitor, BCM)
  - No oscillation (Bunch Oscillation Recorder (BOR))
  - No beam size change (X-ray monitor (XRM))
  - It is not clear if the orbit changed significantly.(Libera)

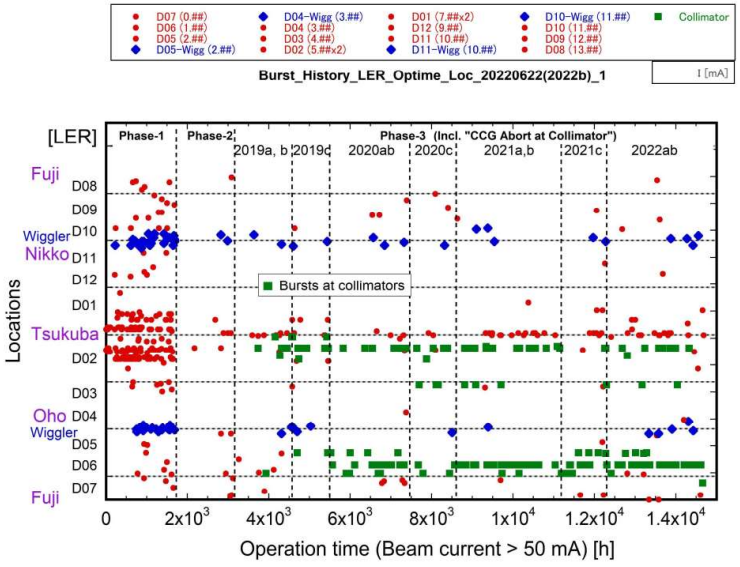


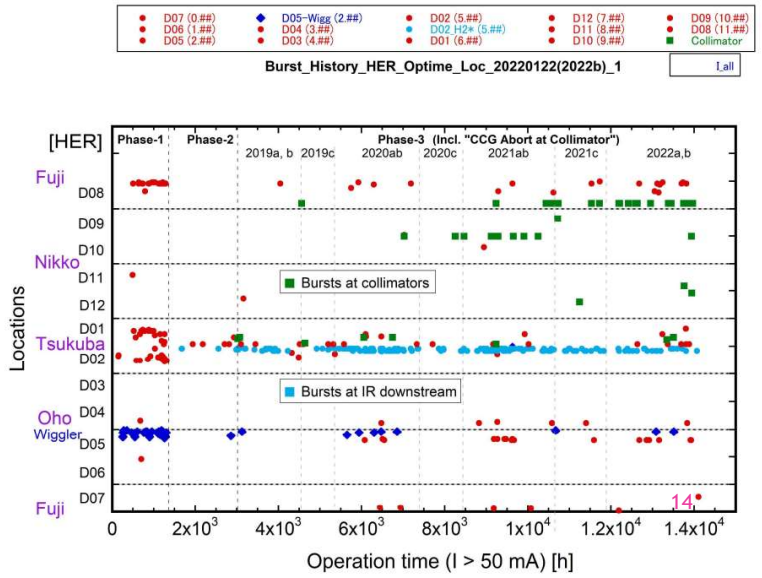




Observations : Vacuum

- Pressure bursts have been observed here and there, and it rarely occurs in the same place except in the collimator section. It may be the result, not the reason.

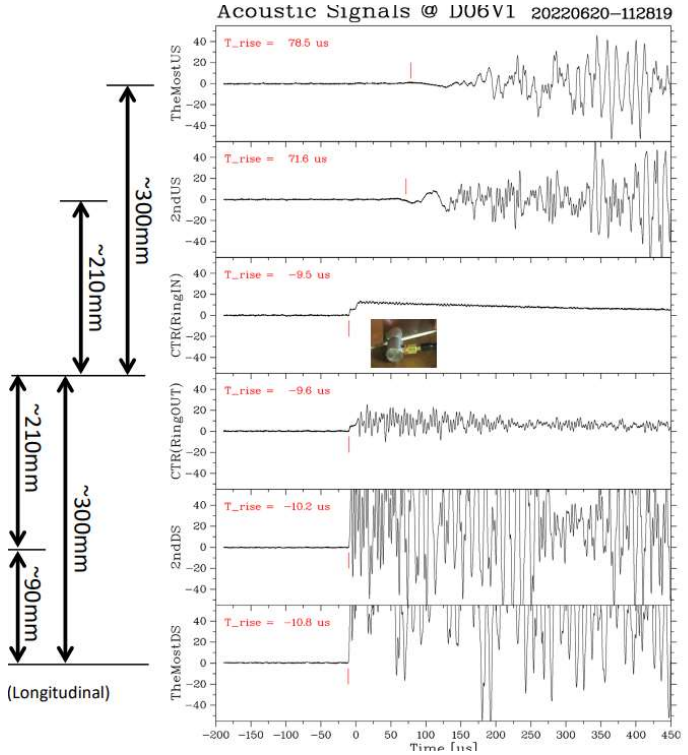


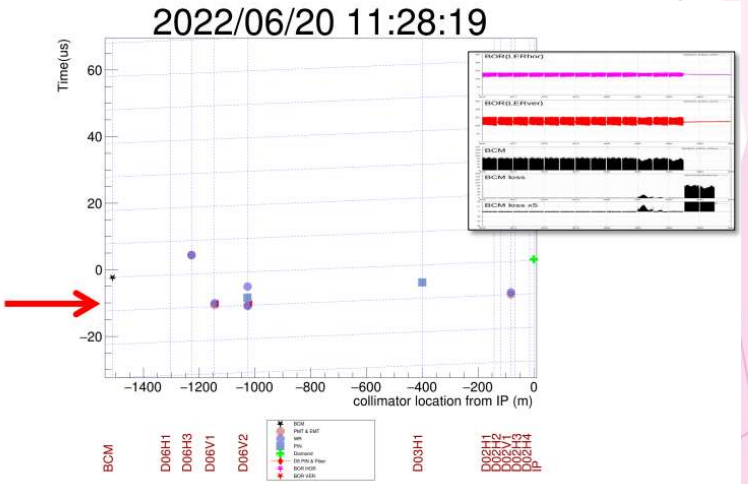


(Y.Suetsugu)

Observations : Acoustic waves

- Acoustic waves were detected at the same time with collimator beam loss.
  - We measure a few event before shutdown





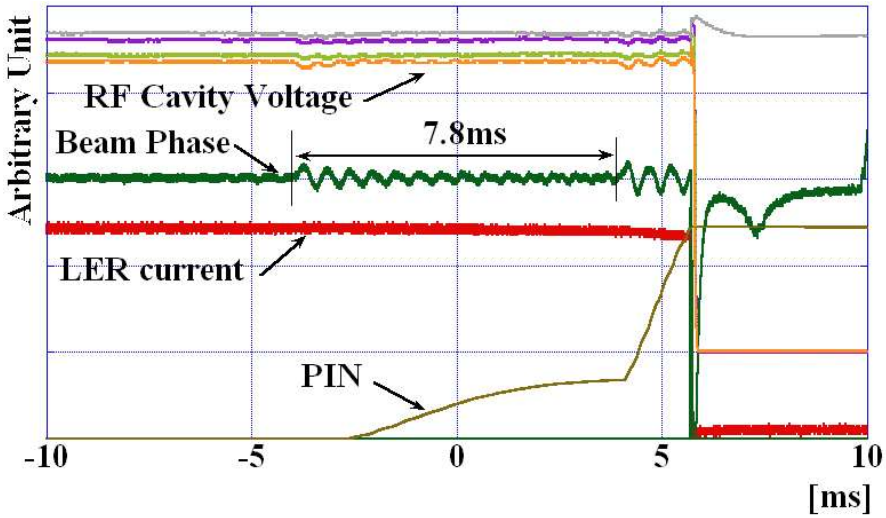
Velocity of acoustic longitudinal (transversal) wave in copper: 4.65 (2.26) mm/us

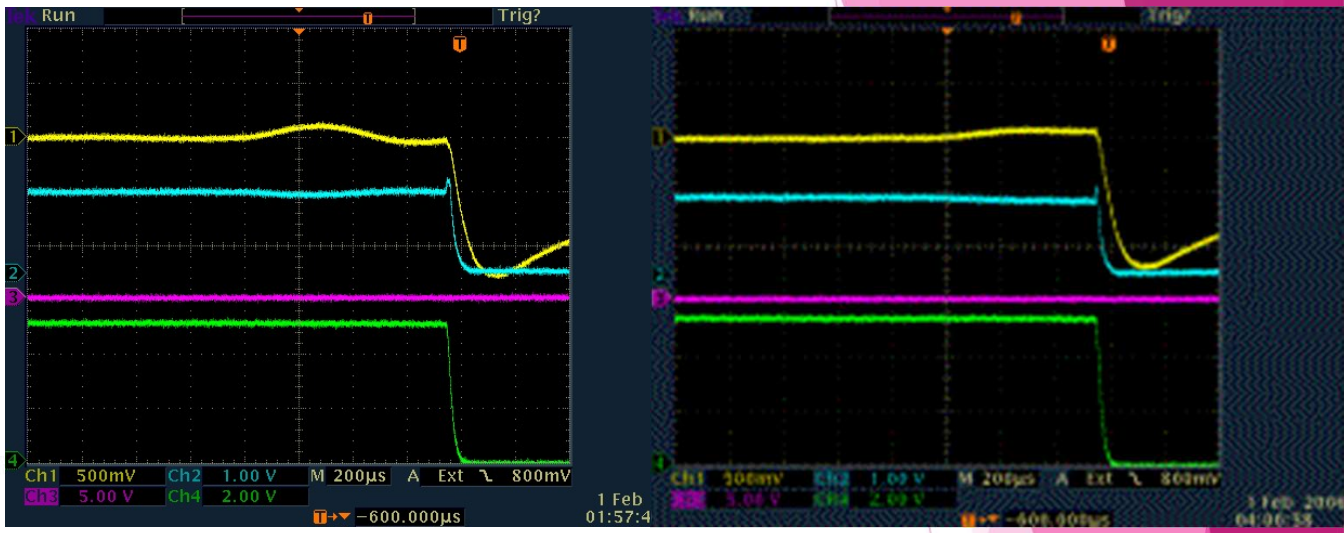
This data suggests that the particle shower produced at the collimator head generated widespread acoustic wave in the downstream of the head, which propagated upstream.

(T.Abe)

Candidate of the beam loss reason

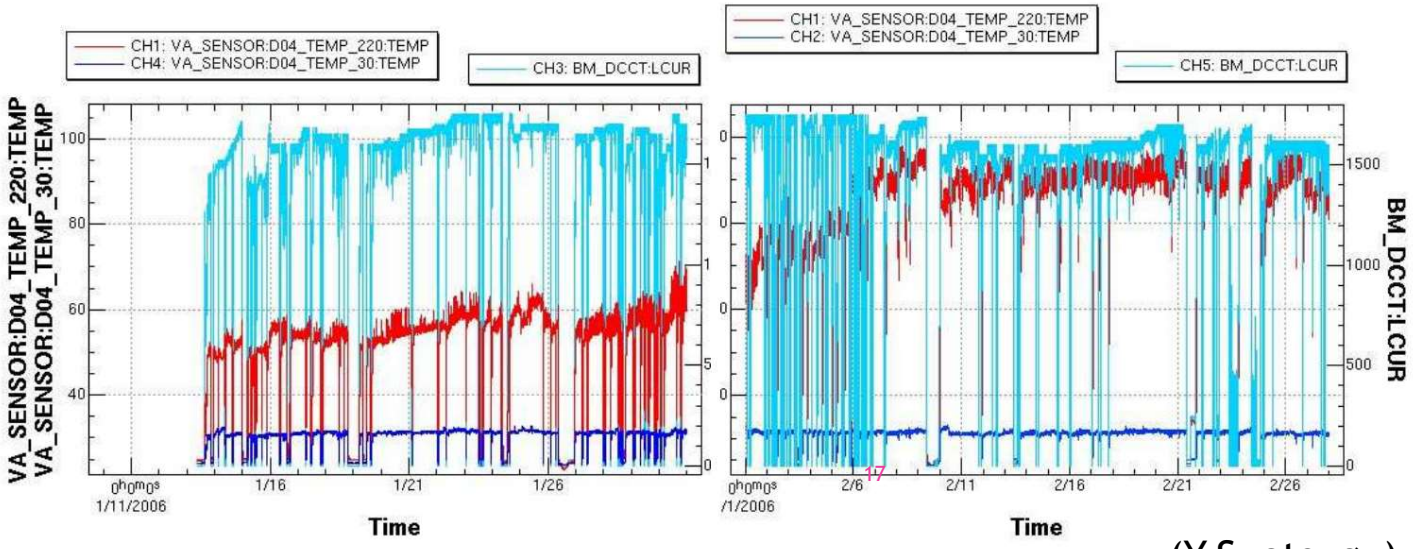
- Damage of vacuum component ： measured @ KEKB & PEP-II
  - phase changes (beam energy losses) had been observed ms ～ hundreds of μs before aborts.
    → not observed in SBL
  - abnormal temperature risings at bellows chambers had been observed and the catastrophic damages in the RF-finger had been confirmed.
- 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
  - Clean or hit the vacuum chamber to remove as much dust as possible and fixed the problem.
  - When the energy of the particles deviates greatly, the loss occurs in the horizontal collimator, so it may be possible to find out something by examining the conditions that the loss occurs in the vertical collimator in more detail.





LERD04シケイン部ベローズ（内側）

(Y.Suetsugu)



(Y.Suetsugu)

Candidate of the beam loss reason

- 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.
- 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.

Candidate of the beam loss reason

- Electron cloud effect in collimator
  - In this case, SBL should be measured at LER only, but HER beam also lost.
  - Looking at the pressure, D06H3 shows strange behavior. An electrical discharge or an electron cloud (or rather, multipacting) may be occurring.
    - But no pressure burst was observed at the timing of SBL
  - Simulation of EC growth is on going.
    - The electron density depends on pressure, secondary electron emission rate, gap spacing, bunch spacing, the incident electron energy that gives the maximum SEY, the bunch current, etc.
    - The electron density is on the order of 1E13-1E14 m^-3 at the highest with general (ordinary) parameters.
    - Not sure how this relates to SBL.
  - If there is a possibility that electron cloud in the collimators can cause the sudden beam loss (under investigating), we may put solenoid coils around them. (T.Ishibashi)

Candidate of the beam loss reason

- Fireball
  - Breakdown triggering mechanism of the RF cavity (after conditioning).
  - Necessary environmental conditions for fireball breakdown
    - A metal with a high and low sublimation point coexist in the same place

Sublimation point in ultrahigh vacuum

	昇華点 [℃] @ 2 x 10^{-7} Pa (in SuperKEKBコリメータ)
W	2018
Ta	1875
Graphite	1587
Mo	1498
Ti	1010
Au	767
Cu	679
Al	649
Ag	[illegible]

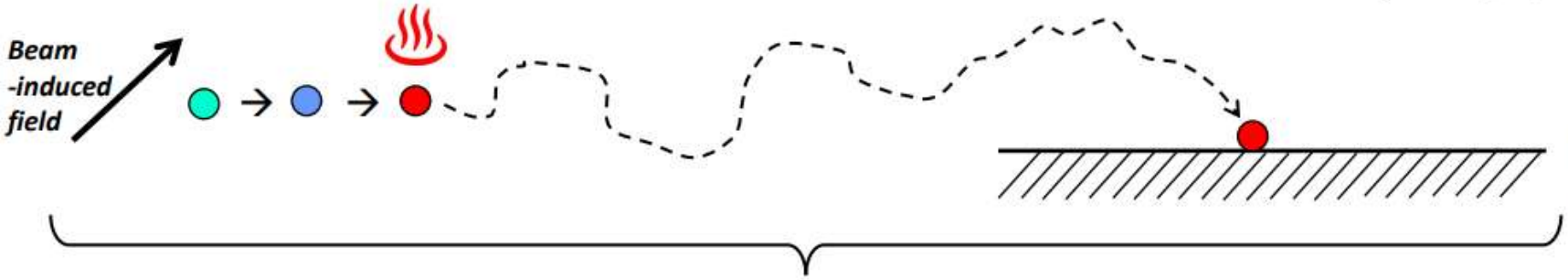
Data from https://www.iap.tuwien.ac.at/www/surface/vapor_pressure

Physical process of the "Fireball" hypothesis, leading to fast beam loss

① A microparticle with a high sublimation point is heated by the beam-induced field.

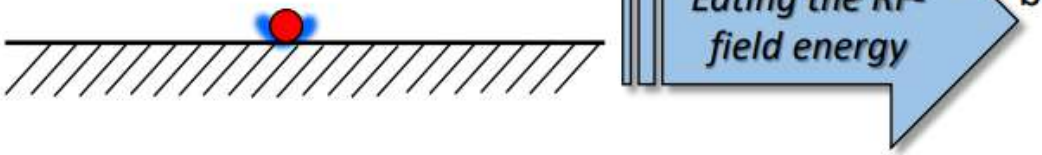
➔ **Fireball**

② The fireball touches some metal surface with a low sublimation point (e.g. copper).

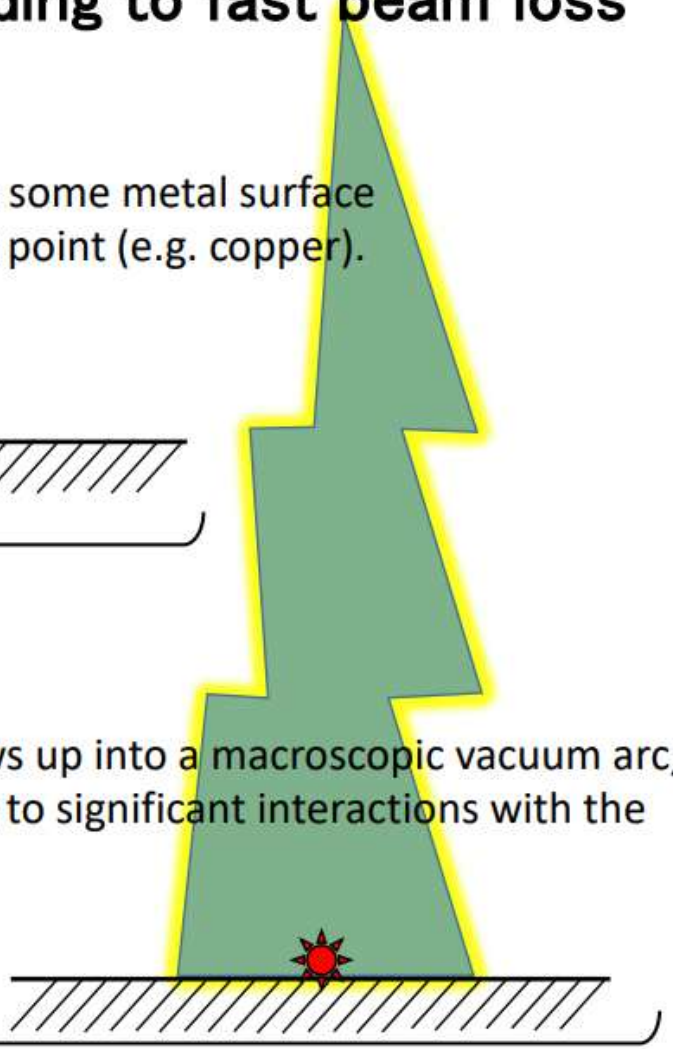


Order of ~s or longer

③ Plasma is generated around the fireball.



④ The plasma grows up into a macroscopic vacuum arc, possibly leading to significant interactions with the beam particles.



Order of ~100 ns at the fastest

(T. Abe)

Future plans

Increase the number of monitors.

- Add new loss monitor for timing analysis and abort trigger
- Add simplified BOR for another place on ring
  - We tried at previous run, but position resolution was not good.
  - Expected much higher resolution on X, Y detection.
  - Put them to two positions with the phase advance roughly 90 deg in order to check the orbit.
- Setup acoustic sensors to most of LER collimator.
- Check the temperature of vacuum component

Assuming the fireball hypothesis is correct,

- Coat the surface of the LER collimator with copper when viewed from the vacuum side, all low sublimation metals.
- In the future, we may consider applying a high sublimation point carbon or tungsten coating on the copper surface around the collimator head.

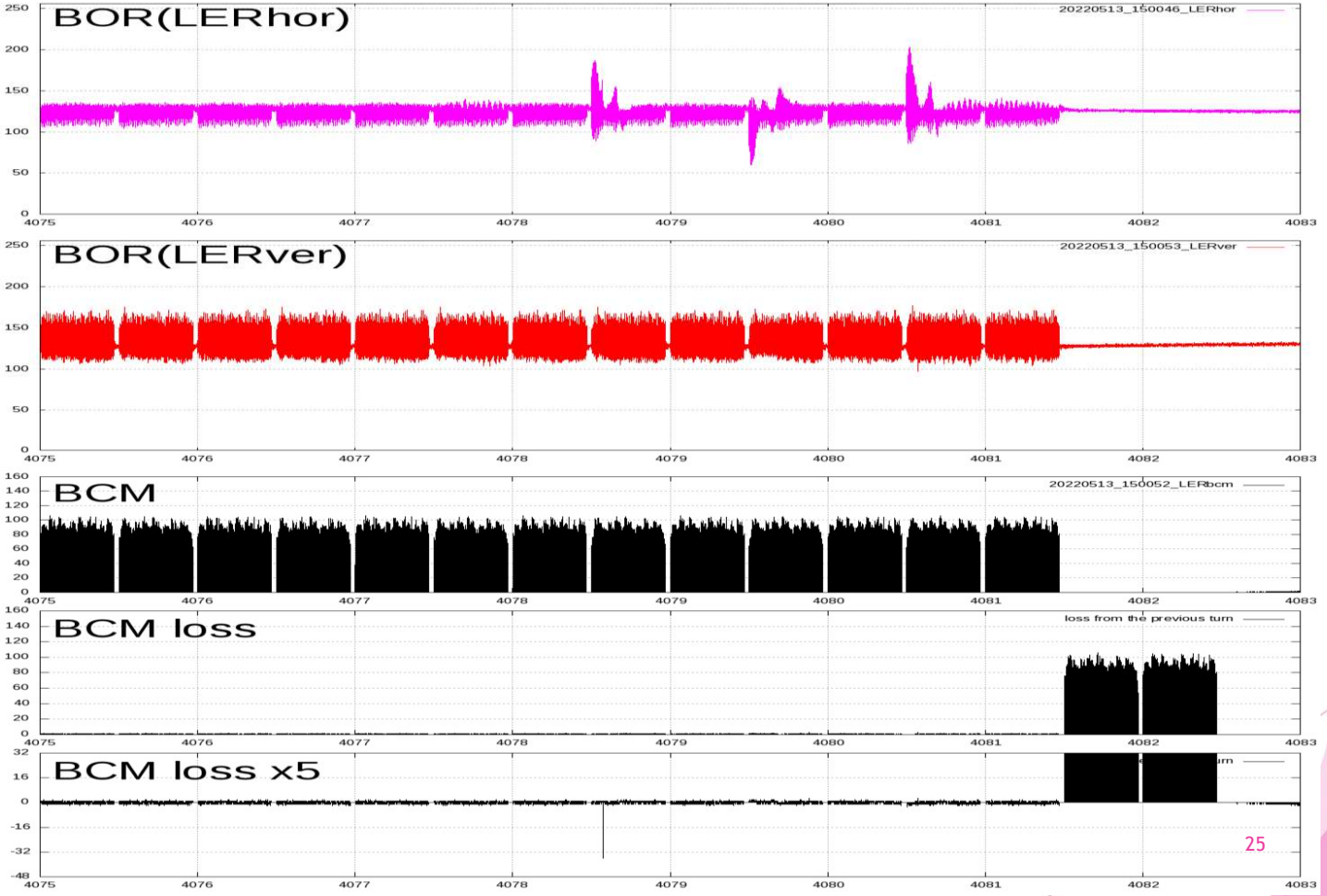
Simulations for each hypothesis are also underway.

Summary

- One of the obstacles for luminosity increasing is sudden beam loss and the cause of the beam loss is still unclear.
  - We have been investigating with Loss Monitor, etc., and have been able to find the point where the loss started, but no phenomena that clarify the cause have been found.
  - Started the international task force to investigate and resolve the cause of the sudden beam loss.
- So far, the fireball hypothesis is the dominant hypothesis to explain SBL.
- In order to collect the information, we are working to improve monitors, and also working to suppress the fireball hypothesis if it is correct.

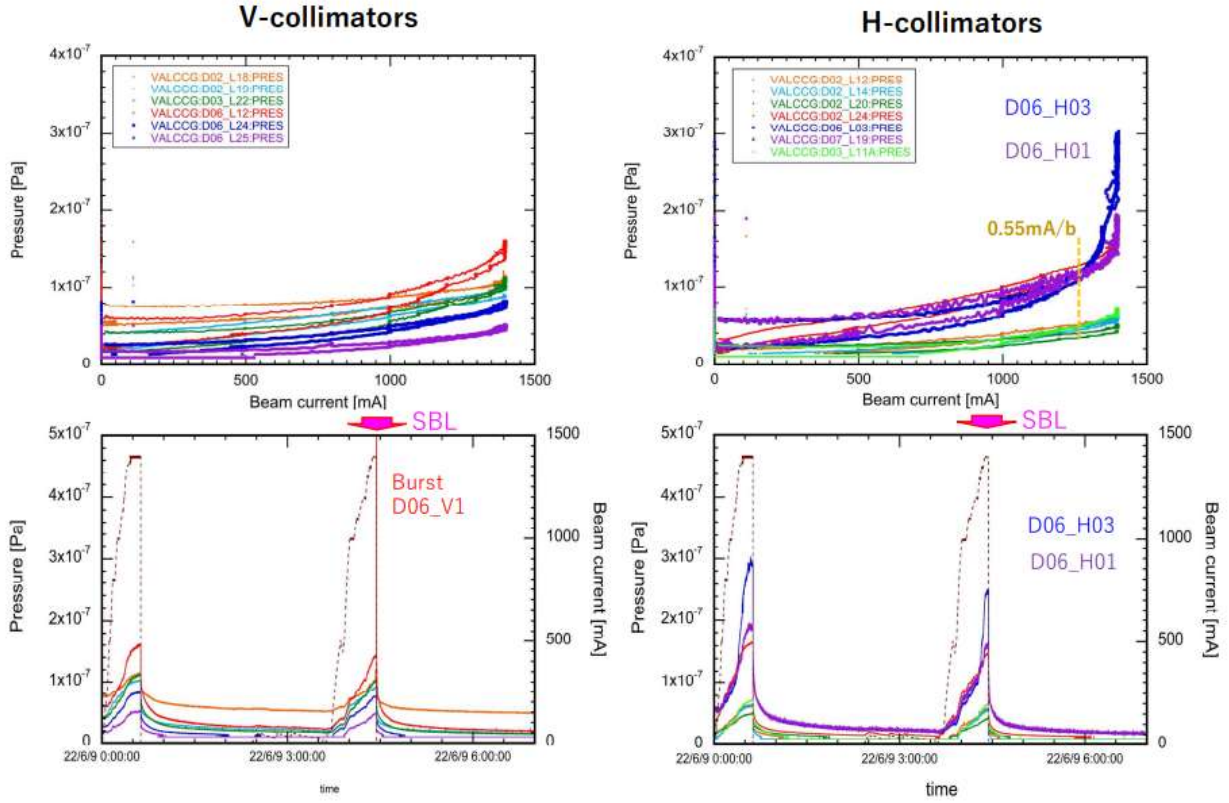
backup

Injection related abort : BOR & BCM



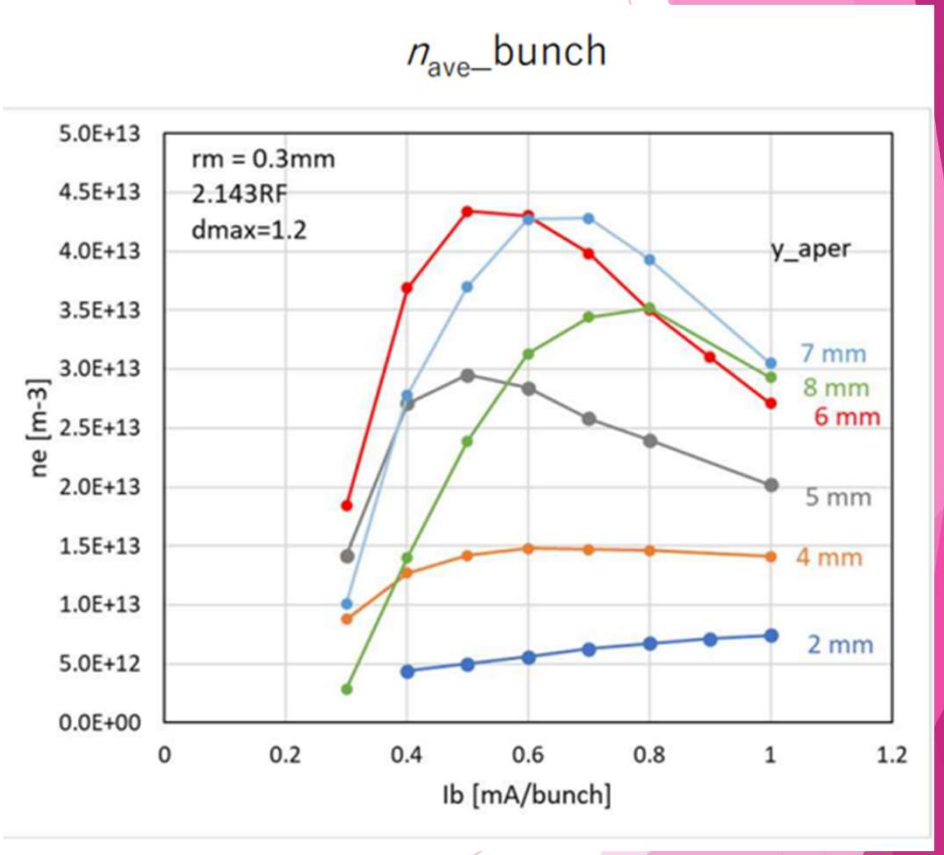
Pressure behaviors

(a) 2022/6/9 0:00~7:00
SBL at 6/9 04:26
Nb=2249
QCS quench

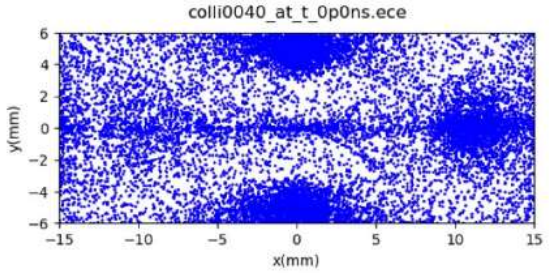


(Y. Suetsugu)

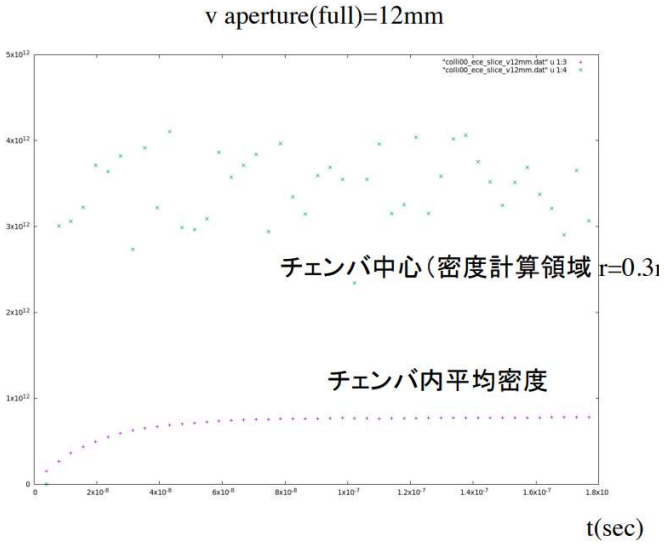
- Simulation using PyECLOUD (2D) (preliminary)
  - The bunch current that gives the maximum ηe changes with y_aperture.
    - The larger the aperture, the higher the bunch current.



(Y.Suetsugu)



t=4nsでの電子密度



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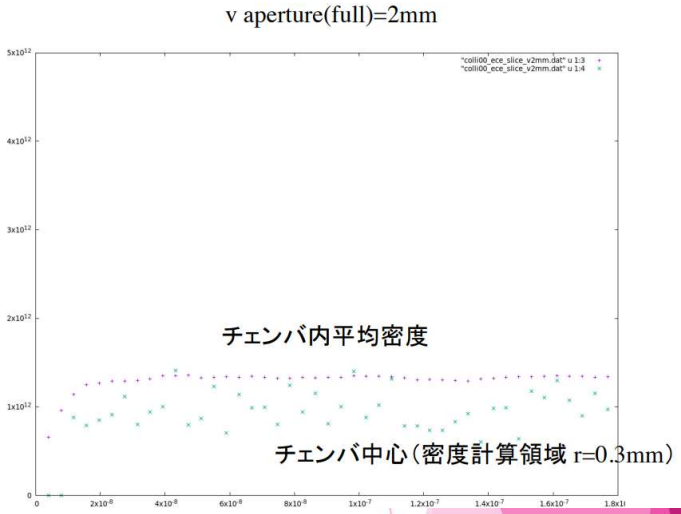

- Calculation of electron cloud in collimator by modified version of CLOUDLAND (preliminary)
- Electrons gather near walls.
- At t=4ns, the electron density at the center of the chamber is about 3.5 times larger than the 2mm case.

(H. Fukuma)