[WEPAB359]

REPORT ON COLLIMATOR DAMAGED EVENT IN SuperKEKB

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INTRODUCTION

- ***Collimator jaws for SuperKEKB were installed to sup-press the background noise (BG) in a particle detector complex named Belle II. The collimators could reduce the BG when the collimator was closed [1]. However, in high-current (>500 mA) operations, the jaws become occasionally damaged by hitting abnormal beams. This problem occurs with a low frequency of once in a commissioning period (2–6 months), but has significant con-sequences, because high voltage cannot be applied on to the detectors in Belle II sometimes due to high BG. The cause of, which occurred this event, has not been clearly identified yet.***
  - The event of the damage jaw triggered by an abnormal beam hitting occurred nine times (LER: 8, HER: 1) to date (5/9/2021). All the damaged jaws were in vertical collimators.

EVENT OF DAMAGED JAW

Overview

- The vertical collimators are the point of the smallest aperture in the ring to prevent QCS quenching and depress BG. The jaw has a tungsten (or tantalum) block as the tip. The jaws damaged by the abnormal beam hitting are shown in Fig. 1.

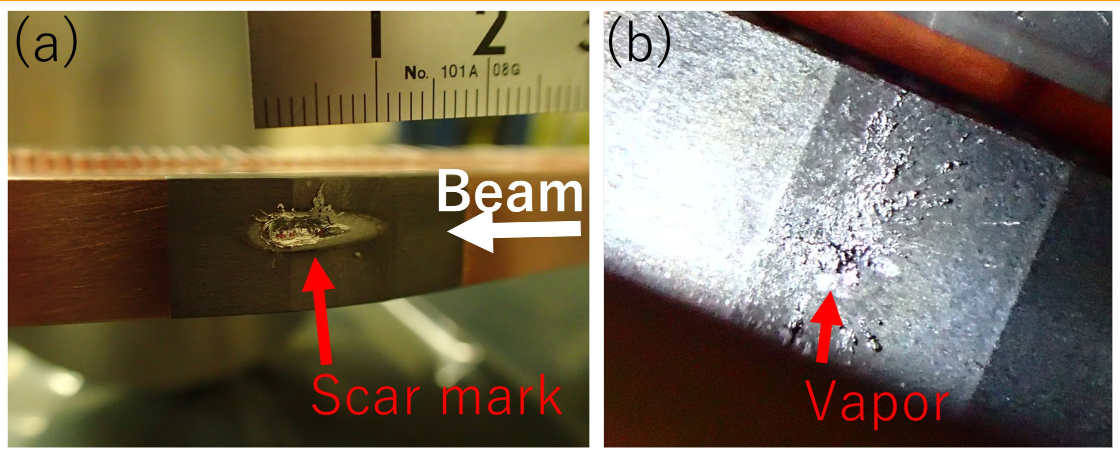

Figure 1: (a) Damaged jaw, (b) protrusion by vapor deposition on the opposite side of the damaged jaw.

Effect of the event of damaged jaw

- The peak value of the BG after this event was **200 times higher** than that before it(Fig. 2).
- When a jaw damage event occurred, a large beam loss was observed in Belle II. The soundness of the DEPFET pixel detector (PXD) in Belle II before and after the jaw was damaged is shown in Fig. 3.

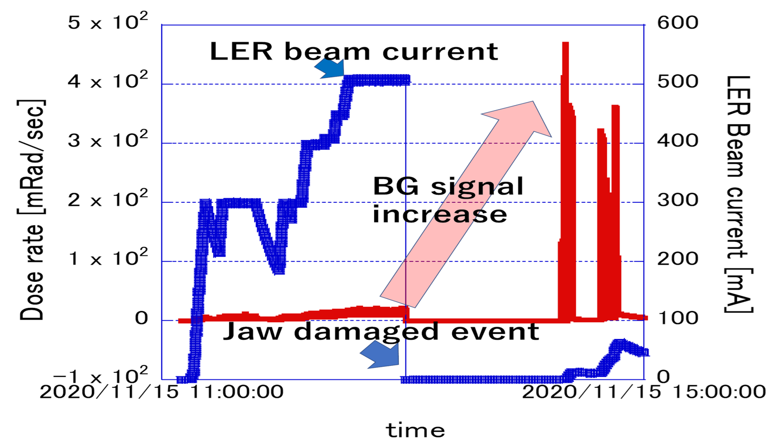

Figure 2: BG signal before and after the event of the damaged jaw.

Cause of the jaw damage event

- In this event, the pressure burst near the collimator (blue line) with the beam abort is shown in Fig. 4(a). In addition, a smaller pressure burst (green line in Fig. 4(a)) was observed at a location different from the location at which the collimator was installed. It is believed that the pressure burst at the green line was caused by the beam interacting with the dust. We consider dust to be the cause of these events because of two reasons.
- The first reason is that the beam operation was hindered owing to the influence of dust in the LER during Phase-1. This phenomenon caused by dust during Phase-1 was observed as the local pressure bursts accompanying beam losses. The longitudinal grooves in the beam pipes for the dipole magnets, which counteract the electron cloud effect, are likely to trap the dust particles during the manufacturing and installation processes. We believe that the pressure bursts in Phase-1 were due to the interaction between the circulating beam and the falling dust particles, which were captured in the groove on the upper surface. To demonstrate the cause of the dust particles, the pressure bursts and simultaneous beam loss were reproduced using the knocker. The probability of reproduction of the pressure bursts accompanying beam losses in this test was 100%.
- The frequency of pressure bursts increased when the beam current exceeded the value, whereas it tended to decrease when the beam current remained almost constant(Fig. 4(b)). Thus, we decided to perform a normal physical run just below the maximum beam current.
- We describe the second reason. We illustrate the data obtained using the bunch oscillation recorder (BOR) (Fig. 5), where the horizontal axis represents the bucket number, and the vertical axis represents the product of the beam intensity and vertical beam position. In conclusion, when this event occurred, **there was no sign of oscillation indicating beam instability, and the data indicated that the intensity of the part of the bunch train suddenly decreased a few turns before the abort.** We consider that part of the bunch train was abnormal upon interacting with the dust particles.

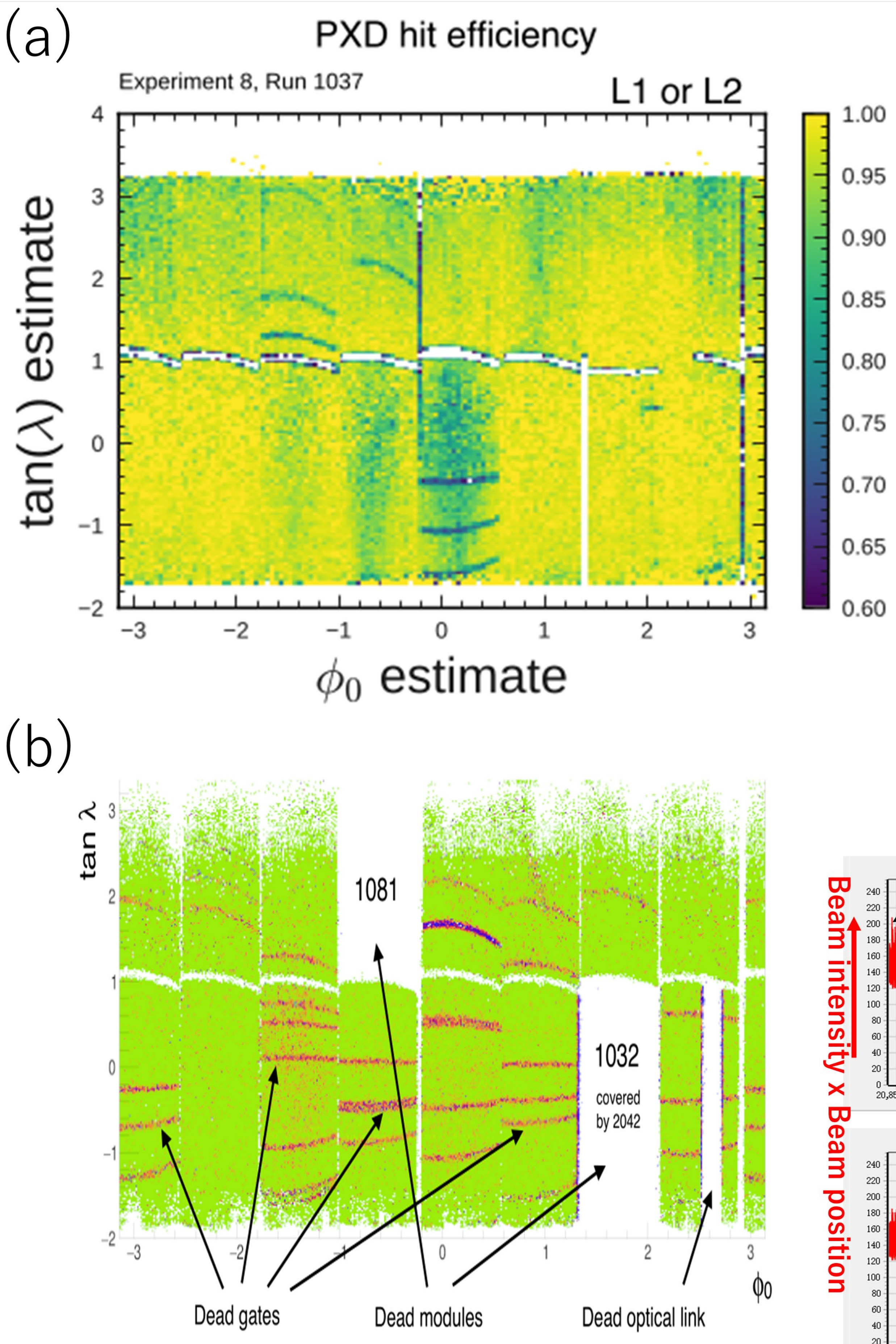

Figure 3: Soundness of the PXD (a) before and (b) after the jaw damage event that occurred.

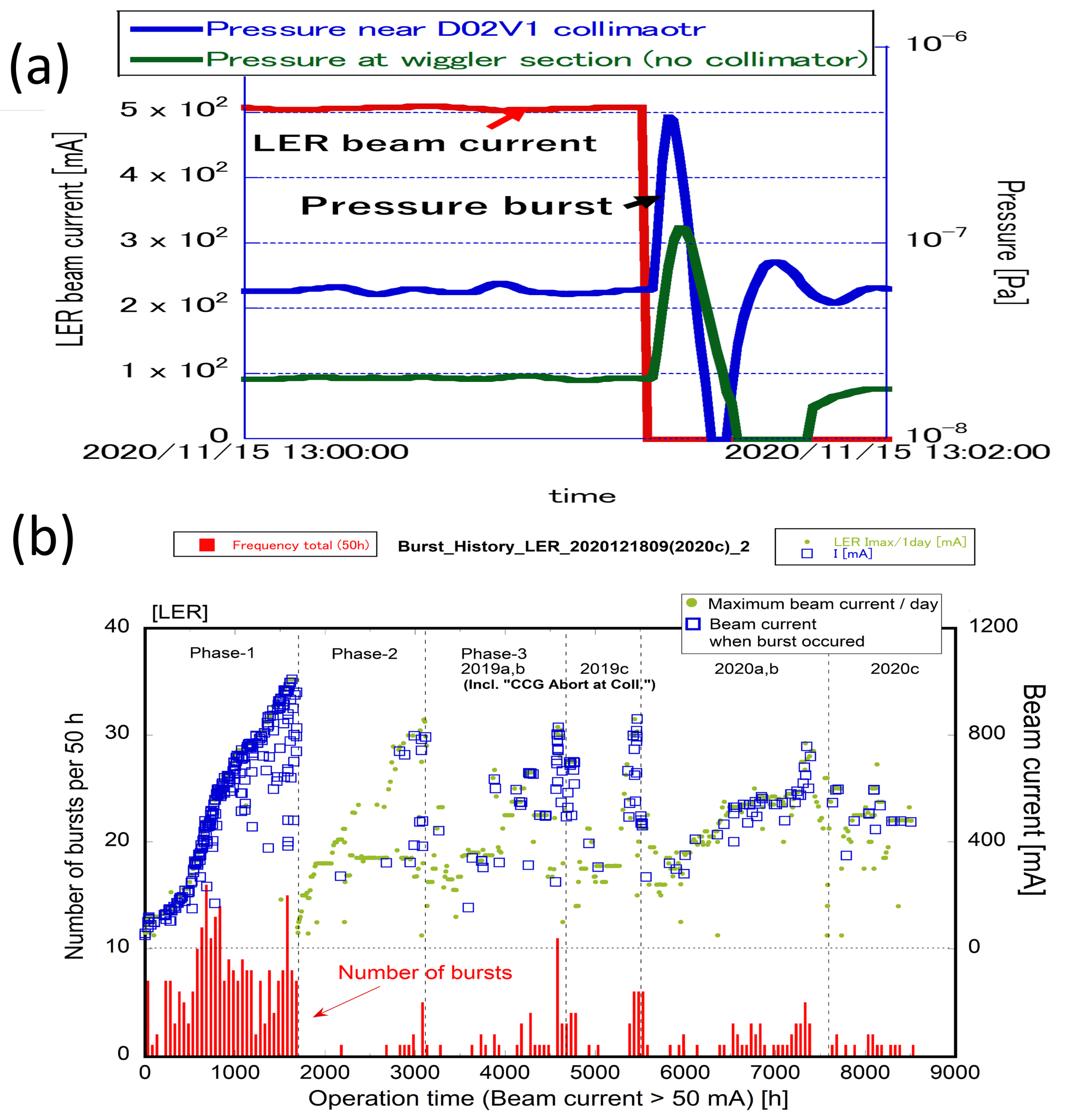

Figure 4: (a)Pressure burst when a jaw damaged, (b) pressure burst history.

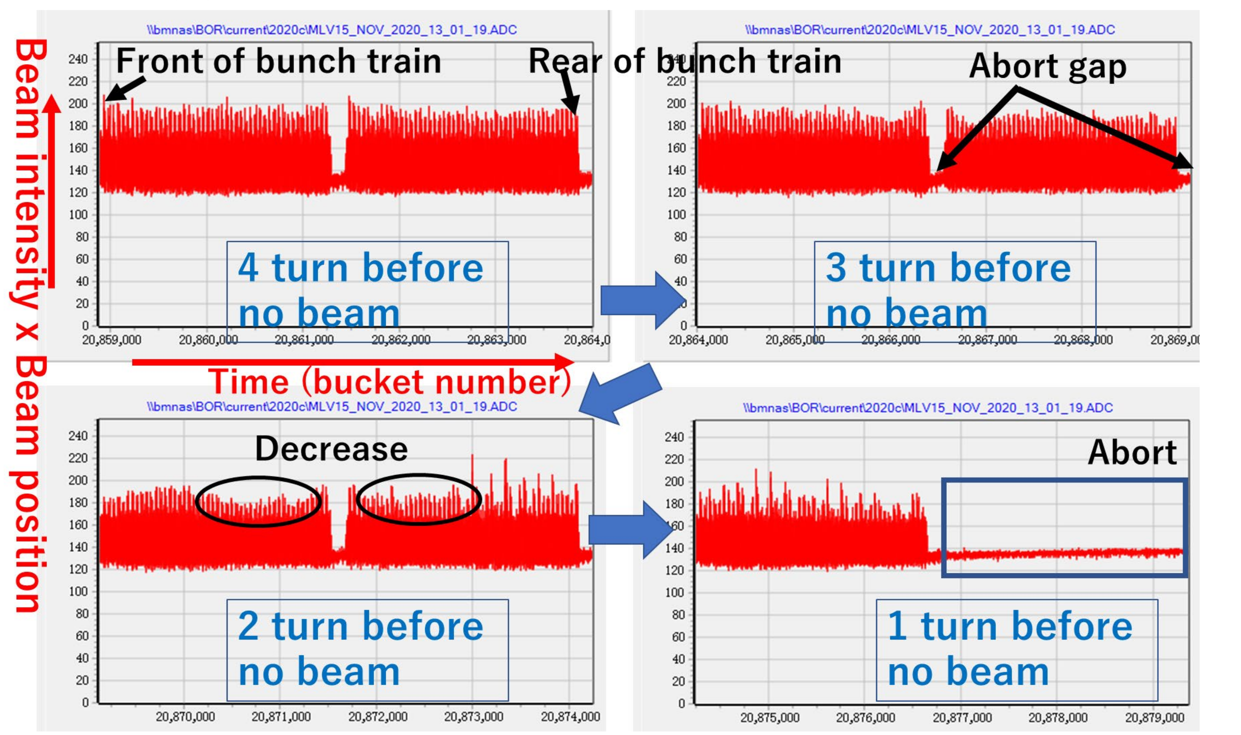

Figure 5: Plot observed using BOR when a jaw was damaged.

SIMULATION RESULTS

Fall trajectory of the charged-up dust

- Assuming that the dust causes this event, a question arises as to why the phenomenon of the interaction between the beam and the dust occurs several times even though the beam size in SuperKEKB is very small. When the dust falls out of the groove, it almost does not interact with the beam if it is not attracted to the beam. Assuming that the beam has a circular transverse cross-section with a diameter of 2 mm and the material of the dust particles is aluminum, the probability of interaction between the dust falling from the groove and the beam is very low (see the black line in Fig. 6(a)).
- **The mechanism is believed to be the charging of the free-falling dust when it passes through the electron cloud. Thereafter, the charged dust is drawn to the positron beam.** Figure 6(b) shows the orbit of the dust with the drawing force caused by the electron cloud, assuming that the energy of the charged-up dust is 50 eV and the dust radius is 10 μm.

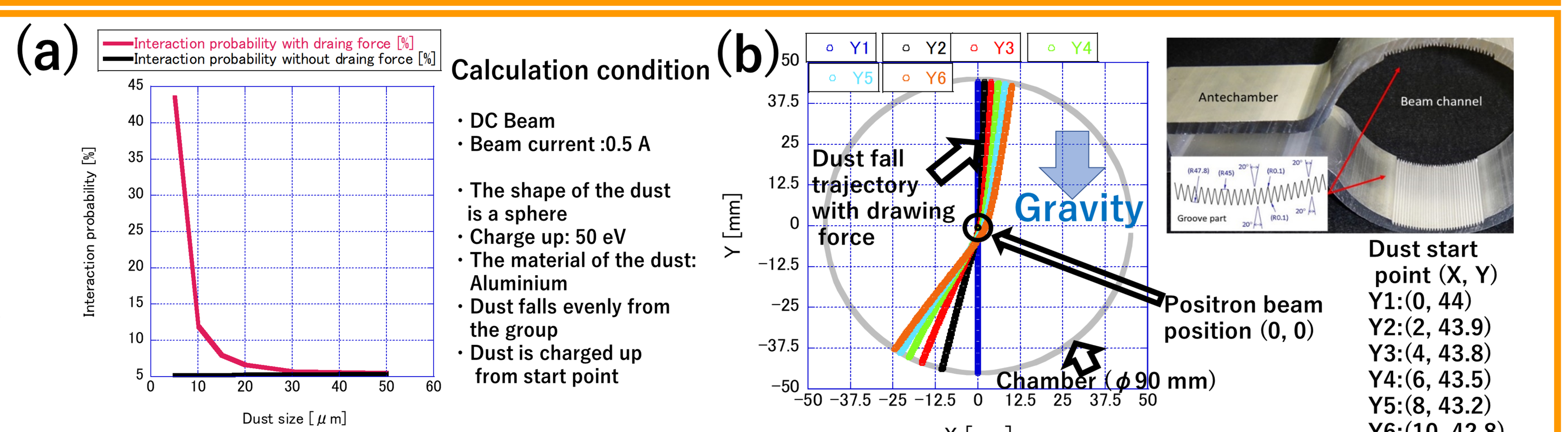

Figure 6: (a) Probability of interaction with/without the drawing force, (b) orbit of the dust (radius = 10 μm) with the drawing force caused by the electron cloud.

Tracking of beam interaction with dust

- We performed a beam tracking simulation to check whether the beam that interacted with the dust collided with the collimator.
- We assumed that the material of the dust particles was aluminum, the dust radius was 500 μm, and the interaction between the beam and the dust occurred at the location at which the pressure burst was observed.
- **Figure 7 shows the results of beam tracking when the D06V2 collimator jaw was damaged. Figure 8 shows a comparison of the scatter plots of particles that collided with D06H1 and D06V2. We observed that the particles were concentrated within a narrow range in D06V2.**

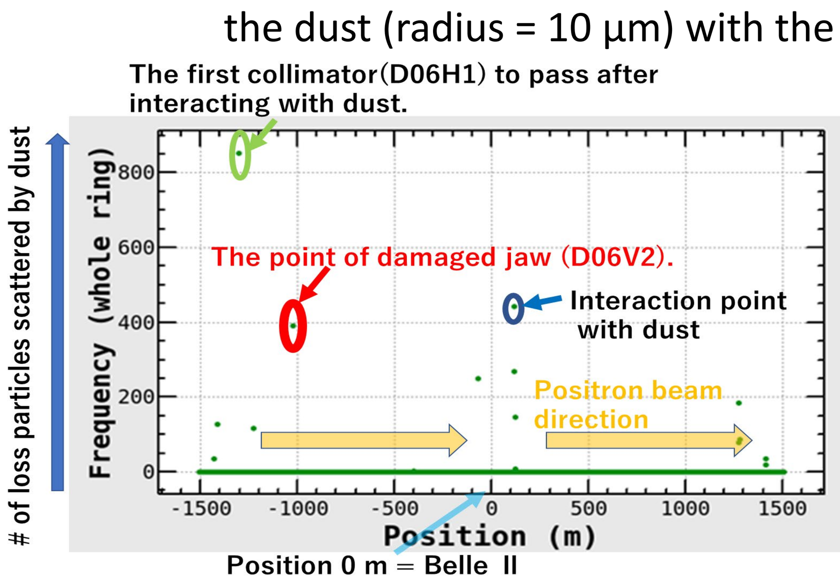

Figure 7: Result of tracking the scattered beam that interacted with dust using PHITS and SAD.

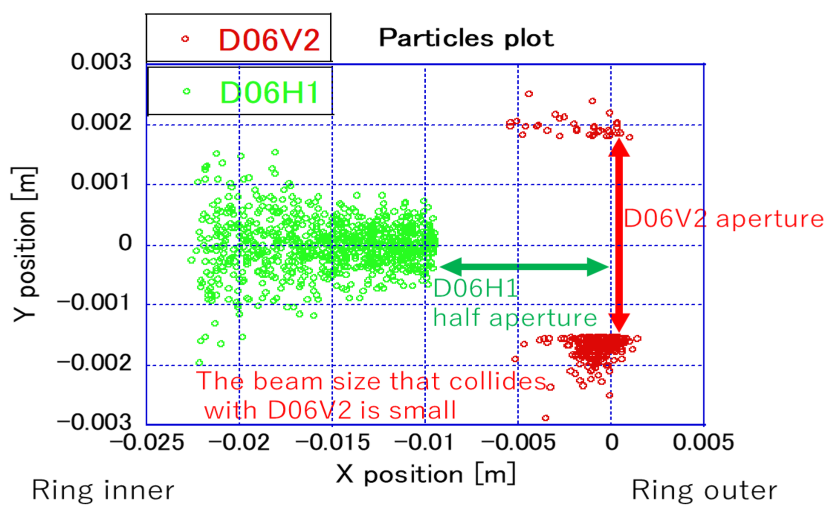

Figure 8: Comparison between the sizes of beams that collided with D06H1 and D06V2.

CONCLUSION

- ***We believe that dust caused damage to the jaw, and accordingly, we described the reasons for this phenomenon. This is because this event is similar to the phenomenon triggered by the dust observed during Phase-1, and there is no sign of beam instability during sudden beam loss.***
- ***We simulated the interaction between the beam and the dust. We showed that, if the dust becomes charged, its probability of interacting with the beam may increase. The simulation result of tracking the interaction of the scattered beam with the dust showed that there are a considerable number of particles hitting the damaged collimator.***
- ***Thus, we developed a low-Z collimator as a counter-measure for these events. This development has been reported in other studies.***