Analysis of beam aborts at SuperKEKB with the bunch current and oscillation recorder

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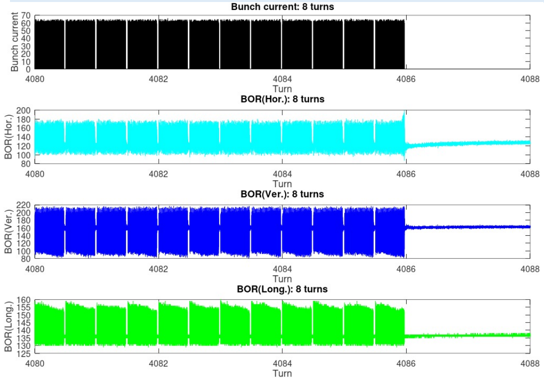
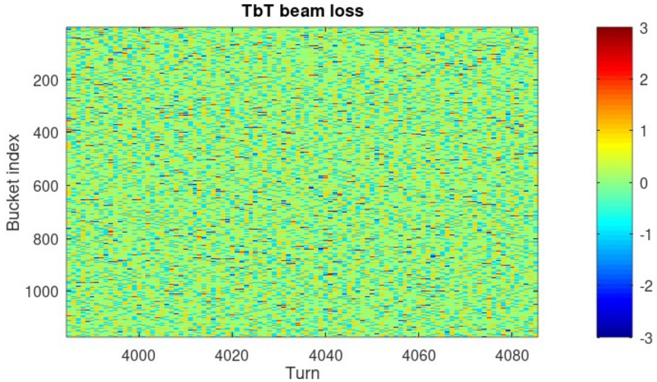
Abstract

In SuperKEKB, the bunch current monitor (BCM) and the bunch oscillation recorder (BOR) have been developed for the bunch-by-bunch feedback system and are also used to record the turn-by-turn (TbT) data in bunch-by-bunch (BxB) mode prior to each beam abort. The causes of the beam aborts can be diagnosed using the dedicated beam abort monitor system. Meanwhile, the BCM/BOR data can provide additional information concerning beam instabilities. For example, the TbT patterns of the BOR data can show a clear correlation with hardware malfunctions. The BxB tunes can be extracted from spectrum analysis of the TbT data, showing certain modes of beam motions. This work reports the preliminary analyses of BCM/BOR data from various beam aborts at SuperKEKB. It represents an effort of correlating the beam aborts with possible hardware malfunctions or beam instabilities.

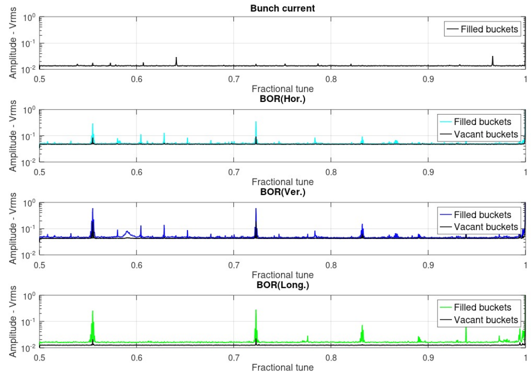
The BCMs and BORs are routinely used as beam instrumentation for the BxB feedback system of SuperKEKB. When beam aborts happen, the rapid change of beam currents in the rings triggers the BCMs and BORs to record 4096 turns of data for all 5120 buckets. The figures below show the BOR/BCM data of high-energy ring (**HER**) and their analysis for a manual abort recorded at 08:04 AM, 2021/05/26 with 680 mA current and 1174 bunches. The analysis of manual abort sets a reference for the analyses of other types of beam aborts.



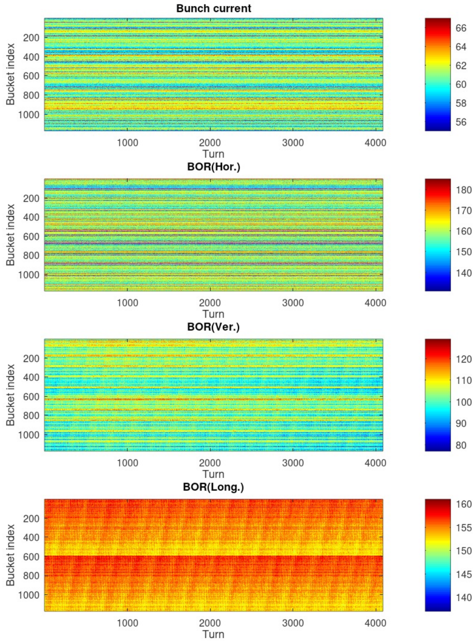
BCM/BOR data of the last 8 turns before abort



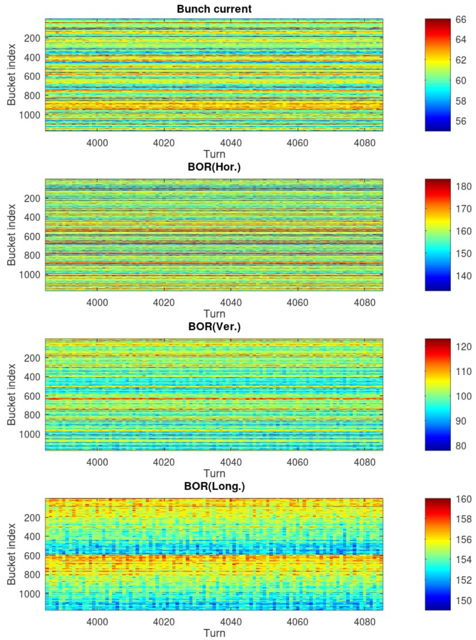
TbT beam loss rate (a.u.) during the last 100 turns by BCM



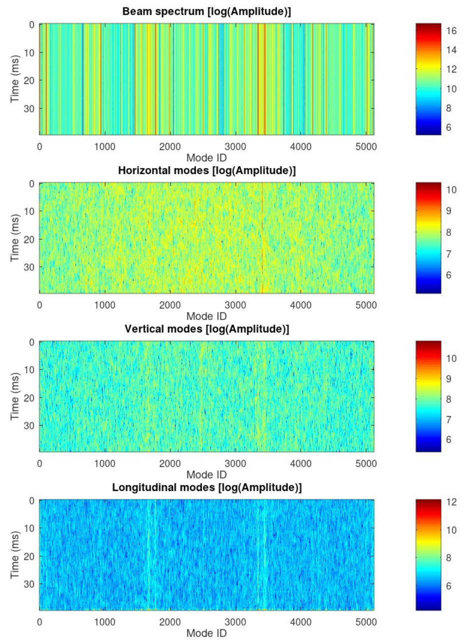
FFT of TbT BCM/BOR data averaged over filled and vacant buckets



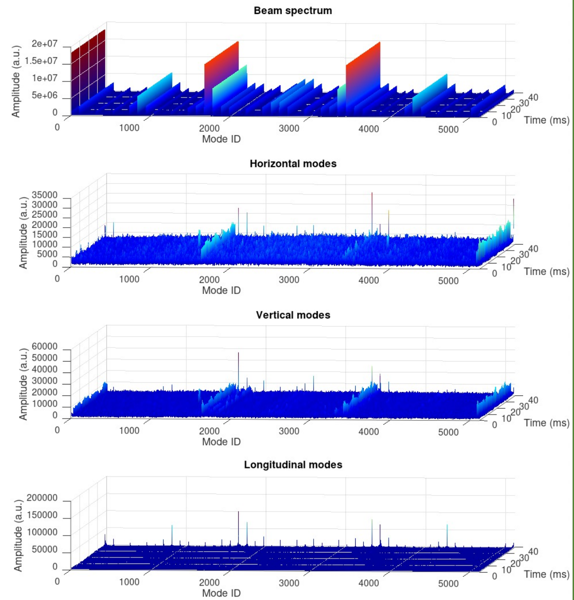
BCM/BOR data of 4096 turns for filled buckets



BCM/BOR data of last 100 turns for filled buckets

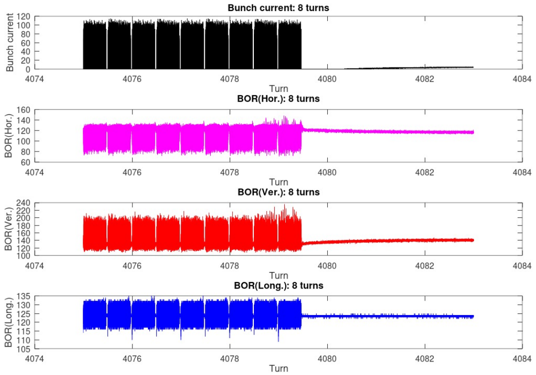


Evolution of coupled-bunch modes (2D log plot)

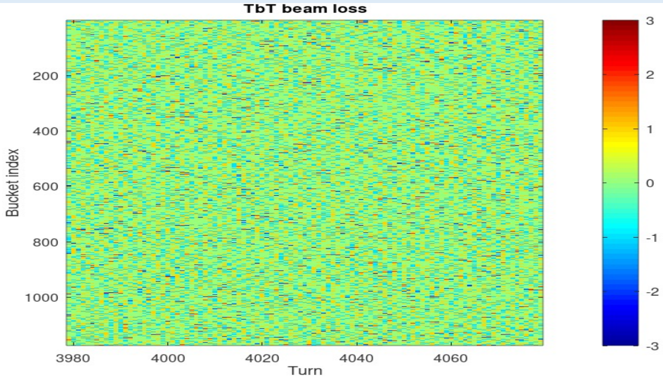


Evolution of coupled-bunch modes (3D linear plot)

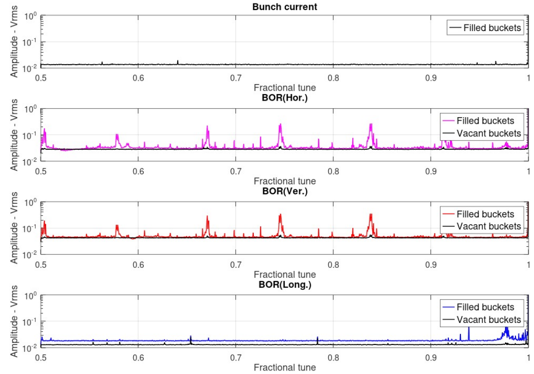
The BCMs and BORs are routinely used as beam instrumentation for the BxB feedback system of SuperKEKB. When beam aborts happen, the rapid change of beam currents in the rings triggers the BCMs and BORs to record 4096 turns of data for all 5120 buckets. The figures below show the BOR/BCM data of high-energy ring (**LER**) and their analysis for a manual abort recorded at 08:04 AM, 2021/05/26 with 840 mA current and 1174 bunches. The analysis of manual abort sets a reference for the analyses of other types of beam aborts.



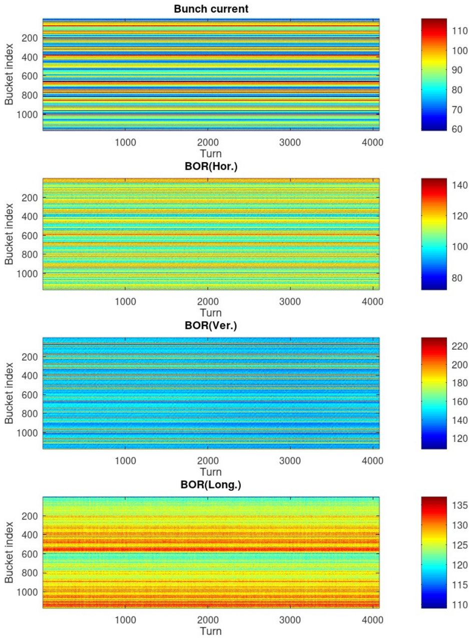
BCM/BOR data of the last 8 turns before abort



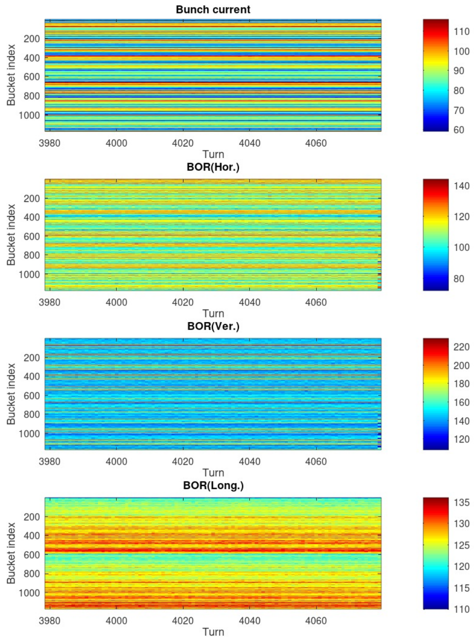
TbT beam loss rate (a.u.) during the last 100 turns by BCM



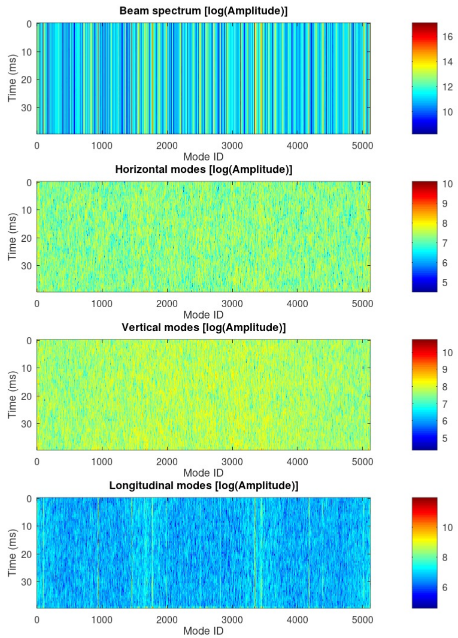
FFT of TbT BCM/BOR data averaged over filled and vacant buckets



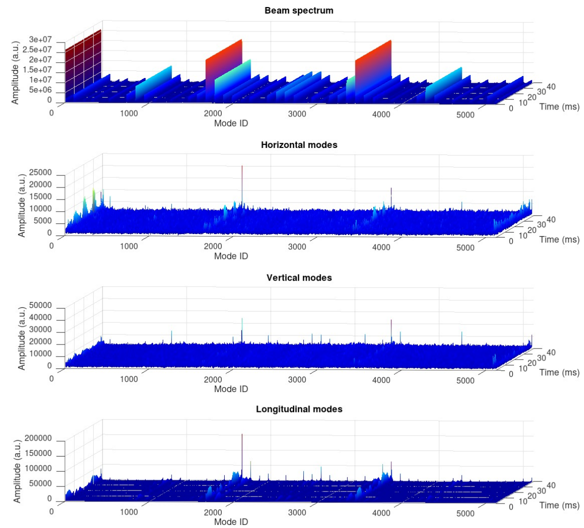
BCM/BOR data of 4096 turns for filled buckets



BCM/BOR data of last 100 turns for filled buckets

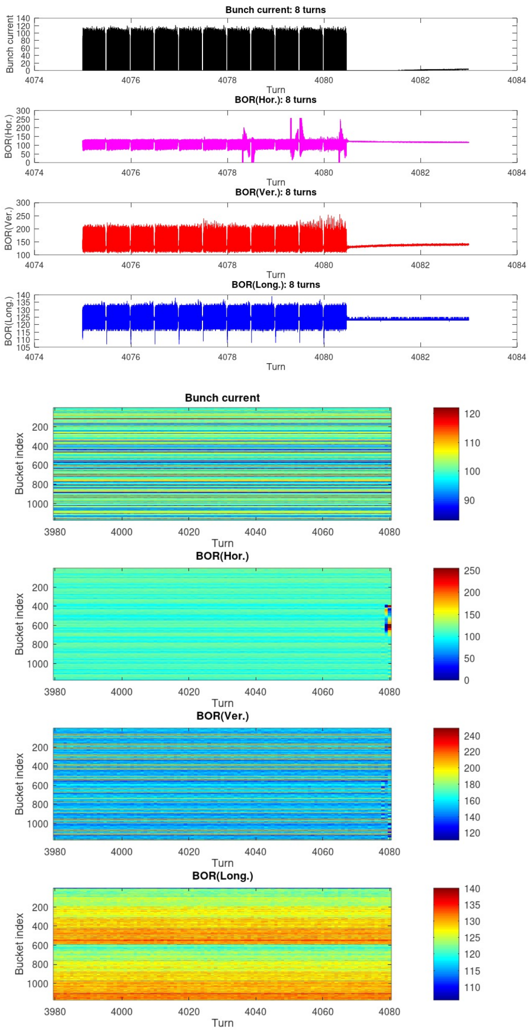


Evolution of coupled-bunch modes (2D log plot)

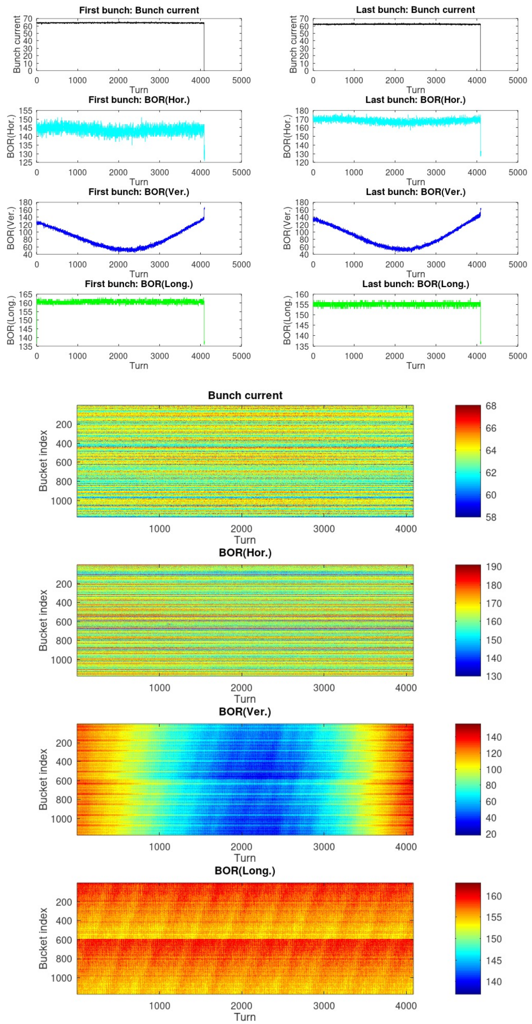


Evolution of coupled-bunch modes (3D linear plot)

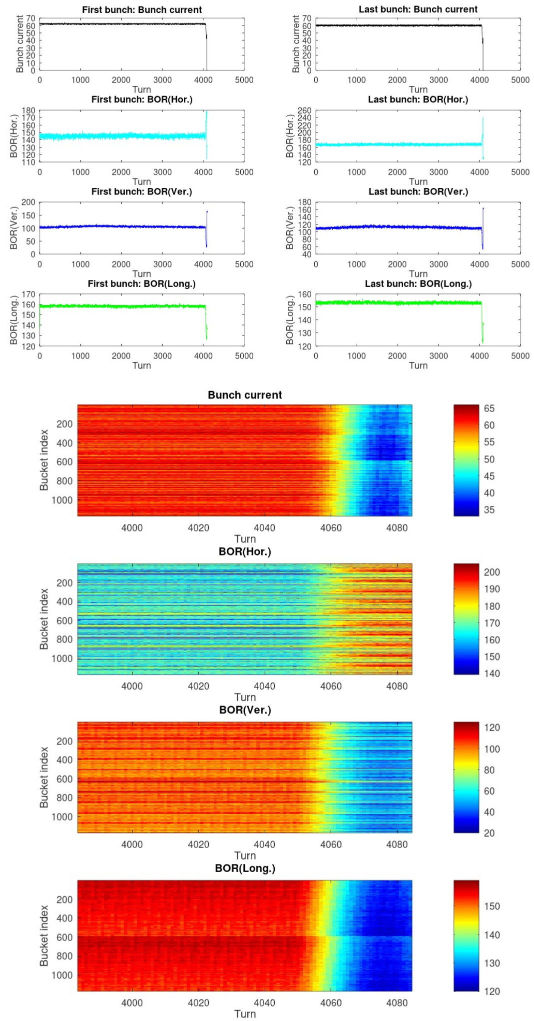
In SuperKEKB, some types of beam aborts can be well understood through the recorded data of the dedicated beam abort monitor system and also the logged data of hardware subsystems. Meanwhile, the BCMs and BORs provide consistent information for these aborts: 1) Aborts related to LER injection kicker mismatch; 2) Aborts related earthquake; 3) Aborts related to beam phase drift because of RF down; etc.



An abort related to LER injection kicker mismatch at 18:39 PM, 2021/06/24. Part of the bunch train in LER was excited in the horizontal direction, resulting in extra Belle2 background which triggered abort.

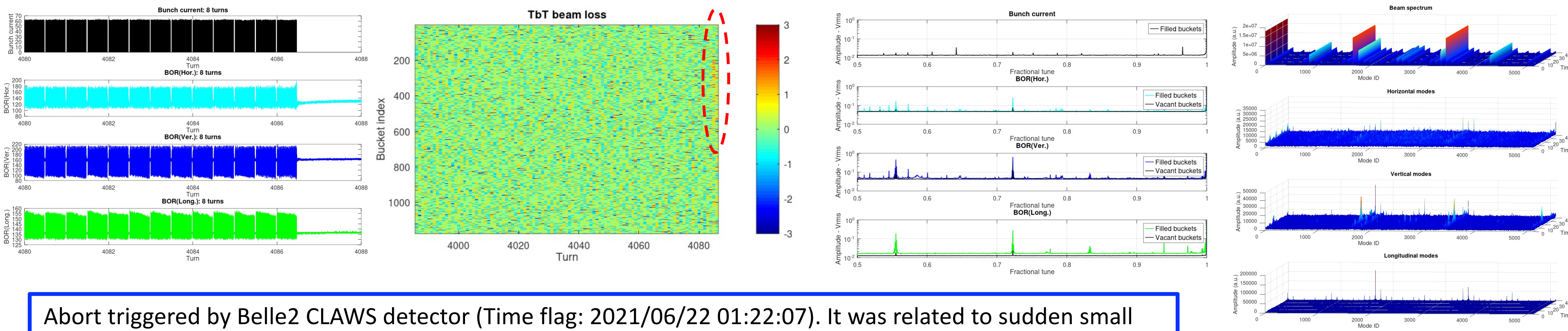


An abort related to earthquake at 23:40 PM, 2021/05/30. The ground motion caused modulation of beam motion in both H/V planes at both HER (LER is similar), resulting in extra Belle2 BG.

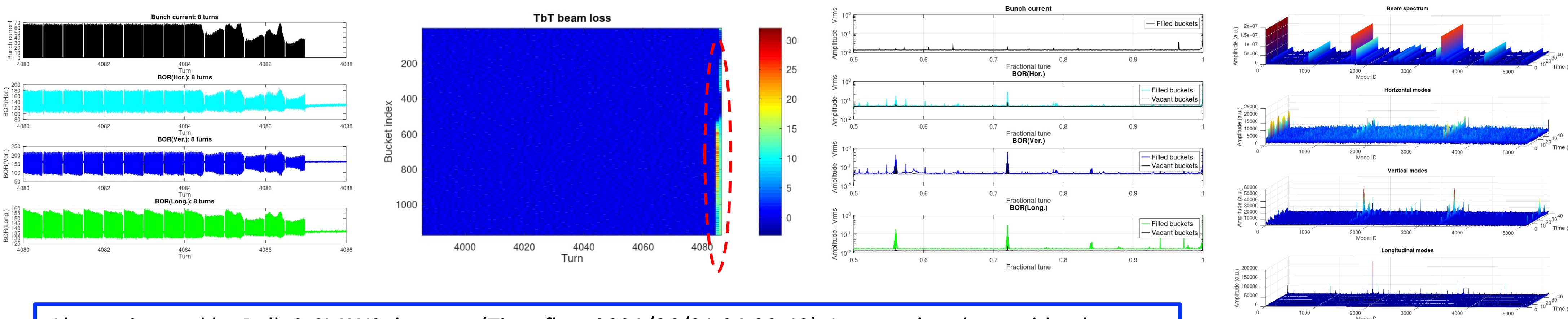


A beam phase abort when one RF cavity was off at 23:18 PM, 2021/06/15. The beam phase drift caused modulation of beam motion in H/V/L at HER. The RF system detected abnormal beam phase and triggered abort.

In contrary to the well-understood beam aborts, some aborts still remain to be understood. From BOR/BCM data, these unidentified aborts had features of: 1) Sudden beam loss happened in a few turns; 2) The beam loss rate varied time by time; 3) The large beam losses to IR region even caused quenches of superconducting QCS magnets; 4) Before the sudden beam loss, no clear signs of single- or coupled-bunch instabilities were detected. We show some examples of such unidentified aborts.

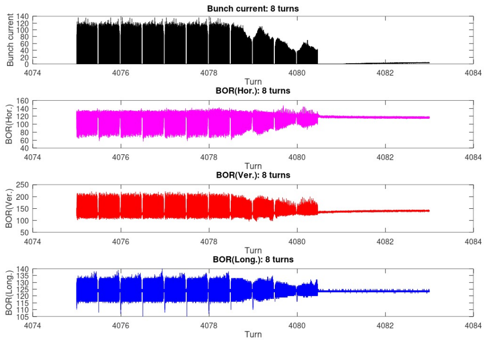


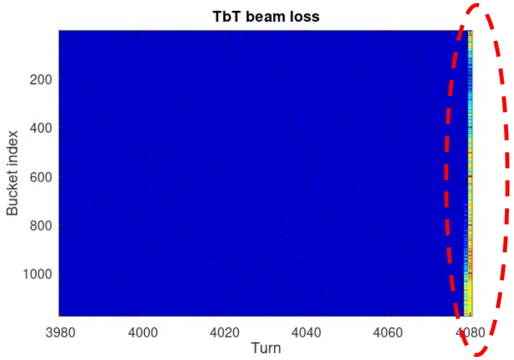
Abort triggered by Belle2 CLAWS detector (Time flag: 2021/06/22 01:22:07). It was related to sudden small beam loss in **HER**. The TbT beam spectra and coupled-bunch modes are similar to those of manual abort.

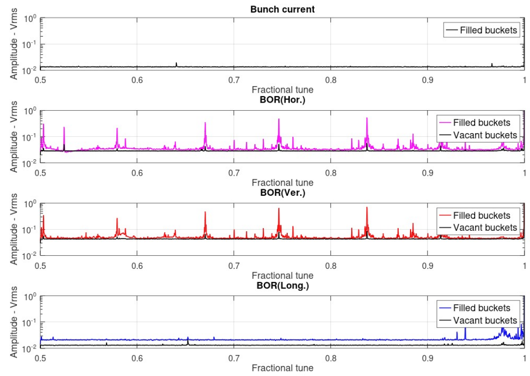


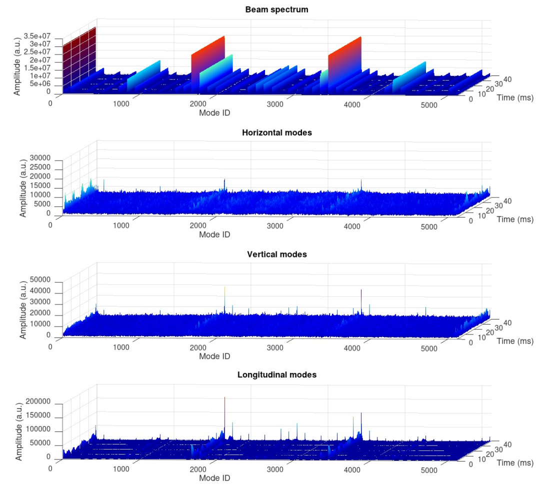
Abort triggered by Belle2 CLAWS detector (Time flag: 2021/06/21 04:29:42). It was related to sudden huge beam loss in **HER**. The TbT beam spectra and coupled-bunch modes are similar to those of manual abort.

In contrary to the well-understood beam aborts, some aborts still remain to be understood. From BOR/BCM data, these unidentified aborts had features of: 1) Sudden beam loss happened in a few turns; 2) The beam loss rate varied time by time; 3) The large beam losses to IR region even caused quenches of superconducting QCS magnets; 4) Before the sudden beam loss, no clear signs of single- or coupled-bunch instabilities were detected. We show some examples of such unidentified aborts (continued).

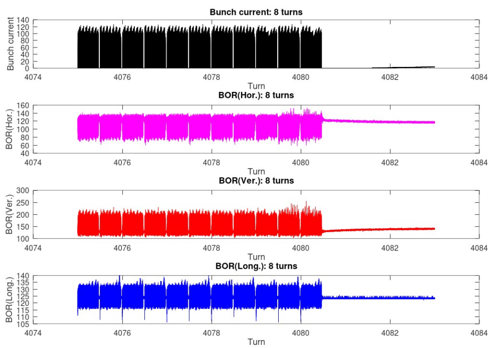


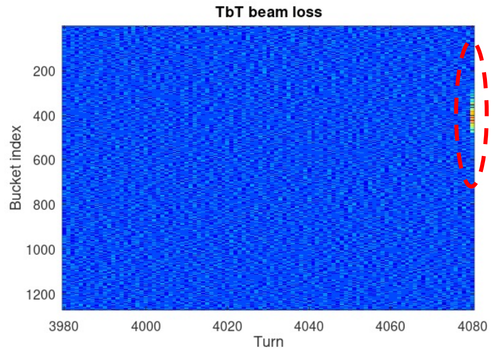


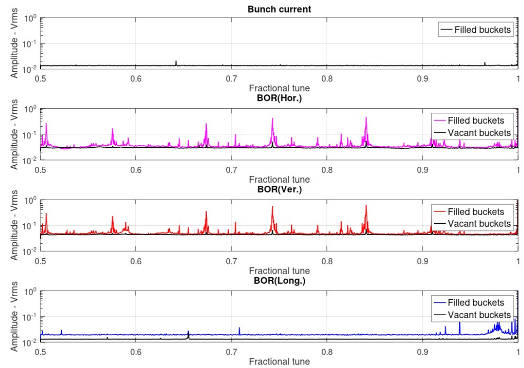


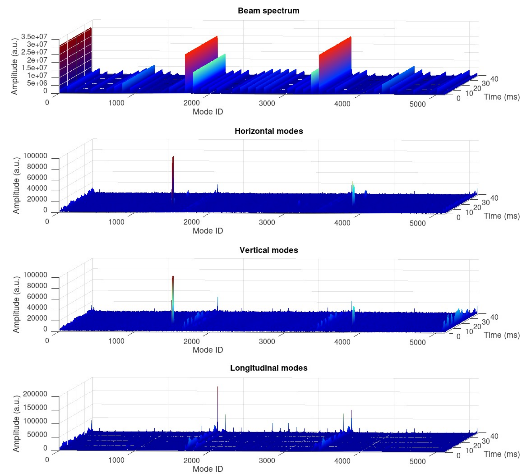


Abort triggered by Belle2 CLAWS detector (Time flag: 2021/06/02 20:13:51). It was related to sudden huge beam loss in **LER**. The TbT beam spectra and coupled-bunch modes are similar to those of manual abort.



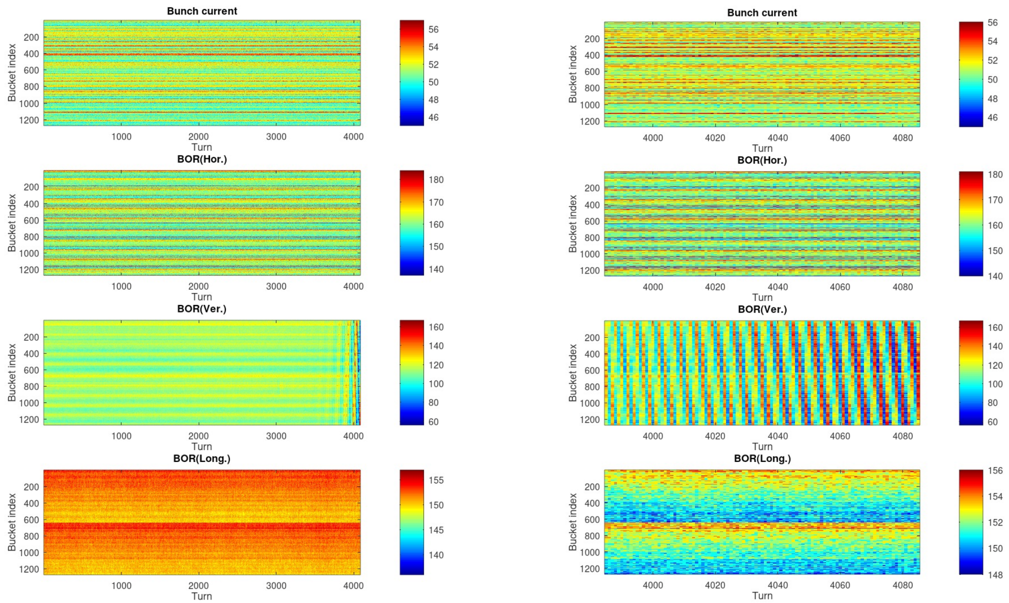


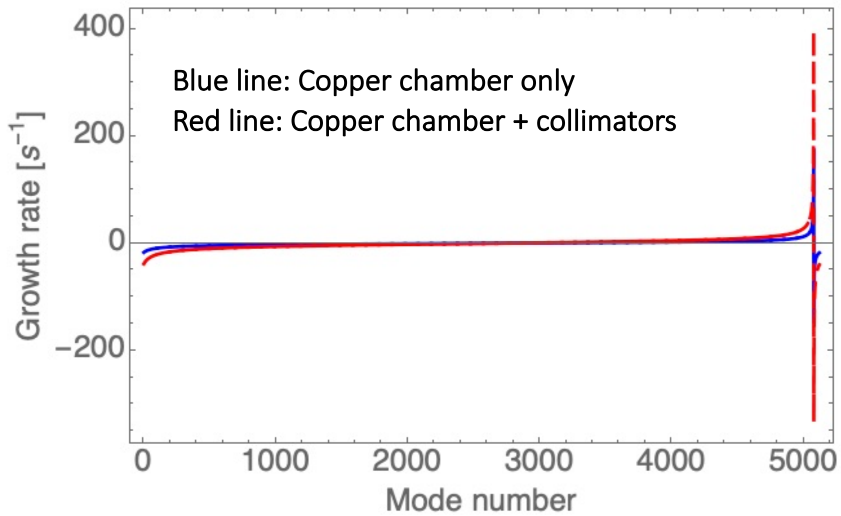




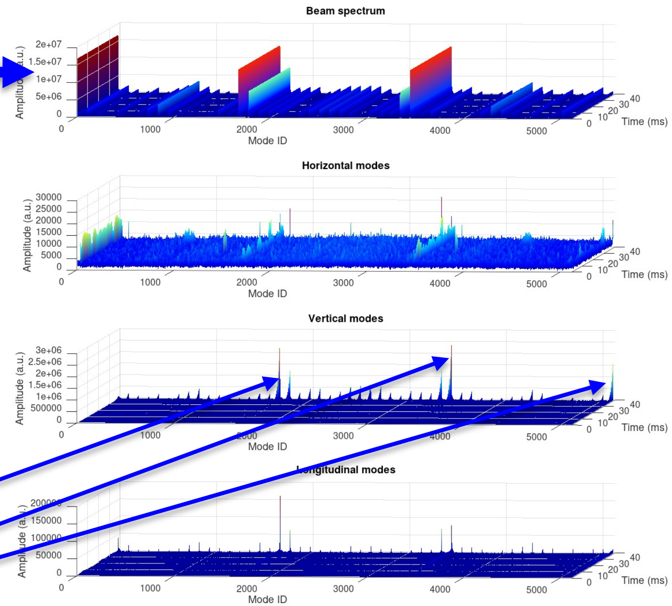
Abort triggered by Belle2 CLAWS detector (Time flag: 2021/07/02 13:41:49). It was related to sudden small beam loss in **LER**. The TbT beam spectra and coupled-bunch modes are similar to those of manual abort.

The BCMs and BORs can be used to record data during dedicated machine studies. Here we show one example of CBI growth time measurement in HER. The dominant CBI modes were found to be -1 modes, and they are identified to be driven by resistive wall impedance.





The first 5 modes of beam current: {0, 1672, 3448, 1776, 3344}
The first 5 modes of hor. motion: {5086, 1638, 3414, 37, 3485}
The first 5 modes of ver. motion: {1671, 3447, 5119, 3343, 1775}
The first 5 modes of long. motion: {5119, 3447, 1671, 1672, 3448}



In vertical direction, the "-1 modes" were found to be dominant. The beam modes {0, 1672, 3448, 1776, 3344}-1 correspond to the vertical modes {1671, 3447, 5119, 3343, 1775} with harmonic number 5120.

Estimate of growth rates vs mode number:

$$\frac{1}{\tau_y(\mu)} \approx -\frac{cI_0 e}{4\pi E\nu_y}\sum_{p=-\infty}^{+\infty} \mathrm{Re}\left[Z_y^{RW}((pM+\mu+\nu_y)\omega_0)\right]$$

Fastest growth rate of RW modes:

$$\frac{1}{\tau_y} \approx \frac{cI_0 e}{4\pi E\nu_y}\frac{1}{\sqrt{1-Q_y}}\mathrm{Re}.Z_y^{RW}(\omega_0)$$

Estimate with Copper chamber (Radius 25 mm): τ_y~5.6 ms

Consider RW of collimators: τ_y~2.5 ms

Fitting the growth time of dominant modes gives ~1.6 ms.

Beam parameters for calculation:

I_0=600 mA, ν_y=43.582, Q_y=0.582