Beam Trip Analysis by Bunch-by-bunch BPM System in BEPCII storage rings

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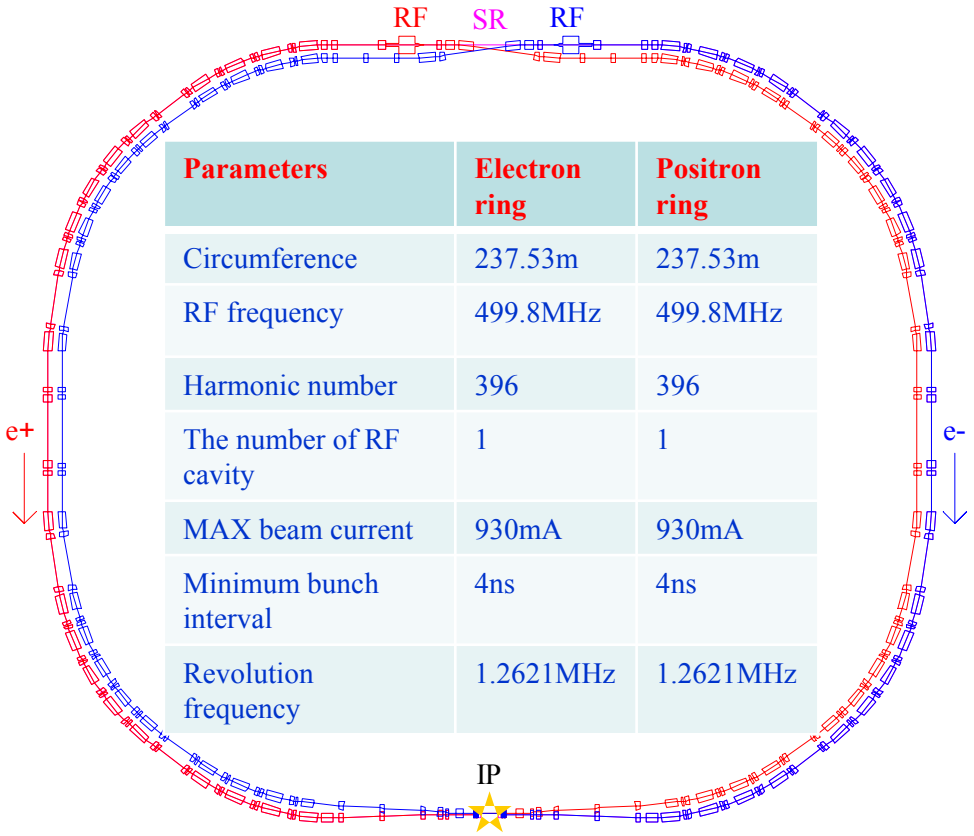
Outline

- BEPCII storage rings
- Bunch-by-bunch system
- Beam trip analysis results
  - RF trip
  - Magnet power instabilities
  - Beam instabilities
- Summary

Beam trip in BEPCII storage ring



Parameters	Electron ring	Positron ring
Circumference	237.53m	237.53m
RF frequency	499.8MHz	499.8MHz
Harmonic number	396	396
The number of RF cavity	1	1
MAX beam current	930mA	930mA
Minimum bunch interval	4ns	4ns
Revolution frequency	1.2621MHz	1.2621MHz

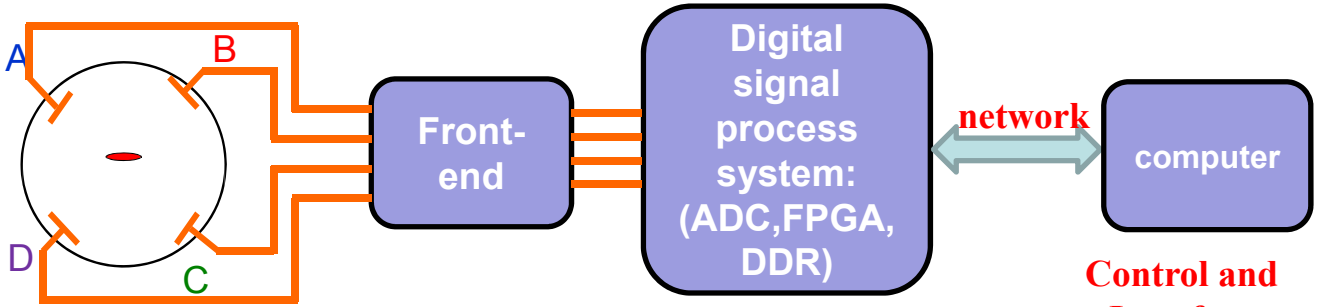
BEPCII double storage rings layout

- **Cause of beam trip**
  - Almost every subsystem failure/instabilities
  - …
- **Result of beam trip**
  - Degrade the operating efficiency
  - Cost troubleshoot time
  - Cause other subsystem trip
  - …

Beam trip analysis (post-mortem diagnose): Urgent! Complicated!

Bunch-by-bunch system overview

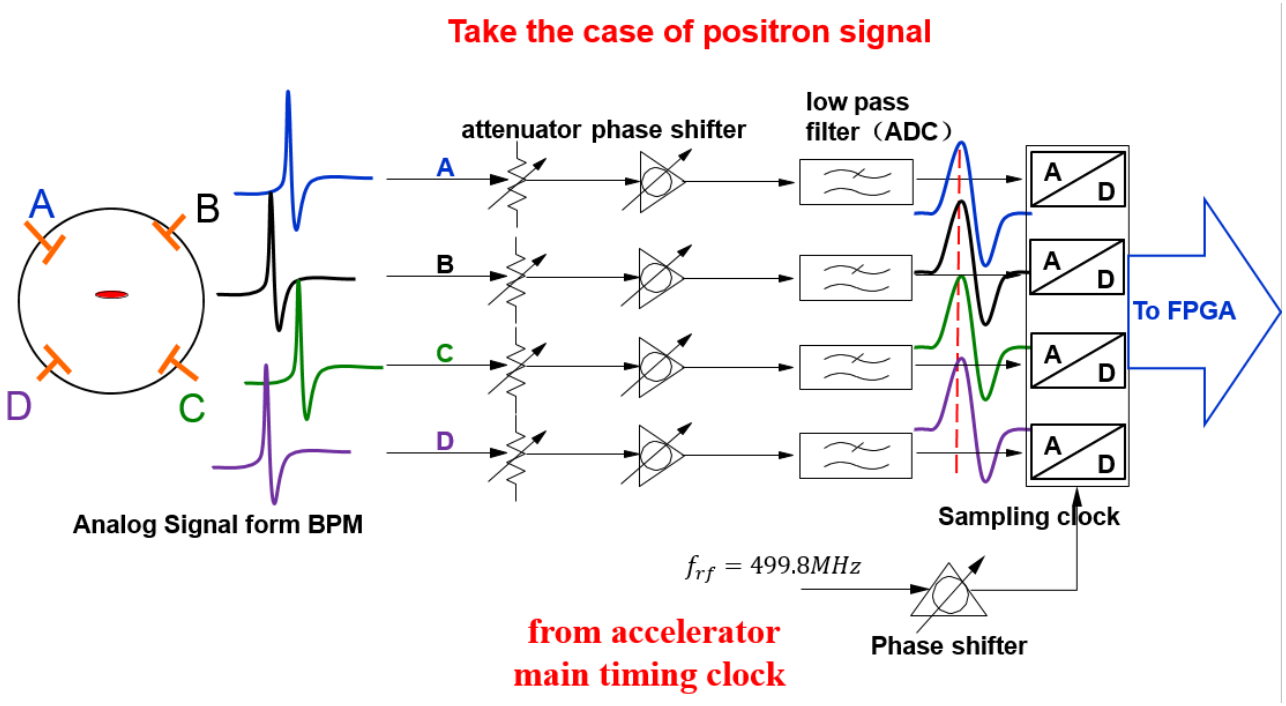
- Bunch-by-bunch position measurement(BPM) prototype for BEPCII storage ring



Four 14bit 500MHz ADC
FPGA: SX550T
Double 4GB DDR3 memory

Front end and sampling

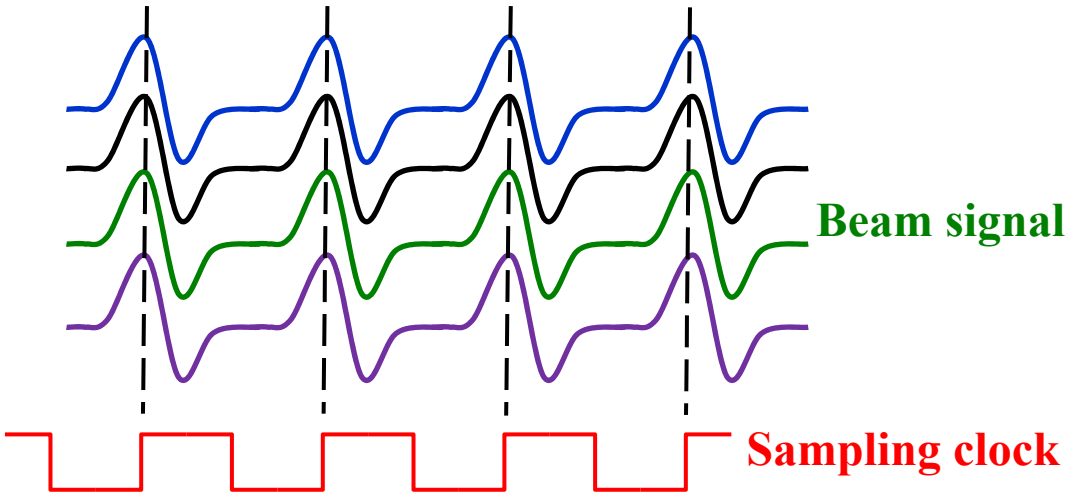
- Sampling rate : RF frequency (499.8MHz).
- To achieve high isolation between neighbouring sampling: All element in the front end should have large analogue bandwidth to prevent bunch-by-bunch signal coupling.
- The front-end adjust the four signal in the same phase.



Front end and ADC schematic

Front end and sampling

- Sampling clock is from the accelerator main timing source.
- Position ideal sampling schematic: ADC sampling at each top of bunch signal.
- Calculate the bunch position and bunch current.



Ideal Sampling schematic

$$\left.\begin{aligned} X &= k_x \frac{V_B + V_C - V_A - V_D}{V_A + V_B + V_C + V_D} \\ Y &= \mathrm{k_y} \frac{V_A + V_B - V_C - V_D}{V_A + V_B + V_C + V_D} \end{aligned}\right\}$$

$$\mathrm{I_{bunch}} = \mathrm{k_C}(V_A + V_B + V_C + V_D)$$

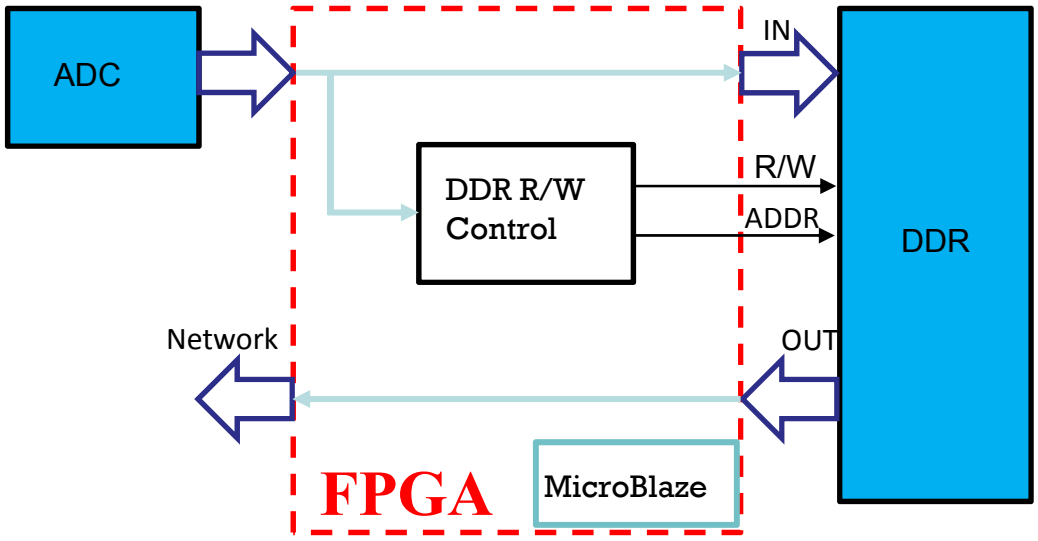
Digital signal process for beam trip detection

- Write all sampling data to DDR.
- 4GB DDR3 memory (2 second bunch by bunch data).
- Logic in FPGA judge beam trip (Regardless of the oscillation):

$$I_{beem} = k \sum_{t_i}^{t_i+t_{rev}} (a + b + c + d)$$

system doesn't need any interlock signal input.

- After beam trip logic lock the DDR data.
- Transport the DDR data to computer

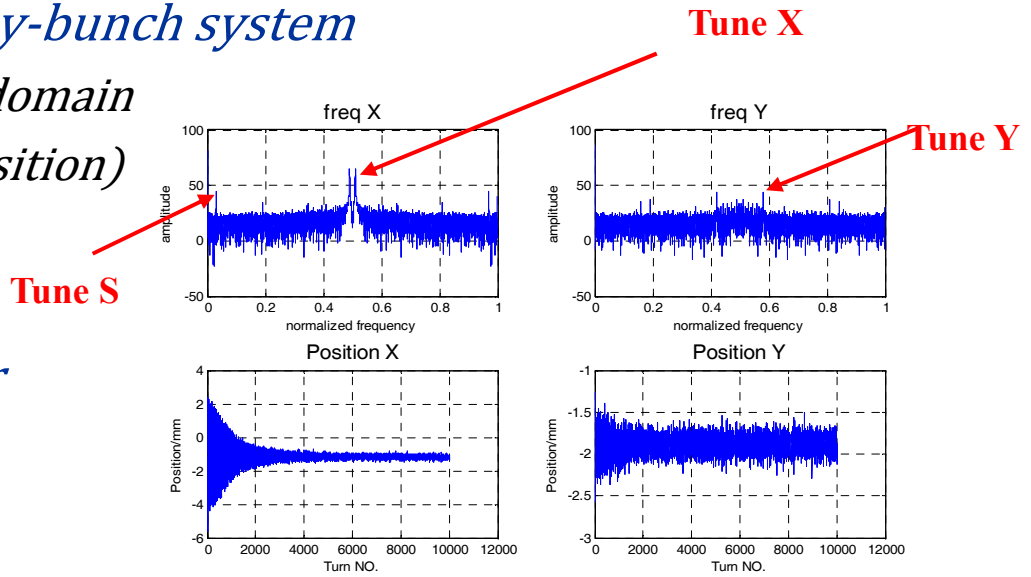


Beam trip research in BEPCII

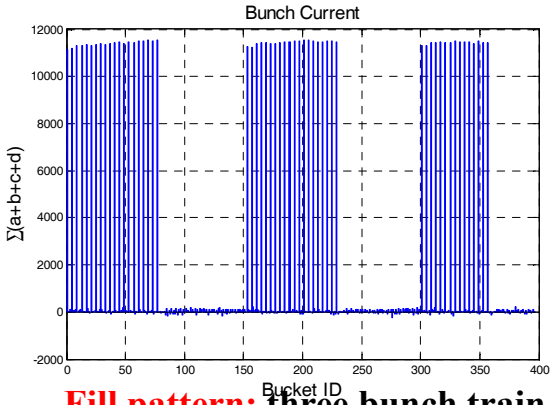
- *Beam trip events*
  - *More than 200 beam trip events had been collected and analysis*
  - *Many contrast experiment*

- *Beam trip analysis by bunch-by-bunch system*
  - *Time domain and frequency domain*
  - *Bunch-by-bunch (current, position)*
  - *Tune in three dimensions*

- *Some trip events become clear*
  - *RF trip*
  - *Magnet power instabilities*
  - *Beam instabilities*
  - *…*

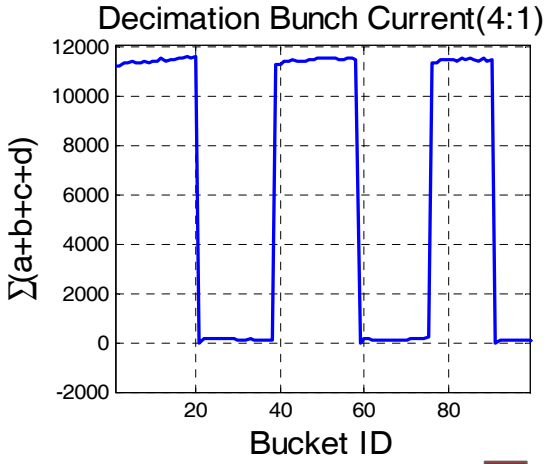


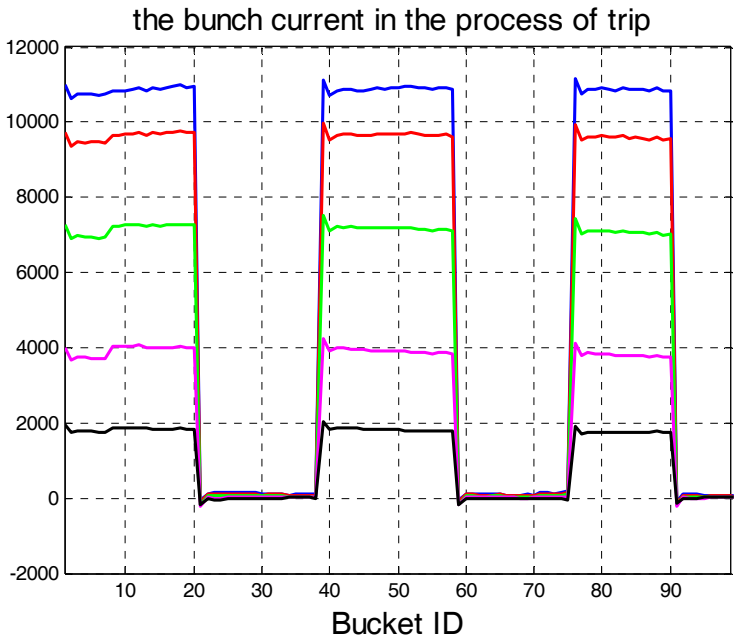
RF trip



Fill pattern: three bunch train
bunch Interval 4 bucket (8ns)

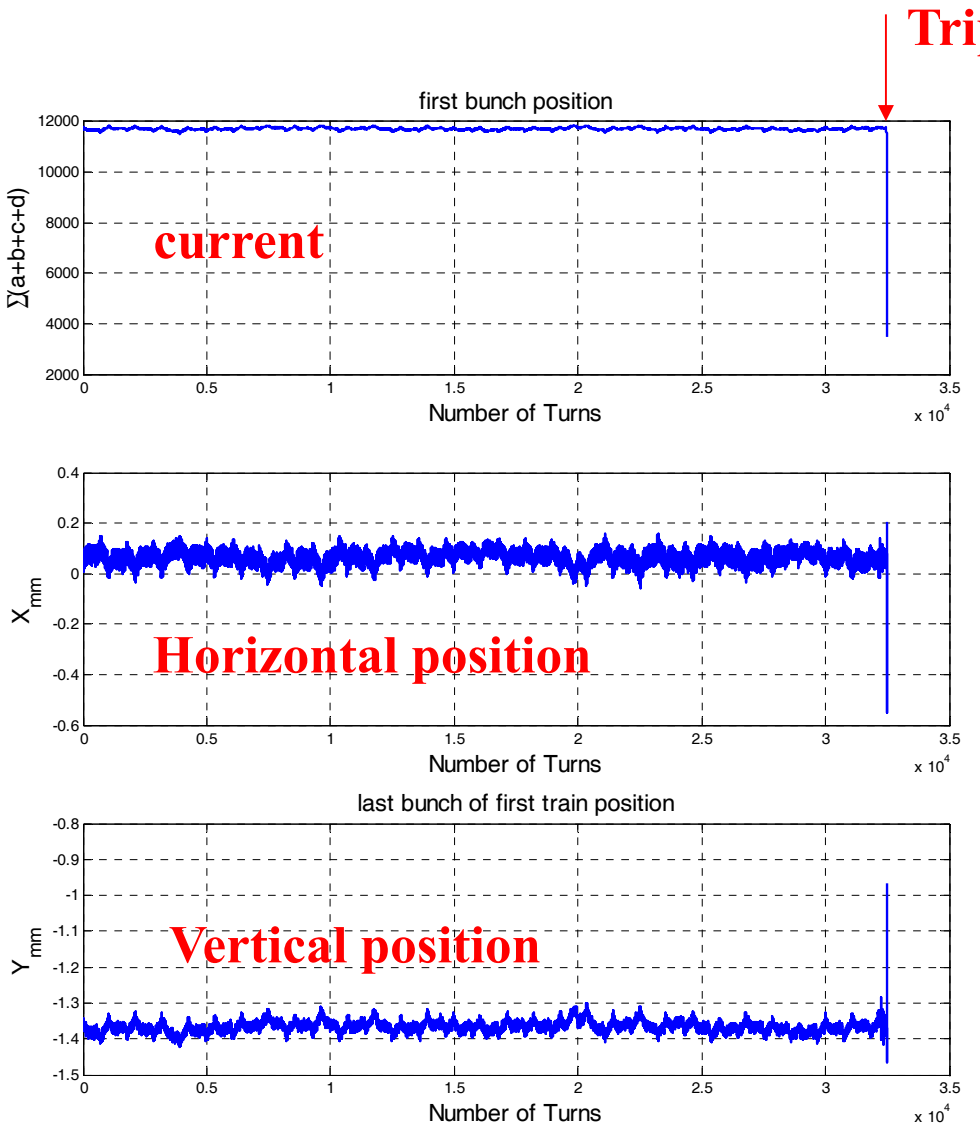
Extraction(1/4)





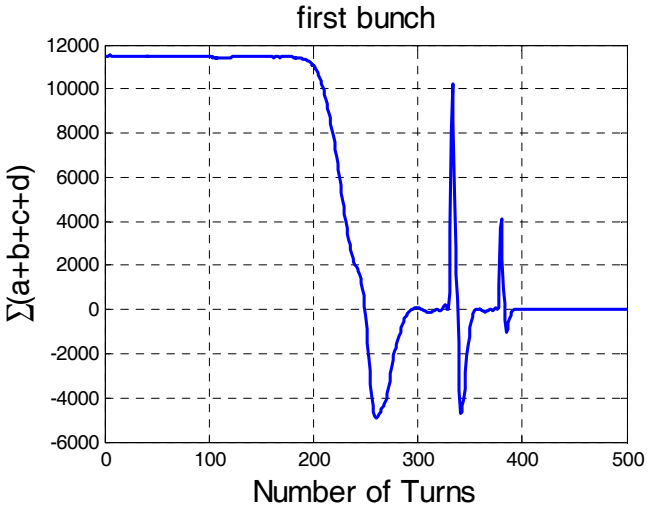
The bunch current is uniform in the process of trip

RF trip

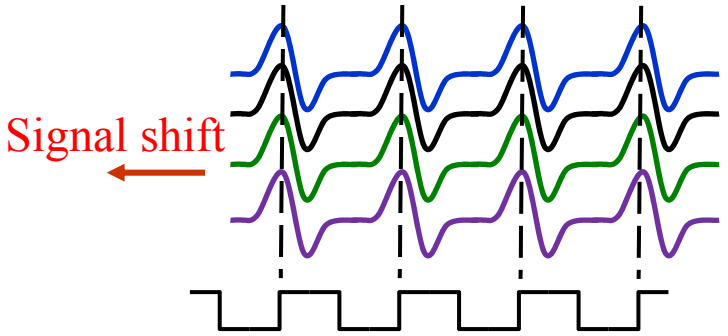


Before beam trip:
No position change,
No obvious Instability oscillation

RF trip



The sum signal in the process of beam trip

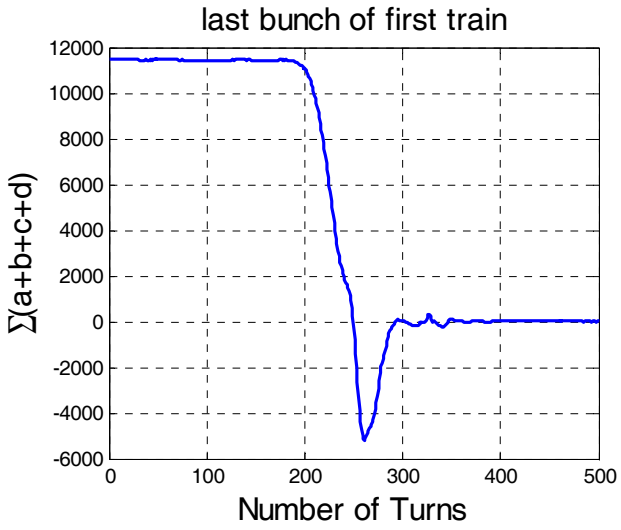


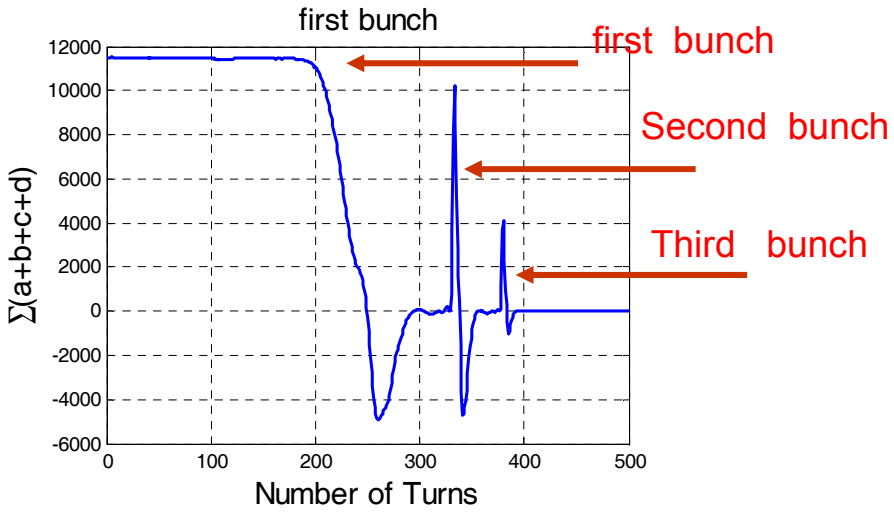
Sampling schematic

- **Sum signal change and appear negative value**
- **The signal change should caused by phase shift between beam signal and sampling clock**
- **Sampling clock is from the accelerator main timing system: stably**
- **Beam signal shift cause this phenomena**

RF trip

- Sample at the next bunch signal, Bunch interval is 8 ns
- Beam longitudinal phase changed violently(20ns) in 200us
- In storage ring, should cause by beam energy change





RF trip

- Conclusion
  - The bunch current is uniform
  - No obvious Instability oscillation
  - No position change
  - Longitudinal phase changed →Beam energy change

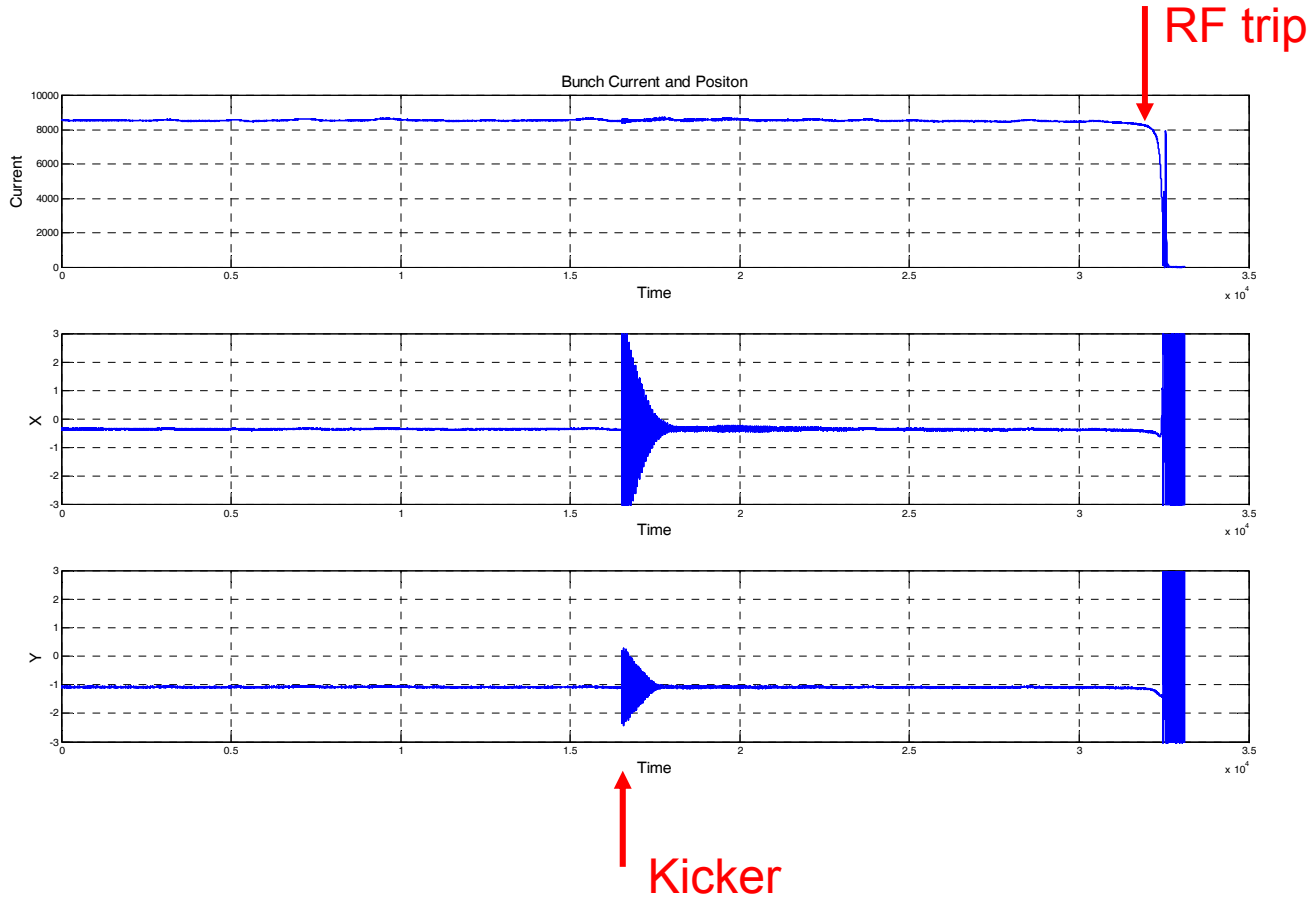
  →RF trip!

- Confirmatory experiment
  - Turn off the RF manually

Almost all the beam trip events in BEPCII storage rings are accompany with RF trip.

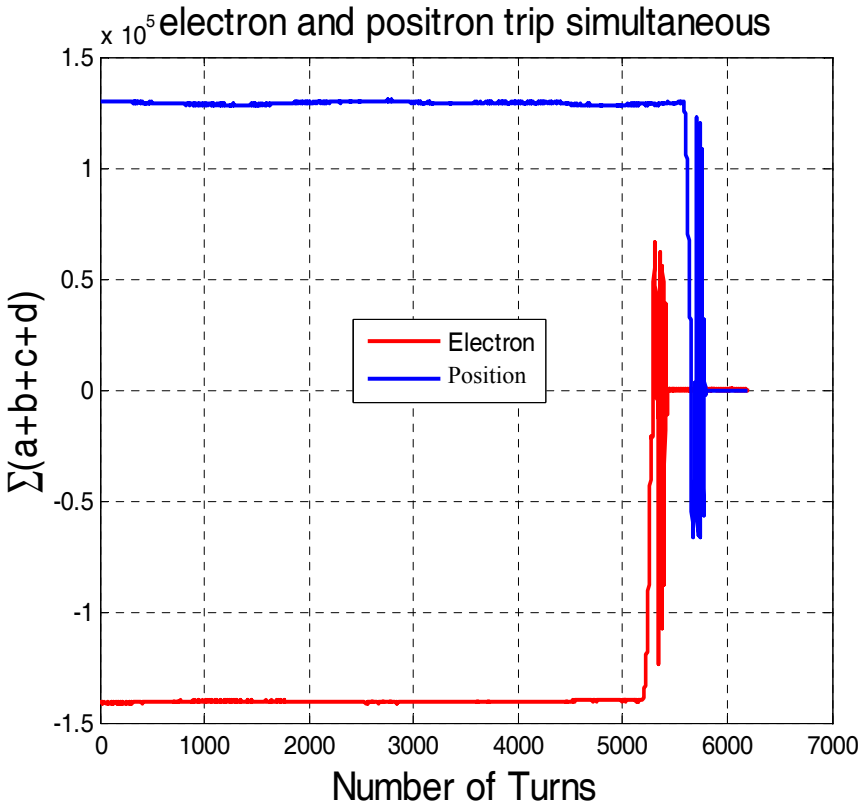
RF trip

- Beam trip in the process of injection



Double rings RF trip

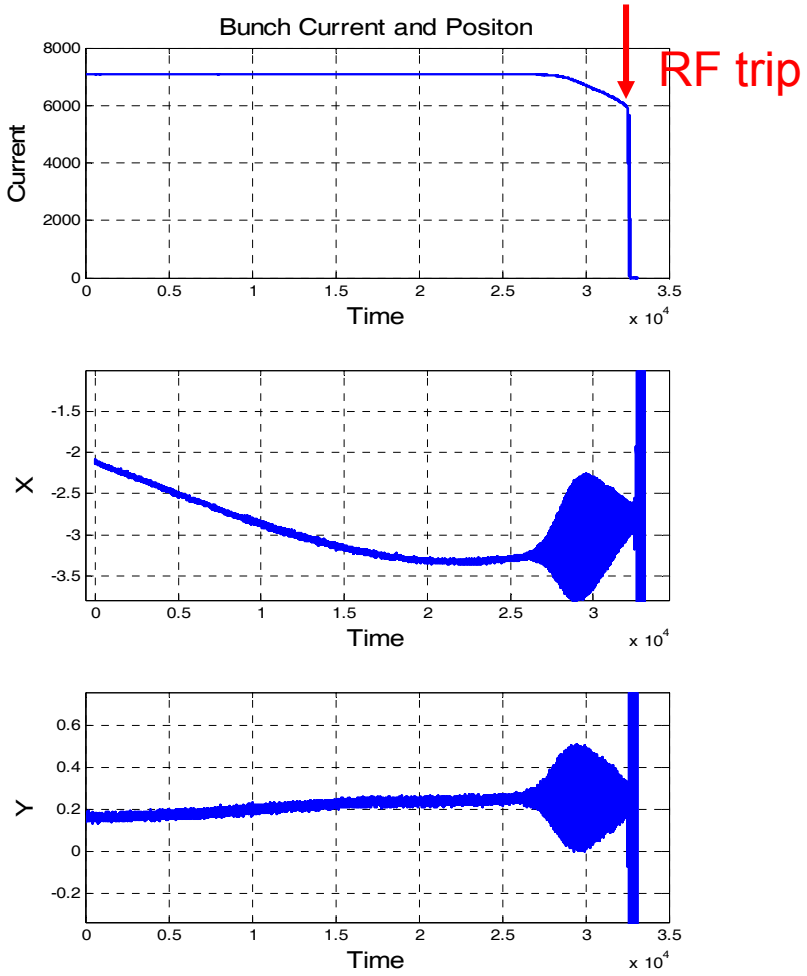
- Many double rings RF trip events



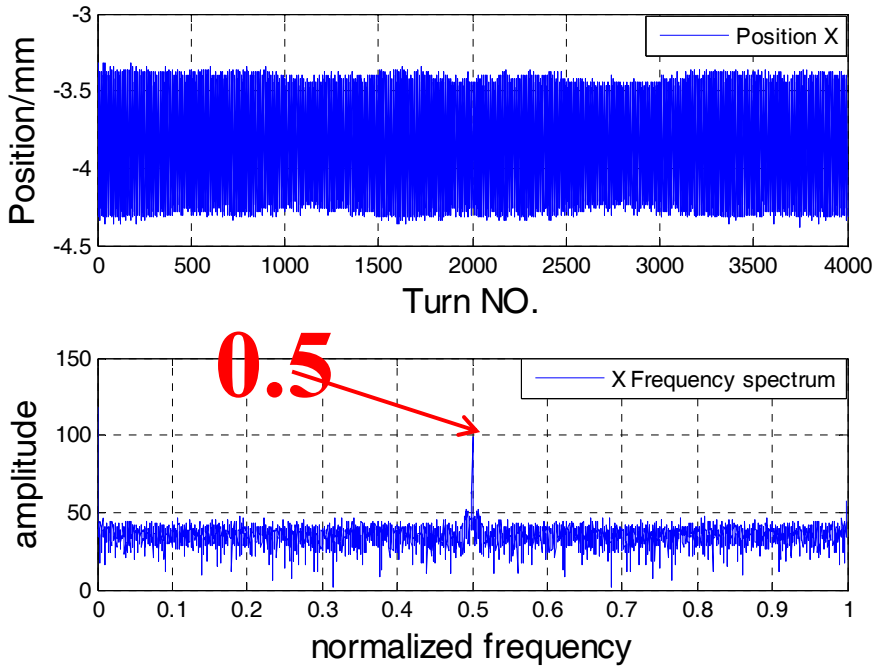
- Electron beam trip earlier than positron beam trip about 0.3ms
- The electron beam trip has no affection the positron beam motion.
- Double RF trip cause double beam trip.

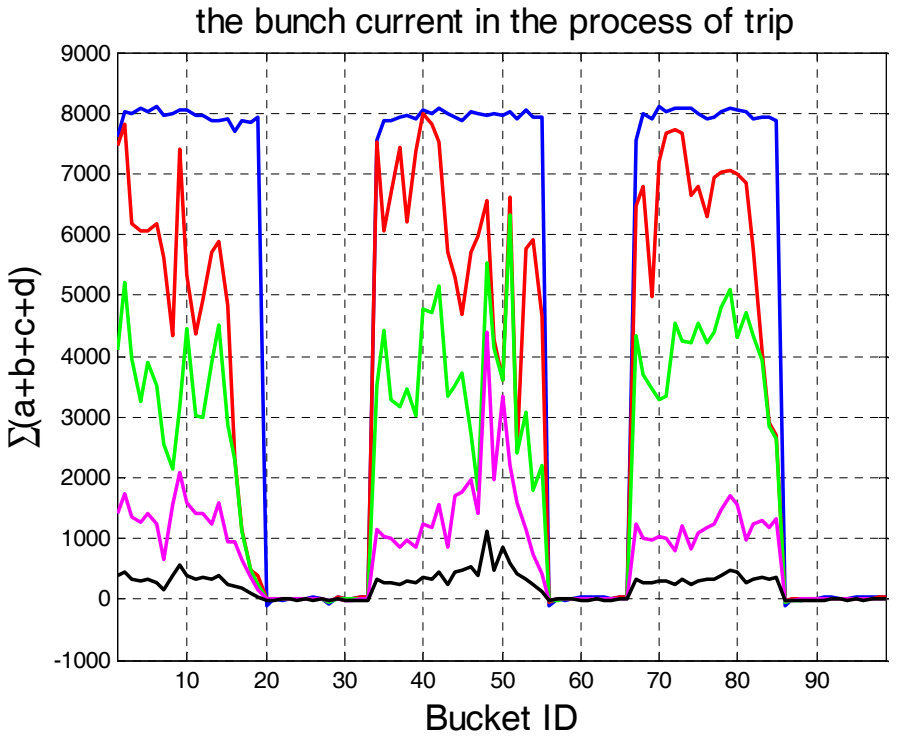
Magnet power instability

- Magnet power failure cause the beam trip is analysis in the right figure.
- Main to analyze the beam trip caused by Magnet power instability.



Magnet power instability: resonance





- In time domain, Beam position oscillation seriously → instabilities
- In frequency domain, the amplitude at 0.5 is very high → resonance
- The bunch current is nonuniform in the process of beam trip

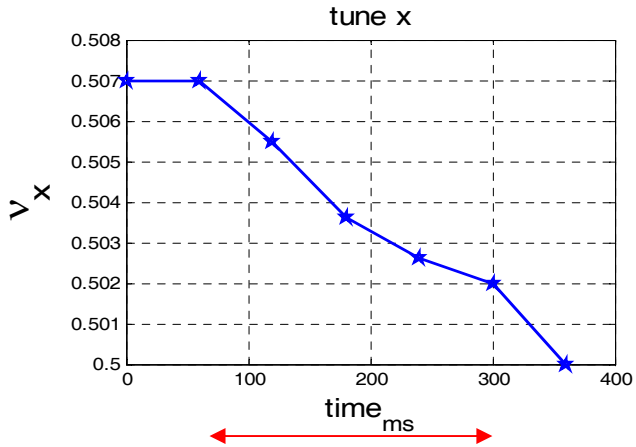
Whole process analysis

Magnet power instabilities (slow process)

→Beam position changed, Tune shift to half integer

→Beam resonance, partial beam loss

→RF trip, all beam loss



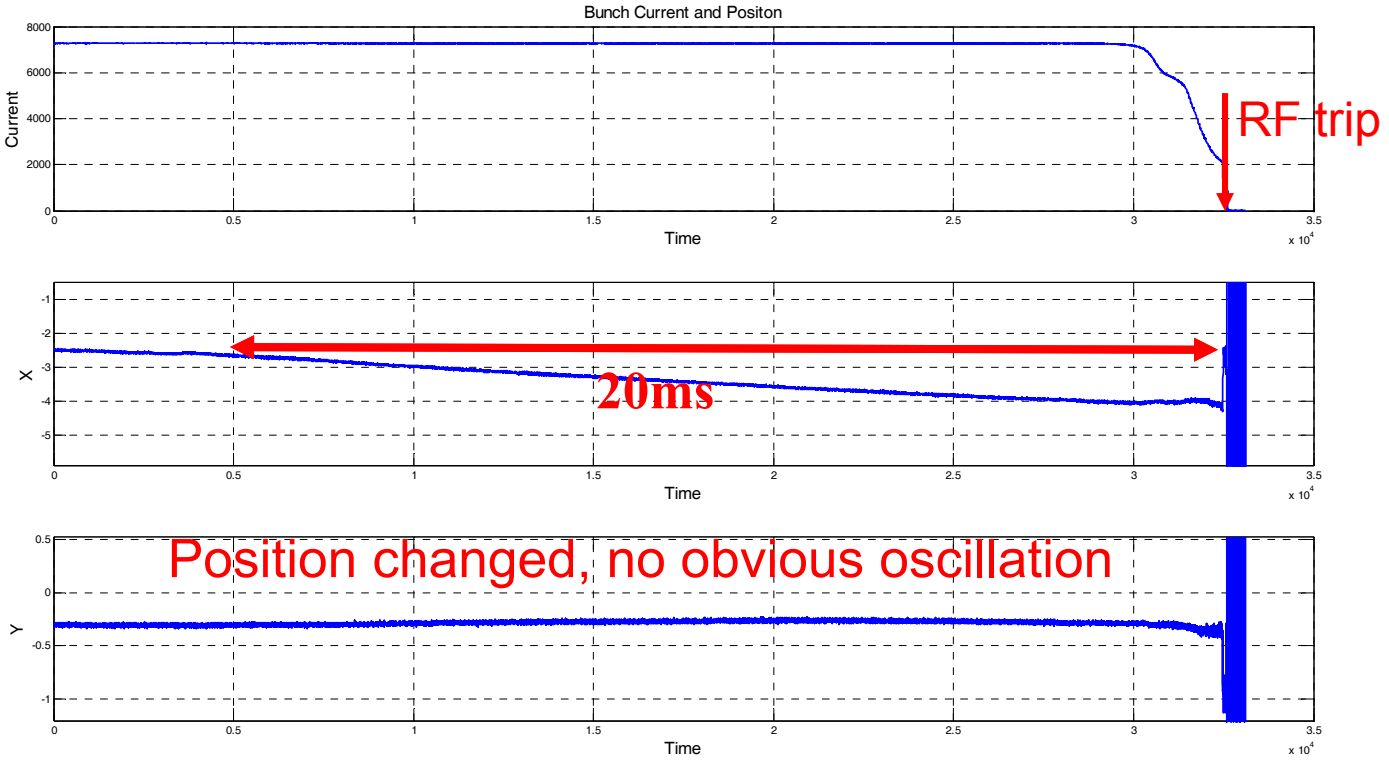
Magnet power instability

Magnet power instabilities (fast process)

→Position change

→Partial beam loss

→RF trip, all beam loss

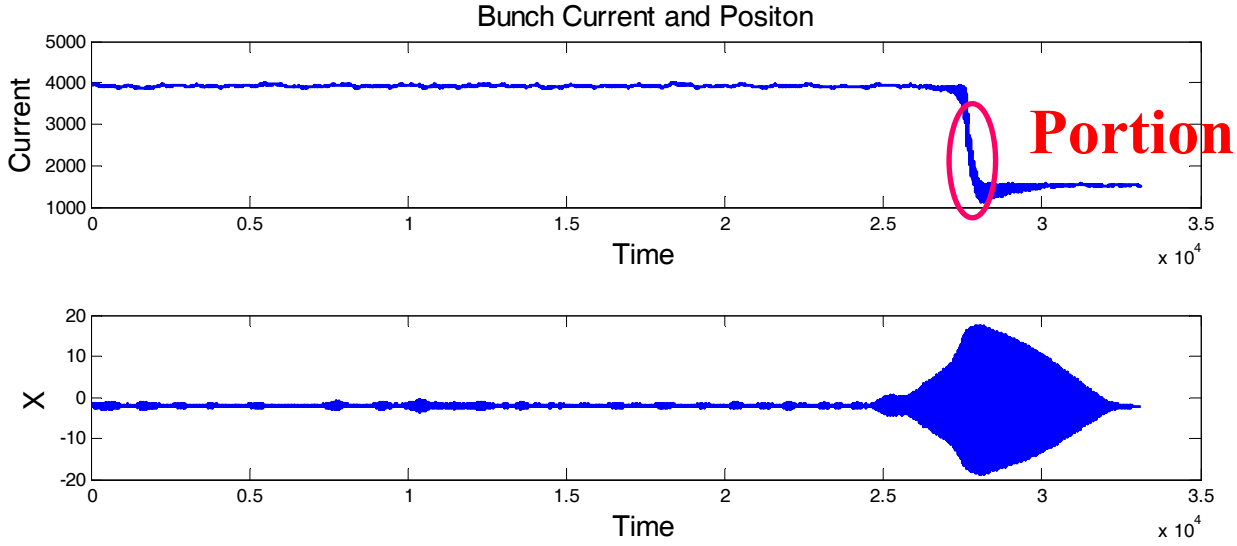


Magnet power instability

- To find the problem magnet, the faster process need faster data
  - Monitor: all magnet power, the monitor system may need as fast as 100Hz.
  - Calculation: form all BPM data in storage ring to find the unstable magnet

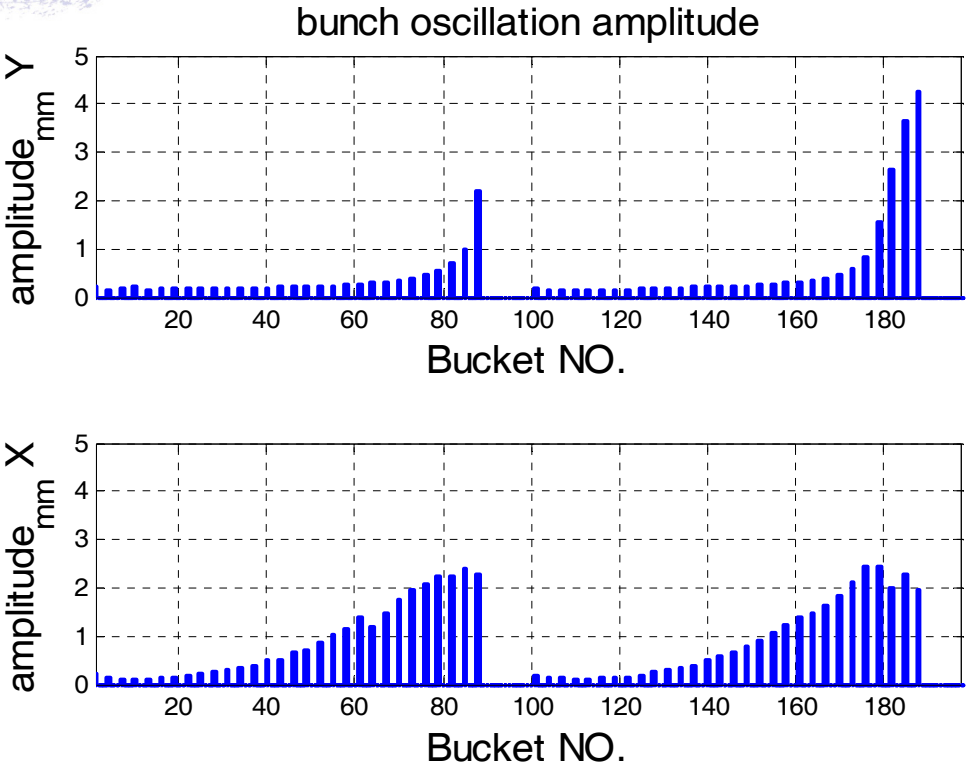
Beam instabilities

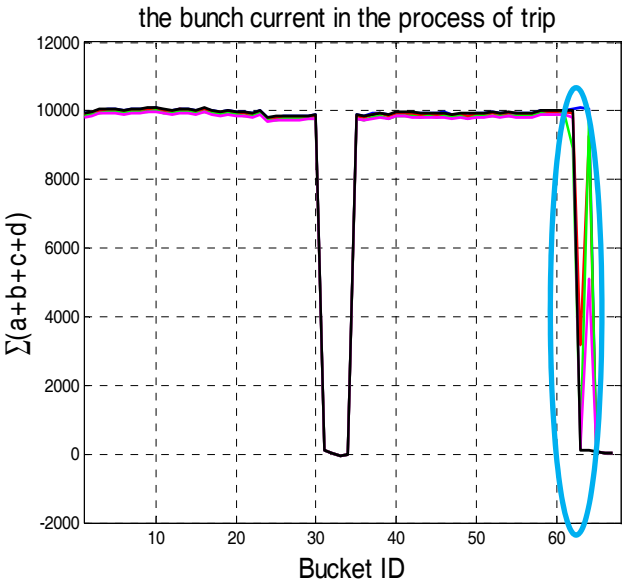
- BEPCII is running at high beam current condition
- Often change the parameters to get higher luminosity
- Beam instabilities feedback system may work at critical state



Portion current loss

Beam instabilities





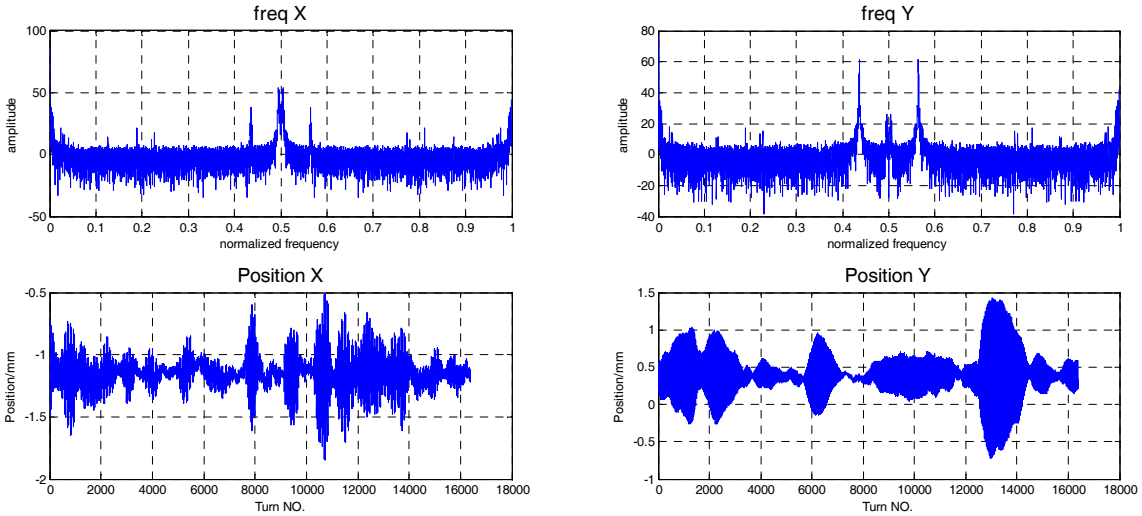
lost

→Beam oscillation increase along bunch trains, both in vertical and horizontal plane.

→The tail bunches at the second bunch train loss firstly cause by oscillation.

→Partial beam loss cause the RF trip, and the all beam loss.

Beam instabilities



Compare beam trip data to the normal beam data:
No Position change
No Bunch tune shift

- Solution for beam instabilities trip:
  - Adjustment the parameters of beam instabilities feedback system.
  - Optimize the fill pattern for high current operation.

Summary

- Advantage
  - System is very simple and stand alone.
  - Beam based Analysis method: directly and accurately .
  - Good at RF trip and multi-bunch instabilities trip analysis.

- Turn-by-turn BPM → Bunch-by-bunch BPM
- Big data!

What is can we do more from bunch-by-bunch BPM?

→ More powerful for beam trip analysis.

→…

- Thank you for your attention !