

SuperKEKBにおけるイベントシステム診断

The Fault Analysis of Timing System in SuperKEKB

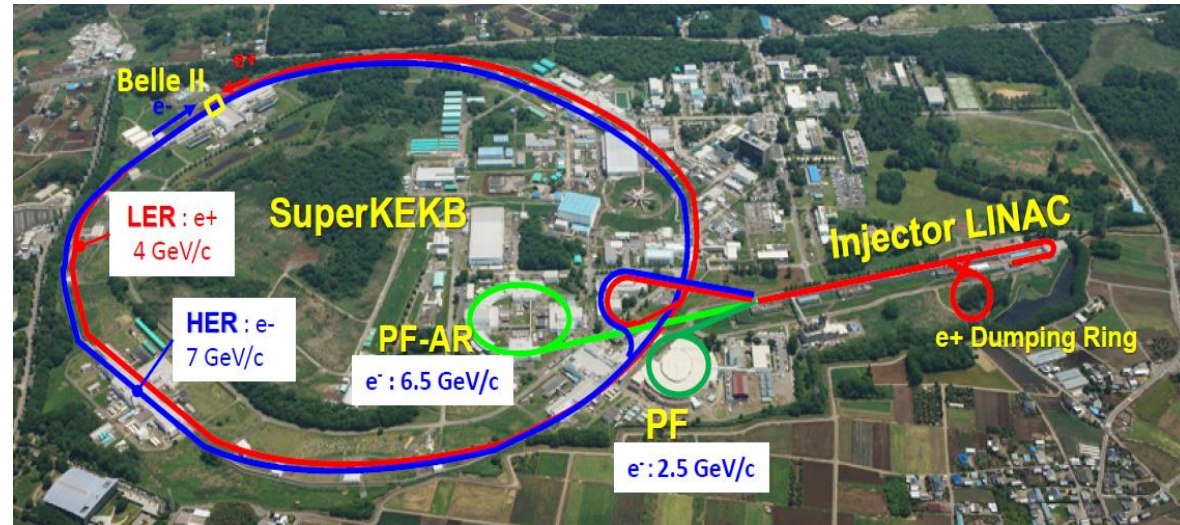
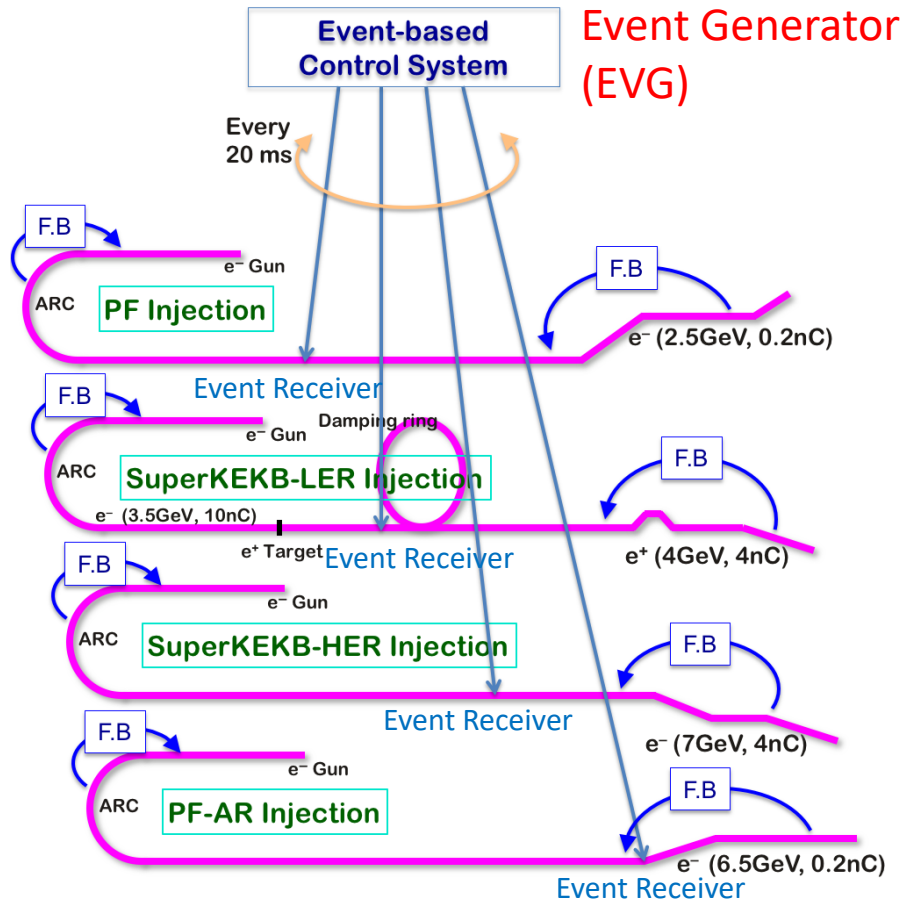
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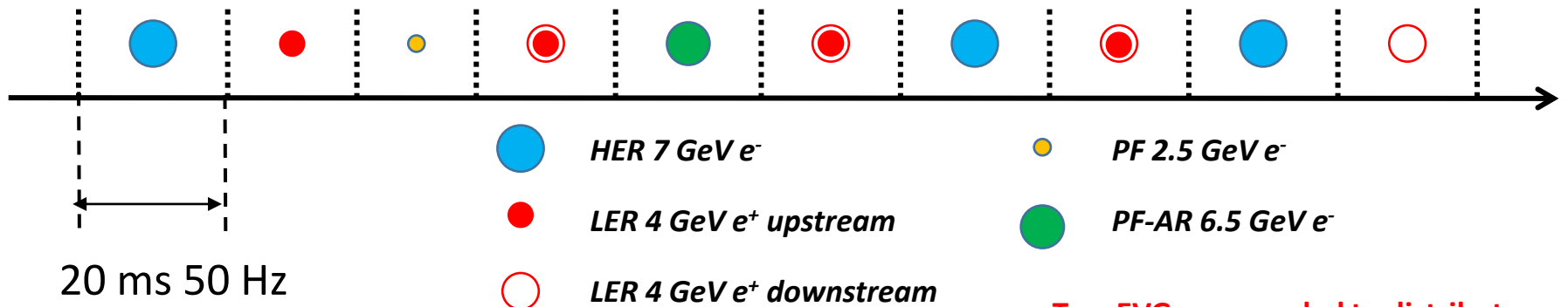
要旨

The high availability of an accelerator timing system is of great significance for the operation of the SuperKEKB electron-positron collider. To distribute the high precision level trigger signals for synchronizing all the relevant components in the accelerator complex, event based timing system is utilized to control the injection procedure in SuperKEKB. Another critical challenge of the timing system is to control the bucket selection of both electron and positron beam bunch. The failure in timing system would definitely affect other systems like pulsed magnet, BPM and so on, and as a consequence leading an unfavorable impact on the effectiveness of the particles collide. Additionally, a newly built positron damping ring decrease the positron emittance but meanwhile brings higher complexity of the bucket selection. In this paper, we will demonstrate the algorithm of the timing system and introduce our fault analysis system which helps up to analyze the timing error, improve the accelerator operation stability.

Timing System in SuperKEKB



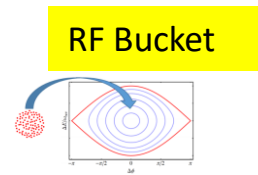
- 4 (+1) rings
- 10 beam modes (5 for normal operation 5 for beam study)
- Positron has three injection options in one pulse:
 - to DR only (upstream)
 - DR to MR only (downstream)
 - both



Two EVGs are needed to distribute event codes to the accelerator

Bucket Selection

- Beam should be injected into the ring RF bucket make sure that the particle always sees an accelerating voltage at RF cavities.
- Define the bucket number `0` as the first bunch which extracts from DR and injects to the MR.
- i.e. by delaying 96.3 ns, we could inject the bunch into DR bucket 49 and MR bucket 49.



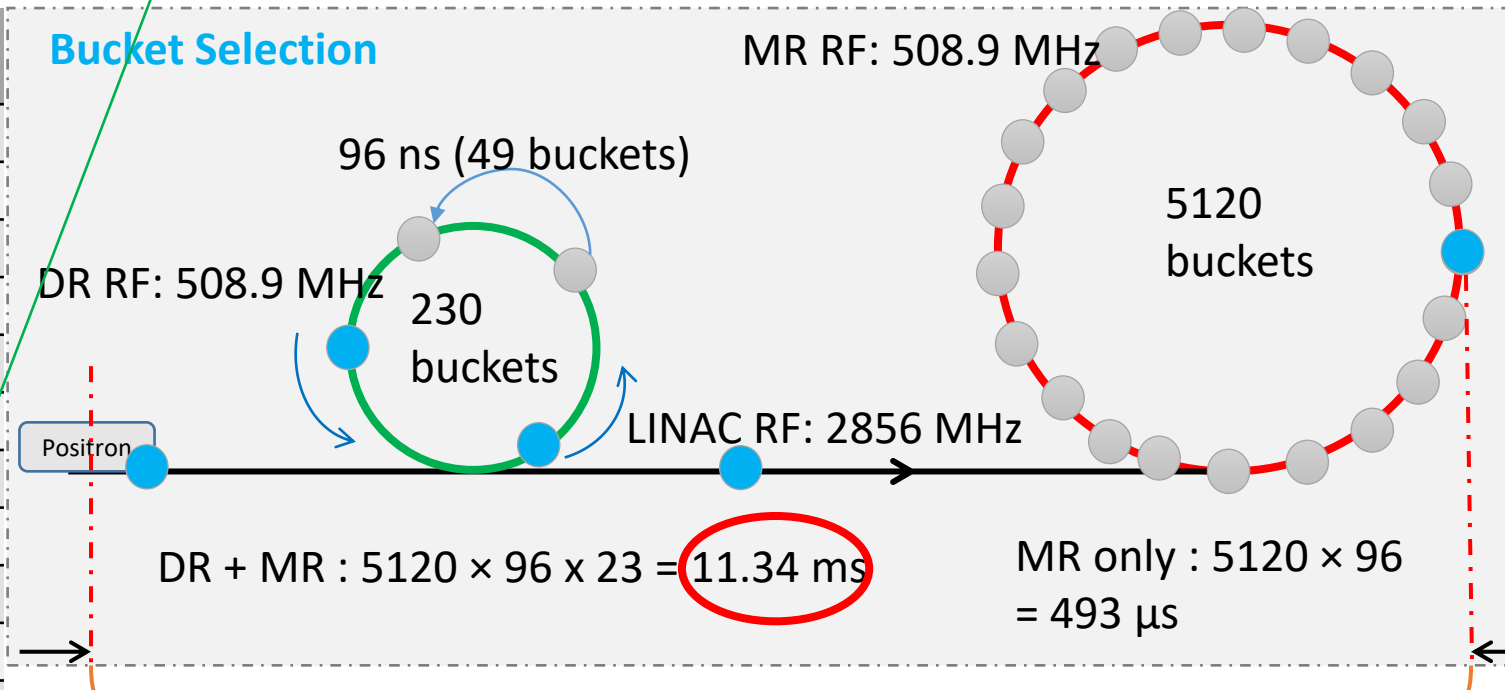
$$BKT_{DR} = Inj_{turn} * 49 \% 230$$

$$BKT_{MR} = Inj_{turn} * 49 \% 5120$$

$$0 = 230 * 49 \% 230$$

$$1030 = 230 * 49 \% 5120$$

Injection opportunity	Delay	DR Bucket	MR Bucket
0	0 ns	0	0
1	96.3 ns	49	49
2	192.6 ns	98	98
3	288.9 ns	147	147
4	385.1 ns	196	196
5	481.4 ns	15	245
...
230	22.1 us	0	1030
...
5120	492.9 us	180	0
...
20771	1.99 ms	29	4019
20772	2 ms	78	4068
...
117,760	11.34 ms	0	0



**Bunch needs to circle many turns (40 ~ 200 ms) in the DR!
40 ms is the minimal damping period.**

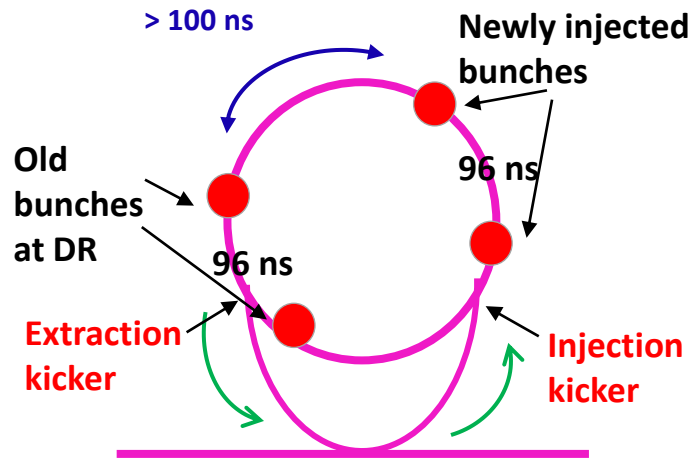
For example:

$$0 = 117760 * 49 \% 230$$

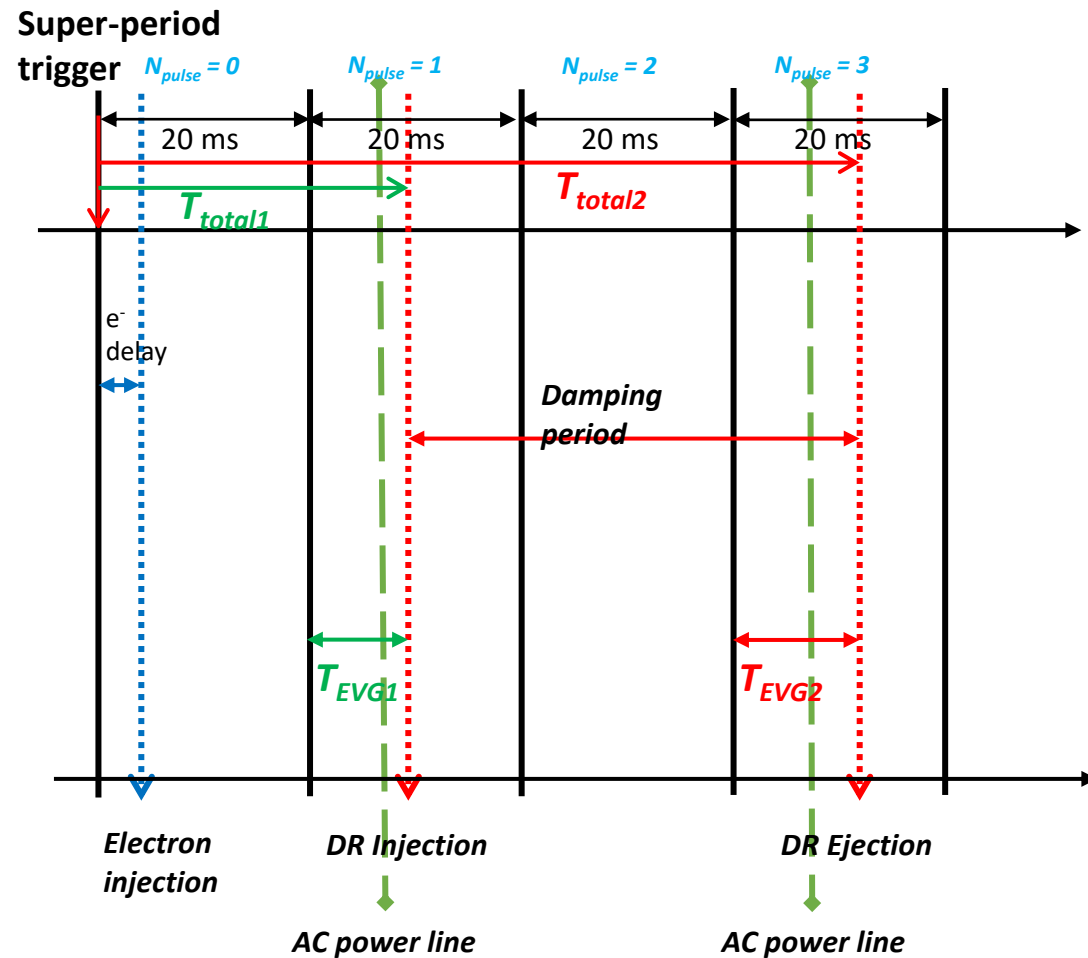
$$0 = 117760 * 49 \% 5120$$

Other Restrictions

- Besides the RF frequency synchronization and bucket selection, other restriction exists too.
- The injection opportunity to the same ring bucket appears every 493 us, so there are 4 opportunities during 20 ms.
- Owing to the hardware requirement (klystron modulator), we choose the opportunity which is closest to the AC Power Line (a.k.a. AC50).
- Owing to the requirement of the kicker magnet at DR, only 2 ms fluctuation is allowed for injection. As a consequence, not all MR bucket can be selected for positron. The solution by shifting the LINAC RF frequency to increase the extraction opportunity is currently under experiment.

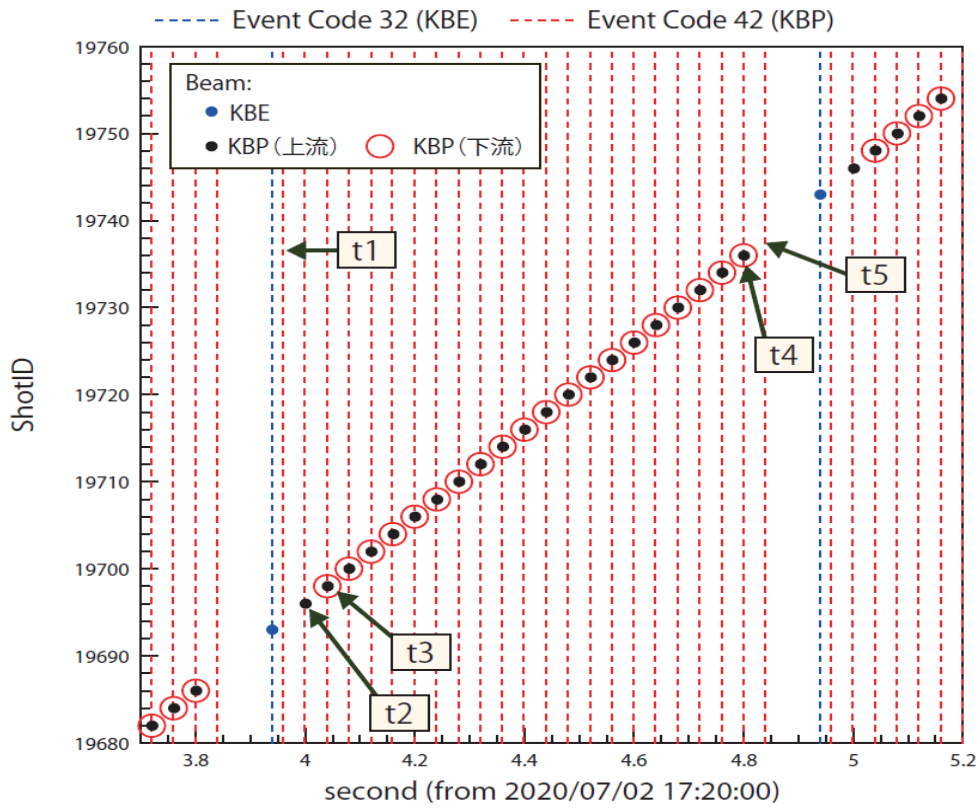
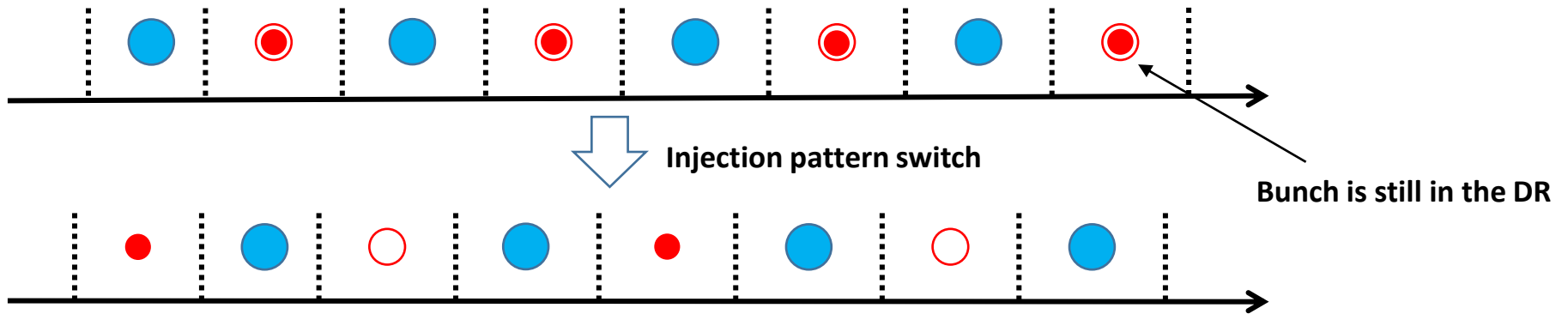


Some buckets in DR cannot be injected

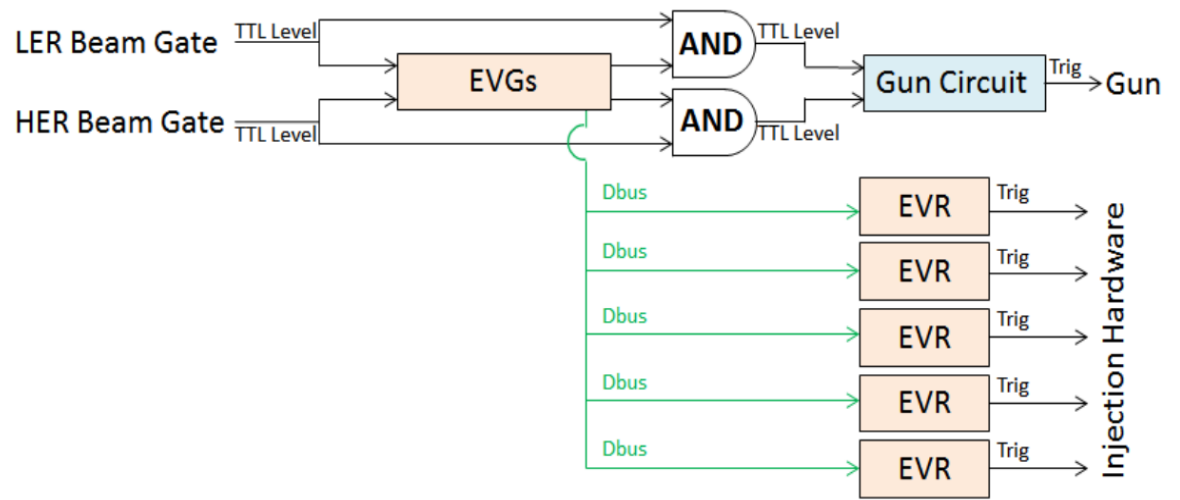


- Using T_{total2} and T_{total1} to calculate T_{EVG2} and T_{EVG1} .
- T_{EVG1} and T_{EVG2} are calculated at the same time but T_{EVG2} value is buffered while T_{EVG1} is sent out immediately.
- Injection should happen near the AC power line.

Timing System Failure Mode



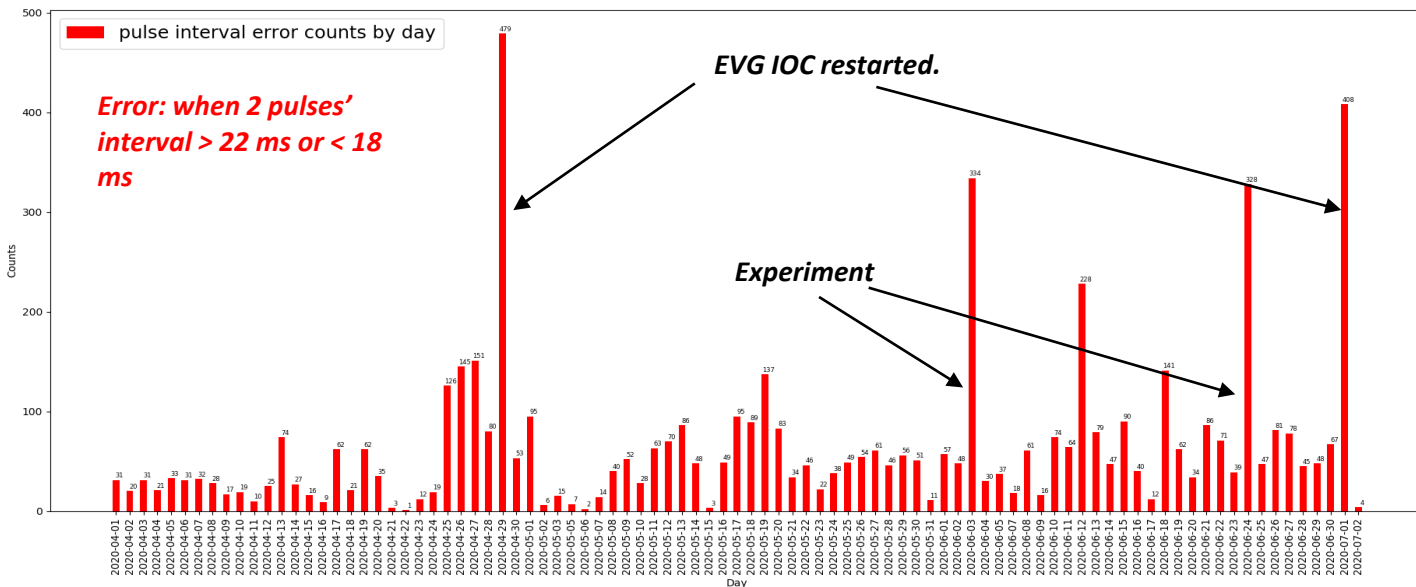
● HER 7 GeV e^- ○ LER 4 GeV e^+ downstream
● LER 4 GeV e^+ upstream



- At pulse t1, the bunch was lost
- At pulse t5, the bunch was not extracted from Damping Ring

- Beam Gate which controls the gun should close during injection pattern switch.
- Besides the pattern switch, the drift of AC power line might also cause error.

Timing System Failure

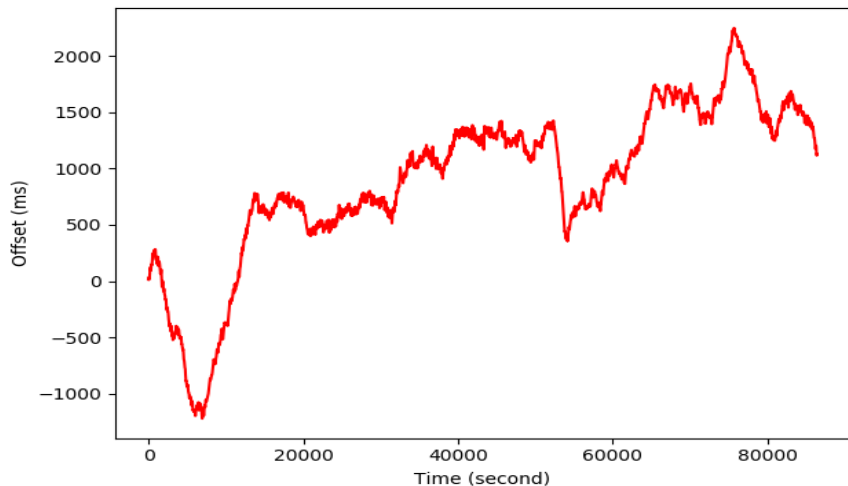


Since beam repetition rate is 50Hz, the interval between two pulse should be within 18 ~ 22 ms.

From 2020-04-01 to 2020-07-02
For better visualization, some kinds of interval error are omitted.

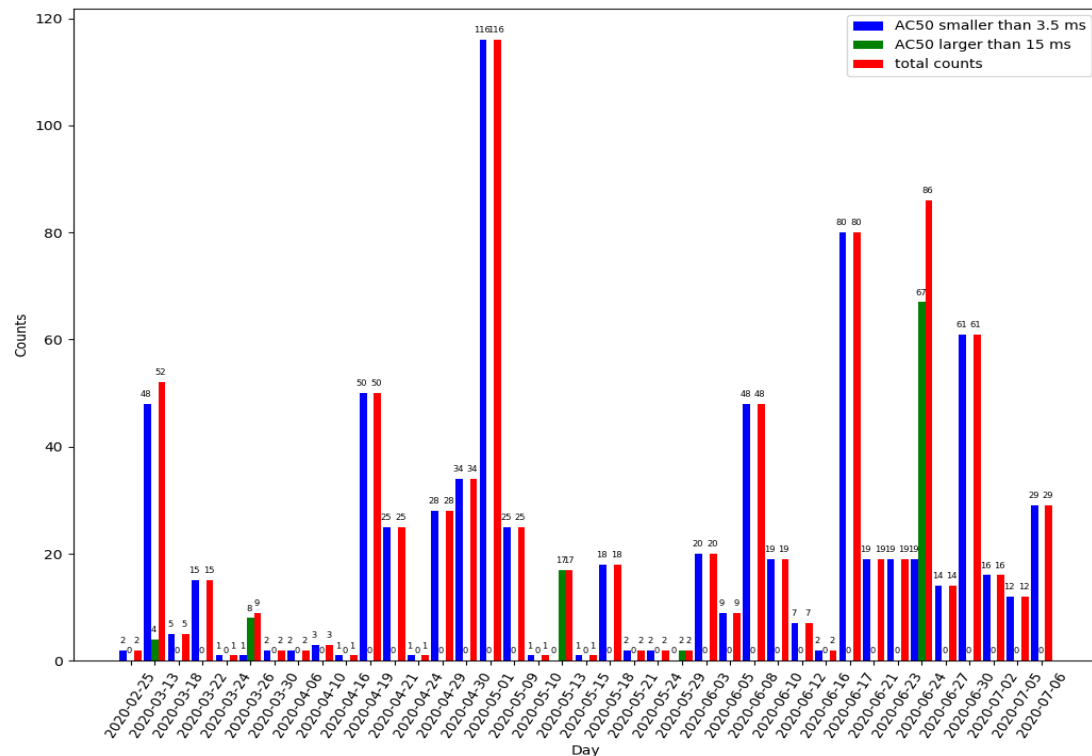
Average error times per day: **64.80**

AC50 Fluctuation Trend on 2019-09-23



AC Power Line always fluctuates and if the fluctuation is sharply timing system might fail to find the injection point.

Right picture: From 2020-01-17 to 2020-07-06
Only edge AC50 values existing days are listed.
Risk AC50 value happens times per day: 21.92



Timing System Monitoring Plan

Event Timing System

Contains 2085 EPICS PVs

Timing System Monitor

Metric

Heartbeat

Logs

Performance Alarm

Error Alarm

Metric Visualize

Critical Data Analytics

Documentation

Archiver

iocStats/
vxStats

Notification Method

Dashboard
(Kibana/
Grafana)

Reflective Memory
Cheat sheet

Beam Gate

Operation Log

Mail list

Event Code

AC50

Bucket Selection

Data Flow

Memo