Analysis of AC Line Fluctuation for Timing System at KEK

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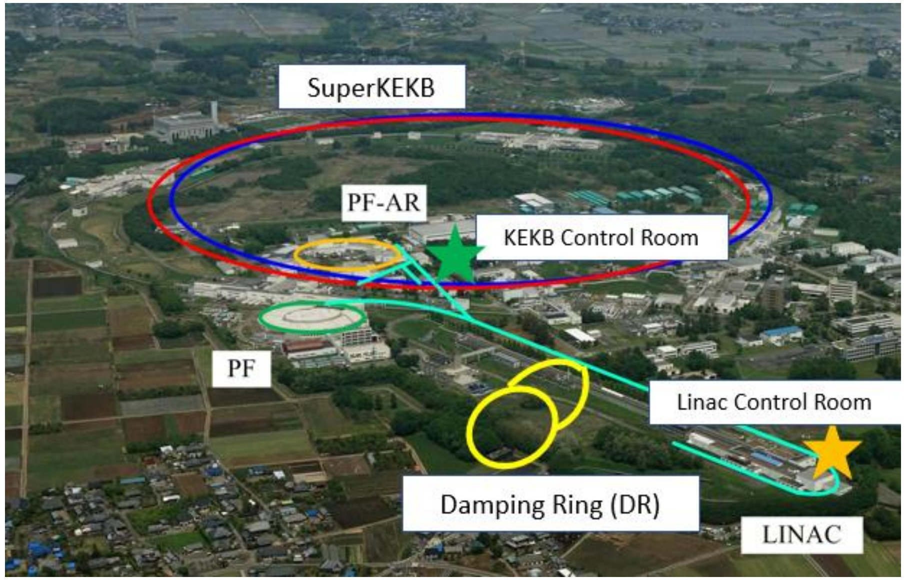
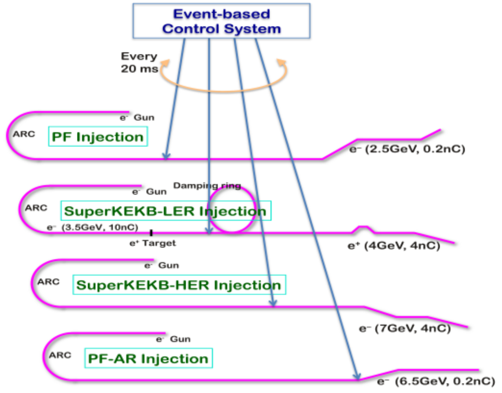
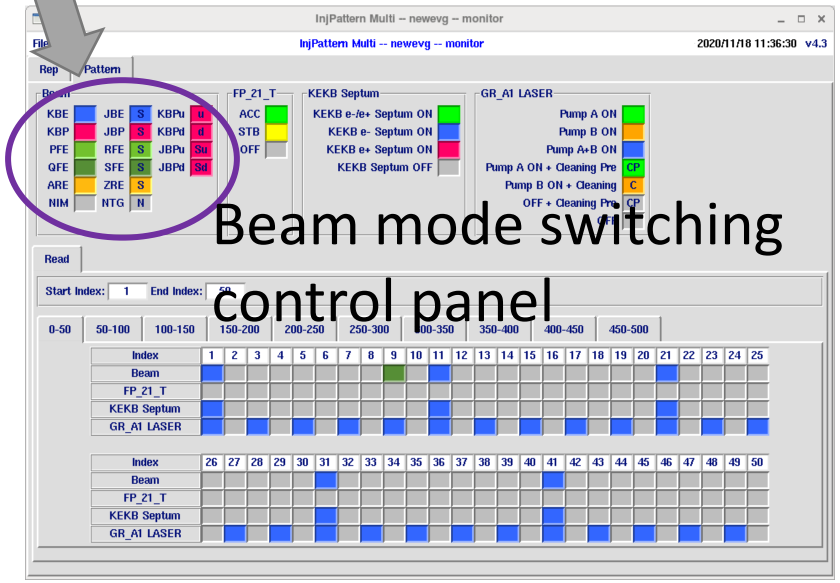


Direction	Particle	Energy (GeV)	Charge (nC)
SuperKEKB-DR	e^+	1.1	4.0
SuperKEKB-LER	e^+	4.0	4.0
SuperKEKB-HER	e^-	7.0	4.0
PF	e^-	2.5	0.2
PF-AR	e^-	6.5	0.2

- One LINAC injects into to 4 (+1) rings simultaneously
  - SuperKEKB DR
  - SuperKEKB Low Energy Ring
  - SuperKEKB High Energy Ring
  - PF
  - PF-AR
- Beam modes switching in 50 Hz operation
- 12 beam modes
- Event-based system
- More than 30 timing modules (EVG, EVR)
  - MRF modules
  - SINAP modules
  - Self-implemented EVRs (for LLRF)



12 defined beam modes



Beam mode switching control panel

Bucket Selection for SuperKEKB LER

Bucket Selection Cycle (BSC): In one bucket selection cycle, all RF buckets can be selected.

Injection opportunity	Delay	DR Bucket number	LER Bucket number
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 µs	0	1030
…	…	…	…
5120	492.9 µs	180	0
…	…	…	…
20771	1.99 ms	29	4019
20772	2 ms	78	4068
…	…	…	…
117,760	11.34 ms	0	0

$$N_{LER} = MOD\left(\frac{T_{delay} * 49}{96.3}, 5120\right)$$

$$N_{DR} = MOD\left(\frac{T_{delay} * 49}{96.3}, 230\right)$$

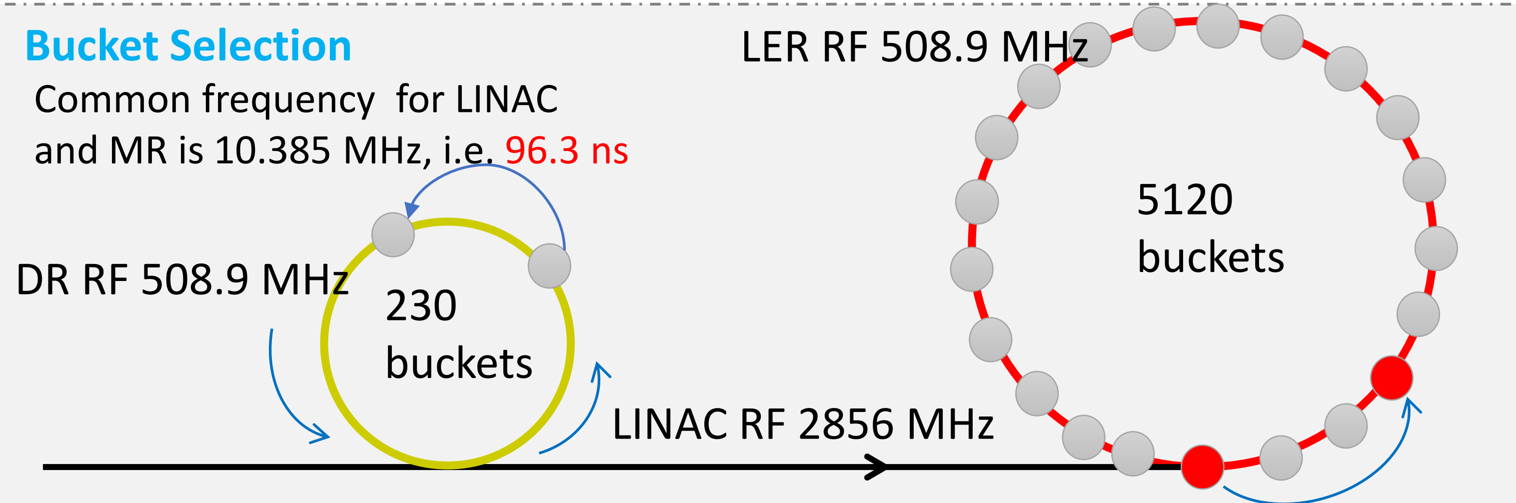
$$T_{BSC-DR} = 230 * \frac{1}{10.385} = 22.15\mu s$$

$$T_{BSC-LER} = 5120 * \frac{1}{10.385} = 492.9\mu s$$

Frequency	Period	Remarks
2856 MHz	350 ps	RF frequency for Linac
508.89 MHz	1.97 ns	RF frequency for DR & LER
114.24 MHz	8.75 ns	Event clock
2.21 MHz	452 ns	DR revolution frequency
99.39 kHz	10.06 μs	LER revolution frequency
45.15 kHz	22.15 μs	BSC for DR only
2.03 kHz	493 μs	BSC for LER only
88.19 Hz	11.34 ms	BSC for DR and LER
50 Hz	20 ms	BRR

Bucket Selection

Common frequency for LINAC and MR is 10.385 MHz, i.e. 96.3 ns



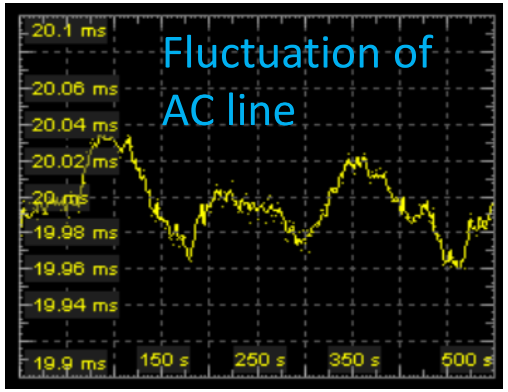
Overall BSC for DR and LER :
508.9 MHz / 49 / 5120 / 23 = 88.19 Hz (11.34 ms)

AC Line Synchronization

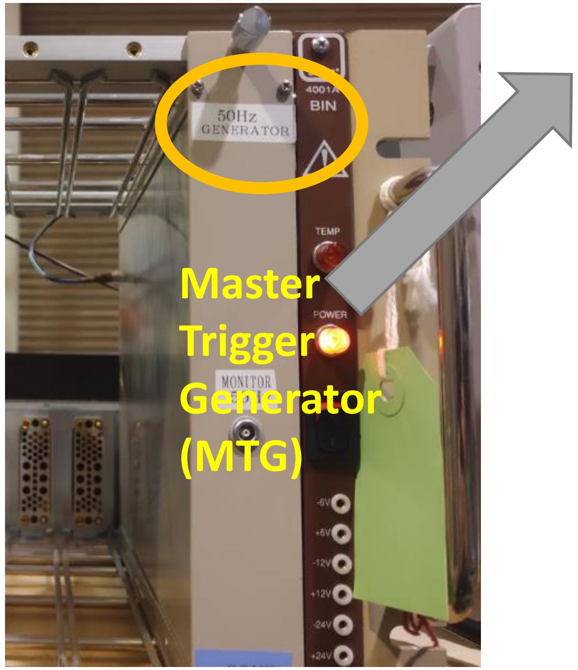
Why?

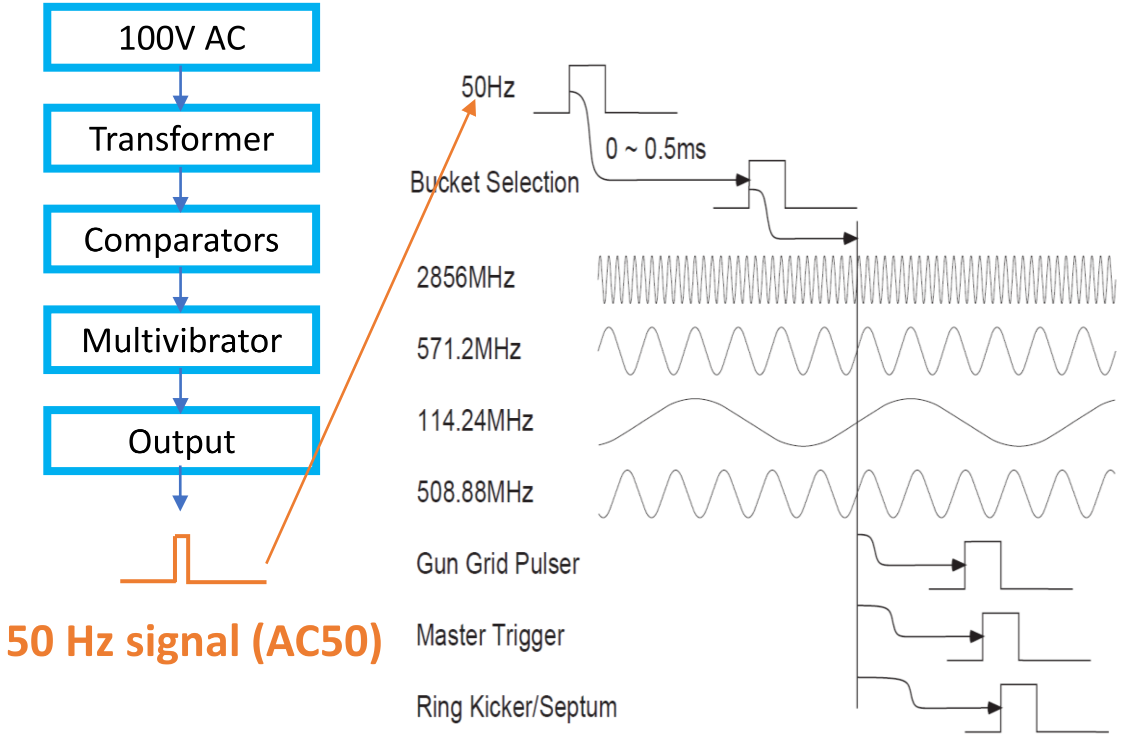
The beam quality measured during KEKB era was related to AC phase, so the timing trigger signal was generated at the same AC phase since KEKB timing system.

The Tokyo Electric Power Company adjusts the AC line frequency (50±0.2 Hz) to meet the market demand.



How?



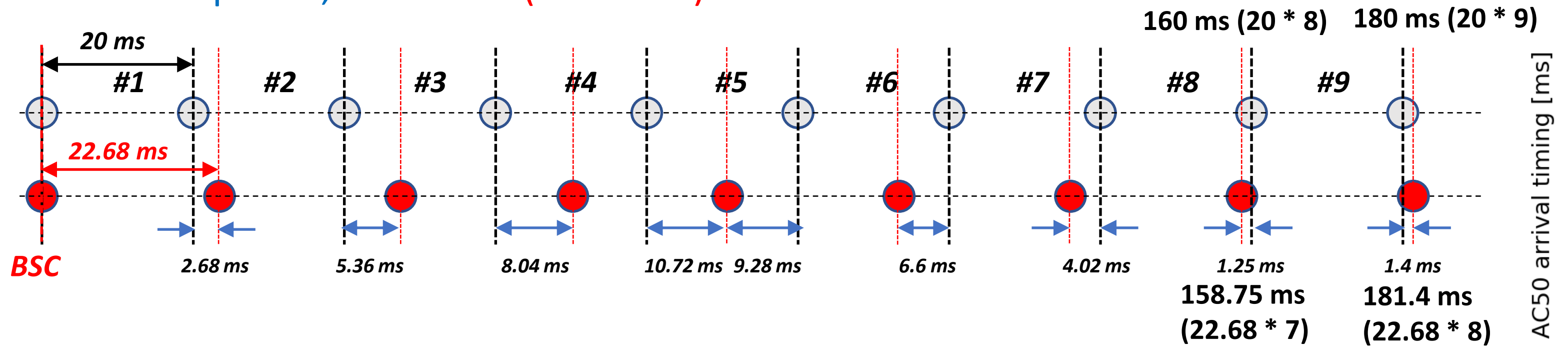


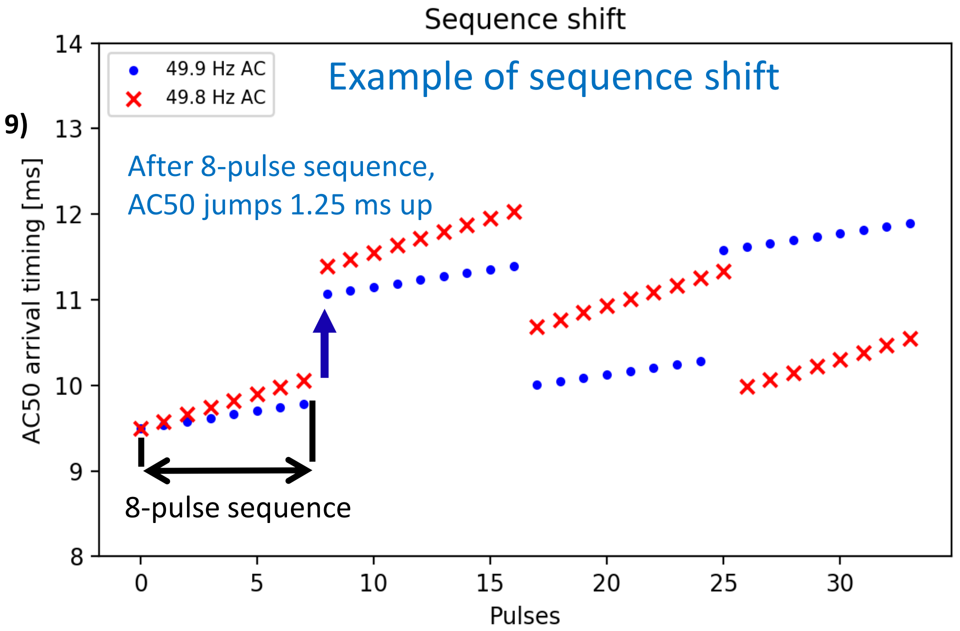
The MTG module (NIM based) receives 100V AC line and output a 50 Hz signal (AC50) to serve as the fiducial for timing system

- AC line synchronization during KEKB era
- Can not work for SuperKEKB as 11.34 ms BSC is too long

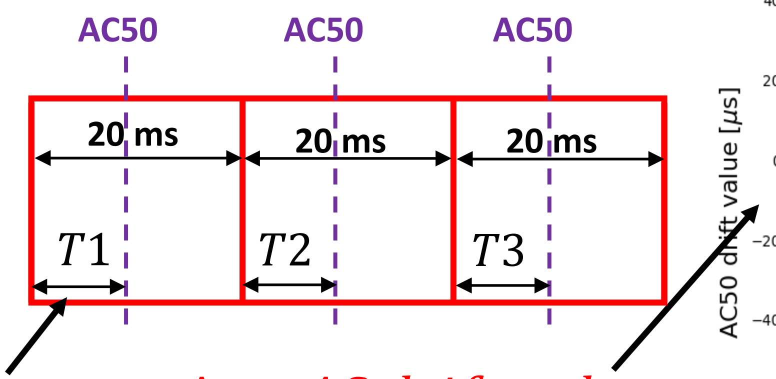
Sequence Shift

Sequence shift is used to synchronize 88 Hz BSC and 50 Hz AC line.
To be simplified, 44 Hz BSC (22.68 ms) is used rather than 88 Hz.





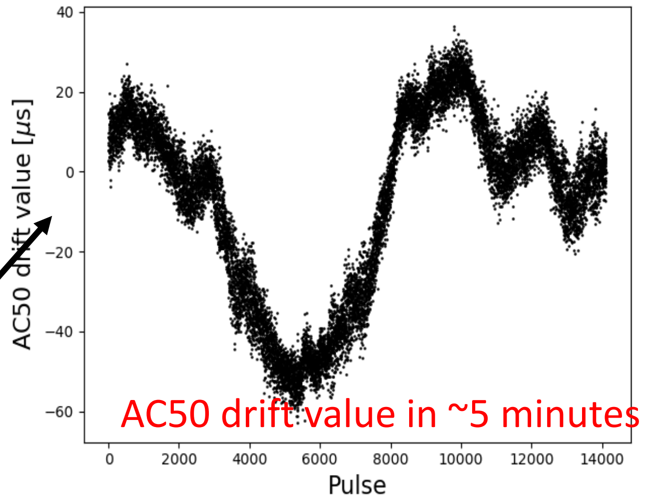
44 Hz BSC can re-synchronize with 50 Hz AC after 8 pulses or 9 pulses.
Then we manage to control AC50 signal arrive in the middle of every 20 ms pulse.



AC50 arrival time

Δ_{AC}: $AC\ drift\ value$

$\Delta_{AC} = T2 - T1$



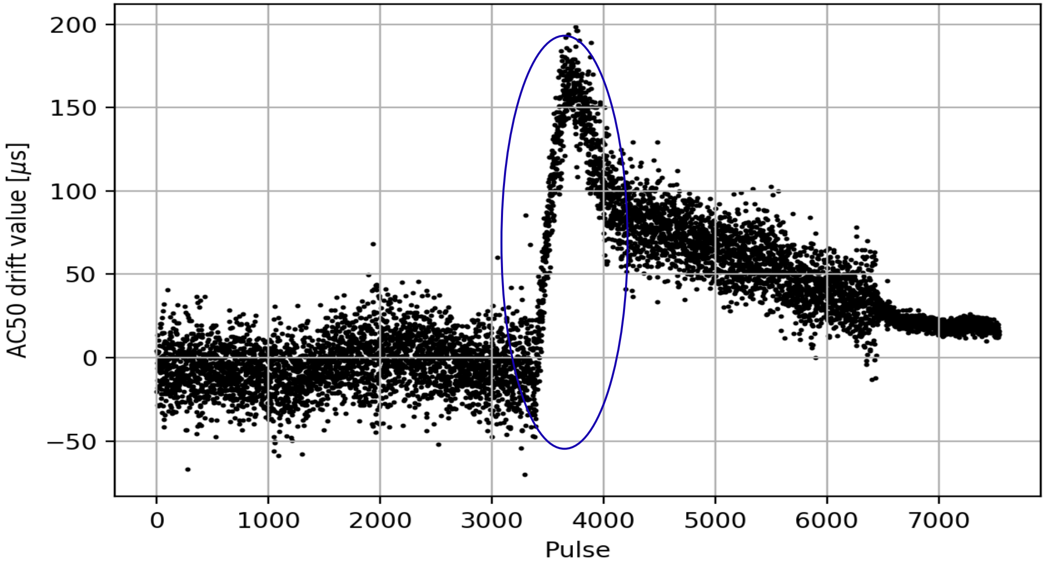
AC50 drift value in ~5 minutes

Main idea of sequence shift: using AC50 arrival time to estimate AC50 value in future pulse and then select proper sequence type for next sequence.

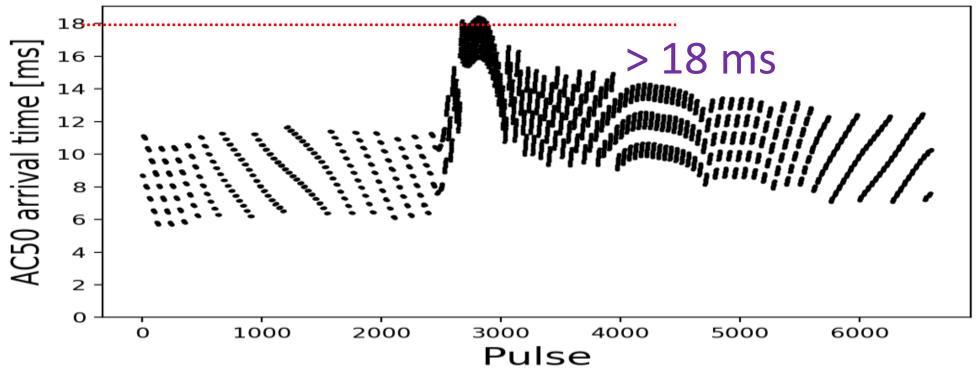
Thus we can keep the AC50 arrival time in the middle of every pulse, i.e., AC50 arrival time is within 5~15 ms every pulse.

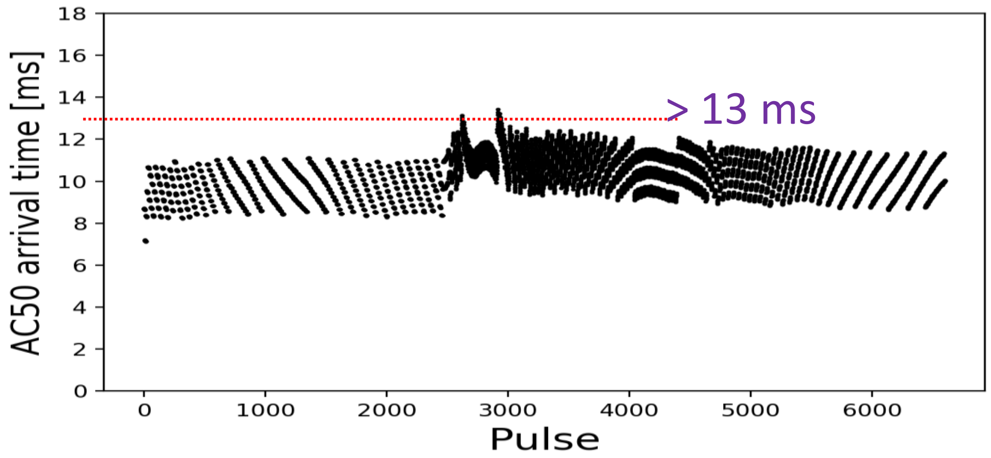
Stabilization of Timing System

Problem: sometimes AC line fluctuates strongly and Δ_{AC} is larger than 80μs (50±0.2 Hz)
If AC50 arrival time is larger than 15 ms or smaller than 4.5 ms, the timing system switch logic fails and timing system fails to control the accelerator.



On Oct 2019, Δ_{AC} becomes very large during ~10 seconds. Then timing system failed and injection was aborted.





By upgrading the sequence shift algorithm ,the timing system now is able to handle such extreme situation and keep beam operation stable.