Timing System

Hiroshi Kaji

Injection Control

Main Trigger Station performs injection control with following three key items.

Large Area Control:
- control whole hardware along 600m beamline
- farthest is injection point of Main Ring ~ 1000m

Timing Synchronization:
- all functions must be synchronized with each other
- also with timing of injection RF-bucket

Pulse-to-Pulse Modulation:
- more than 150 of LINAC parameters must be changed
- for “simultaneous” top-up filling into more than one ring.

All of them are realized with Event Timing System.

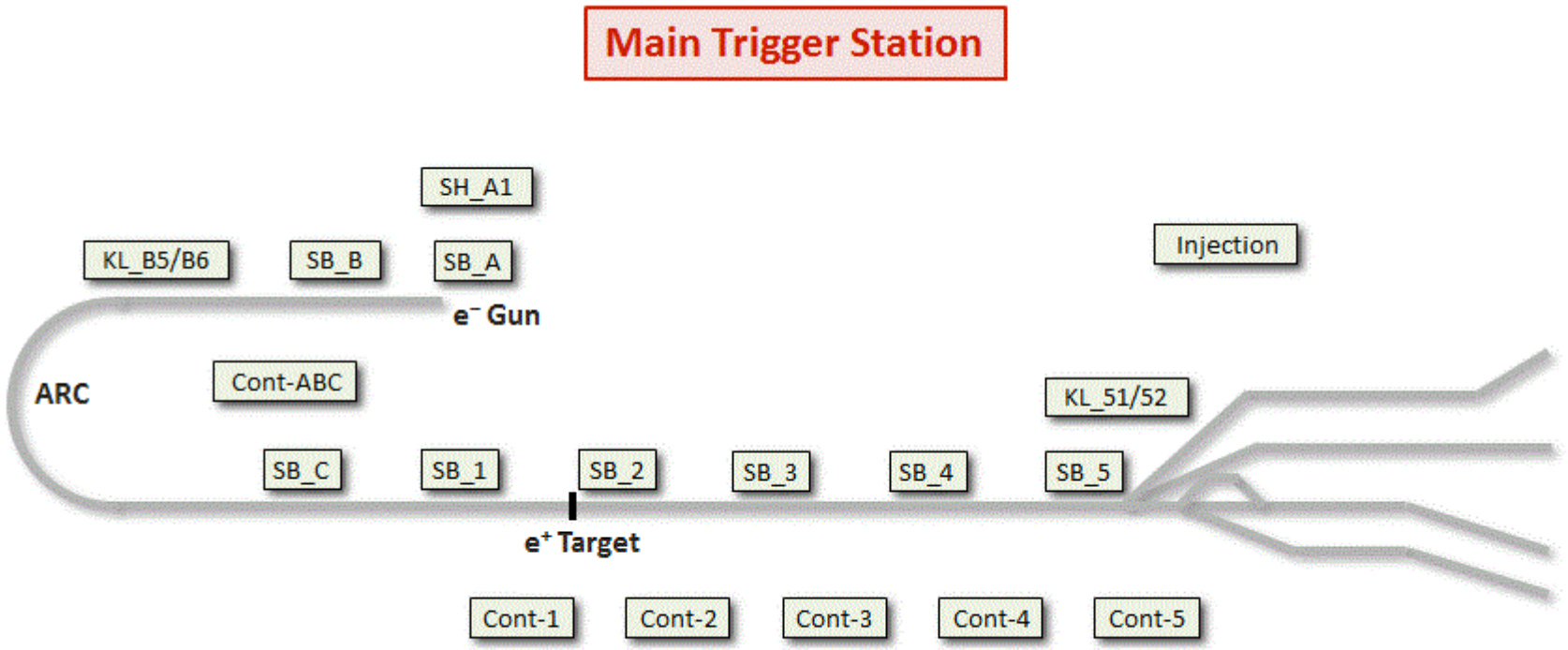
Pulse-to-Pulse Modulation

Top-up operation for 4 rings "simultaneously" with only one Linac

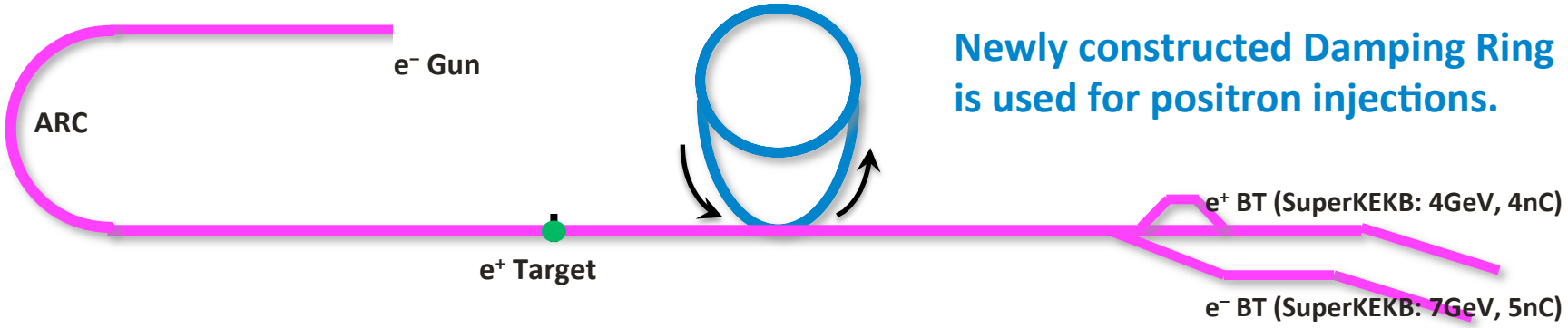
Switch beam types and directions in 50Hz

Change >150 of Linac parameters in 50Hz

Direction	Particle	Energy	Charge
KEKB HER	e^-	7.0 GeV	5.0 nC
KEKB LER	e^+	4.0 GeV	4.0 nC
PF	e^-	2.5 GeV	0.2 nC
PF-AR	e^-	6.5 GeV	5.0 nC



New requirements for SuperKEKB



Newly constructed Damping Ring is used for positron injections.

Followings are needed for positron injection

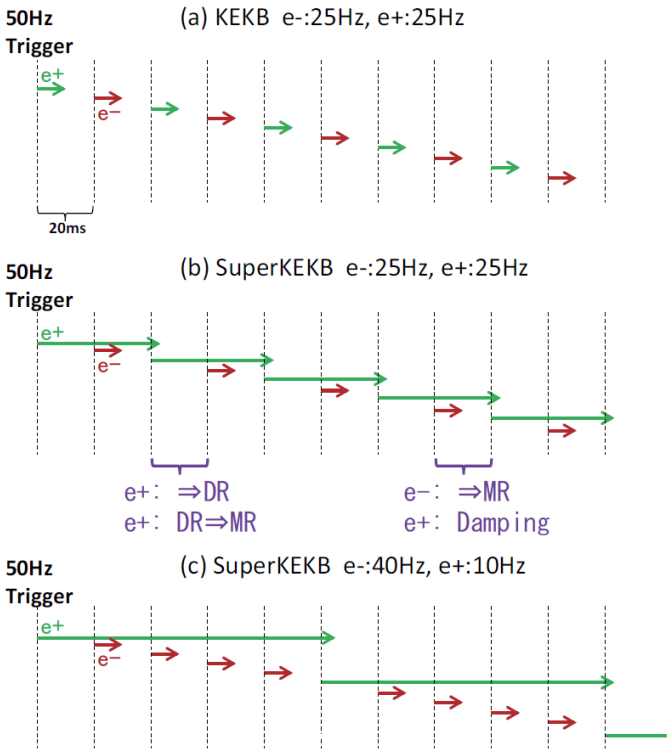
Longer than 40ms control

- Positron damping is implemented at least 40ms.
- Entire process takes more than one injection period.

Electron injection during positron damping

Control 1st and 2nd halves of Linac separately

e⁻ Gun ⇒ DR (1st half)
DR ⇒ MR (2nd half)



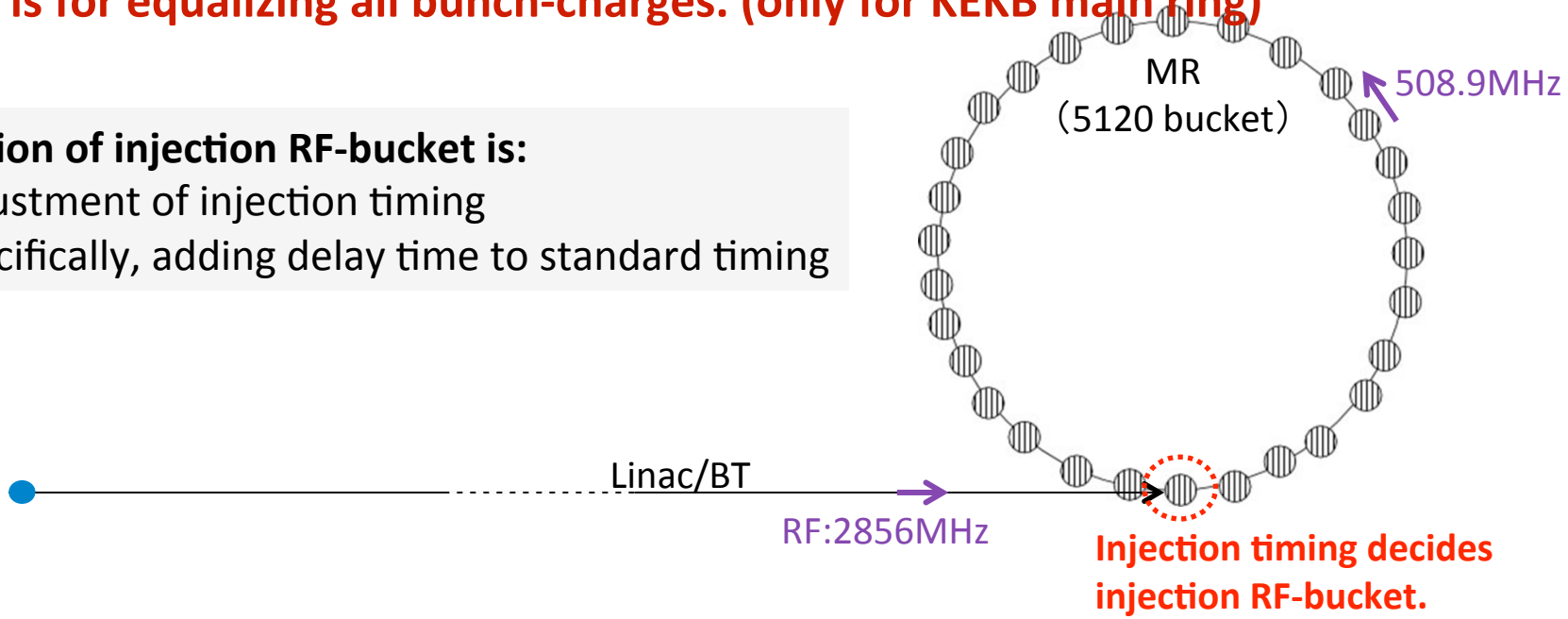
Bucket Selection by the Event Timing System

- Delay time for timing adjustment to select RF-bucket.
- (Note, it is produced by the dedicated modules at KEKB.)

Timing adjustment for Bucket Selection

Injection RF-bucket is selected "on the careful consideration" in each pulse.
It is for equalizing all bunch-charges. (only for KEKB main ring)

Selection of injection RF-bucket is:
- adjustment of injection timing
- specifically, adding delay time to standard timing



Injection timing:

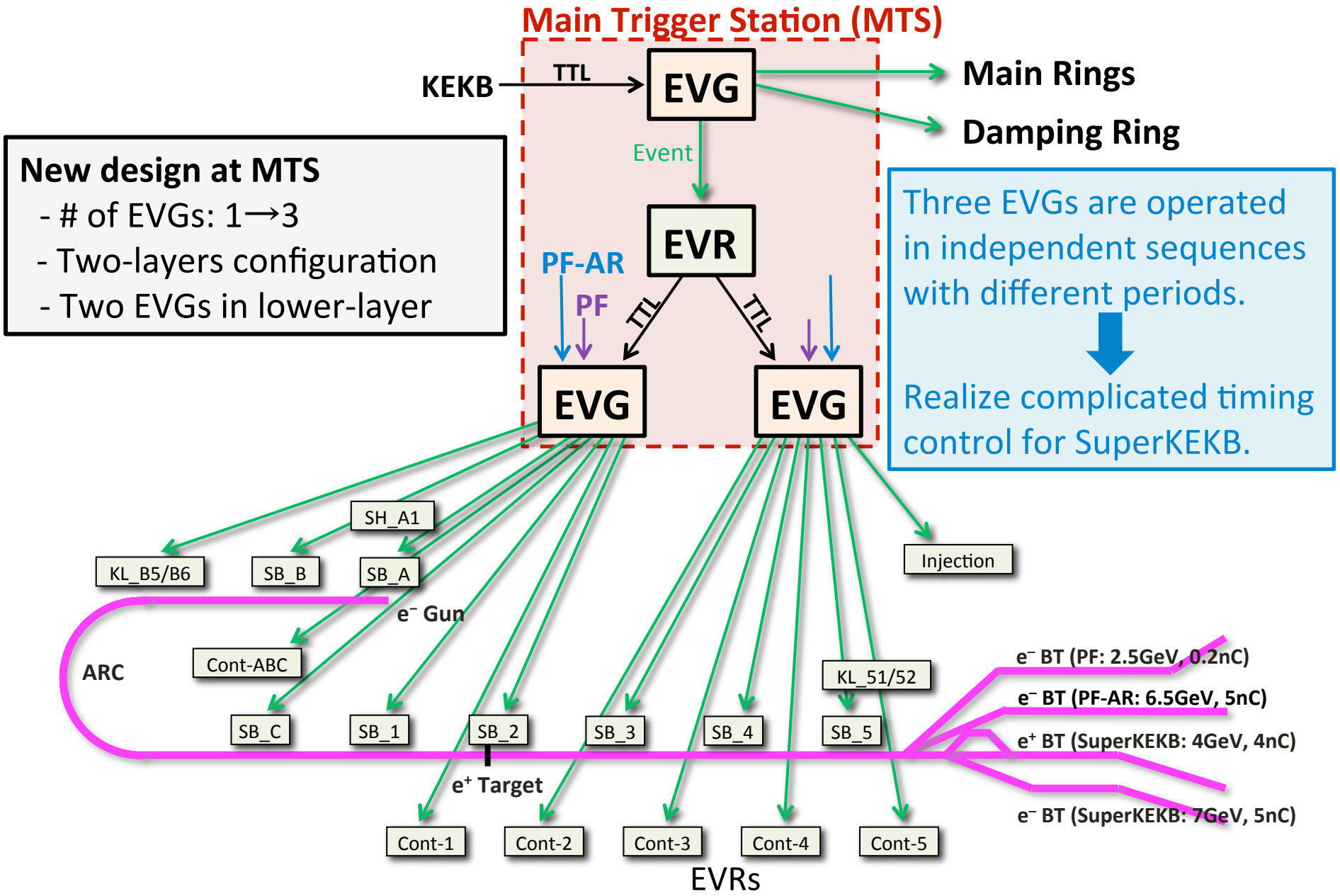
KEKB revolution/49/23 (standard timing) **+ delay**

Delay:

- varying within **0-493μs** for KEKB and SuperKEKB HER **in unit of 96.3ns**,
- and within **0-11.34ms** for SuperKEKB LER.

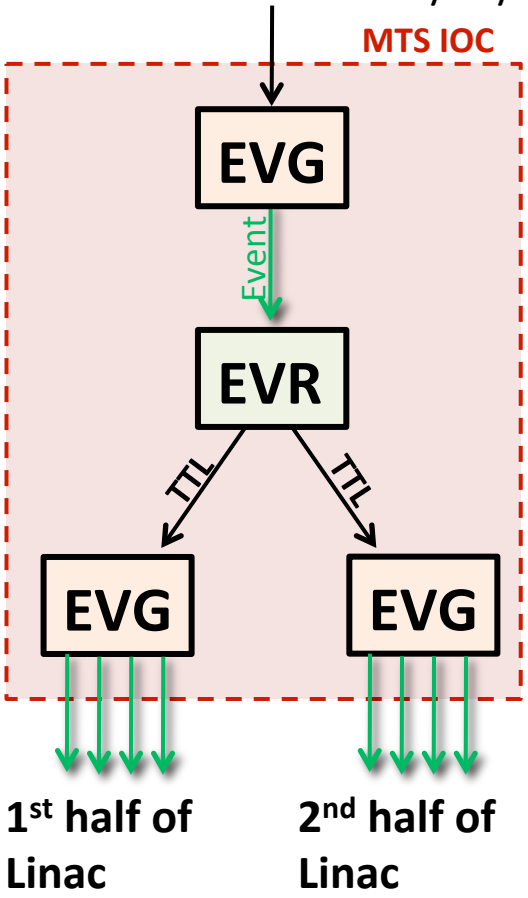
⇒ RF-bucket for both damping and main rings are controlled.

New configuration of Event Timing System

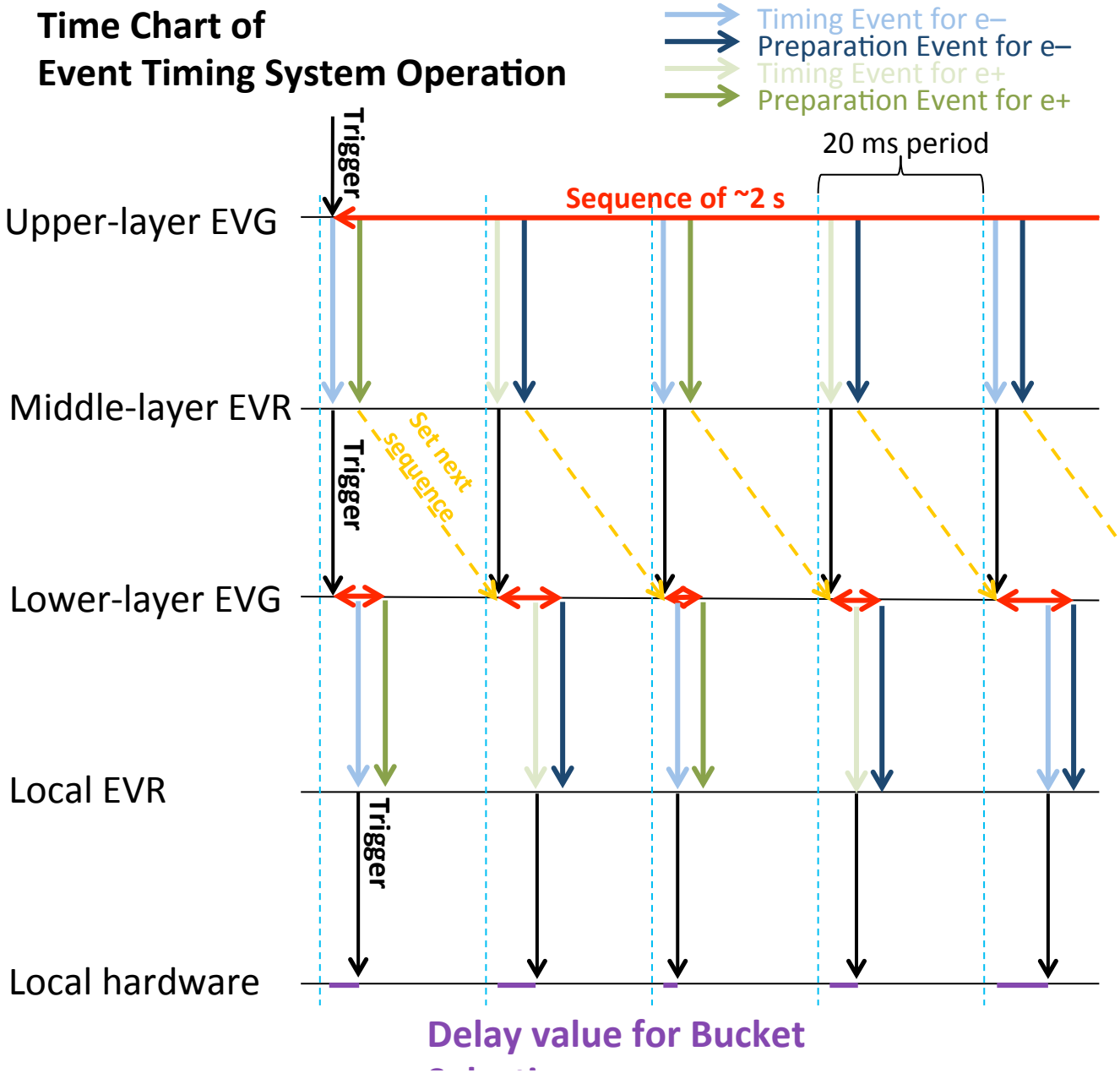


EVG sequence and schedule for Event delivering

Coincidence of AC 50Hz
and KEKB revolution/49/23



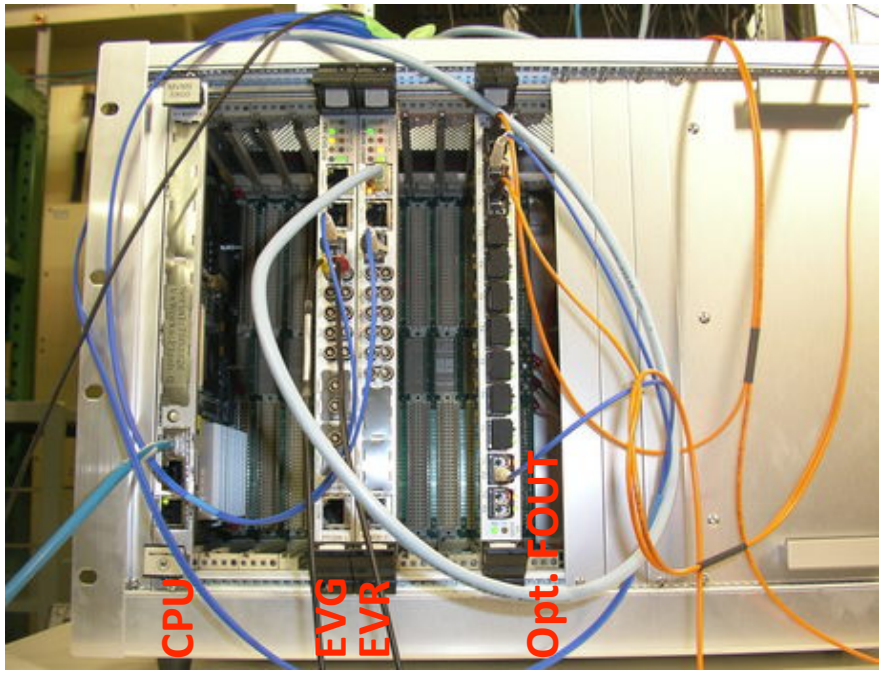
Time Chart of
Event Timing System Operation

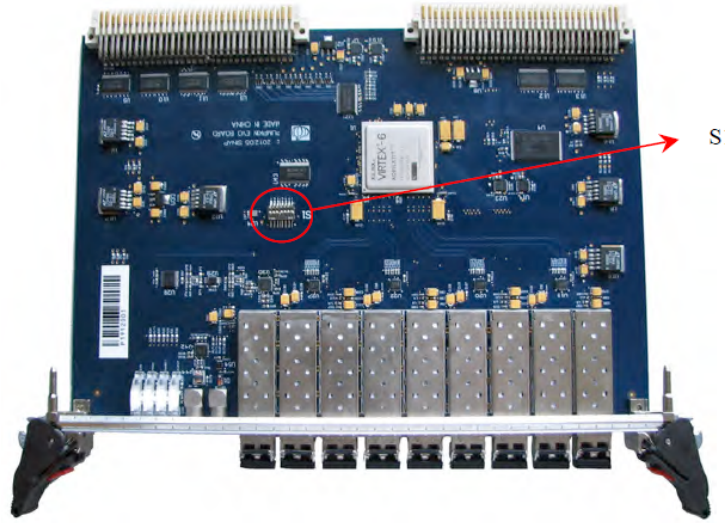


Modules

Main module: MRF's VME-type modules
- VME-EVG-230 and VME-EVR-230
- Knowledge and experiences in the KEKB project
- Already installed at the Linac beamline

Partially: Plan to use SINAP module at Damping Ring
- EVO can work as both EVG and EVR
- Equivalent performance in terms of timing precision





The front panel of VME-EVO is shown in Figure 2-1.

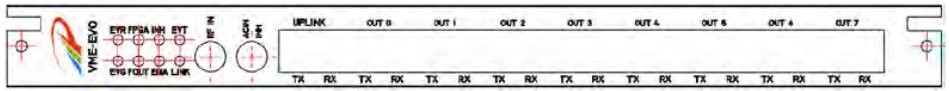
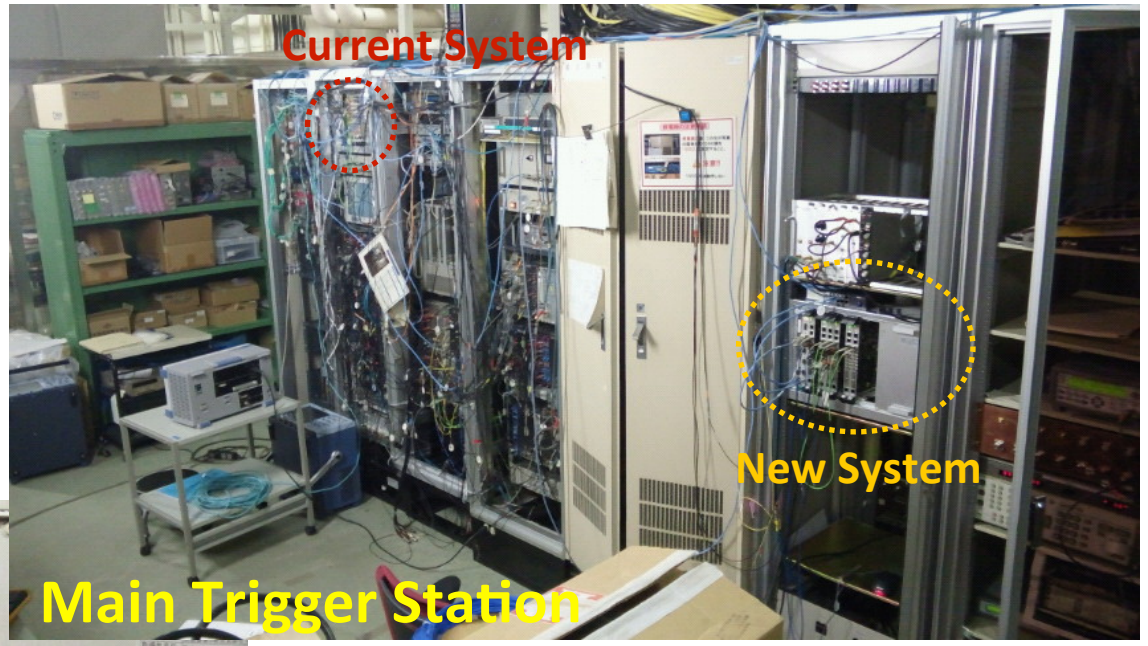
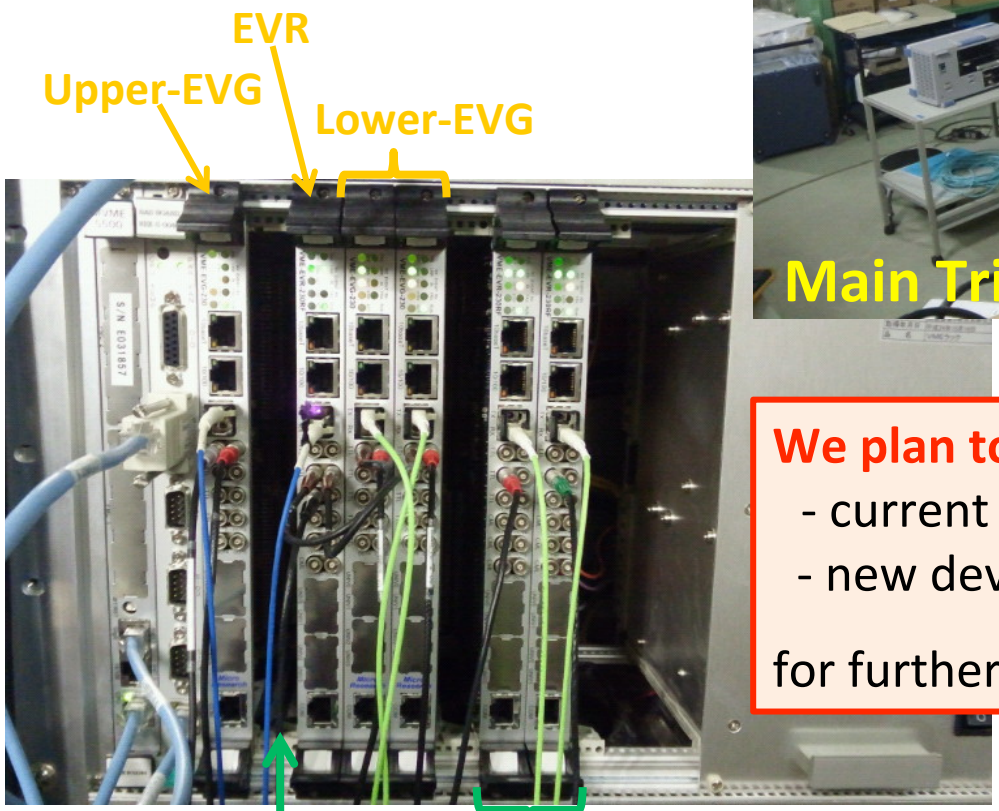


Figure 2-1. The front panel of VME-EVO

Current Status

New system is installed at Main Trigger Station.



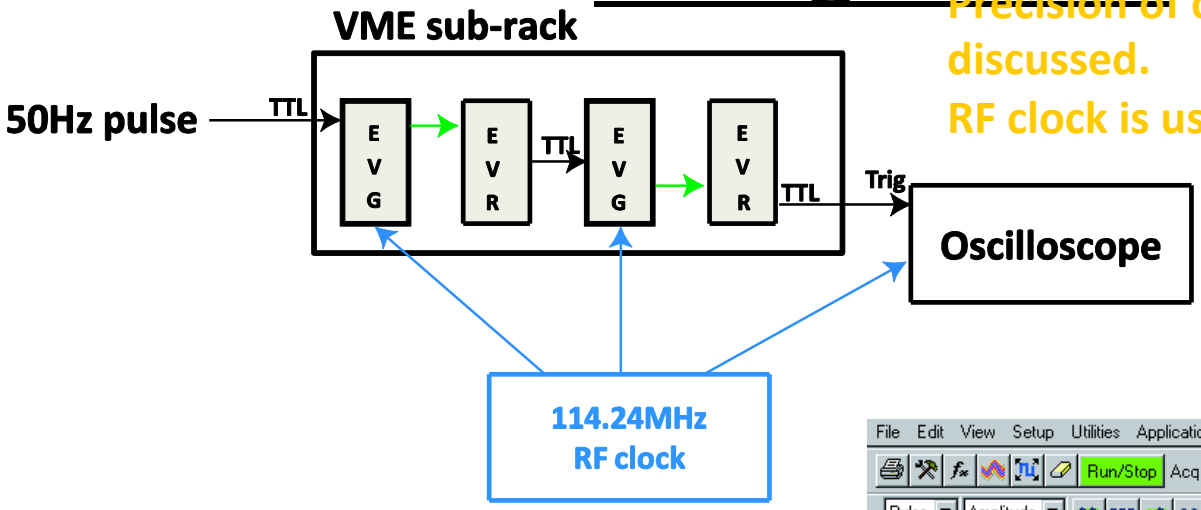


We plan to be redundant Event Timing System
- current working system
- new developed system

for further studies and smooth taking over

Feasibility study for new configuration

Precision of output TTL is measured and discussed.
RF clock is used as a reference.

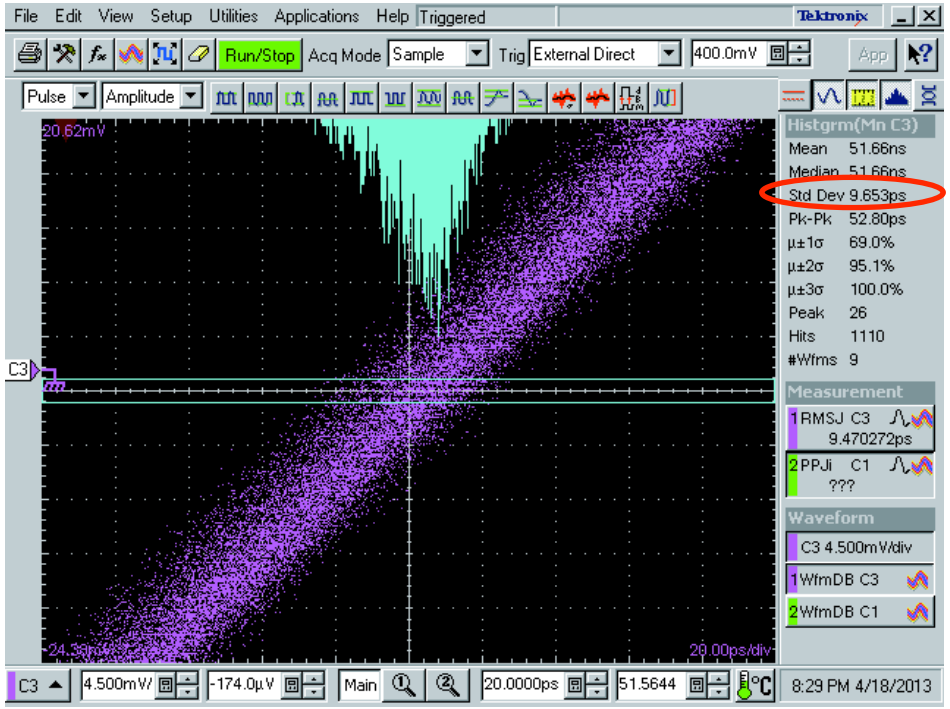


The new functions for new Event Timing System are studied:

- Two-layers of EVGs configuration
- Long period of sequence: ~2 seconds
- Switch input channels in every 20ms

Precision of output TTL timing is compared with the SuperKEKB requirement, O(100)ps.

Long term stability is also studied.



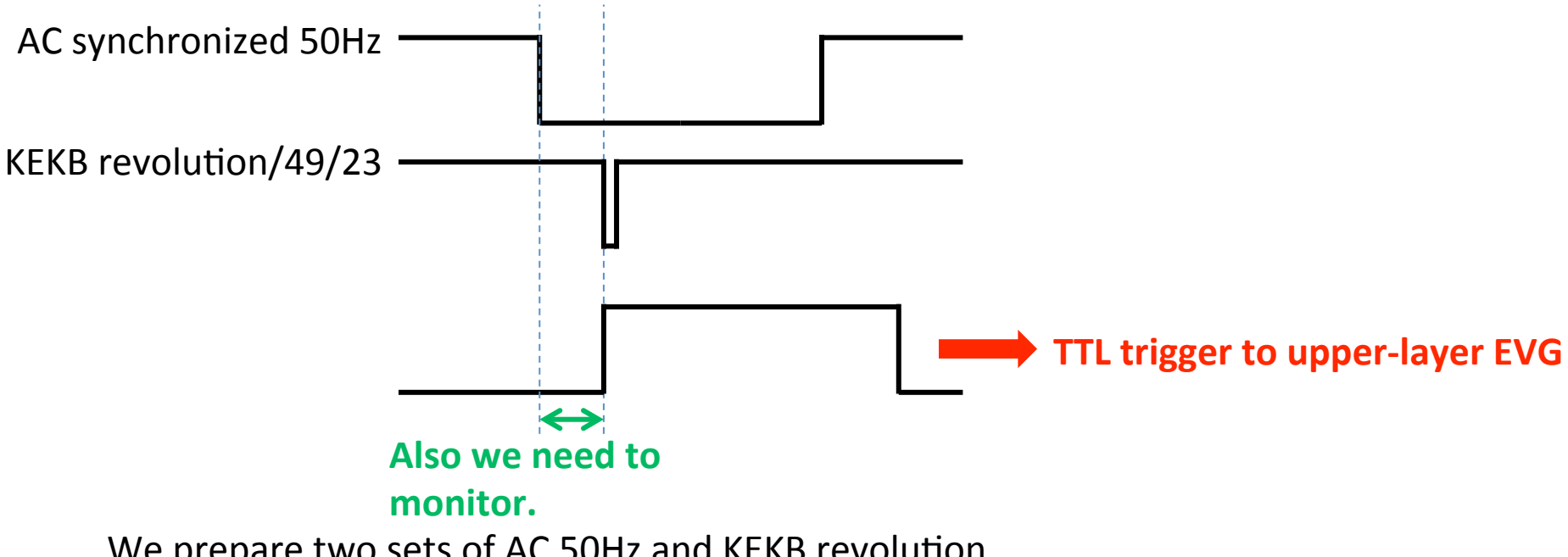
Resultant jitter of 10-15 ps is satisfied the SuperKEKB requirement.

AC 50Hz monitoring

Concrete design will be decided soon.

Injection timing must be synchronized with the revolution of injection ring.
- KEKB revolution/49/23 is used for SuperKEKB.
- Coincidence of 50Hz and above revolution is used for EVG trigger.

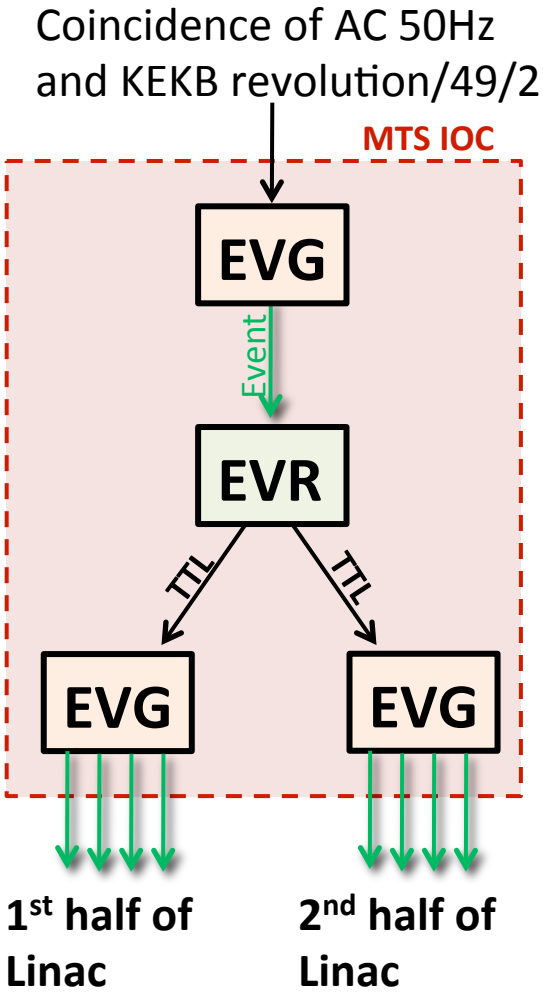
AC synchronized 50 Hz is used for coincidence.
- since Linac operates on the same phase of TEPCO's commercial frequency.
- It is fluctuated, 50.0±0.2 Hz. ⇒ Need monitoring and timing tuning.



We prepare two sets of AC 50Hz and KEKB revolution.
- one for "coincidence ⇒ trigger of EVG"
- the other for "monitoring by TDC" ⇒ **new TDC development, ongoing**

Timing adjustment by lower-layer EVG

(Note it was implemented with dedicated delay modules, TD4V, at KEKB.)



Timing adjustment is implemented with lower-layer EVG.
Sequence of lower-layer EVG must be updated in 50 Hz.

Timing adjustment should be implemented on EPICS.

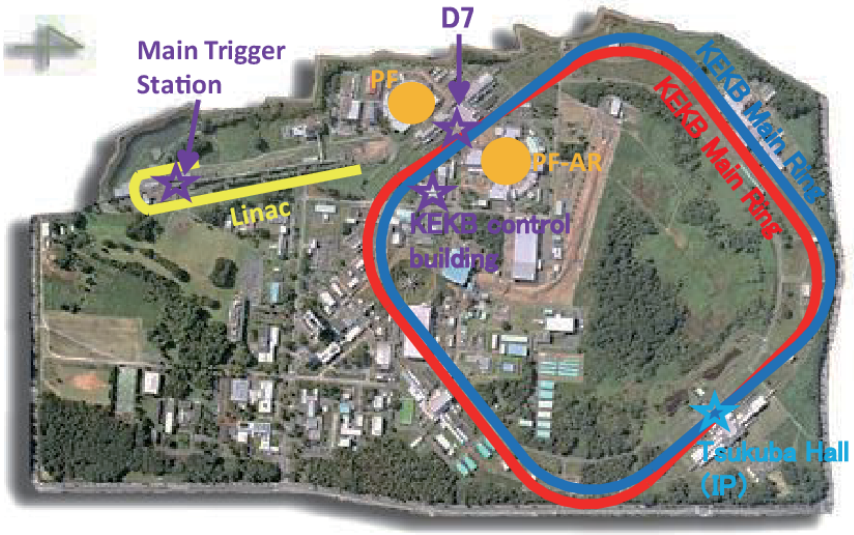
Note, we use MRFIOC2 developed by BNL/LANL.
http://epics.sourceforge.net/mrfioc2/

- However standard "waveform" record is used to manage Event# to be delivered and its delay.
- It doesn't accept input from "ao", "longout", and so on.

We need to develop special device support.

Reflective memory for Bucket Selection

Bucket Selection System configures
- another optical network
- data transferring with **reflective memories**.



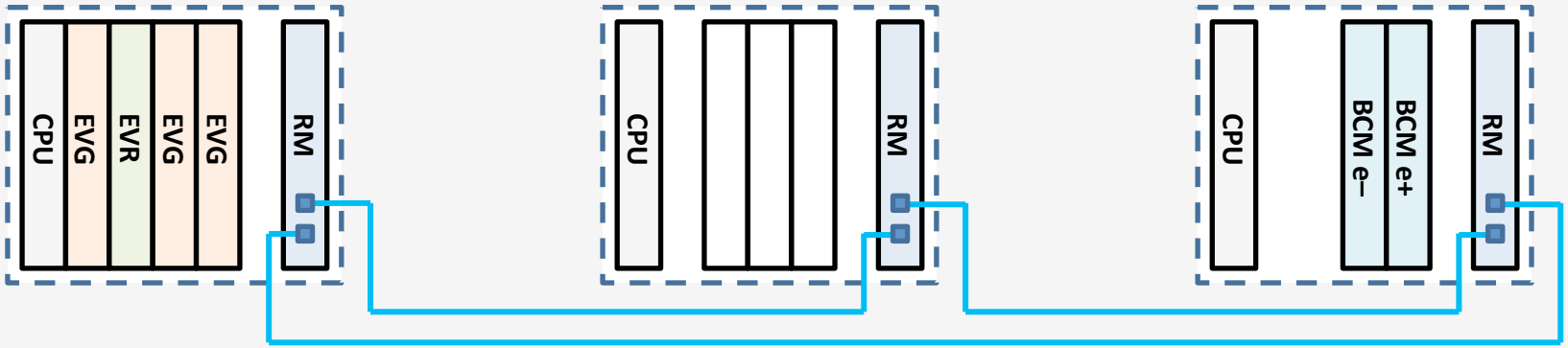
Hardware
- VMEVMI-5565 is selected.
- Data transfer test (MTS-KEKB nodes): 45.5MB/s.

Software
- Need device/driver supports for EPICS.

IOC Main Trigger Station
Adjust injection timing for selecting RF-bucket.

IOC KEKB control
Indicate injection RF-bucket

IOC D7
Measure charge of individual bunches



Summary of upgrade works

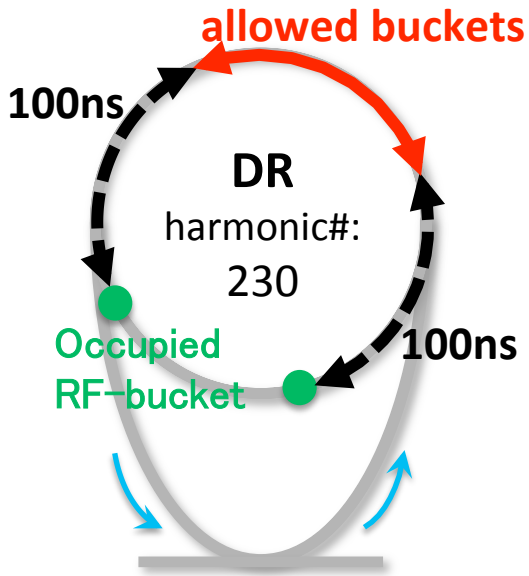
Items	Status	
Operation with new version of firmware and device driver	**Done**	
Tow-layers of configuration with different periods of sequence	**Done**	Feasibility studies are performed with test setup.
Operation with long period of sequence, ~2s (for upper-layer EVG)	**Done**	
Switch input channels for trigger in every 20ms (for lower-layer EVG)	**Done**	
Timing adjustment in every 20ms for Bucket Selection (for lower-layer EVG)	**Need software development**	
Communication with reflective memory for Bucket Selection	**Need software development**	
AC 50Hz monitoring	**Hardware development ongoing**	

Constraints for Bucket Selection at LER

There are a few constraints for Bucket Selection at LER.
In the case “positron injection in >25Hz”,
a half of LER RF-buckets cannot be selected for next injection pulse.

Only 31 buckets can be used if DR-buckets have already occupied with the positrons for one pulse before.
- Note, this condition is for two pulse injection.

Only 13.5% (=31bucket/230bucket) of injection patterns can be used for the next injection.



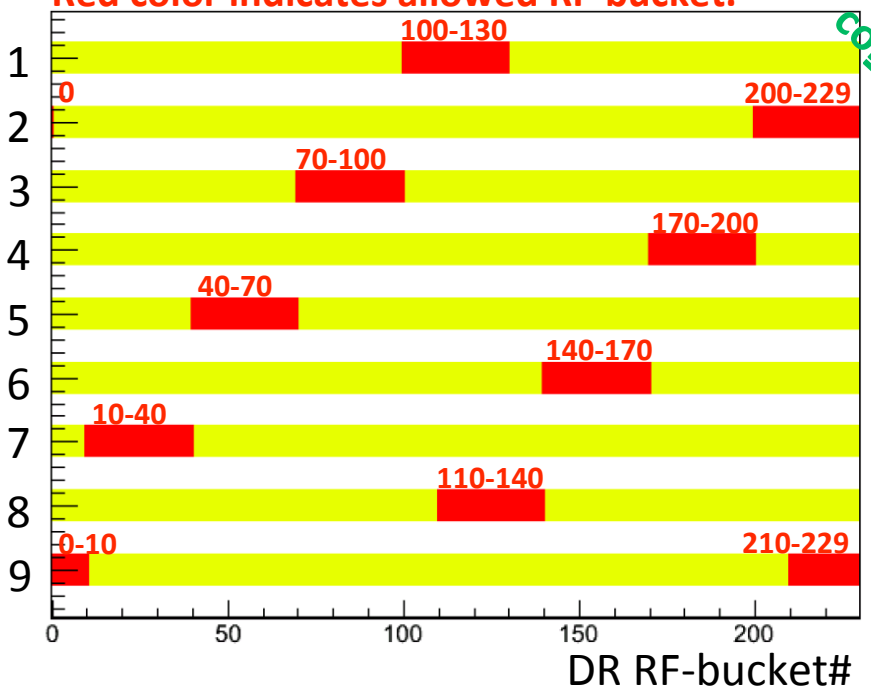
RF-buckets already occupied and their ±100ns region cannot be used for the next pulse.

Example of allowed RF-buckets

If #0 and #49 of DR RF-bucket have already occupied, only #100-#130 are allowed for the next pulse.

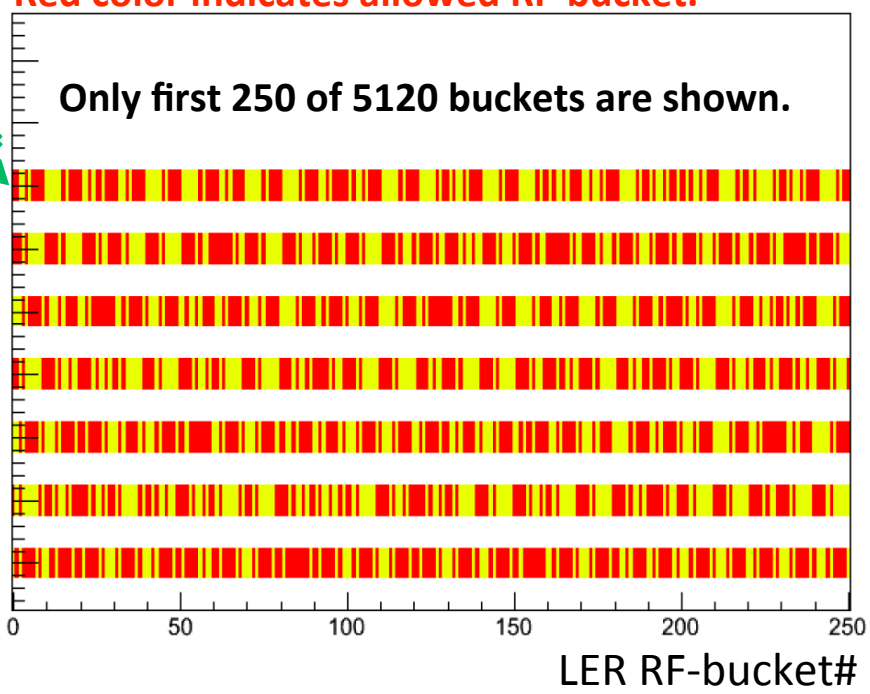
It makes the constraint for LER RF-bucket.
Half of LER RF-bucket cannot be injected.

Red color indicates allowed RF-bucket.



constraint

Red color indicates allowed RF-bucket.



Allowed RF-buckets change every time and they can be controlled by Event Timing System.

We can inject into the aiming RF-bucket within a few pulse.
New Bucket Selection has capability for equalizing charges for individual bunches.

Future upgrade for Bucket Selection

One of difficulties for Bucket Selection is different RF frequency:

- Linac: 2856 MHz (10.385MHz × 275)
- MR, DR: 508.9 MHz (10.385MHz × 49)

⇒ **RF phase shift is planned for "very near" future upgrade.**

Phase shift at 2nd half of Linac and DR are considered.

- Both are commented in the KEKB review 2012.
- We discussed merits/costs/man-powers/time.

⇒ **We decide the Linac as the first priority and DR as the back-up.**

	2nd half of Linac	DR
Range of timing adjustment (from 0-11.34ms)	0-231μs	0-493μs
Number of shift types	49 types including original	230 types including original
When?	just before injection pulse	during damping
How?	just switch phase	change phase gradually **Note, large phase shift is difficult within 20ms.**

Upgrades in both Event Timing System and LLRF are needed.
We plan to use data buffer transferring on the Event Timing System network.

- **indicate RF phase for next injection from Event Timing System**
- **feasibility tests are ongoing.**

Summary

Upgrade of Event Timing System is ongoing for SuperKEKB.
- Positron injection needs special cares because of DR.
- Two-layers of EVG configuration is employed.
- Some developments for software and hardware are remained, however I think, they are not hard tasks.

Bucket Selection System is integrated into the new Event Timing System.
- Delay is added on the lower-layer EVGs.
- Complicated timing management for positrons can be realized.

Bucket Selection for SuperKEKB is discussed.
- Bucket Selection has capability to equalize charges of individual bunches even though there are constraints because of DR.
- After finishing the first configuration and starting commissioning of SuperKEKB, the upgrade is planned.

Software

	KEKB	SuperKEKB
EVG firmware	E403	0005
EVR firmware	D507	0005
EPICS device driver	mrfioc†	mrfioc2‡
EPICS version	R3.14.9	R.3.14.12.1

† developed by SLS/SLAC/LANL
http://epics.svn.sourceforge.net/viewvc/epics/applications/trunk/mrfEventSystem/
‡ developed by BNL/LANL
http://epics.sourceforge.net/mrfioc2/

Constraints for Bucket Selection at LER

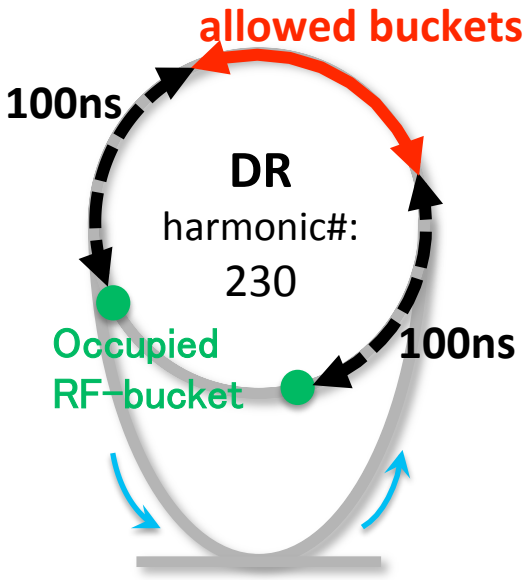
There are a few constraints for Bucket Selection at LER.
In the case “positron injection with >25Hz”,
a half of LER RF-buckets cannot be selected for next injection pulse.

Injection timing should be adjusted in range of 0-11.34ms.
However only 2ms width are allowed in terms of hardware.
- Note, injection must be carried out within 2ms timing window which comes every 20ms.

Only 17.6% (=2ms/11.34ms) of injection patterns can be used for every injection.

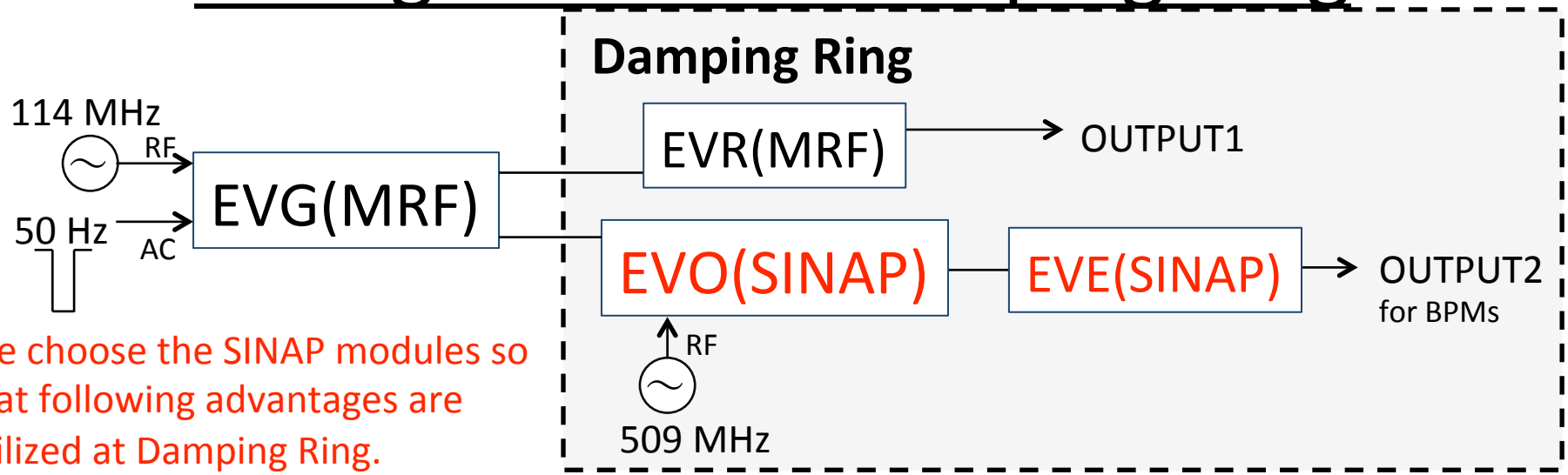
Positrons are injected from 230 of DR-buckets.
However only 31 buckets can be used if DR-buckets have already occupied with the positrons for one pulse before.
- Note, this condition is for two pulse injection.
- This happens when we inject positrons in >25Hz.

Only 13.5% (=31bucket/230bucket) of injection patterns can be used for the next injection.



RF-buckets already occupied and their ±100ns region cannot be used for the next pulse.

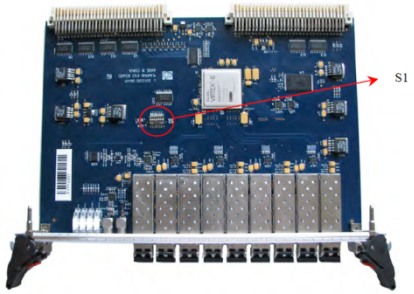
Configuration at Damping Ring



We choose the SINAP modules so that following advantages are utilized at Damping Ring.

EVO works as EVG (or EVR).

- Sequence RAM can be triggered by the upstream Event.
  ⇒ **simplify the Event System configuration**
- can be operated with different frequency from that of upstream-EVG. ⇒ **can be synchronized with RF clock of DR**



The front panel of VME-EVO is shown in Figure 2-1.

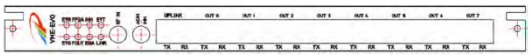
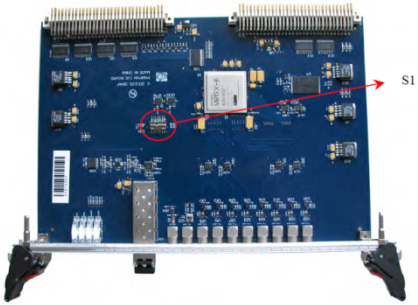


Figure 2-1. The front panel of VME-EVO

EVE works as EVR.

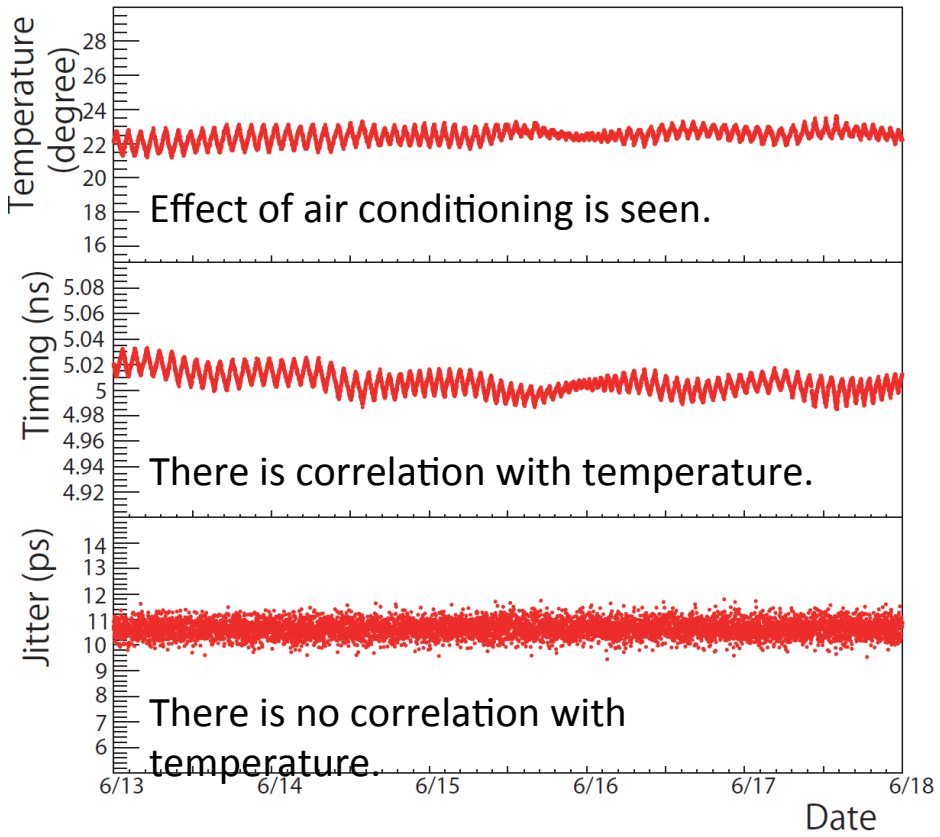


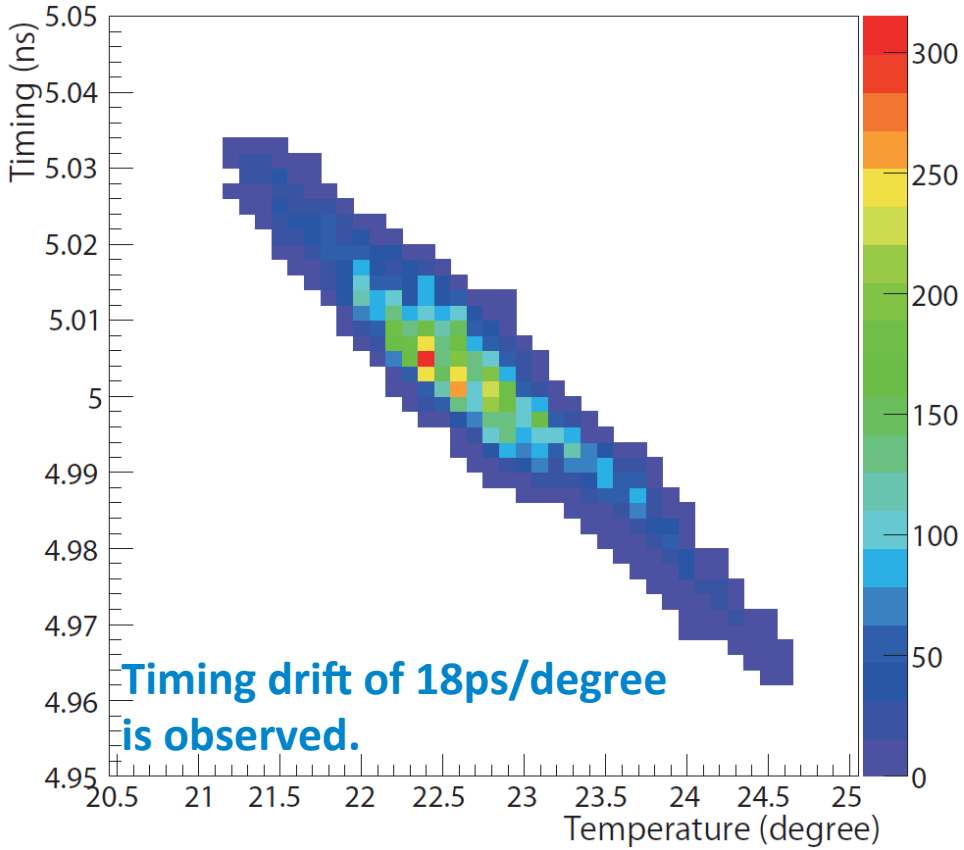
The front panel of VME-EVE is shown in Figure 2-2.

Figure 2-2. The front panel of VME-EVE

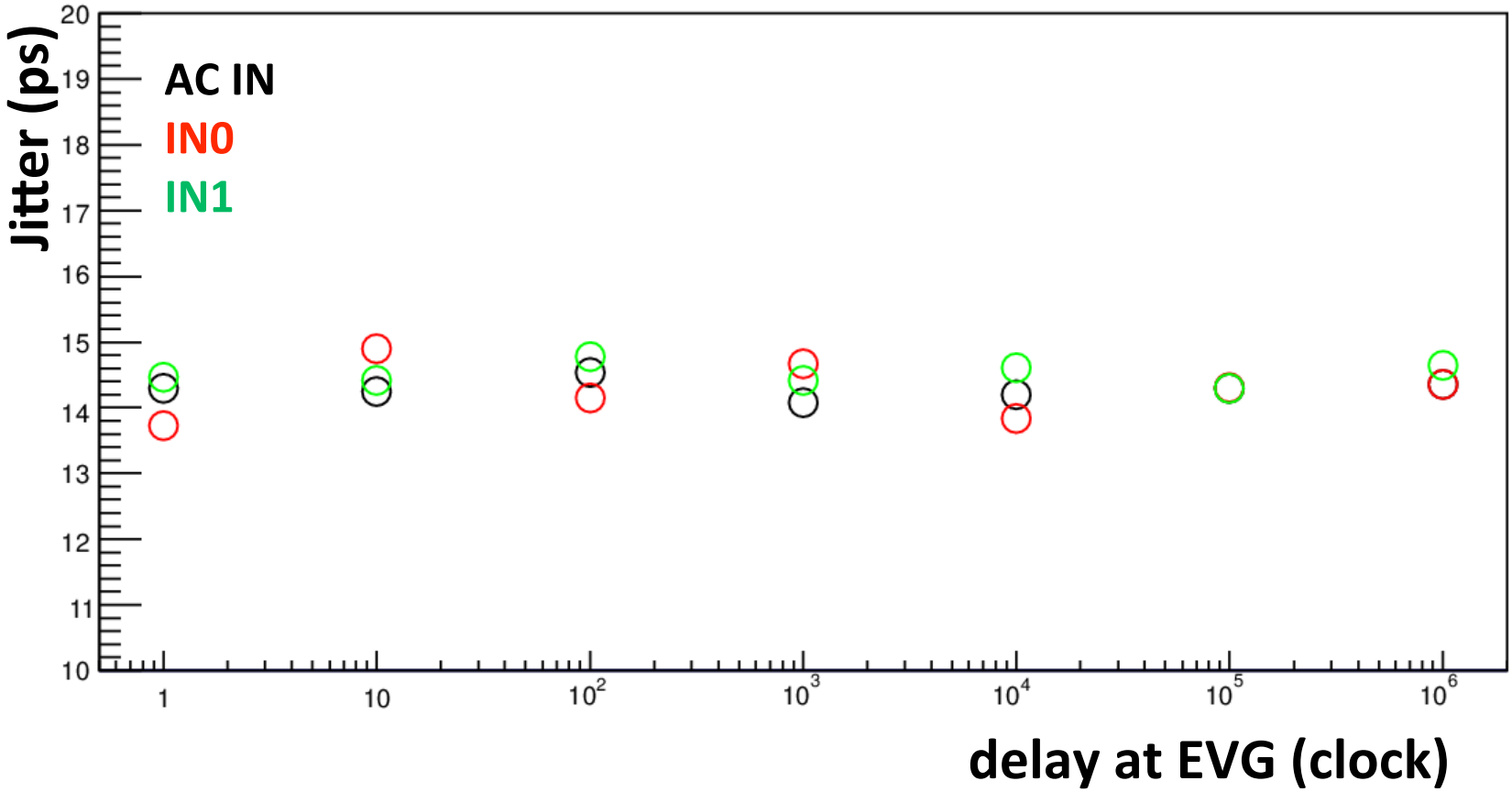
Long term stability

Five days of continuous operation from Jun13 to Jun18 in 2013.
- Mean and jitter of timing is measured in every one minute.
- Room temperature is monitored at the same time.

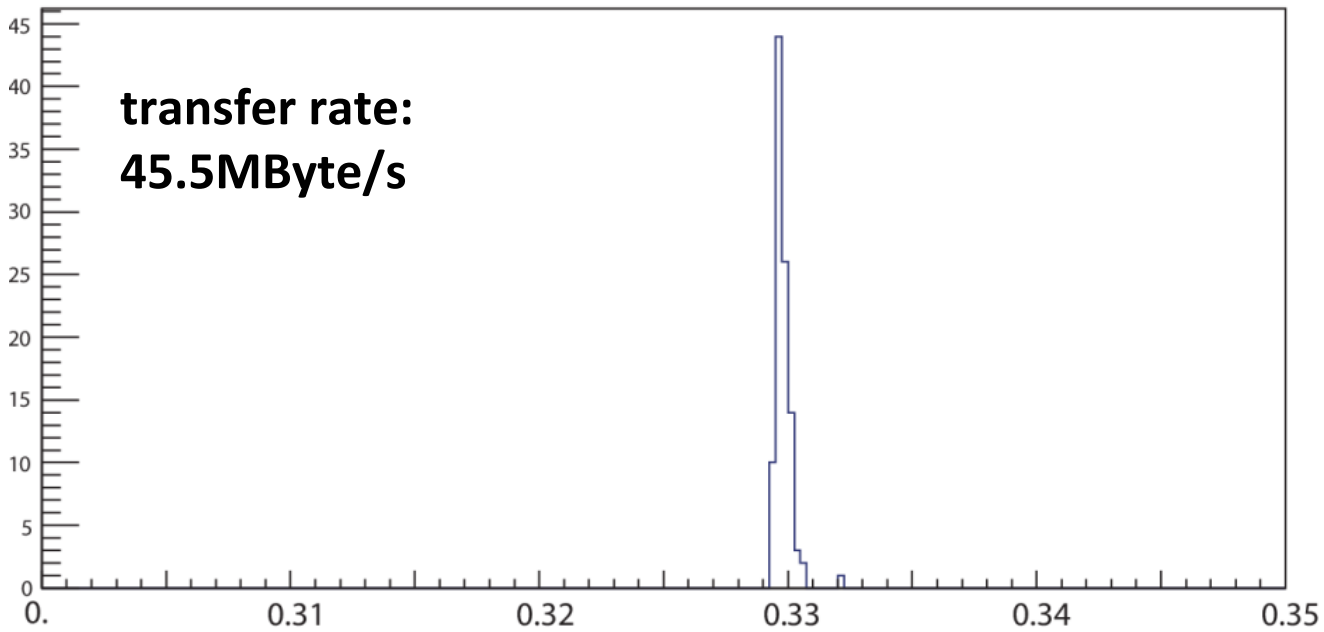




Test of three inputs



Performance Test of Reflective Memory



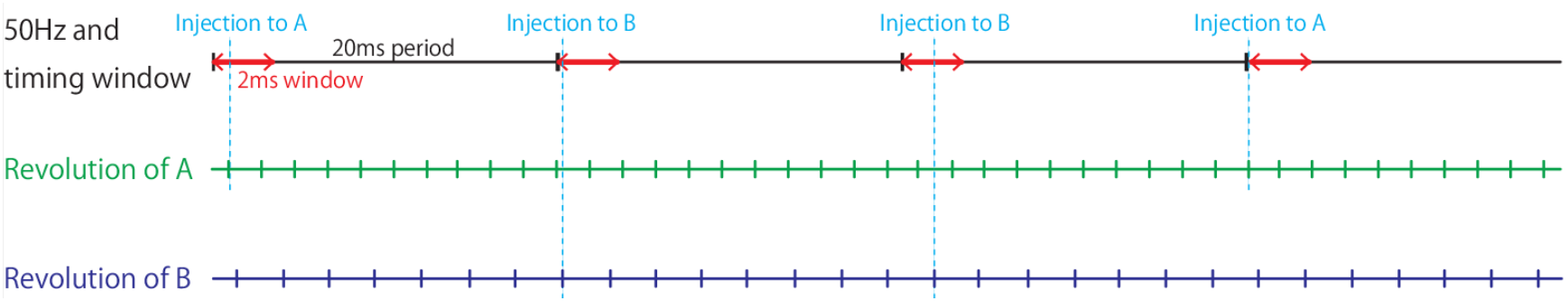
Injection timing

Injection timing must be synchronized with the RF-bucket of ring to be filled, otherwise a beam cannot be injected into the ring.

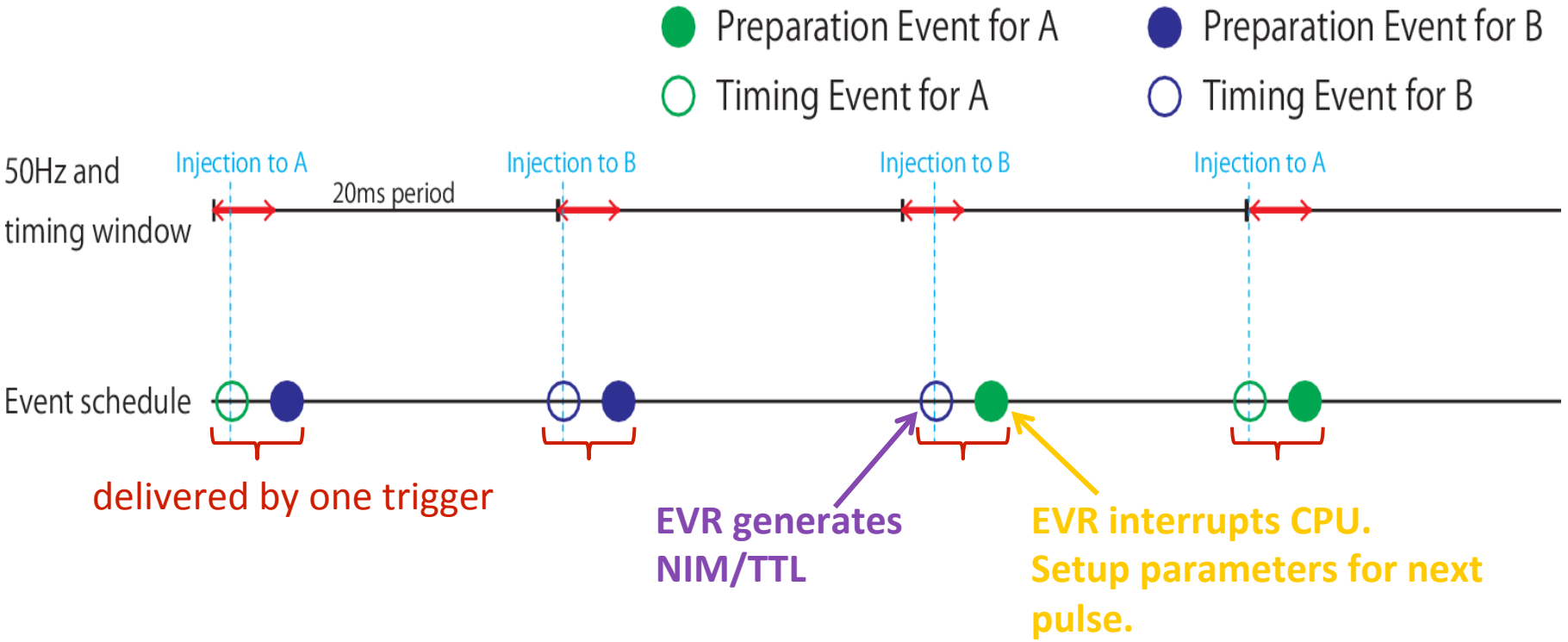
KEK Linac injects e^+/e^- beams into 4 rings in 50Hz.

"Injection in 50Hz" means ...
Injection is performed within 2ms timing window (500μs@KEKB) which comes every 20ms.

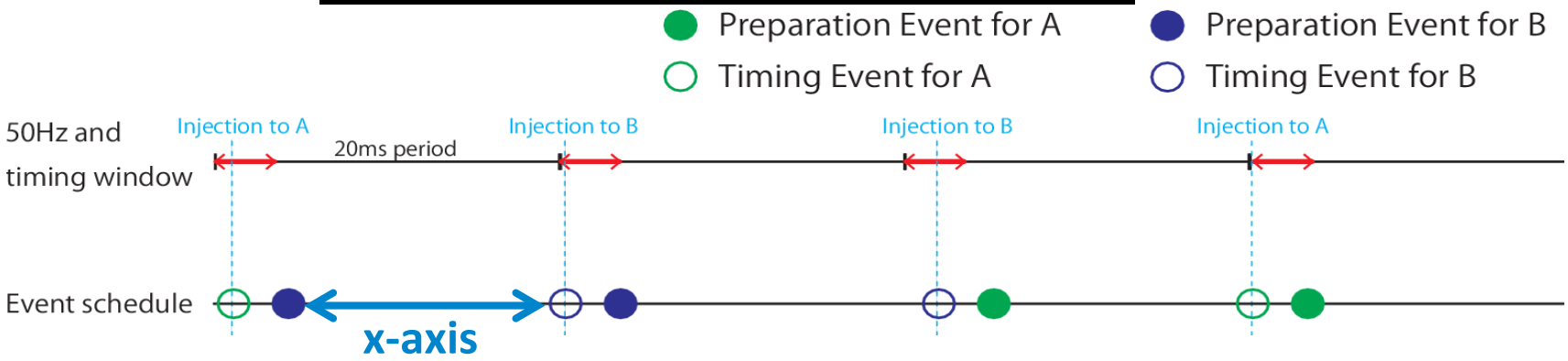
Practically, for this synchronization,
the (frequency divided) revolution signal of injection ring is used.
- revolution/49@KEKB
- revolution/49/23@SuperKEKB

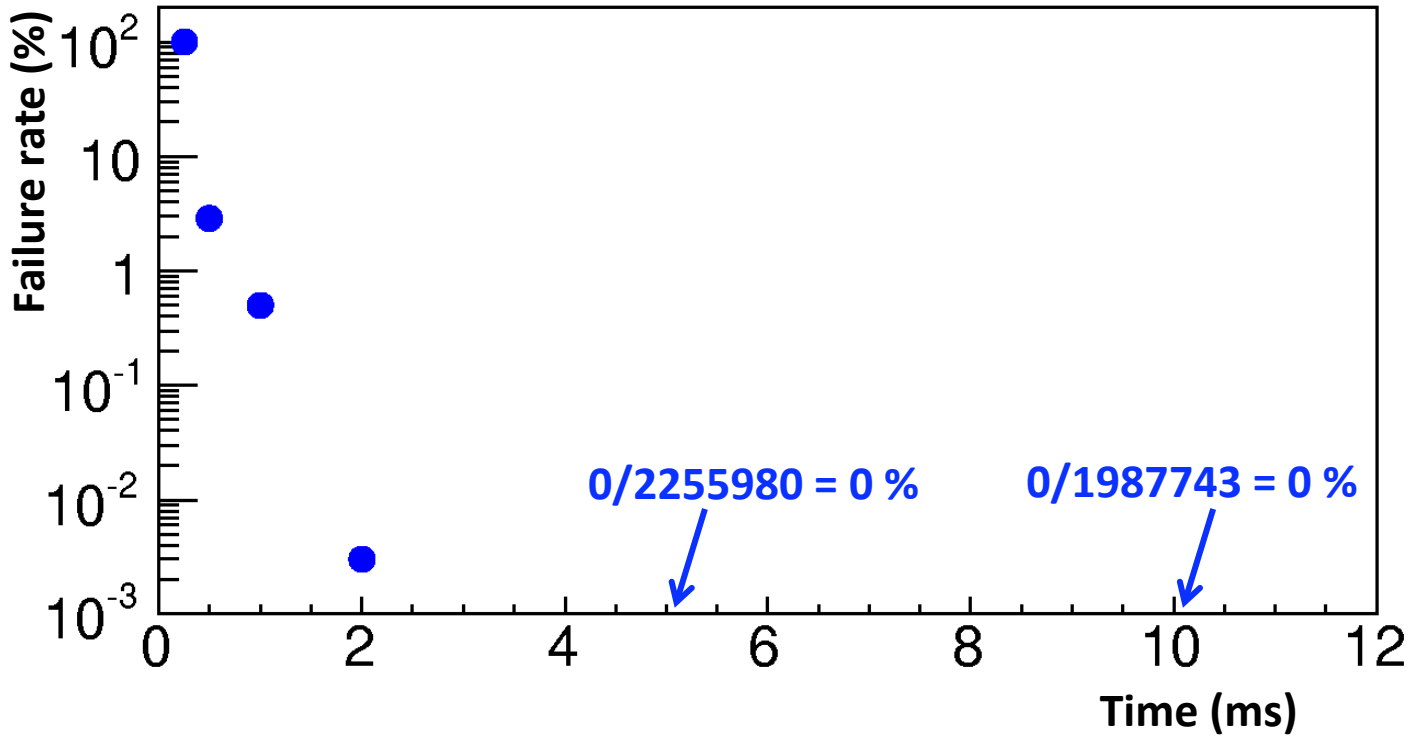


Test for New System

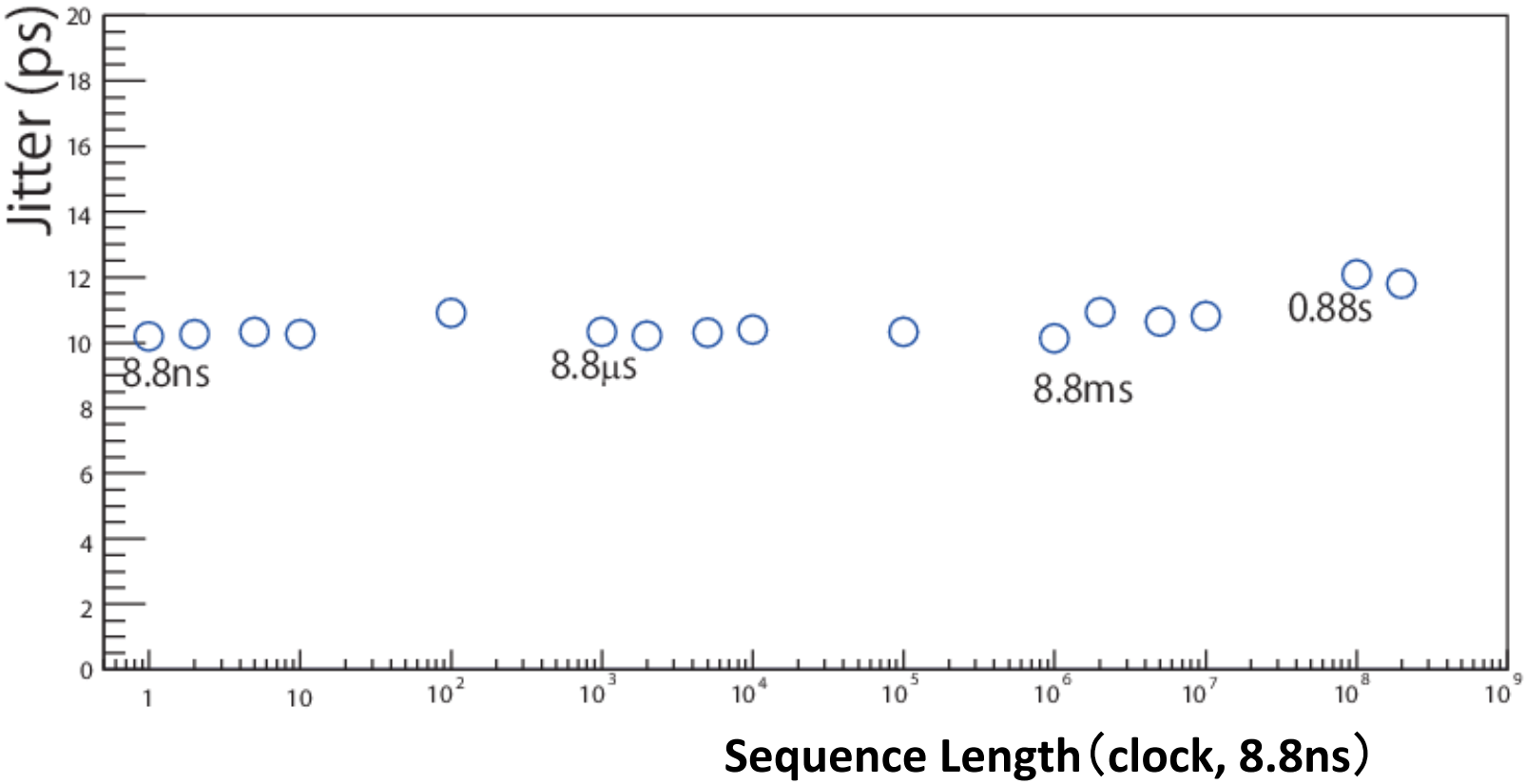


Test for New System





Precision of output TTL

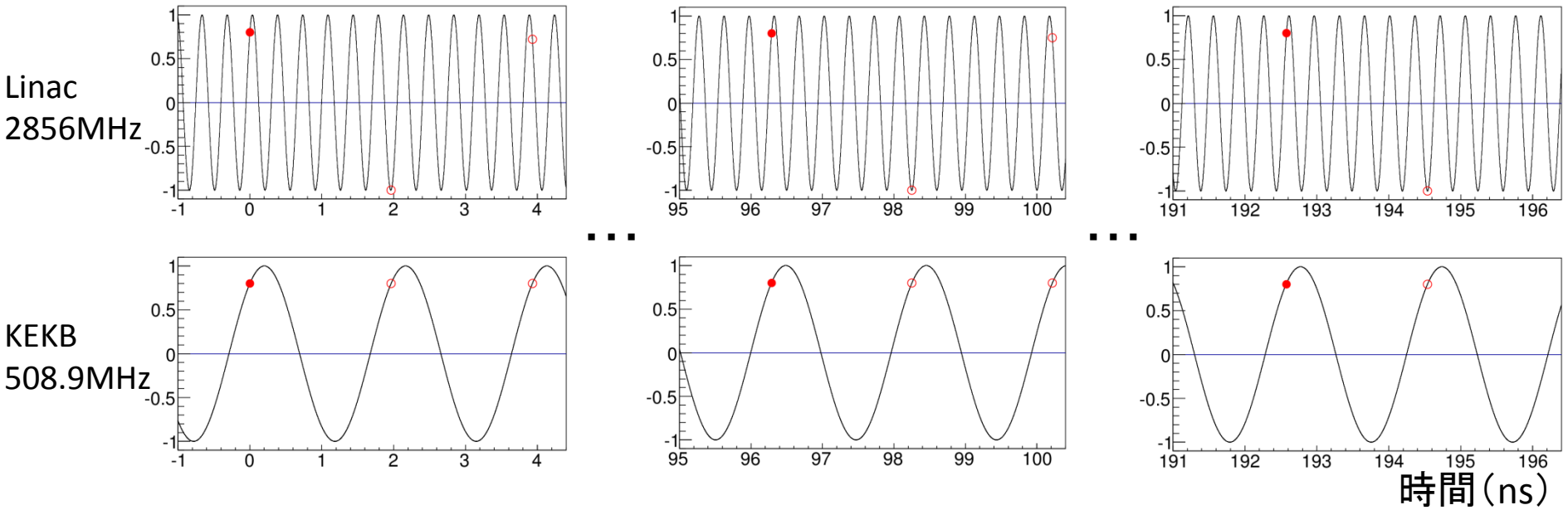


RF周波数による制限

LinacとKEKBでは使用しているRF周波数が異なる

Linac:	2856MHz	(10.39MHz × 275)
KEKB:	508.9MHz	(10.39MHz × 49)

そして入射を実行できるのは両方が「ビームを乗せられる位相」に揃うとき



本当は1.96ns毎（508.9MHz）にバンチが入射点を通過
だけど入射できるのは96.3ns毎（10.39MHz, 49バンチクロッシング毎）

RF phase shift at 2nd half of Linac

Linac後半（DR-MR間）のRF位相を
入射MRバケットに合わせて変調する。
Normal + 48個の変調位相を50Hzで切り替える

例えば、DR#1からMR#1への入射を考える
通常入射では
⇒ **‘delay=3.5ms’**

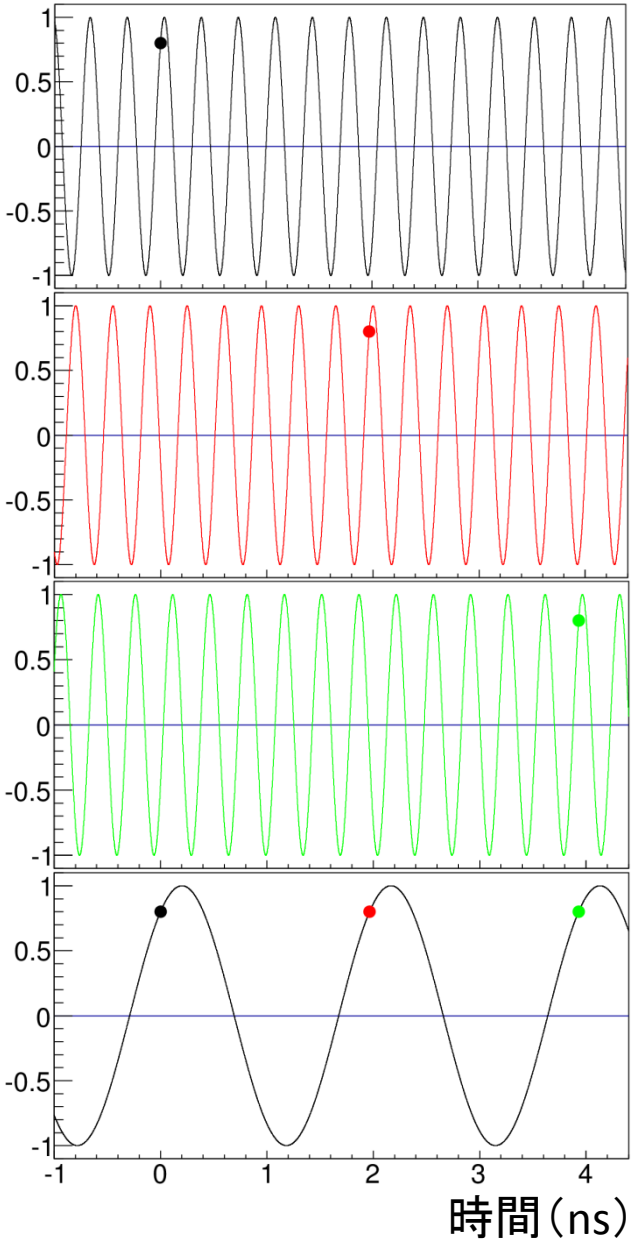
RF位相を2020.4度（MRで360度分）変調
⇒ **‘delay=1.96ns’**

同様にDR#2からMR#2も **‘delay=3.92ns’**

DRバケット#0, #49が埋まっている（#100-#130使用可）
のときMRバケット#0に入射できるのは以下の4つ

DR#	変調あり	変調なし
100	170.6μs	10.35ms
110	210.7μs	3.451ms
120	20.1μs	7.889ms
130	60.2μs	986μs

1.96ns毎に入射機会が得られ
より短期間で各DRバケットに入射機会が訪れる



2856MHz
Linac後半位相

2020.4度
（220.4度）
変調

4040.7度
（80.7度）
変調

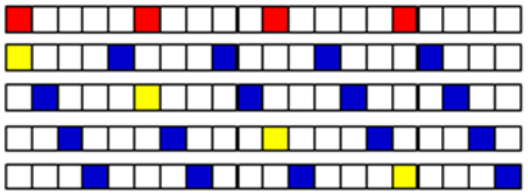
508.9MHz
DR/MR位相

Eventスケジュール

ビームモード	優先順位	要求ビーム	最小長さ	色	単独でのパターン
KEKB e+	1	10 Hz	5 (100ms)		
KEKB e−	2	12.5 Hz	4 (80ms)		

1. 優先順位1 の KEKB e+ により、入射パターンの最小長さが決定

2. 優先順位2 の KEKB e− の希望繰り返しが入射パターンの整数倍で実現できるか、衝突は起こらないかを判断



衝突箇所

長さは問題ないが衝突が発生。
KEKB e− 12.5 Hzは実現不可能

3. NGのため、希望より低い繰り返しで条件を満たすものを探す

10Hzなら長さ、衝突共に問題なしのため、
KEKB e− は 10Hz となる

4. 生成したパターンをEVGに設定する

例えばKEKBでは
#31: MR電子準備
#32: MR電子入射
#41: MR陽電子準備
#42: MR陽電子入射
#61:PF
#62:PF
#71:PF-AR
#72:PF-AR