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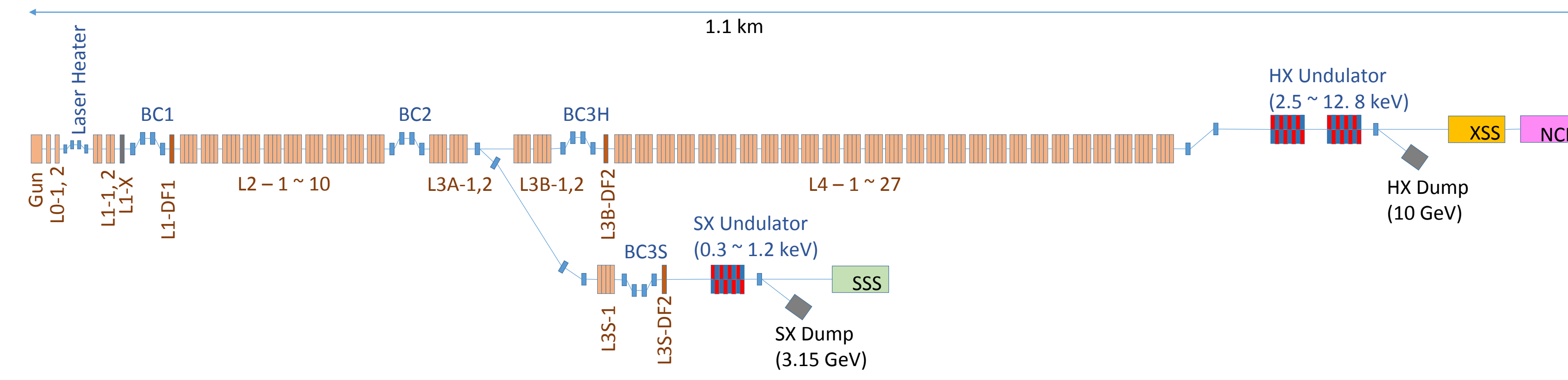
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## Abstract

Though XFEL(X-ray Free Electron Laser) machines can produce X-ray pulses over 100 million times brighter than storage ring-based machines, the XFEL machines have very limited beamlines of 1~3. PAL-XFEL machine includes one hard X-ray beamline and one soft X-ray beamline, but only one beamline can be serviced in each shift period. Efforts to operate the beamlines of PAL-XFEL simultaneously have been made in a manner that bunches of repetition rate 60Hz are directed to each beamline in pulse-by-pulse and real-time style. Because the function of real-time and pulse-by-pulse RF-parameter switching was also essentially required for PAL-XFEL LLRF not had been considered before, a development was performed by software modification of PAL-XFEL LLRF without changing any related hardware. PAL-XFEL including this LLRF function was operated without any problem in test operation. Regular simultaneous operation is expected in the near future.

### Motivation

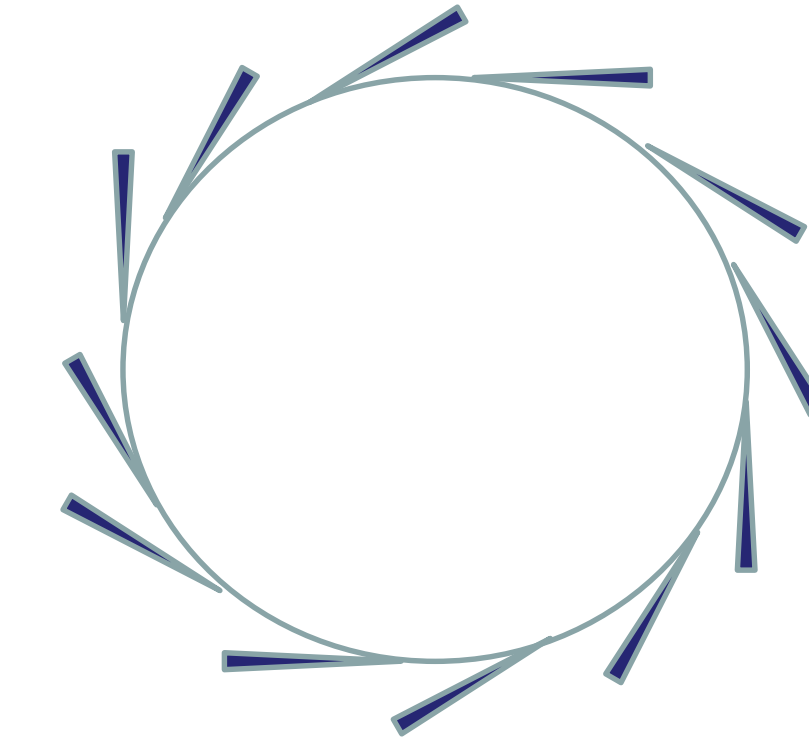
#### PAL-XFEL layout



Only two beamlines : one Hard X-ray(HX) & one Soft X-ray(SX)  
(not simultaneous &  $\leq 60$ Hz repetition rate)

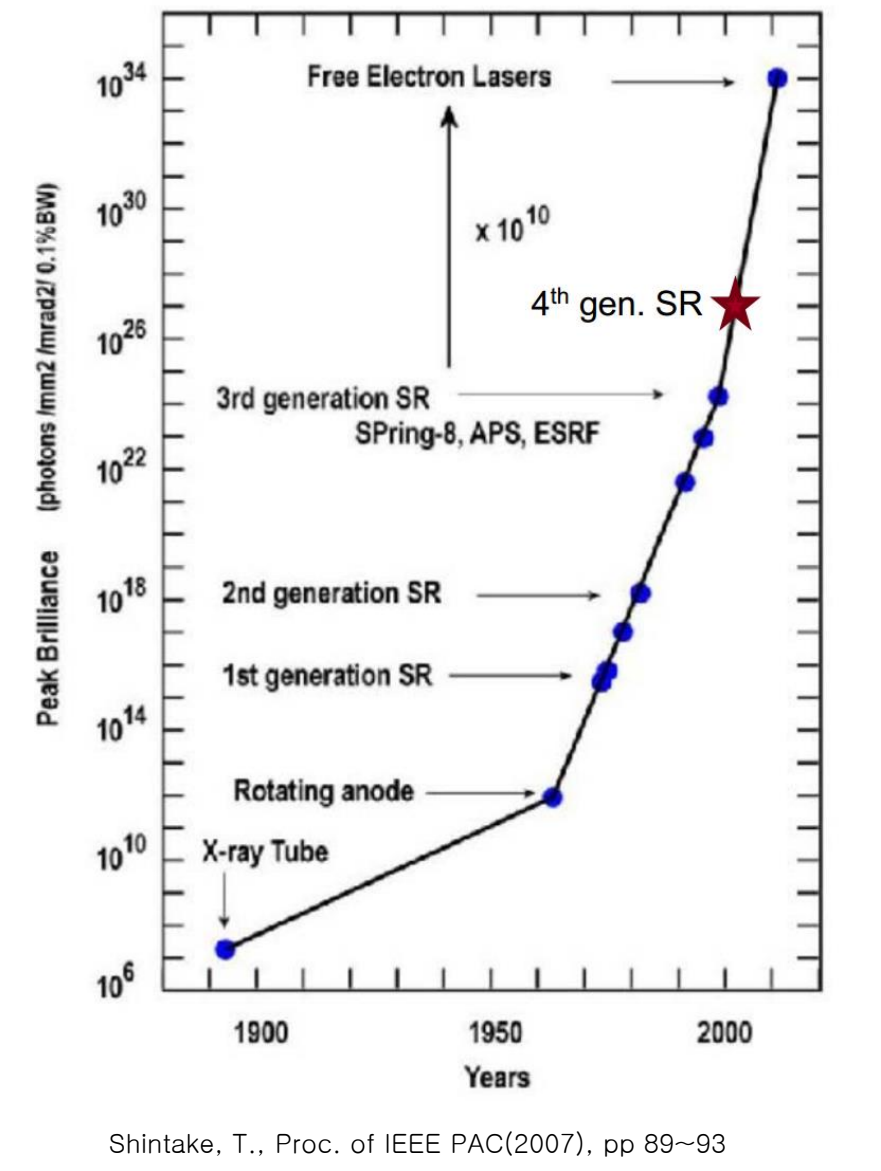
→ Needs : increasing the number of beamlines operated simultaneously

#### A 3<sup>rd</sup> gen. storage ring sketch

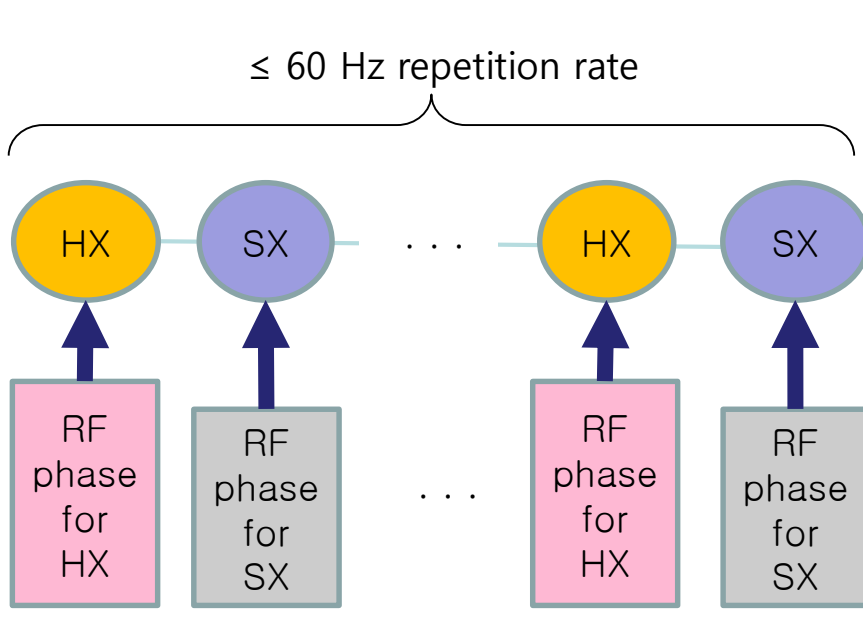


Tens of beamlines  
(all simultaneous &  $\geq$  MHz repetition rate)

#### Peak-brightness comparison



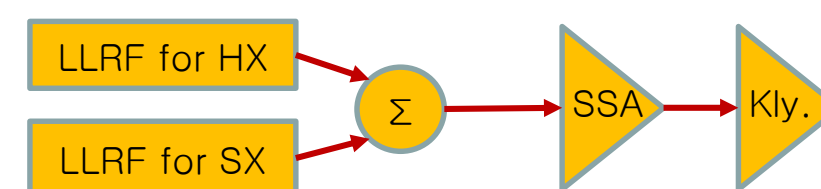
### Concept of simultaneous operation



- Single e<sup>-</sup> bunch generation & acceleration by each RF pulse up to 60 Hz repetition rate
- Generated bunches are distributed pulse-by-pulse by the fast kicker
- SX bunches must be accelerated with RF phases different from HX bunches (different bunch parameters)
- So, for simultaneous operation of HX & SX beamlines pulse-by-pulse RF switching also essentially needed.

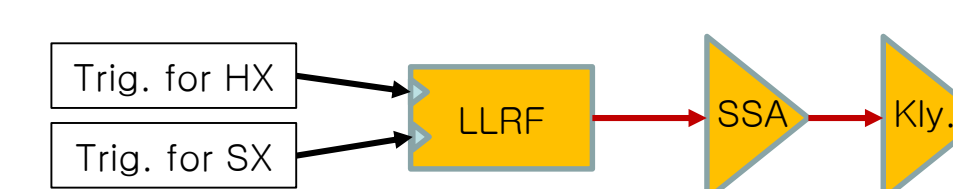
### Approach to pulse-by-pulse RF switching

#### Adding a LLRF unit for SX



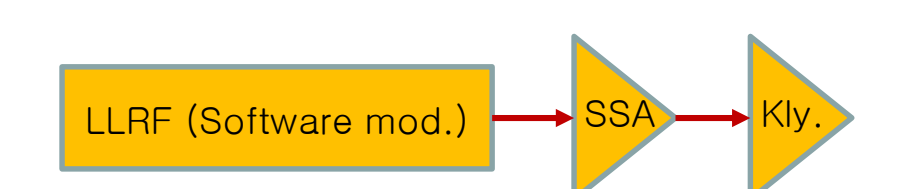
- Needs many LLRF units and peripherals(inputs & outputs)
- Difficult to expand BLs (beamlines)
- Too high cost, abandoned

#### Adding a trigger for SX



- Needs nearly redevelop. of HW(case, digitizer PCB, FPGA HDL) & SW
- Difficult to expand BLs
- Abandoned

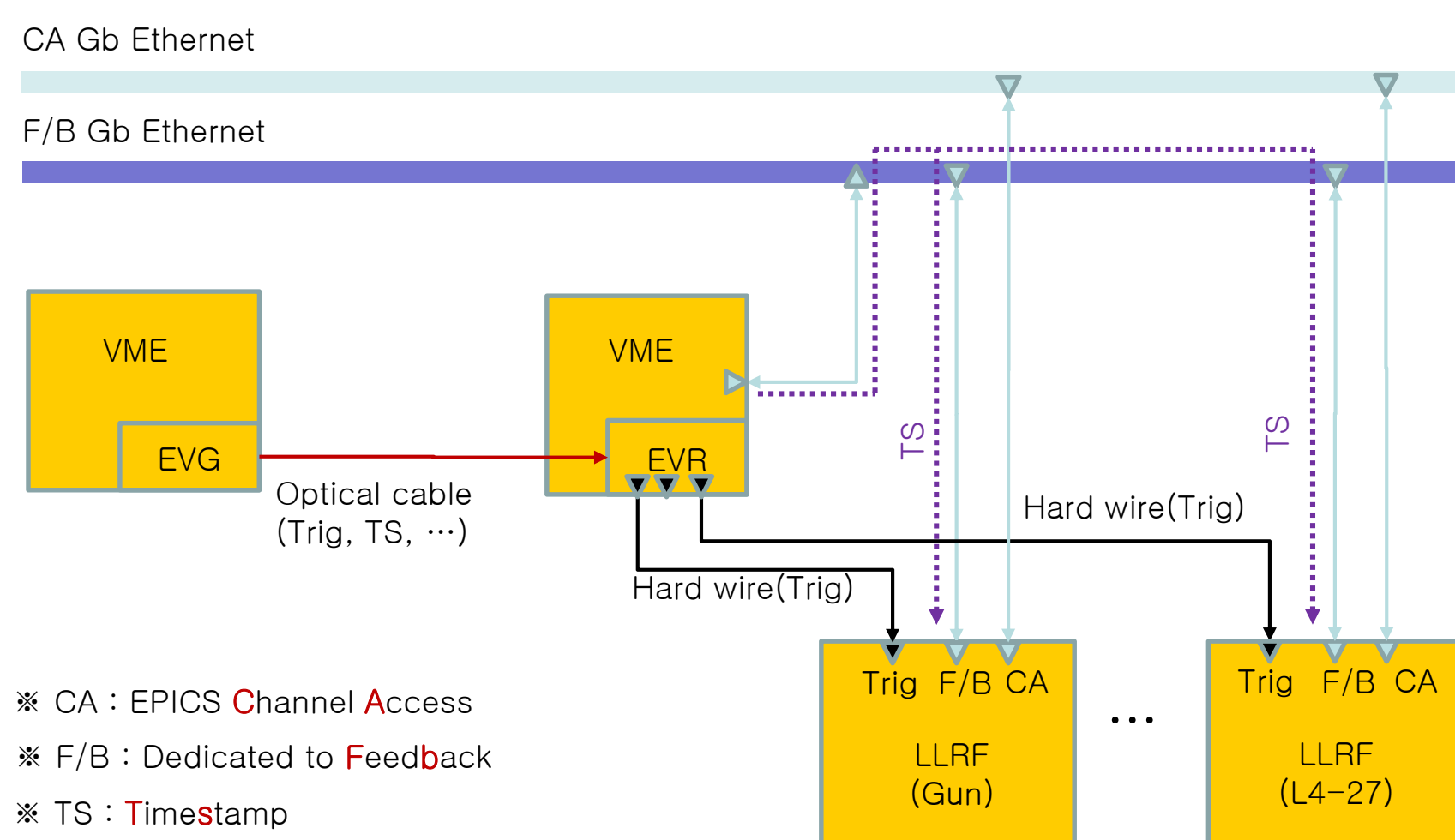
#### Modifying LLRF software



- Needs only SW change
- No cost by in-house develop.
- Easy to expand BLs
- **Selected**

### PAL-XFEL LLRF review

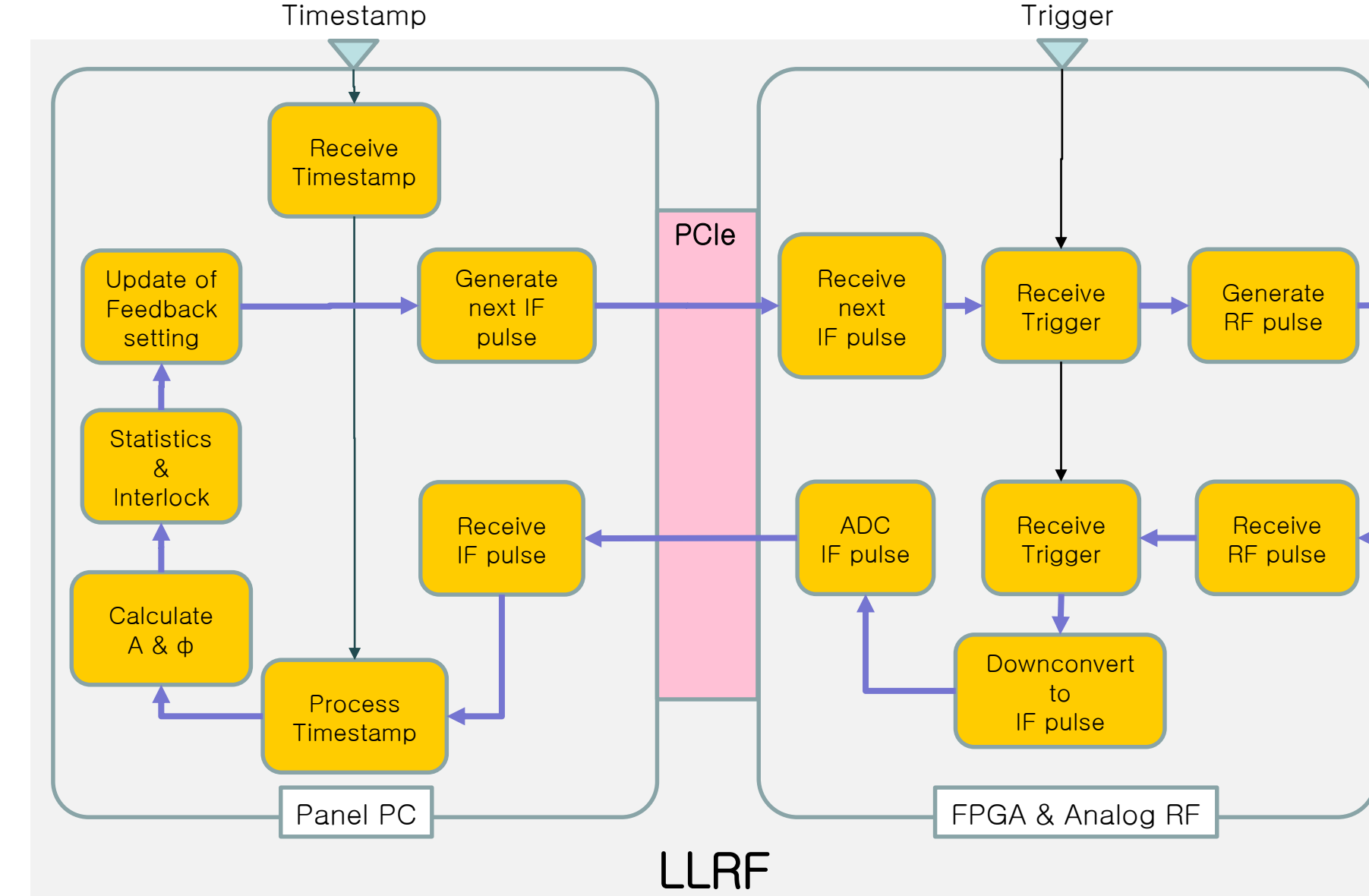
#### Transmission of triggers and timestamps



- \* CA : EPICS Channel Access
- \* F/B : Dedicated to Feedback
- \* TS : Timestamp

- Event system based on SLAC LCLS & MRF system
- From EVG to EVRs, Trigger & Timestamp information is transferred at 360Hz via optical cables
- From EVRs to LLRF units, triggers are transmitted at  $\leq 60$ Hz via hard wire.
- From EVRs to LLRF units, timestamps are transmitted at 360Hz via F/B Gb ethernet

#### Operation cycle within LLRF



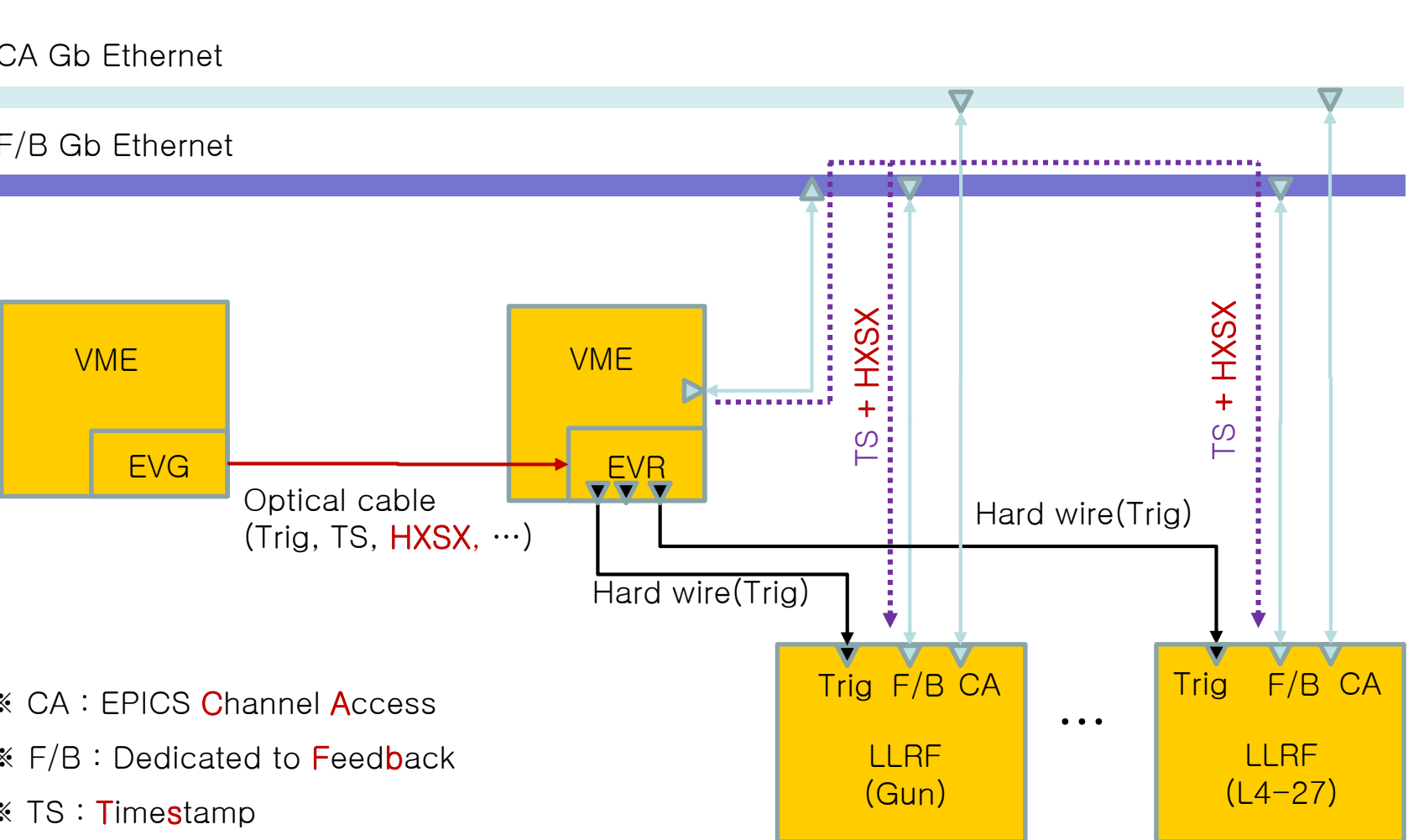
- Between triggers, all RF and data processing cycles are completed within < 5ms
- Timestamp and feedback values are updated pulse-by-pulse
- All digital-data processing by SW (software) within panel PC
- Possibility to process pulse-by-pulse RF switching by changing SW within panel PC

### Concept & Implementation

※ HXSX : beam routing information for multi-beamlines

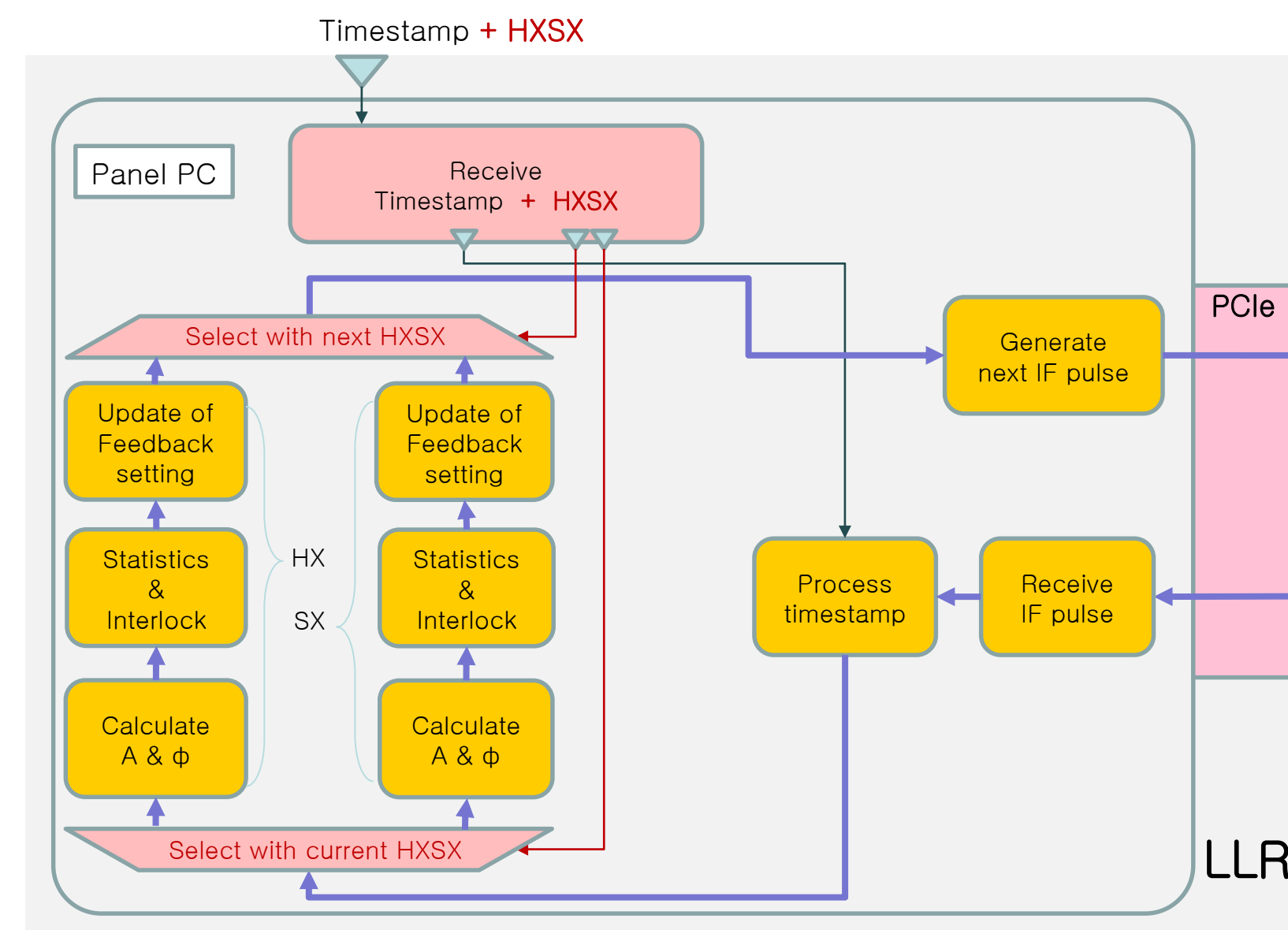
#### Modified operation cycle within LLRF

#### Transmission of triggers and timestamps plus beam routing code(HXSX)



- \* CA : EPICS Channel Access
- \* F/B : Dedicated to Feedback
- \* TS : Timestamp

- Event system slightly modified to send "beam routing information(HXSX)" as well as triggers and timestamps at 360Hz
- Beam routing information (HXSX) is transmitted in the same manner as timestamp transmission



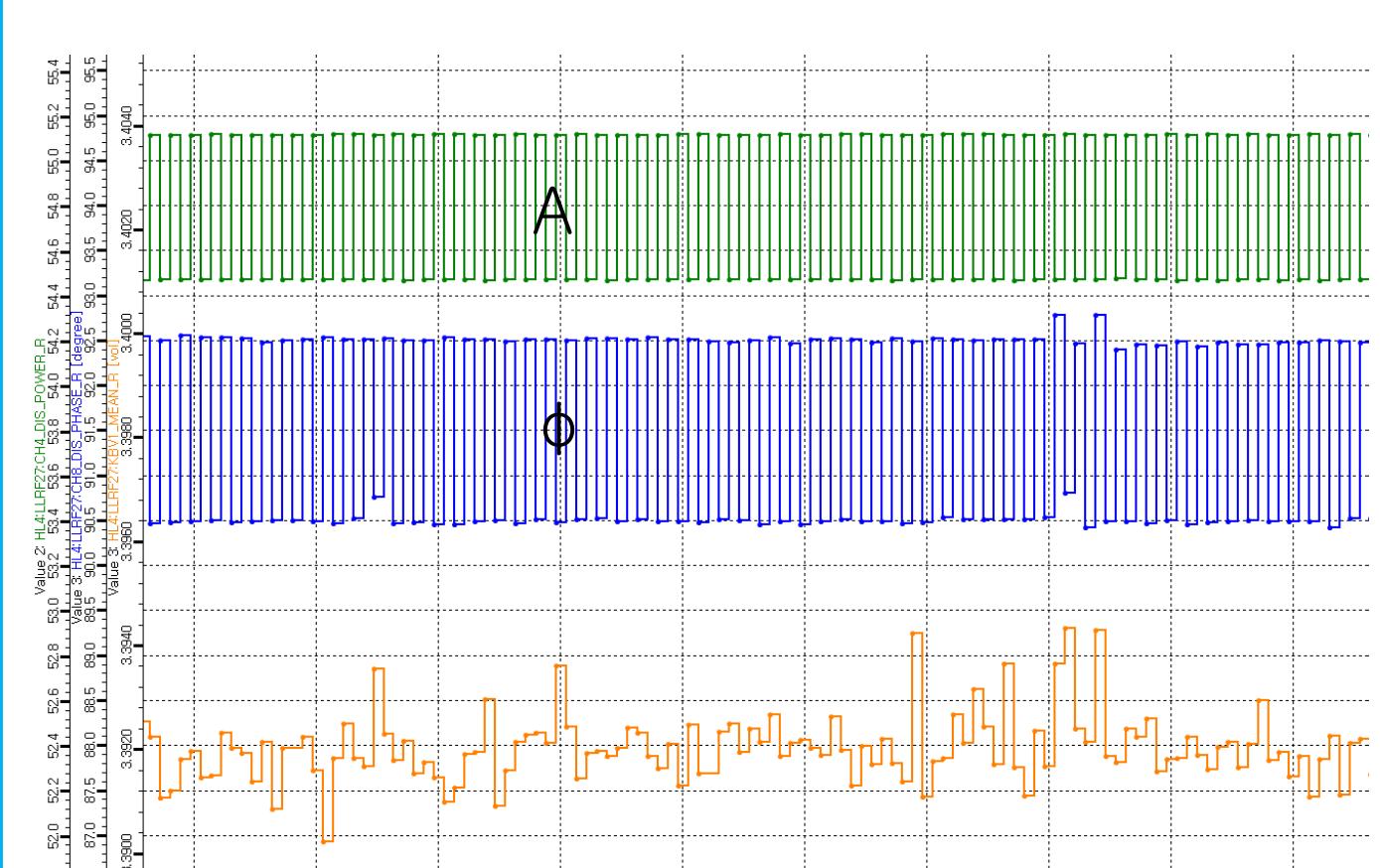
- LLRF SW modified to process according to the beam routing information(HXSX)
- Timestamp receiver modified to include HXSX identification
- Selective data processing in accordance with HXSX information

### Performance

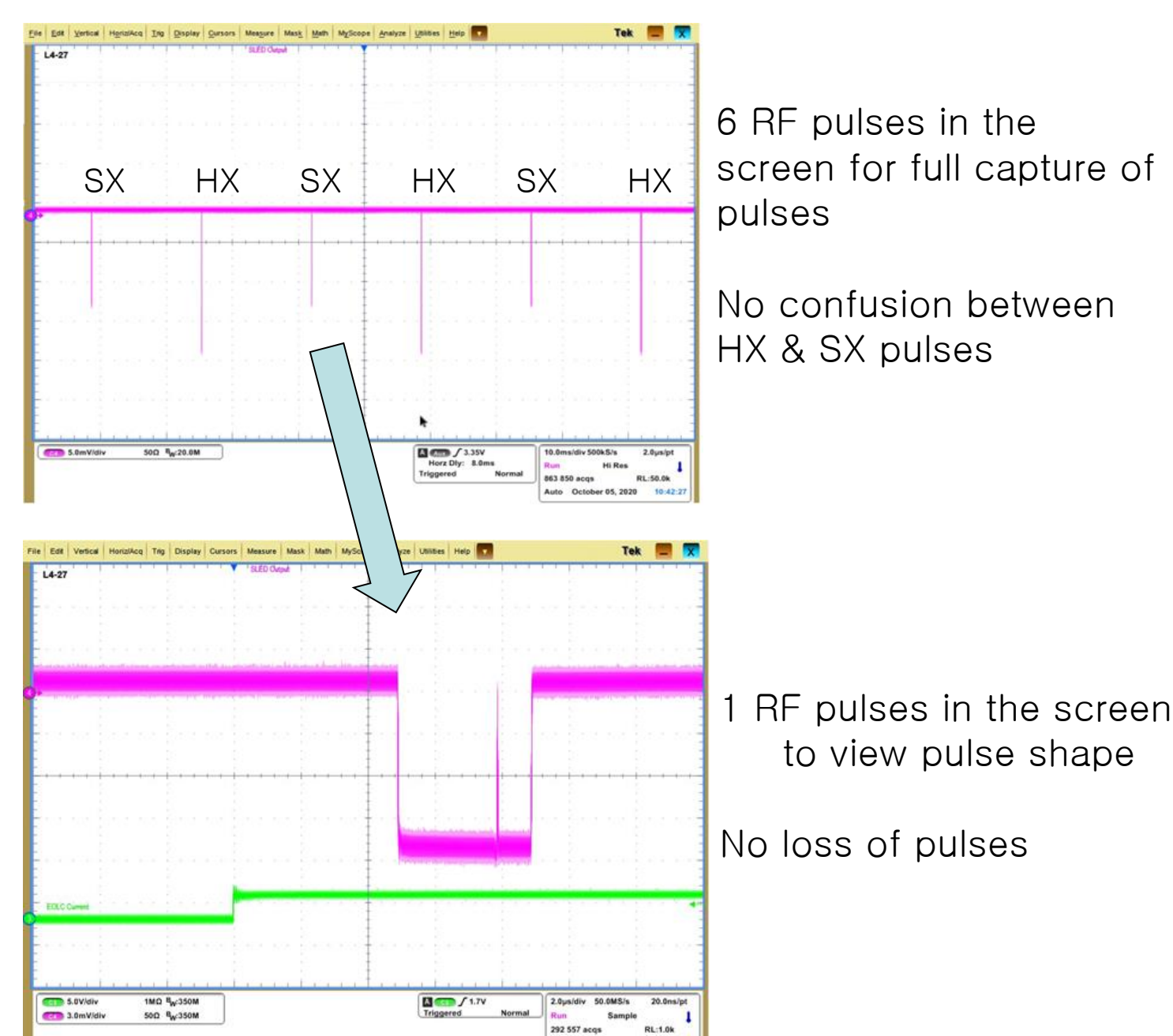
#### Tested on PAL-XFEL machine with HX & SX simultaneous operation

- RF amplitude(A) & phase( $\phi$ ) measured at LLRF receiver for 2 seconds

→ Correct RF switching of HX 30Hz and SX 30Hz

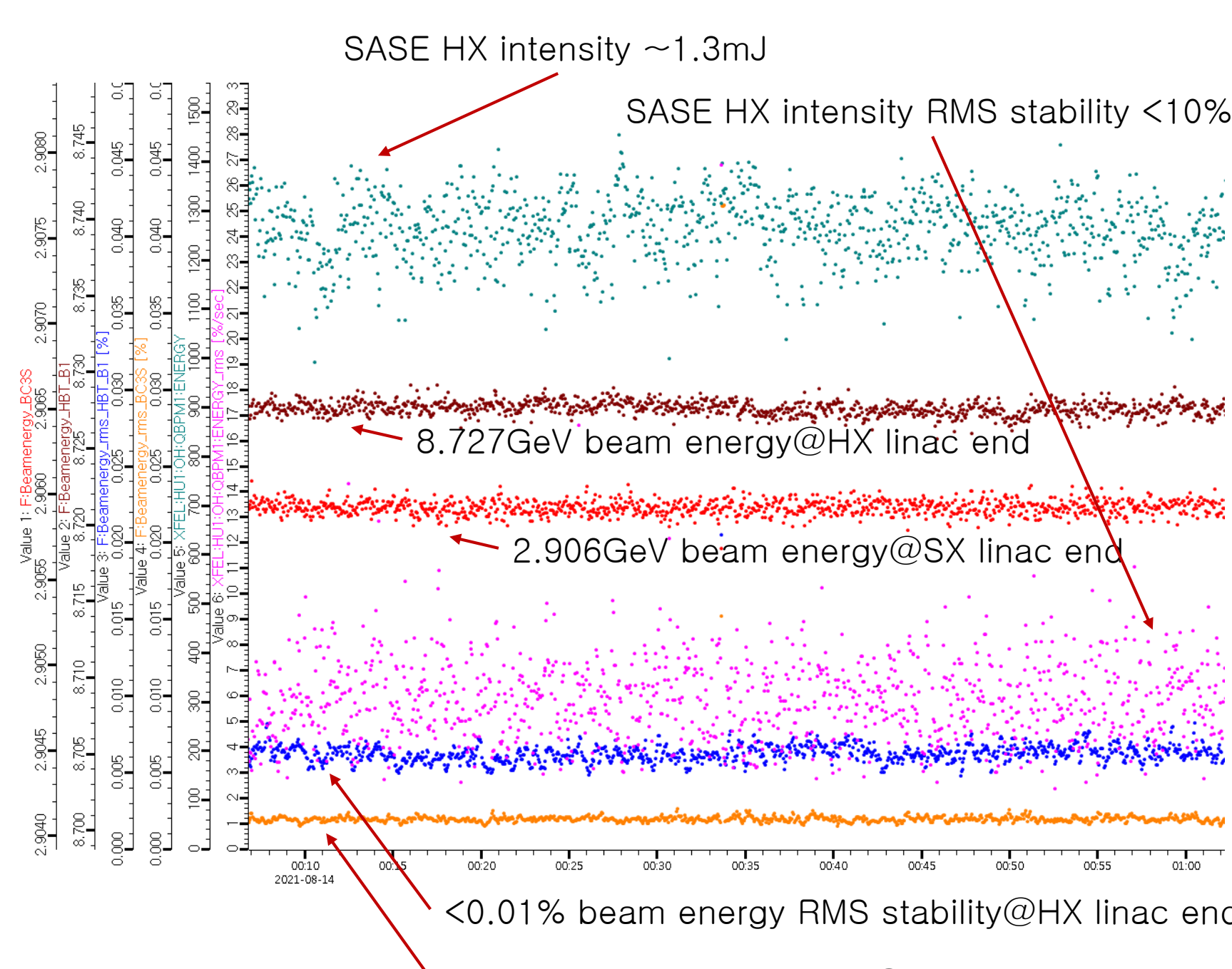


- RF pulses measured at the LLRF output with a diode and an oscilloscope for 2 days per each case (all RF 60Hz & scope 10Hz persistent mode)



- Beam test

Beam energy & SASE intensity are maintained stable in pilot test for ~1 hour



### Conclusion

- Increasing the effective beam time through simultaneous HX and SX operation of PAL-XFEL, requires not only the implementation of a fast kicker, but also pulse-by-pulse RF parameter switching of LLRF
- Event timing and LLRF software modifications were conceptualized and realized in the direction of transmitting and processing pulse-by-pulse beam routing information
- A pilot test showed promising result
- Regular simultaneous operation is expected in the near future.