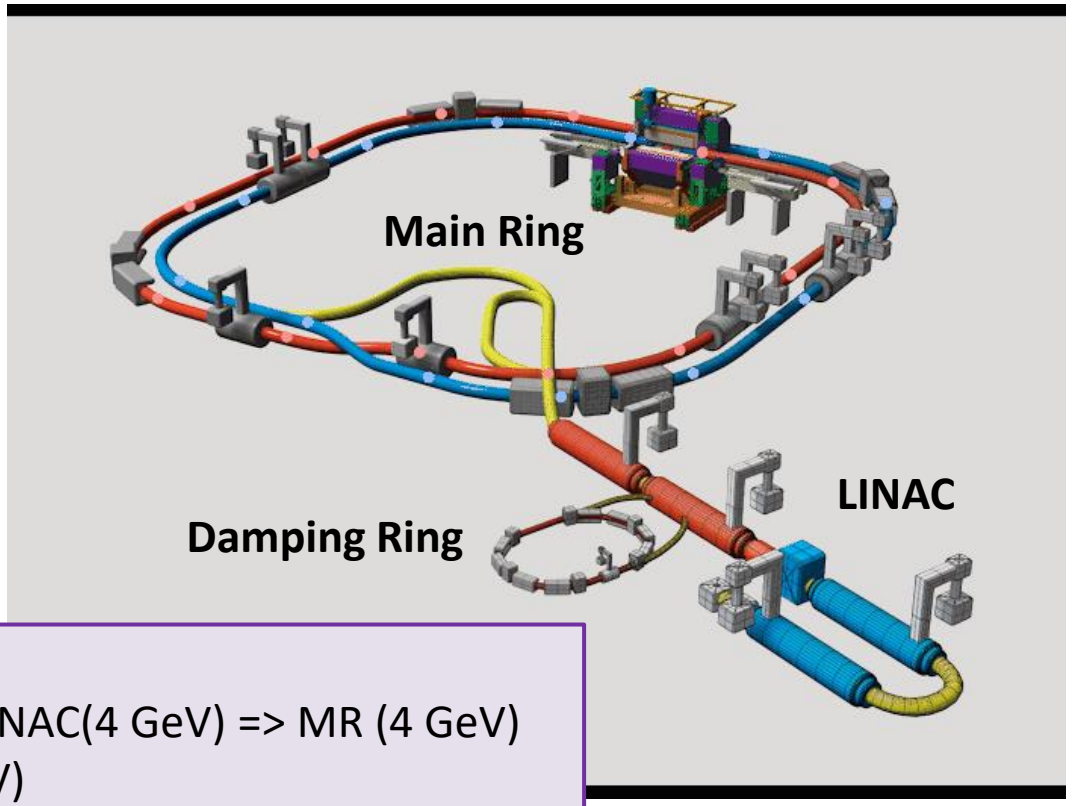
White Rabbit application at KEK

Hiroshi Kaji, Tetsuya Kobayashi, Takaaki Yamaguchi (KEK)
Antoine BACK, Daniel Charlet, Aurélien Martens (IJCLab)

SuperKEKB

SuperKEKB is an electron-positron collider at KEK, Japan.
The luminosity-frontier machine.
(Note, LHC is the energy-frontier hadron collider.)

	Electron	Positron
Energy (GeV)	7	4
Current (A)	3.6	2.6



Injection scheme:
- Positron LINAC (1.3 GeV) => DR => LINAC(4 GeV) => MR (4 GeV)
- Electron LINAC (7 GeV) => MR (7 GeV)

RF frequency: (LINAC:MR = 55:49 with common frequency 10.385 MHz)
- DR/MR 508.9 MHz
- LINAC: 571, 2856 MHz

The injection control (incl. trigger delivery) is carried out with **Event Timing System**. However, we enlarge the **White Rabbit** usage to satisfy the increased requirements for the accelerator timing system.

White Rabbit application at KEK

Delivery of control signal

- The system has already been in use at SuperKEKB.
- Enable/disable control of the injection
- Operation enable/disable at Accelerator Test Facility (ATF)

(Followings are carried out with the IJCLab colleagues.)

RF clock delivery ***R&D on-going***

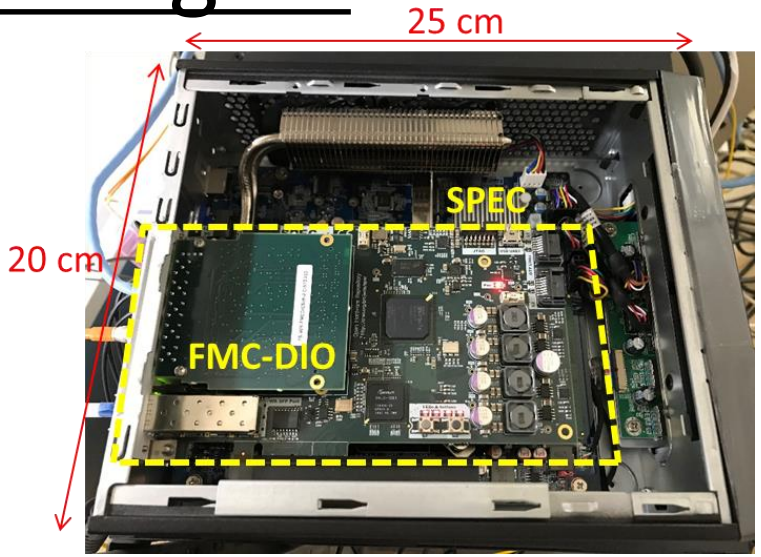
- for the beam diagnose system (not consider inserting to RF cavity) at SuperKEKB
- DAQ system operation for the laser Compton polarimetry at SuperKEKB and ATF

Distributed DAQ ***R&D on-going***

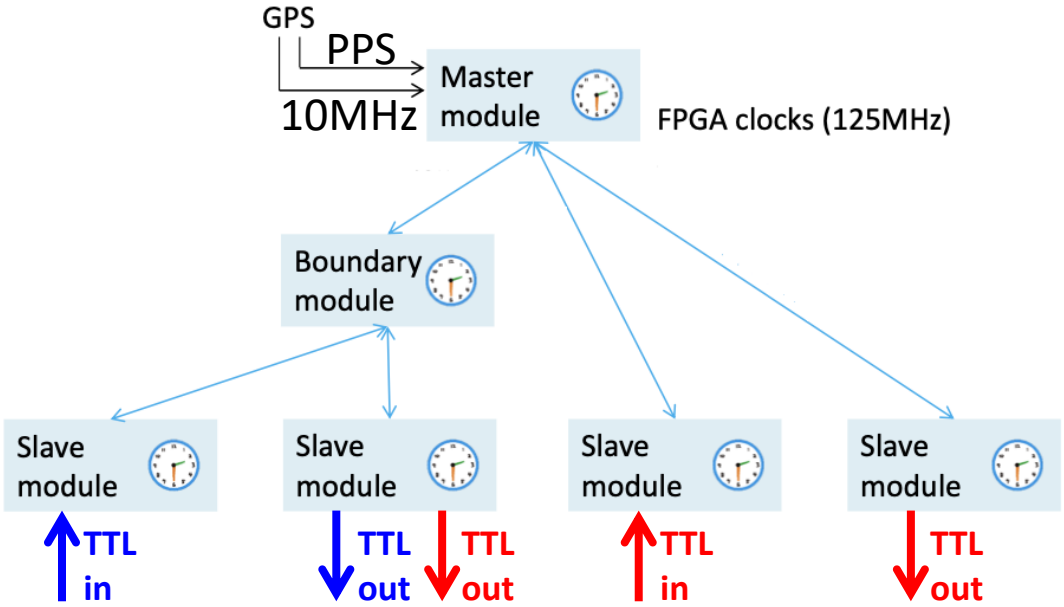
- Accident inspection at SuperKEKB
  1. Beam loss source detection with TDC
  2. Beam oscillation detection with ADC
- many other applications are planed.

Delivery of control signal

Our WR slave node provides and transfers
the control signal (TTL level signal) of the accelerator hardware.
It is developed with
SPEC (Simple PCIe Carrier) and FMC-DIO
Fully available with EPICS.
https://ohwr.org/project/fmc-tdc/wikis/how-to-set-up-the-spec-and-fmc-dio-with-epics



Ubuntu Linux PC



The TTL level signals are transferred among slave nodes.
Arbitrary delay in 8ns step can be added.

It is utilized to transfer the injection enable/disable control signal at SuperKEKB.
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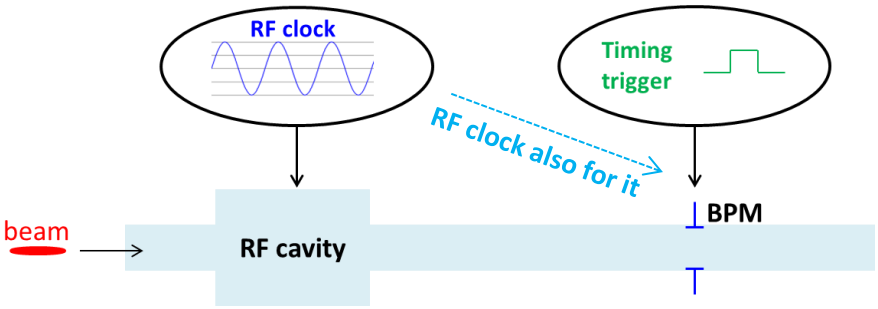
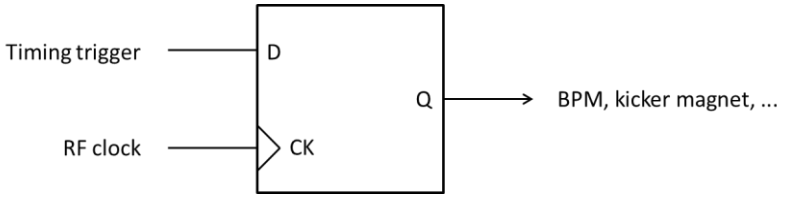
RF clock usage

RF clock usage in the accelerator operation



Timing of the delivered triggers for BPM and pulse magnets is resynchronized to the RF clock with a D Flip-Flop circuit.

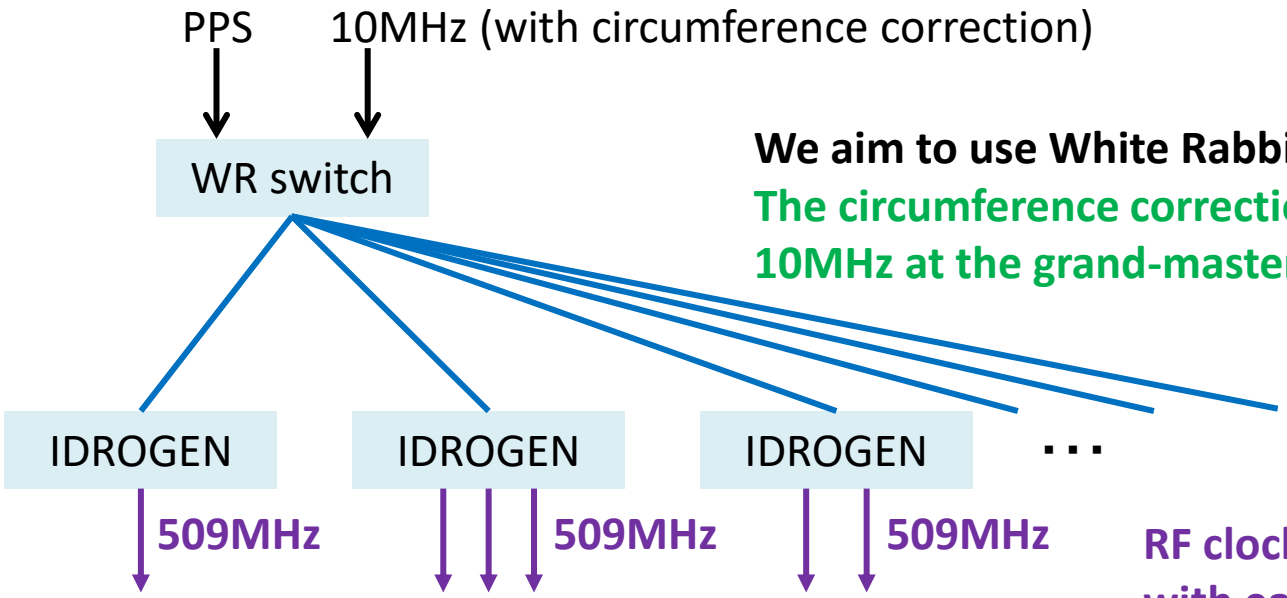


The requirement for the RF clock jitter/stability is different in above two cases.

Usage	Jitter/stability
Timing trigger	*O*(1ps) – *O*(10ps)
RF cavity	*O*(100fs)

The RMS jitter of the current timing system at SuperKEKB is 10-20 ps.
We aim to provide the RF clock for the timing trigger with White Rabbit.

IDEA of RF clock delivery



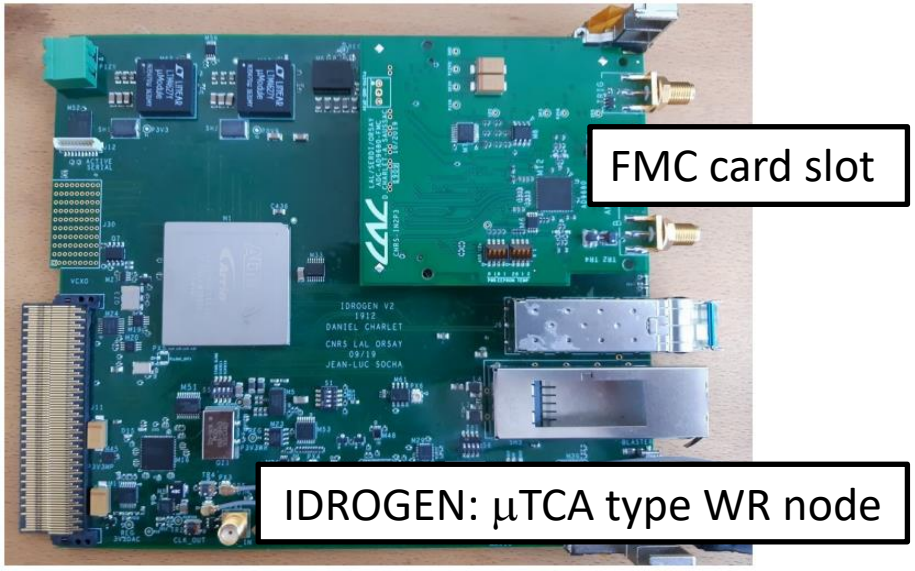
We aim to use White Rabbit as the RF clock generator.
The circumference correction is included in the input 10MHz at the grand-master.

RF clock outputs are synchronized with each other.

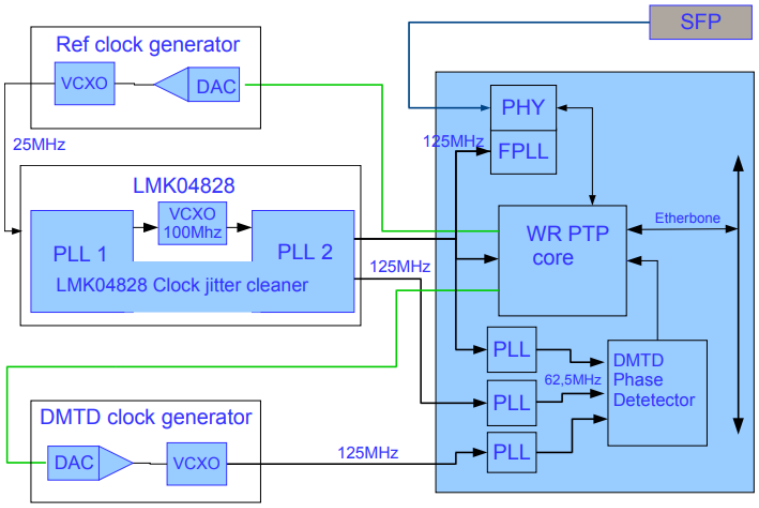
Requirement for RF clock in the accelerator operation.

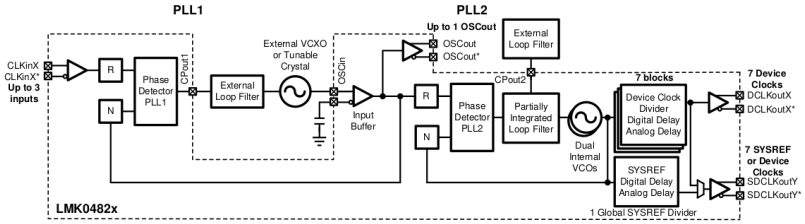
Usage	Jitter
Timing trigger	*O*(1ps) – *O*(10ps)
RF cavity	*O*(100fs)

The RMS jitter for the current timing system SuperKEKB is 10-20 ps.



IDROGEN





The IDROGEN board is developed at IJCLab.
- µTCA.4 type board
- standalone mode, available
- Intel Arria10 FPGA board with SFP and QSFP.

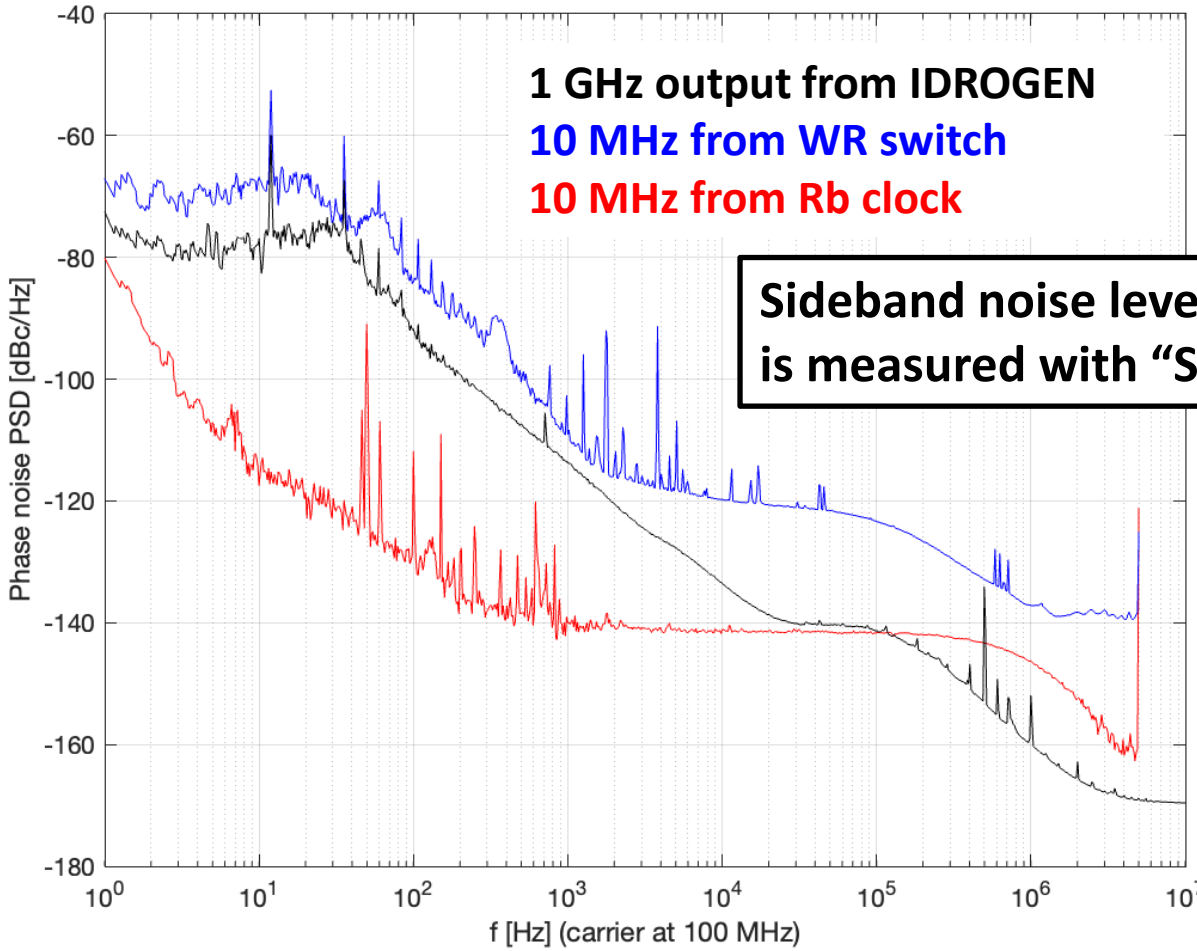
The White Rabbit system is configured.

A few telescopes selected as its timestamp synchronization.
The test stand for superconducting spoke cavity at IJCLab.
Maybe, in future, the accelerator facility for this cavity will select IDROGEN as the RF generator.

KEK participates:
- performance test
- development of the EPICS device support

Application at SuperKEKB and future projects

Sideband noise level



Sideband noise level of 1GHz reference clock is measured with "SSA E5052B".

Jitter

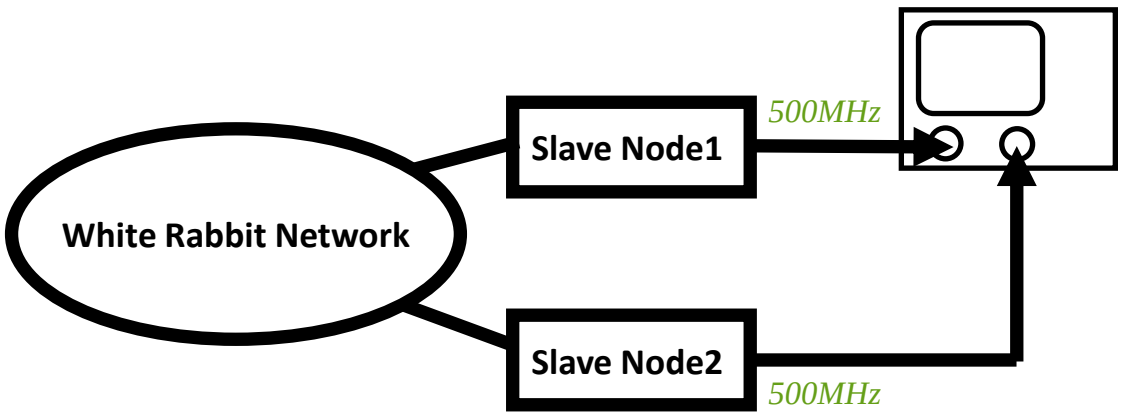
494 fs (100Hz-10MHz)

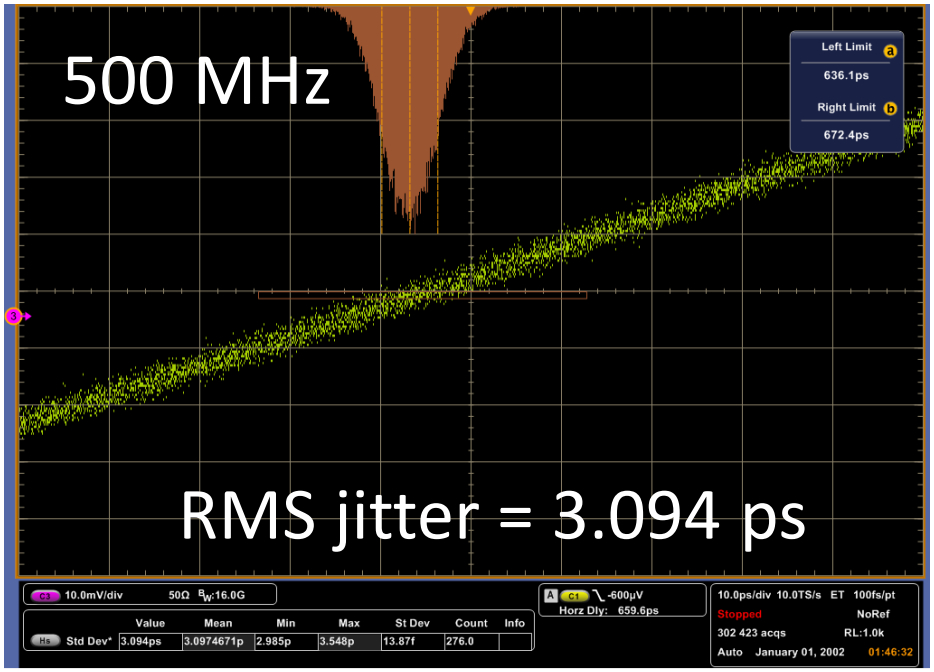
1747 fs (30Hz-10MHz)

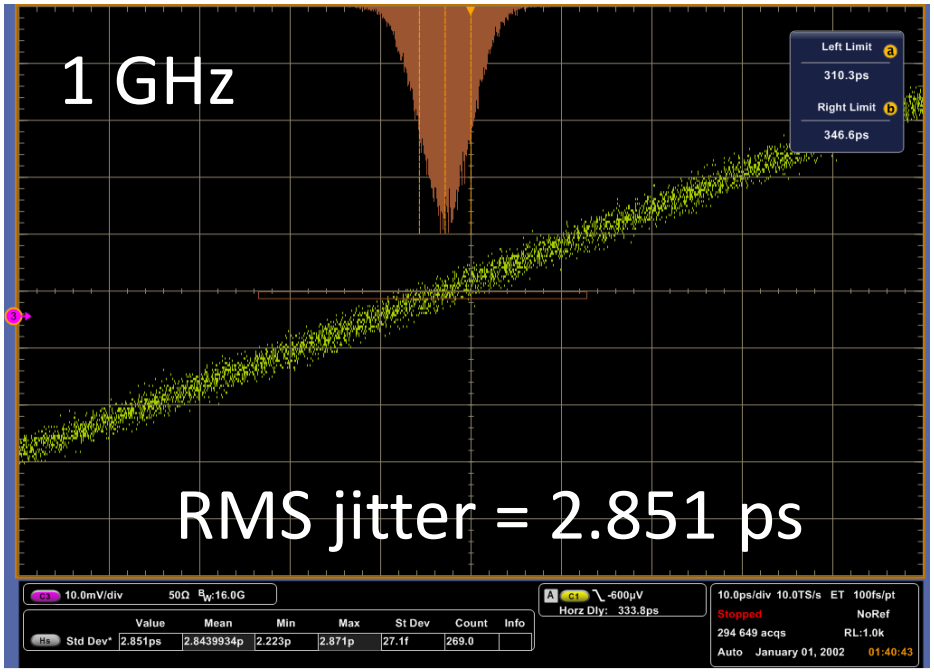
2801 fs (1Hz-10MHz)

It is enough performance for the timing trigger usage.

Relative phase jitter







Future plan

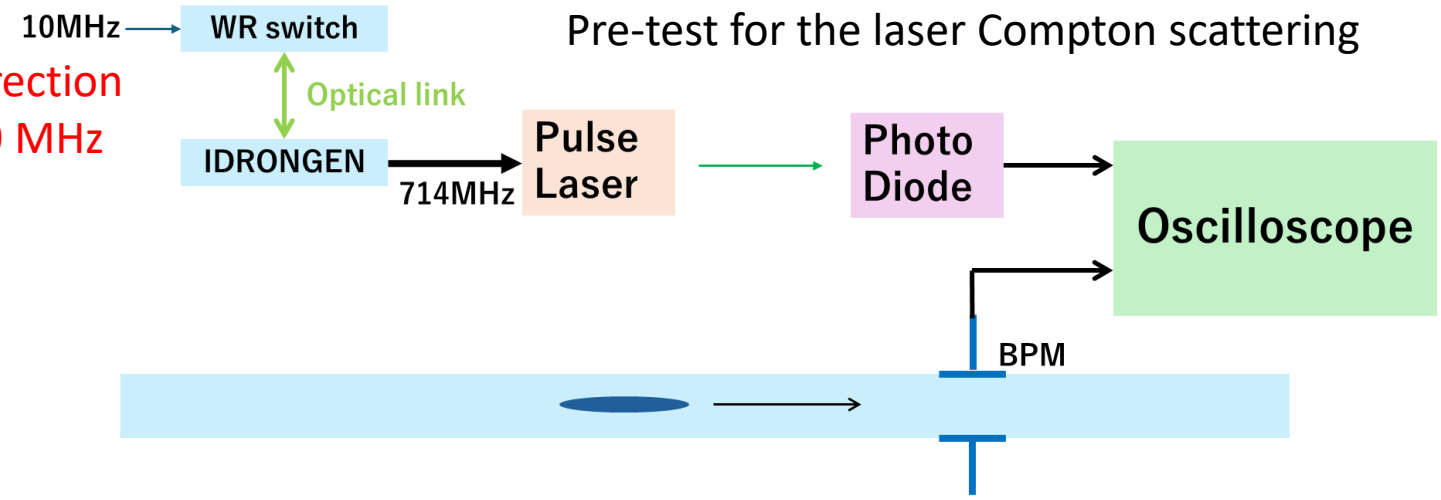
We plan to develop the FMC card which provides 508.9 MHz (SuperKEKB) and 714 MHz (ATF) clock.
Further tests:
- detailed noise measurement
- long-term stability

We consider to develop the function to reproduce the same RF phase between before turn-off and after turn-on.
The laser-beam synchronization test with the ATF electron beam.

Laser-beam synchronization test

Pre-test for the laser Compton scattering

Circumference correction is applied to the 10 MHz reference clock.

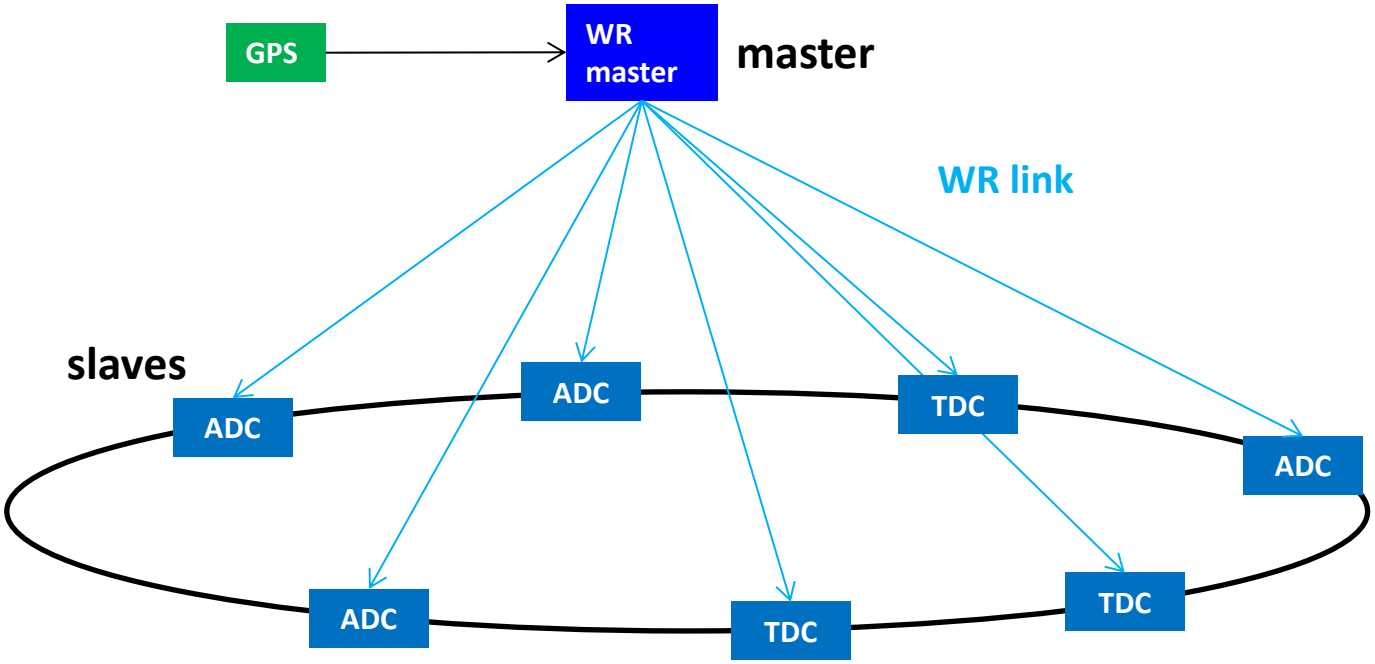


Idea of distributed DAQ system

When there are many Time-to-Digital (TDC) card and Analog-to-Digital (ADC) card in the large-scale beamline, we want to know the causal relation among the individual measurements.

This can be realized with White Rabbit.

By integrating the TDC or ADC card on WR slave node,
by attaching the precise timestamp from WR to individual measured data,
The entire system can be regarded as one huge DAQ system.



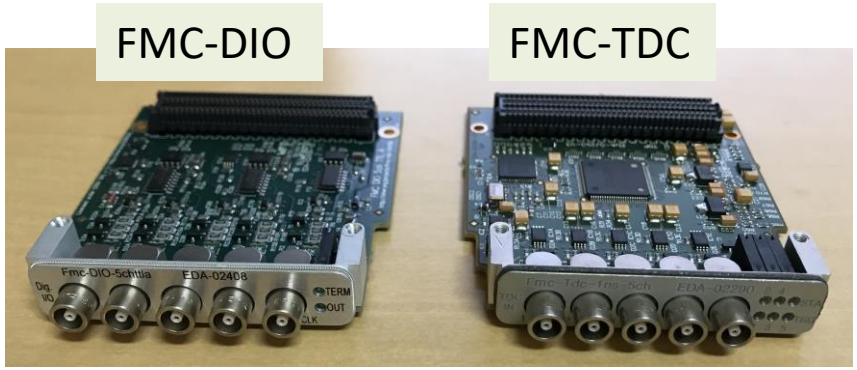
TDC and ADC

TDC system based on SPEC

We already have developed with SPEC and the FMC-TDC card with CERN's kind help.
- timing resolution: 81 ps
  (Note, sync. accuracy of SPEC, *O*(100ps))
- on Ubuntu Linux PC

FMC-DIO also can be used as TDC slave node.
However, in this case, resolution is 8 ns.

EPICS device support available on:
https://ohwr.org/project/fmc-tdc/wikis/how-to-set-up-the-spec-and-fmc-tdc-with-epics

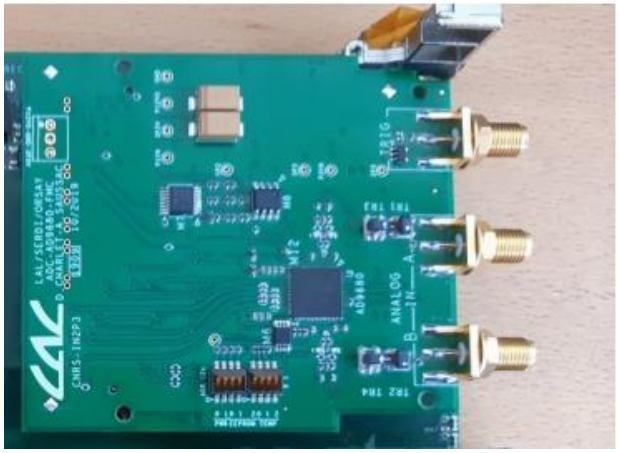


ADC system based on IDROGEN

The R&D of the ADC-type FMC card for IDROGEN is on-going.
IJCLab has two prototypes:
- 14bit-500MHz sampling
  （Need software for application）
- 1GHz sampling card

Maybe, the first application for the radio telescope array will be done soon.

We consider using at SuperKEKB for
- beam oscillation monitor
- luminosity fluctuation monitor



Conclusion

For satisfying the increased requirement to the injection control of SuperKEKB,
we installed **White Rabbit** in addition to **Event Timing System**.

We developed the transfer system of the accelerator control signal via the WR network.
- It consists of “SPEC” and “FMC-DIO” on the Linux PC.
- The injection control system is driven with it.

The R&D for the RF clock generator is on-going.
- IDROGEN, µTCA type slave module is developed by IJCLab.
- The precise synchronization between slave node is realized.
- Tests for Long-term stability is needed.
- The reproduction of the same RF phase necessary when it is turned on/off.

The R&D for the distributed DAQ system is on-going.
- The TDC slave node with SPEC and FMC-TDC is ready for use (EPICS available).
- We plan to develop the ADC slave node with IDROGEN.
- The ADC sampling clock should be synchronized with the RF clock to enhance the beam diagnosis capability.