White Rabbit at SuperKEKB

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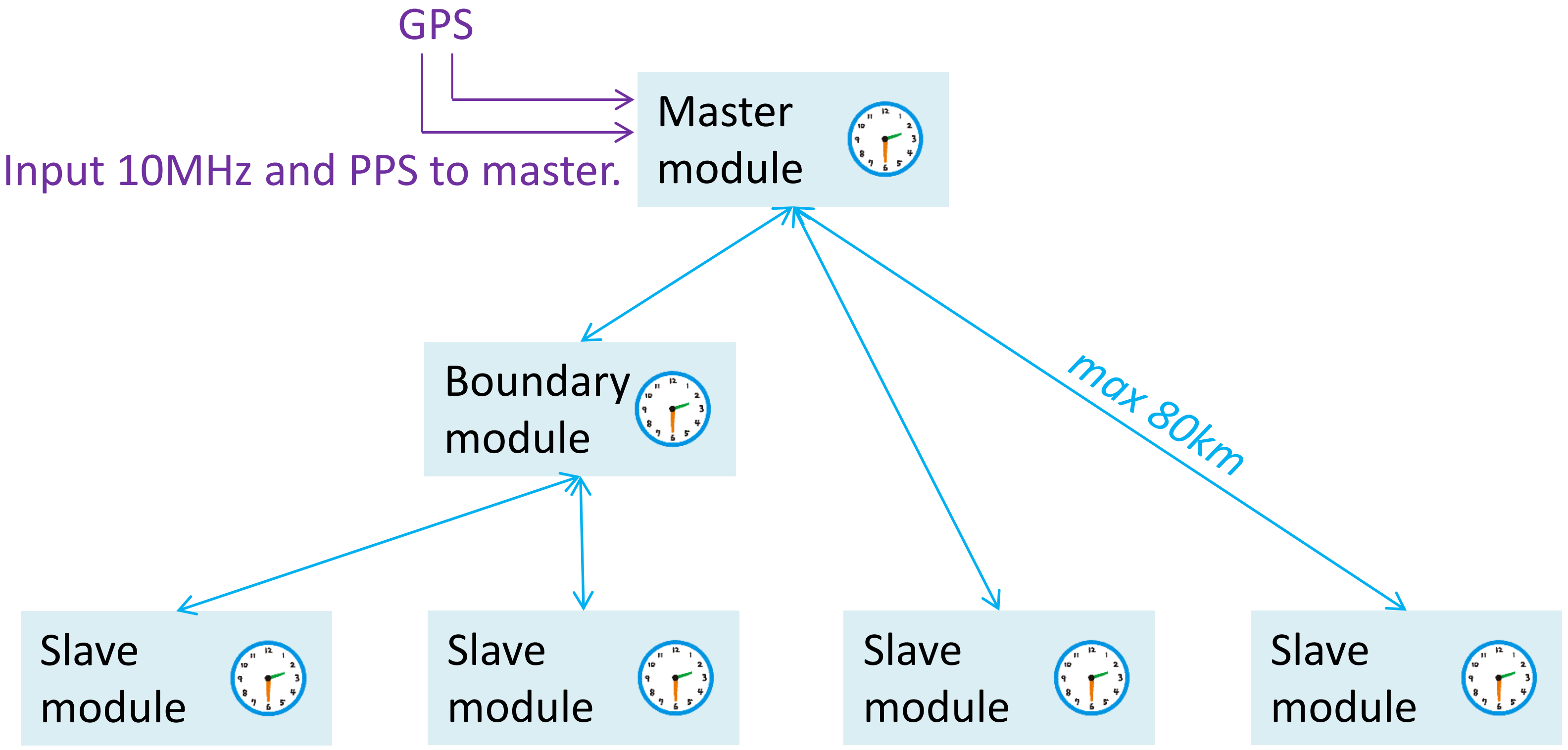
My apology

My family has difficulty traveling oversea.
It is hard to leave the care of our baby to my wife alone.

Thank you very much to give me the opportunity of the remote participation.

What is White Rabbit?

White Rabbit is the module complex that has the common timestamp 🕒.
Each module is an FPGA circuit with SFP for the optical connection.
Their FPGA clock (125MHz) is precisely synchronized and provides the common timestamp.



It is utilized as the timing system, e.g. CERN, GSI, ESRF ...

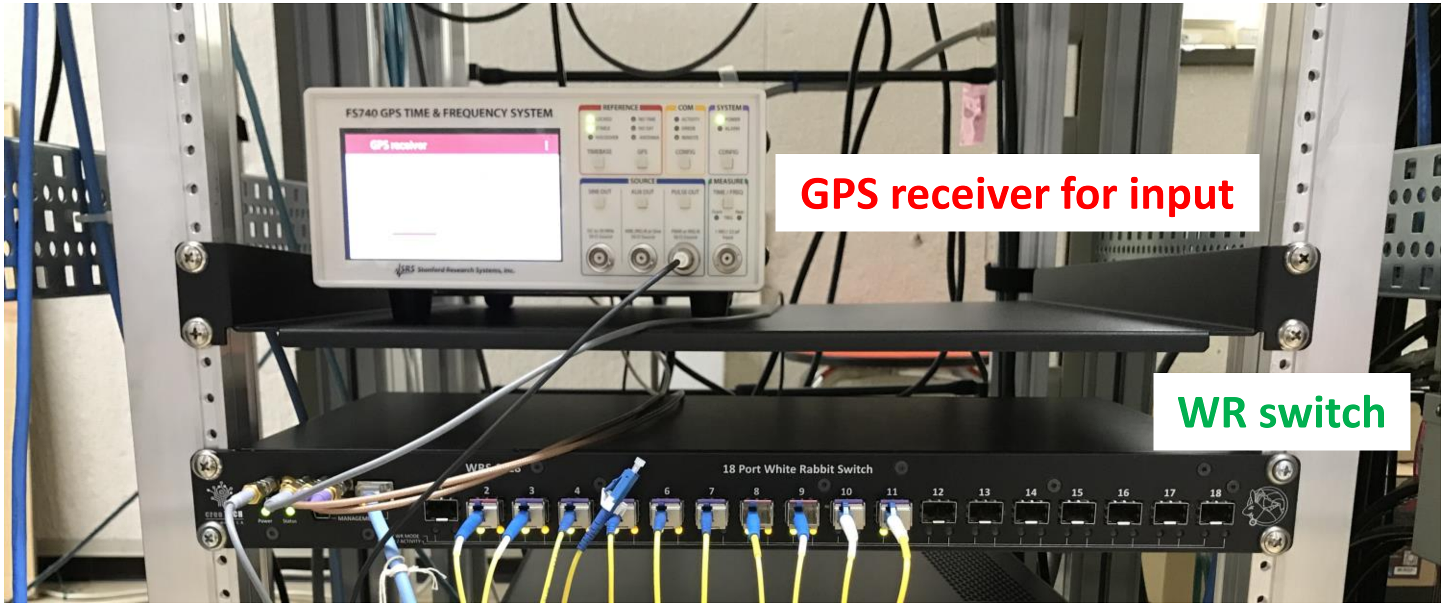
Timestamp synchronization

There levels of the synchronization function is implemented.

- IEEE 1588 PTP: sub-micro second
- Synchronous Ethernet (Sync-E): 8ns
- Dual Mixer Time Difference (DMTD) phase detector: O(100ps)

This is the precision of the White Rabbit timestamp.
The resolution of issued time in the slave setup

White Rabbit master module


FS740 GPS TIME & FREQUENCY SYSTEM
GPS receiver
18 Port White Rabbit Switch

GPS receiver for input

WR switch

WR switch as master module:

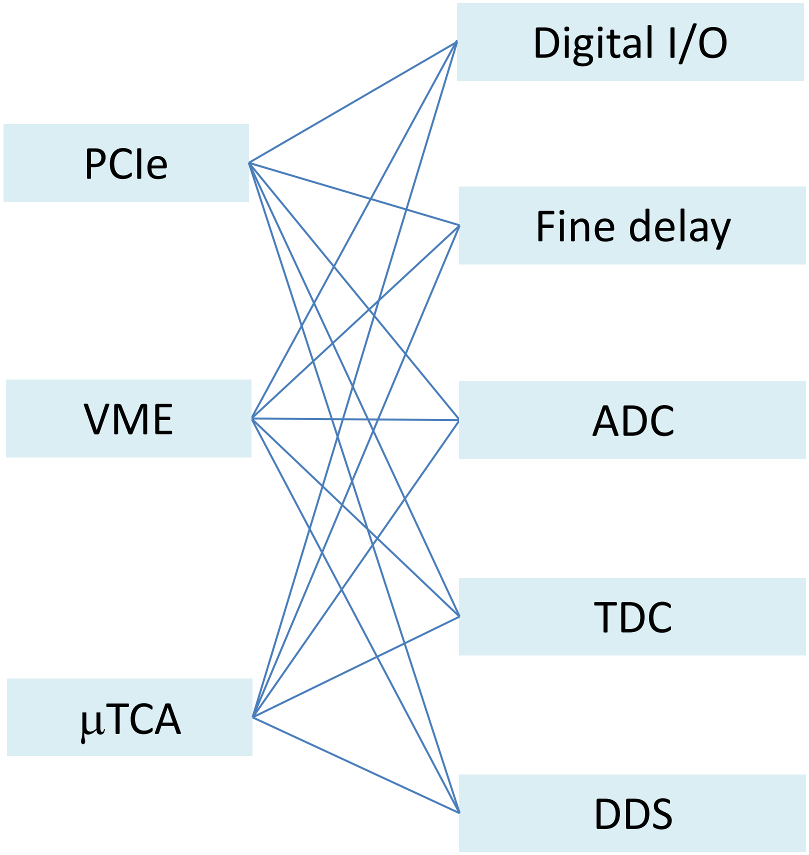
- is 1U height module.
- provides the common timestamp.
- synchronizes the common timestamp with input (10MHz and PPS).
- can be operated as the boundary fanout module.

There are several commercial vendor.

White Rabbit slave module

The slave node is a pair of the carrier and the FMC card.

The preferred platform can be chosen as the carrier module.



PCIe

VME

μTCA

Digital I/O

Fine delay

ADC

TDC

DDS

The function of slave node is configured by the FMC card.
All FMC cards can be operated with all carrier types.

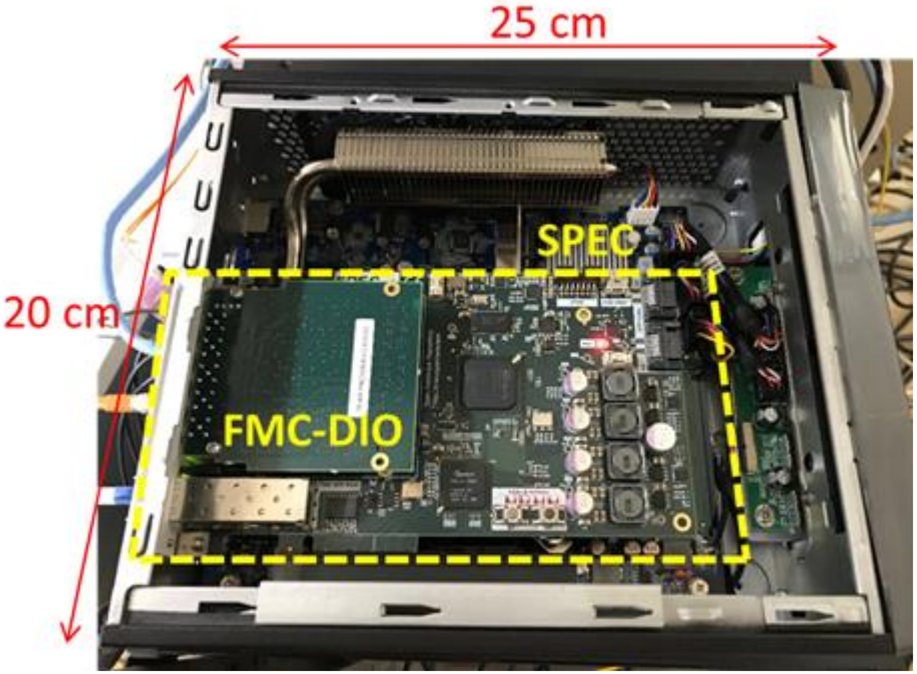
However, the software development is on-going effort.
SuperKEKB uses the only PCIe carrier with FMC-DIO or FMC-TDC.

Slave module at SuperKEKB

SPEC (Simple PCIexpress FMC Carrier)
- PCIexpress x4 module
- carrier of FMC card

FMC card
- FMC-DIO input/output 8ns resolution
- FMC-TDC only input 81ps resolution

and the Linux PC ...



EPICS device support

The EPICS device support is developed for

- SPEC + FMC-DIO

  http://kekb-co-web.kek.jp/~hig-iitk/wr/fmc-dio/fmc-dio_devsup_setup.html

  English page will be prepared soon.

- SPEC + FMC-TDC

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

It works on Ubuntu 18.04LTS or Ubuntu 20.04 LTS.

Channel setting on EPICS PV

In the SPEC+FMC-DIO slave node, the function of the individual channel can be setup with the stringout PV.

```
record(stringout, "$(GR):$(N):DIO:MODE") {
      field(DTYP, "WR DIO MODE")
      field(OUT,  "@IF=$(IF)")
      field(VAL,  "P0DDD")
      field(PINI, "YES")
}
```

- P: PPS output
  (synchronized with a second-hand of common timestamp)
- I: Input (can transfer)
- D: Controlled by device support
  (can output the signal from other channel or node)
- 0: output 0V (can be used as the control signal)
- 1: output +5V (can be used as the control signal)

The issued time for all input or output can be recorded on the TIME field of following PV.

```
record(bi, "$(GR):$(N):DIO:CH0:STA") {
      field(DTYP, "WR DIO STAMP")
      field(INP,  "@IF=$(IF),CH=0")
      field(SCAN, "I/O Intr")
      field(ZNAM, "Low")
      field(ONAM, "High")
      field(TSE,  "-2")
}
```

This is in the case of ch0.

Channel setting on EPICS PV

In the SPEC+FMC-TDC slave node, the function of the individual channels are input only.
- Input timestamp is available on longin or waveform PV.
- the resolution of timestamp is 81ps (Note, it is 8ns in the case of FMC-DIO).

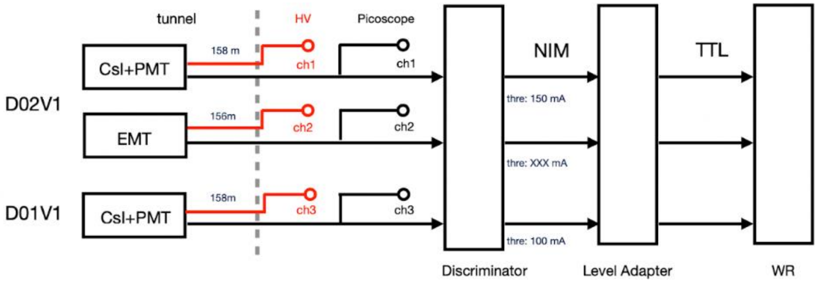
The issued time for all input can be recorded on the VAL field of following PV.

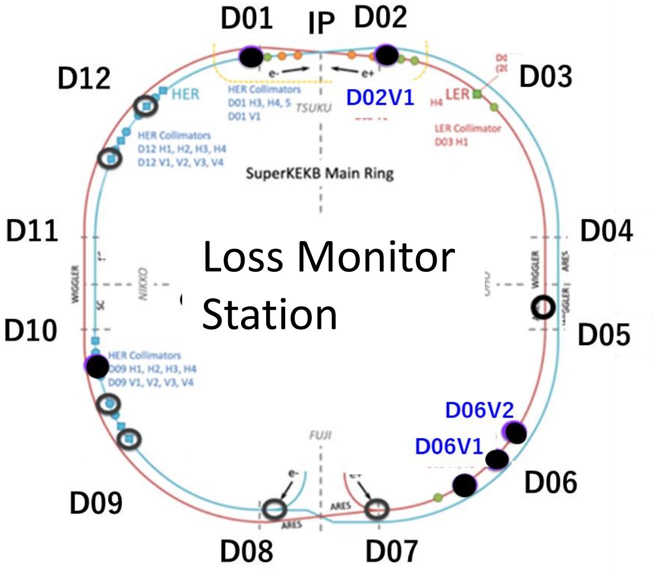
```
record(longin, “SLAVE:TDC:CH0:LI") {
 field(DTYP, "WR TDC STAMP")
 field(SCAN, "I/O Intr")
 field(INP,  "@IF=PCI_ID,CH=0")
 field(TSE,  "-2")
}
```

```
record(waveform, “SLAVE:TDC:CH0:WF") {
 field(DTYP, "WR TDC STAMP")
 field(SCAN, "I/O Intr")
 field(INP,  "@IF=PCI_ID,CH=0")
 field(NELM, "3")
 field(FTVL, "ULONG")
 field(TSE,  "-2")
 field(MPST, "Always")
}
```

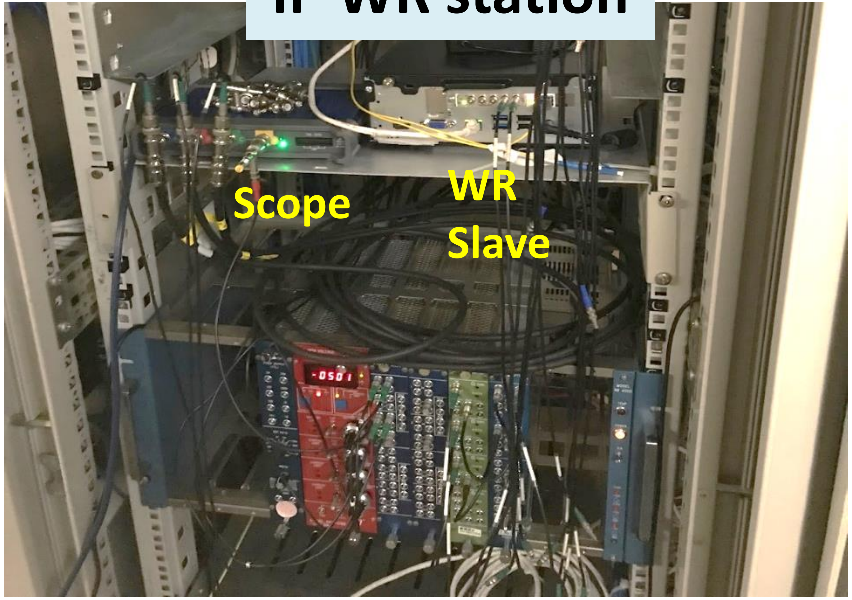
Note, *PCI_ID* is the ID of the PCIexpress board.

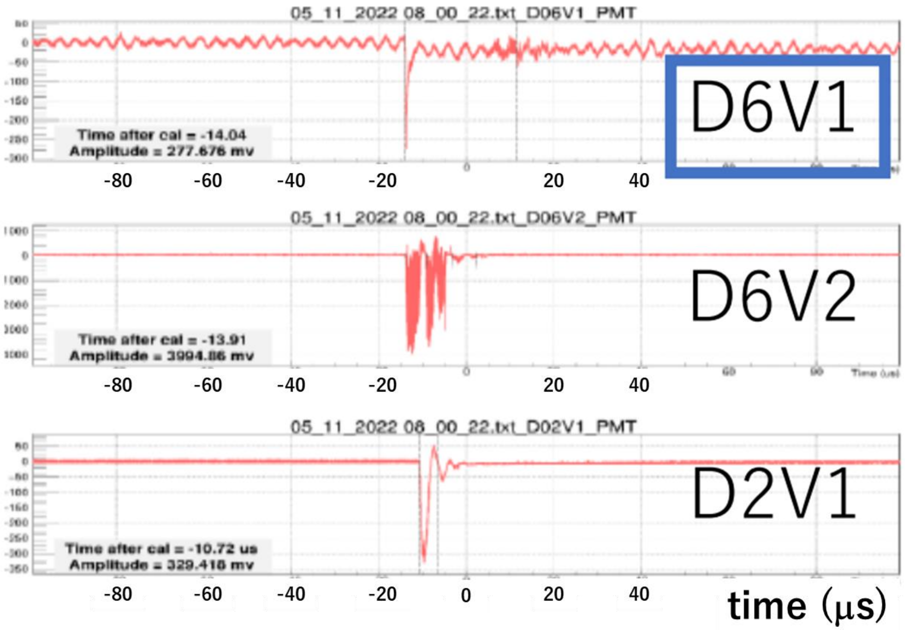
Distributed TDC at SuperKEKB





IP WR station

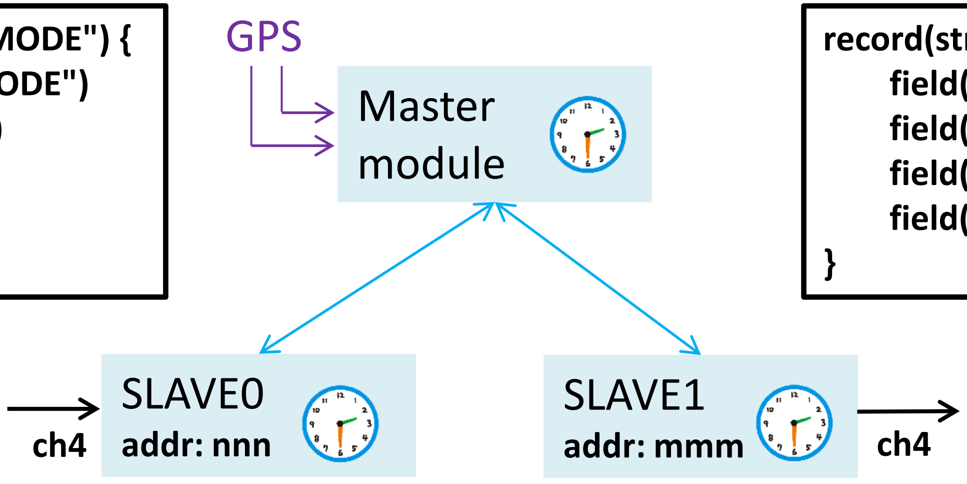




Scope data can be compared directory even though the monitor stations are separated ~ 1 km.

Transfer of Control signal

```
record(stringout, “SLAVE0:MODE") {
      field(DTYP, "WR DIO MODE")
      field(OUT,  "@IF=$(IF)")
      field(VAL,  "P000I")
      field(PINI, "YES")
}
```



```
record(stringout, “SLAVE0:MODE") {
      field(DTYP, "WR DIO MODE")
      field(OUT,  "@IF=$(IF)")
      field(VAL,  "P000D")
      field(PINI, "YES")
}
```

The TTL level signal can be transferred to the other channel or the other node.

That can be setup on PV.

Of course, the issued time is available on PV.

```
record(stringout, “SLAVE0:FWD$(ID):ADDR") {
      field(DTYP, "WR DIO FWD ADDR")
      field(OUT,  "@IF=$(IF),RULE=$(ID)")
} record(longout, “SLAVE0:FWD$(ID):DST_CH") {
      field(DTYP, "WR DIO FWD CH")
      field(OUT,  "@IF=$(IF),RULE=$(ID)")
}
record(longout, “SLAVE0:FWD$(ID):DLY_L") {
      field(DTYP, "WR DIO FWD DELAY")
      field(OUT,  "@IF=$(IF),RULE=$(ID),DLYTYPE=0")
}
record(longout, “SLAVE0:FWD$(ID):DLY_H") {
      field(DTYP, "WR DIO FWD DELAY")
      field(OUT,  "@IF=$(IF),RULE=$(ID),DLYTYPE=1")
}
```

SFP mac address of destination node (mmm in this case).

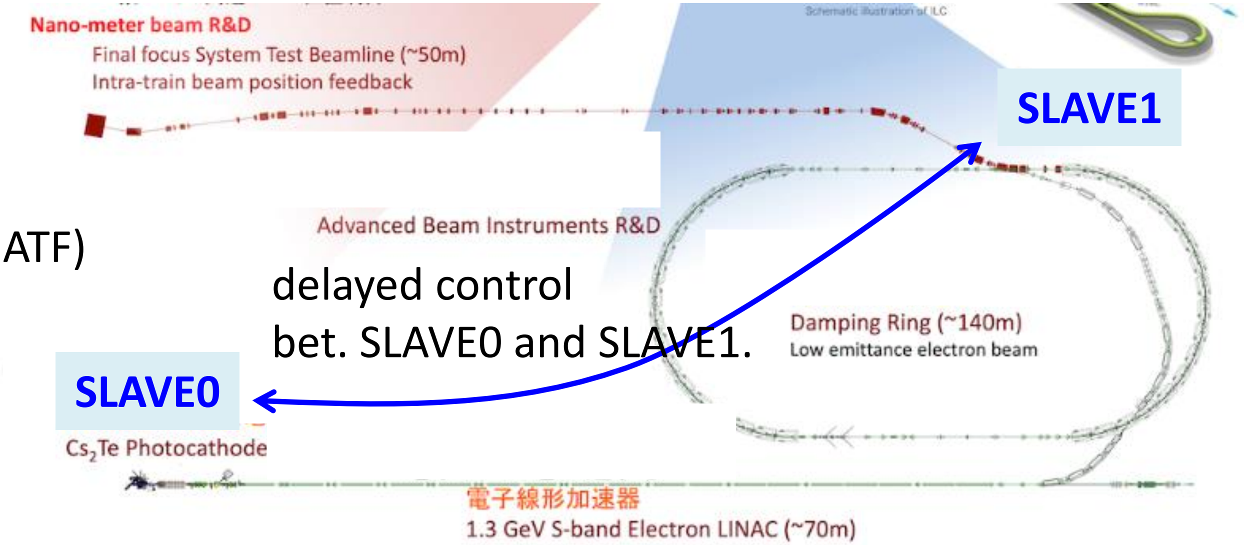
Output channel on the destination node (4 in this case).

Delay from input-time to output-time in the low transition of the signal.

Delay from input-time to output-time in the high transition of the signal.

Test operation at ATF

Accelerator Test Facility (ATF)



SLAVE1

delayed control
bet. SLAVE0 and SLAVE1.

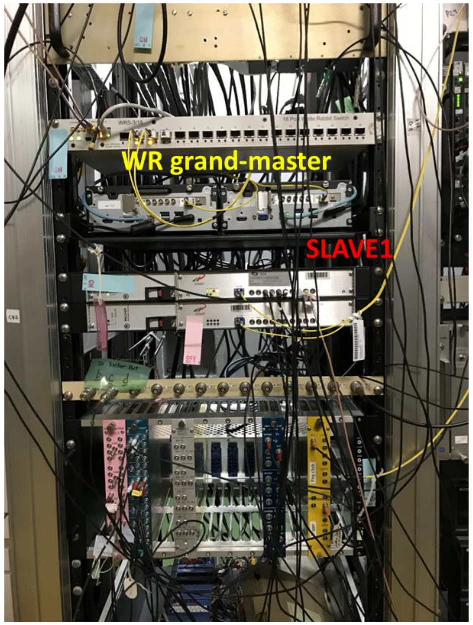
SLAVE0

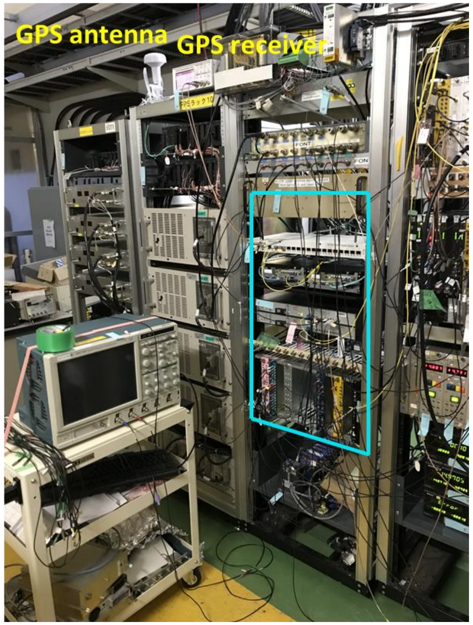
Nano-meter beam R&D
Final focus System Test Beamline (~50m)
Intra-train beam position feedback
Schematic illustration of ILC
Advanced Beam Instruments R&D
Damping Ring (~140m)
Low emittance electron beam
Cs$_2$Te Photocathode
電子線形加速器
1.3 GeV S-band Electron LINAC (~70m)

SLAVE0 controls before damping ring
while SLAVE1 controls after that.

Delay time = damping time.

Test operation will be done since
next month.





Conclusion

White Rabbit is the module complex that has the common timestamp.
- It is, mostly, utilized as the timing system, e.g. cern ...
- The salve module is developed in the several platforms.
- It is commercially available.

SuperKEKB developed the EPICS device support for PCIexpress module.
- The slave node can be configured with two kinds of FMC cards.

We developed two kinds of applications.
- distributed TDC
- transfer of the control signal