The Software-Based Machine Protection System Using EPICS in J-PARC MR

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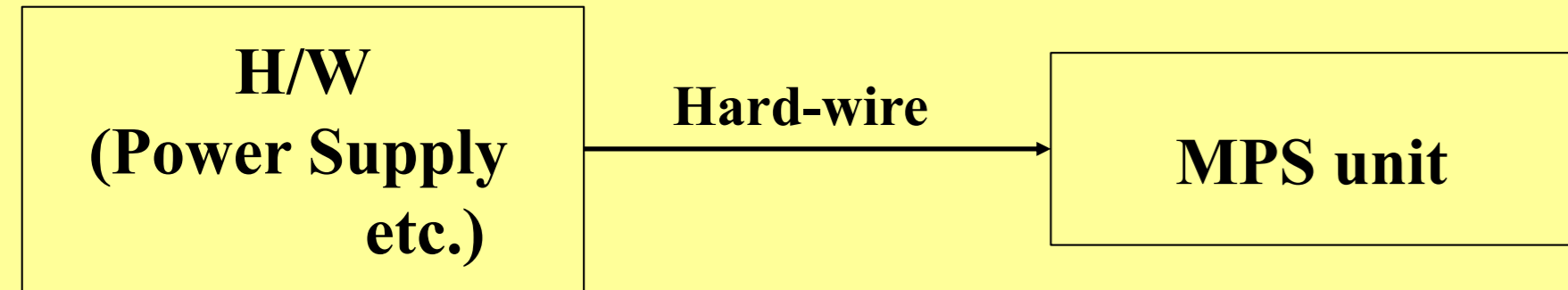
Abstract

In J-PARC, a Machine Protection System (MPS) stops accelerator beam operation automatically when an interlock signal comes. Normal MPS accepts interlock signals by hard-wire, but a software-based MPS, called "Soft-MPS", uses only EPICS PVs without wiring. A PLC controller running Linux was introduced to watch at some EPICS PVs over Ethernet, and outputs Soft-MPS signals to the MPS unit after logical calculates. There are 2 reasons of using Soft-MPS. (1) To install interlock signals rapidly. This type of Soft-MPS will switch to hard-wire later. (2) To use non-hardware parameters: for example, machine operation modes, beam bunch information, etc.
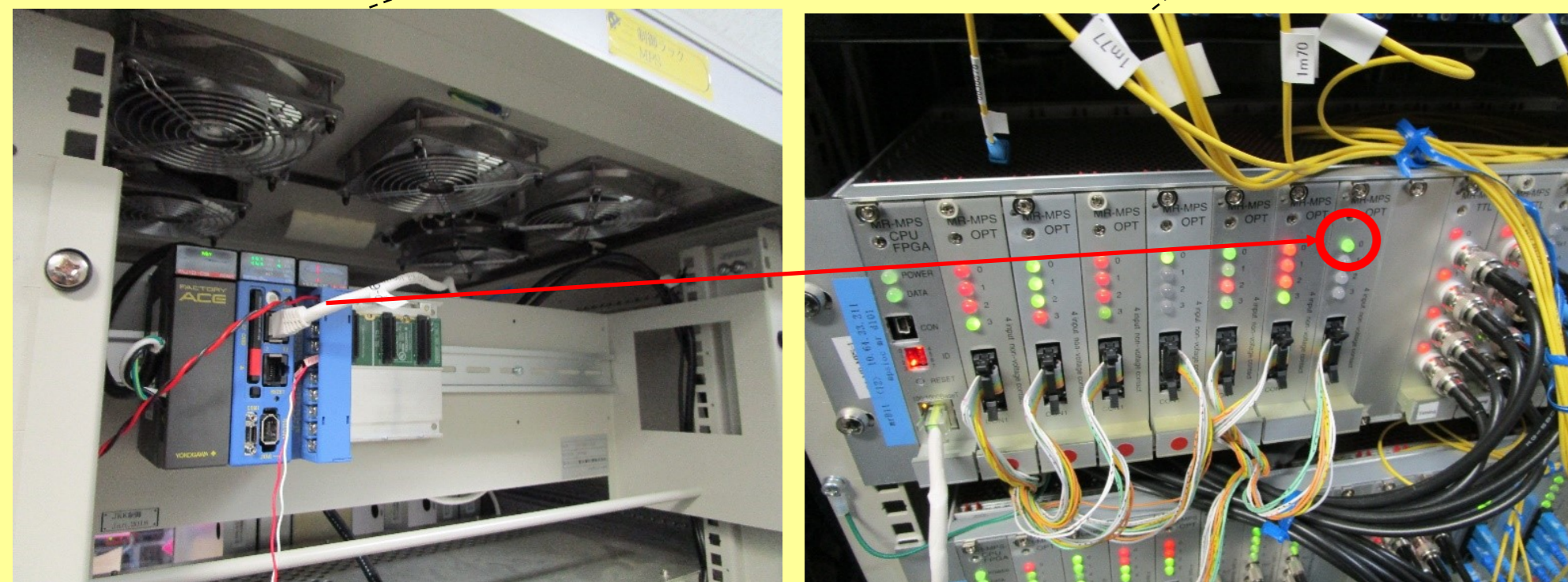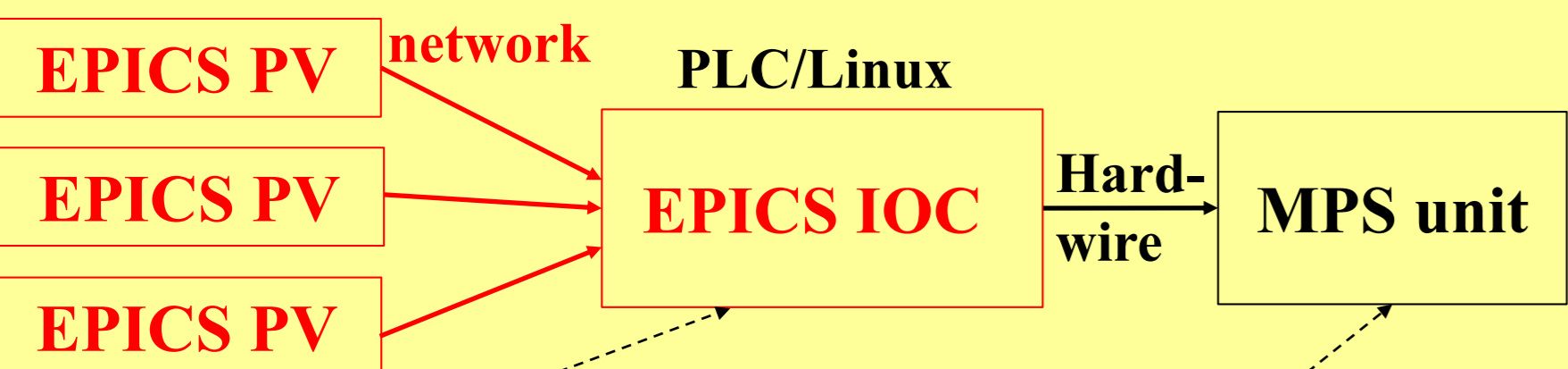
From the first Soft-MPS setup in 2018 spring, 9 Soft-MPS signals are currently used. As more Soft-MPS signals are expected in the future, we need to discuss the policy.

Overview of Soft-MPS

Standard MPS

H/W (Power Supply etc.) — Hard-wire → MPS unit

Soft-MPS

EPICS PV / EPICS PV / EPICS PV — network → PLC/Linux EPICS IOC — Hard-wire → MPS unit

Soft-MPS IOC Using PLC (Yokogawa)

One of MPS unit in J-PARC MR

- **Purposes of Soft-MPS**
  - Beam permission
    - Avoid human error
  - Beam stop (+Beam abort)
    - Avoid damage from a strong beam
  - Temporary implement
    - Until hard-wire MPS is ready
  - Need multiple conditions
    - When use PVs from across multiple hardware

- **3 examples of Soft-MPS**

EPICS IOC:PLC/Linux development

- **To detect PV loss from PLC-IOC**
  - Severity(SEVR) field and alarm status

Alarm	Value	status
NO_ALARM	0	no alarm
MINOR	1	not dangerous (HIGH,LOW)
MAJOR	2	serious state (HIHI,LOLO)
INVALID	3	PV communication loss

←If it is classified as 0 and other than that, communication loss can be included.
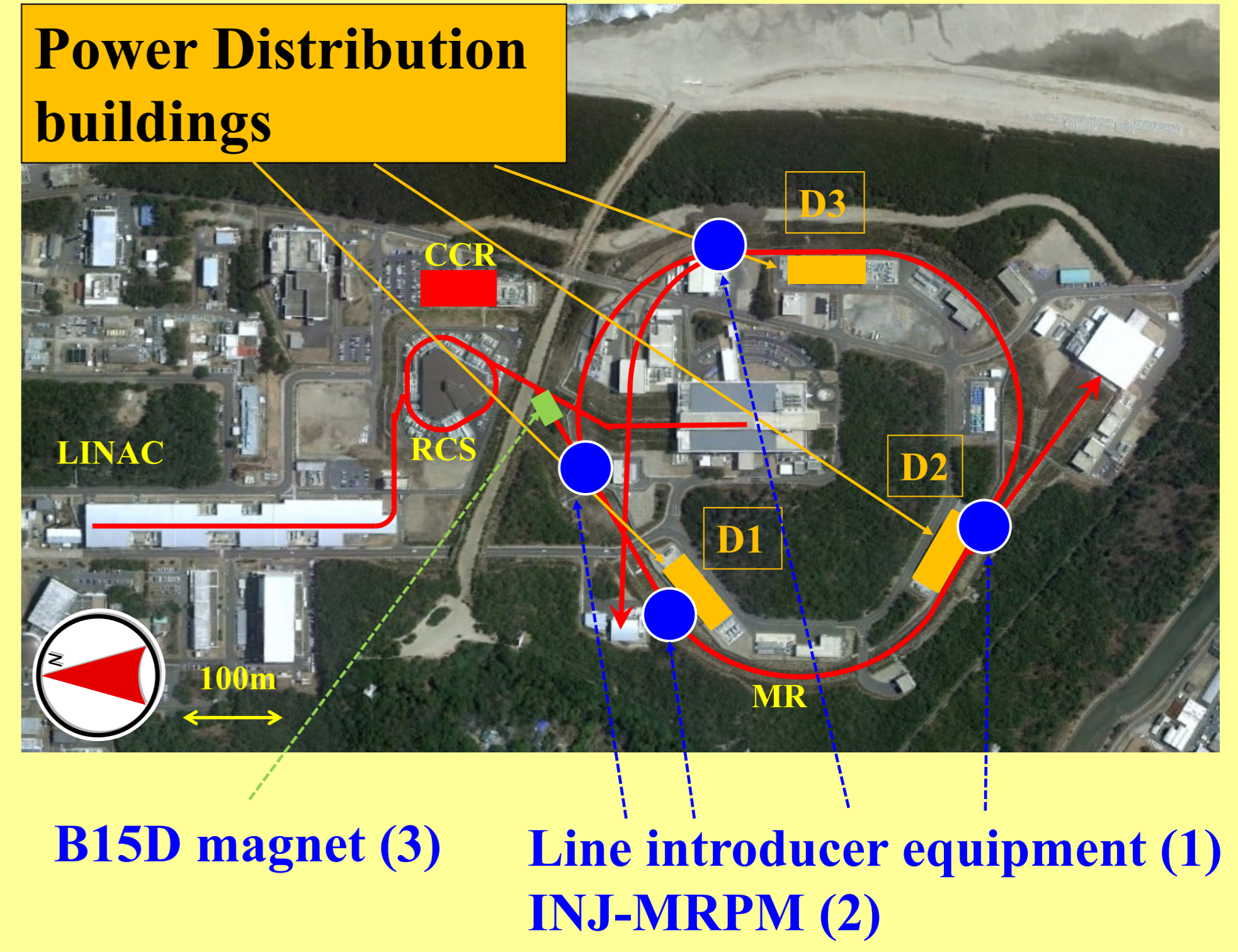
- **To latch alert status**
  - Emulating RS-FF (Reset Set Flip-Flop) circuit on program
  - Do not set "Set" and "Reset" to 1 at the same time. So, devise R' input to avoid "prohibited" state
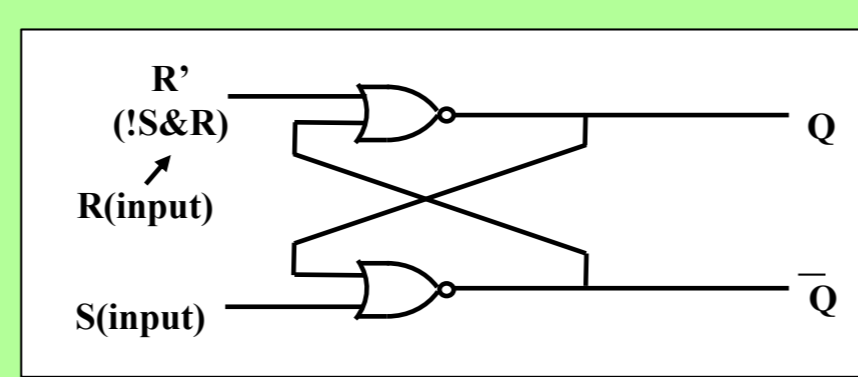
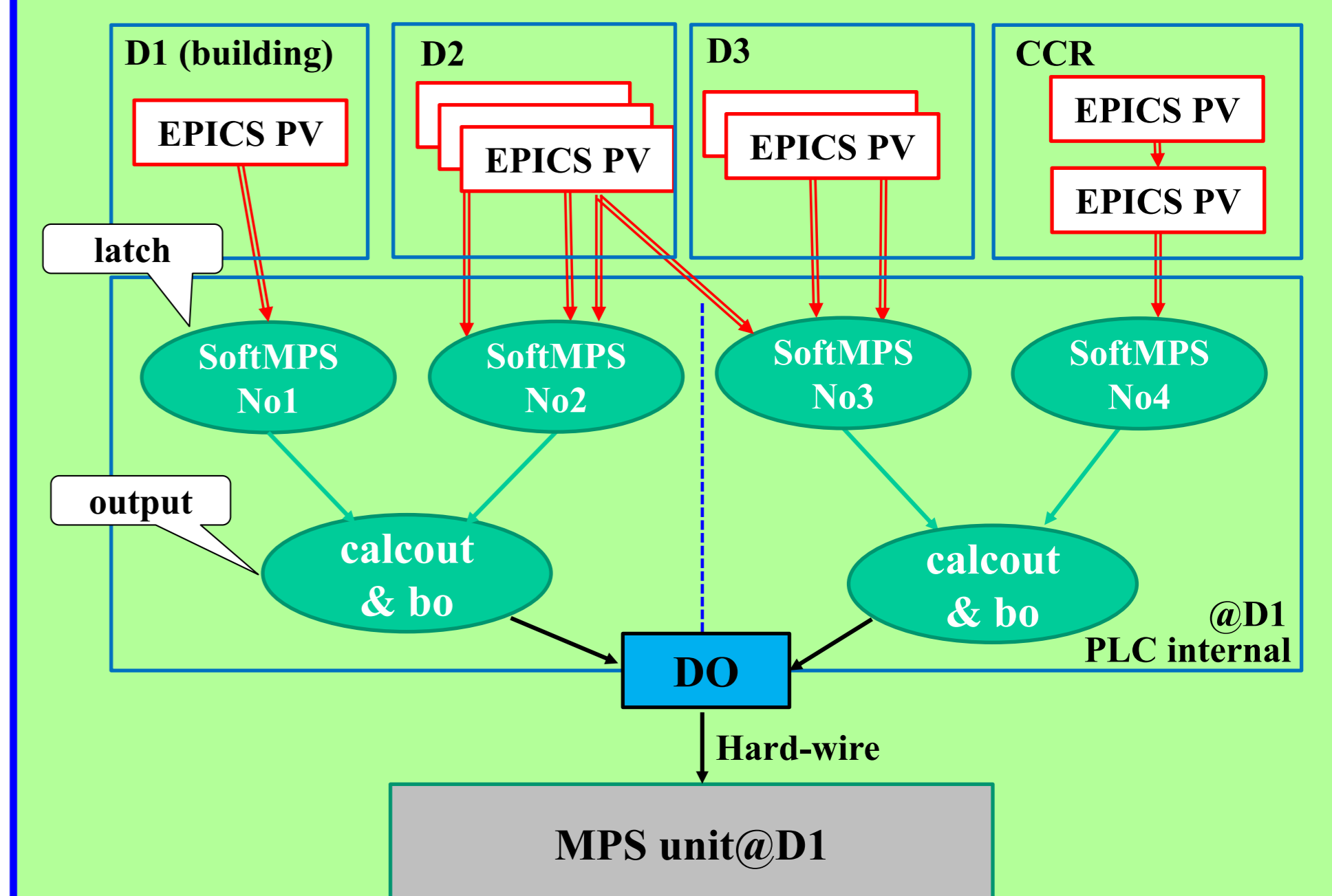| S	R	R'	Q(state)
0	0	1	no change
0	1	1	reset
1	0	0	set
1	1	0	prohibited

```
## RS flip-flop
# 1st NOR circuit (reset side)
record(calc,"$(unit):SOFTMPS_$(conti):CALC:$(name)_RESET_N"){
    field(INPA,"$(unit):SOFTMPS_$(conti):OPE:$(name)_RESET_raw CP") # input reset
    field(INPB,"$(unit):SOFTMPS_$(conti):CALC:$(name)_SET_N CP")  # output 2nd NOR
    field(CALC,"A||!B")
}
# 2nd NOR circuit (set side)
record(calc,"$(unit):SOFTMPS_$(conti):CALC:$(name)_SET_N"){
    field(INPA,"$(unit):SOFTMPS_$(conti):OPE:$(name)_SET CP")       # output 1st NOR
    field(INPB,"$(unit):SOFTMPS_$(conti):CALC:$(name)_RESET_N CP")  # input set
    field(CALC,"A||!B")
}
record(calc,"$(unit):SOFTMPS_$(conti):CALC:$(name)"){
    field(INPA,"$(unit):SOFTMPS_$(conti):CALC:$(name)_SET_N CP")
    field(CALC,"A")
}
record(calc,"$(unit):SOFTMPS_$(conti):OPE:$(name)_RESET_raw"){
    field(DESC,"Process only internal")
    field(INPA,"$(unit):SOFTMPS_$(conti):OPE:$(name)_SET CP")
    field(INPB,"$(unit):SOFTMPS_$(conti):OPE:$(name)_RESET CP")
    field(CALC,"!A&&B")
}
```

J-PARC MR site

Power Distribution buildings

B15D magnet (3)
Line introducer equipment (1)
INJ-MRPM (2)

Soft-MPS signal-relation layout

D1 (building) EPICS PV / D2 EPICS PV / D3 EPICS PV / CCR EPICS PV

latch → SoftMPS No1 / SoftMPS No2 / SoftMPS No3 / SoftMPS No4

output → calcout & bo / calcout & bo → DO @D1 PLC internal

Hard-wire → MPS unit@D1

Example 1. Linear motion guide

- **There are several linear motion guides**
  - 3D scatterer @ D1
  - Multi Ribbon Profile Monitor (MRPM)
    : Injection area (INJ) @ D1
    : Slow Extraction area (SX) @ D2
  - Extinction monitor @ D3
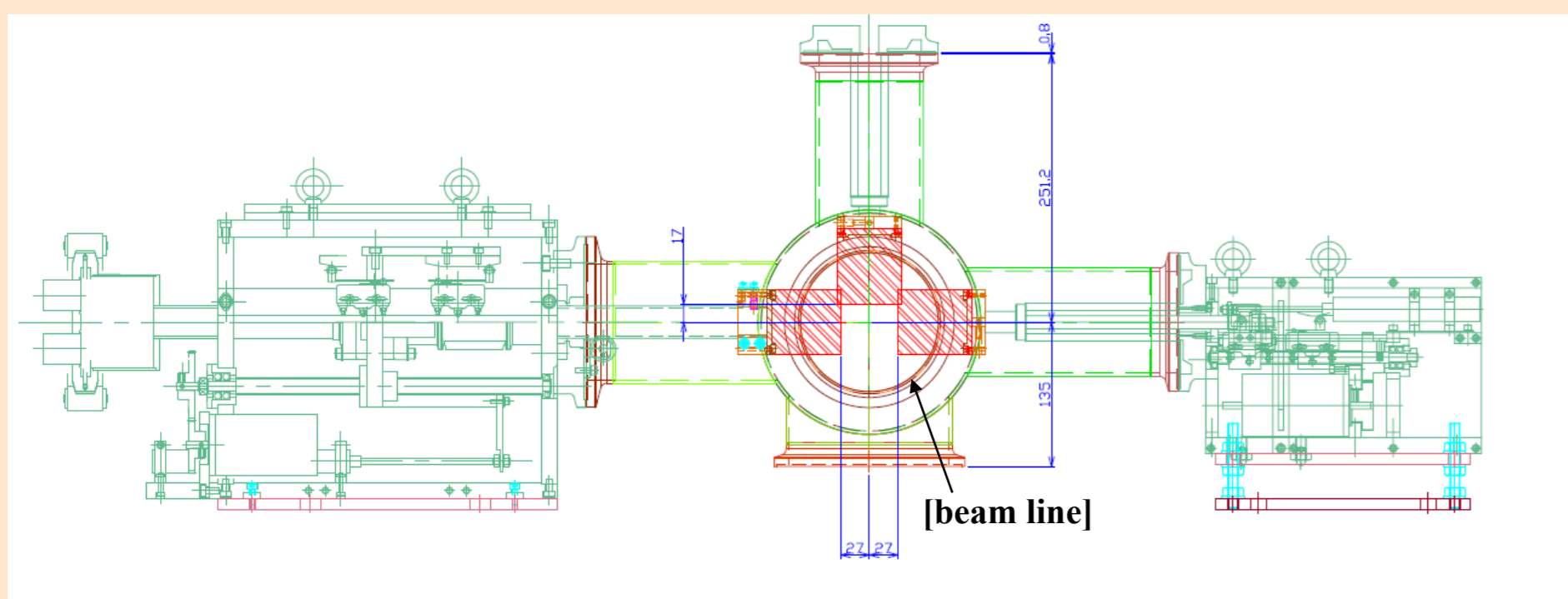
[beam line]

- **Aim of Soft-MPS in this case**
  - Linear motion guides are used only for studies. After the study finishes, it should be removed.
  - In operational mode, Soft-MPS would make an alarm when linear motion guides are still in the beam line.

As a temporary measure, a Soft-MPS setup was implemented using limit switch PVs from linear motion guides

Example 2. MR INJ-MRPM

- **Aim of Soft-MPS in this case**
  - INJ-MRPM uses delicate ribbons
  - Ribbons would be damaged even by a single shot of high-intensity beam
  - Soft-MPS would make an alarm when beam intensity of the next shot is too high

- **Allowed conditions**
  - when INJ-MRPM is in the beamline and
  1. The beam bunch used is only in a specific place
     - MRCO:TMG_CER:DATA:MRBKT20 — K1 '0'
     - MRCO:TMG_CER:DATA:MRBKT21 — K2 '0'
     - MRCO:TMG_CER:DATA:MRBKT22 — K3 '1'
       <= Only this bucket is exist and others are no exist
     - MRCO:TMG_CER:DATA:MRBKT23 — K4 '0'
  2. Beam extraction timing is only 100 turns or less

**A Soft-MPS setup was implemented using beam parameter PVs**

B15D magnet

This magnet is placed at 3-50 Beam Transport upstream 2nd Bending magnet in 3-50 Beam Transport (5 BMs in total)

Example 3. Coil interlayer voltage

- **B15D magnet failed in March-April 2019**
  - B15D is a bending magnet in 3-50 Beam Transport
    - It became unstable since March 15, because of coil inter-layer short. Beam operation stopped.
    - We started to measure inter-layer voltages of coils and temperatures of cooling water.
  - New SoftMPS was implemented using voltages and temperatures. It would stop beam operation when observed PV values are out of threshold values.
  - Apr. 01, beam operation restarted successfully
  - Apr. 24, B15D magnet fail again
    => MR operation stopped again
       we decided to suspend MR beam operation
  - May 09, we disabled the Soft-MPS

←B15D cool water temp. + coil interlayer volt.

Ch2~Ch6 voltage threshold 13.35V ~ 13.80V
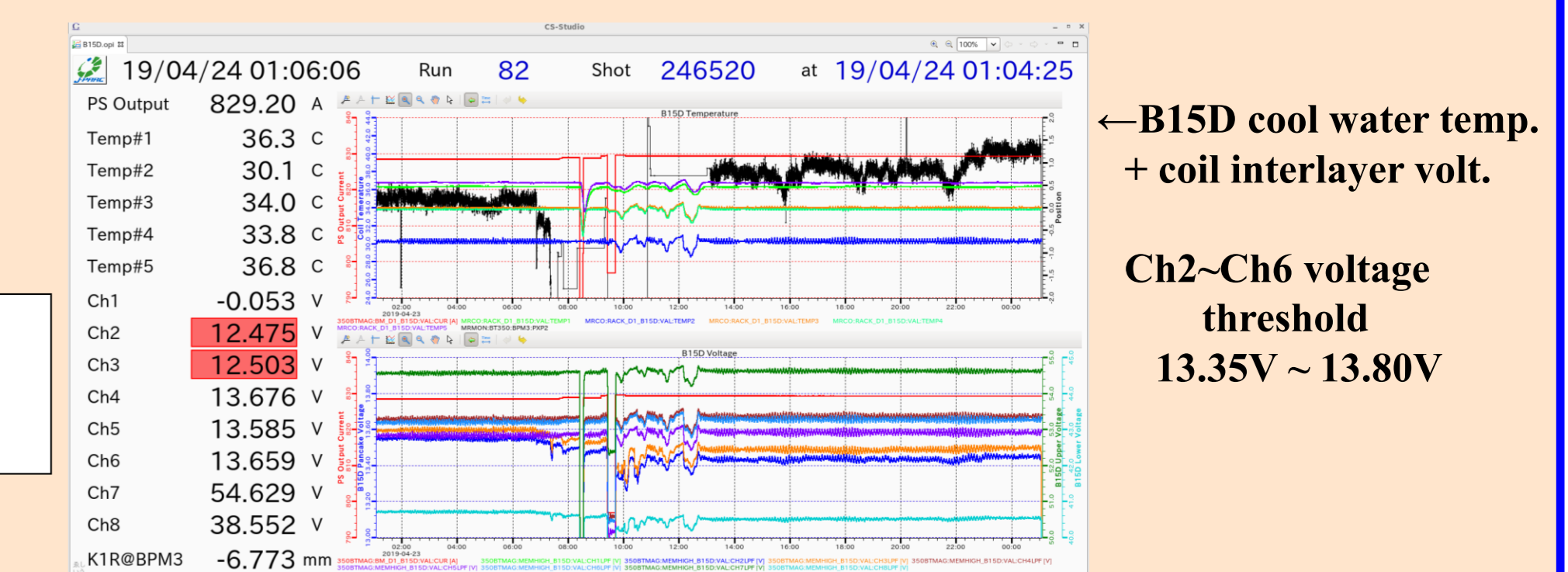
the next deployment

- **Care after introduction**
  - Exclude when finished using, like the B15D voltage
  - Need to replace software with hard-wire as soon as possible.

- **Basic policy of introduction is important**
  - Do not concentrate responsibility
  - It should not to add easily

- **Soft-MPS will increase in the future**
  - LCR temperature, new device, etc.
  - I think, not very welcome