Experience with machine protection system at J-PARC

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October 11, 2022

ESS - J-PARC commissioning workshop

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- **MPS performance**

- **A few samples of MPS failure**

- **Summary**

    - **MPS: Machine Protection System**
   - **PPS: Personnel Protection System**

MPS overview

MPS overview

- ## MPS network
  - **In Linac; MPS interlock signal flow from down- to up-stream**
  - **MPS signal aggregation and transfer to Linac front-end through CCR to stop beam**
    - **Beam stop: all, MR-, MLF-inhibit**
  - **MR/HD/NU MPS signal sent to D3 building and abort beam**

Machine Protection System

Conceptual
Schematic design
during construction era (2006)
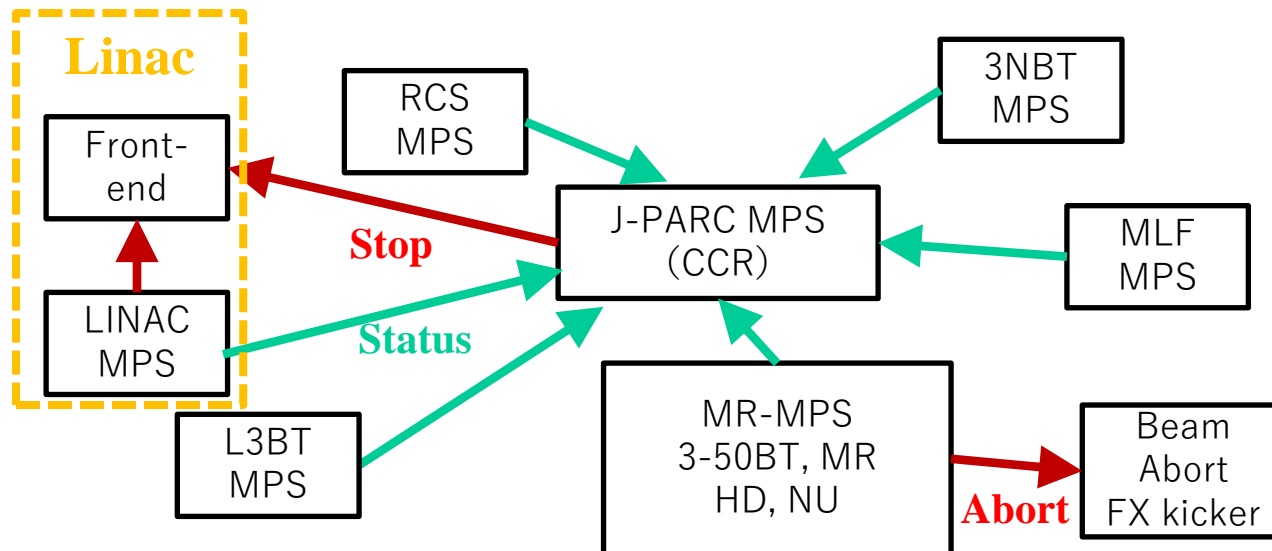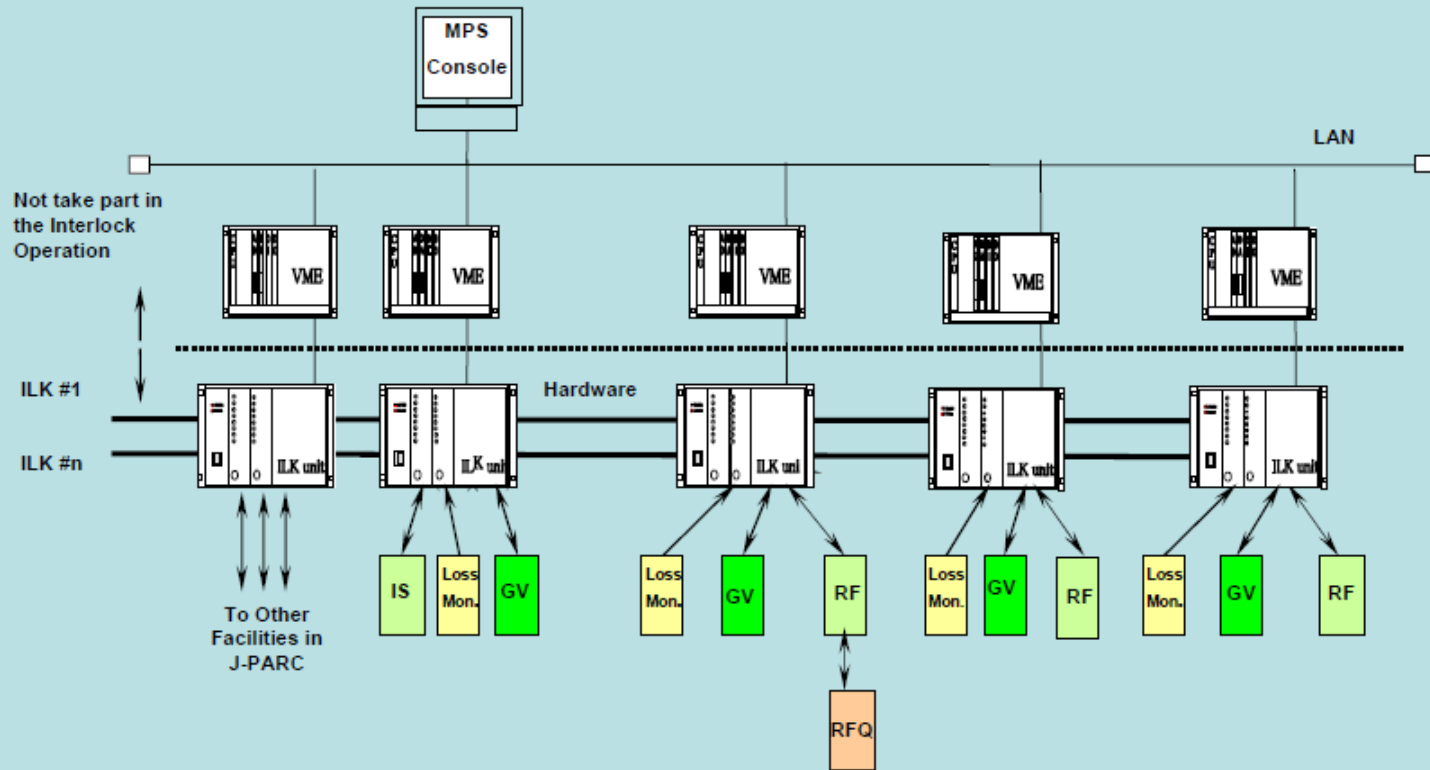
Several kinds of interlock signal gathering:
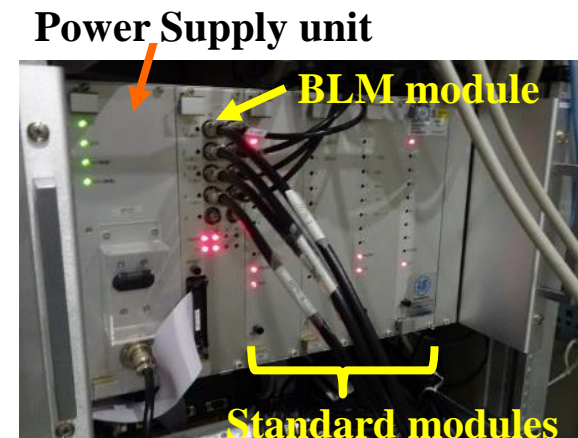vacuum, LLRF, general, beam loss

MPS hardware for Linac/RCS

- ## Linac/RCS
  - **VME size chassis with original backplane**
    - **MPS signals transfer through bus or RS-422/RS-485**
    - **VME/DIO, CPU used to monitor status, control, to be an IOC**
  - **(1) Standard module: 236**
  - **(2) BLM module: 88**
    - **comparator function enable to change threshold**

(1) Standard **(2) BLM**

Power Supply unit

BLM module

Standard modules

(5-a) Front side of MPS chassis. 4 standard modules and 1 BLM module are installed.

Present hardware (Linac/RCS)

- **(3) E/O signal converter module: 16**
  - **Signal transfer for long distance; between buildings**
- **(4) Mask (& aggregation) module: 5**
  - **Signal aggregation and disable interlock logic depends on operational MODE**
- **(5) MPS chassis: 90**
- **+ various "sub" system**
  - **Monitoring key magnet current, status of Liner motion device, beam destructive device…**

MASK

disable interlock

Connectors for E/O and mask module

Connectors for BLM module

(5-b) Back side of MPS chassis. different type connectors are installed.

(3) E/O

(4) Mask
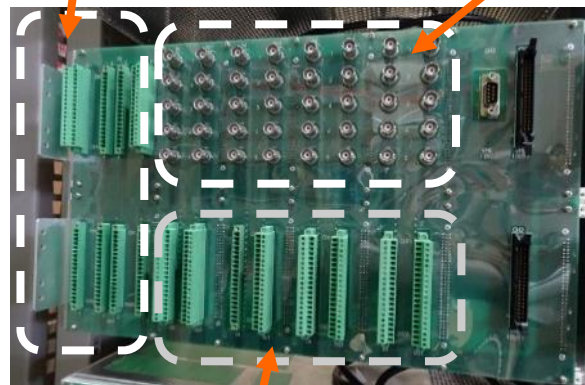
Connectors for standard module

Beam destinations

- A special application selects **"beam destination"** and advances state transition along certain sequences.

- **MPS** modifies interlock mask status according to "beam destinations".

- **PPS** controls "Area", where allowed region to deliver the beam. **PPS** also checks consistencies, modes and device status.

- "beam destination" transition TEST are performed just before beam operation starts.
  – All devices are ready to start beam.
  – It is easy to detect any defects and perform corrections (if necessary), before the scheduled beam operation.

Beam power limiter

- **Beam Current integrator with appropriate timing gate**
- **One hour limiter**
  - **"particle counter"**
  - **Required by PPS**
- **One pulse limiter for MLF and MR**
  - **Chopper (timing) failure caused too much beam**
  - **Since 2015**
- **Vacuum window protection**
  - **Zero degree beam dump (BD0) vacuum window broken within 6 seconds**
  - **Since 2018**
- **FCT at 3-50 BT**
  - **Monitoring numbers of particles for every pulse and one hour total**

Fast beam stop scheme

February 24, 2006
    ATAC 2006
    10
J-PARC Control - 47
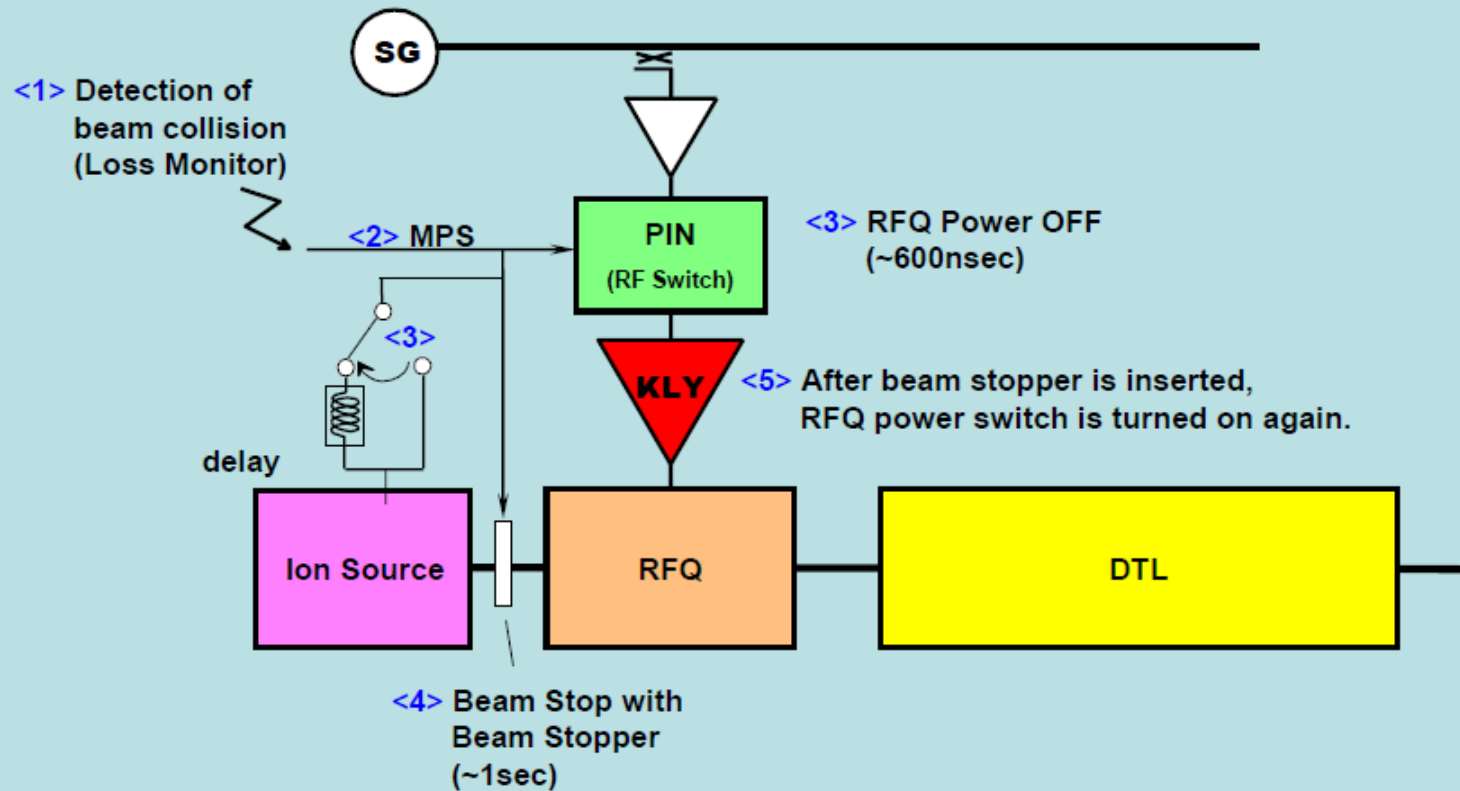
MR inhibit scheme

- **Fast beam stop by switching off RFQ RF**
- **Ion Source Arc- and Extraction voltage shift**
- **Continue MLF beam**
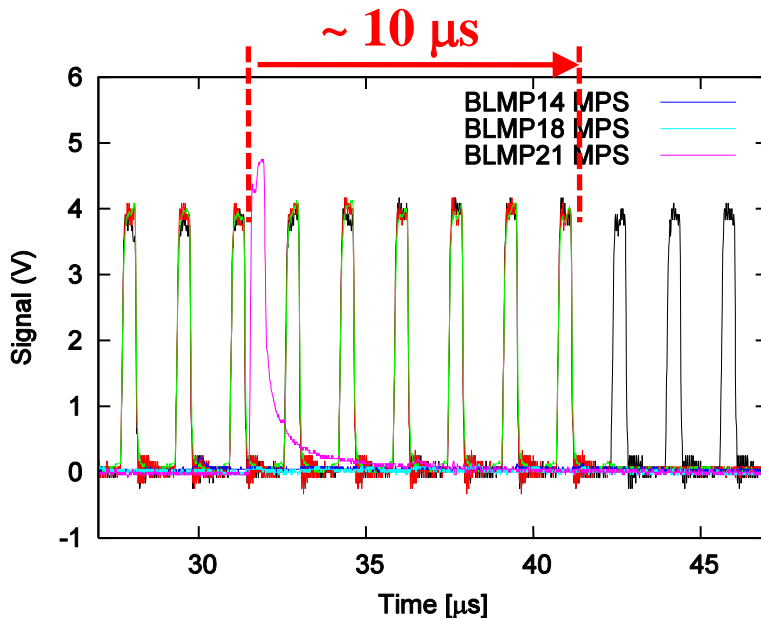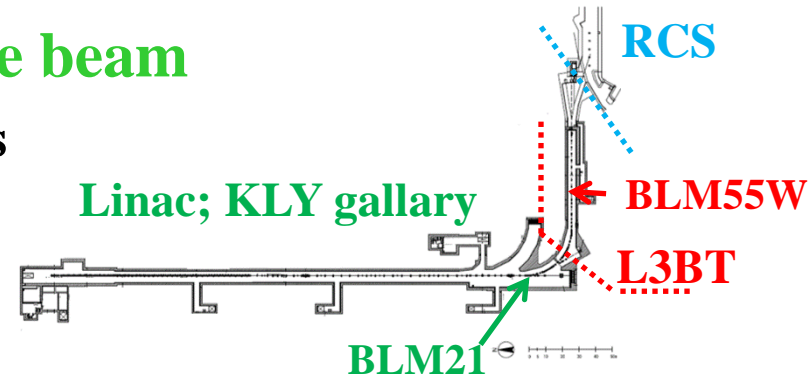 - **These logic realized by specially designed "Logic Controller"**
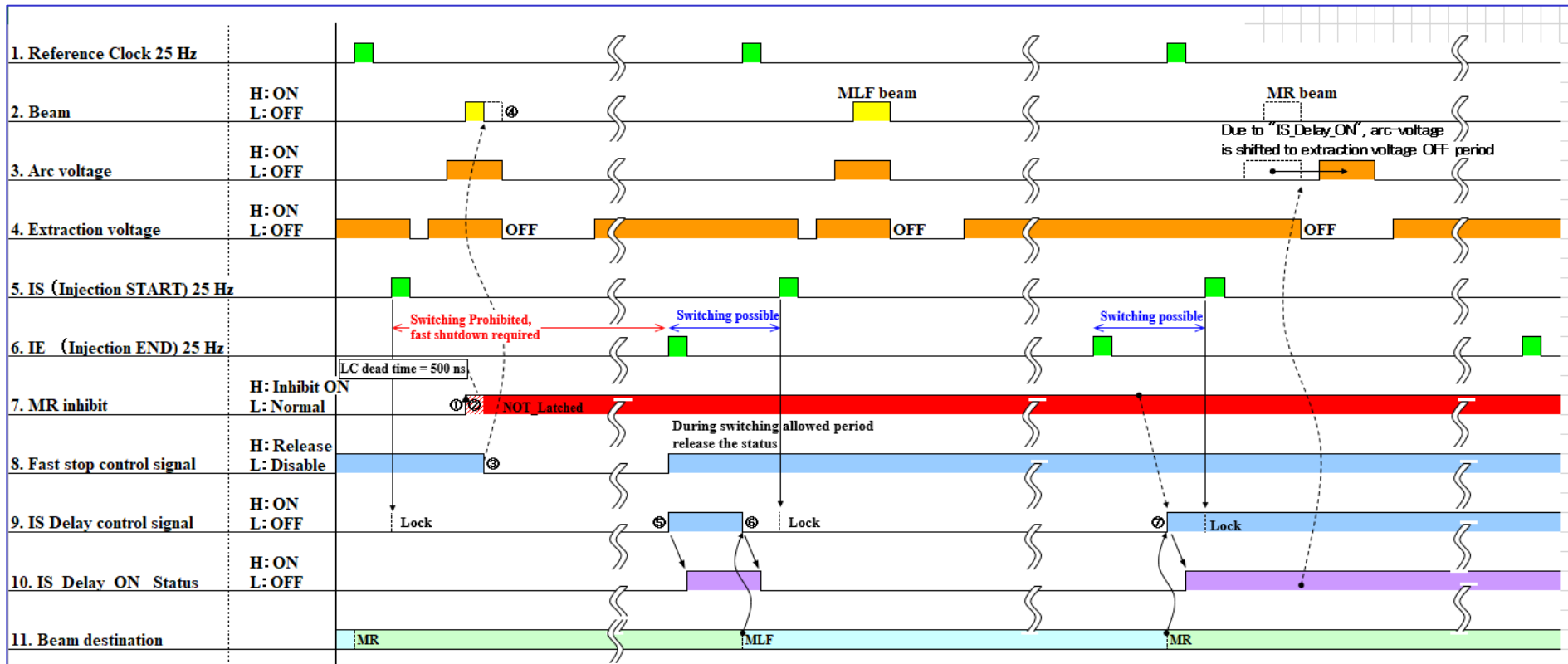
MPS performance

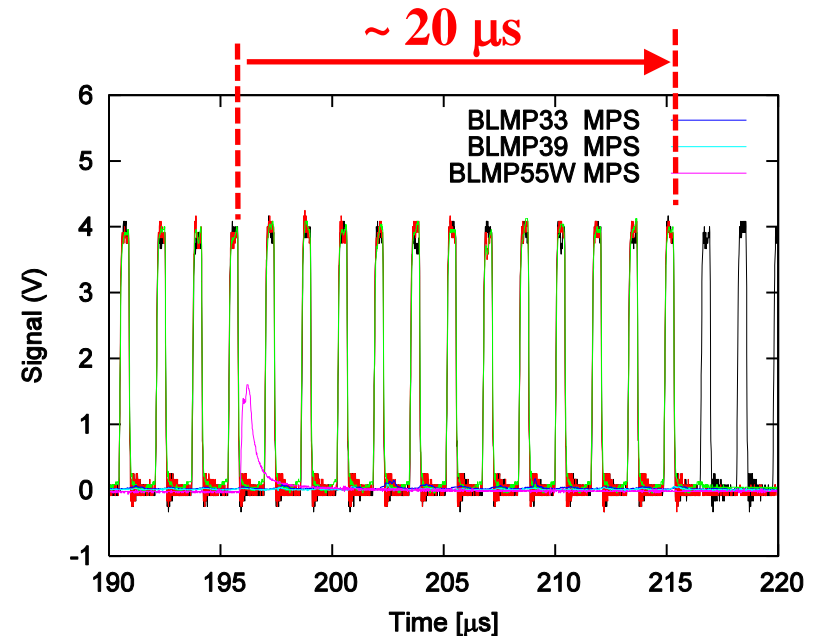# MPS reaction time

- **Linac BLM triggers stopping the beam**
  - **BLM 21@Klystron gallery: ~ 10 μs**
  - **BLM55@L3BT via CCR: ~ 20 μs**

RCS

Linac; KLY gallary

BLM55W

L3BT

BLM21

BLM21 trigger!

BLM55W trigger!

New MPS project for Linac/RCS

- **Requirements**
  - Module aging, parts obsolete, technology succession, …
  - More operational modes: Lack of flexibilities / signal lines
  - compatibility: Old and New system have to be used for some time range

- **New hardware**
  - Proto-type design started in 2018
  - New modules and chassis was designed
  - RCS: Standard modules already replaced
  - BLM modules under design

- **Linac**
  - First replacement has been done during this shutdown
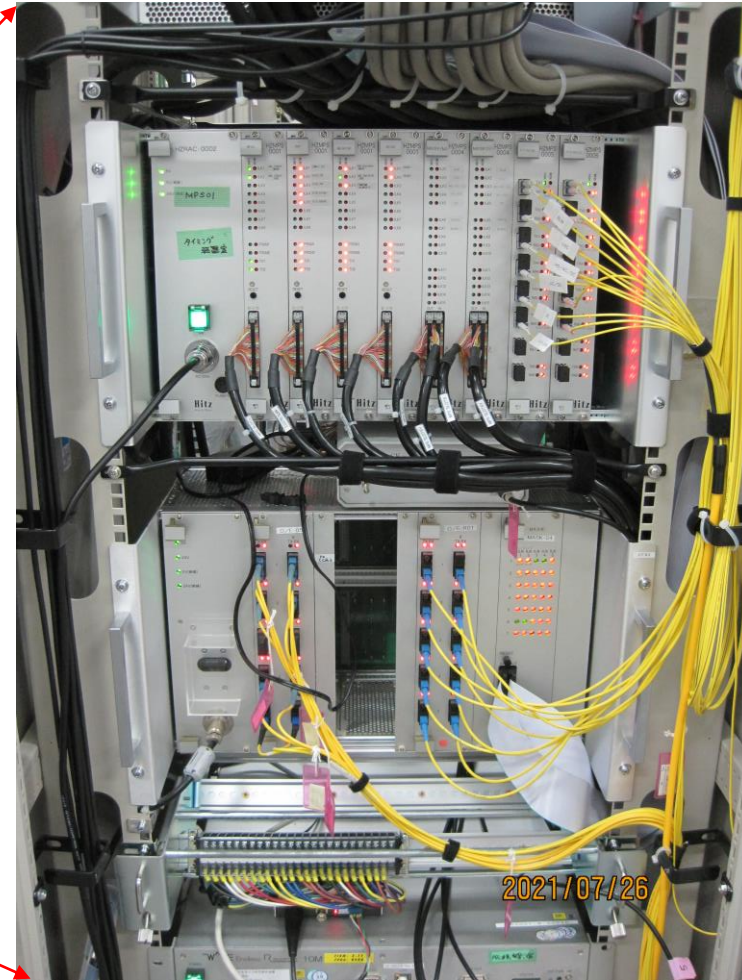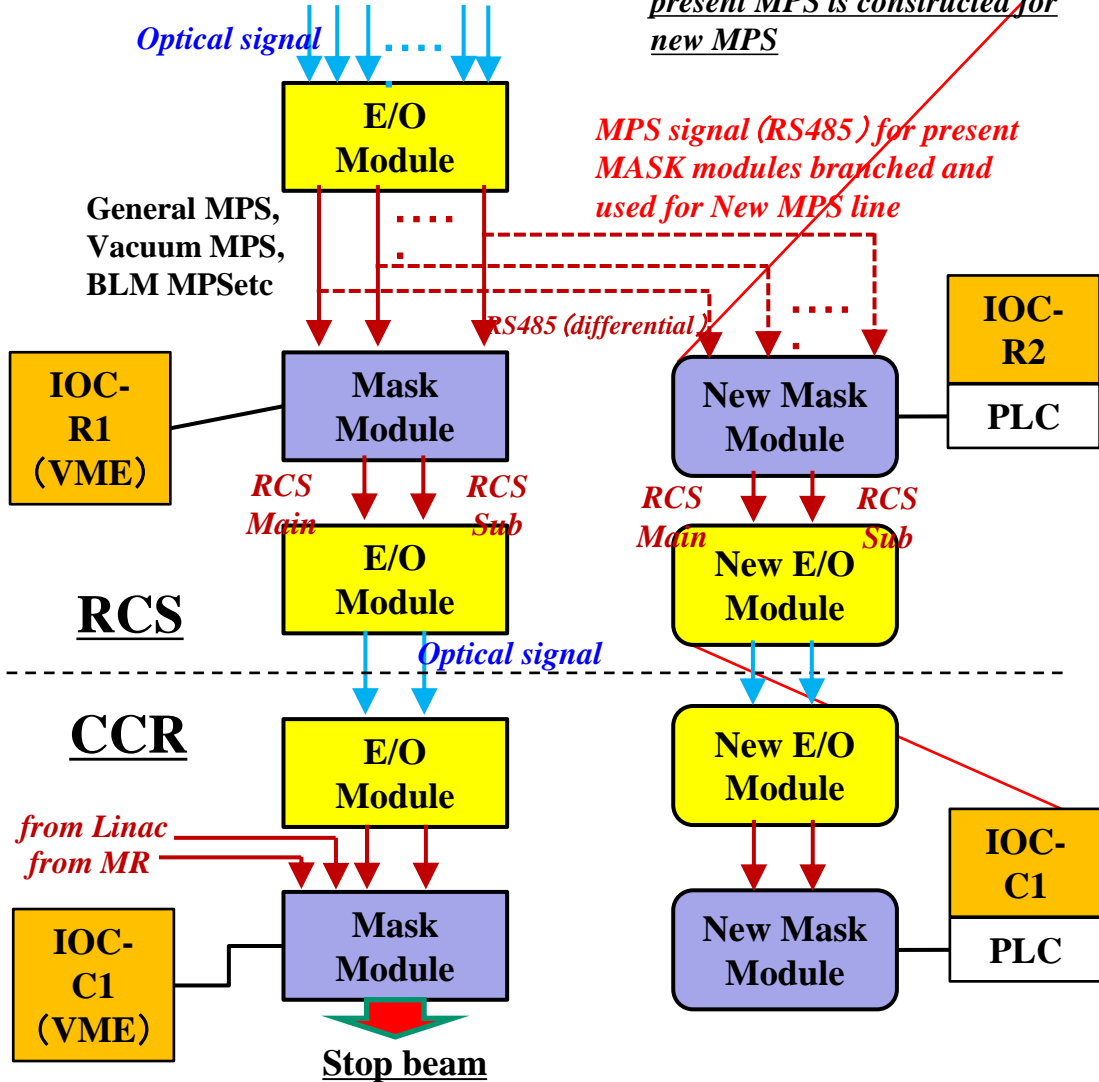   - Postponed for last year due to semi-conductor shortage and late delivery

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Long term test

<RCS MPS>

<RCS New MPS>

The same configuration as the present MPS is constructed for new MPS

MPS signal from various places

Optical signal ↓↓↓ . . . . ↓

E/O Module

MPS signal（RS485）for present MASK modules branched and used for New MPS line

General MPS, Vacuum MPS, BLM MPSetc

RS485 (differential)

IOC-R1 （VME）

Mask Module

New Mask Module

IOC-R2

PLC

RCS

RCS Main   *RCS Sub*

RCS Main   *RCS Sub*

E/O Module

New E/O Module

Optical signal

CCR

E/O Module

New E/O Module

IOC-C1

PLC

from Linac from MR

IOC-C1 （VME）

Mask Module

New Mask Module

Stop beam

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A few examples of failure events

Past malfunction events (1)

- **2011/3/11 Large Earthquake**   **9 months shutdown**
  - **Accelerator was half day maintenance mode**

- **2013/5/23   HD incident**   **6 months shutdown**
  - **Cause: EQ magnet PS failure … new beam abort system**
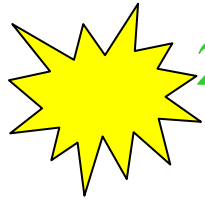
2015/11/2 and later: Chopper malfunction
  - **Fact: Twice intensive beam (8E+13) than intended (4.3E+13)**
  - **Cause: missing trigger pulse (due to O/E module)**
  - **1-shot MPS: "num. of particles limiter for one pulse"**

- **2016/2/25 vacuum chamber leak at MR abort beamline**
  - **Cause: noise stopped ramping up septum in the middle of cycle**
  - **ms-Abort (immediate beam abort system) was introduced**

- **2017/4/19 short power outage (~ 3 seconds)**
  - **Accelerator was half day maintenance mode**
  - **Sudden power outage during operation has been studied?**

Past malfunction events (2)

- **2018/3/30 Small earthquake**　　**Half day interruption**
  - Many MPS and Linac FCT was broken, vacuum leak

- **2018/10/13 LI:BD0 vacuum window breakage**
  - Without stopping beam, 25 Hz pulse beam hit the window after scraper removed.
  - Countermeasure: num. of particles limiter with proper time constant　　03:18:31　Beam destination change :LI BD30 → LI BD0
   - At present only BD0 no other BD…

- **2019/9/11 15:39 Unplanned power outage**
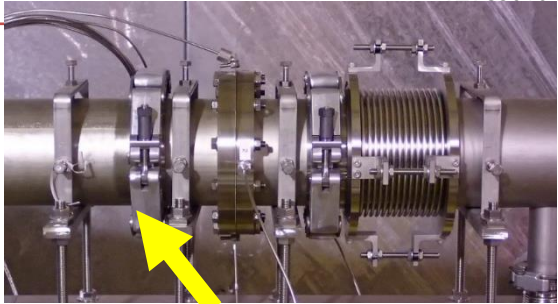 - During summer shutdown, maintenance period

: Already presented

Chopper malfunction

- **2015/11 (November, 2015) and sometimes**
  - Fact: Twice intensive beam (8E+13) than intended (4.3E+13)
  - Cause: missing trigger pulse (due to O/E module)
  - 1-shot MPS: "num. of particles limiter for one pulse"

- **2016/6/29 (29 June, 2016)**
  - Beam current pattern by CT
    - Normal (up) , MPS event (down)
  - Normally the pattern is exact comb shape
  - MPS events shows some residual beam
    - It is due to chopper malfunction
  - No beam loss in the linac
  - But heavy beam loss in the RCS
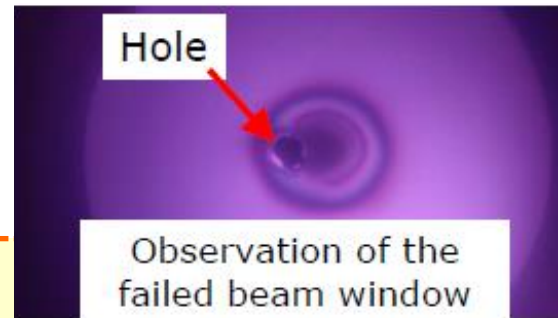 - Root cause is timing module problem
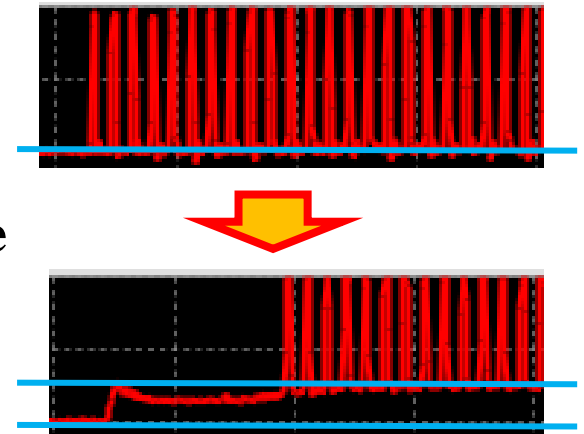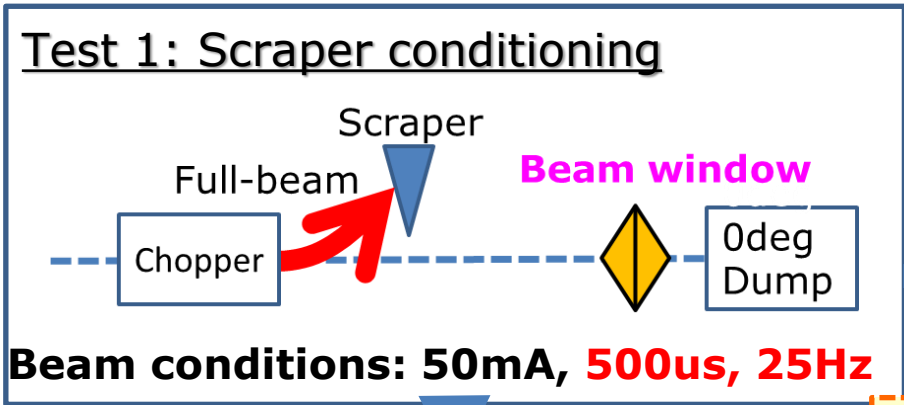
L3BT: Beam window destruction

■ The beam window before the 0deg beam dump was broken by **unexpected high intensity beam** on Oct. 13th, 2018.

Beam window (0.36mm Ni)
To separate vacuum 10^{-7} and 10 pa

Test 1: Scraper conditioning

Scraper

Full-beam

Chopper → Beam window → 0deg Dump

Beam conditions: 50mA, 500us, 25Hz

(Oct. 13th, 2018)

Hole

Observation of the failed beam window

**Beam stop <- "Skip"
(Human error)**

Beam stop:
500us-> 100us, 25Hz-> 2.5Hz

Destruction
(estimated temp.:
~1,500℃ after 1s)

Test 2: Beam studies

Scraper

Chopper → Beam window → 0deg Dump

Beam conditions: 50mA, 100us, 2.5Hz

Test 2: Beam studies

Scraper

Chopper → Beam window → 0deg Dump

Beam conditions: 50mA, 500us, 25Hz
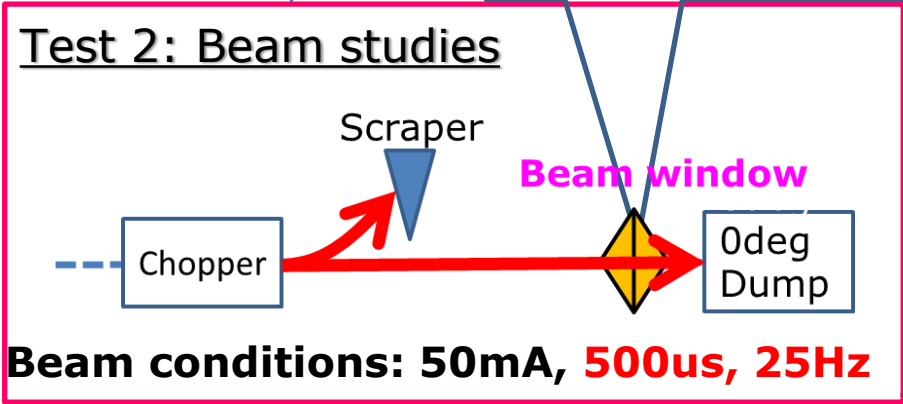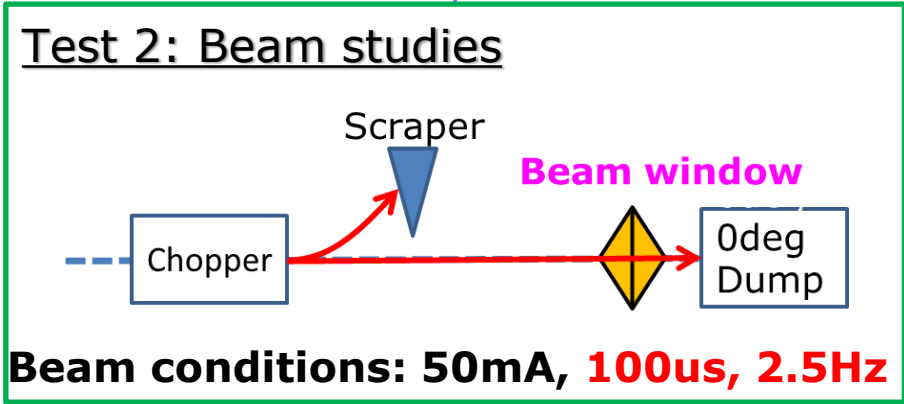
L3BT: Beam window destruction

- **Date**
  - October 13, 2018, 07:15   **LI: beam tuning**

  Stopped by bad vacuum Not by BLM!

- **Event description**
  - MPS: Bad vacuum at zero degree Beam Dump (BD0)

- **Impact / consequence**
  - Nine hours lost to figure it out. BD0 was forbidden for a few months.
  - Beam window was broken. Replaced in the end of year with grate care

- **Root cause**
  - Full beam (50mA, 500us, 25Hz) irradiated the window for six seconds
  - Human error (?) (not following ordinary procedure)
  - (BLM threshold was appropriate level…?)

- **Countermeasure / preventing system**
  - One second integral num. of particle limiter

Summary

- **J-PARC MPS hardware and scheme presented**
  - **Beam power limiter**
  - **Beam stop/inhibit scheme**
  - **Upgrade status reported**
- **Some MPS examples**
  - **MPS performance: response speed**
  - **A few examples of failure events**