J-PARC beam interlock and experience on miss shots

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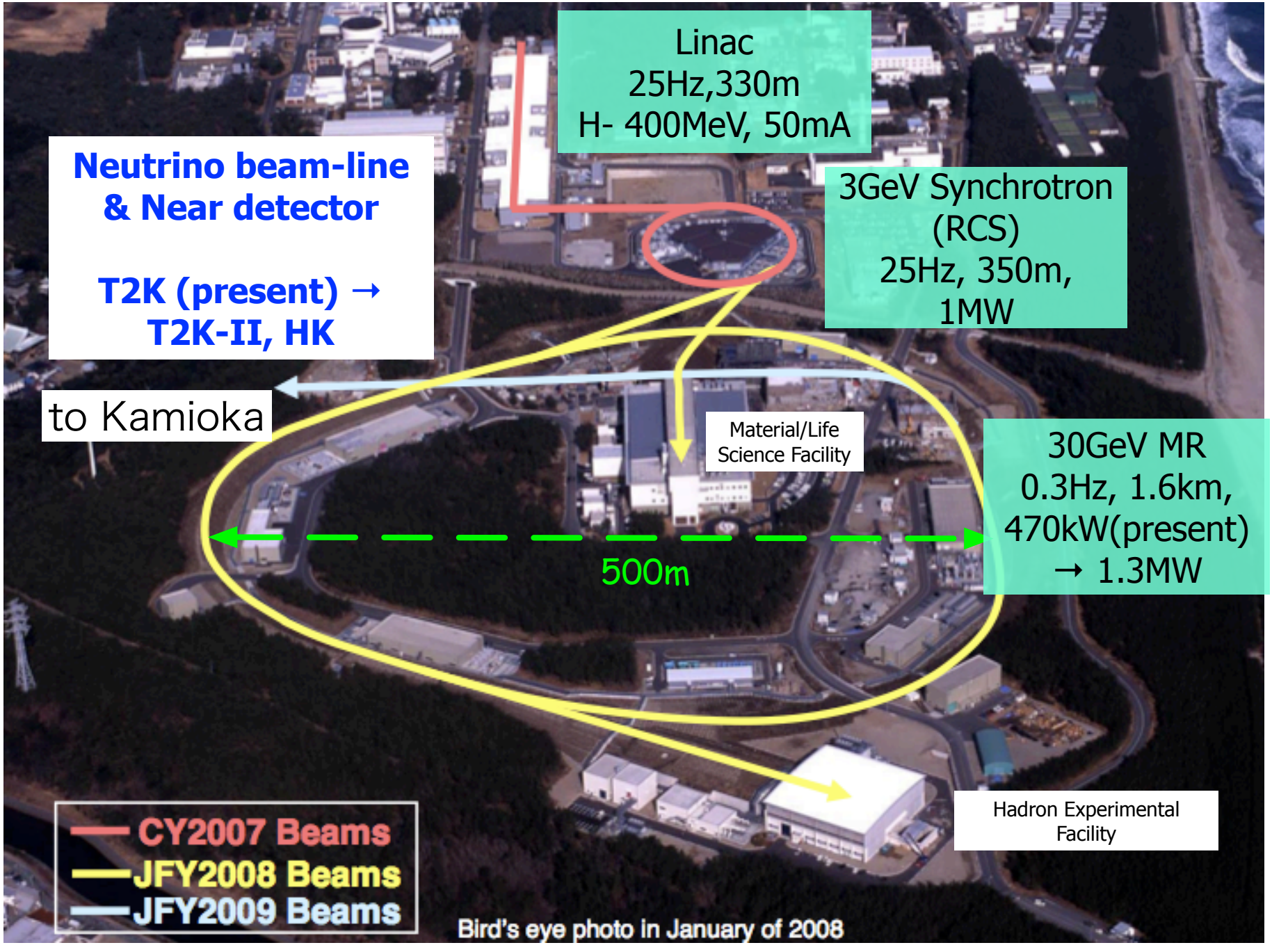
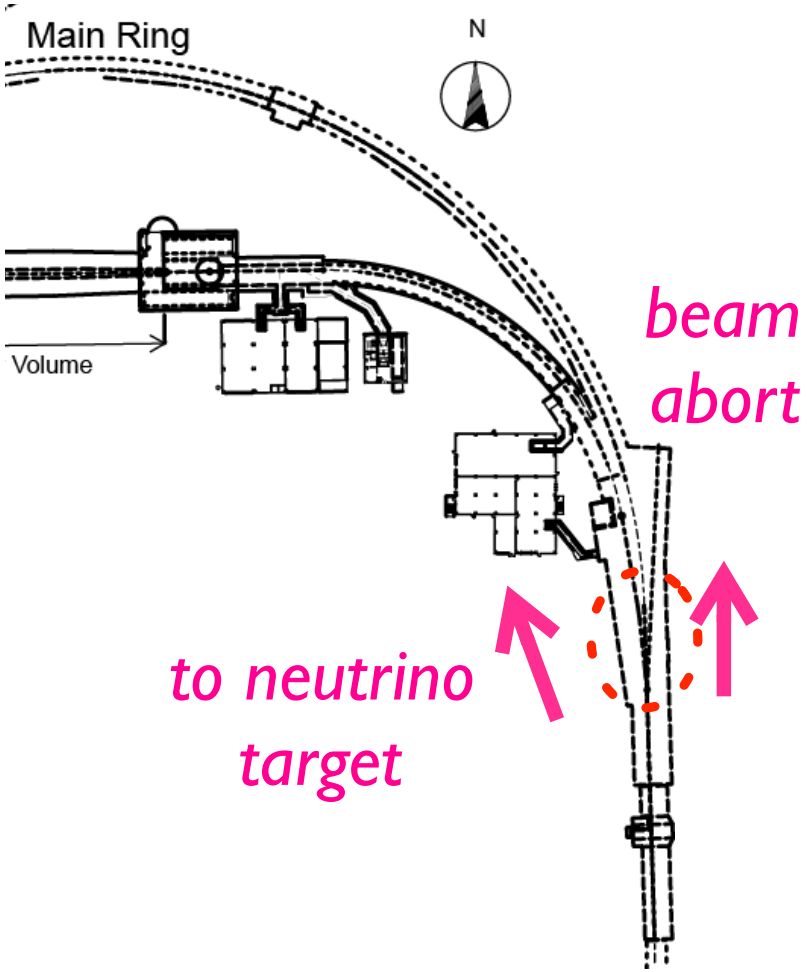
- J-PARC neutrino facility and beam interlock (MPS) system
- Experience of mis shots and improvement
- Improvement plan toward 1.3MW operation
- Summary

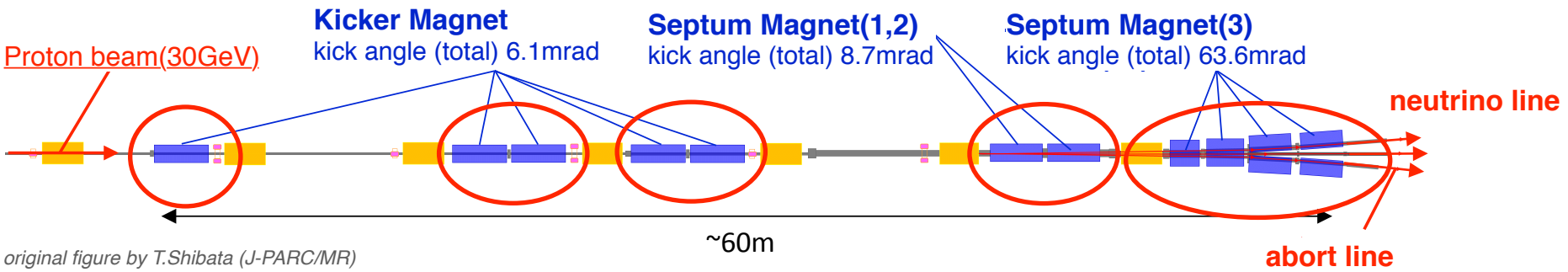
J-PARC & Neutrino beam-line



Fast extraction beam

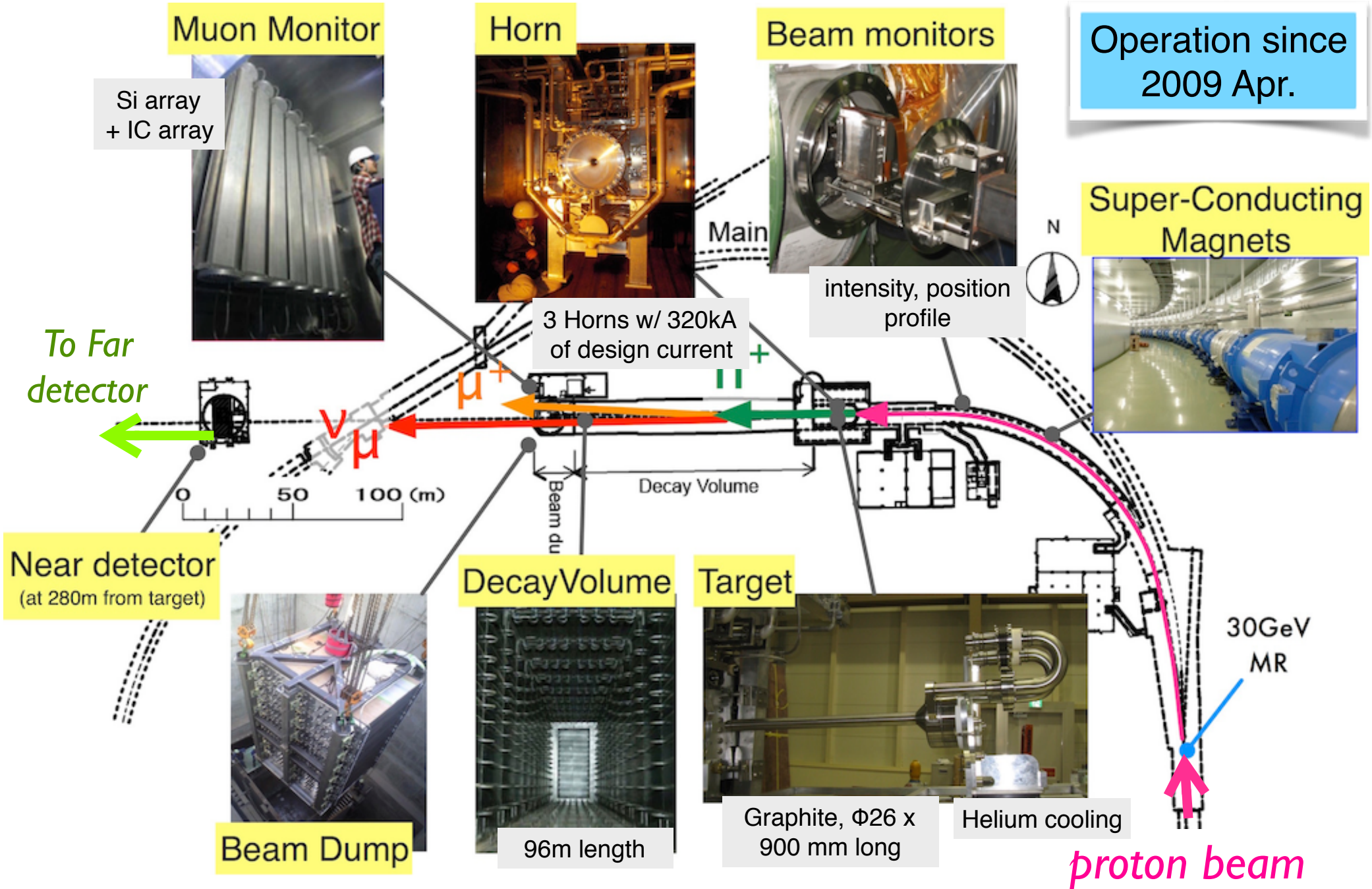
30GeV proton beam is extracted to neutrino beam-line in the fast extraction mode



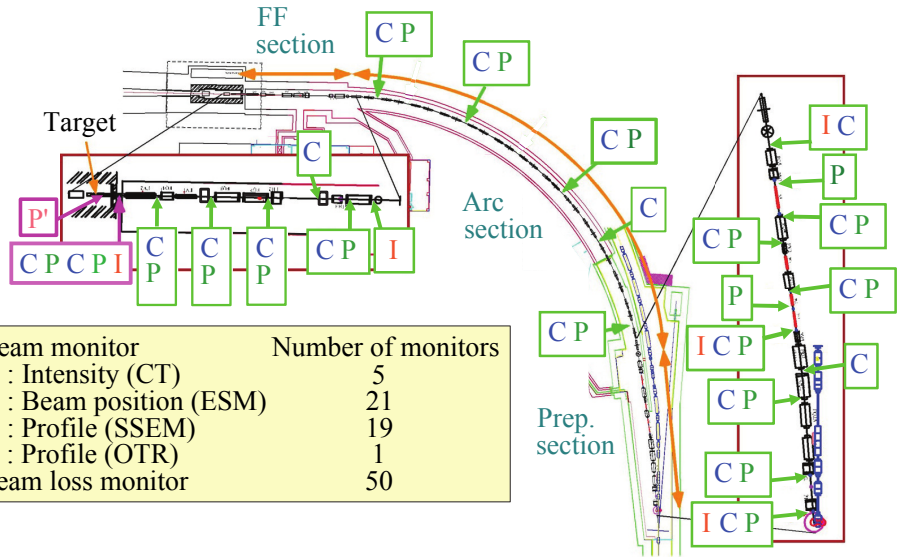


original figure by T.Shibata (J-PARC/MR)

J-PARC Neutrino facility

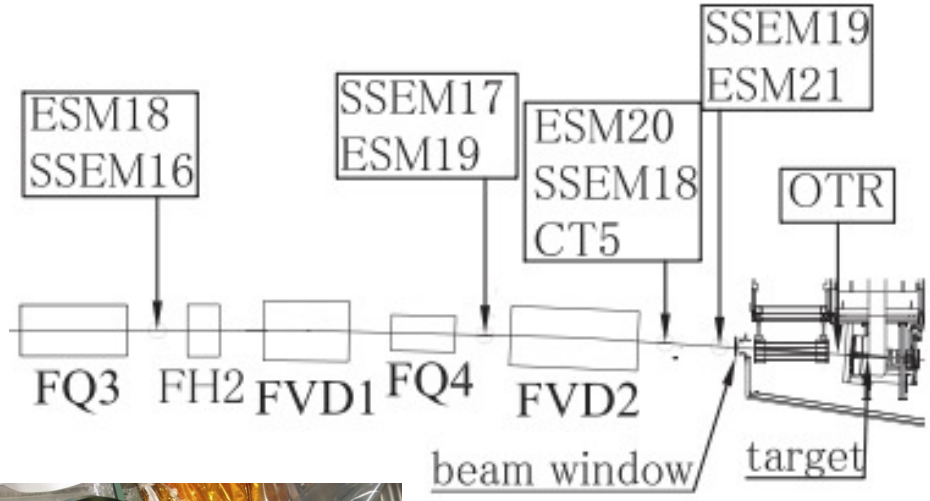


Beam monitor

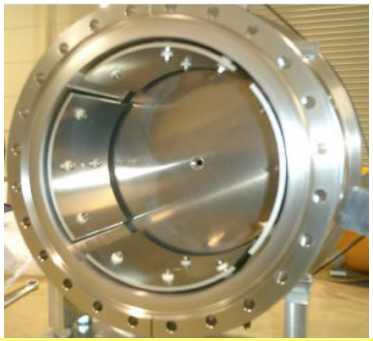


Beam monitor	Number of monitors
I : Intensity (CT)	5
C : Beam position (ESM)	21
P : Profile (SSEM)	19
P' : Profile (OTR)	1
Beam loss monitor	50

Beam monitors before the target

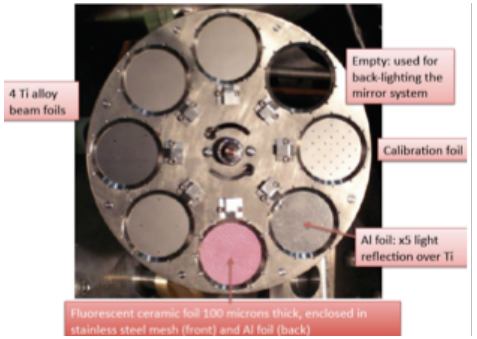


Current Transfomer (CT)

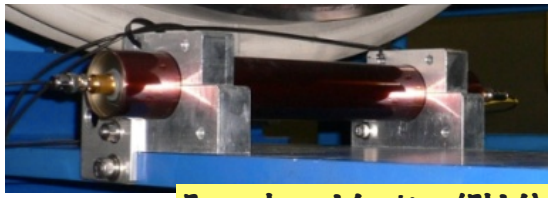


Electro Static Monitor (ESM)

Segmented Secondary Emission Monitor (SSEM)



Optical Transition Radiation (OTR)



Beam Loss Monitor (BLM)

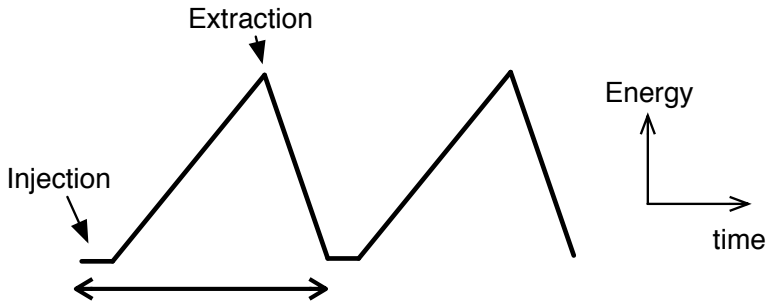
- For beam diagnostics and tuning
- Protect beam-line equipment
- Inputs of ν flux calculation

Beam power and importance of the beam interlock

- Even one shot high intensity (>10^{14} protons per pulse) mis-steered beam can seriously damage the beam-line equipment
- We plan to increase the number of protons per pulse toward 1.3MW

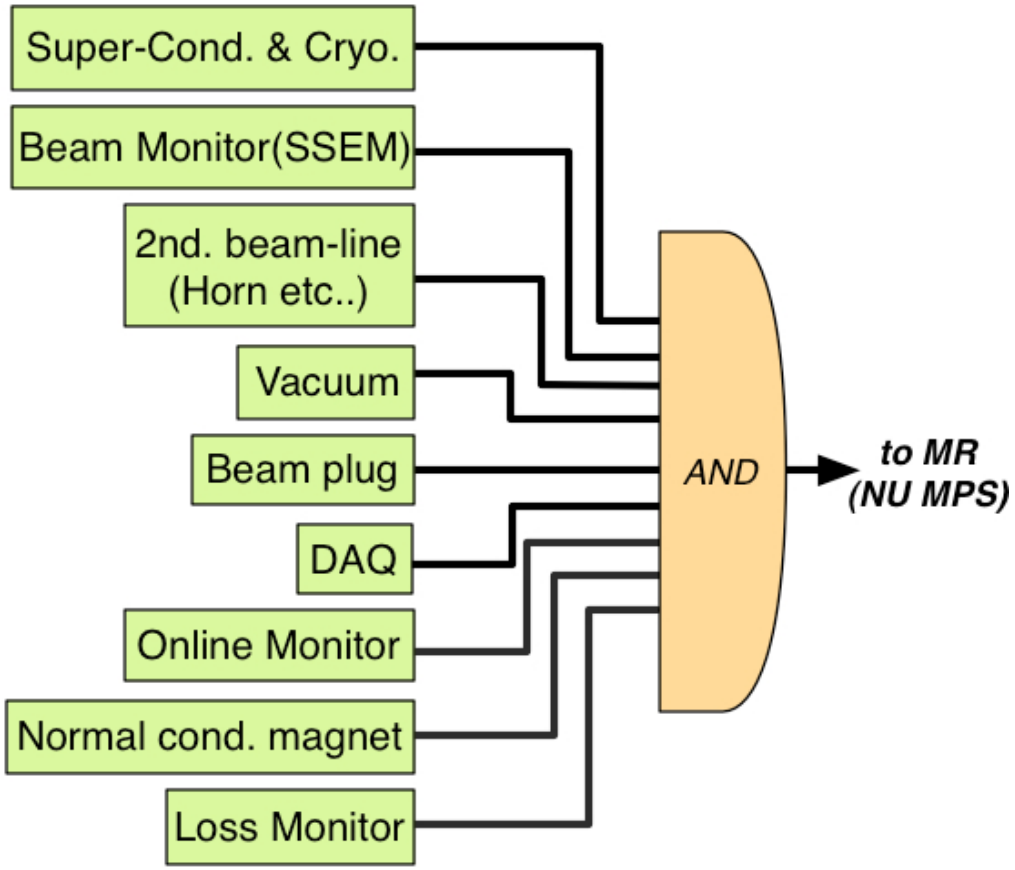
	Achieved	Target
Beam power [MW]	0.47 →	1.3
# of protons per pulse	2.4×10^{14} →	3.2×10^{14}
Rep. Time [sec]	2.48 →	1.16

Beam interlock system is important for high power operation



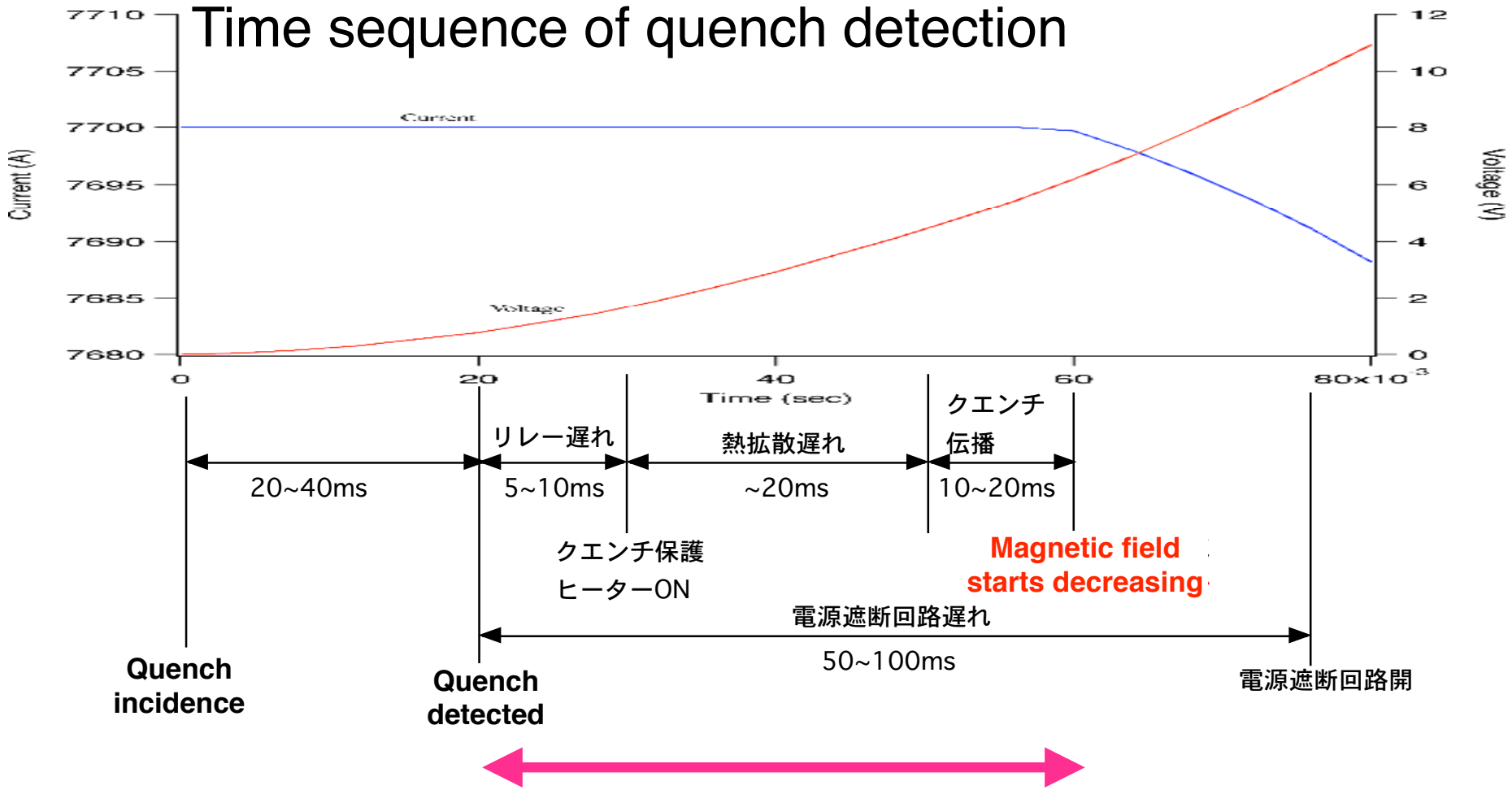
MPS (machine protection system)

- Stop or abort MR beam when equipment status is “not ready”
  - Failure of equipment
  - Detected abnormal condition (equipment, beam itself etc.)
- ~800 interlock sources
- Latency to stop/abort the beam should be enough fast to prevent any damage



Requirement on MPS latency

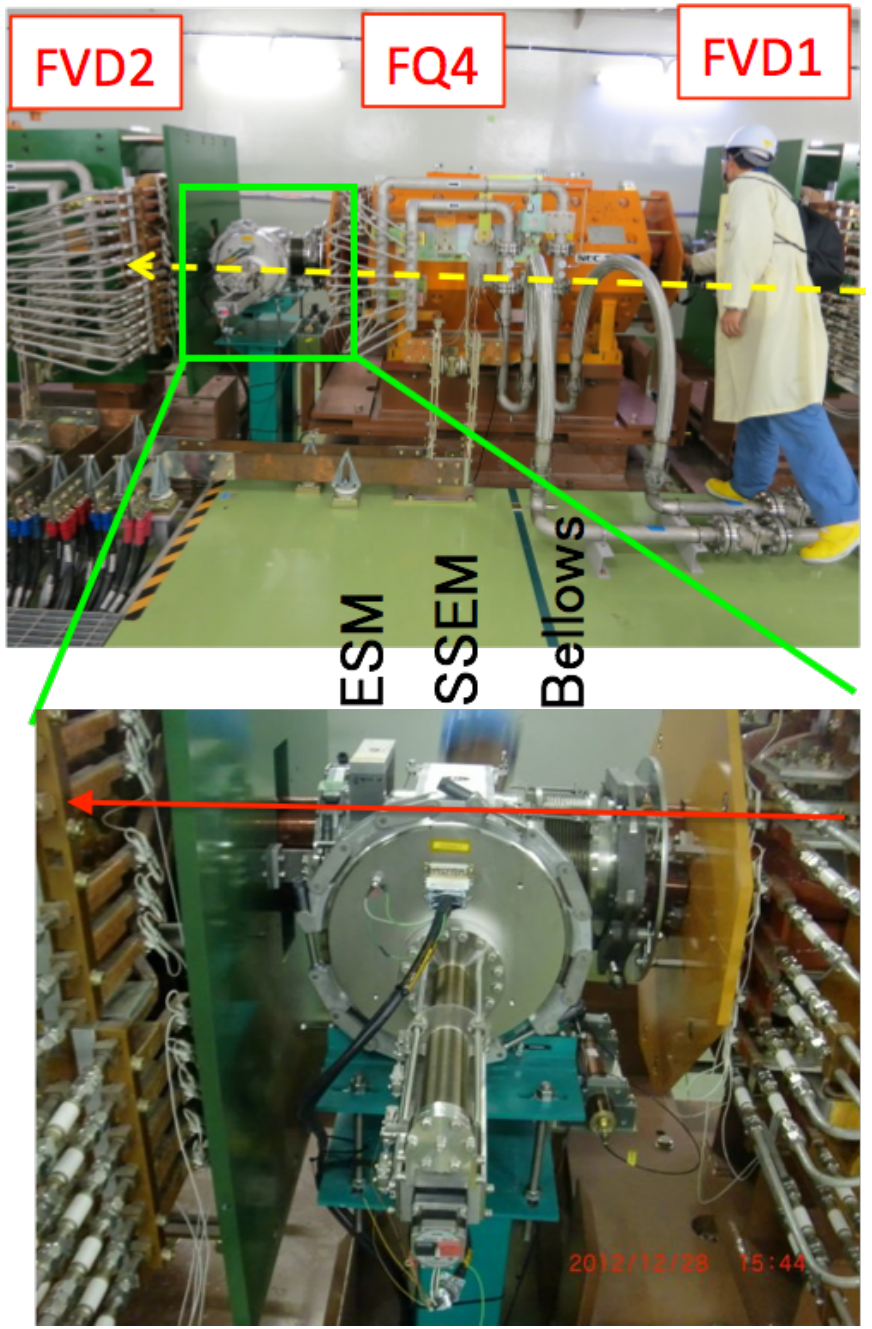
An example : SC magnet quench detection interlock



MPS latency should be less than ~35msec for SC

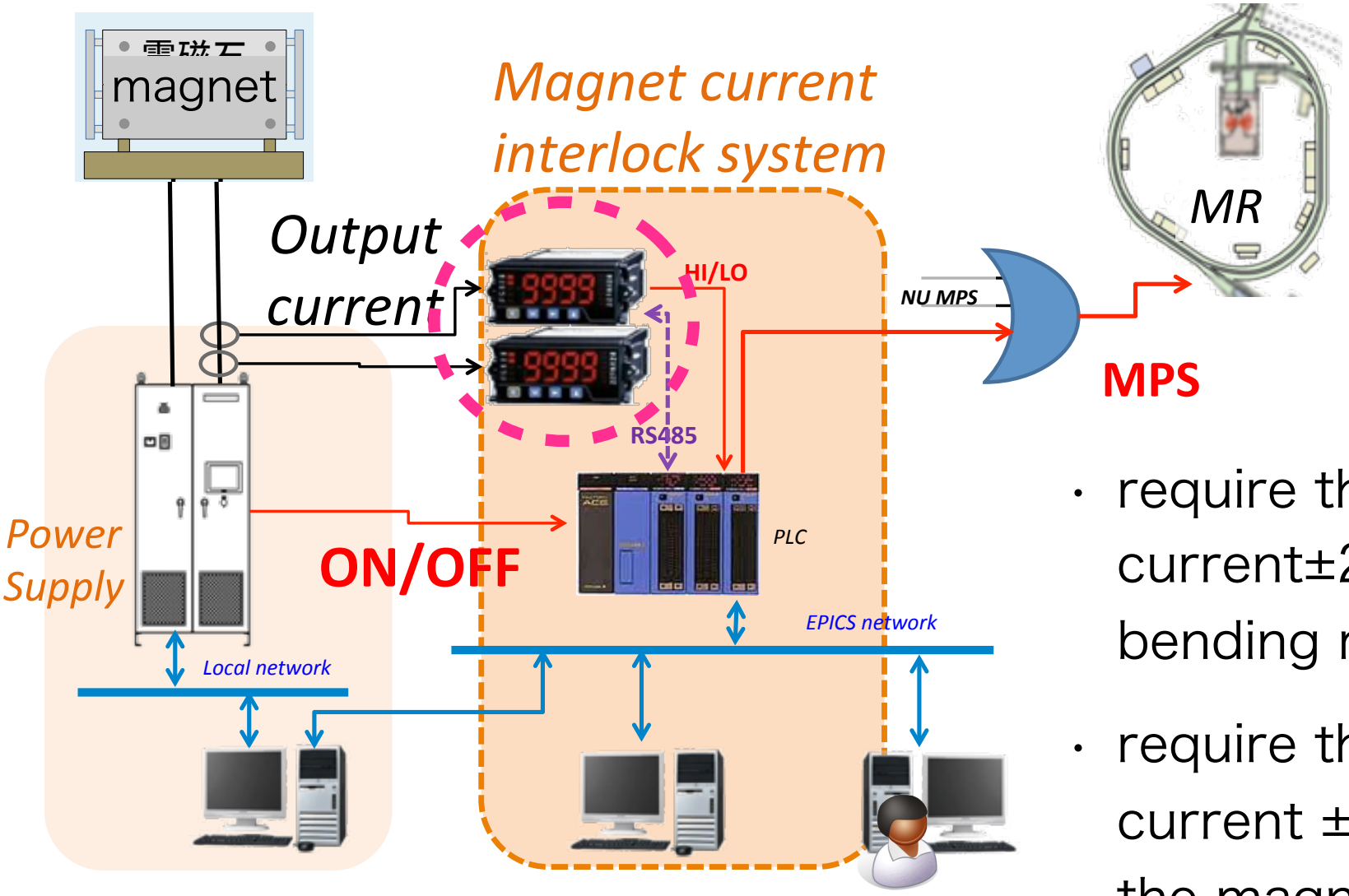
Experience of mis-shots (1)

- Dec. 2012, one shot beam with 217kW (1.1×10^{14} ppp) was extracted to NU although one of vertical bending magnet (25mrad bend) was off
- Beam directly hit the beam monitor (ESM19) and its feed-through was destroyed (then, vacuum break)
- Beam extraction was permitted even though the bending magnet was off ← a loophole of the MPS



Improvement of the interlock

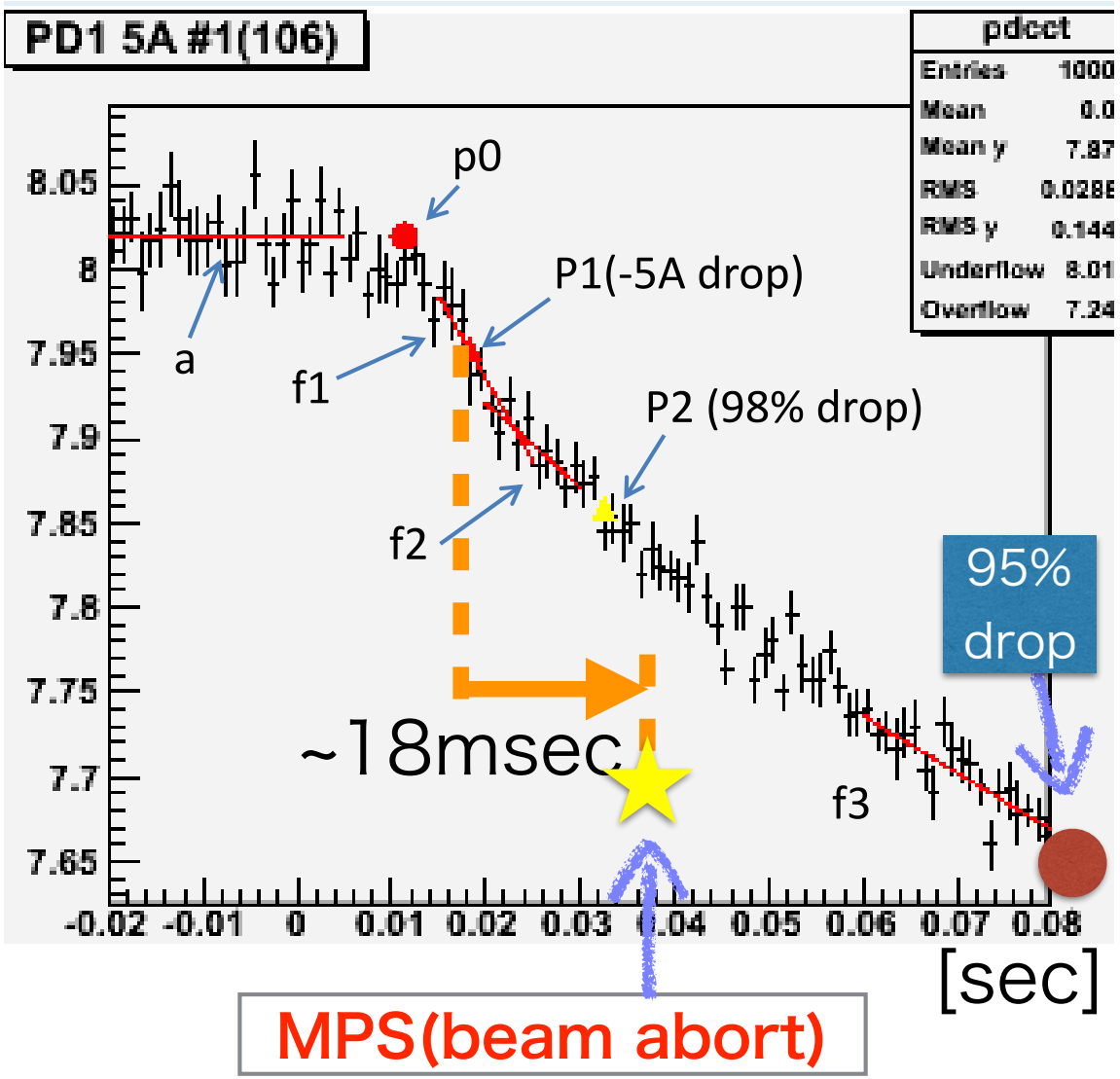
- magnet interlock system was improved



- require the fixed current±20A for the bending magnets
- require the variable current ±5A for all the magnets

Performance of the new interlock

- Latency of new interlock was measured
- MPS should be issued before the magnetic field dropped to 95% of the nominal (where the beam could hit the magnet/duct)
- New interlock can abort the beam (change the kicker polarity) before the 95% drop



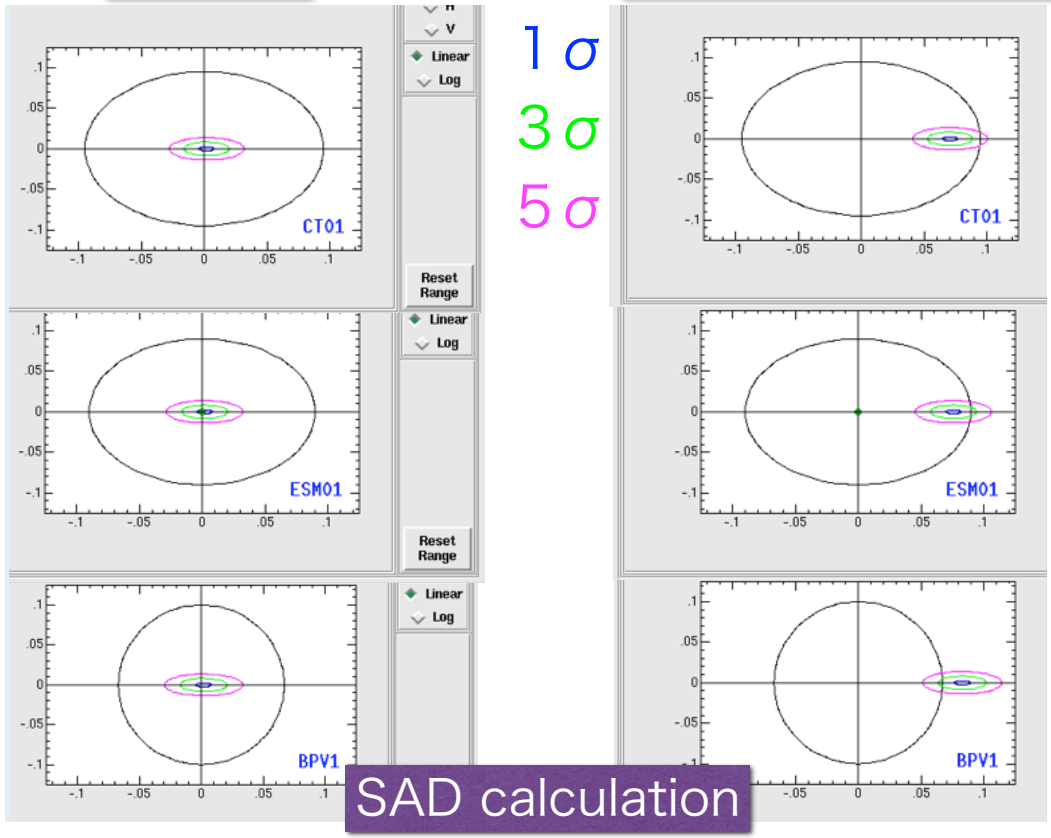
Experience of mis-shots (2)

- Feb. 2016, there were several mis-shots due to FX septum failures (wrong output current which could be caused by noise at the septum power supply)

- Only 60% of kick angle at the FX septum 3 → mis-steered beam was extracted to NU beam-line

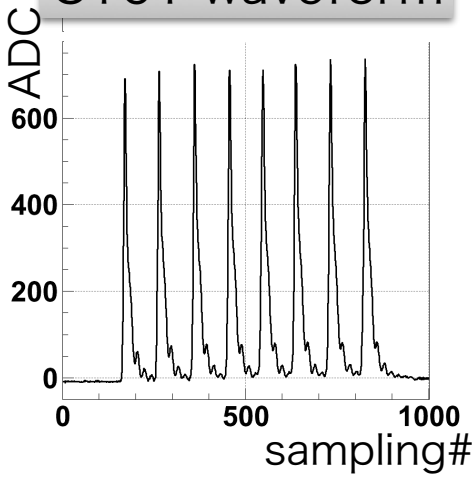
nominal

60% of SM32,33

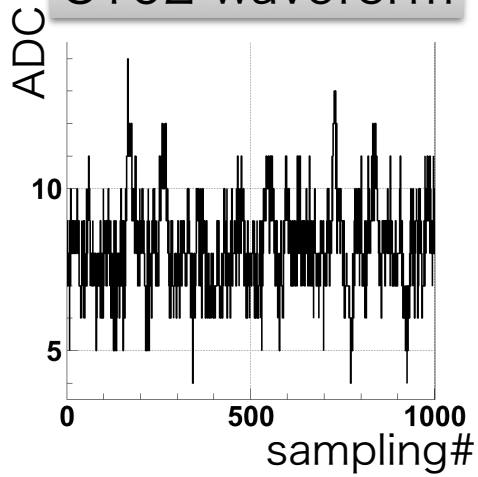


only a half of the expected signal size was observed at CT01 while no signal at CT02 → most of beam lost at the upstream of NU line

CT01 waveform

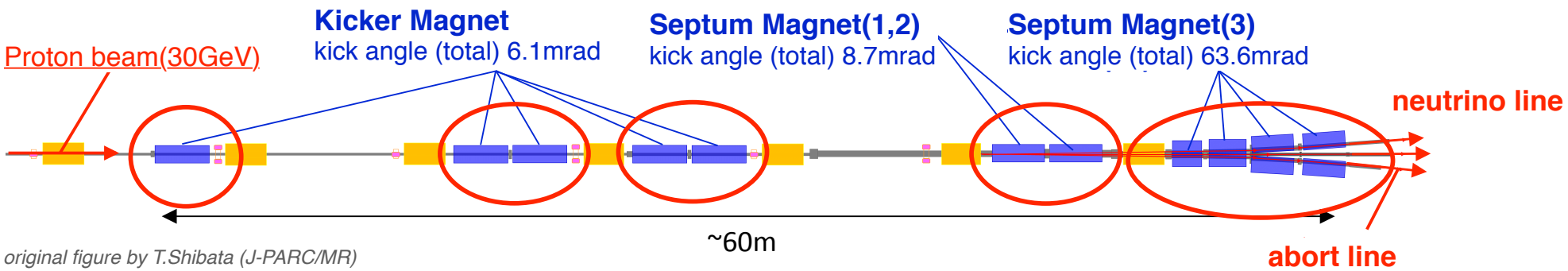


CT02 waveform



Improvement of interlock for FX failure

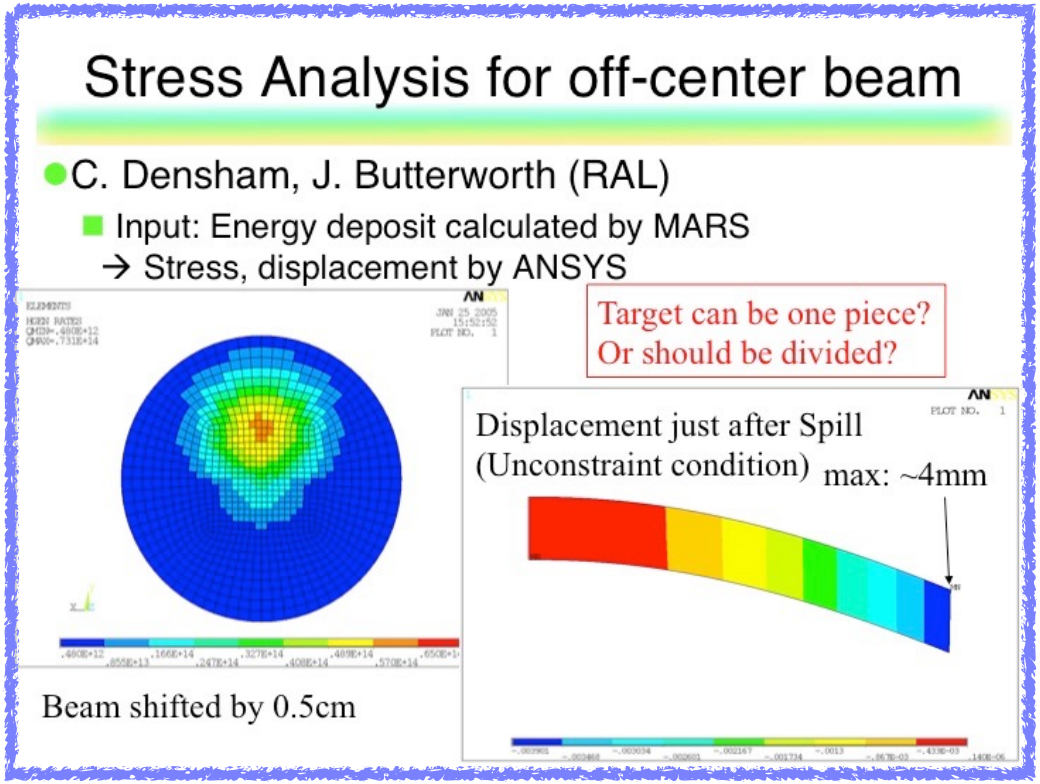
- New interlock to detect wrong output current of the FX septum was implemented after the Feb. 2016 mis-shots
  - all the FX septum output current is checked just 5 msec before the FX kicker fire (beam can go though the NU target (or baffle) based on SAD calculation)
- In addition, FX kicker interlock (detecting any wrong timing mis-fire) was also improved in order to avoid any mis-steered beam extraction
- Further improvement is under consideration



original figure by T.Shibata (J-PARC/MR)

Improvement plan toward 1.3MW

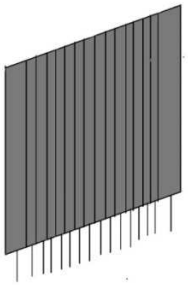
- High intensity beam off-centered at the target can damage the target
- Further improvement of interlock is necessary to avoid such case
  - improve the NC magnet current interlock speed
    → 95% drop to 98% drop
  - new beam position interlock module R&D



Development of beam position/profile interlock module (PAPILLON board)

S.Yamasu (Okayama U)

＜Present system＞



Signal from SSEM

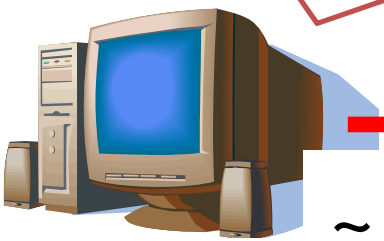
24strip

VME 9U attenuator

Attenuate signal from SSEM

Calculate beam position and profile

Go to FADC and DAQ



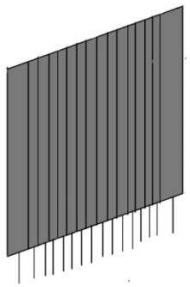
DAQ

MPS

~1sec

Developing a new module whichcan calculate the beam position & profile using FPGAand issue beam interlock

＜New system＞

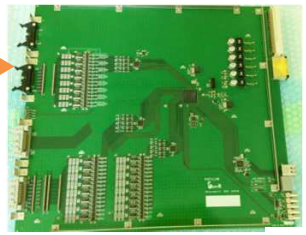


Signal from SSEM

24strip

VME 9U

New module



MPS

Attenuate signal from SSEM
＋Convert the analog signal to the digital signal(FADC)
＋Calculate beam position in FPGA

<10msec

2017/2/6

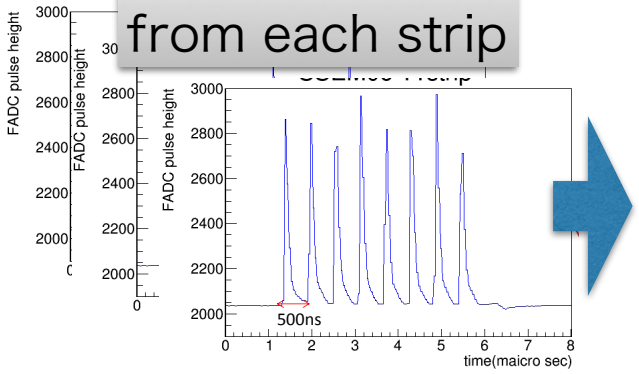
PAPILLON board : http://openit.kek.jp/project/beam_monitor_interlock/beam_monitor_interlock

openit
Open source consortium of Instrumentation

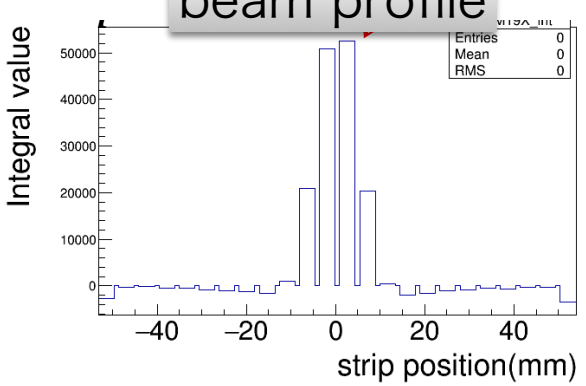
Status of PAPILLON board R&D

- Initial evaluation test with beam was performed (Feb. 2017)
- Plan to do further evaluation and stability check with beam soon
- Plan to finish R&D and install before MR high repetition operation (from 2019)

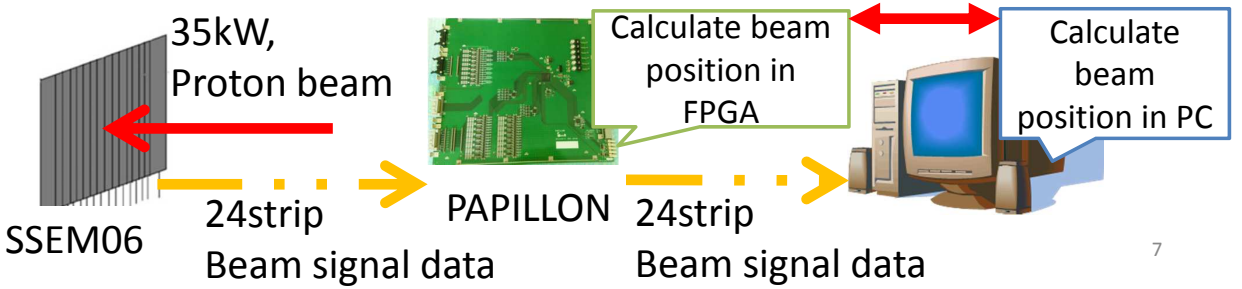
raw waveform from each strip



beam profile



Setup configuration of evaluation test w/ beam



	shot 1	shot 2	shot 3	…
calculated beam pos in PC [mm]	0.432	0.431	0.432	…
calculated beam pos in FPGA [mm]	0.43	0.43	0.43	…

consistent results observed (up to 48 shots)

Summary

- There were several mis-shots during J-PARC neutrino beam facility operation
- Beam interlock (MPS) was improved in order to avoid any serious damage on the beam equipment against such mis-shot experiences
- Further improvement of the beam interlock is in progress