



# ***J-PARC RECOVERY STATUS***

HB2012

52<sup>nd</sup> ICFA Advanced Beam Dynamics Workshop  
on High-Intensity and High-Brightness Hadron Beams

Beijing, China

Sep. 17-21, 2012

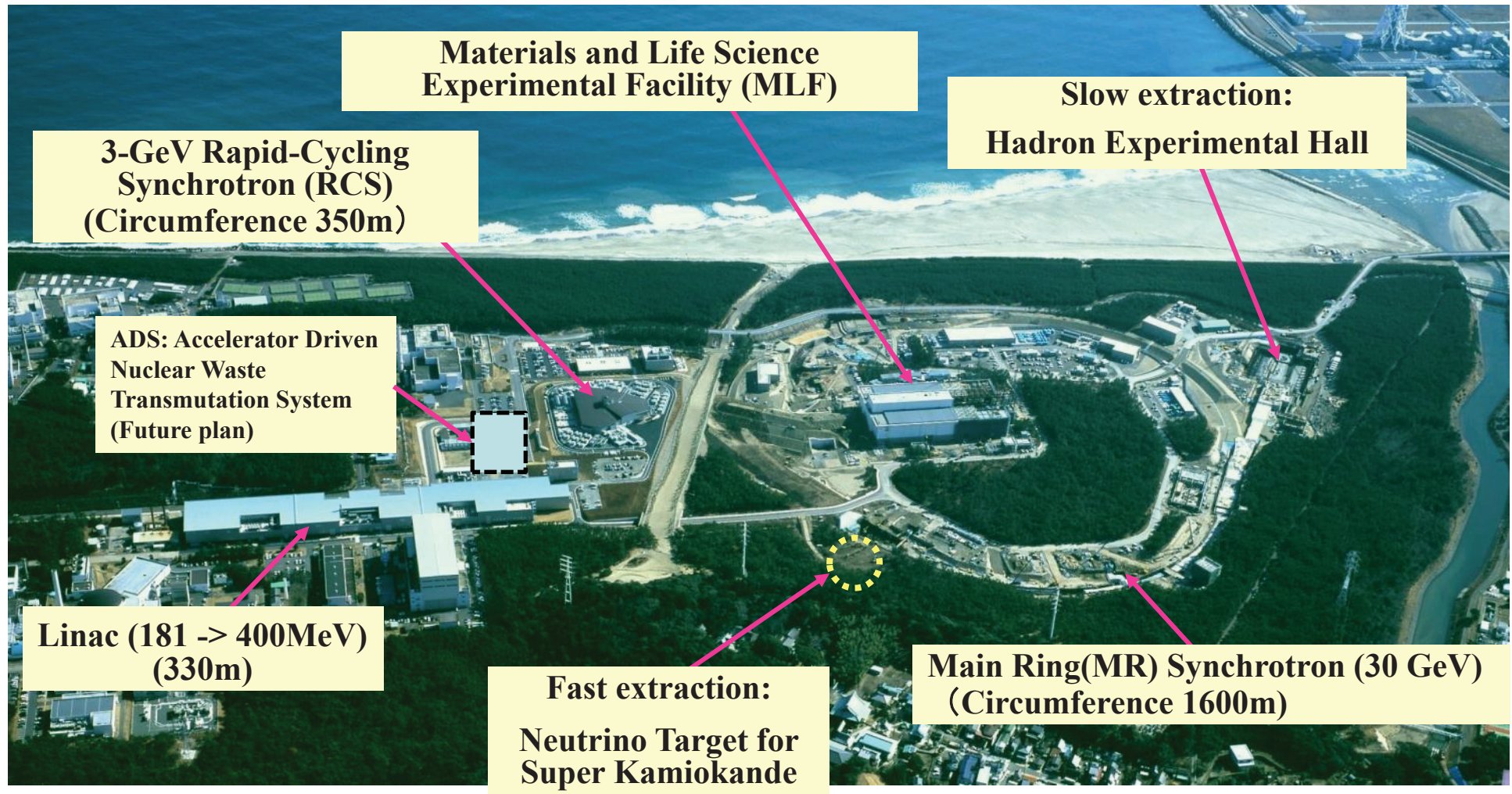
**Kazami Yamamoto**

on behalf of J-PARC Center  
Accelerator Division

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# ***J-PARC Facility Layout at Tokai, JAEA Site***

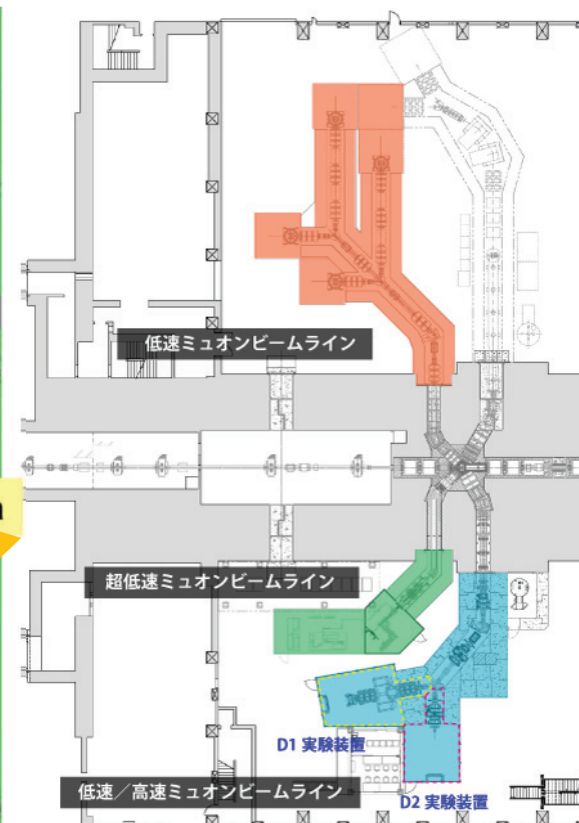
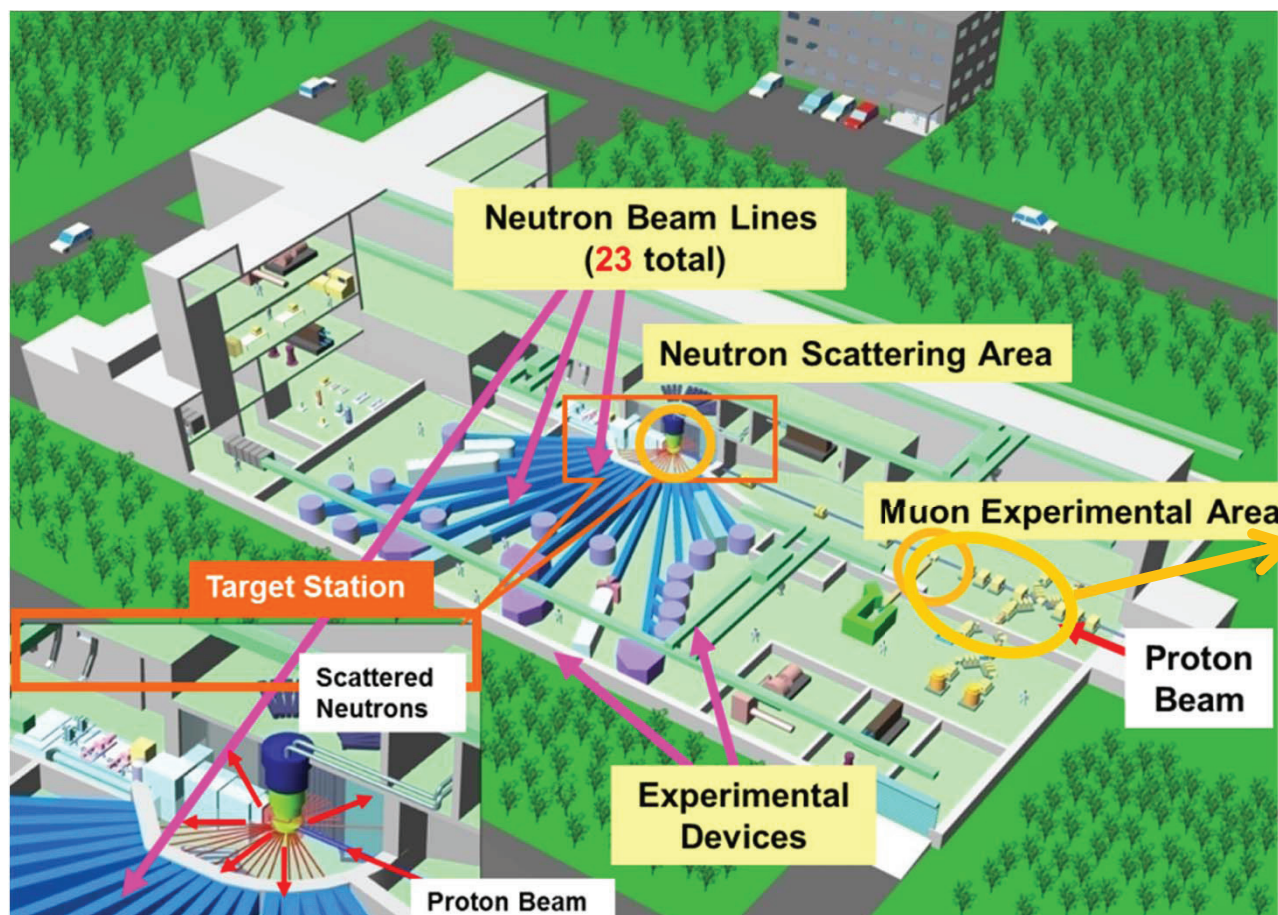


***Multi-Purpose Facility***

**Joint Project between KEK and JAEA**



# Materials and Life science Facility

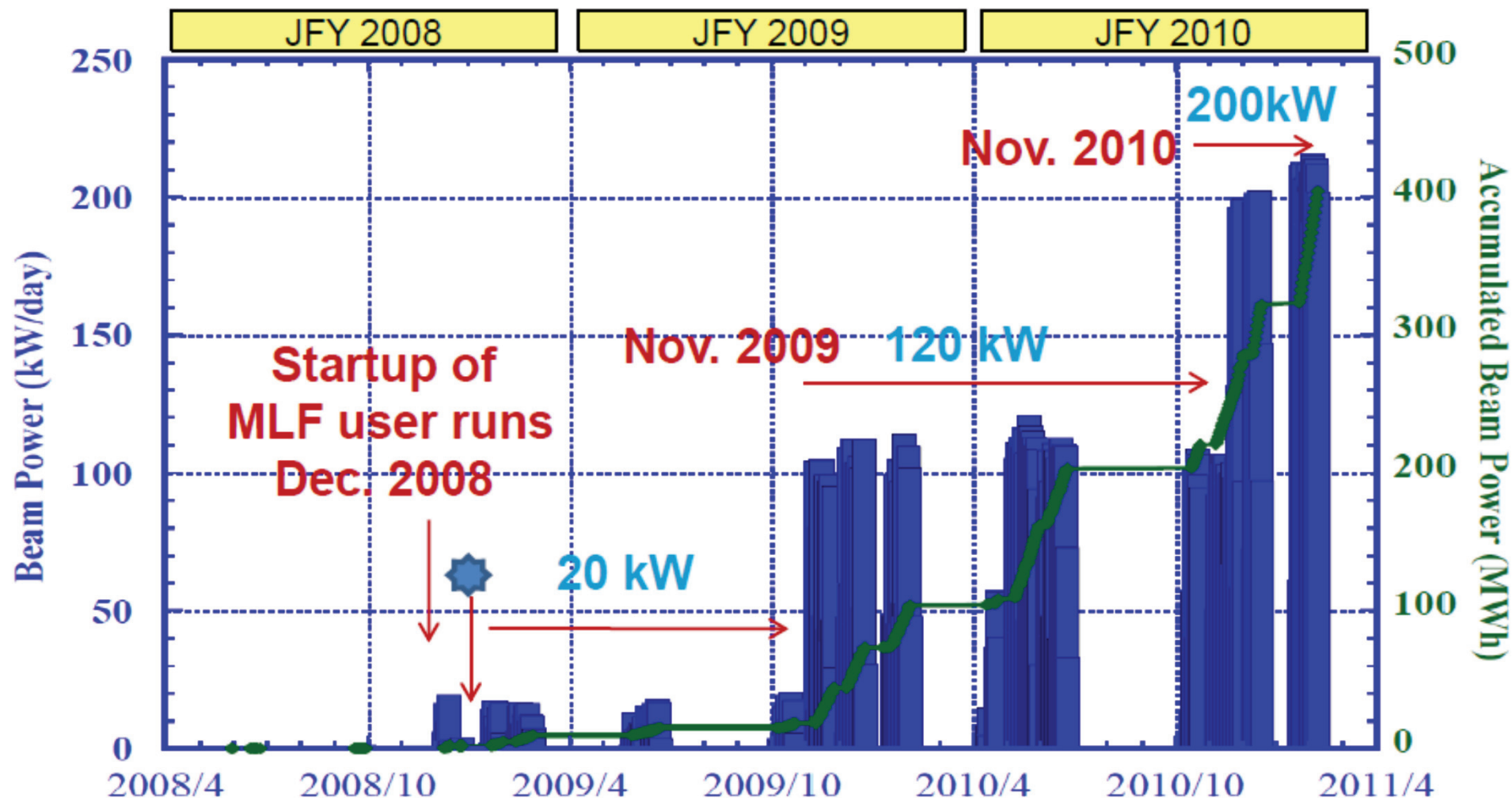


**2 Mu Beam line used**

**Neutron Beam Lines**  
In operation: 10, Beam commissioning: 2, Under construction: 6



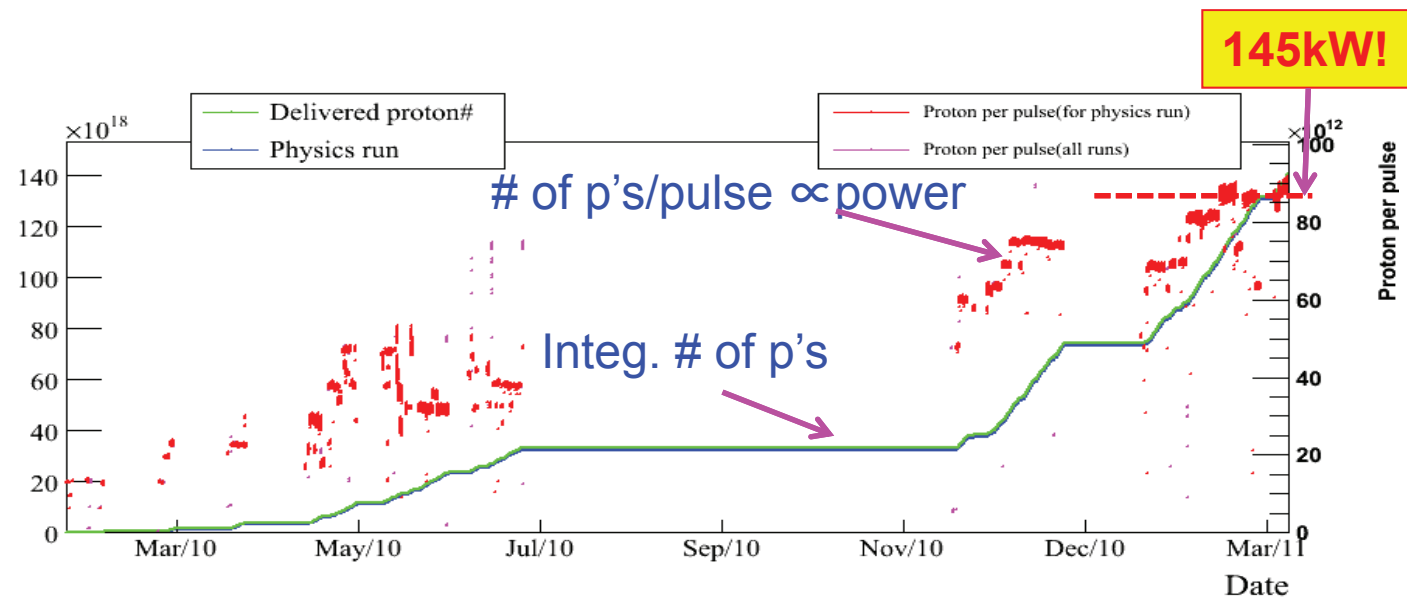
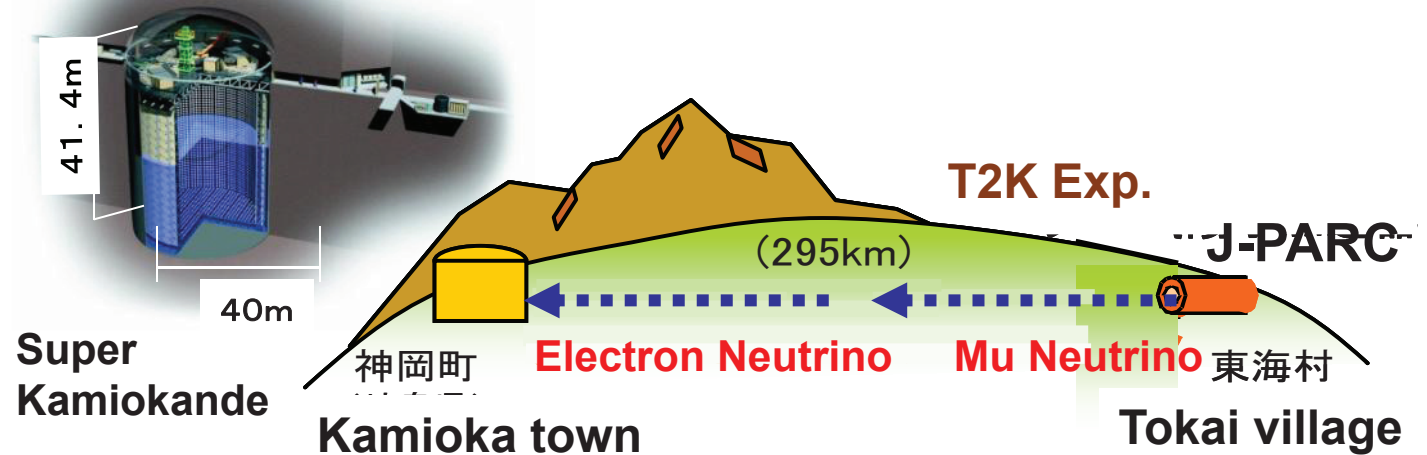
# ***RCS Beam Power (3GeV) to MLF***



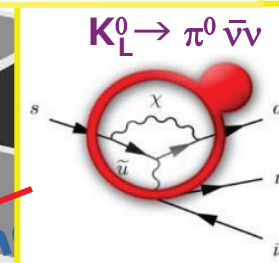
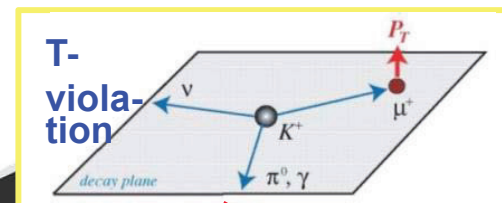
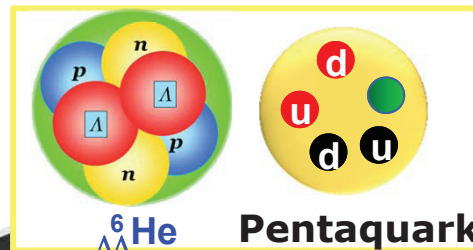
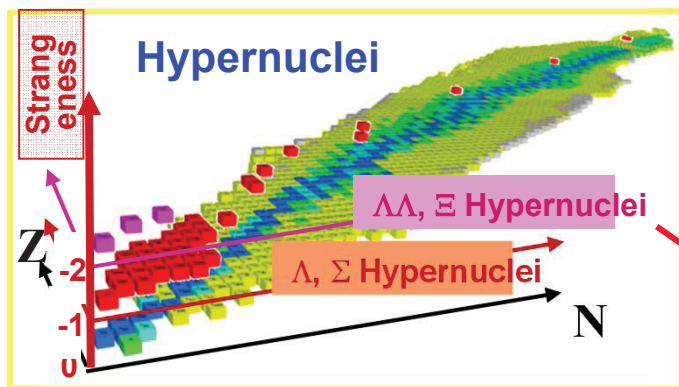
# Neutrino Oscillation (T2K) Experiment by MR

- Stable operation at 145kW ( $\sim 0.9 \times 10^{14}$  ppp) achieved
- $1.45 \times 10^{20}$  pot has been accumulated just before earthquake
- $\nu_e$  appearance search results

- 6 events detected in so far
- Indication of large  $\theta_{13}$

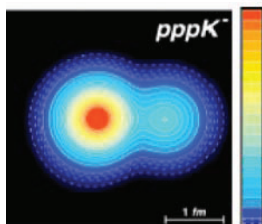
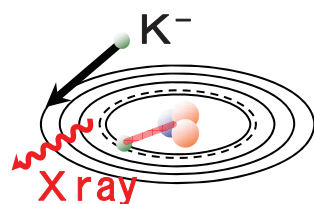


# Hadron Experimental Hall

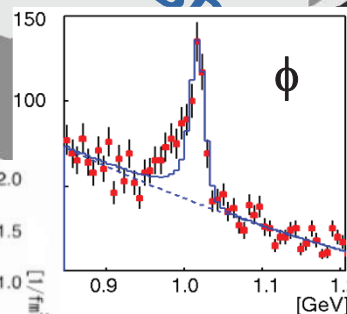


**Proton Beam**

**99.5% Extraction Effi. Achieved**



**Kaonic atomKaonic nucleus**



**Quark**

Free quarks

Bound quarks

**Why are bound quarks heavier? Mass without Mass Puzzle**





## *Summary until Mar. 11 (Earthquake)*

- Beam power has been gradually increased: 200 kW for 3 GeV, 145 kW for Main Ring at 30 GeV.
- 400kW@3GeV demonstrated with allowable loss
- Neutrino Facility: Started to take data at Super Kamiokande. 6 electron-neutrino candidate events were detected. Possibility of large  $\theta_{13}$ .
- Hadron Facility: Ready to run for many experiments. First data for penta-quark search were completed.
- Materials and Life Science Facility: Neutron and muon beams already produced many fruitful data and the results are being published.

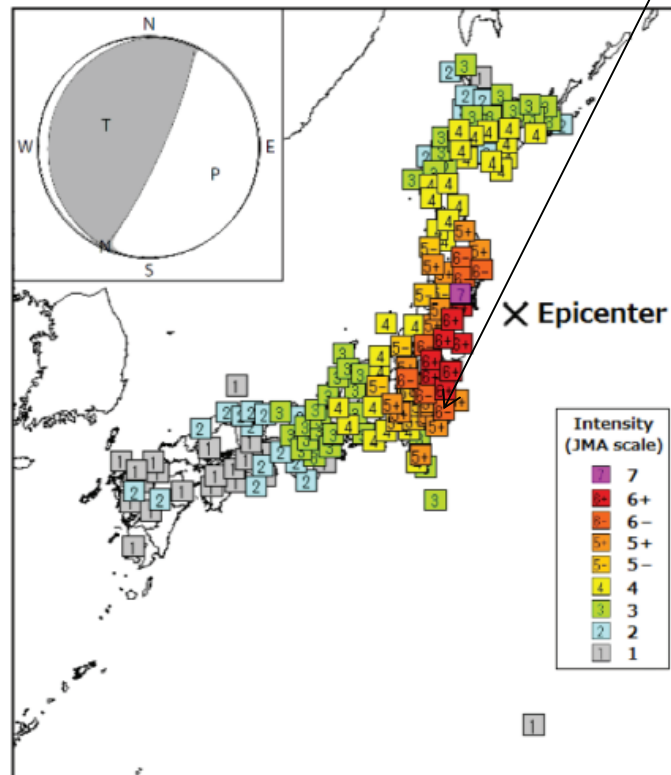
**Accelerators had been working well just before the earthquake<sup>8</sup>.**

# ***Recovery from the earthquake***



# ***The East Japan Great Earthquake***

- The great earthquake occurred on March 11, 2011 at 14:46 JST.
- Although tsunami (>5m) came to the Tokai-site coast, it was well below the floor level of J-PARC.
- The seismic intensity was 6-minus (JMA scale) at J-PARC.



**Seismic Intensity (Data from National Research Institute for Earth Science and Disaster Prevention ).**



## **Entrance of the Linac**

**About 1.5 m drop over a wide area.  
Underground electric wires and  
water pipes were all damaged.**

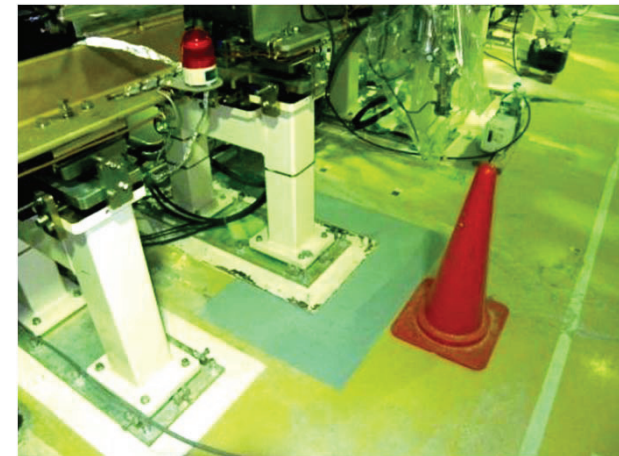


# ***Linac: Flooding in the Tunnel***



Inside of underground tunnel immediately after the Earthquake

**Linac tunnel has many piles that reached to a basement rock. These piles minimized a direct damage to the tunnel. However, groundwater leaked into the tunnel and the water depth increased to 10 cm (100 tons) within two weeks after the earthquake.**



**Repairing water leaks in the tunnel is almost completed.**

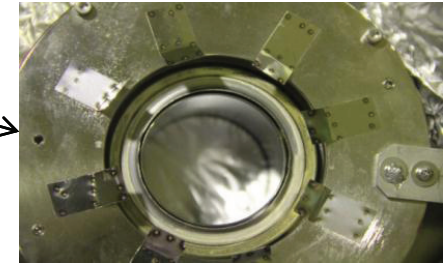
# Restoration of the Linac

## Investigation for the inside of cavity



### Damage of Monitors

- About 15 current monitors had problems.



- No serious problems were found

### Vacuum pumps with waters



↑ Pumps with waters inside.

- Many bolts were dropped from the crane.



bolts that were dropped.

Cracks seen on the pillar for the crane →

### Damage of Crane





## 3 GeV Synchrotron (RCS)

**There was no damage in RCS beam line component!.**

There were severe damages on many facilities around the RCS building.

The restoration work was started after repaved roads for carrying in materials and instruments for the work.

Immediately after the Earthquake



**The road was repaved.**

Immediately after the Earthquake



**The bent stage was repaired. Power was supplied to the RCS building after 5 month.**

After having electricity in September, we were able to start the restoration of the utility systems (cooling water system, air conditioner,) and the detailed check of the components.



# Main Ring (MR) Synchrotron

- Repair of water leaks was done. The facilities for electric power supply and cooling water supply were restored as well.
- All electromagnets (~400) are being realigned at 5 magnets/day.
- Magnets moved more than 1 cm are needed to change a stage position (Photos).



Jacking up an electromagnet to make a space between the magnet and the stage



Hanging up the magnet



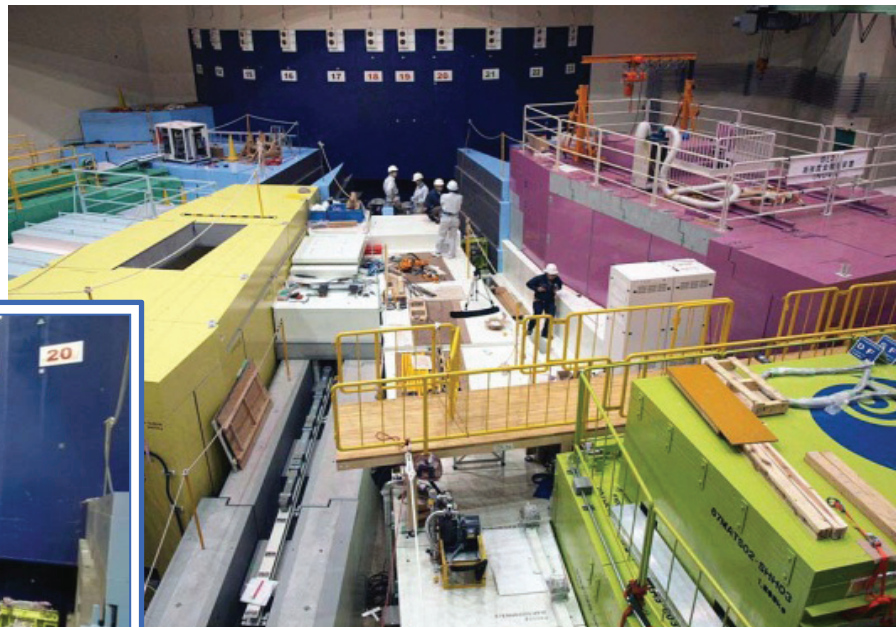
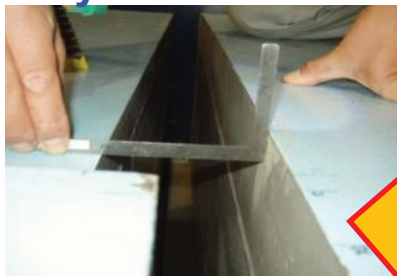
Pulling out the stage to put new longer height-adjust screws

Sometimes we need to place an adapter to put a new longer anchor bolt.

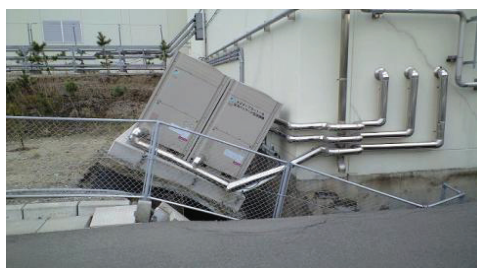


# Experimental hall

Immediately after the Earthquake



Reassembling work of shielding blocks for neutron beams in the 2<sup>nd</sup> experimental hall



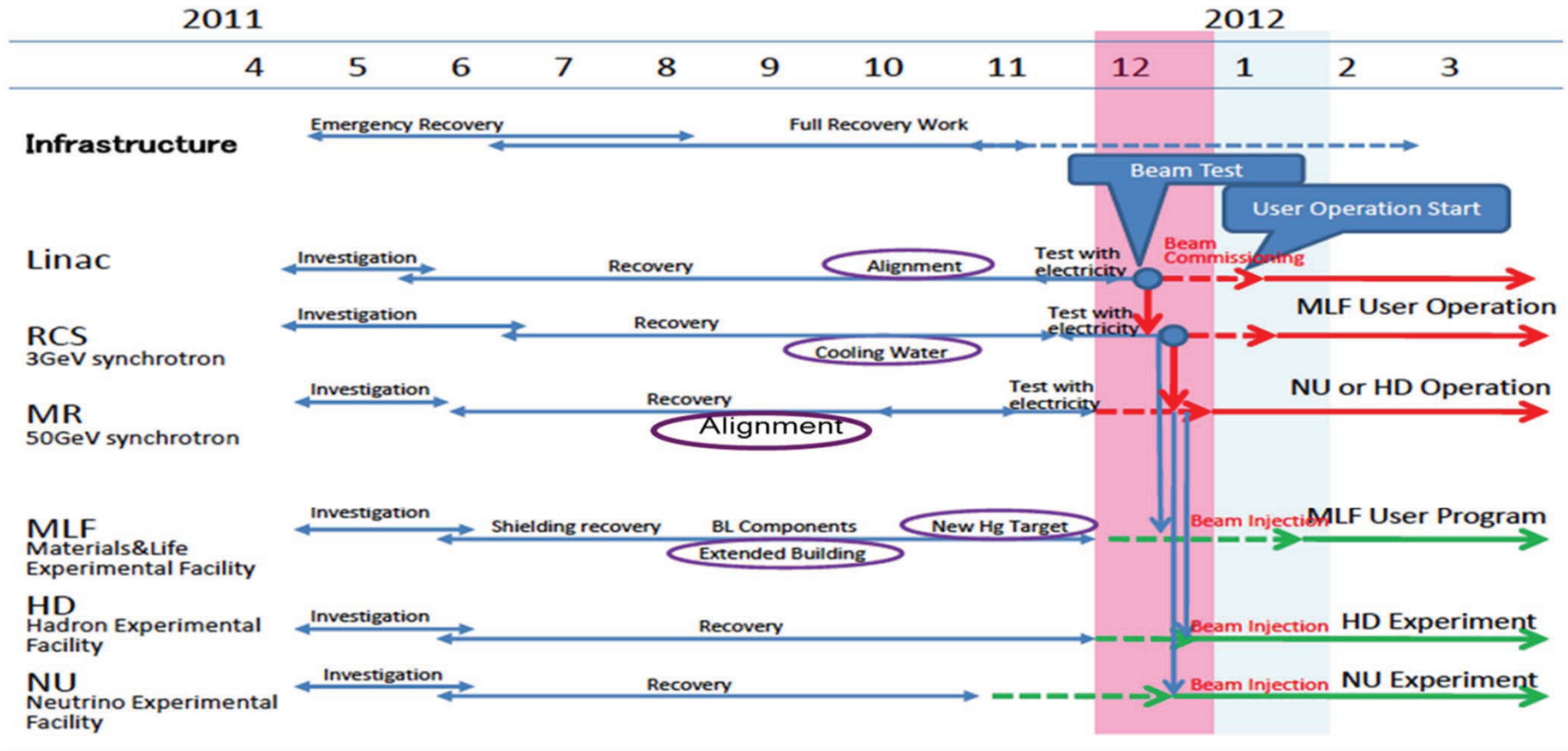
Neutrino Experimental Facility



Hadron Experimental Facility



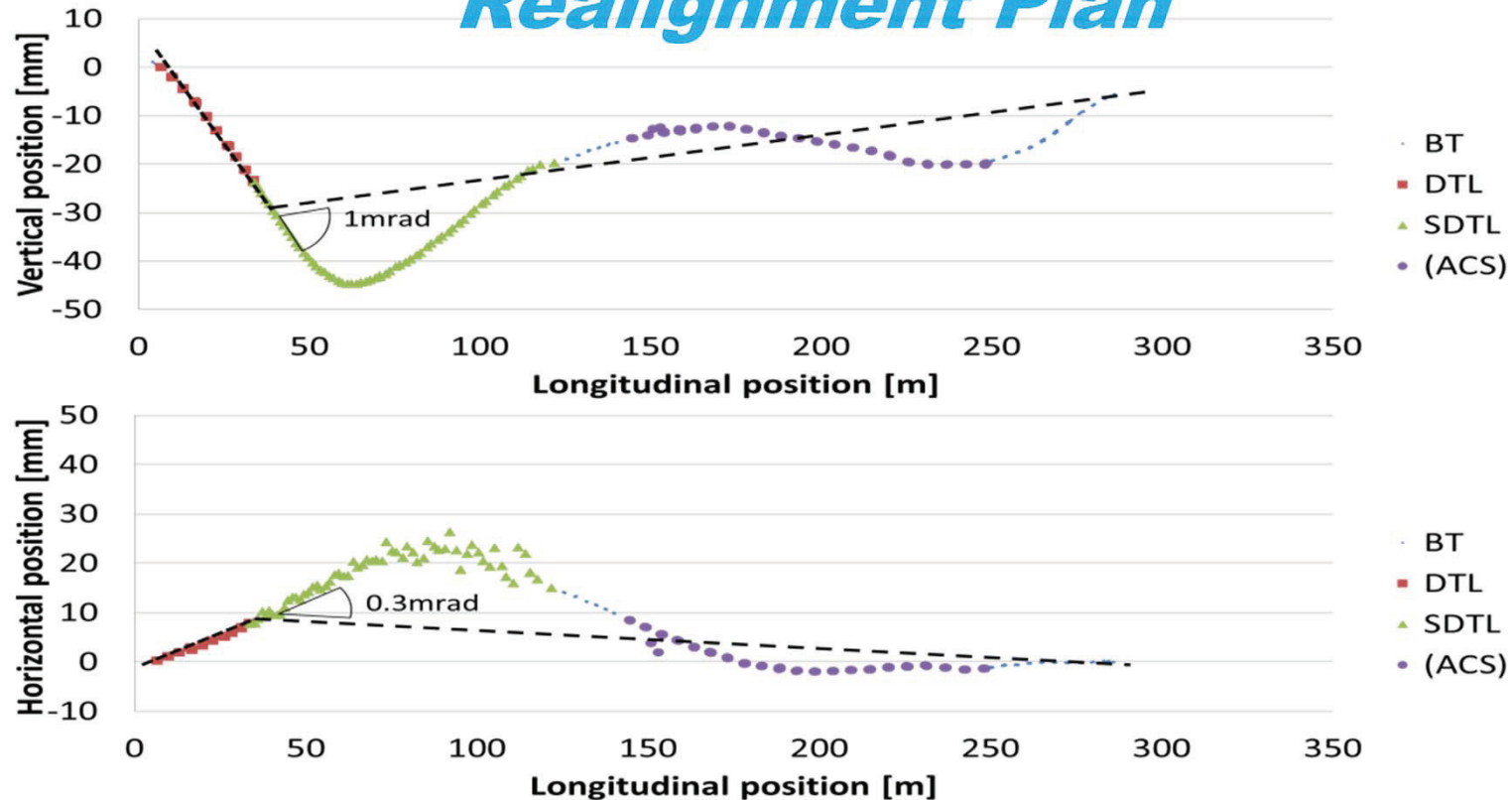
# Recovery Schedule



- We released a recovery schedule in May 2011.
  - Start beam **tuning from December**.
  - Restarted **user program of 44 days until the end of March 2012**.<sup>16</sup>



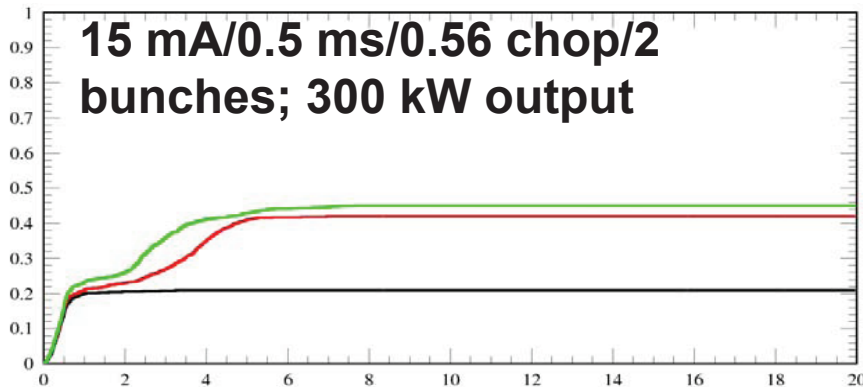
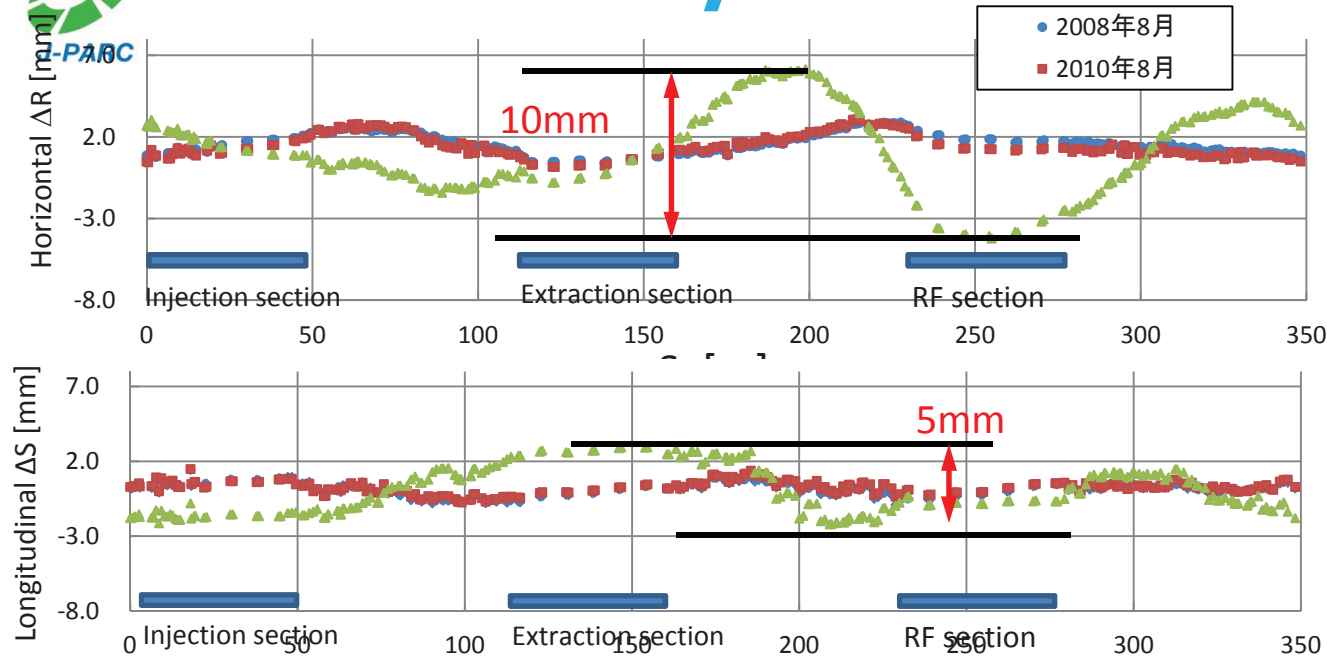
# Measured Displacement of the Linac and Realignment Plan



- The maximum subsidence and horizontal deformation are about 43 mm and about 25 mm, respectively.
- To aim at an early restart of the beam operation, we decided to steer the beam at the steering magnets downstream of the DTL section horizontally and vertically.
- The dashed line shows the target realignment line in the straight section.



# Measured Displacement of the RCS magnets



**Black:** Before the earthquake

**Red:** After the earthquake

**Green:** After the earthquake with tune manipulation

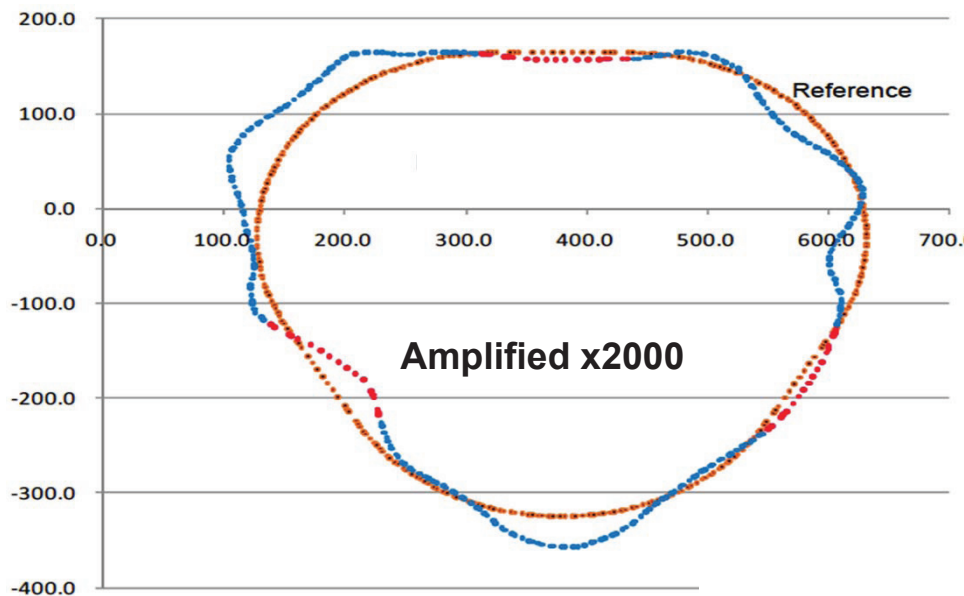
-> Twice larger, but enough acceptable

The simulation shows that the RCS could operate at 300 kW without re-alignment, thus we decided that the re-alignment of RCS will perform in the summer shutdown of 2013.

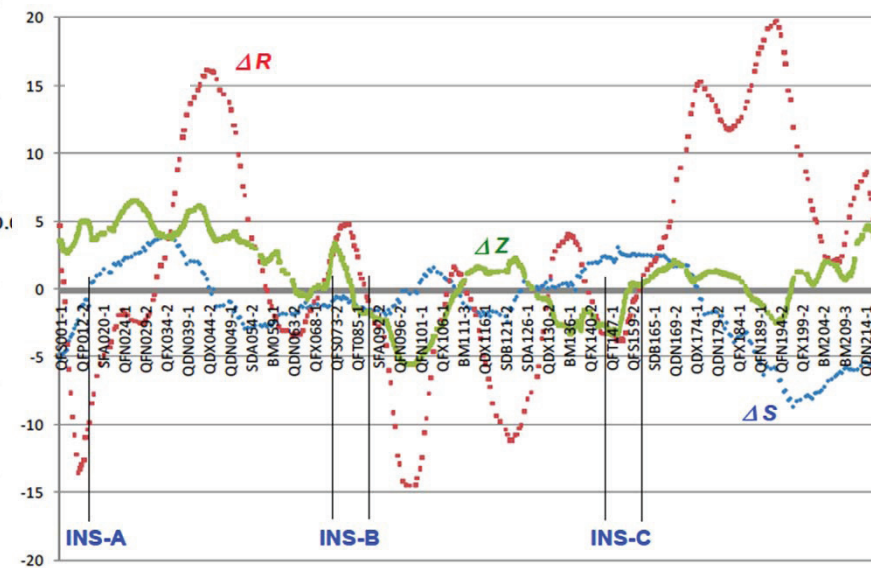


# Measured Displacement of the MR

- There were no serious damages on all MR equipment/instruments, such as electromagnets, but they misaligned in both vertical and horizontal directions.



Red: Reference positions of electromagnets  
Blue: Actual positions after the earthquake  
(Please note the magnitude of displacement is amplified x2000.)



Electromagnet displacement in a vertical direction

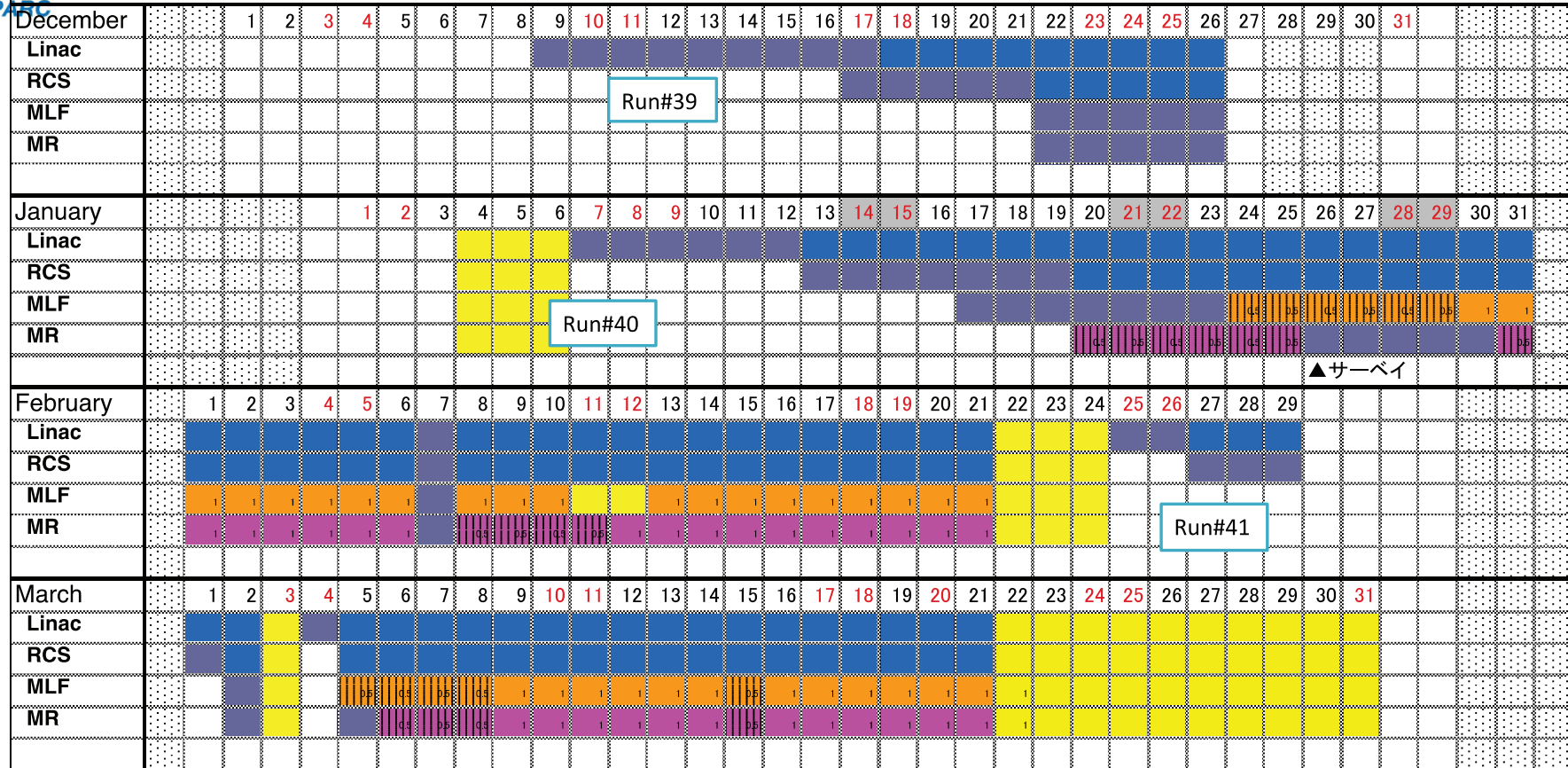
- All the magnets were realigned and set to zero position by the end of November 2011.

# ***Highlights of accelerator operation after recovery***



# Operation summary in JFY2011

2011: Accelerator maintenance & Uses operation plan



Maintenance
  Tuning&Study
  beam delivery
  MLF user operation
  MR user operation
  Half day delivery
  MLF half day user operation
  M R half day user operation

- **After 9-month beam shutdown, J-PARC accelerators resumed beam operation. Beam transport from the linac to the MLF and NU targets with nominal beam energies was successfully achieved in December 2011.**

**Jan. 24-:** Beam delivery to the MLF.

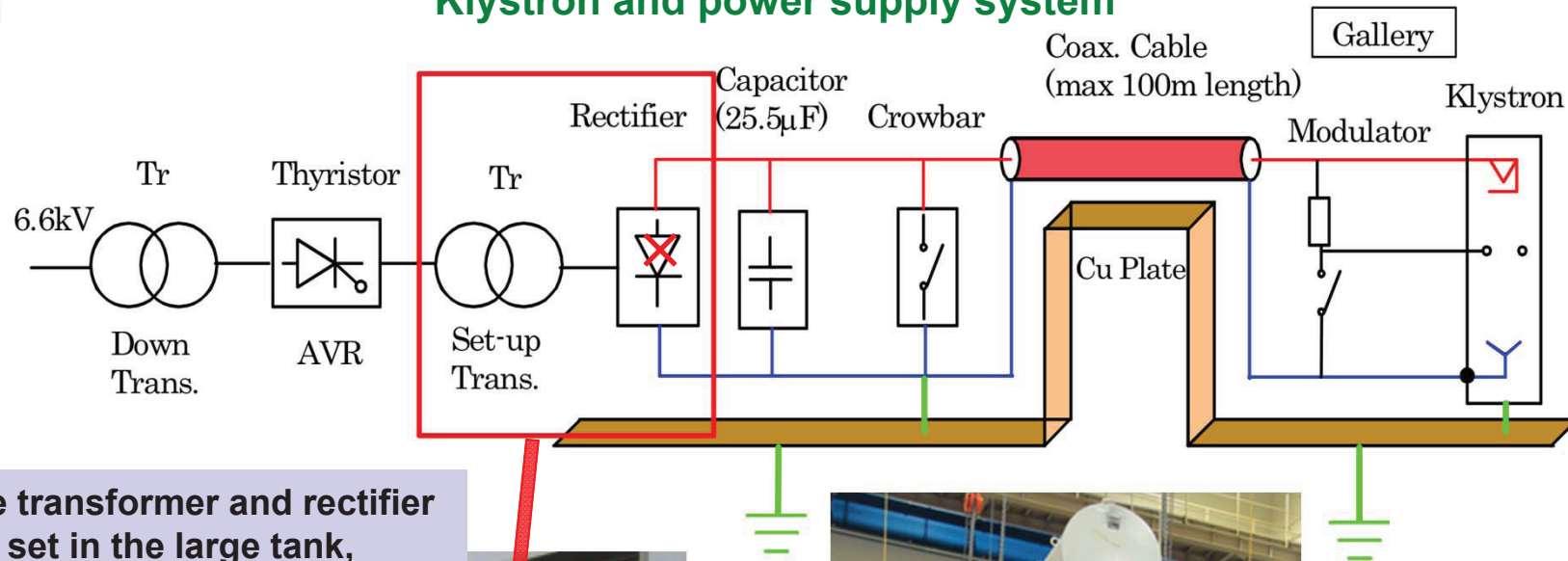
**Jan. 28-Feb. 21 :** Beam delivery to the HD hall.

**March 5 - :** Beam delivery to the the T2K experiment.

**March 22 – April 5 :** **Unscheduled shutdown was caused by a trouble on an HV-PS of the linac klystron.**

# Trouble with the 110kV rectifier for klystron power supply of the linac

## Klystron and power supply system



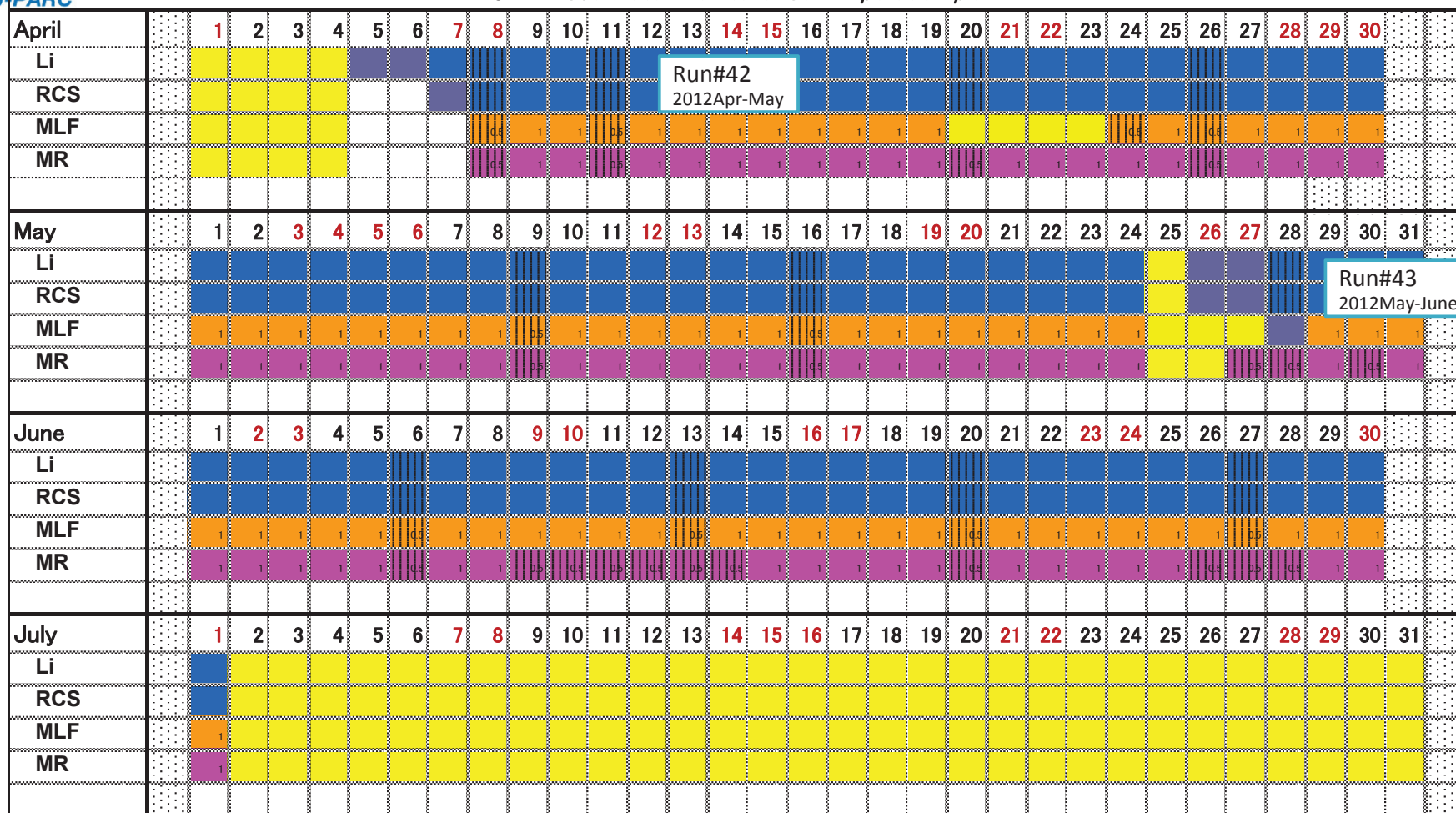
The transformer and rectifier are set in the large tank, which filled with insulation oil.



The oil tank was replaced with a spare ( used in rf test bench)  
→ Linac resumed the beam acceleration from April 5, 2012.

# Operation summary in JFY2012

## 2012: Accelerator maintenance & Operation plan



Maintenance
  Tuning&Study
  beam delivery
  Half day delivery
  MLF user operation
  MLF half day user operation
  MR user operation
  MR half day user operation

**April 8 -:** Beam delivery to the MLF and NU for user operation restarted.

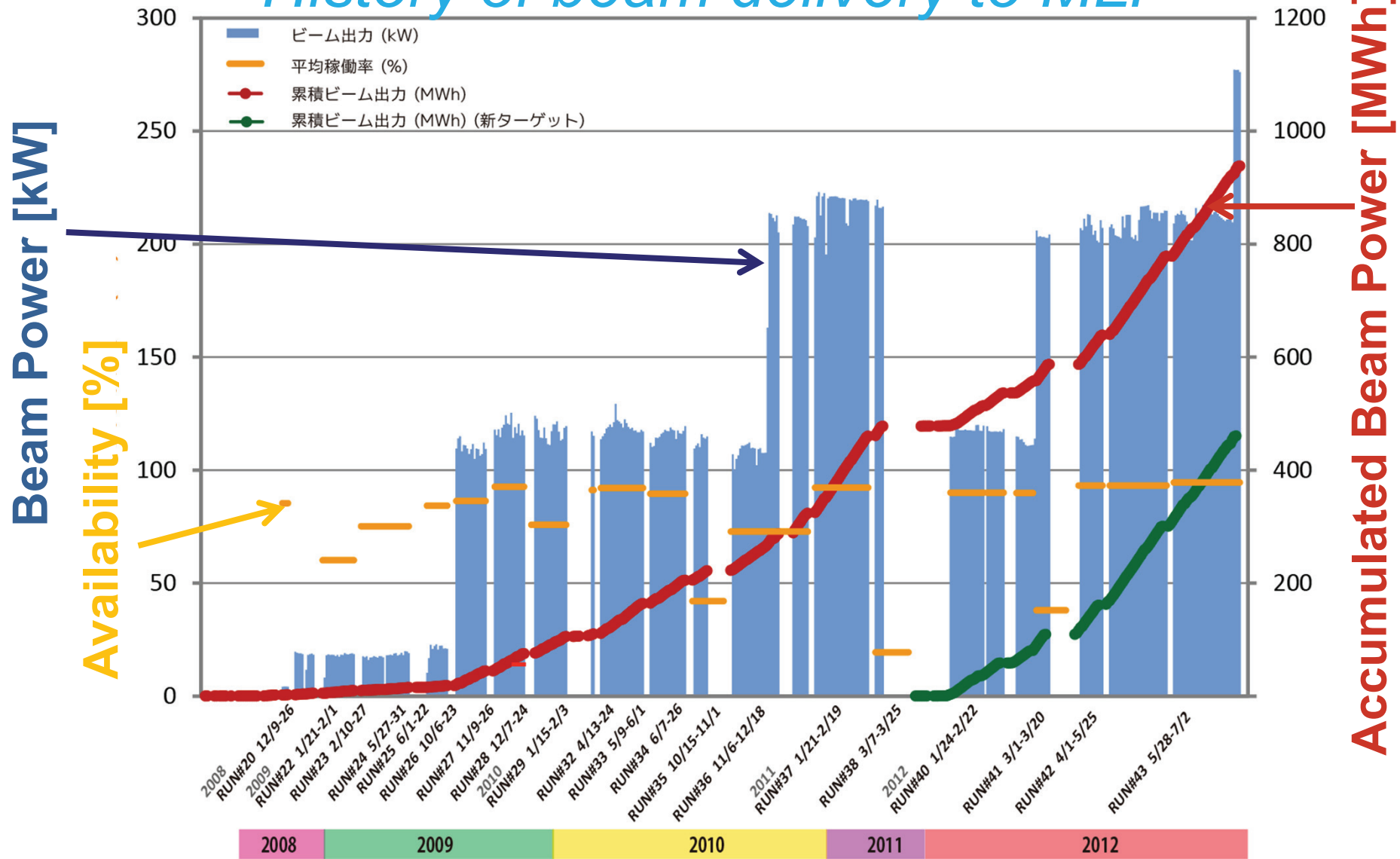
**June 9 :** Operation mode of the MR switched from FX to SX. Beam delivery to the HD users started.

**July 2 :** Beam operation was stopped. The 3-month maintenance period started.



# Linac and RCS

## History of beam delivery to MLF



In the last three days, 275 kW beam was delivered from the RCS to the MLF. 24  
Stable operation of 275 kW was successfully demonstrated.

## The change of the linac residual radiation dose

	Jan. 4, 2012	Jan. 26, 2012	Feb. 7, 2012	Feb. 22, 2012	Mar. 15, 2012	Mar. 22, 2012	Apr. 11, 2012	Apr. 20, 2012	May 16, 2012	May 25, 2012	Jun. 20, 2012	Before Earth- quake
MEBT2-2	4.3	1.5	2.2	8	1.5	1.0	0.70	1.0	0.77	0.40	0.60	0.50
ACS10-11	3.6	2.0	2.5	10	2.5	2.5	1.8	1.8	1.1	1.0	1.1	0.60
SDTL7B	-	-	-	-	1.4	3.4	0.68	0.75	0.28	0.37	0.27	-
SDTL8A	-	-	-	-	2	3	0.41	0.43	0.16	0.30	0.26	0.05
L3BT-DB2	0.08	0.11	0.23	0.22	0.33	0.64	0.65		1.4	1.6	1.8	1.0
L3BT-BM1		0.03	0.06	0.05	0.02		0.02	0.67	2.6	1.6	0.24	-

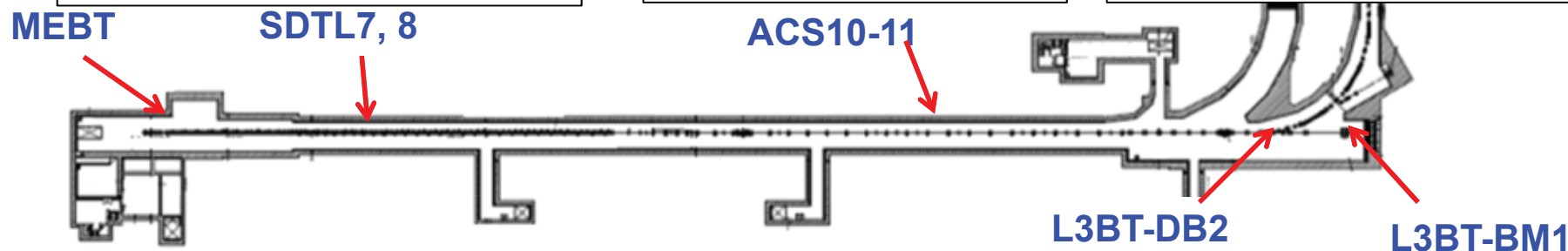
[mSv/h]

Nov 29, 2010

\*Re-alignment of cavities  
\*SDTL5 RF level  
109%→116%

\*Lattice optimization  
\*SDTL4 RF  
100%→83%

\*Modification of the  
beam orbit to remove  
protons.

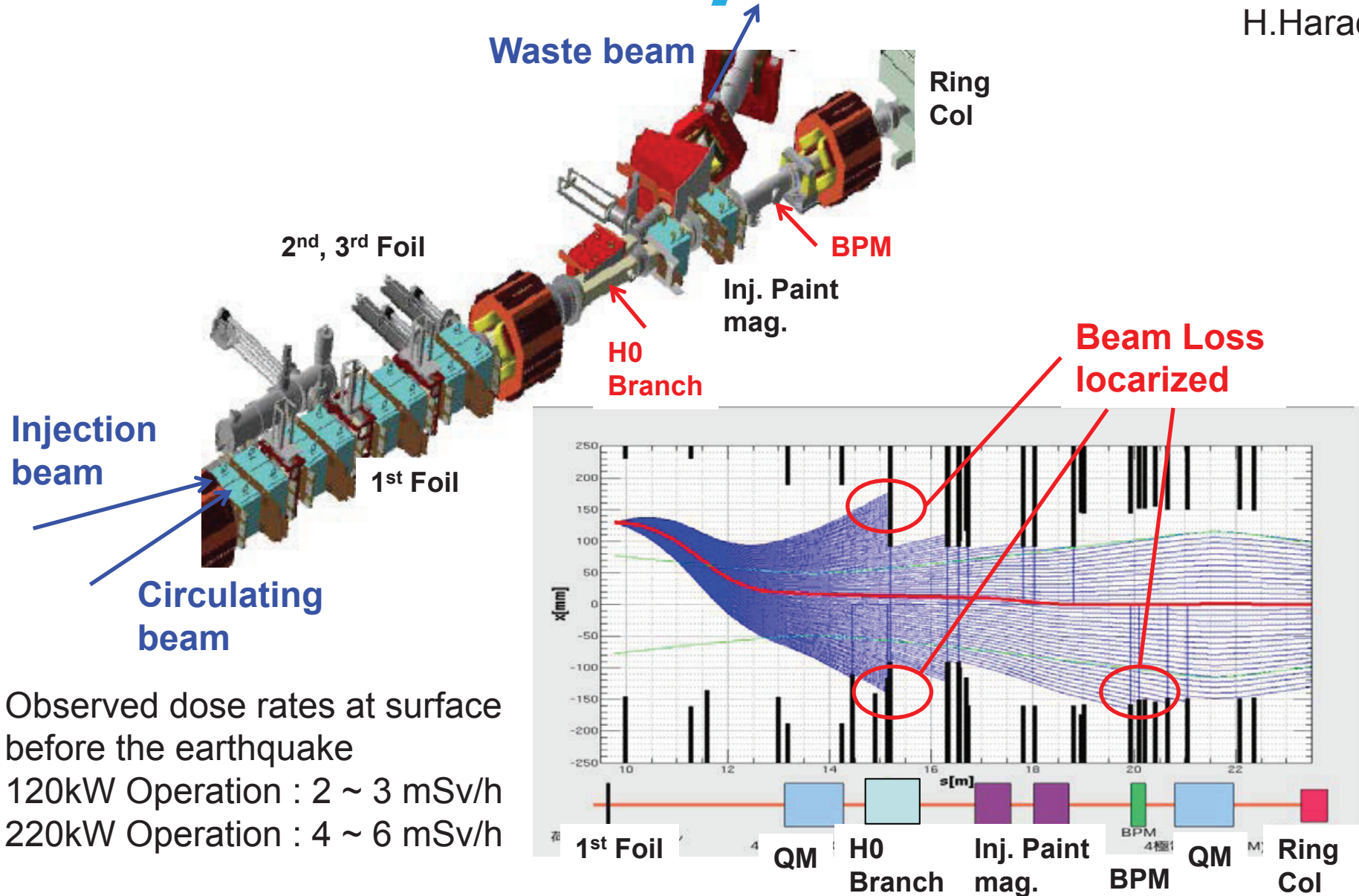


The residual dose is gradually decreasing by the linac tuning.



# ***RCS beam loss before the earthquake***

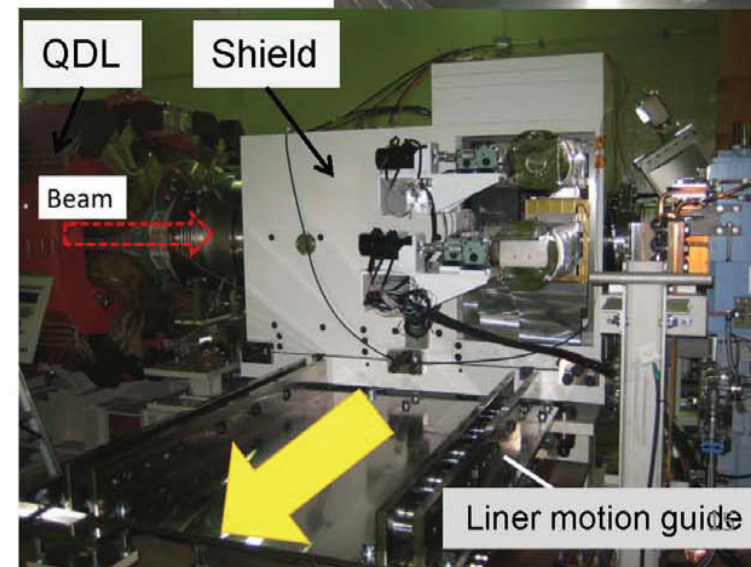
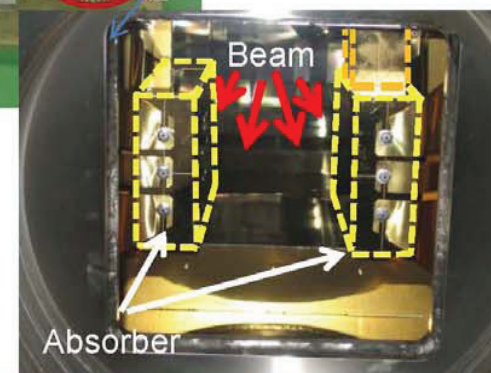
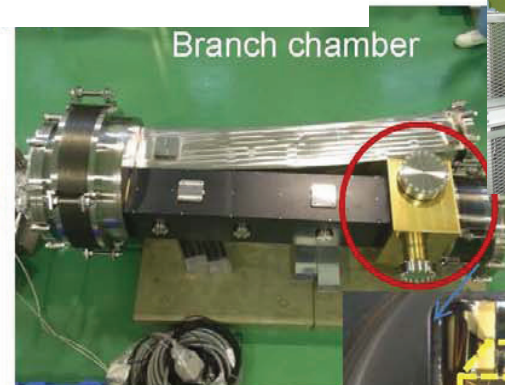
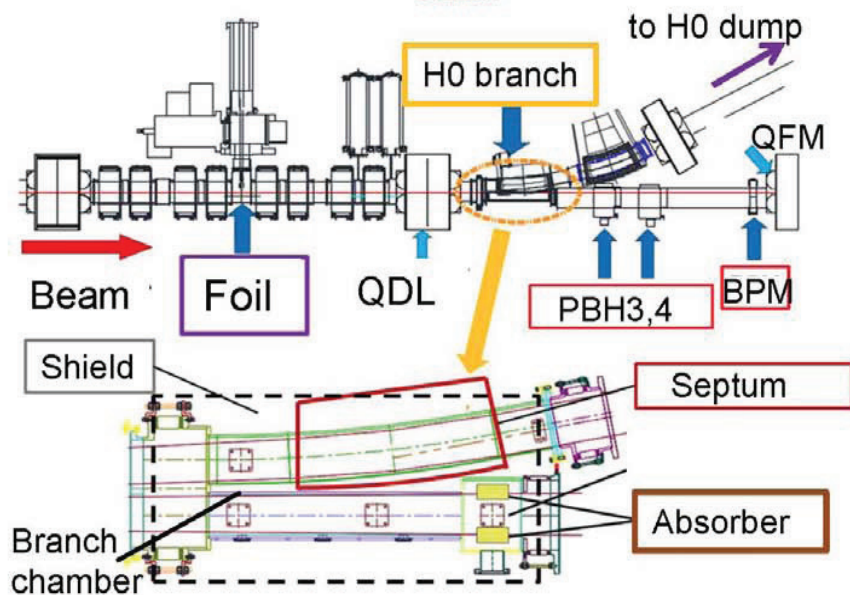
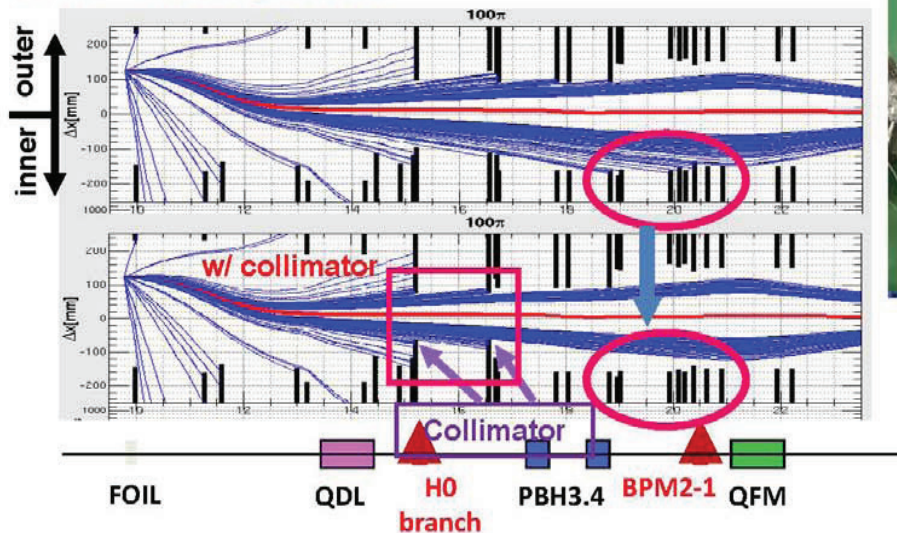
TUO3C  
H.Harada



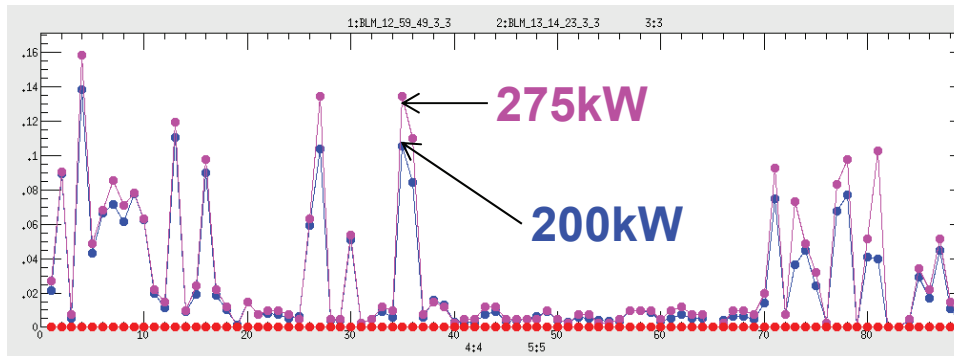


# New collimator

Geant4 + SAD  
w/  $10^8$  macro particles



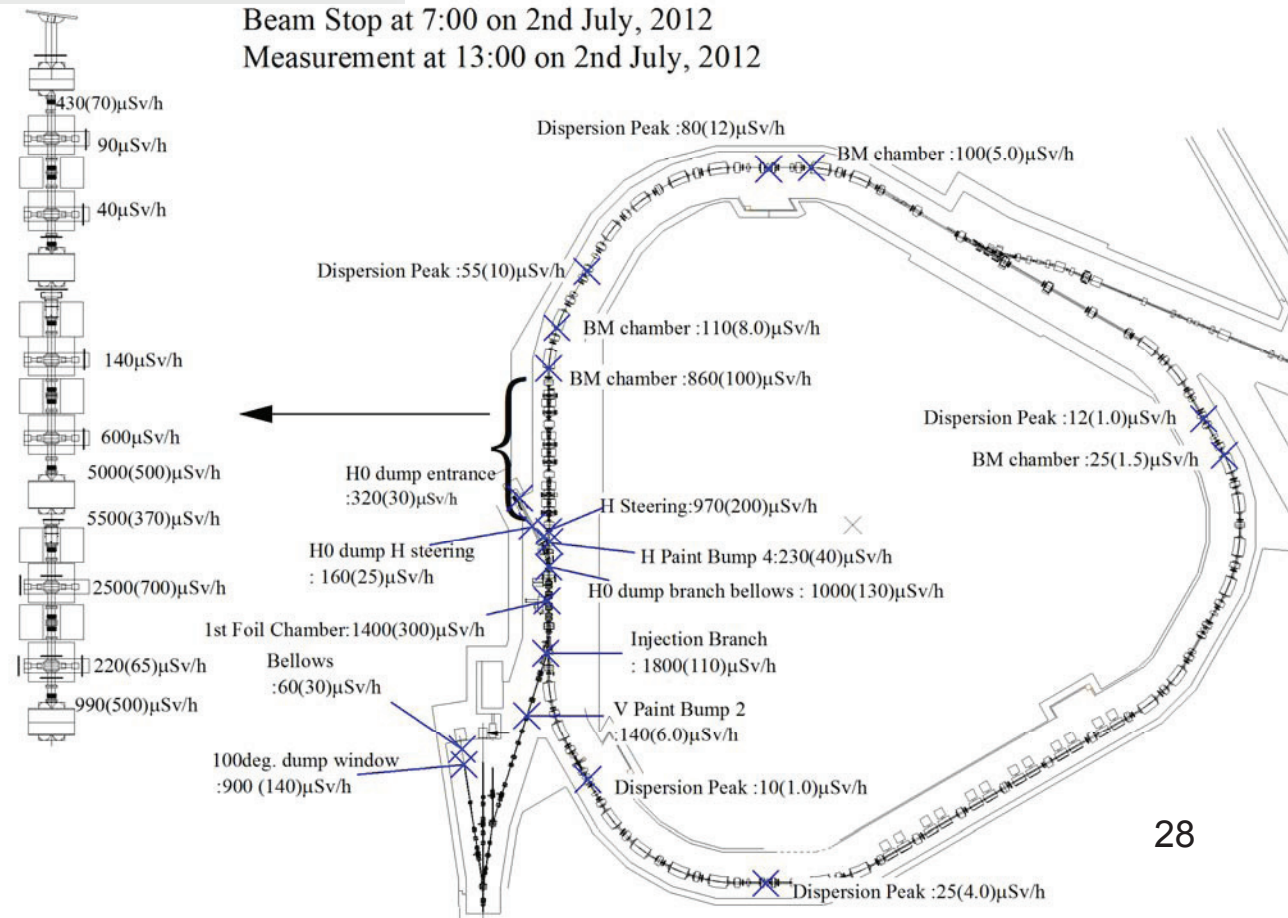
TUO3C  
H. Harada



Ratio of BLM signal level is almost same as ratio of output power.

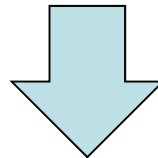
Beam Stop at 7:00 on 2nd July, 2012  
Measurement at 13:00 on 2nd July, 2012

The residual radioactivity is acceptable level.  
The RCS is ready for the beam delivery of 300 kW to the MLF from the autumn of 2012.



**In the MR, not only the restoration from the earthquake but a lot of improvements have been performed.**

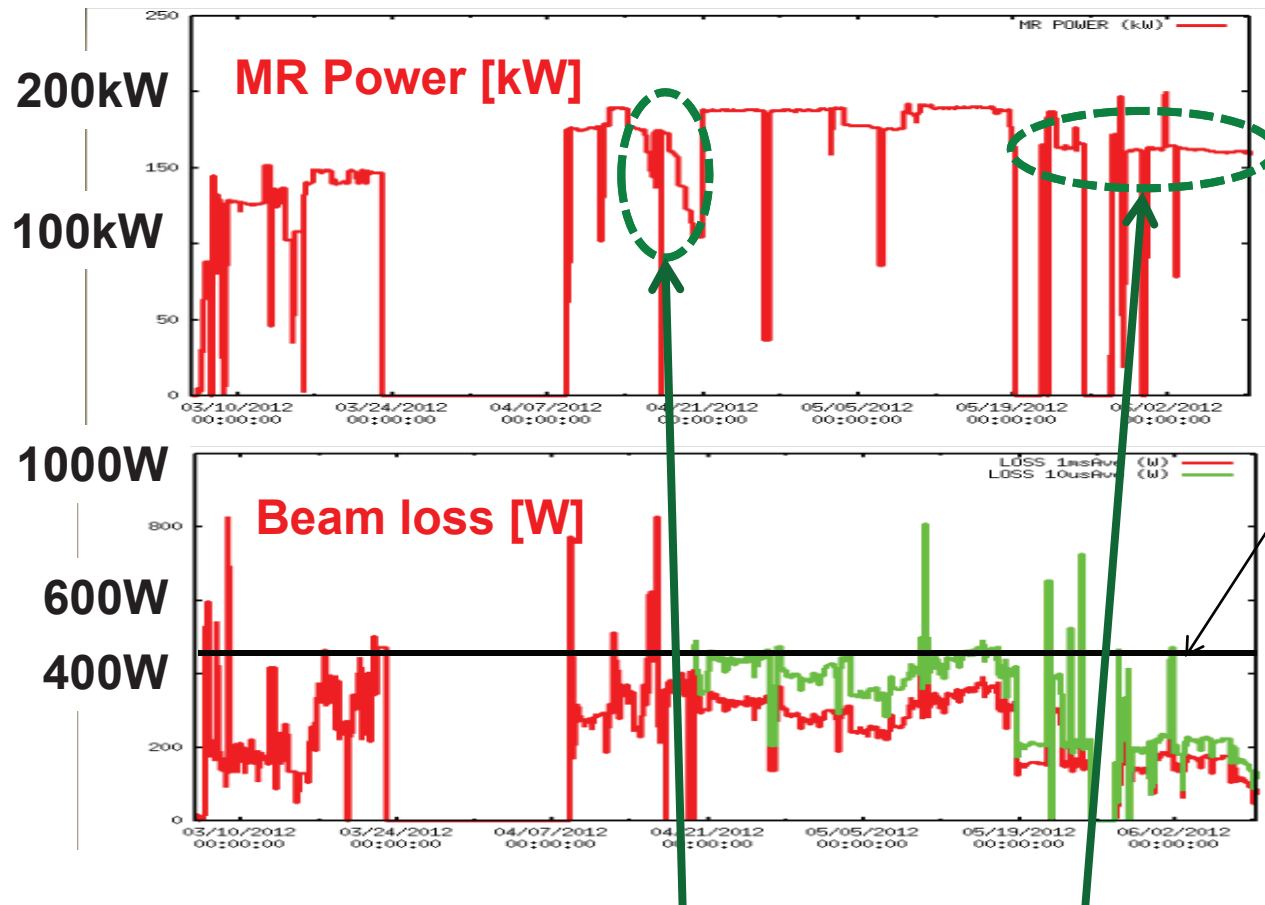
- **Installation of additional shields and absorbers of ring collimators**
- **Installation of new collimator in the slow extraction straight section**
- **Replace the injection kicker system**
- **Installation of 7th and 8th RF cavities**
- **Installation of skew quadrupoles and octupoles for resonance collection and suppression of instabilities**
- **Installation of solenoid coils on the rf excitor and new Ripple Quadrupole power supply for spill feedback system for slow extraction**



**From these improvements, the maximum delivered beam power was increased to 200 kW by fast extraction mode and 6kW by slow extraction mode.**



Delivered beam power to the T2K experiment ; 160 - 200 kW  
MR cycle time is 2.56 s, Bunch by bunch feedback ON,  
Chromaticity is set to  $\sim -3$



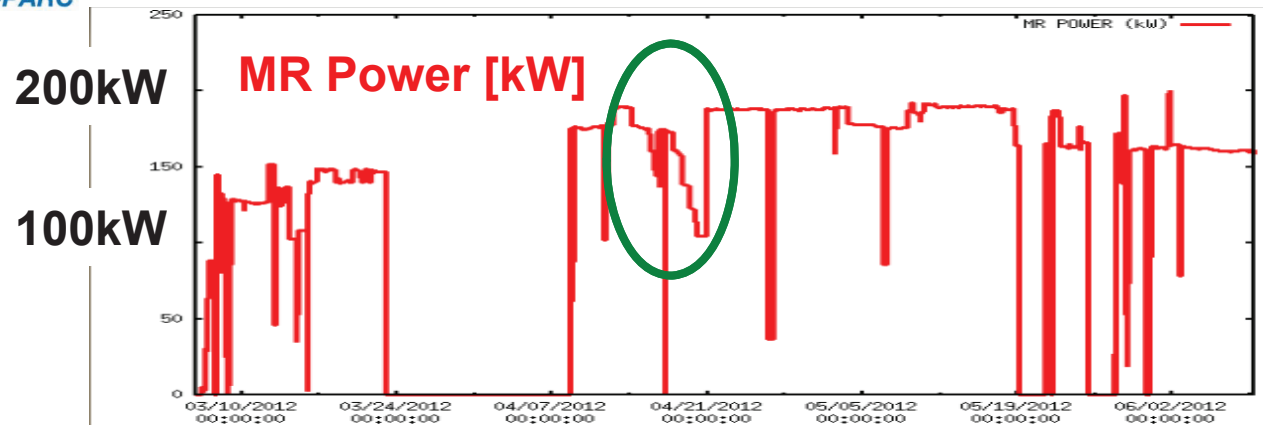
**Present limit of beam loss**  
(450W, capacity of the MR collimator)

**Beam loss:**  
1msAveLoss+Acceleration loss  
Beam loss  
10usAveLoss+Acceleration loss

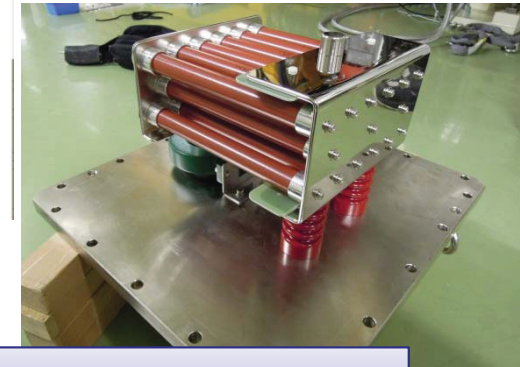
Beam power is limited by beam loss in the collimator section.

The periods shown in the dotted circle, beam power was limited another reason.

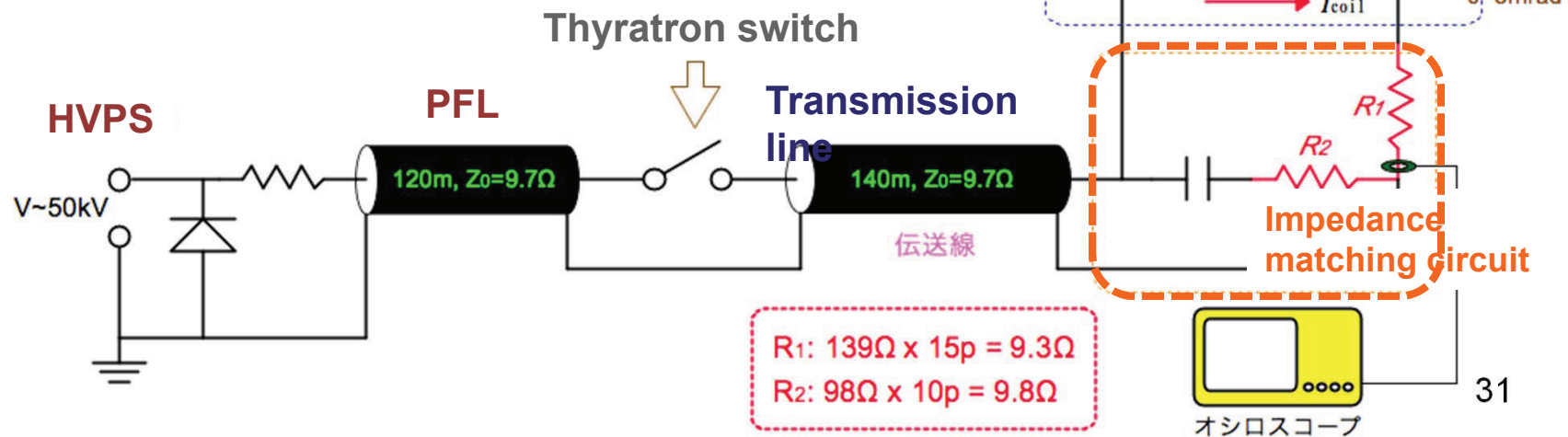
## Power limitation(1) : Deterioration of matching resistors



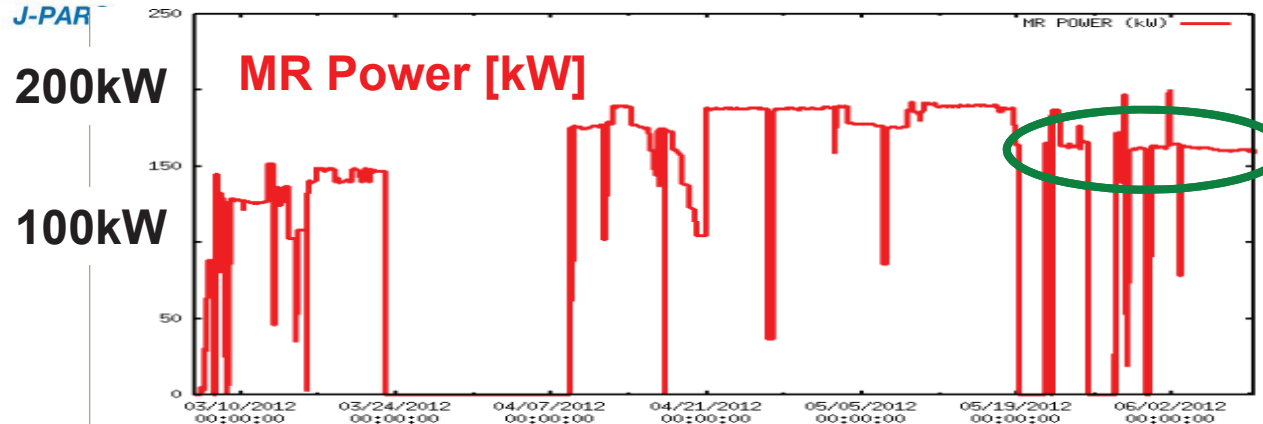
The beam power was limited by beam loss in the injection timing by deterioration of injection kicker performance due to discharge problem of matching resistors. The damaged resistors were replaced on the scheduled maintenance days and then, performance recovered.



Matching resistors 1

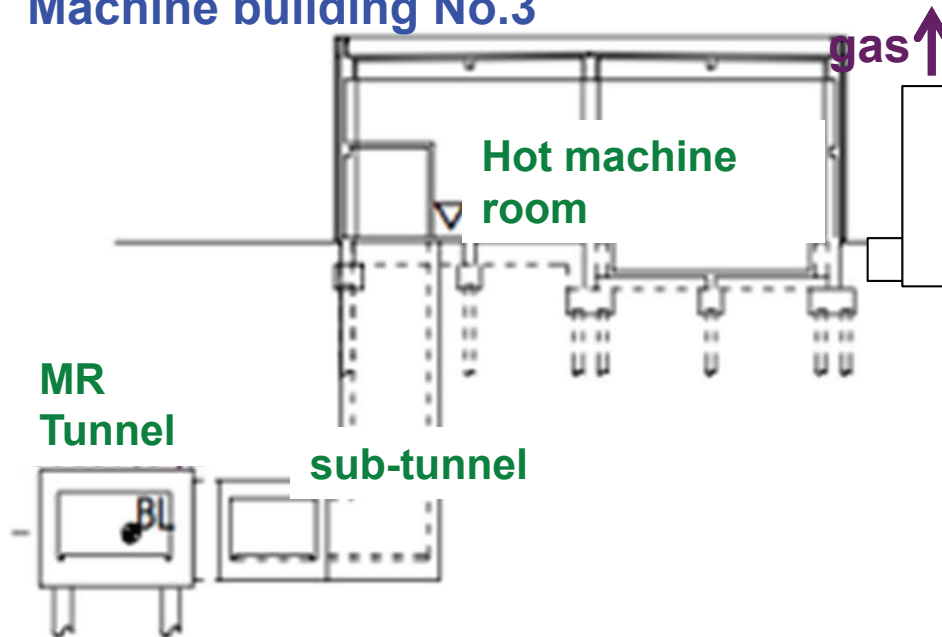


## Power limitation (2) : Radioactivity in exhaust gas



The beam power was limited to ~ 160 kW to suppress the radioactive level of the exhaust gas at the machine building No.3 of the MR .

### Machine building No.3

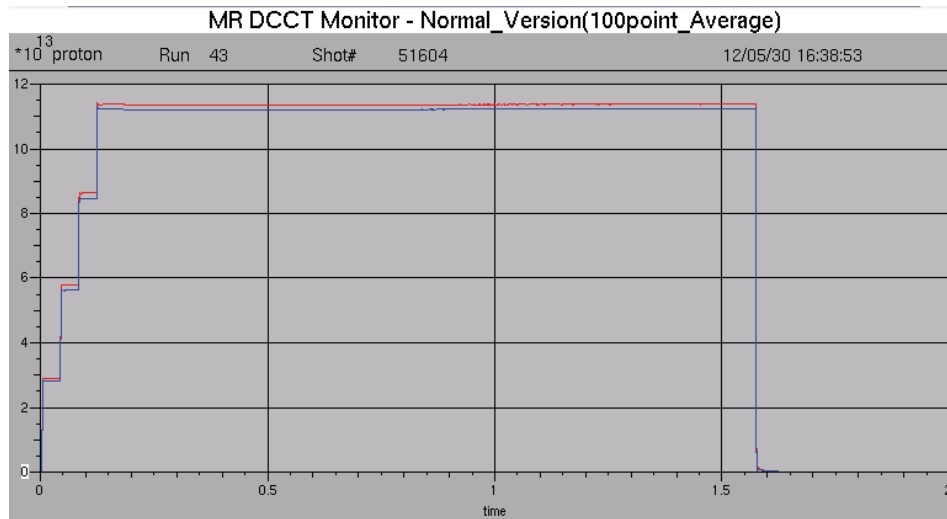


The averaged radioactive level in the exhaust gas becomes higher than 0.5mBq/cc (the permitted value by law) for > 180 kW operation.

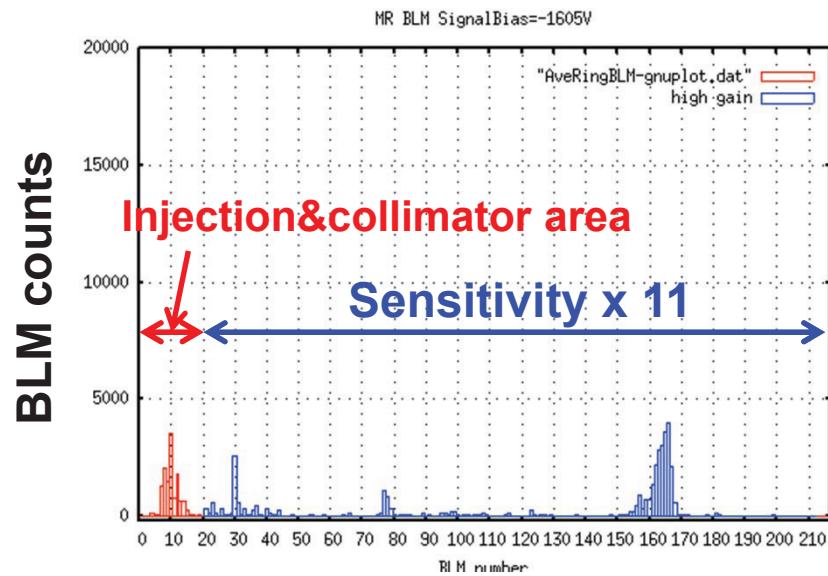
- Dampers of the air conditioner system are replaced by new ones which has a better airtightness.

Air conditioner system keeps negative pressure in the sub-tunnel during beam operation.

# Demonstration of 210 kW eq. beam operation



**Extracted beam is  $1.41 \times 10^{14}$  ppp  
~ 213 kW at 2.56 s cycle**



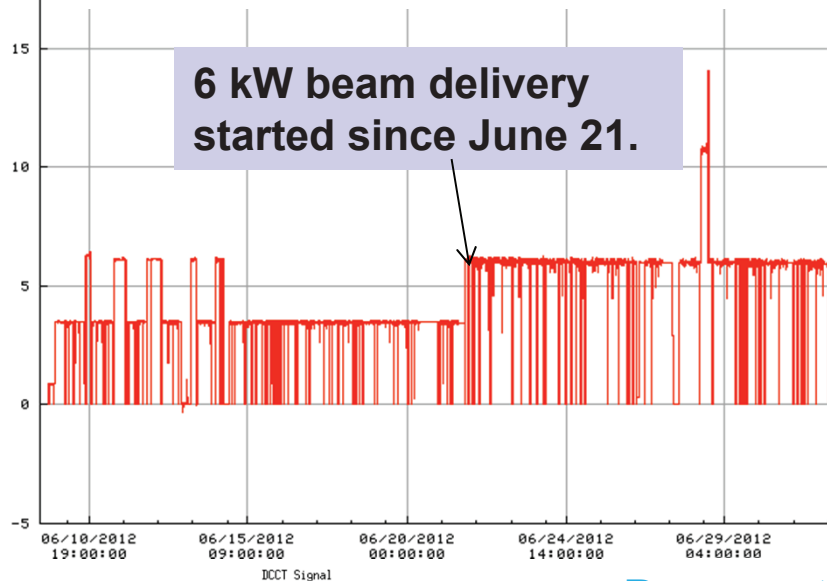
**Measured beam loss is 410 – 520  
W in the 210 kW operation.**





# Operation in SX mode

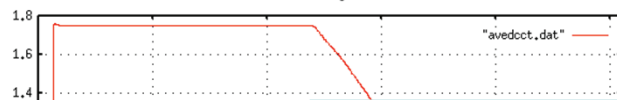
THO1C  
Yoichi Sato



2012/06/09-2012/07/02

MR cycle time is 6.0 s

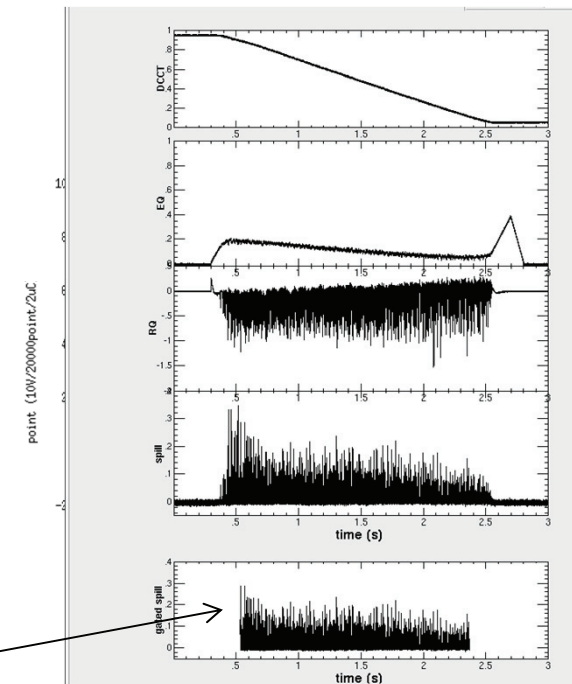
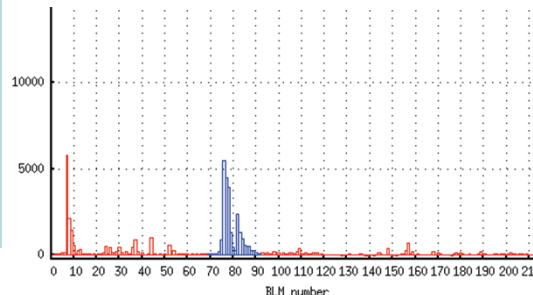
Typical efficiency ~99.5 %



Demonstration of 14 kW  
(1.7e13 ppp) operation

$$Duty = \frac{\left( \int_0^T I dt \right)^2}{\int_0^T dt \int_0^T I^2 dt}$$

$I(t)$ : PM signal  
sampled at 100KHz  
through 10KHz  
LPF  
 $t=0$ : spill start  
 $t=T$ : spill length



duty factor =  
Peak flatness of extracted  
beam

ave. efficiency 99.51%  
ave. duty factor 33.7%

User operation with a beam power > 10 kW beam  
can be started in the next run.

# *Summary*

In spite of difficult situation, we completed the recovery work in only nine months with sustained efforts of all J-PARC members.

In the operation of 6 months (January to June 2012) after the earthquake, J-PARC accelerator delivered the beam to the experimental facilities.

For the MLF,

- 120 - 200 kW beam delivered, 275 kW beam delivered in the last three days.

For the MR high power operation and beam delivery to the T2K experiment,

- 160 – 200 kW beam was delivered, 212 kW equivalent beam was demonstrated in single shot mode.
- User operation with a beam power > 210 kW beam can be started in the 2012 autumn/winter run.

For the HD,

- 3.5-6 kW beam was delivered with duty factor of ~30 % . Extraction efficiency was ~ 99.5 %.
- 14 kW equivalent beam was demonstrated in shingle shot mode. Efficiency was ~ 99.5 %.
- User operation with a beam power > 10 kW beam can be started in the 2012 autumn/winter run.