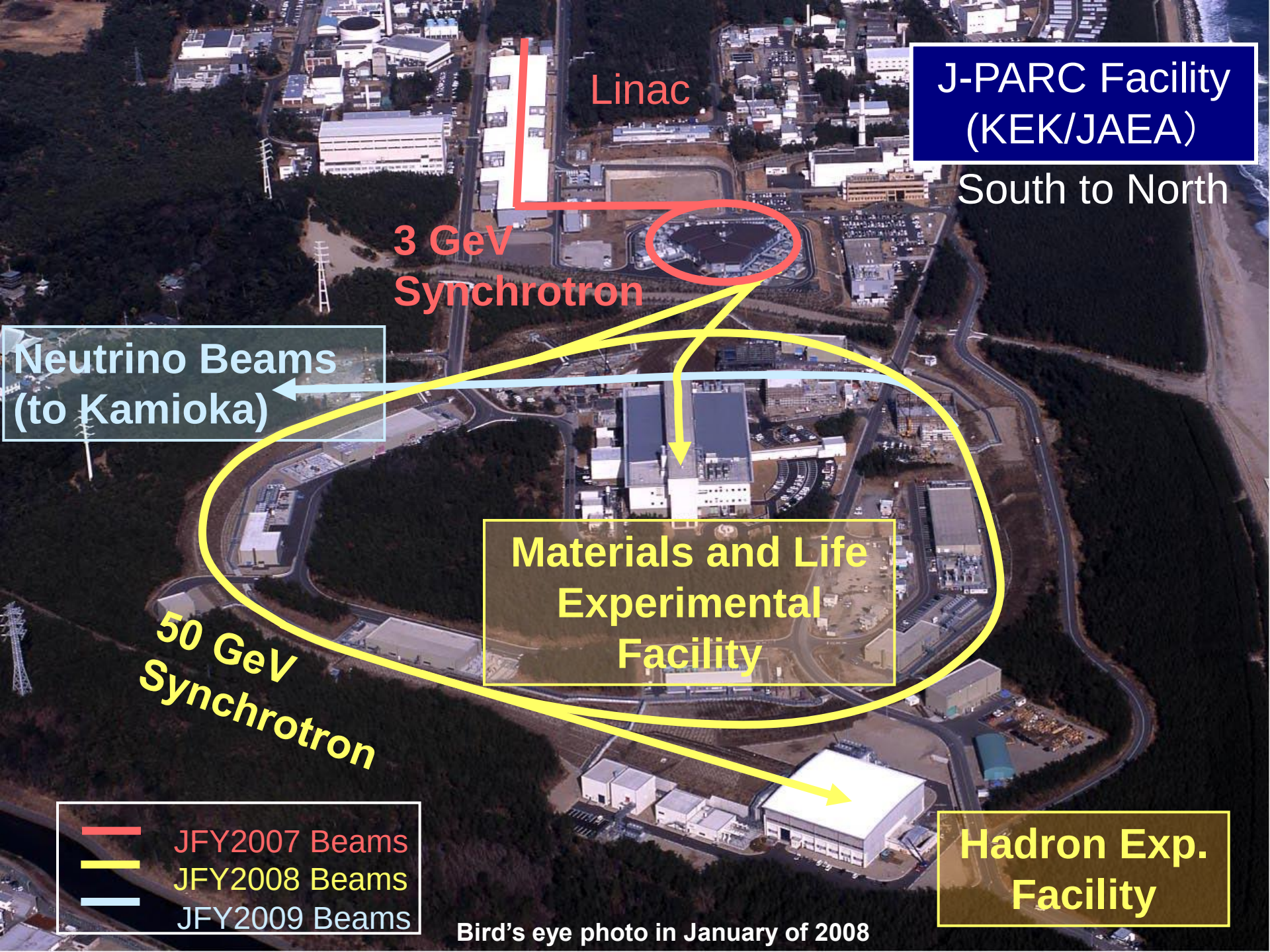
Status of J-PARC Recovered from the Earthquake

Michikazu KINSHO

J-PARC/ KEK&JAEA


Linac
J-PARC Facility
(KEK/JAEA)
South to North
3 GeV
Synchrotron
Neutrino Beams
(to Kamioka)
Materials and Life
Experimental
Facility
50 GeV
Synchrotron
JFY2007 Beams
JFY2008 Beams
JFY2009 Beams
Hadron Exp.
Facility
Bird's eye photo in January of 2008

Major events over the past several years

2008

2 Beam power of 5 kW/pulse (130 kW equiv.), 50 kW extracted at 3 GeV

3 Injection, RF capture and extraction with 3 GeV beams at MR (5/22)

4 Production of Neutrons (5/30)

5

6 Open House (8/10)

7 Beam power of 12 kW/pulse (300 kW equiv.), 210 kW extracted at 3 GeV

8 Production of Muons (9/26)

9

10 Acceleration of Beams to 30 GeV at the 50 GeV MR (12/23)

11 Neutrons + Muons: Beam Usage for General Users (12/23)

12 Extraction of the 30 GeV beams to the Hadron Experimental Hall (1/27)

2009

1 Production of Kaons (Feb.)

2

3 Production of Neutrinos (4/23)

4

5

6 Inauguration Ceremony in Tokyo Kudan-Kaikan (7/6)

7 Open House (8/1) ~4600 visitors

8

9

10 User operation with 3 GeV 120kW beam power; world record of Muon beam at MLF

11 First Neutrino event at On-Site Detector (11/22)

12 Operation with 300kW power for one hour(12/10)

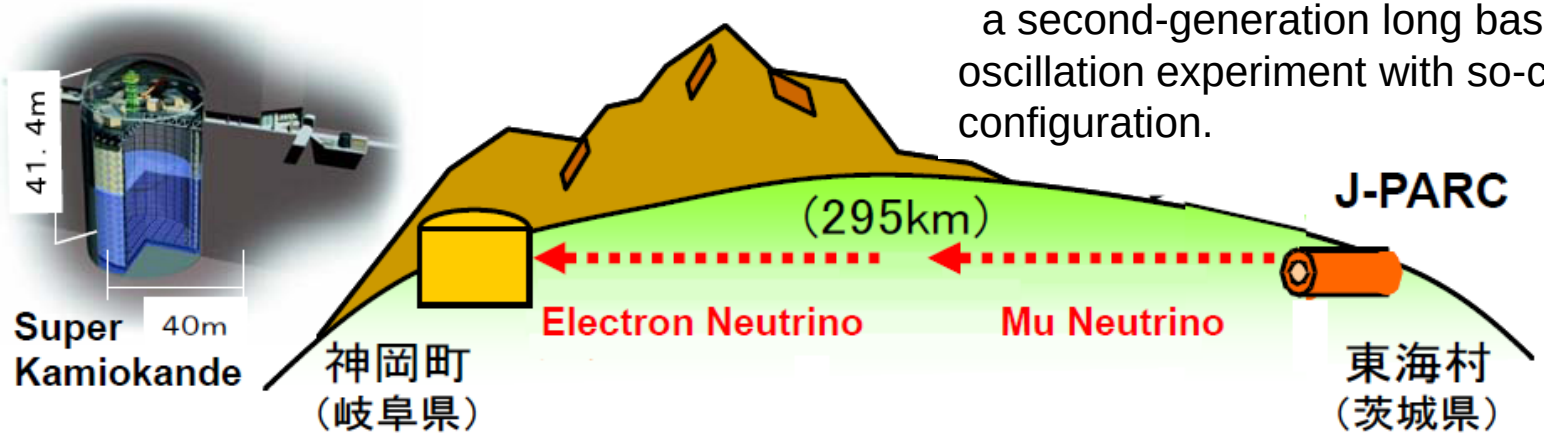
2010

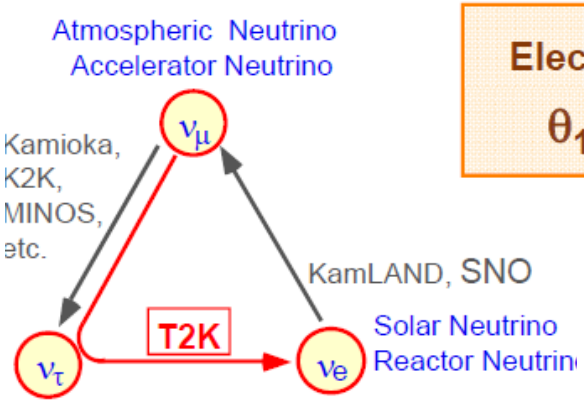
1 First Neutrino event at SuperKamiokanda (2/24)

2

Neutrino Oscillation (T2K) Experiment

T2K experiment :
a second-generation long baseline neutrino oscillation experiment with so-called off axis configuration.





Electron neutrinos ⟵ Mu neutrinos

θ_{13} ⟷ Mixing between the 1st and 3rd generation

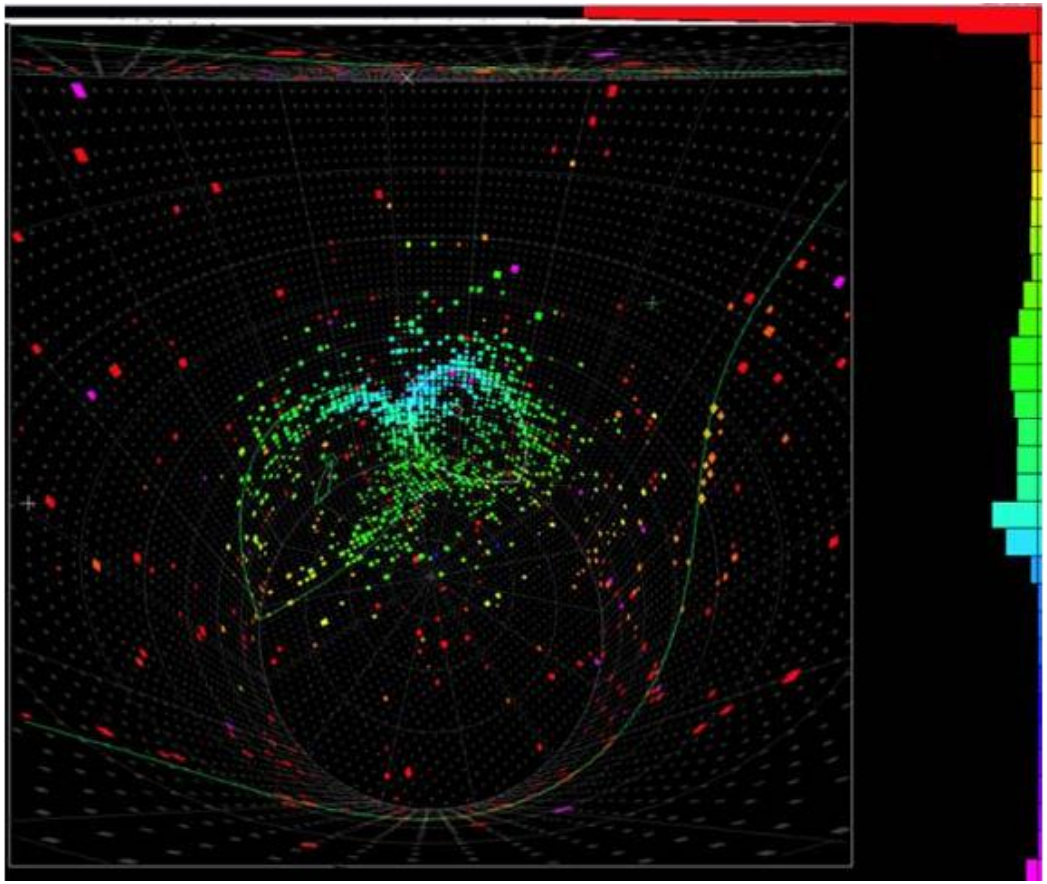
Muon neutrino beam is produced at J-PARC with 2.5 degrees off from the direction to the Super-Kamiokande (SK), travels 295 km across the earth, and is ditected by SK.

The off-axis beam gives us the highest possible intensity of low-energy neutrinos of interest with less high-energy tail, and enables precise measurements *with minimum background.*

The primary goal of the T2K experiment is to determine the last unknown neutrino mixing angle θ_{13} by investigating oscillation where muon neutrinos turn into electron neutrinos.

Goal is to measure $\sin^2 2\theta_{13}$ down to 0.01

Neutrino Detection at SK



First neutrino event measured by SK

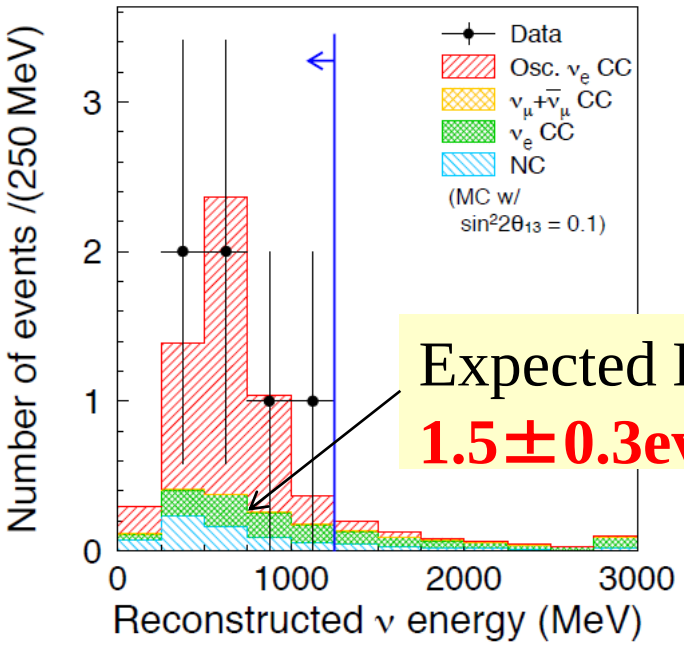
The first neutrino interaction at SK on the beam timing was observed on *February 24, 2010.*

This is one of the most important milestones for the T2K experiment. It also indicated that the timing synchronization between J-PARC and SK worked as expected.

Beam intensity has been increasing, the intensity is about *130kW* now. Many events have been observed so far.

Indication of ν_e appearance (non-zero θ_{13})

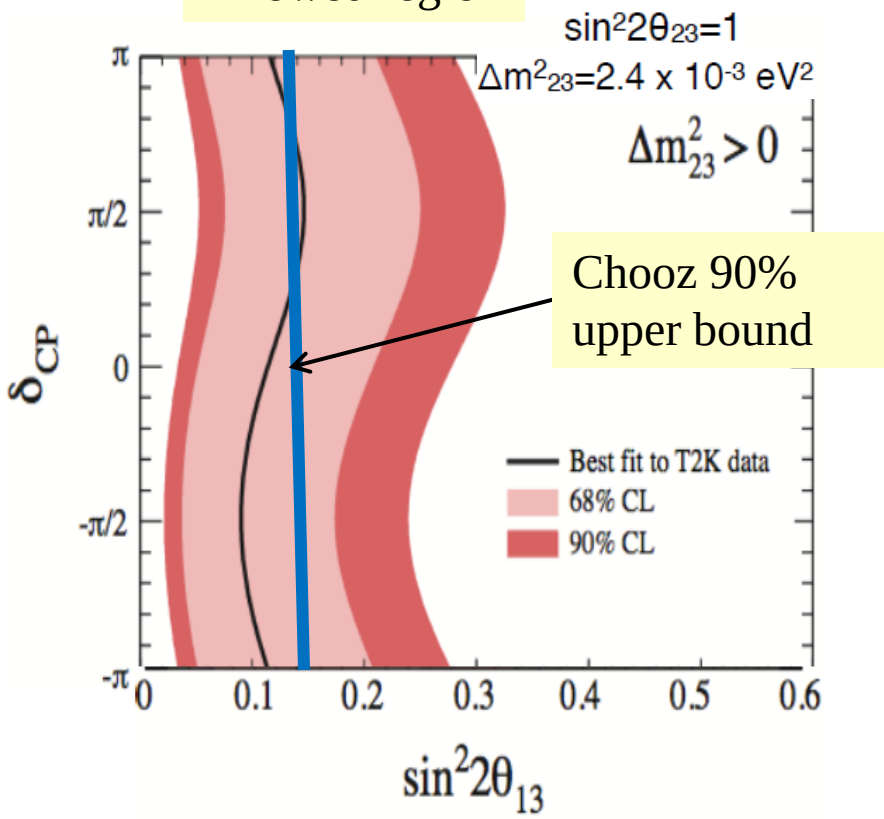
6 ν_e candidates found!



Expected BG
1.5±0.3evts

- Prob. of 6 are all BG: **0.7%**
  (2.5σ equiv)

Allowed region



($\Delta m_{23}^2<0$)

($\Delta m_{23}^2>0$)

$0.03 < \sin^2 2\theta_{13} < 0.28$ **90%CL range** **$0.04 < \sin^2 2\theta_{13} < 0.34$**

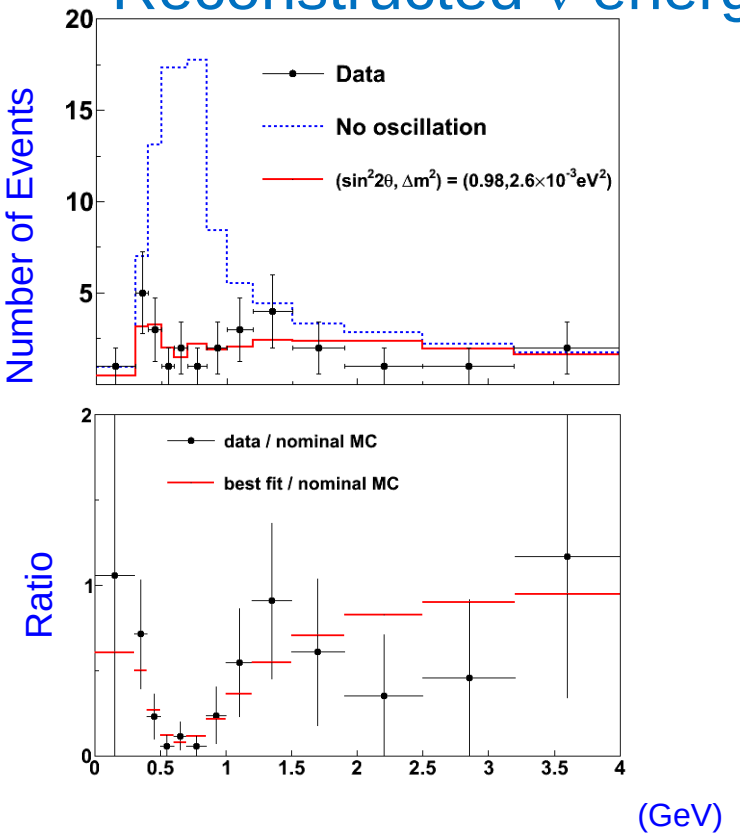
$\sin^2 2\theta_{13} = 0.11$ **Central value** **$\sin^2 2\theta_{13} = 0.14$**

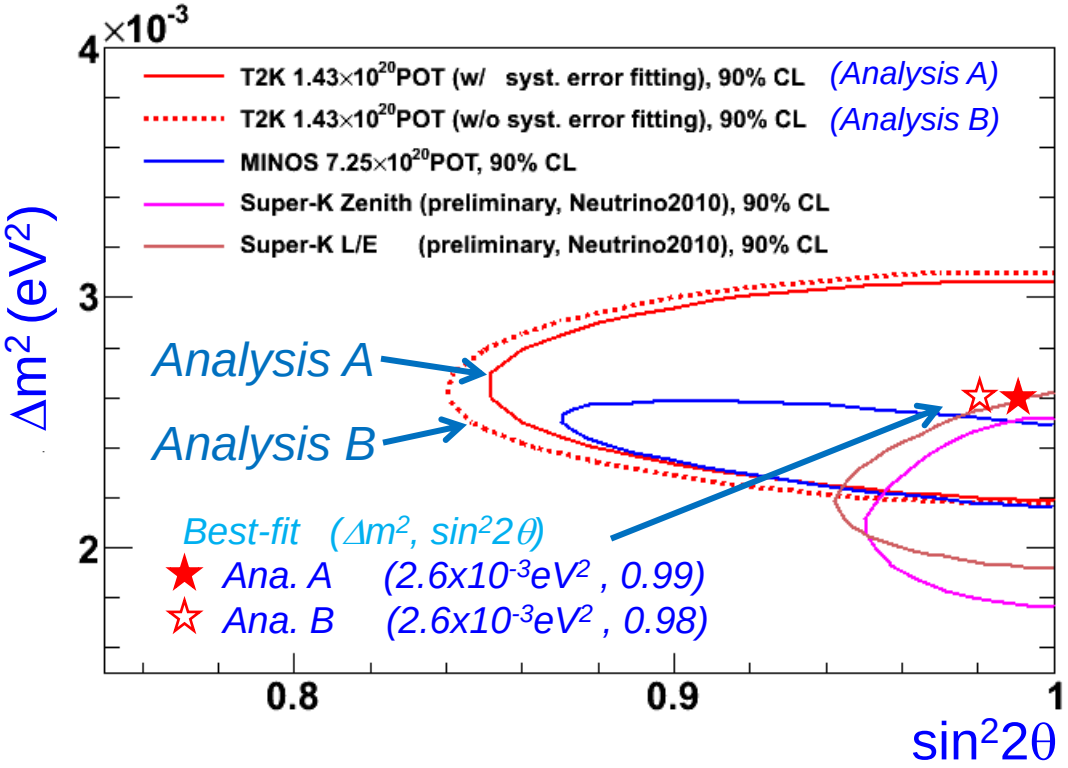
assuming $\Delta m^2_{23}=2.4 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{23}=1$, $\delta_{CP}=0$

Measurement of ν_μ disappearance (Δm_{23}^2, $\sin^2 2\theta_{23}$)

Single–μ ring events
- **104 events expected w/o osc**
- **31 events detected**

Reconstructed ν energ



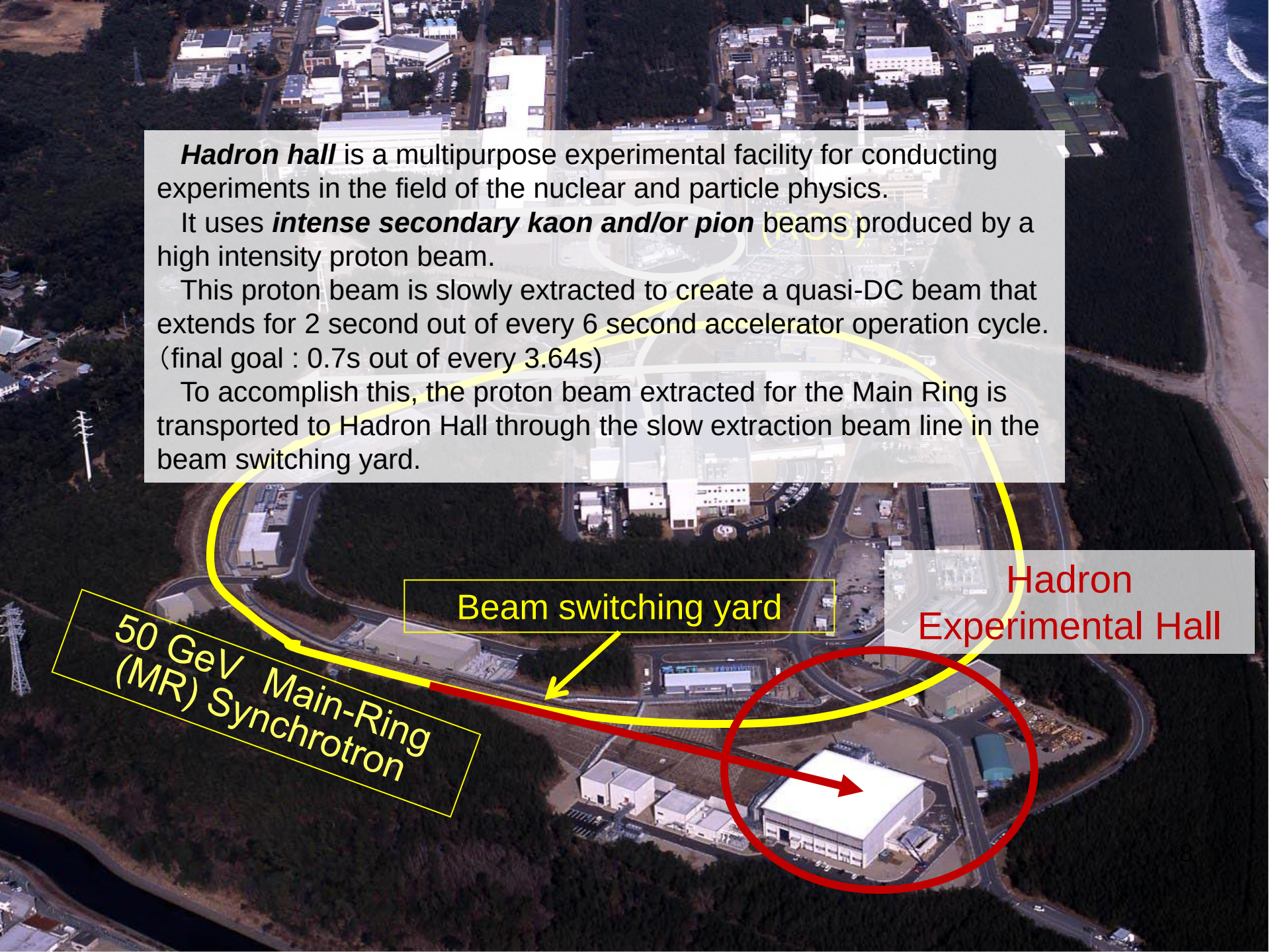


90% C.L. allowed region

	Δm^2 (eV^2)	$\sin^2(2\theta)$
Analysis A	2.1 ~ 3.1 x 10^{-3}	> 0.85
Analysis B	2.1 ~ 3.2 x 10^{-3}	> 0.84

Clear disappearance and oscillation pattern observed!!

Consistent with MINOS/SK results



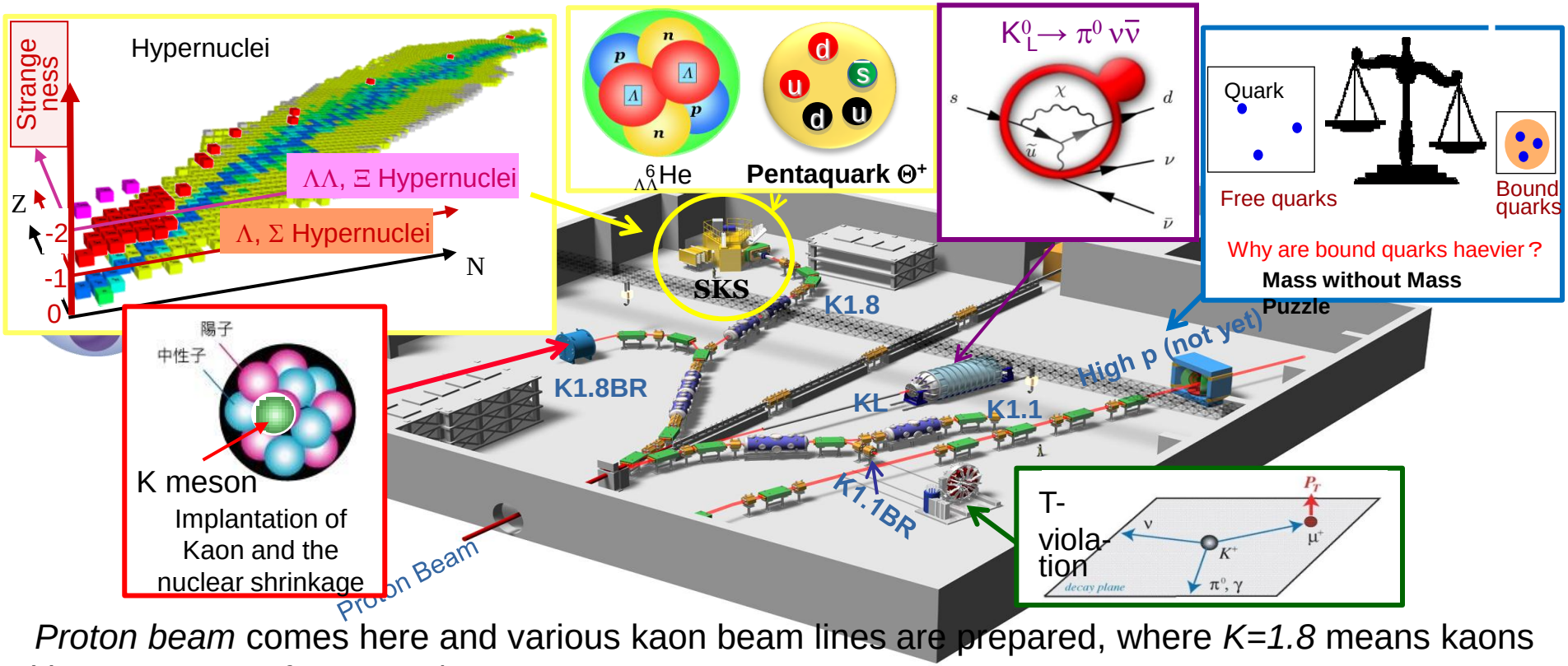
Hadron hall is a multipurpose experimental facility for conducting experiments in the field of the nuclear and particle physics.

It uses ***intense secondary kaon and/or pion*** beams produced by a high intensity proton beam.

This proton beam is slowly extracted to create a quasi-DC beam that extends for 2 second out of every 6 second accelerator operation cycle.（final goal : 0.7s out of every 3.64s)

To accomplish this, the proton beam extracted for the Main Ring is transported to Hadron Hall through the slow extraction beam line in the beam switching yard.

Nuclear & Hadron Physics at J-PARC



Proton beam comes here and various kaon beam lines are prepared, where *K=1.8* means kaons with momentum of *1.8 GeV/c*.

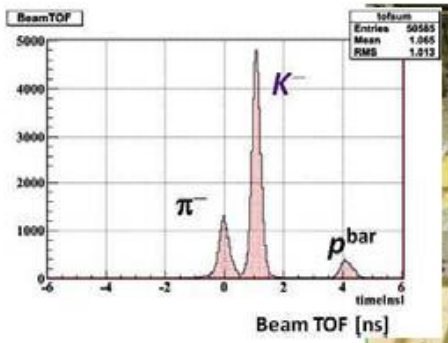
At SKS, hypernuclear spectroscopy will be performed for a variety of nuclei.

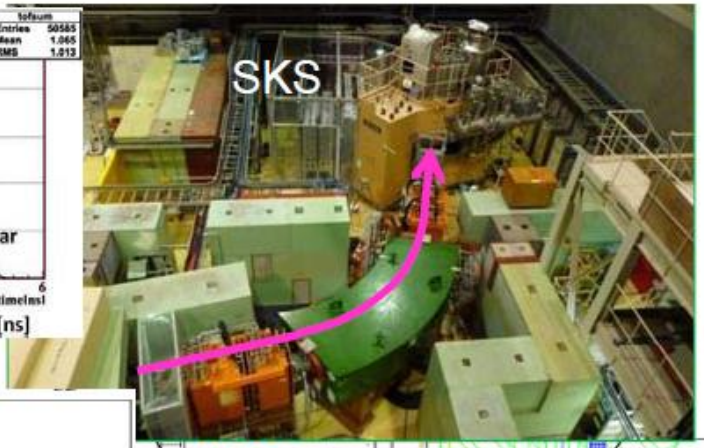
In particular, searches for *double hypernucleus* and *pentaquark* are the highlights in here.

K1.8BR beamline, kaon implantation is planned. When kaon is implanted inside the nucleus, there is a possibility that high density matter is created. Kaonic atom and kaonic nucleus will be studied.

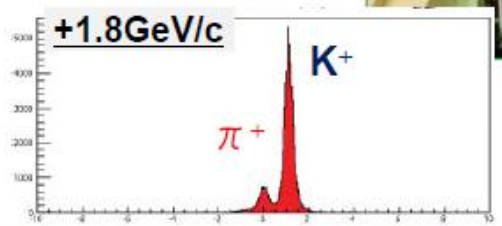
KL beam line is the neutral kaon line to study CP violation, and *K1.1 BR* line is for T-violation experiment.

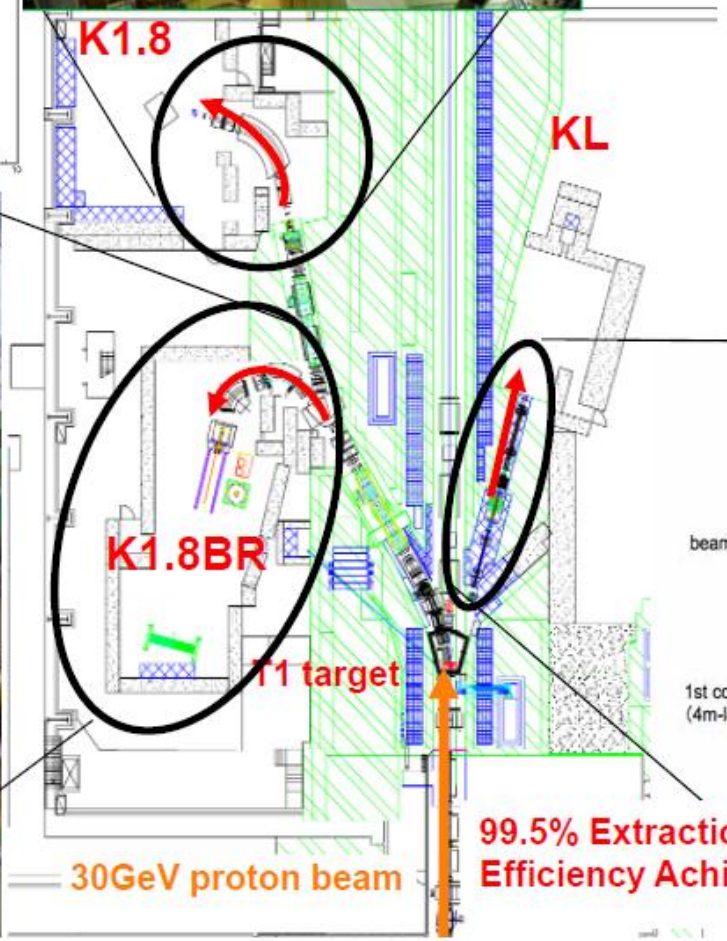
High p line, which is not yet completed, is dedicated to the study of chiral symmetry, namely, the mass generation mechanism of bound quarks.

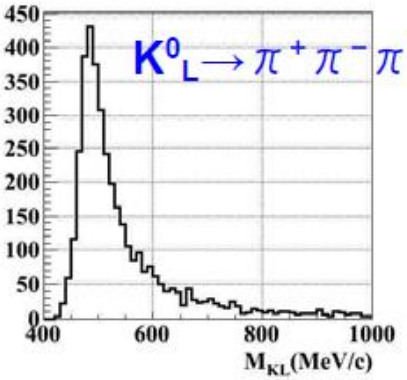


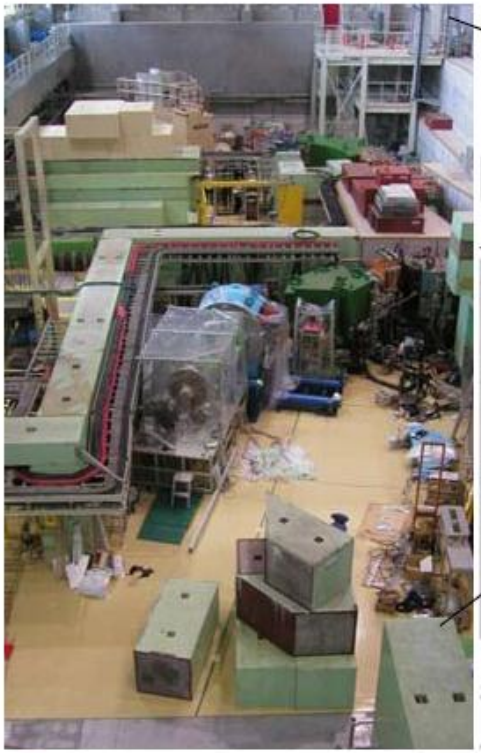


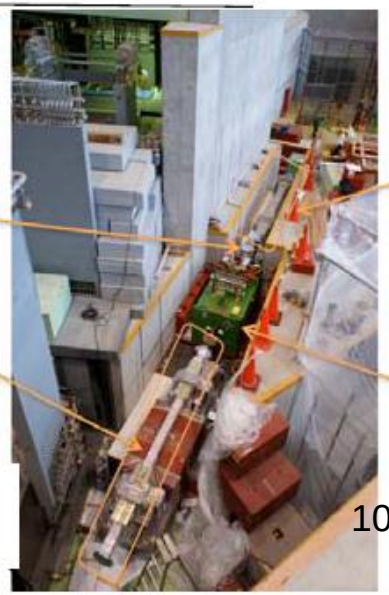
We have observed charged and neutral kaons in the secondary beam lines (**K1.8BR**, **K1.8** and **KL**) of Hadron Experimental Hall.





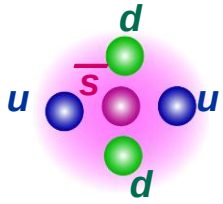




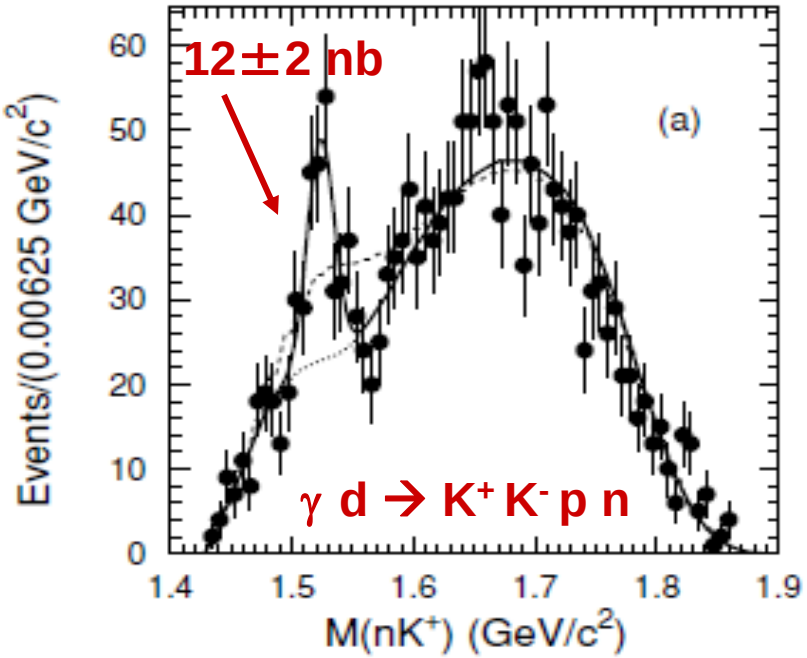


E19 (Naruki et al.)
Search for Pentaquark Θ^+ in $\pi^- p \rightarrow K^- X$ reaction

Physics Motivation



- positive evidences at low energy (LEPS, etc.)
- very narrow width ~ 1 MeV. Why?
- negative results at high energy

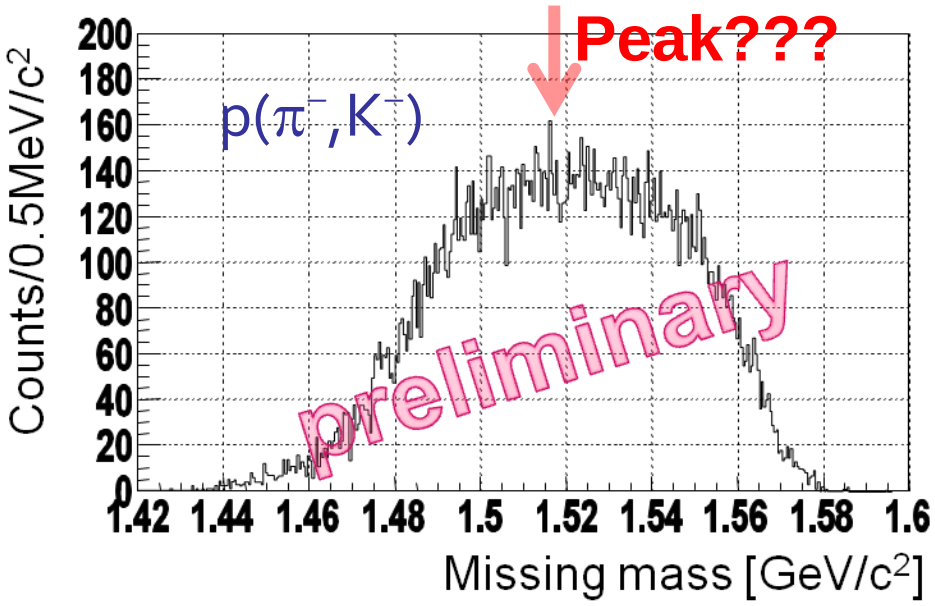


T. Nakano et al.,PRC79 (2009) 025210

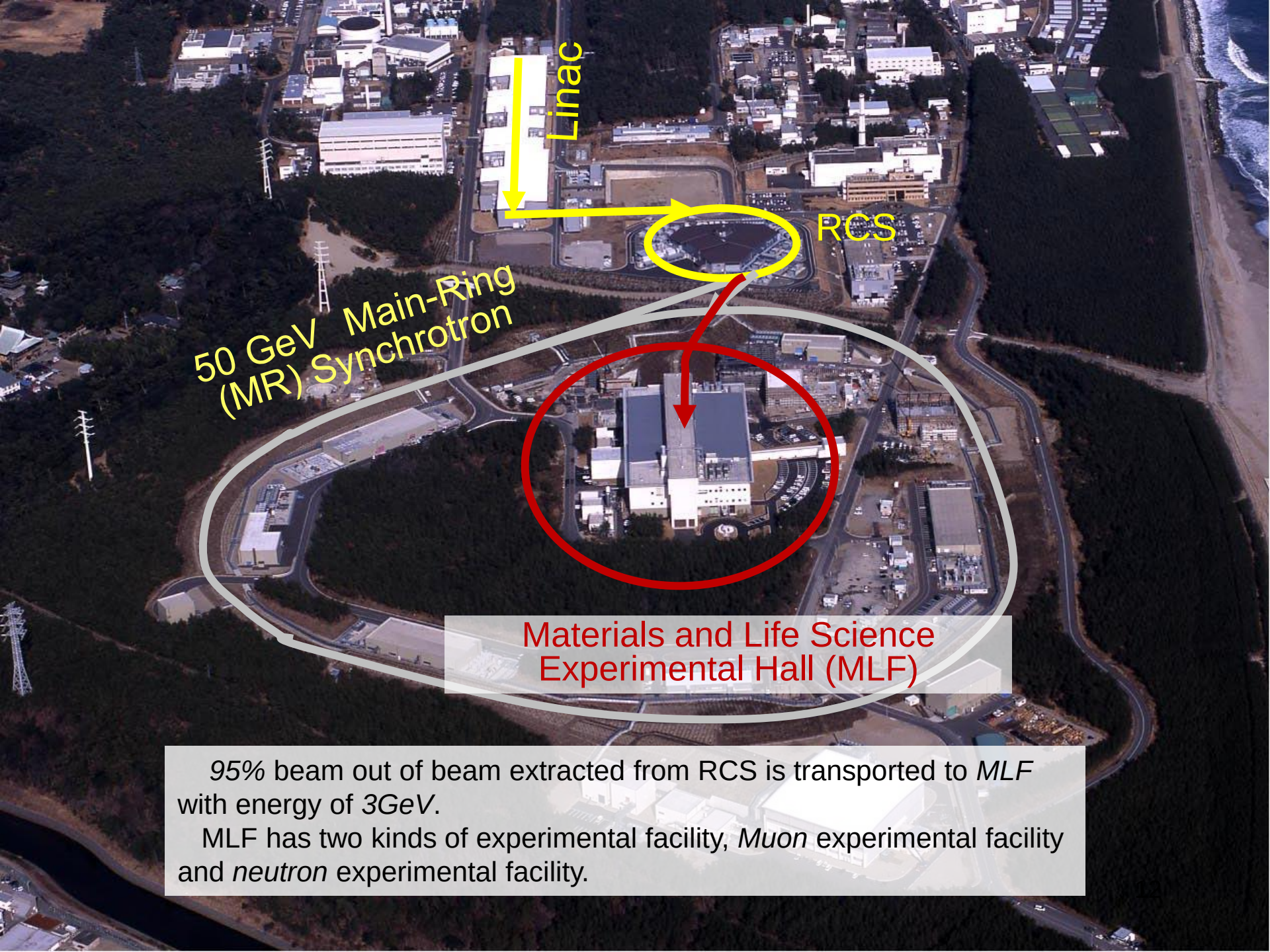
J-PARC E19

- Hadronic "direct reaction"

  $\pi^- + p \rightarrow K^- + X$
- Previous (π^-, K^-) missing mass spectrum shows a hint of 2.6σ.



$K^+ + n$ Experiment to produce directly Θ^+ must be done.

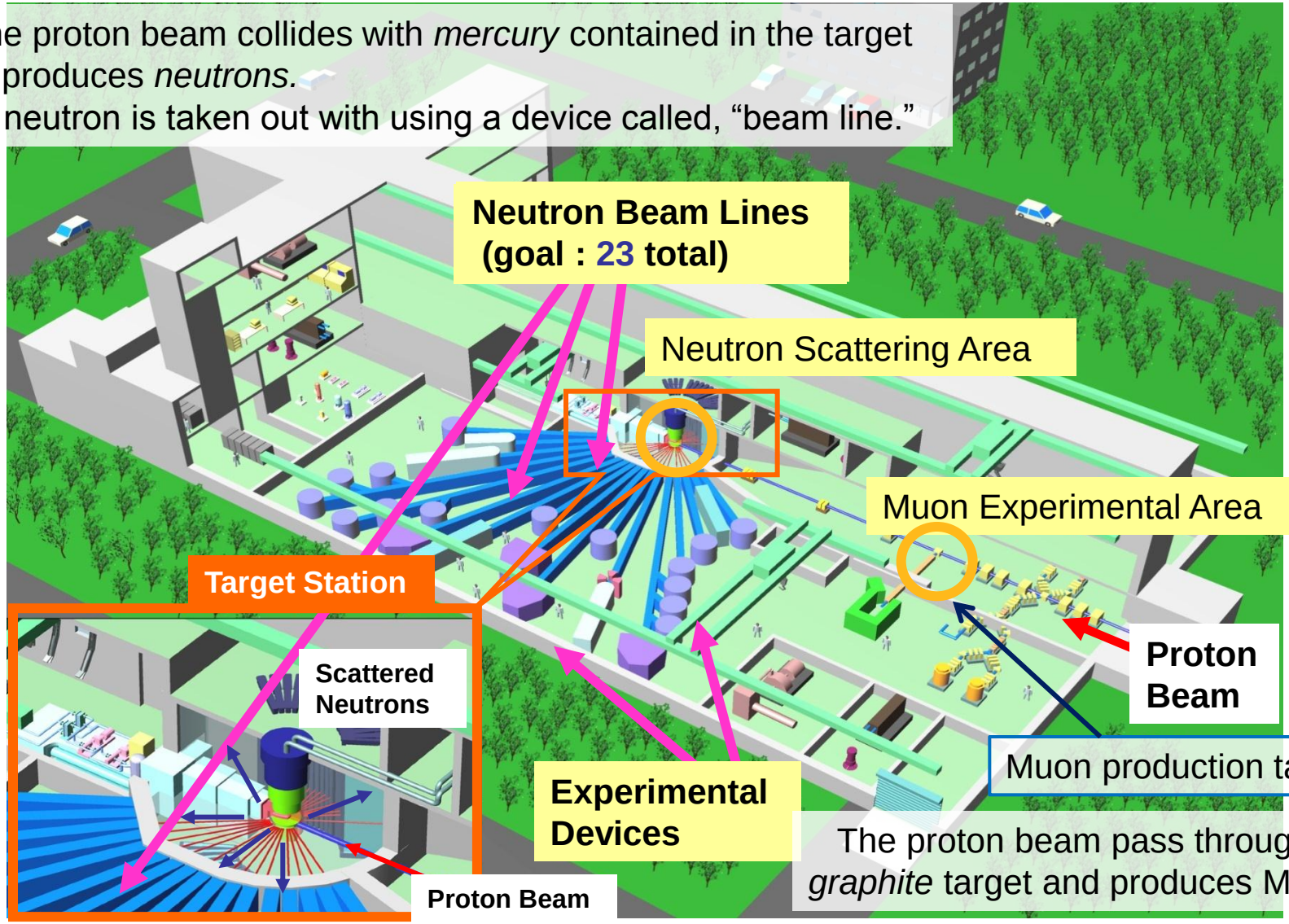


95% beam out of beam extracted from RCS is transported to *MLF* with energy of *3GeV*.

MLF has two kinds of experimental facility, *Muon* experimental facility and *neutron* experimental facility.

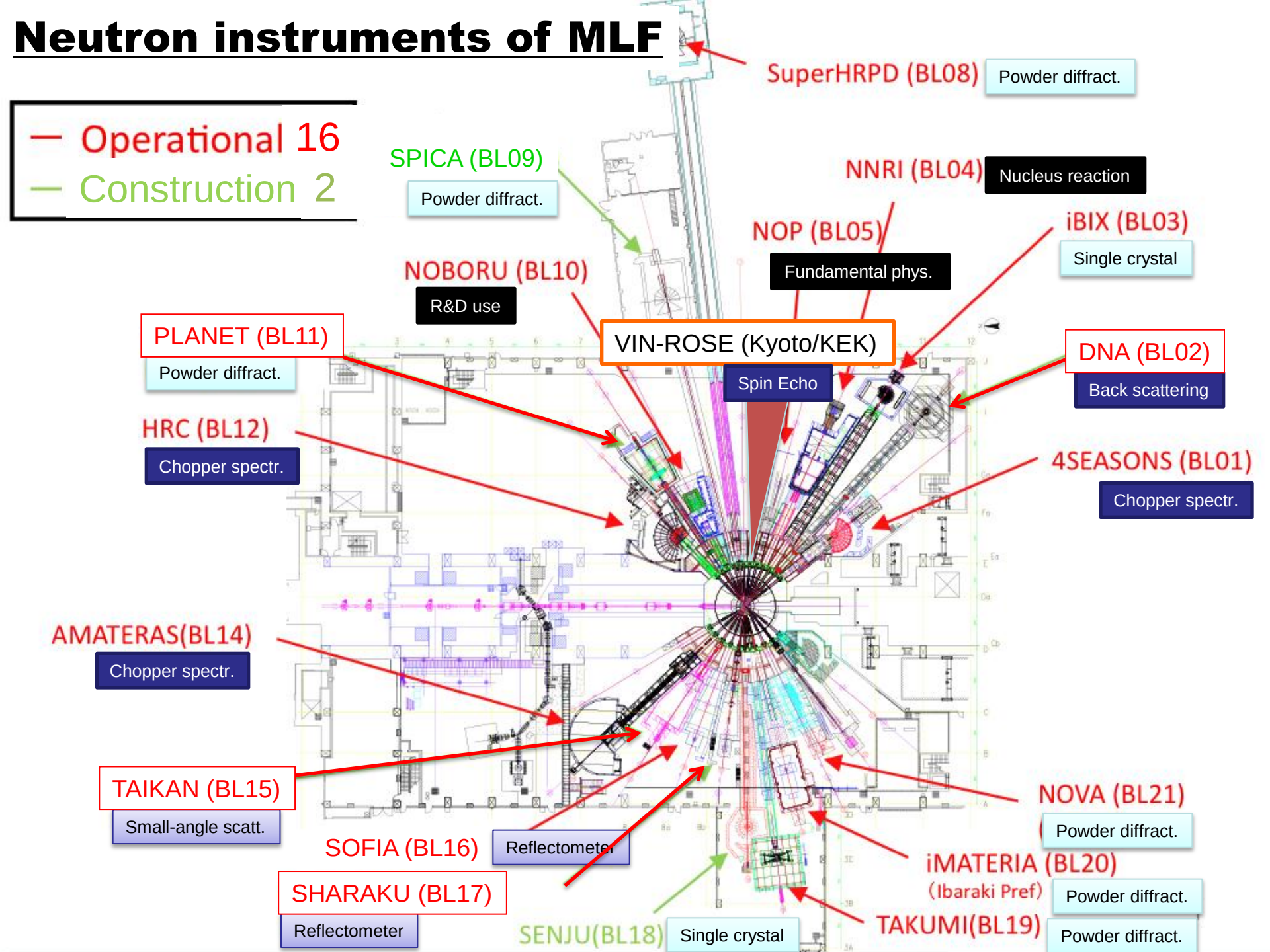
Materials & Life Experimental Facility

The proton beam collides with *mercury* contained in the target and produces *neutrons.*
The neutron is taken out with using a device called, “beam line.”



Neutron instruments of MLF

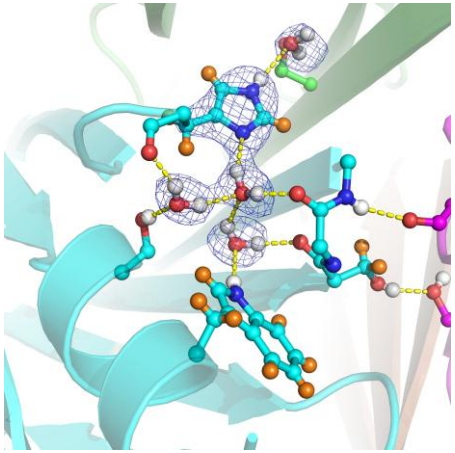
— Operational 16
— Construction 2



Recent Results

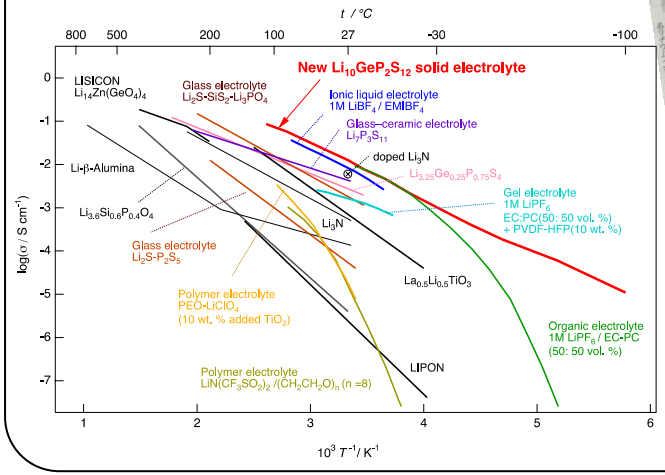
Determination of the position of hydrogen in transthyretin associated with human amyloidosis

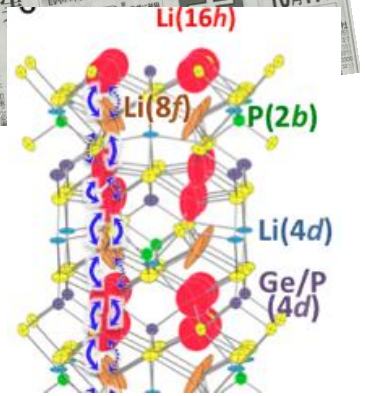
J. Str. Bio., 2011
iBIX (BL03)



Highest Li conductivity of a super-ionic conductor $Li_{10}GeP_2S_{12}$

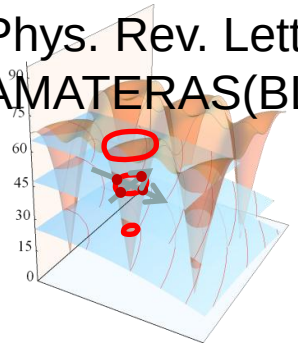
Nature Materials 2011
Super-HRPD (BL08)

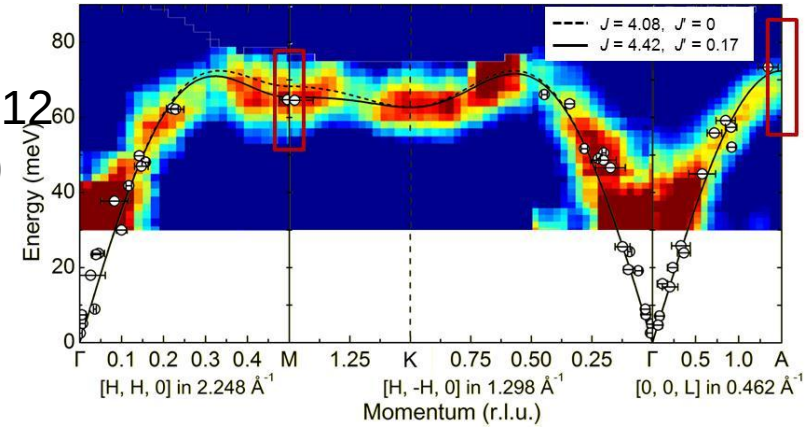




Full dispersion curve of $BiFeO_3$ to explore magneto-electric coupling

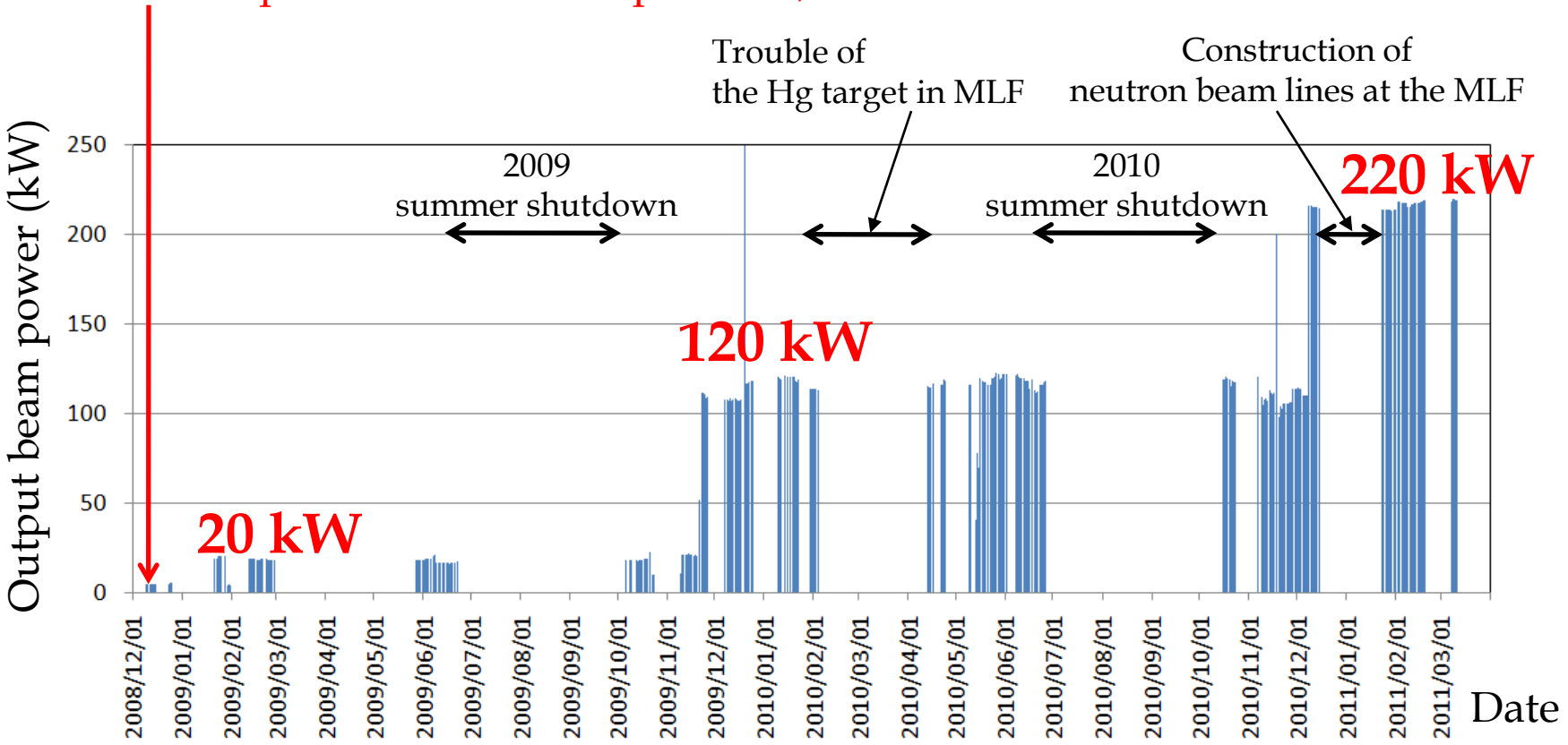
Phys. Rev. Lett. 2012
AMATERAS(BL14)





History of the RCS output beam power to the MLF

- Beam commissioning of the linac ; November 2006~
- Beam commissioning of the RCS ; October 2007~
- Startup of the MLF user operation ; December 2008~

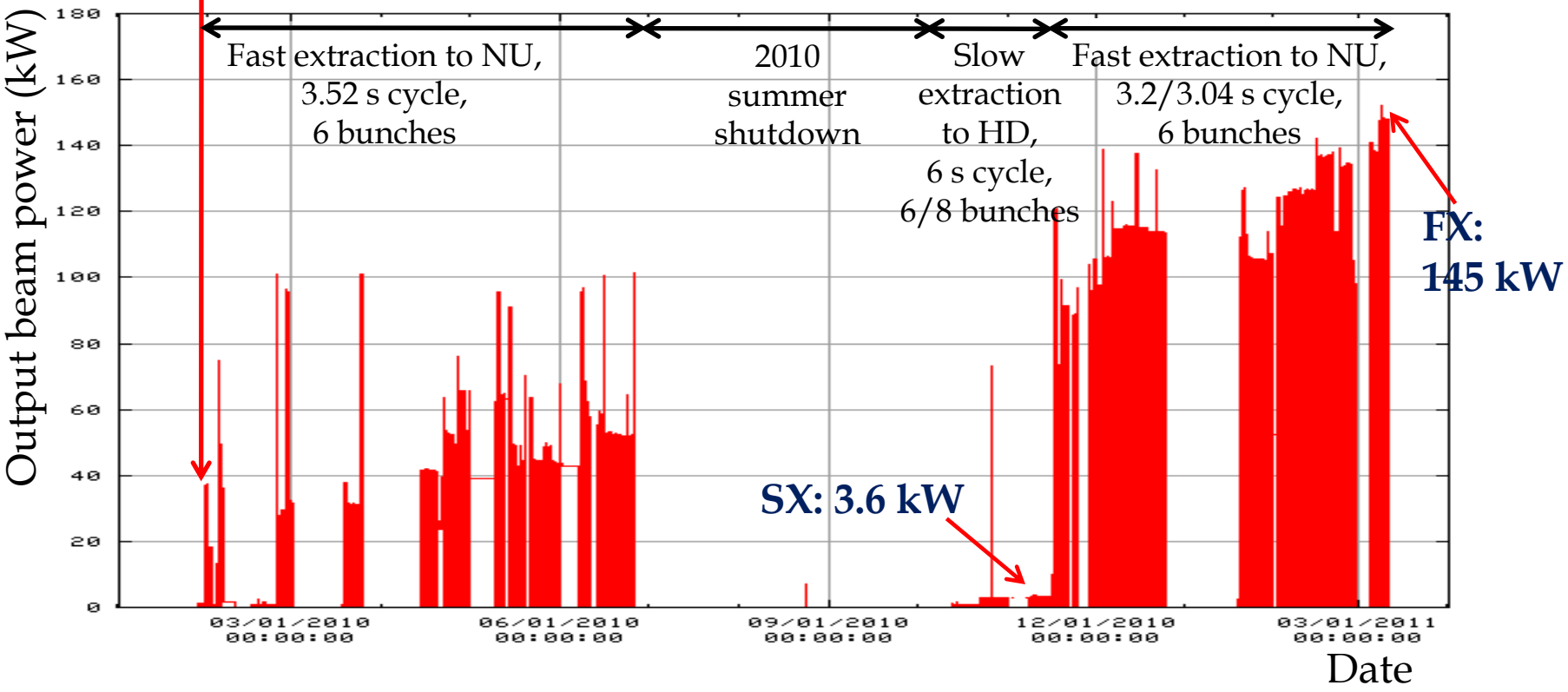


The output beam power to the MLF has been steadily increased following;

- Progression of beam tuning,
- Hardware improvements,
- Careful monitoring of the trend of residual activation levels.

History of the MR output beam power

- Beam commissioning of the MR ; May 2008~
- Startup of the NU user operation ; January 2010~



The output beam power of the MR has been also steadily increased following;

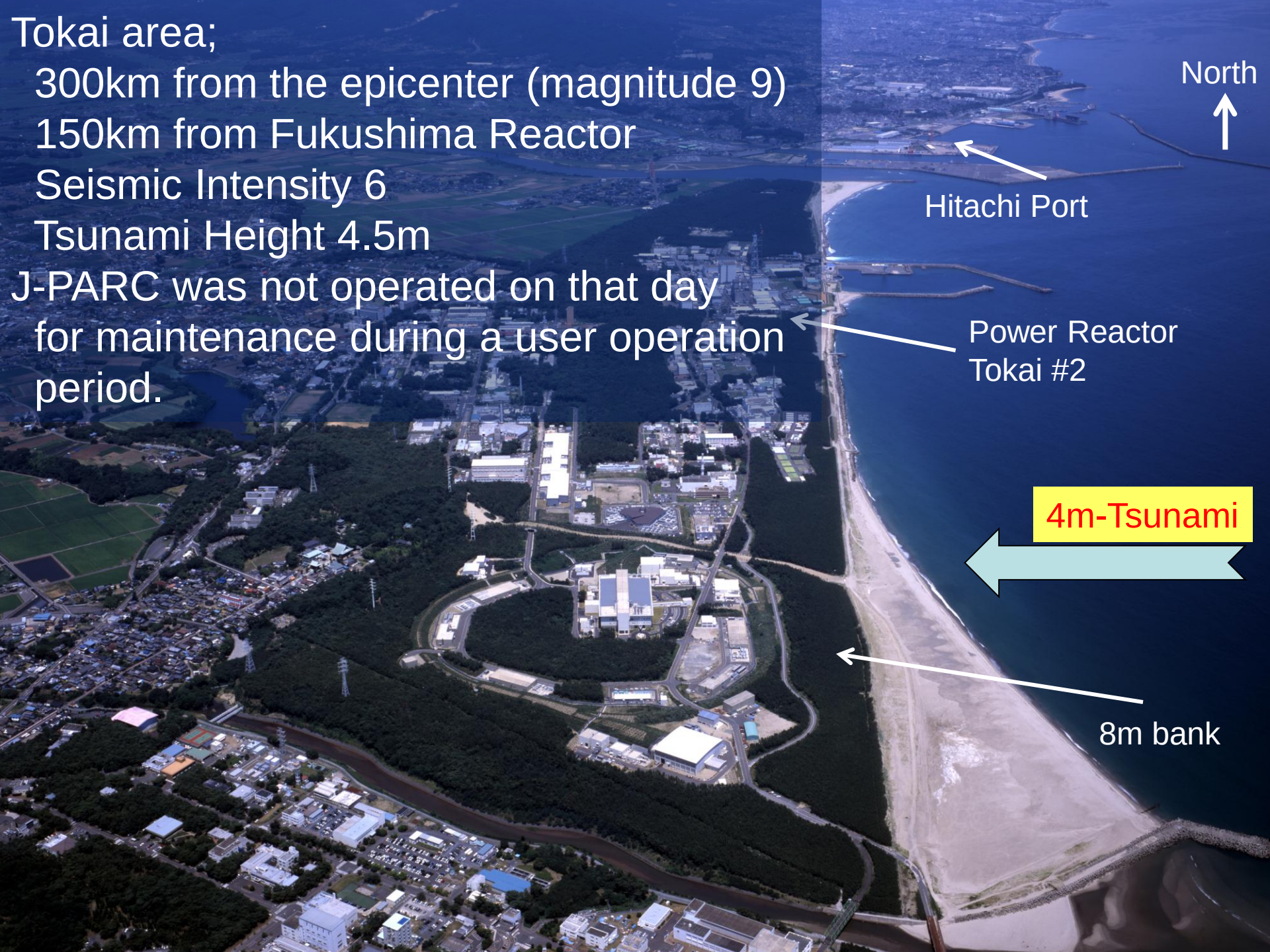
- Progression of beam tuning,
- Hardware improvements,
- Careful monitoring of the trend of residual activation levels.

March 11, 2011

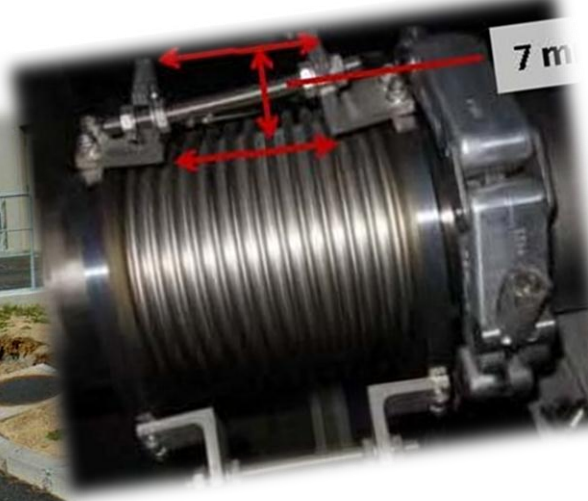
The run cycle of Run#38 began on March 2, and beam delivery to neutrino users at ***145kW*** and to MLF users at ***220kW*** started on March 4 and March 7, respectively.

In the morning on March 11,
the beam operation of **the RCS** and **the MR** was stopped for the radiation survey in the accelerator tunnels as scheduled.
Meanwhile the beam study had been carried out in **the LINAC**.

The earthquake occurred when the beam was stopped temporarily to shift the beam destination from the LINAC to the RCS. The beam was stopped as it was and.

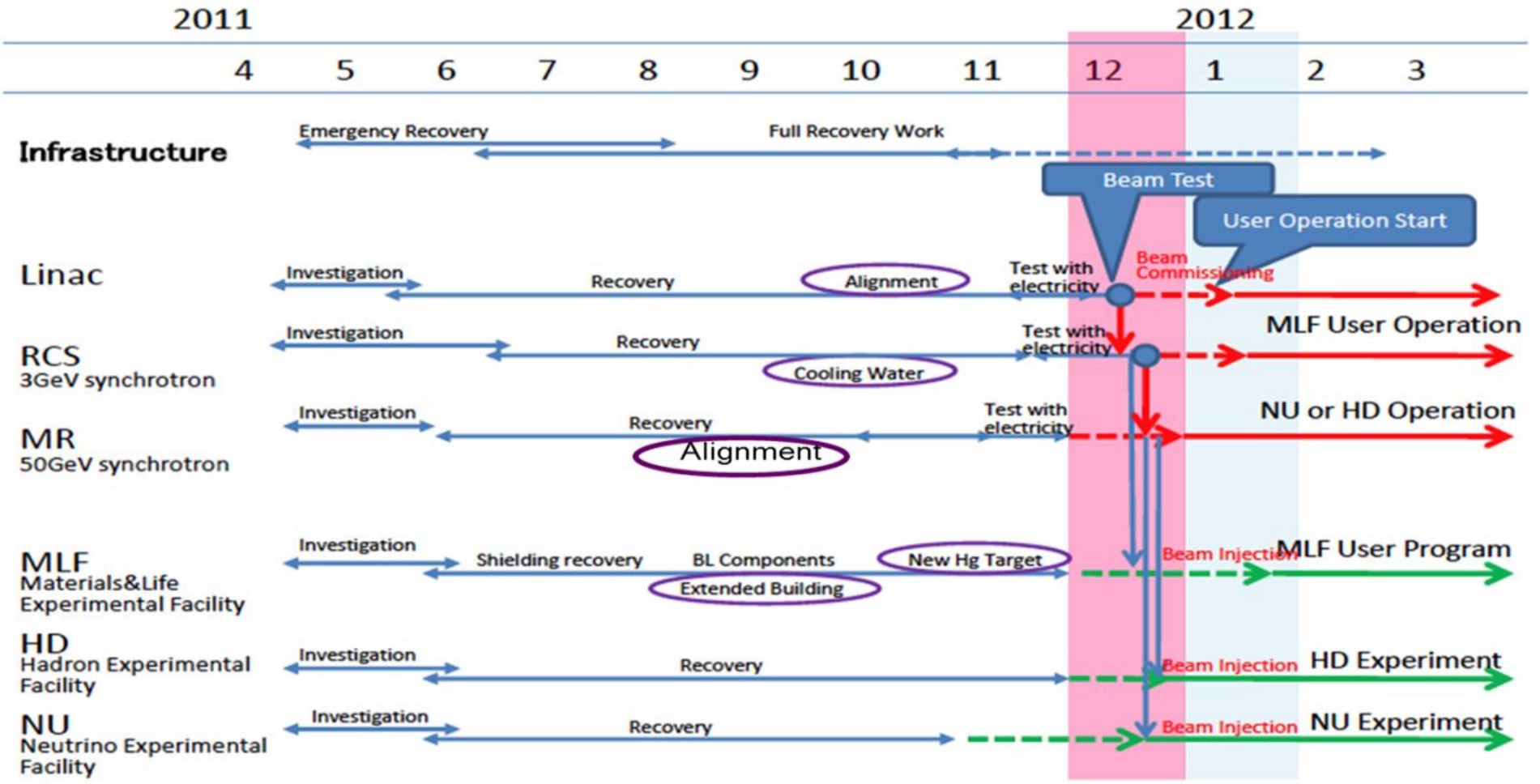

Tokai area;
300km from the epicenter (magnitude 9)
150km from Fukushima Reactor
Seismic Intensity 6
Tsunami Height 4.5m
J-PARC was not operated on that day for maintenance during a user operation period.
North
Hitachi Port
Power Reactor
Tokai #2
4m-Tsunami
8m bank

Damages in J-PARC



Recovery Schedule

@May 20, 2011



- We released a recovery schedule in May 2011.
  - Start beam tuning from December.
  - Restarted user program of 44 days by the end of March 2012.

Neutrino Experimental Facility

Immediately after the Earthquake

AC device tilted toward a depression of a road. Many pipes were damaged

Repairing roads and plumbing have been completed.

Realignment work of electromagnets (above) and superconducting magnets (below) is progressing smoothly. We also try to improve cooling power.

Hadron Experimental Facility

Immediately after the Earthquake

Repairing roads and plumbing have been completed.

Materials & Life Science Experimental Facility (MLF)-1

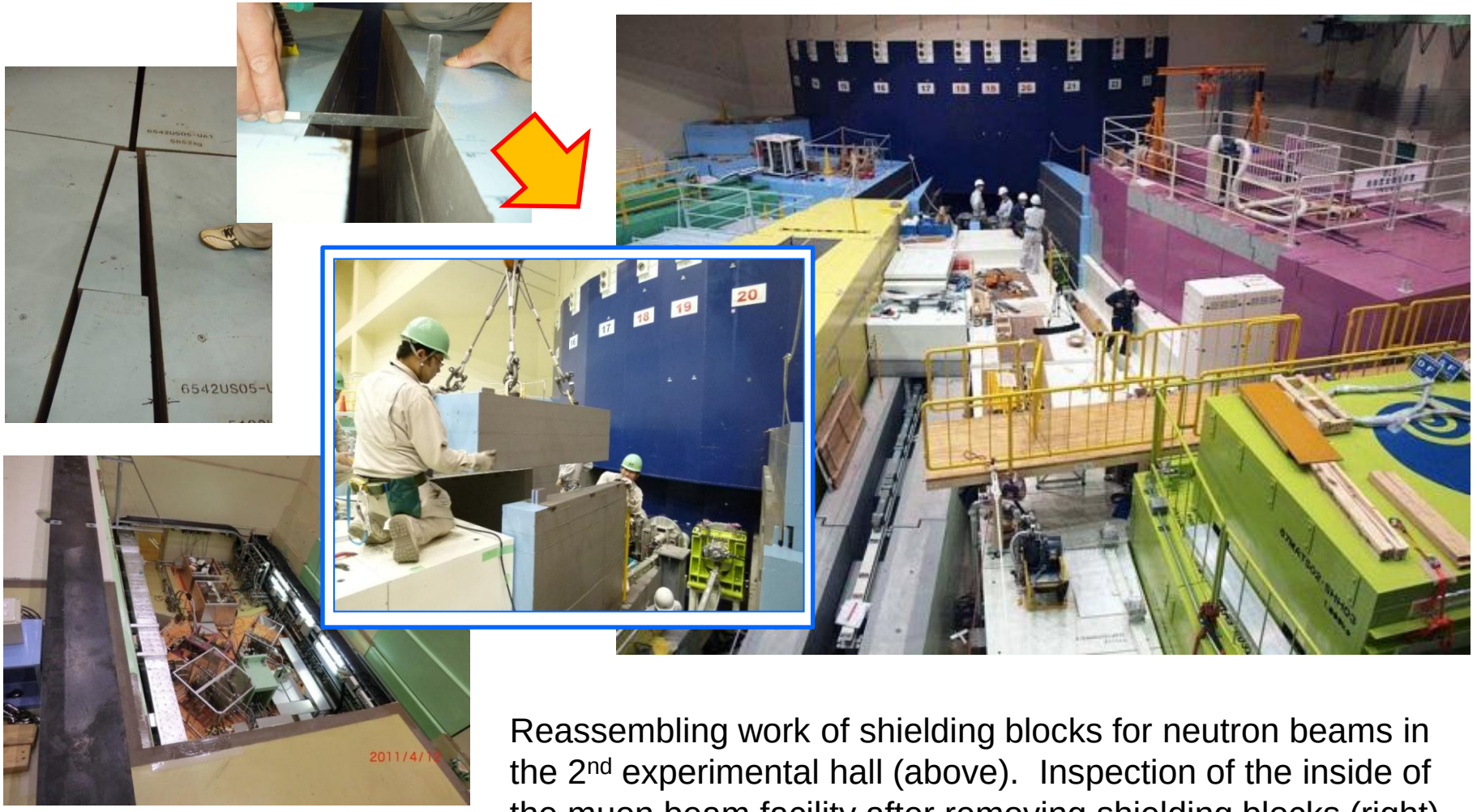
The road was re-opened after filling depressions with pebbles.

A tilted He tank was removed to repair the foundation.

Inspection by the fire department

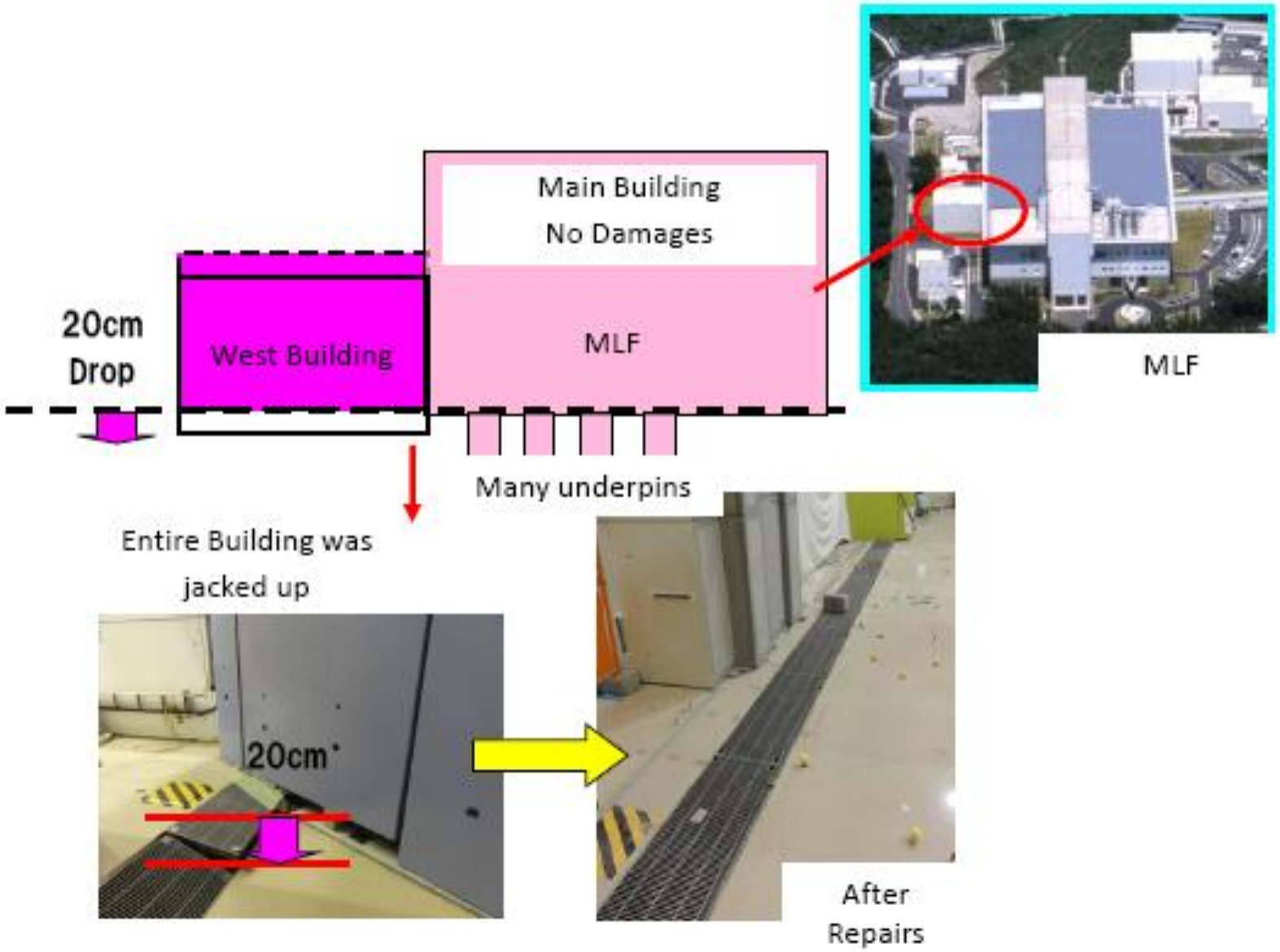
Materials & Life Science Experimental Facility (MLF)-2

Immediately after the Earthquake

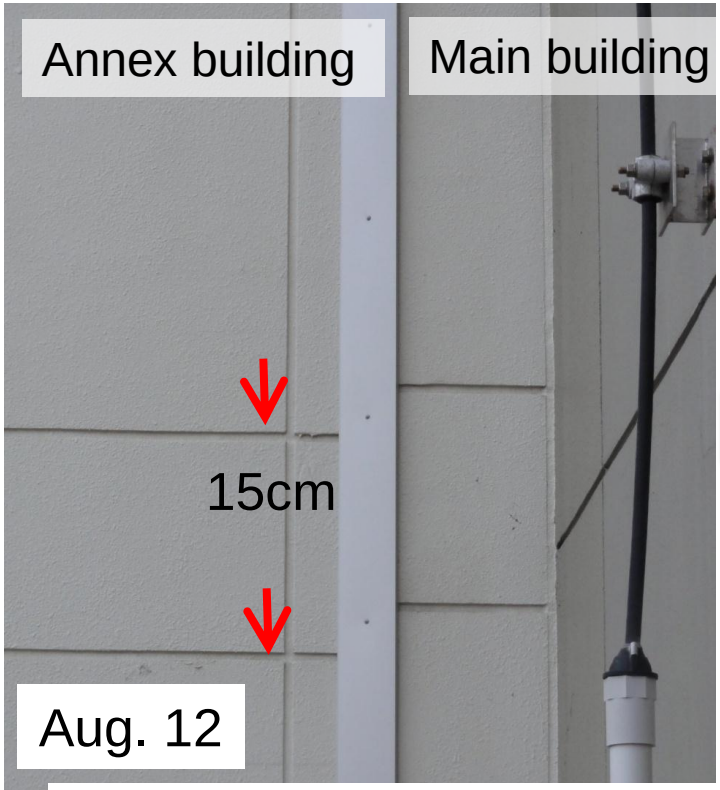


Reassembling work of shielding blocks for neutron beams in the 2nd experimental hall (above). Inspection of the inside of the muon beam facility after removing shielding blocks (right). This area does not have any serious damage.

Materials & Life Science Experimental Facility (MLF)-3

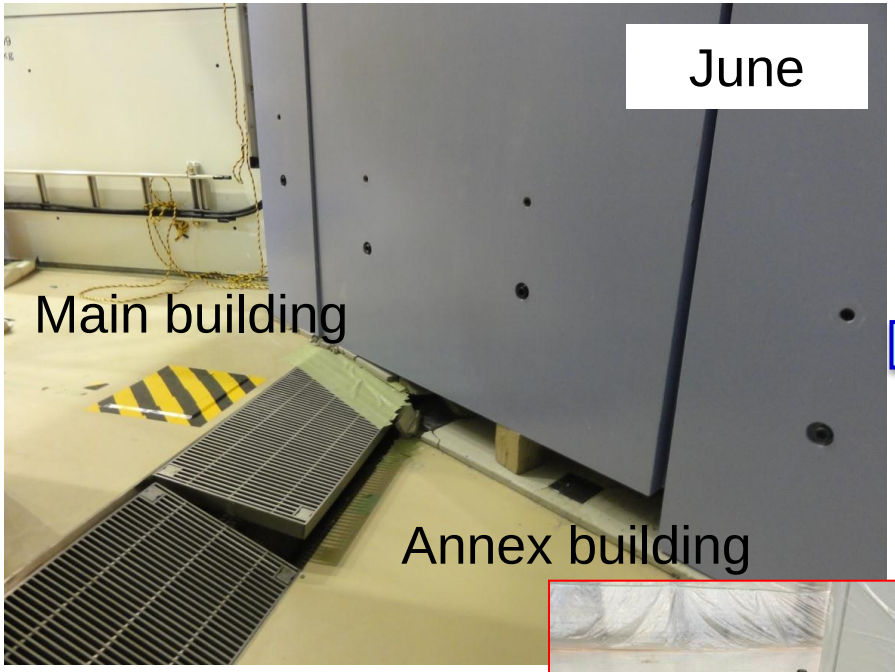


Jack-up of the west annex building



24 200 tons jacks were used to jack-up the building (4000 t)

Evacuation of existing instruments



Injecting grout concrete below the floor

Summary of Damages of Accelerators

Checking work for the soundness of the equipment has been performed for all accelerators. No serious problems were found.

- ***Linac***
  - The flood of about 10 cm was found. The urgent pumping work was carried out.
  - Many CT monitors were damaged and the procurement started.
  - The restoration of some conventional items such as building, cranes, ventilation system, etc. will be a key of the restoration schedule.
- ***RCS***
  - The subsidence of the outdoor yard and surrounding road is extensive. The restoration of the road was started.
- ***MR***
  - Water leakage was happen inside tunnel. The flood of a few cm was found.
  - In some dipole magnets, ceramics or castings had certain damaged.

Repair work

Immediately after the Earthquake

Outside of LINAC building was also heavily damaged.

We are getting water from an outside fire-hydrant, as original cooling water system has not yet been fixed.

Placing a temporal bridge for carrying in materials for repair.

Repair work

Inside of underground tunnel immediately after the Earthquake

・Many damages on partitions and ceiling boards of the building.

・Many spiles reached to a basement rock 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.

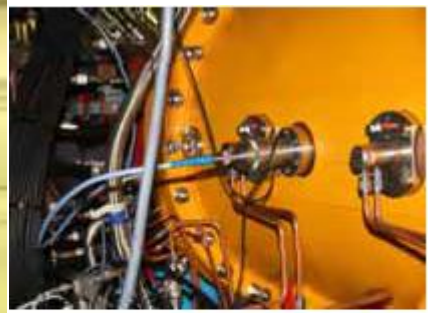
・Repairing water leaks in the tunnel is completed.

Inspection works with using low-voltages

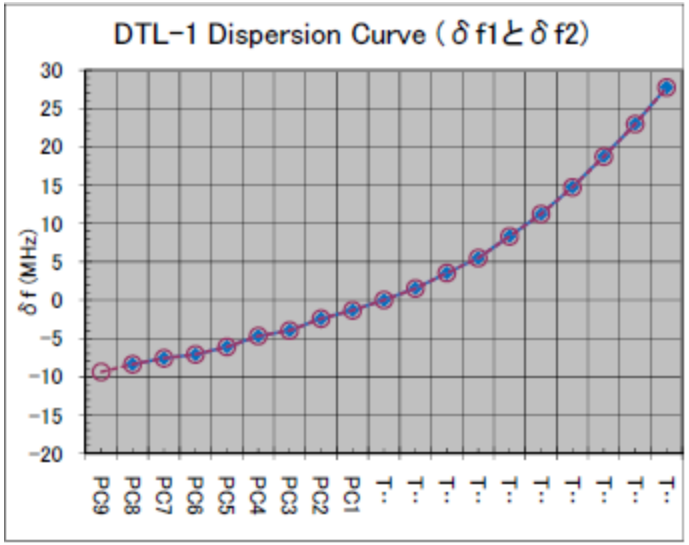
Acceleration Cavity

- Test of the vacuum.
  - No serious problems. Mass spectroscopy detected H_2O.
- Q-value and frequency for DTL measured.
  - No serious problems.
- Inspection of the cavity has been continued.
  - No serious problems.

Low power test for DTL.



Using pick-up board , tests for high frequencies with low power is tested.



Red Before the earthquake.
Blue: After the earthquake.

No significant change observed Before and After.

Monitors

- Many CT's (Current Transformer) and BPM's (Beam Profile Monitor) were damaged.
- Vacuum leak test for individual BPM was done.
  - Replaced.

Ion source and Its power supplies

- High voltage test up to 50 kV.
  - No serious problems.

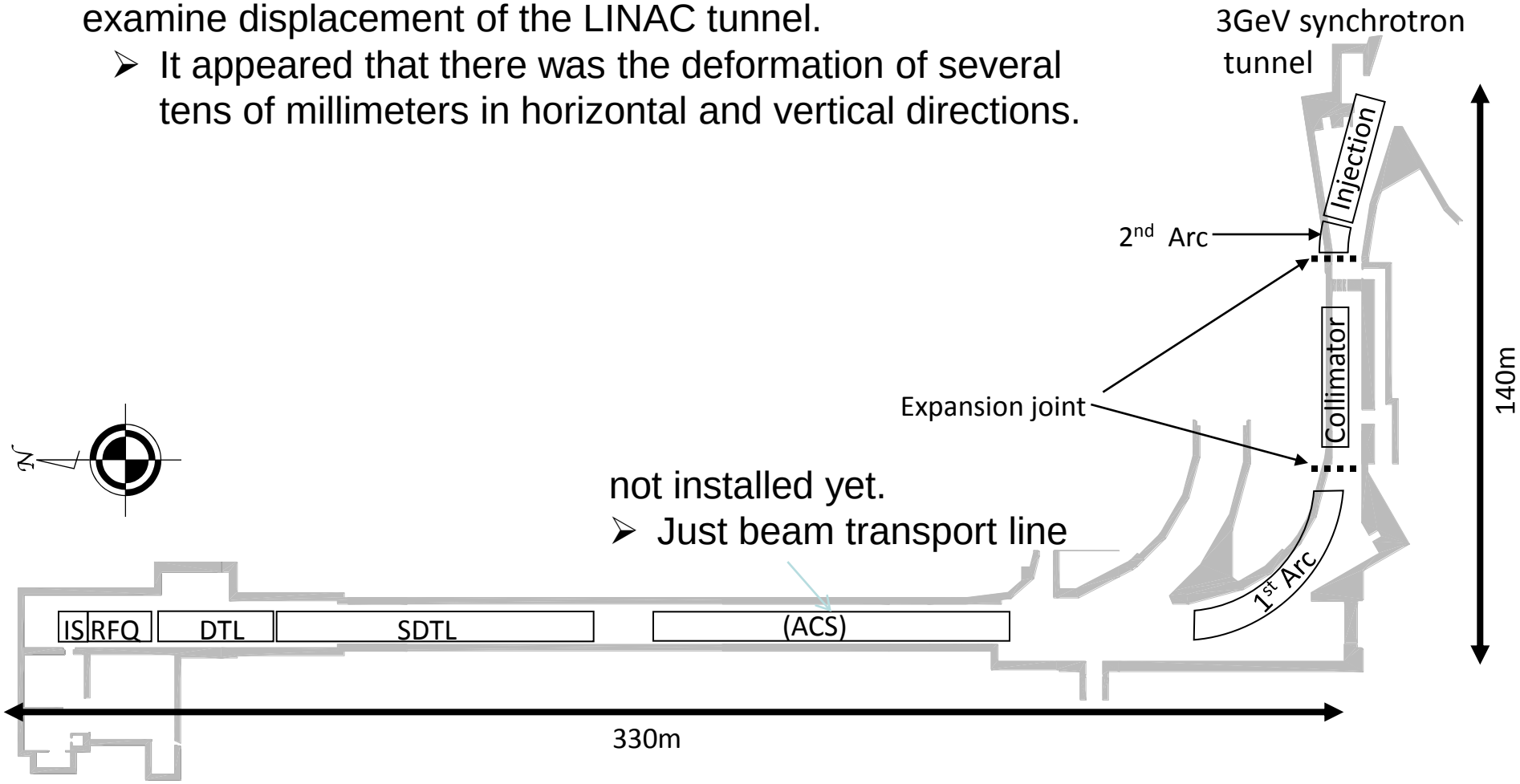
RF (incl. Klystron)

- No serious problems found in so far.
- Need recoveries for Crane, High voltage power and cooling water.

BPM (Beam Profile Monitor) extracted from Q-Magnet. Bellow was desctroyed.

Measurement of LINAC tunnel

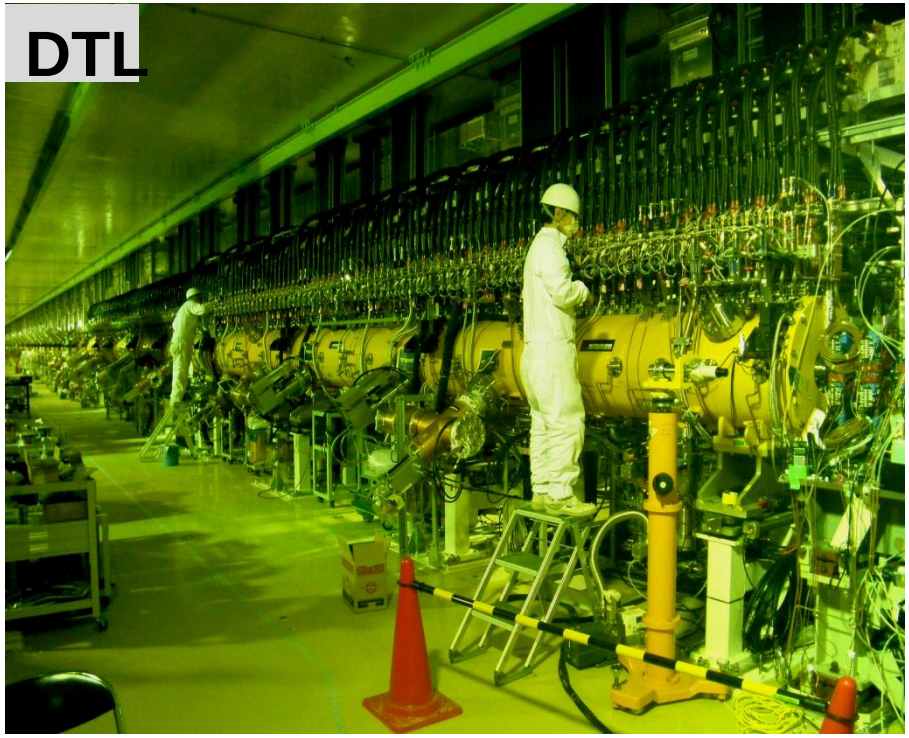
- Leveling and horizontal floor surveys were carried out to examine displacement of the LINAC tunnel.
  - ➢ It appeared that there was the deformation of several tens of millimeters in horizontal and vertical directions.

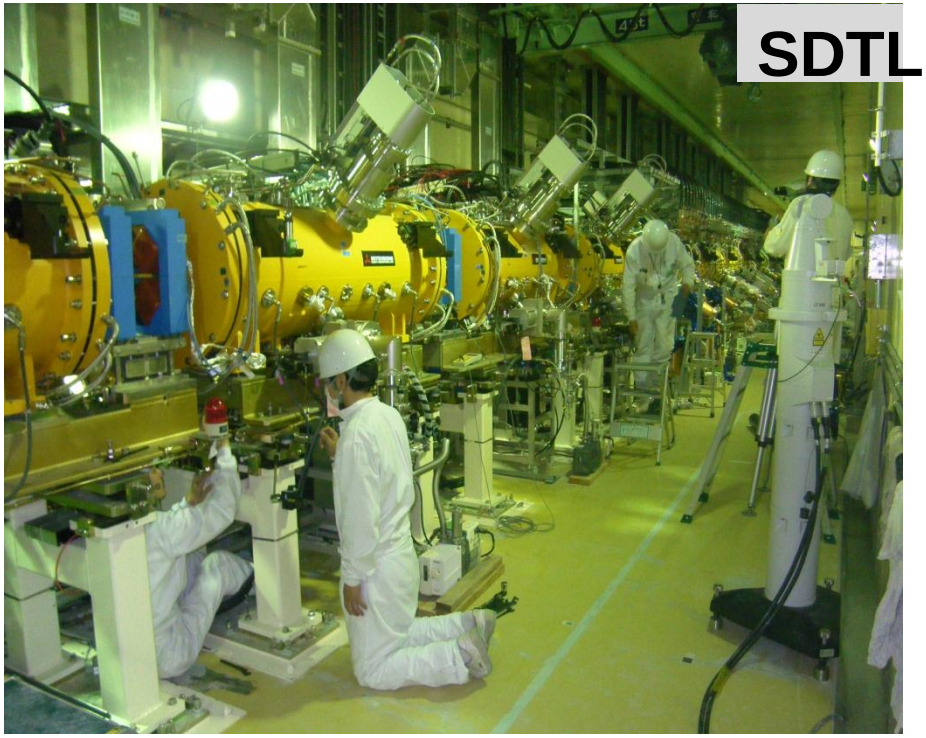


Realignment

The floor level sagged ***4 cm*** downward in the tunnel. Since accelerator cavities should be aligned ***within ±1 mm*** to each other along the beam line for the operation, they have been leveled and realigned where necessary.

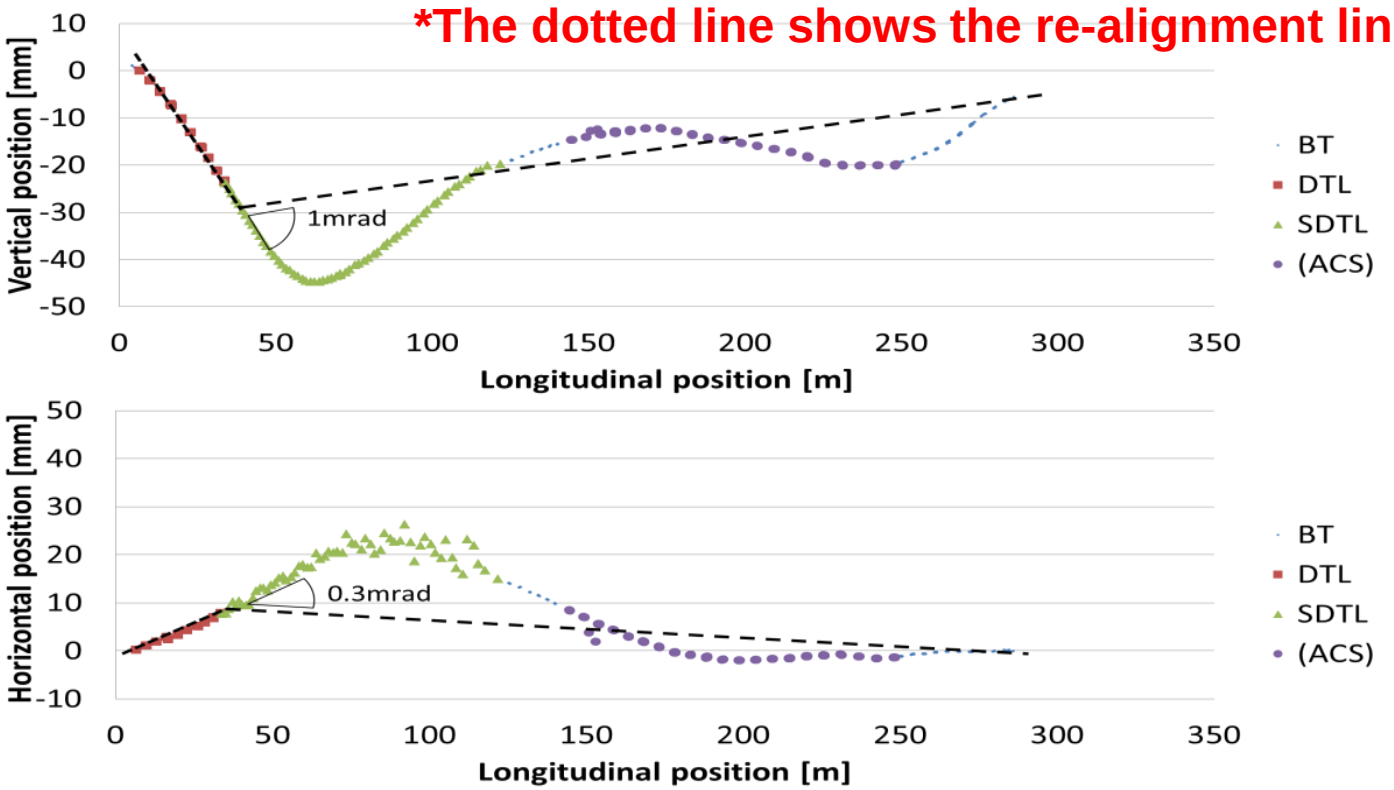
- It is time-consuming work to move the DTLs by several centimeters because a large number of heavy cables for electromagnets are connected.





We considered a better scenario for the realignment of the DTLs and also SDTLs to meet the entire restoration schedule with minimizing an effort on the beam degradation.

Realignment strategy of the linac



- 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.
- This deflection of alignment axis shows no effect in beam simulation and experiment results (Ikegami-san's talk).
- We have no plan to restore the alignment to the original state unless necessary to continue the beam operation is found. This is time-consuming work to move the DTLs by several cm because a large numbers of heavy cable for electromagnets are connected (about a half year is additionally needed).

RCS

Damage - RCS -

The subsidence of the outdoor yard and the surrounding road was extensive at the RCS.

Road around 3 GeV

Wave road. Bump in the middle.
Both sides of the bump were sinking.

3 GeV Electric Device

Stage for electric power devices leaned

Capacitor bank and transformers

Capacitor bank and transformers were tilted. Cables were distorted with heavy weight on them.

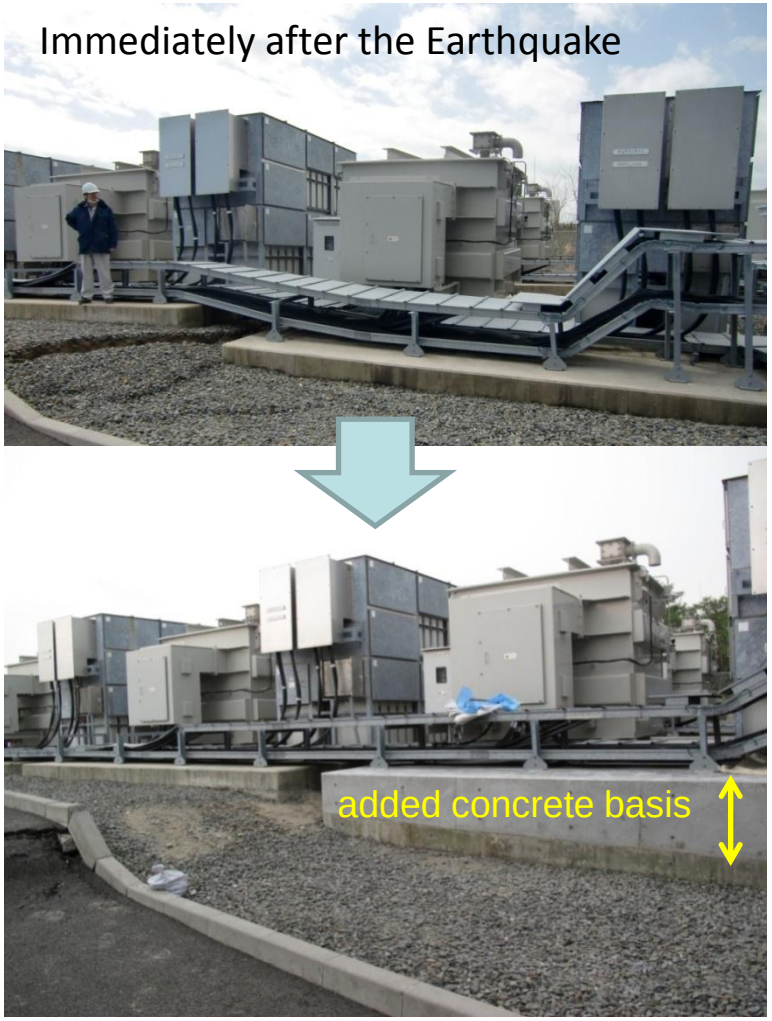
Repair work

・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.

The road was repaved.

The bent stage was repaired. Power could be supplied to the RCS building from September.

Repair work



Tilted capacitors were straightened after re-leveling the bases.

Damaged water pipes were replaced to enable cooling.

Reinforced foundation for a cooling tower (right)
Adjusting alignment of pump/motor (left)

Damage of RCS devices

3 GeV Main Ring

March 29, 2011

No obvious damages were observed.

The confirmation of the vacuum system, rf system and so on has been carried out by securing the lighting with a diesel engine power generator for a while.

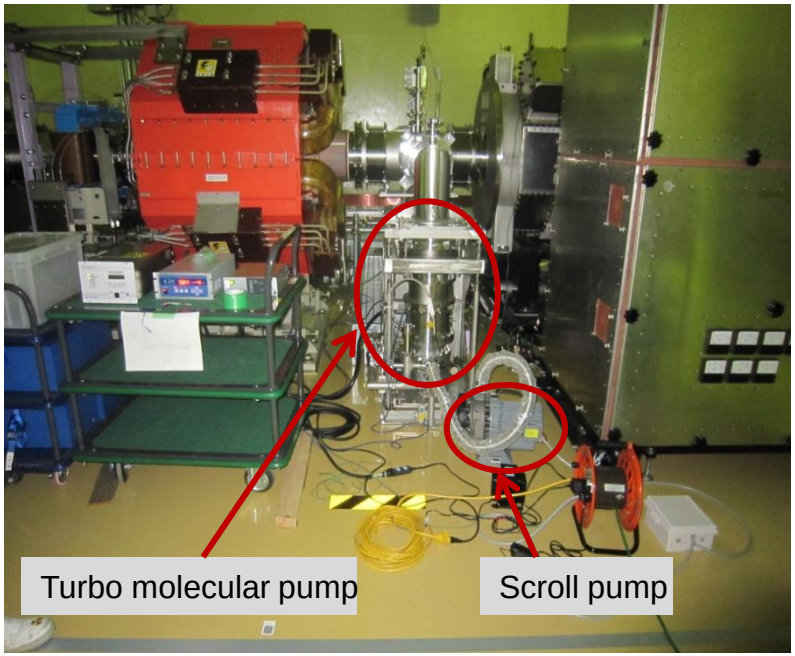
Big problem was not found.

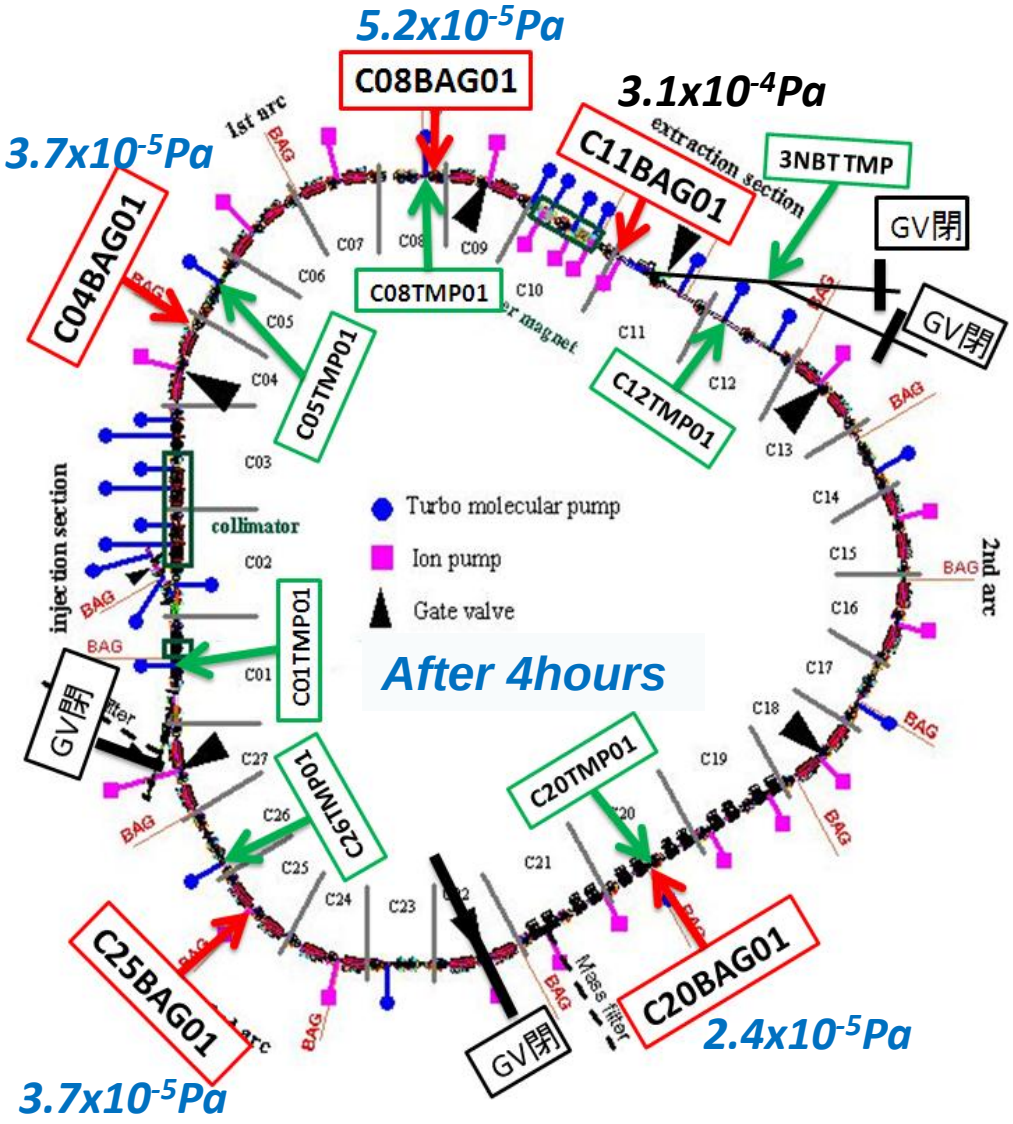
In order to restore the yard and the high voltage electric board, we have had completely power outage from the middle of Jun to the end of August. After having electricity in September, we were able to start the restoration of the utility systems (cooling water system, air conditioner,) and the detailed check of the components.

Vacuum test

Our biggest concern was the status of ceramic chambers.

- We conducted a vacuum test using 6 turbo molecular pumps.
  - The vacuum pressure dropped to an order of 10^{-4}~10^{-5} Pa after 4 hours exhaust.
- ***There were no large leaks in the chambers of the RCS.***

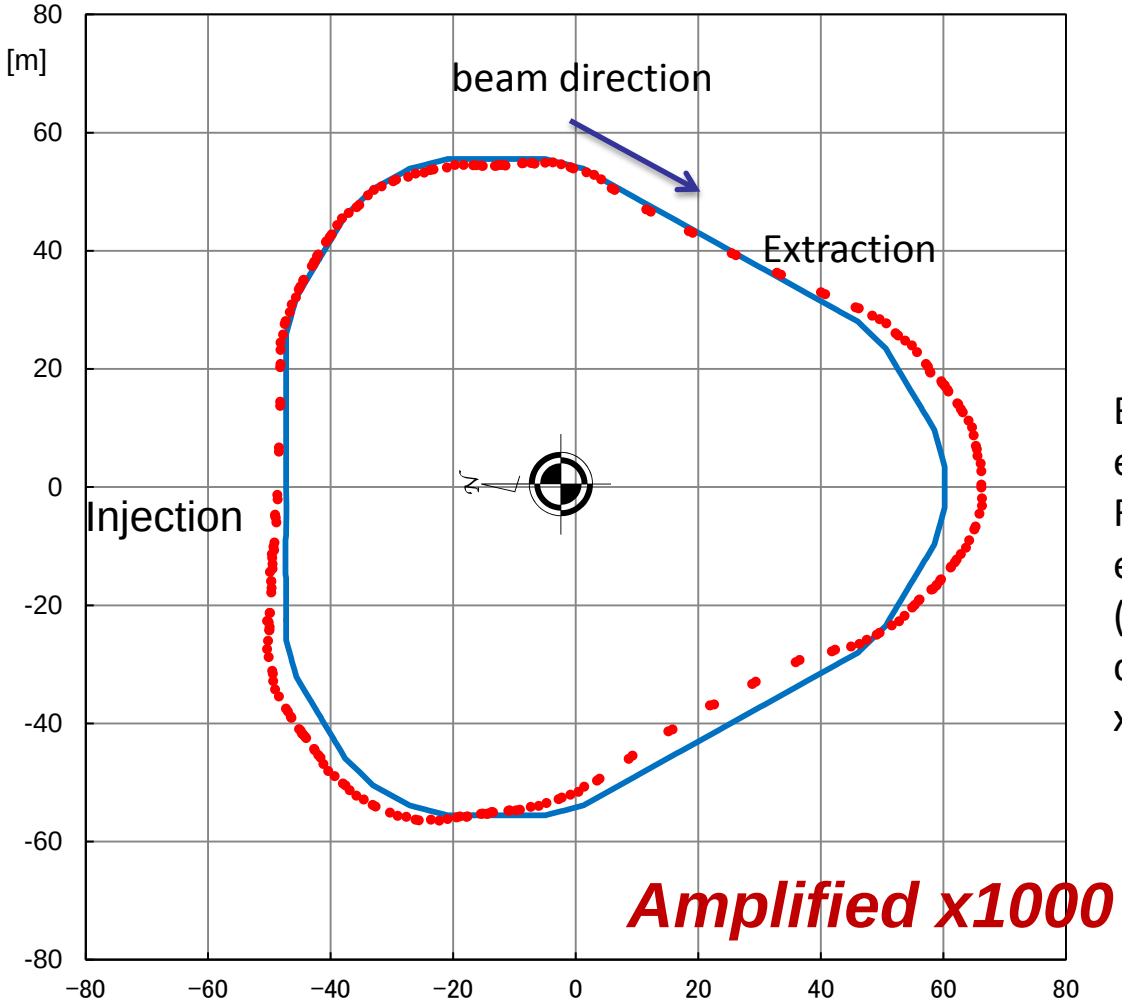




Vacuum pressure of each section after 4 hours pumping

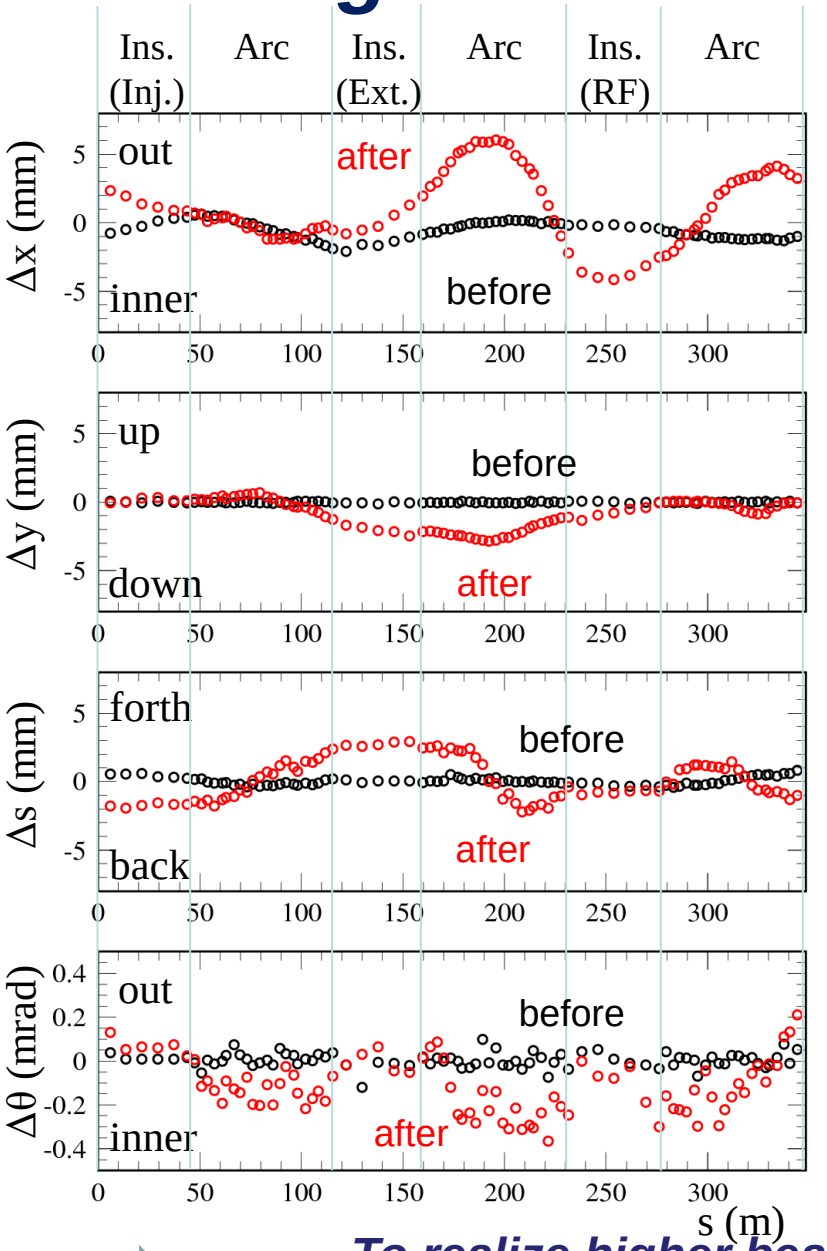
Measurement of RCS main magnets

- No serious damages on the equipment/instruments in RCS tunnel.
- Position of all equipment/instruments, such as electromagnet, were precisely measured. The misalignment was up to ~3.7 mm vertically and up to ~10 mm horizontally.



Blue: Reference positions of electromagnets
Red: Actual positions after the earthquake
(Please note the magnitude of displacement is amplified x1000.)

RCS alignment errors (position & rotation)



- Position errors for horizontal & vertical plane
  - Δx : - 4mm ～ +6mm , Δy : - 3mm ～ +1mm
  - ➢cause the closed-orbit distortion
  - ➢ reduce the physical aperture for the beam
- ➢ ***Correct the COD by the steering magnets***

- Position errors for longitudinal plane
  - Δs : - 3mm ～ +3mm
  - ➢cause the phase advance distortion
- ➢***The effect is very small***

- Rotation errors for transverse plane
  - Δθ : - 0.4mrad ～ +0.2mrad
  - ➢ enhance the liner coupling resonance
- ➢***The effect is small***

It appeared there was a large misalignment in both horizontal and vertical directions.

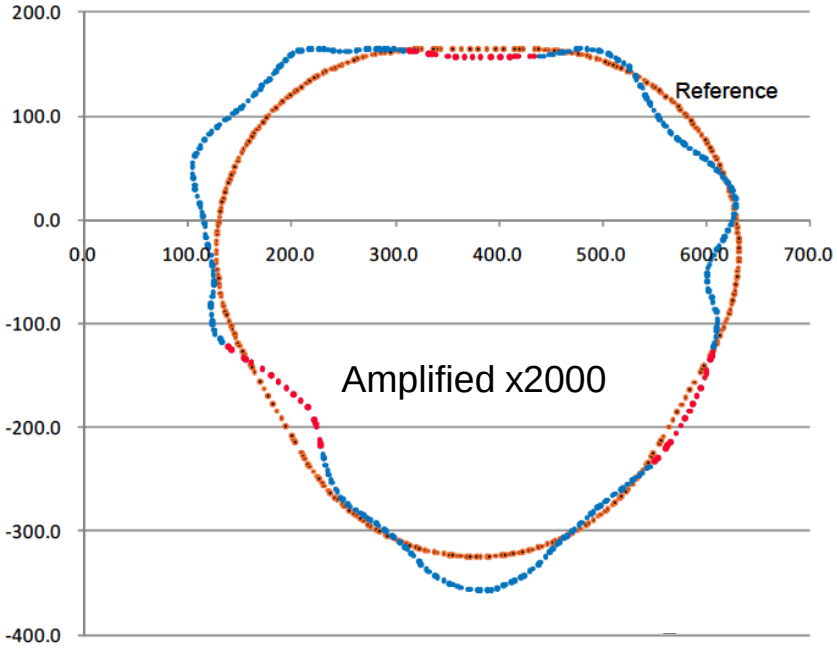
However, since it is possible to correct the beam orbit with correction magnets, we decided that we did not perform realignment at this moment (during this shutdown period).

To realize higher beam power (e.g. 1MW with 400MeV inj.) realignment is planned in the 2013 summer shutdown period.

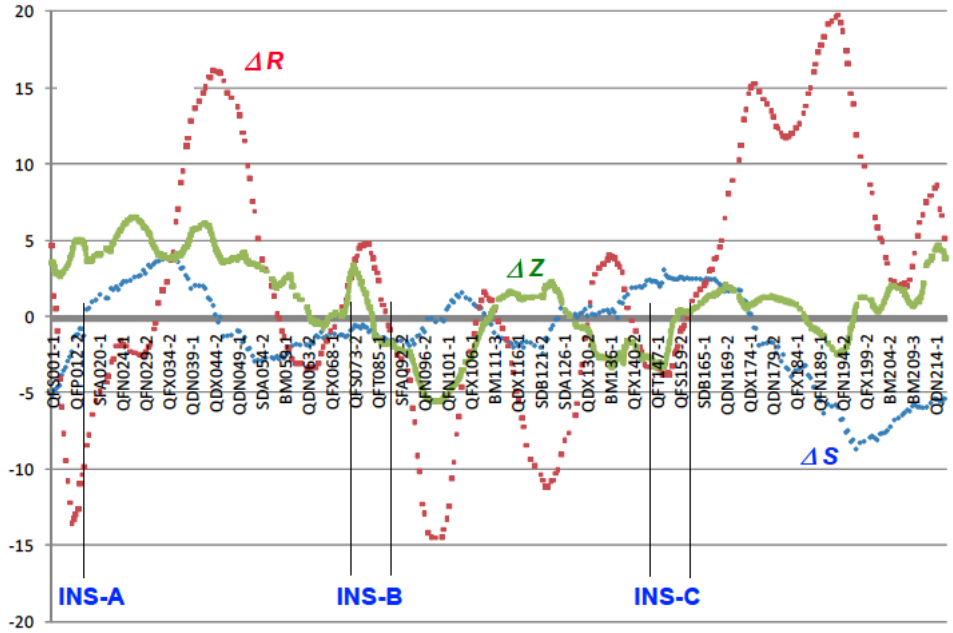
MR

Measurement of MR main magnets

・There were no serious damages on all MR equipment/instruments, such as electromagnets. However, it appeared they misaligned in both vertical and horizontal directions.
・Some electromagnets that misaligned greatly are realigned with replacing a stage and/or an anchor part.



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



Electromagnet misalighnment in a vertical direction

Repair work

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

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

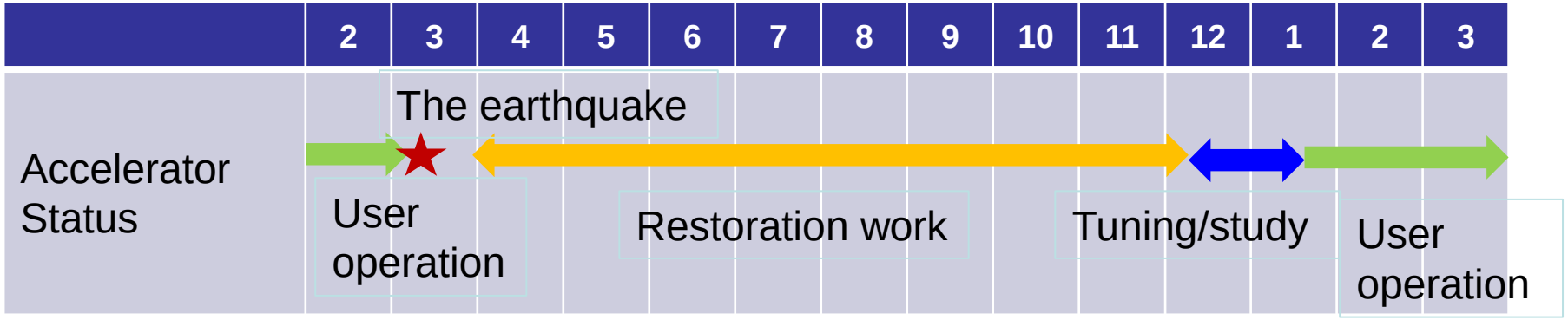
Hanging up the magnet

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.

Calendar (Feb.2010 - Mar.2011)

Work in JFY2011 is nothing but restore from the earthquake.



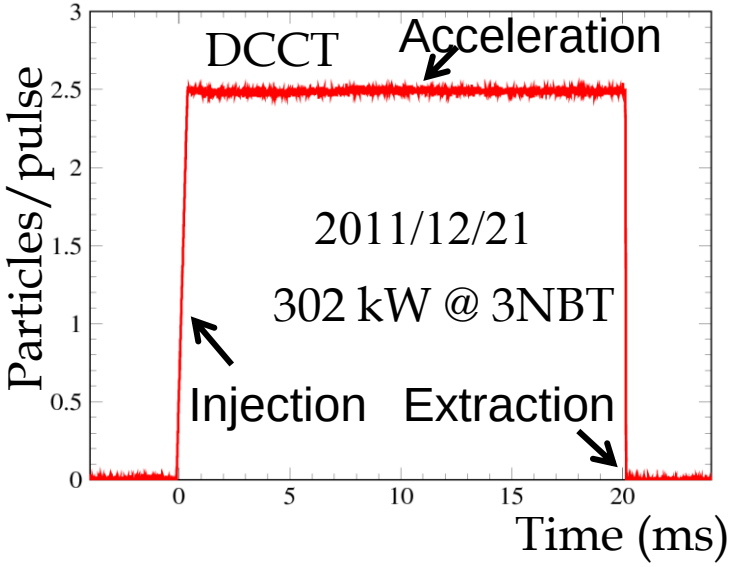
	Tuning start	High Power Demonstration	User Operation
Linac	Dec.9	(15mA, 500us)	(to RCS)
RCS	Dec.17	300kW	(to MLF and MR)
MLF	Dec.22	300kW	120kW
MR	Dec.22	124kW(FX), 10kW(SX)	(to NU and HD)
NU	Dec.24	124kW	60-100kW
HD	Jan.28	10kW, 5kW(for inspection)	3.3kW

Beam commissioning results

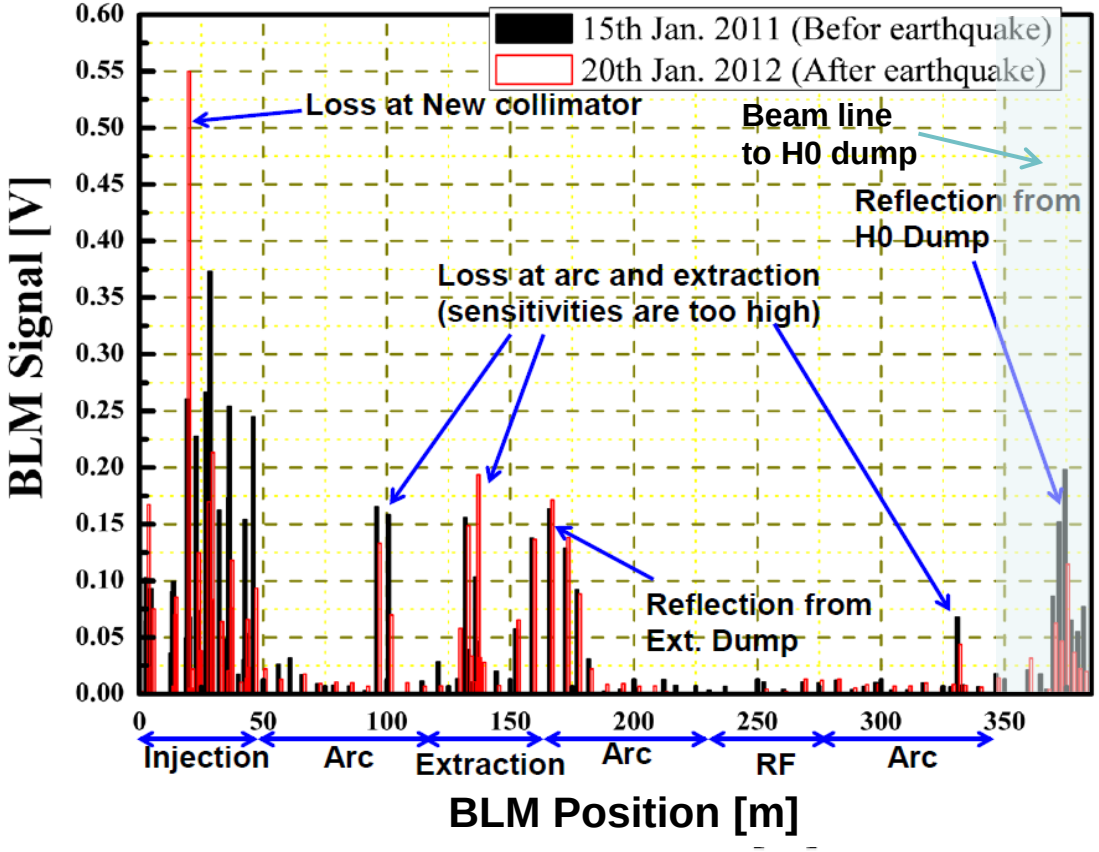
Painting condition :

Transverse paint ; 100 π correlated painting

Longitudinal paint ; V_2/V_1; 80%, $\Delta\phi_2$; -100 to 0, $\Delta p/p$; -



15 mA/0.5 ms/600 ns/2 bunches; 300 kW-eqv.



In the case of 300kW-eqv. beam power

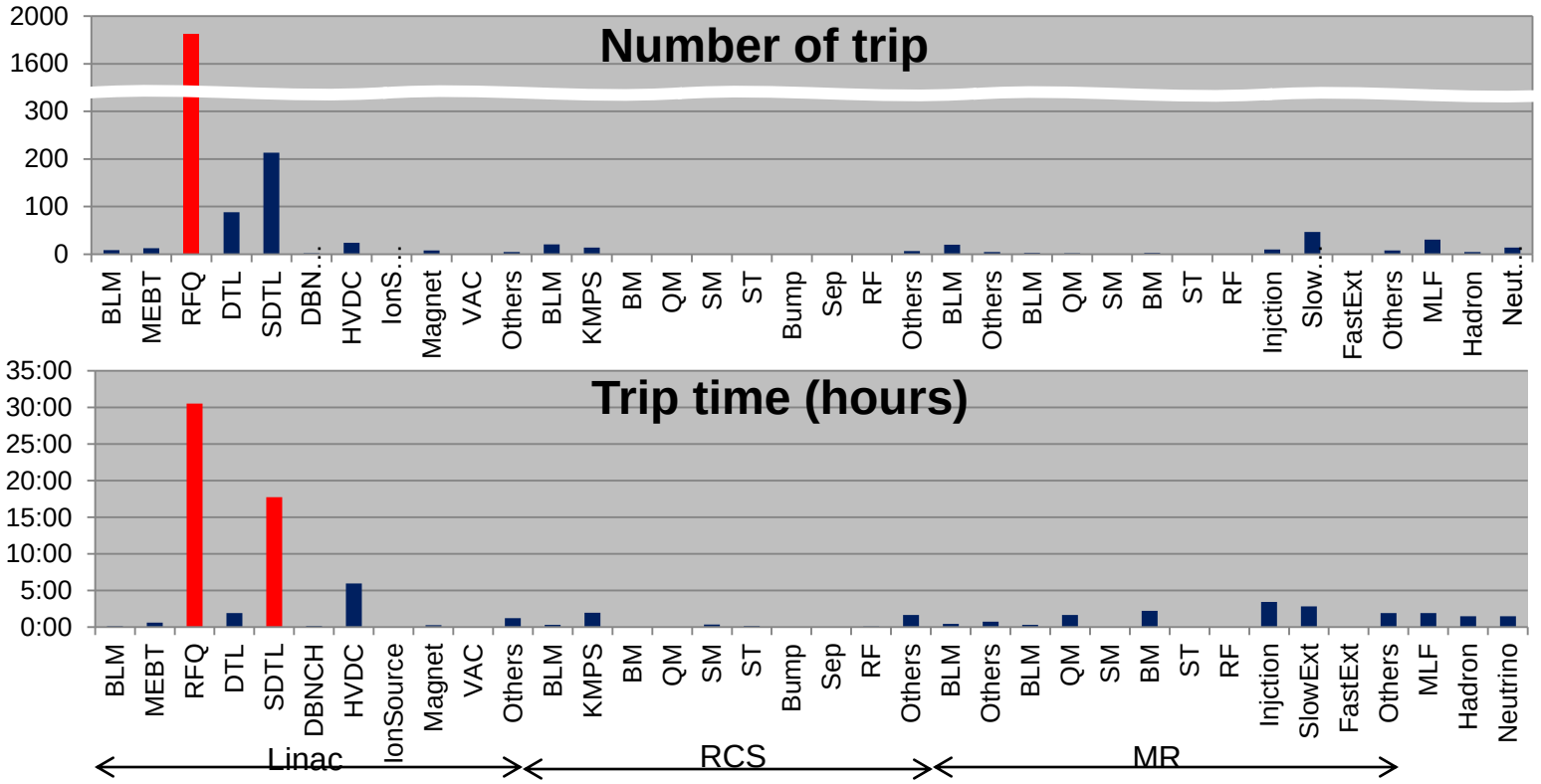
- Beam loss condition and value at RCS was almost same as before earthquake.
- Beam loss value at beam transport line from RCS to MR (3-50 BT) was measured.
  - ➢ Almost same before/after earthquake.

- In the case of 300kW beam operation, realignment of RCS components is not necessary.
- 400kW-eqv. beam with low beam halo is required for MR injection
  - ➢ Possible to deliver

Causes of trips in Jan-Feb 2012

Number (50-60trips/day) and time of beam trips due to the RFQ discharge is dominant.

The situation was similar to the restoration of the RFQ discharge problem in 2009. Based on the experience, the condition will be getting better, but the trend should be carefully watched.



Number and time of beam trips in Run#40 (Jan.7 – Feb. 22, 2012)

Summary

- J-PARC facility resumed beam operation in December 2011 after 9-month long-shutdown due to the earthquake disaster.

- The linac resumed beam study on Dec. 9, the RCS on Dec. 17, the MR and the MLF on Dec 22, the NU on Dec 24 and the HD on Jan.28.

- Goals of the RUN in Dec. 2011 are:
  - Transportation of 4e11 ppb beam to the MLF and the neutrino targets with the nominal beam energies.
  - Demonstration of the 300 kW equivalent beam in the RCS
  - Demonstration of the 60 kW equivalent beam in the MR

    The 60 kW equivalent beam(5e12 ppb) was the maximum intensity to allow the MR BPM operation.

- The accelerator restarted beam tuning and start user operation in January 2012.
  - Demonstration of 124 kW and user operation of 100 kW to NU.
  - Demonstration of 10 kW and user operation of 3.3 kW to HD.
  - User operation of 120 kW to MLF.

- Scientific results start to appear.

Helps from many abroad friends

To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