Recovery of the J-PARC Linac from the Earthquake

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LINAC12
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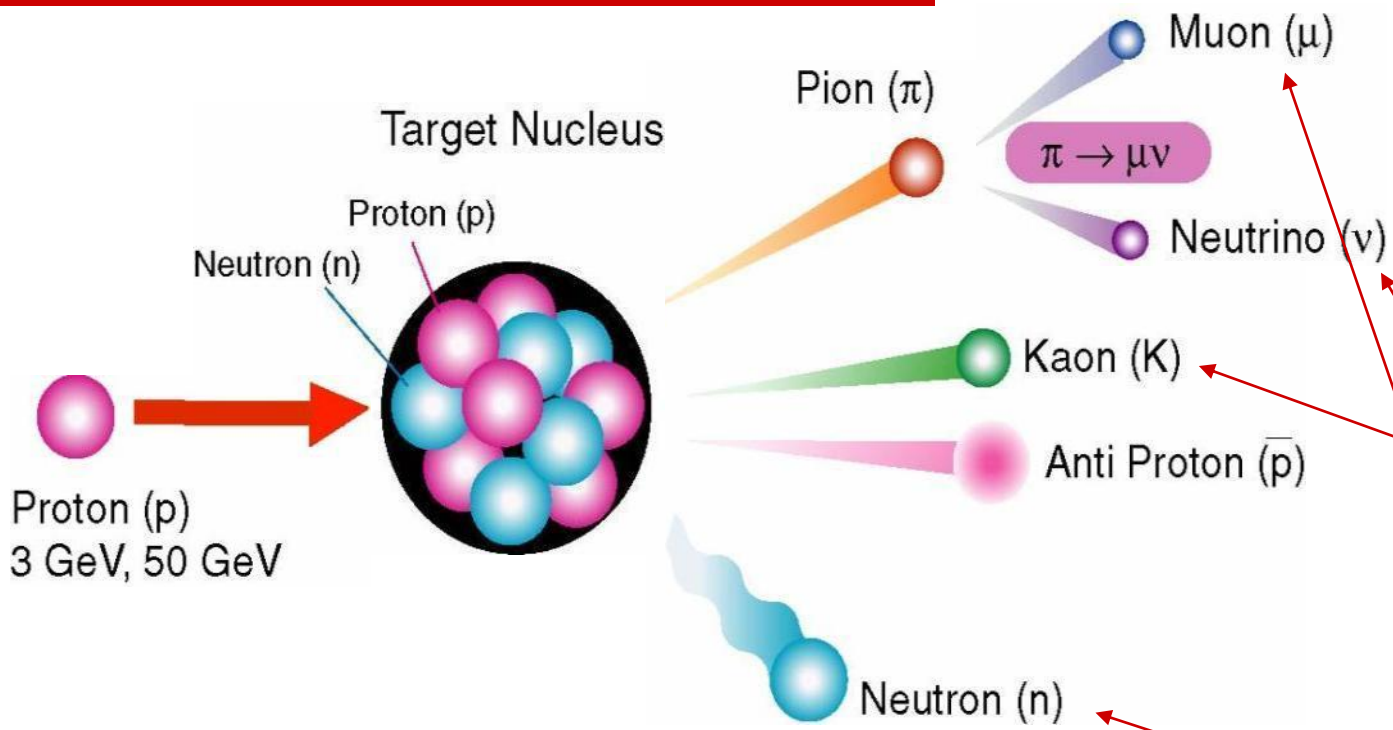
Outline

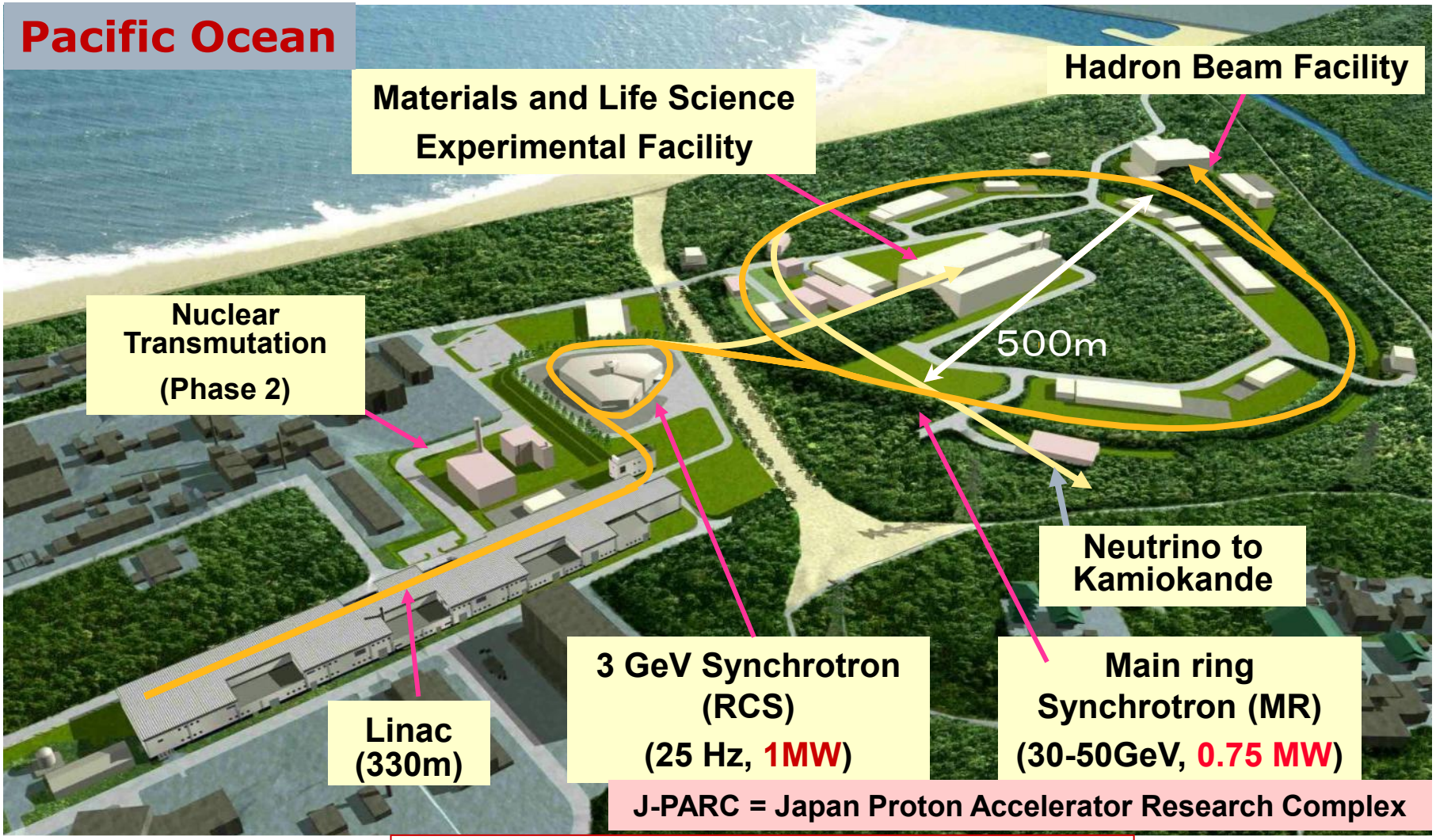
-Introduction of J-PARC facilities and the Linac
-Status before the earthquake
-Status after the earthquake
(restoration and operation)
-Learnt Lessons
-Upgrade plan of the Linac

Goals at J-PARC



- Materials & Life Science at 3 GeV (1MW)
- Nuclear & Particle Physics at 30-50 GeV (0.75MW)
- R&D toward Transmutation at 0.6 GeV (200kW)

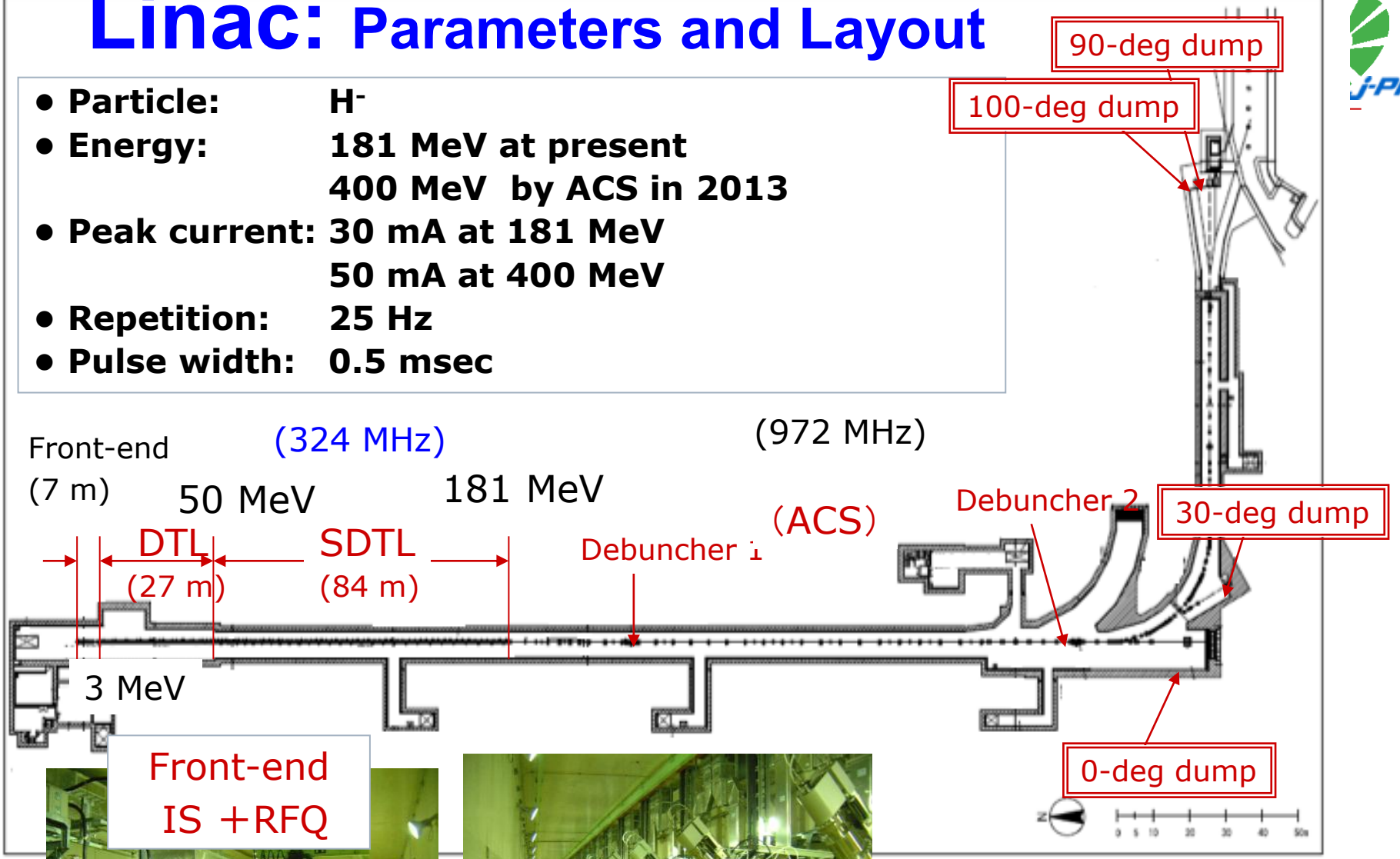
J-PARC Facility



Joint Project of KEK and JAEA

Linac: Parameters and Layout

- **Particle:** H^-
- **Energy:** 181 MeV at present
  400 MeV by ACS in 2013
- **Peak current:** 30 mA at 181 MeV
  50 mA at 400 MeV
- **Repetition:** 25 Hz
- **Pulse width:** 0.5 msec

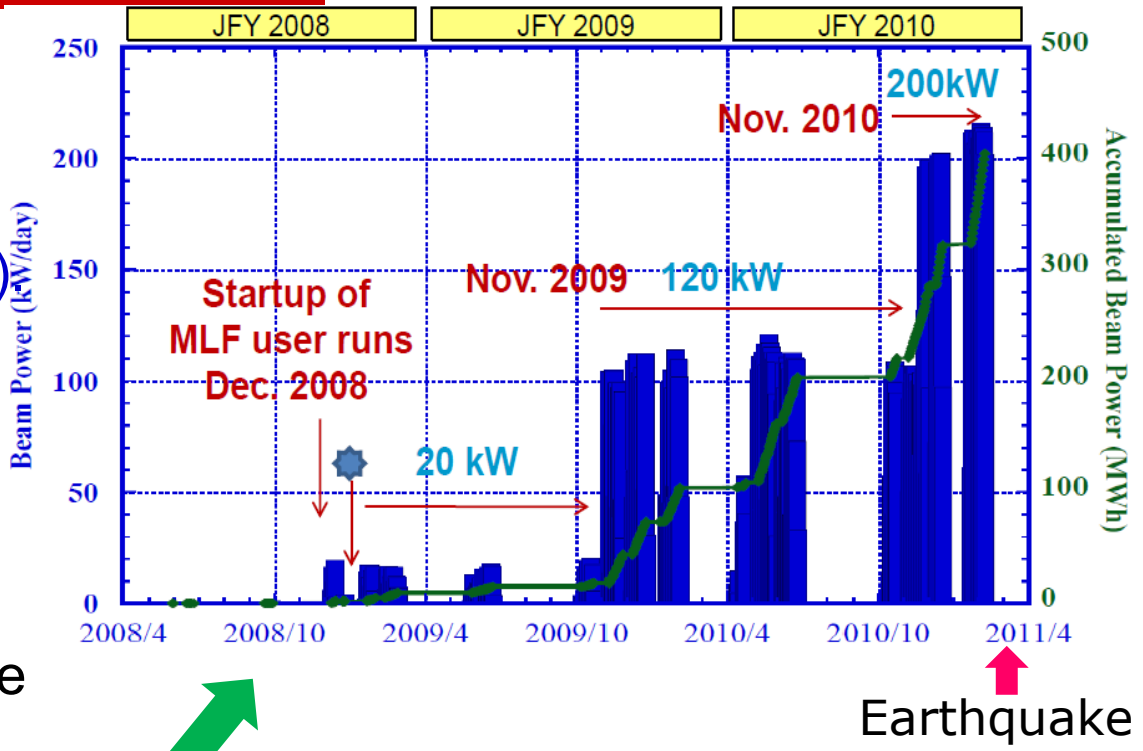


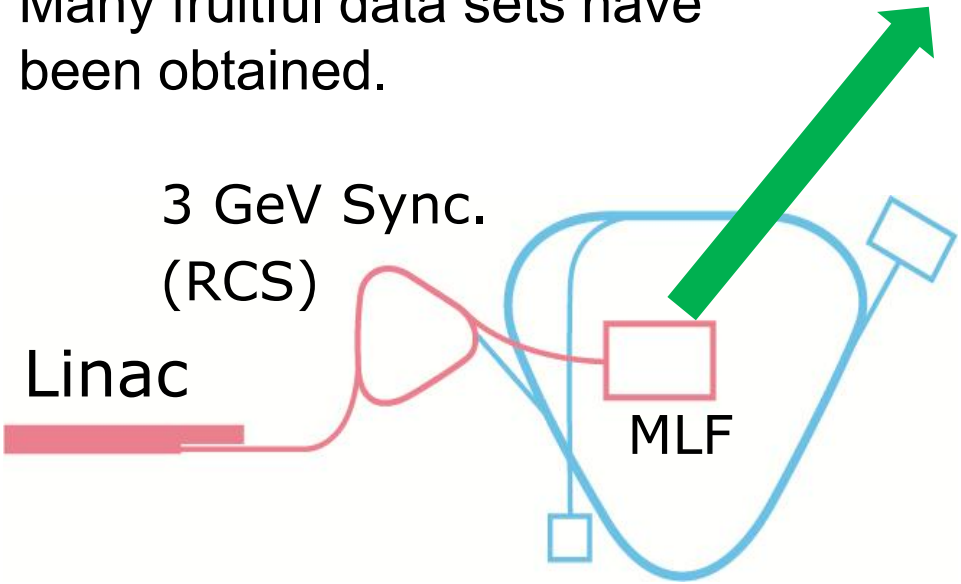
Front-end
IS +RFQ

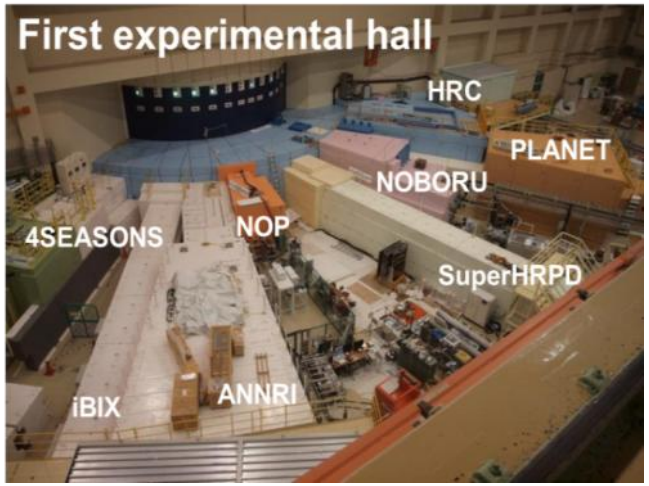
Status (Before the Earthquake)

RCS Beam Power to the MLF

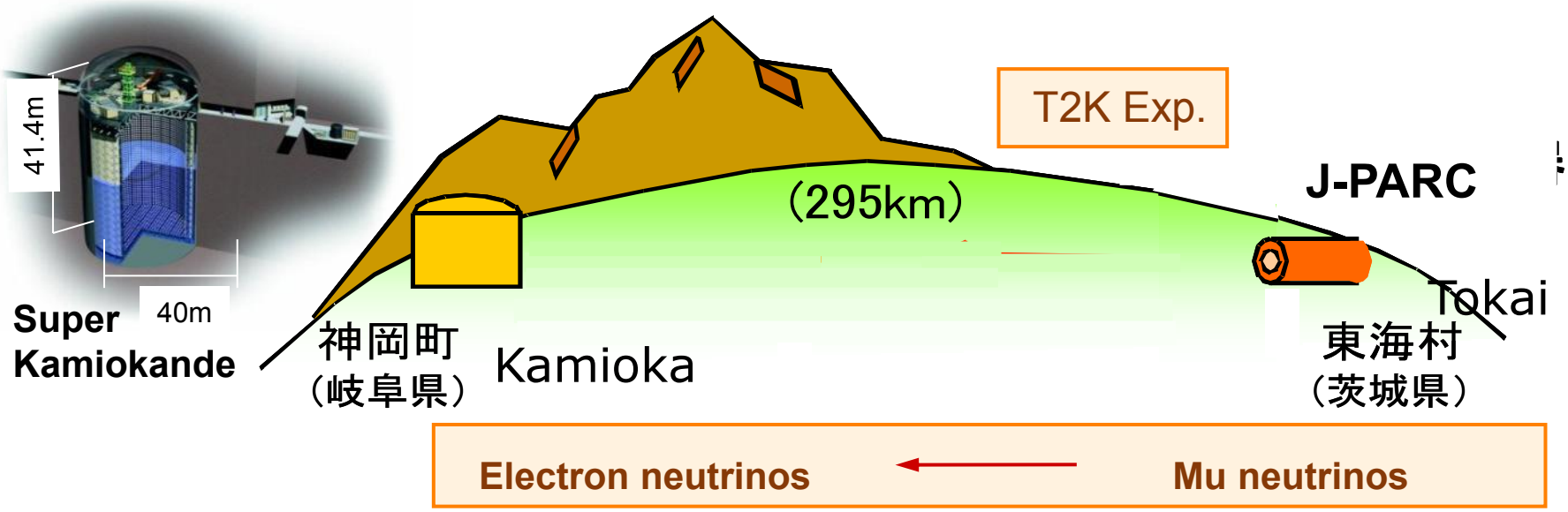
- 3 GeV Beam power from the RCS to the MLF: steadily increased up to 200kW (linac power 12kW)
- MLF: muon and pulsed neutron sources.
- Two neutron experimental halls: occupied beam lines (20 out of 23 funded).
- Many fruitful data sets have been obtained.







Neutrino Oscillation (T2K) Experiment



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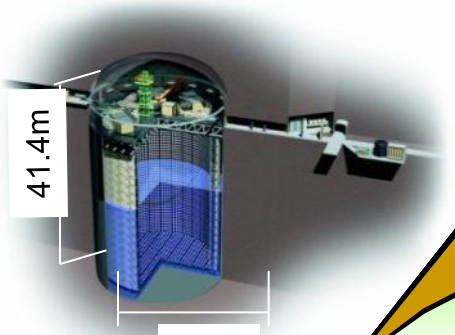
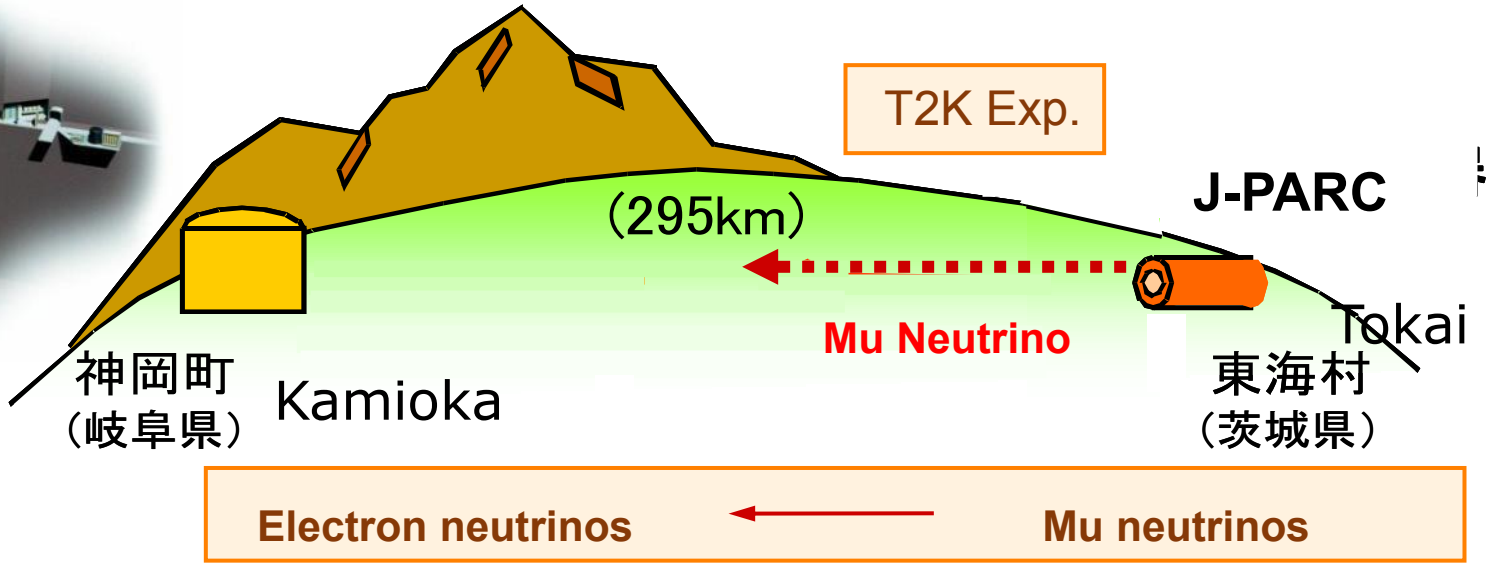
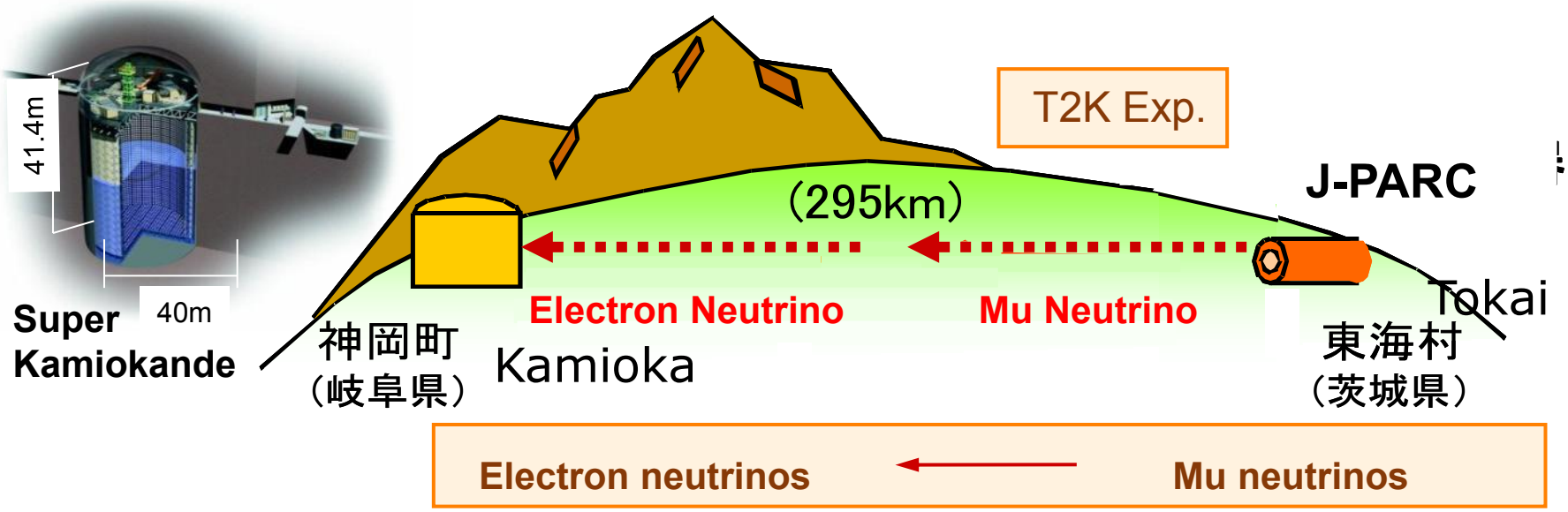


Super Kamiokande



Electron neutrinos ← Mu neutrinos

Neutrino Oscillation (T2K) Experiment



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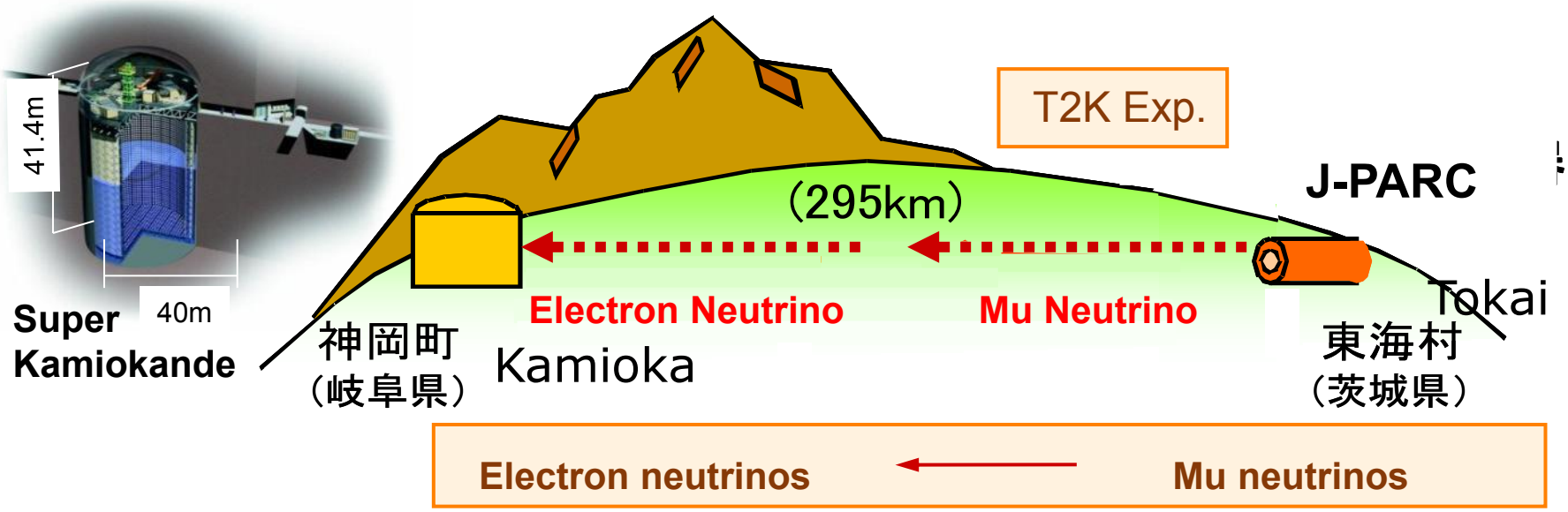
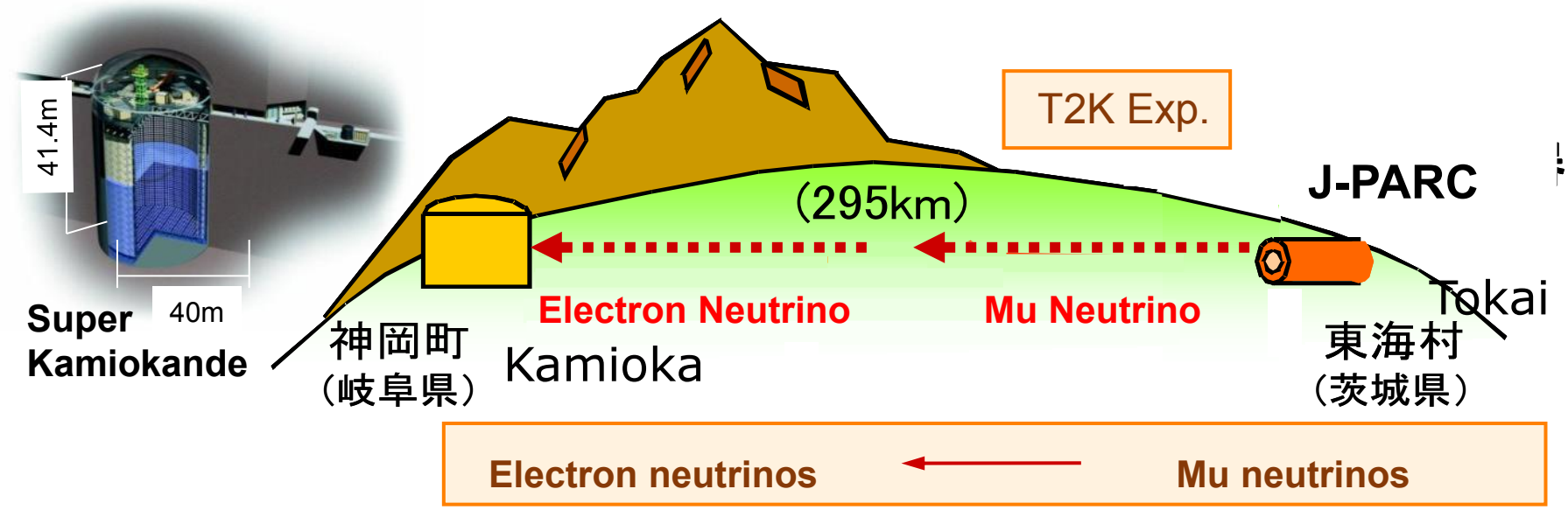


500 non-Japanese joined this experiment ！

Neutrino Oscillation (T2K) Experiment



500 non-Japanese joined this experiment ！

The MR delivered beam at 145 kW before the earthquake.

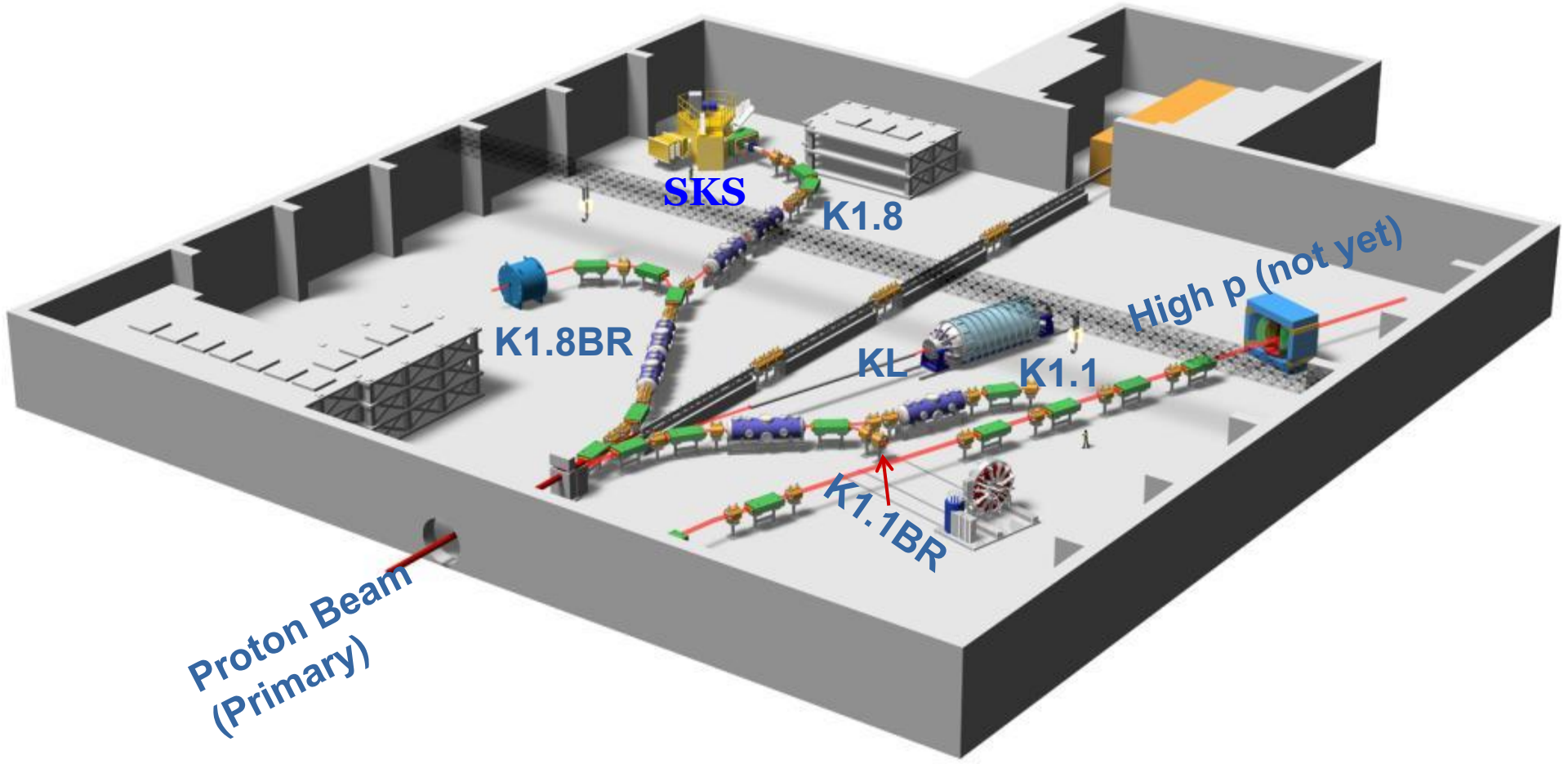
6 ν_e candidates found! (Probability of 6 is all BG: 0.7% (2.5σ)

Selected to one of Physics World Top 10 Breakthroughs in 2011 (England)

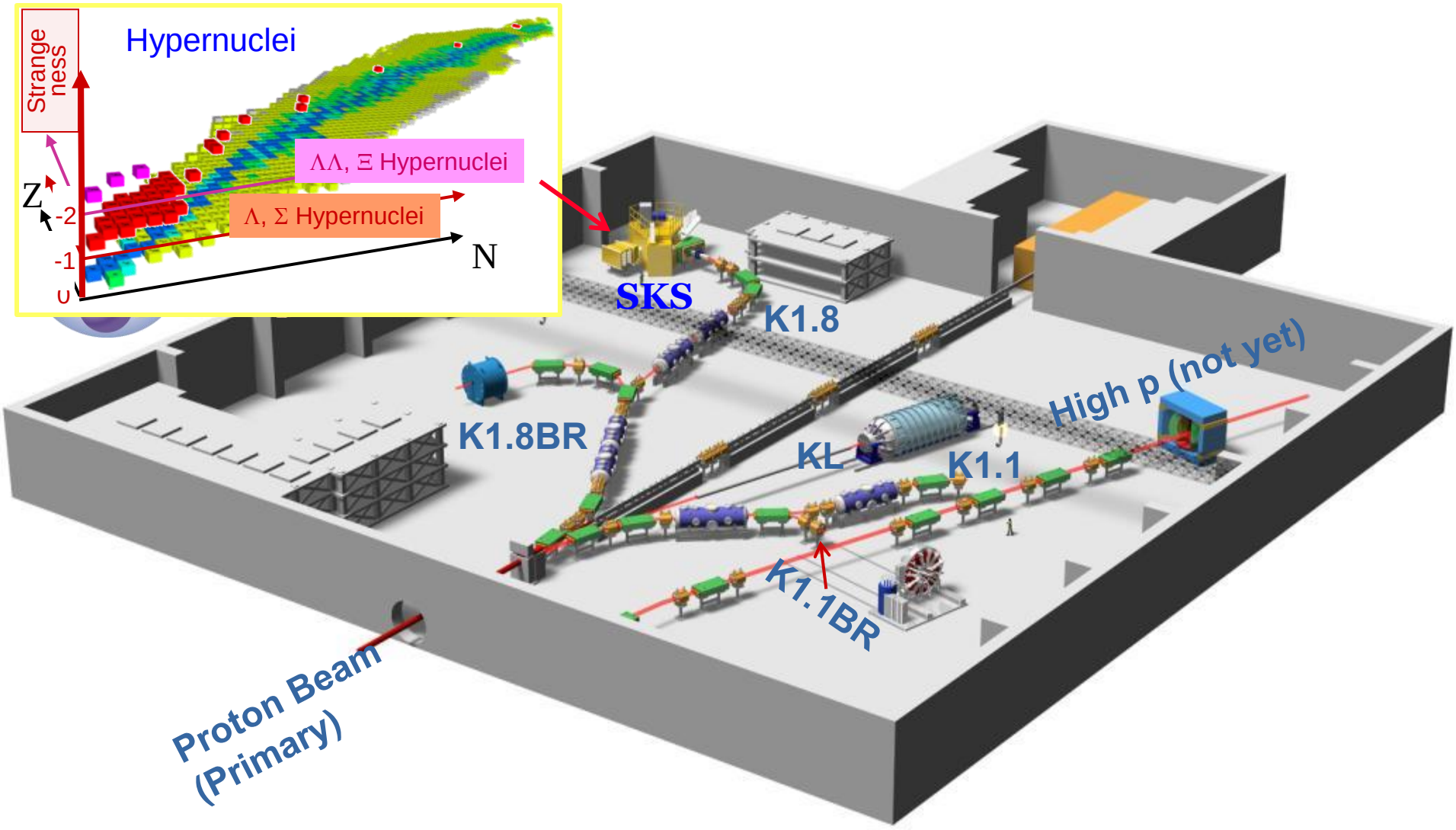
http://physicsworld.com/cws/article/news/48126

Competition with Double Chooz, Diya Bay, FNAL, etc.

Nuclear & Hadron Physics



Nuclear & Hadron Physics



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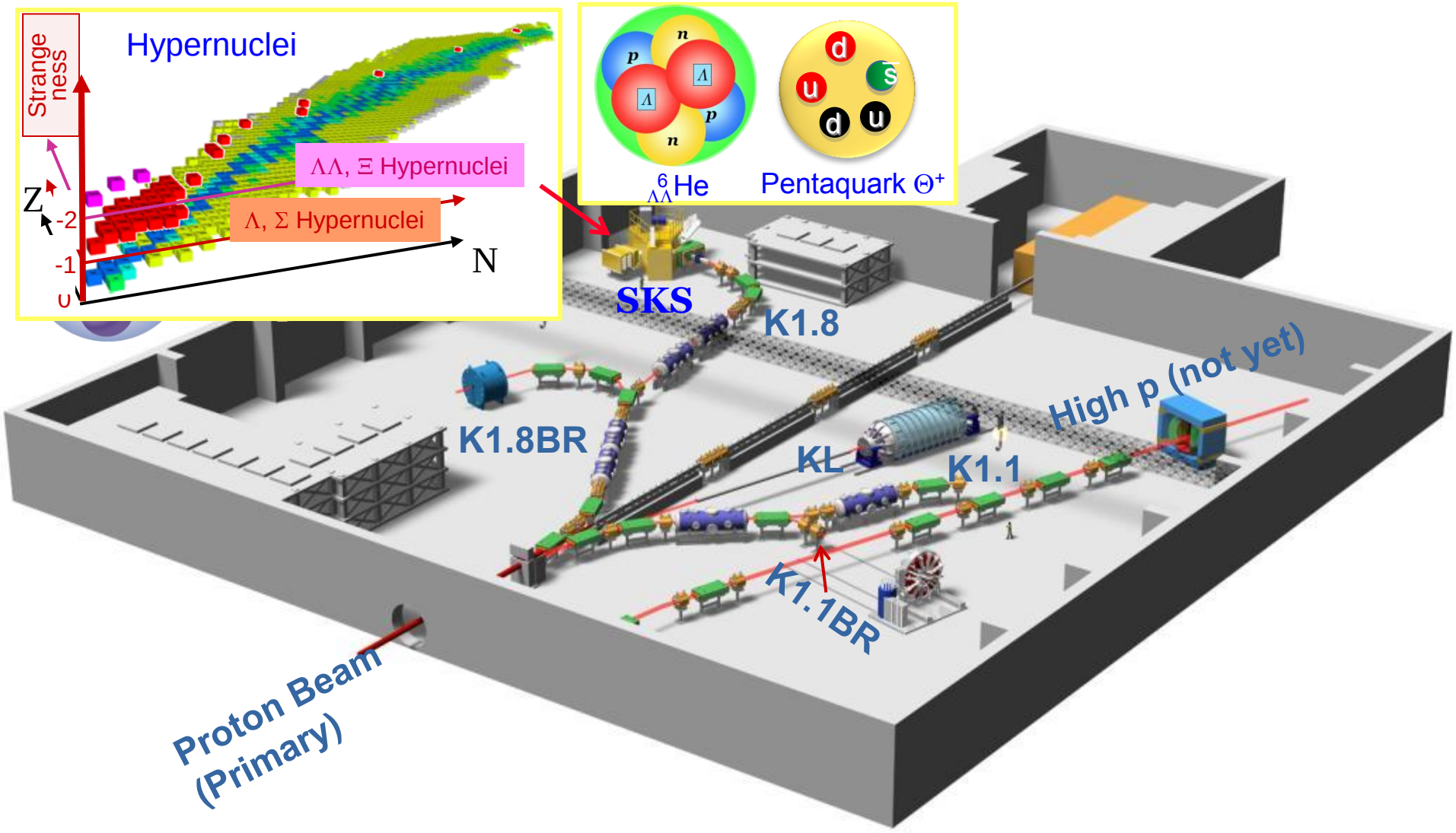

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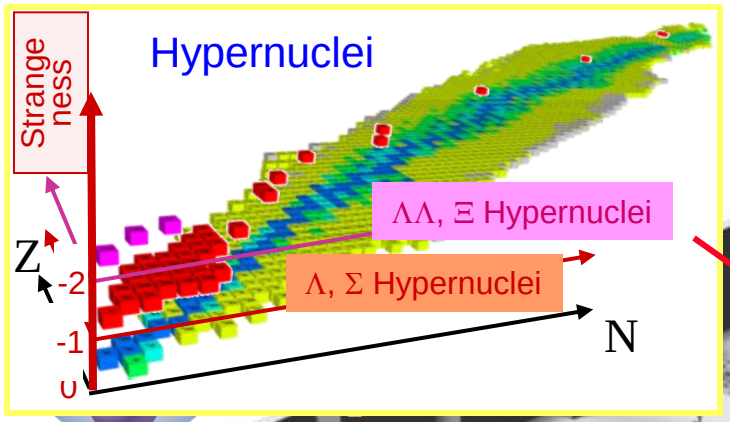

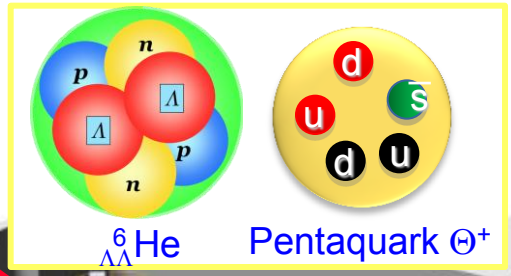

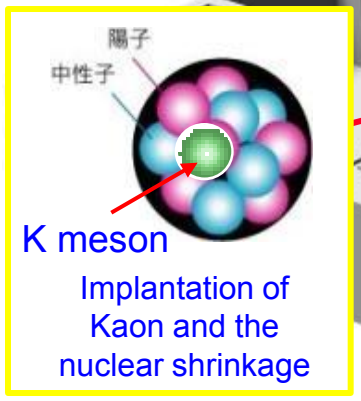

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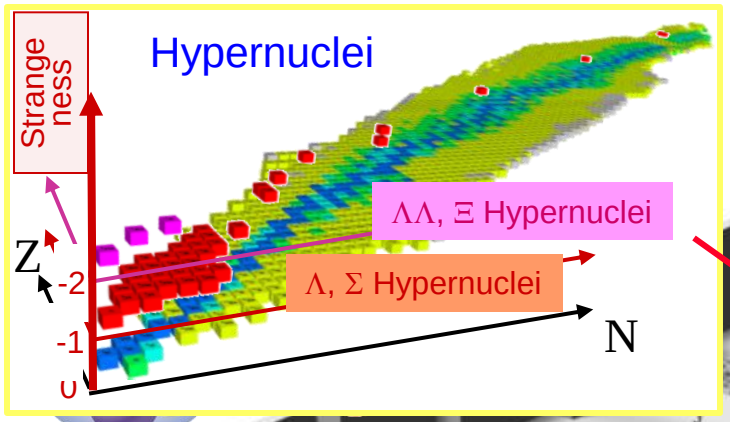
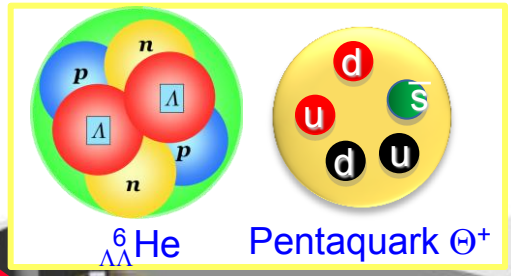
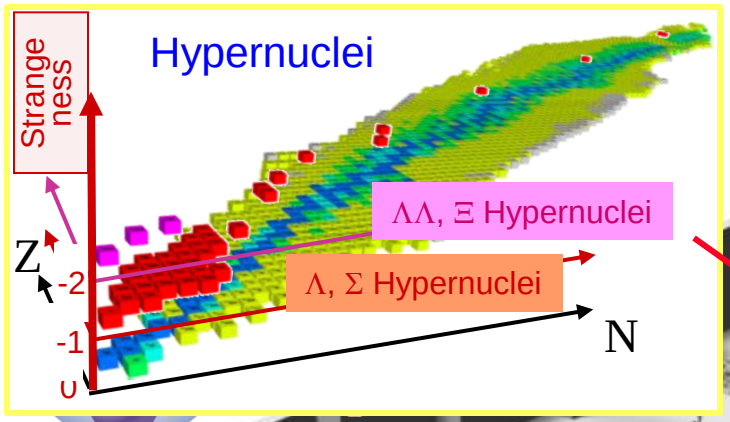


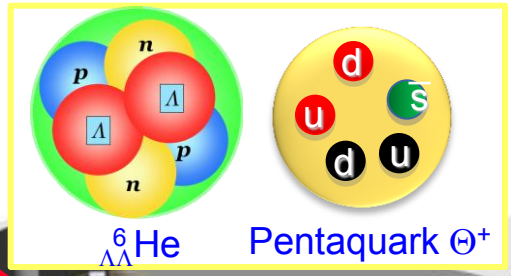


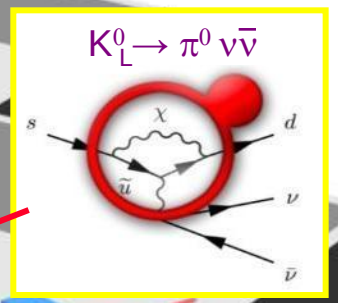
Kaonic atom

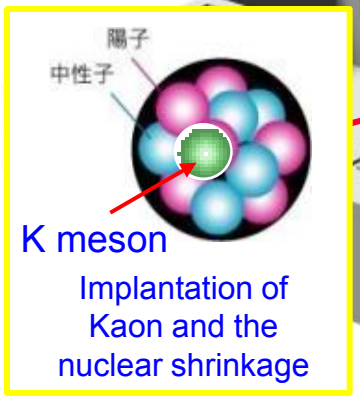
Kaonic nucleus

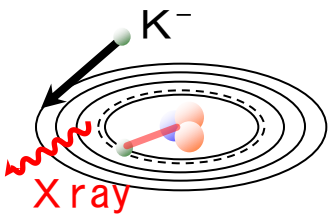
Nuclear & Hadron Physics



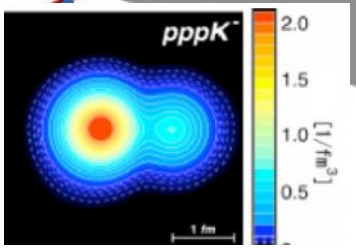








Kaonic atom



Kaonic nucleus

SKS

K1.8

K1.8BR

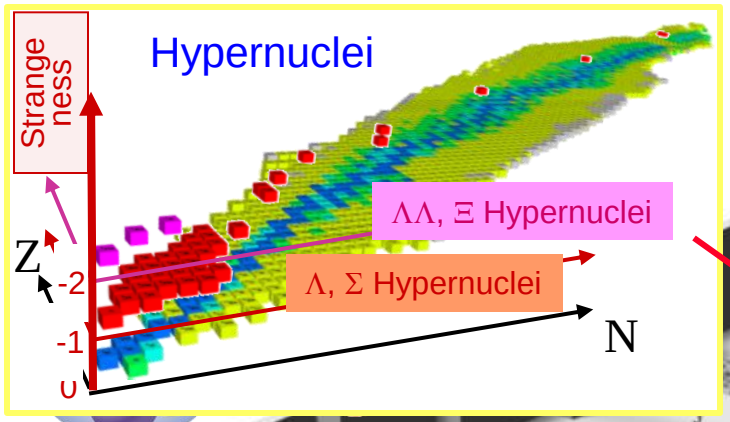
KL

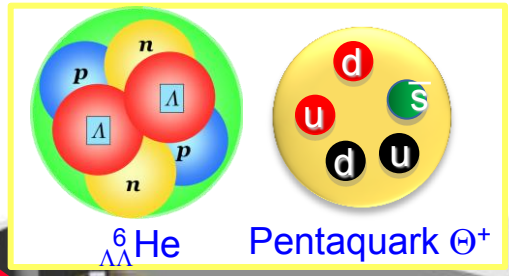
K1.1

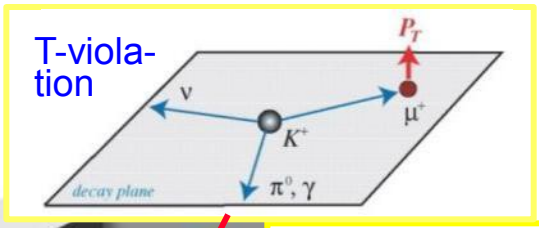
K1.1BR

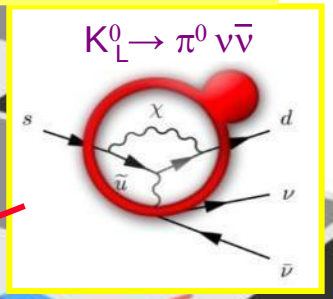
High p

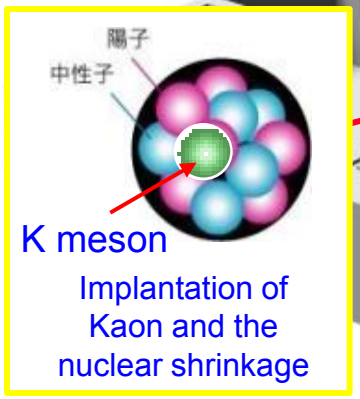
Nuclear & Hadron Physics

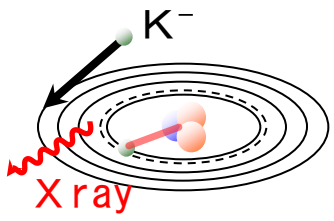


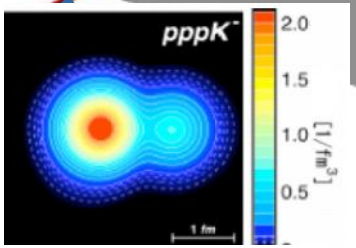




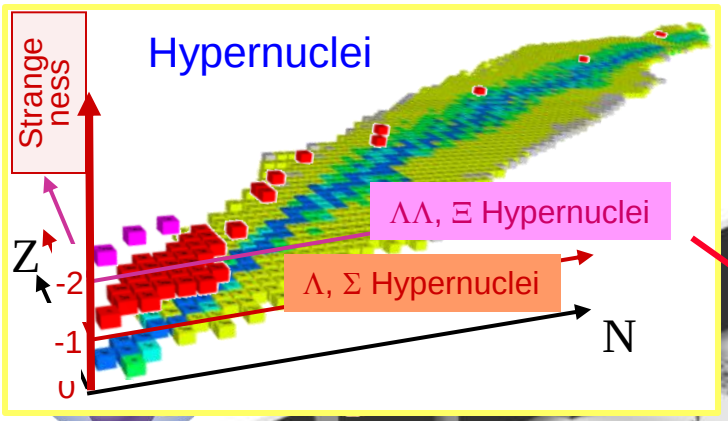


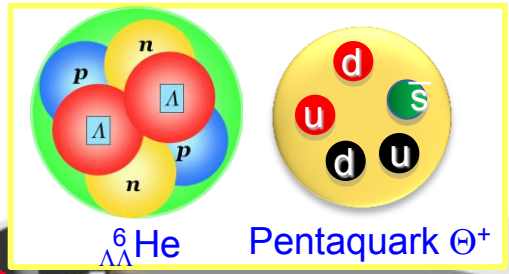


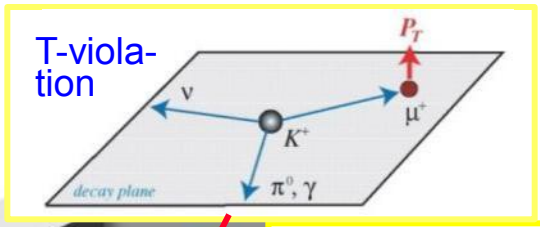


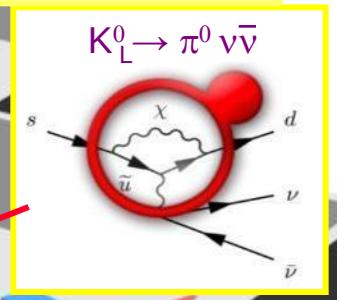


Nuclear & Hadron Physics









The Earthquake

We had steadily increased beam power. Many fruitful data sets and the results were being published. But the earthquake happened.

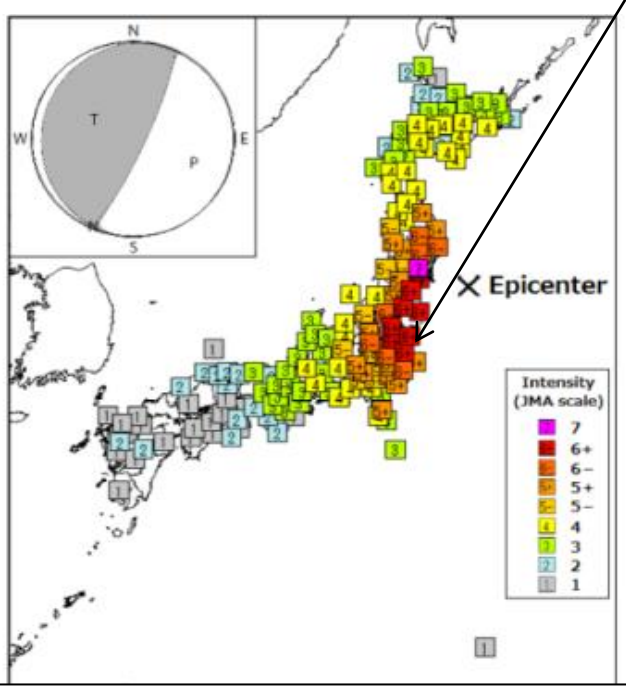
Whereas Japan's land area is only 0.25% of the total land area of the world, 20 % of earthquakes of the world occurs in Japan.

Japan is "a land of earthquakes".

An earthquake can happen anytime, anywhere in Japan.

The East Japan Great Earthquake

- The great earthquake occurred on March 11, 2011.
- The seismic intensity: 6-minus (JMA scale) at J-PARC.
- Although Tsunami hit the Tokai-site coast, the height was fortunately below the floor level of J-PARC.



Seismic Intensity (Data from National Research Institute).

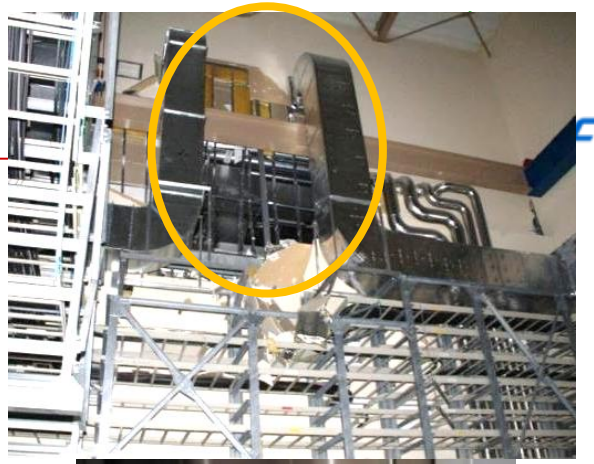
Entrance of the Linac

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

Damages on the Linac

- **Flooding in the accelerator tunnel:** Broken and corroded
- **Deformation of the building:**
  - Displacement: accelerator components
  - Damaged or broken: many partition walls, pillars and floors
  - Unavailable cranes : deformed rails

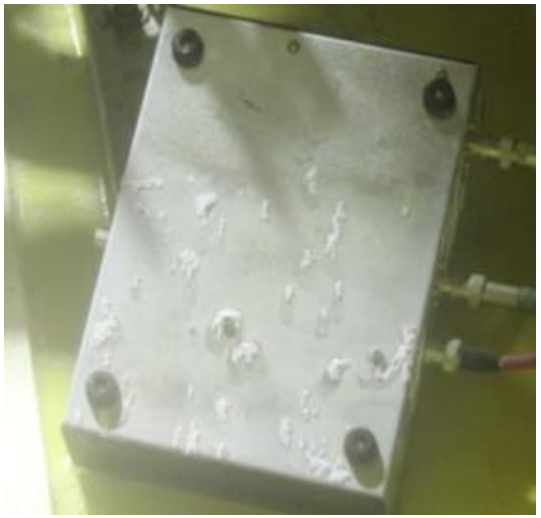
  Restored in the klystron gallery just two weeks ago!
- **Strong shaking:**
  - Broken: beam monitors, bellows, air ducts and water plumbing
  - Wavy road: Not restored yet!
- **Damage on air-conditioning system:** Accelerator components left for several months in poor condition (high temperature and humidity)



Flooding at the Linac Tunnel

Inside of underground tunnel

Groundwater leaked into the tunnel: depth of 10 cm (150 tons) within two weeks

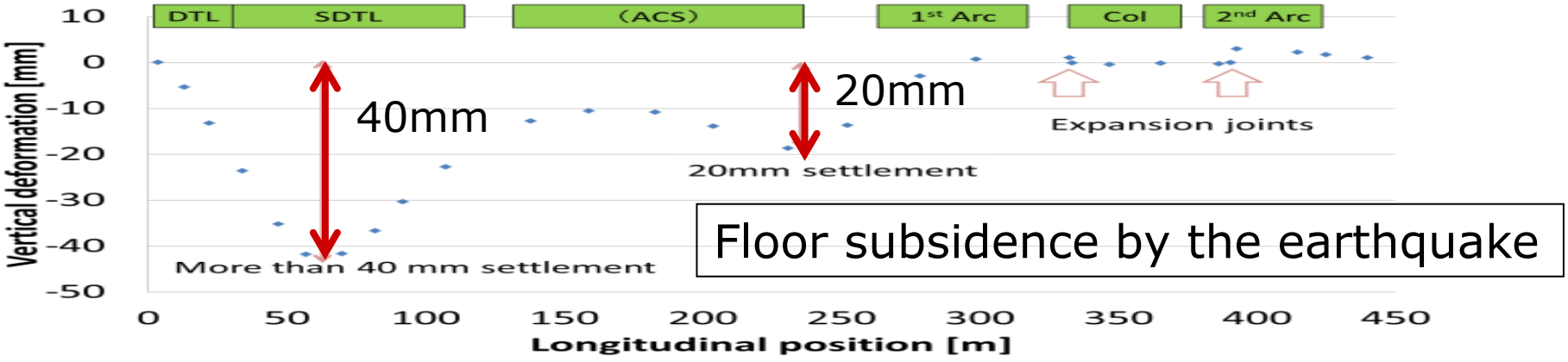


Corroded pre-amplifier boxes on the floor by strong alkaline.

Some flooded pumps were broken.

Subsidence of the Tunnel

- Subsidence: 40 mm (DTL and SDTL section) and 20 mm (now BT, future ACS section)
- Continued floor elevation change by June: precise alignment carried out after that.

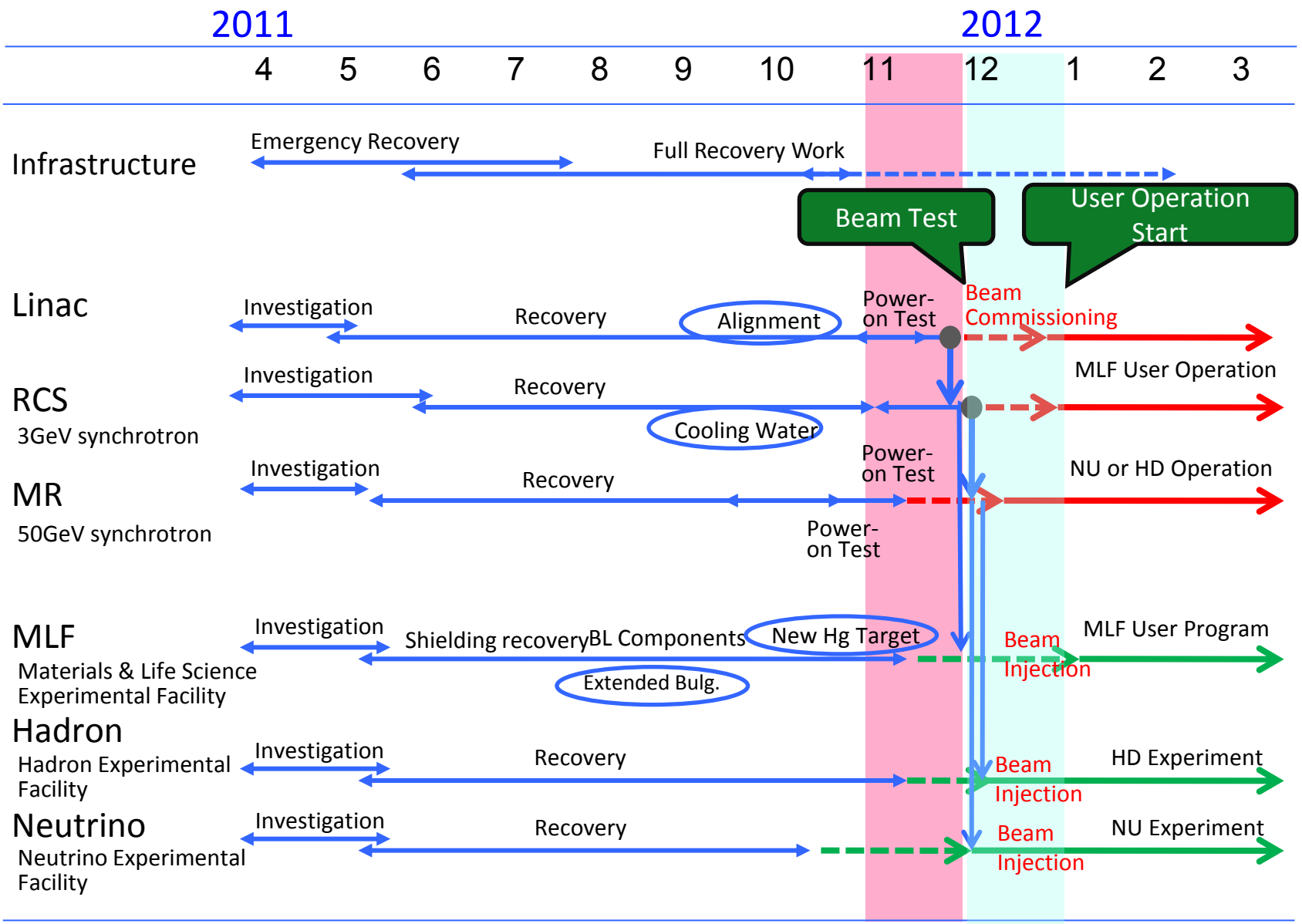


Floor subsidence by the earthquake

Floor level change by June, 2011

Restoration from the Earthquake

J-PARC Recovery Schedule (@2011.5.20)



Reason for the Quick Recovery

Reasons that we had to restore the J-PARC facilities by January, 2012.

- Demands from users, particularly MLF and T2K
- The law requests to supply beams to MLF users within one Japanese fiscal year that will end on March 31.

We decided to take minimum repair of the broken building to resume the beam acceleration as soon as possible.

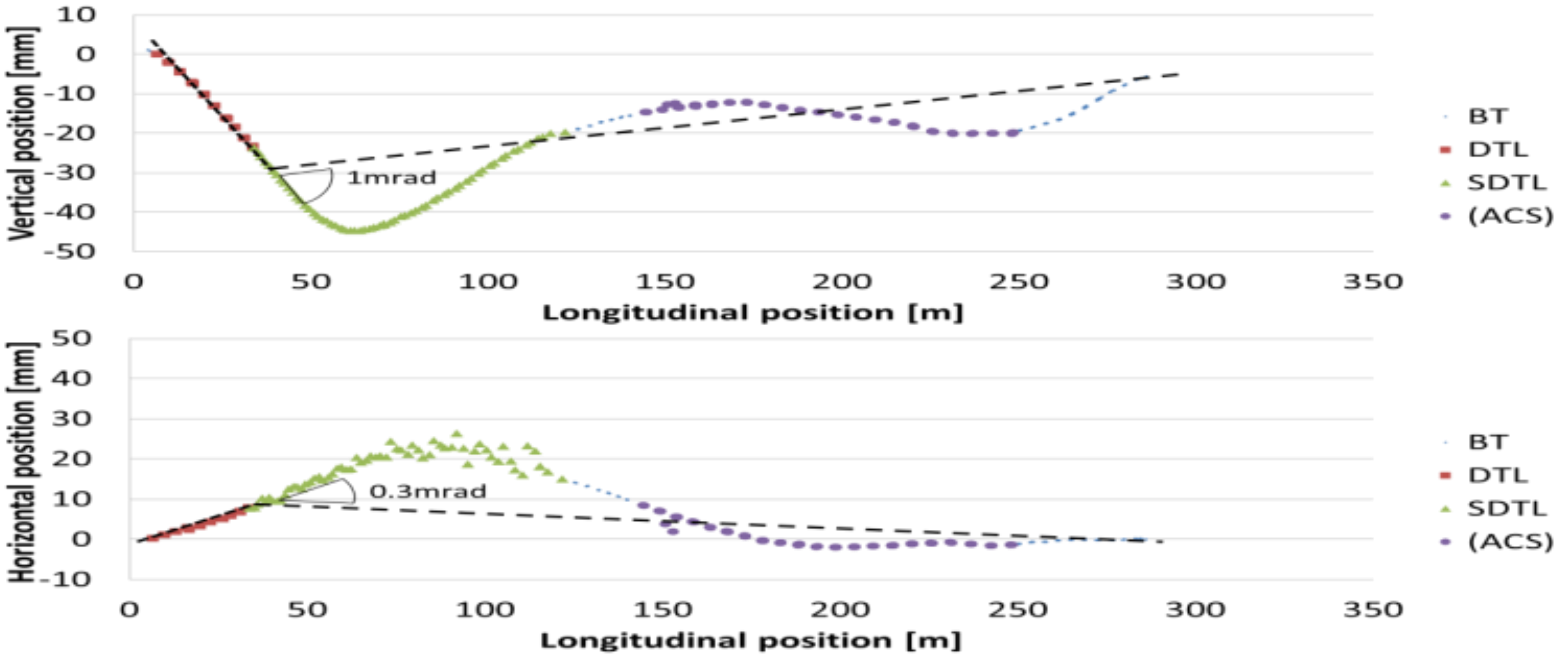
Beam simulation to keep the beam loss as the same level as before the earthquake with least restoration:

Results:

- Linac must be re-aligned but V-shape is approved.
- RCS (a few mm)is usable without re-alignment if power ≤ 300kW
- MR (several cm) must be re-aligned. (400 magnets)

Realignment Strategy of the Linac

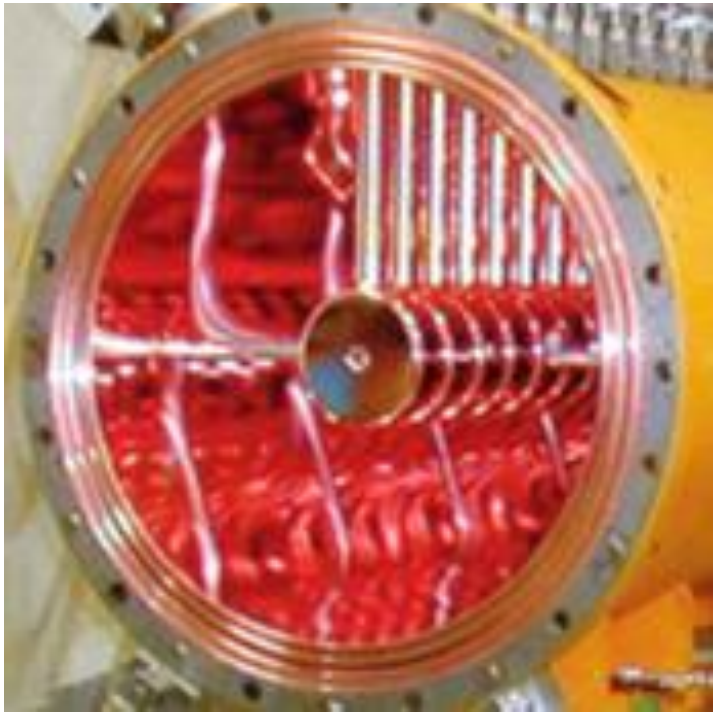
- Realignment of the DTLs is time consuming (estimated half year extra): many heavy cables for magnets, pipes, unit cavities, etc.
- To aim at an early restart, we decided to steer the beam by the steering magnets downstream of the DTL horizontally and vertically. (V-shape)
- This deflection of alignment axis (<1 mrad) shows no effect in beam simulation results.



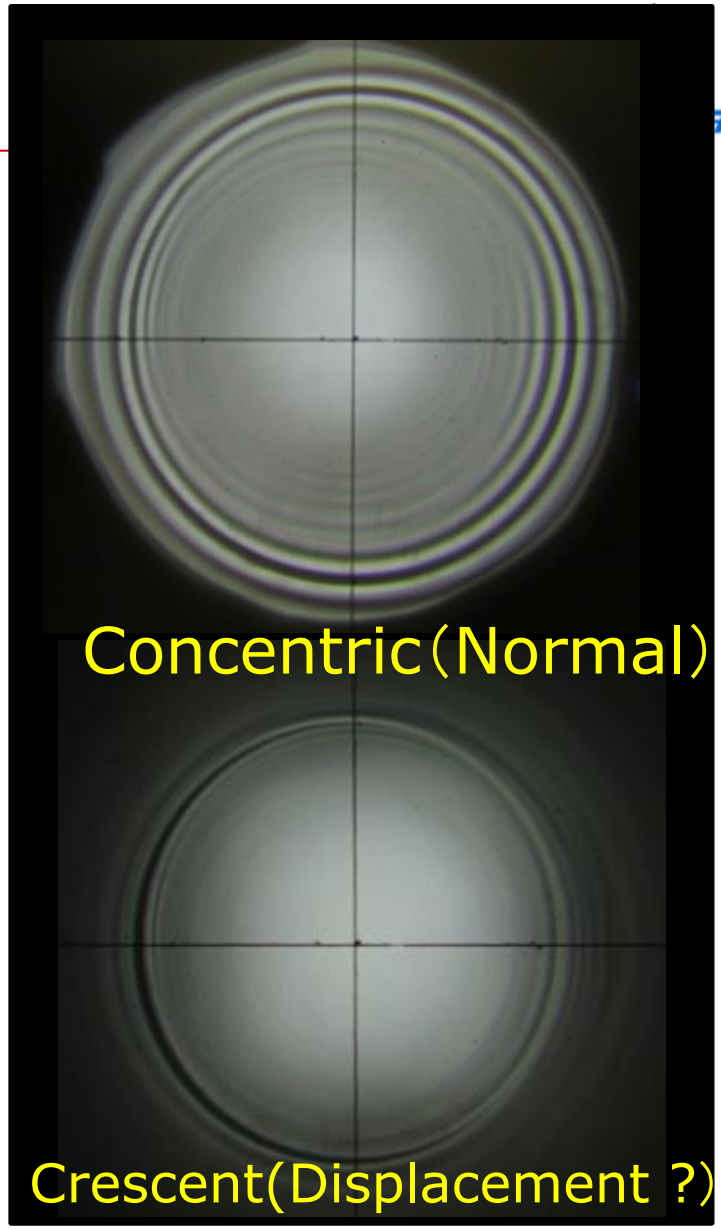
Displacement of components and target realignment line (dotted line)

Drift Tubes in DTL

Our biggest concern was displacement of drift tubes that they were like pendulums.



Inside view of the DTL

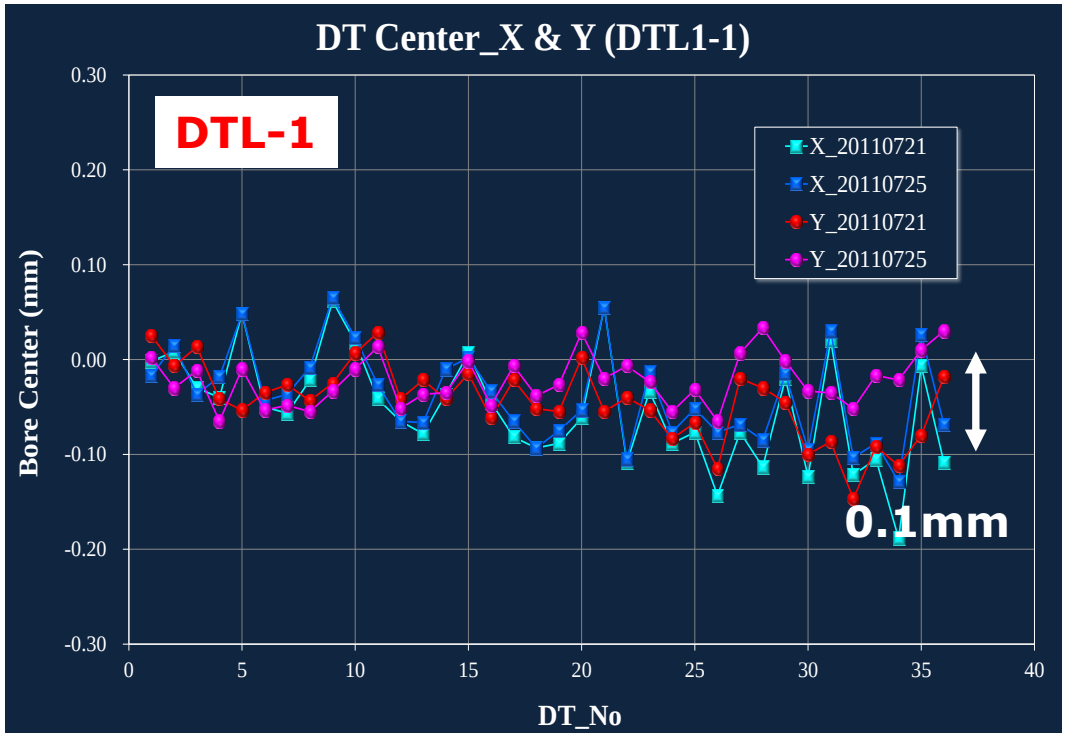


Inner view of the bore of the DTL by an alignment telescope.

Examination of DT Alignment

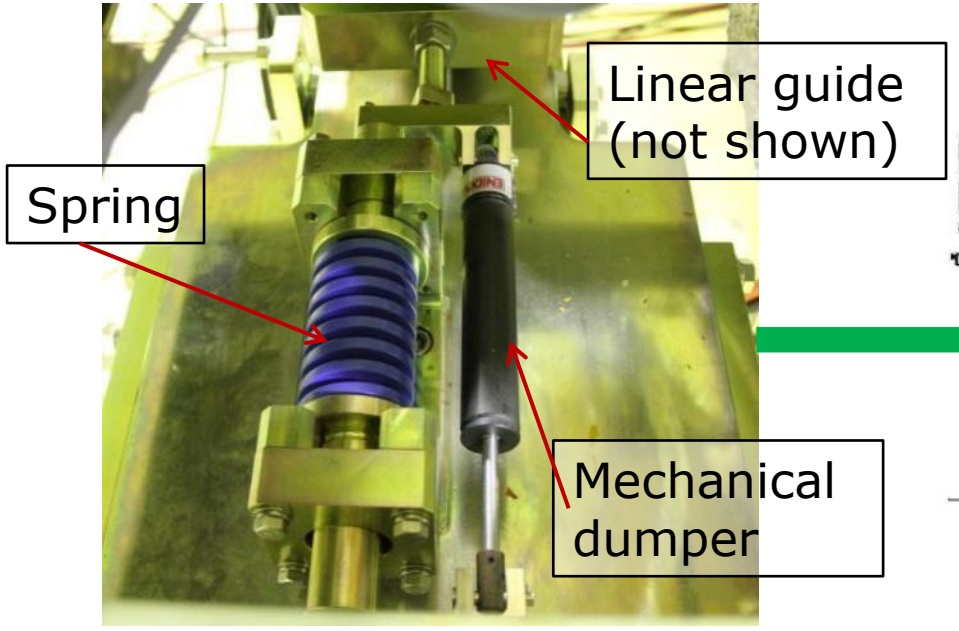
- Displacement of the drift tubes in the DTL and SDTL cavities was examined by an alignment telescope.
- Displacement of 0.1 – 0.2 mm for a few drift tubes in the DTL1: acceptable level by beam simulation

  → We decided not to perform the DT re-alignment.
- In fact, no reduction of the beam transmission rate is observed during the beam operation in this area.

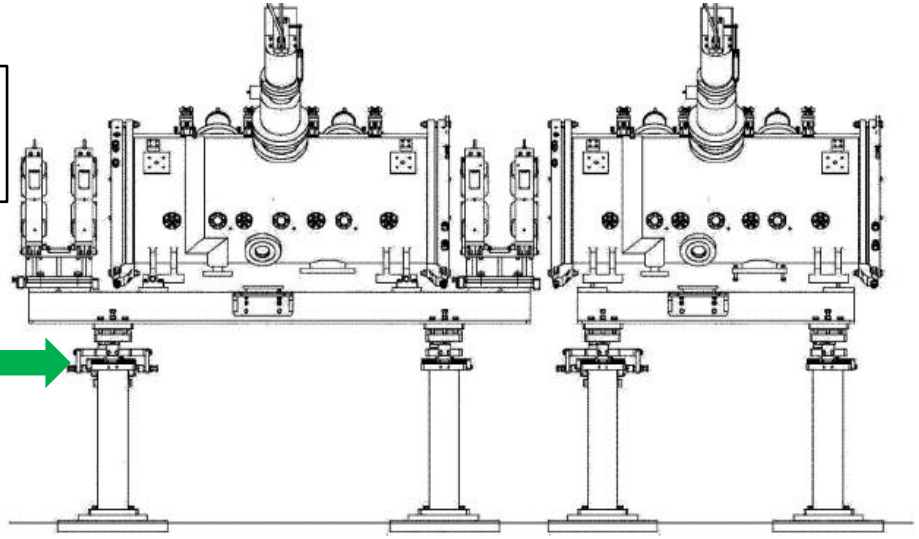


Earthquake Proof System

- An earthquake proof system is equipped to the DTL and SDTL tank support.
- The system gives flexibility to the movement in X and Z axes.
- Thanks to the system, we think, we didn't have significant displacement of the drift tubes.



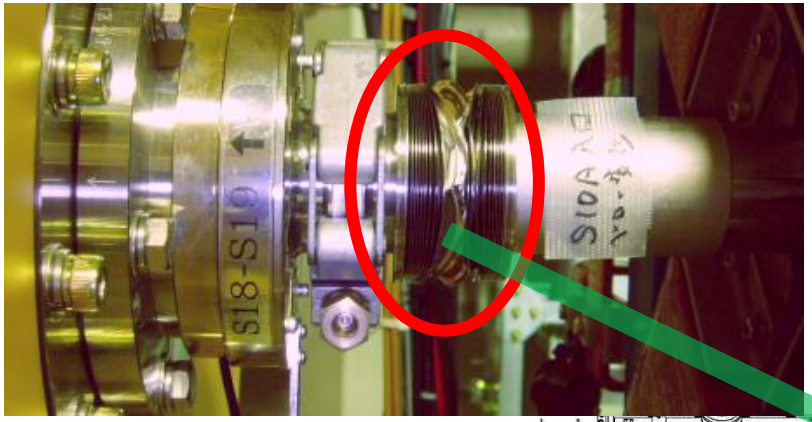
The earthquake proof system



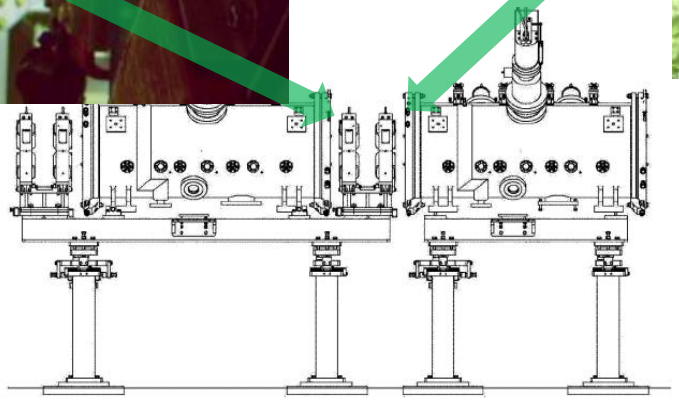
The SDTL cavity and support

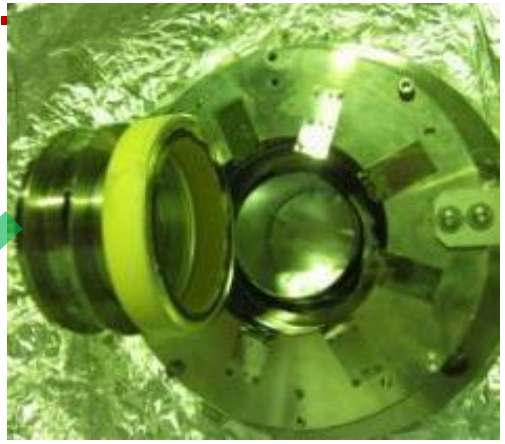
Side Effect of the Earthquake Proof System

- The mechanical flexibility helped against DT displacement.
- But bellows and monitors could not stand for these flexibilities and broken.
- In this case, time of "DT realignment >> monitor rebuild", Contributed shorter restoration, but…….
- Lessons Learnt: We should consider side effects in advance to mitigate the total damage.



Distorted bellows between SDTL tanks



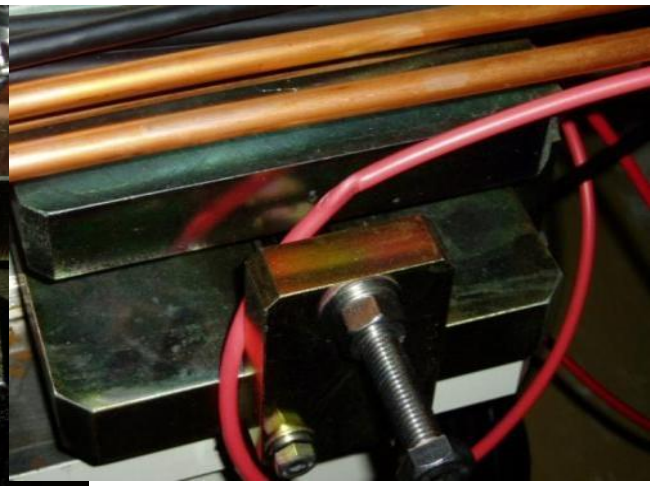


Broken current transformer: separated brazed ceramic parts and stainless parts

Disaster Will Happen

- We had to clear in the movable area to secure the earthquake proof system. But we can see some materials after the earthquake.
- We ignored to check this area, because we didn't expect big earthquakes: today, tomorrow, after tomorrow ---.
- Lessons Learnt: We have to recall the famous Japanese saying "A natural disaster will happen when we least expect it." by Dr. Torahiko Terada, physicist 1878-1935





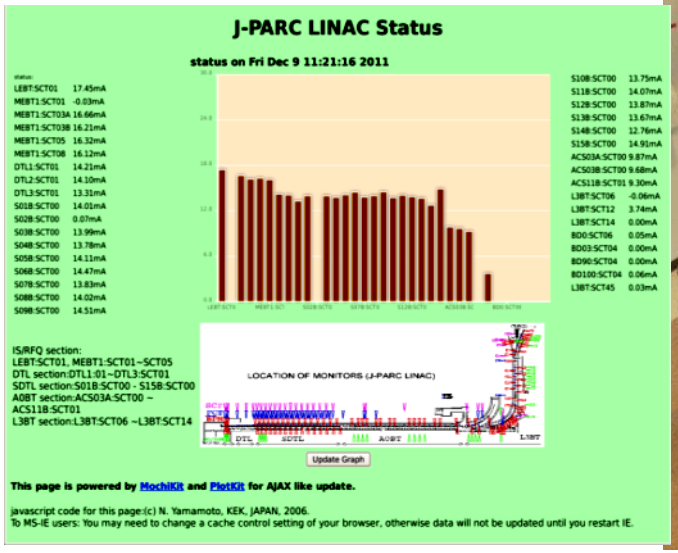
Beam Operation

All the J-PARC members worked hard and coherently to attain
the December Recovery.

The Day One (December 9, 2011)

14:00 Beam went throughout the Linac at 3 MeV with RFQ acceleration.

09:30 Key was on.



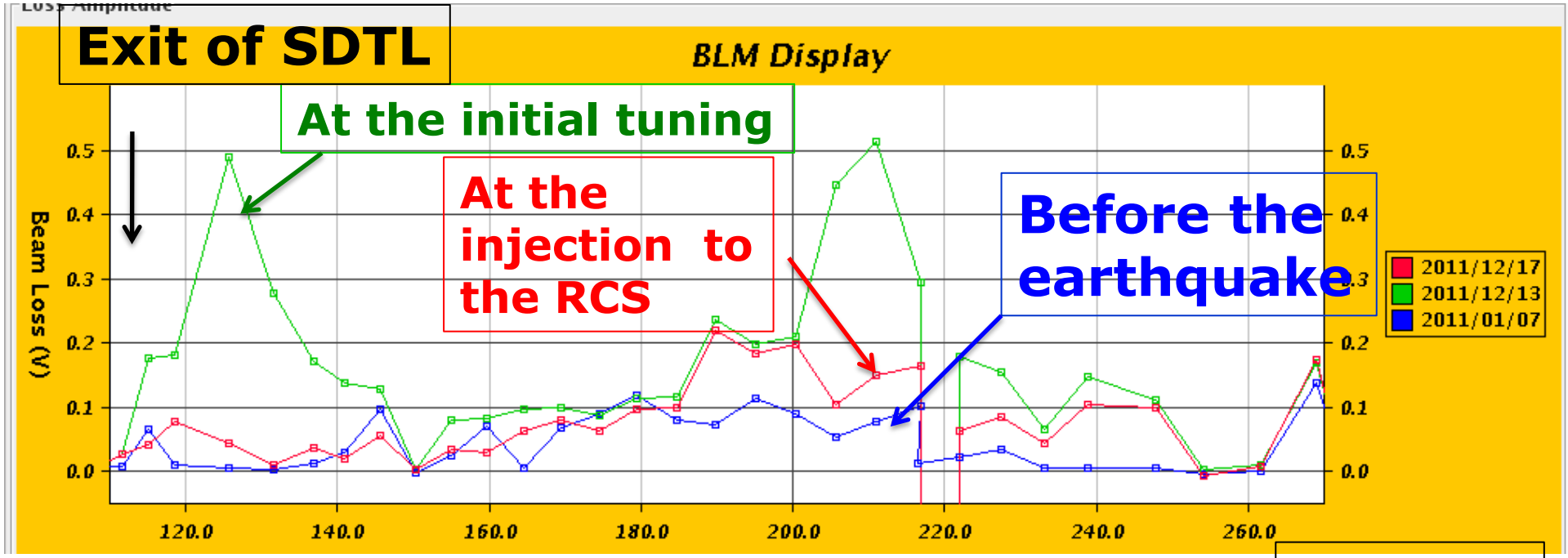
Issues of Linac after Operation

- **Beam loss and residual radioactivity is higher than before the earthquake.**

- **One of the SDTL cavity unit can not be operated at design RF amplitude.**

Beam Loss after the Beam Restoration

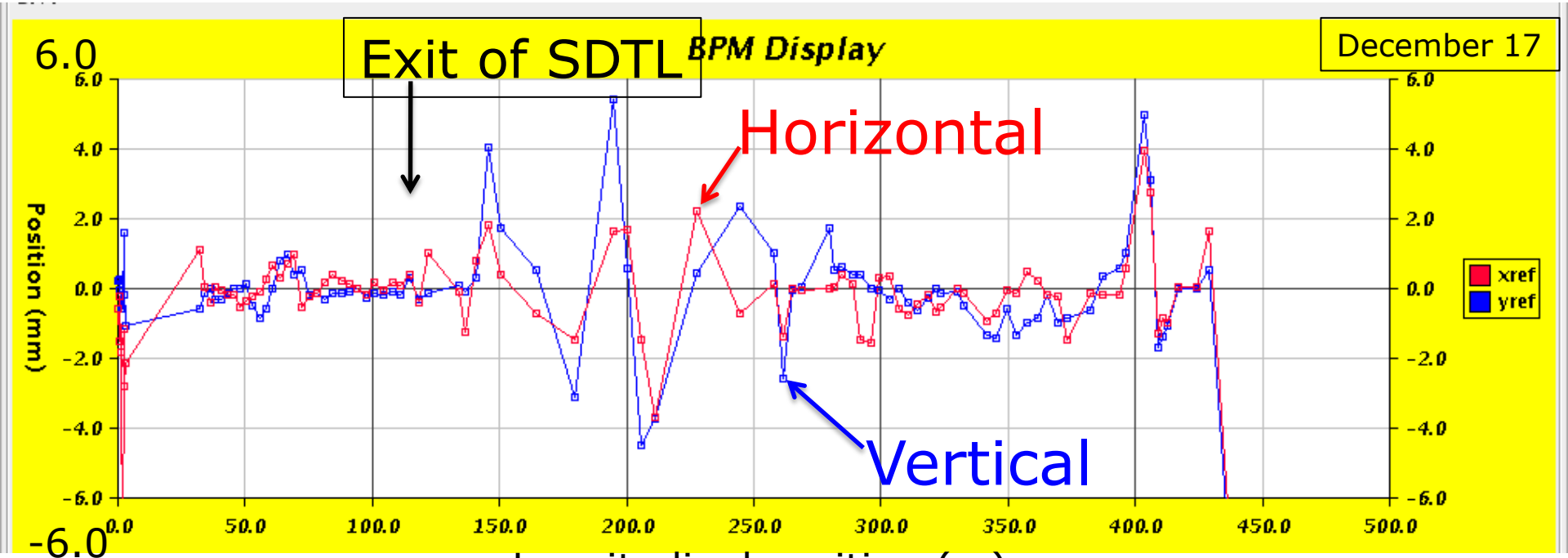
- We had a meaningful loss after the beam restoration, in particular after the SDTL straight beam transport section.
- We adjusted beam trajectories to reduce losses.



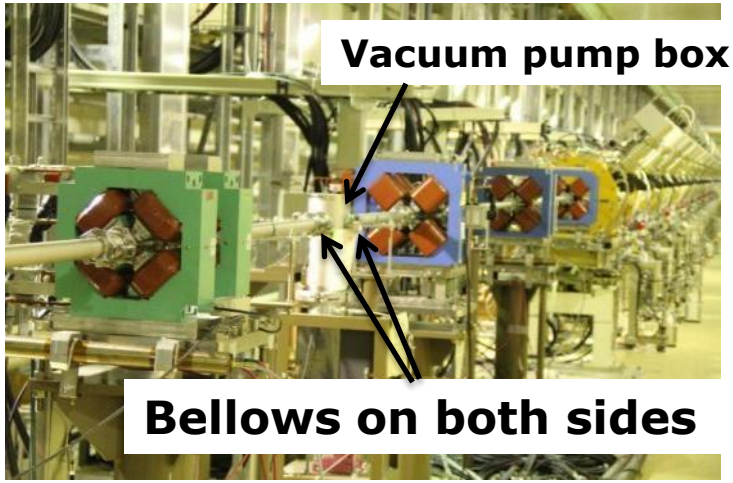
Beam loss monitor signals after the SDTL.

Beam Trajectories

- As a result of study, we found that beam loss was affected by the beam trajectory.
- At the minimum beam loss, we had to adjust beam trajectories at +5 mm and -5 mm.
- This was hard to understand. This is a linac!



Displacement of Beam Duct



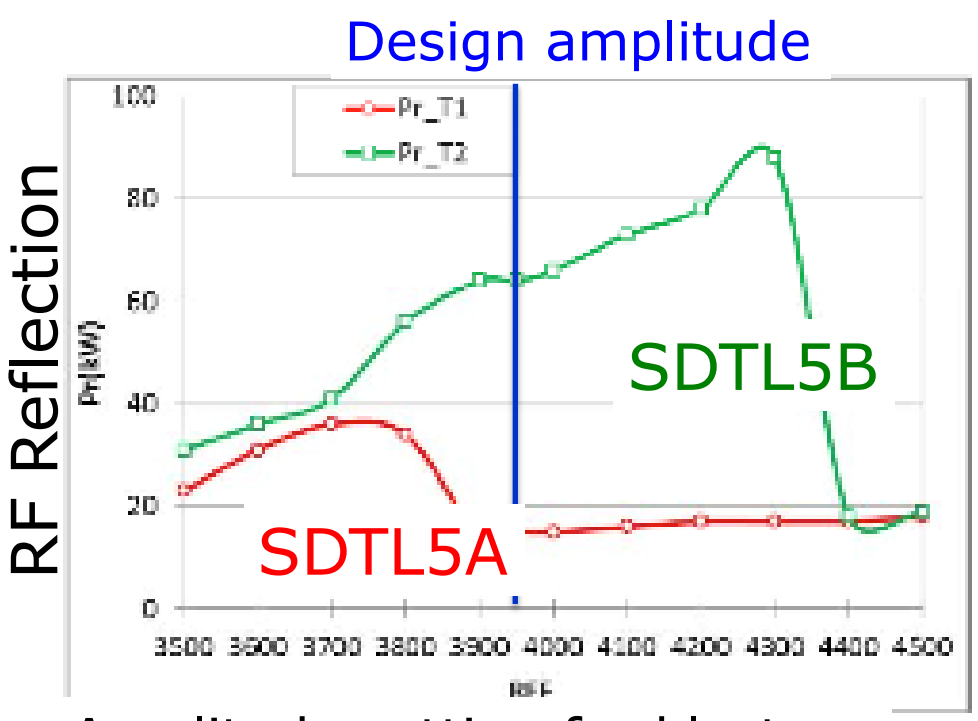
Displacement of the box.
Deformed bellows are shown.

- High radiation dose points at the vacuum pump boxes
  →We found larger displacement than expected.
- After re-alignment of the boxes and ducts, beam loss was reduced as before the earthquake.
- We took little concern of the ducts rather than magnets.

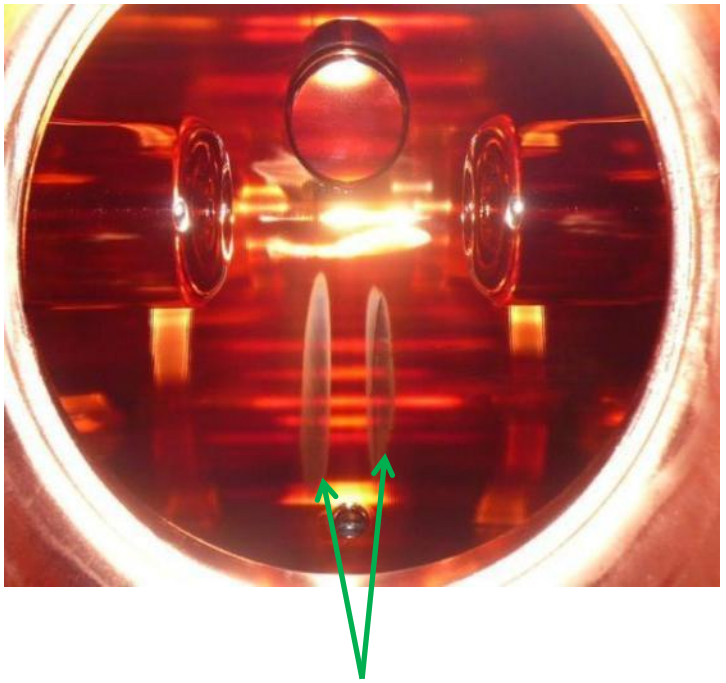
- Lessons Learnt: We should consider peripheral devices as well as the main components.

Discharge Problems at the SDTL

- It is hard to operate at the designed amplitude for SDTL No.5 units after the earthquake.
- To avoid this region, we have to operate at higher amplitude (109 – 116 %) of designed value.



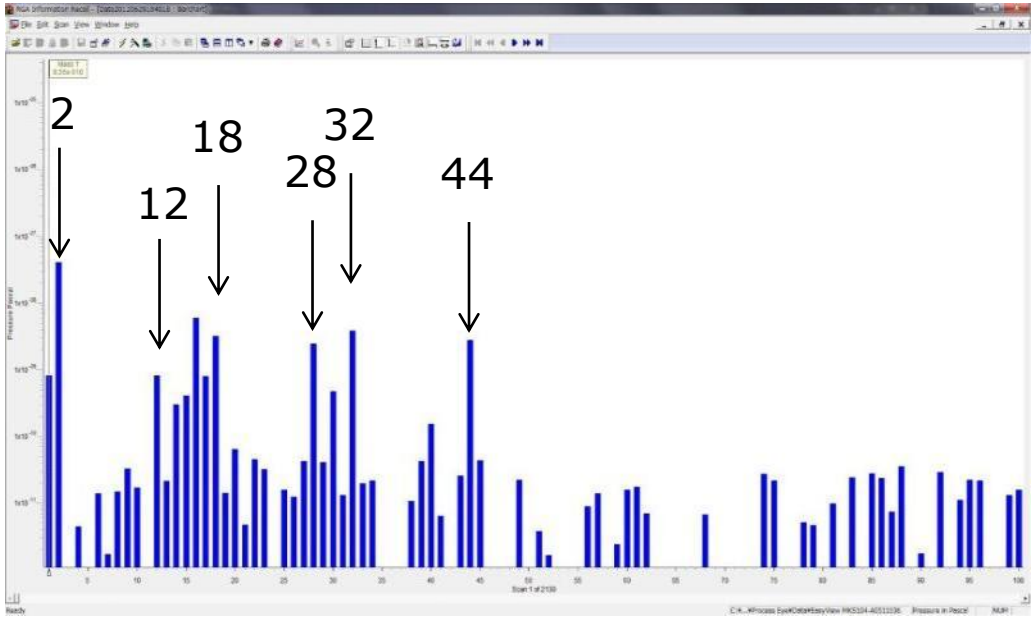
Amplitude setting for klystron



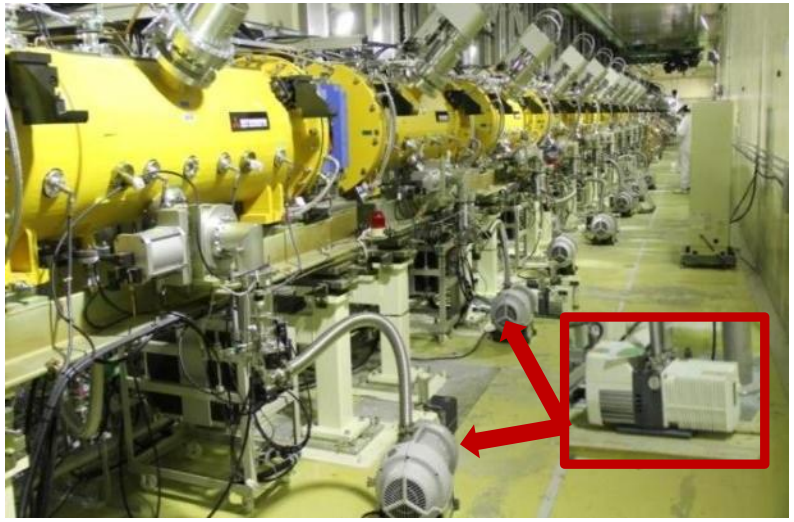
Inside view of the SDTL#5B cavity. Color change bands can be seen.

Measures of the SDTL Discharge

- There are many peaks in the Q-mass data: some hydro-carbon origin components
- We suspect that the cause is multipacting by hydrocarbons.
- We used oil rotary pumps. Routine operation with ion pump had seldom problems, but at restoration, by several vacuum purge processes, oil vapor may back streamed.
  → We replaced oil rotary pumps with oil free ones.
- Lessons Learnt: We should consider quality of vacuum.



Qmass results in the SDTL5B vacuum



Oil rotary pumps are replaced with scroll pumps

Aftereffects of High Humidity

- Used dehumidifiers in the restoration stages.
- But high humidity (> 70 %) caused many troubles after the beam operation: discharge at the ion pump connectors, bad electricity connection, poor insulation.
- Lessons Learnt: We should keep off high humidity. (We know, but in realistic, it is not easy to achieve.)

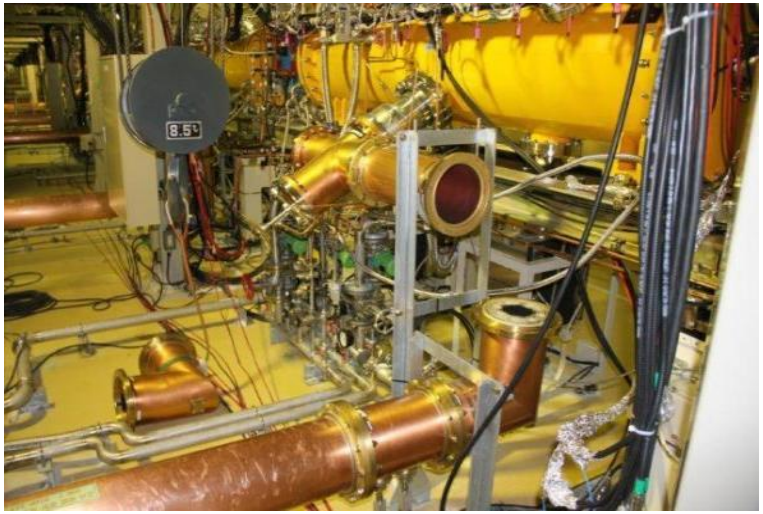
Temperature and humidity at the SDTL cavity

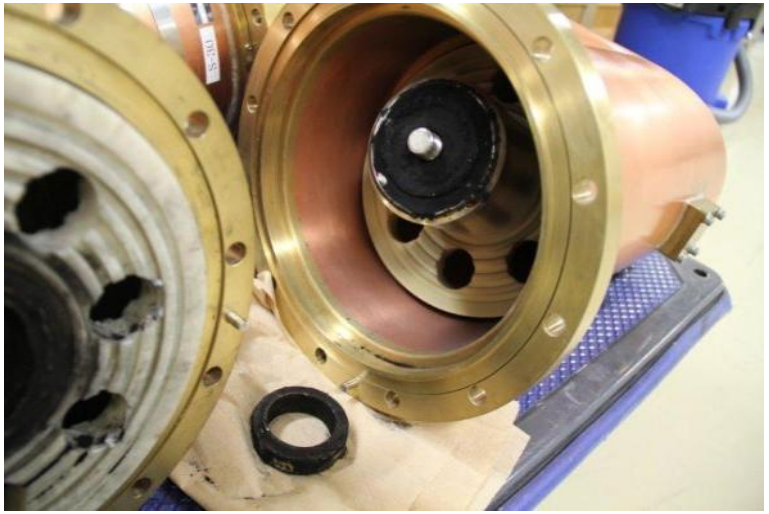
Discharge at the Ion Pump connector at the SDTL9B

Bad electricity connection at the connector box.

Loose Connection of Coaxial Line

- After the user operation, we had troubles several times due to the loose connection of coaxial lines.
- Although we checked the connections during the restoration, the screw became loose.
- Troubles from aftershocks. No spring mechanisms!
- Lessons Learnt: We should consider occasional movement in mechanical design.

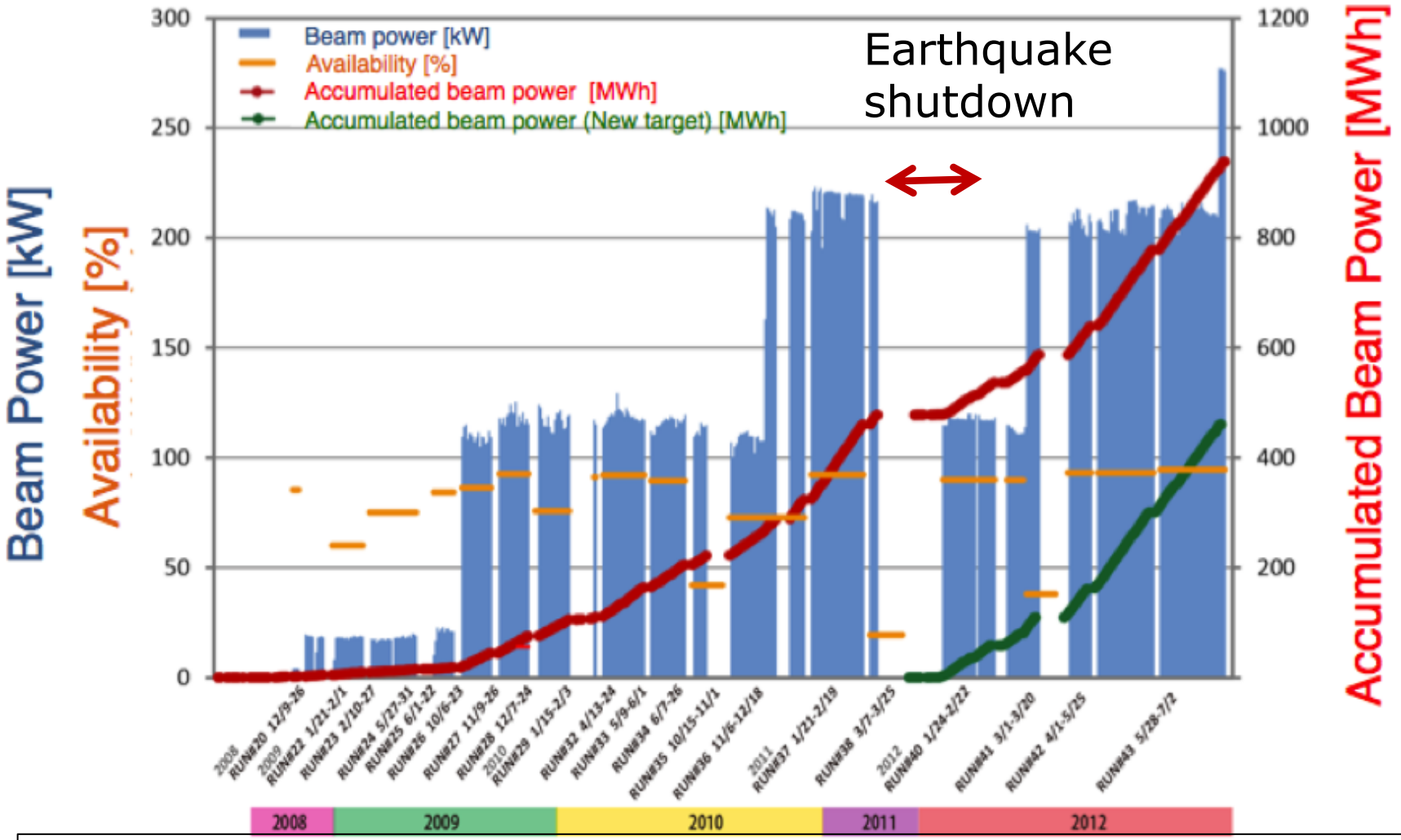




Loose connection of the coaxial line at the SDTL.

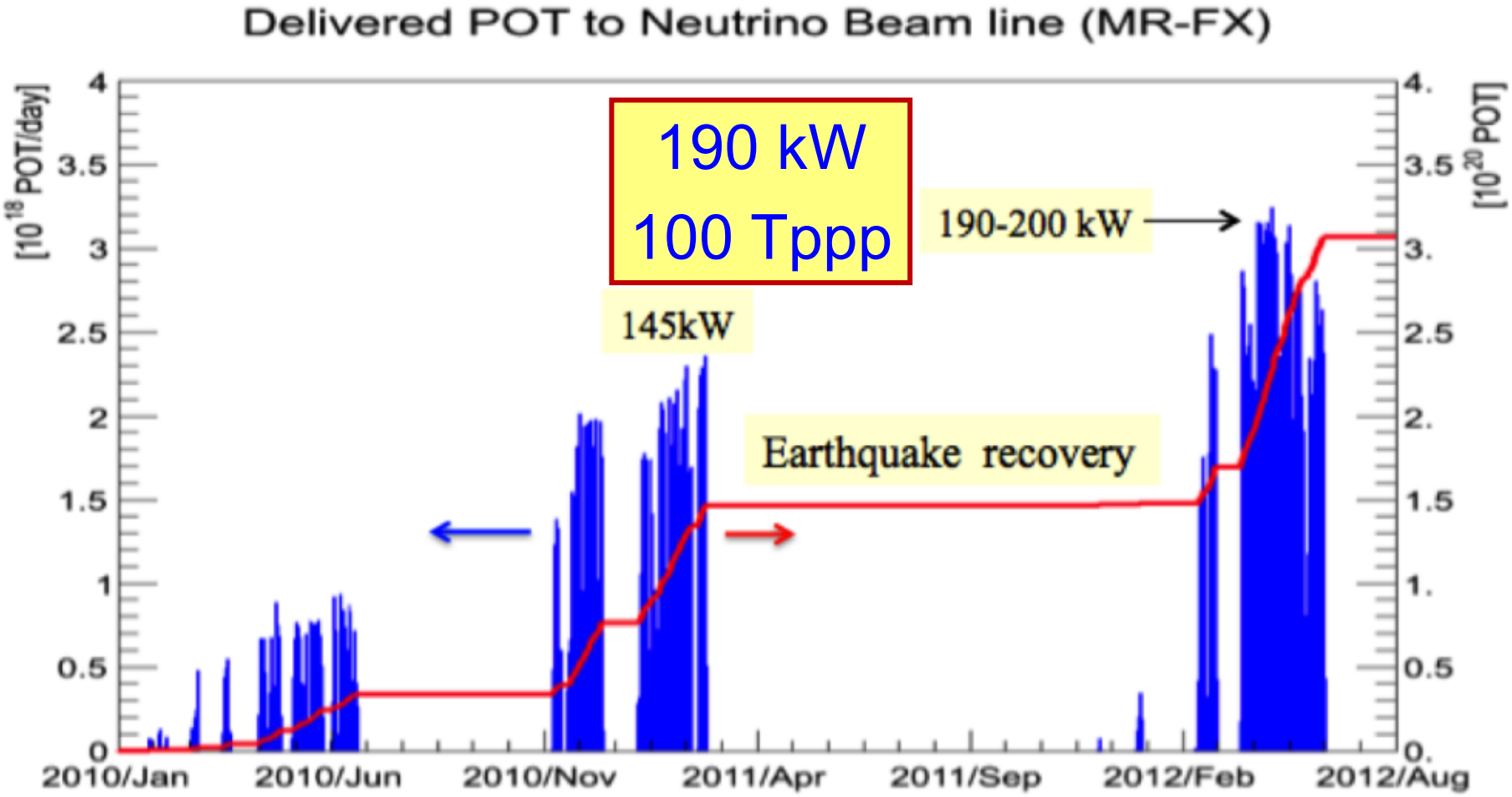
Accelerator Performance and the Future

History of Beam Delivery from RCS to MLF



In the last three days of the run, stable operation of 275kW @3GeV (linac power 16.6kW) successfully demonstrated.
Availability: 94% (April to June, 2012)

History of Beam Delivery to the T2K Exp.



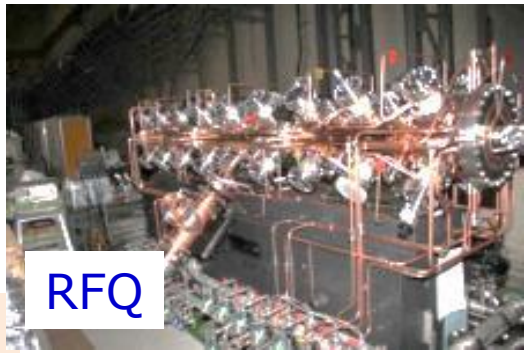
T2K accumulated the beam of ~3x10^{20} POT and
11 electron neutrino candidate events were found.

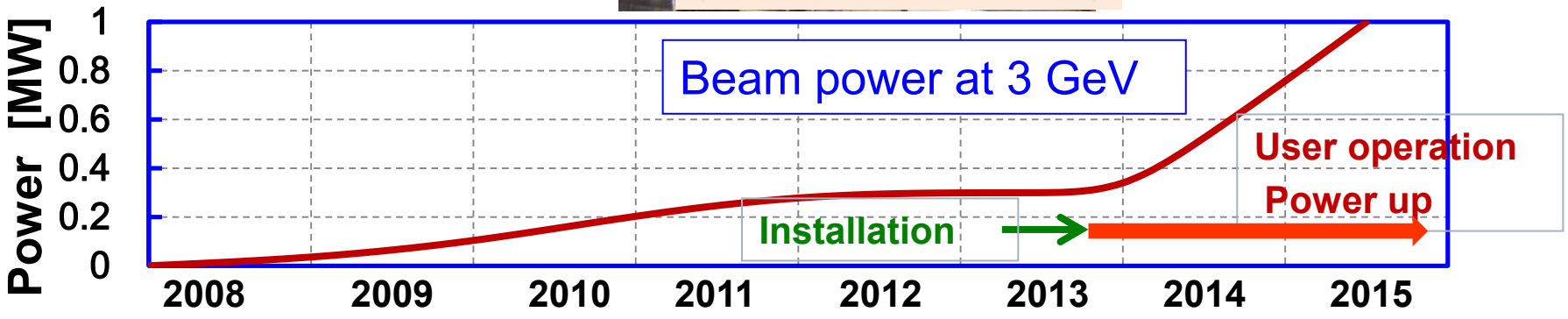
(Before the earthquake: 6 events.)

Upgrade Plan of Linac

- The full energy (400 MeV) linac is necessary to reach nominal performance (1MW@RCS, 0.75MW@MR)
- For beam energy (181 → 400 MeV): New accelerating structure ACS(Annular-ring Coupled Structure), 400 MeV RCS injection
- For peak beam current (30 → 50 mA) : Front-end part (IS+RFQ)

Ion source using rf
(Collaboration with SNS)





Summary (1/2)

- J-PARC had severe damage by the earthquake, but it has been fixed in 9 months. User operation resumed in January 2012.
- Accelerator Performance after the Operation
  - Beam power is the same or higher than that before the earthquake.

Acc.	Energy	Before	Now
RCS	3 GeV	200 kW	200 → 275 kW
MR-FX	30 GeV	145 kW	160-200 kW
MR-SX	30 GeV	3 kW	6 kW

  - Availability for users: 90 to 94% (April to June, 2012)
  - The users accumulate data and many fruitful results are published.
- Linac performance upgrade
  - Construction of the 200-400 MeV linac, development of higher current ion source and RFQ are underway.
  - They will be installed in summer 2013 and we will ramp up the beam power.

Summary (2/2)

- We have many lessons learnt from the earthquake.
  - The earthquake proof system saved our re-alignment time of drift tubes, but we had side effects.
  - Should consider many items to mitigate damages: importance of peripheral devices, quality of vacuum, humidity, aftershocks, etc.
  - "A natural disaster will happen when we least expect it."

We don't hope big earthquakes again, but next time, we could manage better.

Appreciation

- We received encouragement, offers, donations, support, etc. from the world after the earthquake.
- Some facilities accepted user machine time as special allocations.

- We appreciate your kindness from all over the world.

New Start of J-PARC

Sunrise from the Pacific Ocean
on the New Year's day.
May success and happiness!