

Beam-Losses and Beam-Induced Quenches at J-PARC T2K Neutrino Beam Line SC Magnet System

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T2K project and neutrino beam line

● SC magnet system for Neutrino experiment at the J-PARC

- ❖ constructed since 2004
- ❖ completed in 2009
- ❖ no serious damage : the East Japan Great Earthquake
- ❖ restart physics run in this October

@Tokai village

0MeV Linac

3GeV PS

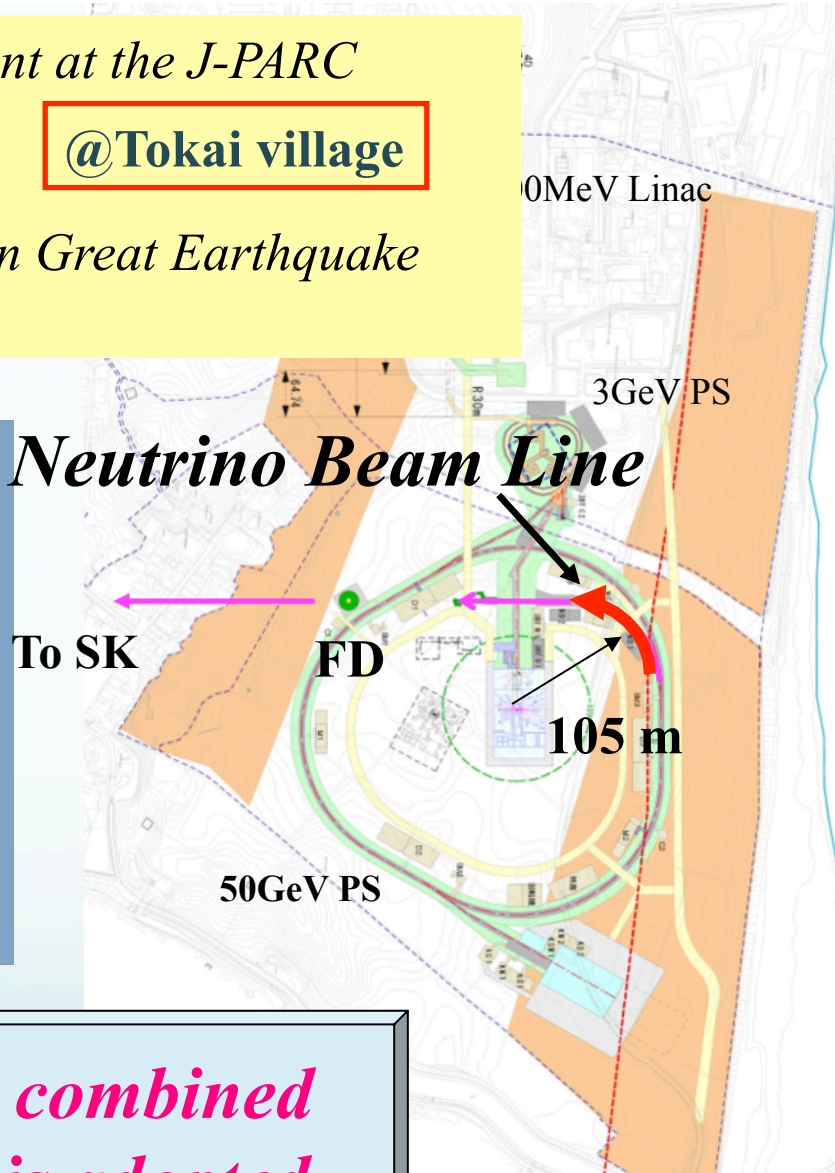
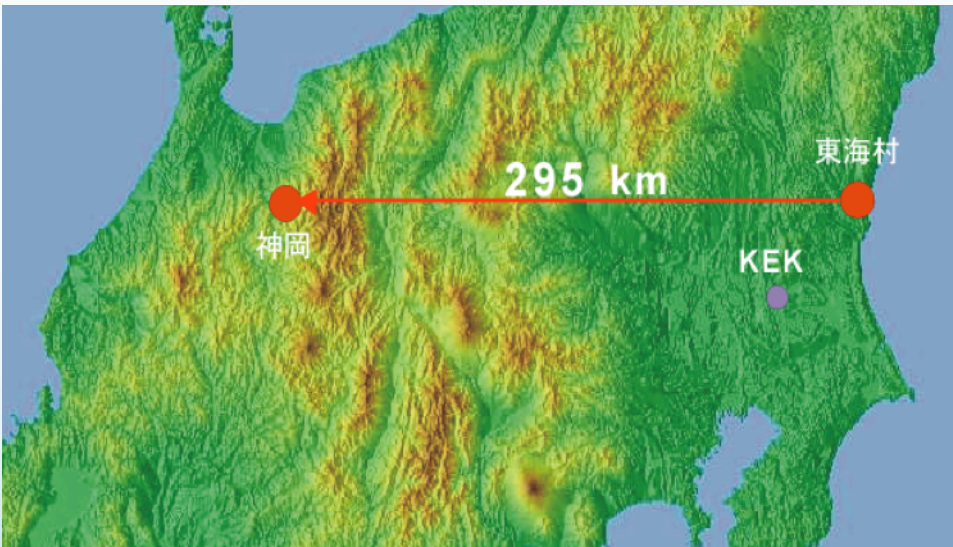
Neutrino Beam Line

To SK

FD

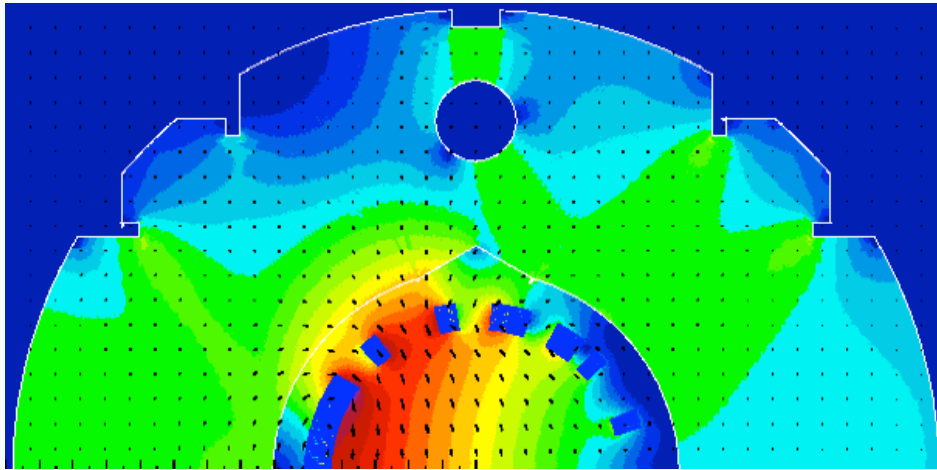
105 m

50GeV PS

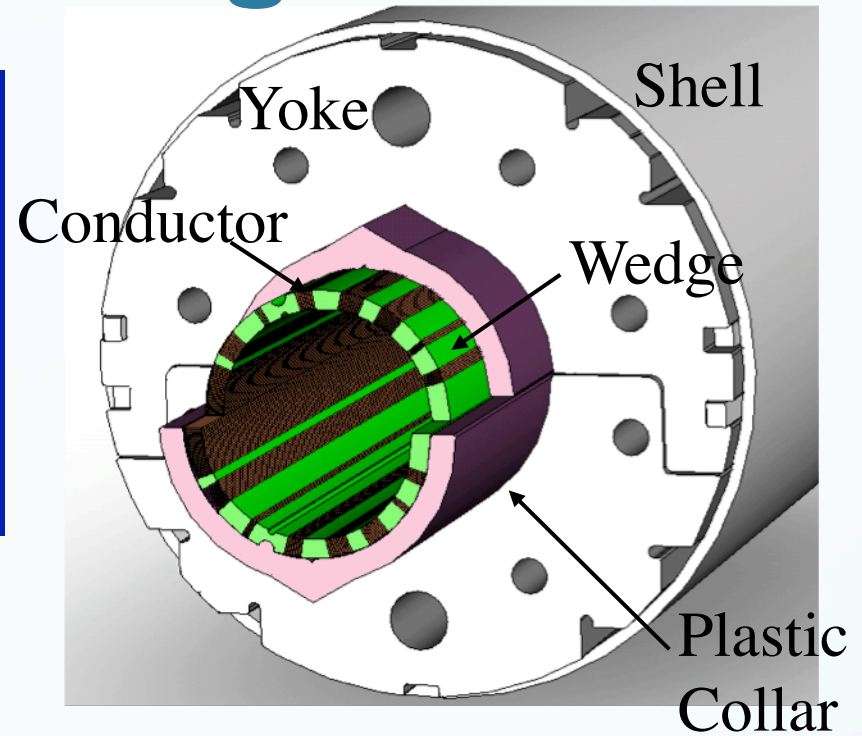


Superconducting combined function magnet is adopted

Magnet Design



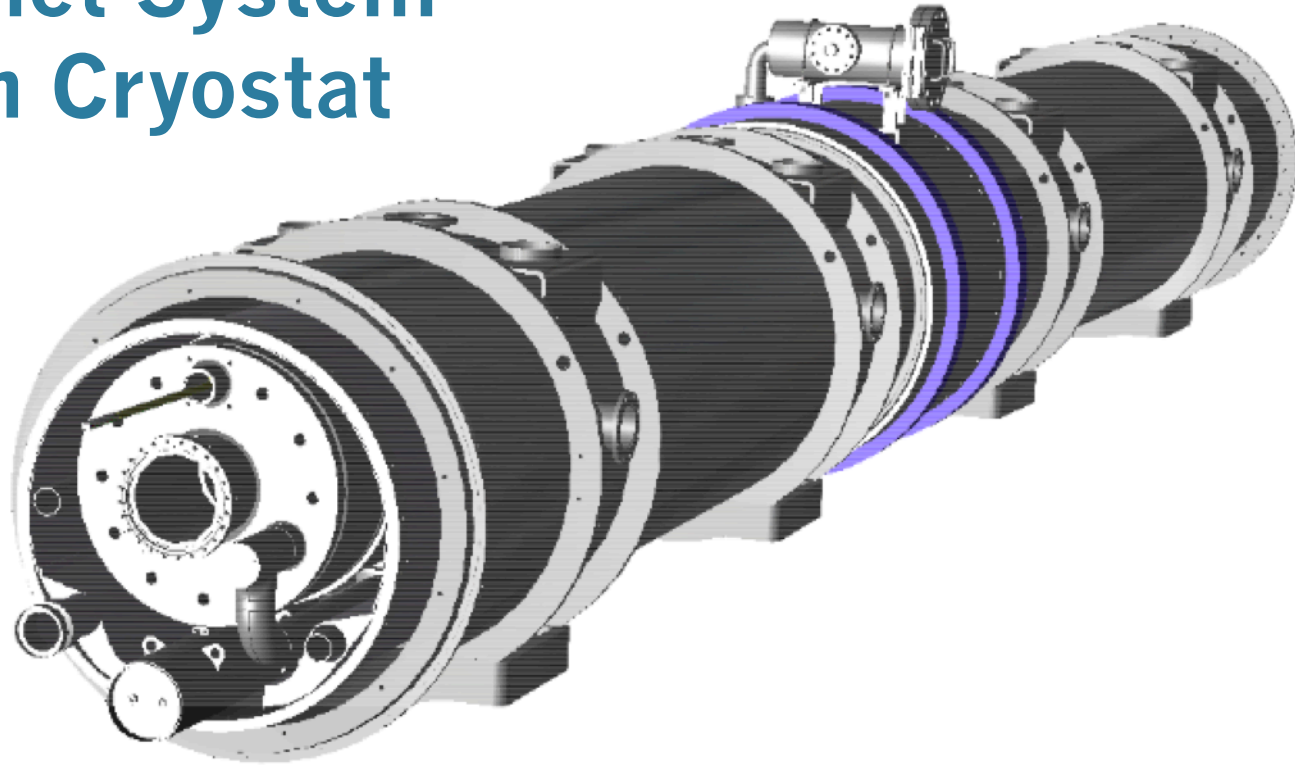
- ✦ **Coil ID.:** 173.4mm
- ✦ **Mech. Length:** 3630 mm @RT
- ✦ **Tmax:** < 5.0K (SHe)
- ✦ **Op. Current:** 7345 A
- ✦ **Dipole Field:** 2.59 T
- ✦ **Quad. Field:** 18.6 T/m
- ✦ **Peak Field on the cable :** 4.7 T



- ✦ **Op. Margin:** 72%
- ✦ **Inductance:** 14.3 mH
- ✦ **Stored Energy:** 386 kJ
- ✦ **SC Cable:** NbTi/Cu for LHC
Dipole Outer-L

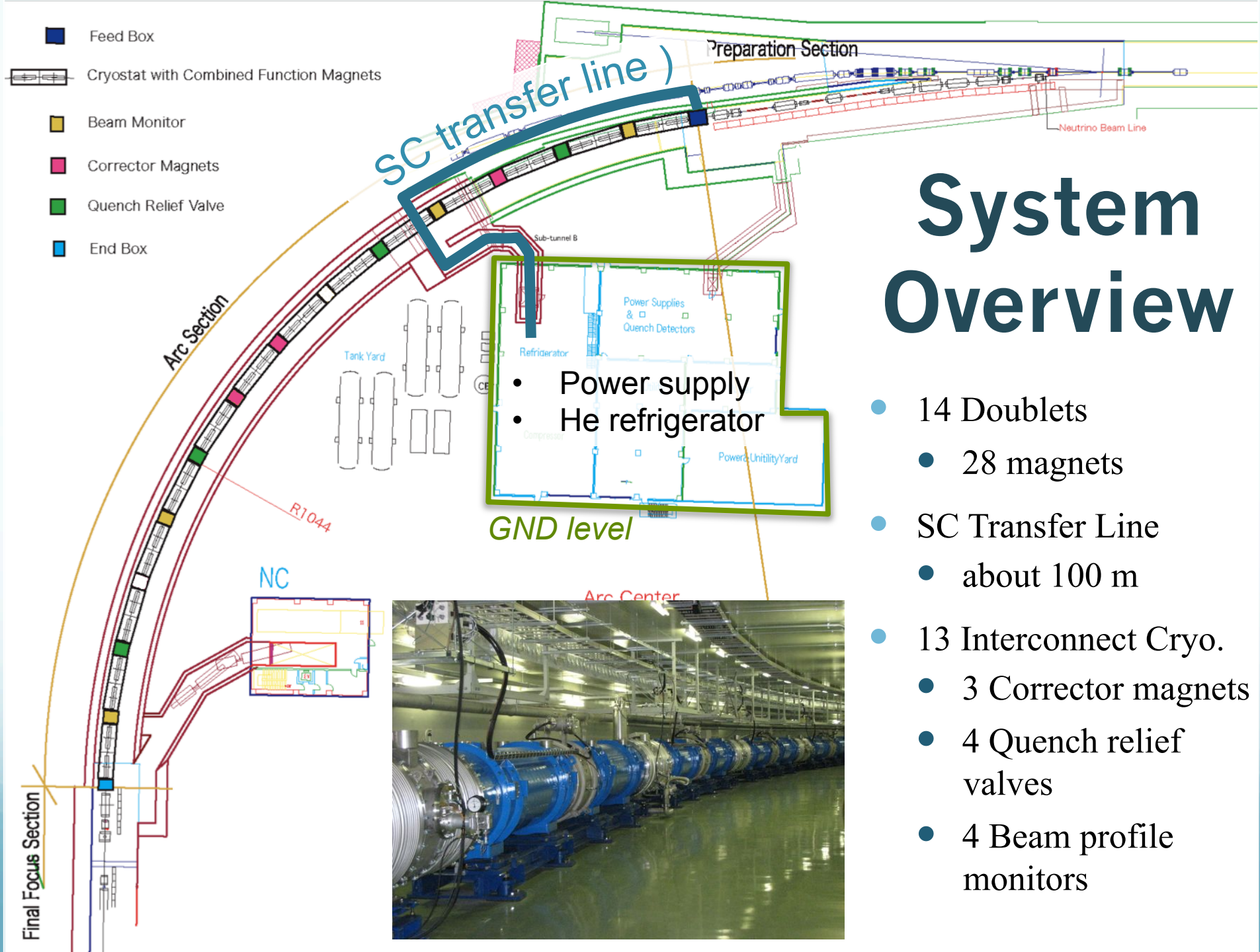
Present operation current : 4640 A for 30 GeV proton beam

Magnet System with Cryostat

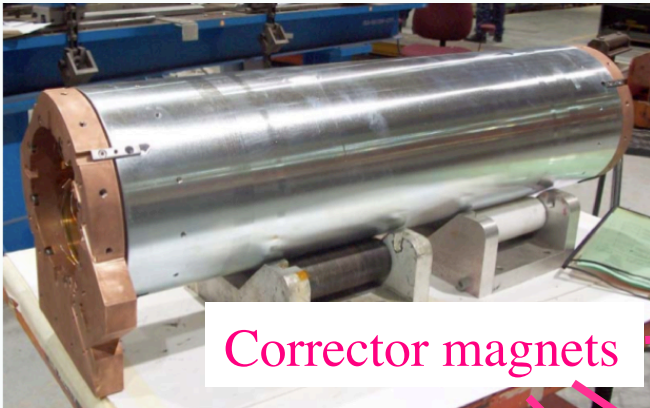


- 2 magnets assemble with 1 cryostat
 - F & D magnets (doublet optics)

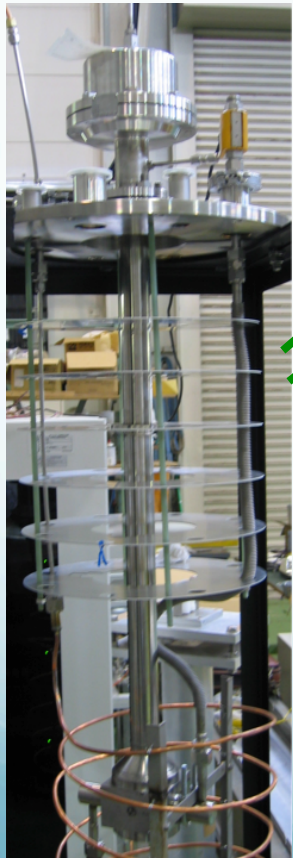




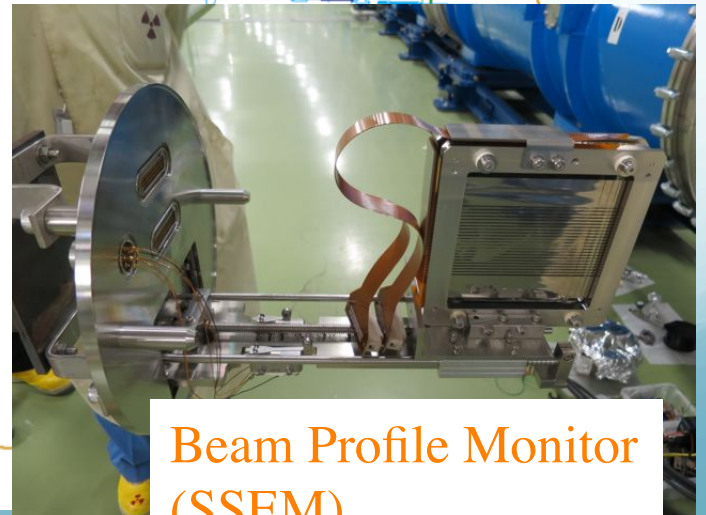
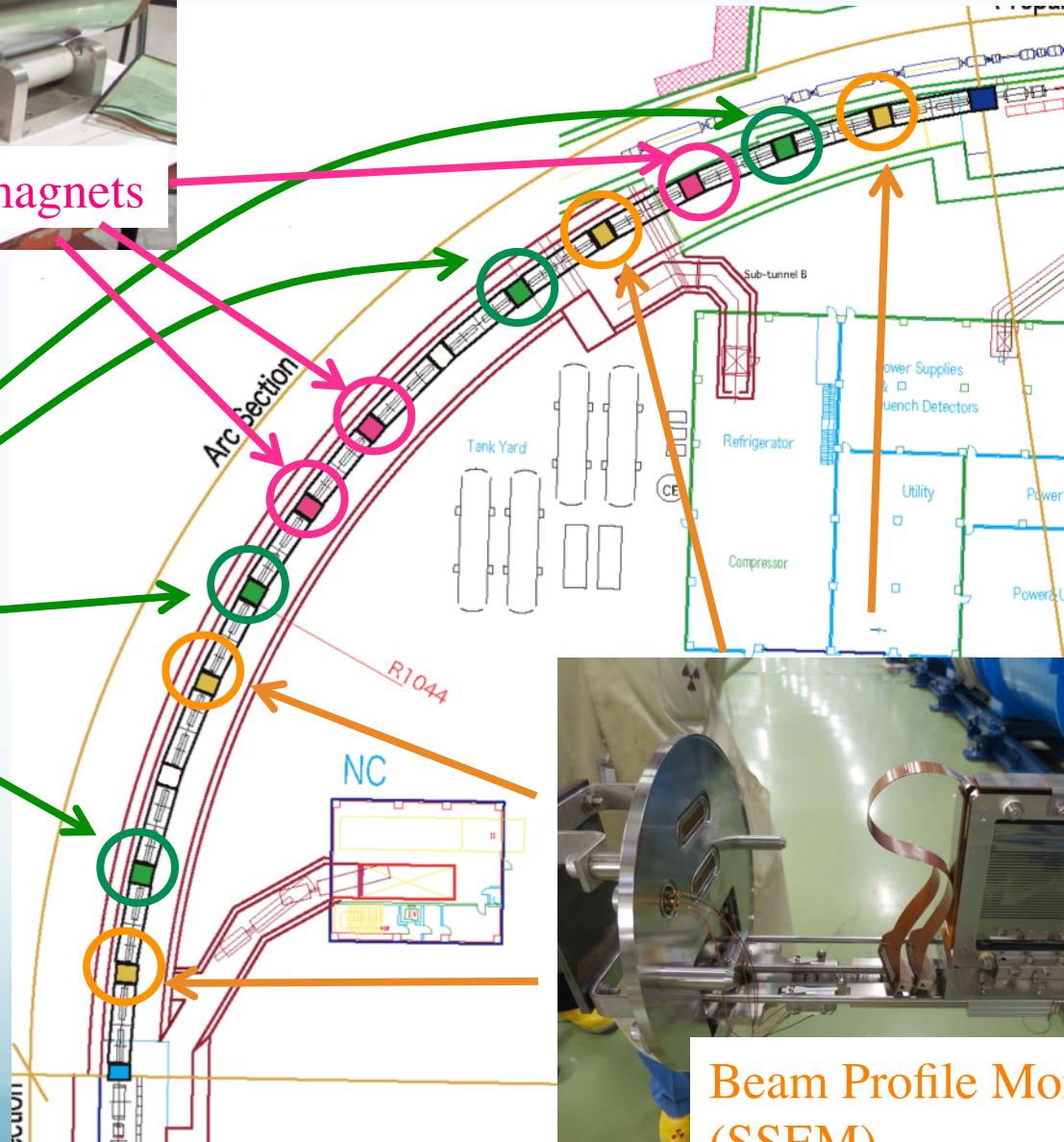
Interconnect



Corrector magnets



Quench relief valve



Beam Profile Monitor (SSEM)

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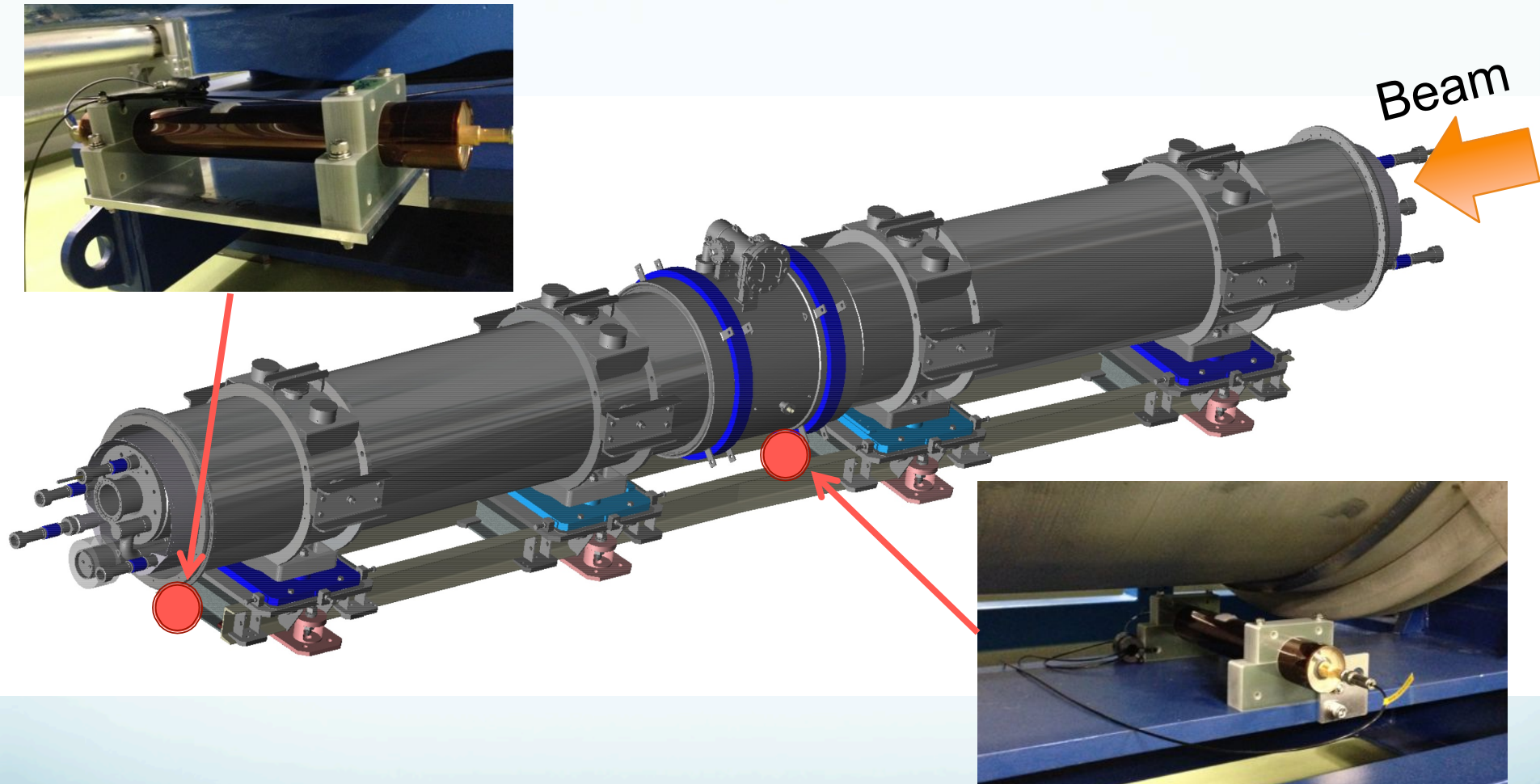
- ▷ Quench protection system

- ▷ 1st BIQ : 2009/05/28

- ▷ 2nd BIQ: 2010/11/28

✎ Summary

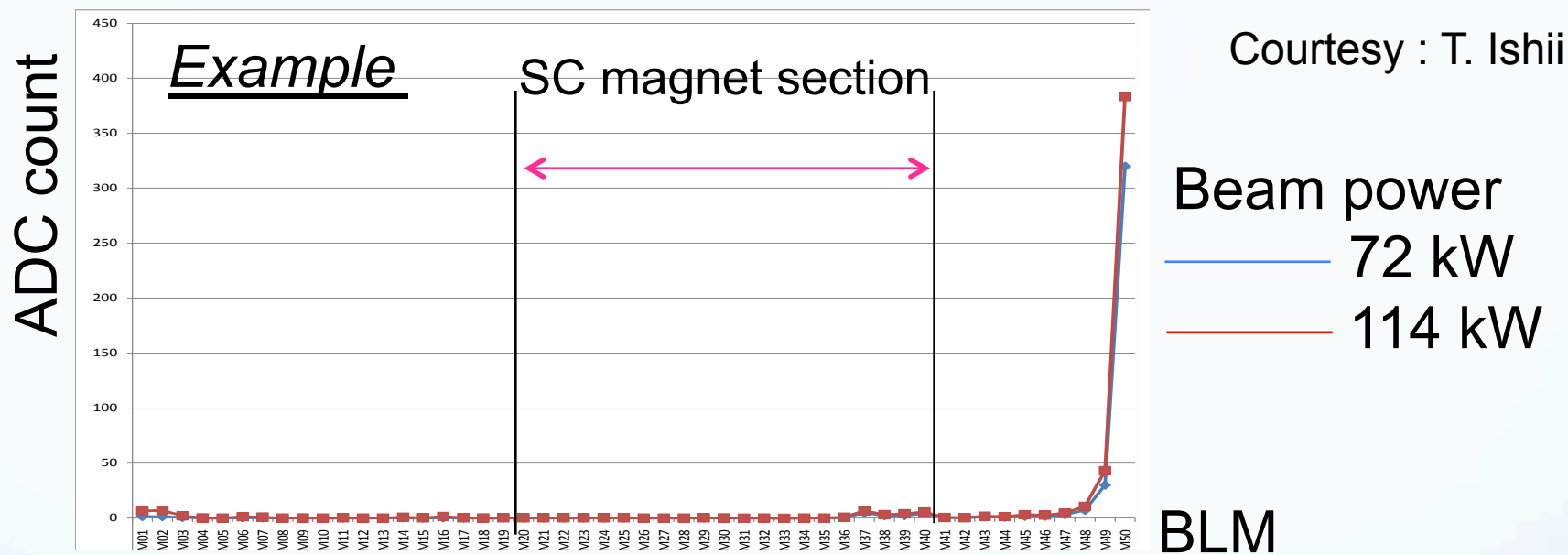
Beam loss monitor



- 21 loss monitors are installed along the beam line
- They are installed underneath the doublet
(SCR01-07 : 2 monitors, SCR08-14 : 1 monitor)

Beam loss during normal beam operation

- Design : 1W/m max. @ 750 kW proton beam



- Max. power in 2013 : 235 kW
 - Almost no signal
 - Sensitivity of BLM : 16 mW

No measurable loss in the SC magnet section during normal beam operation

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Magnet Protection Scheme

- Quench



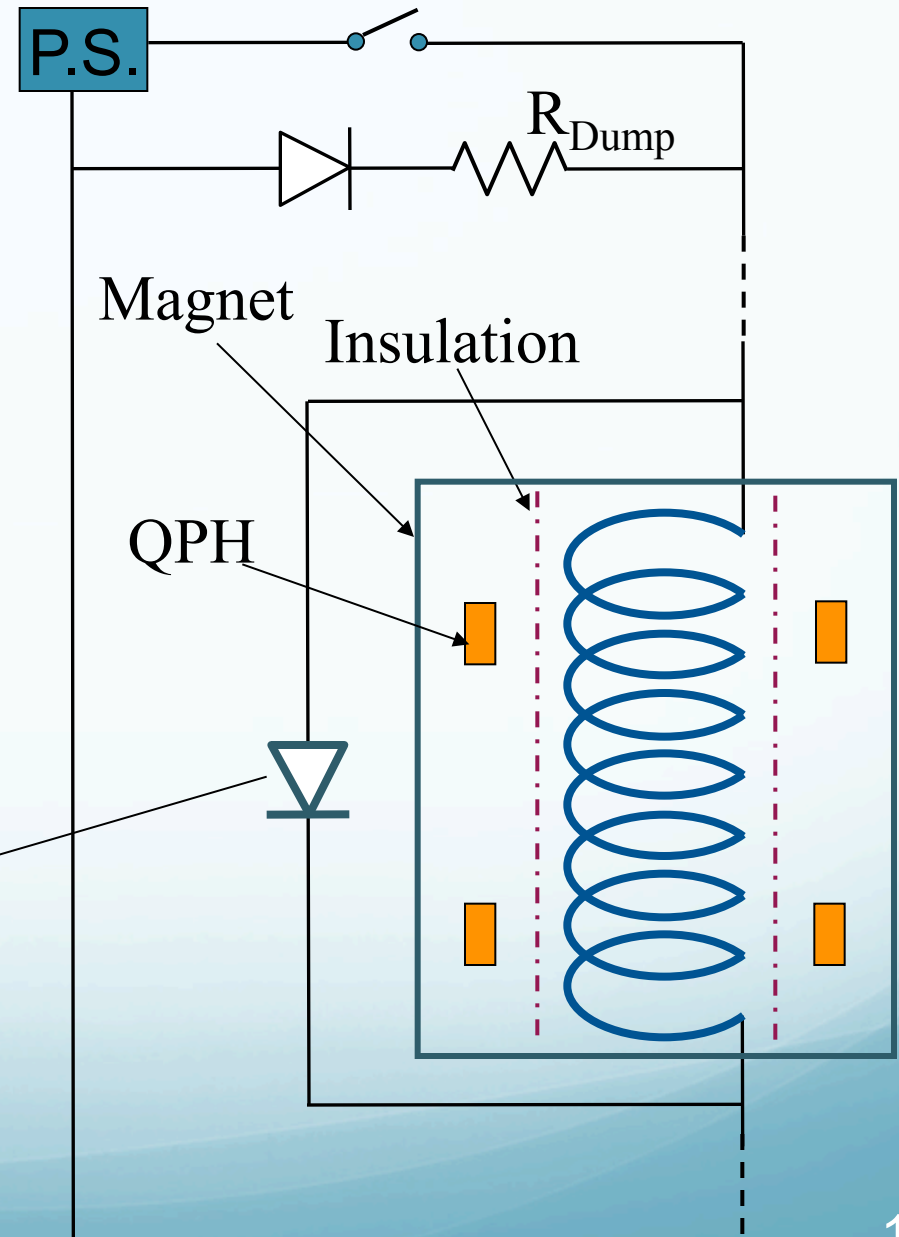
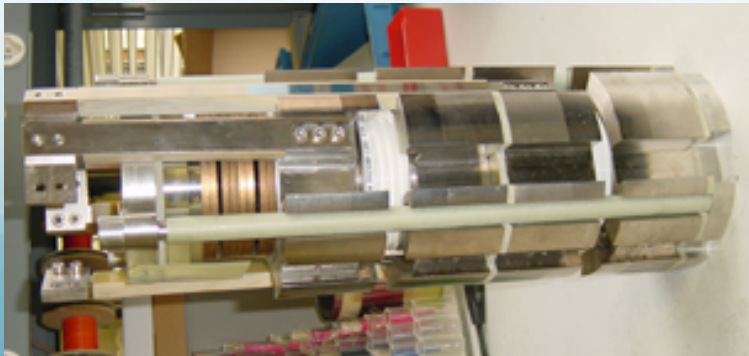
- Detection

- P.S. switch-off
- QPHs are fired



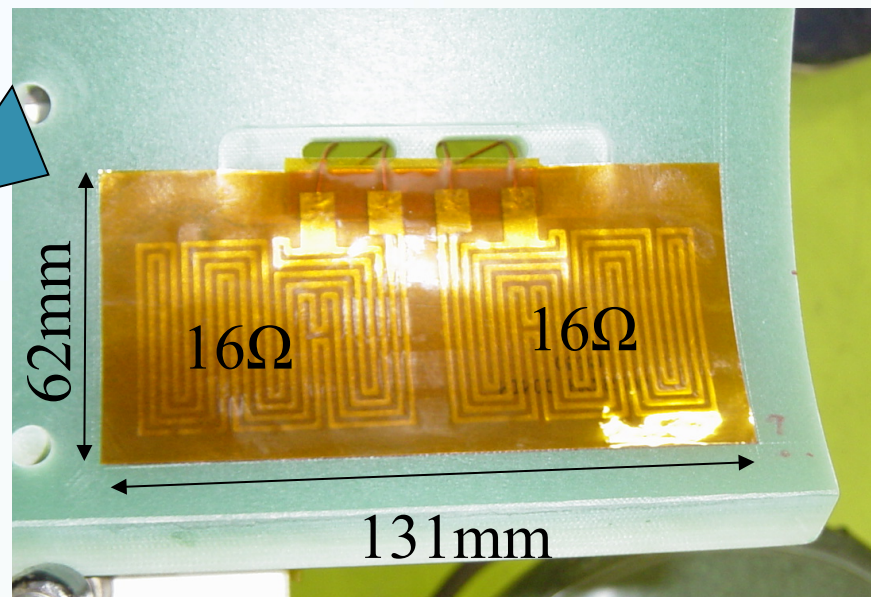
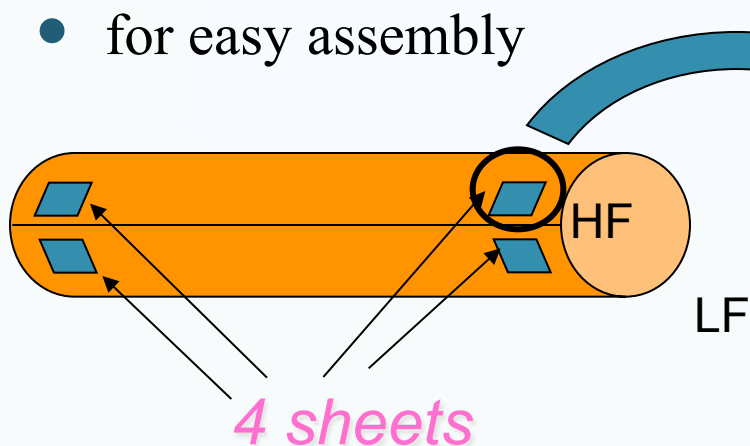
- Bypass to Cold Diode

Cold Diode

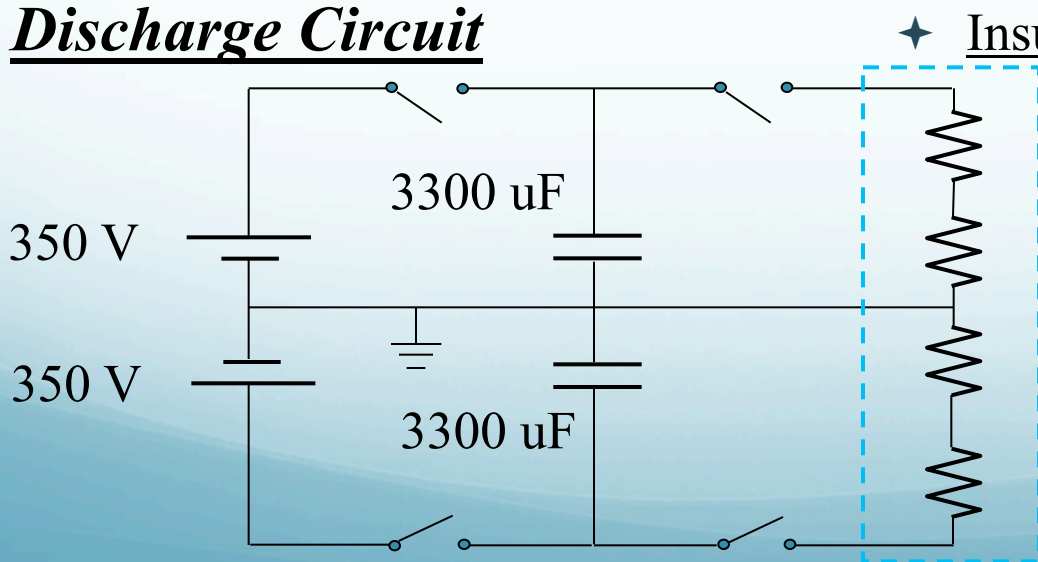


QPH for Production Magnets

- 2 elements on 1 sheet
- for easy assembly



Discharge Circuit



✦ Insulation Thickness = ~ 0.15 mm

× 2 (for redundancy)

Time constant : 0.1 sec

Beam induced quench

- 1st : 2009/05/28
 - During Commissioning
 - Intentional BIQ
 - to check the validity of the quench protection scheme
- 2nd: 2010/11/28
 - During Physics Run
 - Incidental BIQ
 - Human error
 - Fault of interlock system
 - Lack of communication btw Nu group and Acc. operator

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- ▷ 1st BIQ : 2009/05/28

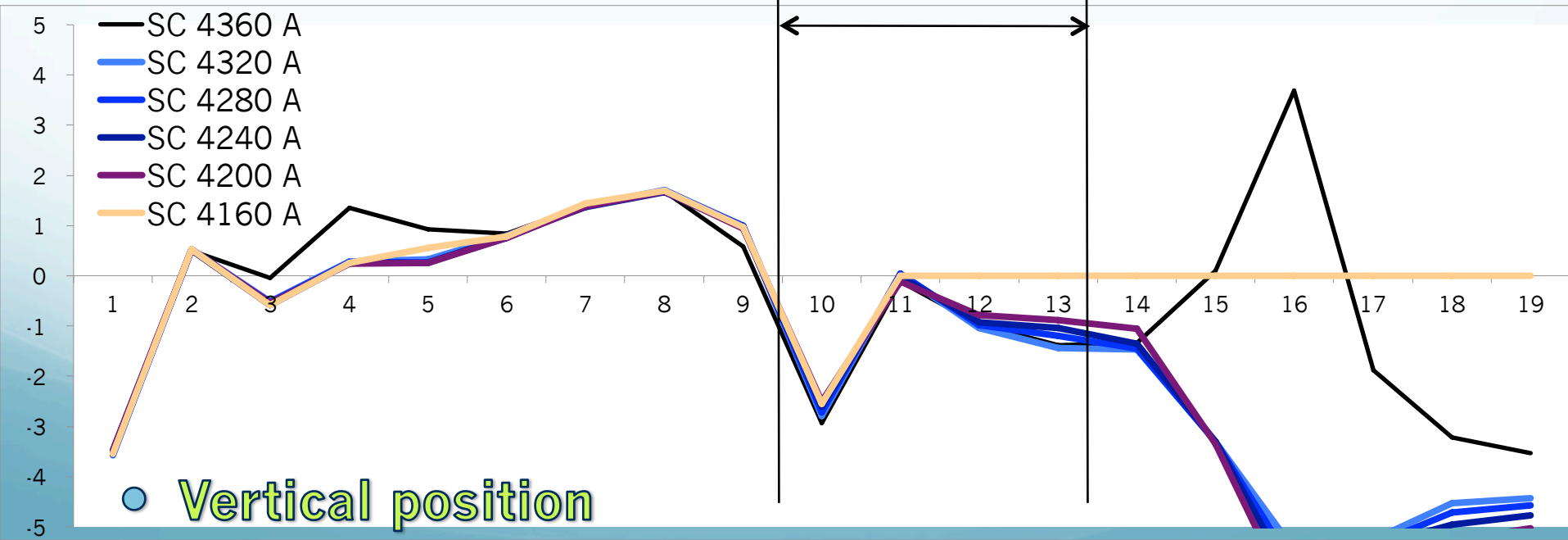
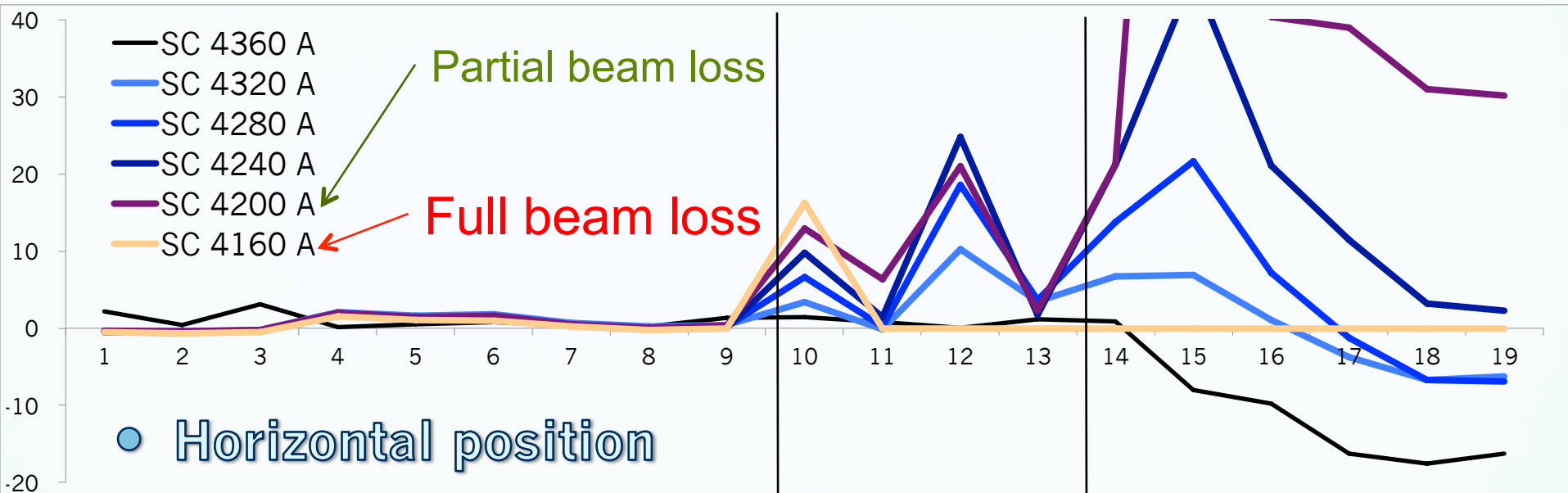
- ▷ 2nd BIQ: 2010/11/28

✎ Summary

First Beam Induced Quench

- 2009/05/28 21:52
 - during the 1st beam commissioning
 - Beam energy : 1.8 kJ / shot (700W)
 - Intentional beam induced quench
 - Objective: check the validity of quench protection scheme
 - Never had spontaneous training quenches.
 - Necessary to confirm a whole sequence of quench protection in the practical beam operation
 - Detection -> Shutdown & QPH fire -> Diode bypass
 - Magnet current was decreased with 40 A step from the nominal current of 4360 A, until the beam actually hit the wall of the beam tube.

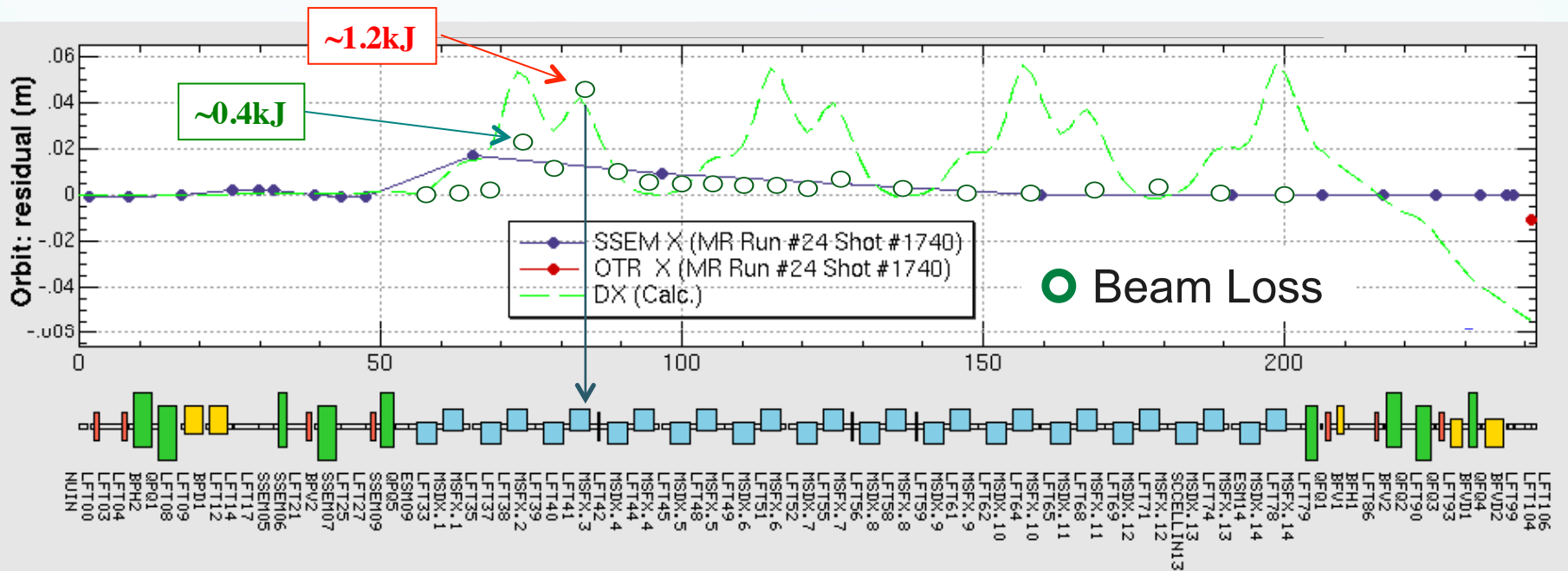
Beam Position at different currents



Full Beam loss

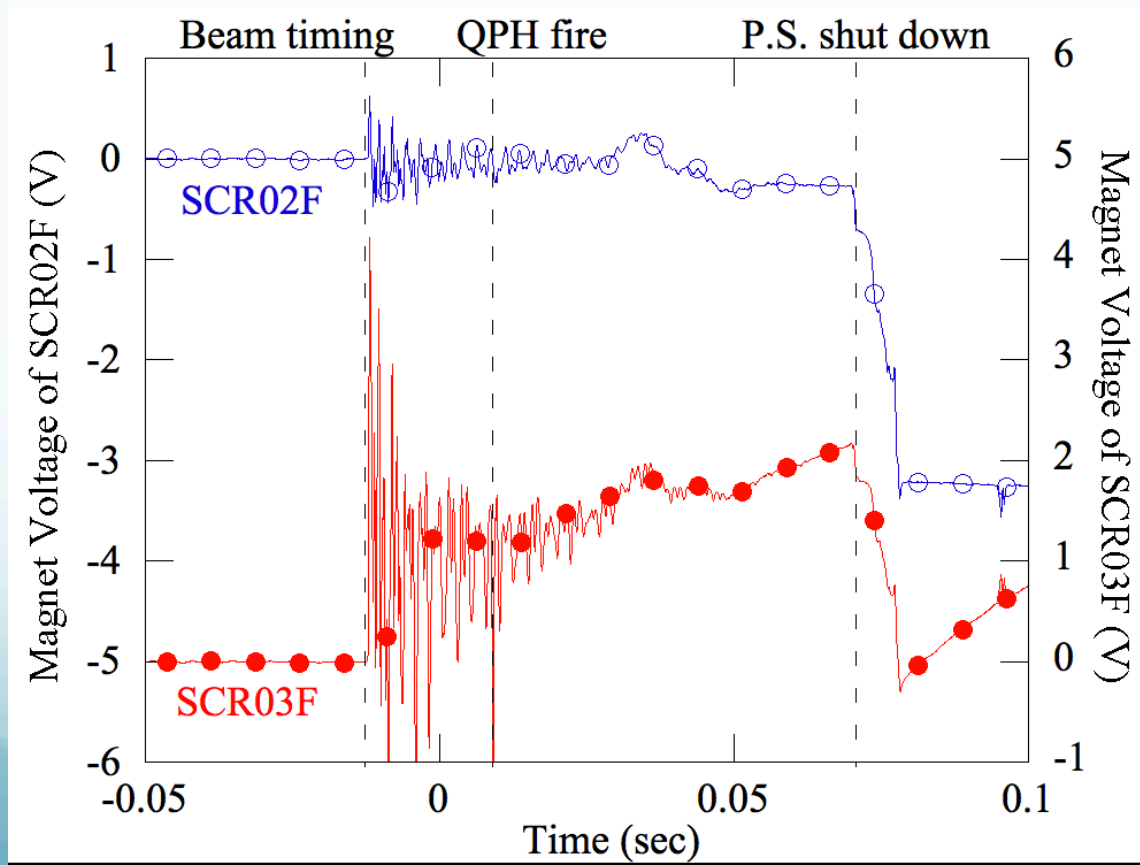
- Observed at 4160 A
 - Beam loss in between SCR2 ~ SCR4
 - 1.2 kJ loss around SCR3F
 - 0.4 kJ loss around SCR2F
 - Quench at SCR3F

Beam power : 1.8 kJ



Voltage signals in the 1st BIQ

- Voltage fluctuation
 - SCR02F and SCR03F <- Noise caused by particle shower
- Voltage shift
 - SCR03F -> Quench started



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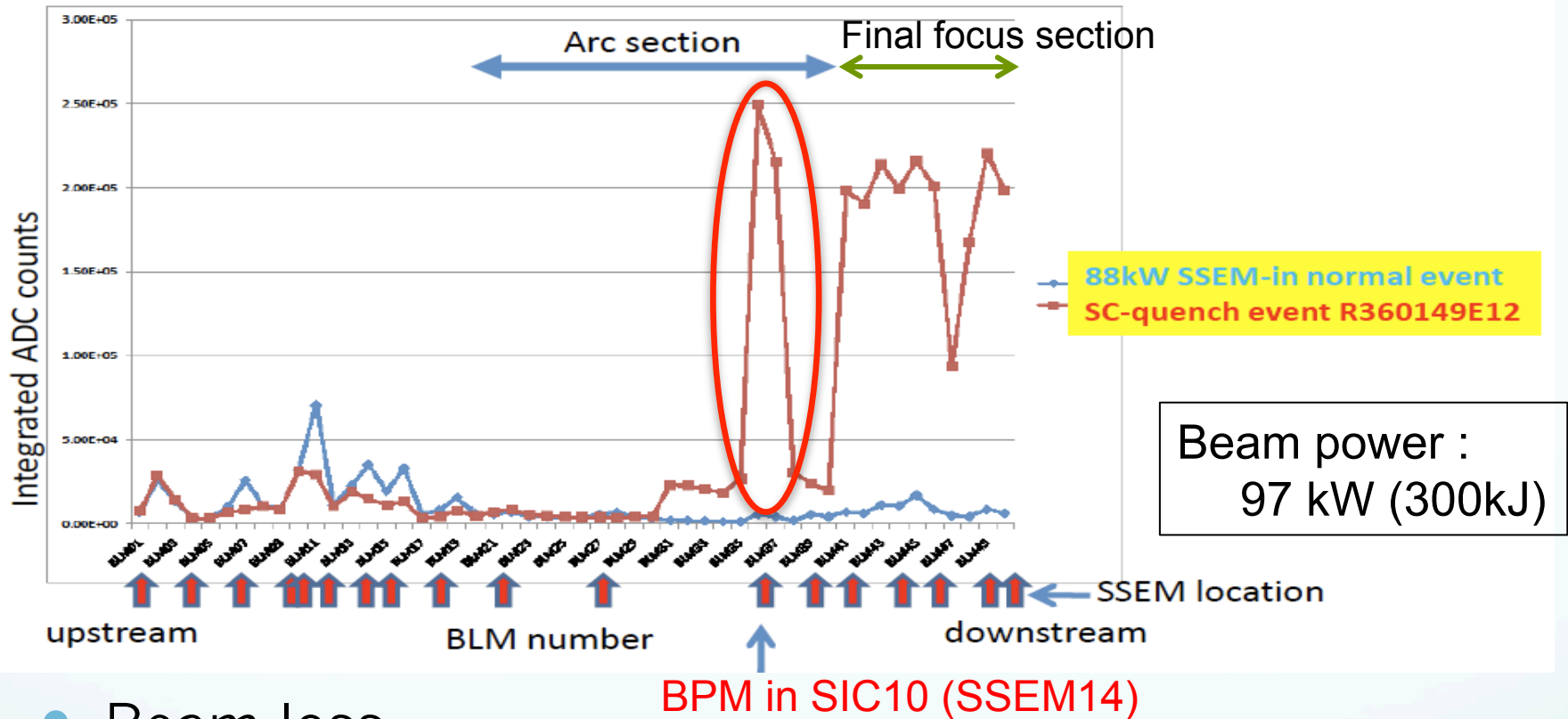
Second Beam Induced Quench

- 2010/11/28 16:13
 - during Physics Run
 - Beam energy : 97 kW(300kJ)
 - Beam induced quench caused by Human error
 - 2010/11/28
 - 15:38 - 16:10 : Physics run with 90 kW beam
 - 16:12 : Beam stopped to increase beam power
 - Beam position monitors started to be inserted in order to see the beam profile change
 - 16:13 : Beam position monitors were still moving, however, 97 kW beam was mistakenly shot.



SCR11F and SCR12D were quenched

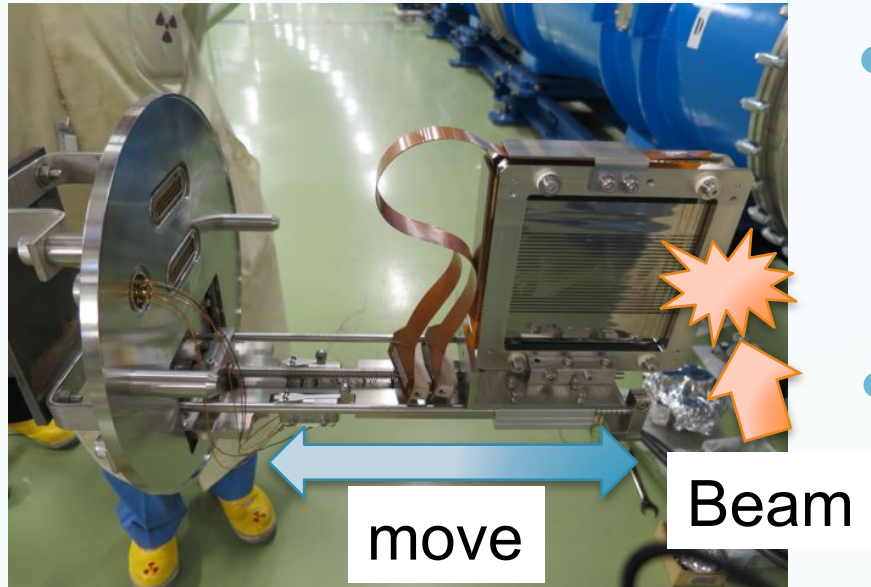
Beam loss monitor data



- Beam loss
 - Arc section : 13 % (13 kW, 40 kJ)
 - Final focus section : 18 % (17 kW, 53 kJ)

Beam hit on the frame of SSEM

Beam loss at BPM

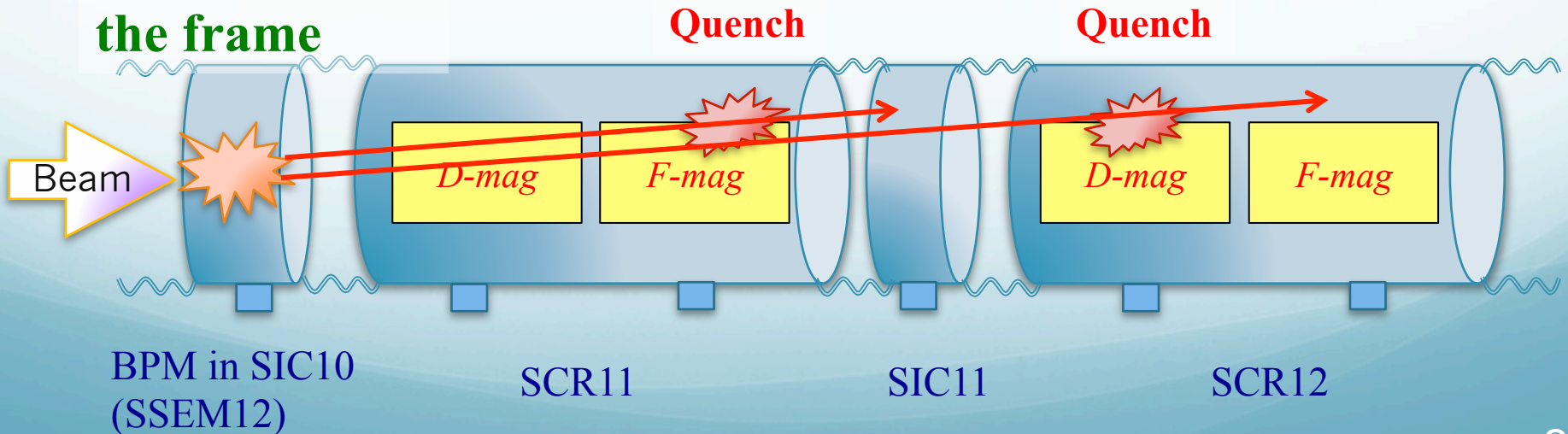


- Monitors could be inserted on demand remotely

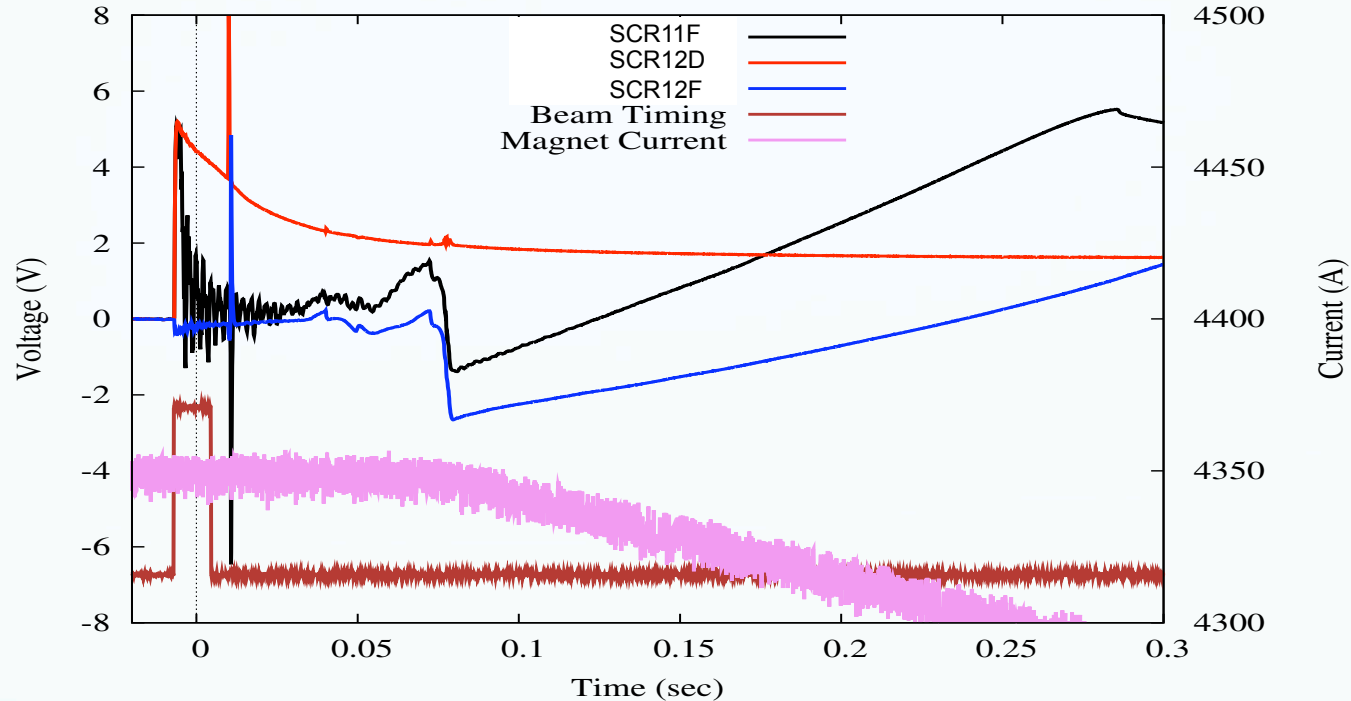


- Beam was mistakenly shot **before** the insertion was completed.

Beam hit on the frame



Voltage signals in the 2nd BIQ



- SCR12D
 - Voltage rises sharply up to turn-on voltage of the diode
 - > Quench occurred over a wide region by scattered beam
- SCR11F
 - Voltage increases faster than other non-quenched magnet
 - > Magnet was warmed over a wide region by scattered beam

Human error

- Interlock system was masked
 - Interlock function to stop the beam during the operation was **already implemented** before this physics run



Revised interlock system and procedure of BPM operation

- Communication between Accelerator and Neutrino group was not sufficient
 - Accelerator people started the beam operation **without** confirming the status of neutrino beam line with Neutrino people (They were in the same control room...)



Change the rule :

Beam operation is surely instructed by Nu group

Summary

Superconducting magnet system for Neutrino experiment at J-PARC

- Beam loss
 - Measured beam loss under the normal operation is much smaller than design value so far.
 - Beam power will continue to increase up to design value of 750 kW
 - > pay careful attention to the BLM data
- Beam induced quench
 - Experienced 2 BIQs
 - did not lead to a serious problem, fortunately.
 - Possible reason
 - Malfunction of power supply, Human error
 - > Periodic inspection, Update interlock system