Commissioning of Superconducting Magnet System for the J-PARC Neutrino Beam Line

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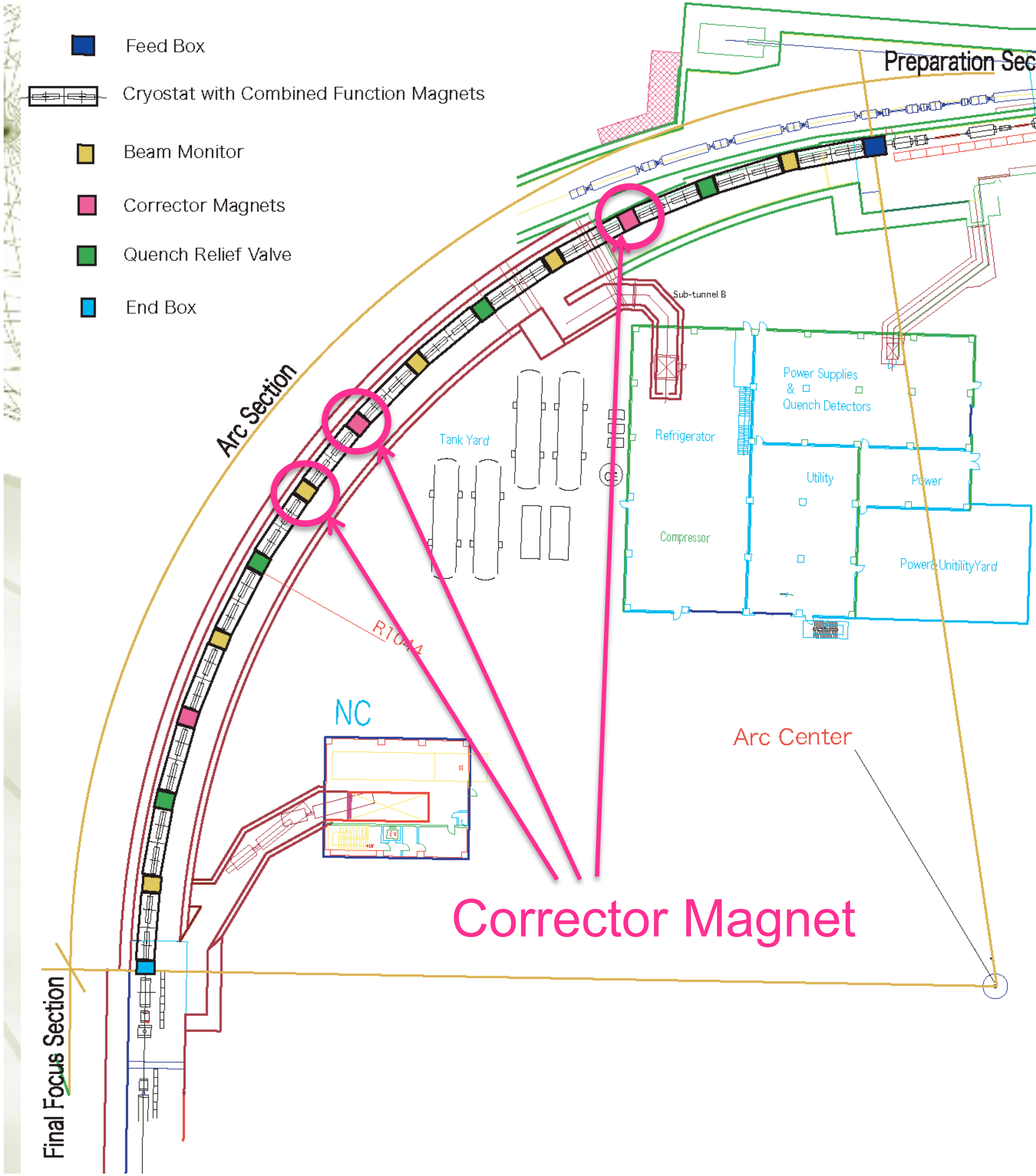
Contents

✎Magnet System Overview

✎Commissioning Results

- ▷Magnet Safety System; MSS
- ▷Magnets
  - ▷Main
  - ▷Corrector

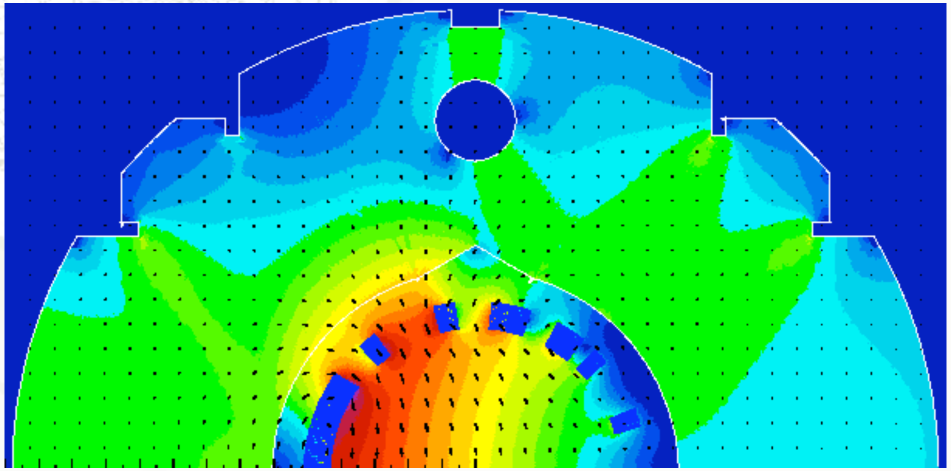
✎Summary & Schedule

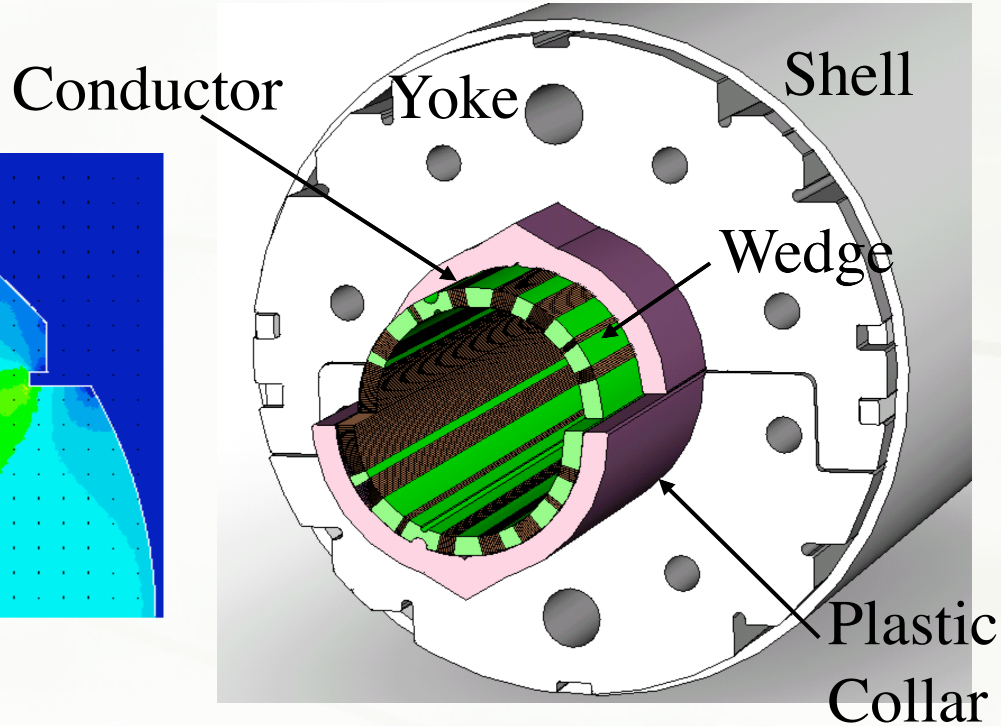


System Overview

- 28 SCFM
  - Dipole 2.6 T
  - Quad 18.6 T/m
  - Length 3.3 m
  - 2 in 1 Cryostat
- SC Transfer Line
- 6 SC Correctors
  - 3 normal
  - 3 skew

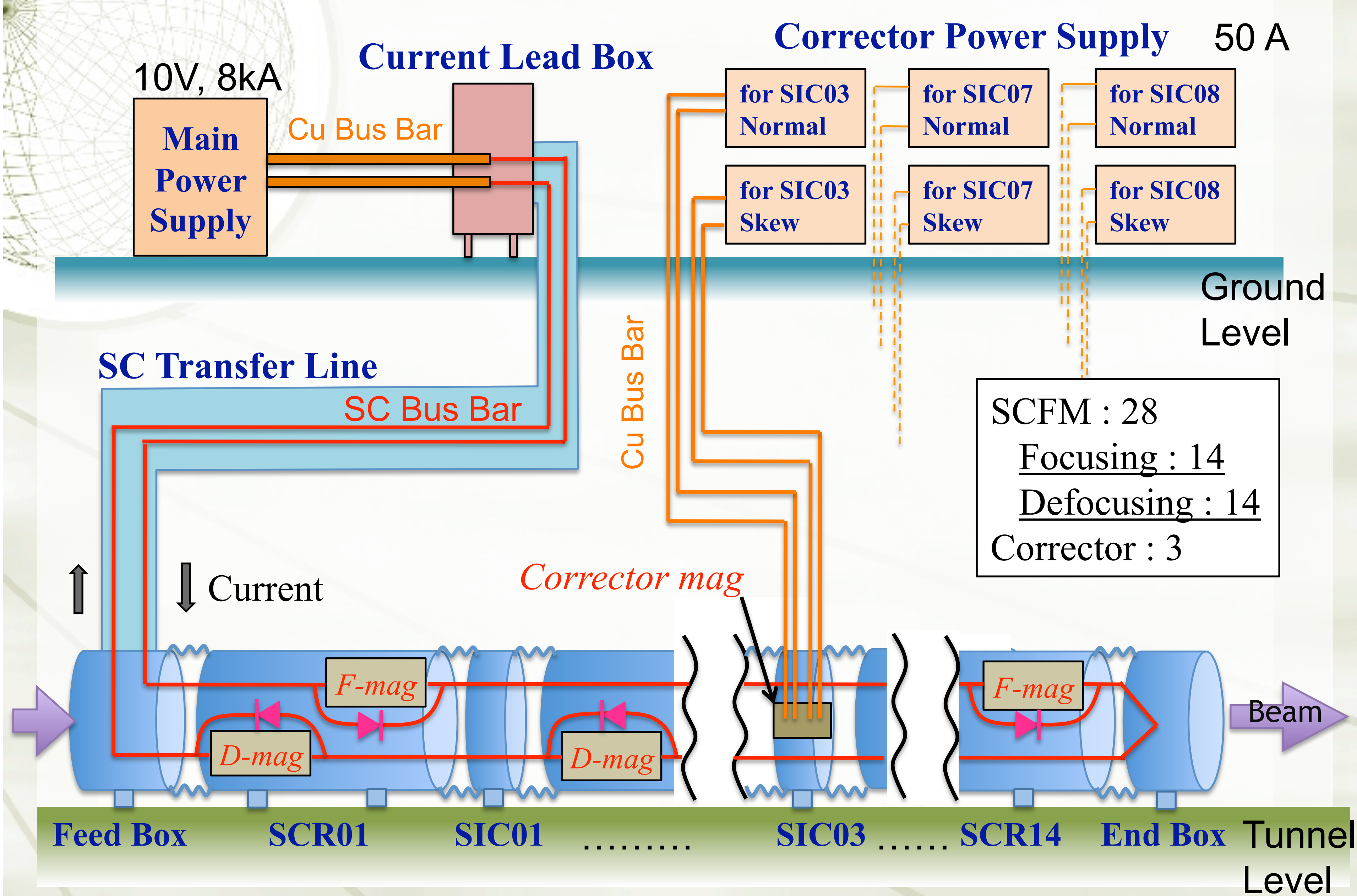
Main Magnet Design





- **Coil ID.:** 173.4mm
- **Mech. Length:** 3630 mm @RT
- **Tmax:** < 5.0K (SHe)
- **Dipole Field:** 2.59 T
- **Quad. Field:** 18.6 T/m
- **Peak Field on the cable :** 4.7 T
- **Op. Current:** 7345 A
- **Op. Margin:** 72%
- **Inductance:** 14.3 mH
- **Stored Energy:** 386 kJ
- **SC Cable:** NbTi/Cu for LHC Dipole Outer-L

Magnet System Overview



Check List

- MSS
  - Cable check
  - Function check
    - Logic signal processing
    - DAQ system operation
- Main magnets (SCFM)
  - Measure RRR and resistance of SC cable connection
  - Quench Protection Heater (QPH)
  - Excitation test up to 5000 A.
- Corrector Magnets
  - Measure RRR
  - Excitation test

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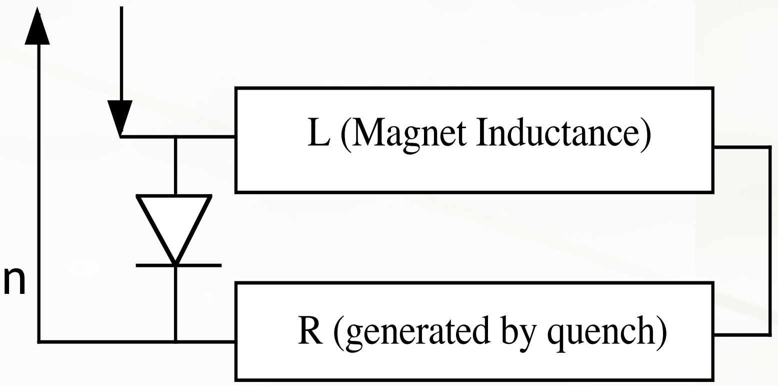
Magnet Safety System, MSS

- Important role
  - To protect the magnet from burn-out during quench.

Basic concept of the quench protection scheme

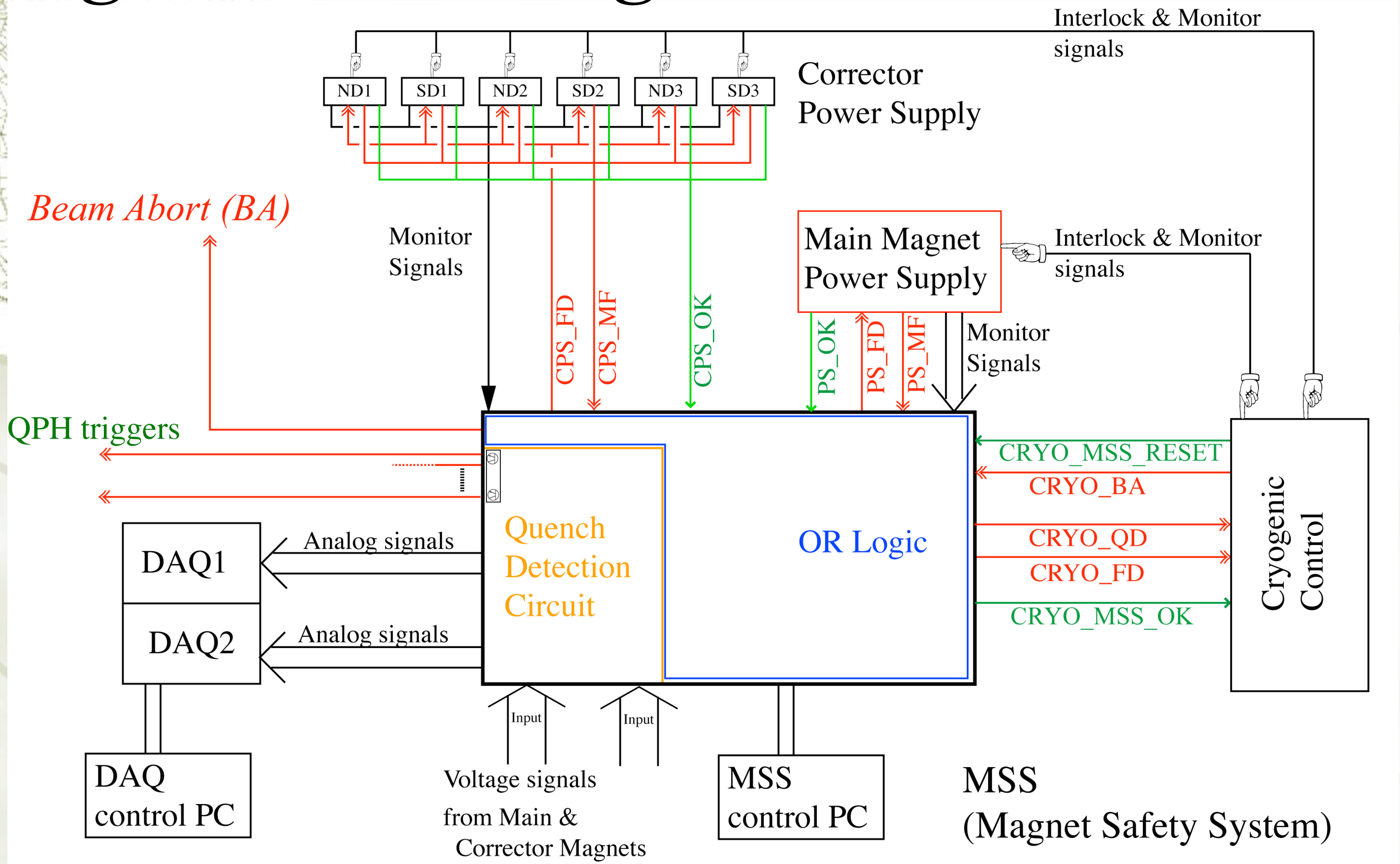
- **The magnets are protected by current bypassing to Cold diode connected in parallel with each magnet.**
  - Only cold diode was not sufficient for the safe protection.
  - Need to accelerate the quench propagation to speed up the current bypassing.
    - need to detect the quench within several tens msec.
    - fire Quench Protection Heaters ASAP



Magnet Safety System, MSS

- Functions
  - To detect the magnet quench.
  - To receive and distribute the safety logic signals.
    - Trigger signals of QPH, shut-down signal for P.S…
  - To monitor and record the analog signals for the diagnosing of the quench event.

Signal Flow Diagram



- MSS plays a key role in the fast safety system.

Magnet Safety System, MSS

- Developed by CEA/Saclay
  - Person in charge : Jean-Paul Charrier
- All the works are done by the system engineering division of Saclay.
  - Design, Provisioning, Assembly, Commissioning

<u>Visiting Tokai site for the commissioning</u>

1. 2008.9.2 ~ 2008.9.16
   - Initialize system, Check cables.
2. 2008.11.26 ~ 2008.12.9
   - Check electrical circuit and cables.
3. 2009.1.28 ~ 2009.2.18
   - Check system, Commissioning with the magnet system.

Summary of MSS commissioning

- Small problems
  - Quench detection (Analog signals)
    - Bad cable connection
    - Remove notch-filters from the input of quench detection signals
  - Safety Logic signals (Digital signals)
    - Polarities of some cables were reversed
  - DAQ system
    - Memory leak in the data retrieving software.
    - Time difference of triggers between analog and digital signals

All of them have been fixed (except for last one..).

↓

Normal operation of MSS could be confirmed.

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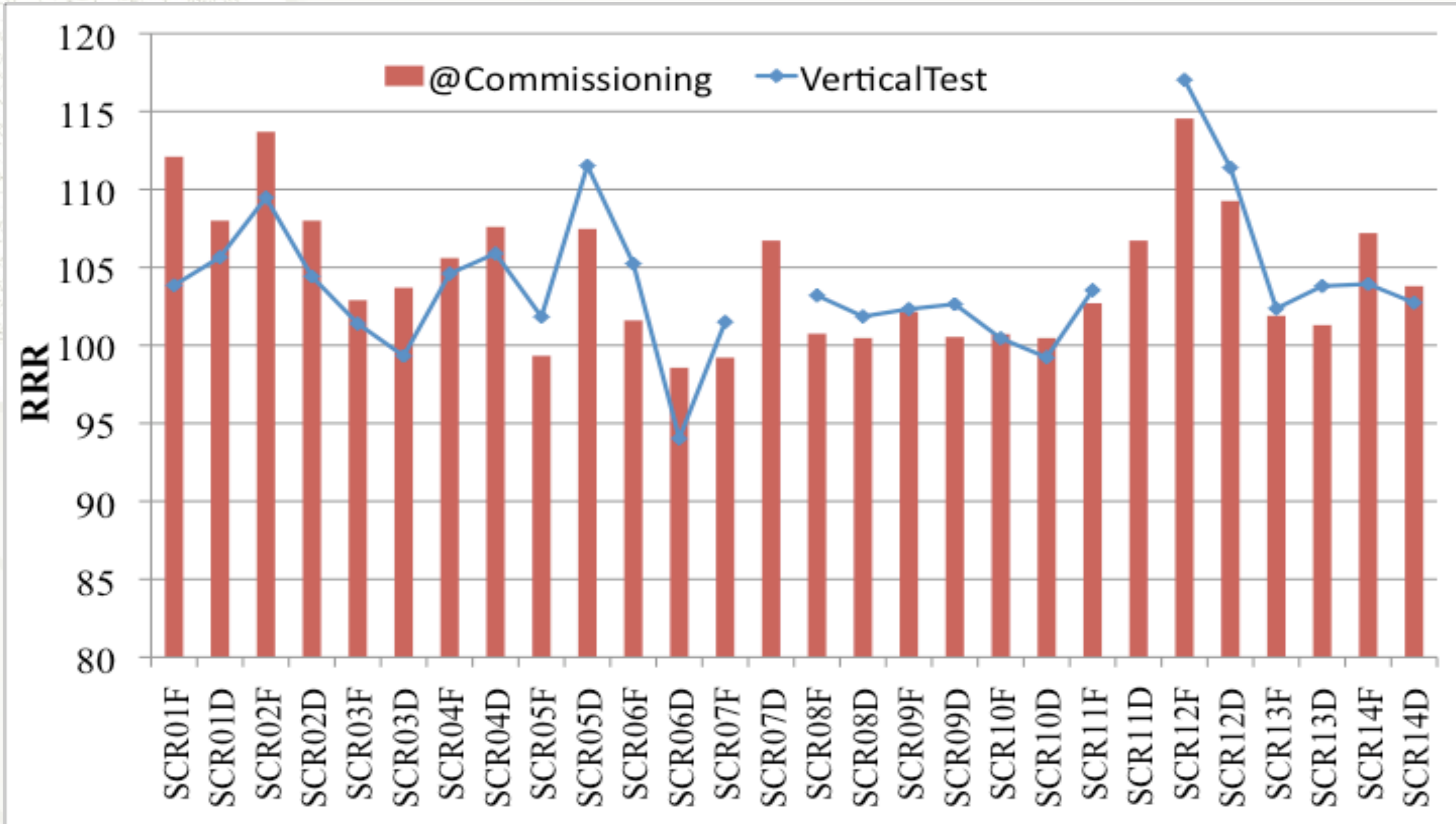
Check List for Main Magnets

- RRR
- Resistance of solder connection of SC cable
- Verify the quench protection scheme
  - Quench Protection Heater
  - Cold diode
- Excitation test up to 5000 A
  - Long term operation test
  - Current loop test

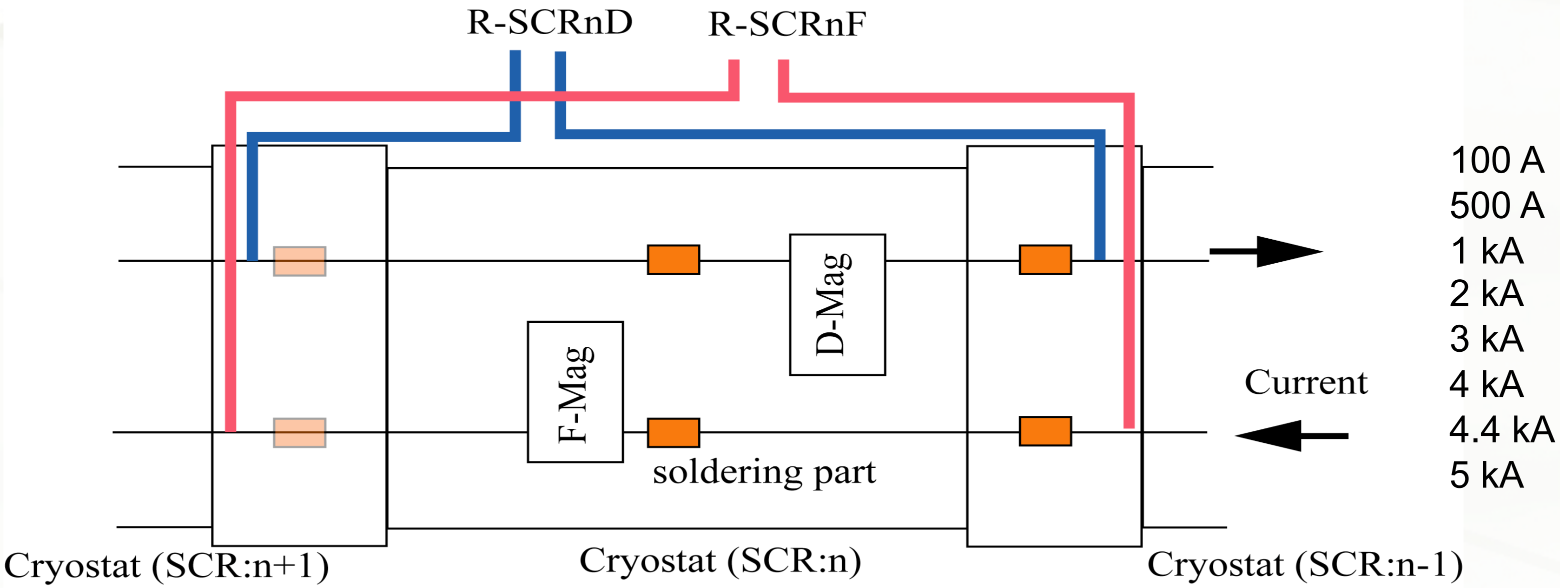
RRR Measurement



- design RRR ~ 100
- Results are similar to those in the vertical test.
- No major trouble in the cable during the system installation.

Resistance of Cable Connection with solder ~ Main Magnets

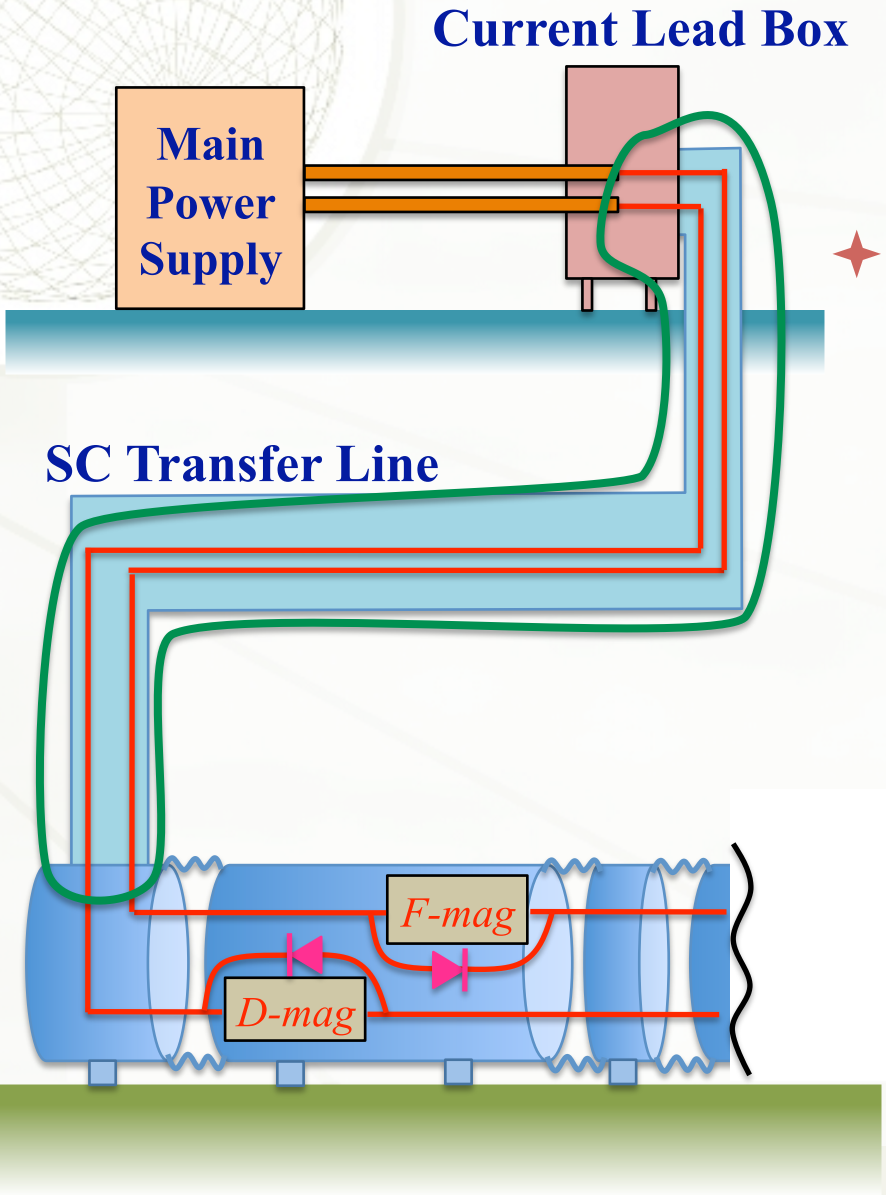
- In the neutrino beam line, all the combined function magnets are connected with solder in series.
  - No. of connections: 57 in the main magnet string.
  - Measure voltages at different currents up to 5 kA.



No relationship between voltage and current

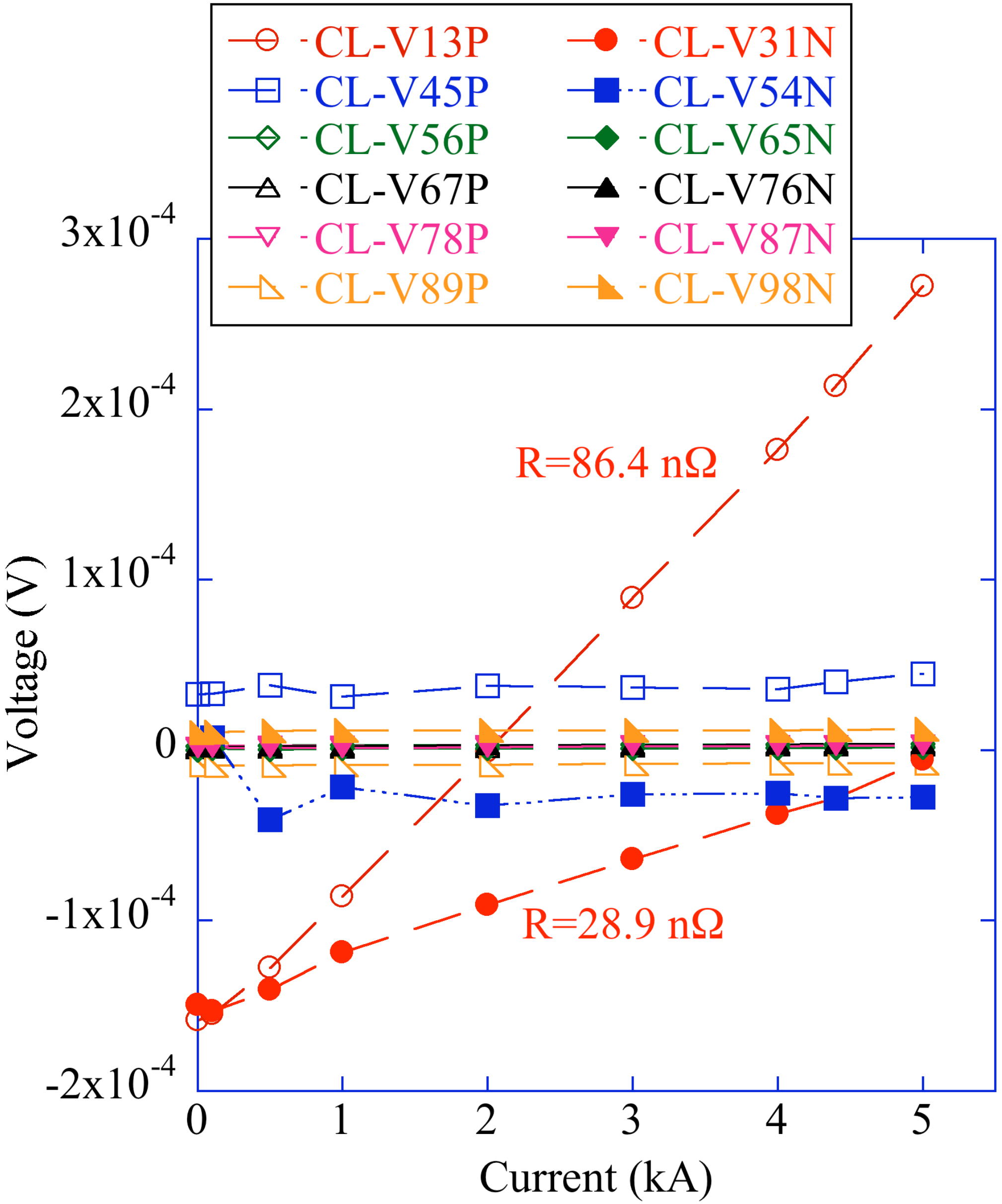
Resistance < 1 μΩ at each connection

Resistance of Cable Connection with Solder ~ SC Transfer Line



- *In SC transfer line and Current Lead Box,*
  - Solder Connection: 10
  - Connection by bolting with indium sheet: 4

Resistance of Solder Connection~ TRT



- No relationship between voltage and current except for <u>*2 signals*</u>

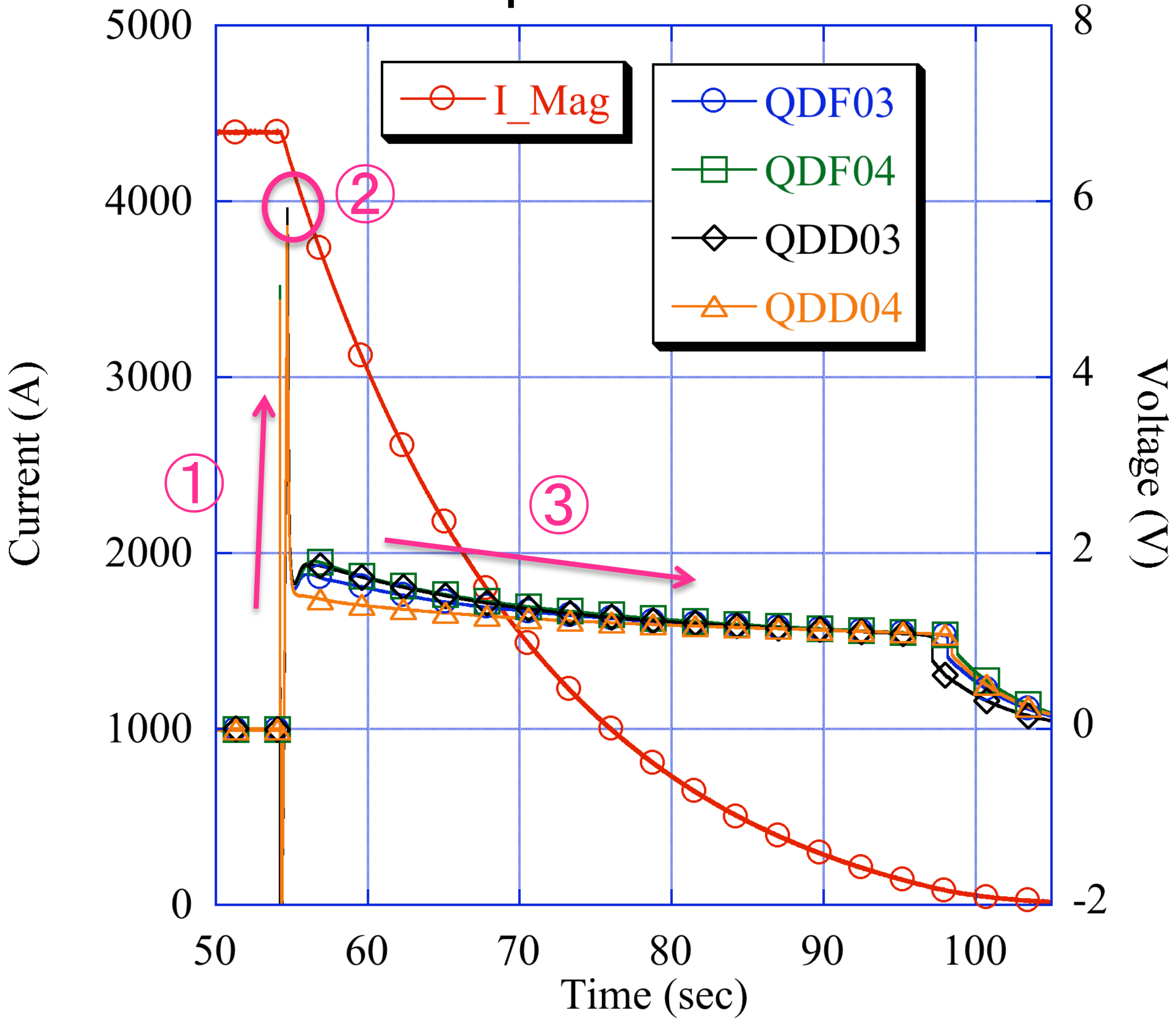
<u>Contact connection with In sheet</u>

- 2.16W @ 5 kA
- No temp. rise around this connection
- This resistance is small enough for the practical use.

Cold Diode

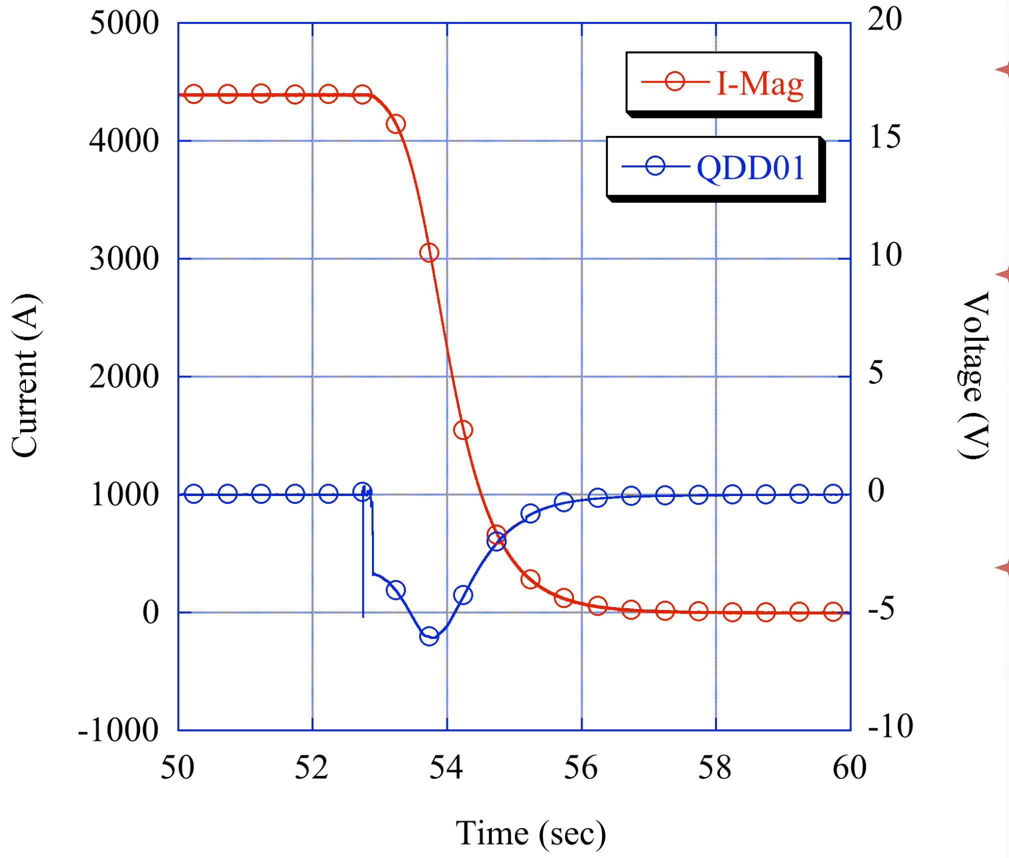
Checked the cold diode performance by quenching the magnet with the QPH

- Example @ 4400 A



1. Magnet voltage rises rapidly after firing the hater
2. Current bypassing start when the voltage exceeds the forward voltage of C.D.
3. Forward voltage decreases with the increase of C.D. temp.

Full Quench Test @ 4400 A



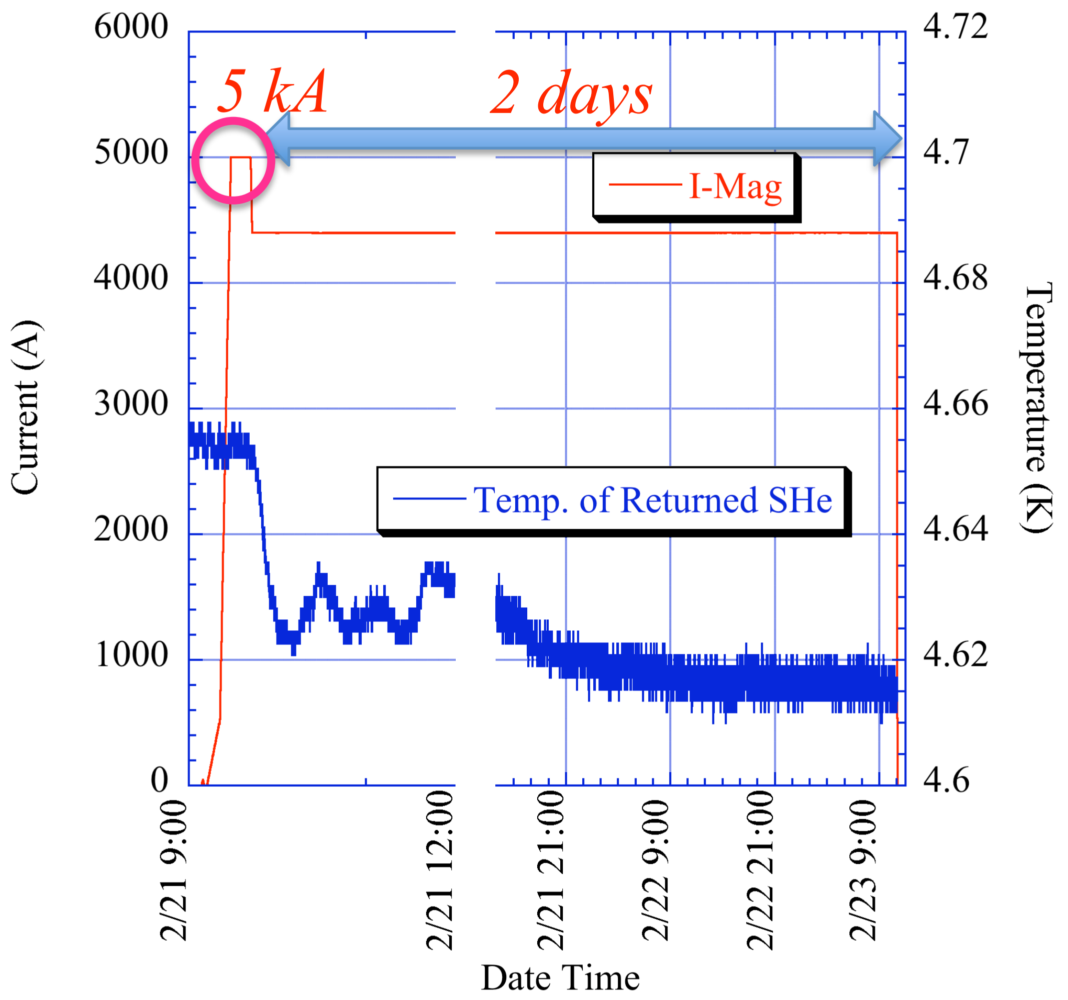
- All magnets were quenched by QPH, and the power supply was shutdown after 0.1 sec.
- Time constant : ~1.23 sec
  - 1.23 sec << ~20 sec
    - because of the resistance of the magnets
- The difference btw full quench and not full quench test is that the current did not bypass to the cold diode due to the inductive voltage.

- From the protection view point, no bypassing is O.K, if the current could decay within the time constant of 3 sec.

- The magnet protection scheme are working well, as we expected.

Excitation test

- The magnet could be excited up to 5000 A on 21 Feb., after several shutdown tests and QPH test at different currents.



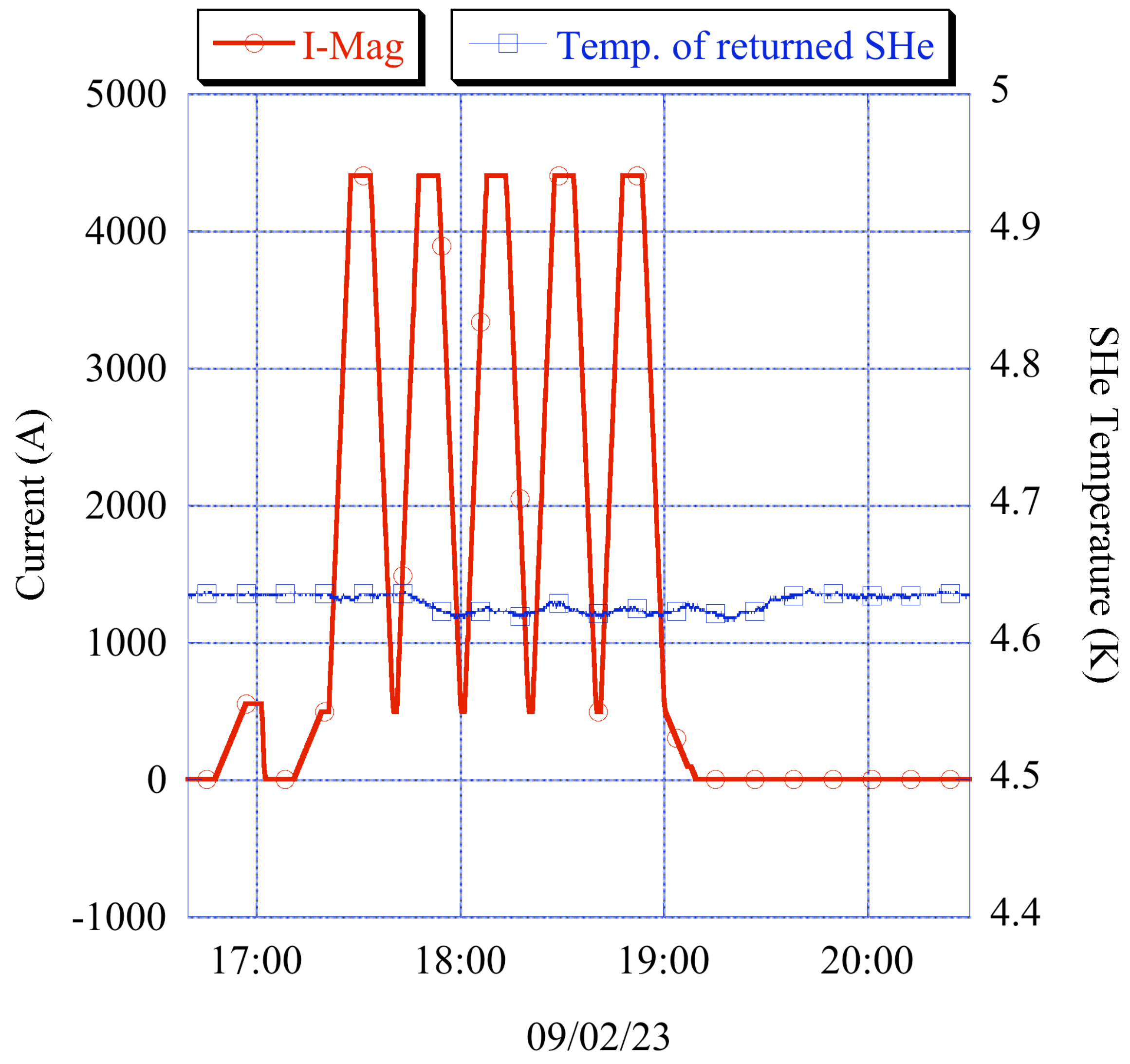
- After 5 kA, we checked the long time stability.

The magnet current of 4400 A could be held for 2 days.

Temp. of returned SHe was stable.

Current Loop Test

- Repeat a current loop 5 times



- Small temperature fluctuation after 23 min delay

No major temperature rise during the repetitive excitation.

Summary of Main Magnet commissioning

- No problem
  - RRR
  - Resistance of cable connection
  - Quench Protection Scheme
  - Magnet excitation up to 5 kA
  - Long time operation
  - Repetitive operation

Normal operation of Main magnets could be confirmed.

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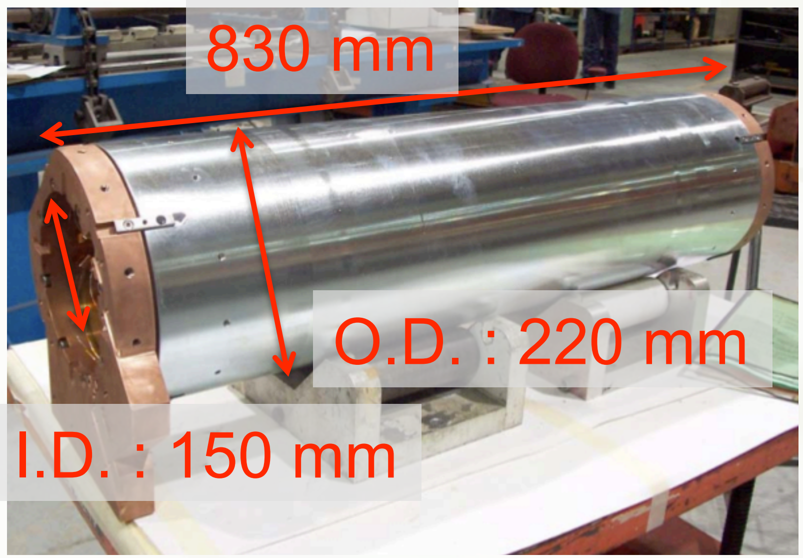
Corrector Magnet

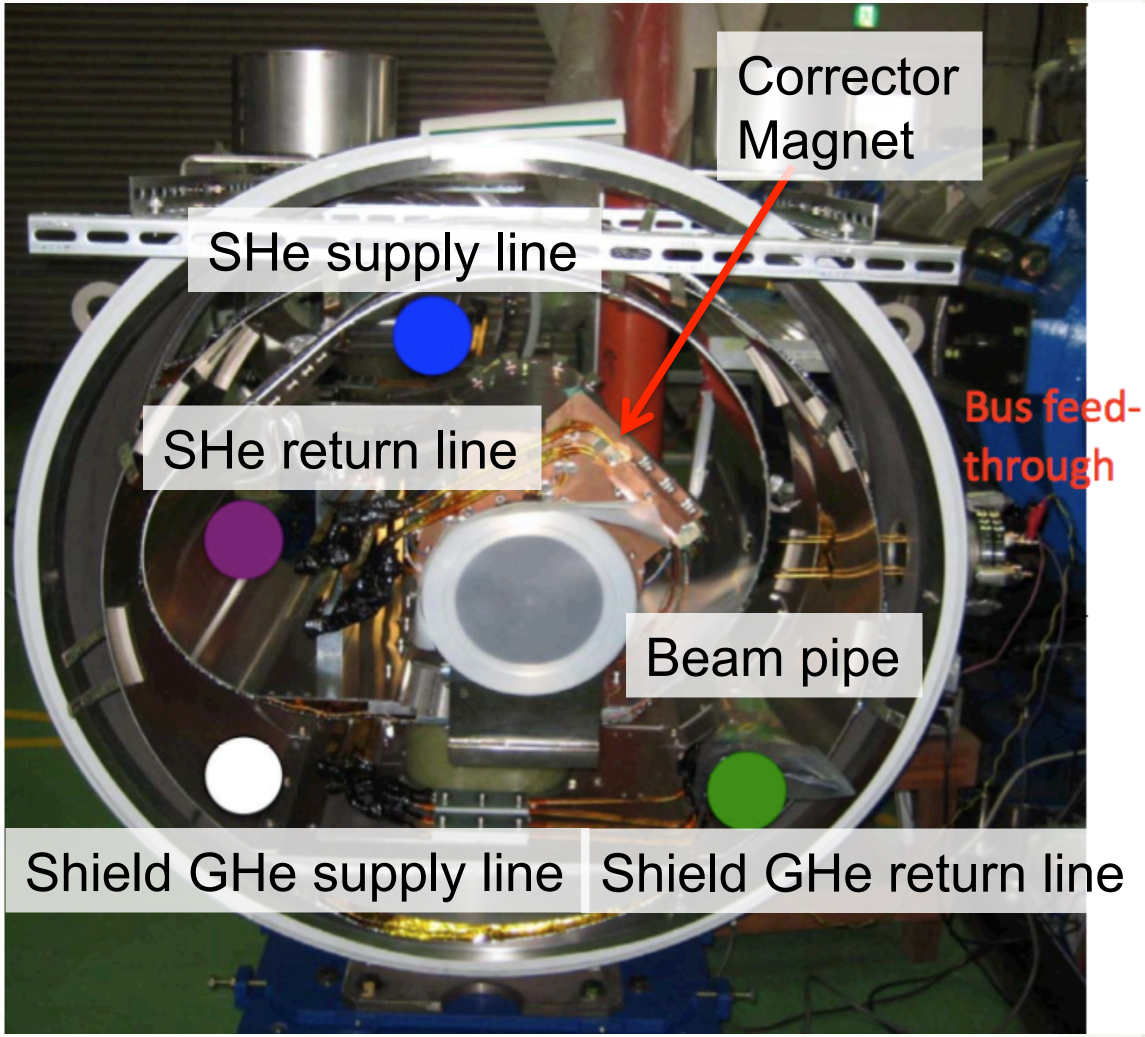
- SC strand (same as RHIC corrector wire)
  - Material : NbTi
  - Diameter : 0.33mm
  - Cu/SC ratio : 2.5/1
- Magnet
  - 2 layers
    - 1st: skew, 2nd: normal
  - Inductance : 1.1 H
  - Nominal Current : 50 A
  - Integral Field @ 41 A: 0.1 Tm
  - Peak Field @ 41A :0.2 T



Corrector and Vacuum Vessel

- Pure Al strip are attached between SHe supply line and the magnet for conduction-cooling

- The bus bars and radiation shields are also thermally connected to the cooling pipe.



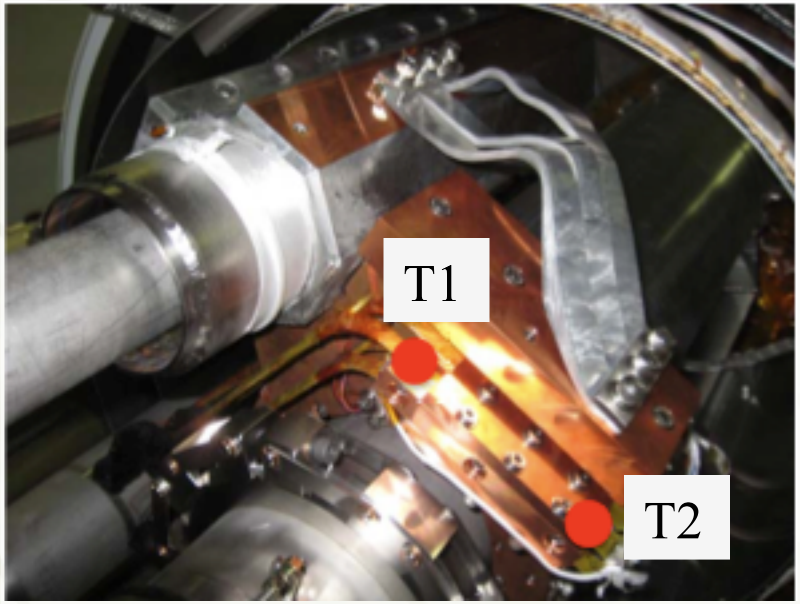
Test Results

Temp. @ 0A	T1 (K)	T2 (K)
SIC03	5.57	5.56
SIC07	6.53	6.61
SIC08	6.06	6.03
Expected	< 6	< 6

◎*Temp. at steady operation @ 0 A*

✧not uniform, but stable

★Confirmed the transition from normal to superconducting state



◎*RRR measurement*

RRR	Normal	Skew
SIC03	105	115
SIC07	110	109
SIC08	102	124
Expected	~100	~100

Excitation Test Results

- All the coil could be excited up to 10 A without a spontaneous quench.
  - Confirmed with a different combination:

	Normal Coils	Skew Coils
#1	+10 A	+ 10 A
#2	-10 A	- 10 A
#3	+10 A	-10 A
#4	-10 A	+10 A

- The currents of 10 A could be held for 2 days.

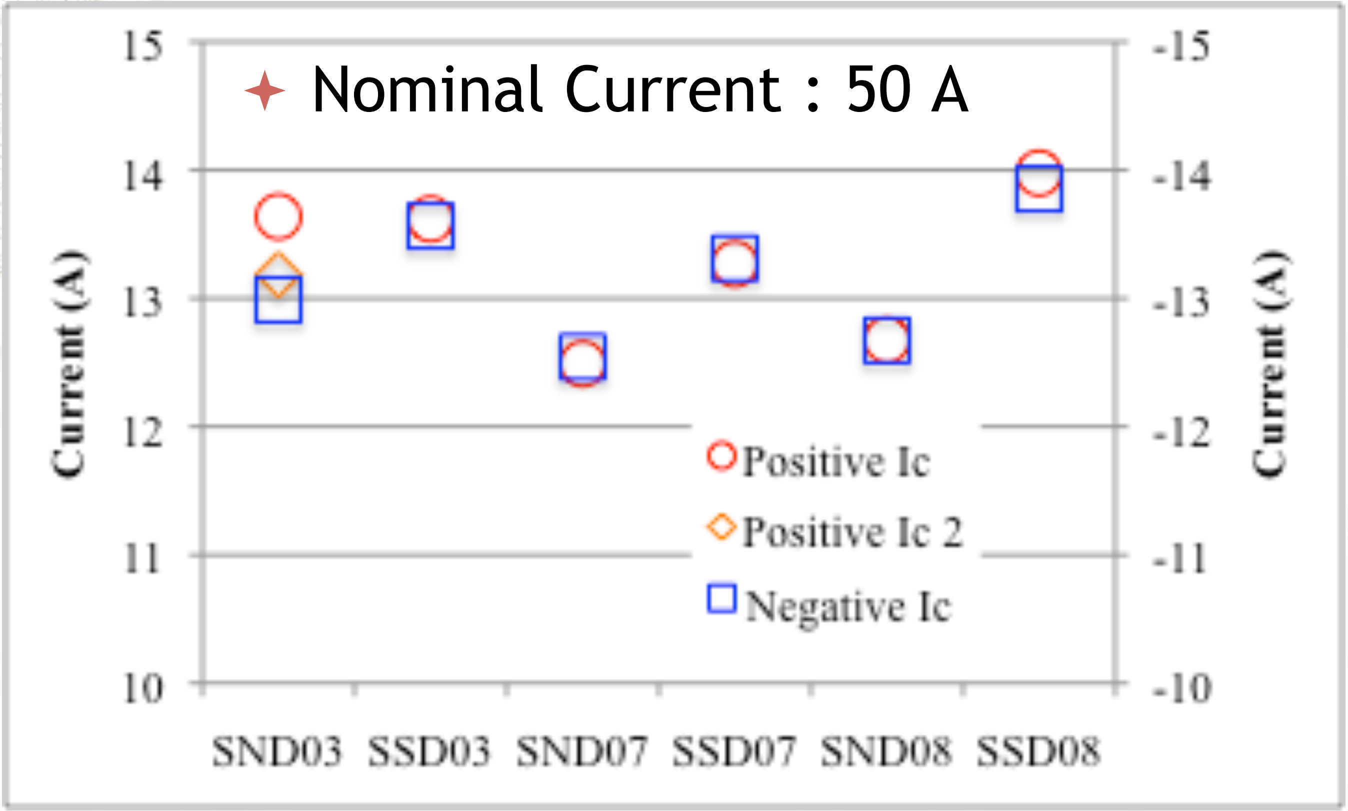
Temp. Rise	ΔT1 (K)	ΔT2 (K)
SIC03	+0.02	+0.02
SIC07	+0.03	+0.04
SIC08	+0.02	+0.02

Temperature rise at 10 A:
< 40 mK

↓

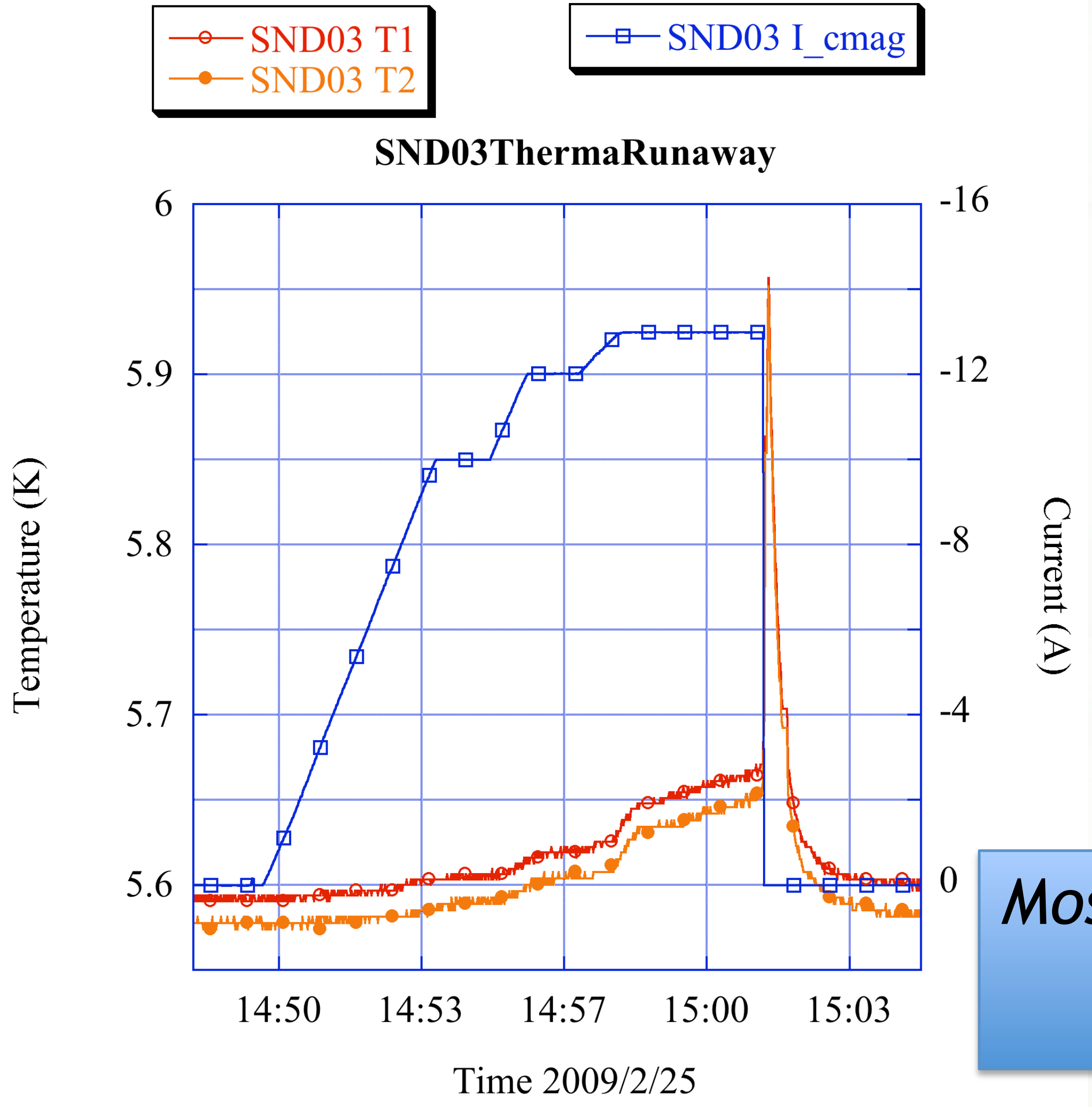
Quench @ ~ 13 A

Quench Summary



- Quench Currents were unexpectedly low and systematically around 13 A.
- All the coils were tested in LHe at BNL.
  - successfully excited up to 60 A w/o spontaneous quench.

Typical Quench Signals



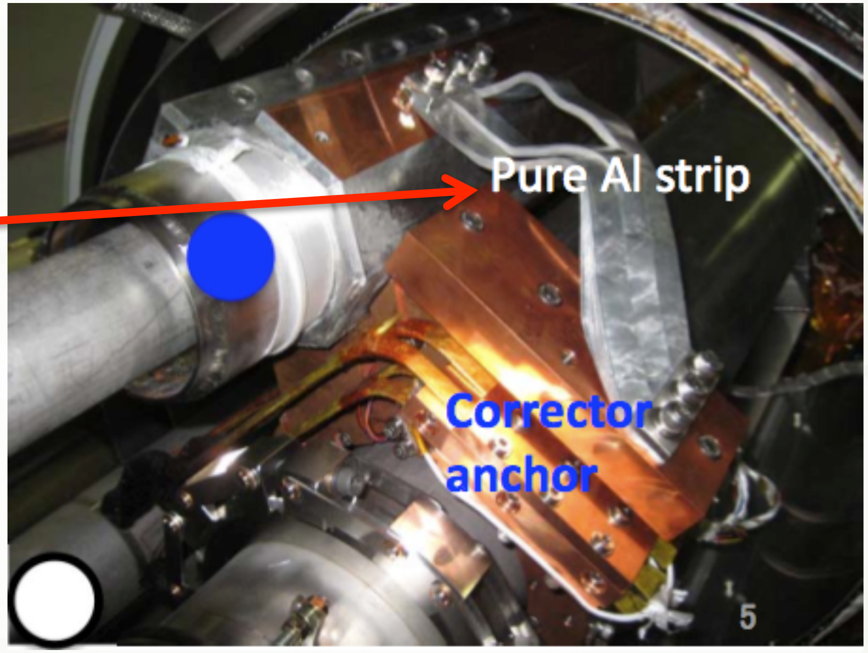
- Quench after holding the current of -13 A for 3 min.
- Temperature kept rising after holding current, and finally, magnet quenched.

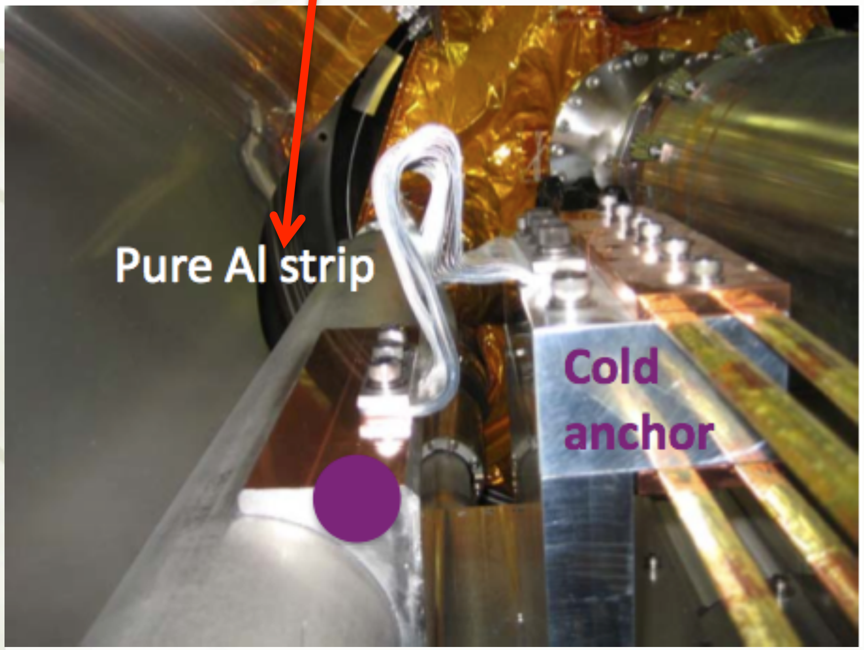
Most likely reason

☑ Poor cooling of Bus bars

Conduction Cooling

- Magnet and Cu bus bar are conduction-cooled by pure Al strip





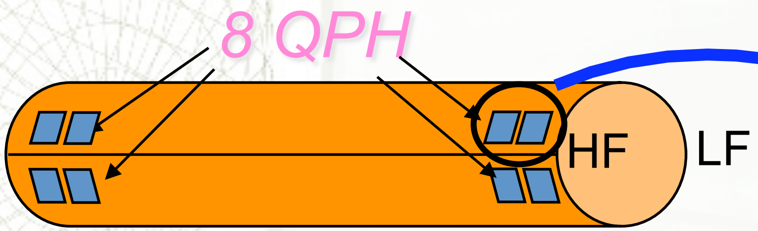
- The ohmic heat in the Cu bus bar would increase the magnet temperature, because of poor heat conduction

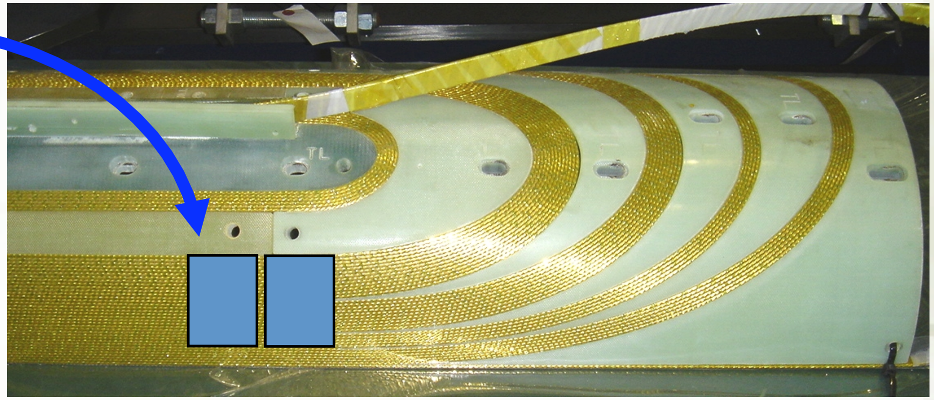
- To improve the quench current , we are planning to open up a vacuum vessel and modify the heat conduction.

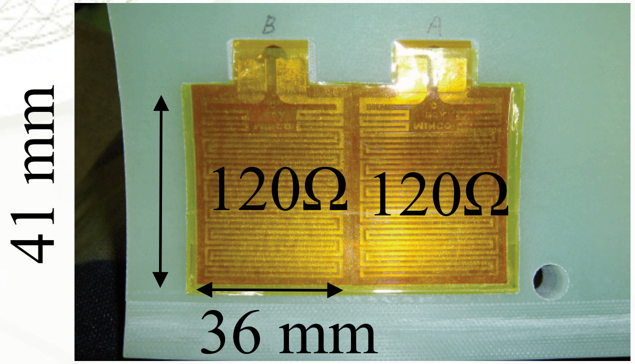
Summary and Schedule

- The commissioning of the magnet system was successfully done.
  - although some minor modifications are required….
- Schedule
  - March 30 & 31
    - Nominal operation tests with all the components including the normal magnets in the Neutrino primary beam line.
  - Beginning of April
    - Beam commissioning will be started.

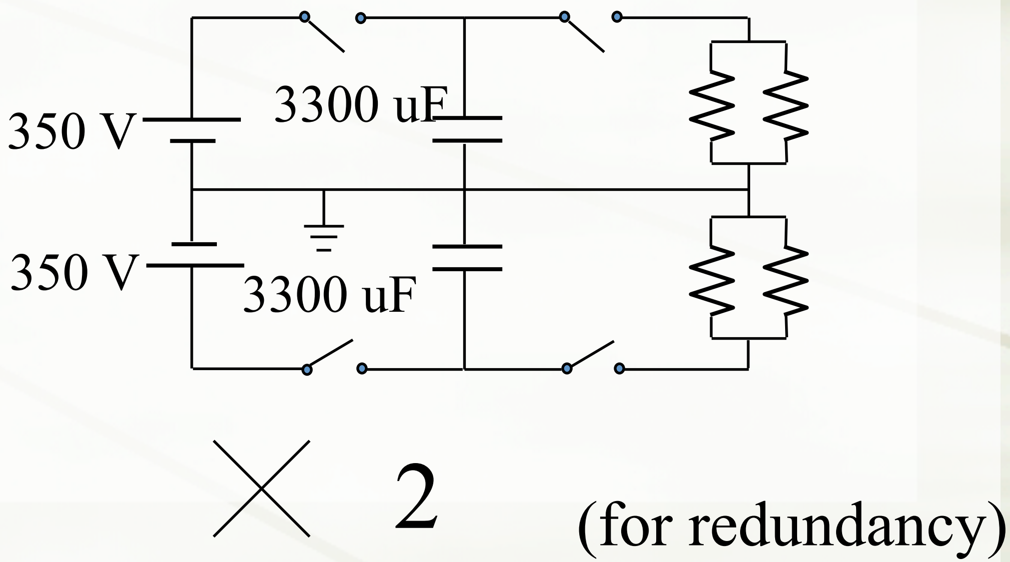
Quench Protection Heaters





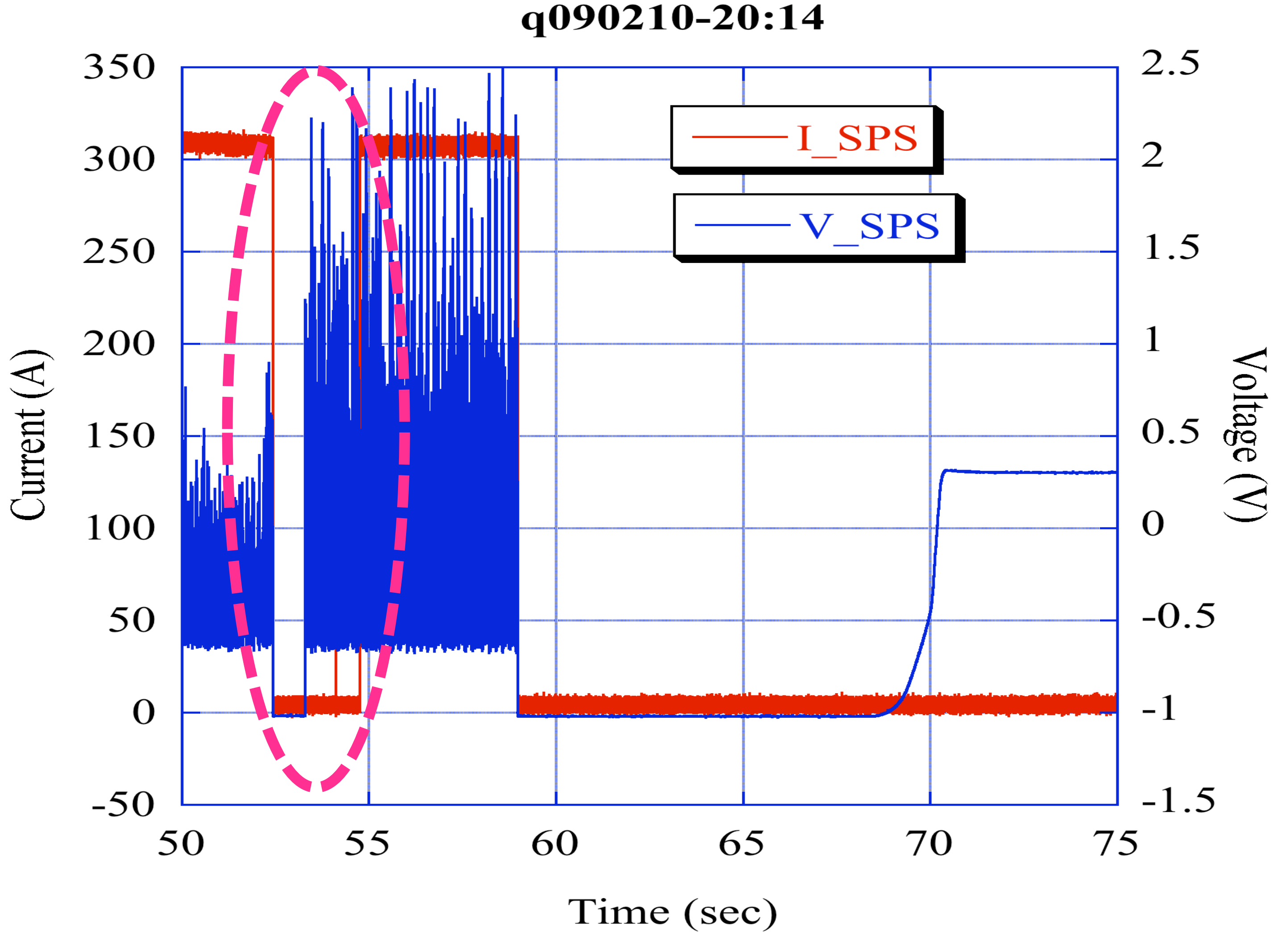


- *Power supply for QPH*
  - Capacitor Discharge Circuit
  - Energy : 100 J /1 element



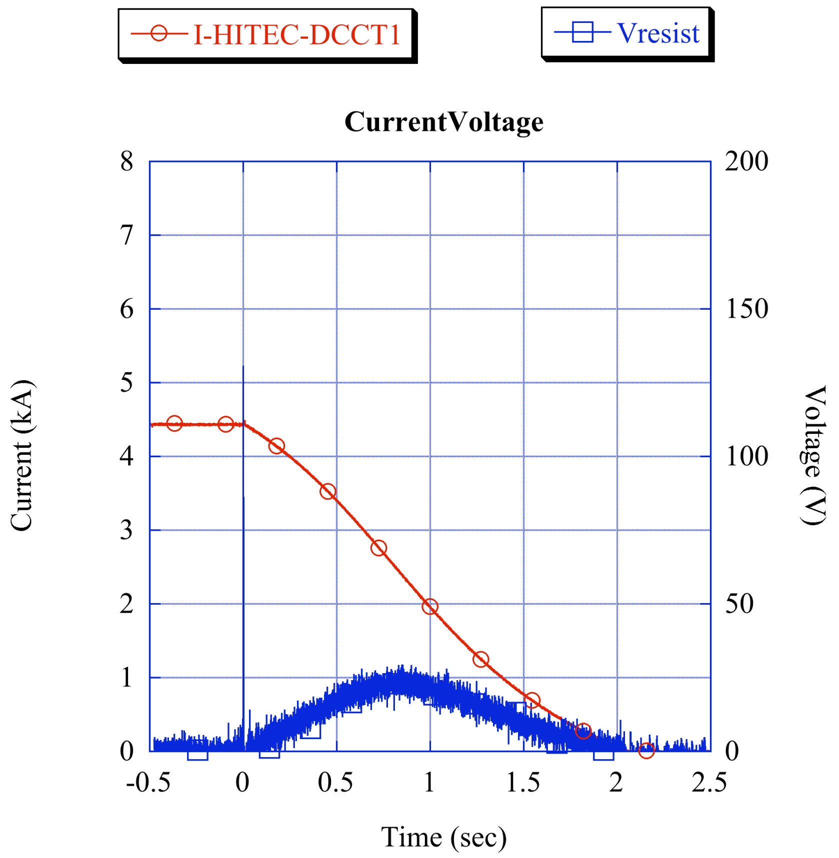
Appendix

- Example : Memory Leak of DAQ ?



Protection by current bypassing

- Example of resistive voltage in the magnet in the single magnet test @ 4400 A



Allowable time constant calculated from MITTs : 3.1 sec

indx	SCR	SCFM	tau	L dI/dt
1	2	4	12.6	4.89
2	4	8	6.3	9.78
3	6	12	4.2	14.67
4	8	16	3.15	19.56
5	10	20	2.52	24.44
6	12	24	2.1	29.33
7	14	28	1.8	34.22