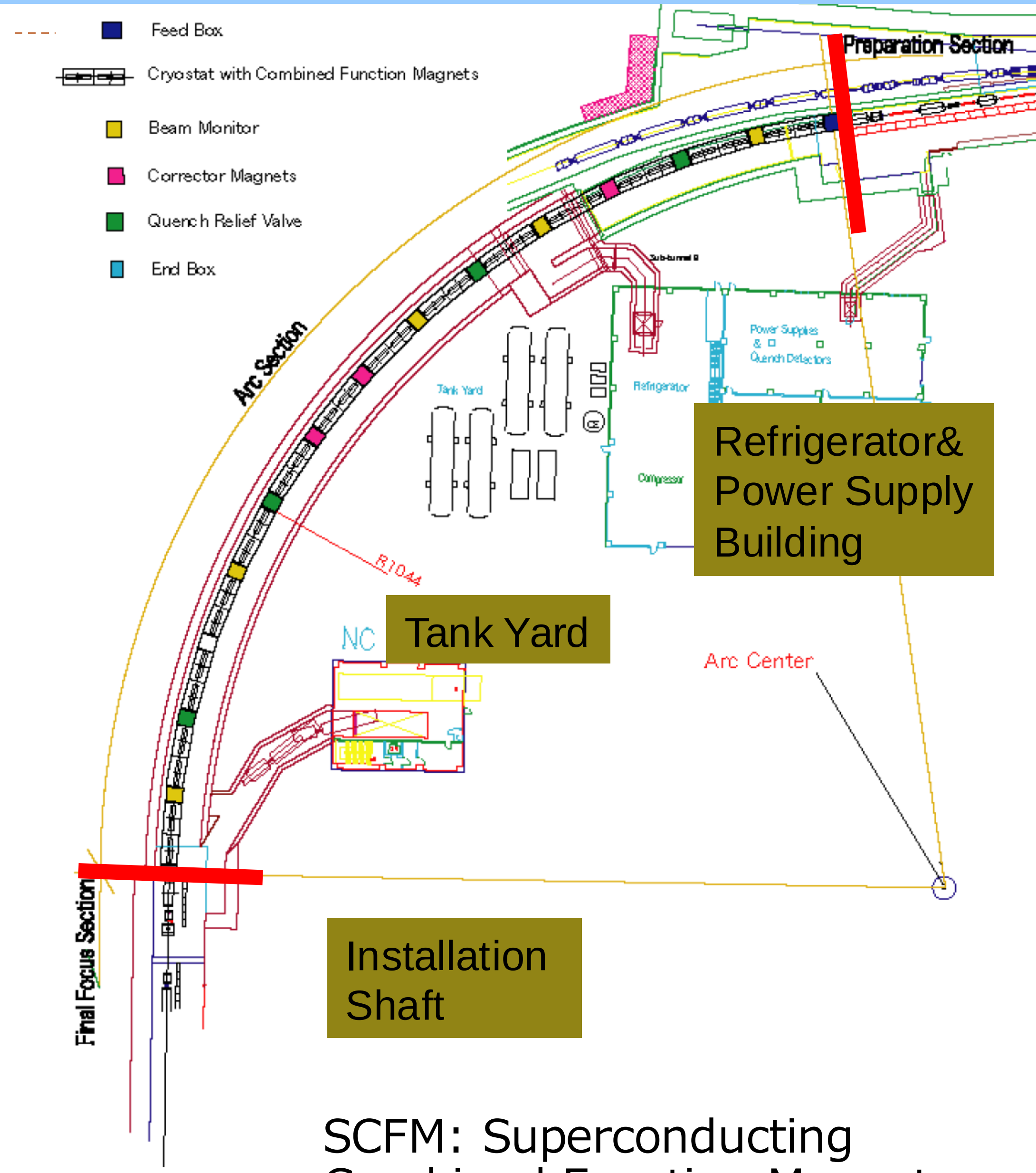
Superconducting Combined Function Magnet System for the J-PARC Neutrino Beam Line

Collaboration with CERN for Cold diode replacement

Ken-ichi Sasaki; KEK

Contents

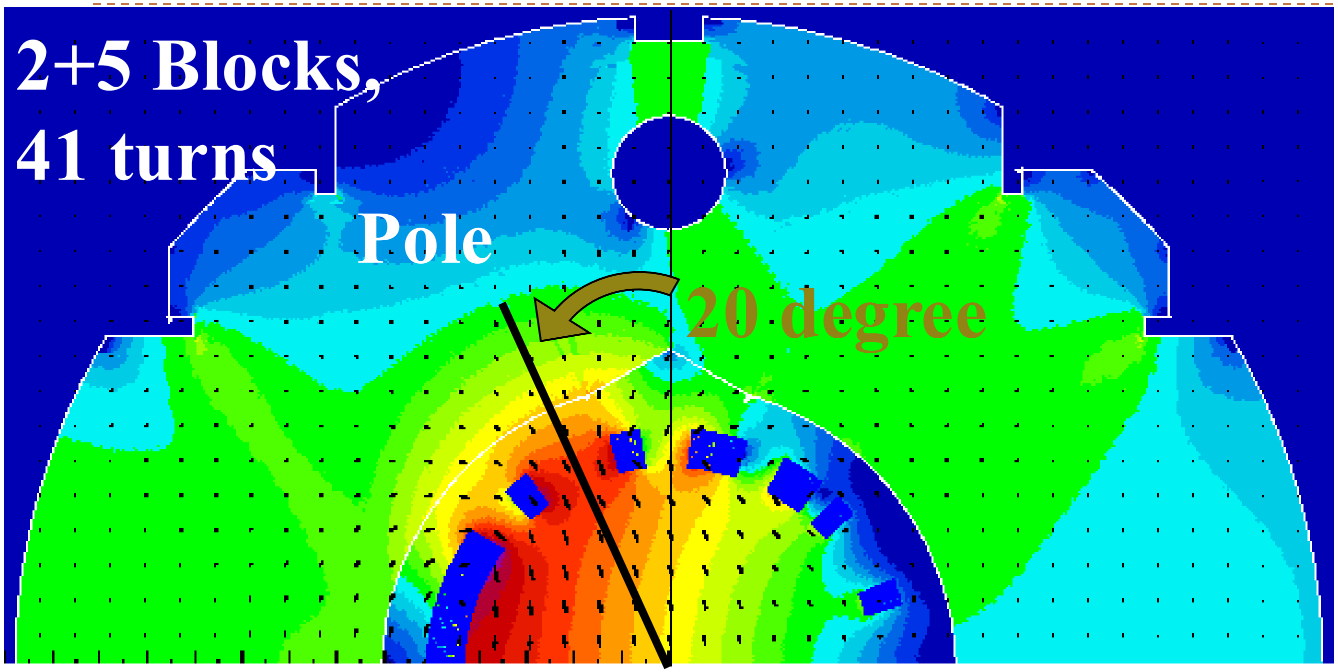
Overview of primary beam line for J-PARC Nu experiment



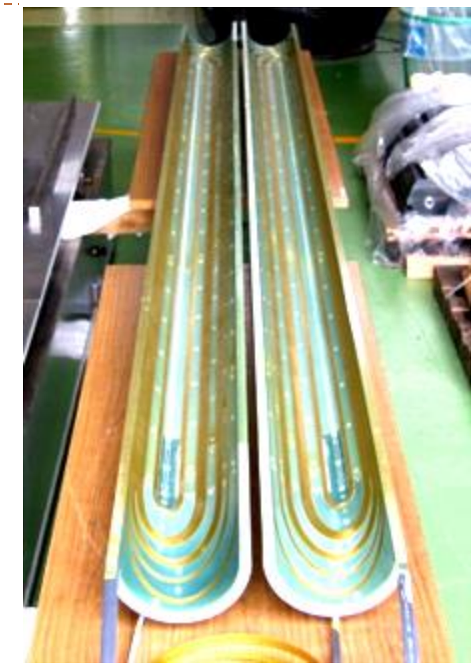
- 28 SCFMs
  - Dipole 2.6 T
  - Quad 18.6 T/m
  - Length 3.3 m
  - 2 in 1 Cryostat
  - Total Stored Energy: 10MJ (50GeV)
- 13 interconnects
  - 5 beam monitor
  - 3 correctors
  - 4 quench valve
  - 1 none

SCFM: Superconducting Combined Function Magnet

Magnet Design



Coils

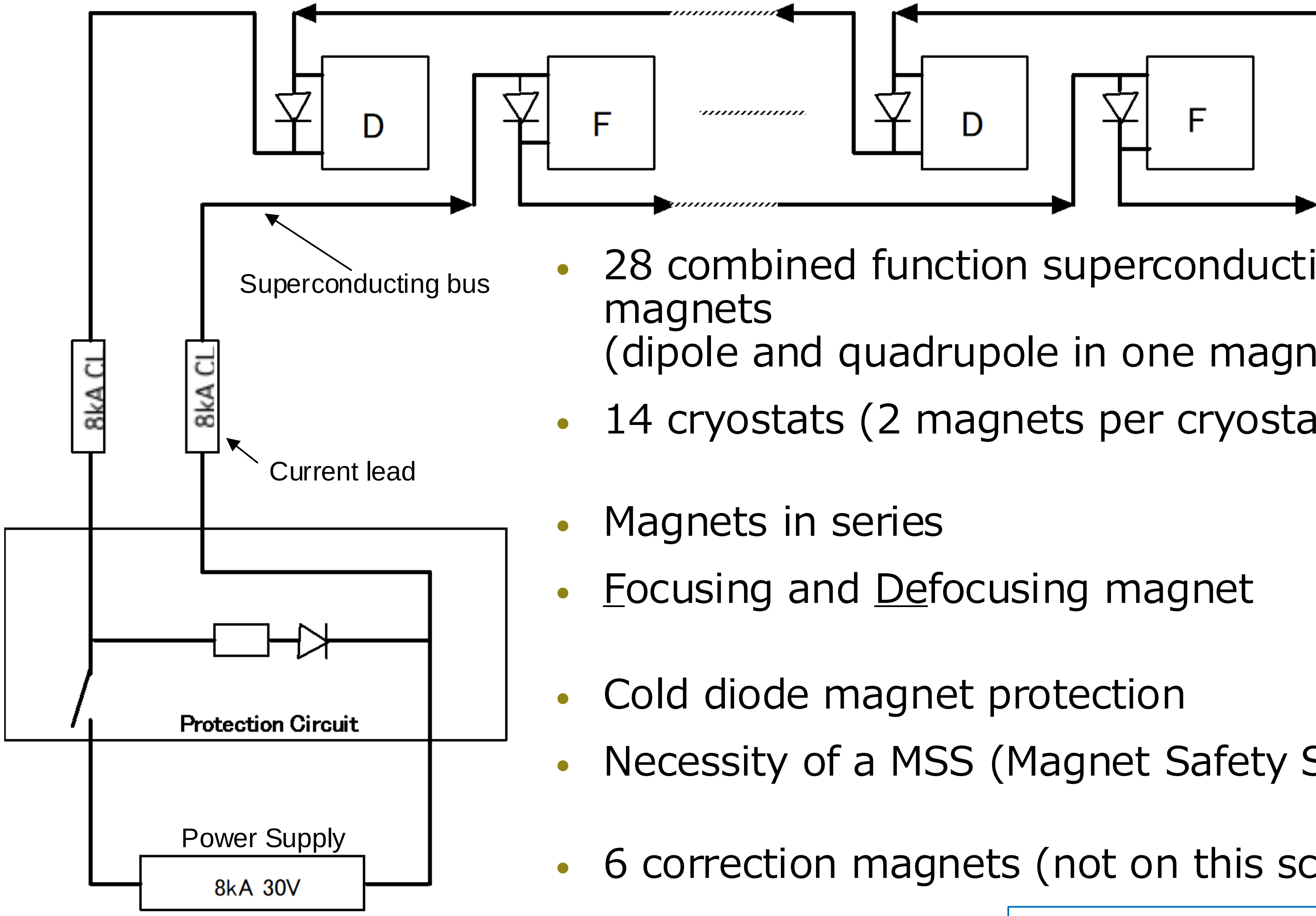


Coil ID.	**:**	**173.4mm**
Mag. Length	**:**	**3300 mm**
Mech. Length	**:**	**3630 mm @RT**
Tmax	**:**	**< 5.0K (Supercritical Helium)**
Dipole Field	**:**	**2.59 T**
Quad. Field	**:**	**18.6 T/m**
Field Error	**:**	**< 10^{-3}**

Op. Current	**:**	**7345 A**
Op. Margin	**:**	**72%**
Inductance	**:**	**14.3 mH**
Stored Energy	**:**	**386 kJ**
# of Magnet	**:**	**28**
SC Cable	**:**	**NbTi/Cu for LHC arc Dipole Outer-L**

- Parameters for 50 GeV

Electrical connection of magnets



- 28 combined function superconducting magnets
  (dipole and quadrupole in one magnet)
- 14 cryostats (2 magnets per cryostat)
- Magnets in series
- Focusing and Defocusing magnet
- Cold diode magnet protection
- Necessity of a MSS (Magnet Safety System)
- 6 correction magnets (not on this scheme)

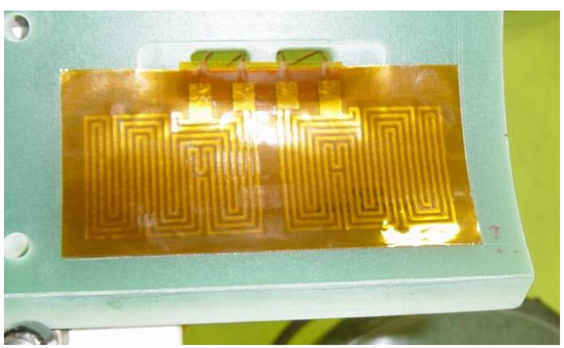
Large inductance -> Long time of current decay <-

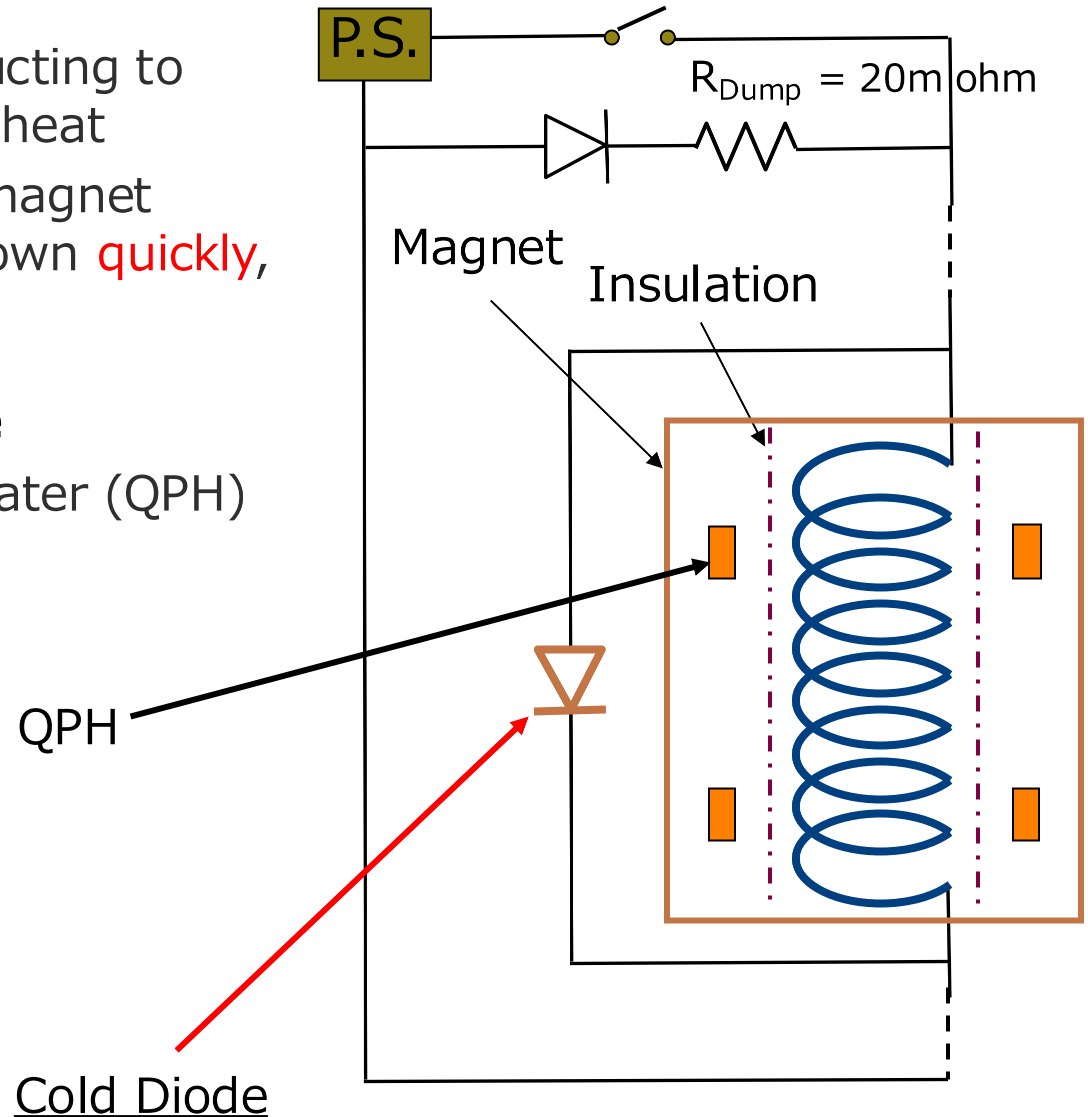
Important point for quench protection scheme

Magnet Protection Scheme

- **Quench**
  - Transition from superconducting to normal states -> generate heat
  - Once quench is occurred, magnet current must be ramped down quickly, otherwise it is burned out

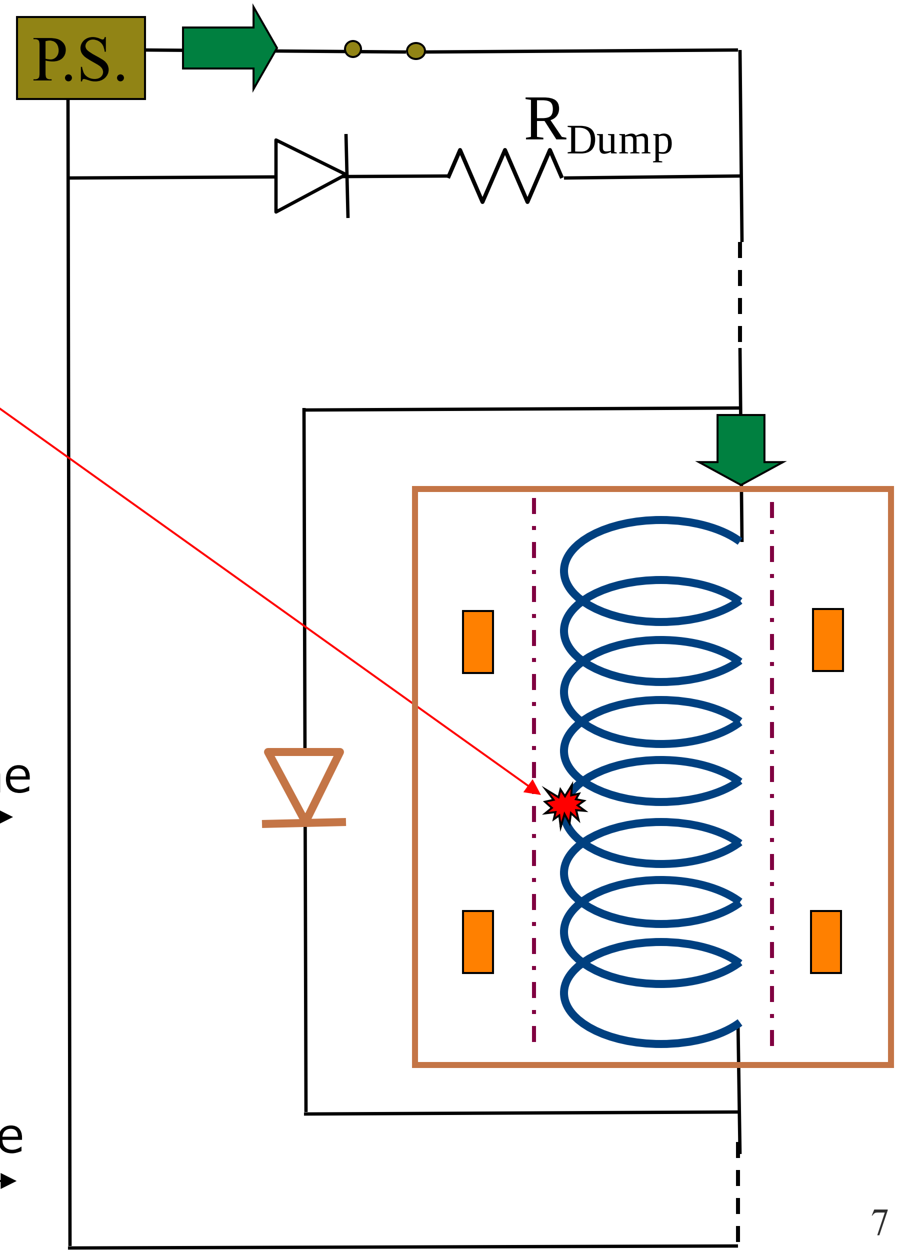
- **Quench protection scheme**
  - Use Quench Protection Heater (QPH) and Cold Diodes





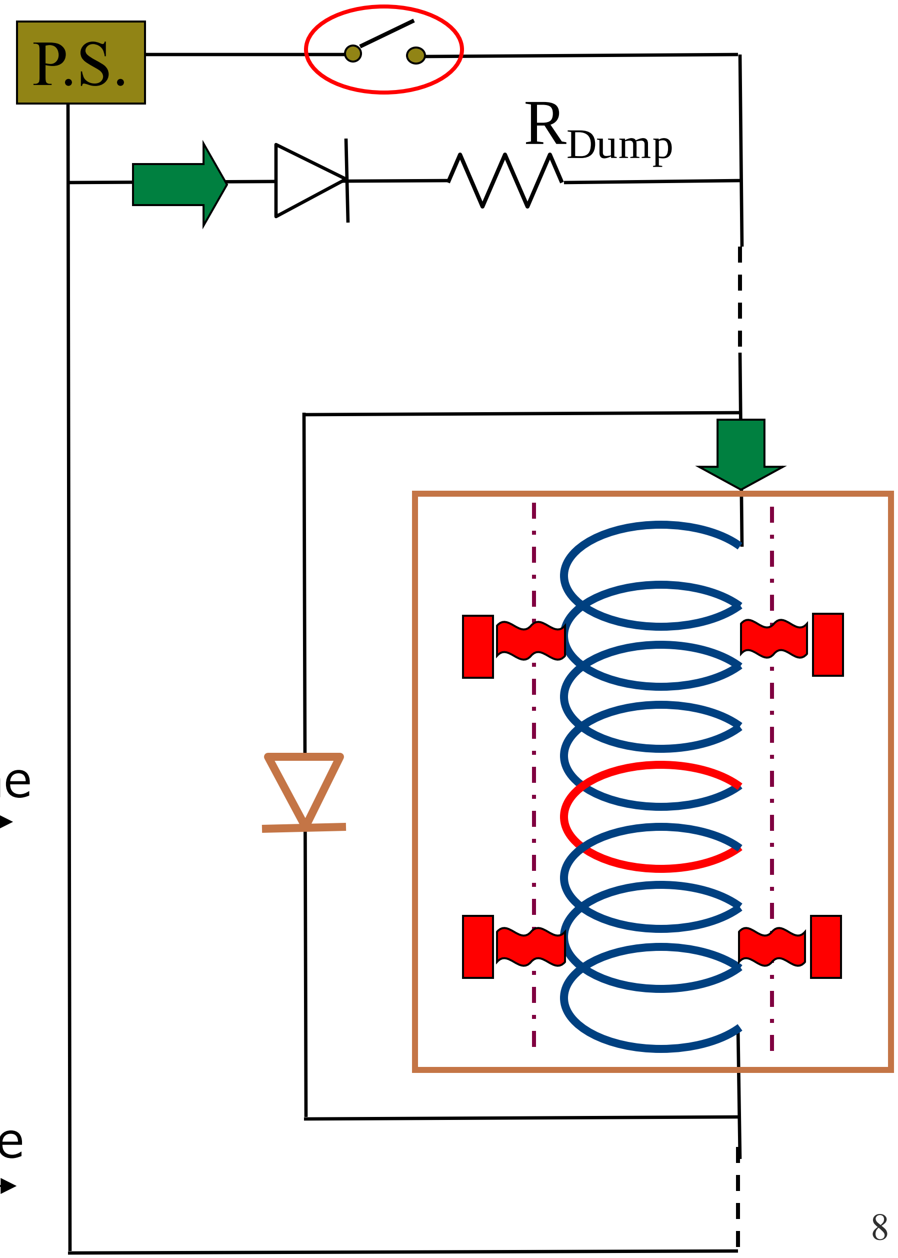
Magnet Protection Scheme

- Quench
- Detection
  - P.S. switch-off
  - QPHs are fired
- Bypass to Cold Diode



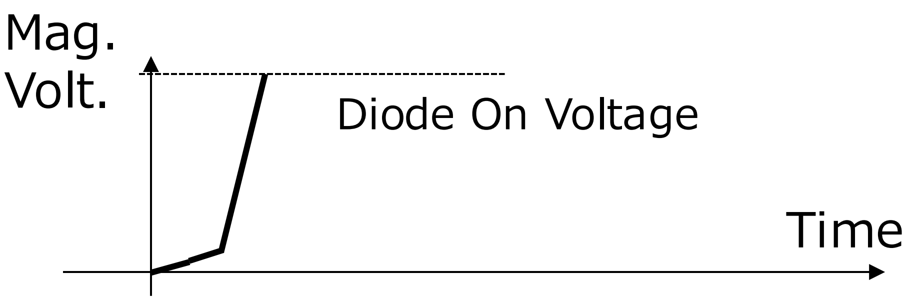
Magnet Protection Scheme

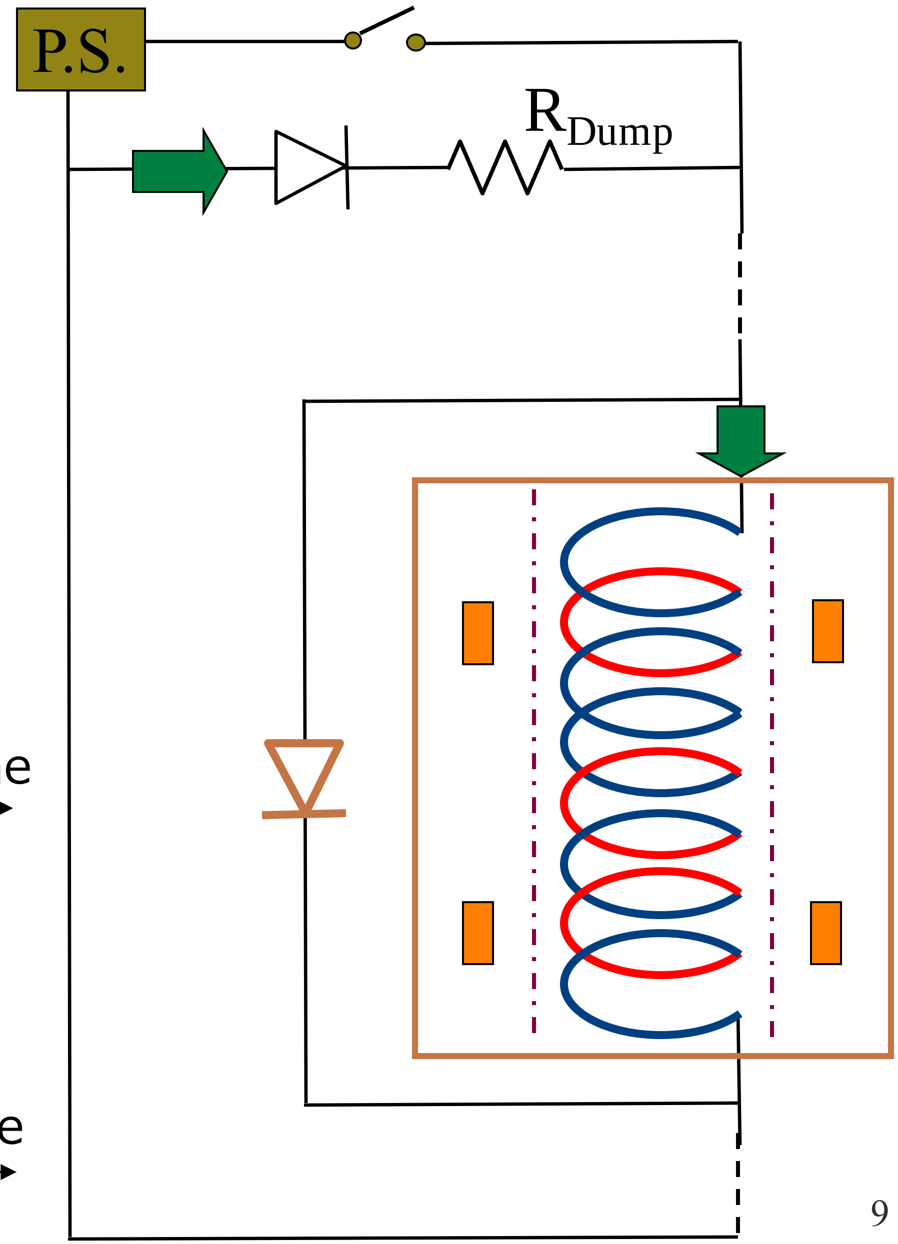
- Quench
- Detection
  - P.S. switch-off
  - QPHs are fired
- Bypass to Cold Diode



Magnet Protection Scheme

- Quench
- Detection
  - P.S. switch-off
  - QPHs are fired
- Bypass to Cold Diode

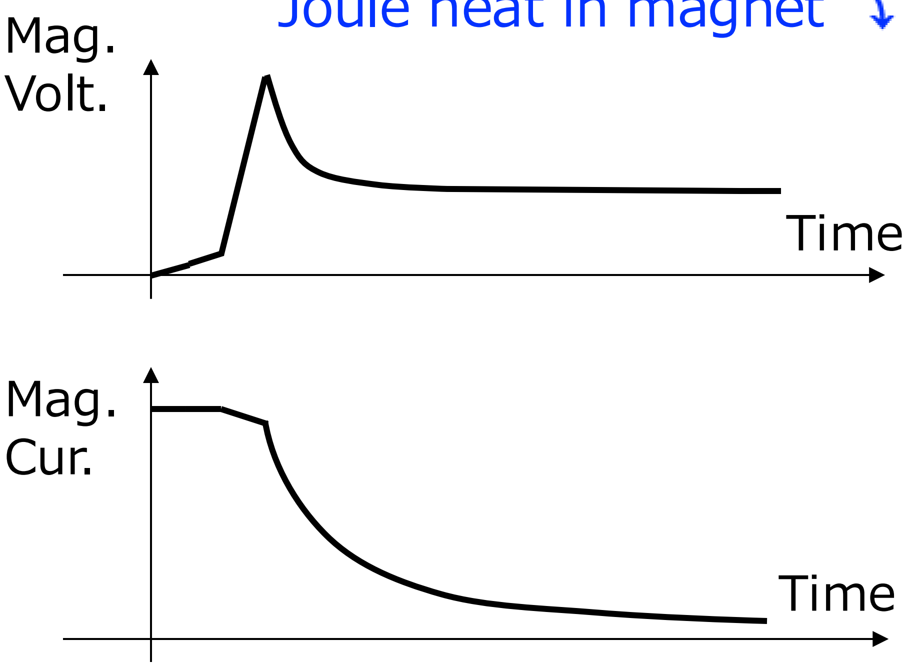


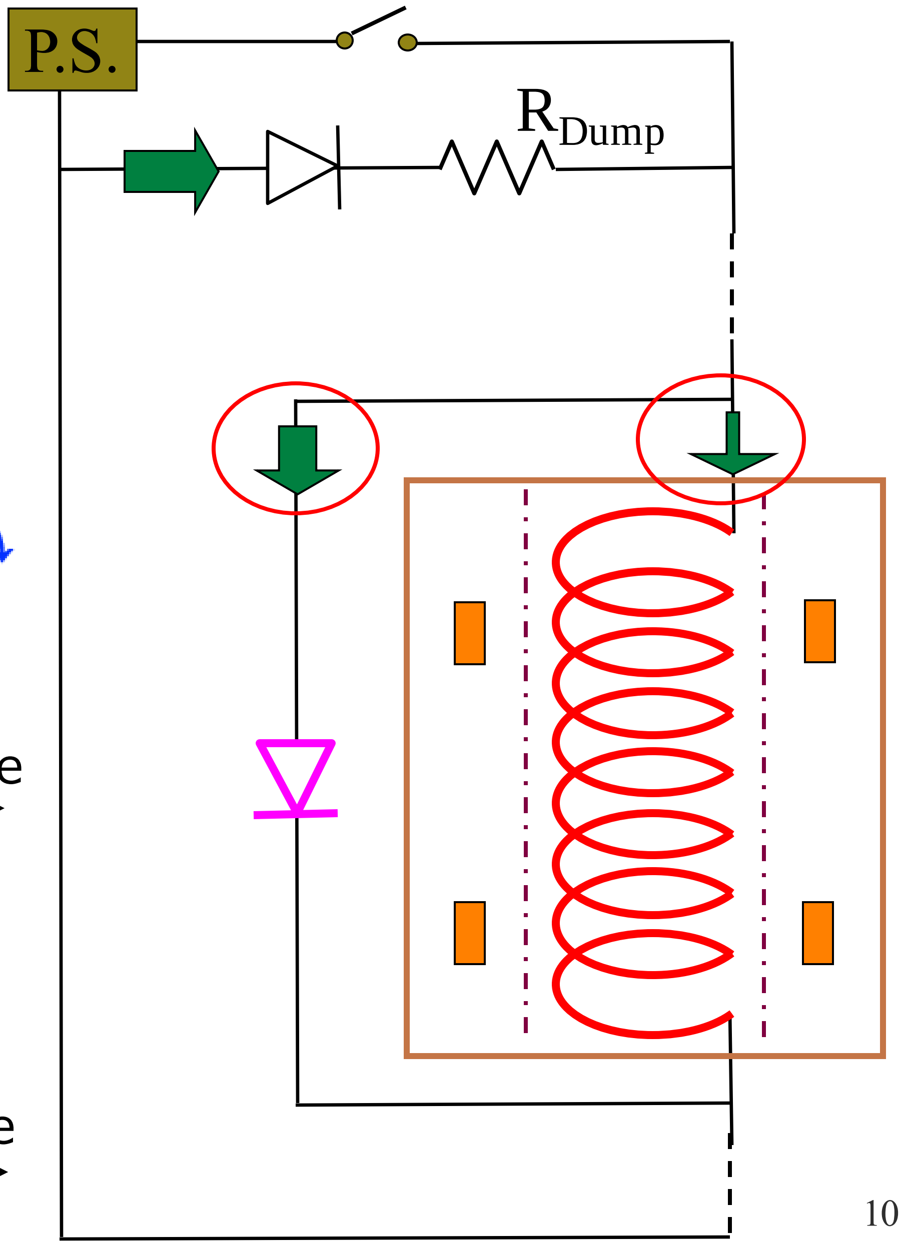


Magnet Protection Scheme

- Quench
- Detection
  - P.S. switch-off
  - QPHs are fired
- Bypass to Cold Diode

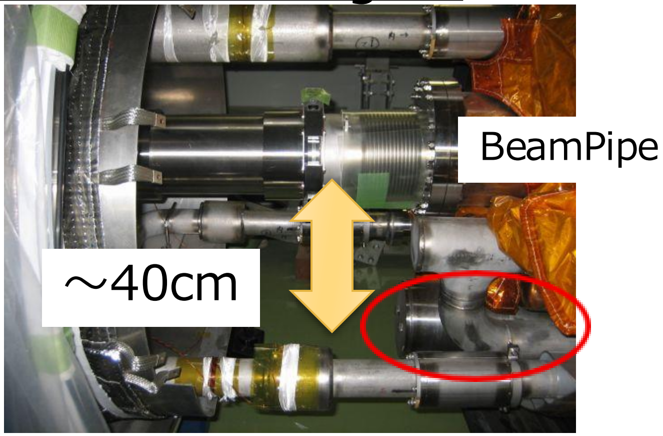
Joule heat in magnet ↘





Cold diode

✓ Key component of quench protection of Nu SC magnet



- Requirement for J-PARC Nu magnet
  - Current capacity at LHe temp. : > 7,345 A
  - Stored energy : 396 kJ
  - Turn on voltage at LHe temp. : ~ 5 V
  - Radiation hardness
    - Original design @ 50 GeV
      - 1 W/m -> 200Gy (1.2 x 10^{13} n/cm^2) for 1 year operation
      - could be operated for several years

- Cold diodes for the CERN/LHC arc quadrupole magnets.
  - Magnet current : 11,870 A
  - Stored energy : 395 kJ
  - Minimized cost because of mass-production for LHC magnets
  - Radiation hardness
    - well studied -> 2 x 10^{14} n/cm^2 is allowable

Sufficient margin for J-PARC use -> Purchased from CERN

System operation summary

- Since 2009
- Operation current : 4320A (design max. 7345A)
- Quench event
  - Two beam induced quenches
    - one is artificial(0304), another is incident(1112)
  - Eight quenches by malfunction of trigger system for quench protection heaters
    - Bad solder joints : figured out and modified in 2012
  - Quench heater performance test
    - Manual trigger of quench heater
      - 10 times

<u>~ 20 times quench events in total</u>

Estimation of irradiation

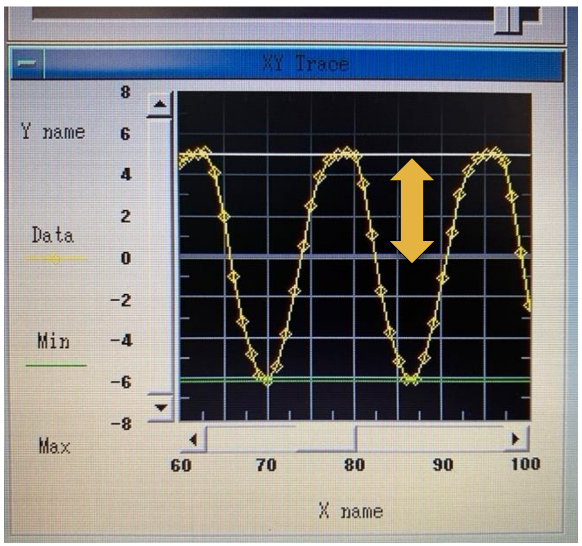
- Old simulation (2000 ~2004)
  - 50GeV, 750 kW proton beam
    - 1 W/m beam loss -> 1.2×10^{13} n/cm^2 / year
      - can operate for 10 years w/o replacement

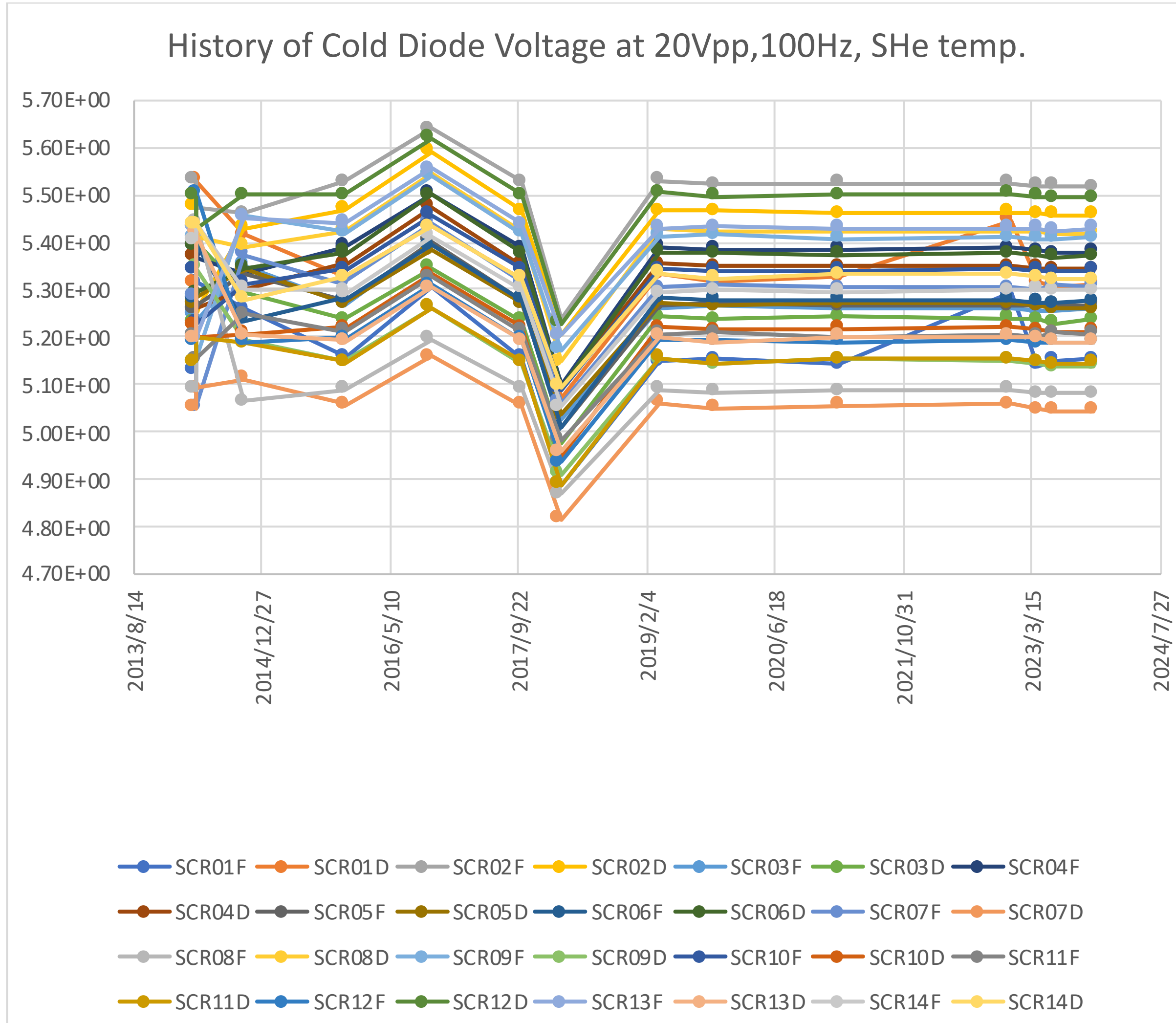
- Recent measurement
  - 40GeV, 550 kW proton beam
    - Measurement result : 0.033 W/m
      - Simple scaling
        - 0.033 x 1.2×10^{13} = 4.0×10^{11} n/cm^2 / year

allowable : 2×10^{14} n/cm^2
from diode test by CERN

Diode ON-voltage log at 4.4K

- Checked diode ON-voltage at cold temperature after cooling down
- Apply AC Current of 100 Hz, get amplitude.





Maintenance plan of diode

- In terms of irradiation effect
  - **No degradation**
  - might be OK even in another 10 years
- But more than 15 years in operation
  -> Need to consider degradation over time

- Replacement scenario
  - Urgent replacement of all diodes are **unnecessary**.
  - Check diode performance regularly
  - The diodes showing performance change would be replaced individually

- *Only one spares now*
  - *One or Two spares will be prepared in collaboration with CERN in 2025.*

Summary

- Superconducting magnet system for J-PARC neutrino beam line was constructed in collaboration with CERN
- The system has been successfully operated in 15 years without serious failures
- Procurement of new cold diode packs for spare is in progress in collaboration with CERN, for the stable operation of neutrino beam line without long down-time.