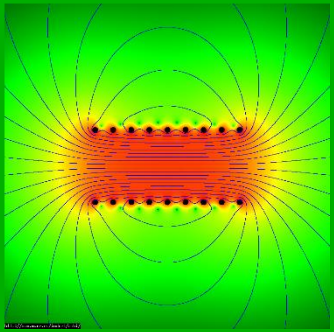
Quench Characteristics of 6T Conduction-cooled NbTi Magnet System



BY

Soumen Kar[1], Vijay Soni[2], P.Konduru[1], R.G.Sharma[1] , D.Kanjilal & T.S.Datta[1]

[1]Cryogenic & Applied Superconductivity Group, IUAC, New Delhi
[2]National Institute of Technology, Rourkela

Plan of the Talk

- Quench : Classification specially for Conduction-cooled magnet system
- FEA simulation of Quench
- Quenching of 6T conduction-cooled NbTi magnet system
- Quench Energy distribution
- Recovery after quench by the Cryocooler
- Summary

Quench: Conduction-Cooled Magnet

Quench: Sudden Transition from Superconducting to Normal state: Adiabatice dumping of stored energy

Cryogen-free magnet system

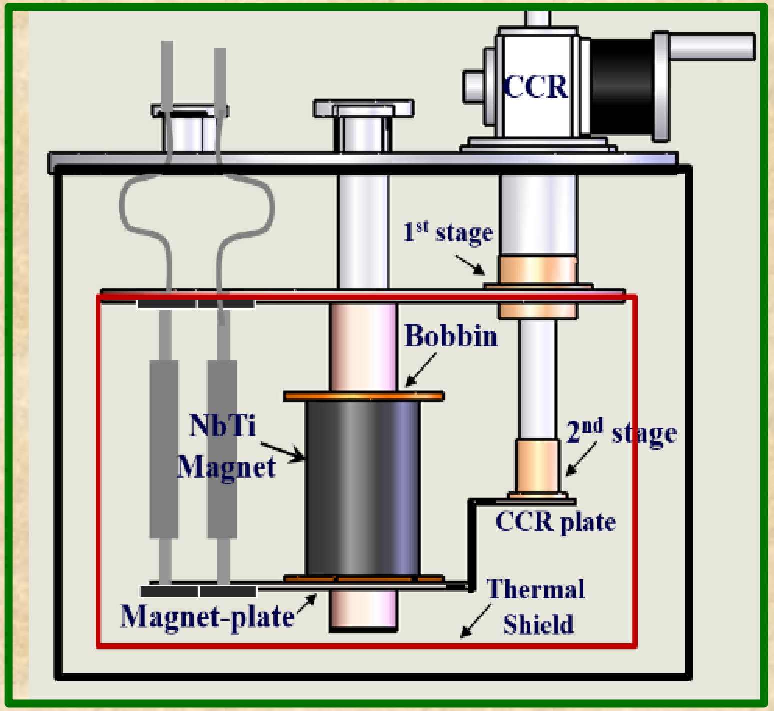
Magnet is cooled by CRYOCOOLER alone through conductive links

Limited Refrigeration Capacity

Poor Heat Transfer

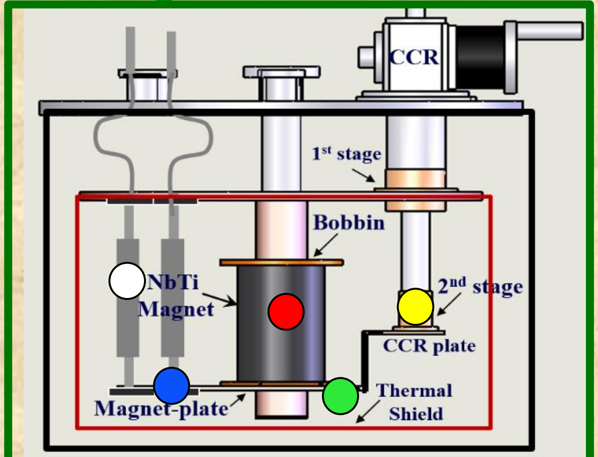
Any small thermal disturbance Will raise the temperature of Magnet

More prone to Quench



Quench Classification

Different Types of quenches in Conduction Cooled Magnet System



- **Other Quenches**
  - AC loss in the Superconductor
  - Joule heating due To the induced eddy current in metallic comp
  - Joule Heating in Inter-lead resistive joints
  - Failure of Cryocooler
  - HTS lead failure can also lead quench …
- **Training Quench**
  - Conductor Movement

Tc (B, J) , Specific Heat of Conductor

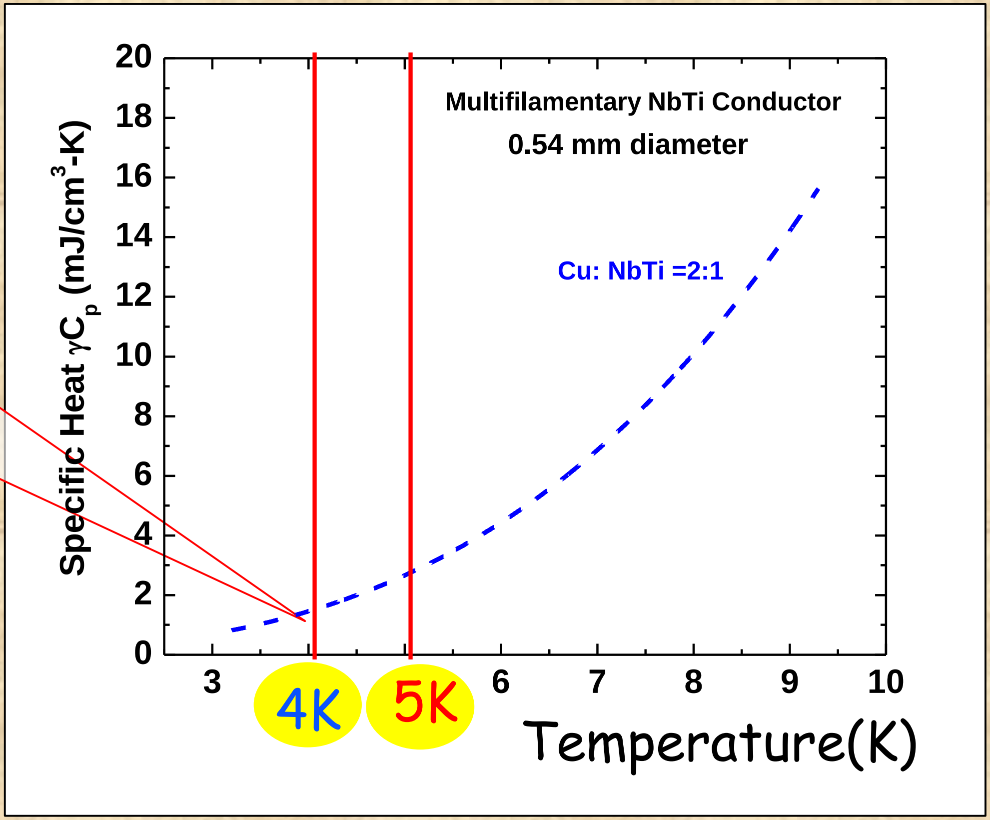
Heat Balance Equation

$$V C_P \frac{dT_{mag}}{dt} = Heating\ [\,Q_{AC}, Q_{I^2R} etc] - \mathrm{Cooling\ (T)}$$

Top ~ 4K : T_C(B=0,J=0) ~ 9.2K

Tcs (B=6T, J= 70% of Jc) ~ 5.0K

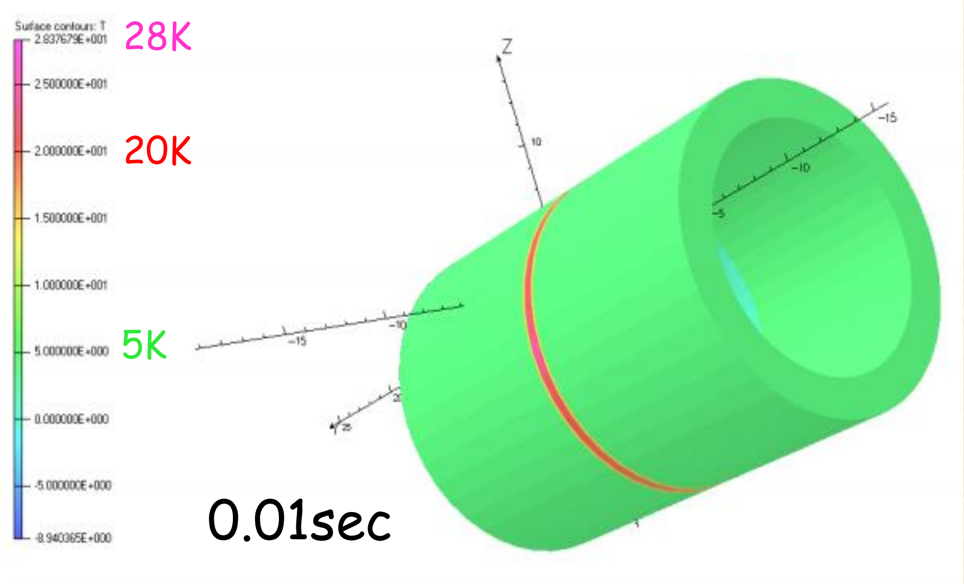
2 mJ/cc heat energy can raise the temp beyond Tc (6T, 102A)

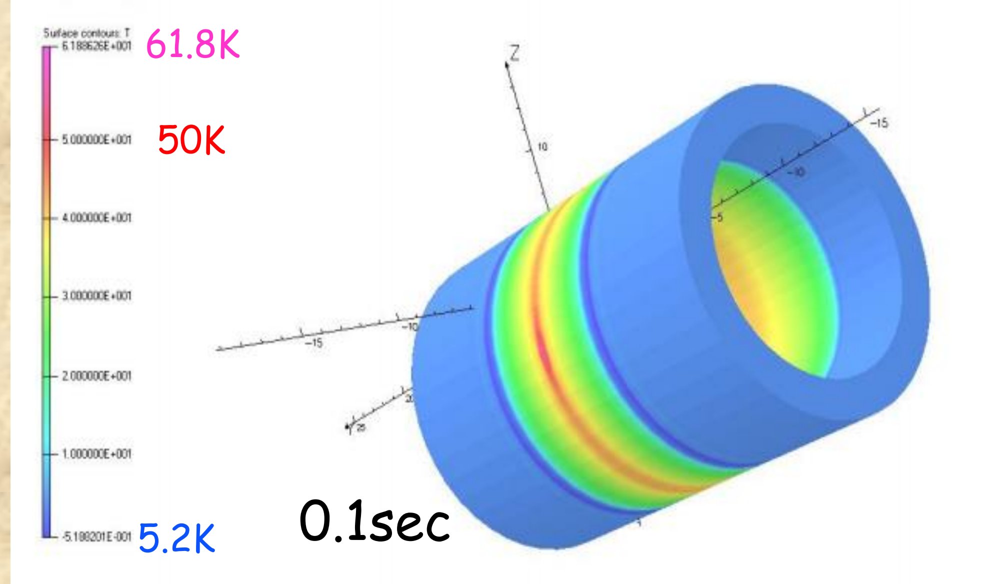


Quench Simulation-1

Transient Thermal Profile

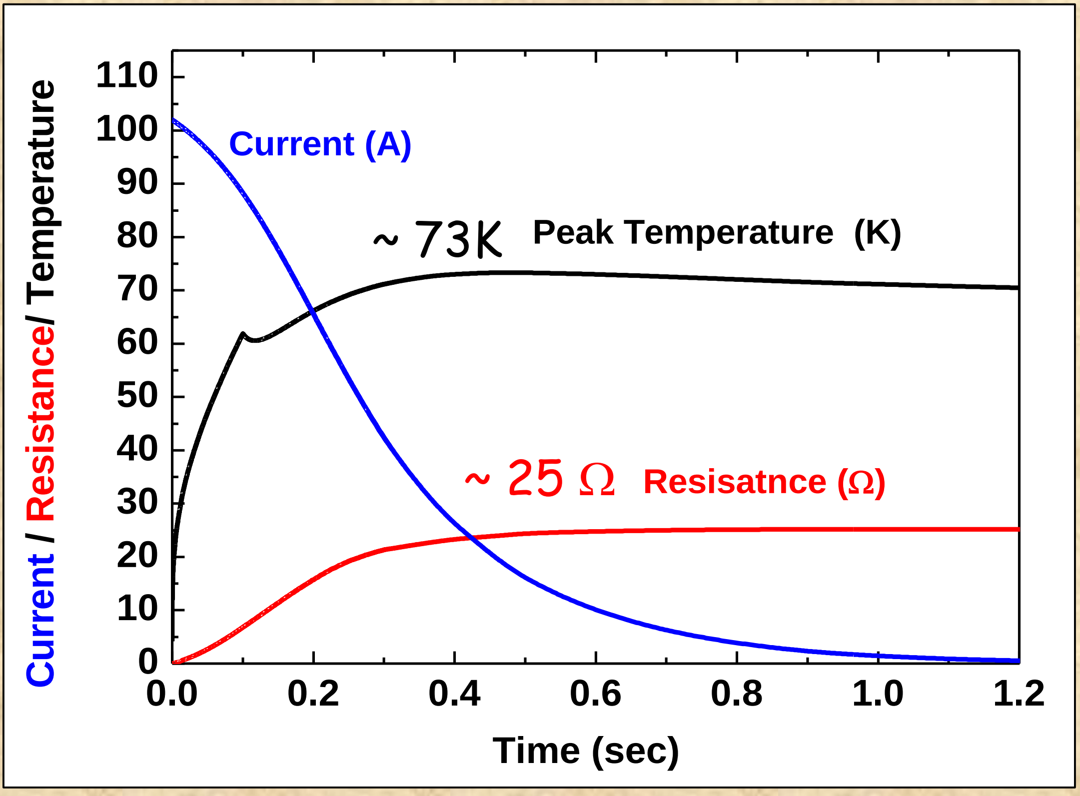
Quench Simulation in Opera-3D shows how the Temperature of the NbTi magnet grows during Quench at 102A





Quench Simulation-2

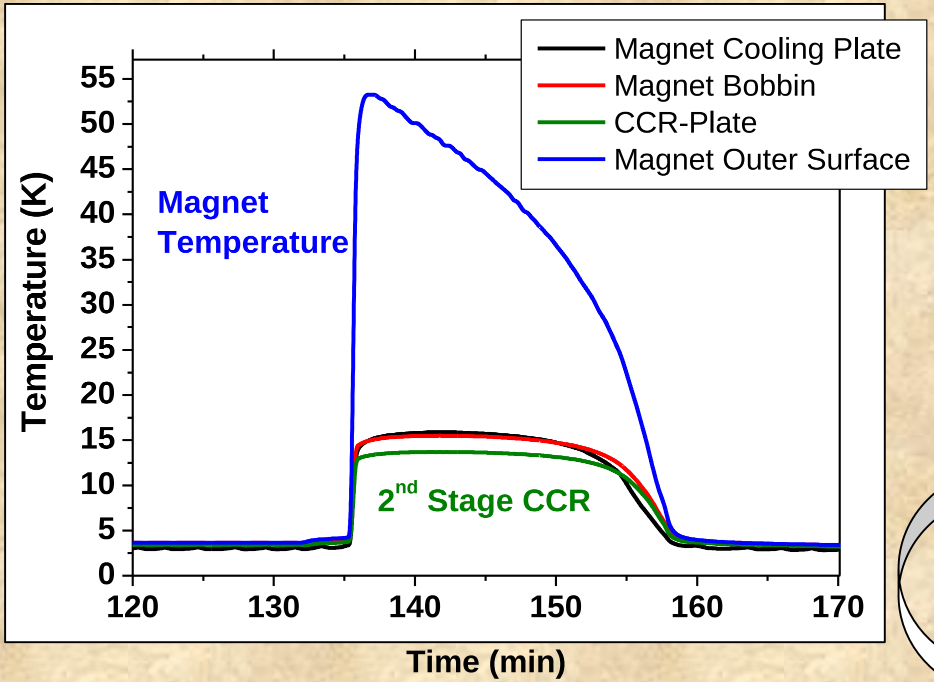
Quench Simulation in Opera-3D also shows the Current Decay, Resistance Growth and the Peak Temperature of NbTi coil during Quench at 102A



Quenching of 6T Conduction-cooled Magnet (1)

Quenching at 101.2A : Training Quench,
Happened during first energization

The heat energy would be distributed in
[NbTi Magnet and all the Components] and [Dump resistor]



$$E_{Total} = \frac{1}{2}LI^2 = E_{Mag} + E_{Dump}$$

$$E_{Mag} = \sum_{i=1}^{i=k} \int_{T_c^i}^{T_h^i} V^i C_p^i(T)\,dT$$

$$E_f = \frac{E_{Mag}}{E_{Total}} = \frac{R_{mag}}{R_{mag} + R_{dump}}$$

$R_{Mag} \sim 25\,\Omega$ $R_{Dump} \sim 5\,\Omega$

$E_f \sim 80\%$

$$E_{Total} = \frac{1}{2}LI^2 = 28\text{kJ} = E_{Mag}(22\text{kJ}) + E_{Dump}(6\text{kJ})$$

Quenching of 6T Conduction-cooled Magnet (2)

Maximum Sweep rate ~ 6A/min

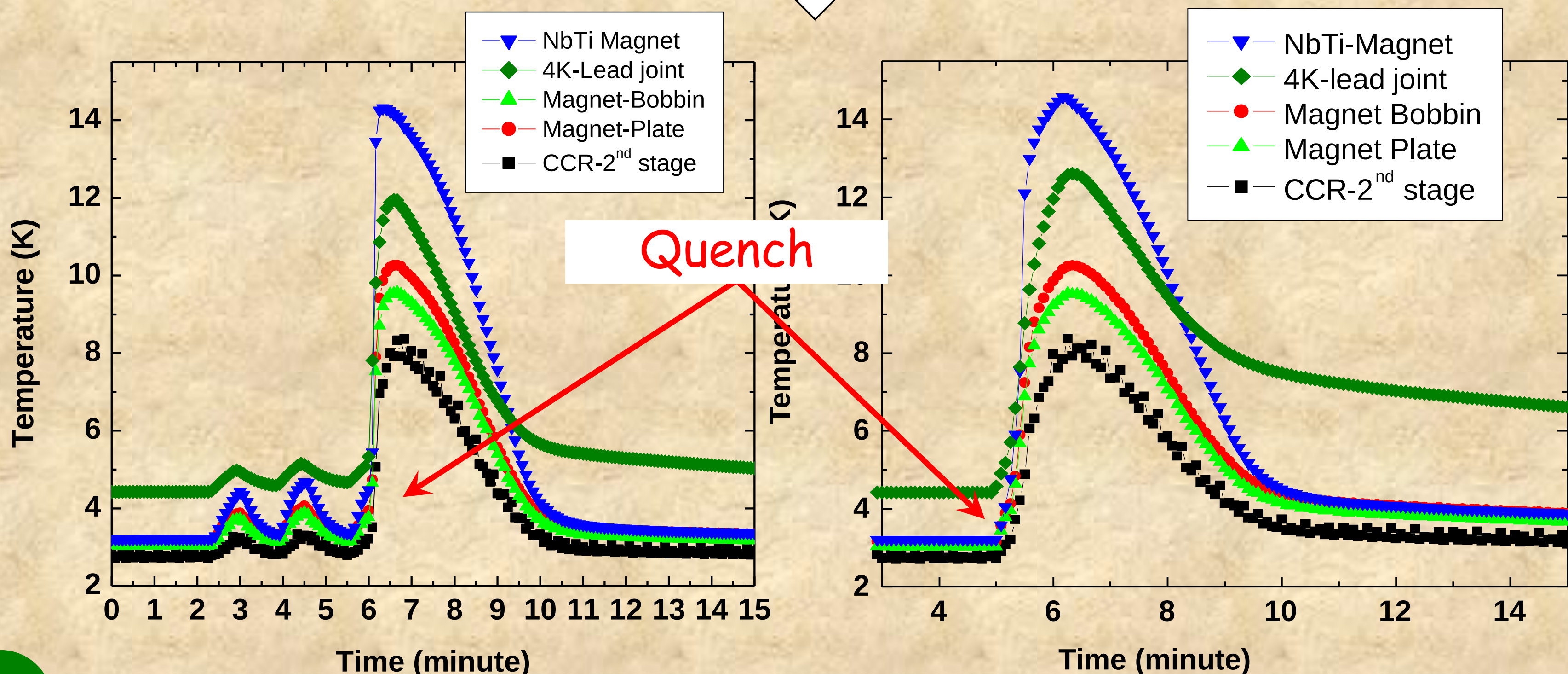
Quench due to excessive AC/Eddy Loss

Intentional Quench

At higher sweep rates

Quenching @ 14A : 8A/min

Quenching @ 4A : 20A/min



Dynamic Losses @ 8A/min at 14A~ Losses @ 20A/min at 4A

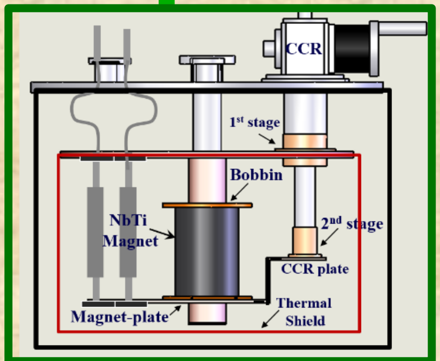
Recovery After Quench by Cryocooler

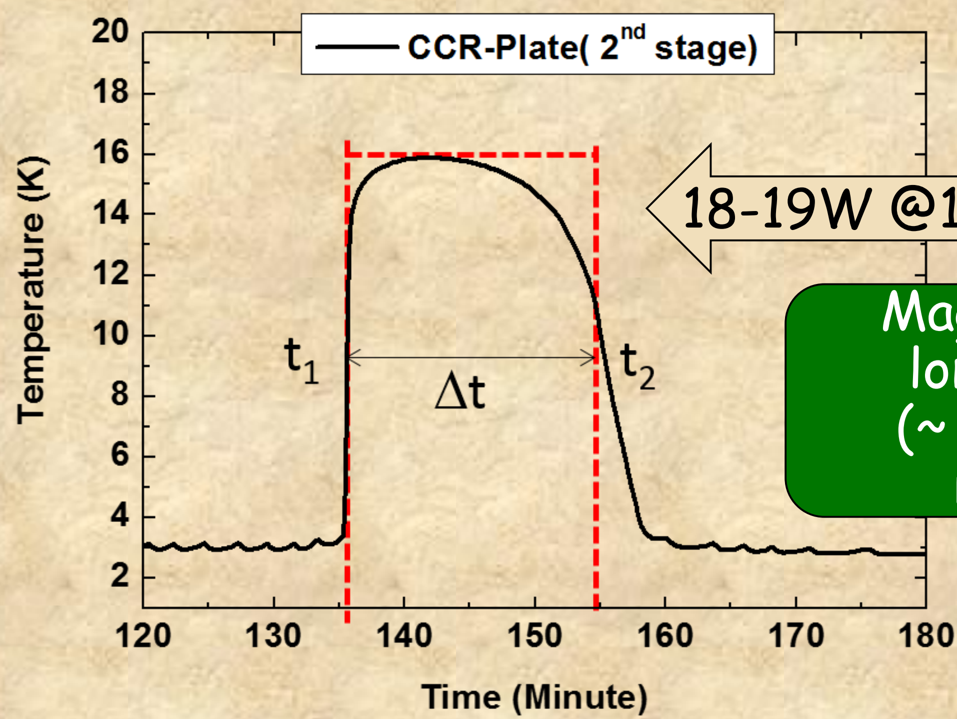
After Quench: Unlike bath cooled magnet :

- The heat energy would be extracted slowly by the Cryocooler through the conductive links
- Limited Refrigeration Capacity of the 2nd stage of cryocooler

$$Q_{CCR} = -\int_{t1}^{t2} R(T)dt = R_{avrg}\Delta t$$

R(T)= Refrigeration capacity of Cryocooler at Temp T

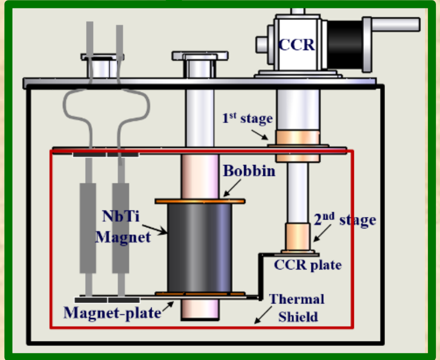




18-19W @16K

Magnet takes longer time (~ 40min) to recover

Summary



More probable reasons for quenching in Conduction Cooled magnet system

Poor Heat Transfer in conduction-cooled Magnet limits the sweep rate

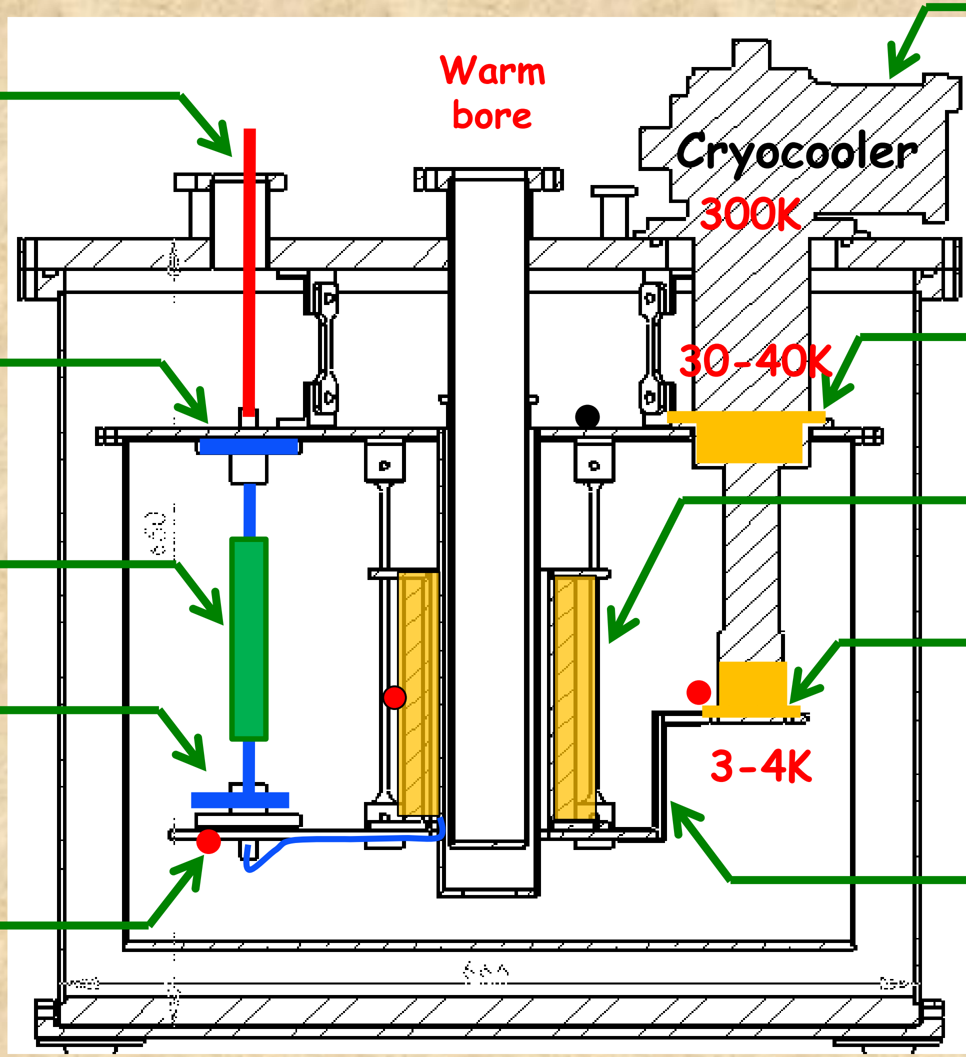
Achieving thermal stability in conduction Cooled system is very important

Limited Refrigeration Capacity and Conductive links make the recovery time longer

Post –quench Energy distribution in magnet system depends on the ratio of dump resistance and resistance growth

Thank You for your Kind Attention

Schematic of CFMS –Major Components



Copper lead

Thermal anchoring block

HTS lead

Thermal anchoring block

T-sensor

2-stage Cryocooler

1st Stage Cold Head

NbTi Magnet

2nd Stage Cold Head

Cooling link

Cryostat (SS-304) +ETP copper Th. Shield

Quench Protection