AT - MTM

Modelling of quench levels induced by steady state beam loss heat load

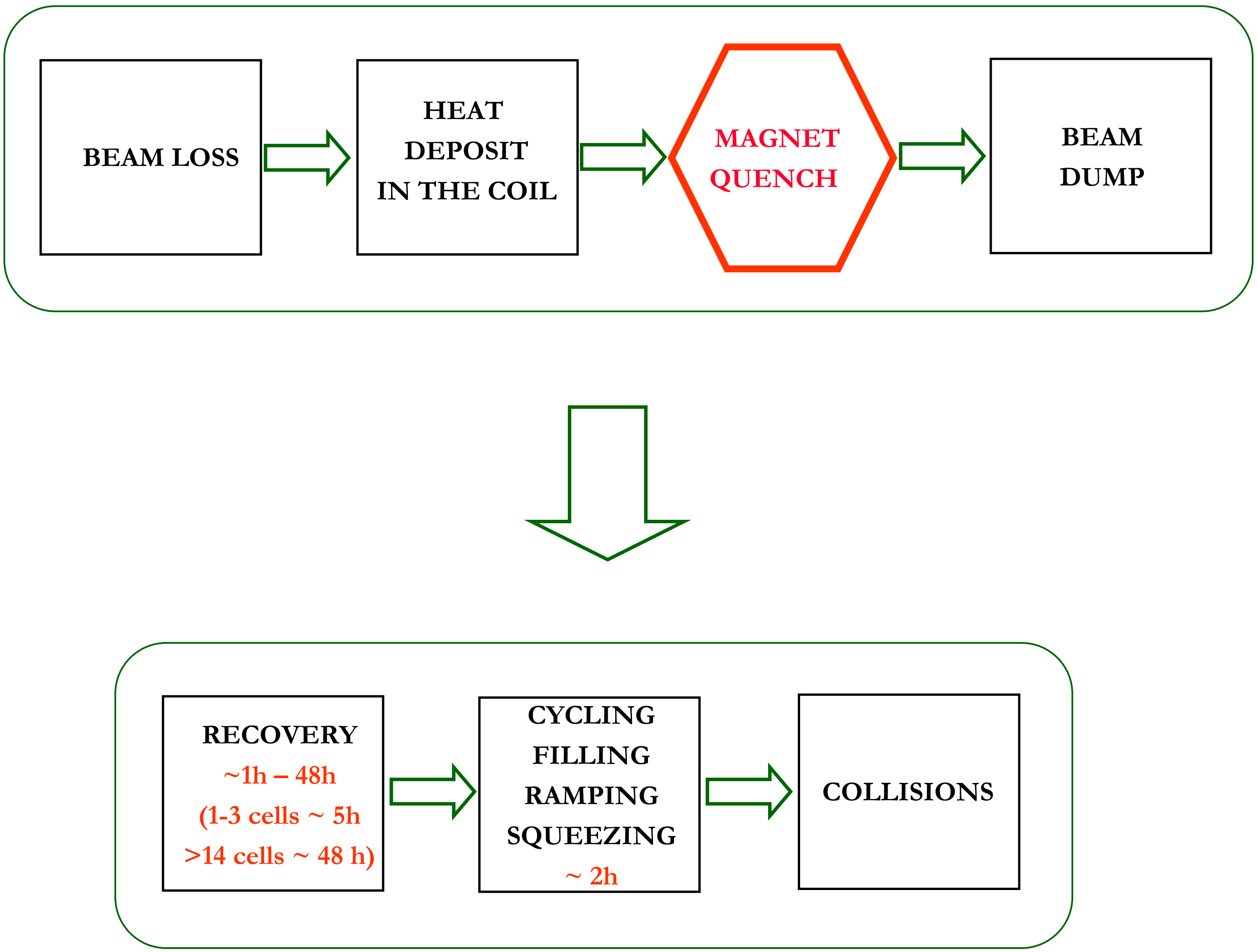
D. Bocian , B. Dehning / AB-BI and A. Siemko / AT-MTM

Acknowledgements: G. D'Angelo, J. Bielski, A. Bonasia, M. Calvi, P.P. Granieri, J. Halik, J. Kaplon, G. Kirby, L. Oberli, R. Ostojic, H. Prin, P. Pugnat, A. Verweij,R. Van Weelderen

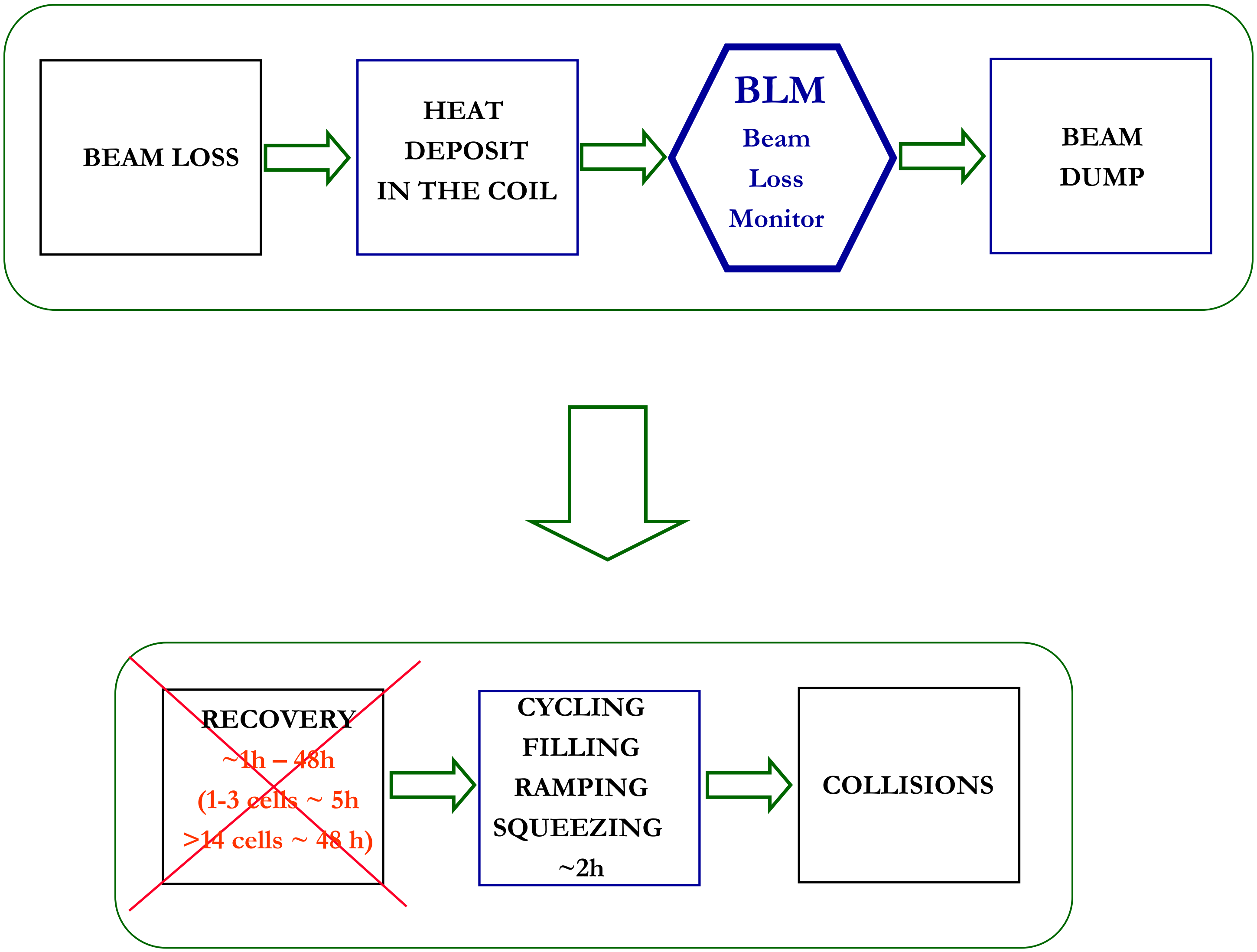
Outline

- **Motivation**
  - Optimise BLM threshold settings (gain the time and money)
  - Integrated luminosity (increase discovery potential of LHC)
  - Reduce of quench number (reduce the number of thermodynamic shocks)
- **Thermodynamics of magnet structure**
  - Heat transport in the magnets
  - Characteristics of superconducting coils
- **Network Model**
  - Model construction
  - Superconducting cable and coil models
  - Electrical equivalent
  - Simulations
- **Validation of the model**
  - Measurements in SM 18
  - Evaluation of the network model quality
- **„Beam loss" simulation**
- **Summary and outlook**

MOTIVATION
LHC beam loss protection



MOTIVATION
LHC beam loss protection



MOTIVATION
LHC beam loss protection

Optimise BLM threshold settings

(gain the time and money)

Integrated luminosity

(increase discovery potential of LHC

Reduce of quench number

(reduce the number of thermodynamic shocks)

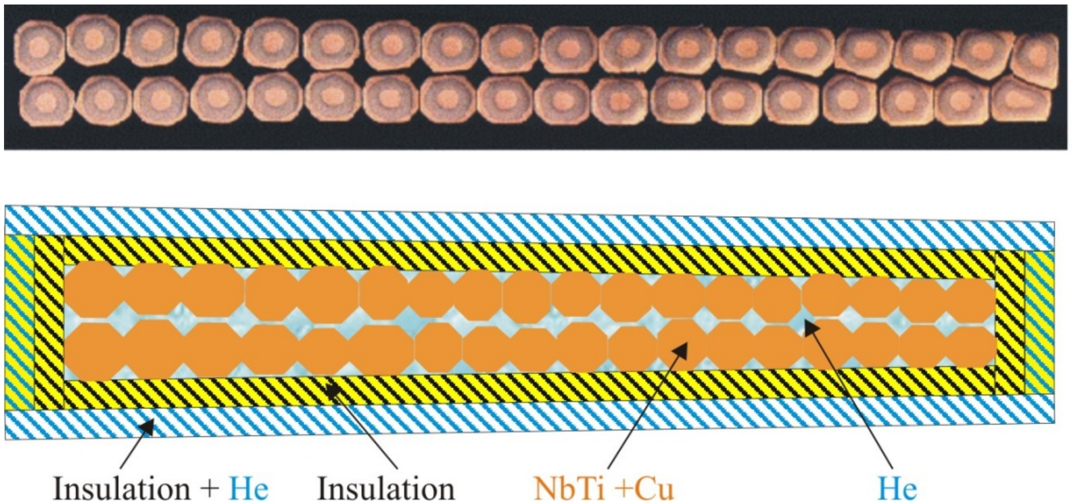
Thermodynamics of magnet structure

Heat transport in the magnets

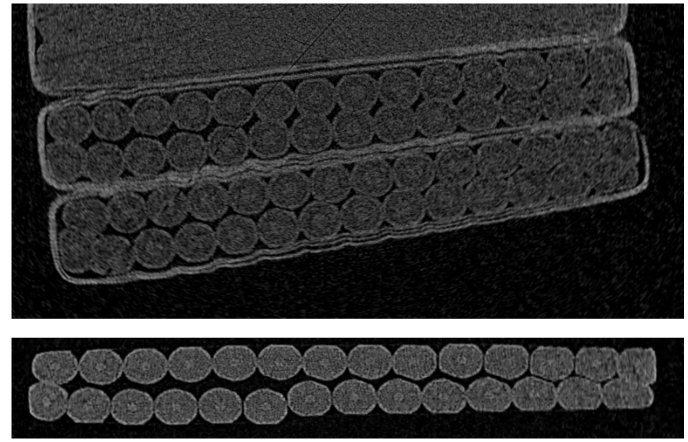
Characteristic of superconducting coils

Heat transport in the cable

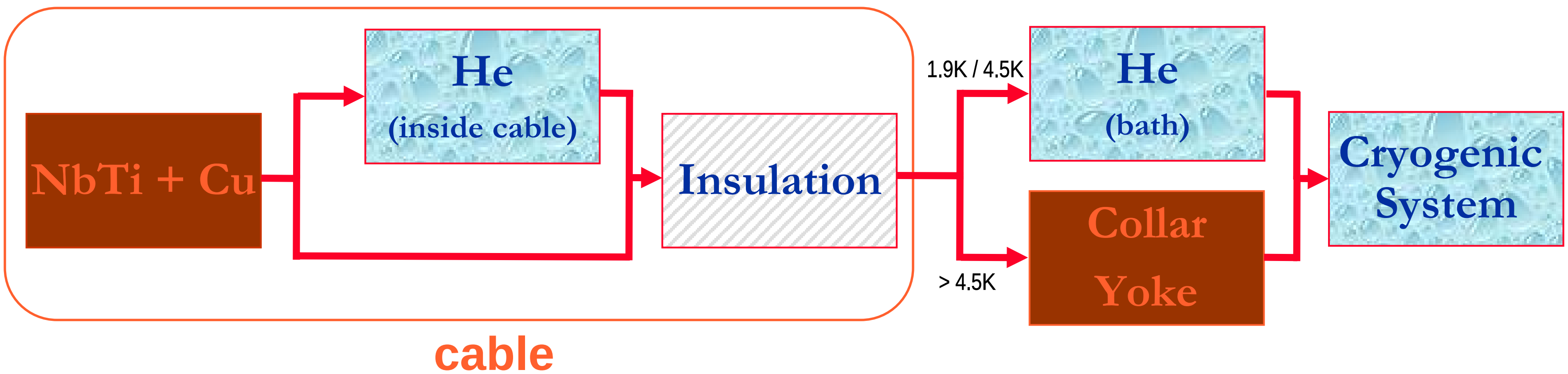
Rutheford type cable



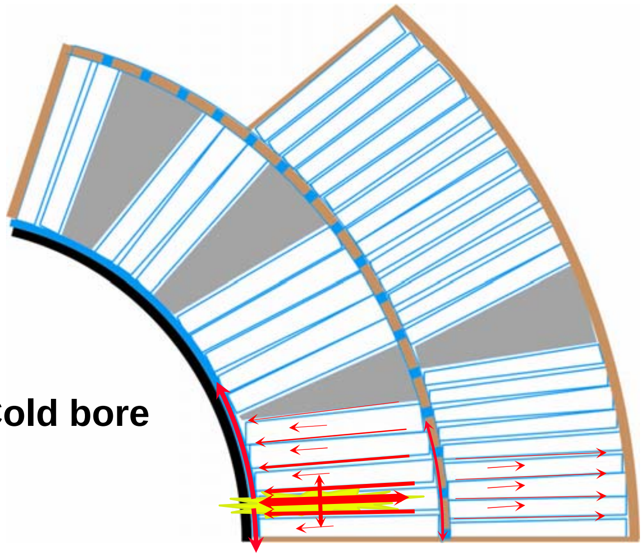
MB magnet – inner layer

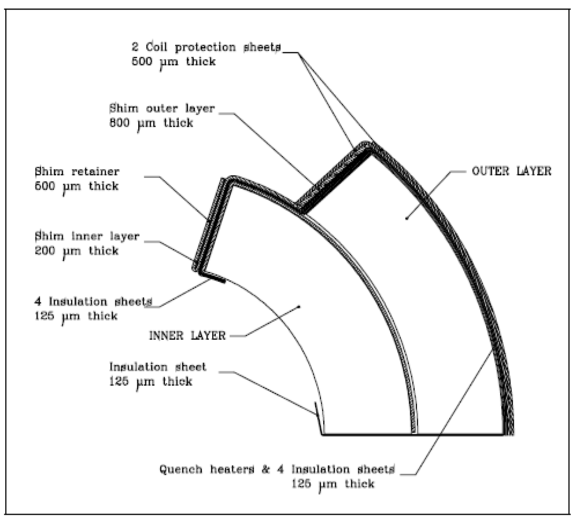


Courtesy C. Scheuerlein

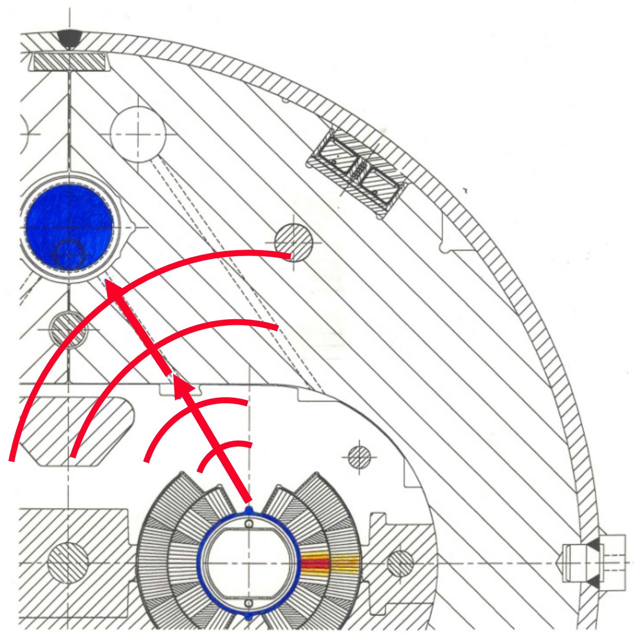


Heat transport in the coil at 1.9K



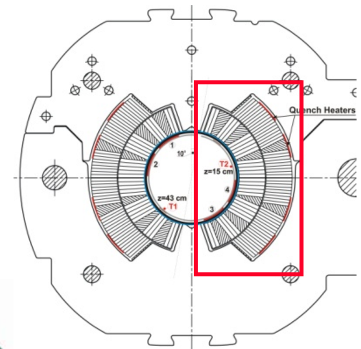


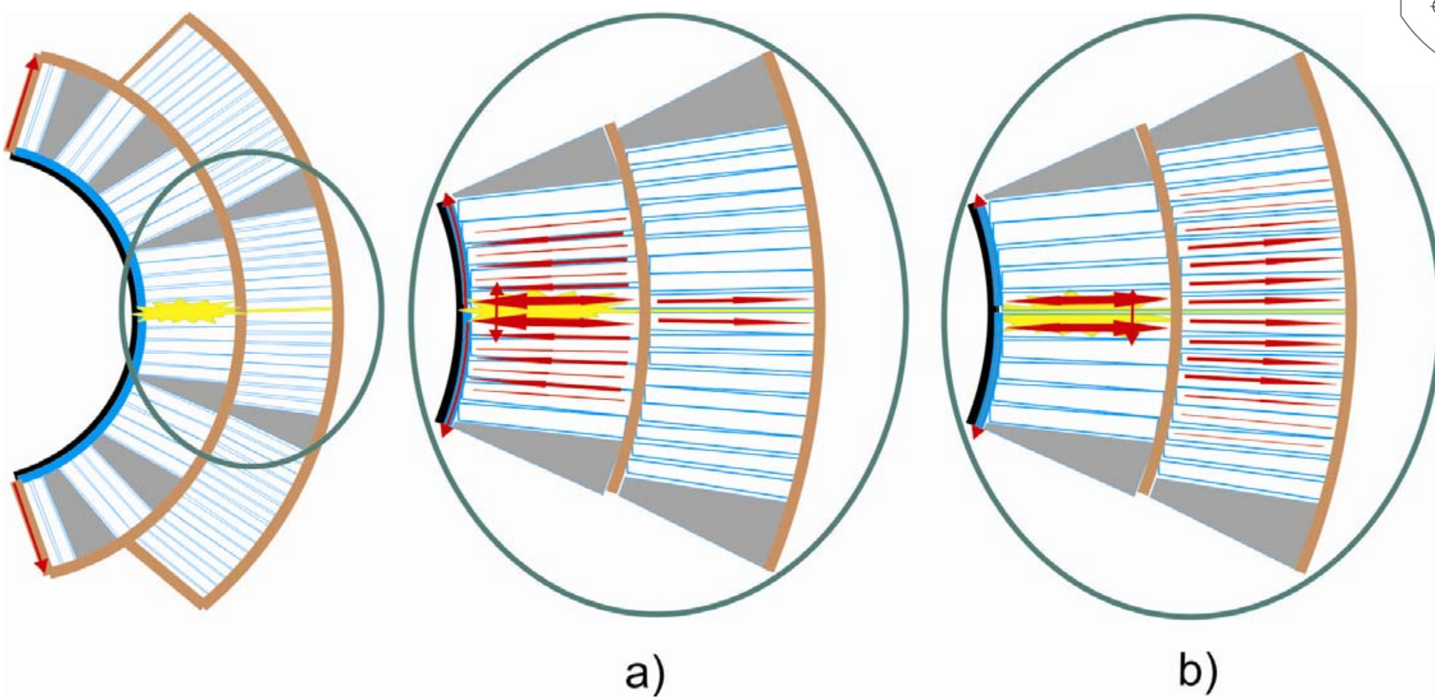
A heat transfer in the main dipole



- Heat transfer from the conductor to the cold source defines the temperature margin
- Electrical insulation is the largest thermal barrier at 1.9 K against cooling

Heat transfer in the magnet coil





A sketch of the heat transfer in the magnet at nominal operations (a) and at quench limit (b).

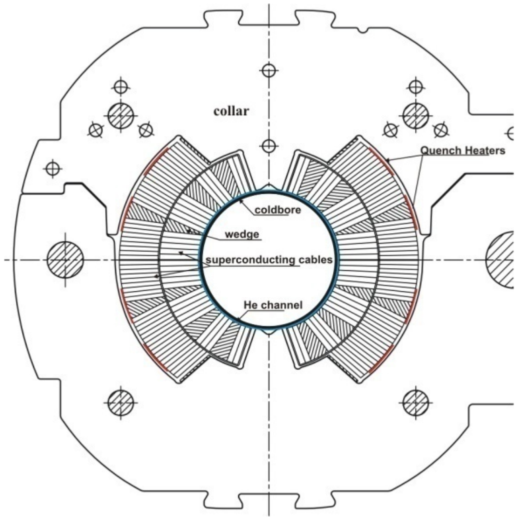
Thermodynamics of magnet structure

Heat transport in the magnets

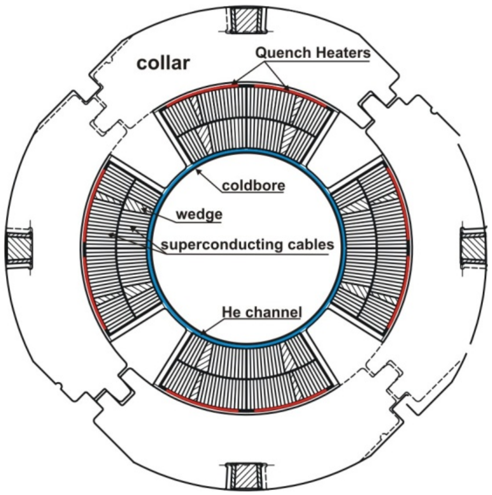
Characteristic of superconducting coils

Magnets coil

MB – arc magnet, T_b=1.9 K



MQM – LSS magnet, T_b=1.9/4.5 K



HEAT FLOW LIMITS

➢ **heat flow barriers**

- **cable insulation**
- **interlayer insulation (MQM)**
- **ground insulation**

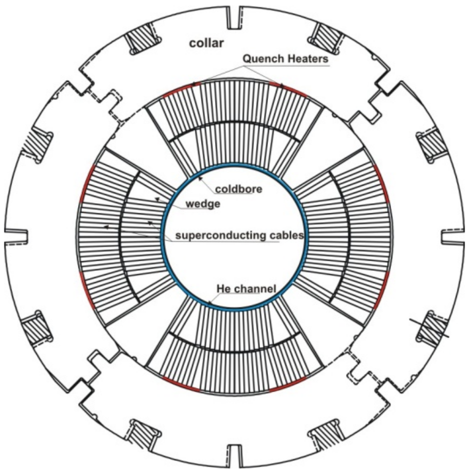
➢ **bath temperature 1.9 K**

- **Transition HeII → HeI: helium channels is blocked = less effective heat evacuation due to the changing of heat evacuation path**

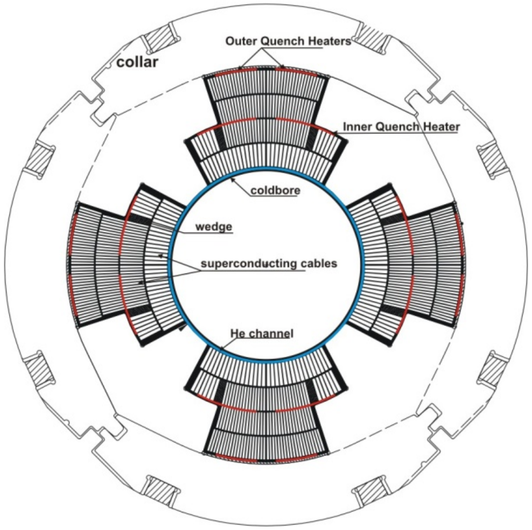
➢ **bath temperature 4.5K**

- **low temperature margin (worst case: MQM 0.45K)**
- **Helium channels does not play dominating role (heat conduction of HeI and polyimide is similar at 4.5K)**
- **less effective heat evacuation path compared to the 1.9K magnets**

MQ – arc magnet, T_b=1.9 K

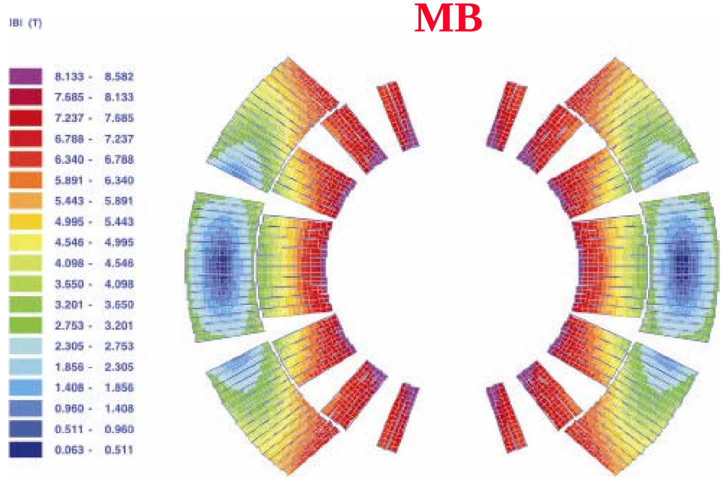


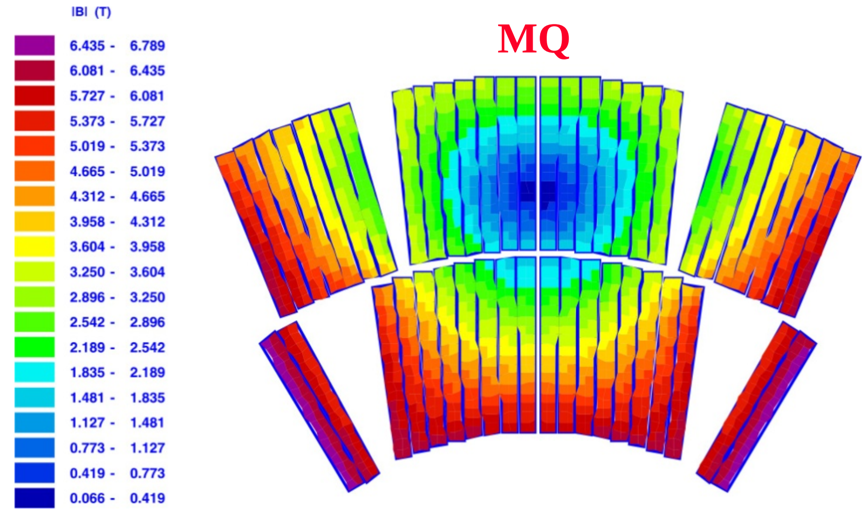
MQY – LSS magnet, T_b=4.5 K



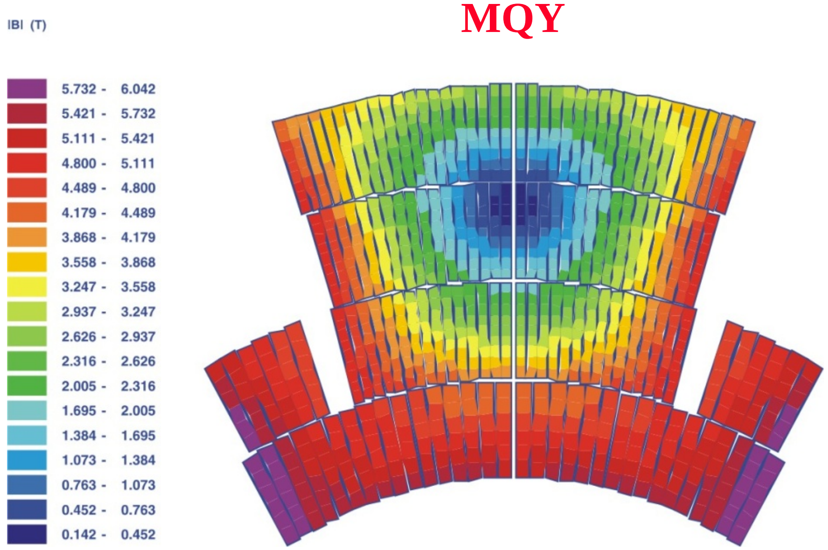
Magnetic field distribution in the coils

MB

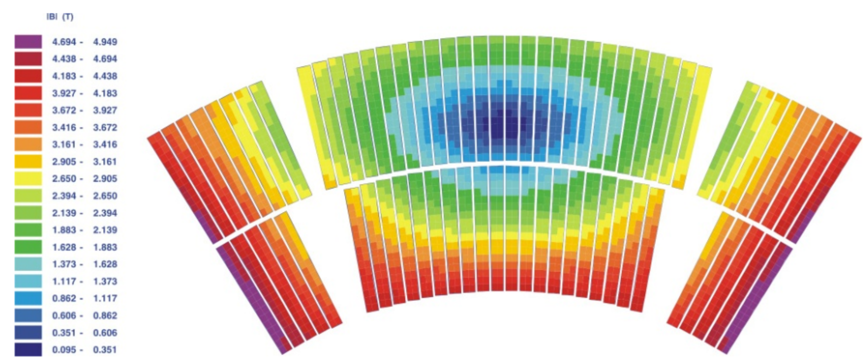




MQY



MQM



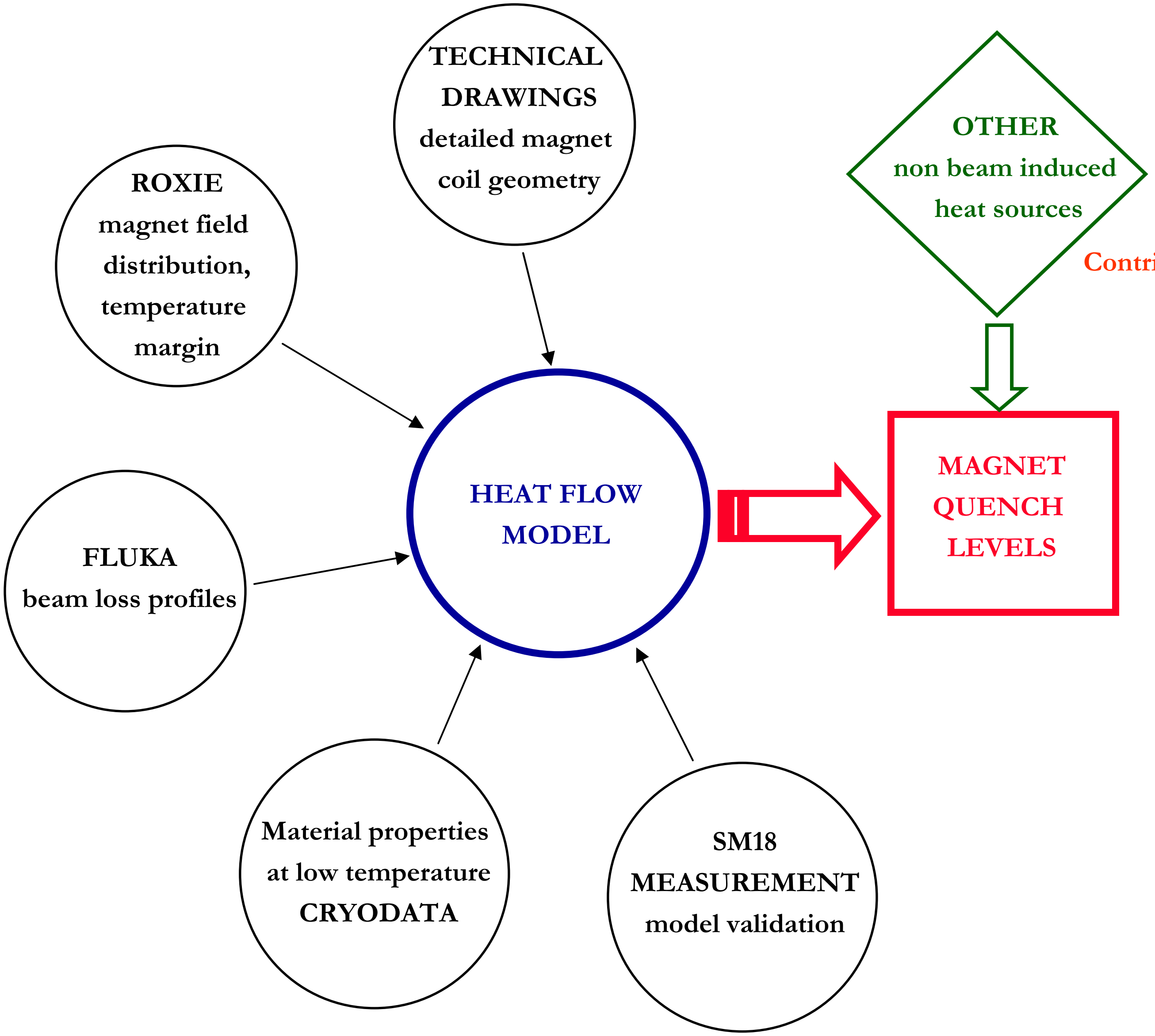
Network Model

Model construction

Model of the superconducting cable and coils

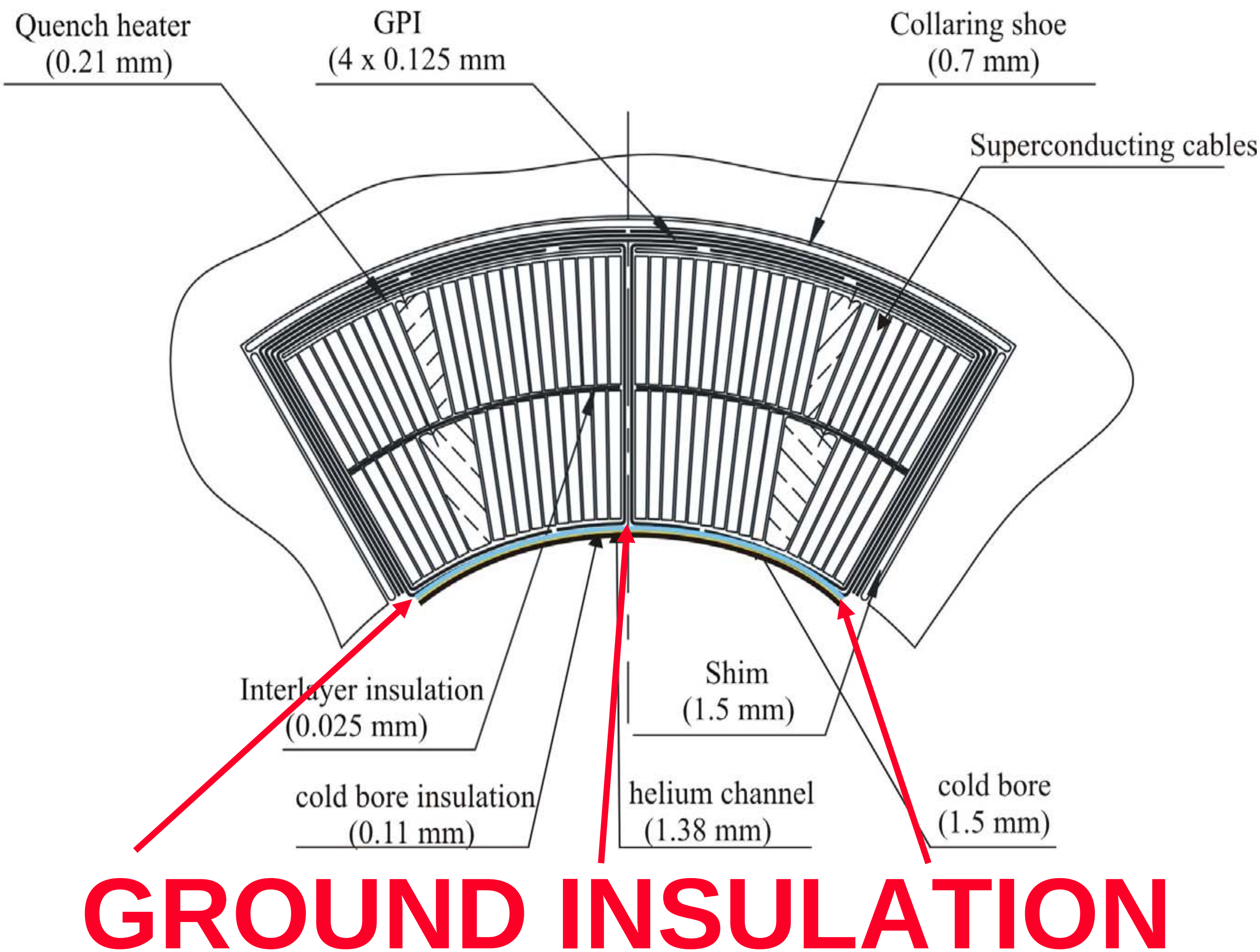
Simulations

Model Construction



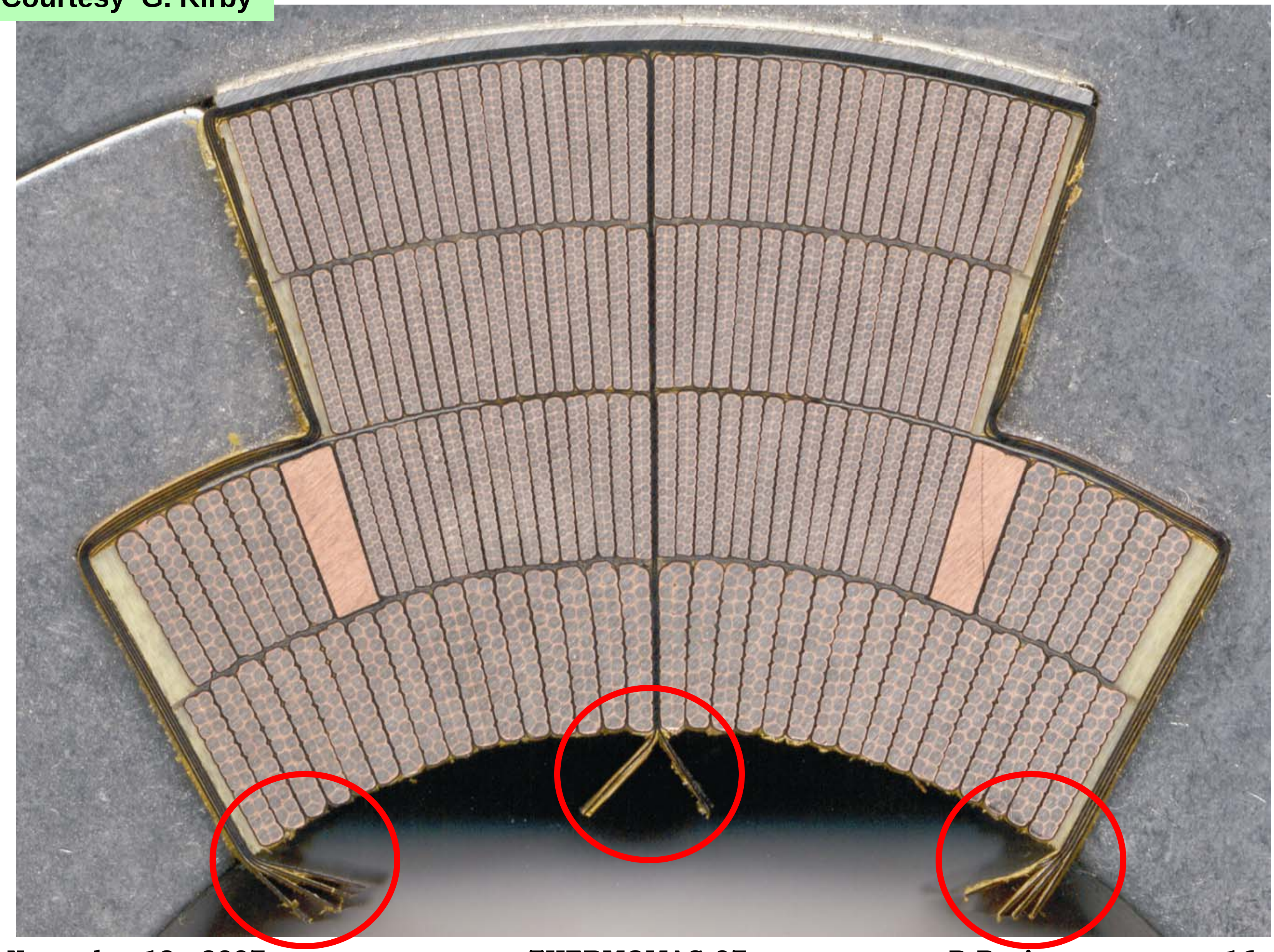
Hysteresis losses
Eddy currents, etc.
A. Verweij
R. Wolf
Contribution to the quench level is order of 1-2%

Model Construction

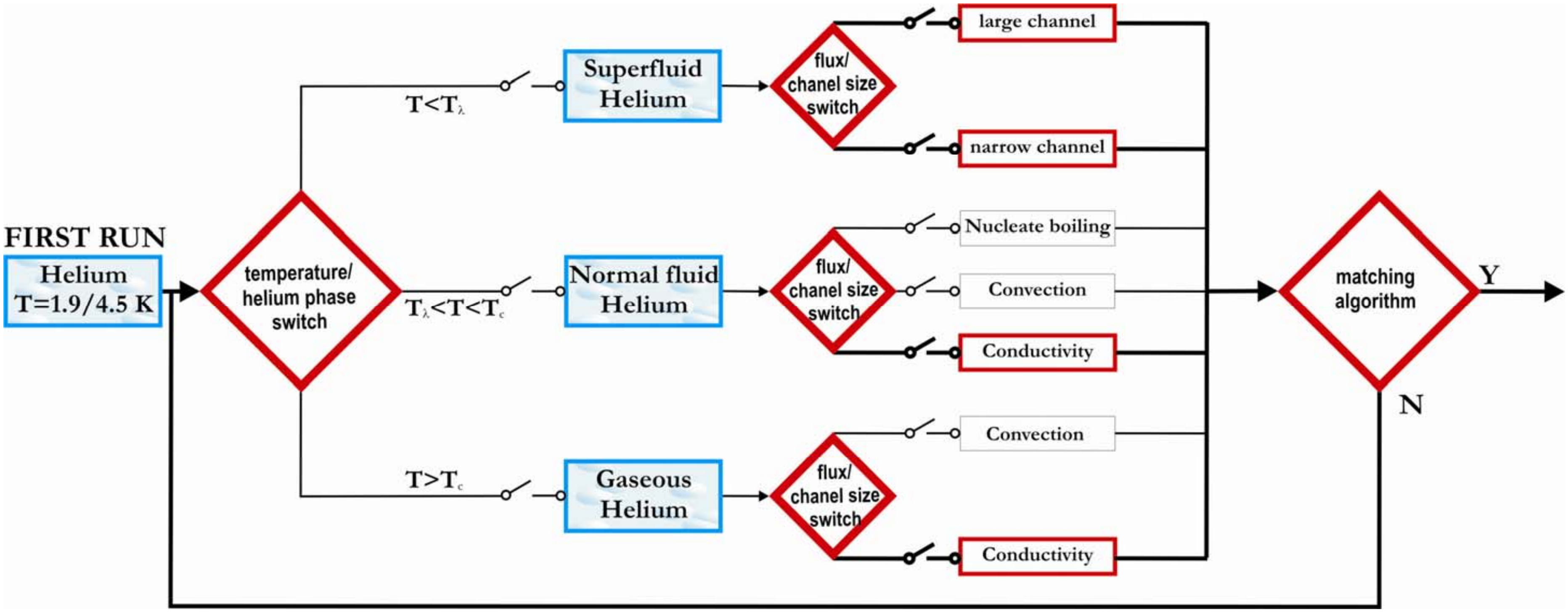


Model Construction

Courtesy G. Kirby



Helium in the Network Model



The volumes occupied by helium in the magnet are considered as:
-**the narrow channels,**
-**semi-closed volumes = inefficient inlet of fresh helium.**

The steady heat load heat up the helium in the semi- closed volumes:
-**Helium temperature well above critical temperature at T_b=4.5K**
- Critical helium temperature reached already below the calculated quench limit

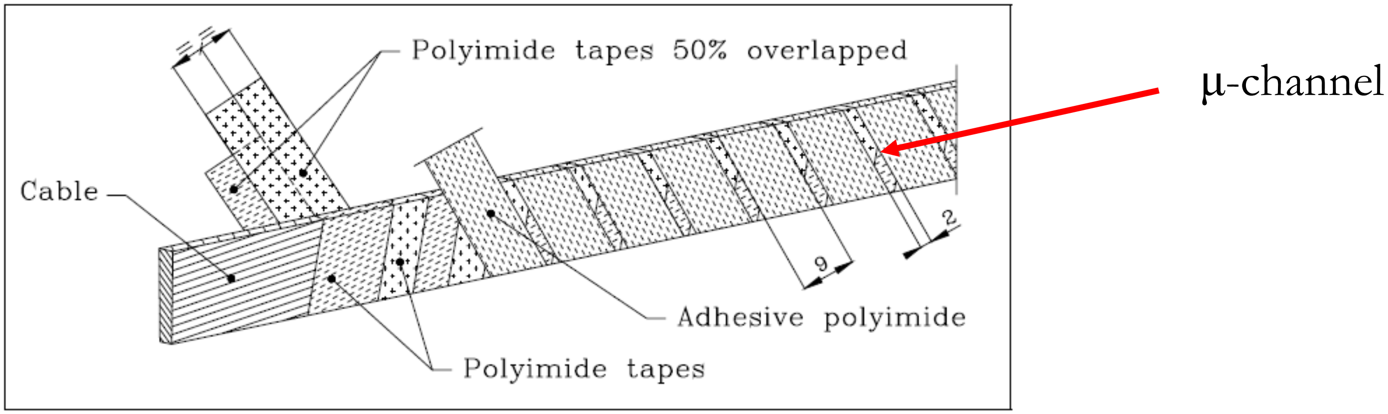
Network Model

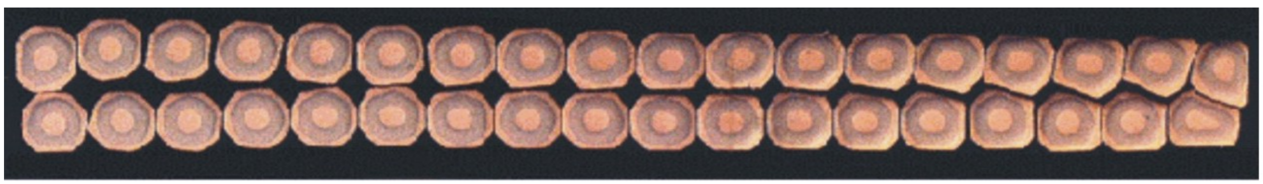
Model construction

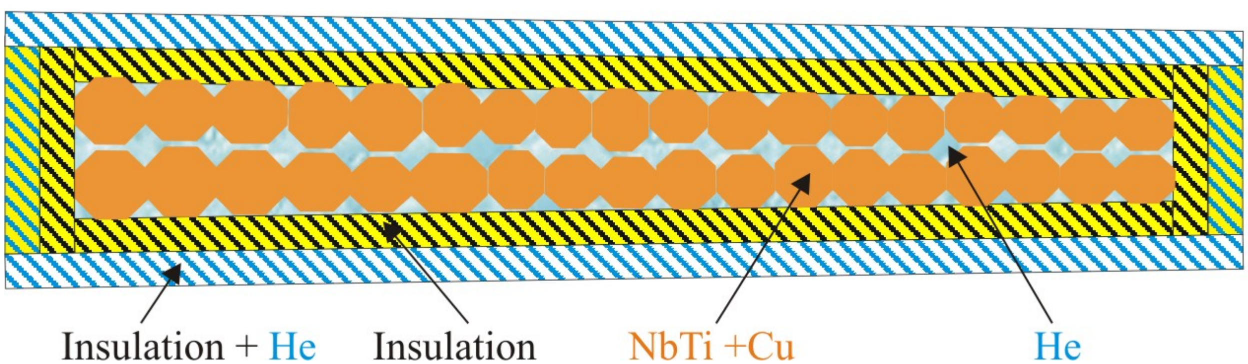
Model of the superconducting cable and coils

Simulations

"WET" superconducting cable modelling





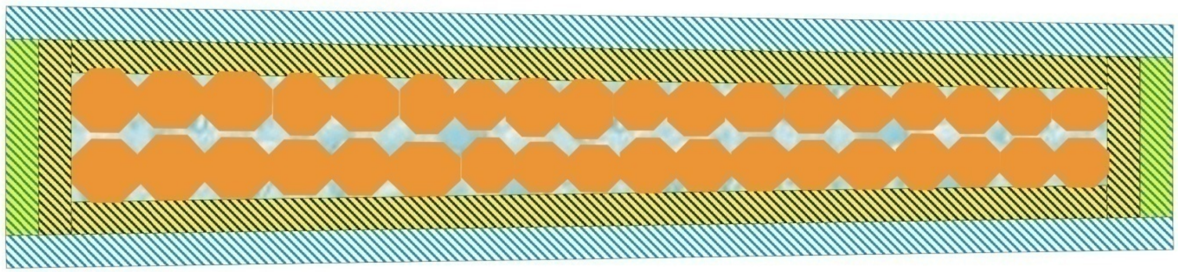


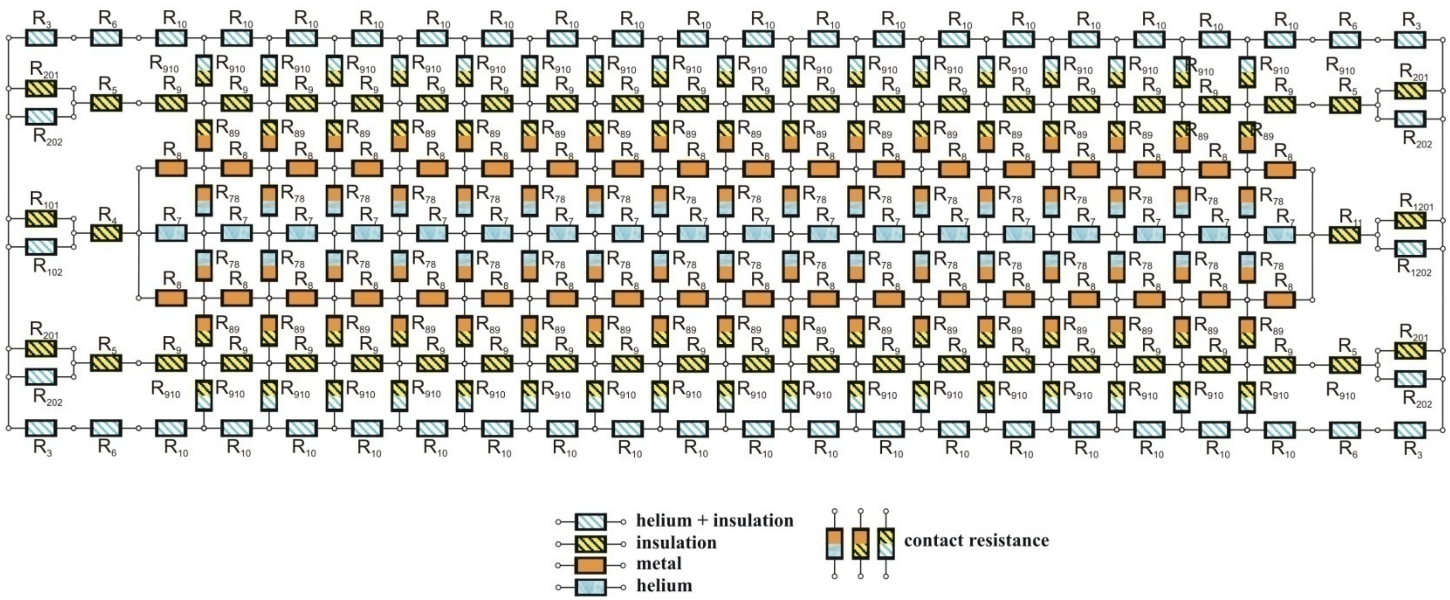
AB-BI-BL

Cable modelling

AT - MTM

Network model of the superconducting cable





Coil modelling

AT - MTM

Network Model

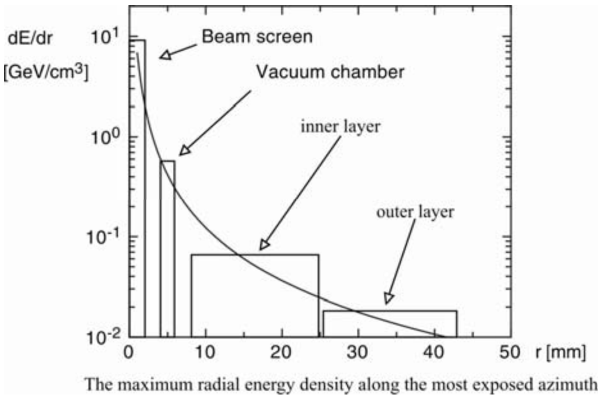
Model construction

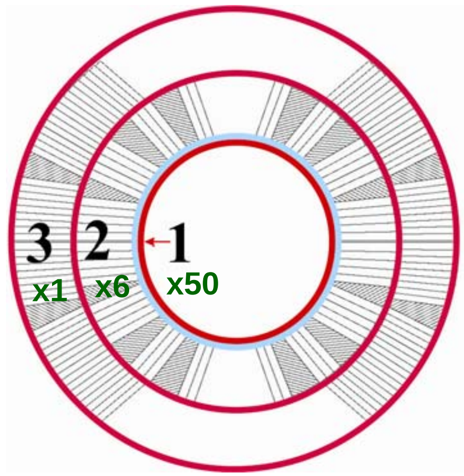
Model of the superconducting cable and coils

Simulations

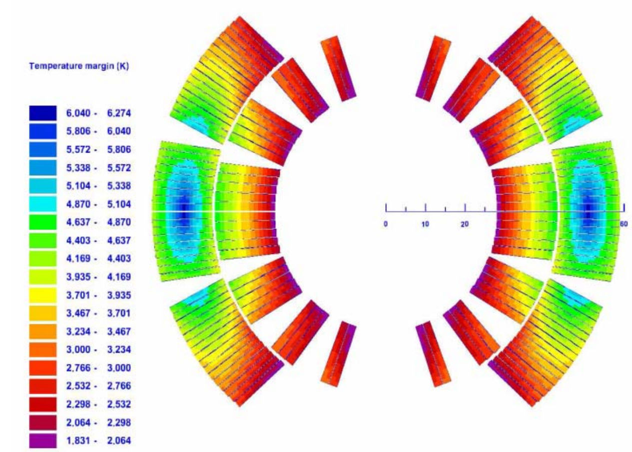
MB magnet - Quench limit simulations
PRELIMINARY RESULTS

1 - cold bore - factor = 50
2 - inner layer - factor = 6
3 - outer layer - factor = 1





Concentric beam loss profile

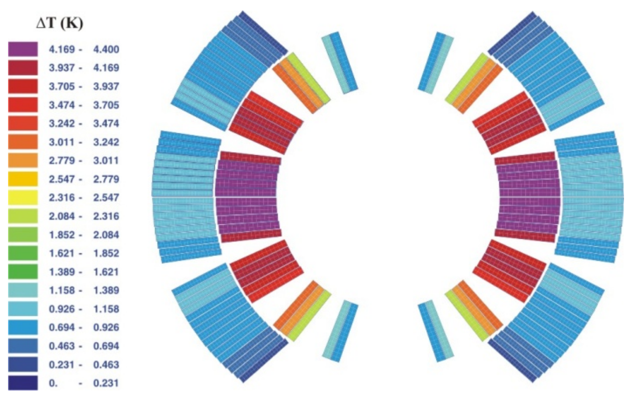


Temperature margin distriution, ΔT

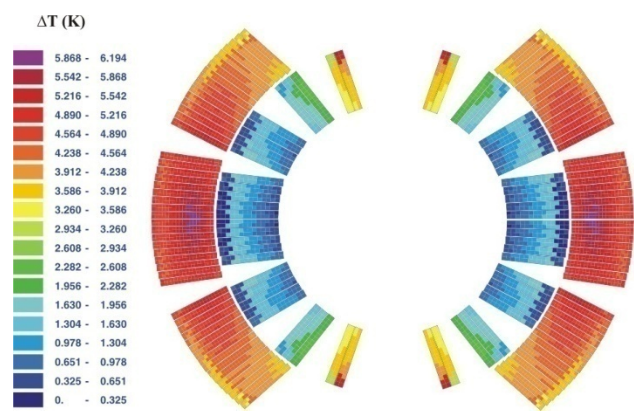
[LHC Project Note 44 (2006)]

Quench limit at 11850A
12 mW/cm³

Quench limit at 12840A
10 mW/cm3



Temperature in the coil, $\Delta T_{simulation}$

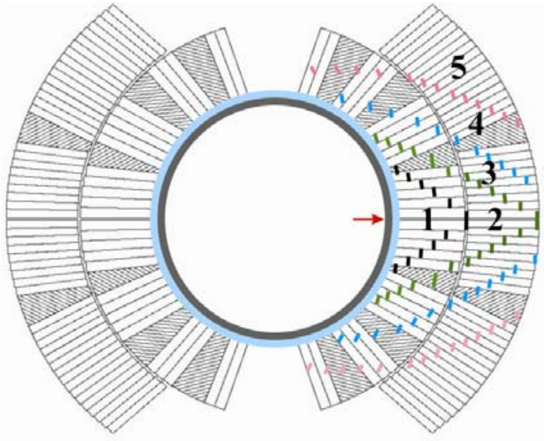


Quench temperature map
$\Delta T - \Delta T_{simulation}$

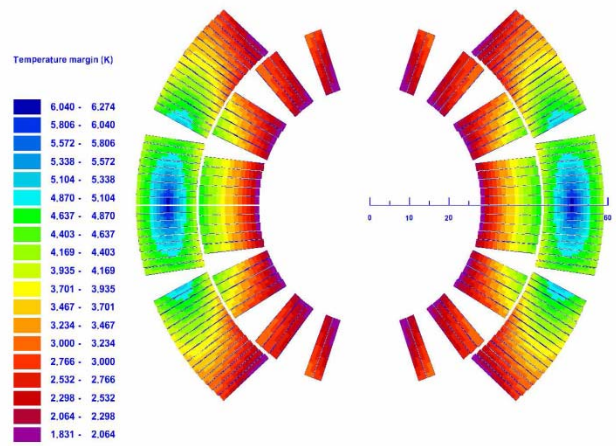
MB magnet - Quench limit simulations
PRELIMINARY RESULTS

FLUKA simulations

1 - factor = 1
2 - factor = 1.0/3.0
3 - factor = 0.4/3.0
4 - factor = 0.1/3.0
5 - factor = 0.03/3.0



Gaussian beam loss profile

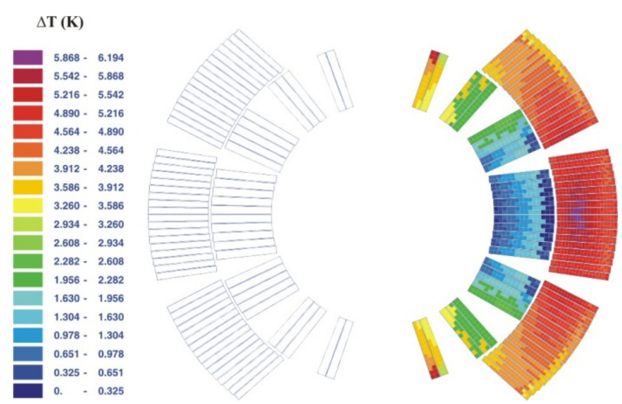


Temperature margin distriution, ΔT

Quench limit at 11850A
17 mW/cm^3

Quench limit at 12840A
14 mW/cm^3

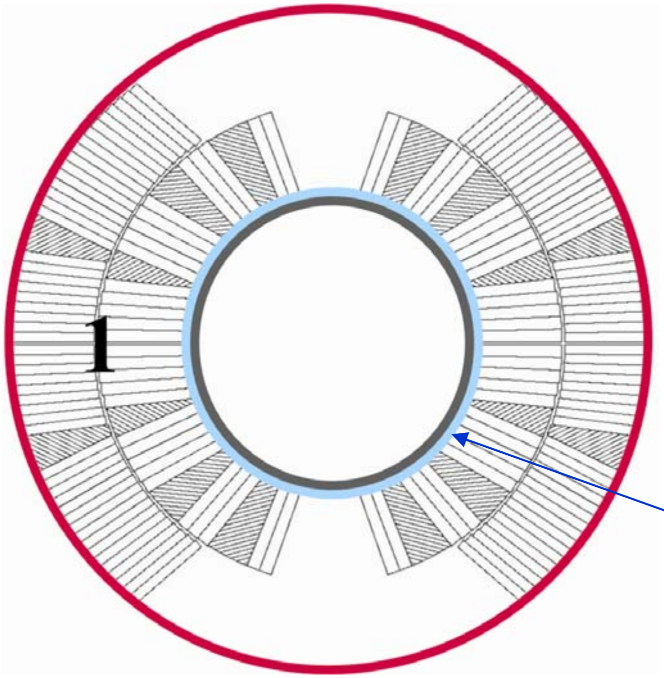
Temperature in the coil, $\Delta T_{simulation}$



Quench temperature map

$\Delta T - \Delta T_{simulation}$

Homogenous beam loss profile in MB magnet
STUDY CASE – cold bore heated/not heated

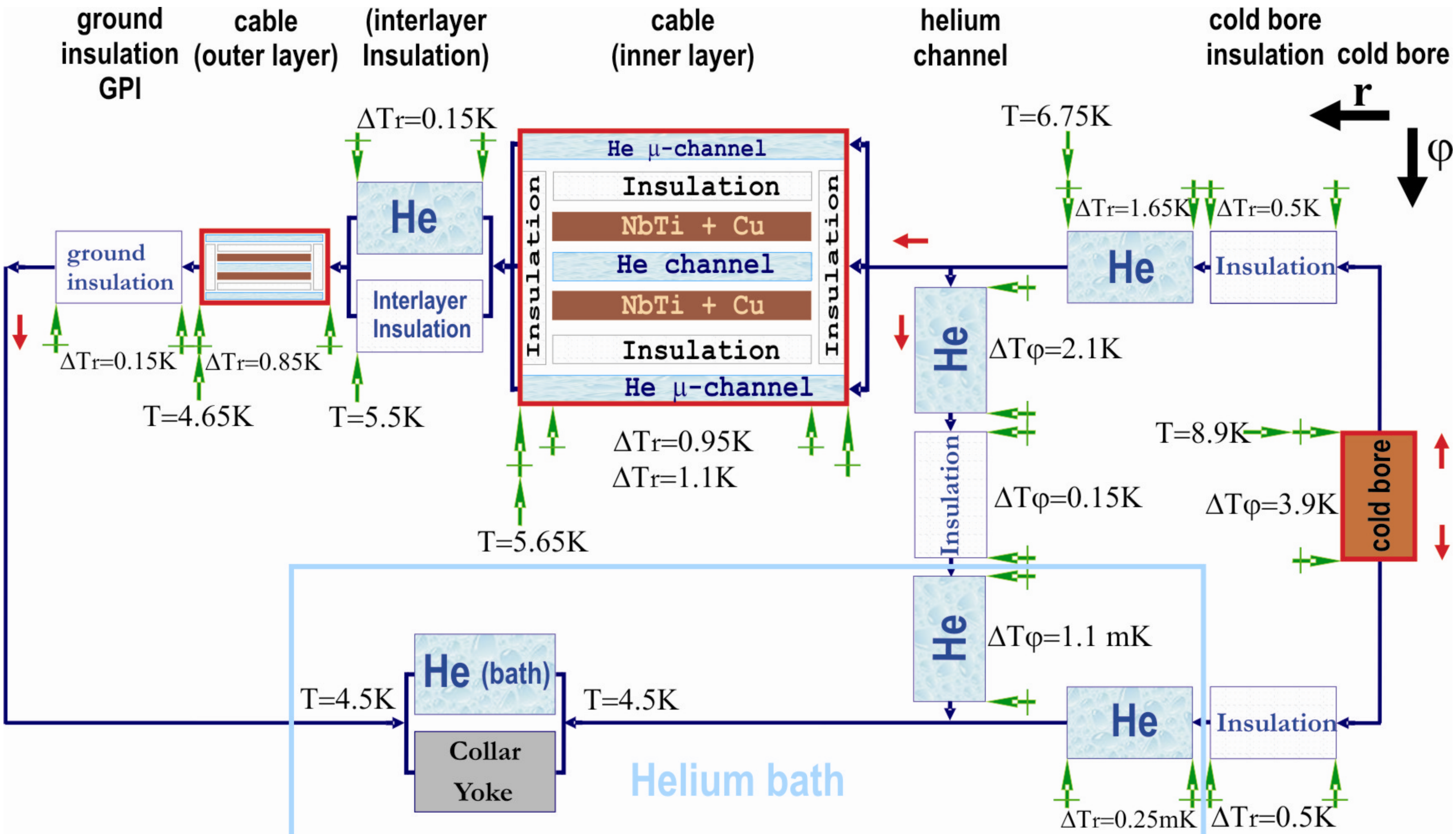


- Beam loss profile with homogenous heat deposition
- no heat load to the cold bore
  - 10500 A → Quench Limit ~ 150 mW/cm³
  - 11850 A → Quench Limit ~ 100 mW/cm³
  - 12100 A → Quench Limit ~ 72 mW/cm³
- with heat load to the cold bore
  - 10500 A → Quench Limit ~ 20 mW/cm³
  - 11850 A → Quench Limit ~ 14 mW/cm³
  - 12840 A → Quench Limit ~ 9 mW/cm³

This is effect of heat flow decrease
in the helium channel around cold bore

A better cooling of the cold bore is needed to increase quench level

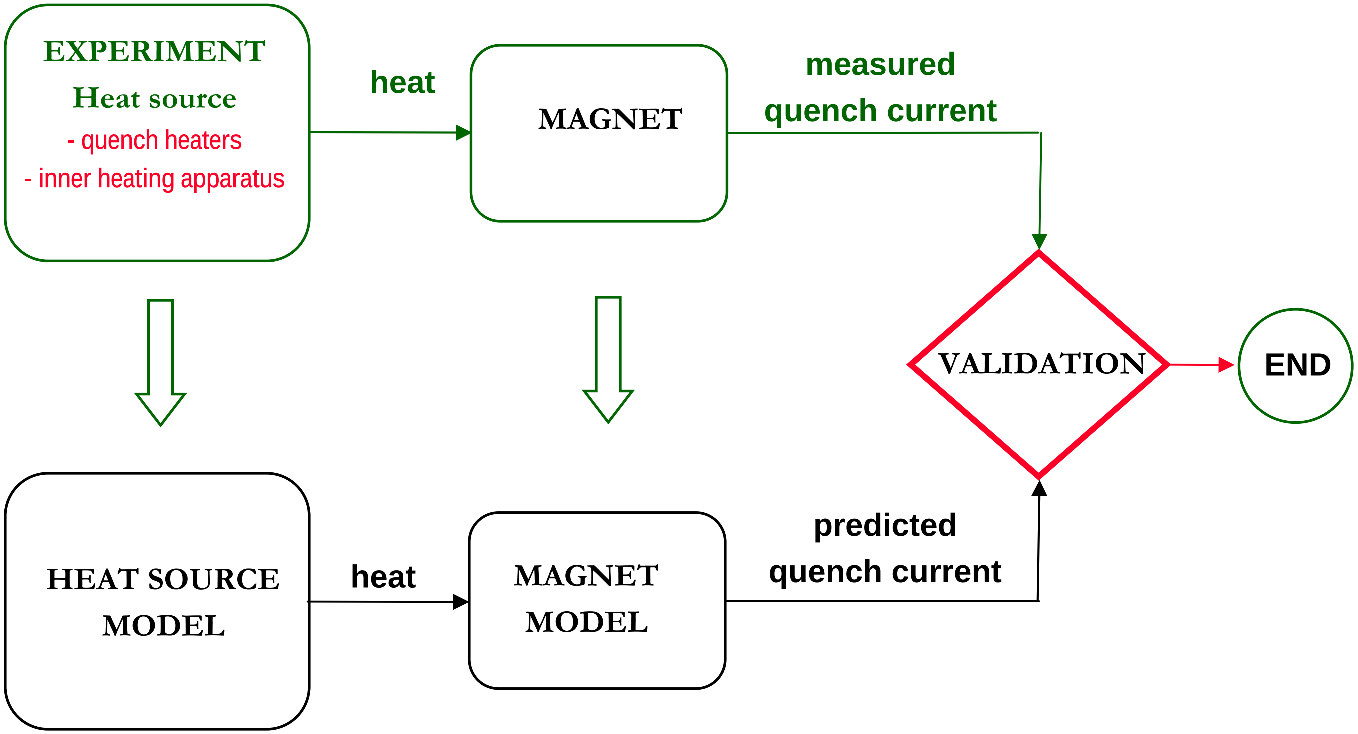
MB magnet - Quench limit simulations
PRELIMINARY RESULTS



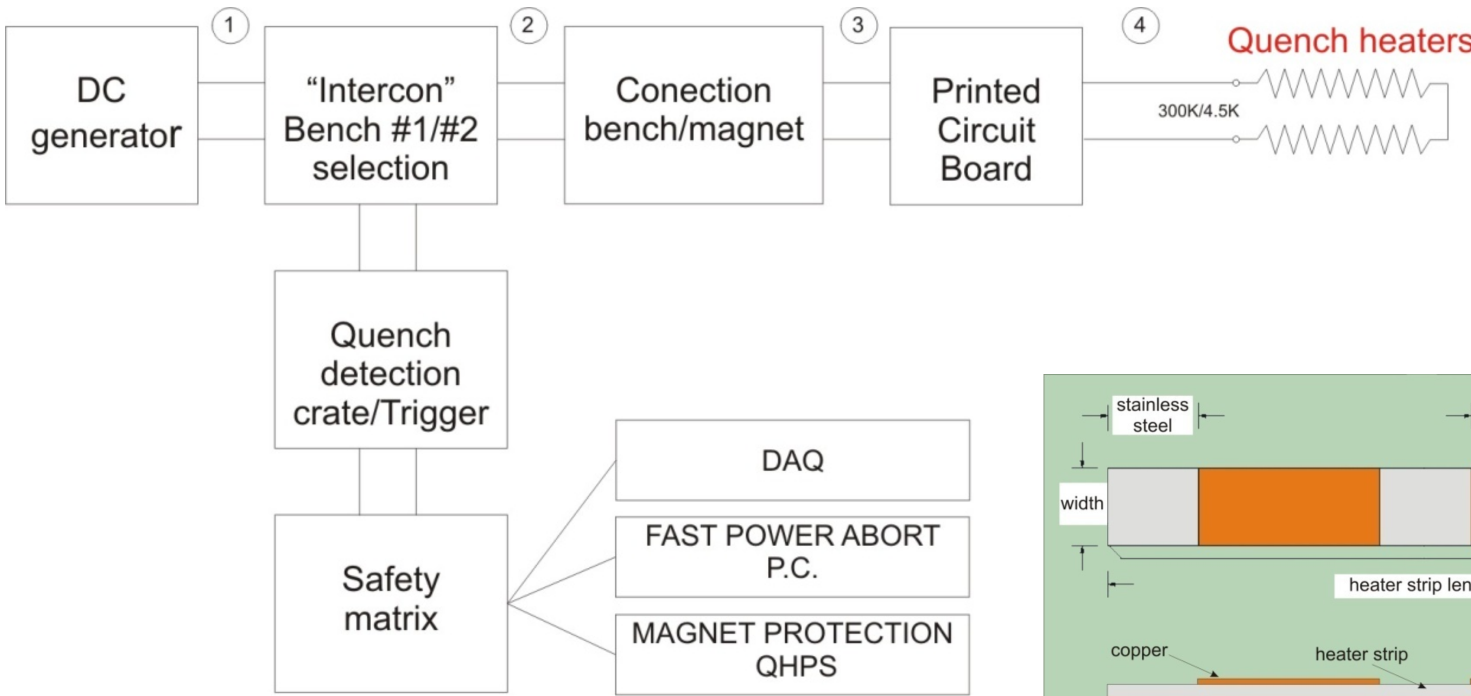
Validation of the model

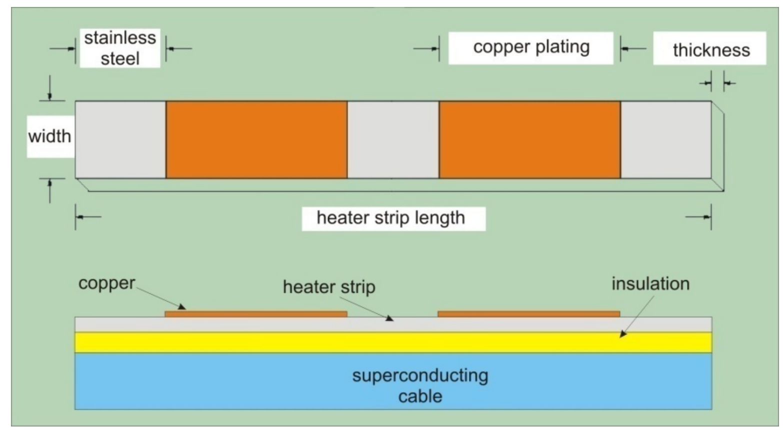
Measurements in SM18

Model validation



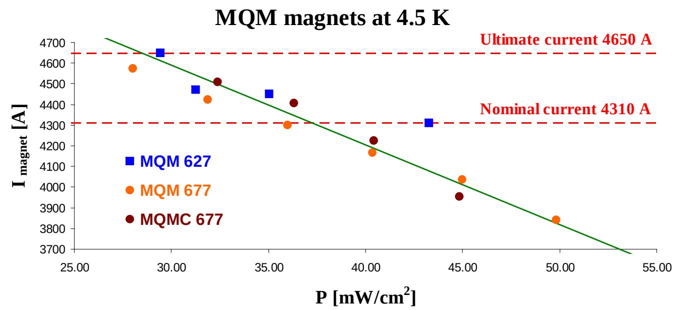
Model validation

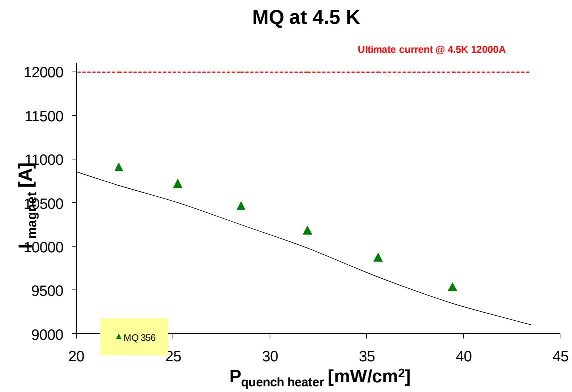


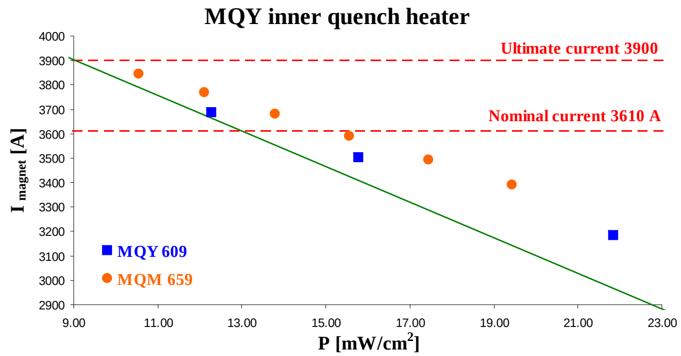


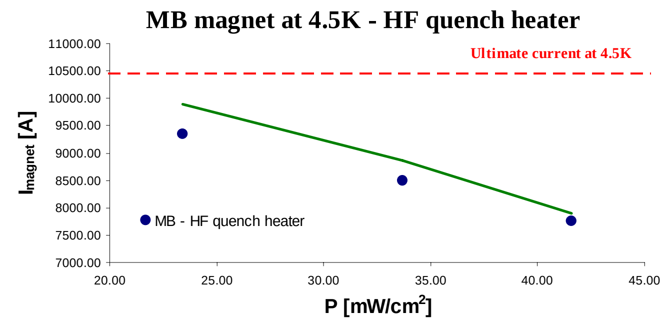
- **Two methods of measurement**
  - I_{coil} =const, increase of I_{QH} with a step of 0.1 A
  - I_{QH} =const, slow ramp of I_{coil} up to the quench after 300 s of coil heating
- **3 MQM, 2 MQY, MQ and MB have been tested at 4.5 K**

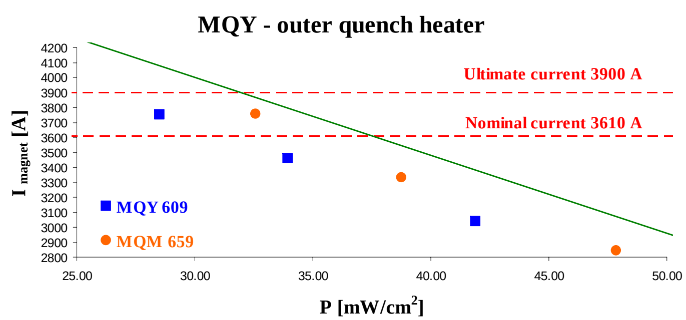
Results of the measurements with QH

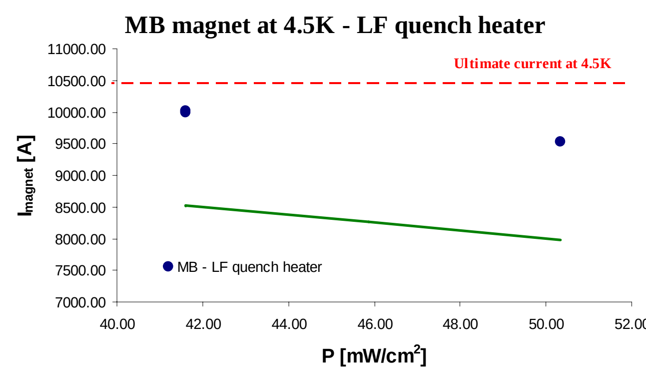








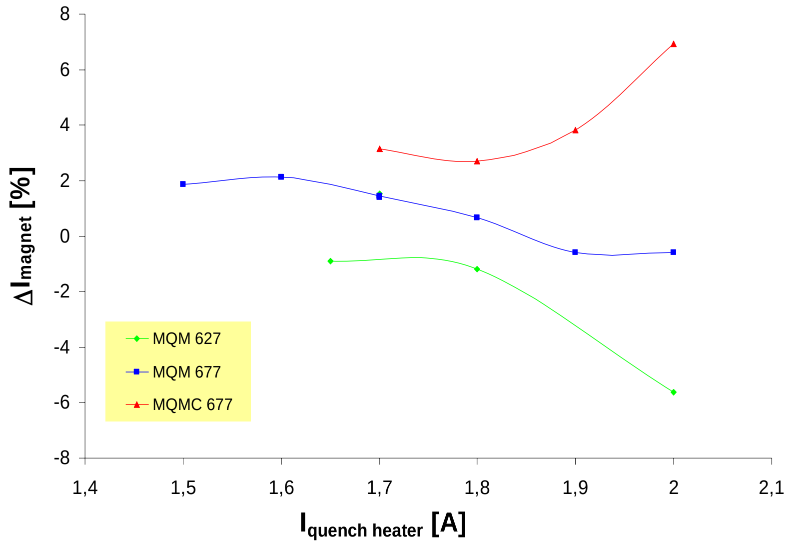


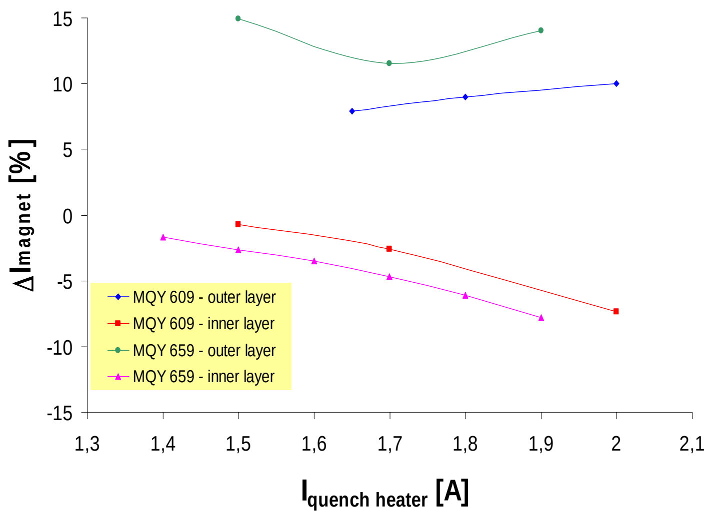


AB-BI-BL

Results of the measurements with QH
Relative difference

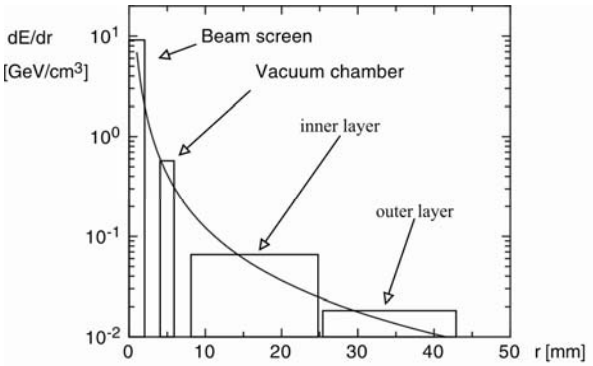
AT - MTM



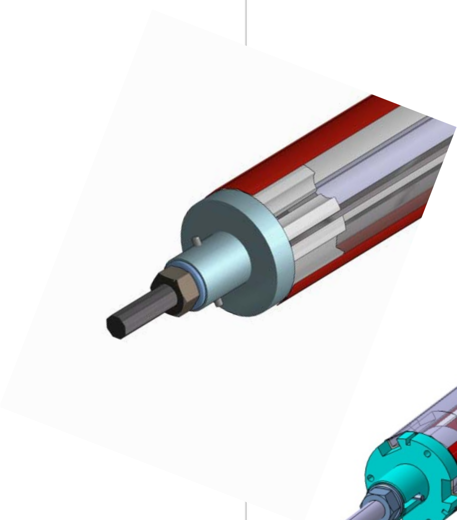


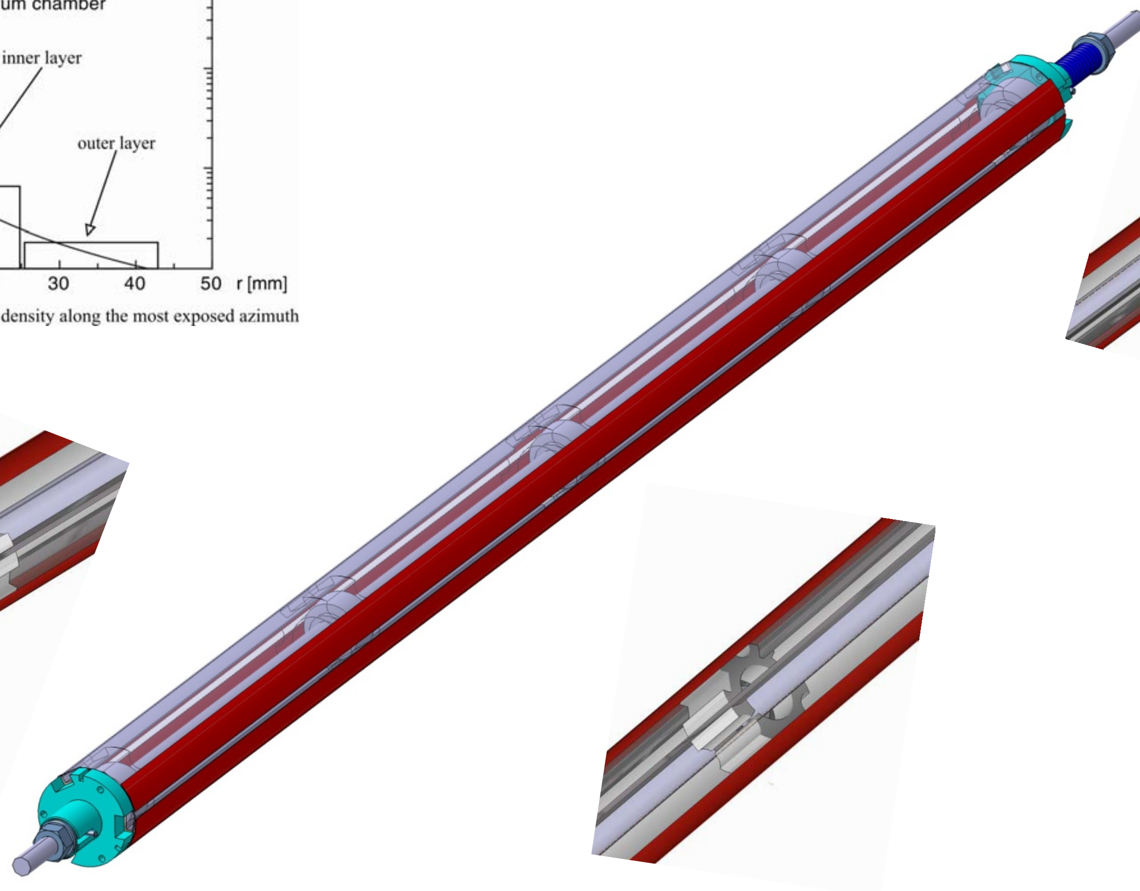
The relative difference between measured and calculated quench values are ranging from 0.6 to 20 % for all measured types of superconducting magnets at 4.5 K.

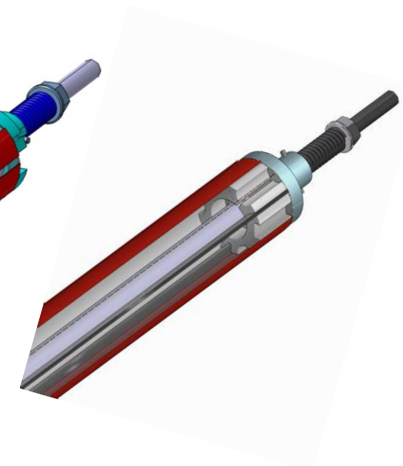
Internal Heating Apparatus



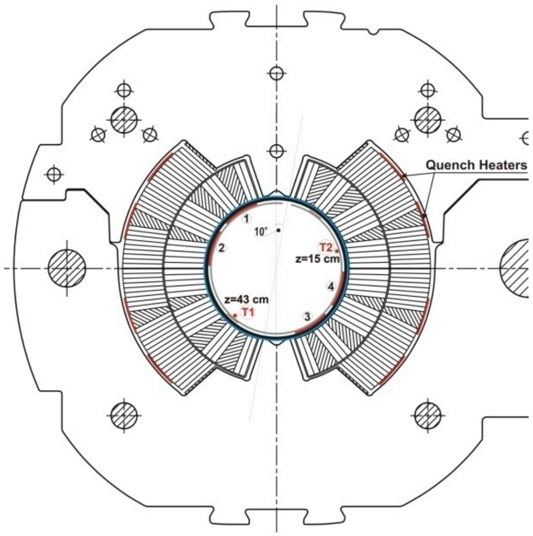
The maximum radial energy density along the most exposed azimuth



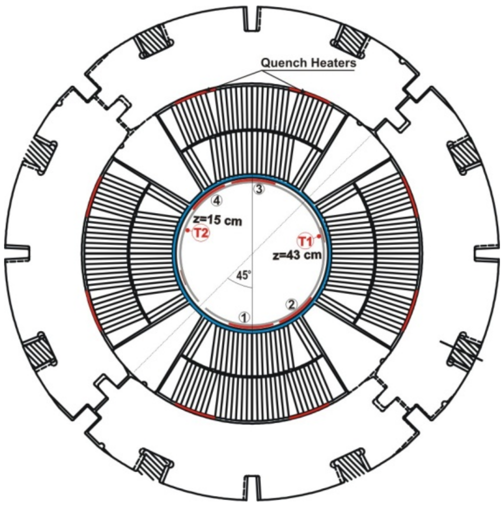




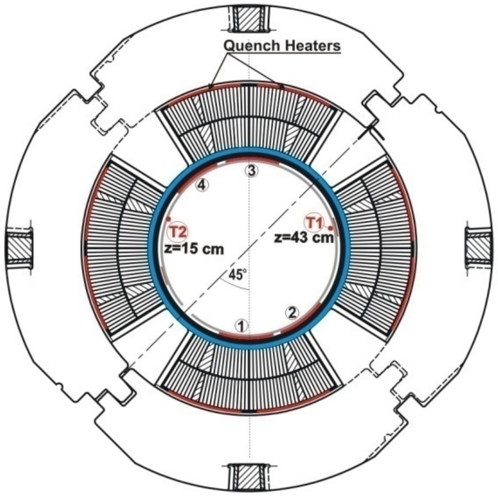
Internal Heating Apparatus



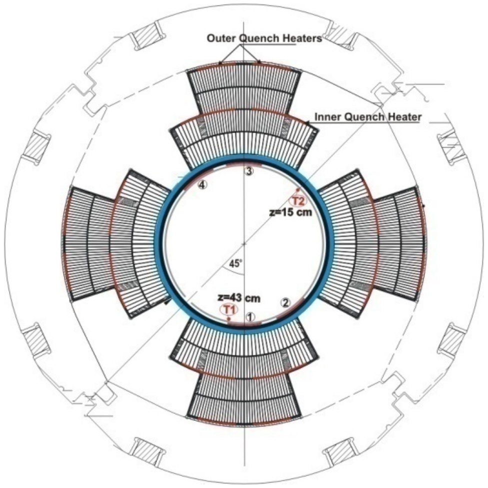
Main Dipole - MB



Main Quadrupole - MQ

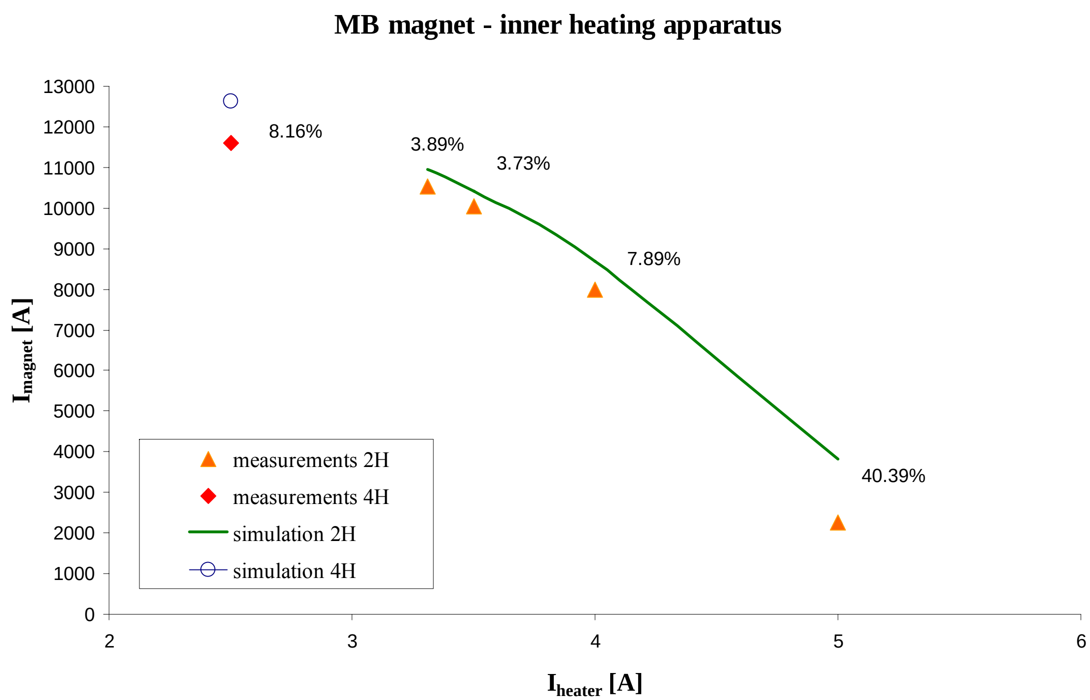


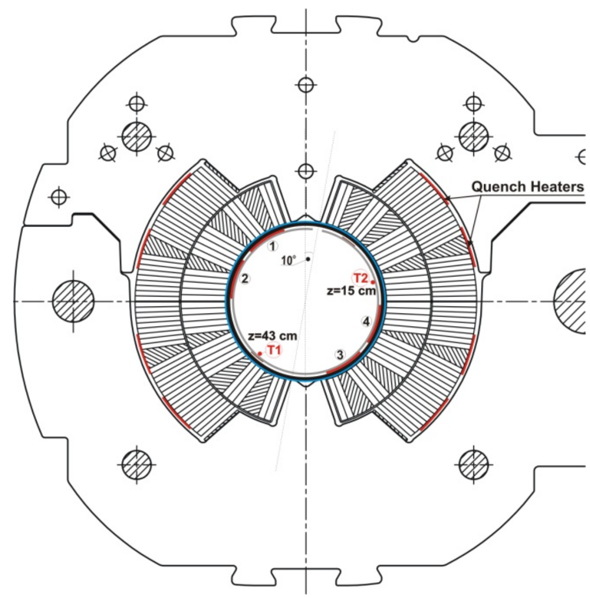
MQM



MQY

Results of the measurements on MB with IHA





ADDITIONAL MEASUREMENTS ANALYSES ARE ON GOING

Summary and outlook

- **Quench limit for the „real" beam loss depends on the beam loss profiles**
  - Two most realistic beam loss scenarios are considered: Gaussian and concentric (factor ~2 difference)
- **The validation of the model with MQM, MQY, MQ and MB magnet at 4.5K were performed successfully.**
  - The agreement between measurements and simulations is in worse case of order of 20%.
- **The first measurements on MB at 1.9K are very successful**
  - Internal Heating Apparatus allows to quench MB magnet in the range from 1kA to 12 kA.
- **The validation of the model at 1.9 K is not completed**
  - Only measurements on MB magnet were performed
  - Model is not yet tunned at 1.9K - μ-channels
- **Quench level for the typical beam losses scenarios are calculated – preliminary results**
- **Transient loss simulations and validations with measurements?**

Motivation I
Gain time by optimised threshold settings

- **Scenarios**
  1. Threshold too high ⇒ quench of the magnets
     (ideally: no beam loss induced quenches)
  2. Threshold too low ⇒ beam abort

  Scenario 1

  After 3 quenches change threshold value (by trial and error)

  ⇒ lost time: 3 recovery times (minimum 3x5h=15 hours)

  Scenario 2

  After 3 aborts change threshold value (by trial and error)

  ⇒ lost time: 3 false aborts (3x2h=6 hours)

- **9 different main magnets family ⇒**

  MB, MQ, MQM @ 1.9K, MQM @ 4.5K, MQY
  MQTL
  MQXA, MQXB, MBR

  ⇒ ~10 kCHf/hour of LHC operation

  ⇒ assuming one threshold setting change per magnet

135 h makes $1.35 \cdot 10^6$ CHF

Heat conductivity