Cold testing of rapidly-cycling model magnets for SIS 100 and SIS 300 – methods and results

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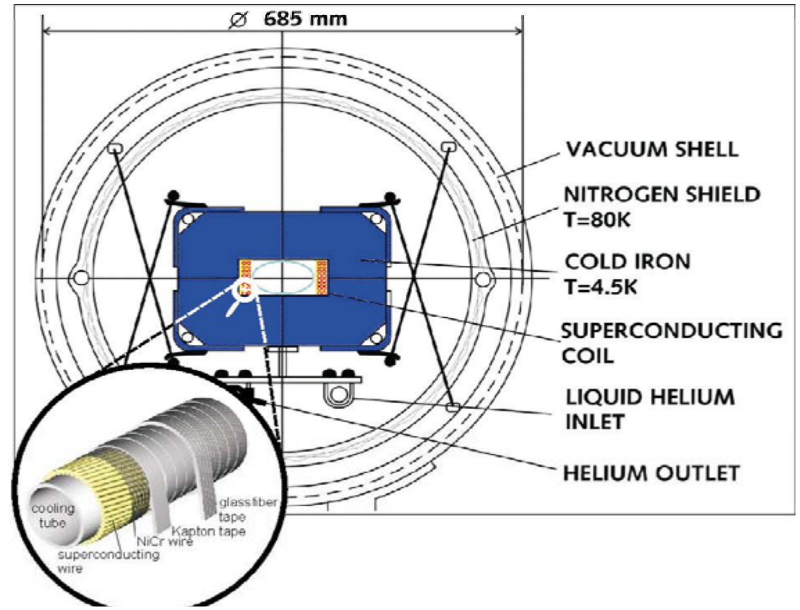
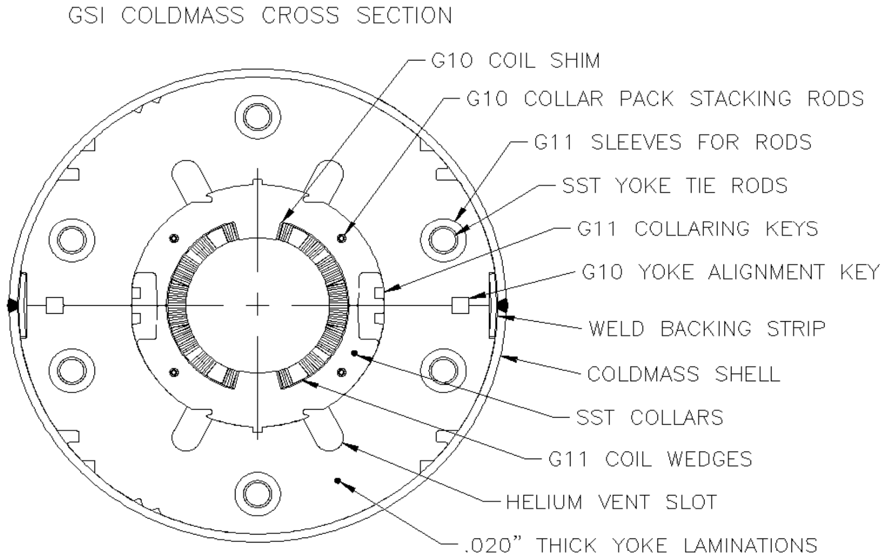
Outline

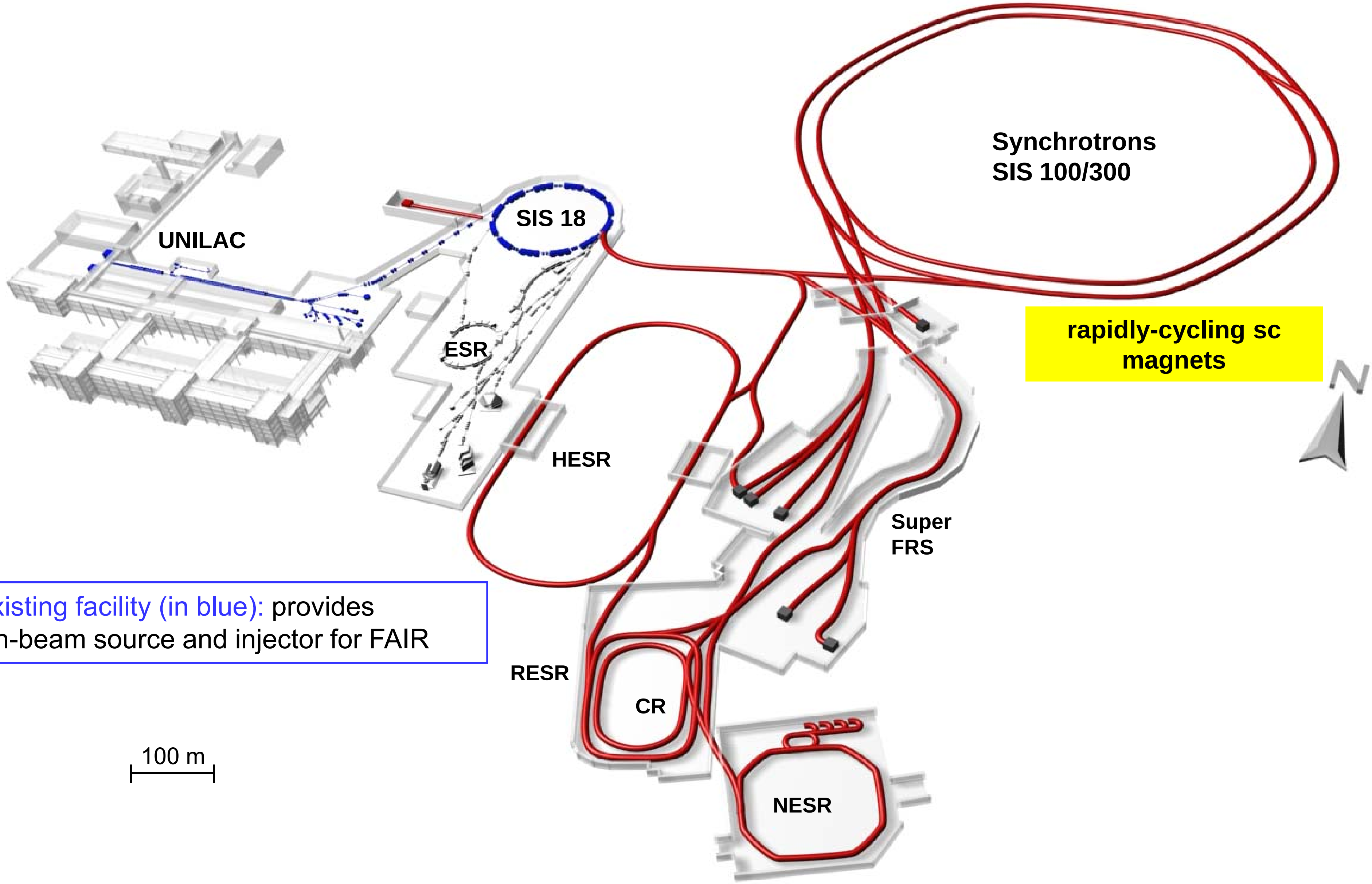
- FAIR @ GSI
- Prototype Test Facility @ GSI
  - mandate
  - parameters to deliver
  - measurement equipment
  - measurement methods
- test results
  - short SIS 100 model 4KDP6a: superferric WF, cooled by forced-flow 2-phase helium
  - model for SIS 300: GSI001 (cos θ, cooled by forced-flow supercritical helium)





The FAIR Facility

New future facility (in red): provides ion and anti-matter beams of highest-intensity and up to high energies



Existing facility (in blue): provides ion-beam source and injector for FAIR

Mandate Prototype Test Facility (PTF)

- Test FAIR Model-, Prototype- and Preseries sc magnets

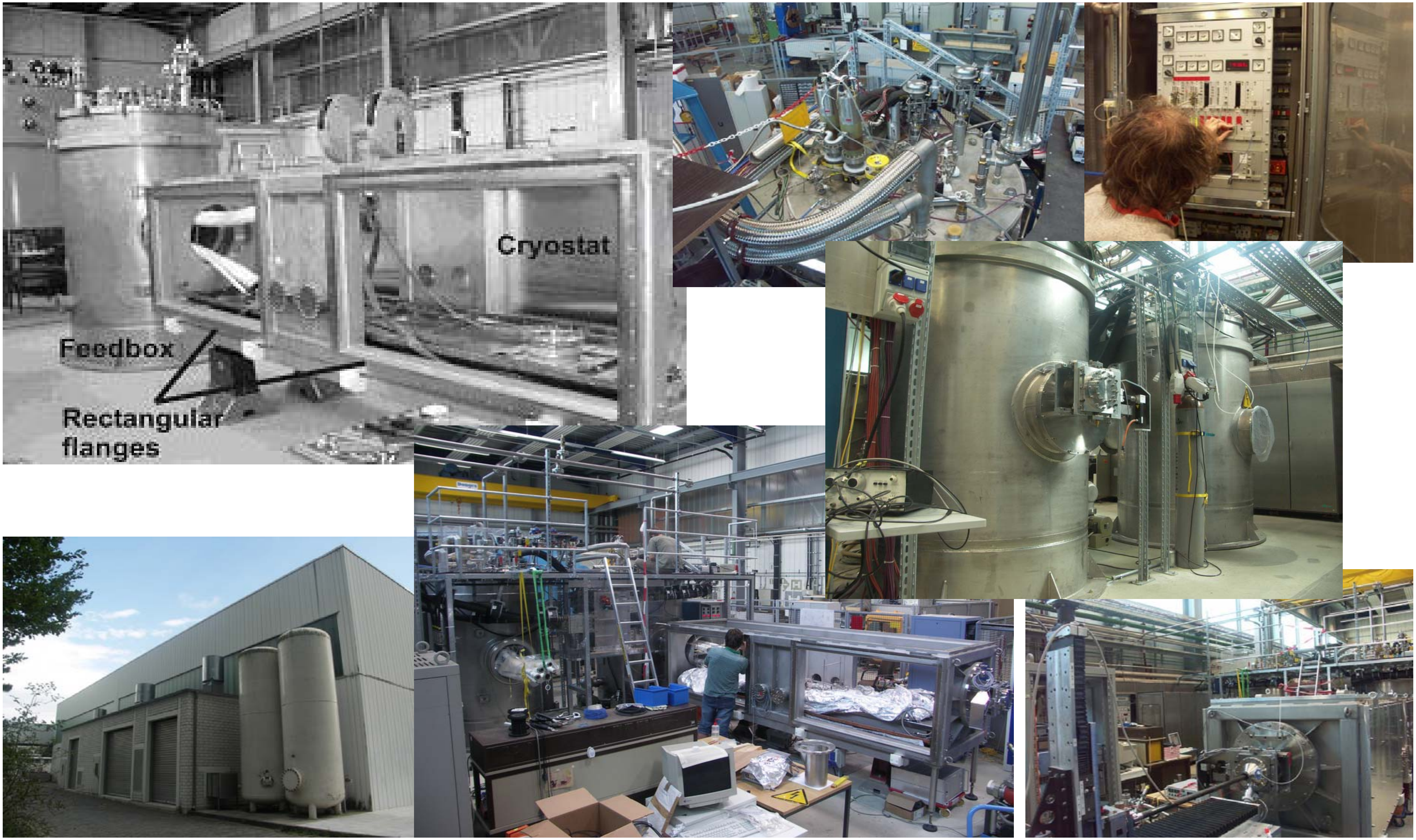
- Develop :
  - Test procedures for Factory Acceptance Tests (FAT) and Site Acceptance Tests (SAT)
  - Acceptance Criteria for FAT and SAT
  - Diagnostic Methods

- Investigate “non conforming” magnets for
  - SIS100 series
  - SIS300 series

Parameters to deliver

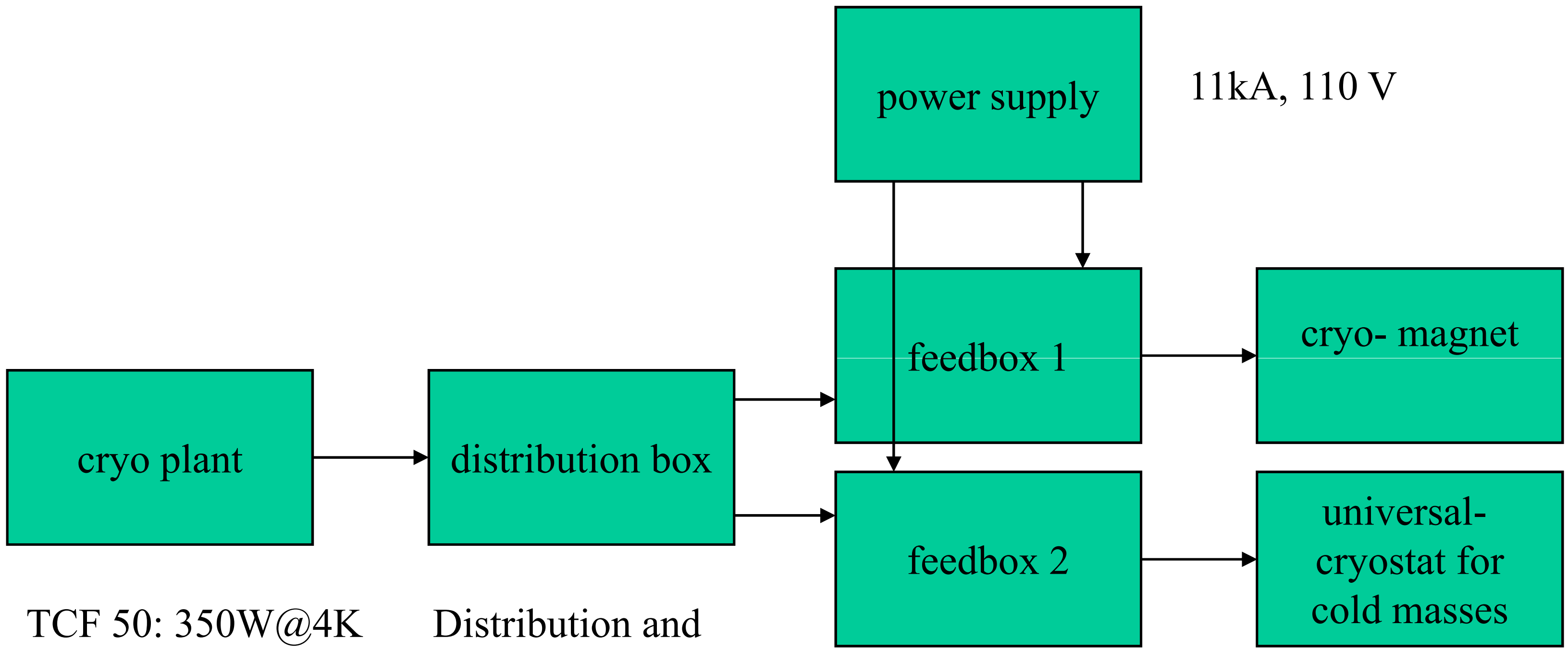
- heat input due to eddy currents and hysteresis → power of the cryoplant
- hydraulic resistance -> maximum acceptable heat load → e.g. parallel cooling channels in SIS 100
- magnetic field (quality, strength, eddy current contribution ...) → beam dynamics
- operation reliability and safety (insulation, quench detection (ramp voltage, cool down, cooling, static heat flow ...)
- alignment and fiduzialisation

Prototype Test Facility



Equipment of the Prototype Test Facility

FAIR



TCF 50: 350W@4K

Distribution and processing of the helium;
- Bath cooling
- 2 phase cooling 5g/s
- Supercritical 150g/s
- Temperatures down to 3.8K
- Pressures between 1.2 and 5 bar

Feeds helium and current into the magnet; measurement of:
- Mass flows
- Temperatures
- Pressures

Enables measurements directly on the magnet;
- Field measurements within the anti-cryostat
- Additional sensors
- 2 Void fraction sensors

Cryogenic losses – V-I method

Energy loss is calculated :

$$E = \sum_{i=1}^{N} V_i \cdot I_i \cdot \Delta t_i$$

Power loss is calculated :

$$P = \frac{1}{\sum_{i=1}^{N} \Delta t_i} E$$

Δt_i = 20.05ms

N – corresponds to 1 current cycle

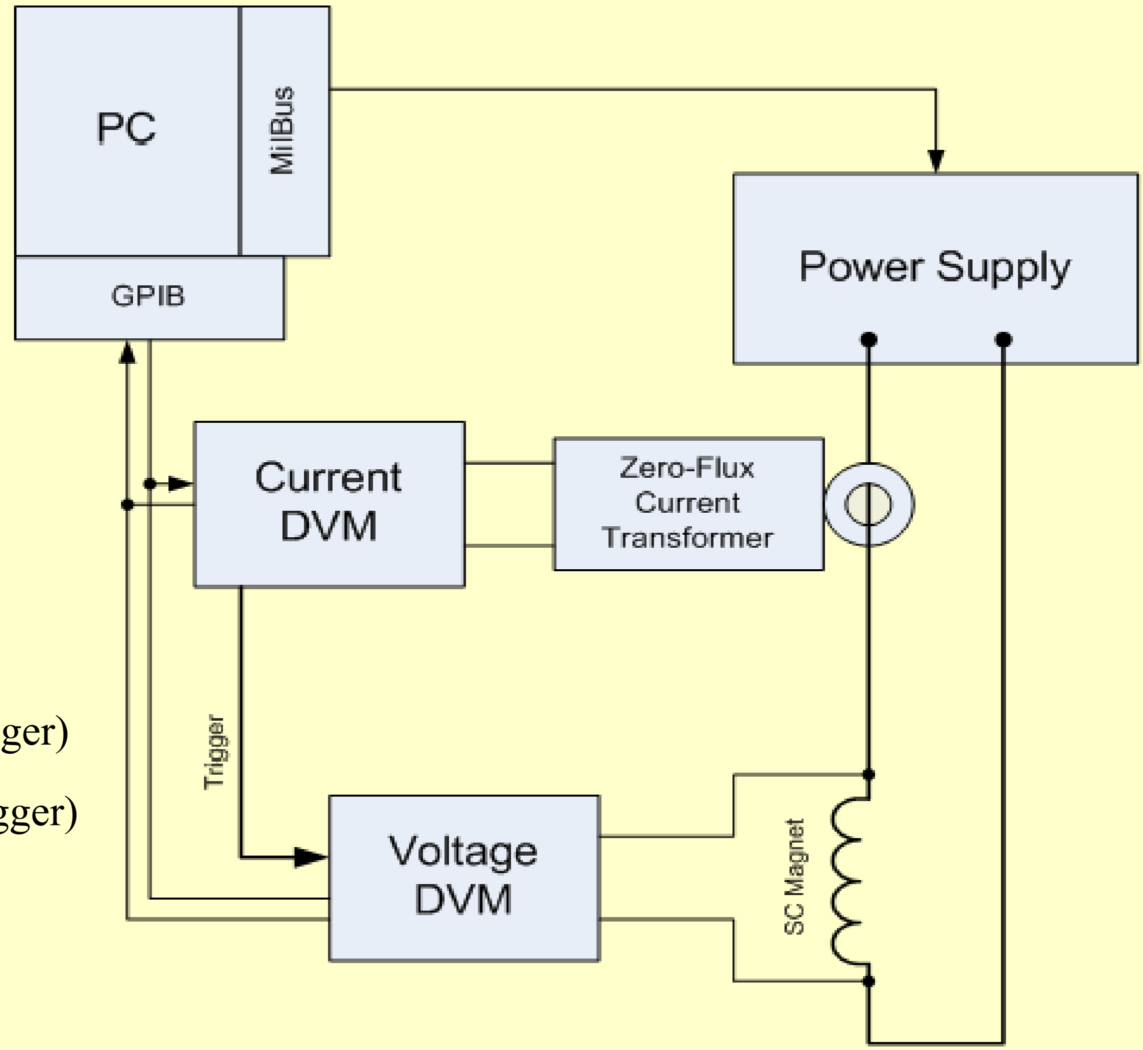
current → DCCT ⟶ DVM (generates trigger)

voltage across magnet DVM (receives trigger)

DVM:

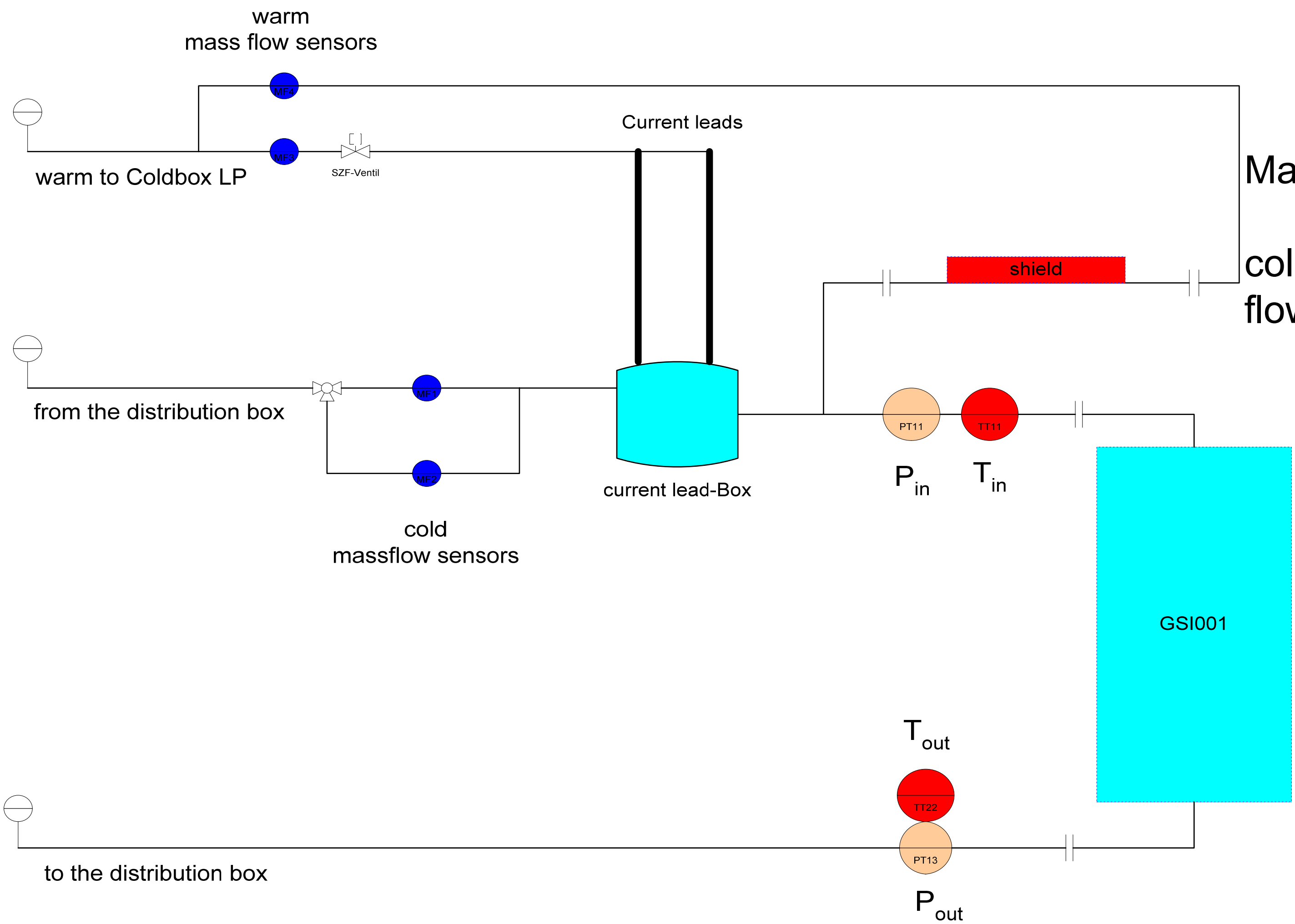
integration time ⟶ 20 ms

processing delay 50 µs.



DVM's - 8.5digit HP 3458A.

Cryogenic losses –calorimetric method (supercritical cooling)



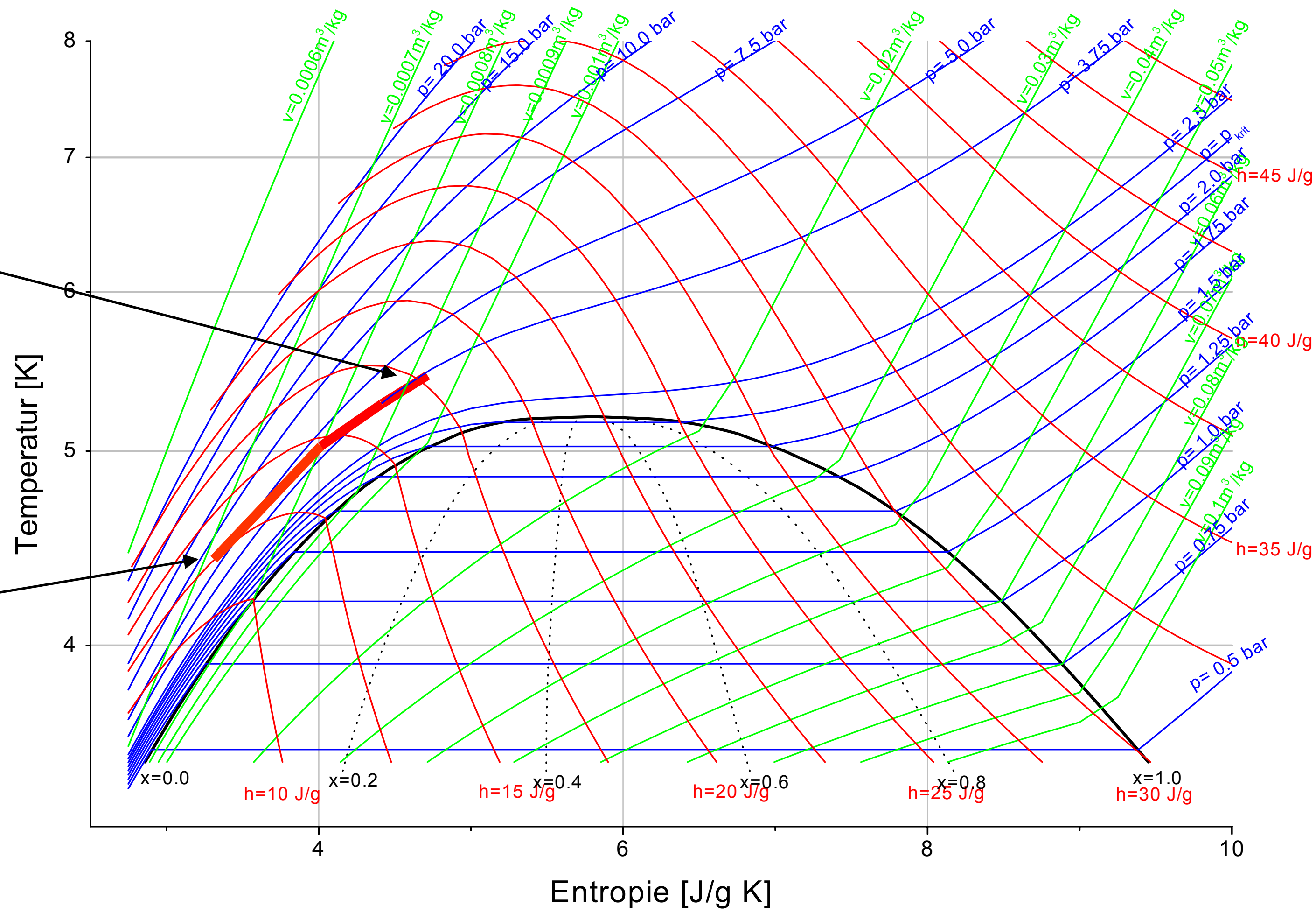
Mass flow through the magnet:

cold mass flow - warm mass flow (measured)

Schematic sketch of the measurement

$$Q_{magnet} = \dot{m}_{He} \cdot \left[h_{out}\left(T_{out}, P_{out}\right) - h_{in}\left(T_{in}, P_{in}\right)\right]$$

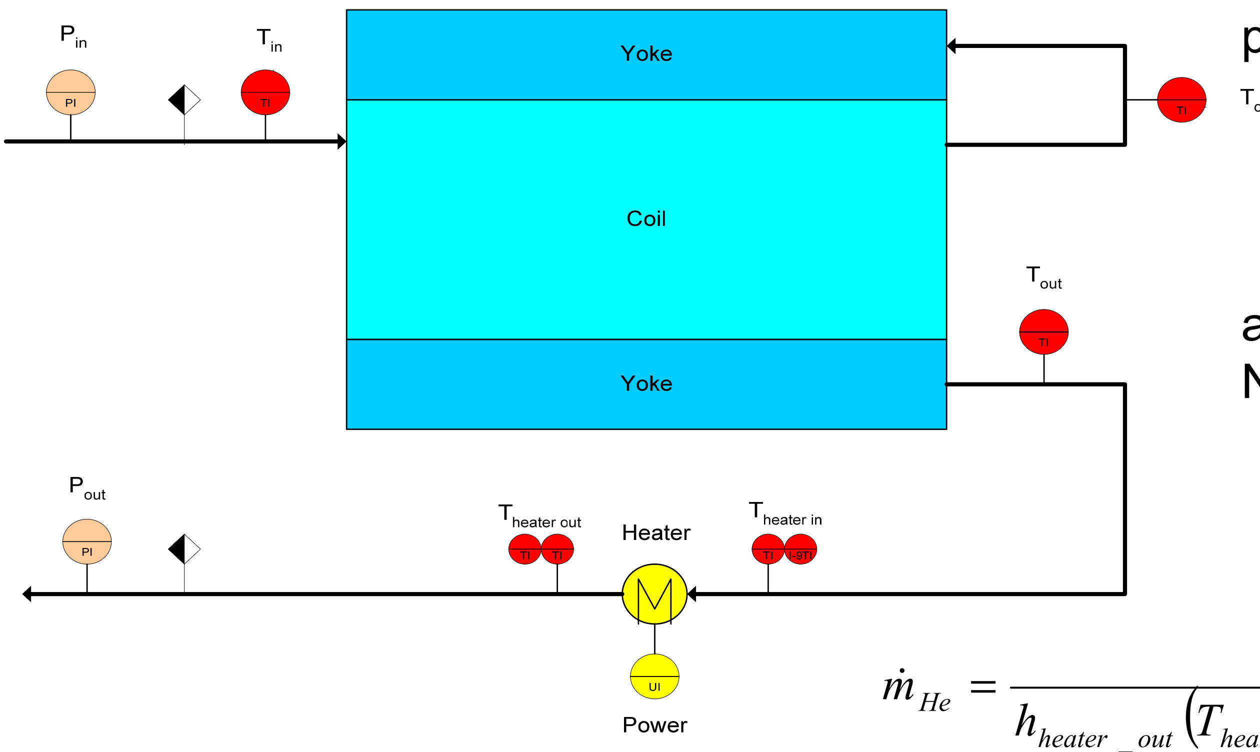
Cryogenic losses –calorimetric method (supercritical cooling)



T_{out}; P_{out}

T_{in}; P_{in}

Cryogenic losses – calorimetric method (2-phase cooling)



coil cooling: 2 phase
measurement points in single phase:
variation of mass flow
→ X = 0 at coil inlet
→ X = 1 at coil outlet

as applied by Dubna for Nuclotron magnet tests

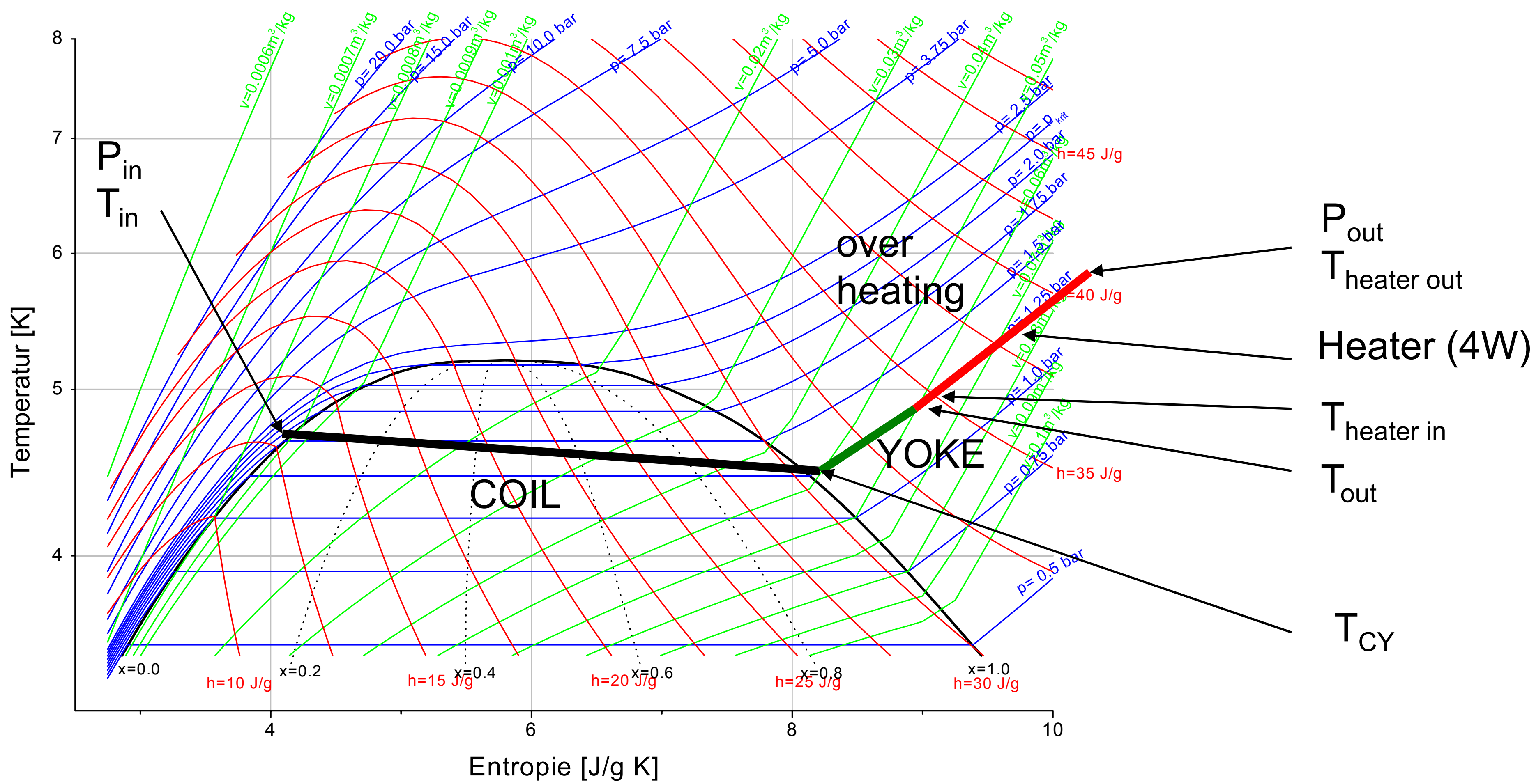
$$\dot{m}_{He} = \frac{Q_{heater}}{h_{heater\_out}\left(T_{heater\_out}, P_{out}\right) - h_{heater\_in}\left(T_{heater\_in}, P_{out}\right)}$$

assumption:
pressure drop only in the coil.

$$Q_{coil} = \dot{m}_{He} \cdot \left(h_{vapor}(x=1, P_{out}) - h_{liquid}(x=0, P_{in})\right)$$

$$Q_{yoke} = \dot{m}_{He} \cdot \left(h_{out}(T_{out}, P_{out}) - h_{CY}(T_{CY}, P_{out})\right)$$

Cryogenic losses – calorimetric method (2-phase cooling)



GSI001 (with beam pipe) –cryogenic losses

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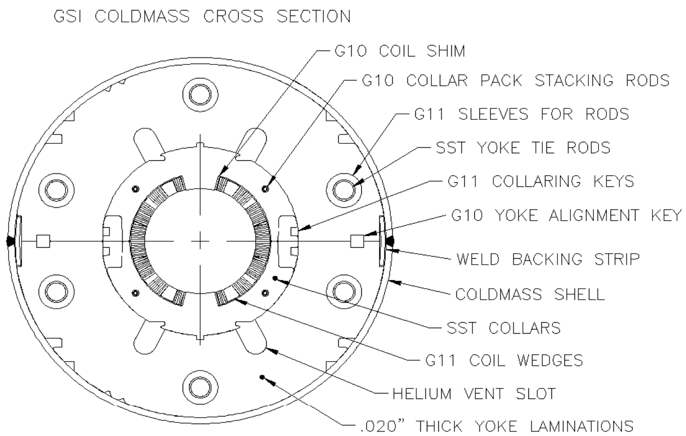
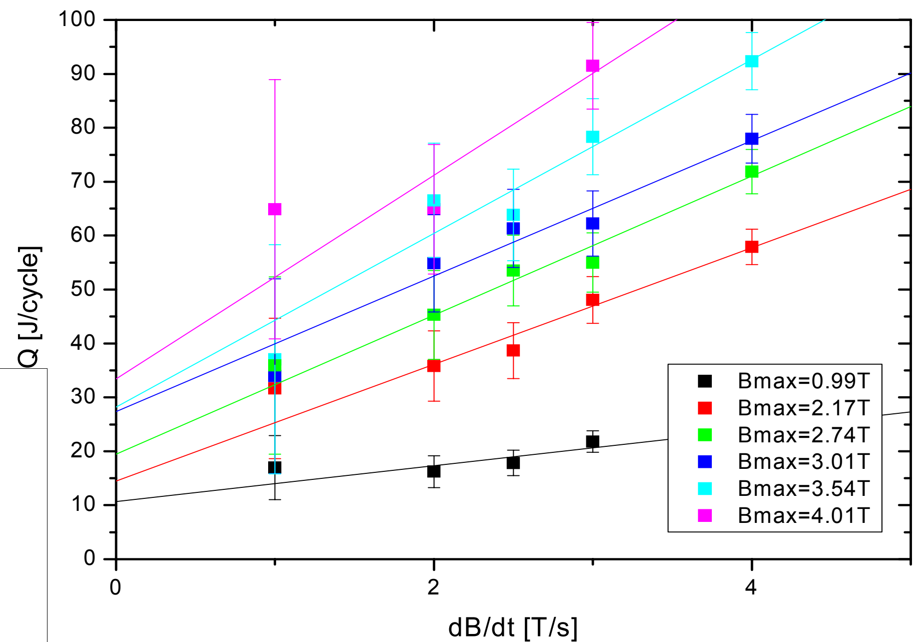
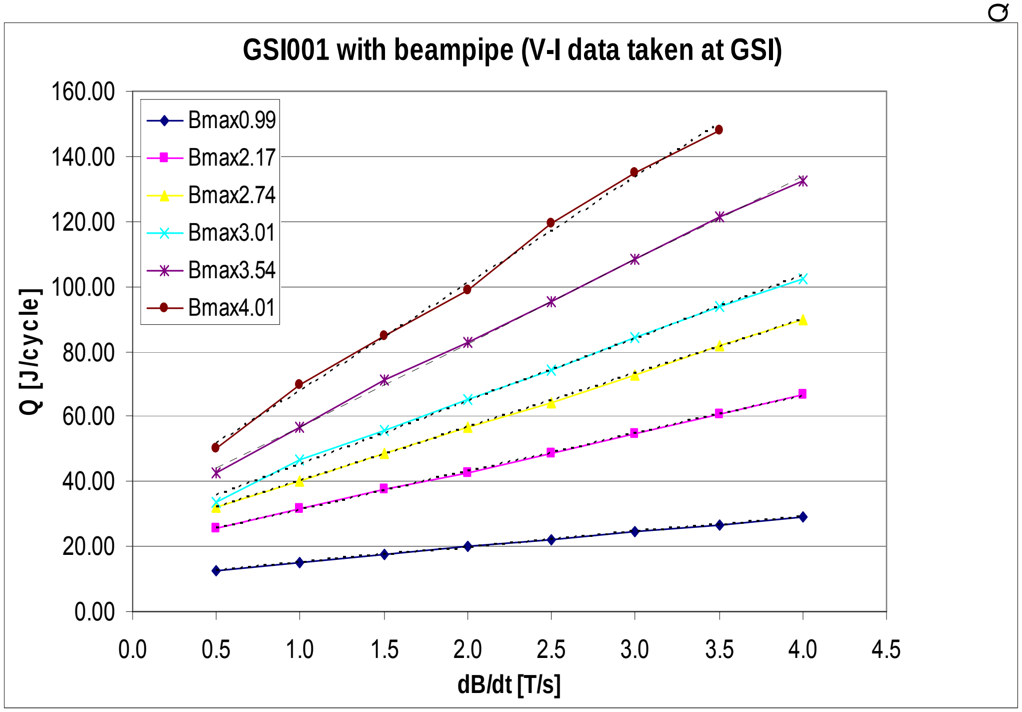
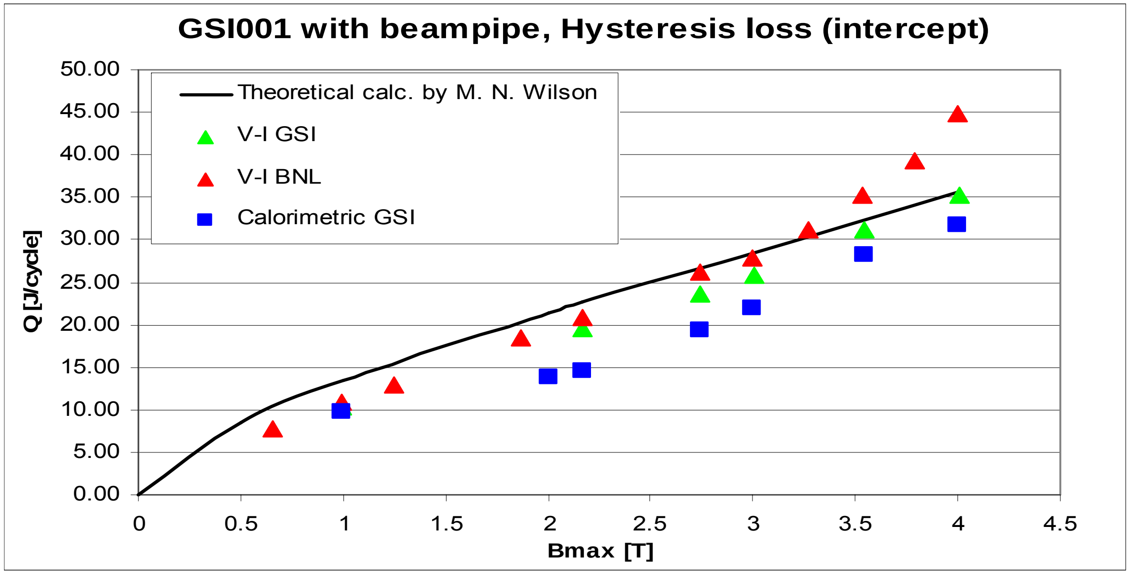


GSI001 with beampipe (calorimetric data taken at GSI)





GSI001 (with beam pipe) –cryogenic losses



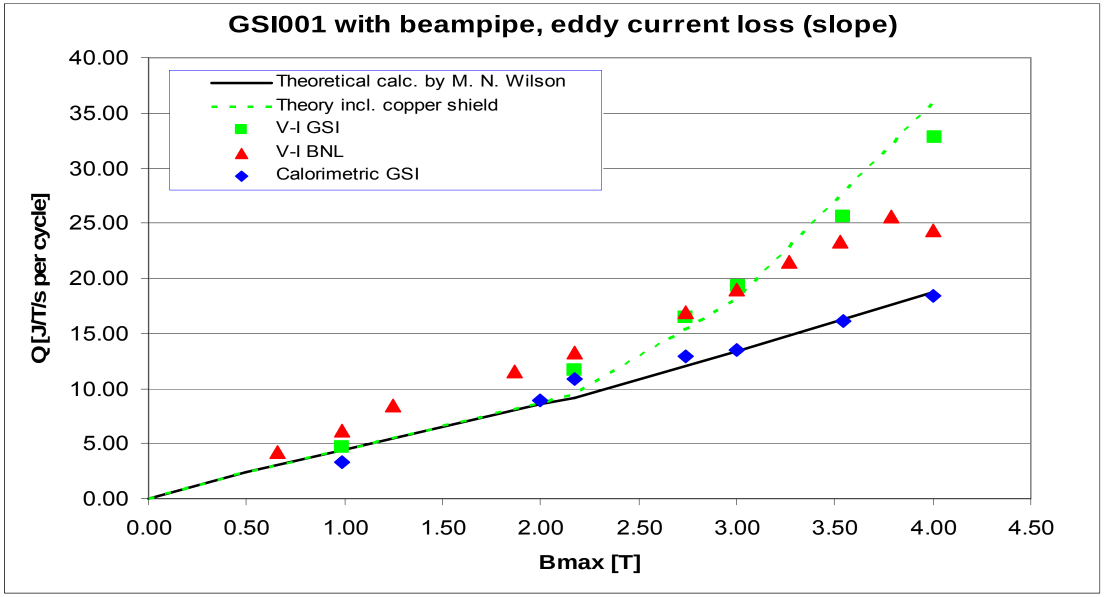
Hysteresis part (including iron and transport current contribution)

measured (short samples) parameters used for calculation:

$\rho_{et}(B) = 1.24\times10^{-10} + 0.9\times10^{-10}$ B with ρ_{et} in Ωm and B in Tesla.

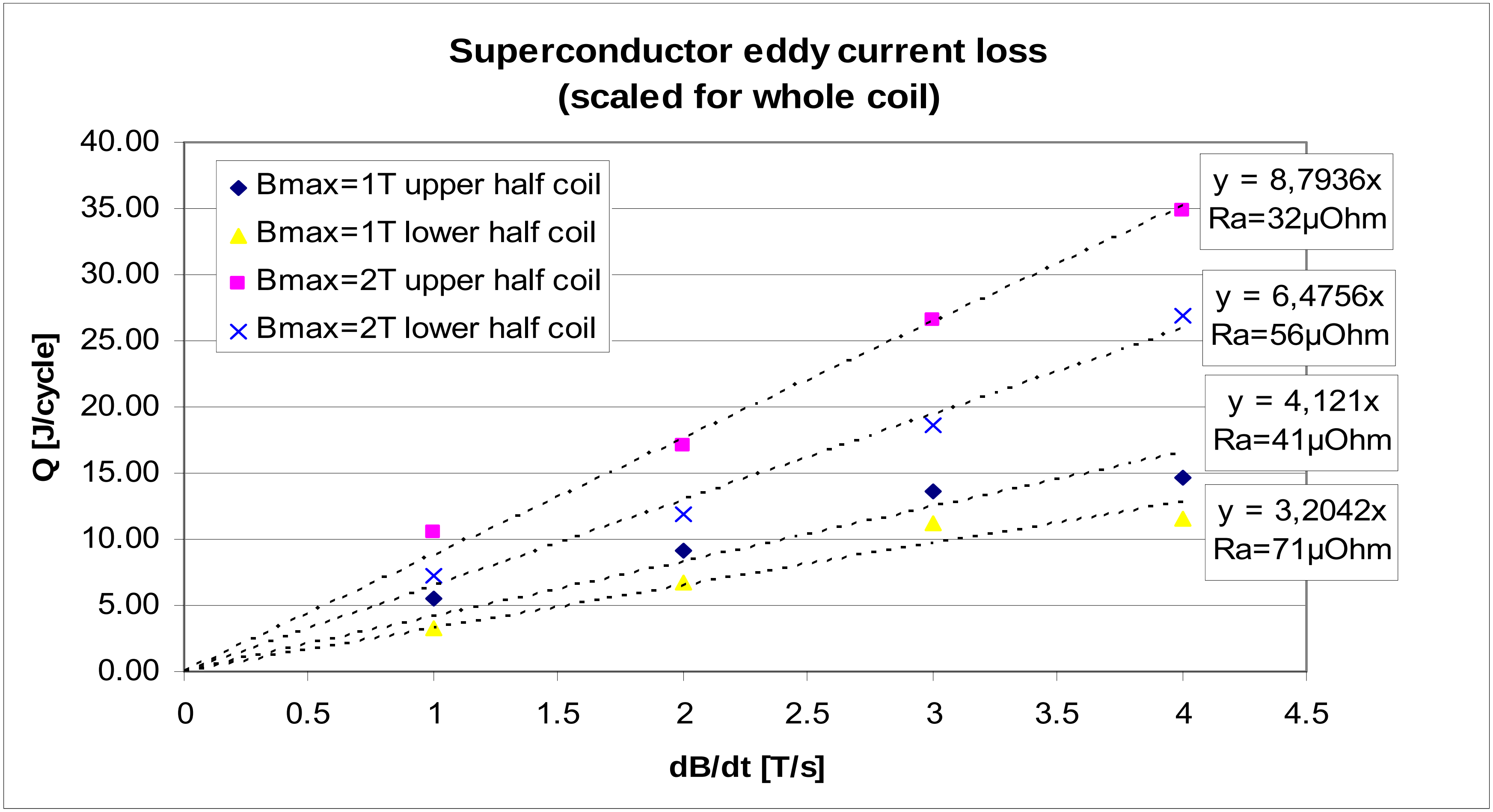
$R_c = 62.5$ m Ω

$R_a = 64$ µΩ



Eddy current part

Top-Down Asymmetry



GSI 001 Ramp Rate Limitation (RRL)

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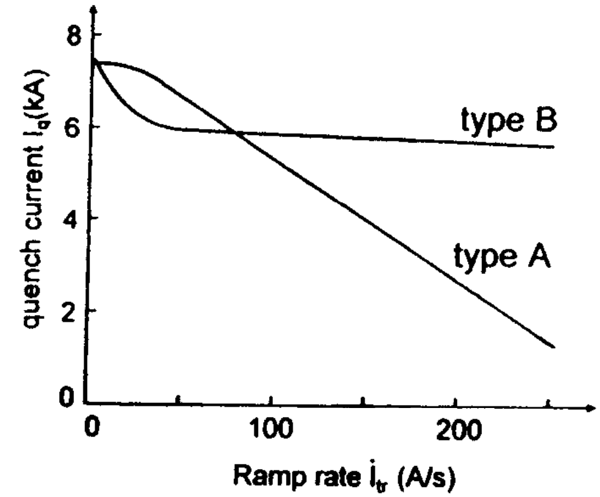
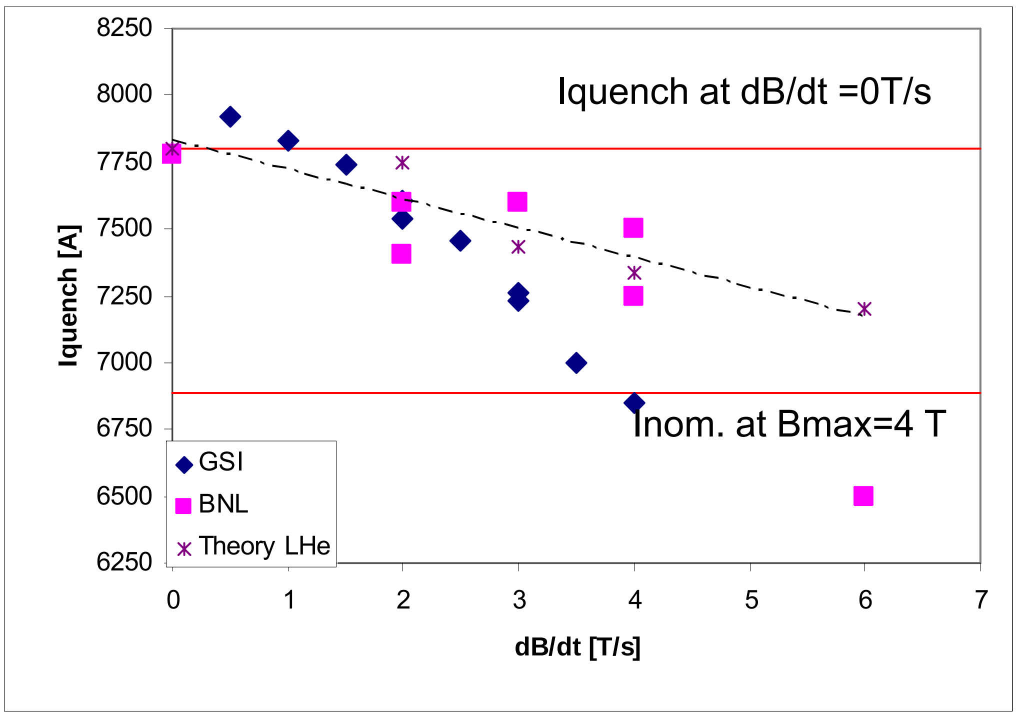
• type 'A' behavior: quench current reduced by AC- conductor heating

• type 'B' behavior: quench current reduced due to unequal current distribution between strands- unwanted!

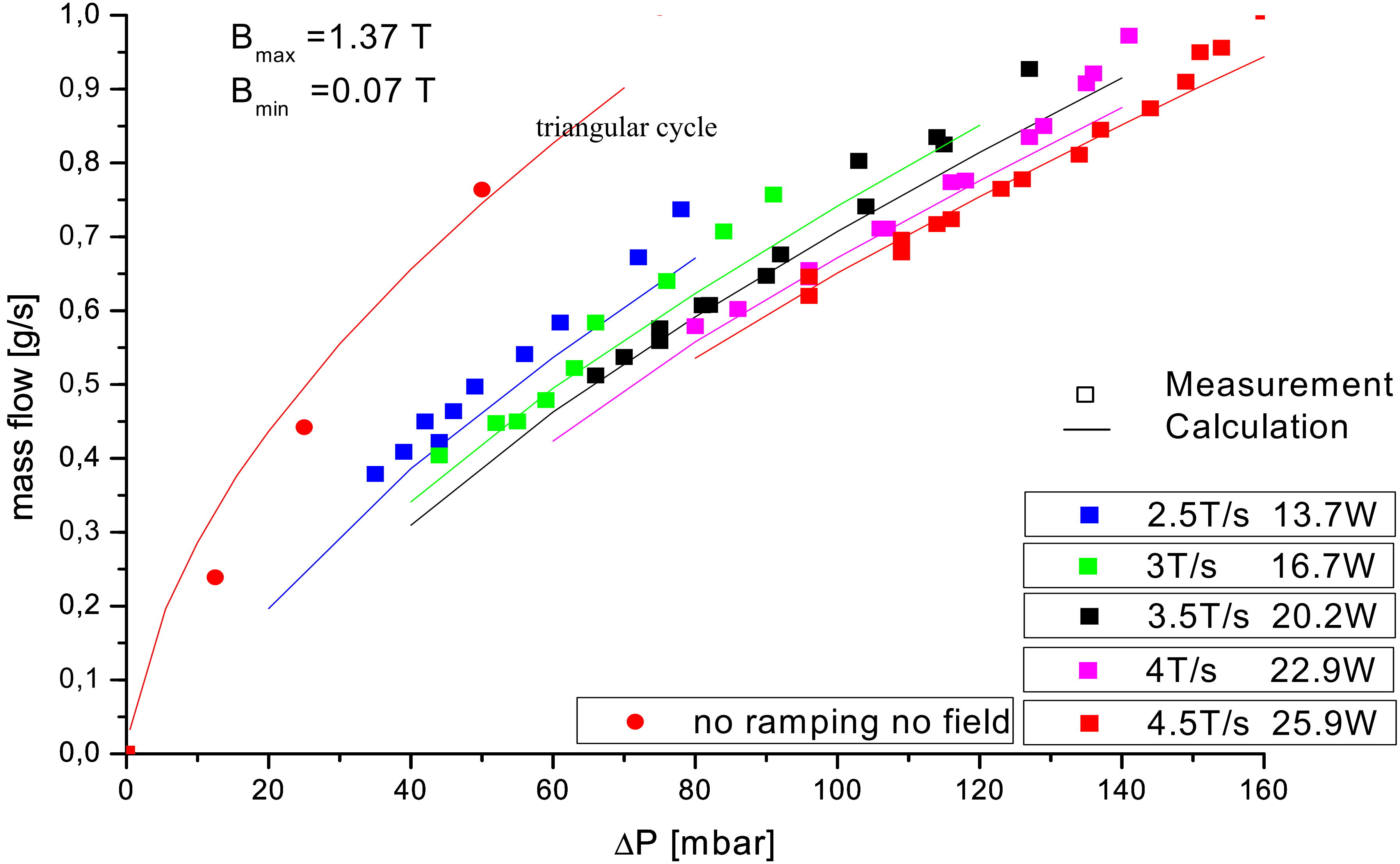




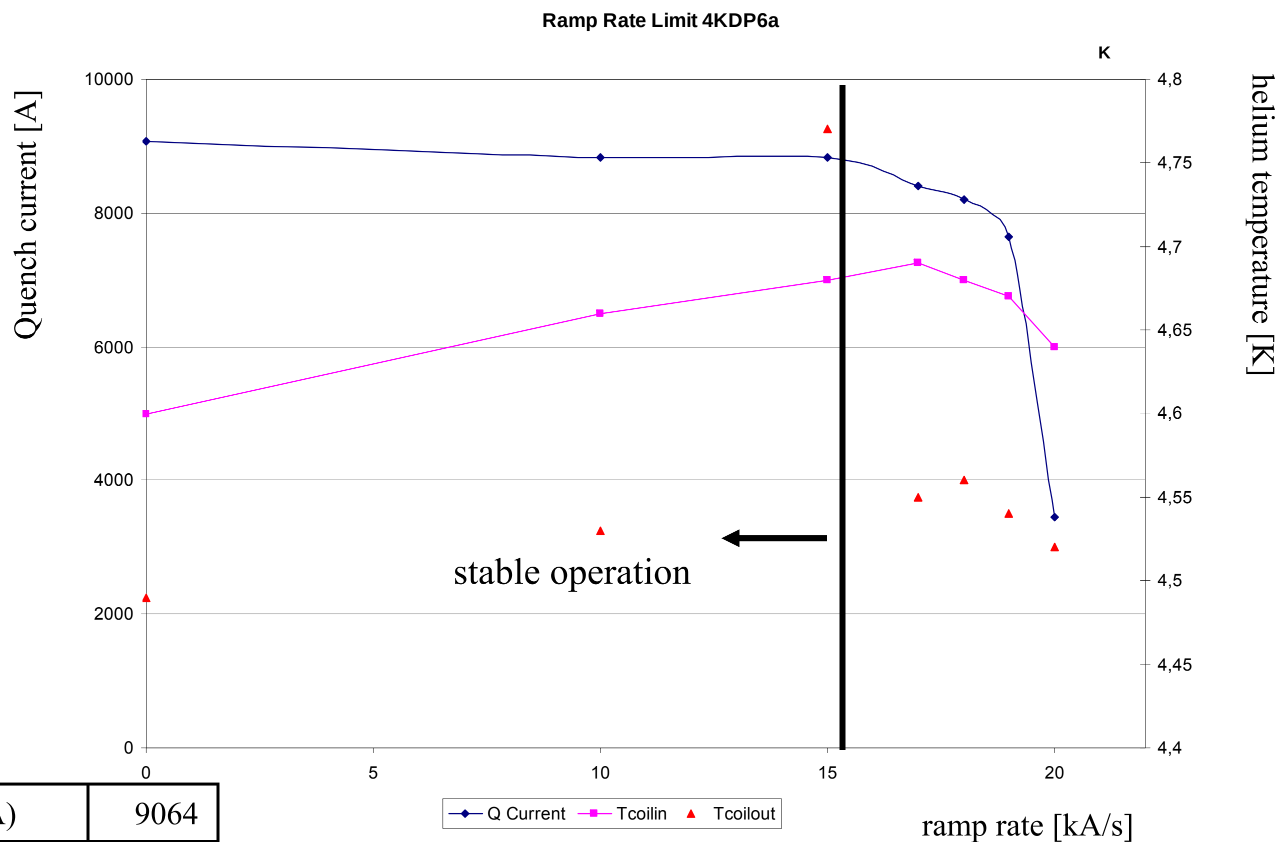
GSI: cooled by supercritical helium

BNL: cooled by helium bath

4KDP6a – mass flow vs. pressure drop (2-phase flow)



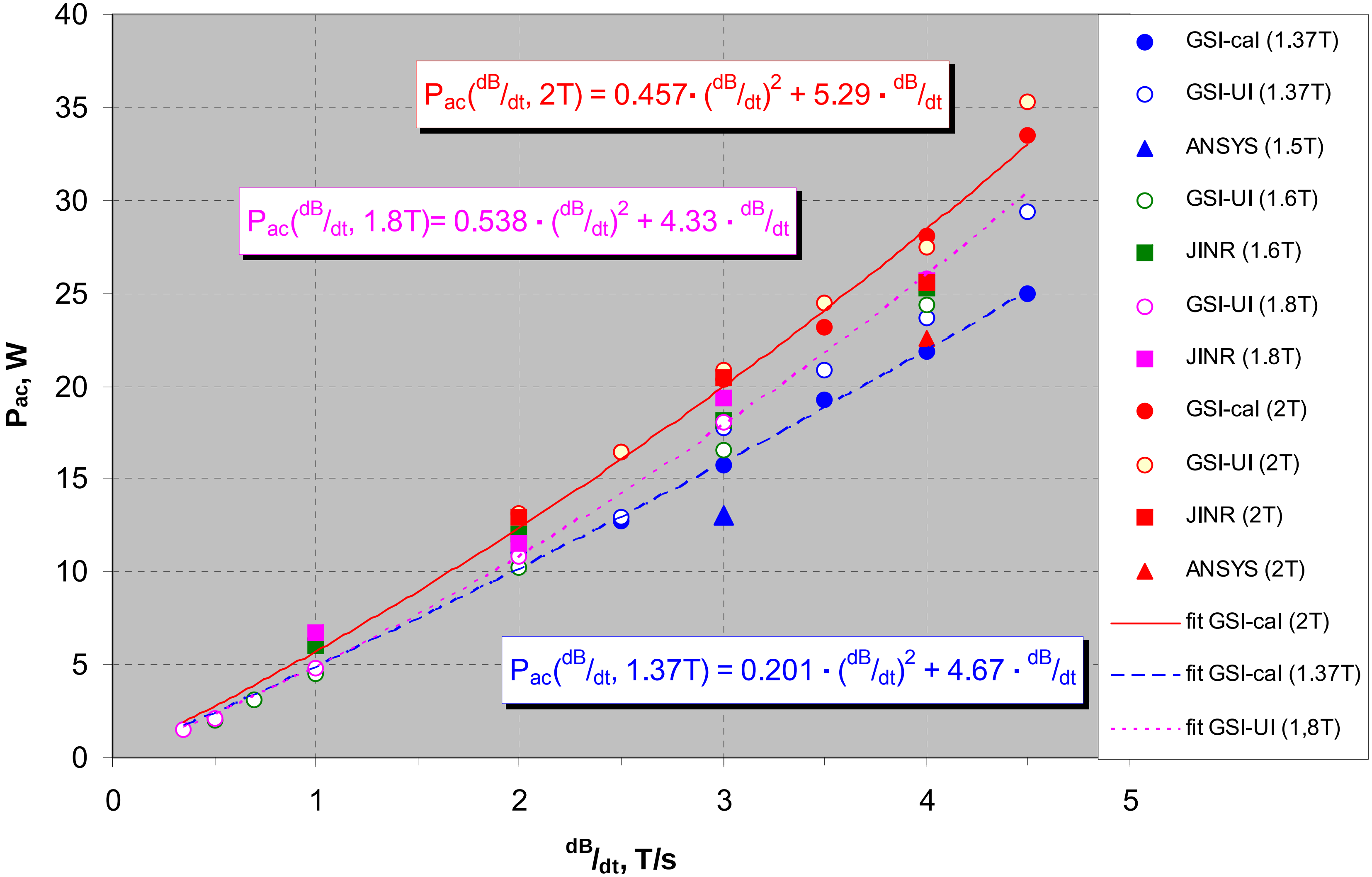
4KDP6a RRL

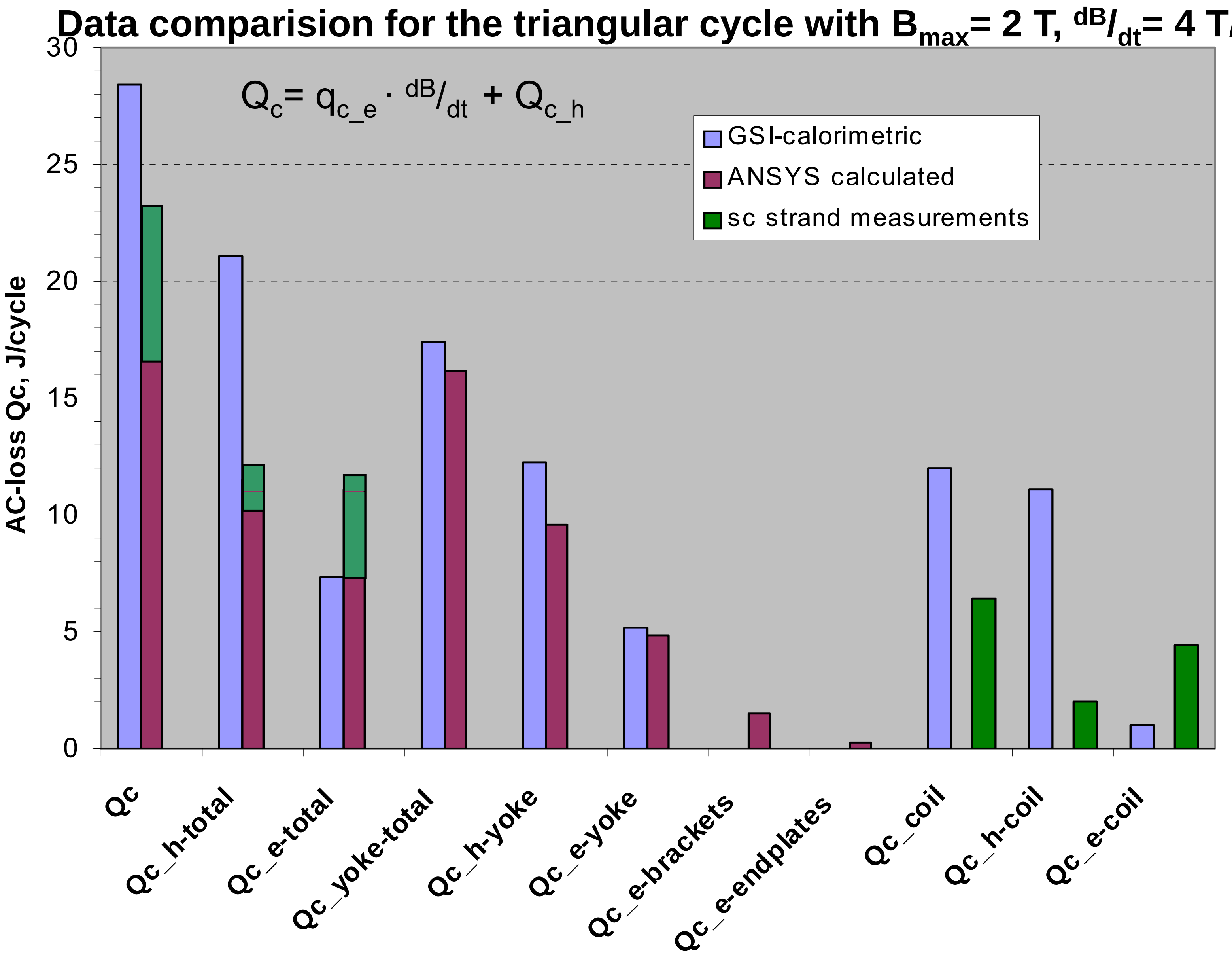


DC quench current (A)	9064
Bmax (T)	2.86
TcB (K)	8.08
Ic(Bmax,4.7K) (A)	10465
Tcs (9064A,Bmax) (K)	5.15
Tcs (9064A,Bmax)-4.7 (K)	0.45

4KDPa: AC Losses @ 4 K

(measured: calorimetric and U-I; calculated: ANSYS)
for various B_{max} at triangular cycles





- **Qc = 25,5 J/cycle +/- 12%**
- reasonable agreement between the overall AC loss data measured (calorimetric and U-I) and calculated (ANSYS) at JINR and GSI for the 4KDP6a dipole model magnet.
- significant thermal contact between coil and iron yoke, not measured
- the technological details of the magnet design and the real material properties are important

FAIR

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