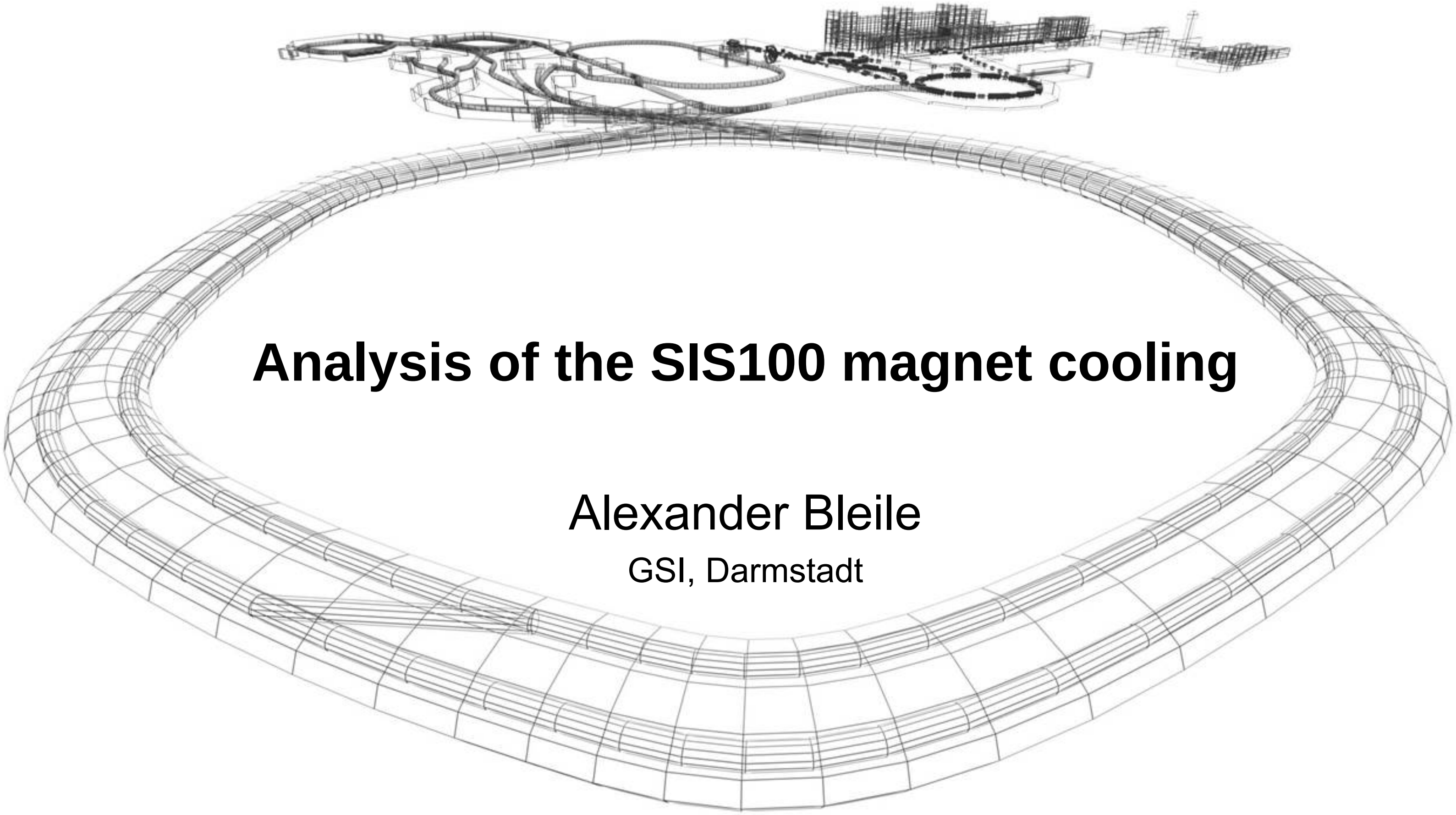


# Analysis of the SIS100 magnet cooling

Alexander Bleile
GSI, Darmstadt

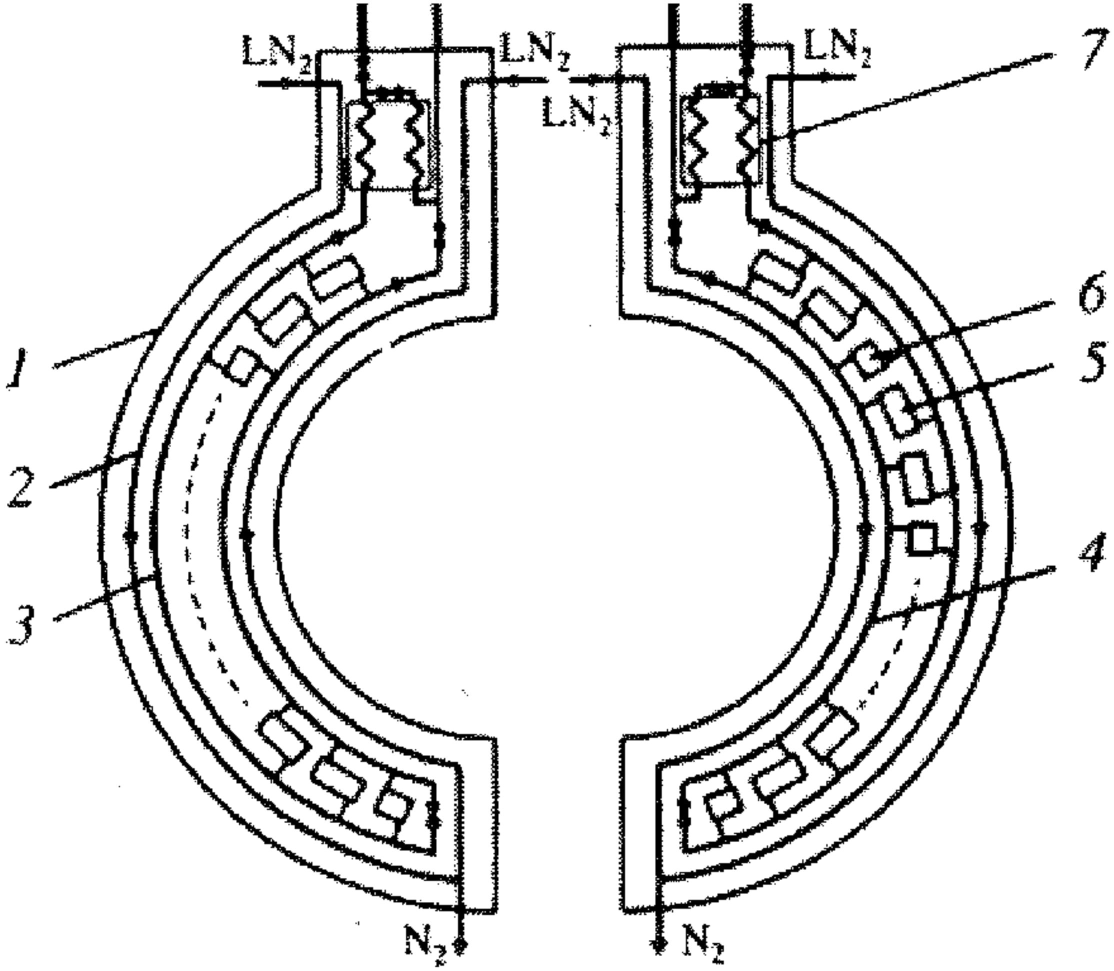
# Outline

- **SIS100 cooling concept**
- **Analysis of the single dipole cooling**
- **Arrangements needed for parallel cooling**
- **Conclusions**

# Nuclotron Ring Cooling

1. vacuum shell
2. nitrogen shield
3. supply header
4. return header
5. dipole magnet
6. quadrupole magnet
7. subcooler

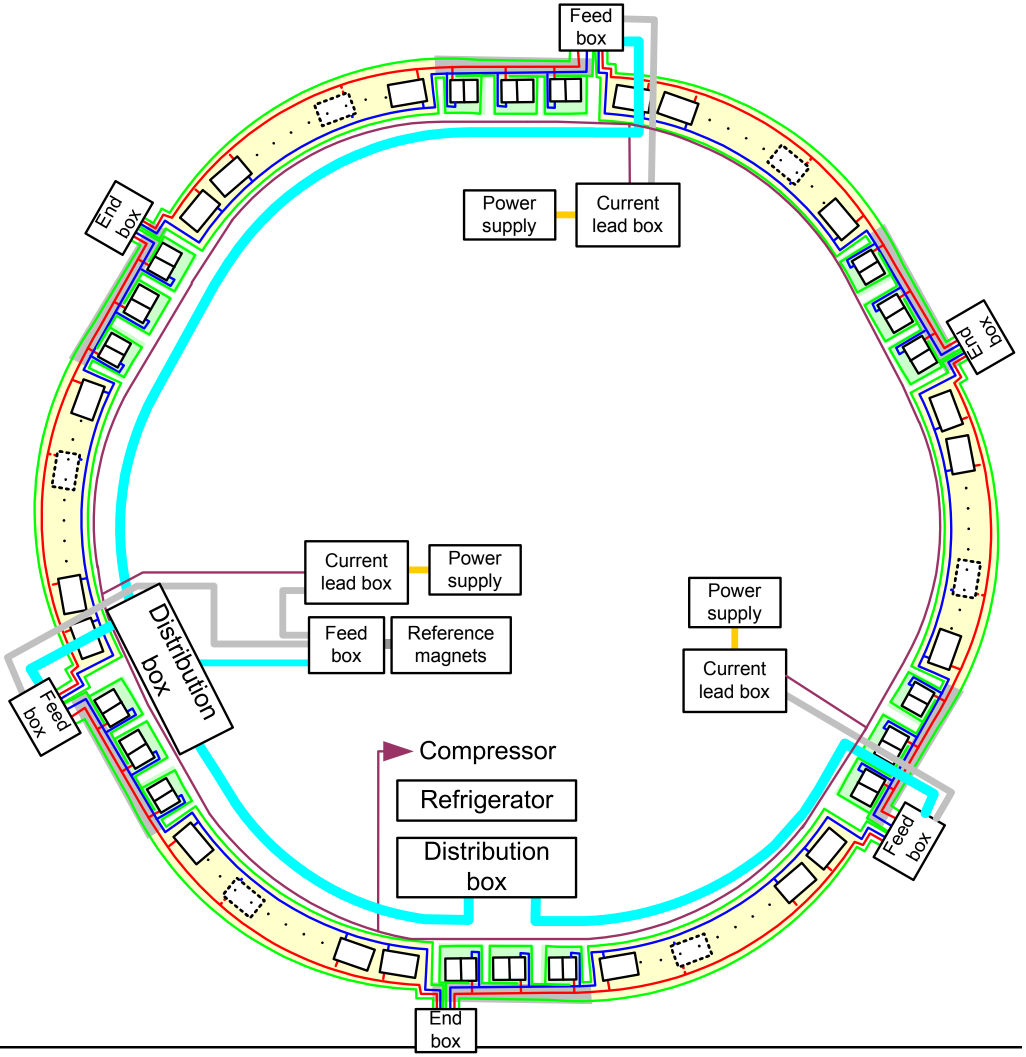
2 x 100 parallel channels



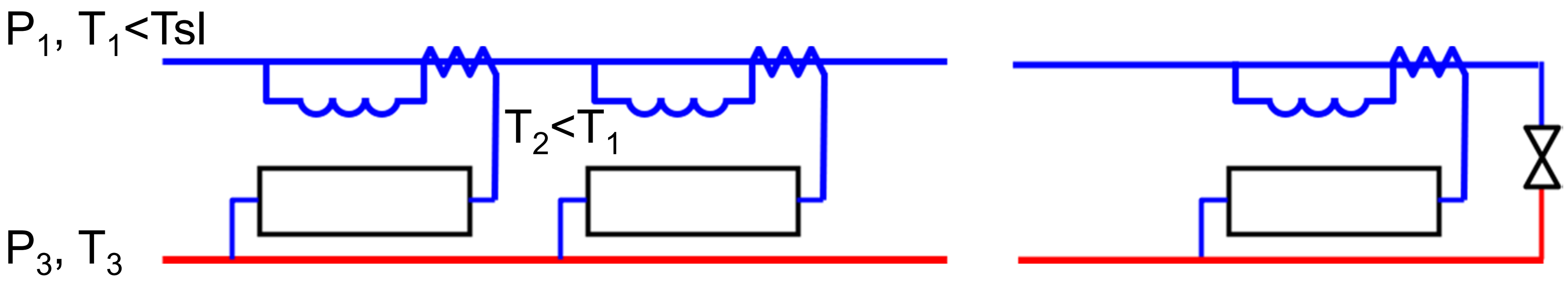
# SIS100 Ring Cooling

*Common Specification for Cryogenic Feedboxes (M.Kauschke, Y.Xiang, Ver. 2010.12.15)*

| | | |
|---|---|---|
| 🟥 | Supply line | 4.4 K |
| 🟦 | Return line | 4.3 K<br>300 K |
| 🟩 | shield cooling | 50-80 K |
| ▬ | Helium transfer lines | |
| ▬ | Cold electrical connection | |
| ▬ | warm electrical connection | |
| 🟨 | Ring cryostat | |
| 🟩 | QP cryostat | |
| ▨ | By-pass line | |



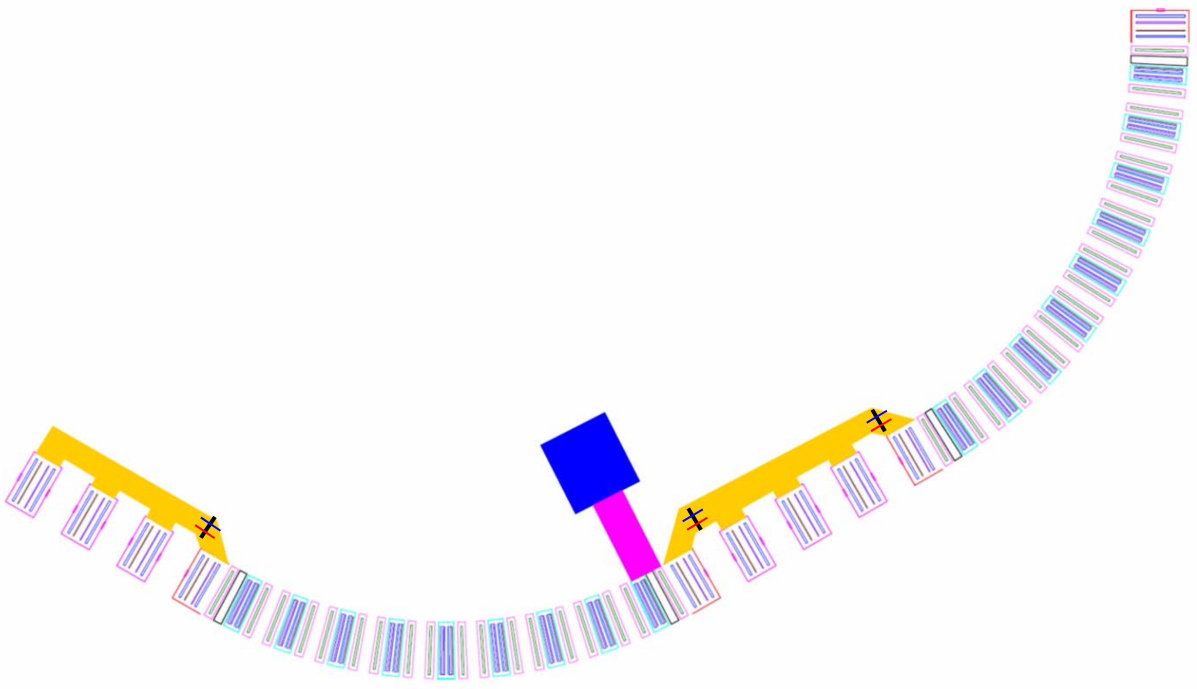
# SIS100 Sector



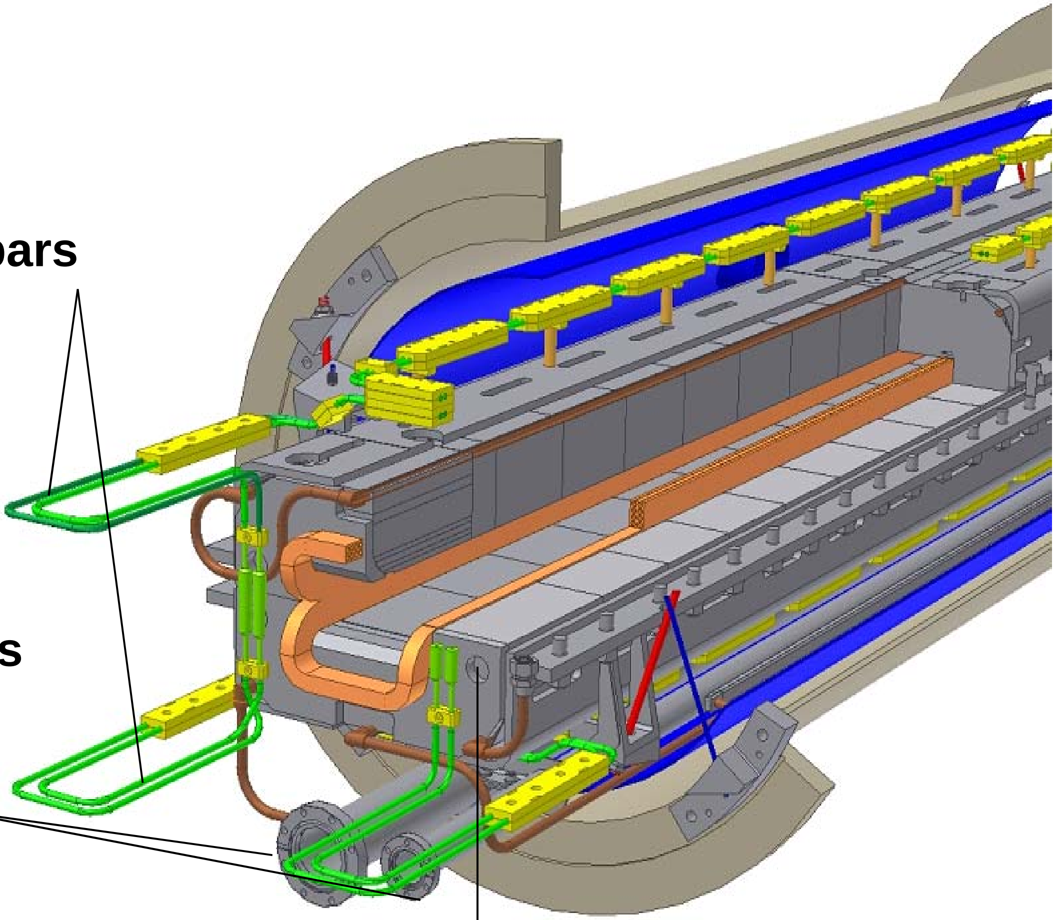
$P_1$, $T_1$<Tsl

$T_2$<$T_1$

$P_3$, $T_3$



# SIS100 dipole cooling



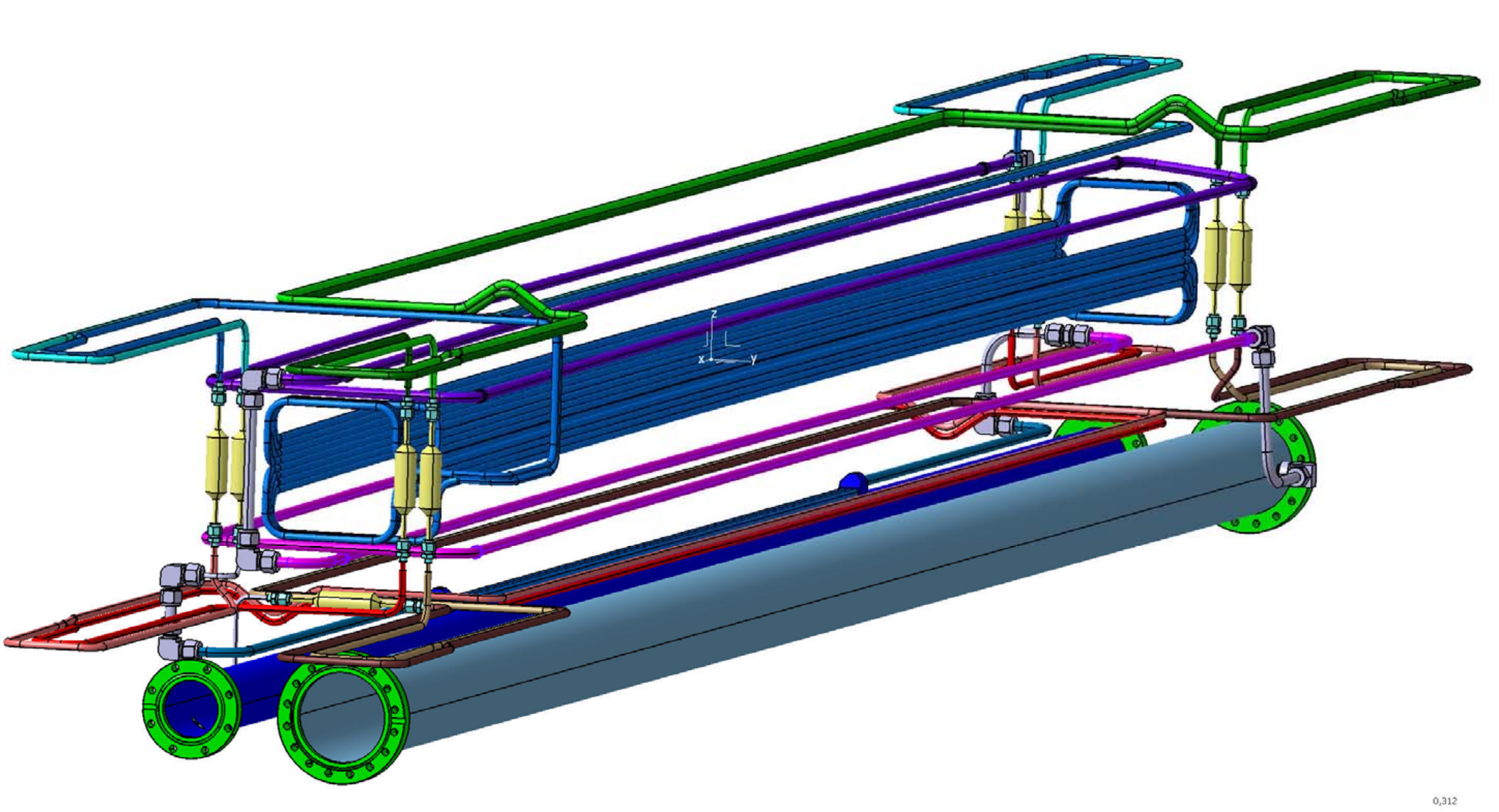
**bus bars**

**He – Supply and return lines**

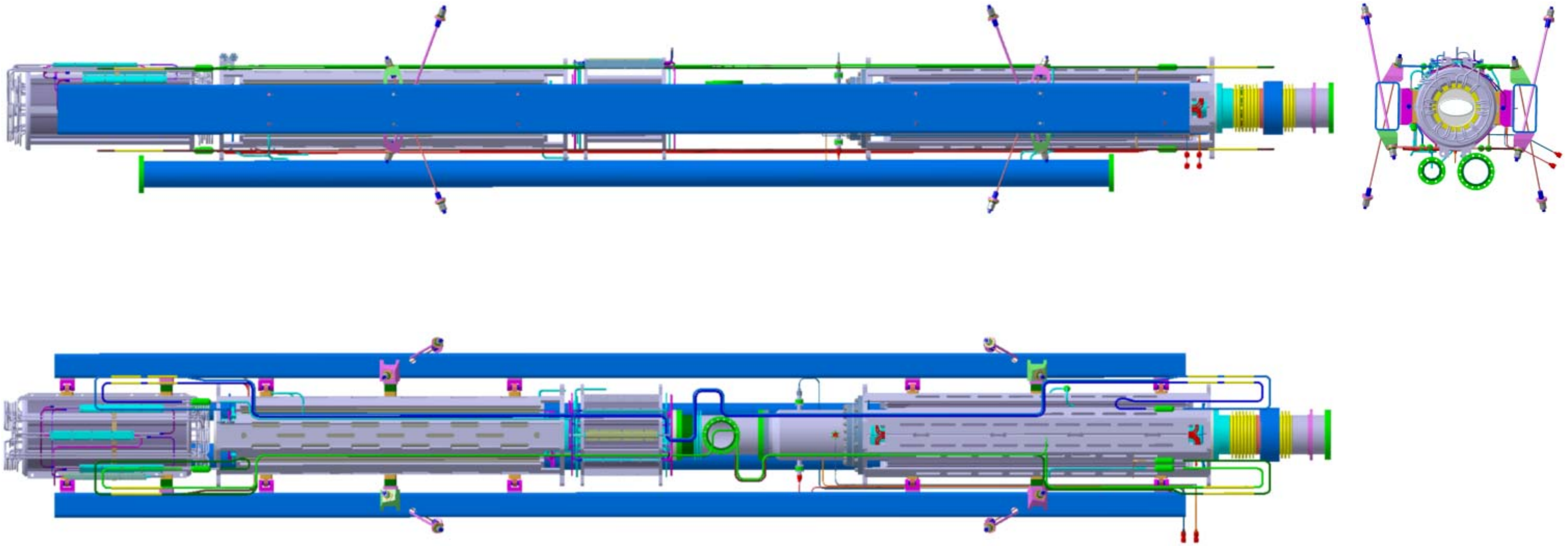
**Supply Header: 66 mm**
**Return Header: 104 mm**

**Joke cooling tube**

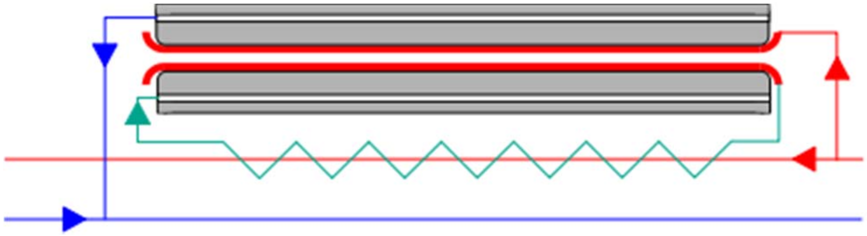
# SIS100 dipole cooling



# Quadrupole Doublet



# SIS100 dipole cooling



Inlet – sub-cooled helium

$P_{in}$ = 1.5 bar, $T_{in}$ = 4.5 K

Coil out:
P = 1.1 bar, two-pase (4.3 K)

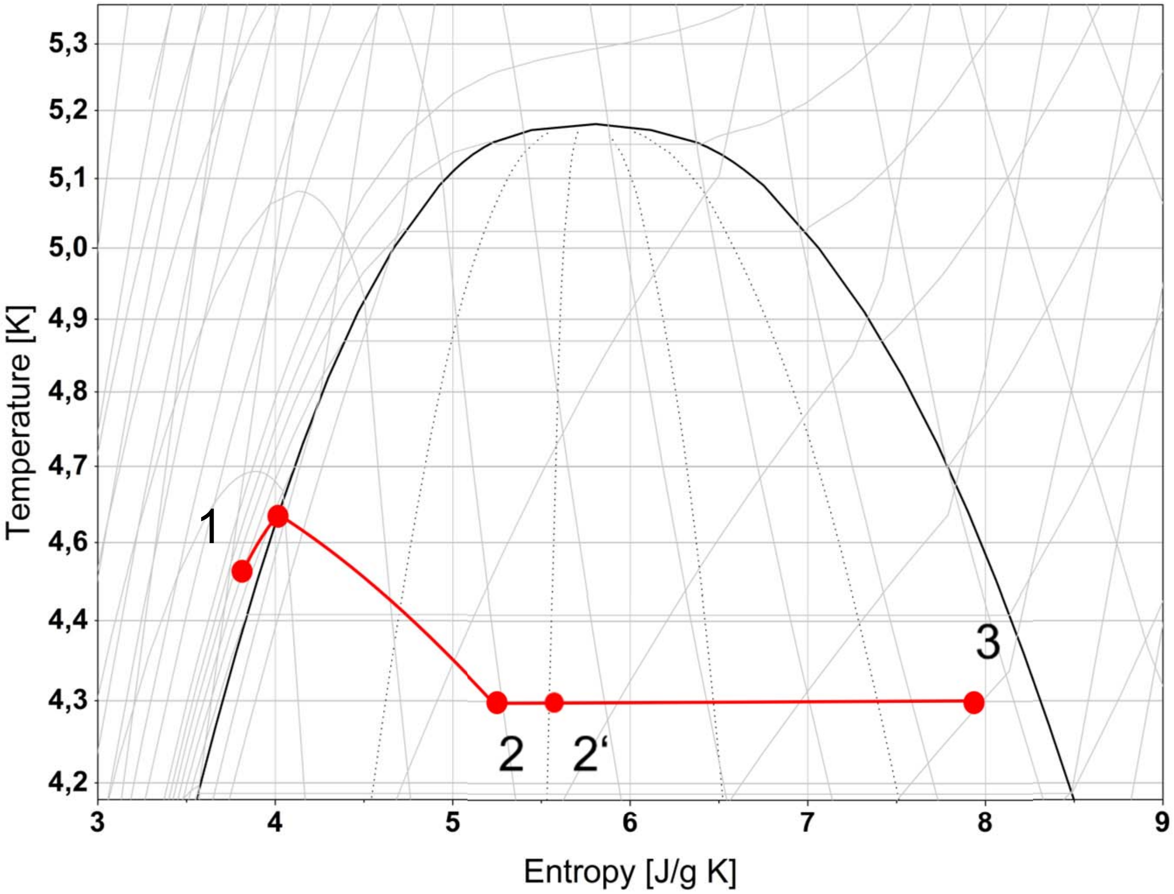
Joke out:
P = 1.1 bar, two-phase, x = 0.9 – 1.0

Heat load:
static: 7 W
dynamic: up to 60 W (triangular cycle)

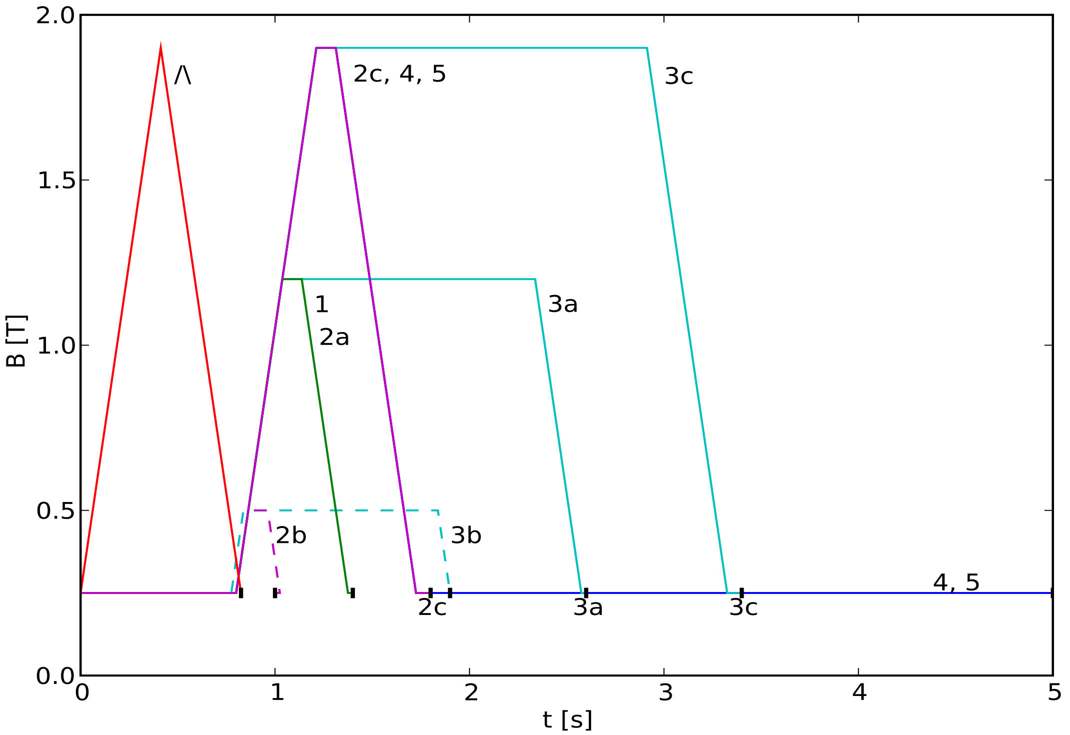
Mass flow: defined by the total heat load

Pressure dprop: defined by the mass flow rate and hydraulic resistance of cooling channels:
cable inner diameter: d = 4.7 mm iron yoke: d = 10 mm
dipole: L = 54 m + 54 m
quadrupole: L = 34 m + 27 m

# Single Magnet: T-S Diagram



# Operating Modes



## Operating cycles

| Cycle | $B_{max}$ [T] | $t_f$ [s] | $t_c$ [s] |
|---|---|---|---|
| 1 | 1.2 | 0.1 | 1.4 |
| 2a | 1.2 | 0.1 | 1.4 |
| 2b | 0.5 | 0.1 | 1 |
| 2c | 1.9 | 0.1 | 1.8 |
| 3a | 1.2 | 1.3 | 2.6 |
| 3b | 0.5 | 1.0 | 1.9 |
| 3c | 1.9 | 1.7 | 3.4 |
| 4 | 1.9 | 0.1 | 5.0 |
| 5 | 1.9 | 0.1 | 5.0 |
| /\ | 1.9 | 0 | 1.0 |

# Expected Losses

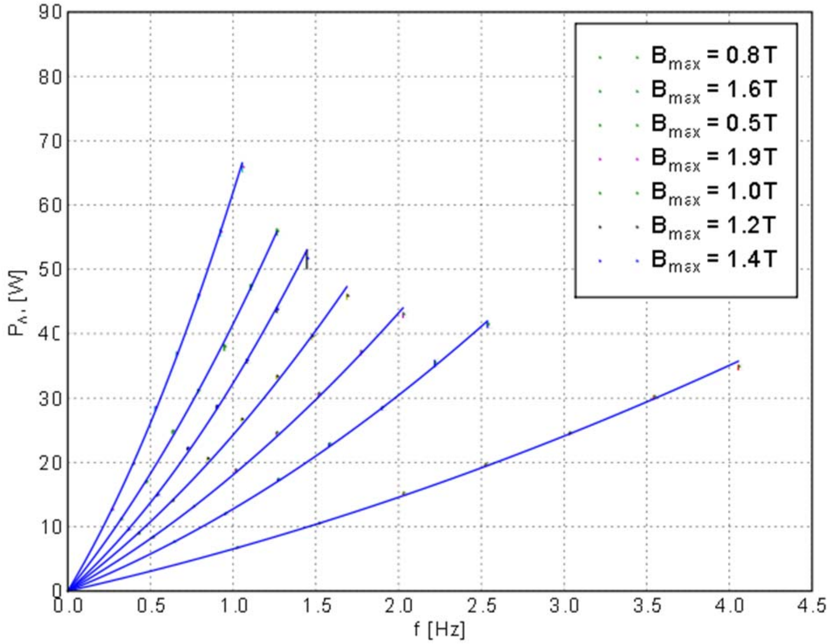
Measurements on dipole prototypes:

dynamic losses:
up to 60 W in the triangular cycle

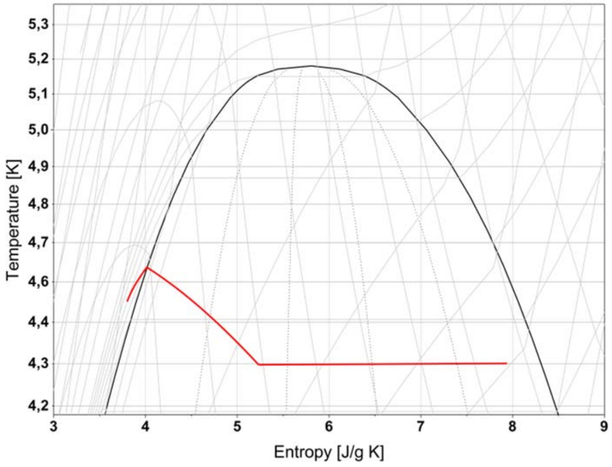
static losses:
up to 10 W

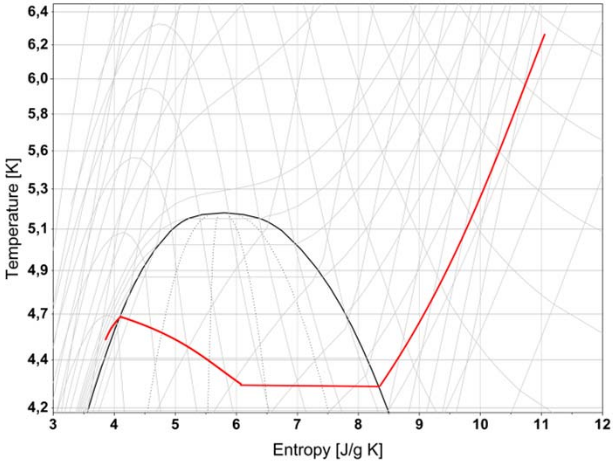
losses in the vacuum chamber
(to be cooled separately):
up to 14 W

Quadrupole unit:
50 % of dipole losses (estimated)



# Dipole cooling





Busbar + Coil: 54 m + 54 m
Minor losses: $\xi = 26.0$

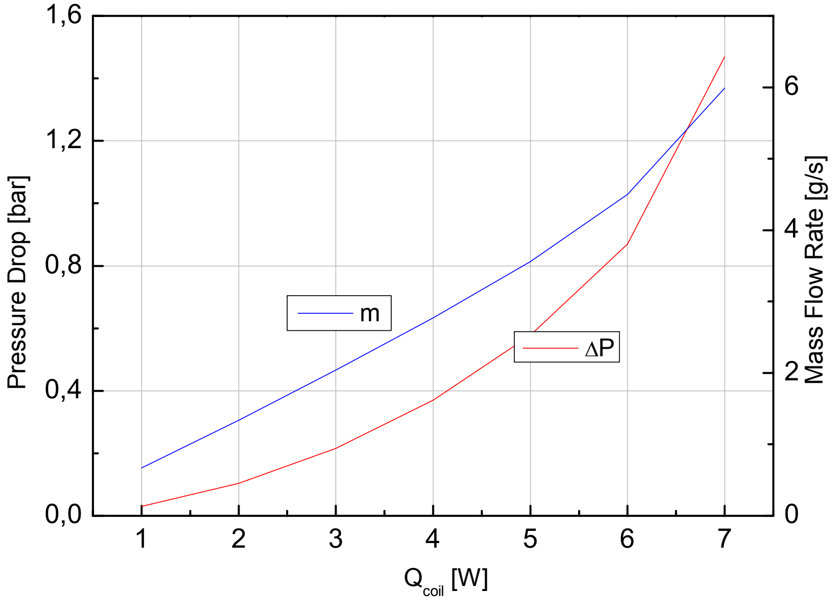
$P_1 = 1.6$ bar, $T_1 = 4.51$ K (subcooled)
$P_3 = 1.1$ bar, $T_3 = 4.31$ K

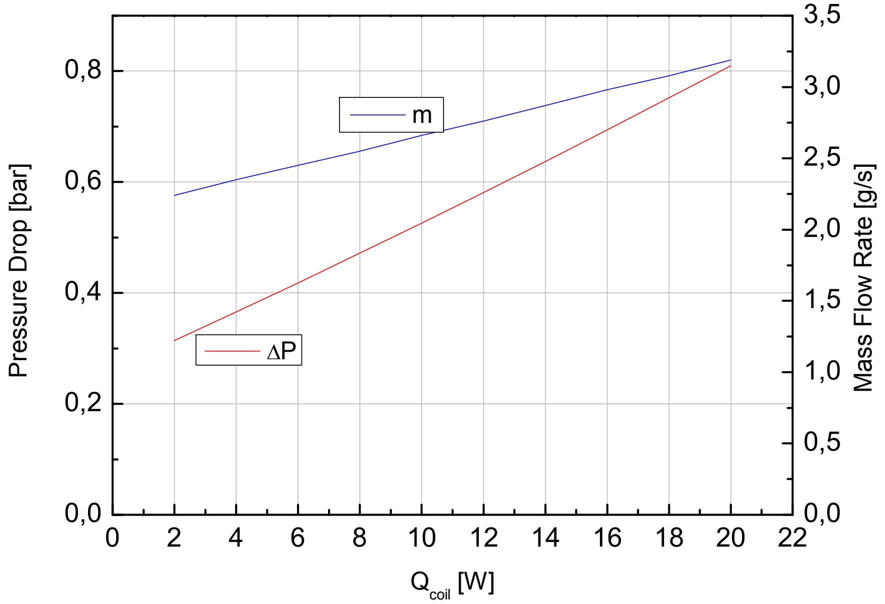
$P_{total} = 40$ W: m = 2.4 g/s
$x_2 = 0.30$
$x_3 = 0.88$

$P_{total} = 70$ W: m = 2.1 g/s
$x_2 = 0.56$
$T_3 = 6.52$ K

# Two-Phase Cooling

$Q_{yoke}$ = 30 W
$T_1$ = 4.55 K





Supercritical Helium:
$P_2$ = 2.3 bar
$T_2$ = 4.7 K
$m = Q_{coil} / (h_2 - h_1)$

Two-Pase Helium:
$P_2$ = 1.1 bar
$X_3$ = 1
$m = (Q_{coil} + Q_{yoke}) / (h_3 - h_1)$

# Two Phase Flow: Baker Diagram

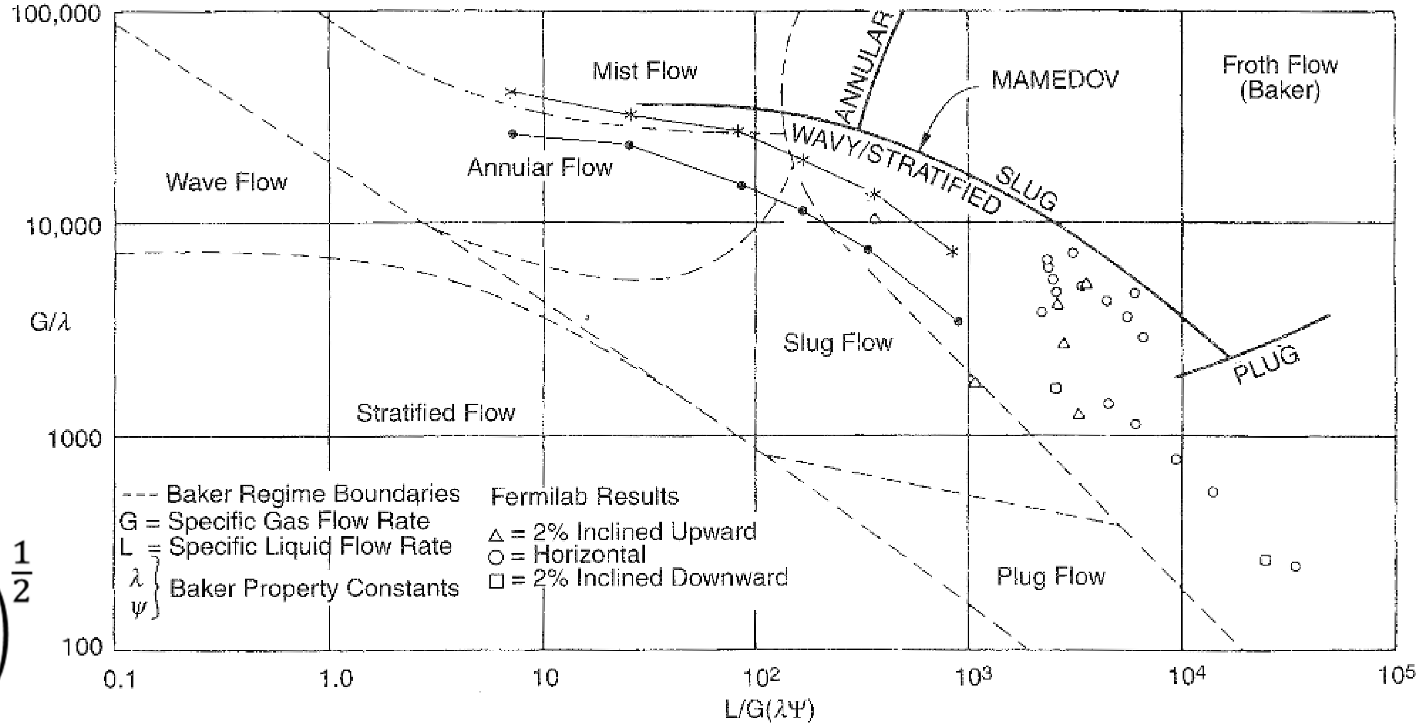
Y axis: gas mass velosity

$$X = \frac{\dot{m}_L}{\dot{m}_G}\lambda\psi$$

$$Y = \frac{\dot{m}_G}{\lambda}$$

$$\lambda = \left(\frac{\rho_G}{\rho_{air}}\frac{\rho_L}{\rho_{water}}\right)^{\frac{1}{2}}$$

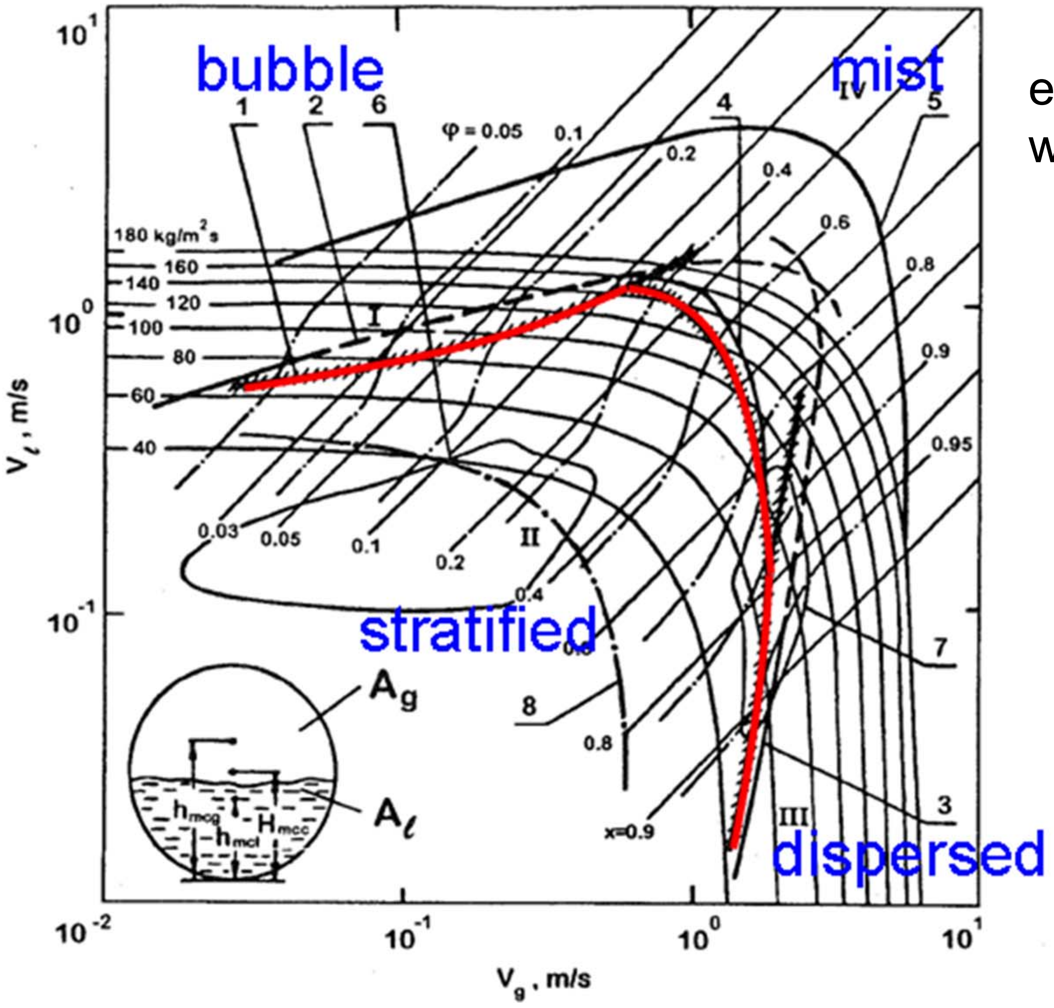
$$\psi = \left(\frac{\sigma_{water}}{\sigma}\right)\left[\left(\frac{\mu_L}{\mu_{water}}\right)\left(\frac{\rho_{water}}{\rho_L}\right)^2\right]^{\frac{1}{3}}$$



X axis: effective liquid-gas ratiio

# flow pattern map

Y. Filippov/Cryogenics 39 (1999) 59–68



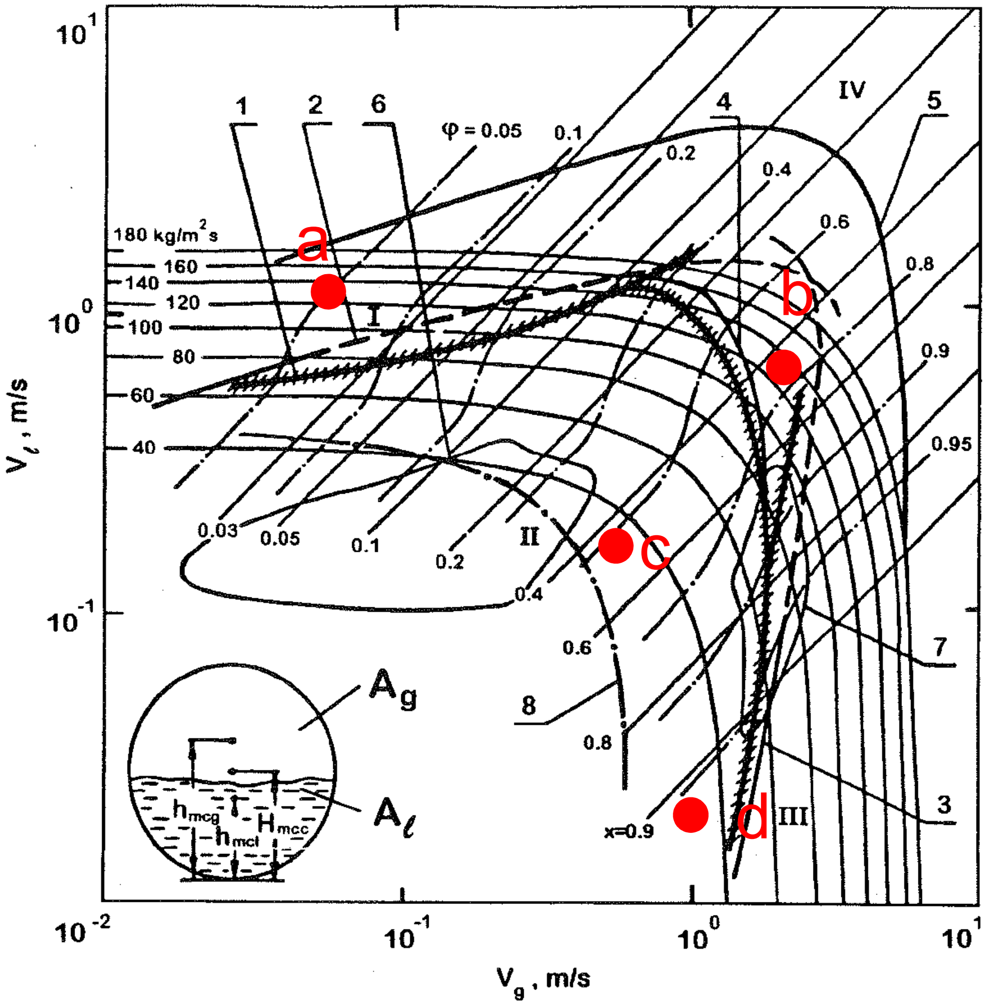
experimental boundaries for a pipe with inner diameter 7.9 mm

$$V_g = \frac{mx}{A\rho_g}$$

$$V_l = \frac{m(1-x)}{A\rho_l}$$

# flow pattern map: P = 70 W

*Y. Filippov/Cryogenics 39 (1999) 59–68*



Triangular cycle:
Ptotal = 70 W
Pcoil = 19 W

$P_1$ = 1.6 bar, $T_1$ = 4.51 K
m = 2.3 g/s

Coil:

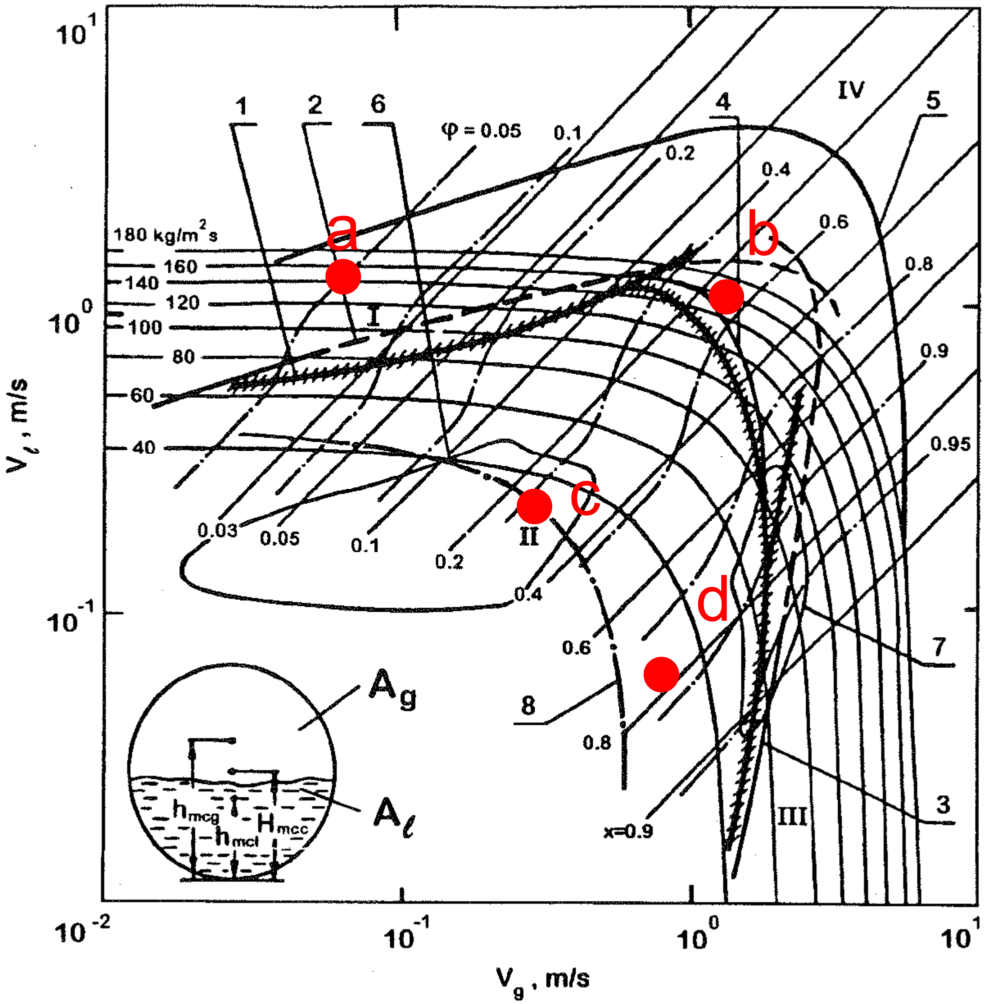
a. P = 1.5 bar, x = 0.05
b. P = 1.1 bar, x = 0.46

Iron:

c. P = 1.1 bar, x = 0.46
d. P = 1.1 bar, x = 0.95

$P_3$ = 1.1 bar, T3 = 5.91 K

# flow pattern map: P = 40 W



Y. Filippov/Cryogenics 39 (1999) 59–68

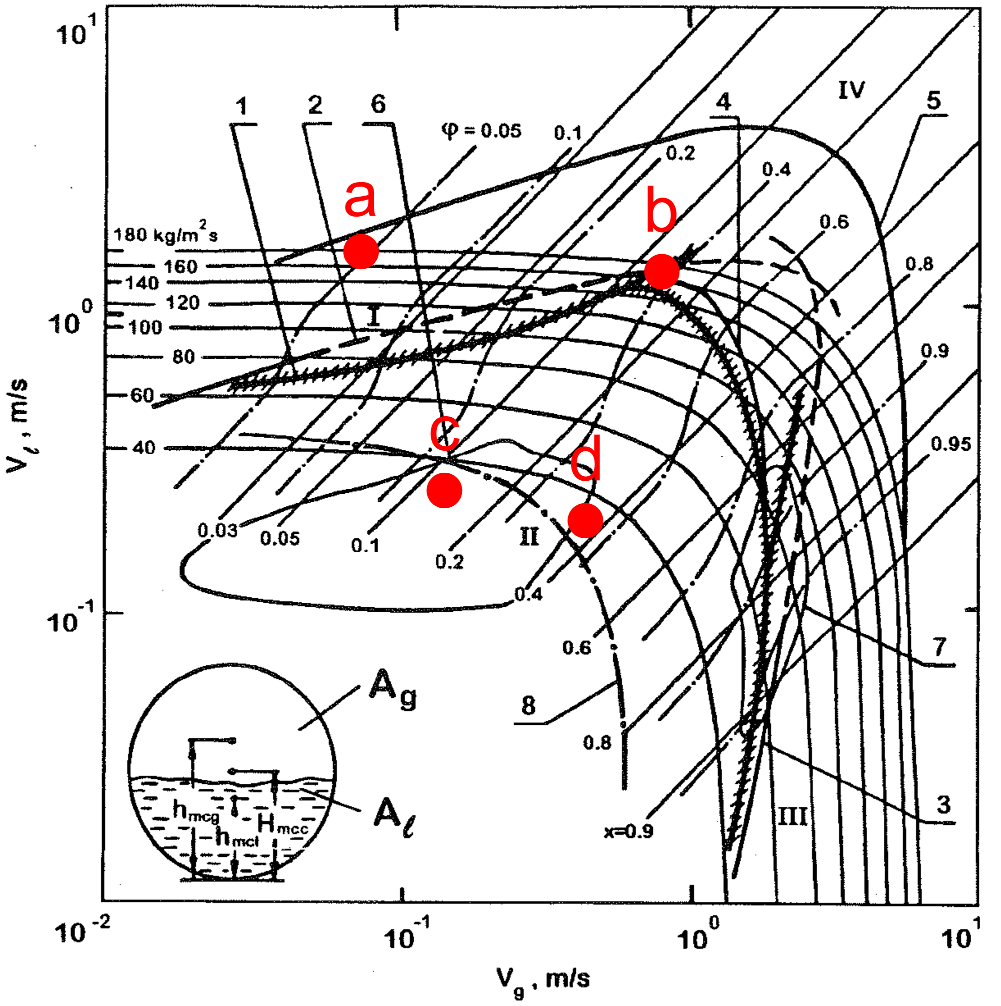
Cycle 2c:
Ptotal = 40 W
Pcoil = 10 W

$P_1$ = 1.6 bar, $T_1$ = 4.51 K
m = 2.7 g/s

Coil:
a. P = 1.5 bar, x = 0.05
b. P = 1.1 bar, x = 0.24
Iron:
c. P = 1.1 bar, x = 0.24
d. P = 1.1 bar, x = 0.79

x3 = 0.79

# flow pattern map: P = 20 W



Ptotal = 20 W

Pcoil = 4 W

$P_1$ = 1.6 bar, $T_1$ = 4.51 K

m = 3.0 g/s

Coil:

a. P = 1.5 bar, x = 0.1

b. P = 1.1 bar, x = 0.12

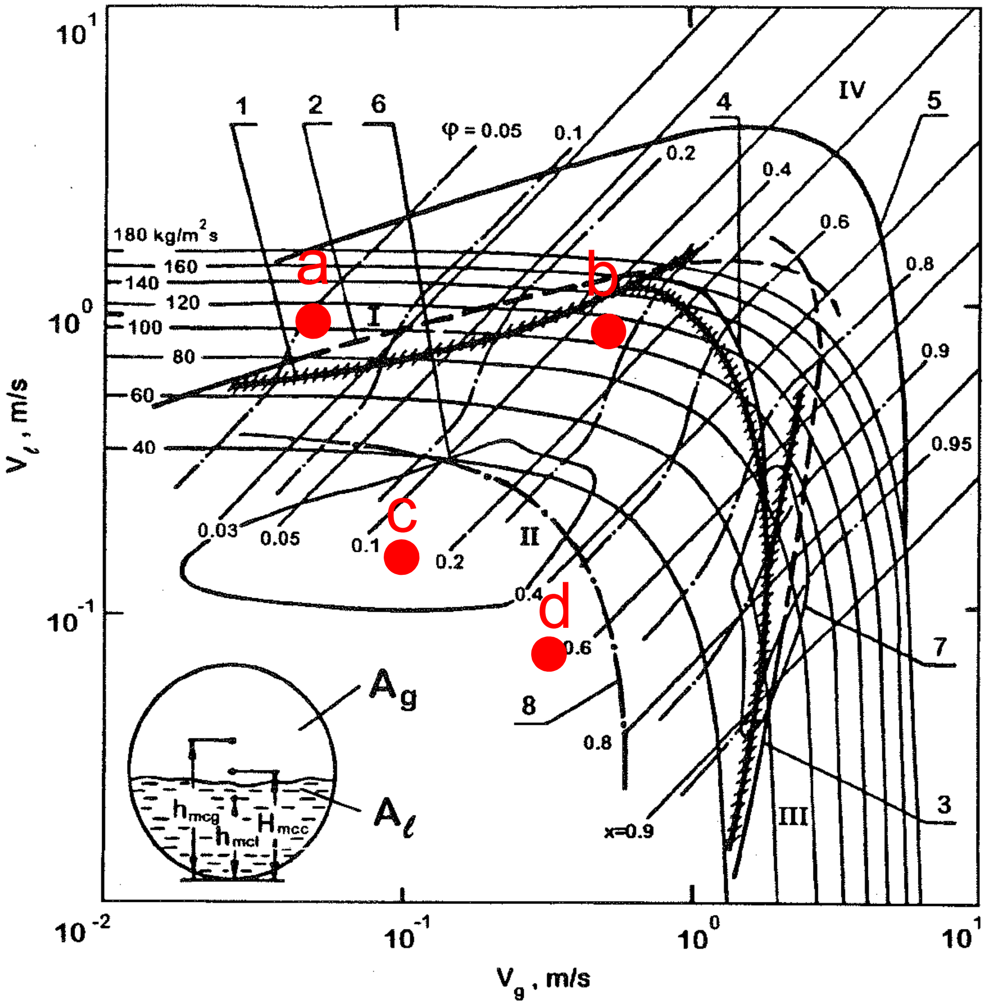
Iron:

c. P = 1.1 bar, x = 0.12

d. P = 1.1 bar, x = 0.39

$x_3$ = 0.39

# flow pattern map: P = 20 W, Pin = 1.35 bar


Y. Filippov/Cryogenics 39 (1999) 59–68

Ptotal = 20 W
Pcoil = 4 W

$P_1$ = 1.35 bar, $T_1$ = 4.51 K
m = 1.9 g/s

Coil:

a. P = 1.5 bar, x = 0.05

b. P = 1.1 bar, x = 0.16

Iron:

c. P = 1.1 bar, x = 0.16

d. P = 1.1 bar, x = 0.58

x3 = 0.58

# Two-Phase Cooling

<u>Potential problems</u>:

- departure from nucleate boiling:

  not expected because of very small heat flux
- stratifyed flow patterns:

  dangerous only when occures in the coil
- instabilities of two-phase flow in vertical channels:

  should be small ($\rho_L/\rho_V \approx 7$)
- instabilities due to parallel channels

  <u>Arrangements needed for parallel cooling:</u>

  subcooled helium in the supply header

  bypass valve in the end box

  adjustments of hydraulic resistance for each channel

# Adjustement of hydraulic resistances

Sector 1:

18 dipoles
14 quadrupole doublets
1 connection cryostat
(missing dipole)
47 parallel channels

quadrupole modules:

each doublet has 2 parallel flow branches

- Q ( 6 units in sector)
- Q + Steerer
- Q + Chr. Sextupole

Multipole Corrector cooled separately

| Magnet Type | Sector | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Dipole | 18 | 18 | 18 | 18 | 18 | 18 |
| Q + ST +Q | 3 | 3 | 3 | 3 | 2 | 3 |
| MC + Q + ST +Q | 2 | 2 | 2 | 2 | 0 | 2 |
| Q + ST + Q + CV (CH) | 8 | 8 | 8 | 8 | 8 | 8 |
| Connection Cryostat | 2 | 2 | 2 | 2 | 2 | 2 |

# Nuclotron Cooling vs. SIS100 cooling

Nuclotron:

- 2 sectors
- 100 parallel chanels / sector
- 4.0 mm cable inner diameter
- beam vacuum chamber cooled by yoke

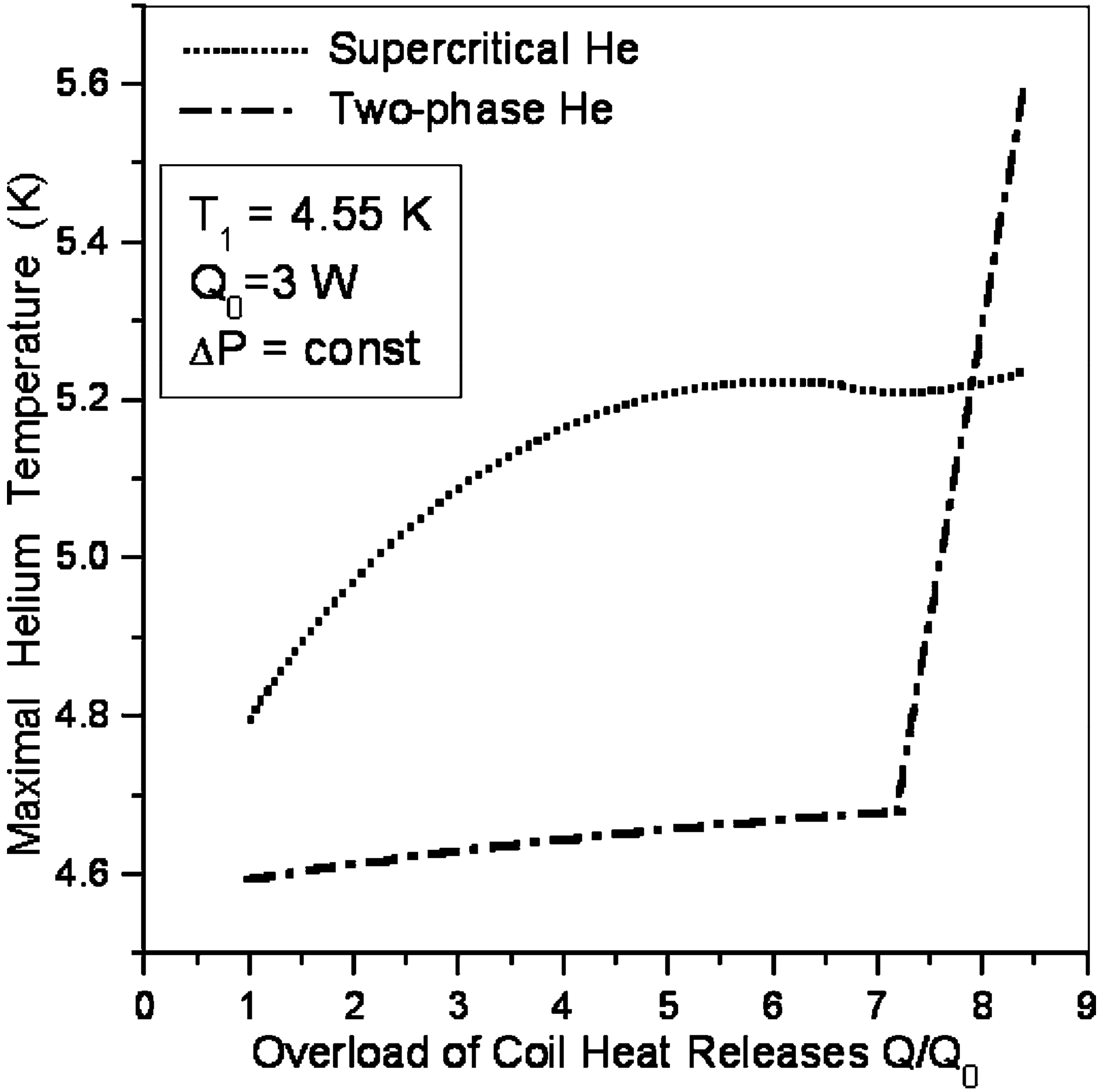
SIS100:

- 6 sectors
- 47 parallel chanels / sector
- 4.7 mm cable inner diameter
- beam vacuum chamber cooled by helium flow

# Conclusions

- SIS100 cooling systems is based on Nuclotron design
- the number of parallel channels is reduced by factor of two
- the phase separation in the coil is not expected
- adjustment of hydraulic resistance has to be performed for each type of cooling channel
- additional valve can be installed on each channel for fine adjustement

# Two Phase vs. Supercritical



# Two-Phase Cooling

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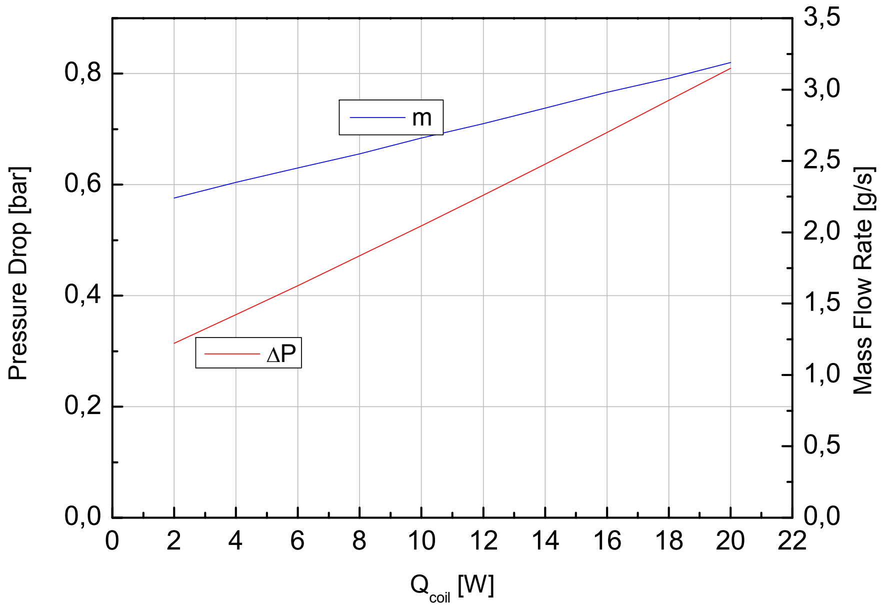
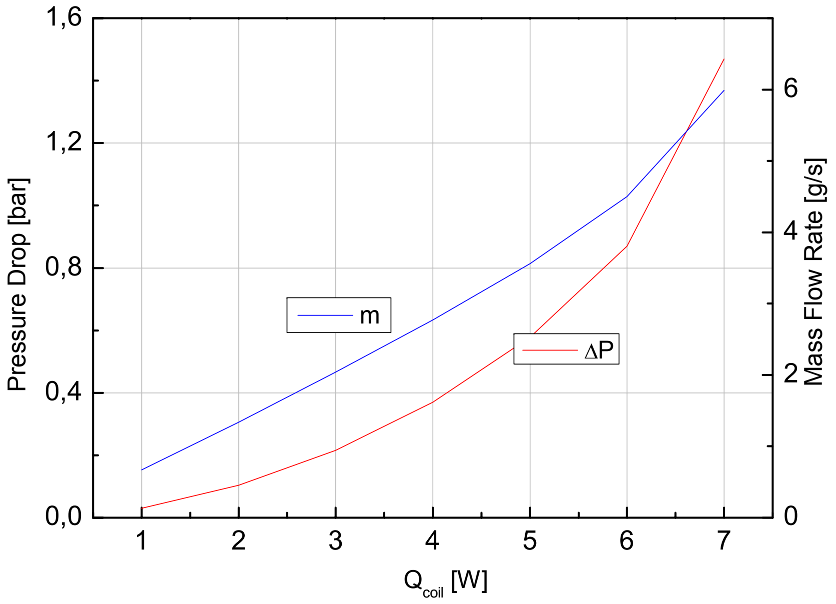
$T_1$ = 4.55 K





Two-Pase Helium:
$P_2$ = 1.1 bar
$X_3$ = 1
$m = (Q_{coil} + Q_{yoke}) / (h_3 – h_1)$

Supercritical Helium:
$P_2$ = 2.3 bar
$T_3$ = 4.7 K
$m = Q_{coil} / (h_2 – h_1)$

# Hydraulic Resistance