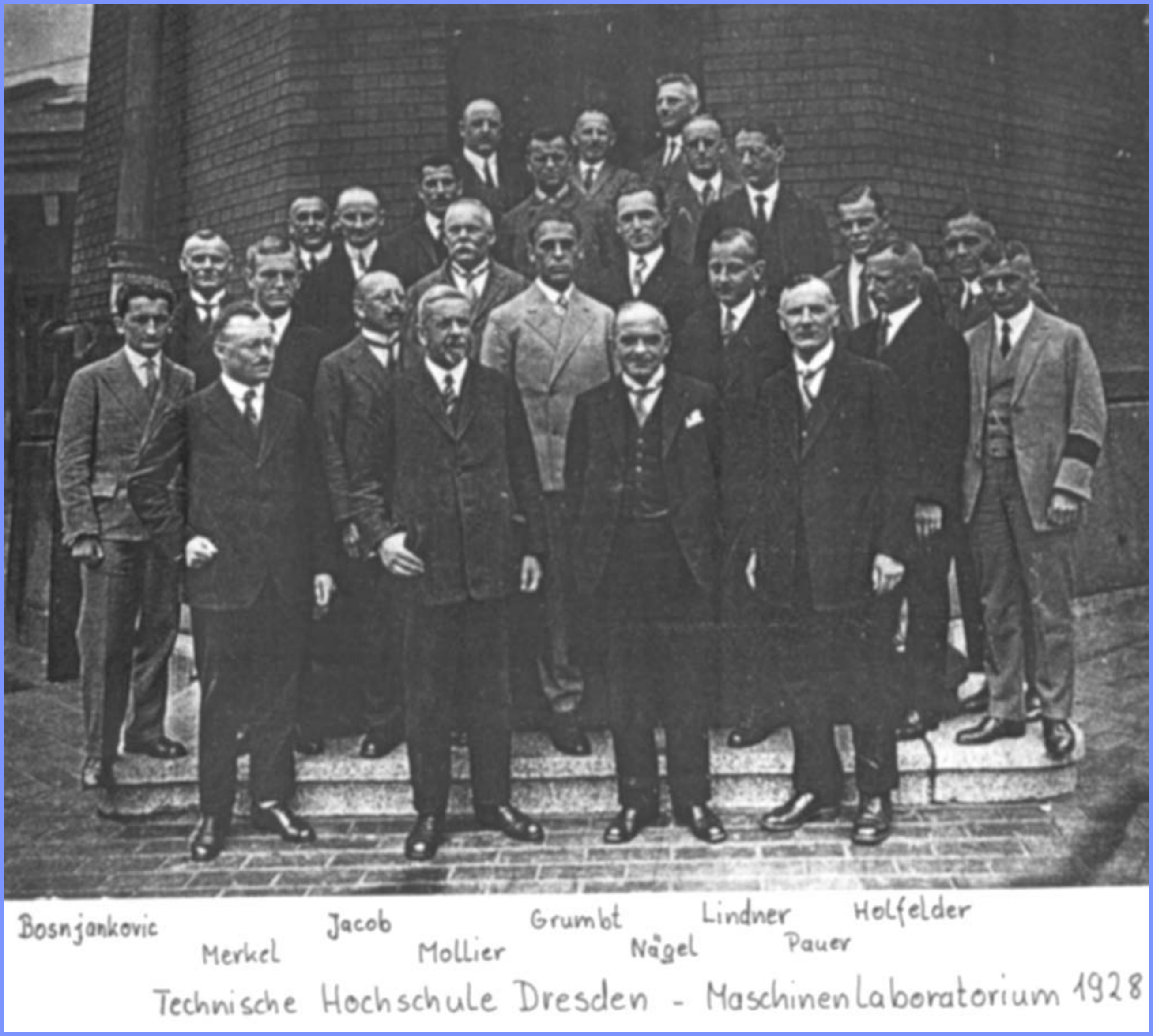
Raffael's Sixtinische Madonna
in der Galerie Alte Meister
in Dresden

Die Neubauten für die Mechanische Abteilung
der Königl. Sächs. Technischen Hochschule zu Dresden
Im Vordergrund das Maschinenlaboratorium


Bosnjankovic
Merkel
Jacob
Mollier
Grumbt
Nägel
Lindner
Pauer
Holfelder
Technische Hochschule Dresden - Maschinenlaboratorium 1928

Maschinenlaboratorium nach der Zerstörung 1945

Cryogenic Engineering

CERN, March 8 - 12, 2004

- Temperature reduction by throttling and mixing
- Temperature reduction by work extraction
- Refrigeration cycles: Efficiency, compressors, helium, hydrogen
- Cooling of devices

Applications of Superconducting Magnets

- Energy technology
  - Fusion reactor
  - MHD generator
  - Turboalternator
  - Tranformer
  - Fault current limiter
  - Magnetic energy storage (SMES)

Mobility

- Levitated train
- MHD ship propulsion

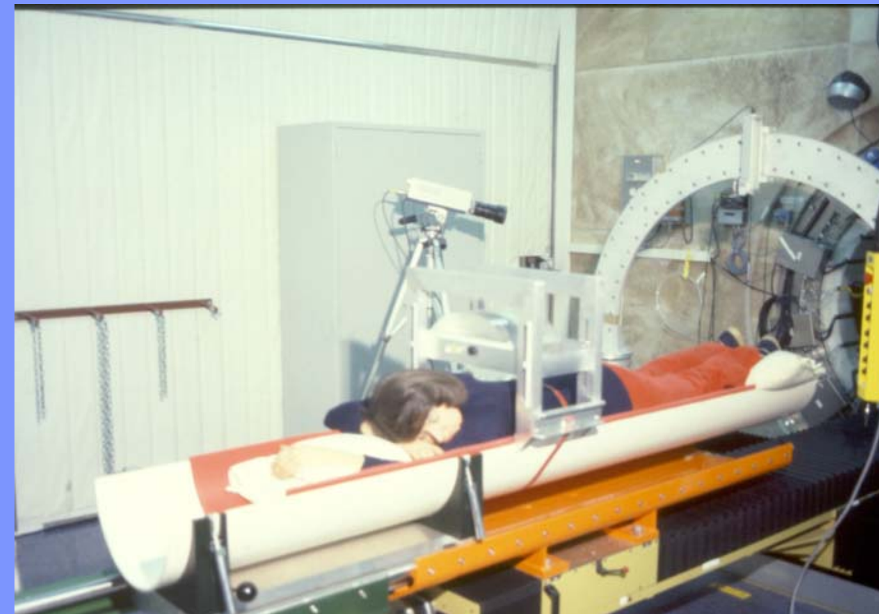
Medicine

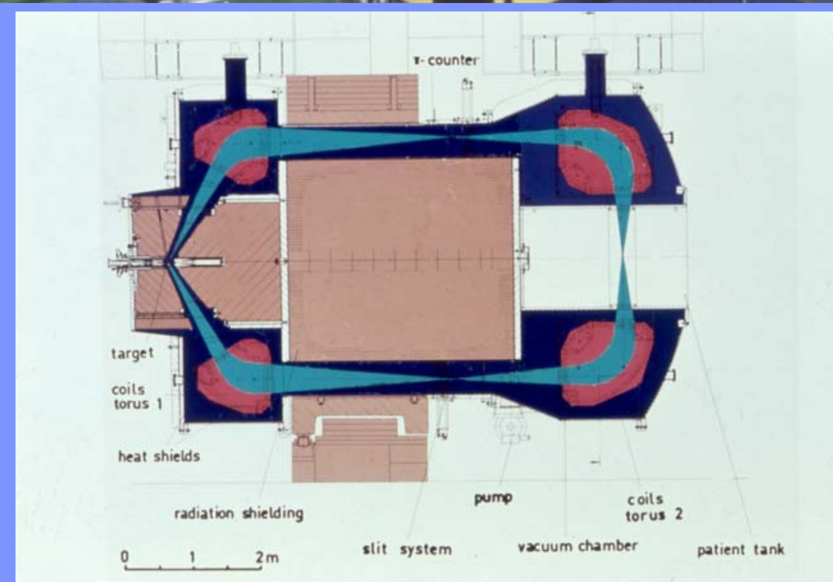
- Magnetic tomography
- Radiation treatment

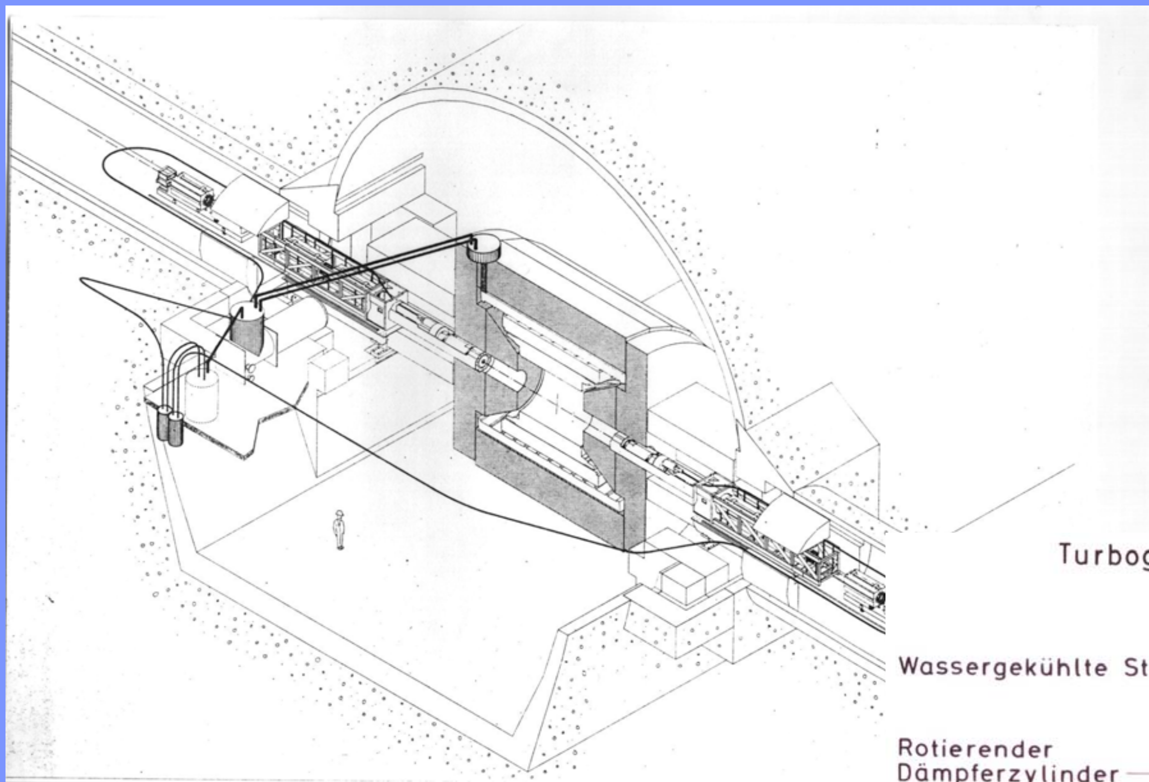
Research

- Accelerators
- Detectors
- Spectrometers
- Gyrotrons

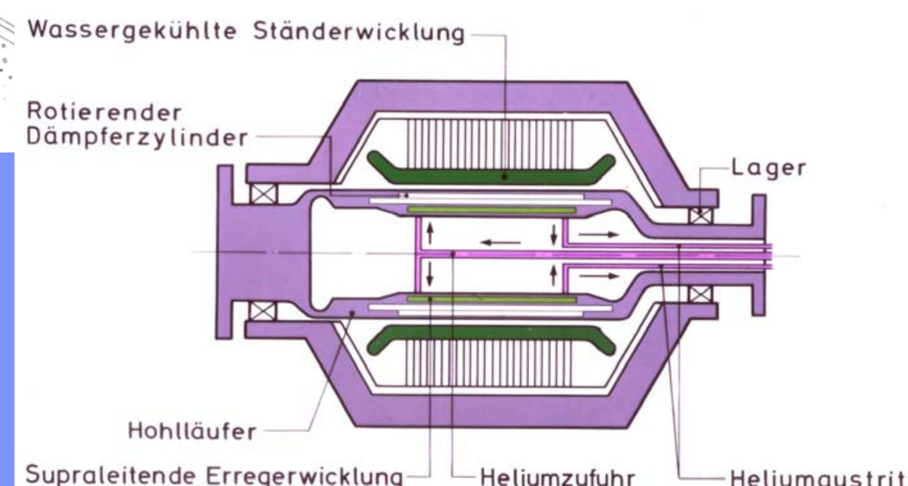

SIEMENS
MAGNETOM




γ- counter
target
coils
torus 1
heat shields
radiation shielding
pump
coils
torus 2
0
1
2 m
slit system
vacuum chamber
patient tank



Turbogenerator mit supraleitender Feldspule (schematisch)



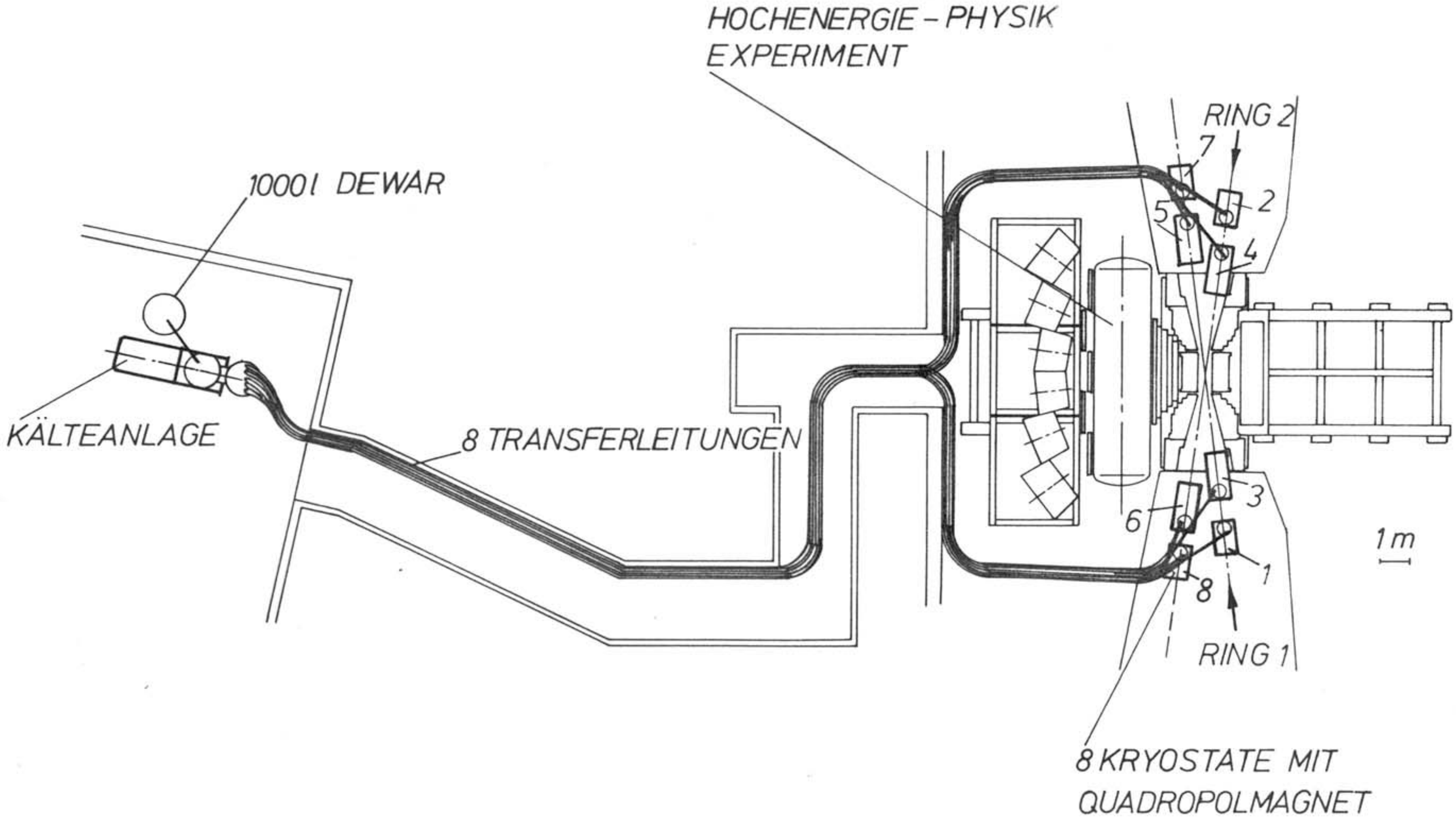
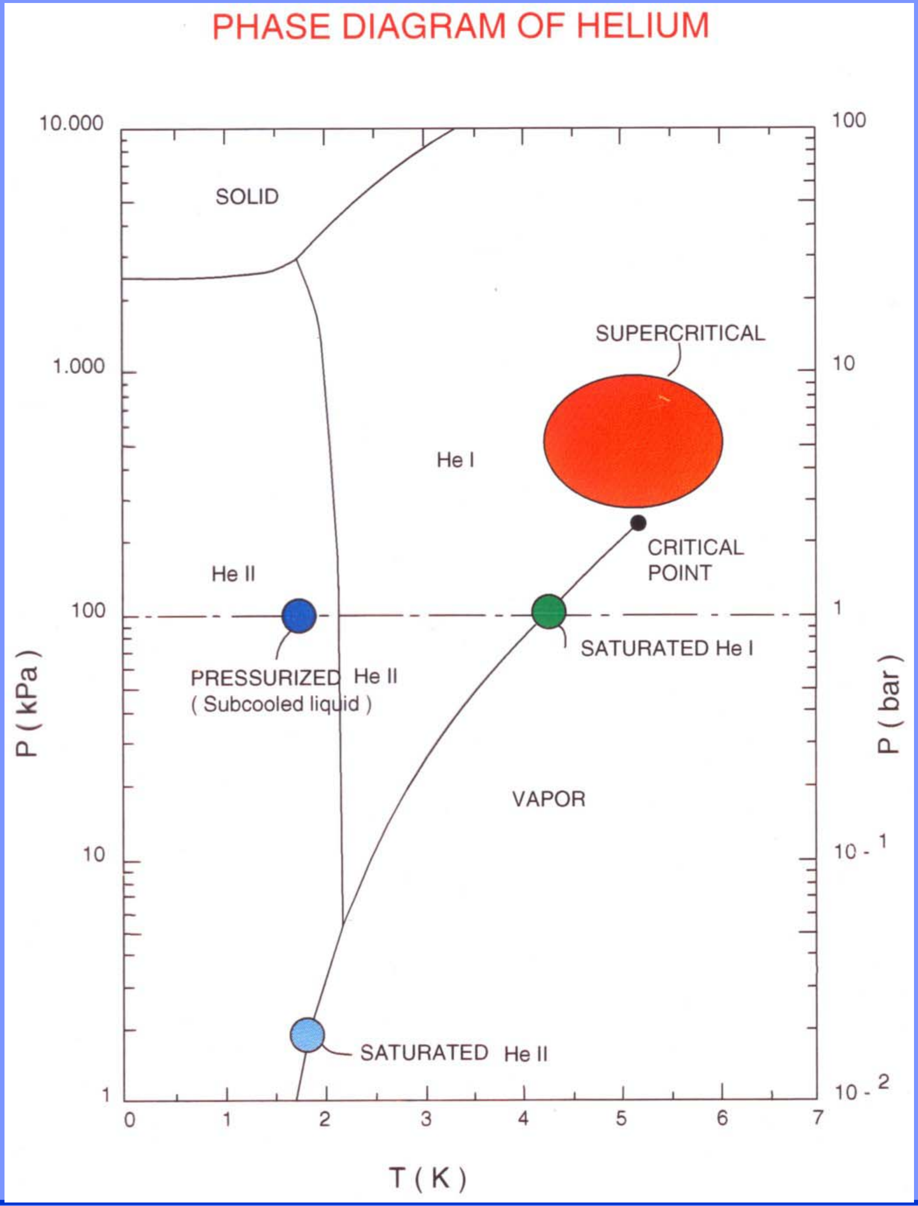


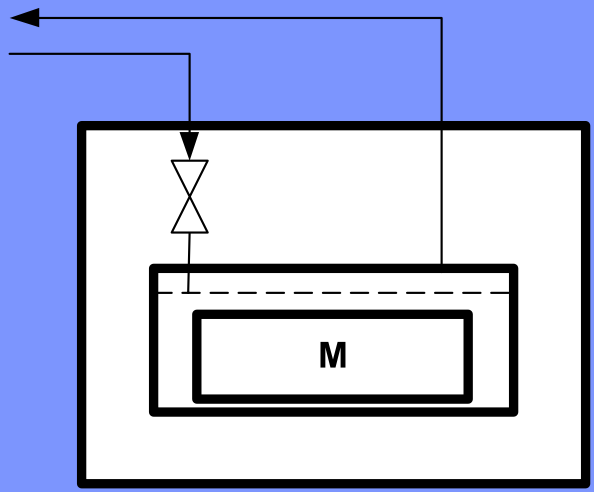
BILD 2.2 INTERSEKTION 8 DES ISR - SPEICHERRINGS



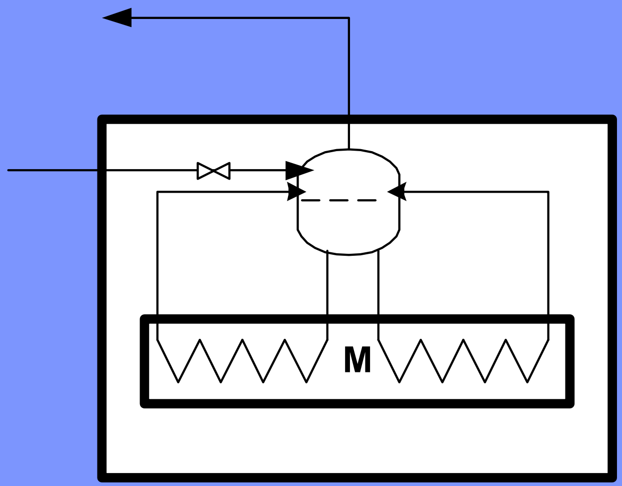
Cooling options with Helium

Cooling Options for Superconducting Magnets

Bath Cooling

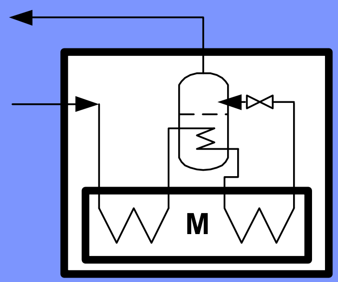


Bath Cooling

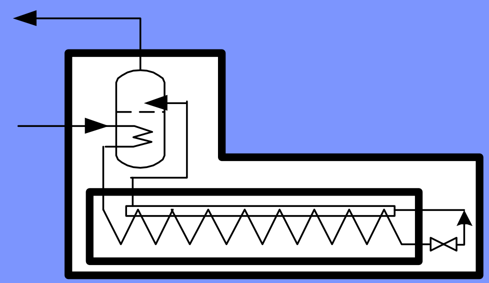


Bath Cooling with Thermosiphon

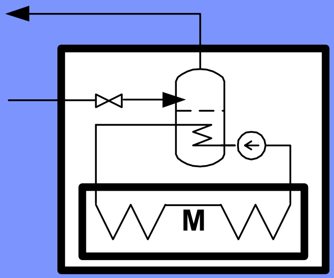
Forced Cooling: One-phase



One-phase with JT-Stream

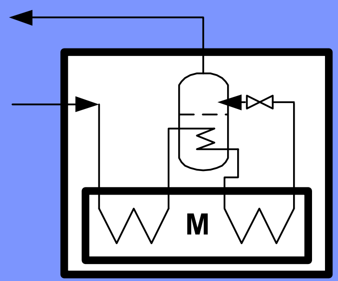


One-phase with Continuous Recooling

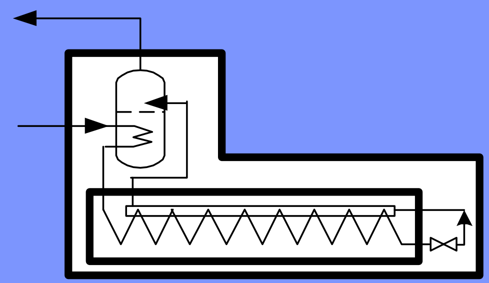


One-phase with Circulation Pump

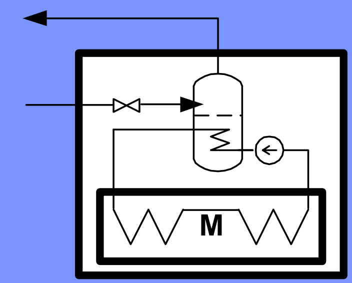
Forced Cooling: One-phase



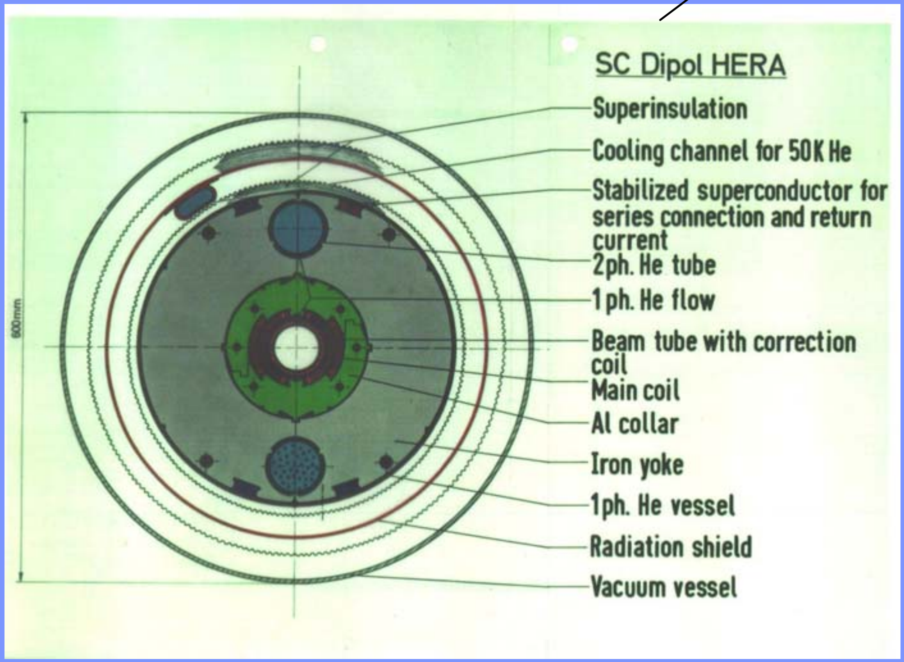
One-phase with JT-Stream

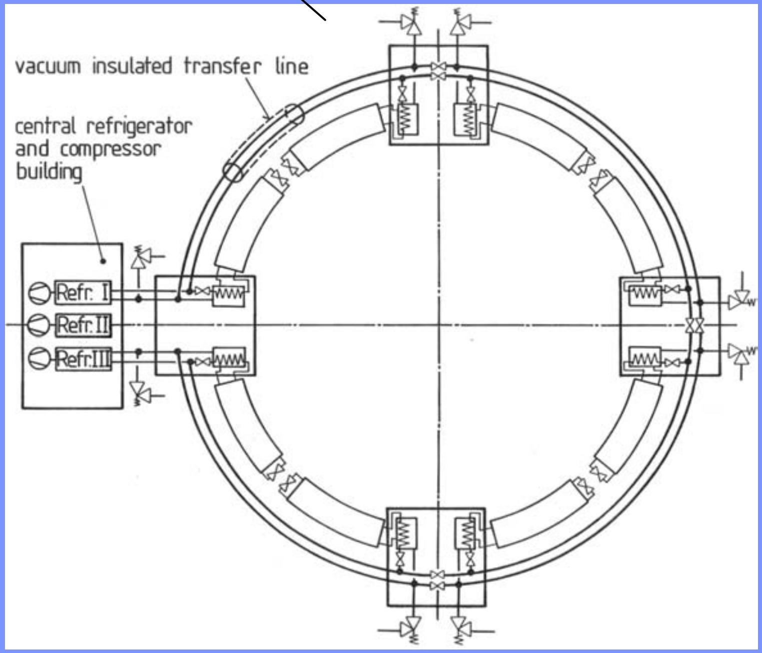


One-phase with Continuous Recooling

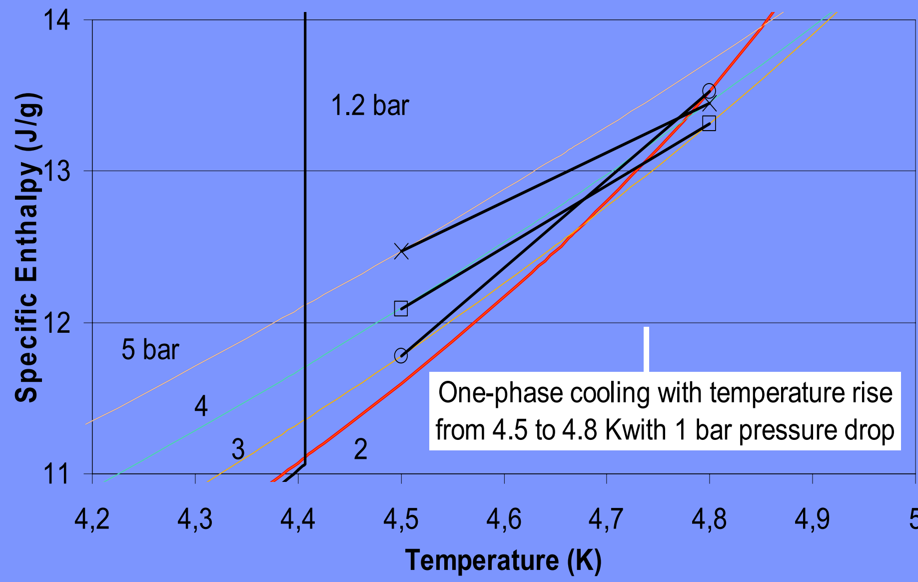


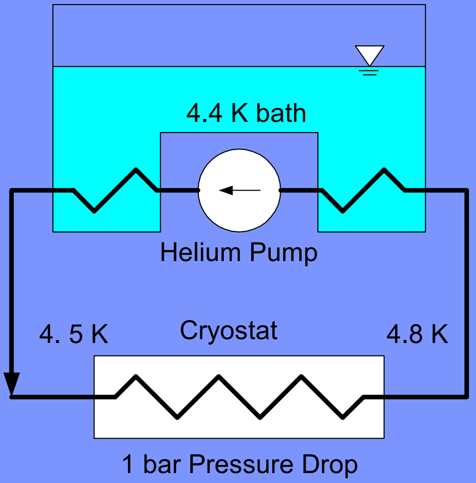
One-phase with Circulation Pump





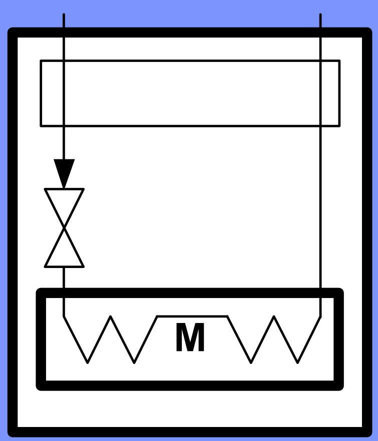
Forced Flow Supercritical Cooling with Pressure Drop



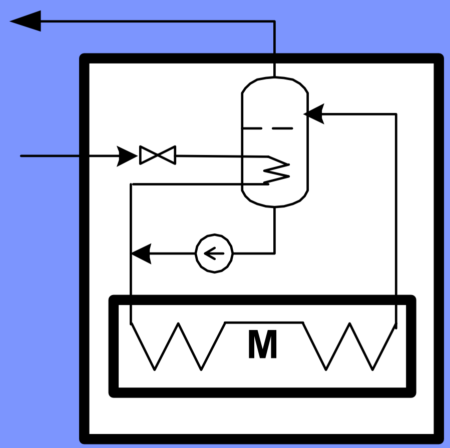


Pressure Drop	Enthalpy rise	Pump work	Ratio
	J/g	J/g	
5 - 4 bar	0,98	0,74	1,3
4 - 3 bar	1,22	0,77	1,6
3 -2 bar	1,75	0,80	2,2

Forced Cooling: Two-phase with Low Quality Outlet

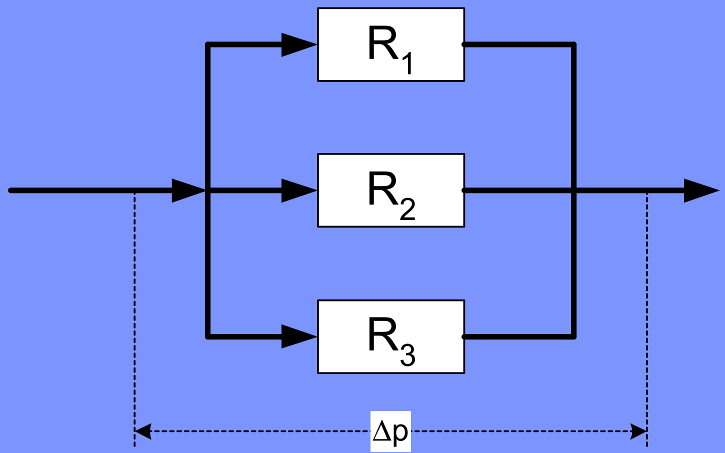


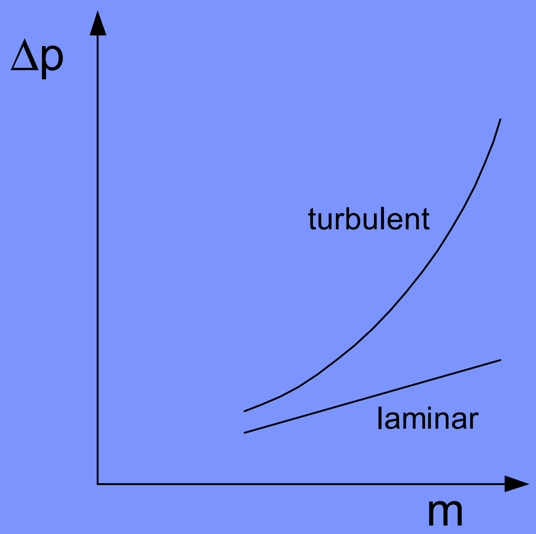
Residual Evaporation
in Heat Exchanger



With Liquid
Recirculation Pump

The maldistribution problem with parallel cooling channels



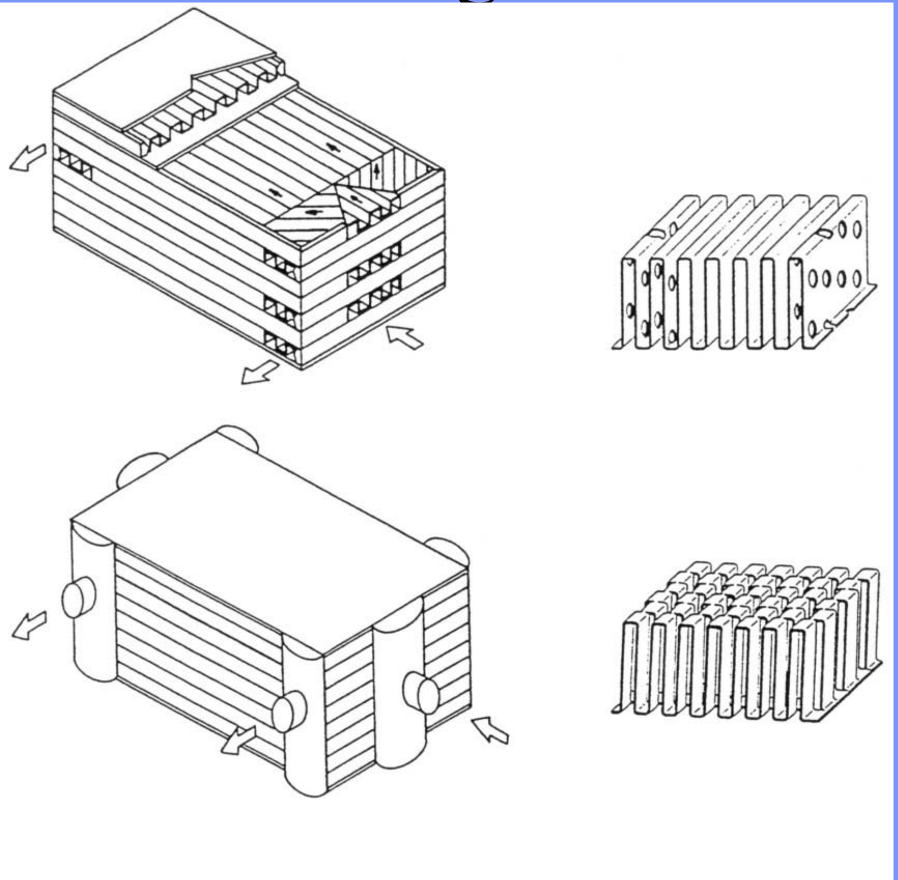


Parallel cooling channels share the same pressure drop. If one channel takes more coolant flow, all others get less.

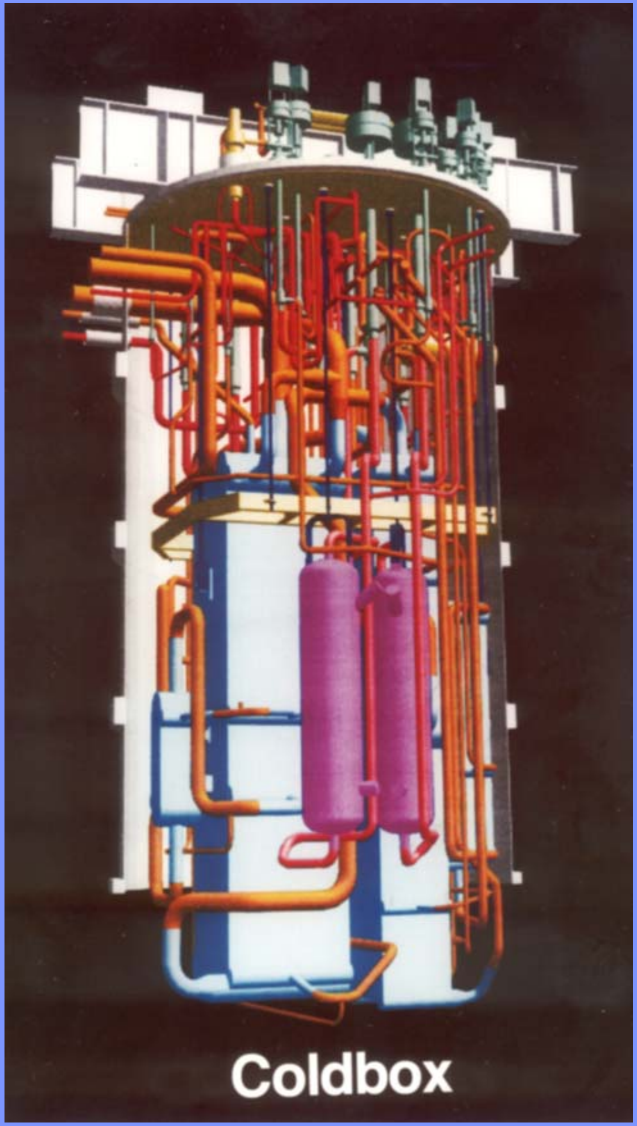
One-phase turbulent flow gives a stable distribution.

One phase laminar flow is less stable, depends on orientation.

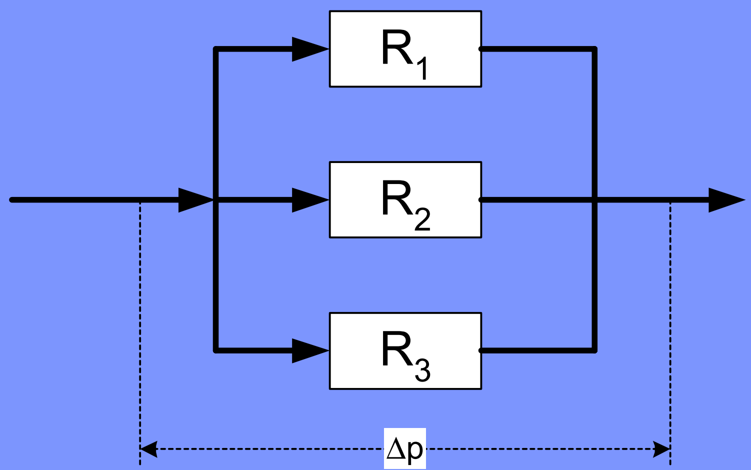
Multi-channel plate-fin heat exchangers

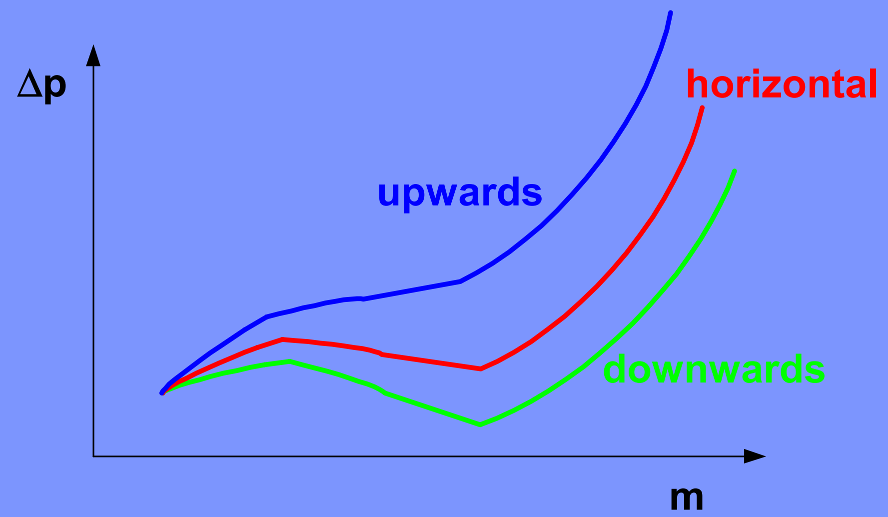


Aufbau von Plate-Fin-Wärmeaustauschern und wichtigste Rippentypen (Linde)



The maldistribution problem with parallel cooling channels with two-phase flow



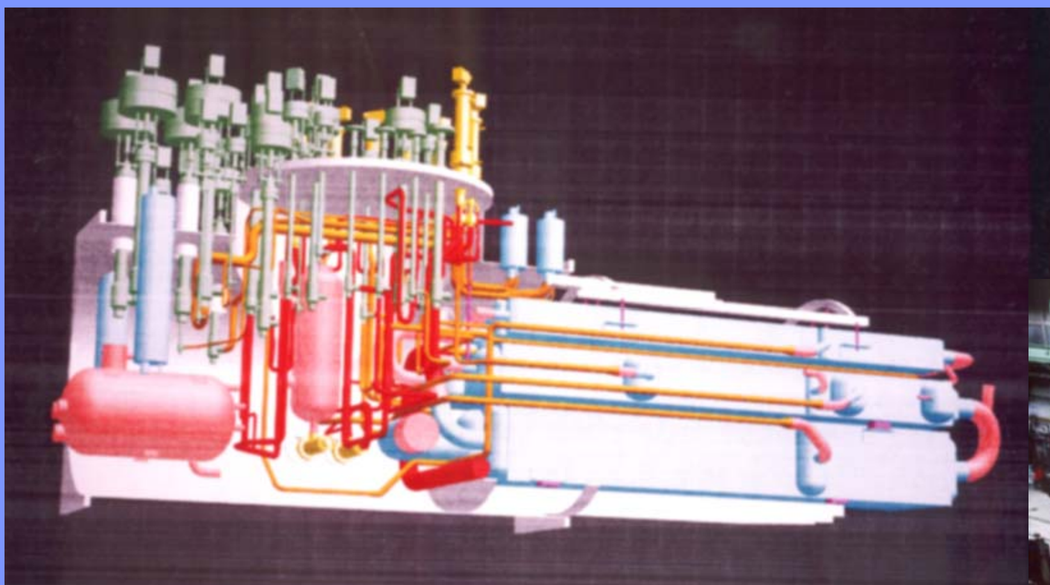


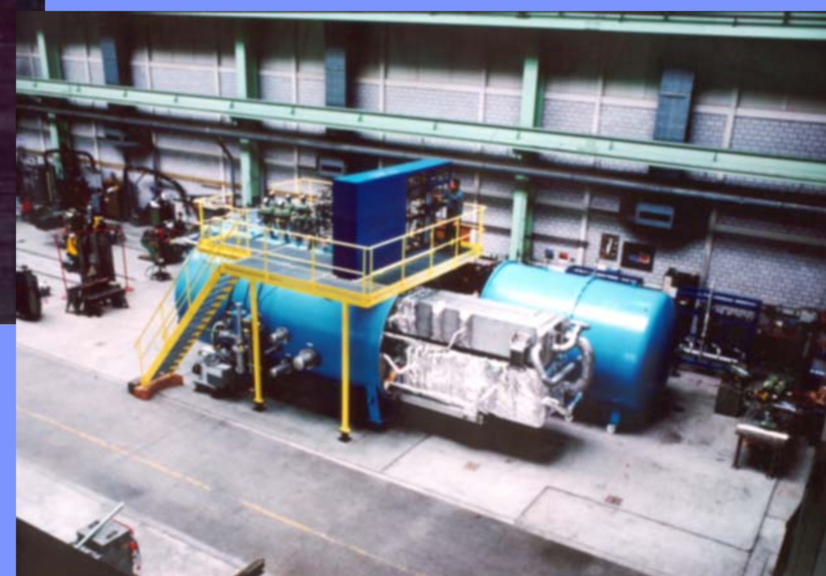
If the flow is upwards, the flow distribution is probably stable.

If the channels are horizontal, the distribution is poor, if the vapour content is too high.

If the flow is downward, the distribution is certainly poor: One channel will take the liquid and the others only get vapour.

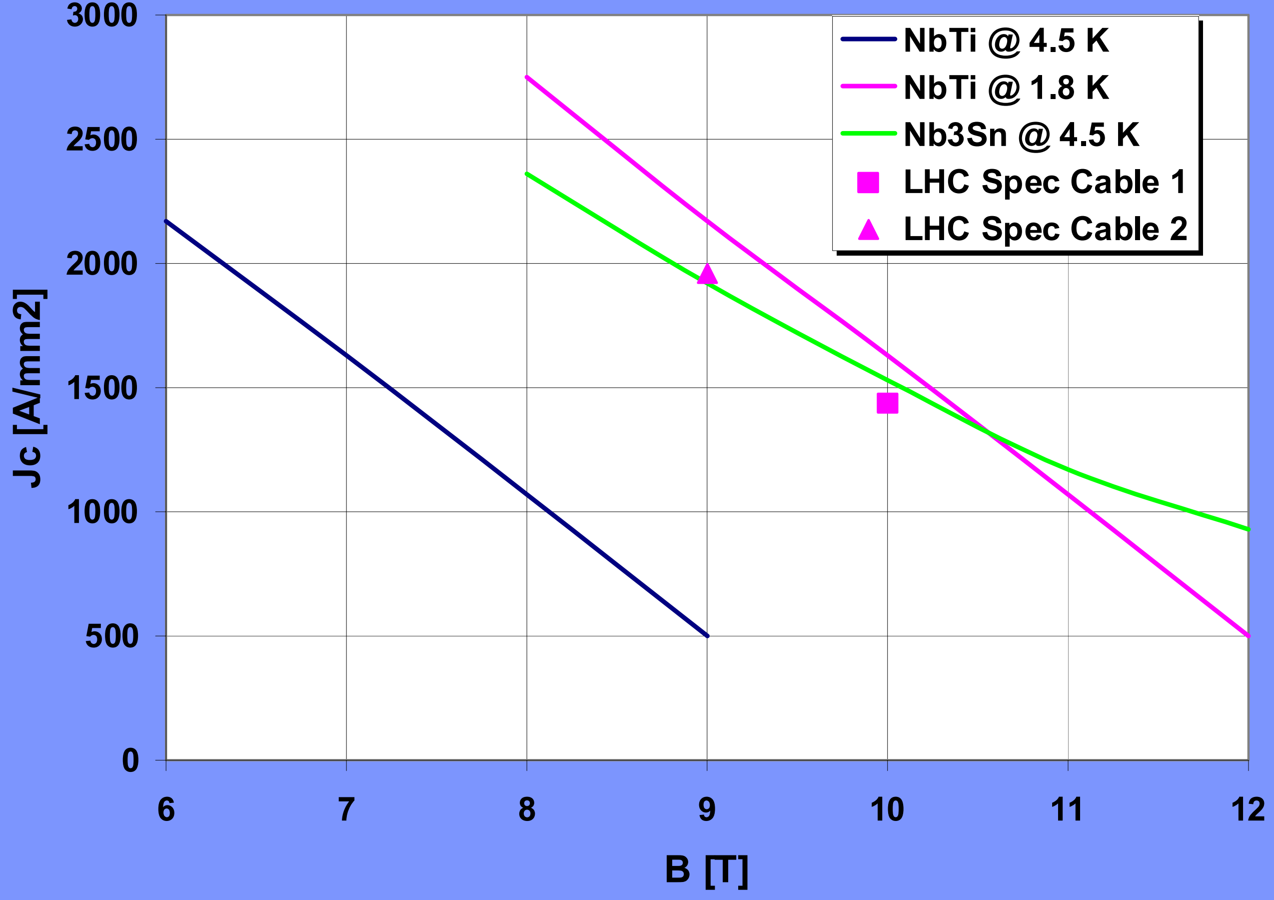
Coldbox with horizontal multi-channel heat exchangers



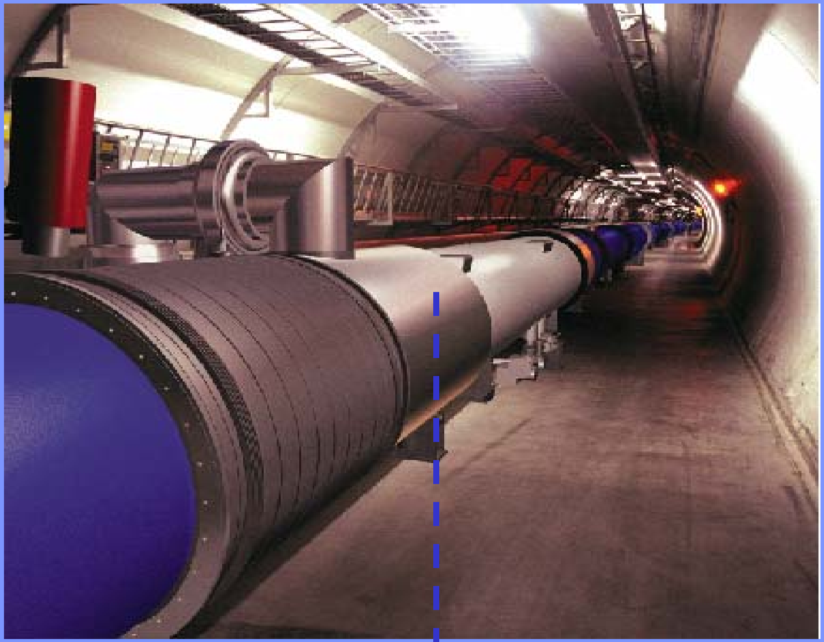


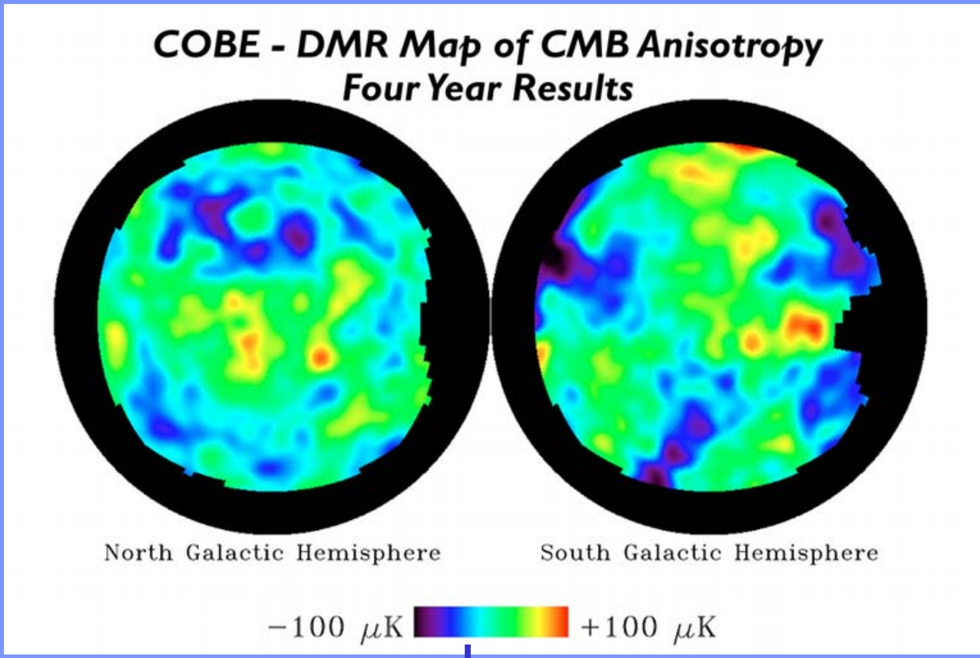
Flow distribution in exchangers is acceptable in the warm section, but has failed sometimes in the Joule-Thomson exchanger.

Critical Current Density of Technical Superconductors



Superfluid Helium Cooled Magnets





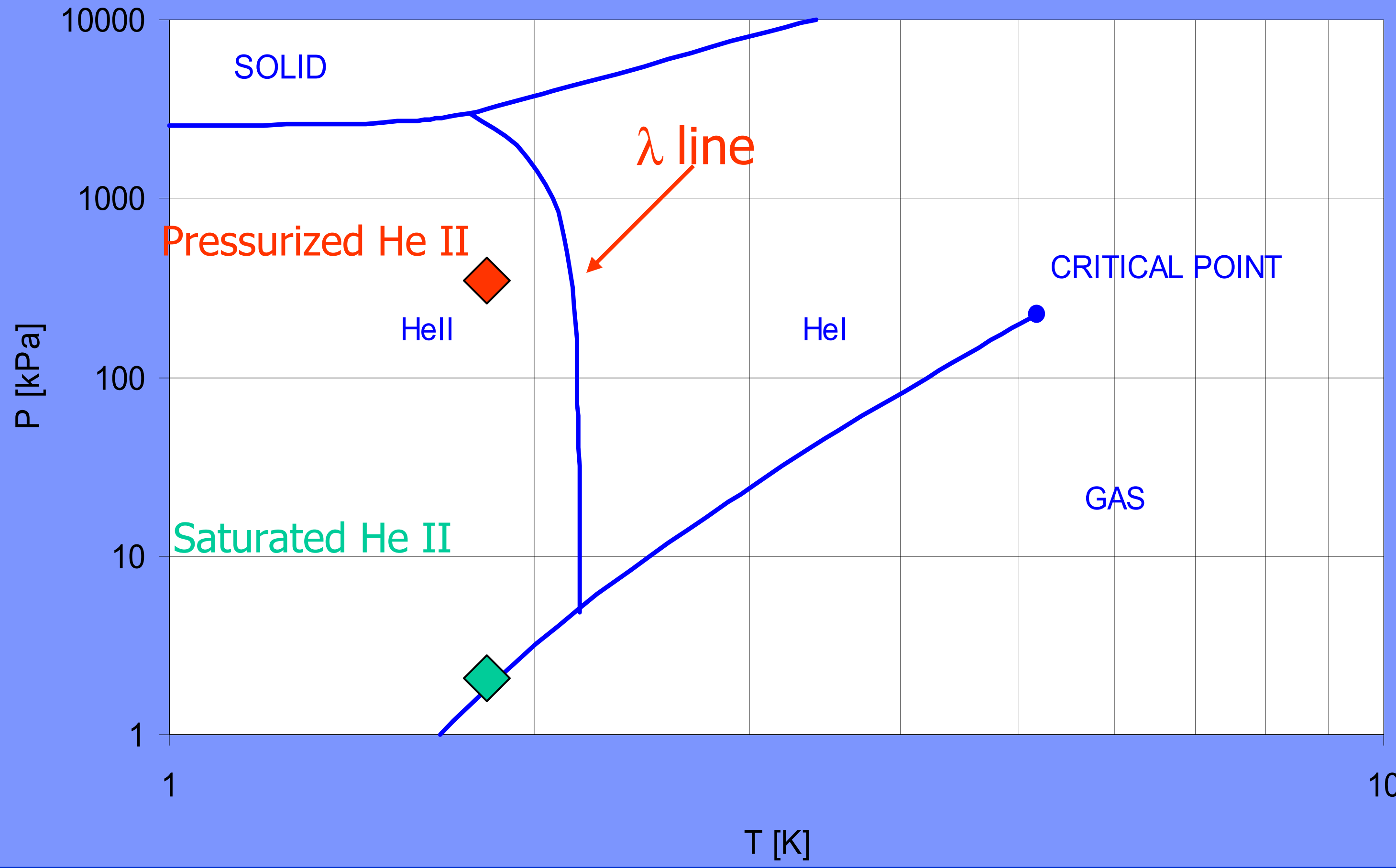
T

1.9 K

2.728 K

The coldest ring in the universe!

Phase Diagram of Helium



Superfluid Helium as a Magnet Coolant

- **Temperature below 2.17 K**
- **Low bulk viscosity**
- **Very large specific heat**
  - 10^5 times that of the conductor per unit mass
  - 2×10^3 times that of the conductor per unit volume
- **Very high thermal conductivity**
  - 10^3 times that of cryogenic-grade OFHC copper
  - peaking at 1.9 K
  - still, insufficient for long-distance heat transport

Equivalent Thermal Conductivity of He II

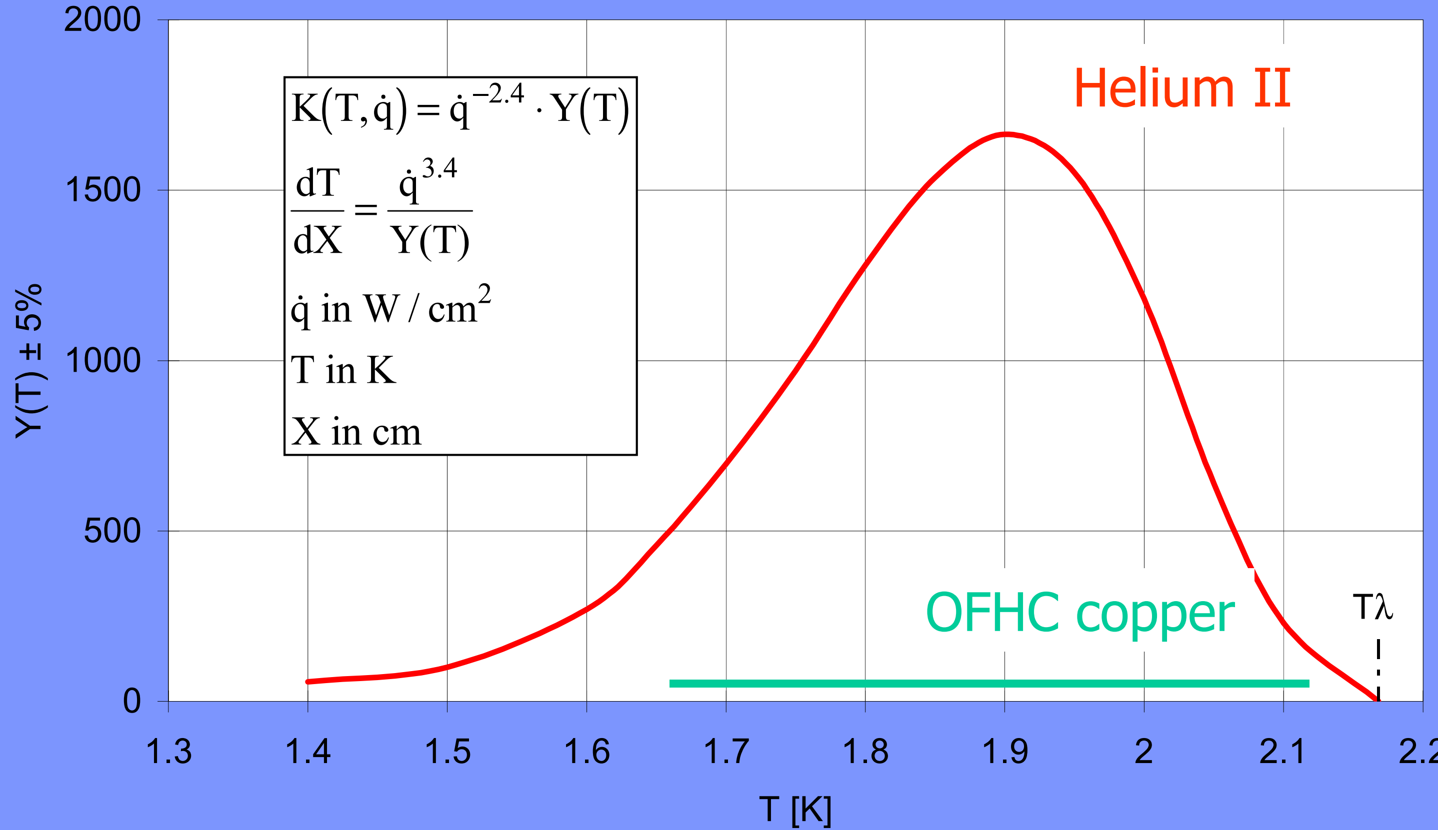
$$K(T,\dot{q}) = \dot{q}^{-2.4} \cdot Y(T)$$

$$\frac{dT}{dX} = \frac{\dot{q}^{3.4}}{Y(T)}$$

$\dot{q}$ in W/cm^2

T in K

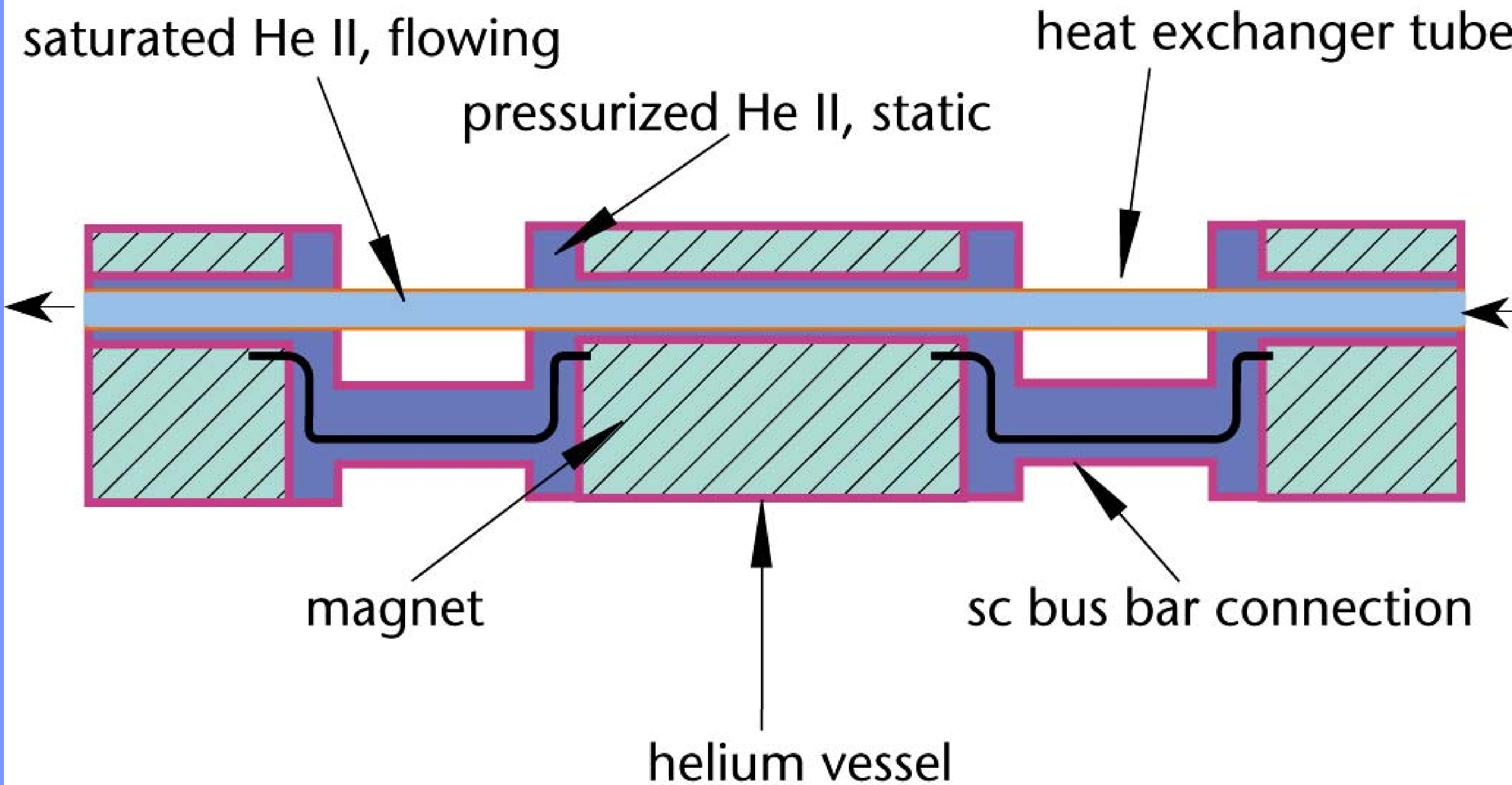
X in cm



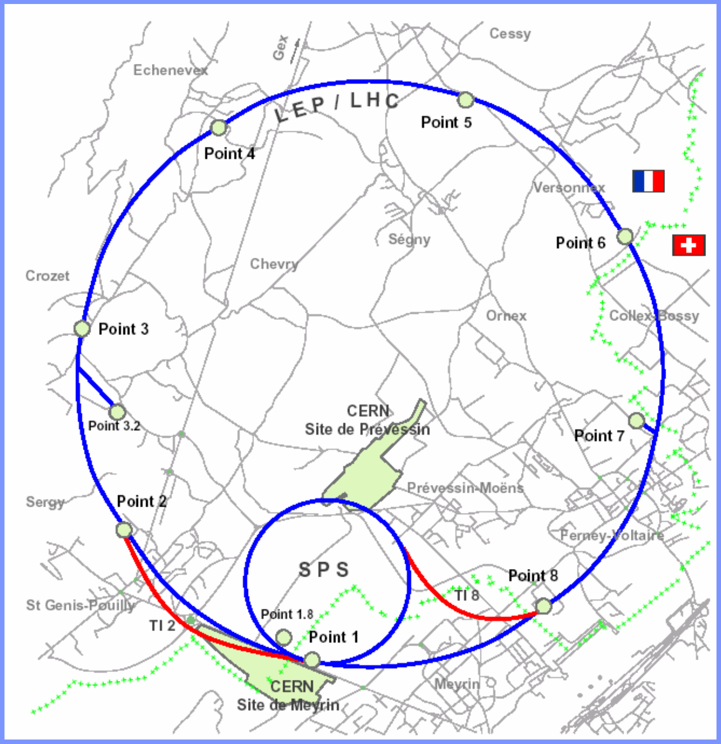
Pressurised vs. Saturated Superfluid Helium

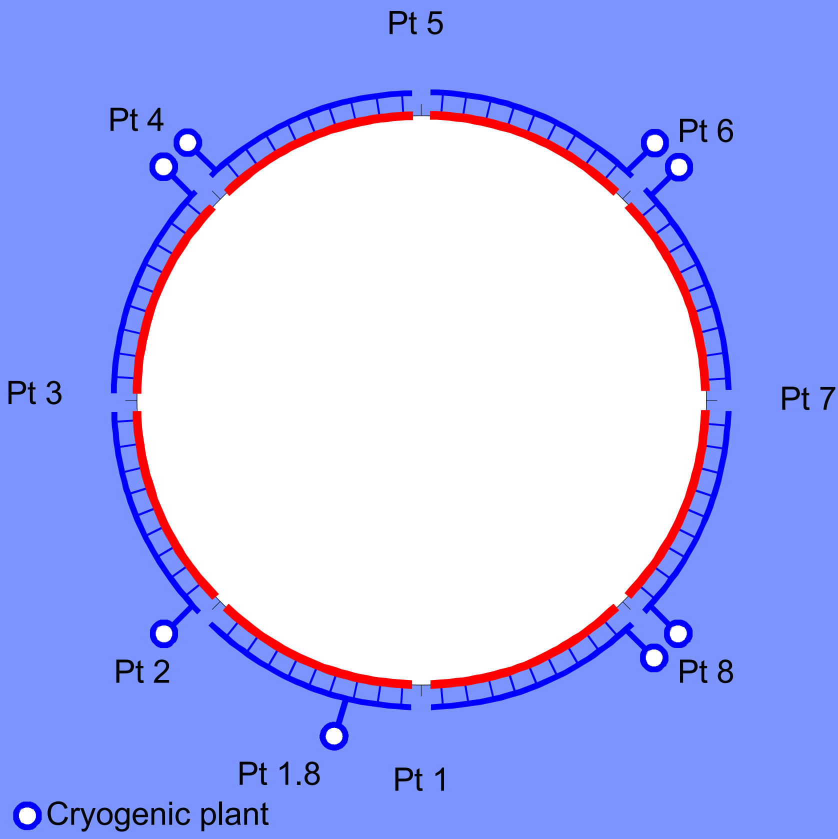
+ Mono-phase (pure liquid)
+ Magnet bath at atmospheric pressure
  - no air inleaks
  - higher heat capacity to the lambda line
+ Avoids bad dielectric strength of low-pressure gaseous helium
– Requires additional heat exchanger to saturated helium heat sink

LHC magnet string cooling scheme

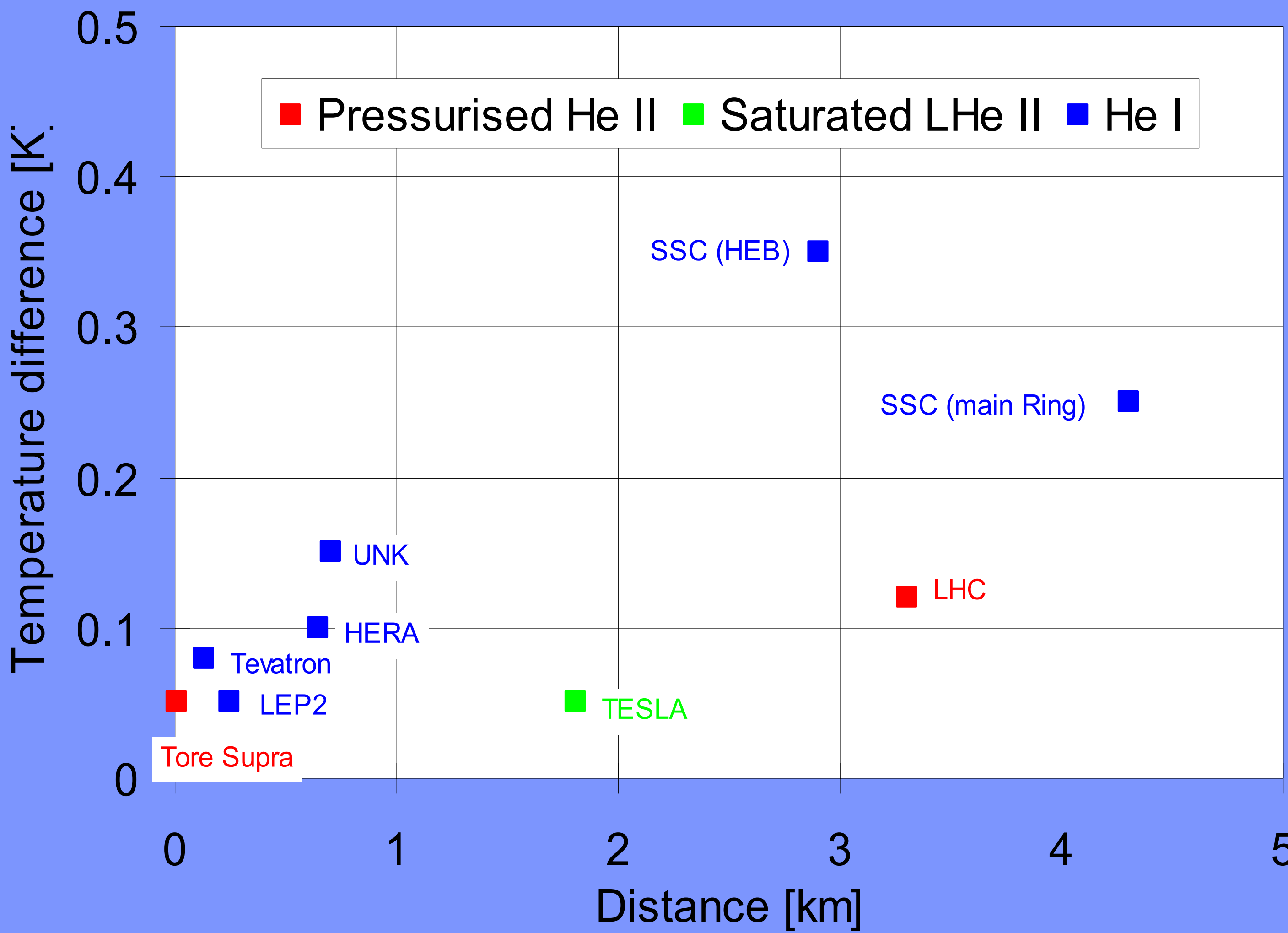


Map of LHC
& General Layout of Cryogenic System

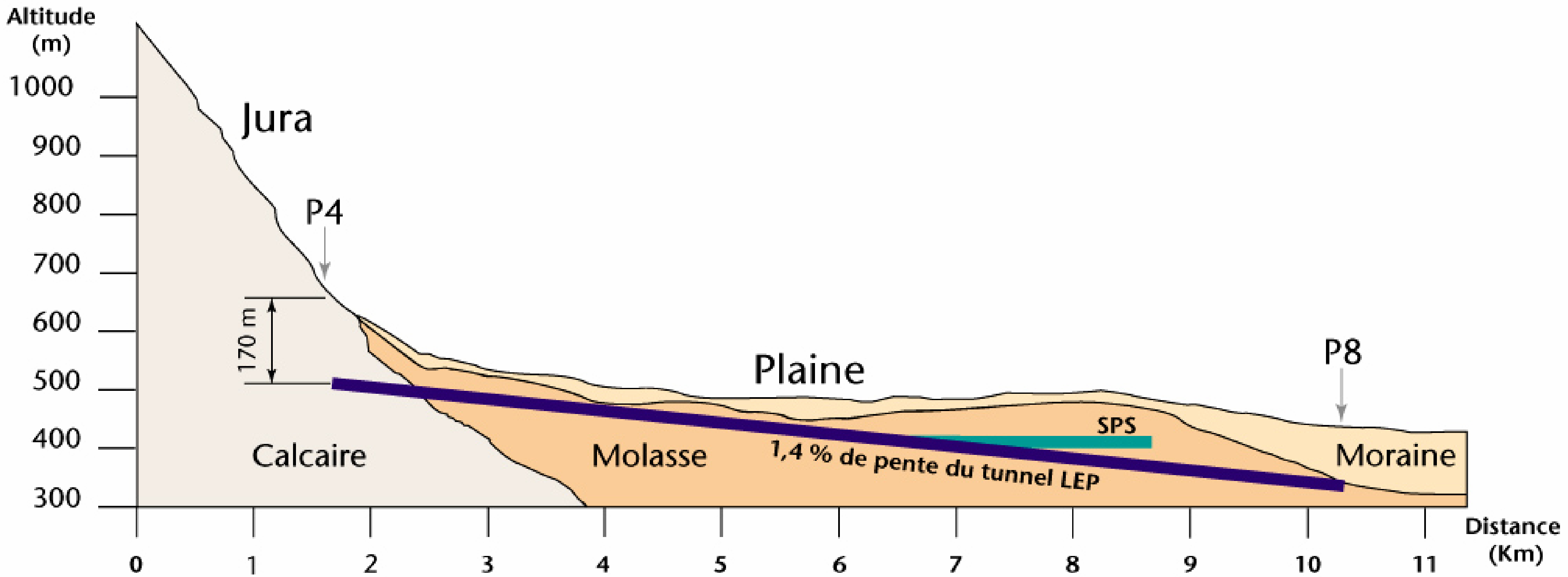




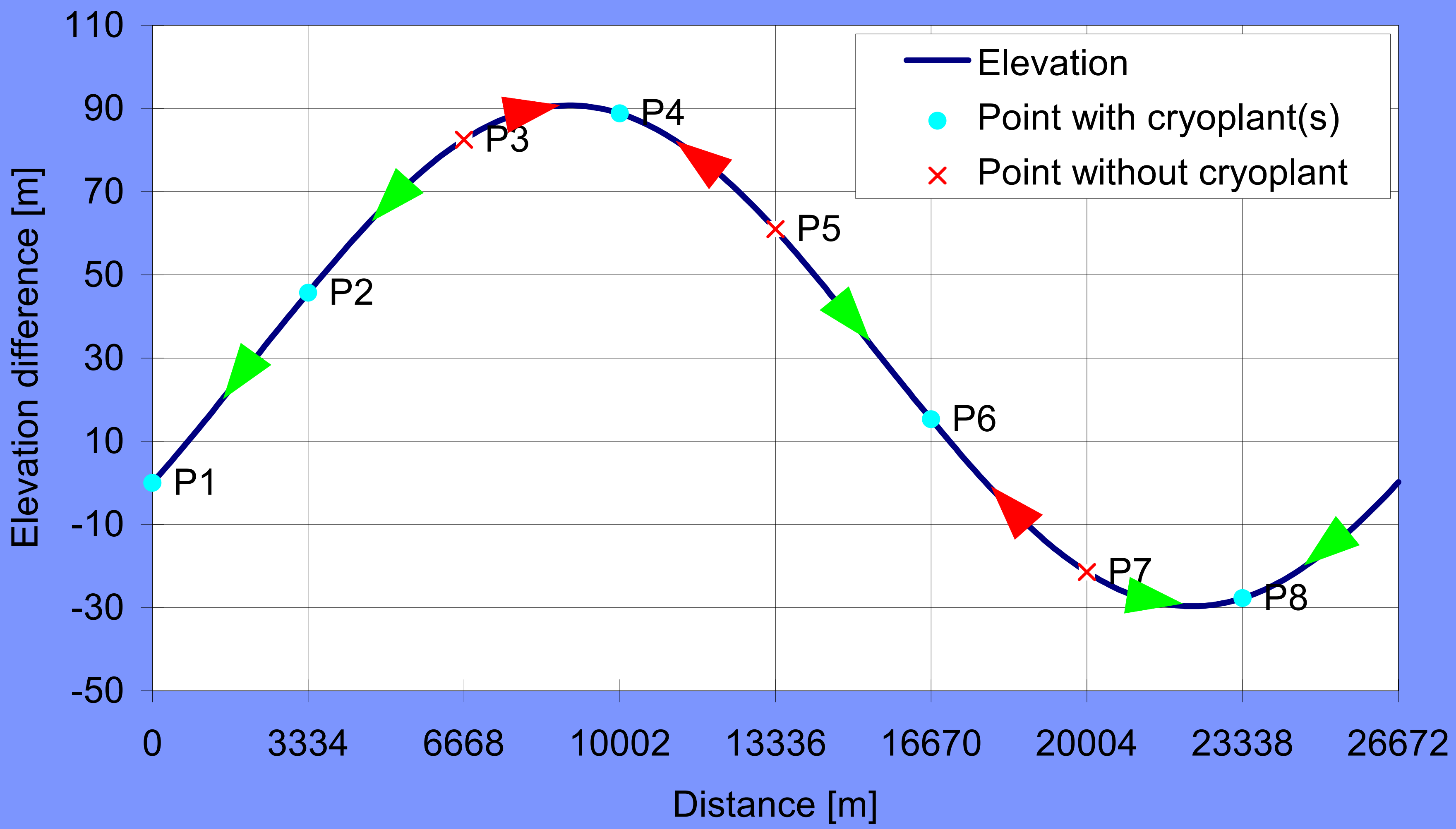
Transport of Refrigeration in Large Distributed Cryogenic Systems

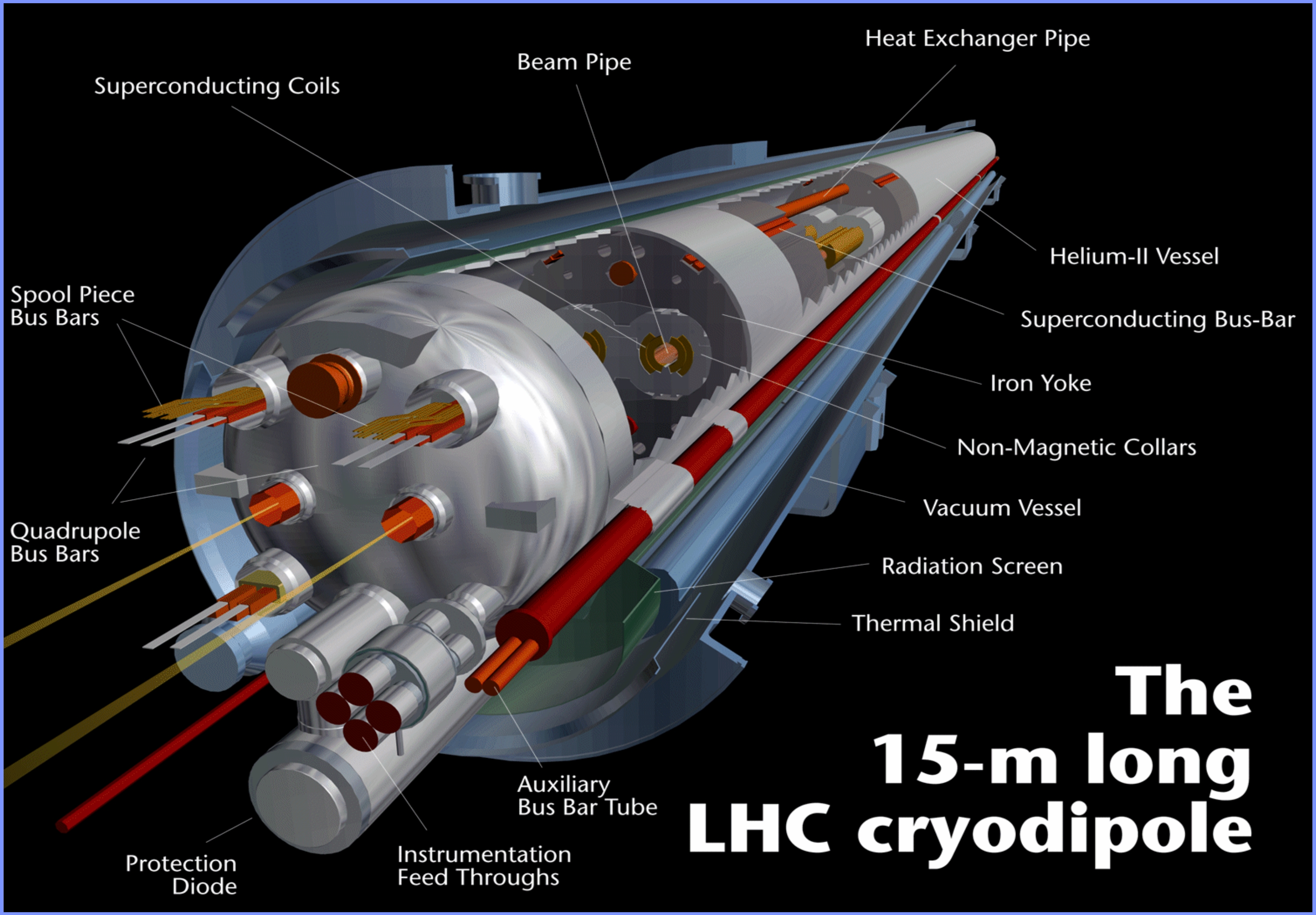


Simplified Geological Section of LHC Tunnel



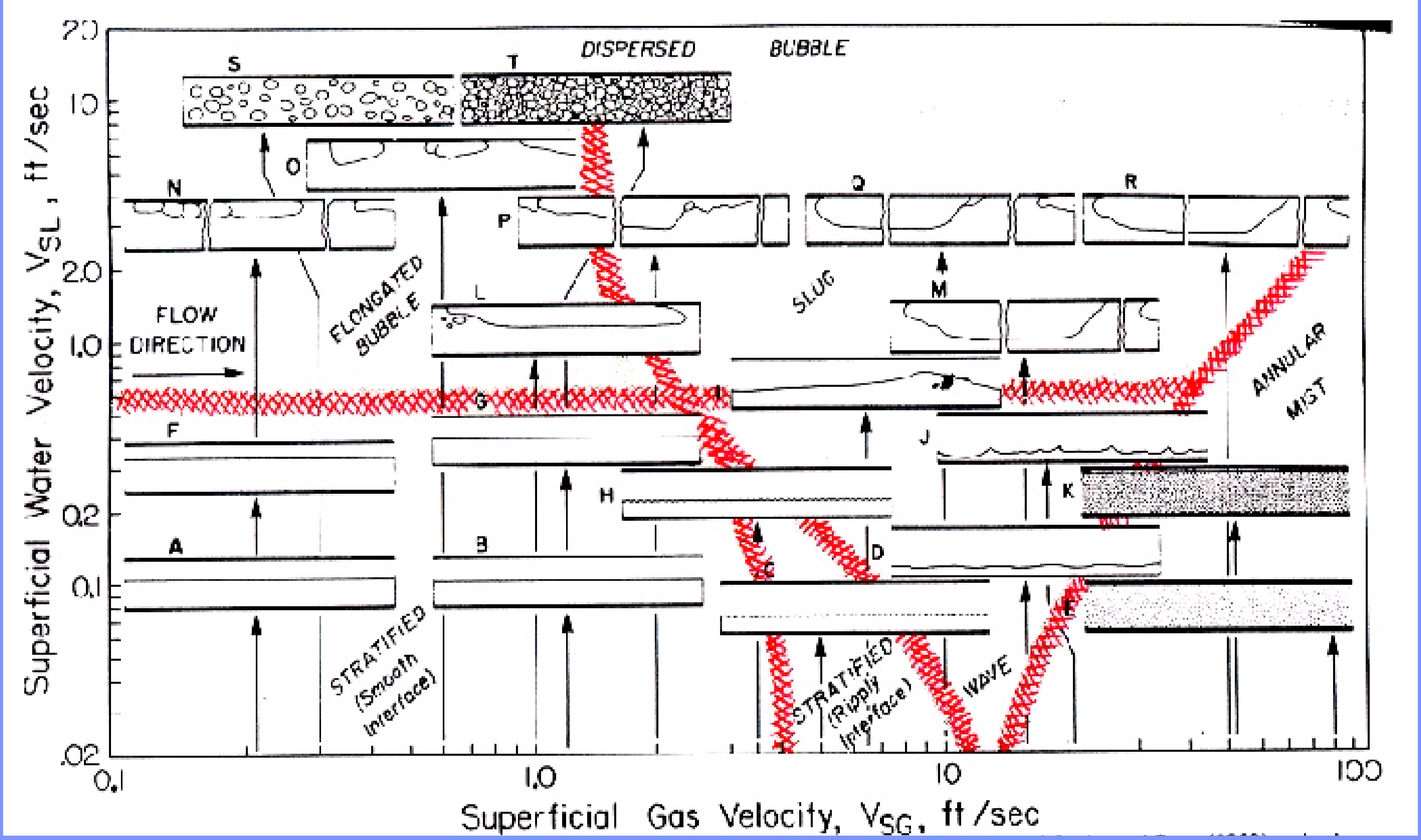
Elevation Difference along LHC Tunnel





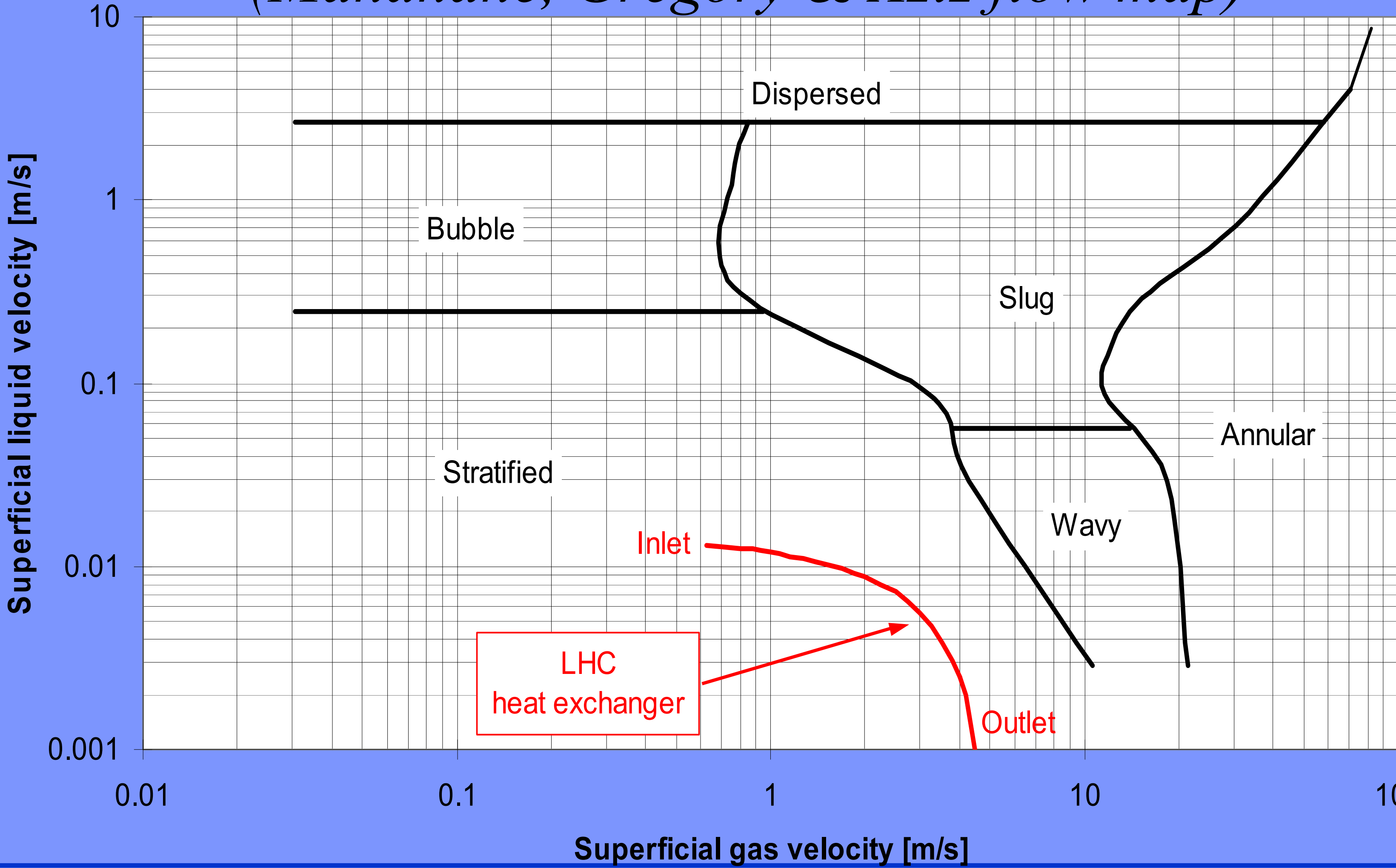
Heat Exchanger Pipe
Beam Pipe
Superconducting Coils
Helium-II Vessel
Spool Piece
Bus Bars
Superconducting Bus-Bar
Iron Yoke
Non-Magnetic Collars
Vacuum Vessel
Quadrupole
Bus Bars
Radiation Screen
Thermal Shield
The
15-m long
LHC cryodipole
Auxiliary
Bus Bar Tube
Protection
Diode
Instrumentation
Feed Throughs

Patterns in Quasi-horizontal Two-phase Flow

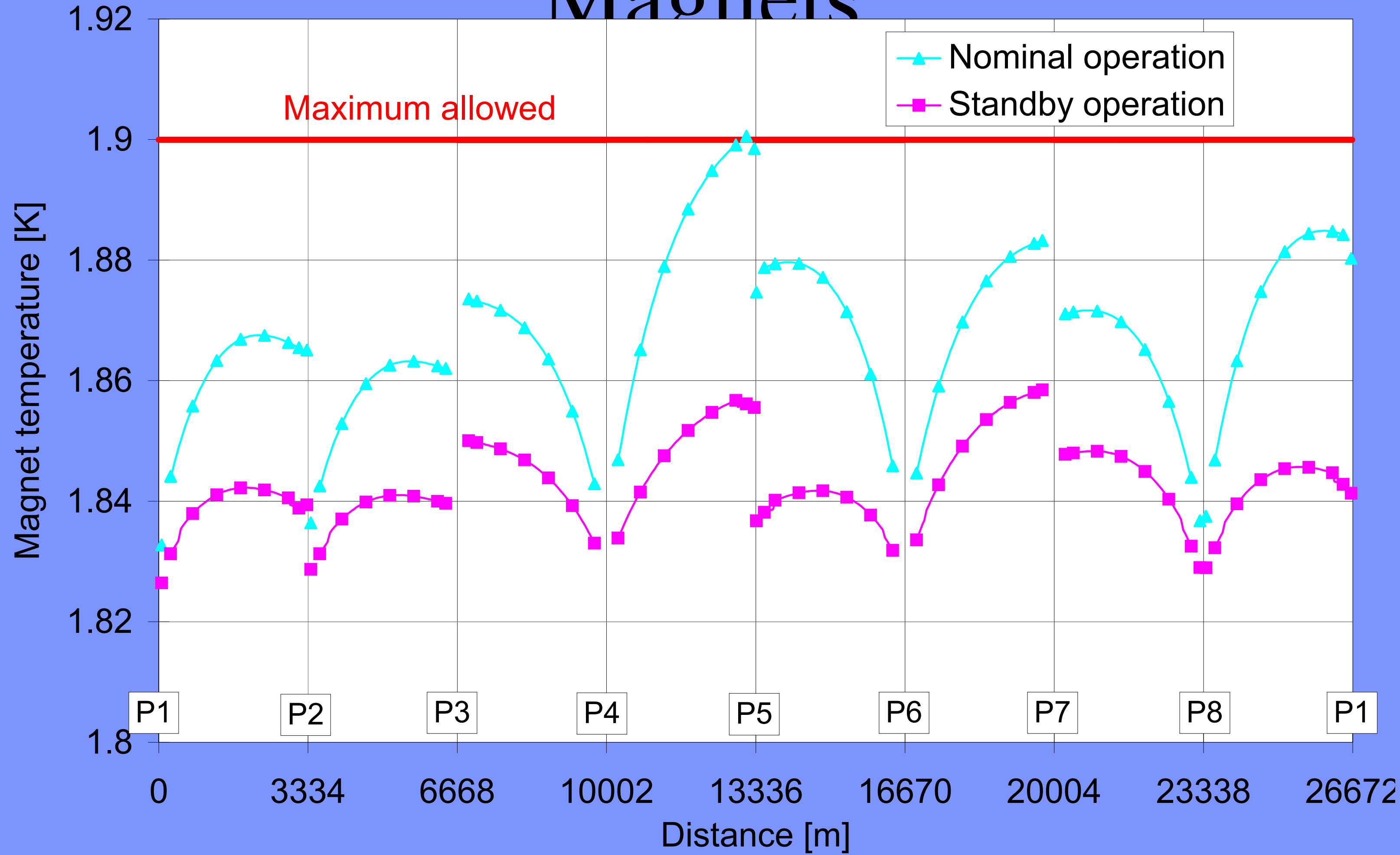


Two-phase Flow of Saturated He II

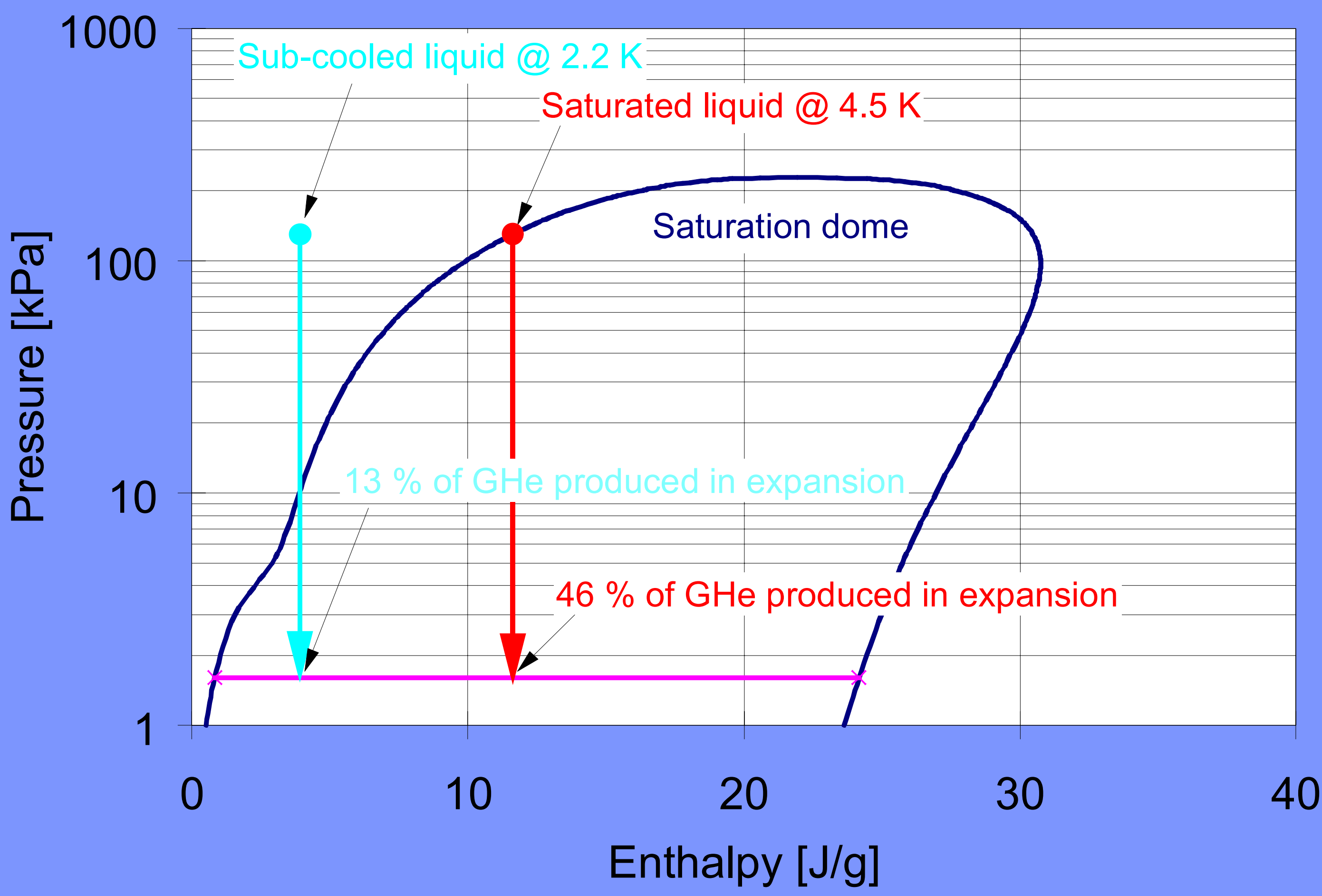
(Mandhane, Gregory & Aziz flow map)



Calculated Temperature Profiles of LHC Magnets



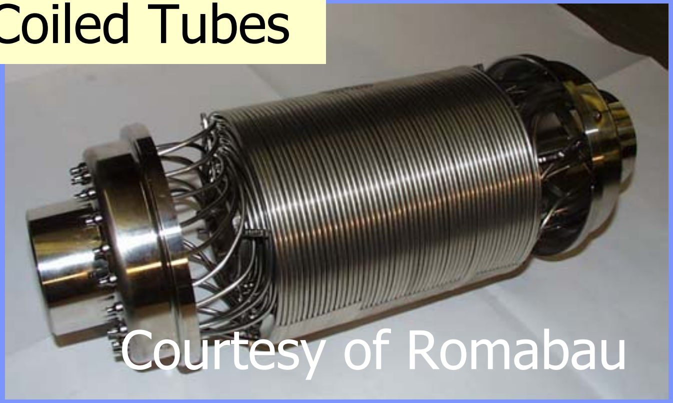
He Subcooling Boosts J-T Expansion



Prototype Subcooling Heat Exchangers

Mass-flow: 4.5 g/s
ΔP VLP stream: < 100 Pa
Sub-cooling T: < 2.2 K

SS Coiled Tubes



Perforated Copper Plates with SS Spacers

Stainless Steel Plate