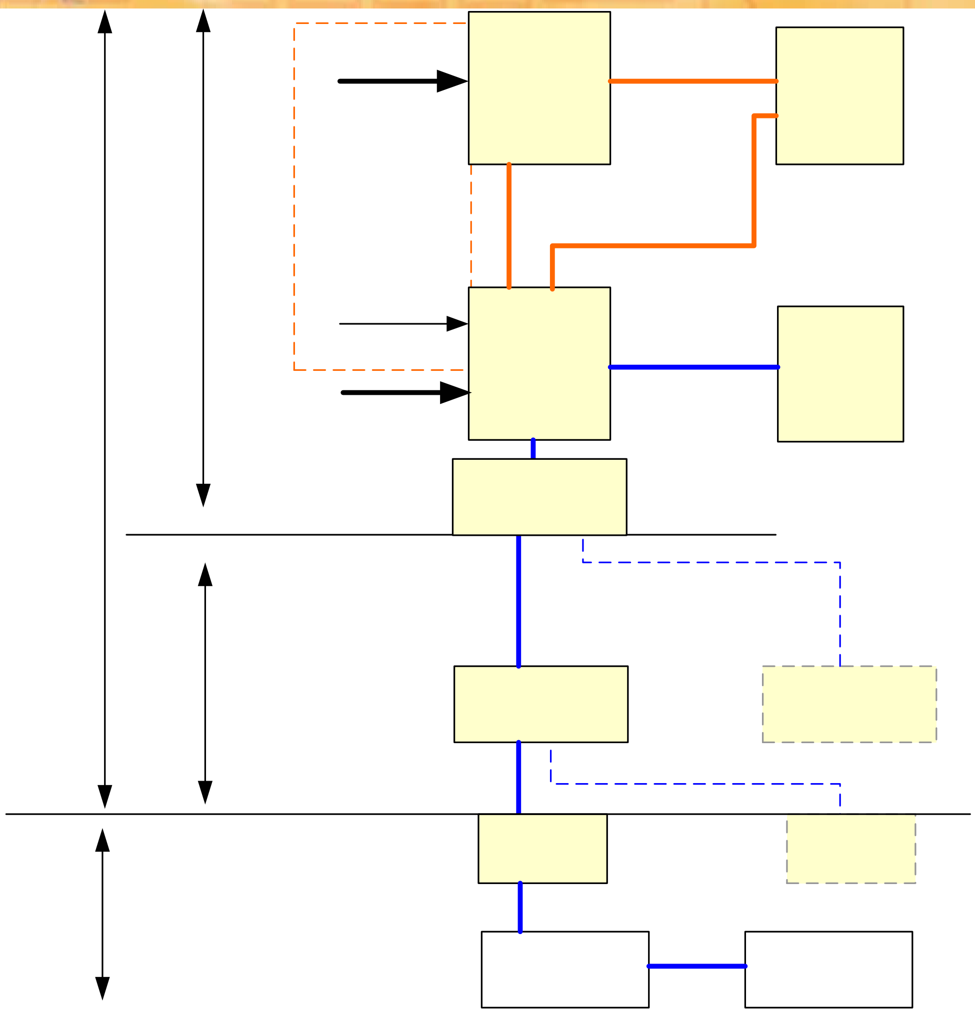
Cryogenic Supply and distribution for FAIR

Marion Kauschke

10th October 2011

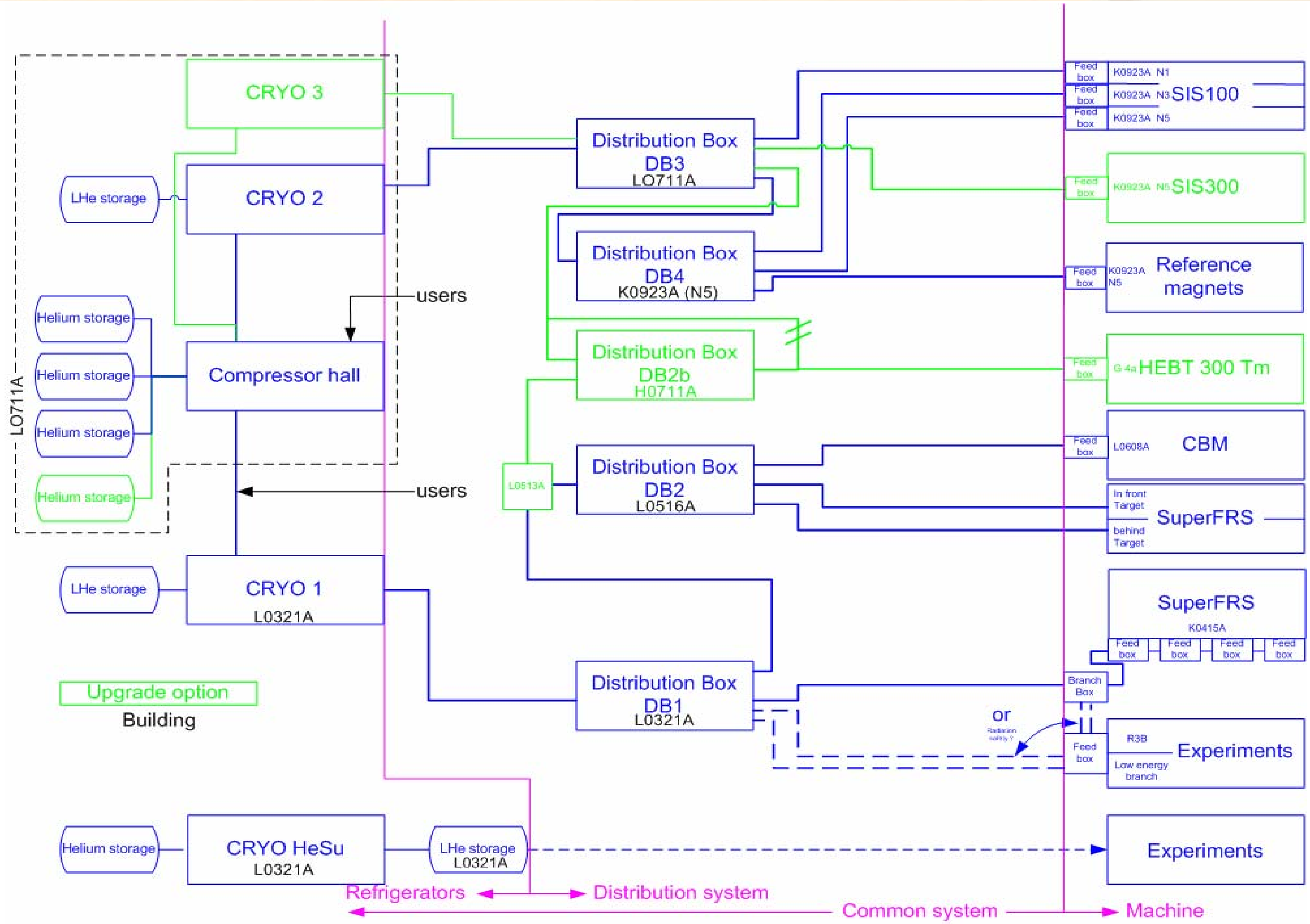
Cryogenic system



Proce
medi
supply

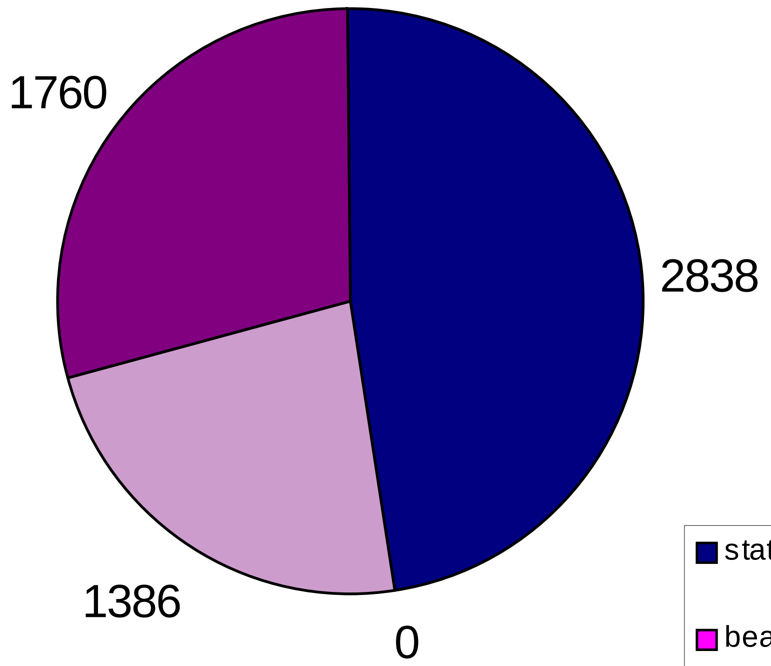
The interface between the distribution system and the consumer is the entrance of the feedbox, whereas the feedbox belongs (incl. specification and pricing) to the consumers.

Cryogenic system - users



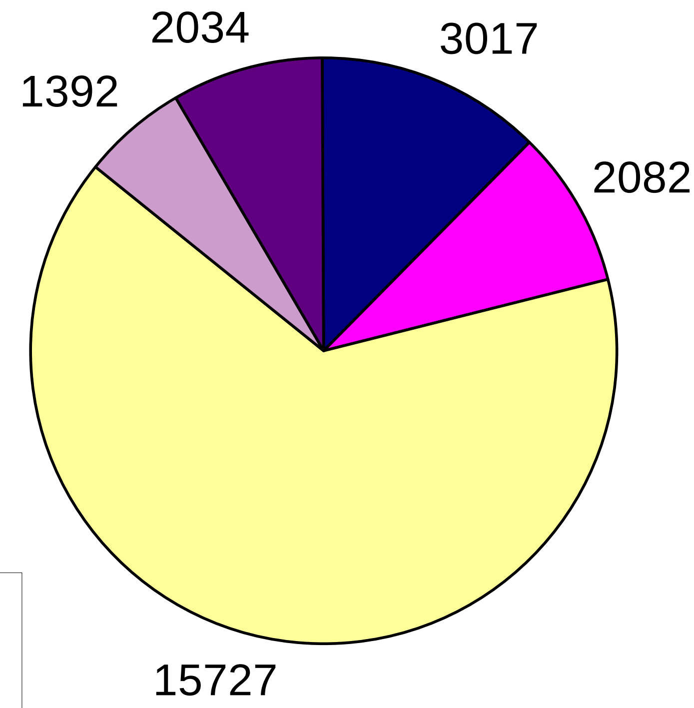
Cryogenic system – refrigerators - loads

CRYO 1



Σ ~ 6 kW

CRYO 2



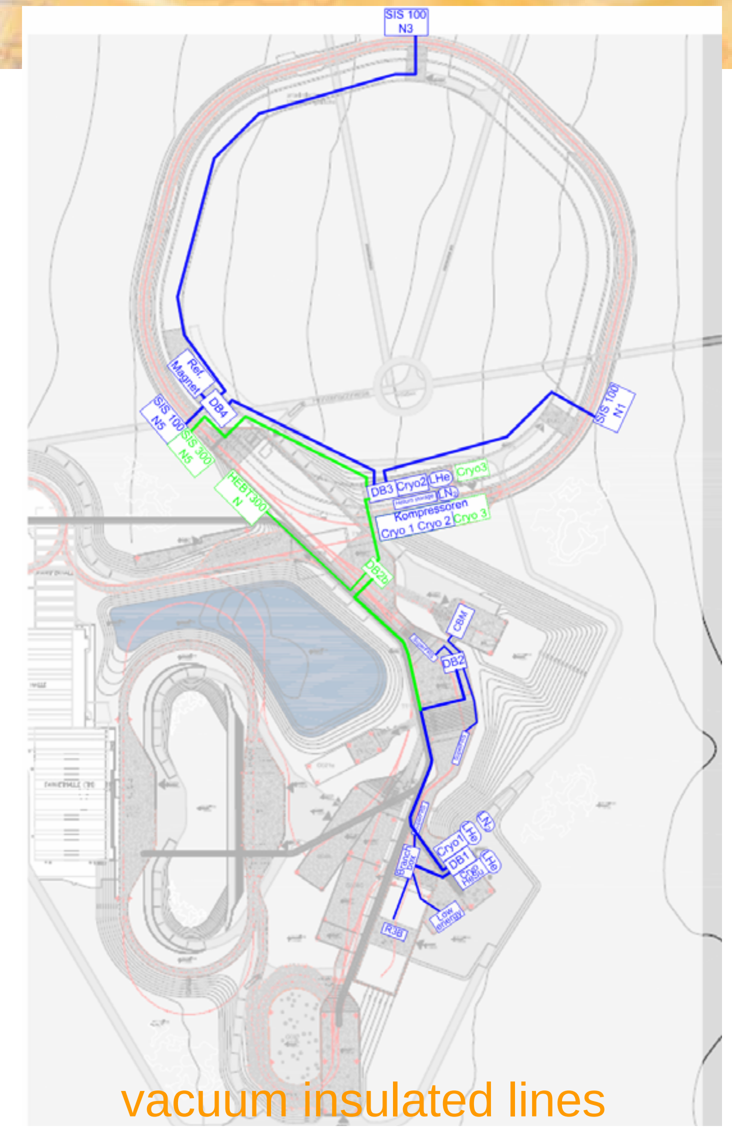
- static load @ 4K
- beam induced losses
- dynamic load @ 4K
- liquefaction
- static load @ 50-80K (4K equivalent)

Σ~ 24 kW

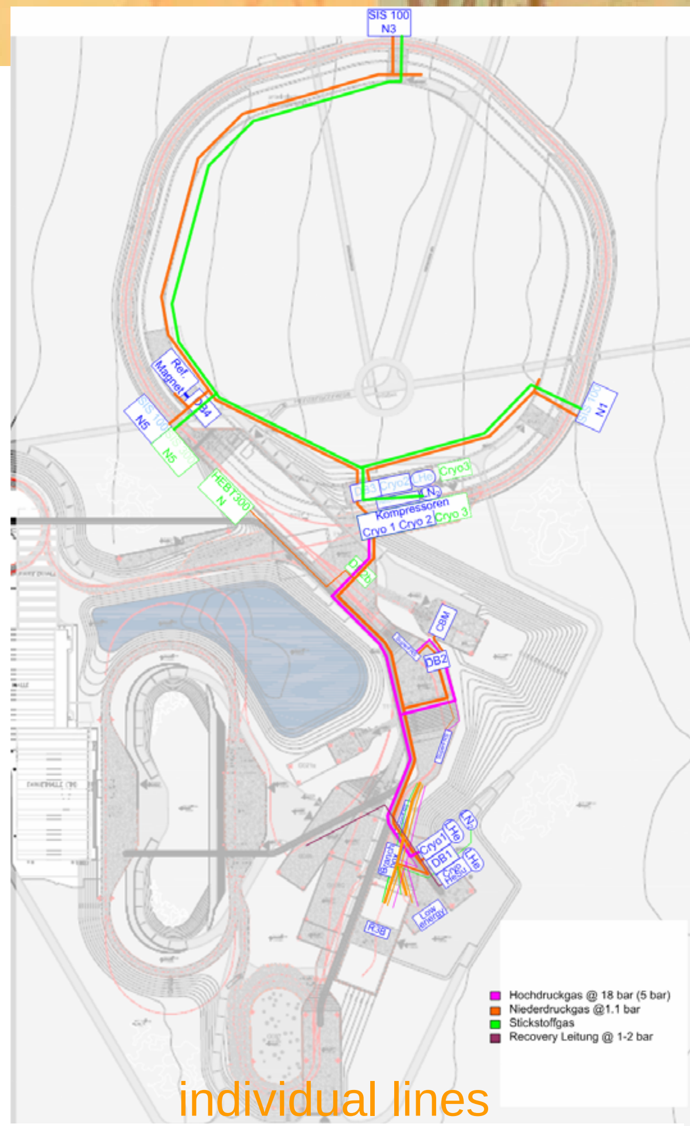
=> 2 design points for operation @ 230W/ W

Including the safety factor 1.5 (TAC 2007)

Cryogenic system - layout



vacuum insulated lines

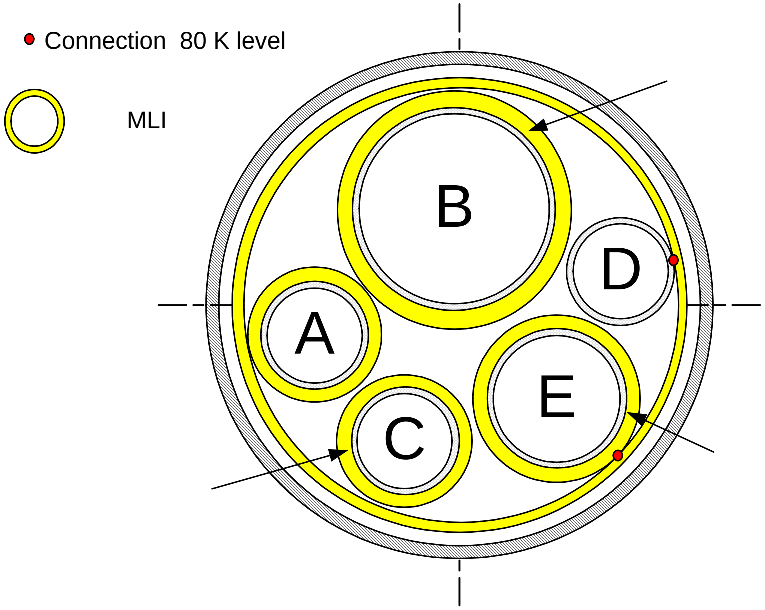


individual lines

Task of Cryogenic group: Dimenisions; routing: external planer supervised by FAIR S&B

Operating Parameter

			label	
			drawings	Nomen clature
4K level				
Normal operation	Supply	4.6 K, 3 bar	A	1
	Suction	1.1 bar, max. 5K allowed	B	2
Cool down distribution system	Supply	18 bar	A	1
	Suction	4 bar	B	2
Intermediate level				
Supply		50K, 18 bar	C	3
Return		80K, 17 bar	D	4
Multipurpose line		1.1 (– 4) bar, pure helium	E	8



=> The conditioning of the helium is done within the feed box, which will be in the responsibility of the machine coordinator or experimental group

Cryogenic system – Design Values

User	mass flow rate [g/s]			Cool down margin [%]
	4K circuit		80K circuit	
	Minimal	Maximal		
SIS100 total	140	1000	70	0
SIS300	100	230	55	0
HEBT300	21	30	30	10
CBM	10			50
SuperFRS	70		60	50
R3B	3		3	50
Low energy branch	4		4	50

=> TG Cryogenic Operation Parameter

Label	Heat load [W/exit]	Pressure drop [Pa]
A	5	5000
B	10	600
C	35	1300
D	35	1300
E	Nonrelevant	

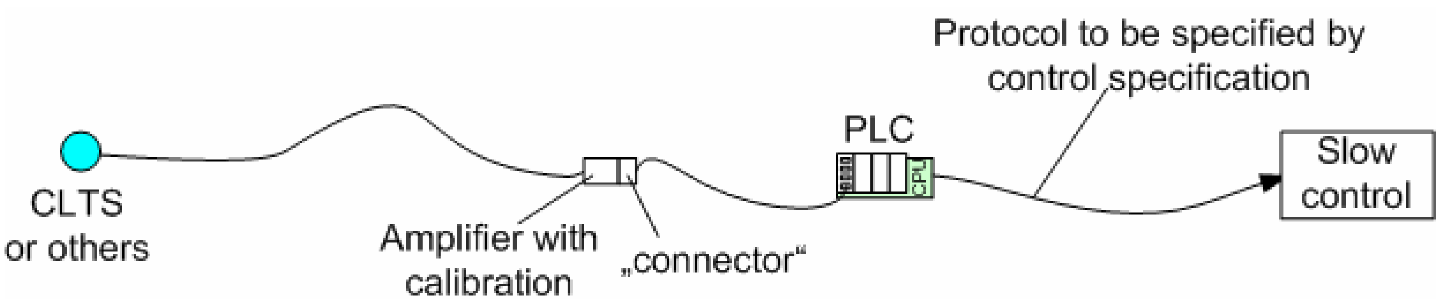
=> CS Cryogenic Distribution Boxes

Refrigerator- Control system

The cryogenic system contains

- Sensors as temperature, pressure, level, flow rates, positioners, rotation speed
- Active components as valves, compressors, turbines

which will be connected to the control system.



We will follow the cryogenic control concept developed for LHC (Unicos).
A co-operation with CERN is started.
The number of gauges: approx. 8000
The implementation of Unicos will be trained at the “new” R3B refrigerator at GSI.

Refrigerator/ Distribution system- time line

Refrigerator

Specification:	0.5 a (incl. fixation of the operating cycles for design points)
Tendering process:	0.5 a
Delivery process:	2 a
Setting into operation:	0.5 a (Full facilities at the cryogenic hall have to be available plus test load)

Distribution system

Specification:	2 a (for building the pipe routing have to be completed, including the collisions test with other equipment –which is not fixed up-to-now- and the transportation lines)
Tendering process:	0.5 a
Delivery process:	1.5 a (splitting in several contracts)
Setting into operation:	1 a (high logistic demands, as transfer lines mostly above transportation lines)

Cryogenic system - HeSu

Liquid **He**lium **Su**pply in dewars for the supply of small or short time experiments.>

Liquefaction rate: 20 l/h
Recovery system is foreseen in the experimental hall; piping HDPE/ alu-stabilized PE
Responsibility ends „at the door“.

Time line:

Specification:	~2m (depending on location)
Tendering:	3m
Delivery:	1 a

=> As soon as possible;

refrigerator can be moved after some time of operation into the FAIR facility.


Deutsche Physikalische Gesellschaft DPG

PHYSIKonkret Nr. 10 September 2011

Helium: rar und kostbar

Helium ist ein auf der Erde seltenes Element [1], das in der Grundlagenforschung, der Medizin und Industrie vielfältig genutzt wird – als Gas und auch verflüssigt [2, 3]. Gefördert wird es als Beimischung von Erdgas, denn in der Atmosphäre beträgt die Konzentration in Bodennähe [4] nur 5,2 ppm (zehntausendstel Prozent). Die Variante Helium-3 wird sogar künstlich hergestellt. Angesichts steigender Nachfrage (Abb. 1) und begrenzter Vorräte wird immer wieder vor einem Engpass gewarnt [2, 5 – 7], da Helium für manche Anwendungen aus heutiger Sicht unentbehrlich ist.

Größter Einzelposten – bei einem Anteil von 28 Prozent am Weltbedarf – ist der Einsatz als Kühlmittel (Abb. 2). Flüssiges Helium ist in vielen Fällen nahezu konkurrenzlos zum Erreichen sehr tiefer Temperaturen (unterhalb von minus 200 Grad Celsius). Zwar haben Rückgewinnungsanlagen und andere technische Entwicklungen den Verbrauch so gesenkt, dass moderne Systeme nur noch gelegentlich befüllt werden müssen. Trotzdem sind insbesondere Magnetresonanz-Tomographen (MRT)

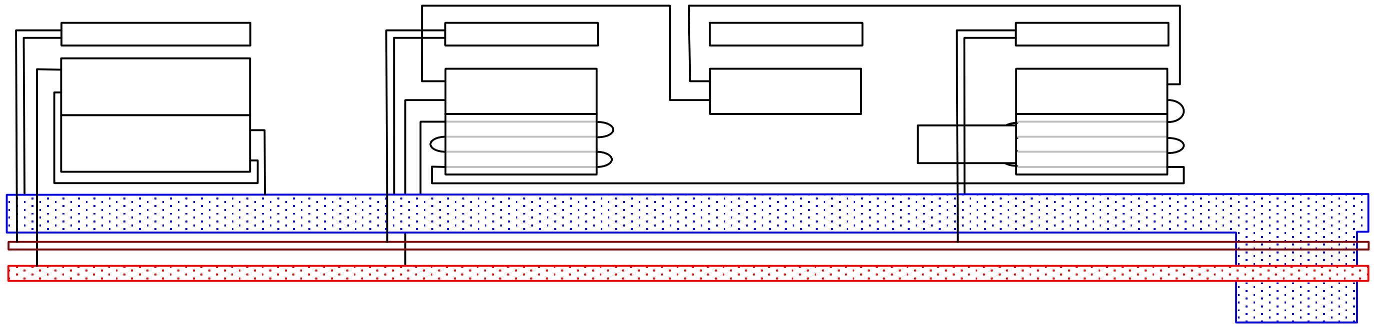
„Helium, heute noch preiswert, morgen rar und kostbar. Wir müssen vorausschauender als bisher damit umgehen.“
Wolfgang Sandner, Präsident der Deutschen Physikalischen Gesellschaft

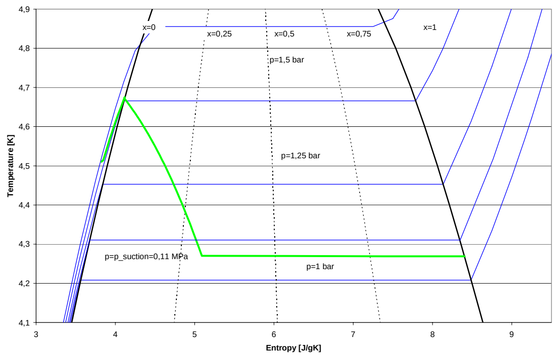
Cryogenic system - Testing

Besides the control system there will be no test of the hardware of the system, as components for 4K supercritical supply system are well understood and a reliable design and manufacturing is state of the technology.
Exceptions may be done for sensors.

SIS 100

Cryogenic system – SIS100





During Operation:

Suction pressure nearly constant
Ramping -> heat load -> required mass flow -> supply pressure will adapted

dipole

q

Thermodynamic optimum at x=1 (full evaporation)
For the design cycle (heat loads) the various components will be connected and hydraulically adjusted by orifices at the supply side.

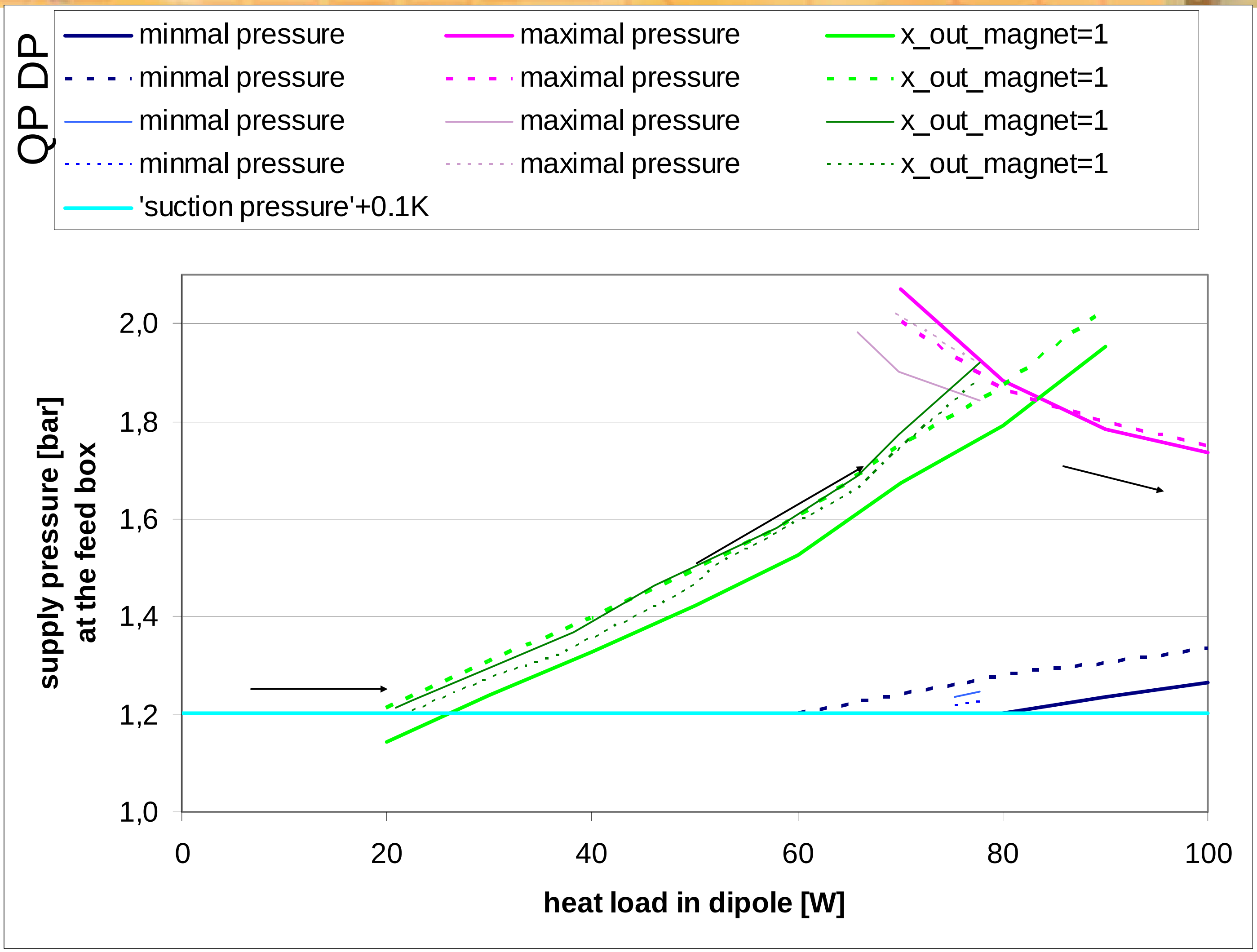
Vacuum chamber will be supplied by an separate line to
- adjust the mass flow in stand by mode
-increase the temperature only in the chamber.

Vacuum chamber

The flow in the supply line is stabilized by an additional end box valve

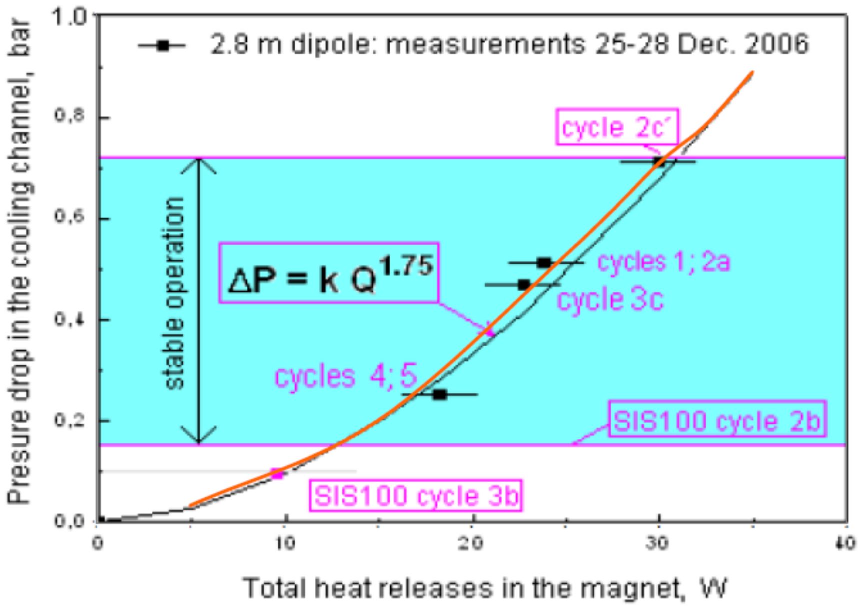
coil

Cryogenic system – SIS100



Dipole + Quadrupole

	Static	dynamic
dipole	5	33,9
q.pole	4	19
correc.	0	5
vacu.Ch.	0	10,6



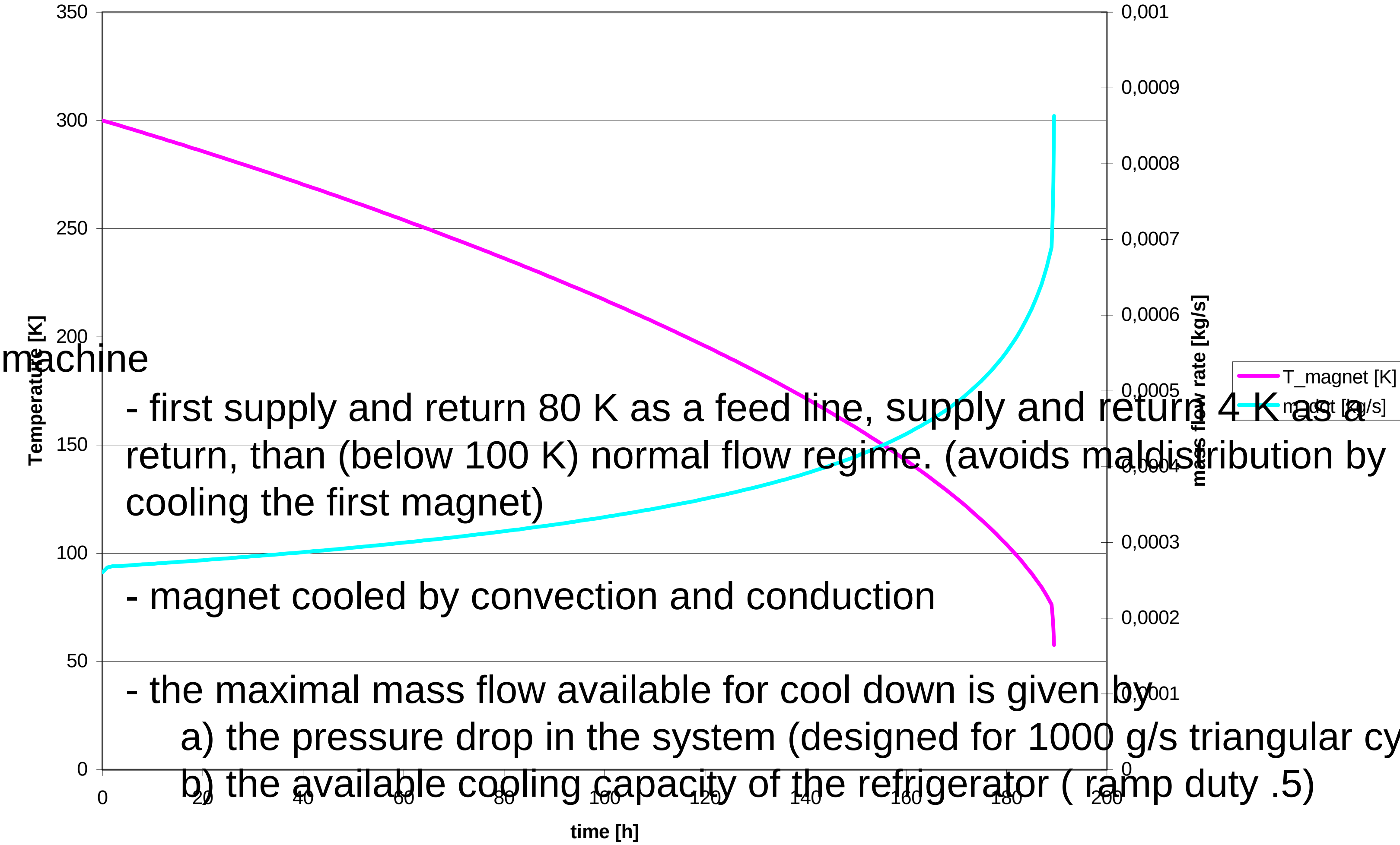
Critical mass flow rate

Phase separation

To avoid phase separation the flow velocity has to be risen. (Baker diagram) Therefore most cycles will be operated with a higher pressure head; the void fraction at the magnet outlet will be much below 1.

The liquid phase in the return flow will be recycled into the supply line by an ejector.

Cryogenic system – SIS100



in machine

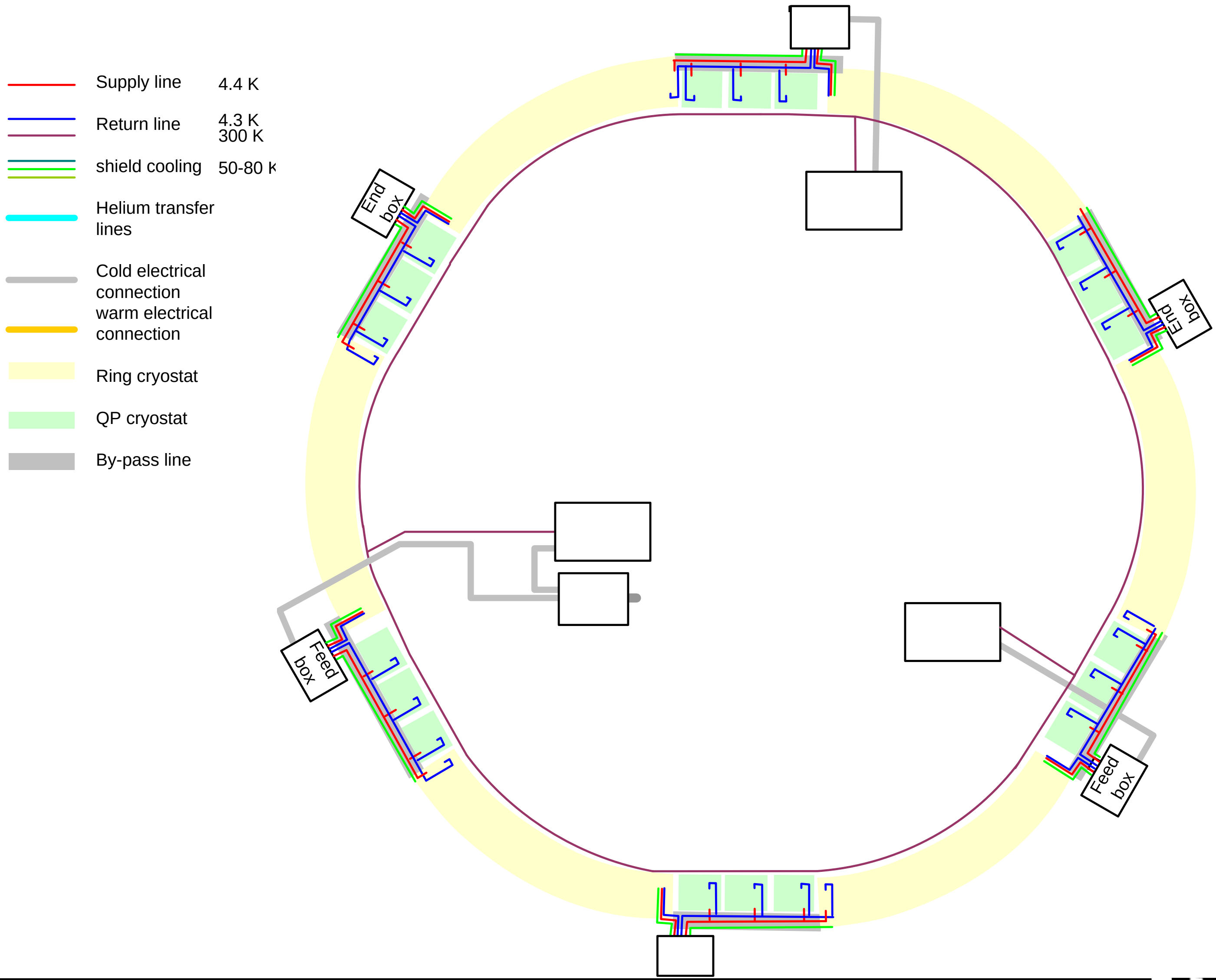
- first supply and return 80 K as a feed line, supply and return 4 K as a return, than (below 100 K) normal flow regime. (avoids maldistribution by cooling the first magnet)

- magnet cooled by convection and conduction

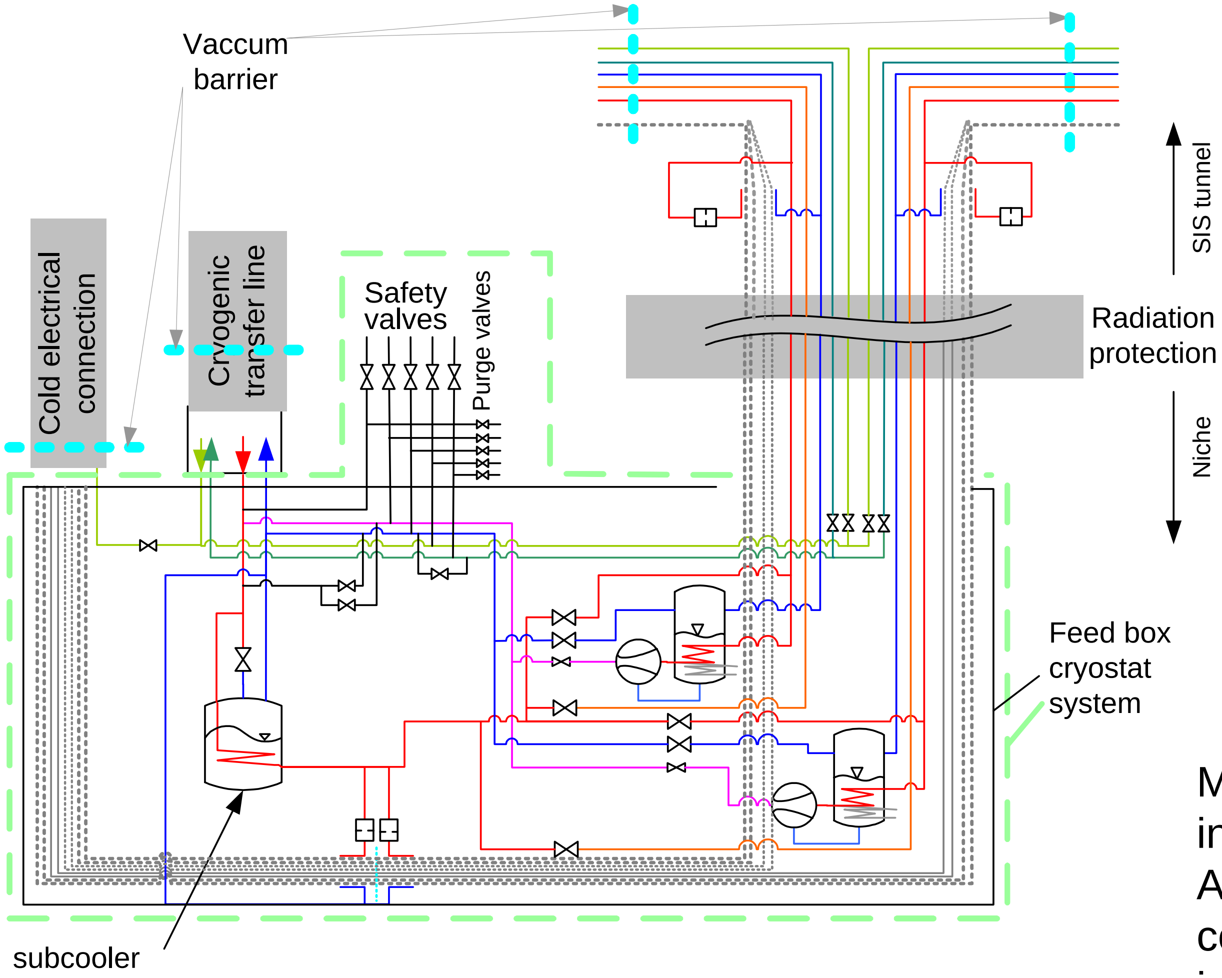
- the maximal mass flow available for cool down is given by
  - a) the pressure drop in the system (designed for 1000 g/s triangular cycle)
  - b) the available cooling capacity of the refrigerator (ramp duty .5)

Cool down time : ~ 9 d (depending on the final cold mass)

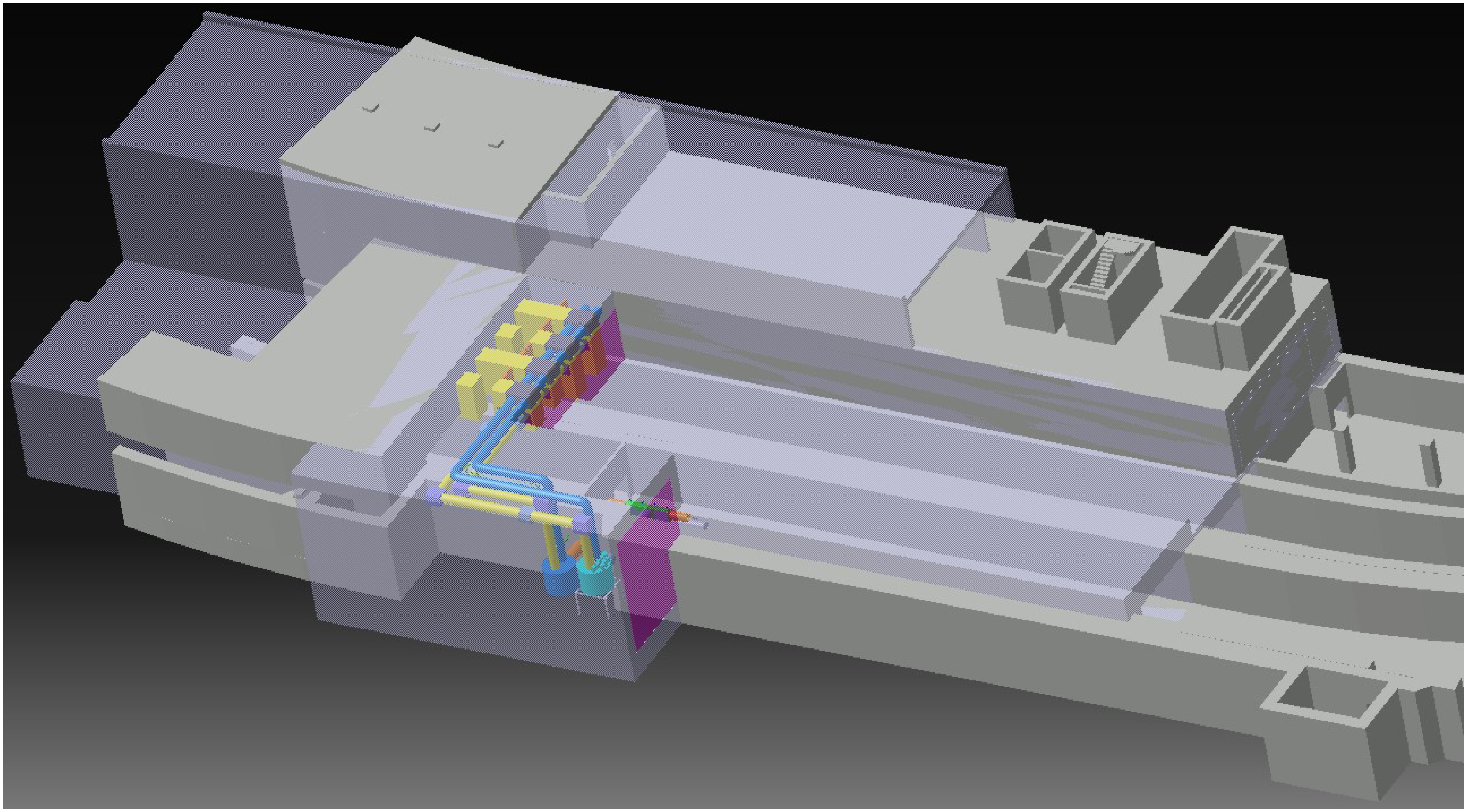
Cryogenic system – SIS100



Cryogenic system – SIS100 Feed box

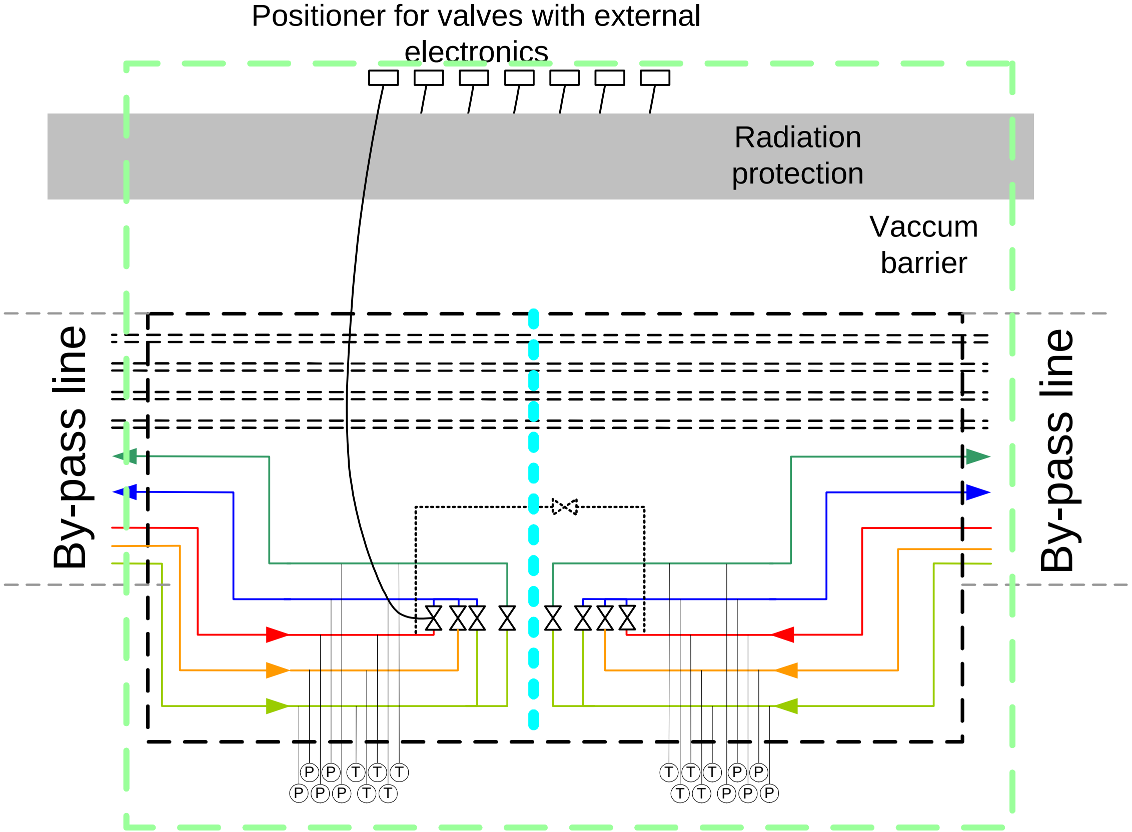


Max. length of section of insulation vacuum: 150 m
An each sector have to be cooled down/ kept cold independently



Courtesy M.Konradt

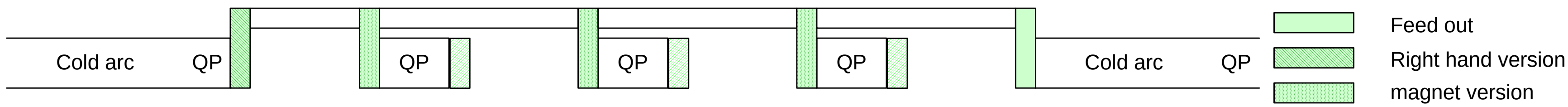
Cryogenic system – SIS100 End box



To minimizes the feed-troughs no valve systems with positioners with external potentiometer

Cryogenic system – SIS100 By-pass line

Connection box



End caps:
Termination of the cold section => CWT

Feed out:
CWT
Transferring helium lines and bus bars into the bypass line
Soldering of busbar connections
Support of pressurized tubes (bends)

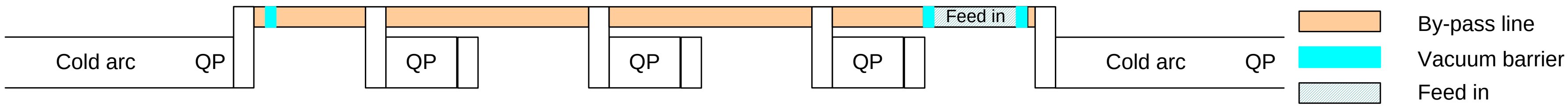
Flipped version

Magnet version:
CWT
Transfer of two QP bus bars
Soldering of bus bar connections
Feed trough of by-pass lines

Amount: 6 (+4 Ref.mag) 6 6 14 +4 extended

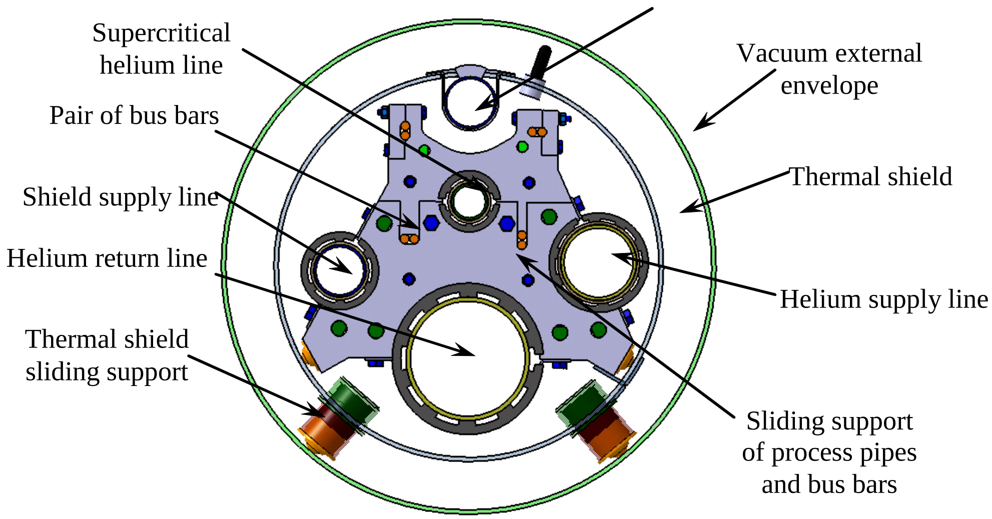
Cryogenic system – SIS100 By-pass line

2.8.12.5 Cryogenic bypass line (including Bus Bars)

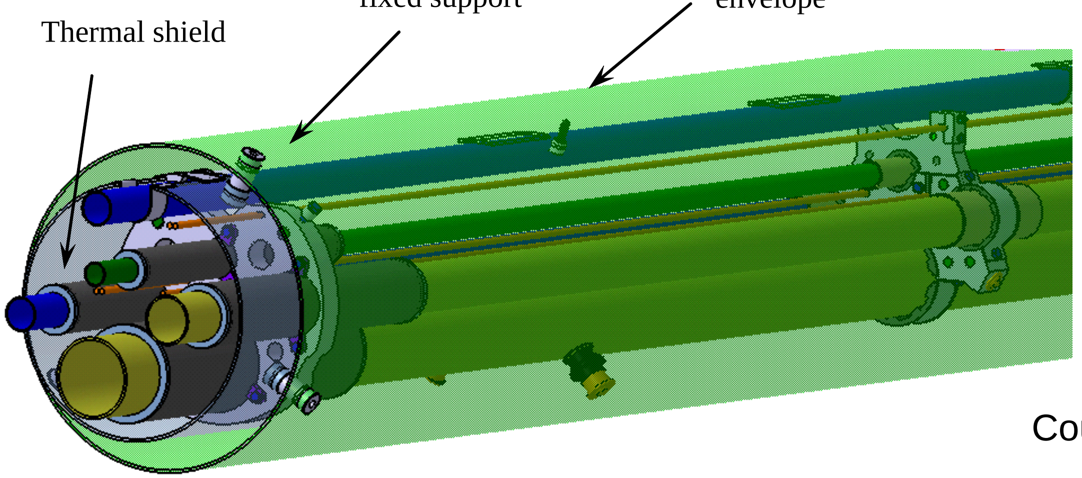


By pass line	Shorter version	End box	feed in
helium connection bus bars	The maximum length of one continuous vacuum is ~150m. Each sector should be kept cold independent. => with vacuum barrier	Terminates helium flow Cool-down/warm up connections Bus bar connection	Supplies helium flow Electrical supply and/or bus bar connection
Amount: 10 (+2)	**6**	**3**	**1 +2**

Cryogenic system – SIS100 By-pass line

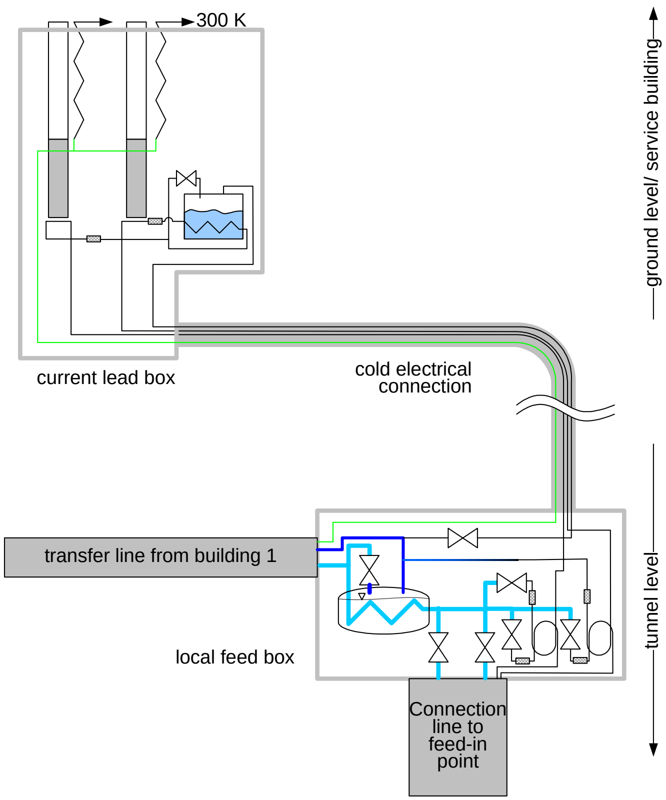


a)



Courtesy WRP

Cryogenic system – SIS100 Electrical Supply



Cryogenic system – SIS100 Testing

Component test and assembly test are required for:

- Bypass line including vacuum barrier with busbar system

- Electrical supply system

These test should consist from an individual component test and a system test (at string test facility)

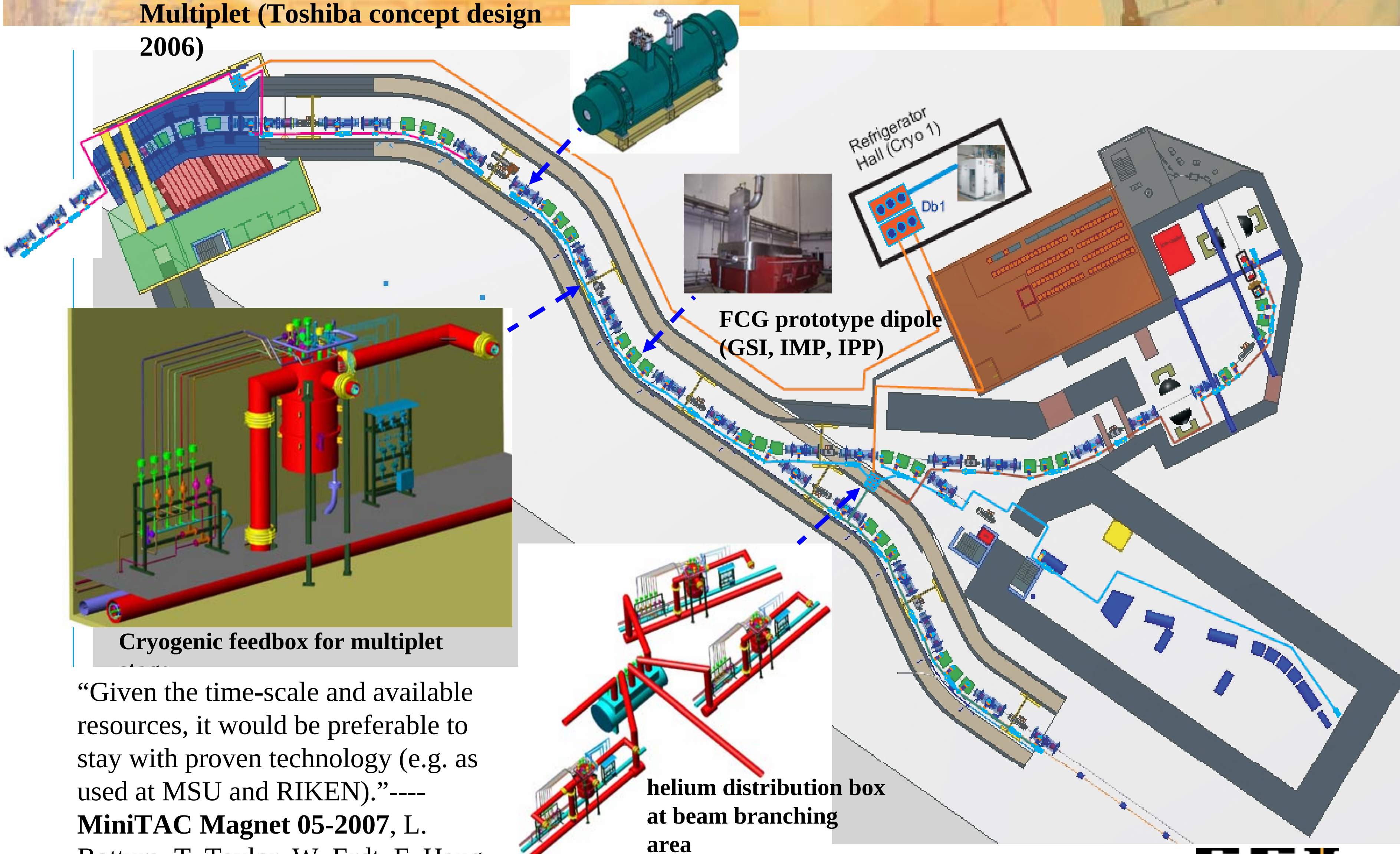
Feed box may be assumed as a reliable 4K design.

SuperFRS

Yu Xiang

Cryogenic Distribution for SC Magnets in the Super-FRS

Multiplet (Toshiba concept design 2006)



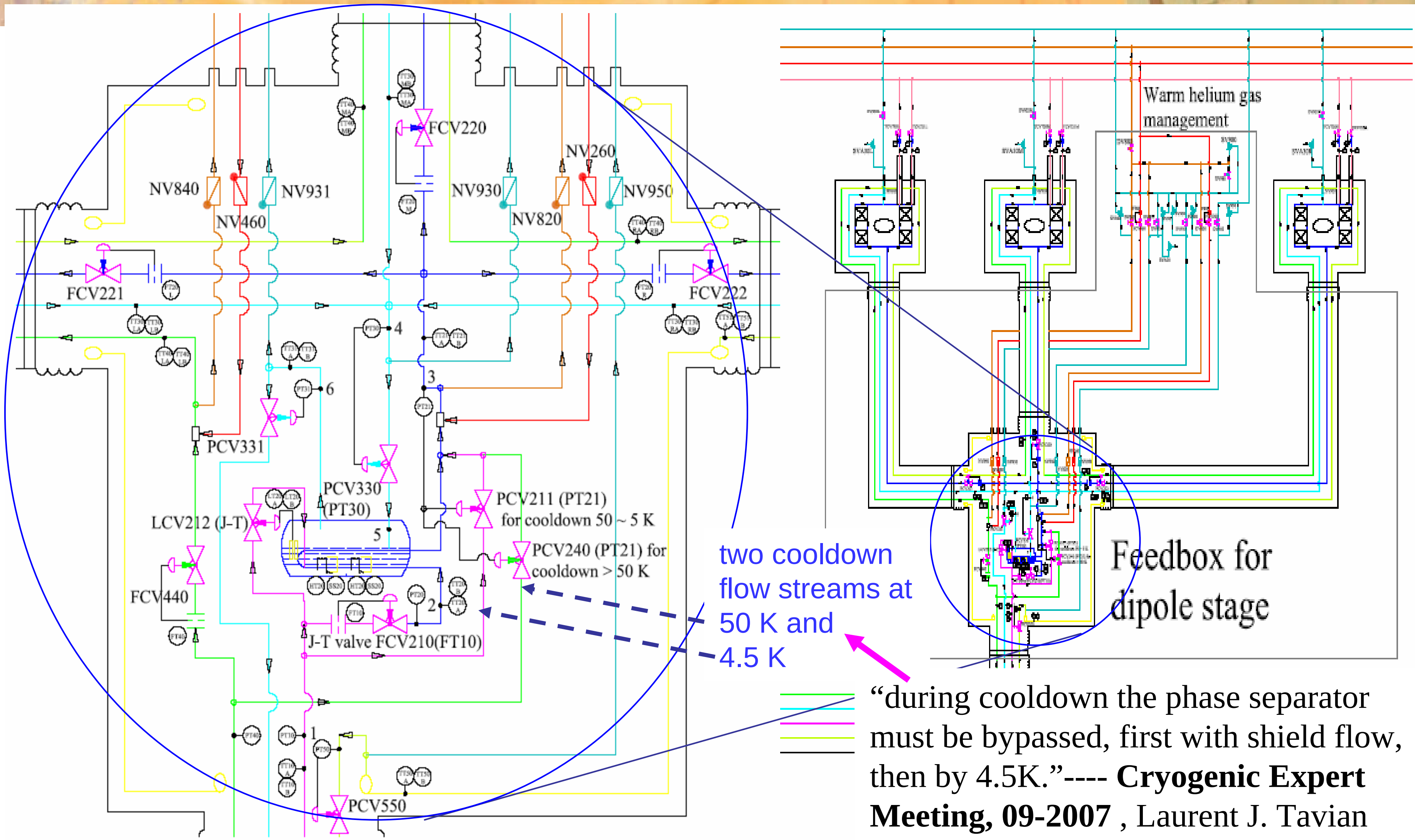
FCG prototype dipole (GSI, IMP, IPP)

Cryogenic feedbox for multiplet

helium distribution box at beam branching area

"Given the time-scale and available resources, it would be preferable to stay with proven technology (e.g. as used at MSU and RIKEN)."---- **MiniTAC Magnet 05-2007**, L. Bottura, T. Taylor, W. Erdt, F. Haug, D. Tommasini, …

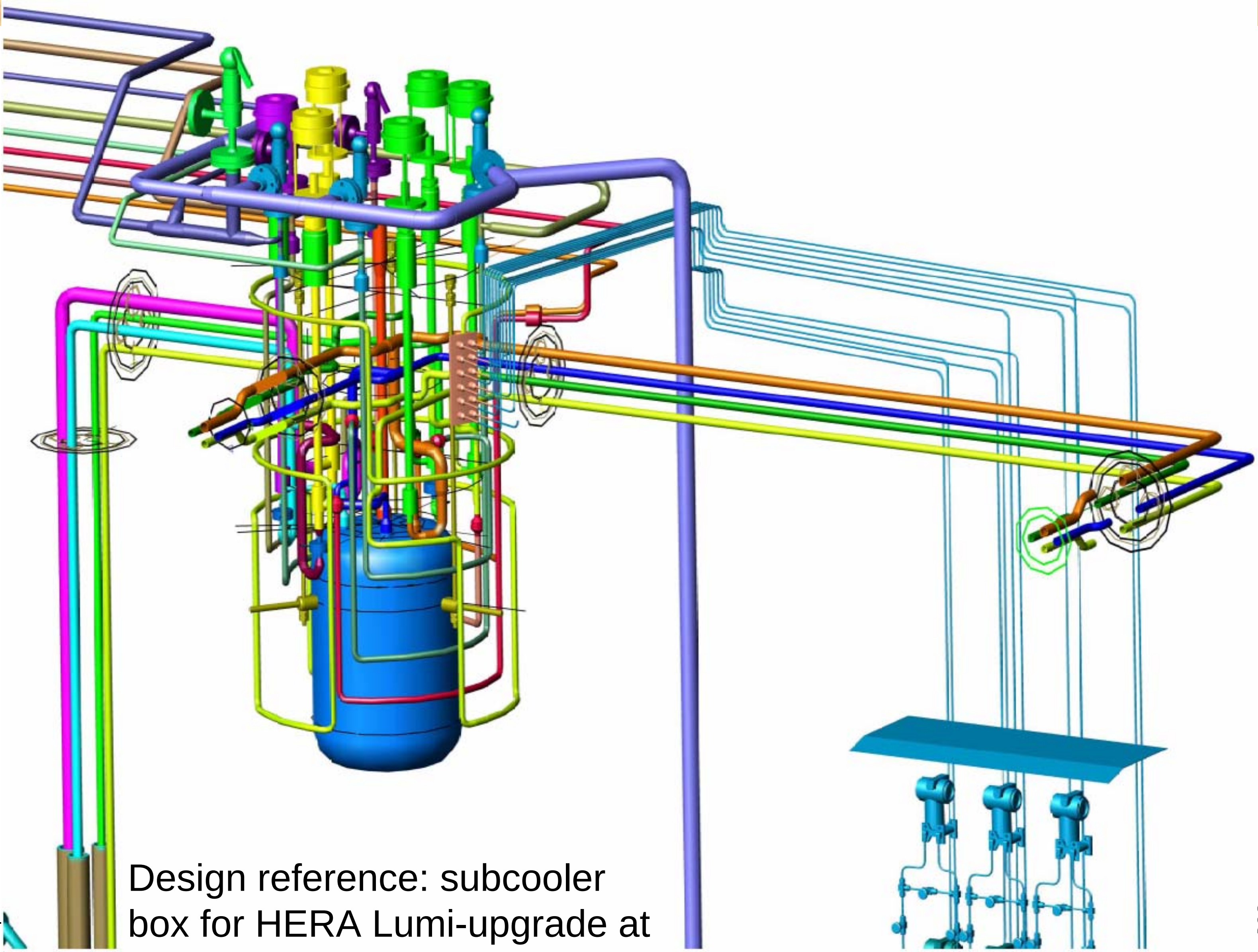
Flow scheme of cryogenic feedbox for one multiplet stage and one dipole stage



"during cooldown the phase separator must be bypassed, first with shield flow, then by 4.5K."---- **Cryogenic Expert Meeting, 09-2007** , Laurent J. Tavian

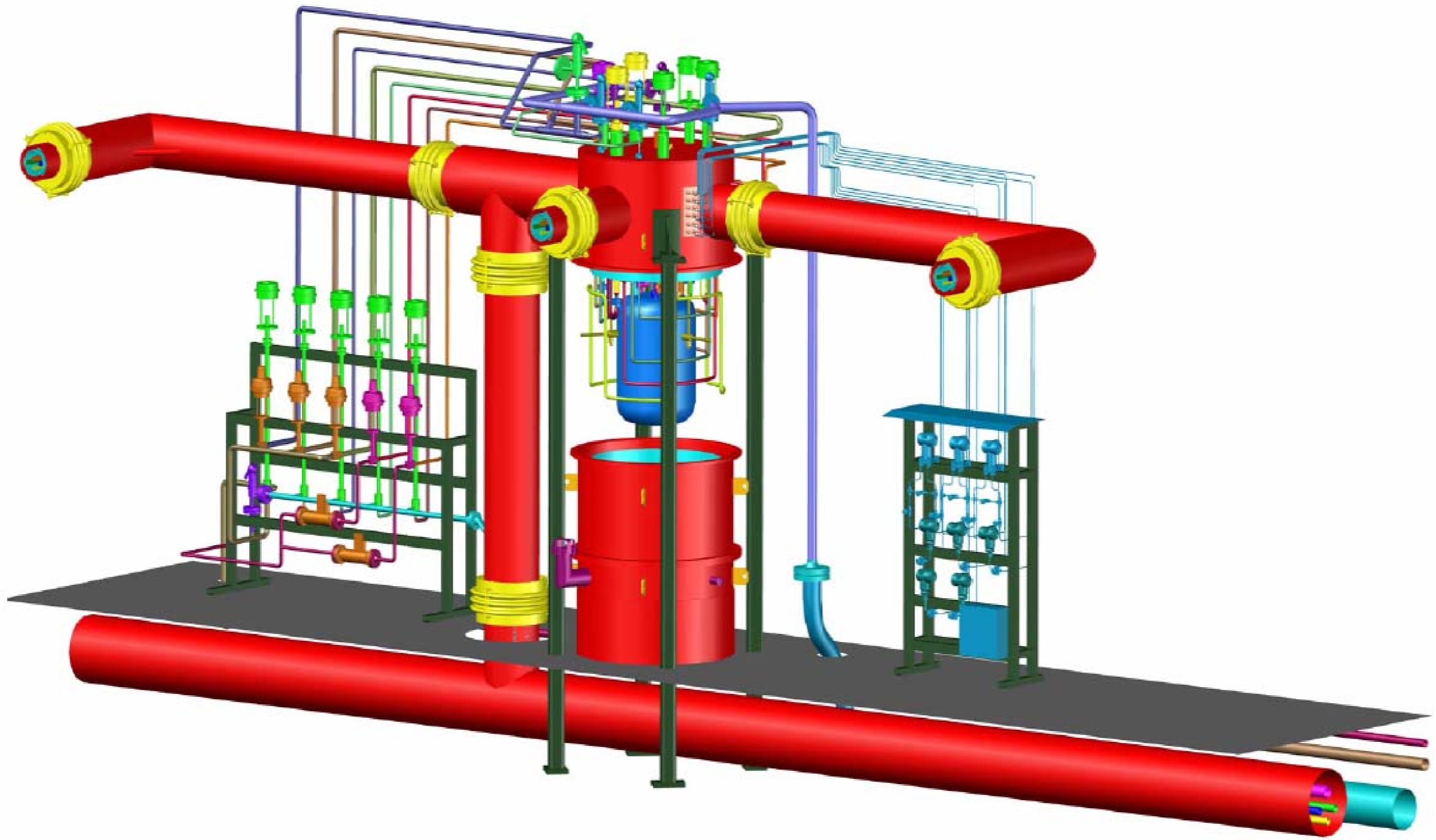
Updated version of feedbox design (29-03-2011)

Inner piping in one cryogenic feedbox to two neighbouring multiplets in one multiplet group/stage

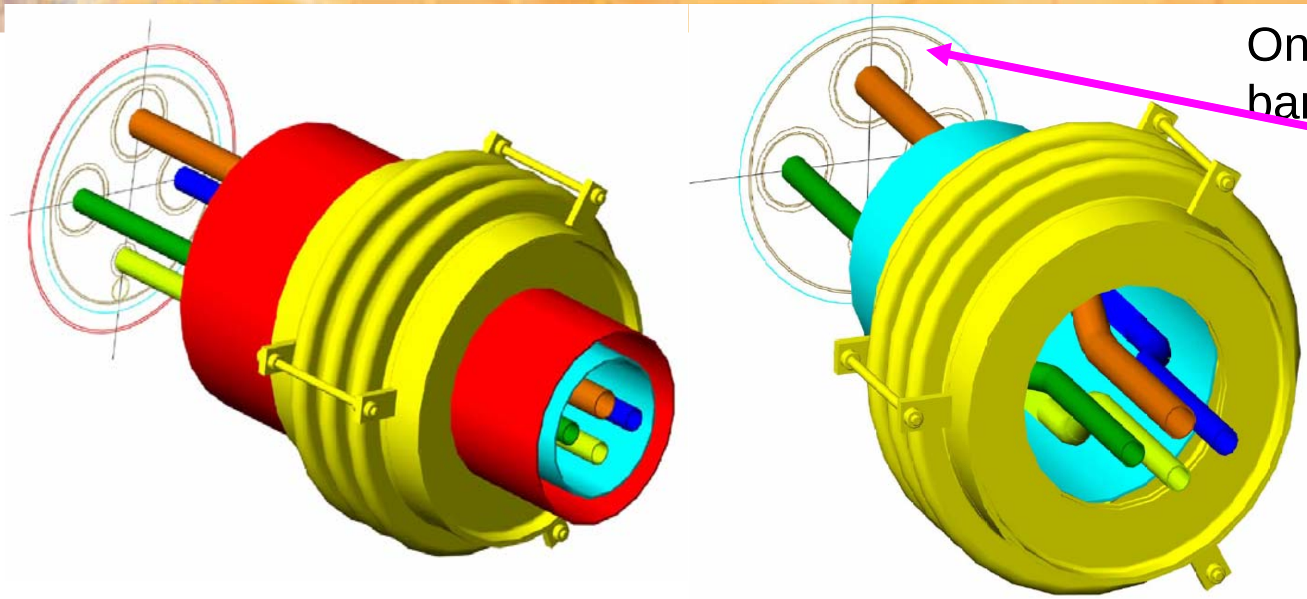


Design reference: subcooler box for HERA Lumi-upgrade at DESY

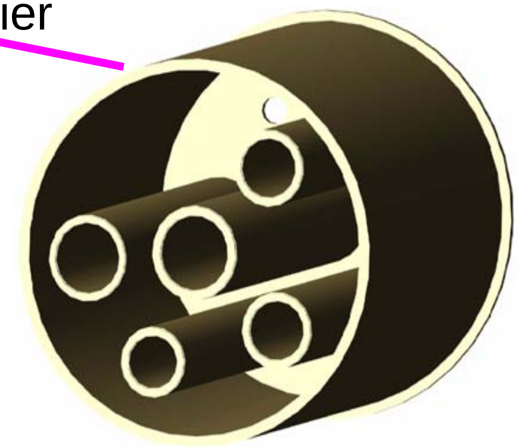
Cryogenic feedbox for three dipoles in one dipole group/stage



Cryogenic interface to magnet cryostat (piping size as reference)

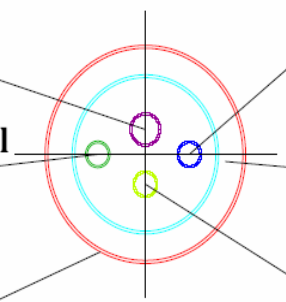


One example of vacuum barrier



back side view

Cryogenic interface to Super-FRS magnet cryostat

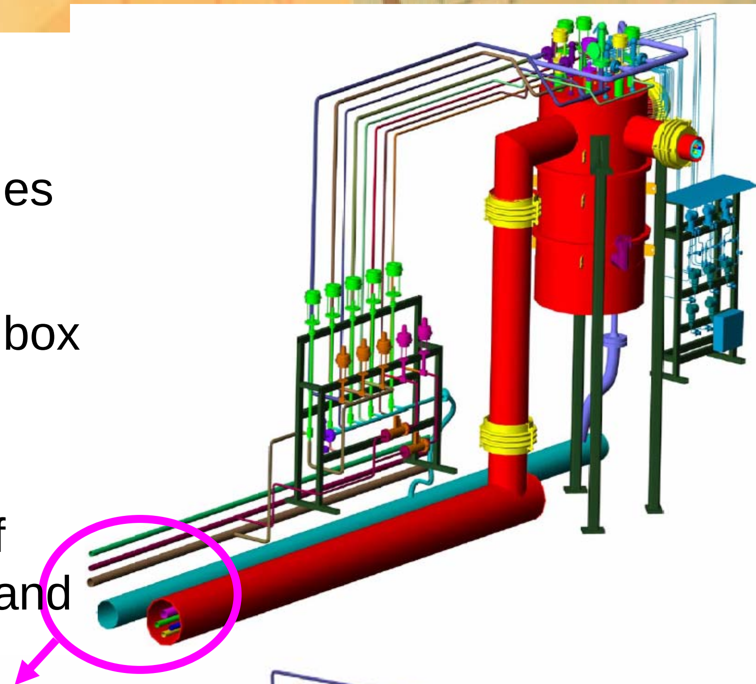


front side view

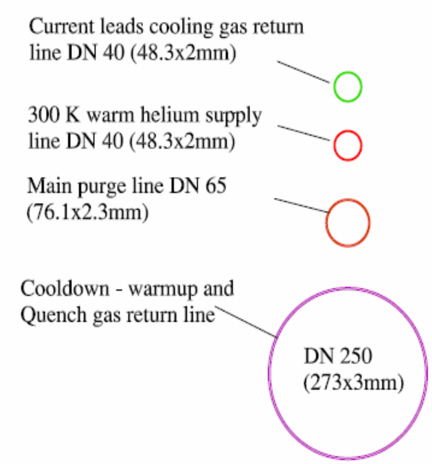
Cryogenic feedbox for magnet testing and its cryogenic interface to cryoplant (piping size as reference)

Testing

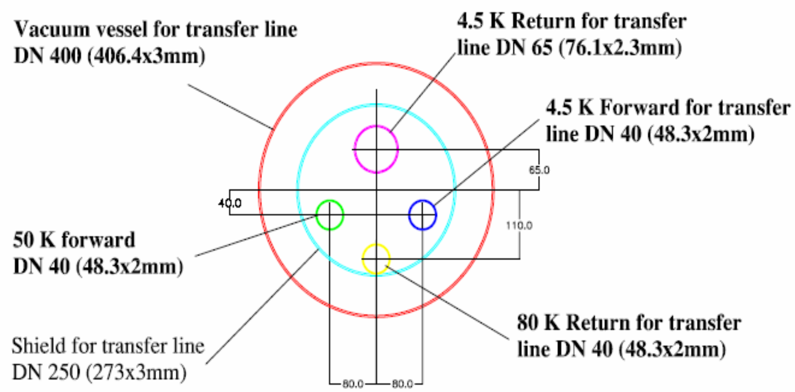
- Cryogenic – Magnet System Integration Testing as pre - commisioning before series production,
  1. hardware facilities (transfer line, feedbox and instrumentation);
  2. software facilities (control and communication system, evaluation of safety protection system for magnet and cryogenic facilities)

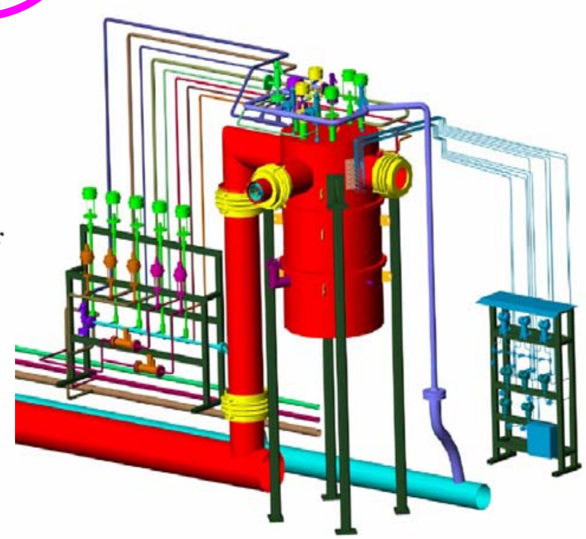


Warm piping for Super-FRS local cryogenics



Cryogenic transfer line for Super-FRS local cryogenics (concept 3, reference : Cryogenic Transfer Line for HERA at DESY)

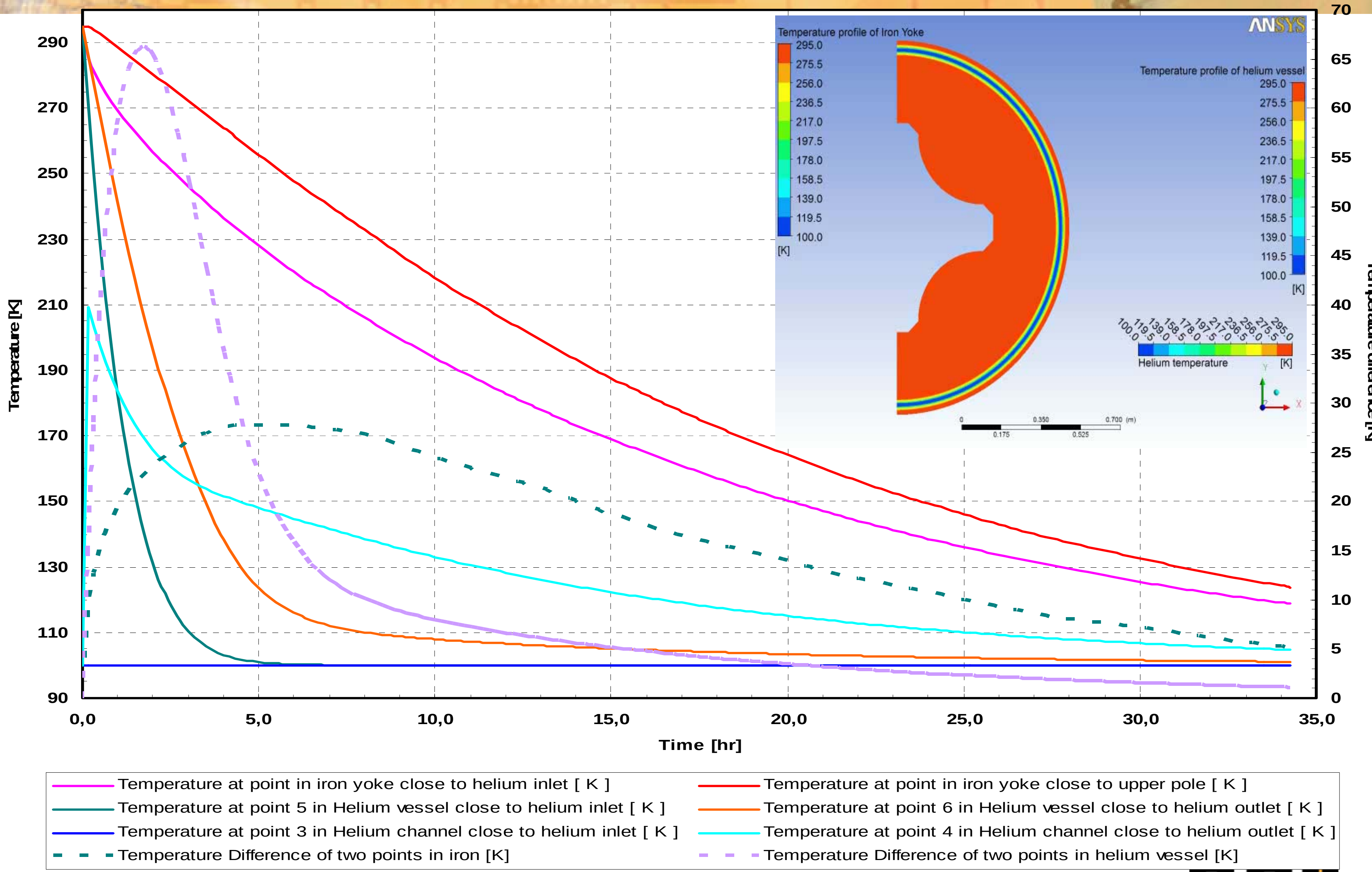




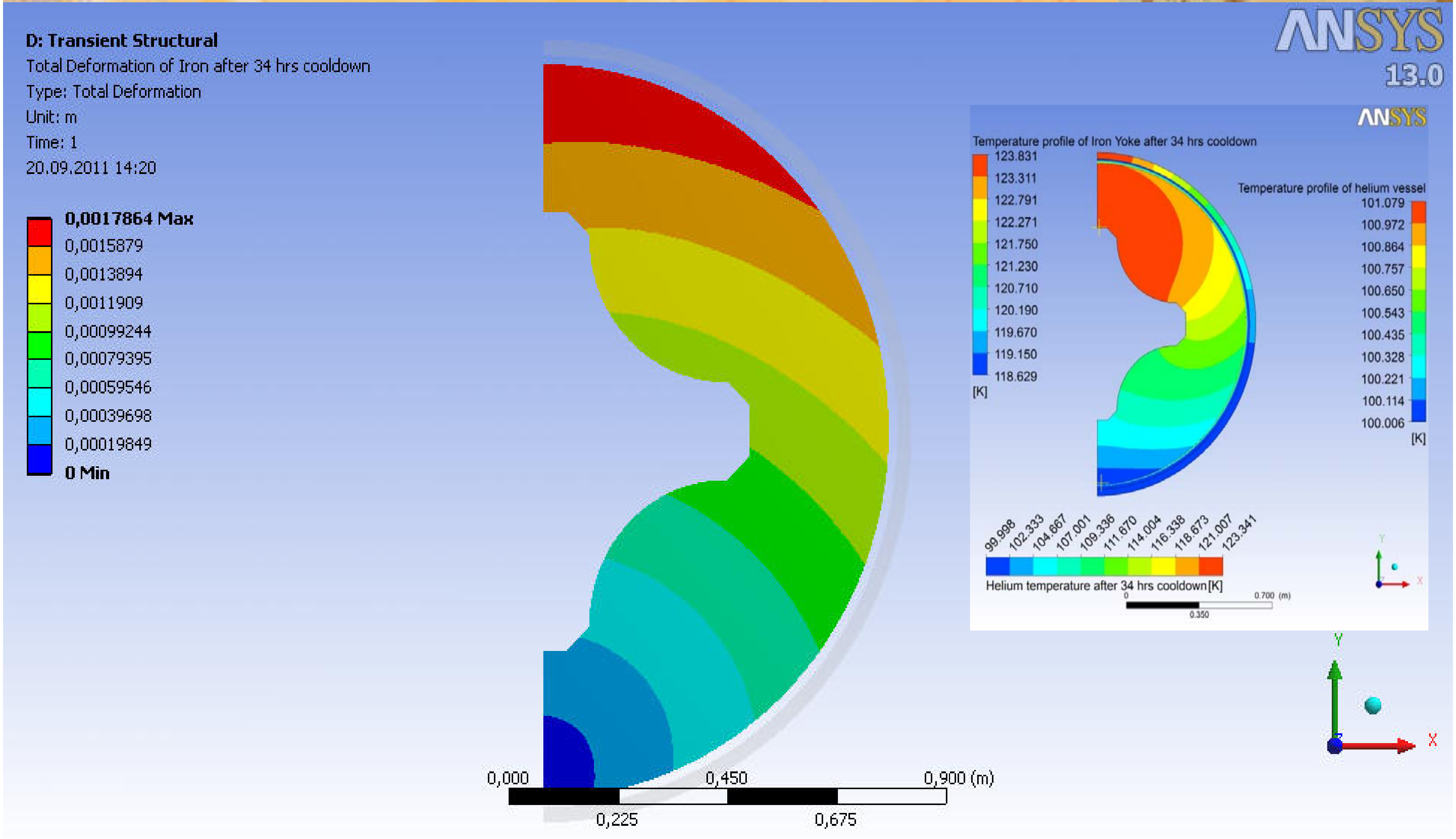
Requirements of cryogenic process flow for multiplet and dipole magnets testing

	Operation	Cooldown 4.5 K circuit	Operation	Cooldown 50 - 80 K circuit
Heat load list	4.5 K	300 K - 70 K	50 to 80 K	300 K - 70 K
Multiplet Stage				
two multiplet cryostat	17.2		179	
one feedbox for two multiplets	15.0		120	
connection lines between magnet cryostat and main part of feedbox	3.6		24	
subtotal of multiplet group [W]	35.8		322.8	
taking design factor 1.5 into account	**53.7**		**484**	
evaporated liquid mass flow in subcooler [g/s]	**2.9**			
helium enthalpy before JT valve (5.3 K, 2.5 bar) [J/kg]	20280			
vapor quality after JT (4.4 K, 1.2 bar)	0.47			
required mass flow rate before JT at 5 K [g/s]	5.4			
required mass flow rate at 50 K [g/s]			4.6	
specified maximal mass flow rate during cooldown for valve sizing [g/s]		30g/s at 3.0 to 5.0 bar		30g/s at 18.0 to 17.0 bar
Dipole Stage				
three dipole cryostat	20.4		134	
one feedbox for three dipoles	15.0		120	
connection lines between magnet cryostat and main part of feedbox	2.7		18	
subtotal of dipole group [W]	38.1		272.4	
taking design factor 1.5 into account	**57.2**		**409**	
evaporated liquid mass flow in subcooler [g/s]	**3.0**			
helium enthalpy before JT valve (5.3 K, 2.5 bar) [J/kg]	20280			
vapor quality after JT (4.4 K, 1.2 bar)	0.47			
required mass flow rate before JT at 5 K [g/s]	5.8			
required mass flow rate at 50 K [g/s]			3.9	
specified maximal mass flow rate during cooldown for valve sizing [g/s]		30g/s at 3.0 to 5.0 bar		30g/s at 18.0 to 17.0 bar

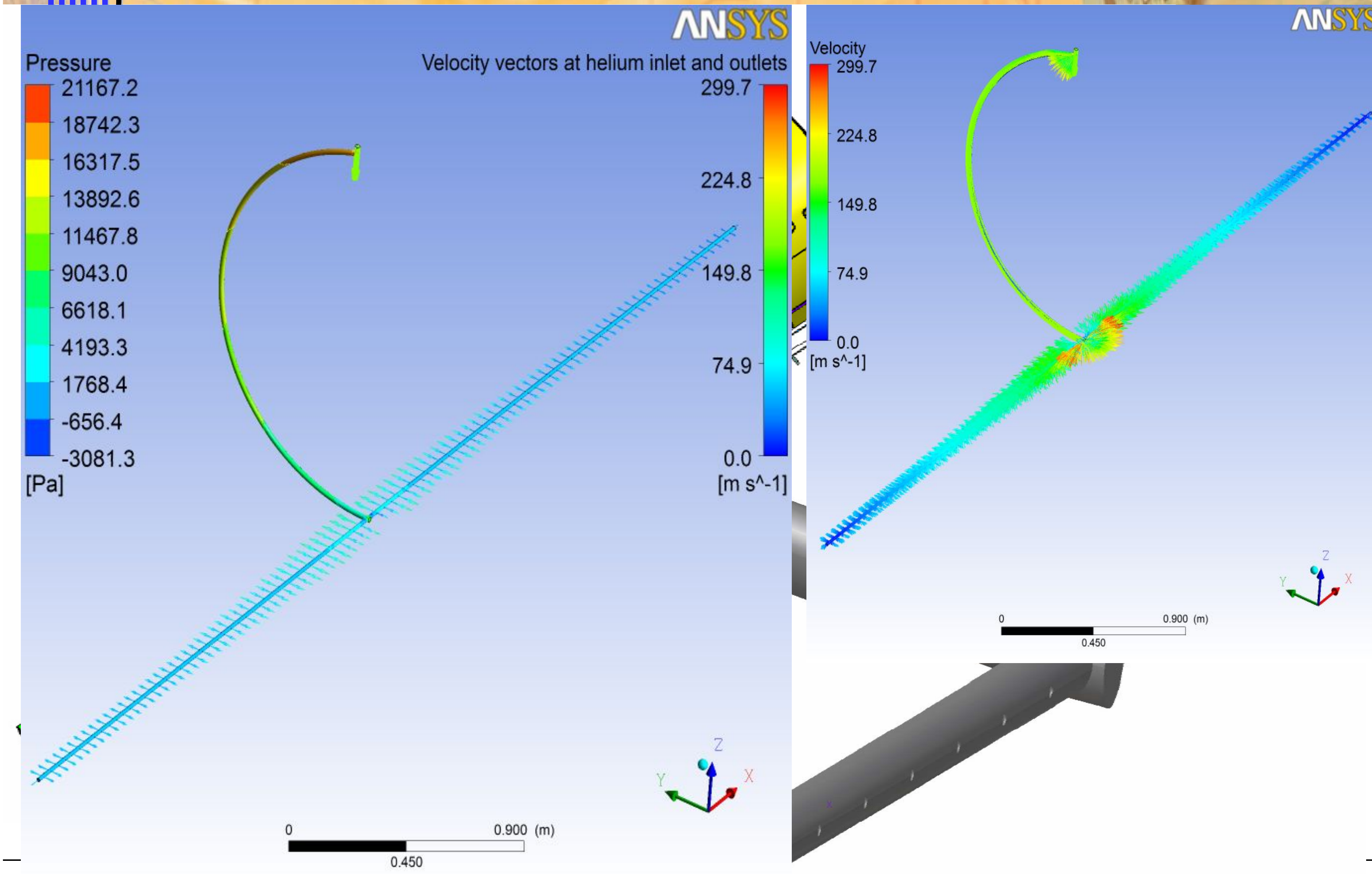
Cooldown simulation for single quadrupole in Super-FRS multiplet cryostat (2D transient flow by ANSYS CFX)



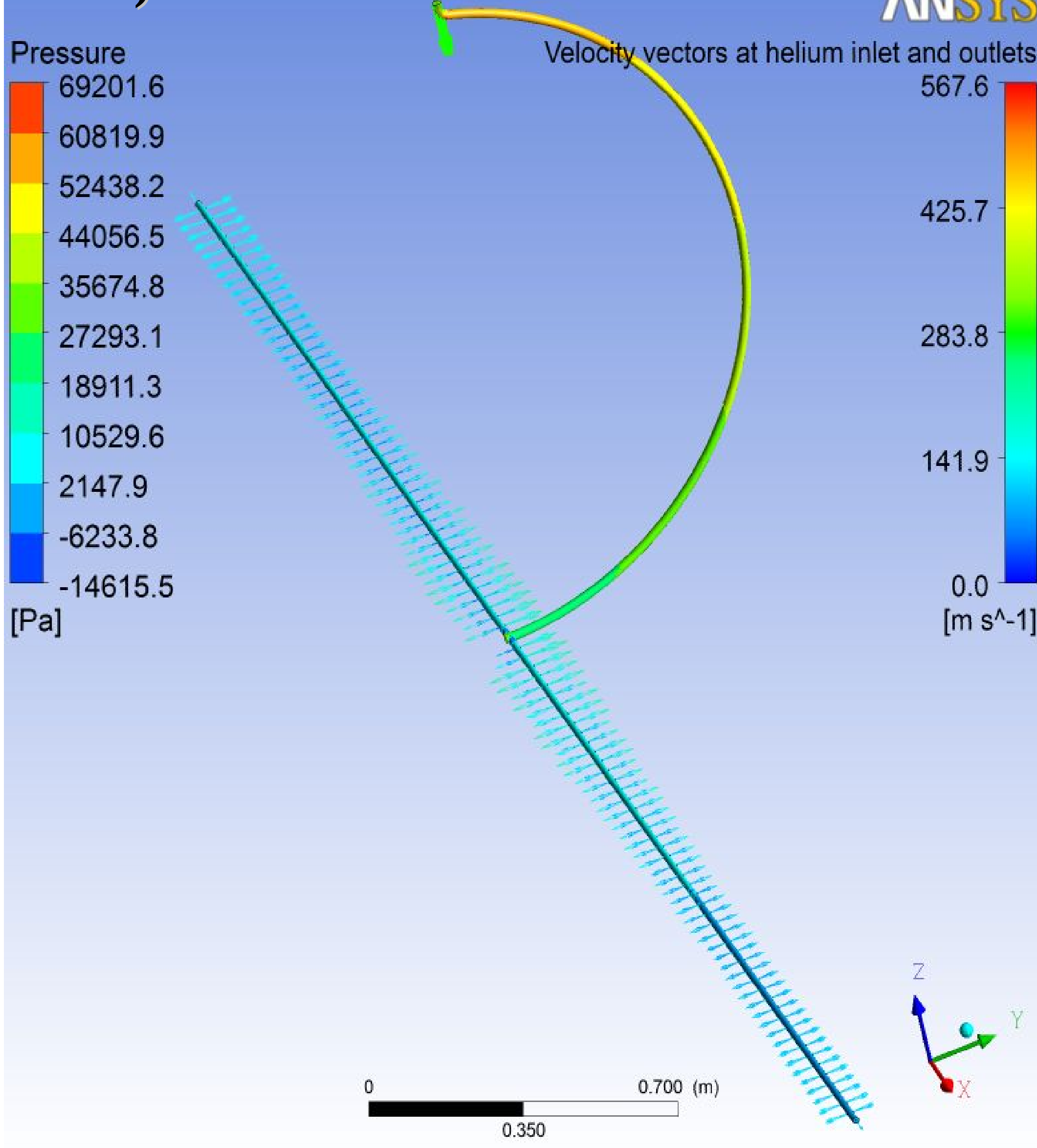
Deformation of iron yoke after 34 hrs cooldown time (2D transient structural analysis by ANSYS workbench)

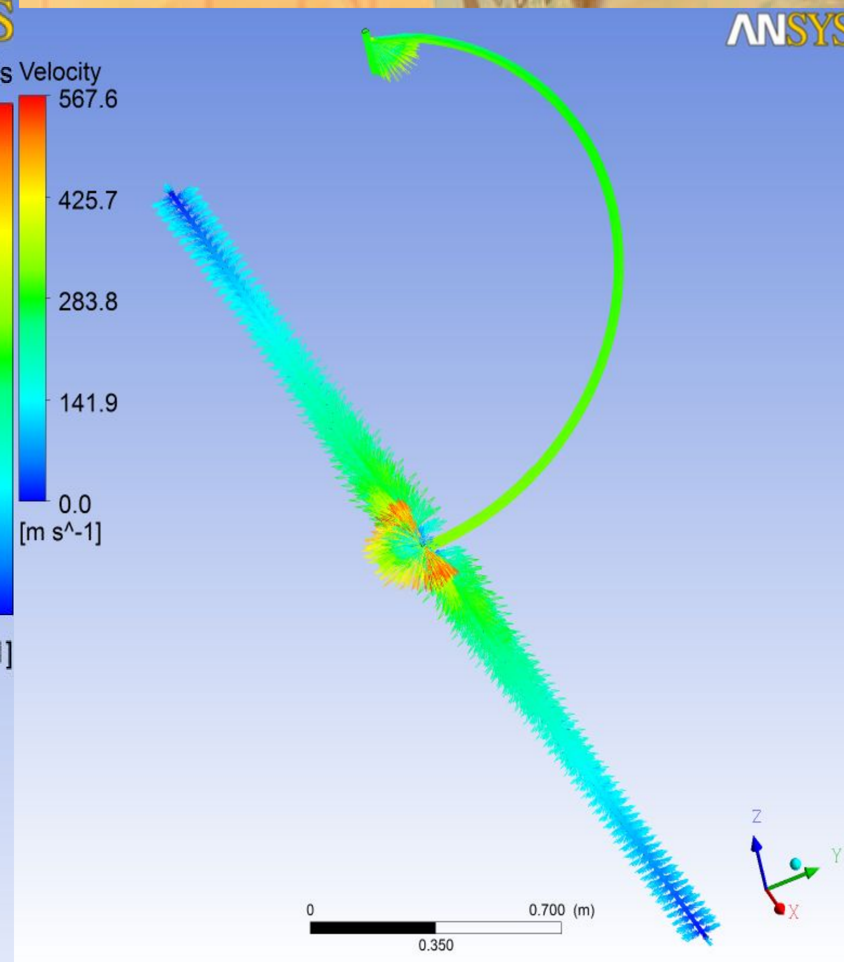


Simulation for helium flow distribution through cooling pipes in Super-FRS multiplet cryostat (3D steady flow by ANSYS CFX, 15 g/s and hole distance 50 mm)

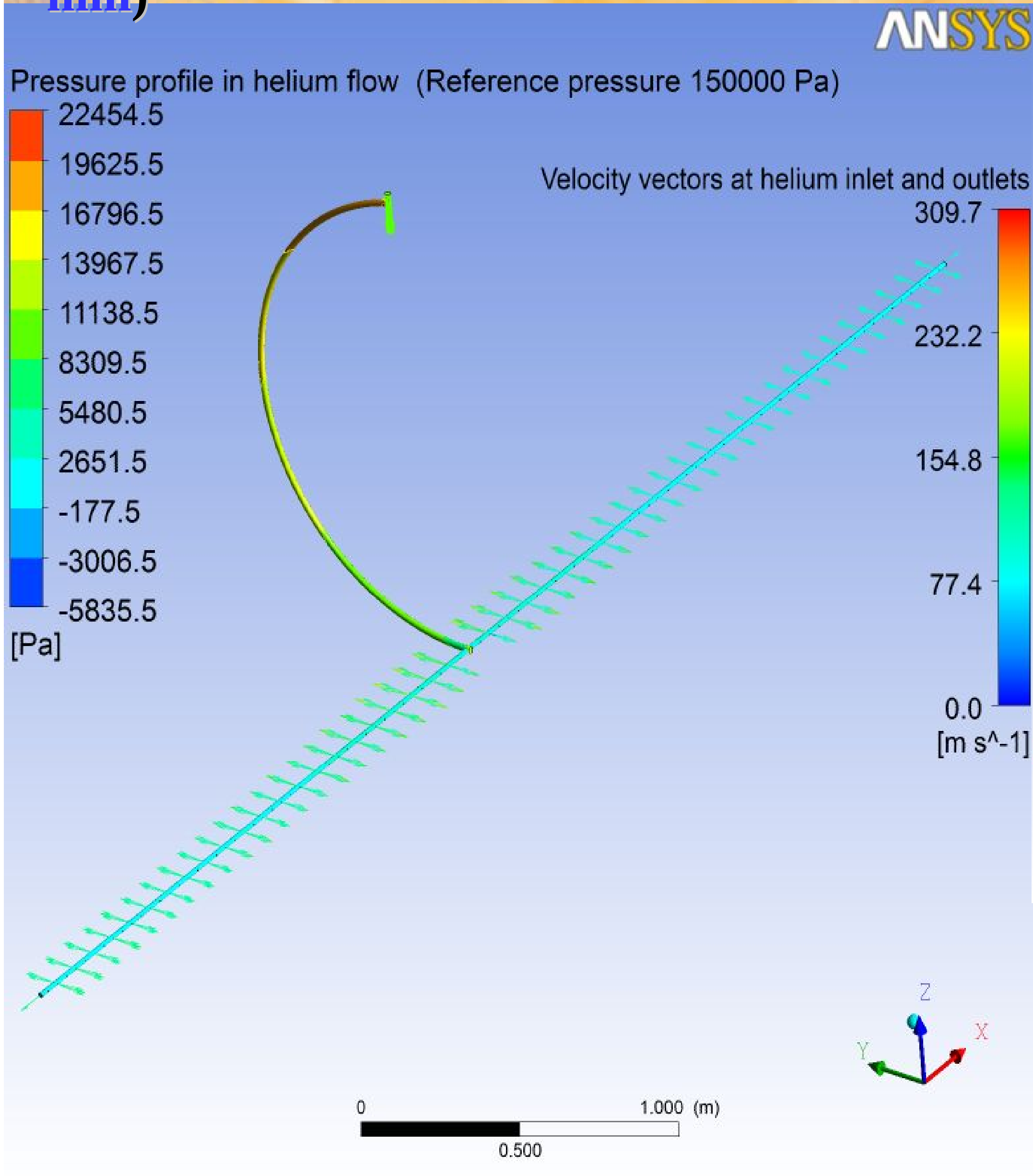


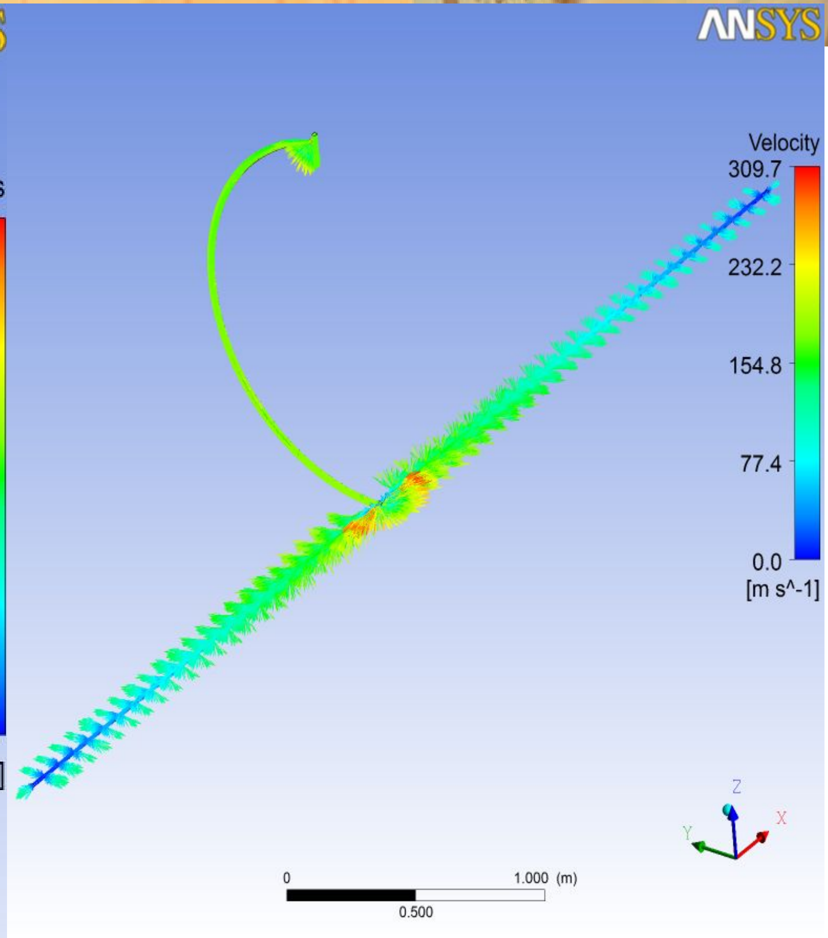
Simulation for helium flow distribution through cooling pipes in Super-FRS multiplet cryostat (3D steady flow by ANSYS CFX , 30 g/s and hole distance 50 mm)





Simulation for helium flow distribution through cooling pipes in Super-FRS multiplet cryostat (3D steady flow by ANSYS CFX , 15 g/s and hole distance 100 mm)

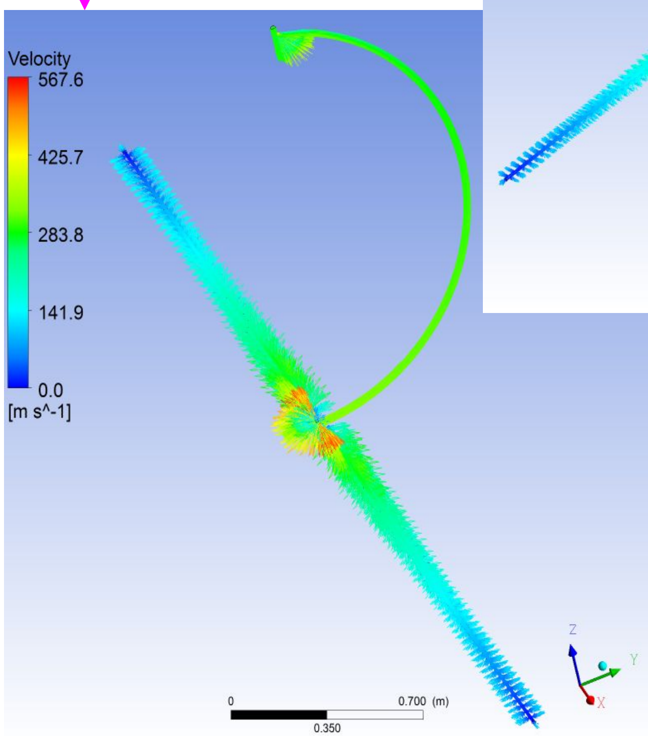


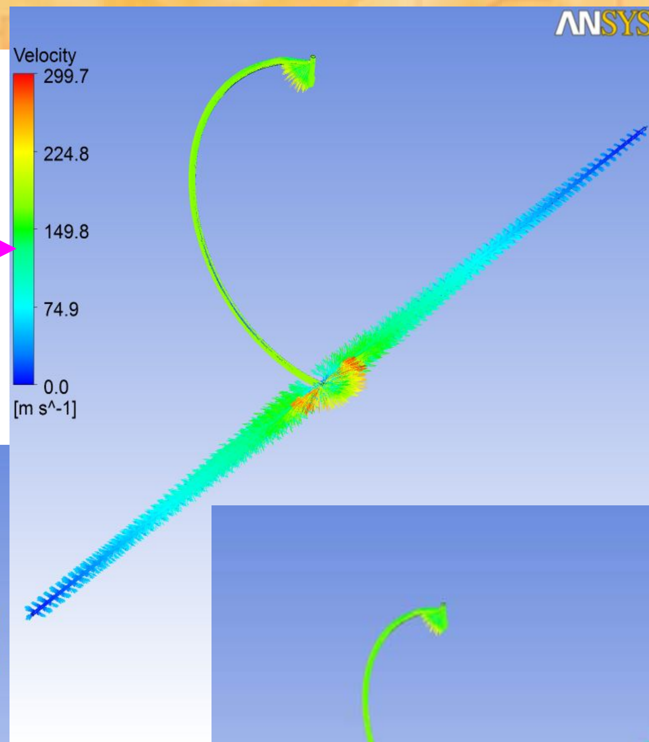


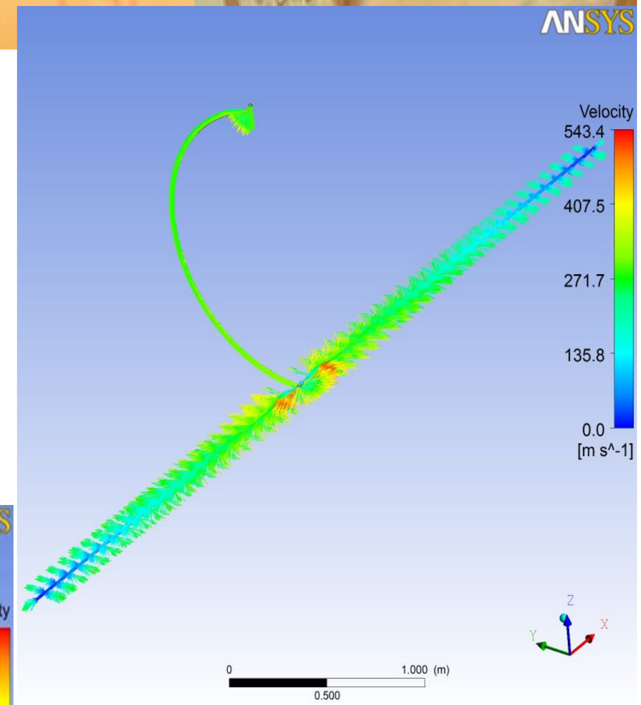
Comparison of helium flow distribution through cooling pipes with two configurations (hole distance 50 mm and 100 mm) under two flow rates (15 g/s and 30 g/s)

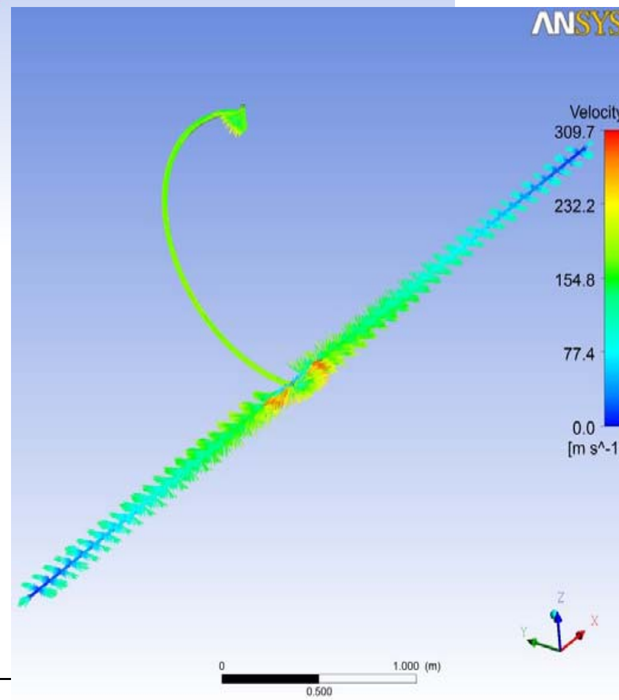
Hole distance: 50 mm

30 g/s and 15 g/s









15 g/s and 30 g/s

Hole distance: 100 mm