Document Title:	**Detailed Specification of the Cooling System of the Arc Termination Quadrupole Modules for SIS100**
Description:	This document represents the detailed specification for the manufacturing and testing of the liquid helium cooling system of the arc termination quadrupole doublet modules for SIS100 synchrotron including special injection / extraction modules.
Division/ Organization:	GSI-PBMT
Field of application:	Project FAIR@GSI

Document History:

Version	Prepared by:	Checked, Date	Released, Date	Comment
V 1.1	A. Bleile 28.07.2015			Draft version
V.1.2	A. Bleile 26.10.2016			
V. 1.3	A. Bleile 30.01.2017			

EDMS **1532603 v.3** status **Released** access **Restricted**
F-DS-MT-83e_SIS100_Cooling_Arc_Termination_QM_v1.3.pdf modified **2017-01-31 08:40**

Abstract

This document represents the detailed specification for the manufacturing, assembling and testing of the liquid helium cooling system of the arc termination quadrupole doublet modules for the arc sections of the SIS100 synchrotron. The quadrupole doublet modules can be divided into four groups regarding the cryogenic flow schemes: regular arc modules, arc termination modules, modules in the straight sections of the SIS100 and special modules for injection / extraction. This document is related to the arc termination modules and special injection / extraction modules; all other modules are specified in dedicated detailed specifications. The document includes the cryogenic flow schemes of the quadrupole doublet modules as well as the flow schemes of the quadrupole units.

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1. Purpose and classification of the document

The purpose of this document is to specify the technical requirements for the production of the 4 K cryogenic system of the arc termination quadrupole doublet modules. The arc termination quadrupole doublet modules in terms of this document are the 12 quadrupole doublet modules located at the ends of the six arc cryostats of SIS100 (Figure 1). The document specifies also the requirements to the cooling systems of two specific arc termination modules in the injection and extraction sectors of SIS100. The related modules are listed in the Table 1.

The cooling systems of the regular arc modules, as well as of the quadrupole modules in the straight sections of SIS100 are described in the related detailed specifications and are not part of this document.

This document is not related to the cooling system of the thermal radiation shield, cold-warm transitions, thermal intercepts of the support structures and other items cooled at 50 K.

Where ever requirements are specified in the General Specifications, Technical Guidelines, Common Specifications or Detailed Specifications they are only referenced in this document.

2. Abbreviations, terms and Definitions

Arc termination modules in term of this document are all quadrupole doublet modules at the ends of the six arc cryostats of the SIS100 including the special modules for the injection and extraction.

Another definitions used in this document are given in [2] section 3.1.

Besides that, this document uses following abbreviations:

QP	quadrupole magnet
QD	defocusing quadrupole magnet
F1 / F2	focusing quadrupole magnet, type 1 and 2
MC	multipole corrector magnet
ST	steering magnet
BPM	beam position monitor
LCL	current leads of the corrector magnets
VC	beam vacuum chamber
COL	cryo ion catcher (collimator)
CAP	cryo sorption pump
T	drift tube
CWT	cold-warm transition
VB	voltage breaker

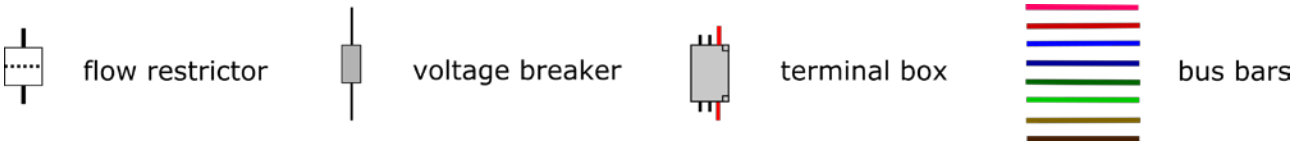
The cooling channel M1 is the cooling circuit of the magnets in the upstream quadrupole unit.

The cooling channel M2 is the cooling circuit of the magnets in the downstream quadrupole unit.

The cooling channel M3 is the auxiliary cooling circuit for the multipole corrector magnet.

The cooling channel V is the common cooling circuit of the beam vacuum chambers in both upstream and downstream parts of the quadrupole doublet.

Symbols used in the flow diagrams:



3. Scope of the technical System

3.1. System Overview

The SIS100 ring (Figure 1) has 6 arc sections with arc termination quadrupole doublets modules located on both ends of each arc (cells 4 and E). Arc termination modules specified in this document are listed in Table 1. Two arc termination modules 1.Ei and 2.4x located in the sector 5 are the special modules for injection and extraction.

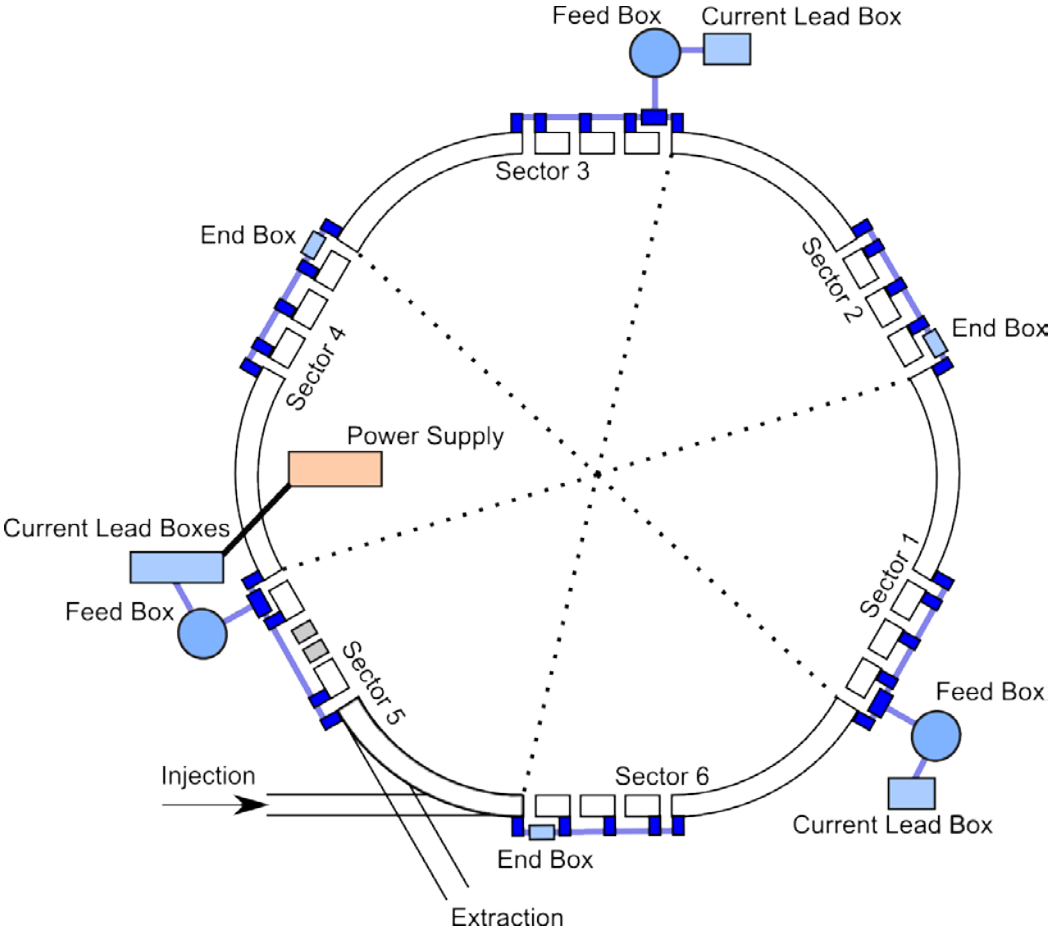


Figure 1: SIS100 cryogenic layout

Table 1: Actively cooled devices of the arc termination modules.

Module type (short name)	Module type (full name)	Q-ty	Channel M1	Channel M2	Channel M3	Channel V
1.E	MQDb-C-SF1Bb	5	MC, QD	ST, F1		VC, COL,VC
1.Ei	MQDi-C-SF1Bi	1				
2.4	QDBb-T-SF2Mb	5	QD	ST, F2	MC	VC, T, VC
2.4x	QDBx-T-SF2Mx	1				

Table 2: Actively cooled devices in the injection and extraction branches (modules 1.Ei and 2.4x).

Branch	Q-ty	Channel M	Channel V
injection	1	QP QP	VC CAP VC
extraction	1	QP QP	VC CAP VC

3.2. Content of delivery

Manufacturing of the cooling system of the QP modules is subdivided in two parts and is included in two different work packages. Section 3.2.1 describes the content of delivery for the contractor responsible for the manufacturing of the QP units. Section 3.2.2 describes the content of delivery for the contractor responsible for the integration of the QP doublet modules.

3.2.1. Quadrupole units

The Contractor responsible for the production of the quadrupole units has to accomplish all items listed below:

- Manufacturing of the helium supply header DN50 with embedded recooler. Each unit will contain one half of the header as described in the section 4.5.
- Manufacturing of the temporary support structure for the supply header
- Manufacturing of the flow restrictor
- Assembly of the heaters for the cooling channels M1, M2 and M3
- Integration of all components of the flow scheme according to chapter 4.5 (Figure 9 - Figure 12)
- Installation of the temperature sensors and heaters on the helium lines according to the instrumentation list for QP units [6]

- Factory acceptance tests (FAT) including checking of the mass flow rate and adjustment of the flow restrictors
- Documentation for all components of the cooling circuit according to the section 5 of [2]

All parts of the helium cooling circuits shall be manufactured and assembled according to the technical drawings provided by the Company. The set of the drawings for each type of the quadrupole unit is referenced in the Detailed Specification [3], section 3.3.

3.2.2. Quadrupole doublet modules

The Contractor responsible for the production of the quadrupole doublet modules has to accomplish all items listed below:

- Manufacturing of the helium supply header DN25 with embedded recooler
- Manufacturing of the helium return header DN100
- Manufacturing of the support structure for the helium headers including the supports in the end parts of the modules (end caps)
- Integration of all components of the flow scheme according to chapter 4.2 (Figure 3, Figure 4, Figure 6 and Figure 8)
- Installation of the remaining temperature sensors on the helium lines according to the instrumentation list for QP doublets [6]
- Factory acceptance tests (FAT) including checking of the mass flow rate for the channel V and adjustment of the flow restrictor
- Documentation for all components of the cooling circuit according to the section 5 of [2]

All parts of the helium cooling circuits shall be manufactured and assembled according to the technical drawings provided by the Company. The set of the drawings for each type of the quadrupole module is referenced in the Detailed Specification [3], section 3.3.

3.3. Spare Parts

No spare parts are required for the 4 K cooling system

4. System Specification

4.1. System Environment and Constraints

The arc termination modules are located on the both ends of the arc section in each sector of the SIS100.

The 4 K cooling circuits of the modules 2.4 and 2.4x are connected:

- on the upstream site to the bypass line
- on the downstream site to the helium headers of the dipole module

The 4 K cooling circuits of the modules 1.E and 1.Ei are connected:

- on the upstream site to the helium headers of the dipole module
- on the downstream site to the bypass line

The sizes and positions of the helium headers DN25, DN50 and DN100 are fixed to assure the interconnection between the magnet modules. These requirements as well as the other limits of the system and environment are specified in [2], section 2.2. The connections to the bypass line are done in the end parts of the quadrupole doublet module (end caps, Figure 2).

The cooling circuit of the arc termination modules has to be manufactured by the Contractor according to the technical drawings provided by the Company.

4.2. Cryogenic Flow Schemes of the Arc Termination Modules

The cooling circuit of the arc termination module consists of 2 or 3 parallel cooling channels M1, M2, M3 for the magnet cooling and one channel V for the cooling of the beam vacuum chambers. The actively cooled components in each channel are connected in series (Table 1).

As shown in Table 1, the actively cooled devices connected in series form four different types of the magnet cooling channels M1 / M2 / M3:

- Quadrupole only (units QDB and QDBb), 6 units
- Steerer + Quadrupole (units SF1Bb, SF1Bi, SF2M and SF2Mx), 6 units
- Multipole corrector only (units SF2M and SF2Mx), 6 units
- Multipole corrector and quadrupole (unit MQD and MQDi), 6 units

The cooling channel V has similar configuration for all arc termination modules and consists of two beam vacuum chambers and either one cryocatcher or one sorption pump. All components are connected in series.

Due to the very different flow resistance of different types of cooling channels the helium mass flow has to be adjusted for each type by means of the flow restrictor (see [2], section 3.4.1). The final sizing of the flow restrictors for each type of the cooling channel will be done after the first cold test of the respective quadrupole unit. The Company will submit the detailed design parameter for the restrictors (length and diameter of capillary). The Contractor responsible for the integration of the Quadrupole Doublet Modules shall manufacture the flow restrictor for the cooling channel V (cooling of the beam vacuum chambers). The flow restrictors for the magnet cooling channels M1, M2 will be manufactured by Contractor responsible for the manufacturing of the Quadrupole Units (see also section 3.2).

The helium flow schemes of each type of the arc termination QP-modules are presented on the Figure 3 and Figure 4. The superconducting bus bars for the main dipoles and quadrupoles are figured as color lines according the notation described in [4]. The bus bars are labeled as DP, F1, F2 and QD with additional letters i and o for the inner and outer bus bars [4]. The red lines between the local current leads (CL) and the coils of the steerer or multipole corrector (ST, MC) denote the superconducting bus bars of the corrector magnets. All bus bars are electrically insulated from each other or from the ground by voltage breakers ([2], sect. 3.4.5).

The cold-warm transitions (CWTs) are equipped with thermal intercepts passively cooled at 50 K.

The cooling circuits of the injection and extraction branches (Figure 6, Figure 8) are connected to the helium supply and return headers located in the ring branches of the modules 1.Ei and 2.4x)

Following tube sizes shall be used:

- Ø8x1 for the supply headers A1 and A2
- Ø18x1 for the return header B

4.2.1. Cooling circuit of modules 1.E / 1.Ei

The helium flow schemes of the modules1.E / 1.Ei are presented in the Figure 3. The cooling circuit consists of two cooling channels M1 and M2 for the magnet cooling and one cooling channel V for the cooling of two beam chambers and one ion catcher.

The module 1.Ei has additional connections to the injection branch (see section 4.3).

The label CL on the flow scheme denotes the cold terminals of the current leads for the multipole corrector magnet (3 pairs) and for the steering magnet (2 pairs).

4.2.2. Cooling circuit of modules 2.4 / 2.4x

The helium flow schemes of the modules 2.4 and 2.4x are presented in the Figure 4. The cooling circuit consists of three cooling channels M1, M2 and M3 for the magnet cooling and one cooling channel V for the cooling of two beam chambers.

The module 2.4x has additional connections to the injection branch (see section 4.4)

The label CL on the flow scheme denotes the cold terminals of the current leads for the multipole corrector magnet (3 pairs) and for the steering magnet (2 pairs).

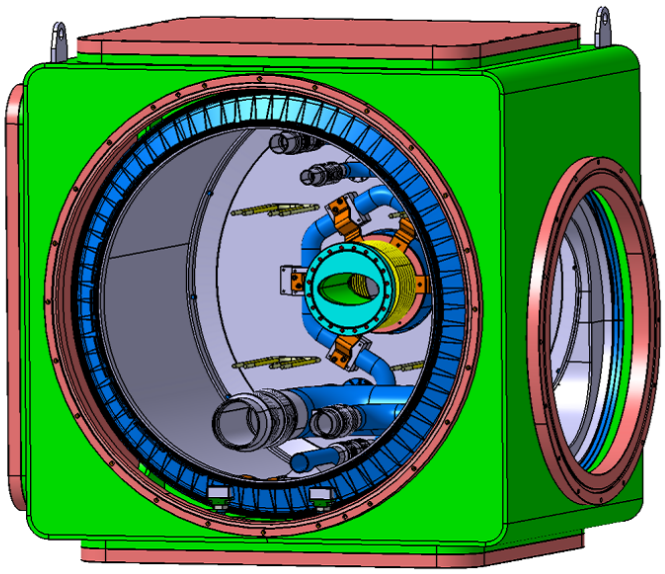


Figure 2: End cap of the arc termination modules

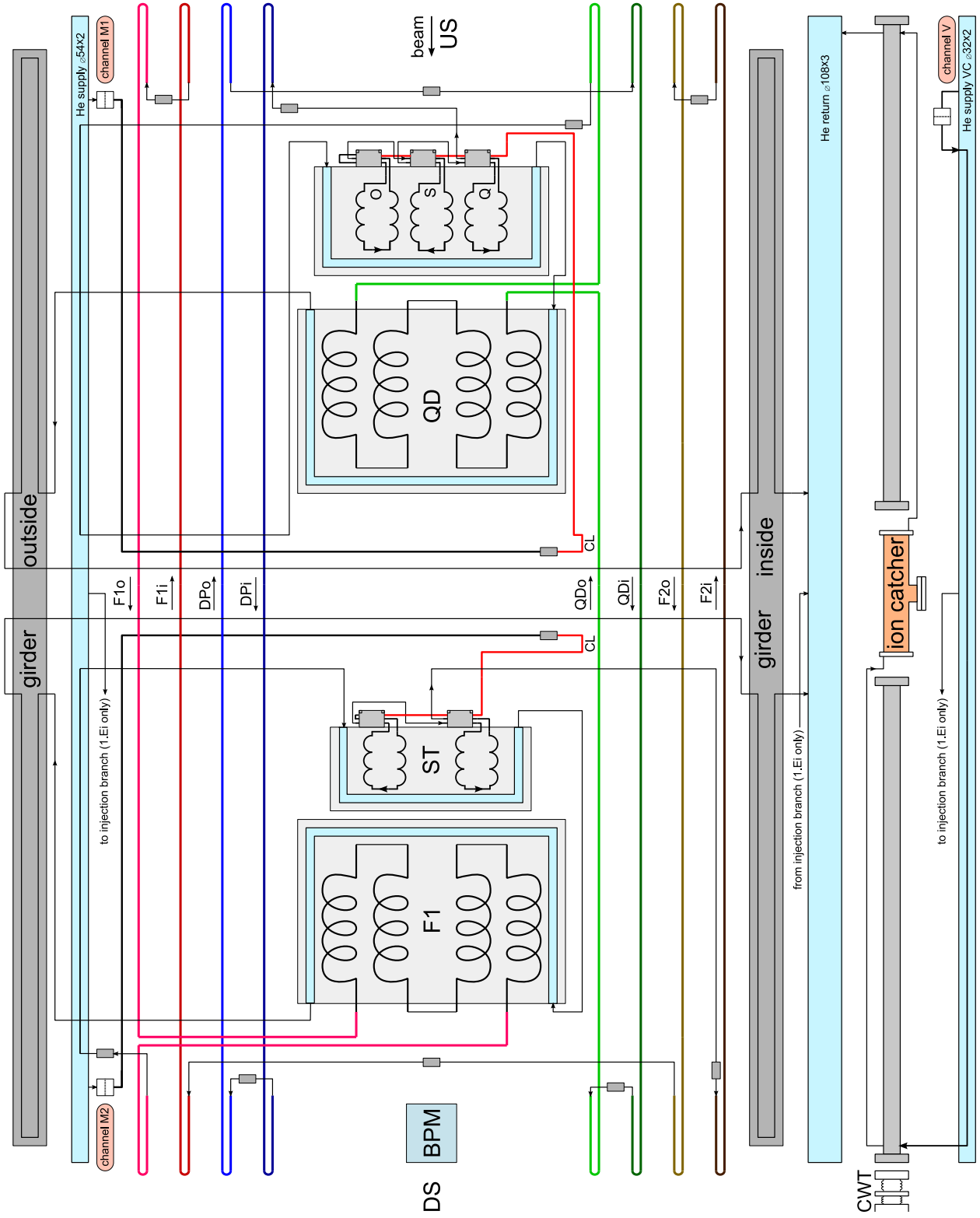


Figure 3: Flow scheme of the module 1.E / 1.Ei

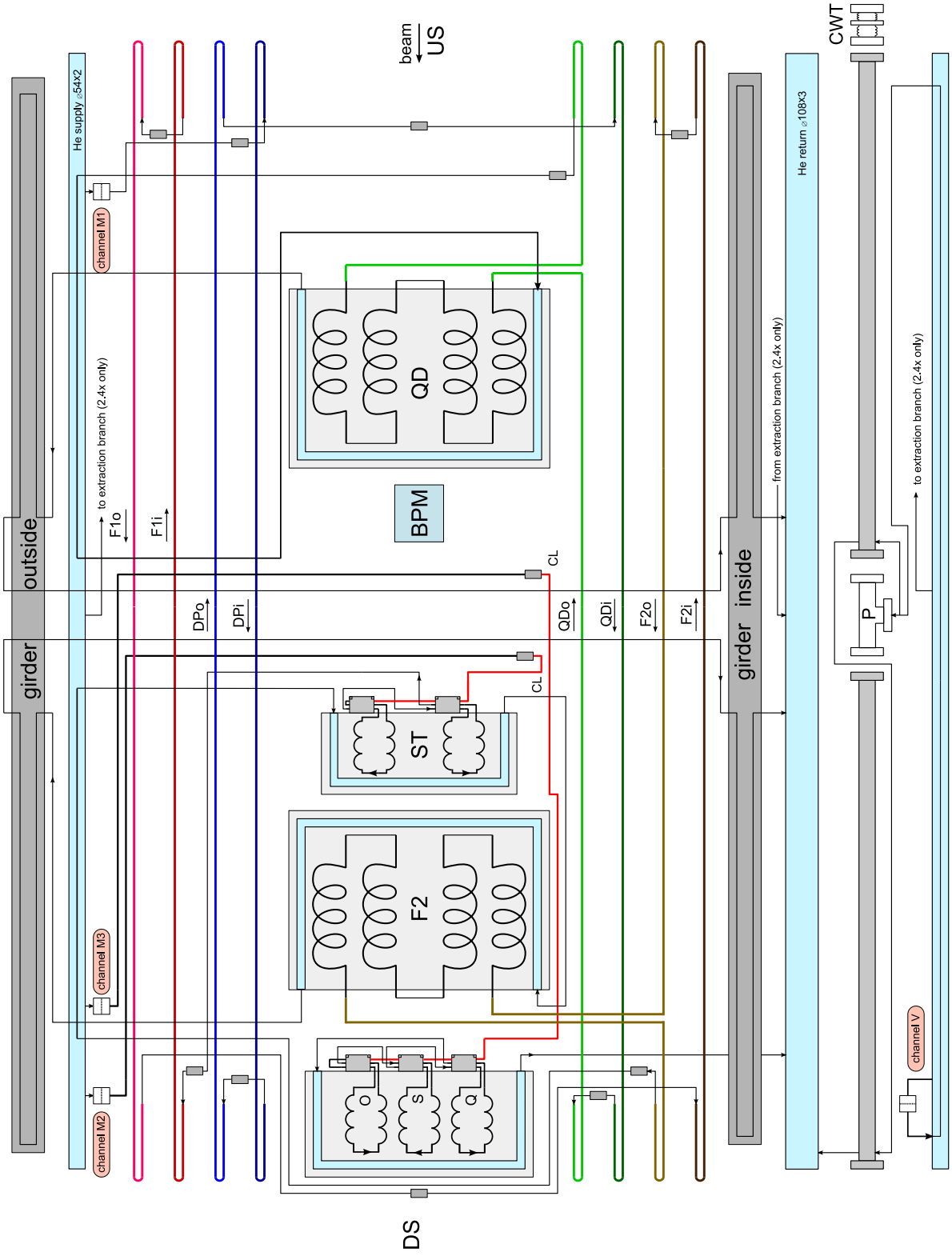


Figure 4: Flow scheme of the module 2.4 / 2.4x

4.3. Injection branch

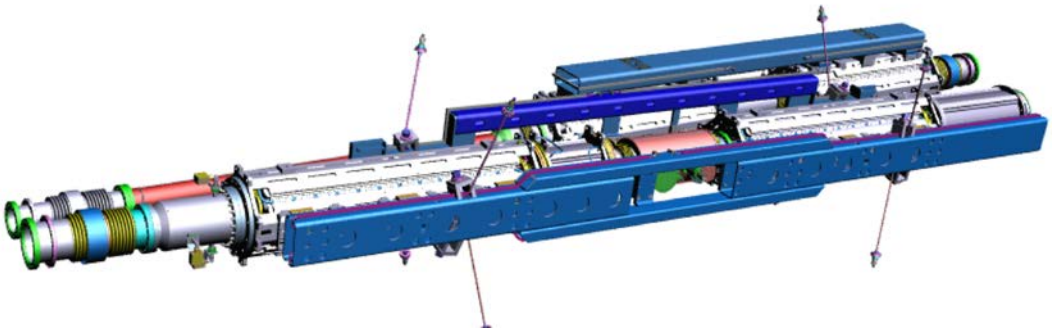


Figure 5: Cold mass of the module 1E.i

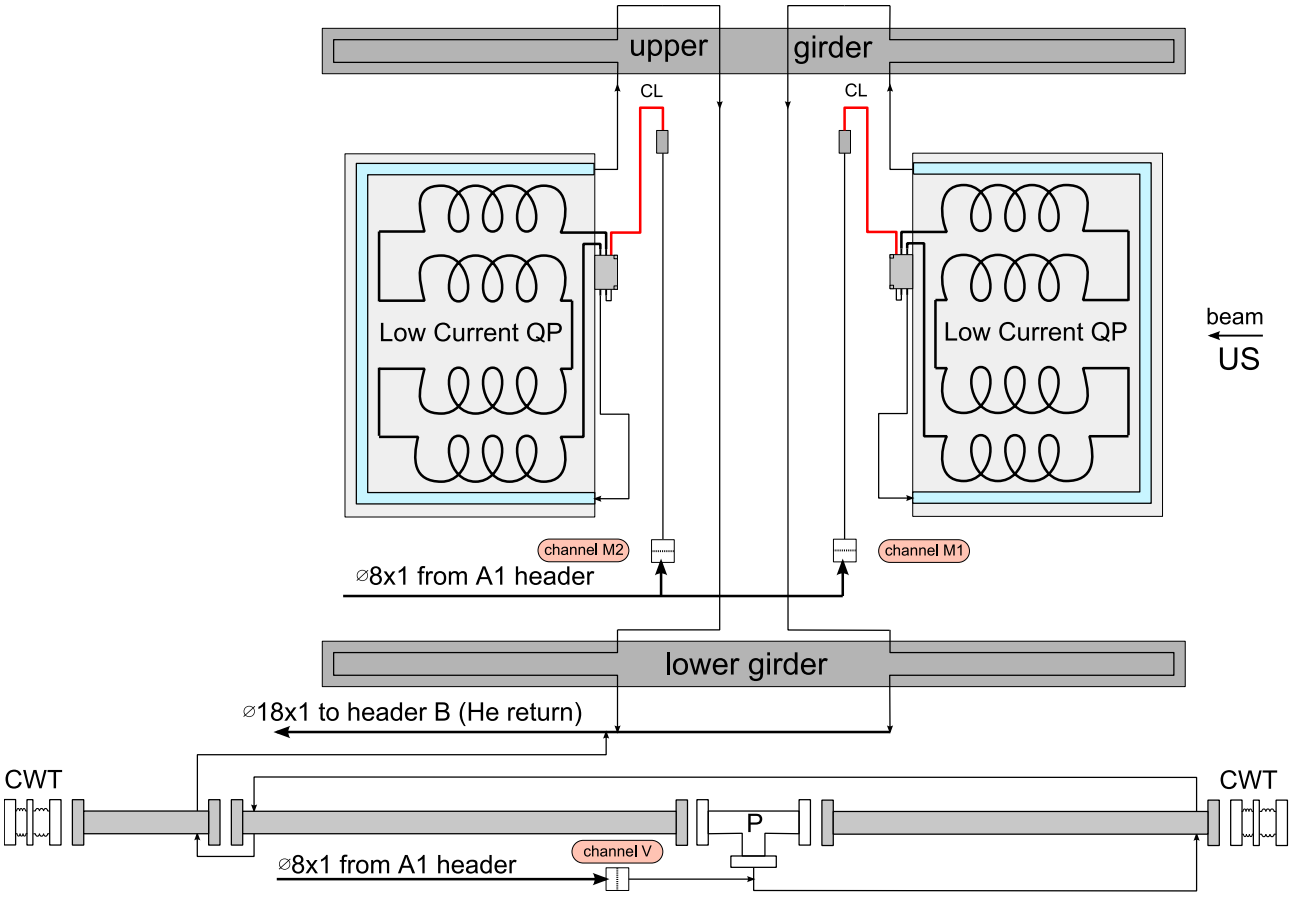


Figure 6: Flow scheme of the injection branch (module 1.Ei)

4.4. Extraction branch

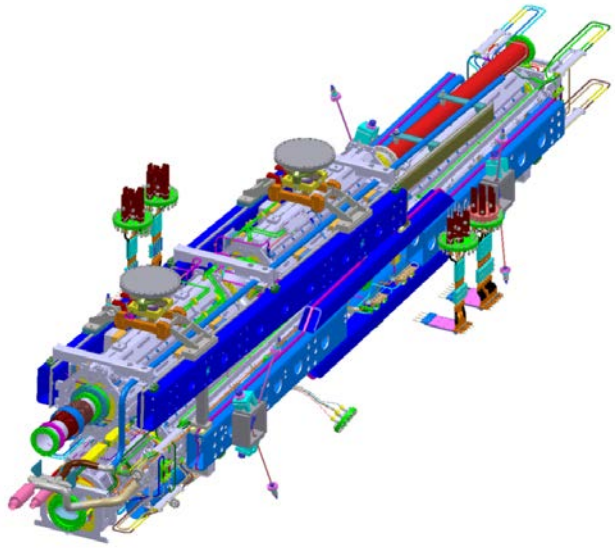


Figure 7: cold mass of the module 2.4x

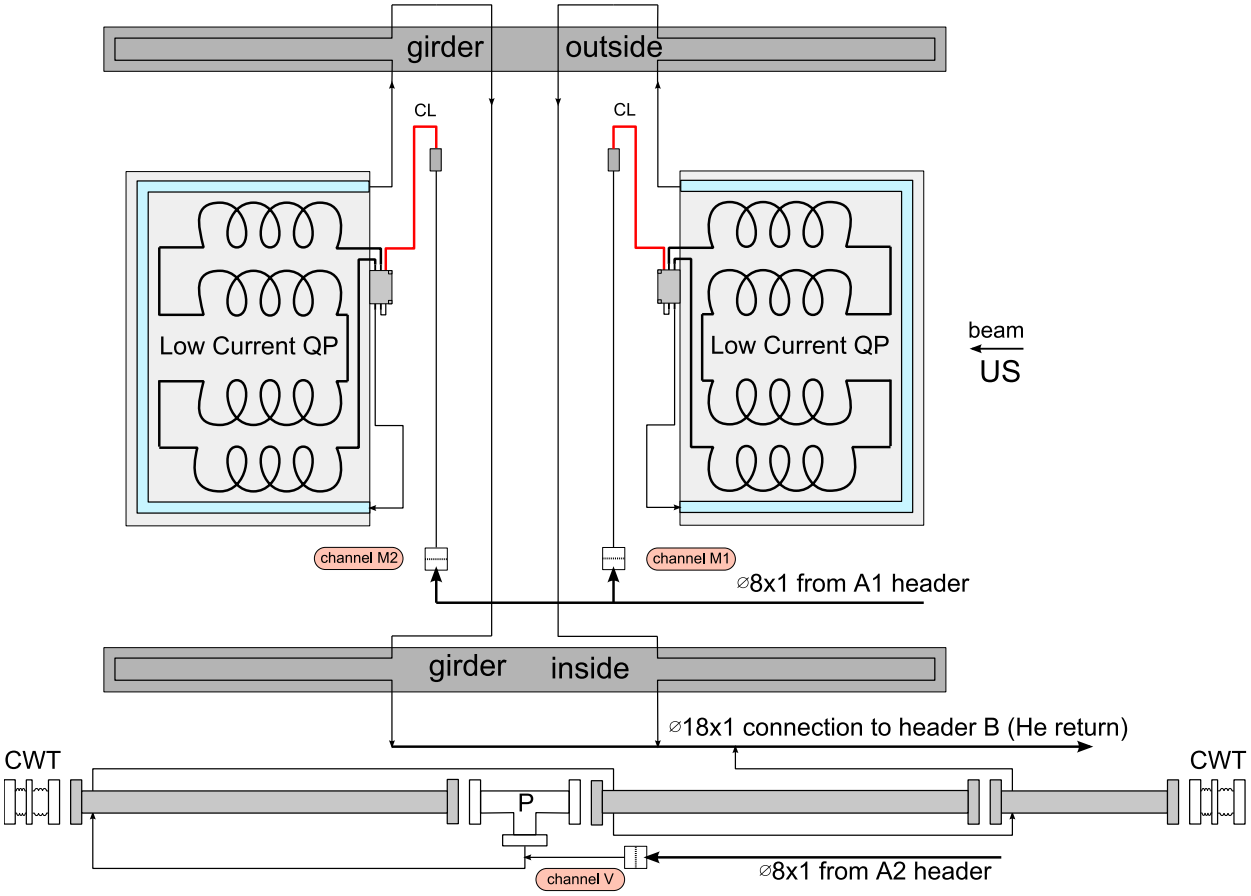


Figure 8: Flow scheme of the extraction branch (module 2.4x)

4.5. Flow schemes of the quadrupole units

The main parts of the magnet cooling channels M1 / M2 shall be assembled and tested at helium temperature as described in [2], section 4.4 (cold testing of quadrupole units). The assembled quadrupole units shall contain all hydraulic elements needed for testing of the hydraulic resistance of the helium circuit. The elements of the flow schemes to be tested are specified below.

4.5.1. Upstream units

The flow schemes of the assembled upstream QP units are shown in Figures 9 – 10.

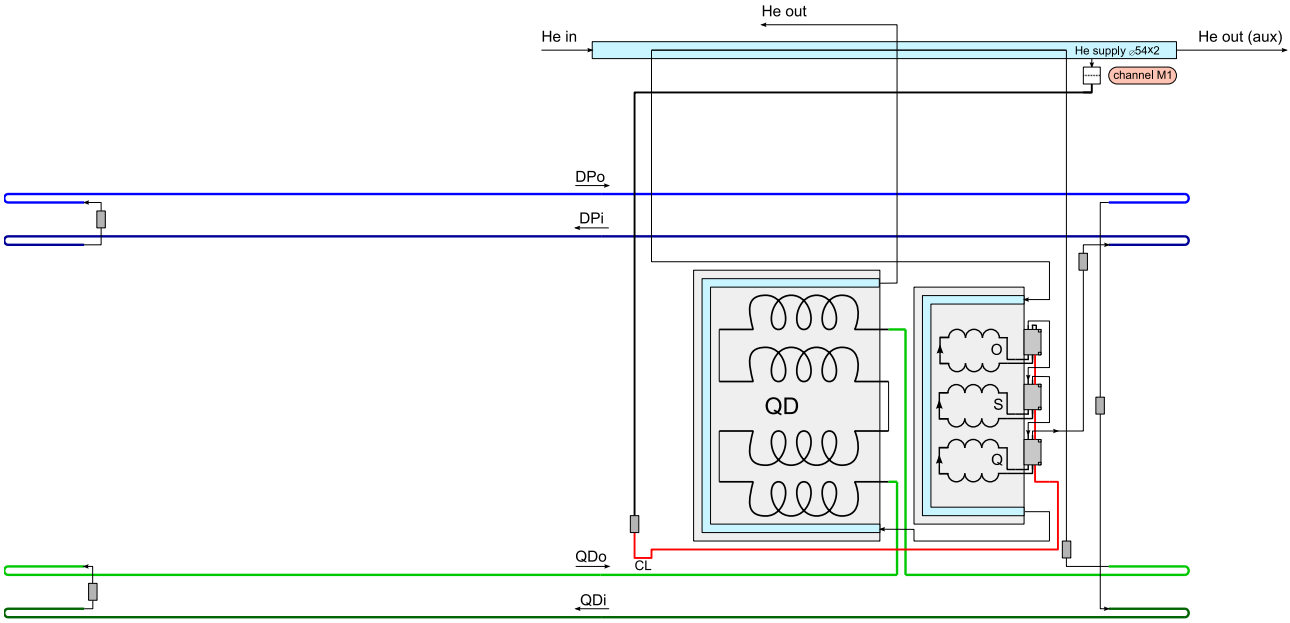


Figure 9: Upstream unit MQD (Modules 1.E, 1.Ei)

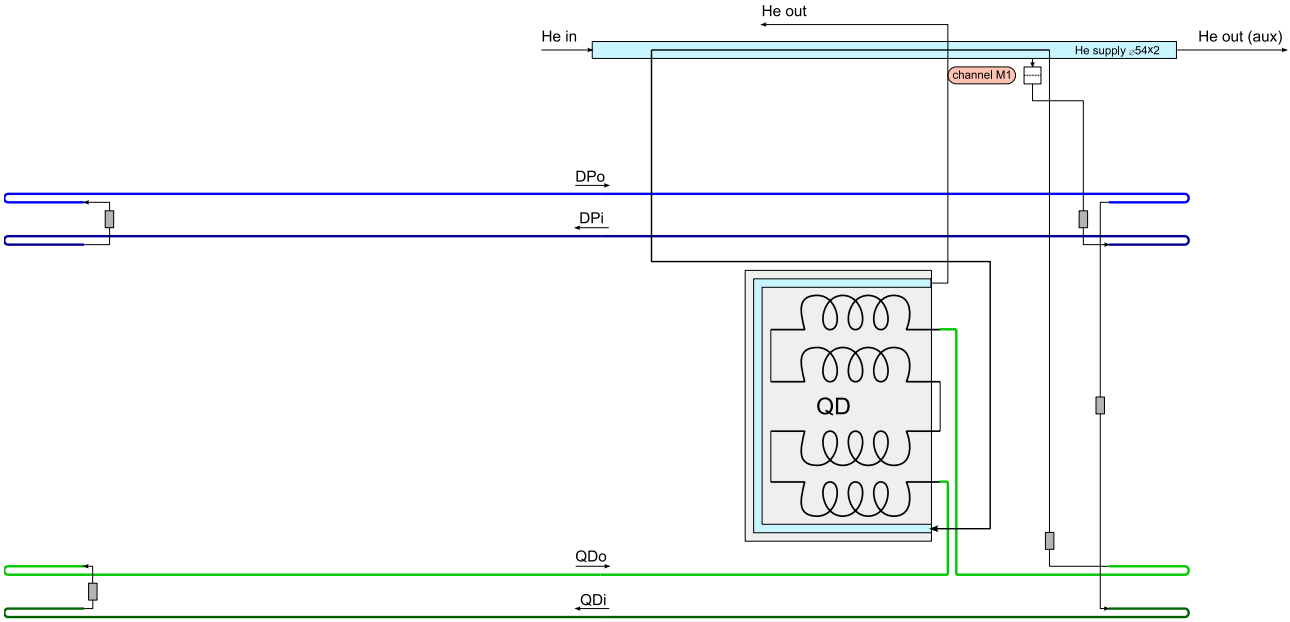


Figure 10: Upstream unit QDBb (Modules 2.4, 2.4x)

4.5.2. Downstream units

The flow schemes of the assembled downstream QP units are shown on Figures 11 - 12.

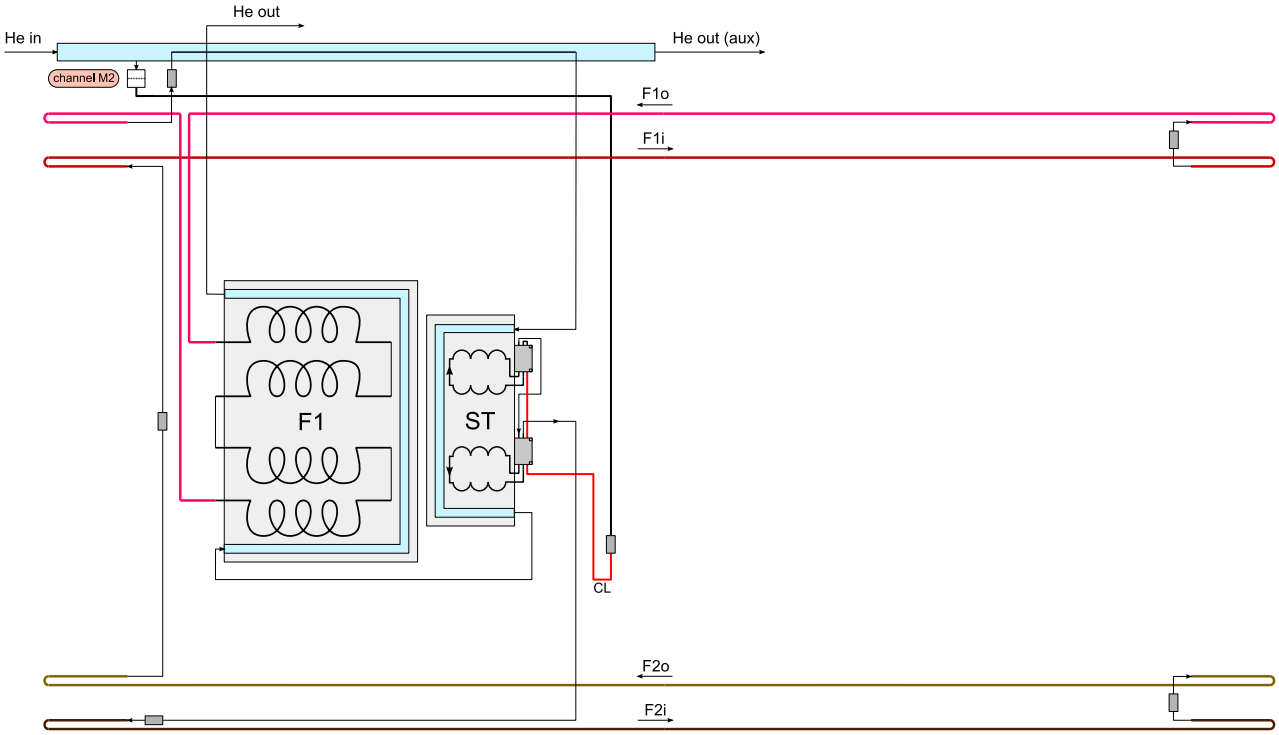


Figure 11: Downstream unit SF1Bb (Modules 1.E, 1.Ei)

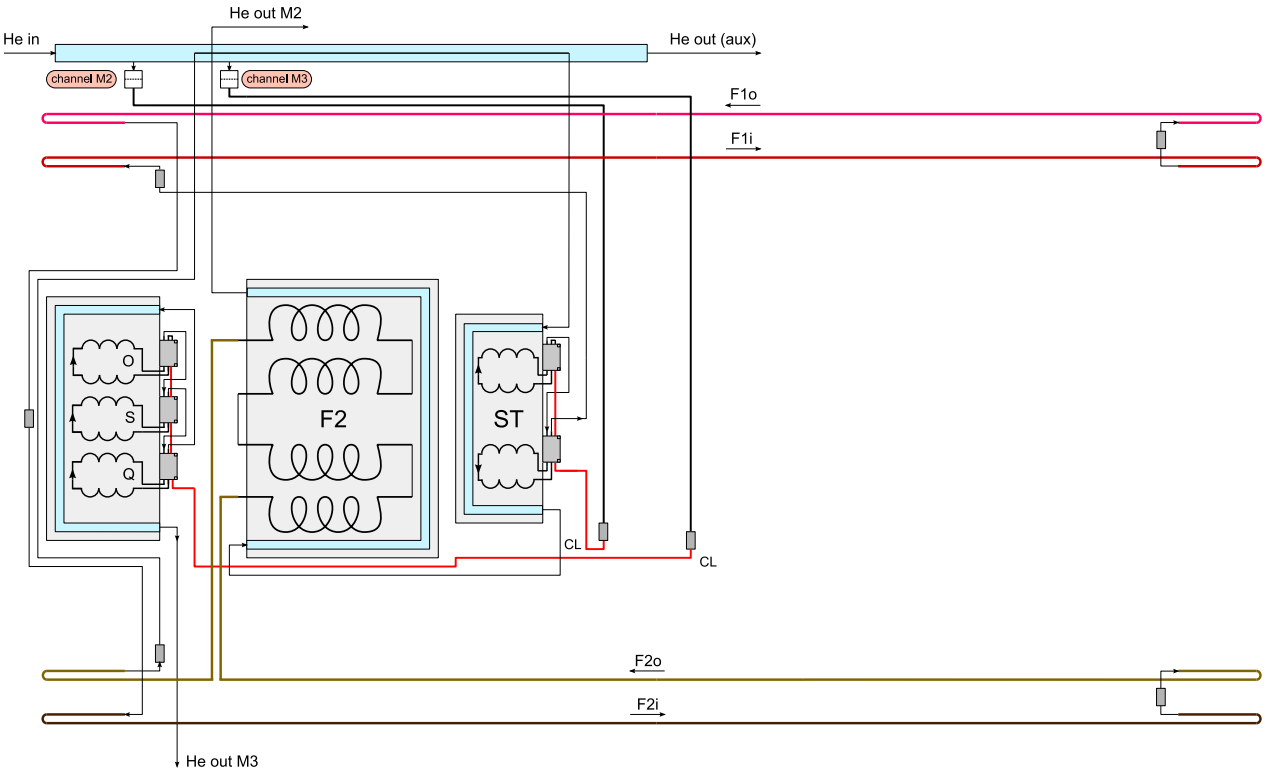


Figure 12: Downstream unit SF2M (Modules 2.4, 2.4x)

4.6. System Components (technical requirements)

The most important components of the flow schemes like superconducting coils and busbars, magnet yokes, beam vacuum chambers, voltage breakers etc. are described in appropriated specifications and will be not specified in this document.

Beside these components the main parts of the cooling system are:

- Helium supply header DN50 with two embedded heat exchangers (recoolers). Each header will be split in two parts in the mid of the length and each part will be fixed on the quadrupole unit by a temporary support structure. Both parts of the header will be cold tested independently and welded together within integration of the QP doublet.
- Helium supply header DN25 with one embedded heat exchanger
- Helium return header DN100
- Flow restrictors [2], 3.4.1
- Connection tubes [2], 3.3

The sizes, positions and technical requirements of the helium supply and return headers DN25, DN50 and DN100 for all quadrupole modules in the arc sections are given in [2], section 3.3.

The helium headers are fixed to the common girders by one fixed and two sliding bearings, as described in [2], section 3.3.

Each cooling channel will be equipped with temperature sensors according to the instrumentation list of the quadrupole module [6]. The sensors will be mounted on the helium tubes and will operate in a vacuum environment.

Each magnet cooling channel M1, M2 and M3 will be equipped with a heater ([2], section 3.10.2) according to the instrumentation list. The heaters are mounted on the helium tubes in vacuum and are located just before the flow restrictors (upstream).

5. Quality Assurance, Tests, and Acceptance

The Contractor responsible for the manufacturing of Quadrupole Units as well as the Contractor responsible for the integration of the Quadrupole Doublet Modules shall perform a series of acceptance and performance tests on the assembled cooling circuit as specified in [2], section 4.2):

1. Document compliance according to the Pressure Equipment Directive
2. Visual inspection
3. Dimensional inspection
4. Pressure test according to the Pressure Equipment Directive
5. Integral leak test
6. Flow rate tests and adjustment of the flow restrictors
7. Test of instrumentation installed on the piping (temperature sensors, heaters)

The Company will perform additional tests of the cooling circuit at helium temperature as described in [2], section 4.3 within the Site Acceptance Test of the magnet module.

6. Documentation

The requirements for the documentation are specified in [2], section 5

7. Related Documents

[1] F-GS-F-01e, FAIR General Specification, EDMS Nr. 1365092

[2] F-CS-MT-04e, Common Specification of the cooling system of the superconducting SIS 100 magnets, EDMS Nr. 1274168

[3] F-DS-MT-107e, Detailed specification for Component Production, Cryostat Construction and Module Integration for the SIS100 Quadrupole Doublet Modules, EDMS Nr. 1533009

[4] F-DS-MT-77e. Detailed Specification, Bus-Bars and Voltage Taps in SIS100 2.5 Doublet, EDMS Nr. 1319884.

[5] F-DS-K-20e, Detailed Specification of the Local Cryogenic By-Pass System for SIS100, EDMS Nr. 1261140

[6] F-DS-MT-108e, Detailed specification of instrumentation for SIS100 Quadrupole-Modules, EDMS Nr. 1561225