Annex 3

To the Collaboration Contract

Between the FAIR GmbH and BINP

For

The design, prototyping, production, delivery, assembly and testing

of the Dipole Magnet

As part of the Work Package PSP 1.1.1.7

For the CBM experiment

This Annex is an integral part of the said Collaboration Contract between the FAIR GmbH and BINP.

Technical Specifications

The technical specifications for BINP's Component for Delivery are specified in the:

1. *General Technical Specifications for Experiments at FAIR*
2. Specific *Technical Specifications*

and attached to this document.

In case of discrepancies between the documents listed above, the statements of the *Specific Technical Specification* prevail.

Established in Darmstadt in three originals.

Authorised to sign on behalf of the FAIR GmbH

Name: Prof. Dr. Boris Sharkov

Position: Chairman of the Management Board /Scientific Managing Director

Date:

Signature:

Name: Ursula Weyrich

Position: Administrative Managing Director

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Name: Prof. Dr. Pavel Vladimirovich Logachev, Director BINP

Position: Director

Date:

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Authorised to sign on behalf of the CBM Collaboration,

To certify that the CBM Collaboration agrees with this Collaboration Contract

Name: Prof. Dr. Peter Senger

Position: CBM Spokesman

Date:

Signature:

Document Title:	**CBM Dipole Detailed Specification**
Description:	This document describes the superconducting dipole magnet of the Compressed Baryonic Matter (CBM) experiment at FAIR.
Division/ Organization:	CBM/GSI
Field of application:	CBM

Document History:

Version	Prepared by:	Checked, Date	Released, Date	Comment
V 1.0	G.Moritz	22.04.2014		
V 1.1	G.Moritz	08.05.2015		
V1.2	G.Moritz, P. Senger, W.F.J. Mueller, W. Niebur M. Martinez-Lopez, M. Kauschke Y. Xiang, C. Betz, P. Szwangruber C. Muehle, C. Will, I. Pschorn	28.04.2016		
V1.3	G.Moritz, P. Senger, W.F.J. Mueller, W. Niebur M. Martinez-Lopez, M. Kauschke Y. Xiang, C. Betz, P. Szwangruber C. Muehle, C. Will, I. Pschorn A. Kraemer, H. Mueller	24.05.2016		

V1.4	G.Moritz C. Betz M. Martinez-Lopez	31.8.20016		Chapter of Cryogenic Control System (4.12) modified Chapter 4.9 modified (Branchbox added) Field map part of the SAT Minor corrections
V1.5	G.Moritz M. Martinez-Lopez W.F.J. Mueller	17.10.2016		Misc. changes after BINP meeting Parameter and tolerances modified Installation space inserted QA Cryogenics
V1.6	W,F.J. Mueller	25.10.2016		Added STS Installation space including space for support structure (rail system) Added field mapping specification

Abstract

This document describes the superconducting dipole magnet for the Compressed Baryonic Matter (CBM) experiment at FAIR. The magnet houses the Silicon Tracking System (STS), and provides a magnetic field integral of 1 Tm which is needed to obtain a momentum resolution of $\Delta p/p=1$ % for track reconstruction at FAIR beam energies.

The magnet gap has a height of 144 cm and a width of 300 cm in order to accommodate the STS with a polar angle acceptance of $\pm 25°$ and a horizontal acceptance of $\pm 30°$. The magnet is of the H-type with a warm iron yoke/pole and cylindrical superconducting coils in two separate cryostats like the SAMURAI magnet at RIKEN. The potted coil uses Nb-Ti wire with a total Cu/SC ratio of more than 9.1 . The coil case made of stainless steel contains liquid helium for cooling. The vertical force in the coils is about 250 tons. The cold mass is suspended from the room temperature vacuum vessel by suspension links. Cylindrical support struts compensate the vertical forces. The energy stored in the magnet is about 5 MJ. The magnet will be self-protecting. However, in order to limit the temperature rise to 100 K in case of a quench, the energy will be dumped in an external resistor.

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1. Purpose and classification of the document

The purpose of this document is to specify the detailed magnetic and technical requirements of all parts and components of the superconducting CBM dipole. Wherever requirements are specified in the General Specifications and Technical Guidelines they are only referenced in this document.
This document belongs to the Technical part of the contract. All commercial and organisational conditions are not treated here.
General regulations and requirements are specified in the General specification and the Technical guidelines. They are only referenced here.

2. Abbreviations, terms and Definitions

Abb. Term	Definition
GSI	Helmholtzzentrum für Schwerionenforschung
FAIR	Facility for Antiproton and Ion Research in Europe GmbH
CBM	Compressed Baryon Matter
HADES	High Acceptance DiElectron Spectrometer
STS	Silicon Tracking System
MUCH	Muon Chamber
RICH	Ring Imaging Cherenkov detector
TRD	Transition Radiation Detector
FAT	Factory Acceptance Test
SAT	Site Acceptance Test
TDR	Technical Design Report
FB	Feedbox
BB	Branchbox
DB2	Distribution Box 2
CDR	Conceptual Design Review
PDR	Preliminary Design Review
FDR	Final Design Review
QUENCH	Transition of the magnet from superconducting state to normalconducting state
QP/QD	Quench Protection/Quench Detection System
MPL	Multi Purpose Line
NMR	Nuclear Magnetic Resonance
PC	Power Converter
P&ID	Piping and Instrumentation Diagram

3. Scope of the technical System

3.1. System Overview

The CBM superconducting dipole magnet is a central part of the detector system of the CBM experiment. A general review of the physics of compressed baryonic matter, the theoretical

concepts, the available experimental results, and predictions for relevant observables in future heavy-ion collision experiments can be found in the CBM Physics Book [1]. The target station and the Silicon Tracking System are placed in the magnet gap. The magnet has to provide the vertical magnetic field with a bending power of 1 Tm over a length of 1m from the target.
Figure 1 and Figure 2 show an overview of the experimental facility with the dipole and with different detectors.

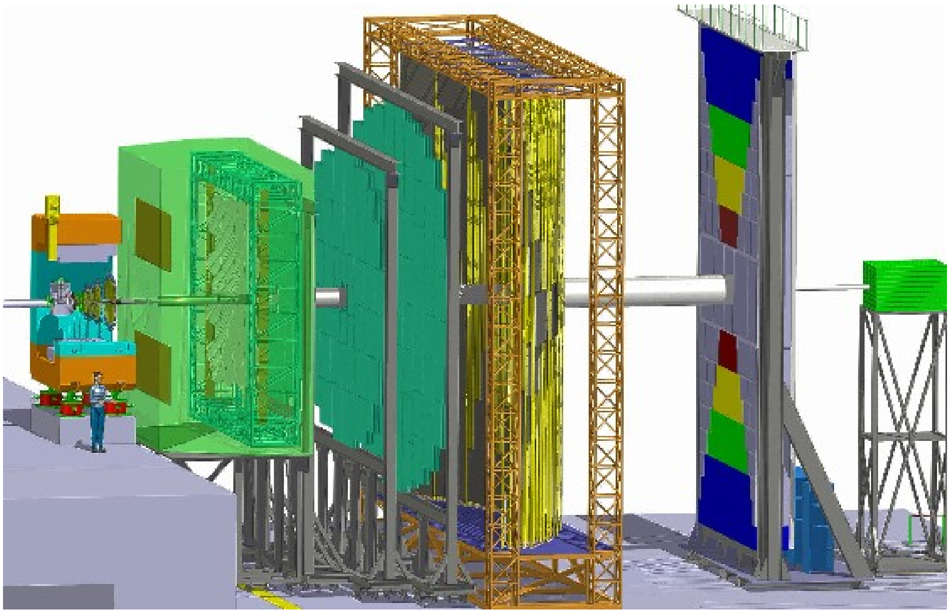


Figure 1 : The CBM experimental facility with the electron detectors RICH and TRD

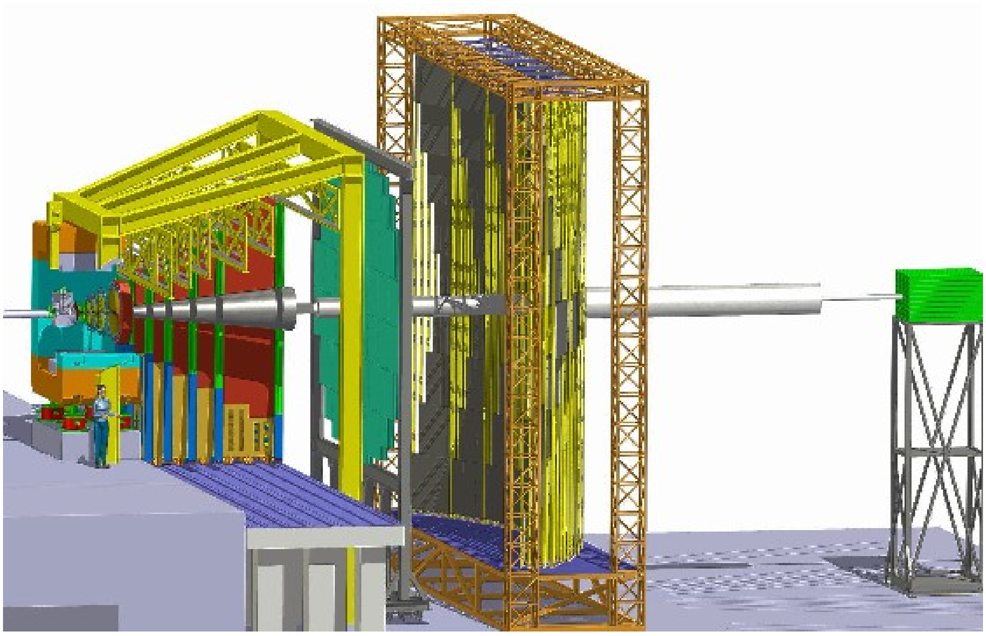


Figure 2: The CBM experimental facility with the muon detection system MUCH

3.2. Scope of Deliveries

In General

The scope of delivery includes:

- Magnetic and engineering design of the magnet including all necessary tools, dimensioning calculations for stands and lifting units, etc.
- Engineering design of the Feed Box and the Branch Box incl. the cryogenic connection line
- Production and delivery of the magnet (consisting of yoke, cold masses and cryostats, alignment components, Feed box and stand), the Branch Box, the cryogenic connection line and all tools
- Engineering design, production and delivery of the Power Converter
- Transportation of all components to site, complete assembly and the preparation of installation
- Documentation

Scope of delivery by company (FAIR GmbH)

Scope of delivery of Contractor

Referring to the work breakdown structure (work breakdown structure element PSP code = 1.1.1.7):
The contractor will deliver the complete magnet system with all necessary components:

- Magnetic (2D/3D) and engineering design of the magnet including all necessary tools, dimensioning calculations for stands and lifting units, etc. This task includes the generation of a complete set of drawings on paper and on CD (3D- Model in Catia V5 or Step, drawings in CATIA V5 or DXF and pdf), also for the special production tools
- Production and delivery of the magnet (consisting of yoke, cold masses and cryostats, current leads, Feed box and Branch box including the cryogenic interconnection line, alignment components and stand
- All cryogenic and insulation vacuum instrumentation for cryostats, current leads, Feed box and Branch box according to [27] ,[28],[30], [31])
- Power Converter and Quench protection and detection scheme
- All tools (lifting units, turning units, etc.) which are necessary for assembly and transportation of the magnet on site
- Security check and certification of TÜV -if necessary- for the tools
- Security check and TÜV certification of the magnet, the Feed box, the Branch box (European pressure vessel regulations, German “Druckbehälterverordnung”, etc.) .) and all related documentation (risk assessment, HAZOP) needed to reach the CE conformity for the completed system
- Quality assurance of all components
- Test assembly of magnet at contractor site, operation up to full field during FAT
- Field mapping at contractor site of core and downstream fringe field (see section 5.2)
- Transportation of all components to site
- Assembly and preparation of installation on site
- Documentation which will include: all layout drawings, detailed drawings of important components, part lists, welding procedures, thermal calculations, mechanical calculations and a mechanical analysis with failure modes (e.g. loss of insulation vacuum), description of the cryogenic control system as well as Process and Instrumentation Diagrams (P&ID)

for the cryogenic process. The P&IDs should be following the name convention defined in a Technical Guideline which is now under development and which will be supplied to the Contractor as soon as available

The magnet has to be equipped with references for fiducialisation as well [14].

The contractor is responsible for calculation of the stiffness and for the protection against buckling of the stands during transportation and at installation position. The results are part of the documentation of the components.

Further points concerning the scope of delivery and tasks of the contractor are defined in [7], especially chapter 2.6.

Parts of the magnet as for example the conductor, the leads etc. can be delivered by a 3rd party.

Tasks of different suppliers

If components are produced by a 3rd party the following tasks have to be carried out by the contractor and the 3rd party:

Contractor:

- Organisation of the cooperation between contractor and 3rd party
- Review of component design parameters, interfaces and time schedule in coordination with the 3rd party
- Participation at the acceptance test of the components at the 3rd party's site
- Check of incoming components which are delivered by the 3rd party to the contractors site (completeness, damaging, labelling etc.) and documentation of the results
- Installation of components into the magnets
- FAT of the components after their installation in the magnets

3rd party:

- Organisation of the cooperation between 3rd party and contractor
- Design of components
- Review of design parameters, interfaces and time schedule with the contractor
- Production of components
- FAT: the contractor and the Company will take part in the FAT of the defined components
- Documentation, see chapter 6
- Delivery of components to Contractor or Company site

4. Functional and Technical Specification

4.1. Limitations and specific surrounding conditions

Dimensions
Hall entrance: 4.5m x 4.6m (width x height)
Lifting hole: 6m x 10m, 29m from hall entrance
Cave dimensions: 36.7m x 21.7m x 17.4m (length x width x height). The Cave is shared with HADES experiment. For the final distribution of the CBM hardware inside the Cave, the Contractor should contact the Company.
Height of the beam axis over magnet base: 2.7m
Magnet base (concrete) over floor level: 3. 0m
Cryogenic distribution: There are several cryogenic boxes placed on a balcony inside the CBM Cave. For their description and approximate distribution refer to Section 4.9. For the final distribution of the cryogenic hardware the Contractor should contact the Company.

Weight limits
Weight restriction: crane 30 tons (including lifting jacks) in hall and cave
Maximum floor load: 100 tons/m^2

4.2. Interfaces

Installation Space
Overall installation space of the magnet incl. Feed Box:
Width < 6400 mm
Height < 5500 mm over magnet base (concrete)
Length: not longer than yoke (exception: dismountable field clamps)

Installation space Branch Box:
Width: enough space
Height: < 2500 mm
Depth (defined by the width of the balcony): < 1200 mm

Installation space for the cryogenic transfer lines (looking towards the wall, refer to Figure 4):

- DB2 to BB: coming from the top left
- BB to CBM dipole Feed: going to the left, downwards
- BB to HADES Feed: going to the right, same height

Details will be defined later by the company.

Detectors
The STS detector has to be mounted inside the magnet gap, the RICH and MUCH detectors outside of the magnet. The geometrical interfaces with these detectors have to be defined in agreement with the responsible experiment coordinator of the CBM collaboration.

Vacuum interfaces
There must be one gate valve and one CF flange on each cryostat for the turbo molecular pump providing the cryostat insulation vacuum. The magnetic field should not disturb these pumps. . In addition a DN 40 CF flange has to be foreseen, where a vacuum gauge will be mounted.
CF flanges are specified in a Technical Guideline [16].

At the installation site there is an available nitrogen gas line which could be used for the purge/venting of the cryostat vacuum vessel. Refer to Section 4.9 for the interface requirements.

Transport
The listed Technical Guidelines should be considered.
Transport with crane:
Lifting units have to be installed on the cryostat and on the balks of the iron yoke. Individual transport of the parts must be possible.

Stand and Feet
Refer to Chapter 4.13.

Current leads
Leads are normal conducting optimized leads. The connection to the cable must be designed together with the company.

Cryogenic Interfaces

Refer to sections and 4.12 Cryogenic Control System.

4.3. Design procedure

- The design work comprises the magnetic (2D/3D) and engineering design of the magnet including all necessary tools, dimensioning calculations for stands and lifting units, etc.
- The design work comprises the design of Branch Box and Power Converter as well.
- The design will be checked by reviews: CDR, PDR, FDR
- This task includes the generation of a complete set of drawings on paper and on CD (3D-Model in Catia V5 or Step, drawings in CATIA V5 or DXF and pdf), also for the special production tools.
- The design has to include a 3D model of the magnet (yoke, cold mass, cryostat and Feed box), including stand and feet.
- All 2D drawings have to be approved by the customer.
- The work started before the release of drawings might be refused. The costs have to be carried by the contractor.
- This release process does not absolve the supplier from its design responsibility.

4.4. Design Parameter

The following list contains the required parameters of the dipole magnet:

Geometry (refer to Figure 3)

- Opening angle: ±25° vertically, ± 30° horizontally from the target
- Free aperture: 1.44 m vertically   x 3.0 m horizontally, no conical geometry.
  The Silicon Tracking System (STS) and its services will occupy all available space in the aperture, from left to right vertical yoke. It requires also space between lower coil and the vertical yoke bar, for detailed description see appendix in chapter 10. Changes in the space allocation for STS and magnet services only after consultations between contractor and company.Distance target- magnet core end: 1m (STS detector must fit in)
- Total length: 1.5 m
- Free space upstream of the magnet: >2 m

- Field integral within STS detector (along straight lines): 0,972 Tm -> max. Field ≈ 1 T, depending on the magnet length
- Field integral variation over the whole opening angle along straight lines: ≤ 20% (± 10%)
- Fringe field downstream < reasonable value of the order of 50 to 100 Gauss at a distance of 1.6 m from the target at the position of the first RICH box(RICH only) (see Figure 13)

Operating conditions
- Operates at both polarities
- 100% duty cycle, 3 months/year, 20 years
- No real time restriction on the ramp: 1 hour up ramp
- Radiation damage (<10MG for organics): no problem
- Radiation Energy deposit in the cryosystem: max. 1 W

Assembly
- Field clamps dismountable for MUCH
- Assembly in situ
- Weight restriction: crane 30 tons (including lifting jacks)
- Maximum floor load: 100 tons/m2
- Beam height over magnet base: 2.7 m

Alignment
- Position accuracy: ± 0.2 mm
- Orientation accuracy (roll): ± 0.5 mrad

The requirements given above are mandatory.

The CBM superconducting dipole will be designed as follows:
- Warm iron yoke (huge vertical and horizontal balks)
- Warm round (tapered) poles
- Removable field clamps
- Cylindrical NbTi coils wound on cylindrical bobbin , cooled with LHe
- Thermal shield cooled with Helium gas (50-80K)
- Two independent cold masses and cryostats
- Vertical forces transferred from the coil to the cryostat and finally to the yoke
- Normal conducting leads

Such a design follows very closely the design of the SAMRAI dipole [2]. A suggested design is summarized in the TDR [3].

This functional specification differs from the TDR in two key parameters:
- the free aperture was increased from 1.4m (TDR) to 1.44 m. However, the integral field was decreased in order to keep the nominal current the same as in the TDR.
- the vertical yoke bar had a tapered shape in the TDR. To gain more space for the STS and its services the proposed shape, shown in Figure 3, is now a cuboid. The impact on the magnetic design, especially on the fringe field, must be investigated. In particular the fringe field in the region of the RICH photodetector should not significantly differ from the level shown in Figure 13 .The final yoke geometry will be decided in the CDR.

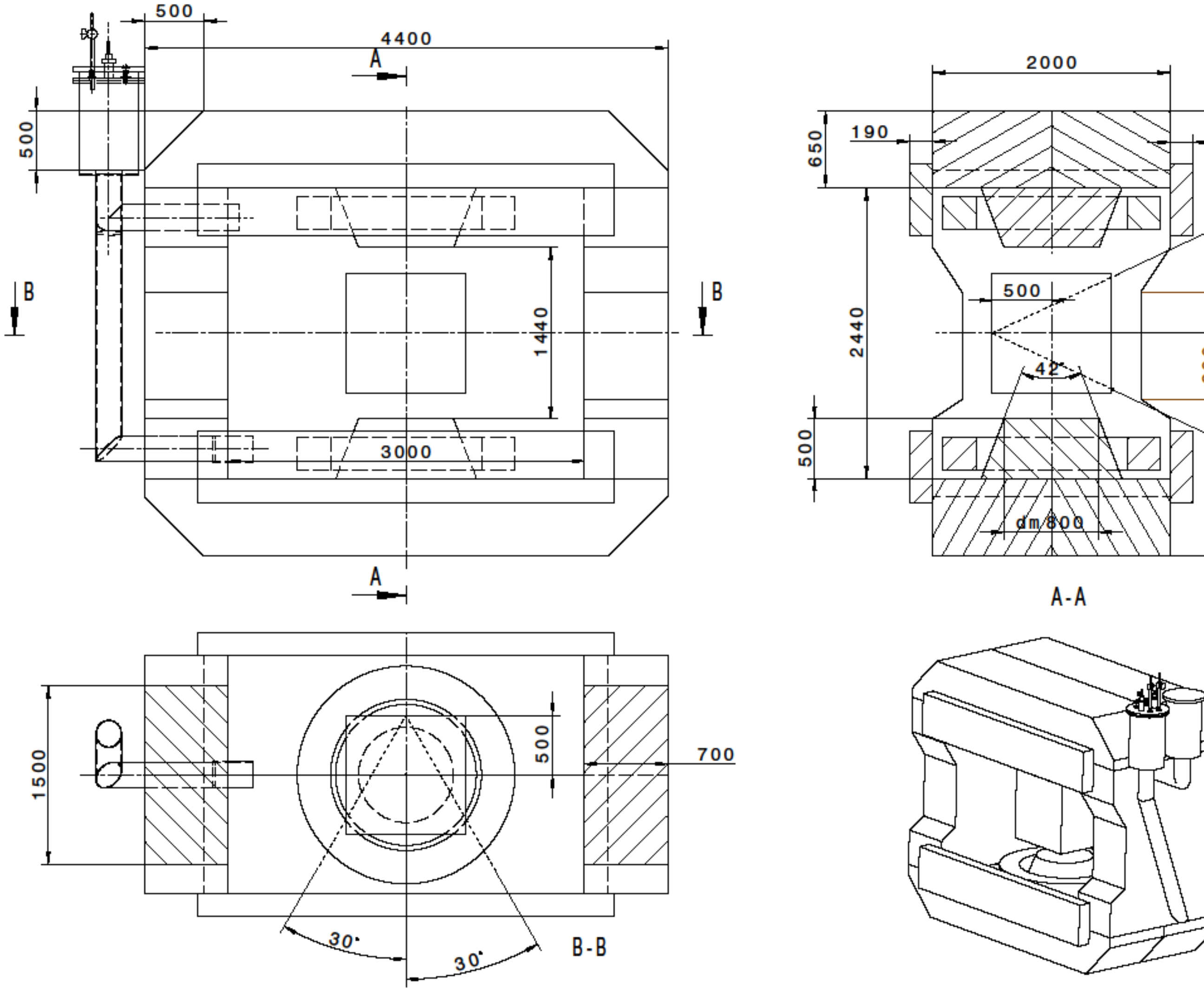


Figure 3: Scheme of the CBM dipole geometry

4.5. Iron yoke

Choice of steel
It is the responsibility of the contractor to choose the appropriate steel. Field calculations with different steel should be presented at the CDR for a final decision in agreement with the company.
The properties of two different steels 1010 and 1020 are given below. Steel 1010 has a higher permeability while steel 1020 shows better saturation properties.
Definition:
American Iron and Steel Institute (AISI) classify alloys by chemistry 4 digit number:

- 1st number is the major alloying element (in our case 1 for low carbon steel)
- 2nd number designates the subgroup alloying element OR the relative percent of primary alloying element.
- last two numbers approximate amount of carbon (expresses in 0.01%)

The properties of soft magnetic materials are given in [4] and in the following tables:

chemical composition

http://www.precisionsteel.com/technical-data/chemical-analysis/low-carbon-sheet-strip

AISI	C	Mn	P	S	SAE
1008 ★	.10 Max.	.30 - .50	.040	.050	1008
1010 ★	.08 - .13	.30 - .60	.040	.050	1010
1012	.10 - .15	.30 - .60	.040	.050	1012
1015	.12 - .18	.30 - .60	.040	.050	1015
1016	.12 - .18	.60 - .90	.040	.050	1016
1017	.14 - .20	.30 - .60	.040	.050	1017
1018	.14 - .20	.60 - .90	.040	.050	1018
1019	.14 - .20	.70 - 1.00	.040	.050	1019
1020 ★	.17 - .23	.30 - .60	.040	.050	1020

Russian analogs of SAE steels

Steel 08

GOST 1050-88

C	Si	Mn	Ni	S	P	Cr	Cu	As
0.05 - 0.12	0.17 - 0.37	0.35 - 0.65	< 0.3	< 0.04	< 0.035	< 0.1	< 0.3	< 0.08

Steel 10

GOST 1050-88

C	Si	Mn	Ni	S	P	Cr	Cu	As
0.07 - 0.14	0.17 - 0.37	0.35 - 0.65	< 0.3	< 0.04	< 0.035	< 0.15	< 0.3	< 0.08

Steel 20

GOST 1050-88

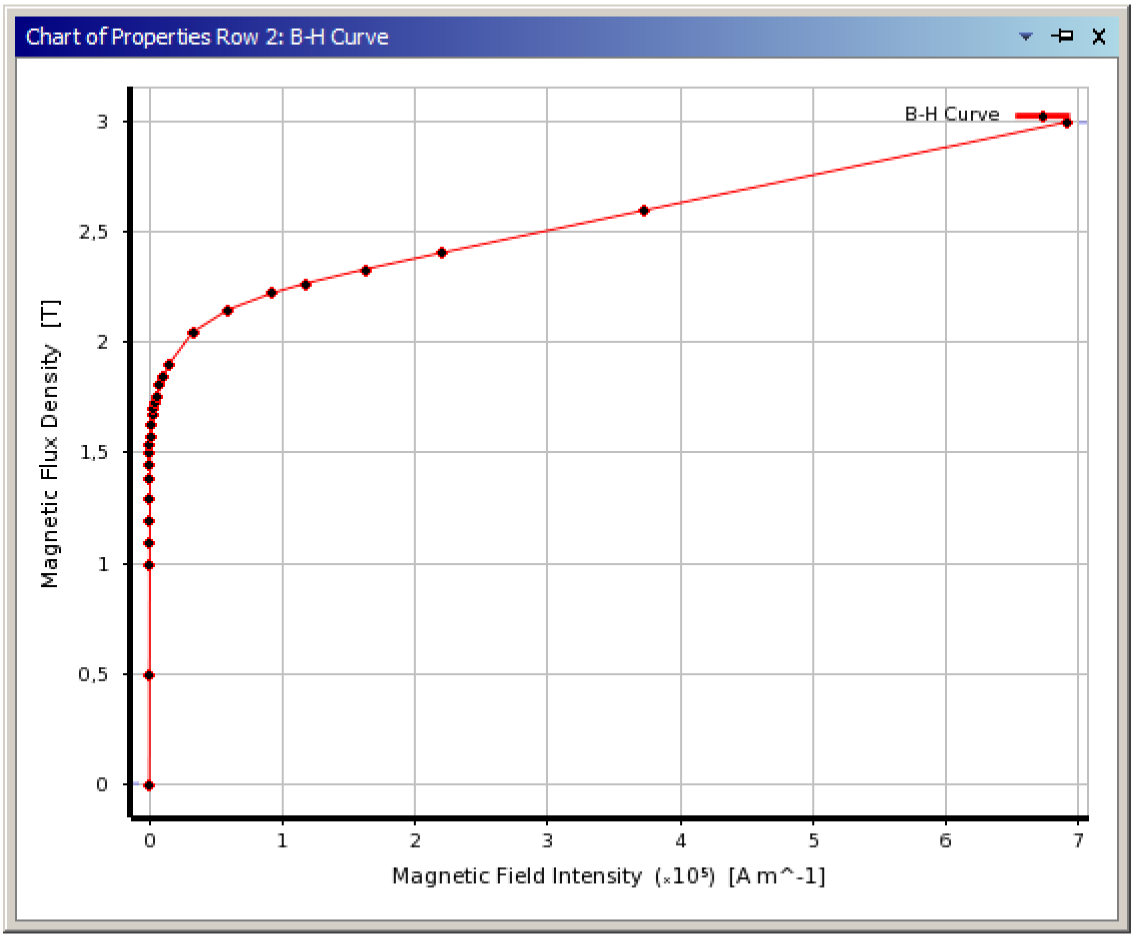
C	Si	Mn	Ni	S	P	Cr	Cu	As
0.17 - 0.24	0.17 - 0.37	0.35 - 0.65	< 0.3	< 0.04	< 0.035	< 0.25	< 0.3	< 0.08

The steel has to have at least the data of the following H-B curves:

SAE 1010

Table of Properties Row 2: B-H Curve

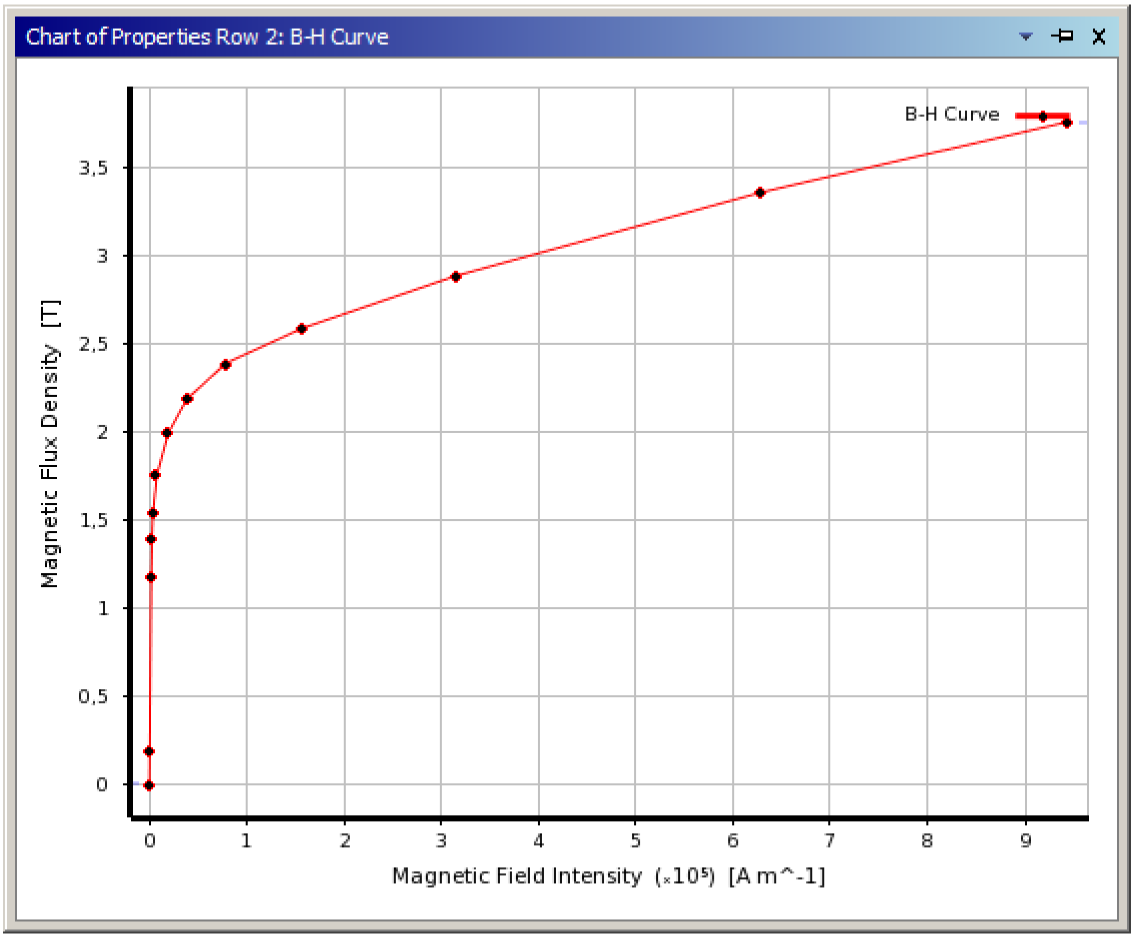
	A	B
1	Magnetic Field Intensity (A m^-1)	Magnetic Flux Density (T)
2	0	0
3	90	0,5
4	270	1
5	318,25	1,1
6	384,5	1,2
7	479,5	1,3
8	608,56	1,3875
9	755,44	1,45
10	939,19	1,5
11	1188,9	1,545
12	1407,9	1,575
13	2077,3	1,6275
14	3117,9	1,6738
15	3969,4	1,7023
16	4843,7	1,7275
17	6081,3	1,7583
18	8581,1	1,8088
19	11066	1,85
20	14986	1,9025
21	33003	2,05
22	59203	2,15
23	93215	2,2263
24	1,1888E+05	2,27
25	1,6356E+05	2,3338
26	2,2079E+05	2,4075
27	3,7397E+05	2,6
28	6,9228E+05	3



SAE 1020

Table of Properties Row 2: B-H Curve

	A	B
1	Magnetic Field Intensity (A m^-1)	Magnetic Flux Density (T)
2	0	0
3	394	0,198
4	1969	1,178
5	2756	1,395
6	3937	1,55
7	7874	1,756
8	19685	1,995
9	39370	2,193
10	78740	2,391
11	1,5748E+05	2,589
12	3,1496E+05	2,885
13	6,2992E+05	3,36
14	9,4488E+05	3,76



Yoke tolerances:

Poles coaxiality	≤ 0.5 mm
Flatness of pole surface	≤ 0.1 mm
Pole orientation relative to the symmetry plane	≤ ± 0.5 mrad
Parallelism of pole surface and reference surfaces	≤ 1 mrad
Typical position accuracy of the coils relative to the yoke (as taken from the SAMURAI magnet)	≤ 1mm

Typical mechanical tolerances for dipoles are given in [13].

4.6. Conductor

The amount of conductor should be sufficient for at least 3 coils.
Material: NbTi
Copper to superconductor ratio: > 9.1
Filament size: less than 60 µm
Insulation: The conductor insulation consists of 2x 0.05 mm polyimide tape and 2 x 0.1 mm glassfiber material (tape or braid), in total 0.3 mm.
The nominal current should be less than 50% of the critical current at 4.5K along the load line and less than 30% of the critical current at the max. coil field at nominal current:
$I_n/I_{loadmax} < 0.5$
$I_n/I_c(4.5K,B_m) < 0.3$

4.7. Coil

interlayer insulation (mm)	0.3
ground insulation thickness (mm)	2

Concerns exist about a possible damage of the coil during the welding of the coil case. The welder has to be especially qualified and trained. To guarantee the successful welding a mockup of a coil case (one sector only) should be built.

4.8. Cryostat and heat loads

The cryostat of the magnet consists of the Helium vessel, the thermal shield and the outer vacuum vessel. The dipole coil will be cooled by a liquid Helium bath and the thermal shield by gaseous Helium in the range of 50 K to 80 K. The Contractor should refer to the Technical Guideline: *Cryogenic Operation Parameters [26]* .

The design pressure of the Helium vessel containing the coils is 20 bar. The corresponding European pressure vessel regulations have to be fulfilled. The Helium vessel has to be equipped with pressure relief valves and a rupture disc.

Any movement of the cryostat during operation has to be avoided. Any deformation of the vacuum vessel during pumping must be below 0.1 mm. The common specification of cryostats [8] has to be fulfilled and the corresponding Technical Guidelines for Cryostats of section 8 and 9 should be observed.

The heat load per cryostat must be lower than 11W at 4.5K and the liquefaction for the current leads must not exceed 0.15 [g/s].
The total heat load per cryostat at 80K must not exceed 45 W.
Much better values should be reached [2].

Cryostat design, the calculated heat loads and the final volume of the helium vessel should be communicated and discussed with the Company for acceptance. If in any moment some of the parameters could not be met it should be timely discussed with the Company for evaluation.

The heat loads of the Feed Box for CBM and the Branch Box shall not exceed 20W at 4K and 50W at 80K.

4.9. CBM Feed Box (CBM FB) and Branch Box (BB)

CBM as well as HADES share the same experimental space, called the CBM cave represented in Figure 4. As represented in this figure, HADES is placed on the side of the beam entrance (right side) and CBM is on the back (left side). The purpose of the Brach Box (BB) is the cryogenic distribution to both experiments simultaneously, as well as separately.

The cryogenic distribution to this cave and to both experiments will be performed via the Distribution Box 2, DB2, located at Building 18. From DB2 a transfer line will enter the cave via an opening in the wall (L x W x H: 2m x 1.5m x 0.5m) and it will connect to the BB sitting on the balcony. The Feed box for HADES will be also placed on the balcony next to the BB, and the Feed box for CBM will form part of CBM itself, so a transfer line will go from the BB to the CBM Feed box as represented in this figure.

The CBM FB and the BB should be designed in a way that allows the access for installation and maintenance of the equipment, being the site description and available space discussed in Section 4.1 *Limitations and specific surrounding conditions*. All instrumentation contained in the CBM FB should be radiation resistant, see document [27] *Instrumentation of FAIR cryogenic cooling,* regarding instrumentation guidelines and section 4.11.

CBM magnet and its FB as well as the BB and the transfer line to the CBM FB are part of the scope of the delivery, the interface between the BB and the CBM FB and HADES is discussed at 4.9.2. The design of the CBM FB and BB should follow the technical guidelines regarding cryogenic equipment listed at Section 8 and 9.

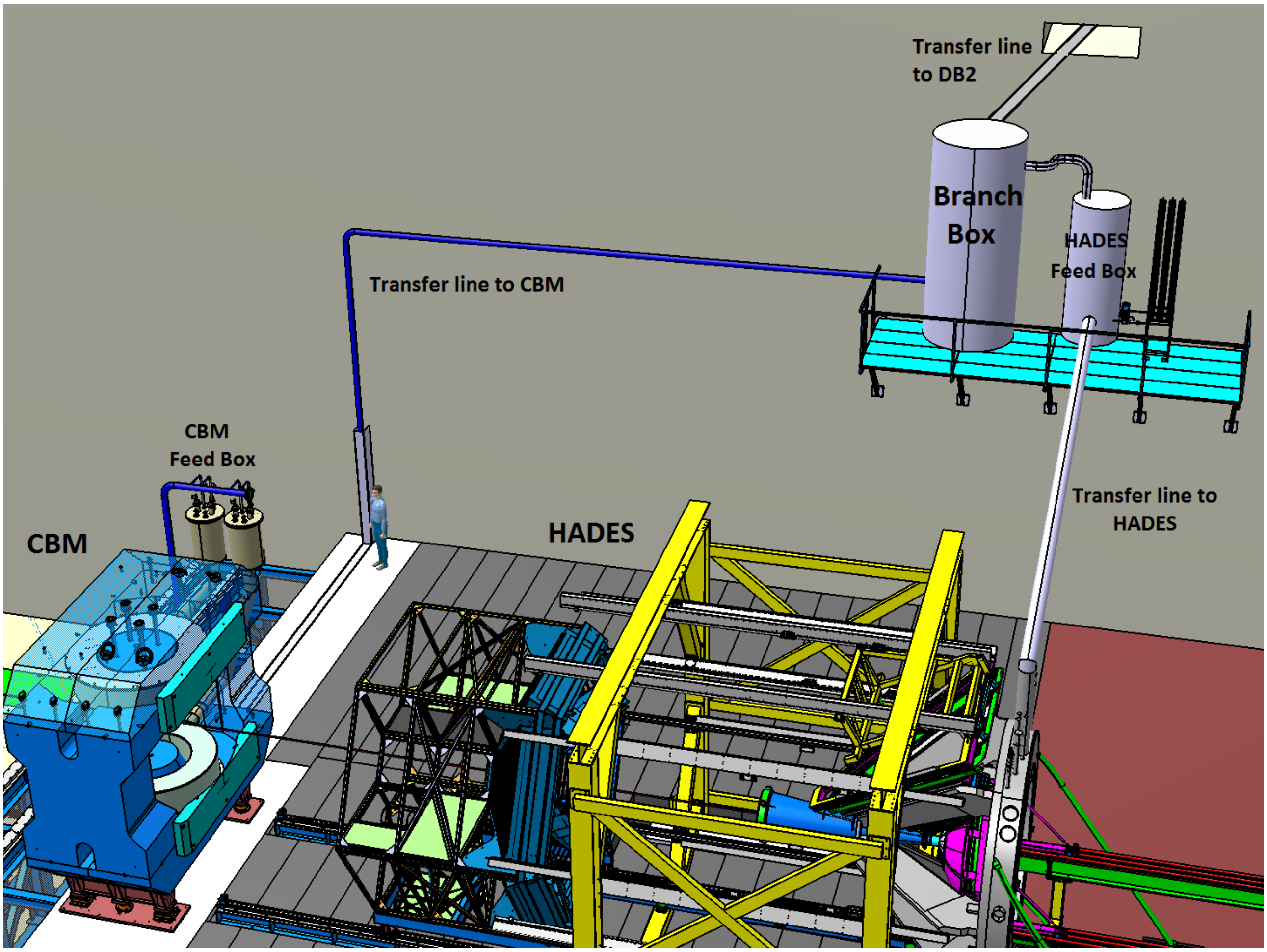


Figure 4: CBM cave: Cryogenic distribution for the experiments CBM and HADES

The BB should distribute the cryogenic fluids to HADES and CBM. The CBM FB should allow to perform the cooling down, normal operation and warm up of the CBM system. The Contractor has the freedom to design the cryogenic interface for the CBM dipole but the design shall be agreed upon the parts. In Section 4.9.2. possible cooldown/warm up scenarios are discussed.

A summary of the different hardware housed on the CBM Cave appears as well as a representation of the different cryogenic lines appears in Figure 5: Distribution of the different experiments and cryogenic hardware inside the CBM Cave.

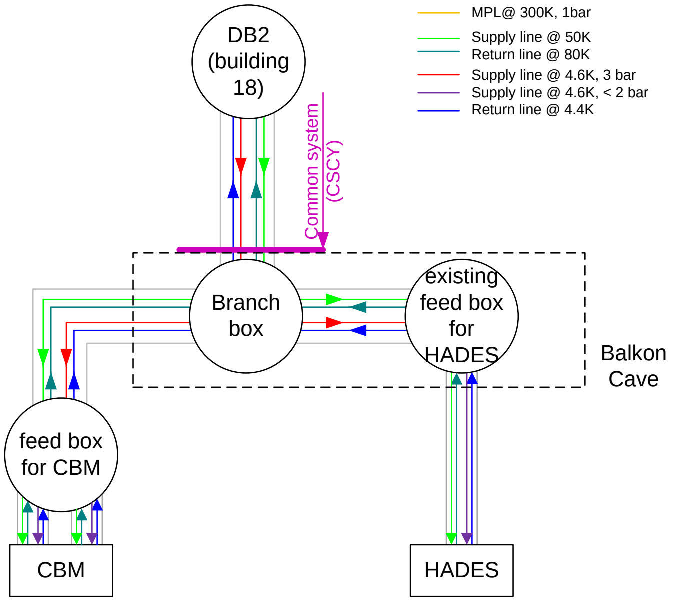


Figure 5: Distribution of the different experiments and cryogenic hardware inside the CBM Cave

4.9.1. Functional and technical design requirements for the CBM FB and BB

The Contractor should refer to the Technical Guideline: *Cryogenic Operating Parameters* [26]. A resume of the main design parameters are the next:

- All helium lines have to be designed for a maximum pressure of 20 bar*.All pressures are in absolute units.
- The cryoplant will supply the CBM FB via the Branch Box helium at 50K and 18 bar and helium at 4.6K and 3bar. The 50K helium can be used for the shield design of the CBM FB and cryostat but once served its purpose has to be sent back to the BB and the cryoplant with a temperature of around 80K and a pressure of 17 bar. The helium at 3bar and 4.6K can be used via JT expansion to fill the CBM cryostats with liquid helium; the returning gas needs to be sent back to the cryoplant at temperatures not higher than 5K and pressures not below 1.25bar.
- A multipurpose line (MPL) will be available at the interface point to send the return gas which is not at the pressure or temperatures mentioned in the point above (for example during a cooldown of the CBM and HADES and during normal operation for the shield of HADES). The MPL working range is 5-300K, 1.2-18 bar.

The main requirements for the process and the instrumentation of the CBM FB and BB are:

General requirements CBM FB:

- The valves contained at the CBM FB will allow filling both CBM magnet coil cases with LHe and controlling their level independently.
- Previous to the cooldown of the dipoles, the CBM and its Feedbox should have the possibility of being purged from air. The contractor should make sure that the necessary warm helium gas (300K, 18bar) and a purge return gas connection to be available. An example of the warm gas utility appears in the schematic of Figure 6: Functional diagram representing the cryogenic piping and instrumentation in the CBM cave. All purging valves need to be designed to be controlled remotely.
- The gas used for cooling down of the FB and CBM that is at higher temperature than the 80K return or 4.5K return cannot be sent back to the cryoplant, therefore this gas has to be sent via the multipurpose line (MPL) as appears in the P&ID.
- The gas used for the current leads cooling shall have its own return to the “current leads cooling gas return” which will be at a pressure of 1.2 bar.

Specific requirements CBM FB:

- The design of the FB should include the possibility of mixing helium at different temperatures in order to control the cooling rate of the CBM magnet, being this rate defined by the magnet designer. The mixing could be performed at the FB as appears in the functional process diagram introduced in Chapter 4.9.2.
- The cooldown of CBM should not require more than 2 weeks.
- During normal operation the JT expansion could be directly performed in the coil cryostats.
- If one of the two CBM coils quenches, the pressure increases inside the cryostat, FB and the rest of the local cryogenics have to be protected. An active pressure relief of the quench gas will be performed via the multi-purpose line via the control valve in the Feedbox and through the quench relief valves on the coil cryostats, as appears in the P&ID diagram of Figure 5.
- The CBM FB shall provide the sufficient cooling for all operating modes for the heat load specified in Section 4.8. In addition the heat load of the FB itself should not exceed 20W at 4K and 50W at 50K.

General requirements BB:

- The disposition of the valves of the BB shall allow cooling down and warming up both experiments independently.
- Previous to the cooldown of CBM and HADES, the BB should have the possibility of being purged from air. The contractor should make sure that the necessary warm helium gas (300K, 18bar) and a purge return gas connection to be available. An example of the warm gas utility appears in the schematic of Figure 6 for CBM FB. A similar setup shall be design for the BB. All purging valves need to be designed to be controlled remotely.
- The gas used for cooling down of CBM and HADES that is in conditions of temperature and pressure that cannot be returned to the cryoplant should be sent via the multipurpose line (MPL) as appears in the P&ID.

Specific requirements BB:

- The cryoplant will supply HADES via the Branch Box with helium at 50K and 18 bar and helium at 4.6K and 3bar. The pressure of the helium at 50K should be **reduced** below 3 bar in order to be used for the shield cooling of HADES, the return gas from the shield can not go back to the cryoplant so it should be sent via the MPL.
- The BB should be dimensioned in a way that it can provide enough cooling power for HADES and CBM. The cooling power for HADES is expected to be around 400W at 50K and 2 bar and around 150 W at 4.3K and 2.8bar. HADES uses approximately 0.5g/s for the current leads.
- The BB shall provide the sufficient cooling for all operating modes for the heat load specified in Section 4.8. In addition, the heat load of the FB itself should not exceed 20W at 4K and 50W at 50K.

4.9.2. Functional Process and Instrumentation Diagram of the CBM FB and the magnet cryostats

In this chapter a possible functional diagram, P&ID, as well as the main design requirements for the CBM Feed Box are introduced. **This diagram is just a reference** and it is the Contractor responsibility to design the final process diagram.

A basic P&ID diagram is represented in Figure 7 and it is based on the magnet design proposal that appeared in *Technical Design Report for CBM, October 2013 [3]*. The Contractor should deliver the final P&IDs concerning the CBM FB as well the one of CBM itself and all operating scenarios.

*All pressures are in absolute units

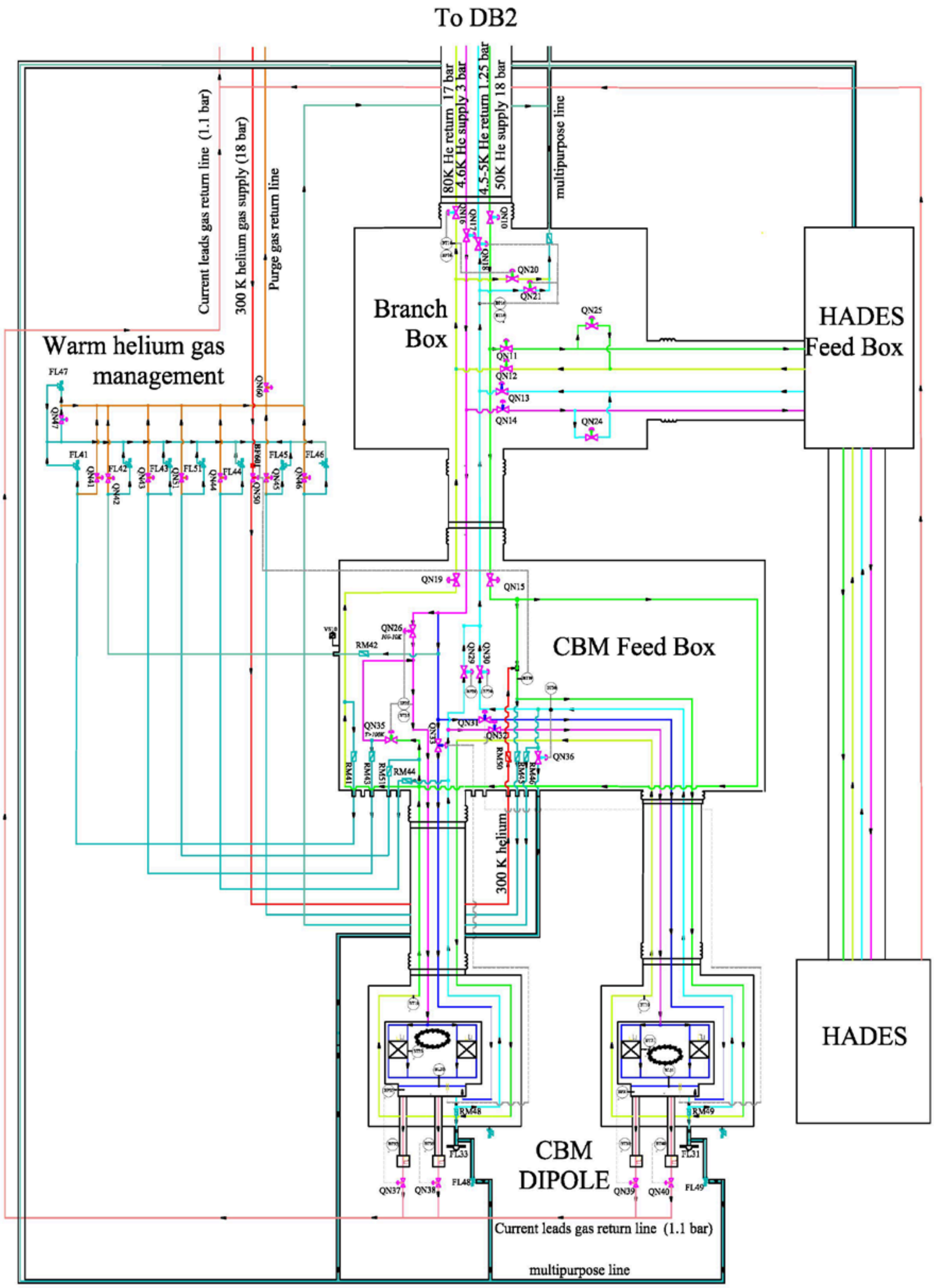


Figure 6: Functional diagram representing the cryogenic piping and instrumentation in the CBM cave

The instrumentation necessary for the control of the system in our example has been kept to an operational minimum. It is the Contractor responsibility to provide with sufficient instrumentation to operate the experiment. Additionally, sensors in difficult access positions or of key importance should have redundancy.

In this section the next operational scenarios will be analyzed:

- **Cooldown of CBM**

We assume the Branch Box is operational and able to provide helium at 50K 18bara for the shield and 4.6K and 3bara for the cold mass. The operation of CBM is independent of the state of operation of HADES, but it is not necessary to cool down both magnets at the same time.

For the epoxy-impregnated superconducting coil which is proposed to be used for the CBM coil winding, studies at CERN and other laboratories show that epoxy resin becomes brittle at lower temperature and the so-called epoxy failures may occur, which means micro-cracking and micro-fractures occur during cooldown. The reason is that the epoxy has a higher thermal contraction than the composite superconductor (to which it is glued) and the resin is in tension after cool-down. Therefore the appropriate cooldown rate of the overall coil structure is one of the important parameters to limit the epoxy failures as much as possible. The experience at CERN and in other institutes is that one should **keep the cooldown rate of the epoxy-impregnated coil structure below 1.0 K / hour during the cooldown from 300 K to 100 K**. The fact is that the thermal contractions of almost all the engineering materials used in the coil structure are finished when the cooldown temperature reaches 100 K. Therefore thermal stress issues don't limit the cooldown rate below 80 K.

During the first phase of the CBM cooldown, the 50K, 18 bar helium cooling flow will be used to cooldown the shield as well as the cold mass of CBM from room temperature to 100K. In this example, the 50K helium flow will first be divided in two, one part cooling the CBM FB shield and the other will cool down the two shields of the CBM coils in series, but all three shields (FB and coils) could be also cooled down in series. The 50K flow, after passing the two coil shields, will flow into the 3bar 4.6 line via QN35 and will cooldown the coils cold mass from the bottom of the cryostats also in series and exiting towards the MPL via QN36. This cooling could be performed in such a way that the temperature gradient over the shield structures and over the cold masses of the two coils could be conveniently adjusted, especially during the cooldown phase from 300 K to 100 K, mixing the 50K gas with the 300K gas supply, opening QN50. During this time, QN19 will be initially closed to avoid a thermal short, making sure the helium flows through the CBM coils. Once the coils have been cooled down to around 100K, QN19 can start to open. The gas returning from the FB shield still having a temperature higher than 80K could be sent conveniently to the MPL via QN20 and closed QN16 located at the Branch Box. The position of the main valves in this first phase will be as follows:

Phase 1: Cooldown CBM from 300K to 100K	
Valve	**Valve position**
QN15, QN32, **QN35**, QN50	Open
QN19**, QN26**, QN27, QN28, QN29, QN30, QN31 and QN33	Closed
QN36 (MPL)	Open

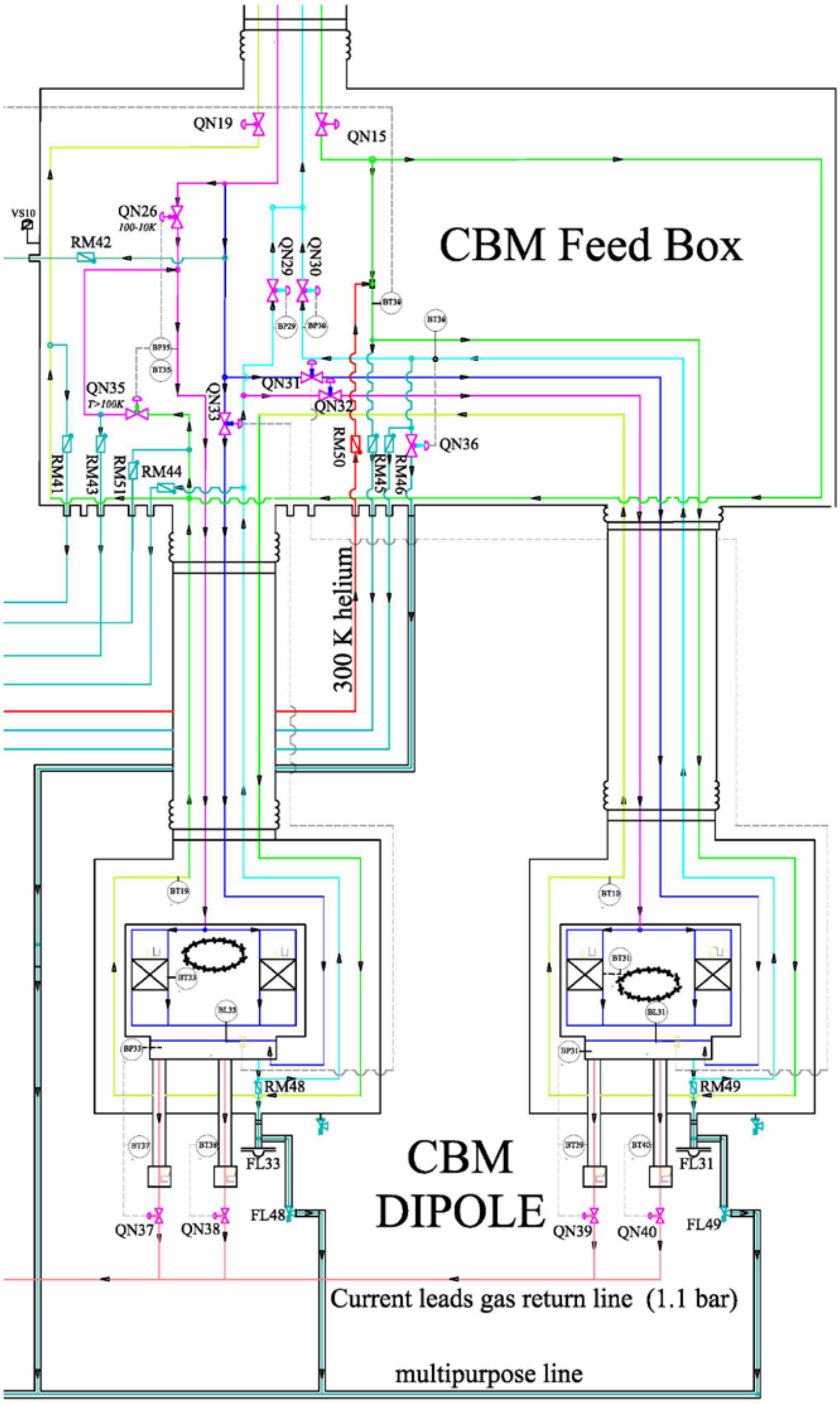


Figure 7: Functional piping and instrumentation diagram of the cryogenic system for CBM and its Feedbox

Once the temperature at the CBM coils has reached temperatures around 100K, the cooldown proceeds to Phase 2 using helium from the 4.6K 3 bar line sending it to the bottom of the magnet coils via the transfer lines (in pink). For doing this, first the supply of 50K helium at 18 bar into the 4.6K line will stop closing QN35, the pressure will decrease to around 3 bar and then QN26 will open to use the gas at 4.6K.

Phase 2: Cooldown CBM from 100K to 10K	
Valve	**Valve position**
QN15, QN19, **QN26**, QN32	Open
QN35, QN28, QN29, QN30, QN31, QN33, QN50	Closed
QN36 (MPL)	Open

Now that the temperature is below 10K the CBM, Phase 3 stops cooling the coils from the bottom of the cryostats, closing QN26 and QN32, and starts to send helium via the two JT valves QN31 and QN33, that once the temperature is low enough will allow to fill both cryostats with liquid helium. As soon as the return gas reaches a temperature below 5K the MPL will close and the return valves QN29 and QN30 will open.

Phase 3: Cooldown CBM below 10K and filling	
Valve	**Valve position**
QN15, QN19, **QN31**, **QN33**, **QN29** and **QN30**	Open
QN35, QN26**, QN34**, **QN32** and QN36 (MPL)	Closed

If in any moment the return gas into the BB may be above 4.5K, it could be sent to the MPL, via the upper BB connection, using QN21 during Phase 3. QN21 will close and QN16 will open as soon as the temperature is below 4.5K in the return line.

During normal operation, the valves QN33 and QN31 will be controlled by the helium level inside the coil cryostats, allowing a faster or slower filling in function of the helium level changes.

- **Warm up of CBM**

No more helium at 50K and 4.6K will be provided to CBM by means of closing QN15, QN33 and QN31. If heaters are provided inside the coil cryostats, the liquid helium could be actively evaporated. The Contractor should study the benefits of this option. Another possibility is just let the liquid to evaporate normally. In any case, during the evaporation of the liquid reservoirs, the return valves will be kept open, so the 4.5K return gas can flow back the cryoplant. Once no more liquid is left, the return valves will close and the gas will go back to the cryoplant via the MPL. The warm up could be controlled using warm helium gas via QN50 and with the valve configuration of “cooling down from 300 to 100K” in case the design of the magnet requires a specific temperature increase rate.

- **Quench protection and recovery**

The effect of a quench will cause a sudden evaporation of the helium contained in the quenched coil cryostat. The quench gas will be collected via the multipurpose line, MPL, directly by its connection to the cryostat and by opening QN36 placed at the CBM FB, this valve could be triggered during the case of a quench to contribute to the pressure release and recovery of the helium boil-off, QN29 and QN30 should close fast enough to guarantee no pressure increase in the return line. If the pressure increase becomes too high the quench gas will be released via the safety valves, FL33 and FL31, ensuring the integrity of the magnet cryostat. It is the Contractor responsibility to rate the safety valves to the appropriate relief pressures to ensure no damage could occur to the equipment.

Once the temperature at the coil has reached an approximate temperature of 80K and the pressure has decreased to 3 bar, the recovery could start, going directly to phase 2 of the cooling down of CBM discussed in this section.

It is the Contractor responsibility to assess all risk scenarios and take measures for the protection of the hardware, the experiments and the people. These scenarios will need to be reviewed and the safety measures validated as sufficient by the Company.

4.9.3. Cryogenic Interfaces

The CBM Feedbox Box FB has three interfaces:

- **Interface to the Branch Box**

The interface between the CBM FB and the BB is to be defined by the Contractor and the Company and based on the design of the CBM dipole magnet.

It will be responsibility of the Contractor to make an appropriate thermo-mechanical study of all the interfaces (forces during cooldown/warm up and operation of the experiments).

- **Interface to the multipurpose line (MPL) and warm process lines**

For the operation of both experiments the connections to other process lines will be required:

Process headers	DIN Dimensions	Outer diameters (mm)
10-300K MPL, 1.2 bar, vacuum isolated	TBD	
300K, 18bar He gas	TBD	
300K, 1.2 bar current leads He gas return*	TBD	
300K, 5bar, N2 gas	TBD	

*The current leads He gas return line shall be connect directly to the CBM magnet and not via the FB.

- **Interface to CBM dipole**

The interface between the CBM FB and CBM is to be defined by the Contractor and the Company and based on the design of the CBM dipole magnet.

It will be responsibility of the Contractor to make an appropriate thermo-mechanical study of all the interfaces (forces during cooldown/warm up and operation of the experiments).

- **Interface to HADES Feed Box**

The interface between the BB and the HADES Feed Box is to be defined by the Contractor and the Company and based on the design of the HADES Feed box.

It will be responsibility of the Contractor to make an appropriate thermo-mechanical study of all the interfaces (forces during cooldown/warm up and operation of the experiments).

4.10. Quench detection and protection

The quench detection for the CBM magnet (Figure 8) shall consist of one balance bridge detector connected to the magnet and four voltage recording cards dedicated for copper current leads.

The role of the quench detection system is a fast and reliable detection of:

- a quench (transition from superconducting to normal state) in a magnet coil;
- a thermal runaway in copper current leads.

Each copper current lead is protected against the thermal runaway with a quench detection card marked in Figure 8 as CLD1. These detection cards need to be able to detect a thermal runaway at adjustable threshold (10-20 mV above the voltage drop across the current lead at nominal current) A typical quench detection sequence is depicted in Figure 9.
When a quench or thermal runaway happens, CLD1 or the bridge detector needs to send a trigger to the power supply control unit. The trigger signal needs to be compatible with the input power supply unit.

The bridge detector shall detect the quench at 600 mV. It is a recommended value. Threshold could be also lower. However it is expected that the bridge signal will contain a lot of noise (measurement in a long high impedance loop). The input of the bridge card needs to withstand 1.5 kV (maximum voltage when using an extraction resistor of 2.1 Ω).

Quench detection system shall be powered from a power grid secured with UPS.

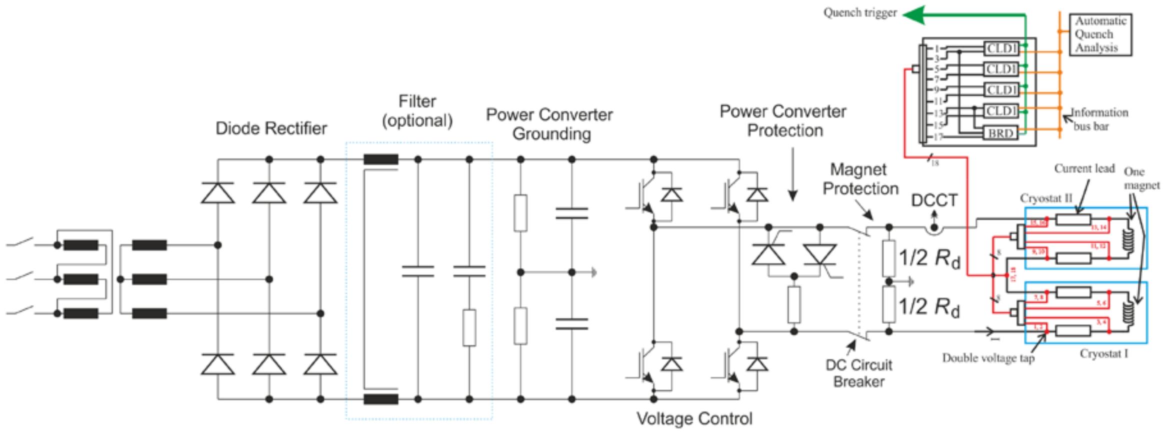


Figure 8: Electrical circuit of the CBM dipole including the power supply, protection resistor (Rd) and quench detection electronics.

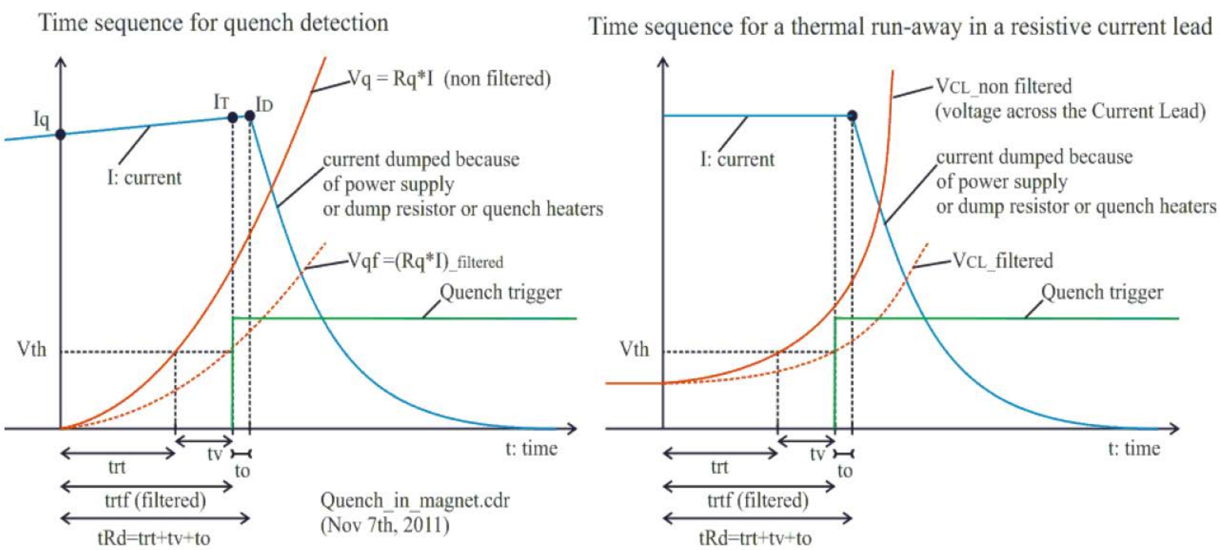


Figure 9: Quench detection time

(trt – time to reach the threshold, tv – validation time, to – opening time of the protection switch (if applicable), tRd – time to dump the current)

The CBM dipole magnet has very large dimensions and will store about 5.15 MJ at its nominal current. Adequate magnet protection means minimizing of the peak coil temperature and of the resistive-inductive voltage imbalances, which can generate large voltages to the ground.
The dipole magnet must be self-protecting. It means that the hot-spot temperature and the voltages (turn-to-turn, coil-to-ground, layer-to-layer), induced by a quench, do not damage the magnet insulation without any dump resistor. **The maximum quench voltage must be lower than 1500 V, the maximum hot spot temperature lower than 120 K (exceptionally 150K)**.
However, in order to avoid vaporization of helium, an external dump resistor will be used (Figure 8). In that case a significant part of the magnet energy will be dumped in the external resistor (placed at 300 K) instead of heating up the helium.

The protection scheme presented in Figure 8 with “always on” dump resistor is a proposal only. The detailed description of this scheme can be found in [3]. One can also use a scheme with switches that connect the dump resistor and disconnect the power supply.
There are two voltages that have to be considered in the protection design:

- Vq = quench voltage (time) = quench resistance(time) * current(time);
- VRd=maximum voltage across the dump resistor = Rd * Imax.

When choosing the Rd value one has to make a compromise. From one hand, one would like to choose Rd as high as possible to reduce the hot-spot temperature and the quench recovery time. On the other hand high Rd yields with high VRd.
When using no Rd the quench voltage is Vq=1250 V, the maximum hot-spot temperature Tmax = 160 K and all the magnet energy is dissipated within the coil. In order to reduce Tmax and quench recovery time, Rd=2.1 Ω yields to Vq=250 V, Tmax = 70 K and ~80 % of the magnet energy is dissipated in the external dump resistor located at warm. Disadvantage of using Rd=2.1 Ω is high VRd which will be close to 1500 V. This might be a problem for the voltage taps wires and sockets, which will be placed in helium gas environment and therefore the Paschen effect needs to be considered.

The Power Converter together with details of the QD-/QP scheme is specified in a separate Detailed Specification as part of this Annex 3. In the conductor design the contractor has to make sure the heat load caused by the ripple of the Power Converter does not lead to a quench.

4.11. Magnet Instrumentation

For Cryogenic and radiation resistant instrumentation, the Contractor must follow the Technical Guide line “*Instrumentation of FAIR cryogenic cooling” [27].*

Voltage taps
The CBM magnet shall be equipped with at least 20 voltage taps as shown in Figure 8. Voltage taps are doubled to obtain redundancy. Voltage taps need to be soldered to the conductor or current leads in the way that a good electrical contact is preserved. Also good mechanical stabilization is required.
To avoid too high static head load the cross section of voltage tap wire shall be lower than 0.2 mm^2. The insulation of the voltage tap wire needs to withstand the test voltage (Vtest=2*Vmax =3 kV in case of Rd=2.1 Ω). Voltage tap wires shall be rout carefully in shrinking tubes. Whenever possible they shall be twisted in order to increase the electromagnetic compatibility (EMC).
Voltage taps sockets shall also withstand the test voltage. Here the Paschen effect shall be considered (Figure 10). The helium pressure in the cryostat is around 1.3 bar. In this case to provide good insulation pin-to-pin and pin-to-ground distances within the socket shall be minimum 12 mm.
Recommended distance is 24 mm (CERN experience) or one can install sockets with reinforced insulation with shrinking tubes and special insulating epoxy (Figure 11 [10]).

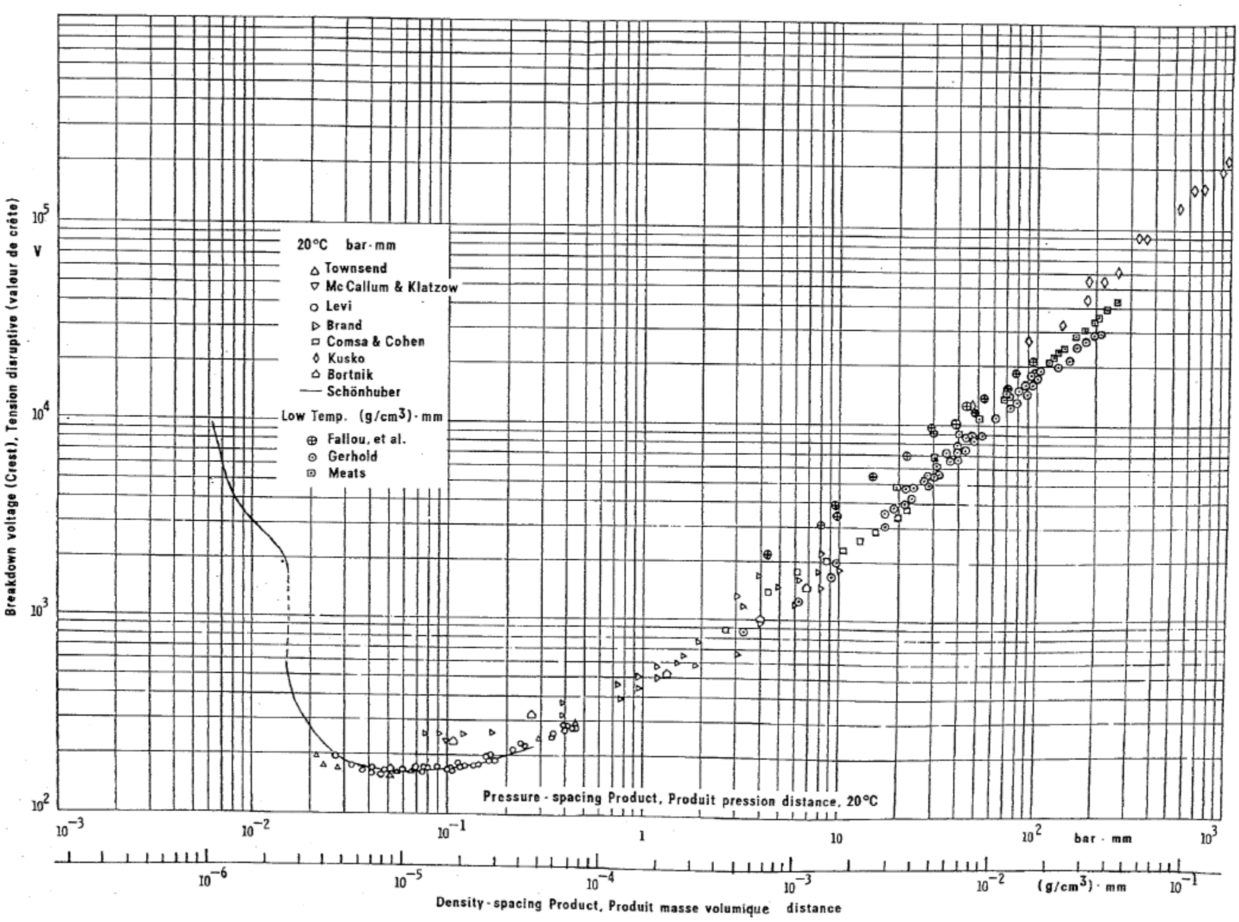


Figure 10: Paschen curve for helium in log-log scale. Temperature 20°C (Electra, No 52, page 83).

Figure 11: Upgrade of a standard electrical connector (Fischer Connectors, photo by CERN).

Temperature sensors

Each current lead needs to be monitored by two temperature sensors: one for the warm terminal and another for the cold terminal. Each magnet pole (coil in the helium casing) needs also to be monitored by two temperature sensors.
Temperature sensors need to have good thermal contact with the measured surface and at the same time need to be electrically insulated from the life-circuit (i.e. 3 kV of test voltage).). To reinforce the electrical insulation and provide a good thermal contact, use of Sapphire plate could be considered.

Other components
Other components as for example heaters or pressure gauges should be used, if it is necessary according to the design of the magnet and/or for the successful testing.

Magnetic field sensors
At least one calibrated Hall sensor (accuracy 0.01%) must be installed in the homogeneous part of the magnet gap. A NMR-probe is very desirable.

4.12. Cryogenic Control System

The Contractor will deliver all information and instrumentation hardware required to implement the control system for the Branch box (BB), the Feed box (FB), the local cryogenic of the magnet and the current leads. His delivery mainly includes the functional documentation and is based on the technical guideline F-TG-C-10e "Functional Analysis UNICOS Control System Applications" [28] and its subdocuments.

The contractor has to follow the project phases and the tests for instrumentation insulation described in F-TG-K-3.82e "Electrical Interconnections between Cryostats and Cryogenic Controls" [30].

The delivery includes, but it is not limited to:

- Documentation of the process: P&IDs, process flow scheme, functional analysis, interlocks...
- Documentation of the instrumentation hardware, manuals, instrumentation list, results and documentation of the full risk assessment process based on HAZOP examination or similar methods and required to declare CE conformity,...
- The information required for the development of a simulation is for all types of main components, such as heaters, valves, piping & vessels etc., their physical characteristics. For example for a heat exchanger: operation temperatures, operation pressures, mass flow, He volume, and Al mass are required.

The defined data format for the components listed above will be supplied by the Company. The Company will also supply a list of instrumentation hardware components (sensors, actuators, ...), for details please refer to [27].

Any deviation from these lists or the above named documentation should be communicated and discussed between the parties.

In the P&IDs in Figure 7 appear in dashed gray lines possible control relations between the cryogenic instrumentation. These are just examples and the contractor should define the logic control within the functional analysis document and provide it to the company.

The instrumentation represented is just the minimum for representing the basic functional requirements of the FB. It is the Contractors responsibility to provide the systems with all the necessary instrumentation hardware to successfully test and operate the magnet.

The Contractor should choose the instrumentation following the technical guideline F-TG-K-3.76e "*Instrumentation of FAIR cryogenic cooling" [27],* additionally the contractor has to respect the technical guideline F-TG-K-10.19e “Reference Designations for Cryogenics” [30] for the naming of the instruments.

4.13. Alignment

The basic Alignment Parameters are given in Chapter 4.4. The requirements for reaching alignment ability is described in detail in [11][12][13][14][15].

In case of the split yoke and bolted assembly of the CBM magnet, each single yoke part needs to get additional individual reference planes and at least 16 fit drill-holes of Ø10H7, even if dowel pins are used between mating parts (Figure 12). The geometry of these drill-holes relative to the gap center is to be given from the manufacturer in a unique coordinate system (see [11], section 4.4).

The position of the yoke parts among each other shall be checked after reassembling at GSI by a Laser Tracker. Reproducibility of the position of upper and lower yoke among each other after disassembling and reassembling must be guaranteed to 0.2 mm.

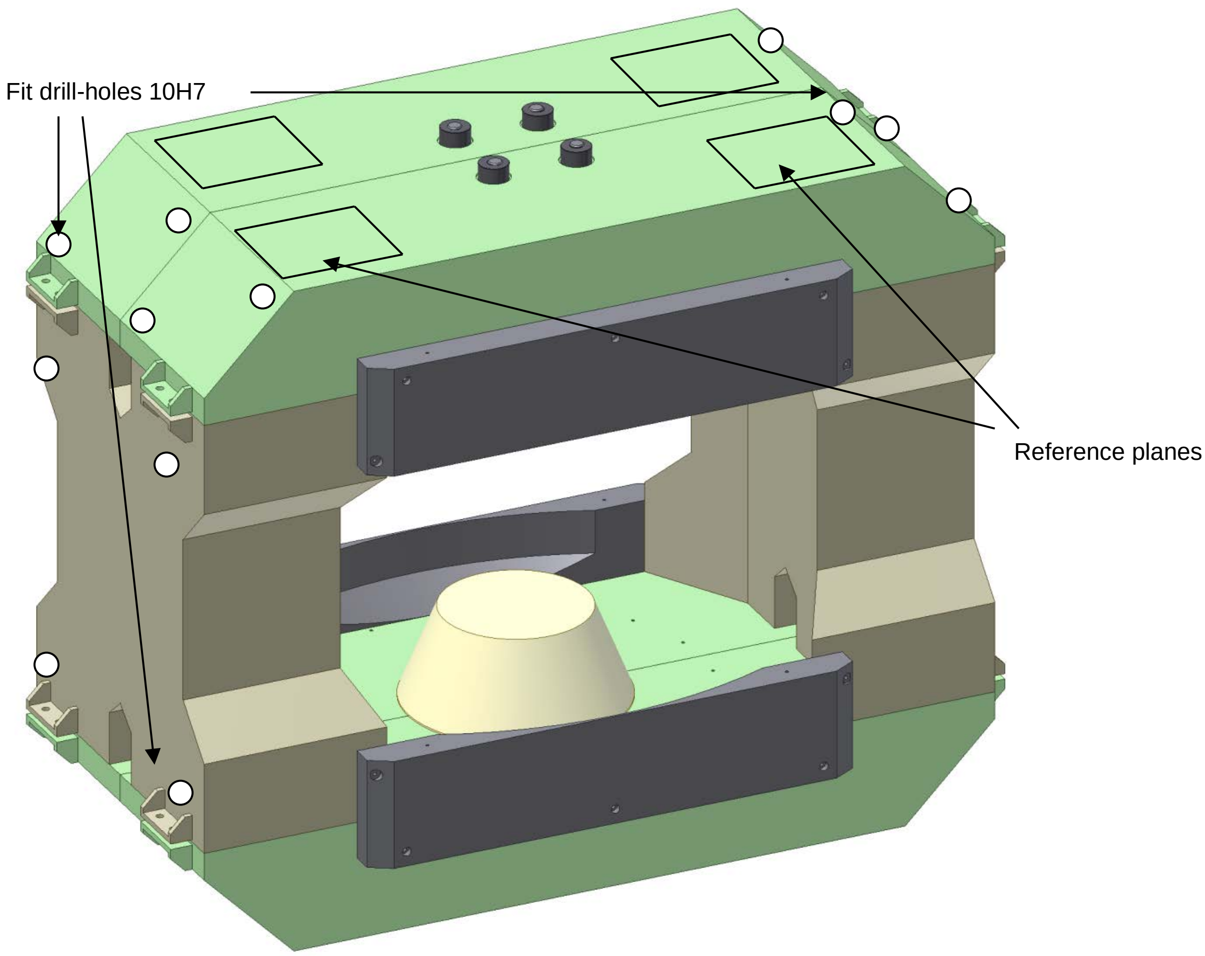


Figure 12: Schematic View of the CBM dipole with reference planes and drill holes

In assembled condition the magnets reference planes, fit drill-holes and groove (defining the beam/symmetry axis) – especially at the vertical endplates – have to be reachable and visible by optical measurement tools. They have to be protected against corrosion, but not varnished.

Above described reference holes, grooves and planes will be used for fiducialisation purposes. They are usually not suitable for alignment purposes due to problems with line of sights, but describe the relation to the non-touchable object (the beam) that needs to be aligned.
As a convention they should be named as 'references', while the term 'fiducials' should be applied to the marks which will be used directly for alignment within the cave.

Magnets which need to be aligned to tight tolerances have to be equipped with fixed reference marks – the fiducials – which can be seen or touched by instruments and which are used for precise alignment within the tunnel and cave. The fiducials consist of a fiducial socket respectively fiducial target seat and a removable target (usually a 1,5" sphere with reflector), which is only inserted during measurement and part of the survey and alignment equipment. The position of these fiducials onto the magnet needs to be chosen concerning the final place of the magnet within the tunnel and thus concerning the possible position of the measurement instrument applied to align the magnet.
Concerning the superferric CBM magnet the 16 fiducial target seats are located directly on the yoke. The relation between the pole geometry (defining the magnetic field vector) and the dedicated references on the yoke and the fiducials needs to be precisely determined during the fiducialisation measurements. Once measured the fiducials must not change their position. The positions of the fiducial target seats have to be agreed with the Company.
The Technical Guidelines concerning reference surfaces and fiducial target seats and other aspects concerning the alignment of the magnet have to be observed.

Design principles of stand and feet

- Two support beams, each on the right and the left hand side of the magnet (under the vertical beams), to reach approximately the beam height
- Alignment installations as close as possible to the magnet yoke, on top of the support beam
- Independent vertical (z) and horizontal (x,yz) movement
- 3 jacks for vertical alignment, supporting a base plate
- 3 x-y alignment tables, mounted on the base plate
- Alignment range: ±40 mm in x,y,z
- Resolution: 0.1 mm

4.14. Production

- Monthly progress reports have to be delivered by the contractor.
- Video conferences should be organised, if needed, but at least every other month.
- Milestones for production, FAT and SAT of the magnet are defined in Table 1 .By the time of the Plan Review they can be modified and the corresponding dates have to be added.

Table 1: Milestones for production, FAT and SAT of the magnet

Milestone	Phase	Object of Agreement (Validation Criterion)	Date
1.	design	FDR accepted/ Planning completed (Milestone M7 of General Plan)	
2.	procurement	Steel delivered, properties accepted	
3.	procurement	Stainless steel delivered, properties accepted	
4.	procurement	Insulated conductor delivered and tested	
5.	production	Productions and assembly tools finished	
6.	production	Yoke parts finished and tested	
7	production	Coil mockup finished and tested	
8	production	Stand and feet completed	
9.	production	First coil finished and tested	
10	production	Second coil finished and tested (start of winding second coil after successful test of first coil)	
11	production	Cold masses assembled and tested	
12	production	Cryostats finished and tested	
13	production	Cold masses assembled in cryostats and tested at 4K and low current	
14	production	Feedbox finished and tested	
16	production	Magnet assembled and installed (including Feedbox, power converter and QD/QP system)	
17	production	Magnet tested at 4K and full current (nominal current + 20%) Magnet field map finished FAT finished	
18	delivery	Magnet dis-assembled and shipped	
19	installation	Magnet parts inspected after shipping, magnet reassembled and aligned by S&A group and installed	
20	installation	Magnet tested at 4K and full current SAT finished	

5. Magnet Quality Assurance, Tests, and Acceptance

The complete Quality Acceptance process is described in the "General Specification"[6].
The special safety requirements for the cryostat against overpressure are given in [33].

5.1. Tests during production

The contractor provides all tools which are necessary for the acceptance procedure.
The Company is allowed to repeat all tests after delivery.
The factory acceptance tests have to be done by the contractor and 3rd party. Test results have to be approved by the company before the delivery of the components.
The following tests will be part of the FAT for the superconducting CBM dipole:

Yoke material tests

Test samples of each steel charge in form of rings (D=114mm / d=76mm, 12mm thick) have to be sent to GSI for testing and approval for the magnet from each charge prior to the machining of the steel parts.
Further requirements for the quality assurance, tests and acceptance of the yoke are given in the Common Specifications of normal conducting magnets for FAIR [7].

Conductor approval tests

Assuming a "wire-in-channel" conductor one needs

- The geometrical dimensions of the conductor
- The copper content of the copper stabilizer
- The contact resistance between strand and stabilizer
- The data of the sc strand as measured according the prescriptions below.

For a good example of a Detailed Specification (DS) of a superconducting strand refer to [29].

Acceptance tests for the superconducting strand
From one billet n spool pieces will be produced. The measurements mentioned in the following sections shall be done n+1 times for each billet: one measurement per spool piece and 2 measurements for the inner most spool piece. In the report the values for both ends of each spool piece have to be given (using the measurement results from the adjacent spool pieces).
The material temperature shall be measured during the room temperature measurements of the Cu resistivity and the strand linear resistance. The Contractor must provide written reports of the tests required by the present specification, together with a copy of any and all test certificates. The contractor shall send the complete set of measurements one week after measurement completion and at least one week before for the contractor sends the strands to the contracting entity. All measurement results shall also be presented in one excel file (that reminds the specified values and indicates how many measurements are within the specification for each specified magnitude).
The Contractor shall deliver to the Company one 20 m long strand test sample for each piece length. The test length shall be adjacent to the location used by the Contractor for the strand matrix-to-superconductor measurement, twist pitch measurement and mechanical tests. A part of this test length (approximately 10 m) can be used by the Company for additional critical current and linear resistance measurements. The residual length (approximately 10 m) will be stored by the Company as a witness sample.

Mechanical and Geometrical Measurements

Matrix-to-Superconductor volume ratio
The matrix (Cu) content must be determined by etching and weighing of various samples.

Strand diameter and ovality
The Contractor shall verify the strand diameter by means of a calibrated laser micrometer. The strand must be measured continuously and on line with a two axis laser micrometer. The Contractor must provide statistical analysis of the laser micrometer measurements. Another procedure for measuring the strand diameter may be used after agreed upon with Company.
The strand diameter measured on each of the two axes must be within a tolerance of ± 5 μm compared to the nominal diameter over the full length. The ovality of the strands, defined as the difference between the diameters measured for the two axes, must be less than 4 μm.

Filament diameter
The nominal geometrical filament diameter and filament spacing is determined by the billet design. The average filament diameter will be verified by the Contractor by calculation. The calculation will be based on the measured diameter, the measured matrix-to superconductor ratio from the stable portion of the billet production and the number of filaments.

Strand twist
The strand twist direction must be verified on each strand piece length. The value of strand twist pitch must be verified after the setting of the twisting machine and on the both ends of each strand piece.

Sharp bend test
In order to ensure that the strands are well suited for cabling, the Contractor shall subject the strand to a sharp bend test (by a procedure agreed with the Company). The sharp bend test must be performed on three adjacent samples. The sharp bend test must be performed on a minimum of 3 locations in the billet, selected from widely separated strand piece lengths.
Before etching, no deterioration of the bond between the superconducting filaments and the copper matrix and no sign of cracking at the outer diameter of the sharp bend must be visible under a magnification of at least 50. After etching, the bent sample must show not more than about 5 % of broken filaments.

Spring back test
The spring back test must be performed on three adjacent samples. The spring back test must be performed on a minimum of 3 locations in the billet, selected from widely separated strand piece lengths. The maximum acceptable value of unwinding of the spring for any strand is 3+1/2 turns.

Electrical measurements

Bulk resistivity of CuMn
The bulk resistivity of CuMn shall be measured at 4.2K, 77K and 293K on 3 samples.

Critical current and “n” value
The critical current and “n” value measurement is carried out at least for the external fields of 0.5, 1.0, 1.5, and 5 T, applied normal to the strand axis and at the measured temperature of a liquid helium bath. The critical current in the strand is defined as the current measured at an electric field of E=0.1 μV/cm. No correction is made for self-field effects. The "n" value (or quality index) is defined from data taken up to a voltage corresponding to an electrical field in the range from 0.1 μV/cm to 1 μV/cm, and at a current ramping rate not larger than 20 A/s.

Critical current and n-value tests have to be done on n+1 samples, n being the number of spool pieces. The critical current will be measured with an estimated accuracy of 1 %. The "n" value must be greater than 30.

Strand linear resistance

The strand electrical resistance per unit length shall be determined at room temperature and just above the transition temperature of NbTi (10 K). These two quantities are designated as rl (300K) and rl(10 K) expressed in Ohm/m. The measurement shall be done as follows:

- Measure the linear resistance a room temperature over 1 m which gives rl(300K)
- Cut one piece of this 1 m, measure its resistance (R300K) at 300 K (the room temperature shall be measured and written in the measurement certificate) and then measure the resistance at 10 K (R10K) of this short sample.
- rl(10 K) is given by rl(300K)/R(300K)*R(10K). Measurement certificates shall clearly give rl(10 K) and rl(300 K) and not RRR as for Cu strands.

DC Magnetization

DC magnetization on 3 samples from different spool pieces shall be performed up to 3 T to measure the effective filament diameter and hysteresis loss.

Mechanical Measurements

They have to be done before and after the complete assembly of the magnet and must guarantee the requested parameters in chapter 4.5 and 4.13. A good overview over mechanical measurements is given in [17].

Coil tests

Inductance measurements and high voltage tests of the coil are defined in [18][19].

Insulation tests of instrumentation hardware

A test of dielectric strength has to show the insulation between active (current-carrying) parts of the (magnet-) cryostat and all instrumentation contacts. The test voltage has to be selected according the highest possible voltage of the magnet coils. Additionally the grounding of the feedthroughs has to be checked.
Test of dielectric strength and grounding resistance has to be repeated before commissioning and later periodically. Details are defined in [28] or related documents.

Pressure and Vacuum tests

The pressure and vacuum tests of the helium casing and the vacuum vessel are defined in the Technical Guidelines [20][21][22][23]. The tightness of the connections has to be proven as well [24][25]. For operating the magnet an approval by the local authorities e.g. TÜV is necessary. This approval incorporates the proof of the design, the construction as well as final tests. The extent of this approval is given in the pressure vessel directive and differs according to the classification of the vessel. The European Guideline for pressure vessels 2014/68/EU must be observed.

Tests of the assembled cold mass/ cryostat/ Feedbox

The contractor should provide the cryogenic testing conditions which reproduce as close as possible the working conditions at the installation site. In case that is not possible, the Contractor should discuss alternative ways of testing with the Company.

- Leak Test
- Pressure Test
- Test of instrumentation
- Functionality test of the Feed box-as far as it is possible at this time
- Controlled cooldown: measurement of RRR and test of superconductivity (low current)
- Measurement of the heat load by measuring the helium boil-off at zero current and low current
- Measurement of current lead helium return flow
- Controlled warm up

The results of the tests above must be approved by the company before the winding of the second coil starts.

Complete Assembly of the magnet

- Demonstration of feasibility of the assembly
- Mechanical measurements as described above
- Demonstration of the alignment procedure

5.2. Factory Acceptance Test (FAT)

- Determine the field direction /polarity
- Check the powering and quench detection and protection scheme
- Measure the coil resistance at 300 K
- Controlled cooldown by measuring the magnet resistance
- Determine the cryogenic losses at 0 A
- Measure the cryogenic losses at nominal current
- Magnet ramping (0A -> nominal current -> 0A)
- Single ramp up to 1.2 * nominal current
- Quench tests at nominal current with /without dump resistor accQuench tests at 1.2 * nominal current with/without dump resistor acc
- HV to ground test at cold.
- Measurement of the heat load at 4.5K and 80K
- Controlled warm up by measuring the magnet resistance

Remark: nominal current is the operating current at which the ∫Bdl equals to 0.972 Tm

Magnetic measurements:

- Local excitation curve, By to be measured in the center of magnet with hall probe. 16 current values from I=0A to $I=1.2*I_{nom}$
- Integral excitation curve, By to be measured on the central line with stretched wire 16 current values from I=0A to $I=1.2*I_{nom}$

The required accuracy relative to the peak field in the main region of the STS detector is 0.1%.
A standard cycle 0A $-I_{nom}$-0A has to repeated three times before each measurement.
The precision of the data should be determined by repeating the measurement several times.

Field map:

All three components B_x, B_y, B_z will be measured. The field region of interest is shown in Figure 13. We distinguish 2 different areas:

- Area inside the opening angles
- Area of the downstream fringe field up to at least 2500mm downstream of the target position over the full acceptance cone of ±35º horizontal and ±25º vertical. The final size of the mapping region will be determined based on the calculated field map of the final magnet design and be fixed latest at the time of the CDR.

The field data close to the coil allow to determine the high field point in the coil.
The map is requested at the nominal field level of about 1 T, one with and one without the detachable field clamps and at least three field values at partial excitation. The field values will be determined based on the calculated field maps and the predicted saturation effects and be fixed latest at the time of the CDR
The required accuracy relative to the peak field in the main region of the STS detector is 0.1%.
A standard cycle 0A –I_{nom}-0A has to repeated three times before each measurement.

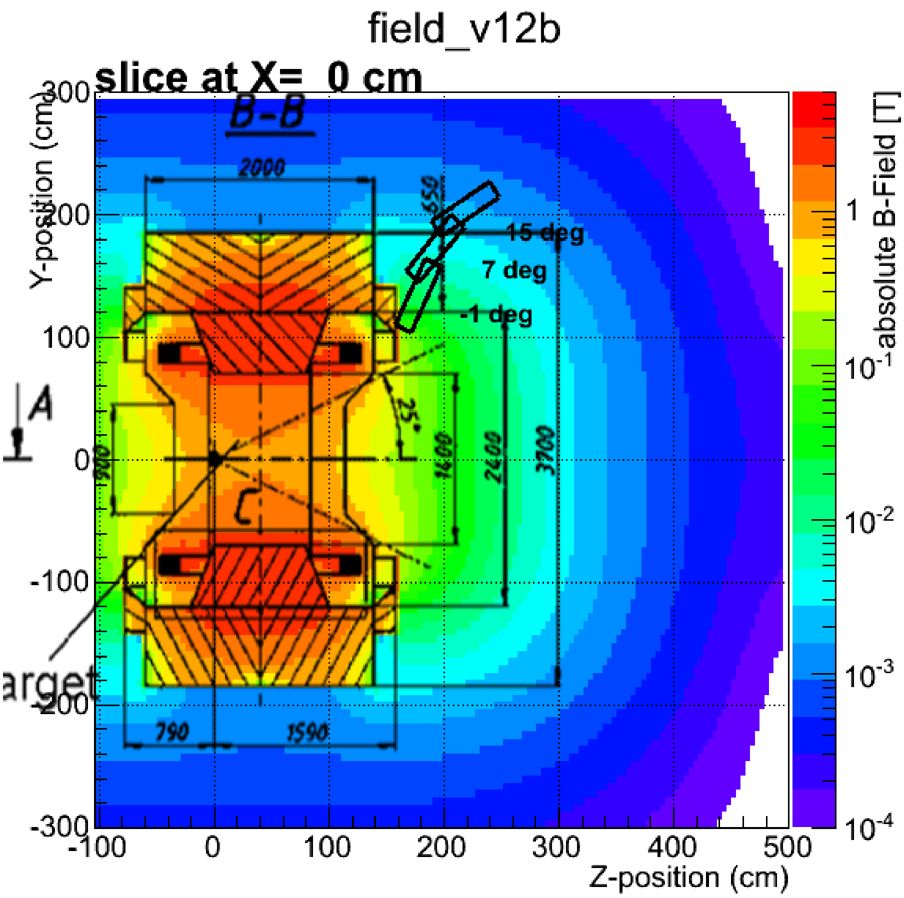


Figure 13: Magnetic field distribution in the y-z-plane at x=0.The three boxes correspond to possible positions of the RICH photodetector.

5.3. Site Acceptance Test (SAT)

Steps immediately after delivery:

- Visual inspection of all components
- Insulation tests of the coil
- Insulation tests of the instrumentation hardware
- Tightness of the connections

Tests of the assembled magnet including FB and BB

The tests performed during the FAT will be performed again at the installation site. Any functionality test of the Feed Box which was not able to be tested at the FAT will be performed during the SAT as well as the functionality tests of the Branch Box. Contractor and Company should agree in advance regarding the necessary tests.

Required measurement during the operation of the magnet:

- Determine the field direction /polarity
- Check the powering and quench detection and protection scheme
- Measure the coil resistance at 300 K
- Control the cooldown by measuring the magnet resistance
- Determine the cryogenic losses at 0 A
- Measure the cryogenic losses at nominal current
- Magnet ramping (0A -> nominal current -> 0A)
- Single ramp up to 1.2 * nominal current
- Quench tests at nominal current with /without dump resistor acc. Table 2
- Quench tests at 1.2 * nominal current with/without dump resistor acc. Table 2
- HV to ground test at cold.
- Measurement of the heat load at 4.5K and 80K
- Control warm up by measuring the magnet resistance

Remark: nominal current is the operating current at which the ∫Bdl equals to 0.972 Tm

Table 2: Testsequence for the magnet

.Test sequence	Rd/Rd_{nom}
1	1
2	0
3	1
4	0
5	1
6	0

Details can be found in [5].

Magnetic measurements:

- Local excitation curve, By to be measured in the center of magnet with hall probe. 16 current values from I=0A to I=1.2*Inom

- Integral excitation curve, By to be measured on the central line with hall probe
  16 current values from I=0A to I=1.2*Inom
- Field map in order to check the reproducibility of the data obtained during FAT (from the upstream side only)

The required accuracy relative to the peak field in the main region of the STS detector is 0.1%.
The required field accuracy in the fringe field is 0.2 mT.
A standard cycle 0A –Inom-0A has to repeated three times before each measurement.
The precision of the data should be determined by repeating the measurement at some points several times.

Task of contractor at site

- The contractor is responsible for the transport of all components to the company site, the assembly of the magnet on site and the preparation of installation. The contractor will participate in the SAT.
- The company is responsible for the transport of components on site, the installation, fiducialisation and alignment and SAT (including commissioning and magnetic
  measurements).

6. Quality Assurance of Feed Box and Branch Box

The complete Quality Acceptance process is described in the "General Specification"[6]. The special tasks during FAT and SAT for the cryogenic Feed Box and Branch Box are defined in [32].

7. Documentation

- Design calculations
- Drawings
- Material certificates
- Production documentation (yoke, coil, cryostat)
- Minutes of meetings
- TÜV checks including minutes
- Production tests certificates (bilingual) and FAT results
- P&IDs diagrams and functional analyses
- Documentation for cryogenic control system according to [28]
- Assembly instructions
- Maintenance instructions
- Operating manuals (in German, to be delivered with the component)
- List of spare parts

8. Literature

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[6] F-GS-F-01e-General_Specification_v1_2
[7] F-CS-MT-01e NC-Magnets_V1.6.doc Common specification Normal Conducting Magnets for FAIR
[8] F-CS-CR-01e_Cryogenic_Module_Cryostats_20111115
[9] F-CS-MT-02e Super-FRS Dipole-Magnets Common Specifications Superconducting Super-FRS Dipole Magnets
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[12] F-TG-A-3.55e_Layout_of_a_fiducial_target_seat_V2.0
[13] F-TG-A-3.12e_Mechanical_tolerances_of_dipoles_20120524
[14] F-TG-A-3.20e_References_of_fiducialisation_of_dipoles_20100329
[15] F-TG-A-3.6e_Alignment_feet_v2.0.pdf
[16] F-TG-V-3.4e Manufacturing of CF-Knife Edges_20110706.pdf.
[17] F-TG-MT-7.6e Mechanical approval magnets_20090925.xls
[18] F-TG-MT-01e DC high voltage insulation tests for SC Magnets 20110217.doc
[19] F-TG-MT-7.5e Electrical Approval Magnets
[20] F-TG-K-7.16e Acceptance Test for Cryostat Vacuum Vessels 20110915.pdf
[21] F-TG-K-7.19e Vacuum Testing of Cryostat Vacuum Vessels 20110404.pdf
[22] F-TG-K-7.28e Vacuum Test Cryogenic Modules 20110404.pdf
[23] F-TG-K-7.30e Acceptance Test Cryogenic Modules 20110404.pdf
[24] F-TG-K-7.23e He_Leak_Testing_of_Cryogenic_Tubing_20110404.pdf
[25] F-TG-K-7.24e Pressurised_Leak_Testing_of_Cryogenic_Tubing_20110404.pdf
[26] F-TG-K-50.1e_Cryogenic_Operation_Parameter_20160419.pdf
[27] F-TG-K-3.76e_ Instrumentation of FAIR cryogenic cooling
[28] F-TG-C-10e_FA_UNICOS_CS_v1.0.pdf
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[30] F-TG-K-3.82e_Electr_Interconn_Cryostats_Cryogenic_V1.0.pdf
[31] F-TG-K-10.19e_Reference_Designation_Cryogenics_v1.0.pdf
[32] F-TG- xxxx (under design, will be added later)
[33] F-TG-K-3.6.2_Cryostat_Overpressure_Saftey_Sytem_20110104.pdf

9. Related Recommended Technical Guidelines

F-TG-A-3.12e Mechanical Tolerances Dipoles 20120524.pdf
F-TG-A-3.20e References for fiducialisation of dipoles 20100329.xls
F-TG-A-3.55e_Layout_of_a_fiducial_target_seat_V2.0.pdf

F-TG-B-01e Material_Selection_Radiation_20110617.pdf
F-TG-B-02e DARL-T1 20120508.pdf
F-TG-B-03e DARL-T2 20120508.doc
F-TG-B-04e KRL 20120209.doc

F-TG-K-2.30e Cryostat_Flange_Materials_20120329.pdf
F-TG-K-2.31e Thermal_Shield_Materials_20110404.pdf
F-TG-K-2.32e Cryostat_Vacuum_Vessel_Materials_20110404.pdf
F-TG-K-2.33e Epoxy Fibre Composite Materials for Cryostat construction 20110404.pdf
F-TG-K-2.34e MLI Materials 20110404.pdf
F-TG-K-2.35e Materials Cryogenic Tubing 20110404.pdf
F-TG-K-2.38e Materials_Compensation_Bellows_at_Cryogenic_Temperatures 20110404.pdf
F-TG-K-3.52e Cryogenic_Temperature_Sensors_v2.0.pdf
F-TG-K-3.53e LV_Feedthroughs_20110802.pdf
F-TG-K-3.54e MLI_Design_20110404.pdf
F-TG-K-3.56e Low_Power_Cabling_for_Cryogenic_Purposes_20110802.pdf
F-TG-K-3.57e Adhesive Tapes for Cryogenic Purposes 20110802.pdf
F-TG-K-3.61e Thermalisation Straps 20110404.pdf
F-TG-K-3.62e Cryostat Overpressure Safety Systems 20110404.pdf
F-TG-K-3.64e Cryostat Flange Design 20110531.doc
F-TG-K-3.66e Cryostat Insulation Vacuum Gaskets 20110915.doc
F-TG-K-5.5e Surface Coating for Mild Steel Cryostat Vacuum Vessels 20110531.doc
F-TG-K-6.11e Cleaning_Cryostat_Vacuum_Vessels_Components_20110531.doc
F-TG-K-7.18e Cleanliness test High vacuum components 20110530.doc
F-TG-K-7.20e Acceptance Test for Cryostat Thermal Shields 20110404.pdf
F-TG-K-7.26e Flow_Rate_Test_Cryogenic_Pipes_20110406.pdf
F-TG-K-7.27e Residual_Moisture_Test_Cryogenic _Pipes_20110406.pdf
F-TG-K-9.11e Packaging_Cryogenic_Modules_Component_20110404.pdf
F-TG-K-10.7e Cryostat Label Plates _20110404.pdf
F-TG-K-10.8e Documentation and Certificates for Cryostat Vacuum Vessels 20110404.pdf
F-TG-K-10.13e Documentation and Certificates for Cryostat Thermal Shields_ 20110915.pdf
F-TG-K-10.14e FEM Documentation 20110404.pdf
F-TG-K-10.16e Documentation and Certificates for Cryogenic Modules 20110404.pdf
F-TG-K-13.2e Handling Packaging Storage MLI 20110519.doc
F-TG-K-13.5e T_sensor_Installation_20110802.pdf
F-TG-K-52.0e Safety_Devices_for_Cryogenics_20100907.pdf

F-TG-MT-2.39e Local coordinate axes for magnet drawings v1.0.pdf
F-TG-MT-3.27e Designing a Grounding for Magnets
F-TG-MT-7.8e Magnetic Measurement Dipole_20091209.xls
F-TG-MT-7.10e Conditioning_of_magnets_before_measurement_20090609.pdf

F-TG-S-3.38e Anchor_bolts_for_securing_in_the_floor_20090907.pdf
F-TG-S-5.2e Coloring_magnets_20110331.pdf F-TG-T-01e Transport 20101101.xls
F-TG-S-9.4e Transportation_by_air_cushions_20100412.pdf
F-TG-S-10.1e Documentation of Magnets_20091125.xls

F-TG-T-01e Transport 20101101.xls
F-TG-T-02e Existing infrastructure for transport, unloading, handling_20101101F-

F-TG-V-2.19e Additives_for_TIG_Welding_of_Stainless_Steel_20100512.pdf
F-TG-V-3.3e Design of O-Ring Grooves 20100624.pdf
F-TG-V-3.42e Copper_Gaskets_for_ConFlat_Flanges_20101012.pdf

Remark: Valid is always the latest version of the guidelines!

10. Appendix A: STS Installation Space

The STS is housed in a cuboid box designed to fit into the magnet acceptance of

- height between pole shoes: 1440 mm
- width between magnet yokes: 3000 mm

The STS box will be sitting on a mechanical support resting on two rails which in turn are supported by carrier structures on the left and right hand sides of the lower magnet coil.

- The carrier structures are fixed to the lower horizontal yoke bar.
- Enough space for the rail system must be available over the full depth of the magnet.
- The carrier structure can have openings giving space for the cyrogenic supply lines of the magnet coil.
- The detector will be installed from the upstream side into the magnet. The procedure will include the installation of an extension of the rail system.

The concept is shown in **Figure** 14 (view in beam direction) and **Figure** 15 (view from side). The pictures are included to visualize the required space, not to indicate a specific design of rail system and the carrier structure between rails and yoke.

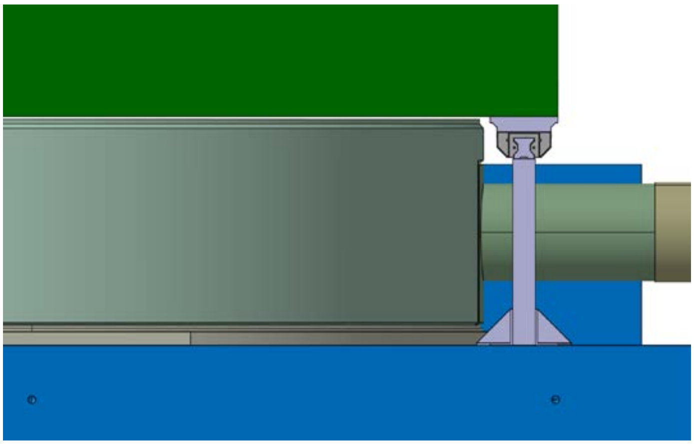

Figure 14: STS box (green) and rail system

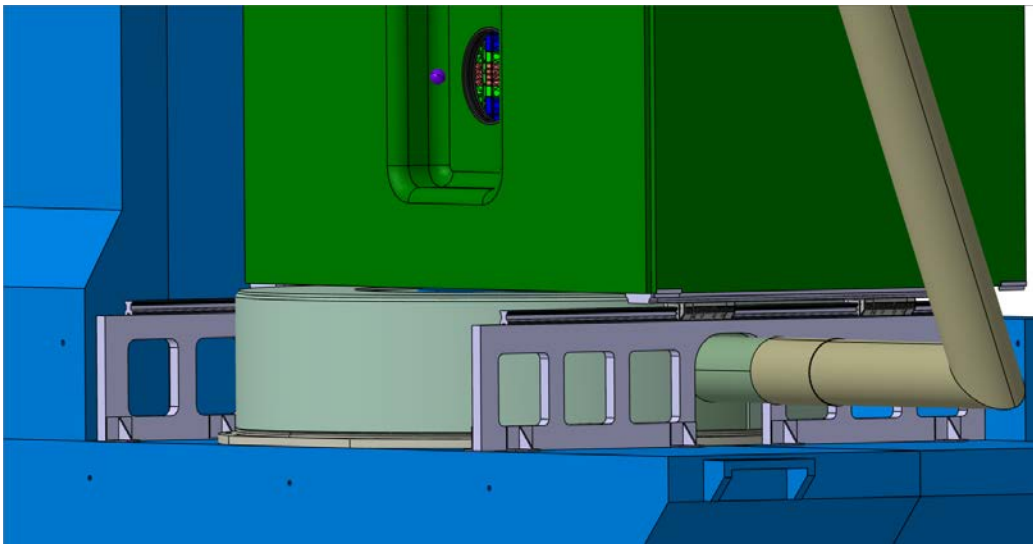

Figure 15: STS box, rail system and carrier structure