Draft Magnet Interface Document
version 0.8, revision 773

The Panda Magnet Group

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Preface

The purpose of this document is to collect in a single reference document the existing criteria for and parameters of both magnets of the $\overline{\text{P}}$ANDA Target Spectrometer (TS) and Forward Spectrometer (FS) and all ancillary equipment. This includes supplies and support structures, which may in parts also be relevant to other subsystems of the detector. It specifies interfaces between sub-components and other detector subsystems where relevant. However, this document does not, in itself, cover integration issues between other detector subsystems though sometimes shown for illustration.

As such the document should, in its final form, be the basis of the documentation for tender of the aforementioned systems.

COMMENT by Inti: Currently under restructuring.

Approved By	On Behalf of	Signature	Date
	the Dubna group		
	the Genova group		
	the Glasgow group		
	the GSI group		
	the CUT group		
	the PANDA Collaboration		

Contents

Chapter 1

Introduction & Terms of Reference

1.1 Introduction

Appropriate magnetic fields are the prerequisite of any momentum reconstruction and subsequent particle identification for charged particles. The two large spectrometer magnets of $\overline{\mathrm{P}}$ANDA are designed to provide an ideal combination of fields: a solenoidal magnetic field of 2 T around the interaction region and a dipole field of up to 1 T for particles emitted at forward angles below 5(10)°.

The central field of 2 T will be generated by a superconducting solenoid which will leave an inner diameter of 1.9 m free for detector placement. Its split coil design permits the allocation of a vertical target feed pipe at about 1/3 of the length of the coil. The whole system, which weighs more than 300 t will be placed on a movable platform in order be able to retract the system for commissioning and maintenance. Forward going particles will experience a field integral of 2 Tm generated by a dipole magnet with a total weight of 220 t and an aperture of about 1 m×3 m, which also will be instrumented. This system will be complemented by a large array of detectors on another movable platform further downstream.

The experiment will be located in the $\overline{\mathrm{P}}$ANDA Hall and utilise the antiproton beam of the High Energy Storage Ring (HESR) which is under construction at the Facility for Antiproton and Ion Research (FAIR) at Darmstadt, Germany.

Please find a general overview in the recent Technical Design Report [1] noting that wherever details have been modified this document should be consulted.

1.2 Definitions

This document defines the specifications of the following components of the $\overline{\mathrm{P}}$ANDA Target Spectrometer (TS): the superconducting solenoid and ancillary systems including cryostat, coil and cryogenic chimney (in the following, simply referred to as "the Solenoid"), the flux return yoke including barrel and upstream and downstream doors and framing ("the Yoke") and the platform supporting the Yoke and used for moving the whole TS from the parking position to the in-beam position ("the Platform"). In addition, this document details the specifications of the large-aperture dipole magnet of the $\overline{\mathrm{P}}$ANDA Forward Spectrometer (FS) ("the Dipole").

This document was approved by $\overline{\mathrm{P}}$ANDA Collaboration, which represents the final customer of the magnets. $\overline{\mathrm{P}}$ANDA Collaboration will nominate a committee which will supervise the project, the manufacturing, the installation and the tests of all equipment. This committee will be the only recognised authority for authorisations and approvals required in the present document. In the following of this document, to the committee, which represents the $\overline{\text{P}}$ANDA Collaboration, will be referred simply as "the Customer".

The aim of this document is to give to the candidate manufacturer industries a basis to develop an executive project and a quotation for the $\overline{\text{P}}$ANDA magnets: the quotations and projects will be evaluated by the Customer to choose the best one. A contract will be signed by the Customer and the industry which presented the chosen project for the solenoid manufacturing. The industry which will sign the contract will be responsible for construction, delivery at FAIR, tests and installation in the experimental hall of the solenoid, according to the terms defined in the following of this document. In the following this industry will be referred to simply as "the Manufacturer".

1.3 Approvals and Verifications of the Manufacturing Status

The Manufacturer will provide to the Customer the following documents for approval:

1. preliminary project with time-scale and milestones; managerial plan of the project and quality control program;
2. engineering project featuring mechanical and magnetic analysis, quench analysis, cryogenic analysis and safety control systems; in addition, the material supply plan and the test plan are requested;
3. final test program at the Manufacturer site.

The approvals for these three points will be discussed in formal meetings at the Manufacturer site, respectively 3, 6 and 20 months after the contract signature.

1.4 Designs Provided by the Customer

1.5 Standards and Norms

1.6 Linked Documents

Chapter 2

Common Aspects

In this chapter requirements are listed which are common to both the Target Spectrometer (TS) and Forward Spectrometer (FS).

2.1 Common Requirements

Below all common requirements (CR) are listed.

CR-1 Appropriate safety margins have to be chosen according to the EN Eurocodes [2] (other appropriate well established norms may be chosen with the consent from the Customer).

2.2 Accelerator Interface

The $\overline{\mathrm{P}}$ANDA detector magnets will interact with the antiprotons stored in High Energy Storage Ring (HESR) through the magnetic field seen by the beam circulating in the storage ring. For a smooth operation of the storage ring the integral of the magnetic field, apart from the machine optics, seen by the circulating beam in a complete round must be zero. The asymmetric chicane which will accomplish this is sketched in Fig. 2.1.

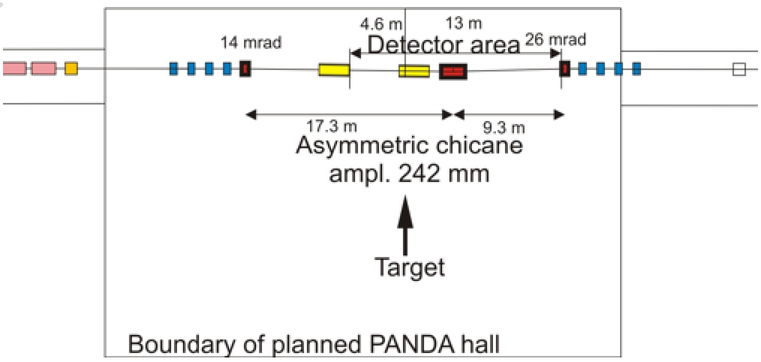


Figure 2.1: Tentative HESR layout showing the straight section where the $\overline{\mathrm{P}}$ANDA experiment is located. The $\overline{\mathrm{P}}$ANDA detectors will be within the "Detector area". The $\overline{\mathrm{P}}$ANDA solenoid and compensating solenoid (to the left of it) are indicated in yellow, the $\overline{\mathrm{P}}$ANDA dipole and the 2 dipoles of the chicane in red, and the quadrupoles in blue.

In the Target Spectrometer (TS) the longitudinal component of the magnetic field B_z of the solenoid, oriented along the machine axis, is 2 T at maximum over a length of several metres. Thus, the integral of the field along the beam of the $\overline{\mathrm{P}}$ANDA Target Spectrometer is $\sim 7\,\mathrm{Tm}$ and influences the divergence of the beam significantly. To avoid coupling effects between the beam motions in the transverse planes a compensating coil of similar strength will be installed as close as possible to the $\overline{\mathrm{P}}$ANDA solenoid, *i.e.* after the focusing quadrupoles and upstream of the $\overline{\mathrm{P}}$ANDA solenoid. Due to the magnetic field integral of 7 Tm a superconducting solenoid with a magnetic length of less than 2.5 m is used, sharing the refrigeration system with the $\overline{\mathrm{P}}$ANDA Target Spectrometer. Both solenoids are operated such that a full compensation of the B_z integral is reached. Normally, they will be set to the nominal current at the beginning of a measurement period and remain unchanged for the full period. A lower field setting is only required for measurements at some beam energies below injection energy.

In the Forward Spectrometer (FS) the dipole magnet deflects the whole of the beam. Thus the transverse component B_y of the dipole field must be compensated. This is realised using two dipole magnets amounting to the same integral bending power of the $\overline{\mathrm{P}}$ANDA dipole. They are arranged asymmetrically around the dipole in order to keep the necessary space for the solenoidal magnets and detectors, *i.e.* at 17.3 m and 9.3 m before and after the centre of the dipole, respectively. Thus they form a chicane in the straight section of the HESR with bending angles of 14 mrad and 26 mrad, respectively. Thus the beam reenters the straight section after the whole chicane to the nominal orbit of the HESR, and the total field integral in vertical direction B_y is balanced to zero.

The HESR ring will provide $\overline{\mathrm{P}}$ANDA with antiprotons with momenta between 1.5 and 15 GeV/c. These will be injected at the fixed energy of 3.8 GeV/c and HESR will operate as a slow synchrotron, ramping from the injection energy to the final energy required for the experiment.

To keep the antiproton beam on the nominal orbit, the chicane dipoles, including the Forward Spectrometer dipole, must ramp simultaneously with the HESR magnets, hence the chicane being an integral part of the HESR accelerator. The ramp time of the HESR of about 60 s would introduce too large time delays of the magnetic field due to eddy currents if a solid iron core had been chosen for the dipole. Therefore, a moderate lamination is mandatory.

2.3 Floor Space and Geometrical Constraints

The space occupied by the magnets and its anxiliary systems is limited by the floor space in the $\overline{\mathrm{P}}$ANDA hall, in particular, inside the HESR ring area (see Figs. A.1 and A.2). Note, that the space availible in those figures is partially used by other equipment.

Chapter 3

Overall Target Spectrometer Requirements

The Target Spectrometer (TS) falls into three parts: 1) the Solenoid, 2) the TS Yoke and 3) the TS Platform. These are discussed separately in chapters 4 and 5. In this chapter a special emphasis is laid on the interfaces between the magnet and other detector parts, the buildings and the magnet sub-components.

3.1 Spatial Occupancies

COMMENT by Inti: The following paragraph needs to be altered!

As an interim measure, to facilitate progress in all areas of detector design, the Magnet Group has settled on two defined Magnet Volumes for the cryostat and yoke (in Table 3.1[1]), which are reported as they stand after the Technical Board Meeting of February 13th 2008, with a slight increase in the yoke radial extent from 2240 to 2300 mm to accommodate the increase in the muon layer gaps from 25 to 30 mm. Although the current forward door design envelope is now smaller than the envelope given in the Magnet Volumes, the Magnet Volumes have not been reduced in this region. There is still some debate regarding the lamination detail in this area and, as such, it is wise to retain the full region inside the Magnet Volume as a location which requires special attention. In the Detector Volumes (all areas outside of the Magnet Volumes) there will be no major interference with the physical structure of the solenoid and any detector arrangement is possible without requiring detailed negotiation with the Magnet Group. The Magnet Group also require space to mount the cryostat on the yoke and for cryo-supply, these volumes are not yet clearly defined but will be mostly located in the gap between the cryostat and the yoke, aside from the space occupied by the cryostat chimney and its attachment.

Inside the Magnet Volumes, it is foreseen that space may be made for other detectors and, obviously, the muon detectors will be interspersed throughout the magnet yoke volume. However, it is essential that any detector system which has to enter the Magnet Volumes, with cabling and/or detector parts, or to reach the outside (e.g. the Barrel DIRC) needs to be designed by a process involving close communication and negotiation with the Magnet Group to ensure that an optimal solution is reached, allowing both magnet and detector to

[1] It should be noted that the radii represented here apply only to the barrel section and not to the forward and rear doors which may require supporting structures which sit proud of the main barrel radii. The radii are defined as the minimum possible radial distance from the beamline to the relevant yoke and cryostat face, i.e in the centre point of each yoke beam, perpendicular to the faces.

Dimensions of	radius / mm	axial length / mm	$z_{min.}$ / mm	$z_{max.}$ / mm
Cryostat Inner	950	3090	-1190	1900
Cryostat Outer	1340	3090	-1190	1900
Yoke Inner	1490	4050	-1585	2485
Yoke Outer	2300	4875	-1970	2905

Table 3.1: Summary of magnet and cryostat maximal dimensions hereafter known as the Magnet Volumes. Nothing should be placed between the inner and outer cryostat limits and the inner and outer yoke limits (in the Magnet Volumes) without prior discussion with and agreement by the Magnet Group.

function as required. The Magnet Group agrees to keep the magnet design within these defined Magnet Volumes for the main magnet structure. Should we require to encroach on the Detector Volumes, we will obtain the agreement of the Technical Board.

3.2 Magnetic Field

In addition to the main requirement that the magnetic field has to be 2 T in the solenoid centre, there are several requirements for field homogeneity and stray field, which are summarised in the following.

Criteria	Absolute Value	Definition
Micro Vertex Detector		
Dimensions, longitudinal: $-0.25\,\text{m} < z < 0.2\,\text{m}$, radial: $0.0\,\text{m} < r < 0.12\,\text{m}$		
$\frac{\Delta B}{B_0} < 2\%$	$\Delta B := \lvert B(r,z) - B_0 \rvert$	$B_0 :=$ nominal field, *i.e.* 2 T $B(r,z) :=$ field at any point in given region
Central Tracker		
Dimensions, longitudinal: $-0.4\,\text{m} < z < 1.1\,\text{m}$, radial: $0.15\,\text{m} < r < 0.42\,\text{m}$		
$\frac{\Delta B}{B_0} < 2\%$	$\Delta B := \lvert B(r,z) - B_0 \rvert$	$B_0 :=$ nominal field, *i.e.* 2 T $B(r,z) :=$ field at any point in given region
$I_B(r, z_0) < 2\,\text{mm}$	$I_B(r, z_0) := \int_{z_0}^{-400} \frac{B_r(r,z)}{B_z(r,z)}\, dz$	$z_0 :=$ any z value in region $B_r, B_z :=$ radial, long. field components, resp.

Table 3.2: Criteria for the homogeneity of the solenoidal magnetic field in the region of the Micro Vertex Detector (MVD) and central trackers of $\overline{\text{P}}$ANDA. The first respective rows for the MVD and central tracker show the longitudinal (*i.e.* along the z axis) and radial dimensions of the trackers, and hence the validity region of the give criteria. The criteria which must be kept are listed in the first column, where the definitions of the variables are given in columns 2 and 3.

Tracker Region Three tracking systems will be used to reconstruct charged particle tracks in $\overline{\text{P}}$ANDA. (Please also refer to Fig. **??**.) The inner tracker will be an array of Micro Vertex

Detectors (MVD) surrounding the beam pipe closely and extending up to 12 cm radially. The central tracker will either be a Straw Tube Tracker (STT) or Time Projection Chamber (TPC). Any of the two tracking devices will occupy a length of 1.5 m extending to a radius of 42 cm. In addition, three layers of GEM detectors will be used to track particles exiting at small angles. In the region occupied by the MVD and the central tracker there are very stringent requirements on the magnetic field homogeneity. The absolute magnitude of the field must not vary by more than 2% from the nominal field of 2 T over the whole tracker region. Furthermore, the radial component of the magnetic field B_r must remain as low that any integral along z to the central tracker read-out plane, located at $z = -400$ mm, results in a value below 2 mm if started from any given point inside the central tracker. This ensures that charges which are produced inside the TPC at any $z = z_0$ do not experience too large an offset to be assigned to the right track. These requirements on the magnetic field are summarised in Table 3.2.

Field Limits As much as fields are required in certain areas, some components, in particular certain read-out electronics and vacuum pumps, restrict the maximum tolerable field strength. Often this is directional, *e.g.* a photo-multiplier tube is able to withstand different maximum fields along its axis than perpendicular to it. This includes fields inside and outside the flux return yoke. Clearly, the former fields will be generally strong while the latter will be shielded largely by the return yoke. Stray fields become important at the following places.

1. At the location of the readout of both DIRC detectors inside the flux return.
2. At the location of the turbo-molecular pumps for the target generator and dump. The latter ones will be further from the solenoid centre and hence experience smaller fields.
3. The pumping stations for the beam line before and behind the solenoid are denoted by “s1” and “s2” in Table 3.3, respectively.

The maximum allowable fields and the locations in the $\overline{\text{P}}$ANDA coordinate system where those become applicable are listed in Table 3.3.

Detector	Item	Radius [m]	z [m]	$B_{\max}$ [mT]
Disc DIRC	1	1.4	2	1200
Barrel DIRC	1	0.7	-1.6	1200
Target gen	2	2	0	5
Target dump	2	2.3	0	5
Pump s1	3	0	-2.3	5
Pump s2	3	1	3	5

Table 3.3: Summary of maximum tolerable magnetic fields for sensitive detector components or pumps. The item number from the list in Sec. 3.2 is given. The radial and longitudinal extent z from the interaction point are given as rough indication for their locations. Most of the components actually cover extended non-trivial volumes. (See also Sec. **??**)

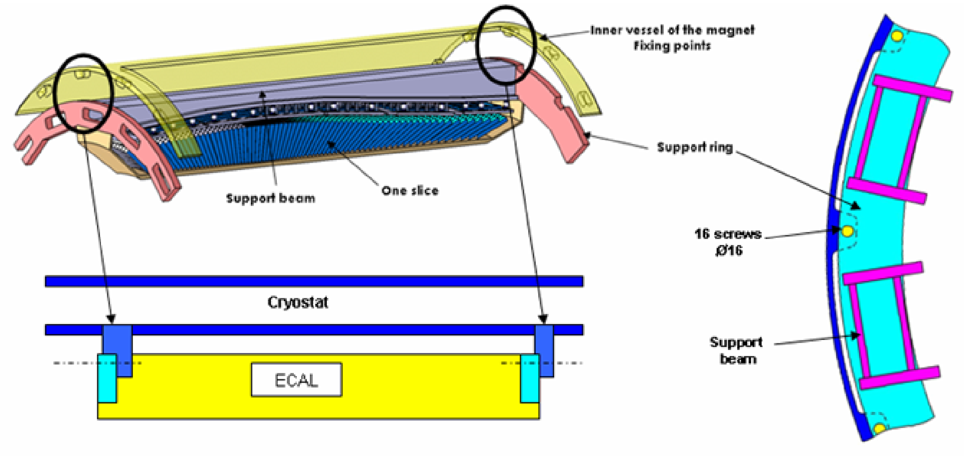


Figure 3.1: Tentative attachment of the EMC barrel to the cryostat.

3.3 Detector Support

There are three distinct areas where mountings for the detector support will be attached.

- At the upstream end of the yoke barrel, support structures will be mounted. These hold cables and supply lines, and serve as mounting points for the Barrel DIRC and the upstream side of a frame to support the inner detectors and the beam pipe.
- At the downstream end of the yoke barrel similar support structures will be installed to hold the forward end-cap detectors and their housings and supplies. They will also hold the cable and supply lines from parts of the EMC.
- Special ribs on the cryostat will serve as mounting points for the Electromagnetic Calorimeter (EMC). The downstream side of the frame holding the inner detectors will be mounted such that part of the load is effectively resting on the downstream rib of the cryostat.

The Electromagnetic Calorimeter (EMC) will be attached, as shown in Figure 3.1, to the inner surface of the cryostat shell via special ribs to which the support structure of the EMC will be attached by screws. The EMC and all of the other detectors inside the cryostat must be supported by attachment to the solenoid yoke via the cryostat. Attachment points for all other detectors will come from the eight corners of the octagonal yoke. The currently known detector weights and attachment points are shown in Table 3.4.

3.4 Target Integration

A warm bore of 100 mm in diameter should be foreseen between the two parts of the magnet coils, and a hole of 350 mm through the barrel yoke is required to accommodate the internal target system. A rectangular recess is required from a radial distance of 2 m to the interaction point with dimensions of 1 m × 1.2 m in x and z, respectively. The recess may have rounded corners. Furthermore, in the remaining part of the yoke the hole needs to be opened further than 350 mm to accommodate the pumping cross. In the region of the Turbo Molecular Pumps, the magnetic field must not exceed 5 mT. The closest pumps will be installed in the generation part 2 m vertically from the interaction point. The fore pumps will be located such that they neither interfere with the yoke iron nor with the foreseen support construction.

Detector	Supported via	Magnet attachment point	Mass		
			Det. [kg]	Cable [kg]	Total [kg]
MVD	Central Tracker	Cryostat	15	100	115
Central Tracker	direct	Cryostat	45	100	145
Barrel TOF	direct	Cryostat	380	50	430
Barrel DIRC slabs	direct	Cryostat	360	–	360
Barrel DIRC read out	direct	Yoke (upstr.)	800	200	1000
Barrel EMC	direct	Cryostat	20,000	1500	21,500
Barrel Muon	direct	Yoke (uniform)	4,000	200	4,200
Forward GEMs	direct	Cryostat	110	40	150
Forward DIRC	Forward EMC	Yoke (downstr.)	1,000	200	1,200
Forward EMC	direct	Yoke (downstr.)	5,190	810	6,000
Forward Muon	direct	Downstr. door	1,000	50	1,050
Backward EMC plug	direct	Yoke (upstr.)	1,000	500	1,500
Totals	Supported by cryostat				22,700
	Supported by upstream yoke				2,500
	Supported by downstream yoke				7,200
	Supported uniformly in yoke or door				5,250

Table 3.4: Detectors located inside the solenoid, their total masses and main support point on the solenoid. The detectors are attached either to both ends of the cryostat simultaneously or the upstream or downstream ends of the yoke. It should be noted that, where supplied with a possible mass range, only the upper limits are reported.

The target generation system will be accessible during normal maintenance to allow to switch between pellet and cluster jet target. Only a partial modification of the target dump will be required when the target system will be changed: anyhow, to make the first installation of the target dump easier, a minimum clearance of 85 cm between the floor and the support structure of the yoke barrel is foreseen. This clearance is foreseen over the whole width (in x direction) of the support structure, such that any equipment can be brought in from this direction. The magnet weight is transferred to the floor with two symmetric structures at the end of the barrel and under the end doors.

3.5 Assembly and General Detector Access

The solenoid should be mounted on a movable rail-guided carriage to be transported from the assembly area to its operational position. The downstream end cap of the solenoid should open up. The two semi-segments should slide apart on skids. The upstream end cap of the solenoid should also open in order to allow access for detector installation, wiring and maintenance and to facilitate cryostat installation.

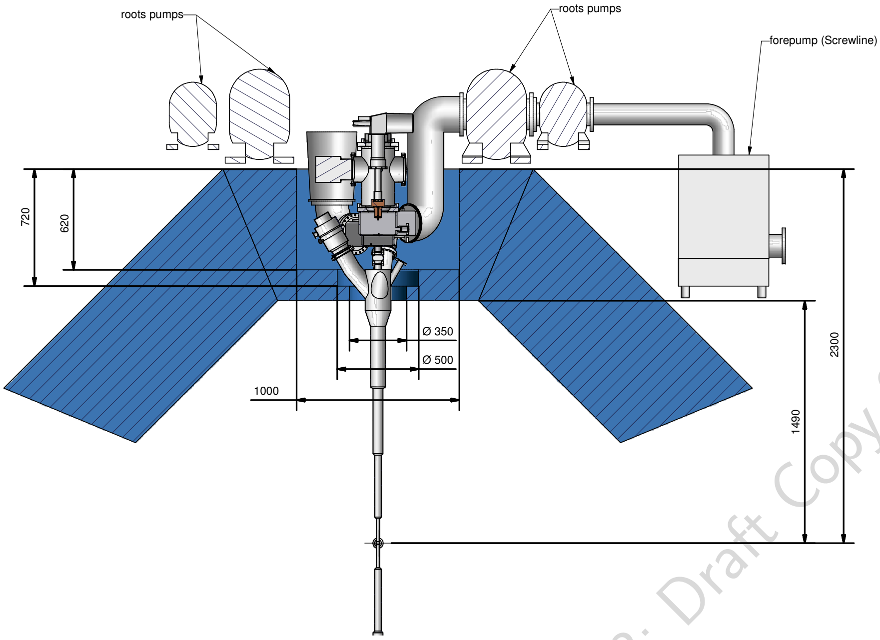


Figure 3.2: View of the foreseen integration of the generator of the cluster-jet target in the yoke of the solenoid, supplied by Alfons Khoukaz and Alexander Täschner 25/07/2008.

3.6 Cable and Supply Routing

Signal cables and supply lines from all detectors except the MVD and central tracker will require to be fed past the cryostat to the outside of the yoke through cut-outs at the upstream and downstream ends of the barrel. The inner and central trackers will route their supplies trough the upstream opening of the door and hence do not affect the following considerations. Apart from an integral cross section for cables some supply line require a minimum clearance. This is the case for the cooling lines of the EMC which, including their insulation, have a diameter of 12 cm. In Table 3.5 all the requirements concerning the space for cable and supply routing are listed. These space should preferably be distributed along the circumference of the flux return yoke.

Detector	Cross section [mm^2]
Downstream routing	
GEM stations	40,000
Forward DIRC	40,000
Forward EMC	160,000
Muon counters	160,000
Total	400,000
Upstream routing	
Barrel EMC	203,800
Barrel DIRC	20,000
Muon counters	200,000
Total	423,800

Table 3.5: Minimum required space for the routing of cables and supply lines at the upstream and downstream ends of the flux return yoke. Cross sections are given by the area of packed cables and supplies. A minimum dimension of 120 mm is given by the diameter of the cooling lines of the EMC. This limits the geometrical design of the cut-outs.

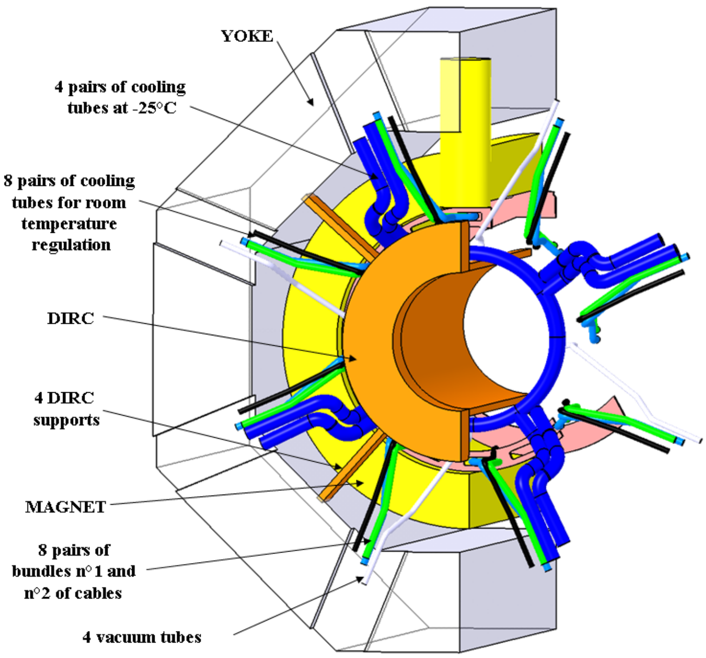


Figure 3.3: Schematic view showing the routing of the cooling pipes (blue) and all other supply lines and signal cables of the Barrel EMC at the upstream end of the solenoid. For visibility details have been omitted and magnet and detectors are cut in half.

3.7 Cryostat-Yoke Interface

This section details the interface between the cryostat of the Solenoid and the inside of the Yoke where it will be attached. In addition, the interface between the cryogenic ancillaries for the Solenoid are discussed here. Other issues apart from those are discussed in the respective chapters.

COMMENT by Inti: Should we discuss the interface between the cryogenic chimney/ancillaries with the yoke here as well? If not where else?

3.7.1 Summary of Requirements

1. All common requirements as listed in Sec. 2.1, in particular **CR-1**, have to be fulfilled.

2. The cryostat-yoke interfaces (*i.e.* support points on the Cryostat and Yoke as well as the connecting structures detailed here) must ensure the safe support of all equipment in all operational modes and exceptional cases as detailed in this document.

3. The expected forces and their action point (z_g: axial offset, $x_g = y_g = 0$) are listed in Table 3.7.2. Any design must ensure the stability for any combination of listed loads within the given ranges, even in a most unfavourable addition of those.

4. All cryogenic equipment mounted on top of the cryostat should be located upstream of the target to maximise available space for detectors and wiring in the forward region. The cryostat chimney will be located as far upstream as possible in order to simplify cryostat insertion into the yoke. All cryogenic equipment needs to be supported by the Yoke.

5. The mechanical stability of the Yoke must be such that the following can be guaranteed. The maximal deviation of the inner contour of the Yoke at any stage (including the moving procedure) will be: in vertical direction $\Delta Y = \pm 1.5$ mm, in horizontal direction $\Delta X = \pm 1.5$ mm.

   COMMENT by Jost,Inti: I think $\pm$ does not harm here, right?

3.7.2 Forces Transferred between Cryostat and Yoke

COMMENT by Inti: Below information from Jost, amended.

The solenoid yoke must support the weight of the cryostat and the weight of those detectors which will be attached to the cryostat. The majority of axial forces generated by the energised coils will be balanced within the coils and their mandrel. Any remaining net axial force should be minimised as far as practicable and should not exceed the value given in Table 3.7.2. All the resulting forces (including seismic forces) must be supported against the barrel part of the Yoke.

Estimates on the weights to be expected are given, which act in negative y direction. Possible x and z components due to an inclination of the experiment will not exceed a few kN and are hence neglected here.

Magnetic forces and their upper bounds are deduced from field calculations, where the following possible misalignments have been considered. A scenario where the coil would be positioned by 2 cm downstream of its nominal position leads to $F_z \pm 100$ kN. A possible lateral misalignment between the coil axis and the yoke axis by 15 mm and an angular misalignment

		F_x [kN] horiz.	F_y [kN] vertical	F_z [kN] axial	z_g [mm]
Weight	Coil+cryostat	—	-120^{+20}_{-20}	—	355^{+20}_{-20}
	Inner det.	—	-220^{+20}_{-20}	—	220^{+20}_{-20}
	Cryo. chimney	—	??	—	$-1390^{+??}_{-??}$
Force	Magnetic	0 ± 75	0 ± 75	-70^{+100}_{-100}	355^{+20}_{-20}
	Seismic	0 ± 23	—	0 ± 23	264^{+20}_{-20}

Table 3.6: Summary of forces (F) transmitted from the Solenoid to the Yoke, and axial coordinate for the centre of action for those (z_g while $x_g = y_g = (0 \pm 15)$ mm). Forces acting on the yoke which are not transmitted via the cryostat are listed in Table 3.4.

of 3 mrad between coil axis and yoke axis (at the centre-of-gravity of the coil) is considered deducing limits for F_x and F_y to ≤ 70 kN in any orientation.

For the lateral seismic forces an acceleration of 0.75 m/s is assumed (rated value for the region of Darmstadt). Vertical seismic forces are expected to be negligible compared to all other forces [2].

3.7.3 Detailed Interface Description/Proposal

The bearings which support the cryostat inside of the yoke should be configured such that a minimal interference is obtained between the 3 coordinates in a Cartesian system. The Cartesian coordinate system is chosen such that the origin coincides with the nominal interaction point of the experiment and the vertical axis is denoted by y while axes in the horizontal plane perpendicular and parallel to the beam are denoted by x and z, respectively. For simplicity we identify in the following x, y, z with horizontal, vertical and axial, respectively. In this way it is possible to avoid an interdependence of the forces, *e.g.* a rise of the axial force on the cryostat will not change the reaction forces in the vertical bearings appreciably. It is assumed that only normal forces are acting on the bearing surfaces. Lateral (shear) forces will have to be reduced by appropriate means. Fig. 3.4 outlines the general concept.

The position of the supports are indicated in the respective perpendicular planes in Fig. 3.5. For the vertical supports, Fig. 3.5(a), the plane of the support faces on the cryostat will be at $y = -1310$ mm (below the z-x plane), the corresponding plane on the yoke (near to the bottom octagon) will be at $y = -1450$ mm. For the axial supports, Fig. 3.5(b), the plane of the two upper support faces on the cryostat will be at $z = -960$ mm (upstream), the plane on the two lower axial support faces at $z = 1670$ mm. For the horizontal supports, Fig. 3.5(c), the support faces are symmetric about the y-z plane. The positions are at $x = \pm 1310$ mm.

In Fig. 3.6 possible layouts of the vertical and axial support structures are depicted. The vertical support would be consisting of 2 pairs of axial spherical plain bearings (at top, at bottom, DIN ISO 12240-3) and a commercially available spreader with a fine thread. This set-up can compensate small misalignment angles, and it can take small lateral deflections with low friction. The vertical supports will be subject only to pressure, not to tension. One of the vertical supports will be supplied with a spring (100 kN/mm rigidity, pre-strain 1 mm). Attention should be paid that the maximum normal force on any of the vertical supports will not exceed 150 kN.

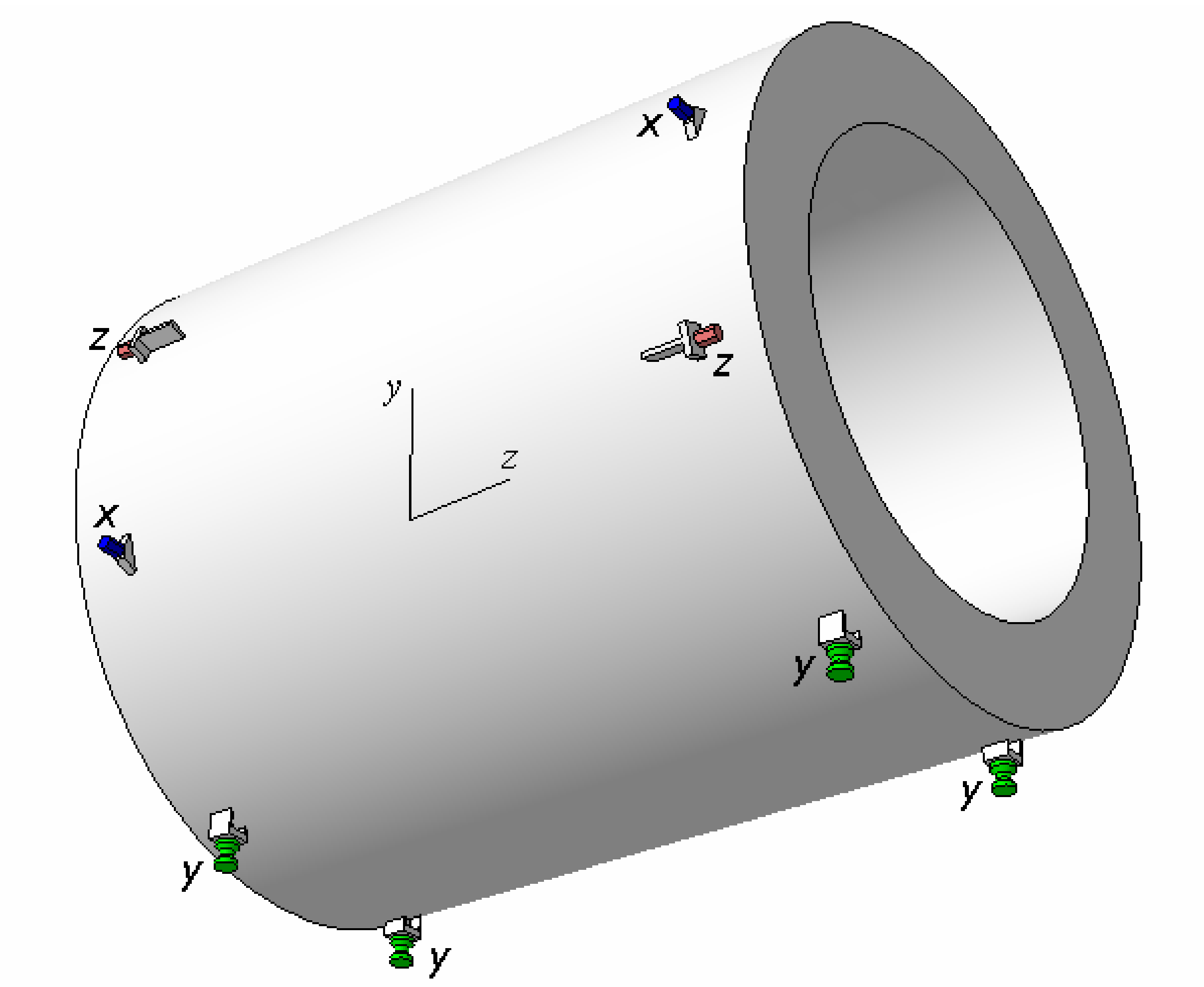
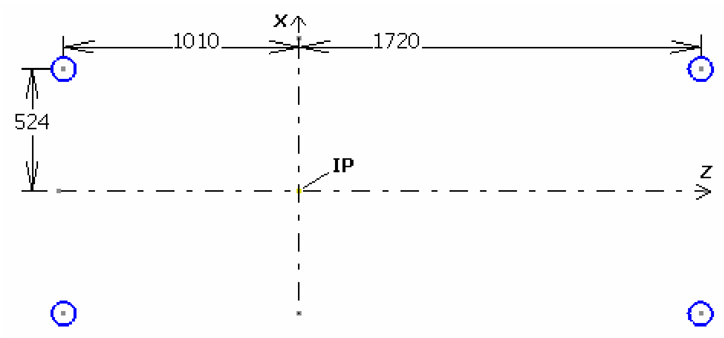


Figure 3.4: Schematic view showing the support points of the cryostat inside the yoke. The supports are: 4 vertical (y, green, only at the bottom), 4 axial (z, red) and 4 horizontal (x, blue). All supports are symmetric wrt. the y-z plane.

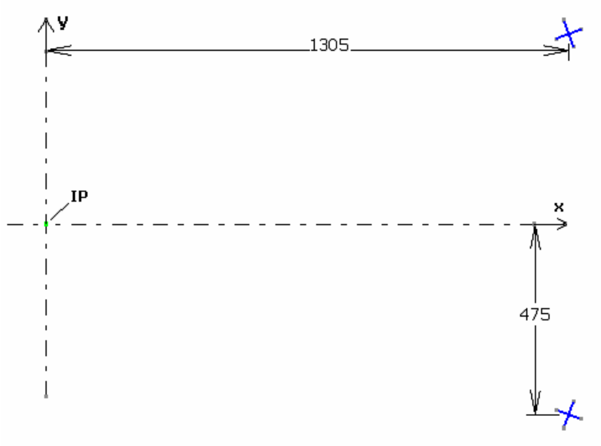
The axial (z) supports will consist of a threaded strut and two countering tie rods, as sketched in Fig. 3.6(b). They can be loaded in both directions (compression and tension). The rods and the strut are mounted with pairs of spherical washers (DIN 6319). The axial positioning will be done using the struts on both ends of the cryostat. Having completed this, with a low pre-load, the position of the struts will be secured with the tie rods. This method makes sure that the axial force will not be kept only at one end of the cryostat but will be shared at all axial supports. The maximum force on any of these supports is expected to be 75 kN.

The horizontal (x) force will not be as big as the axial force. Therefore the horizontal supports will only consist of struts, which will not be pre-loaded with a big force. If a seismic or magnetic force will arise in x-direction only two struts of one side of the cryostat will be under pressure, not the struts on the other side. The maximum force on any of the struts is expected to be 75 kN.

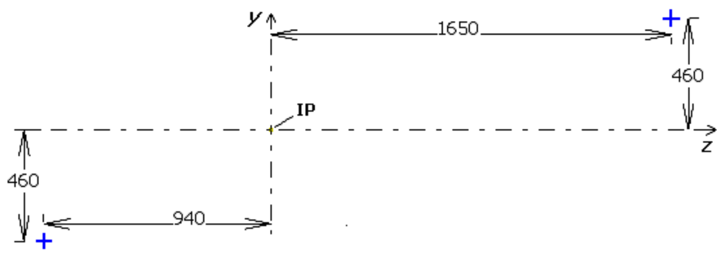
COMMENT by Inti: To what level we want to require this exact solution? We should clearly identify what is required and what is a mere suggested solution.



(a) vertical in the x-z plane

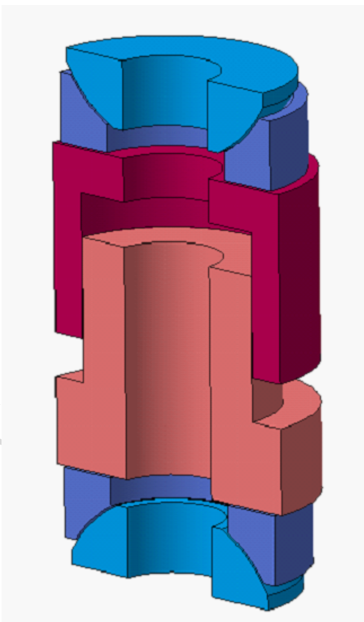


(b) axial in the y-x plane

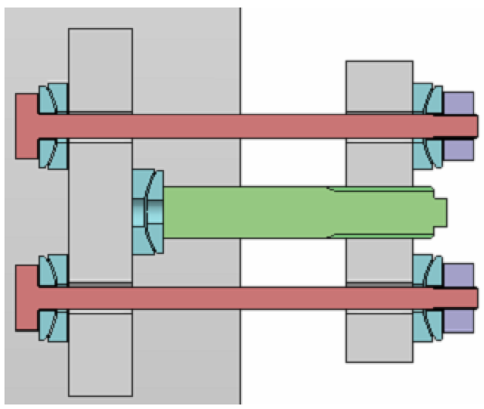


(c) horizontal in the y-z plane

Figure 3.5: Positions of the supports of the cryostat inside the yoke. All dimensions are in millimetres, beam is on z-axis, IP indicates the nominal position of the target.



(a) vertical support



(b) axial support

Figure 3.6: Sketches of the design principle of the supports for the cryostat inside the yoke.

3.8 Yoke-Platform Interface

This section details the interface between the Yoke and the Platform of the TS.

COMMENT by Inti: Please note that this section is still very preliminary.

3.8.1 Summary of Requirements

1. All common requirements as listed in Sec. 2.1, in particular **CR-1**, have to be fulfilled.
2. The yoke-platform interfaces (*i.e.* support points on the Yoke and the Platform as well as the connecting structures) must ensure the safe support of all equipment in all operational modes and exceptional cases as detailed in this document.
3. The weight of the TS magnet (including Solenoid and Yoke) and all detectors and supplies supported by it has to be supported by the Platform. The total weight is estimated to be 360 t.
4. The total weight (Yoke, Cryostat, detectors and ancillaries) has to be distributed between 12 support pads on the top surface of the Platform according to Fig. 3.7 within the ranges given in Table 3.8.2. The Platform must support these forces accordingly.

COMMENT by Inti: Work in progress...

3.8.2 Detailed Interface Description/Proposal

Support point	F_y [kN]
1 and 1'	-270^{+130}
2 and 2'	-410_{-110}
3 and 3'	-220^{+160}_{-100}
4 and 4'	-220^{+160}_{-100}
5 and 5'	-410_{-110}
6 and 6'	-270^{+130}
Total	-3600

Table 3.7: Distribution of forces (F) on the support points given in Fig. 3.7. Maximal deviations are indicated by subscripts and superscripts.

COMMENT by Inti: Below information from Evgeny, which I have amended. Please check if I have interpreted things correctly. In some cases it is not clear to me why we need to constrain ourselves so much.

Table 3.8.2 details the ranges of vertical forces acting on the support pads specified in Fig. 3.7. These loads depend on the rigidity of the assembly base and on the positions of carriage points of rest. The range of all possible weight loads on the support pads is specified in Table 3.8.2. The possible deviations of the weight loads in the support points from the values obtained for the magnet assembly on an absolutely rigid base are indicated in superscripts and subscripts (these deviations correspond to the carriage support beam rigidity specified in item **??**). During normal operation conditions all loads are symmetric with respect to YZ-plane

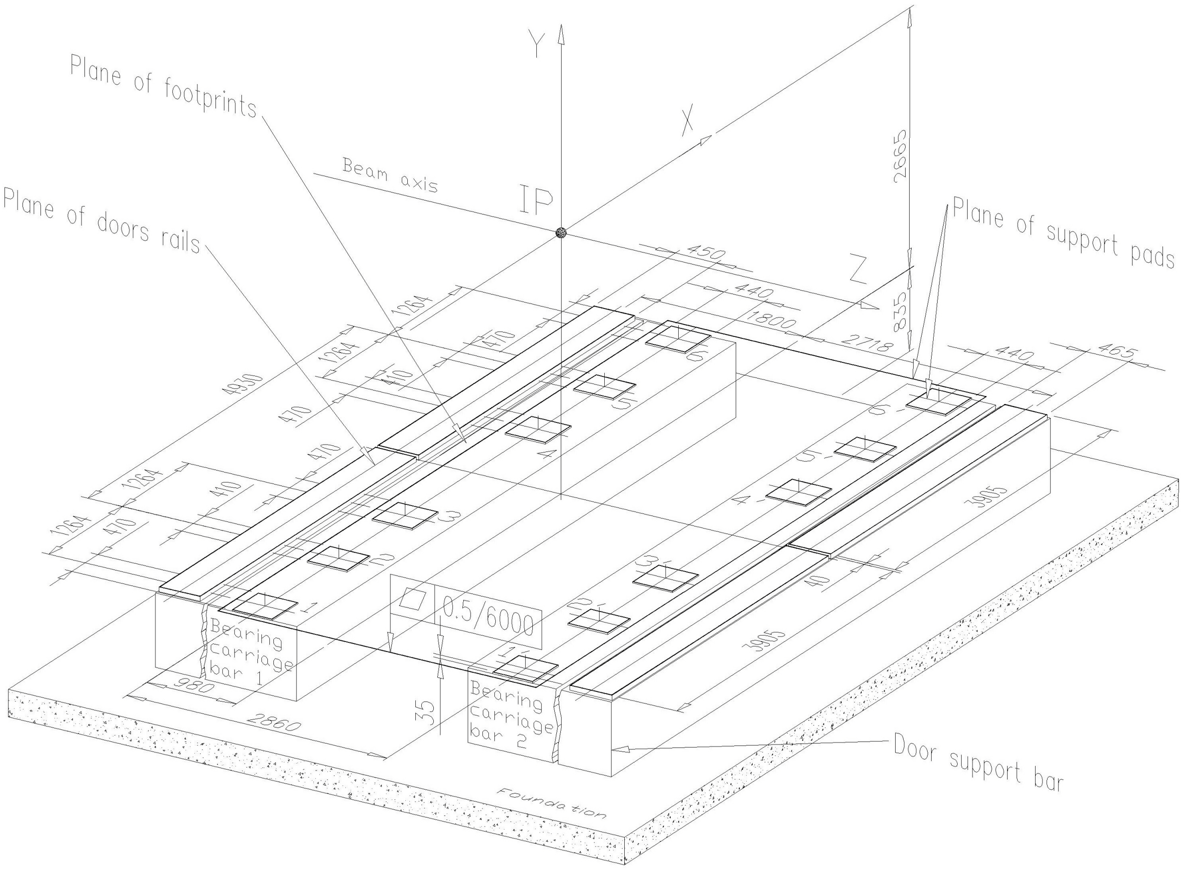


Figure 3.7: Sketch indicating the locations of the interfaces between the Yoke and the Platform. All dimensions are given in millimetres.

and approximately symmetric relative XY-plane. In abnormal regimes the symmetry can be lost but all loads are within confidence intervals specified in the Table 3.8.2.

A single horizontal plane at $Y = -2660$ mm is defined as the plane in which the Yoke (via support pads) and the door rails attach to the Platform. A deviation from this plane by no more than 0.5 mm can be tolerated before the yoke assembly. Additional leveling of the support surfaces will be done by means of metal shims in the process of assembly. The dimensions and locations of the support pads and the door-rail plane are indicated in Fig. 3.7 in the $\overline{\text{P}}$ANDA coordinate system.

COMMENT by Inti: A requirement on the area moment of inertia was proposed by Evgeny. It was based on extreme scenarios and it is not sure if it can be reasonably achieved. It was agreed on 1/4/2011 that this needs to be re-iterated.

COMMENT by Inti: Below I have tried to re-phrase item 7 of Evgeny's list, but I'm not sure I understand why it is important.

The maximum load will be transferred to the platform at support points 2(2') and 5(5') (corresponding to the yoke frame vertical uprights) which are separated by 4930 mm in x and 2860 mm in z. Therefore, the moving supports for the Platform should be located at these locations or closer in x.

The doors of the Yoke need to be supported by rails located on separate pads at $z = -1800$ mm and $z = +2718$ mm as shown in Fig. 3.7. The rails will be loaded by the door weights in the process of magnet assembly or for certain detector installation operations. This will be done in the assembly and in-beam positions only. During any movement of the TS the door wheels will not interfere with the rails. Any vertical deformation of the door rail supports under action of a concentrated load of 25 t has to remain ≤ 0.2 mm.

Chapter 4

Solenoid of the Target Spectrometer

COMMENT by Inti: This chapter is what had been introduced by Andrea as "very preliminary" appendix and basically unchanged.

4.1 Summary

The Solenoid is formed by a superconducting coil operating at $4.5\,\mathrm{K}$, thermally insulated by a aluminium alloy or stainless steel cryostat. The magnetic field is shielded by a three parts magnetic yoke, which provides the mechanical support for the cryostat too. The later is discussed in the next section.

The proposed conductor is a niobium-titanium Rutherford cable, co-extruded in a matrix of pure aluminium, which guarantees the thermal stability and the protection if a quench occurs.

The magnetic forces cannot be supported by the cable itself, so an aluminium alloy containing cylinder is needed. In the present specifications a solution based on internal winding technique is sketched: in this case, the cylinder provides the coil support too. It is anyway possible to propose any other solution, whose technical reliability and performances be demonstrated as specified in the present document.

The Solenoid is indirectly cooled with a flux of biphasic liquid helium, with a flux of $30\,\mathrm{g/s}$, circulating in a net of pipes welded on the external surface of the containing cylinder.

The Solenoid is protected against heating due to the transition to the normal conducting state by an active system based on a *normal conducting state transition detection* device, which acts on a system of switches that deviates the current on a discharge circuit, featuring a power resistor.

Several aspects of the executive projects are not defined in this document: the Manufacturer can propose the solution in which it trusts and ask for approval to the Customer. The approval or denial from the Customer will be communicated in 15 days from each document reception.

4.2 Consignment Definition

The Manufacturer will provide the needed tools, materials and structures to build the final project, the manufacturing, the tests and the delivery at FAIR of the Solenoid here defined. The Solenoid consists of a superconducting coil integrated in a cryostat with a chimney, and of a cryostat for the current leads and the hydraulic circuitry, and of the needed instruments for the magnet operations. The consignment main components are:

1. superconducting solenoid;
2. solenoid mechanical suspension;
3. cryostat with cooling circuit and radiation shields;
4. service chimney with hydraulic circuitry, power cabling and vacuum system ports;
5. control cryostat with liquid helium reservoir, control valves and current leads;
6. control instruments;
7. quench detection system.

Consignment must furthermore include the assistance for transportation to the experimental hall ($\overline{\mathrm{P}}$ANDA Hall), the installation in the iron yoke at FAIR and the tests on site. The Manufacturer will, at last, provide all the documentation defined in this document.

The present document, including annexes, defines the requirements for the project, the manufacturing, the delivery, the installation and the tests of the superconducting solenoid required by the Customer for the $\overline{\mathrm{P}}$ANDA detector, in the $\overline{\mathrm{P}}$ANDA Hall on the HESR machine under construction at FAIR.

4.3 Requirements

4.3.1 General Requirements

4.3.1.1

The Manufacturer must be qualified according ISO9001/EN29000 standard. As a consequence, all the documentation concerning the consignment (project, materials, tools, fabrication, tests, sub-components specifications) must accomplish the mentioned standard.

4.3.1.2

The Manufacturer will ask the Customer for the approval of all the project designs, calculations and technical notes, materials specifications, etc., relatively to the engineering project of the Solenoid as specified in 4.3.12. The engineering project can be divided in sub-projects if needed, with the explicit approval by the Customer. The Customer won't take any responsibility on the achievability of tools and materials before the preliminary project approval.

4.3.1.3

The Manufacturer will prepare and present to the Customer for approval the manufacturing programs and tests as specified in 4.3.13. The Customer approval will be in written form, in time for further comments, explanations and modification requests.

4.3.1.4

The Customer will approve the final engineering project of the Solenoid and the project for ancillary apparatuses, tools and manufacturing as specified in 4.3.12, and the manufacturing programs and tests prepared by the Manufacturer as specified in 4.3.13. In any case, the Manufacturer is responsible of the engineering project and of the manufacturing of the complete system.

4.3.1.5

If some advantage or need will arise, so that the manufacturing programs or tests should be changed after the Customer approval, these changes can be proposed by the Manufacturer and be adopted after a dedicated approval by the Customer.

4.3.1.6

Every design presented for approval as specified in 4.3.1.8 and 4.3.12, will be delivered to the Customer both as standard design printed on paper and in electronic format (to be agreed). A complete set of the designs relative to the whole project, in its final version, will be delivered to the Customer both printed on paper and in electronic format, before the contract closing.

4.3.1.7

The Solenoid must be delivered at the FAIR facility, Darmstadt, DE, under the responsibility of the Manufacturer.

4.3.1.8

The Manufacturer will be present, lead and approve the Solenoid installation in the $\overline{\mathrm{P}}$ANDA iron yoke at FAIR. Having been informed by the Customer on the installation date, the Manufacturer will approve the installation procedure and tools and will be present during the whole operation. Once the Solenoid has been connected to the electrical, cryogenic and electronic systems of FAIR in the $\overline{\mathrm{P}}$ANDA Hall, the Manufacturer will be present, lead and approve the system tests as specified in **??**. After the positive response of the tests, the contract will be closed.

4.3.1.9

The Solenoid must be fully contained in the space limits defined in Fig. 4.1 annex to this document, and the cryostat in the dimensions defined in 4.3.3.6. This design shows the allowed volume for the cryostat, the clearance for the chimney and the space reserved for the control dewar. The positions for the supports needed for the cryostat suspension in the yoke are detailed in Sec. 3.7 and for the detectors suspension in the cryostat in Sec **??**. No modification to this design will be tolerated without explicit Customer approval.

4.3.1.10

The radial thickness of the Solenoid must be within 0.25 and 0.5 nuclear interaction lengths, i.e. the aluminium equivalent thickness must be within 98.5 and $197\,\mathrm{mm}$.

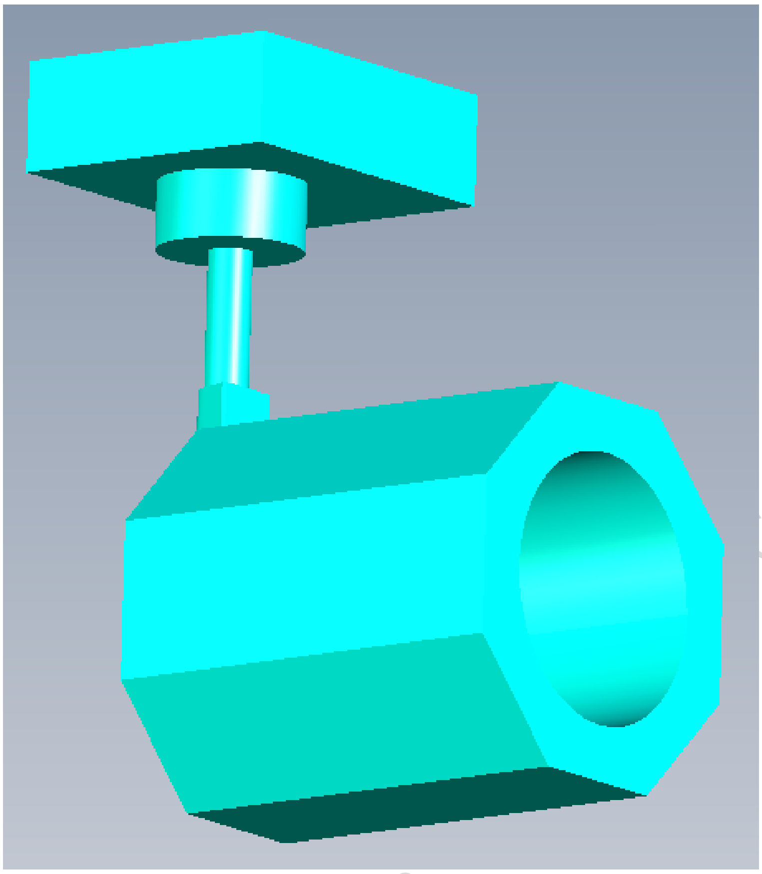


Figure 4.1: Keep-out Volume for the solenoid and proximity cryogenics. A detailed technical drawing is presented in the annex.

4.3.1.11

The cold mass supports must be designed and built to minimise the heat inlet at $4.5\,\mathrm{K}$. Moreover, they must satisfy the mechanical requirements defined in 4.3.1.12 and 4.3.5.

4.3.1.12

The coil axis must be aligned with the cryostat axis with a maximum deviation of $\pm 1.0\,\mathrm{mr}$. The coil position w.r.t. the cryostat must be fixed and measured with a maximum deviation of $\pm 2.0\,\mathrm{mm}$ in every direction when the coil is cooled and energised. The maximum displacement of the coil w.r.t. the cryostat must be less than $\pm 2.0\,\mathrm{mm}$ in every direction during the cool-down and the power cycling of the coil, taking into account the residual forces specified in 4.3.5.1. No modification or exception to this specification will be accepted.

4.3.1.13

The control cryostat with the liquid helium reservoir will feature the safety valves for the cryostat over-pressure as specified in 4.3.6.4. The control dewar will be manufactured to work at low temperature and in non-magnetic material, as described in 4.3.9.4. In addition, it will be built according to the specification defined in 4.3.5.2 and 4.3.9.5.

4.3.1.14

The Manufacturer will provide the Customer two samples of the aluminium stabilised superconducting cable, $3\,\mathrm{m}$ long each, for each crop of the cable to be used, before the winding of the coil. The samples will be obtained at the ends of each crop, at a minimum distance of $2\,\mathrm{m}$ from the end. The samples will be clearly identified as specified in 4.3.14.2 to allow a comparison with the short samples defined in 4.3.14.5, points 1, 2 and 3. The manufacturer will provide two samples, $3\,\mathrm{m}$ long each, of each crop of the Rutherford cable, with the documentation specified in 4.3.14.2. Moreover, the manufacturer will provide 2 samples, $3\,\mathrm{m}$ long each, of the original superconducting wire, from the ends of each coil on which the wire is wound after the production.

4.3.2 Magnetic Field Requirements

4.3.2.1

The magnetic field at the solenoid centre will be equal to $2\,\mathrm{T}$ at the nominal current. In this document, it is referred to this field as B_0.

4.3.2.2

The reference geometry of the iron yoke will be supplied to the Manufacturer at the contract signature. The flux-return yoke is presented in Sec. 5. The Manufacturer will design the Solenoid according to the reference geometry and the dimensions specified in 4.3.3.6 to have a field uniformity $\Delta B/B_0 \leq \pm 2\%$ in the tracker volume, defined as $-300 \leq z \leq 500\,\mathrm{mm}$ and $0 \leq r \leq 150\,\mathrm{mm}$ (inner tracker) and $-400 \leq z \leq 1100\,\mathrm{mm}$ and$150 \leq r \leq 420\,\mathrm{mm}$ (outer tracker), where $B_0 = 2\,\mathrm{T}$.

4.3.3 Winding Requirements

4.3.3.1

The coil will be built with a Rutherford cable, made of multi-filamentary NbTi wires. The cable will be stabilised in high-purity aluminium (better than 99.993% pure), showing a good metallurgical coupling with the Rutherford cable, to bear a shear stress at the aluminium-Rutherford interface greater than $30\,\mathrm{MPa}$. A different conductor can be suggested by the Manufacturer, but any modification to this reference scheme must be approved by the Customer.

4.3.3.2

The nominal to critical current ratio measured for short cable sample cannot exceed 0.4 at the maximum field on the coil.

4.3.3.3

The winding insulation must be $0.4\,\mathrm{mm}$ thick. The thermal conductivity divided by the material thickness must greater than $8 \cdot 10^{-3}\,\mathrm{W/cm^2K}$. The insulation to ground will be tested as specified in 4.3.4.9 and will be $1\,\mathrm{mm}$ thick. Its thermal conductivity must be grater than $4 \cdot 10^{-3}\,\mathrm{W/cm^2K}$. The thickness and thermal conductivity values refer to the solenoid at $4.5\,\mathrm{K}$ and at the nominal current.

Dimension	Value
Maximum extension in upward direction	1190 mm
Maximum extension in downward direction	1900 mm
Minimum clearance diameter for target pipe	100 mm
Minimum inner radius	950 mm
Maximum outer radius	1340 mm

Table 4.1: Solenoid cryostat dimensions summary

Dimension	Value
Maximum extension in upward direction	1020 mm
Maximum extension in downward direction	1730 mm
Minimum clearance diameter for target pipe	300 mm
Minimum inner radius	1050 mm
Maximum outer radius	1100 mm

Table 4.2: Suggested coil dimensions summary

4.3.3.4

The coil will be supported by an aluminium alloy cylinder, put on the outside of the coil itself and designed to keep the radial deformation due to the magnetic forces lower than $1\,\mathrm{mm}$.

4.3.3.5

The coil will be mechanically glued and glued to the containing cylinder with an epoxy resin. The resin impregnation will be performed in vacuum ($0.1\,\mathrm{mbar}$). A different gluing technique can be proposed, if the performance equivalence to the vacuum impregnation is demonstrated.

4.3.3.6

A schematic of the solenoid cryostat dimensions is reported in Table 4.1 and a schematic of the suggested coil dimensions is reported in Table 4.2.

4.3.4 Electrical Requirements

4.3.4.1

The nominal current must not exceed $5000\,\mathrm{A}$. The maximum current density in the metallic part of the conductor must not exceed $65\,\mathrm{A/mm^2}$. The project current must be at least 5% greater than the nominal one.

4.3.4.2

The Solenoid must be able to operate at any current smaller or equal to the project current, with both polarities. During operations, the coil and the current leads must be able to bear the project current or every fraction of it in a stable and proper way.

4.3.4.3 Electrical Sub-System Features

The electrical sub-system is formed by the DC power supply, the power switches, the protection resistor and the control panel. The main issue of this sub-system is the power cycle, control and protection of the solenoid. The protection is achieved using monitoring instruments and starting a fast or slow discharge, according to the observed alarm. This subsystem operates in 4 different ways.

1. Power up: the supplied current is slowly increased to the level defined by the Current Control System. The nominal current (to achieve the nominal field of $2\,\mathrm{T}$) must be reached in no more than $60\,\mathrm{minutes}$.

2. Steady State: the power supply must be able to supply every current between 0 and the project current. Moreover, in the $1 \div 2\,\mathrm{T}$ central magnetic field, the power supply must be stable within $\pm 1\%$ in a $24\,\mathrm{hours}$ period.

3. Slow Discharge: The electrical subsystem must be able to slowly discharge the coil. when the solenoid is energised at the nominal current, $B_0 = 2\,\mathrm{T}$, the discharge time must be smaller than $60\,\mathrm{minutes}$. The discharge must be acted automatically if some alarm arise, or manually if needed. The slow discharge should be built preferably inverting the power supply polarity rather than discharging on resistive elements.

4. Fast Discharge: the fast discharge must be possible in emergency or manually triggered. The fast discharge must be performed in less than $3\,\mathrm{minutes}$. The discharge starts when the switch in series on the supply circuit receives the opening command. The solenoid energy is released in an air-cooled protection resistor. The discharge voltage must not exceed $550\,\mathrm{V}$, and the resistor temperature must not exceed $120\,^{\circ}\mathrm{C}$. The protection resistor must be installed in a proper way to avoid injuries to the operating personnel.

4.3.4.4

The Solenoid must be chargeable in both polarities to the project current.

4.3.4.5

The current leads, cooled by cold helium flux, must be able to operate at the nominal current without any damage for a period not shorter than $4\,\mathrm{minutes}$ after a helium flux interruption.

4.3.4.6

The Solenoid must resist without damage to a transition to the normal state (spontaneous or during the tests specified in 4.3.14.8), from the project current or every fraction of it. The maximum temperature of the coil must be smaller than $100\,\mathrm{K}$ in case of protection circuit failure.

4.3.4.7

The Solenoid must discharge, without transition to the normal state, from the nominal current or every fraction of it, through the power circuit, which has an estimated impedance of $10^{-4}\,\Omega$ and a voltage drop of $\sim 1\,\mathrm{V}$ along the protection diodes.

4.3.4.8

If a transition to the normal state occurs, the current must be lowered to 0 disconnecting the power supply and making the current flow through a protection resistor, permanently connected in parallel to the coil. The maximum discharge voltage w.r.t. ground must be smaller than $500\,\mathrm{V}$. The electrical centre of the resistor must be connected to ground.

4.3.4.9

The Solenoid must be tested applying $\pm 500\,\mathrm{V}$ DC w.r.t. a proper ground as specified in 4.3.14. The maximum leakage current for each polarity will be evaluated to define the positive or negative outcome of the test, as specified in 4.3.14.3, point 2.

4.3.4.10

The Solenoid must be tested at 30% of the nominal current at the factory, before the delivery at FAIR, as specified in 4.3.14.8. After the installation in the iron yoke in the $\overline{\mathrm{P}}$ANDA Hall, it will be tested at the project current, as specified in 4.3.14.8.

4.3.4.11

Some heating elements will be installed in contact with the inner part of the coil, before the impregnation. These heaters will be at least 10 and will be distributed along the solenoid axis: they will spread the quench to avoid local overheating during a fast discharge. They will be controlled and energised independently from the coil by the control panel.

4.3.5 Mechanical Requirements

4.3.5.1

The Solenoid will be designed to bear all the mechanical stresses due to the cooling to $4.5\,\mathrm{K}$, power up and down, operations of the coil up to the project current, transition to the normal state and heating to the room temperature.

1. As shown before in Fig. **??**, the cryostat is suspended to the iron yoke. The cryostat must bear $\sim 30\,\mathrm{t}$ suspended inside of it.

2. The cold mass of the control cryostat, the supports of the solenoid cold mass, the thermal shields, the vacuum chambers, the hydraulic circuitry and the instruments placed inside the cryostat must bear all the stresses and deformations induced by the cooling at $4.5\,\mathrm{K}$, the heating to room temperature and the operations of charge and discharge of the Solenoid.

3. The cold mass of the Solenoid, the cold mass support system, the thermal shields, the vacuum chambers, the hydraulic circuitry and the instruments placed inside the cryostat must bear the stresses due to the magnetic forces at the project current and at every fraction of it. The magnetic forces, due to misalignment w.r.t. the iron yoke, asymmetry between the end doors and parasitic currents during charge and discharge must be considered simultaneously.

   The magnetic forces at the project current must be considered as follows:

a) an axial force of $60\,\mathrm{t}$ in upward direction plus the force due to a misalignment of $2\,\mathrm{cm}$ w.r.t. the nominal position, in each direction;

COMMENT by Inti: This seems outdated, right?

b) a radial force of $10\,\mathrm{t}$, at the project current, or the force due to a misalignment of $2\,\mathrm{cm}$ w.r.t. the nominal position, in each direction.

4. The control dewar cold mass, the support system of the solenoid cold mass, the thermal shields, the vacuum chambers, the hydraulic circuitry and the instruments installed inside the cryostat must bear the stresses and deformations due to the transition to normal state, fast and slow discharge of the coil, at the nominal current or at any fraction of it, as described in 4.3.4.7 and 4.3.4.8, and to the deformations described in 4.3.5.1, points 1, 2, 3.

5. The solenoid must bear the stresses and deformations due to earthquakes, as foreseen by the enforced German law, in addition to the stresses and deformations described above.

4.3.5.2

COMMENT by Inti: The word "solicitation" sounds odd to me. Are you sure this is the correct technical term?

The Solenoid must bear the following anomalous solicitations, simultaneously to the ones defined in 4.3.5.1, points 1, 2, 3, 4, with no damage neither performance degrade:

1. anomalous solicitation of the vacuum chamber due to vacuum loss, as defined in CGA S-1.3, paragraph 4.9.1.1;

2. anomalous solicitation of the vacuum chamber (pressure variation) due to fire, as defined in CGA S-1.3, paragraph 5.3.5;

3. anomalous solicitation due to refrigerating fluid internal circuitry failure;

4. anomalous solicitation of the vacuum chamber due to pressure lost, as defined in CGA 341, paragraph 6.4.2;

5. other solicitations: the Manufacturer will identify other solicitation sources relatively to its project and solve the arising problems with proper solutions.

4.3.5.3

The Solenoid must bear the solicitations due to its transportation to FAIR and its installation in the iron yoke in the $\overline{\text{P}}$ANDA Hall. Removable supports to fixate the cold mass during the transportation are allowed.

4.3.5.4

If high vacuum flanges are used, they must feature double gasket with a pumping port in between.

4.3.5.5

Reinforcing elements will be placed on the inner surface of the lateral cryostat flanges, to keep accidental solicitations of the coil. These elements cannot be in contact with the thermal shields neither with the cold mass during solenoid normal operations: their aim is to limit the movement of the cold mass in case of support system failure.

4.3.6 Insulating Vacuum Requirements

4.3.6.1

The Solenoid vacuum system as a whole (vacuum chambers, hydraulic circuitry, valves and fittings) must be leakage free, according to the specified limits. The maximum leakage of the part of the cryogenic system surrounded by vacuum (hydraulic circuitry, current leads, and instruments feed-throughs) cannot exceed $1 \cdot 10^{-8}\,\mathrm{mbar} \cdot \mathrm{l/s}$ at every temperature, between room temperature and $4.5\,\mathrm{K}$. For the part not surrounded by vacuum, the maximum leakage is $1 \cdot 10^{-6}\,\mathrm{mbar} \cdot \mathrm{l/s}$.

4.3.6.2

During the construction, the Manufacturer will perform vacuum test on components and sub-components using a mass spectrometer with a minimum sensitivity of $1 \cdot 10^{-10}\,\mathrm{mbar} \cdot \mathrm{l/s}$, with helium gas.

4.3.6.3

The diameter of the horizontal section of the chimney must be smaller than $300\,\mathrm{mm}$. The cryogenic components installed inside the chimney must be optimised to reduce the impedance of the conduit. Two standard flanges CF150 must be connected to the chimney as shown in Fig.???. To these flanges two turbomolecular pumps (supplied by the Customer) will be attached.

4.3.6.4

A safety valve must be installed on the chimney to protect the insulation vacuum. This valve must be dimensioned to evacuate all the gas coming from and accidental failure of the hydraulic system without any damage to the vacuum system.

4.3.7 Cryogenic Requirements

4.3.7.1

The Solenoid must be designed to be cooled down from room temperature to $4.5\,\mathrm{K}$ in less than $150\,\mathrm{hours}$. The pre-cooling at $40 \div 60\,\mathrm{K}$ will be performed using cold helium gas in a controlled way. The final cooling will be performed with liquid helium.

4.3.7.2

The Solenoid must be projected to allow a forced heating to room temperature, with an analogous procedure to cool-down one.

4.3.7.3

The Solenoid must be operable with a natural flux of liquid helium as supplied by FAIR. The inlet temperature and pressure are $4.2\,\mathrm{K}$ and $1.3\,\mathrm{bar}$ and the flux is $70\,\mathrm{l/h}$.

4.3.7.4

The valves, the hydraulic circuitry, the control system and the instruments supplied by the Manufacturer must be adequate o operate the cool-down of the solenoid and of the thermal shield in safe condition. The set-up must be compatible with the LHe supply described in 4.3.7.3.

4.3.7.5

The pre-cooling can be operated using cold helium gas, cold nitrogen gas or liquid nitrogen. If nitrogen is involved, the hydraulic circuitry must be purified and then the cool-down must be continued with pure helium gas: the solution without nitrogen is preferable. The liquid helium and the cold helium gas are supplied through a flexible coaxial transfer line in the control dewar, where the mixing with room temperature pure helium is performed to achieve the proper temperature. The gas is injected into the cooling circuit of the solenoid and is recovered through another transfer line. The gas mixing is performed using proportional control valves and a sensors and logic circuit based control system. The helium will be available in liquid phase at a pressure ???? and with a maximum flow of ??????, or in gaseous phase at a temperature ?????, pressure ??????? with a maximum flow of ??????. Pure helium gas at room temperature will be available at a pressure ?????? and a maximum flow of ????. A tentative, simplified scheme of the refrigerating circuit is shown in Fig.???.

COMMENT by Andre: numbers are missing...

4.3.7.6

The Manufacturer will be responsible for the definition of a safe and controlled procedure for the cool-down of Solenoid and thermal shields.

4.3.7.7

The thermal shield will be cooled down from the room temperature to the operating temperature progressively and simultaneously with the cold mass, using cold helium gas or nitrogen gas: again, the solution without nitrogen is preferable.

4.3.7.8

The same refrigerator used to keep cold the thermal shield will be used to intercept the heat flux passing through the cold mass supports and the sensor cables.

4.3.7.9

The thermal shield will be designed to allow its cooling independently from the cold mass temperature.

4.3.7.10

The liquid helium supply control valve will be placed in the Solenoid control cryostat. The Manufacturer will install three equal liquid helium level meters (one active, two spares) in the control cryostat. The control units must be included in the control system supplied by the Manufacturer.

4.3.7.11

The Manufacturer will define all the operating control requirements. These requirements, together with the proposed operating processes, must be approved by the Customer.

1. The control system supplied by the Manufacturer must satisfy all the cryogenic requirements, including the cool-down from room temperature and the heat-up from operating temperature, the operations required during the solenoid transition to the normal state and all the requirements defined by the Manufacturer in 4.3.7.11. The process controller must be approved by the Customer and must include a digital communication port to be connected to the $\overline{\text{P}}$ANDA DAQ. From this port, the magnet status must be readable.

2. The Manufacturer is responsible of all valves and actuators check.

3. The Manufacturer must provide all the documentation relative to the mapping of all the parameters and function in the cryogenic control system.

4. The Manufacturer will provide all the software codes.

5. The Manufacturer will provide all the electrical schemes and diagrams of the control system.

6. The Manufacturer will provide a controller able to give as output through a data port the status of the cryogenic system: the liquid helium level in the control dewar, the various temperatures and pressures of the system and each other useful information to effectively manage the cryogenic system. The Manufacturer will supply all the information about the communication and interface protocols.

7. The controls will be configured to minimise the negative interference with the solenoid and the FAIR cryogenic plant.

8. All the valves controls must be switchable to manual control.

9. The Manufacturer will supply only valves which could be internally modified to achieve the maximum operation flexibility.

4.3.7.12

Maximum allowable heat loads:

1. The total heat load, due to radiation and conduction, including the current leads contribution, to the $4.5\,\mathrm{K}$ circuit, during normal operations (that is the coil carrying the project current or every fraction of it, with the thermal shield operating at $60\,\mathrm{k}$) can never exceed $20\,\mathrm{W}$.

2. The total heat load, due to radiation and conduction to the $60\,\mathrm{K}$ thermal shield, during normal operations can never exceed $200\,\mathrm{W}$.

4.3.7.13

The transfer line contribution to the total heat load at $4.5\,\mathrm{K}$ cannot exceed $3\,\mathrm{W}$.

4.3.7.14

The design pressures for the various parts of the cryogenic system, in nominal conditions, with the coil energised at nominal current are:

1. $5000\,\mathrm{l}$ dewar: $0.04\,\mathrm{MPa}$
2. Solenoid control cryostat: $0.03\,\mathrm{MPa}$
3. Liquefier recovery: $0.01\,\mathrm{MPa}$

4.3.7.15

The pressure drop through the current leads will be optimised to achieve an adequate cooling of the leads themselves and a correct control of the liquid helium flux at the nominal current and at every fraction of it.

4.3.7.16

The temperature everywhere on the outer surface of the solenoid cryostat cannot be more than $5\,^{\circ}\mathrm{C}$ lower than the room temperature, both in normal operations and during cool-down and power cycling. If it will turn out to be impossible to build the current leads in a way to completely avoid humidity condensation and freezing on the outer surfaces, the Manufacturer will provide a heating system to keep the outer surfaces temperature always less than $5\,^{\circ}\mathrm{C}$ lower than the room temperature. During operations, the room temperature will be in the range 4 to $32\,^{\circ}\mathrm{C}$ and the relative humidity in the range 20 to 80%.

4.3.7.17

The Customer will supply the flanges and fittings to connect the cryostat to the transfer lines for the coil and thermal shields cool-down.

4.3.7.18

The pressure measurement lines will feature intercepting valves externally to the cryostat. The differential pressure measurement lines will feature an external balance system.

4.3.7.19

The Manufacturer will perform a thermal shock test on every welding where feasible and all the cryogenic components where feasible, with a liquid nitrogen shower. After the thermal shock, a leak test will be performed.

4.3.8 Operating Cycles and Life Requirements

4.3.8.1

The Solenoid must be designed and built to have an operating life longer than ten years.

4.3.8.2

The Solenoid must be projected and built to bear more than 150 cool-down and heat-up cycles from the room temperature to the operating temperature and vice versa.

4.3.8.3

The Solenoid must be projected and built to bear more than 2500 power cycles, at the current project or every fraction of it, in addition to the cycles needed to the tests specified in 4.3.14. The normal discharge procedure will be the slow discharge described in 4.3.4.7.

4.3.8.4

Even if the Solenoid must be projected and built to be energised and work at the nominal current without transitions, it must be also projected and built to resist more than 20 quenches without the protection circuit (fast discharge circuit) defined in 4.3.4.8.

4.3.8.5

The Solenoid must be projected and built to bear more than 400 quenches from the nominal current or every fraction of it, discharging through the fast discharge circuit defined in 4.3.4.8.

4.3.9 Project Development and Codes Requirements

4.3.9.1 Analytical Approach

The Manufacturer will submit to the Customer for approval the Codes he intends to use in the project development. The Customer will approve the Codes after, if needed, a validation from an external committee. An analytical analysis will be accepted if proper and adequately detailed.

4.3.9.2 Structural Analysis Methodology

The structural analysis must be performed with the most modern tools available, on every system element. The elastic and plastic behaviour of all elements must be studied considering all the solicitations defined in 4.3.5. The plastic deformations must be studied to demonstrate that there is no violations of the defined limits.

4.3.9.3

The stress intensity criterion must be used for the combined stress analysis.

4.3.9.4

No ferromagnetic material is allowed in the Solenoid.

4.3.9.5

The ASME Codes, Section VIII, Division 1, must be the basis of the vacuum components project. It is not required that all the vessel be code stamped. The vessel must be designed to work in high vacuum conditions ($0.1\,\mathrm{MPa}$) and to resist to internal pressures between $0.09\,\mathrm{MPa}$ and $0.2\,\mathrm{MPa}$).

4.3.9.6

The Manufacturer will supply all the documentation about the analysis performed during the project development, to demonstrate that all the vacuum vessels have been designed according to 4.3.9.5.

4.3.9.7

All the vacuum vessels and all the vacuum circuitry must feature the safety valves required by ASME Section VIII for the vacuum recipients and ANSI B31.3 Codes for the standard pipes. The valves dimensions must be compliant with the solicitations defined in 4.3.5.2. The Manufacturer will supply a documented analysis to operate in safe conditions and to dimension the safety orifices.

4.3.9.8

All the materials involved must be chosen to have acceptable properties in the whole operating temperature range. In any case, it must be referred to the worst working condition to check the material compatibility. The material properties at low temperature must be based on NBS or equivalent data for low temperature use, if not present in the ASME Codes. All the materials used in the coil, the coil former, the cryostat and the cryostat chimney must be qualified to keep their properties after the exposition to a $1\,\mathrm{MRad}$ dose. If, in Customer's opinion, there are no sufficient data to qualify a material, the Manufacturer will be requested to perform dedicated tests to verify the interest properties of the material itself. The results of these tests must be checked and approved by the Customer.

4.3.9.9

The material certifications will be supplied by the manufacturer for all standard elements (plates, pipes, fittings...) used in the Solenoid construction. No certification is required for all the elements supplied to automatically satisfy the requirements defined in this document.

4.3.9.10

The Manufacturer will supply to the customer all the welding certifications.

4.3.10 Safety Factors and Mechanical Analysis Limits Requirements

4.3.10.1

The allowable stresses for the solicitations defined in 4.3.5, if no otherwise defined in ASME Section VIII Codes, are presented in table 4.3.

Element	Normal Solicitation	Anomalous Solicitation
Flat Elements	$s_m \leq 2/3 s_{elastic}$	$s_m \leq s_{elastic}$
	$s_m \leq 1/4 s_{breaking}$	$s_m \leq 3/8 s_{breaking}$
Circular Elements	$s_b \leq s_{elastic}$	$s_b \leq s_{elastic}$
	$s_b \leq 3/8 s_{breaking}$	$s_b \leq 3/8 s_{breaking}$
Flat + Circular Elements	$s_m + s_b \leq s_{elastic}$	$s_m + s_b \leq s_{elastic}$
Flat + Circular Elements	$s_m + s_b \leq 3/8 s_{breaking}$	$s_m + s_b \leq 3/8 s_{breaking}$
Traction Elements	$s_m \leq 1/4 s_{breaking}$	$s_m \leq 3/8 s_{breaking}$

Table 4.3: Stress limits summary

4.3.10.2

For the buckling analysis, a safety factor of 5 must be applied if the boundary conditions are not precisely defined. In any other case, a safety factor of 4 can be used.

4.3.10.3

Where composite non metallic materials are used, the maximum allowable stress is limited to 20% of the breaking limit of the material itself, to avoid plastic deformations.

4.3.10.4

Where non reinforced, non metallic materials are used, the maximum allowable stress is limited to 10% of the breaking limit of the material itself, to avoid plastic deformations.

4.3.10.5

In the finite elements analysis on the safety margins, the nominal thickness for standard pipes and plates must be used.

4.3.10.6

The cyclic stresses analysis must be performed according to the requirements defined in 4.3.8, where the requested life must be multiplied by a safety factor of 4.

4.3.11 Control System, Instrumentation and Valves Requirements

4.3.11.1

The Manufacturer will supply all the instruments needed to operate the Solenoid in safe conditions. Cables and connectors must be compatible with the cryogenic, vacuum, high voltage, radiation and accessibility limitation conditions. The minimum control instrument set is defined in 4.3.11.2, 4.3.11.3, 4.3.11.4, 4.3.11.5, 4.3.11.6, 4.3.11.7; the minimum valve set is defined in 4.3.11.9. The whole control system must refer to a controller comprehensive of:

1. analogue acquisition of sensors data;

2. drive of the control elements (valves, relays, switches etc.);
3. data interface;
4. user interface.

4.3.11.2

The coil must have at least 3 voltage gauges, one at its centre and two at the ends. These gauges must be separately connected to the coil, to be physically and electrically redundant.

4.3.11.3

The minimal instrumentation for the temperature monitoring system is summarised here.

1. Temperature of each axial and radial support measured on the coil former: as an example, Lake Shore carbon glass resistor ($500\,\Omega$ at $4.5\,\mathrm{K}$), model CGR-1-500-4B, 4-wires measured, calibrated by the producer in the temperature range between 4 and $40\,\mathrm{K}$.
2. Temperature of each axial and radial support measured on the $60\,\mathrm{K}$ intercept: as an example, Lake Shore platinum resistor ($100\,\Omega$ at $273\,\mathrm{K}$), model PT-102-77Lm, 3- or 4-wires measured, calibrated by the producer in the temperature range between 50 and $325\,\mathrm{K}$.
3. Temperature of the helium bath in the control dewar: as an example, Lake Shore carbon glass resistor ($500\,\Omega$ at $4.5\,\mathrm{K}$), model CGR-1-500-4B, 4-wires measured, calibrated by the producer in the temperature range between 4 and $40\,\mathrm{K}$.
4. Temperature of the liquid helium recovered in the control dewar, with the same instrument as at point 3
5. Temperature of the liquid helium arriving at the coil, with the same instrument as at point 3
6. Temperature of the liquid helium leaving the coil, with the same instrument as at point 3
7. Temperature of the coil former near the service chimney, at the coil centre and at the opposite end w.r.t. the service chimney, at the upper and lower side of the coil former for each axial position: as an example, Lake Shore carbon glass resistor ($500\,\Omega$ at $4.5\,\mathrm{K}$), model CGR-1-500-4B, 4-wires measured, calibrated by the producer in the temperature range between 4 and $325\,\mathrm{K}$.
8. Temperature of the coil inner surface at the two ends and at the centre, at the upper and lower side of the coil for each axial position: as an example, Lake Shore carbon glass resistor ($500\,\Omega$ at $4.5\,\mathrm{K}$), model CGR-1-500-4B, 4-wires measured, calibrated by the producer in the temperature range between 4 and $325\,\mathrm{K}$.
9. Inner and lower temperature at the two ends of the coil and at the centre of the coil, both at the upper and lower side (12 in total), with the same instrument as at point 2.
10. Temperature of the cold helium gas for the thermal shields, arriving and leaving from the control dewar, with the same instruments at point 2.

11. Temperature of the cold helium gas for the supports, arriving and leaving from the control dewar, with the same instruments as at point 2.

12. Temperature of the warm end of the current leads, with the same instruments as at point 2.

13. Temperature of the cold end of the current leads, with the same instruments as at point 1.

14. Temperature of the inner and outer surface of the vacuum chamber, both in the cylindrical part and in the end flanges, with the same instrument as at point 2.

4.3.11.4

The minimal instrumentation for the pressure monitoring system is summarised here.

1. Liquid helium pressure at the control dewar inlet, as an example using Rosemont Inc. Model 115GP6E1215, calibrated to work in the range 0 to $1\,\mathrm{Bar}$, tested at the maximum pressure reachable during a quench, i.e. $6\,\mathrm{Bar}$, accuracy 0.25%.

2. Liquid helium pressure at the coil inlet and outlet, as an example using Rosemont Inc. Model 115GP6E1215, calibrated to work in the range 0 to $0.1\,\mathrm{Bar}$, tested at $6\,\mathrm{Bar}$, accuracy 0.25%.

3. Cold helium gas pressure at the control dewar outlet, as an example using Rosemont Inc. Model 115GP6E1215, calibrated to work in the range 0 to $1\,\mathrm{Bar}$, tested at $6\,\mathrm{Bar}$, accuracy 0.25%.

4.3.11.5

The cooling fluid flux measurement minimal instrument set is summarised here.

1. Helium flux from and to the control dewar measurement, as an example using Venturi Plus Rosemont Inc. Model 115DP4E1215 with proper calibration.

2. Helium flux from to the two current leads, as an example using Brooks High Mass Flow Controller Readout, Model 5853I with proper calibration.

4.3.11.6

The minimum instruments to monitor the liquid helium level in the control dewar are two identical level gauges, as an example American Magnetics superconducting liquid helium level gauge, with redundant power supplies and readout electronics.

4.3.11.7

The minimum instrument set to monitor the vacuum conditions in the cryostat and in the ancillary subsystem consists in a couple of low- and high-vacuum gauges placed in the following positions:

1. the cryostat vacuum chamber;

2. the control dewar;

3. the current leads insulating vacuum.

The high vacuum gauges must be sensitive down to 10^{-10} mBar, the superimposition between the low- and high-vacuum gauges sensitivities must exceed one decade and the pressure must be measurable up to 10^3 mBar.

4.3.11.8

All the support rods of the cold mass must be monitored by two redundant proper deformation gauges, placed near the warm end of the supports themselves.

4.3.11.9

The manufacturer will provide a set of valves for the control dewar, with transducers and control electronics: for every valve, the control system must be replaceable. As an example, the linear valve Valtek Mark One Model 25, standard spring pneumatically acted, can be used. The requested valves are:

1. coil liquid helium inlet valve;
2. coil outlet valve;
3. liquid helium cool-down line valve;
4. cold helium gas supports cooling line valve;
5. cold helium gas thermal shields cooling line valve.

4.3.11.10

The Manufacturer will propose the suppliers for all instruments and valves to the Customer for approval. After the project approval, the Manufacturer can propose some supplier change: these changes must be submitted to the Customer for a dedicated approval.

4.3.12 Apparatus, Tools and Manufacturing

4.3.12.1

The Manufacturer will supply all the projects for the following apparatuses, tools and manufacturing, to get the Customer approval. The construction, purchase or use of these tools cannot initiated without Customer approval:

1. apparatus for cable bending and positioning;
2. apparatus for cable cleaning and insulation;
3. coil blocking procedure;
4. apparatus for resin impregnation and thermal treatment;
5. tools for end flanges installation;
6. apparatus for thermal shields and vacuum chamber installation;
7. tools for the cold mass support structure installation;
8. cooling lines connected to the cold mass and connection to the cryogenic circuit.

4.3.12.2

If the Manufacturer will find necessary or convenient some modification to apparatuses, tools or procedures after the Customer approval, all modification must be presented to the Customer for a dedicated, fast approval.

4.3.13 Procedures and Programming

4.3.13.1

The preparation and approval of procedures and planning follows the following rules:

1. all procedures and program described in 4.3.13.2 must be documented by the Manufacturer;
2. all documents must be written in English;
3. the written description of any manufacturing procedure must feature the description of the manufacturing phases and required tools: in addition it must feature all the intermediate steps, all the tests, measurements and controls required to demonstrate that the procedure is compliant with the requirements;
4. the Customer must revise and approve all the specified procedures as a part of the final approval: no manufacturing referring to any procedure can be started before the procedure approval;
5. if, in any moment during the contract execution, it appears necessary or useful that an approved procedure be modified, this modification must be approved by the Customer before being considered operative.

4.3.13.2

The Manufacturer will provide documented description for the following procedures and planning:

1. tests and controls on the winding apparatus;
2. cable junction techniques;
3. cable pre-stressing;
4. cable winding and impregnation;
5. end flanges installation;
6. gauges and gauges services;
7. thermal shield installation;
8. cold mass support installation;
9. vacuum chamber installation;
10. alignment supports installation;

11. electrical and hydraulic connections outside the cryostat;
12. cooling circuit connection to the coil former and to the hydraulic circuitry connections;
13. chimney mounting;
14. control dewar mounting;
15. chimney and cryostat integration;
16. power supply, quench detector and controls;
17. cryogenic control system;
18. delivery and moving the Solenoid as a whole;
19. delivery plan;
20. control and inspection plan at FAIR.

4.3.14 Tests, Inspections and Controls

4.3.14.1

The preparation and approval of tests and controls follows the following rules:

1. all the inspection defined in 4.3.14.5 must be written documented by the Manufacturer;
2. the description of a test, an inspection or a control as specified at point 1 must feature the list of used instruments, a description of the procedures and a data analysis sufficient to demonstrate that the requirements are satisfied;
3. the Customer will receive for approval the description of all tests, measurements and inspections specified in 4.3.14.5: this documentation is compulsory for the project approvals as defined in Section 6;
4. if, in any moment during the contract execution, it appears necessary or useful that an approved test result be verified again, this revision must be approved by the Customer and the Manufacturer jointly.

4.3.14.2

The Manufacturer will provide documented description for the controls and inspections according to the following guidelines.

1. All the measurements, tests and inspections performed by the manufacturer or by a Manufacturer deputy must be documented when they take place. The tested components and the relative measurements and documentation must be clearly identified and archived in a way to avoid ambiguity. The documentation must be complete, must feature the data and place of the test and the signatures of the tester and of the person that certifies the test. The test result will be clearly indicated and archived as specified in 4.3.14.3. If the test is performed by a Manufacturer deputy, the documentation must be certified both by the Manufacturer and by the Manufacturer deputy when the documents are submitted to the Customer, and archived according to this specifications, points 3 and 4.

2. A photographic documentation must be prepared during the assembling of complex parts. For each photo a sufficiently detailed description containing the date and all information necessary to identify unambiguously the documented process will be prepared. The photos, in digital jpeg format, not compressed, will have a resolution greater than 3 MegaPixel. The "P" letter included in the inspection, test or measurement specification defined in 4.3.14.5 means that for the defined operation a photographic documentation is required.

3. All the documents defined in this document will be delivered to the Customer in 2 weeks from the test, inspection or measurement.

4. The Manufacturer will archive all this documentation for a period not shorter than 5 years after the completion of the Solenoid manufacturing.

4.3.14.3

Tests, inspection and measurements must be presented to the Customer to be approved as follows:

1. the Customer will approve the tests specified in 4.3.14.9, points 5, 6, 8 and 9 at the engineering project approval;

2. the Manufacturer will inform the Customer about each element in the manufacturing which is not evaluated consistent with the specifications or whit the tests. The manufacturing, refurbishment or modification to this element must be approved by the Customer before the operations. A complete documentation of the operation must be presented: no exception to this specification will be allowed.

4.3.14.4

The Customer will be informed in advance about every test, to be allowed to send a representative to attend to the test itself.

4.3.14.5

The Manufacturer will perform a minimal set of tests on specific components or subsystems, presenting detailed documentation to the Customer, as specified in the following.

1. Superconducting wires:
   (a) critical current measurement on wire samples, selected as defined in 4.3.1.14, for magnetic field up to $5\,\mathrm{T}$, perpendicular to the sample;
   (b) measurement of the quality factor, or extraction of the superconducting filaments with acid aching and inspection of ten representative filaments (P);
   (c) measurement of the filament diameter for 5 representative wires (P);
   (d) measurement of the winding step for 5 representative wires;
   (e) count of the filament number in 5 representative wires;
   (f) chemical composition of 5 representative wires;
   (g) copper to superconductor ratio measurement for 5 representative wires;

(h) RRR measurement for 5 representative wires;

(i) diameter measurement for 5 representative wires.

2. Rutherford cable:

   (a) measurement of the winding step for each sample obtained as defined in 4.3.1.14;

   (b) final dimensions after compacting (P);

   (c) critical current measurement on short samples, for magnetic field up to $5\,\mathrm{T}$, perpendicular to the sample.

3. Stabilised conductor:

   (a) chemical analysis of the components before the co-extrusion;

   (b) measurement of the mechanical coupling between Rutherford cable and aluminium matrix for all the cable pieces;

   (c) continuous monitoring of the extrusion process critical parameters: temperature, extrusion speed, extrusion pressure and in-line ultrasonic exam or Foucault current exam for the Rutherford cable to aluminium connection monitoring;

   (d) position of the Rutherford cable in the aluminium matrix, measured at the ends of each cable piece (P);

   (e) critical current measurement on cable samples, selected as defined in 4.3.1.14, for magnetic field up to $5\,\mathrm{T}$, perpendicular to the sample;

   (f) conductor section measured on samples obtained from each end of each conductor piece;

   (g) RRR and elastic limit measured on short samples obtained from each end of each conductor piece.

4. Coil winding: even if a particular winding technique is described in detail in this document, and the measurements described here refer to this technique, an equivalent measurement set is required if a different technique will be adopted. The required tests are:

   (a) internal diameter, eccentricity and diameter variations along the coil former;

   (b) production and inspection of 5 junctions on cable samples with test up to $2.5\,\mathrm{T}$;

   (c) conductor insulation at the coil entrance inspection (P);

   (d) end flanges positioning inspection;

   (e) measurement of the conductor section every 30 spires and registration of the conductor dimensions;

   (f) continuous monitoring of the conductor quality and registration of each defect during the winding, with comment and signature of the operator;

   (g) continuous monitoring of the insulation quality and registration of each defect during the winding, with comment and signature of the operator;

   (h) axial and angular location of each junction (P);

   (i) inspection of the insulation near each junction (P);

(j) inspection of each junction (P);
(k) measurement of each inter-coil spacer position;
(l) measurement of the axial pre-stress;
(m) application of the quench spreader heaters;
(n) insulation preliminary tests;
(o) documentation about the vacuum impregnation and the thermal treatment of the epoxy resin;
(p) high voltage insulation tests as specified in 4.3.4.9, performed after the impregnation;
(q) measurement of the coil electric resistance at room temperature.

5. Hydraulic circuitry on the coil former tests:
   (a) high pressure test as defined according to ASME B31.3;
   (b) gas leakage test.
6. Tests on the cryostat thermal shields:
   (a) shields diameter measurement at the centre and at the ends;
   (b) insulation control at the dielectric insulator ends;
   (c) high pressure test as defined according to ASME B31.3;
   (d) gas leakage test.
7. Cryostat vacuum chamber tests:
   (a) internal and external cylinder diameter measurement, at the centre and at the ends, to be performed before the mounting;
   (b) end flanges diameters measurement;
   (c) shield diameters measurement after the vacuum chamber installation;
   (d) measurement of the coil position w.r.t. the vacuum chamber after the coil installation with its supports;
   (e) high vacuum leakage test after the vacuum chamber installation with the cryogenic chimney.
8. Cold mass supports tests:
   (a) breach test of a redundant axial and radial support at room temperature (P);
   (b) test at 125% of the nominal stress for each support;
   (c) gas leakage at the $60\,\mathrm{K}$ intercept.
9. Current leads tests:
   (a) radiographic inspection of each welding and brazing for each current driving part;
   (b) test of the current leads at working temperature and current;
   (c) power switch opening test with the coil connected and energised at 30% of the nominal current;

(d) high voltage test of the power supply circuit w.r.t. ground, with leakage current lower than $1\,\mathrm{mA}$: the ground is obtained connecting the cryostat vacuum chamber to a proper ground with a proper cable;

(e) data acquisition and control system test as required in 4.3.14.8 point 9.

10. Magnet instrumentation tests:

    (a) verification of temperature gauges calibration via temperature measurement at room temperature and at liquid nitrogen temperature;

    (b) verification of pressure gauges calibration;

    (c) verification of flux gauges calibration;

    (d) verification of vacuum transducers calibration;

    (e) calibration of stress gauges via apparent stress measuring in the temperature range from 300 to $4.2\,\mathrm{K}$;

    (f) calibration of stress gauges applying a constant stress to each support;

    (g) functional verification of each heater.

11. Chimney mounting:

    (a) vacuum test of all the hydraulic and cryogenic circuitry according to 4.3.6;

    (b) high pressure test of all the hydraulic and cryogenic circuitry;

    (c) vacuum test of the external vessel;

    (d) current leads DC resistance measurement.

12. Control cryostat mounting:

    (a) vacuum test as defined in 4.3.6;

    (b) vacuum test of all hydraulic and cryogenic circuitry as defined in 4.3.6;

    (c) high pressure test of the hydraulic and cryogenic circuitry;

    (d) functional test of the over-pressure safety valve;

    (e) vacuum test of the outer vessel according to4.3.6;

    (f) operating test of the safety valve.

4.3.14.6

Dewar and cryogenic chimney tests: to be noted that for these tests the current leads are supposed to be short-circuited and hosted in a temporary vacuum system with proper cryogenic connections. The required tests are:

1. pressure test of the cryogenic circuit and cryogenic vessels;

2. vacuum test of the cryogenic circuit and cryogenic vessels, according to ASME V, Article 10, Appendix V Code;

3. hydraulic impedance test of the hydraulic circuit and cryogenic vessels;

4. inspection of all safety valves of the helium system;

5. system cooling to the operating temperature, measurement of the current leads cold end temperature and of the electric resistance of the system as a whole;
6. vacuum test of the system at 0 current;
7. vacuum test of the system at project current;
8. high voltage insulation test between a current lead and the reference ground to which the cryostat is connected as specified in 4.3.4.9, with leak current lower than $0.1\,\mathrm{A}$, with the complete system at working temperatures, pressures and coolant flows.

4.3.14.7

Combined power supply and transition detection system tests must be performed in accordance with the tests described in 4.3.14.5 point 9.

4.3.14.8

A set of tests on the Solenoid as a whole are required to the Manufacturer, before the Solenoid itself be delivered at FAIR.

1. pressure test of the hydraulic circuit and cryogenic vessels;
2. vacuum test of the hydraulic circuit and cryogenic vessels;
3. hydraulic impedance test of the hydraulic circuit and cryogenic vessels;
4. high voltage insulation test between a current lead and the reference ground to which the cryostat is connected as specified in 4.3.4.9, with leak current lower than $0.1\,\mathrm{A}$, with the complete system at working temperatures, pressures and coolant flows;
5. system cooling to the operating temperature, measurement of coil temperature distribution with the gauges defined in 4.3.11.3 as a function of time; for this inspection and for all inspection defined up to point 14 of this section, the helium flux rate and temperature must be the ones defined in 4.3.7.3;
6. vacuum test of the system at 0 current;
7. power cycle of the coil at 1% of the nominal current to verify the electrical connections and the functioning of the voltage and temperature gauges;
8. coil charge and discharge cycles to the following fraction of the nominal current: 5%, 10%, 15%, 20%, 25%, 30%: for each current, it will be performed both the fast and slow discharge; for all the test time, with proper acquisition rate, of all temperature gauges on the coil, coil former, thermal shields, protection circuit resistors, liquid helium inlet and outlet, all pressures of vacuum vessels, cooling circuit, control cryostat and the liquid helium flux rate; all these measurements will be performed for the tests described at points 10, 11, 12, 13 and 14;
9. it must be verified that the solenoid can be energised at 30% of the nominal current according to the time defined in 4.3.4.3, point 1;
10. the tests described at point 8 and 9 must be repeated inverting the current polarity;

11. the coil must be kept energised for a period longer than 12 hours;
12. it must be verified that the coil can be energised at 30% of the nominal current according to the nominal ramp;
13. it must verified the functioning of the quench spreader heaters, inducing quenches at 15%, 20% and 30% of the nominal current;
14. the magnetic field generated by the coil during tests defined at points 8, 11 and 12 in a series of positions defined by the Customer.

4.3.14.9

A set of tests will be performed at FAIR, after the Solenoid installation in the iron yoke. The Manufacturer is requested to be present at these tests for supervision: the test list is provided in this document for sake of Manufacturer knowledge:

1. pressure test of the hydraulic circuit and cryogenic vessels;
2. vacuum test of the hydraulic circuit and cryogenic vessels;
3. hydraulic impedance test of the hydraulic circuit and cryogenic vessels;
4. high voltage tests;
5. static vacuum tests;
6. system cool-down;
7. electrical components inspection;
8. charge and discharge cycles;
9. charge and discharge time measurement;
10. quench tests;
11. field stability over long period measurement;
12. field mapping;
13. system heating.

Chapter 5

Flux Return Yoke of the Target Spectrometer

It has been generally agreed that the solenoid yoke will be an octagonal prism. The yoke will be fully laminated in the radial direction to allow maximal instrumentation for muon detection. The forward endcap will be divided into two doors which will slide apart on skids to allow access to detectors in the forward region. In the backward region, the yoke will have a hole large enough to allow the Barrel DIRC to extend outside of the yoke, and will also be divided into two doors.

5.1 Overall Dimensions

It was agreed by all members of the Magnet Group that the yoke barrel should be prolonged in order to allow the placement of the Barrel DIRC readout within the return yoke, should readout of the Barrel DIRC within a magnetic field be effected. There must be 500 mm of space (in the z-direction) within a radius of 500 mm between the end of the EMC barrel and the inside of the yoke in order to allow sufficient room for the internal readout of the Barrel DIRC.

Axial yoke dimensions and the positioning of the cryostat and target chimneys is shown in Table 5.1. The cryostat chimney has been placed as far upstream as possible to simplify the cryostat installation procedure. The cryostat chimney inserts into a U-shaped recess in the uppermost barrel segment. The final detailed shape of the upstream door is still subject to some discussion and may change as a result of further information becoming available with regard to the DIRC readout requirements and / or field and cost optimisation. It should be noted that the doors require free space to the sides for the movement and the railing systems. Any installations foreseen in that region need to be closely coordinated with the magnet group.

Accommodation of Muon Detectors In order to allow the detection of muons, to facilitate muon and pion separation, both the forward doors and the main barrel of the solenoid yoke will be laminated. Simulations have shown the need for a range system of staggered muon detectors and iron covering forward angles up to at least 70° azimuthal angle. Such a system becomes more effective the more layers are provided. In an iterative process taking into account space and cost considerations the following optimum solution was found to provide a good overall muon reconstruction efficiency. In the barrel part in total 13 layers of muon detectors will be placed, while 5 layers will be accommodated in the downstream doors. The innermost layer

Yoke Component	Length / mm	$z_{min.}$ / mm	$z_{max.}$ / mm
Upstream Door	385	-1970	-1585
Laminated Barrel	4070	-1585	2485
Cryostat Chimney Position	350	-1565	-1215
Target Chimney Position	350	-175	175
Downstream Door	420	2485	2905
Total Yoke Extent	4875	-1970	2905

Table 5.1: Axial yoke dimensions. To fully understand the dimensions of the shaped upstream door, it is necessary to study the figures in Appendix A.

will be a double layer allowing to reconstruct two coordinates, while the intermediate layers will consist of single layers. Each layer of muon detectors requires a free space of 25 mm.

To allow for the fact that the iron layers have a typical flatness tolerance of the order of 3 mm per metre, thus a 30 mm gap is foreseen for the muon detectors between the layers of iron. Between the cryostat and flux return a minimal space of 10 cm will be left such that in addition to the double layer of muon counters further space for supplies, tolerances and alignment are available. In the forward region the 6 layers of detectors will be augmented by a range system installed between the solenoid and dipole magnets. The chosen solution is detailed in the sections concerning the design of the flux return yoke.

5.2 Barrel Yoke

It has been agreed by all parties that the barrel yoke should be fully laminated to allow maximal instrumentation for muon detection. In the unified magnet design there are thirteen layers of Iron in the solenoid barrel. The Iron layers are 30 mm in lateral extent, save for the innermost and outermost layers which are each 60 mm thick. There are 30 mm gaps between each of the layers in order to allow for full muon instrumentation. The Iron layer thicknesses and locations are specified in Table 5.2. All radial thicknesses and locations are specified as measured in the centre point of each face, in a line normal to the face, intersecting at right angles with the beam axis.

5.3 Upstream Doors

5.4 Downstream Doors

In the forward region, there are very tight constraints on the magnet return yoke due to the many detectors which have to co-exist. In the unified magnet design there are five layers of Iron interleaved with 25 mm gaps in which to place muon detectors, with a total Iron thickness of 300 mm and door thickness of 400 mm as shown in Table 5.3. Again, there is some possibility that the lamination detail will change in order to increase the gaps left for muon detectors.

Layer Outward from Centre	Thickness / mm	$r_{min.}$ / mm	$r_{max.}$ / mm
1	60	1490	1550
2	30	1580	1610
3	30	1640	1670
4	30	1700	1730
5	30	1760	1790
6	30	1820	1850
7	30	1880	1910
8	30	1940	1970
9	30	2000	2030
10	30	2060	2090
11	30	2120	2150
12	30	2180	2210
13	60	2240	2300
TOTAL	450 mm of Iron	1490	2300

Table 5.2: Table detailing the radial Iron lamination of the solenoid yoke. All dimensions are given in the radial direction, normal to the octagonal face of the yoke, beginning from the innermost layer to the outermost.

5.5 Mechanical Considerations

5.6 Cable and Supply Routing

Requirements from the routing are particularly important to the yoke design. As they may affect the Solenoid as well they are detailed in Sec. 3.6.

Layer Axially Outward from Centre			
	Thickness / mm	$z_{min.}$ / mm	$z_{max.}$ / mm
1	60	2485	2545
2	60	2575	2635
3	60	2665	2725
4	60	2755	2815
5	60	2845	2905
TOTAL	300	2485	2905

Table 5.3: The axial iron lamination of the solenoid yoke forward doors, beginning from the innermost layer to the outermost.

1390
Chapter 6

Platform of the Target Spectrometer

COMMENT by Inti: We need to see if we can fill this... ...it could also be in another document

Chapter 7

Forward Spectrometer

7.1 General Requirements

7.1.1 Spatial Occupancies

The Forward Spectrometer at $\overline{\text{P}}$ANDA is required to cover particles emitted with angles below 5 and 10 degrees in vertical and horizontal direction, respectively.

7.1.2 Magnetic Field

A field integral of 2 Tm is necessary in order to achieve the required resolution of 0.5 to 1% in $\Delta p/p$ for protons, pions and kaons with momenta up to 12 GeV/c. This resolution is essential to identify and study several benchmark channels, e.g. to study conventional and exotic charmonium states decaying into $D\bar{D}$ and $\Lambda\bar{\Lambda}$ production. The dipole magnet of the Forward Spectrometer needs to have a large aperture as it is located at 3.5 m downstream of the interaction point. At the same time the magnet needs to reach the field integral over a length of less than 2.5 m.

Description	Value
Field integral	2 Tm
Bending variation	$\leq \pm 15\%$
Vert. Acceptance	$\pm 5^\circ$
Horiz. Acceptance	$\pm 10^\circ$
Ramp speed	1.25%/s
Total length in z	≤ 2.5 m

Table 7.1: Main requirements for the Forward Spectrometer. The field integral maximum variation of the bending angle is valid for charged particles with momenta of no lower than one fifth of the beam momentum originating at the target within the given acceptance.

7.1.3 Accelerator Interface

The dipole magnet will form part of the accelerator lattice and, hence, will need to be ramped synchronously with the ring magnets. To avoid orbit changes and beam losses the synchronisation of the field needs to be accurate during the whole ramping procedure. The maximum ramp speed will be at 1.25% change of current per second relative to the maximum current. The ramp will generally not be started from zero current but rather at 25% of the maximum current. Both ramp-up to full current and ramp-down to 10% current will be required as standard procedure. The main requirements are summarised in Table 7.1.

The yoke is to be built out of plates of low carbon steel. We foresee AISI 1006 here, which is a high quality, low carbon (0.06%) magnetic steel. The flux return yoke will be segmented for two reasons. First of all a moderate segmentation is mandatory as the magnet needs to be ramped with the acceleration of particles in HESR. At the anticipated ramp time of 60 s and a plate thickness of 20 cm the eddy currents will stay below 5 A/cm^2, the power dissipation below 400 W, and the delay between the current and field will be less than two seconds (see Sec. **??**). Secondly, the weight of each individual magnet part is below 15 t and so the crane in the experimental area can carry each part. Hence there is no need for an additional crane for assembly. The total assembled weight will be of the order of 220 t. An exploded view showing the mounting points for the coils is shown in Fig. **??**. Three projections in the three coordinate planes are shown in Figs. A.4 to A.6, respectively.

The opening of the yoke and its coils are designed such that particles emitted from the target with vertical angles below 5° in the vertical plane traverse the magnet fully and reach the detectors in the forward region. As the mounting structure and the frames of the in-gap detectors (see Sec. **??**) use some of the space, the rectangular upper and lower coils are located 5.5 cm outside the upper and lower 5° planes (see Fig. **??**). The use of inclined coils rather than horizontal coils reduces the forces on the muon filter by a factor of 3 and reduces the power consumption. The pole shoes will be manufactured such that the frame has the appropriate space while keeping the iron of the flux return closing in as far as possible to reach a maximum field integral. In addition the surfaces will be kept without steps in order to keep field gradients minimal. A tentative sketch of the envisaged design in shown in Fig. 7.1. The yoke aperture opens out from 0.80 m to 1.01 m in vertical direction while staying constant at 3.1 m in the horizontal plane. The constant horizontal aperture width will facilitate the installation of tracking and time-of-flight detectors to distinguish slower particles that do not exit the magnet.

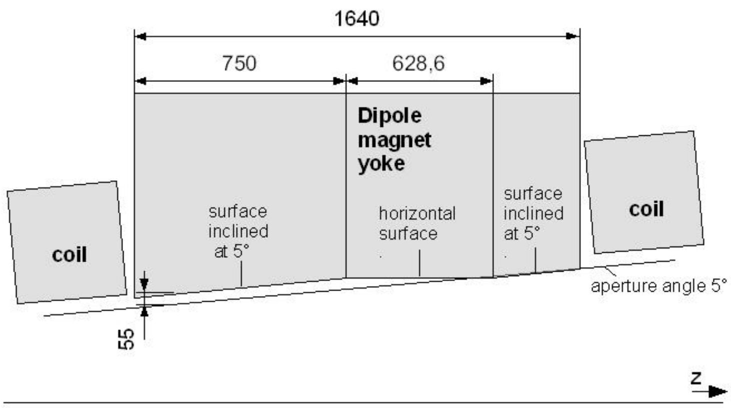


Figure 7.1: Sketch of the pole shoe geometry in the $z - y$ plane. This shape allows the accommodation of in-gap detectors without constraining the vertical acceptance while keeping the field maximal and continuous.

Copper is the selected conductor material, despite being slightly more expensive than aluminium, due to its lower resistivity and better ductility. Only with copper the required small bending radius can be achieved. Copper can cope with higher current densities and reduces operational costs due to a 37% reduction in power dissipation. It is calculated that the increased purchase cost due to the selection of copper rather than aluminium will be fully compensated by the reduced power consumption costs in less than one year of operation. Additionally, the choice of a copper conductor allows a more compact magnet design, thereby reducing the cost for the forward detectors. The selected hollow copper conductor has a $30 \times 24\,\text{mm}^2$ cross section and a cooling channel diameter of 10 mm. A likely arrangement would be to have 6 double pancakes with $14 + 14$ windings each in both the upper and lower coils. The main parameters of the magnet are listed in Table 7.2.

Item	Value
Coils	
Type	Resistive
Material	Copper
Weight	$\sim 18\,\text{t}$
Arrangement	Race track, inc. $\pm 5°$
Conductor diam.	$30 \times 24\,\text{mm}^2$
Water cooling	Channel $\varnothing = 10\,\text{mm}$
Conductor current	2.16 kA
Current density	3.38 A/mm^2
Total current	727 kA
Single turn length	8.68 m
Mean resistivity	18.5 nΩ m
Total dissipated power	360 kW
Inductance (incl. yoke)	0.87 H
Stored energy	2.03 MJ
Flux Return Yoke	
Material	Steel XC06
Lamination	$\sim 20\,\text{cm}$
Weight	$\sim 200\,\text{t}$
Dim. $(H \times W \times D)$	$3.88 \times 5.3 \times 1.64\,\text{m}^3$
Gap opening $(H \times W)$	$0.80 - 1.01 \times 3.10\,\text{m}^2$

Table 7.2: Overview of the main parameters of the dipole magnet. The depth D denotes the length along the beam direction z axis.

We assume that the 24 pancakes will be fed by cooling lines in a parallel arrangement, where the water inlet and outlet are located on the inner and on the outer sides of the winding, respectively. Then we would require 3.9 l/s of water and the temperature difference between inlet and outlet would be 22 K. The water velocity in the cooling channels of 10 mm would reach about 2 m/s and the pressure drop would be 8 bar.

7.1.4 Detector Support

7.1.5 Assembly Procedure

7.2 Support of the Dipole

7.3 Supplies and External Requirements

7.4 Slow Control System

To ensure a proper operation of the dipole magnet, a slow control system will be built which provides the interface to HESR and diagnostic systems. The following magnet systems will be monitored

- **Interface to** HESR**.** This system will guarantee that the control and diagnostic systems of HESR exchange information and are fully synchronised with all systems of the $\overline{\mathrm{P}}$ANDA dipole. The precise layout is not yet defined.
- **Current control** will be used to monitor the magnetic field intensity and the stability of the dipole magnet.
- **Temperature control.** The temperature of the copper coils will be monitored by several temperature sensors located at different positions on the upper and lower coils.
- **Magnetic field control.** Two Nuclear Magnetic Resonance (NMR) probes and 5–10 Hall probes in critical places are foreseen to be used to directly measure the magnetic field intensity and stability.
- **Cooling water flow control.** The flow of cooling water will be controlled by water flow meters at several locations.

The chief tasks of the diagnostic system are listed in the following.

1. Process signals fast to generate alarm and interlock signals for magnet safety in emergency situations.
2. Record control parameters in the normal operation regime and provide data logging.
3. Allow remote control of all parameters, in particular the full integration within the HESR control systems. Display the data at the operator's console.
4. Process signals to generate control responses to optimise the magnet operation.

The magnet and auxiliary equipment control system will incorporate a distributed computer control system composed of commercially available components. Detailed design of the slow control system will be performed starting from 2010.

Chapter 8

Set-Up and Commissioning

8.1 Transport to Site

8.2 Assembly in Hall

8.3 Commissioning

8.4 Field Mapping

8.4.1 Target Spectrometer

8.4.2 Forward Spectrometer

The field mapping will be performed using existing equipment at GSI and with the help of the GSI Magnet Technology Group. It is envisaged that for each of 5 different current settings one full 3D field map would be determined with a grid size of 7, 5 and 2 cm in x, y and z, respectively. This work will be performed as soon as the magnet is fully commissioned and 60 days are estimated for the measurements. Interpolating between the grid points and maps would allow us to determine the magnetic field at every point in the spectrometer opening and any current to sufficiently high accuracy.

The magnet design has been optimised and is finalised to a high level of detail. A few minor modifications to the design might, however, be imposed by constraints or recommendations from the manufacturer during the tendering process.

Chapter 9

Tasks and Responsibilities

The two large spectrometer magnets will be built by seven groups from universities and research institutes in Germany, Italy, Russia, Poland and the UK. The institutions and their abbreviations are listed in Table 9.1.

Abr.	Institution
CUT	Cracow University of Technology, Kraków, Poland
FZJ	Forschungszentrum Jülich, Jülich, Germany
Gla	University of Glasgow, Glasgow, United Kingdom
GSI	GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany
INFN	INFN, Sezione di Genova, Genova, Italy
JINR	Joint Institute for Nuclear Research, Dubna, Russia
UJ	Jagiellonian University, Kraków, Poland

Table 9.1: Table of abbreviations and institutions responsible for the design and construction of the magnets at $\overline{\mathrm{P}}$ANDA.

Five distinct primary work packages have been identified. These comprise the design and construction of the following items.

1. The coil and cryostat of the Target Spectrometer. The overall responsibility is taken by INFN, Genoa.
2. The flux return yoke of the Target Spectrometer, which will serve simultaneously as multi-layer absorber for a large-angle muon detection system. The overall responsibility is taken by JINR, Dubna.

3. The large-aperture dipole magnet for the Forward Spectrometer. The overall responsibility is taken by the University of Glasgow.

4. The support structures and detector mountings for all of the Forward Spectrometer. The overall responsibility is taken jointly by the Jagiellonian University, Kraków and the Cracow University of Technology.

5. The railing systems and movement of the whole Target Spectrometer and the platform with the Forward Spectrometer detectors. The overall responsibility is taken jointly by GSI, Darmstadt and Cracow University of Technology.

The Forschungszentrum Jülich takes care of the $\overline{\text{P}}$ANDA spectrometers' integration into the HESR, which is particularly important for the dipole, since it will be part of the accelerator/storage ring lattice.

The responsibility for the detector mountings inside the Target Spectrometer will remain with the individual detector groups, while the magnet group will provide only mounting points. A detailed list of work packages has been worked out, and responsibilities have been identified, which have been approved by all groups. These are listed in Table 9.2, where the responsible institutions are listed by their abbreviations specified in Table 9.1. Where responsibilities are shared the main responsible is given first and the secondary is indicated in brackets. The main responsible institution will always supervise the work package and take responsibility for a timely and full completion.

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Task	Responsible
Instrumented Flux Return	
Design, documentation, tender, supervision of construction	JINR
Material procurement, manufacturing, assembly and transport preparation	JINR
Assembly and tests at company	JINR
Transport to FAIR	JINR
Interface for muon system	JINR
Coil & Cryostat	
Cold mass cooling circuit design	INFN
Selection of cable	INFN
Mandrel and winding (spacers, connectors...) design	INFN
Mechanical suspension of the cold mass in the cryostat	INFN
Design of intermediate temperature shields	INFN
Feed lines and turret	INFN(FZJ)
Coil Protection system	INFN
Coil diagnostic and DAQ	INFN(GSI)
Tender and procurement	INFN
Follow-up of the cable procurement & tests	INFN
Follow-up of the coil construction	INFN
Follow-up of the cryostat construction	INFN
Follow-up of the cryogenic turret feed lines	INFN
Coil, cryostat, turret final assembly at manufacturer site	INFN
Cryogenic and electric tests at company	INFN
Transport to FAIR	INFN
Dipole Magnet	
Final dipole design	Gla
Procurement and quality assurance (no assembly)	Gla
Dipole slow control	Gla
Detector Support Structures	
Platform for the FS detectors	CUT
Supports in the dipole magnet gap	CUT
Wire chamber supports of the FS	UJ
Absorber system for muon filtering between TS and FS	CUT
Magnet Support Structures	
Rail system and moving of solenoid	GSI(CUT)
Solenoid support structure	JINR
Dipole support structure	Gla
Assembly and Commissioning at FAIR	
Assembly of yoke and support structures	JINR
Installation of cryostat and supply lines	INFN (JINR)
Assembly of dipole magnet and power supply	Gla
Alignment of magnets	GSI (FZJ)
Commissioning of solenoid	INFN (JINR)
Commissioning of dipole	Gla

Chapter 10

Conclusions

The major overall requirements are that the spectrometer magnets need to provide magnetic fields such that the identification and momentum reconstruction of charged tracks in PANDA becomes feasible to the required level. Simulations have shown that a 2 T field along the axis of the beam is required for the Target Spectrometer, while an integral of 2 Tm bending power is needed to obtain the required momentum resolution of 1% in the Forward Spectrometer. Both magnets need leave enough free space to host all detectors required for particle identification.

Space constraints both at the in-beam position inside the HESR tunnel as well as inside the hall constrain the maximum extend of the magnets (see Fig. A.1). The installation of detectors and their supplies within the magnets and the sequence of their installation is an important constraint to the design of the spectrometer magnets.

This document is far from complete. Any comments and input are most welcome! Please mail the Magnet Group PANDA-MAGNET@gsi.de.

Bibliography

[1] PANDA Collaboration, Technical Design Report for the PANDA Solenoid and Dipole Spectrometer Magnets, Technical report, FAIR–GSI, 2009, arXiv:0903.3905 [hep-ex].

[2] European Commission, EN Eurocodes, `http://eurocodes.jrc.ec.europa.eu`.

Appendix A

Magnet Design Diagrams

A.1 HESR and Hall

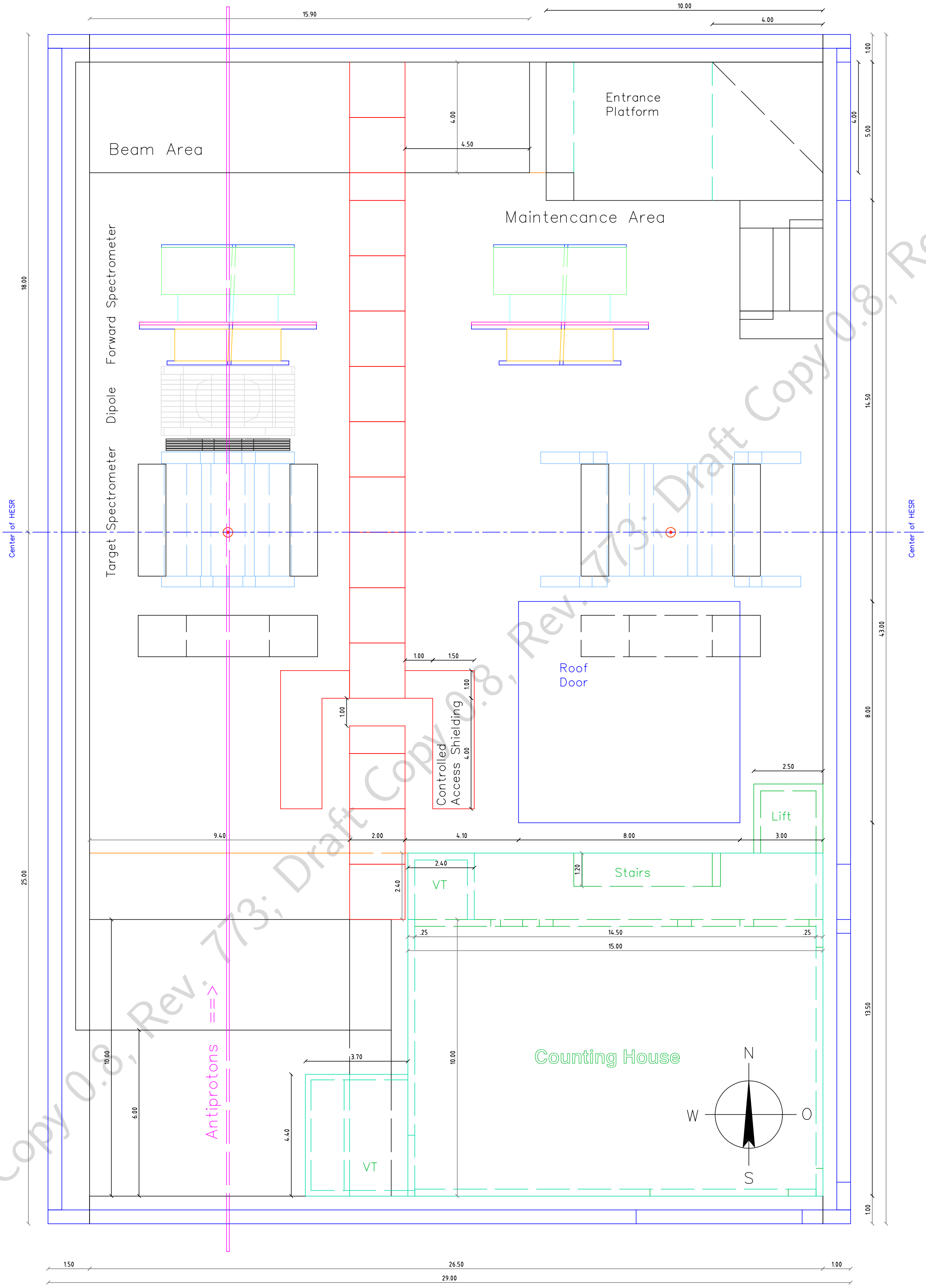
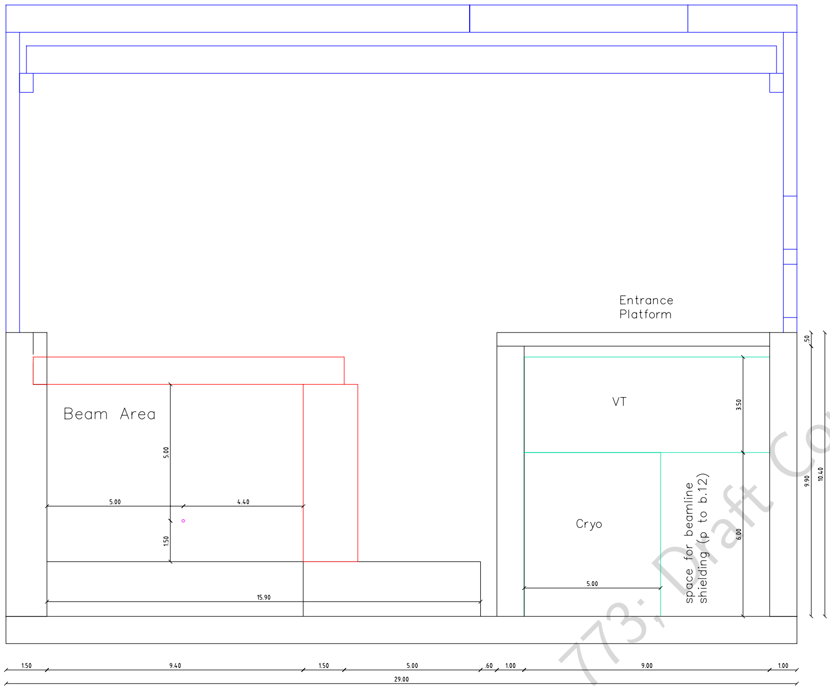
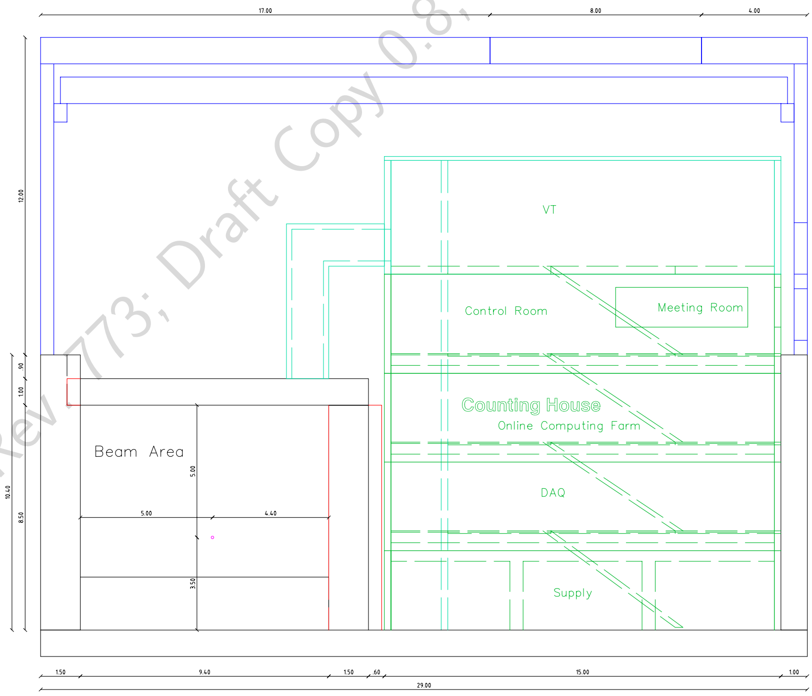


Figure A.1: Floor plan of the $\overline{\text{P}}$ANDA hall showing the location of the solenoid and dipole magnets. The solenoid with its detectors and the platform with the FS detectors can be moved from the in-beam position inside the HESR ring (western area) to a parking position depicted in the eastern area. In the maintenance position the solenoid is shown with open doors, which is required for service access to the inner detector components. Please also refer to Sec. **??**.



(a) Northern cross section



(b) Southern cross section

Figure A.2: Cross sections of the Panda hall in the east-west plane. In the northern view the shielding of the beam area and the entrance platform with the usage of the lower area for service technology (VT) and the cryogenic interface is shown. The southern view shows the levels of the counting house together with the interface block to the beam area.

A.2 Solenoid

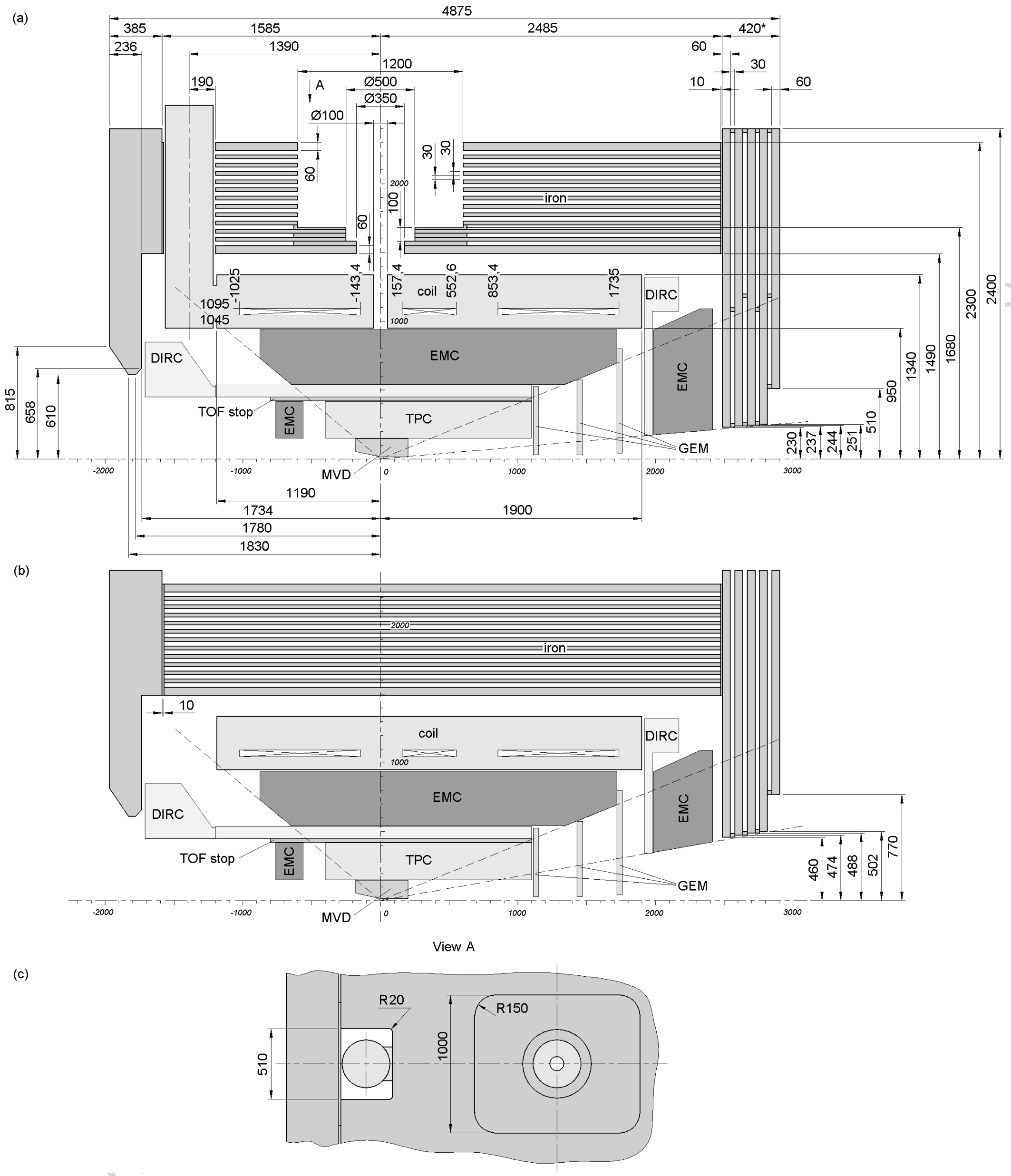


Figure A.3: Cross sections of the Target Spectrometer showing the yoke layout: a) upper half cross section in the $z-y$ plane showing the recess for the target generator at the top, b) half cross section in the $z-x$ plane c) top view of the upstream top surface showing the cut out for the cryogenic chimney and the target recess. The detectors are indicated schematically for illustration only.

A.3 Dipole

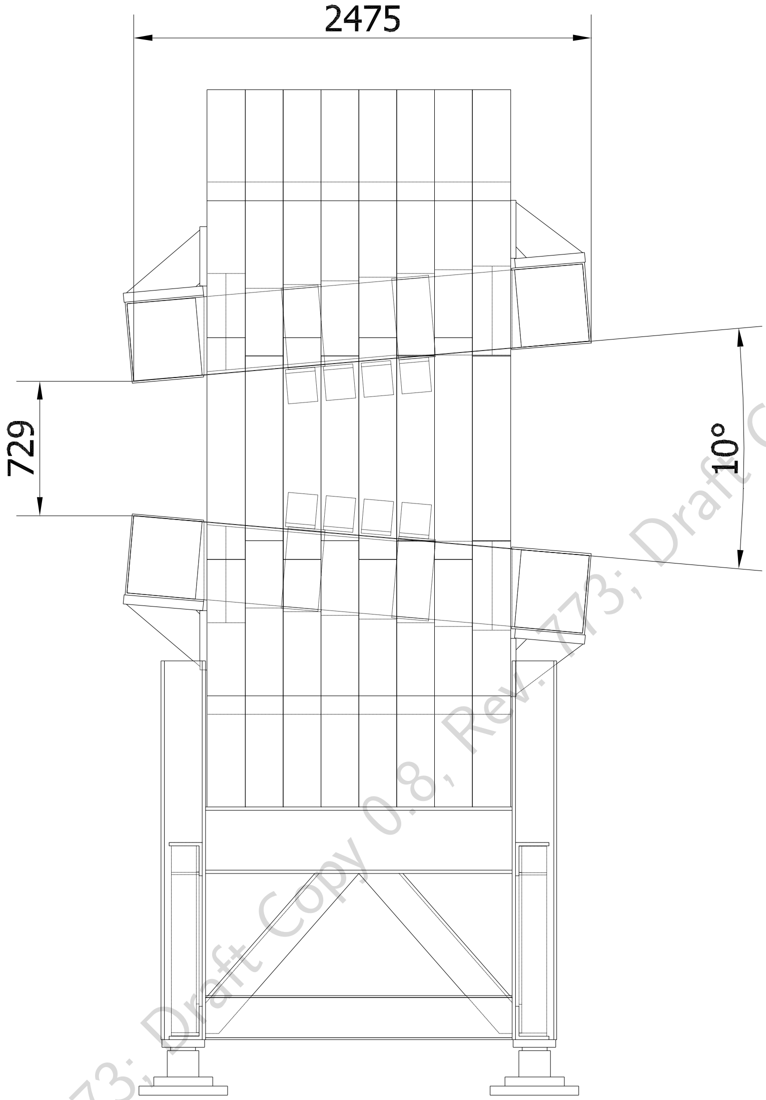


Figure A.4: Side projection of the dipole magnet showing the overall length and minimal gap in millimetres. The beam comes in from the left. Please note that the opening angle of the coils given here does not fall on the $\pm 5°$ line from the interaction point.

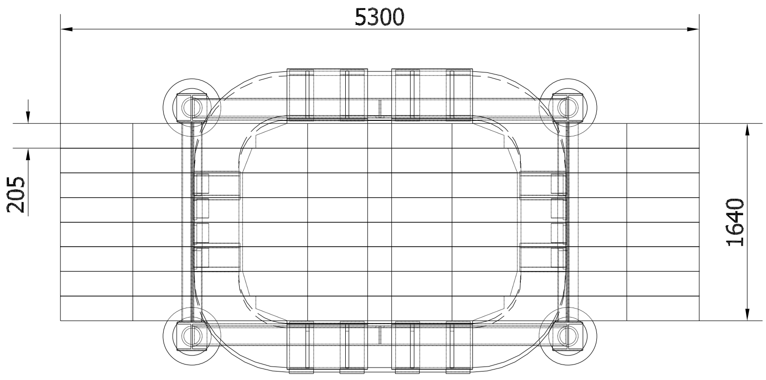


Figure A.5: Top projection of the dipole magnet showing the dimensions of the yoke in millimetres. The beam comes in from the top.

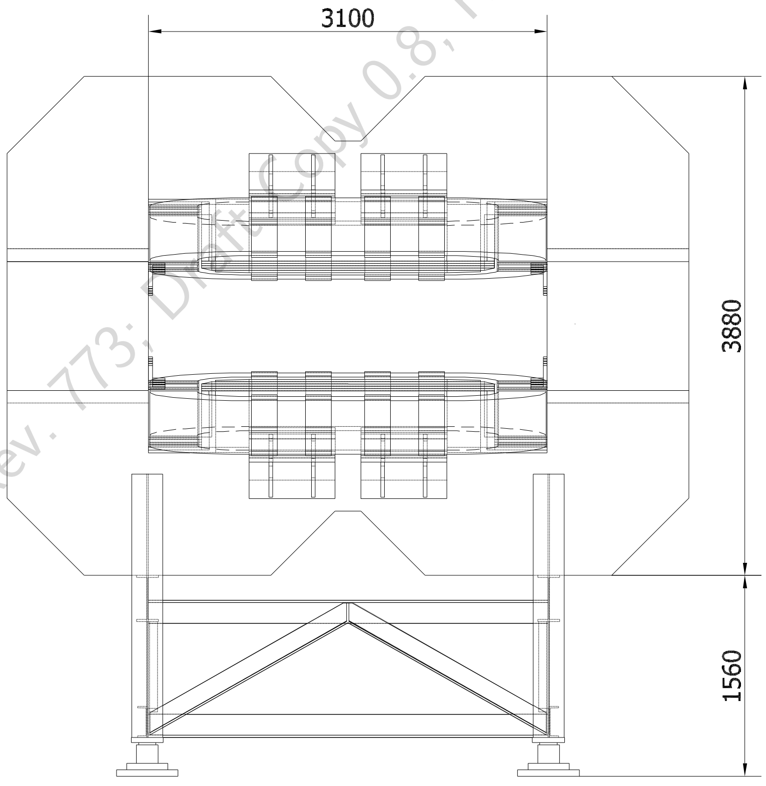


Figure A.6: Projection from the downstream side of the dipole magnet showing the dimensions of the yoke, the gap opening and the distance to the HESR floor in millimetres.

Appendix B

List of Acronyms

Customer committee, which represents the $\overline{\mathrm{P}}$ANDA Collaboration

Dipole large-aperture dipole magnet of the $\overline{\mathrm{P}}$ANDA FS

FAIR Facility for Antiproton and Ion Research, international accelerator facility, Darmstadt, Germany, (founded 4/10/2010) `http://www.fair-center.de`.

GSI GSI Helmholtz Centre for Heavy Ion Research, international research centre, Darmstadt, `http://www.gsi.de`

HESR High Energy Storage Ring, Accelerator and storage ring for antiprotons ($1.5\,\mathrm{GeV/c} \leq p \leq 15\,\mathrm{GeV/c}$) at FAIR (planned).

IP Interaction Point, nominal position corresponding to origin of $\overline{\mathrm{P}}$ANDA coordinate system

Manufacturer industry which will manufacture the $\overline{\mathrm{P}}$ANDA magnets, (all or partially as appropriate).

Platform platform supporting the whole $\overline{\mathrm{P}}$ANDA TS

Solenoid superconducting solenoid and ancillary systems of the $\overline{\mathrm{P}}$ANDA TS, including cryostat, coil and cryogenic chimney but not the Yoke.

TS Target Spectrometer of the $\overline{\mathrm{P}}$ANDA detector

FS Forward Spectrometer of the $\overline{\mathrm{P}}$ANDA detector

Yoke flux return yoke of the $\overline{\mathrm{P}}$ANDA TS, including barrel and upstream and downstream doors and framing supporting it on the Platform.

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