ADDENDUM No. KEXYZ

to

THE MEMORANDUM OF UNDERSTANDING FOR COLLABORATION IN THE HIGH LUMINOSITY LHC PROJECT AT CERN

between

THE EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH ("CERN")

and

UPPSALA UNIVERSITY (the "University")

concerning

Collaboration in the design and construction of the magnetic *measurement test bench* composed of two main parts:

1. **anticryostat: modification of the existing cryostat to have a volume at room temperature and pressure**
2. **magnetic measurement system: motorized system with induction-coil magnetometer able to measure the magnetic field at different locations**

CERN and Uppsala University hereafter individually referred to as "the Party" and collectively as "the Parties."

CONSIDERING:

- The Memorandum of Understanding for Collaboration in the High Luminosity LHC Project ("HL-LHC Project") at CERN (the "MoU") signed by CERN as the Host Organization of the HL-LHC Project and the institutes, laboratories, universities, and funding agencies contributing to the HL-LHC Project (individually referred to as the "Participant").

- That Article 2.2 of the MoU provides that each Participant's contribution to the HL-LHC Project and all related details shall be set out in an Addendum to the MoU.

- That the University wishes to contribute this Addendum KEXYZ/TE/HFM (the "Addendum"). This Addendum shall be subject to the provisions of the MoU; it is understood that in case of divergence, the provisions of this Addendum shall prevail;

AGREE AS FOLLOWS:

1. Scope

This Addendum covers the contribution by the Parties to the design and fabrication of two magnetic-measurement test benches (the "Deliverables"), one to be installed at FREIA and one at CERN. These magnetic-measurement test benches aim to enable measurements of the magnetic flux density field and field quality of superconducting accelerator magnets operated at cryogenic temperatures. Moreover, the magnetic-measurement test benches will allow the use of a rotating-coil scanner held at room temperature and pressure.

In accordance with these objectives, the Collaboration aims for the design, production, and assembly of a total of four (4) anticryostats (2 for each Party) and a total of two (2) measurement systems (1 for each Party) required for magnetically qualifying superconductive magnets featuring minimum 50 mm diameter bore.

2. Duration

The Collaboration shall extend from the date of signature of this Addendum to no later than 30 September 2025; this Addendum shall also cover any activities related to its subject matter executed by the Parties before it enters into force.

3. Each Party's contribution

The Work Packages and their respective Lead Partners are indicated in the table below. There will be a collaboration between the Parties on all Work Packages. The Lead Partner of a specific Work Package is the Partner providing the more significant part of the financing and that is responsible for the Work Package. "Both" indicates a close-to-equal division of financing and responsibility.

Work Packages	**Lead Partner**
Requirements and conceptual design (**WP0**)	BOTH
Design anti-cryostat (**WP1**)	CERN
Production and assembly of the magnetic measurement shaft (**WP2**)	BOTH
Procurement and assembling of **four** (2 x 2) anti-cryostats (**WP3**)	FREIA
Rack and electronics (**WP4.1**) for the two measurement systems	CERN
Micro Drive Unit (MDU) + motor controllers (**WP4.2**)	CERN
PCB for rotating-coil magnetometer and extensions (**WP4.3**)	CERN
Translating vertical systems and motor controllers (**WP4.4**).	FREIA
Assembly of the system (**WP4.5**).	BOTH
Quality and safety (**WP5**)	BOTH
Handling tools for **four** anti-cryostats (**WP6**)	FREIA

The financing of the overall project shall be by equal portions from the Parties. The financing of procurements of materials and instruments will follow the responsibilities in each work package to the extent possible. If the cost for the procurement of materials and instruments exceeds the estimated amount, the cost-sharing between FREIA and CERN shall be adopted accordingly to achieve an overall equal sharing.

The ownership of the magnetic measurement test bench for installation in FREIA will be with Uppsala University, and the ownership of the magnetic measurement test bench for installation at CERN will be with CERN.

The work packages' technical details and cost estimates are given in Annex 1 and Annex 2, respectivly.

3.1 CERN's contribution:

3.1.1 CERN shall provide:

1. The technical specifications of the Deliverables, including specification drawings; see Annex 1.
2. Technical support, i.e., assistance for the manufacturing, assembly, and testing activities performed at the University or in the industry; see Annex 1.
3. Training on applying the Quality Plan and the tools for managing the documents and records linked to the Deliverables.

3.1.2 CERN shall make a financial contribution in the amount of 400 000 CHF (four hundred thousand Swiss francs).

3.1.3 CERN shall define the acceptance criteria for the Deliverables, which shall then be agreed upon by the Parties. The acceptance criteria will be based on four steps:

- Verification and approval of conformity with requirements during production in Sweden;
- Verification and approval of conformity with requirements during testing in Sweden;
- Verification and approval of conformity with requirements upon testing at CERN; and
- Verification and approval of safety conformity.

3.1.4 Initial conformity with requirements will be analyzed during the Production Readiness Reviews (the "PRRs"). Production shall not start before the validation of the PRRs.

3.2 The University contribution

3.2.1 The University shall provide:

- A series of components and subassemblies for constructing four (4) anti-cryostats.
- All tooling agreed between the Parties as necessary for the maintenance and handling at CERN of each of the Deliverables over the operational life span and as agreed between the Parties as tooling to be delivered to CERN;
- The shipment of the Deliverables to CERN, according to the packaging and transport specifications and the schedule defined in Annex 1.

3.2.2 The University shall make use of the existing infrastructure and manpower and, if needed, increase the workforce to adapt to the set of deadlines defined jointly by the Parties.

3.2.3 Where the University contracts with third parties in the execution of the Collaboration, the University shall:

- Keep CERN informed in due time of its selection of industry partners and the terms of any contracts with the industry partners selected.
- Ensure that the provisions of its contracts with any industry partners are consistent with the provisions of this Addendum and the MoU, including, but not limited to, the provisions related to intellectual property and in respect of the Quality Plan obligations; and
- Inform CERN of the terms of any contracts with its industry partners.

3.2.4 Where the University considers it would be necessary for experts who do not qualify for the association with CERN as per Article 5 of the MoU to come to the CERN site in the execution of the Collaboration (as may, in particular, be the case for the employees of any industry partners referenced in Article 3.2.3), the University shall so notify CERN three months ahead of the contemplated date of arrival of such experts at CERN. CERN shall facilitate granting such experts of a (non-personnel) status that will allow the University to execute its contribution effectively.

3.2.5 The University's contribution is detailed in Annex 1.

4 Safety documentation

Each Party is in charge of conformity with the legal framework applicable to its premises, including compliance with safety rules applicable to its premises.

CERN shall provide the specific safety requirements that the Deliverables must comply with. The University shall provide the safety documentation/certification as agreed with CERN to establish the conformity of the Deliverables with CERN's safety rules.

5 Testing and Acceptance Procedures

The CERN Technical Coordinator shall grant acceptance of the deliverables in three phases.

5.1 Phase 1:

- Shipping agreement. CERN shall approve the shipment to CERN of the Deliverables
- The documentation relative to the production of each of the Deliverables.
- The documentation relative to the results of performance evaluation tests of each of the Deliverables.

5.2 Phase 2: Provisional acceptance. CERN shall grant provisional acceptance within one (1) month from the delivery date to CERN based on the successful completion of acceptance tests at CERN.

5.3 Phase 3: Final acceptance. CERN's Technical Coordinator shall grant final acceptance of each of the Deliverables concerned for installation in HL-LHC within six (6) months from the date of provisional acceptance by CERN.

5.4 The detailed production schedule for the Deliverables is given in Annex 1.

5.5 In the event of non-acceptance by CERN of a Deliverable, because of a defect of the deliverable concerned, the Parties shall establish a protocol either for repairing such deliverable at the CERN premises by University experts or for returning such deliverable to the University for repair or replacement.

5.6 Non-conformities shall be treated according to the Quality Plan. The Parties shall agree upon corrective and preventive actions in non-conformity.

5.7 The Deliverables shall become CERN property upon issuing the final acceptance certificate.

5.8 The University shall intervene and repair any hidden defect caused by the non-compliant execution of the quality assurance procedures forming part of the University's scope of delivery and that may be discovered within two (2) years from acceptance.

6 Organization and coordination

6.1 Steering Committee

6.1.1 The Parties shall create a Steering Committee comprising qualified representatives of each Party.

6.1.2 Each representative may be assisted, in an advisory capacity only, by any specialist of his or her choice, including the Technical Coordinator referred to in Article 6.2 below, subject to prior written notification to the other Party.

6.1.3 The Steering Committee shall monitor the execution of this Addendum. It shall ensure compliance with the requirements in Annex 1. If necessary and upon the Technical Coordinators' advice, shall recommend solutions to the Parties in the event of execution problems, it being understood that this shall not diminish the obligations of the Party responsible for the work concerned. It may also propose any modification to this Addendum, that it deems required in technical and financial matters.

6.1.4 The Steering Committee shall act as a body enabling the Parties to resolve any differences or disputes.

6.1.5 The Steering Committee shall meet at least twice a year, or more frequently upon the request of a Party, in the presence of the University and CERN ad hoc representatives. Meetings may be conducted by electronic means.

6.1.6 The University representatives on the Steering Committee shall be:

Tord Ekelof – Project Leader

???

6.1.7 The CERN representatives on the Steering Committee shall be:

Arnaud Devred – TE-MSC Group Leader

Stephan Russenschuck – TE-MSC-TM Section Leader

Frederic Savary – TE-MSC-CMI Section Leader

Alessandro Bertarelli - EN/MME Section Leader

Carlo Petrone – TE-MSC-TM project engineer

6.1.8 Each Party may nominate a successor/successors to the Steering Committee delegates identified above, subject to prior written notification to the other Party.

6.2 Technical Coordinators

6.2.1 The Parties shall each nominate a Technical Coordinator to coordinate the technical aspects of the execution of this Addendum. The Technical Coordinators shall also act as Safety Correspondents and be responsible for safety matters.

6.2.2 CERN's Technical Coordinators and Safety Correspondents shall be:

Carlo Petrone – TE-MSC-TM project engineer

Luca Dassa - ??

…. – …

6.2.3 The University's Technical Coordinators and Safety Correspondents shall be:

Tord Ekelof? – anticryostats Project Manager

…. – …

…. – …

6.2.4 Each Party may designate a successor/successors to the Technical Coordinators and Safety Correspondents identified above, subject to prior written notification to the other Party.

7 Intellectual property

7.1 Intellectual proprieties with the design of the device are with CERN.

7.2 Any deliverables (including in the form of intellectual property) provided by the University under this Addendum shall be deemed to include a perpetual license for their free and unlimited use, including for their repair, modification, and replacement by CERN, or by any third party designated by CERN, within the scope of CERN's scientific program.

7.2 The documentation provided by the University with each deliverable and the information therein shall belong to CERN.

7.3 The provisions in this Article 6 shall apply in addition to the intellectual property provisions in Article 7 of the MoU.

8 Confidentiality

8.1 Except as expressly authorized by and subject to any obligations under this Addendum, each Party agrees to keep confidential and not to disclose to any third party any information, document, or other material designated as confidential or which should reasonably be understood to be confidential. Each Party shall limit the circle of recipients of such confidential information on a need-to-know basis and shall ensure that the recipients are aware of and comply with the obligations defined in this Article.

8.2 The obligation of confidentiality applies, in particular, to the information contained in the documentation provided by the University with each deliverable (cf. Article 6.2).

8.3 Notwithstanding the above, no confidentiality obligation shall apply to such information, document, or other material which:

- The receiving Party demonstrates in the public domain before its communication by the disclosing Party;
- Became part of the public domain after such communication but not through any fault of the receiving Party;
- Has been lawfully received by the receiving Party from a third party without any confidentiality obligation; or

- Has been developed by the receiving Party independently and outside the scope of this Agreement.

9 Miscellaneous

9.1 The University shall grant access to CERN personnel or third-party personnel mandated by CERN, and, where so required, subject to the establishment of non-disclosure agreements and with modalities to be agreed to its premises and the premises of industrial partners involved in the execution of the work under this Addendum.

9.2 Subject to the continued validity of the MoU, this Addendum shall remain in force for as long as necessary to give effect to the Parties' respective rights and obligations under this Addendum.

9.3 Articles 7, 8, and 10 shall survive the termination of this Addendum, howsoever caused.

9.4 Written agreement by the Parties may amend this Addendum.

10 Governing law and dispute resolution

10.1 The terms of this Addendum shall be interpreted in accordance with their true meaning and effect and as a consequence of CERN's status as an Intergovernmental Organization, independently of national and local law. Provided that if and insofar as this Agreement does not expressly stipulate, or any of its terms is ambiguous or unclear, then in those circumstances only and not in respect of this Agreement as a whole, reference shall be made to Swiss substantive law.

10.2 The Parties shall settle any difference concerning this Addendum amicably. Where this is not possible, the Parties shall resort to arbitration in accordance with a procedure to be specified by the Parties. Notwithstanding reference of the dispute to arbitration, the Parties shall continue to perform their obligations under this Addendum.

11 Termination

11.1 In the event of a substantial breach by the University of its obligations under this Addendum, CERN may terminate this Addendum in whole or in part if no corrective action satisfactory to CERN is taken within two (2) months of the issue of a letter of notice by CERN to the University. In the event of such termination by CERN, the University shall reimburse CERN for all costs wholly and necessarily incurred by it as a result of such termination.

11.2 In the event of a substantial breach by CERN of its obligations under this Addendum, the University may terminate this Addendum in whole or in part if no corrective action satisfactory to the University is taken within two (2) months of the issue of a letter of notice by the University. In the event of such termination by the University, CERN shall reimburse the University for all costs wholly and necessarily incurred by it as a result of such termination. The amount of such reimbursement shall not exceed the remaining amount payable by CERN to the University as of the date of termination of this Addendum.

11.3 In the event of a withdrawal of the University within four (4) months from the signature of this Addendum, due to the impossibility to identify a suitable industrial partner, no reimbursement shall be claimed by CERN upon the issue of a letter of notice by the University.

This addendum has been drawn up in two copies in the English language and signed by the authorized representatives of the Parties.

The European Organization for Nuclear Research (CERN)	Uppsala University
…………………..	……………………
Dr. Arnaud Devred	Prof. Eva Åkesson
TE-MSC Group Leader	Vice Chancellor
On:…………………2023	On:…………………2023

……………………..

Thierry Lagrange

Head of Industry, Procurement, and
Knowledge Transfer Department

On:…………………2023

……………………..

Anders Unnervik

Head of Procurement and Industrial Services

On:…………………2023

Annex 1: Technical description

The magnetic measurement test bench comprises a rotating-coil measurement system and vertical anti-cryostats. The project aims to design, manufacture, assemble, and test magnetic measurement systems and anti-cryostats, allowing field scanning with ambient-temperature measurement heads to qualify superconducting magnets mounted vertically in the already existing cryostats.

The following describes the magnetic measurement test benches and the scope of the supply, limits of responsibility, and technical description to allow a contributing institute to express its interest and elaborate a proposal. Together with a cost estimate, this document defines the responsibilities and cost-sharing options.

12 Introduction

The **T**est and magnetic **M**easurement section (TM) of the **M**agnet, **S**uperconductors, and **C**ryostat group (MSC), as part of the **TE**chnology department (TE) at CERN, is in charge of the qualification of all the magnetic elements for the accelerator complex at CERN. The TM section's mandate includes acceptance and characterization tests of the field strength and quality of new and existing magnets and the measurement of the property of magnetic materials. For stable particle beams, high-accuracy field distribution measurement is required: the magnetic flux density generated by accelerator magnets must be known accurately to have complete control of the trajectory and resonances in particle beam dynamics. For this aim, the TM section develops magnetic-field sensors, instruments, calibration, test hardware, and data acquisition systems. Different systems are used to measure the magnetic flux density. Among others, the rotating-coil magnetometer is one of the most used methods.

The FREIA Laboratory Division is part of the Department of Physics and Astronomy at Uppsala University. It has more than 30 employed researchers, engineers, and technicians and is directed by a Board led by the Head of the Division. The scientific goal of the FREIA Laboratory is to enable new leading experimental investigations in particle and nuclear physics, atomic and molecular physics, chemistry, molecular biology, and material, energy, and environmental science. The leading equipment of the FREIA Laboratory currently includes a high-capacity Helium liquefier, a large horizontal and a vertical cryostat, powerful vacuum-tube radiofrequency sources, advanced hard- and software for process control and safe test bunkers, allowing for tests of high-power superconducting equipment like magnets and accelerating cavities. Currently, FREIA is collaborating with CERN on the fabrication of cryogenic equipment (DHFX and DHFM cryostats) and superconducting corrector magnets (MCBXF) tests for HL-LHC.

The measurement test benches will be installed on the French side of the CERN (building SM18 – Cluster D) and in the FREIA laboratory at UPPSALA university (GERSIMI). Both laboratory's needs and requirement specifications for the equipment were shaped in several collaboration meetings. Hereafter the indico link to those meetings https://indico.cern.ch/category/14910/ . In the spirit of mutual Collaboration, CERN and FREIA teams initiated, at the beginning of 2022, a preliminary design study of the anti-cryostat. This led to defining the project's technical requirements, which are in part based on CERN's previous experience on a similar project. The compatibility between the two design software types used in the laboratories – CATIA and

SOLID WORKS – were evaluated, and the CERN D-Flow Feature Model Data Format (MDU) step files were successfully integrated into the SOLID WORKS environment used at FREIA. Moreover, a CERN Engineering Data Management System (EDMS) platform has been established for sharing files and drawing contributions (EDMS 2791221).

13 Measurement Procedure Description

Magnetic measurements will be carried out in an anti-cryostat, which must keep the rotating-coil magnetometer at ambient temperature and pressure. A rotating-coil magnetometer consists of one or two nested segments based on the same principle as CERN's previous similar anti-cryostat design project (e.g., CEA Saclay).

The operation steps of a rotating-coil magnetometer for a magnetic field scan are as follows:

- The anti-cryostats installed in the magnet apertures reach from the top flange of the cryostat to the bottom of the magnets.
- A rotating-coil magnetometer mounted at the end of a shaft is inserted from the top inside the anti-cryostat to perform magnetic measurements.
- The rotating-coil magnetometer operates at the ambient conditions (room temperature and pressure) ensured by the anti-cryostats.
- The level of the magnet excitation current is acquired during the magnetic measurement at several vertical magnetometer positions along the entire length of the magnet aperture.
- A motorized vertical positioning system allows vertical measuring shaft displacement and precise position measurements.
- The vertical position must remain constant and sufficiently stable during the measurements. The scan is performed step-by-step, i.e., the rotation of the shaft is stopped, and the shaft is moved to the next vertical position.
- The motor-drive unit (MDU type, design CRNMMAMR_AC0001) will be connected to the positioning system and be used to turn on the rotation to the rotating-coil magnetometer.
- The CERN-developed software framework (FFMM) is used to send commands to the Motor Drive Unit (MDU) for the rotating-coil magnetometer at a frequency typically a few Hertz, acquired at each command the voltage signals from the induction coil.
- The measurement procedure is repeated until the desired measurement space has been scanned.

14 Work-Package 0 (WP0): technical requirements and technologies

The WP0 intends to build the foundation to define the project's technical requirements. This milestone will be considered achieved once the stakeholders agree on these requirements. The technical requirements shall allow the system to be used to test magnets required for the High Field Magnet (HFM) project at CERN and similar projects at other accelerator laboratories. The main characteristics of these magnets are as follows:

- Double aperture magnet with a diameter of **50 mm** per aperture.
- Distance between aperture axis: **between 180 and 220 mm**.

After the signature by CERN and the Uppsala University of the Collaboration Agreement, a Conceptual Design Review will be held between the parties to make final adjustments and approve the Project's Technical Specifications defined as the deliverable of the WP0 (TBD).

14.2 The vertical anti-cryostats

The function of the anti-cryostat is to create atmospheric conditions in the bore of a cryo-magnet tested under cryogenic conditions. The anti-cryostat is built as a coaxial tube consisting of a seamless stainless steel inner tube to be held at ambient temperature (the warm bore) and an outer stainless-steel tube at cryogenic temperature (the cold bore). The cold bore's outside diameter must be smaller than the inside diameter of the cryo-magnet's bore (50 mm). At the same time, the warm bore must provide as much space as possible for the insertion of the magnetometer to perform high-resolution magnetic measurements.

The key characteristics of the vertical anti-cryostat are as follows:

- The warm bore must be well-insulated with respect to the cryo-magnet. Flexible heaters can be bonded to the inner tube and equipped with temperature sensors. The regulation of heat dissipation relies on the temperature recorded with these temperature sensors and an appropriate control unit.
- The outer part of the anti-cryostat is exposed to a bath of liquid helium at 4.5 K above the Lambda plate and a bath of superfluid helium at 1.9 K below the Lambda plate, which implies that the exterior of the anti-cryostat is at cryogenic temperature.
- A vacuum is created between these two concentric tubes to minimize the convection heat transfer. Additionally, Multi Layers of Insulation (MLIs) are wrapped around the inner tube to minimize the radiation heat transfer between the concentric tubes. The MLIs shall be designed following CERN's reference drawings and 3D models.
- A bellow above the Lambda plate level for the internal tube provides the flexibility required to compensate for the thermal contraction. Spacers can be placed along the inner tube to maintain the two concentric tubes. These spacers, made of composite material, shall be designed to minimize the conduction heat exchange between the two concentric tubes as much as possible: the external tube is around 2 K, while the internal tube shall be at room temperature.

- To guarantee ambient temperature, an active control system is required. This system consists of modular foil with temperature sensors (E.G., PT100) installed between the 2 tubes and distributed all along the length of the anti-cryostat. The heaters and temperature sensors will be bonded to the exterior of the internal tube to heat it and measure its temperature.
- Once the modular foil heaters and the temperature sensors are mounted, MLIs will be wrapped around the internal tube to insulate it from the outer tube at cryogenic temperature thermally.

14.3 The rotating-coil measurement system

Both the rotating-coil magnetometer (equipped with the induction-coil element) and the motor drive unit (MDU) are mounted on a 1-axis translation stage system. The shaft is displaced vertically inside the bore of the magnet. No *on-the-fly* measurements are performed; the translation stage will have its stable and precise position before the data acquisition starts. The procedure requires precise knowledge of the displacement.

14.4 The linear displacement stage (tower)

The linear displacement stage, in the form of a tower mounted on the cryostat top cover, shall be equipped with a mounting system for the motor drive unit (MDU - CERN provides the step file of the MDU). The overall height of the 1-axis stage assembly shall be less than 2.5 m and cover the 2 m displacement range.

The key characteristics of the linear displacement stage are as follows:

- The stage shall guarantee the positioning of the shaft and the magnetometer and reduce vibration after reaching the target position. This could be accomplished, for example, by pneumatic breaks, locking mechanisms at the spindle, or feedback loops in the controllers with a suitable frequency.
- The vertical shaft and the magnetometer shall keep their positions within 1 mm In case of a power cut.
- The mechanical linear stage support shall have enough stiffness to allow precise gravity alignment and a sufficient adjustment range.
- The overall weight of the 1-axis stage assembly shall be compliant with the laboratory station limits.
- The linear stage shall be equipped with hoist rings and rollers to facilitate crane handling and storage. A retention system shall be provided to avoid damage during transport.
- Reference surfaces shall be provided for mounting level meters and fiducial markers referencing the axis stage.
- The geometrical shape of the system must remain within the required tolerances after transportation, which must be validated during the acceptance test.
- Reference points shall provide the linear position of the rotating shaft and its magnetometer on the connection plate.
- The absolute positioning error using the displacement motor and its position readout shall be below 0.1 mm in the scanning range.

14.4.1 Linear encoders and movement control

- The shaft with the magnetometer shall be equipped with a linear encoder guaranteeing an accuracy consistent with the requirements for its positioning (0.05 mm).
- Referencing should not require any displacement adjustment of the system at the motor controller switch-on.
- There shall be three ways of controlling the movement of the shaft and the magnetometer:
  - By software via sending commands.
  - By a wired remote control (min. 10 m cable length).
  - Manually activated (in case of power failure or for pre-alignment of the magnetometer).

14.4.2 Machine interfaces - drivers and motors

A real-time display of the position of the magnetometer given by the encoders shall be available with the number of digits corresponding to the resolution of the encoders.

The linear motor controller should not interfere with the control of the rotation motor, which will be operated in the frequency range (0-50 Hz) once the target position is reached.

The linear and rotation motors shall be equipped with thermal- and torque-overload interlocks.

The linear displacement motor controller should have required software libraries to allow communication and the user manual with commands description.

14.4.3 End switches and cable chains

In addition to the built-in end-stop switches of the stages, external limit switches (stopping any movement in case of power cuts or software failure, etc.) shall be present. They shall be manually adjustable to limit the measuring range physically.

The wiring shall be adequately guided in adequate cable chains. A cable chain of min. 30 x 30 mm (or equivalent cross-section), and a connection shall be installed to host the signal cables from the rotating-coil magnetometer mounted at the extremity of the shaft.

The motor controller/drivers shall be mounted in a movable rack. The length of the cabling must be adjusted to fit the position of the test stations (5 m). The high-precision linear motors shall work in a lab environment under the following operating conditions: +15 °C to 32 °C

All necessary documentation on the 1-axis stage assembly, controllers, and drivers shall be provided in English and shall include the following:

- Installation (including an alignment procedure), operation, maintenance, instructions for internal transport, and safety manuals.
- The installation and operation manuals must contain a detailed description of the procedure to guarantee a correct installation and alignment in case of transfer of the system to a different location.

15 Construction norms and regulations

The main regulatory context at CERN shall be defined by the Health & Safety and Environmental Protection (HSE) unit. This framework applies only to equipment to be installed and used at CERN. The HSE unit will be required to produce a written report with clear indications of the conformity procedures to follow. All the relevant mechanical systems shall comply with applicable safety rules. Three main sub-systems are identified: the anti-cryostat, the magnetic measurement system, and the lifting accessories. Pressure Equipment Directive 2014/68/E.U. And Machinery Directive 2006/42/E.C. should be followed and may be imposed by the laboratory Safety Units. Safety rules may differ between CERN and FREIA: in the case of equipment built for both laboratories, the equipment shall conform to the most stringent applicable Safety Rule.

15.1 Safety for the anti-cryostat

The content of this section is valid only for preliminary assessment. The HSE unit will be required to indicate the applicable requirements to the project. The appliable safety rule to the anti-cryostat design, manufacturing, inspection, test, and use should be the GSI-M-4 (see http://safety-rules.web.cern.ch/GSI-M-4_EN.htm and EDMS 1327191). The anti-cryostats are modifying the pressure-containing envelope of the existing CERN and FREIA vertical cryostats: it may be required to adopt quite a heavy conformity approach to safety rules since the cryostat is classified with a high-risk category (following PED Directive 2014/68/E.U. requirements).

15.2 Safety for magnetic measurements system

The content of this section is valid only for preliminary assessment. TBD

The HSE unit will be required to indicate the applicable requirements to the project. CERN does not foresee a specific rule applicable to machinery equipment. So, the European Machinery Directive 2006/42/E.C. should be the applicable reference regulatory context, considering the installation on the French territory of CERN. Following this approach, the HSE unit may request to produce CE-marked machinery following Directive 2006/42/E.C.

15.3 Safety requirements at FREIA

The FREIA safety unit shall define the safety requirements at the FREIA laboratory. TBD

15.4 Pressure vessels safety

Regarding pressure equipment, CERN will first ensure the compliance of the pressure equipment with its own safety rules. FREIA will then check if CERN's design and manufacturing/testing strategy comply with Swedish/E.U. safety rules, and if not, will combine these requirements into the designs. It is considered improbable that equipment that is up to CERN safety directives will not be up to Swedish\European directives. Pressure equipment at U.U. may need the intervention of Notified Body. This will be handled as and if it happens.

15.5 Machinery safety

If the machinery manufactured by FREIA needs a C.E. safety marking, FREIA will take on this. Since FREIA will not sell these machines, C.E. markings will likely not be required. Each Party will ensure that the design satisfies its own safety regulations for machinery manufactured by U.U. Since FREIA will not sell these machines, C.E. markings will likely not be required. Each Party will ensure that the design satisfies its own safety regulations for machinery manufactured by FREIA.

15.6 Safety design requirements

Additional regulatory contexts:

- Moving or rotating parts, e.g., worm gears, shall be protected against external contact.
- Retention measures shall be included to guarantee that any lubricant is contained in case of a leak (if applicable).
- A mobile emergency stop device shall be available and provide an operating range of up to 5 meters from the base. This emergency device shall stop all stage movements within a delay equivalent to a 2 mm travel range at maximum speed and without switching off the electrical power.
- A flashing light on the top of the axis stage assembly shall indicate any movement of the stages.

16 Work-package 1 (WP1): design of the anti-cryostats

It is assumed that two anti-cryostats (for double aperture magnets) shall be installed at CERN and at the FREIA test station. Each of the two vertical cryostats shall be modified to the extent required to accommodate the common anti-cryostat. As the two laboratories feature a significant difference in cryostat length (magnet available space: 2.8 m at FREIA vs. 5.2 m at CERN), a common anti-cryostat design would not be possible. (TBD)

16.1 Deliverables

The Technical reference standard for design will be based on Section 15. For instance, CERN rules state a list of technical standards. It is assumed that one of the following technical standards shall be used for a preliminary evaluation: EN 13445, EN 13458, EN 13480.

The deliveries of the WP1 are:

- 3D models as per requirements specified according to CERN standard
- Manufacturing drawings
- Mechanical calculation reports
- Thermal calculation reports
- Assembly procedure reports
- Technical specifications for manufacturing
- Test procedures.

16.2 Adaptation CERN vertical cryostat (Clusted D)

The main drawing for the station at CERN (Cluster D) is CRNQLKJH0328. Some modifications will be required to adapt it to the geometry of the common anti-cryostat. CERN will finance these modifications outside the CERN-Uppsala agreement (TBD).

16.3 Adaptation UPPSALA vertical cryostat (Gersemi)

Some modifications will be required to adapt it to the geometry of the anti-cryostat FREIA. The financing of these modifications is not included and will be provided by Uppsala University.

16.4 Calculation (mechanical, thermal, manufacturing)

CERN will be responsible for the mechanical and thermal calculations (TBD)

16.5 Writing technical specifications for manufacturing

CERN will be responsible for writing the technical specifications for manufacturing (TBD)

16.6 Flexible PCB design for the heaters

The heater design (installed on the anti-cryostat) may impact the quality of the magnetic measurements because the heater may generate current loops creating field errors. CERN has experience designing and manufacturing these heaters (based on flexible printed circuit technology). Figure **1**1 and 2 show a flexible heater for the HL-LHC anti-cryostat project.

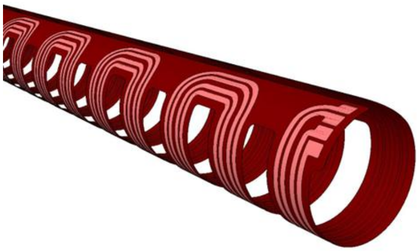


Figure 1 3D rendering of flexible heaters designed and manufactured at CERN

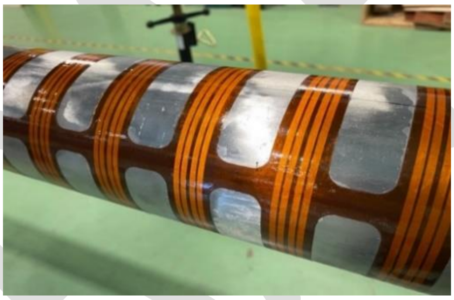


Figure 2 Image of flexible heater for the HL-LHC anti-cryostat

17 Work-package 2: design of the magnetic measurement system

The magnetic measurement system is based on the rotating coil measurements method. It comprises a rotating coil magnetometer with five tangential coils and a rack with all the electronic components based on a PXI crate. The FFMM (Flexible Framework for Magnetic Measurements) software used to perform the measurements runs under Windows, and Microsoft Visual Studio, with a dedicated script for the measurement. The deliverable of the WP2 are:

1. Measurement shaft and PCB design for magnetic measurement
2. Adaptation and motor (MDU) interface
3. A vertical linear displacement (scanning) system design
4. Documentation (risk analysis, user manual, etc.…).
5. The Technical and Safety files requested by the Machinery Directive 2006/42/E.C.

18 Work-package 3: procurement and assembly of the anti-cryostats

18.1 WP3.1 Procurement of raw material (total)

Deliverables of this sub-work package are:

- Hardware: raw materials mainly
- Certifications for procured components (e.g., material certificates for raw material)

18.2 WP 3.2 Manufacture (total)

As inputs at this stage are:

- Acceptance tests on the procured hardware.
- Raw materials and production drawings.

Deliverables of this sub-work package are:

- Machining
- Welding / Certifications
- Documentation (Procedures)
- Acceptance Tests
- Quality reports

18.3 W3.3 Assembly / Integration (total)

Some activities shall be foreseen on the complete the anti-cryostats:

- Instrumentation installation (Modular foil heaters and temperature gauges)
- Cable routing
- MLI installation

- Electrical test -> Report
- Test of the assembled system

Deliverables:

- User manuals
- Documentations (procedures, quality, and test reports)

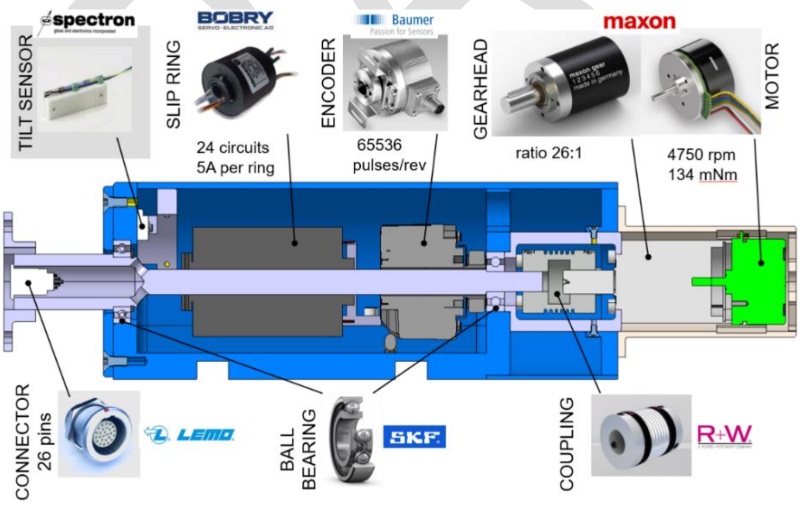
18.4 W3.4 Inspection / Verification (QA) by CMI (total)

TBD

19 Work-package 4: procurement, assembly, and calibration of the magnetic-measurement system

The magnetic measurement system consists of the electronic rack and the measurement transducer based on the rotating-coil method, consisting of a rotating shaft containing induction coils placed in the magnet bore and held in place by two adjustable positioning stages (designed in WP2). The rotating-coil measurement acquires induced voltages from the measurement coils at different levels of the magnet excitation current. The coils are designed to scan the magnet, including its fringe field region, to measure the integrated field strength. A rotating shaft will contain five tangential coils to compensate for the main signal. To increase the signal-to-noise ratio (SNR), these coils will be connected in a compensation scheme (bucking). Quadrupole bucking is achieved by connecting the external coil (A) in anti-series with the middle and central coils (B and C) and in series with the opposing middle coil (D): both absolute and compensated signals are acquired simultaneously by using two Fast Digital Integrators (FDI).

The Motor Drive Unit (MDU) and measuring shaft are fixed on a vertical scanning system. The software application used for controlling the hardware and acquiring the data is the framework FFMM developed at CERN. CERN proposes to use an already designed motor unit (MDU) containing a motor, a reduction gear, a rotary optical encoder, slip rings, and an electromechanical shaft interface. **Error! Reference source not found.** lists the MDU drawing reference numbers for future development. It will allow the rotation of the shaft in the magnet bore, keeping the electrical connection with the measurement head and the electronic acquisition system. The following figure shows the MDU cut, including the main electronic parts.



MDU and main inner parts

The rotating coil shaft contains five radially mounted induction coils. CERN proposes producing induction coils using printed circuit boards as the new standard. Motorization will allow the motor (MDU) and the measurement shaft connected to be precisely displaced vertically to scan the measurement region in the magnet bore under test according to the measurement needs. The proposed scanning system will guarantee the stability required during the measurement in each position and precisely repositioned automatically among different longitudinal places; consequently, reading on the position is required (e.g., linear encoder).

As foreseen for the WP2, it is required to assemble and test the entire measurement system, composed of measurement unit + linear unit + power unit + control unit + C.E. certification (if required by safety units) + documentation + final tests.

20 Work-package 5: quality control and safety

The impact of safety rules shall be considered and may lead to slightly different designs. It is proposed that assembling, integration, and commissioning be done independently in both laboratories.

20.1 Quality control for drawings

The quality plan of the EN-MME design office will be done on three levels:

- control 1: design control - ISO GPS.
- control 2: if it meets the final needs, functional.
- control 3: integrability concerning the final laboratory.

20.2 Quality Follow up

Constant follow-up of documentation and compliance with specification shall be granted for all components (anti cryostats, measurement systems, lifting tools). Above all, when a small series production is used in different laboratories, it is required to respect safety rules. It is so considered that a person shall be charged with this role.

20.3 Safety Follow up

As mentioned in previous sections, safety rules apply to each sub-component; these rules may differ following the laboratory where the equipment is installed, adding complexity to the activity.

In parallel with the design and manufacture, it is essential to look at the systems' safety and perform various risk analyses to grant the compliance of the systems with applicable rules.

Identifying the owner of every component will be required to facilitate the discussion about compliance with Safety Rules.

Safety regulations must be followed as the anti-cryostat changes the boundary of the existing cryostats. Required documentation and certification for pressure vessels may differ between the two laboratories (UPPSALA following European safety standards and CERN following internal safety rules that are inspired (but not identical) to E.U. regulations. The pressurized anti-cryostat will have to follow the safety rules for pressure vessels and be in electrical compliance. As this equipment is expected to be used at CERN (SM18), the equipment has to respect the CERN safety Rules (e.g., case GSI-M-4 and may require the application of the PED Directive 2014/68/E.U.). Similarly, the motorized shaft and the rotating coil should follow the machinery directive 2006/42/E.C.: it is required that both laboratories inquire about the applicable rules, as specified early in this document.

The anti-cryostat lifting tool has to be C.E. certified as lifting equipment.

Due to the complexity of the regulatory framework for this project, it is recommended to appoint reference persons for safety at CERN and at FREIA in order to facilitate exchanges about safety all along the project.

21 Work-package 6: handling tools

21.1 Documentation Handling, Quality Control, and Quality Assurance

All the documentation shall be stored in EDMS. The collaborators shall plan, establish, implement, and adhere to a documented quality assurance program that fulfills all the requirements described in this technical specification and shall be submitted in electronic format:

- Drawings in CATIA® or AUTOCAD®
- Text documents in Microsoft Word® and/or PDF format
- Cost breakdowns and equipment list in Microsoft Excel® format
- Schedule in Microsoft Project® format

21.2 Tests to be carried out

List of tests (TBD):

- Assurance of the correct functioning of all operation and safety aspects.
- Acceptance testing before shipment by checking the static and dynamic behavior with laser tracker systems.
- Leak test for the anti-cryostat
- Pressure test for the anti-cryostat
- Electrical test for the heater on the anti-cryostat
- Magnetic measurements

Annex 2: Financial contributions

The following table lists the cost estimations for the work packages discussed in Annex 1.

Cost estimate and work breakdown for both systems, including 2x2 anti-cryostats and two measurement systems	**Estimations CHF**	**CERN**	**UU**
Requirements and conceptual design (**WP0**)	TBD	TBD	TBD
Design anti-cryostat (**WP1**)	41 440	41 440	TBD
Design magnetic measurement (**WP2**)	40 320	16 800	23 520
Procurement and assembling of **four** (2 x 2) anti-cryostats (**WP3**)	327 600	119 900	207 700
Rack and electronics (**WP4.1**) - 2 measurement systems	120 000	120 000	0
Micro Drive Unit (MDU) + motor controllers (**WP4.2**)	40 000	40 000	0
Specific rotating probes, PCB, and extensions (**WP4.3**)	40 000	40 000	0
Translating vertical systems and motor controllers (**WP4.4**).	60 000	TBD	60 000
Assembly of the system (**WP4.5**).	TBD	TBD	TBD
Quality and safety (**WP5**)	25 000	25 000	
Handling tools for **four** anti-cryostats (**WP6**)	78 400		78 400
Total (CHF)		403 140	395 220
	%		