



Alignment and Survey

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HL-LHC AUP Pre-Series Production Readiness Review – Aug 23th, 2023



Outline

- Functional Requirement Specification
- Data Traceability
- Coordinate and Reference Frames
- Status
- Alignment/Survey for Cold Mass (CM)
- Alignment/Survey for Cryostat
- Survey details
 - FSI – Frequency Scanning Interferometry is the system for the Cold Mass Position Monitoring provided by CERN
- Summary
 - FDR – Final Design Report
 - Vector – Fermilab Traveler System

WBS 302.4.02+03: Alignment FRS for CM and Cryostat

- Cold Mass *LMQXFA Functional Requirement Specification doc-db 64*
 - R-T-06 Nodal point distance between both MQXFA is 4806 ± 5 mm (at 1.9 K)
 - R-O-01 Maximum deviation of each MQXFA magnet axis to common axis must be within ± 0.5 mm in both horizontal and vertical direction.
 - R-O-01 Maximum deviation of each MQXFA field angle to common magnetic field angle is within ± 2 mrad.
 - R-O-02 The common magnetic axis w.r.t. to the cold mass fiducials is determined with an accuracy of 0.2 mm to both nodal points.
 - R-O-02 The common average MQXFA field angle w.r.t. to the cold mass fiducials is determined with an accuracy of 0.5 mrad.
 - R-O-02 The magnetic length and the nodal points of each of the two MQXFA magnets in the cold mass is known within ± 1 mm accuracy w.r.t. the cold mass fiducials.
- Cryostat *LQXFA/B Functional Requirement Specification doc-db 246*
 - R-T-05 Cryostat Position has to be as described by ICD doc-db 375
 - R-T-06 Alignment Requirements from LMQXFA FRS doc-db 64 must be met after assembly
 - R-T-07 Cryostat reference frame as described in doc-db 3281

Alignment

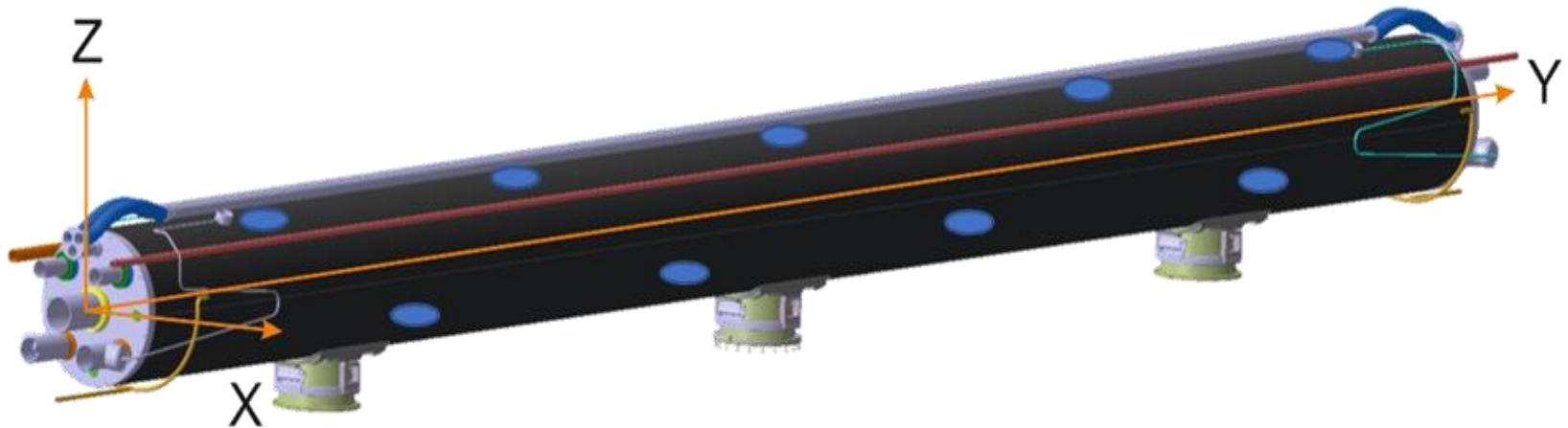
- FNAL is doing all the survey and alignment to satisfy the requirements
- CERN developed systems
 - Coordinate System definitions and survey/alignment procedures and template for data upload
 - FSI Cold Mass Position Monitoring System Design and Functionality
 - Installation is part of the 302.4.03 scope
 - Cold Bore “Mole” Design
 - CERN would like to use a “mole” to measure the cold bore tube deflection, design and procurement of system by CERN

Data traceability

- Each MQXFA's assembly mechanical survey/alignment + SSW
 - Vector: 464478 "MIP MQXFA (LBNL) Traveler" in section 7.5
- Each MQXFA's cold test magnetic measurements
 - Vector: 464573 "MQXFA Vertical Testing Interface Traveler" in section 5.0
- Each MQXFA's undergoes a cross check of the mechanical survey/alignment + SSW before insertion into the CM
 - Vector: 464574 "MQXFA Incoming Inspection and QA Traveler" in section 5.0
- The magnets alignment is secured by the CM assembly alignment table (see Tony' Tooling Talk) and checked via SSW measurements
 - Vector: 464525 "Q1 Q3 Cold Mass Assembly Traveler" in section 7.0 (pre weld)
 - Vector: 464525 "Q1 Q3 Cold Mass Assembly Traveler" in section 12.10 (post weld)
- A summary template for the CM survey will be using the template in US-HiLumi-doc-3278
 - Vector: 464525 "Q1 Q3 Cold Mass Assembly Traveler" in section 20
- The cryostat assembly will have several survey steps, plus the cold testing and final checks before shipment. Again, using template US-HiLumi-doc-3278 the data will be stored
 - Vector: LQXFA shipment to CERN traveler

Mechanical Coordinate System

- CM and Cryostat Alignment is part of the QA/QC procedures defined in US-HiLumi-doc-3278.



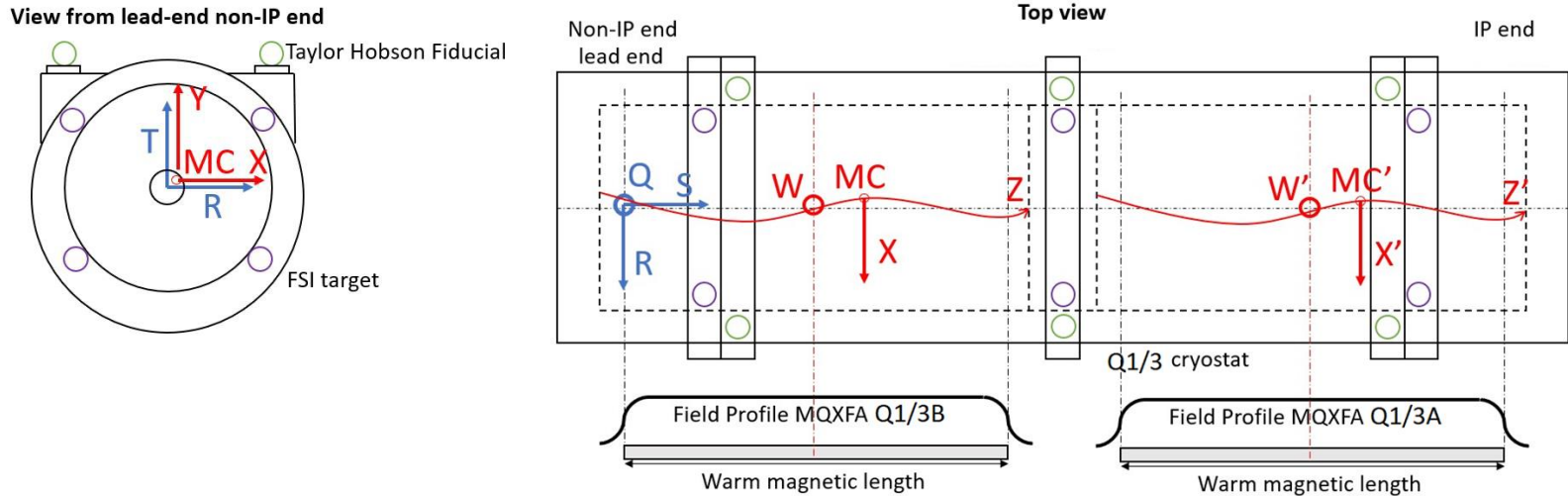
To perform the CM survey/alignment we will install 13 temporary references markers on the shell (highlighted in blue)

The mechanical coordinate system is given as

- Z-axis is the normal vector to the plane of the 3 CM supports
- X-axis is the normal vector to the plane including the best fit line of the cold bore measurements and its projection to the XY plane,
- Y-axis is perpendicular to both forming a right-handed cartesian coordinate system

Magnetic Data Coordinate System

- Definitions of Survey and Magnetic Data for the inner triplet system at IR1 and 5' US-HiLumi-doc-3281



- The position of points Q, the origin of the RST frame, W and W', the origins for magnetic data, is determined in warm conditions
 - R axis is oriented to the right when looking at the magnet MQXFA Q1/3B from the lead end
 - S axis is the average magnetic axis of the MQXFA magnets
 - T axis is normal to the RS plane so that it forms a right-handed reference frame.

Status

- Design values & fabrication drawings ✓
- Cold Mass supported on flat surface ✓
 - Laser Tracker (LEICA AT900 Series) & acquisition software (Spatial Analyzer) ✓
 - Corner Cube reflectors in 0.5" and 1,5" diameter ✓
 - 12mm shank diameter reflector holder for the CM extremity points (provided by CERN with next CM parts shipment) ✓
 - 6mm shank diameter reflector holder for the CM extremities flanges (provided by CERN with next CM parts shipment) ✓
 - Short model 6mm shank diameter reflector holder for the FSI supports (provided by CERN with next CM parts shipment) ✓
 - Self-centering mole (CERN, undergoing a revision, will be send in the next delivery upon finishing)
 - FSI support shims installed on the CM (CERN) ✓
 - Microsoft Excel template report (CERN) ✓
- Stable reference network around the CM ✓



Survey/Alignment during CM assembly

- Several times during the CM assembly process FNAL will assure proper alignment of the magnets relative to the cold mass vessel (and each other) as well as relative to the cold mass shell and end cover
 - Survey effort (SSW) to find the common and individual magnet axis, the centers of the magnets relative to each other and relative to the shell and the field angle of the cold mass before and after welding the shell and end cover
 - Temporary targets on the CM shell will allow to transfer the data from the MQXFA magnets to the final LMQXFA CM fiducials
- Tooling design (see talk by Tony) ensure we fulfill the CM alignment requirements. The tooling locates the two MQXFA magnet with respect to each other and with respect to the CM Shell and End Cover, survey is used to demonstrate compliance

Survey/Alignment during Cryostat assembly

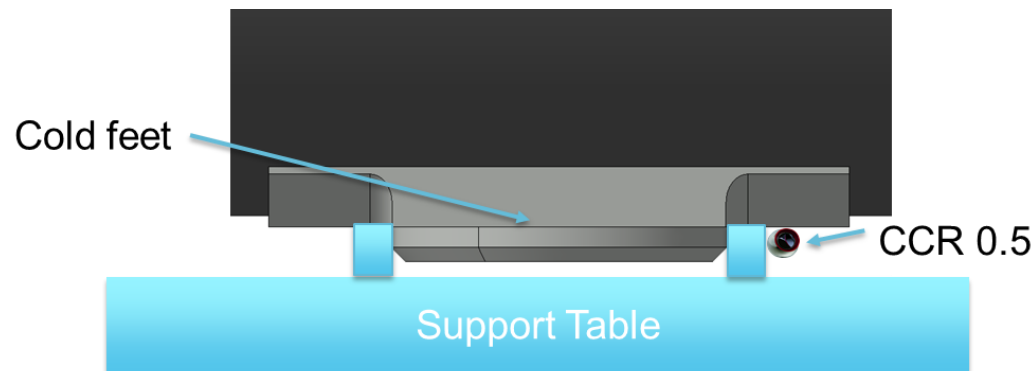
- Survey will be done several times during the assembly process to assure proper alignment of the cold mass relative to the vacuum vessel
- To ensure compliance with flatness the cold mass support will be surveyed before and after installation of the cryostat feet
 - FSI target location after tack welding FSI base on the CM
 - Cold mass survey before and after insertion of the cold mass into the vacuum vessel using the CM fiducials
 - FSI reflector support location upon completed cryostat assembly
 - Cryostat piping location including the heat and radiation shield will be surveyed before and after installation
 - A measurement of the magnet axis at cold will be performed vis SSW technique during the horizontal testing (system is under commissioning)
 - A measurement of the cold bore tube deflection at cold will be performed using a mole device as prescribed in US-HiLumi-doc-3278.

Survey/Alignment Cold Mass Supports

- “Inspection Table”
 - Requires co-planarity $60\ \mu\text{m}$
 - Horizontal location tolerance $\pm 100\ \mu\text{m}$

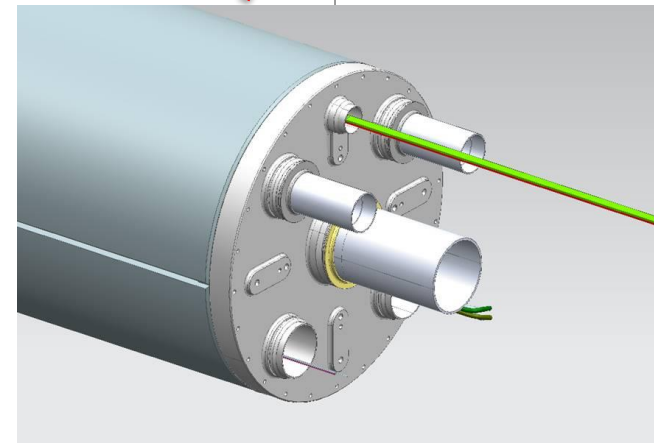
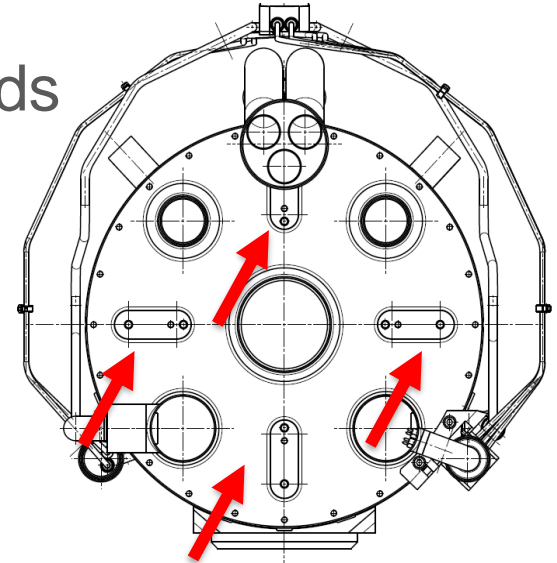
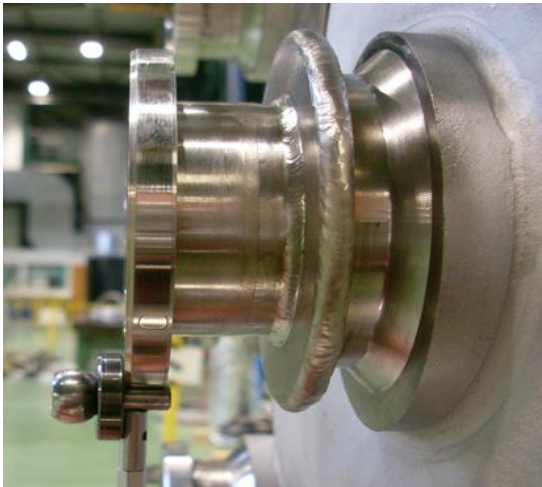


- CM measurement



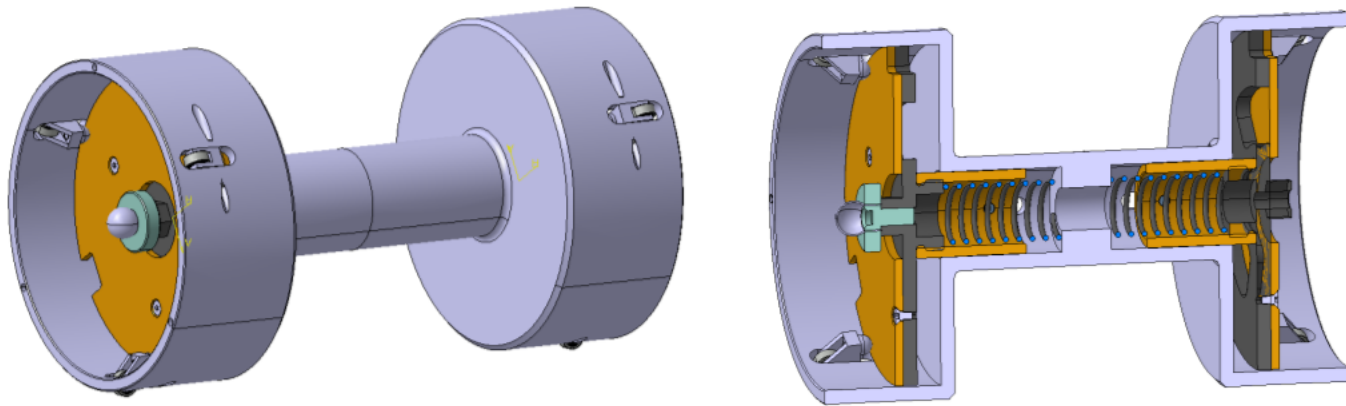
Survey/Alignment Extremities

- Extremities measurement
 - Locate 4 extremities on both CM ends
 - Measure cold bore flanges location



Survey/Alignment Cold Bore Tube

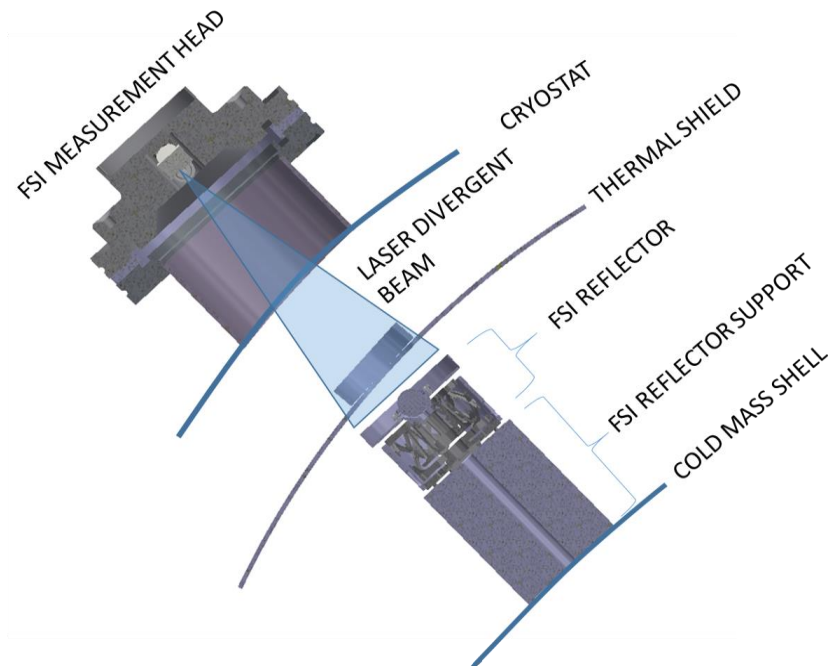
- Cold Bore Tube measurement
 - Self-centering mole
 - Drawings complete, in production at CERN



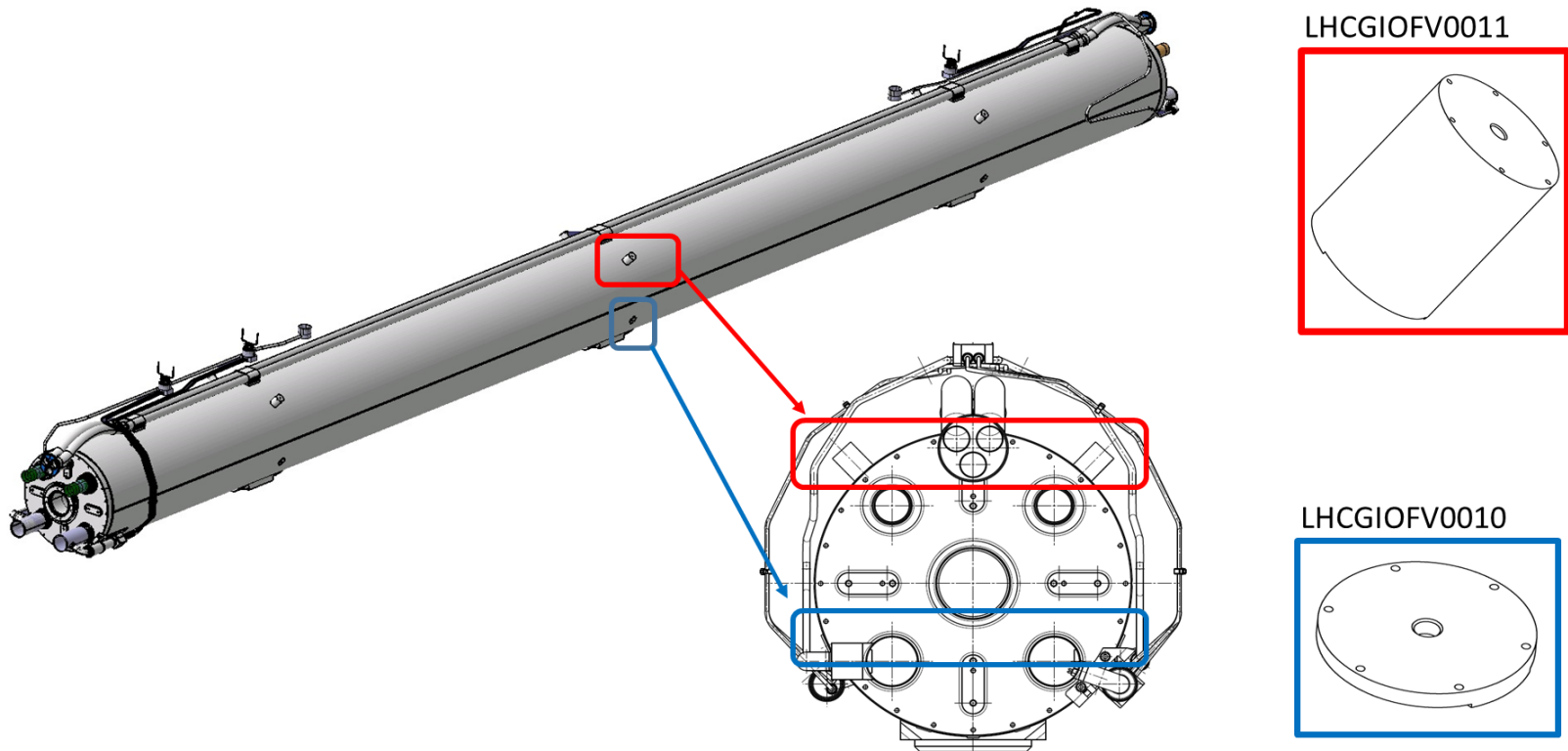
- Rotating probe measurement system uses three targets to correct for tilt

Cold Mass Position Monitoring

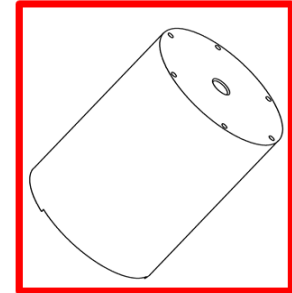
- To survey the Cold Mass during accelerator operation, a remote monitoring device was developed by CERN
- Using Interferometric technique, the system will provide feedback for alignment of the CM's in the HiLumi LHC beam
- Fully CERN responsibility, they provide
- Installation Procedure
 - US-HiLumi-doc-3284
- Survey and Measurement Procedure
 - US-HiLumi-doc-3278



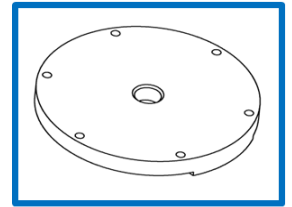
Cold Mass Position Monitoring



LHCGIOFV0011



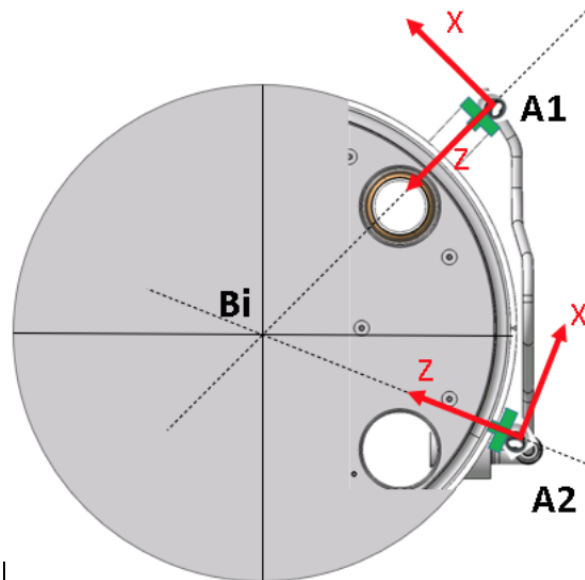
LHCGIOFV0010



- Placement of the long (CERN DWG LHCGIGV0011) and short (CERN DWG LHCGIGV0010) reflector supports
- Model is complete

Cold Mass Position Monitoring

Survey/Alignment and Coordinate System



With in a cylindrical reference system:

- A_i : Shank reflector holder coordinates (in the mechanical coordinate system of the cold mass)
- B_i : Projection of A_i on the Y-axis of the coordinate

Specific cartesian coordinate system for A_i

- Z axis : line A_i to B_i
- Y axis corresponds to the Y-axis of the mechanical coordinate system
- X axis is perpendicular to both axes forming a right handed cartesian coordinate system
- Origin : A_i

Figure 4. FSI reflector supports measurements using cylindrical coordinate system

Summary

- CM + Cryostat survey/alignment procedure established
- Data collection and storage from magnet to CM to final product fully developed
- Multiple surveys in CM and Cryostat assembly ensure FRS are met
- Measurement systems are ready and tested on CA01 and CM02/03 assembly
- For LHC beam alignment in the tunnel an FSI system will be installed