Internal metrology and fiducialisation WP15.4.1

Review of HL-LHC alignment and Internal Metrology

Patrick Bestmann

Outline

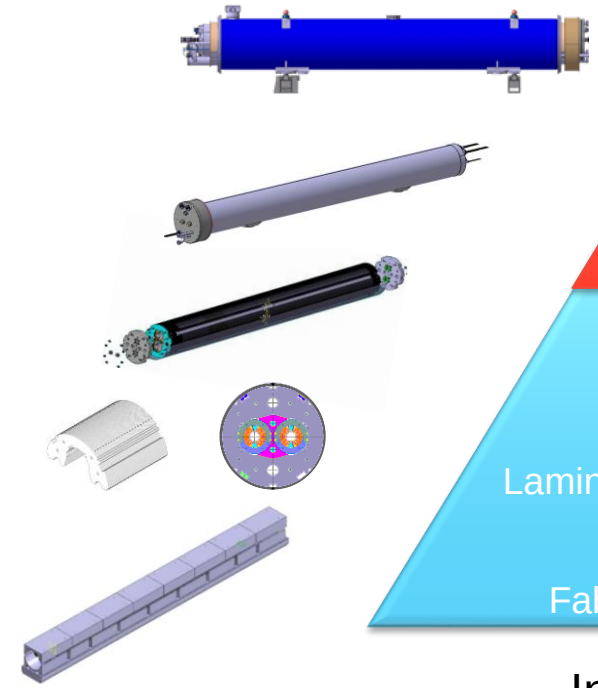
- Definitions & Scope
- Internal metrology
- General Fiducialisation strategy
- Results, data storage & documentation
- Measurements by equipment type
- Tolerances
- Summary
- Next steps

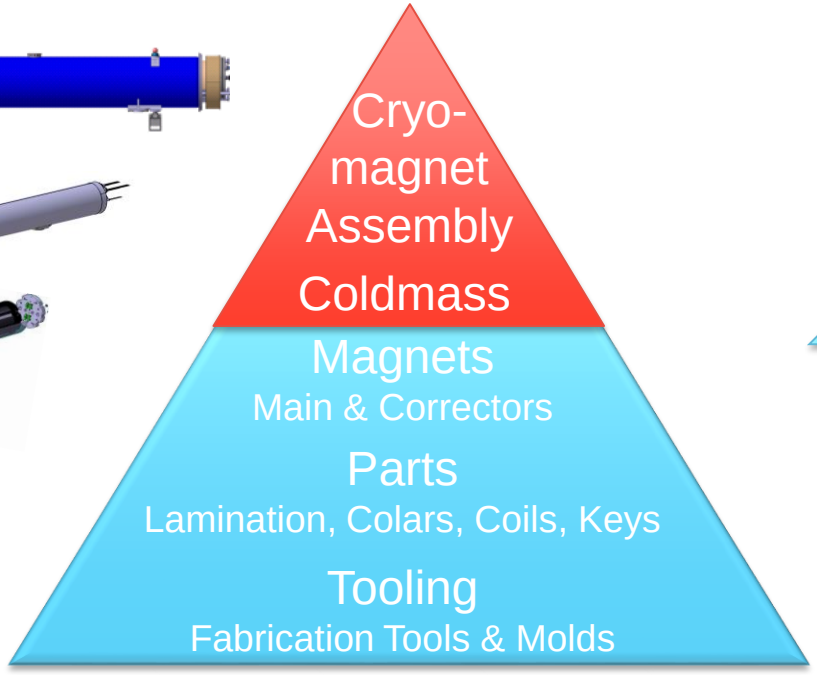
Internal Metrology & Fiducialisation

- Internal metrology
  - All metrology measurements needed for the assembly of magnets, coldmasses and Cryo-assemblies....

- Fiducialisation
  - Transfer of the mechanical axis to the external fiducials on the vacuum vessel
  - Baseline is a best fitting mechanical axis for aperture optimisation
  - Done with a Laser Tracker and a self centering beam tube probe
  - Often combined with geometrical conformity control of extremities
  - Transfer of the magnetic axis measured by streched wire is also possible

Internal Metrology





Internal metrology

MSC & Industry

Survey

Fiducialisation

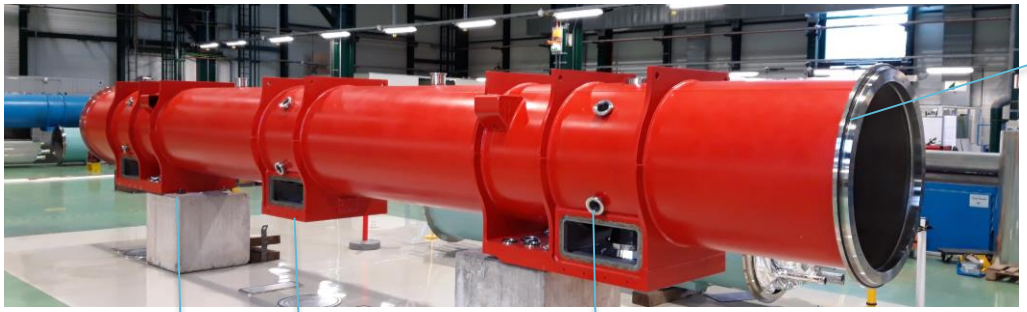
Assembly-metrology

Assembly-Metrology

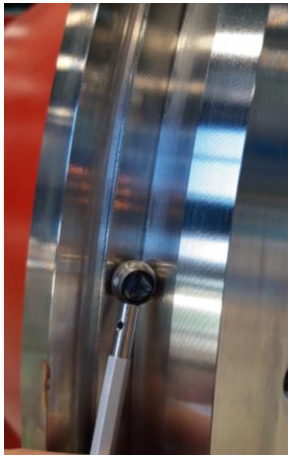
Parts & Tools metrology

Metrology

Fabrication control of first Q1 vacuum vessel

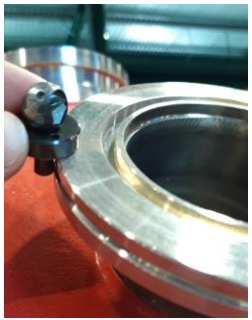


Extremity flanges

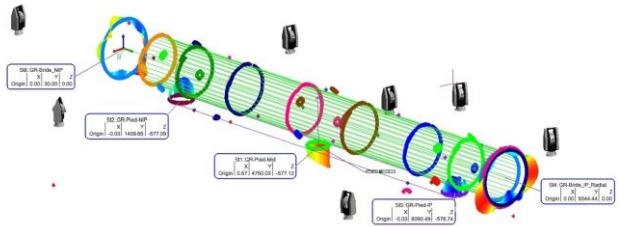


Jack Interfaces

Cold feet support flanges



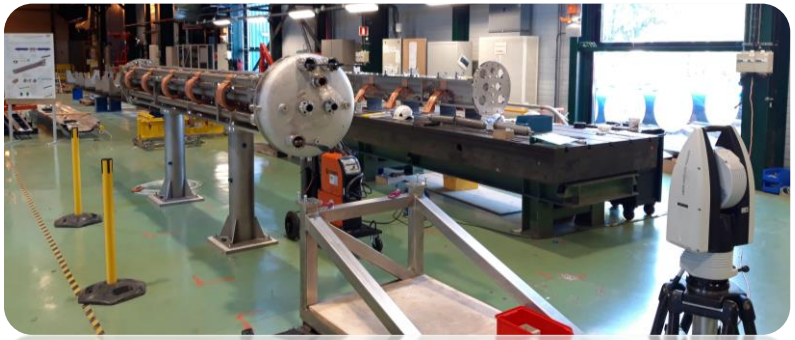
FSI flanges



Metrology

Construction metrology

- Coldbore alignment for QEP connection cryostat
- Flange adjustment
- Control after welding

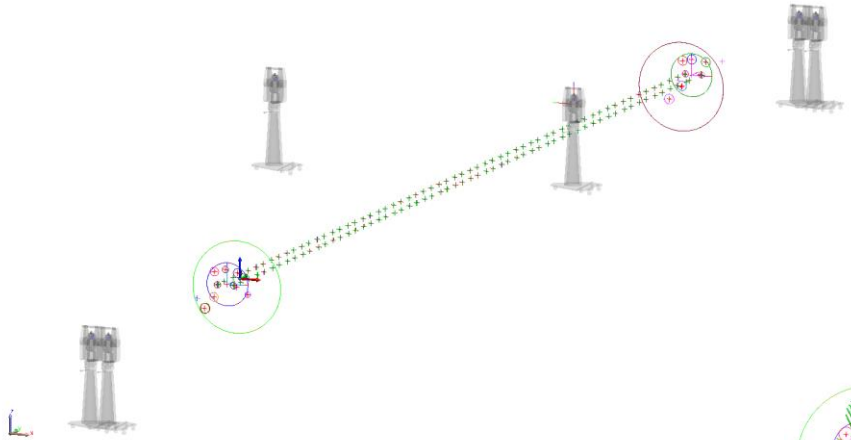


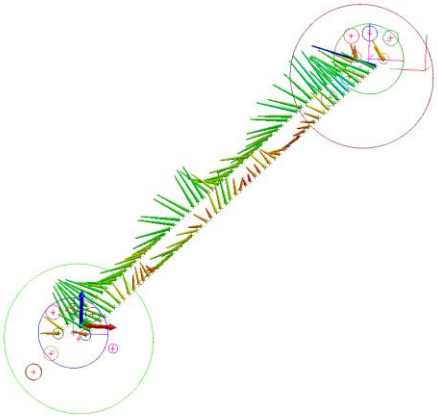
Cryostating control for 11T Dipole

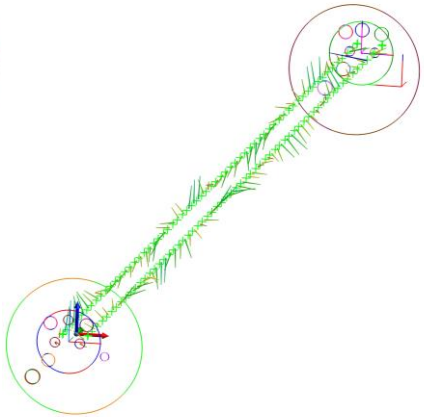
Fiducialisation strategy

- Measurement of coldbore mechanical axis from both extremities for redundancy
- Laser Tracker & self centering probe pulled by a steel wire inside the coldbore
- Best fit on theoretical shape for the axis system definition
- Measurement of extremitiy lines
- Data aquisition with SpatialAnalyzer and scripts
- Calculation & Data analysis with CGC software

Fiducialisation strategy



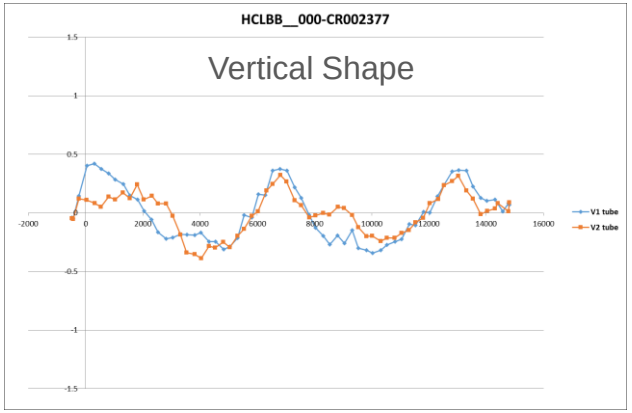


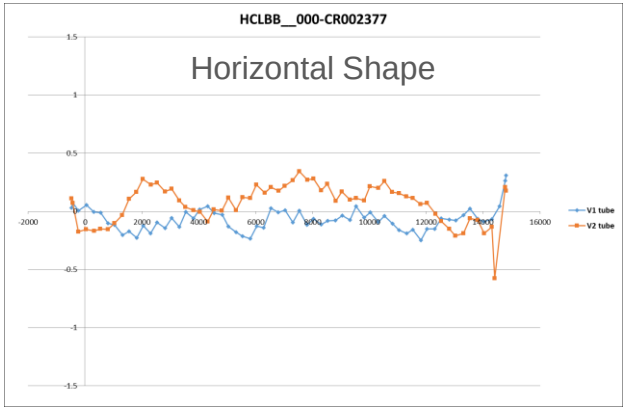


- 6 AT930 Instrument stations
- 12 Network points
- 66 Points in each coldbore
- 15 Extremity flanges
- Internal precison of 30µm RMS

RST system definition
by Best Fit on nominal geometry

Fiducialisation results





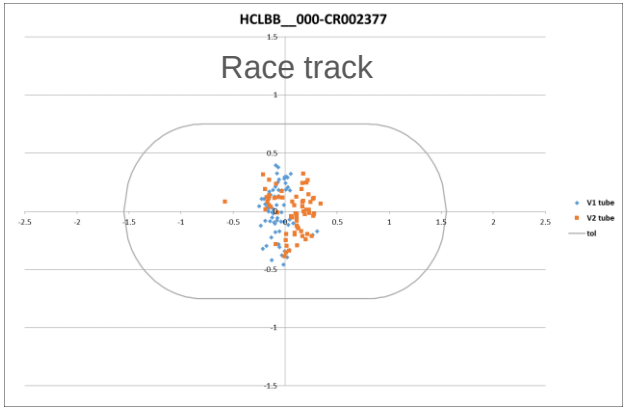
LHC part ID

HCLBB__000-CR002377

- Fiducial RST Parameters

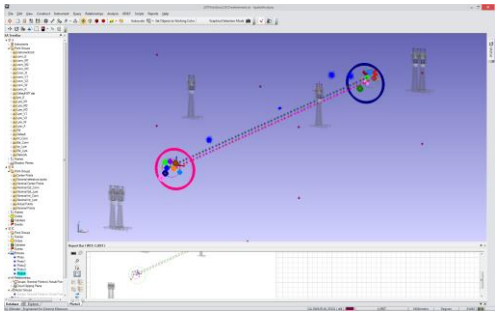
ID	R [mm]	S [mm]	T [mm]	RMS R	RMS S	RMS T	Total RMS
FiducialE	267.501	1771.838	418.040	0.018	0.016	0.019	0.031
FiducialM	267.439	7171.999	416.475	0.008	0.005	0.006	0.012
FiducialS	266.618	12571.613	420.125	0.020	0.017	0.021	0.033
FiducialT	-264.907	12571.167	419.596	0.020	0.016	0.019	0.032

	Tilt (mrad)
Cold mass:	0
Fiducials:	0.994



Documentation

- Raw measurement files and Excel reports are stored in MTF

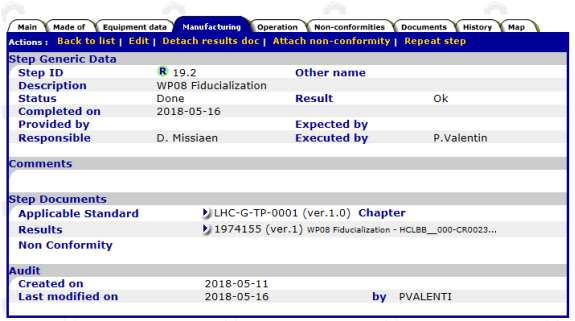


- Connection side (Values expressed in local coordinate system)

	X (mm)				Z (mm)			
ID	Measured X	Nominal X	Delta X	Tolerance X	Measured Z	Nominal Z	Delta Z	Tolerance Z
E	-269.43	-270.00	0.57	2	-289.70	-290.00	0.30	2
M1	-139.80	-140.00	0.20	1.15	145.00	145.00	0.00	1.15
M2	140.35	140.00	0.35	1.15	145.06	145.00	0.06	1.15
M3	-144.82	-145.00	0.18	1.15	-144.96	-145.00	0.04	1.15
N	309.85	310.00	-0.15	2	-70.67	-70.00	-0.67	2
X	0.61	0.00	0.61	1.15	180.58	180.00	0.58	1.15
W	2.03	0.80	1.23	2	-79.81	-80.00	0.19	2

- Lyra side (Values expressed in local coordinate system)

	X (mm)				Z (mm)			
ID	Measured X	Nominal X	Delta X	Tolerance X	Measured Z	Nominal Z	Delta Z	Tolerance Z
E	-269.30	-270.00	0.70	2	-289.33	-290.00	0.67	2
M1	-139.56	-140.00	0.44	1.15	145.07	145.00	0.07	1.15
M2	140.10	140.00	0.10	1.15	144.67	145.00	-0.33	1.15
M3	-145.06	-145.00	-0.06	1.15	-144.39	-145.00	0.61	1.15
X	0.32	0.00	0.32	1.15	179.85	180.00	-0.15	1.15
W	1.25	0.80	0.45	2	-78.95	-80.00	1.05	2



- Automatic comparison with tolerances
- Geometrical Non-Conformities are created
- Fiducial parameters will also be stored in the MTF database for an automatic dataflow towards the survey Database

Measurements by Type

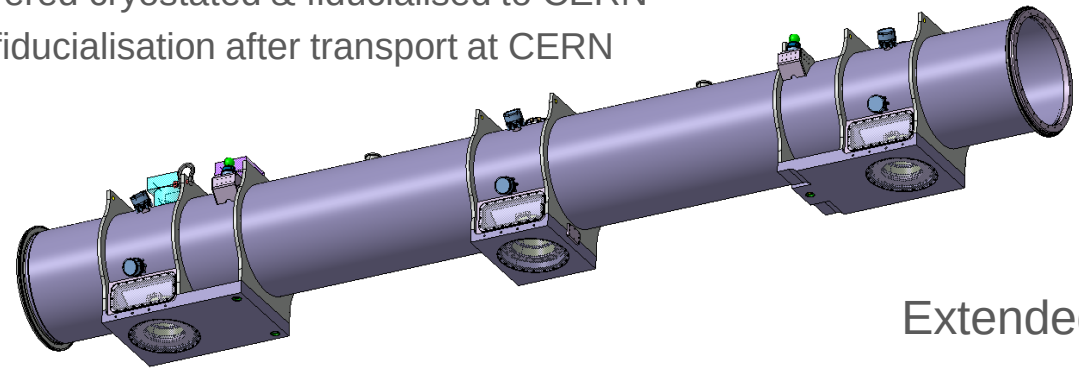
- Triplet Magnets Q1,Q2,Q3
- CP, D1, D2
- 11T Dipole
- LEP Connection cryostat
- QEN Cryobypass & Collimator

Triplet Magnets

- Q1 & Q3
  - Coldmass metrology made by FNAL
  - Vacuum vessel controls at CERN
  - Delivered cryostated & fiducialised to CERN
  - Full fiducialisation after transport at CERN

Available Procedures

Vacuum Vessel: https://edms.cern.ch/document/2168890/1
Coldmass: https://edms.cern.ch/document/2168888/1
Fiducialisation: https://edms.cern.ch/document/2168886/1

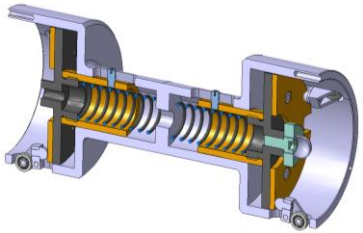


Extended control needs for FSI integration

- Q2
  - Coldmass build at CERN
  - Assembly metrology by MSC with support from 15.4
  - Full fiducialisation at CERN

Triplet Magnets

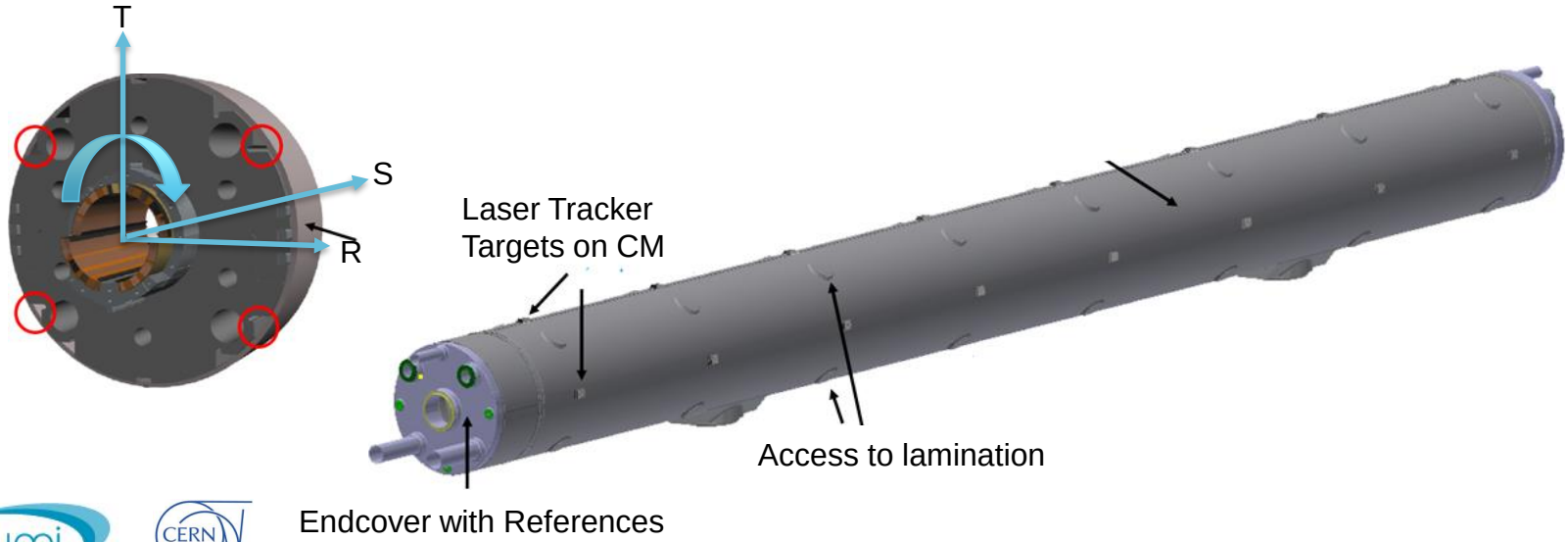
- Discussions with FNAL colleagues converging to final procedure
- First measurements at FNAL will be made with CERN assistance
- CERN will provide:
  - The methodology (defined and agreed on)
  - The procedures (under approval)
  - The beam tube probe (drawings under approval)
  - Metric reflector supports (to be purchased)
- Mechanical coldbore axis is measured with large diameter probe
- Best fit axis calculation, but field direction is needed for the orientation
  - Obligatory from previous magnetic measurements via endcover references
- All extremity flanges will be measured and controlled as well



136.7mm beam tube probe
https://edms.cern.ch/document/2141786/1

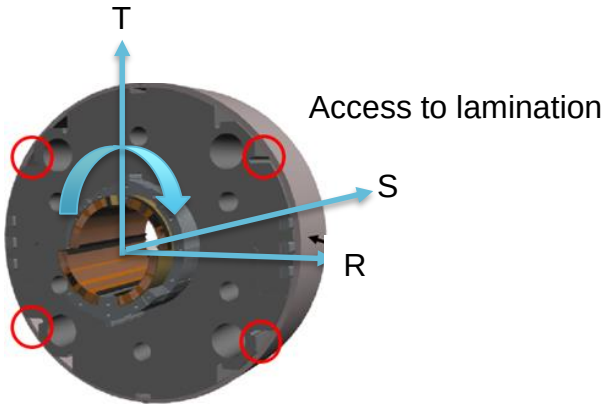
D1 Magnets

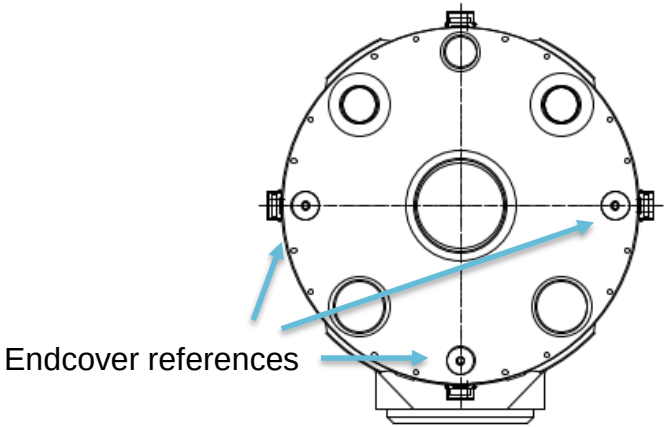
- First contact & discussions with KEK colleagues
- Very well defined production procedure
- Fully compatible with planned metrology measurements
- Access to lamination until last moment for field direction



D1 Fiducialisation

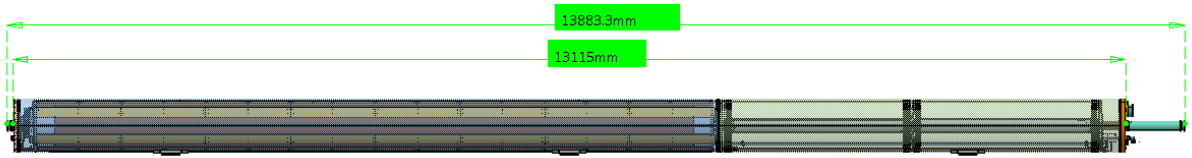
- Mechanical coldbore axis is measured with large diameter probe
- Best fit axis calculation, but field direction is needed for the orientation
  - either from lamination plane also via endcover references
  - or from previous magnetic measurements via endcover references
- All extremity flanges will be measured and controlled as well

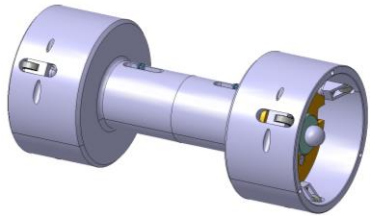




D2 Fiducalisation

- Build at CERN by MSC
- Assembly measurements are made by MSC
- Mechanical coldbore axis is measured with large diameter probe
- Best fit axis calculation, but field direction is needed for the orientation
  - Obligatory from previous magnetic measurements via endcover references
- All extremity flanges will be measured and controlled as well



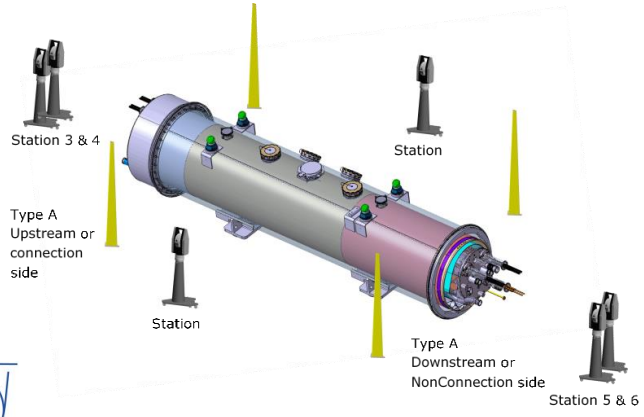


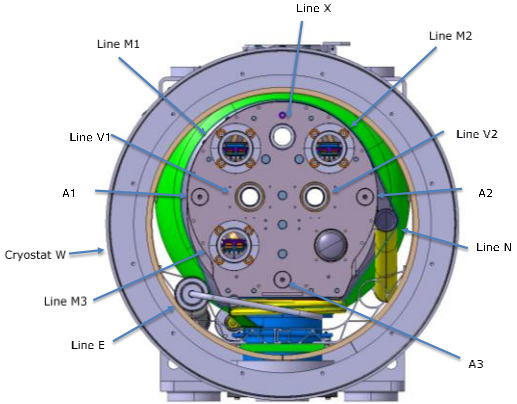
94mm beam tube probe

https://edms.cern.ch/document/2141794/1

11T + LEP Fiducialisation

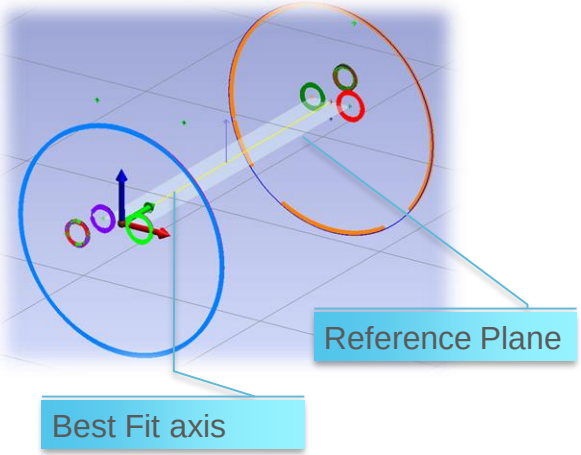
- Very similar to standard LHC Dipole process
- Procedure to be finalized
- Mechanical coldbore axis is measured with probe
- Best fit on theoretical shape for the axis system definition
- Measurement of extremitiy lines
- Standard dataflow





Cryo-bypass & Collimator

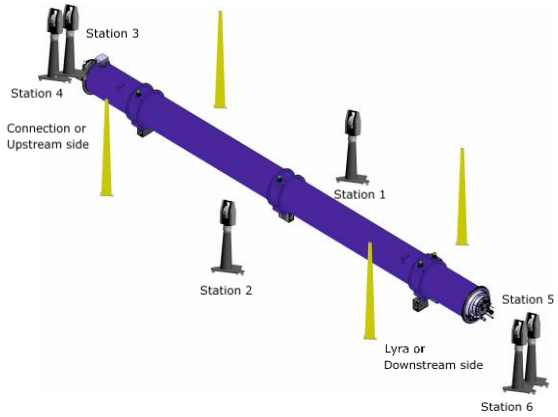
- QEN Bypass
  - Alignment of cold-warm transitions
  - Fiducialisation with 4 extremity flanges only
  - After cold-warm transition and beam screen installation
  - The reference plane is defined by the 4 points
  - The axis as a best fit axis
  - Procedure to be prepared

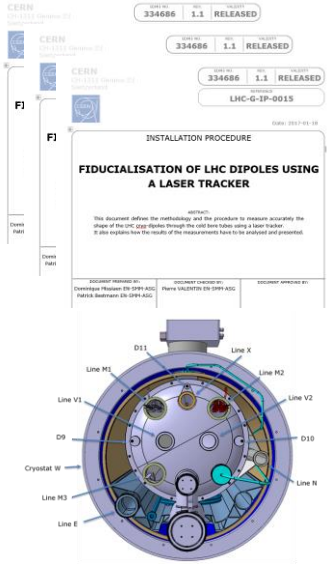


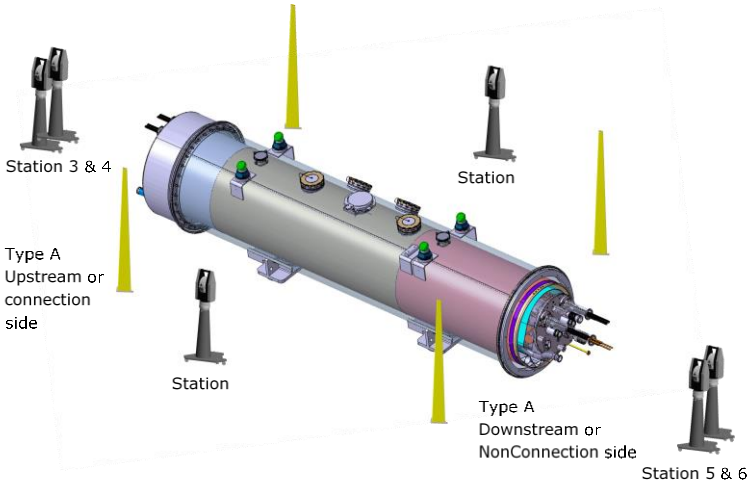
- TCLD Collimators
  - Standard Collimator Fiducialisation
  - Procedure is ready

Fiducialisation summary

- All procedures in preparation or control state
- Measurement hardware is ready
- Waiting for more inputs from the Workpackages concerning acceptance criteria, tolerances & naming conventions







Fiducialisation summary

- All magnets will be fiducialised after cold test at CERN
  - By definition for magnets produced at CERN (LEP, 11T, D2 and Q2)
  - Produced by the collaboration as check for movements and integrity

- Procedures are derived from existing LHC Cryomagnet procedure
  - LHC-G-IP-0015 v.1.2
  - In order to be as universal as possible the naming conventions are extremly important
  - Introduction of a universal report template

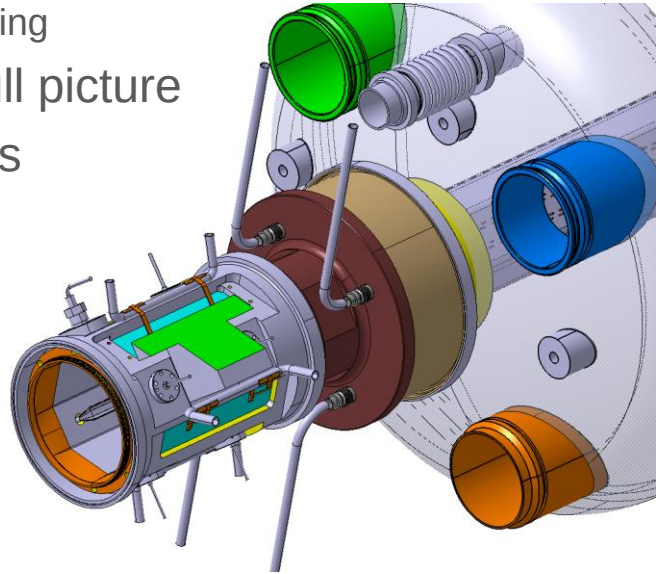
- Need to clarify magnetic measurement needs
  - Will be defined with the assembly workflows by the WP
  - During constructions, cold test and final Fiducialisation
  - Transfer measurements are done by Survey

Tolerances

- We need to separate position tolerances of extremity flanges and coldbore from the fiducialisation
- There is no tolerance for a fiducialisation!
- At the present state of the project the evaluation of conformity of a given magnet shape for a particular slot is the responibility of the MEB
- There is a document specifying the geometrical tolerances for the qualification of the LHC magnets from 2007 http://cds.cern.ch/record/1038087/files/lhc-project-report-1007.pdf
- Additional documents are under preparation covering the HL-LHC aspects
  - Tolerances are different along the assembly process and the WP will define those tables for the different elements
  - A common specification for the interfaces with tolerances will be approved

Further Metrology

- The assembly procedures are being compiled at the moment
- There is some need for further metrology after the fiducialisation
  - Beam screen alignment & control after welding
  - Beam Position Monitor alignment & control after welding
  - Cold WarmTransition alignment & control after welding
- So far nothing exceptional, but we need a full picture
- Need to approve the references & tolerances



Next steps

- Need to finally approve baseline mechanical fiducialisation strategy
- Define needs of additional magnetic axis & field direction transfert
- Define and approve cold warm correlations for all assemblies
- Tolerances
  - Need to have approved tolerance tables for each assembly type
- Some survey procedures are to be finalized
- Dataflow & exchange with colleagues
  - The detailled workflows are being defined right now, we need to ensure
    - Uniform reference frame definition
    - Uniform naming conventions
    - Standard templates
    - MTF as common platform
- Documentation
  - As usual, all measurements are documented with raw data, reports and travellers in MTF
  - Implementation of a new approach to store fiducial paramater data in MTF for an automatic dataflow towards the survey Database is ongoing


High
Luminosity
LHC