Cold Mass and Cryostat Assembly AUP

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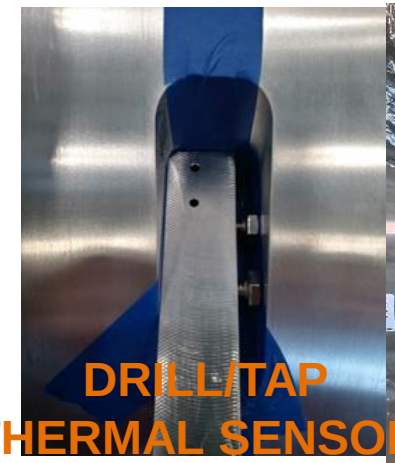
12th HL-LHC Collaboration Meeting
Uppsala, Sweden September 2022

Outline

- LMQXFA-01 Cold Mass Assembly
- Weld/Welder Qualifications
- Longitudinal & Circumferential Phased Array Ultrasonic Test
- Pressure Vessel Safety Requirements
- Pressure Test & Combination Leak Test
- LMQXFA-01 Cold Mass Assembly Non-Conformities
- LMQXFA Cold Mass Assembly Design Changes
- LQXFA-01Cryostat Assembly
- Summary

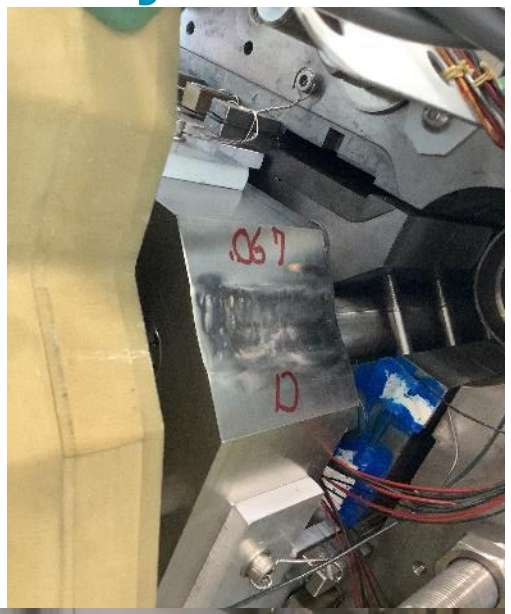
LMQXFA-01 Cold Mass Assembly

- MQXFA 03 & 04 magnets received, inspected, surveyed & prepared for assembly
- Alignment of magnets completed

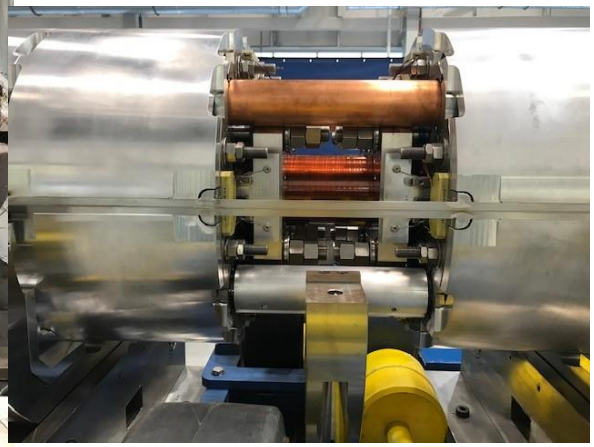


LMQXFA-01 Cold Mass Assembly

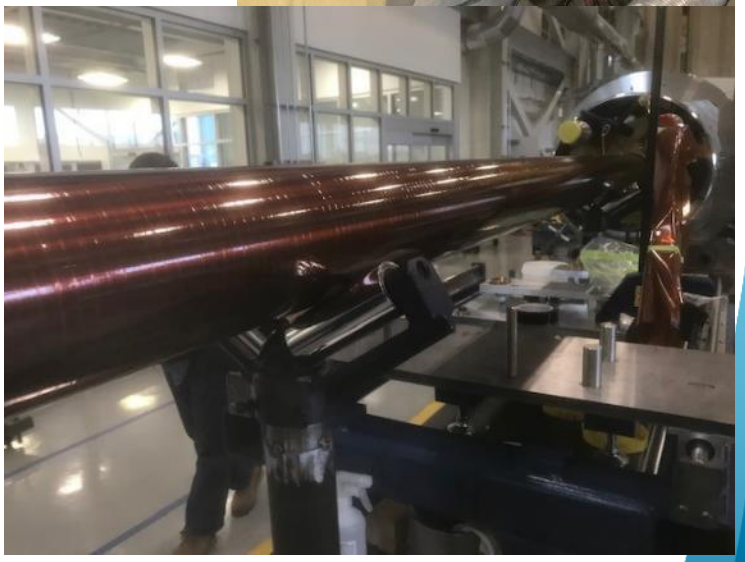
- Beam Tube Install complete
- Heat Exchanger Install complete
- Bus Installation complete



Heat Exchanger Installation



Bus & Loop Installation

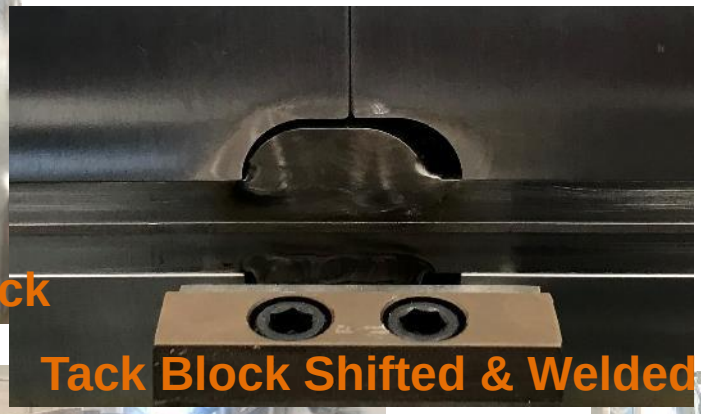


Beam Tube Installation

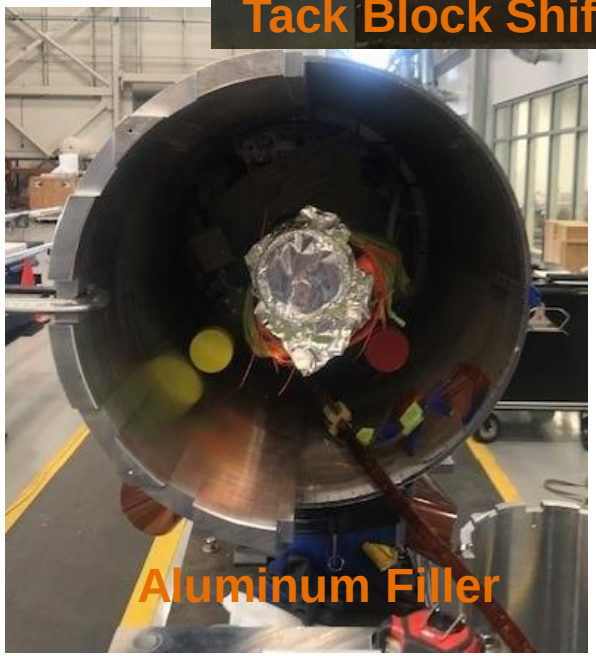
LMQXFA-01 Cold Mass Assembly

- Fit, tack & SS shell welding of LMQXFA-01 (No Shims)


Tack Block


Tack Block Shifted & Welded


Shell fit up & tack


Aluminum Filler


Shell Longitudinal Seam Welding

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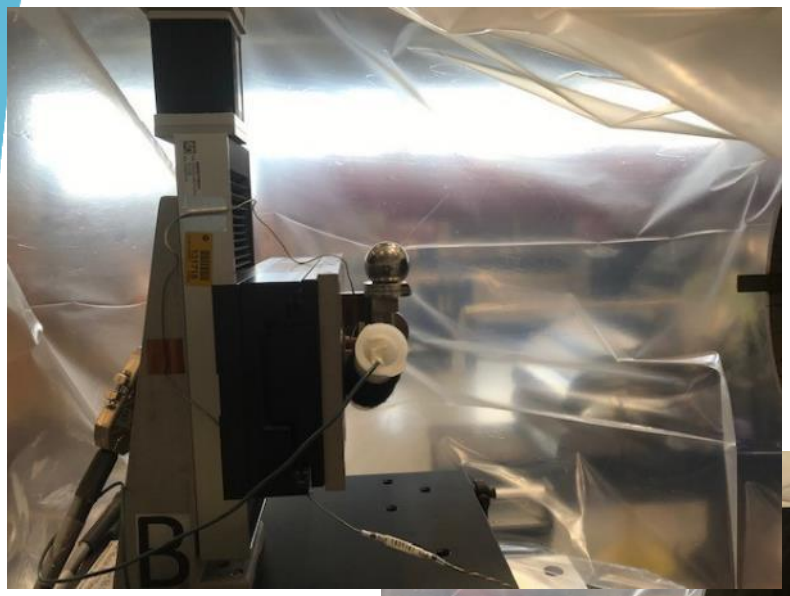
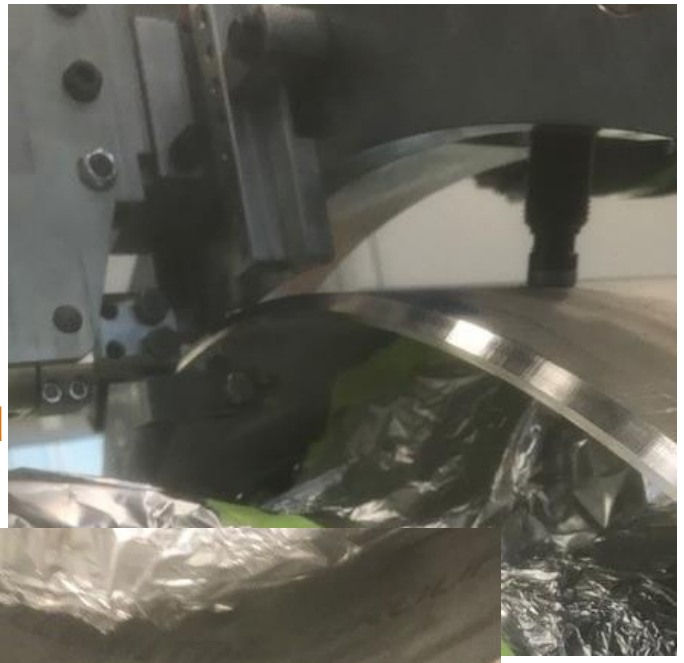
Fermilab

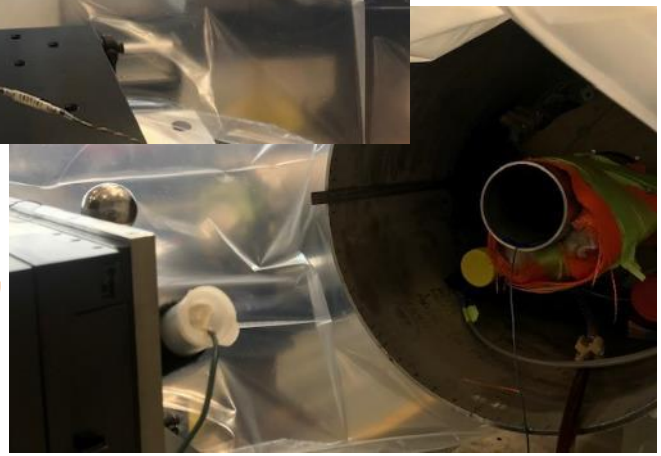
LMQXFA-01 Cold Mass Assembly

- SSW and Survey Group assist to set up cutter square and on point
- Shell prepared for End Cover fit up





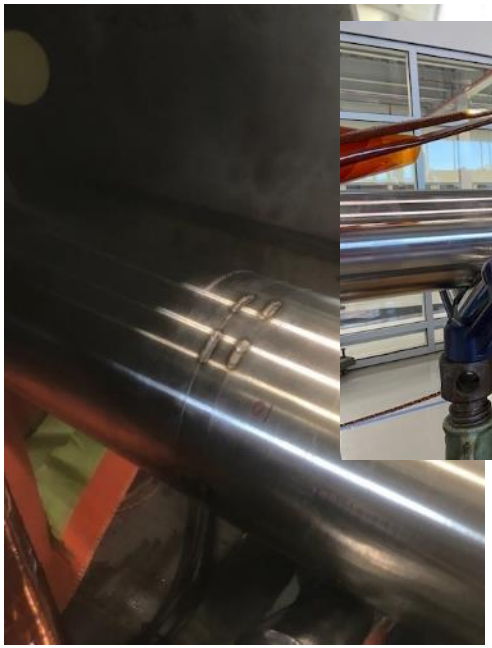
Orbital Cutting, Boring& Weld Beveling



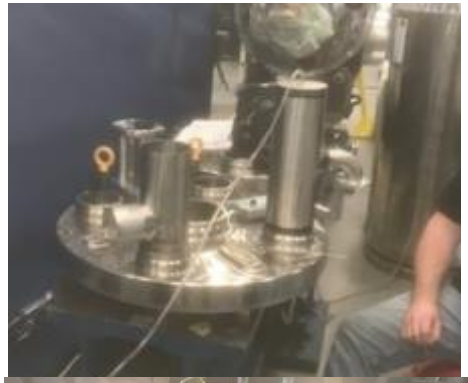
SSW Measurements, Survey & Mole Measurement

LMQXFA-01 Cold Mass Assembly

- Beam tube defects found forced a replacement
- End Cover nozzles purged and welded
- End Cover fit up and tacked w/ Survey Group assistance



Beam Tube replaced

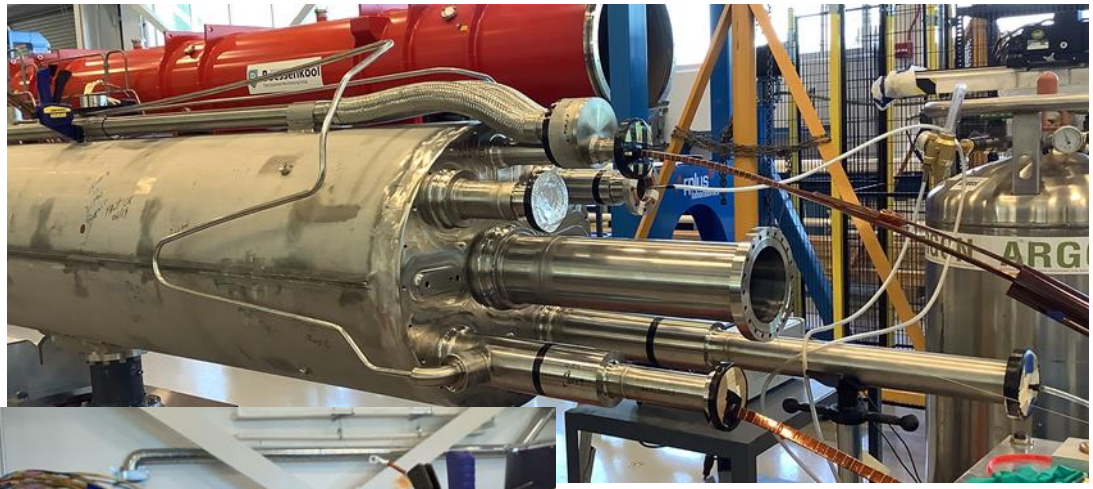


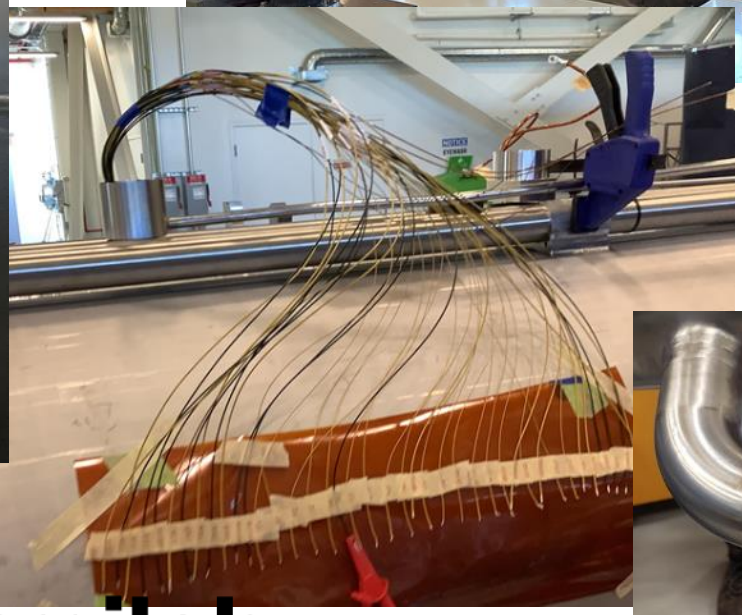
End Cover aligned and tacked

LMQXFA-01 Cold Mass Assembly

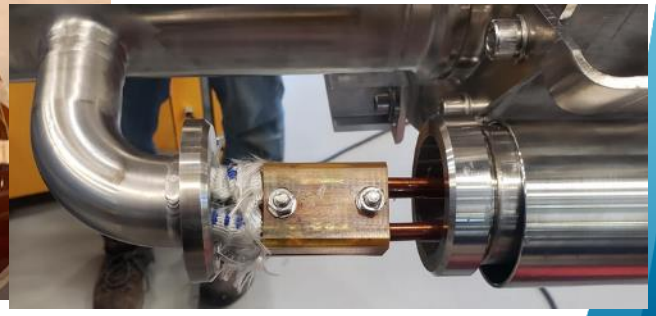
- End Covers, Nozzles fit & welded then re-surveyed
- Test Nozzle Extensions & IFS capillary tube assembly forming/welding

End Cover Welding





Nozzle & Capillary assembly



LMQXFA-01 Cold Mass Assembly

- Saddle aligned, fit & welded
- Pipe brackets, N lines, FSI Targets and test covers welded

Cold Mass move

Index pins and Talyvel Digital Level used

Saddles aligned &/surveyed

Weld/Welder Qualifications

- Welding Qualifications per ASME B&PV Code complete
  - Weld Procedure Specification (WPS) for Cold Mass welds are completed per ASME requirements
  - Supporting Procedure Qualification Records (PQR) are completed
  - Welder Performance Qualification (WPQ) for multiple welders completed per ASME requirements
- Phased Array Ultrasonic Testing (PAUT)
  - Non-Destructive Testing vendor and procedure for PAUT is approved for use by both, FNAL & CERN
  - Cold Mass -01 He pressure shell circumferential & longitudinal welds were scanned complete. Some defects were found, repaired & re-scanned complete to meet acceptance requirements per CERN Safety Agreement
- Record of Decision: Welding of LMQXF01 document exists and can be found at US-HiLumi-doc-4301

Long & Circ Phased Array Ultrasonic Test

- Long. & circ. welding PAUT – complete & repairs accepted

IRIS NDT

ULTRASONIC INSPECTION REPORT | Report Number: HAA2265179 #2

Page: 2 of 10 | Date: 06/08/22

Client: Fermin Lab Accelerator Laboratory | **Job #:** HAA2265179

Location: Batavia, IL | **WO #:**

Unit #: Fermi Lab Accelerator Laboratory | **Item Inspected:** LMQXFA Cold Mass Vessel

Evaluation results for each scan are tabulated in the next table below:

Weld	Scan #	Indication #	Location(in)	Length (in)	Height(in)	Depth(in)	Categorization	Result	Fig.
C1	C1-S1-90T	1	0	3.500	0.088	0.153	Subsurface/LOF	Rejected	4
		2	55.886	1.120	0.045	0.045	Surface/LOF	Rejected	5
	C1-S3-270B	3	56.139	1.700	0.080	0.141	Subsurface/LOF	Rejected	6
C2	C2-S1-90T	1	58.232	6.000	0.072	0.130	Subsurface/LOF	Rejected	7
		2	93.661	5.800	0.096	0.136	Subsurface/LOF	Rejected	8
	C2-S1-270B	3	167.920	3.300	0.025	0.000	Surface/LOF	Rejected	9
	C2-S2-90T	4	133.000	2.600	0.110	0.170	Subsurface/LOF	Rejected	10
	C2-S2-270B	5	146.786	3.850	0.025	0.000	Surface/LOF	Rejected	11
		6	161.356	9.200	0.030	0.000	Surface/LOF	Rejected	12
CL1	CL1-S1-90L	--	--	--	--	--	--	Accepted	13
CL2	CL1-S1-270R	--	--	--	--	--	--	Accepted	14

IRIS NDT

ULTRASONIC INSPECTION REPORT | Report Number: HAA2265179 #3

Page: 2 of 6 | Date: 06/08/22

Client: Fermin Lab Accelerator Laboratory | **Job #:** HAA2265179

Location: Batavia, IL | **WO #:**

Unit #: Fermi Lab Accelerator Laboratory | **Item Inspected:** LMQXFA Cold Mass Vessel

Evaluation results for each scan are tabulated in the next table below:

Weld	Scan #	Indication #	Location(in)	Length (in)	Height(in)	Depth(in)	Categorization	Result	Fig.
C1R1	C1-S1-90T	1	0					Accepted	4
		2	55.886					Accepted	5
C2R1	C2-S2-270B	5	146.786					Accepted	11
		6	161.356					Accepted	12

IRIS NDT

ULTRASONIC INSPECTION REPORT | Report Number: HAA2265179 #4

Page: 2 of 7 | Date: 06/14/22

Client: Fermin Lab Accelerator Laboratory | **Job #:** HAA2265179

Location: Batavia, IL | **WO #:**

Unit #: Fermi Lab Accelerator Laboratory | **Item Inspected:** LMQXFA Cold Mass Vessel

Evaluation results for each scan are tabulated in the next table below:

Weld	Scan #	Indication #	Location(in)	Length (in)	Height(in)	Depth(in)	Categorization	Result	Fig.
C1R1	C1-S3-270B	3	56.139					Accepted	4
C2R1	C2-S1-90T	1	58.232					Accepted	5
		2	93.661					Accepted	6
	C2-S1-270B	3	167.920					Accepted	7
	C2-S2-90T	4	133.000					Accepted	8

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Fermilab

Pressure Vessel Safety Requirements

- Welding Qualifications are considered complete for ASME requirements and FESHM Safety requirements
  - Design Calculations complete and documented in Engineering note which is reviewed and approved for operation at Fermilab

- Additional Destructive Tests for weld verification to satisfy CERN requirements which go beyond ASME & FESHM requirements that have not been completed yet
  - Charpy Notch Impact Tests at 4.2K
  - Fracture Toughness Tests at 4.2K

- Additionally, a couple more requirements have not been satisfactorily completed as I will show on the next slides

Pressure Vessel Safety Requirements

Tests	EN Standards	ASME standards	Welding Qualification	Acceptance	Results
	Destructive Tests (**)				
Longitudinal tensile test within the weld bead 1 required	EN 5178 ISO 6892-1	ASME Section IX, QW-150	X [(i)]	[5]	Report # P-0187619 - 90100 psi - 35% Elong (LONG. Weld) Report # M-0191234a – 97200psi – 33% Elong (CIRC. Weld)

- Test for elongation verification are extremely sensitive which can give false Information
- Testing will be performed by CERN to confirm elongation Values

Pressure Vessel Safety Requirements

Tests	EN Standards	ASME standards	Welding Qualification	Acceptance	Results
Micrograph	ISO 17639	ASTM E3	X	[9] EN 5817	Report # P-0187619- Long. weld meets Level B, ISO 5817 Report # M-0191234a – Circ. weld meets Level B, ISO 5817
Macrography	ISO 17639	ASME Section IX, QW-184	X	[8] EN 5817	Report #P-0187619 - Long weld meets Level B, ISO 5817 Report # M-0191234a – Circ weld Meets Level B, ISO 5817

- Weld coupon did not meet the weld toe requirement per ISO 5817 Quality Level B, No. 1.12 (α≥150°). Weld toe angle of 148° met Quality Level C (α≥110°)

.

- The base metal for the weld coupon exhibited a fully austenitic microstructure with no evidence of residual delta ferrite or sigma phase
- The weld metal exhibited no significant delta ferrite in a matrix of austenite throughout the cross section. Additionally, the weld exhibited complete penetration

Pressure Test & Combination Leak Test

- Heat Exchangers (73 psig or 5 bar differential) & He Shell (363 psig or 25 bar differential) pressure testing completed individually
- Pressure on He Shell reduced to design Pressure (290 psig or 20 bar differential) and a leak test completed

Pressure/Leak Test

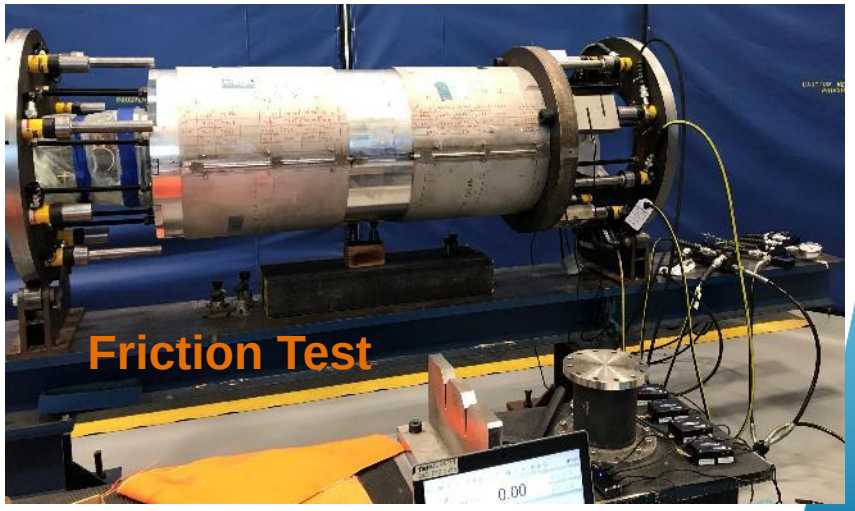

Test Cover Removal

LMQXFA-01 Cold Mass Assembly Non-Conformities

- CM01 has few Non-conformities that need to be addressed and resolved
  - One of the heater wire is open
  - One of the V-tap wire is open (this V-tap location has lot of redundancy)
  - Alignment of the two cold mass as it was measured with Stretched Wire system is out of tolerance slightly – need to be confirmed this with rotation coil measurements

LMQXFA Cold Mass Assembly Design Changes

- Design Changes incorporated
  - Shell prestress:
    - **OLD**: The interference between magnet and cold mass shell shall be kept under control and the coil pre-load increase shall not exceed **15 MPa** at room temperature
    - **NEW**: The circumferential average interference after welding between the SS shell inner surface and magnet outer surface along each magnet length must be ≥ - 0.2 mm, resulting in average coil pre-load increase ≤ **3.2 MPa** at room temperature
    - Friction Test conducted on MQXFS1 to study affects of shims and shim thickness sizing
  - Pressure Wave:
    - During cryogenic operation, the cold mass may experience up to a 2.5 Bar differential on either of the magnet faces
    - Shear load tests conducted to verify capacity of tack block bolts: mock-up & lab test at LN2 temp.



LQXFA-01Cryostat Assembly

LQXFA-01Cryostat Assembly

- Cryostat tooling was installed in February 2021 by Fermilab personnel in cooperation (in-person and virtually via Hololens) with personnel from Applus, the company contracted by CERN to manufacture the tooling.

Controls cabinet

Decryostating winch and assembly table

Assembly table

Cryostating winch and vessel supports

Alignment

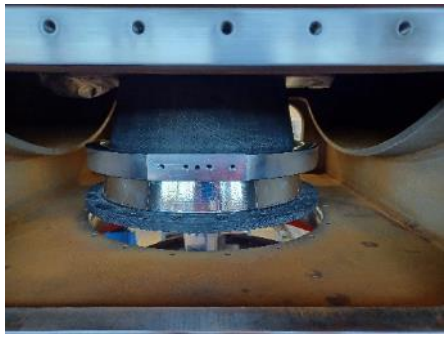
LQXFA-01Cryostat Assembly

- Cryostat tooling was used for cryostating and de-cryostating exercises with a dummy cold mass in August-September 2021 and December 2021.

Dummy cold mass in vacuum vessel

Dummy cold mass and thermal shield being inserted into vacuum vessel

Thermal shield support installed



Cold mass support post installed

Support post thermalization strap installed

LQXFA-01Cryostat Assembly

- Assembly of first cryo-assembly in August-September 2022 with on-site engineering oversight from CERN.

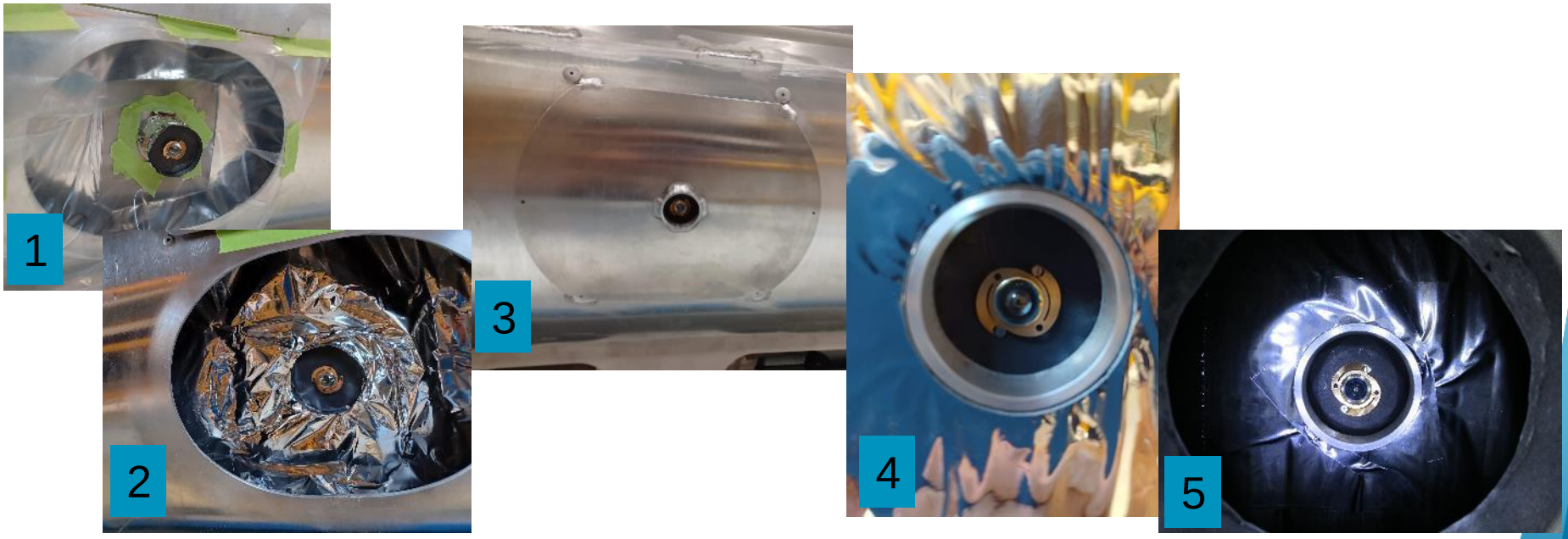
Installation of piping

Installation of thermal shield after cold mass MLI installation

Cold mass and thermal shield integrated and insulated

LQXFA-01Cryostat Assembly

- FSI installation steps, following CERN procedures and working closely with CERN personnel
  - FSI heads installed on cold mass.
  - MLI patches installed, integrated with cold mass MLI.
  - FSI thermal shield covers positioned with metrology to ensure that targets will remain visible through the port after cool-down.
  - MLI patches installed, integrated with thermal shield MLI.
  - Final inspection after cryostating to ensure that targets are still well-placed and visible.

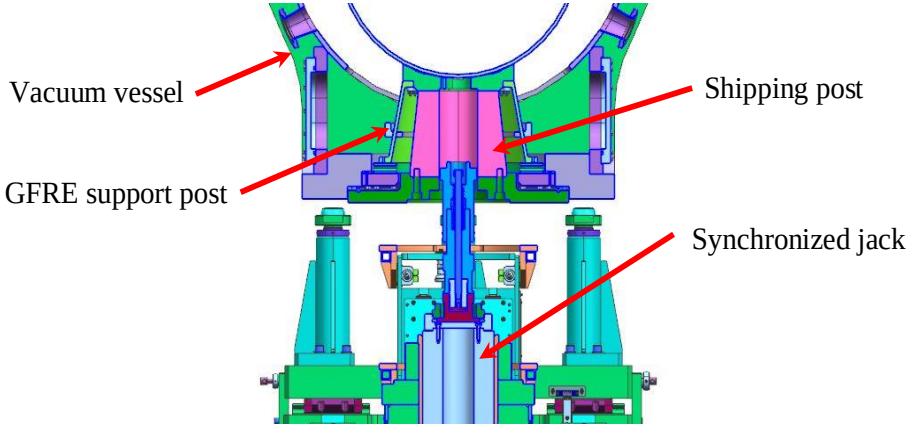


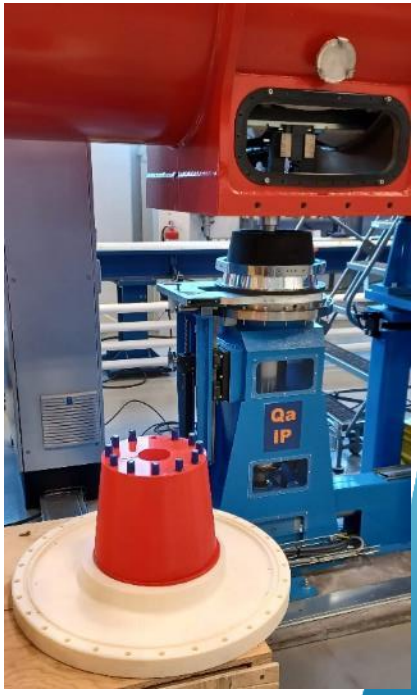
LQXFA-01Cryostat Assembly

- August 31, 2022: first insertion of an AUP HL LHC cold mass into a vacuum vessel

LQXFA-01Cryostat Assembly

- Shipping post
  - Designed by Fermilab, shipping posts will be used to unload the delicate GFRE support posts during Cryo-Assembly shipment from Fermilab to CERN.
  - A 3-D printed shipping post will be test fit during fabrication of the first cryo-assembly, LQXFA/B-01





Summary

- LMQXFA-01 Fabrication complete. MIPs, Travelers and NCR's utilized for fabrication process
- Welding procedures & Welders qualified per ASME requirements
- LMQXFA-01 longitudinal & circumferential welds ultrasonically tested using approved Phased Array method
- Cold Mass & heat exchangers pressure tested to ASME and PED Specifications
- LMQXFA-01 was transferred for Cryostat Assembly Work
- Cryostat tooling was installed and used for cryostating and de-cryostating exercises
- Assembly and welding of first cryo-assembly shield complete
- First insertion of an AUP HL LHC cold mass into a vacuum vessel completed August 31st

Thank you for your attention!

BACK UP SLIDES

Weld/Welder Qualifications

REPORT OF CHARPY IMPACT TEST

MATERIAL: Welded Coupons, Identified as "Long MIG FEB-2022"
METHOD: ASTM A370-18
SPECIMEN TYPE: V-Notch
SPECIMEN SIZE: 7.5 mm x 10 mm
TEMPERATURE OF TEST: -325°F
RESULTS:

WELD METAL	FOOT LBS.	LATERAL EXPANSION	%SHEAR
1	66	0.042	40
2	56	0.028	30
3	60	0.044	50
Average	61	0.038	40
HAZ	**FOOT LBS.**	**LATERAL EXPANSION**	**%SHEAR**
4	136	0.070	70
5	136	0.079	80
6	122	0.072	80
Average	131	0.074	77

REPORT OF CHARPY IMPACT TEST

MATERIAL: 1 Ea. Welded Coupon, 1" X 22", Identified as "Flat MIG April-2022"
METHOD: ASTM A370-21
SPECIMEN TYPE: V-Notch
SPECIMEN SIZE: 7.5 mm x 10 mm
TEMPERATURE OF TEST: -325°F
RESULTS:

WELD METAL	FOOT LBS.	LATERAL EXPANSION	%SHEAR
1	68	0.070	70
2	70	0.068	70
3	78	0.042	70
Average	72	0.060	70
HAZ	**FOOT LBS.**	**LATERAL EXPANSION**	**%SHEAR**
4	118	0.067	70
5	120	0.069	70
6	116	0.067	70
Average	118	0.068	70

NOTE: 40 J = 29.5 ft-lbs

Tests	EN Standards	ASME standards	Welding Qualification	Acceptance	Results
Magnetic permeability	EN 60404-15	ASTM A342	X	[10]	Report # P-0187619 & Report # M-0191234a - Acceptable (LONG. & CIRC Weld)

Test Method 3 used – Low-MU Permeability Indicator; Severn Gauge. Inserts calibrated per NIST, Test Method A342/A342M-21 in a magnetic field strength of 100 Oe [8 kA/m] at 25°C. Unable to perform Test Method 4; readings <1.01