LMQXFA/B Functional Requirements

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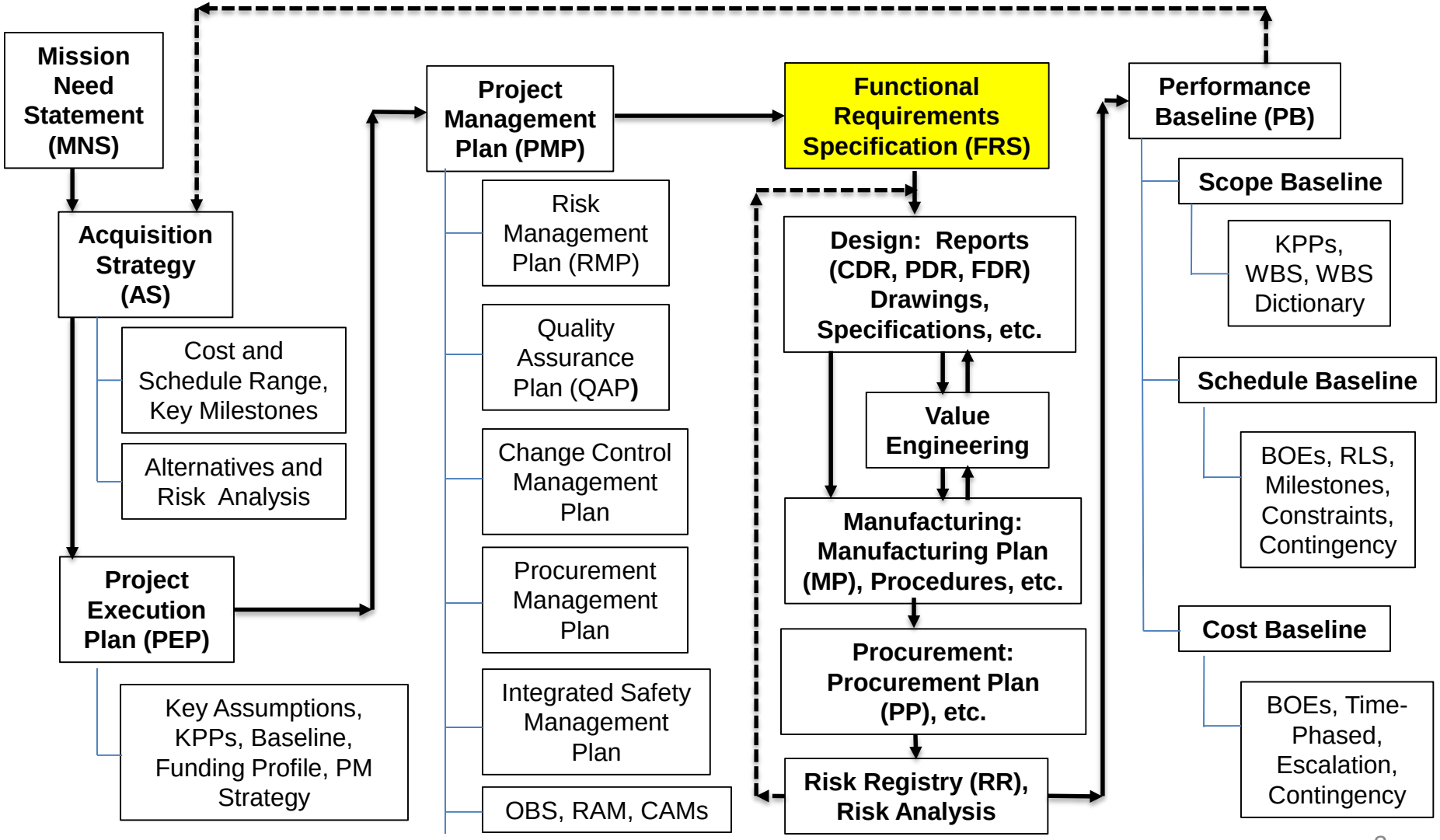
October 28, 2015

Functional Requirements

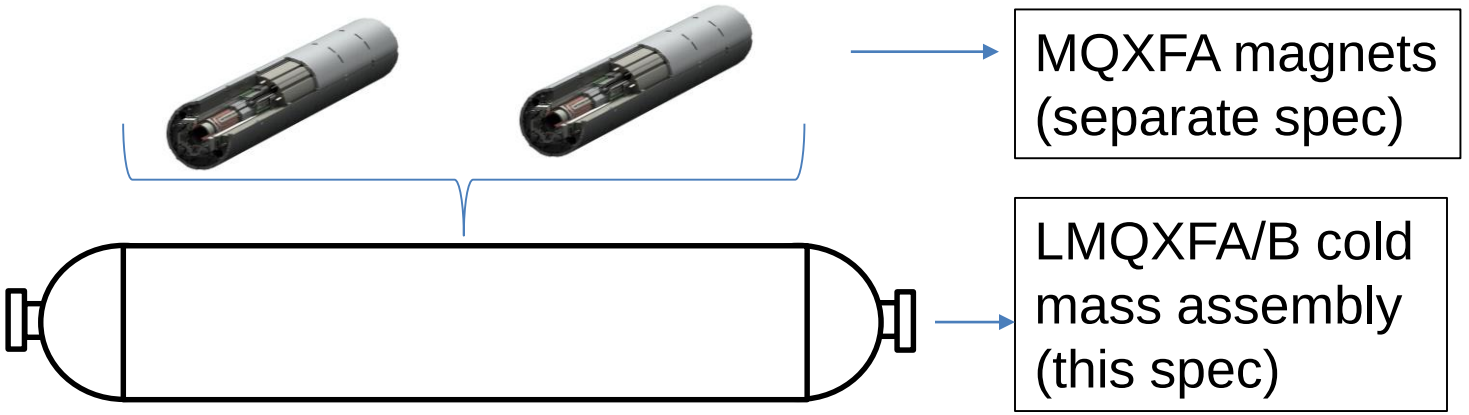
- A clear specification of functional requirements for U.S. deliverables is needed to support the DOE Order 413.3B project management process for the US-HiLumi project
- These requirements should not be embedded in other documents (e.g., design reports) or mixed with requirements for other systems
  - Functional requirements for the U.S. project deliverables should be documented in a stand-alone document
  - These requirements should be such that their verification means that the project deliverable(s) are fit for the intended use
    - They do not include design parameters, only the functions that the deliverable must satisfy
  - Functional Requirements must be reviewed and approved by the end user (CERN), well in advance of the project baseline establishment for the CD-2 DOE review
    - A signed document should be finalized in less than a year from now

Main Project Planning Documents



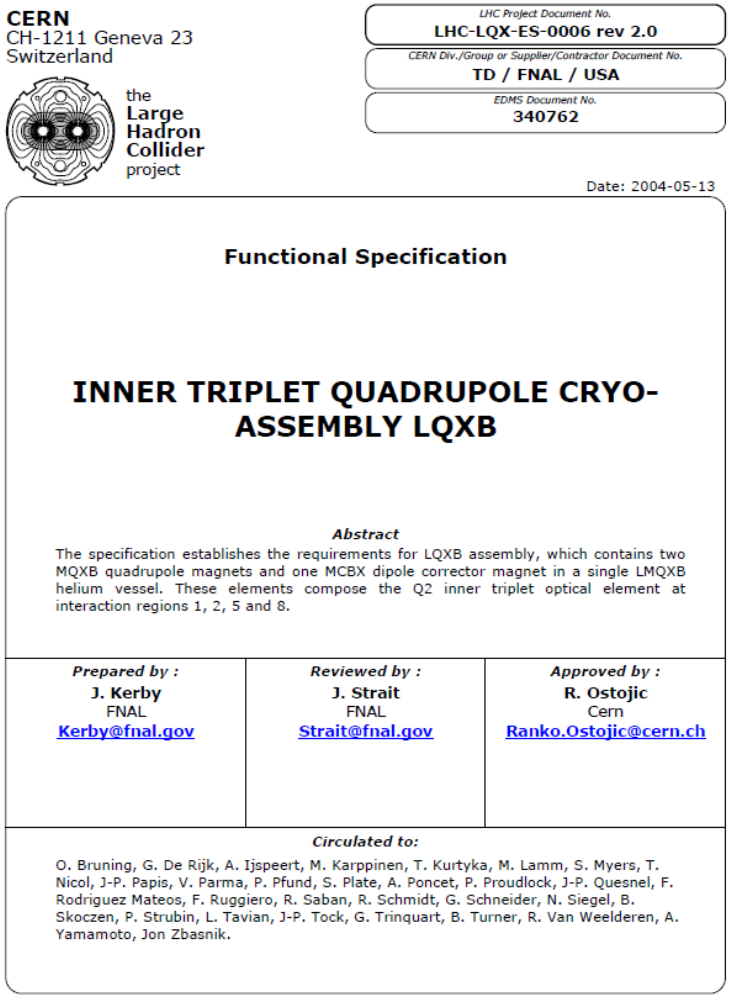
Scope

- This presentation is for the LMQXFA/B cold mass assembly functional requirements only
- LMQXFA: Q1 cold mass; LMQXFB: Q3 cold mass (small differences)



- The two identical MQXFA magnets have a separate functional requirements document

Previous Example: LQXB FRS



CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No.
LHC-LQX-ES-0006 rev 2.0

CERN Div./Group or Supplier/Contractor Document No.
TD / FNAL / USA

EDMS Document No.
340762

Date: 2004-05-13

Functional Specification

INNER TRIPLET QUADRUPOLE CRYO-ASSEMBLY LQXB

Abstract

The specification establishes the requirements for LQXB assembly, which contains two MQXB quadrupole magnets and one MCBX dipole corrector magnet in a single LMQXB helium vessel. These elements compose the Q2 inner triplet optical element at interaction regions 1, 2, 5 and 8.

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- Example of a previous FRS for the present Inner Triplet Quadrupole Cryo-assembly LQXB for Q2
- Some parameters for LMQXFA/B FRS were taken from the MQXB FRS, but they need to be confirmed by CERN

LMQXFA/B FRS

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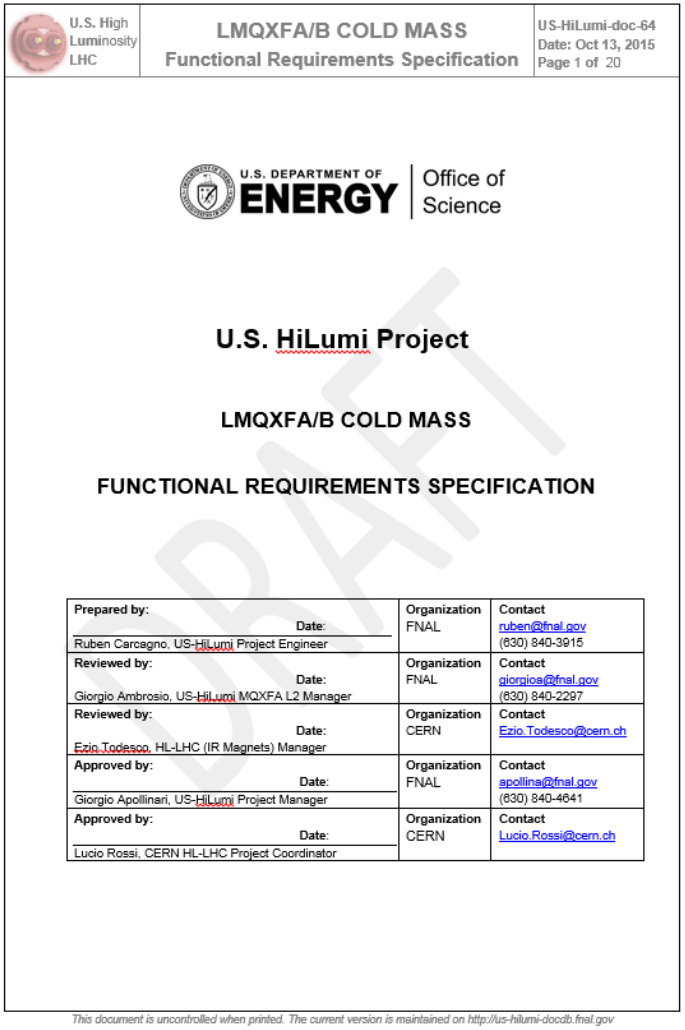

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U.S. DEPARTMENT OF ENERGY | Office of Science

U.S. HiLumi Project

LMQXFA/B COLD MASS

FUNCTIONAL REQUIREMENTS SPECIFICATION

DRAFT

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- Draft prepared as a US-HiLumi project document to guide discussions
- Attempts to collect all the **functions** that the LMQXFA/B cold mass assembly must satisfy
- Several parameters need discussion and confirmation by CERN

Functional Requirements

- Classified into two groups:
  - Threshold Requirements (T): project must meet
    - Usually related to "nominal" parameters, but not always (e.g., we must train to ultimate current, which is 108% of nominal current)
  - Objective Requirements (O): project should meet and will strive to achieve
    - Usually related to "target" or "ultimate" parameters, but not always (e.g., reliability requirements that are hard or too costly to verify such as number of thermal cycles)
- Acceptance criteria and procedures will be defined in a separate document
  - At CERN's discretion, deliverables that fall short of the threshold requirements may still be acceptable
    - Example: a cold mass assembly deliverable trained to 107% of nominal current instead of 108% (the threshold requirement)

LMQXFA/B FRS Table

- Threshold Requirements

ID	Description
R-T-01	The LMQXFA/B assembly physical length (cold bore flange to cold bore flange) must be **TBD** mm, and the physical shell outer diameter must not exceed **630** mm. These dimensions are at room temperature (296 K).
R-T-02	LMQXFA/B must include piping of minimum inner diameter **TBD** mm allowing for two heat exchangers passing straight through the upper half of the MQXFA, and in addition two identically sized pipes in the lower half symmetric with the upper passages (see Figure 5 and Table 2 for a concept layout)
R-T-03	The LMQXFA/B cold mass assembly must not have any obstructions or interferences to allow insertion of two **74** mm OD heat exchanger tubes and their supports through the top two MQXFA cooling channels and along the entire LMQXFA/B length.
R-T-04	The LMQXFA/B magnetic elements are two identical MQXFA magnets connected in series. The MQXFA magnets must satisfy the MQXFA functional requirements specification [1] and the LMQXFA/B interface specification [3]
R-T-05	The distance between MQXFA magnetic lengths is **646** mm ± **TBD** mm at nominal operating temperature (1.9K) [reference to lattice layout?]
R-T-06	The LMQXFA/B cold mass assembly must include provisions for powering each MQXFA magnet independently at a minimum of 10 A AC current during 1.9 K testing to measure and verify relative alignment with a Single Stretched Wire (SSW) measurement system.
R-T-07	The LMQXFA/B is a pressure vessel that must be designed and documented in accordance with CERN and US-HiLumi safety agreements [5]
R-T-08	The LMQXFA/B pressure vessel material for the cylindrical shell and end domes must be Austenitic Stainless Steel Grade **304L**. The material for the cold bore is specified in R-12
R-T-09	The LMQXFA/B provides a 1.9K helium vessel that must be designed for a Maximum Allowable Working Pressure (MAWP) of **20** bar differential.
R-T-10	The LMQXFA/B cold mass assembly must be capable of sustaining axial loads resulting from up to **20** bar of pressure differential without physical damage or performance degradation.
R-T-11	The LMQXFA/B beam tube material must be seamless Austenitic Stainless Steel Grade **316LN** and must comply with CERN technical specification LHC-VCC-CI-0001 and interface requirements specified in [3].
R-T-12	Two (**2**) temperature sensors attached to the return end plate of each MQXFA magnet assembly. These sensors are the short type thermometer assembly (36 mm x 12 mm x 4.2 mm) typically used by CERN and specified in [9]
R-T-13	A **50** W warm up heater attached to each of the four MQXFA end plates.
R-T-14	A beam loss monitor located in one of the iron yoke cooling channels not used by the heat exchanger tubes or by the busbars.
R-T-15	The LMQXFA/B cold mass assembly must include a total of **8** voltage tap pairs to verify the splice resistance requirement **R-21** between each MQXFA magnet and the main current bus.
R-T-16	Quench protection heater leads and warmup heaters leads are **20** Gauge polyimide coated wire, voltage taps are **26** Gauge polyimide wires, thermometer leads are **30** Gauge polyimide coated wire, and beam loss monitor are **TBD** wires.
R-T-17	The LMQXFB (Q3) cold mass assembly must have provisions to route all instrumentation wiring from LMQXFA (Q1), LMQXFC (Q2a), and LMQXFD (Q2b).
R-T-18	LMQXFA/B instrumentation wiring must be terminated in Hypertronic-style connectors similar to the ones used in the present inner triplets. The exact connector pin layout is specified in [3]
R-T-19	The bus work must include expansion loops at both LMQXFA/B end domes sufficient to accommodate up to **TBD** mm of axial movement of the bus work due to differential expansion and contraction.
R-T-20	Splices are to be soldered with CERN approved materials [TBD]
R-T-21	The LMQXFA/B assembly must include **TBD** leads for CLIQ. These leads are specified in [**TBD**].
R-T-22	The LMQXFA/B cold mass assembly voltage limits must meet or exceed the MQXFA voltage limit requirements specified in [1].
R-T-23	The LMQXFA/B quench performance requirements must meet or exceed the MQXFA magnet quench performance requirements specified in [1].
R-T-24	After installation and routing of heat exchanger tubes, instrumentation wiring, and superconducting busses there must be a free LMQXFA/B cross section area of **TBD** mm^2 in the helium volume to allow for an adequate quench venting path.
R-T-25	The LMQXFA/B cold mass assembly must meet the detailed interface specifications with the following systems: (1) MQXFA magnets; (2) The CERN supplied QQXFA/B Cryostats; (3) the CERN supplied Cryogenic System; (3) the CERN supplied power system; (4) the CERN supplied quench protection system, and (5) the CERN supplied instrumentation system. These interfaces are specified in [3].
R-T-26	The LMQXFA/B cold mass assembly must meet the corresponding Work Package (WP) Launch Safety Agreement (LSA) specifications [5].
R-T-27	CERN provided parts for LMQXFA/B assemblies are specified in Table 5.

- Objective Requirements

ID	Description
R-O-01	The relative alignment target requirements of two MQXFA magnetic axis within the LMQXFA/B Cold Mass Assembly are: transverse offset within **500** microns, relative roll within **1** mrad, and relative pitch and yaw within **0.1** mrad.
R-O-02	Splice resistance target is less than **2** nΩ at 1.9K.
R-O-03	All MQXFA components can withstand a maximum radiation dose of **30** MGy.
R-O-04	LMQXFA/B reliability requirements are the same as the MQXFA reliability requirements specified in [1].

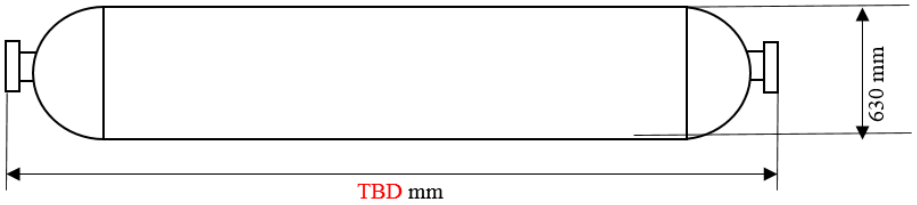
- Parameters in **black** are more certain. Parameters in **red** less certain or still under discussion

Next Slides

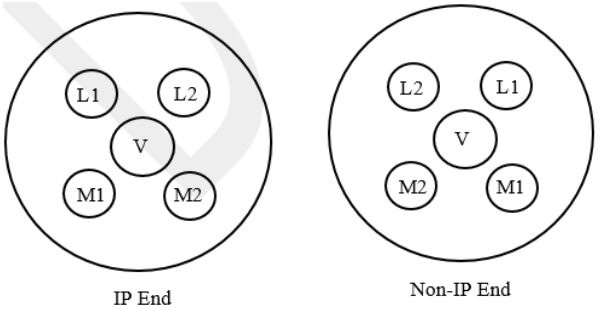
- Next slides will provide an overview of the draft LMQXFA/B requirements
  - These requirements should be such that their verification means that the MQXFA magnet deliverables are “fit” (suitable) for the intended purpose, i.e., they will satisfy CERN’s needs for HL-LHC
- The purpose is to generate discussions and answer questions such as:
  - Are there any missing requirements?
  - Are requirements properly stated?
  - Are requirements verifiable?
  - Is there agreement/confirmation of parameters in **black**?
  - Is there enough information to specify parameters in **red**?

MQXFA Physical Requirements

- T: Length: TBD mm; Diameter: 630 mm
  - Room Temperature (296K) dimensions



- T: Piping (dimensions, positions TBD):

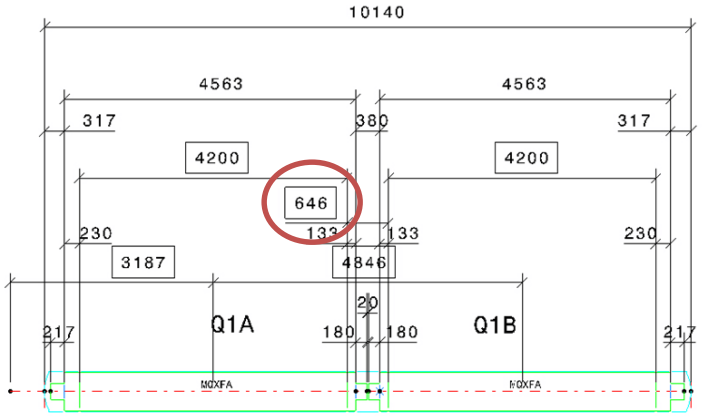


Pipe	Function
V	Cold Bore Tube
M1	Helium Vessel Connection (Bus Routing)
M2	Helium Vessel Connection (Instrumentation Routing)
L1	Heat Exchanger External Shell 1
L2	Heat Exchanger External Shell 2

Is it Ok for quench venting? All piping occupied…

Alignment Requirements

- T: Distance between MQXFA magnetic lengths is 646 ± TBD mm at 1.9K



Reference to lattice?

- O: Relative MQXFA magnetic axis: transverse offset < 500 um, relative roll < 1 mrad, relative pitch/yaw < 0.1 mrad
  - These values are for the present Q2a and Q2b. Are these the the same for HL-LHC Q1a/Q1b and Q3a/Q3b?
- T: To verify with SSW system, each MQXFA magnet must be capable of being independently powered with a minimum of 10 A AC current during 1.9K testing

Pressure Vessel Requirements

- T: Design and documentation in accordance with CERN and US-HiLumi safety agreement (TBD)
  - Not expected to include a CE or ASME stamped vessel. **Need to converge soon** on the details of this agreement to asses U.S project cost and schedule impact (meeting scheduled October 29)
- T: Material is 304L SS, except cold bore which is 316LN and compliant with LHC-VCC-CI-0001
- T: Maximum Allowable Working Pressure (MAWP) of 20 bar differential at 1.9K

Forces Requirement

- T: Capable of sustaining axial loads resulting form up to 20 bar of differential pressure
  - Originate from quenching of neighboring cold masses. Other sources? How to verify?

Heat Exchanger Reqs

- T: Heat Exchangers: Must allow insertion of two 74 mm OD heat exchanger tubes and their supports through the top two MQXFA cooling channels along the entire LMQXFA/B Length
  - Are these tubes part of the cryostat scope or part of the cold mass assembly scope? If the latter, propose to have CERN supply the HT tubes
- T: Cold Bore: must be seamless Austenitic Stainless Steel Grade 316LN and comply with LHC-VCC-CI-0001 and interface requirements TBD.
  - Beam tube supplied by CERN

Instrumentation Requirements

- T: Two (2) temperature sensors attached to return end plate of each MQXFA magnet
  - Temperature sensor blocks supplied by CERN
- T: A 50 W warm up heater attached to each of the four MQXFA end plates, independently powered
  - Warmup heaters supplied by CERN
- T: Beam Loss monitor located in one of the free iron yoke cooling channels
  - Beam loss monitor supplied by CERN
- T: 8 Voltage Taps pairs to verify splice resistance

Wiring Requirements

- T: Wiring: 20 gauge polyamide coated wire for quench protection leads and warmup heaters, 26 Gauge polyamide wires for voltage taps, 30 Gauge polyamide coated wire for thermometer leads, TBD wires for beam loss monitor
  - All wiring supplied by CERN
- T: LMQXFB (Q3) must have provisions to route all instrumentation wiring from Q1 and Q2
  - Do we still want to do this, or prefer to have wiring come out at each cryostat interconnect?
- T: Instrumentation wiring must be terminated in Hypertronic-style connectors, layout TBD.
  - Do we still want to do this, or prefer to have wiring terminated in other ways?

Electrical Bus Requirements

- T: Main bus made of Nb-Ti Cable rated for 20 kA (specs?) plus TBD leads for CLIQ
- T: Must include expansion loops at both LMQXFA/B End Domes to accommodate up to TBD mm of axial movement
- T: Splices soldered with CERN approved materials
- O: Slice resistance target is less than 2 nOhm at 1.9K

Voltage, Quench, Radiation, Reliability

- T: Voltage Limits same as MQXFA. Hipot values:

Circuit Element	Vmax	V hi-pot	I hi-pot
Quench Protection Heaters - Coil	500 V	TBD	< TBD μA
Magnet Coil - Ground	1,000 V	TBD (2,500 V?)	< TBD μA

- Quench requirements same as MQXFA:
  - T: Trained to 108% of nominal operating current (17.8 kA, nominal operating current is 16.5 kA).
  - O: Must remember training and reach nominal operating current with a target of no more than 1 quench after a room temperature thermal cycle
  - T: Must not quench while ramping down at 300 A/s from nominal current
- Radiation requirements same as MQXFA
  - O: All MQXFA components must withstand a maximum radiation dose of 30 MGy
- Reliability Requirements same as MQXFA
  - O: Survive 25 thermal cycles, 3,000 powering cycles, and 50 quenches

Free Cross Section?

- T: After installation and routing of heat exchanger tubes, instrumentation wiring, and superconducting busses there must be a free LMQXFA/B cross section area of at least TBD mm^2 in the helium volume to allow for an adequate venting path
  - Is this requirement properly stated?
  - The value depends on the design of the CERN-provided relief system

Interface Requirements

- T: Comply with Interface Specifications for:
  - The MQXFA magnets
  - CERN QQXFA/B Cryostats
  - CERN Cryogenic System
  - CERN Power System
  - CERN Quench Protection System
  - CERN Instrumentation System

All these interface specifications To Be Defined

Safety Requirements

- T: Comply with the corresponding CERN Work Package Launch Safety Agreement (LSA) specification (TBD)
  - Need to converge soon on the details of this agreement to asses U.S project cost and schedule impact (meeting scheduled October 29)

CERN Provided LMQXFA/B Parts

Item	Quantity
Beam tubes	10
Heat exchanger tubes[1]	20
Instrumentation wire AWG 20	TBD km
Instrumentation wire AWG 26	TBD km
Thermometer cable, 4 x AWG 30 (twisted)	TBD km
Temperature Sensors	40
Warm up heaters	20
Beam Loss Monitor	1
Instrumentation Connectors and Feedthroughs (if applicable)	TBD

[1]If Heat Exchanger Tubes are part of the cold mass assembly scope (to be discussed)

Path Forward

- Are there any missing requirements?
- Are requirements properly stated?
  - Is there agreement/confirmation of parameters in **black/blue**?
  - Is there enough information to specify parameters in **red**?
- Are requirements verifiable?
- US-HiLumi Project Office is working with HL-LHC WP3 Manager (Ezio Todesco) to address these points
  - Process for final CERN approval?
- **US-HiLumi is going to need final, approved MQXFA and LMQXFA/B requirements documents in less than a year from now**
  - Needed to support U.S. project baseline freezing prior to CD-2
  - MQXFA draft has already gone through several iterations with CERN
    - MQXFA requirements discussion scheduled for Friday afternoon