MQXFA Functional Requirements

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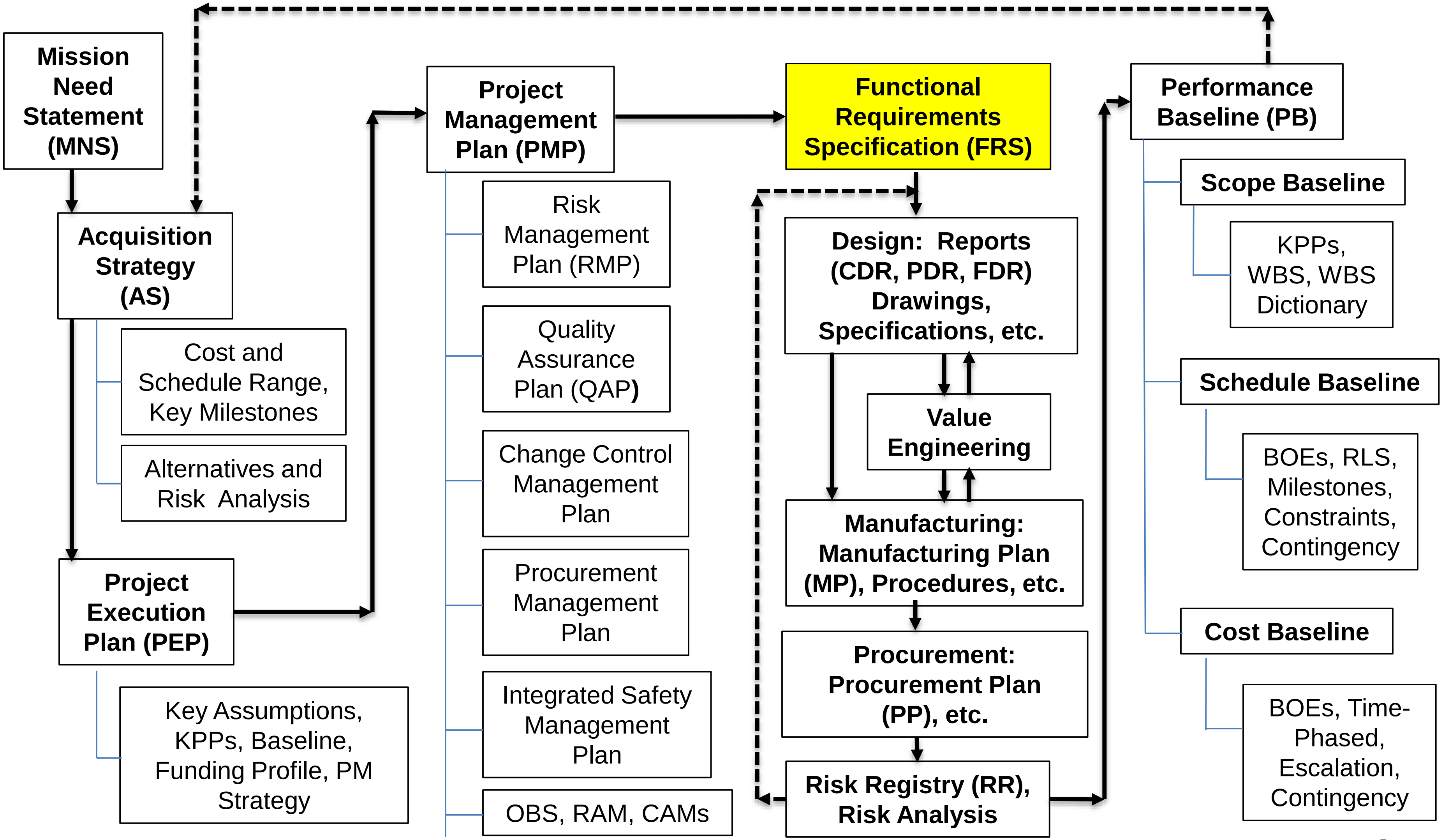
Functional Requirements

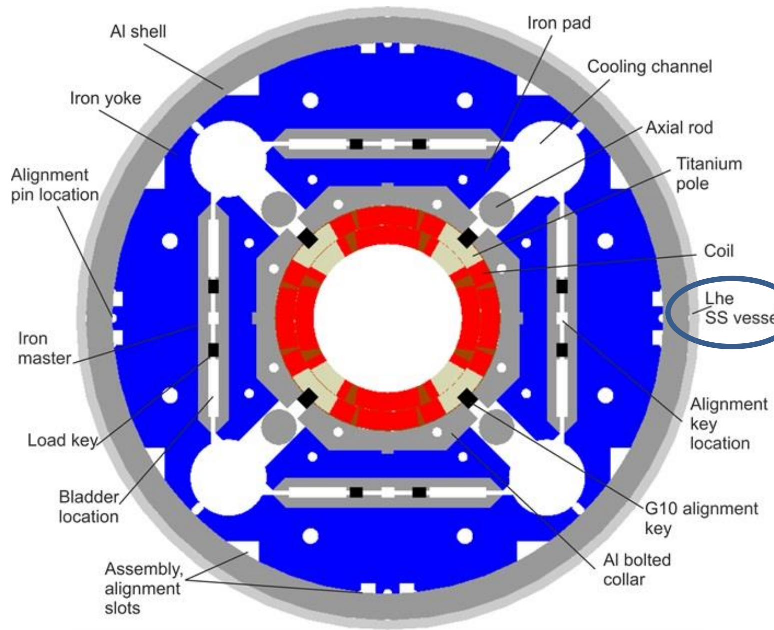
- A clear specification of functional requirements for U.S. deliverables is needed to support the DOE Order 413.3B project management process for the US-HiLumi project
- These requirements should not be embedded in other documents (e.g., design reports) or mixed with requirements for other systems
  - 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 MQXFA functional requirements for Q1 and Q3 only:



SS vessel not part of MQXFA

- The MQXFA magnets for Q1 and Q3 are assumed to be identical
- A separate, similar functional requirements document is also available for the Q1, Q3 Cold Mass Assembly (LMQXFA/B)

Previous Example: MQXB FRS

CERN
CH-1211 Geneva 23
Switzerland

the **Large Hadron Collider** project

LHC Project Document No. **LHC-LQX-ES-0002 rev 1.1**
CERN Div./Group or Supplier/Contractor Document No. **TD/FNAL/USA**
EDMS Document No. **256806**

Date: 2001-04-23

Functional Specification

INNER TRIPLET QUADRUPOLE MQXB

Abstract

This specification establishes the functional requirements for the MQXB quadrupole magnets. Two of these elements form the Q2 inner triplet optical element at interaction regions 1, 2, 5 and 8. Since the elements are identical whether installed at the low luminosity or high luminosity interaction regions, the functional requirements to the magnet design are identical for all MQXB assemblies.

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- Example of a previous FRS for the present Inner Triple Quadrupole MQXB for Q2
- Some parameters for MQXFA FRS were taken from the MQXB FRS, but they need to be confirmed by CERN

LARP

High Luminosity LHC

MQXFA FRS

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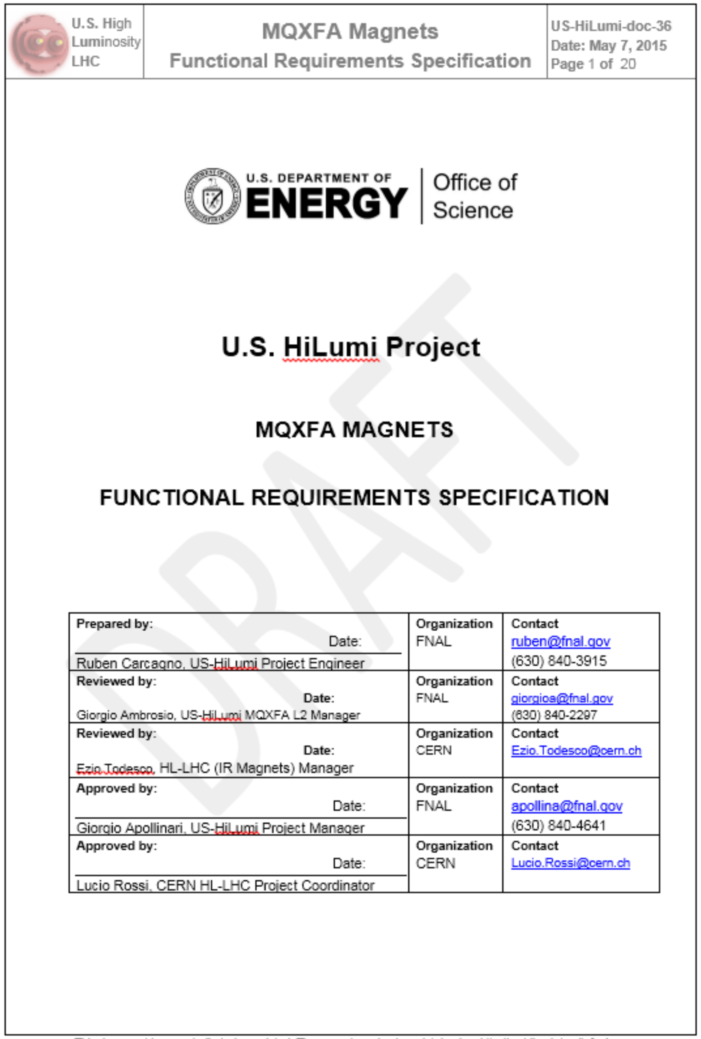

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U.S. DEPARTMENT OF ENERGY | Office of Science

U.S. HiLumi Project

MQXFA MAGNETS

FUNCTIONAL REQUIREMENTS SPECIFICATION

DRAFT

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- Draft prepared as a US-HiLumi project document to start discussions
- Attempts to collect all the **functions** that the MQXFA magnet must satisfy
- Several parameters need definition 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 magnet deliverable trained to 107% of nominal current instead of 108% (the threshold requirement)
- The MQXFA draft was first presented during the Joint LHC-LARP meeting on May 2015 and already went through several iterations with CERN

LARP

High Luminosity LHC

MQXFA FRS Table

- Threshold Requirements

ID	Description
R-T-01	The MQXFA coil aperture requirement **is 150 mm**. This aperture is the coil inner diameter at room temperature, excluding ground insulation, cold bore and beam screens.
R-T-02	The MQXFA physical outer diameter must not exceed **614 mm**.
R-T-03	The MQXFA magnet must be capable of reaching a nominal operating gradient of **132.6 T/m** and an ultimate gradient of **143 T/m**. These values are in superfluid helium at 1.9 K and for the magnetic length specified in R-T-04.
R-T-04	The MQXFA magnetic length requirement **is 4.2 meters** at 1.9 K.
R-T-05	MQXFA magnets must be capable of operation in pressurized static superfluid helium (HeII) bath at **1.3 bar** and at a temperature of **1.9 K**
R-T-06	The MQXFA cooling channels must be capable of accommodating **two (2)** heat exchanger tubes running along the length of the magnet in the yoke cooling channels. The minimum diameter of the MQXFA yoke cooling channels that will provide an adequate gap around the heat exchanger tubes is **77 mm**
R-T-07	At least **40%** of the coil inner surface must be free of polyamide
R-T-08	The MQXFA structure must have provisions for the following cooling passages: (1) Free passage through the coil pole and subsequent G-10 alignment key equivalent of **8 mm** diameter holes repeated every **50 mm**; and (2) free helium paths interconnecting the yoke cooling channels holes
R-T-09	The MQXFA magnet structure must be capable of sustaining a sudden rise of pressure from atmospheric up to **20 bar** without damage and without degradation of subsequent performance.
R-T-10	The MQXFA magnet structure must be capable of surviving a maximum temperature gradient of **TBD K** during testing without degradation in its performance.
R-T-11	The MQXFA magnets must be capable of operating at **14 A/s**
R-T-12	The MQXFA magnet must withstand a maximum operating voltage of **800 V to ground** during quench.
R-T-13	MQXFA magnets must be delivered with a (+) Nb-Ti superconducting lead and a (-) Nb-Ti superconducting lead rated for **18 kA** and adequately stabilized for connection to the Cold Mass LMQXFA or LMQXFAB electrical bus
R-T-14	Voltage Taps: the MQXFA magnet shall be delivered with **three (3)** quench detection voltage taps located on each magnet lead and at the electrical midpoint of the magnet circuit; **two (2)** voltage taps for each quench strip heater; and **two (2)** voltage taps for each internal MQXFA Nb_3Sn-NbTi splice.
R-T-15	The MQXFA magnet coils and quench protection heaters must pass a hi-pot test in liquid helium at 1 atm pressure as specified in **Table 3** (to be defined)
R-T-18	MQXFA magnets must be delivered trained to ultimate current of **108% (17.8 kA)** of the nominal operating current.
R-T-19	MQXFA magnets must not quench while ramping down at **300 A/s** from the nominal operating current
R-T-20	The MQXFA quench protection components must be compatible with the CERN-supplied quench protection system and comply with the corresponding interface document specified by CERN [3] (to be defined)
R-T-21	The MQXFA magnets must meet the detailed interface specifications with the following systems: (1) other LMQXFA(B) Cold Mass components; (2) 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] (all to be defined)
R-T-22	The MQXFA magnets must meet the corresponding Work Package Launch Safety Agreement (LSA) specification [4] (to be defined)

- Objective Requirements

ID	Description
R-O-01	MQXFA magnet mechanical twist target is < 1 mrad / 5m, and mechanical straightness target is < 100 μm / 5 m
R-O-02	The MQXFA field harmonics must be optimized at high field. Table 2 provides specific target values for field harmonics at a reference radius of **50** mm.
R-O-03	The fringe field target at a **TBD** cm distance from the MQXFA magnetic field axis is **50** mT or less.
R-O-04	Splice resistance target is less than **2** nΩ at 1.9K
R-O-05	The MQXFA cross section must have provisions for routing the LMQXFA or LMQXFB superconducting busses.
R-O-06	After training and after following a thermal cycle to room temperature, MQXFA magnets can attain the nominal operating current with a target of no more than **1** quench.
R-O-07	All MQXFA components can withstand a maximum radiation dose of **30** MGy.
R-O-08	MQXFA magnets can survive **25** thermal cycles during HL-LHC tunnel operations.
R-O-09	MQXFA magnets can survive **3,000** powering cycles during HL-LHC tunnel operations.
R-O-10	MQXFA magnets can survive **50** quenches during HL-LHC tunnel operations.

- 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 MQXFA 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 still any missing or improperly stated requirements?
  - Can we start converging on agreement for parameters in **red?**

MQXFA Physical Requirements

- T: 150 mm aperture, ≤ 614 mm outer diameter
- O: ≤ 1 mrad/5m twist, ≤ 100 um/5m straightness

Magnetic Field Requirements

- T: nominal gradient 132.6 T/m, ultimate gradient 143 T/m (8 % above nominal) in superfluid helium at 1.9K and for a magnetic length of 4.2 m

- O: Fringe field target at TBD distance from the magnetic axis < 50 mT

Magnetic Field Requirements

- O: Field harmonics optimized at high field with the following targets:

	Triplet field quality version 4 - May 20 2015 - R_{ref}=50 mm															
	Straight part										Ends		Integral			
	Systematic						Uncertainty		Random				Q1/Q3		Q2a/b	
Normal	Geometric	Ass. & cool	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field	Conn. Side	Non conn. Side	Injection	High Field	Injection	High Field
2									10	10						
3	0.000	0.000	0.000	0.000	0.000	0.000	0.820	0.820	0.820	0.820			0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.570	0.570	0.570	0.570			0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.420	0.420	0.420	0.420			0.000	0.000	0.000	0.000
6	-2.200	0.900	0.660	-20.000	-21.300	-0.640	1.100	1.100	1.100	1.100	8.943	-0.025	-16.692	0.323	-18.593	-0.075
7	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.190	0.190	0.190			0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.130	0.130	0.130	0.130			0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.070	0.070	0.070			0.000	0.000	0.000	0.000
10	-0.110	0.000	0.000	4.000	3.890	-0.110	0.200	0.200	0.200	0.200	-0.189	-0.821	3.119	-0.175	3.437	-0.148
11	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.026	0.026	0.026			0.000	0.000	0.000	0.000

Skew																
2									10.000	10.000	-31.342		-2.985	-2.985	-1.753	-1.753
3	0.000	0.000	0.000	0.000	0.000	0.000	0.650	0.650	0.650	0.650			0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.650	0.650	0.650	0.650			0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.430	0.430	0.430	0.430			0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.310	0.310	0.310	0.310	2.209		0.210	0.210	0.124	0.124
7	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.190	0.190	0.190			0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.110	0.110	0.110			0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.080	0.080	0.080			0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.040	0.040	0.040	0.065		0.006	0.006	0.004	0.004
11	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.026	0.026	0.026			0.000	0.000	0.000	0.000

Cryogenic Requirements

- T: Operate at superfluid helium bath at 1.3 bar and 1.9K
- T: Minimum cooling channel diameter is 77mm to accommodate two 74mm O.D. copper heat exchanger tubes
- T: 40% inner coil surface free of polyamide
- T: provisions for cooling passages are 8mm pole holes every 50 mm and free helium paths interconnecting the yoke cooling channel holes
- T: 20 bar peak pressure
- T: Maximum temperature gradient of TBD K during testing

Electrical Requirements

- T: ramp rate of 14 A/s
- T: maximum operating voltage of 800 V to ground during quench
- T: Nb-Ti leads for connection to the bus, stabilized and rated for 18 kA
- T: Splices to be soldered with CERN approved materials
- O: Splice resistance target is less than 2 nΩ at 1.9K
- O: Provisions for routing LMQXFA/B superconducting busses
- T: 3 quench detection voltage taps, 2 voltage taps for each quench strip heater, 2 voltage taps for internal splice
- T: hi-pot test in liquid helium at 1 atm pressure with following limits:

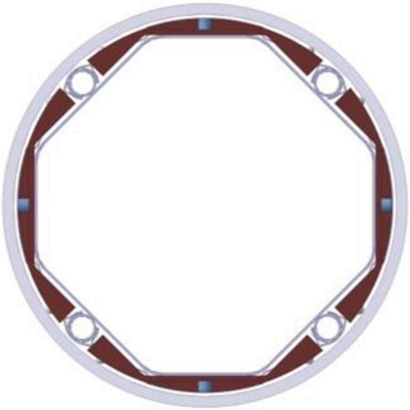
Circuit Element	**Vmax**	**V hi-pot**	**I hi-pot**
Quench Protection Heaters - Coil	500 V	TBD	< TBD μA
Magnet Coil - Ground	1,000 V	TBD (2,500 V?)	< TBD μA

Quench Requirements

- T: trained to a current of 108% (17.8 kA) of the nominal operating current
- O: 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
- T: quench protection components compatible with CERN-supplied quench protection system

Radiation Hardness Requirements

- O: can withstand a maximum radiation dose of 30 MGy
  - Assumes beam screen with tungsten absorber (provided by CERN):



Reliability Requirements

- O: can survive 25 thermal cycles, 3,000 powering cycles, and 50 quenches

Interface Requirements

- T: Comply with Interface Specifications for:
  - Other LMQXFA(B) cold mass components
  - 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)
  - Meeting scheduled for October 29

Path Forward

- The MQXFA draft was first presented during the Joint LHC-LARP meeting on May 2015 and already went through several iterations with CERN
  - Are there still any missing or improperly stated requirements?
  - Can we start converging on agreement for parameters in **red?**
- 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 a final, approved MQXFA requirements document in less than a year from now**
  - Needed to support U.S. project baseline freezing prior to CD-2