WBS 475.04.05 Cryogenic Distribution

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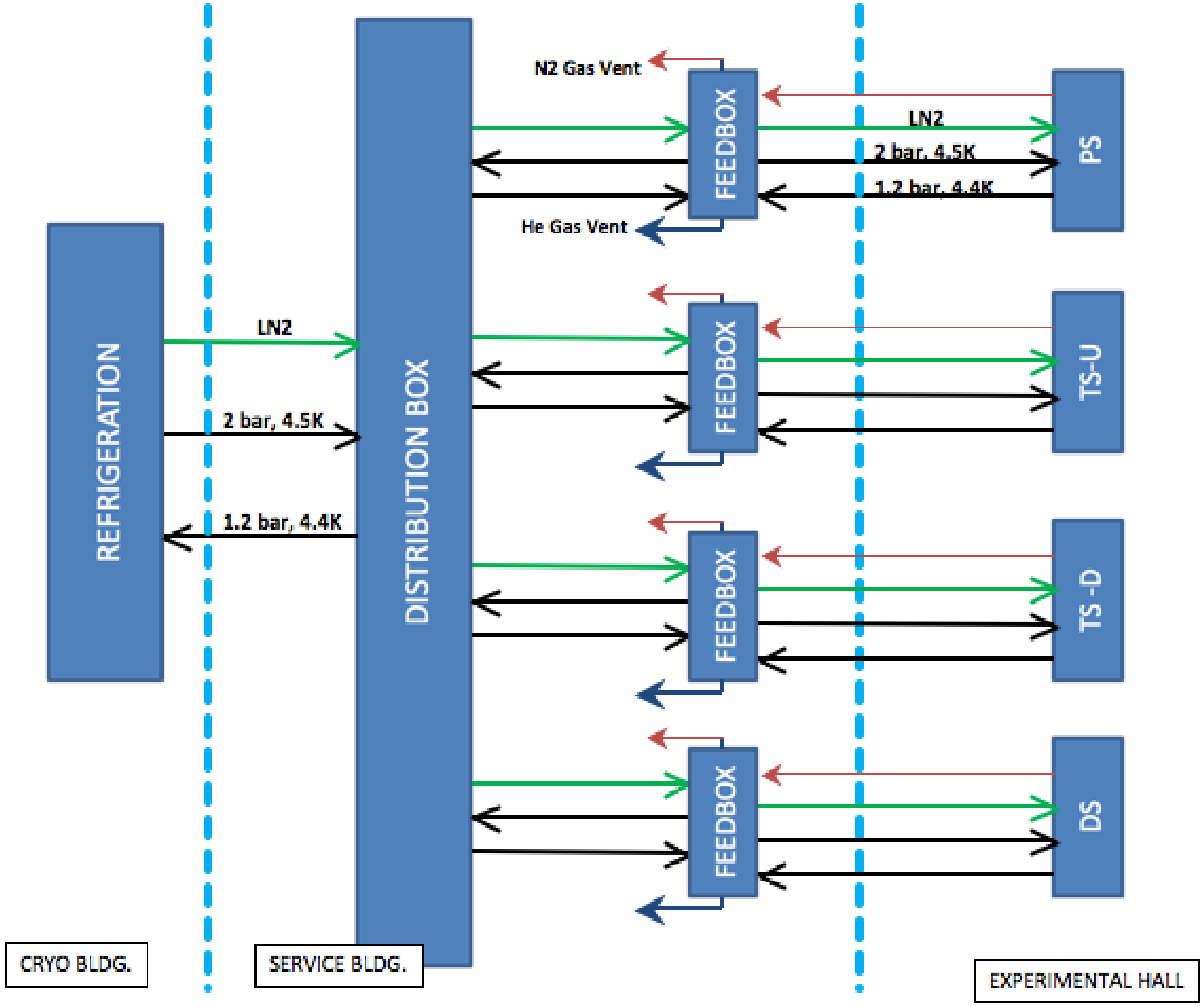
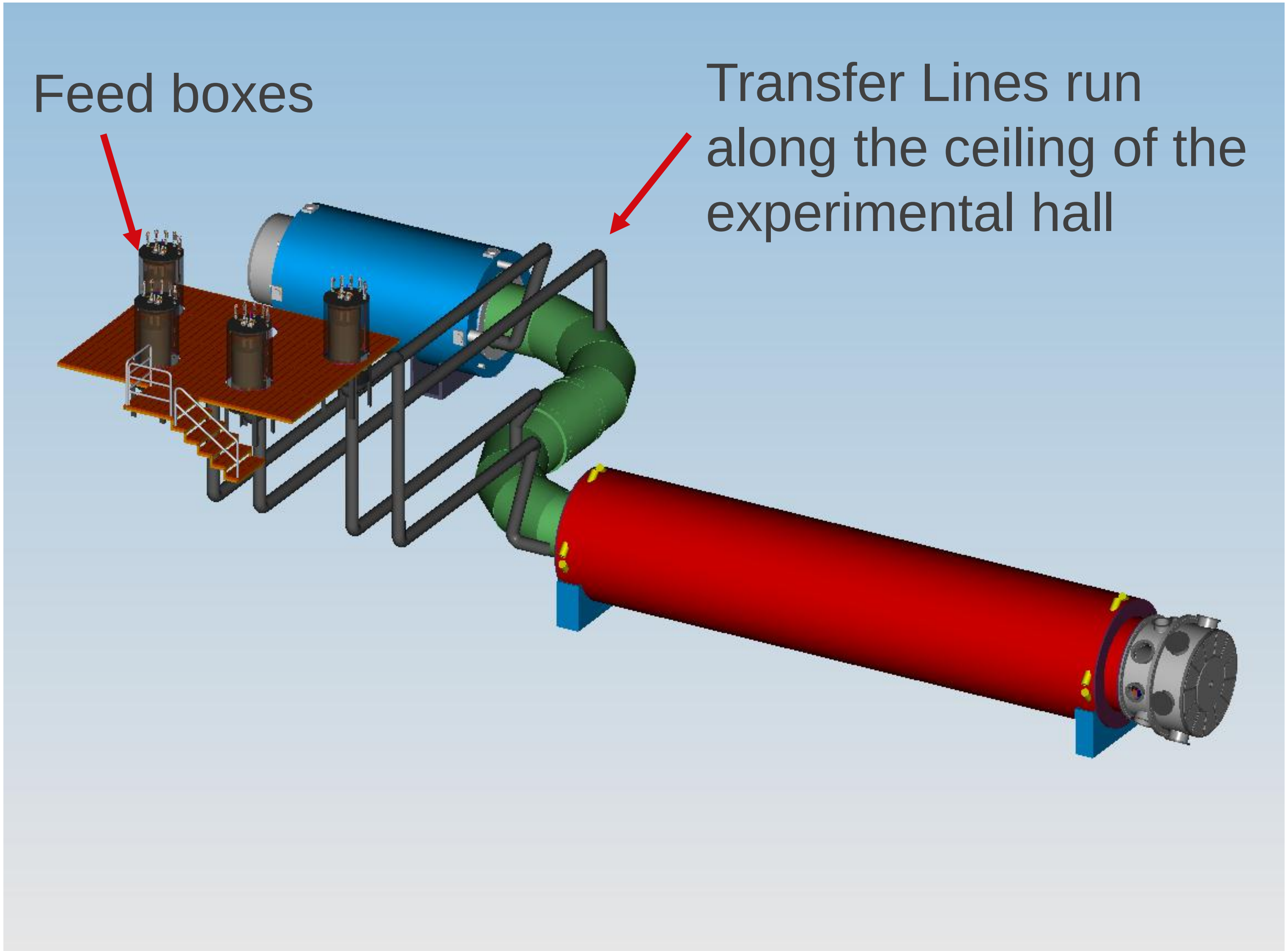
Requirements

- Cryogenic Distribution Requirements Document: DocDB 1244
- Distribution Box Functional Requirements Document: DocDB 3784
- Summary of requirements
  - The solenoids are divided into 4 separate cryogenic circuits fed from a common distribution box. This allows the magnets to be cooled down and warmed up independent of each other.
  - All solenoid coils will be indirectly (conduction) cooled by liquid helium.
    - PS and DS magnets are cooled using a thermal siphon system.
    - TSu and TSd magnets are cooled using a forced flow system.
  - Liquid nitrogen will be used to cool the thermal shields and thermal intercepts within the magnet cryostats and transfer lines.
  - During operation the insulating vacuum should be below 10e-6 torr.
  - Feed boxes will be installed on the main level of the Mu2e building, the magnets are installed in the lower level of the Mu2e building.
  - Steady state operation will be within the limits of one satellite refrigerator.

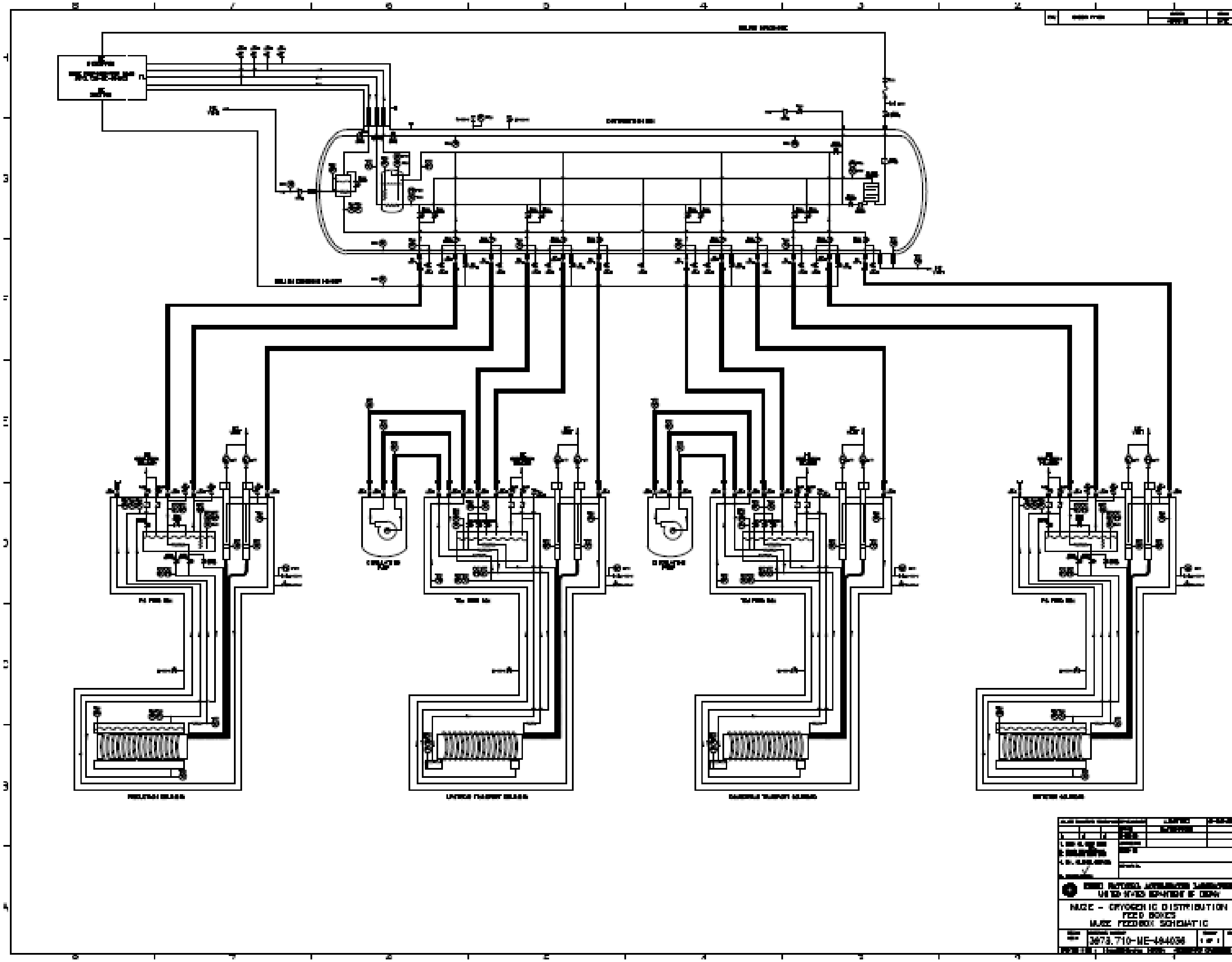
Block Diagram of Mu2e Cryogenic System



Cryogenic Distribution model



Preliminary P&ID



Design

- A distribution box in the service building interconnects the refrigeration system with the solenoid feed boxes. Interconnections will be for:
  - Liquid helium supply
  - Helium vapor return
  - Liquid nitrogen supply
- Liquid nitrogen comes from LN2 storage to the distribution box
- Distribution box passes cryogens to four feed boxes, one for each magnet assembly
- Transfer lines and bayonets allow isolation of feed boxes from distribution box

Design

- Control valves in feed boxes
  - No cryogenic control valves in high radiation / high magnetic field areas
- Transfer lines from feed boxes to magnets carry cryogens to and from its magnet as well as electrical bus to the same magnet
- Insulating vacuum is separate for each feed box / magnet system such that separate warm up and isolation of magnets is possible.

Changes since CD-1

- The transfer line routing has changed since CD-1
  - The DS transfer line penetrates through shielding near the downstream end of the DS magnet.
  - The TSd transfer line is routed under the shielding in a trench in the Mu2e building floor.
- Cryogenic Controls WBS (formally 475.04.05.06) has been moved to Quench Protection WBS (475.04.07.03).

Downselects

- The Detector Solenoid will be cooled using a thermal siphon system.
- The Transport Solenoids will be cooled using a forced flow system.

Performance – Heat Load to 80 K

Best Estimates (no contingency)	Production Solenoid	TSu	TSd	Detector Solenoid	Total
Nominal Temperature	**80 K**				
80 K Magnet Heat (W)	128.5	252.0	252.0	539.0	1171.5
80 K Feedbox and Transfer Line* Heat (W)	140.0	140.0	140.0	140.0	560.0
Total 80 K Heat (W)	268.5	392.0	392.0	679.0	1731.5
Nitrogen usage for Magnet (liquid liters/day)	147.42	215.22	215.22	372.80	950.67
Number of 10kA HTS Leads	2	0	0	2	4
Number of 2kA HTS Leads	0	2	2	0	4
N2 10kA lead flow per magnet (g/s)	2.2	0	0	2.2	4.4
N2 usage for 10kA leads (liquid liters/day)	235.54	0.00	0.00	235.54	471.08
He vapor 2kA lead flow per magnet (g/s)	0	0.16	0.16	0	0.32
He vapor usage for 2kA leads (liquid liters/day)	0	110.592	110.592	0	221.18

*Transfer Line length only from feedbox to magnet considered

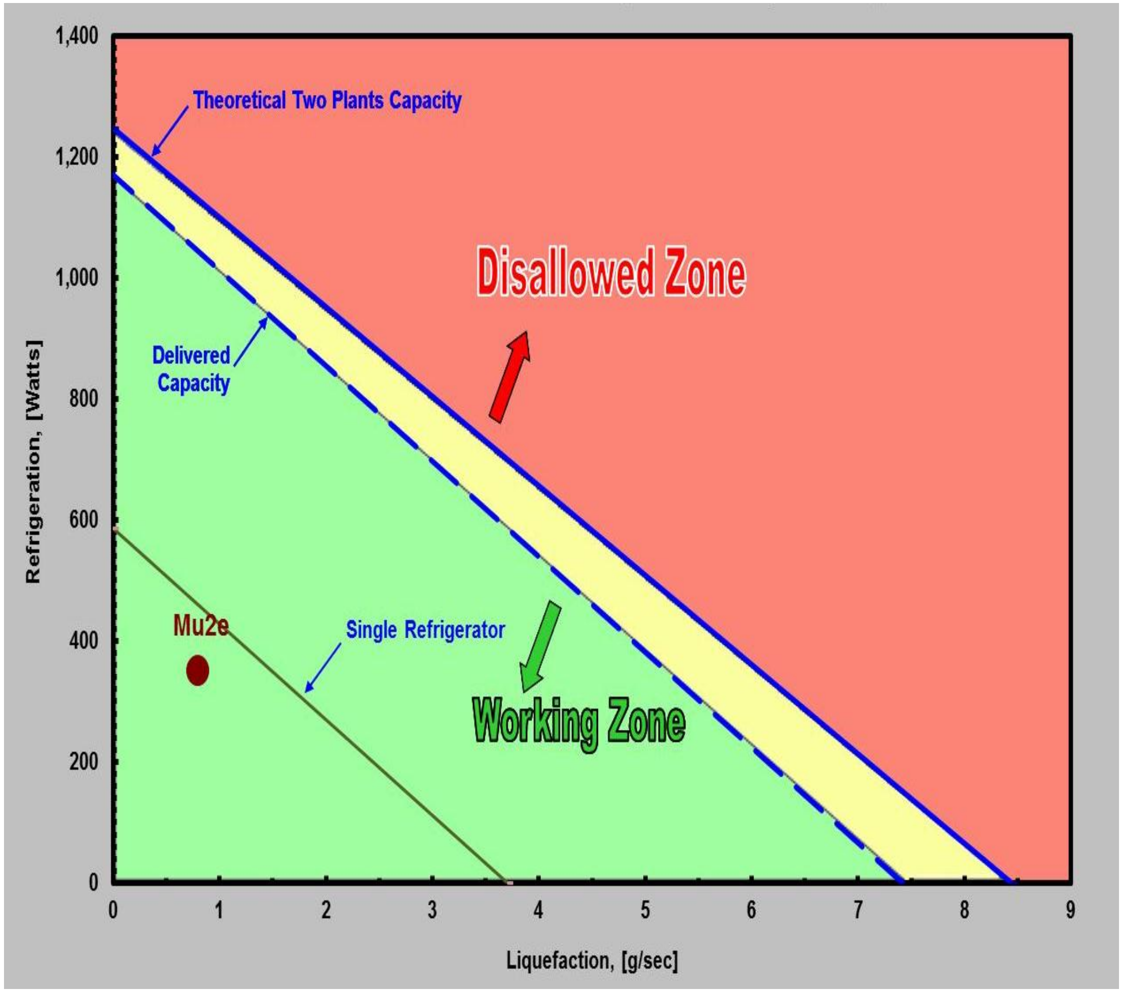
Performance – Heat Load to 4.7 K

Best Estimates (no contingency)	PS	TSu	TSd	DS	Total
Nominal Temperature			**4.7 K**		
4.7 K Magnet Heat (W)	66.7	44.0	42.0	32.2	184.9
4.7 K Feedbox and Transfer Line** Heat (W)	14.0	14.0	14.0	14.0	56.0
Thermosiphon					
Total heat load (W)	80.7	0	0	46.2	126.9
Total helium flow (g/s)	4.78	0.00	0.00	2.74	
3.0 bar to 2.7 bar forced flow					
Helium inlet temperature (K)		4.7	4.7		
Total heat added (W)		58.0	56.0		
Selected flow rate (g/s)		50.0	50.0		
Exit temperature (K)		4.82	4.81		
Circulating pump real work (W)		25.0	25.0		
Circulating pump system static heat (W)		15.0	15.0		
Total load for forced flow (W)	0	98.0	96.0	0	194.0
Total refrigerator cooling load at 4.7 K (W)					320.9

**Transfer Line length only from feedbox to magnet considered

Performance – One Satellite Refrigerator

- Two satellite refrigerators dedicated to Mu2e.
- Steady state operation will utilize one refrigerator.
- Second refrigerator is used during cooldown and upset conditions.
- Refrigerators are part of the Muon Campus Cryo AIP.



Remaining work before CD-3

- Complete qualification of the existing HTS power leads.
- Develop feed through for 2kA power leads.
- Complete the detailed final design and specification of the feed boxes and transfer lines.
- Complete the detailed final design and specification of the insulating vacuum system.
- Complete the detailed final design and specification of the distribution box.

Organizational Breakdown

- WBS 4.5
  Cryo Distribution
  R. Schmitt (T. Page)
  - WBS 4.5.1
    Power Leads
  - WBS 4.5.2
    Feed Boxes
  - WBS 4.5.3
    Transfer Lines
  - WBS 4.5.4
    Interconnects
  - WBS 4.5.5
    Insulating Vacuum
  - WBS 4.5.7
    Distribution Box

Quality Assurance

- Power leads are tested to full current prior to sending to vendor for integration.
- Inspections, leak checks and pressure tests during fabrication prior to vessel closure.
- Regular vendor meetings and vendor visits during fabrication.
- Travelers will be written for installation at FNAL.

Risks

- Opportunity for the Distribution Box
  - Move the design of the distribution box to the Cryo AIP.
  - Savings to Mu2e project would be ~ $1.5M.
- Tevatron HTS leads do not perform to Mu2e specifications
  - Three out six pairs of HTS leads have been qualified.
  - Testing of remaining leads continues.
  - Project needs 4 pairs plus one spare pair to fully retire risk.

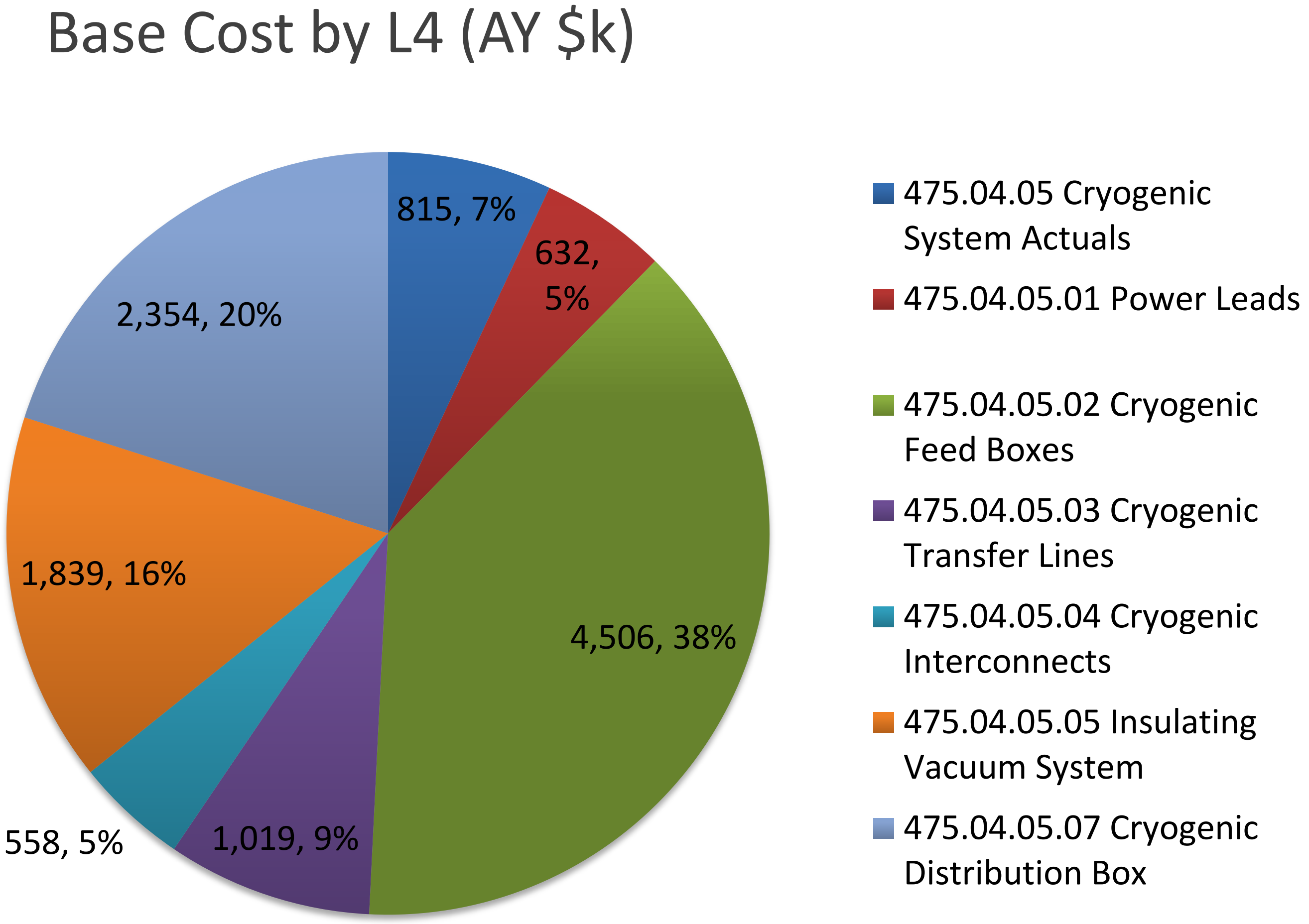
ES&H

- Oxygen Deficiency Hazards (ODH)
  - FESHM chapter 5064 (ODH) will be followed
- Pressure vessel, pressure piping, vacuum vessels, cryogenic system review
  - FESHM chapters 5031, 5031.1, 5032, 5033 and associated material
- General cryogenic safety practices
  - “Burn” protection, PPE
  - Written procedures and training as required

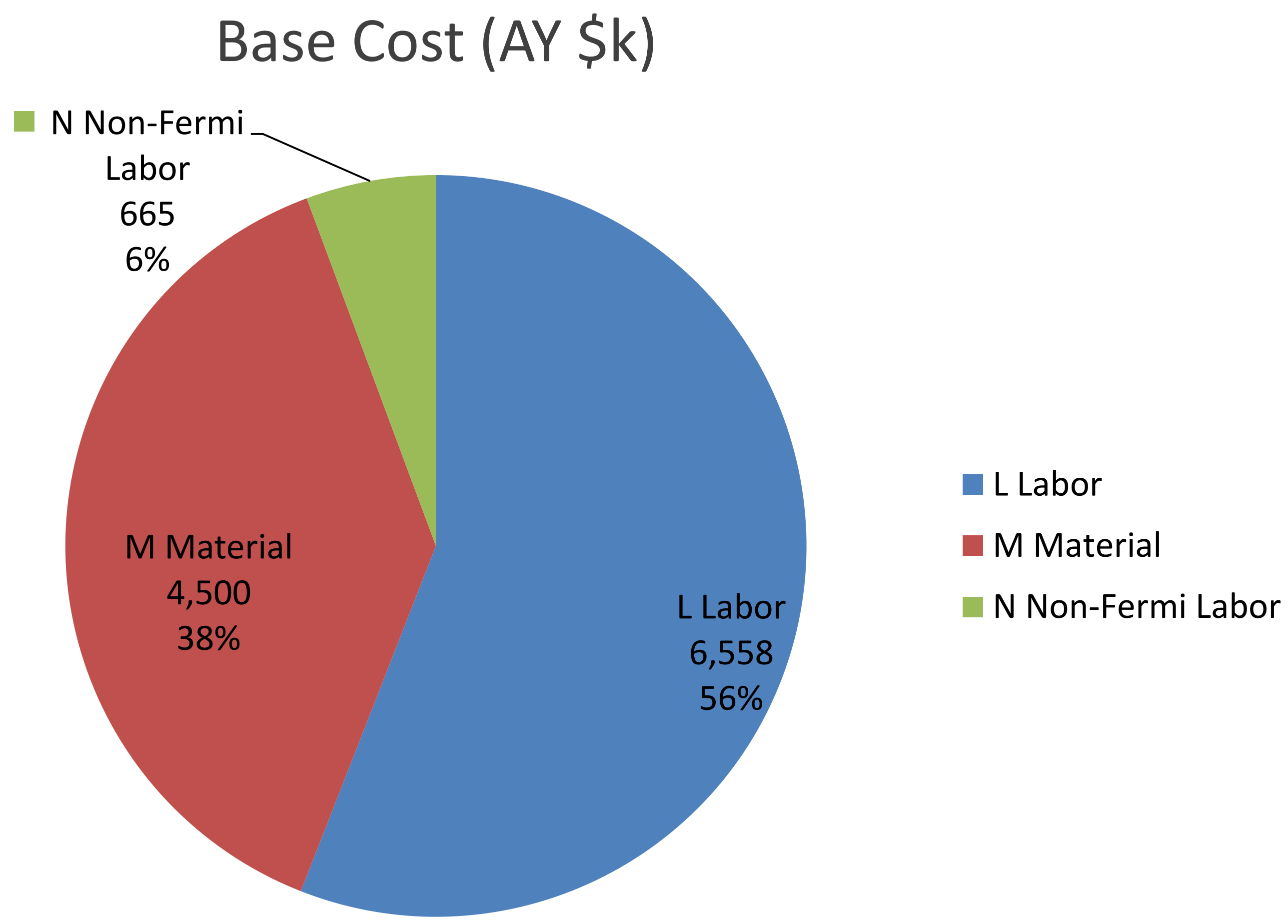
Major Milestones

- Final Designs Complete
- Vendors selected and POs issued
- Components accepted and delivered to the Mu2e building.

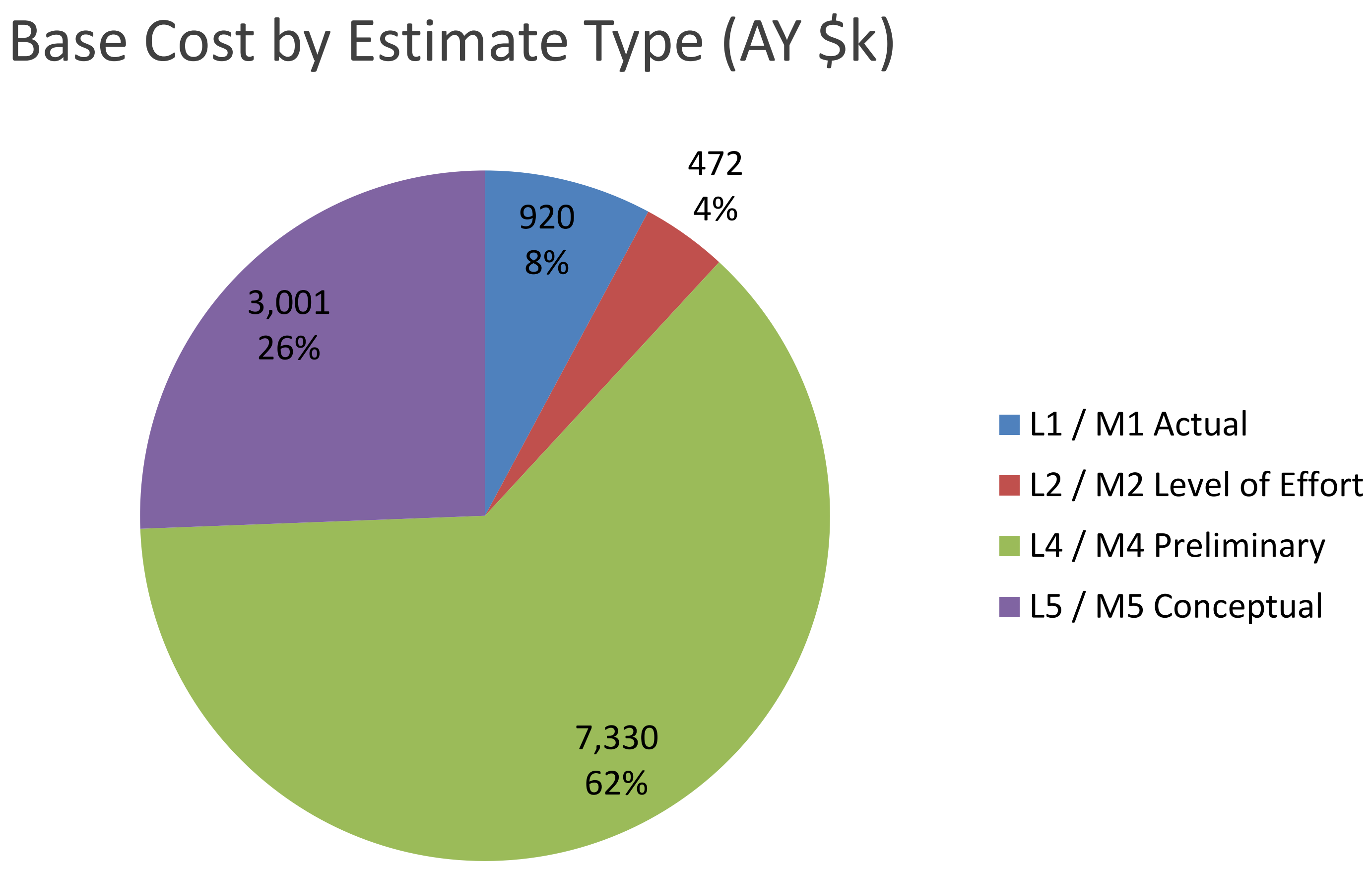
Cost Distribution by L4



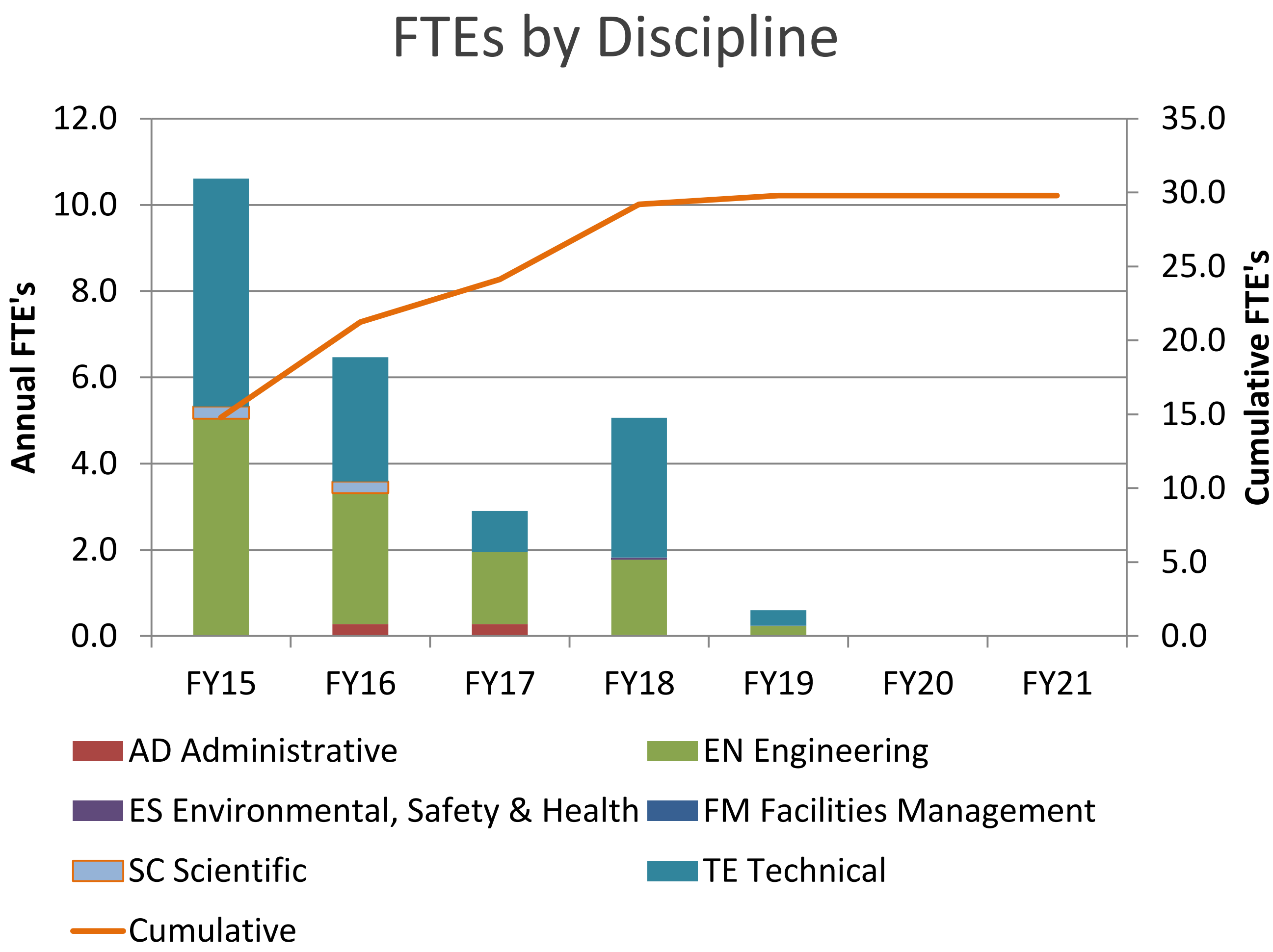
Cost Distribution by Resource Type



Quality of Estimate



Labor Resources



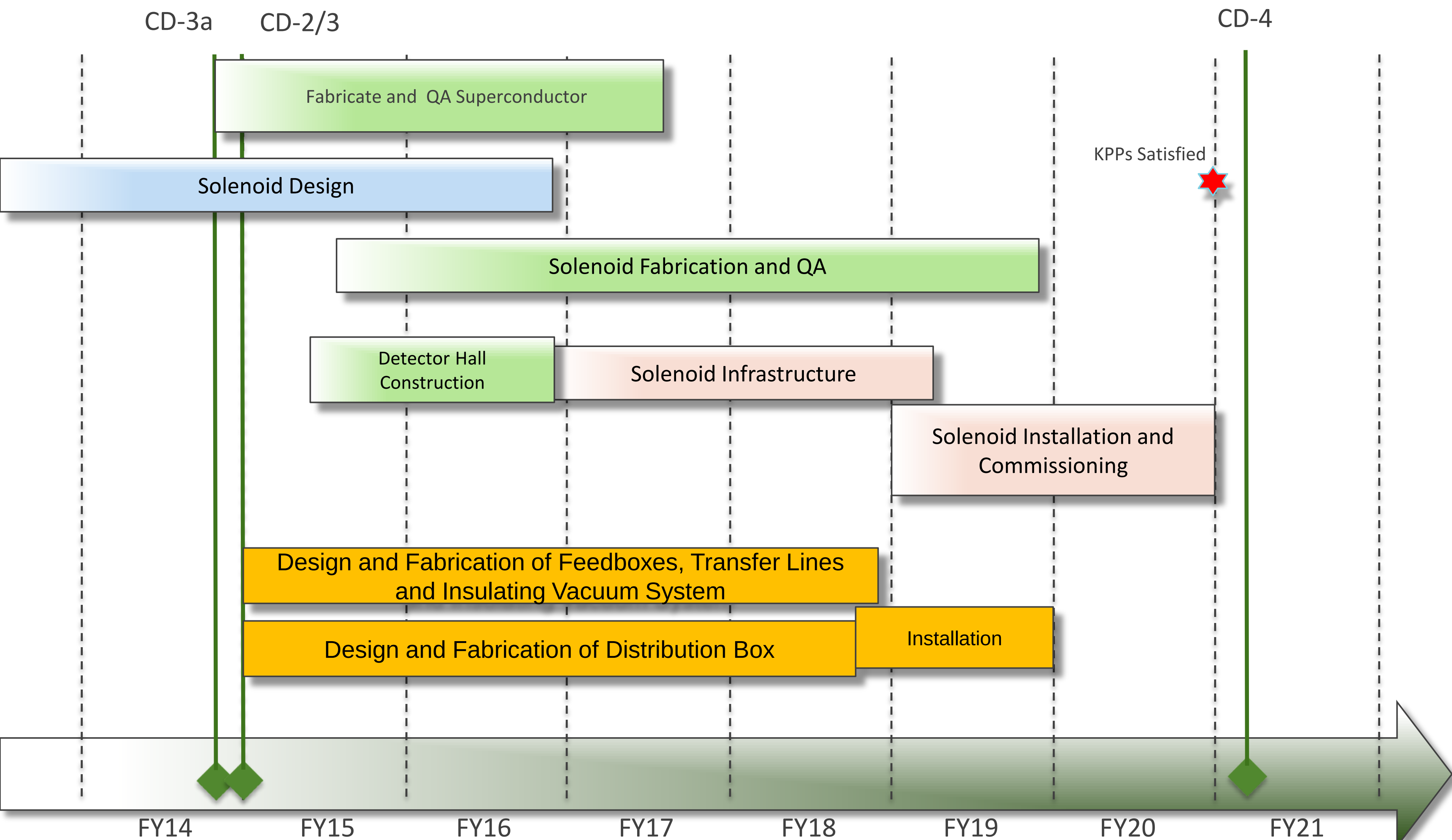
Cost Table

WBS 4.5 Cryogenic Distribution System

Costs are fully burdened in AY $k

	Base Cost (AY $k)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining costs)	% Contingency on ETC	Total Cost
475.04 Solenoids						
475.04.05 Cryogenic System						
475.04.05 Cryogenic System Actuals	10	805	815	7		822
475.04.05.01 Power Leads	84	548	632	239	43%	871
475.04.05.02 Cryogenic Feed Boxes	2,581	1,926	4,506	1,761	39%	6,267
475.04.05.03 Cryogenic Transfer Lines	265	753	1,019	434	44%	1,452
475.04.05.04 Cryogenic Interconnects	120	438	558	194	35%	752
475.04.05.05 Insulating Vacuum System	1,059	780	1,839	613	33%	2,452
475.04.05.07 Cryogenic Distribution Box	1,046	1,307	2,354	873	37%	3,227
Grand Total	5,165	6,558	11,723	4,122	38%	15,844

Schedule



CD-3a
CD-2/3
CD-4
Fabricate and QA Superconductor
Solenoid Design
KPPs Satisfied
Solenoid Fabrication and QA
Detector Hall Construction
Solenoid Infrastructure
Solenoid Installation and Commissioning
Design and Fabrication of Feedboxes, Transfer Lines and Insulating Vacuum System
Design and Fabrication of Distribution Box
Installation
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- Preliminary design is complete.
- Resources are in place to complete the final design and specifications.
- The Cryogenic Distribution system is ready for CD-2.