WBS 475.04.05 Cryogenic Distribution

Thomas Page
Project Engineer
DOE CD-2/3b Review
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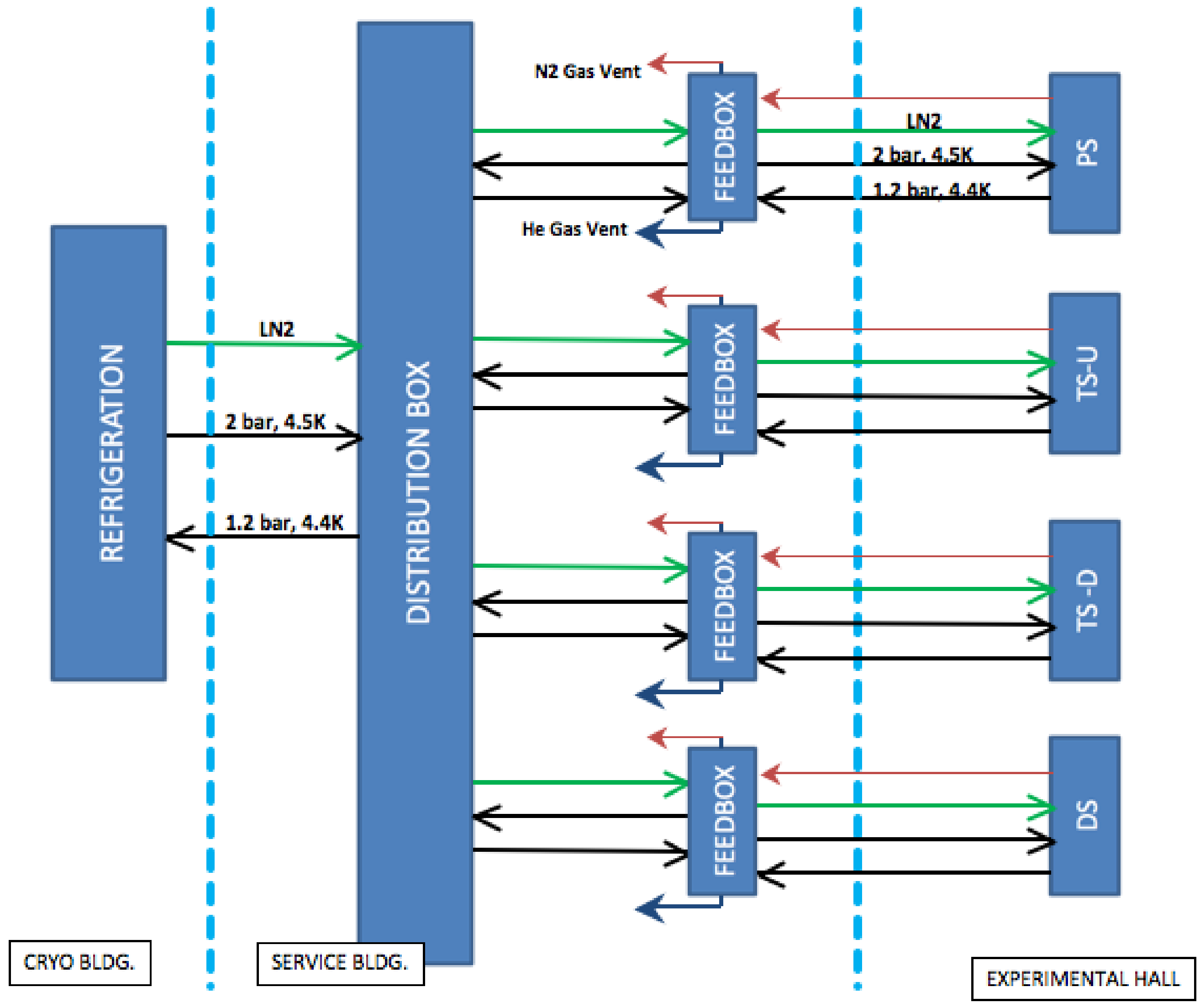
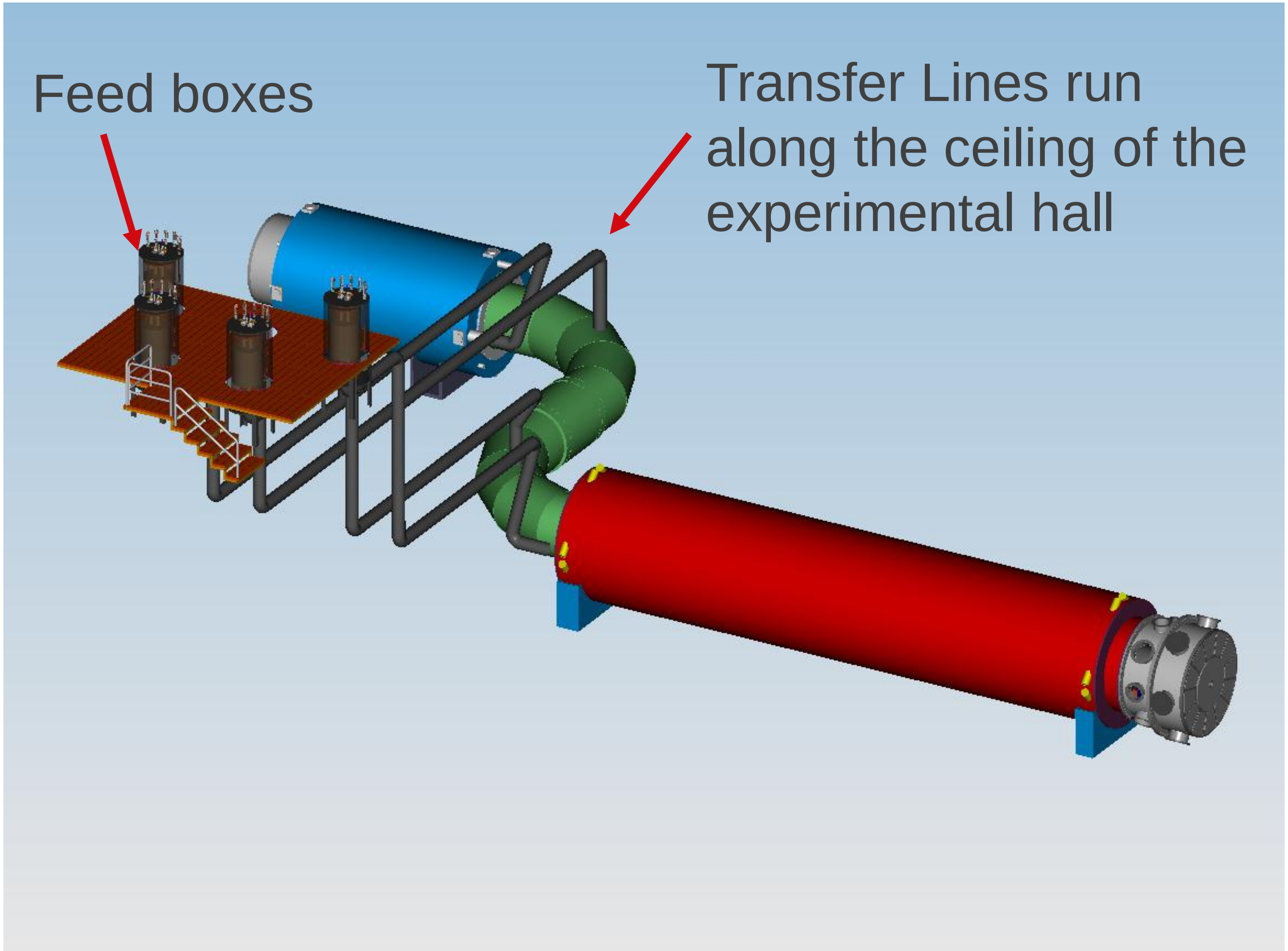
Requirements

- 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.

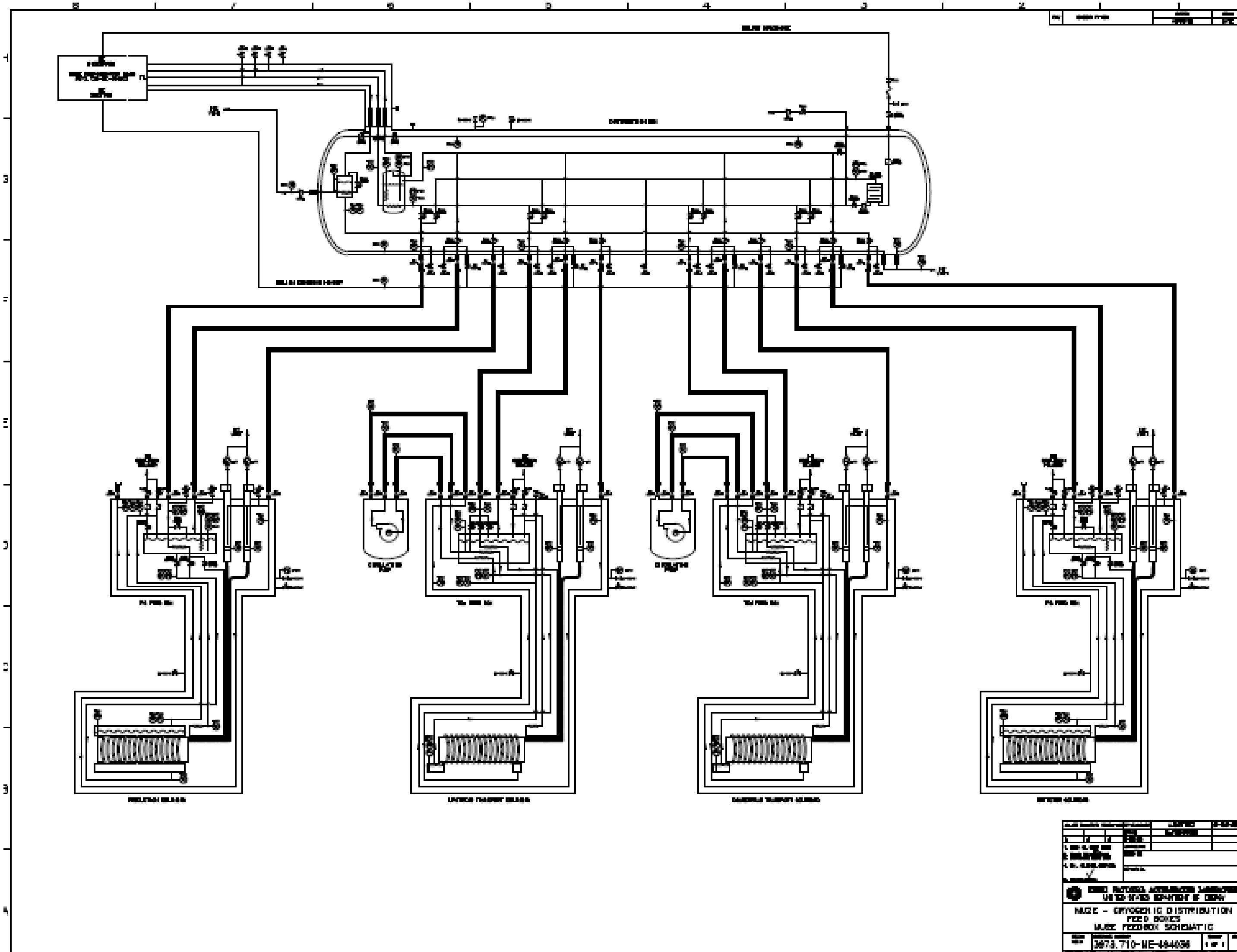
Block Diagram of Mu2e Cryogenic System



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.
- 10kA power leads for PS/DS
  - Re-purpose Tevatron HTS leads.
  - Validate each pair and reconfigure lower end for conduction cooling.

Improvements 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)	129	252	252	539	1172
80 K Feedbox and Transfer Line* Heat (W)	140	140	140	140	560
Total 80 K Heat (W)	269	392	392	679	1732
Nitrogen usage for Magnet (liquid liters/day)	148	215	215	373	951
Number of 10kA HTS Leads	2	0	0	2	4
Number of 2kA 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)	236	0	0	236	472
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	111	111	0	222

*Transfer Line length only from feedbox to magnet considered

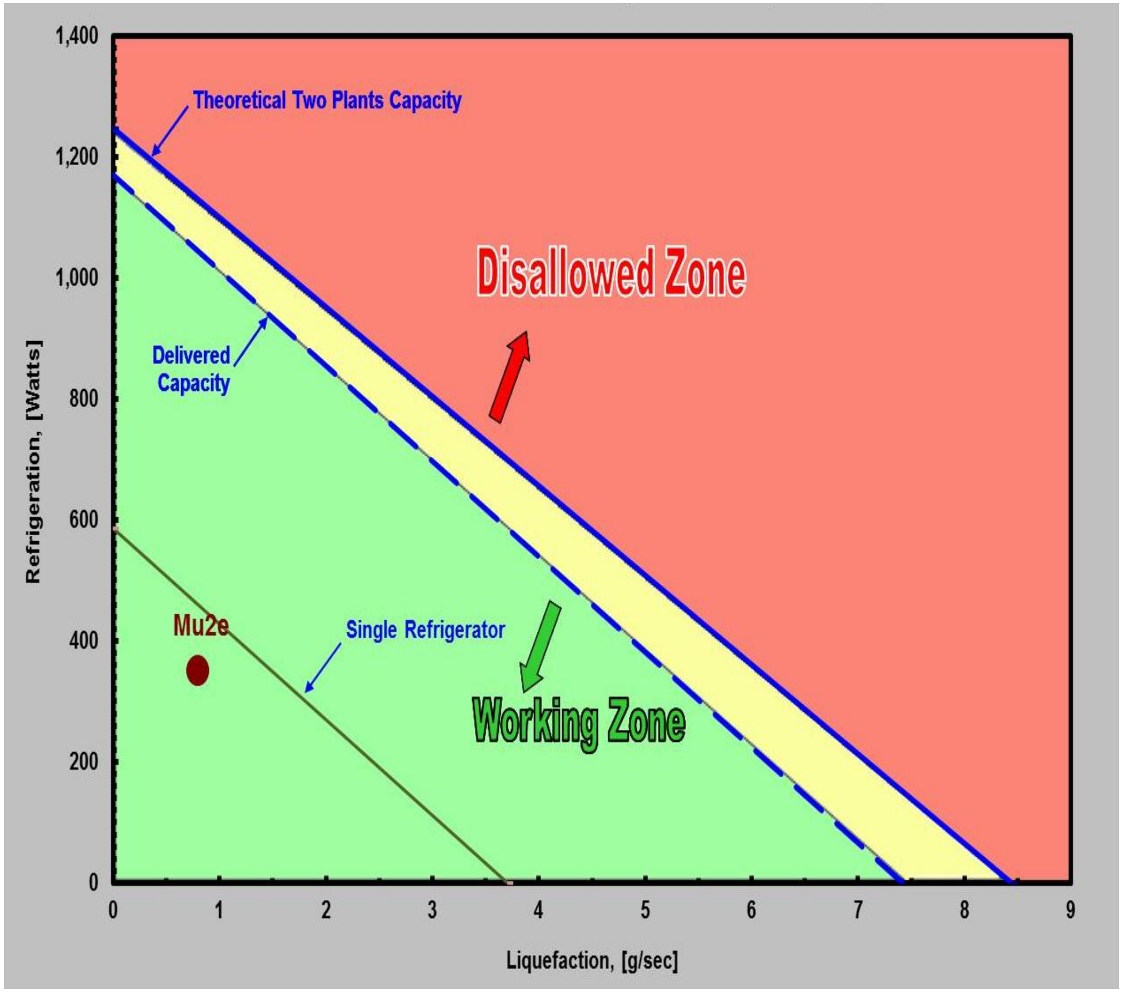
Performance – Heat Load to 4.7 K

Best Estimates (no contingency)	PS	TSu	TSd	DS	Total
Nominal Temperature			**4.7 K**		
4.7 K Magnet Heat (W)	67	44	42	32	185
4.7 K Feedbox and Transfer Line** Heat (W)	14	14	14	14	56
Thermosiphon					
Total heat load (W)	81	0	0	46	127
Total helium flow (g/s)	4.8	0	0	2.8	
3.0 bar to 2.7 bar forced flow					
Helium inlet temperature (K)		4.7	4.7		
Total heat added (W)		58	56		
Selected flow rate (g/s)		50	50		
Exit temperature (K)		4.82	4.81		
Circulating pump real work (W)		25	25		
Circulating pump system static heat (W)		15	15		
Total load for forced flow (W)	0	98	96	0	194
Total refrigerator cooling load at 4.7 K (W)					321

**Transfer Line length only from feedbox to magnet considered

Performance – One Satellite Refrigerator

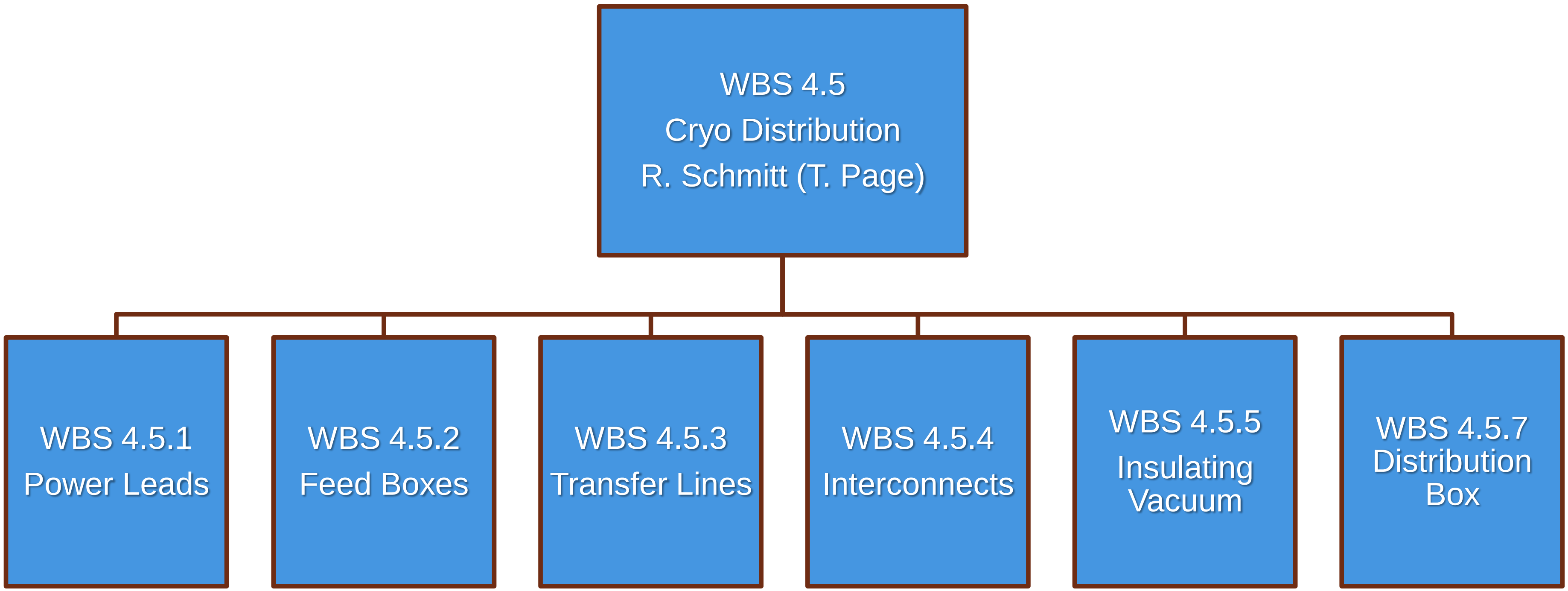
- Two satellite refrigerators dedicated to Mu2e.
- Steady state operation will utilize one refrigerator.
- Second refrigerator is used during cooldown and upset conditions.
- Refrigerators are part of the Muon Campus Cryo AIP.



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



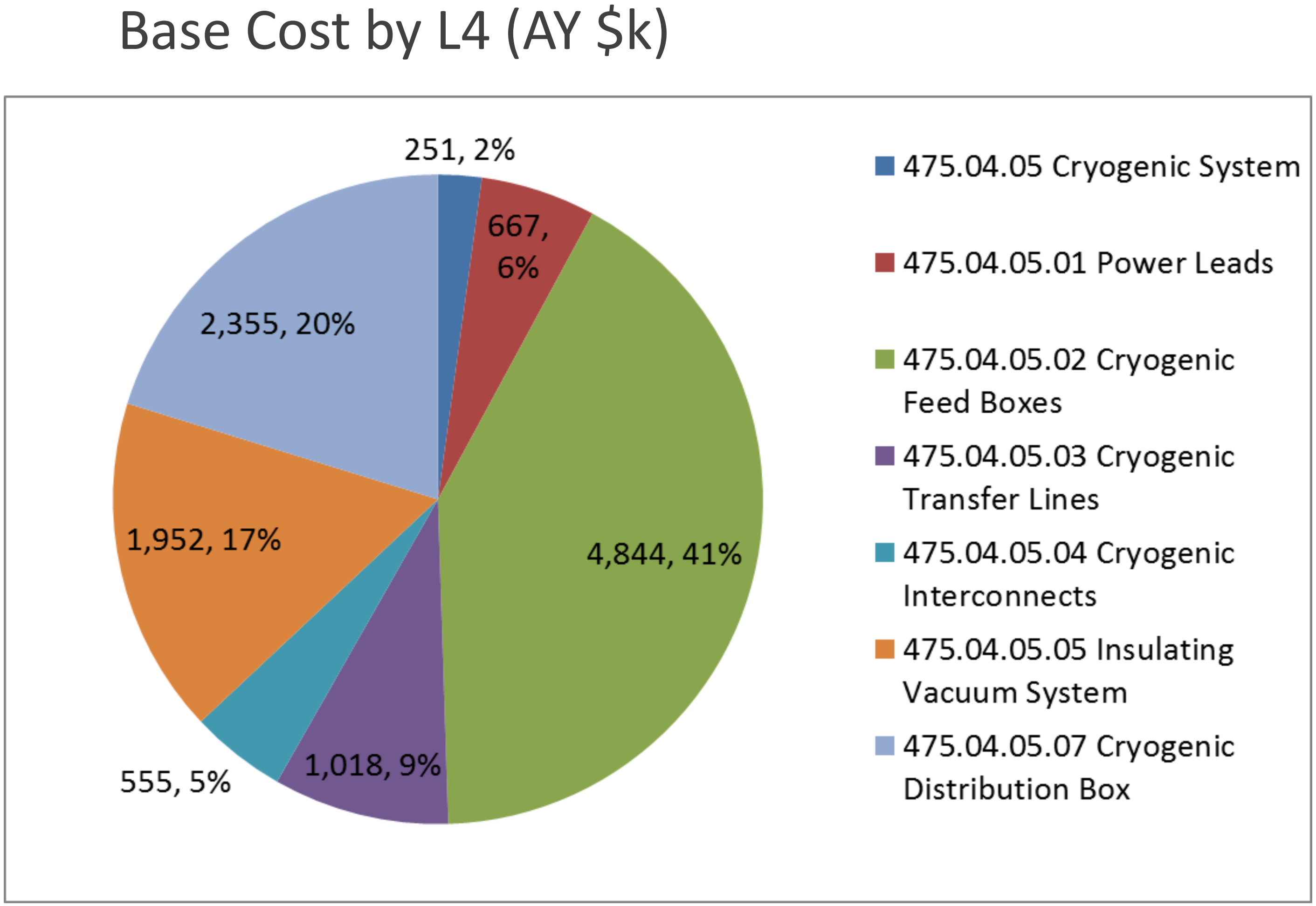
Quality Assurance

- 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.

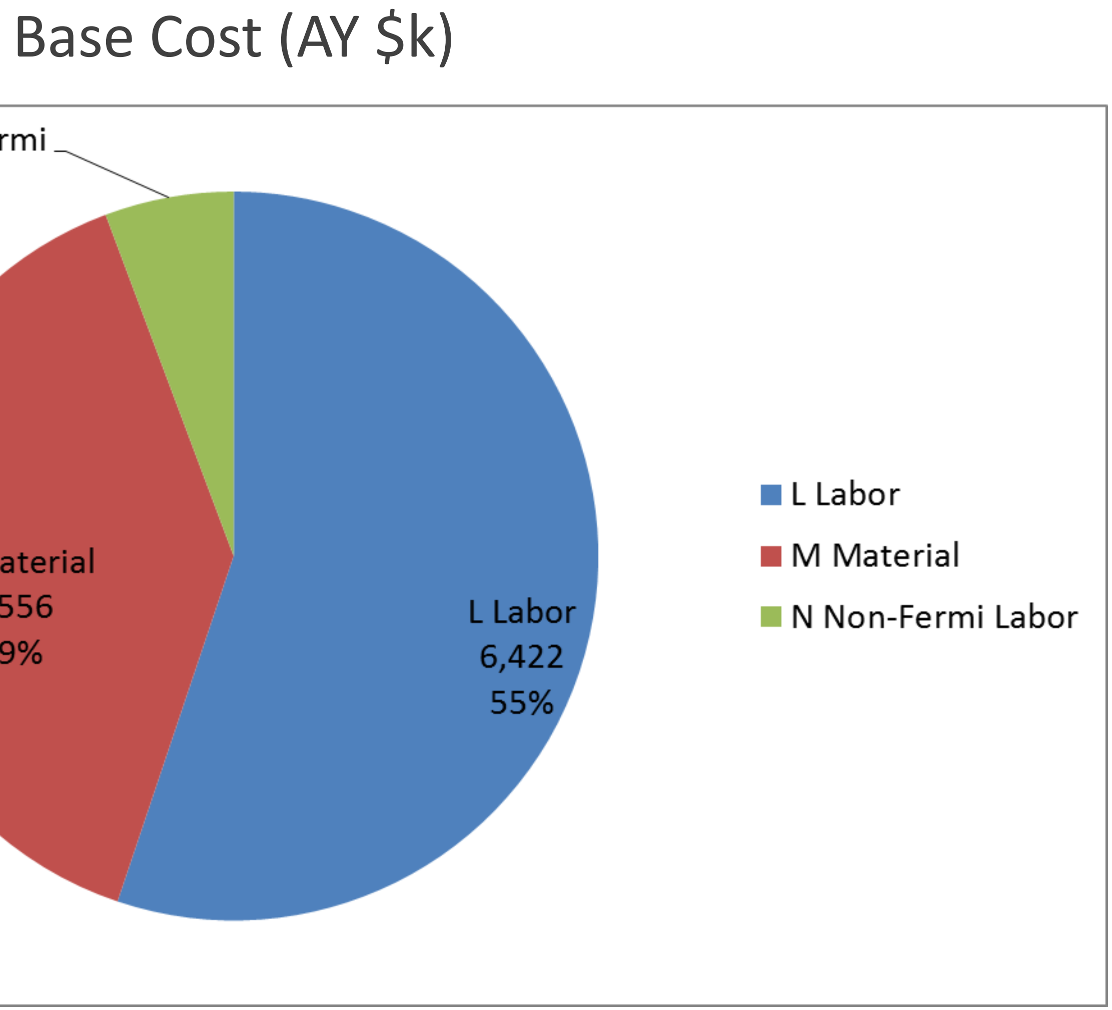
ES&H

- 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

Cost Distribution by L4

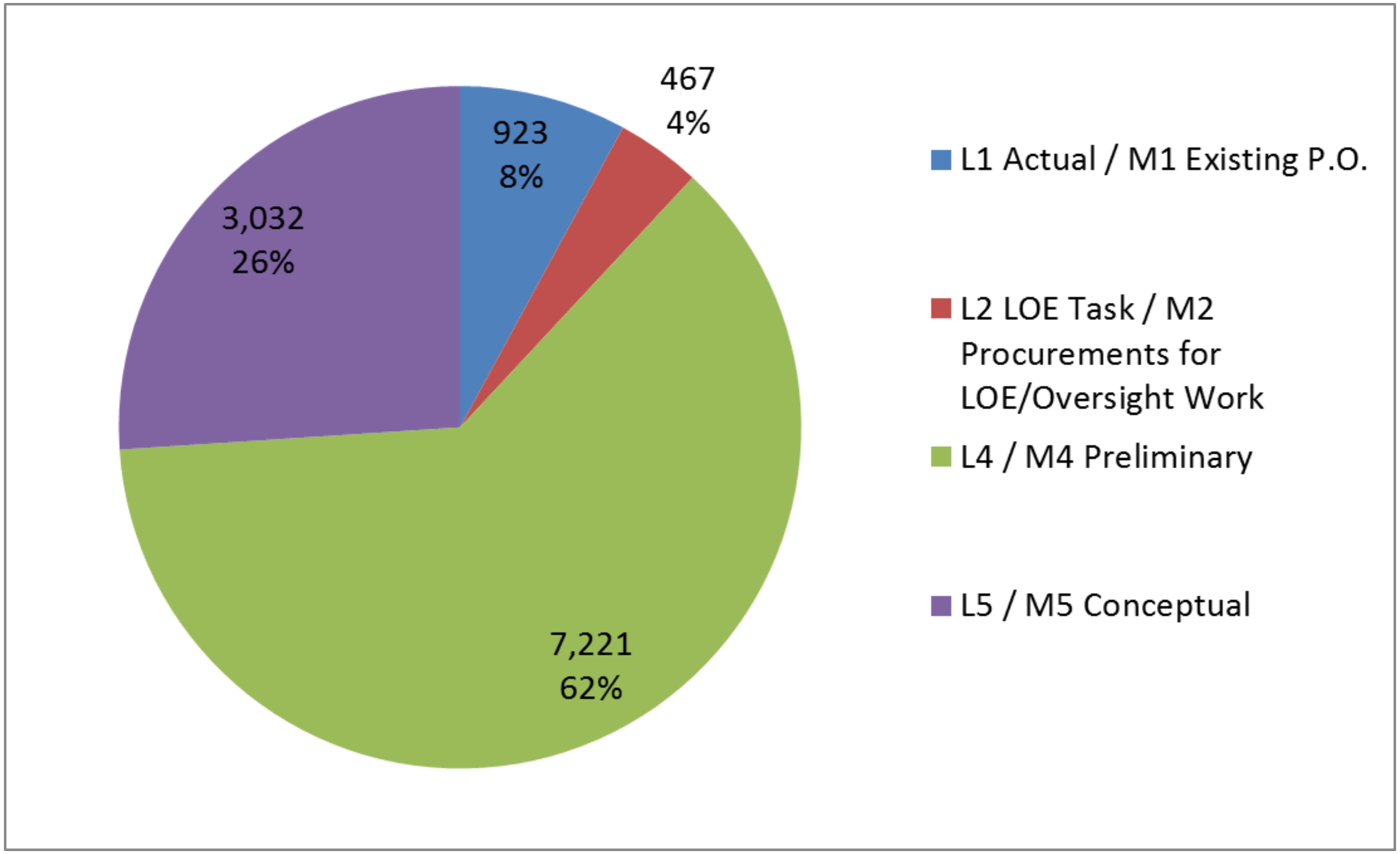


Cost Distribution by Resource Type



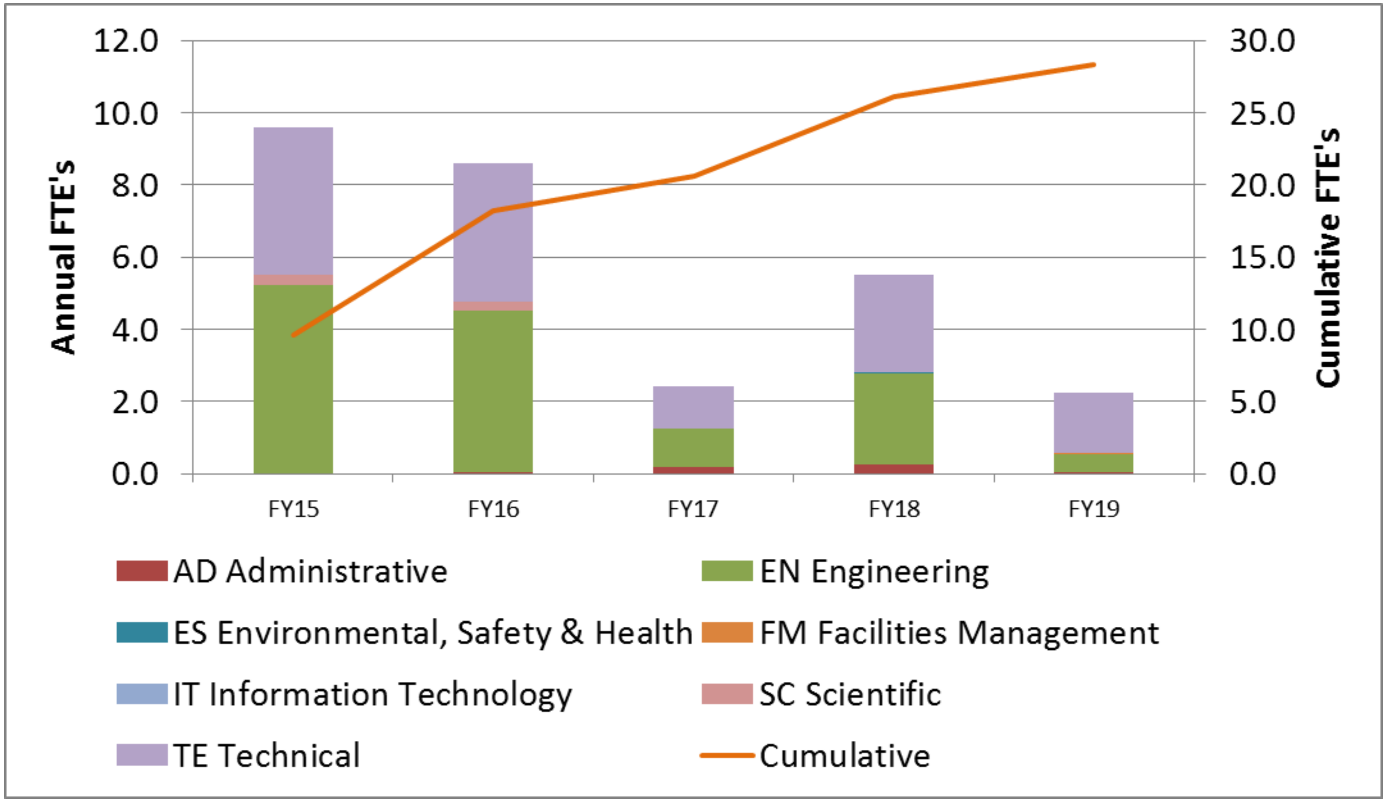
Quality of Estimate

Base Cost by Estimate Type (AY $k)



Labor Resources

FTEs by Discipline



Cost Table

WBS 4.5 Cryogenic Distribution System

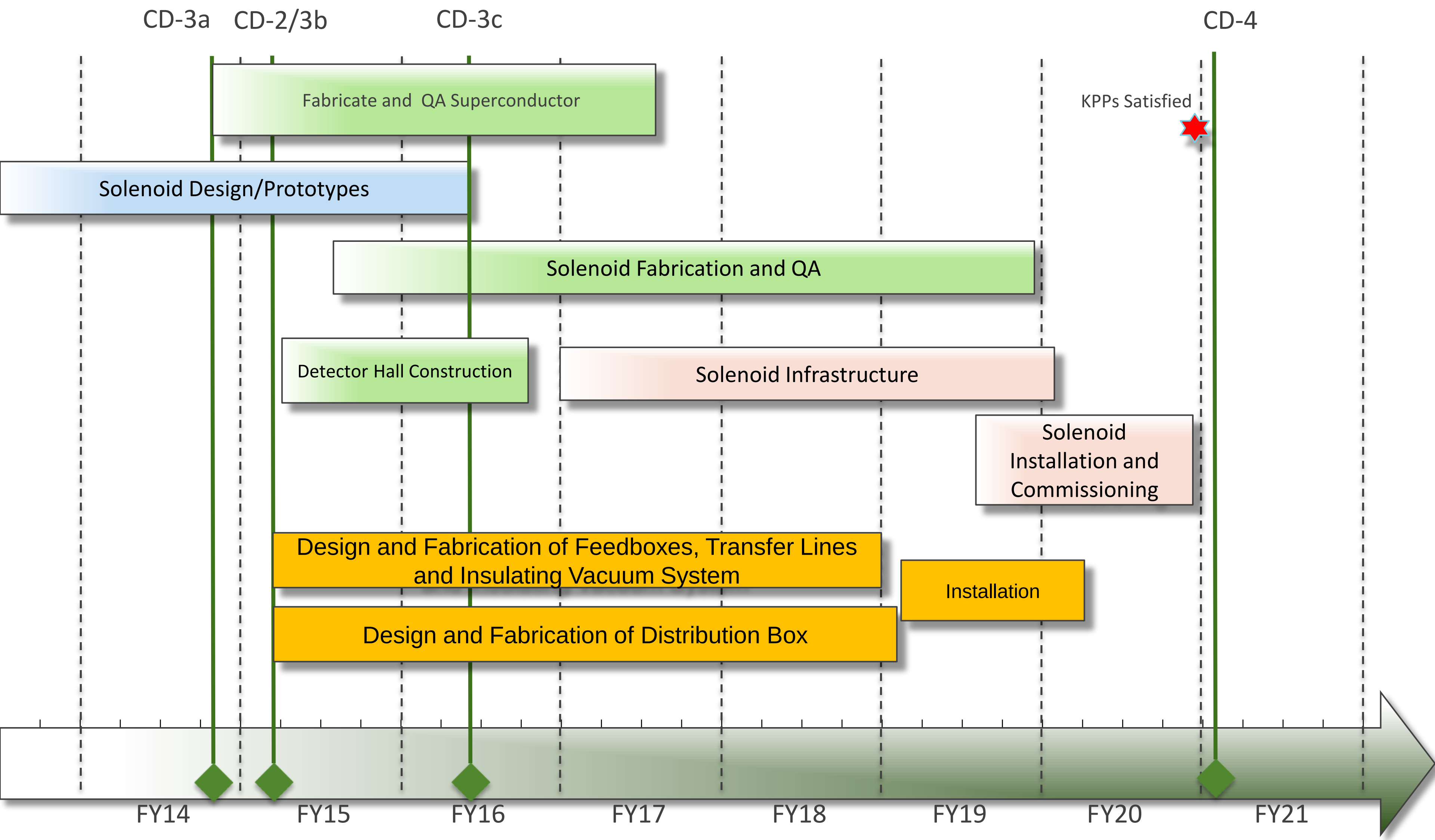
Costs are fully burdened in AY $k

	Base Cost (AY K$)					
	M&S	Labor	Total	Estimate Uncertainty (on remaining budget)	% Contingency on (on remaining budget)	Total Cost
475.04.05 Cryogenic System						
475.04.05 Cryogenic System		251	251			251
475.04.05.01 Power Leads	70	598	667	199	42%	867
475.04.05.02 Cryogenic Feed Boxes	2,596	2,248	4,844	1,734	39%	6,578
475.04.05.03 Cryogenic Transfer Lines	268	750	1,018	385	41%	1,403
475.04.05.04 Cryogenic Interconnects	121	434	555	194	36%	749
475.04.05.05 Insulating Vacuum System	1,104	848	1,952	623	33%	2,575
475.04.05.07 Cryogenic Distribution Box	1,061	1,294	2,355	874	38%	3,229
Grand Total	5,221	6,422	11,643	4,010	38%	15,652

Major Milestones

Activity ID	Activity Name	Date
47504.5.1.001106	T5 - Final design of Cryogenic System Power Leads complete	5/4/2016
47504.5.2.001125	T5 - Advanced Procurement Plan for Feed Boxes Fabrication complete	3/28/2016
47504.5.2.001330	T5 - Final design of Cryogenic Feed Boxes complete	5/13/2016
47504.5.2.001336	T5 - Vendor for Feed Boxes Fabrication selected	8/29/2016
47504.5.2.001353	T5 - Final design of Cryogenic Feed Boxes Platform complete	8/1/2016
47504.5.2.001380	T5 - Vendor for Feed Box platform Fabrication selected	10/4/2016
47504.5.2.001400	T5 - PO issued for Feed Boxes Fabrication	1/3/2017
47504.5.2.001500	T5 - PO issued for Feed Box platform Fabrication	4/25/2018
47504.5.3.001150	T5 - Final design of Cryogenic Transfer Lines complete	3/25/2016
47504.5.3.001240	T5 - Vendor for cryogenic transfer lines Fabrication selected	3/24/2017
47504.5.3.001270	T5 - PO issued for cryogenic transfer lines Fabrication	4/5/2017
47504.5.4.001140	T5 - Final design of Cryogenic Interconnects complete	6/13/2016
47504.5.5.001170	T5 - Advanced Procurement Plan for purchased vacuum system items complete	2/27/2015
47504.5.5.001220	T5 - Final design of Insulating Vacuum System complete	12/16/2015
47504.5.5.001280	T5 - Vendor for purchased vacuum system items selected	9/25/2017
47504.5.5.001300	T5 - PO issued for purchased vacuum system items	10/2/2017
47504.5.7.002090	T5 - Advanced Procurement Plan for Distribution Box Fabrication complete	9/7/2016
47504.5.7.002120	T5 - Distribution Box Final Design Complete	10/5/2016
47504.5.7.002175	T5 - Vendor for Distribution Box Fabrication selected	5/9/2017
47504.5.7.002250	T5 - Deliver Distribution Box to Mu2e Experimental Hall Complete	10/5/2018

Schedule



CD-3a
CD-2/3b
CD-3c
CD-4
Fabricate and QA Superconductor
KPPs Satisfied
Solenoid Design/Prototypes
Solenoid Fabrication and QA
Detector Hall Construction
Solenoid Infrastructure
Solenoid Installation and Commissioning
Design and Fabrication of Feedboxes, Transfer Lines and Insulating Vacuum System
Installation
Design and Fabrication of Distribution Box
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.