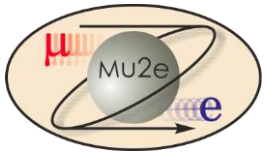
Fermilab

Mu2e CD-2 Review: Instrumentation & Controls



Brian Drendel
L3 Project Manager
10/22/2014

WBS 475.02.03 Instrumentation and Controls

- **Technical Objective**
  - The technical objective is to design and fabricate the equipment for the accelerator controls and instrumentation upgrades required for beam delivery to Mu2e. This includes implementing system that:
    - Provide Accelerator controls in the Muon Campus for Mu2e specific controls needs.
    - Provide Accelerator controls connectivity to the Mu2e Building and M4 beam line.
    - Provide instrumentation capable of measuring beam intensities, profiles and losses in the M4 beam line.
    - Provide instrumentation capable of measuring the Delivery Ring tune and Delivery Ring beam intensity.

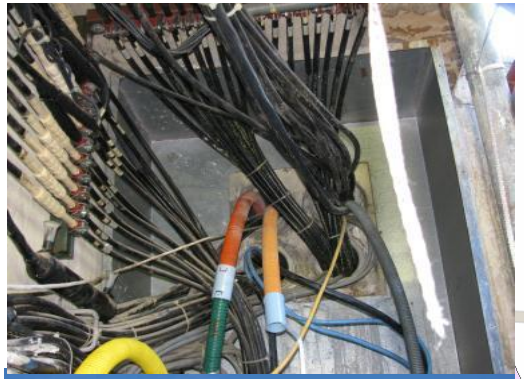
Standard Specifications: Accelerator Controls

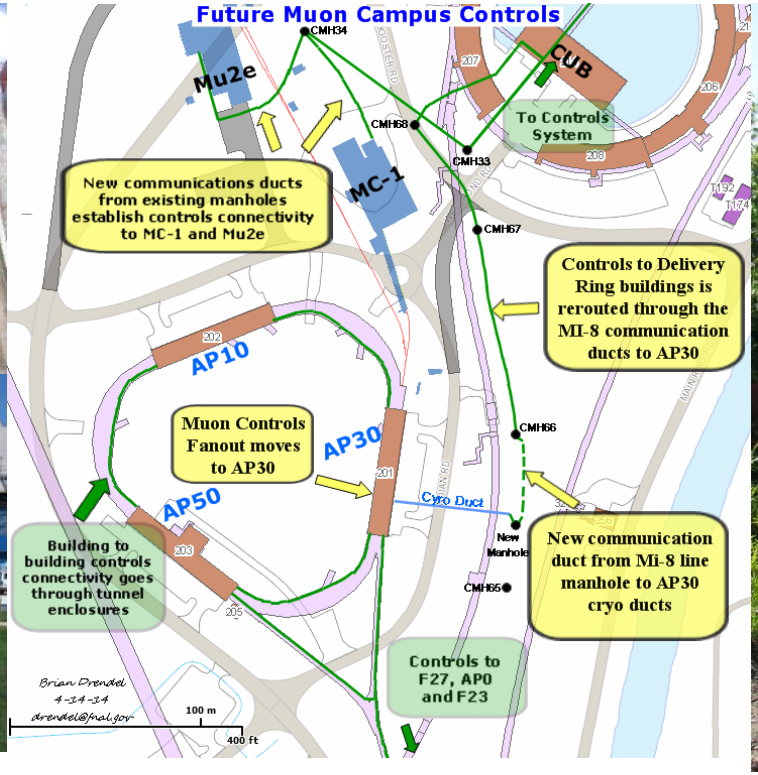
- Ethernet (Controls & General): Communicating with controls system and the outside world.
- Experiment data: > 1GB/s pipeline between Mu2e and FCC.
- Camac/HRM: Communication with ACNET controls.
- Timing Links: TCLK timing for devices.
- Beam Synch: RF synched timing for devices.
- Permit Loop: Permit for Delivery Ring beam abort.
- FIRUS: Fire and Utility system for building monitoring.
- Safety System: Interlocks and safety system for Mu2e and M4 enclosure.
- SEWs: Site Emergency Warning system.
- Radmux: Collects data from connected radiation monitors throughout the accelerator areas, beam line areas, and test areas at the Laboratory
- Phone: Hard-lined phone connection to building.

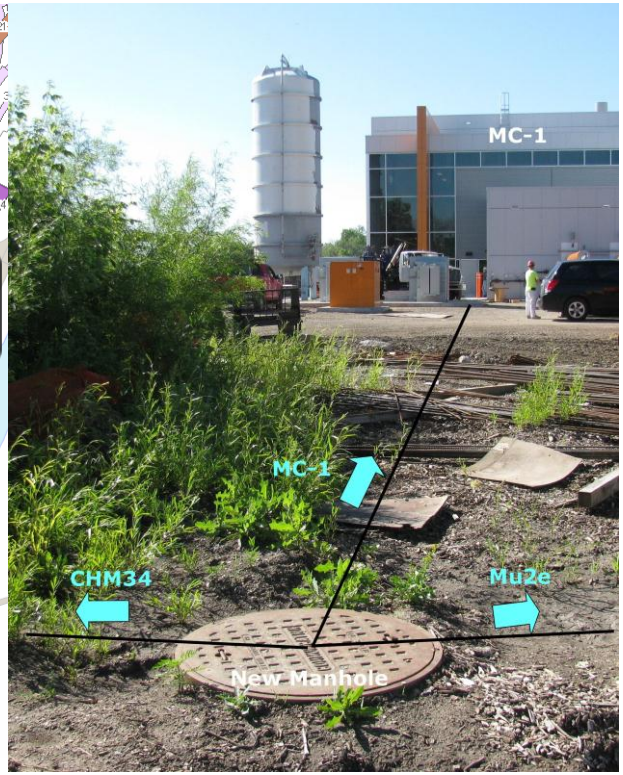
Controls Design

- This WBS covers provides the connectivity of all of the controls signals on the previous slide to Mu2e.
  - This includes everything up to any front end device in the Mu2e service building.
  - Controls needs specific to any given system are included in the costing for that system.
- Software formerly handled in the Operations Preparation WBS for CD-1 have been moved to operations since they will not be required until after project completion.
  - Any special software needs for specific systems that are needed before project closeout are covered in the costing for that system.
- Controls cable pulls and terminations have been moved to conventional construction BoE 475.03.04.05 to coordinate controls infrastructure availability with Mu2e building beneficial occupancy.

Controls Scope

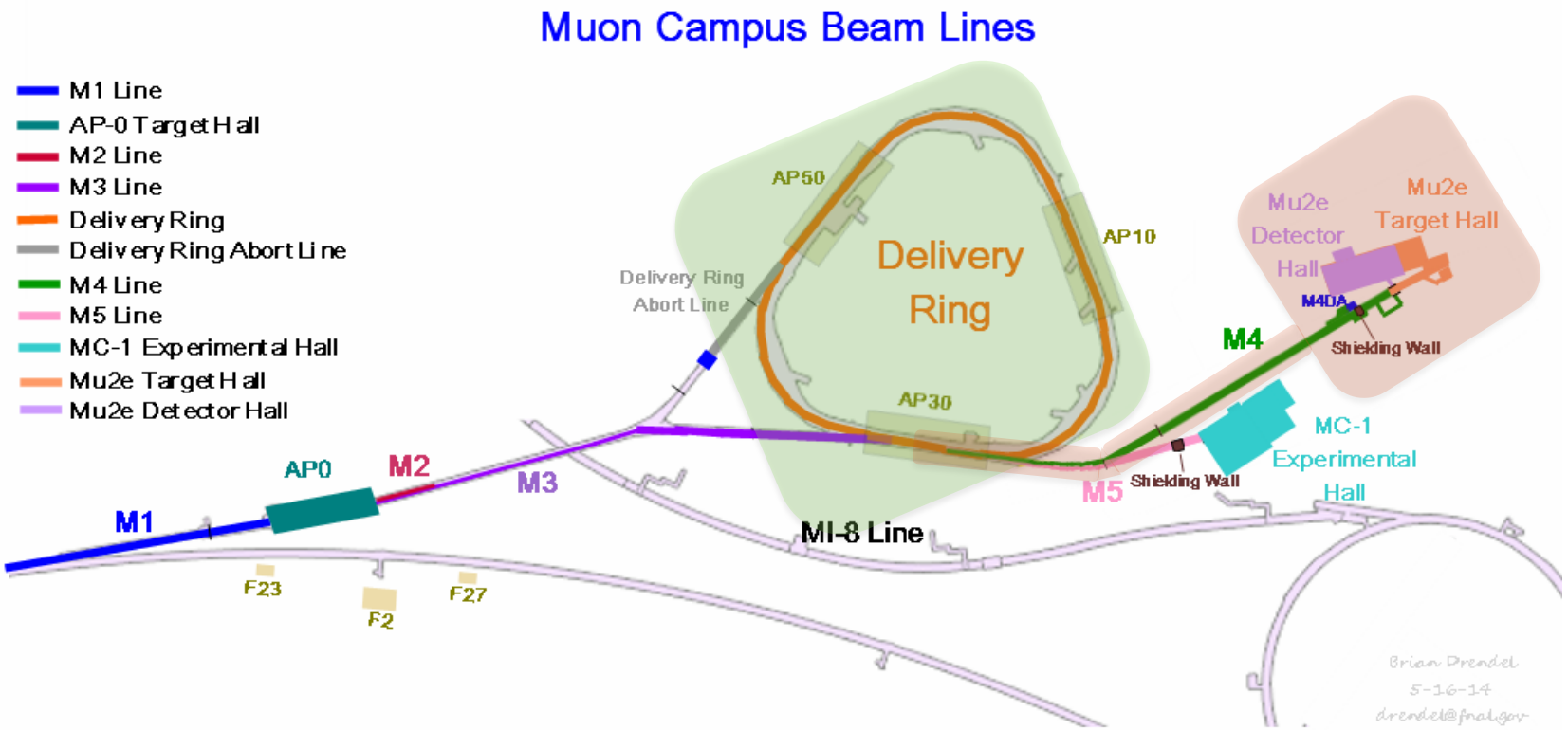






- New controls and communications connectivity will be established from the cross gallery to the Mu2e service building.
  - 96 pair bundle of single mode fiber.
  - 36 pair bundle of multi-mode fiber
  - Various multi-conductor copper cable.

Mu2e Instrumentation Scope



- Delivery Ring Protons (1E12 -> 2E10)
  - Intensity: DCCT
  - Tune: Schottky

- Extraction Line (2E7 slice every 1.69usec)
  - Intensity: Ion Chambers
  - Position/Profile: Multiwires
  - Losses: BLMs

Instrumentation Scope

- Instrumentation is funded by five different sources as shown below. The focus of this talk are the items covered under my Mu2e WBS.

Category	Instrumentation Type	Funding Source
Beam Lines (P1, P2, M1 and M3)	Toroid	Beam Line AIP
	Beam Position Monitor	Beam Line AIP
	Beam Loss Monitors	Beam Line AIP, RR AIP
	Profile Monitors	Beam Line AIP, RR AIP
Delivery Ring	**DCCT**	**Mu2e Project**
	Beam Position Monitor	Delivery Ring AIP
	Beam Loss Monitor	Delivery Ring AIP
	Tune Measurement System	**Mu2e Project**
Abort Line	Toroid/Ion Chamber	g-2 Project
	Profile Monitor	g-2 Project
	Beam Loss Monitors	Delivery Ring AIP
Extraction Line (M4 line)	**Ion Chamber**	**Mu2e Project**
	Profile Monitor	**Mu2e Project**
	Beam Loss Monitor	**Mu2e Project**

Requirements: Instrumentation

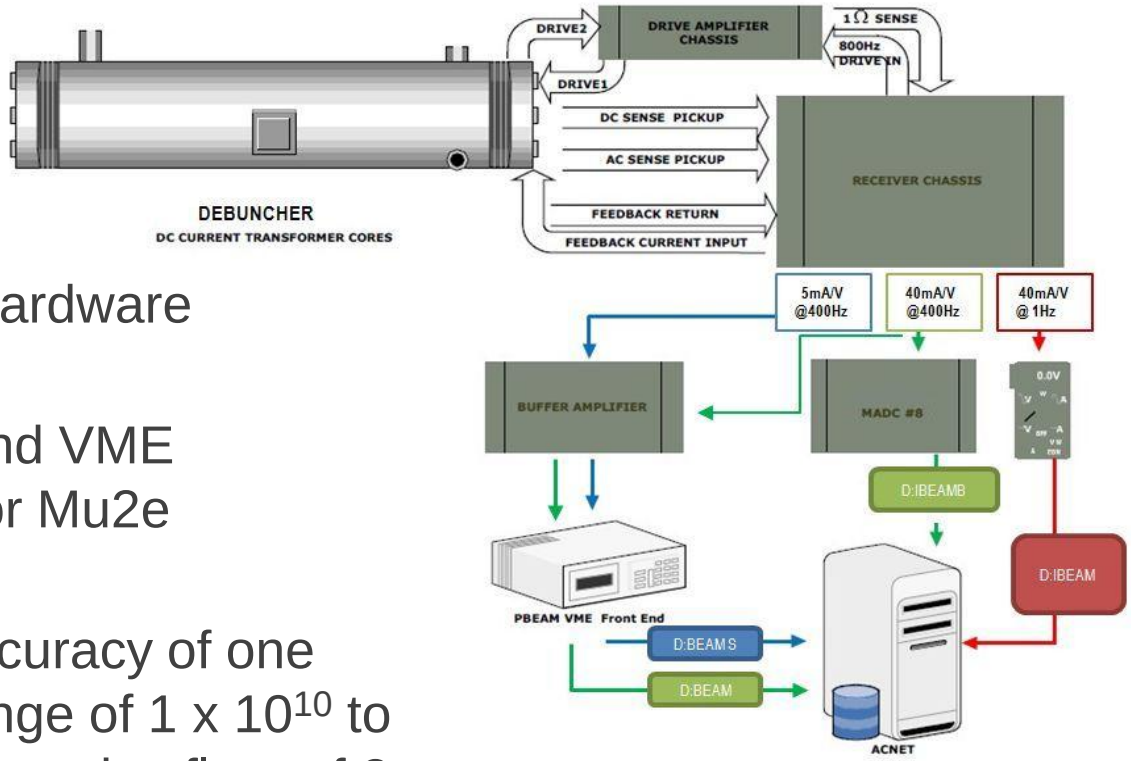
- Instrumentation designed to measure proton beam based on the Proton Beam Requirements Mu2e-doc-1105.

	Beam Line	Delivery Ring	Abort Line	Extraction
Beam Line Names	P1 Stub, P1, P2, M1, and M3	Delivery Ring	Abort Line	M4
Particles	Protons	Protons	Protons	Protons
Momentum (GeV/c)	8.88626	8.88626	8.88626	8.88626
# of Particles	1E12	1E12 -> 2E10 slow spill over 54msec	2E10 at the end of every cycle or up to 1E12 when beam permit is pulled.	Slices of 2E7 every 1.695usec totaling 1E12 over the 56msec slow spill cycle.
Bunch Length	120nsec	120 nsec	120 nsec	120 nsec
Transverse Emittance (mm-mrad)	15pi	19pi	40pi	40pi
Beam Line Length	~975m	505m	72m	244m

Delivery Ring Instrumentation Design

Measurement	Device	Beam Line	Specific Location
Intensity	DCCT	Delivery Ring	Between D1Q2 and D1Q3
Horizontal Tune	Schottky	Delivery Ring	Between D5Q3 and D5Q4
Vertical Tune	Schottky	Delivery Ring	Between D5Q2 and D5Q3

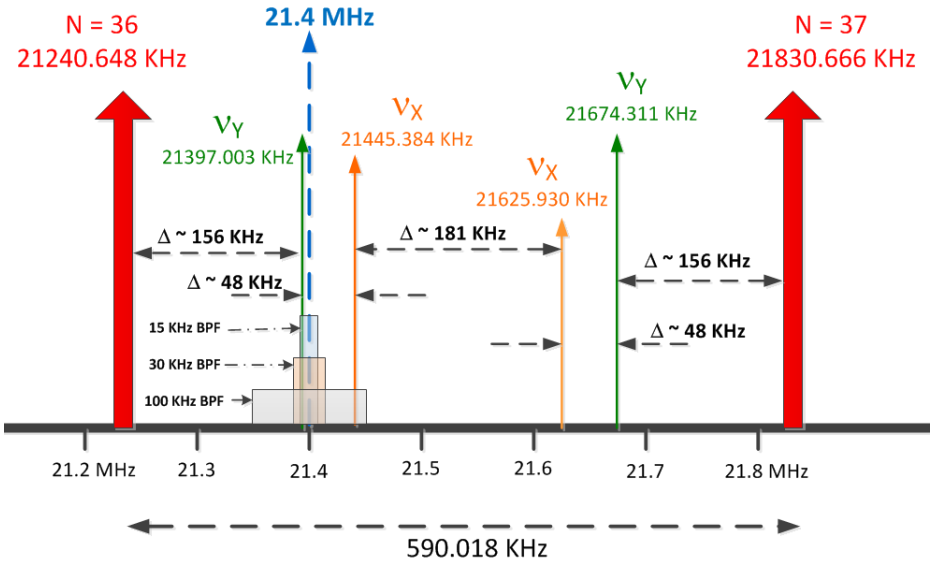
Delivery Ring Instrumentation: DCCT

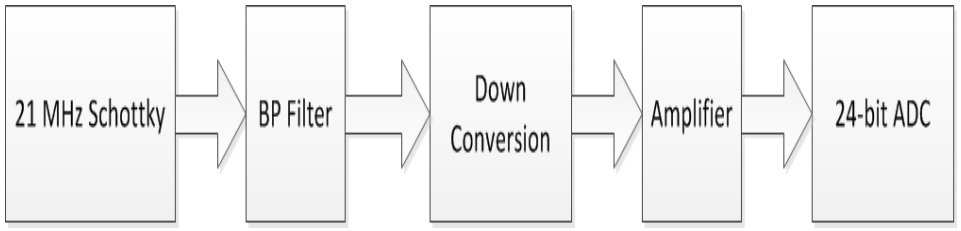


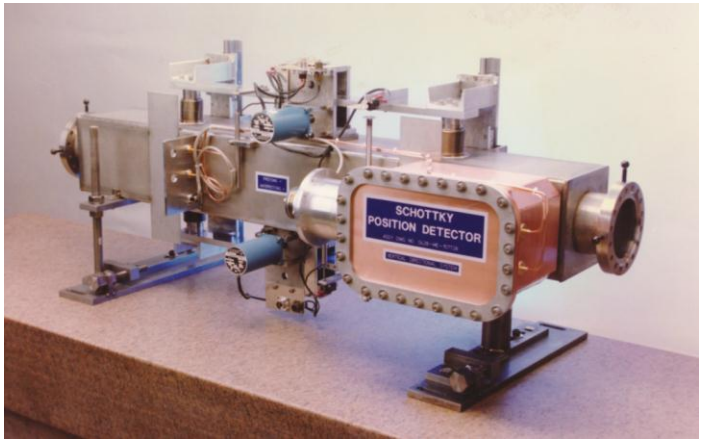
- Delivery Ring DCCT hardware repurposed.
- Analog conditioning and VME electronics modified for Mu2e operation.
- The system has an accuracy of one part in 10^5 over the range of 1×10^{10} to 2×10^{12} particles with a noise floor of 2×10^9.
- The Accumulator unit will become a working spare.

Delivery Ring Instrumentation: Tune Measurement

- Repurpose Tevatron 21.4MHz Schottky which has an acceptable aperture.
- Down convert from 36th/37th harmonics to 1st harmonic (0 to 590 KHz)
- Use 24-bit ADC to sample signal
  - 2 to 4 MHz sampling
  - 100 db dynamic range
- Use digital signal processing to produce tunes
  - Tunes to ±0.001 at 590 Hz
  - Tunes to ± 0.0001 with averaging over many spills

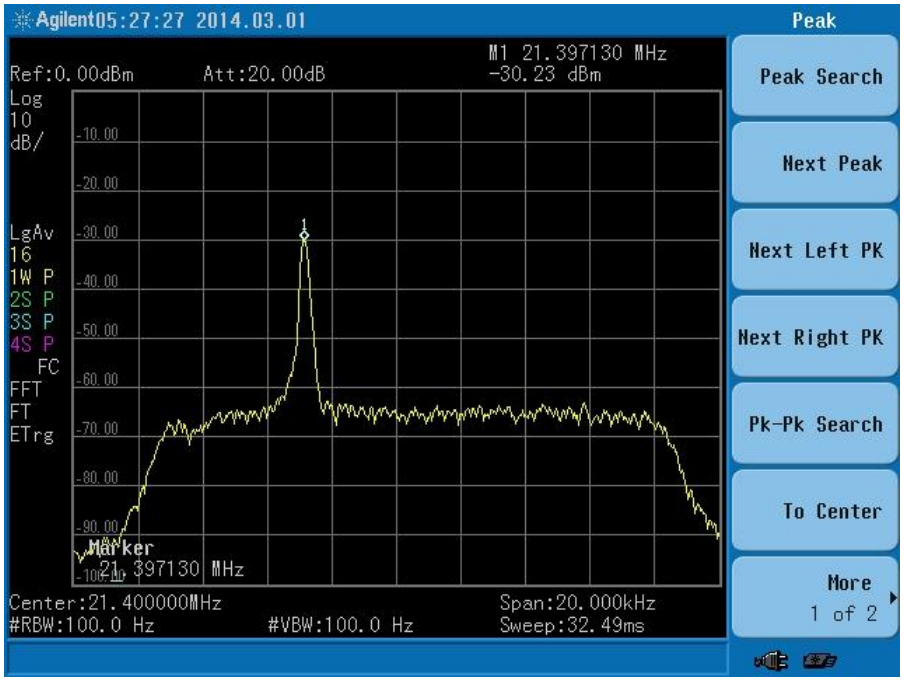


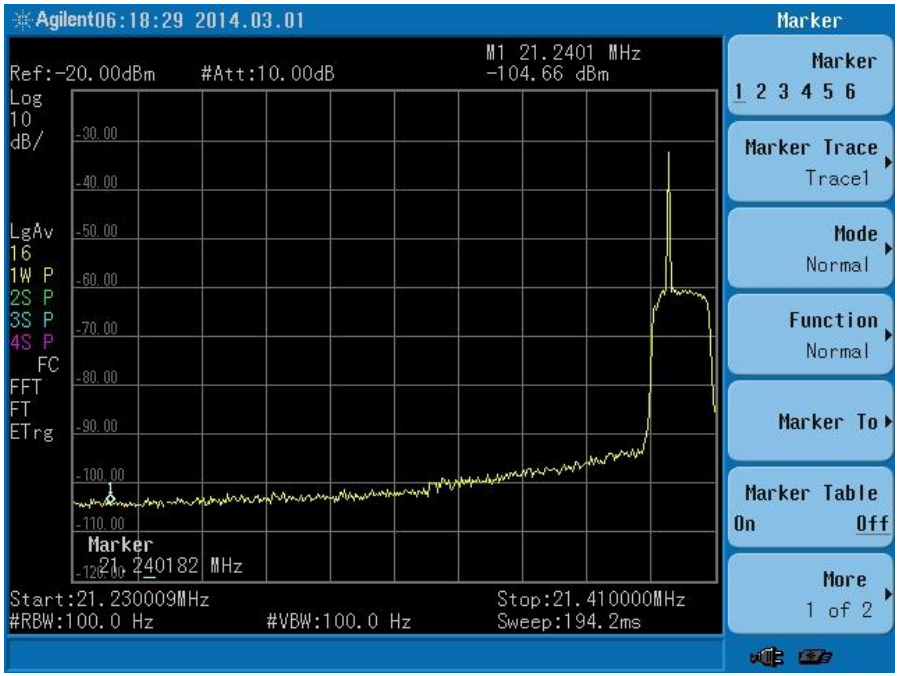




Performance: Schottky Tune Measurement

- 5.3e10 protons in Debuncher
- 21.397130 MHz is equal to a vertical tune of 0.7348
- Pbar Schottky tune was 0.7348





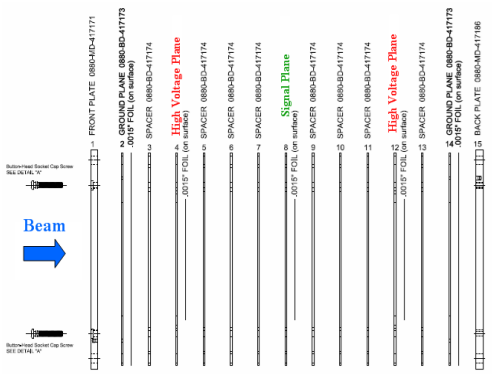
- Performance was sufficient to continue with Schottky tune measurement system.

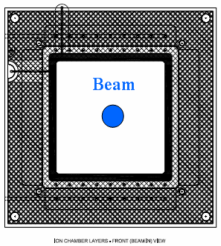
Extraction Beamline Instrumentation Design

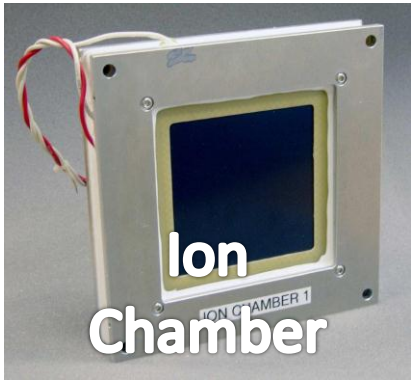
Name	Device	Beam Line	Specific Location
MW900	Multiwire	M4	Immediately downstream of c-magnet
IC901	Ion Chamber	M4	Immediately upstream of V901
MW903	Multiwire	M4	Immediately upstream of Q904
MW908	Multiwire	M4	Immediately downstream of Q908
MW910	Multiwire	M4	Immediately upstream of H910
MW914	Multiwire	M4	Immediately downstream of Q914
MW918	Multiwire	M4	Immediately downstream of H918
MW928A/B	Multiwire	M4	*Each side of extinction collimator at 928
MW932A/B	Multiwire	M4	*Each side of extinction collimator at 932
MW921A/B	Multiwire	M4	Each side of AC Dipole
MW936A/B	Multiwire	M4	*Each side of extinction collimator at 936
IC938	Ion Chamber	M4	Immediately upstream of Q939
MW945A/B	Multiwire	M4	*Each side of shielding wall near the Diagnostic Absorber
MW947	Multiwire	M4	Immediately downstream of Q947
MW950	Multiwire	M4	Immediately downstreamof IC950
IC950	Ion Chamber	M4	Immediately downstream of Q950
MW952	Multiwire	M4	Immediately downatream of HT952

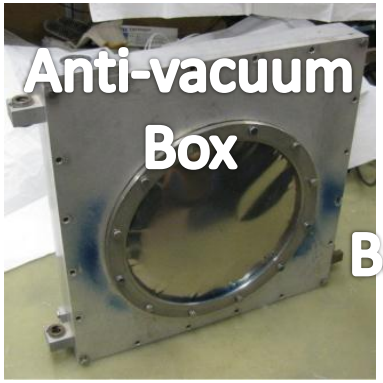
*Two profile monitors used on either side of the collimators only for commissioning and later moved to other locations.

Extraction Instrumentation: Ion Chambers





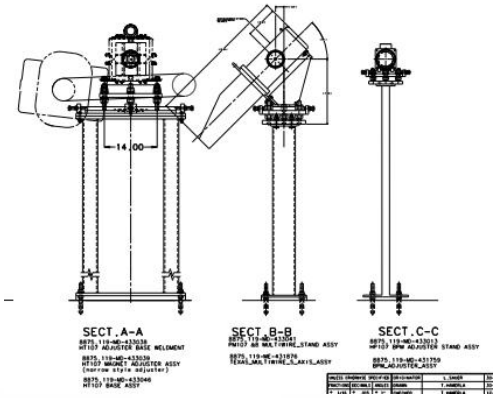


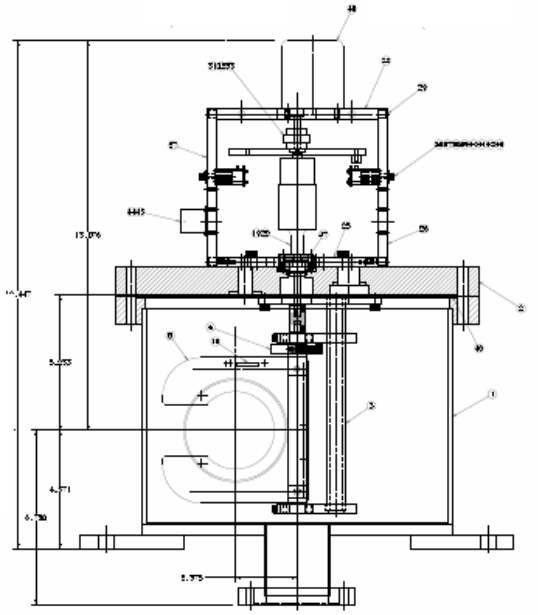


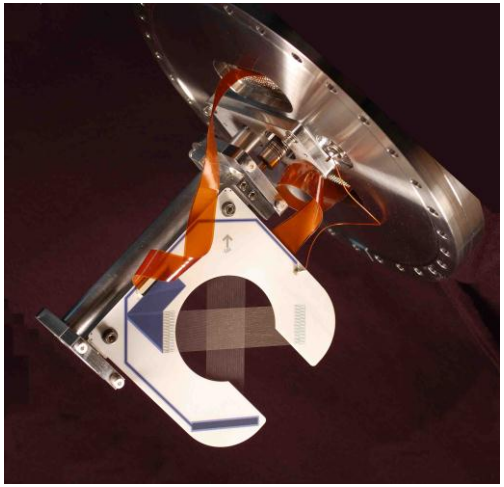
- Ion chamber uses prototype FNAL design.
- The ion chamber to fit in existing anti-vacuum box.
- The anti-vacuum boxes will be installed inside of bayonet vacuum vessels that are being repurposed from Switchyard
- The bayonet type drive slides the ion chamber linearly into and out of the beam with a screw drive system.
- The detector linear drive shaft is housed in a collapsible bellows that seals it from atmosphere.

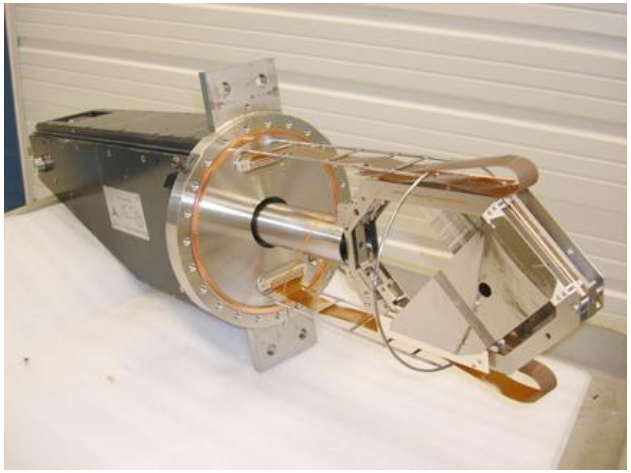
Extraction Instrumentation: Multiwires

- NuMI multiwire design used with a gap in the ceramic that allows the wires to be moved into and out of the beam while beam is running.
- New vacuum cans will be constructed based on the NuMI design.
- 11 available Texas Multiwire cans will be repurposed.









Extraction Instrumentation: BLMs

- The M4 Line Beam Loss Monitor (BLM) system has been designed to measure a 0.2% localized loss with microsecond integration.
- This will allow seeing losses develop inside of an individual slow spill.
- 30 BLMs will be placed at key locations along the 245m beam line.
- This system design is identical to the existing Main Injector, P1, P2, M1 and M3 line BLM systems.
- There is not a sufficient pool of spare hardware and electronics so new parts will need to be purchased and constructed to build the system.

Changes since CD-1

Controls

- Pull additional fiber optic channels to the Mu2e service building to cover necessary signals and future expansion.
- Additional items covered in Value Engineering Slide.

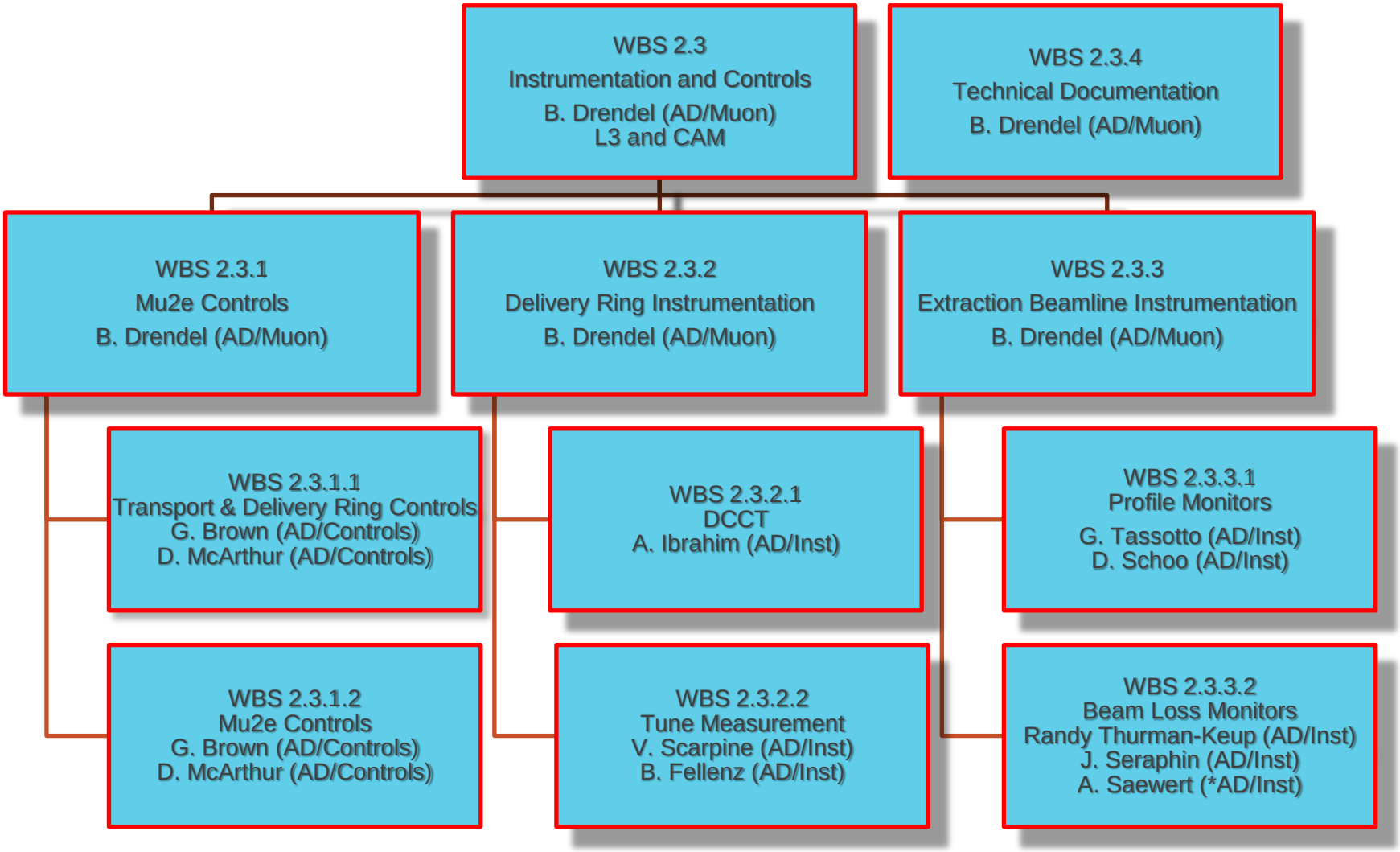
Instrumentation

- Covered in Value Engineering Slide.
- Two additional multiwires, one just upstream of the target and one just downstream of the target were added to my scope.

Value Engineering since CD-1

- Controls
  - Splice into nearby existing phone lines to save on costly cable pulls and/or VOIP installations.
- Instrumentation
  - Tune Measurement
    - Repurpose Tevatron Schottky detectors for our tune measurement system.
  - M4 Line Profile Monitors
    - Changed type of profile monitor in the M4 line to save on labor and refurbishment costs
    - Use ANU multiwire design for M4 line multiwires.
    - Repurpose Texas Multiwire vacuum cans for our M4 line multiwires
    - Reduced amount of external beamline instrumentation by allowing for the early use of final focus section instrumentation for commissioning the extinction section.
  - Retractable Ion Chambers
    - Repurpose Switchyard Bayonet vacuum cans for ion chambers.
    - Modify PWC design to fit ion chamber.
  - M4 Line beam loss monitors.
    - Use log amp system for BLM electronics. No engineering time required.

Organizational Breakdown



Quality Assurance: Controls

- **Use of Government Lab and Project QA Standards**
  - Fermilab Engineering Manual http://www.fnal.gov/directorate/documents/FNAL_Engineering_Manual.pdf
  - Fermilab's Integrated Quality Assurance Program https://esh-docdb.fnal.gov:440/cgi-bin/RetrieveFile?docid=2469
  - Mu2e Quality Management Plan http://mu2e-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=677.
  - Mechanical Engineering QA practices, policy and procedures http://mu2e-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=4646
- **Quality Assurance for Controls**
  - All innerduct and cable pulls will be completed by contract electricians under the direction of Accelerator Division management.
  - Fiber optic terminations will be completed by contract electricians, safety system cable terminations will be managed by FNAL ES&H personnel, and phone cable termination will be managed by Business services section, telecommunications department.
  - All controls links, FIRUS configuration and network connections work will be managed by Accelerator Division Controls Department personnel.
  - All parts are expected to be procured by FNAL personnel and inspected before being installed. Final testing and calibration of controls devices will be performed by FNAL technical staff before locating equipment in the service buildings.
- **Quality Assurance for Instrumentation**
  - Repurposing, design, upgrading, building and commissioning of M4 line instrumentation will be completed by qualified Accelerator Division Instrumentation and Controls Department Engineers and Technicians under the direction of Instrumentation and Muon Department management.
  - All necessary parts will be procured by FNAL personnel and inspected by qualified Instrumentation engineers or technicians prior to installation.
  - Final testing of instrumentation devices will be performed by FNAL technical staff before devices are installed.
  - Controls checkout and beam commissioning of each device will be completed by qualified Instrumentation, Controls and Muon Department technical staff.

Risks

- ACCEL-015 Injection Damper Required for Delivery Ring
  - ◊ Orbit control in the beam lines may not adequately control trajectory and may lead to excessive emittance dilution.
  - ◊ Note: Delivery Ring injection will be made to work for g-2 before the need for Mu2e.
  - ◊ Threat: $240K
  - ◊ Mitigation: If beam studies indicate instabilities of injected beam into the Delivery Ring, an injection damper system will be developed.
- ACCEL-140 Proton Beam not available for FY'13 beam studies
  - ◊ Beam studies in the Delivery Ring are scheduled in order to understand and address various technical concerns associated with the delivery of beam to Mu2e. These beam studies can only be performed when the Lab is operating the accelerator system.
  - ◊ **Threat Retired**: Beam studies were completed.

ES&H

Tunnel Enclosures and Service Buildings

- Electrical hazards from exposed bus work and high voltage connectors.
- Mechanical hazards (sharp edges, protruding fixtures)
- Radiation hazards
  - Potentially lethal doses during beam operation
  - Residual radioactivity after beam operations
  - Radioactive surface and air contamination

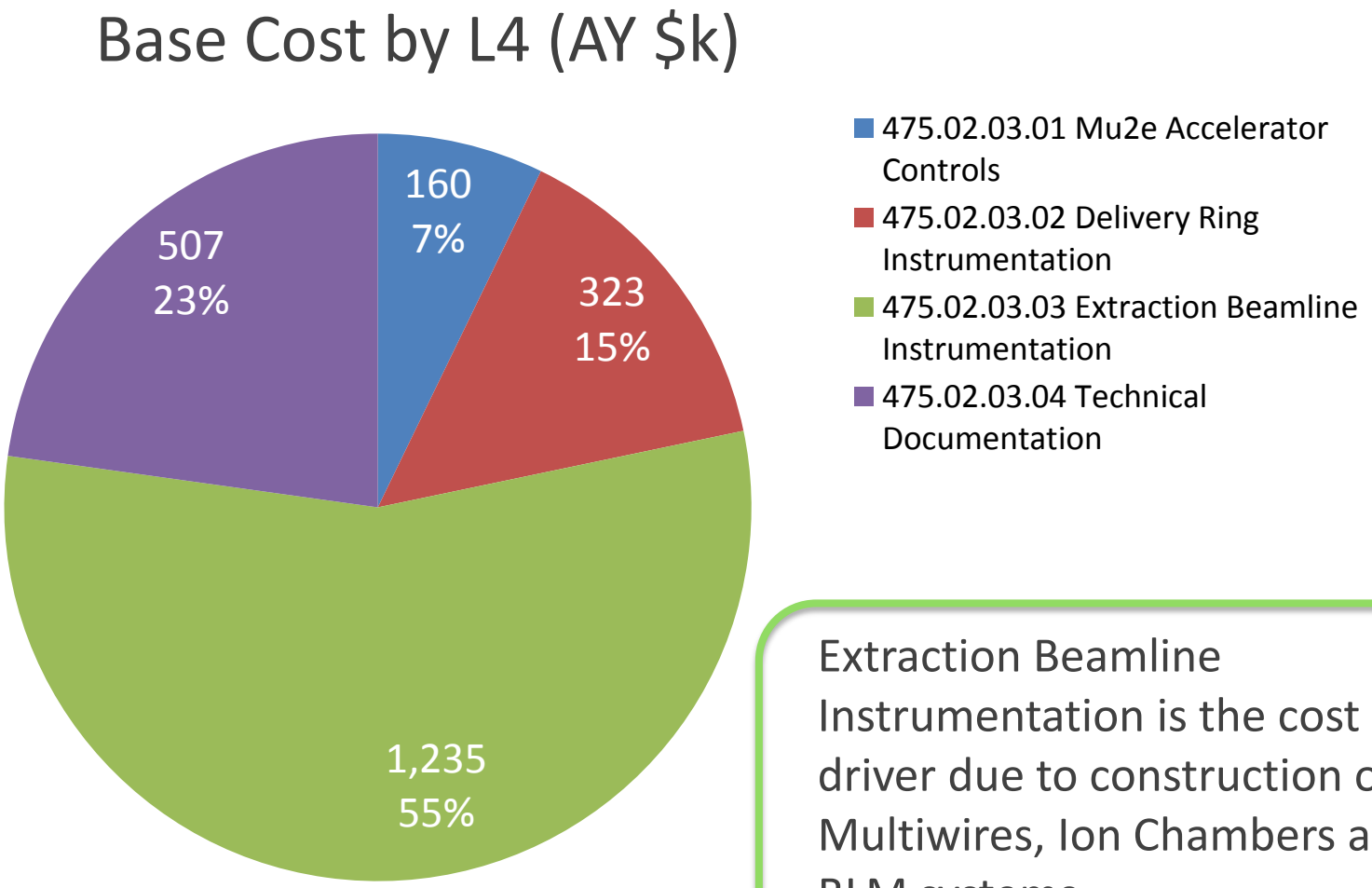
Laboratory ES&H

- Instrumentation and controls systems will all be implemented within the guidelines documented in the Fermilab Environment, Safety and Health Manual (FESHM) which can be found online at http://esh.fnal.gov/xms/FESHM.
  - Laboratory safety practices will be observed for all work.
  - Job hazard analyses will be performed for installation and other appropriate work.

Mu2e ES&H

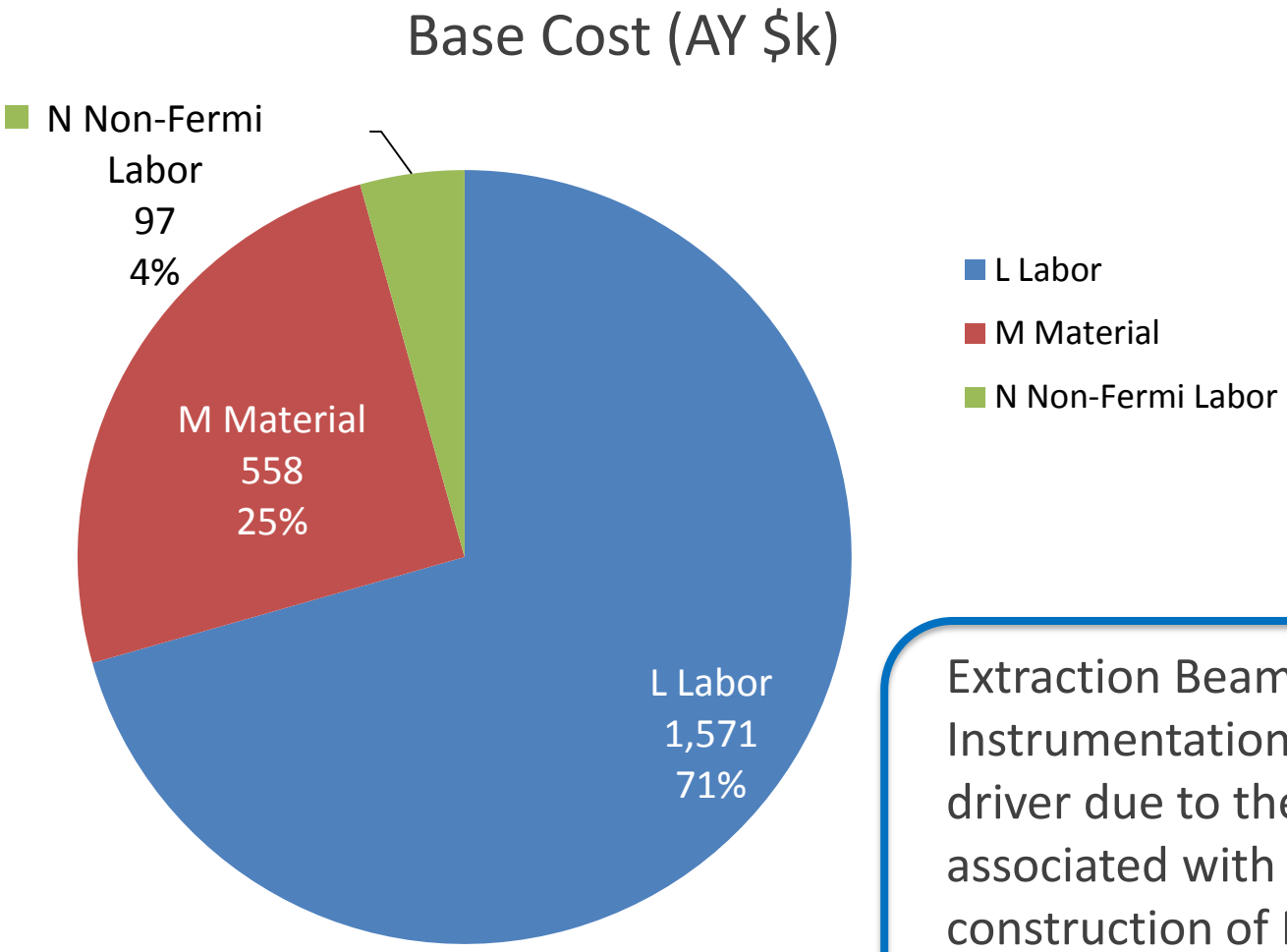
- All hazards in this WBS are covered in the Mu2e Hazard Analysis Report document Mu2e-doc-675 (http://mu2e-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=675).

Cost Distribution by L4



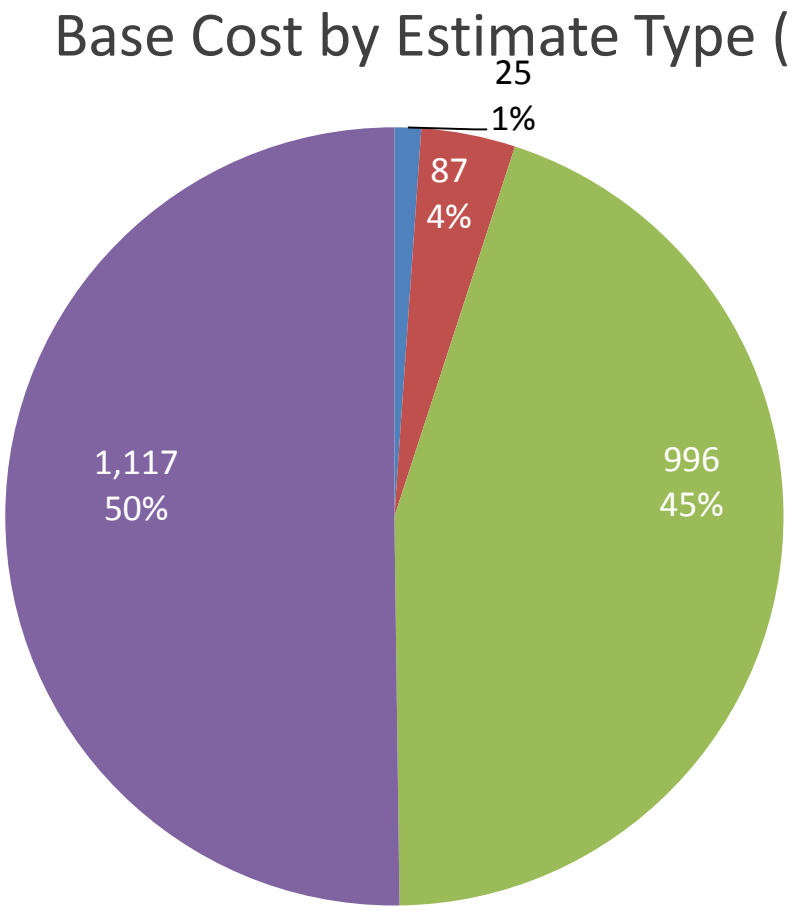
Extraction Beamline Instrumentation is the cost driver due to construction of Multiwires, Ion Chambers and BLM systems.

Cost Distribution by Resource Type



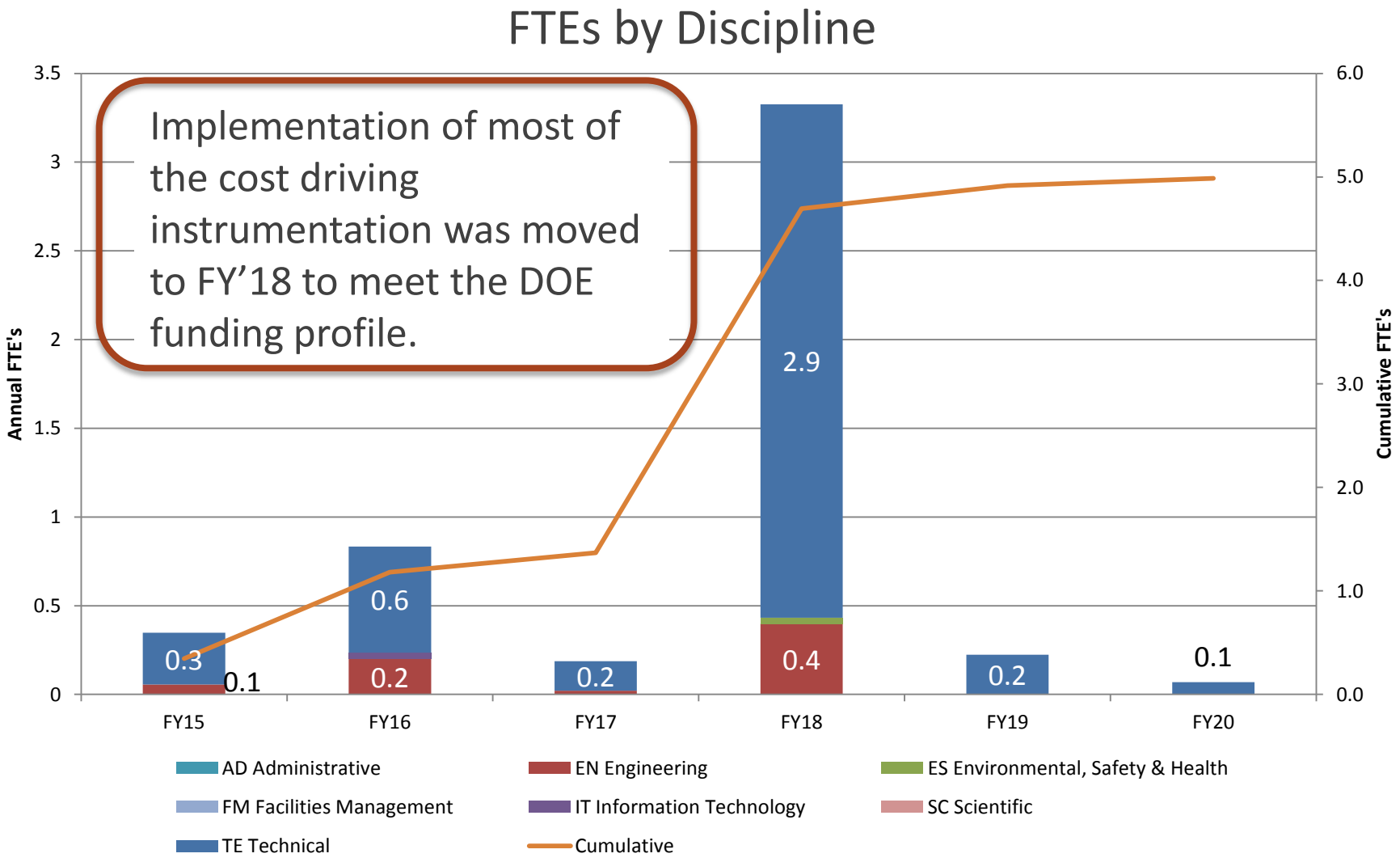
Extraction Beamline Instrumentation is the cost driver due to the labor costs associated with the construction of Multiwires, Ion Chambers and BLM systems.

Quality of Estimate

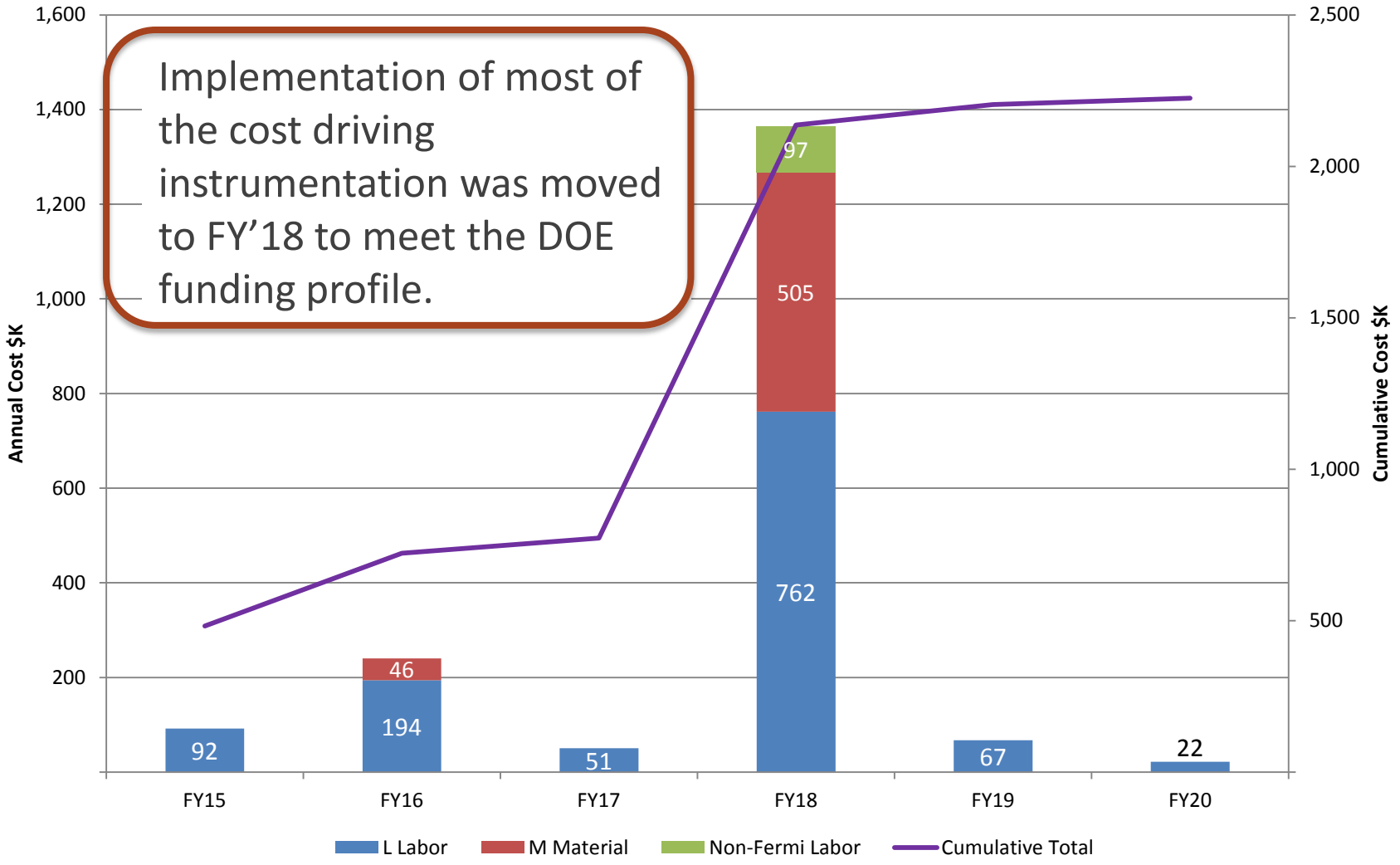


100% of estimates are at the preliminary level or better. Most of the preliminary estimates will be at the advanced level by the time of the DoE CD-3 review.

Labor Resources



Labor and Material Breakdown



Cost Table

WBS 2.3 Instrumentation and Controls — Base Cost (AY K$)

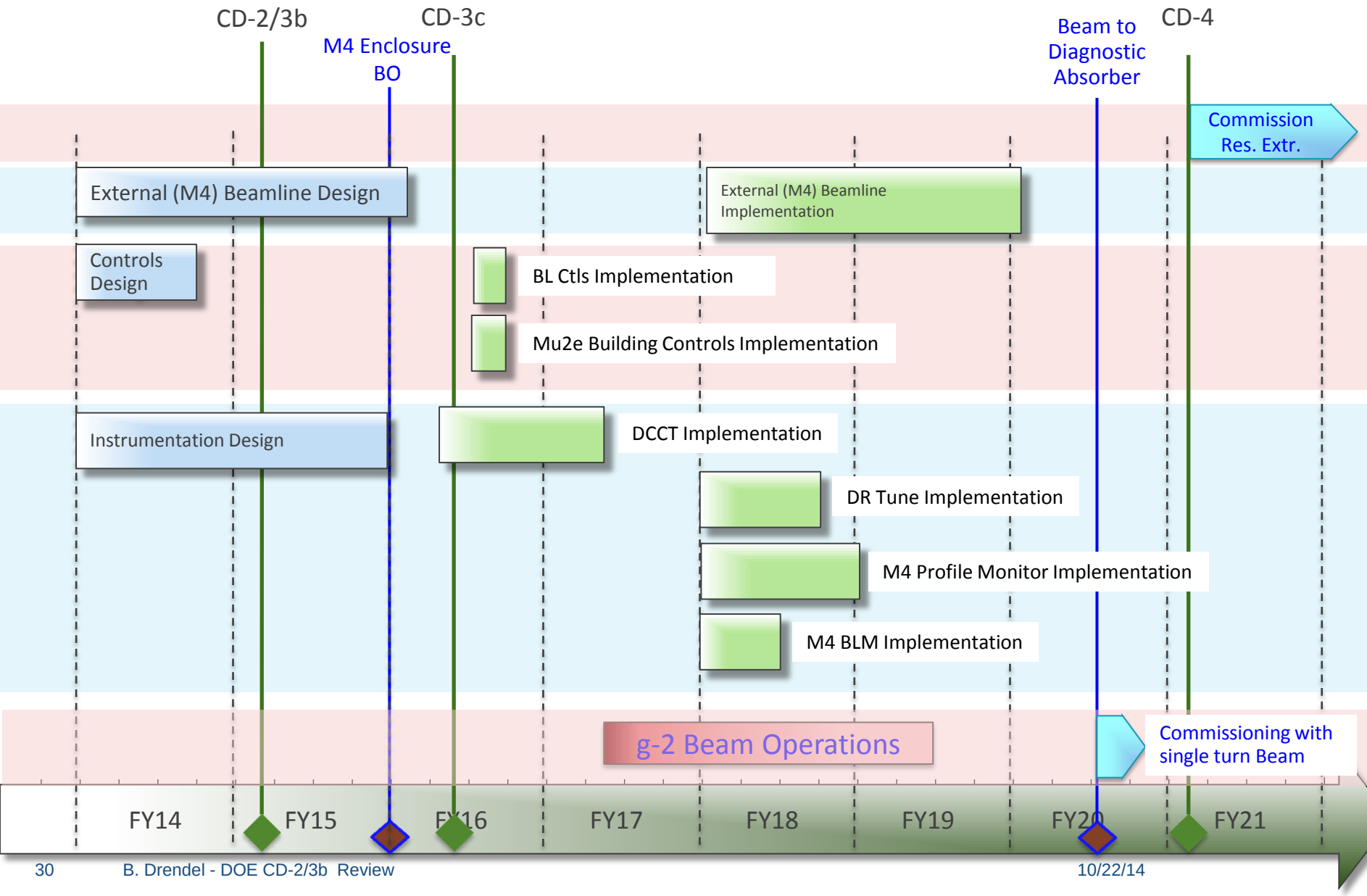
	M&S	Labor	Total	Estimate Uncertainty (on remaining budget)	% Contingency on (on remaining budget)	Total Cost
475.02.03.01 Mu2e Accelerator Controls	45	115	160	26	21%	186
475.02.03.02 Delivery Ring Instrumentation	46	277	323	52	29%	375
475.02.03.03 Extraction Beamline Instrumentation	563	671	1,235	310	26%	1,545
475.02.03.04 Technical Documentation		507	507	94	27%	601
Grand Total	655	1,571	2,225	482	26%	2,708

Total project cost plus contingency is $2.7M with 26% contingency on remaining budget. Extraction beam line instrumentation is the cost driver and the largest contingency is on the Delivery Ring instrumentation.

Major Milestones

Activity Name	Start	Finish	Milestone Tier
T5 - External Beamline Instrumentation Design Complete		13-Oct-15	T5
T5 - Final Design of Profile and Intensity Monitors Complete		13-Oct-15	T5
T5 - Instrumentation & Controls CD-3c Approval Granted		23-Feb-16	T5
T5 - Mu2e Experimental Hall Controls Complete		20-May-16	T5
T5 - Abort Controls Complete		1-Jun-16	T5
T5 - Transport and Delivery Ring Controls Complete		1-Jun-16	T5
T5 - Controls Implementation Complete		2-Jun-16	T5
T5 - Delivery Ring DCCT Complete		3-Feb-17	T5
T5 - Start M4 beamline Profile and Intensity Monitor Procurements	2-Oct-17		T5
T5 - Start M4 Beamline BLM Procurements	2-Oct-17		T5
T5 - Start M4 Beamline BLM Assembly and Installation	21-Nov-17		T5
T5 - M4 Beamline BLM Procurements Complete		30-Nov-17	T5
T5 - Start of M4 Beamline Ion Chamber and Multiwire Assembly	11-Jan-18		T5
T5 - Ion Chamber Assembly Complete		26-Mar-18	T5
T5 - External Beamline BLM Installation Complete		6-Apr-18	T5
T5 - BBQ Tune Measurement System Complete		10-Apr-18	T5
T5 - Delivery Ring Instrumentation Complete		8-May-18	T5
T5 - Schottky Tune Measurement System Complete		8-May-18	T5
T5 - Delivery Ring Tune Measurement Systems Complete		8-May-18	T5
T5 - Multiwire Assembly Complete		14-Jun-18	T5
T5 - Instrumentation & Controls Implementation Complete		4-Sep-18	T5
T5 - Instrumentation & Controls ready to run beam to the diagnostic absorber		4-Sep-18	T5
T5 - Instrumentation Implementation Complete		4-Sep-18	T5
T5 - External Beamline Instrumentation Complete		4-Sep-18	T5
T5 - Multiwire and Ion Chamber Installation Complete		4-Sep-18	T5

Schedule


CD-2/3b
CD-3c
M4 Enclosure BO
Beam to Diagnostic Absorber
CD-4
Commission Res. Extr.
External (M4) Beamline Design
External (M4) Beamline Implementation
Controls Design
BL Ctls Implementation
Mu2e Building Controls Implementation
Instrumentation Design
DCCT Implementation
DR Tune Implementation
M4 Profile Monitor Implementation
M4 BLM Implementation
g-2 Beam Operations
Commissioning with single turn Beam
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- The technical objective is to design and fabricate the equipment for the accelerator controls and instrumentation upgrades required for beam delivery to Mu2e.
- **Controls**:
  - Controls will provide all of the necessary communications links and infrastructure to connect the Mu2e experimental hall with the existing Accelerator Division controls systems.
- **Instrumentation**:
  - Instrumentation for the Delivery Ring will consist of an intensity measuring DCCT and tune measurement system.
  - Other Delivery Ring instrumentation are funded from other sources.
  - Instrumentation for the Extraction Beamline will consist of intensity measuring retractable ion chambers, position measuring multiwires loss measuring beam loss monitors.
  - Instrumentation for beamlines upstream of the Delivery Ring are covered by other sources.
- **Preliminary design is complete and we are ready to baseline our schedule.**

Beam Parameters:

- Peak intensity: 1e12 protons
- Beam energy: 8 GeV
- Bunch structure: Single 2.5 MHz bunch
- Nominal bunch length: 40 ns
- Bunch base width: 200 ns
- Resonant slow-spill extraction over 58 ms
  - 30e6 protons extracted per turn

Tune Parameters:

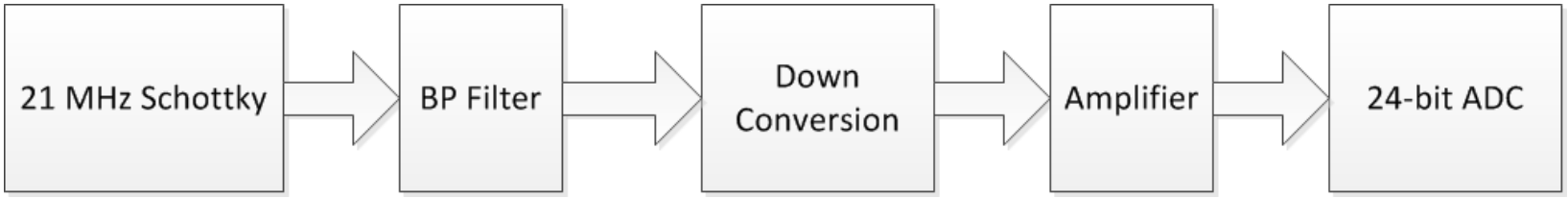
- Nominal tunes
  - $\nu_x = 9.653$
  - $\nu_y = 9.735$
- Buncher revolution freq: 590.018 KHz

Measurement Requirements:

- Measure tune and transverse emittance
  - Measure tune throughout slow-spill
- Tune resolution:
  - 0.0001 (with averaging)
  - 0.001 @ 600 Hz

Proposed Mu2E Schottky System

- Filter out revolution harmonics
- Down convert from 36^{th}/37^{th} harmonics to 1^{st} harmonic (0 to 590 KHz)
- Use 24-bit ADC to sample signal
  - 2 to 4 MHz sampling
  - 100 db dynamic range
- Use digital signal processing to produce tunes
  - 0.001 tunes at 590 Hz
  - 0.0001 tunes with averaging over many spills



WBS 475.02.03 Instrumentation and Controls

- **Technical Objective**
  - The technical objective is to design and fabricate the equipment for the accelerator controls and instrumentation upgrades required for beam delivery to Mu2e.
- **Scope of Work Statement**
  - Design and implementation of required controls systems upgrades for beam transport to the Delivery Ring including Delivery Ring Abort controls, External (M4) beamline control system, instrumentation upgrades, instrumentation for the External (M4) beamline.
- **Deliverables**
  - Upgraded control system for beam transport to the Delivery Ring, Delivery Ring abort controls, External (M4) beamline control system, Delivery Ring instrumentation upgrades (DC beam current and tune measurement instrumentation), External (M4) beamline instrumentation (beam profile, loss, and intensity monitoring).
- **Relationships/Interfaces to other WBS Elements/Inputs**
  - Installation of M4 beamline controls and instrumentation requires beneficial occupancy of the M4 beamline enclosure (Beamline Enclosure GPP), the MC-1 building (MC-1 Building GPP), and the Mu2e building (475.03 Mu2e Conventional Construction).
- **Assumptions**
  - The existing Muon Campus controls infrastructure will remains in place and will continue to function.
  - Restoring controls connectivity to the Delivery Ring service buildings after the extraction tunnel construction will be successfully completed prior to Mu2e operations and funded through the Delivery Ring AIP.
  - Controls and Instrumentation items reserved in the Mu2e MOU for re-used components will be functional and remain available at the time of Mu2e implementation.