Mu2e Cosmic Ray Veto

E. Craig Dukes
Level 2 Manager: Cosmic Ray Veto
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Outline

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- Design
- Changes Since CD-1
- Value Engineering Since CD-1
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- Remaining Work Before CD-3
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- Costs
- Major Milestones
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- Summary

Requirements: Fundamental

The requirements for the Cosmic Ray Veto are described in detail in Mu2e-doc-944.

Fundamental (detector independent) requirements:

1. To reduce the conversion-like electron background from cosmic rays to less than 0.1 events over the course of the run
2. To provide a cosmic-ray trigger primitive to the DAQ
3. Not to produce more than 10% dead time
4. Not to use more than 20% of the DAQ bandwidth

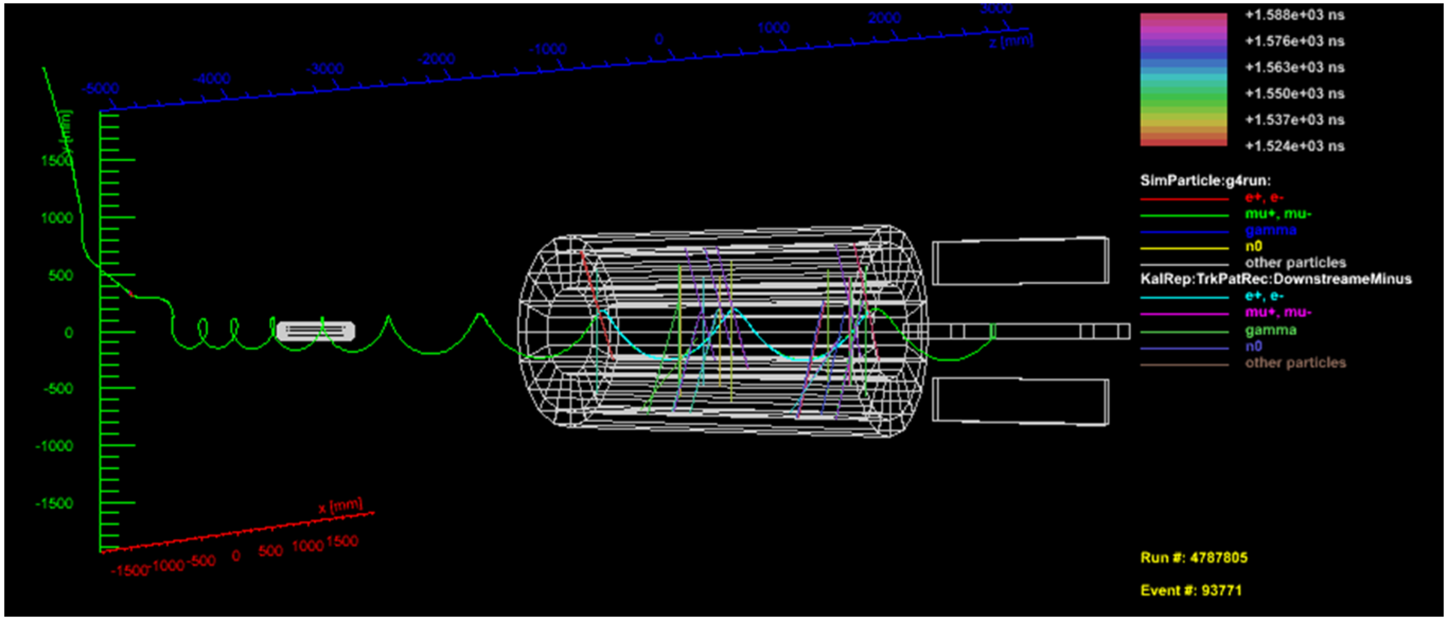
Note: about 1 conversion-like electron per day is produced by cosmic-ray muons

Requirements: Derived

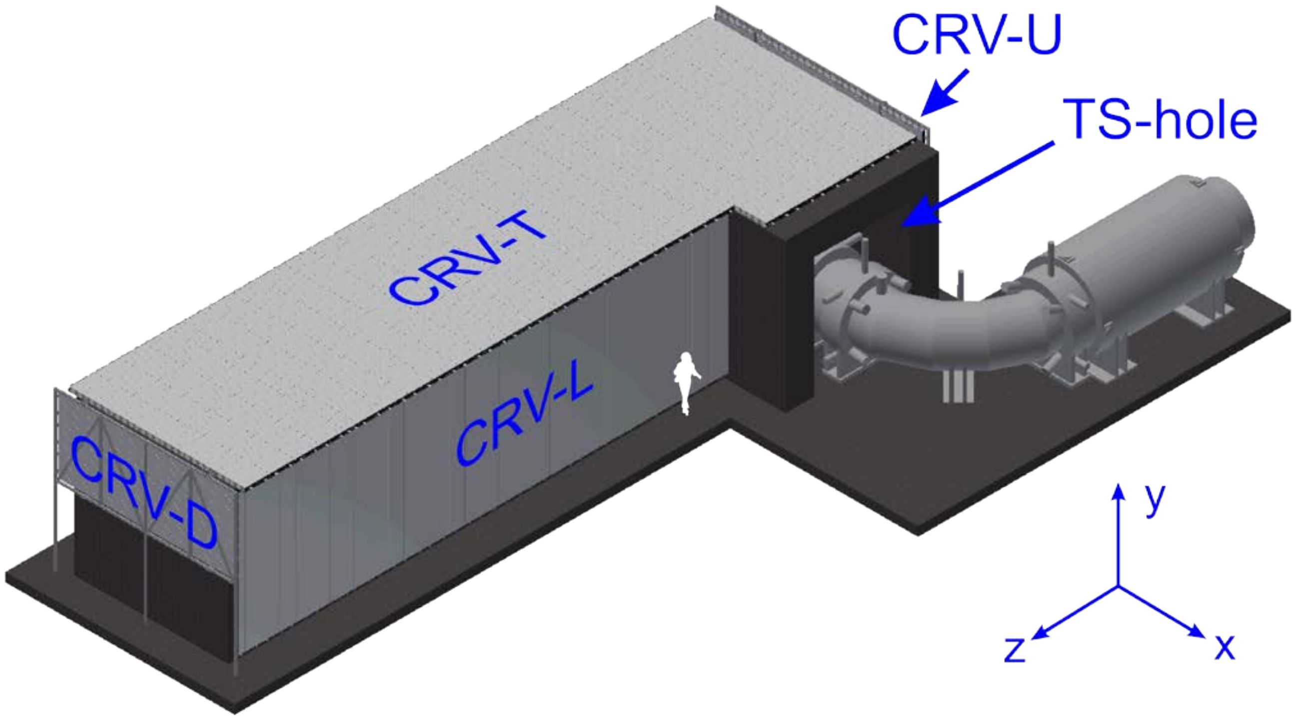
1. The overall inefficiency for identifying cosmic-ray muons must be no worse than $1x10^{-4}$.
2. The tracker/calorimeter should resolve muons from electrons.
3. The photoelectron yield of the cosmic-ray scintillation counters must be at least 14 PE/cm.
4. The time resolution of the cosmic ray veto should be on the order of 5 ns in order to reduce the random two-counter coincidence rate from counter “noise”.
5. The hit rate per photodetector (SiPM) should be no more than 1 MHz.
6. The total neutron dose to the photodetectors and front-end electronics must be less than 1×10^{10} n/cm^2, and the electronics much survive this dose with no untoward effects.
7. The DAQ should trigger on no more than 1/100 microspills.
8. The detectors and DAQ should run during the interspill period.

Requirement: Background Rejection

- Simulations of 28 billion cosmic ray muons show that an inefficiency of no worse than10^{-4} is required.
- Simulations have also vetted the CRV coverage described in the CDR.
- Targeted simulation of ~100% of the total live time show that no electron conversion-like background events come through the TS “hole”, however there are muons that mimic conversion-electron events that need to be removed by the calorimeter and tracker.



Design: Layout



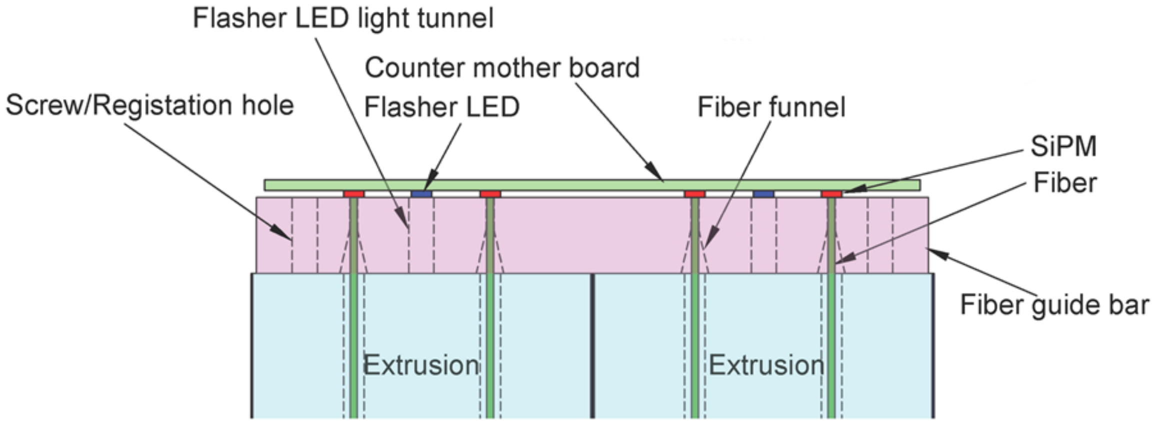
Design vetted in outside CRV-Review (June 3, 2014)

Details:
- Area: 323 m^2
- 82 modules 7 sizes
- 5,152 counters
- 10,254 fibers
- 18,944 SiPMs

- Design driven by need for excellent efficiency, large area, small gaps, high rates, access to electronics, and constrained space.
- Technology: Four layers of extruded polystyrene scintillator counters with embedded wavelength shifting fibers, read out with SiPMs.
- A track stub in 3/4 layers, localized in time and space produces a veto.

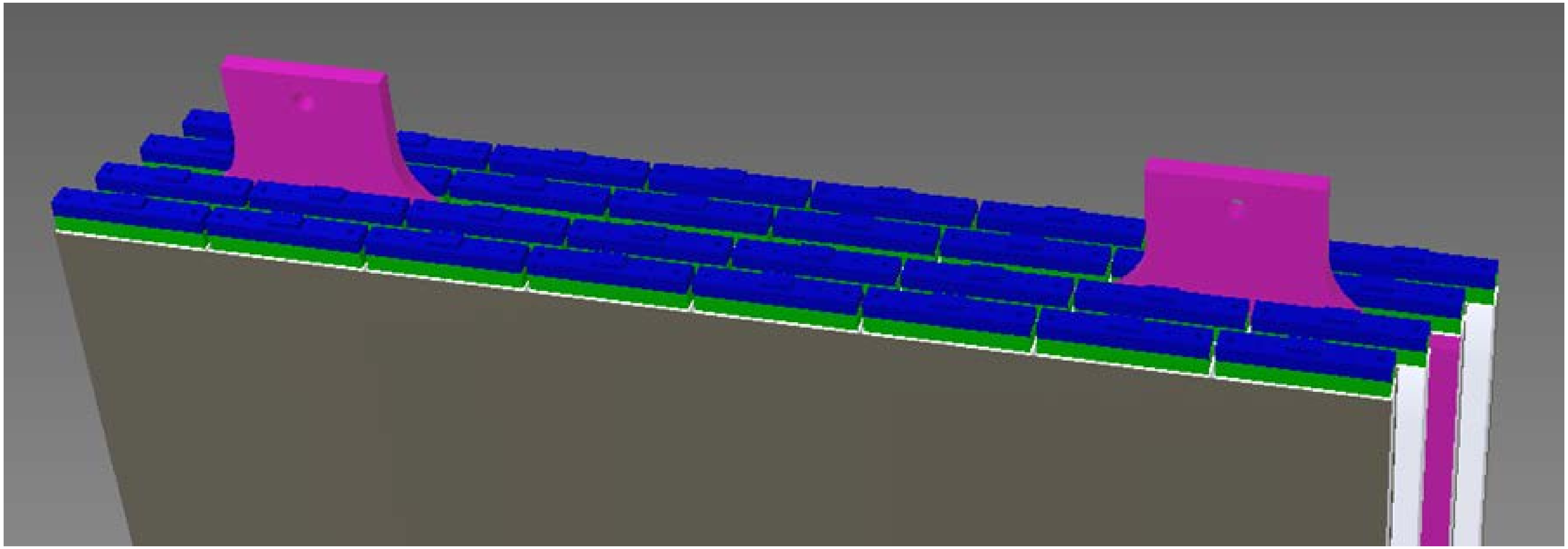
Design: Counter

- Fundamental element of the CRV
- 50 x 20 x 900-6600 mm^3
- Extruded at the FNAL-NICADD facility
- Two 1.4-mm diameter wavelength shifting fibers
- Readout: two 2 x 2 mm^2 SiPMs
- Flasher LED for calibration and monitoring
- Glue two extrusions together to form di-counters that are served by one counter motherboard



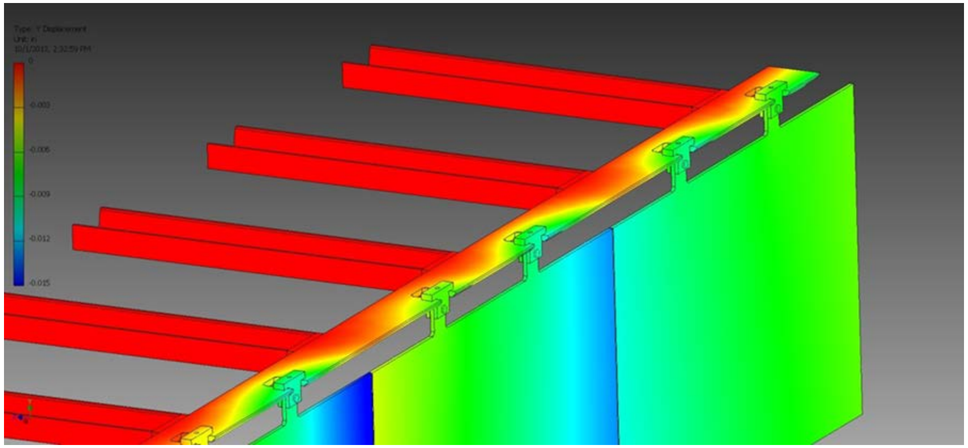
Design: Modules

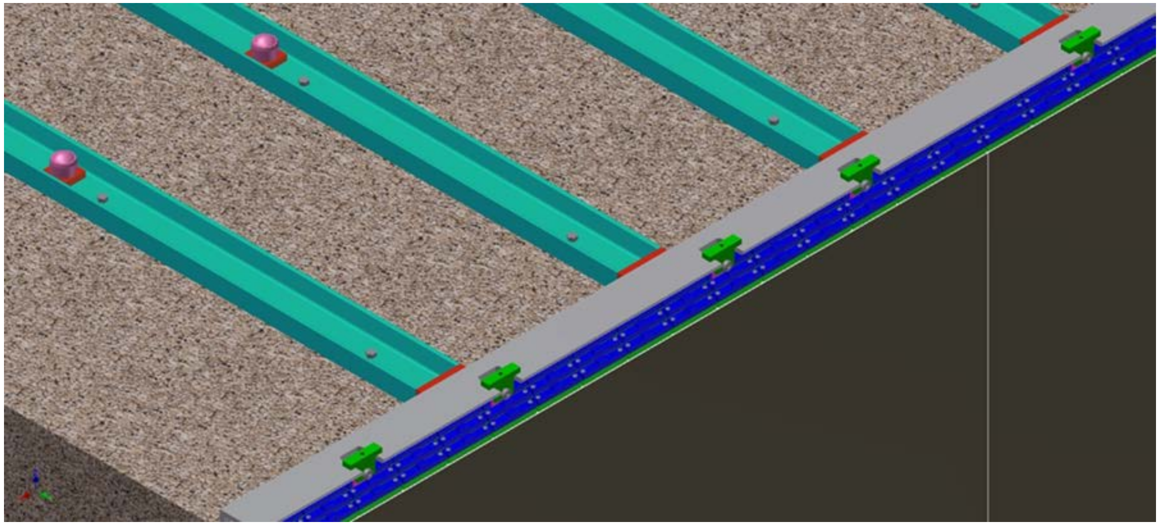
- Fundamental mechanical element of the CRV
- 4 layers of counters: 4 x 16 = 64 (narrow: 4 x 8 = 32)
- 12.7 mm center Al absorber, 9.5 mm outer Al absorbers
- Di-counters glued to Al absorbers
- Layers are offset to avoid projective gaps between counters
- Total: 82; with two different widths; five different lengths



Design: Support Structure

- Designed to minimized gaps between modules, to allow modules to be installed and removed without undue difficulty, and to allow access to electronics.
- Simple design that sits on top of the concrete shielding blocks.

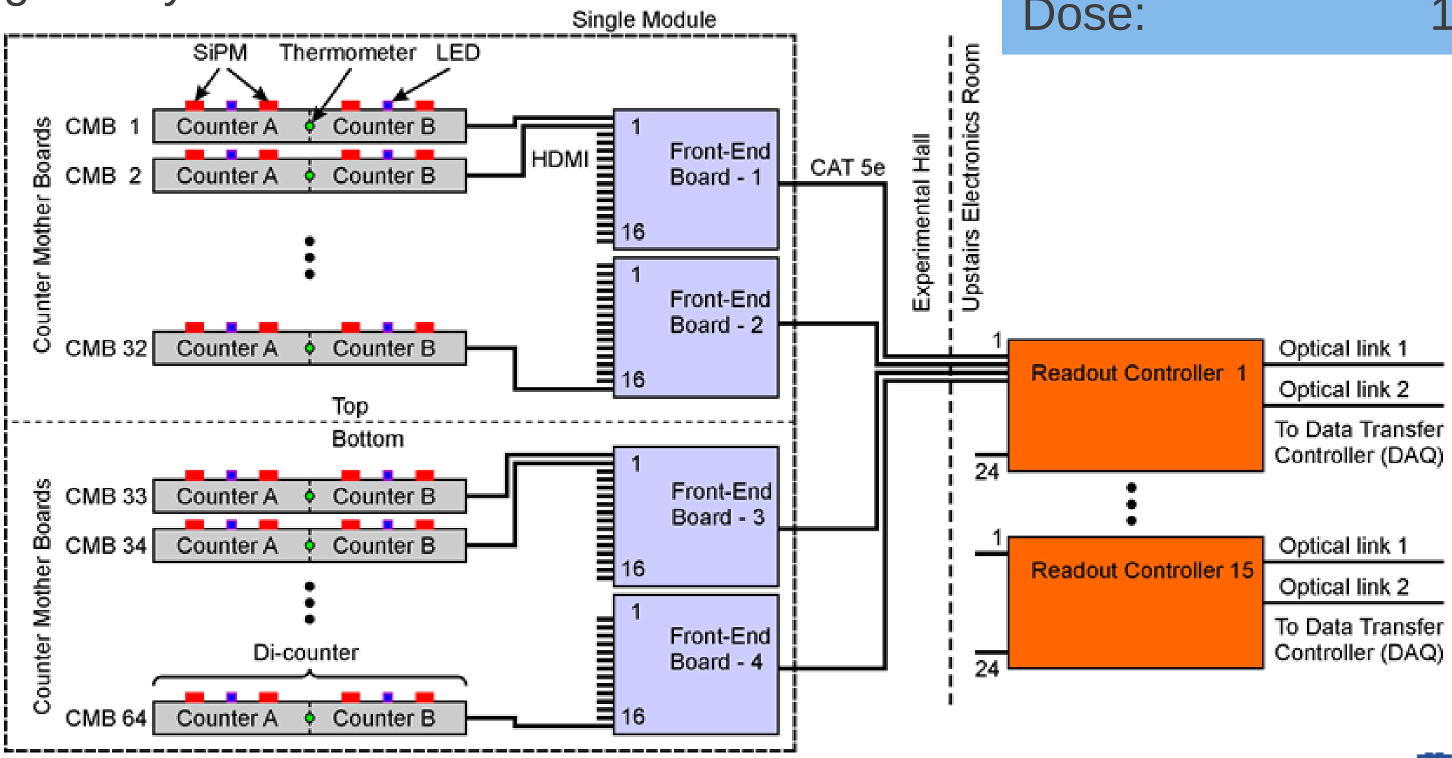




Design: Electronics

- Three components: (1) Counter Motherboards (CMB: 4736), (2) Front-end Boards (FEB: 296), (3) Readout Controllers (ROC: 15)
- Design based on MTB wire chamber readout
- All COTS parts (80 MHz ultrasound octal ADC)
- Triggered system

Dynamic range:	2000
Max rate/SiPM:	1 MHz
Rate to DAQ:	76 MB/s
Data per run:	1.1 PB
Time resolution:	~ 1ns
Magnetic field:	~ 0.1 T
Dose:	10^{10} n/cm^2



Changes since CD-1

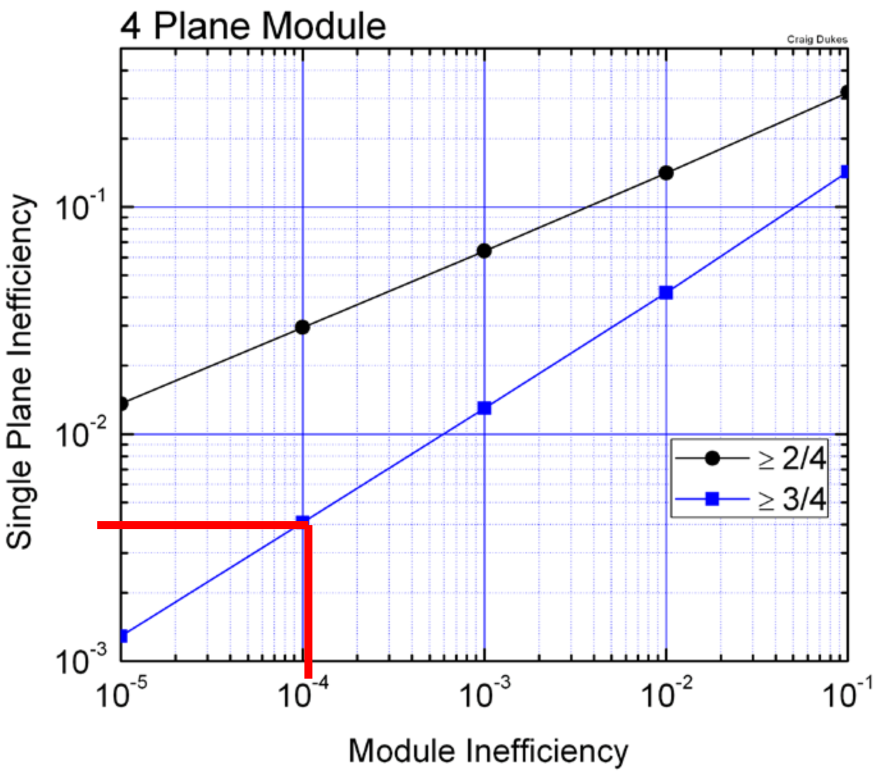
- Extensive simulation work by the Neutron Working Group has shown that the rates from neutrons and gammas are higher than CD-1 estimates (extrapolated from MECO studies).
- To mitigate the higher rates we have:
  - added shielding to the CD-1 design (see Muon Beamline WBS 475.5)
  - added an extra layer of counters (2/3 → 3/4)
  - made the Al absorber layers thicker (to kill thru-going electrons)
  - moved to a triggered readout
- Moved to a 50 x 20 mm^2 extrusion profile: (1) because of difficulties in extruding quality, high-aspect ratio 100 x 10 mm^2 extrusions, and (2) to increase the light yield (energy deposit) from muons traversing each layer.
- The standard module width has been reduced by ~25% to ease fabrication and handling.
- Whitmore added as deputy and L3 *Photodetectors*, Fagan L3 *Detector Assembly & Installation*

Value Engineering since CD-1

- We incorporate value engineering at every stage of design.
- Based on studies of other projects using large numbers of SiPMs, we cut back our testing from 100% to 10%.
- We are investigating using wider (60-70 mm vs 50 mm) extrusions, which will lower the fiber/SiPM/electronics channel count and save costs. This is listed in the Risk Register as an opportunity.

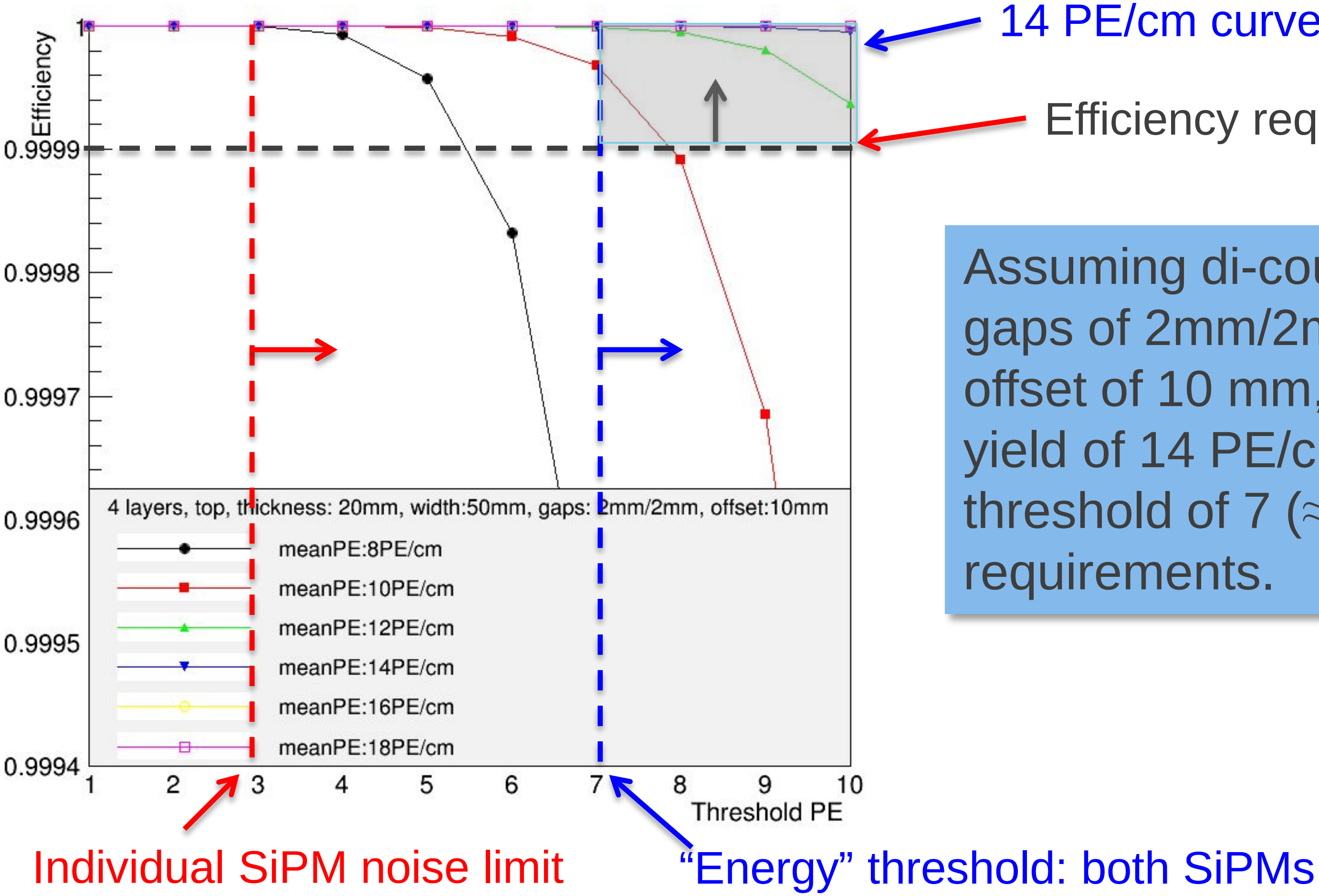
Performance: Efficiency Requirement

- An inefficiency of 10^{-4} in finding muon track stubs with a 3/4 hit plane requirement demands a 99.5% single-plan efficiency.
- The efficiency of a particular plane depends on the angle the muons make and the size of the gaps between counters.



Performance: Efficiency Requirement

The single-plane efficiency requirement of 99.5% can be best couched in terms of a photoelectron yield requirement.



Assuming di-counter inner/outer gaps of 2mm/2mm, a layer offset of 10 mm, and a light yield of 14 PE/cm, then a PE threshold of 7 (≈1 MeV) meets requirements.

Performance: Efficiency Requirement

- Extrapolations from test-beam data of a pre-prototype counter, and from NOvA measurements of PE yield vs fiber diameter show that 14 PE/cm at the far end of a long counter can be achieved with a 1.4 mm diameter fiber.
- Important: the key parameter is meeting the efficiency requirement is the photoelectron yield.
- The means by which we meet the required PE yield is through the wavelength shifting fiber diameter.
- Extrapolations from test-beam data show that a 1.4-mm diameter fiber should meet the PE requirements.

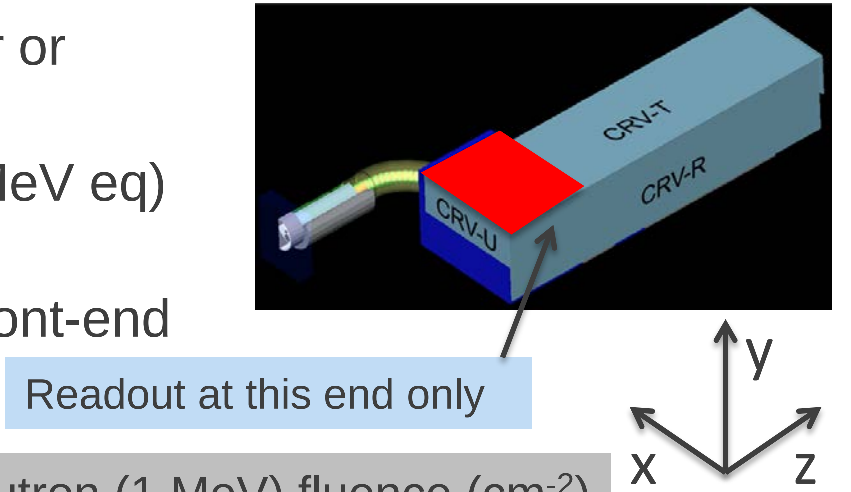
Simulations: Integrated Rates & Deadtime

- Simulations of the rates due to neutrons and gammas have been done using a G4beamline model of the apparatus, shielding, and beam
- Rates have been checked with MARS
- Factorized simulation: beam → secondary transport → rates using CRV efficiencies determined from G4beamline, GEANT4, and MCNP
- A full non-factorized simulation in the Mu2e framework is underway
- **The PE (energy) cut will be applied offline, not in real time**
- **The veto will be applied offline, not in real time**

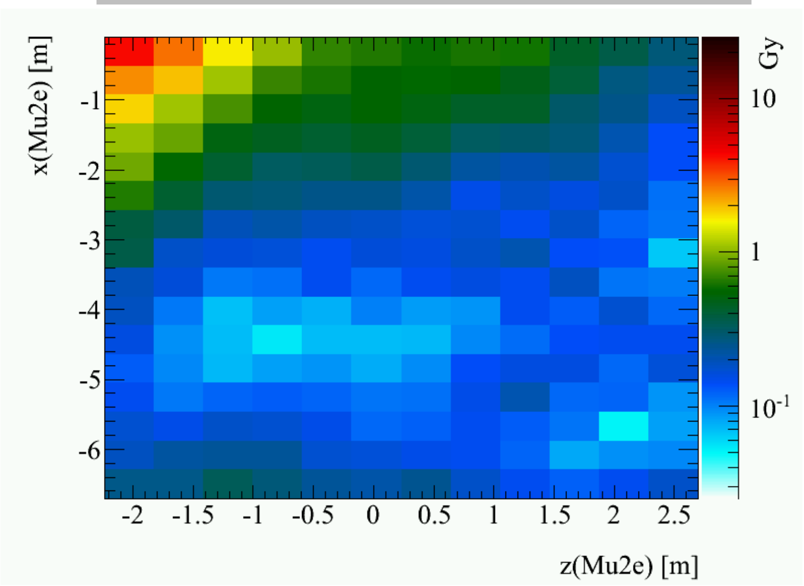
	Threshold [MeV]	Max Instant Rate [kHz]	Average Rate [kHz]	Fractional dead time [%]
Front-end hit threshold: a few PE	0.1	685	127	NA
Offline energy threshold	0.5	260	48	4.4
Offline energy threshold	1.0	160	30	1.2

Simulations: Radiation Damage

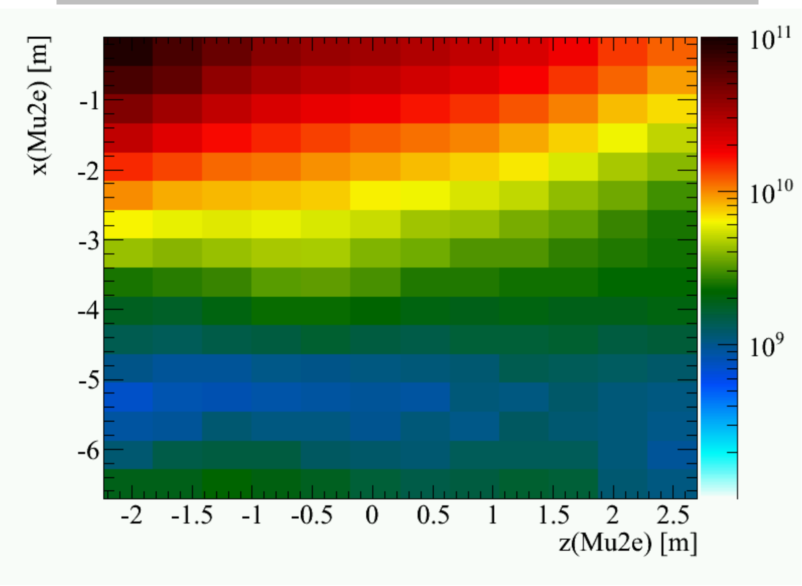
- Ionizing dose: not a problem for detector or electronics
- Non-ionizing dose: max. rate < 10^{10} (1 MeV eq) n/cm^2 is on the edge of needing testing
- Will study performance of SiPMs and Front-end Boards at 10^{10} n/cm^2



Ionizing Radiation Dose



Neutron (1 MeV) fluence (cm^{-2})



Remaining Work Before CD-3

- Simulations:
  - Perform non-factorized simulations in software framework to confirm work done on rates and radiation levels by the Neutron Working Group.
  - Complete the conversion-like electron background simulations: the goal is to simulate targeted areas with at least 10X the expected flux.
- Design: produce final engineering design.
- Requirements: fabricate and measure PE yield of counter prototypes using baseline fiber, SiPMs, and extrusions. Use results to select the fiber size.
- SiPMs: perform radiation and longevity tests; select vender.
- Electronics: produce and test prototype front-end boards and readout controllers.
- Module fabrication: make large mechanical prototype module, two small electronics test modules, two large side modules.
- Detector installation: test mounting scheme for side modules.

Organizational Breakdown

WBS 8 Cosmic Ray Veto
Craig Dukes / Virginia
Julie Whitmore / Fermilab (Deputy)

8.1 Project Management
Craig Dukes
Virginia

8.2 Mechanical Design
Craig Dukes
Virginia

8.3 Scintillator Extrusions
Anna Pla-Dalmau
Fermilab

8.4 Fibers
Yuri Oksuzian
Virginia

8.5 Photodetectors
Julie Whitmore
Fermilab

8.6 Electronics
Sten Hansen
Fermilab

8.7 Module Fabrication
Craig Group
Fermilab / Virginia

8.8 Detector Assembly & Installation
Jim Fagan
Fermilab

Quality Assurance

- We are following guidelines outlined in the project Quality Management Plan (Mu2e-doc-677).
- QA/QC procedures are integrated into each component of the Cosmic Ray Veto, and in fact consume a large fraction of the resources devoted to each task.
- See Level-3 breakout talks for details on QA/QC.
- Example: Module Factory
  - Details given in “Quality Assurance and Safety Program for Cosmic Ray Veto Module Factory” (Mu2e-doc-4150).
  - Each module will have their photoelectron yield measured over their entire area to insure they meet the photoelectron yield requirement, and after shipping to Fermilab they will be tested for damage.

ES&H Issues

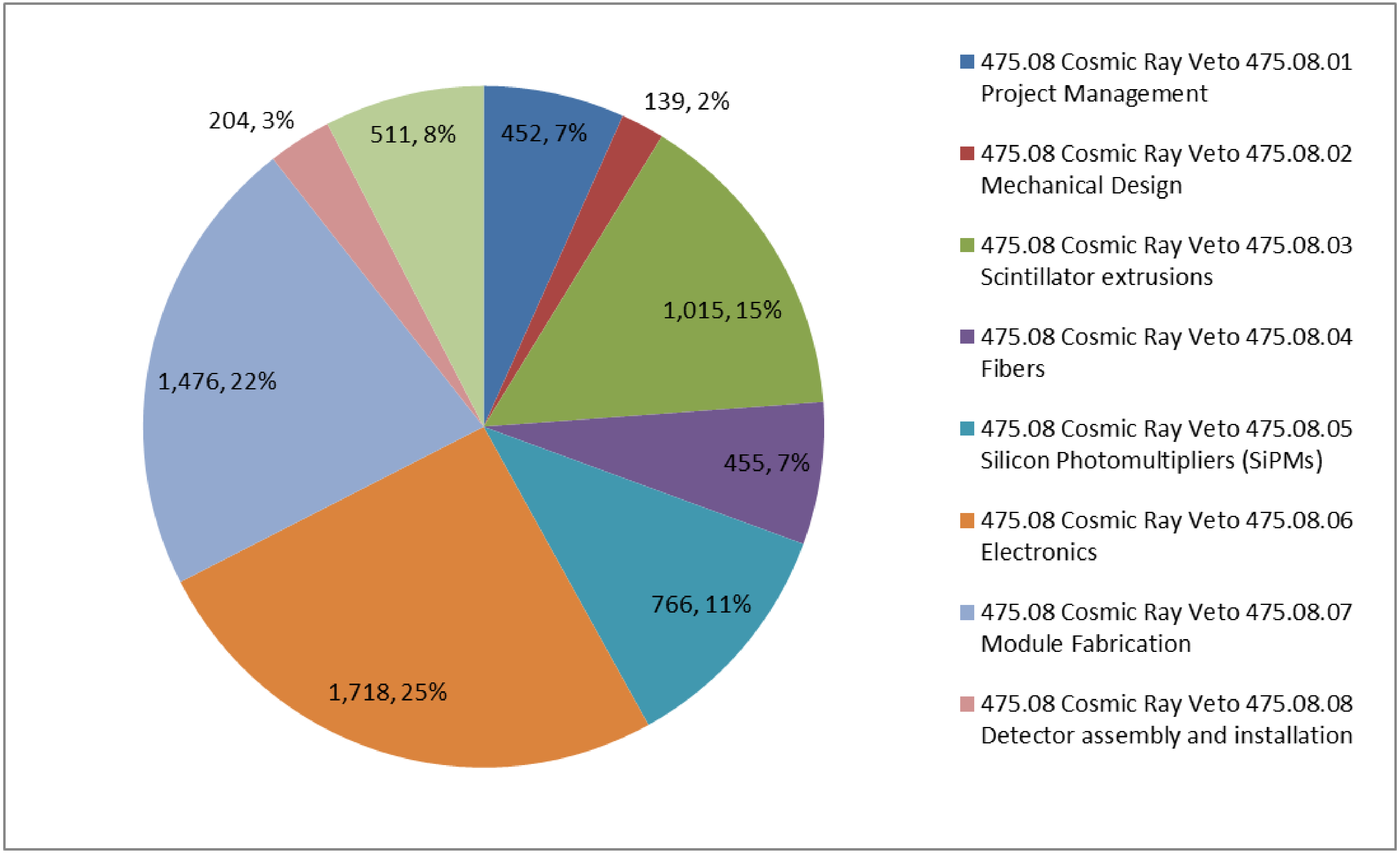
- CRV has standard detector-related issues that are common at Fermilab
  - Electrical hazards from low voltage
    - No exposed high or low voltages
    - Everyone working on the electronics will receive basic electrical safety training
  - Mechanical hazards
    - CRV modules are heavy: procedures for the safe handling of them are being developed for the module factory and for installation at Fermilab.
    - Compressed gas cylinders at the module factory.
  - Toxic materials
    - Polystyrene is classified according to DIN4102 as a “B3” product, meaning highly flammable or easily ignited. The storage of the extrusions and fibers will take these properties into account.
    - Adhesives will be used in potting the fibers and for module assembly. Appropriate measures will be taken to reduce the fumes to safe levels.
- These hazards are all discussed in the Mu2e Hazard Analysis document (Mu2e-doc-675) and in the Quality Assurance and Safety Program for the Cosmic Ray Veto Module Factory (Mu2e-doc-4150).

Risks & Opportunities

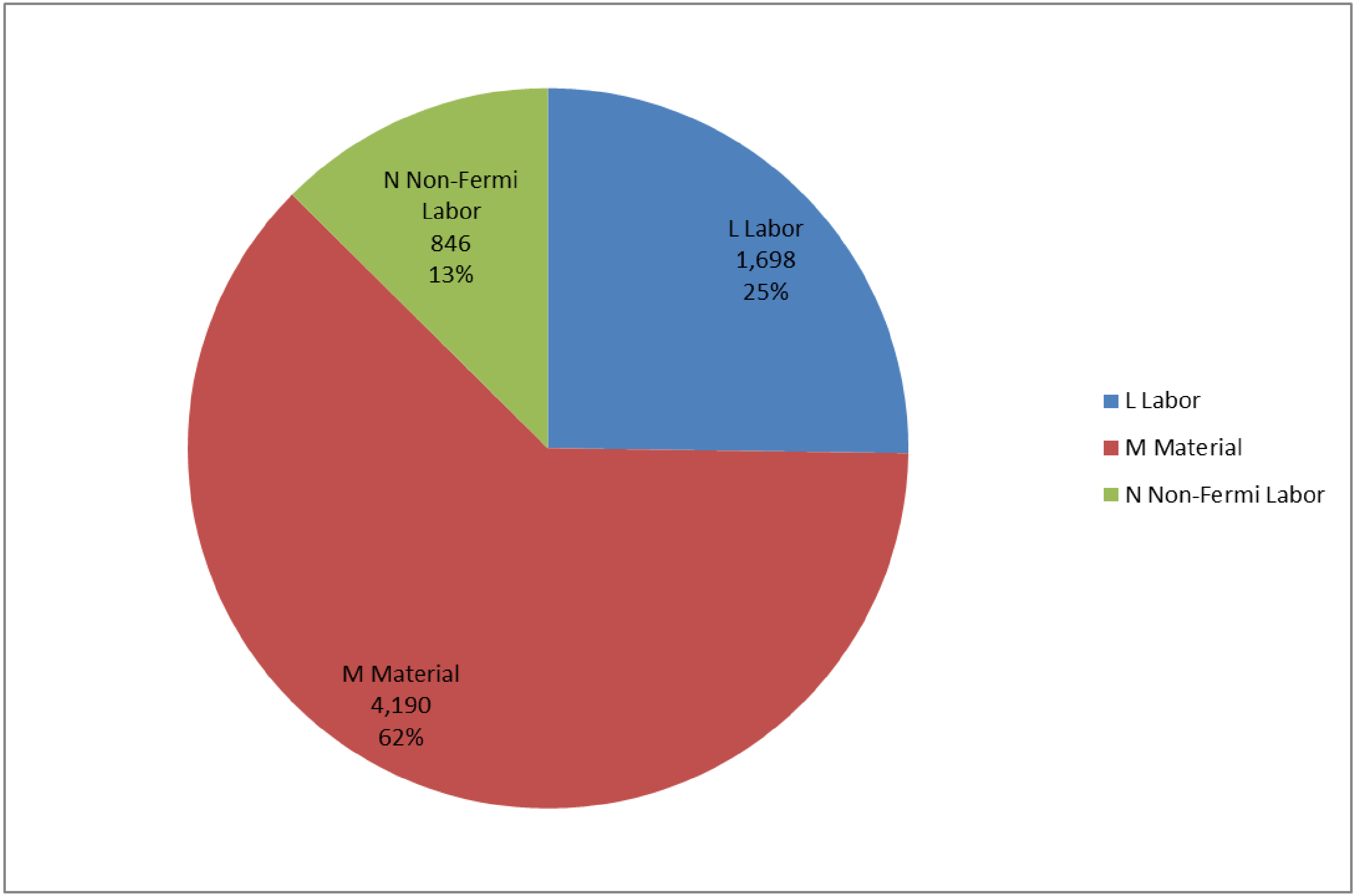
There are no major cost or schedule risks

- More sophisticated simulations indicate higher rates
  - Risk: low
  - Mitigation: more shielding in targeted areas
- Photoelectron yield too low / too high
  - Risk/Opportuntiy: low/moderate
  - Mitigation: tune fiber diameter
- Fiber vender goes out of business
  - Risk: low
  - Mitigation: order fiber asap; use larger diameter inferior fibers
- Simulations indicate that more CRV coverage needed
  - Risk: moderate
  - Mitigation: fabricate extra modules

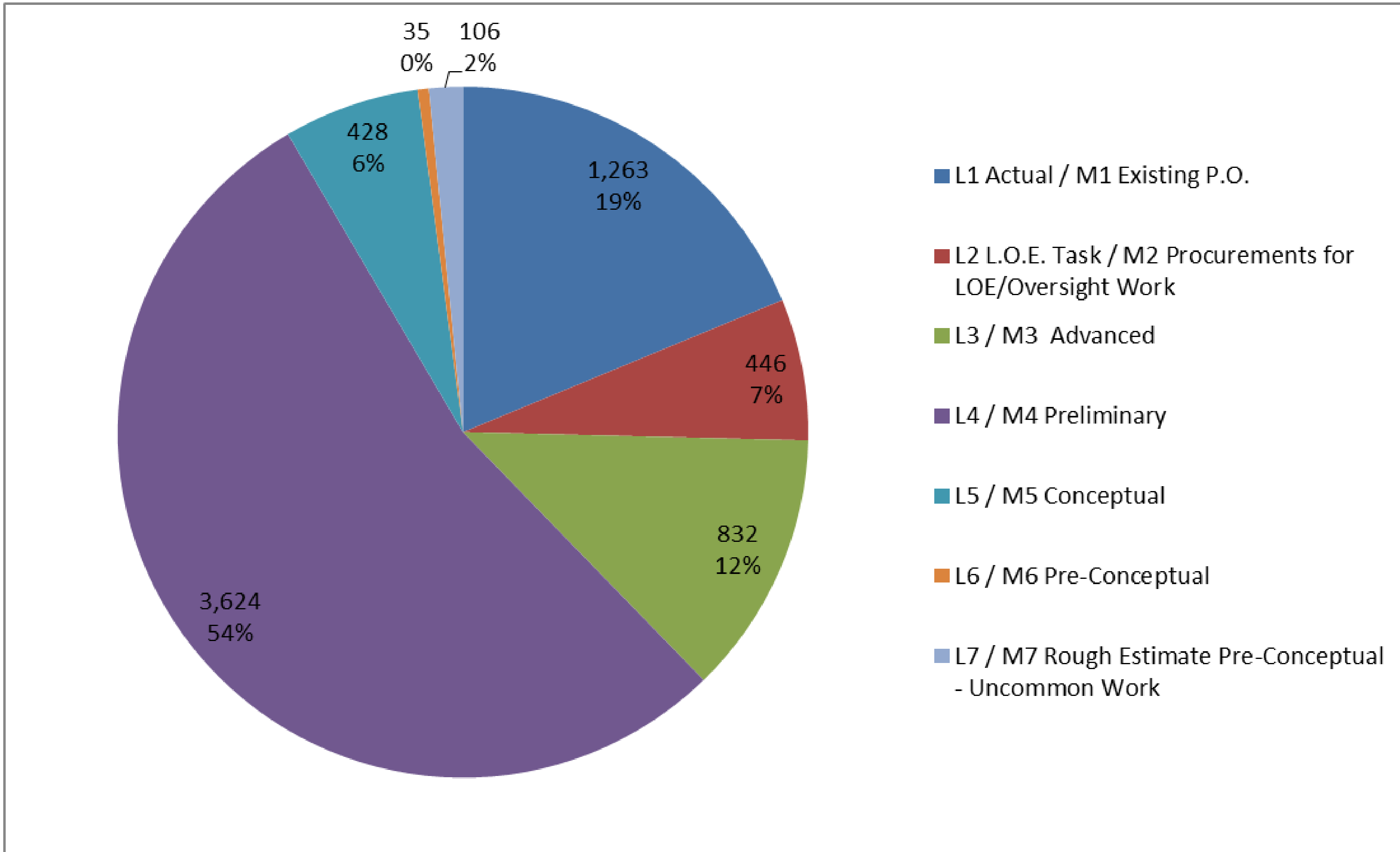
Cost Breakdown: Sub-Project



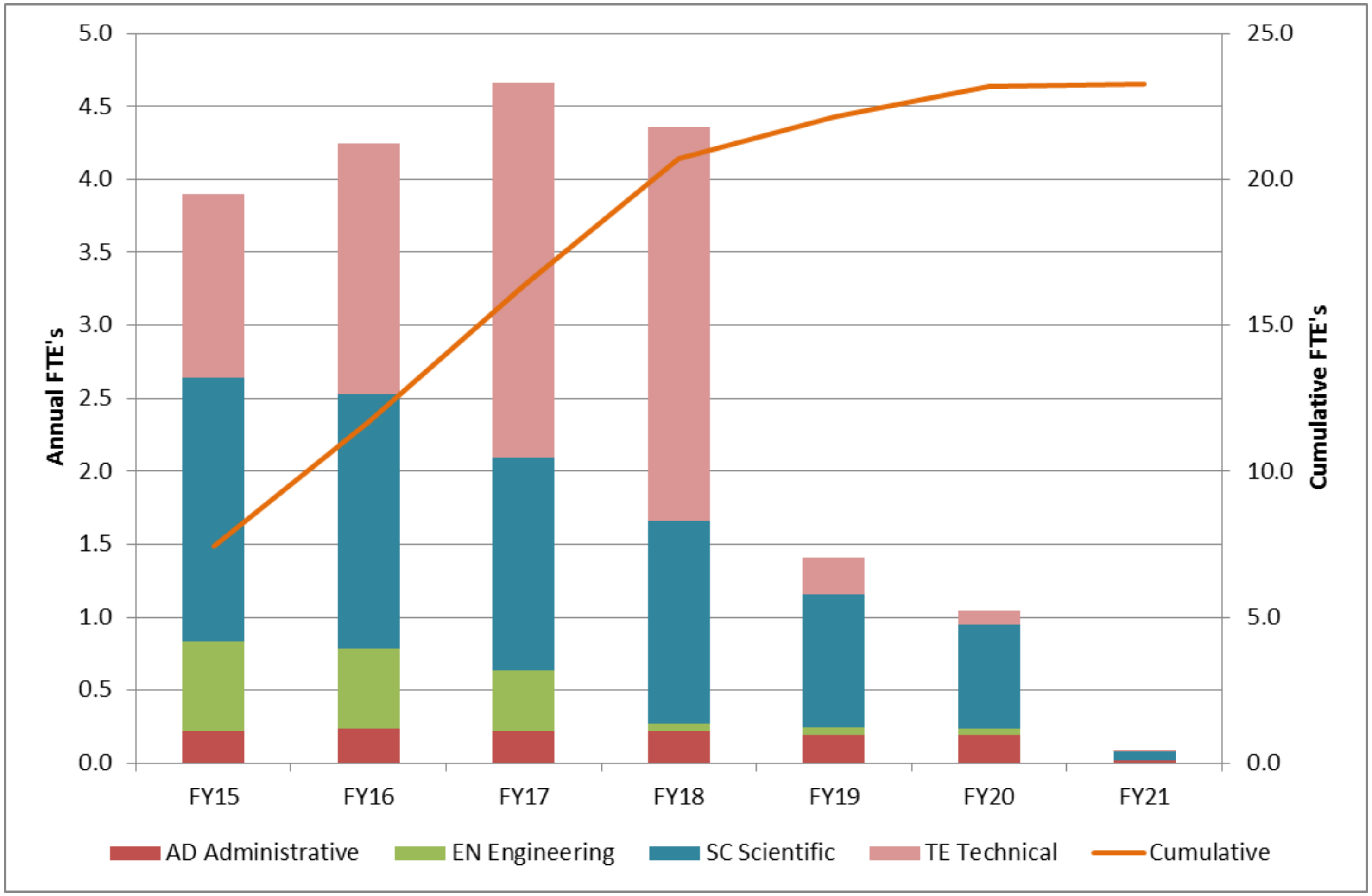
Cost Breakdown: Resource Type



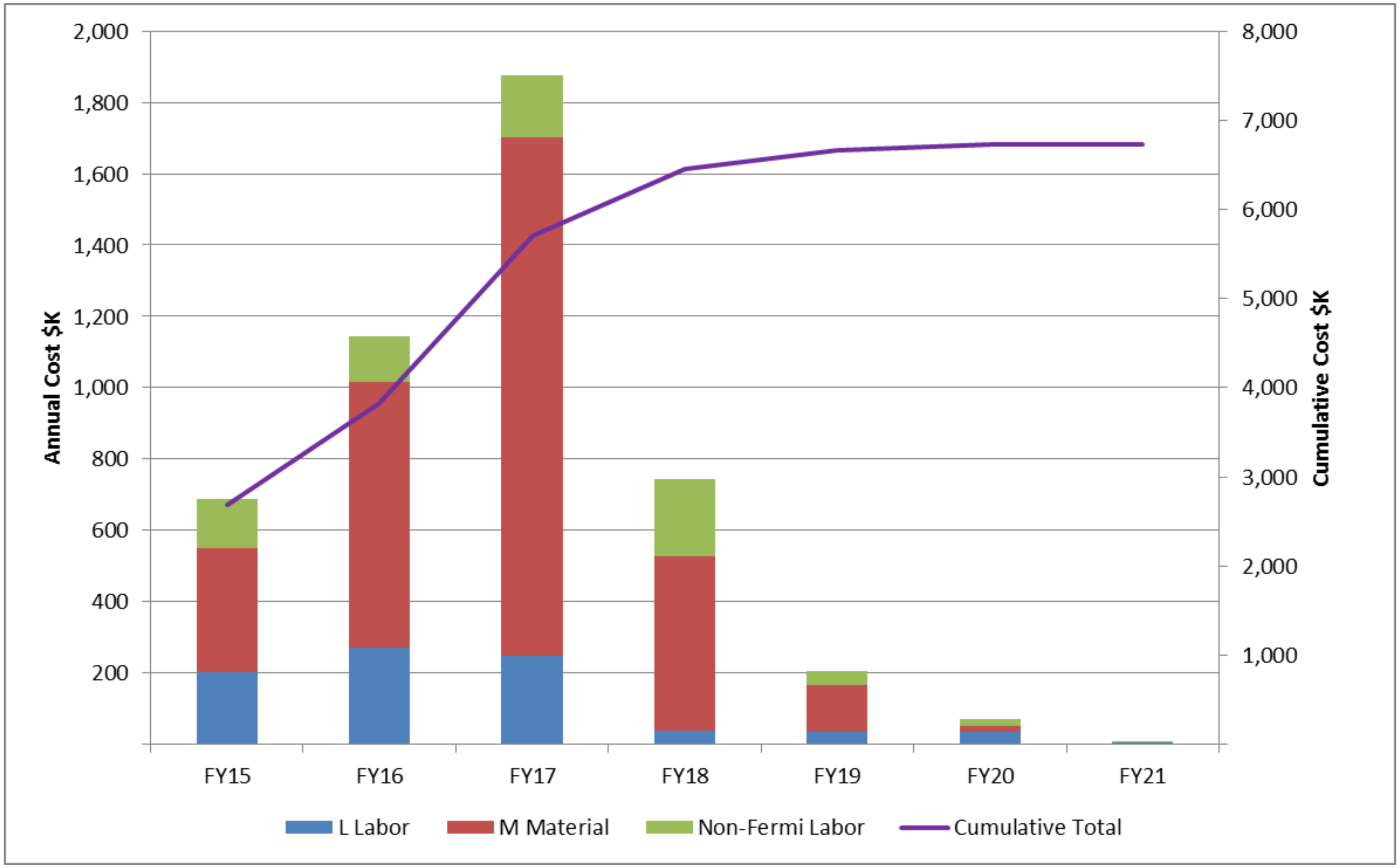
Quality of Estimate



Labor Resources by FY



Labor / Material Breakdown by FY



Cost Table: CRV

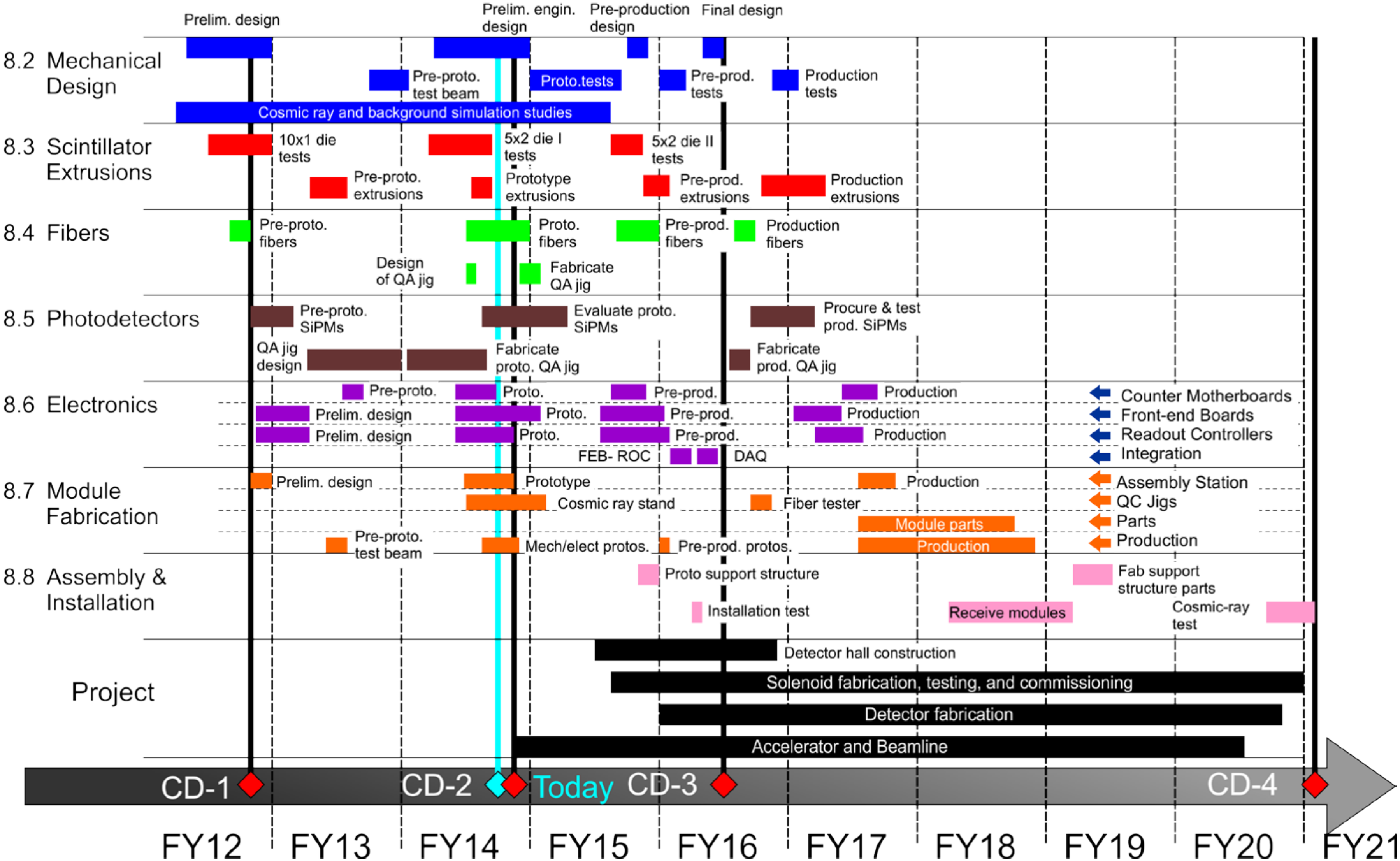
	M&S	Labor	Base Cost	Estimate Uncertainty	% Contingency on ETC	Total
475.08.01 Project Management	273	178	452	75	20%	526
475.08.02 Mechanical Design	136	3	139	24	29%	163
475.08.03 Scintillator extrusions	559	457	1,015	206	22%	1,221
475.08.04 Fibers	455		455	105	24%	559
475.08.05 Silicon Photomultipliers (SiPMs)	460	306	766	188	36%	954
475.08.06 Electronics	1,312	406	1,718	509	32%	2,227
475.08.07 Module Fabrication	1,460	16	1,476	462	34%	1,938
475.08.08 Detector assembly and installation	124	80	204	63	35%	267
475.08.09 Cosmic Ray Veto Conceptual Design/R&D	258	252	511	0	0%	511
Risk Based Contingency				323		323
Total	5,036	1,698	6,735	1,955	36%	8,690

Note: Labor FNAL only.

Major Milestones

- Jun 2015: Select SiPM
- Apr 2016: Final engineering design complete
- Sep 2016: Wavelength shifting fiber tested and ready
- Feb 2017: Production of extrusions complete
- Feb 2017: SiPMs tested and accepted
- Feb 2017: Front-end boards fabricated and tested
- May 2017: Readout controllers fabricated and tested
- May 2017: Module production begins
- Jan 2019: Modules received at Fermilab

Schedule



Prelim. design
Prelim. engin. design
Pre-production design
Final design
8.2 Mechanical Design
Pre-proto. test beam
Proto.tests
Pre-prod. tests
Production tests
Cosmic ray and background simulation studies
8.3 Scintillator Extrusions
10x1 die tests
5x2 die I tests
5x2 die II tests
Pre-proto. extrusions
Prototype extrusions
Pre-prod. extrusions
Production extrusions
8.4 Fibers
Pre-proto. fibers
Proto. fibers
Pre-prod. fibers
Production fibers
Design of QA jig
Fabricate QA jig
8.5 Photodetectors
Pre-proto. SiPMs
Evaluate proto. SiPMs
Procure & test prod. SiPMs
QA jig design
Fabricate proto. QA jig
Fabricate prod. QA jig
8.6 Electronics
Pre-proto.
Proto.
Pre-prod.
Production
Prelim. design
Proto.
Pre-prod.
Production
Prelim. design
Proto.
Pre-prod.
Production
FEB- ROC
DAQ
Counter Motherboards
Front-end Boards
Readout Controllers
Integration
8.7 Module Fabrication
Prelim. design
Prototype
Production
Cosmic ray stand
Fiber tester
Module parts
Pre-proto. test beam
Mech/elect protos.
Pre-prod. protos.
Production
Assembly Station
QC Jigs
Parts
Production
8.8 Assembly & Installation
Proto support structure
Fab support structure parts
Installation test
Receive modules
Cosmic-ray test
Project
Detector hall construction
Solenoid fabrication, testing, and commissioning
Detector fabrication
Accelerator and Beamline
CD-1
CD-2
Today
CD-3
CD-4
FY12
FY13
FY14
FY15
FY16
FY17
FY18
FY19
FY20
FY21

Summary

- We have a design that meets requirements, can be built, and is costed.
- The design is simple and relies on technologies that have been proven in several recent Fermilab experiments.
- We understand exactly what needs to be done to get to CD-3, and have a well-developed plan on how to get there.
- The Cosmic Ray Veto sub-project is ready for approval of its performance baseline.