# Mu2e CD-2 Cosmic Ray Veto
# 8.6 Electronics

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Level 3 Manager
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# Requirements

- 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 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 contribute more than 10% experiment dead time → precise timing
  4. Not to use more than 20% of the DAQ bandwidth

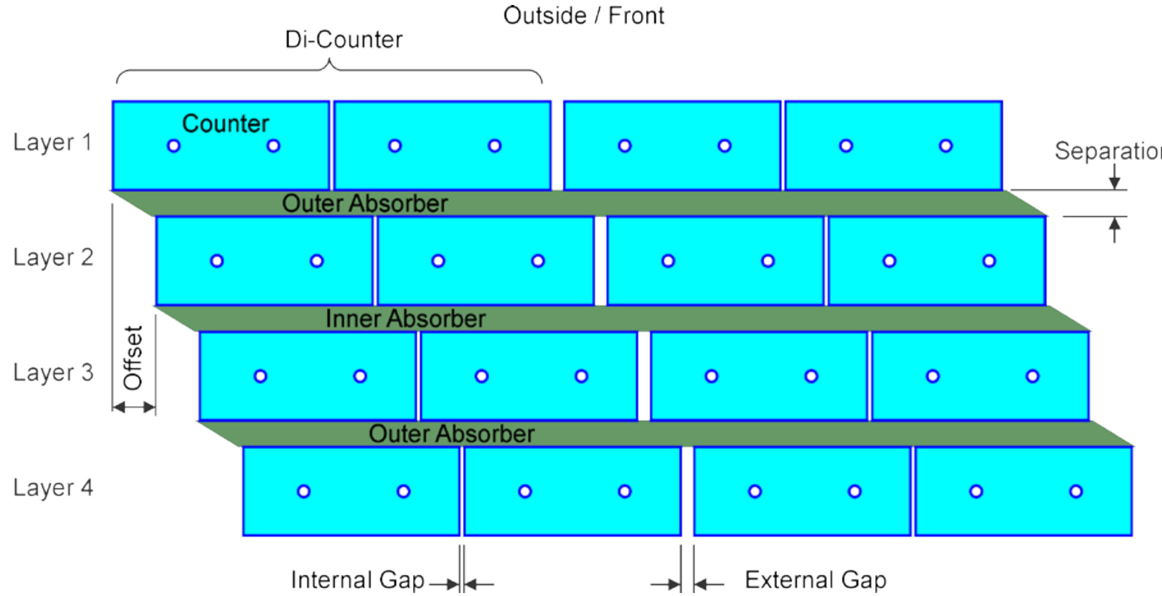
# Design

There are three board types in the system:

- 1: A counter mother board (CMB) which holds four SiPMs, two flasher LEDs, flash gate drivers and a temperature sensor.
- 2: A front-end board (FEB) which digitizes the signals from 64 SiPMs.
- 3: A readout Controller (ROC) which gathers data from and supplies power to 24 front-end boards over Cat-5 cables. Interfaces to the DAQ/timing/control system.

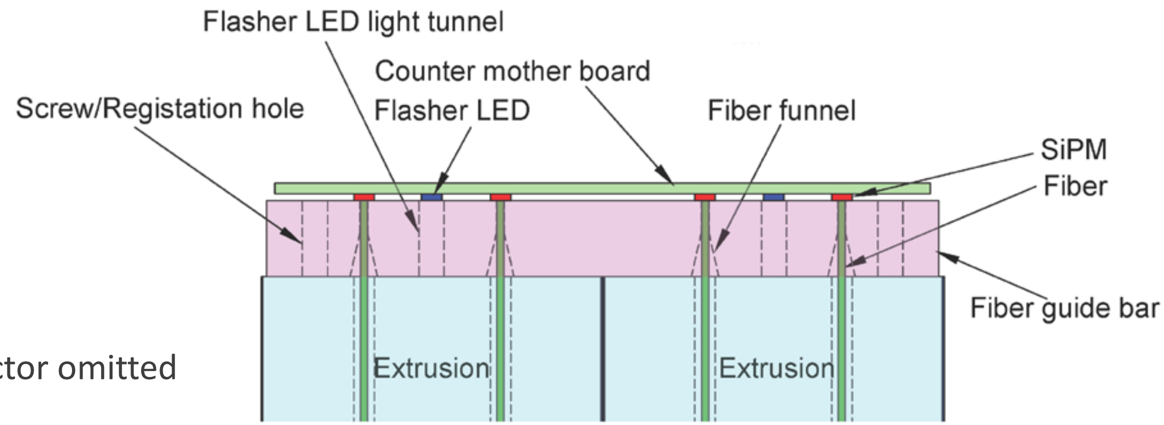
# Design

Extrusion Arrangement :



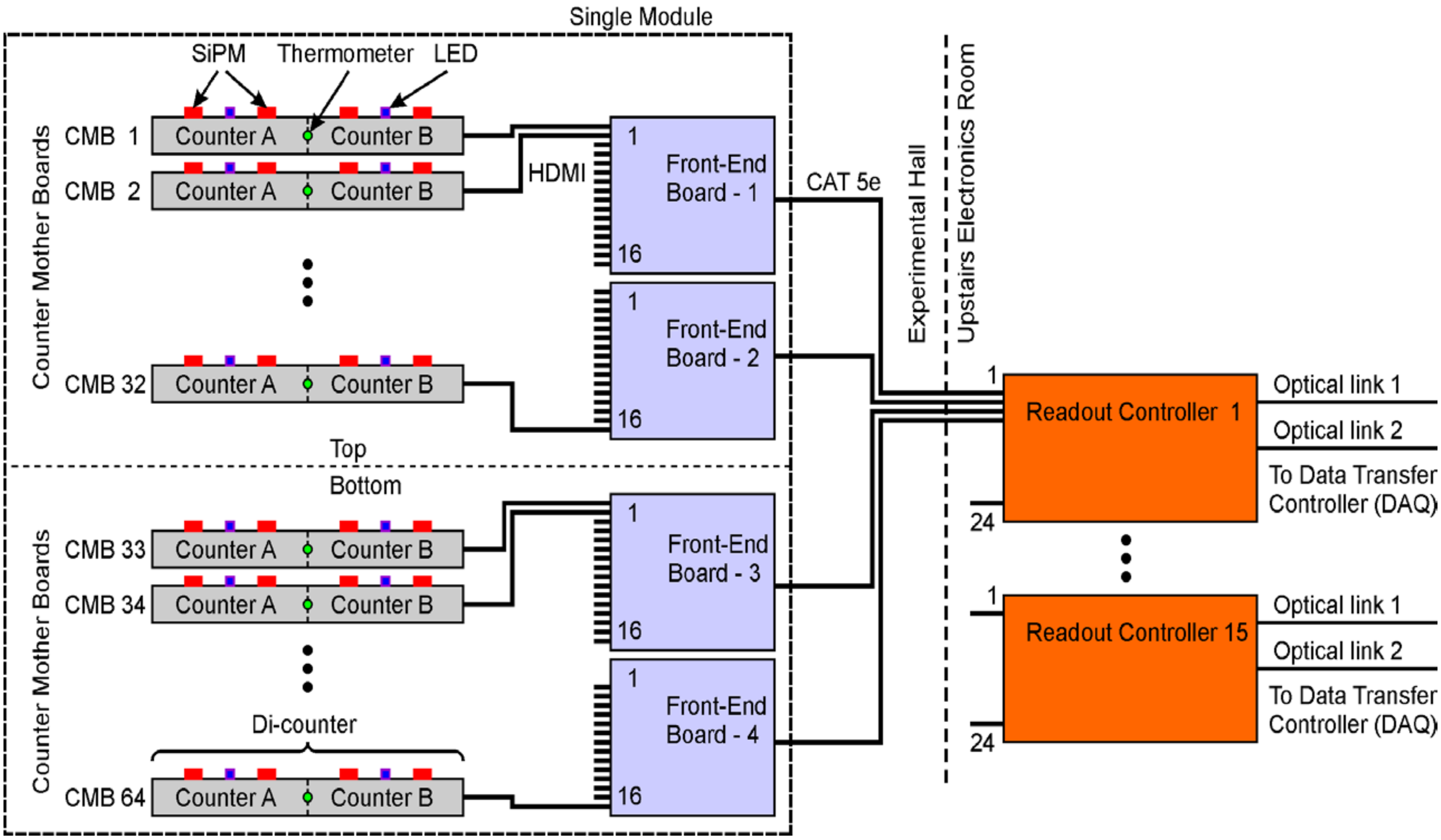

Counter motherboard:

HDMI connector omitted



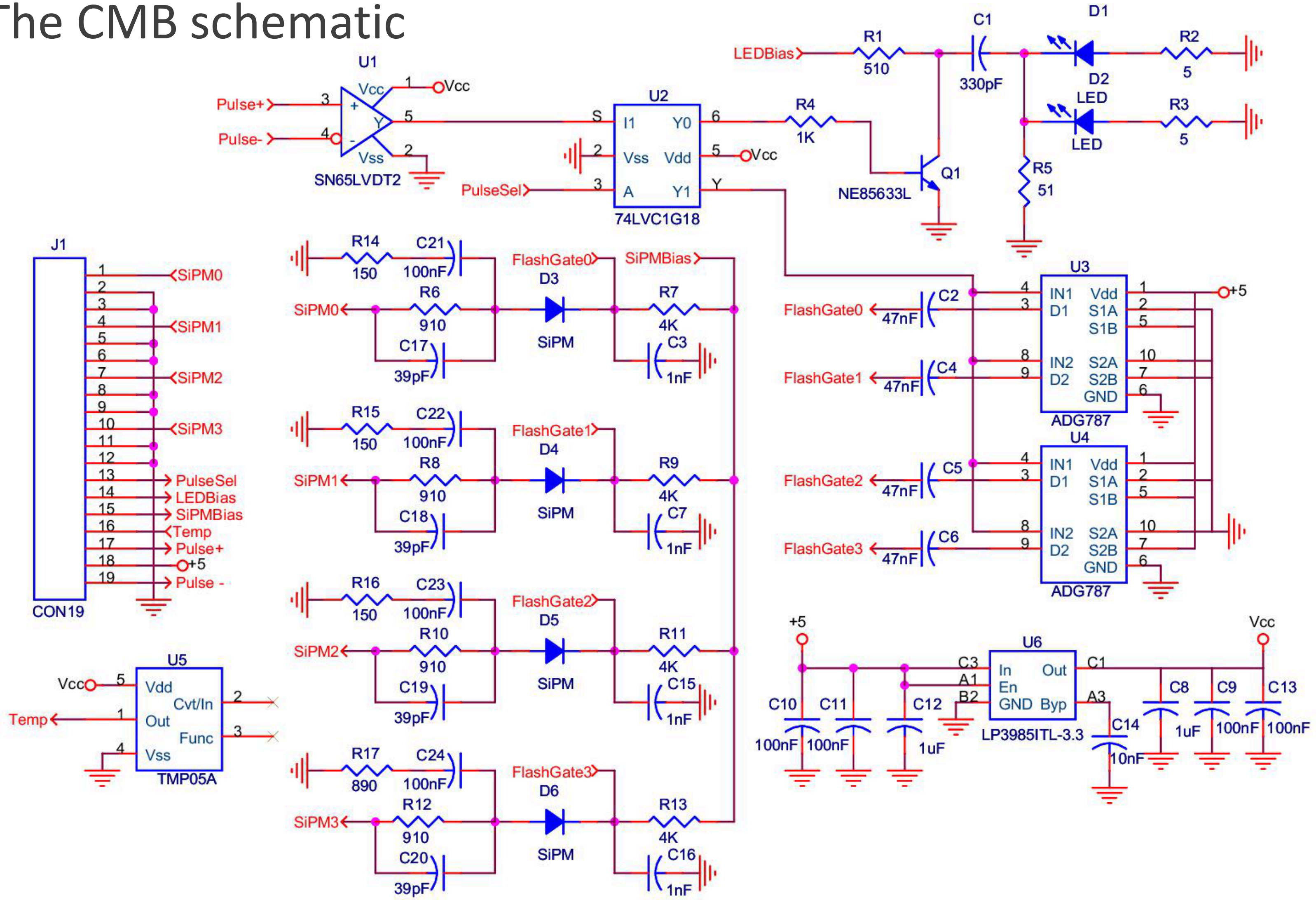
# Design

Diagram showing interconnection of all three board types:



# Design

## The CMB schematic

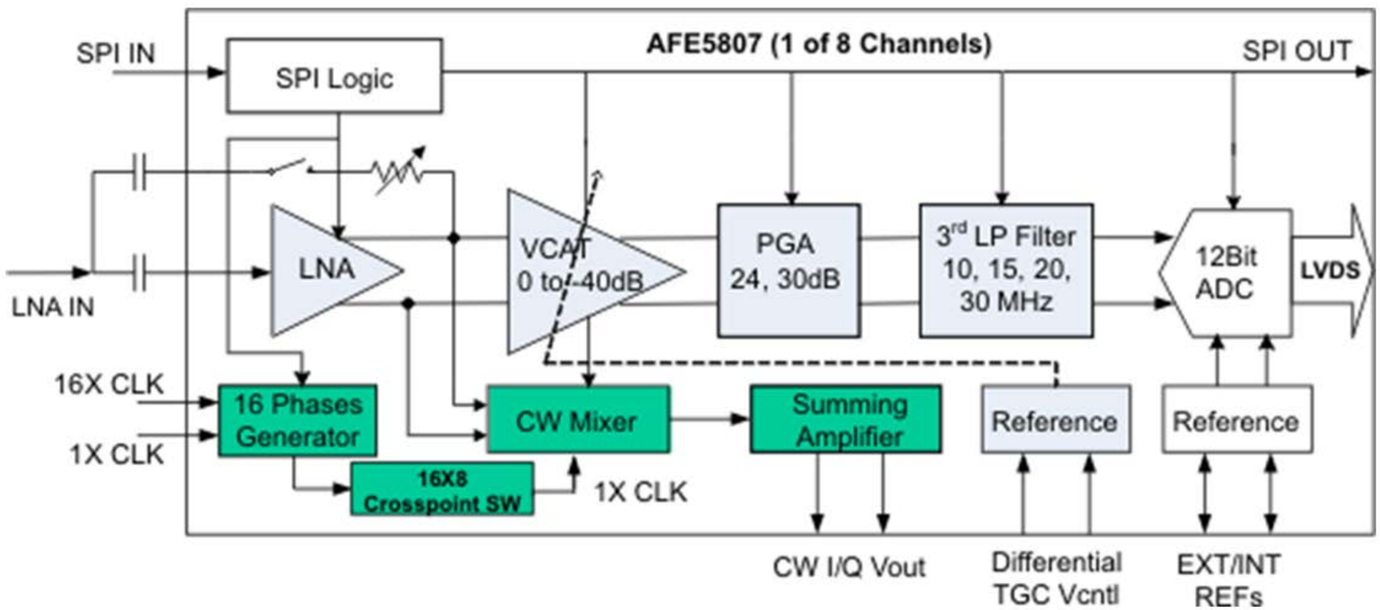





Fermilab

# Design

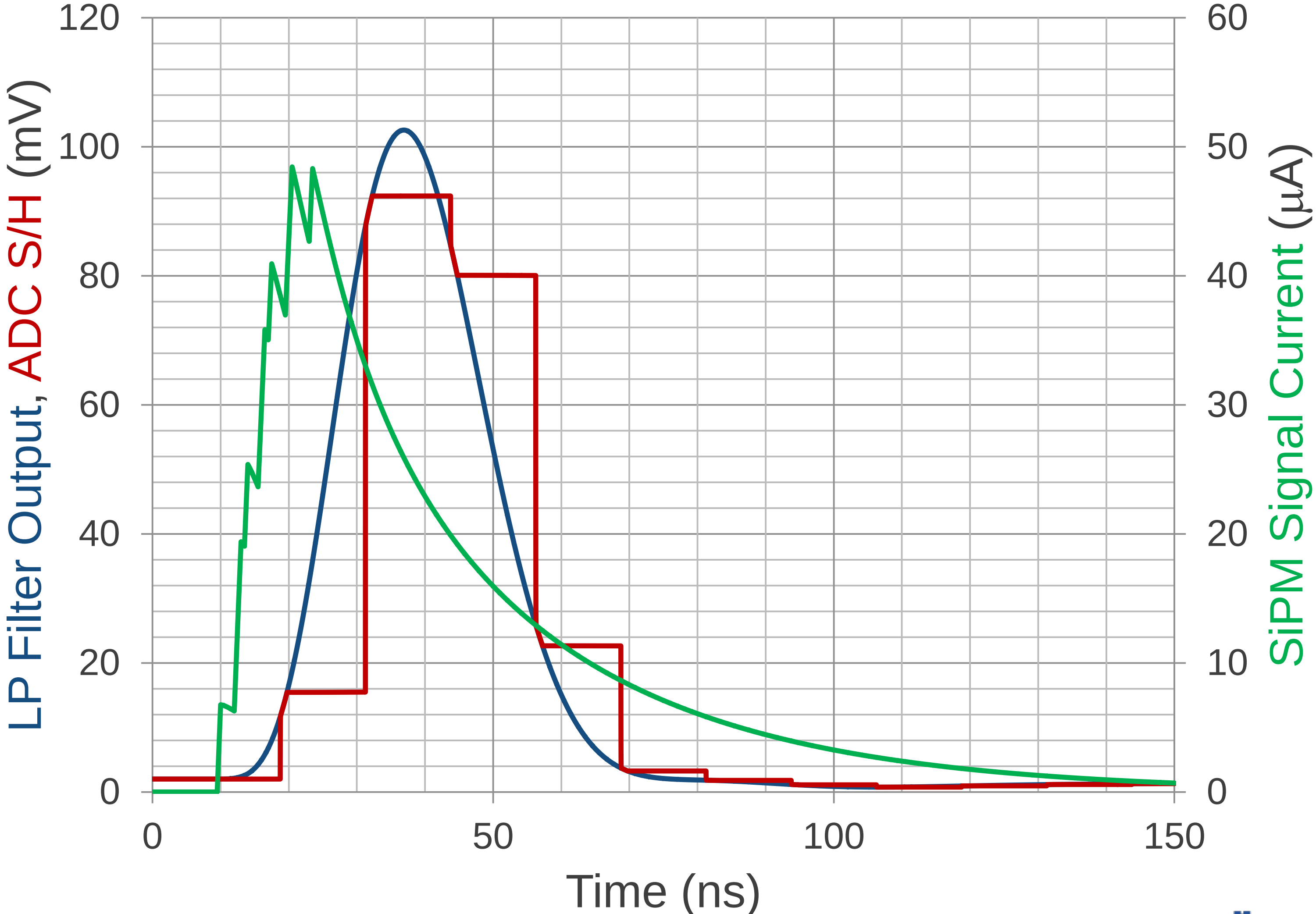
The core of the readout is a commercial ultrasound chip:




Eight channels of: low noise preamp, variable gain amp, programmable gain amp, programmable low pass filter, 80msps 12 bit ADC. $8 per channel, 120mW per channel. Adjust gain such that 1p.e. = 10 ADC counts.

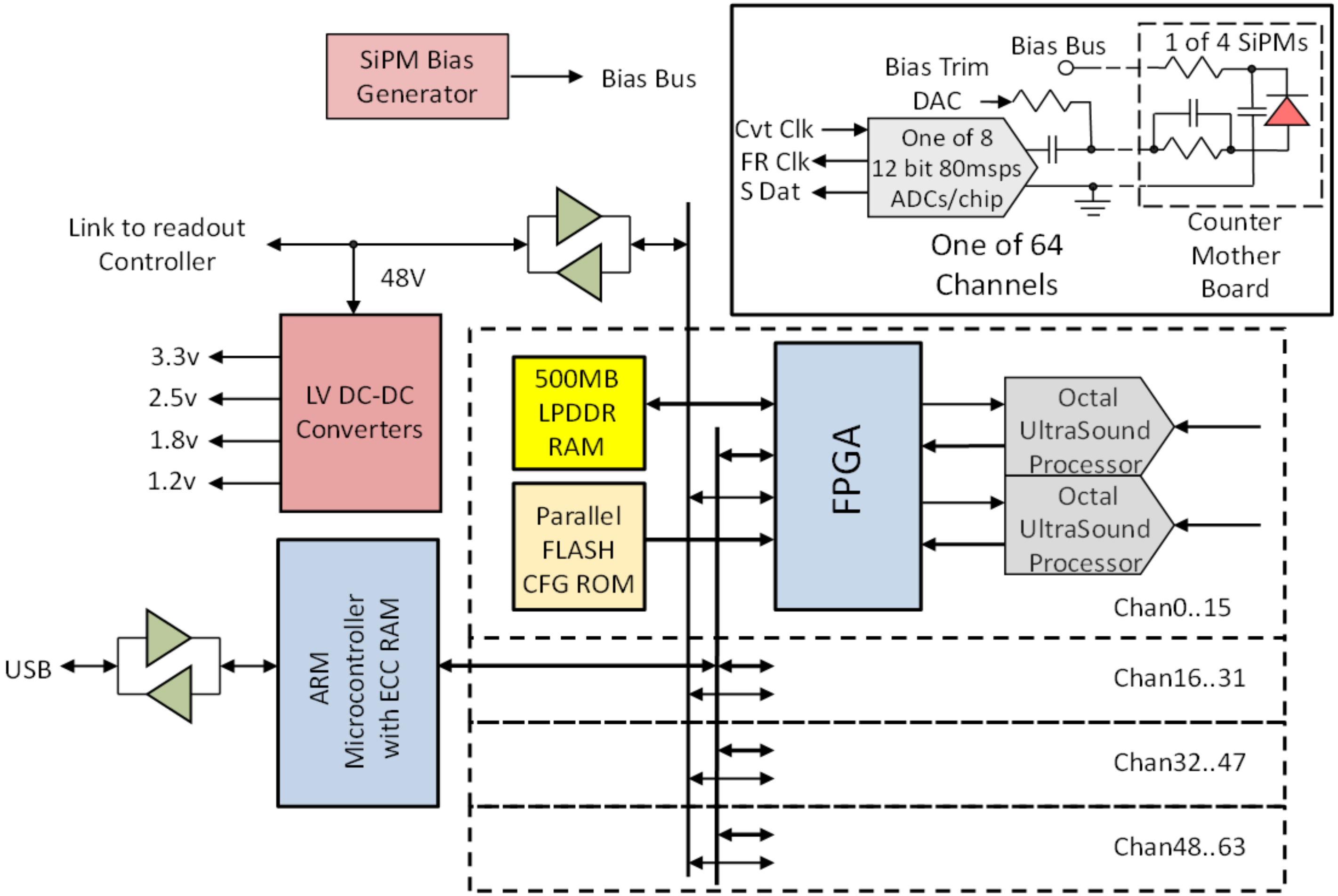
# Design

Simulation of a 10 p.e. SiPM signal showing tail cancellation:



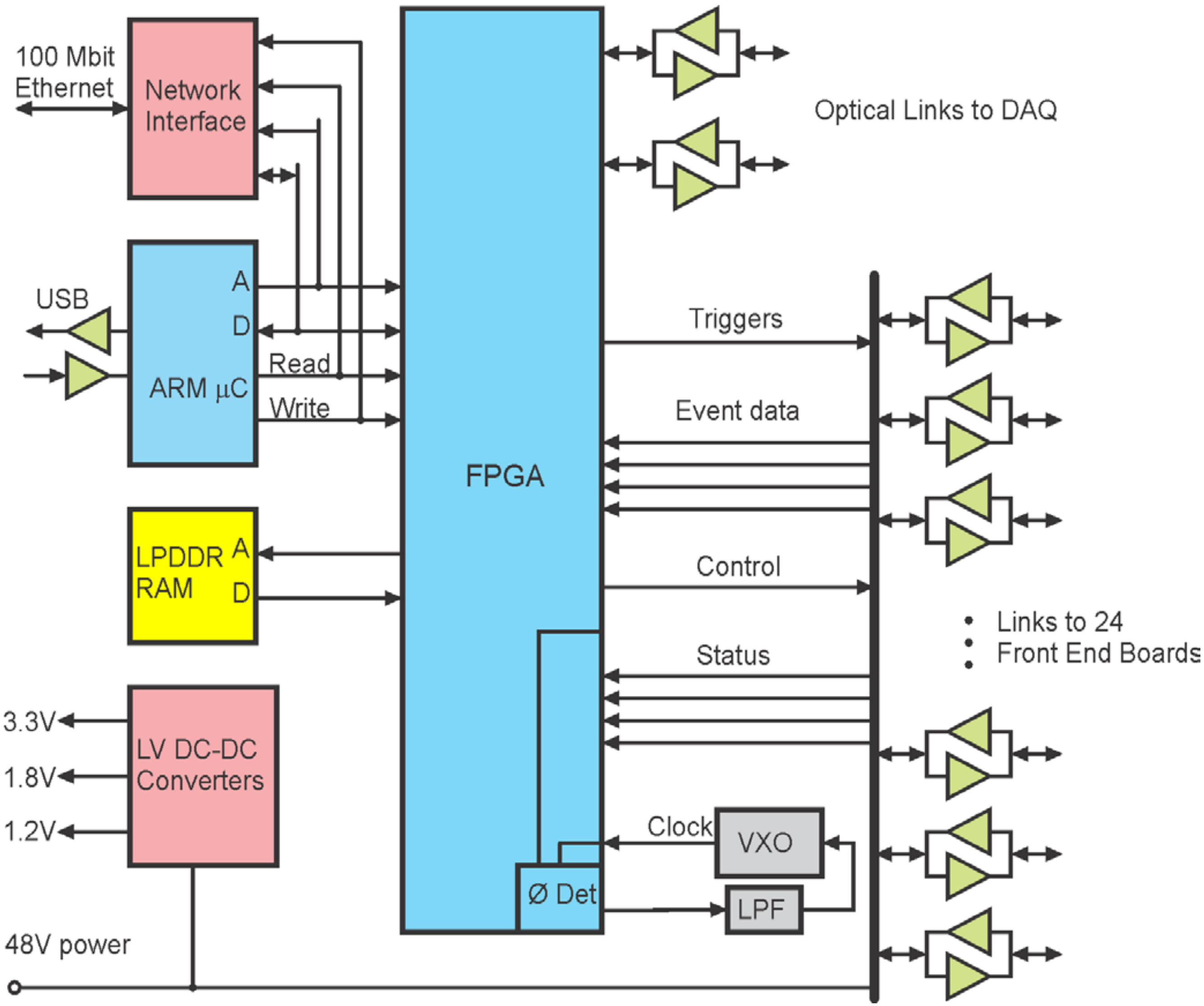
# Design

Front end board block diagram:



# Design

Controller block diagram:



# Design

Rate Estimates:

| | Item | Average | Design |
|---|---|---|---|
| Live Spill Period | Instantaneous hit rate/counter (channel) | 127.0 kHz | 1000.0 kHz |
| | Hit event size | 12 bytes | |
| | Instantaneous data rate/channel | 1.5 MB/s | 12.0 MB/s |
| | Spill length (s) | 0.497 | |
| | Spill duty factor | 0.528 | |
| | Average data rate/FEB | 51.5 MB/s | 405.7 MB/s |
| | Total data per FEB per live spill | 25.6 MB | 201.6 MB |
| Interspill Period | Instantaneous hit rate/counter (channel) | 10.0 kHz | 100.0 kHz |
| | Instantaneous data rate/channel | 0.1 MB/s | 1.2 MB/s |
| | Interspill length (s) | 0.836 | |
| | Interspill duty factor | 1.000 | |
| | Average data rate/FEB | 7.7 MB/s | 76.8 MB/s |
| | Total data per FEB per interspill | 6.4 MB | 64.2 MB |
| Total | Average data rate/FEB | 24.0 MB/s | 199.4 MB/s |
| | Average data rate/CRV | 7.1 GB/s | 59.0 GB/s |
| | Total data per FEB per cycle | 32.0 MB | 265.9 MB |
| | Total data CRV per cycle | 9.5 GB | 78.7 GB |
| FEB to DAQ | Trigger rejection | 100 | |
| | Data rate out per FEB | 0.2 MB/s | 2.0 MB/s |
| | Average data rate to a ROC | 5.8 MB/s | 47.9 MB/s |
| | Total CRV data rate to DAQ | 71.1 MB/s | 590.2 MB/s |
| | Total CRV data for run | 1.0 PB | 8.0 PB |

10 MB/s Links
FEB to Controller

200 MB/s Links
Controller to DAQ

# Changes since CD-1

- Background rates have gone up >10x
- Signal tail cancellation implemented to improve double pulse resolution
- Flash gate implemented
- Channel count has increased 33%
- 1E10 Neutrons/cm$^2$ total dose.
- Damage is not an issue, SEUs are
- Single event upset mitigation required
- 100mT ambient field
- Magnetic field tolerance required (shield magnetic components)
- Controllers are to be placed in the electronics room to avoid magnetic field and radiation dose

# Value Engineering since CD-1

- Change from self triggering to externally triggered. All data analysis beyond zero-suppression and trigger primitive is done offline. Reduces FPGA programming labor, reduces data rate

# Performance

- We will use the ADC data to track SiPM gain variations based on single p.e. signals during the interspill in order to apply a known energy threshold during the spill.
- For a typical muon track we expect timing accuracy of 5ns.
- An 80 msps ADC can resolve adjacent pulses down to ~40ns. There is no efficiency loss if two pulses are counted as one, but the time accuracy suffers. Time resolution degrades as pulse separation goes below 60ns.

# Remaining work before CD-3

- Build and test prototypes of all three card types

# 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

# Organizational Breakdown

**WBS 8.6 Electronics**
Sten Hansen / Fermilab

**8.6.1 Counter Mother Boards**
This task covers the design, fabrication, and testing of the electronics boards that sit directly on the counters, and onto which the SiPMs, flasher LEDs, and temperatures sensors are mounted. It includes the ancillary electronics boards needed to read out the counter mother boards in the absence of front-end boards and the front-end board/counter mother board test jig.

**8.6.2 Front End Boards**
This task covers the design, fabrication, and testing of the electronics that: (1) amplifies, shapes, and digitizes the output of the photodetectors, producing data for the DAQ and the trigger; (2) sets the bias for the photodetectors; (3) controls the flasher system; and (4) reads out the temperature sensors.

**8.6.3 Readout Controllers**
This task covers the design, fabrication, and testing of the devices that serves as the links between the front-end boards and the slow and fast data acquisition systems. It includes prototypes, production, and testing.

**8.6.4 Integration with DAQ**
This labor-only task covers the integration of the slow and fast DAQs with the readout controllers and front-end boards.

# Quality Assurance

- Extensive testing regimen
- Prototype FEB
- Test for single event upsets
- Test magnetic field tolerance
- Rate testing in a beam
- Stability testing with cosmic rays.
- Test link to DAQ
- Pre-production prototype FEB
- Incorporate changes based on results from above
- Build test fixture, test software

# Risks

- Risk: The background rates are higher than expected
- Mitigation: Additional shielding. No impact on electronics costs.

- Risk: Radiation dose is higher than expected
- Mitigation: Same as above

# ES&H

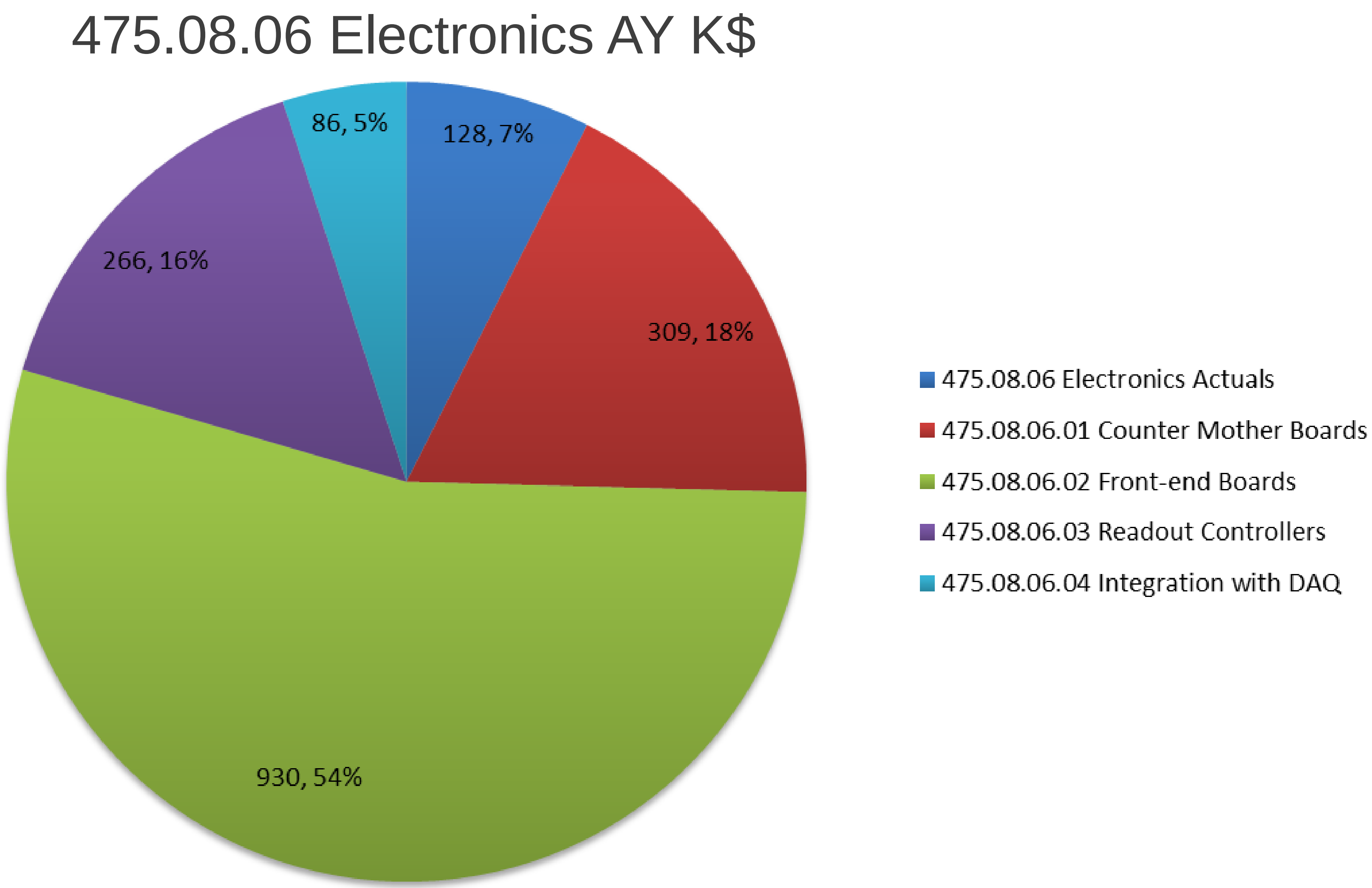
- There are no special concerns with the CRV electronics
- There will be moderate voltages (<100V) present for biasing the photo detectors. Stored energy values are in the milli-Joule range. Moderate power levels (700W) in the controllers.

# Cost Table

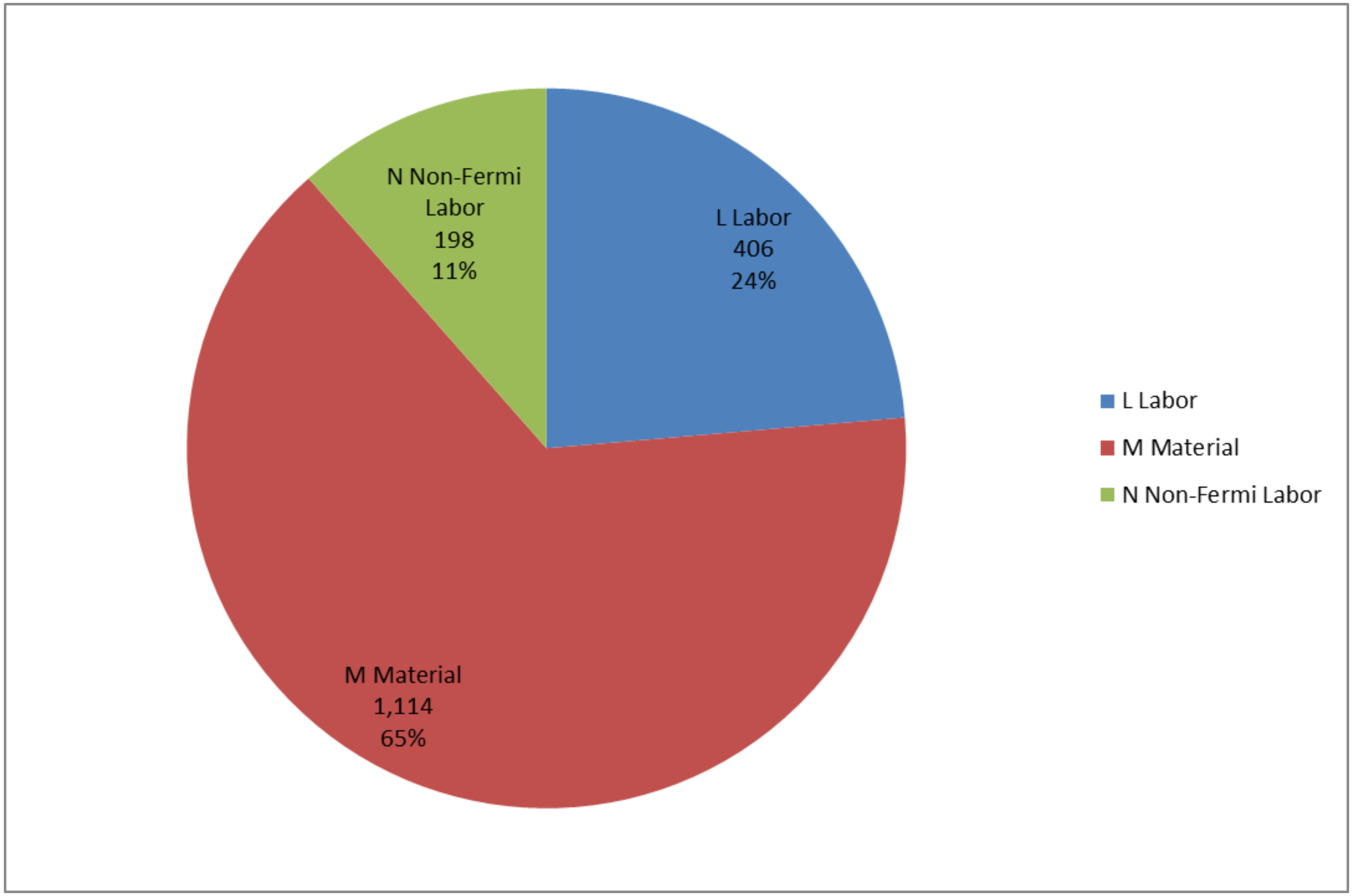
| | Base Cost (AY k$) | | | | | |
|---|---|---|---|---|---|---|
| | M&S | Labor | Total | Estimate Uncertainty (on remaining costs) | % Contingency on ETC | Total Cost |
| 475.08 Cosmic Ray Veto | | | | | | |
| 475.08.06 Electronics | | | | | | |
| 475.08.06 Electronics Actuals | 92 | 36 | 128 | | | 128 |
| 475.08.06.01 Counter Mother Boards | 309 | | 309 | 85 | 30% | 394 |
| 475.08.06.02 Front-end Boards | 636 | 294 | 930 | 269 | 29% | 1,199 |
| 475.08.06.03 Readout Controllers | 260 | 6 | 266 | 85 | 32% | 351 |
| 475.08.06.04 Integration with DAQ | 15 | 71 | 86 | 69 | 80% | 155 |
| Grand Total | 1,312 | 406 | 1,718 | 509 | 32% | 2,227 |

Note: Labor FNAL only.

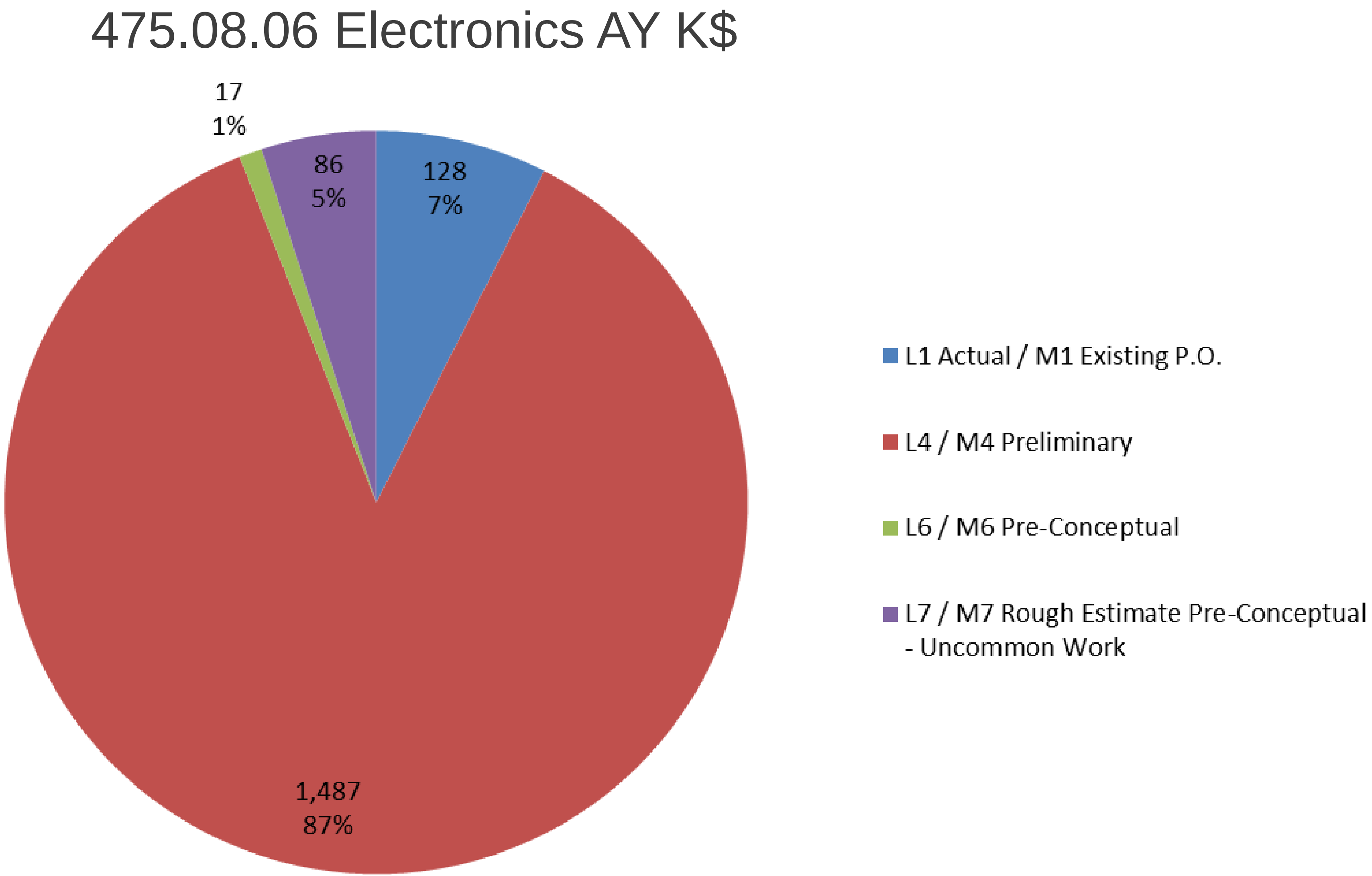
# Cost Breakdown



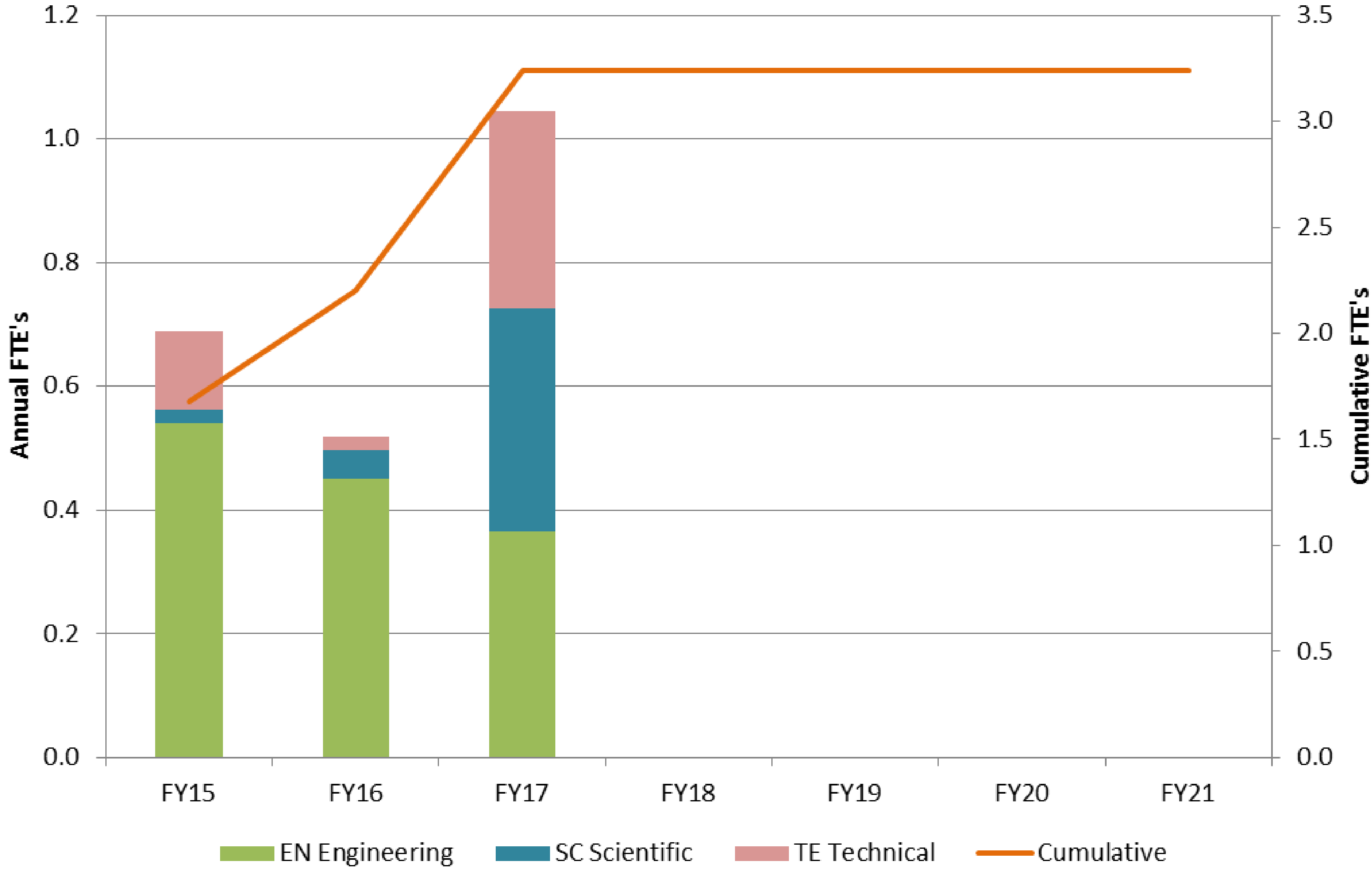
# Cost Breakdown: Resource Type



# Quality of Estimate



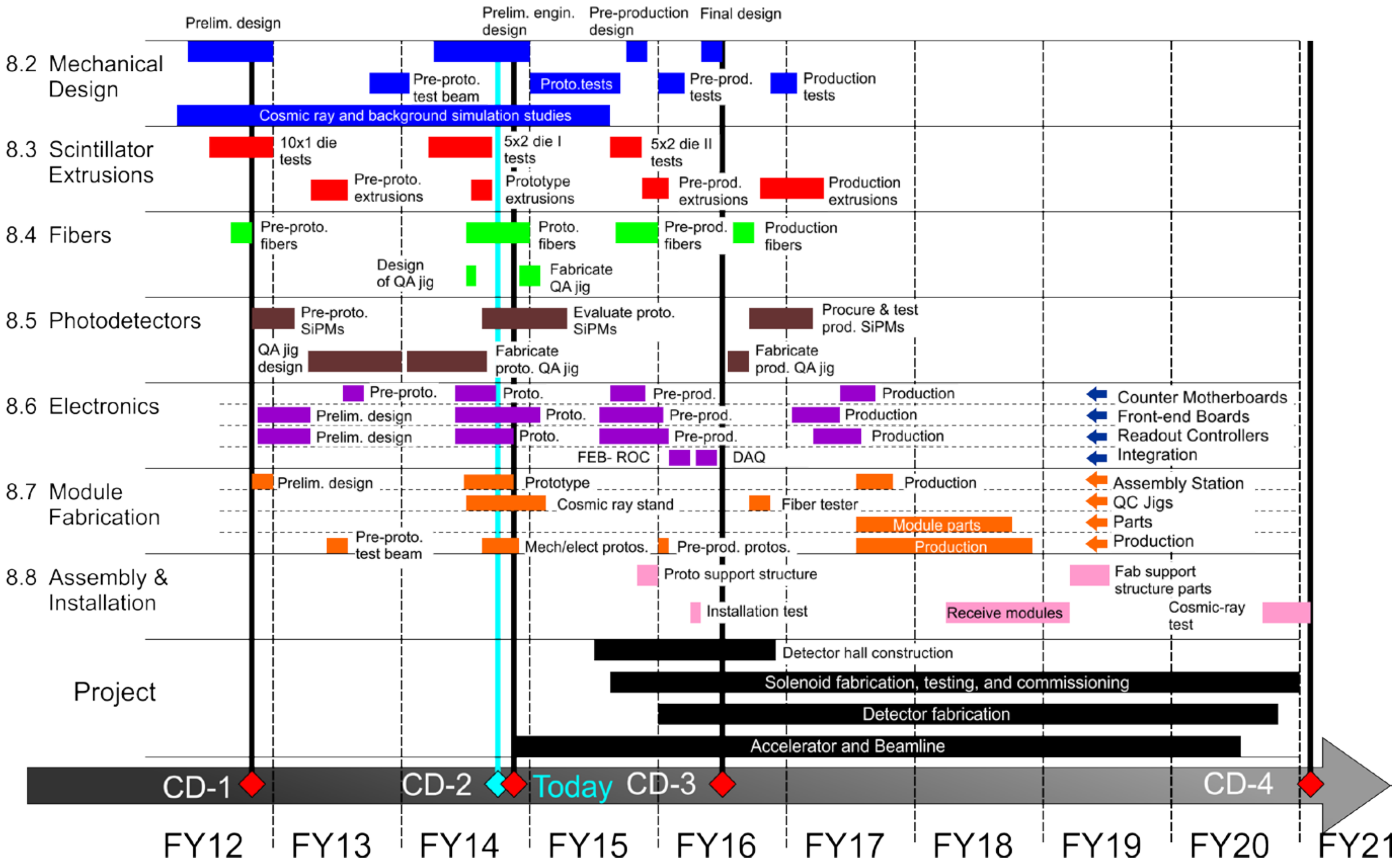
# Labor Resources by Discipline



# Major Milestones

- Completion of prototypes
- Completion of magnetic field and radiation tests
- Testing of one fully instrumented module
- Completion of pre-production prototypes
- Completion of production
- Completion of testing
- Completion of integration with the DAQ

# 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

- The electronics is commercial off the shelf
- The design is derived from previous successful projects
- We have begun design and fabrication of the first prototypes. The uncertainties will decrease significantly after getting our first set of test results
- We will test performance in a magnetic field and during radiation exposure