Calorimeter

Mu2e Independent Cost Estimate

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Calorimeter requirements and scope

- The Mu2e calorimeter measures the energy of putative conversion electron candidates, provides positive identification of the candidates as electrons, rejects cosmic ray muons that evade the main veto system, and can provide a seed for charged particle track-finding, as well as an independent trigger for the experiment
- It consists of
  - two annular disks containing 1860 BaF_2 scintillating crystals
  - two photosensors mounted on each crystal
  - analog and digital readout electronics
  - bias voltage supplies for the photosensors and low voltage supplies
  - a calibration and monitoring system
  - temperature and radiation monitoring systems
  - mechanical support for all of these systems

Organization

475.7
Calorimeter
L2: S. Miscetti (Frascati)
Deputy: D. Hitlin (Caltech)

475.7.1 Project Management
L3 – S. Miscetti – (LNF)
CAM – D. Hitlin

475.7.2 Crystals
L3 – D. Hitlin (Caltech)
CAM - D. Hitlin

475.7.3 Mechanics
L3 – F. Happacher (LNF)

475.7.4 Photosensors
L3 – I. Sarra (LNF)
CAM – D. Hitlin

475.7.5 Digitizer
L3 – F. Spinella (Pisa)
CAM – D. Hitlin

475.7.6 Calibration
L3 – F. Porter (Caltech)
CAM – D. Hitlin

475.7.7 Frontend electronics and power
L3 – G. Corradi (LNF)

475.7.8 Assembly and Installation
L3 – A. Saputi (LNF)
CAM – D. Hitlin

Basis of Estimates

- Vendor quotes
- Preliminary designs
- Engineering estimates based on application of similar technology and/or previous closely-related realized project

Cost

WBS 7 Calorimeter

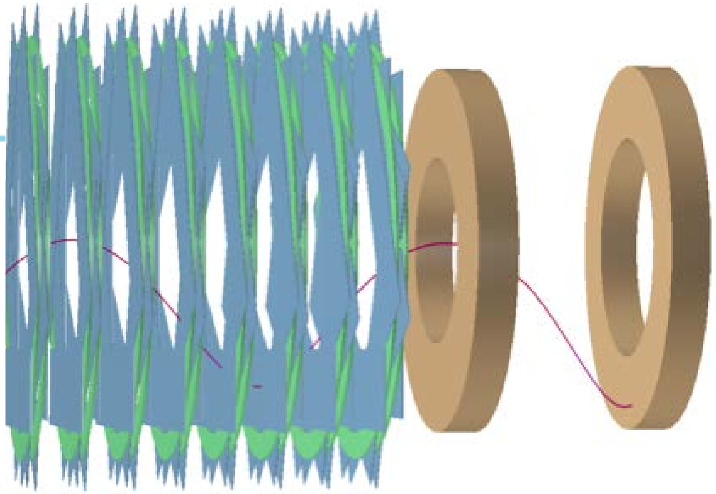
Costs are fully burdened in AY $k

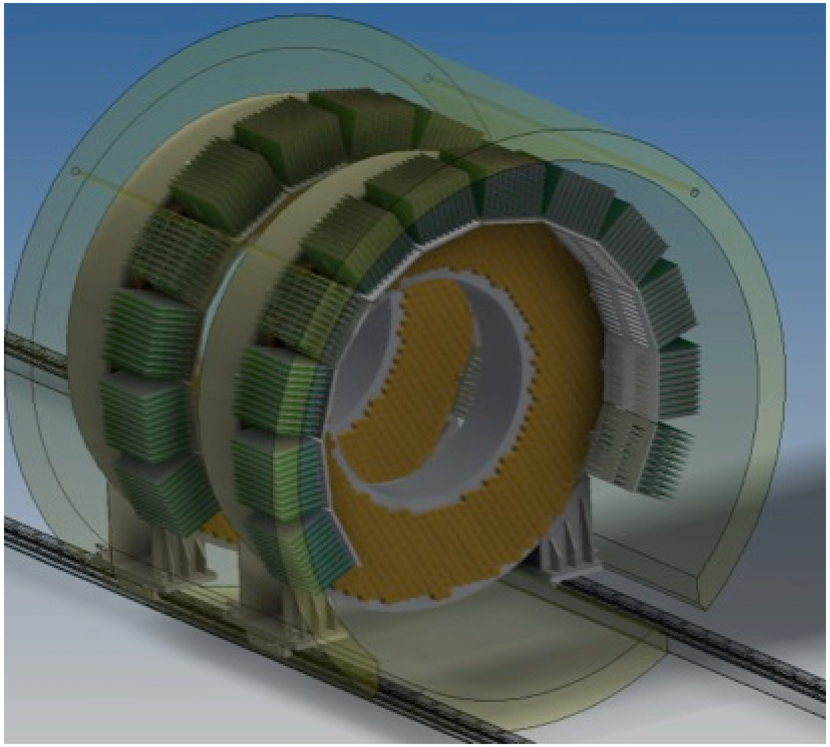
	M & S	Labor	Base Cost	Estimate Uncertainty	Contingency on ETC	Total
475.07.01 Project Management	262	7	269	31	20%	300
475.07.02 Crystals	3,071	54	3,125	509	16%	3,634
475.07.03 Mechanical Support	162		162	32	20%	195
475.07.04 Photosensors	1,089		1,089	216	20%	1,304
475.07.05 Digitizer and Front End Electronics	108		108		0%	108
475.07.06 Calibration Systems	660	60	720	206	29%	927
475.07.07 Power		4	4	1	30%	5
475.07.08 Installation	47	268	315	110	35%	425
475.07.99 Risk Based Contingency				523		523
Total	5,400	393	5,793	1,628	29%	7,421

Calorimeter layout

The calorimeter consists of two annular disks comprised of a total of 1860 hexagonal BaF_2 crystals:

- → Dimensions
  r_{inner} = 351 mm, r_{outer} = 660 mm
  depth 10 X0 (200 mm)
- → The distance between disks is optimized at ½ wavelength of the helical conversion electron trajectory (70 cm)
- → Each crystal is read out by two
  large area APD's (9x9 mm^2) (3920 total)
- → Analog (FEE) and digital electronics is located in nearby electronics crates
- → Radioactive source and laser systems provide absolute calibration as well as fast and reliable monitoring capability





475.07.02 Crystals

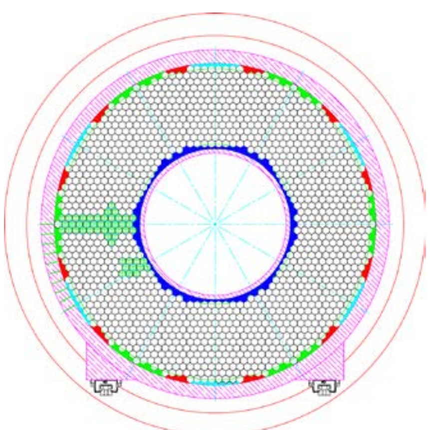
Barium fluoride (BaF_2)

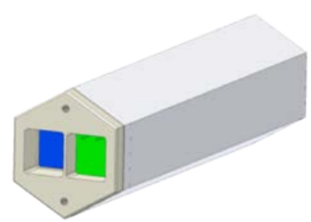
- radiation hard, non-hygroscopic
- very fast (220 nm) scintillation light
- larger slow component at 300 nm should be suppressed for high rate capability

⇒ Photosensor should have extended UV sensitivity and be "solar"-blind

- Crystal dimensions: hexagonal shape 33 mm across flats, 200 mm (10 X_0) long, read out by two APD sensors

	BaF_2
Density (g/cm^3)	4.89
Radiation length (cm)	2.03
Moliere Radius (cm)	3.10
Interaction length (cm)	30.7
dE/dx (MeV/cm)	6.52
Refractive index	1.50
Peak luminescence (nm)	220 (300)
Decay time (ns)	1 (650)
Light yield (rel. to NaI)	5% (42%)
Variation with temperature	0.1% (-1.29)% / ^{o}C

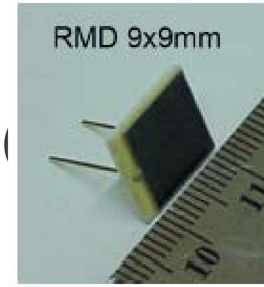


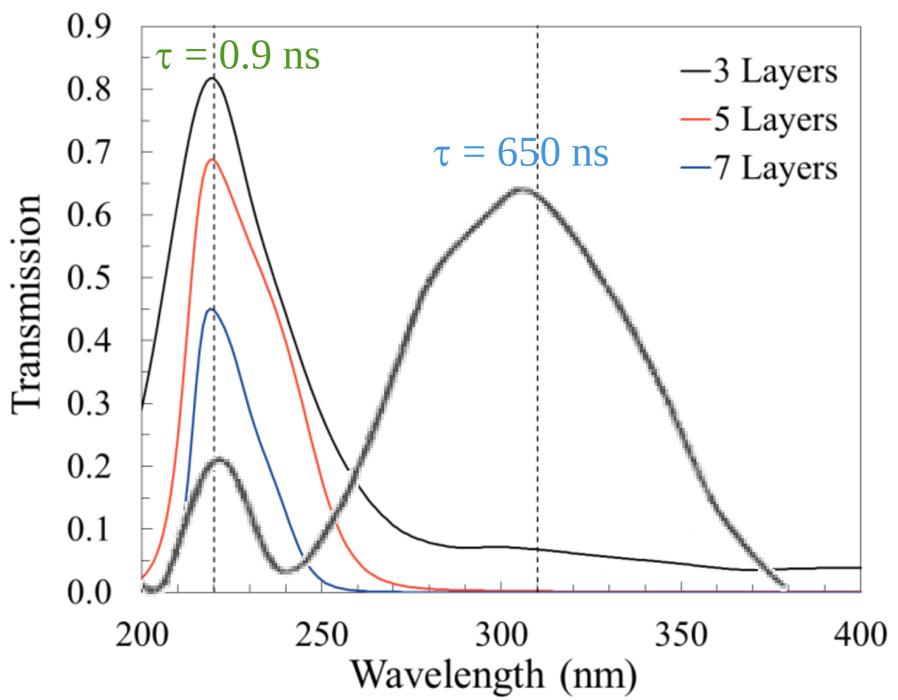


475.07.04 Photosensors

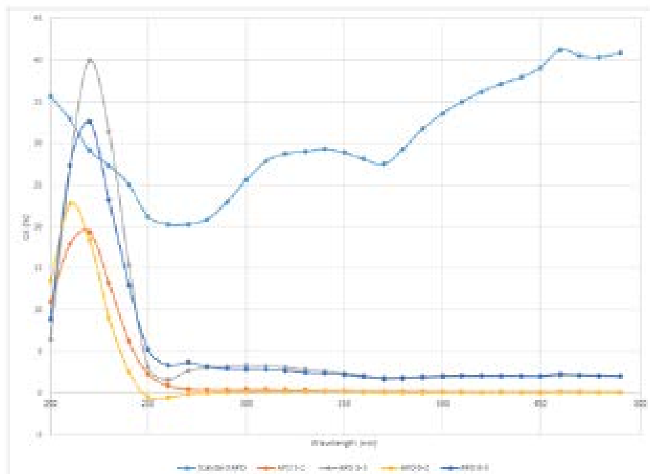
We have been awarded an SBIR grant for a Caltech/JPL/RMD consortium to develop an existing large area RMD avalanche photodiode (APD) into a delta-doped super-lattice device that incorporates an atomic layer deposition (antireflection filter to obtain

- high quantum efficiency at the 220 nm fast scintillation component
- efficiency <10^{-3} at the 300 nm slow scintillation component

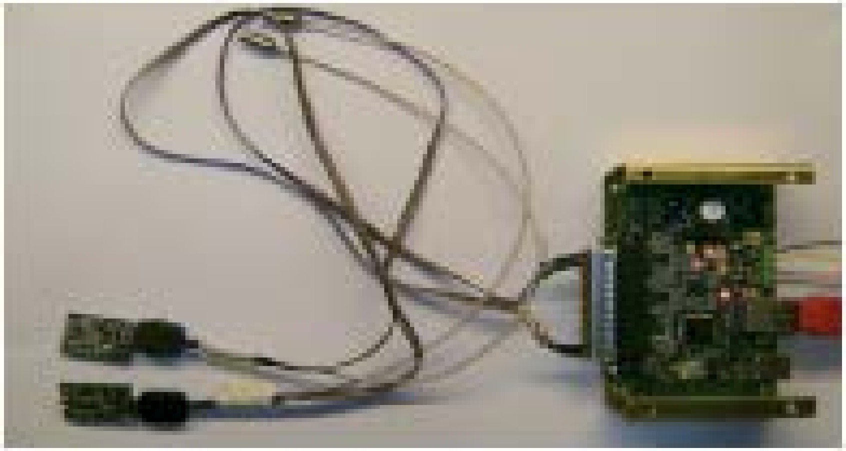




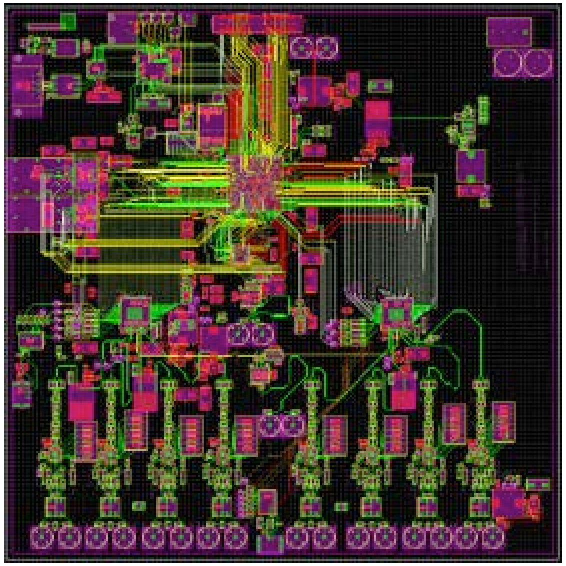
Prototypes with the ALD filter applied are indeed solar blind



475.07.05 FEE & Readout



- The FEE consists of discrete chips connected to the photosensors: a preamplifier and a local bias voltage regulator.
- 16 FEE channels driven are by an ARM-controller to generate/distribute bias and power voltages
- 50 prototype FEE channels and 5 ARM controllers have been produced by INFN-Frascati

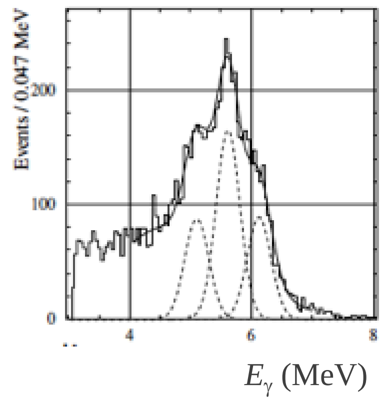


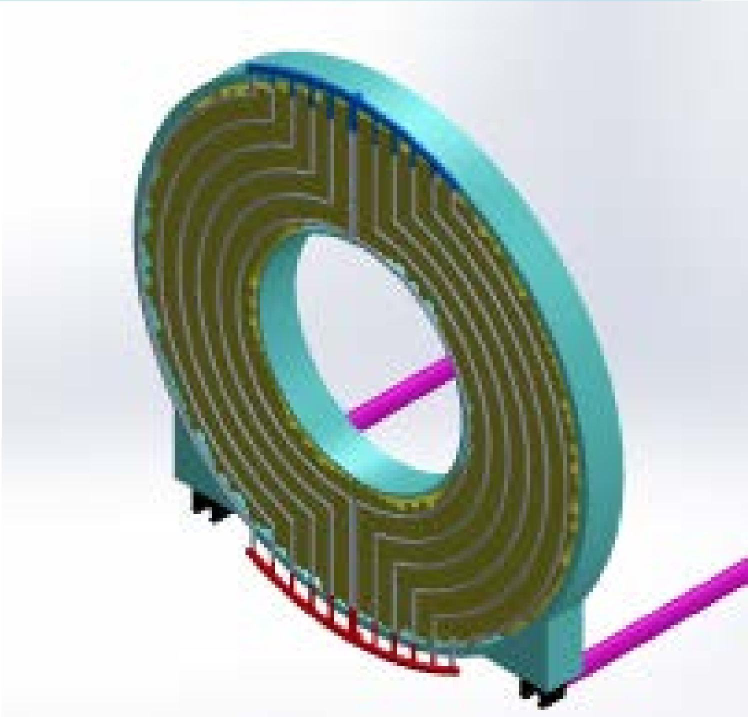
- The digitizer board has 32 channels with 12 bit resolution and 200 ms/s, based on a Smart Fusion FPGA.
- Five 8 channel prototypes are under construction at University of Illinois
- Design of the final digitizer is underway as a joint project of INFN Pisa and University of Illinois.

475.07.06 Calibration system

Based on the *BABAR* system: repurposes many components

- Neutrons from a deuterium-tritium (*d-t*) generator adjacent to the detector irradiate a fluorine-rich fluid (Fluorinert)
- The activated liquid is piped to the front face of the calorimeter disks
- This provides switchable calibration lines with 6 to 10 times the energy of long-lived radioactive sources
- Allows setting an energy scale to a few tenths of a percent accuracy
- Final experiment scale is set using DIOs

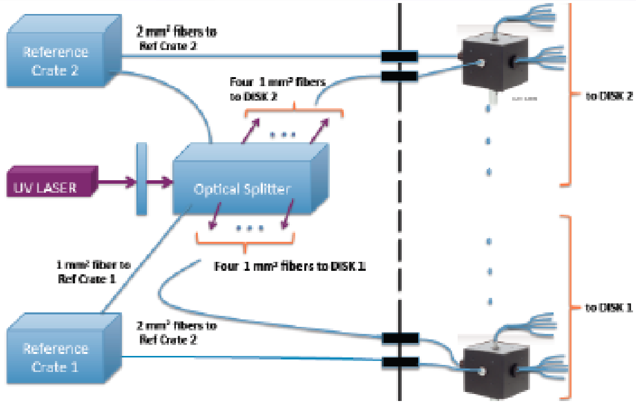




neutron generator: $d + t \rightarrow n(14.2\ \mathrm{MeV}) + {}^{4}\mathrm{He}$

$$^{19}F + n \rightarrow {}^{16}N + \alpha$$
$$^{16}N \rightarrow {}^{16}O^{*} + \beta \quad t_{1/2} = 7\ \mathrm{s}$$
$$^{16}O^{*} \rightarrow {}^{16}O + \gamma(6.13\ \mathrm{MeV})$$

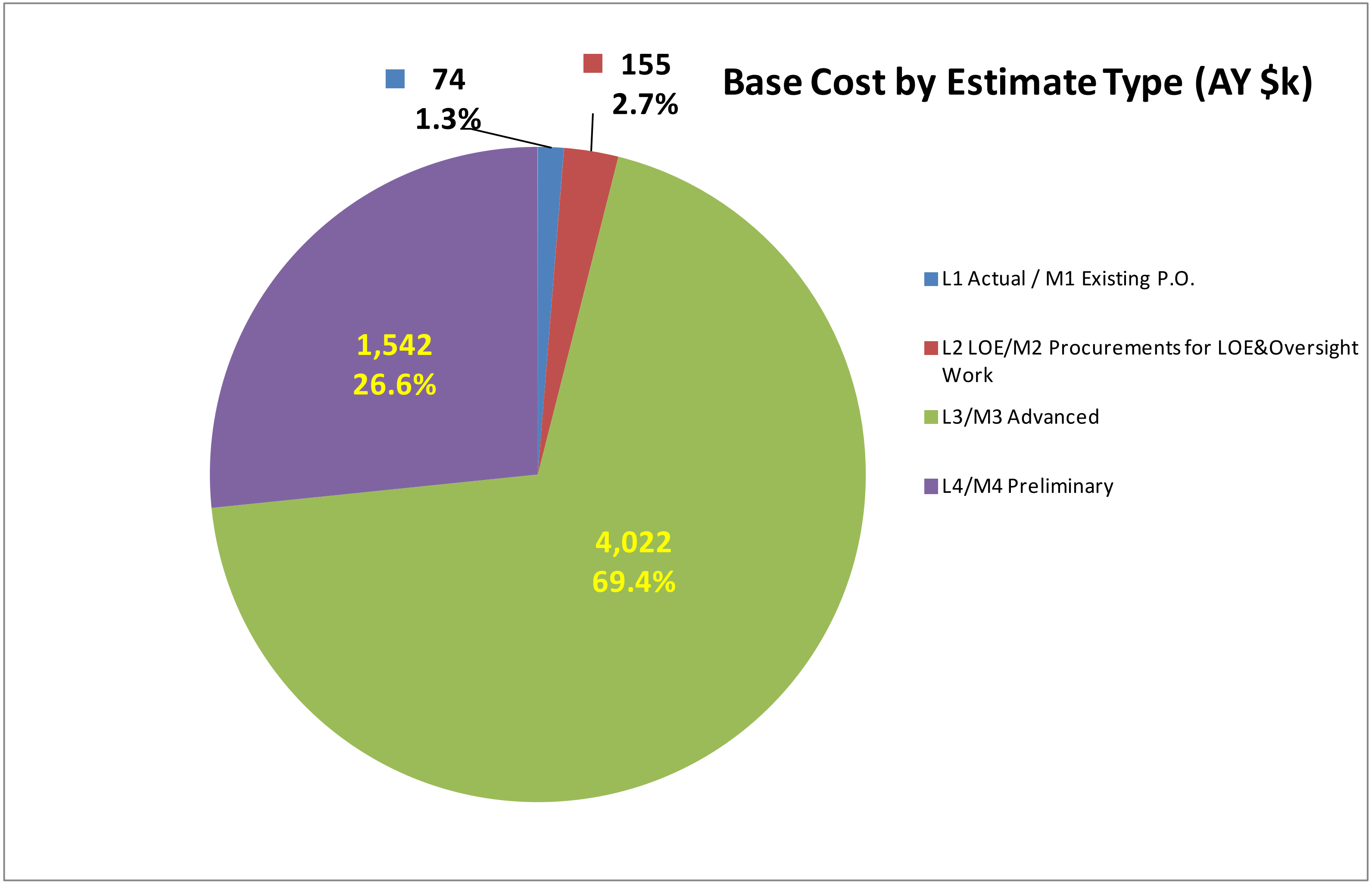
- There is also a laser monitoring system adapted from CMS calibration system that uses UV light to monitor the variation of the photosensor gain (INFN responsibility)



Risks

- CAL-108
  - INFN cannot deliver full in-kind scope
- CAL-148
  - Cannot develop UV-extended solid state photodetector that is blind to longer wavelengths
- CAL-170
  - US/Russia relations could impact the purchase of the calibration system DT generator in FY2017/2018
  - It is reasonable to assume that normal commercial activity will be re-established on that time scale
  - There is a (more expensive) US vendor

Quality of Estimate



Summary

- The calorimeter design has advanced since CD-1
  - BaF_2 crystal design and disk geometry are the baseline
- Responsibilities have been divided between US and Italian groups
  - Discussions concerning INFN funding are well-advanced
- We have vendor quotes or budget estimates for the largest M&S items
- Risks are understood and mitigate plans exist
  - Contingency should cover risks
  - Performance risks are acceptable
- Estimates are traceable
  - A comprehensive set of BOEs has been developed