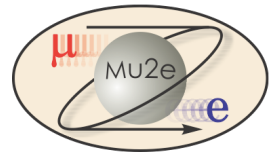
Mu2e CD-2 Calorimeter 475.07.06 Calibrations



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Requirements I – Calorimeter Calibrations (DocDB 864v6)

- The fundamental requirement for the Mu2e Calorimeter (Ecal) is to provide measurements of energy, timing and position of conversion electrons in the high-rate, high-radiation Mu2e environment that will supplement information provided by the tracker.
- To meet these goals, several different calibrations will be used to set the energy scale and track stability of the calorimeter response:
  - Absolute energy calibrations using mono-energetic ~6 Mev photons supplied by a source calibration system
  - A laser system to monitor photodetector response and any changes in light transmission in the scintillating crystals
  - for energies > ~6 MeV: cosmic rays, muon DIOs
- The source and laser calibrations will be implemented using dedicated Ecal hardware subsystems.
  - Calibrations with cosmic rays and DIOs require no dedicated Ecal subsystem(s).

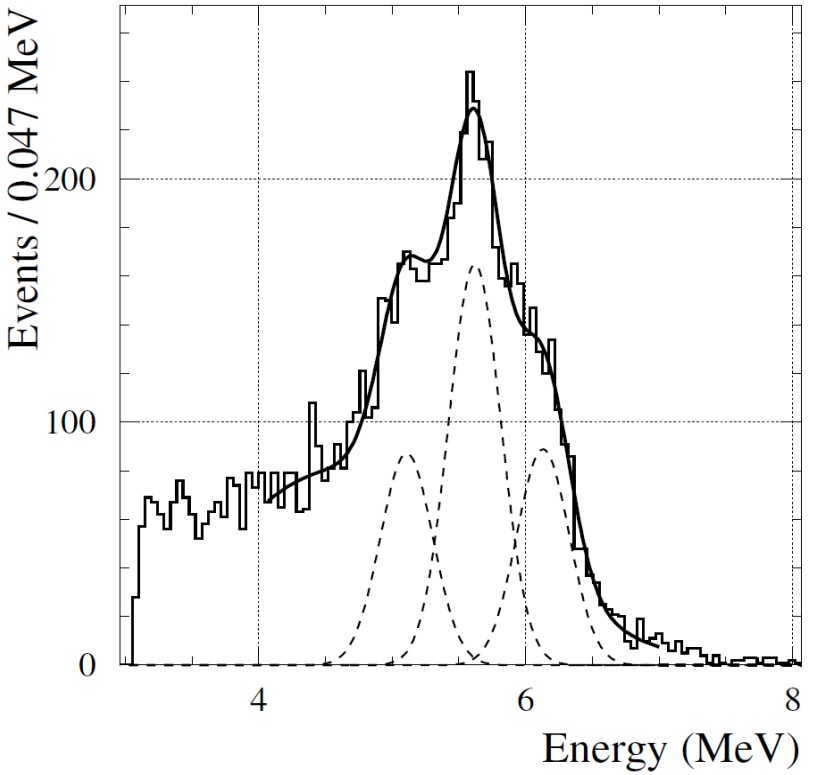
Requirements II – Calorimeter Calibrations (DocDB 864v6)

- The requirement on precision of the energy scale from the source calibration has been determined by requiring that the calibration uncertainty contribute no more than 5% to the total energy resolution, which amounts to a 0.64% contribution.
- Requirements on the laser system are similarly set so that the uncertainty on measurements of scintillating crystal transmission and photo-sensor response should be no greater than 0.5%.
- There are no specific requirements for calibrations with cosmics or DIOs.

Design I – Source Calibration System

- Mu2e has adopted an approach formerly devised for the *BABAR* electromagnetic calorimeter, which used a 6.13 MeV photon line produced in the decay of a short-lived activated fluorinated fluid.
- This system could be switched on and off as needed and was successfully used for routine weekly calibrations of the *BABAR* calorimeter. It is an ideal match to the Mu2e requirements.
- We have obtained the major elements of the *BABAR* system through salvage and begun to refurbish them for use in Mu2e.

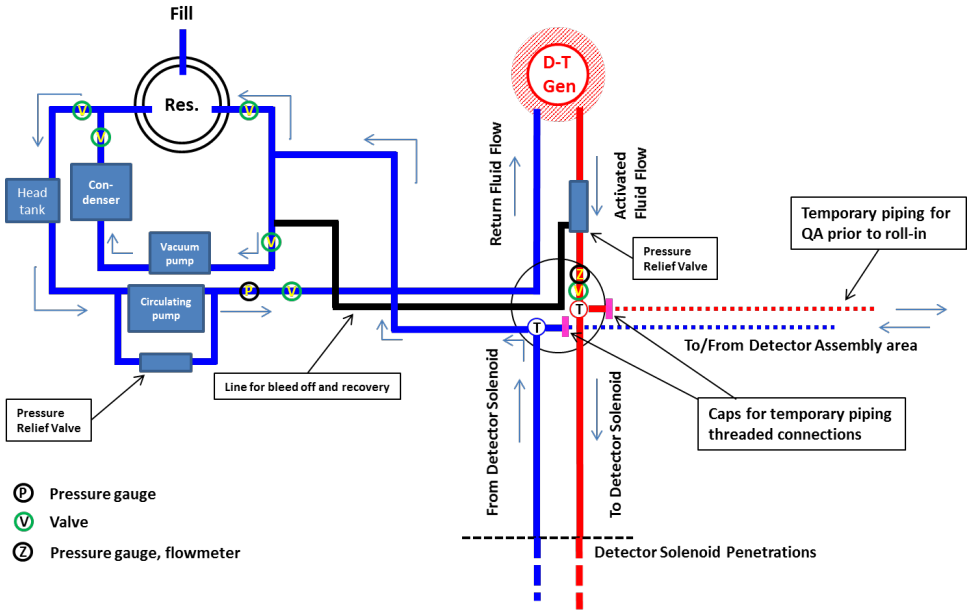
$$^{19}F + n \rightarrow {}^{16}N + \alpha$$
$$^{16}N \rightarrow {}^{16}O^* + \beta \quad t_{1/2} = 7\ \text{s}$$
$$^{16}O^* \rightarrow {}^{16}O + \gamma(6.13\ \text{MeV})$$

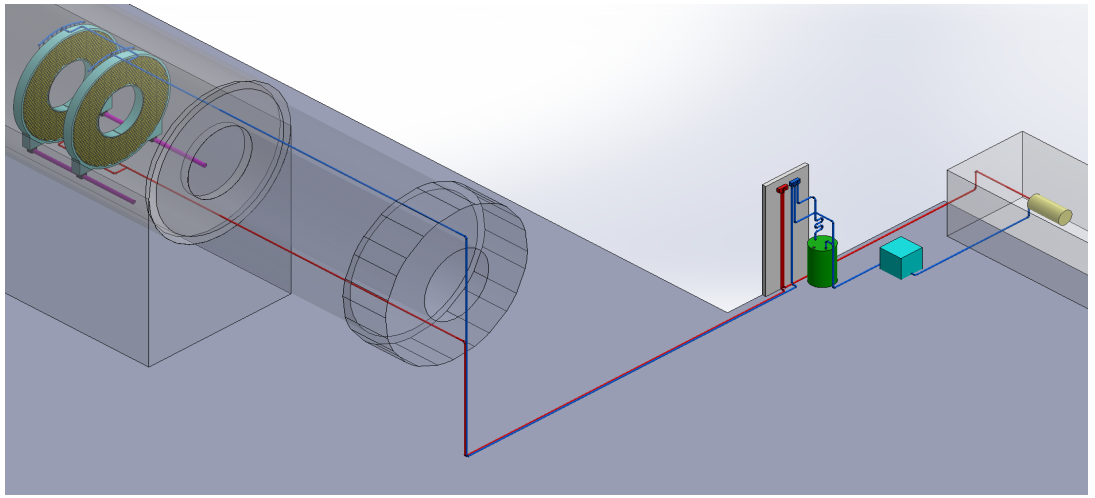


Typical source calibration spectrum from a *BABAR* CsI(Tl) crystal showing the 6.13 MeV peak, along with two escape peaks.

Design II – Source Calibration System

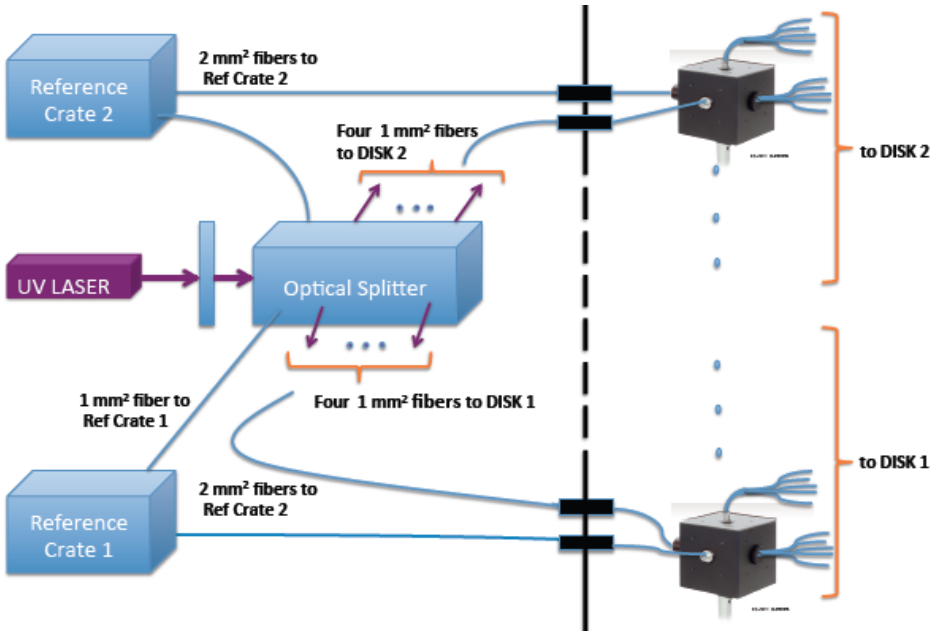
- The fluorine is activated using 14.2 MeV neutrons provided by the salvaged *BABAR* deuterium-tritium (DT) generator.
- The DT generator is surrounded by a bath of fluorine-containing liquid Fluorinert™, which is then circulated through a system of manifolds and pipes to the face of the calorimeter disks.





Design III – Laser Monitoring System

- In order to monitor variations in scintillator transmittance and APD gains, a laser monitoring system similar to the one used for the CMS calorimeter[1] has been designed, in which laser pulses are sent through an optical splitter that feeds eight ~20m long fibers.
- Each fiber terminates in an integrating sphere, four per calorimeter disk, with each sphere subsequently outputting light to two bundles of 150 fused silica fibers.
- In order to monitor calorimeter response linearity, a neutral filter wheel with gradually changing absorption values is inserted between the primary beam and the light distribution system.



1 M. Anfreville *et al*., "Laser Monitoring system for the CMS lead tungstate crystal calorimeter", *Nucl. Inst. and Meth*. A594 (2008) 292-320.

Design IV – Other Calibrations

- Muon DIO (Decays in Orbit) events provide a high statistics set of tracks with peak momentum ~45-50 MeV/c, which can be used to tie together the calorimeter and tracker energy/momentum scales.

- Cosmic rays also provide calibration datasets at energies above the ~6 MeV source calibration photon. The use of cosmics will require detailed pattern recognition in order to accurately determine the path length of a cosmic ray muon in an individual crystal to better than the calibration accuracy.

Changes since CD-1

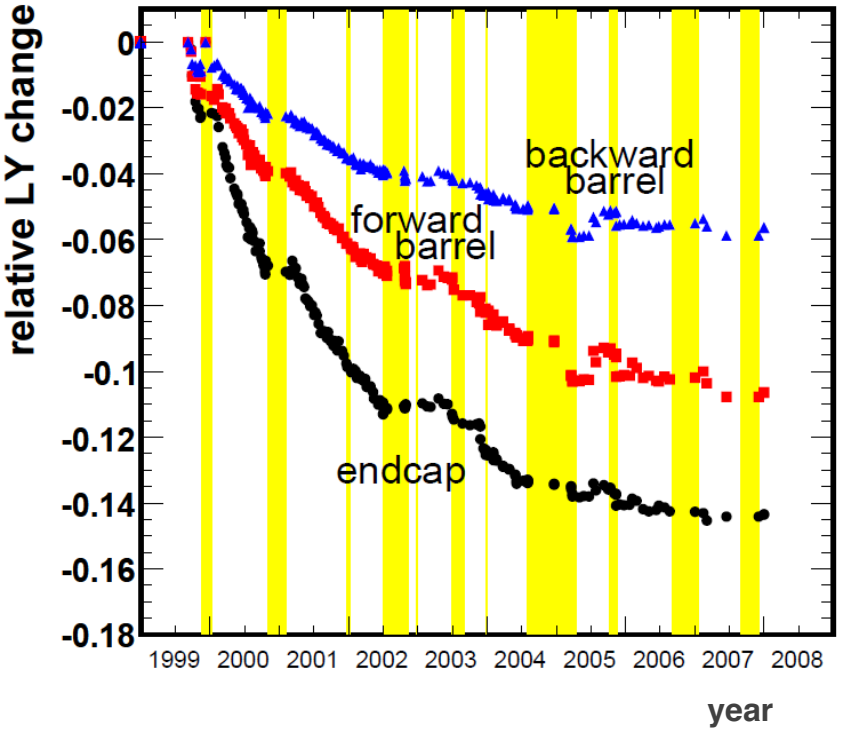
- Crystal has been changed from LYSO to BaF_2 due to the high cost of LYSO.
- This has required adaptation of the laser pulser to match the deeper UV peak response of BaF_2 relative to LYSO.

Value Engineering since CD-1

- Crystal has been changed from LYSO to BaF_2 due to the high cost of LYSO.
  - Impacts laser calibration system
    - No cost impact or risk

Performance – Source Calibration System

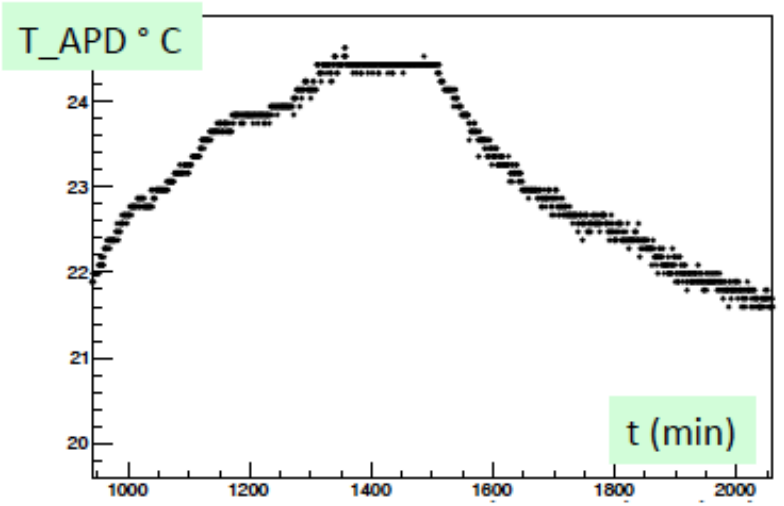
- The *BABAR* source calibration system enabled precision tracking of changes in crystal light yields over the several years of *BABAR* data-taking.
- A similar precision is expected at Mu2e, which will meet the requirement of <0.64%.

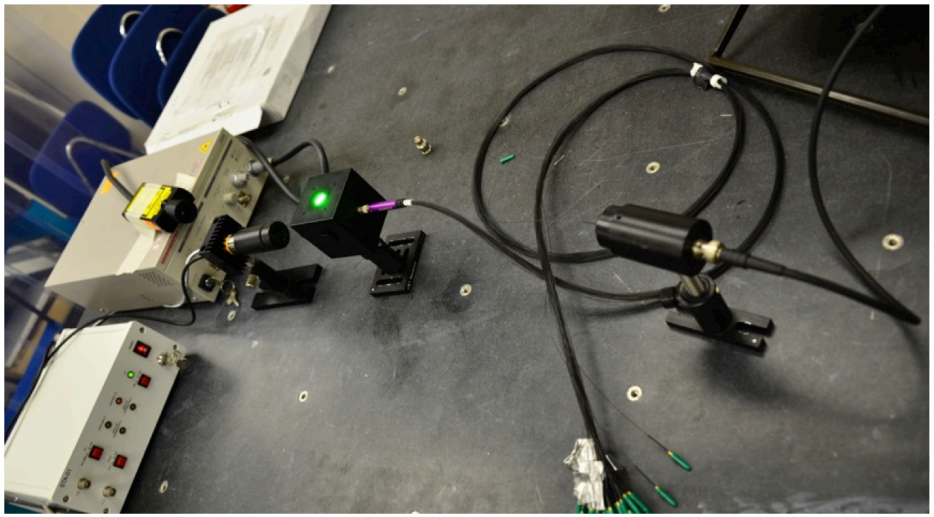


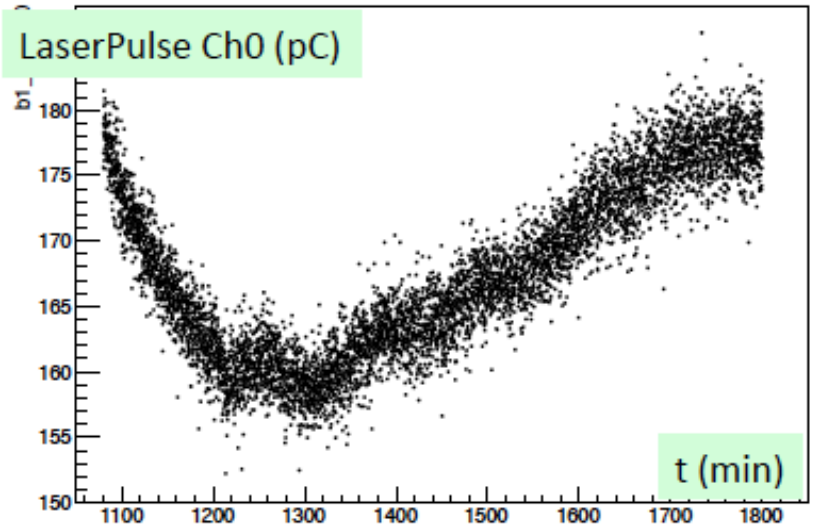
Change in light yield (LY) for the *BABAR* EMC CsI(Tl) crystals over the experiment's data-taking period

Performance – Laser System Prototype

- A prototype of the laser system (below) was used to study, e.g., laser pulse stability.
- The plots (right) show the anti-correlation between temperature and APD gain, as well as the ~5% pulse-to-pulse variation.







Remaining work before CD-3

- Refurbishment of the salvaged *BABAR* neutron generator, plumbing and fixtures, and incorporation into the prototype source calibration system being developed at Caltech.
- Evaluation of deep-UV lasers matched to the peak of the BaF_2 fast light component.

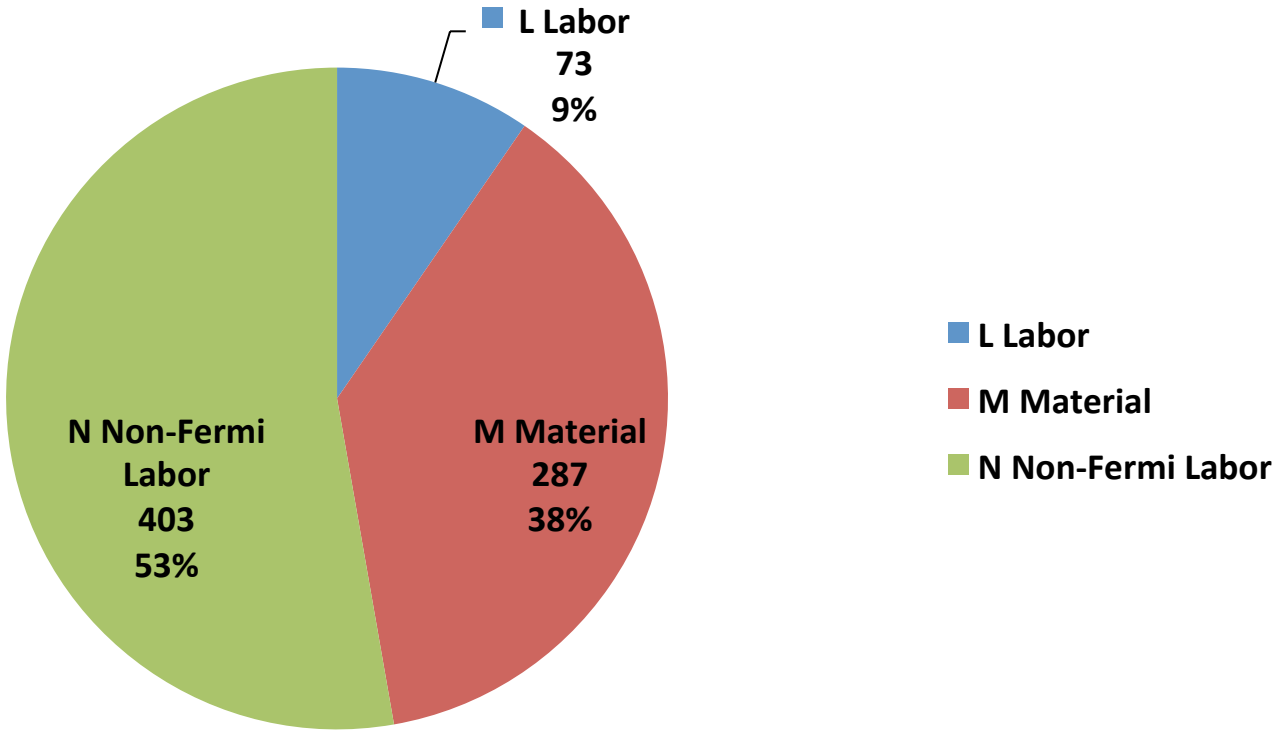
Quality Assurance – Calorimeter Calibrations

- Refurbished source calibration system will be tested at Caltech by developing calibration constants for crystal arrays.
- Italian prototype demonstrates good performance of the laser system and readouts.

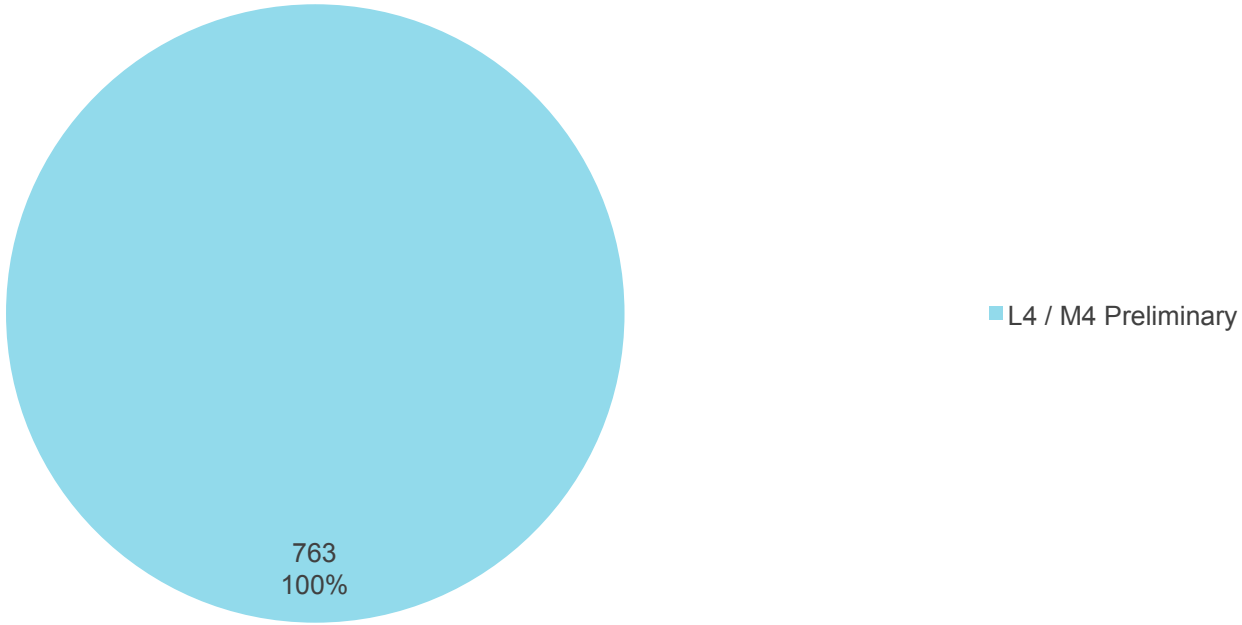
ES&H

- Radiation
  - The DT generator is a radiation-producing device that must be licensed and appropriately shielded for safe operation.
  - Proposed bunker design for generator installation at FNAL has been simulated using MARS, showing acceptable levels of radiation in accessible areas.
  - Caltech has obtained State of California licensing for operation of the DT generator at Caltech.
- Electrical
  - Main fluid circulation pump is three-phase.
- Chemical
  - The source calibration working fluid is a fluorinated liquid, Fluorinert™ FC-770, which should be protected from accidental release to the environment. Residual activation of the fluid is suppressed by its seven-second half-life.

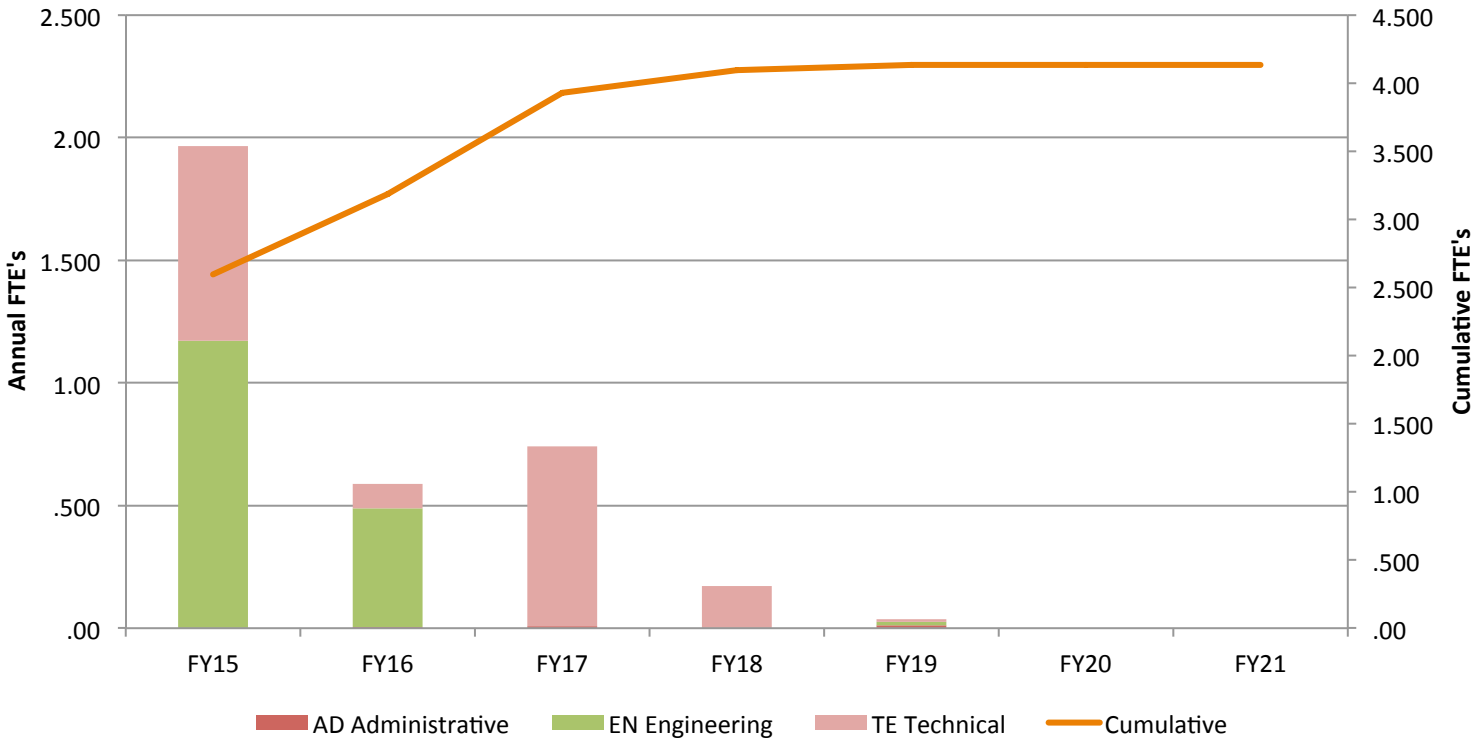
Calibration: Resource type



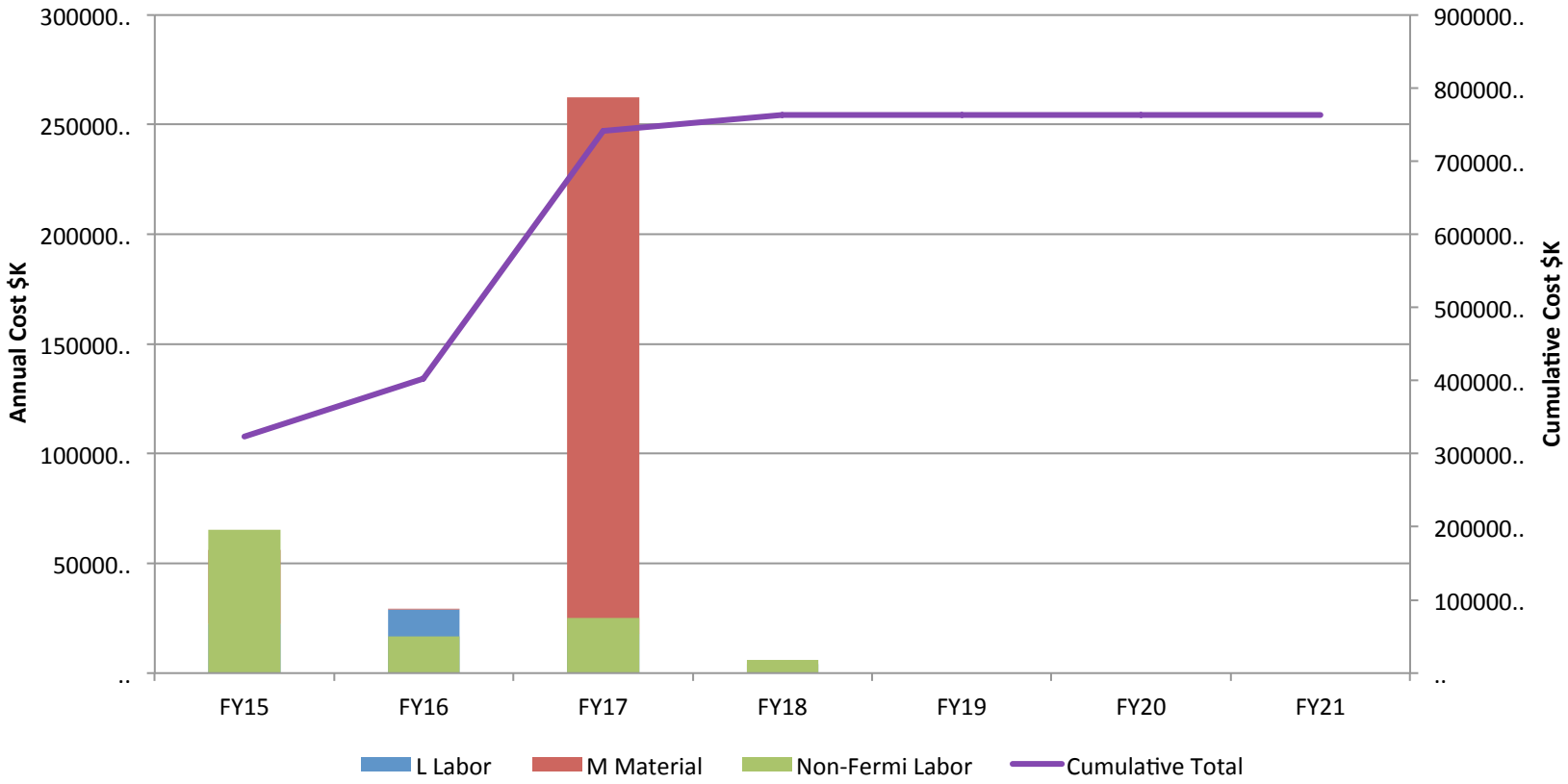
Calibration: Quality of Estimate



Calibration: Labor resources



Calibration: Labor/Material profile



Major Milestones

47507.6.001130 Design of a prototype source system -- 7/31/15

47507.6.001330 Assemble prototype source system -- 9/30/15

47507.6.001361 Design of the final source system -- 8/15/16

47507.6.001440 Prepare contract award for material for final source system -- 9/26/16

47507.6.001513 Deliver materials for source system -- 1/26/18

47507.8 Installation -- 8/6/20

Summary

- Development of prototype calorimeter calibration systems is under way at Caltech (source calibration) and INFN (laser calibration).
  - *BABAR* source calibration system salvage received last month at Caltech.
- A bunker for the DT generator has been integrated into the Mu2e detector hall design.
- Studies of cosmics and DIOs for energy calibrations will continue.