Director CD-2 review: Mu2e Calorimeter

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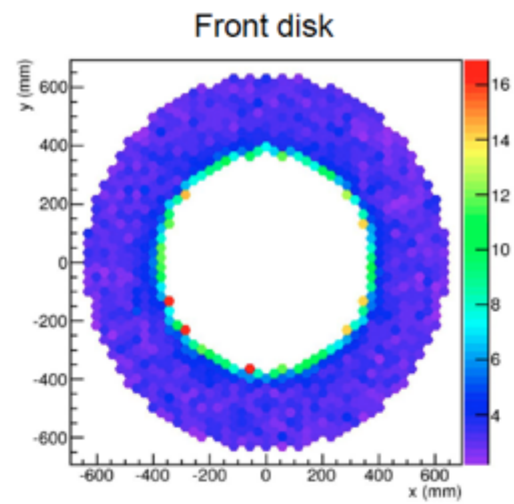
Calorimeter L2 Manager
June 8 2014

Requirements

The calorimeter requirements are described in DOCDB-864

The calorimeter, EMC, should:

- Provide a “seed" to improve/help tracker pattern recognition;
- Provide information that, in combination with information from the tracker, can distinguish electrons from muons and pions;
- Provide a clean, independent, software trigger, based on energy deposition;
- Have large acceptance for signal electrons.



Function in the unique mu2e environment:

→ Sustain a Ionization Dose of < 12 krad/year per crystal

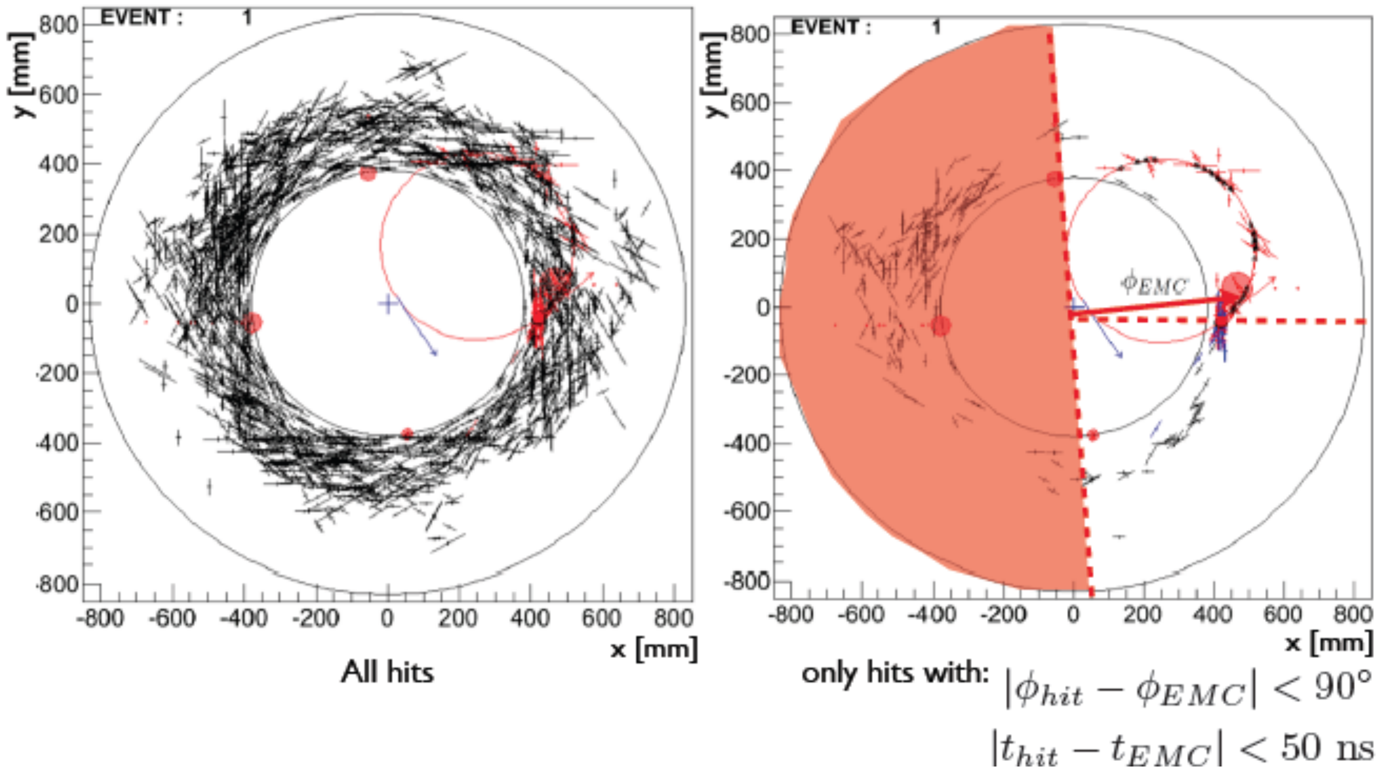
→ Work in a B field of 1 Tesla

→ Work in a high rate environment

(from 5-12% occupancy at 1 MeV threshold)

Breakout talk : P.Murat

Requirements – assisting the tracker



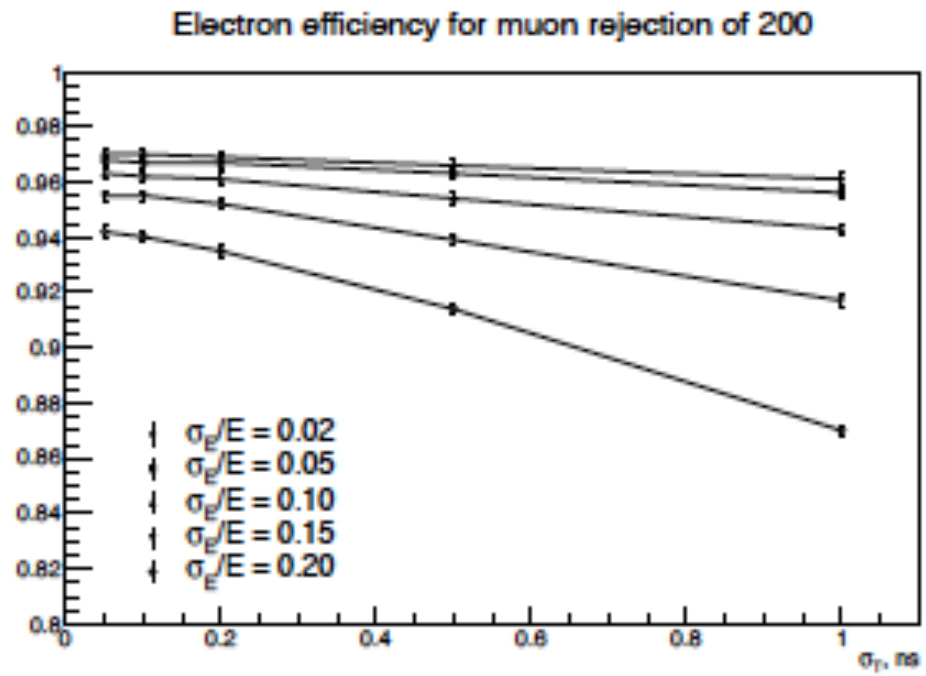
- ✓ **Pattern recognition of tracks improves when requiring "Straw" hits in time** (50 ns window) and space connected with the most energetic cluster.
- ✓ **Calorimeter assisted tracking increases of +12% the overall signal** reconstruction efficiency and provides stability as a function of background rate.

Requirements – powerful PID mu/e

- ❑ After full Track Selection ~1 muon that cannot **be vetoed by the CRV** is reconstructed as a Conversion Electron (CE).

- ❑ To keep the background of muons that fake electrons below 0.01 events

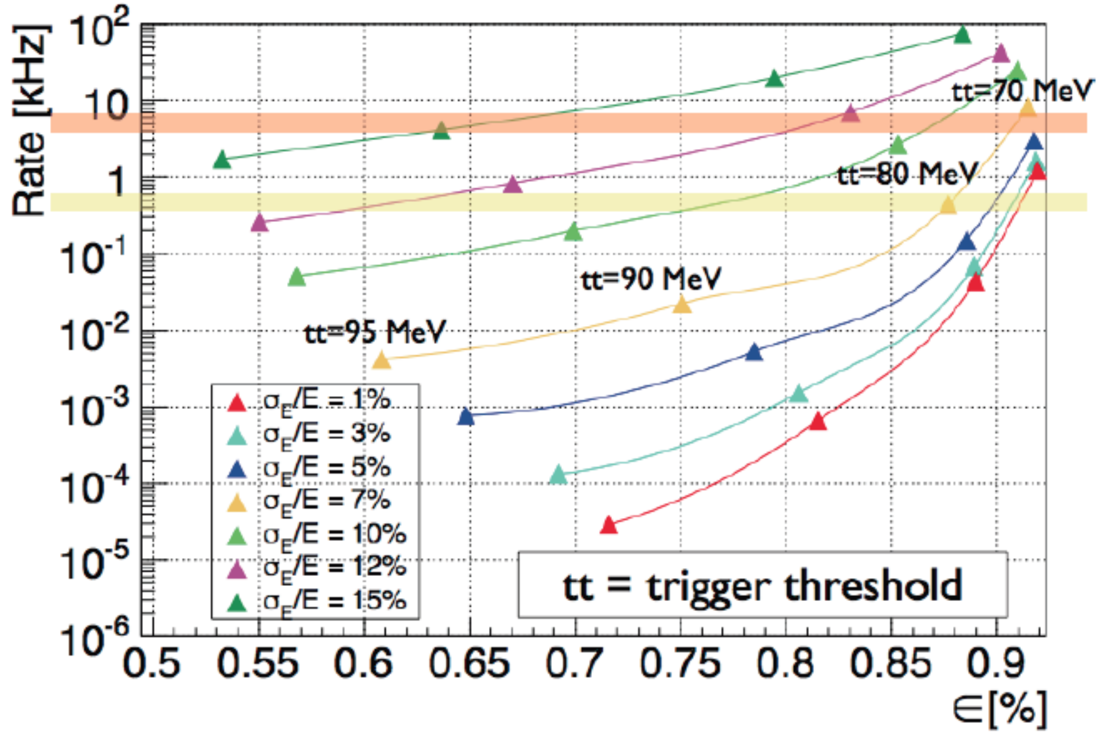
→ **We need a calorimeter muon rejection of 200 while keeping the highest possible efficiency**



Rejection & efficiency evaluated with a log-likelihood based on Eclu/P and ΔT = T_trk-Tclu distributions. Toy MC adds gaussian spread on calorimeter timing and energy determination → **Energy res. 5% and time res. < 500 ps is a good working point.**

Requirements – trigger

- ❑ Fast and track-independent HLT selection based on EMC cluster reconstruction.
- ❑ **Reduce storage rate to 2 kHz (5 PB/year) .**
- ❑ Toy MC suggests a calorimeter with < 7% energy resolution.

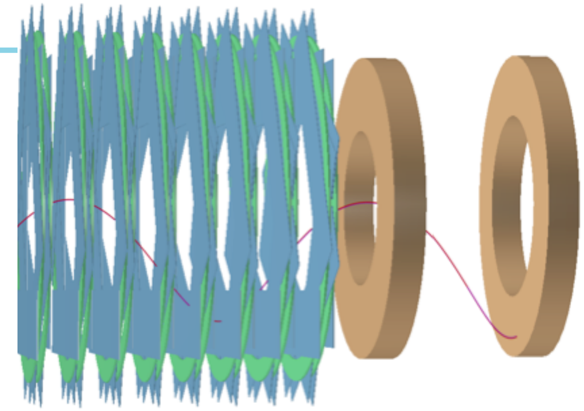


The combination of these constraints translate to calorimeter specifications as follows:

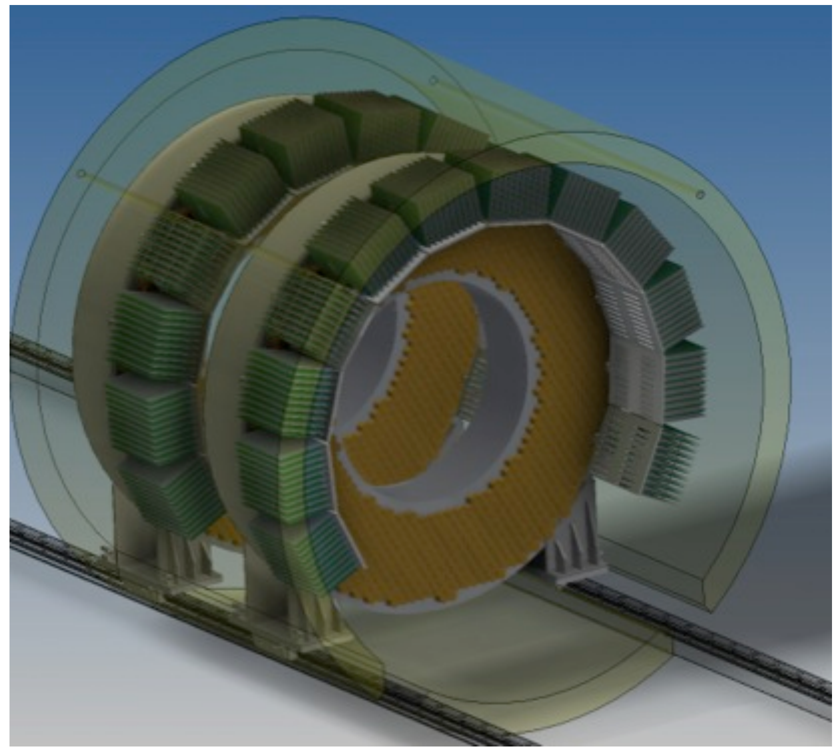
98% acceptance for CE tracks, O(5%) energy resolution O(1 cm) position resolution and a time resolution < 0.5 ns.

Calorimeter Layout

The Calorimeter is composed of two disks with 1860 BaF_2 hexagonal crystals:



- → R_{in} = 351 mm, R_{out}=660 mm
- → Distance between disks optimized at ½ wavelength (70 cm)
- → Each crystal is readout by two large area APD's (9x9 mm^2)
- → FEE and Digitizers are located in near-by electronics crates
- → Source and laser systems provide absolute calibration and fast and reliable monitoring capability



Calorimeter components → crystals

Barium Flouride (BaF_2)

- Radiation hard,
- very fast (220 nm)
- non-hygroscopic
- Contains a slow component at 300 nm → need to suppress it due to high rates
- Photo-sensor should be UV extended and "solar"-blind
- Crystal dimension: hexagonal faces of 33 mm across flats, 200 mm length (10 X_0)

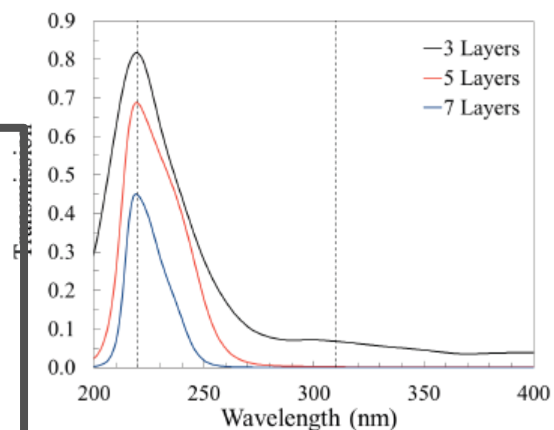
	BaF_2
Density (g/cm3)	4.89
Radiation length (cm)	2.03
Moliere Radius (cm)	3.10
Interaction length (cm)	30.7
dE/dX (MeV/cm)	6.52
Refractive index	1.50
Peak luminescence (nm)	220 (300)
Decay time (ns)	1 (650)
Light yield (rel. to NaI)	5% (42%)
Variation with temperature	0.1% (-1.29)% / deg-C

Breakout talk: S.Miscetti

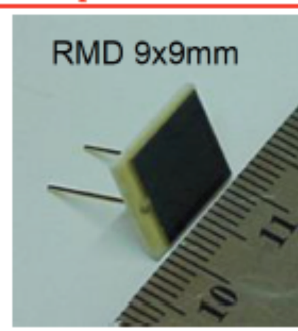
Calorimeter components: photo-sensors

A Caltech/JPL/RMD consortium has been formed to develop a Large area RMD APD **into a delta-doped super-lattice APD with high Q.E. @ 220 nm** incorporating also **an Atomic Layer Deposition antireflection filter** to reduce efficiency for wavelength > 300 nm.

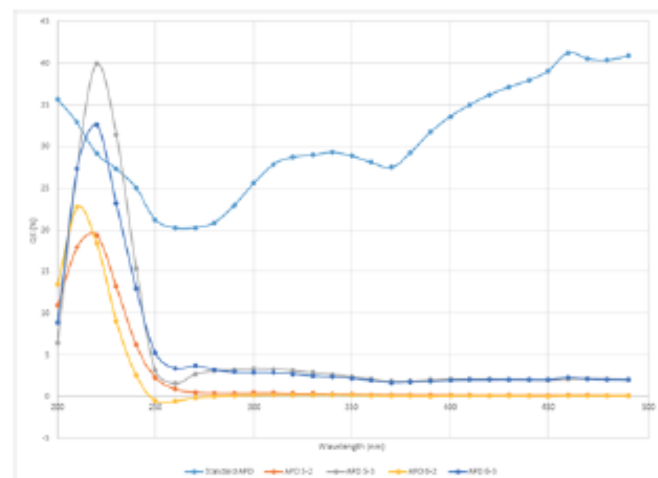
- ✓ 60% QE @ 220 nm
- ✓ ~ 0.1 % QE @ 300 nm
- ✓ capacitance ~ 60 pF (1/5 of Ham S8664)
- ✓ HV ~ 1800 V
- ✓ Operation Gain ~ 500
- ✓ Decay time ~ 25 ns.



deltadoped APD from RMD

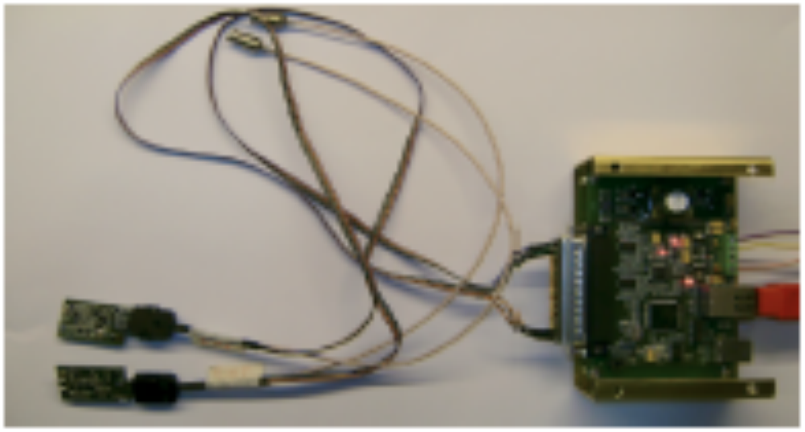


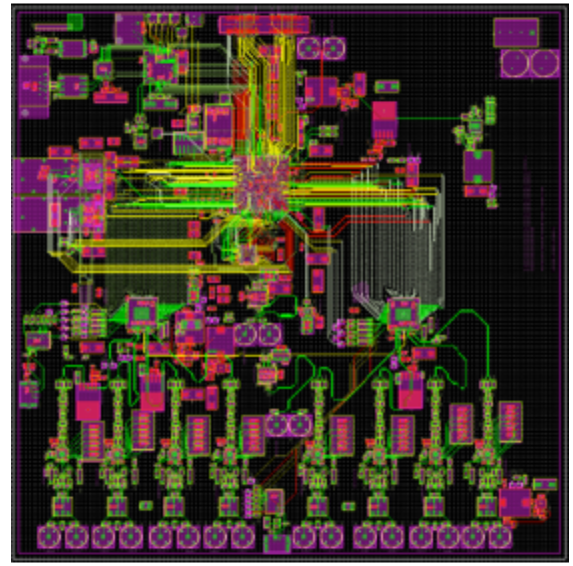
Tests on few prototypes with ALD applied proved that “solar” blindness works



Breakout talk: F.Porter

Design: Calorimeter FEE & Readout





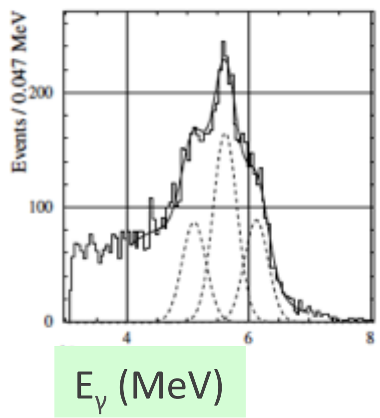
- FEE is a discrete chips connected to the photo-sensor: V preamp & Local V-bias regulator.
- 16 FEE channels driven by an ARM-controller to generate/distribute Vbias, Low Voltages
- 50 FEE channels and 5 ARM controllers produced by INFN- Frascati for LYSO prototype.
- **New development in progress to adapt this FEE to the BaF_2 crystals.**

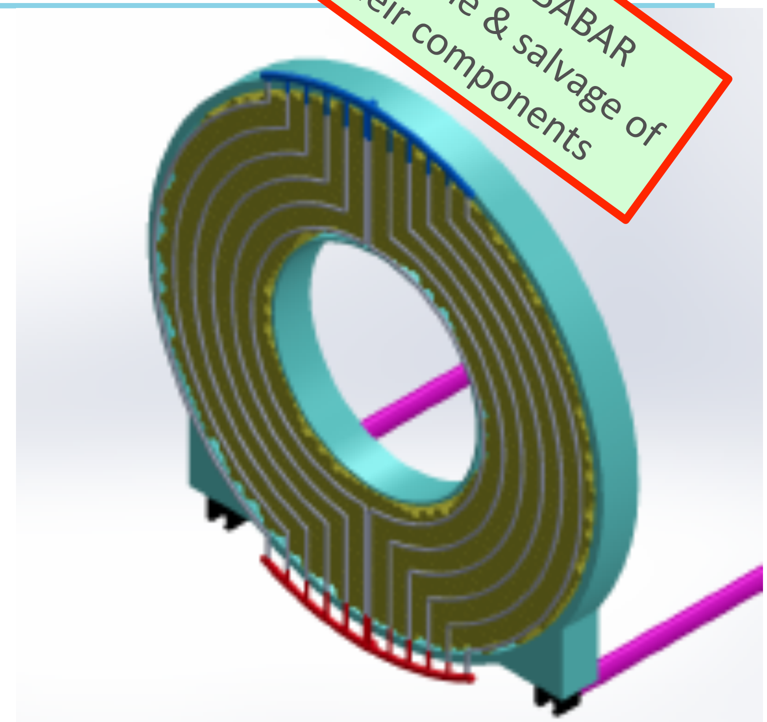
- Digitizer board with 32 channels 12 bit resolution, 200 msps, Smart Fusion FPGA.
- 5 prototypes 8 channels under construction at University of Illinois
- **Design of final digitizer under way as a joint project between INFN Pisa and University of Illinois.**

Breakout talk:
I.Sarra

Calorimeter Calibration system

- Neutrons from a neutron generator irradiate Fluorinert fluid outside the detector
- Activated liquid pumped through pipes to the calorimeter front face
- **Few per mil energy scale in few minutes. Linearity.**
- **E/P with DIO for final experiment scale**

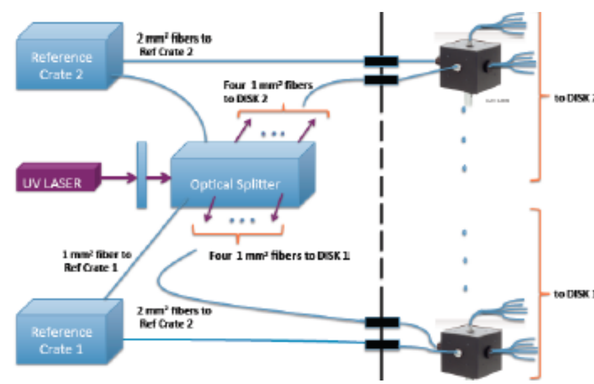




Based on BABAR scheme & salvage of their components

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

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



Laser system adapted from CMS calibration system.

UV light to monitor continuously the variation of the photo-sensor gain.

Breakout talk: K.Flood

Changes since CD-1

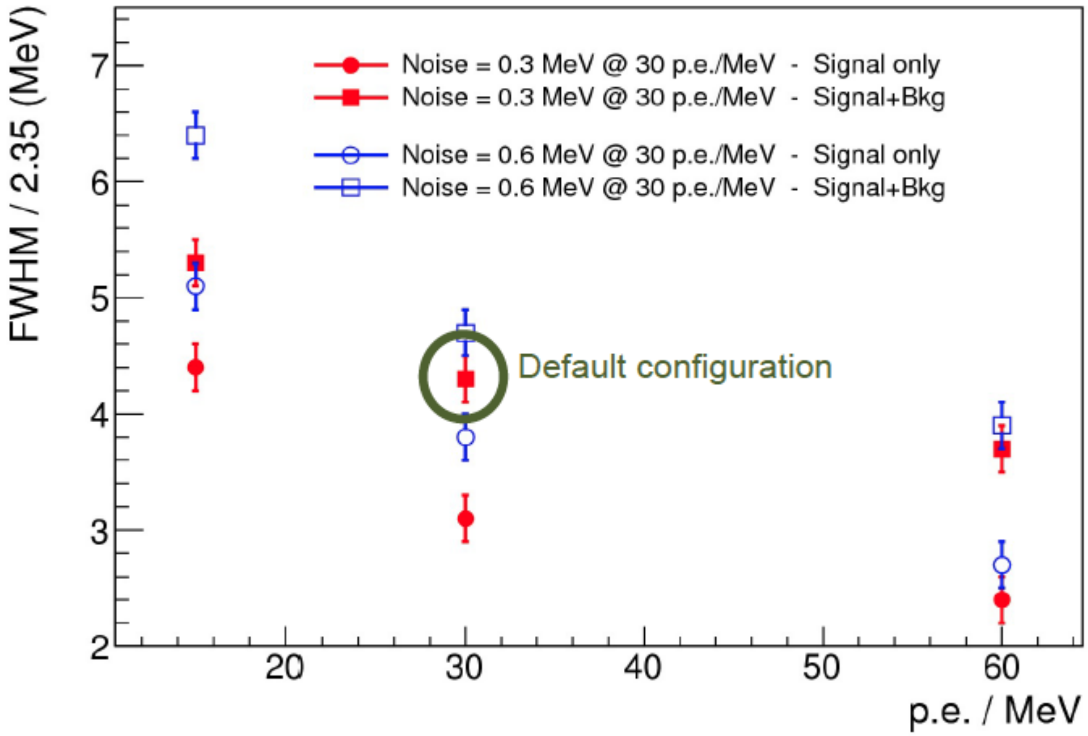
Two significant changes happened since CD-1:

- **Geometry has been changed from Vanes to Disks**
  - → (+) Larger acceptance
  - → (+) Identical response and acceptance for electrons and positrons
  - → (+) Easier mechanics
  - → (-) More background on the crystals, (+) better shielding for photo-sensors

- **Baseline crystal has been changed from LYSO to BaF_2**

  Due to LYSO cost increase (x 2.5 since CD-1)
  - → (-) Photo-sensors, FEE and readout design choices were finalized
  - → (-) The LYSO has negligible dependence on T and is really rad-hard
  - → (+) The BaF_2 is faster, it could be used for Mu2e-2 sustaining a x10 increase in the rate.

Performance: Energy resolution

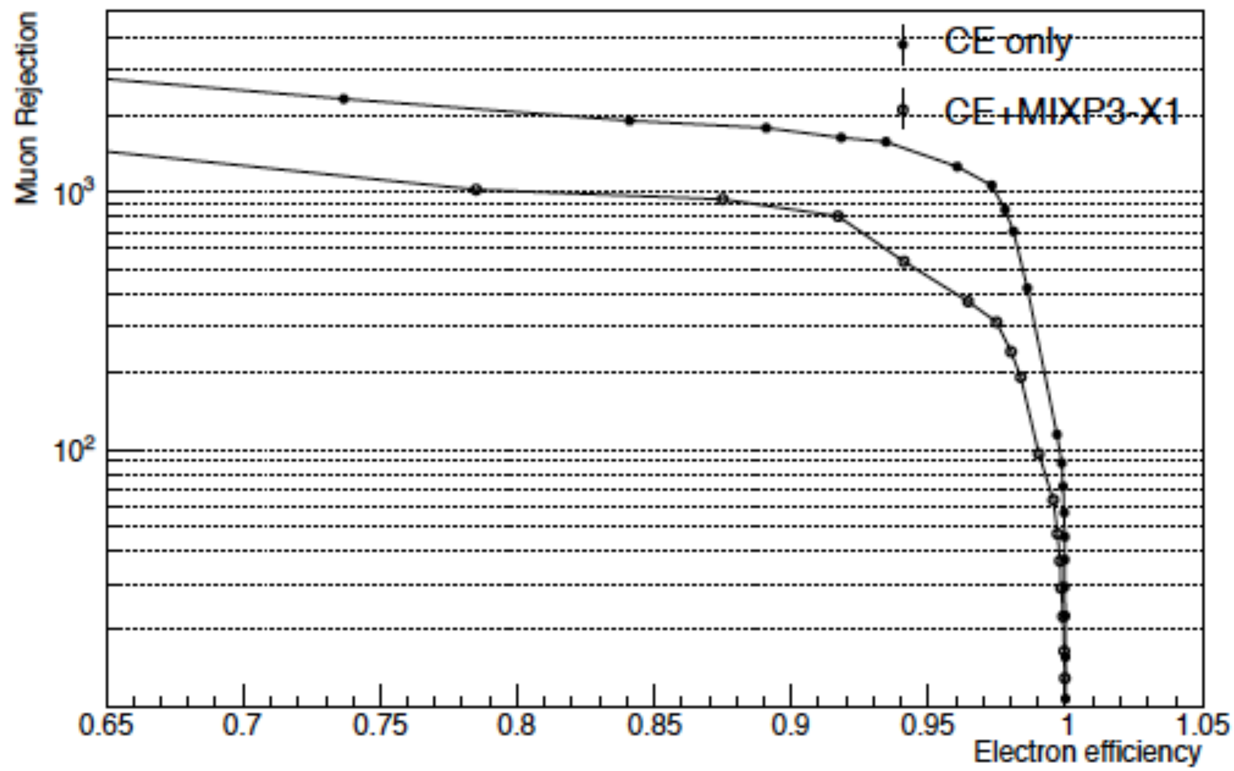


Breakout talk: B.Echenard

- ❑ L.Y.=30 pe/MeV from crystal measurement with PMT scaled by APD area and Q.E (1.3%)
- ❑ Electronics noise of 300 keV by scaling down measurement for LYSO and RMD/ Hamamatsu APD properties → adds another relevant term to the resolution (1.3%).
- ❑ 2% leakage and albedo
- ❑ Pileup contributes additional 3 % to the total resolution.

Performance: PID

- ❑ Full simulation with pileup background included.
- ❑ Pre-selection based on track to cluster matching (space & time).
- ❑ PID is based on Log-Likelihood with E/P and ΔT



- ✓ For a muon rejection of 200 → **electron ID efficiency is 98%**
- ✓ Adding pre-selection cuts → **Total PID efficiency is > 95%**

Breakout talk: G.Pezzullo

Remaining work before CD-3

- ❑ BaF_2 crystals perform as expected (light yield with PMT ~ 100-160 pe/ MeV), however RMD/JPL APD RMD to be proven fully matching their specifications.

  → Modification of FEE to adapt to RMD/JPL APD under way.
  To be completed for beginning 2015.

- ❑ **Internal Technology Choice review** to be held at the end of 2014 to compare baseline with backup solution (pure CsI and MPPC).

- ❑ Mockup of smaller size Disk to test mechanics and mounting scheme.

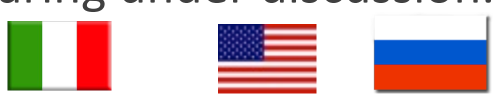
- ❑ Adapt QA stations/Laser to final crystal and photo-sensors

Organizational Breakdown

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

- 7.1 Project Management – S. Miscetti – Frascati
- 7.2 Crystals – D.Hitlin – Caltech
- 7.3 Mechanics – F.Happacher – Frascati
- 7.4 Photo Sensors – I.Sarra – Frascati
- 7.5 Digitizer – Spinella – Pisa
- 7.6 Calibration – F.Porter – Caltech
- 7.7 FEE& Power – G.Corradi – Frascati
- 7.8 Assembly & installation – A.Saputi – Frascati

- ❑ MoU agreement in progress between INFN and JINR.
- ❑ DOE/INFN Sharing under discussion. Presented at INFN HEP committee.



Quality Assurance

- QA stations for crystals and photo-sensors exist in INFN and Caltech.

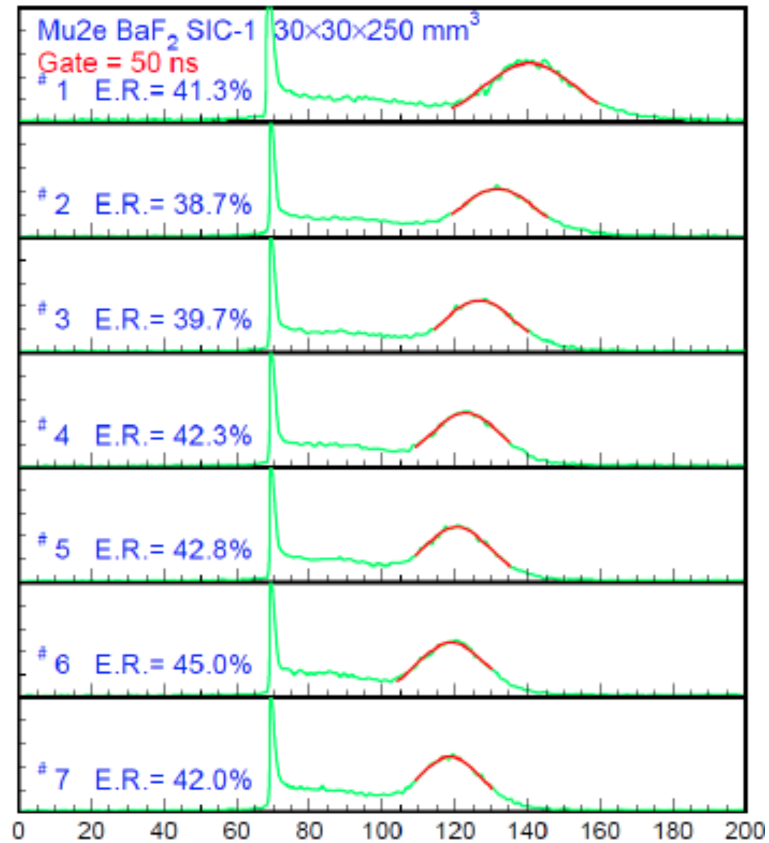
Crystal stations are being modified to adapt to the BaF_2 deep UV emission. **Feedback with vendor ensure meeting specifications.**

→ Test longitudinal transmittance, light yield response to a ^{22}Na source and measurement of longitudinal uniformity for all crystals

→ Measurement of gain, I-leakage and their dependence on Vbias for each photo-sensor;

- Bench test planned for the FEE and Digitizer systems.

- Burn in test for HV system



Risks

1. **Technical Risk:**
   Cannot develop UV-extended solid state photo-detector that is blind to longer wavelengths.

   Mitigations:
   → Active R&D is in progress now.
     → "blindness" of the readout has been proven.
   → Development of high quantum efficiency APD is in progress
   → Work on Backup solution is carried out by INFN (CsI + MPPC)

2. **Management Risk:**
   INFN cannot deliver full in-kind scope.

   Mitigations:
   → continuous discussion is in progress between INFN and DOE representatives.
   → INFN is carrying out its own review of the project.
   → First response of the INFN HEP committee is positive.
   → Final review for financial commitment starts next autumn.

ES&H

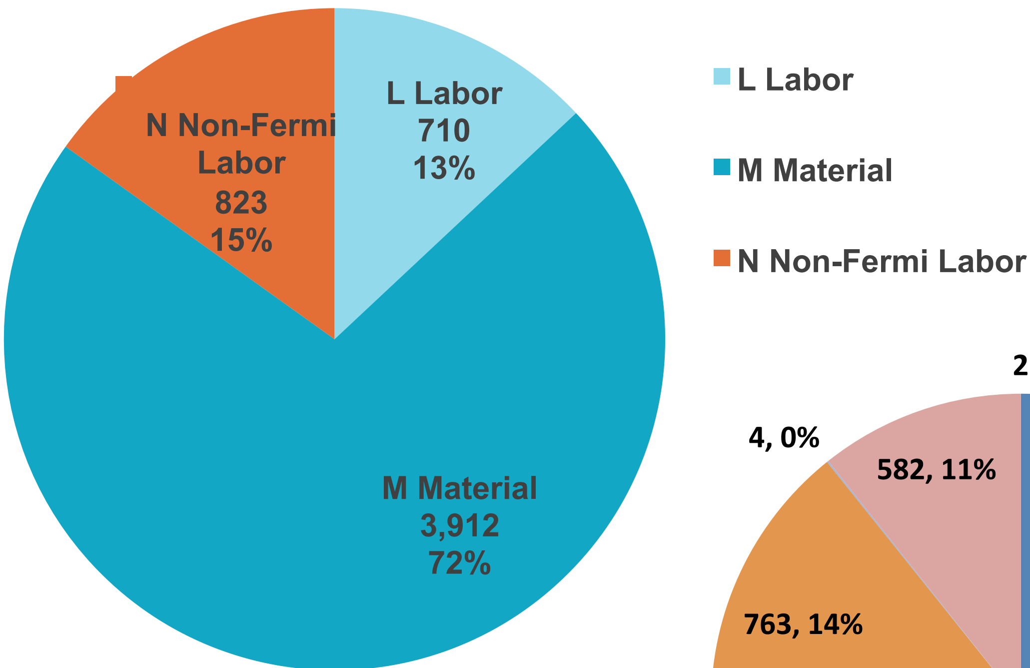
- Calorimeter has standard detector related issues that are common at Fermilab
  - Electrical hazards from both High and Low voltage.
  - Mechanical hazards (calorimeter is heavy)
  - Toxic materials
    - Epoxy may be used to assemble calorimeter (attach APDs).
  - **Activated Fluorinert with a neutron generator used as Source system.**
    - Operation of the source in a remote control in a no access condition
    - Shielding and interlock the neutron generator
    - Compute the maximum exposure in case of a fluid leak
    - **Used in BaBar @ SLAC.**
  - **Lasers used as part of a flasher system.**
    - Laser will be enclosed.
- These hazards are discussed in the Mu2 Hazard Analysis document (Mu2e-doc-675).

Calorimeter DOE Cost Table

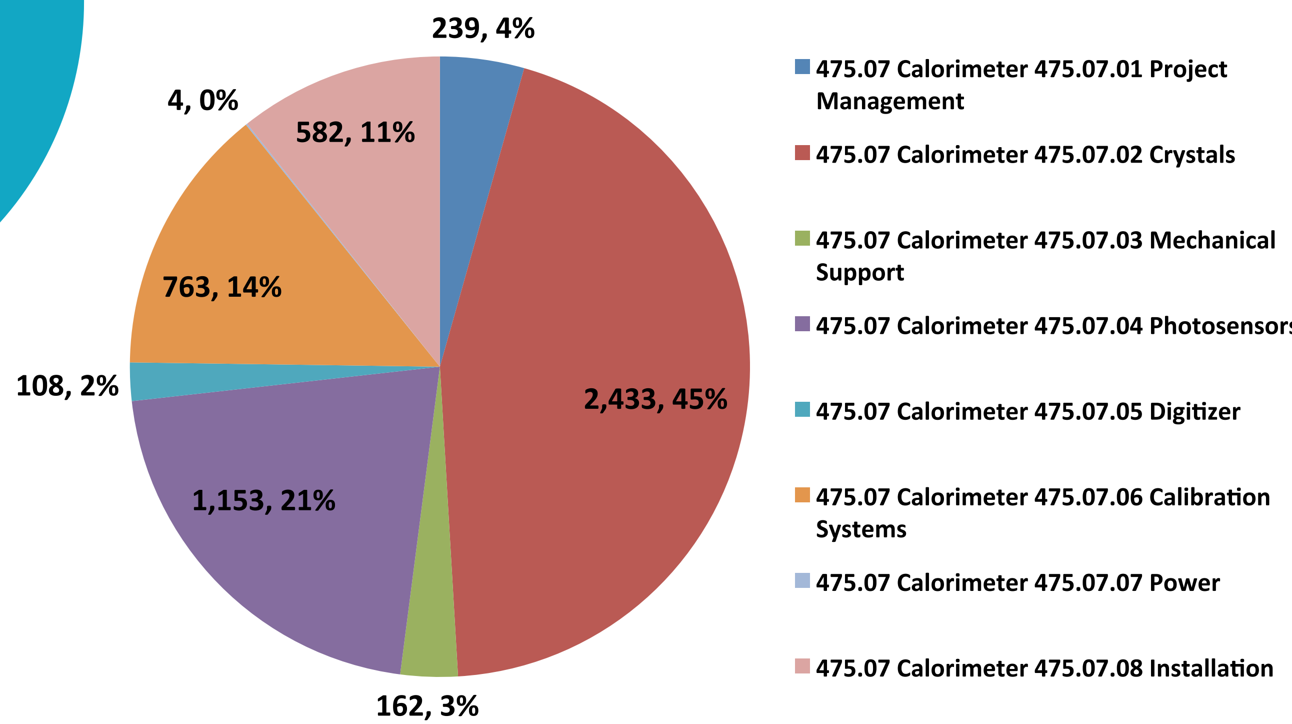
	M&S	Labor	Base Cost	Estimate Uncertainty	% Contingency on ETC	Total
475.07.01 Project Management	232	7	239	25	20%	264
475.07.02 Crystals	2,379	54	2,433	416	17%	2,848
475.07.03 Mechanical Support	162	0	162	32	20%	195
475.07.04 Photosensors	1,153	0	1,153	486	42%	1,639
475.07.05 Digitizer	108	0	108	0	0%	108
475.07.06 Calibration Systems	690	73	763	240	31%	1,004
475.07.07 Power	0	4	4	1	30%	5
475.07.08 Installation	11	571	582	174	32%	756
Risk Based Contingency				523		**523**
Total	4,735	710	5,444	1,898	36%	7,342

It assumes INFN pays 1/3 of Crystals, ½ of Photosensors and provide
In-kind the Laser system, the mechanics, and all FEE/Digitizer electronics

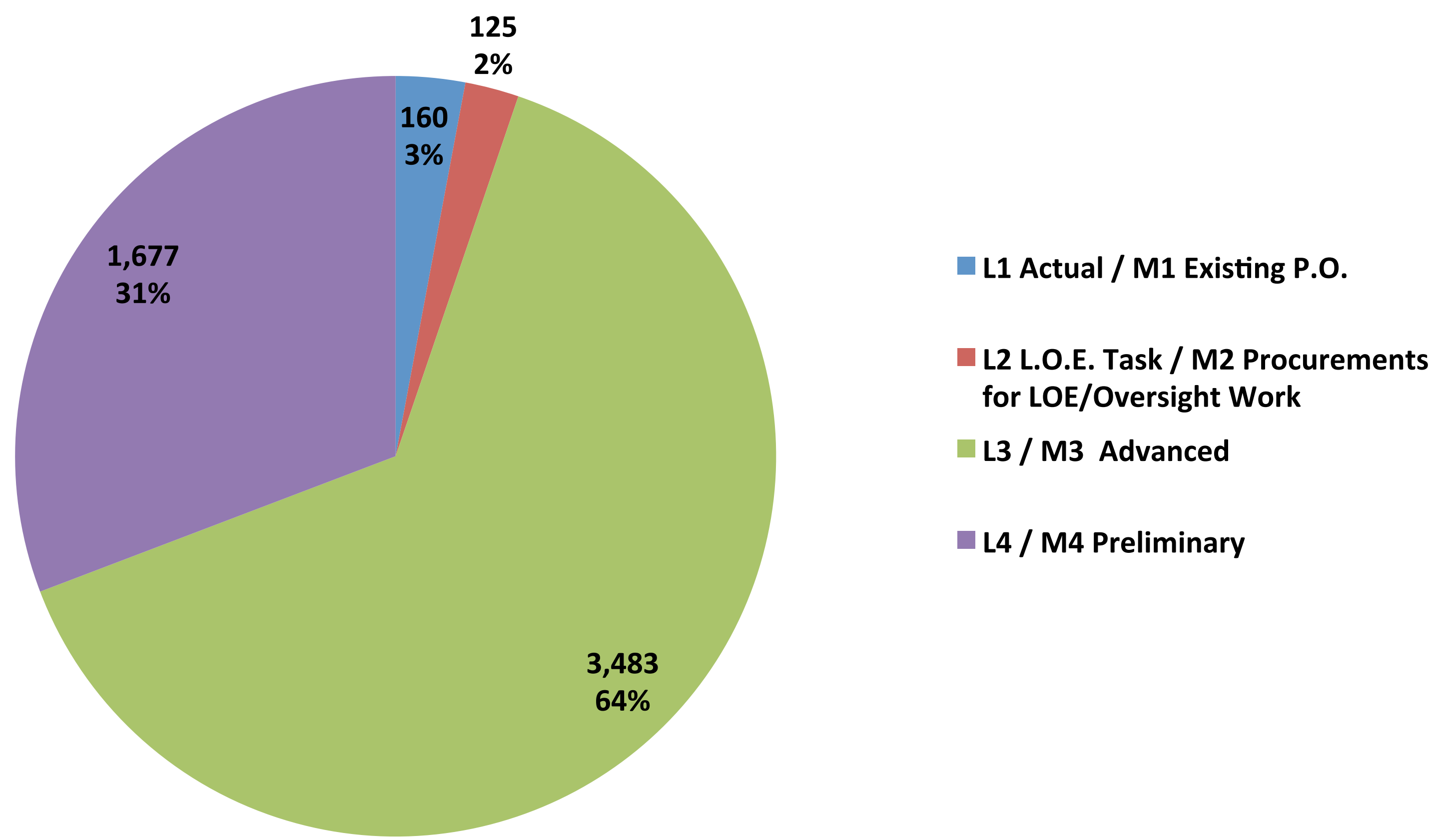
Calorimeter Cost Breakdown



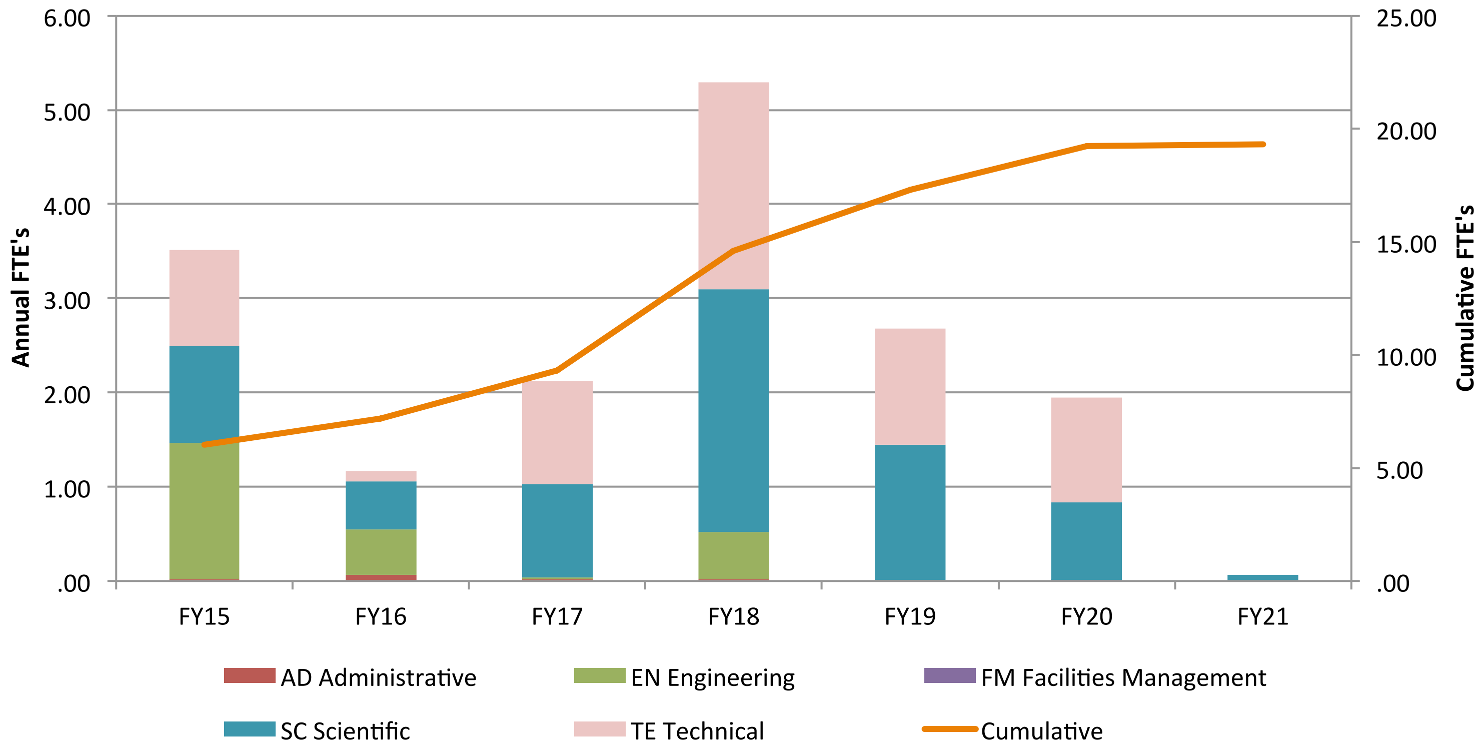
BASE COST in AY$K



Quality of Estimate



Labor Resources by FY

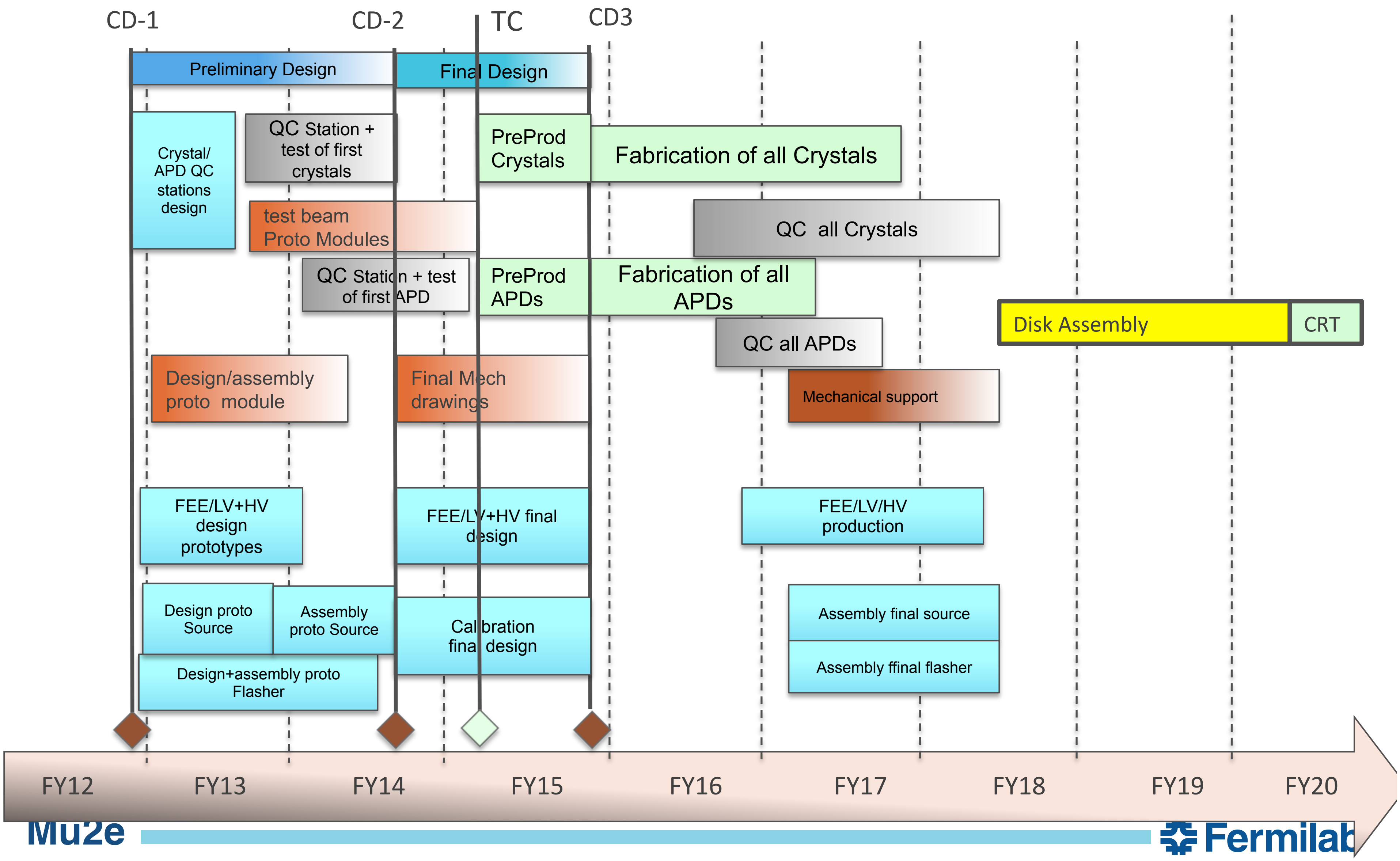


- ❖ Labor peaks in 2015 to get final design and pre-production ready
- ❖ Second labor peak in 2018 due to QC and assembly

Major Milestones

1. 47507.5.001320 **Final Crystal Choice** 26 Dec 2014
2. 47507.5.001320 **Final Design of FEE complete** 13 Feb 2015
3. 47507.2.001860 **Readiness Review for production crystals** 2 Sept 2015
4. 47507.2.011990 **PO issued for production crystals** 26 Jan 2016
5. 47507.4.000700 **PO issued for production photo-sensors** 1 Mar 2016
6. 47507.6.001510 **PO issued for source system material** 3 Jan 2017
7. 47507.4.000790 **QC of all photo-sensors complete** 13 Jul 2017
8. 47507.5.001590 **Assembly of full readout chain** 1 Mar 2018
9. 47507.2.092145 **QC of all crystals complete** 23 Apr 2018
10. 47507.8.002410 **Ready for cosmic ray system test** 17 July 2020

Calorimeter schedule



Summary

- The EMC generates an independent trigger, helps the pattern recognition and provides a strong **μ/e** PID.

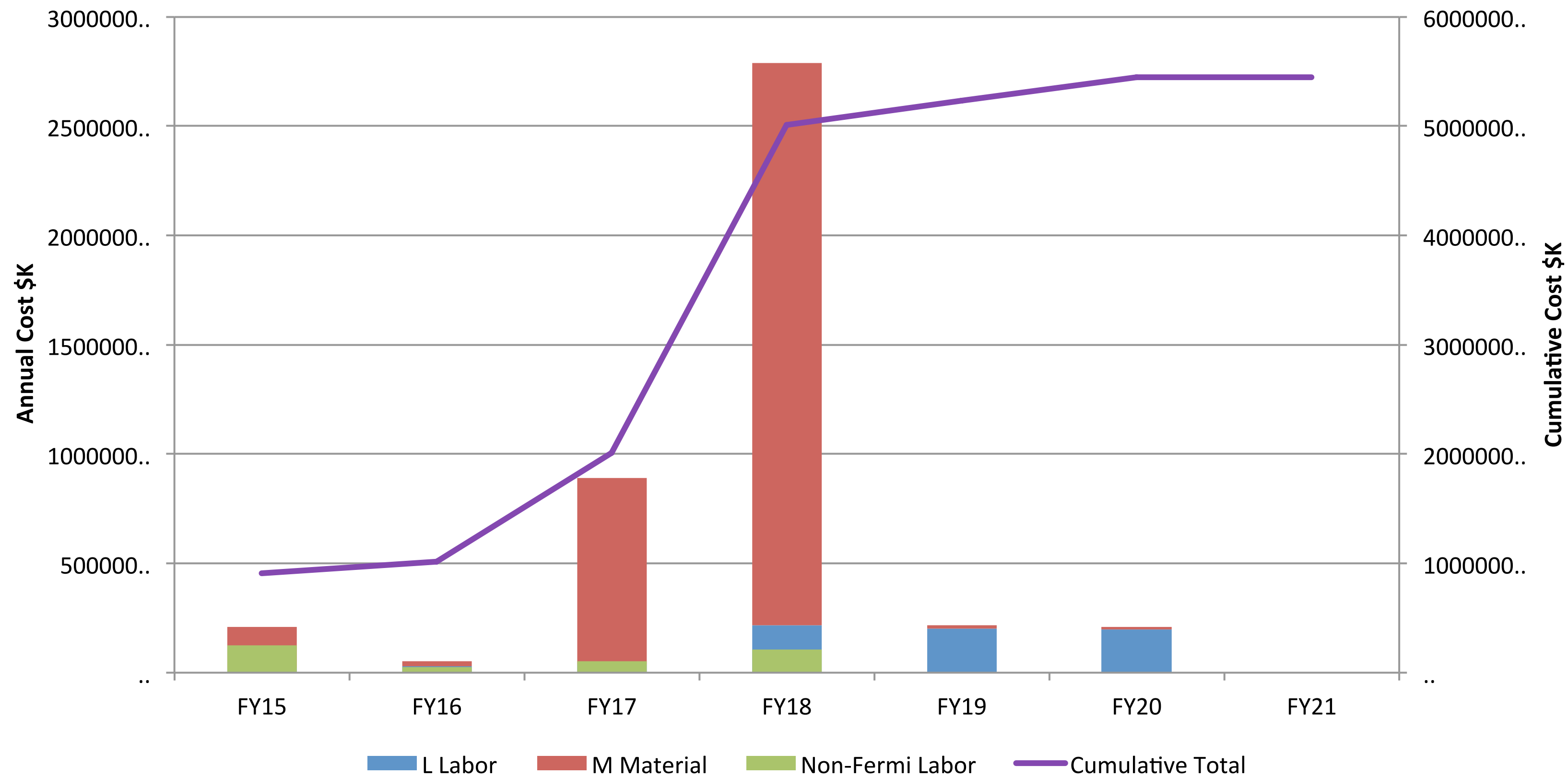
- The LYSO solution has been abandoned due to its cost. Baseline crystal is now BaF_2 readout with a new "solar-blind" APD from the RMD/JPL/Caltech consortium.

- **Active R&D is in progress to certify this choice and new prototypes of calorimeter, FEE and readout are being delivered.**

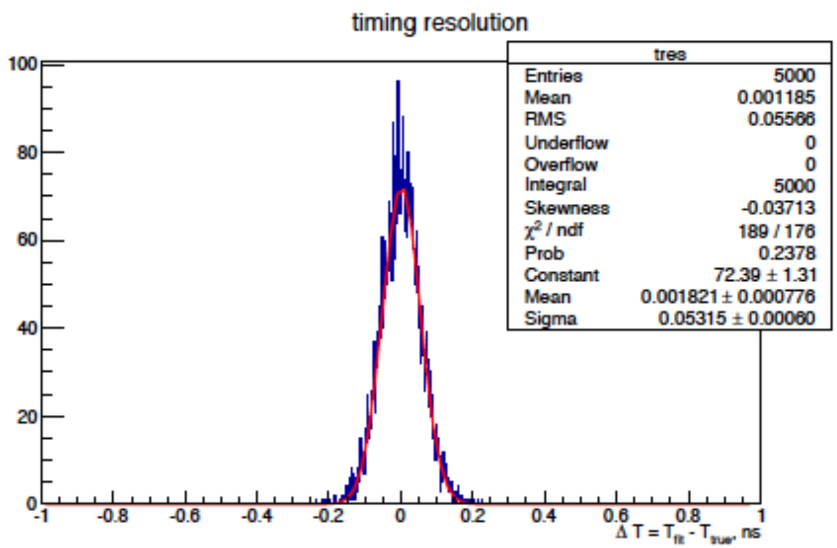
- **Backup solution considered.** Technology choice set for end 2014 to proceed quickly for final engineering design.

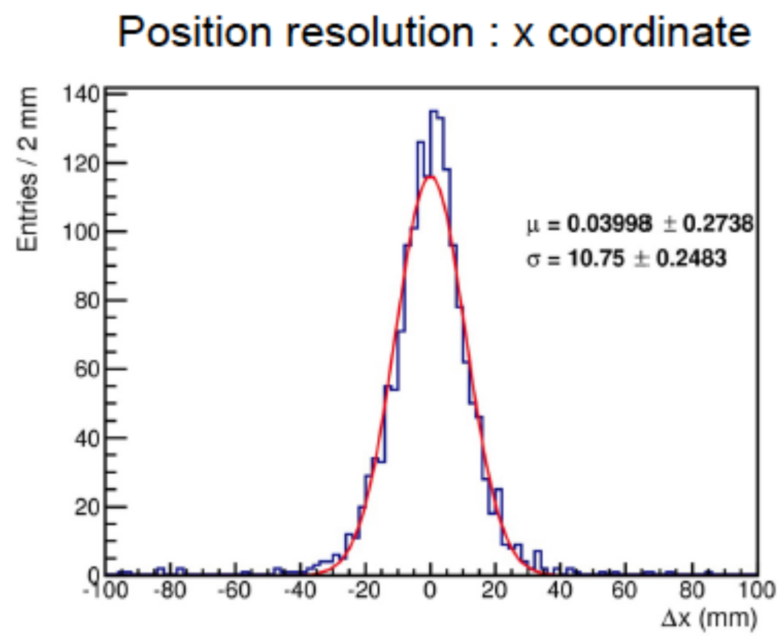
Additional Material

Labor/Material spending profile



Performance: Timing & space resolution

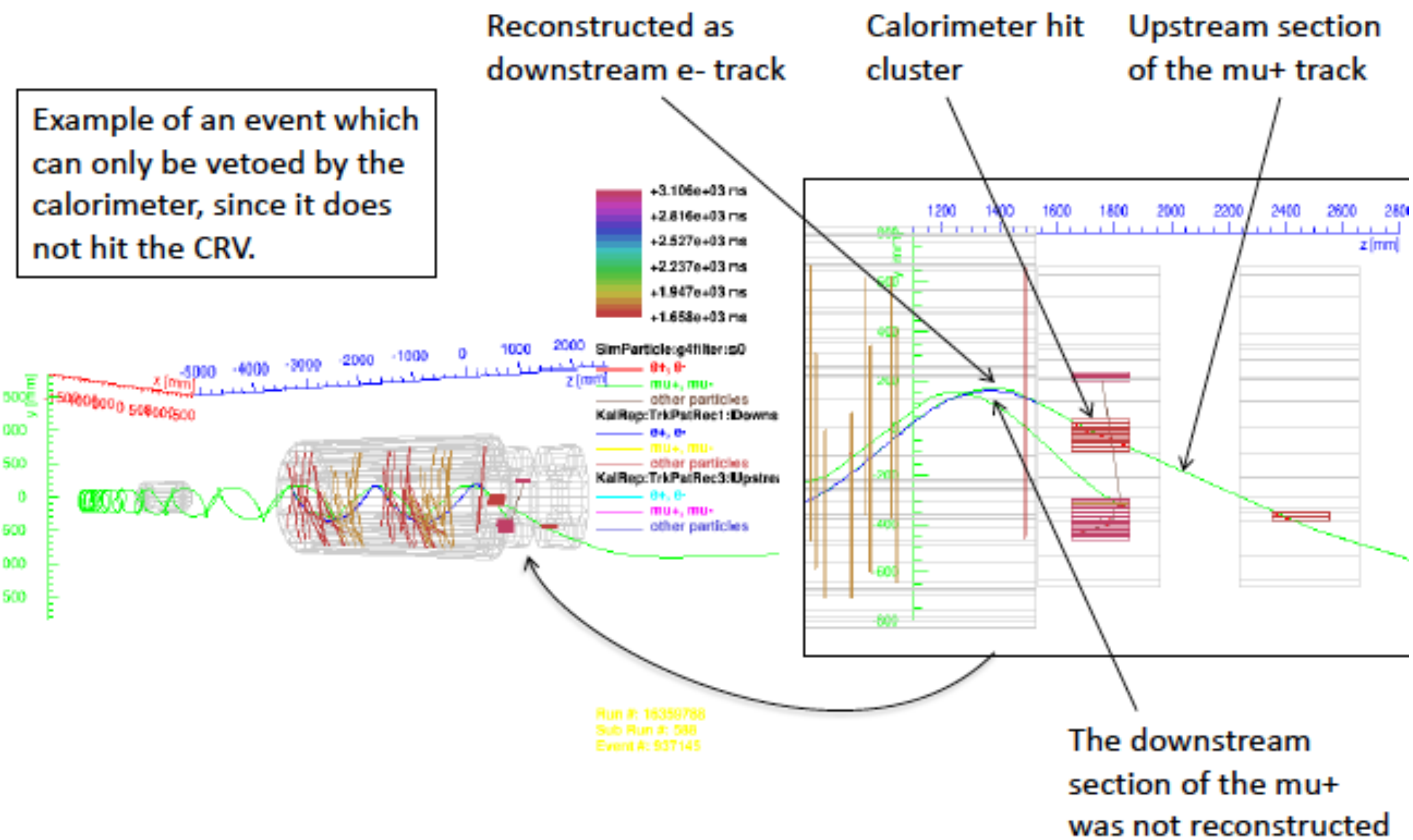




- ✓ Electronic noise contribution to T-Res estimated by simulating & fitting the signal shape with noise → **50 ps.**
- ✓ Contribution of pulse shape stability and trigger jitter expected to be small.
- ✓ Shower time fluctuation < L/v_light (1 ns/sqrt(12)) **should be < 280 ps.**

Calorimeter Cluster centroid (log weighted) at shower max.

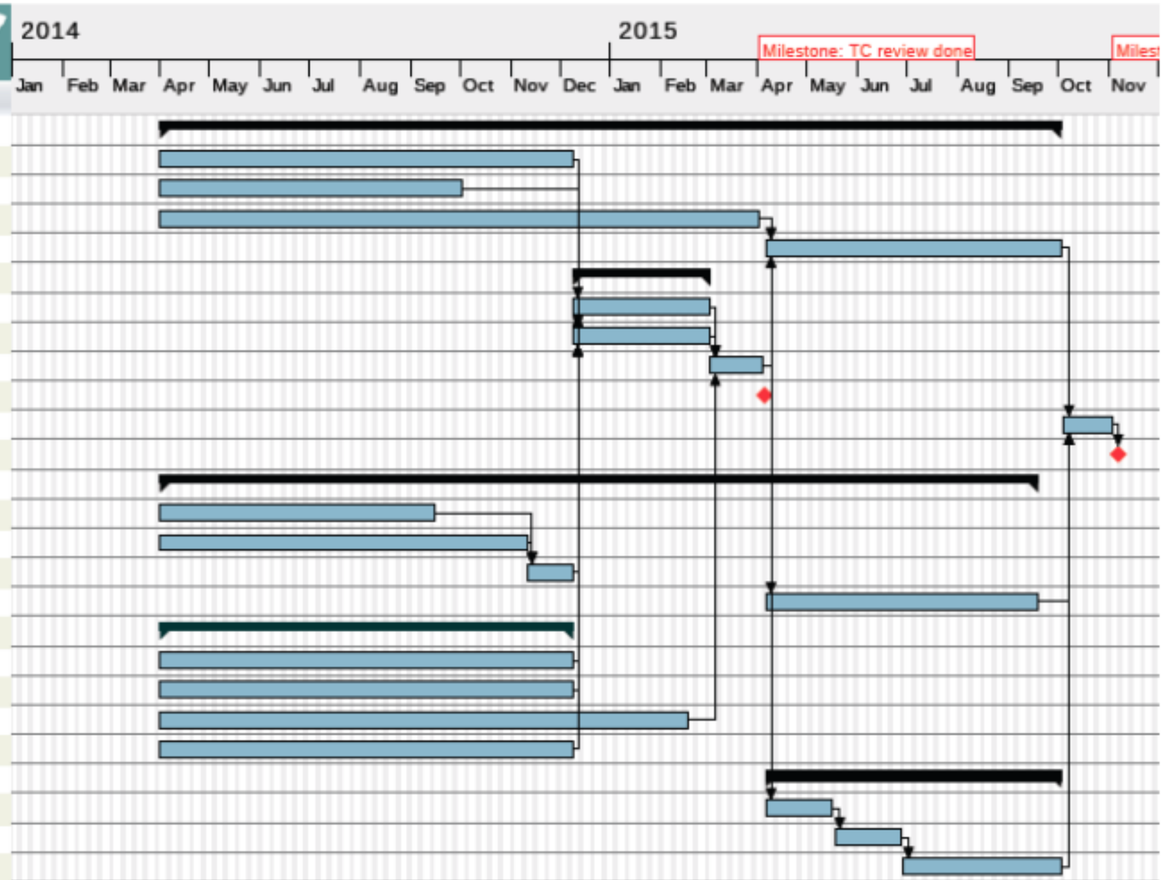
Requirements – PID



- Simulation of CR events faking electrons carried out by the CRV group → 9 events Not Vetoed : (6 mu-, downstream) (3 mu+,upstream)
- Applying the CutC selection → they correspond to 2.2 events

Short term DOE/INFN R&D schedule

Name	Begin d...	End date
▼ Photosensor Task	4/1/14	10/2/15
RMD Development	4/1/14	12/8/14
New SIPM test	4/1/14	10/1/14
New QA station	4/1/14	4/1/15
Pre-production PS	4/6/15	10/2/15
▼ Alternative Study	12/9/14	3/2/15
BaF2+RMD tests	12/9/14	3/2/15
CsI+SIPM tests	12/9/14	3/2/15
Technology Choice Review	3/3/15	4/3/15
Milestone: TC review done	4/2/15	4/2/15
Engineering Ready Review	10/5/15	11/3/15
Milestone: ER review done	11/4/15	11/4/15
▼ Crystal Task	4/1/14	9/18/15
New Na22 station	4/1/14	9/15/14
New UV source	4/1/14	11/10/14
QA BaF2/CsI	11/11/...	12/8/14
Pre-production crystal	4/6/15	9/18/15
▼ FEE task	4/1/14	12/8/14
new FEE for RMD	4/1/14	12/8/14
new FEE for SIPM	4/1/14	12/8/14
Disk Preliminary Design	4/1/14	2/16/15
New Proto Mechanics	4/1/14	12/8/14
▼ Laser Calib task	4/6/15	10/2/15
Laser Choice	4/6/15	5/15/15
Sphere & PIN Choice	5/18/15	6/26/15
Design Optimization	6/29/15	10/2/15



INFN Total Cost CORE

v1.0 by S.Miscetti **1/3/14**

Cost Of Baseline	Work Package	Cost	Cont	Total
	Crystals (1/3 of Total)	€922,000.00	€138,000.00	€1,060,000.00
	Photosensors (1/2 of Total)	€525,000.00	€105,000.00	€630,000.00
	Mechanics (100 %)	€216,000.00	€44,000.00	€260,000.00
	FEE (100 %)	€189,000.00	€28,350.00	€217,350.00
	WaveForm Digitizer (100%)	€311,000.00	€46,650.00	€357,650.00
	Laser System (100%)	€135,000.00	€21,000.00	€156,000.00
	Source (0%)	0	0	0
	Total apparati - crys-ps	€851,000.00	€140,000.00	€991,000.00
	TOTAL	**€2,298,000.00**	**€383,000.00**	**€2,681,000.00**
			0.166666667	€2,681,000.00
Fract of (elec+mech+cal)/(Crys+APD)	**0.369638195**			
Contingency over all system	**0.166666667**			
Contingency over (elec+mech+cal)	**0.164512338**			
Cost if Option CsI + MPPC (50% share)				
	Crystals (0.5/cc x 0.5/0.33) = 0.75	€691,500.00	€103,500.00	€795,000.00
	mppc UV extended (0.83)	€435,750.00	€87,150.00	€522,900.00
	TOTAL	**€1,978,250.00**	**€330,650.00**	**€2,308,900.00**
Cost if LYSO(11 cm)				
		€1,982,300.00	€296,700.00	€2,279,000.00
	TOTAL	**€3,358,300.00**	**€541,700.00**	**€3,900,000.00**
Cost if LYSO(8 cm)				
		€1,427,256.00	€213,624.00	€1,640,880.00
	TOTAL	**€2,803,256.00**	**€458,624.00**	**€3,261,880.00**

Mu2e Ecal Source Calibration

- Ecal absolute energy calibration with a source of known-energy, known-path photons allows monitoring for changes in crystal gain and measurements of noise in energy units, along with an initial set of calorimeter gain settings prior to first beam
- Mu2e Ecal source calibration system is based on a similar system salvaged from SLAC/BaBar
- Salvage items were delivered to Caltech about two weeks ago for refurbishment and development into the system to be deployed at FNAL
- Support for the source calib system has recently been integrated into the detector hall design and work begun to integrate with Ecal mechanics

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