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MUSE

Discussion on the Mu2e Laser System

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MUSE networking meeting: Mu2e vs g-2 Calibration systems

4 August 2016

Mu2e

INFN Istituto Nazionale di Fisica Nucleare

EMC Calibration Team

Calorimeter experience from Crystal Ball, Mark II, BaBar, SuperB

BaBar source calibration system was Caltech responsibility

- Frank Porter (Caltech):
  - EMC Calibration L3 Manager
- Kevin Flood (Caltech):
  - Engineering physicist, source
- Jason Trevor (Caltech):
  - Engineer, source
- Bertrand Echenard (Caltech):
  - Simulation, source

- Pasha Murat (Fermilab):
  - Decays in orbit, $\pi^+ \to e\,\nu$
- Marco Cordelli (INFN-LNF)
  - Laser system
- Stefano Miscetti (INFN-LNF)
  - Laser system

Scope 475.7.6 - Calorimeter calibration

This task contains all aspects needed to build an operative calibration system both with the radioactive source for the determination of the absolute scale and with the laser system for a monitor of the photo-sensor gains. The laser system will be provided by INFN as in-kind contribution.

Requirements

The EMC requirements are described in docdb-864

R1) Online calibration sufficient for calorimeter trigger, online diagnostics

(R2) Precision commensurate with calorimeter resolution requirement of FWHM/2.35 ~ 5% at 100 MeV

(R3) Absolute precision and stability better than 1%

(R4) Independent calibration of each crystal

(R5) Track time dependence

(R6) Perform (source) calibration of entire calorimeter in ~10 minutes

(R7) Timing resolution better than 0.5 ns (driven by PID)

(R8) Position resolution < 1 cm

Design choice for calorimeter calibration

- Unchanged since CD-2 (2014) except for adjustments for change from BaF2 to CsI
  - Laser frequency changed from UV to green

Our solution to calorimeter calibration requirements

- Pre-insertion calibration with 6 MeV source
- Weekly crystal-by-crystal calibration with 6 MeV source
- Monitor readout on shorter time scale with LASER pulsing system
- Higher energy with DIOs (Decays In Orbit)
  - Interpolation and extrapolation with source
  - Tracker can be used, low field for outer crystals
  - Absolute spectrum (at lower fields)
  - Check of MC extrapolation
- Cosmic rays as independent check
- $\pi^+ \rightarrow e^+\nu_e$ as optional independent check (70 MeV e^+)
- Monitor electronics gains with pulser
- Monitor temperatures

6 MeV source calibration

Reaction yielding 6.13 MeV photons is:

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

- Low energy neutrons from a DT generator irradiate Fluorinert™ fluid outside detector
- Activated liquid pumped through pipes to front faces of crystals
- DT neutron generator d+t -> n(14.2 MeV): 10^9 n/s (ING-07)

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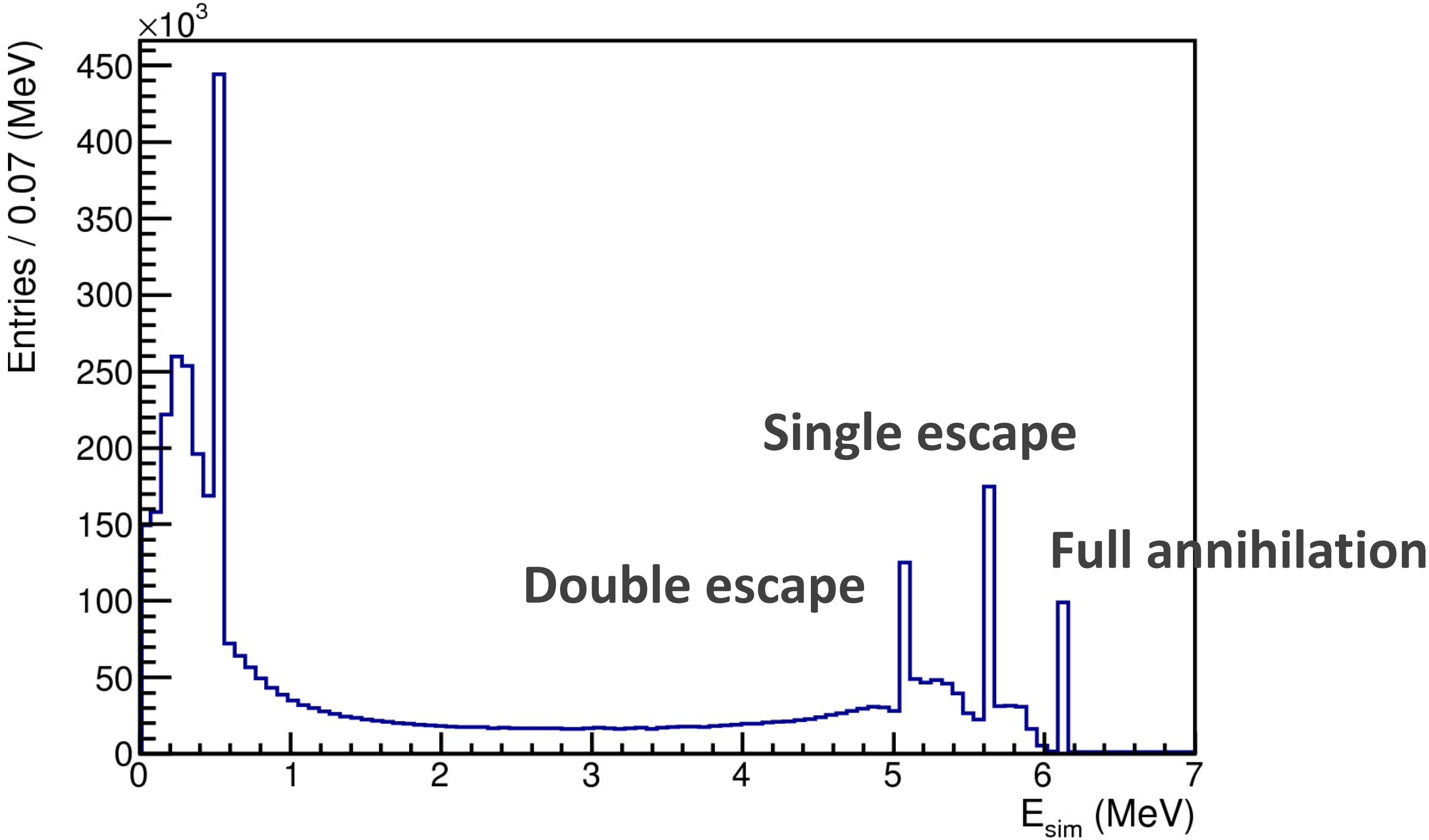
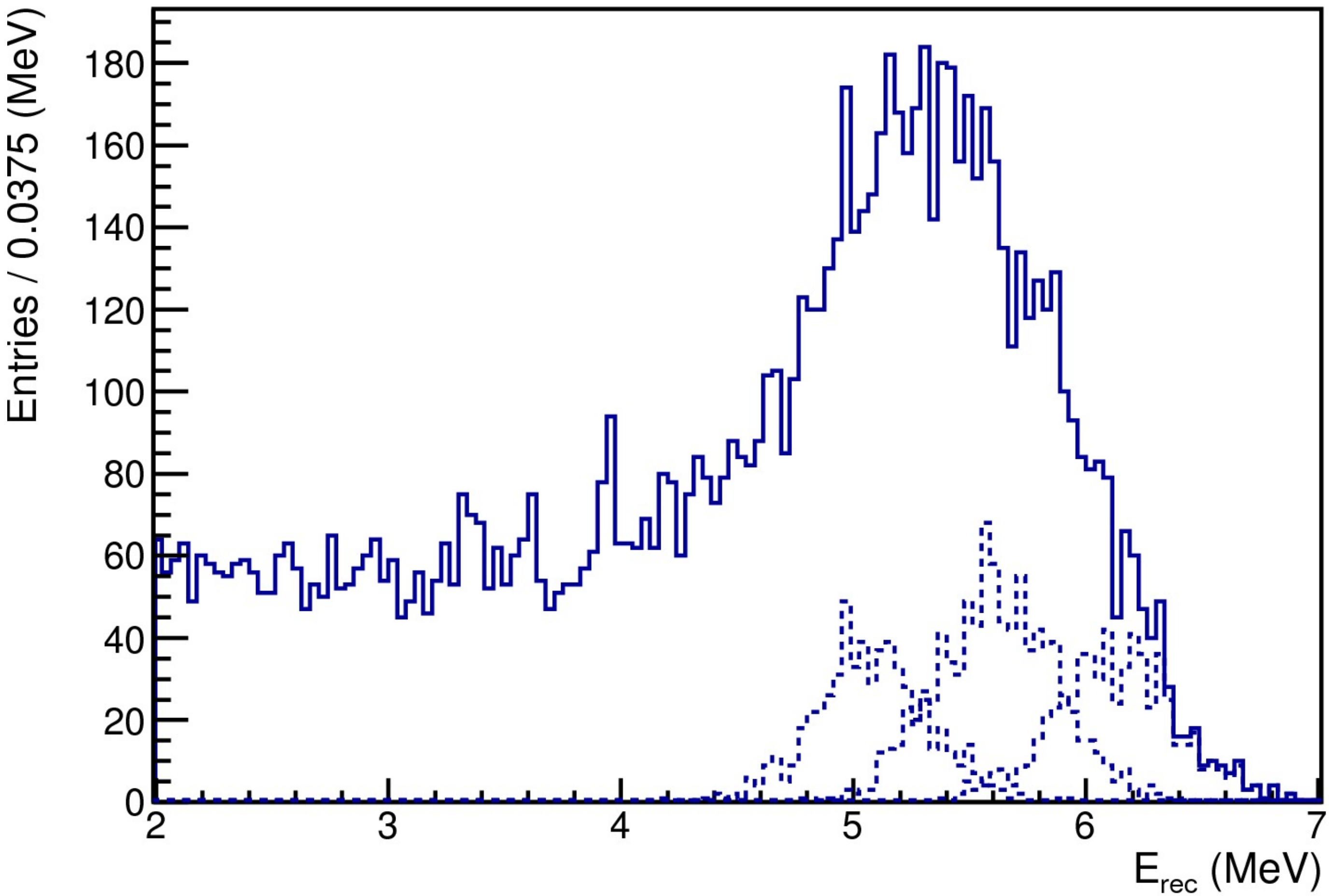
Energy of each crystal hit at the generator level



Full annihilation, single and double escape peaks + Compton

Spectrum corresponding to 10,000 calibration photons



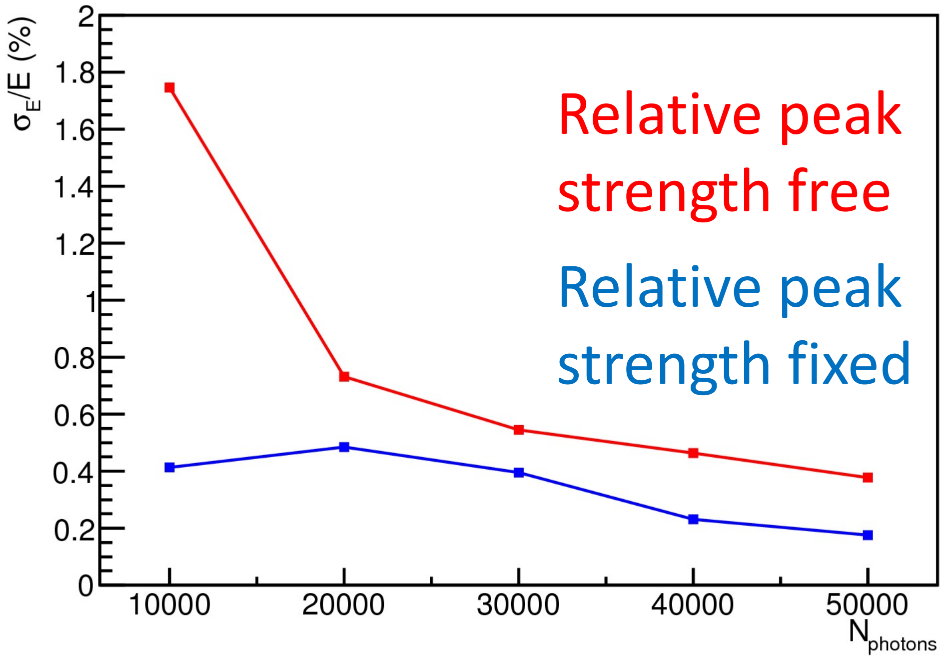
Performance - Source calibration simulation results

Source rate is ~10,000 entries/crystal/10 min

Precision (%) to have
10% effect on resolution

Resolution (%)	Calibration precision (%)
3	1.4
4	1.8
5	2.3

Precision (%)



LASER System

Laser System requirements

- To keep the timing and energy resolution required we need also a continuous monitoring of the detector gain and of the timing offsets.
- ENERGY: While absolute energy scale will be provided by weekly calibration with the source, a control of faster gain changes (due to irradiation, increase of leakage current or temperature variation) will be performed to keep the detector equalization constant. Since we expect slow variation trends, the **relative gain change, at 0.5 % accuracy, can be tracked each hour.**
- TIMING: Similarly the determination of channel by channel timing offsets, T_0, and pulse height dependence, slewing, has to be determined to compensate for small differences on cable lengths, transit times of SIPM response or electronics delays/jitters. **Timing calibration to be kept below few tens of ps.** Final calibration of the timing scale between calorimeter and tracker will be provided "in situ" by means of DIO electrons.

Laser System specifications

- Laser system to **have enough power to get light to all 1374** crystals by means of an optical distribution system and to a **monitoring system that tracks the variation of the Laser light at the source**. We are tuning this system to get a **laser signal with a pulse height equivalent to 100 MeV electrons, 3000 Npe.**

- **The laser has to emit on blue or green wavelengths** to be in a region far from the CsI emission peak (310 nm), to be in a region where transmittance changes due to irradiation are small. This isolates photosensor gain variation.

- **The Laser has to be pulsed with a settable frequency below 100 Hz** by means of an external trigger. During running the Laser will be pulsed at a rate of 0.1 Hz and will be synchronized to be in the "beam-off" region.

- **Laser output to be controlled in amplitude to allow a measurement of the response linearity** for the photosensors and FEE chain.

- **The monitoring system will be based on PIN diodes** in a thermally controlled box

Laser System Scheme

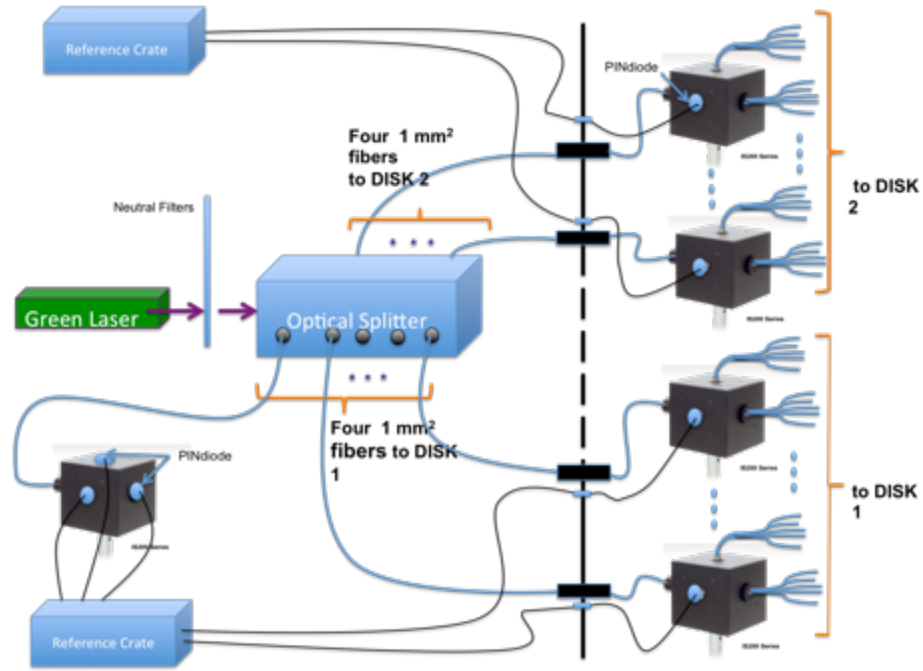
- ❑ The laser beam intensity is attenuated up to a factor of 10 by a graduated **neutral density filter**

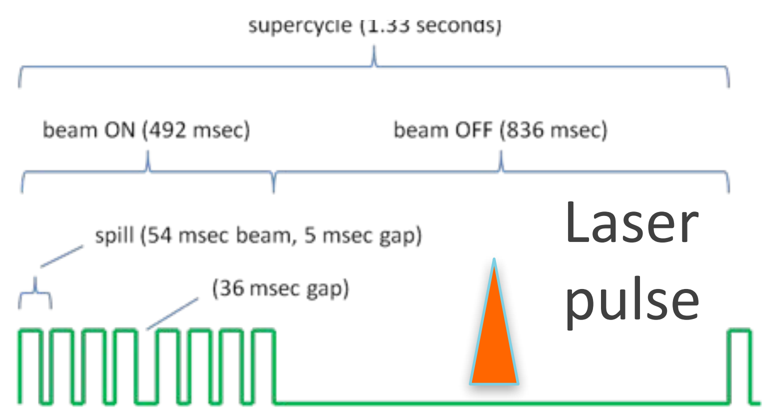
- ❑ The beam will be split, by means of semi transparent mirrors to 8 beams and focused by optical lens to 1 mm diameter Fused Silica fibers. 1/3 of the light will be sent to a 2" diffusing sphere with 3 pin-diodes for monitoring.

- ❑ Eight 60 m long fibers, routed from the counting room to the DS bulkhead brings the light to 8 2" diffusing spheres on the mechanical structure

- ❑ Each sphere, will have 1 pin diode for monitor and 3 bundles of 200 µm silica fibers. Each fiber will be inserted into a lodging in the back of the crystals close to the SIPM holders.

- ❑ Laser Trigger will be synchronized with the DAQ Clock signals and delayed into the beam-off region.





'igure 11.1. Mu2e Beam Structure.

Laser Model specifications

LaserHead+Laser
Controller Box
Diode Pumped Nd:Yag
Solid-State **Micro Laser**

Table of Typical Micro Laser Models

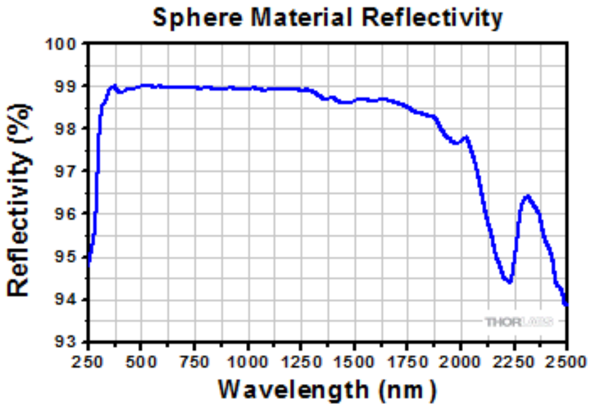
Models	STA-01SH-1	STA-01SH-2	STA-01SH-3	STA-01SH-4	STA-01SH-5
Wavelength, nm			532		
Average output power (max), mW	40	25	50	20	100
Pulse energy, μJ	4	5	50	0.2	100
Pulse width (FWHM), ns	0.5	< 0.7	0.5	0.5	0.5
Repetition rate (max), kHz	10	5	1	100	1
Beam Profile			$M^2 < 1.1$		
Pulse spectral structure			single longitudinal mode		
Polarization ratio			> 100:1		
Beam Waist diameter inside the laser head $1/e^2$, μm*			25-200		
Pulse spectrum FWHM, pm			< 5 (near transform limited)		
Pulse to pulse energy stability RMS			< 0.5		
Power stability over six hours**			< ± 1,5%		
External power supply voltage, V AC			100-240		
Operating temperature, °C			15 - 40		
Interfaces			USB, External trigger (TTL rising edge) 1HZ…max repetition rate		
Laser head dimensions:					
diameter, mm			25		
length, mm			76.5		

- ❑ Available @ different emission wavelengths → similar product also @ 355 nm.
- ❑ It is a good match between very high pulse-energy, good power stability, repetition rate and command from an external trigger. It has been used for the prototype phase.
- ❑ 5 μJ pulse → equivalent to 10^{13} photons produced at the source.
- ❑ Distribution losses are large but light output is more than enough for our purposes.

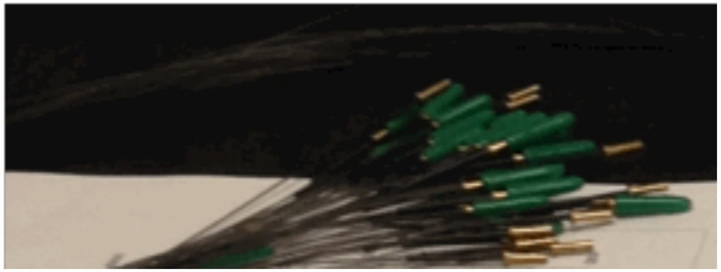
Light distribution system

ThorLab-IS200 Sphere

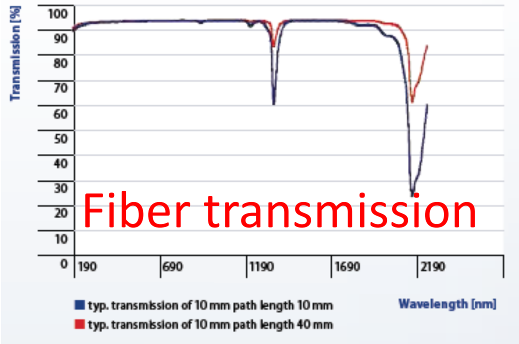
- 1 input, 4 output ports
- PIN-diode ThorLab-SM05PD1A
- 3 Bundle of fibers with SMA connector in the port and final ferrule on each fiber.



- ✓ Loutput/μJ $=2\times10^{12}$
- ✓ T(filter+optical) = 10^{-3}
- ✓ Tfiber = 7×10^{-5}
- ✓ Ttotal = 7×10^{-8}



- ✓ LY = 10^{5} Nphotons/pulse
- ✓ LY (NPE) = LY x QE = 3×10^{4}

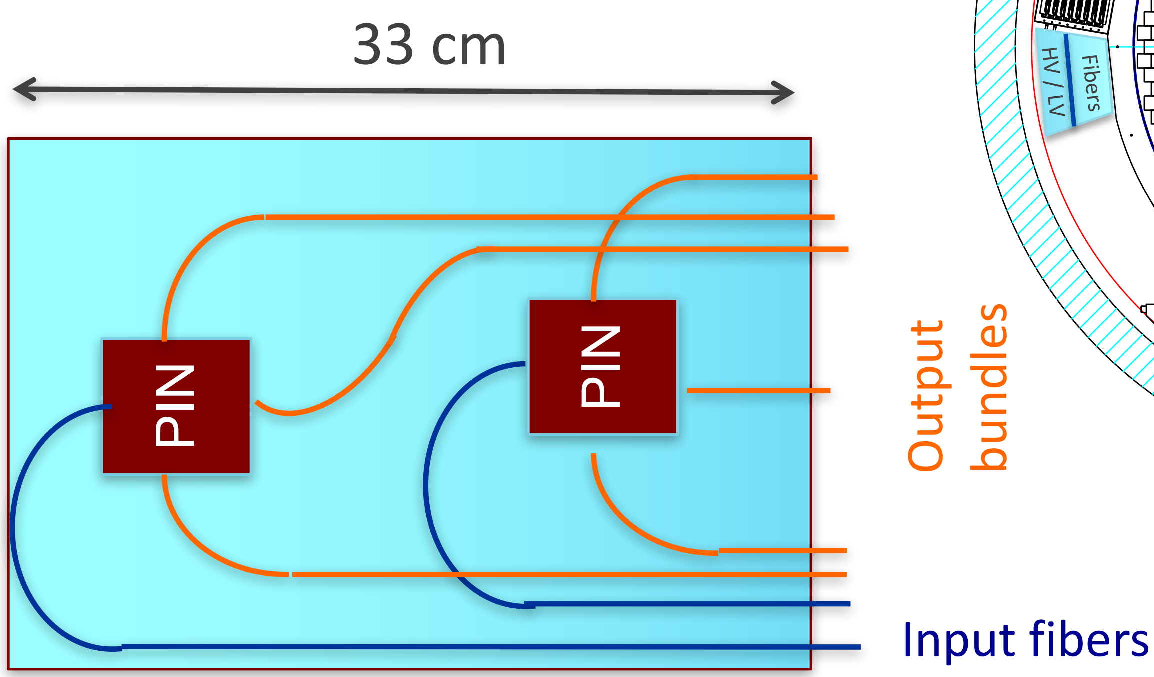


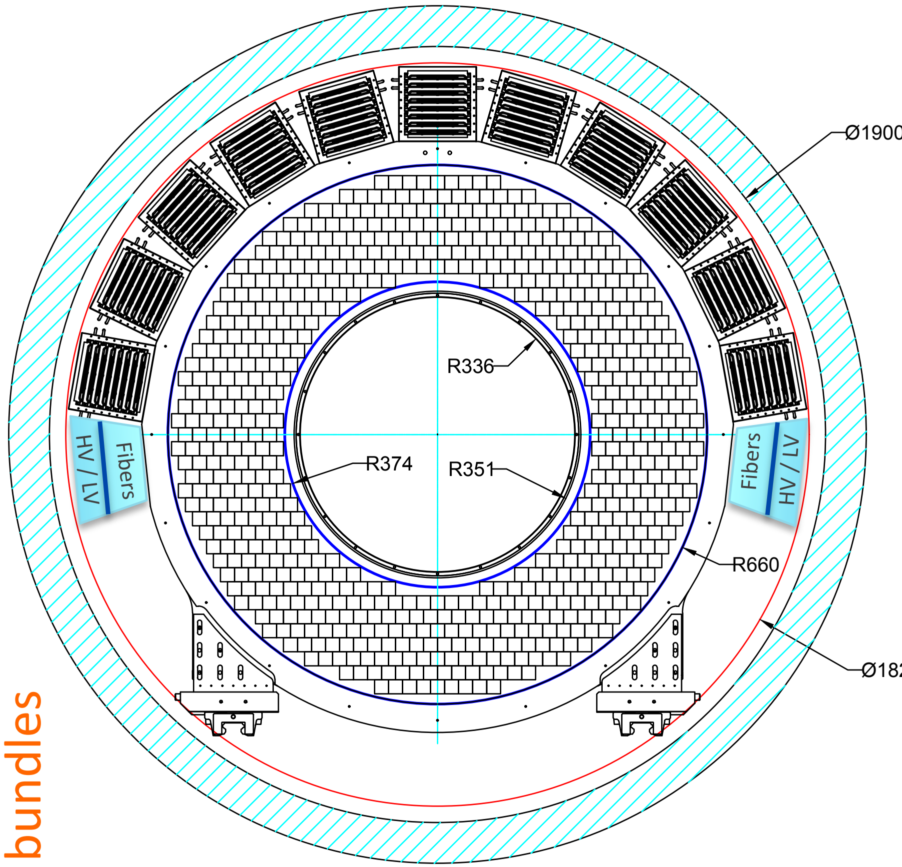
- Fused silica fibers have good transmission for the wavelengths under consideration (from 355 to 500 nm), high reliability and radiation hard for Mu2e.
- **We have tested them up to 90 krad and 10^{12} n/cm^2 seeing no deterioration.**

Fiber routing

After last round of optimization, the number of channels is frozen and we are completing the cable routing for the fibers:

- 2 HV/LV/Fiber Box will be located at $\pm$ 7° in ϕ.
- 1 serving the Top area, 1 serving the Bottom area
- Each sphere will have 1 input and 3 output fiber bundles (225 total), serving 170 crystals+ 1 PIN Diode





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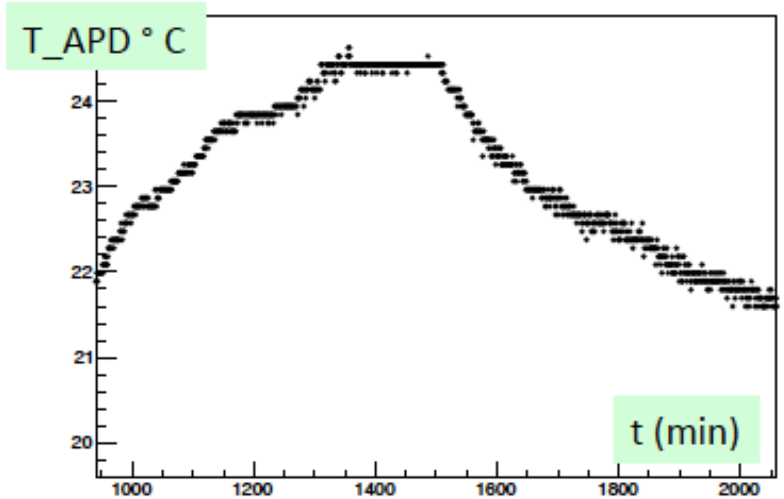
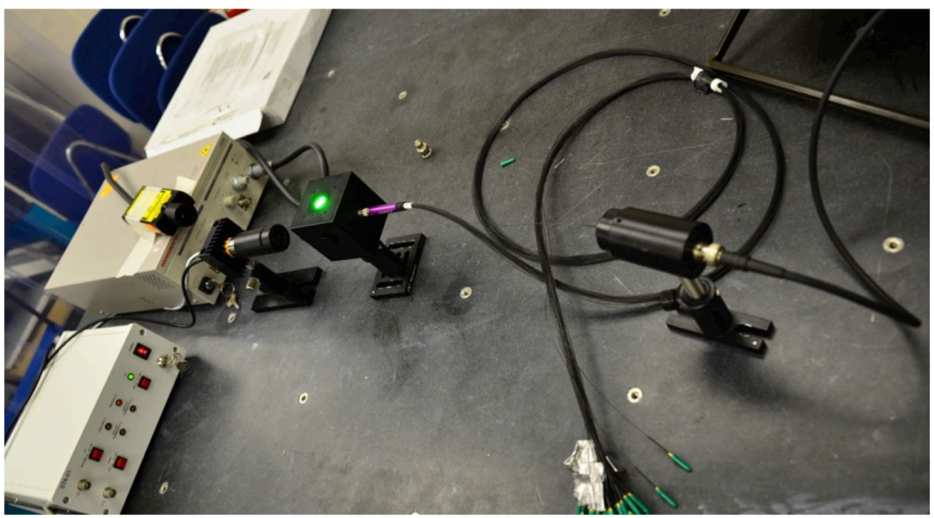
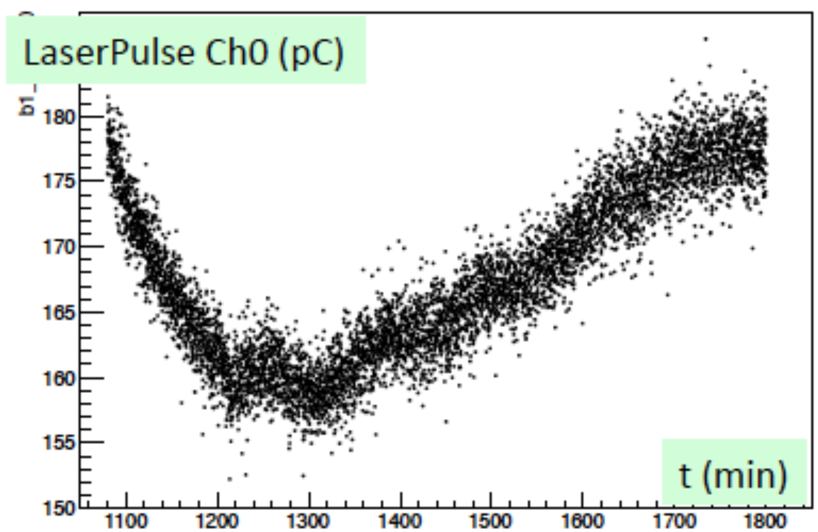
Performance – Laser System Prototype

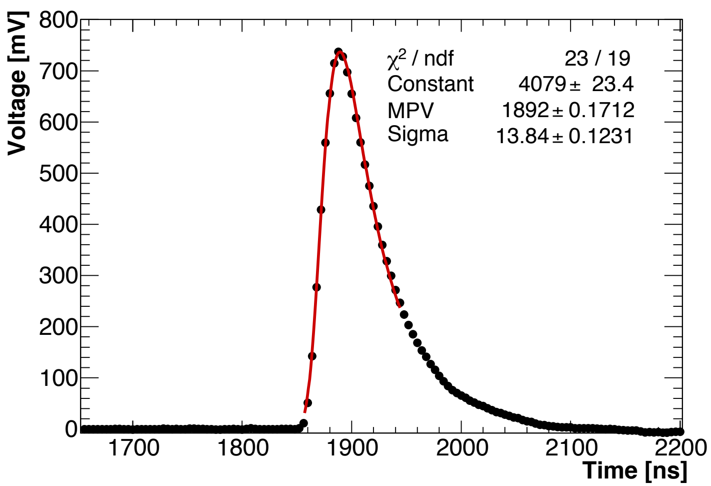
- A prototype of the laser system (below) was used to study, e.g., laser pulse stability.
- The plots (right) show the anti-correlation between temperature and APD gain, as well as the ~5% pulse-to-pulse variation.







Prototype system performance @ LYSO test beam for timing



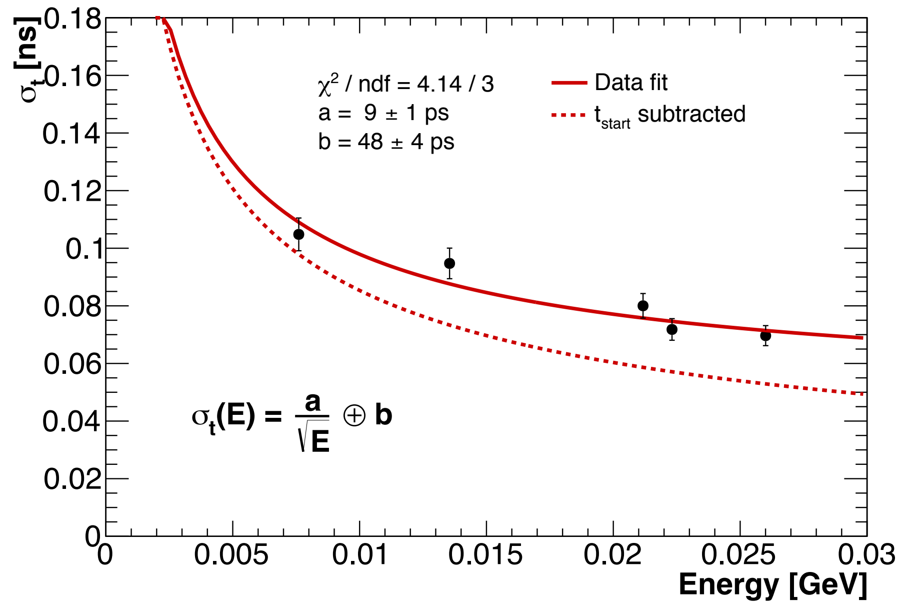


Figure 13: Time resolution for laser signals as a function of the equivalent deposited energy.

Environment, Safety & Health

- Radiation (Mu2e HAR: DocDB 675)
  - The DT generator is a radiation-producing device that must be licensed and appropriately shielded for safe operation
  - Bunker design for generator installation at FNAL has been simulated using MARS, acceptable levels of radiation in accessible areas. Survey with fluid to be performed
  - We have California licensing for operation of the DT generator at Caltech, and radiation survey records
  - **Light flasher laser will be appropriately enclosed**
  - Residual activity of the fluid is suppressed by its 7 s half-life
- Electrical
  - DT generator operates at ~100 kV, standard HV precautions and interlocks will apply. Under keyed control
- Chemical
  - The source calibration working fluid is Fluorinert™ FC-770, will be protected from accidental release to the environment

Points to be addressed

- **LASER Choice:**
  → Compromise between Pulse Energy and distribution system
  → Maximum repetition rate
  → Long term reliability and duration of Laser Head ?

- **Safety Class for LASER and Laser HUT**

- Primary optical distribution and PIN-Diode selection for Monitoring
- **Laser Wheel:** Model Home-made or COTS (Comm. Off the Shelfs)?
- PIN diode resistance to radiation and change of response with temperature.

- Integrating Sphere under Vacuum? Problems?
  → Pro/contra of Diffusers ? Dimension and technical Specs?