Mu2e crystals qualification

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PADME ECal Meeting

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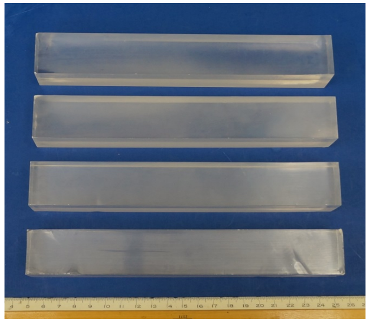
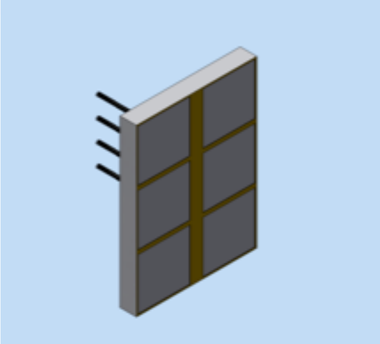
Mu2e Calorimeter: state of the art

The Calorimeter consists of two disks with 674 CsI 34x34x200 mm^3 square crystals:



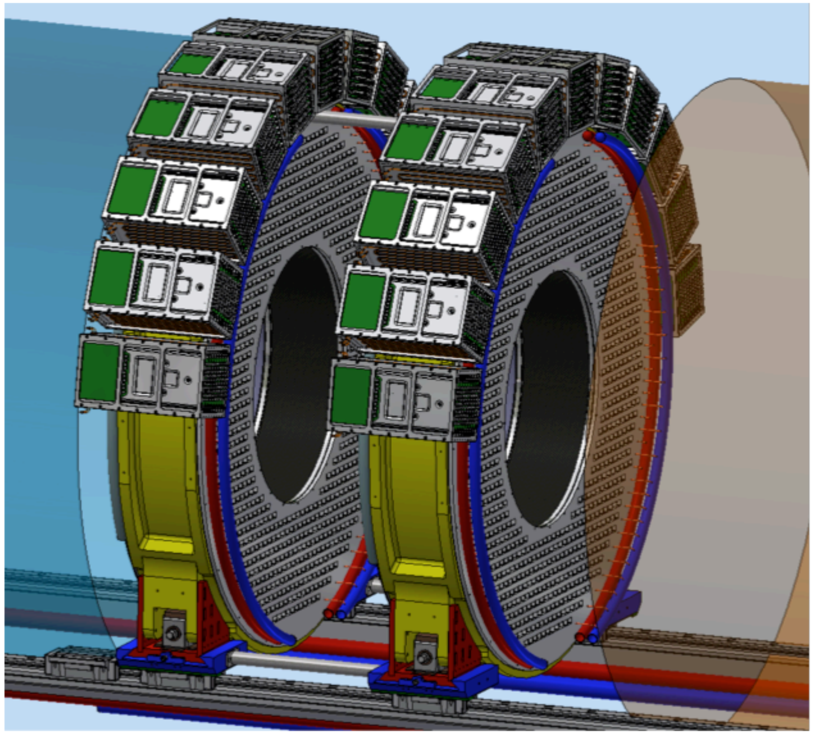


→ R_{inner} = 374 mm, R_{outer}=660 mm, depth = 10 X_0 (200 mm)

→ Each crystal is readout by two large area UV extended SiPM's (14x20 mm^2)

→ Analog FEE is on the SiPM and digital electronics is located in near-by electronics crates

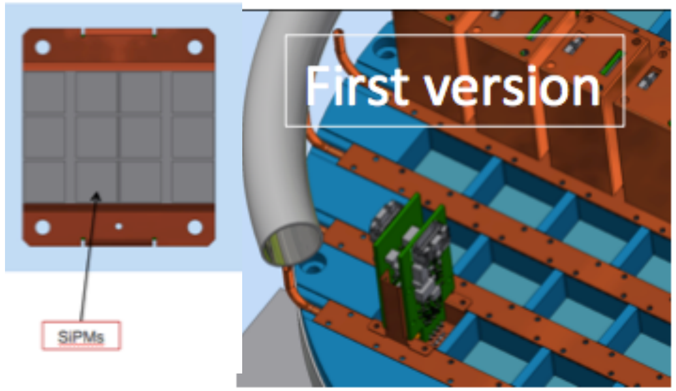
→ **Radioactive source and laser system provide absolute calibration and monitoring capability**



Mu2e Calorimeter: state of the art (2)

High granularity crystal based calorimeter with:

- 2 Disks (Anuli) geometry to optimize acceptance for spiraling electrons
- Crystals with high Light Yield for timing/energy resolution → **LY(photosensors) > 20 pe/MeV**



- **2 photo-sensors/preamps/crystal** for redundancy

and reduce MTTF requirement → now set to 1 million hours/SiPM

- Fast signal for Pileup and Timing resolution → **τ of emission < 40 ns + Fast preamps**
- Crystals and sensors should work in 1 T B-field and in vacuum of 10^{-4} Torr and:

→ **Crystals survive a dose of 100 krad and a neutron fluency of 10^{12} n/cm^2**

→ **Photo-sensors survive 20 krad a neutron fluency of 3×10^{11} n_1MeV/cm^2**

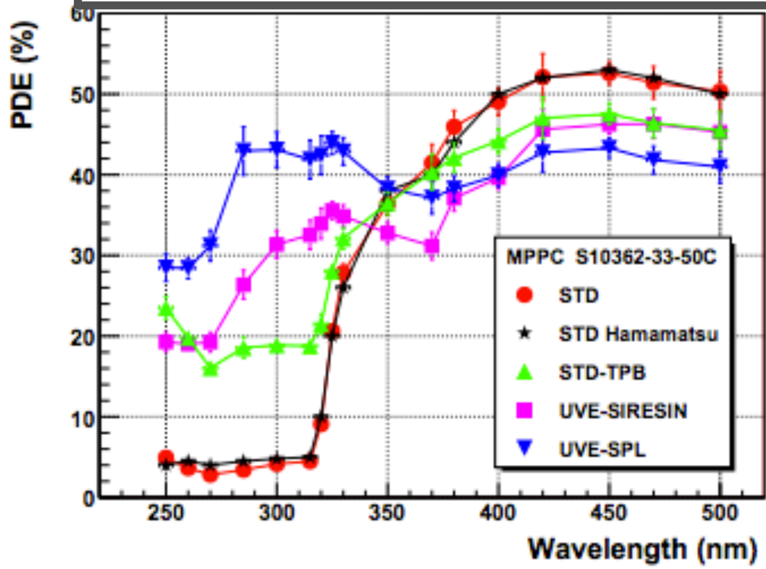
Design: Crystals and Sensors choice

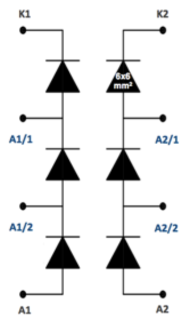
	BaF_2	CsI
Radiation Length X_0 [cm]	2.03	1.86
Light Yield [% NaI(Tl)]	4/36	3.6
Decay Time[ns]	0.9/650	30
Photosensor	RMD APD	SiPM
Wavelength [nm]	220/300	310

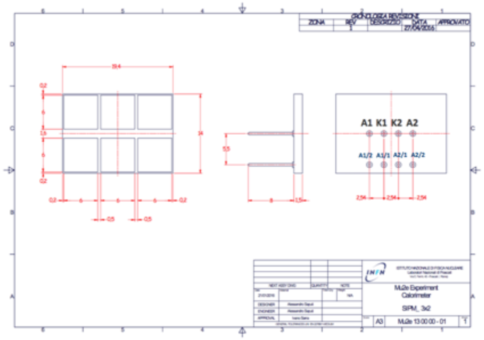
Undoped CsI

- Adequate radiation hardness
- Slightly hygroscopic
- 30 ns emission time, small slow component.
- Emits @ 310 nm.
- Comparable LY of fast component of BaF_2.
- Lower cost (6-8 $/cc)
- **Well know crystal. Mass produced before .. KTeV**

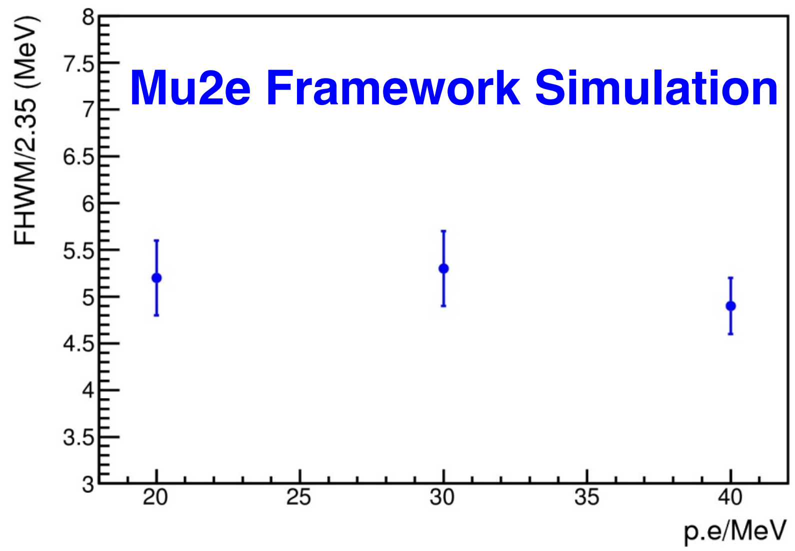
TSV with SPL SiPMs

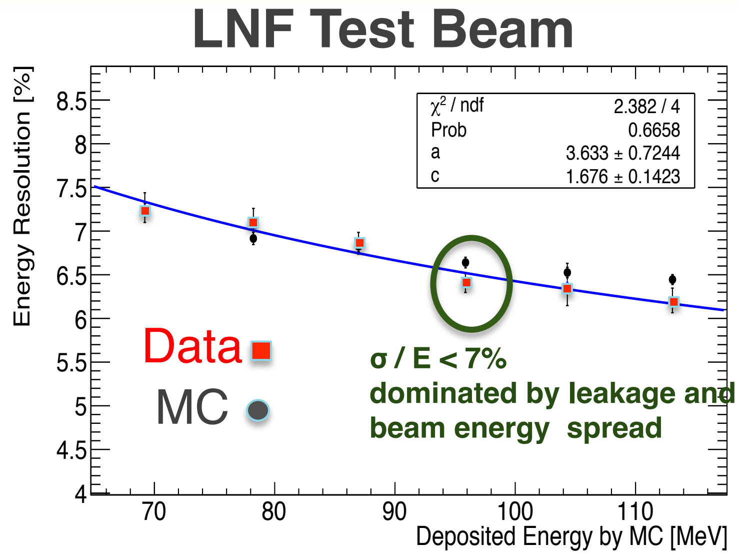


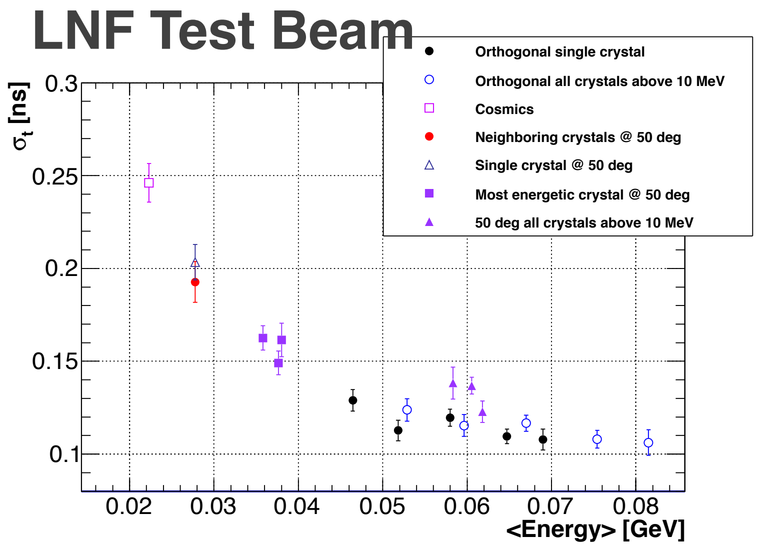




Design: meeting the requirements







- Simulation performed as a function of LY and many other variables → **CsI+SIPM match requirements.**
- Test beam with e⁻ @ BTF, LNF 80 to 130 MeV → 3x3 array of 30x30x200 mm³ CsI + MPPC
- Good energy (7%) and timing (110 ps) resolution
- **Exp tests → Matching EMC requirements**

Design: Radiation hardness & cooling

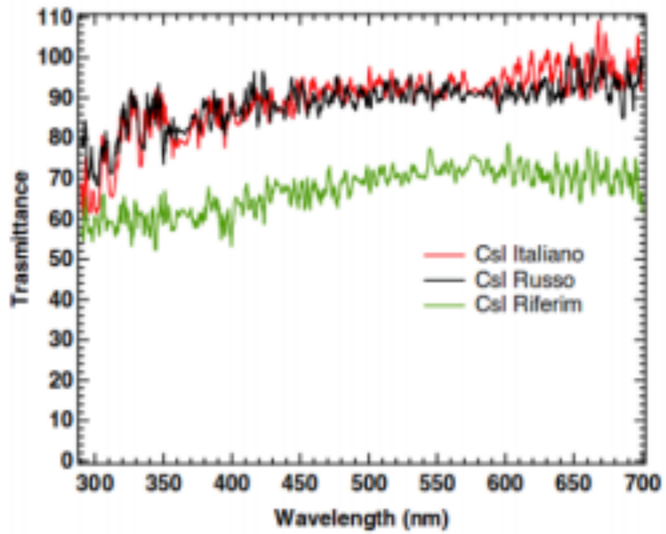
- **Crystals have been tested up to 100 krad and 10^{12} n/cm^2 with 14 MeV neutrons** i.e. the doses in the experiment with a safety factor of 3 applied.
  → No major issues/damages observed (LY drop 40% @ 100 krad)
  → Radiation hardness will be part of our QA test procedure
  → Effect of thermal neutrons on Radiation Induced Current being investigated

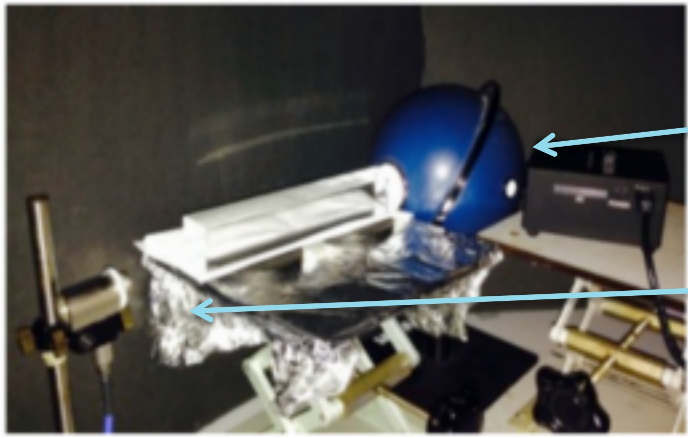
❑ **Photosensors have been tested up to 20 krad and 3 x 10^{11} n/cm^2.**
→ No problems with dose
→ With neutrons, sensors are still working but leakage current increases to too high values (a factor ~2000)
→ **Cooling photo-sensors to 0 °C is needed.**

Crystals: Quality Control

Transmittance of the pure CsI has been much improved from 2014

From left to right: SICCAS (2014 sample), Opto Materials and ISMA CsI crystals





D^2 lamp and diffusive sphere

Spectrometer

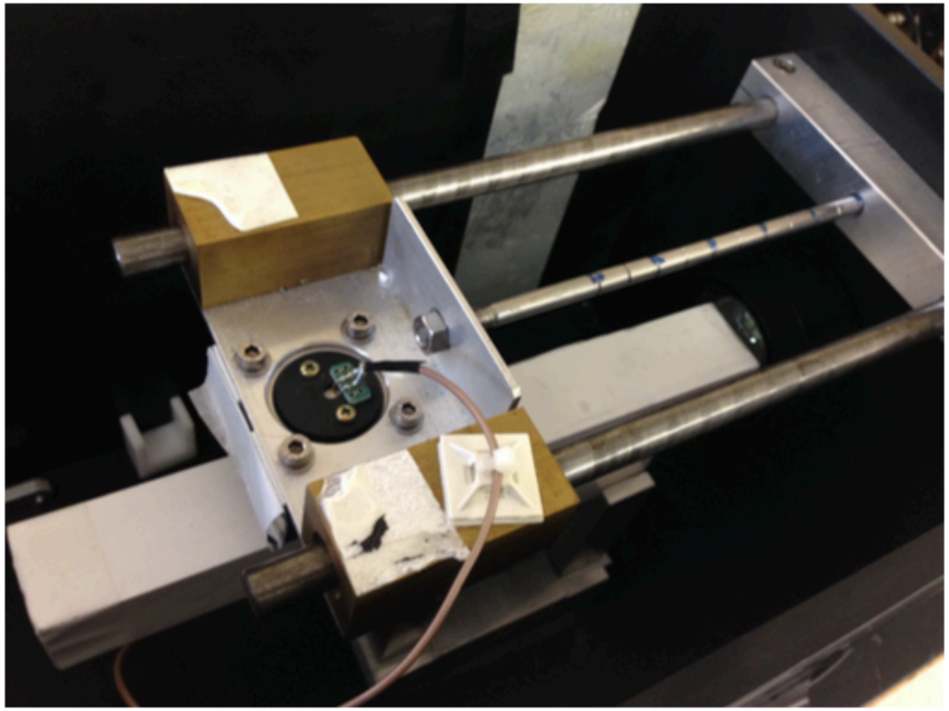
Crystals: Quality Control (2)

- To study the **light yield** and **longitudinal uniformity** of each crystal, we used a low intensity collimated ^{22}Na source which irradiates them in a region of few mm^{2};
- The source is placed between the crystals and a small tagging system, constituted by a 3×3× 10 mm^3 LYSO crystal, readout by a 3×3 mm^2 MPPC;
- One of the two back-to-back 511 keV photons produced by the source is tagged by this monitor while the second photon is used to calibrate the crystal under test, which is readout by means of a 2” UV extended photomultiplier tube (PMT) from ET Enterprises.
- The whole system is inside a light tight black box.

Crystals: Quality Control (3)

- For each crystal, a longitudinal scan is done in **eight points**, with 2 cm steps, with respect to the readout system.
- In the scan, the source and the tag are moved together along the axis of the crystal under test with a manual movement.

- A complete longitudinal scan takes about 10 minutes. We take 20000 events/point at 500 Hz.
- All crystals are tested wrapped with reflector material (Tyvek).

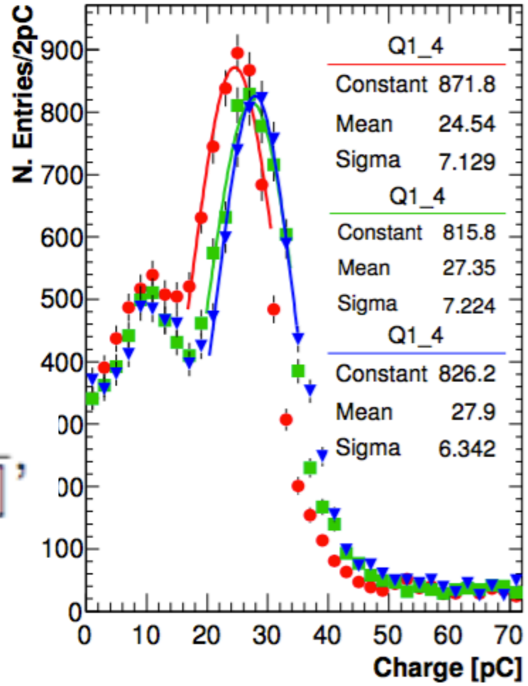


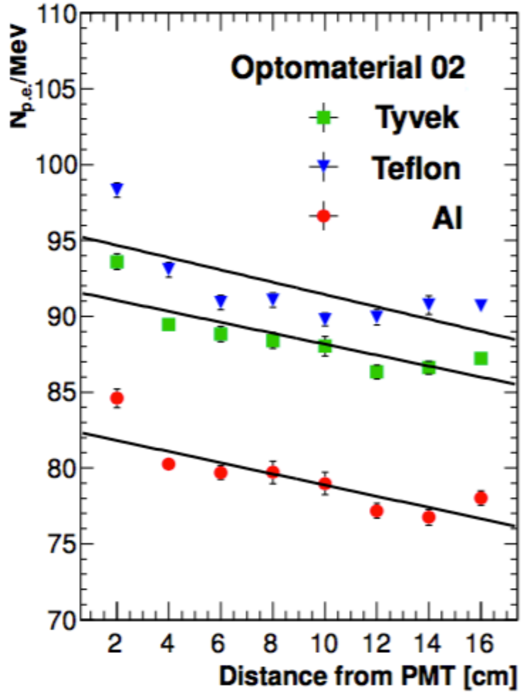
Quality Control: Examples

- Charge distributions with the source placed in the central position;

- LY, defined as:

$$\frac{Np.e.}{MeV} = \frac{\mu_{Q1[pC]}}{G_{PMT} \cdot E_{\gamma}[MeV] \cdot q_{e^-}[pC]},$$





- To evaluate the longitudinal uniformity, LRU, we plot the light yield as function of the distance of the source from the PMT and we fit the number of photoelectrons produced per MeV with a linear function.

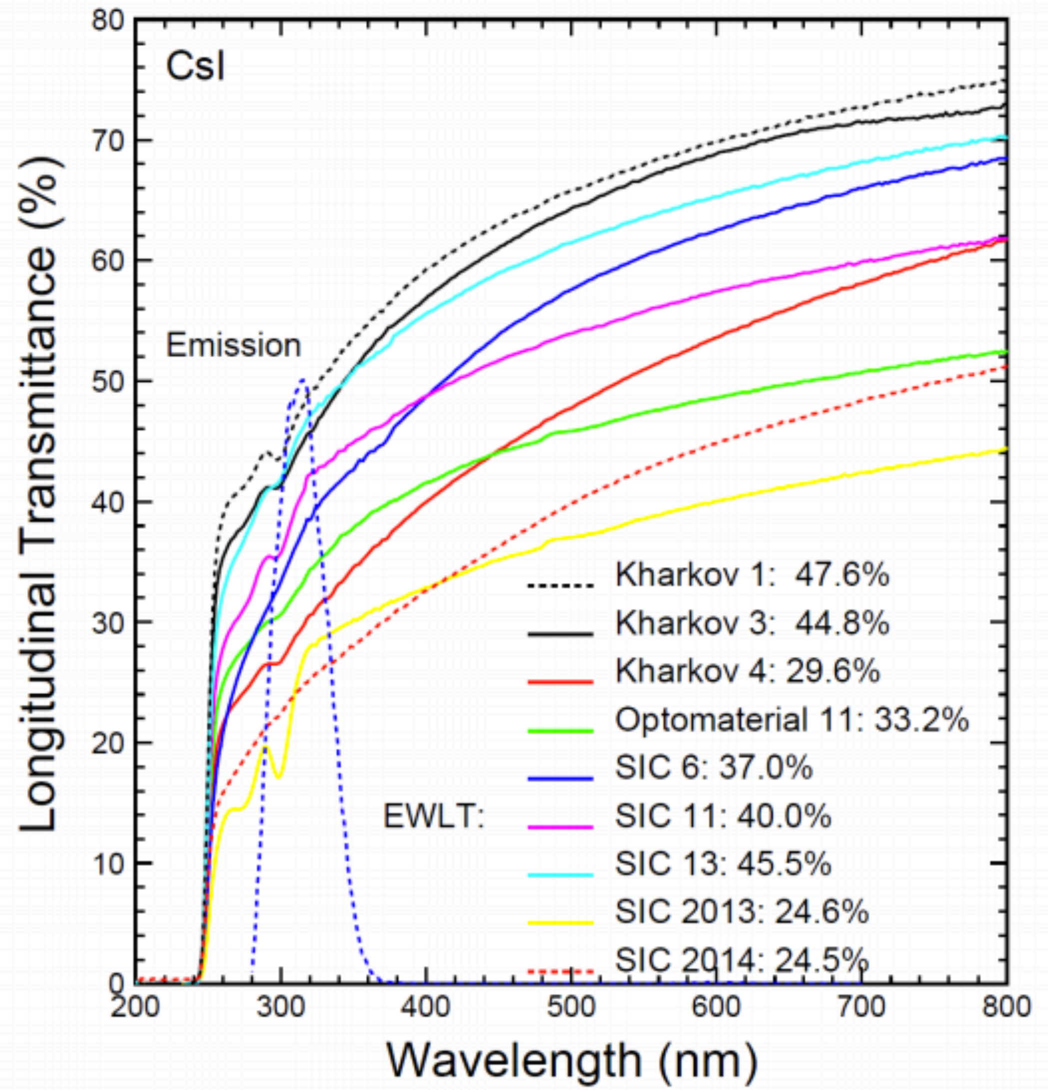
Quality Control: Specifications

- ✓ Angular coefficients are used to evaluate the LRU.
- ❑ Specifications are defined according to samples characterized: Kharkov (Ukraine), Opto Materials (Italy), SICCAS (China) and Saint-Gobain (France);
- ❑ Crystal lateral dimension: ±100 μm, length: ±100 μm.
- ❑ Scintillation properties measured by a bi-alkali PMT with air gap, coupled to the crystal wrapped with two layers of Tyvek paper:
  - → **Light output (LO): > 100 p.e./MeV with 200 ns integration gate, will be defined as XX% of a candle crystal provided;**
  - → **FWHM Energy resolution: < 45% for ^{22}Na peak;**
  - → **Fast (200 ns)/Total (3000 ns) Ratio: > 75%;**
  - → **Light response uniformity (LRU): < 10%.**
- ❑ Radiation hardness:
  - → Normalized LO after 10/100 krad > 85/60%.
  - → Radiation Induced Current (RIC) @1.8 rad/h: < 0.6 MeV.

Quality Control: Specifications (2)

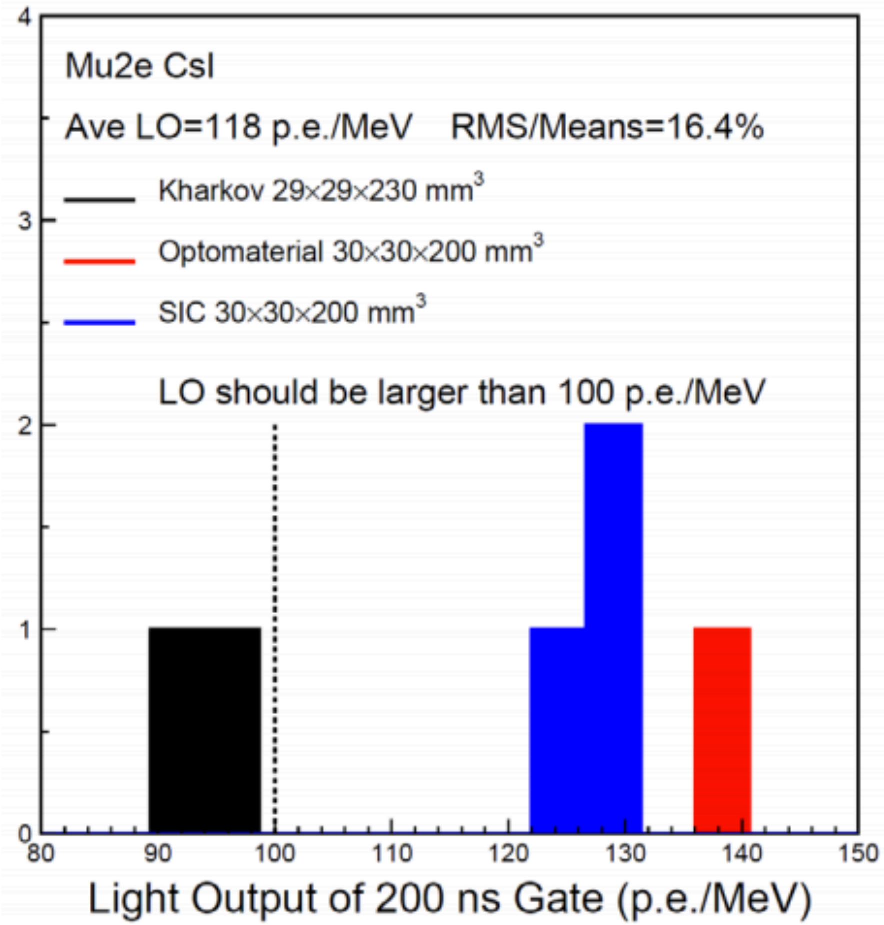
LT of CsI depends on crystal surface quality, so can not be used in specification.

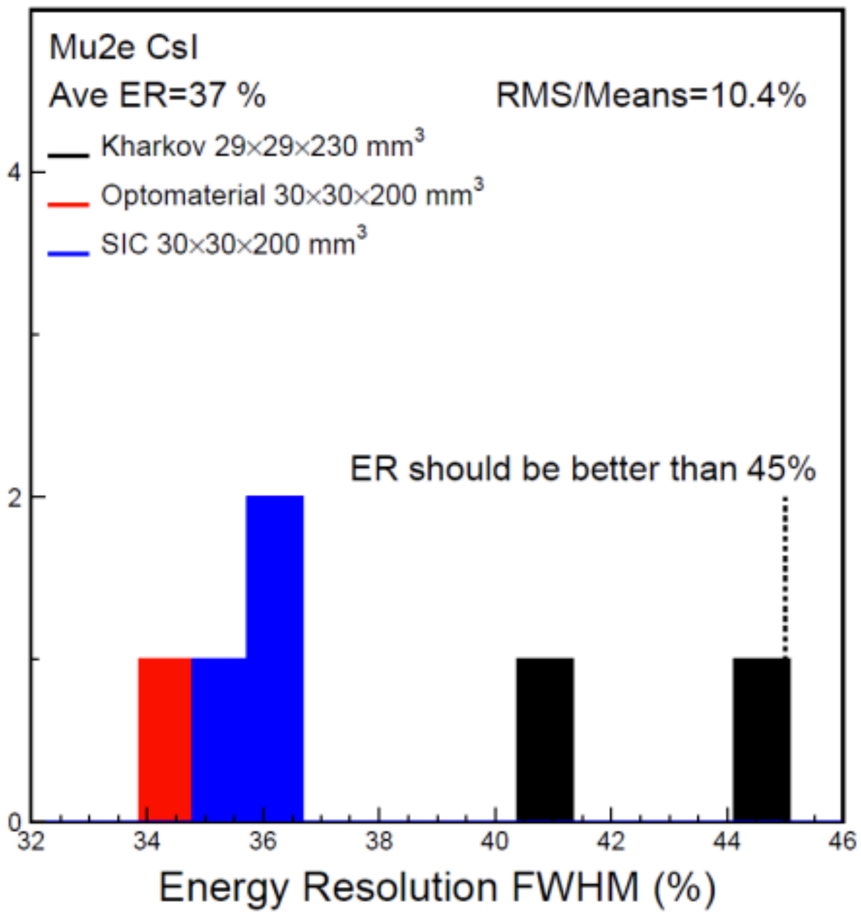
LT and emission weighted LT (EWLT) may be used in radiation damage investigation provided that crystal surface is kept stable.



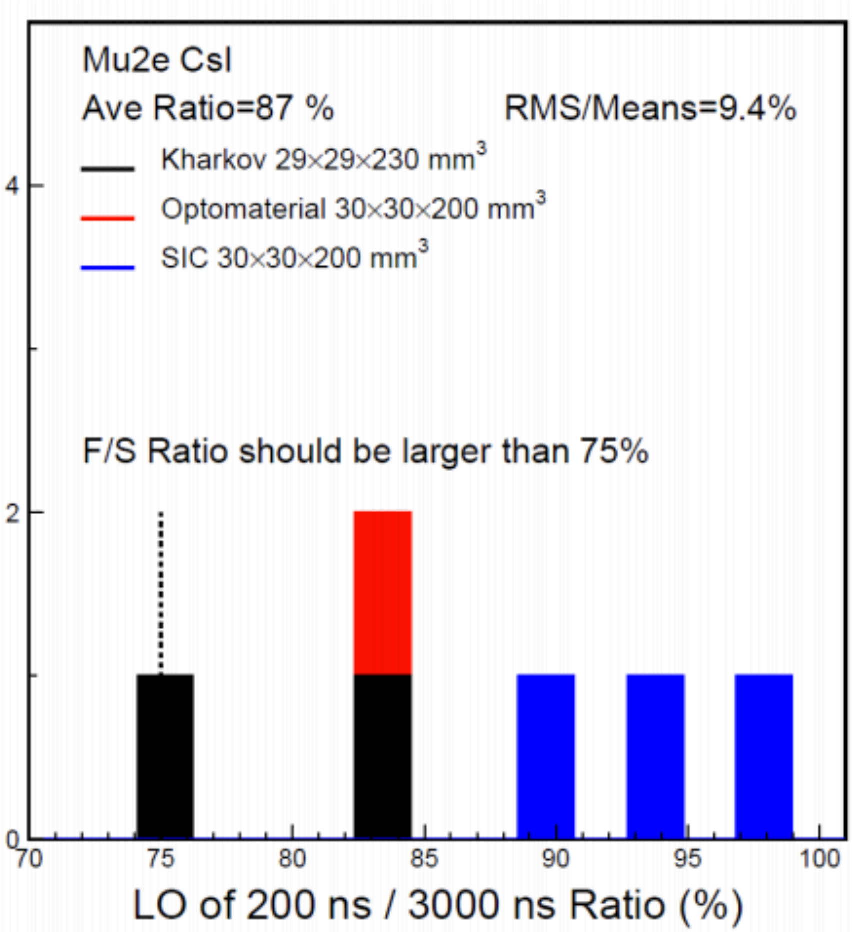
Specifications: LO and FWHM ER Examples

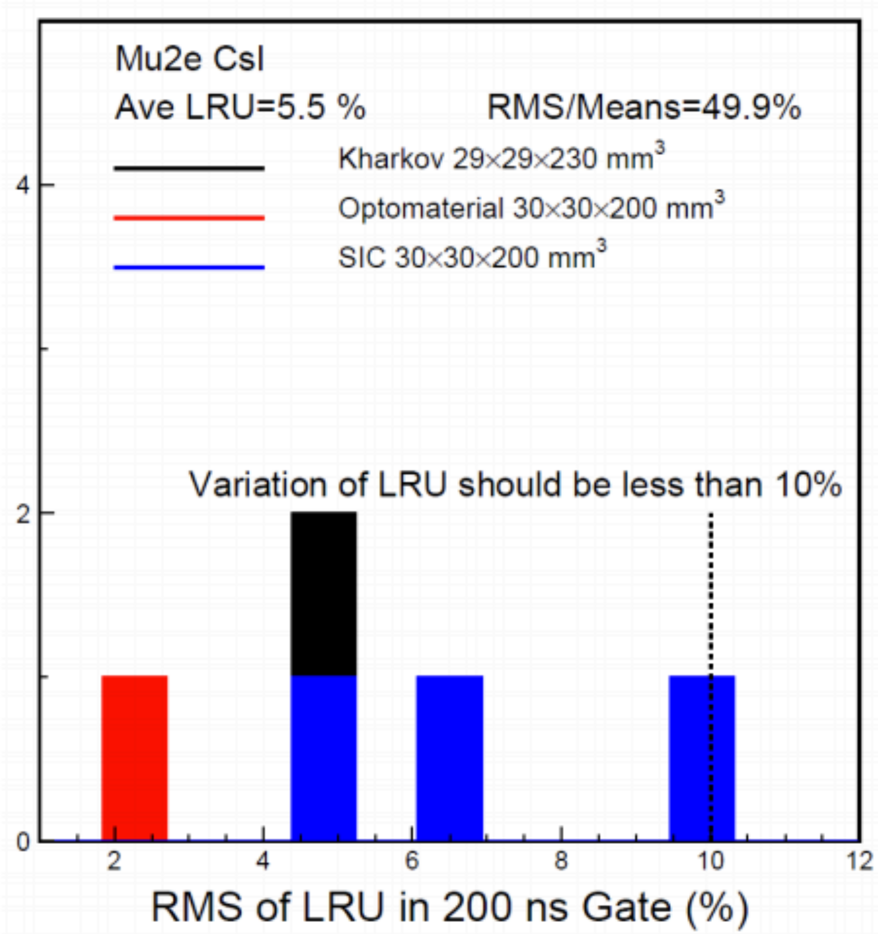
Kharkov samples are longer, so have lower LO





Specifications: F/S Ratio and LRU Examples

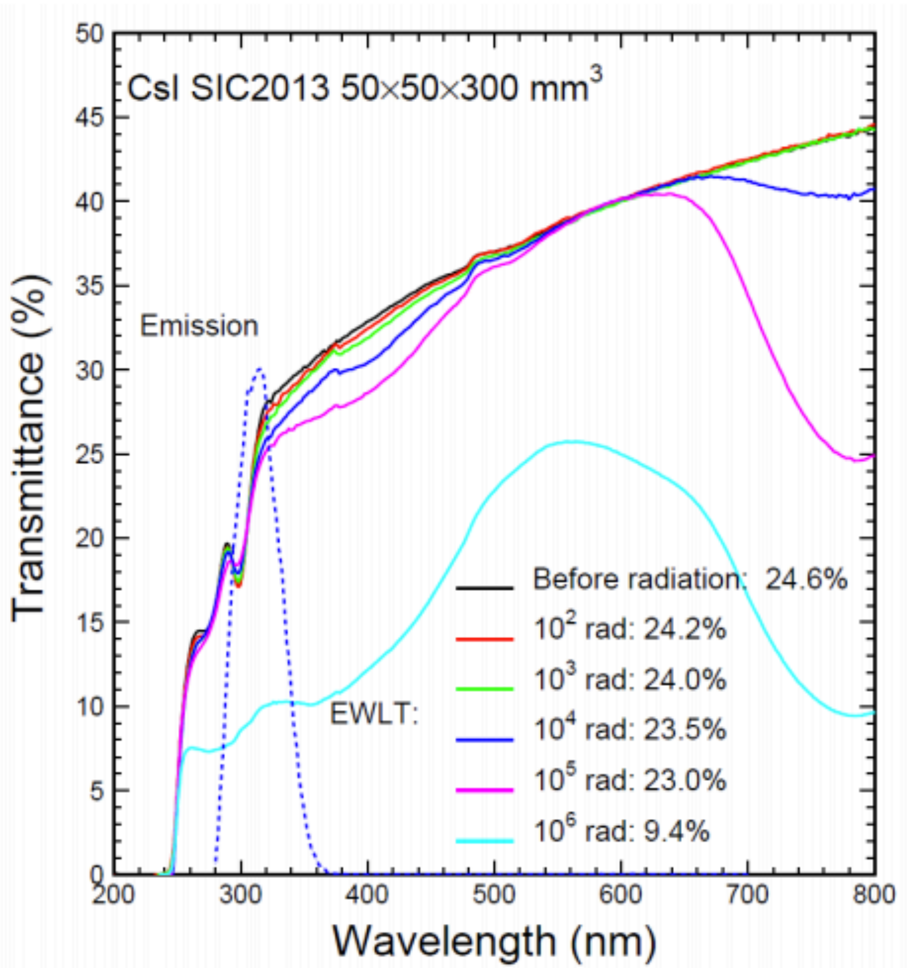


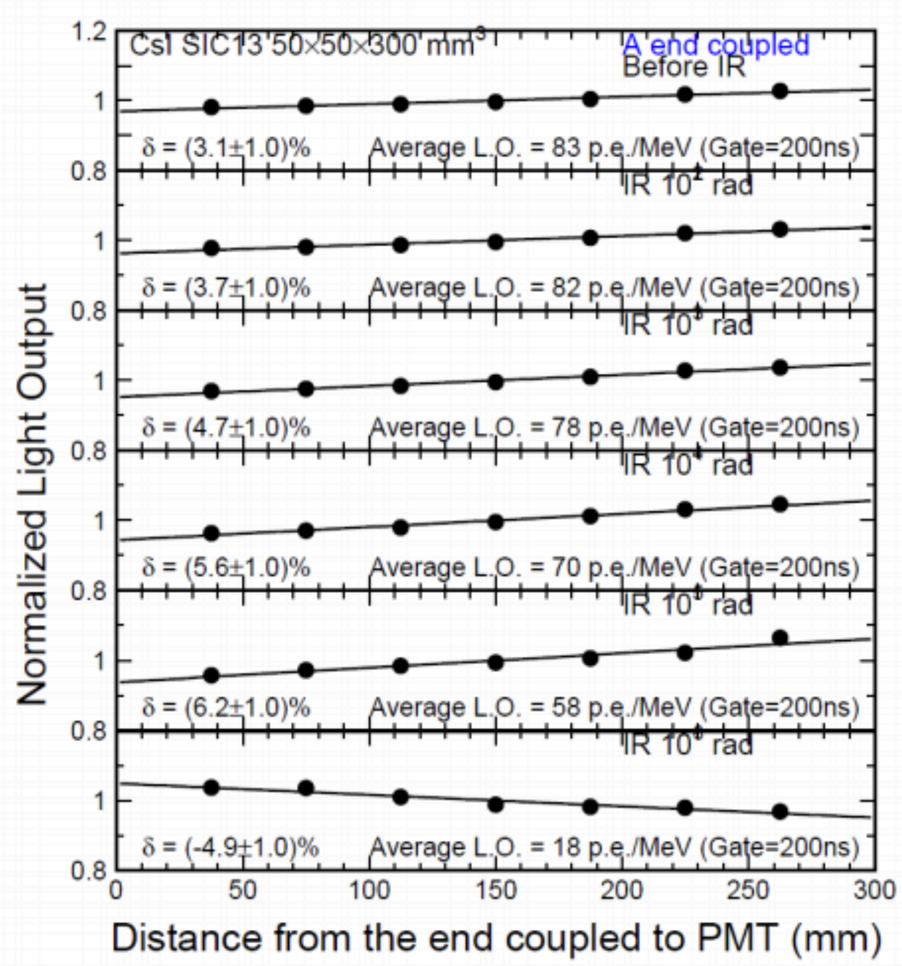


SPARES

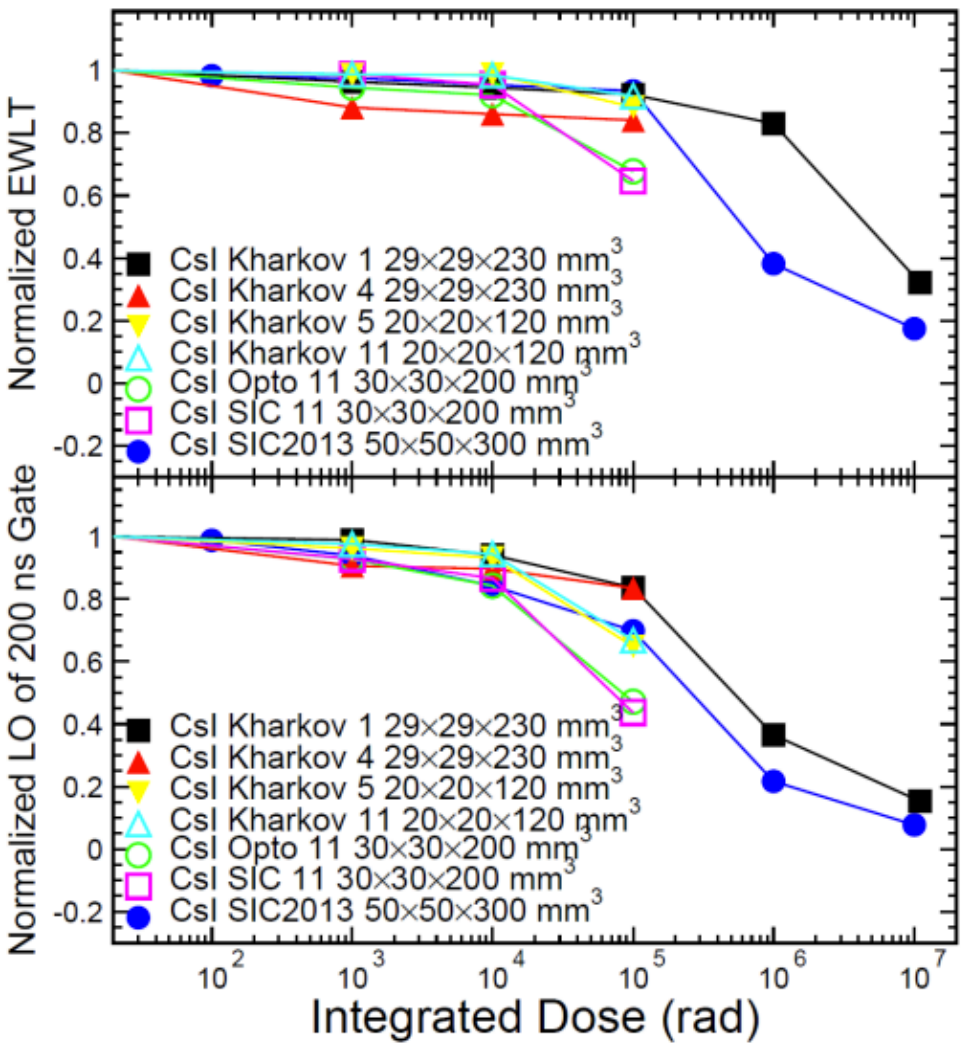
Radiation Damage (1)

No significant degradation in LO and LRU up to 10 krad





Radiation Damage (2)



Consistent radiation hardness: no significant degradation in LO and LRU up to 100 krad, but not beyond.

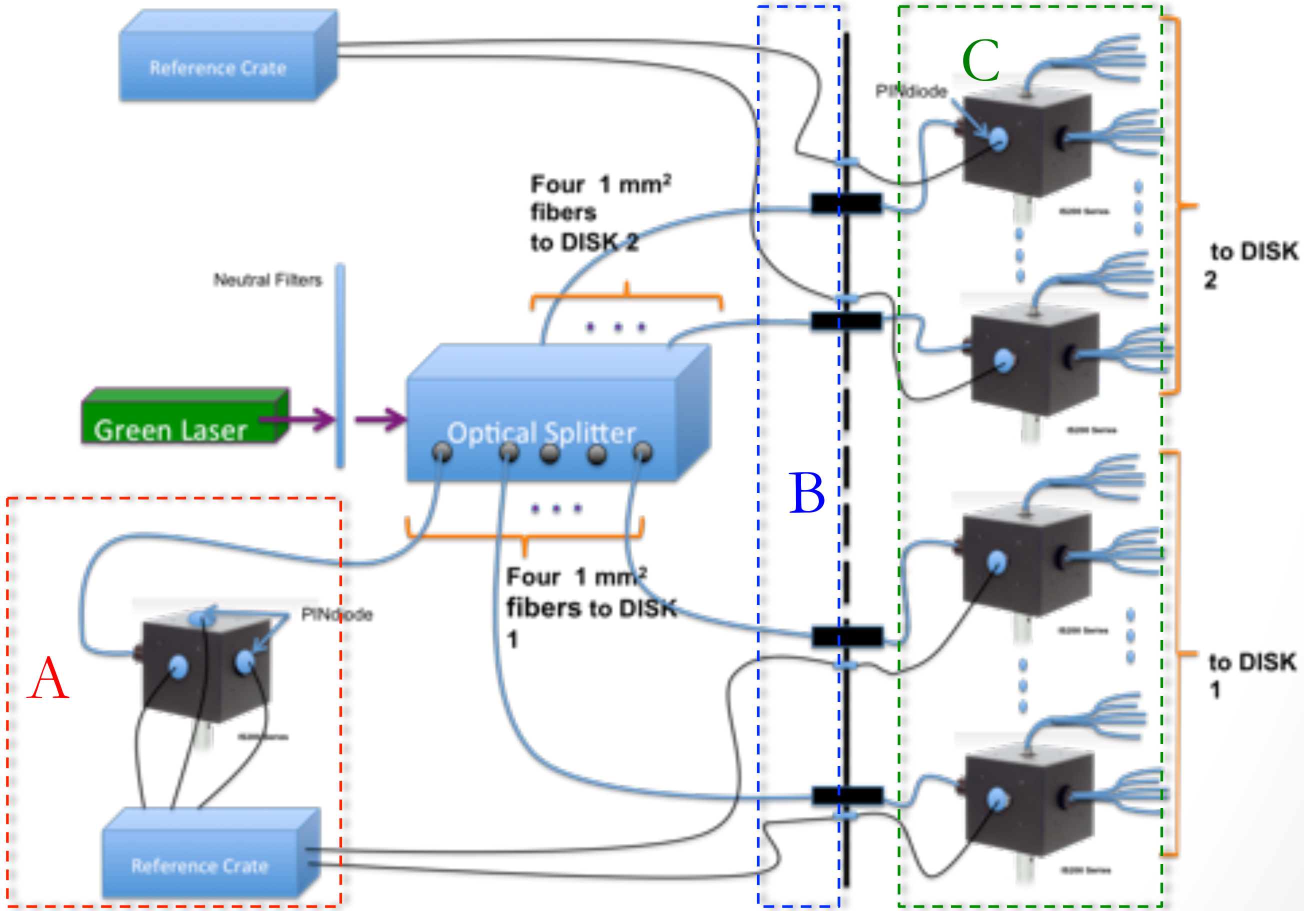
Cost of damage investigation is high because of no recovery/annealing

Laser monitoring system -1-

The Mu2e laser system has the main purpose of:

1) Monitor the MPPC Gain

2) Allow fast debugging of FEE + setting (good experience during the last three test beams)

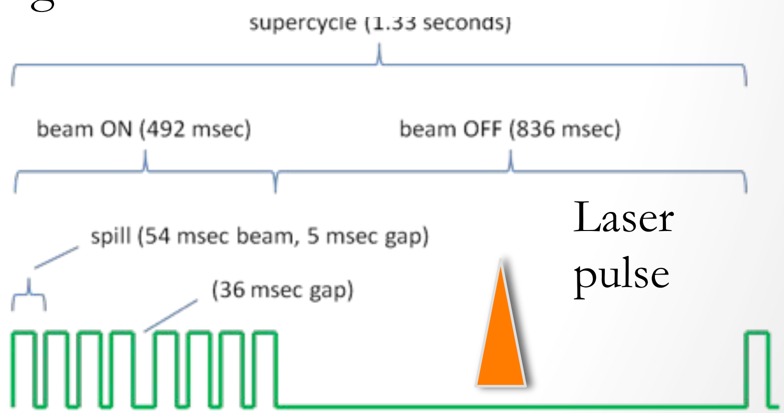


Laser monitoring system -2-

- The laser 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 → A
- 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 → B
- 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 → C
- Laser Trigger will be synchronized with the DAQ Clock signals and delayed into the beam-off region.

Outside the DS

Feed-throughs for 8 optical fibers
8 Pin Diode cables [coaxial]
Total cross section < 10 cm^2



igure 11.1. Mu2e Beam Structure.