Production and quality assurance of Mu2e calorimeter CsI crystals

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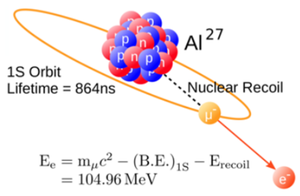
The Mu2e Experiment: a search for $\mu + N \rightarrow e + N$

The **Mu2e Experiment** will search for coherent, neutrinoless conversion of muons into electrons in the field of an Aluminum nucleus.

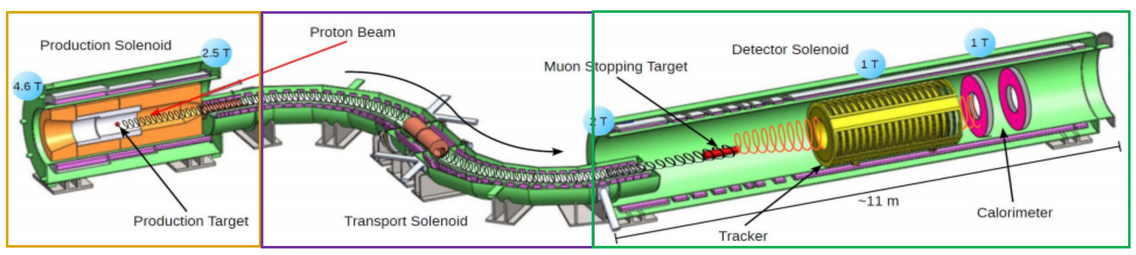


The signature of this process is a single electron with energy slightly below the muon rest mass. If no conversion events are observed in three years of running, Mu2e will set a limit on the ratio between the conversion rate and the capture rate: $R_{\mu e} < 6 \times 10^{-17}$ **(@ 90% C.L.)**, increasing by four order of magnitude the current best limit set by the SINDRUM-II collaboration.

PRODUCTION SOLENOID
- Protons hitting the target and producing mostly π
- Graded magnetic field reflects slow forward π

TRANSPORT SOLENOID
- π decay to μ
- Selection and transportation of low momentum μ^-

DETECTOR SOLENOID
- Capture μ on the Al target
- Momentum measurement in the tracker and energy reconstruction with calorimeter
- CRV to veto cosmic ray events

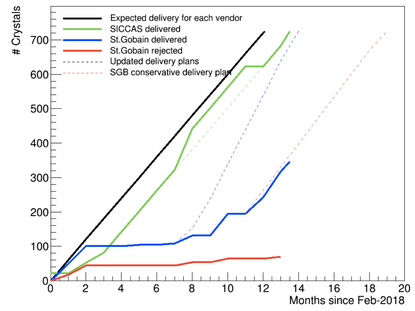


The Mu2e Crystal production

The Mu2e crystal calorimeter is composed of 1348 undoped CsI crystals of 3.4x3.4x20 cm^3. The crystals are arranged in **two disks**, separated by 75 cm, with inner and outer radii of 37.4 cm and 66 cm respectively. After a long pre-production phase, 2 vendors (Saint Gobain and Siccas) were selected.
In order to meet the physics requirements of the calorimeter, several specifications on the crystal have been selected. In case of failing a particular selection, a crystal is sent back to the vendor.

Siccas
- 725/725 crystals received = 100%
- Rejection factor: ~ 4%

St.Gobain getting stabilized
- Expected end of SGB production: **October 2019**

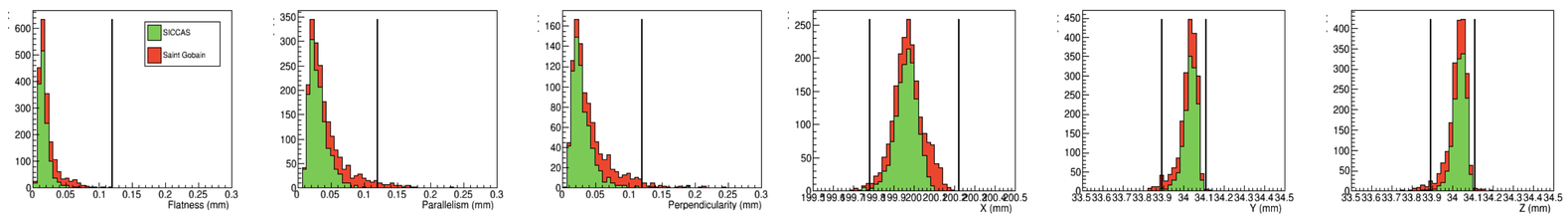


Each month, crystals arrive from the two different vendors. After the mechanical tests, a part of the batch is sent to Caltech group while the remaining batch is tested at SiDet at FNAL. Both group will test:

- **Light Output measurement** (LY >100 p.e./MeV, σ(E)< 19% @ 511 keV, LRU <5%, F/T >75%)
- **Radiation Induced Noise** (RIN < 0.6 MeV for a dose rate of 1.8 rad/h)
- **Irradiation tests** are performed at Caltech at the ^{137}Cs γ-ray Irradiation Facility. (LY higher than 85% (60%) of the initial value after receiving a TID of 10 krad (100 krad);
- Since neutron damages on CsI properties are negligible no characterization test is needed

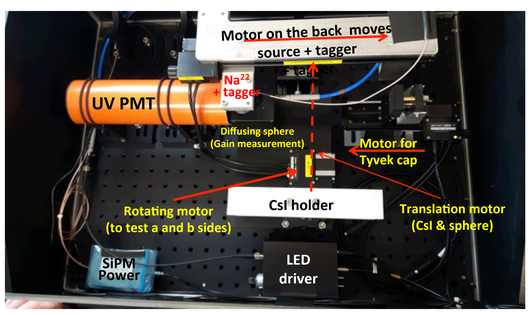
Dimensional measurement

Requirements on the mechanics guarantee the correct staking and alignment of crystals during the assembly and operation phase. With a Coordinate Measurement Machine (CMM) the following requirement are verified:
- preserved mechanical integrity of the crystal (no cracks, chips, fingerprints or bubbles);
- the deviation from a perfect 3-dimensional parallelepiped has to be less than 200 μm;
- the mechanical tolerances for the transversal (longitudinal) dimensions has to be of ± 200 (200) μm.

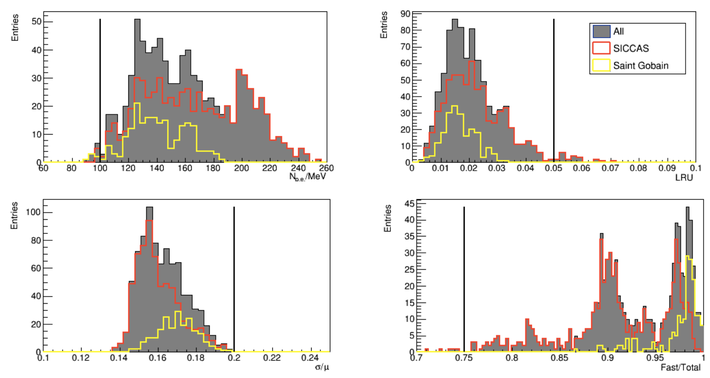


Optical properties measurement

Most relevant optical properties, such as the Light Yield (LY), the Longitudinal Response Uniformity (LRU), energy resolution and Fast/ Total ratio component are measured by an automatized station.



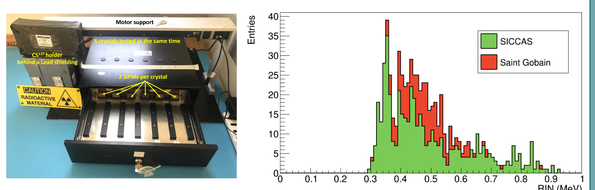
<u>Procedure:</u>
- Wrap the crystal with 150 μm Tyvek
- Insert the crystal in the station;
- Step motor insert a Tyvek on the opposite side of the PMT to grant reflection
- ^{22}Na source moved along the crystal axis with a LYSO crystal (3×3 × 10) mm^3 above it connected to SiPM and used to tag one of the two 511 keV photons coming from annihilation process in ^{22}Na
- Rotate the crystal and repeat the measurement



Radiation Induced Noise measurement

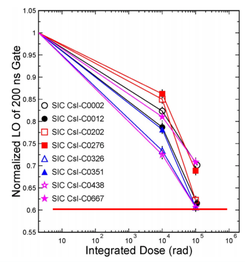
- Six crystals are inserted inside a light tight drawer and each of them is coupled to SiPMs.
- ^{137}Cs source, remotely controlled by a translational stepper motor, stopped at the center of the top face of each crystal for one minute.
- From the acquired current the RIN as evaluated as:

$$\frac{\sqrt{N_{p.e.}}}{LY} = \frac{\sqrt{\frac{I}{G_{SiPM}} \cdot \frac{\Phi_{Mu2e}}{\Phi_{lab}} \cdot 200\ ns}}{LY}$$



Irradiation tests

8 Siccas crystal have been irradiated at the ^{137}Cs γ-ray Irradiation Facility at Caltech. After 10 krad and 100 krad of irradiation the crystals' optical properties was tested.
Their average light output after 10 and 100 krad is 80% and 64%, respectively. All meet the Mu2e CsI Radiation Hardness specification after 100 krad. Their light output after 100 krad is higher than 95 p.e./MeV, indicating a working calorimeter for the entire Mu2e operation.



Conclusions

The Mu2e calorimeter is composed of 1348 CsI crystal arranged in two annular disk. Starting from March 2017 the characterization on the crystals has started. After a visual inspection and the mechanical test performed with a CMM, the optical properties and the irradiation damages are measured at the same time in Caltech and Fermilab. All the crystals from Siccas have already been tested while the expected end of Saint Gobain production is October 2019. The crystals from both vendor show excellent performance in agreement with the experiment specifications.

This work was supported by the US Department of Energy; the Italian Istituto Nazionale di Fisica Nucleare; the US National Science Foundation; the Ministry of Education and Science of the Russian Federation; the Thousand Talents Plan of China; the Helmholtz Association of Germany; and the EU Horizon 2020 Research and Innovation Program under the Marie Sklodowska-Curie Grant Agreement No.690385. Fermilab is operated by Fermi Research Alliance, LLC under Contract No. De-AC02-07CH11359 with the US Department of Energy.

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