High LY crystals: a possible use for the Mu2e normalization

Ivano Sarra, Stefano Miscetti, R. Donghia

Laboratori Nazionali di Frascati

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The Mu2e normalization

- As muons are captured in excited energy levels of aluminum atoms they promptly cascade down to the 1s state emitting characteristic X-rays. Captured muons also produce excited nuclei which emit γ-rays with known energies and intensities.

For an aluminum target we will have the following signal photons:

- Prompt **347 keV X-ray** from the 2p-1s transition, **emitted promptly**, O(ps), after the muon stops, **with a rate of 79.7% of stopped muons**.
- Semi-prompt **1809 keV γ-ray** from the reaction 27Al(μ–, νnγ)26Mg with intensity **51 ± 5% of muon nuclear captures**. **Has the same lifetime as muonic aluminum (864 ns).**
- Delayed **844 keV γ-ray**, from the decay of activated 27Mg → 27Al, with intensity 13%(27Mg production) × 72%(27Mg beta decay) = **9.3% of muon captures**. **Has half-life 820 seconds (9.5 minutes).**

The Mu2e normalization

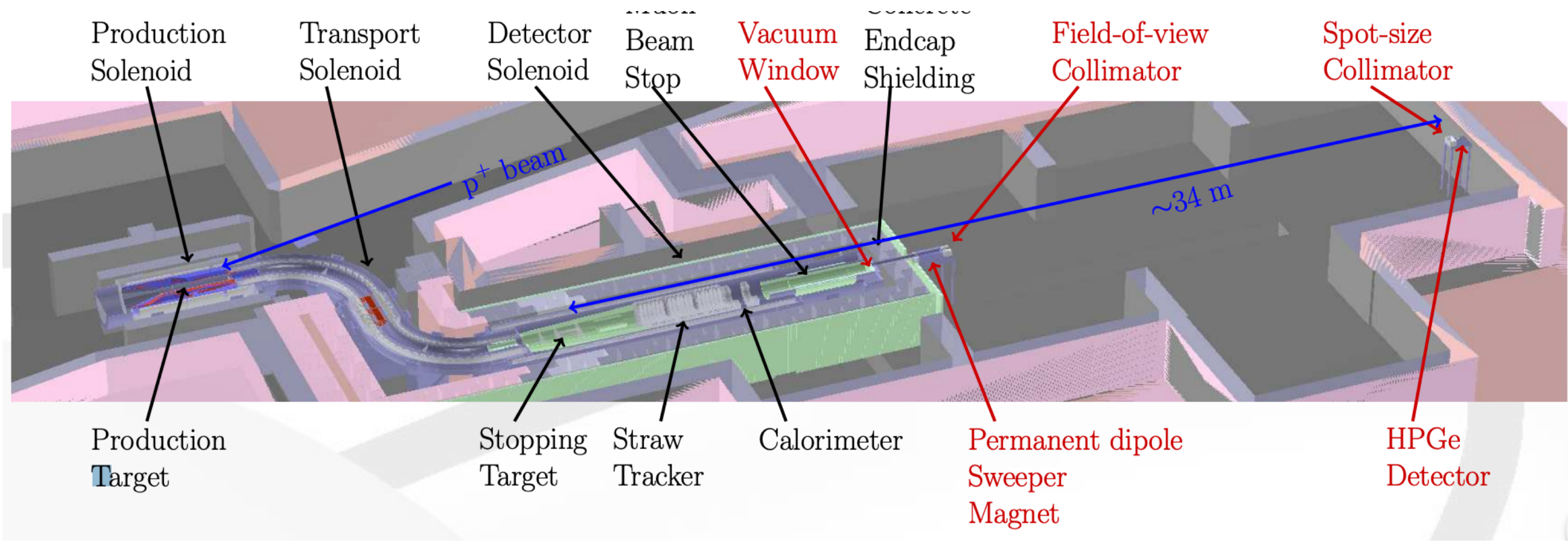
- In the Mu2e experiment, the **Stopping Target Monitor**, will measure these X- and γ-rays using a **high-purity germanium detector** to measure the normalization for Mu2e: Γcapture(*μ*Al).

- The Stopping-Target Monitor of the Mu2e Experiment intends to provide a **10%** measurement of the rate of muon stops in the target.

- ***To overcome the extremely high background rates and avoid severe radiation damage*** the detector is placed far downstream of the Muon Stopping Target, and employ a dipole magnet to sweep away charged particles, a series of collimators to ensure the detector only views the Muon Stopping Target, and shielding to mitigate effects from background radiation.

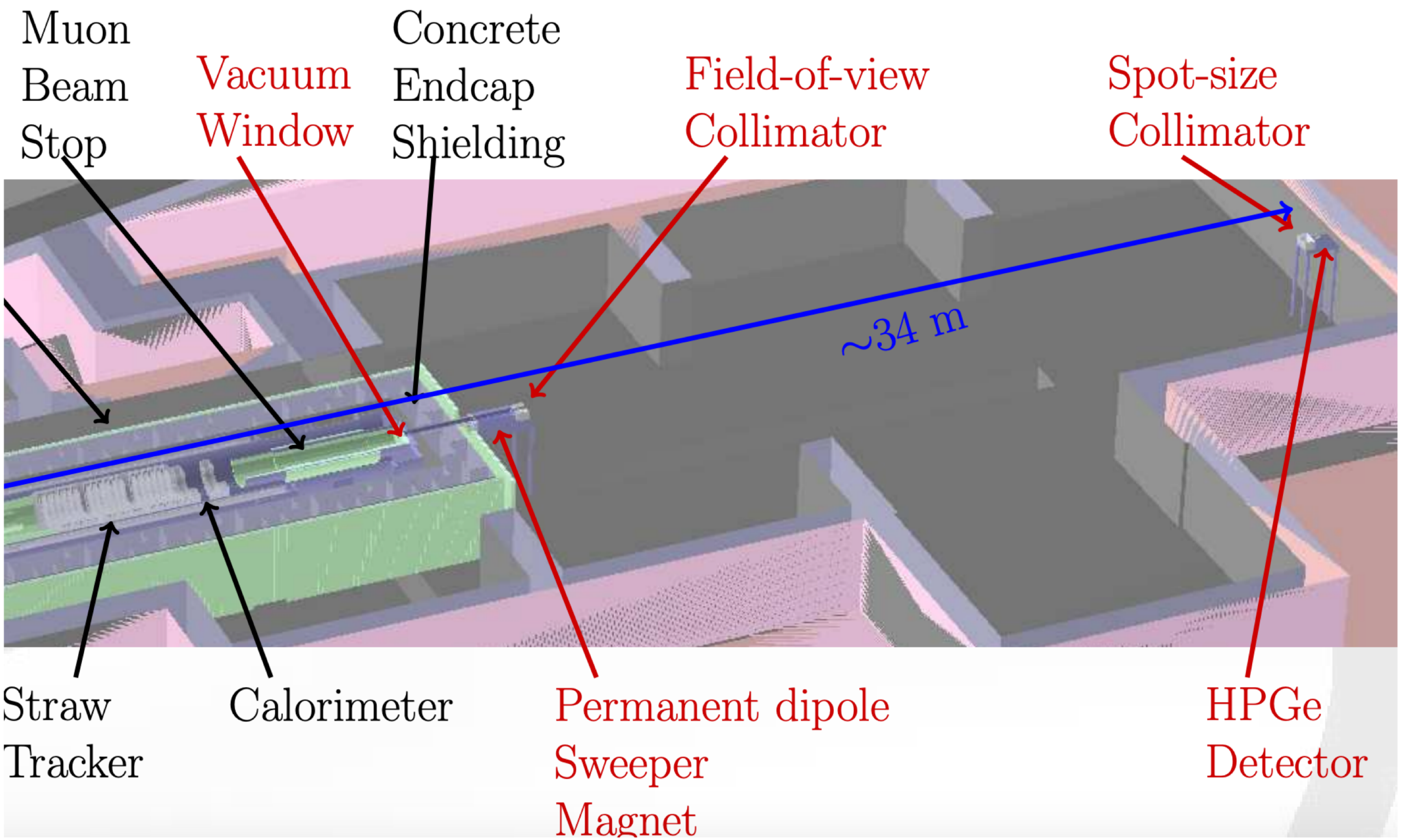
The Mu2e normalization

A sketch the layout:



The Mu2e normalization

A sketch the layout (zoom):



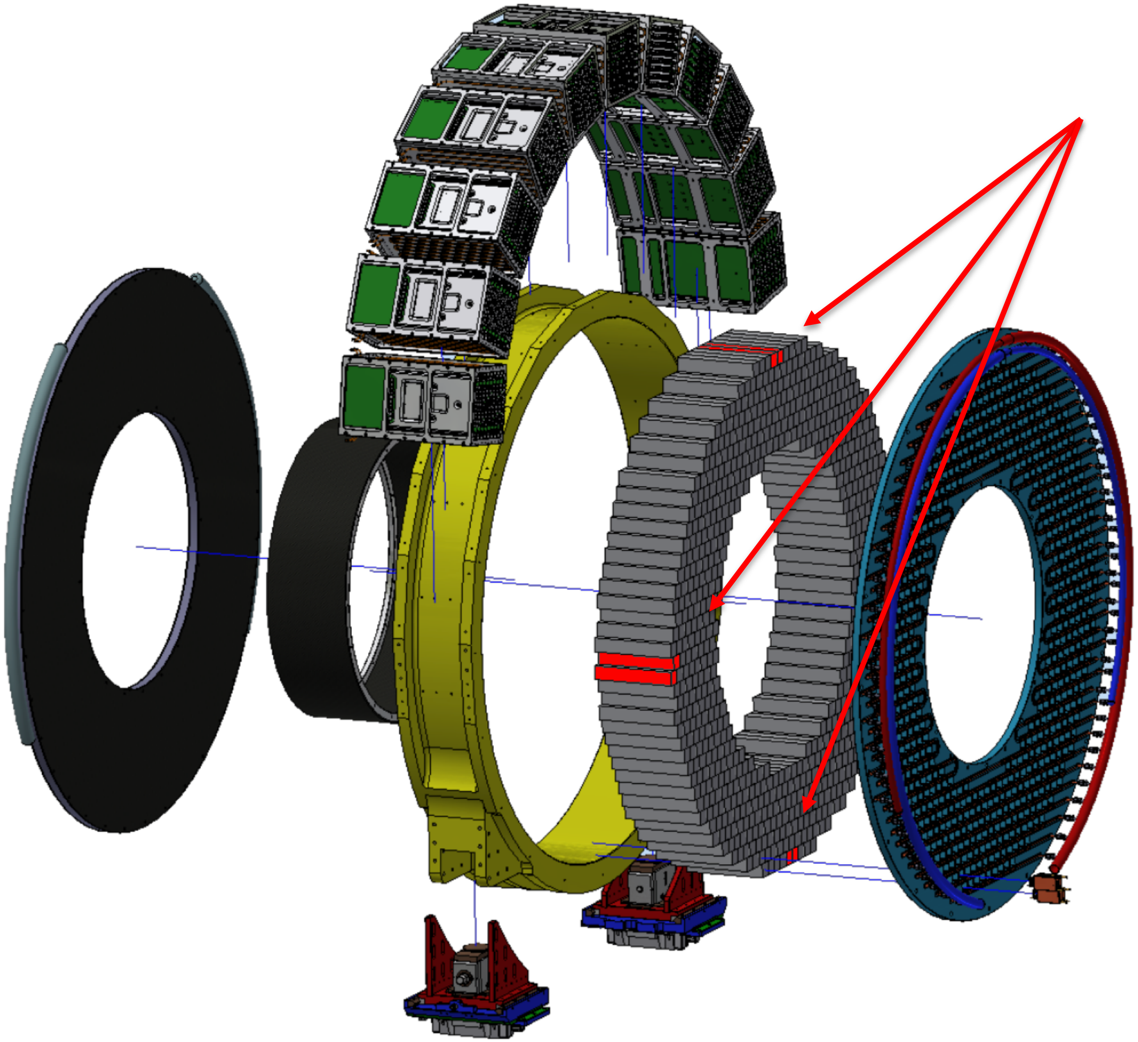
The Calorimeter

- Can the Calorimeter perform a parallel measurement of the rate of muon stops in the target?

The idea:

- We can use high LY crystals (i.e. $LaBr_3$) coupled with our costum MPPCs to measure the X- and γ-rays from the muons stopped in the target.

The Calorimeter



Idea:

- Some high LY crystals (i.e. LaBr3) in the external positions
- Standard MPPCs-FEE-FADC readout

LYSO+MPPCs

A possible solution:

- We have many LYSO crystals → we tried to use them with the Na22 source to measure the response at 511 keV

- We tried the same measurement with a LaBr3 sample from Saint Gobain

↓

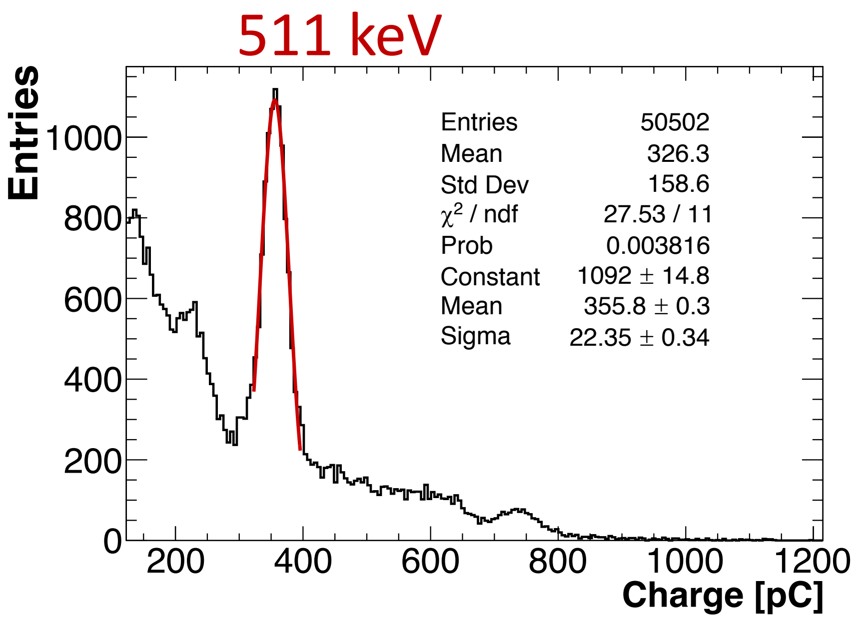
Results are the topics of this talk

Setup with Lyso

- We tested one LYSO crystal from SICCAS with dimension 30x30x130 mm^3, wrapped with ESR super reflective by 3M.

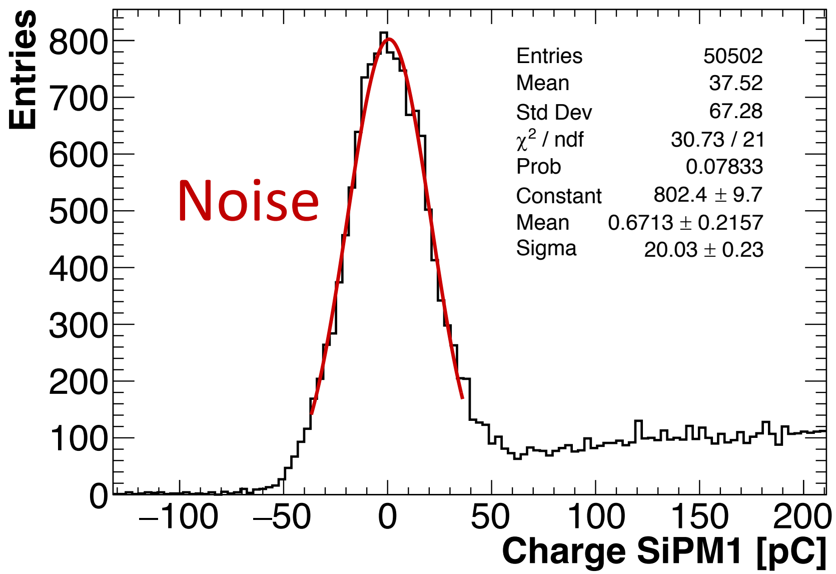
- Readout: 2 Mu2e custom MPPC plugged in the final holder with the final FEEs (NO optical grease).

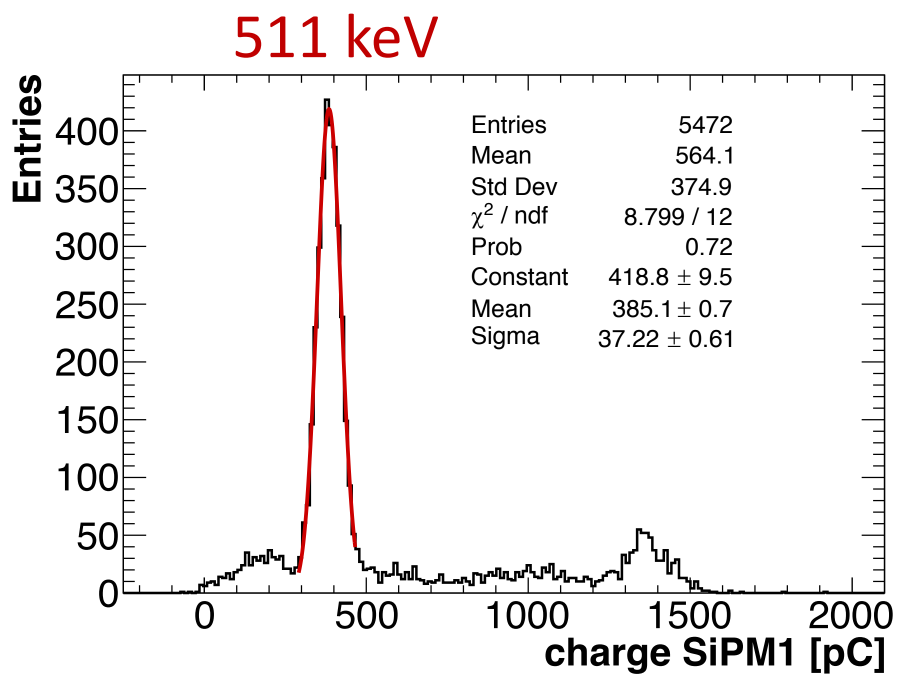
- Tagger for the Na22 source made with a 3x3x20 mm^3 LYSO crystal readout with a 3x3 mm^2 standard MPPC.



Results with LYSO

- Applied cuts around the 511 keV peak of the tagger and the coincidence time between the two MPPCs signals and the tagger itself.

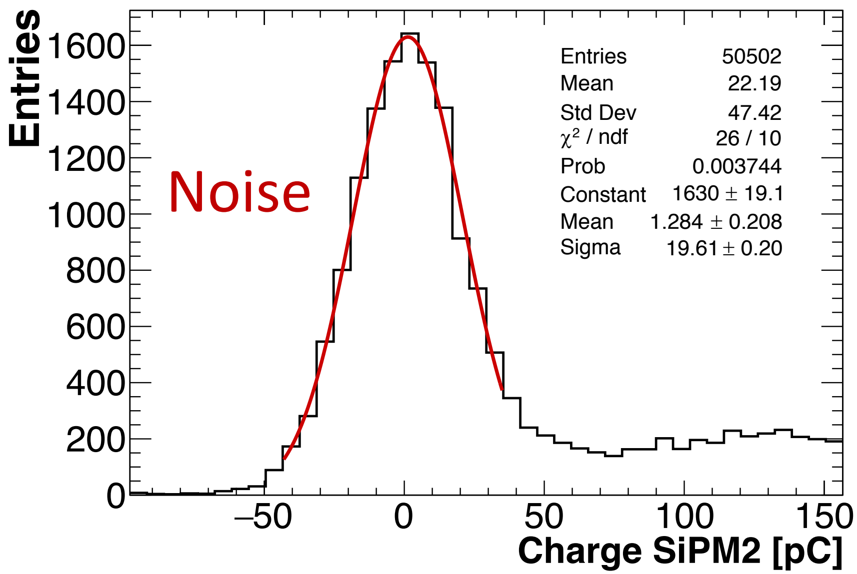


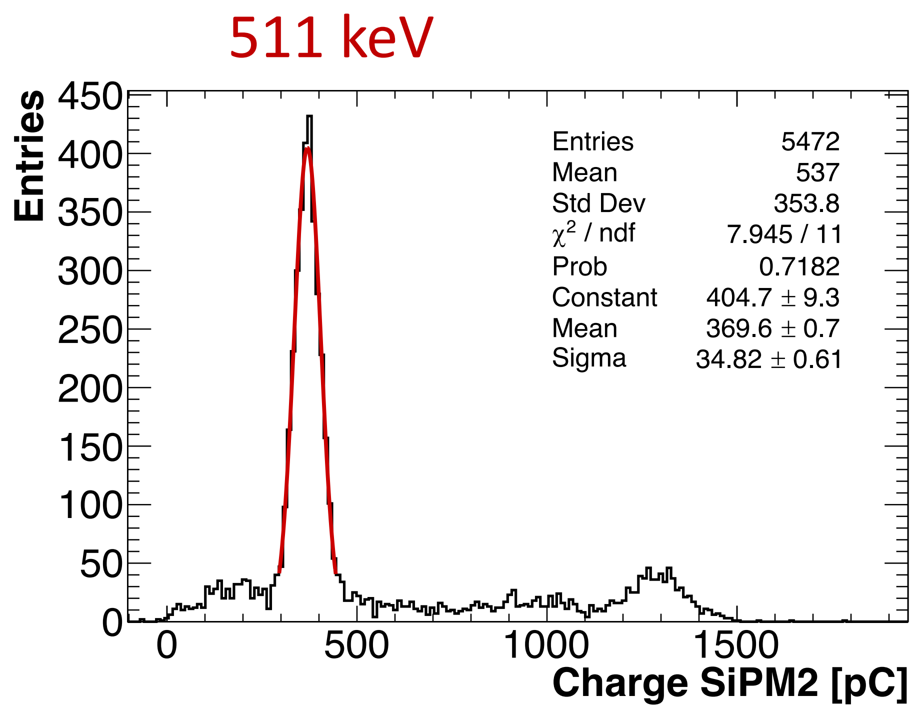


- **Npe = 354 (@511 keV),** $G_{SiPM}(Vop) = 1.7E6$, $G_{amp} = 4$
- **Res = 8.1%,** noise subtracted

Results with LYSO

- Applied cuts around the 511 keV peak of the tagger and the coincidence time between the two MPPCs signals and the tagger itself.

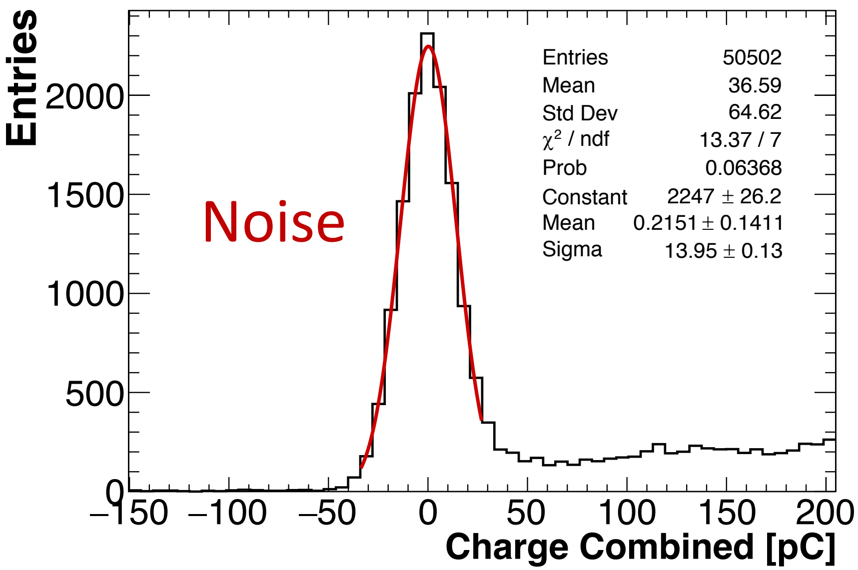




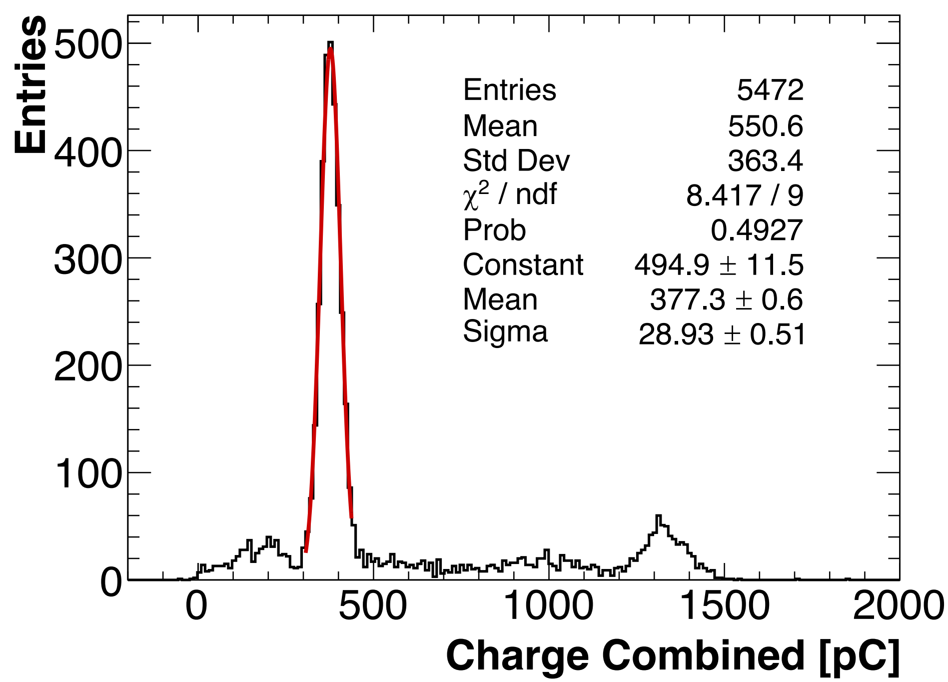
- **Npe = 340 (@511 keV),** $G_{SiPM}(Vop) = 1.7E6$, $G_{amp} = 4$
- **Res = 7.8%,** noise subtracted

Results with LYSO

- Combination of the two MPPCs ($\frac{SiPM1+SiPM2}{2}$)



511 keV



- **Res = 6.7%,** noise subtracted

Setup with LaBr3

- We tested one 38 mm diameter by 38 mm long LaBr3 crystal from St. Gobain, wrapped/painted (I am not sure), in the aluminum box and with a transparent optical window for the coupling with the SiPMs.

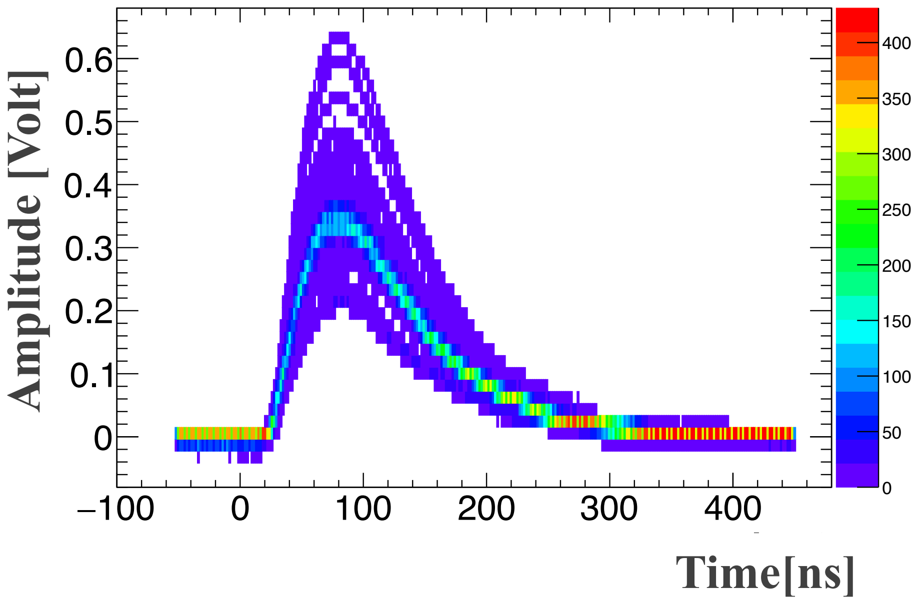
- Readout: 2 Mu2e custom MPPC plugged the final holder and the test beam electronics (**Test has been done in Sidet - NO optical grease**).

- Tagger for the Na22 source made with a 3x3x20 mm^3 LYSO crystal readout with a 3x3 mm^2 standard MPPC.

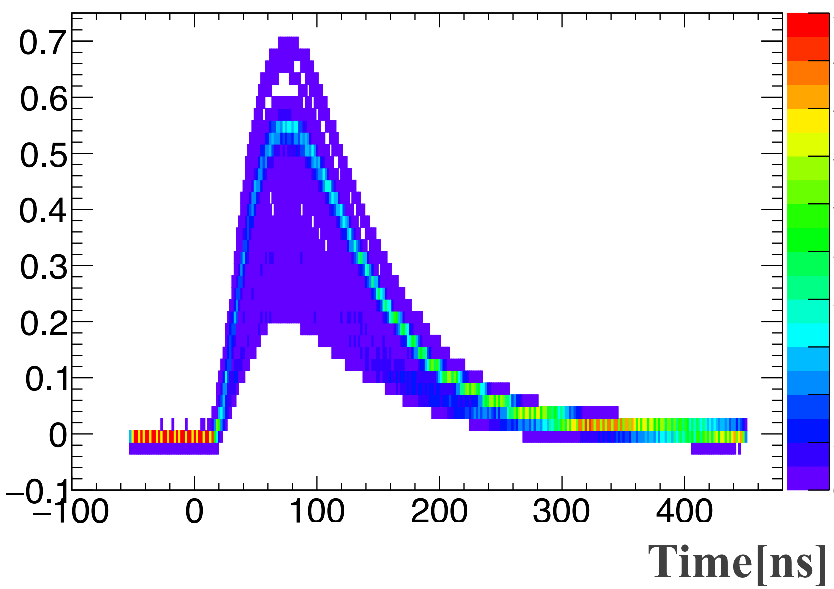
Results with LaBr3

- Problem with the cabling due to the shape of the crystal.. One SiPM has readout ~ a factor 2 more the light compared to the other one.

Waveform SiPM1



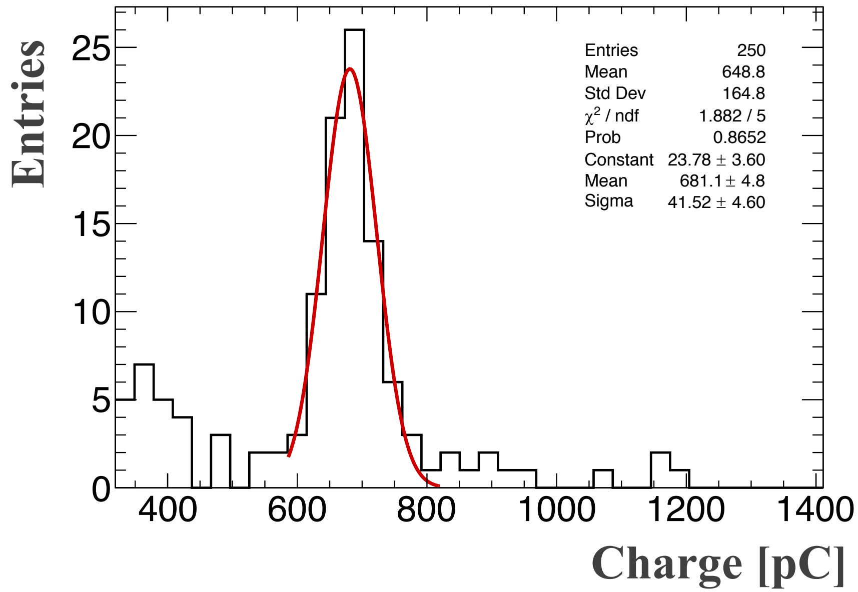
Waveform SiPM2



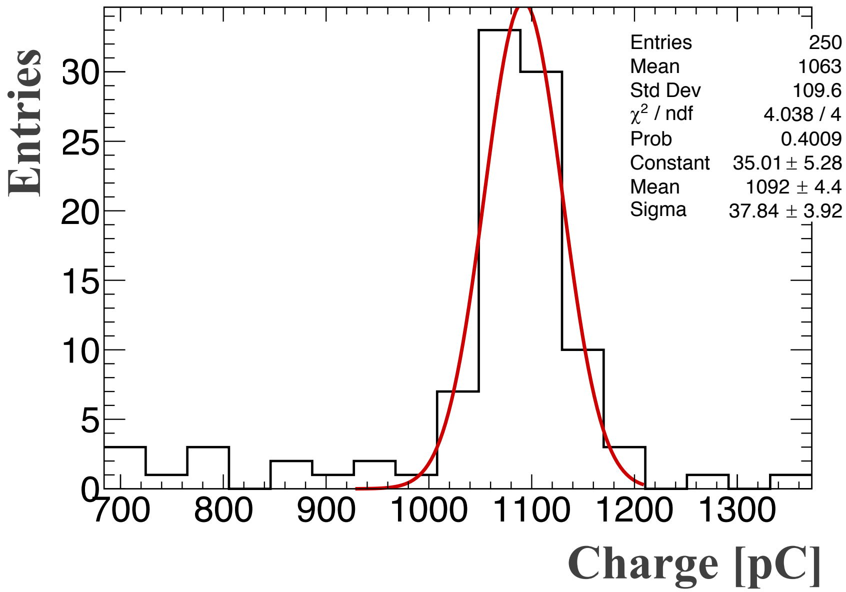
Results with LaBr3

- Applied cuts around the 511 keV peak of the tagger and the coincidence time between the two MPPCs signals and the tagger itself.

511 keV – SiPM1



511 keV – SiPM2



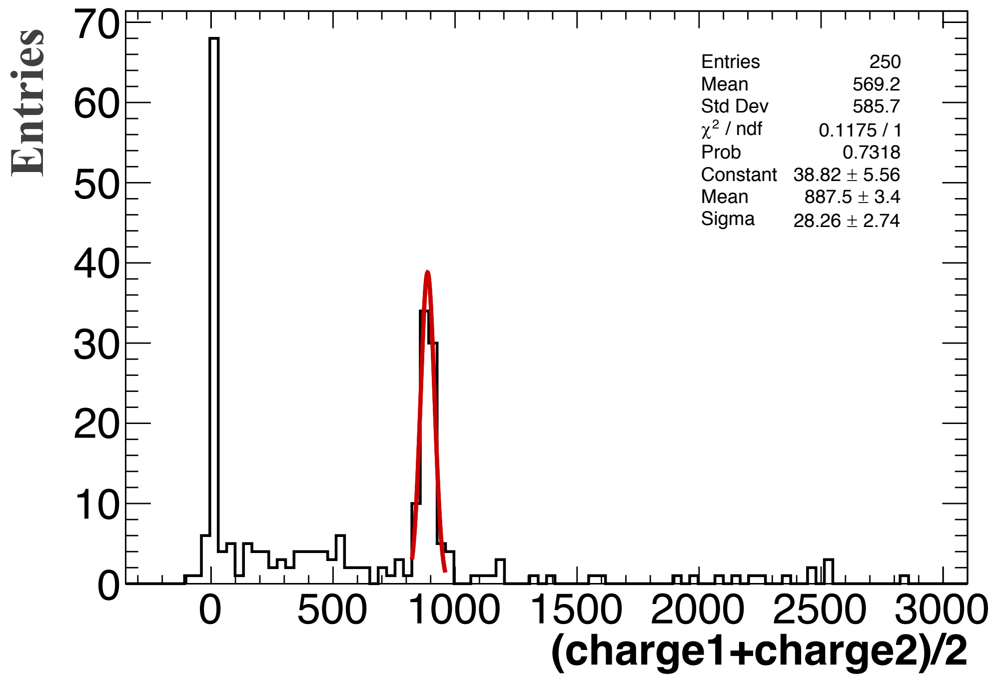
- **Npe = 626 (@511 keV),** $G_{SiPM}(Vop) = 1.7E6$, $G_{amp} = 4$
- **Res = 6%,** NOT noise subtracted

- **Npe = 1003 (@511 keV),** $G_{SiPM}(Vop) = 1.7E6$, $G_{amp} = 4$
- **Res = 3.5%,** NOT noise subtracted

Results with LaBr3

- Combination of the two MPPCs ($\frac{\text{SiPM1+SiPM2}}{2}$)

- **Res = 3.2% @ 511 keV,** NOT noise subtracted



LaBr3 Test: Consideration

- The setup has been arranged in few days at SiDET
- A LeCroy scope has been used for the acquisition :
  → very slow;
  → statistics must be increased for better studies.
- The procurement of a larger size LaBr3 crystal must be seriously taken into account.
- My suggestion is a > 10 cm long crystal to try a more realistic configuration.

Conclusions

- **LaBr3/LYSO** + MPPCs + FEE can easily identify X- and γ-rays from the muons stopped in the target;
- The Energy Resolution is good:
  → an improvement has been archivied using the LaBr3 (more than a factor 2, 63000 vs 27000) of photons produced compared to the LYSO)
  → 3.2% @ 511 keV with our SiPMs is a great result!
- Acceptance in the experiment must be evaluated with MC;
- Bkg is low for the external crystals: low contamination and the possibility to measure the **1809 keV γ-ray** from the reaction 27Al(μ–, νnγ)26Mg in the Mu2e acquisition window.

SPARES

Spares

- Bkg is low for the external crystals: low contamination and the possibility to measure the **1809 keV γ-ray** from the reaction 27Al(μ−, νnγ)26Mg in the Mu2e acquisition window

  → **We are far away from the LYSO self emission endpoint (1 MeV).**

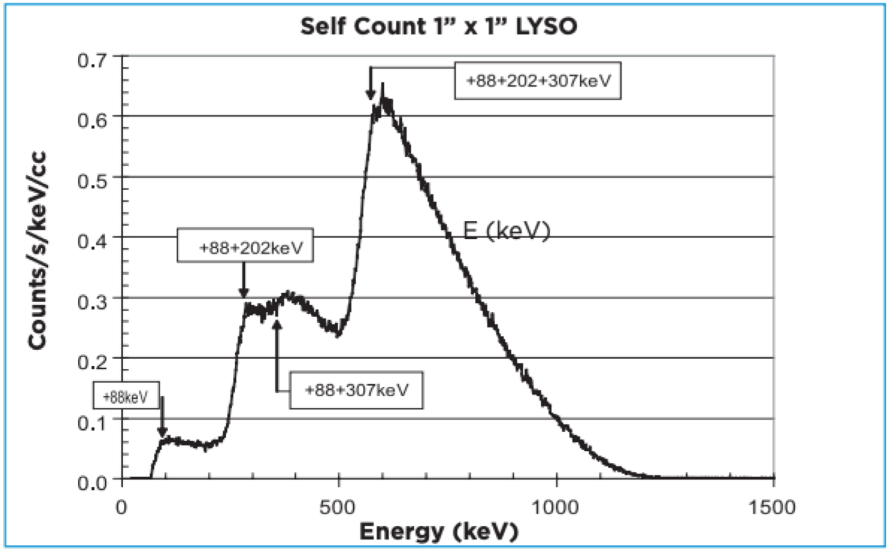


Figure 3. LYSO is a Lutetium-based scintillator which contains a naturally occurring radioactive isotope 176Lu, a beta emitter. The decay results in a 3 gamma ray cascade of 307, 202 and 88 keV, where self-absorption of these photons results in the above spectra in a 1"x1" cube. Total rate for this activity is 39 cps/g.