A Calorimeter Alternative for Mu2e-II

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Calorimeter Requirements

Requirements (see Luca’s talk):

Crystals:

- Hardness to dose
- Moderate light yield for energy and timing resolution

Photosensors:

- Fast
- Good QE
- High radiation hardness to neutrons

Conversations With Myself -1-

Requirements (see Luca's talk):
Crystals:
- Hardness to dose
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Photosensors:
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- Good QE
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Are these two points compatible?

Mu2e experiences:
CsI LY 4%(NaI), SiPM 30% PDE(@310 nm, 50 μm pixel size)
1) LY~30 p.e./MeV
2) Cooling -10 ^{o}C
3) 10^{12} neutrons/cm^2 total → ~ 1MeV threshold

Conversations With Myself -2-

Requirements (see Luca's talk):
Crystals:

- Hardness to dose
- Moderate light yield for energy and timing resolution

Photosensors:

- Fast
- Good QE
- High radiation hardness

Are this two points compatible?
4) 10^{13} neutrons/cm^2 total -> SiPM 50um pixel @ -30/-40 °C ???
We must demonstrate that >15 μm pixel size work at 10^{13} neutrons/cm^2

We have to test as well FBK SiPMs
(Mu2e experiences: the FBK SiPMs radiation hardness is lower than Hamamatsu SiPMs)

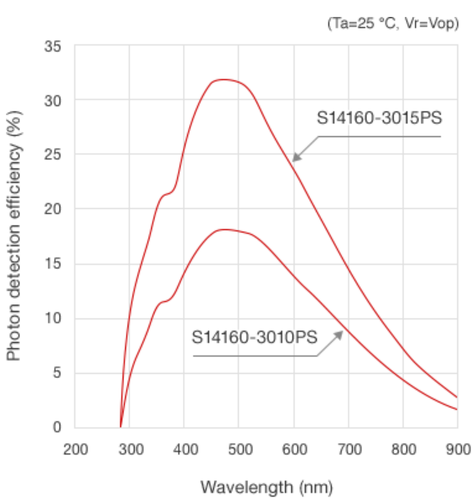
What we are doing for Muon Collider

Crilin: Fast and Rad. Hard. Semi-homogeneous calorimeter

https://iopscience.iop.org/article/10.1088/1748-0221/17/09/P09033
https://iopscience.iop.org/article/10.1088/1748-0221/17/05/T05015

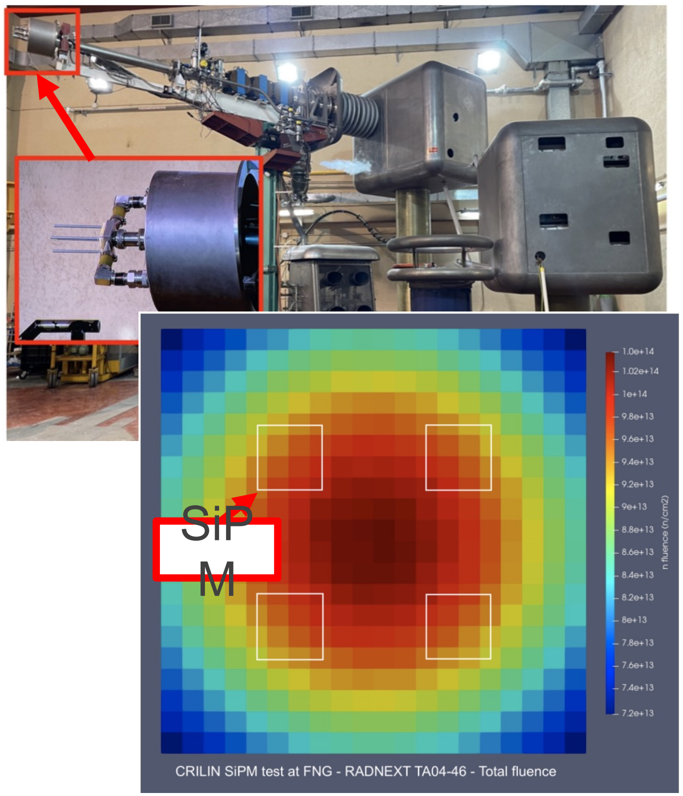
What can be translated to Mu2e-II?
- Photosensors
- Electronics

Crucial point is the radiation hardness. We tested SiPM of 10 and 15 um

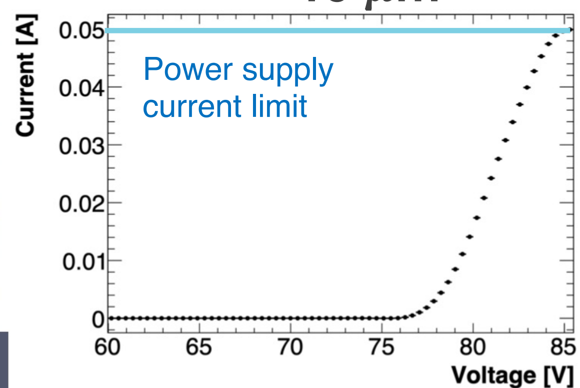


SiPMs Characterisation

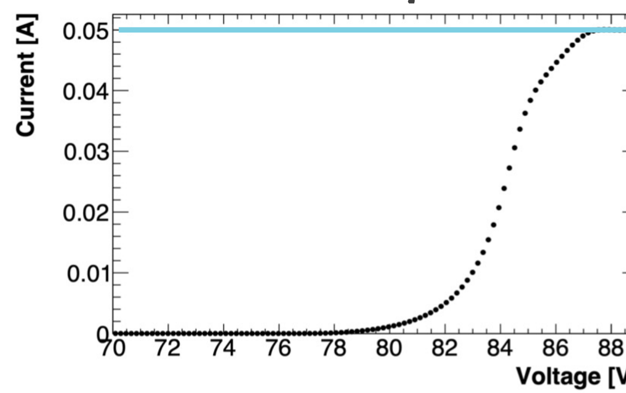
Neutrons irradiation: 14 MeV neutrons with a total fluence of 10^{14} n/cm^2 for 80 hours on a series of two SiPMs (10 and 15 μm)

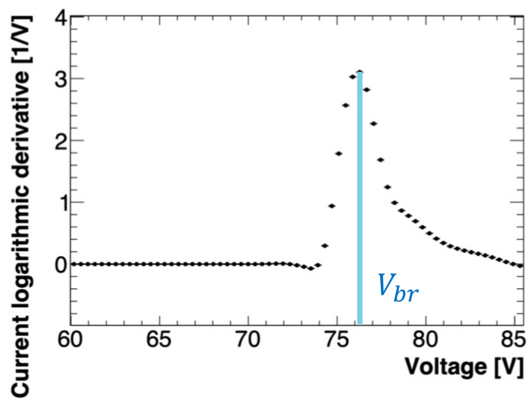


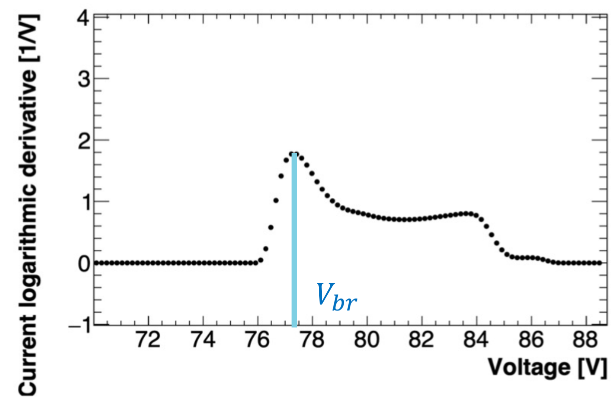
15 μm



10 μm



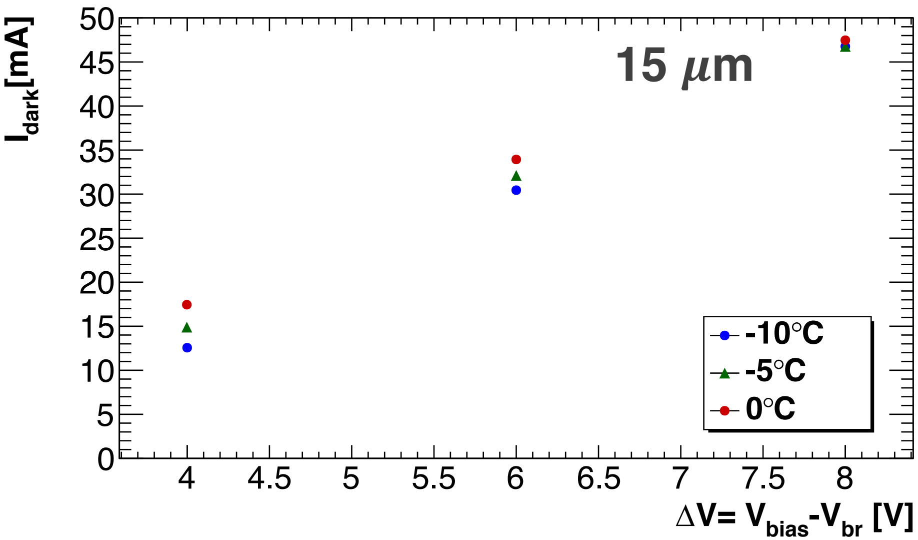


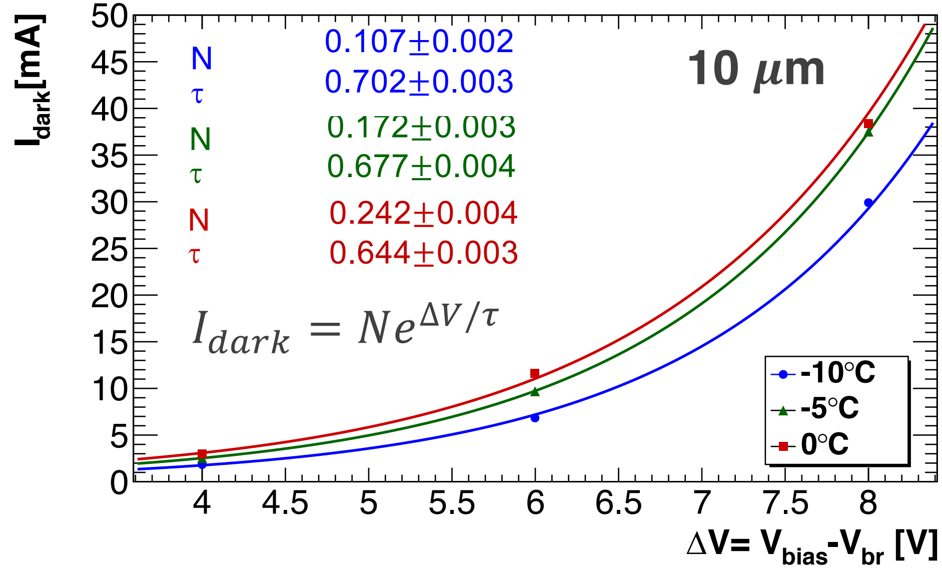


SiPMs Characterisation-2

Extrapolated from I-V curves at 3 different temperatures:

- Currents at different operational voltages.
- Breakdown voltages;





For the expected radiation level, **the best SiPMs choice is the 10 μm one** for its minor dark current contribution.

SiPMs Characterisation-3

15 μm

Temperature [°C]	V_{br} [V]	$I(V_{br}+4V)$ [mA]	$I(V_{br}+6V)$ [mA]	$I(V_{br}+8V)$ [mA]
-10 ± 1	75.29 ± 0.01	12.56 ± 0.01	30.45 ± 0.01	46.76 ± 0.01
-5 ± 1	75.81 ± 0.01	14.89 ± 0.01	32.12 ± 0.01	46.77 ± 0.01
0 ± 1	76.27 ± 0.01	17.38 ± 0.01	33.93 ± 0.01	47.47 ± 0.01

10 μm

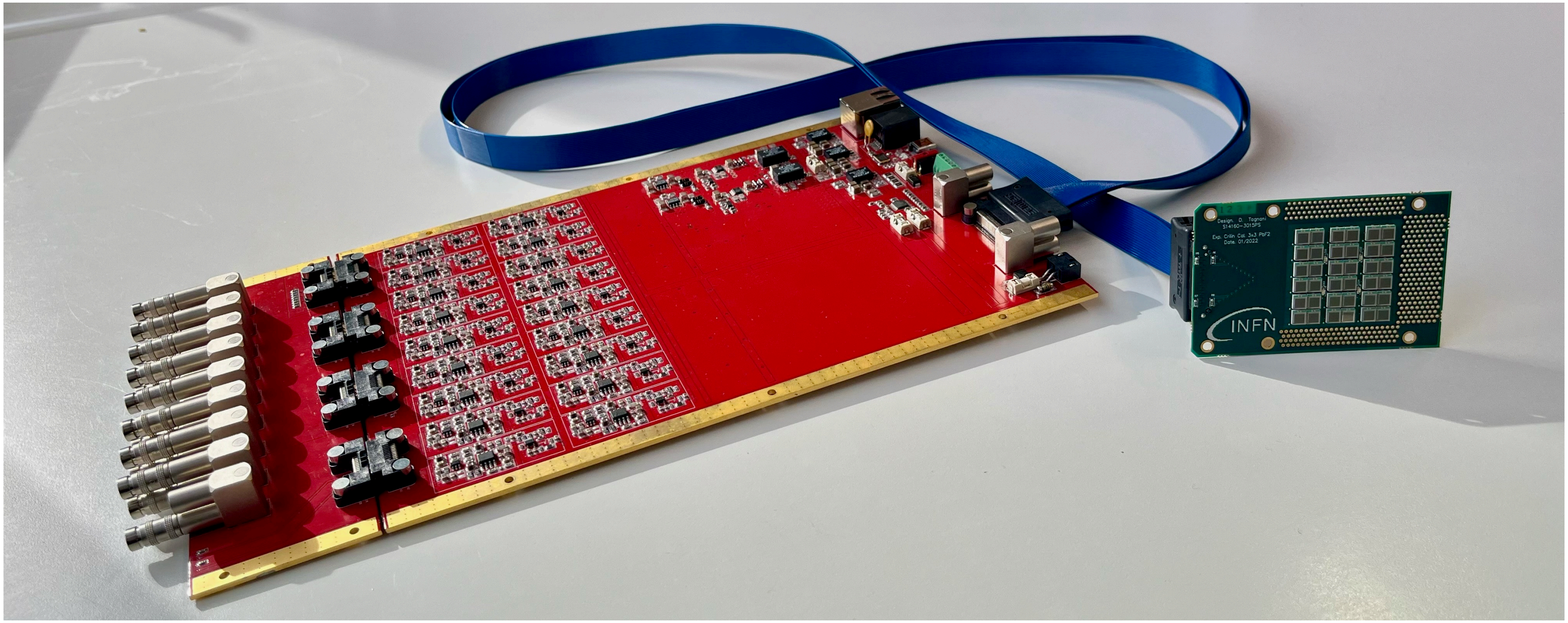
Temperature [°C]	V_{br} [V]	$I(V_{br}+4V)$ [mA]	$I(V_{br}+6V)$ [mA]	$I(V_{br}+8V)$ [mA]
-10 ± 1	76.76 ± 0.01	1.84 ± 0.01	6.82 ± 0.01	29.91 ± 0.01
-5 ± 1	77.23 ± 0.01	2.53 ± 0.01	9.66 ± 0.01	37.51 ± 0.01
0 ± 1	77.49 ± 0.01	2.99 ± 0.01	11.59 ± 0.01	38.48 ± 0.01

At 10^{13} n_{1MeV}/cm^2:

- 10 μm pixel size OK, with Mu2e calorimeter cooling system
- 15 μm pixel size OK, probably with the Mu2e calorimeter cooling system → specific tests should be done

Electronics

- SiPMs are connected via 50-ohm micro-coaxial transmission lines to a microprocessor-controlled Mezzanine Board which provides signal amplification and shaping, along with all slow control
  1 ch → 2 micro-coax cables



Alternative Solution

- Is a signal waveform of 200 ns total width acceptable?

NOT: consider this talk over and these slides as a list of problems to be solved

YES: next slide

Short LYSO crystal calorimetER - SLYER -

- An alternative proposal is a compromise between Mu2e actual calorimeter and Crilin.

- What would remain of the Mu2e cal.:
  1) Calibration Source
  2) Laser
  3) Cooling
  4) All the Mechanics

- What would change:
  1) pure CsI 34x34x200 mm^3 → LYSO 34x34x80 mm^3
  2) 50 um SiPMs → 10 um SiPMs
  3) FEEs + cabling → only 2 cables per SiPM

SLYER - Advantages

- 8 cm length LYSO are enough to achieved O(5%) energy resolution
- Not problem of ENE and good LRU
- Great timing resolution still after 10^{13} neutrons/cm^2
- SiPMs already exist **NOT R&D needed**
- High LY → SiPM @ low over voltage → enhanced resistance → lower power dissipation
- Not Front End Amplifier is needed → not problems with irradiation level

SLYER – Disadvantages (maybe)

- LYSO ~30$/cc vs ~10$/cc BaF2
  (17$/cc vs **10$/cc for equal X0)**

SLYER proposal:
Total cost of the LYSO crystals for the 2 disks = 3.8M$
(Mu2e: 20 cm CsI + FEE = 1.7M$ + 0.2M$)
(14 cm BaF2 + FEE = 2.2M$ + 0.2M$)

- *Emission time of 40 ns of LYSO vs <1 ns of BaF2*

Per i referee -1-

La mia idea è testare singoli componenti e poi vedere se realizzare un prototipo l'anno prossimo (richieste 2025).

Per il 2024:

- 2 Lyso 34x34x80 mm3 ~ 8 keuro (4k LNF + 4k Pisa)

Lettura con 4 SiPM 6x6 mm^2 da 10 um pixel per cristallo in serie da 2. Non esistono da catalogo (per ora) dovremmo arrangiare un PCB con 16 SiPM da 3x3 mm^2

- 16 x4 SiPM 3x3 mm2 (10 um pixel size) ~ 2 keuro (1k LNF + 1k Pisa)
- 4 PCB con SiPM on board ed amplificatori alla Crilin ~ 3.5 keuro (LNF)

Abbiamo già progettato e realizzato per Next-100 singoli amplificatori alla Crilin (TTA_22LNF_135).

Sunto richieste: 8.5 keuro a LNF e 5 keuro a Pisa.

Per i referee -2-

Cose da fare per dimostrare la fattibilità dell'idea:

- Simulazione → Stefano D. et al → bisogna capire se 200 ns di segnale sono accettabili per Mu2e-II
- MIP → valutare il LY e la linearità
- Test beam a singolo canale @ BTF
- RIN
- Neutroni/Dose con Cristallo + SiPMs per valutare il noise aggiuntivo

Parecchio lavoro da fare… ma fattibile a partire da marzo 2024 (assemblaggio finito, parte di fte LNF più liberi, forte sinergia con Crilin [abbiamo vinto il PRIN e non spariremo])

Fare R&D è importante per tenere vivo il gruppo (soprattutto i giovani).

Per il 2025 poi possiamo pensare ad un piano più ambizioso ed a un vero prototipo.