A proposal for a different technology choice for the Mu2e-II Calorimeter

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- L3 Mu2e Calorimeter – Assembly and Installation
- Convener Mu2e-2 Calorimeter system

Riunione Preliminare con INFN CSN1 referee

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Thoughts on Mu2e-II calo requirements - 1

Requirements (see Luca and SDF's talks):

Crystals:

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

Photosensors:

- Fast
- Good QE
- High radiation hardness

Are these two points compatible?

Short summary from Mu2e experience and Tech choices:

- pure CsI LY 4%(NaI),
- Ham UV-extended SiPMs 30% PDE(@310 nm, 50 μm pixel size)
    - LY~30 p.e./MeV (10% LY drop at 100 krad)
    - Cooling needs to reduce noise, -10 °C on SiPMs
    - 10^{12} neutrons/cm^2 total → ~ 1MeV noise level/crystal

Thoughts on Mu2e-II calo requirements - 2

Requirements (see Luca and SDF's talks):

Crystals:

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

Photosensors:

- Fast
- Good QE
- High radiation hardness

Are these two points compatible?

- ❑ In Mu2e-2, we expect x10 increase in n-flux up to 10^{13} n/cm^2 total

→ SiPM 50um pixel @ -30/-40 ^{o}C ???

→ *We must demonstrate that* ***Ham SiPMs with >15 μm pixel size can work at 10^{13} neutrons/cm^2***

→ ***We have to test as well FBK SiPMs*** (from Mu2e R&D: the FBK SiPMs radiation hardness is lower than Hamamatsu SiPMs)

What we are doing for Muon Collider

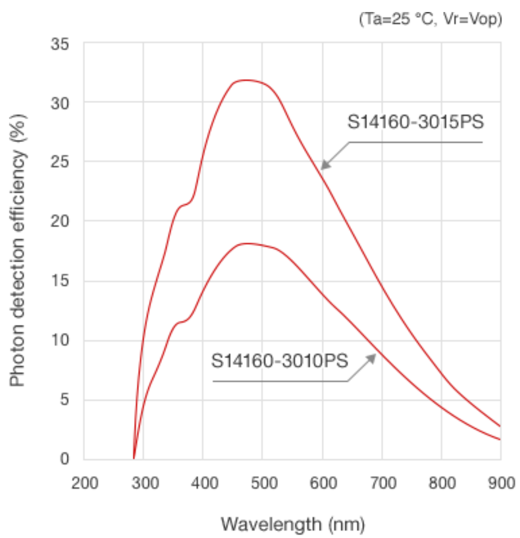
Crilin: Fast and Rad. Hard. Semi-homogeneous calorimeter

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

CRILIN
CRYSTAL CALORIMETER WITH LONGITUDINAL INFORMATION

What can be used/proposed also to Mu2e-II?
- Photosensors
- Electronics

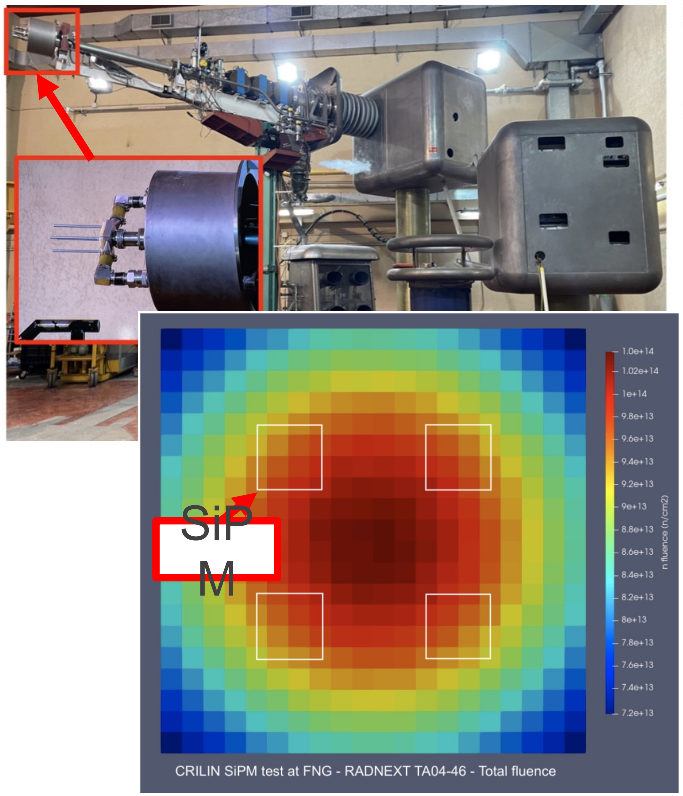
Crucial point is the radiation hardness. We tested SiPM of 10 and 15 um



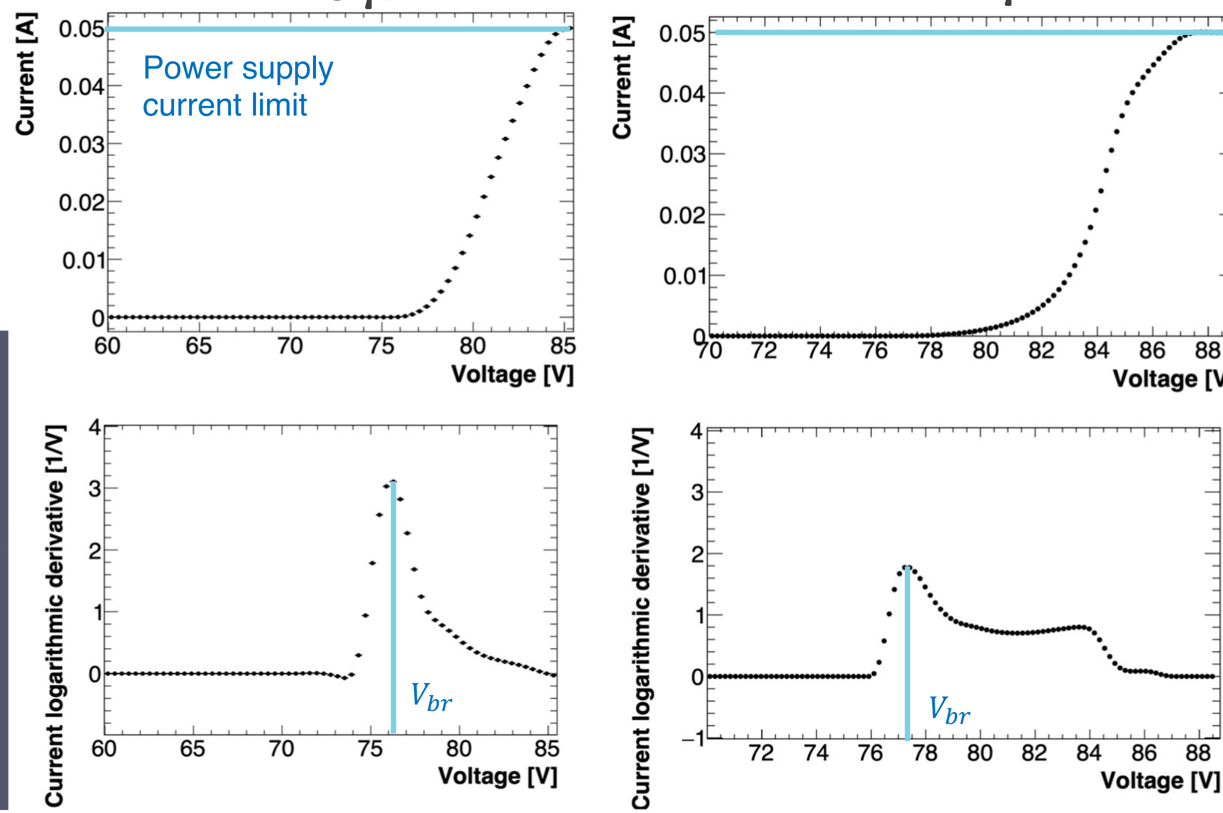
Crilin Picture/CAD ???

SiPMs Characterisation done: neutrons-1

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)



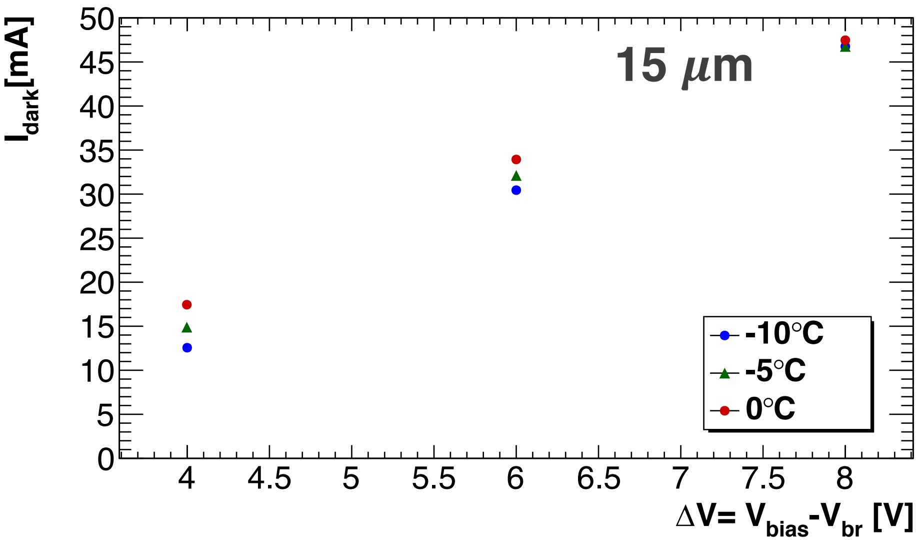
15 μm **10 μm**

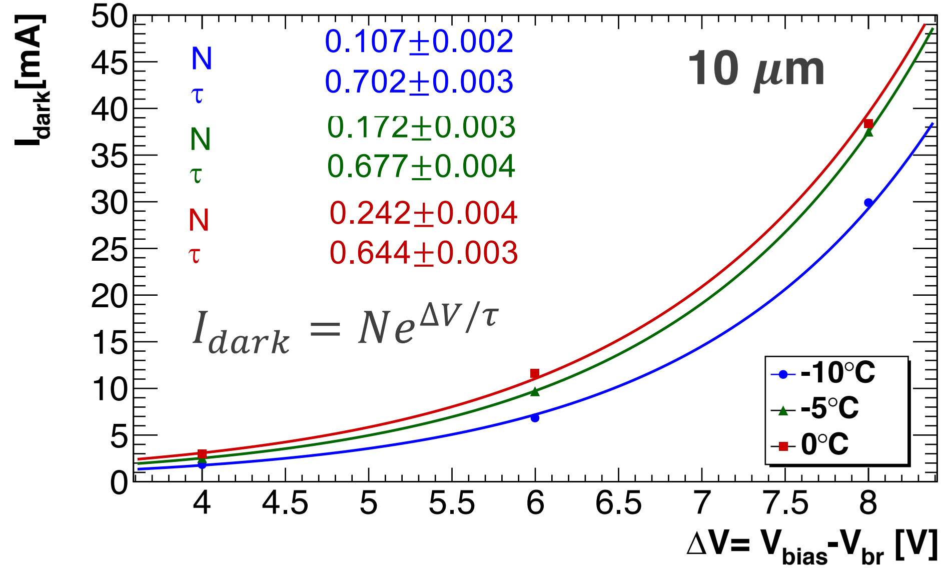


SiPMs Characterisation done: neutrons -2

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 done: neutrons-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

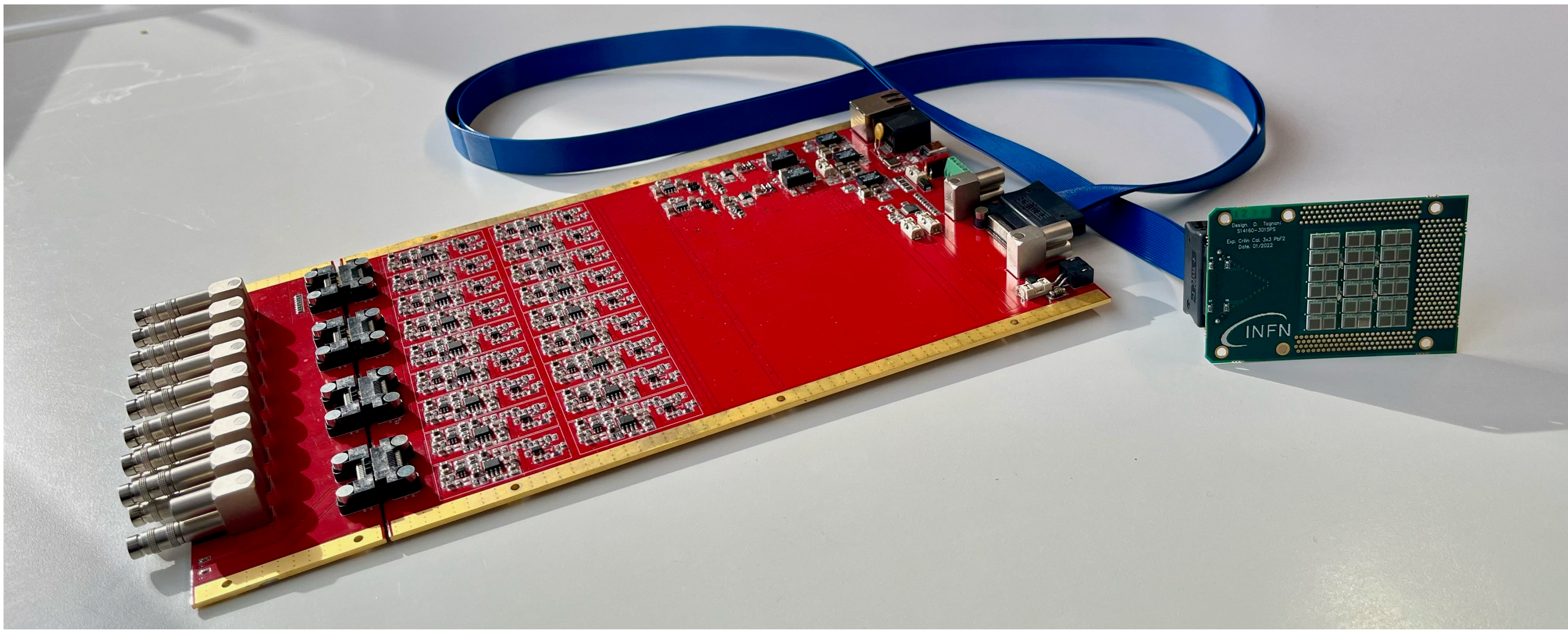
Temperature [°C]	V_{br} [V]	$I(V_{br}+4V)$ [mA]	$I(V_{br}+6V)$ [mA]	$I(V_{br}+8V)$ [mA]
-10 ± 1	76.76 ± 0.01	1.84 ± 0.01	6.82 ± 0.01	29.91 ± 0.01
-5 ± 1	77.23 ± 0.01	2.53 ± 0.01	9.66 ± 0.01	37.51 ± 0.01
0 ± 1	77.49 ± 0.01	2.99 ± 0.01	11.59 ± 0.01	38.48 ± 0.01

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

- **10 μm pixel size OK**, with current Mu2e calorimeter cooling system
- **15 μm pixel size probably OK** with the current Mu2e calorimeter cooling system → few specific tests should be still carried out

Electronics - developments

- 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



Huge advantages here: reduceTID requirement to FEE – easier cabling

Short LYSO crystal calorimetER - SLYER -

- The Mu2e-II calo alternative design we propose is a compromise between the current Mu2e calo and Crilin.

- **What we can re-use of the Mu2e calo:**
    1) The Calibration Source
    2) The Laser System
    3) The Cooling distribution and cooling station
    4) All the support Mechanics
    5) **The digitizers??**

- **What we need to procure and do:**

    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 crystals are enough to achieve O(5%) energy resolution
- Not problem of Equivalent Noise Level nor probably RIN
- Reasonably small LRU
- Great timing resolution still after 10^{13} neutrons/cm^2
- SiPMs already exist – other **R&D not needed**
- High LY → SiPM @ low over voltage → enhanced resistance → lower power dissipation
- Not Front End Amplifier needed → no problems with TID

SLYER – Disadvantages

- **Buy expensive crystals**
  budgetary estimate:
  - LYSO ~30$/cc vs ~10$/cc BaF2
  - **(17$/cc** vs **10$/cc for equivalent X0**, X0-Lyso (1cm), X0-BaF2 (2cm)

- **Total cost of SLYER full proposal**
  - Slyer LYSO crystals for 2 disks = 3.8M$
  - Mu2e: (20 cm CsI + FEE = 1.7M$ + 0.2M$)
  - Mu2e-2-baseline: (14 cm BaF2 + FEE = 2.2M$ + 0.2M$)
  - Relaxed price for SiPMs:
    - 600 k$, no R&D needs
    - wrt 500 k$ R&D for SolarBlind SiPMs

- **SLYER reduced proposal:** 1 disk only, specific radial regions

- *Emission time of 40 ns of LYSO w.r.t. 0.9 ns of BaF2*

Per i referee -1-

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

Per il 2024: 2 Lyso 34x34x80 mm^3 **~ 8 keuro**

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) **~ 2.5 keuro**
- 4 PCB con SiPM on board ed singoli amplificatori **~ 3.5 keuro**

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

Totale richieste: 14 keuro

Per i referee -2-

Cose da fare per dimostrare la fattibilità dell'idea:

- Simulazione → Stefano DF. 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
- Studiare il RIN
- Neutroni/Dose con Cristallo + SiPMs per valutare il noise aggiuntivo

Parecchio lavoro da fare… ma fattibile a partire da estate 2024 (assemblaggio finito, parte di FTE più liberi, forte sinergia con RD_Mucol)

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.