Timing Performance Optimization of FBK Silicon PhotoMultipliers

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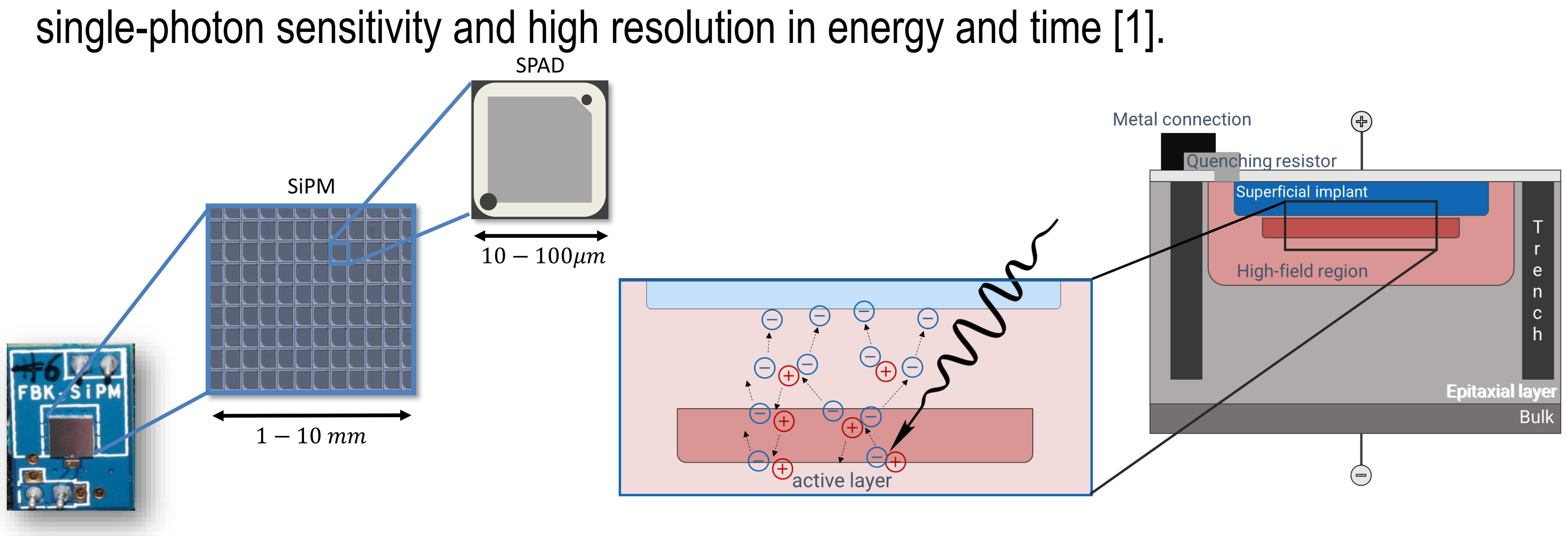
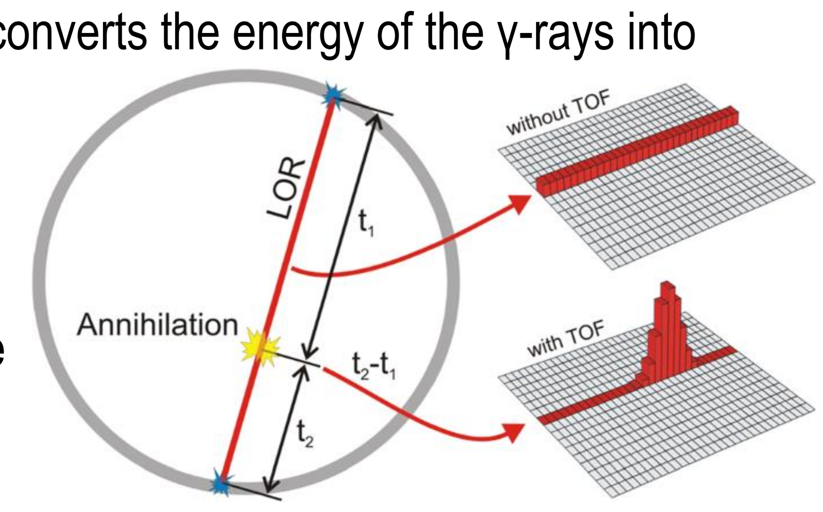
Research context and motivation

- Silicon PhotoMultipliers (SiPMs) are made of arrays of Single Photon Avalanche Diodes (SPADs). SPADs are silicon single-photon sensitive photodetectors biased above the breakdown voltage. A photon that impinges on the SPAD generates a large output electric signal due to the internal avalanche multiplication.
- The SiPM output signal is the sum of the single SPAD signals, thus it is proportional to the number of photons impinging on the device. SiPMs allow the detection of photons with single-photon sensitivity and high resolution in energy and time [1].

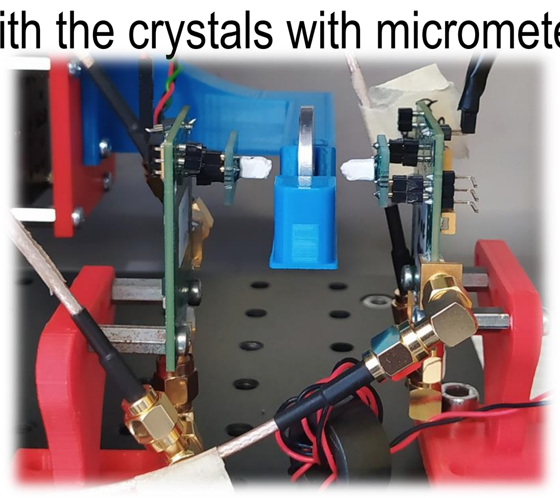


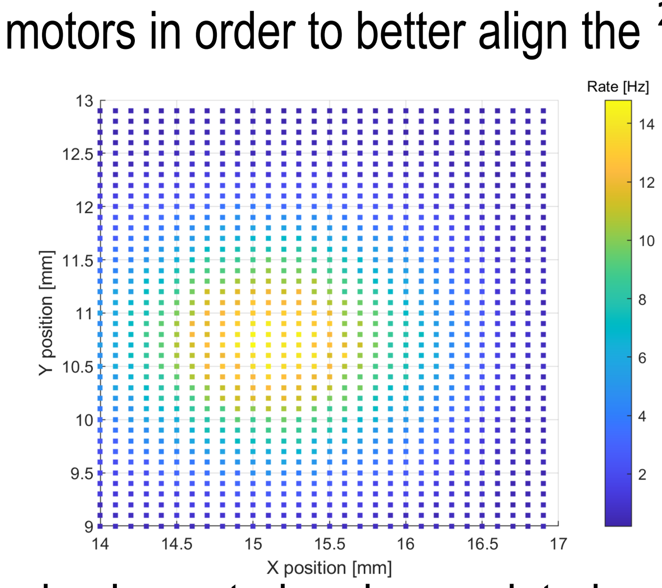
- SiPMs are widely used in High Energy Physics experiments and Biomedical applications such as Positron Emission Tomography (PET). The working principle of PET is based on the detection in coincidence of two back-to-back 511 keV γ-rays emitted by the radioactive tracer in the tumor volume. A scintillator crystal converts the energy of the γ-rays into scintillation light, then detected by the SiPM and converted into an electronic signal by means of the electronic readout.
- The localization of the emission point of the two back-to-back photons along the line-of-response (LOR) depends on the time difference (Time-of-Flight - ToF) between the two photons themselves, whose accuracy is given by the Coincidence Resolving Time (CRT) of the detection chain. Recently it has been proposed the ambitious target of 10 ps CRT, corresponding to a spatial resolution on the annihilation position better than 1.5 mm. State-of-the-art commercial ToF-PET scanners achieve about 200ps CRT accuracy resulting in a event localization of about 3cm [2].



Novel contributions

- The timing setup has been enhanced with stepper motors in order to better align the ^{22}Na source with the crystals with micrometer accuracy.

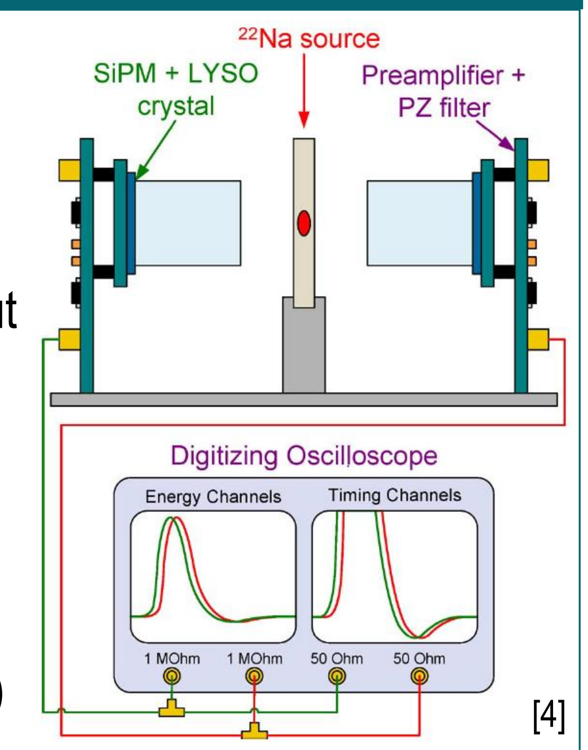




- A High-Frequency readout electronics is going to be implemented and an updated acquisition analysis software is under implementation.

Adopted methodologies

- The experimental setup foresees a ^{22}Na source that generates two back-to-back 511 keV photons that are detected in coincidence by two FBK NUV-HD low-CT technology SiPMs coupled with $3x3x5\ mm^3$ LYSO:Ce co-doped Ca crystals. The signals are processed by a readout electronics. The energy information is determined by charge integration of the signal in order to select events in 511 keV peak. Several leading edge thresholds return the time tag of both the timing signals, then giving the coincidence time intervals. The time intervals are plotted in a histogram for each threshold. The lower Full Width High Maximum (FWHM) of the time interval distributions is taken as CRT value.



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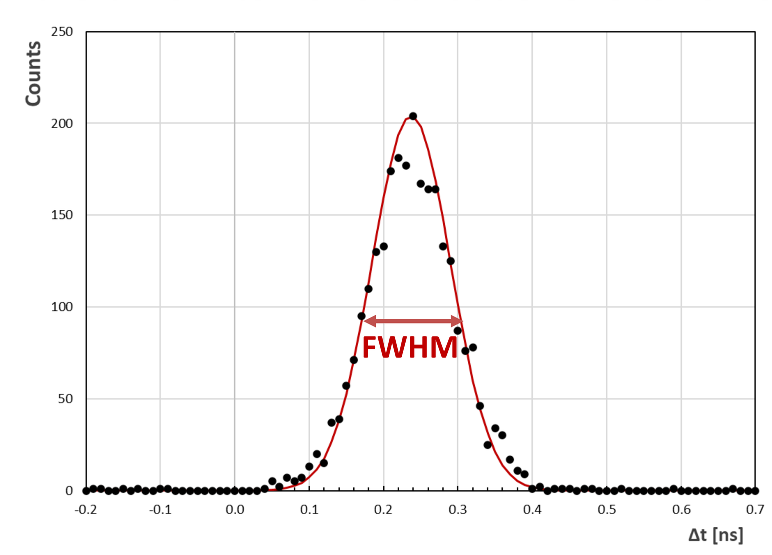
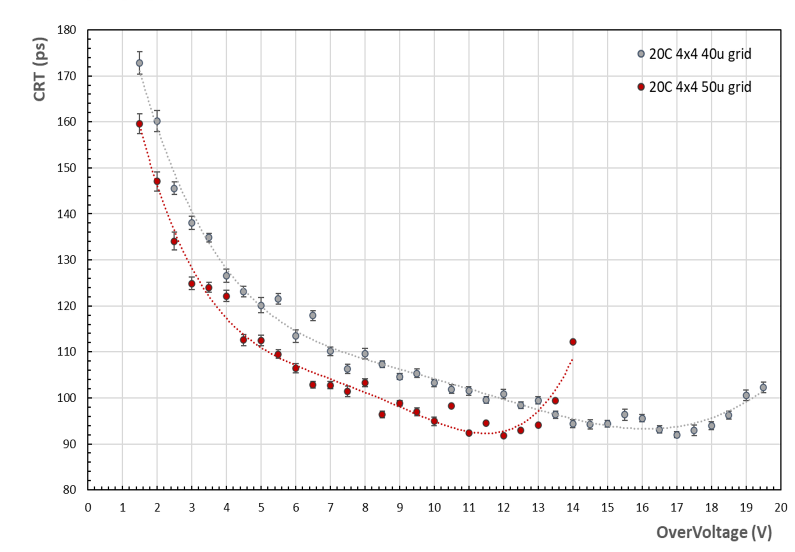


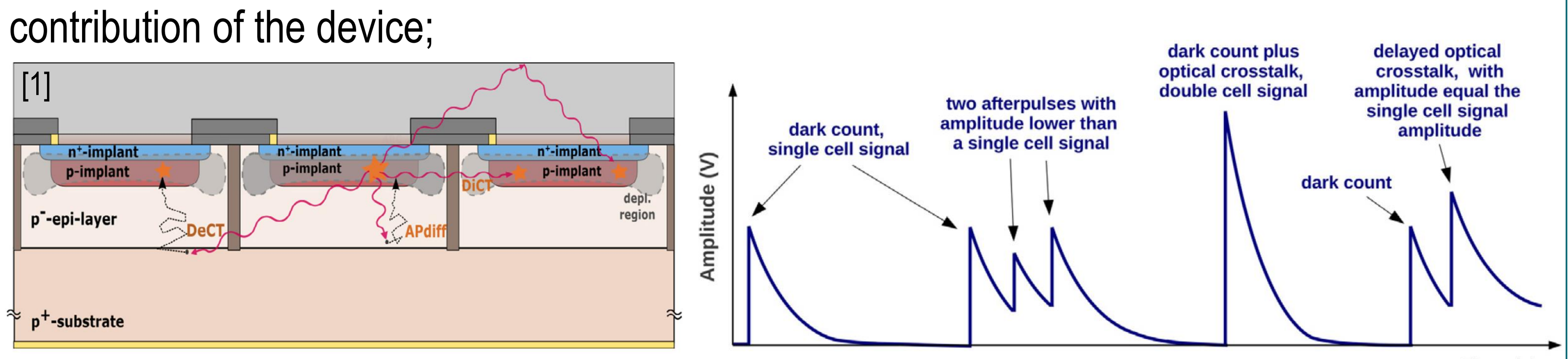


Addressed research questions/problems

- Optimizing the timing performance requires the improvement of the experimental setup:

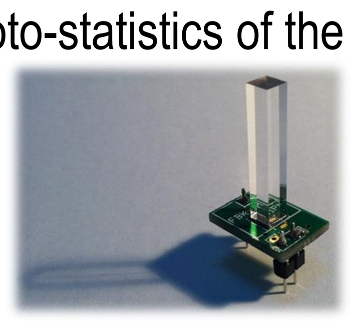
The SiPM detector

Improve Photon Detection Efficiency, Single Photon Time Resolution and decrease the noise contribution of the device;



The crystal

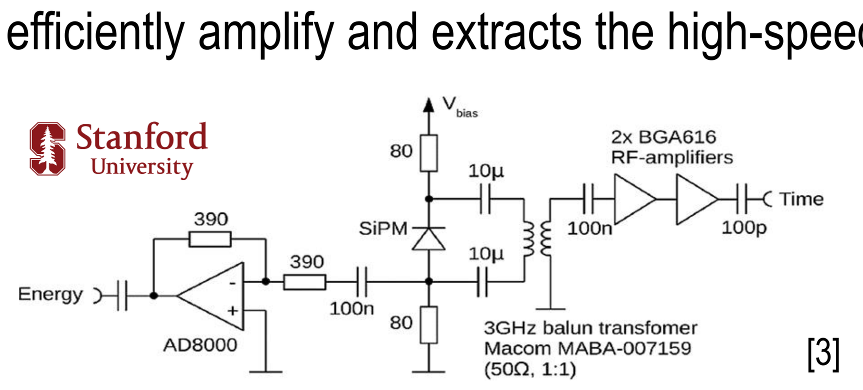
Improve the photo-statistics of the scintillation process (Light Yield, rise and decay time);



Scintillator	Light yield (photons/keV)	Light ouput(%) of NaI(Tl) bialkali pmt	Temperature coefficient of light output(%/C) 25°C to 50°C	1/e Decay time(ns)	Wavelength of max emission lm(nm)
LYSO $Lu_{1.8}Y_{.2}SiO_5(Ce)$	33	87	-0.28	36	420
BGO	8 - 10	20	-1.2	300	480

The electronics

Improve electronics to efficiently amplify and extracts the high-speed high bandwidth signal from the SiPM [3].



Submitted and published works

Future work

- Implementation of a High-Frequency readout to boost timing performance.
- CRT and SPTR measurements of
  - Different SiPM technologies, dimensions and cell sizes using also different crystal materials.
- CRT measurement and study of the BGO cherenkov photons used as ultrafast time tagger
- Simulations for a close study of
  - The sensor geometry and properties
  - The crystal properties and the optical/physical phenomena involved

References

- [1] Acerbi F.,Gundacker S., "Understanding and simulating SiPMs", Nuclear Inst. and Meth. in Phys. Res., A, 2018
- [2] Lecoq P. et al, "Roadmap toward the 10 ps time-of-flight PET challenge", Phys. Med. Biol. 65 21RM01, 2020
- [3] Gundacker S. et al, "High-frequency SiPM readout advances measured coincidence time resolution limits in TOF-PET", Phys. Med. Biol. 64 055012, 2019
- [4] Gola, A. et al. "Analog Circuit for Timing Measurements With Large Area SiPMs Coupled to LYSO Crystals", IEEE Transactions on Nuclear Science 60, 2013

List of attended classes

- XXX Giornate di Studio sui Rivelatori - Scuola F. Bonaudi 2022 (13/6/2022, 27.93h)
- 01UAZOQ - Electronic transport in crystalline and organic semiconductors (27/6/2022,40h)
- 01DOJRV - Computational (opto)electronics: a journey through device-level models (July 2022, 18h)*
- 01QRGRV - Microelectronics for radiation detection I (July 2022, 30h)*
- 01SWPRV - Time management (12/12/2021, 2.67h)
- 01DOCRV - The Hitchhiker's Guide to the Academic Galaxy. […] (16/06/2022, 26.67h)
- 01UNXRV - Thinking out of the box (16/09/2022, 1.33h)
- 08IXTRV - Project Management (24/09/2022, 6.65h)

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