MPPC Characterization for FCC Calorimetry

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ATENEA

GENERALITAT VALENCIANA

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

CSIC
Consejo Superior de Investigaciones Científicas

Vniversitat de València

IFIC Institut de Física Corpuscular

Excelencia Severo Ochoa

New ATENEA FCC calorimetry project (IFIC-CIEMAT)

- Title: **Advanced data processing Technologies for Exploring NEw Physics in future pArticle colliders (ATENEA)**
  - Funded with 600k € during 2025-2029 by Generalitat Valenciana under the Prometeo program for excellence research groups (CIPROM/2024/69).
- Researchers (physicist / engineer):
  - **IFIC:** Arantxa Ruiz (PI), Alberto Valero, Ximo Poveda, Fernando Carrió, Juan Valls, Ana Arranz (PhD student), 1-2 electronic engineers joining soon
  - **CIEMAT:** Cristina Fernández, Ignacio Redondo
- **Context & Motivation:**
  - Support **Future Circular Collider (FCC)** development.
  - Contribute to **ECFA Detector R&D Roadmap** in **DRD6** (Calorimetry) and **DRD7** (Electronics)
- **Main Goals of the project**:

Physics case studies for FCC-ee & FCC-hh	**Develop advanced calorimeter components:** Multi-channel SiPMs / MPPCs, Radiation-hard readout/control electronics.	**Innovate DAQ systems** for massive data rates	**Real-time signal processing** with **NNs on FPGAs**	**Cross-disciplinary technology transfer** (electronics, computing, photodetectors)

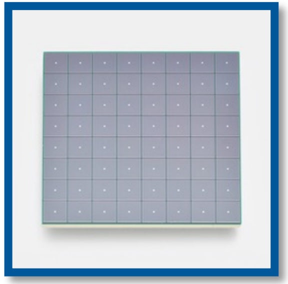
Multi-Pixel Photon Counters (MPPCs)

Develop advanced calorimeter components:
Multi-channel SiPMs / MPPCs, Radiation-hard readout/control electronics.

→ Characterization of Silicon Photomultipliers (SiPMs) / **Multi Pixel Photon Counters (MPPCs)** .

- High gain, $g = Q/e$, $10^5 - 10^6$
- Can be operated at room temperature and in magnetic fields up to $7\mathrm{T}$
- Requiring operating voltages of only $50\ \mathrm{V}$.
- High photon detection efficiency ~ 40%
- Excellent time resolution - tenth of ps
- Wide spectral response range of $320 - 900\ \mathrm{nm}$

Picture of a PMT.



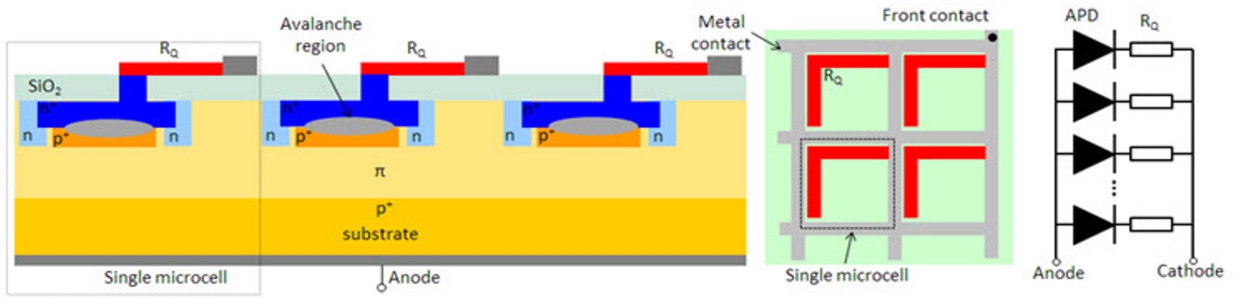
Picture of a MPPC.

Studying the **gain dependence with temperature and operation voltage**.

Multi-Pixel Photon Counters (MPPCs)

A MPPC is a pixelated device where each pixel is a series combination of an **Avalanche PhotoDiode (APD)** and a **quenching resistor (R_Q)** operating in **Geiger mode**.

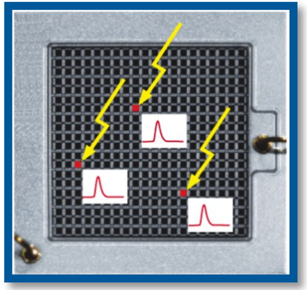
An incident photon can trigger an avalanche producing a **current pulse**.



[1] Scheme of the typical structure of a SiPM by Hamamatsu

The current pulse is independent of the magnitude of the ionising photon signal.

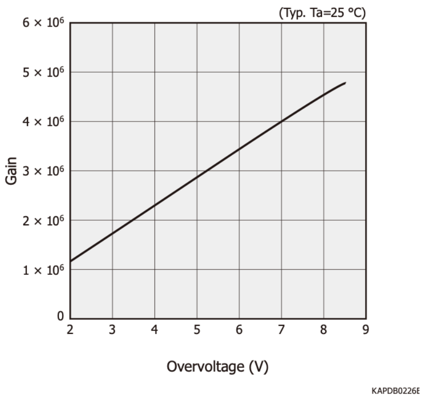
The number of hit pixels is proportional to light intensity (number of photons).

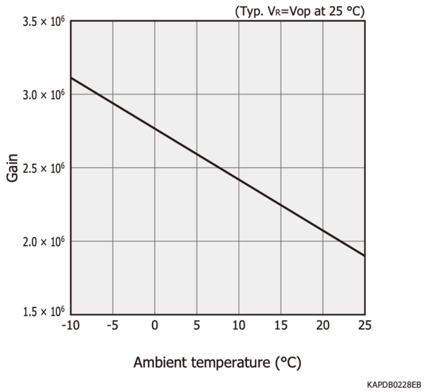


MPPCs by Hamamatsu

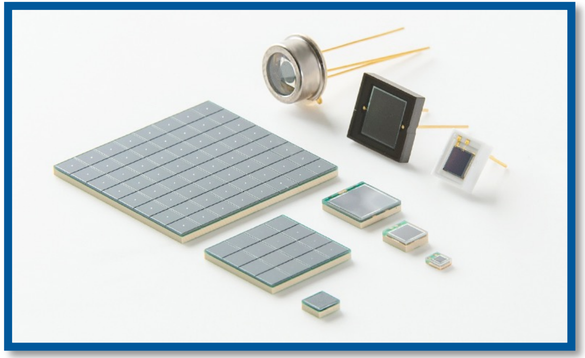
MPPC S13361 from Hamamatsu characteristics (T= 25ºC, V = 56V):

- 64 channels, 3584 pixels/channel.
- Blue sensitive (light from scintillators), peak sensitivity wavelength 450nm.
- Pixel pitch $50\ \mu\mathrm{m}$, fill factor 74%.
- Breakdown voltage of $53 \pm 5\mathrm{V}$ and overvoltage of $3\mathrm{V}$.
- Efficiency ~ 40%.





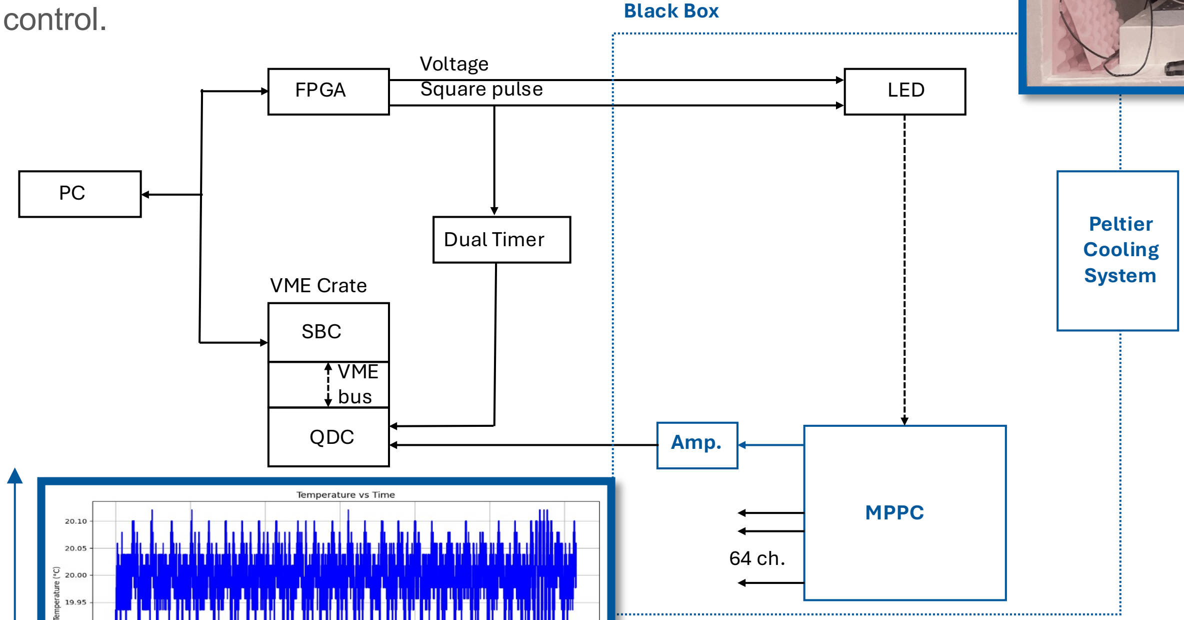
HAMAMATSU

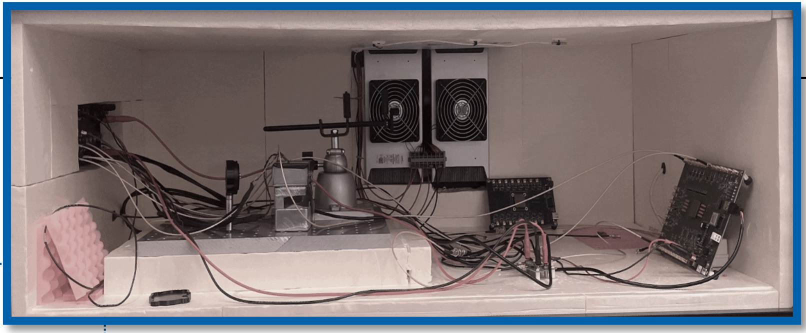


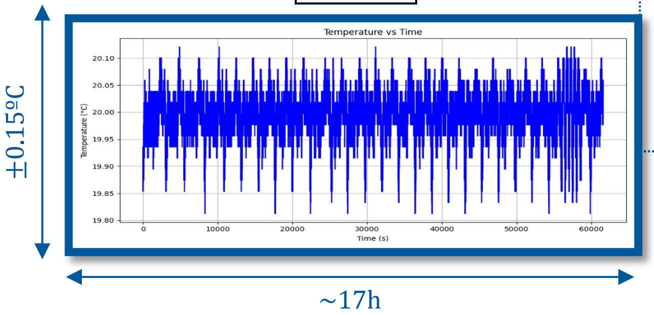
[2] MPPC S13361 3050 series 64 channels datasheet

Setup

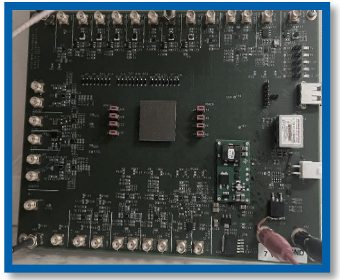
Black box equipped with a Laird 480W **Peltier** thermoelectrical assembly module for temperature control.







The MPPCs are coupled to a four-layer printed circuit interface board.

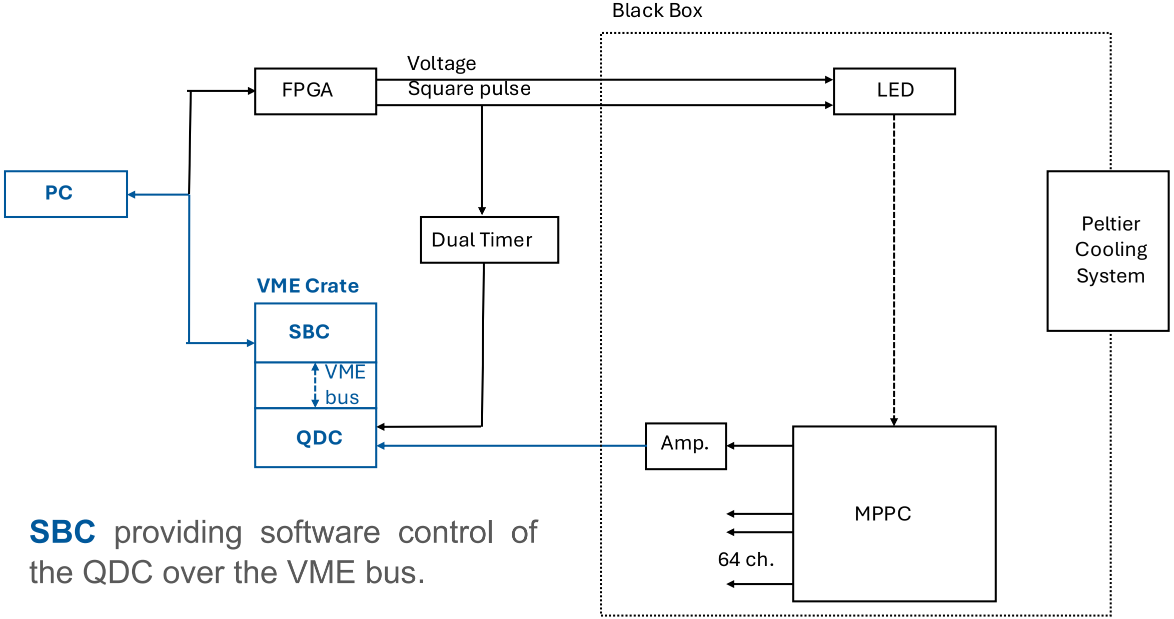


Readout implemented through a **Gali 74+RF monolithic amplifier** [3]

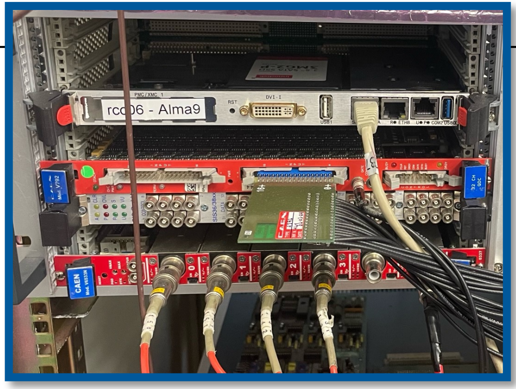
- 18.0 dB (at 2 GHz) per channel

Setup

The **VME crate** includes a single board computer (SBC) and a QDC.



SBC providing software control of the QDC over the VME bus.



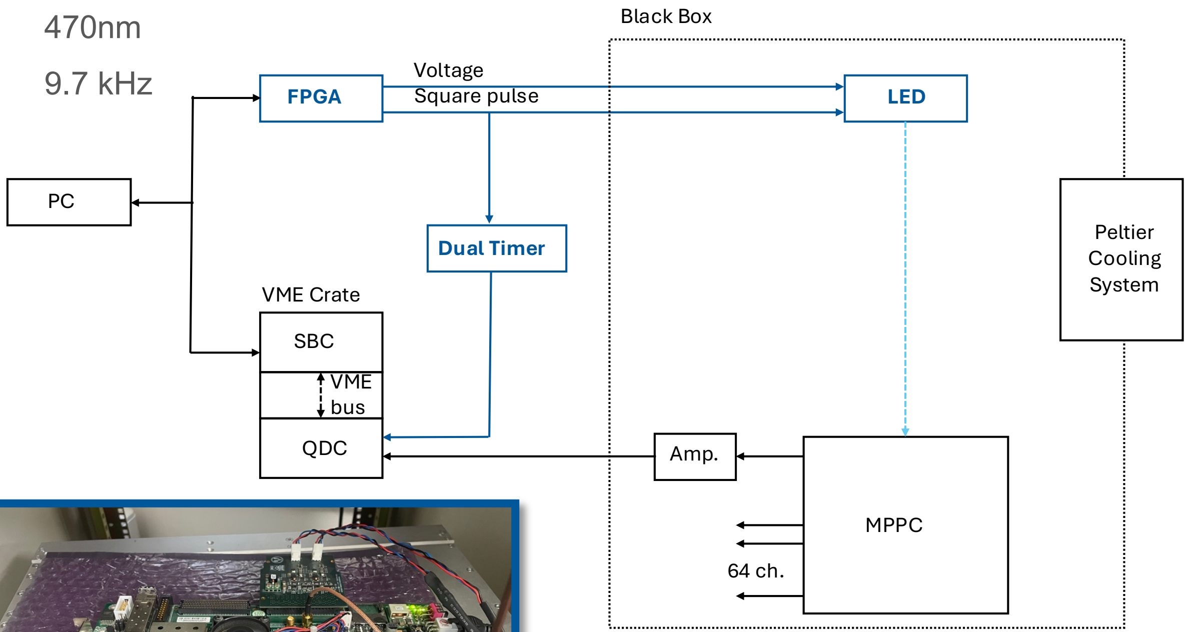
Signal digitalization achieved through a **CAEN 32-channel QDC** V792.

- 12 bits ADCs.
- 0.1 pC per ADC count conversion.

Setup

LED characteristics and configuration:

- 9.4 V
- 470nm
- 9.7 kHz



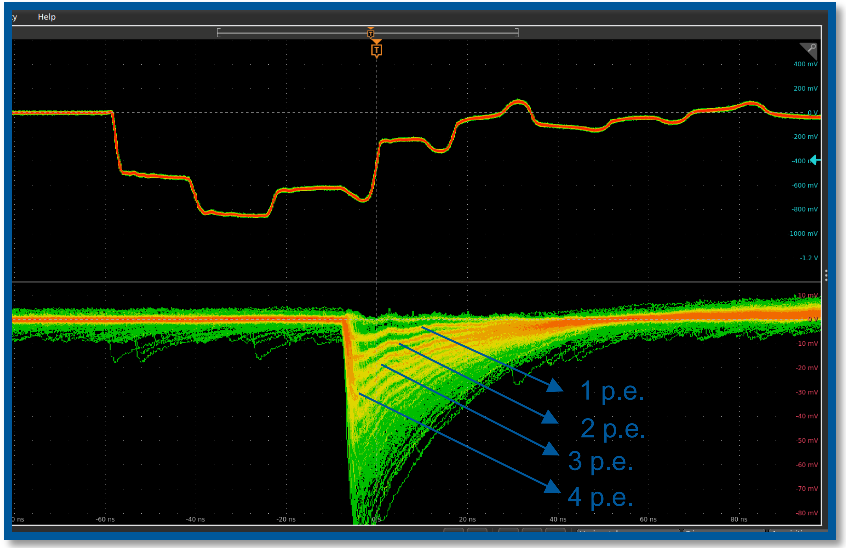
The **LED control** board is implemented in an **FPGA.**

Two combined signals sent:

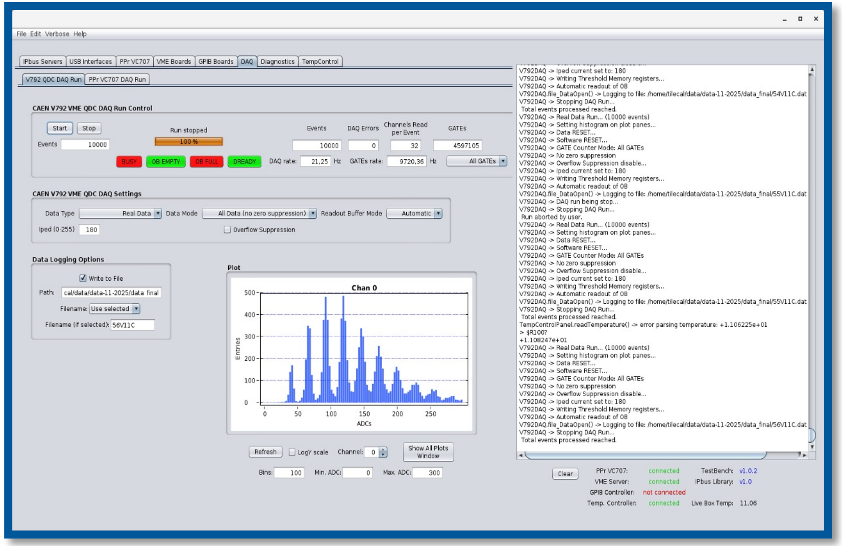
- **DC bias voltage** to charge the LED capacitor, defining the amount of emitted light.
- **A square pulse** is used to simultaneously trigger the LED activation and the data acquisition system through a dual timer module.

MPPCs response

Lecture of **channel 0**.



Osciloscope image of the trigger pulse and the detector response.



Personalized **data acquisition program**.

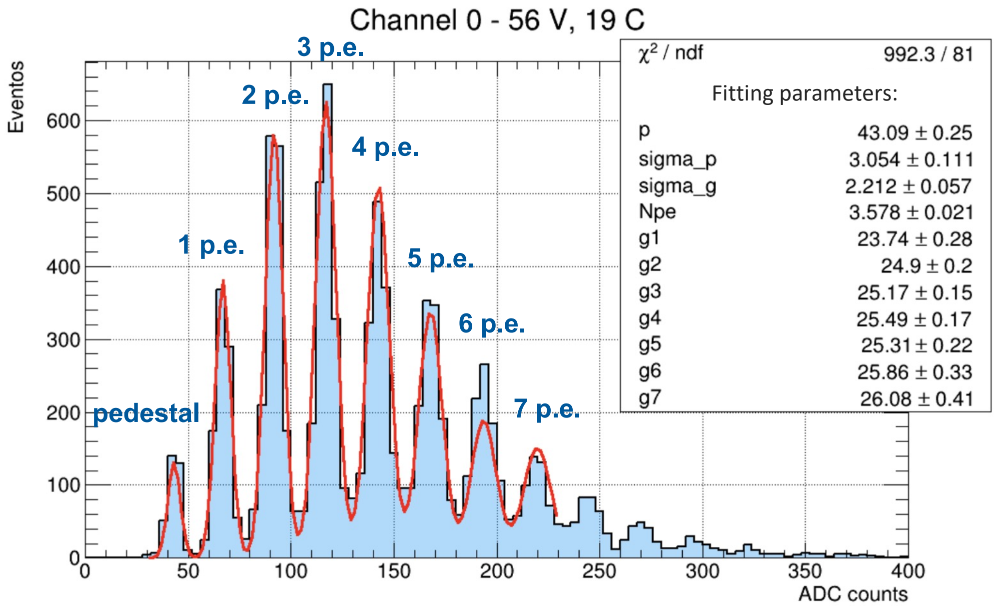
MPPCs response

The pulse height spectra is fitted to a **sum of Gaussian functions convoluted with Poissonians**.

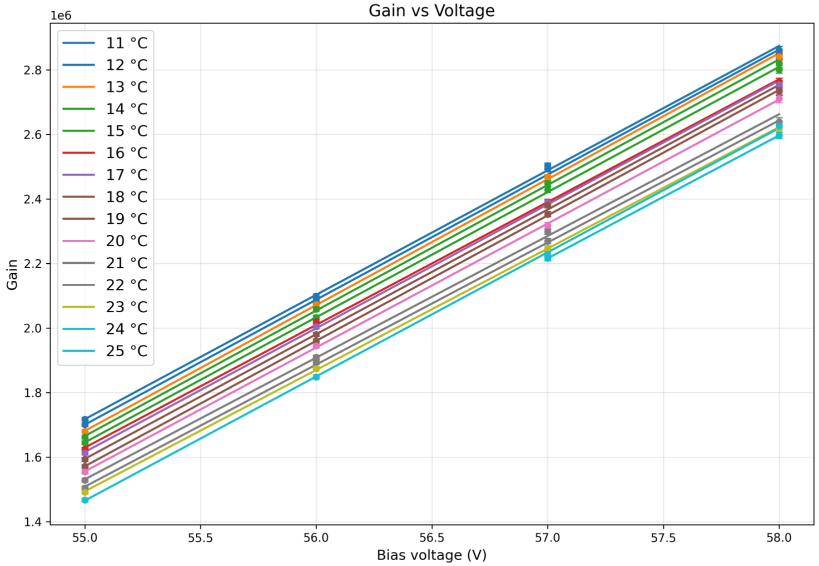
$$S(q) = \sum_{n=0}^{\infty} S_n(q) = N \sum_{n=0}^{\infty} G_n(q) \frac{(N_{pe})^n}{n!} e^{-N_{pe}}$$

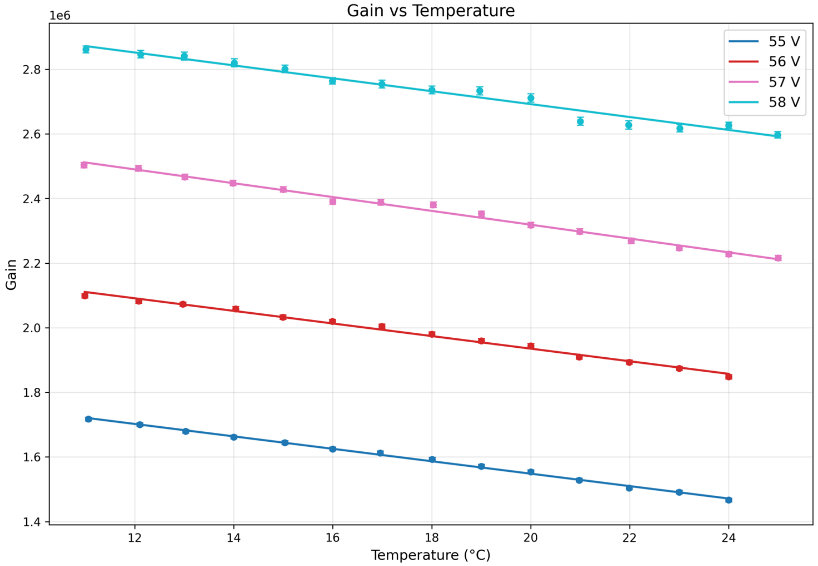
$$G_n(q) = \frac{1}{\sqrt{2\pi\sigma_n}} exp\left[-\frac{1}{2}\left(\frac{q-p-n\cdot g}{\sigma_n}\right)^2\right]$$

$$\sigma_n = \sqrt{\sigma_p^2 + n\cdot\sigma_{gain}^2}.$$



Results





Configuration	Hamamatsu	Values obtained
58V and 25ºC	$2.80 \cdot 10^6$	$2.60 \cdot 10^6$
57V and 25ºC	$2.40 \cdot 10^6$	$2.20 \cdot 10^6$
56V and 15ºC	$2.25 \cdot 10^6$	$2.05 \cdot 10^6$

Conclusions

The gain of the MPPCs increases with bias voltage and decreases with temperature.

Gain values compatible with those provided by the manufacturer.

Continue characterizing the devices:

- MPPC with 16 channels *S13361 – 6050 series.*
- Simultaneous reading of more channels through other amplifiers.
- Study dark count rate and other noise sources.
- Efficiency.
- Time resolution.
- …

Developing a prototype with scintillators.

Consider characterization of other alternative devices.

References

[1] Scheme of the typical structure of a SiPM by Hamamatsu, https://hub.hamamatsu.com/us/en/technical-notes/mppcsipms/what-is-an-SiPM-and-how-does-itwork.html#:~:text=A%20silicon%20photomultiplier%20(SiPM)%20is,a%20photomultiplier%20tube%20(PMT).

[2] Hamamatsu MPPC 3050 series 64 channels datasheet, https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/ssd/s13361-3050_series_kapd1054e.pdf

[3] Gali-74+ monolithic amplifier datasheet, https://www.minicircuits.com/pdfs/GALI-74+.pdf?srsltid=AfmBOordSQABRQK2nMBz3hGGqcqpcPQscdko0_9zpsPvwIobtIq7WBTf

BACKUP

New ATENEA FCC calorimetry project (IFIC-CIEMAT)

Work plan organized in six work packages (WPs)

Key activities / deliverables:

- Build test benches for SiPMs.
- Design front-end & back-end electronics.
- Implement high-speed optical links.
- Develop FPGA-based AI algorithms.
- Simulate detector performance & optimize designs.
- Fabricate prototypes and validate in beam tests.

	2025		2026				2027				2028				2029		
Task	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
Work Package 1 (WP1): Evaluation and Certification of Silicon Photomultipliers (SiPMs)																	
1. Identify commercially available and prototype SiPMs for evaluation.	■	■	■														
2. Develop a PMT test bench for detailed performance analysis, including light yield, timing, and noise characteristics.			■	■	■	■	■	■	■								
3. Test radiation tolerance and longevity under high-radiation environments.									■	■	■	■					
4. Publish findings on SiPM performance for potential FCC applications.											■	■	■	■			
Work Package 2 (WP2): Development of Readout and Control Electronics																	
1. Design front-end electronics for signal amplification, shaping and digitization.	■	■	■	■	■	■	■										
2. Integrate control systems to manage device operation and calibration.			■	■	■	■	■	■	■	■							
3. Prototype readout modules and validate their performance in a controlled laboratory environment.								■	■	■	■	■	■				
4. Ensure compatibility with FCC detector system requirements.												■	■	■			
Work Package 3 (WP3): Data Acquisition (DAQ) Systems Development																	
1. Design front-end DAQ components to digitize signals from SiPMs.	■	■	■	■	■	■	■	■	■	■							
2. Develop high-speed optical links for data transfer.			■	■	■	■	■	■	■	■							
3. Implement a modular back-end system for data processing and storage.							■	■	■	■	■	■	■	■			
4. Test DAQ systems under simulated FCC data conditions.												■	■	■	■	■	
Work Package 4 (WP4): Signal Processing and Reconstruction Algorithms																	
1. Develop neural network-based algorithms for real-time signal processing on FPGA platforms.			■	■	■	■	■	■	■	■	■	■	■	■			
2. Optimize algorithms for noise filtering and particle flow reconstruction.							■	■	■	■	■	■	■	■	■		
3. Benchmark the algorithm performance against traditional reconstruction methods.								■	■	■	■	■	■	■			
4. Test and integrate algorithms with the DAQ system.												■	■	■	■	■	■
Work Package 5 (WP5): Feasibility Studies and Simulations																	
1. Develop simulation models for high-granularity calorimeter configurations in FCC-ee and FCC-hh environments.	■	■	■	■	■	■	■										
2. Study energy resolution, efficiency, and particle flow reconstruction under different scenarios.						■	■	■	■	■	■						
3. Analyze detector performance in terms of radiation hardness and long-term stability.										■	■	■	■	■	■		
4. Provide optimization recommendations for detector designs based on simulation results.													■	■	■	■	■
Work Package 6 (WP6): Prototyping and Test Beam Campaigns																	
1. Fabricate 3,Äì5 prototype calorimeter modules based on DRD6 recommendations.								■	■	■	■	■	■	■			
2. Integrate SiPMs, electronics, and DAQ systems into prototypes.								■	■	■	■	■					
3. Conduct test beam campaigns at CERN SPS or similar facilities to validate performance.										■	■	■	■	■	■	■	■
4. Analyze results to refine detector design and implementation strategies.															■	■	■