37th JEM-EUSO Collaboration Meeting
June 5th, 2025 – Paris (remotely connected)

REPORT
"Test & Calibration Elementary Cell units for PBR Cherenkov Camera"

Coordinator: Rossella Caruso
on behalf of **Catania PBR Team:**

- CARUSO Rossella [a, b], PETTA Catia [a, b]

Associate Professors in Experimental Physics

- BRIO Vanessa [a], CROCCO Anna [a]

Researcher Fellow University of Catania, Master's Degree student

- SACCA' Gaspare [b], GUARDONE Nunzio [a,b]

Engineer - Head of INFN-CT Electronics Section, Electronics Technician

(a) Dipartimento di Fisica ed Astronomia "E. Majorana" - Università di Catania
(b) INFN - Sezione di Catani

UNIVERSITÀ degli STUDI di CATANIA

DIPARTIMENTO DI FISICA E ASTRONOMIA "ETTORE MAJORANA"

INFN CATANIA

Agenzia Spaziale Italiana

I PART: PREMISE

Study of performances and characterization of SiPMs for the next generation of telescopes in balloon-borne & space-based experiments

II PART: APPLICATION to PBR case

The test and calibration system for the SiPM tiles of the Cherenkov Camera for the PBR Mission

The italian ASI/INFN EUSO-SPB2 Project

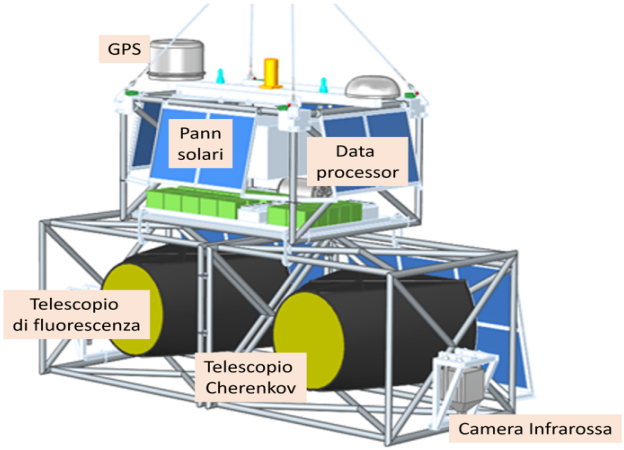
The development of detectors based on SiPM photosensors for acquisition of fast signals coming from Cherenkov and fluorescence emission started by astroparticle showers in the atmosphere, is the main goal of the **current ASI/INFN Agreement n. 2021-8-HH.2-2022, named "EUSO-SPB2 (Extreme Universe Space Observatory – Super Pressure Balloon 2)" (P.I. G.Osteria)** useful for the next generation of telescopes in balloon-borne and space-based experiments.

PARTNERS:

- **ASI**
- **INFN : BA CT, NA, ROMA2, TO**

SUB-PARTNERS:

- **University of CATANIA**
- **University of TORINO**



Agenzia Spaziale Italiana

Istituto Nazionale di Fisica Nucleare

UNIVERSITÀ degli STUDI di CATANIA

UNIVERSITÀ DI TORINO

- **started in 2021 and extented until May 2025**
- **just prolonged for other 9 months (February 2026)**

The ASI/INFN EUSO-SPB2 WP#4400

WP4400: “Selection, characterization and test of SiPMs”

Unit: Catania University & INFN - Catania Division
P.I.: Rossella CARUSO

The main item of this Working Package is the definition of a procedure for characterising and selecting the SiPMs that best fit the experimental requirements.

The study of performances of different SiPMs available on the market has been performed to identify the best sensors for space applications.

The protocol foresees to measure **several parameters: breakdown voltage (Vbd) , quenching resistance (Rq), gain (G), dark count rate (DCR), probability of cross-talk (pCT) as function of temperature.**

INFN CATANIA

UNIVERSITÀ degli STUDI di CATANIA

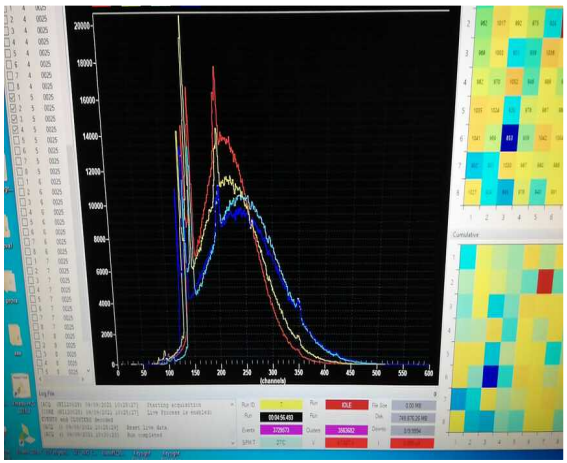
DIPARTIMENTO DI FISICA E ASTRONOMIA "ETTORE MAJORANA"

R&D on SiPMs for space-based missions (2021-2023)

Involved members: Caruso R., Petta C., Lombardo C., Persiani R., Tortorici F. Saccà G. & Guardone N.

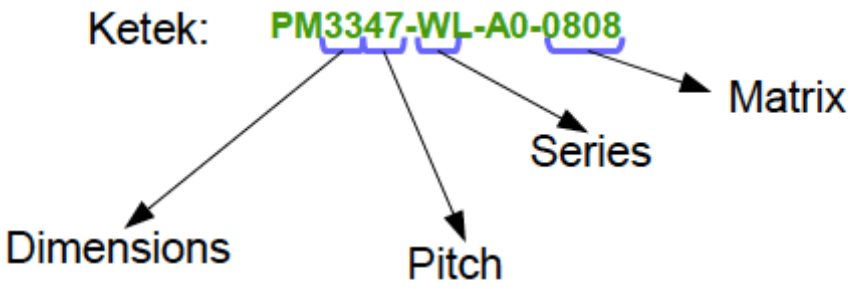
Measurements on SiPMs basic properties at controlled T conditions:

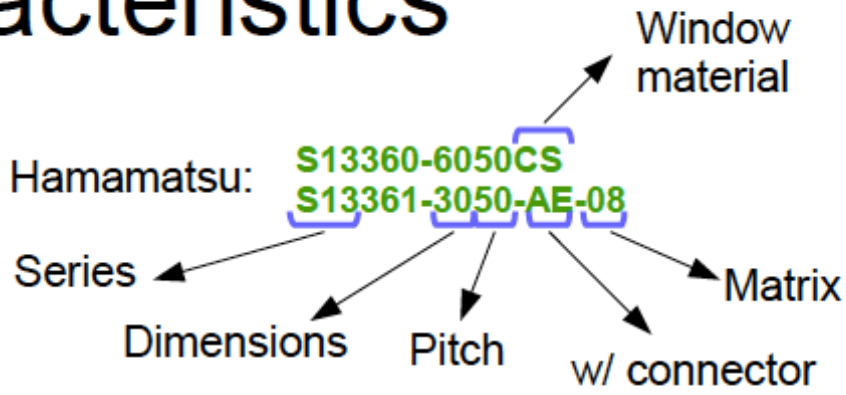
- R&D on SiPMs with several prototypes from Hamamatsu, SensL, AdvanSid (FBK), Kernell, Ketek manufactures;
- visual inspection (scratches, bubbles…): in clean room using a microscope;
- measurements at temperature variations (- 40 °C ÷ 150 °C) in a climate chamber: Dark Current Ratio (DCR); Gain (G); Photon Detection Efficiency (PDE); Cross-Talk; After-Pulse; I-V (Current-Voltage) curve.



Produttore	Modello	Qt	V_{bd} (V)	V_{op} (V)	Connettore	Chs	PCB
Hamamatsu	S14160-1315PS	2		41,77	to sold	1	
	S14160-4050HS	2	37,9	40,6	to sold	1	
	S14160-1310PS	2		42,4	to sold	1	
	S14160-3010PS	2		42,66	to sold	1	
	S14160-3015PS	2		42	to sold	1	
	S13360-6050CS	2	50,97	53,97	PIN A-K	1	
	S13360-1325CS	2	52,65	57,65	PIN A-K	1	
	S13360-6025C	2	51,87	56,87	PIN A-K	1	
	S13360-1350CS	2	49,49	54,49	PIN A-K	1	
SenSL	ARRAYJ 30035 16P PCB	1			CONN	4X4	
	ARRAYC 60035 64P PCB	1			CONN	8X8	Arrayx BOB6 64S GEVK
	MICROFC 10010 SMT TR1	6			to sold	1	
	MICROFC SMA 30035 GEVB	1			SIPM ON BORD		
	MICROFC SMTPA 60035 GEVB	1			PIN A-K	1	
	MICROFC 30035 SMT TR1				to sold		
	MICROFC 60035 SMT TR1				to sold		
	NO NOME				PIN A-K		
	MICROFC SMA 60035 GEVB				SIPM ON BORD		
	MICROFC SMTPA 10010 GEVB	1			PIN A-K	1	
	MICROFC SMA 10010 GEVB	1			SIPM ON BORD		
	Arrayx BOB6 64S GEVK		Eval board				
	Arrayx BOB6 64p GEVK		Eval board				
Broadcom	AFBR S4E001	1	Eval board				
	AFBR S4N44P163	1				4X4	
Ketek	PA3347-WL-A0-A0-0808	1			Samtec	8x8	
	PM3347-WL-A0 PIN	2			PIN A-K	1	
	PM3325-WB-D0 PIN	1			PIN A-K		
	PM3315-WL-A0	2			PIN A-K		
	PM3335-WL-A0	2			PIN A-K		
	PM3315-WL-A0 PIN	2			PIN A-K		
	PM3335-WL-A0 PIN	2			PIN A-K		

SiPM characteristics





Operating temperature: -40 °C / 60 °C

Operating temperature: -20 °C / 60 °C

Spectral response range: 320 – 900 nm (270 – 900 nm for HPK with CS option)

Peak sensitivity wavelength: 450 nm

	N of pixels	Fill Factor (%)	Window R-index	Active Area (mm^2)
PM3335-WL-A0	7396	80	1.52	3.0 x 3.0
PM3347-WL-A0	4096	80	1.52	3.0 x 3.0
PM3347-WL-A0-0808	4096	80	1.52	3.0 x 3.0
S13360-1350CS	667	74	1.41	1.3 x 1.3
S13360-6050CS	14400	74	1.41	6.0 x 6.0
S13361-3050-AE-08	3584	74	1.55	3.0 x 3.0

First set-up for R&D on different SiPMs: (I phase: 2021-2022)

- **Acquisition System (Front End Board):**

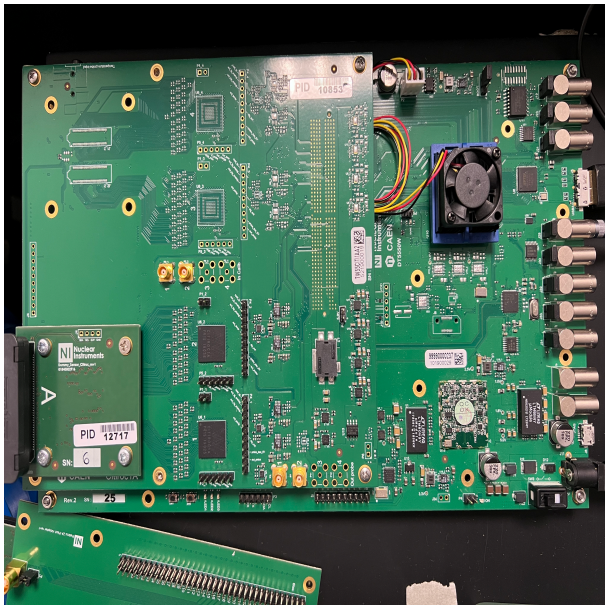
CAEN DT5550W (with piggyback 2 Citiroc1A)

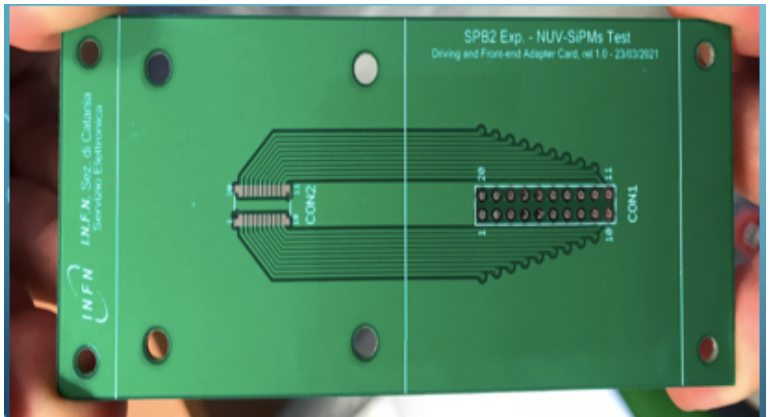
- **PCB:** designed and made by INFN-CT Elettronica
- **Power Supply:** Keysight 0-100 V, CAEN A7585
- **Climate chamber (fig 2):** ESPEC-SH242

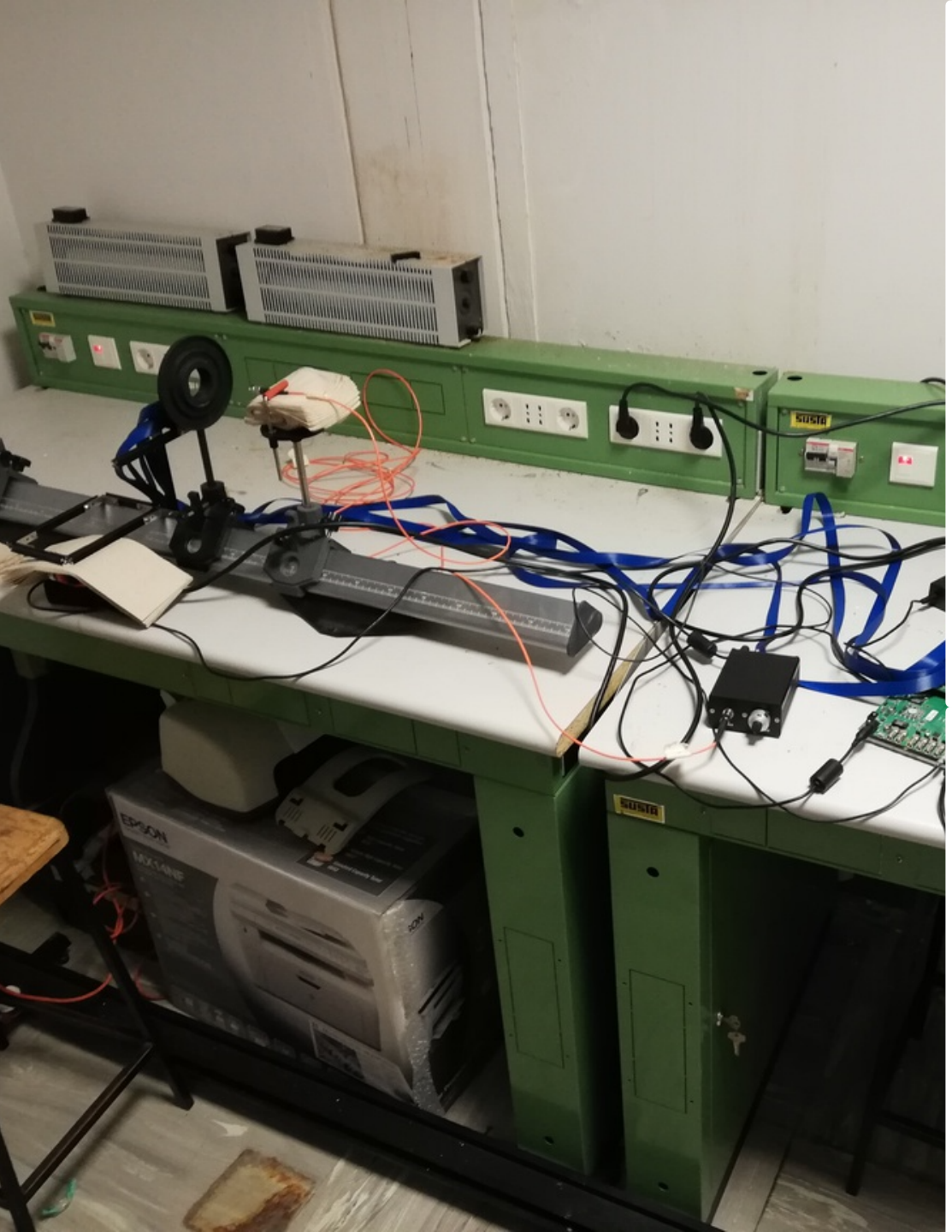
(-40°C ÷ + 180°C) (300 x 250 x 300) mm^3

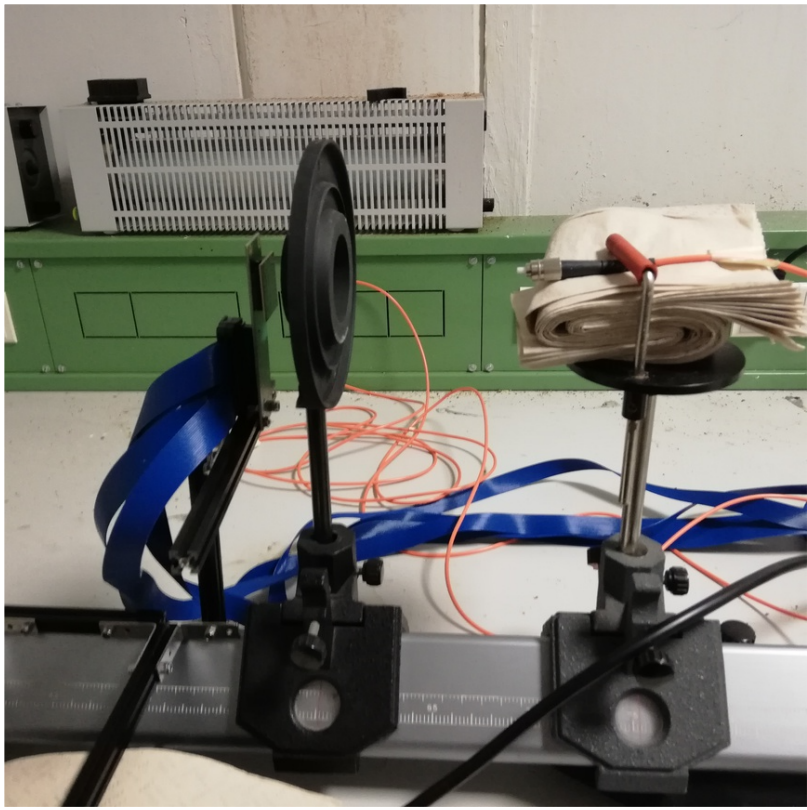
- **3LEDs + Driver (fig3):** CAEN SP5601 (400 nm)
- **LASER (fig 4)**: Picoquant PDL 800-D with

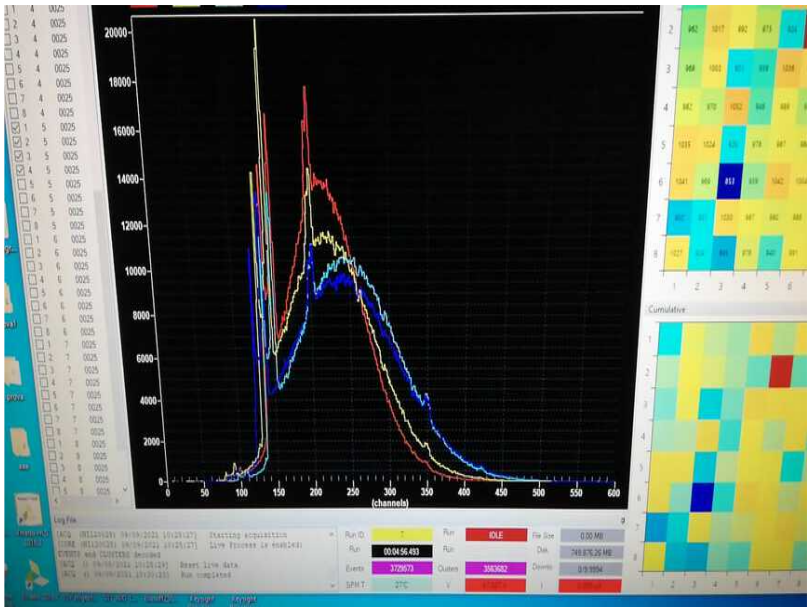
LDH P-C 405B head (402 nm, <80 ps)

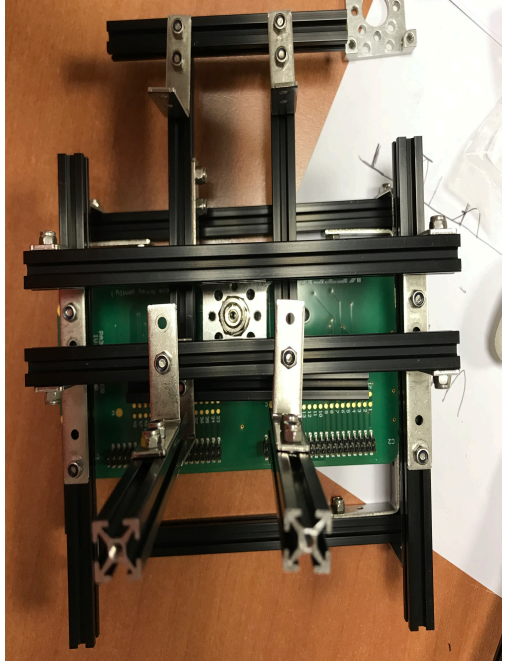


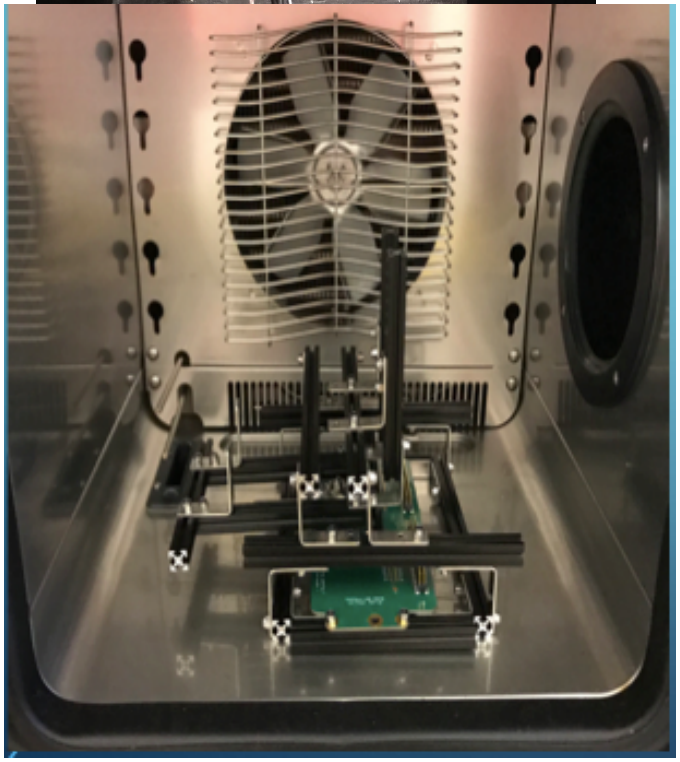


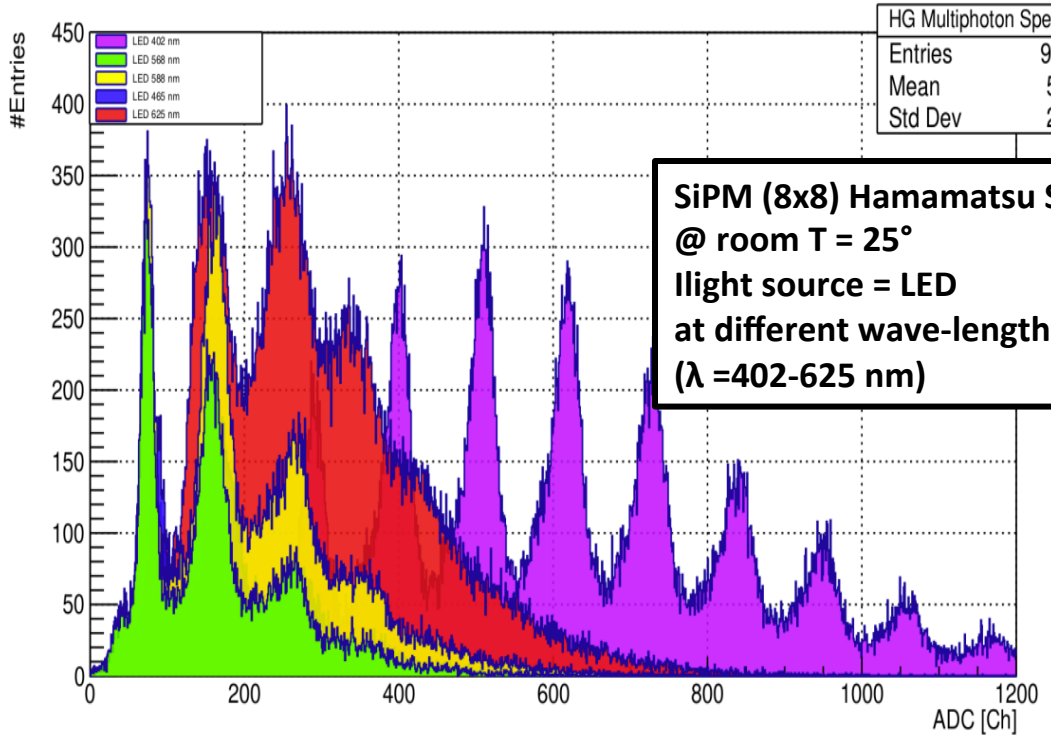





20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
50
100
150
200
250
300
350
400
450
500
550
600
(channels)
Cumulative
IDLE
00:04:56.493

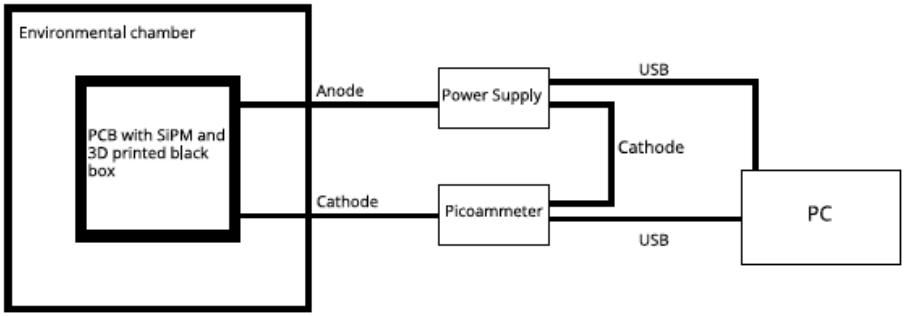






SiPM (8x8) Hamamatsu S13
@ room T = 25°
Ilight source = LED
at different wave-length
(λ =402-625 nm)

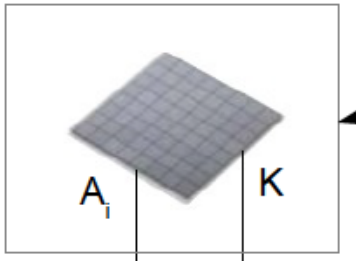
2nd PHASE (2022-2023)
(I-V) set-up or different SiPMs



ed for I-V measurements.

I-V measurement setup

ESPEC SH-242
Environmental chamber



Masurements of:

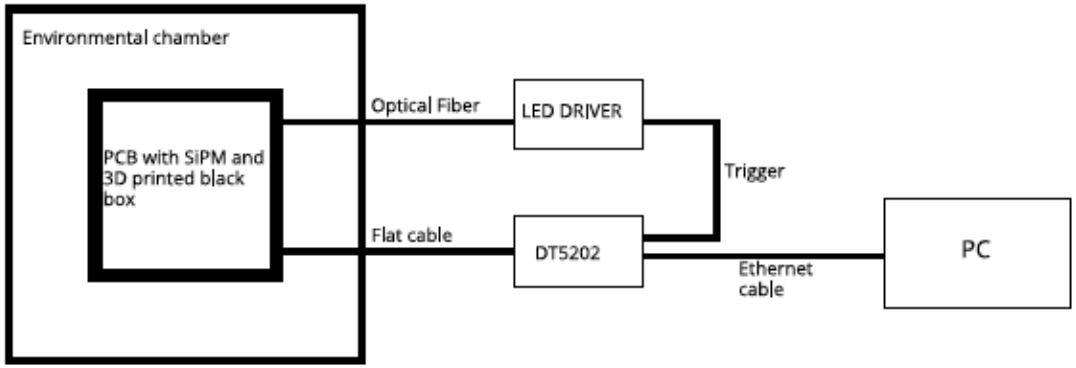
- V_{BD} = break-down voltage;
- R_q = quenching Resistance

Keithley 6487
picoammeter

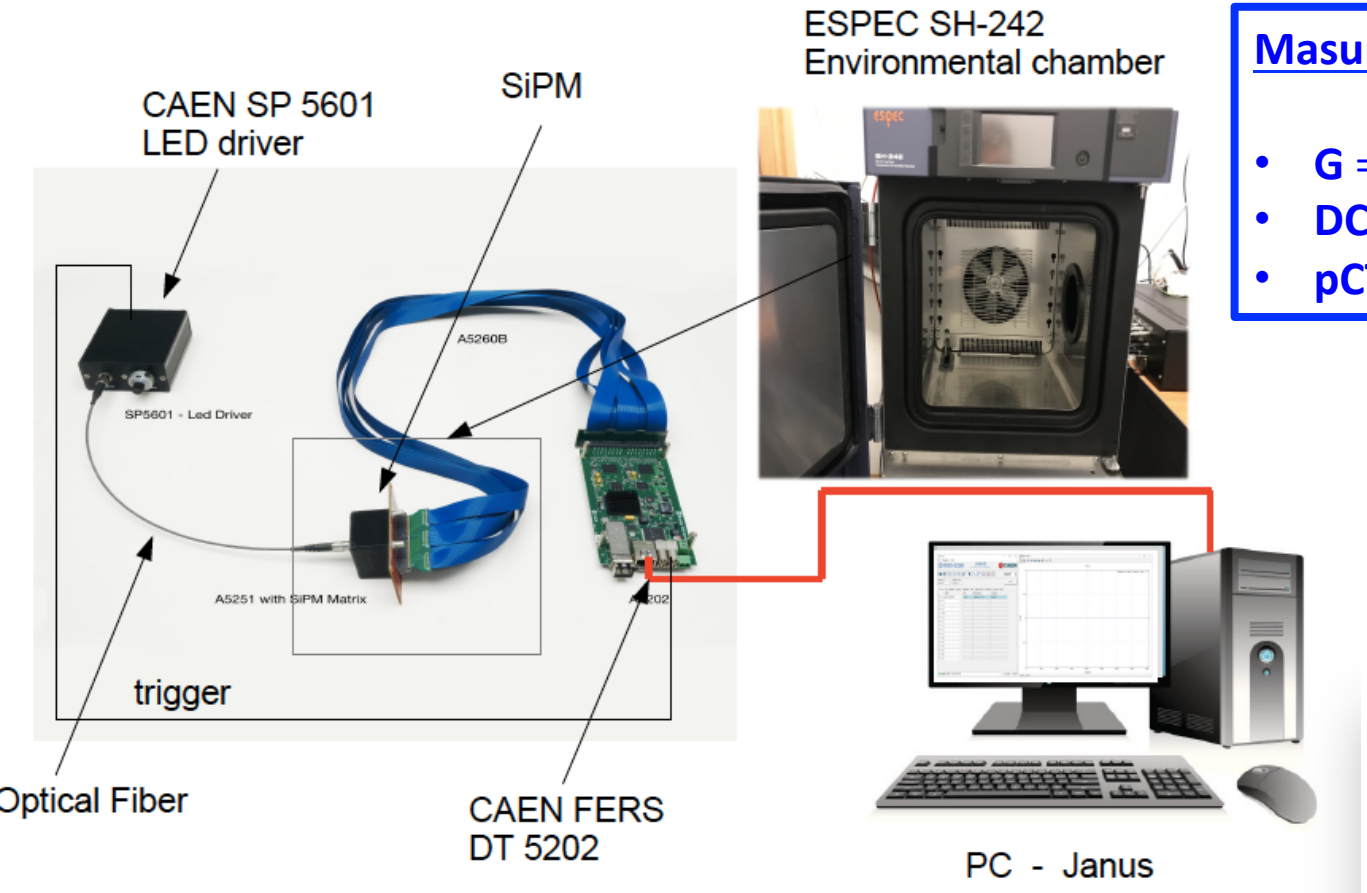
Keysight 36106 B
DC power supply

PC - LabView

II Phase (2022-2023) Set-up for Hamamatsu SiPMs



Multiphoton & staircase setup



Masurements of:

- **G** = Gain,
- **DCR** = Dark Count Rate,
- **pCT** = probability of Cross-Talk

SiPM parameters

Breakdown Voltage: V_{bd} → the most important parameter

↓

Gain(V_{ov})

PDE(V_{ov})

Best specified versus the overvoltage applied

$$V_{bias} = V_{bd} + V_{ov}$$

Breakdown voltages have been measured at several temperatures ranging from -40 °C up to 25 °C

SiPM parameters

All measurements were performed at fixed V_{bias}

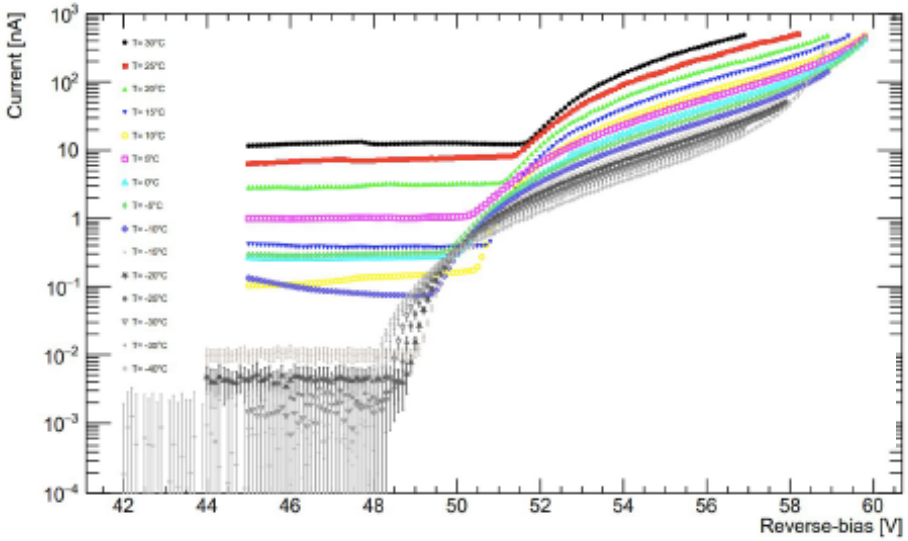
All measurements repeated in the temperature range: -40 °C / 25 °C

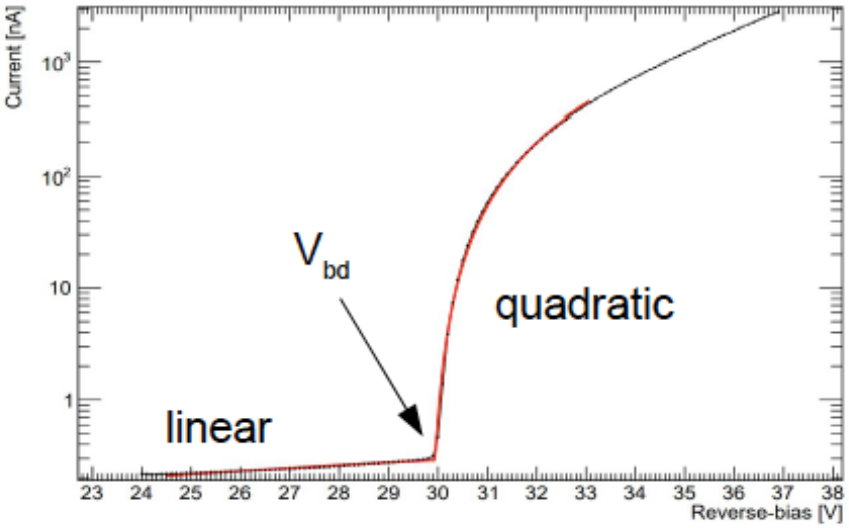
I-V curve
- reverse-bias → Breakdown Voltage → V_{bd} → $V_{bd}(T)$
- forward-bias → Quenching Resistance → R_q → $R_q(T)$

Multi-photon spectrum → Gain → G → $G(T)$
- → @ different overvoltages → $G(V_{ov})$ ← @ 25 °C (fixed)

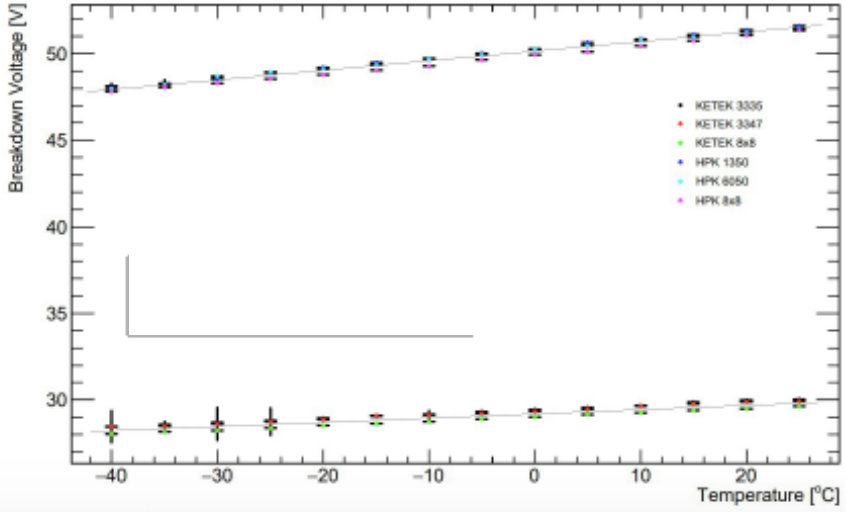
staircase
- Dark Counts Rate → DCR → $DCR(T)$
  - → @ different overvoltages → $DCR(V_{ov})$ ← @ 25 °C (fixed)
- Probability of Cross Talk → pCT → $pCT(T)$
  - → @ different overvoltages → $pCT(V_{ov})$ ← @ 25 °C (fixed)

I-V curve: reverse bias



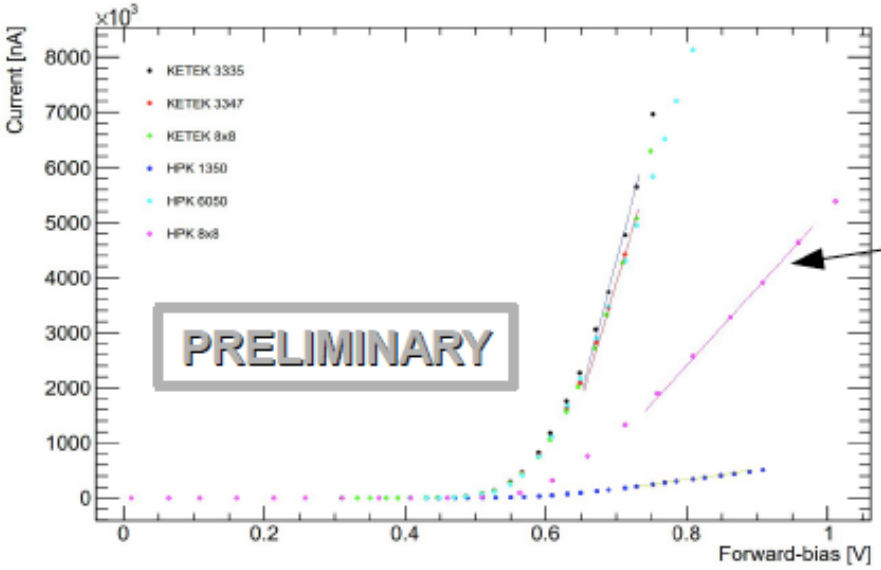


$V_{bd}(T)$

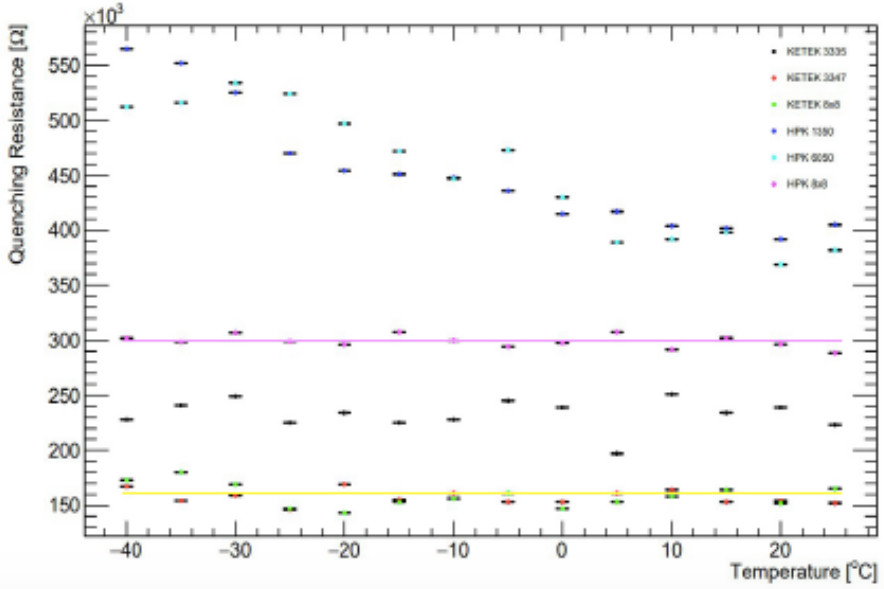


- I-V curves at different temperature
- Automated fit procedure to extract V_{bd}
- Measurement of single curve: 1 hour
- Temperature dependance of Vbd:
  - HPK: 55 mV/°C
  - Ketek: 29 mV/°C

I-V curve: forward bias

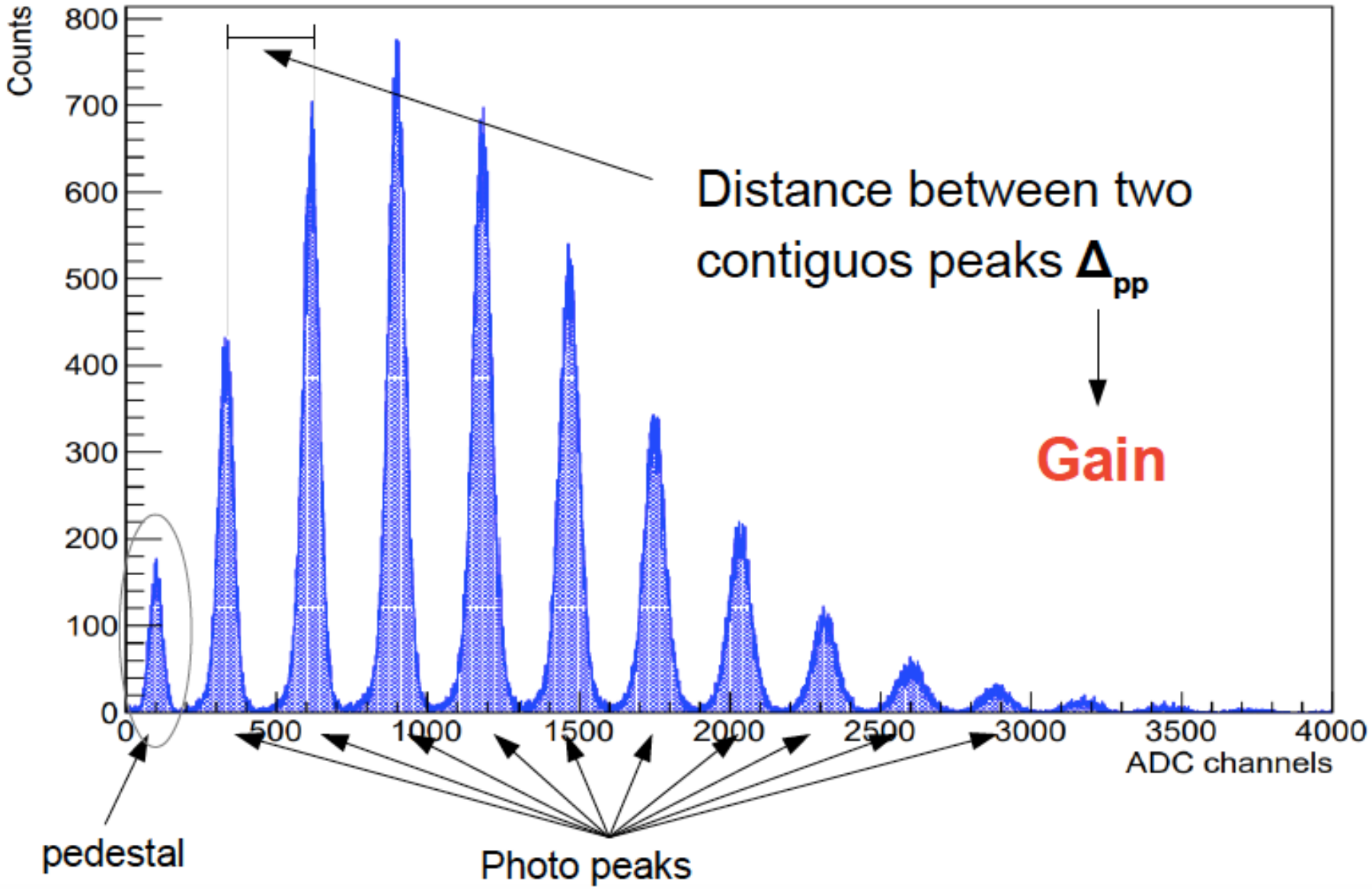


Linear fit → Quenching Resistance

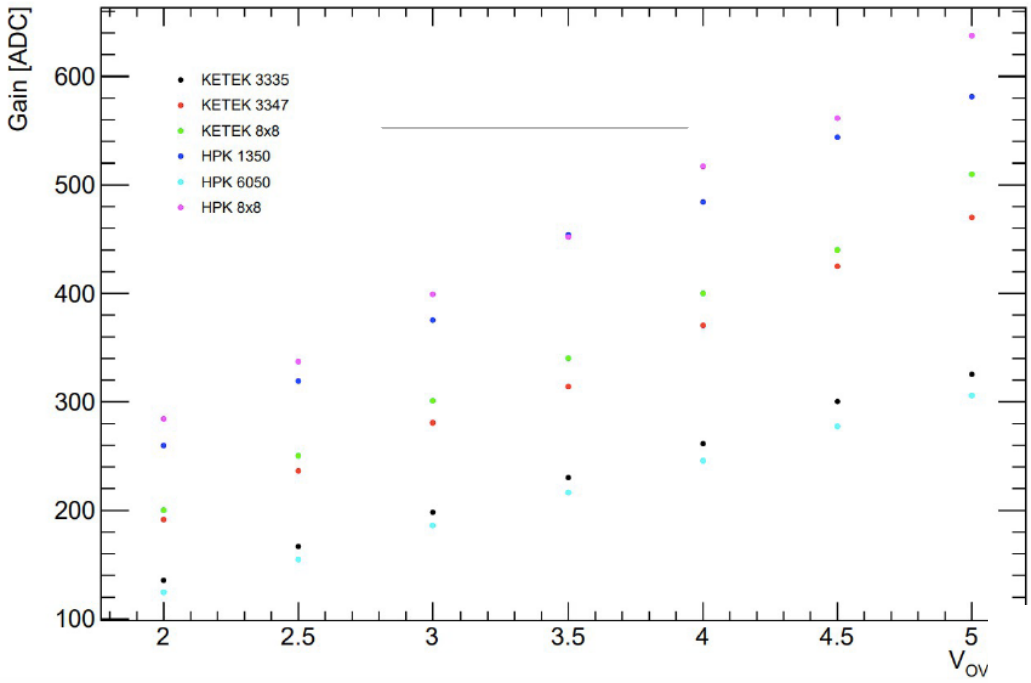


- Recovery time of the SiPM microcell depends on the R_q
- Foundamental to check that R_q deos not depend on temperature
- All ketek devices show an R_q independent on temperature
- HPK devise show a linear dependence on temperature, but not for HPK matrix

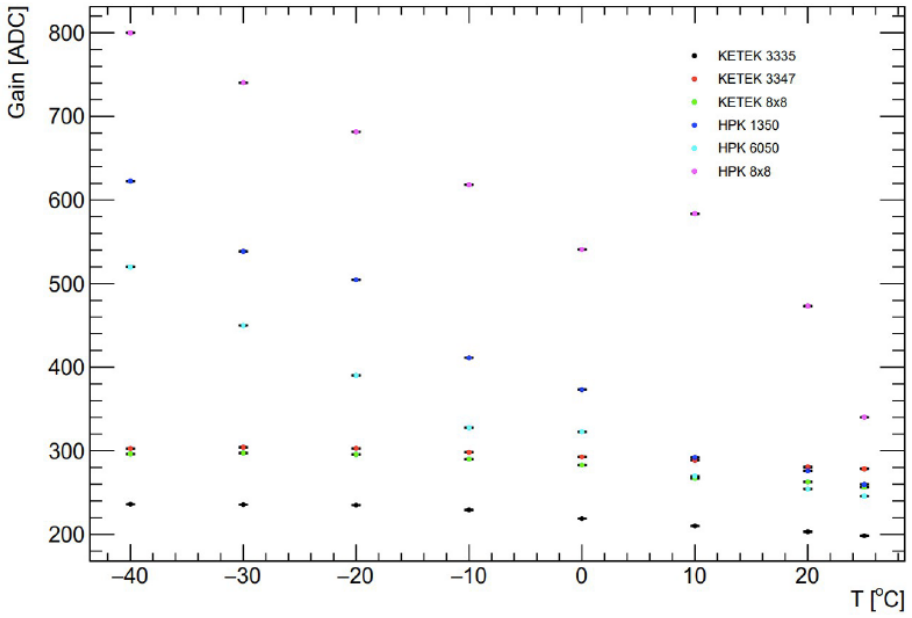
Multiphoton spectrum



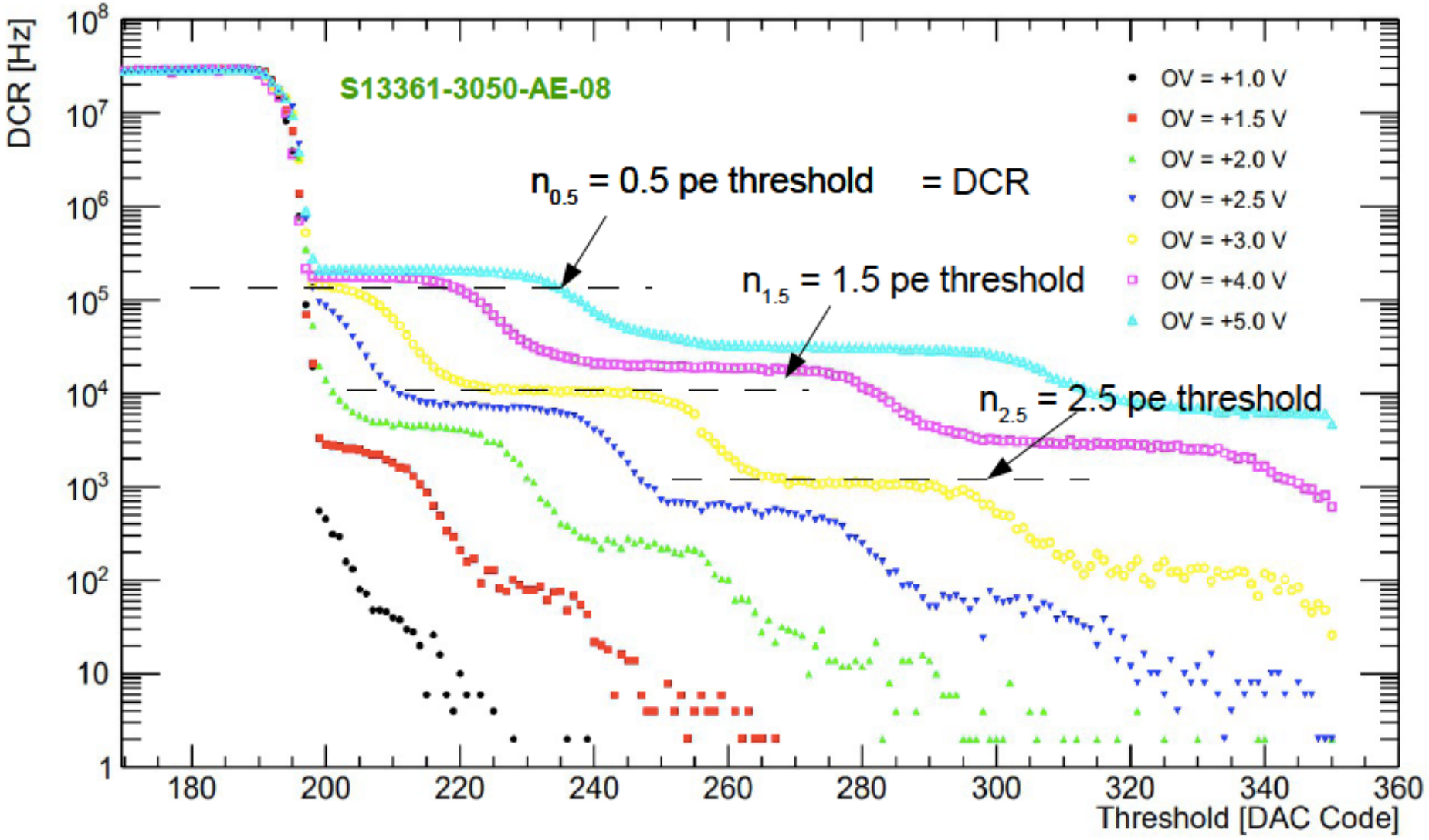
Gain(V_{ov})



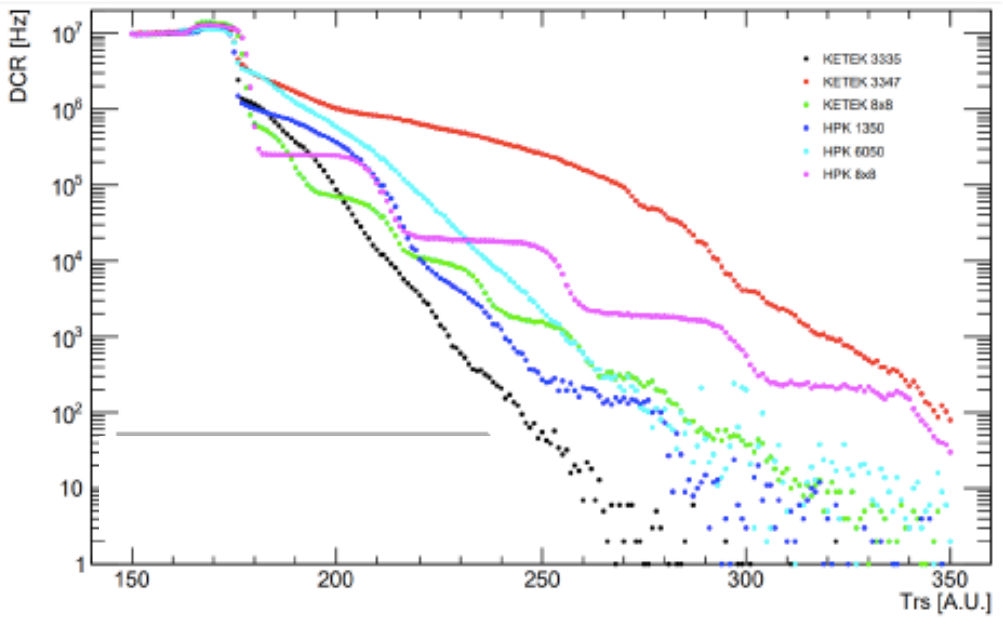
Gain(T)



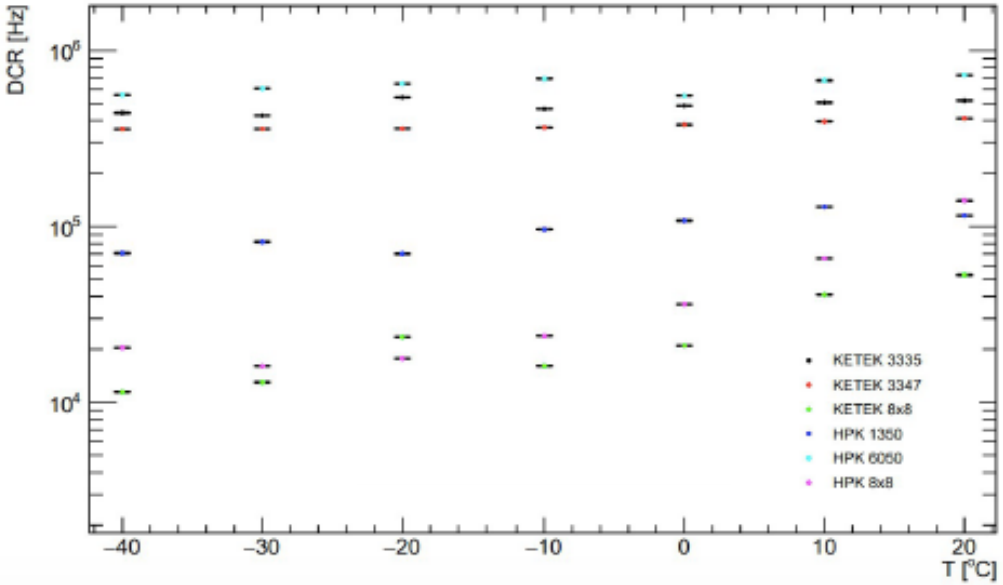
Staricase - DCR(V_{ov})



DCR



- Staircases are well defined for matrices
- Automatic fit to extract the step height
- DCR = $N_{0.5}$



- DCR decreases with decreasing temperature
- Both matrices has the lowest DCR
- The decreas is important for both matrices

Characterisation of Hamamatsu S13161-3050AE-08 SiPM (8 x 8) array at different temperatures with CAEN DT5202

R. Persiani[a,b], C. Lombardo[a,b,*], S. Millesoli[a,b], F. Tortorici[a,b], S. Albergo[a,b], F. Cappuzzello[a,c], R. Caruso[a,b], C. M. A. Petta[a,b], C. Tuvè[a,b]

[a] *Department of Physics and Astronomy "E.Majorana", University of Catania, Via S. Sofia 64, Catania, 95125, Italy,*
[b] *INFN section of Catania, Via S. Sofia 64, Catania, 95125, Italy,*
[c] *INFN Laboratori Nazionali del Sud, Via S. Sofia 62, Catania, 95125, Italy,*

NIM A, Vol. 1057, December 2023, 168732
doi: 10.1016/j.nima.2023.168732

Abstract

Silicon PhotoMultipliers, SiPMs, constitute the enabling technology for a diverse and rapidly growing range of applications: medical imaging, experimental physics, and commercial applications are only a few examples. In this work, a characterisation protocol for SiPM qualification has been applied to Hamamatsu S13161-3050AE-08 SiPM (8 x 8) array in the (-40 ÷ +30)°C temperature range. The protocol foresees to measure several parameters: breakdown voltage, quenching resistance, gain, dark count rate and probability of cross-talk. Methods to extract them and their dependence on temperature at fixed overvoltage are shown and the results are discussed.

Keywords: SiPM characterisation, breakdown voltage, quenching resistance, gain, dark count rate, probability of Cross-Talk.

5. Conclusions

This work is mainly focused on the characterization of an (8x8) SiPM matrix (Hamamatsu model S13360-3050AE-08) over a wide range of temperatures from 30 °C down to -40 °C. Two different configurations were adopted: the first uses a picoammeter to measure accurately the leakage currents in order to determine both V_{bd} and R_q, and the second one adopts a CAEN DT5202 readout system to evaluate gain, DCR and pCT. V_{bd} decreases as the temperature decreases, while the R_q seems almost independent [illegible] of fixing the same bias voltage for all temperatu constant is more convenient. Consequently, the ga the DCR level decreases as the temperatures decre

Characterization of HAMAMATSU SiPM tile: 64 channels: (8x8) matrix, (3x3) mm^2 area from -40°C to + 30°C

6. Acknowledgements

Special thanks to R. Santoro from INFN section of Milan for the several discussion on technical aspects. This work was possible thanks to the support of the University of Catania, in particular with *Finanziamento di Ateneo-Linea, di intervento 2 Piaceri, progetto MODICO*, *Finanziamento di Ateneo-Linea, di intervento 2 Piaceri, progetto MAYORANA*. This work would not have been possible without the financial support of the "A.S.I. (Italian Space Agency)"; in particular, thanks to the "ACCORDO ATTUATIVO ASI-INFN n.2021-8-HH.0 e suo Addendum n.2021-8-HH.1-2021 Accordo Quadro ASI/INFN", Research Project "EUSO-SPB2 (Extreme Universe Space Observatory-Super Pressure Balloon)", WP4400 "Characterization, Selection & Test of SiPM tiles". This

Thanks to dedicated funds by ASI, in agreement with INFN in the framework of Project "EUSO-SPB2"

I PART CONCLUSION

WP4400: "Selection, characterization and test of SiPMs"

- Founded a **Laboratory of "Photosensors for Astroparticle Physics"** at the Department of Physics and Astronomy – University of Catania & INFN-CT
Scientific Coordinator: R. CARUSO

- **Specific experimental set-ups for SiPMs measurements in thermal excursions**
- Sotware codes (LabView and Janus) developed
- Analysis tools (almost) automatized

- Inventory of SiPMs and many FE and DAQ devices acquired and usable for next tests and measurements

- **S13 Hamamatsu (8x8) SiPM tile with best performances as function of temperature (-40° - + 30°) for future applications**

- **published paper:** R.Persiani et al. NIM A, Vol. 1057, December 2023, 168732

- **contribution** presented at **Conference ASAPP2025**:
R.Caruso : *"Study of performances and characterization of SiPMs (Hamamatsu S13161-3050AE-08) for the next generation of telescopes in balloon-borne & space-based experiments"*

UNIVERSITÀ degli STUDI di CATANIA

DIPARTIMENTO DI FISICA E ASTRONOMIA "ETTORE MAJORANA"

INFN CATANIA

Agenzia Spaziale Italiana

I PART: PREMISE

Study of performances and characterization of SiPMs for the next generation of telescopes in balloon-borne & space-based experiments

II PART: APPLICATION to PBR case

The test and calibration system of the Elementary Cell for the PBR Cherenkov Camera

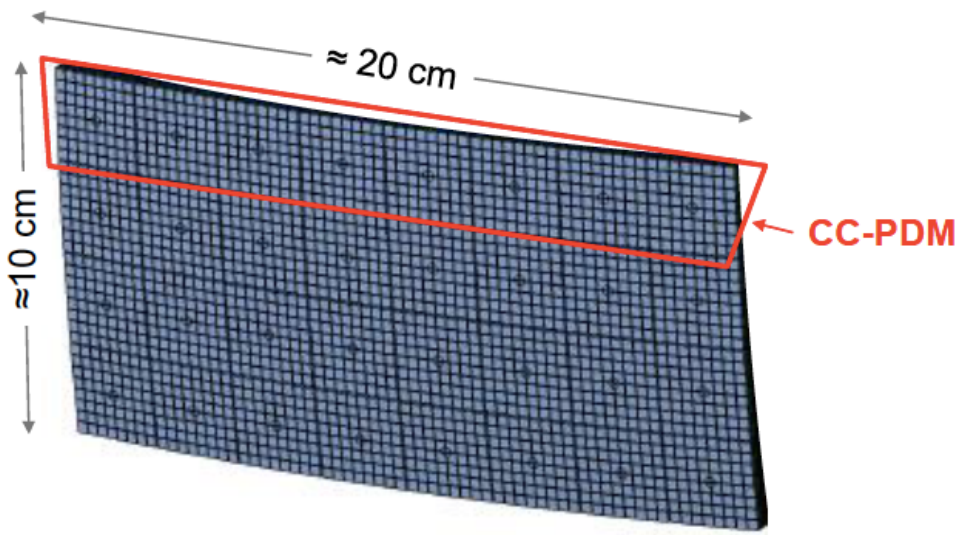
CHERENKOV CAMERA OVERVIEW

Requirements: (from simulations)

- **Pixel size: 3 x 3 mm²**
- **Pixel FoV: 0.2°**
- **Total FoV: 12° x 6°**

Implementation:

- **SiPM arrays:**
  - 64 pixels (8 x 8)
    - 4 x 8 = 32 SiPM arrays
    - 2048 pixels
  - four **CC-PDM**s (1x8 SiPM arrays, 512 pixels)



SIPM ARRAY STATUS

Hamamatsu S13361-3050 series

- S13361-3050-NE-08 (8x8ch), pixels 3mm²

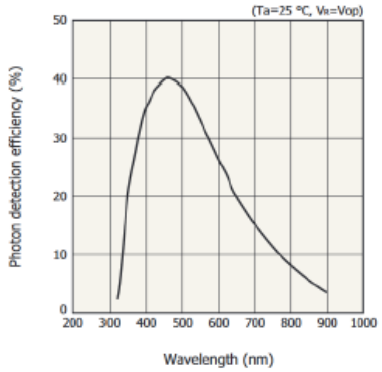
Absolute maximum ratings

Parameter	Symbol	S13361-3050NE-04	S13361-3050AE-04	S13361-3050NE-08	S13361-3050AE-08	Unit
Operating temperature*2	Topr	-20 to +60				°C
Storage temperature*2	Tstg	-20 to +80				°C
Soldering temperature*3	Tsol	240 (twice)	-	240 (twice)	-	°C

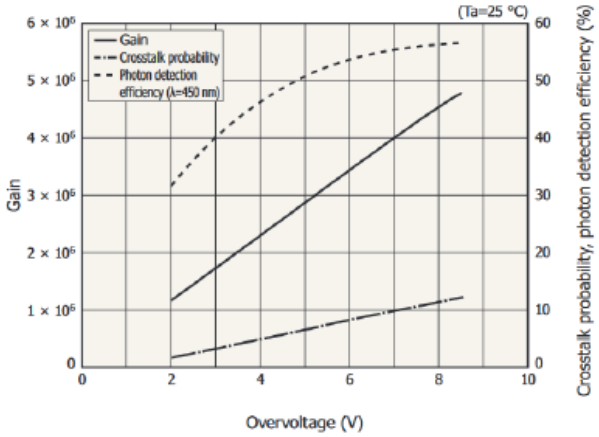
Electrical and optical characteristics (Typ. Ta=25 °C, Vover=3 V, unless otherwise noted)

Parameter		Symbol	Value	Unit
Spectral response range		λ	320 to 900	nm
Peak sensitivity wavelength		λp	450	nm
Photon detection efficiency (λ=λp)*4		PDE	40	%
Dark count*5	Typ.	CD	0.5	Mcps
	Max.		1.5	
Terminal capacitance		Ct	320	pF
Gain		M	1.7×10^6	-
Breakdown voltage		VBR	53 ± 5	V
Recommended operating voltage		Vop	VBR + 3	V
Vop variation between channels in one product	Typ.	-	0.1	V
	Max.		0.3	
Temperature coefficient of recommended operating voltage		ΔTVop	54	mV/°C

Photon detection efficiency vs. wavelength (typical example)



Overvoltage specifications of gain, crosstalk probability, photon detection effici

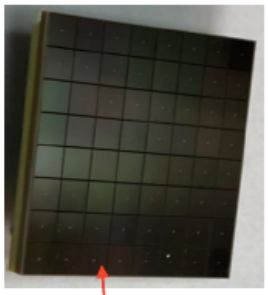


S13361-3050-NE-08

- 17 available for prototyping studies
- 50 ordered (delivery by the end of January)

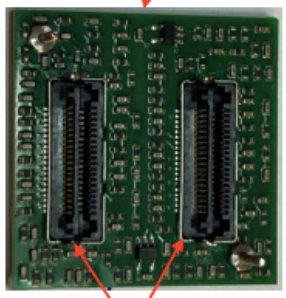
THE ELEMENTARY CELL

Status:
- 13 prototypes manufacture

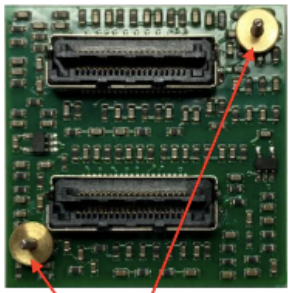


S13361-3050AE-08

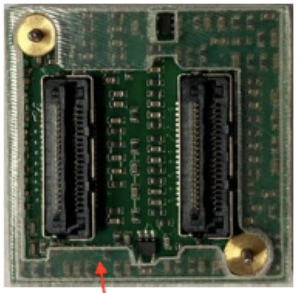
Custom PCB



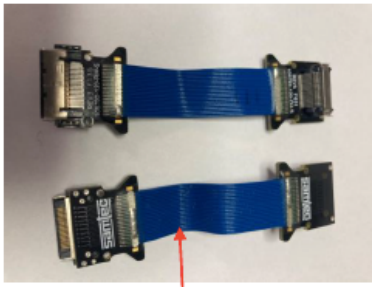
(Samtec) 40 positions
LSHM-120-02-5-L-DV-A-S-TR



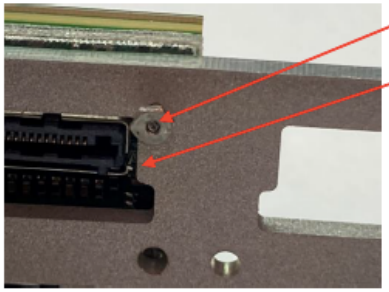
M1 screws



3D printed spacer



(Samtec) 40 positions 38 AWG coax
HLCD-20-12.00-TD-TH-1



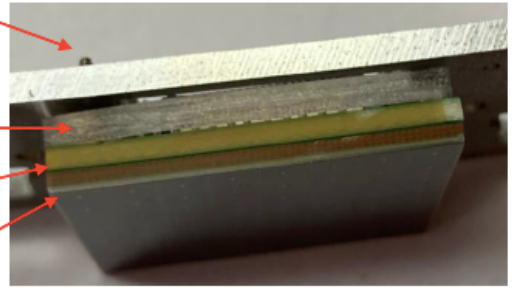
M1 screw

(Samtec) 40 positions
LSHM-120-…

3D printed spacers

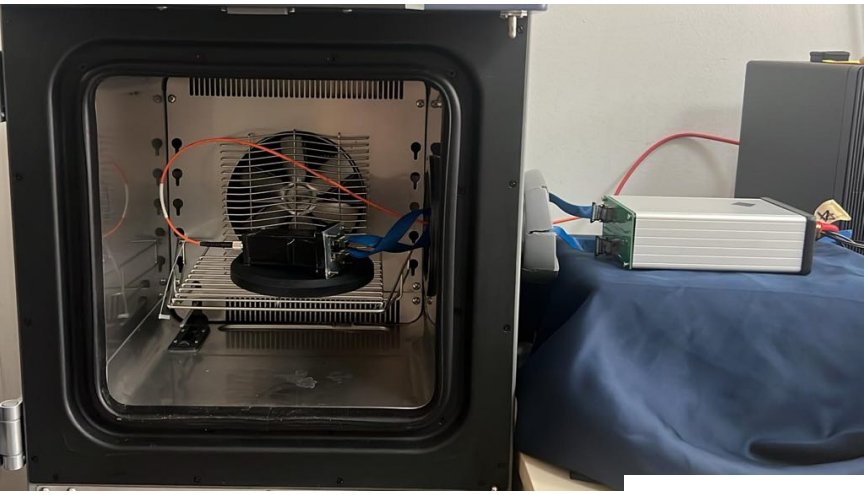
Custom PCB

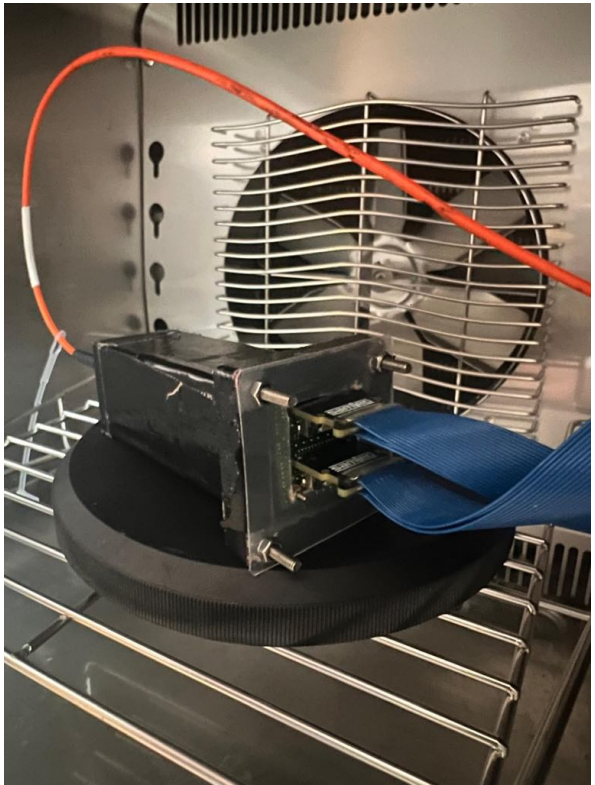
S13361-3050AE-08

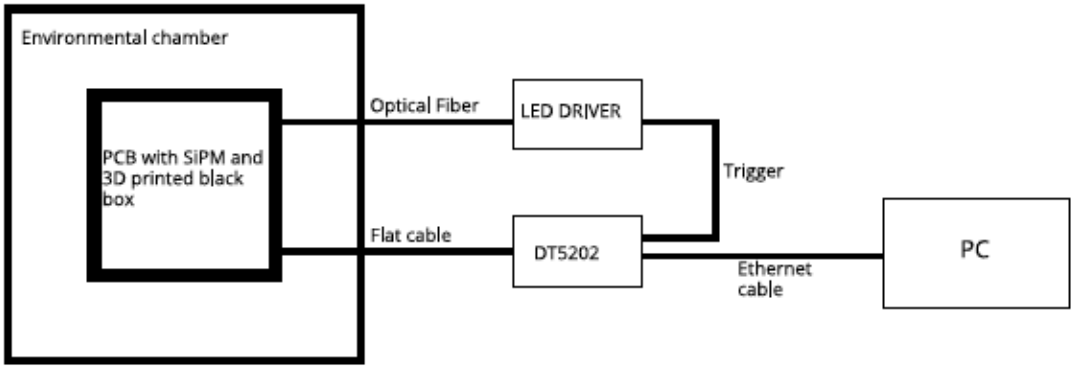


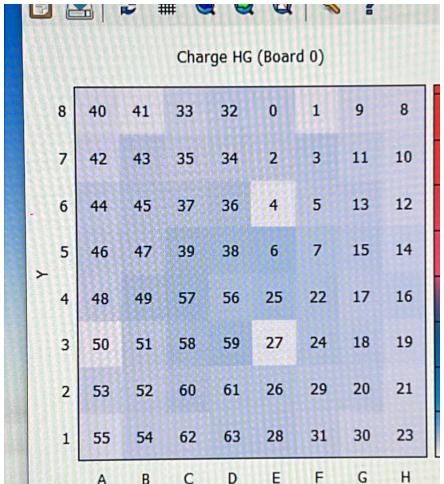
Elementary cell (side view)

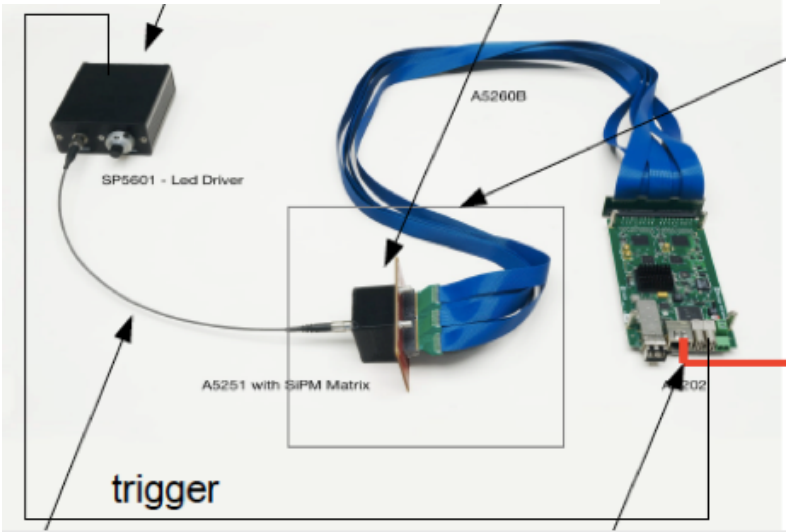
- **On April 17th, 2025, the shipment of one Elementary Cell arrived in Catania from Naples.**
- **We started with test and meaurements of basic parameters at different temperatures!**

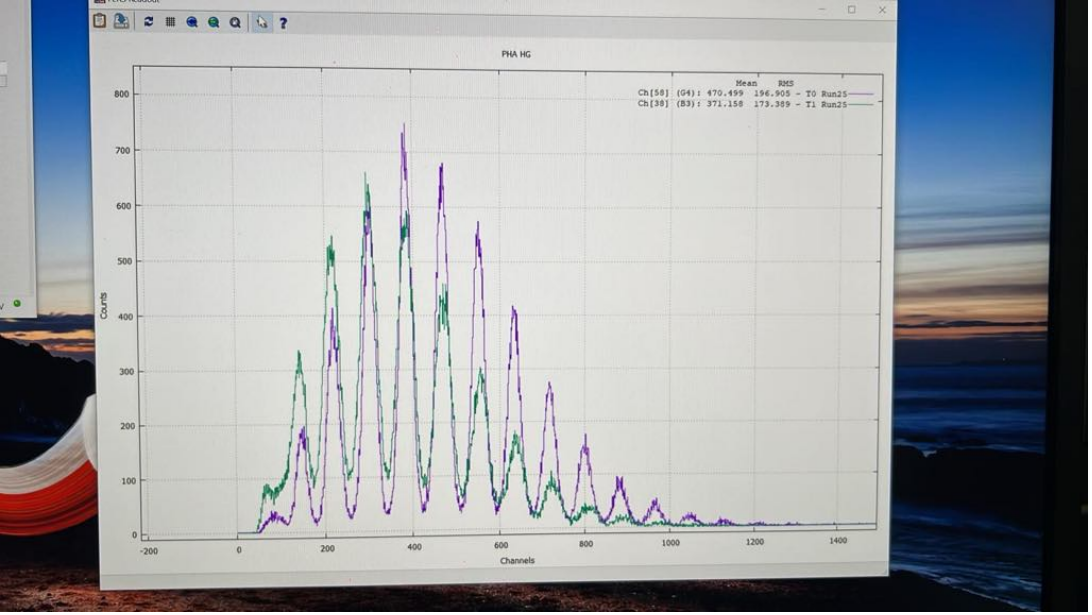





Environmental chamber
PCB with SiPM and 3D printed black box
Optical Fiber
Flat cable
LED DRIVER
DT5202
Trigger
Ethernet cable
PC


Charge HG (Board 0)
8 40 41 33 32 0 1 9 8
7 42 43 35 34 2 3 11 10
6 44 45 37 36 4 5 13 12
5 46 47 39 38 6 7 15 14
4 48 49 57 56 25 22 17 16
3 50 51 58 59 27 24 18 19
2 53 52 60 61 26 29 20 21
1 55 54 62 63 28 31 30 23
Y
A B C D E F G H


SP5601 - Led Driver
A5260B
A5251 with SiPM Matrix
trigger



Use of **Notion Sotware**:
the open AI Workspace for archive and sharing data files, documents, plots, …

Test SIPM ...

Search
Home
Inbox 1

Private
Getting Started
1:1 notes
Scratchpad

Teamspaces
Gruppo Catania
Test SIPM
SPB2
Accordo ASI

Settings
Templates
Trash

Gruppo Catania / Test SIPM / Dati SIPM 00

Share

Dati SIPM 00

Table

Primo Test a passi di 10°C da [-20

Aa Temperatura [°C]	Range V
T= 30° ± 0.5	54.0 - 58.0
T= 20° ± 0.5	53.0 - 57.0
T = 10° ± 0.5	52.5 - 56.5
T = 0° ± 0.5	52.0 - 56.0
T = -10° ± 0.5	51.5 - 55.5
T = -20° ± 0.5	51.0 - 55.0

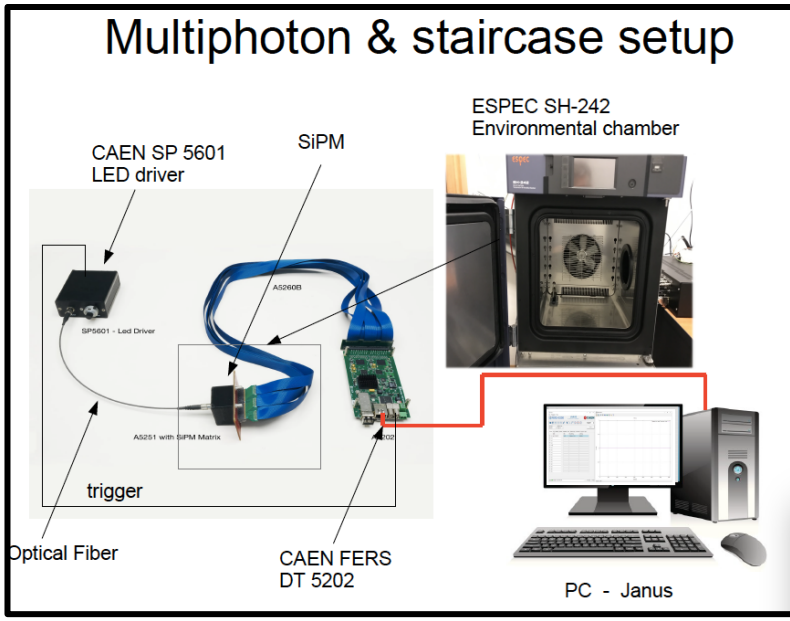
New page

SiPM00_Temp00.root 2342.4KB

N° Run	Vbias [V]	Intensità LED
183	52.0	8.5
184	52.5	8.5
185	53.0	8.5
186	53.5	8.5
187	54.0	8.5
188	54.5	8.5
189	55.0	8.5
190	55.5	8.5
191	56.0	8.5
174	52.0	0
175	52.5	0
176	53.0	0
177	53.5	0
178	54.0	0

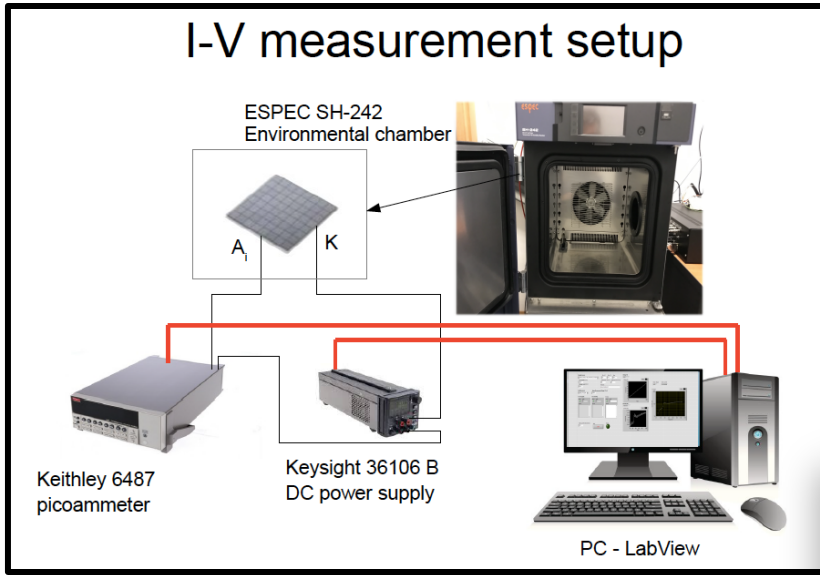
Performed MEASUREMENTS:

- **(-40° ÷ +30°)** temperature range; step **ΔT = 10 C°**
- for each T, 9 diffent V_{bias}
- **Multi-peak spectrum (at low intensity LED) → G**
- **Staircase curve (OFF LED) → dark count rate (DCR)**
  cross-talk probability (pCT)
- **Analysis in progress (conclusion: next week)**



MEASUREMENTS To BE DONE

- **(-40° ÷ +30°)** temperature range; step **ΔT = 10 C°**
- **(I-V) curve → break-down Voltage (V_{BD})**
  quenchin Resistance (Rq)
- COMPARISON of results of two HAMAMATSU S13 analysed in 2 different phases
- protocol of measurements & list of key parameters to be fixed for massive calibrations



Procedure *deep* for EC massive calibration and timing

- Test at 20 °C and -50 °C; 40 minutes from 20 °C to -50 °C, 35 minutes from -50 °C to 20 °C

For each EC:

- dark spectrum + light spectrum: 60-90 minutes for the entire tile
  - Multi-peak spectrum, Poissonian on first fingers;
  - use PDE/spectrum to find broken pixel;

- IV-curve (at least 100 points), 10 minutes x each

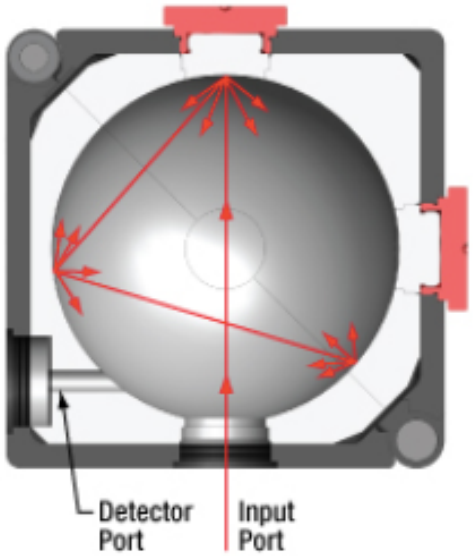
2x 8 hours test!

N.2 Integrating Spheres & accessories

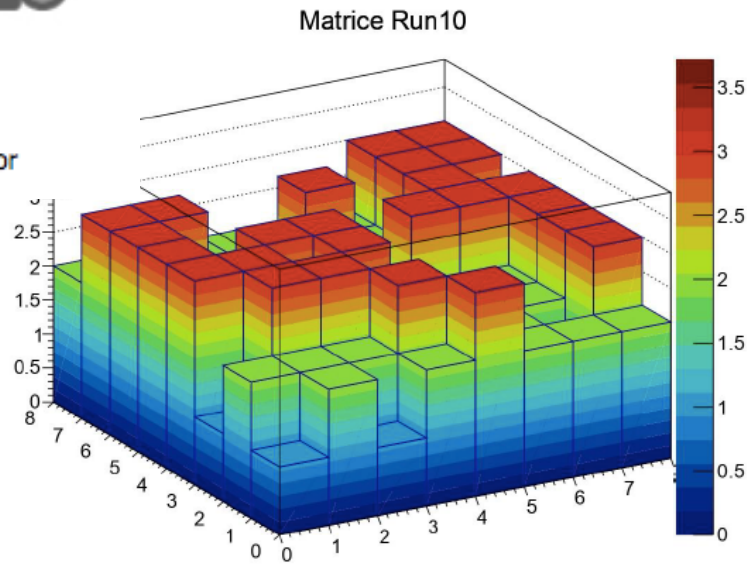
2P4M Thorlabs 50 mm

available at Laboratory of photosensors for Astroparticle Physics
for uniform illumination of the CC EC and/or PDE and/or FS
and **photon detection efficiency (PDE)** of the EC

Click to Enlarge
Layout of Ports on Integrating Sphere Housing



Click to Enlarge
Integrating Sphere Interior

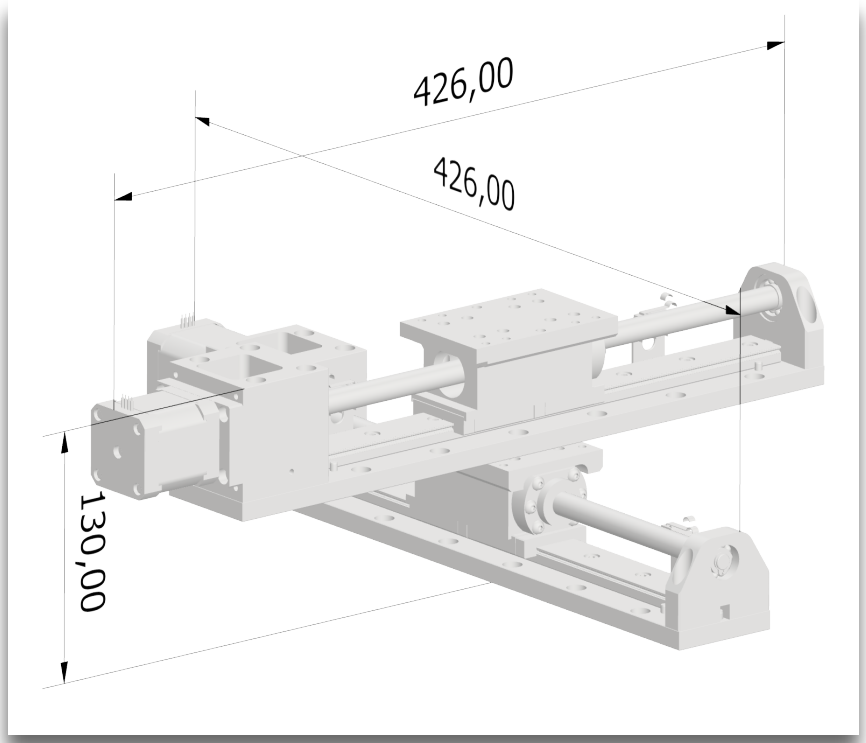


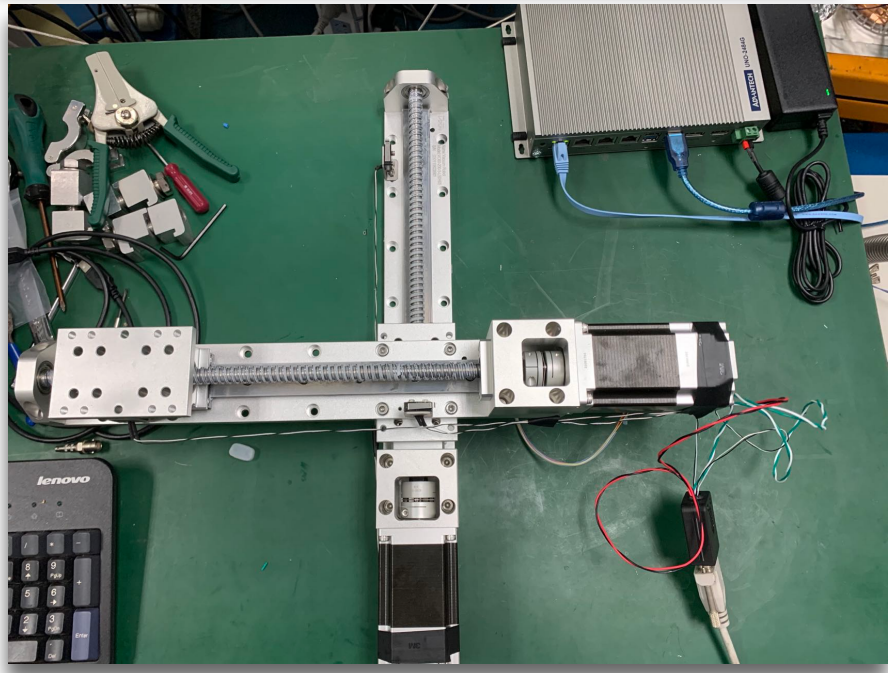
POSSIBLE DEVELOPMENT in the set-up!

POSSIBLE DEVELOPMENT in the set-up!

STANDA XYZ translation system
426mm (X) x 426mm (Y) x 130 (Z)
operation temperature range
(-50° + 85°)
possible to be procured
for regular precise moviments in illuminating the CC PDM or FS

Alternatively:
Thorlabs XY Ztranslation stage
150 or 300 mm
not for lower temperatures





Parameter	Value
Travel range:	200 mm
Max speed:	5 mm/sec
Operation temp.:	-50 ÷ +85 C
Weight:	3 kg

POSSIBLE DEVELOPMENT in the set-up!

Bigger and powerful **Climate Chamber**
600mm (L) x 801mm (W) x 694mm (H)
wider temperature range
(-75° + 180°)
available at INFN - CT

GENERALI		
RAFFREDDAMENTO		
Potenza frigorifera	kW	37,2
Potenza assorbita totale	kW	15,1
EER		2,47
SEER		6,01
Portata d'acqua	l/s	2,01
Prevalenza utile pompa	kPa	152,68

DIMENSIONI (mm)		
A - Lunghezza	**B - Profondità**	**C - Altezza**
2255	1022	1788

PESI (Kg)			
Peso netto		kg	587

DATI ELETTRICI			
F.L.A. CORRENTE ASSORBITA ALLE MASSIME CONDIZIONI AMMESSE			
F.L.A. - Totale		A	39,7
E1 MASSIMA POTENZA ASSORBITA			
E1 - Totale		kW	19,2
L.R.A. MASSIMA CORRENTE ALLO SPUNTO DELL'UNITA'			
L.R.A. - Valore		A	124,1

NEXT STEPS & CONCLUSIONS

- waiting for next stock of EC of the PBR CC in Catania for testing and calibrating all them step by step

WE ARE READY!

- next calibration of the each CC PDM or the whole PBR Focal Surface?

- possible improvements in the set-ups

- Catania SIPM Test Facility as Calibration Site for the PBR Collaboration!