FBK SiPM measurements summary

Maura Spanu (University of Milano Bicocca)

on behalf of MiB, Bologna, Ferrara, CIEMAT, Prague, IFIC and NIU groups

DUNE Collaboration Meeting

Sept 21, 2021

Tests overview

On June 2021 we received a batch of 250 SiPM boards from FBK (including both single trench and triple trench).

As usual, boards were split between labs in order to perform the usual measurements and compare the results.

Measurements, performed at LN2 temperature, are:

- **I-V curve (both at RT and LN2)**
- **Gain**
- **Noise (correlated and dark)**
- **S/N**
- Measurements were performed with SiPM voltage to obtain 40%, 45% and 50% of PDE.

Laboratories overview (FBK)

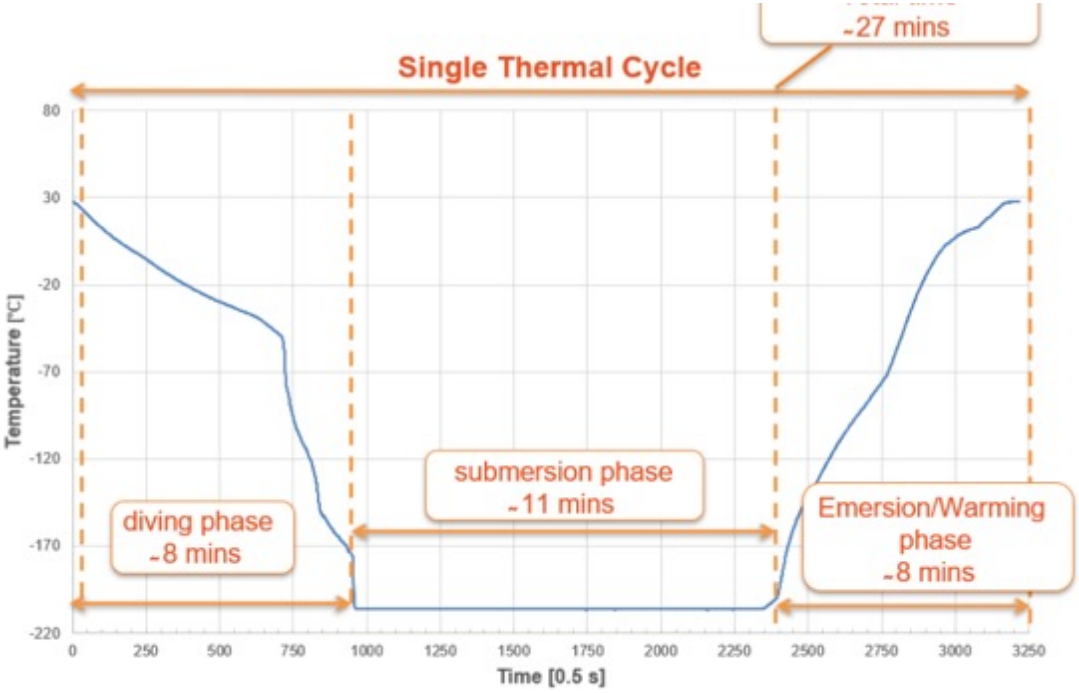
		LN2 - First cycle								LN2 - Last cycle							
Institute	**Model**	**Vbd**	**Rq**	**Gain**	**AP**	**XT**	**DCR - burst**	**DCR + burst**	**S/N**	**Vbd**	**Rq**	**Gain**	**AP**	**XT**	**DCR - burst**	**DCR + burst**	**S/N**
M-Bicocca	NUV-HD-Cryo									X	X	X	X	X	X	X	X
	Triple Trench									X	X	X	X	X	X	X	X
IFIC - Valencia	NUV-HD-Cryo	X	X	X	X	X	X	X	X	X	X	X					X
	Triple Trench	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Bologna	NUV-HD-Cryo									X	X		X	X			
	Triple Trench									X	X		X	X			
Ferrara	NUV-HD-Cryo									X	X		X	X	X	X	
	Triple Trench									X	X		X	X	X	X	

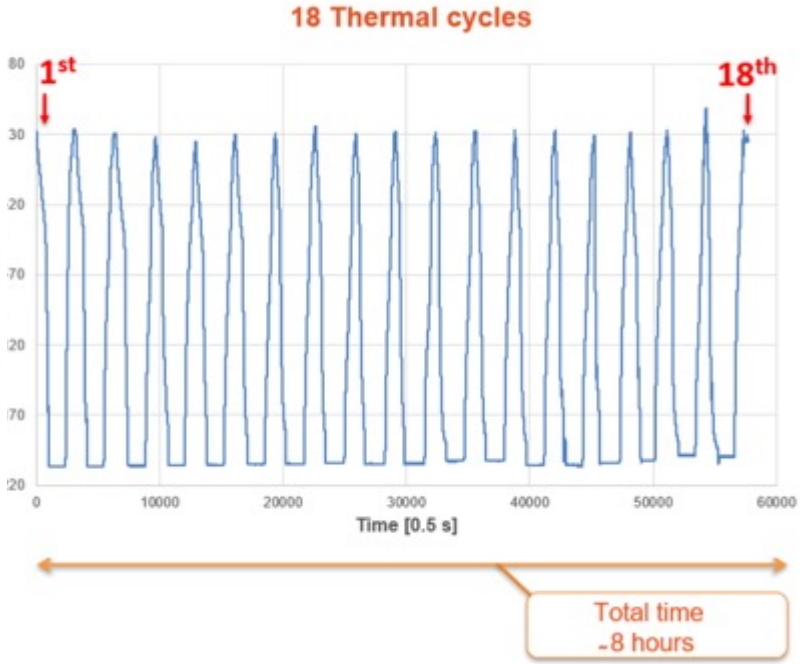
I-V curve was measured on all SiPM before and after a cycle of 16 thermal cycles, to obtain 20 cycles in total (2+16+2).

After the thermal cycles, we also had the “scope” measurements on one sample board per type.

Slow thermal cycles @Bologna

All the laboratories followed the same specific procedure for thermal cycles.





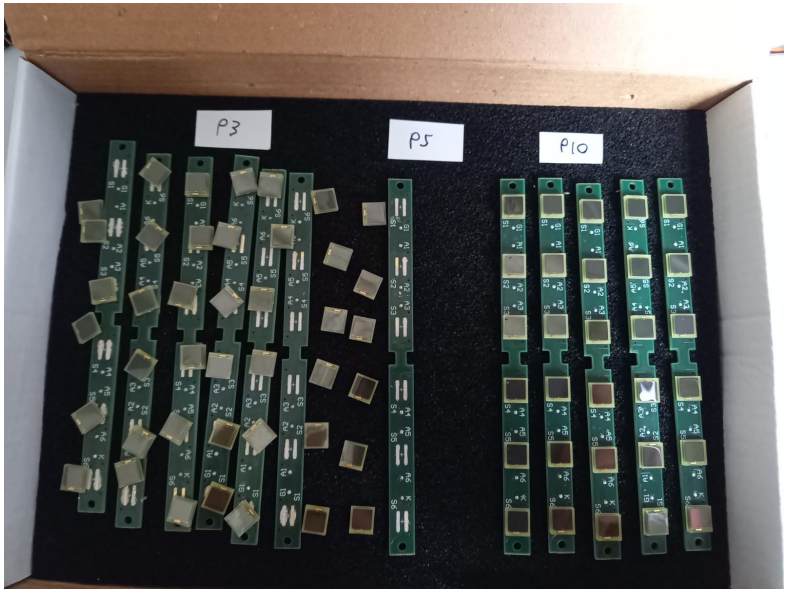
SiPM “escape” after termal cycles

After the first thermal cycle, half of the 3T SiPM broke away from their boards. The same happened to the 1T after the 19th cycle.

According to FBK, they were all coming from the same production batch so there was probably a human mistake on the gluing step.

They sent the SiPM back to Milan in July and we managed to complete the tests.

3T

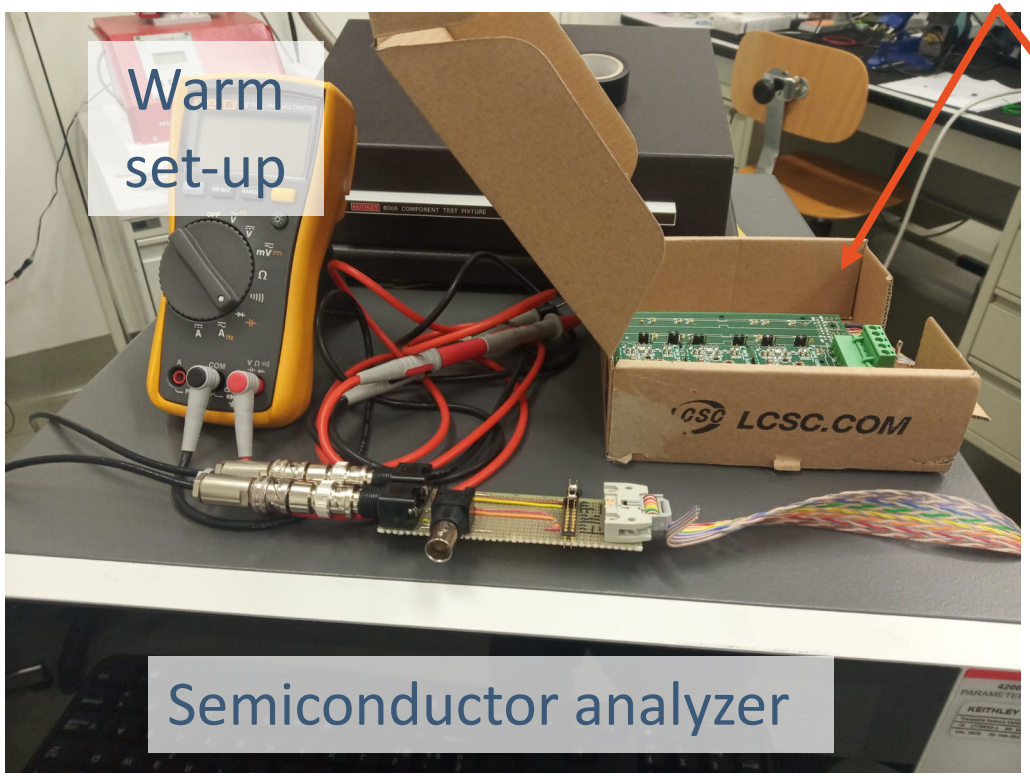


1T

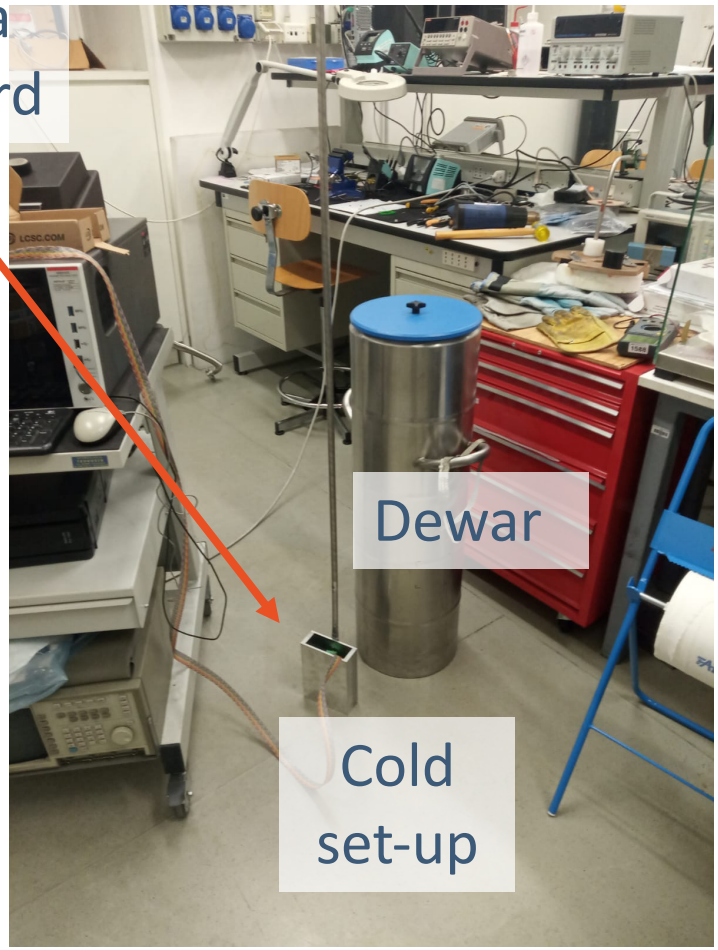
SiPM tests summary

- I-V curve
- Gain
- Noise (correlated and dark)
- S/N

I-V curve measurements @ Milano Bicocca



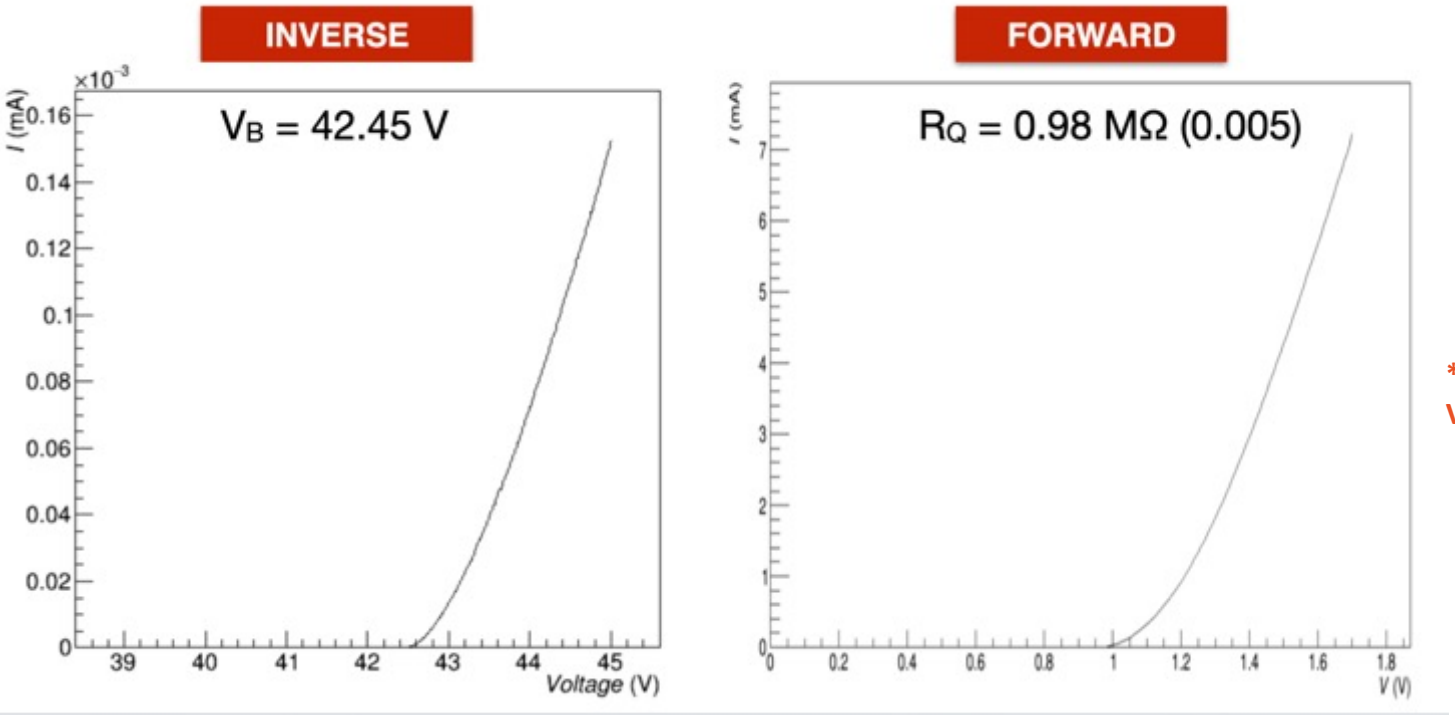
Bologna
cold board



I-V curves measurements

Breakdown voltage is measured with SiPM in reverse mode.

Quenching resistance is measured with SiPM in forward mode (between 1.1 and 1.5 V). The measured resistance must be multiplied for the micro-cells number, in order to obtain the quenching resistance value.

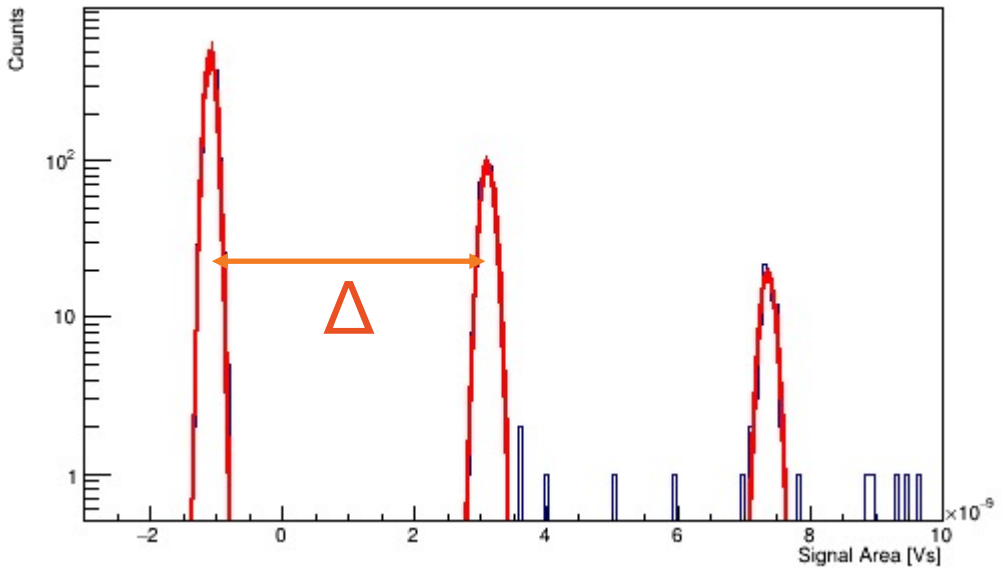


* HPK 6050-LRQ @IFIC-Valencia

SiPM (scope) tests summary

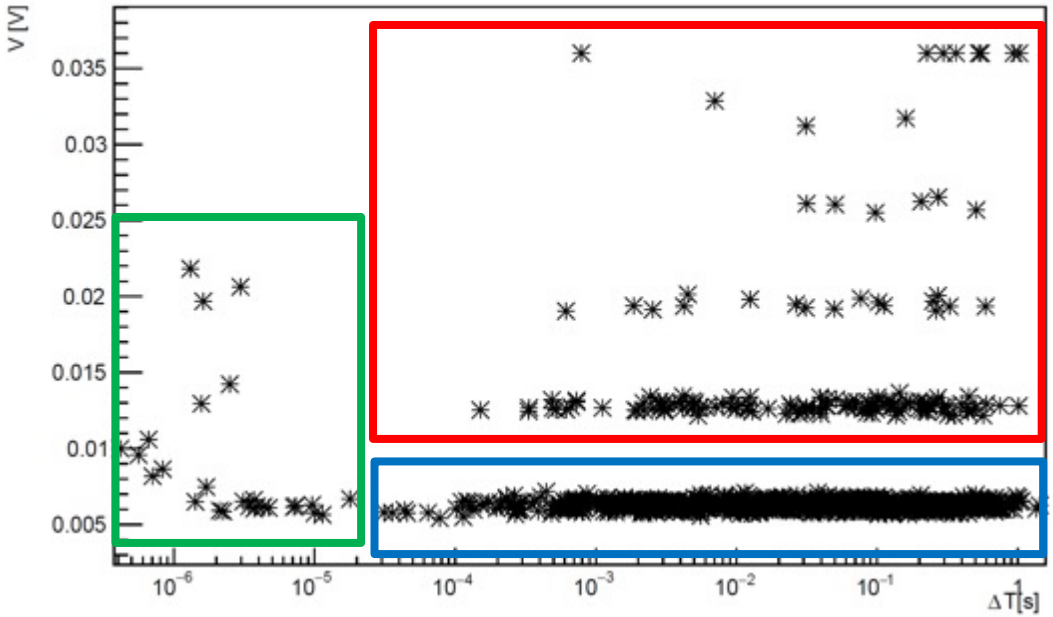
- I-V curve
- Gain
- Noise (correlated and dark)
- S/N

Gain measurements



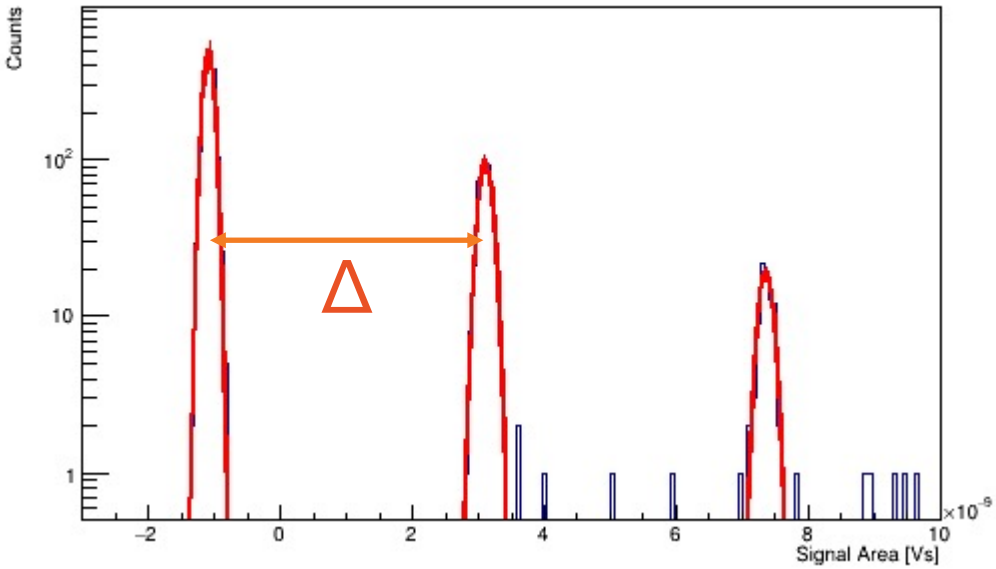
- The gain measurements were performed with the SiPM enlightened by a LED pulser.
- Waveforms per SiPM per OV have been collected with an oscilloscope (2 μs window and 2 ns sampling).
- The waveform integral is then plotted, the distance between 0 pe and 1 pe peak is the gain.

Dark Noise measurements



- For dark measurements, waveforms were acquired in dark condition, triggering at 0.5 pe level.
- As **crosstalk** the ration between events with peak > 1.5 pe and the ones with peak > 0.5 pe is considered.
- The **afterpulse** probability is the number of events with one or more peaks after the **main pulse**, divided by the number of main pulses.

S/N ratio



To measure the S/N ratio, the same waveforms collected for the gain were used.

Three S/N definition have been considered:

- S/N 1 = Δ/σ_{1pe} ←
- S/N 2 = Δ/σ_{0pe}
- S/N 3 = $\Delta/\sqrt{[(\sigma_{1pe})^2+(\sigma_{0pe})^2]}$

Further test: ganging test @MiB

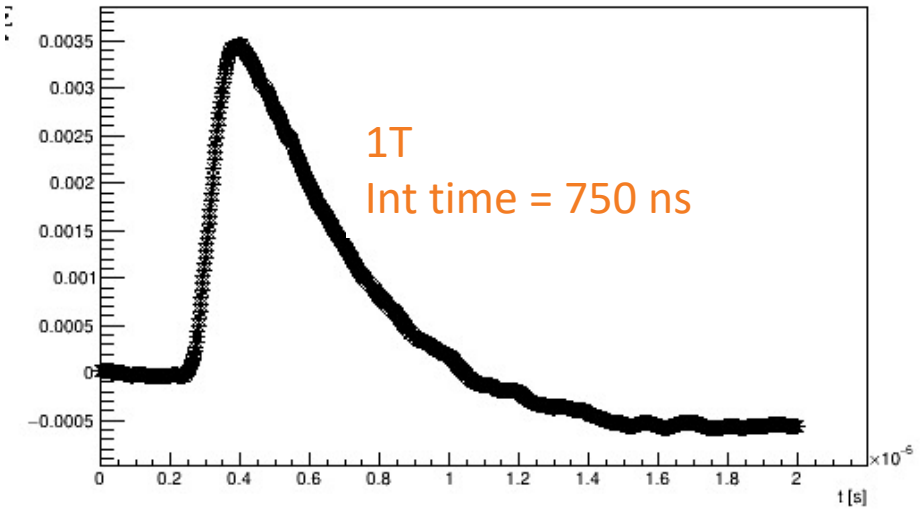
We performed tests on all FBK SiPM for 40%,45%,50% PDE.

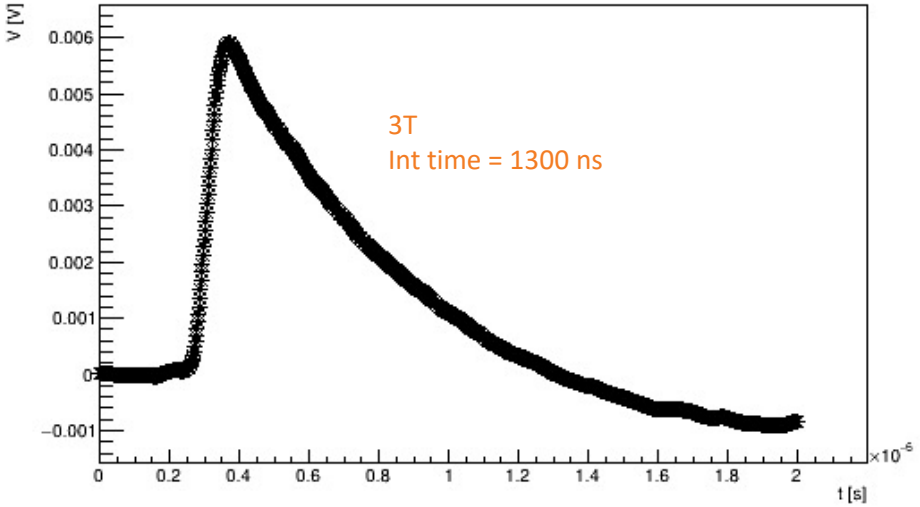
Voltages are :

- 1T : 4 V – 5 V – 7.5 V OV
- 3T: 3.5 V – 4.5 V – 7 V OV

No change was performed in amplification chain with respect to HPK measurements.

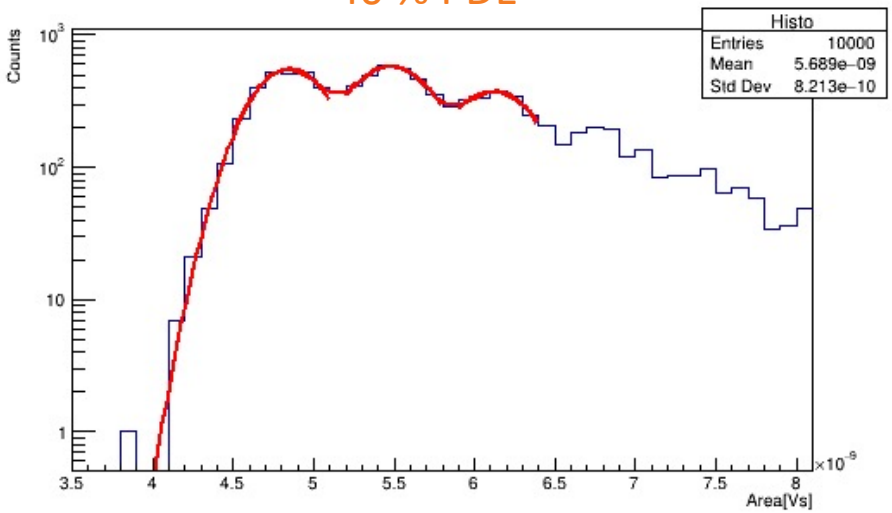
More details on the ganging test and electronics setup at Claudio Gotti's talk on Thursday.



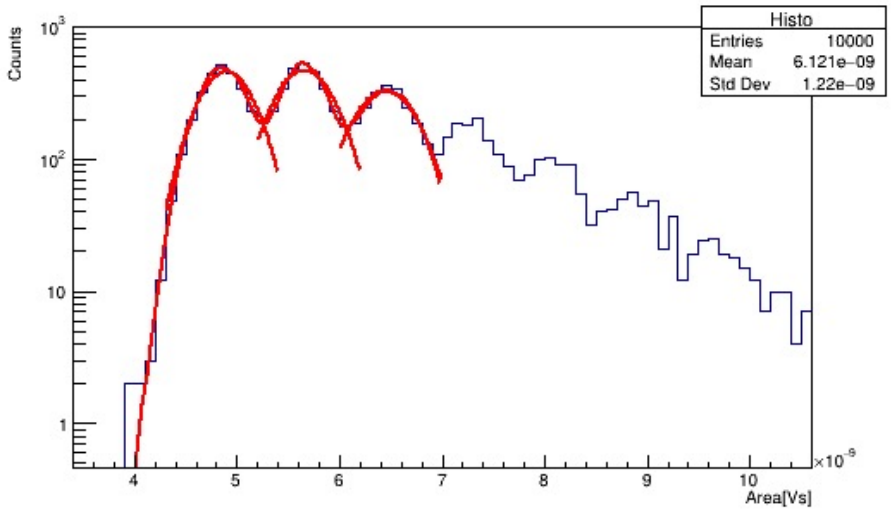


1T

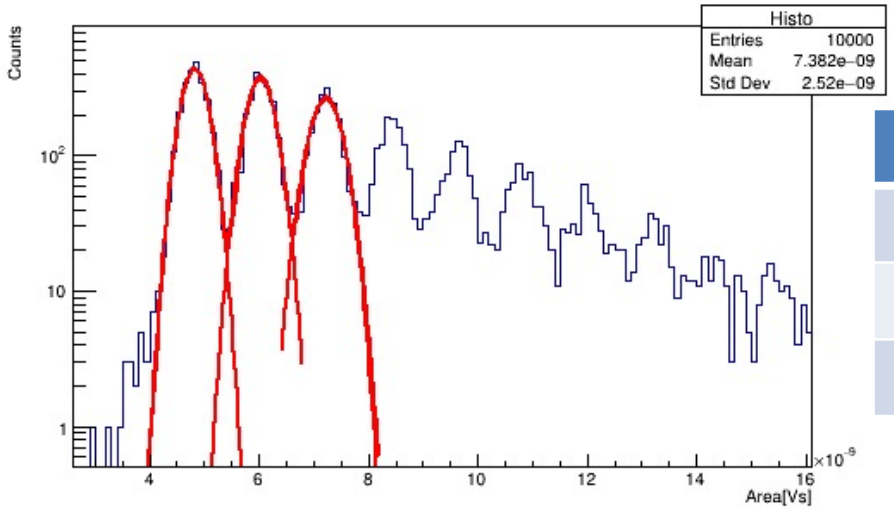
40 % PDE



45 % PDE



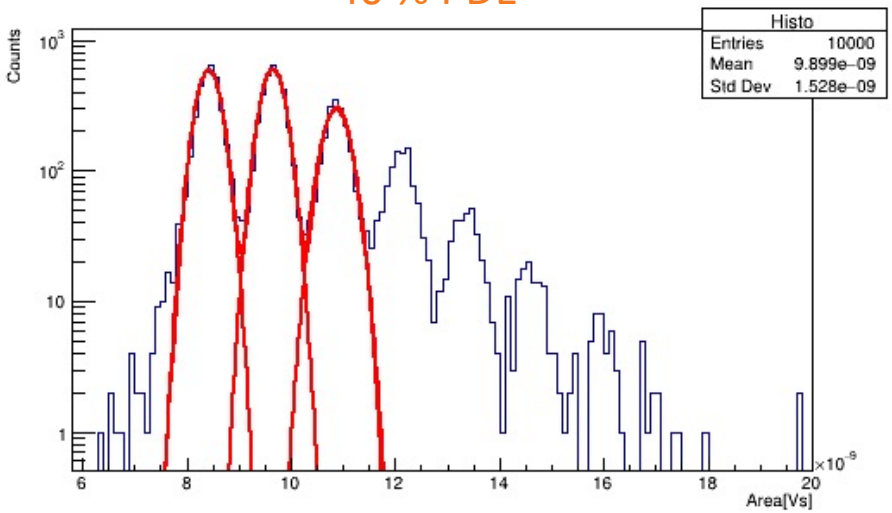
50 % PDE



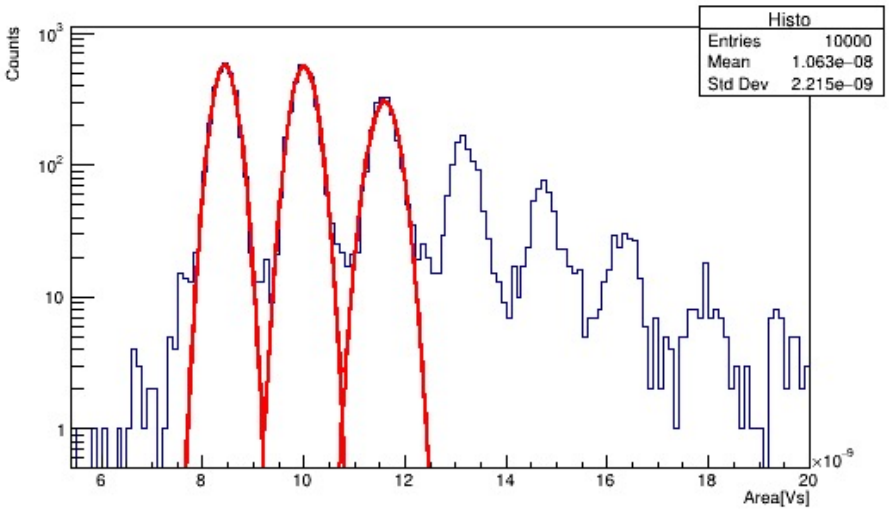
PDE	SN_0	SN_1	SN_2	SN_C
40%	2.97	3.00	2.83	2.11
45%	3.49	3.94	2.76	2.61
50%	5.37	5.35	4.65	3.79

3T

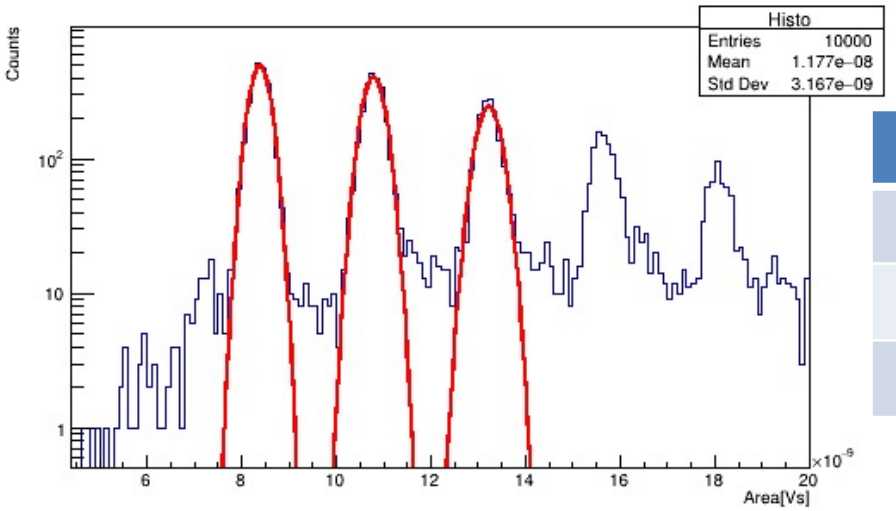
40 % PDE



45 % PDE



50 % PDE



PDE	SN_0	SN_1	SN_2	SN_C
40%	5.64	5.69	5.14	4.00
45%	7.56	7.16	6.30	5.20
50%	11.32	10.34	9.52	7.63

Global Results for FBK

Global Results – Vb and RQ

		LN2 - First cycle				LN2 - Last cycle(20)			
	Model	Vb(V)	STD	Rq (Ω)	STD	Vb(V)	STD	Rq (Ω)	STD
Milano Bicocca	NUV-HD-Cryo	27.14	0.03	75.27		27.13	0.02	71.64	
	Triple Trench	27.10		242.10		27.10		238.00	
IFIC - Valencia	NUV-HD-Cryo	27.14	0.02	70.5	1.01	27.17	0.02	70.12	1.12
	Triple Trench	27.03	0.02	225.43	2.38	27.06	0.03	224.75	2.11
Bologna	NUV-HD-Cryo	26.82	0.03	75.11	0.01	26.80	0.03	74.97	0.01
	Triple Trench	26.78	0.03	237.76	0.01	26.76	0.03	238.30	0.01
Ferrara	NUV-HD-Cryo					27.10	0.05	74.48	3.75
	Triple Trench					27.07	0.04	249.4	10.6

		Room Temp			
	Model	Vb(V)	STD	Rq (Ω)	STD
Milano Bicocca	NUV-HD-Cryo	32.95	0.04	17.38	0.3
	Triple Trench	32.89		51.13	
IFIC - Valencia	NUV-HD-Cryo	33.23	0.06	20.55	0.10
	Triple Trench	33.06	0.09	50.99	0.35
Bologna	NUV-HD-Cryo	33.11	0.03	18.37	0.01
	Triple Trench	31.84	0.03	49.9	0.01

Global Results – GAIN

			LN2 - First cycle		LN2 - Last cycle(20)	
	Model	OV	STD	MEAN	STD	MEAN
Milano Bicocca	NUV-HD-Cryo	4			1.99E+06	3.11E+04
		5			2.46E+06	2.46E+04
		6			3.54E+06	3.81E+04
	Triple Trench	3.5			4.75E+06	3.81E+04
		4.5			6.04E+06	8.52E+04
		7			9.15E+06	6.10E+04
IFIC - Valencia	NUV-HD-Cryo	4	1.97E+06	9.18E+03	2.00E+06	1.95E+04
		5	2.39E+06	7.69E+03	2.43E+06	1.75E+04
		6	2.81E+06	1.04E+04	2.87E+06	2.47E+04
	Triple Trench	3.5	4.66E+06	1.34E+04	4.69E+06	2.75E+04
		4.5	5.89E+06	1.69E+04	5.96E+06	2.49E+04
		7	8.80E+06	3.06E+04	8.81E+06	2.97E+04

Global Results – After pulses

			LN2 - First cycle		LN2 - Last cycle(20)	
	Model	OV	MEAN	STD	MEAN	STD
Milano Bicocca	NUV-HD-Cryo	4			1.59	0.2
		5			2.02	0.29
		6			3.03	0.51
	Triple Trench	3.5			2.66	0.48
		4.5			3.21	0.44
		7			3.97	0.47
IFIC - Valencia	NUV-HD-Cryo	4	1.17	0.10		
		5	1.12	0.08		
		6	1.08	0.09		
	Triple Trench	3.5	3.50	0.37	1.53	0.24
		4.5	2.676	0.2696	2.28	0.29
		7	3.022	0.2544	2.61	0.26
Bologna	NUV-HD-Cryo	4			1.50	0.23
		5			1.6	0.3
		6			2.5	0.3
	Triple Trench	3.5			1.0	0.1
		4.5			1.6	0.1
		7			3.0	0.2
Ferrara	NUV-HD-Cryo	4			1.2	0.2
		5			1.1	0.2
		6			0.95	0.18
	Triple Trench	3.5			3.8	0.3
		4.5			1.7	0.2
		7			0.9	0.2

Global Results – Crosstalk

			LN2 - First cycle		LN2 - Last cycle(20)	
	Model	OV	MEAN	STD	MEAN	STD
Milano Bicocca	NUV-HD-Cryo	4			17.96	1.7
		5			22.92	1.32
		6			35.4	1.62
	Triple Trench	3.5			13.69	0.74
		4.5			17.43	1.69
		7			40.42	4.01
IFIC - Valencia	NUV-HD-Cryo	4	17.68	0.41		
		5	23.32	0.40		
		6	28.92	0.55		
	Triple Trench	3.5	21.00	0.96	17.53	0.87
		4.5	23.12	0.87	20.98	0.94
		7	32.78	0.96	31.73	1.01
Bologna	NUV-HD-Cryo	4			9.23	0.60
		5			15.6	0.83
		6			28.33	1.2
	Triple Trench	3.5			7.97	0.38
		4.5			13.20	0.43
		7			28.80	0.68
Ferrara	NUV-HD-Cryo	4			12.6	0.5
		5			17.7	0.7
		6			25	0.8
	Triple Trench	3.5			9.7	0.5
		4.5			19.4	0.6
		7			39.1	0.9

Global Results – DCR with bursts

DCR + burst			LN2 - First cycle		LN2 - Last cycle(20)	
	Model	OV	MEAN	STD	MEAN	STD
Milano Bicocca	NUV-HD-Cryo	4			75.4	6.61
		5			61.53	8.1
		6			89.17	3.24
	Triple Trench	3.5			78.73	5.28
		4.5			85.25	5.78
		7			86.88	6.57
IFIC - Valencia	NUV-HD-Cryo	4	78.96	0.73		
		5	83.60	0.62		
		6	88.12	0.77		
	Triple Trench	3.5	49.5	0.9	40.3	0.8
		4.5	59.4	0.9	43.6	0.8
		7	84.2	1.2	62.3	1.0
Ferrara	NUV-HD-Cryo	4			59.35	0.98
		5			67.83	0.84
		6			37.80	0.60
	Triple Trench	3.5			154.8	2.4
		4.5			177.5	2.6
		7			198.35	2.7

Global Results – DCR without bursts

DCR			LN2 - First cycle		LN2 - Last cycle(20)	
	Model	OV	MEAN	STD	MEAN	STD
Milano Bicocca	NUV-HD-Cryo	4			25.02	5.05
		5			32.75	10.02
		6			33.67	6.37
	Triple Trench	3.5			34.26	9.05
		4.5			41.73	9.89
		7			50.96	13.64
IFIC - Valencia	NUV-HD-Cryo	4	17.81	0.55		
		5	20.40	0.47		
		6	22.98	0.61		
	Triple Trench	3.5	21.30	0.76	17.23	0.72
		4.5	26.18	0.82	15.80	0.65
		7	37.54	1.24	23.23	0.75
Ferrara	NUV-HD-Cryo	4			22.1	0.61
		5			33.0	0.60
		6			15.85	0.39
	Triple Trench	3.5			27.6	1.0
		4.5			29.0	1.0
		7			36.6	1.0

Conclusions

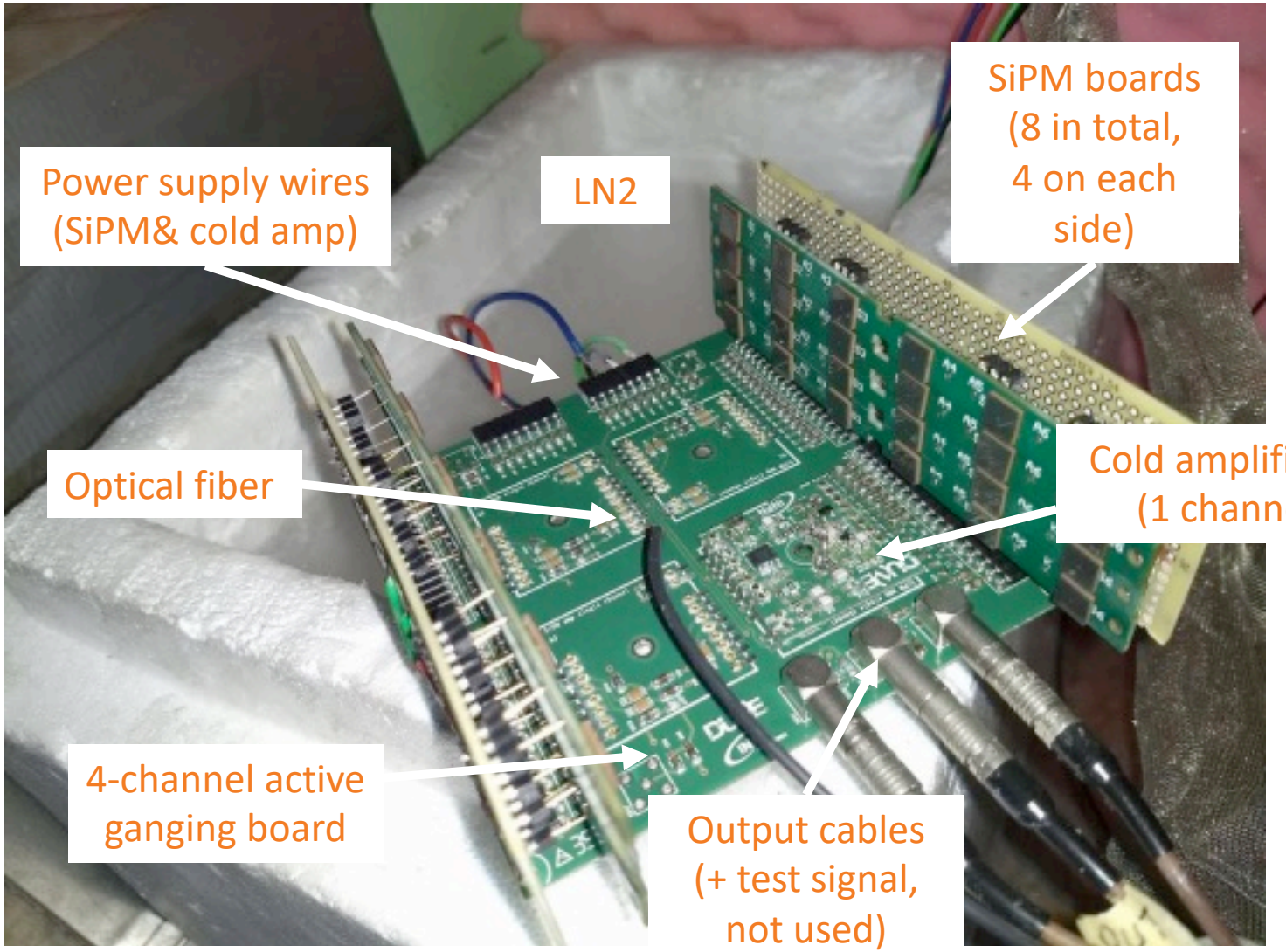
There are not significant differences on measurements results between labs (except for correlated noise from MiB and Bologna, work in progress).

All the SiPM fulfill the DUNE specifications and we're also getting good results from ganging tests.

Other comments from the labs?

Backup slides

Ganging setup - cold



Ganging setup - warm