Characterization and validation of SiPMs for the DUNE Far Detector Photon Detection System

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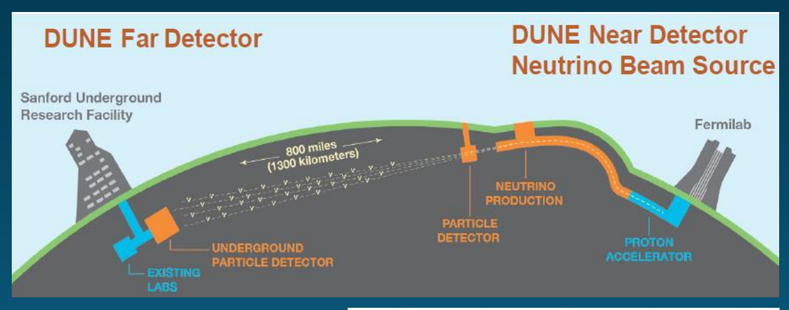
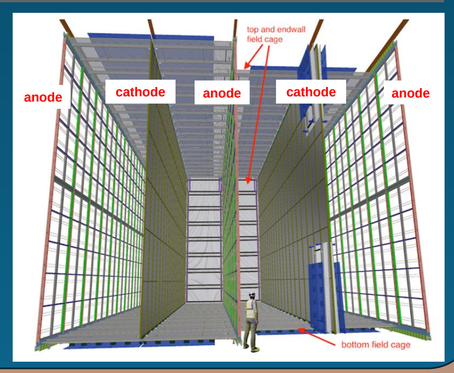
The Deep Underground Neutrino Experiment (DUNE)

DUNE is a future new generation neutrino experiment aimed to study neutrino oscillation.



Its long-baseline design foresees a **Near Detector** and a **Far Detector** complex at a distance of ~1300 km.

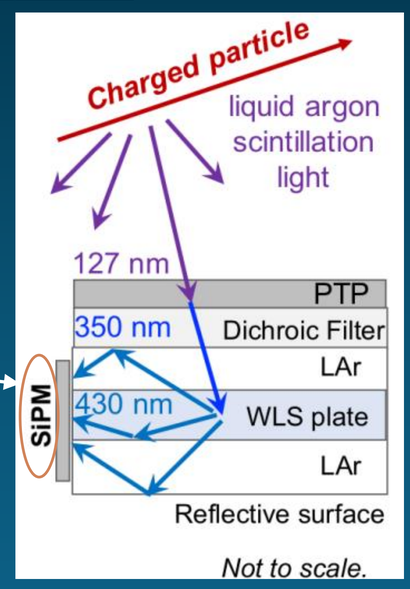
The **Far Detector** will be composed of four detector modules of Liquid Argon Time Projecting Chamber (LAr TPC) [1].



The DUNE Photon Detection System

To collect the scintillation light produced inside the **LAr TPC** after neutrino interactions, the **Far Detector** will be equipped with a **Photon Detection System** operating in a Liquid Argon (LAr) bath.

The light is trapped inside light collectors with highly reflective internal surfaces and guided to **Silicon Photonmultiplier (SiPM) [2]**.



Groups of 48 SiPMs are electrically ganged in parallel, in order to sum their signals and reduced the total number of read out channels of the detector.

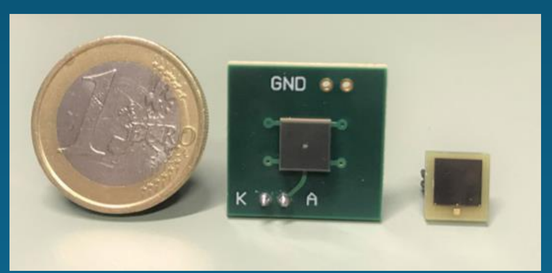
→ ~ 300000 SiPMs for the first module of DUNE Far Detector

Selection of SiPMs

Complete characterization of samples with different technologies produced by: **Hamamatsu Photonics K.K.** (**HPK**) and **Fondazione Bruno Kessler** (**FBK**).

Evaluated models:

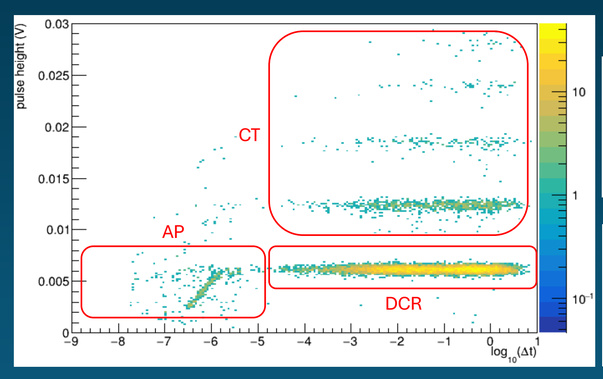
- **HPK Hole Wire Bond** technology (50 and 75 µm cell pitch);
- **FBK Near Ultra Violet-High Density-Cryo** (30 and 50 µm cell pitch)



Requirements verified in LN_2:

recovery time τ_{rec}	200 - 1000 ns
maximum global spread for V_{bd}	<2 V
Dark Count Rate (DCR)	<200 mHz/mm^2
Crosstalk (CT) probability	<35%
Afterpulsing (AP) probability	<5%
Thermal cycles	>20

Results of the selection



	cell (μm)	R_q (Ω)	V_{bd}(max-min) (V)	DCR (mHz/mm^2)	AP (%)	CT (%)
HPK	50	98.5±0.7	0.2±0.4	34±0.7	4.3±0.2	7.2±0.3
	75	93.9±0.4	0.4±0.4	38±0.4	4.6±0.1	14.3±0.2

	cell (μm)	R_q (Ω)	V_{bd}(max-min) (V)	DCR (mHz/mm^2)	AP (%)	CT (%)
FBK	30	112±0.7	0.1±0.4	40.8±0.7	2.8±0.1	16.9±1.1
	50	334.6±0.4	0.1±0.4	53.4±0.4	4.1±0.1	14.2±0.2

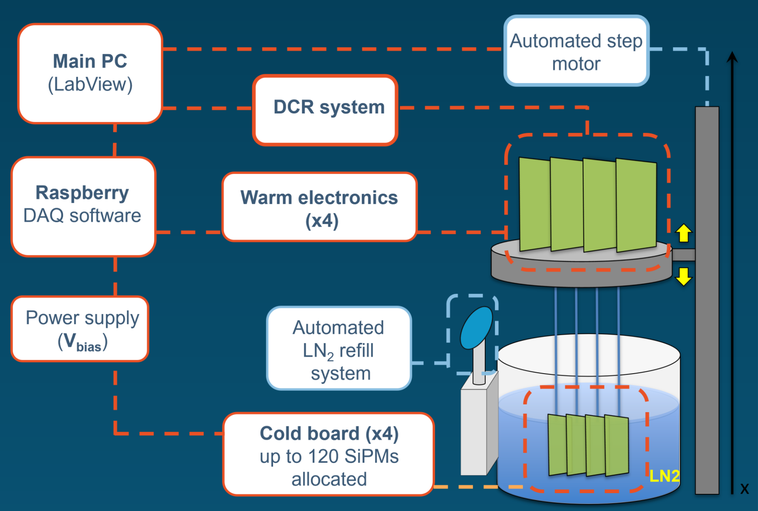
Selected models:

- HPK with 75 µm cell pitch [2]
- FBK with 50 µm cell pitch.

→ Mass production of ~300000 SiPMs for the first module of Far Detector

Cryogenic system for SiPMs validation

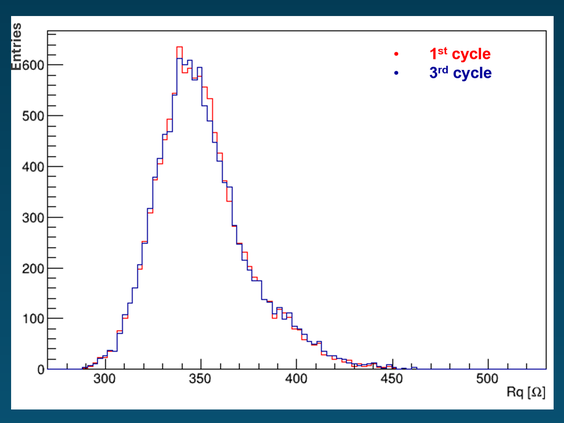
Semi-automated system for cryogenic validation of SiPMs for the Photon Detection System of the first module of DUNE **Far Detector**.



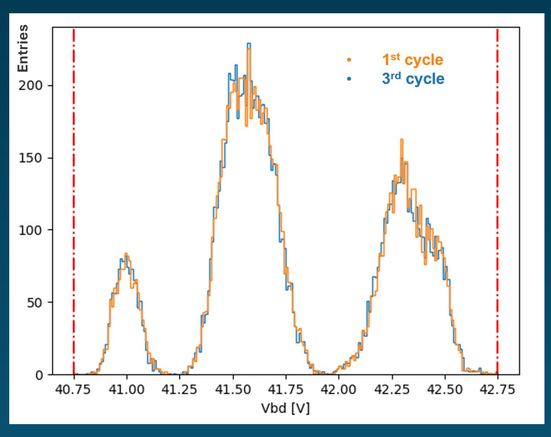
Validation protocol:

- I-V characteristic at T_{room} and T_{LN2} (77 K);
- Thermal stress tests to evaluate the packaging mechanical reliability;
- Study of the Dark Count Rate (DCR).

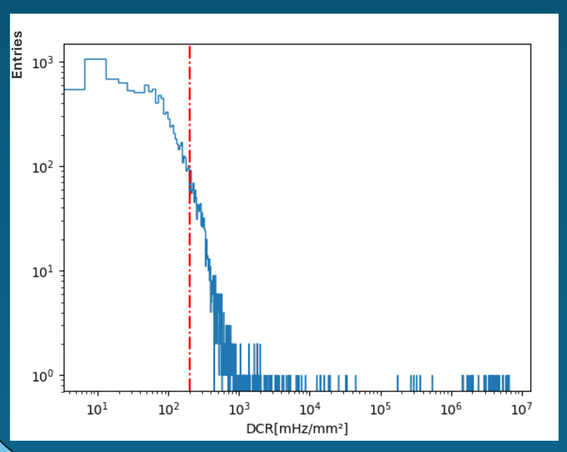
Results



Distribution of the quenching (R_q) measured at 77 K before and after the thermal cycles.



Breakdown Voltage (V_{bd}) measured at 77 K before and after the thermal stress tests
→ **Overall spread <2 V**



Study of the Dark Count Rate (DCR) as primary noise source

→samples with DCR > 200 mHz/mm^2 will be fully characterized in a dedicated facility with a detailed waveform analysis

Conclusions and future perspectives

Through the evaluation of different proposed samples, the SiPM model that best meets the experiment requirements for each vendor was identified.

Based on these results, the production and validation of ~300,000 SiPMs for the DUNE Far Detector was started.

Reference

[1] B. Abi et al. Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume IV: Far Detector Single-phase Technology. 2020

[2] E. Segreto et al. “Liquid argon test of the ARAPUCA device”. In: Journal of Instrumentation 13.08 (Aug. 2018),

[3] M. Andreotti et al. “Cryogenic characterization of Hamamatsu HWB MPPCs for the DUNE photon detection system”. In: Journal of Instrumentation 19.01 (Jan. 2024)