Objective : Stability-degradation analysis of DUNE S13360-9935 SiPM in LN_2 at +3, +4V and +5V OV

DUNE S13360-9935 SiPM have been qualified in cold at INFN MiBi, operated at 2V, 2.5V and **3V** OV in $LN_{2.}$ No evidence of performance degradation was detected over the period of test (~1 month).[1] It is the interest of DUNE PD to extend the qualification test in cold of the S13360-9935 SiPM at higher OVs, over a mid-long test period.

Therefore, the goal of the BNL test is to investigate if there is any observable difference when S13360-9935 SiPM operates at **3V and higher 4V, and 5V OV**, by continuously running in LN_2 over a 3-month period. We are <u>not targeting any absolute parameters, rather the drift of the parameters during the test period, if any</u>, over measurement statistical fluctuation. Also of interest, is eventually to determine whether the drift, if any, is enhanced when operated at **4V, and 5V OV compared to 3V OV.**

Devices: HPK S13360-6075HS-HRQ SiPM (S13360-9935, hole wire bond, silicon resin window, 6x6 mm^2, 75 µm pixel, 1.28 nF). 54 SiPMs provided by INFN MiBi to BNL for this test.
3 arrays of 6 to be operated at +3V, +4V, and +5V OV.

[1] M. Andreotti et al, 'ryogenic characterization of Hamamatsu HWB MPPCs for the DUNE photon detection system,' JINST 19 T01007 2024.
"... after 20 thermal cycles have shown <u>no difference within the measurement experimental uncertainty…"</u>

Test Condition: It is important that all set of test devices *must be continuously biased at 3V, 4V, and 5V OV*, respectively, above $V_{break\text{-}down}$ in LN_2 (~41V) at all times over the entire testing period of 3 months inside a completely light tight dewar. This light tight arrangement together with its mechanical support structure must remain intact and uninterrupted during weekly periodic filling of LN_2. This arrangement will need some effort to implement and to validate.

Read out electronics: We will use the latest version of the LArASIC (2x32 readout channels – total of 64 channels, programmable 0.5, 1, 2, 3 μs peaking time, ASIC charge gain of 7.8, 14, 25 mV/fC, 2MS/s ADC sampling rate). It has a small footprint. An adapter board would be needed for the connection of the SiPM arrays (54 SiPMs in total) to the SBND ASIC board. With 'smart' 0.5-pe self-trigger implemented on the FPGA and utilizing the waveform snippet data collection scheme, all 54 SiPM channels can be exploited.

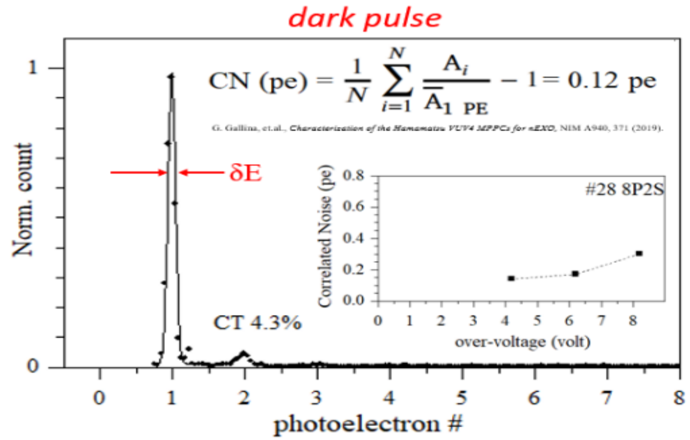
Coincident timing study on sets of or all SiPMs with triggered LED can be performed offline. Time-correlated rare events triggered on >n-pe intense Cherenkov light by the passage of cosmic muon in the active volume or LN2 can also be examined offline.

Non-observables:

Since all devices are continuously biased at 3V, 4V, and 5V OV at all times, no IV measurements are possible. Because of the ~μs charge integration time of the LArASIC, after-pules occurring within ~μs after the main pulse will be collectively included in the 1-photoelectron information. After-pulses of SiPMs in cold are nominally <3%, correlated noise is generally dominated by cross-talk >3%. Any slightly elevated extrinsic dark counts caused by Cherenkov light generated by passage of cosmic rays inside the LN_2 maybe delineated by time coincidence detection from several SiPMs.

Observables in Dark:

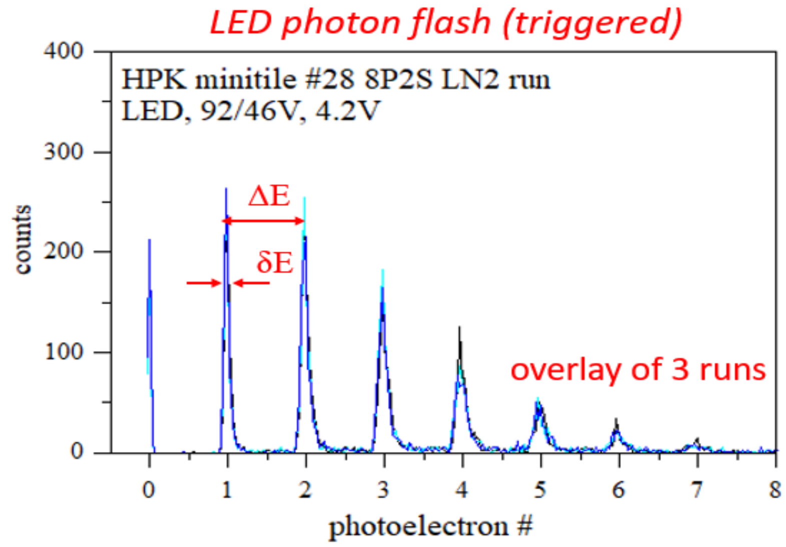
1. bias draw current on each set of arrays from the HV bias units.
2. dark pulse waveforms (*waveform snippet): all dark pulse with amplitude >0.5-pe, over a predefined recording time will be recorded with a time stamp*. Its corresponding DCR will be logged. For example, a raw dark signal trace occurred within a 10 μs window (for 1 μs peaking time) contains 20 samples at 2 Msps (as per Nyquist) will be recorded as a ***waveform snippet***. After offline (possibly on-line) sinc-interpolation the amplitude (and timing information for triggered LED pulses) will be extracted to reconstruct its pulse histogram. Empty signal will be discarded to better manage the data flow rate of all 54 SiPMs in LN_2. Using waveform snippet, *a well manageable <50 GB storage will be needed for 3 months period of dark pulses recording.*
3. Cross-talk (CT) and step plot extracted from the dark histogram. The typical low DCR would require a prolong predetermined collection time to build up the statistics. Continuously updating of the dark count rate and build-up of dark histogram can be made.



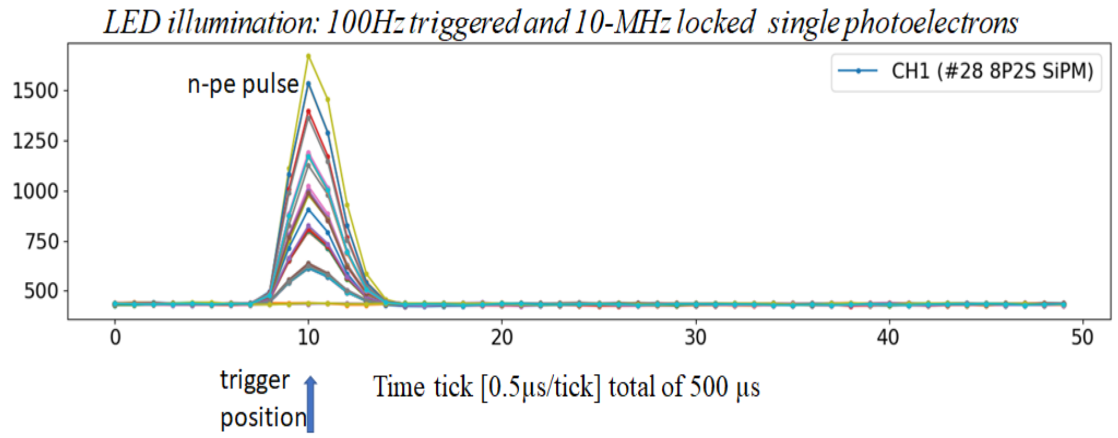
With Pulsed LED (1 run/week)

With a stable, repeatable, triggered, 10-MHz locked, low light level pulsed 450 nm fiber-coupled quasi-uniform LED illumination (need some effort of implementation):

1. Relative PDE from the peak of the charge histogram
2. Relative charge gain from the spacing of photoelectron peaks.

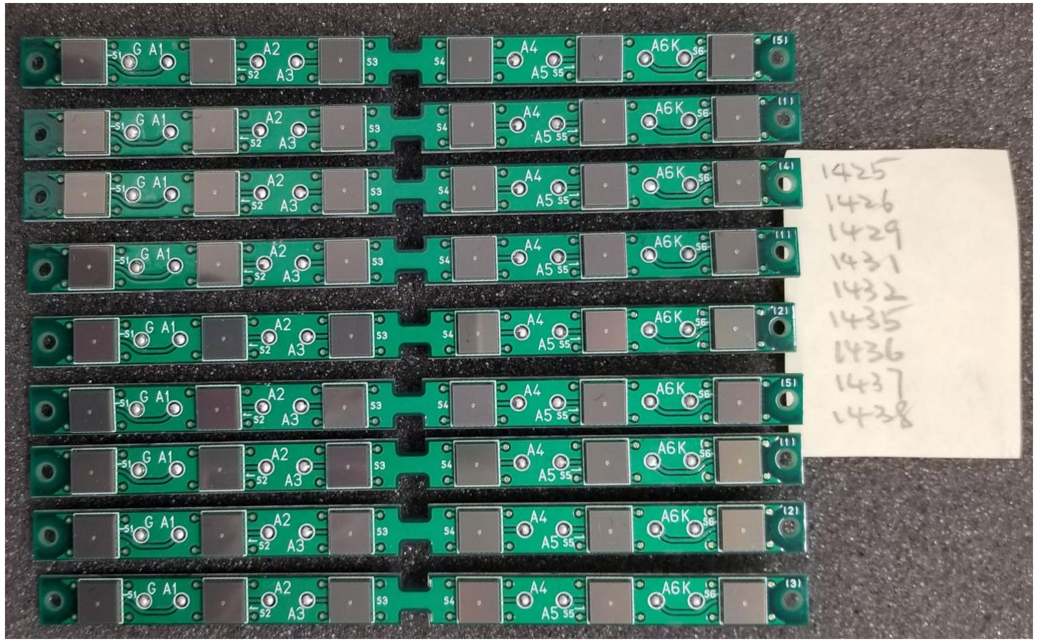


LED illuminated light pulses with amplitude ≥0.5-pe, over a predefined recording will be recorded with a time stamp. With the 10-MHz clock frequency locked to the 2 MS sampling rate of the ADC, a time triggered, well-defined, n-photoelectron histogram can be accumulated quickly in minutes of signal waveform collecting. Again, using waveform snippet with 100 Hz of photon trigger rate, all 54 SiPM channels can be accessed simultaneously. No data flow rate limitation anticipated.

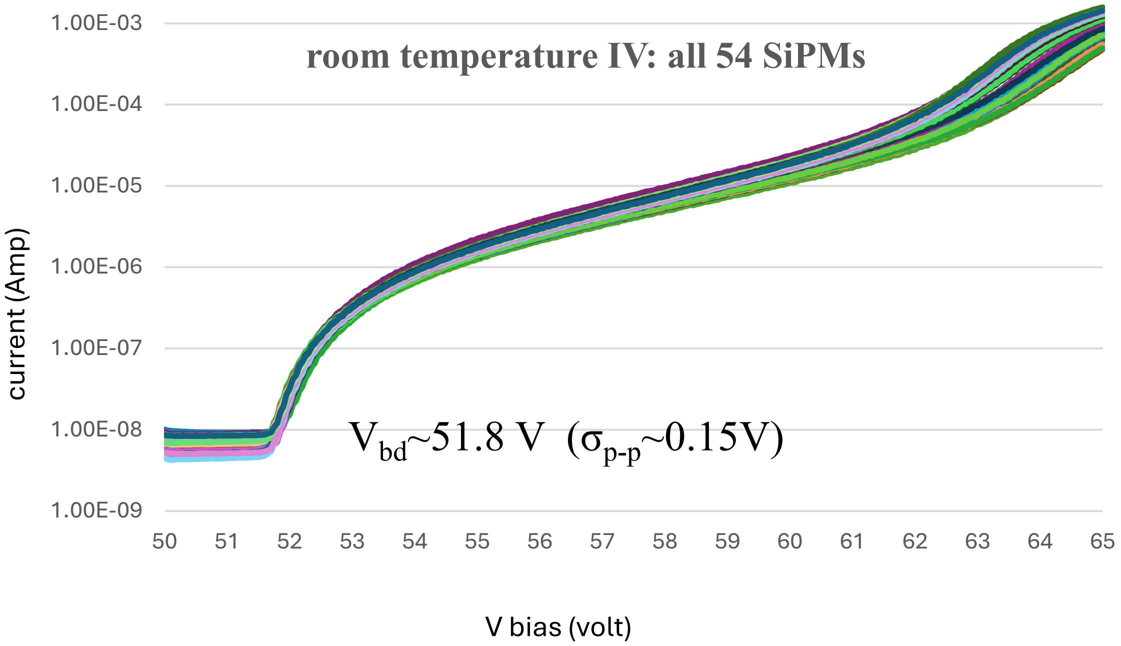


Devices: 9x6 SiPMs (HPK S13360-6075HS-HRQ) provided by INFN MiBi to BNL for this test.

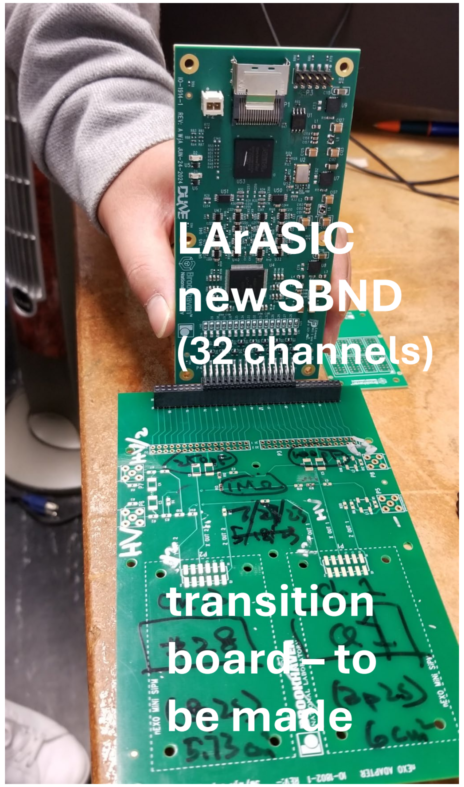
RT IV of all 54 devices have been measured: good uniformity on V_bd and low I_dark spread observed.



9x6 SiPMs received at BNL



sketch of the stability-degradation test arrangement



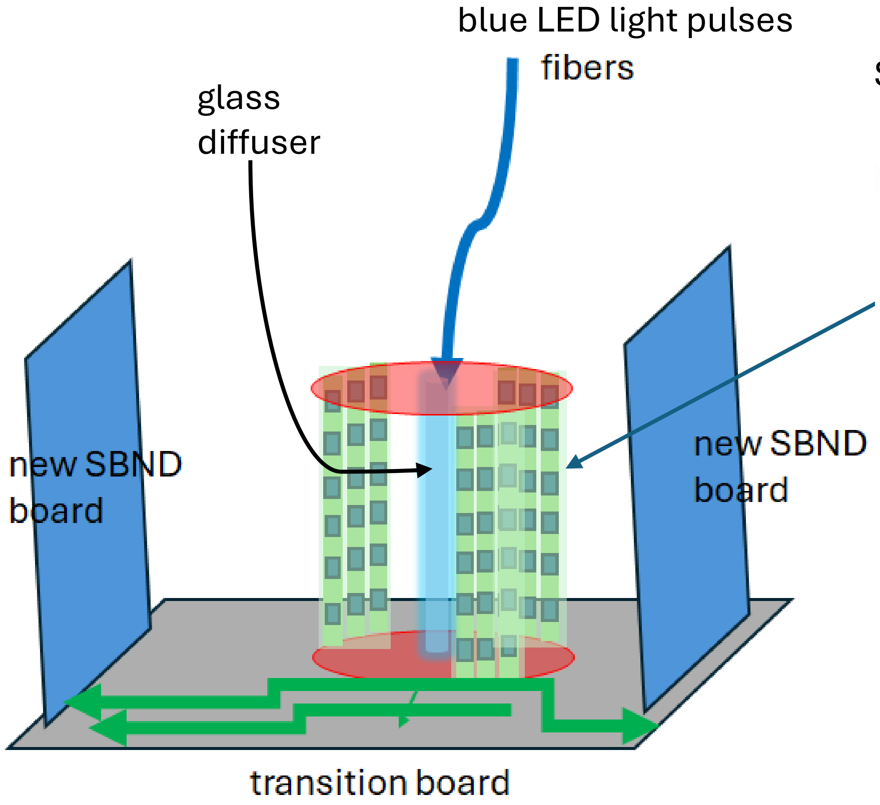


illustration: transition board top

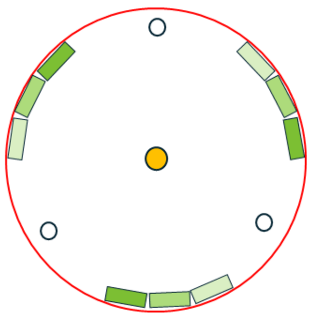
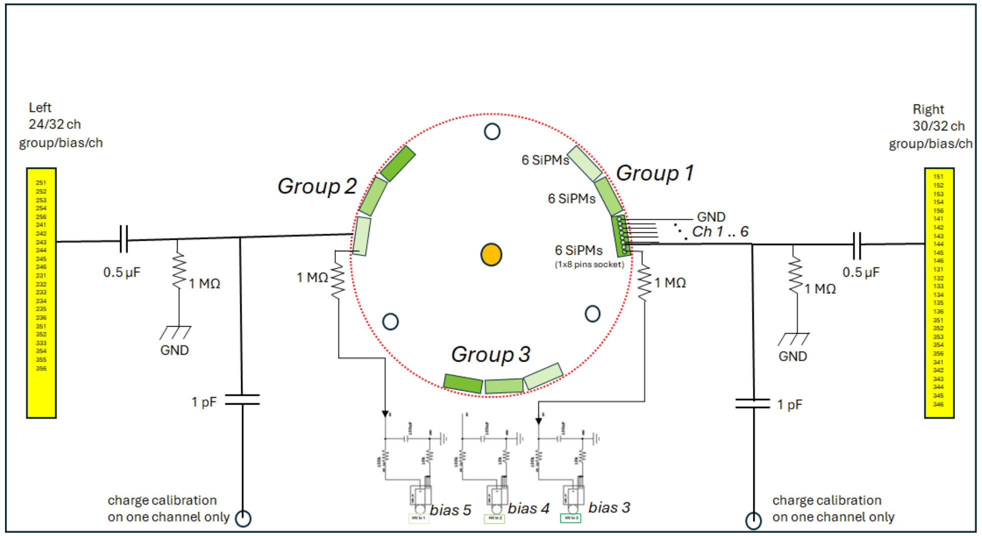


illustration: transition board bottom



3 arrays of 6 to be operated at +3V, +4V, and +5V OV, respectively.

Work in progress !