plan for long-term stability test of DUNE HPK SiPM *[MPPC- S13360-6075HS-HRQ (S13360-9935)]*

FLC - PD Consortium - PhotoSensor Mtg - Oct 1, 2024

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PRELIMINARY

MPPC (S13360 for DUNE)

Nov. 11, 2019

SPECIFICATION SHEET

■ Structure

Parameters \ Type No.	S13360 -6050HS-LRQ (S13360-9932)	S13360 -6050HS-HRQ (S13360-9933)	S13360 -6075HS-LRQ (S13360-9934)	S13360 -6075HS-HRQ (S13360-9935)	Unit
Effective photosensitive area	6.0 x 6.0				mm^2
Pixel pitch	50		75		μm
Number of pixel	14,331		6,364		-
Window	Silicone resin				-
Window refractive index	1.57				-
Package	Surface mount type				-

■ Absolute Maximum Ratings

Parameters	Symbol	Value	Unit
Operating temperature *1	Topr	LN2 T -196 to +60 (TBD)	°C
Storage temperature *1	Topr	-196 to +80 (TBD)	°C
Maximum temperature cycle (below -40°C to room temperature) *2	-	10 times (TBD)	-
Soldering conditions *3	Tsol	Peak temperature 240 °C x 3 times	-

*1: No condensation
*2: Please avoid rapid temperature change.
*3: Moisture sensitivity Level: 5A (Defined by IPC/JEDEC J-STD-020E)

■ Electrical and optical characteristics (Typ. T = 25 deg C, Vr = Vop unless otherwise noted)

Parameters \ Type No.	Symbol	S13360 -6050HS-LRQ (S13360-9932)	S13360 -6050HS-HRQ (S13360-9933)	S13360 -6075HS-LRQ (S13360-9934)	S13360 -6075HS-HRQ (S13360-9935)	Unit
Spectral response range	λ	280 to 900				nm
Peak sensitivity wavelength	λp	450				nm
Photon detection efficiency at λp *4	-	40		50		%
Breakdown voltage	Vbr	53 +/- 5				V
Recommended operating voltage *5	Vop	Vbr + 3.0				V
Dark count rate	DCR	2.0 (MAX:6.0)				Mcps
Terminal capacitance at Vop	Ct	1280				pF
Gain	M	1.7 x 10^6		4.0 x 10^6		-
Temperature coefficient of reverse voltage	Δ TVop	54				mV/°C
quenching resistor around room temperature	Rq	280	500 (TBD)	280	500 (TBD)	kΩ
Temperature coefficient of quenching resistor	Δ TRq	Low	High	Low	High	Ω/°C

*4 : Photon detection efficiency does not include crosstalk and after pulse.
*5 : Refer to the data attached for each products.

MPPC- S13360-6075HS-HRQ (S13360-9935)

- MPPC/SiPM Fundamental Characteristics exhibit dependency on **Operating V** or on **T** - or on **both** (additional dependency on W.L. not considered here).
- *S13360-9935* is rated for a wide operating T range extending down to LN2 T.
- *S13360-9935* - A_{sens} =6x6 mm^2 (Pixel Pitch 75μm) can operate in range of V_{ov} above V_{bd} (gain setting range) - **with a recommended V_{ov} value (+3 V)**, used for reference measurements (at typical RT of 25° C)
- *S13360* MPPC characteristics vary in these ranges - optimum V_{ov} and T should be selected to match specific application.
- MPPC/SiPM are rated for long operation lifetime (>10yrs). No explicit indications of known aging or accelerated degradation mechanisms are found in literature (to my knowledge) - except for high dose radiation damage with critical effect of **increase of dark count rate** (inducing loss of single PE resolution).

SiPM Stability test plan

To be agreed here and defined in detail with BNL

- Operating at Low T and very Low Rad/Low Evt. Rate, at V_{ov} within its range of operation - allows (expectation of) very long Lifetime (>20yrs for DUNE) -

- No direct systematic (>20-30 yrs) longevity test/proof for *S13360-9935* has been attempted so far (to my knowledge).
  Similar to CE longevity proofs at BNL in the past, this should require - presumably - a large SiPM sample O(100) immersed in LAr, at high V_{ov} (over-stress condition - out of range of specs) for an extended period of time O(1yr) - ***this is not affordable at this stage of the project.***

- What CAN BE afforded - at BNL + available local support from SBU and help from FNAL - is a:

    - ***Mid-Long-term tests for comparative stability-degradation for SiPM samples O(10 units) immersed in LN2, continuously operated at few different (fixed) V_{ov} values, over a period of O(3months).***

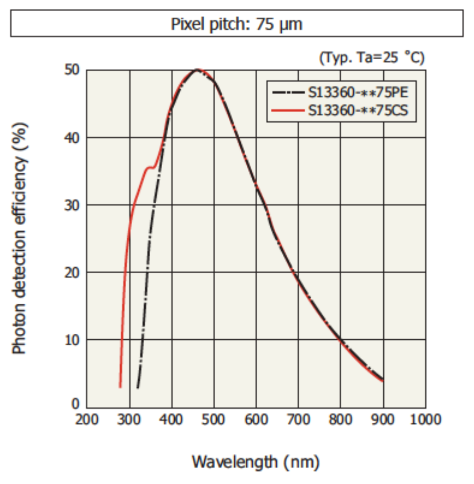
    - ***Reference Sample at V_{ov} = 3V*** - to compare with TWO Samples at V_{ov} = 4V and V_{ov} = 5V - all in cold-LN2 and Dark conditions -

    - ***Observable Metrics*** for a stability-degradation comparative analysis need to be agreed in detail - here in the following some are proposed for discussion

SiPM/MPPC Fundamental Characteristics

[S13360-6075HS-HRQ (S13360-9935)] A_{sens} =6x6 mm² (Pixel Pitch 75μm)

Dependency on OV

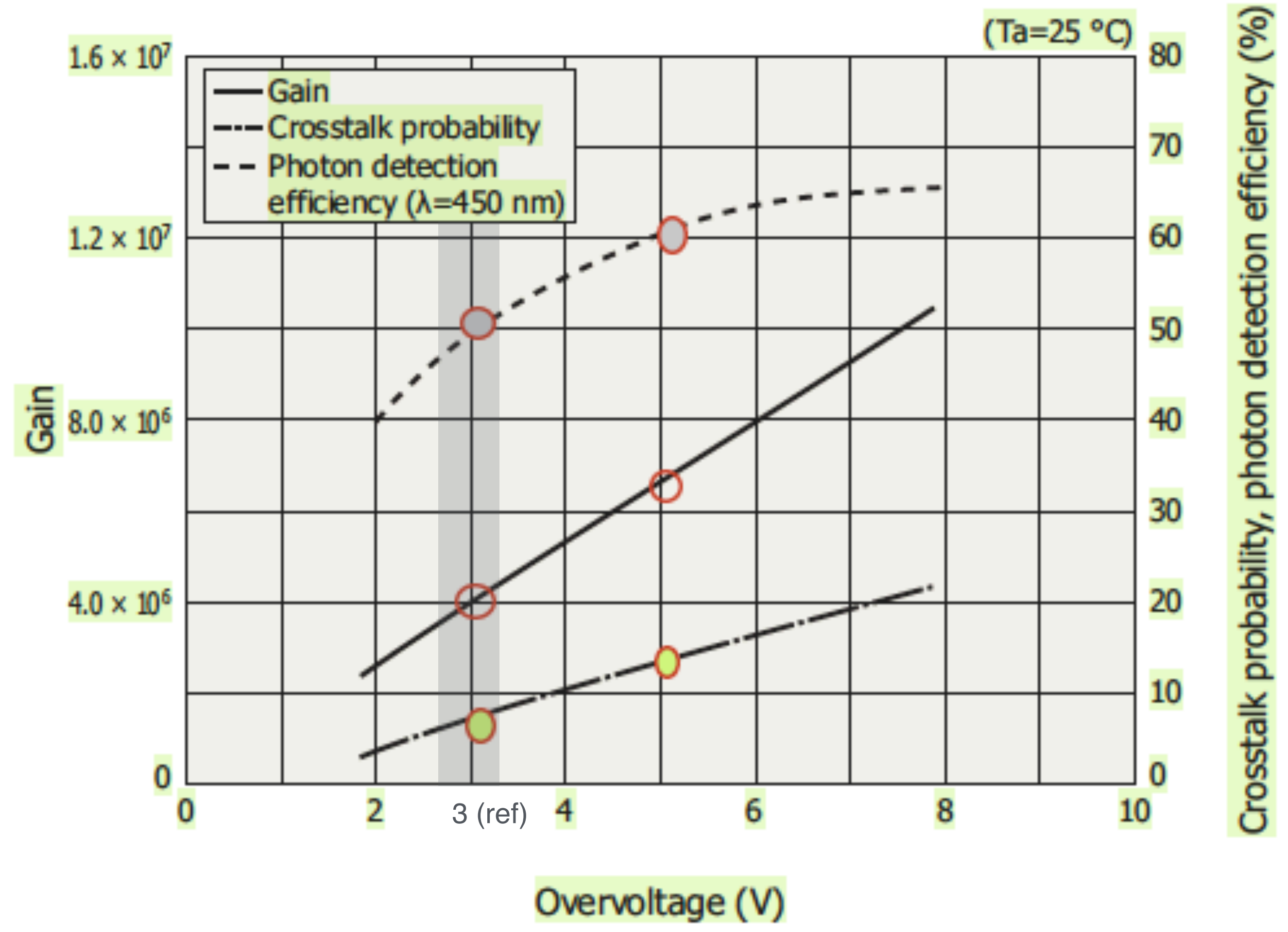
- PDE vs OV (PDE vs w.l. )

- Gain vs OV
- Optical (prompt) XT vs OV
- DCR vs OV

MPPC (multi-pixel photon counter) | **S13360 series** → Reduced XT

Previous products achieved lower afterpulse through the improvement of material and wafer process technology, but with the S13360 series, low crosstalk has been achieved in addition to low afterpulse.

Pixel pitch: 75 μm

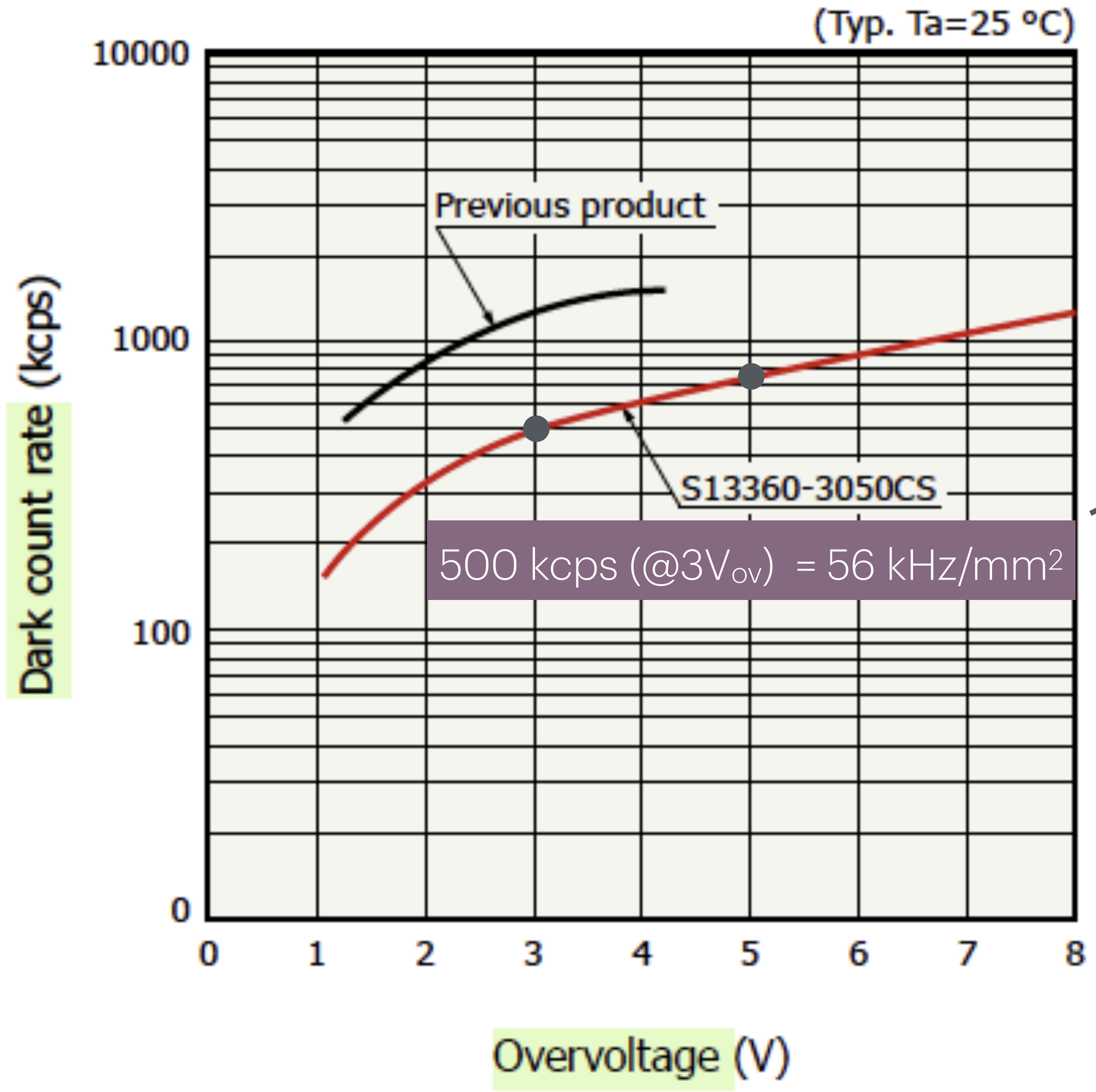


■ Overvoltage specifications of gain, crosstalk probability, photon detection efficiency (Vr = Vop = Vbr + 3.0V, typical example)

@ RT (25°C)	3 V_{ov}	5 V_{ov}	Δ (rel)
PDE	50%	60%	20%
Gain	4x10⁶	7x10⁶	70%
XT	7%	14%	100%
DCR	56 kHz/mm²	85 kHz/mm²	50%

KAPDB0326EA

MPPC characteristics vary with the operating voltage. Although increasing the operating voltage improves the photon detection efficiency and time resolution, it also increases the dark count and crosstalk at the same time, so an optimum operating voltage must be selected to match the application.



@ RT (25°C)

Δ-DCR: +1000 Kcps (+28 kHz/mm²) [+50%rel]

extrapolated from 3x3 mm² (50μm pixel pitch)

Δ-DCR: +250 Kcps = +28 kHz/mm² [+50%rel]

SiPM/MPPC Fundamental Characteristics

[S13360-6075HS-HRQ (S13360-9935)] A_{sens} =6x6 mm² (Pixel Pitch 75μm)

Dependency on Temperature

- V_{bd} vs *T*↓ : *mild* ↓ *(C_T=0.054 V/deg)*

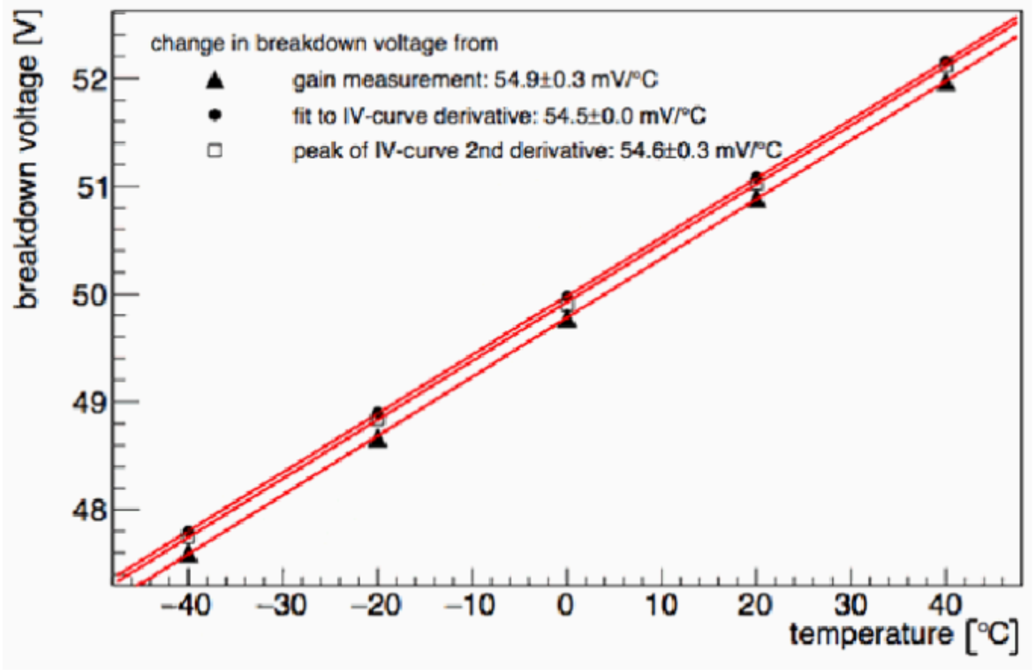


Figure 2. Dependence of breakdown voltage on temperature for Hamamatsu S13360-3050CS SiPM.

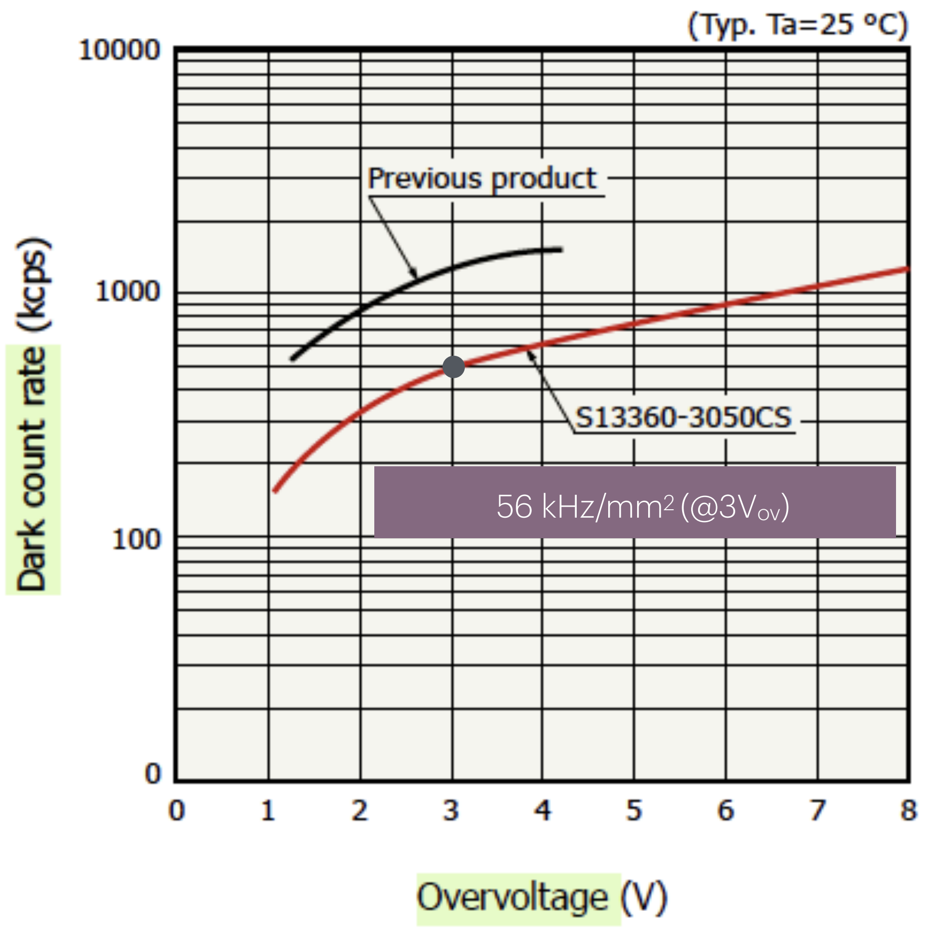
Temp. Coefficient CT (slope): C_T = *0.054 V/deg*

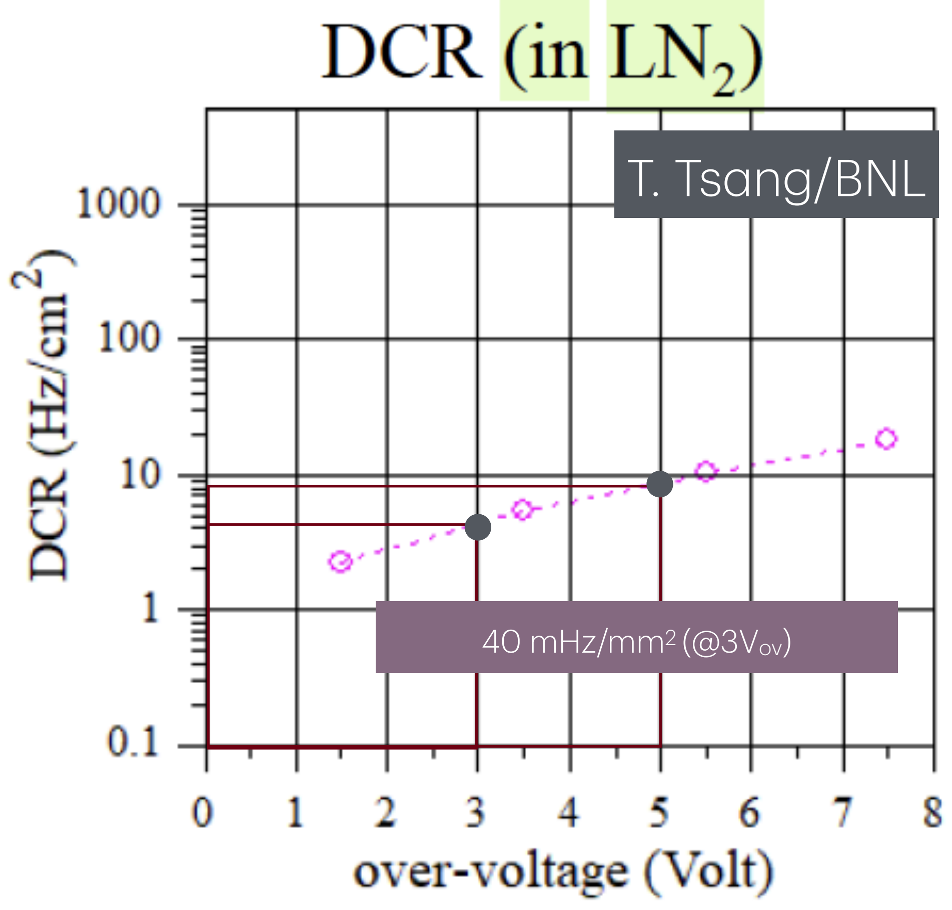
V_{bd} (@RT) = 53 V → V_{bd} (LN2 T) = 41.1 V (ΔV_{bd} = 11.9 V)

→ V_{bd} (LAr T) = 41.7 V (ΔV_{bd} = 11.3 V)

- DCR vs *T*↓ : *strong* ↓

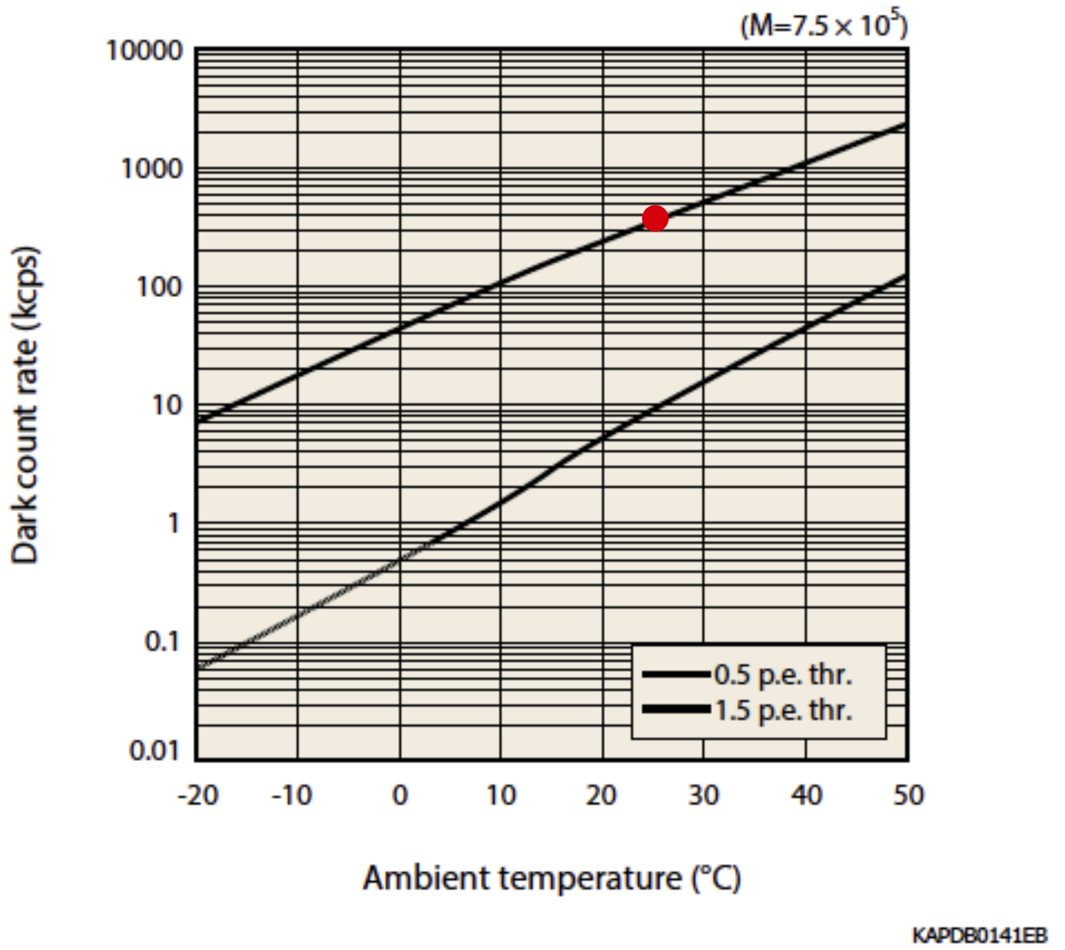
@ LN2 T (77 K)	3 V_{ov}	5 V_{ov}	Δ (rel)
DCR	45 mHz/mm²	75 mHz/mm²	60%





extremely low dark rate

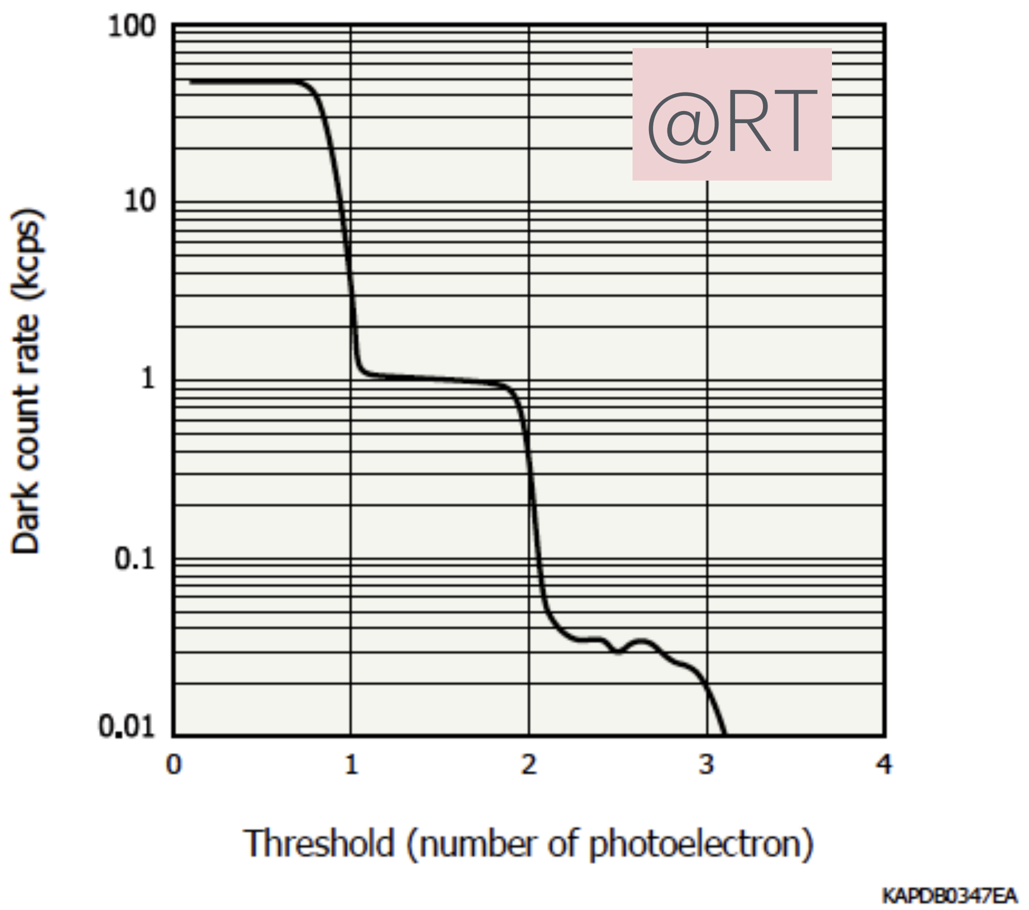
$$DCR(\text{LN2}-\text{T}) = \left(\frac{1}{2}\right)^{\frac{\Delta T}{10}} \cdot DCR(\text{RT}) \geq 10^{-6}\ DCR(\text{RT})$$



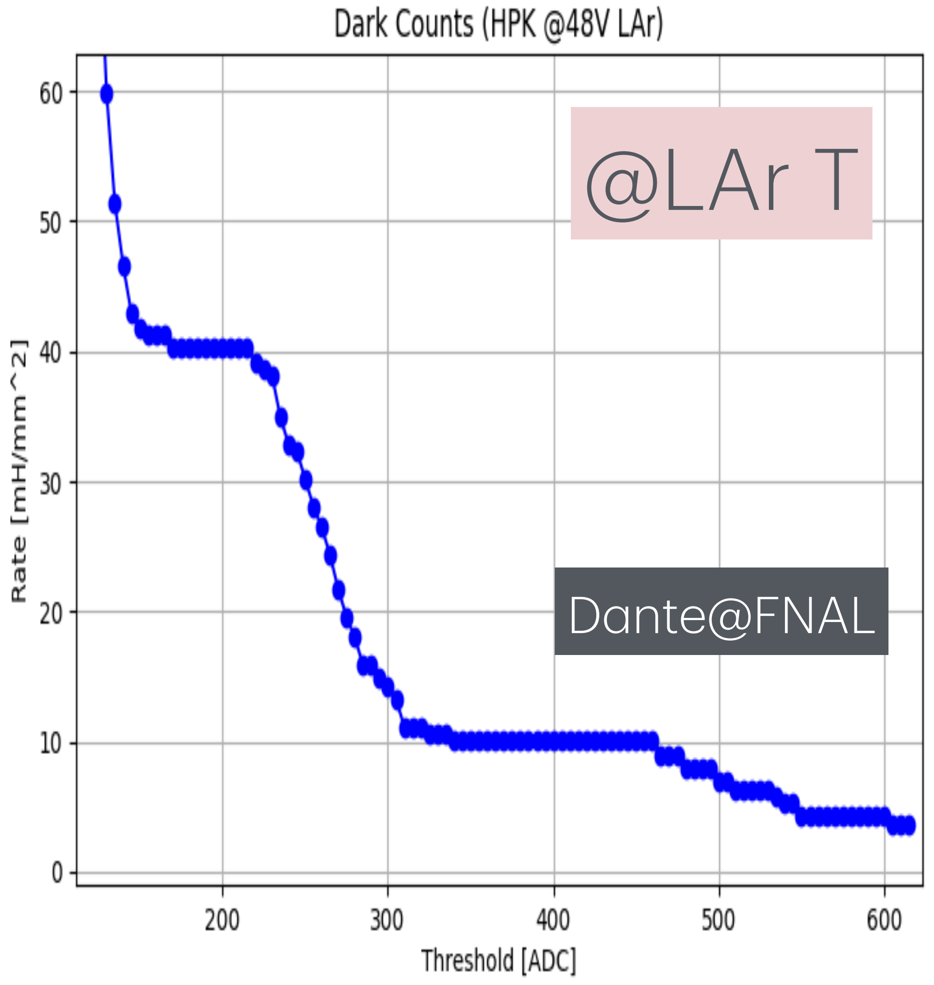
DCR decreases ↓ with decreasing T ↓

by a rate of 1/2 for every ~10° C drop in T

[Figure 1-24] DCR vs. counting discriminator threshold



As pulse-height (threshold) increases ↑ by 1PE,
DCR decreases ↓ by 1 order of Magnitude



SiPM/MPPC Fundamental Characteristics

[S13360-6075HS-HRQ (S13360-9935)] A_{sens} =6x6 mm² (Pixel Pitch 75µm)

Dependency on Temperature

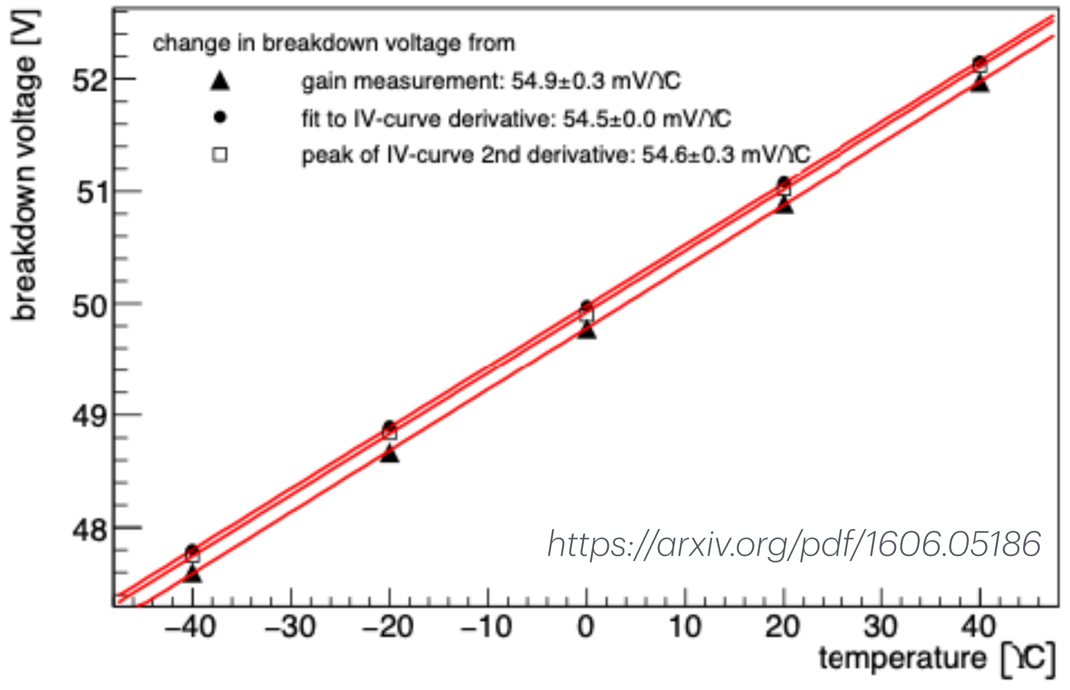
- V_{bd} vs T↓ : *mild ↓ (C_T=0.054 V/deg)*

The temperature-induced change of ΔV_{bd} affects the Gain and also other characteristics such as PDE, XT and AP.

However, at fixed V_{ov} eliminate gain-temperature dependence

@fixed V_{ov}

- **Gain vs T↓** : *no / weak*
- Optical (prompt) XT vs *T↓ : no / weak*
- PDE vs *T↓ : no / weak ↑*



(b) Hamamatsu S13360-3050CS

Temp. Coefficient CT (slope): C_T = 0.054 V/deg

V_{bd} (@RT) = 53 V → V_{bd} (LN2 T) = 41.1 V (ΔV_{bd} = 11.9 V)

→ V_{bd} (LAr T) = 41.7 V (ΔV_{bd} = 11.3 V)

@ LN2 T (77 K)	3 V_{ov}	5 V_{ov}	Δ (rel)
Gain	4.4x10⁶	7x10⁶	70%

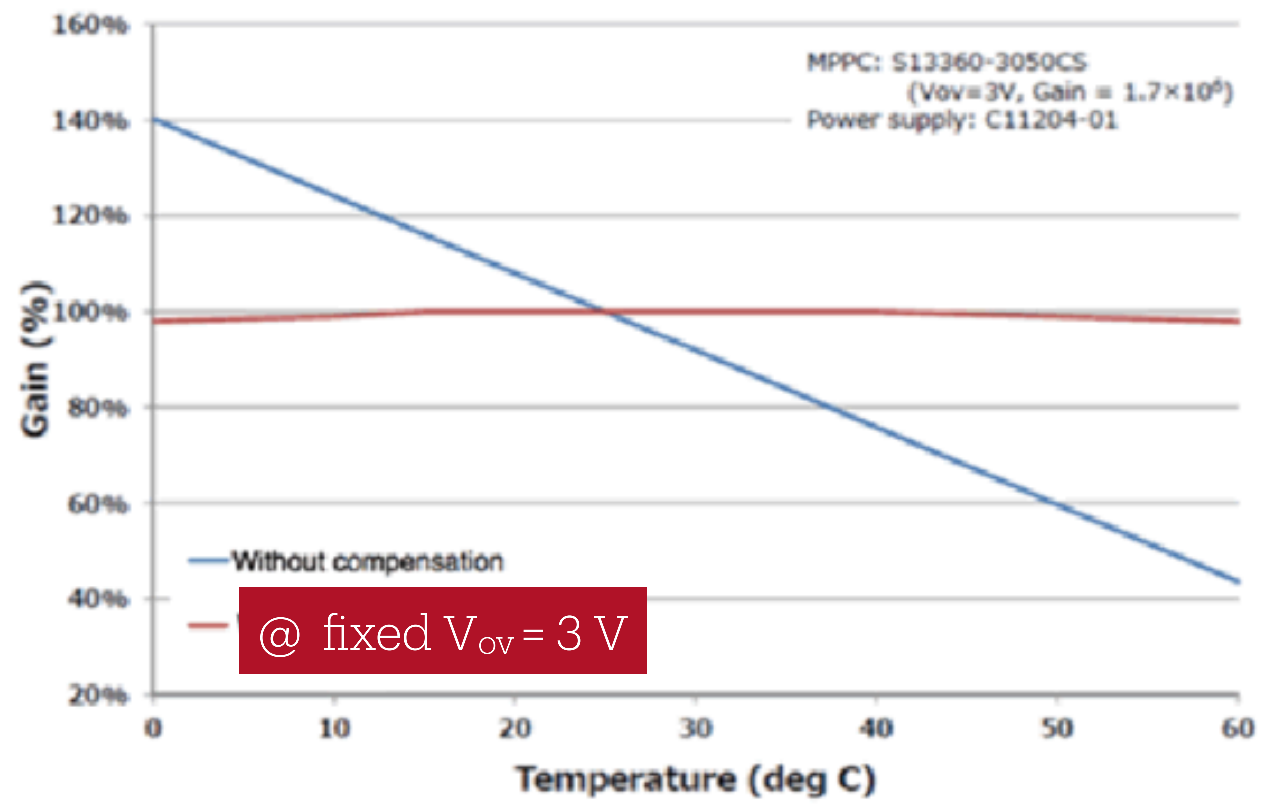
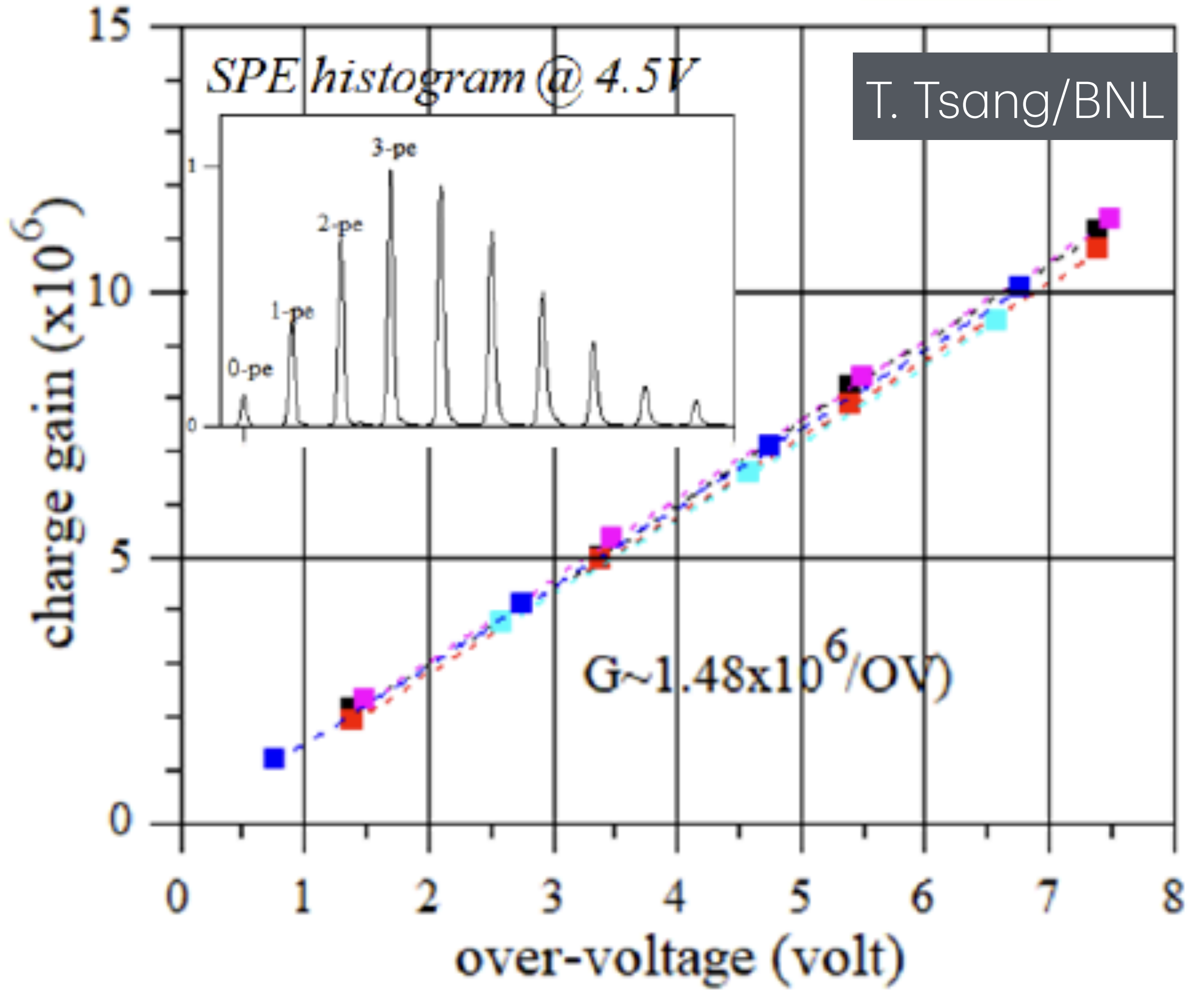
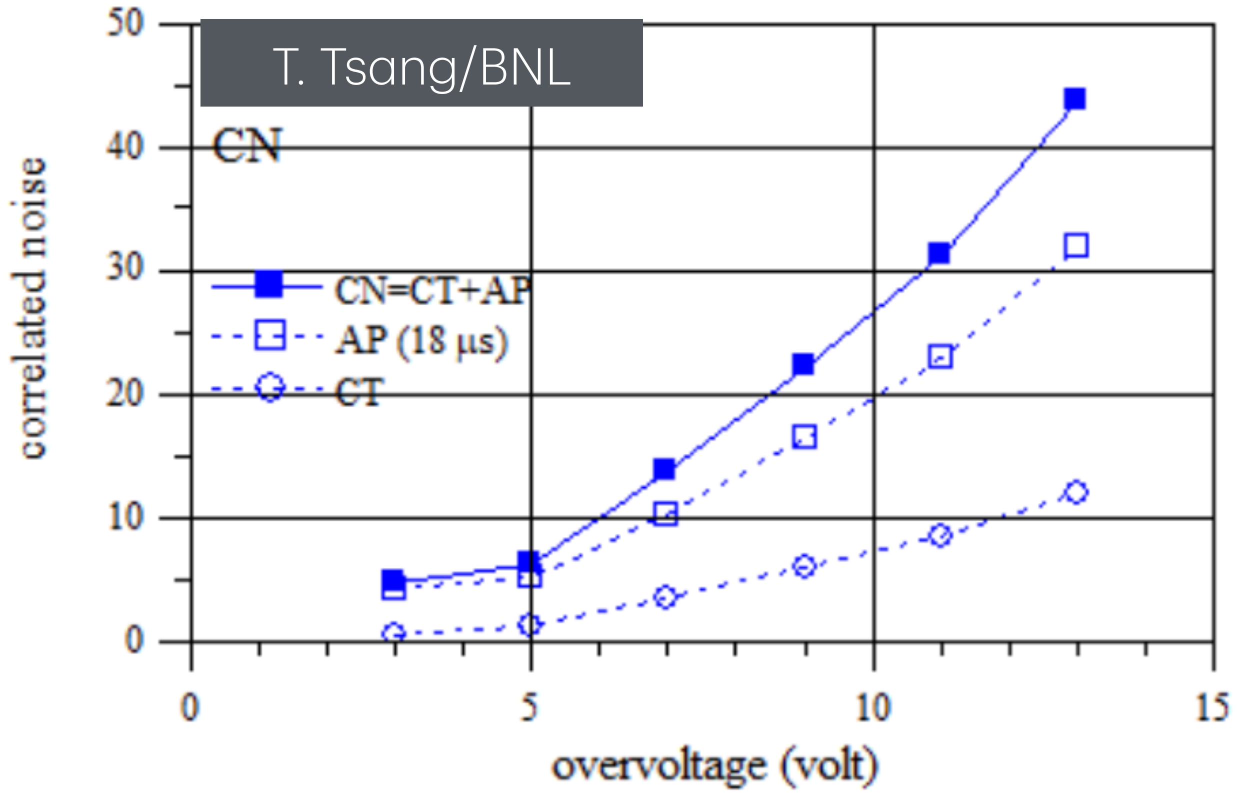


Figure 4. Gain variation versus temperature for Hamamatsu S13360-3050CS

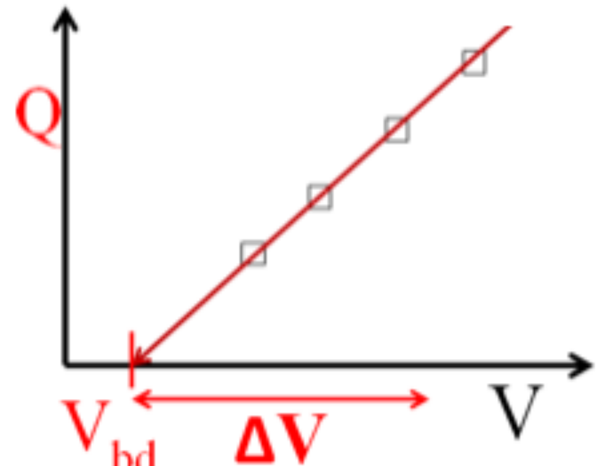
charge gain (in LN_2)





- gain measured from well resolved photoelectron peaks
- breakdown voltage linearly extrapolated

$$C_{\mu cell} = \frac{gain}{(V - V_{bd})} e$$



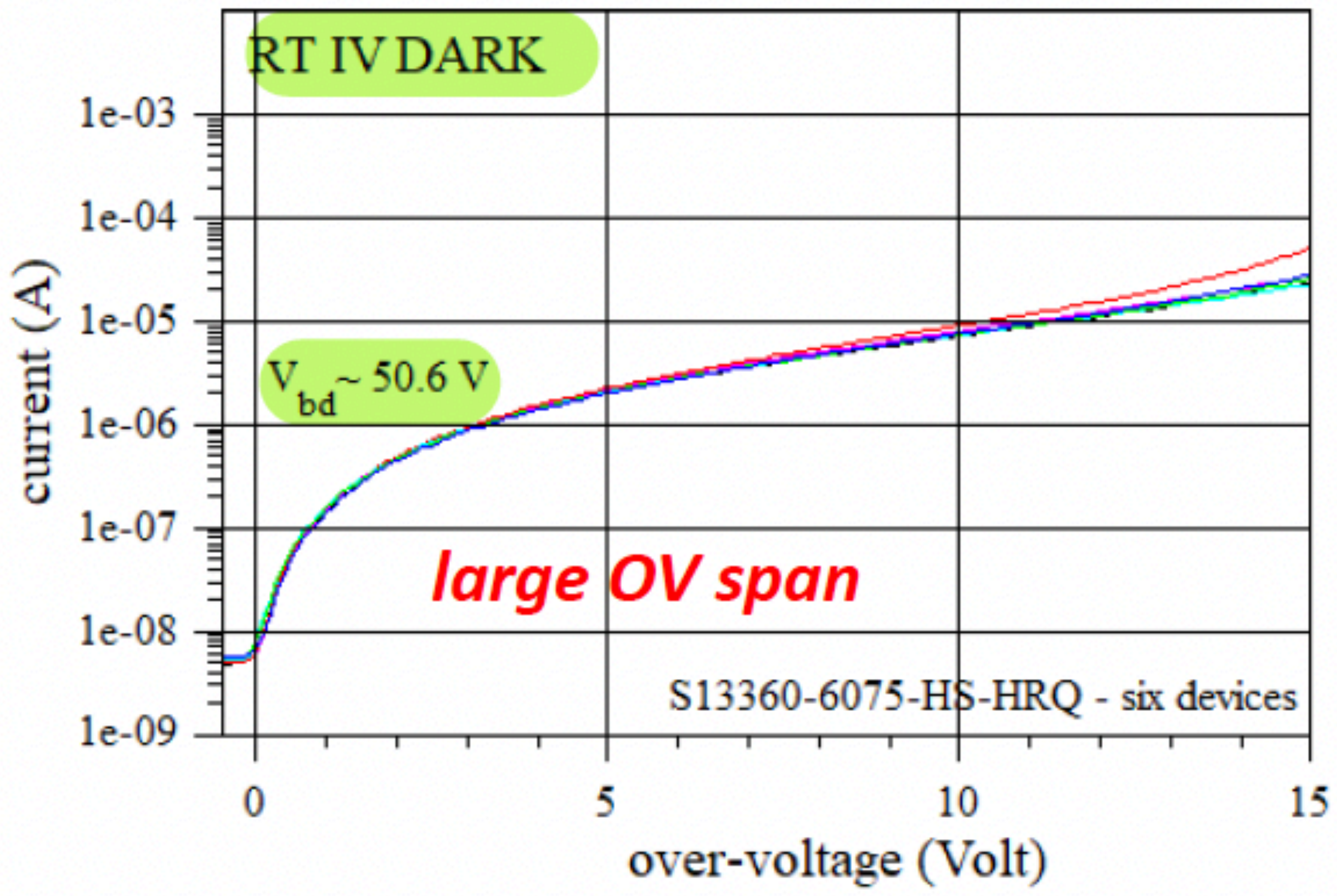
V-I curves (from RT to LN2 T, impact of light leakage)

DUNE S13360-6075-HS-HRQ

high R_q, normal V_{bd}

IV

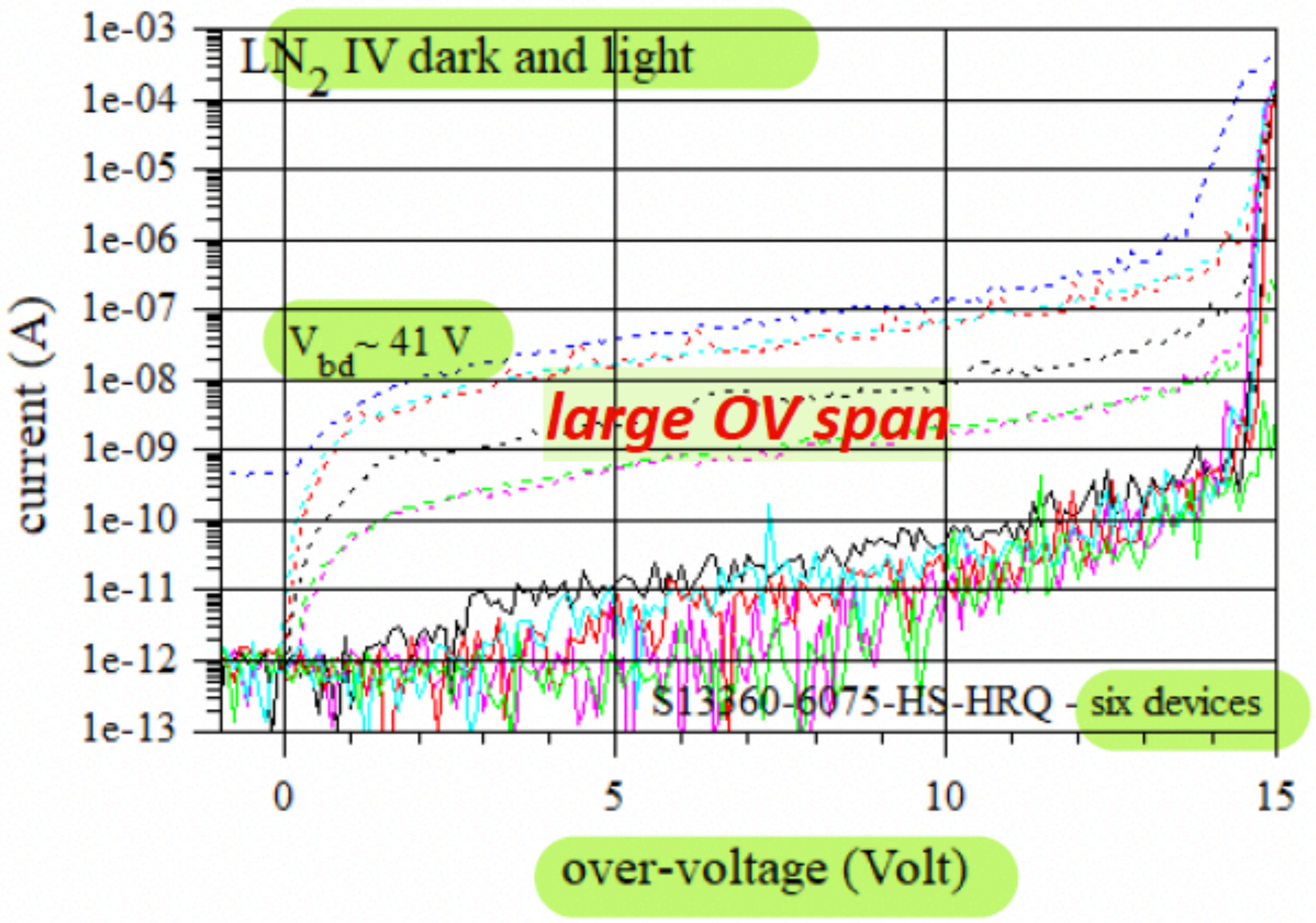
Room Temp.



T. Tsang/BNL

IV

LN_2



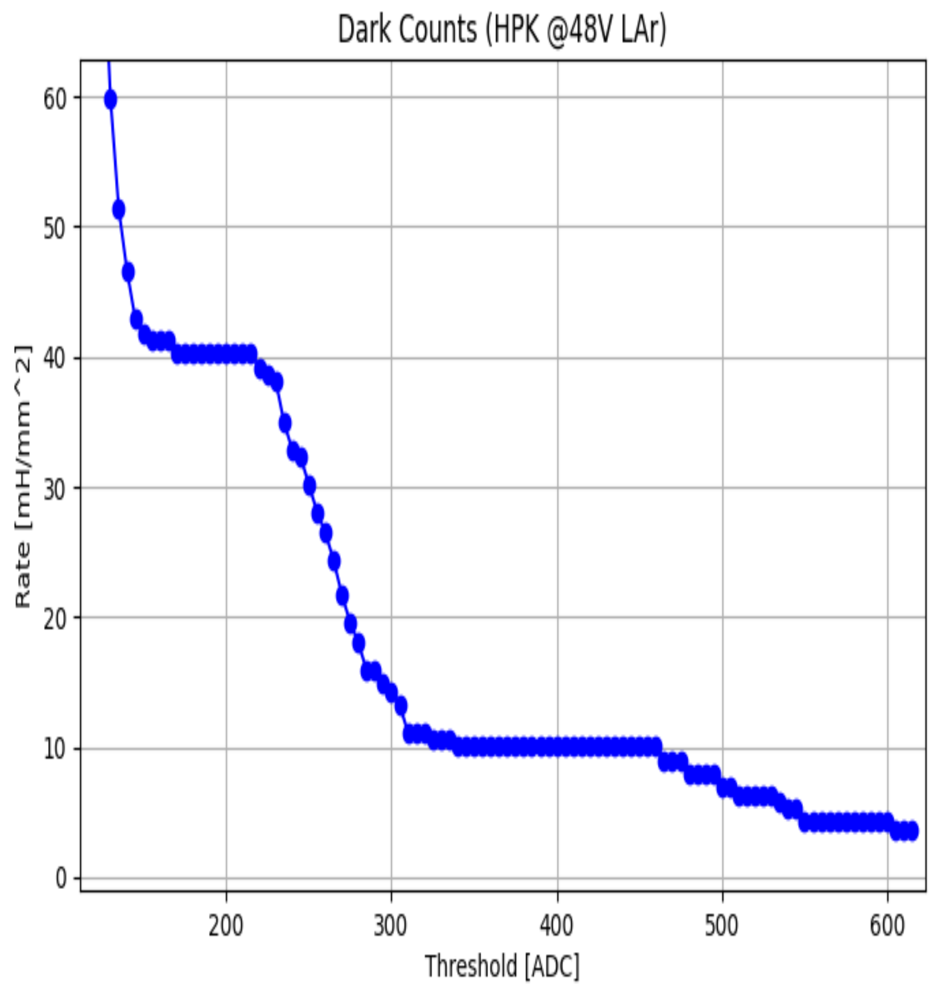
$$DCR(\mathrm{LN2-T}) = \left(\tfrac{1}{2}\right)^{\frac{\Delta T}{10}} \cdot DCR(\mathrm{RT}) \geq 10^{-6}\ DCR(\mathrm{RT})$$

the sum of all of the dark counts generates the "dark current" of a SiPM.

Presumably - not easy to monitor dark current variations at such low current (require strictly DARK conditions, any leakage may perturb the result)

Observable Metrics

for a stability-degradation comparative analysis at different V_{ov} in Cold



- Test set-up: **3 samples of 6** *S13360-9935 MPPCs* at +3 V_{ov}, +4 V_{ov} and +5 V_{ov} above BD **in LN2** - **with pulsed LED flash (low) illumination** capability.

- Perform periodically (e.g TWO times per Week) short runs with pulsed LED, and record data:

    - "**DCR**" vs counting discriminator Threshold (from **0.5 PE to 3.5 PE pulse amplitude**)

- Observe and monitor for any variation in Rate and Amplitude over a 3-4 months would give a good indication for stability or onset of degradation at V_{ov} (+4V, +5V) w.r.t. V_{ov} (+3V_{Ref}).

  Collected data should allow to derive and monitor Gain and XT stability at the same time

★ In addition test can be expanded with the addition of:

- One (or more) separated sample(s) of **6 SiPM** (optically protected from leakage light - and no LED) in LN2 to monitor periodically Dark Current (picoAmp) in a large(r) span of V_{ov} [0 - 8V]: i.e. monthly/biweekly acquisition of V-I Curves (each SiPM) - with V_{ov} fixed (+3, or +4, or +5 V_{ov}) during time btw. I-V curve measurements].