# Characterisation of SiPM at cryogenic temperatures

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# Overview

Outlook:

- Background
- Setup
- Measurements
- Burst effect
- Results
- Conclusions

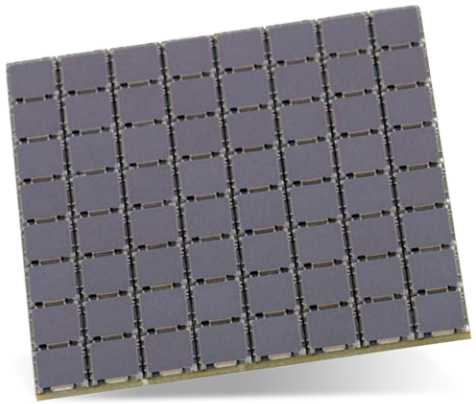
# Background

**"Photodetectors and sensors for particle identification and new physics searches"**

Need best performances from each photodetector in terms of:

- Photodetection efficiency (PDE);
- Gain;
- S/N;
- Dark count rate (DCR);
- Correlated noise;
- Radiation hardness;
- Resilience to stresses;
- Cost;
- Adjustable shape;

⇨ SiPMs could be a solution!



Study and characterize sensors in different conditions of operation

# SiPM models for initial tests

**HPK 13360-3025CS: 2022**
- 3x3mm$^2$ area
- 25um pitch
- Glass epoxy

**HPK 13360-3025PE: 2022**
- 3x3mm$^2$ area
- 25um pitch
- Ceramic

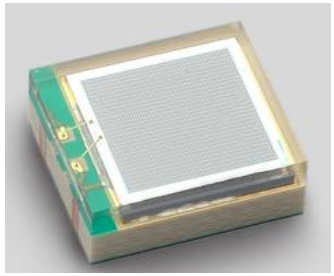
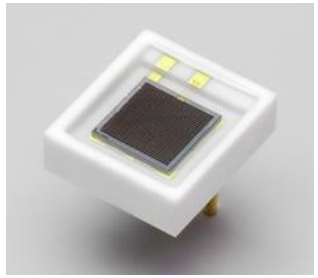
**HPK 14160-3015PS: 2022**
- 3x3mm$^2$ area
- 15um pitch
- Surface mount

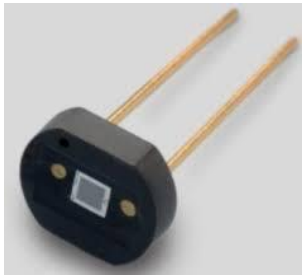
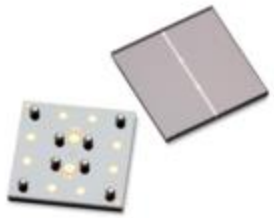
**HPK 13360-3050HS: 2022**
- 3x3mm$^2$ area
- 50um pitch
- Surface mount

**HPK 13360-3050VE: 2022**
- 3x3mm$_2$ area
- 50um pitch
- Surface mount

**HPK 13081-050CS: 2015** (discontinued)
- 1x1mm$_2$ area
- 50um pitch

**New FBK + Broadcom sensors procurement**

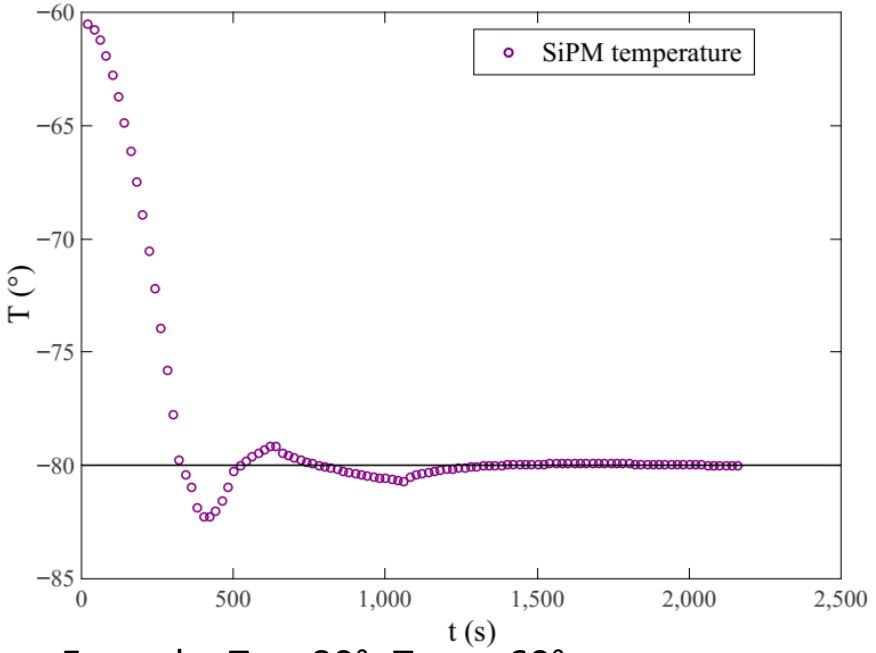




# Setup (1)

Multipurpose setup for SiPM characterization in a wide temperature range (from -150° to 25°)

**Setup:**

- liquid nitrogen cryostat (LN2) 14l;
- source meter unit Keithley SM2450 resolution <1pA, triaxial cables ;
- stabilized power supply Keysight E3630;
- oscilloscope (Tektronix MSO 64) 12bit res., 2.5GHz bandwidth, sampling 25GS/s;
- mechanical linear stage software controlled;
- cold amplifier not designed for fast signals;
- led system at 470nm;
- pulsed UV laser Hamamatsu PLP10 @405nm, 50ps pulse width ;
- fast amplifiers Hamamatsu and Fast 2GHz bandwidth.




Example: $T_{set}$=-80°, $T_{initial}$=-60°

PYTHON SCRIPT | MECHANICAL STAGE | PT100 TEMPERATURE SENSOR | SIMPLE FEEDBACK CONTROL | LN2 VAPOUR

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# Setup (2)

**The setup can perform:**

- **IV curve through the source meter unit SM2450**

Quenching resistor $R_q$;

Breakdown voltage $V_{bd}$;

- **DCR analysis through power supply + amplification + oscilloscope**

Primary DCR;

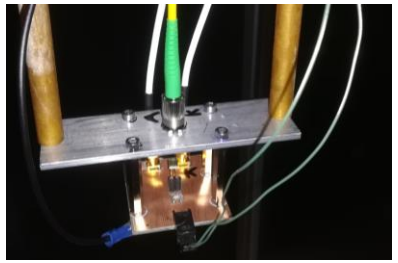
Afterpulses;

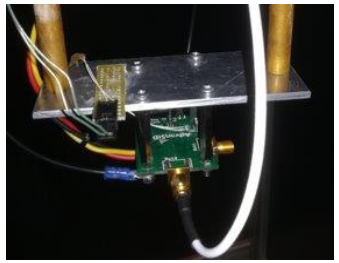
Cross-talk;

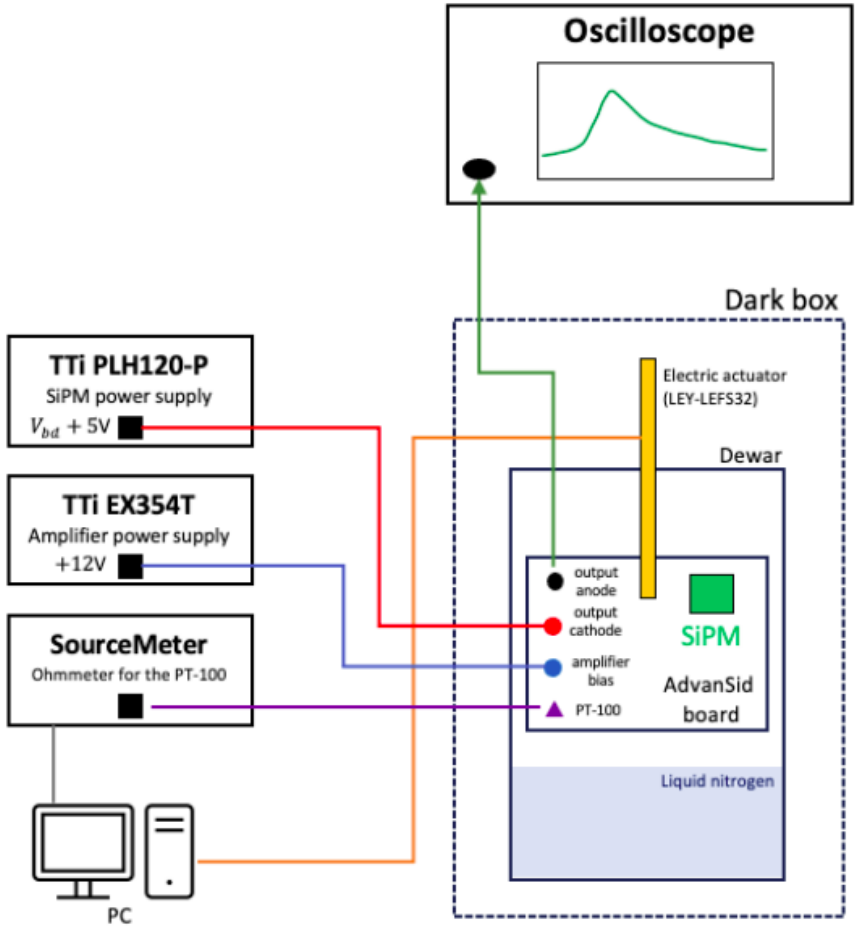
Burst effect;

- **Temporal study through power supply + amplification + oscilloscope + Laser source**

Time resolution





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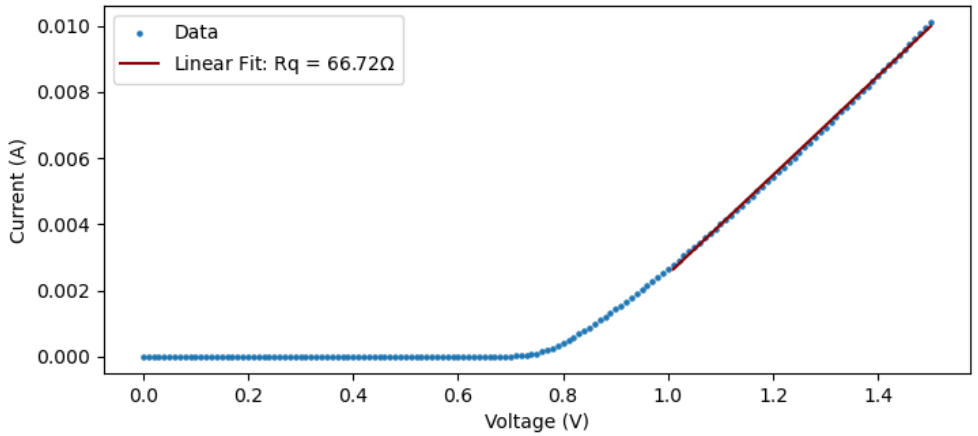
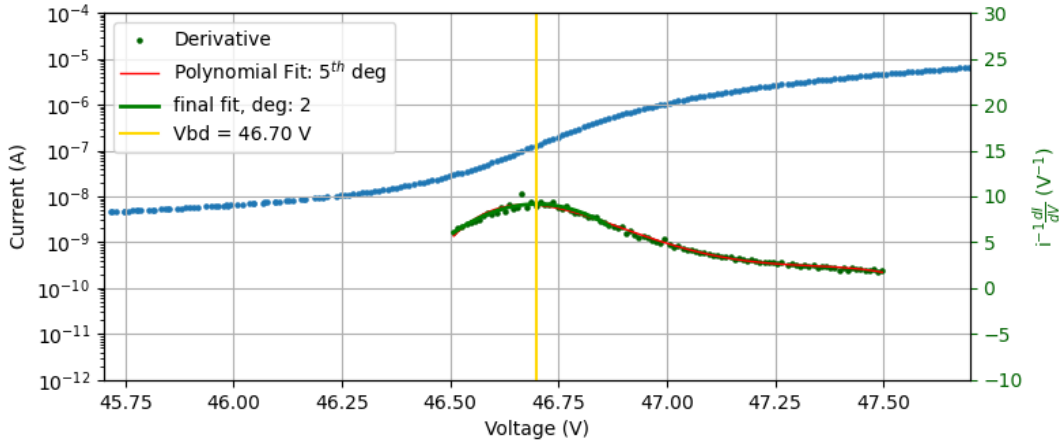
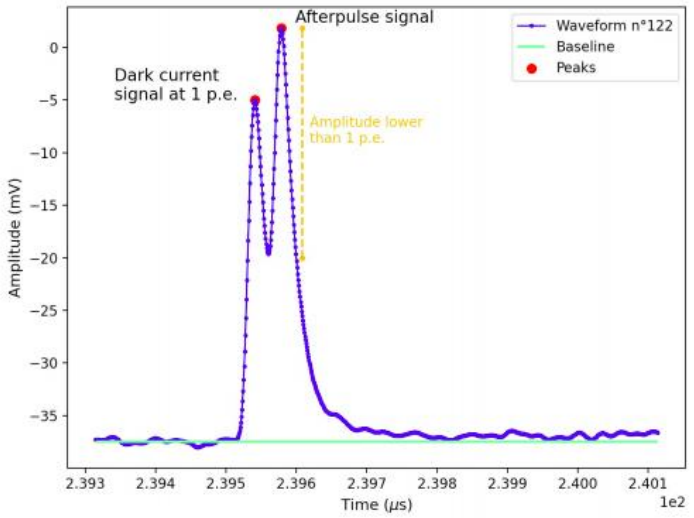
# Setup (3)

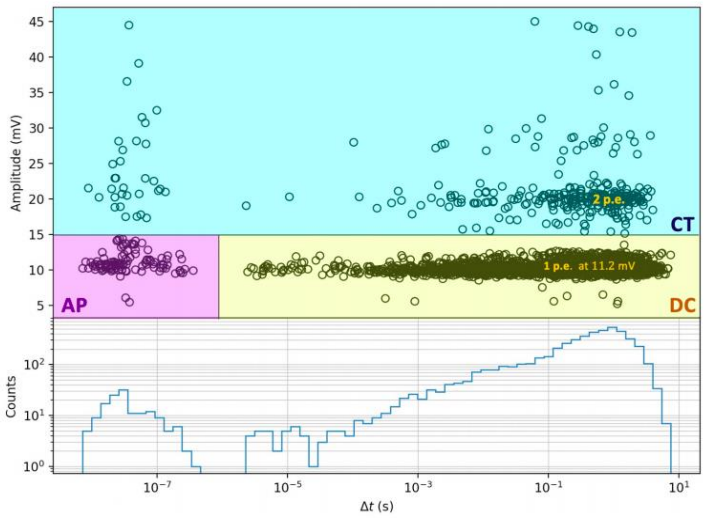



**Analysis through Python Scripts:**

- Linear fit in direct IV;
- Polynomial fit in normalized derivative reverse IV;
- Peak amplitude in waveform
- Time study;
- Peak shape;
- Hystograms;




Example: SiPM 13360-3025CS @-60°

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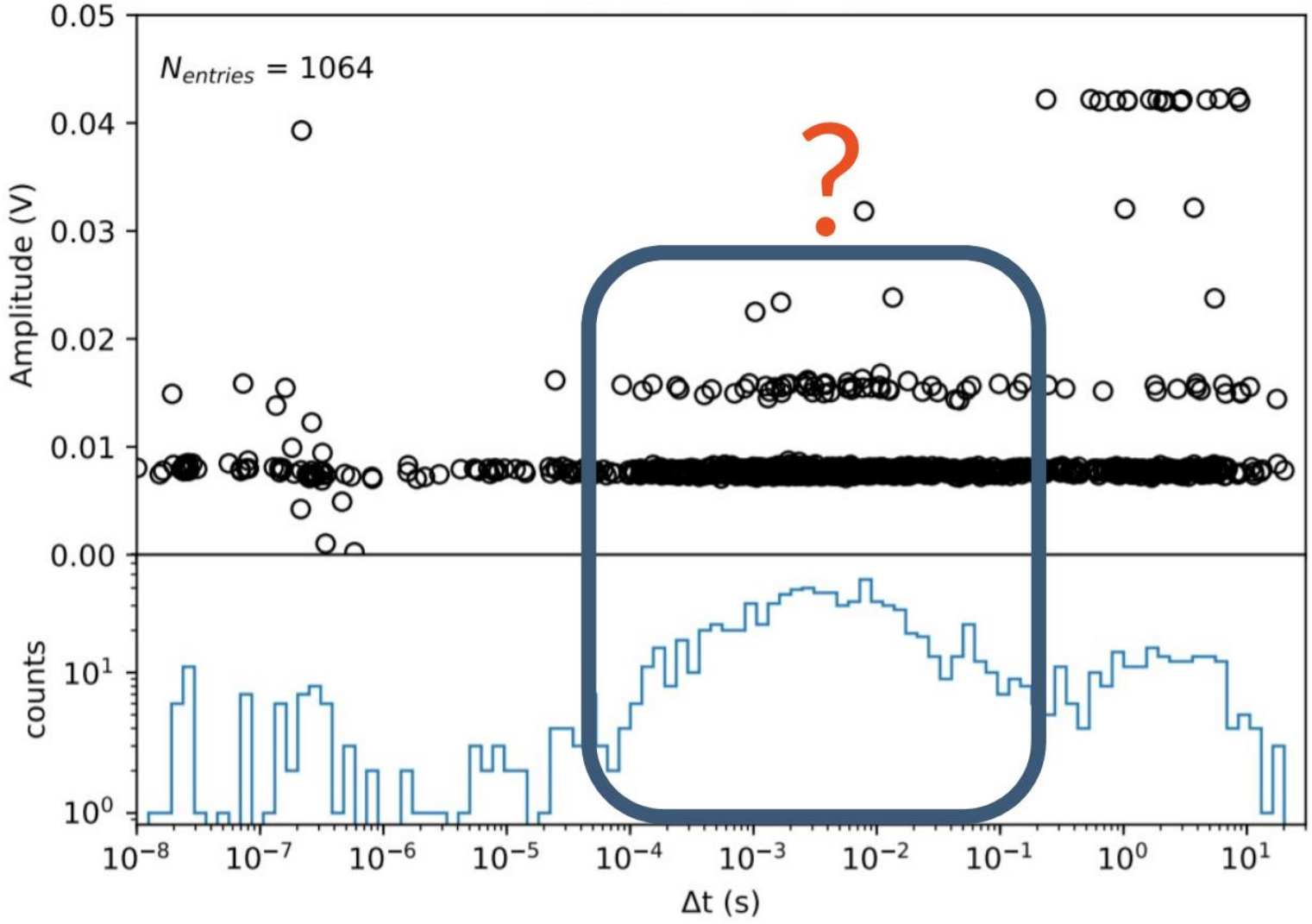
# Signals in DCR: burst of events



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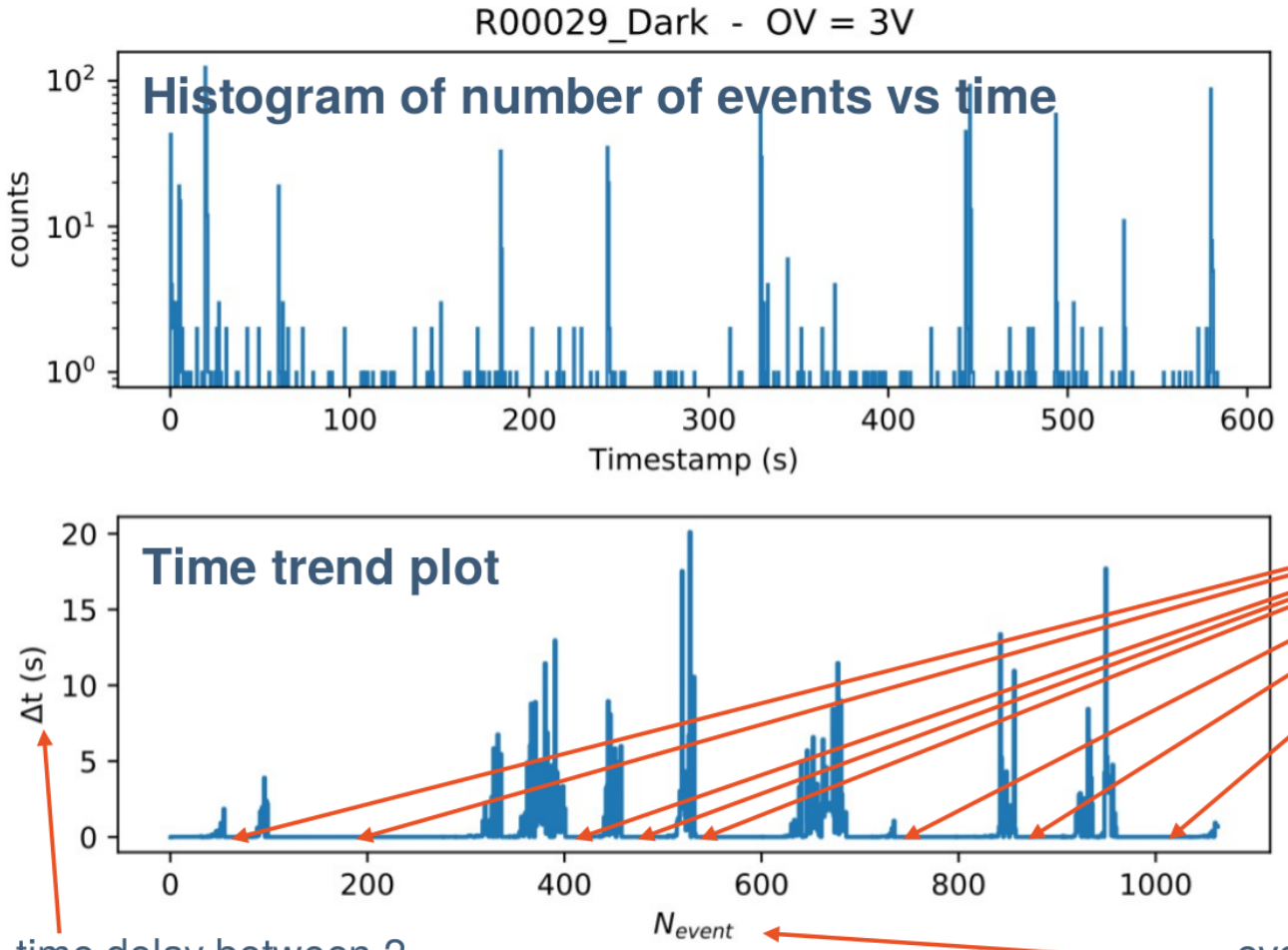
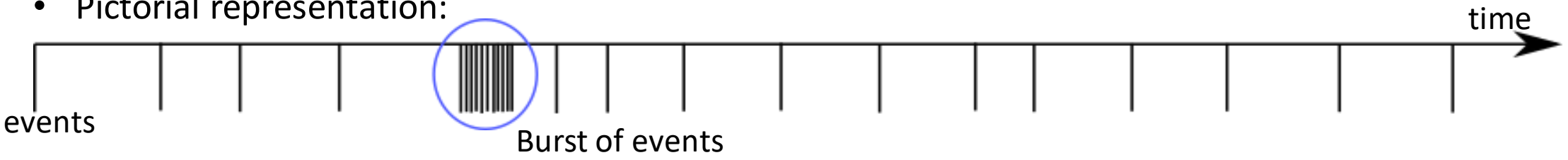



**The broad peak in 2-dim plot centered at 0.01Hz is due to burst of consecutive events at frequencies in the range (100 Hz-1kHz)**

# Signals in DCR: burst of events

**The bursts:**

- Consecutive random events with 1ms to 10ms time delay between each other
- Duration of one burst between 100ms-2s;
- A burst can contain from tens to hundread of single events (average ~ 50events);
- The mean amplitude of the events in the burst is 1p.e.;
- Observed from T=-60° in some samples;
- Different from model to model;
- Under further investigations
- Pictorial representation:

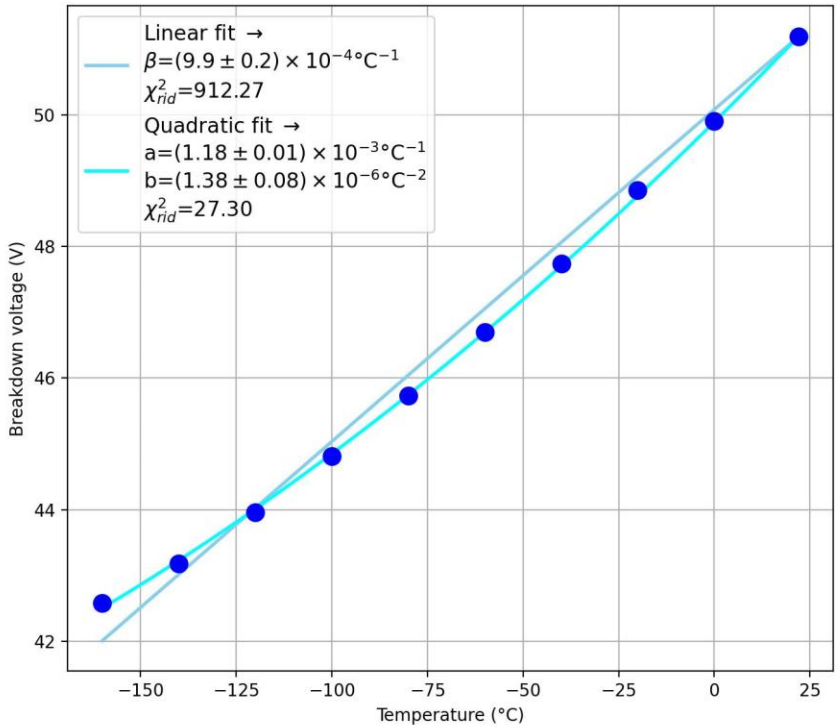



**For more detail see:**

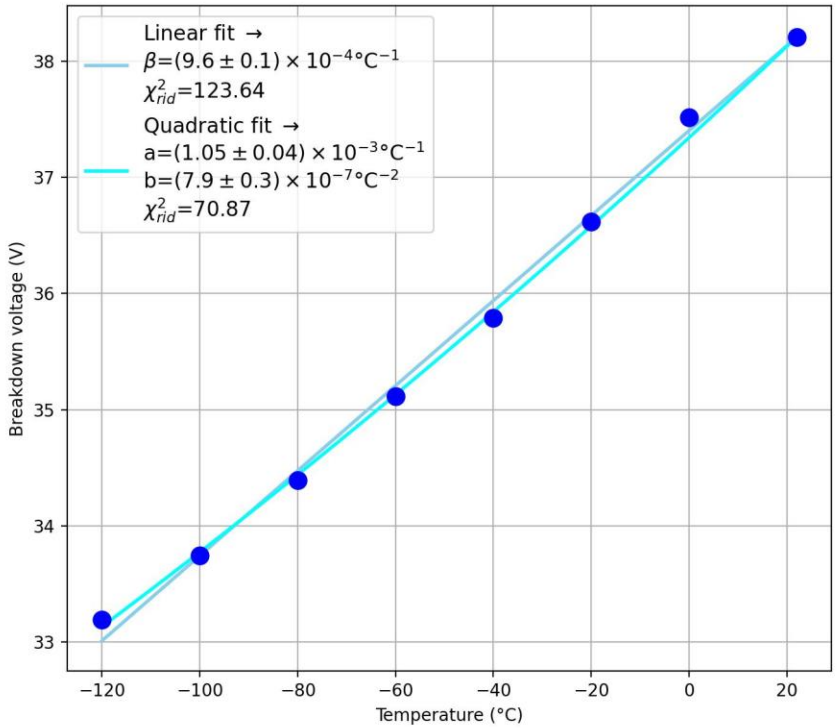
"A newly observed phenomenon in the characterisation of SiPM at cryogenic temperature" M. Guarise et al., Journal of instrumentation, vol16 (2021) **DOI** 10.1088/1748-0221/16/10/T10006

# Results: breakdown voltage

Example of HPK S13360-3025CS



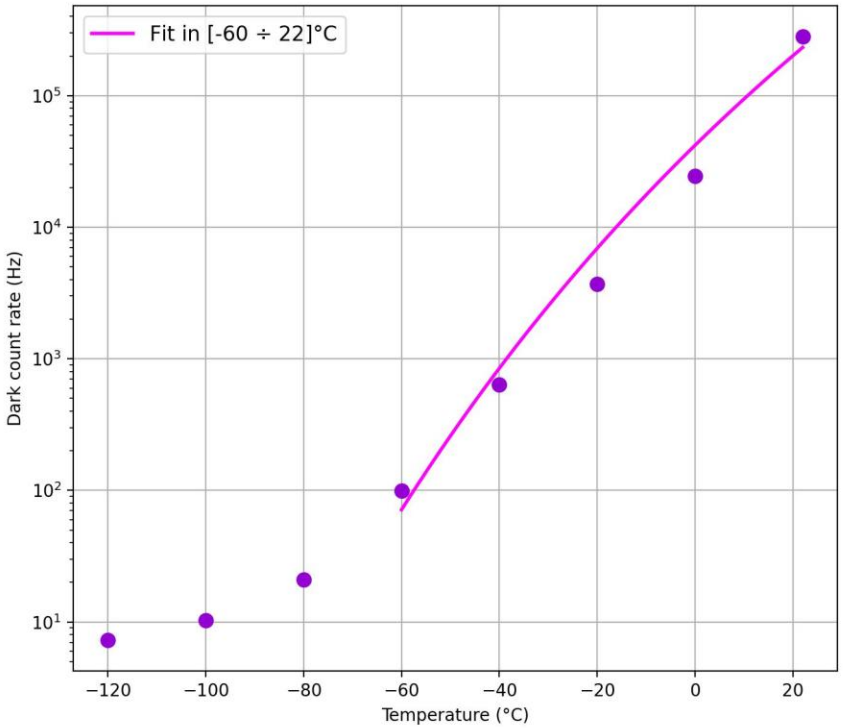

Example of HPK S14160-3015PS



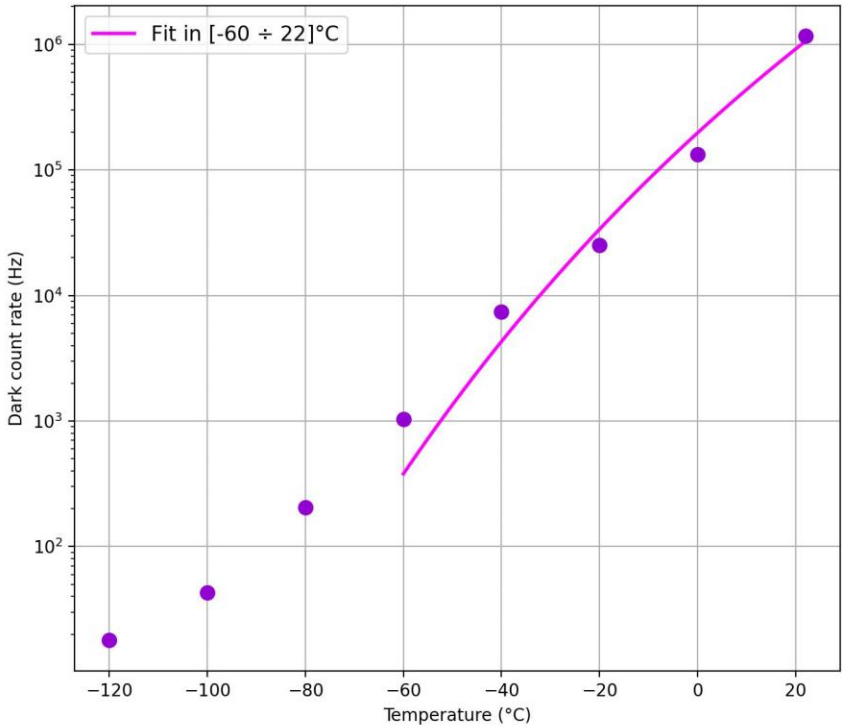

Empirical models: linear & quadratic

# Results: DCR

Example of HPK S13360-3025CS



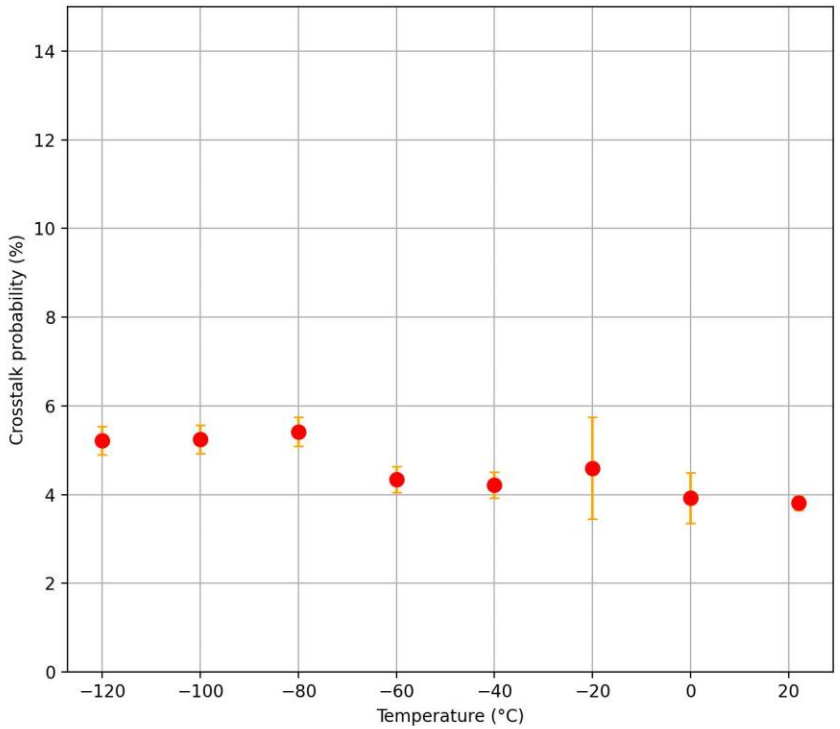

Example of HPK S14160-3015PS



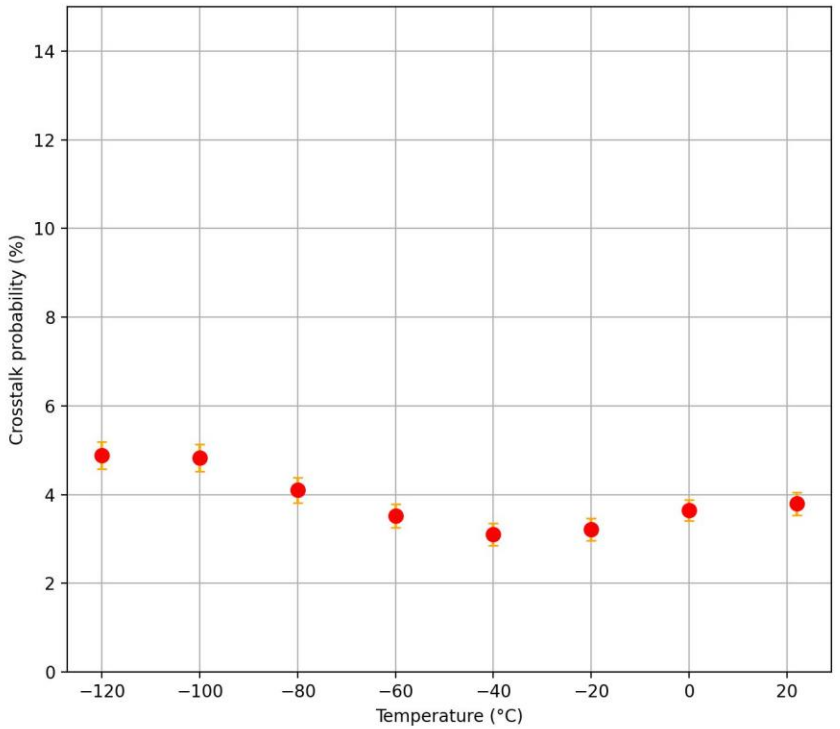

Empirical model: $DCR(T) = a \cdot T^2 \cdot \exp\left(-\frac{b}{k_B T}\right)$ b: activation energy~0.5eV

# Results: CT

Example of HPK S13360-3025CS



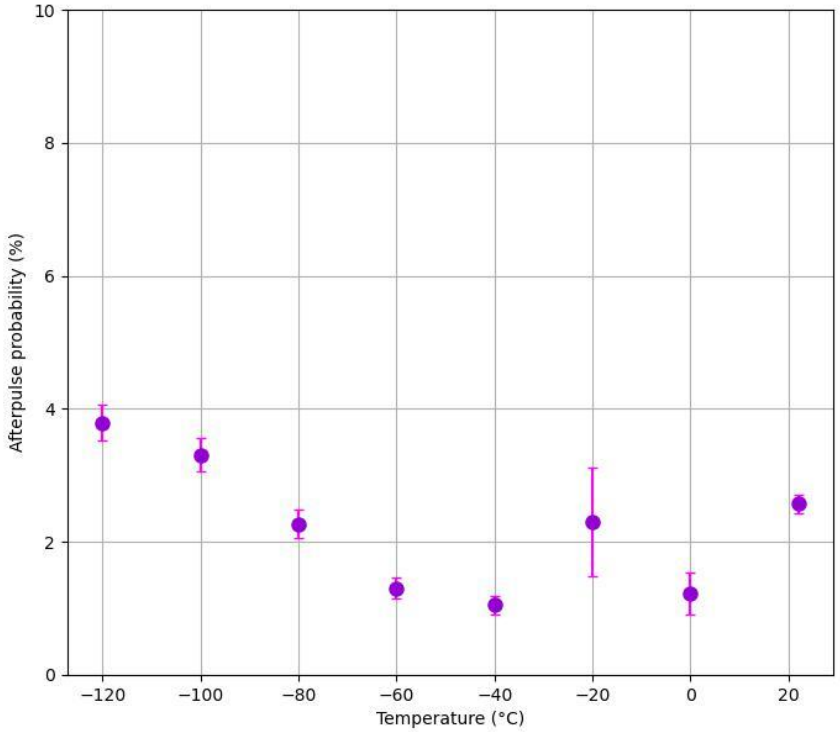

Example of HPK S14160-3015PS



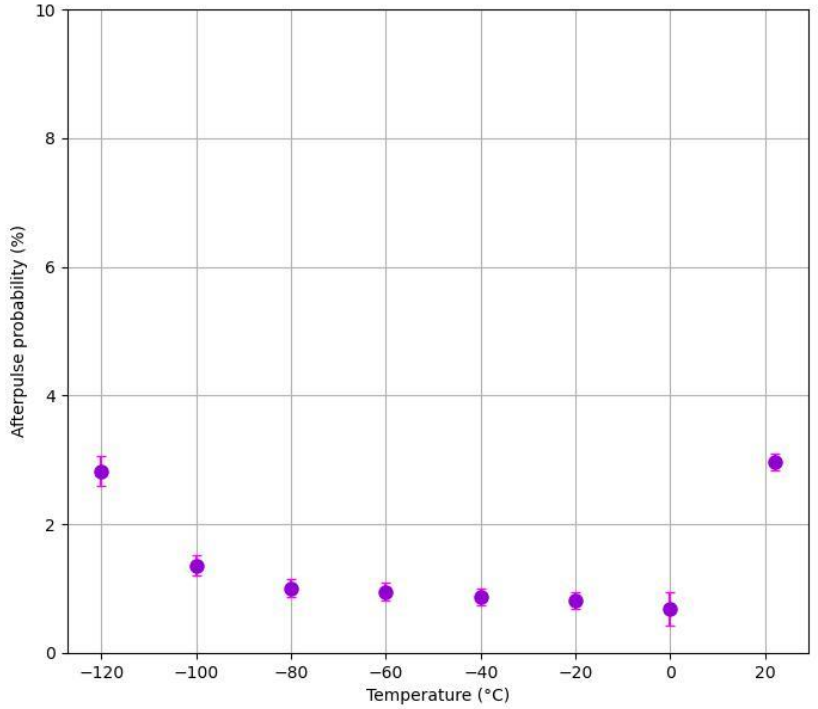

Roughly constant trend

# Results: AP

Example of HPK S13360-3025CS




Example of HPK S14160-3015PS




Roughly constant trend

# Resume of results before irradiation

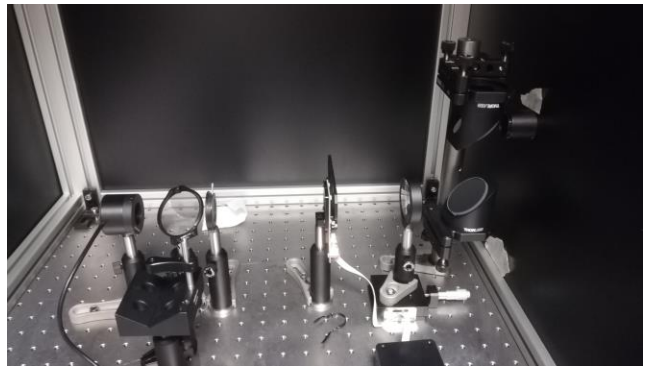
For almost all SiPM models we performed IV and DCR characterization in the range [–120:25]° in step of 20°

| | S13360 -3025CS | S13360 -3025PE | S13360 -3050VE | S14160 -3015PS | S14160 -3050HS | S13081 -050CS |
|---|---|---|---|---|---|---|
| $R_q$ range ($\Omega$) | $[51.3 \div 94.1]^*$ | $[50.9 \div 79.7]$ | $[69.9 \div 81.1]$ | $[20.0 \div 33.6]$ | $[118.8 \div 245.5]$ | $[367.0 \div 761.6]$ |
| $R_q$ th. coef. ($\Omega$/°C) | $[-2.2 \pm 0.1] \times 10^{-1}$ | $[-2.02 \pm 0.09] \times 10^{-1}$ | $[-7.9 \pm 0.5] \times 10^{-2}$ | $[-9.0 \pm 0.6] \times 10^{-2}$ | $[-7.8 \pm 0.7] \times 10^{-1}$ | $[-2.5 \pm 0.2]$ |
| $V_{bd}$ range (V) | $[42.59 \div 51.19]^*$ | $[43.87 \div 51.25]$ | $[43.71 \div 51.33]$ | $[33.29 \div 38.21]$ | $[33.17 \div 39.19]$ | $[44.90 \div 52.49]$ |
| $V_{bd}$ th. coef. (V/°C) | $[5.04 \pm 0.08] \times 10^{-2}$ | $[5.41 \pm 0.08] \times 10^{-2}$ | $[5.6 \pm 0.1] \times 10^{-2}$ | $[3.66 \pm 0.05] \times 10^{-2}$ | $[3.64 \pm 0.04] \times 10^{-2}$ | $[5.54 \pm 0.07] \times 10^{-2}$ |
| 1 p.e. (mV) at 22 °C | $[10.5 \pm 0.5]$ | $[10.7 \pm 0.5]$ | $[20 \pm 1]^{**}$ | $[5.8 \pm 0.6]$ | $[20 \pm 1]^{**}$ | $[36.5 \pm 0.6]$ |
| DCR range | [7.3 Hz ÷ 282 kHz] | [1.4 Hz ÷ 325 kHz] | [25 ÷ 466] kHz *** | [18 Hz ÷ 1.2 MHz] | [1.1 ÷ 1.4] MHz *** | [0.5 Hz ÷ 59 kHz] |
| $E_{act}$ (eV) | $[0.49 \pm 0.03]$ | $[0.50 \pm 0.06]$ | | $[0.48 \pm 0.02]$ | | $[0.46 \pm 0.05]$ |
| Burst events | ✓at −80 °C | ✓at −120 °C | | × | | × |
| CT (%) | $[3.8 \div 5.2]$ | $[3.6 \div 6.8]$ | $[10.8 \div 15]^{***}$ | $[3.1 \div 4.9]$ | $[3.9 \div 27]^{***}$ | $[6.0 \div 9.4]$ |
| AP (%) | $[1.0 \div 3.3]$ | $[0.7 \div 3.0]$ | $[3.7 \div 13.0]^{***}$ | $[1 \div 10]$ | $[22 \div 49]^{***}$ | $[2 \div 11]$ |

# Perspectives

**Plans for the (near) future:**

- **Improve the setup:** new shielded box for SiPMs, new low noise amplifier, new power supply filter,...;
- **Complete the characterization of the models presented;**
- **New models procurement:** different area, cell pitch, technology,...
- **Irradiation campaign:** define place, dose, kind of sensors, number of sensor,...;
- **Instrument the setup for PDE measurements:** monochromator, calibrated photodiode, room T calibration;
- **Further test on burst behaviour:** HPK & FBK synergy, new models, further tests,...



**N.B. DRD4 Framework**

# Conclusions

**In Ferrara:**

- We can peform SiPM characterization down to LN2 temperature in LN2 vapour through a dedicated custom multipurpose system (IV, DCR & correlated noise, time resolution);
- We tested so far 6 different HPK models (different pitch, different package, different fill factor, different chip, …);

**Some results:**

- IV standard behaviour (also temperature dependeance);
- DCR behaviour with burst effect (random train of pulses at kHz);
- DCR decreses from MHz at room temperature down to Hz at -120°;
- DCR lower value: 150mHz/mm$^2$ @ -120° for 13360-3025PE;

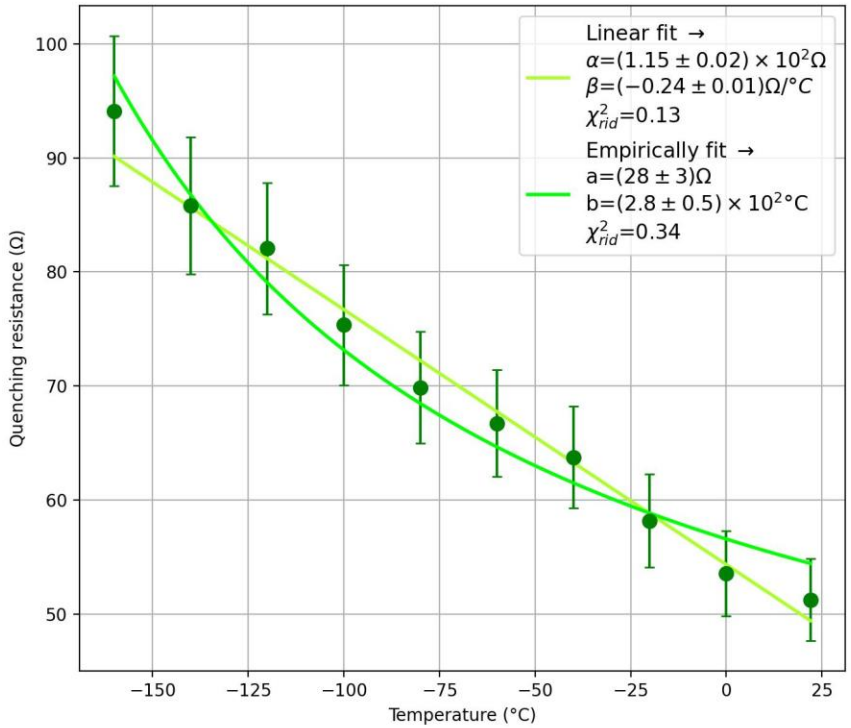
**For the near future:**

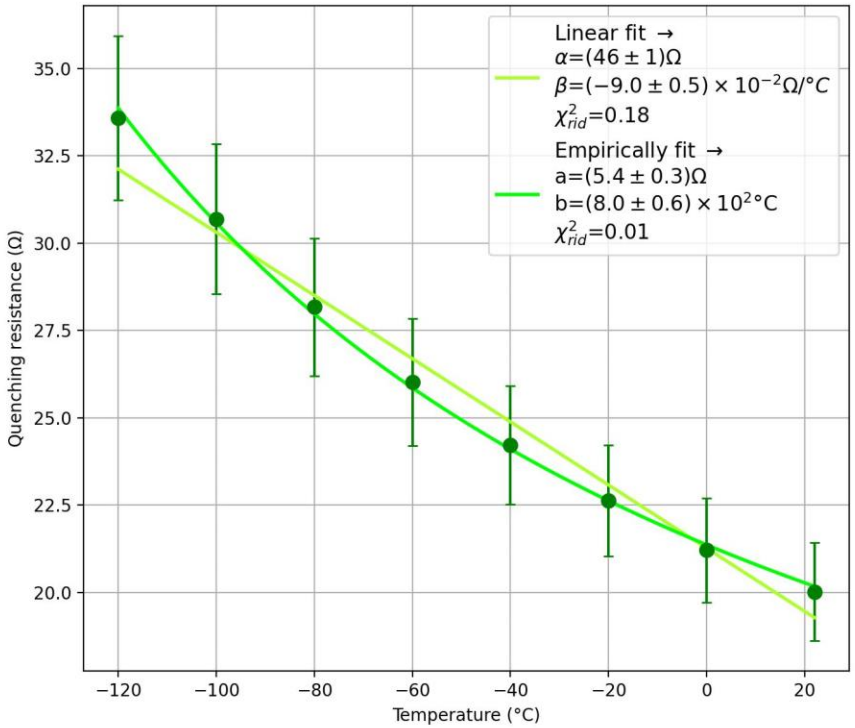
- Upgrade of setup (noise reduction);
- We plan to instrument PDE test setup;
- We plan to test these sensors after different dose irradiation ;
- We plan to test the irradiated sensors after different annealing procedure;

# The end

**Thanks!**

# Back-up: quenching resistor



# Back-up: time resolution