Burst effect in SiPMs at cryogenic temperature

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PISA MEETING ON ADVANCED DETECTOR 2024 LA BIODOLA

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Outlook

- Overview of SiPMs
- Dark noise in SiPMs
- Burst effect
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  - Features
- SiPMs tested
- Measurements
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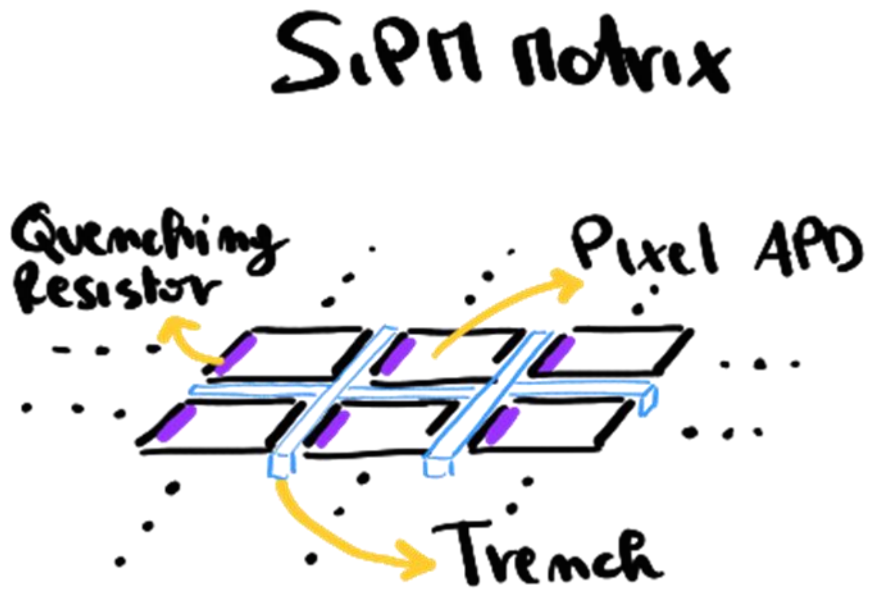
- Conclusions

SiPMs

Silicon Photomultipliers are solid state photodetectors based on the Geiger mode.
Widely used in many applications (Calorimeters, TPC, Cherenkov, PET, LIDAR,...).

Important features:

- Compact detectors
- Single p.e. detection
- High gain
- Large UV-VIS PDE
- Simple & low voltage
- Cryo resilience
- Magnetic field immunity
- Good fill factor
- High dynamic range
- Low cost



Dark signals in SiPMs

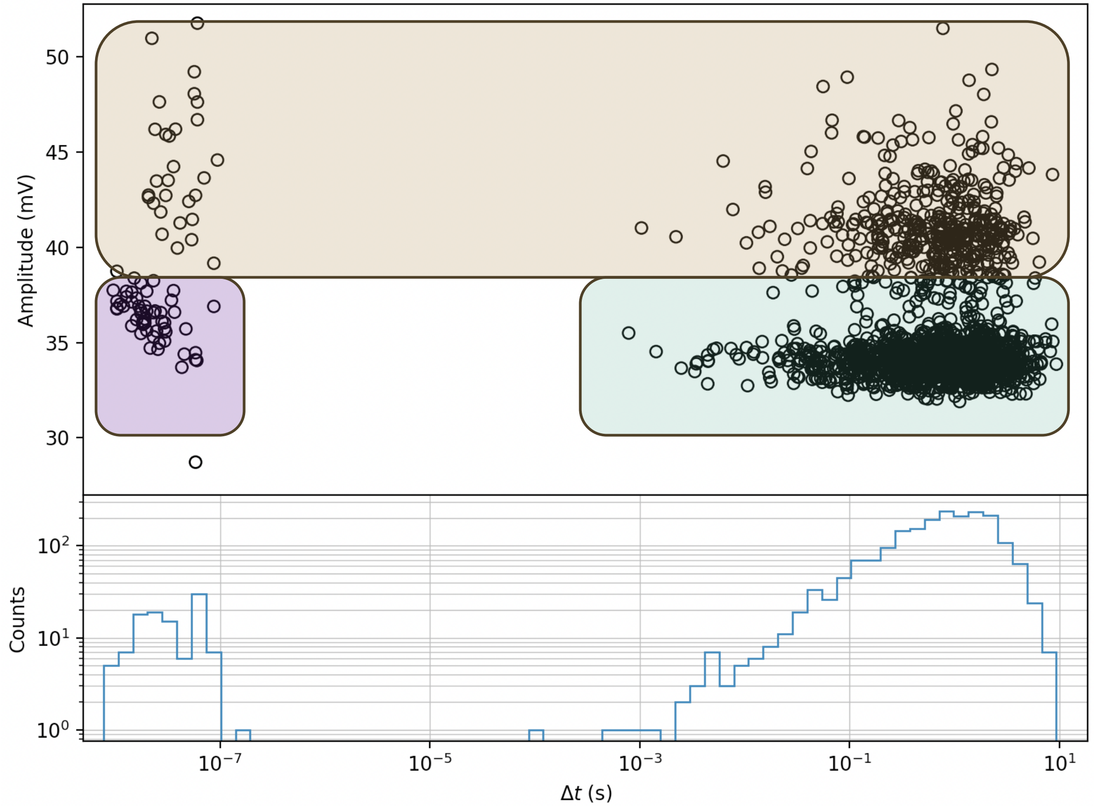
When in complete darkness, signals are due to:

- Thermal promotion of e^- in the conduction band ➡ dominant at room temperature
- Interband tunnel effect ➡ dominant at cryogenic temperature under -100°C

Depending on the amplitude and temporal occurrence, DCR signals can be divided into:

- *Primary noise signals*
- Correlated noise signals: *cross talk events* (direct-indirect) and *afterpulses*

Typical values:
Warm: ~100KHz/mm2
LN2: ~100mHz/mm2

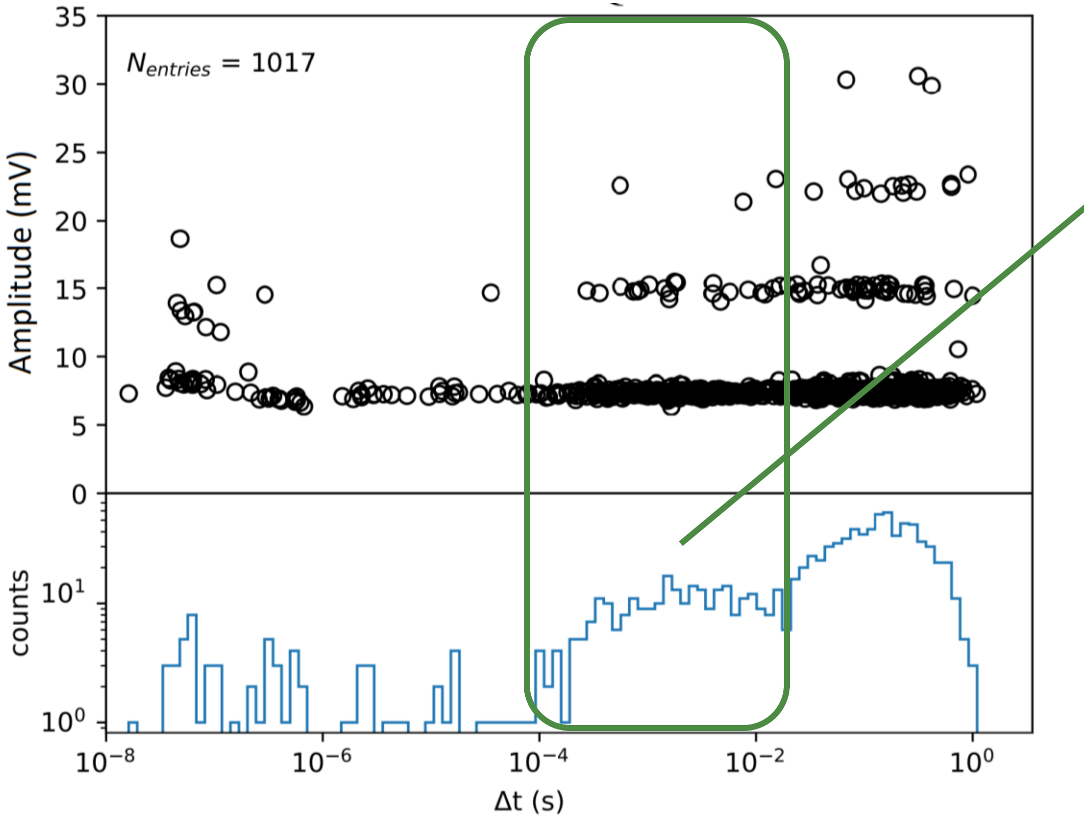


Example: HPK 13081-050CS @ -100°C

Bursts of dark signals at cryo temperature

They are a *new kind of DCR* observed at cryo temperature (at warm dominated by primary DCR)

2D plot with amplitude VS time difference between consecutive events for dark signals at cryogenic temperatures.



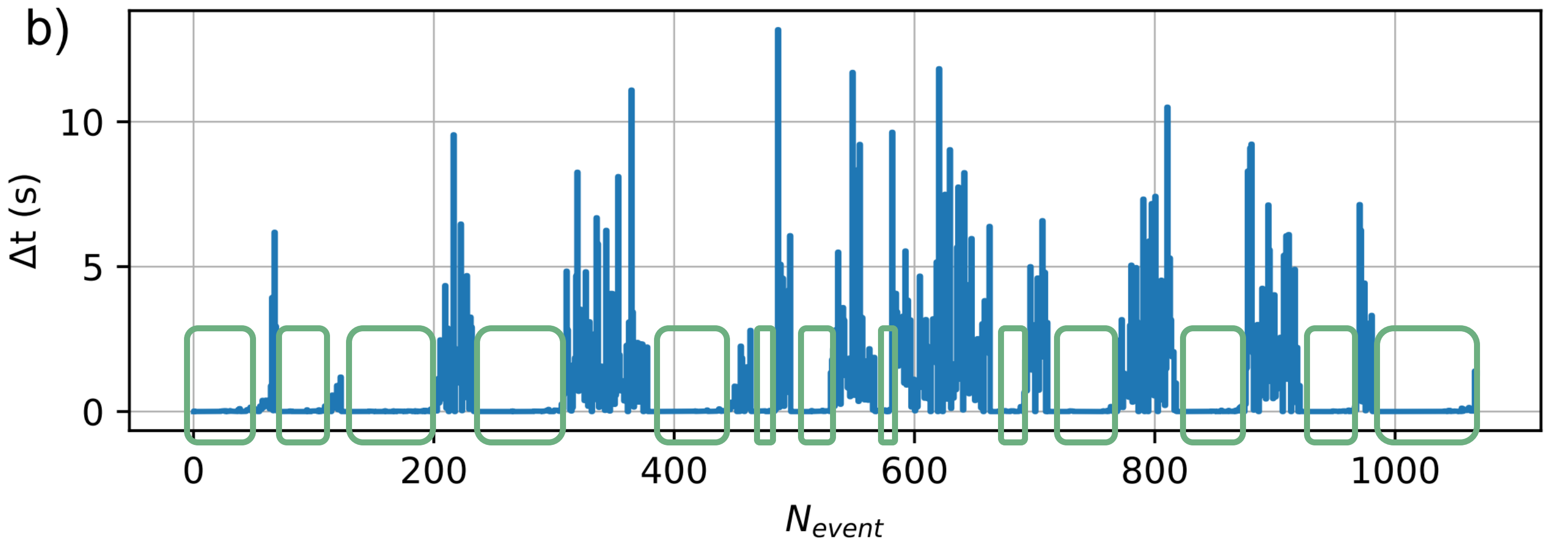
Strange and not expected behavior! This broad peak center at kHz is due to *"trains" of consecutive events that happened randomly*. They occur at a frequency of kHz.

Example of HPK 13360-6075 DUNE split @3OV, LN2 temp

Guarise, M., et al. "A newly observed phenomenon in the characterisation of SiPM at cryogenic temperature." *Journal of Instrumentation* 16.10 (2021): T10006.

Bursts of dark signals at cryo temperature

Time-stamp plot: time delay with the previous event as a function of the number of event



The distribution is not flat (expected if uniform DCR distribution)! *Valleys* are *series of consecutive events at small Δt*. These events are exactly the same strange events in the 2dim plot

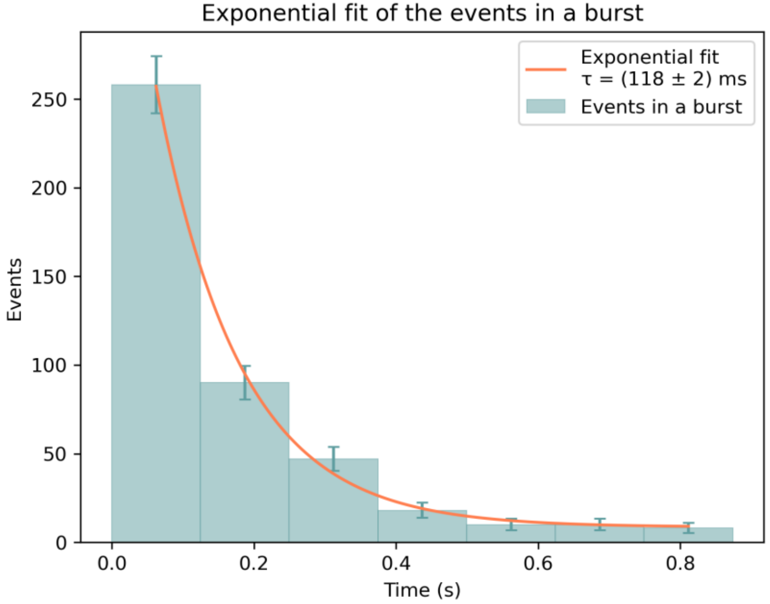
Bursts of events!

Not all SiPM show bursts effect: bursts are a combination of external causes (always present) and an internal mechanism (depends on the SiPM model)

Features of the bursts

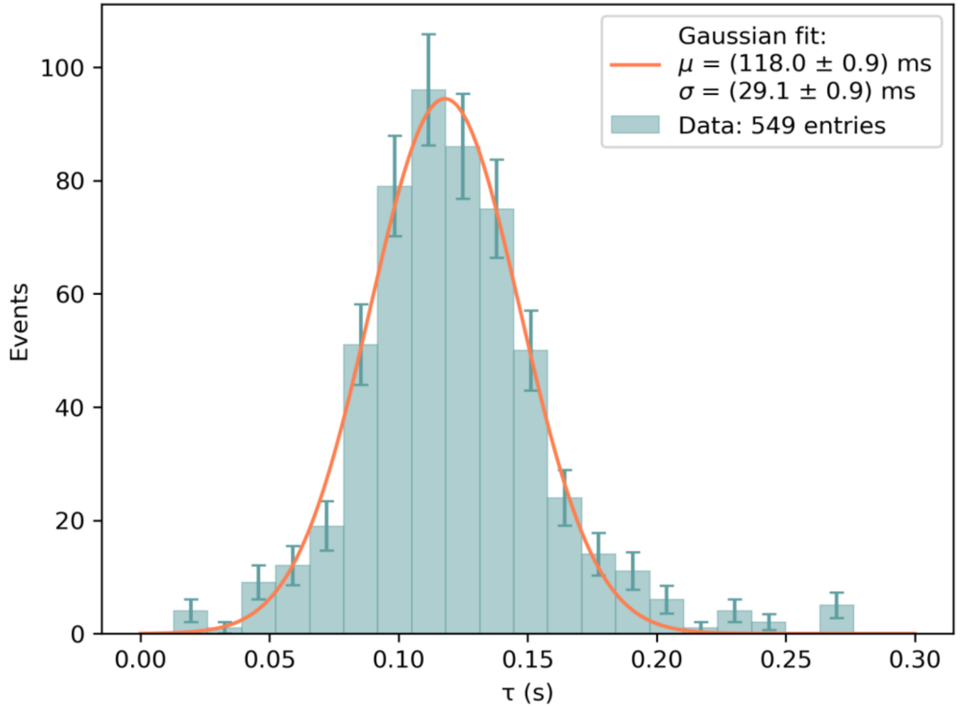
By analyzing more than 800 bursts we identify some common features:

- Start with a high amplitude event (higher than 3p.e.)
- Contain from few tens to hundreds of single signals
- Time delay between events is distributed in [1-10]ms range
- Last for few hundreds of milliseconds
- Single events in the burst follow an exponential decay



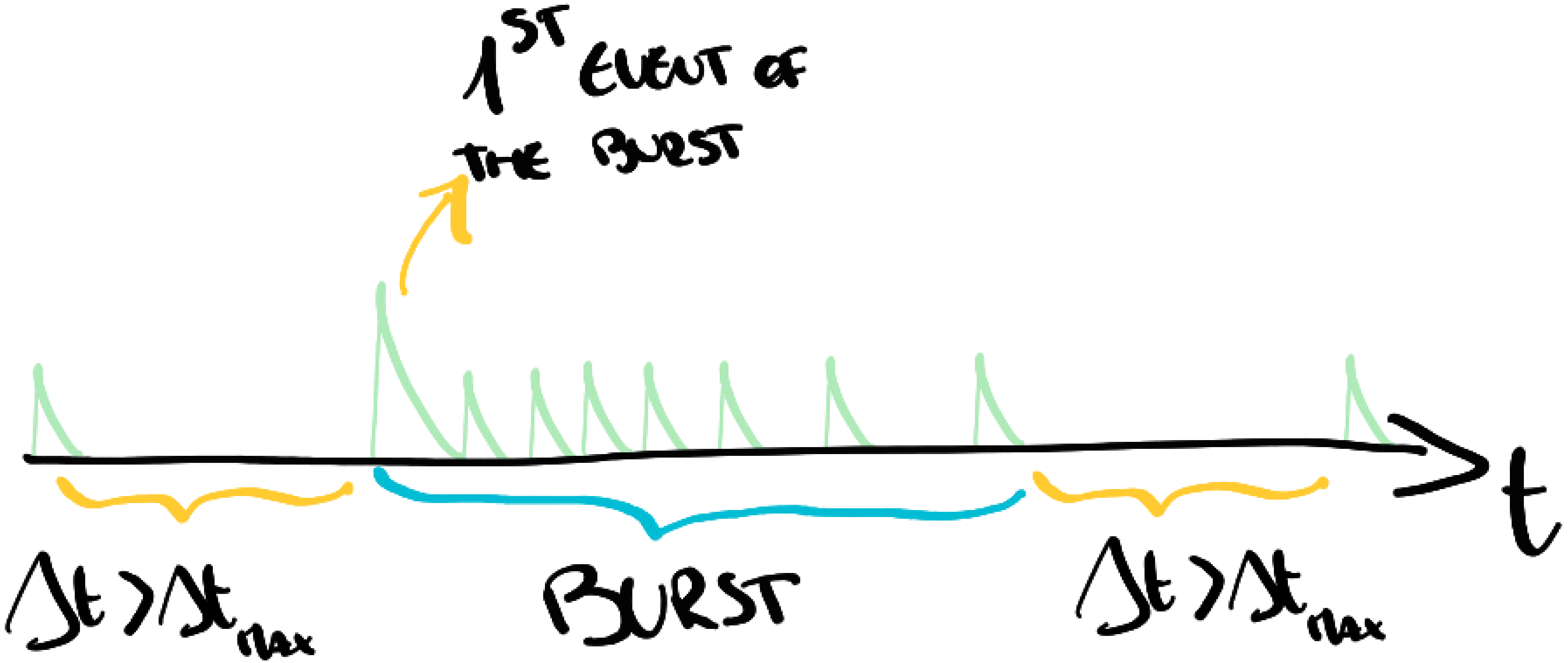
A burst is divided into slices and we count single events in each one.

Events(t)=A(0)exp(-t/T)
T=(118±0.9)ms



Bursts of dark signals at cryo temperature

Pictorial representation:



Tested SiPMs

Hpk models:

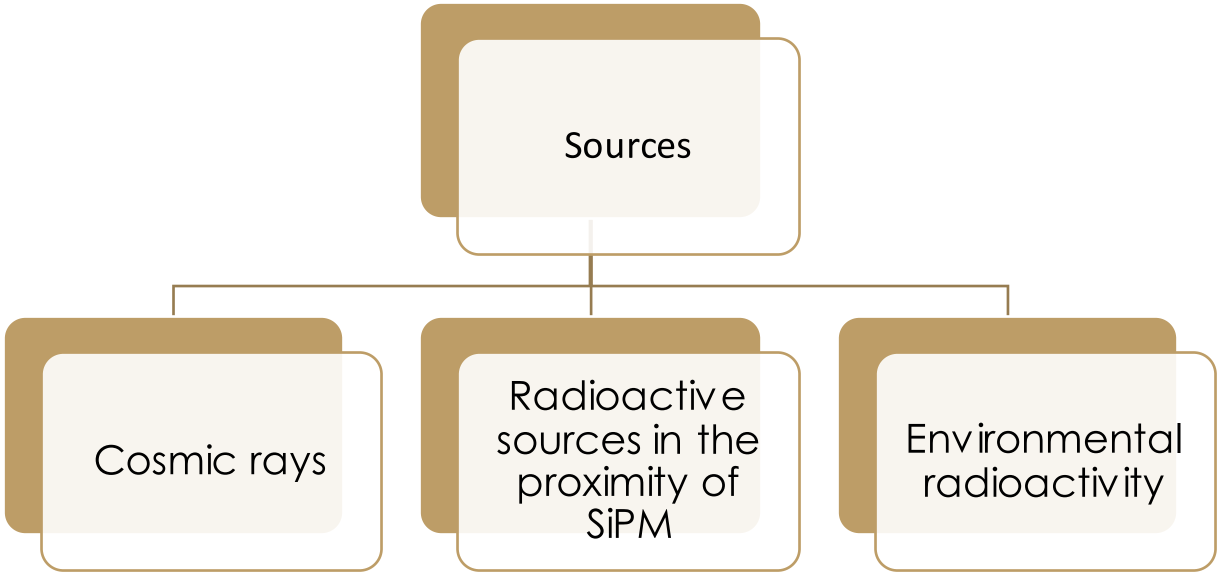
Model	Pitch(um)	Area(mm^2)	Package	Bursts
13360-6050LRQ (DUNE)	50	36	SMT	yes
13360-6050CS (2018)	50	36	Ceramic	no
13360-6050VE	50	36	SMT	yes
14160-6050HS	50	36	SMT	yes
13360-3025PE	25	9	SMT	yes
13081-050CS	50	1.7	SMT	no

FBK models:

Model	Pitch(um)	Area(mm^2)	Package	Bursts
CRYO-NUV-HD (DUNE)	30	36	SMT	yes
CRYO-NUV-HD-TT (DUNE)	54	36	SMT	yes

Investigation measurements

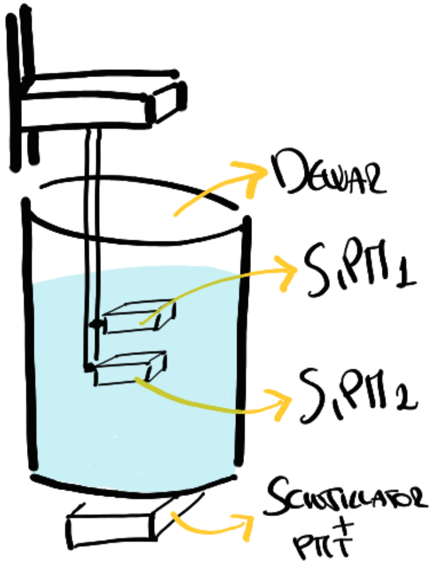
Bursts seems to be randomly triggered, but we investigated if any external cause triggers these events. We would like to understand if there is a correlation between bursts and ionizing radiation that deposit energy in the sensor.



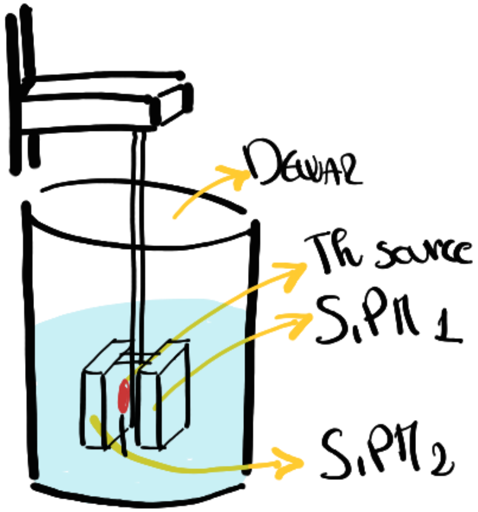
Idea: Cryogenic investigation in a completely dark environment by placing the sensors in different orientation, looking at coincidences of bursts, and using ionizing radiation sources

Measurements: setup

Setup used for investigations with cosmic rays



Setup used for investigations with Thoriated source



Instrumentation:

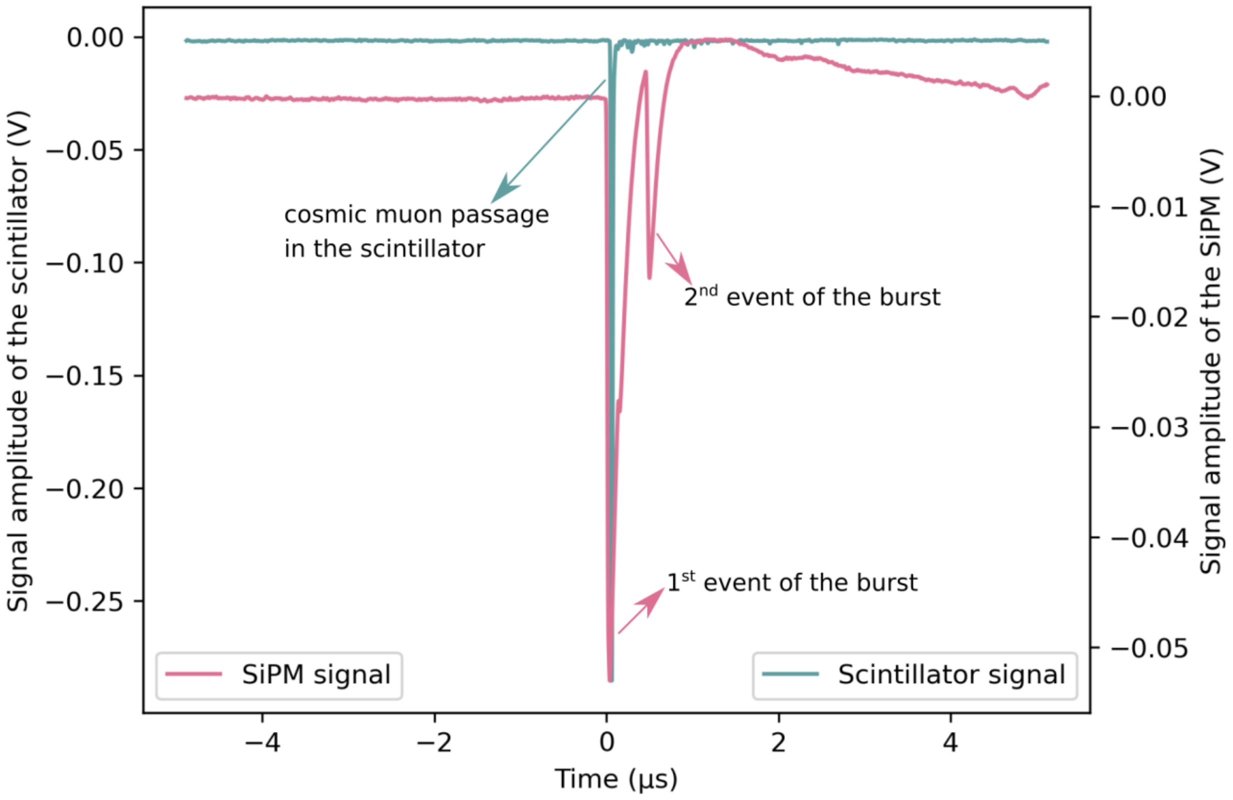
- SiPM (HPK 13360-6075)
- Oscilloscope (Tektronix MSO64B)
- Custom amplifier
- LN2 dewar (14l)
- Mechanical stage (60cm travel)
- Low noise power supply (TTi PLH120P)

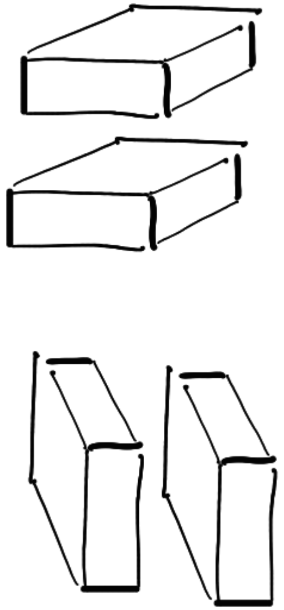
Methodology:

Trigger on 1 SiPM (@0.5p.e.) and search for coincidences looking at the first event of the burst in the other channel.
SiPMs are covered to prevent LN2 scintillation photons.

Results with cosmic rays

Measure the passage of cosmic muons in the SiPM thanks to a scintillator in coincidence





Horizontal configuration:
Expected coincidences: (3.2 ± 0.3) mHz
Measured coincidences: (3.8 ± 1.3) mHz

Vertical configuration:
Expected coincidences: 0
Measured coincidences: 0

Looking at a single sensor in the vertical-horizontal configuration we can estimate the burst rate due to the environmental radioactivity: $R_{env} = (16 \pm 1)$ mHz

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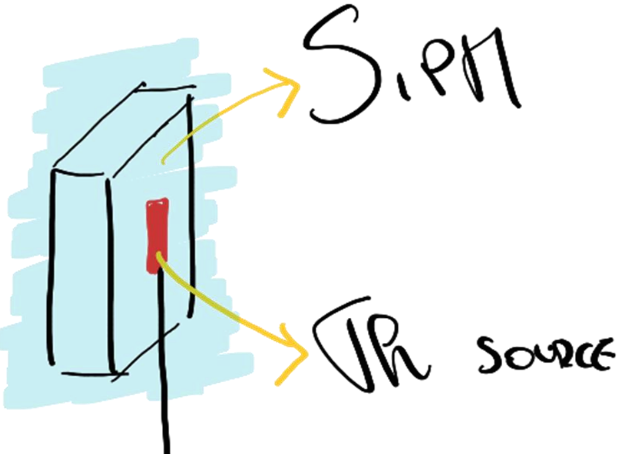
Measurements: results with Th source

No burst coincidences between the 2 SiPMs are expected because no crossing both
Looking at one sensor placed in the vertical configuration:
$R_{bursts} = R_{env} + R_{Th}$

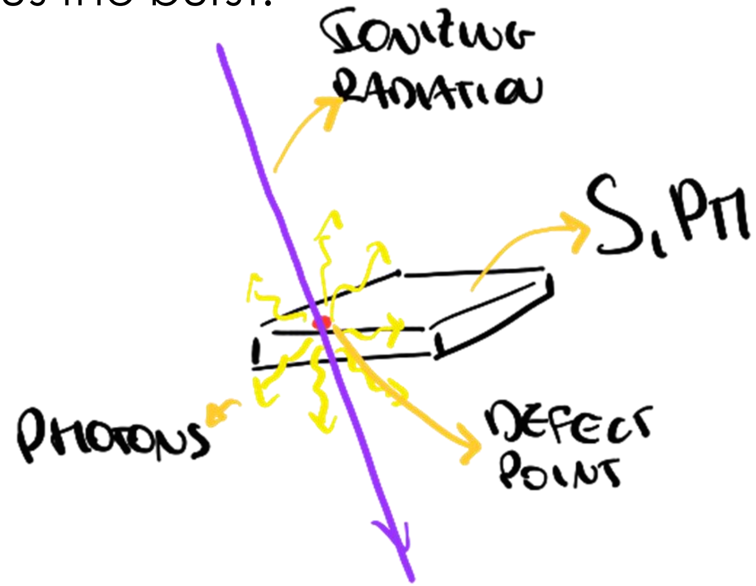


Results:
Expected: (81 ±1) mHz
Measured: (77 ±7) mHz

The rate of particles emitted by the Th source has been measured using MiniPix sensor

...but why are there bursts? Possible explanation

External cause: bursts are triggered by ionizing radiation that passes through the sensor.
Internal cause: the exponential behavior of bursts recalls a luminescence process:
We can imagine a defect area in the sensor that, once excited by external ionizing radiation, releases photons with a typical lifetime of the order of ms that can then be detected by the SiPM itself producing thus the burst.



Conclusions

- *Bursts of events in SiPMs*: new kind of DCR at cryogenic temperature
- Bursts affect the performance of SiPMs increasing the DCR
- Bursts: *trains of consecutive single p.e. pulses*
- Randomly triggered
- Present in almost all tested sensors
- Common features
- Temporal evolution of events in the burst is *exponential decay with T ~120ms* (for the ones tested)
- Caused by *ionizing radiation that interacts in the SiPM* volume
- *Internal causes not well understood*
- Synergy with vendors

For more info see our 2 papers:

Guarise, M., et al. "A newly observed phenomenon in the characterisation of SiPM at cryogenic temperature." *Journal of Instrumentation* 16.10 (2021): T10006.
Guarise, M., et al, "Investigation of the burst phenomenon in SiPMs at liquid nitrogen temperature"" ArXiv preprint, submitted to JINSTRUM

The end

Thanks for your attention