



# Characterization of the SiPMs for the scintillation detectors of IceCube

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**Tutor**

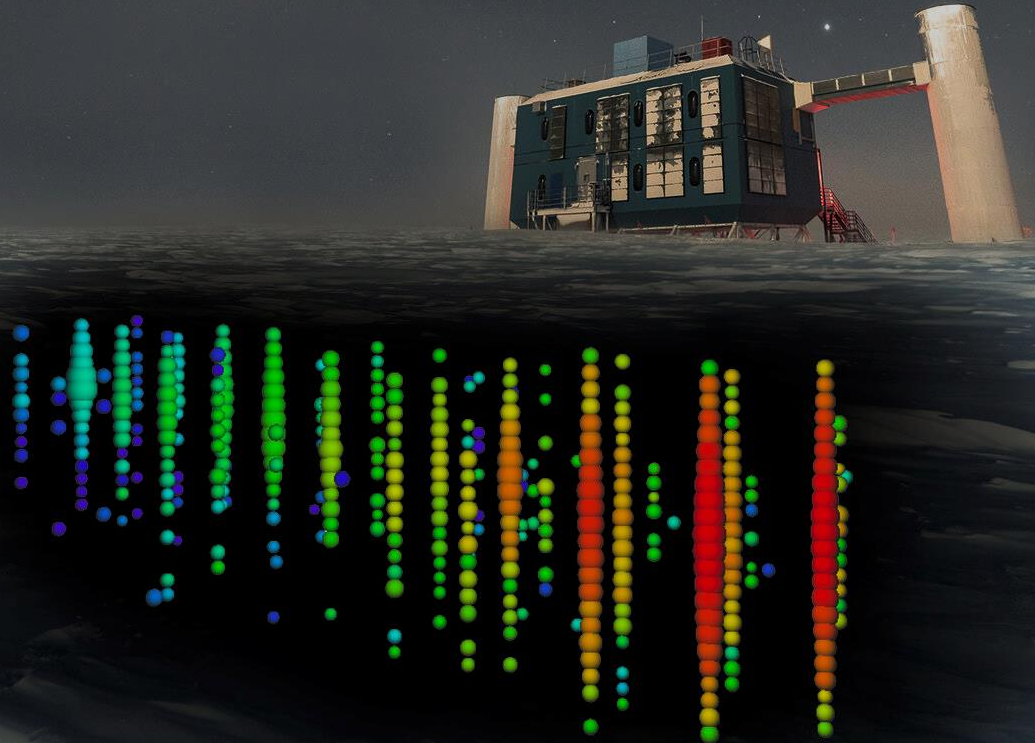
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Shefali Shefali

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**Anno accademico:** 2020/2021

## IceCube – Gen 2

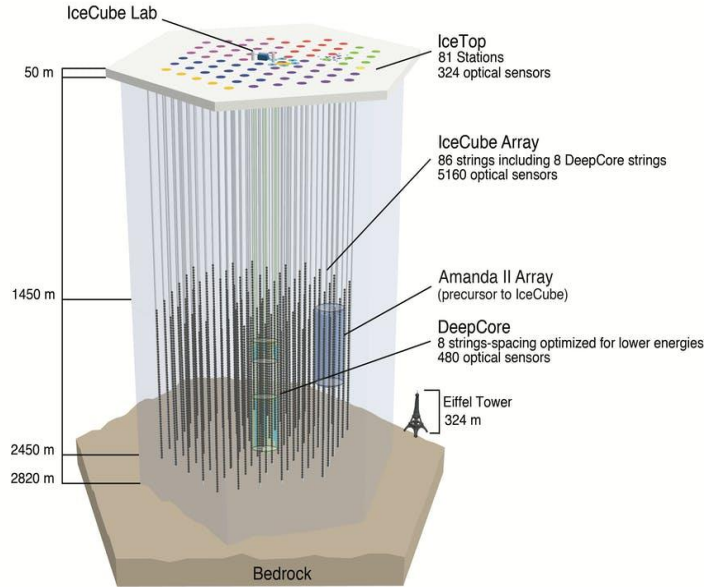
- The first gigaton detector ever built
- Search for neutrinos and cosmic rays from the most violent astrophysical sources
- Detection of particles using Antarctic's transparent ice and Cherenkov effect










## Ice Top

- A surface array of scintillation detectors used as a partial veto for the down-going background of penetrating muons
- Detection of air showers with an energy resolution from  $P_{ev}$  to  $E_{ev}$
- 162 tanks of ice each instrumented with two standard IceCube sensors: two Digital Optical Modules (DOMs), a 10 inch photomultiplier tube (PMT) and electronics

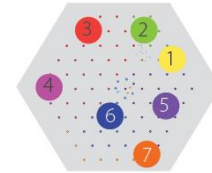


### Detector Design

-  1 gigaton of instrumented ice
-  5,160 light sensors, or digital optical modules (DOMs), digitize and time-stamp signals
-  1 square kilometer surface array, IceTop, with 324 DOMs
-  2 nanosecond time resolution
-  IceCube Lab (ICL) houses data processing and storage and sends 100 GB of data north by satellite daily

### Detector Construction

7 seasons of construction, 2004-2011



28,000 person-days to complete construction, or 77 years of continuous work



2.1 million kilograms of cargo was shipped, 0.5 million of which was the drill



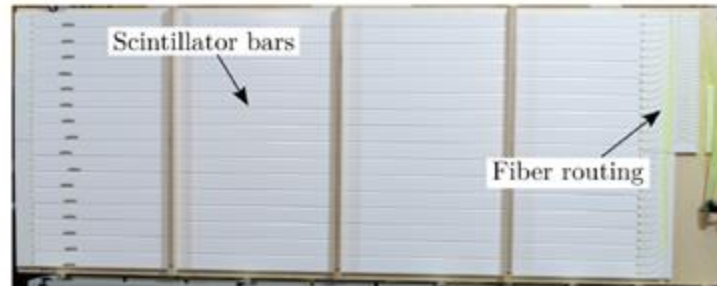
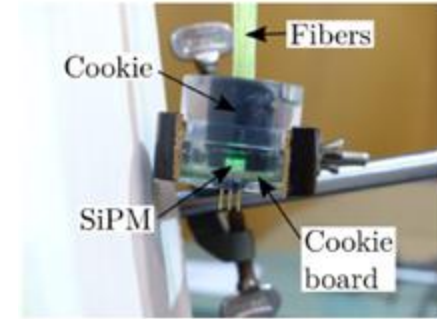
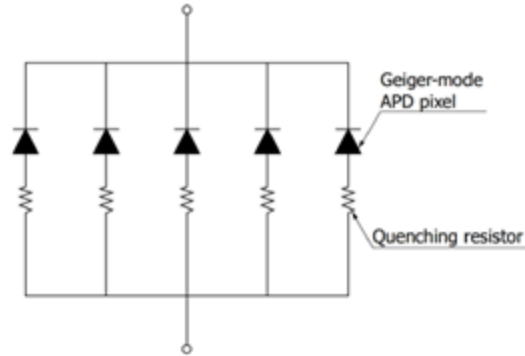
48 hours to drill and 11 hours to deploy sensors per hole



4.7 megawatts of drill thermal power with 760 liters of water per minute delivered at 88 °C and 7,600 kilopascals

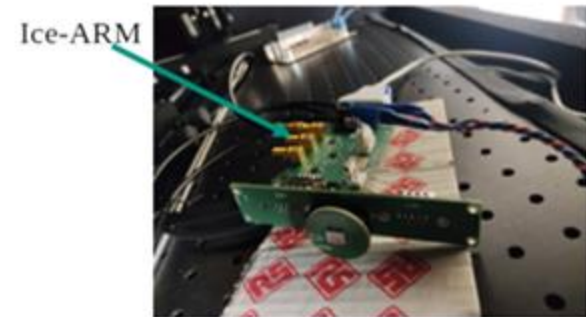
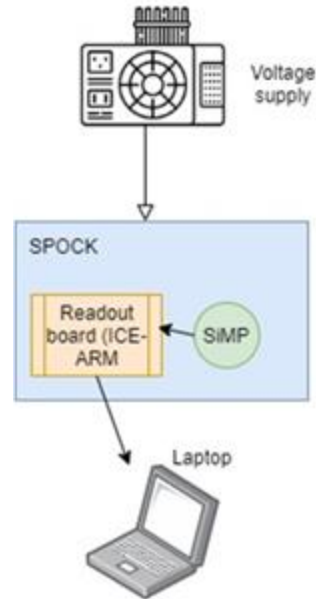
## SiPMs for the upgrade of IceTop

- SiPMs are **semiconductor photosensors** consisting of an array of avalanche photodiode (APD) microcells.
- The photons produced when crossing the **scintillator bars** are collected and guided via **wavelength-shifting fibers** to a SiPM.
- It is connected to a data acquisition board (microDAQ).
- Main characteristics: gain, IV curve, dark-count rate, crosstalk probability, PDE, temperature readout



## Internship project

- The analysis of the IV curve allows to obtain important parameters
- In the **operational zone** of the SiPM, it is possible to find a linearity between the output signal and the number of incident photons
- The **setup**: SPOCK (Single Photon Calibration Stand at Kit), +5V voltage supply, a Python script to control the output voltage
- For each SiPM, three sets of current and voltage values are collected. The output voltage ranges from 55 V to 75V.



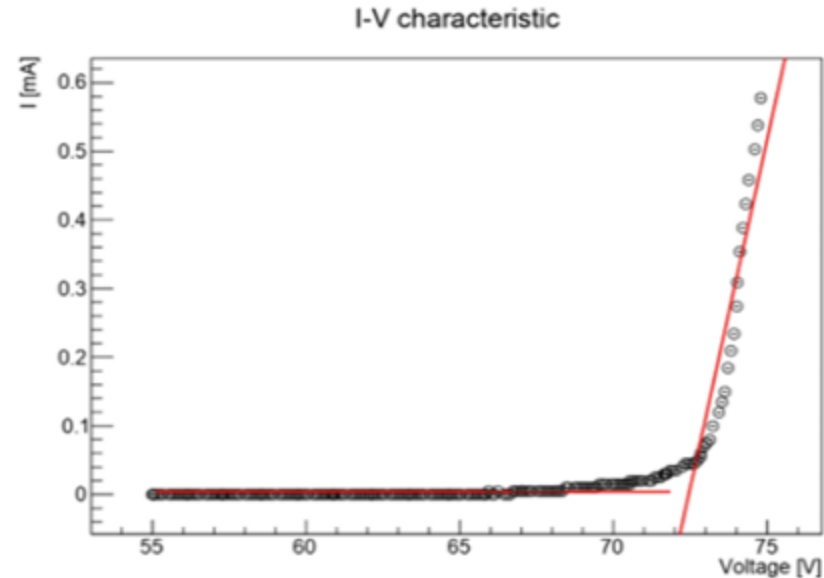


## Analysis of IV characteristics

- **Breakdown voltage:** bias voltage of the SiPM when the SiPM's current increases rapidly.
- The overvoltage can be expressed as a function of the breakdown voltage:

$$V_{ov} = V_{bias} - V_{break};;$$

- A ROOTCern script finds the rapid increase of the current and fits the data points with two linear curves.
- The **intersection** between the curves corresponds to the breakdown voltage.
- The error of the breakdown voltage is obtained by propagation of the errors on the parameters of the lines.



*My first fitting attempt*

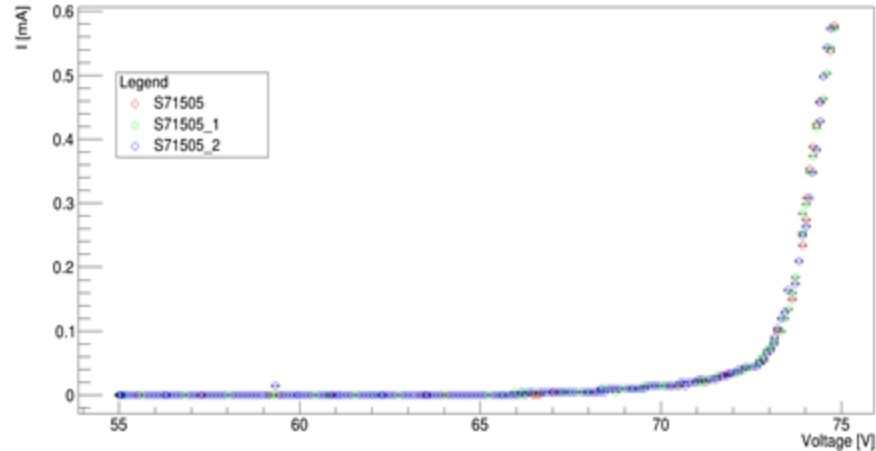
## Multiple measurements

- An **average** is calculated between corresponding values of current and voltage
- The error attributed on the average is the **standard deviation**

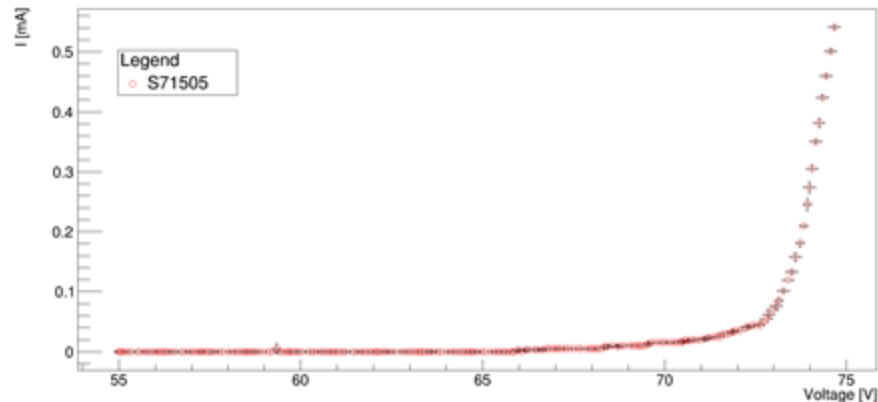
$$\sigma = \frac{1}{\sqrt{N}} \sqrt{\frac{\sum_{i=1}^N (x_i - \bar{x})^2}{N-1}}$$

- A further **systematic error** of 0.1 V is added for the voltage value
- Each SiPM is given a serial number S7XXXX

IV curve



IV curve

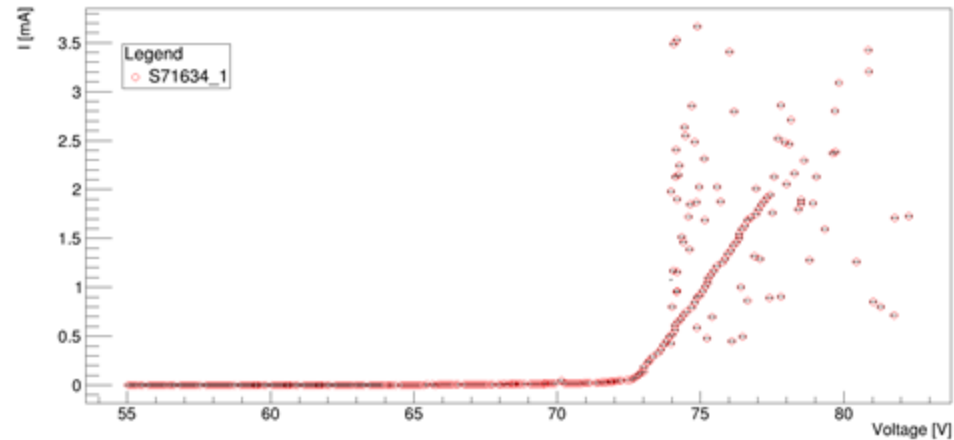




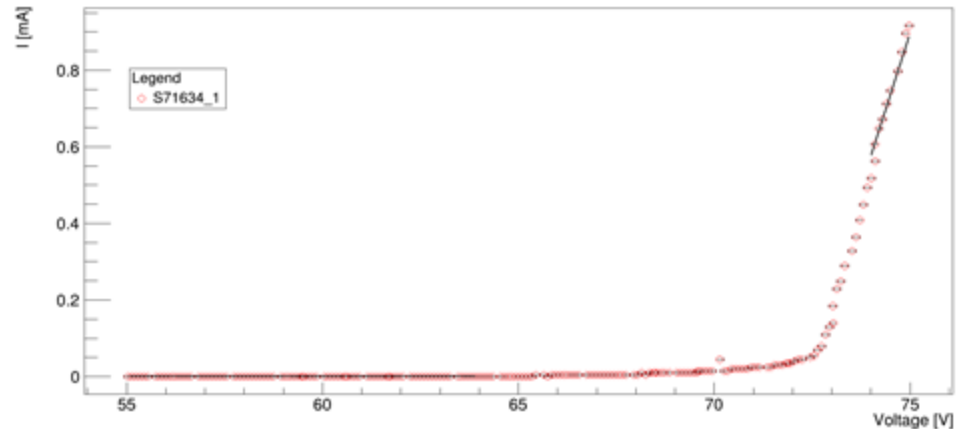
## Analysis of scattered points

- When the applied voltage is higher than 75V, **instability effects** occur.
- The increased depletion zone of the APDs causes collisions between electron hole pairs and the semiconductor lattice of the SiPM.
- Data points above 75 V or those with a change of current higher than 0.5 mA between the previous point and the next one are removed.

IV curve



IV curve



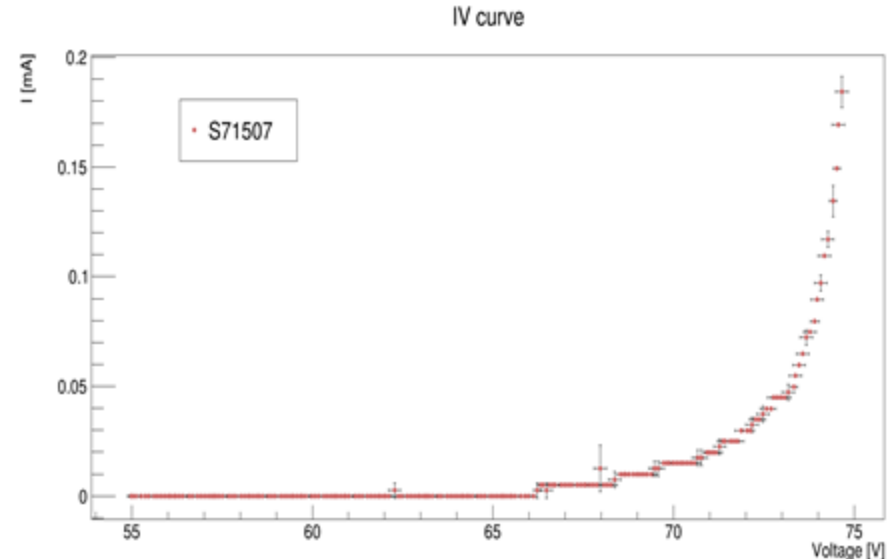
## Fitting the data

There are two ways to consider specific data points for the regression.

- First method: the script analyzes the absolute change of current and voltage between points of a **set**:

$$Abschange = \frac{I(i+separation) - I(i)}{V(i+separation) - V(i)}$$

- The separation represents the number of points constituting a data set
- The regression data on the left is taken up until the absolute change is higher than 0.02 mA/V
- The regression data on the right is taken up until the absolute change is lower than 0.06 mA/V.

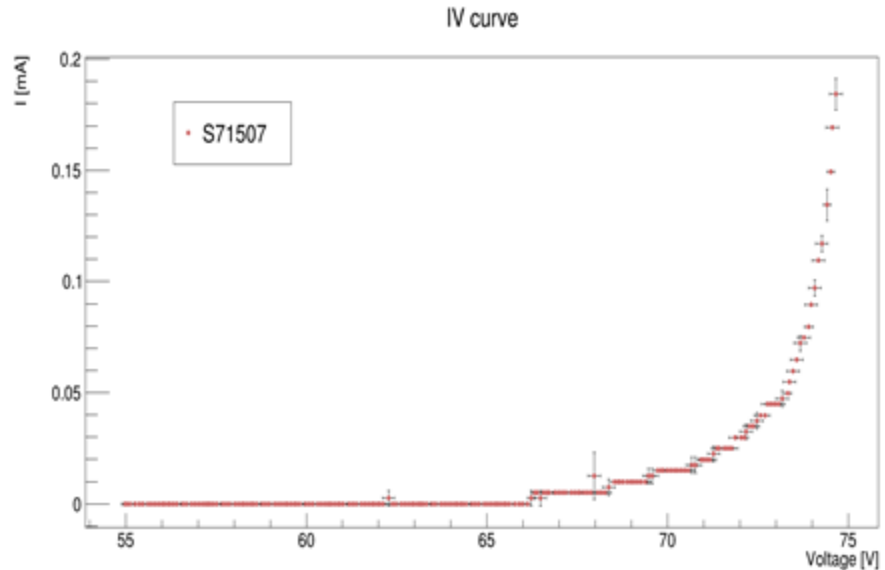


## Fitting the data

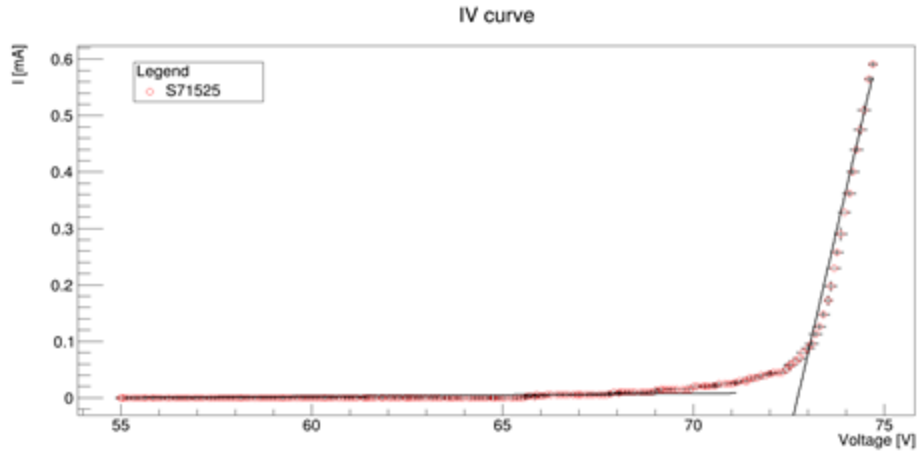
- Second method: the script analyzes the relative change of current and voltage between one set of points and the previous one.

$$Relchange = \frac{Abschange(i+1)}{Abschange(i)}$$

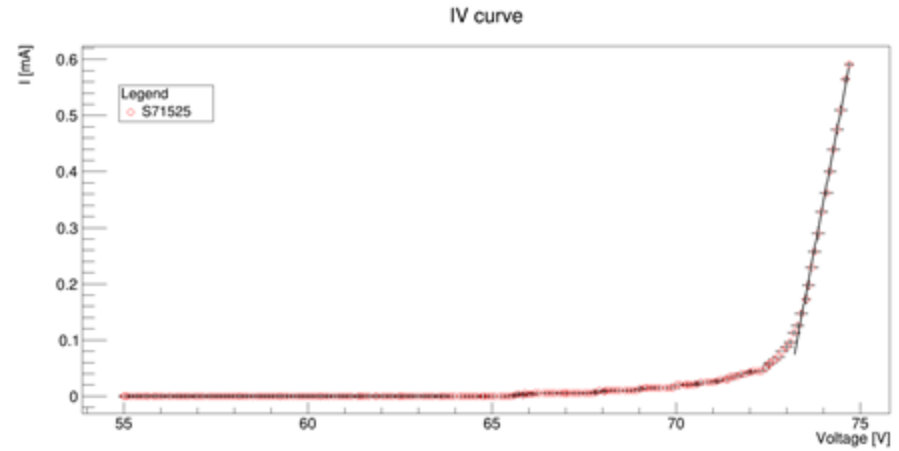
- The regression data on the right and on the left is taken up until this change differs from the previous one by 20%.



## Fitting the data



*Regression using the first method*



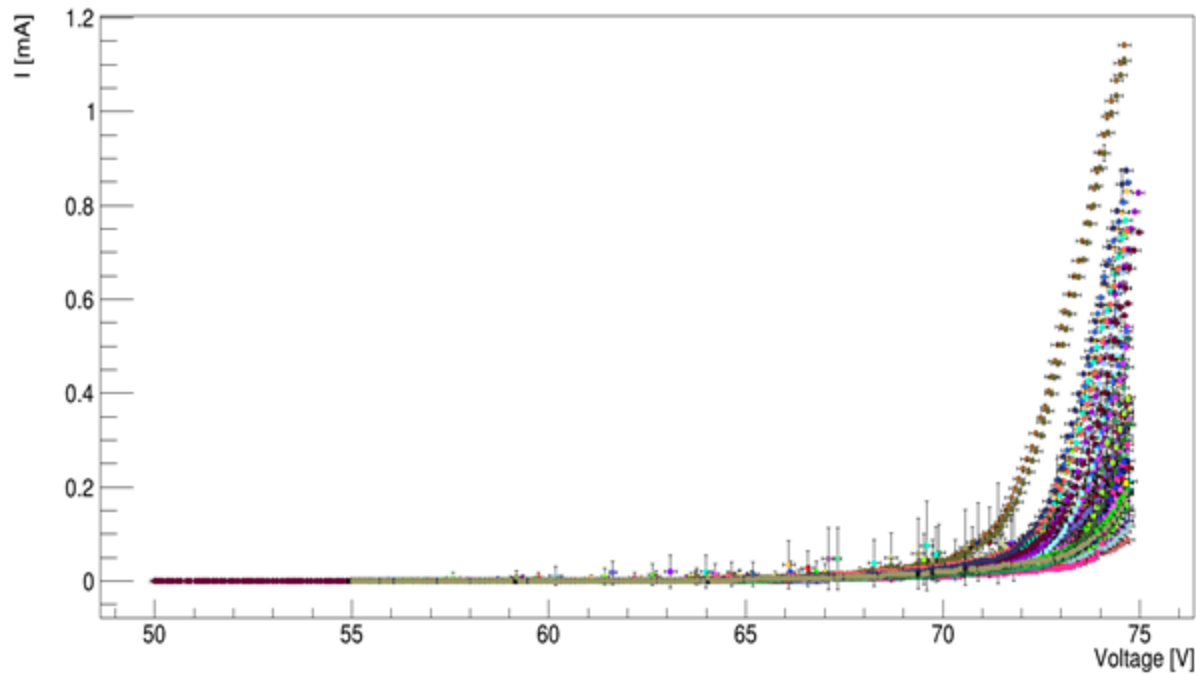
*Regression using the second method*

	Breakdown voltage (V)	Error (V)
1° Method	72	2
2° Method	72	1



# Multiplotting

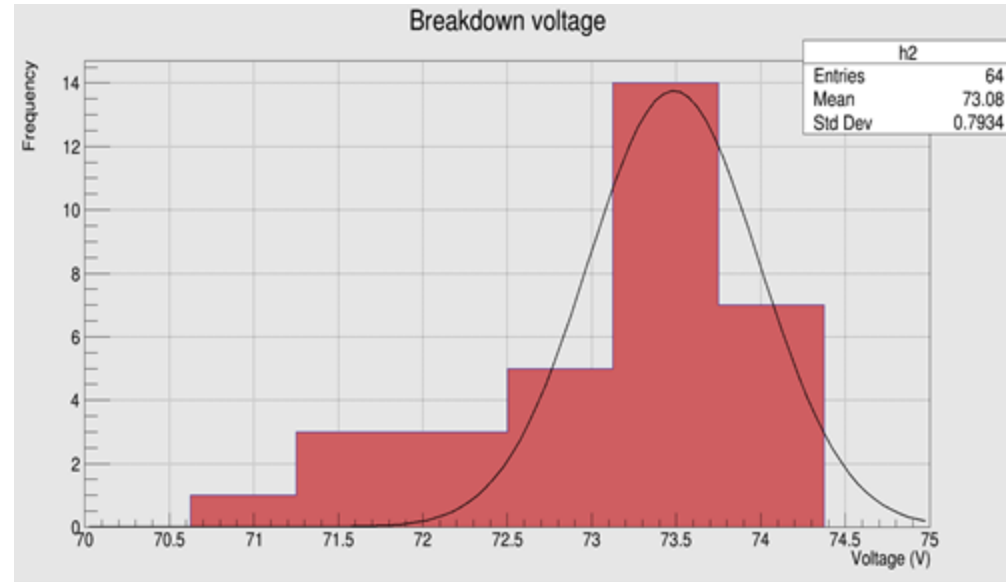
IV curve



- |   |         |   |           |
|---|---------|---|-----------|
| ● | S71570  | ● | S71497    |
| ● | S71571  | ● | S71499    |
| ● | S71575  | ● | S71502    |
| ● | S71576  | ● | S71504    |
| ● | S71578  | ● | S71505    |
| ● | S71580  | ● | S71507    |
| ● | S71581  | ● | S71510    |
| ● | S71582  | ● | S71513    |
| ● | S71588  | ● | S71516    |
| ● | S71592  | ● | S71518    |
| ● | S71593  | ● | S71524txt |
| ● | S71594  | ● | S71525    |
| ● | S71596  | ● | S71526    |
| ● | S71598  | ● | S71527    |
| ● | S71631  | ● | S71530    |
| ● | S71632  | ● | S71531    |
| ● | S71635  | ● | S71532    |
| ● | S71637  | ● | S71533    |
| ● | S71638  | ● | S71534    |
| ● | S71639  | ● | S71535    |
| ● | S771550 | ● | S71536    |
|   |         | ● | S71539    |
|   |         | ● | S71540    |
|   |         | ● | S71541    |
|   |         | ● | S71543    |
|   |         | ● | S71544    |
|   |         | ● | S71545    |
|   |         | ● | S71547    |
|   |         | ● | S71549    |
|   |         | ● | S71551    |
|   |         | ● | S71552    |
|   |         | ● | S71553    |
|   |         | ● | S71554    |
|   |         | ● | S71555    |
|   |         | ● | S71556    |
|   |         | ● | S71557    |
|   |         | ● | S71558    |
|   |         | ● | S71559    |
|   |         | ● | S71560    |
|   |         | ● | S71563    |
|   |         | ● | S71566    |
|   |         | ● | S71568    |
|   |         | ● | S71569    |

## Analysis of breakdown voltage

	Result (V)	Error (V)
Average	73.1	0.1
$\mu$	73.48	0.05



- To work in the operational zone, for most of the SiPMs a bias voltage higher than  $\mu$  should be applied

## Conclusion

The final version of the script:

- Plots the voltage and current measurements without entering them manually;
- Automatically multiplots different SiPMs on the same canvas;
- Takes into consideration the scattered points on the canvas and deletes them;
- Analyzes the trend of the data points and fits them with two linear curves;
- Calculates the breakdown voltage and its error
- Collects the values of breakdown voltage and error in a `.txt` file

## Outlooks

Other SiPM features are studied (cross-talk rate, PDE, dark counts);

The distribution of breakdown voltage is useful to apply a proper bias voltage;

The Geiger zone lies between 73 V and 75 V;

Semiconductor effects should be studied to have a deeper knowledge of SiPMs' behaviour

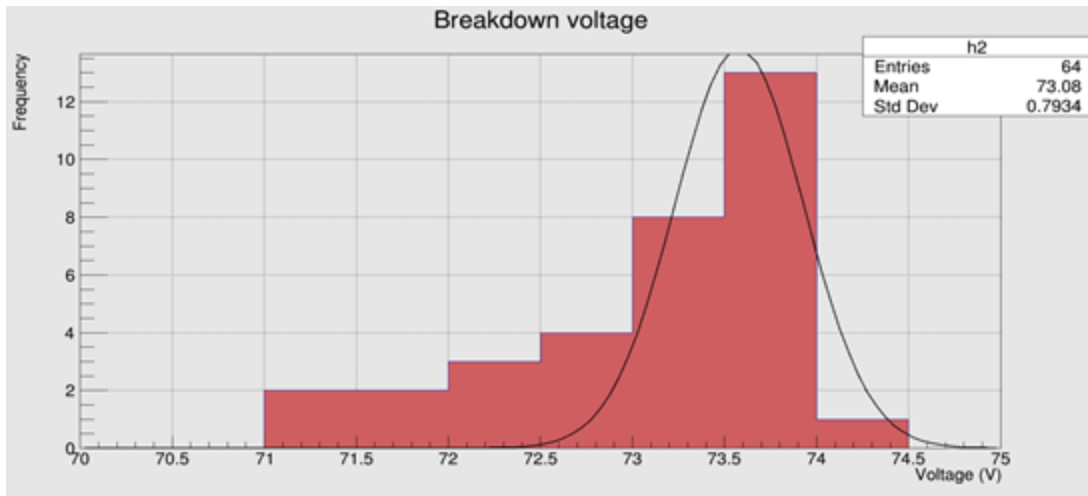




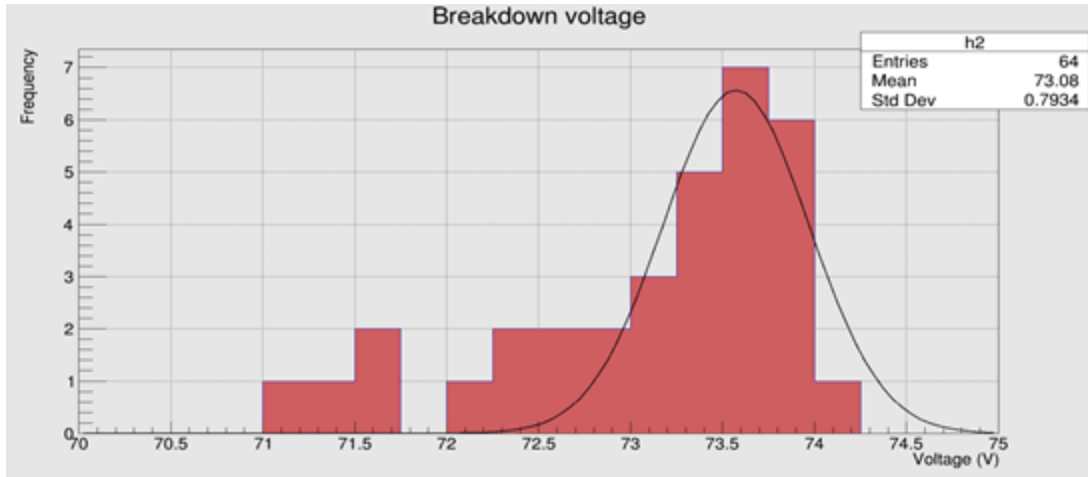


# Thank you for your attention!





$X_0$	$13 \pm 1$
$X_1$	$73.58 \pm 0.03$
$X_2$	$0.35 \pm 0.06$



$X_0$	$6 \pm 1$
$X_1$	$73.57 \pm 0.06$
$X_2$	$0.40 \pm 0.09$

### IV curve

