CHARACTERIZATION STUDY OF SILICON PHOTOMULTIPLIER

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Outline

- Introduction to SiPMs
- SiPM Characterization Tests (forward I-V, noise parameters and gain dependence on temperature)
- Summary & Conclusion

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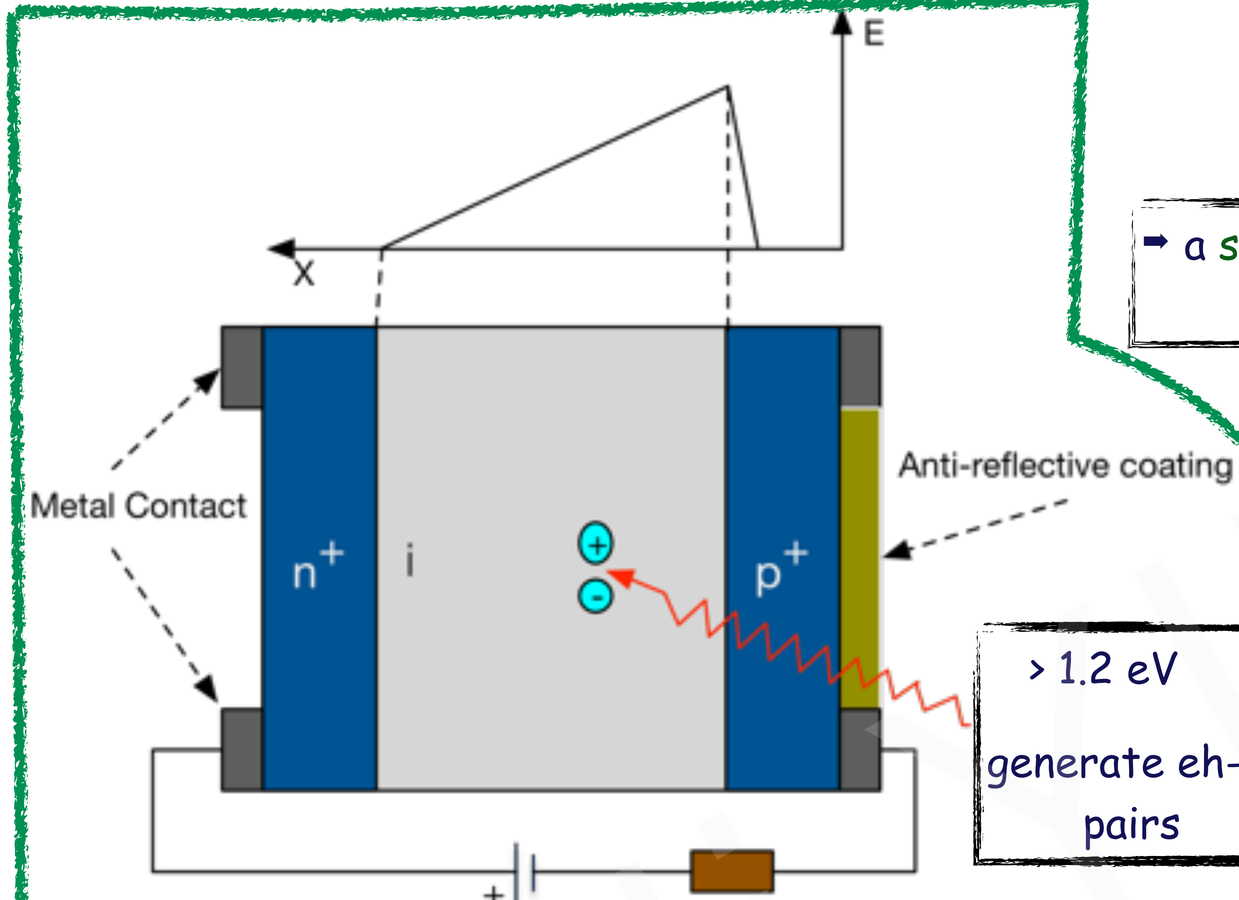
Introduction: pin Photo-Diodes



> 1.2 eV

generate eh-pairs

has a very fast time response to a signal (~ns)

Gain = 1 because no intrinsic amp.

insensitive to single p.e.

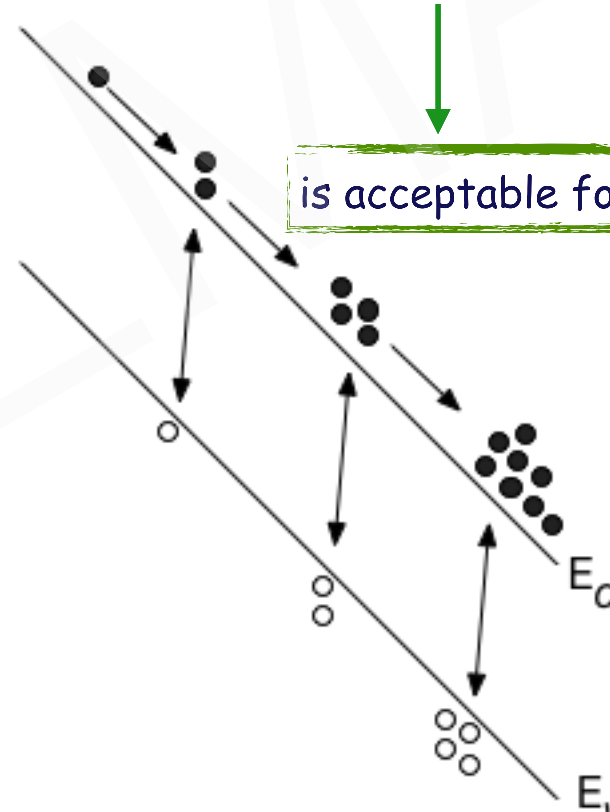
not acceptable for low intensity photon flux exp

Avalanche Photo-Diodes

- operate above V_{Break}, reverse V_{Bias}
- same working principle with pin PD

- a single photon can trigger an avalanche develops and produces an amplified current signal → linearly dependent on # of detected photons

is acceptable for low intensity photon flux exp



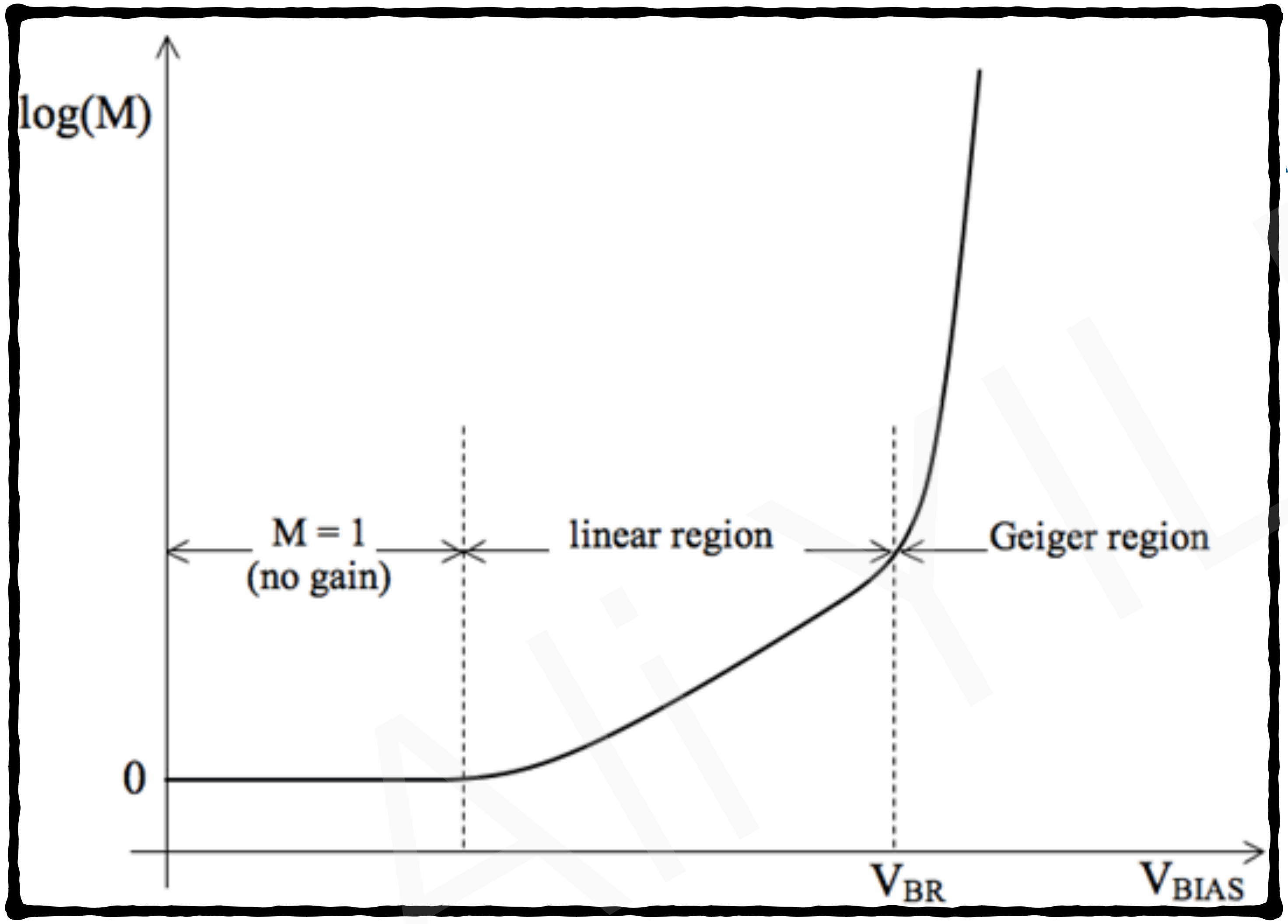
Gain ~ 300

rev-V_{Bias} increasing, Gain also increases BUT & noise gets WORSE cond.

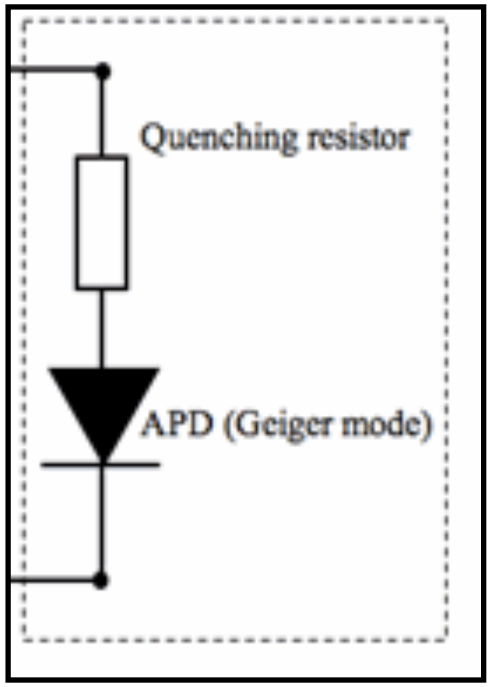
strongly dependent on Temp and the Vop

Introduction: Geiger-Mode Avalanche Photo-Diodes (G-APDs)

characterized by a V_{Bias} above the V_{Break} of the APD



# of charge carrier increases exponentially with time



Gain theoretically **infinite**

in reality, a **finite number**

I quenched by placing a resistor

Introduction: SiPMs

new type of PMTs widely used in many fields;

- experimental particle
- high energy physics
- astroparticle
- medical physics

advantages of SiPM, compared to traditional PMT;

- higher quantum efficiency over a wide range of wavelength
- insensitive to the magnetic field
- so compact allow to build
- high timing performances,
- low cost,
- hardness to radiation damage and
- are sensitive to detect a single p.e.
- order of 10^6

disadvantages of the devices

- a large (due to temperature dependance) noise
- dark current

SiPMs: Properties of SiPMs

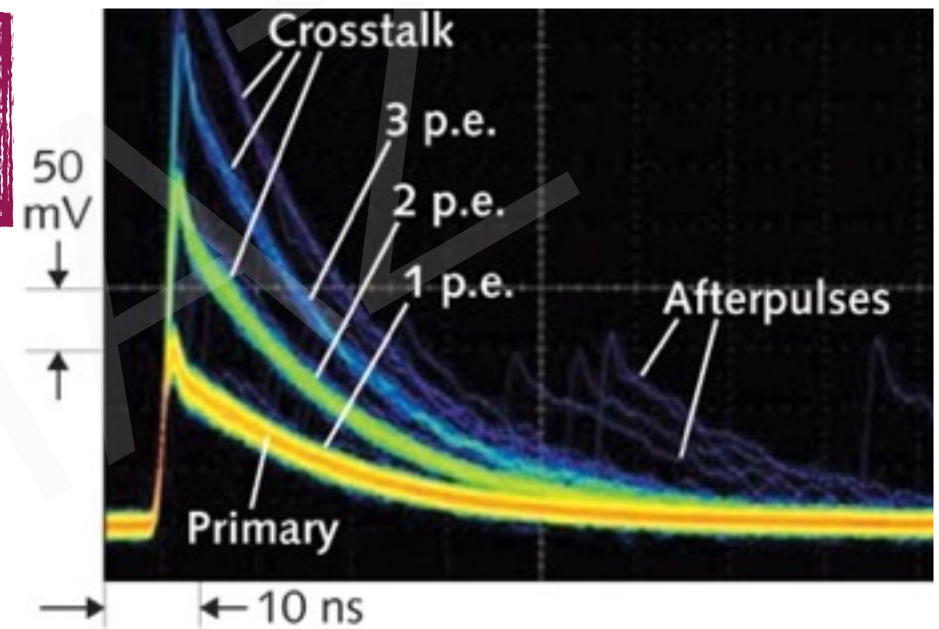
★ **Gain:**

$$G = \frac{Q_{out}}{e} = \frac{C_{pixel} \times (V_{bias} - V_{break})}{e}$$

$$\cong \frac{C_{pixel} \times V_{ov}}{e}$$

★ **Afterpulsing:**

delayed release of e trapped when avalanche occurs



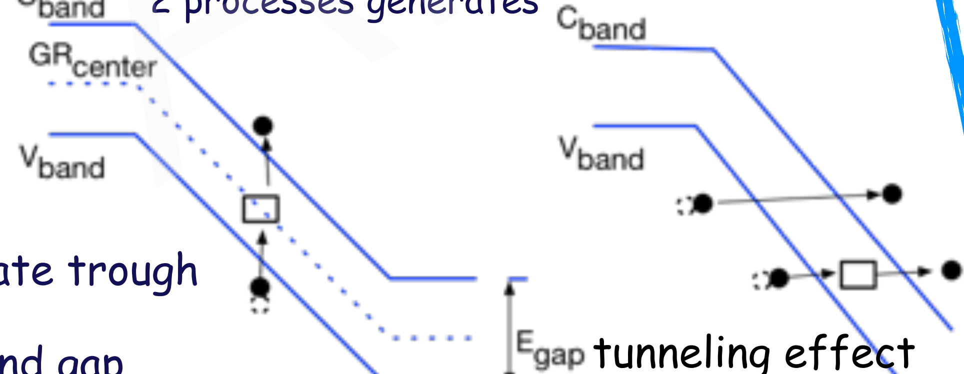
★ **Thermal Noise:**

- e-h pairs also created by thermal excitation
- not possible to distinguish the output signal generated by a photon or thermally one
- measurements have to be done at the same temperature & operating condition to remove this effect
- commonly ~ few kHz @ room temp

★ **Dark Noise Rate :**

- is one of the most important disadvantages of SiPMs
- restricts the sensitivity of low photon flux
- starts unplanned Geiger-discharge @ dark cond.

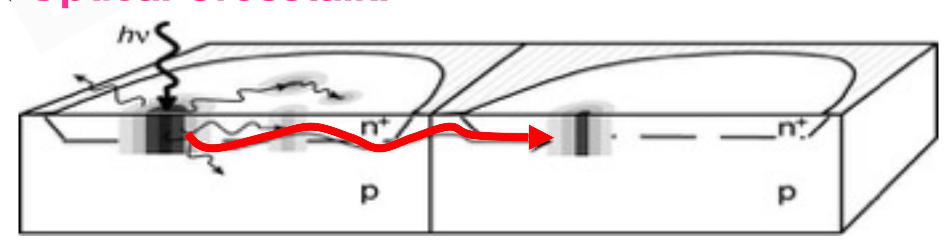
2 processes generates



penetrate trough the band gap

tunneling effect

★ **Optical Crosstalk:**



Sketch from Cova et al. NIST 2003 Workshop on single photon detectors

photons can trigger additional cells

- called optical crosstalk
- artificial increase in signal
- Excess Noise Factor of SiPM
- can be quite significant problem in applications

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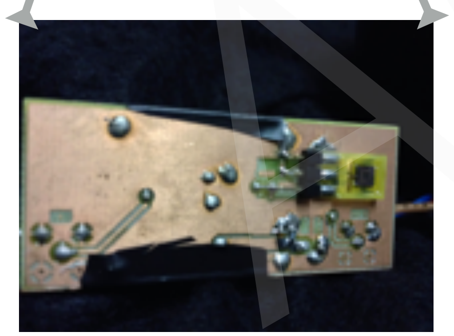
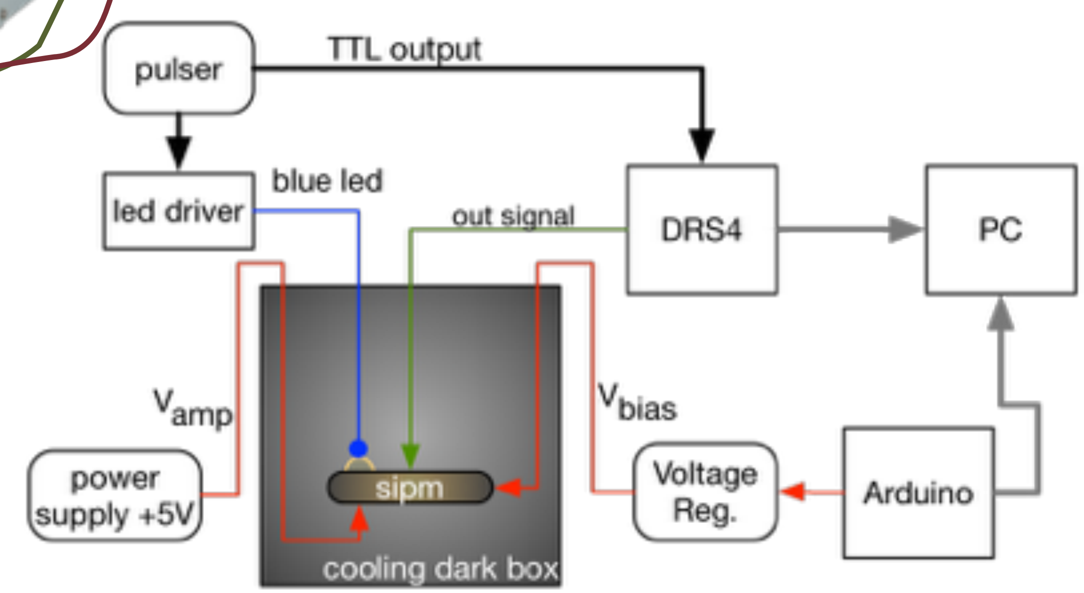
SiPM Characterization Tests: Setup



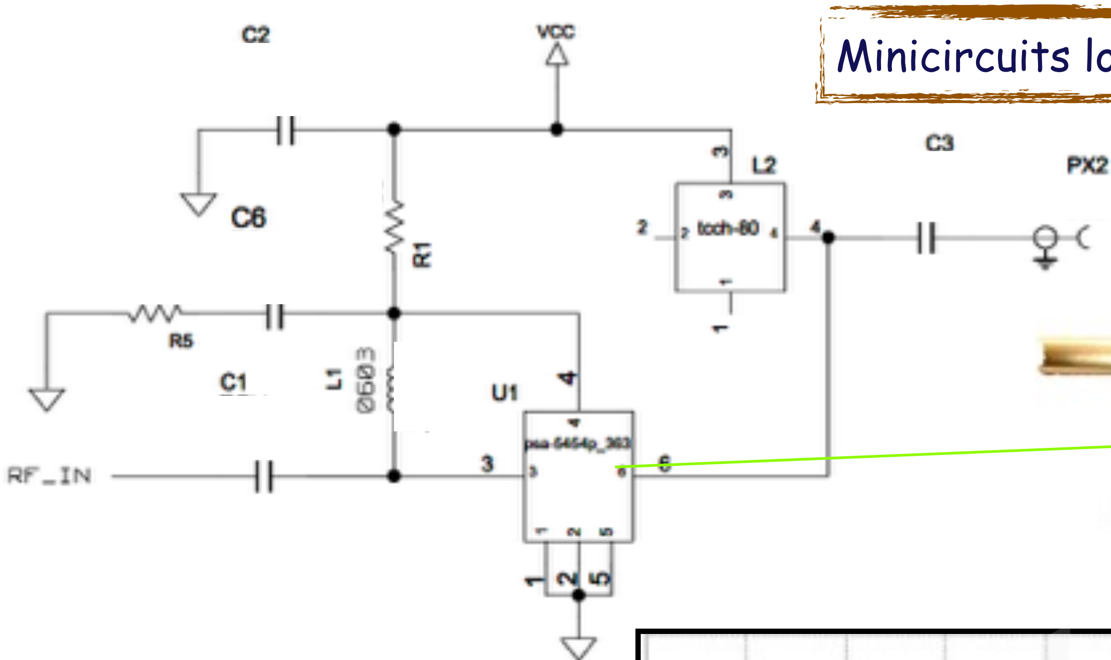
measurements

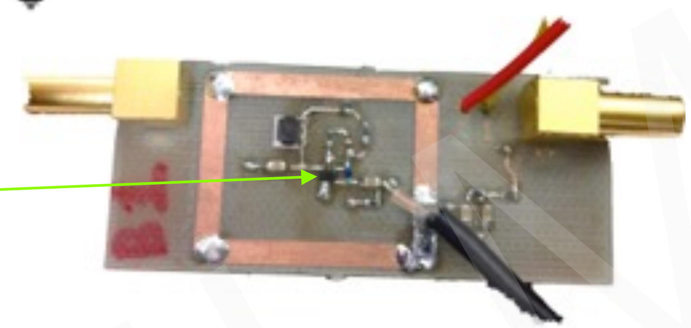
- ✱ amplification factor,
- ✱ (phe) separation,
- ✱ cross talk,
- ✱ afterpulsing,
- ✱ gain dependence on temp

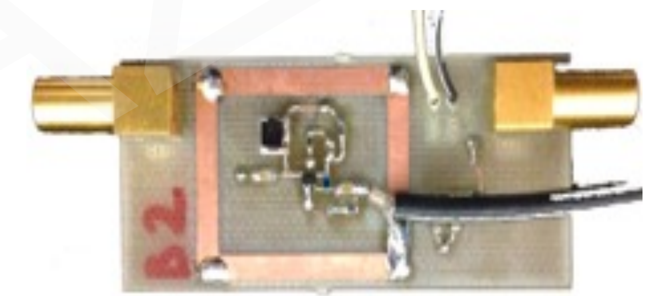


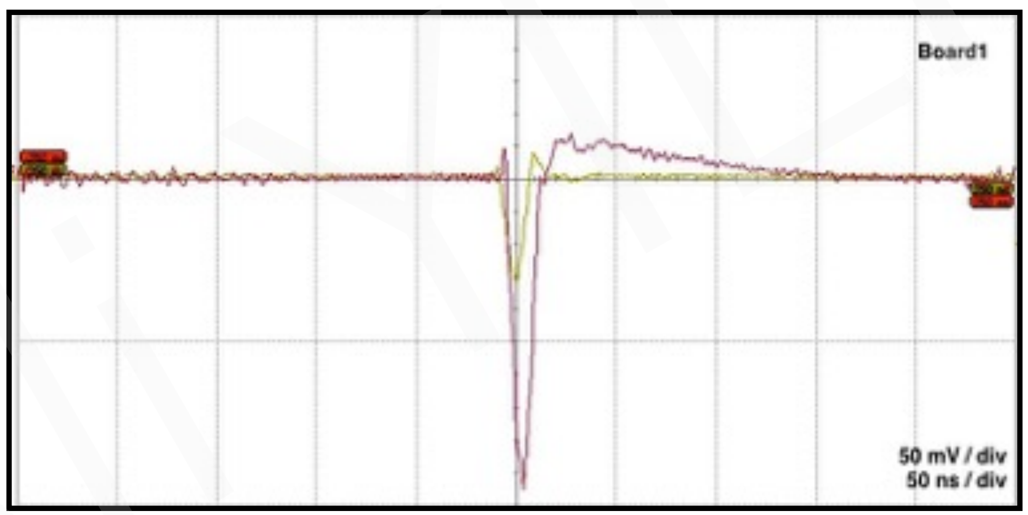
- **SiPM Characterization Tests: amplifierBoard**

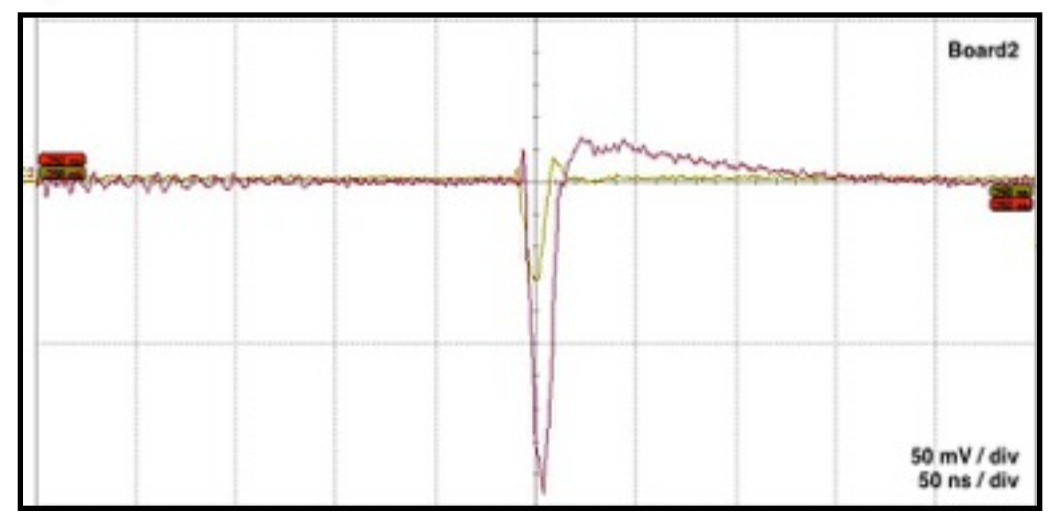
Minicircuits low noise ampl, PSA545+











$$G_{Amp} = 20 \times log_{10}\left(\frac{V_{out}}{Vin}\right)$$

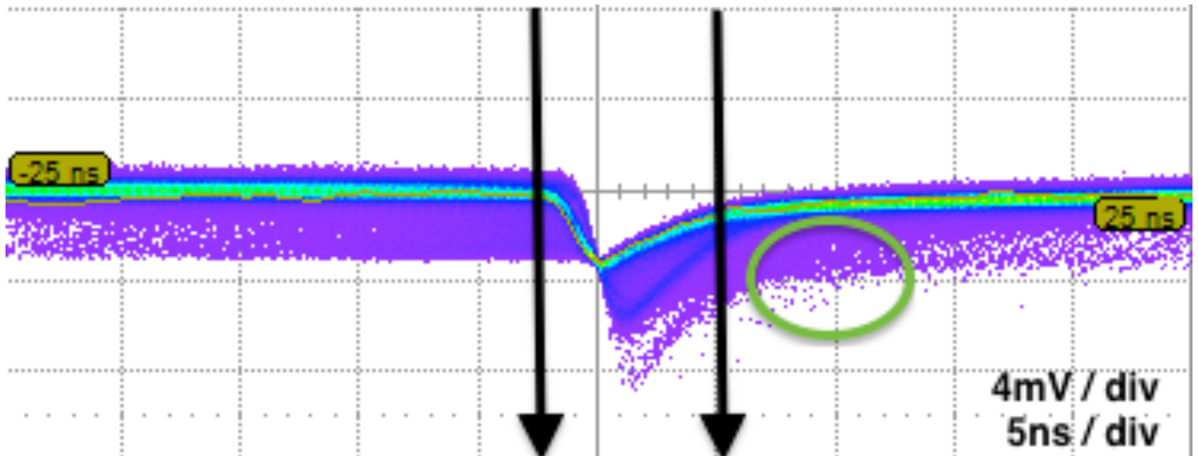
15.7 dB

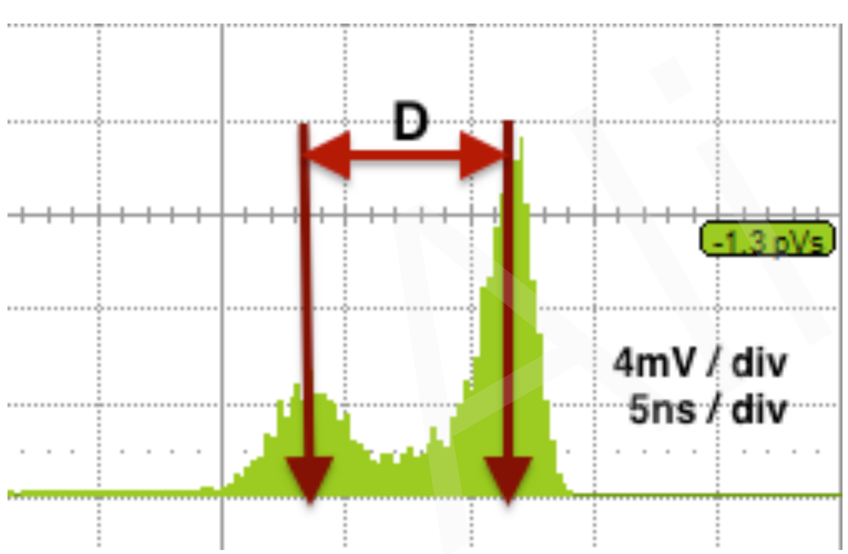
amplification factor is $\beta = 6.1$

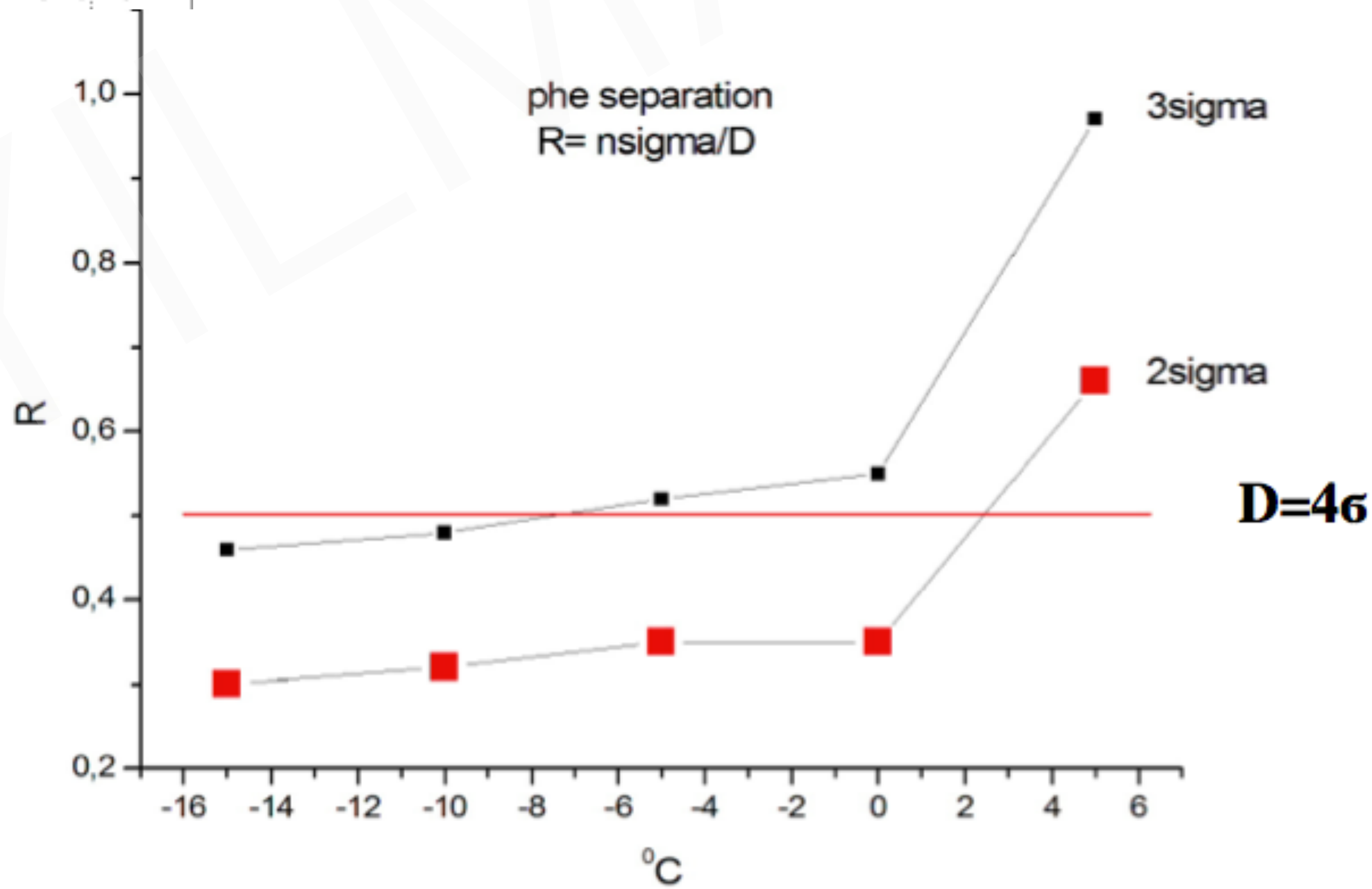
16.0 dB

$\beta = 6.3$

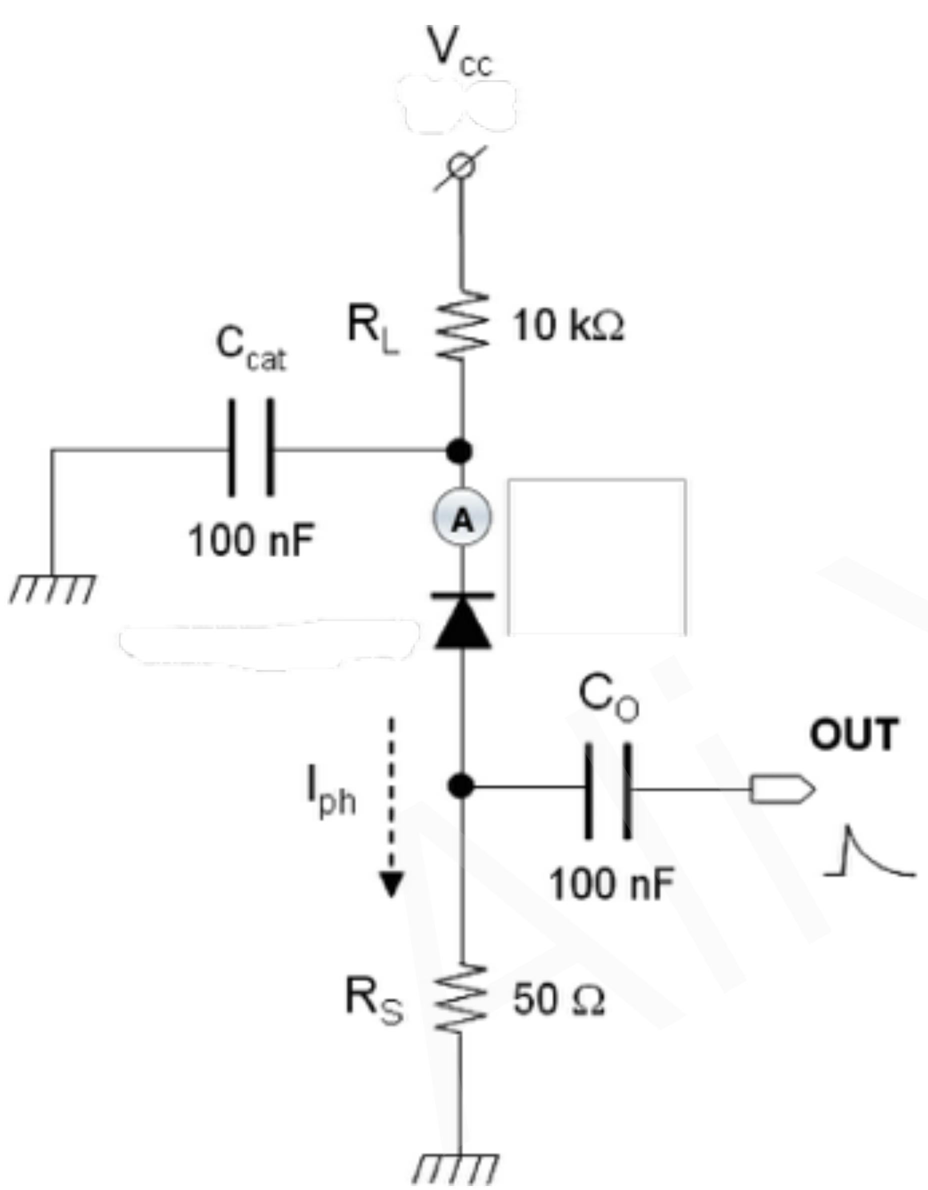
1. SiPM Characterization Tests: (phe) separation

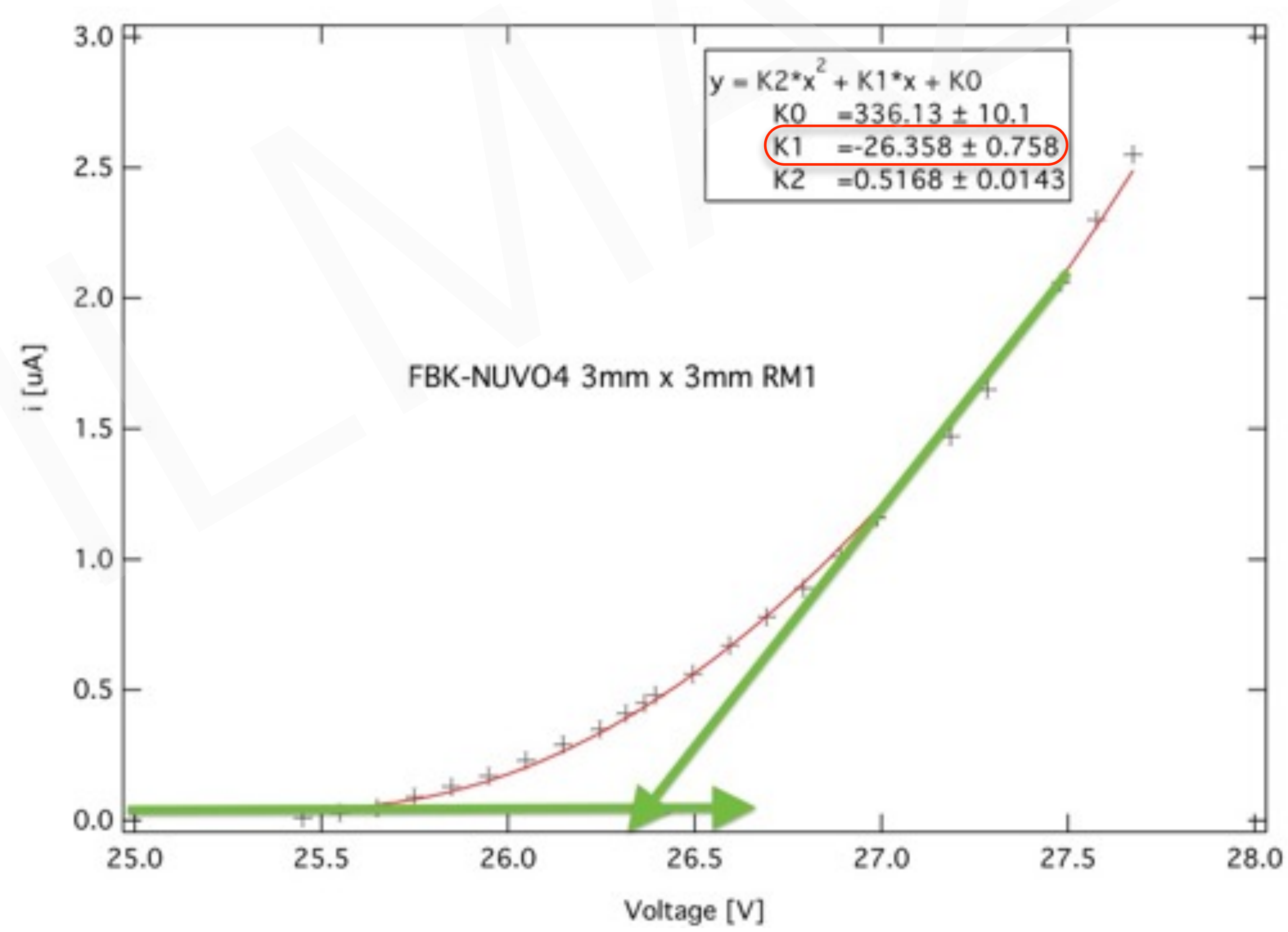






1. SiPMs: Forward I-V Measurement

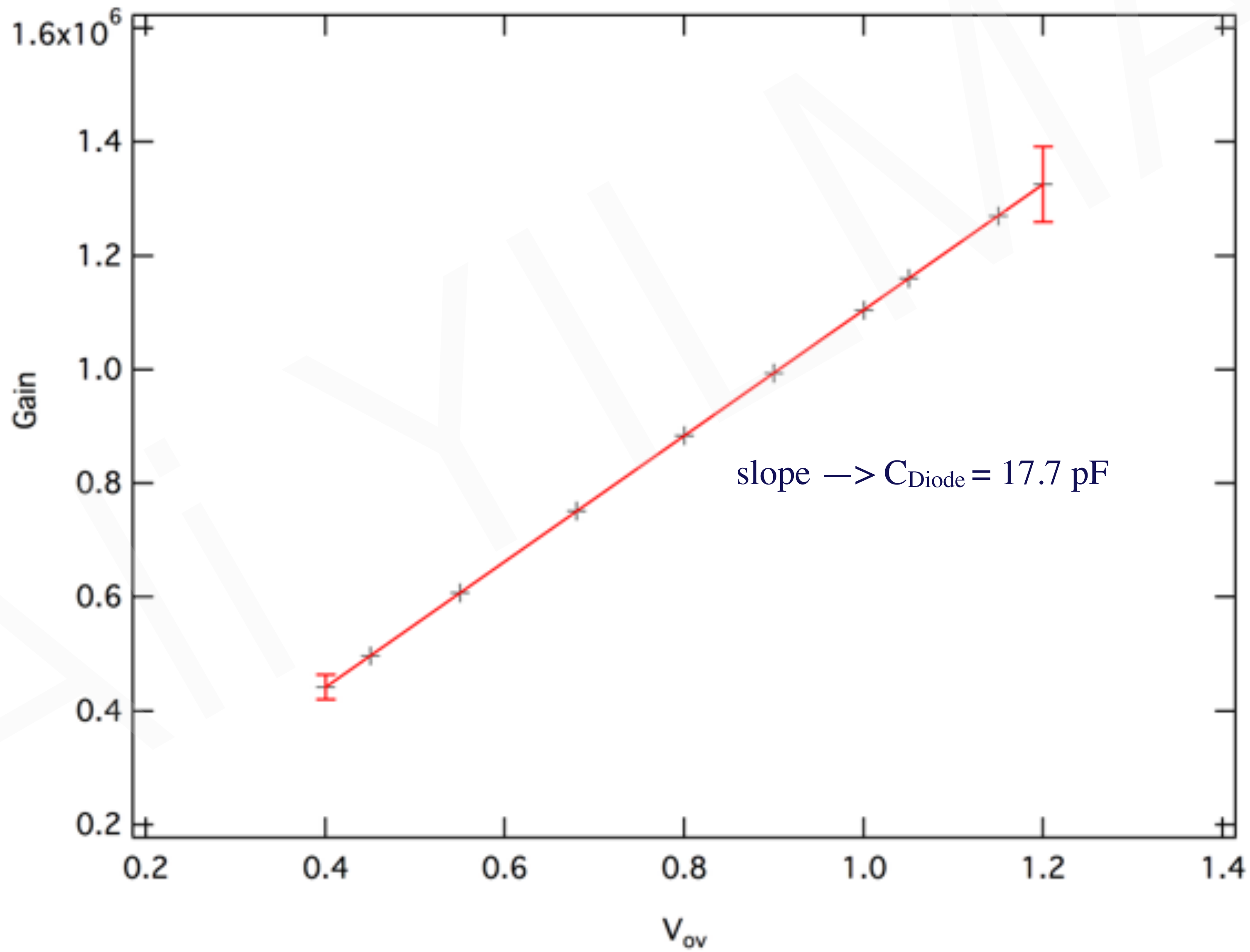




1. SiPMs: Gain

$$G = \frac{Q_{out}}{e} = \frac{C_{pixel} \times (V_{bias} - V_{break})}{e}$$

$$\cong \frac{C_{pixel} \times V_{ov}}{e}$$



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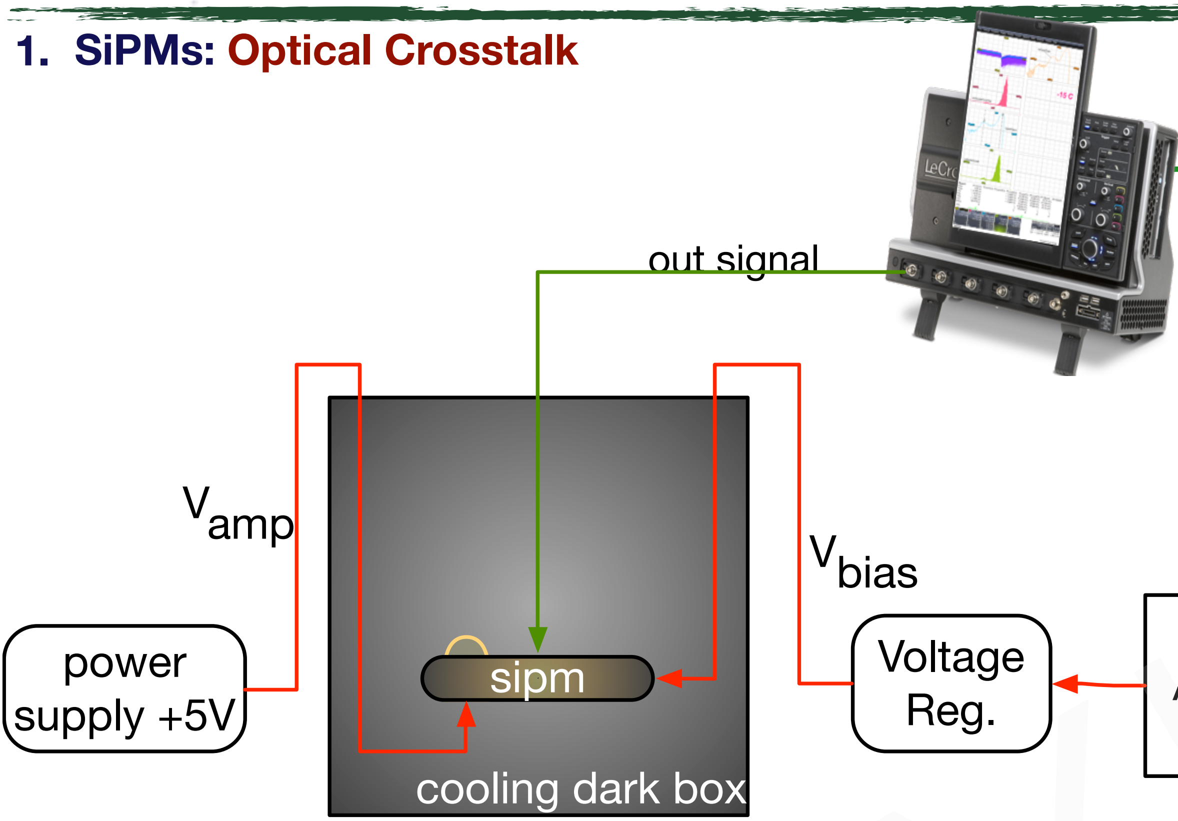
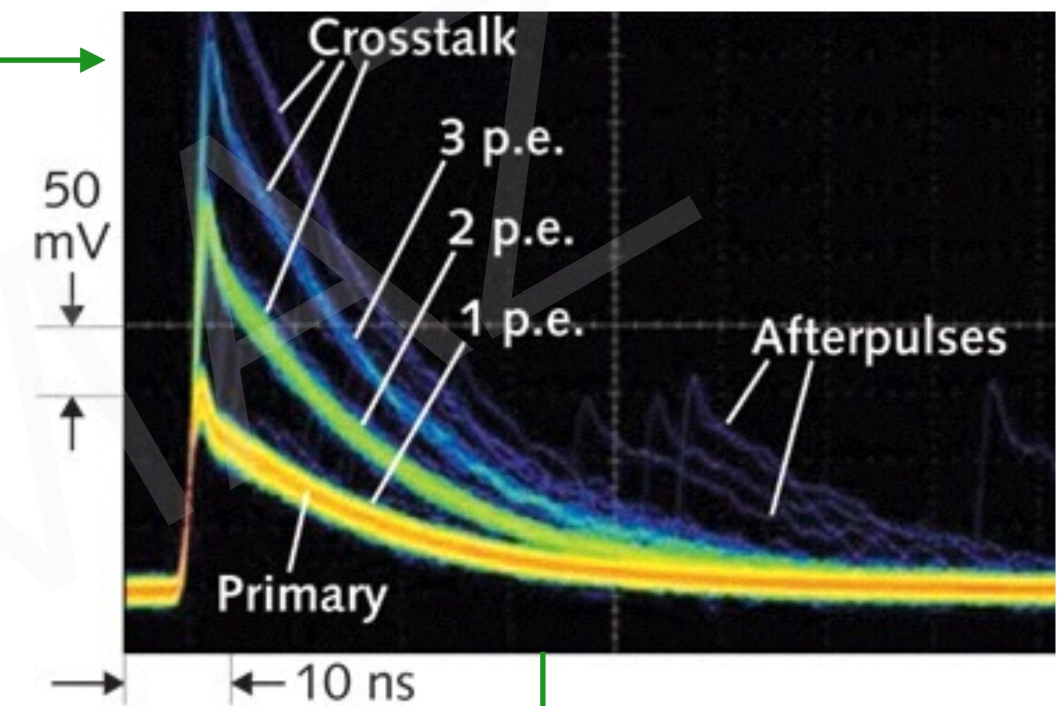
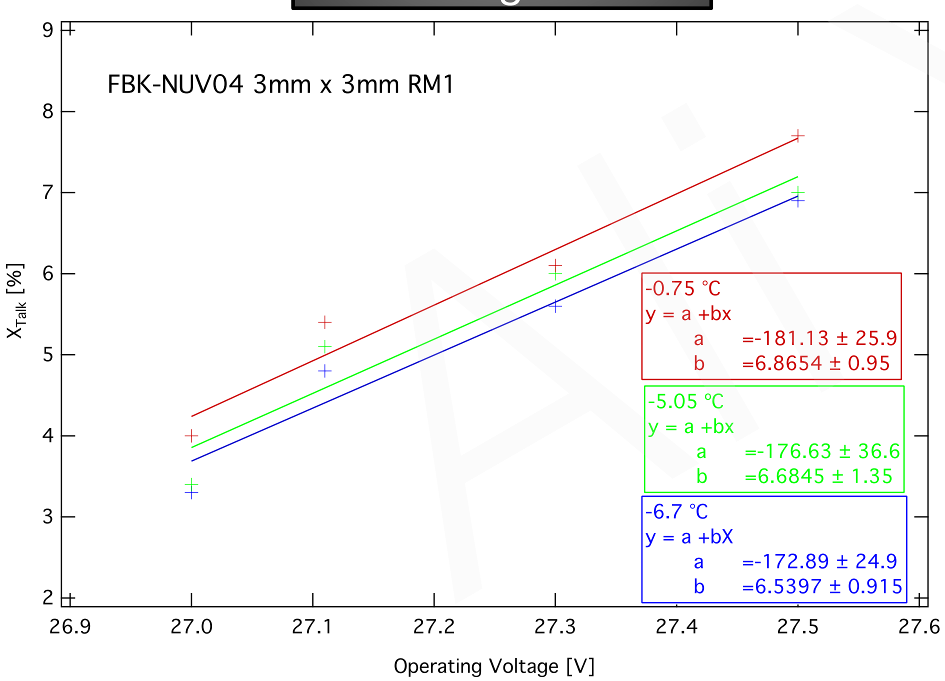
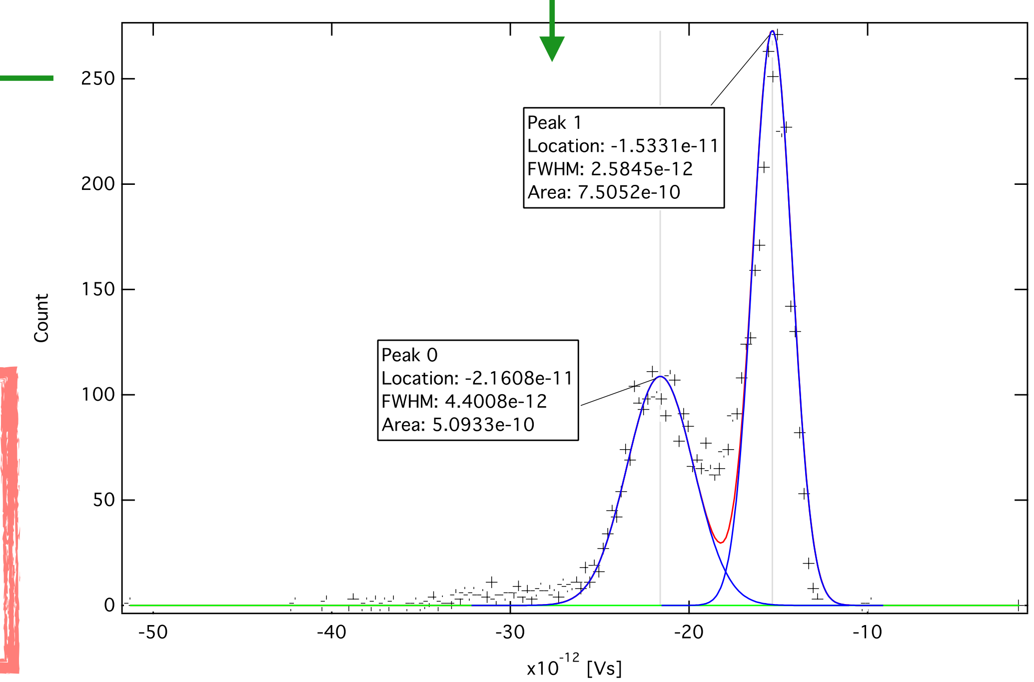
1. SiPMs: Optical Crosstalk









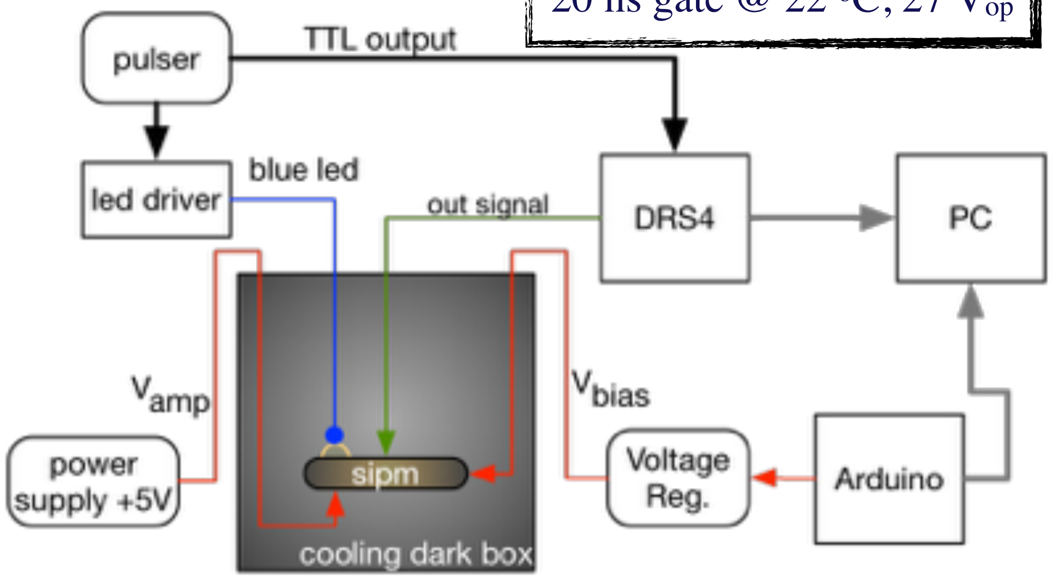
5.4 °C change in T; X_{Talk} = 0.6%

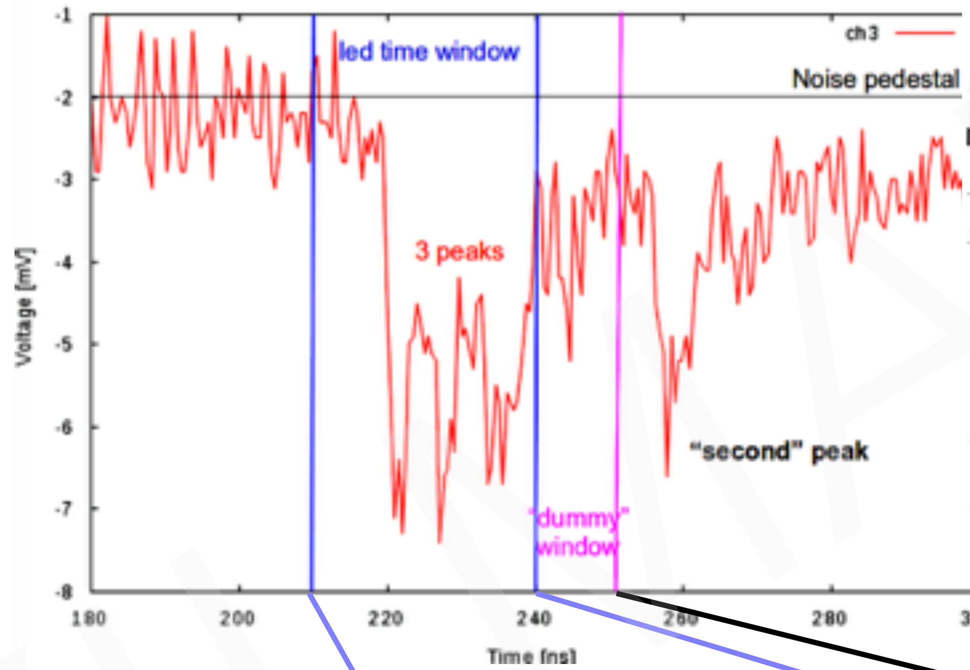
0.1 V change in V_{op}; X_{Talk} = 1.5%

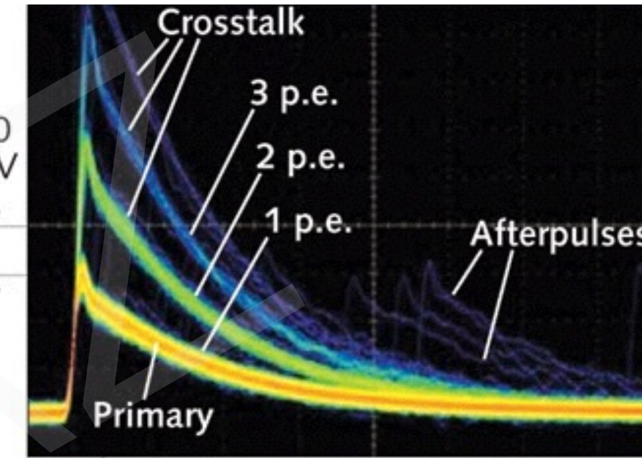
➡ mostly dependent on V_{bias}

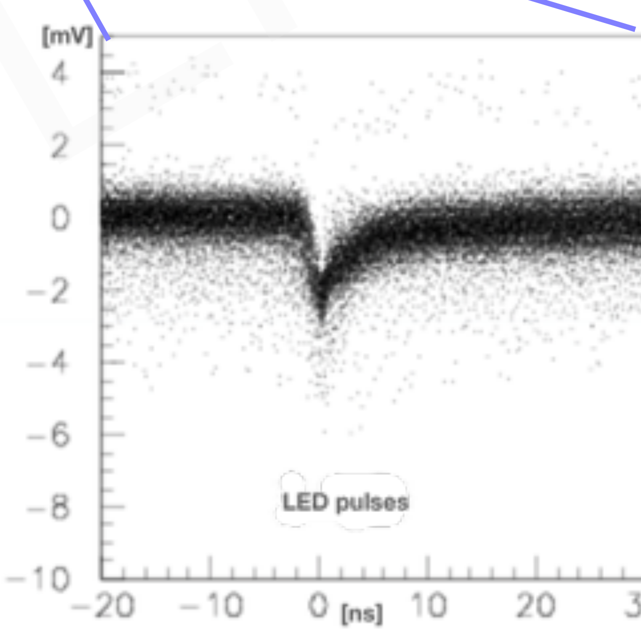
1. SiPMs: Afterpulse

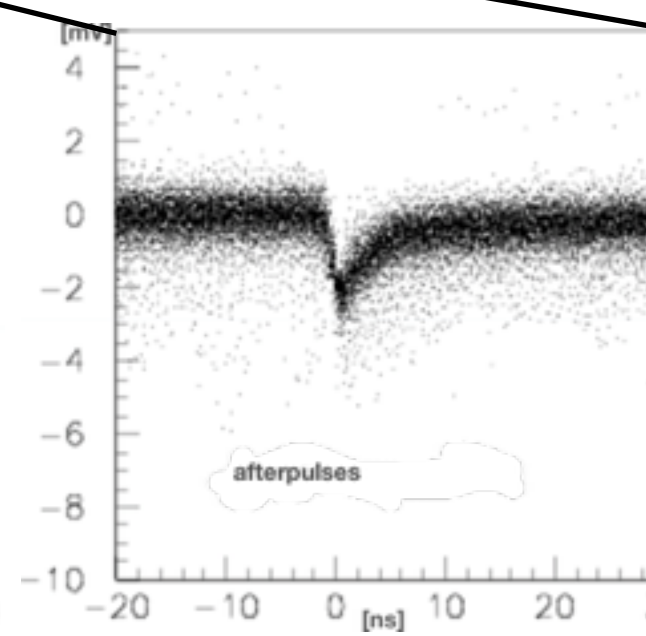
20 ns gate @ 22 °C, 27 V_{op}

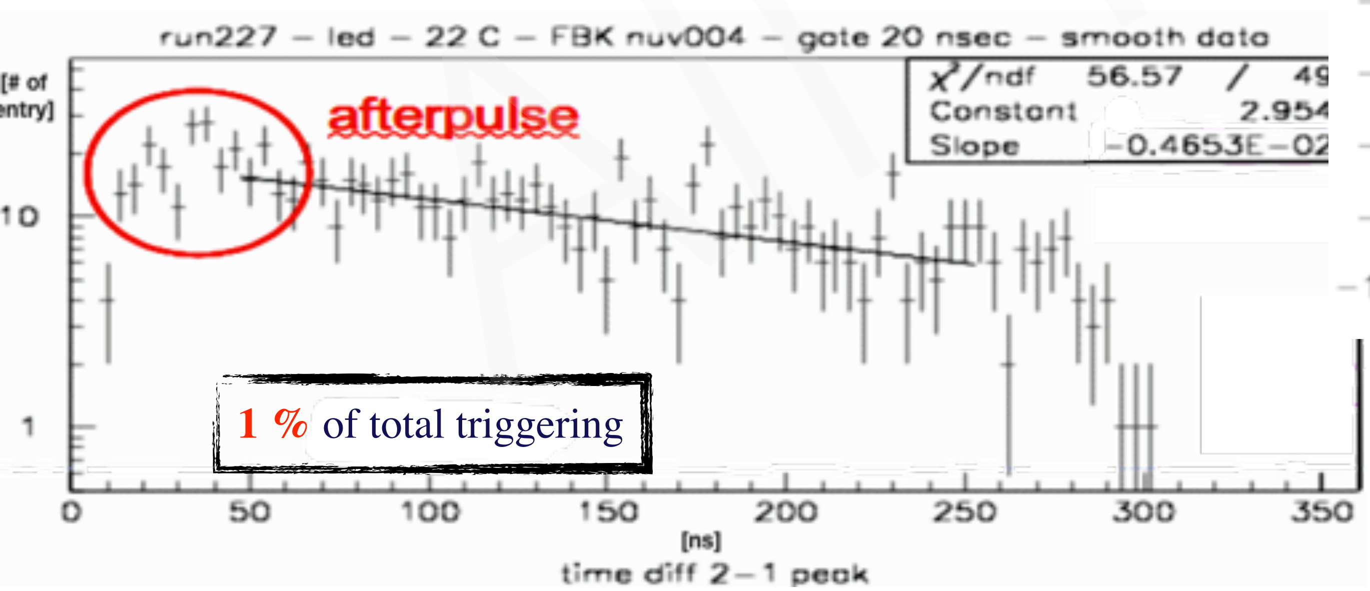












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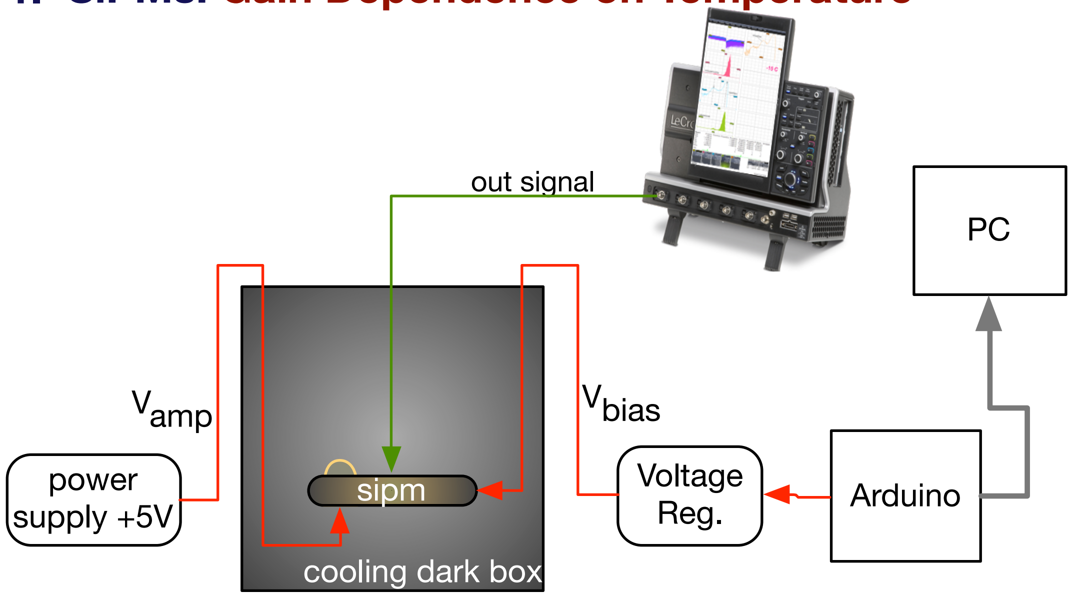
FCC Physics, Detector and Accelerator Workshop @ Istanbul
March 11-12, 2016

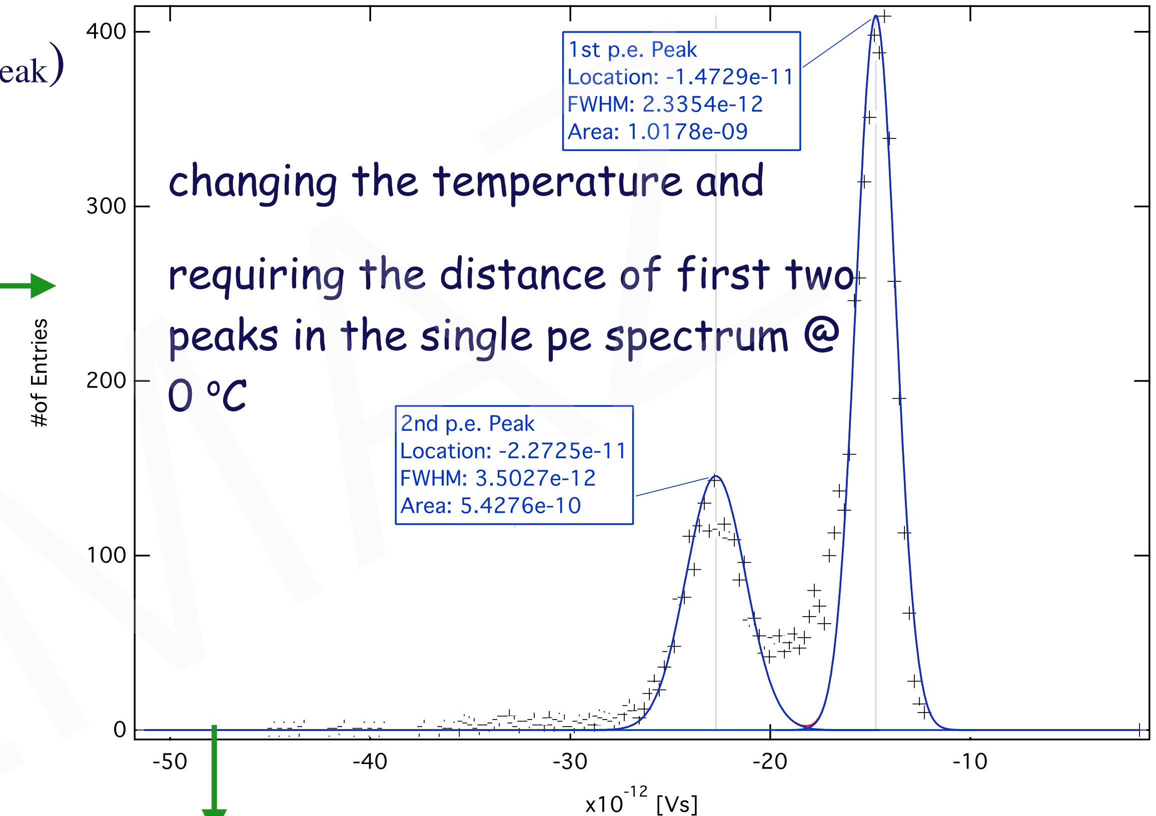
1. SiPMs: Gain Dependence on Temperature

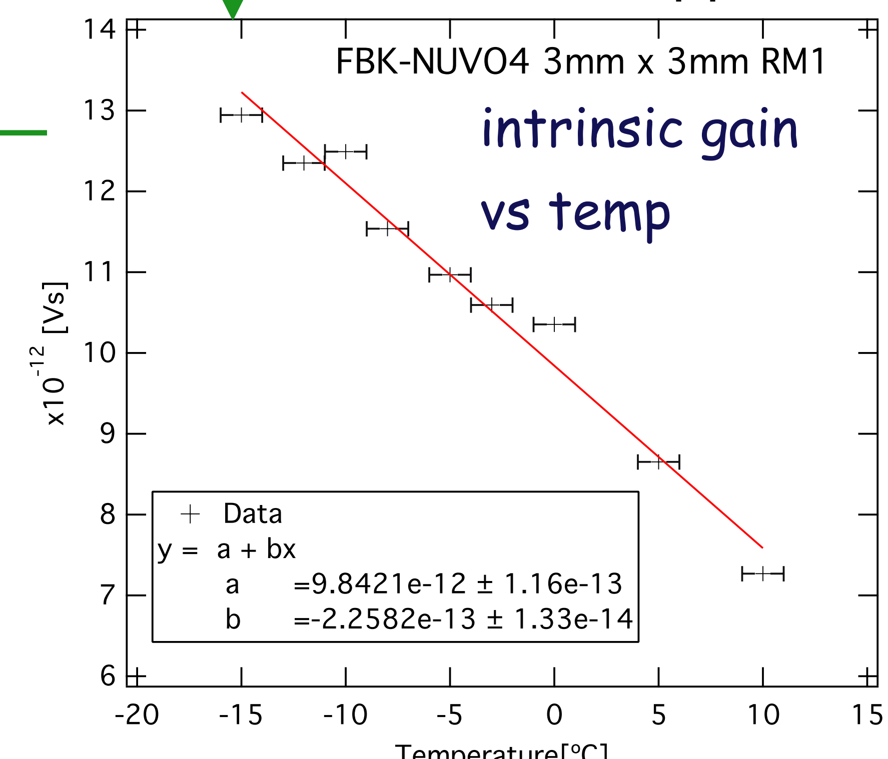


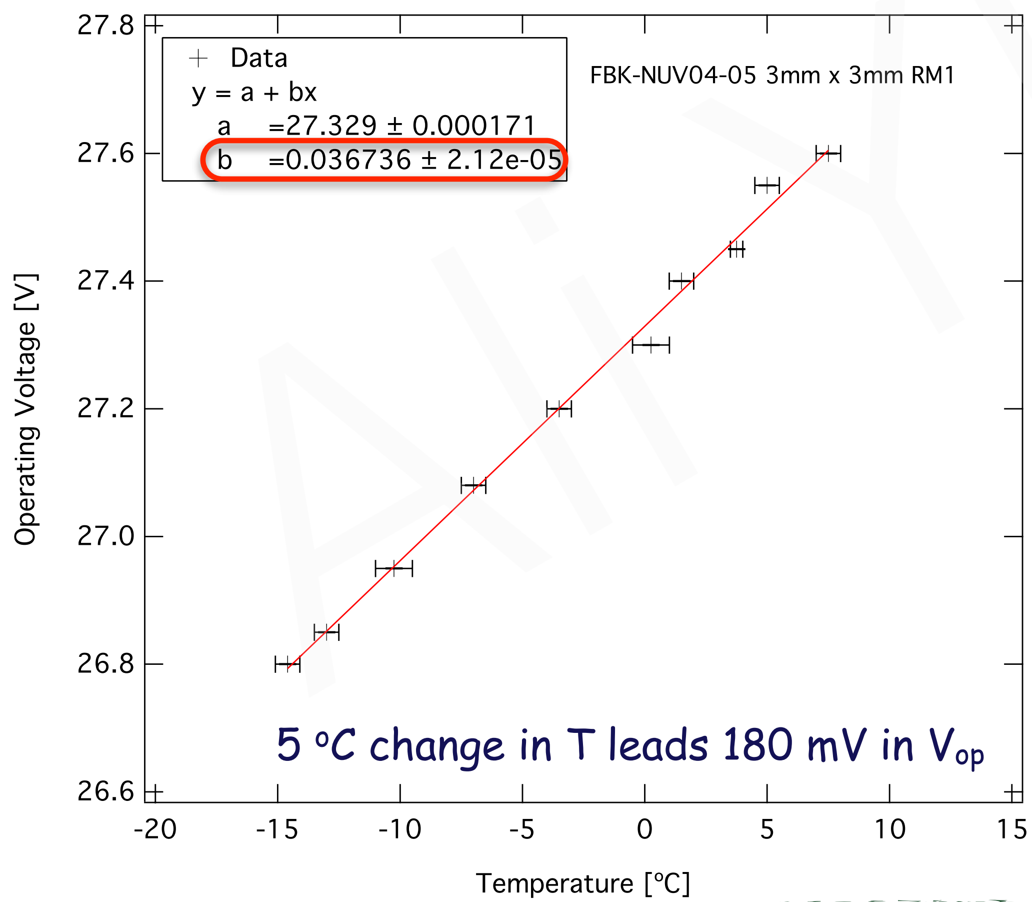
$$G \sim V_{ov} = (V_{bias} - V_{break})$$

$$V_{break} = V_{T0} + \xi \cdot T$$

$$\frac{\Delta Q}{pixel} = Q_2 - Q_1$$

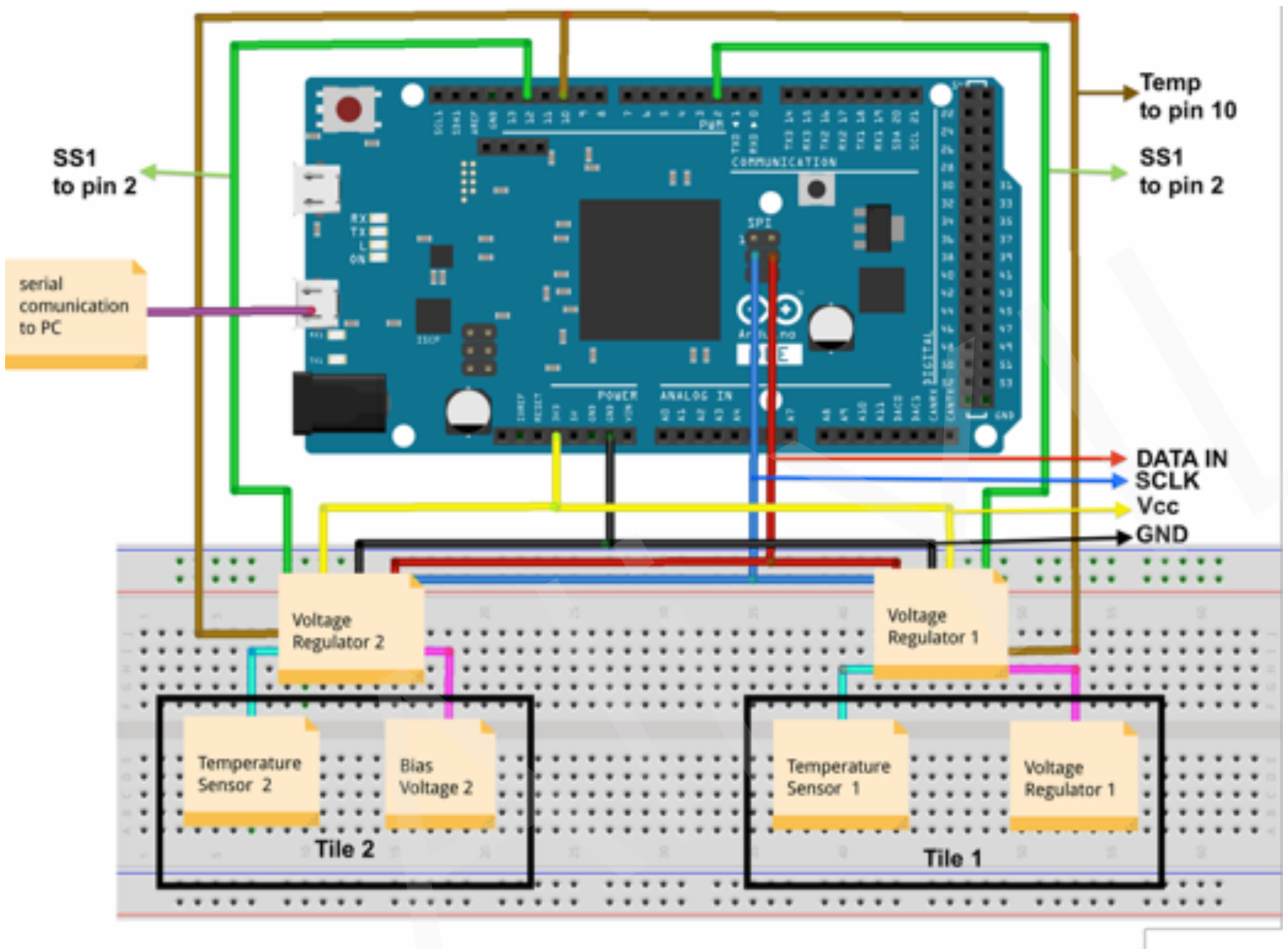


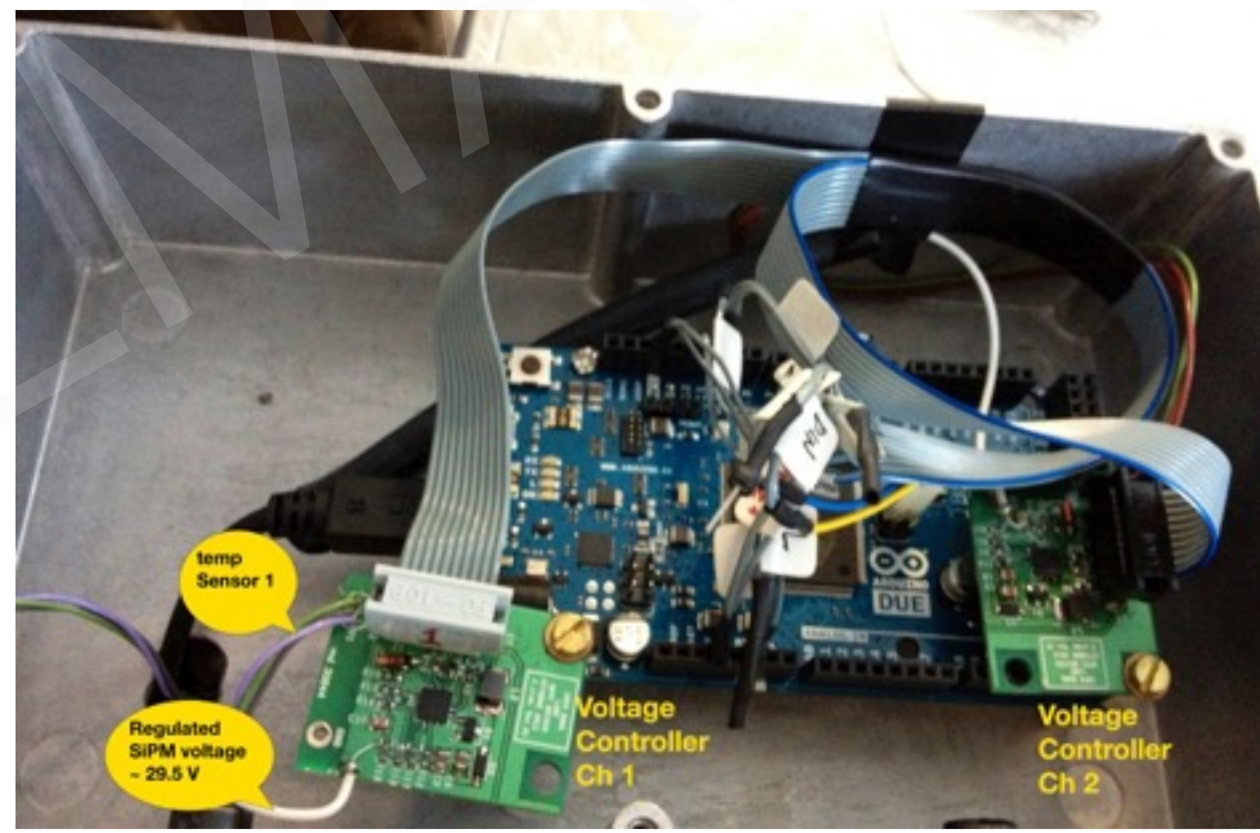




1. SiPMs: Gain Dependence on Temperature

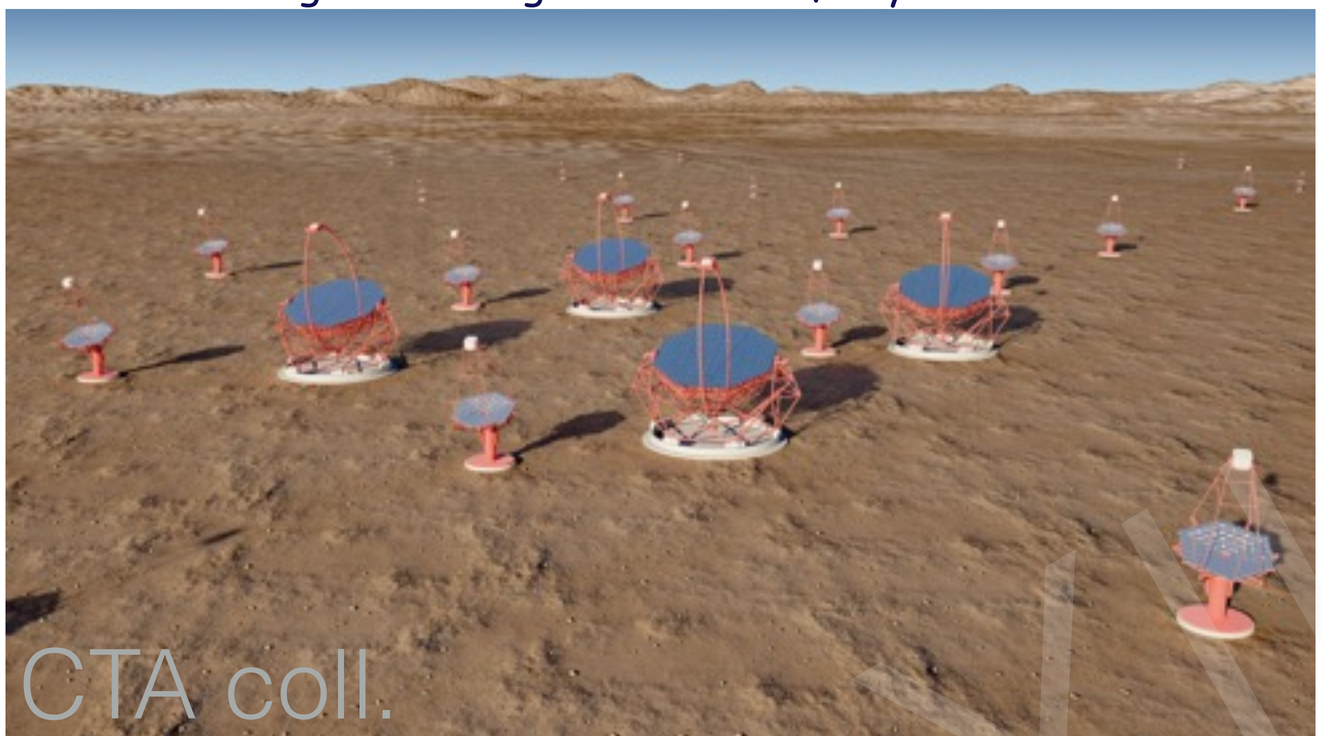
keeping the gain constant while temp changing was done by Arduino micro controller

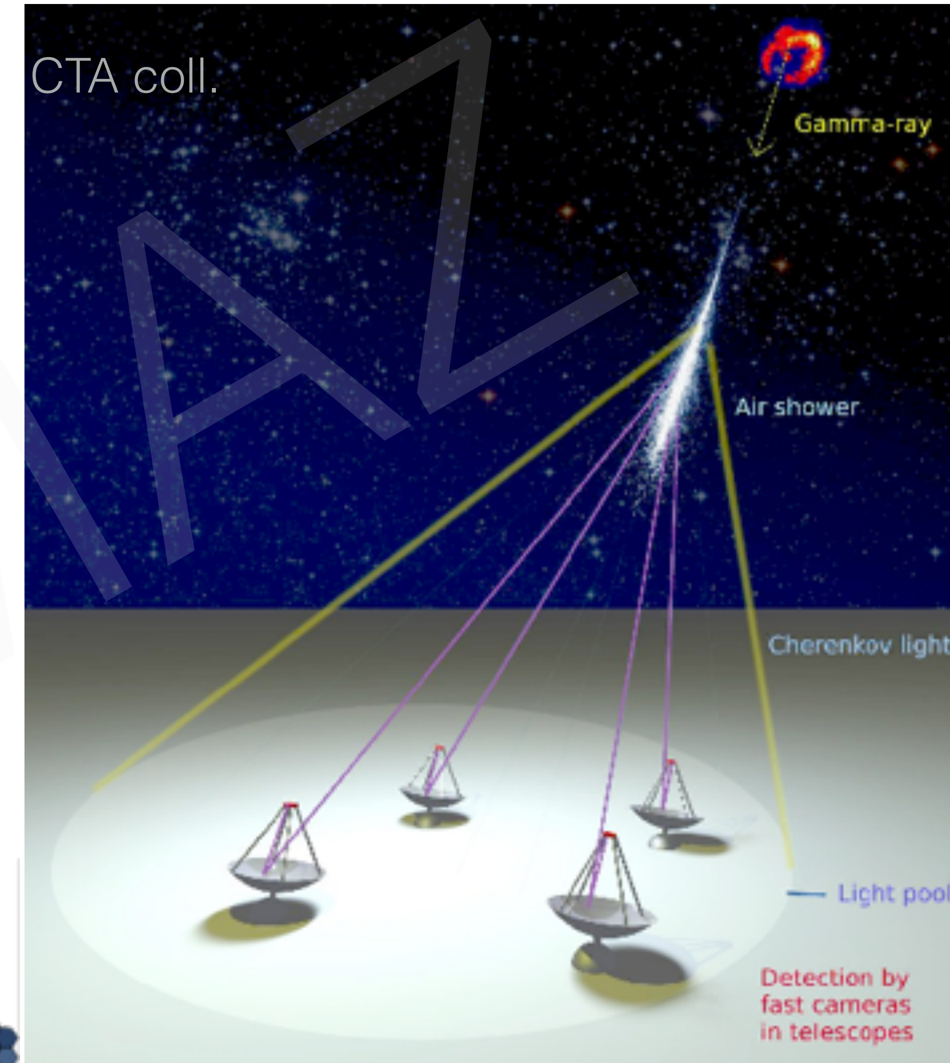


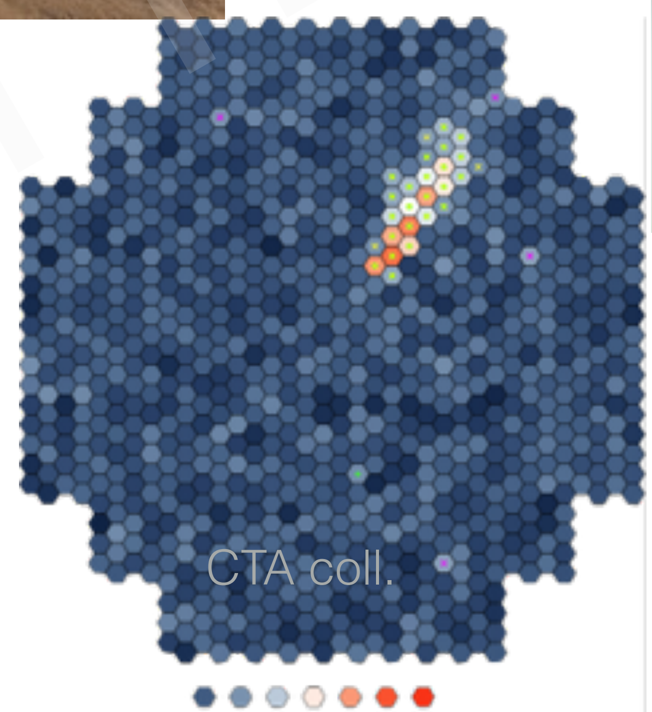


3. Cherenkov Light Detection : Cherenkov Telescope Array

is the next generation ground-based γ-ray instrument



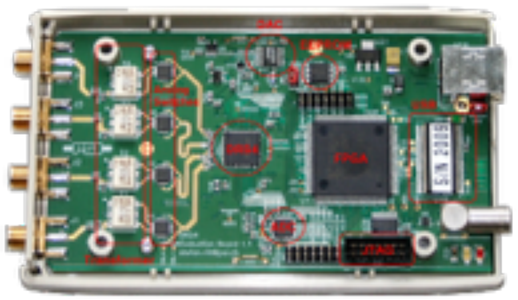




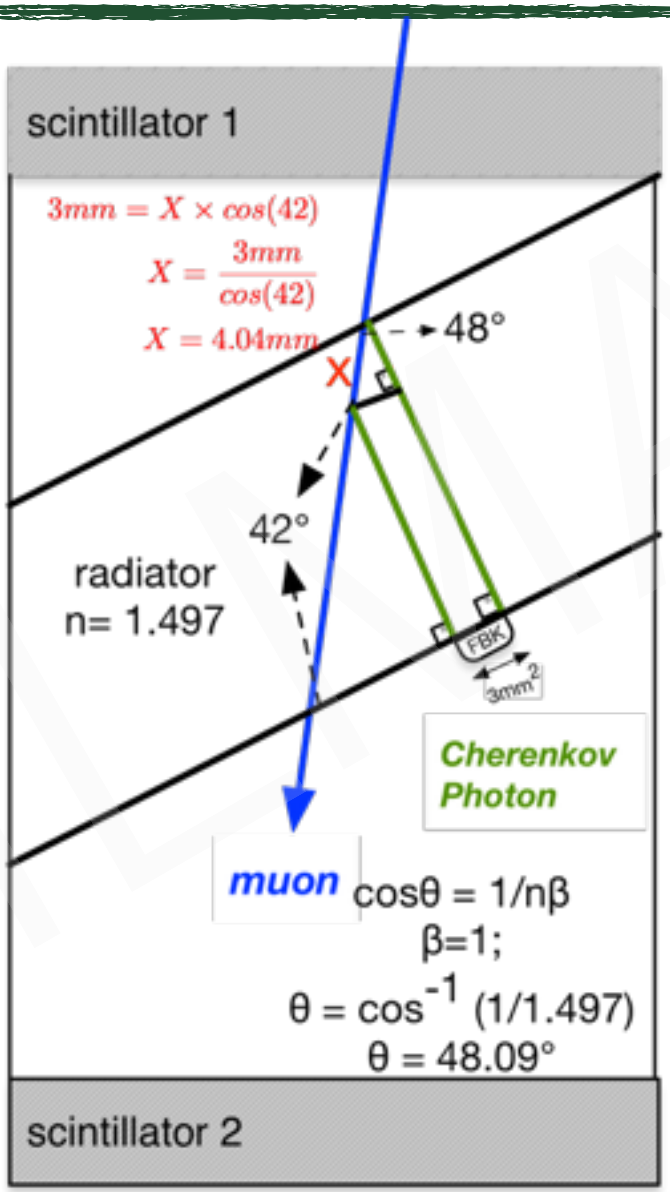
Cherenkov light cone, produced by a primary γ ray from within a cosmic ray source

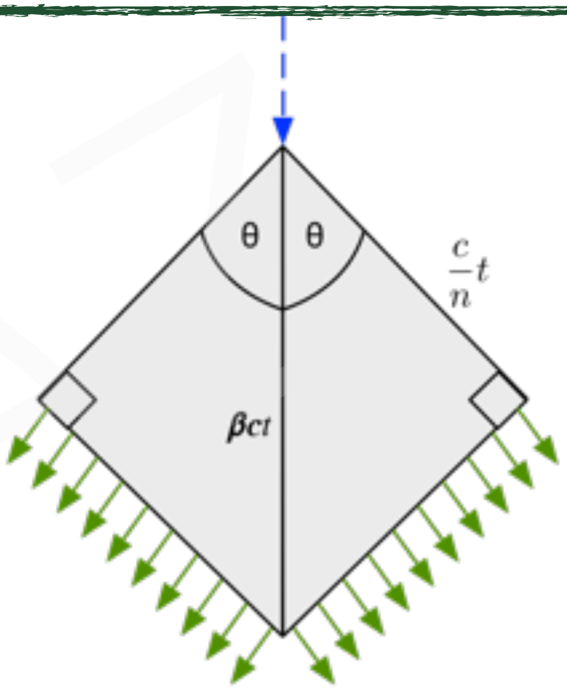
3. Cherenkov Light Detection : Setup

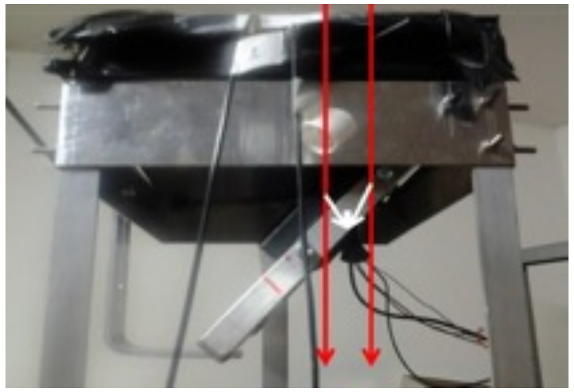
pmt gives coincident signal to register

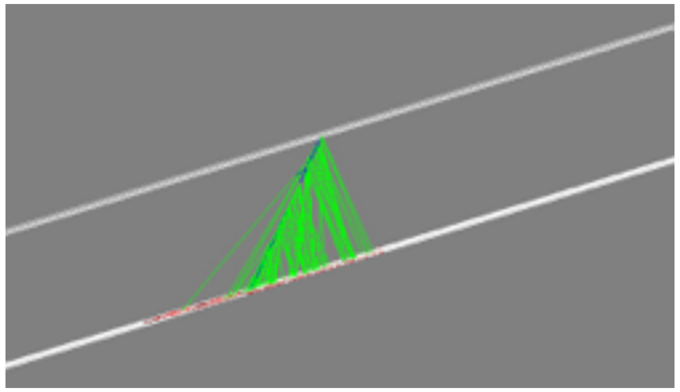


triggering rate ~ 3.9 mHz



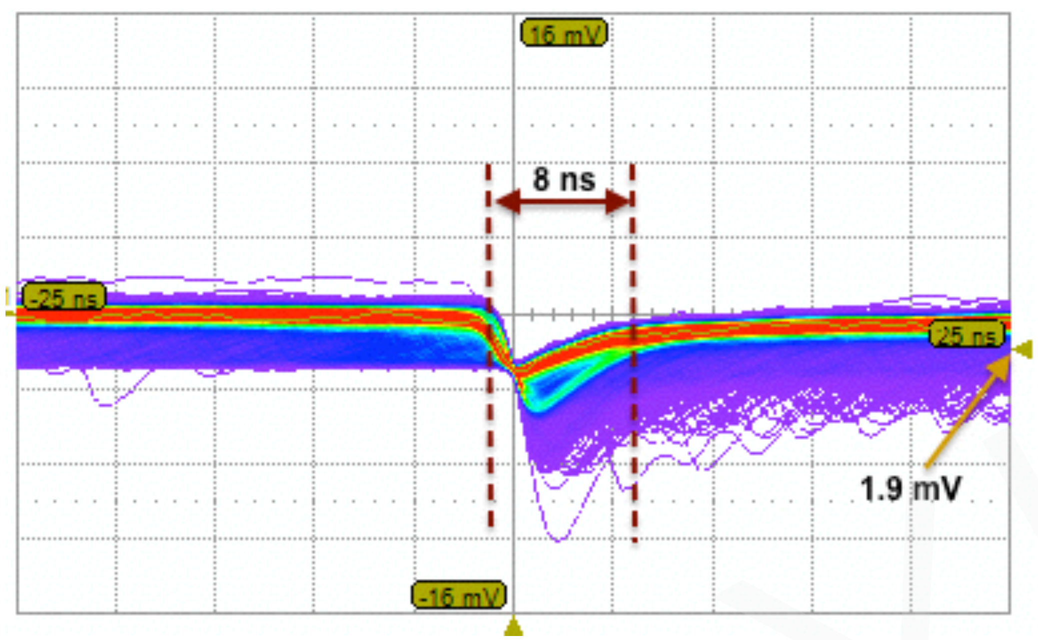




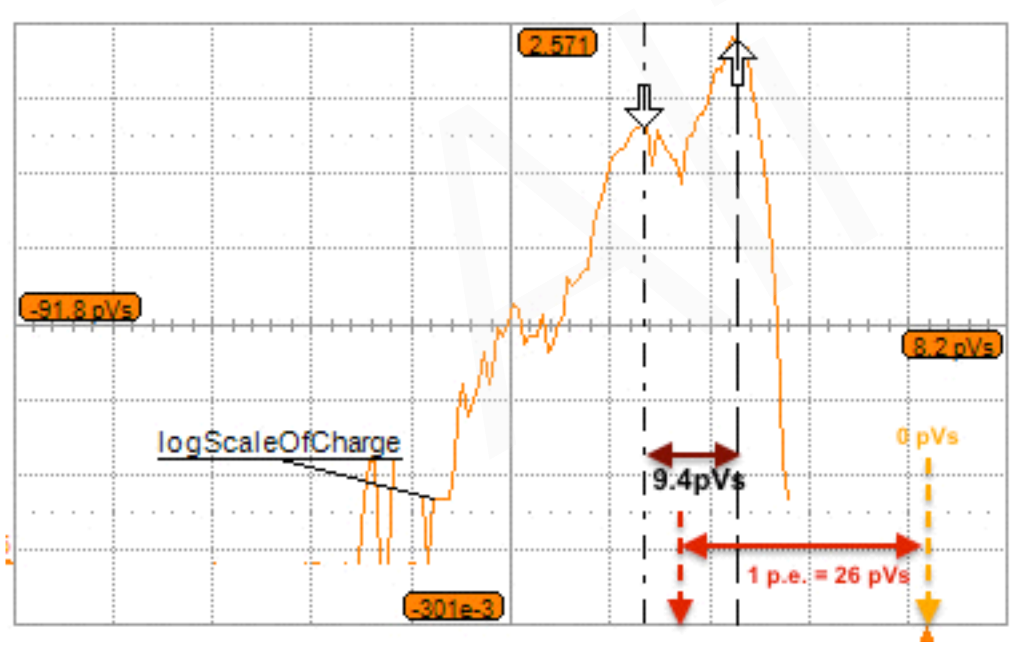


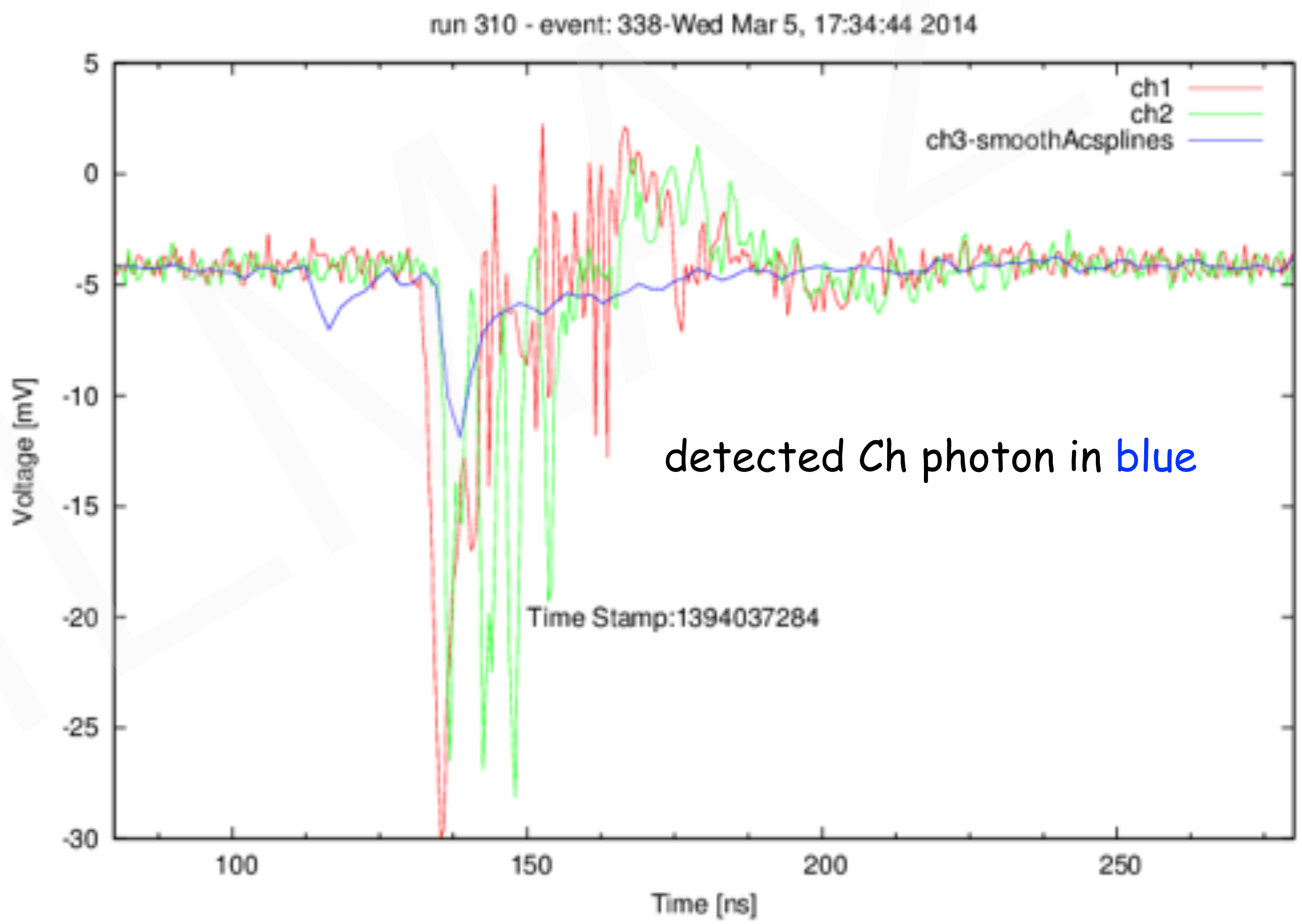
3. Cherenkov Light Detection : Analysis

sipm p.e sep. signals



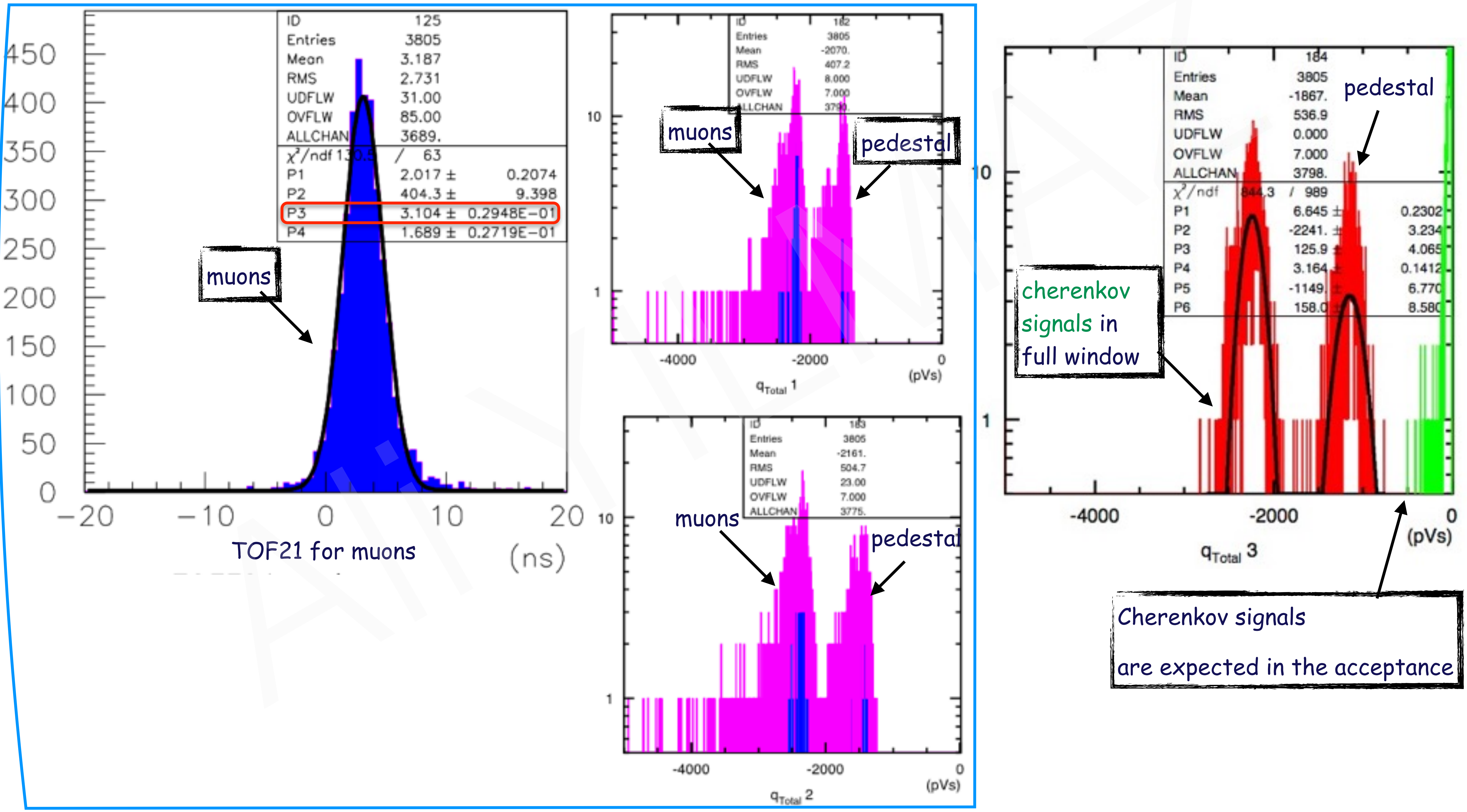
charge histos of peaks



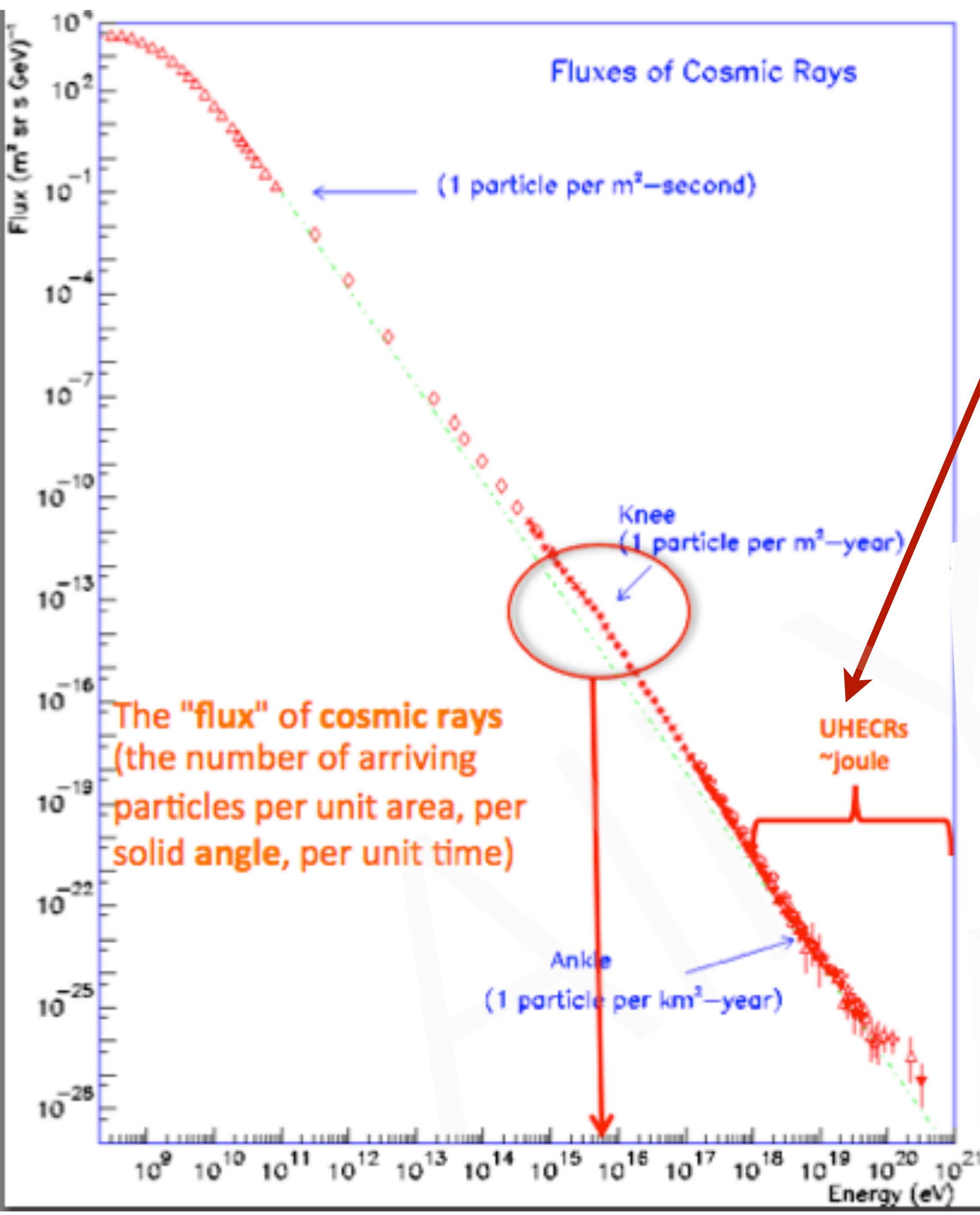


red & green are PMT signal to trigger

3. Cherenkov Light Detection : Analysis



4. Cosmic Ray Detection Studies @ Sphinx : TAUWER project

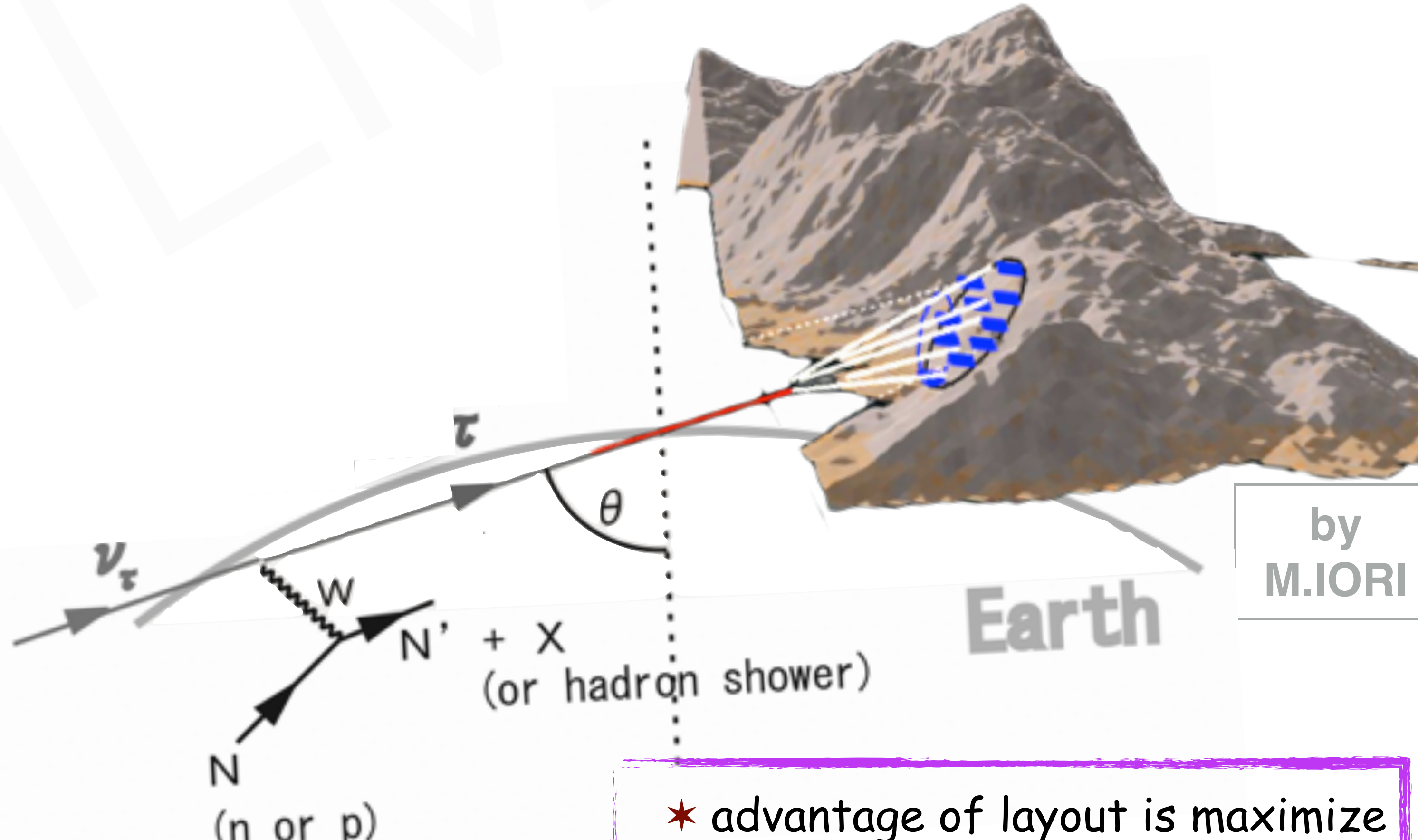


✶ is a ground based surface array designed to measure UHE (0.01-100 EeV) neutrinos using the Earth-skimming technique.

Goals:

✶ is to establish high-energy τ neutrino spectrum for energies in the AGN range and above.

✶ measure τ neutrino spectrum above the 'ankle' to look for evidence of GZK effects on neutrinos.



✶ advantage of layout is maximize the τ shower acceptance

✶ is supported by National Science Foundation (NSF) - USA

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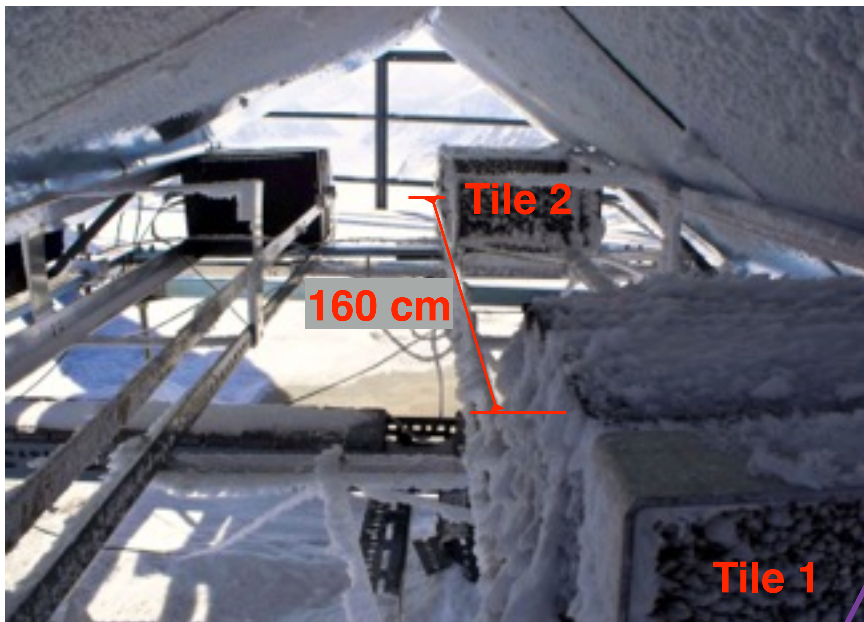
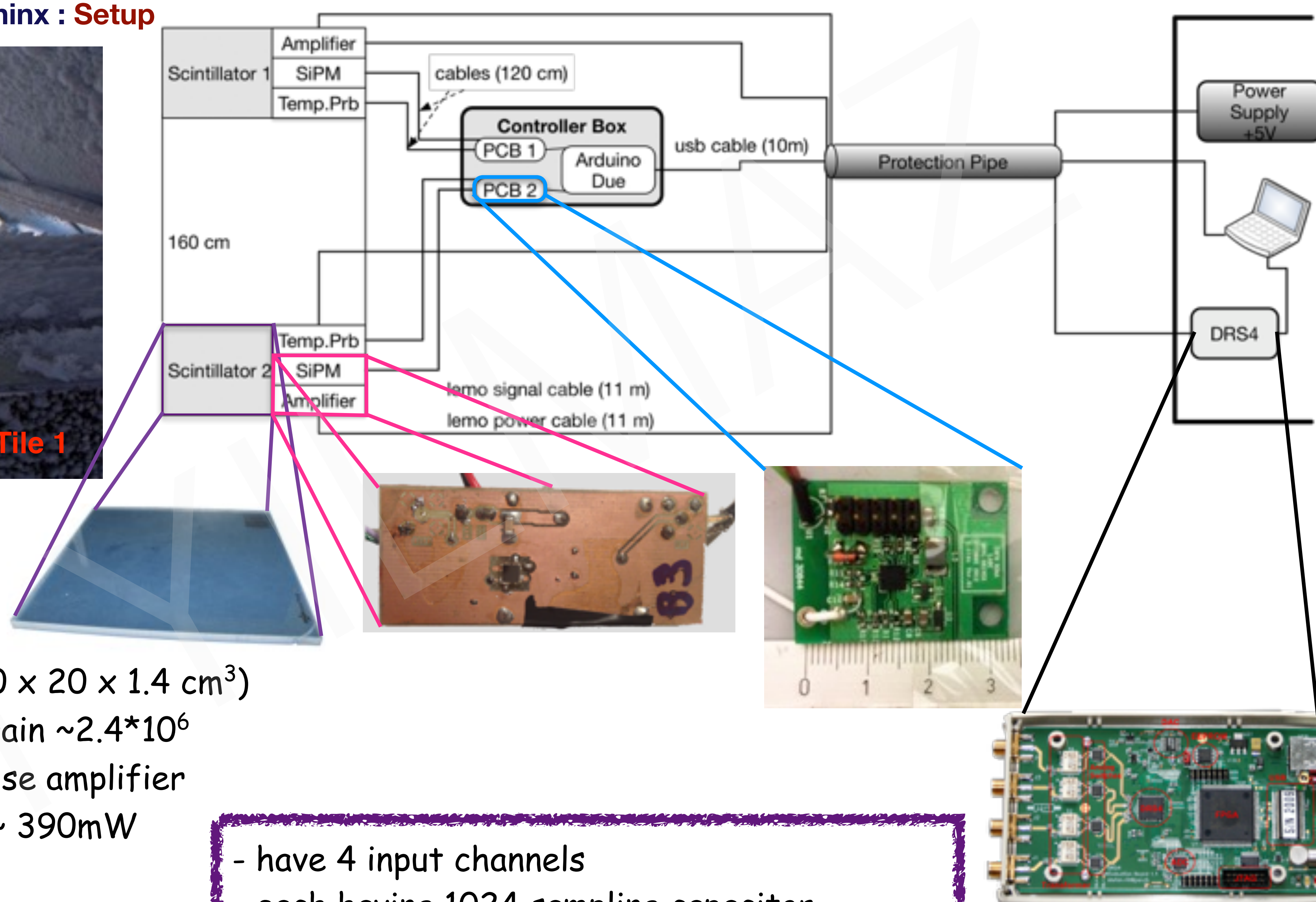
4. Cosmic Ray Detection Studies @ Sphinx : Setup





Counter box :

- Kuraray Organic Scintillator (20 x 20 x 1.4 cm^3)
- SiPM SensL 30035FM series ; gain ~2.4×10^6
- read out by mini circuits low-noise amplifier PSA5454+ - dissipation power ~ 390mW

- have 4 input channels
- each having 1024 sampling capacitor
- Domino wave circuit generates a write pulse which opens analog switches at the sampling cells of each channel.

Summary & Conclusion:

In this studies;

- ✓ dealt with the study of two types of silicon photomultipliers (with same dimension)
- ✓ the development of a complete readout system for light detection applications
- ✓ extensive characterizations studies of SiPMs were done
- ✓ dark noise rate and afterpulsing probability were found around 6 MHz and 1%

- ✓ first investigated problem was the dependence of the breakdown voltage, and accordingly the overvoltage on the temperature constant of proportionality of 36 mV/°C
- ✓ an automatic implementation method of V_{ov} developed to monitor the temperature and regulate the bias voltage accordingly via Arduino
- ✓ the application made on the components of the **Cherenkov light detection camera module** (includes 1 SiPM for now)
- ✓ **Cherenkov signals** were detected by the developed setup

- ✓ The **DAQ programs** were written, working in **automatically**, in shell / perl C++ programming language with implementation ROOT binary output

Thank you

Grazie tutti