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CHARACTERIZATION OF SIPM'S

Masterthesis | 2024-25 | Danté Bouckhout

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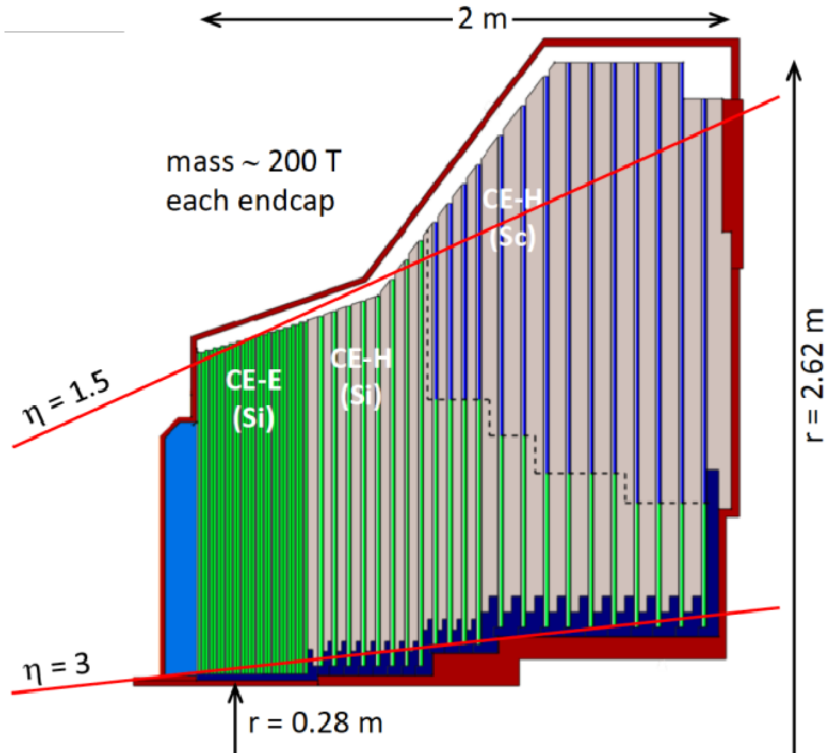
CONTENT

- SiPM refresher
- Cooling mechanism
- Box Design
- Temperature
- Dark current + Breakdown Voltage
- Future plans: Gain measurement + Dark Count Rate
- DT5550W



cross-section view of HGCAL at CMS endcap. in blue with SiPM-in-scintillators tiles.
(Bouyjou, 'HGCROC2: the front-end readout ASICs for the CMS High Granularity Calorimeter', 2022)

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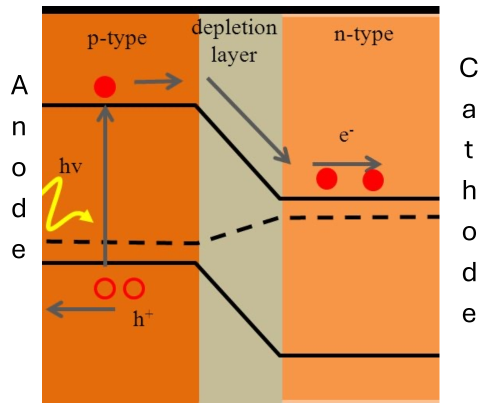
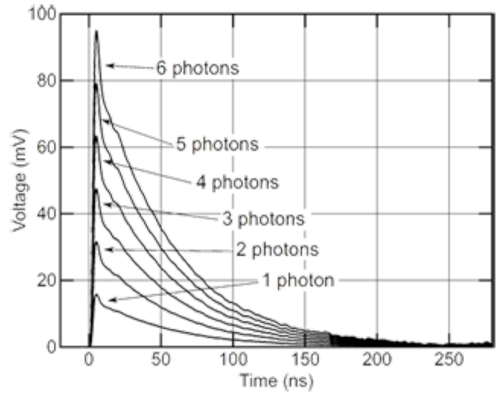
SILICON PHOTOMULTIPLIER

- Array of SPAD's
  - Single photon avalanche diode
  - Diode in reversed bias
  - Photon creates e^{-}, h^{+} pair
  - Breakdown Voltage -> accelerated e^{-} creates more e^{-}, h^{+} pair
  - Avalanche becomes self sufficient

- SiPM outputs sum of all SPAD charge contributions
  - Photons easily countable
- Particle detection
  - used together with scintillator



illuminated pn junction diode
(Calnan, Coatings, 2014)



Pulse Response to a Different Number of Photons
(Broadcom , 2024)

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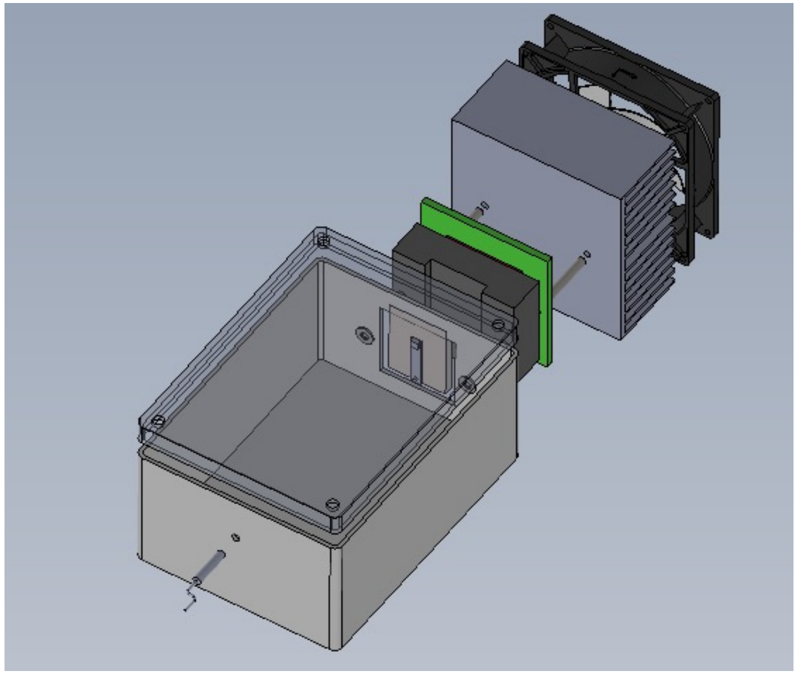
BOX DESIGN

- Peltier module
- Fan+ heatsink
- Sliding mechanism to change SiPM
- Light tight entrance
- Temperature sensors
- Photon source



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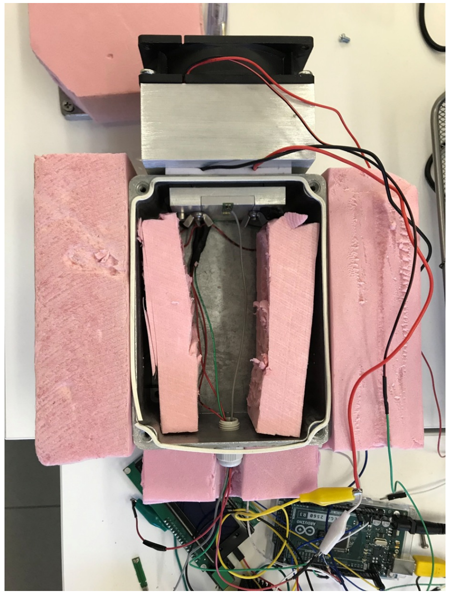
BOX DESIGN

- Finished just before end of last semester
- Good light-tightness
- Insulation not yet ideal
- But is easy to use



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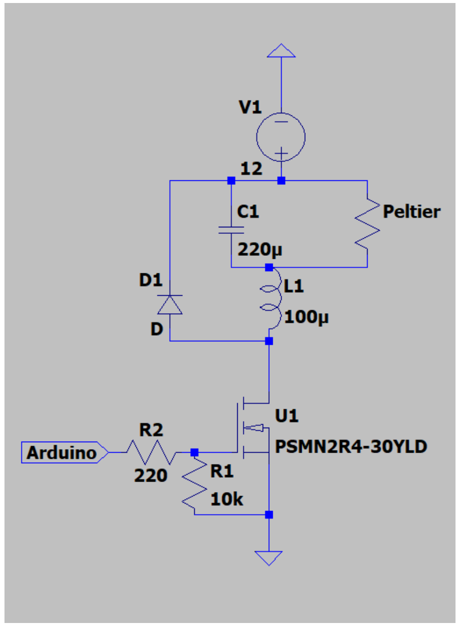
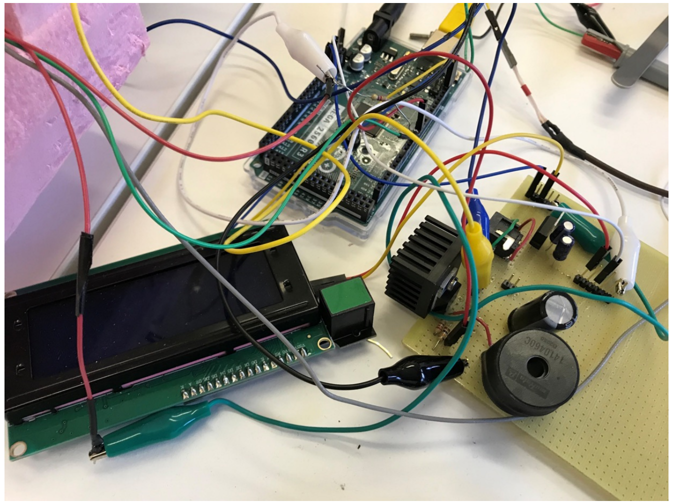
COOLING MECHANISM

- Working prototype circuit to control the power input of the Peltier device
- Feedback loop via Arduino with temperature sensors
- Self correcting algorithm to minimize undershoot when cooling
- Also possible to heat in the same way if peltier is connected in reverse



LC-smoother circuit

Peltier element



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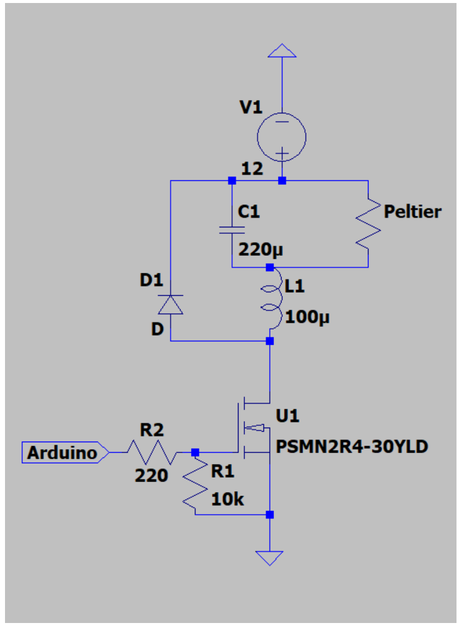

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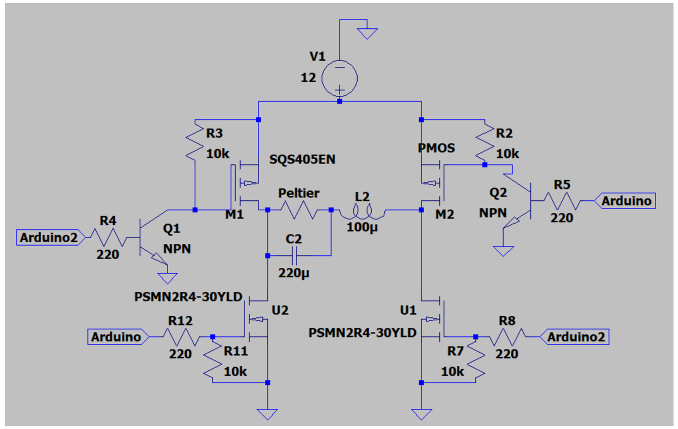

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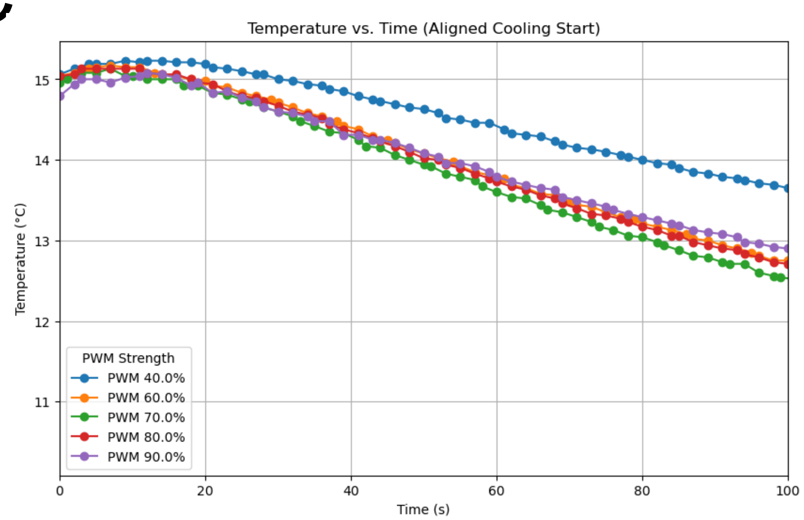
TEMPERATURE MEASUREMENT

- Testing of temperature showed a strange result: peltier seems to work best at voltage of 10V instead of the prescribed 12V
- Also testing done to show stability of algorithm
- Lowest temperature (thusfar) = 5°C



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DARK CURRENT + BREAKDOWN VOLTAGE

- **Dark current** is the unwanted electrical current that flows through a SiPM without exposure
- Impact: Increases noise and limits detector sensitivity.
- Dependency: Higher temperature → more thermal carriers → higher dark current.
- **Breakdown voltage** is the minimum reverse bias voltage at which a SPAD enters Geiger mode, where even a single charge carrier can trigger an avalanche.

- Measuring?
- By using the keithley 6487 piccoammeter
- Can measure the SiPM current even at 10 E-9 A
- Through GPIB port and SCPI commands we can make everything happen from python
  - Put voltage on, do measurements, go to next voltage and so on
  - Though serial interface with Arduino we can even get temperature at every measurement

```
# ================= CONNECT TO DEVICES =================
print("Connecting to Keithley 6487...")
rm = pyvisa.ResourceManager()
keithley = rm.open_resource(GPIB_ADDRESS)
keithley.timeout = 60000

print("Connecting to Arduino...")
arduino = serial.Serial(ARDUINO_PORT, BAUD_RATE, timeout=5)
time.sleep(2)

# ================= CONFIGURE KEITHLEY =================
def configure_keithley():
    keithley.write("*RST")
    keithley.write("FUNC 'CURR'")
    keithley.write("SYST:ZCH ON")
    keithley.write("CURR:RANG 2E-9")
    keithley.write("INIT")
    keithley.write("SYST:ZCOR:STAT OFF")
```

The used piccoammeter
(Tektronix)

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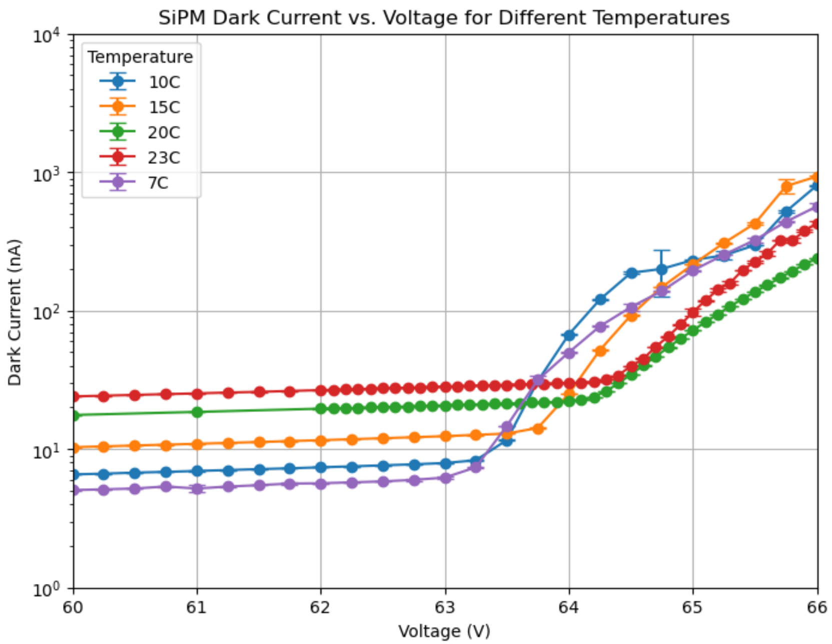
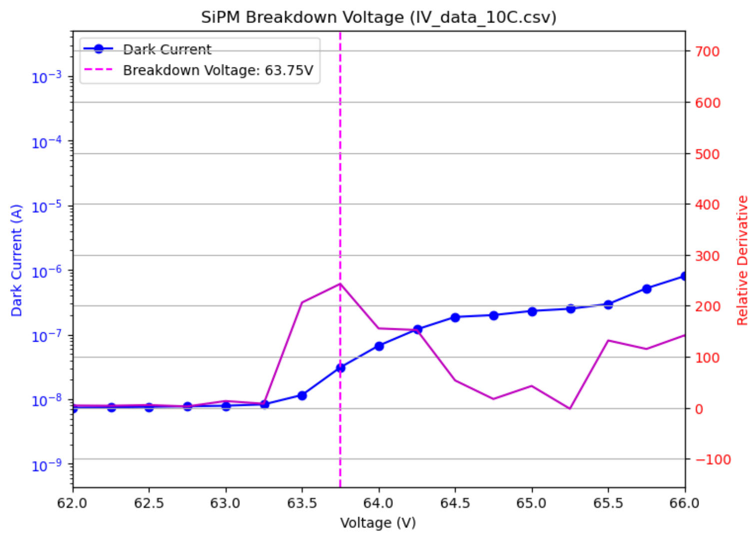
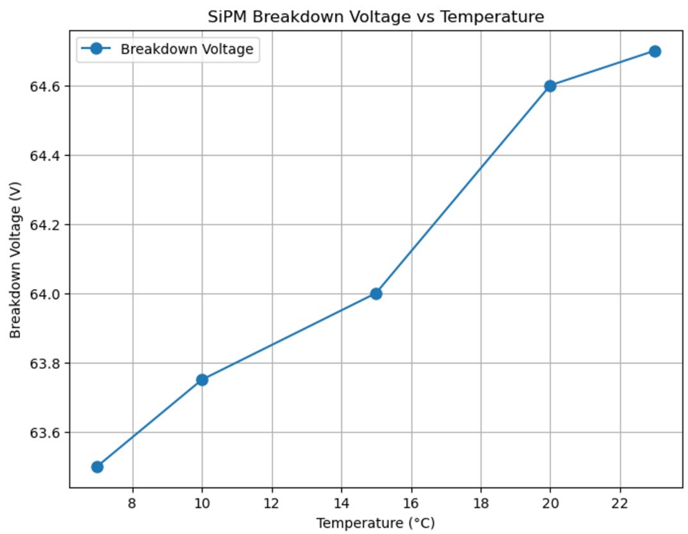
DARK CURRENT + BREAKDOWN VOLTAGE

– Results







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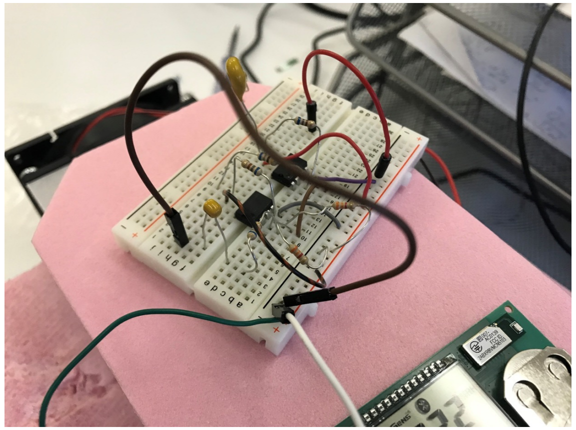
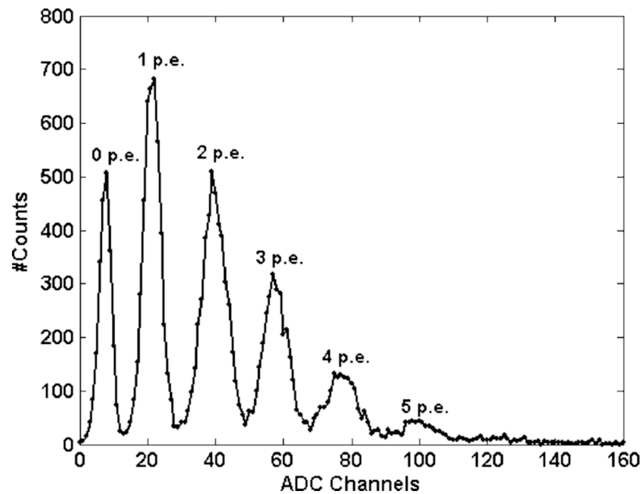
NEAR FURURE: GAIN MEASUREMENT

- Charge produced by one photon
- Influences the sensitivity and accuracy of the SiPM
- Pulser circuit with LED attached -> through optical fiber to SiPM in box
- Very low signal makes amplifier a must; especially for digital signal
- MCA8000d
  - Input: analog pulse
  - Output: amplitude of each pulse represented in a counts vs amplitude graph
- Several peaks should be seen, each corresponding to a certain number of photons (amplitude of SiPM signal)
- Distance between peaks is a representation of the gain





A counts vs amplitude graph (Mazillo et al, 2009)

MCA8000D (Amptek)

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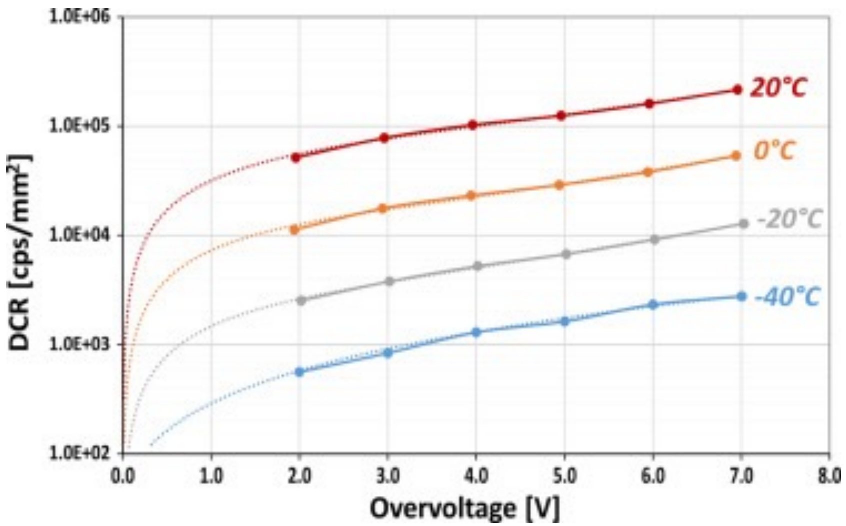
NEAR FUTURE: DCR

- Spontaneous breakdown of a Geiger-mode single photon avalanche diode (SPAD) triggered by thermally generated electrons will release the same charge as when a photon is detected
- Can be done in the same way as the gain
- Or with a pulse counter module
- We obviously expect the DCR to be higher at higher voltages and temperature



Example of DCR result
(Acerbi, 2019)

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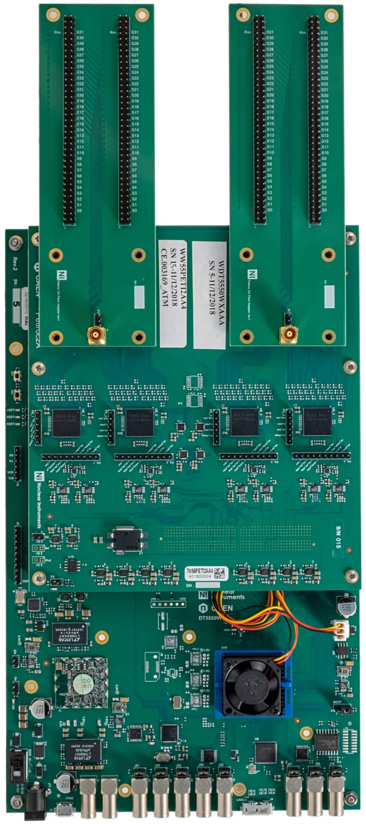
DT5550W BOARD

- A lot of time spend on this
- Could make the previous amplifier + MCA + voltage source (for SiPM) setup redundant since it should be able to do everything
- Can be used with 128 SiPM simultaniously
- Sadly we haven’t gotten it to function properly



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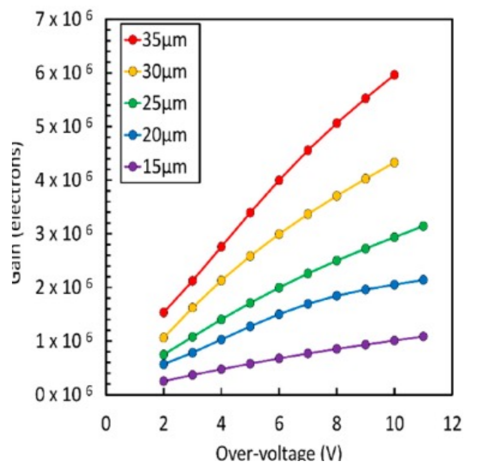
OTHER IMPROVEMENTS

- Thusfar some of the same type of data measurement were done in different circumstances => try and do everything in a same day
- Figure out why we can't cool more (Peltier on its own can go to -3°C)
- Make it more userfriendly for the future
- Test with different wavelengths of photons



The impact of different wavelength photons on the gain (Korpar, Synergies between the EIC and the LHC, 2022)

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Danté Bouckhout

Master thesis

Experimental Particle Physics and Gravity

E Dante.bouckhout@ugent.be
M +32 484 69 21 11
www.ugent.be

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CROSSTALK

- a primary discharge (avalanche) in a microcell triggers secondary discharges in one or more adjacent microcells
- According to: the size of a microcell, the layered architecture and the overvoltage
- How to measure?
- In dark environment we expect only one SPAD to give a signal from a thermal electron => count when amplitude exceeds certain limit
- Repeat for larger limits

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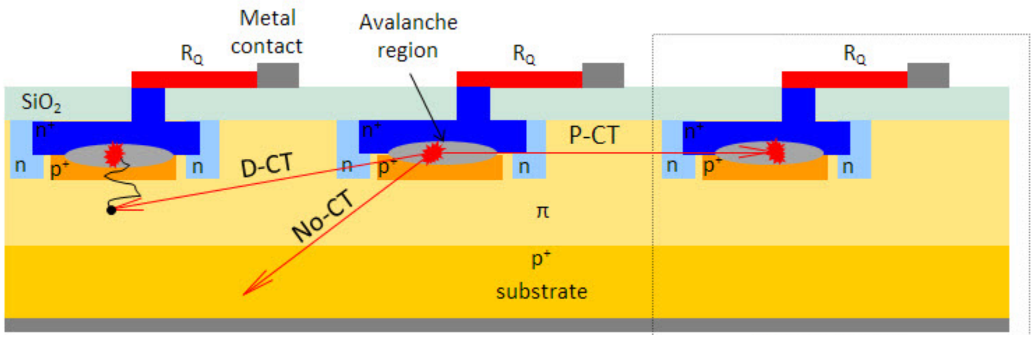

Crosstalk diagram for the prompt (P-CT), delayed (D-CT), and no (No-CT) crosstalk. (Hamamatsu, technical notes, 2016)

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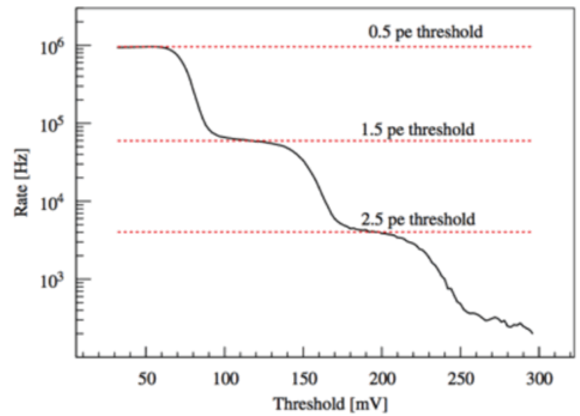
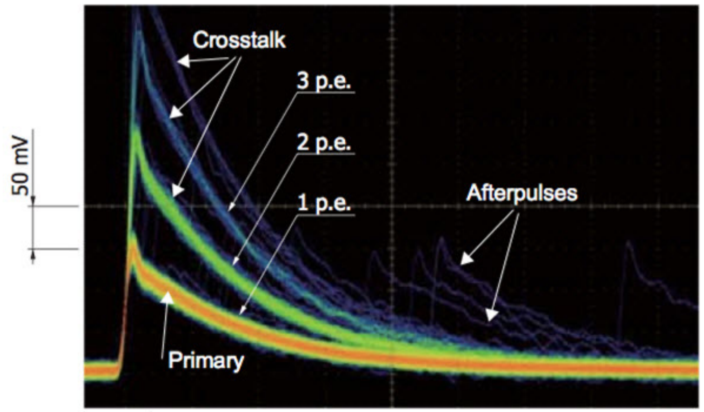


Plot of experimental data producing characteristic "staircase."(Hamamatsu, technical notes, 2016)



10 ns

An oscilloscope trace with the Cross talk visible (Hamamatsu, technical notes, 2016)

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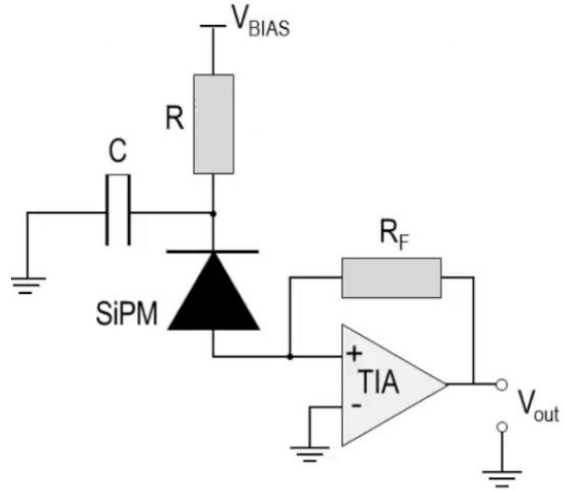

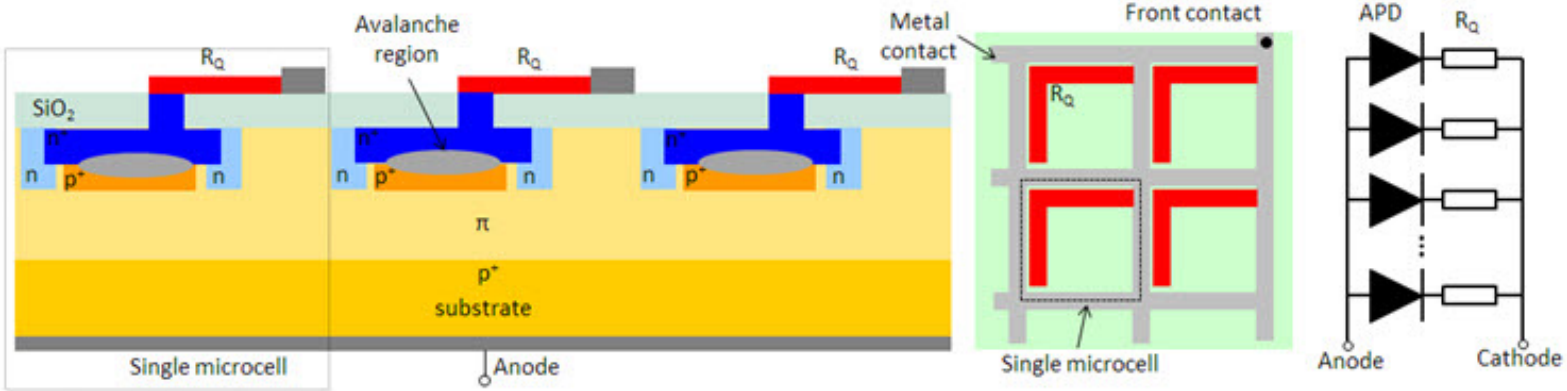

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