OUTLINE

I) Introduction
II) SiPM Dark Current
III) Healthy vs Irradiated
IV) Experimental Setup
   • Basic (Manual)
   • Semi-automatic
   • Completely automatized
V) Results
VI) Current Issues and Future Plans
INTRODUCTION

• SiPMs are used in the polarimeter in CoSy at Forschungszentrum Jülich along with the LYSO crystal.

• A photon, as a result of the recombination in the crystal, triggers the APD (Avalanche Photo-Diode) recording the event and the energy of the photon.

• SiPM array is a matrix of 16 (8x8) of such APD which are set to geiger mode

• For this presentation, all the SiPM array modules used and the results obtained are from SensL ArrayJ 30020 8x8
SIPM DARK CURRENT

• Dark Current is current generated in the absence of photon
  - Phenomena such as thermal excitation, defects in crystal lattice etc.

• Dark current is the noise in the signal.

• Range of dark current in our lab conditions:
  - 1 to 10 µA @ 26 V

★ Dark current of 160601-02 @ 26 V is 6.471 µA
# HEALTHY VS IRRADIATED

<table>
<thead>
<tr>
<th>Healthy SiPM</th>
<th>Irradiated SiPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low dark current ➔ low noise</td>
<td>High dark current ➔ high noise</td>
</tr>
<tr>
<td>Very good resolution</td>
<td>Very low resolution</td>
</tr>
<tr>
<td>Reading are consistent over time</td>
<td>Reading varies because of annealing over time</td>
</tr>
<tr>
<td>In lab conditions: 1 - 10 µA at 26 V</td>
<td>After irradiation: 500 - 7000 µA at 26 V</td>
</tr>
</tbody>
</table>

Note: Values are for 8x8 SiPM matrix
INSPIRATION

- SiPMs in CoSy are exposed to radiation
- SiPMs are not completely radiation hard

- To understand the effects and to know the limitations of the device
- Need instrumentation to study irradiated SiPM?
  - Dark current of the SiPM matrix
  - Dark current of individual SiPM
  - Ability to control voltage
  - Observe the change in dark current
  - Observe the radiation effects (patterns)
  - Observe annealing effects
EXPERIMENTAL SETUP

Ideas and goals to achieve

• Measure the dark current of each SiPM in the matrix
• Compare the analysis data to the old datasets (also in batch)
• Generate reports of one or several SiPMs along with their comparisons
• Change the supply voltage to the SiPMs
• Monitor recorded data live on web browser during the measurements
• Workaround for the heating issues during measurements
• Timely measurements without human intervention
EXPERIMENTAL SETUP

Basic setup

• SiPM matrix has 64 SiPMs.
• Channeling of each SiPM from SensL SiPM development board with 5 multiplexer was designed by Dr. Fabian Müller
• Controlled by Raspberry Pi
• Measurement script on python
• Instruments:
  - Pico-ammeter - Keithley
  - Voltmeter - Fluke
  - Power supply - GW
EXPERIMENTAL SETUP

Manual device

- Onboard potentiometer was replaced by a switch connecting a series of resistors
- Housing for the switch was printed
- Voltage could be changed by rotating the switch
- Separate switch to turn on and turn off the power supply
EXPERIMENTAL SETUP

Manual device

• Issues with this setup
  - Manually switching for several measurements would be tedious
  - Connector in the switch had bad contact
  - Switch added an extra varying resistance to the circuit
EXPERIMENTAL SETUP

Semi-automatic device

- Switch was replaced by a series of connectors around the resistors
- The connection was made manually by wires with option to add a multiplexer
- Power on / off was controlled by Raspberry Pi

Issues:
  - Still manual to change voltage
EXPERIMENTAL SETUP

Automatic device

• Multiplexer was added and circuit was adjusted to choose the required resistance
• Voltage could be changed to pre-determined values through Raspberry Pi
• Scanning dark current through different voltages is possible
• An algorithm was devised to avoid heating issue - reads SiPM which are always the farthest from the previous SiPM
RESULTS

Accidental damage in CoSy

• Examples of the reports generated after the measurement

• By observing the patterns ⇒ location of the beam

• Identify defective or broken SiPM

• Observe the change in dark current after annealing in the oven
RESULTS

Accidental damage in CoSy

- Examples of comparison reports generated

- Change in dark current can be visualised

- Examples:
  - 0 - 20 hours annealing
  - 0 - 266 hours annealing
  - 243 - 266 hours annealing
RESULTS

Investigating the radiation hardness of the SiPM arrays

• Healthy SiPM was exposed to totally of 11 Gy from Cyclotron

• Dark current was measured during irradiation and also when radiation was switched off

• Radiation film was placed on the SiPM to observe the radiation pattern and uniformity

• Live feed of the dark current was set up to observe the changes instantly

• Radiation damage with Cyclotron was similar to the damaged caused in the accident for the SiPMs in the second ring
RESULTS

Investigating the radiation hardness of the SiPM arrays

• Dark current of each SiPM in the matrix for different voltages is measured

• Increase in the dark current with increasing voltage can be observed
RESULTS

Investigating the radiation hardness of the SiPM arrays

• Dark current of the SiPM matrix for different voltages

• Change in dark current over the period of 2 months of annealing

• Data was recorded every 12 hours for a period of 7 days
CURRENT ISSUES

• Random jumps in the current recorded
• No pattern has been found yet

*Calibration of the setup was performed by replacing SiPM board with 27kΩ resistor

Voltage and current were measured at all times. Resistance of the resistor was calculated using

\[ R = \frac{V}{I} \]

• Measuring dark current of the whole matrix gives comparable results but not individual SiPM results

• Voltage drift in the power supply
FUTURE PLANS

• Identifying the root cause for jumps
• Adding an external reference to have much higher stability in supply voltage

Thank you
BACK-UP

Full report of 160601-02
BACK-UP

Full report of pattern plot

Dark Current Map of SiPM 161123-28
$V_{\text{bias}} = 26V$ 2019.10.16 - 07:41

- Total current = 5067.341 µA
- Average = 79.177 µA
- RMS = 17.348 µA
- Maximum Current = 117.309 µA @ pixel 63
- Minimum Current = 52.584 µA @ pixel 48