Determination of Hardness Factors for Various Proton Beams

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October 16, 2018

Outline

Introduction

Utilizing the **I–V** and **C–V** characteristics of **BPW34F photodiodes**, the **Hardness Factors**, κ, of three different proton beams have been measured.

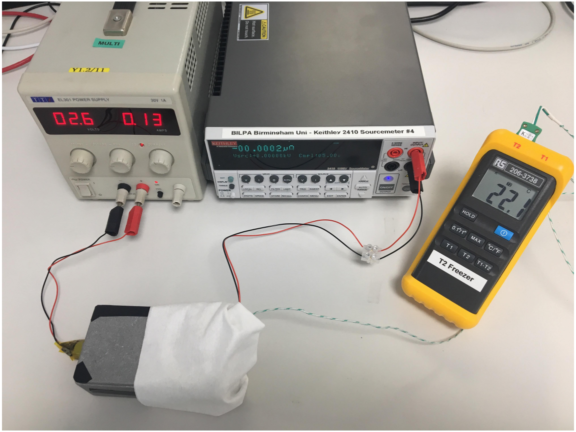
- The **MC40 Cyclotron** at the **University of Birmingham** (25 MeV).
- The **IRRAD Proton Facility** at **CERN** (24 GeV).
- The **Irradiations Facility** at the **Karlsruhe Institute of Technology** (24 MeV).

For **IRRAD**, the Results were compared to a similar study undertaken by **I. Mateu** this year.

Other Studies and Current Values

- Current **MC40 cyclotron** value: **2.2** for **25 MeV protons** [1].
- **KIT**: $\mathbf{2.05 \pm 0.61}$ for **24 MeV protons**, with a previous assumption of **1.85** for **26 MeV protons** [2].
- **Tabulated values** from RD50: $\sim$ **2.56** for **25 MeV protons** [3].
- Studies at the **IRRAD facility**: **0.56** (2015), and **0.60** (2016) for **24 GeV protons** [4].

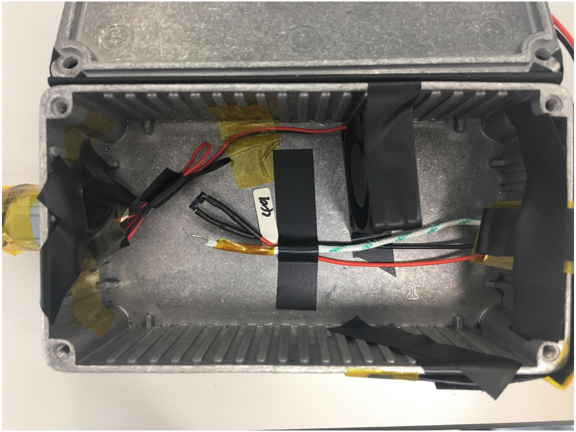
I–V Measurements
Setup



Experimental setup for I–V measurements.

I–V Measurements

Setup



Aluminium shielding box.

C–V Measurements

Current – Voltage Relation and Maximum Depletion Voltage.

- The **capacitance** of a photodiode is related to the **reverse bias** by [5]:

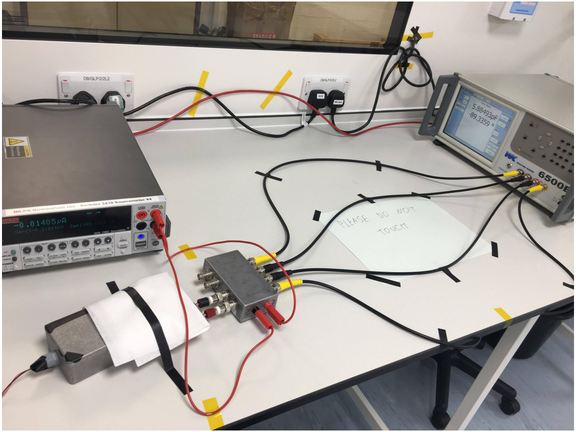
$$C = \frac{f\sqrt{\epsilon_{Si}\epsilon_0}}{\sqrt{V}}$$

- At **maximum depletion voltage**, capacitance becomes independent of voltage.

- Plotting **capacitance vs voltage** on a log plot should therefore show a straight line, with a **deviation** at maximum depletion.

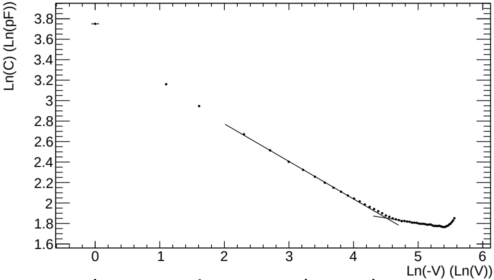
C–V Measurements

Setup



Experimental setup for C–V measurements.

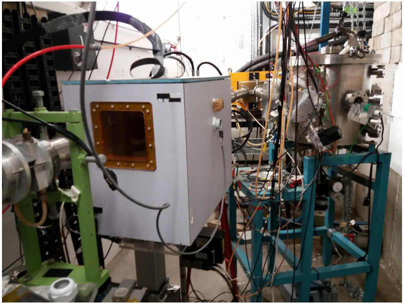
- By calculating the **intersect** of the two fits, the point at which the trend deviates from a straight line could be calculated.
- Applying this method, a maximum depletion voltage value of $\boldsymbol{V_{dep} = -90.8 \pm 5.1}$ **V** was inferred.



log capacitance vs log voltage.

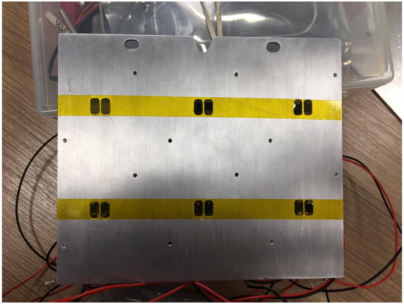
Proton Irradiations

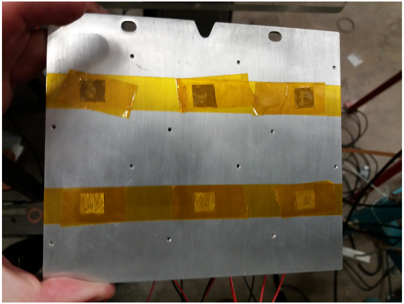
ATLAS Chamber



The isolation box within the ATLAS chamber, the box was used to cool the photodiodes to -27°C.

$\otimes$ Beam direction.





Aluminium mount. The nickel foils were used to measure the incident fluence.

- Post irradiation, all photodiodes were annealed for 80 minutes at 60°C.
- The **change in leakage current** before and after irradiation is related to **proton fluence** by [6]:

$$\Delta I = \alpha L^2 w \phi$$

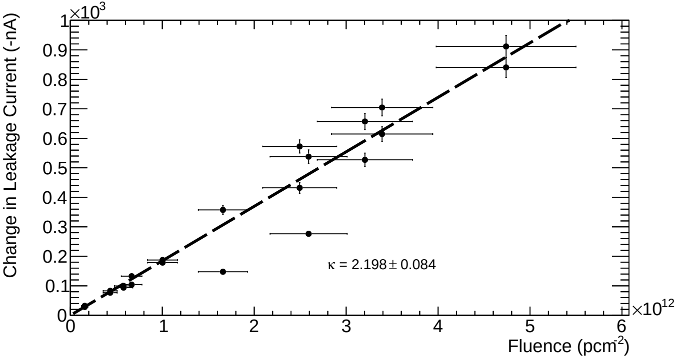
- The **hardness factor** can be written as:

$$\kappa = \frac{\alpha}{\alpha_{neq}} \quad \text{since} \quad \kappa = \frac{\phi_{neq}}{\phi}$$

Where $\alpha_{neq} = (3.99 \pm 0.03) \times 10^{-17}$ Acm^{-1} [6].

Results

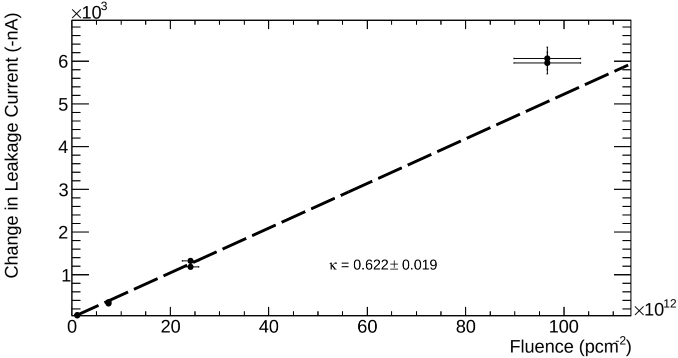
Hardness Factor of the MC40 Cyclotron



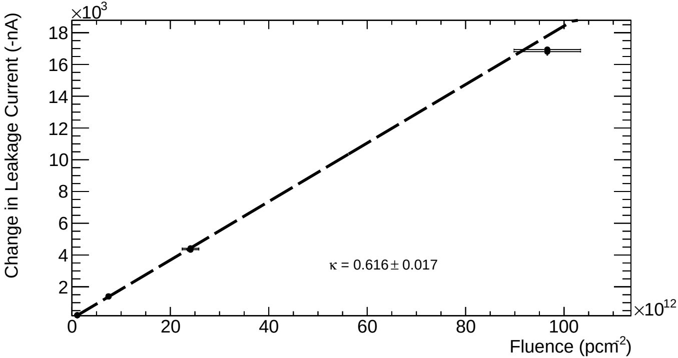
From this, a value of $\kappa_{MC40} = \mathbf{2.198 \pm 0.084}$ for **25 MeV protons** was inferred.

Results

Hardness Factor of the IRRAD Proton Facility

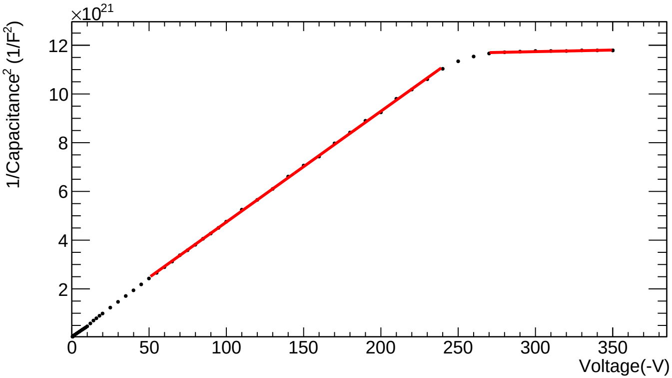


Using the same method as for the MC40 Cyclotron, a value of $\kappa_{IRRAD} = \mathbf{0.622 \pm 0.019}$ for **24 GeV protons** was inferred.



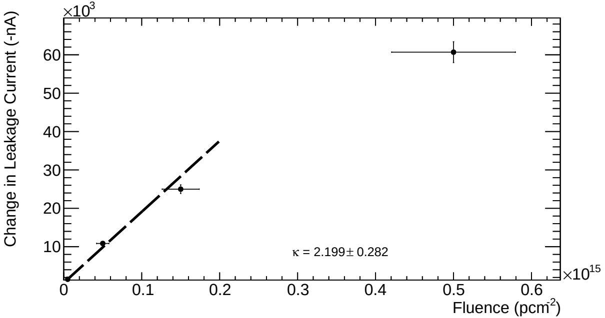
Analysis of I. Mateu's data yields a value of $\kappa_{Mateu} = \mathbf{0.616 \pm 0.017}$, which is in agreement with his own analysis (0.632) and our result.

For Isidre's data, the maximum depletion voltage was calculated for each sensor, and so was not kept constant across all data points.



Example $\frac{1}{C^2}$ −V curve for I. Mateu's data analysis.

Hardness Factor of the KIT Irradiations Facility



The highest fluence point was ignored to omit the non-linearity region ($\sim 10^{13}$ n_{eq}/cm^2 [7]). This gave a value of $\boldsymbol{\kappa_{KIT} = 2.199 \pm 0.282}$ for **24 MeV protons**.

Conclusion and Outlook

- The I–V and C–V characteristics of BPW34F photodiodes have been analysed.
- Using these characteristics, hardness factors for various proton beams have been determined.
- The results are in good agreement with other studies.
- In the future, it is suggested that studies are done to determine the current related damage rate for neutrons (This study assumed a value of $\alpha_{neq} = (3.99 \pm 0.03) \times 10^{-17}$ Acm^{-1} [6]), and therefore, determine independent hardness factor values.

References I

T. Price. *Experimental Determination of the Hardness Factor for the Birmingham Irradiation Facility*. 30th RD50 Workshop (Krakow). June 2017. URL: https://indico.cern.ch/event/637212/contributions/2608664/.

A. Dierlamm. *Proton Irradiation in Karlsruhe*. 16th RD50 Workshop. 2010. URL: https://indico.cern.ch/event/86625/contributions/2103519/attachments/1080676/1541436/Irradiations_Ka.pdf.

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Isidre Mateu et al. *NIEL hardness factor determination for the new proton irradiation facility at CERN*. 28th RD50 Workshop. June 2016. URL: http://cds.cern.ch/record/2162852/files/AIDA-2020-SLIDE-2016-002.pdf?version=1.

G. Casse. "The effect of hadron irradiation on the electrical properties of particle detectors made from various silicon materials". PhD thesis. Universite Joseph Fourier-Grenoble, 1998.

M. Moll. "Radiation Damage in Silicon Particle Detectors". PhD thesis. University of Hamburg, 1999.

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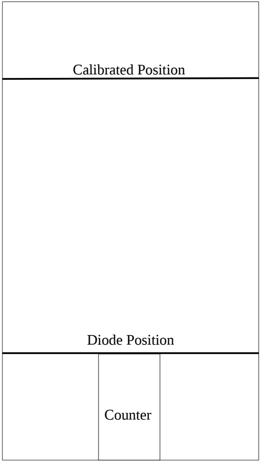
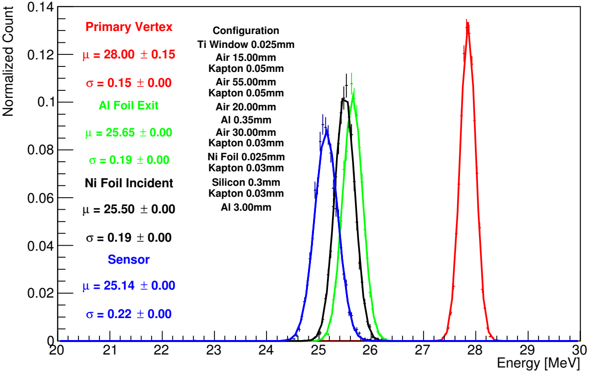


Schematic diagram of germanium counter.

- The **irradiated nickel foils** were analyzed using a **germanium counter**.
- Due to the weak activity of the foils, they had to be placed directly on top of the counter.
- A **ratio of counts** was taken between this position and the calibrated position.
- The measured counts from the foils were then converted into **proton fluences**.



Geant4 simulation revealing the incident beam energy, the energy at the nickel foils, and the energy at the sample (Courtesy of Dr. T. Price).