Determination of Hardness Factors for Various Proton Beams

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Outline

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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).

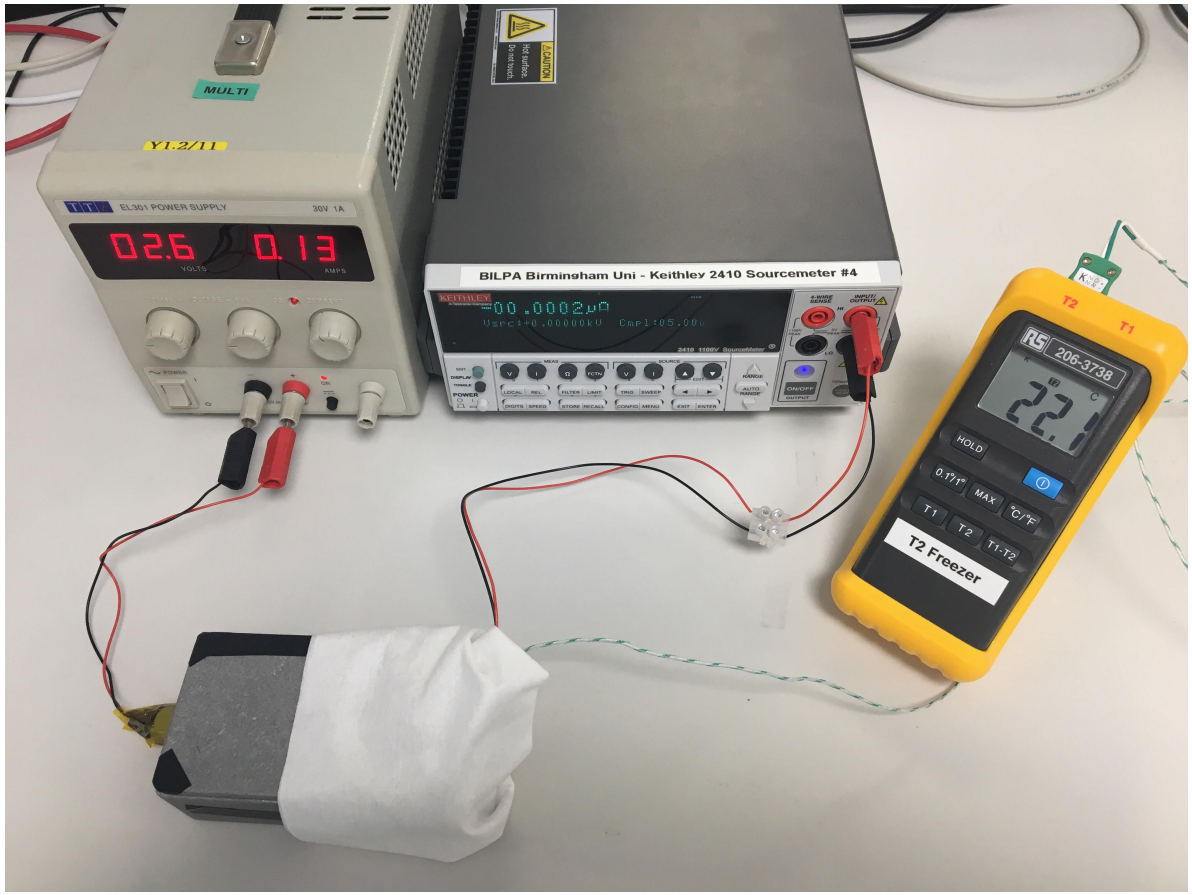
For **IRRAD**, the Results were compared to a similar study undertaken by **I. Mateu** this year.

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

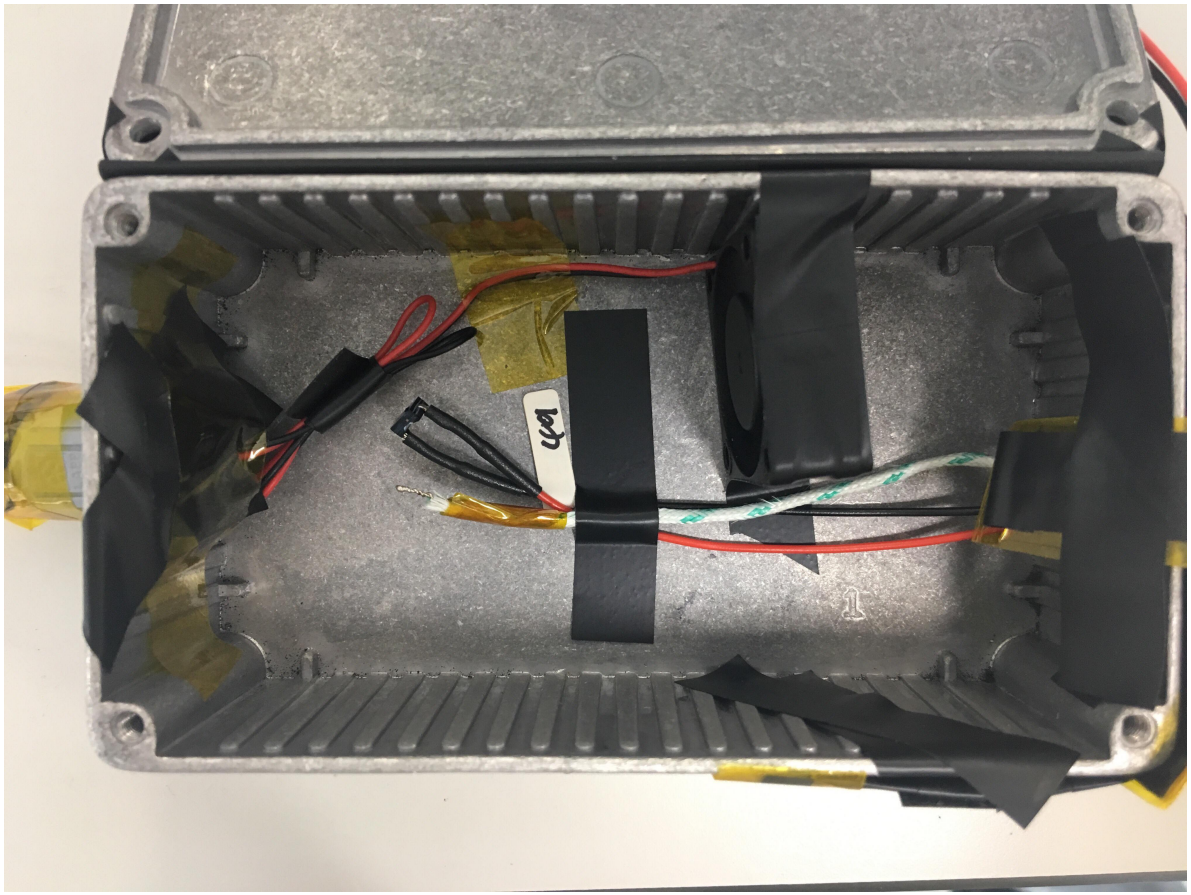
Setup



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]:

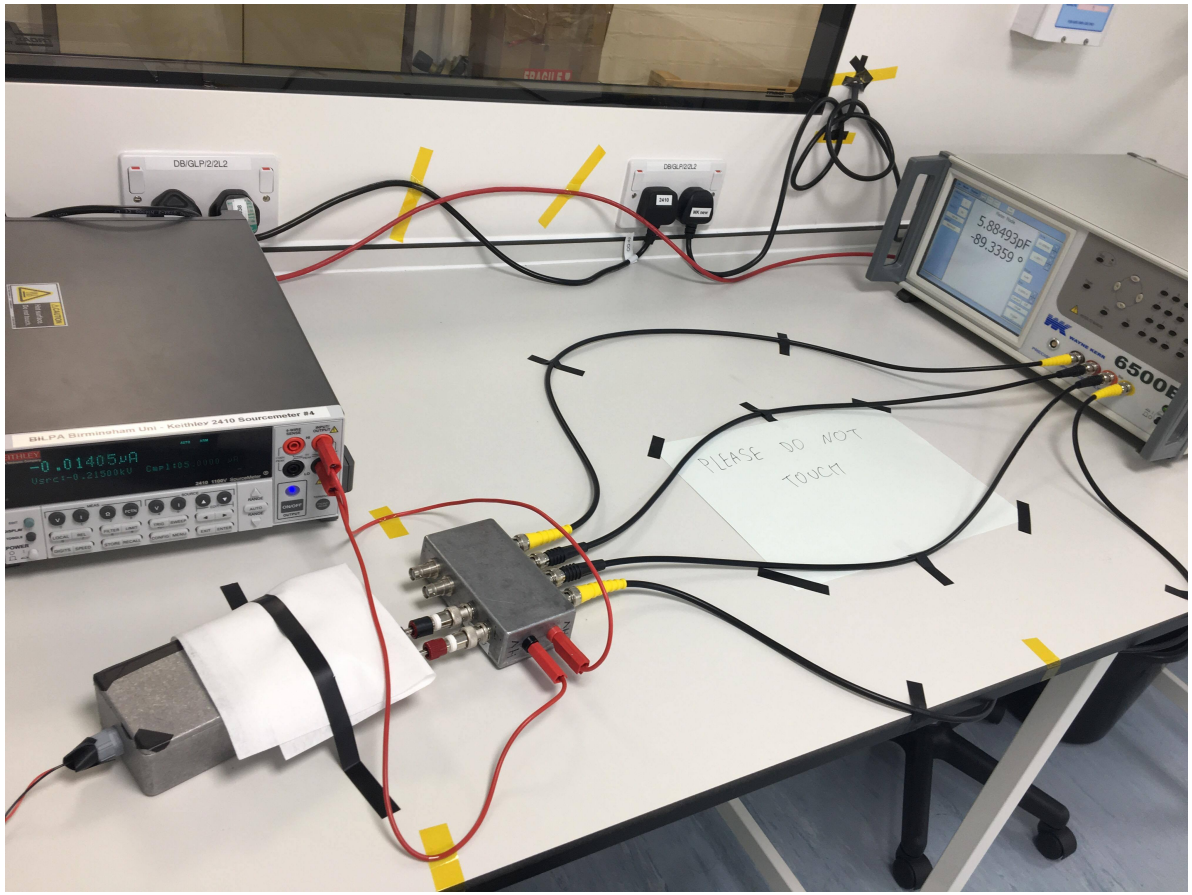
$$C = \frac{f\sqrt{\epsilon_{Si}\epsilon_0}}{\sqrt{V}}$$

- 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

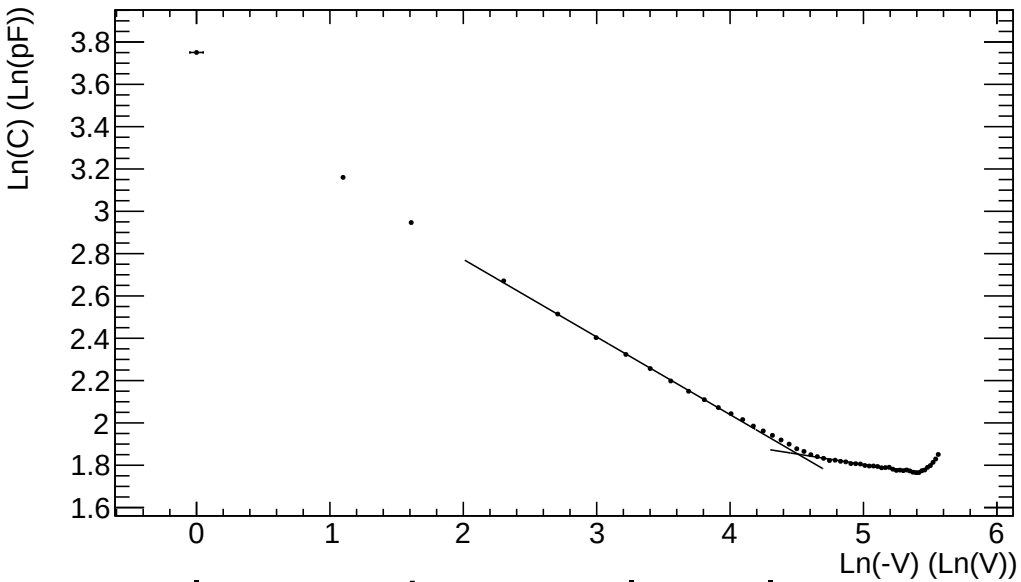


Experimental setup for C–V measurements.

C–V Measurements

Calculating Maximum Depletion Voltage

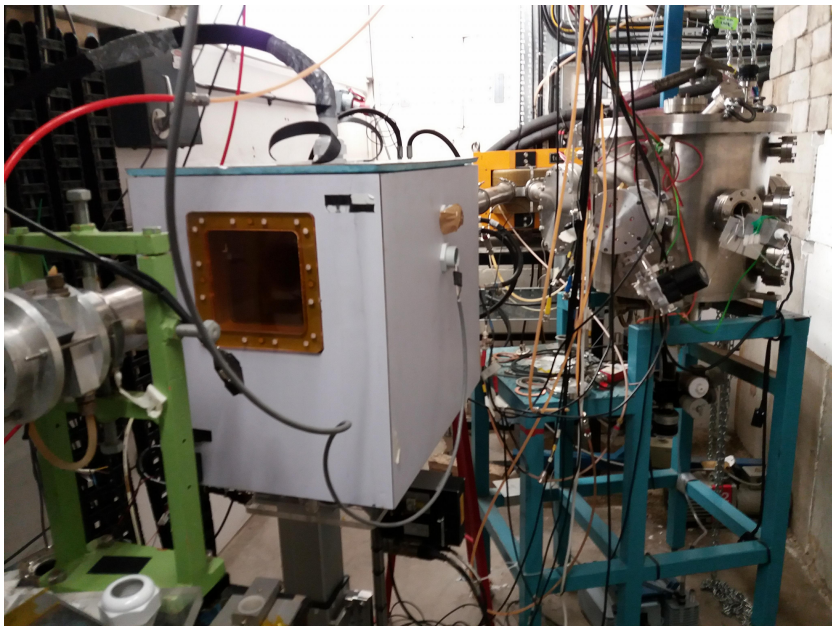
- By calculating the **intersect** of the two fits, the point at which the trend deviates from a straight line could be calculated.
- Applying this method, a maximum depletion voltage value of $\boldsymbol{V_{dep} = -90.8 \pm 5.1\ \mathbf{V}}$ was inferred.



log capacitance vs log voltage.

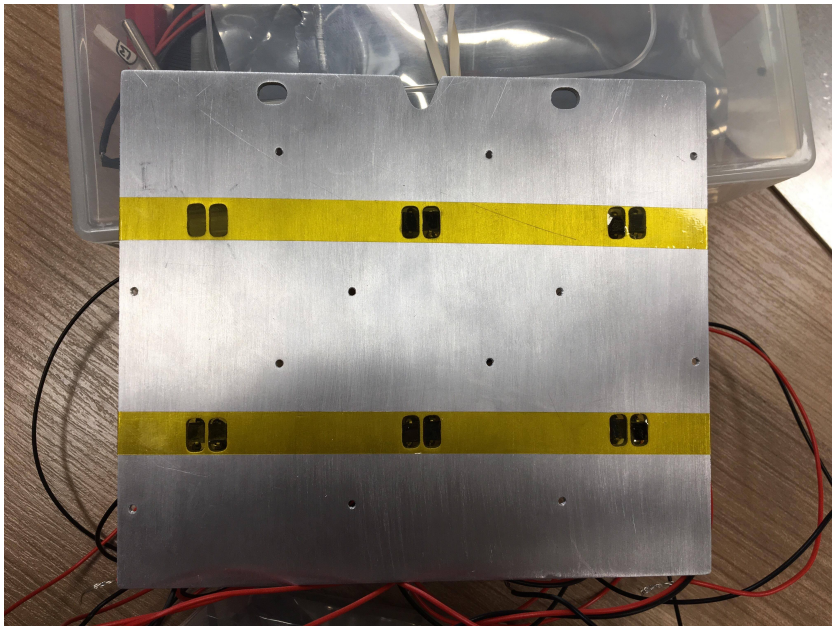
Proton Irradiations

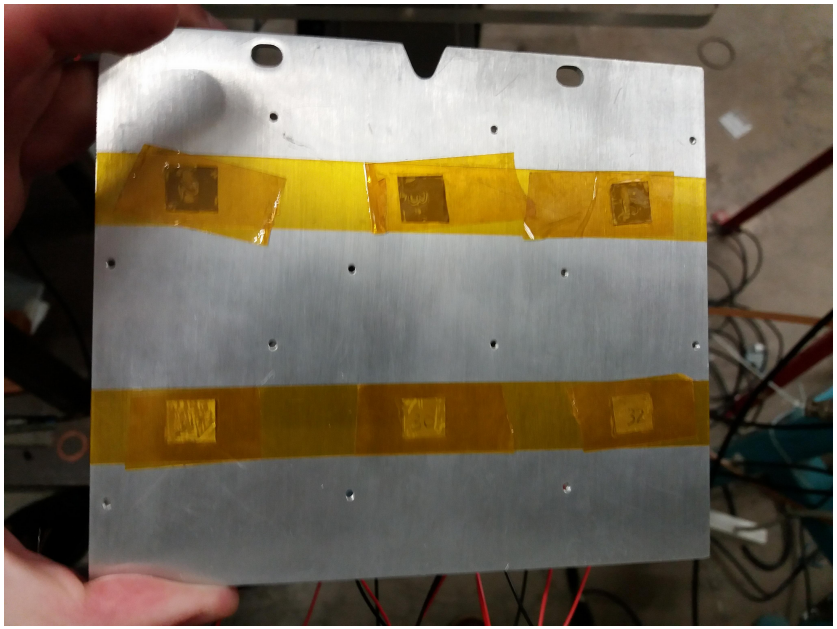
ATLAS Chamber



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.

Computing Hardness Factors

Leakage Current Variation with 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]:

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

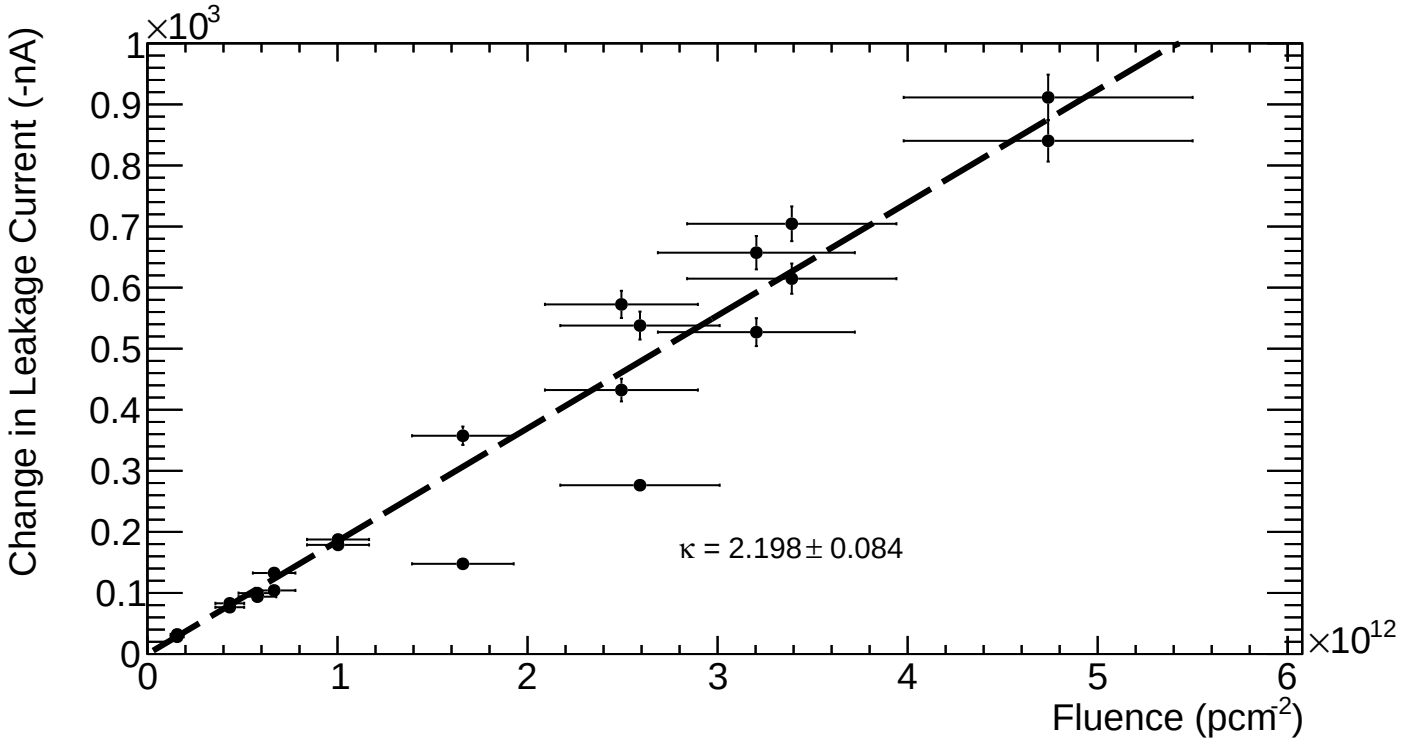
- The **hardness factor** can be written as:

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

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

Results

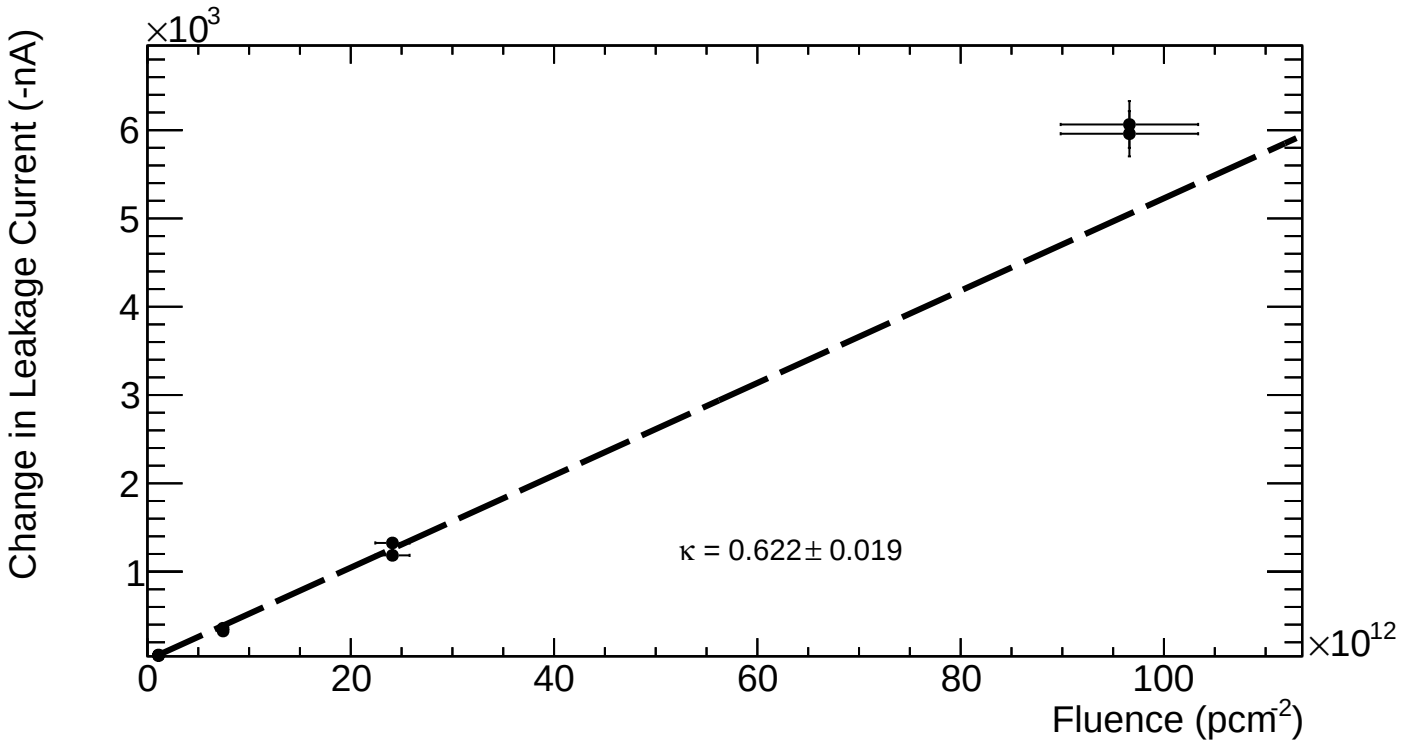
Hardness Factor of the MC40 Cyclotron



From this, a value of $\kappa_{MC40} = \mathbf{2.198 \pm 0.084}$ for **25 MeV protons** was inferred. These data were obtained with BPW34F photodiodes.

Results

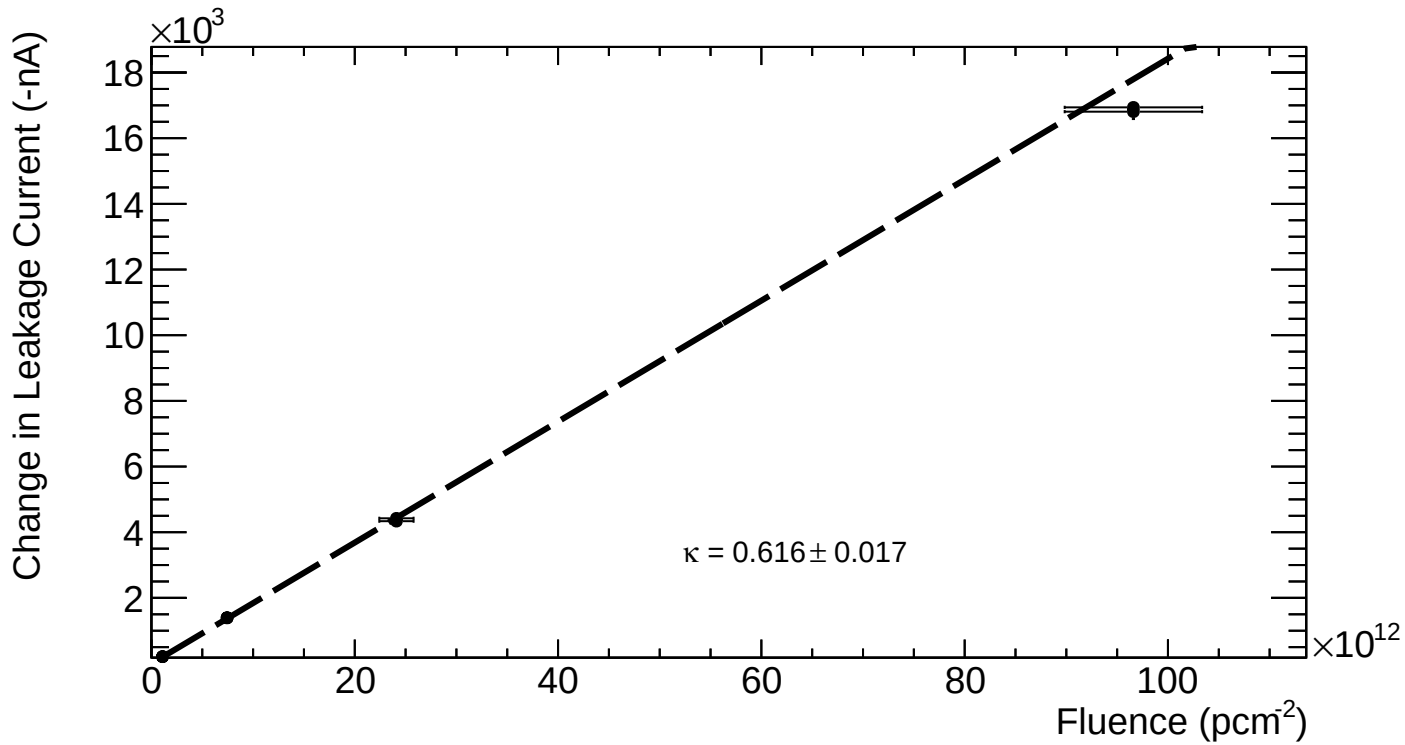
Hardness Factor of the IRRAD Proton Facility



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. These data were also obtained with BPW34F photodiodes.

Results

Hardness Factor of the IRRAD Proton Facility - Comparison with I. Mateu's Data

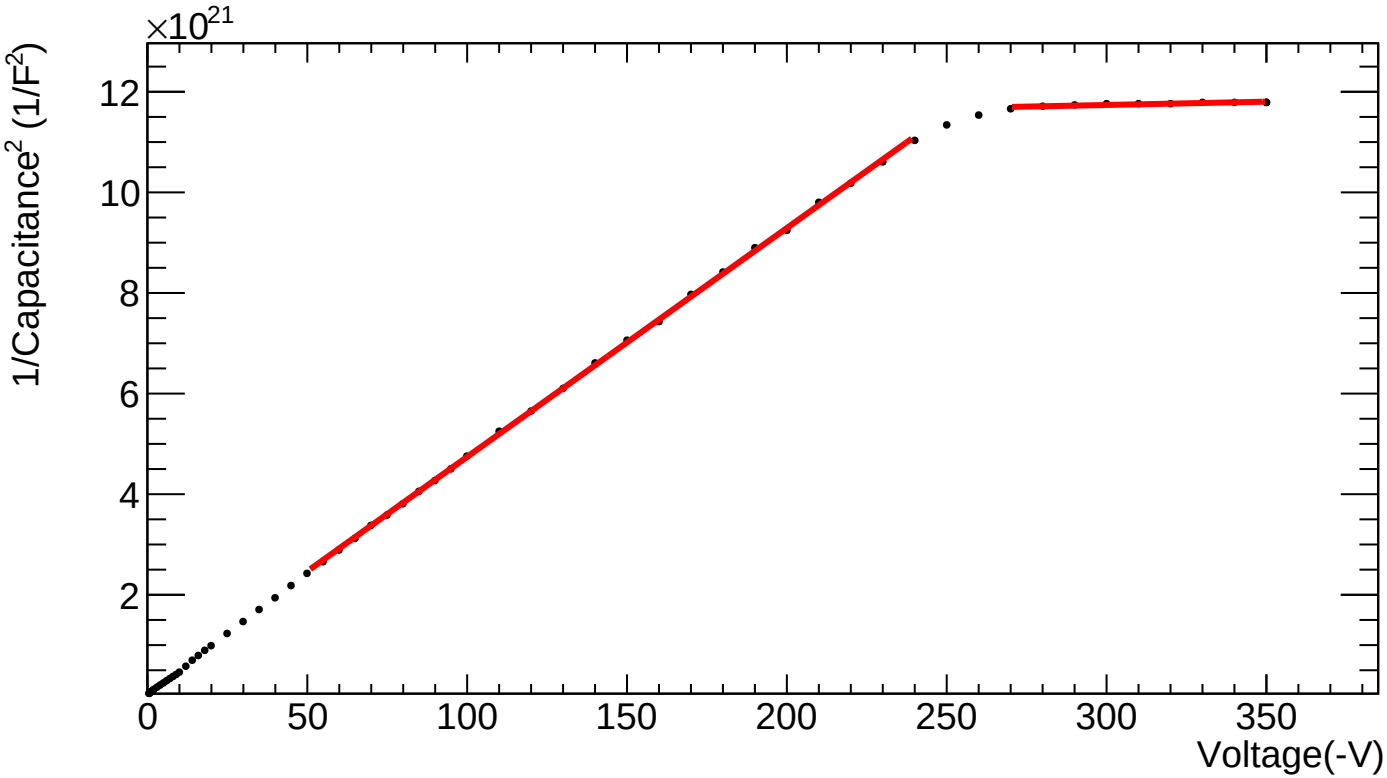


Analysis of I. Mateu's data yields a value of $\kappa_{Mateu} = \mathbf{0.616 \pm 0.017}$, which is in agreement with his own analysis (0.632) and our result. These data were obtained with FZ pad diodes.

Results

Hardness Factor of the IRRAD Proton Facility - Comparison with I. Mateu's Data

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.

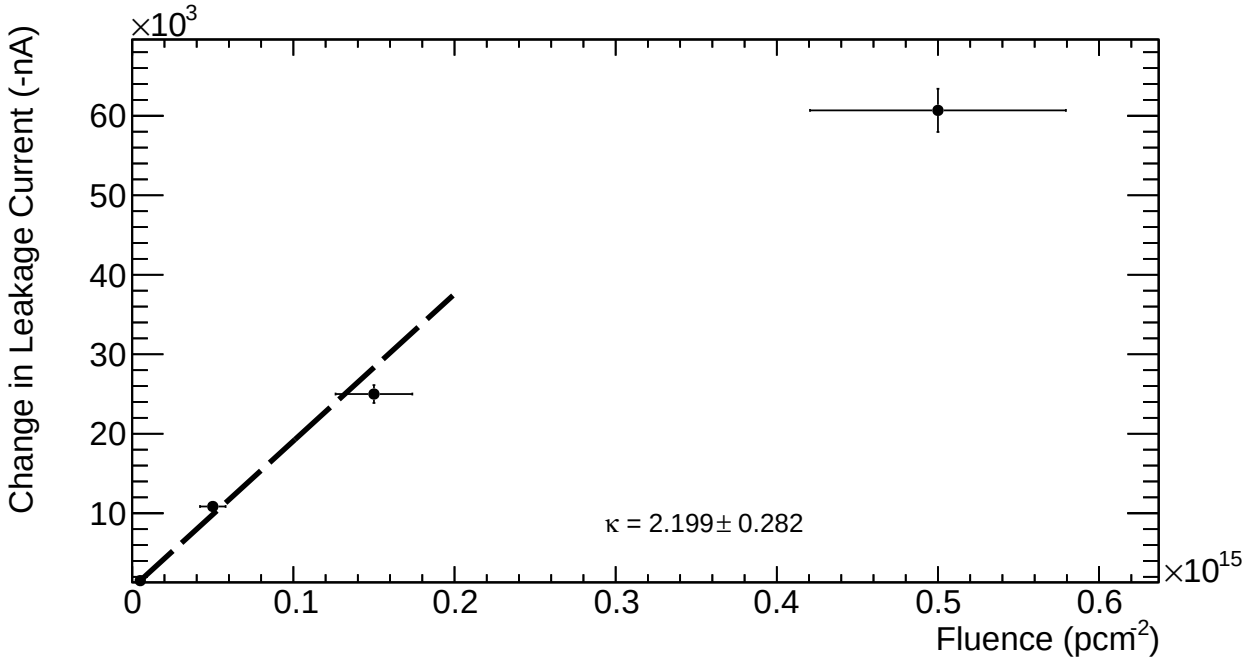
Results

Hardness Factor of the IRRAD Proton Facility - Comparison with I. Mateu's Data

Sensor Name	Max. Dep. Voltage (-V)	Fluence (p/cm^2)
W332-C4	250 ± 2	7.44×10^{12}
W332-F2	83 ± 2	9.66×10^{13}
W332-F8	191 ± 7	2.41×10^{13}
W332-M10	281 ± 3	1.09×10^{12}
W332-M12	81 ± 1	9.66×10^{13}
W332-M4	282 ± 4	1.09×10^{12}
W332-M6	207 ± 9	2.41×10^{13}
W332-M7	252 ± 2	7.44×10^{12}

Table: Obtained maximum depletion voltages for I. Mateu's data.

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**. These data were obtained with BPW34F photodiodes.

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.


RD50. Mar. 2018. URL: http://rd50.web.cern.ch/rd50/.

References II

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.

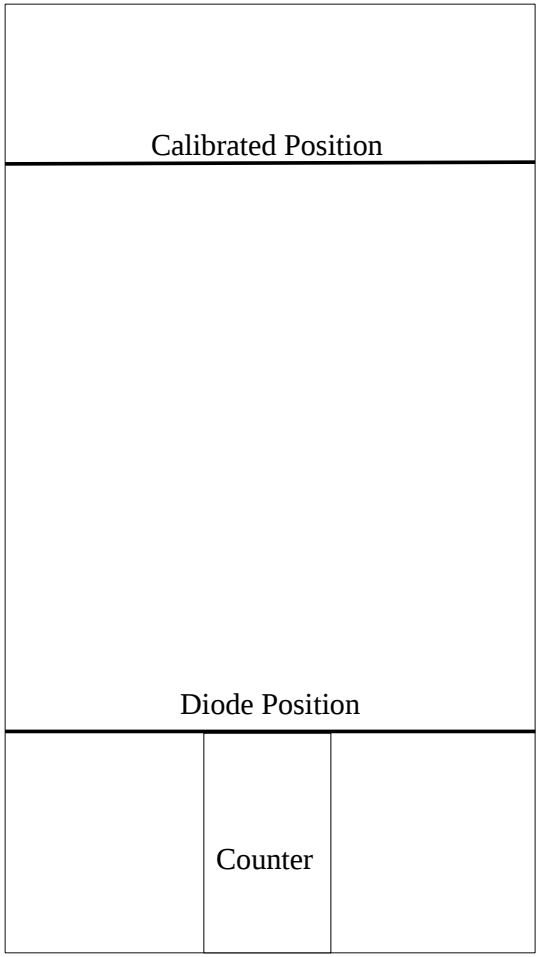
M. Moll. "Radiation Damage in Silicon Particle Detectors". PhD thesis. University of Hamburg, 1999.

References III

F. Ravotti et al. "BPW34 commercial p-i-n diodes for high-level 1-MeV neutron equivalent fluence monitoring". In: *2007 9th European Conference on Radiation and Its Effects on Components and Systems*. 2007, pp. 1–8. DOI: 10.1109/RADECS.2007.5205483.

Extra Slides

Fluence Determination

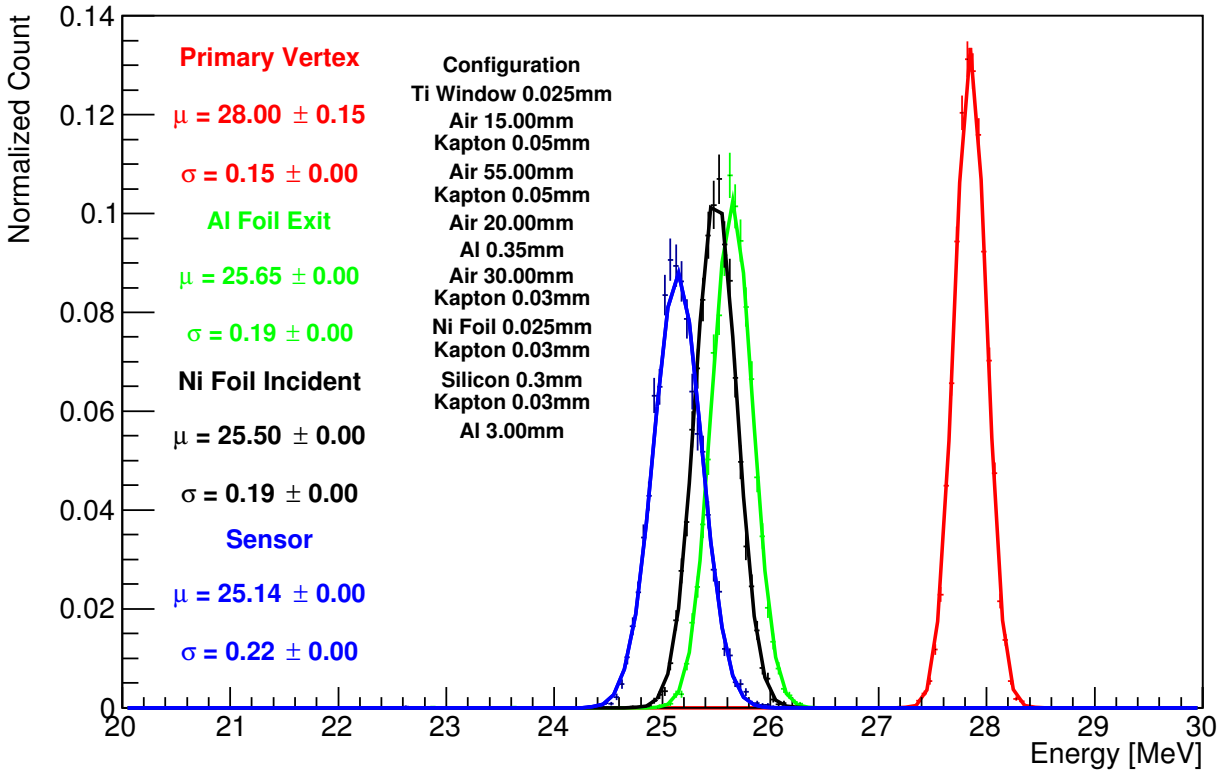


Schematic diagram of germanium counter.

- 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**.

Extra Slides

Beam Energy Determination



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