UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

WP 11.5: University of Birmingham MC40 Cyclotron

Laura Gonella (on behalf of the UK irradiation team)

AIDA-2020 3rd Annual Meeting, Bologna

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The UK irradiation team

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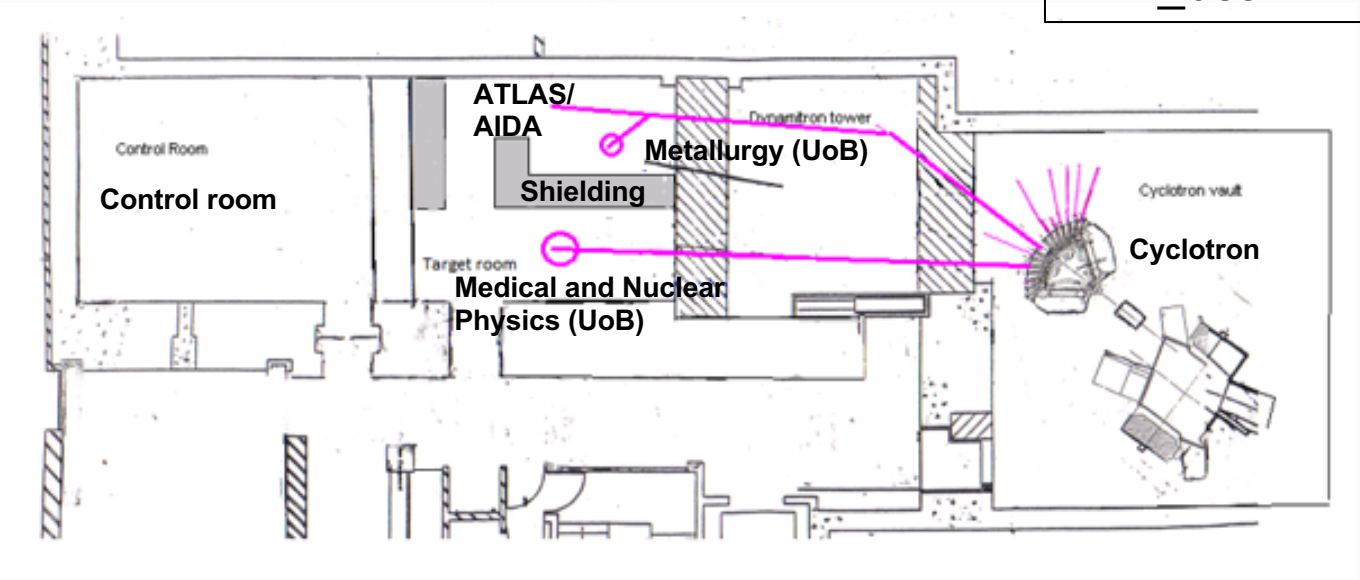
Introduction

- The MC40 cyclotron at the University of Birmingham is primarily used for radio-isotope production for mainly medical applications
  - Proton energies up to 40 MeV possible at extraction
  - Currents ranging from pA to μA
- A high intensity irradiation line was commissioned for particle physics in early 2013 and has irradiated over 300 samples
  - Established through STFC support for UK ATLAS Upgrade
  - AIDA-2020 Transnational Access Facility as “Remote Scientific Service”

Irradiation Facility

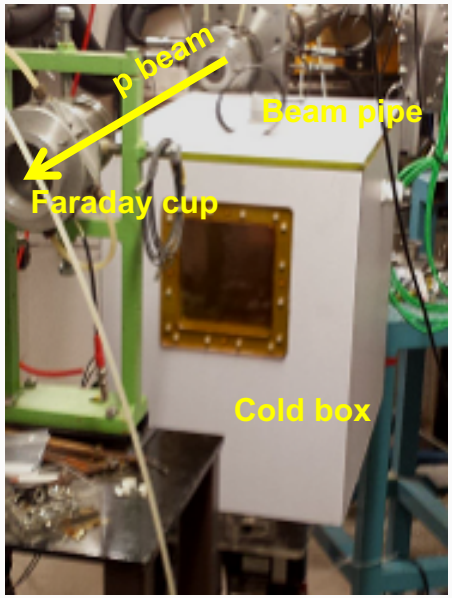
- Proton current: up to 2μA (cooling permitting)
- Beam spot: **10mm × 10mm** via collimation
- Flux: up to 10^{13} protons/s/cm^2

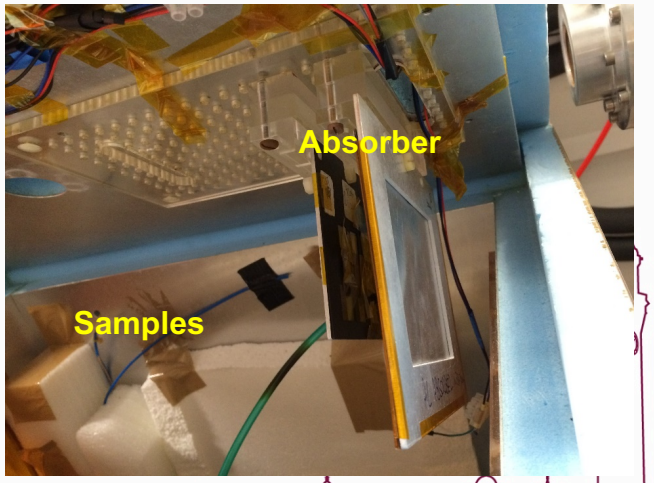
Typically:
E_beam= 28MeV
I_beam = 0.1-0.4μA



Irradiation setup

- **XY-axis scanning system** allows areas of 15cm × 15cm (orthogonal) to be uniformly irradiated
- **Liquid nitrogen evaporative cooling** system ('Norhof LN2')
  - Typ. T = -27°C during irradiation
- **Dry N2** is used to keep low humidity.
  - Typ. RH = ≤10% during irradiation
- Sealed feed-through allow external read-out and monitoring during irradiation
- Samples are suspended from the lid in the box
- 0.3mm aluminum absorber in front of samples used to remove low energy component
- **Faraday cup** after the cold box used to measure beam current

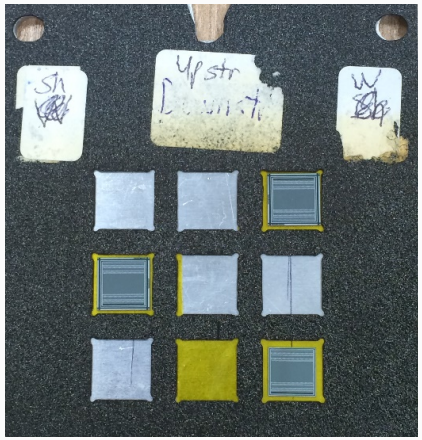




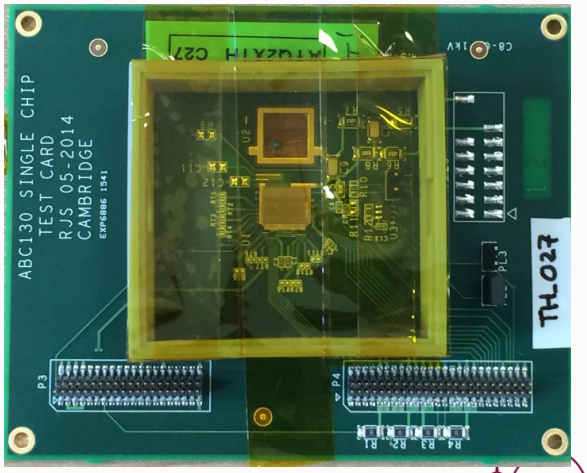
Samples preparation

- Carbon fiber frames are available to predetermined dimensions to fit bare sensors
  - Sensors are held in place with kapton tape
- For ASICs/sensors on PCB a 3D printed frame is used to protect the wire bonds
- Carbon frame with sensors/PCBs fixed to Al-frame which can be fixed to the lid of the box
- **Nickel foils** cut to appropriate areas are placed in front of the sample to determine the fluence

Example:
ATLAS12 mini strip sensors



Example:
ABC130 chip on PCB

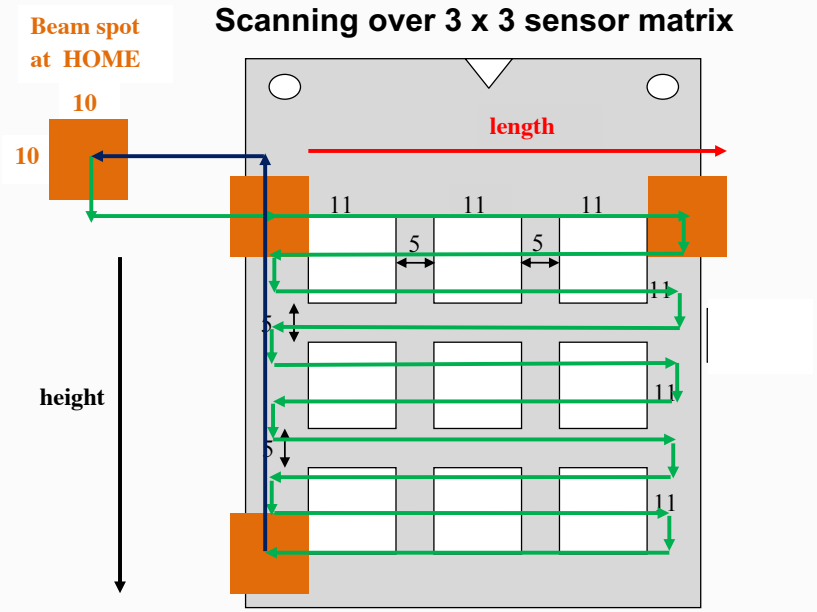


Irradiation modes

- **Scanning** irradiation
  - Sample equal or larger in area than the beam
  - User specified scan path to ensure uniform irradiation
  - Typ. samples are scanned in 2.5mm spaced rows at an horizontal speed of 4mm/s
  - Max current = 400 nA

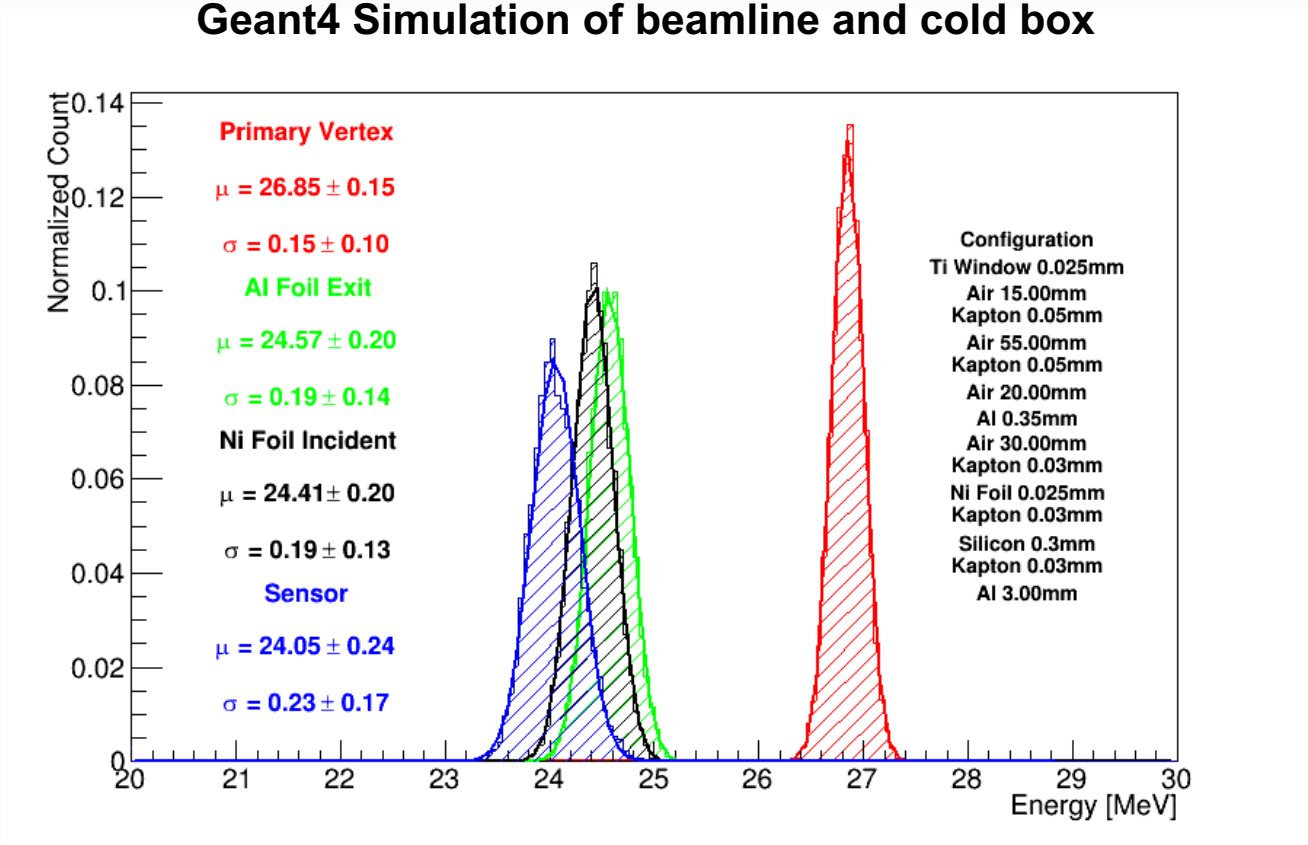
- **Point-to-point** irradiation
  - Sample smaller than the beam
  - Fixed beam position
  - More sensitive to beam non-uniformity
  - Max current = 100 nA

Example:
Scanning over 3 x 3 sensor matrix



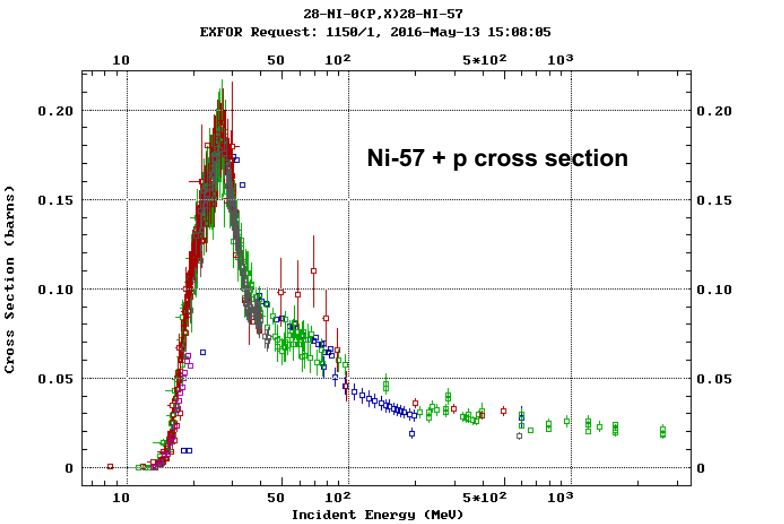
- **Gafchromic film** is used before irradiation to measure the beam position and profile to set the scan parameters/beam position on sample

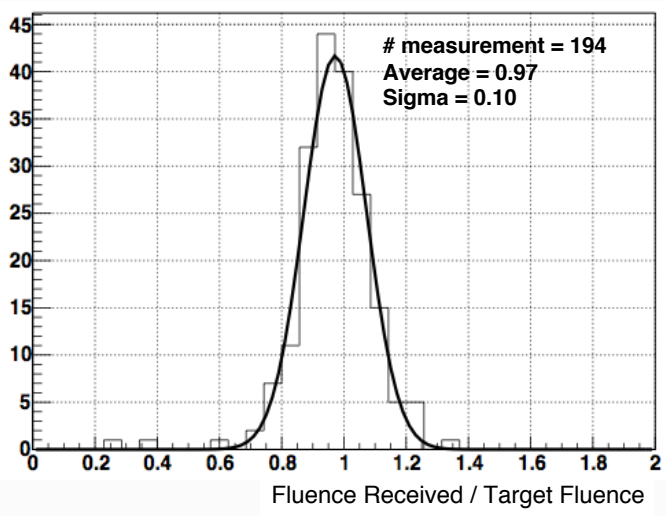
Beam Energy at Target



Dosimetry

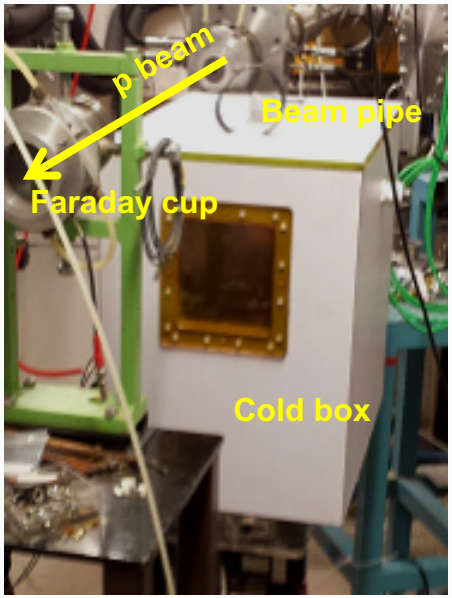
- The fluence is measured using **Ni foils** placed in front of the sample
- The activity of the Ni-57 isotope is measured with a germanium spectrometer
- Intensity of 1377keV peak + cross section for production of Ni-57 = **number of incident protons**
- Measured and target fluence **agree within 10%**





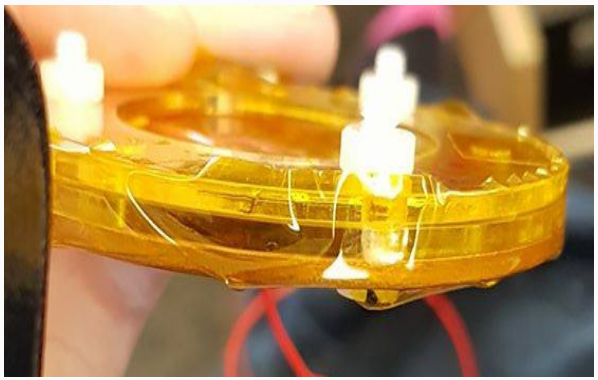
Improved current monitoring

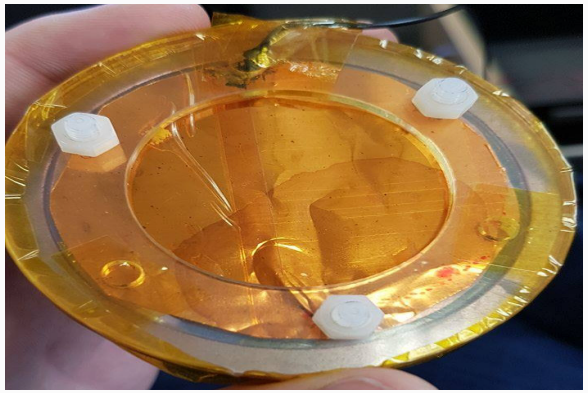
- Proton current monitored whilst irradiating on faraday cup downstream of cold box
  - Passive material causes scattering and beam loss
  - Different factor required for every new irradiation set-up
- Work currently underway to monitor the beam during irradiations before the sample using an **ionization chamber** placed right after the beam collimator

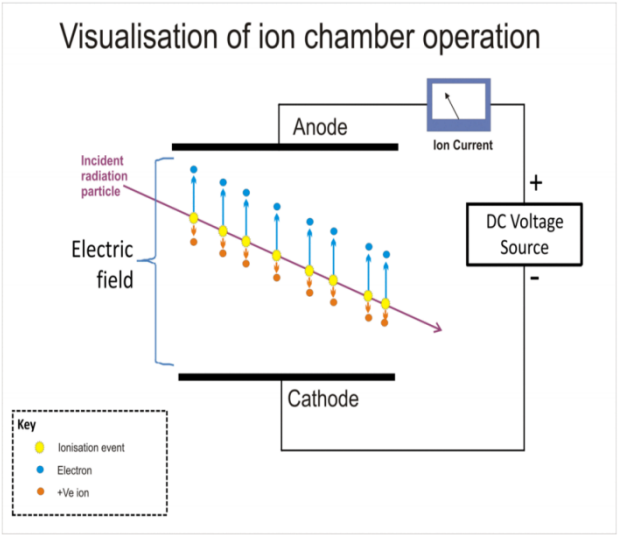


Ionization chamber

- Uniform surface will not introduce non uniformities to the beam
- Made of 2 Cu sheets separated by 2mm
- Cu guard ring to reduce leakage current from the atmosphere
- A voltage is placed across the 2 sheets and the current across them is measured.
- A proton at 28MeV is predicted to ionise 126 electron/ion pairs over 2mm. Hence for every nA of beam current we expect to measure 126nA current
- The current is readout to a computer via an arduino measuring the voltage across a resistor of known value

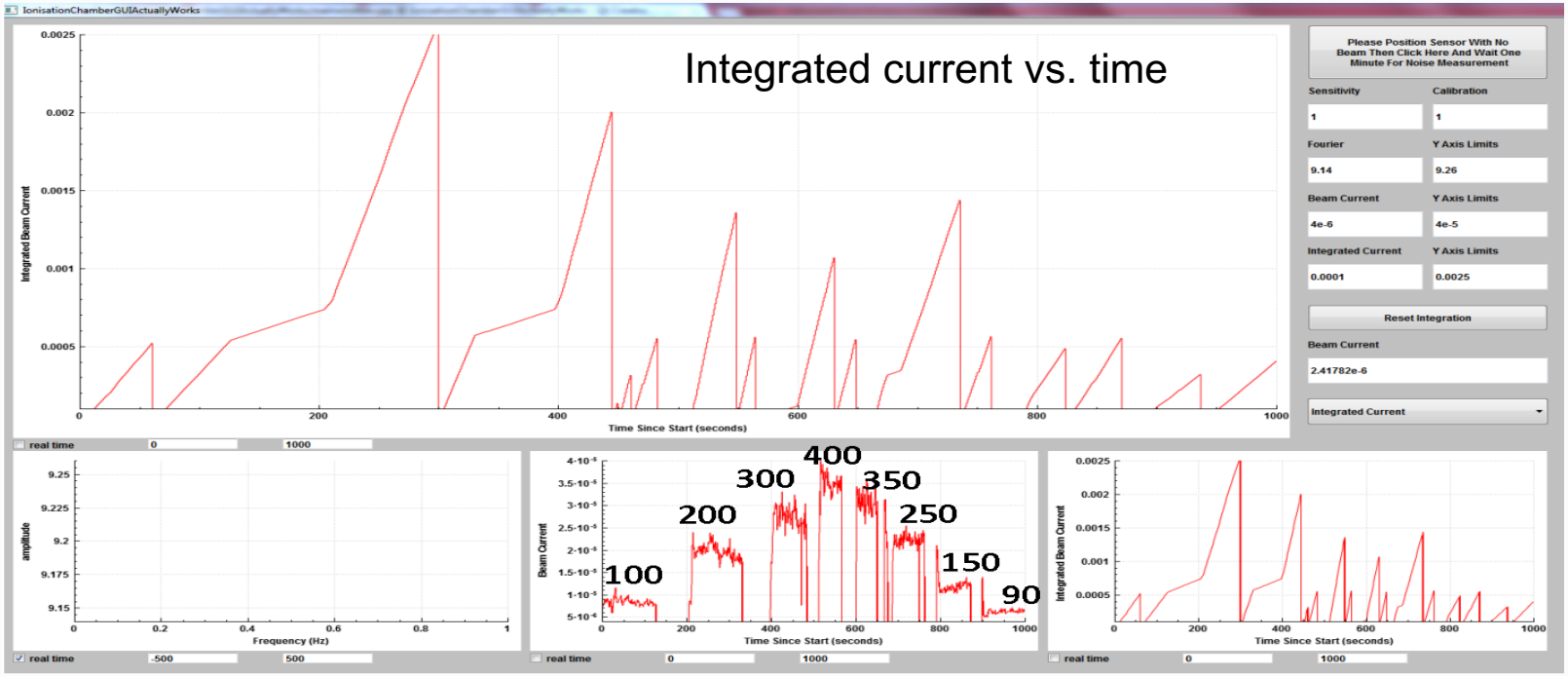






Preliminary tests

- Test run at the cyclotron running at various currents
- Current monitoring GUI (under development)

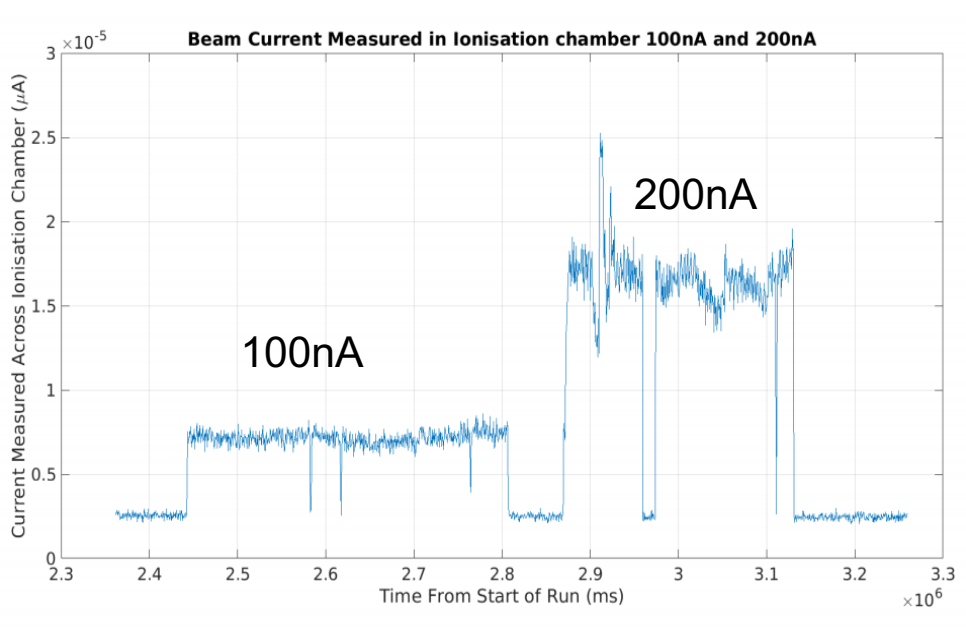


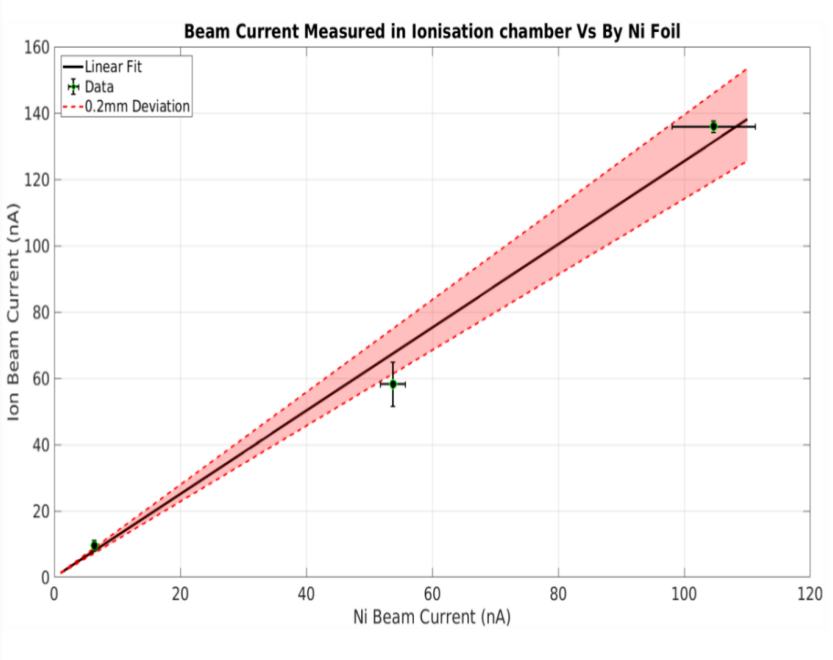
Beam current vs. time

Integrated current vs. time

Preliminary tests

- Beam current measured from the ionization chamber as a function of time
  - Fluctuations in beam current due to RF instability

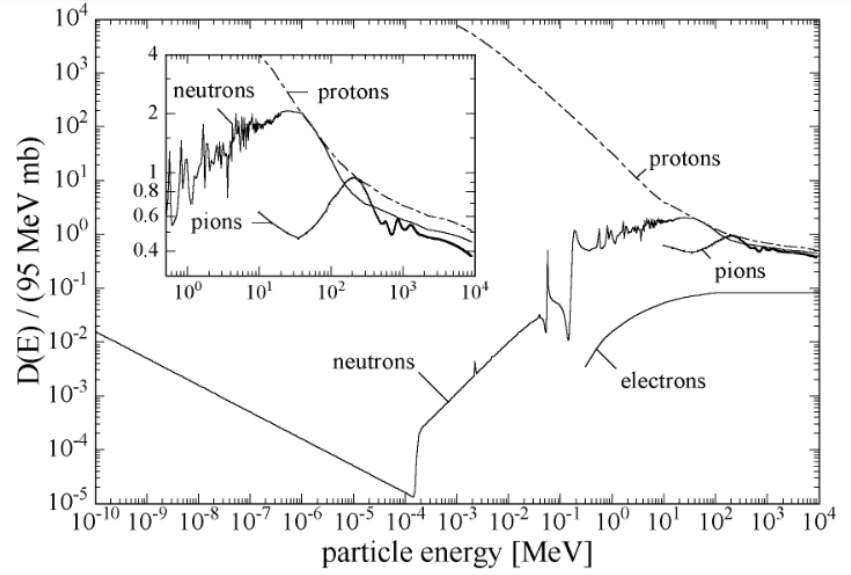




- Calibration of current measured with ionization chamber and nickel foils for three different beam currents

Hardness Factor Measurements

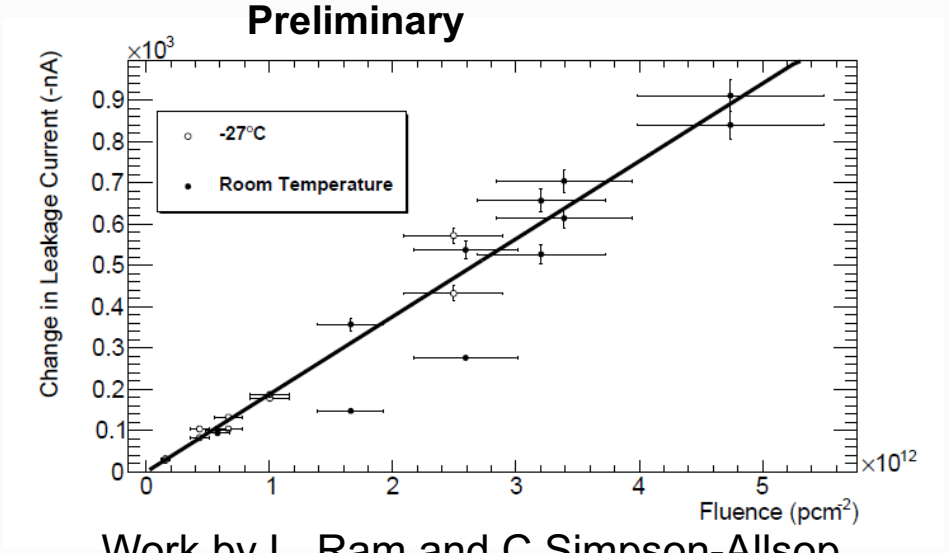
- The hardness factor we currently use for our protons is **2.2**
- However, different values can be found in the literature for our energy range
  - KIT: k = 2
  - Tables from RD50: k = ~2.58
  - M. Moll reported k = 1.85 for 26 MeV protons in 2014
- Student project to evaluate our hardness factor experimentally using BPW34F photodiodes



M. Moll, Radiation Damage in Silicon Particle detectors, PhD thesis

Hardness Factor Measurements

- Irradiated BPW34F diodes up to 5×10^{12} protons/cm^2 as measured on Ni foils
- Irradiations at -27C and room temperature following guidelines at the UoB ATLAS irradiation facility
- Diodes annealed for 80 minutes @ 60C following RD50 guidelines
- Leakage current measured at full depletion of -91V for each diode
- $\alpha_p = (8.93 \pm 0.34) \times 10^{-17}$ A/cm
- $\alpha_{1MeV} = 3.99 \times 10^{-17}$ A/cm
- **$\kappa = 2.24 \pm 0.09$ for 25 MeV protons incident on BPW34F silicon**

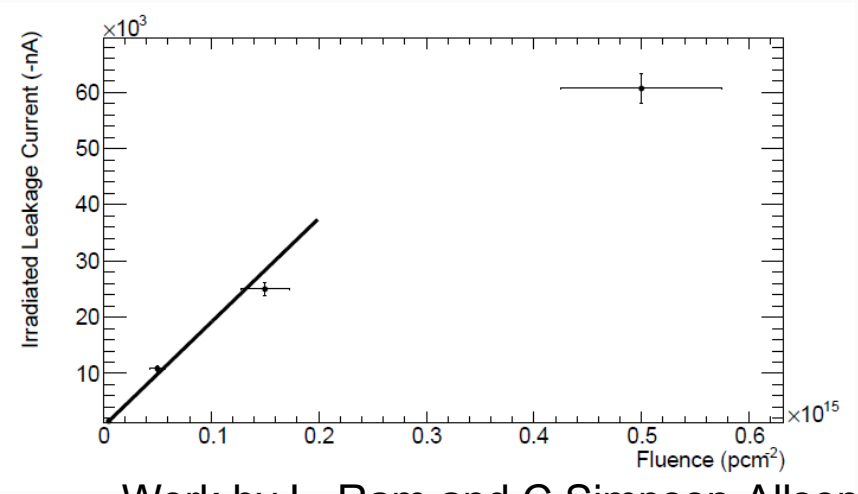


Work by L. Ram and C Simpson-Allsop

Hardness Factor Measurements - KIT

- Irradiated BPW34FS diodes up to $5x10^{14}$ p/cm^2 at the KIT facility
- Fit to $1.5x10^{14}$ p/cm^2 due to non-linearity of BPW34F at these fluence
- Analysis performed following the same procedure as the UoB diodes
- $\alpha_p = (8.77 \pm 1.06) \times 10^{-17}$ A/cm
- $\alpha_{1MeV} = 3.99 \times 10^{-17}$ A/cm
- **$\kappa = 2.20 \pm 0.27$ for 23 MeV protons**

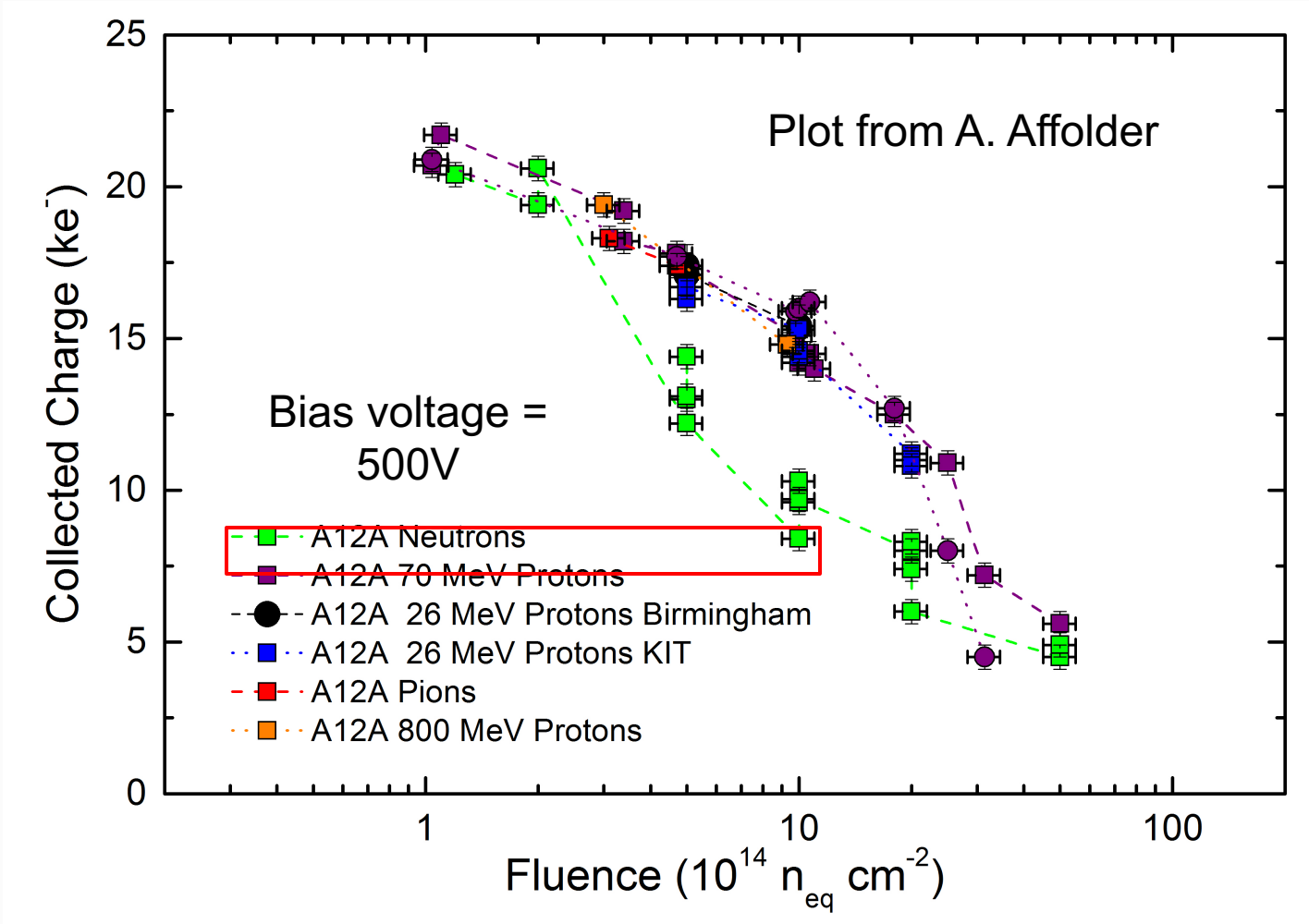
Preliminary



Work by L. Ram and C Simpson-Allsop

Comparison with other facilities

- Using ITk strip mini sensors



UoB

- No. of projects

No. of projects M1-M18	No. of projects M1-M24	No. of projects M1-M28	No. of projects M1-M36*
6	8	11	12

- No. of users

No. of users M1-M18	No. of users M1-M24	No. of users M1-M28	No. of users M1-M36*
19	26	40	43

- No. of access units

No. of access units M1-M18	No. of access units M1-M24	No. of access units M1-M28	No. of access units M1-M36*
104	143.5	197	230.5

* Two projects still missing, paperwork ongoing