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The University Of Sheffield.

The Birmingham irradiation facility

Laura Gonella on behalf of the UK irradiation team

RD50 workshop, Torino

07/06/2106

AIDA 2020

Outline

- Overview of the irradiation facility
- Results from sensors irradiations
- Dosimetry
- Ongoing and future irradiation program
- Conclusion

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Introduction

- The **MC40 cyclotron** at the University of Birmingham is primarily used for radio-isotope production for mainly medical applications
- It was commissioned as an irradiation facility for particle physics in early 2013 and has irradiated around 300 samples in total
- Joint activity by the **Universities of Birmingham, Liverpool and Sheffield** through STFC support for UK ATLAS Upgrade
- The Birmingham Irradiation facility is an **AIDA-2020 Transnational Access** Facility

The UK irradiation team

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The University Of Sheffield.

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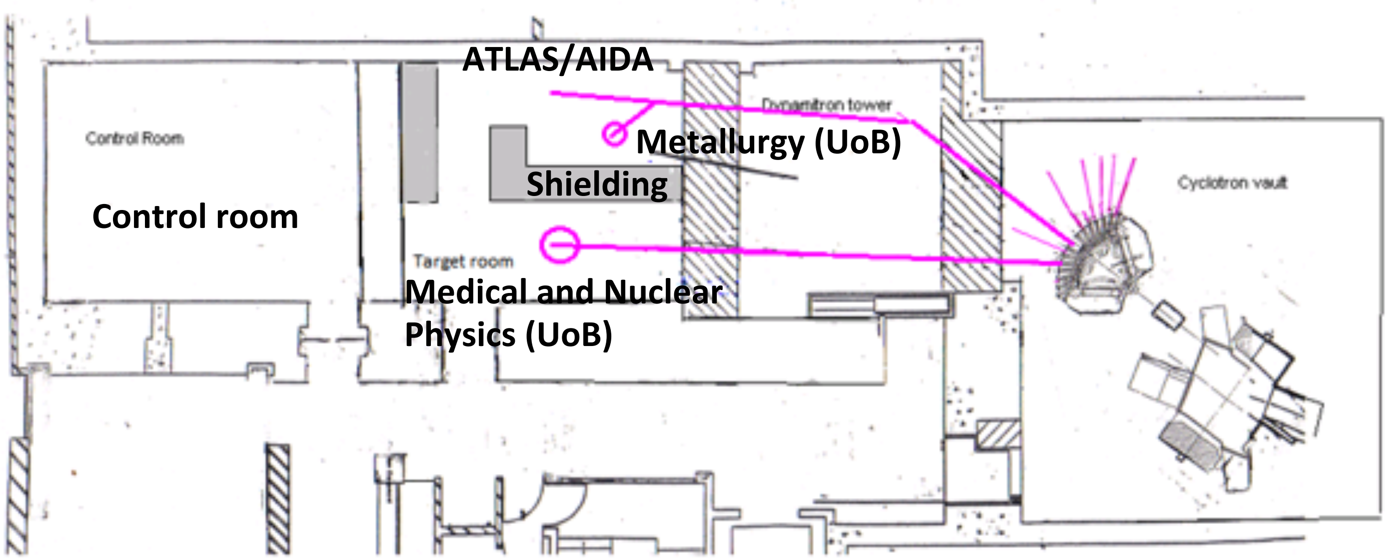
Irradiation facility

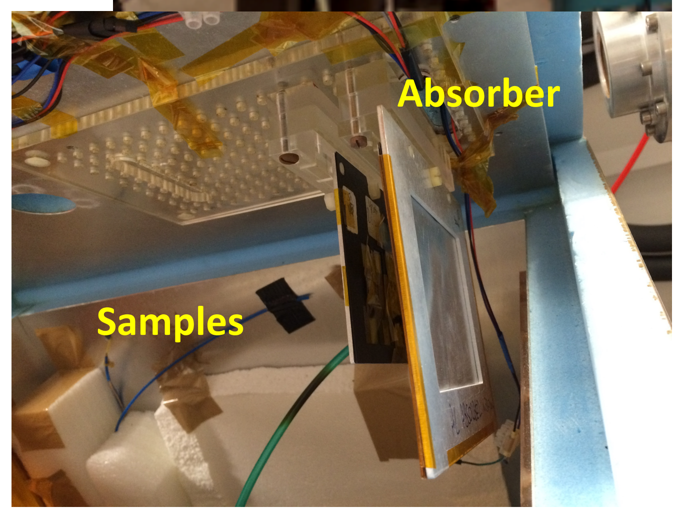
- Proton energy at extraction: up to 40MeV
- Proton current: up to 2μA (cooling permitting)
- Beam spot: approx. **10mm × 10mm**
- Flux: up to 10^{13} protons/s/cm^2

Typically:
E_beam= **27MeV**
I_beam = **0.1-0.5μA**



Irradiation setup

- Temperature controlled box mounted on XY-axis (45cm×40cm) scanning system allows areas of 15cm×15cm (orthogonal) to be uniformly irradiated at low temperatures
- Liquid nitrogen evaporative cooling system ('Norhof LN2'). Typ. **T = -25ºC** 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 components
- **Faraday cup** used to measure beam current



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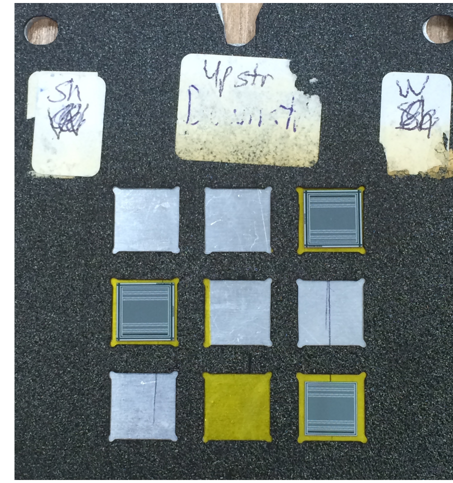
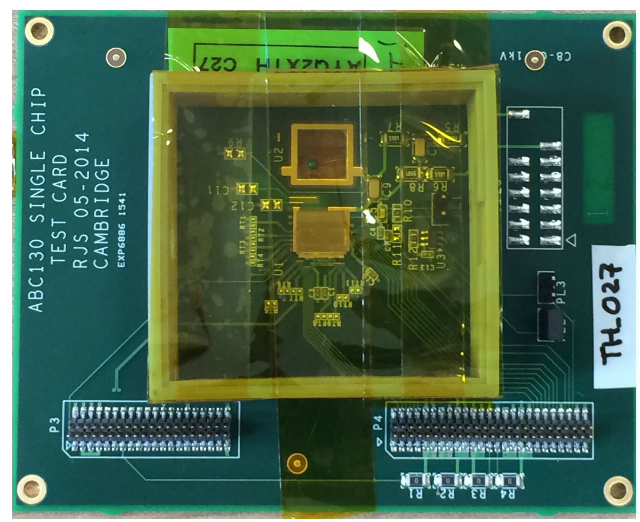
Samples preparation

- **Carbon fiber frames** are available to predetermined dimensions to fit bare sensors
- Sensors are held in place with kapton tape
- For ASICs 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

ATLAS12 mini sensors (strips)

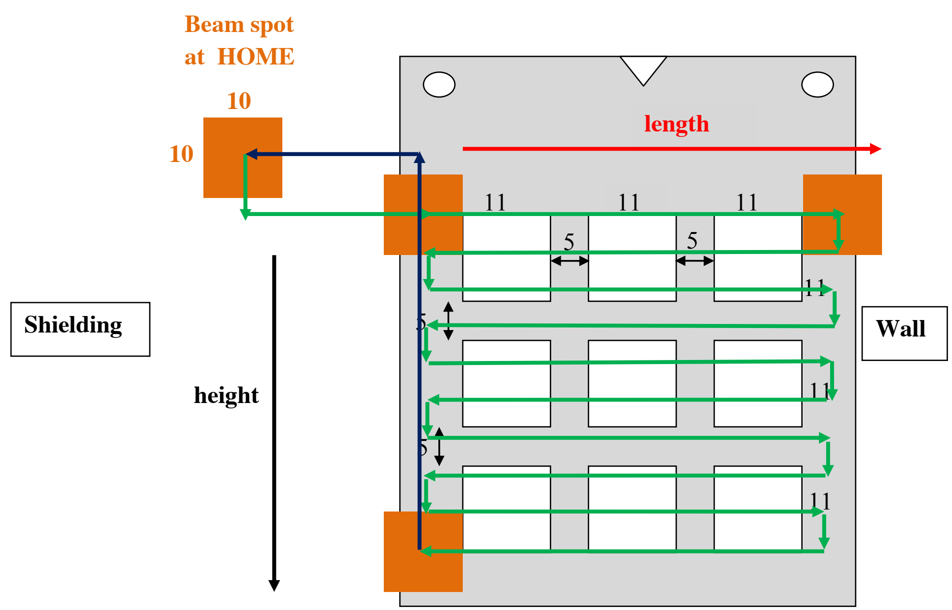


ABC130 chip on PCB



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 5mm spaced rows at an horizontal speed of 4mm/s
- **Point-to-point** irradiation
  - Sample smaller than the beam
  - Fixed beam position
  - More sensitive to beam non-uniformity



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

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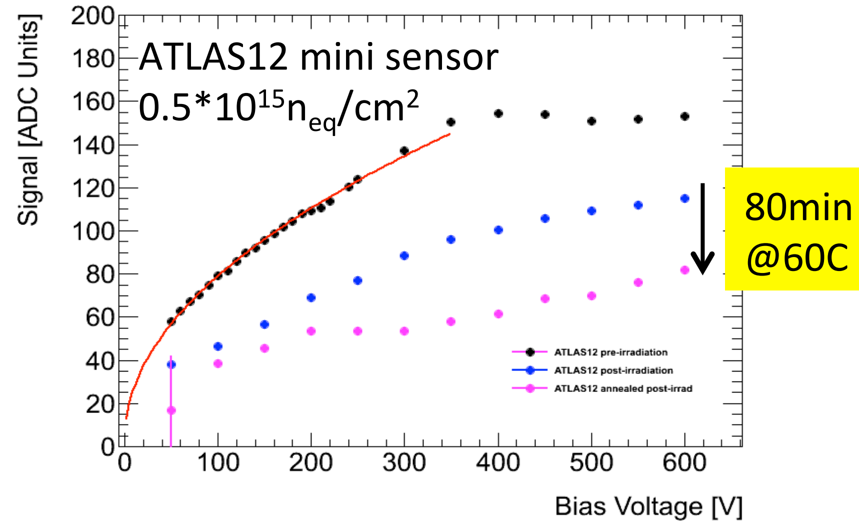
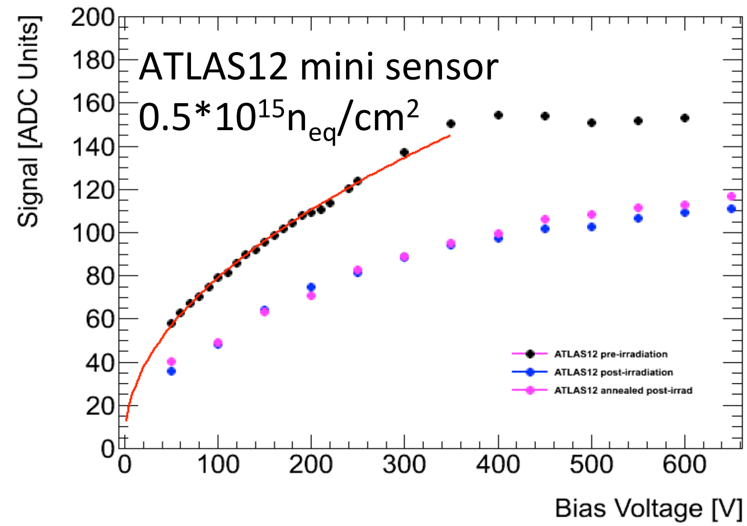
Early results and problems

- For many irradiation runs at the Birmingham cyclotron the **signal was seen to be anomalously low** compared to results at other facilities for the same fluence
- These irradiation samples also showed evidence of **broad clusters**
- Prague, Freiburg and Santa Cruz also reported **reduced inter-strip isolation** for sensors irradiated at Birmingham
- In some cases, **annealing tended to further reduce the signal**

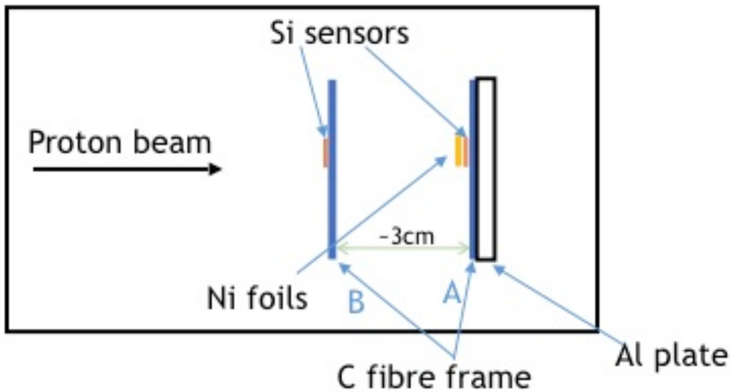
Pre-rad Irrad Annealed (80min@60°C)



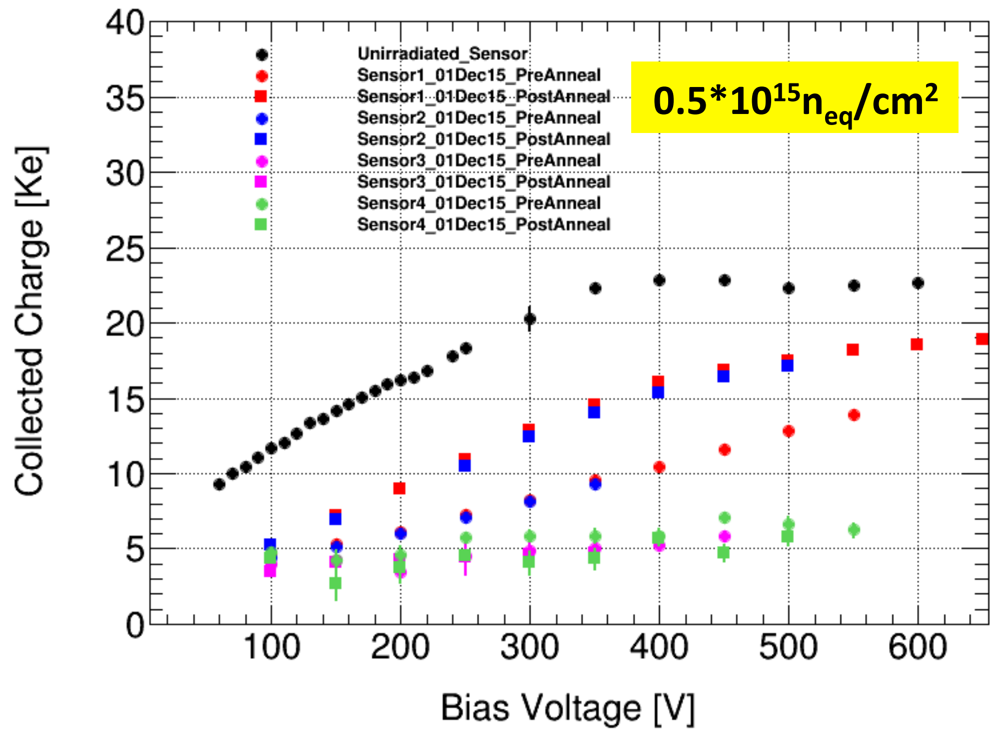


Investigations - I

Sketch of setup (Side view)



ATLAS12 mini sensors
Scanning mode irradiation, I = 100nA, v = 4mm/s



- Sensors downstream show results as expected
- They are behind 0.3mm of Si and the Ni foils

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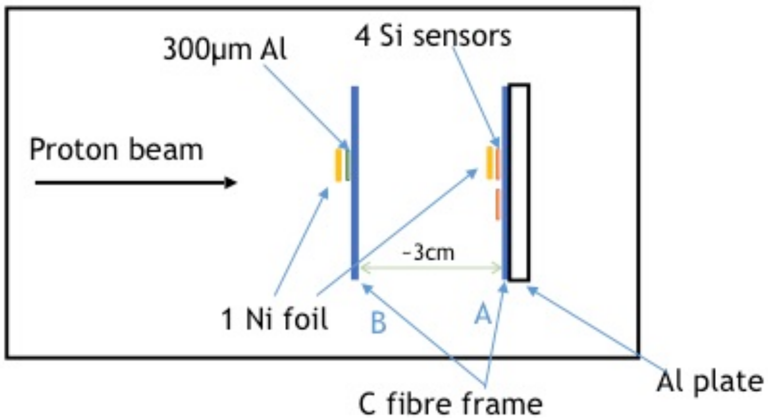
Investigations - II

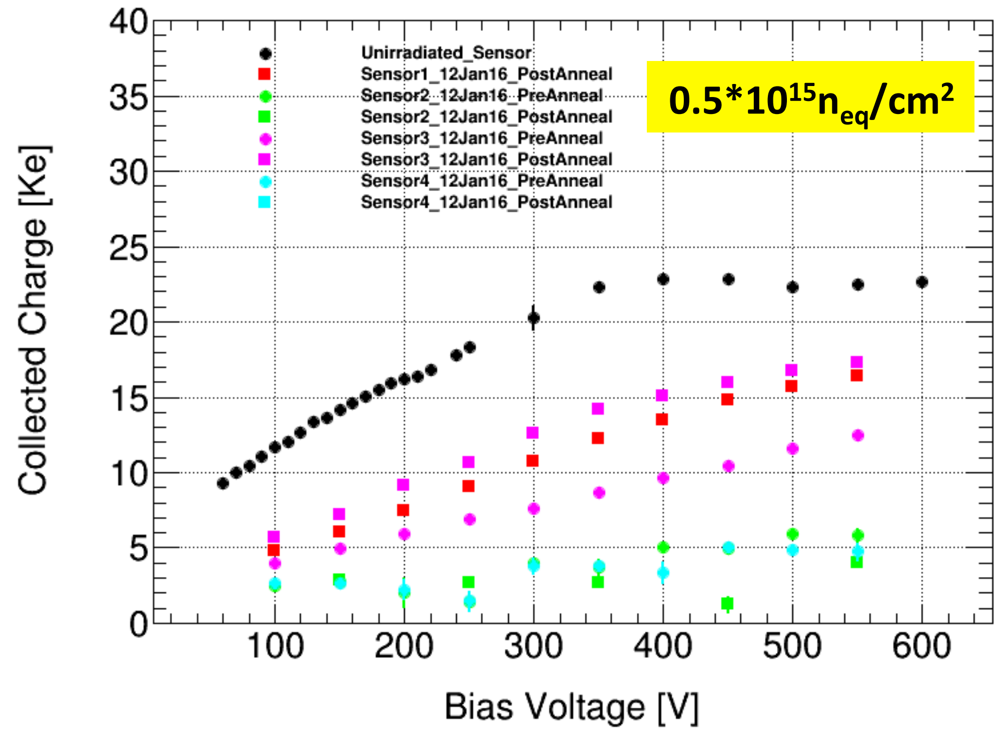
Sketch of setup (Side view)



Jan16	Sensor 1	Sensor 2	Sensor 3	Sensor 4
Kapton Enclosure	✓	✓	x	x
Ni Foils	✓	x	x	✓
300μm Al Absorber	✓	x	✓	x

ATLAS12 mini sensors

Scanning mode irradiation, I = 100nA, v = 4mm/s



- Sensors downstream (i.e. behind 0.3mm of Al) show good results
- Kapton enclosure and Ni foil make no significant difference

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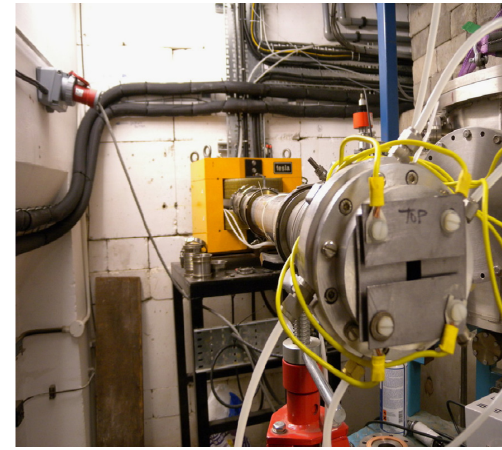
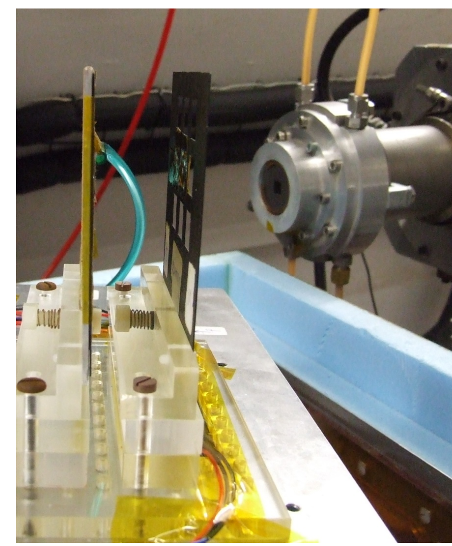
Conclusion on investigations



- Signals for sensors with 0.3mm Si/Al upstream during irradiation show good results

→ **Contamination in the beam possibly due to some low energy component**

- Consistent with 3-7MeV protons, but other particles are not excluded
- Possible source of these low energy components is at the interaction of the beam with the collimator
- A check of the collimator and a measurement of the Bragg peak close to the collimator are planned to try to get further insight into this
- From an operational point of view this means that we now run with a **0.3mm thick Al-absorber** in front of the samples to be irradiated



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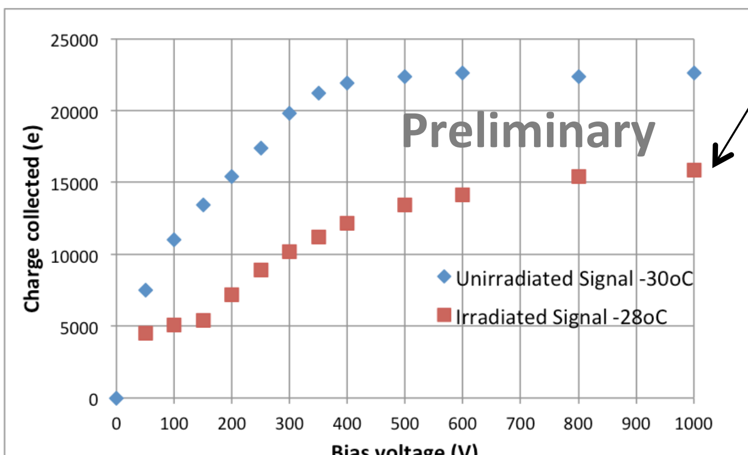
Recent results at $1.0*10^{15}\ n_{eq}/cm^2$

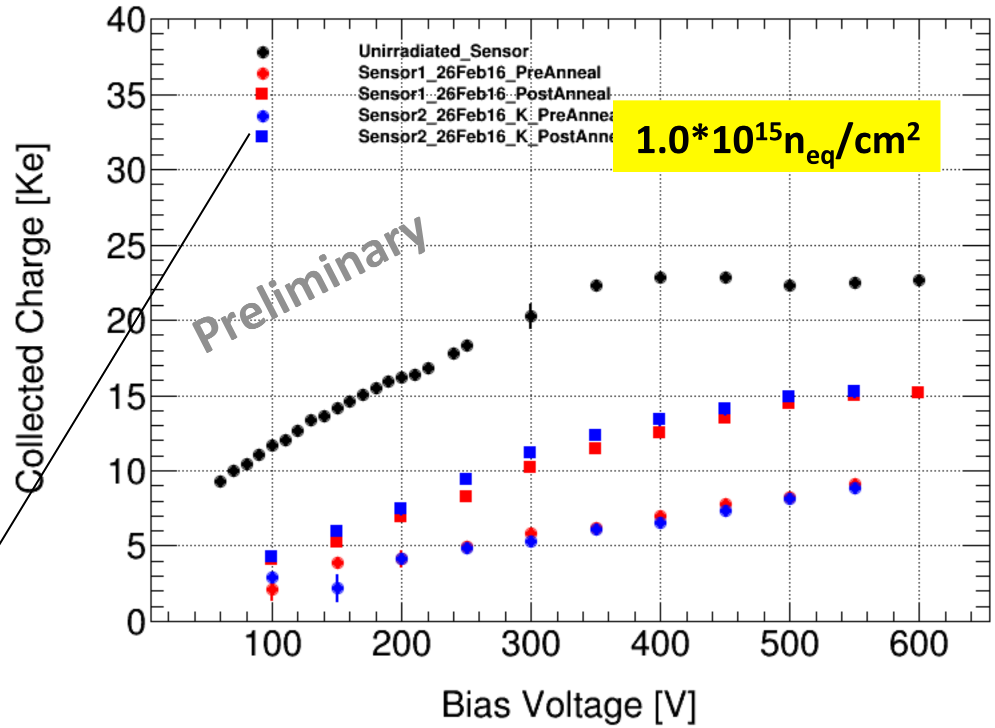
- Six sensors irradiated to $1.0*10^{15}\ n_{eq}/cm^2$
- Testing more irradiation parameters (current, speed, irradiation mode, …)
- Four more sensors to test
- Currently upgrading Alibava setup to reach HV = 1kV



ATLAS12 mini sensors

Red: Point-to-point mode, I = 100nA

Blue: Scanning mode, **I = 400nA**, v = 4mm/s



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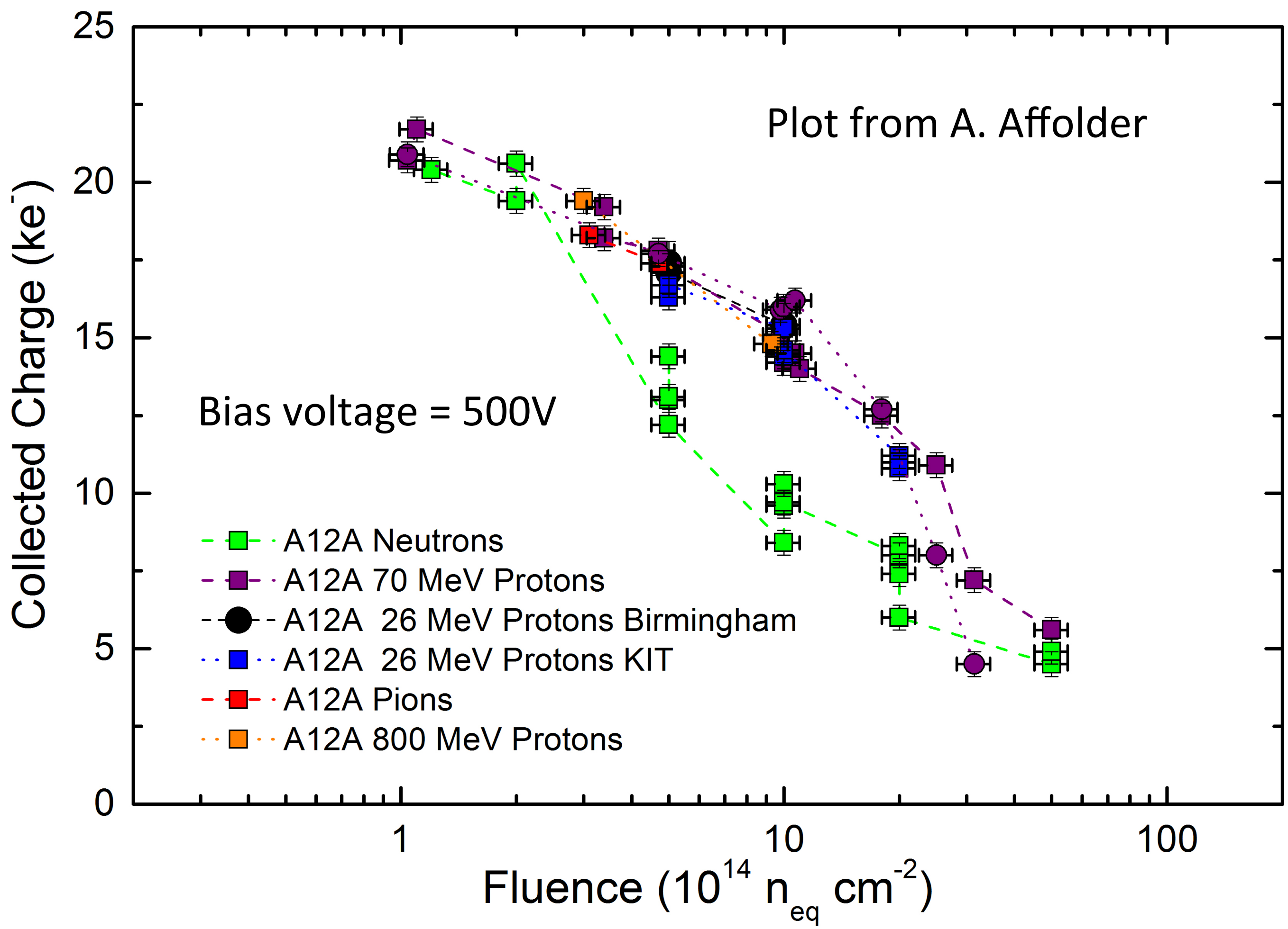
Comparison with other facilities



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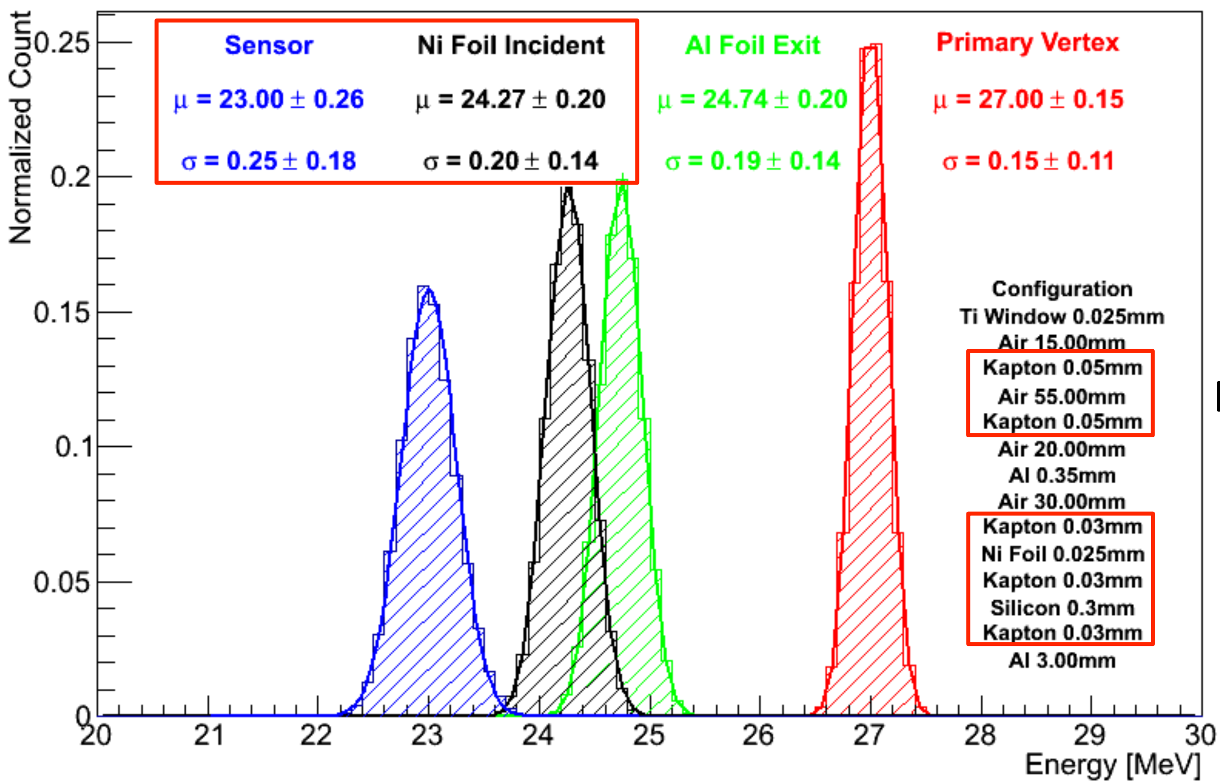
Beam energy at target

- Geant4 simulation used to determine beam energy at different locations between collimator and sample
- Proton beam energy = **27MeV** → proton energy at the sample = **23MeV**

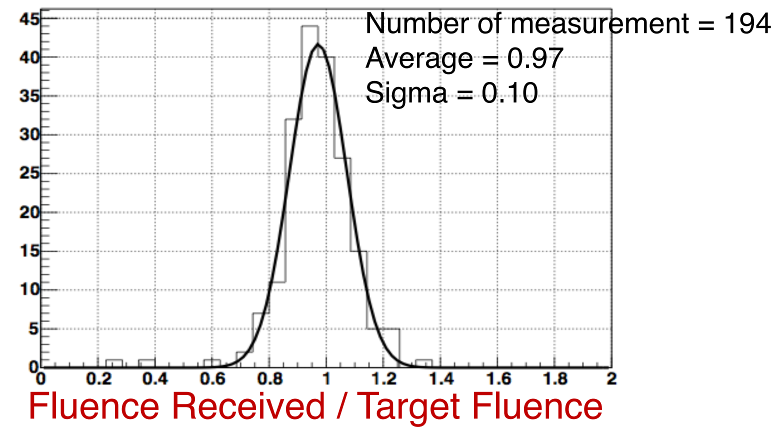


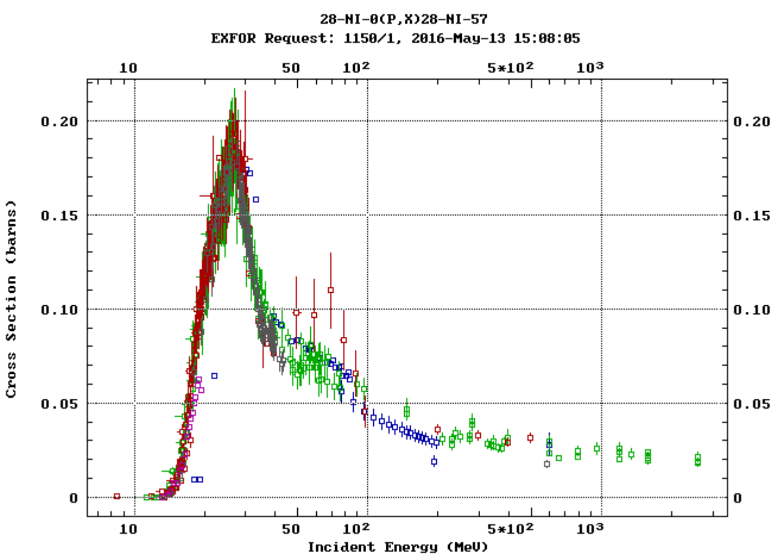
Box window

Sample with kapton and Nickel foil

Dosimetry

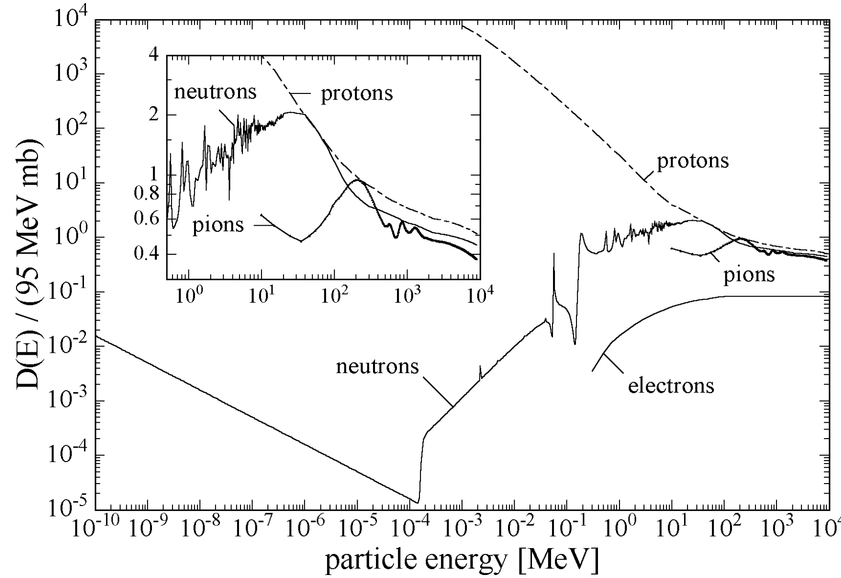
- The fluence is measured using **nickel foils** placed in front of the sample
- The activity of the Ni-57 isotope is measured with a germanium spectrometer
- Intensity of 1377keV peak + cross section for production of Ni-57 = **number of incident protons**
- Measured and target fluence **agree within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





Hardness factor

- The hardness factor we use for our protons is **2.2**
- However, different values can be found in the literature for 23MeV protons
  - KIT: k = 2
  - Tables on RD50: k = ~2.58
- We plan to determine k experimentally with measurement of diode leakage current vs. fluence



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

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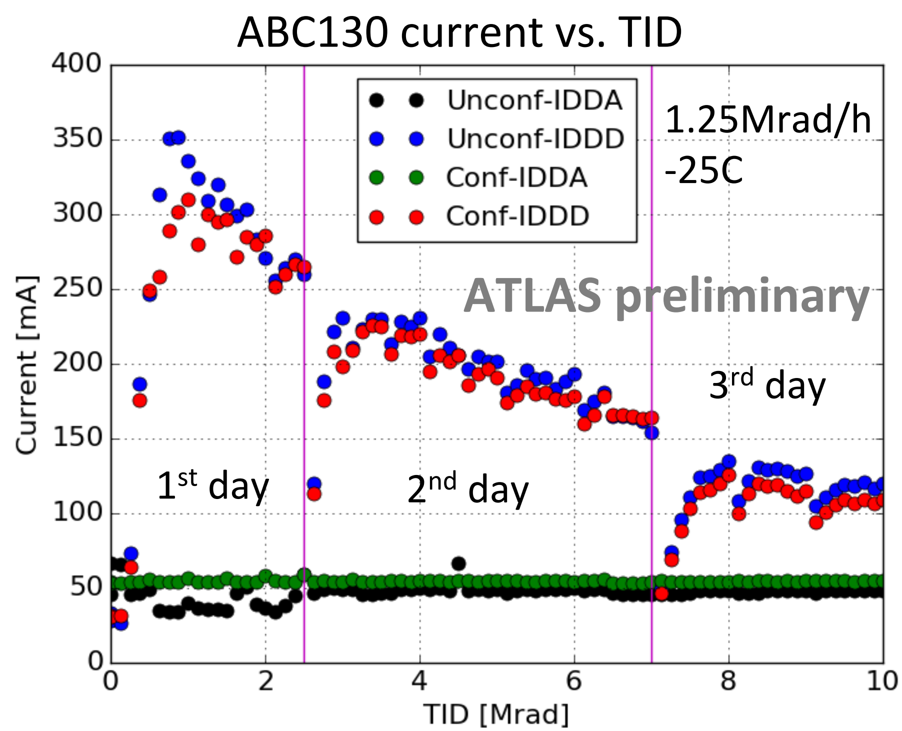
Notes on TID at cyclotron

- TID relevant for electronics irradiation
- dE/dx for 23Mev protons = ~18 MeV cm²/gr
- **1*10¹⁵ n$_{eq}$/cm² → ~130Mrad**
- For comparison at the PS the TID for the same fluence is a factor ~3 lower



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Ongoing and future irradiation program

- Recent irradiations
  - Heavily involved in TID irradiations of **ITk strips ASICs**
  - **LFoundry planar sensor** irradiated to $1*10^{15} n_{eq}/cm^2$ (Uni Bonn)
  - **Scientifica Foam samples** irradiated to $1*10^{15} n_{eq}/cm^2$ (IFIC Valencia)
- Requests
  - Strip barrel mini irradiations (ATLAS ITk collaboration)
  - **ATLAS pixel** quad modules & single AC coupled devices (Liverpool)
  - **Carbon fiber** structures (Liverpool)
  - HV-MUX **JFET** (BNL)
  - Pixel SC active edge module (MPI)
  - **Humidity probes** (Uni Wuppertal)
  - …

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Conclusion

- The Birmingham irradiation facility is operational with results in good agreement with other facilities

- More work is planned to understand the low energy component responsible for previous contradicting results, and to refine the dosimetry

- A number of irradiations are ongoing and planned within the AIDA-2020 framework, including sensors, ASICs, mechanical components, …

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Acknowledgments

- Many thanks to the team at the MC40 accelerator:
  - Prof. D. Parker
  - Mr. Mike Smith
  - Mr. Robert Goodwin
  - Mr. Robert Wheeler
  - Mr. Gregory Wood

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References

- Talks
  - “CCE and Signal Broadening with MC40 Irradiations” - James Broughton, https://indico.cern.ch/event/369608/
  - “Update of irradiation at Birmingham cyclotron” – Daniel Briglin, https://indico.cern.ch/event/461382/contributions/1132821/attachments/1228086/1799170/ITKFeb16_Birmingham_Irrad_Update.pdf
- Papers
  - P. Dervan et al: “Upgrade to the Birmingham Irradiation Facility”, Nuclear Instruments and Methods in Physics A, Volume 796, 1 October 2015, Pages 80–84, 2013 http://www.sciencedirect.com/science/article/pii/S0168900215001734
  - P. Dervan et al: “The Birmingham Irradiation Facility”, Nuclear Instruments and Methods in Physics A, Volume 730, 1 December 2013, Pages 101–104, 2015 http://www.sciencedirect.com/science/article/pii/S0168900213007675
- Weblinks
  - http://www.np.ph.bham.ac.uk/pic/cyclotron
  - http://aida2020.web.cern.ch/content/uob

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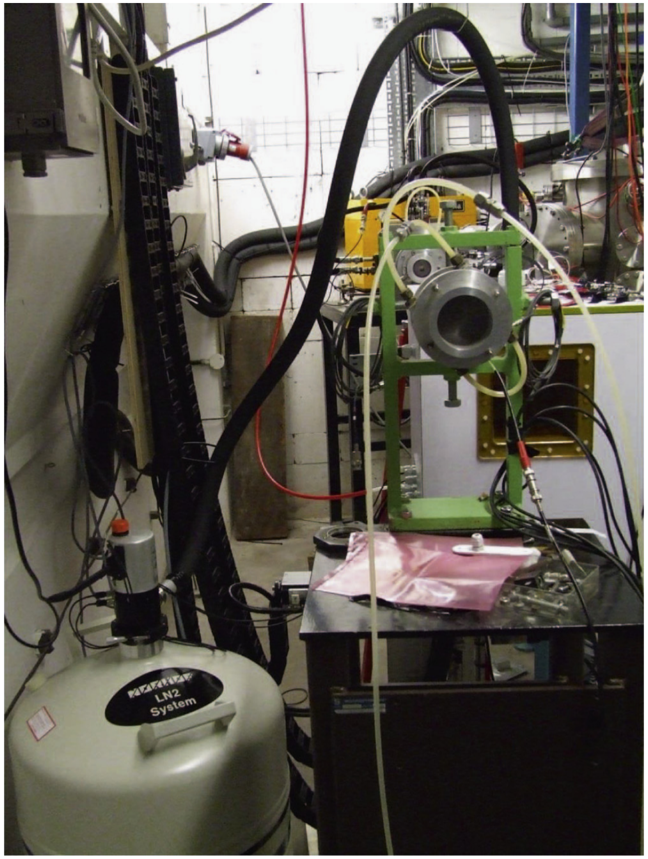
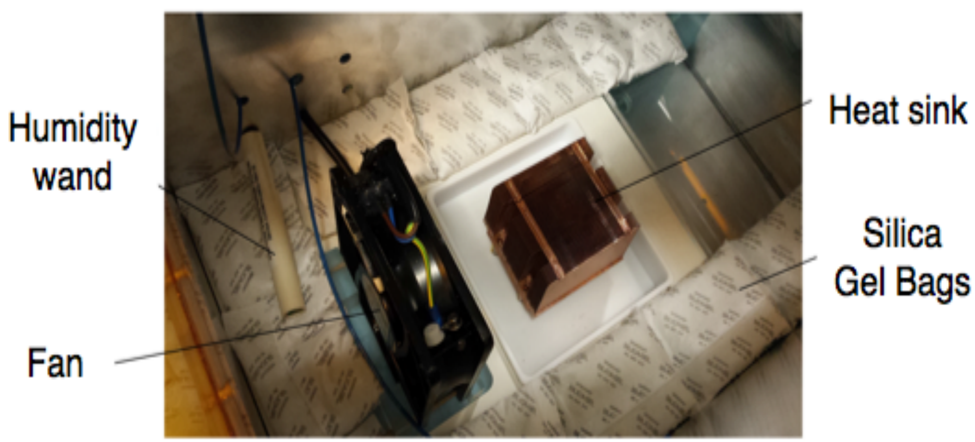
Backup

Irradiation area



Cooling

- A Norhof liquid nitrogen (LN2) system using evaporative cooling is installed. The LN2 is dripped on to a heat sink located at the base of the cold box. The LN2 evaporates to produce very cold N2 gas. The flow of LN2 in to the cold box is adjusted automatically by the Norhof system, which operates by monitoring the temperature and pumping in LN2 to achieve the preset required temperature of the cold box. The new cooling system can achieve a stable temperature of $50^{o}C$ in 30 minutes.



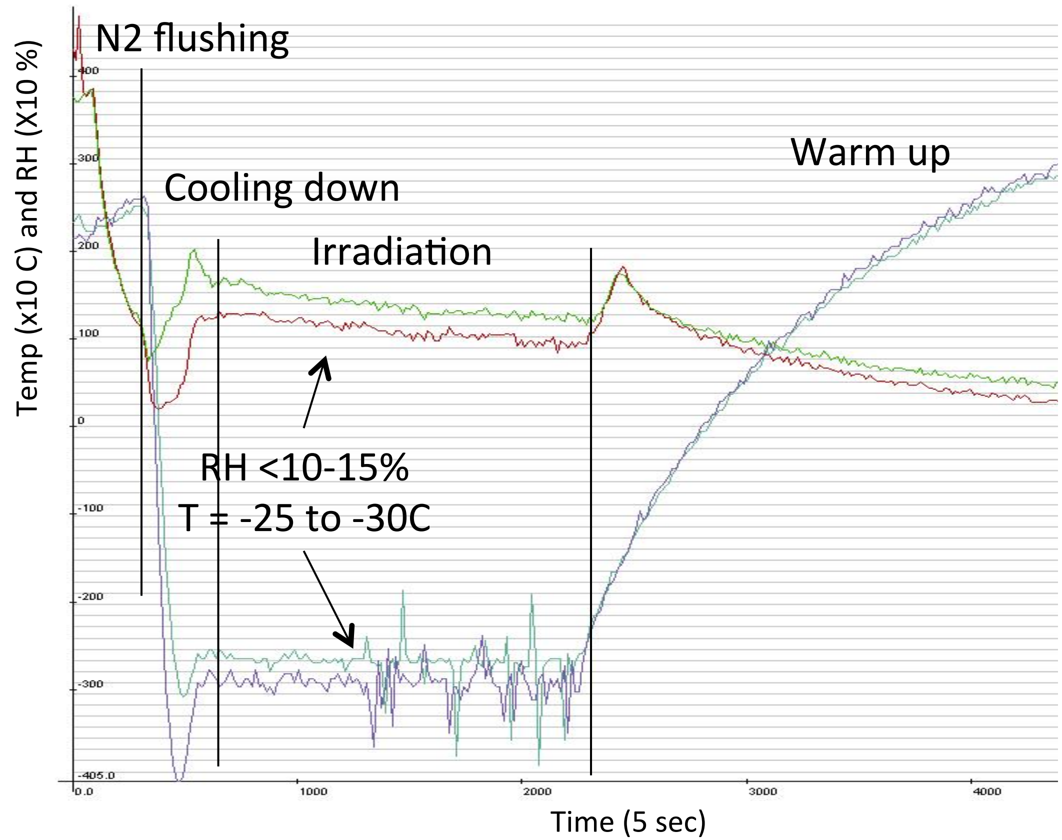
Cold box details

- Styrofoam box structure clad with Aluminum foil and Formica
- Thin double skinned Polyamide window to allow beam entry and exit
- Inlets for cooling and N2
- Fans within the box are used to ensure good air circulation

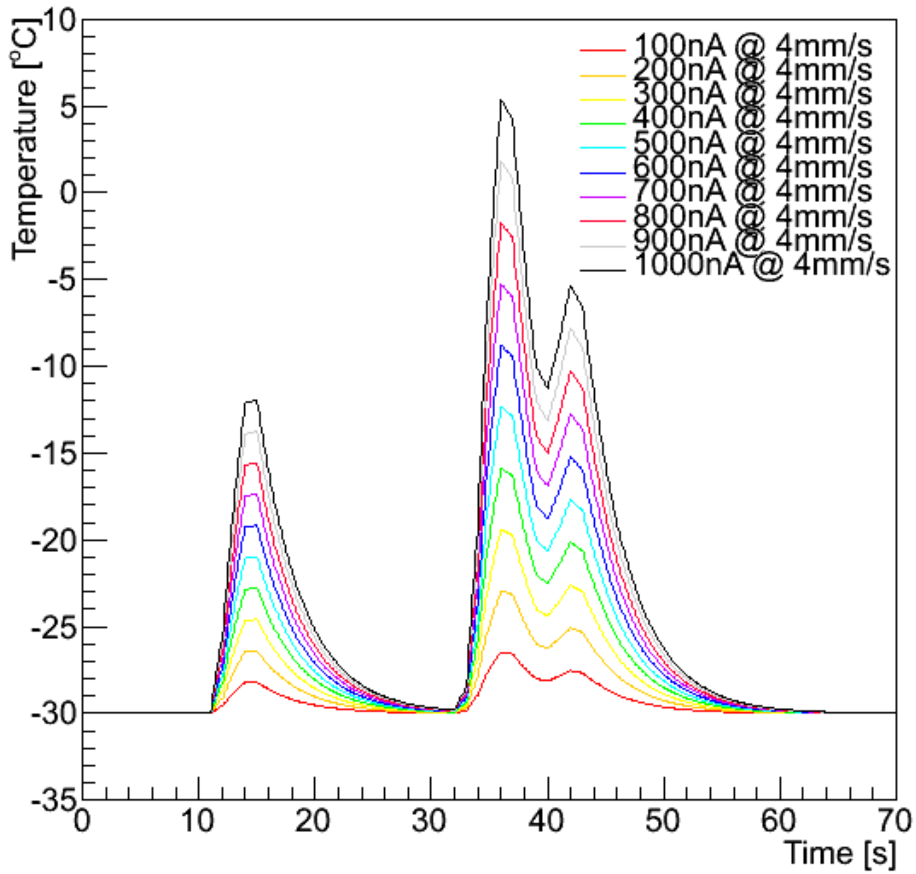
Example of T and RH monitoring during irradiation

- Temperature and humidity logged with Arduino-Uno system. Three temperature and two humidity sensors placed at different locations in the box

Stable irradiation temperature achieved within 20 minutes



Temperature on sensor during irradiation



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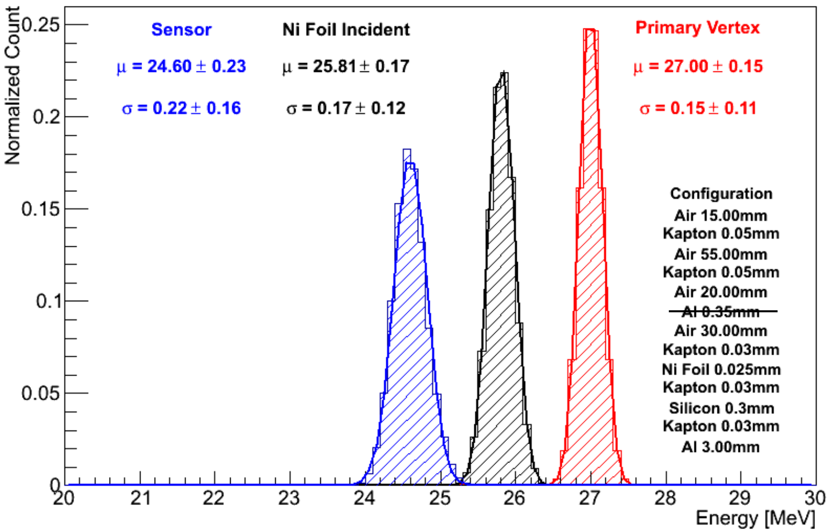
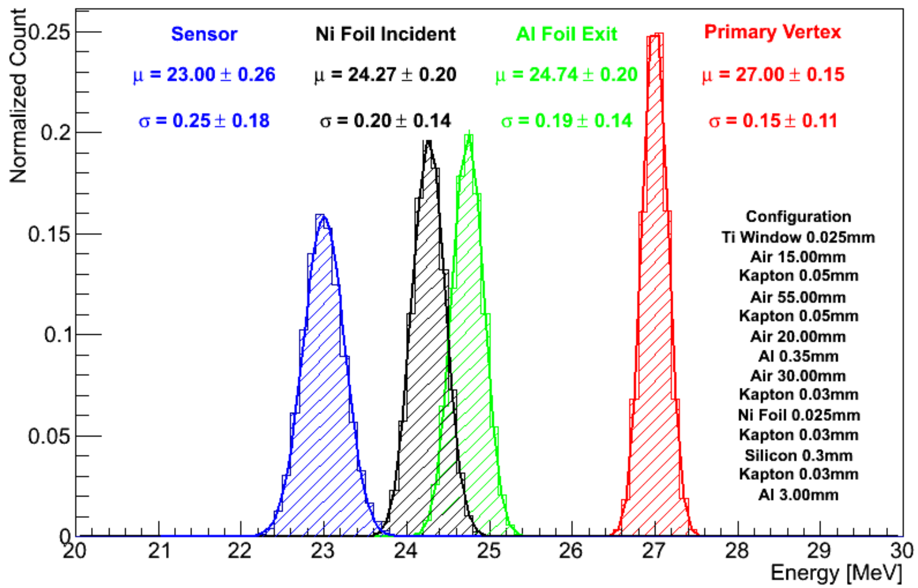
Beam energy



No absorber
@ Ni foil = 25.81MeV
@ sensor = 24.60MeV



Absorber
@ Ni foil = 24.27MeV
@ sensor = 23.0MeV

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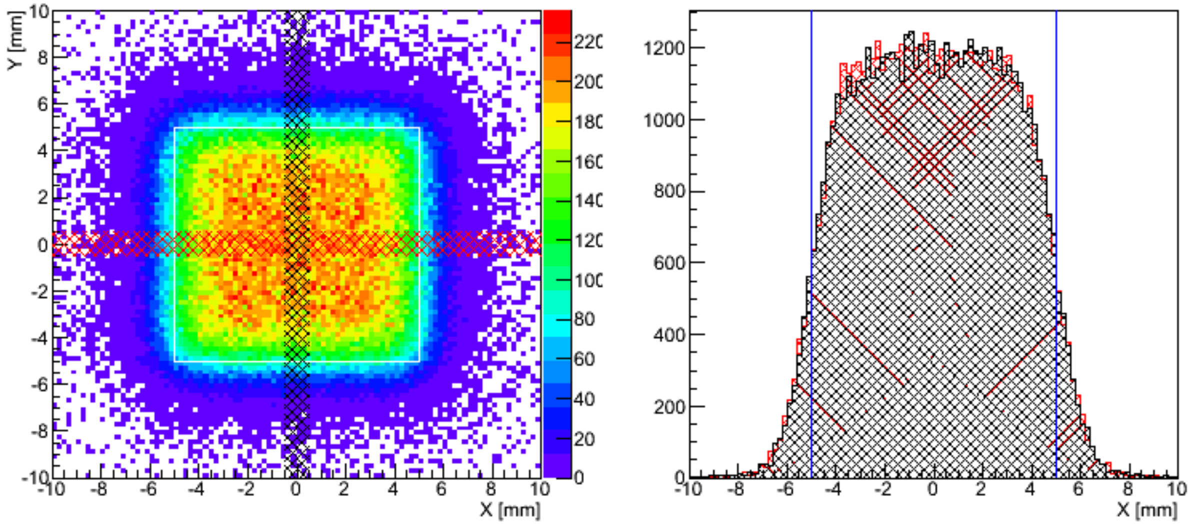
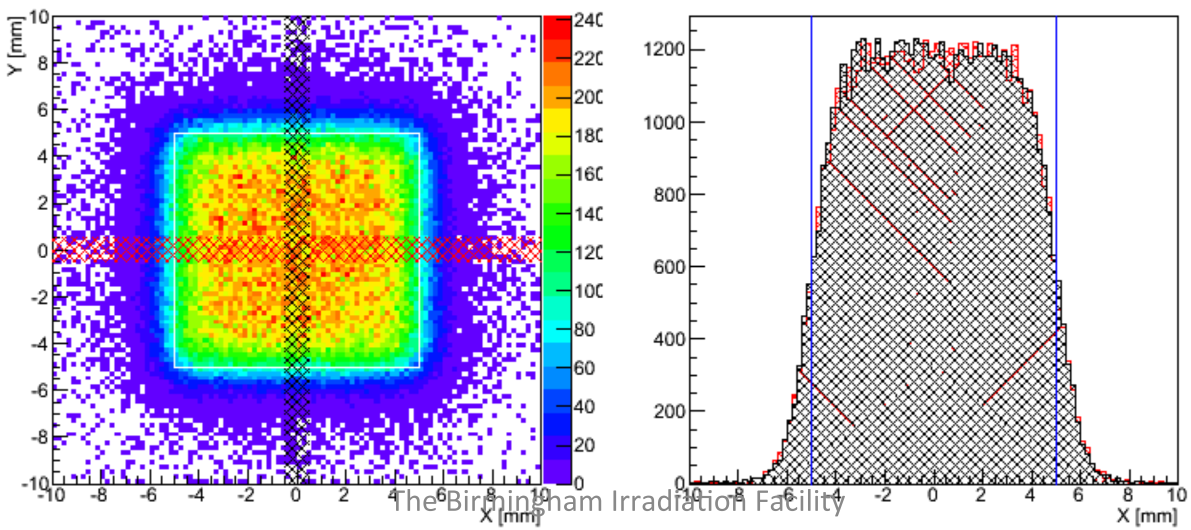
Beam profile

Absorber



No absorber

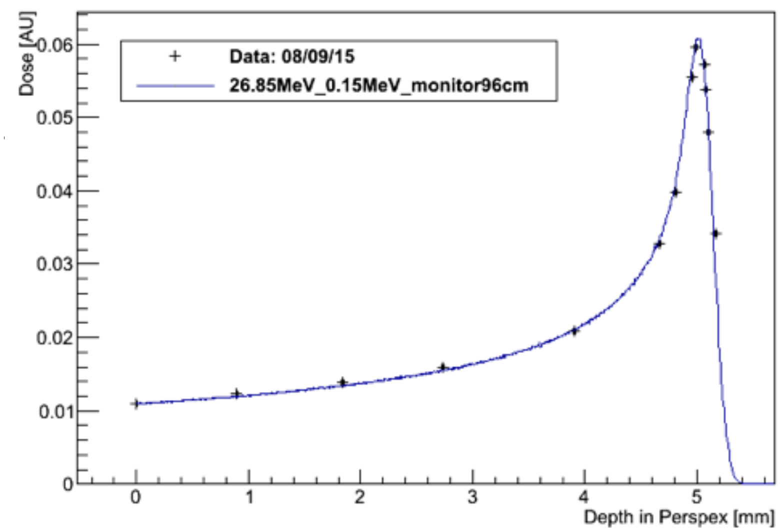


Low energy component

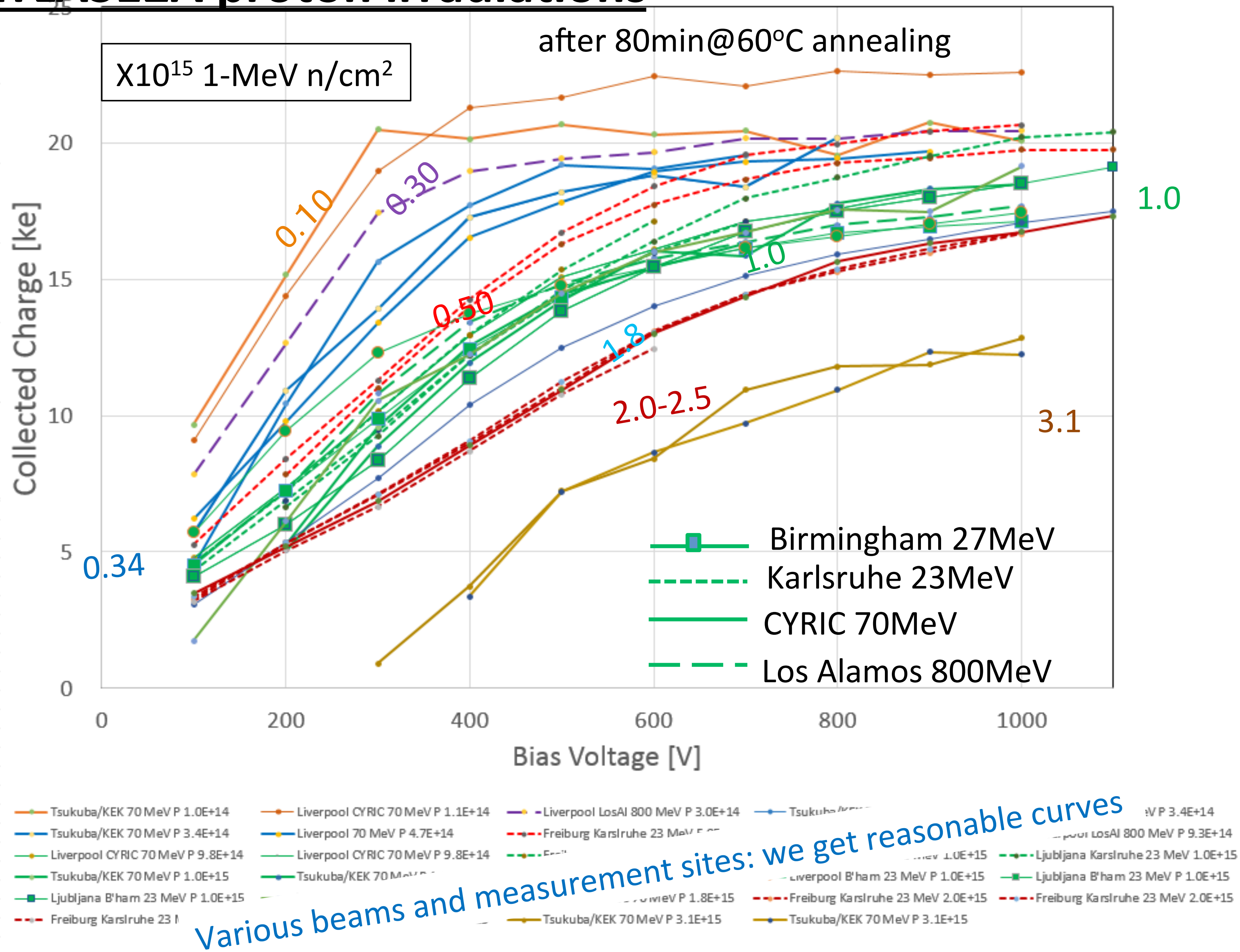
- A 3 MeV proton has a range of 107mm +/- 4.5mm in air with a density of 0.00163 g/cm3 (ICRU-104 material)
- Protons must have energy more than this to traverse 10cm of air between collimator and sample
- A 7MeV proton looses around 1MeV in 10cm of air
- A 6.5 MeV proton has a range of 296µm +/- 12.6µm in pure Al so would be stopped
- Values taken from SRIM

Bragg peak

- Optimal energy is 26.85 MeV with a Gaussian spread of 0.15 MeV
- Apparatus placed 1m downstream (only available position at present). Energy loss corrected for this distance
- As a consequence of the large separation between the end of the beam line and apparatus the low energy protons are absorbed in the intervening air. So there is no low energy components shown in the plot
- Will redo measurements closer to the collimator when possible - should then see low energy components
- This is important to check if some of the low energy protons may have energies greater than 6.5MeV and so not be stopped by the 0.3mmm of Al. We need to check that our 0.3mm of Al is sufficient to remove the low energy contamination



ATLAS12A proton irradiations



ATLAS12A proton irradiations