Proton Irradiation for quality assurance of ATLAS18 strip sensors with the Birmingham MC40 cyclotron

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ITk Strips QA Programme

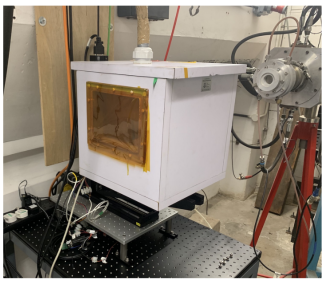
- For the High Luminosity Large Hadronic Collider (HL-LHC), ATLAS Inner Detector (ID) will be **replaced with fully silicon Inner Tracker** (ITk); pixel sensors in the inner region and strip sensors in the outer region[1]
- HL-LHC presents a **very harsh radiation environment**, ITk strip sensors will see expected doses up to 1.6×10^{15}neq/cm^2 and 66 Mrad
- 24,010 ATLAS18 strip sensors to be produced, 17,888 (165 m^2 of silicon) to be installed. Quality Assurance (QA) radiation hardness requirements must be met on all batches[2]
- To avoid damaging sensors, **dedicated test structures** from same wafers are **irradiated then tested** in globally distributed programme
- These include 10mmx10mm mini sensors, tested post-irradiation for Charge Collection Efficiency (CCE) using a β source

Birmingham MC40 Cyclotron

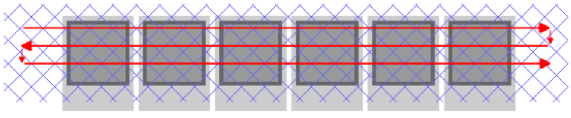
- Operational since 2004, the MC40 Cyclotron accelerates protons to 2.7 - 40 MeV, at currents up to 2μA
- Beams delivered to multiple applications, predominantly production of radioisotopes for medical use
- QA irradiations performed on dedicated beam line; **27 MeV protons at 500nA**, in 10x10mm beam following collimation

Irradiation Facility

- To prevent uncontrolled annealing samples must be **continuously scanned through beam during irradiation**
- Samples placed within cold box held by two 300mm Zaber motor stages
- Controlled via custom C++ software, running on Linux machine in control room

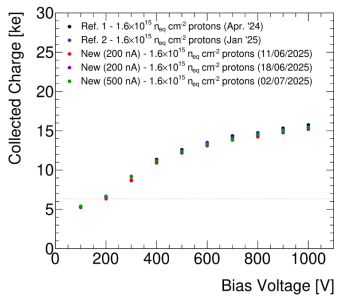


- Rows of 6 mini sensors placed on aluminium plate in cold box, scanned across beam repeatedly until desired fluence achieved
- Dosimetry performed using nickel foil placed over sensors, measured following irradiation, **fluence precision** $< 10\%$
- **Scanning patterns** leave 5mm clearance each side of sensors, vertically increment 2.5mm each scan, all **generated automatically by control software**
- Irradiations of mini sensors to ITk QA fluence performed with 10mm/s scanning speed (upgraded from 4mm/s), **taking 1.25 hours per row of 6**

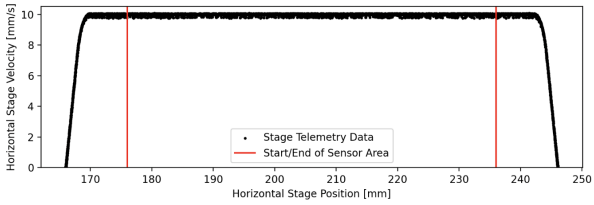


Post-Upgrade Validation

- Current set-up is result of recent upgrades to sample scanning system
- Scanning speed and beam current were increased to 10mm/s and 500nA; giving **50% reduction in irradiation time**
- Test irradiations performed on mini sensors to validate performance against previous system

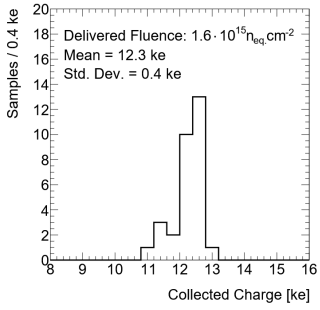


- **CCE tests** on irradiated sensors **show consistency with previous system** and other sites
- Telemetry shows **stage operation sufficiently accurate**, uniform scanning speed over sensors verified



Performance Overview

- Site qualified for ITk Strips QA program in 2021, routine mini sensor irradiations performed since
- **Over 300 sensors irradiated** and tested at Birmingham so far
- Post-irradiation tests at Birmingham and other sites have allowed acceptance of $\sim$ 600 sensor batches, **less than 1% rejected**



What next?

- Following $\sim$ 2 months of upgrades mid 2025, **facility now fully operational again with doubled capacity**
- Routine QA mini sensor irradiations to continue, sensor production expected to finish early 2026
- Following end of production additional MD8 diode pieces will be irradiated, providing performance catalogue for later reference

[1] "Technical Design Report for the ATLAS Inner Tracker Strip Detector," CERN, Geneva, Tech. Rep., 2017.

[2] S. Hirose et al., *JPS Conf. Proc.*, vol. 42, p. 011 017, 2024. DOI: 10.7566/JPSCP.42.011017.

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