Radiation Hardness Studies and Irradiation Facilities

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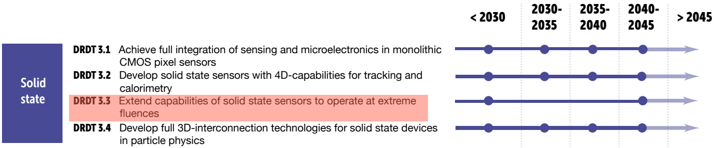
The behaviour of semiconductor materials at the fluence levels foreseen at FCC-hh (around 10^{18} $n_{eq.}$ cm^{-2}) is largely uncharted territory!

> *"The understanding of the silicon properties at fluences above 1×10^{16} $n_{eq.}$ cm^{-2} is a must for developing the sensors for experiments operating at or above that fluence level"*
>
> **ECFA detector research and development roadmap (2021)**



Goal - Contribute to DRDT 3.3 with a programme of radiation hardness studies to map the fundamental properties of silicon detectors up to 10^{18} $n_{eq.}$ cm^{-2}

- **New Facilities:** Substantially extend the UK's irradiation capability
- **New Measurements:** Conduct an extensive irradiation campaign with dedicated test devices to study effects at FCC-hh fluence levels for the first time
- **New Models:** Exploit groundbreaking data to contribute to the development of the next generation of radiation damage models / simulation strategies

UNIVERSITY OF BIRMINGHAM | CYCLOTRON FACILITY

Birmingham MC40 Cyclotron

- Proton or He ion beams with energy up to 38 MeV
- Capable of $\mathcal{O}(\mu A)$ beam currents
- Used for a wide variety of applications, including nuclear physics research, radioisotope production and as a test beam and irradiation facility

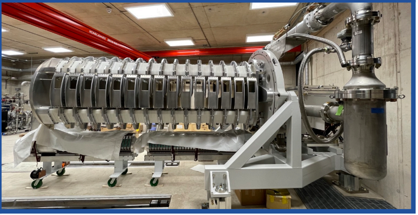
Extensively used for particle physics detector R&D through transnational access agreements:

- AIDA-2020 (2015 - 2020)
- EURO-LABS (2022 - 2026)

Only facility to provide regular monthly proton irradiations for the ATLAS ITk strip sensor QA programme

Birmingham High Flux Accelerator-Driven Neutron Facility

UNIVERSITY OF BIRMINGHAM HIGH FLUX ACCELERATOR-DRIVEN NEUTRON FACILITY



State of the art high intensity neutron source recently began operations (late 2022)

- Based on commercial system designed for Boron Neutron Capture Therapy (BNCT), housed in an extension to UoB Medical Physics building
- Uses a 2.6 MeV proton beam on a rotating Lithium target, to produce fast neutrons (≈ 1 MeV) via the $^7\text{Li}(p, n)^7\text{Be}$ reaction
- With initial $> 30\,\text{mA}$ proton beam, expect fluence rate of $1.8 \times 10^{11}\,\text{cm}^{-2}\text{s}^{-1}$
- Upgrade planned (from 2024) to add Deuteron beam, increasing fluence rate beyond $3 \times 10^{12}\,\text{cm}^{-2}\text{s}^{-1}$ (i.e. HL-LHC fluences in minutes)

Exciting prospect to substantially extend UK-based irradiation capability for particle physics applications!

Commission Birmingham Neutron Irradiation Facility for HEP Devices

- Develop dedicated end-station at ADNF for irradiation of sensors and electronics
- Facility designed for continuous operation, could deliver $10^{18}\,n_{\text{eq.}}\,\text{cm}^{-2}$ in around 10 days at ultimate intensity of $3 \times 10^{12}\,\text{cm}^{-2}\text{s}^{-1}$ (from 2024)

Upgrade of Birmingham Proton Irradiation Facility

- Accelerator capable of very high beam currents, up to 10 μA (!), but present beamline and sample enclosure limit operations to lower currents (typically 0.2 μA)
- Upgrade beamline and sample enclosure to open possibility of high-current operation (around $2 \times 10^{17}\,n_{\text{eq.}}\,\text{cm}^{-2}$ in a 5 hour run at 1 μA, per $1\,\text{cm}^2$ sample)

Dedicated Test Devices

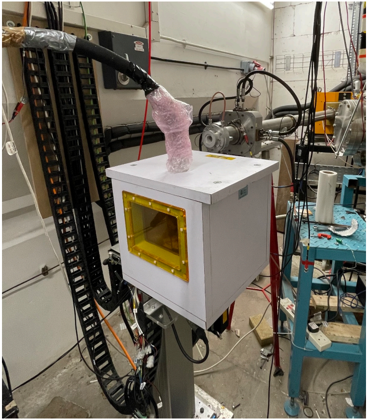
- Design submission of simple pad detectors / diodes with a range of substrate and structural parameters, similar to "RD50 diodes"
- Target UK-based foundry with history of engagement with small submissions for HEP applications (e.g. Teledyne e2v or Micron)

Irradiation and Measurement Campaign → Model / Simulation Development

- Irradiate test devices with <u>both</u> protons and neutrons (separately) to a range of fluence points spanning the path towards $10^{18}\,n_{\text{eq.}}\,\text{cm}^{-2}$
- Thoroughly characterise devices both before and after irradiation with typical suite of measurements at institutes accross the UK
- Exploit data for development of radiation damage models / simulation strategies

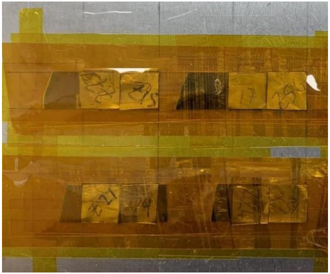
Additional Slides

Proton Irradiation Setup at Birmingham MC40 Cyclotron



- 27 MeV proton beam, operating at a current of 100 − 400 nA (nominally 200 nA)
- Square beam spot of 10 mm × 10 mm
- Samples mounted inside N_2 flushed cold box, maintained at −27°C

- Cold box mounted on tracking stage capable of both static positioning and periodic scanning during irradiation
- 300 μm of Al foil shielding in front box entrance window
- Sensors mounted on Al plate (2 mm thick) and overlaid with Ni foil for dosimetry, all suspended within cold box



The temperature of the Al plate has been monitored during the irradiation and does not exceed −20°C