The Irradiation Facility at the Bern Cyclotron

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Motivation for Irradiation Studies in High Energy Physics

- The current HEP detectors are exposed to radiation levels up to $\sim 2.5\times10^{14}$ Si 1 MeV n_{eq} cm^{-2} ($\sim$20 Mrad) [1]
- With the upgrade for HL-LHC, higher radiation levels up to $\sim 6.5\times10^{15}$ Si 1 MeV n_{eq} cm^{-2} ($\sim$400 Mrad) [1] will be reached and thus components have to be tested to such high radiation levels (see plot on the right [2])
- The Bern medical cyclotron is a proton accelerator facility that allows for irradiation studies using a versatile and novel set-up

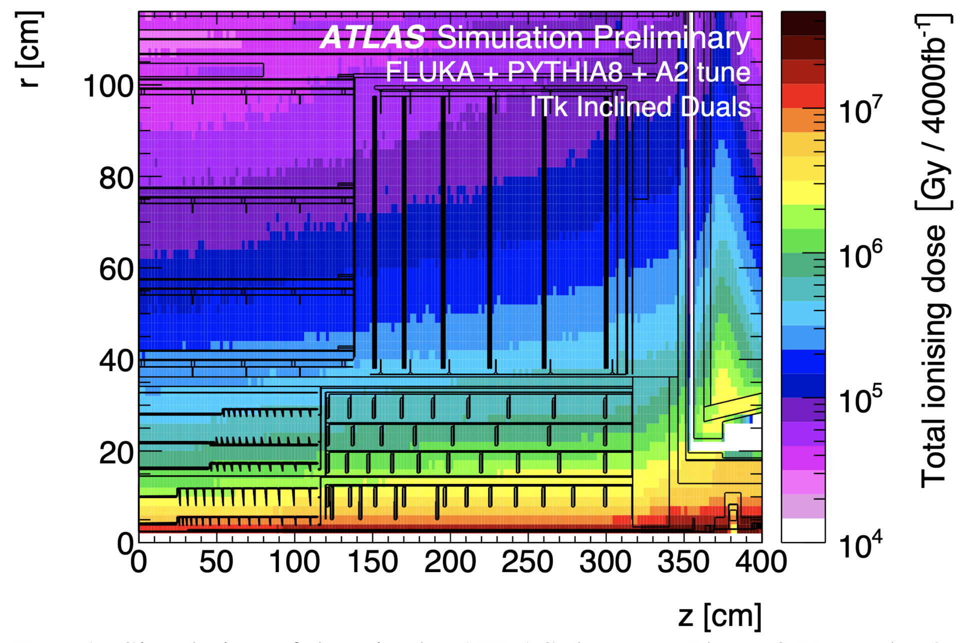
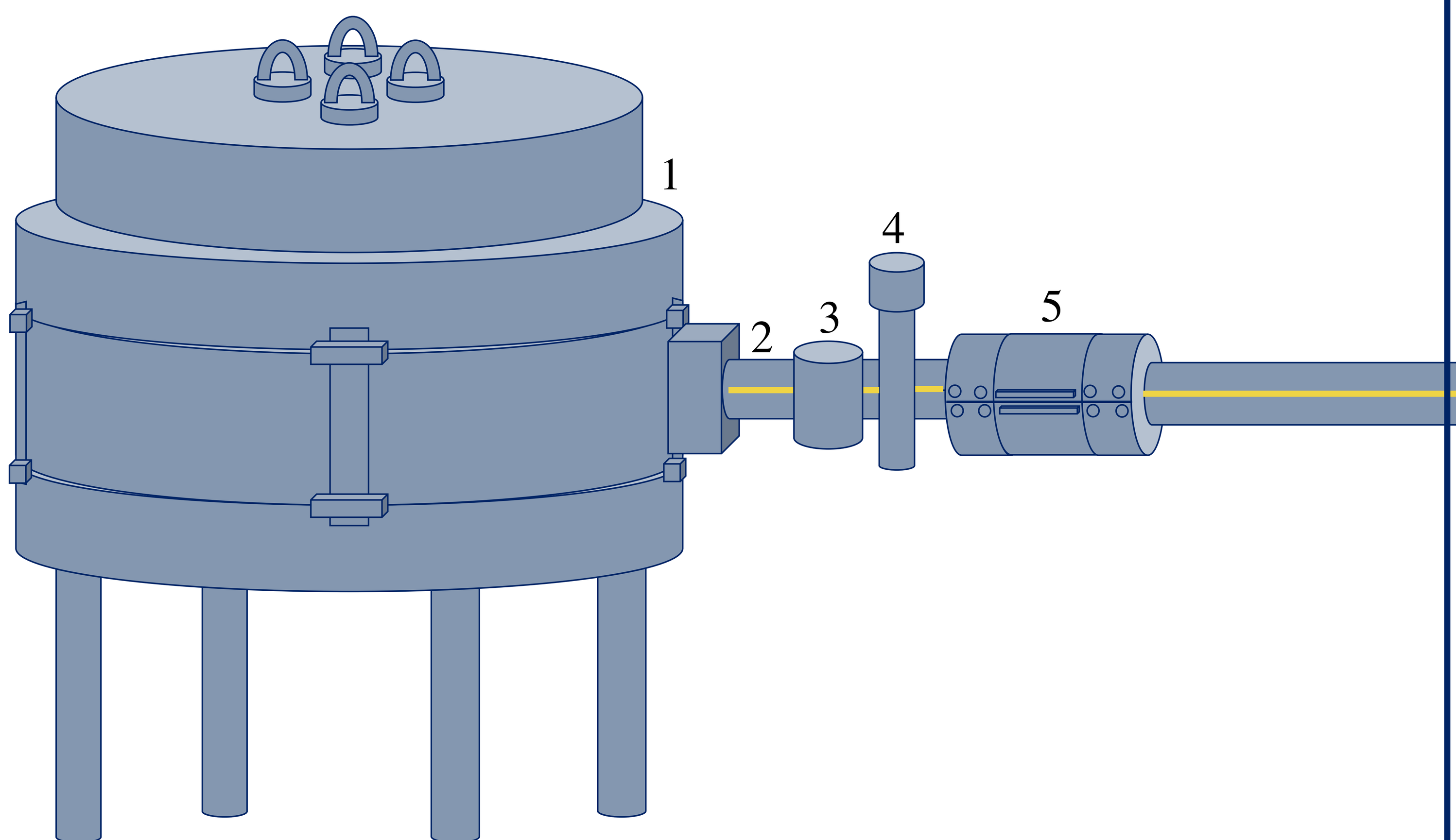


Fig. 1: Simulation of dose in the ATLAS detector, Phase-2 Upgrade [2].

I. Bern Cyclotron



1: Cyclotron, 2: BTL, 3: Steering Dipoles, 4: Beam Viewer

- Medical cyclotron (1) (^{18}F and other radioisotope production) used also for multi-disciplinary research [1]
- Protons are accelerated to 18 MeV and extracted into the Beam Transport Line, BTL (2)
- X and Y steering dipoles (3) for steering the beam
- Beam viewer for monitoring (4) and quadrupole doublet for focusing (5) the beam
- Variable beam current: pA - μA, leading to different achievable dose rate values (e.g. for Si): 10 - 10^6 rad/s (10^7 - 10^{13} 1 MeV $n_{eq}/(cm^2 s)$)

III. High TID Irradiations

Example 1: H35DEMO HV-CMOS Sensor

- Irradiation campaign of H35DEMO HV-CMOS prototype sensors in multiple steps up to 2×10^{15} 1 MeV n_{eq}/cm^2 ($\sim$ 200 Mrad [6])
- Depletion depth measured with Transient Current Technique [5], here for a 200 Ω cm resistivity sample at -80 V bias voltage (Fig. 4)

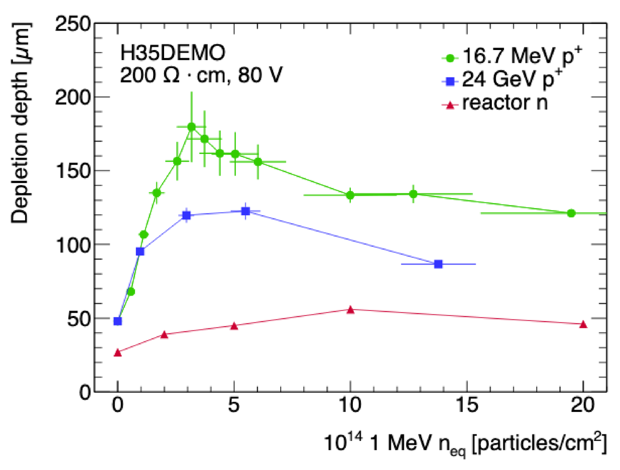


Fig. 4: Measurements of depletion depth of an irradiated H35DEMO sample [5].

Example 2: Twinax Cable (Nov. 2019)

- Irradiation of 6m Twinax cable in multiple steps up to 91.2 Mrad ($\sim 1\times10^{15}$ 1 MeV n_{eq}/cm^2)
- In between irradiation tests: measurements of power loss (by M. Chatterjee, Bern University) to ensure functionality (Fig. 5)

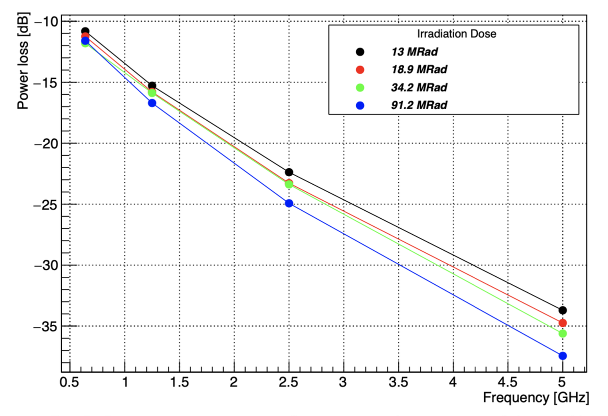
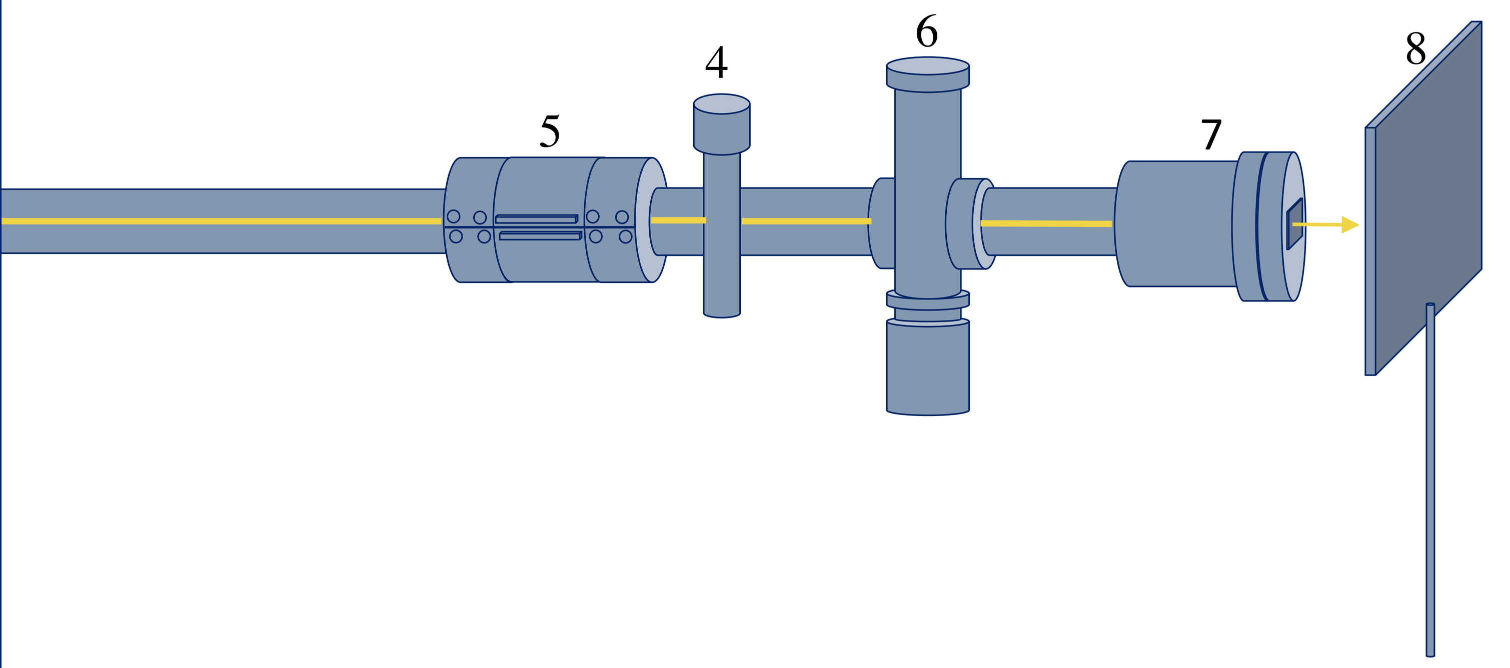


Fig. 5: Measurement of power losses of irradiated Twinax cable, performed by M.Chatterjee.

Example 3: Optobox Connectors (Feb./March 2020)

- Irradiation of connectors up to 15 Mrad ($\sim 1.4\times10^{14}$ 1 MeV n_{eq}/cm^2) to ensure their functionality at planned optobox locations
- Pre- and post-irradiation tests of resistance show no loss of functionality

II. Beam Transport Line



5: Quadrupole Doublet, 6: π^2 Detector, 7: Collimator, 8: 2D Stage

Beam Monitoring (6):

- π^2 Detector for beam monitoring, developed at LHEP [4]
- Protons hitting a aluminium foil coated with P47 and emit photons
- Fluorescence is detected using a National Instruments Smart Camera and visualised as 2D beam shape (Fig. 2)

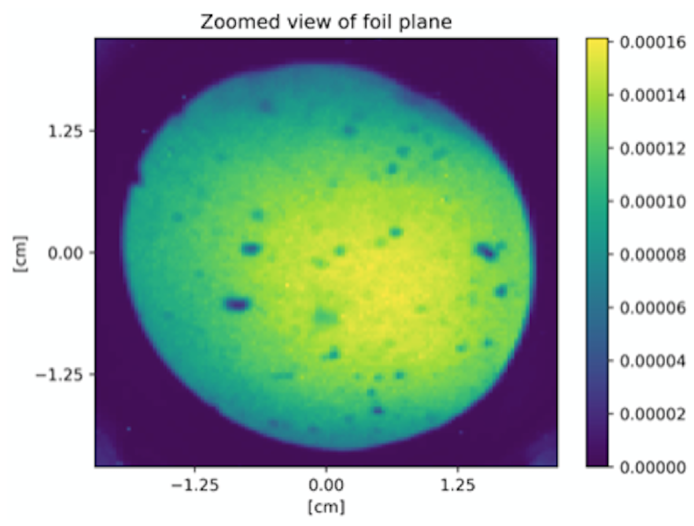


Fig. 2: 2D beam profile, color-scale in A.U. [4]

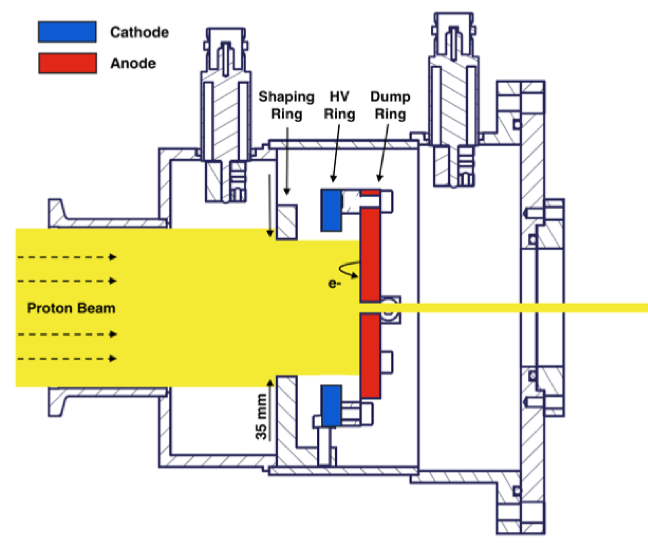


Fig. 3: Collimator for beam current and dose measurement [4].

Current Measurement (7):

- Collimator for beam shaping and current measurement (Fig.3), developed at LHEP [4]
- Flat beam goes through a shaping ring and hits the dump ring which acts like a Faraday cup and measures the current density
- The beam is extracted through a changeable opening window in the dump ring to air/the sample

2D Stage (8):

- 2D movable stage, can be controlled online and from remote
- Grid of screw holes (spacing 25mm, M6 screws), allowing various samples to be irradiated without requiring entry into the radiation bunker

IV. Future Developments: Low Dose Irradiation

The flexibility of the facility is planned to be extended, such that electronic devices can be read out during irradiation with low doses (e.g. measuring SEU rates at dose rates of 10 krad/s)

Development Part 1: Real-time dose measurement

- The current required for such low doses is too low to be detected with the collimator (see Box II, Current Measurement)
- π^2 Detector can be used to measure number of photons and thus current for low doses
- Calibration with Faraday cup and/or radiochromic films is required

Development Part 2: Read out during irradiation

- Read-out chain that can be read out during irradiation to measure SEUs and delaying effects in electronics
- Can be realised with a transportable computer that is left in the irradiation bunker and accessed remotely

References:

[1] http://radsim.cern.ch/devels (Run 2 (2015-2018) geometry model for 150/fb, ITk Step 3.1Q6 geometry model for 4000/fb)
[2] Radiation Simulation Working Group. Radiation simulation public results. https://twiki.cern.ch/twiki/bin/view/AtlasPublic/RadiationSimulationPublicResults
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[5] J. Anders, and others. Charge collection characterisation with the Transient Current Technique of the ams H35DEMO CMOS detector after proton irradiation. *JINST* 13-10-2018, arXiv:1807.09553
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