

4.2 Radiation levels

The expected radiation levels in the HGTD are an important parameter in the sensors, electronics and overall detector design. The simulations were performed for an integrated luminosity of $\mathcal{L} = 3000 \text{ fb}^{-1}$ using the FLUKA [62, 63] and GCALOR simulation packages. No safety factor is applied for the simulation results shown in this section. Three different HGTD layouts have been studied:

- “HGTD-SiW”: the HGTD pre-shower option with three 3.5 mm thick tungsten plates between the silicon layers. Beyond $|\eta|=3.2$, i.e. in the radial range $R=110-284 \text{ mm}$, the tungsten is replaced by borated polyethylene.
- “HGTD-Si”: the HGTD timing option with the tungsten replaced by borated polyethylene, giving a total of 10 mm moderator over the full radial range of the HGTD and
- “HGTD-Air”: an option with HGTD Si layout but without moderator inside the HGTD volume.

In the FLUKA simulation the HGTD detector has been described by azimuthally symmetric disks, but with a detailed layer structure along the z -axis, representing the different materials and sensitive layers of HGTD. The z position of the HGTD is: $346 \text{ cm} < z < 352 \text{ cm}$. In the radial range $R=700-800 \text{ mm}$ a gap for service routing is left. In the simulations this region contains only air. As a reference the run 2 moderator layout, without HGTD and the space filled with 50 mm moderator, is used.

The predictions from FLUKA simulations for the silicon 1 MeV neutron equivalent (NIEL_{Si}) fluence in the ITk volume at $342 \text{ cm} < z < 346 \text{ cm}$, i.e. just next to the HGTD, and the ionizing dose in the silicon layer of HGTD closest to the endcap calorimeter, are shown in Figure 25 and Figure 24, respectively. The maximum expected radiation levels for 3000 fb^{-1} in the HGTD (at $R=110 \text{ mm}$; $|\eta|=4.2$) are equal to $4 \times 10^{15} \text{ cm}^{-2}$ NIEL_{Si} equivalent fluence and 3 MGy. Within statistical uncertainties the ionizing dose is the same for all HGTD layout options considered and agrees, within 30%, with the results obtained by the GCALOR simulations. If this discrepancy between the two simulations is caused by small differences in the material or geometry descriptions, e.g. of the rapidly evolving ITk layout, remains subject to further comparisons.

The presence of the tungsten plates increases the ionizing dose up to a factor of 3 in the radial range covered by the tungsten ($R > 30 \text{ cm}$) with respect to HGTD-Si option, and has to be taken into account in the electronics design of the HGTD.

The replacement of the 50 mm thick moderator of the ATLAS baseline layout by the HGTD leads to a significant increase of the NIEL_{Si} in the adjacent ITk volume. The effect is most pronounced for the HGTD-SiW option, where the maximum reaches a factor of 2.5 above the no-HGTD layout. A replacement of the tungsten by a total of 10 mm borated polyethylene has only a moderate reduction effect on the NIEL_{Si} levels.

In Figure 26 the NIEL_{Si} inside the ITk volume is shown as a function of radius for two z locations. At $R=40 \text{ cm}$ and $296 < z < 300 \text{ cm}$, which corresponds to the lowest edge of the outermost ITk strip disk, the NIEL_{Si} is about 30% and 50% above the baseline value for the HGTD-Si and HGTD-SiW options, respectively. The effect of the missing moderator quickly dilutes with distance from the endcap and at $z=\pm[140,160] \text{ cm}$ the effect remains below 20% for all HGTD layouts considered.

This means that the effect of replacing the existing 50 mm of moderator by the HGTD is largest at the edge of the outermost ITk strip disk, which already in the baseline layout is exposed to the highest fluence. A simulation study was conducted to determine the thickness of moderator needed to recover the baseline

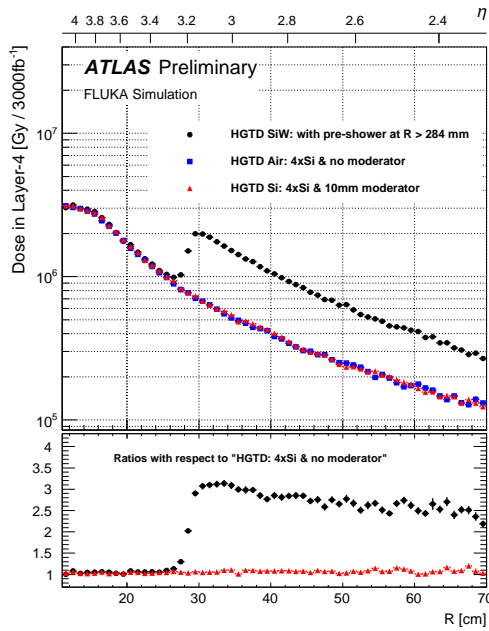


Figure 24: Ionising dose in the readout chip layer of the HGTD closest to the ATLAS endcap calorimeter. The histograms represent the three different HGTD layouts studied: HGTD-SiW (black circles), with 3.5 mm thick tungsten plates between $R=284$ mm and $R=700$ mm, continued with borated polyethylene moderator of the same thickness down to $R=110$ mm. The HGTD-Si option with the tungsten replaced by borated polyethylene (red triangles), giving a total of 10 mm moderator over the full radial range of the HGTD and the HGTD-Air option with no moderator inside the detector (blue squares). No safety factor for the simulations are included in these figures. No safety factor is applied for the simulation.

1638 level with the HGTD-SiW option installed. The results, shown in Figure 27 verify that re-introducing
 1639 the 50 mm between the HGTD and the ITK would be sufficient. The attenuation of the neutron albedo in
 1640 the moderator is exponential, but a constant⁵ term describing all other contributions, e.g. from charged
 1641 hadrons, means that going much beyond 50 mm would not bring any significant further reduction. The
 1642 slope of the fitted exponential term is $\sim -0.25 \text{ cm}^{-1}$, which implies that 50 mm of moderator should give
 1643 a reduction by a factor of 3.5. The significant constant term, however, causes that the net effect is less than
 1644 a factor of 2.

1645 Discussions with the ATLAS Technical coordination, ITK and HGTD groups started to see ways to insert
 1646 more moderator, including in the ITK region, in parallel with calculations performed by the ATLAS
 1647 radiation simulation group for the various possible scenarios of additional moderator.

1648 4.3 Requirements

1649 The preliminary HGTD detector design results from constraints (geometrical and environment) and
 1650 performance requirements to achieve the best physics potential

⁵ This term is constant with respect to variation of the moderator thickness, but it is a function of the position within the ITK

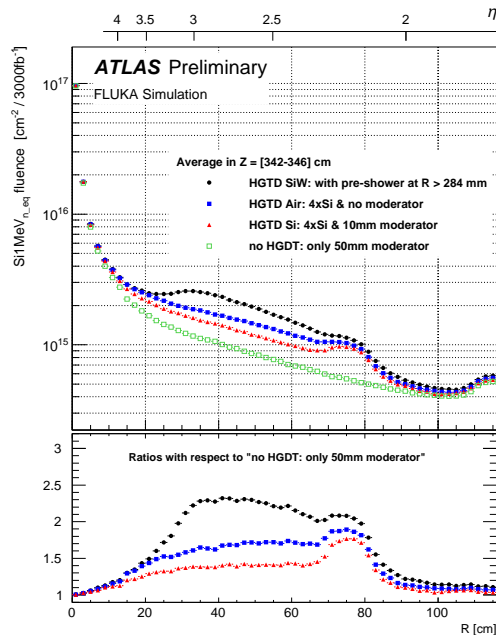


Figure 25: Comparison of the 1 MeV Si equivalent non-ionisation energy loss ($NIEL_{Si}$) in the ITk region close to the endcap for three alternative HGTD layouts with respect to the baseline configuration without the HGTD, but 50 mm of borated polyethylene all over the calorimeter endcap face. The histograms represent the HGTD-SiW option (black circles), with 3.5 mm thick tungsten plates between $R=284$ mm and $R=700$ mm, continued with borated polyethylene moderator of the same thickness down to $R=110$ mm. The HGTD-Si option with the tungsten replaced by borated polyethylene (red triangles), giving a total of 10 mm moderator over the full radial range of the HGTD and the HGTD-Air option with no moderator inside the detector (blue squares). The fourth histogram (green open squares) shows the baseline case with 50 mm moderator and no HGTD. No safety factor for the simulations are included in these figures. No safety factor is applied for the simulation.

1651 4.3.1 Constraints

1652 As discussed in the overview section, the space allocated to the HGTD in the present ATLAS experiment
 1653 is quite limited and defines some of the HGTD geometrical parameters as shown in Figure 28.

1654 • Overall Rapidity Coverage :

1655 The rapidity coverage has been chosen to cover the region of the forward calorimeter and the EM
 1656 endcap inner wheels where the calorimeters themselves have less segmentation and the rates are
 1657 highest. The baseline coverage is: $2.4 < |\eta| < 4.2$. This corresponds to a radial extent ⁶ from 110 mm
 1658 to 650 mm at about $z=3.5$ m. The inner radius is constrained by a conflict during the endcap
 1659 cryostat opening with a pump located on the beam pipe. The outer radius has been selected to cover
 1660 the EMEC inner wheel, including the transition region between the two wheels, but an extension
 1661 at larger radius would be mechanically possible. The outer region of the HGTD ($R > 280$ mm,
 1662 $2.4 < |\eta| < 3.2$) in front of the EMEC might be equipped by tungsten layers to improve electron/photon
 1663 performance. Extending the tungsten layer to larger rapidity will deteriorate the performance of
 1664 jets reconstructed in the FCAL located about one meter more away the HGTD along the beam axis.
 1665 The inner rapidity extension should be easily replaceable by itself after a number of years due to

⁶ The active HGTD sensor region can start only at 120 mm

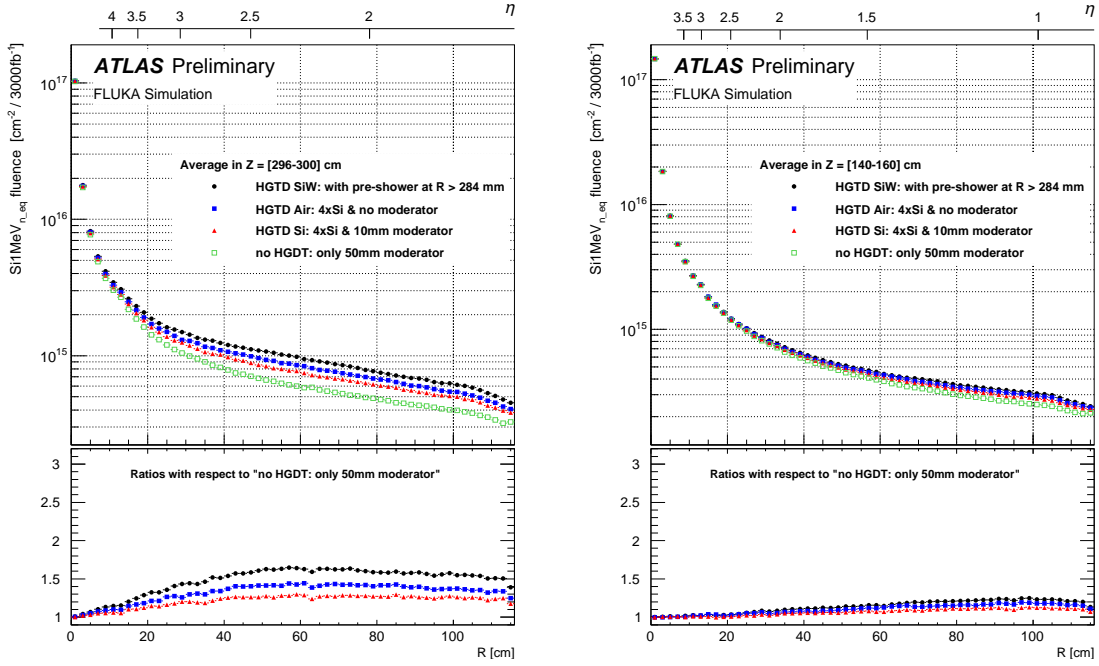


Figure 26: Comparison of the 1 MeV Si equivalent non-ionising energy loss ($NIEL_{Si}$) at $296 < z < 300$ cm (left), i.e. the location of the outermost ITk strip disk and half-way towards the IP at $140 < z < 160$ cm (right). The three alternative HGTD layouts are compared with the baseline configuration, i.e. no HGTD, but 50 mm of borated polyethylene all over the calorimeter endcap face. The histograms represent the HGTD-SiW option (black circles), with 3.5 mm thick tungsten plates between $R=284$ mm and $R=700$ mm, continued with borated polyethylene, the HGTD-Si option with the tungsten replaced by borated polyethylene (red triangles), giving a total of 10 mm moderator over the full radial range of the HGTD and the HGTD-Air option with no moderator inside the detector (blue squares). The fourth histogram (green open squares) shows the baseline case with 50 mm moderator and no HGTD. No safety factor is applied for the simulation.

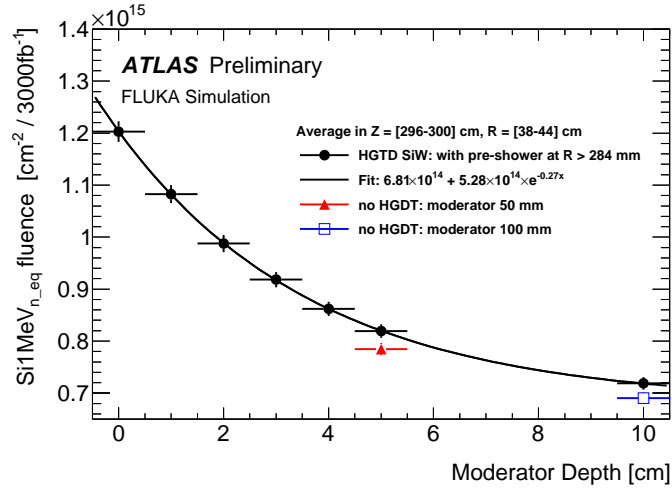


Figure 27: Non-ionisation energy loss (NIEL) in the ITk strips region as a function of the moderator thickness between the ITk strips and the HGTD-SiW detector. Each point is based on the simulation results of the same 5000 pp -events. The only parameter changed in the simulations is the moderator thickness. No safety factor is applied for the simulation.