PROCEEDINGS OF SCIENCE

A High-Granularity Timing Detector for the ATLAS Phase-II upgrade

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The High Luminosity Large Hadron Collider is scheduled to begin in 2027 where faster and more radiation hard detectors are needed to cope with higher track multiplicity and higher radiation levels. With a luminosity of $7.5\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ the average pile-up will be about 200 in the High Luminosity Large Hadron Collider, resulting in 1.8 vertices/mm on average. A powerful new way to address this challenge is to exploit the time spread of the interactions to distinguish between collisions occurring very close in space but well separated in time. In this context, timing information can be used to resolve the ambiguities. In a high pile-up event, multiple vertices will occur in the same z but, by adding timing information, vertices could be distinguished. A High-Granularity Timing Detector, based on low-gain avalanche detector technology, is proposed for the ATLAS Phase-II upgrade to mitigate pile-up effects and improve the overall ATLAS performance in the forward region by combining the High-Granularity Timing Detector high-precision time measurement with the Inner Tracker position information. The High-Granularity Timing Detector layout, including sensors and readout electronics are presented. The test beam results are discussed as well.

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1. Introduction

High Granularity Timing Detector (HGTD) is currently developed to upgrade the ATLAS detector [1] for Phase II. An increase in the number of collisions per bunch crossing at the high luminosity LHC (HL-LHC) [2], brings a further challenge for the ATLAS upgrade. The HGTD will improve the ATLAS capability in the forward region (2.4<$|\eta|$<4.0), by mitigating the impact of the pileup. The resolution of the longitudinal trajectory impact parameter (Z_0) must be better than the average distance between interaction points (0.6 mm for HL-LHC). The Z_0 resolution is well below this limit in the central region, but becomes very large in the forward region, reaching up to 5 mm for particles with low transverse momentum (p_T) as seen in Fig.1. HGTD secures performance in the forward region: with a per-track time resolution (30 ps at the beginning and 50 ps at the end of the detector lifetime), it produces accurate time information which allows an extra dimension, time, to resolve the hard scattering vertex and consequently attenuates the pile-up's impact.

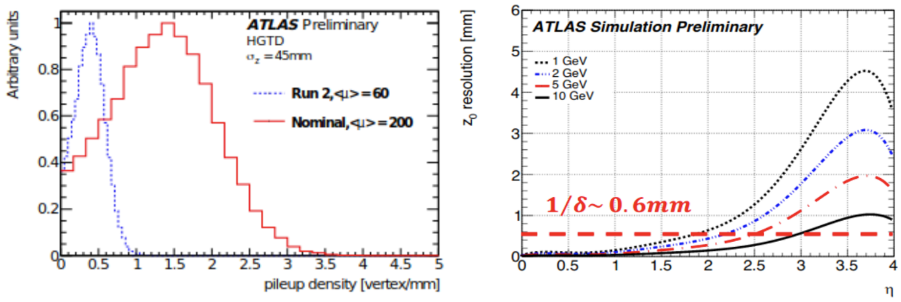

Figure 1: Left: Current and HL-LHC local pileup vertex density. Right: The resolution of the longitudinal track impact parameter, Z_0, as a function of η for different p_T values [3].

2. HGTD Layout

The fundamental unit of the HGTD is the hybrid module, composed of 30 ×15 pixel sensor connected via bump bonding with two ASICs. It is made up of: a bare module, with a flexible printed circuit board, linking it to the peripheral electronics. The modules are hosted on support units to facilitate the assembly process.

Due to the limited space available in ATLAS, HGTD will be installed in front of the LAr calorimeters (about 3.5 meters from the interaction point), and its radius will be between 11 and 100 cm. Each vessel contains two double-sided layers (each layer has modules on both sides) and two moderators, in a way that the modules partially overlap by 20% for r > 470 mm, 54% for 230 mm < r < 470 mm and 70% for r < 230 mm (covering a region of pseudorapidity 2.4< $|\eta|$ <4.0). Through this ring structure, it is easiest to replace the smaller radius sensors, which are those most damaged by the radiation. At 1 000 fb^{-1} the inner ring will be replaced, the middle one every 1 000 fb^{-1}, while the external one will be conserved. This will lead to a dose below $5\times10^{15} n_{eq}/cm^2$ received by each sensor.

3. Sensors and readout electronics

The HGTD sensors will be fabricated using low-gain avalanche detector (LGAD) technology [4]. It consists of n-over-p silicon detectors equipped with a highly doped layer that creates an internal gain. To reach this gain, an extra highly doped p-layer placed below the p-n junction, as shown in Fig.2, this creates a very high electric field region due to this heavily doped region. An avalanche of electrons is created by this field, producing additional electron-hole pairs. The HGTD technical design report [3] contains the analysis results of LGAD sensors from different suppliers (CNM, HPK, FBK, and recently NDL) with their different characteristics, 1.3 mm × 1.3 mm was chosen as basic pixel size, with 50 µm active thickness.

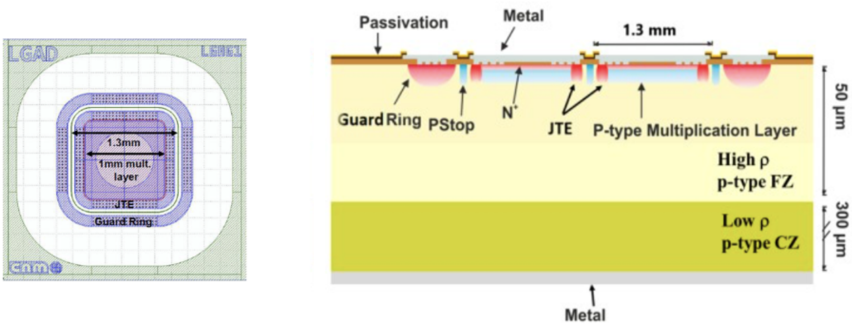

Figure 2: One single pad LGAD sensor produced at CNM and working principle of LGAD sensor [5].

The LGAD signals are collected and processed by an ASIC-based readout called ALTIROC, which should keep the intrinsic excellent time resolution of LGAD. The electronics contribution to the time resolution is presented by :

$$\sigma^2_{\text{elec}} = \sigma^2_{\text{jitter}} + \sigma^2_{\text{TimeWalk}} + \sigma^2_{\text{TDC}},$$

where σ_{jitter} depends on the noise and the pulse slope.

Each pixel readout channel (Fig. 3) will include a preamplifier plus a discriminator, in order to generate two time measurements per LGAD: Time Of Arrival and Time Over Threshold. ALTIROC will also generate tracking information and hit counts for luminosity measurements. The timing accuracy goal of ASIC is 25 ps per channel.

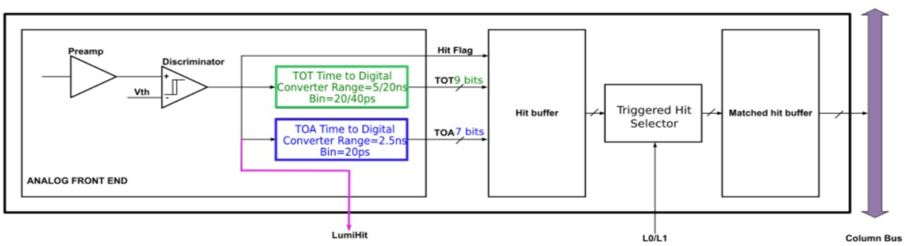

Figure 3: Schematic of a single pixel readout [3].

4. HGTD test beam results

A laboratory study and beam tests have been realized, in order to evaluate the performance of the sensor, before and after the irradiation. According to the Fig.4 (left), we note a decrease in time resolution until the gain of 20, in this phase, the increase in gain does not improve the time resolution and the Landau fluctuations become dominant. The same figure illustrates that it is possible to achieve a time resolution better than 30 ps for a non-irradiated sensor.

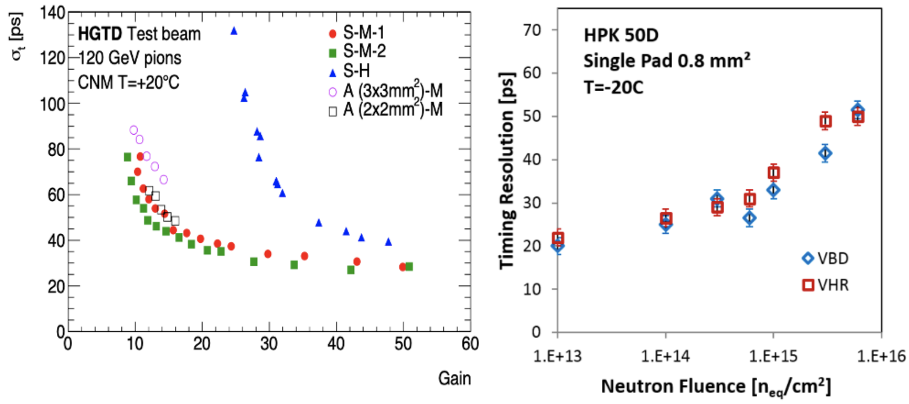

Figure 4: Left: The time resolution as a function of the gain for single pads and arrays is presented. Right: The Time resolution of an LGAD pixel as function of the neutron fluence [5].

It also needed to investigate the time resolution after irradiation as well, because the operation of HGTD will be in a high radiation environment. It can be observed that it degrades, as shown in Fig.4 (right), and this is caused by a decrease of the gain due to the waste of the effective doping concentration in the duplicate layer, we can also notice that at high fluence, there is no difference between a device with and without an amplification layer, but a gain is observed due to the creation of deep effective acceptors by the irradiation. By the end of the HGTD operation, the maximum neutron equivalent fluence is estimated to be $9\times10^{15}n_{eq}/cm^2$, corresponding to 50 ps at the time resolution level. Therefore, with three effective layers at low-radius and two layers elsewhere, time resolution can be preserved in 30 ps during HGTD operation.

5. Conclusion

To deal with the effect due to the increase in pile-up at the HL-LHC, a High Granularity Timing Detector was proposed for ATLAS upgrade. An LGAD technology and an ASIC readout will be used in order to achieve 30 to 50 ps of precision. Over the last few years, several prototype tests have been performed, including beam tests, as well as physics performance, which are documented in the technical design report [3].

PoS(LHCP2021)176

References

[1] ATLAS Collaboration,*The ATLAS Experiment at the CERN Large Hadron Collider*. JINST 3 (2008) S08003. URL: https://cds.cern.ch/record/1129811/files/jinst8_08_s08003.pdf

[2] G. Apollinari et al., *High-Luminosity Large Hadron Collider (HL-LHC): Technical Design Report V. 0.1*, URL: http://cds.cern.ch/record/2284929

[3] ATLAS Collaboration, *Technical Design Report: A High-Granularity Timing Detector for the ATLAS Phase-II Upgrade*,CERN-LHCC-2020-007, URL: https://cds.cern.ch/record/2719855

[4] G.Pellegrini et al., *Technology development sand first measurements of Low Gain Avalanche Detectors (LGAD) for high energy physics applications*, Nucl. Instrum. Meth. A765 (2014)12-16, URL: http://apachepersonal.miun.se/~gorthu/LGAD/Technologydevelopmentsandfirstmeasurementsof LowGain.pdf

[5] L.Masetti,et al.,*Beam test measurements of Low Gain Avalanche Detector single pads and arrays for the ATLAS High Granularity Timing Detector*, JINST 13 (2018) P06017, URL: https://cds.cern.ch/record/2313951?ln=en