

# Assembly and Testing of Detector Modules for the ATLAS High-Granularity Timing Detector

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## Why timing?

The High-Luminosity LHC (HL-LHC) will operate at instantaneous luminosities of up to  $7.5 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$  and deliver an integrated luminosity of the order of  $4000 \text{ fb}^{-1}$ . The result is an average of  $\langle \mu \rangle \approx 200$  inelastic proton–proton interactions per bunch crossing, against the  $\langle \mu \rangle \approx 50 - 60$  in Run 3. Assigning a track to its production vertex, the operation underlying essentially every physics-object definition, therefore becomes much harder, especially in the forward region.

The way out is to add a fourth coordinate. Collisions within one bunch crossing are spread in time with an r.m.s. of about 180 ps, so a per-track time measurement with a resolution of a few tens of picoseconds separates vertices that are unresolvable in  $z$  alone. This is the task of the ATLAS High-Granularity Timing Detector (HGTD), a silicon timing detector installed in front of the liquid-argon end-cap calorimeters at  $|z| \approx 3.5 \text{ m}$ , covering  $2.4 \leq |\eta| < 4.0$ . Its requirement is a per-track resolution of 30 ps at the start and 50 ps at the end of the HL-LHC [1].

## The detector and its modules

Each HGTD end-cap consists of two double-sided layers, for a total of 8032 modules and about 3.6 million readout channels of  $1.3 \times 1.3 \text{ mm}^2$ . A module is built from two hybrids and one flexible printed circuit, the module flex. A hybrid is a Low Gain Avalanche Diode (LGAD) of  $15 \times 15$  pads and  $50 \mu\text{m}$  active thickness, bump-bonded to the ALTIROC front-end ASIC. The LGAD is an n-in-p diode with an extra p-doped gain layer, whose moderate internal gain of 10–20 produces the fast rise time and large signal-to-noise ratio behind the excellent time resolution; the ASIC digitises time-of-arrival and time-over-threshold with an electronics jitter below 25 ps at 10 fC. The module flex is glued on top of the two hybrids and wire-bonded to the sensors (bias voltage) and to the ASICs (power and signals).

## Module assembly and quality control in Mainz

The 8032 modules of the HGTD have to be built, and every one of them has to be tested multiple times before it goes into the detector. Mainz is one of the assembly sites and will deliver about 1000 modules and 50–60 detector units. We are currently in preproduction,

