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

Poster prize talk 1
High Luminosity LHC (HL-LHC)

- HL-LHC is foreseen to start running in ~ 2028.
- Instantaneous Luminosity: $L \approx 7.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
- Integrated Luminosity (10 years): $L \approx 4000\text{ fb}^{-1}$
- Up to 200 p-p interactions per bunch crossing.

Pileup: one of the main experimental challenges during HL-LHC

Difficult to well separate pile-up jets from Hard scatter jet

Integrated Luminosity (10 years): $L \approx 4000\text{ fb}^{-1}$
To mitigate the high pileup effect, the ATLAS detector will be upgraded: ITK+HGTD

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<th>ITK (Inner Tracker)</th>
<th>HGTG (High Granularity Timing Detector)</th>
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<td>* Extended pseudo-rapidity: $</td>
<td>\eta</td>
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<td>* Better position resolution on tracks in the central than in the forward region.</td>
<td>* High-precision time measurement: 30 - 50 ps time resolution per track.</td>
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<td>* Assign time to each track in the forward region: $2.4 &lt; \eta &lt; 4.0$</td>
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<td>* Improve pileup rejection and correct track-to-vertex association.</td>
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Hybrid bare module: 2 LGADs bump bonded to 2 ASICs.
Low Gain Avalanche Diode (LGAD)

- n-p Si detector with an additional thin (<5 µm) and highly doped $10^{16}$ p-type multiplication layer with a high E field providing an excellent time resolution: <30 ps before irradiation.
- HGTD prototypes are produced by CNM (Spain), HPK (Japan), FBK (Italy) and NDL (China).

Pad size of 1.3×1.3 mm$^2$, 5 µm thickness ensures:
- Small dead areas between pads.
- Low sensor capacitance.
- Configurable in arrays.

HGTD Front-End Electronics

- Signal from each LGAD will be read out using the ATLAS LGAD Timing Readout Chip (ALTIROC) ASIC: Integrated chip $2 \times 2$ cm$^2$
- Design
  - Readout Channel=
    - Analogue( Preamplifiers, Time Of Arrival TOA, Time Over Threshold TOT CFD) +
    - Digital (data buffer and transmission).
- Requirements
  - $\sigma_t < 25$ ps
  - Threshold: 2 fC.
  - Minimise noise and power consumption
  - Digitised measurement of TOA and TOT
  - TOT correction minimises $\sigma_{walk}$ contribution to
  - Hit counting for luminosity measurements
- Utility
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Radiation Hardness

- Radiation tolerance: $2.5 \times 10^{15}$Neq/cm$^2$, 2MGy
- The operating voltage in each HGTD section has to be increased to compensate for the radiation damage.

The sudden changes at 2000 fb$^{-1}$, 3000 fb$^{-1}$ and 4000 fb$^{-1}$ are due to the replacement of the inner and middle rings.
- Time resolution $\sigma_t$ improves after the rings replacements.
Performance measurements of LGAD sensors

Laboratory

$^{90}$Sr is used to characterise the LGAD response to minimum ionising particles (2 MeV electrons).

Scanout boards

3D printed support

Better than 70 ps time resolution is obtained at 4 fC for all the sensors at different fluences.

Test Beam

Data collected with 120 GeV pion beam (CERN SPS) and 5 GeV electron beam (DESY).

- Hit efficiency defined as hits on sensor with > 2 fC. Response is ~100% in the active area.
- At higher bias voltages, all sensors satisfy the HGTD requirements.

HGTD physics enhancement

Simulation results have shown good object reconstruction and physics performance by adding HGTD to ITK:

- Pileup-jet rejection:
  - increases by a factor of 1.4 (for 85% efficiency)
- Lepton isolation:
  - Efficiency increases up to 25 %.
  - HGTD removes majority of pileup deterioration
Summary

• HGTD is expected to start data taking in 2028 and will be the first large-scale application of LGAD technology to highly reduce pileup in the forward region of the ATLAS detector during the HL-LHC physics program.

• LGADs and their readout ALTIROCs are optimised to reach a $\sigma_t < 50$ ps per track up to the end of lifetime.

• Measurements of LGAD sensors from laboratory and test beams have shown promising results.

• Simulations have shown great improvement in HL-LHC physics performance by adding the HGTD to the ITK.

Reference