ATLAS High Granular Timing Detector
Conceptual design and R&D

L. Serin on behalf of the ATLAS collaboration

- Detector location & requirements
- Sensor R&D
- Electronics R&D
- Conceptual design and on going optimisation
- Conclusion
Minimum Bias Trigger Scintillator (MBTS)
2.1 < \eta < 3.9
Z = +/- 3.5 m
\Delta Z = 5 cm (2 scint +3 cm moderator)
Operational up to 2018
Proposed HGTD:
Radially constrained by ITk/HGTD services (64cm) and pump (12cm)
2.4 < η < 4.0
Thickness constrained to ΔZ = 7.5 cm (+ 5 cm moderator)
Detector with individual planar layers (modularity/installation)
Preliminary HGTD construction schedule
Schedule is assuming a TDR end 2018, a approval by LHCC mid 2019 so that CORE money can start to be used end 2019 for pre-production.
Most critical components will be sensor and ASIC.
DR schedule slightly modified (next slide) does not include a second iteration on ASIC before pre-production.

Evaluate impact of ASIC iteration on a second version of schedule

Proposed HGTD:
Radially constrained by ITk/HGTD services (640mm) and pump (120mm)
2.4 < \eta < 4.0
Thickness constrained to \Delta Z = 75 mm (+ 50 mm moderator)
Detector with individual planar layers (modularity/installation)

Requirement of 30 ps time resolution per mip during HL-LHC running

- Excellent timing sensor \rightarrow \text{Thin LGAD}
- Excellent Front End Electronics \rightarrow \text{Dedicated ASIC ALTIROC}
Expected radiation levels

- Max neutron fluence / dose after 4 ab⁻¹, including safety factors:
  - At r=12 cm \(9 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2\) and 9 MGy
  - \(~20\%\) of sensors + ASICs (r<30 cm) need replacement at 1/2 life time of HL-LHC

  \[\Rightarrow \text{max. doses: } 4.5 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2 \text{ and } 4.5 \text{ MGy (r < 30 cm)}\]
  \[4.0 \times 10^{15} \text{n}_{\text{eq}}/\text{cm}^2 \text{ and } 2.1 \text{ MGy (r > 30 cm)}\]

- No safety factor applied in these plots
  - 1.5 for simulation
  - x 1.5 for ASIC

Radiation
  \[\Rightarrow \text{Operation at } -30^\circ\text{C}\]
  \[\Rightarrow \text{C02 cooling}\]
Thin LGAD

Standard n-p silicon diode with an extra highly doped p layer
- Moderate gain ~20 with respect to pin diode
  → increase signal and keep sensor noise limited

- Thin detector:
  → better radiation hardness and short rise time
  (smaller jitter and Landau fluctuation)

A lot of work done with the RD50 collaboration and with 3 possible vendors: CNM, HPK and FBK

Tests with different fabrication technologies, different structure, doping level, pad size before and after irradiation …..
Unirradiated sensors performance (50 µm LGAD)

Breakdown and gain depends on multiplication layer doping
Gain up to 50 achieved but target is 20
Uniform over pads
Time resolution:
- 25 ps at large gain (Landau term dominated).
- 35-40 ps at G=20
- Similar performance HPK/CNM

HGTD publication to be submitted to JINST in December
Irradiated sensors performance (50 µm LGAD)

G. Kramberger et al, to be submitted

Radiation damage:
- Trapped of charge carriers (→ thin sensor)
- Increase of leakage current (→ -30 °C)
- Modification of effective doping concentration
  → modification of multiplication layer
  → Reduction of gain thus increase of time resolution. Partially mitigated by larger bias voltage

Time resolution:
- Operate at safe bias voltage / breakdown
- Achieved 50 ps up to $6 \times 10^{15} n_{eq} / cm^2$ at -20 °C

On going R&D
- Improving radiation hardness (Ga/B, C spray)
- Thinner LGAD 35 µm (excellent first measurements)
- Improving fill factor
Electronics

Broadband preamplifier common source configuration followed by fast discriminator and TDC (vernier lines)
- TOA measurement (20 ps) + TOT measurement (40 ps) + local FIFO until L0/L1
TSMC CMOS 130 nm
Electronics

Single pixel

Data formatting/ suppression + rate average

225-channel ASIC to readout 2 x 2 cm² sensors made of 15 x 15 pixels of 1.3 mm x 1.3 mm

Luminosity block: provides hits in 3 ns window centered on bunch crossing and outside the window at 40 MHz

Dedicated back end
ALTIROC Front End ASIC

ALTIROC0: 4 channels only analog part

ALTIROC1: 25 channels with full single pixel readout (analog+TDC+FIFO)

to be submitted in Feb 2018, and bump bonded to sensor Q3/1018

25 ps for one mip (10 fC at G=20)

→ Noise to be improved and bandwidth too small
→ New version in building block submitted in December

Has been bump bonded to LGAD and exposed to beam
Total HGTD CO2 cooling for 4 layers/side: 20 kW

1.4 m² LGAD sensor area per layer
Module / stave definition still to be optimized
Thermal conductivity/ overlap /modularity
→ Technical prototypes in Q18

Thin plate with pre-assembled modules (bolted to cooling plate)

Cooling & Local support panel

Longest “stave” (2x15 modules in recto & verso)
Optimisation towards final baseline design

Sensor size (4x2 cm²):
- fitting the inner radius
- sensor yield and flip-chip yield
- unique sensor size

Granularity (1.3x1.3 mm²):
- occupancy < 10 %
- Time resolution (detector capacitance)

Number of layer:
- Dead area / efficiency
- Time resolution after irradiation

<table>
<thead>
<tr>
<th></th>
<th>Two layers</th>
<th>Three layers</th>
<th>Four layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{\text{hits}} \geq N_{\text{layers}}$</td>
<td>86%</td>
<td>82%</td>
<td>78%</td>
</tr>
<tr>
<td>$N_{\text{hits}} = 0$</td>
<td>0.5%</td>
<td>0.11%</td>
<td>0.07%</td>
</tr>
<tr>
<td>$\langle N_{\text{hits}} \rangle$</td>
<td>2.04</td>
<td>3.08</td>
<td>4.1</td>
</tr>
<tr>
<td>$\langle \sigma_t \rangle$</td>
<td>43 ps</td>
<td>37 ps</td>
<td>32 ps</td>
</tr>
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</table>

< 1 % geometrical inefficiency for 2 layers
From 32 ps to 43 ps at worse radiation level radius assuming 60 ps/hit

Integration:
- Half disk/vessel for easier installation
- Inner module wheel

→ 2 (3) hits at large (small) radius might be a good compromise
Conclusion

Intensive R&D since organised activity started mid 2015

→ 30 ps time resolution for mip over HL-LHC period looks feasible but still R&D on sensors and electronics to validate it

Overall detector design under optimisation to find the best trade-off between performance, construction/installation complexity/schedule and cost (to be provided in Technical Proposal in April 2018)

A highly motivated community (~20 institutes from 7 countries) is willing to build it for Phase II and improve the ATLAS detector performance under the harsh HL-LHC environment.
Back up
HV along radius
Expected sensor alone time resolution at HL-LHC
Preliminary performance with 35 µm LGAD
Pulse shape with irradiation

Fluence
## Main HGTD parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudorapidity coverage</td>
<td>$2.4 &lt;</td>
</tr>
<tr>
<td>Position in $z$</td>
<td>$3420 &lt; z &lt; 3545$ mm including 50 mm of moderator</td>
</tr>
<tr>
<td>Position of active layers</td>
<td>$3435 &lt; z &lt; 3485$ mm</td>
</tr>
<tr>
<td>Radial extension (active area)</td>
<td>110–1100 mm (120 mm–640 mm)</td>
</tr>
<tr>
<td>Time resolution of HL-LHC running</td>
<td>30 ps / MIP</td>
</tr>
<tr>
<td>Pixel size</td>
<td>1.3 $\times$ 1.3 mm$^2$</td>
</tr>
<tr>
<td>Number of layers</td>
<td>2–4 per side</td>
</tr>
<tr>
<td>Number of channels</td>
<td>3.15 (6.3M)</td>
</tr>
<tr>
<td>Number of Si sensors (2 $\times$ 4 cm$^2$ each)</td>
<td>6976 (13952)</td>
</tr>
<tr>
<td>Number of ASICs (2 $\times$ 2 cm$^2$ each)</td>
<td>13952 (27904)</td>
</tr>
<tr>
<td>Total Si active area</td>
<td>5.6 m$^2$ (11.2 m$^2$)</td>
</tr>
</tbody>
</table>
A 4-layer design would fit in the allocated thickness but strict tolerance required.
Number of layers/performance/cost on going optimisation

0.5 % geometrical inefficiency for 2 layers
From 32 ps to 43 ps at worse radiation level radius assuming 60 ps/hit
CO2 cooling

<table>
<thead>
<tr>
<th>Component</th>
<th>Power</th>
<th>Total (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensor</td>
<td>&lt; 20 mW/cm²</td>
<td>2.23</td>
</tr>
<tr>
<td>ASIC</td>
<td>&lt; 200 mW/cm²</td>
<td>15.2</td>
</tr>
<tr>
<td>Flex cable</td>
<td>25 mW/flex</td>
<td>0.35</td>
</tr>
<tr>
<td>HGTDM cold vessel heaters</td>
<td>&lt; 100 W/m²</td>
<td>&lt; 0.9</td>
</tr>
<tr>
<td>EC calo cryostat heaters</td>
<td>120 W/m², 50% up to $R = 1600$ mm</td>
<td>&lt; 0.6</td>
</tr>
<tr>
<td><strong>Total for CO2 cooling</strong></td>
<td></td>
<td><strong>19.2</strong></td>
</tr>
<tr>
<td>Off-detector electronics</td>
<td>30% of ASICs power consumption</td>
<td>5</td>
</tr>
</tbody>
</table>
HGTD integration

Moderator Extended brackets for HGTD bolting to EC Lar Calorimeter

Calo Heaters on the cryostat front wall

CO2 return pipes

Off detector electronics

CO2 capillary inlet

Neutron poly-moderator (inside & outside cold vessel)

Central Warm tube of the End Cap calorimeter (Rin=180.mm)

HGTD global positioning in the ATLAS coordinates system, using EC Calorimeter central warm tube

12 existing M8 threads for extended brackets bolting (at R=900.mm)
HGT D integration

- Front cover with over-pressure stiffeners
- Outer ring with service feedthroughs (not shown)
- MBTS threaded holes to be used for HGT D bolting on the cryostat wall
- Inner ring holding high performance thermal shield for beam pipe bake-out
- 30mm moderator inside cold vessel holding detector layers & electronic boards (not shown)
- Back cover
- 20mm moderator outside the HGT D vessel