order of a few tens of pico-seconds is being considered as a way to mitigate these pile-up effects (see Section XI.2.7). Precision timing would allow the association of clusters in the calorimeter to a small area of the luminous region around the primary vertex, and a combination of timing and precision position information would enable ATLAS to develop algorithms for local pile-up subtraction on an event-by-event basis in the reconstruction of topological clusters and jet constituents, as shown in Section XI.

V.5.1 HGTD in the gap between the LAr barrel and end-cap cryostats

The gap between the barrel and end-cap cryostat will be occupied by the ITk services, the ITk end-plate, and a poly-boron shield, as shown in Fig. 44.

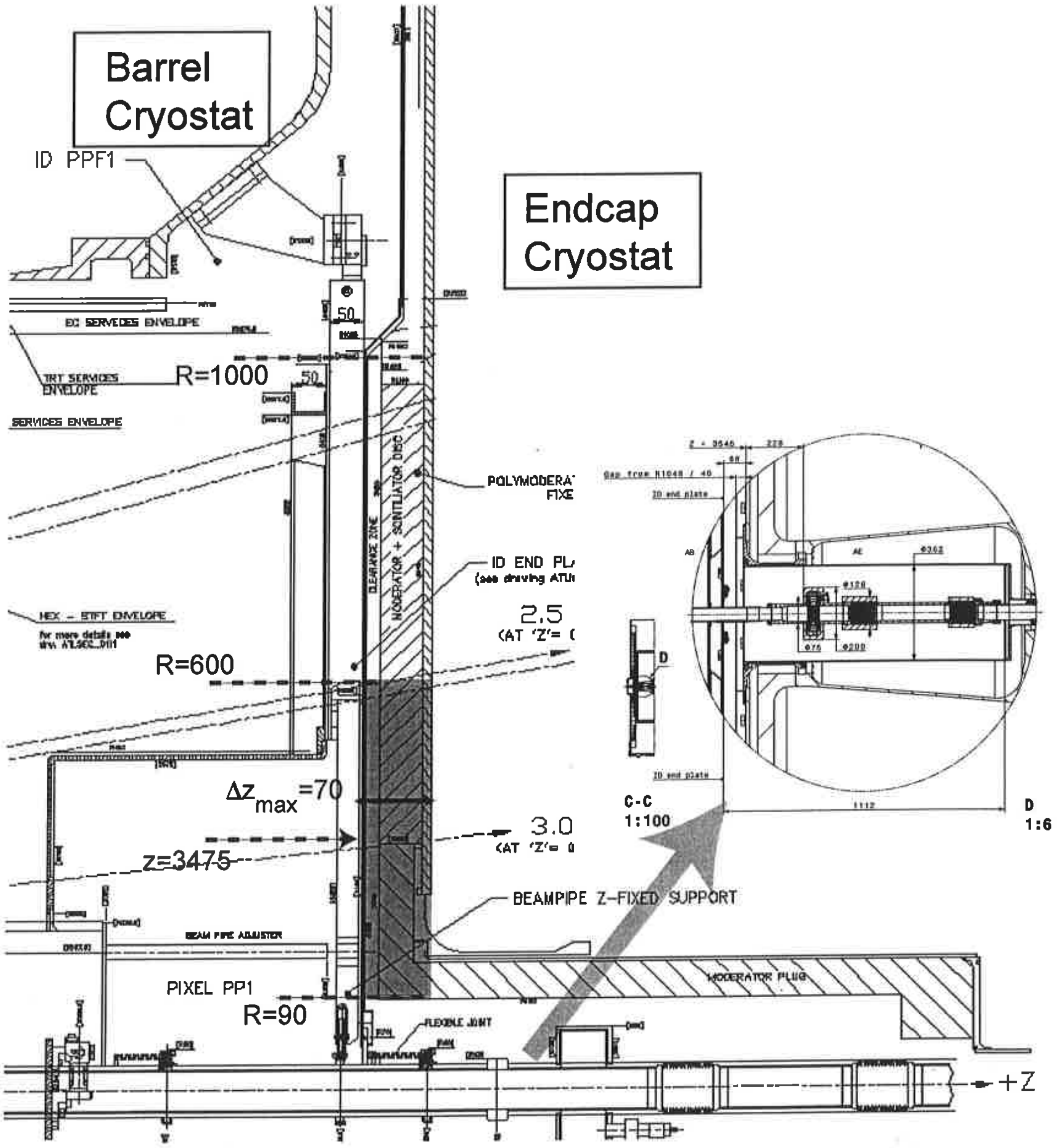

Figure 44. Cross-section of the ATLAS experiment and transition between the barrel and end-cap cryostats.

The distance between the ID end-plate (z=3458 mm) and the end-cap cryostat walls (z = 3548 mm) is $\Delta z = 90$ mm.

A reconfiguration of the region is possible considering that the minimum bias trigger scintillators needs to be replaced for operations at the HL-LHC. Under investigation is the possibility of installing a new detector with high granularity and excellent time resolution, fitting within an envelope of $\Delta z = 60-70$ mm and extending radially between $R = 90-600$ mm, corresponding to $2.4 < |\eta| < 4.3$. A further extension to $|\eta| \simeq 5$, equivalent to a coverage down to $R \simeq 50$ mm, is also considered, but requires additional engineering and performance studies.

Also under consideration is an integrated silicon-based detector deployed in both the end-cap and forward regions. The use of a single technology for these two detectors would enable an integrated solution without an additional transition region.

V.5.2 Detector technologies under investigation

Different technologies are considered for an optimised performance in the region under consideration: Multi-Channel Plate (MCP)-based detectors, single-crystal or poly-crystalline diamonds, and different silicon-based detectors in different technologies.

A silicon-based option would benefit from synergistic R&D with the tracker community and with the technology chosen by the CMS collaboration, for their Phase-II e.m. end-cap calorimeter upgrade, and with the developments by the CALICE collaboration for the Si-W based ECAL calorimeter [50]. In the end-cap region 4-5 layers of silicon-detectors could be deployed in the volume described in Section V.5.1. Optionally, the active layers could be interleaved with W-absorbers to configure the detector as a pre-shower device (3-4 X_0) allowing for the conversion of photons and π^0's. In the forward region a MiniFCal could be designed as a fully absorbing e.m. calorimeter with up to 30 X_0 in 180 mm. Detailed simulation studies of both scenarios are needed to prove there is no impact on the performance of the LAr calorimeters sub-systems.

The NA62 collaboration [51] has reported a resolution of 260 ps of their GigaTracKer sensors, read-out by TDCpix ASICs, exposed on a beam-test. Furthermore, recent developments in Low-Gain Avalanche Detector (LGAD) [52] and High Voltage CMOS (HV-CMOS) sensors (e.g. see Ref. [53]) make these technologies interesting for this application, achieving time resolution of the order of 100 ps on small scale prototypes: the timing resolution is essentially determined by the Signal-to-Noise ratio (S/N) for MIP-like signals. In the case of LGADs S/N is boosted by adding a low-amplification layer in the silicon bulk structure, and in the case of HV-CMOS sensors, by dimensioning the pixel/pad to collect significant ionisation charges from an e.m. shower, while keeping the pixel capacitance and the electronics noise as low as achievable.

V.5.3 Time-line

In the upcoming years, intense simulation studies and R&D is required to optimise the performance of the HGTD and to develop the best sensor technology for this application, including test-beam campaigns. An combined IDR of the LAr calorimeter upgrade is envisaged for 2016 followed by a TDR in 2017. After finalising the design, the construction time is estimated to be 2 years, with final assembly and integration at CERN in 2023/2024. Installation is scheduled for the second half of 2025.

V.5.4 Cost Estimates

Table 20 summarises the CORE costs for the construction and installation of a HGTD in the LAr Calorimeter end-cap region. The cost estimates are based on LGAD sensor technology and assume

Table 20. CORE costs for a High-Granularity Timing Detector in the Reference cost scenario. No Timing Detector is being planned for the Middle and Low cost scenarios.

WBS ID	Upgrade Item	Reference [kCHF]
3.3	**HGTD**	**4,558**
3.3.1	Sensors and on-detector active electronics	1,921
3.3.2	Front-end readout	1,988
3.3.3	Back-end readout	450
3.3.4	Services	200

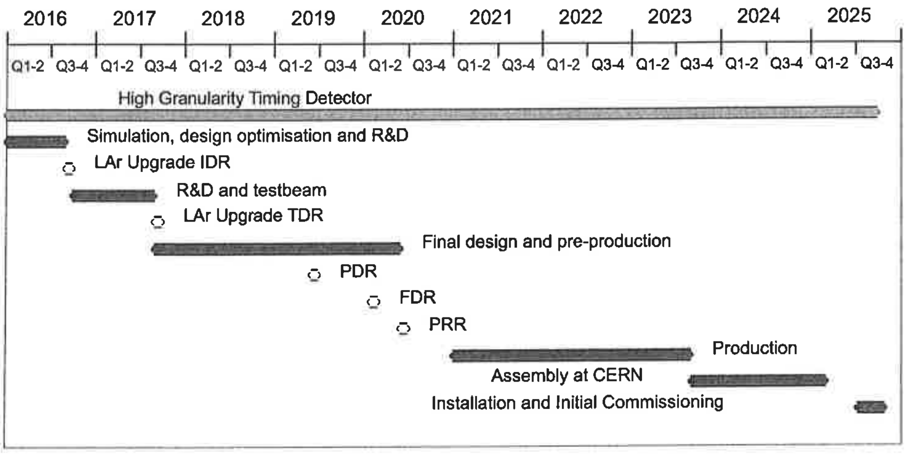

Figure 45. Overview of the time-line and milestones for the implementation of the HGTD.

that 9 m^2 of active detector area are equipped with a sensor granularity of 5×5 mm^2.

V.5.4.1 Cost Drivers and Cost Risk Analysis

The sensor and front-end readout costs are the main cost items of the HGTD. The cost uncertainties are therefore concerning

- the optimal sensor technology and the involved costs, which are currently based on LGAD detectors;
- the number of readout channels in the front-end and back-end in order to match the sensor granularity with the optimal performance.

V.5.5 Schedule and Milestones Summary

The R&D, production and installation schedule of the HGTD is summarised in Fig. 45, together with reporting and review milestones. The HGTD upgrade will be integral part of the overall LAr Phase-II IDR and TDR, planned for 2016 and 2017, respectively.