Abstract

This document provides a crude costing estimate for an upgrade of the ATLAS detector to exploit an increase by one order of magnitude in luminosity of LHC beyond the design value, as requested by the POFPA working group. Where possible, dependencies in the costing on the value of the bunch crossing frequency are indicated. Due to its crude nature and the very early stage in studies for upgrading ATLAS, this costing estimate has large uncertainties.
1 Introduction

In the following, first cost estimates for an upgrade of ATLAS are given, to be able to exploit the increase in luminosity of a future SLHC, as requested from ATLAS by the CERN POFPA (Physics Opportunities for Future Proton Accelerators) Inter-departmental working group. Three areas are distinguished, costs for an upgrade of the tracking detectors (which will have to be replaced to cope with the significant increase in particle flux), costs for improvements/replacements in the shielding and costs for upgrades possibly needed in other detector components. It should be noted that the cost estimate is not following strictly the CORE costing procedure. Due to the large numbers of modules expected in some areas, production in industry would likely be used and thus (partially) also labor costs have been included in the estimate. For modules to be produced in industry, the associated cost for production will have to be assessed more thoroughly, and presently this fact contributes to the uncertainties of the estimate. The cost estimate presented here addresses only the costs expected for the production, not for the R&D needed. The amounts quoted are estimates as of today; no estimate for inflationary corrections has been done.

2 Cost estimate of tracker upgrade

The cost estimate for the tracker upgrade is based on a straw man layout, and takes into account as much as possible the knowledge gained during the production of the present Inner Detector. At this stage, no detailed layout for an all silicon tracker exists, which has been optimized in terms of performance for pattern recognition vs. cost. It is already clear however that the system will contain several layers of pixel sensors closest to the beam pipe, followed by several layers of silicon strip type detectors, likely to be divided in two regions with different granularity. The exact parameters will have to be adjusted to match the increase in particle flux (i.e. occupancy for the present granularity) in order to be able to perform the tracking and vertexing necessary for good identification and reconstruction of high p_T objects at SLHC. Future results of detailed performance studies will provide more precise estimates of the granularity necessary (i.e. the channel count) as well as of the total surface area of a Si tracker.

2.1 Pixel detectors

The cost estimate is based on a total area of 3.5 m^2 for pixel sensors, arranged in 3 or 4 layers, where the innermost layer will have to be of a special, innovative nature due to the highest fluencies. The following breakdown of the production costs has been obtained:

- Modules: 11.0 MCHF
- Mechanical support: 3.0 MCHF
- Services: 2.7 MCHF
- Power supplies (HV,LV): 1.0 MCHF
- Readout: 1.5 MCHF
- Module Assembly: 2.5 MCHF
- Contingency/spares: 8.5 MCHF
- NRE: 2.3-3.8 MCHF
- Total of 32.5-34.0 MCHF

The costs of R&D have not been included in the above breakdown and are estimated to amount to 1.5 to 2.3 MCHF.

2.2 Strip detectors

In case of the strip detectors, a total area of 130 m^2 is assumed, divided into about 10000 (inner) ministrip detectors and about 100000 (outer) strip detectors. Assuming the same detector pitch for each detector type, about 100000 frontend chips are needed for each.

- Ministrip detectors: 11 MCHF
- Outer detectors: 11 MCHF
- Front-end electronics: 6 MCHF
- Module parts (hybrids, components): 17 MCHF
- Readout (optical) and local power cables: 5 MCHF
• Contingency/spares: 5 MCHF
• Services, power supplies: 10 MCHF
• Engineering and large scale supports: 30 MCHF
• Assembly costs: 20 MCHF
• Total of: 105 MCHF

As mentioned above, labor costs for engineering and assembly have been included in the cost estimate, to allow for industrial production. Also, the costs for R&D are not included and could amount to approx. 15% of the total cost.

2.3 Installation

Based on the present knowledge of the Inner Detector installation, an amount of about 10 MCHF will likely be needed for the cabling of the new tracker, including the tooling necessary (about one third of the costs).

3 Cost estimate of shielding upgrade

As at the time of writing this note, no concrete design for machine elements (moved closer to the IP) thus exists, no serious cost estimate is possible. Studies have been performed however on possible improvements on the shielding and the beam pipe, in order to reduce for the present interaction layout the background rates. Based on the costs for the present shielding and the present beam pipe, an estimate of 5 MCHF is obtained. This includes the extension of the Beryllium part of the beam pipe and modifications to the forward parts of the shielding. It has to be stressed that this estimate will have to be revised when a concrete interaction layout is proposed by the machine, where also services needed for the machine elements will have to be taken into account. If the need for a different shielding material (e.g. Tungsten) were to arise, the costs would be significantly larger.

4 Cost estimate on further upgrades, including electronics

In the following, several other components of ATLAS are discussed in view of possible modifications and upgrades needed for higher luminosity, indicating where already known differences exist for various bunch crossing frequencies.

4.1 Calorimetry

The forward region of the LAr calorimeter systems might need to be upgraded. Studies are being prepared to assess in detail at what extent it would require modifications and they should be compared to the impact on physics with a degraded response between $|\eta|=3.2$ and 4.8. It may affect either the FCAL detector whose complete replacement would have a core cost up to 3.5 MCHF and the HEC cold electronics which may not or may marginally survive neutron fluence at the expected SLHC rates. In case of need to transport a cryostat on the surface the overall costs and resources required will be at large extent influenced by all the operations to move and to do the actual upgrade.

The infrastructure for the LAr calorimeters will be kept. If no failures (in components) due to radiation (resp. lifetime or reliability) are to be expected and if the TTC clock can be scaled down (outside of the LAr frontend electronics boards), no upgrade of the LAr frontend-electronics is needed. Upgrades in the backend electronics (readout drivers) would be needed in both scenarios, e.g. to accommodate multiple sets of optimal filtering coefficients. The power supplies are tightly coupled to the front-end electronics. Changes however would have to be made in the back-end electronics, especially in the readout drivers (ROD). First cost estimates for a ROD replacement are about 5.5 MCHF and (if necessary) about 17 MCHF for the front-end electronics, together with corresponding power supplies.

For the Tile calorimeter, it is expected that there should be no need for upgrading the calorimeter, except for the gap and crack scintillators: These will have to be replaced after few years of LHC operation. Replacements of the TileCal electronics (including LV power supplies) would be needed only if the present front-end electronics fails under the radiation levels expected at SLHC and/or the electronics is not able to cope with all bunch crossing frequencies. A first crude cost estimate, on the basis of the 1995 CORE cost, is of the order of 10 MCHF where TileCal PMTs are not replaced. A more refined cost value is under evaluation.
4.2 Muon system

The operation and the performance of the trigger chambers, RPCs and TGCs, is directly related to the different scenarios for the bunch-crossing frequency. Both systems were designed for 40 MHz, and could operate up to about 45 MHz. If the bunch crossing frequency would be higher, and the electronics would have to operate at this frequency, all on-detector components would have to be rebuilt and installed (in a very labor intense operation). The costs involved would likely amount to several MCHF for each system, which is not considered presently to be our choice. The alternative option would be to operate the electronics at half of the bunch crossing frequency (e.g. at 40 MHz for 12.5 ns spacing), resulting in two sub-sequent bunch crossings not being identified for each clock cycle. However, for the RPC system, additional electronics (as discussed in the TDAQ part) could be added to recover the bunch crossing identification. In case of the TGC detectors, a modification to the local coincidence between wires and strips would allow as well to recover the bunch ID, with the need to build a new sector logic.

Under this scheme, the muon trigger system would work with 12.5 or 15 ns bunch interval with limited upgrade in the electronics. The choice of 12.5 ns is preferred, since the necessary modifications are minimal. The case of 15 ns bunch spacing is also possible but would involve more work (and costs). The upgrade cost, as discussed below, is included in the trigger and DAQ cost in Section 4.3.

Major modifications will be needed to accommodate a spacing of only 10 ns, and the bunch crossing identification based on the TGC detectors will be substantially degraded.

The precision chambers (MDT and CSC) could be operated with different values of the bunch crossing frequency. The front-end electronics has been tested up to 55 MHz, and substantial upgrades are presumably necessary for frequencies above 66 MHz. However, as for the trigger system, the read-out of the precision chambers could be driven at a frequency lower than the bunch crossing. This is already done in the current read-out scheme for the CSCs, driven at 20 MHz.

Irrespective of the bunch crossing frequency, the increased luminosity might demand an upgrade in band-width of the MDT read-out. This is related to the background rate, which will be known accurately only after the start-up of LHC, and which will depend on changes in the shielding and beam-pipe configurations, as discussed above in Section 3. The cost of an upgrade is roughly estimated to be about 2 MCHF. This includes the replacement of electronics in the regions of larger dose.

The issue of detector performance and stability under Super-LHC conditions is relevant for all muon detectors. For our system in particular, this is related to the background rates. Using an improved shielding, and assuming that present nominal background estimates are confirmed with first collision data, the detectors should substantially work, with limited loss of performance in the regions of highest rate. It is however possible that the detectors close to the beam pipe (inner and middle station) will have to be replaced with different ones. Furthermore, the question of ageing remains and needs to be studied further. These are subject for further investigations and are not included now in any cost estimate.

4.3 Trigger and DAQ

For the first-level trigger, very preliminary estimates suggest that a change in the bunch-crossing frequency to 80 MHz would imply costs between 5-10 MCHF, assuming that the present detectors (LAr, Tiles, RPC and TGC) can be retained. Going to values of 10 ns or 15 ns for the bunch spacing would result in further costs, likely to be at least twice as large as the above ones. It must be stressed that much more detailed studies would be needed before reaching conclusions on the feasibility of retaining the present detectors and some of the electronics (lifetime in high-radiation environment; detector time resolution; trigger background rates).

For the calorimeter trigger, the preprocessor will not operate at frequencies above the nominal bunch-crossing rate of 40 MHz and would have to be rebuilt. In addition, in this case also the links between the preprocessor and the cluster (CP) and jet-energy (JEP) processors would have to be rebuilt (as well as part of the logic inside the CP resp. the JEP would no longer work). Thus a complete replacement of the LVL1 calorimeter trigger would be the preferred solution to be considered.

In the case of the muon trigger, going to 12.5 ns would imply adding electronics cards to all so called high-pt PAD boxes mounted on the outer RPC detectors, which would be a sizeable manpower effort. For 10ns or 15 ns significantly more extensive modifications would have to be made involving both the high-pt and low-pt Pad boxes.
Concerning the TGC-based trigger in the end-cap region, only a bunch spacing of 12.5 ns could be used without hardware modifications to the electronics. At this stage it is not clear whether, in this scenario, the TGC intrinsic time resolution would be sufficient; this is even more doubtful for a spacing of 10 ns.

The interface of the muon trigger and the central trigger processor itself would likely have to be rebuilt. As discussed also below, large parts of the TTC system would have to be replaced in case of a bunch-crossing frequency different from 40 MHz.

It should be noted that the above estimates are very crude and in many areas the need for an upgrade will only be determined after operation of the trigger under real collisions.

Concerning the HLT and DAQ, for some components (e.g. the CPU farms) a 3 year replacement policy is foreseen already. This could be used to adapt the system (partially) towards the new challenges of SLHC. However some components (mostly custom made) will have to be replaced, e.g. the readout buffers. Presently an estimate of possible costs of 10 MCHF is assumed. To first order, HLT and DAQ will not be directly influenced by the value of the bunch crossing frequency.

### 4.4 Electronics

If the bunch crossing frequency were to change from 40 MHz to a different value corresponding to 10 resp. 15 ns, changes would be required in the TTC system, namely a replacement of all QPLL crystal oscillators. This could be a labor intense operation, likely requiring several months of work. Further issues could arise in all systems, where the system clock is derived from the LHC clock, such as in the back-end electronics (readout drivers) and the front-end links themselves. If the need were to arise to change the link technology, this would involve major costs (for both front-end and back-end electronics boards, necessitating complete redesigns).

### 5 Summary

This note presents the first cost estimate for upgrading ATLAS for an SLHC, following the request from the CERN POFPA working group. Due to the very early point in time in studies of an upgrade, large uncertainties are associated with this estimate. The largest fraction of the cost for an upgrade would be in the replacement of the present tracker (Inner Detector), where due to the need to rebuild the electronics no dependence on the bunch crossing value exists. The present estimate of the tracker upgrade costs is about 150 MCHF; additional upgrade costs for other components vary between values of 25 to 60 MCHF, with some areas of concern not yet addressed in this estimate. It has to stressed again that these estimate are of a very crude nature and do have large uncertainties. Finally it should be noted that the above estimate does not include the cost for R&D.