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COMPUTER SIMULATION OF THE COOL DOWN OF THE ATLAS LIQUID ARGON BARREL CALORIMETER

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A computer program simulating the cool down of the detector by calculating the local heat transfer throughout a simplified model has been developed. The program evaluates the cool down time as a function of different contact gasses filling the spaces within the detector.

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INTRODUCTION

To exploit the capabilities of the future CERN Large Hadron Collider (LHC) with colliding protons and heavy ions, four large particle detectors are being constructed. ATLAS [1] will include a liquid argon ionization sampling calorimeter [2] housed in three independent cryostats. The central cryostat, used by the electro magnetic barrel calorimeter, has a 45 m^3 liquid argon volume, and will be refrigerated by evaporating liquid nitrogen circulated through six heat exchangers placed in the liquid argon bath. Four of these heat exchangers will also be used for the cool down of the barrel calorimeter from room temperature to about 120 K, a process during which 7500 MJ has to be extracted from the system.

A simulation program has been developed to estimate the cool down time of the barrel calorimeter as a function of different gasses filling the gaps in the detector structure. This program calculates the cool down time of the detector under the condition that the temperature gradients across the overall structure of the detector and the cryostat should never exceed 50 K since this would give rise to unacceptable mechanical stresses.

THE BARREL LIQUID ARGON CALORIMETER

The barrel liquid argon calorimeter has a cylindrical geometry consisting from two identical wheels (see Figure 1). The calorimeter is divided in modules made of “accordion” shaped particle absorber plates alternating with copper electrodes. The absorbers are constructed from lead sheets sandwiched between stainless steel plates which are glued by a layer of adhesive. At the inner and the outer edge these sandwiches are encased in precision bars made of glass-fiber reinforced epoxy. These bars, referred to as the inner and outer bar, are fixed to stainless steel support rings in order to keep the absorber in place. Each calorimeter module is built from 64 of these radially arranged accordion-shaped absorbers and 16 of these modules are needed to complete a wheel.

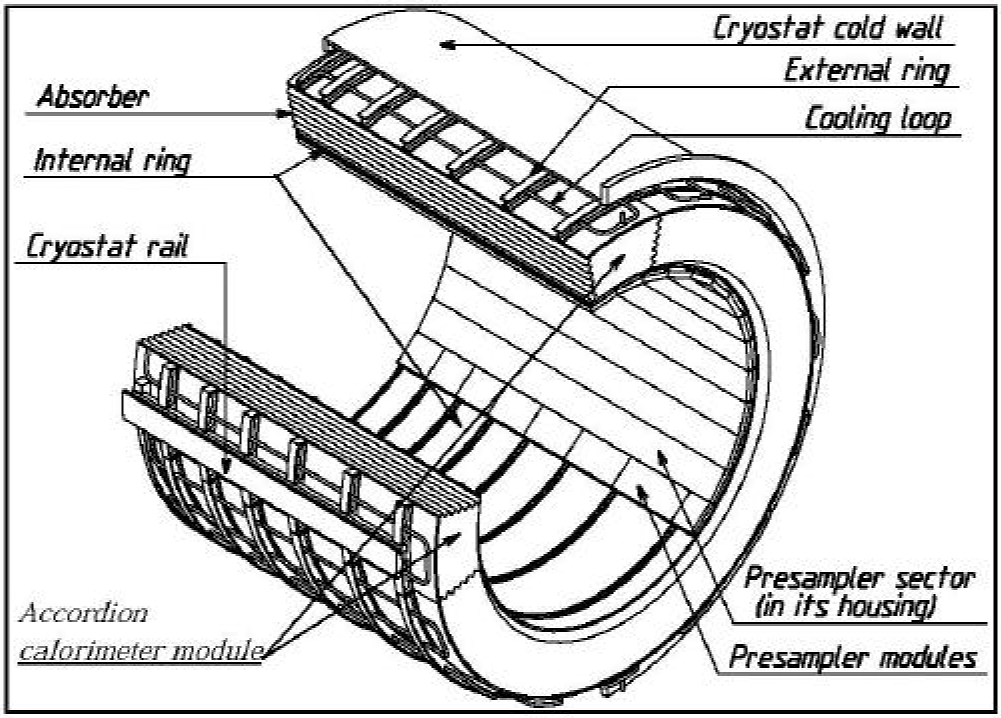

Figure 1 Layout of a barrel wheel

The presampler acts as a thin (11 mm) active layer of liquid argon, which provides a first sampling of the showers in front of the accordion electromagnetic calorimeter. It is formed by 32 identical sectors per wheel fixed to the inside of the internal ring. It is built from thin glass epoxy shells.

The accordion calorimeter and the presampler require about 120000 signal and calibration cables crossing the liquid argon bath towards the signal feed troughs. During cool down these cables locally prevent the free convection of the filling gas present in the detector structure.

THE SIMULATION MODEL

The cool-down of the barrel liquid argon calorimeter is a transient heat transfer problem in three dimensions. The heat is transferred by conduction, convection and radiation. A simplified model was developed in order to simulate the complex thermal behavior of the cool-down process. The model used for the calculations has been based on the following assumptions:

- The temperature distribution in the tangential and longitudinal direction of the barrel will be uniform thus reducing the simulation to a one-dimensional case.
- The gas located in the calorimeter is assumed to be confined in three independent volumes (see Figure 2): volume between outer cold vessel wall and outer glass fiber epoxy bar (outer gas gap), volume between inner glass fiber epoxy bar and the presampler (middle gas gap) and the volume between the presampler and the inner cold vessel wall (inner gas gap).
- The cryostat cold vessel is assumed to be built from two independent parts: the outer cold vessel and the inner cold vessel. The end walls of the cryostat cold vessel are integrated as part of the outer cold vessel. The heat leak into the cryostat outer cold vessel is assumed to have a linear temperature dependence.
- All cables are placed in the outer gas gap, locally preventing the free convection in this area. The heat conduction by the cables is neglected.
- Heat transfer by radiation is neglected.
- The cooling power of the heat exchangers will stay constant during each cool down calculation.
- The gas pressure in the cryostat is assumed to be constant over the cool down.

- The calculations are made in time steps (0.7 seconds) during which all thermal properties are assumed to be constant

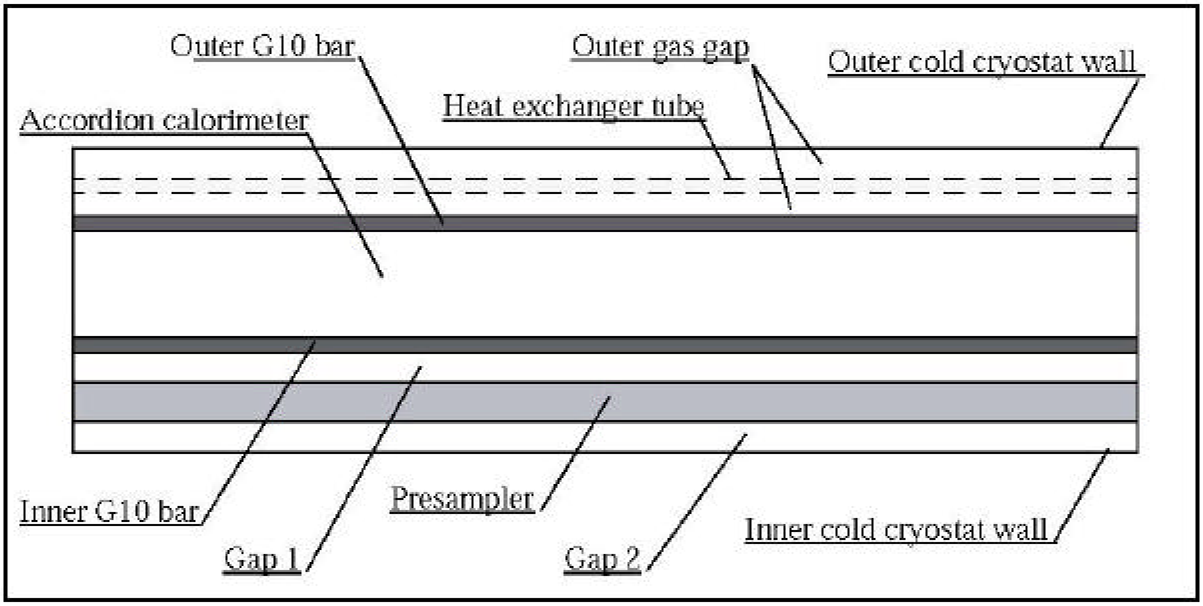

Figure 2 Cross section of the barrel model in longitudinal direction, showing the top half of the model

THE COOL DOWN SIMULATION

The model for simulation of the cool down of the barrel liquid argon calorimeter is based on the real dimensions of the calorimeter and the assumptions described above. The simulation consists of a set of calculations carried out for different constant cooling powers of the heat exchangers. For each calculation all temperatures were initiated at 300 K at time step zero. During each of the following time steps a complete calculation of the heat transferred between all the detector interfaces and within all the detector parts has been made as well as a mapping of the absolute temperatures of these items.

The calculation was continued till the warmest part of the calorimeter had reached about 120 K, or till a temperature difference of more than 50 K was reached between any two parts of the calorimeter. In the first case the constant cooling power of the heat exchangers was increased before the calculation was restarted while in the second case the constant cooling power of the heat exchangers was diminished before restarting the calculation. The simulation is stopped when the cool down time is optimized with respect to the constant cooling power of the heat exchangers.

This operation has been repeated for three different modes: non-condensing argon gas, helium gas and condensing argon as filling medium, in the last case however with the limitation that the argon should have evaporated before it can touch the outer bars encasing the absorber plates. The results of the optimal cool down time simulation for the three different cases are shown in Figure 3, while the maximum temperature gradients created during the cool down modes are shown in Figure 4. These maximum gradients can always be found between the outer and inner cold vessel. From Figure 3 one can see the considerable advantage of the use of helium compared to the use of argon gas. Under the same maximum temperature gradients, the cool down time is diminished by a factor three compared to the non-condensing argon gas mode. Furthermore the use of the condensing argon mode diminishes the cool down time compared to the non-condensing mode by about 30%.

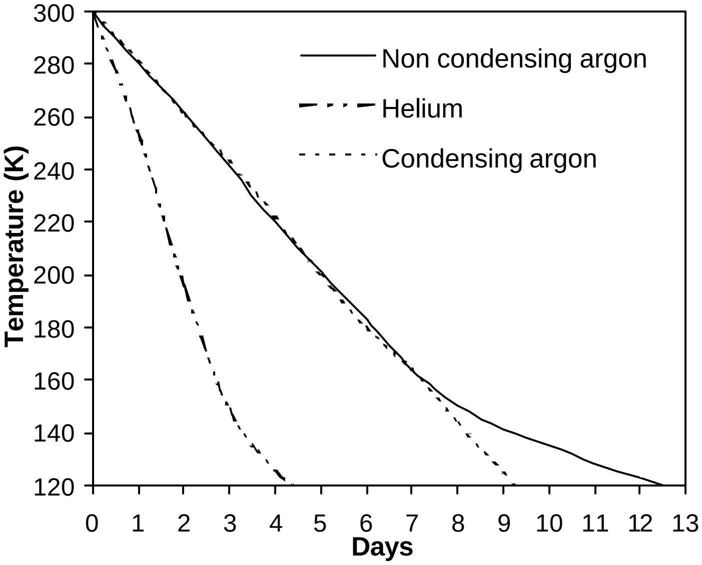

Figure 3 Temperature of barrel calorimeter during cool down using different filling gasses

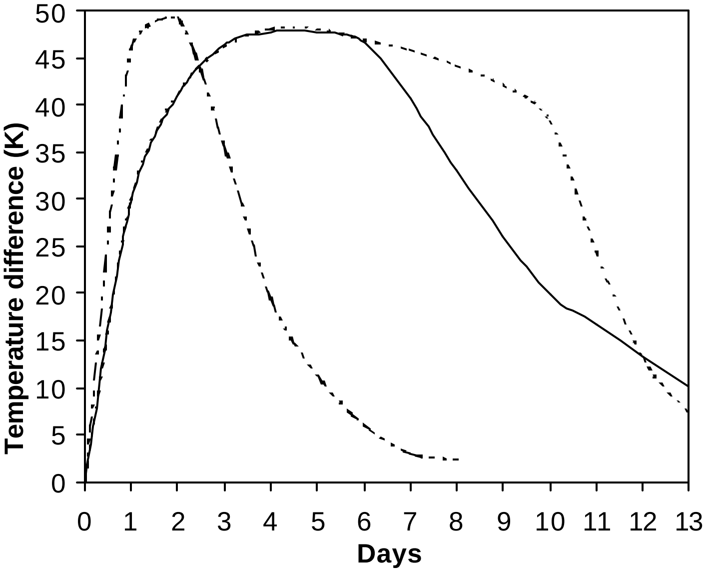

Figure 4 Maximum temperature gradients over the barrel calorimeter during cool down using different filling gasses

CONCLUSIONS

The simulation has indicated that the cool down of the barrel liquid argon calorimeter can be carried out by means of the internal heat exchangers within an acceptable time using the non-condensing argon gas mode. One can even expect that the cool down time of the calorimeter will be shorter as the 50 K temperature gradient limit between the outer and the inner cold vessels might, in the real cool-down situation, be less restrictive since we have assumed in our model that the two vessels are thermally decoupled.

Furthermore, the results of the simulation program on the cool down of the barrel show that the use of helium as filling gas during the cool down diminishes significantly the cool down time without creating unacceptable temperature differences. However, helium will be used only as an extreme back-up solution since it is impossible to fully extract the helium gas from the detector at the end of the cool-down process and the presence of residual helium gas absorbed by the various detector components might affect the performance of the detector.

The condensing argon mode would also diminish the cool down time. The calculations show that the gain is made only in the last part (below 160 K) of the cool down process. In the upper part the cool down rate is limited by the maximum allowable temperature gradient as shown in Figure 4. Therefore we prefer to make the first part of the cool down in the non-condensing argon mode, thus eliminating the risk of argon droplets falling on parts of the detector.

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