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Microchannel CO2 cooling for the LHCb VELO Upgrade

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The LHCb Vertex Detector (VELO) will be upgraded for the run III (scheduled to start in 2021) to a lightweight, pixel detector capable of 40 MHz readout and operation in very close proximity to the LHC beams. The thermal management of the system will be provided by evaporative CO2 cir- culating in micro-channels embedded within thin silicon plates. This technique was selected due to the excellent thermal efficiency, the absence of thermal expansion mismatch with silicon ASICs and sensors, radiation hardness of CO2, and very low contribution to the material budget.

The upgraded VELO modules will each host 4 silicon hybrid pixel tiles, each readout by 3 VeloPix ASICs with a total power consumption of up to 30 W. The implemen- tation of a efficient and radiation hard cooling system is mandatory in order to remove the heat produced by the ASICs and keep the sensors below -20°C, which mitigates the radiation damage. The solution created is to use a cooling substrate composed of thin silicon plates with embedded micro-channels that allow the circulation of boiling CO2. The direct advantages of this technique include the low and uniform material contribution, matching thermal expansion coefficients between the sensor-ASIC tiles and cooling substrate, and high heat transfer capacity.

This talk will cover the key points of the microchannels R&D with includes design optimization, fabrication, robustness tests, cooling performance and fluidic characterization.

A major challenge to be overcome concerned the reliable connection of the input cooling pipes to the substrate, via the fluidic connector. The connction must be completely leak tight to maintain the integrity of the vacuum and able to withstand the highest operational pressures. A flux free connector soldering solution was developed, in order to protect the cooling network from any long term chemical degredation. This solution also respects the planarity and correct positioning required for the subsequent construction of the precise tracking system. The procedure is a many step process, using formic acid cleaning and very close temperature control in both vacuum and atmospheric pressure environments. The integrity of the final joint is checked by tomography and helium leak tests. During the development phase of this procedure the solder joints were also tested for long term effects of creep and fatigue. The creep effects were enhanced by applying high temperatures and mechanical tension. The fatigue was studied with temperature (-40 to 60 degrees) and pressure (1 - 200 bar) cycles.

Various experimental setups were used to characterise the cooling performance. For proof-of-principle a setup was used that mimics the power dissipation of the final module via by special heaters designed to simulate the heat pattern in the ASICs and sensors, and measuring the temperature difference between the coolant and the irradiated module tip. The fluidic characteristics of the final system were assessed for a range of flows, including the nominal one of 0.4 g/s per module. In addition, setups with module pairs were used to study the cooling flow interplay between modules, in extreme situations such as loss of power on one module.

Two alternative solutions were pursued in parallel to the microchannel development, and these will be briefly described. In the end the microchannel evaporative cooling was selected due to the superior physics performance,

The status of the project, production, and prototypes will be described.

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