Physics in the LHC era

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CO_2 COOLING FOR SILICON DETECTORS

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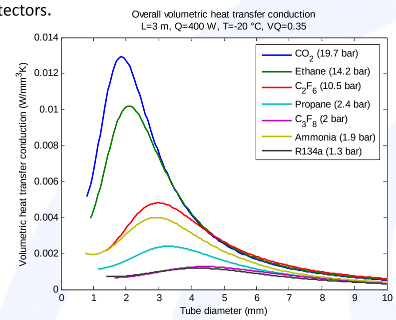
Abstract

CO_2 cooling has become an interesting technology for current and future tracking particle detectors. A key advantage of using CO_2 as refrigerant is the high heat transfer capabilities allowing a significant material budget saving, which is a critical element in state of the art detector technologies. Two CO_2 cooling systems are now in use by LHCb at CERN and AMS on the International Space Station. CO_2 cooling has been accepted as the baseline technology for most future upgrade silicon detectors in HEP.

Many CO_2 systems for laboratory test purposes have been developed at CERN together with international partners. Two new systems for detector use are under construction. One for the ATLAS Pixel Insertable B-Layer and a second for the Phase I Upgrade CMS Pixel detector.

Benefits of CO_2 cooling

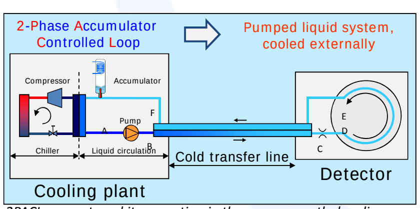
CO_2 cooling is due to its favourable physical properties the best choice for small size cooling pipes. The beneficial properties for the use in small pipes are the low viscosity (Low pressure drop) , the high latent heat (low flow) and the high pressure (limited gas expansion). The use of CO_2 allows a network of long small piping over large distances and is therefore the best choice in HEP detectors.

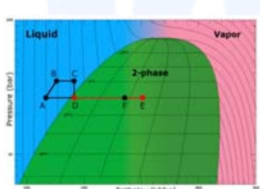


Comparison of the performance of different 2-phase fluids as a function of tube diameter

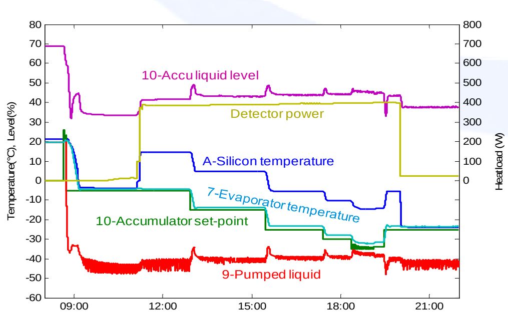
CO_2 cooling system

A special technology for a conditioned CO_2 injection into the detectors evaporator tubes have been developed called 2-Phase Accumulator Controlled Loop (2PACL). This concept pumps CO_2 around in liquid mode and evaporates only partly in the detector cooling pipes such that the best heat transfer is guaranteed. The returning 2-phase mixture is condensed and sub cooled by an external chiller. The boiling pressure is controlled by a pressure controlled 2-phase storage vessel. The 2PACL method is originally developed from space technologies and applied in the space born AMS detector. The method is now used for most new CO_2 systems in HEP.





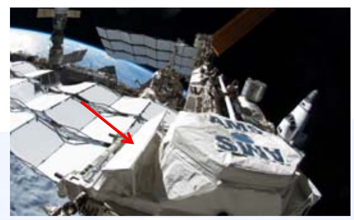
2PACL concept and its operation in the pressure-enthalpy diagram



A 2PACL system allows the detector temperature to be very stable at a wide range of set-point temperatures. The heat dissipation is not affecting the 2PACL performance, so a stable evaporator temperature is achieved at any time (cyan line). Operational temperature range of a 2PACL is from room temperature down to -40°C. Shown plot is from the LHCb-Velo CO_2 cooling system.

Running systems

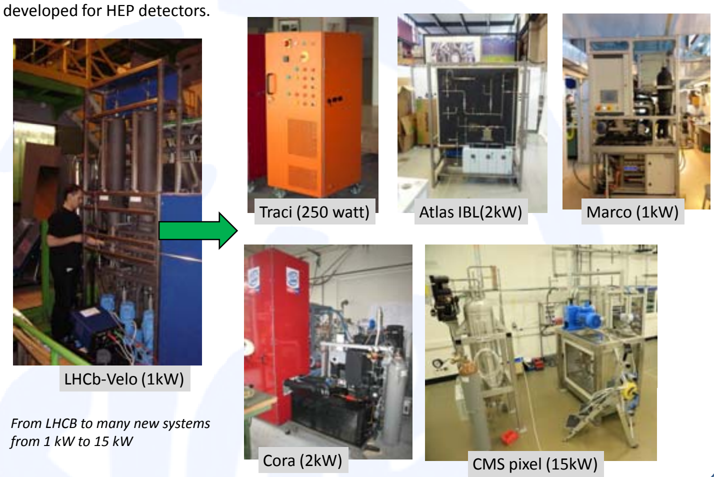
Two CO_2 cooling systems are in use by HEP detectors with good track record. The LHCb-velo and the AMS silicon tracker cooling system. The LHCb-Velo cooling system is operational since 2009 and AMS is orbiting the earth on board the ISS since 2011. Both system have so far a good and reliable track-record.



The AMS with the CO_2 cooling radiators visible (left) and LHCb-Velo with the CO_2 cooling evaporators (right)

Cooling systems development

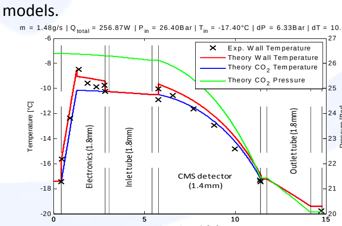
The AMS inherited 2PACL concept used in LHCb is now the default for most new systems being developed for HEP detectors.

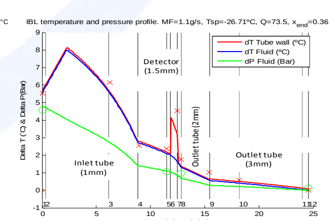


From LHCB to many new systems from 1 kW to 15 kW

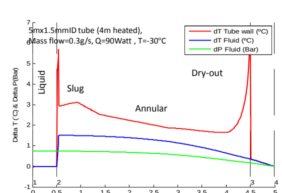
Modelling and testing

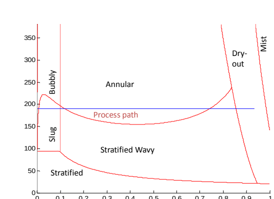
To predict the CO_2 cooling behaviour in small cooling pipes a Matlab based modelling program called CoBra has been developed. This program can predict the complex temperature profiles along the long cooling lines by calculating the pressure drop and heat transfer using the latest available models.





Temperature and pressure test results of the CMS pixel upgrade cooling branch (left) and the Atlas IBL cooling branch (right). Comparison of the CoBra calculator towards experimental measurements





The model accounts for the several flow patterns and fluid states. It uses the different models and physical properties depending on the actual state. The complex temperature distribution along pipes can be predicted using CoBra.