Investigation of CO_2 - based Cooling for the CBM Silicon Tracking System

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Introduction

The Compressed Baryonic Matter (CBM) experiment at FAIR [1] will play a unique role in the exploration of the QCD phase diagram in the region of high net-baryon densities (μB $\geq$ 500 MeV) at SIS100 ($\sqrt{s_{NN}}$ = 2.7 – 4.9 GeV). In particular due its design to run at unprecedented interaction rates (upto 10MHz), the experiments will focus on:

- QGP phase transition & critical point
- onset of chiral symmetry restoration
- new forms of strange matter
- in-medium modifications of hadrons

Motivation

- The Silicon Tracking System (STS) [2] located in the dipole magnet provides track reconstruction & momentum determination of charged particles from beam-target interactions.
- Rad. tolerance of innermost sensors $\Rightarrow$ End-of-lifetime criterion $= 10^{14}$ n_{eq} cm^{-2} after 5-10 months equivalent running with Au+Au collisions at 25 AGeV & at 10MHz interaction rate.
- Sensor operation at -5°C is mandatory to avoid thermal runaway and reverse annealing of the sensors. This requires complete heat removal from the FEE boards ($\sim$40kW)
- So STS will be operated in a thermal insulation box & will use CO_2 cooling for the FEE.

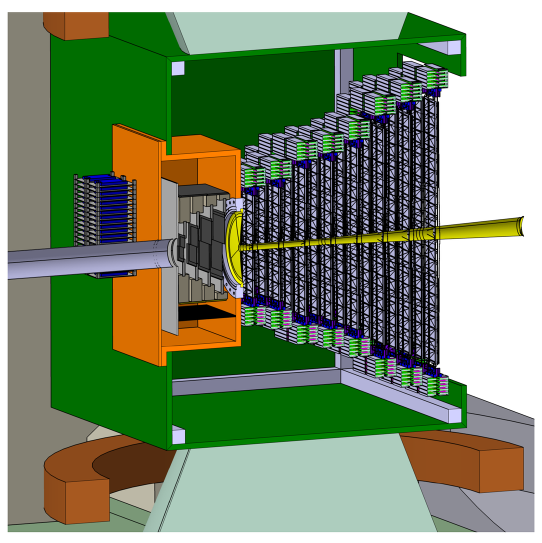

Figure 1: CBM Silicon Tracking System [2]

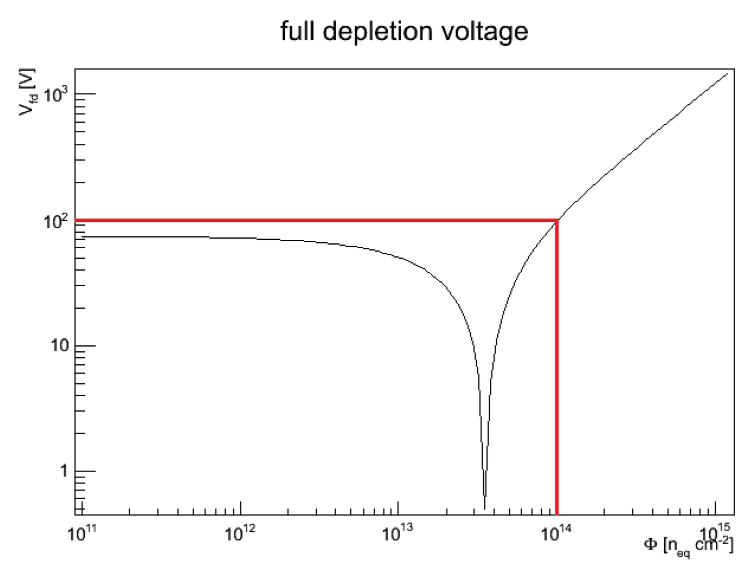

Figure 2: Full-depletion voltage v/s non-ionizing dose [2]

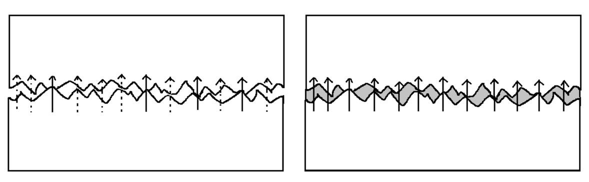

Figure 3: Thermal interface between surfaces [3]

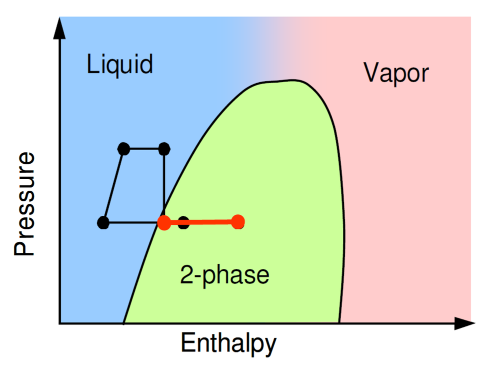

Figure 4: CO_2 phase diagram

- Due to micro level imperfections in the mating surfaces, the in-between air-filled gaps with very low thermal conductivity (0.026 W/(m·K)) act as a thermal barrier [3].
- An ideal Thermal Interface Material (TIM) fully replaces the air to increase the overall thermal conductivity.
- Important for extracting maximum enthalpy available for efficient cooling (i.e., maximum heat absorption for a certain coolant temp.)
- Water is used instead of CO_2 here, because interface measurements are relative in nature.

Experimental Setup

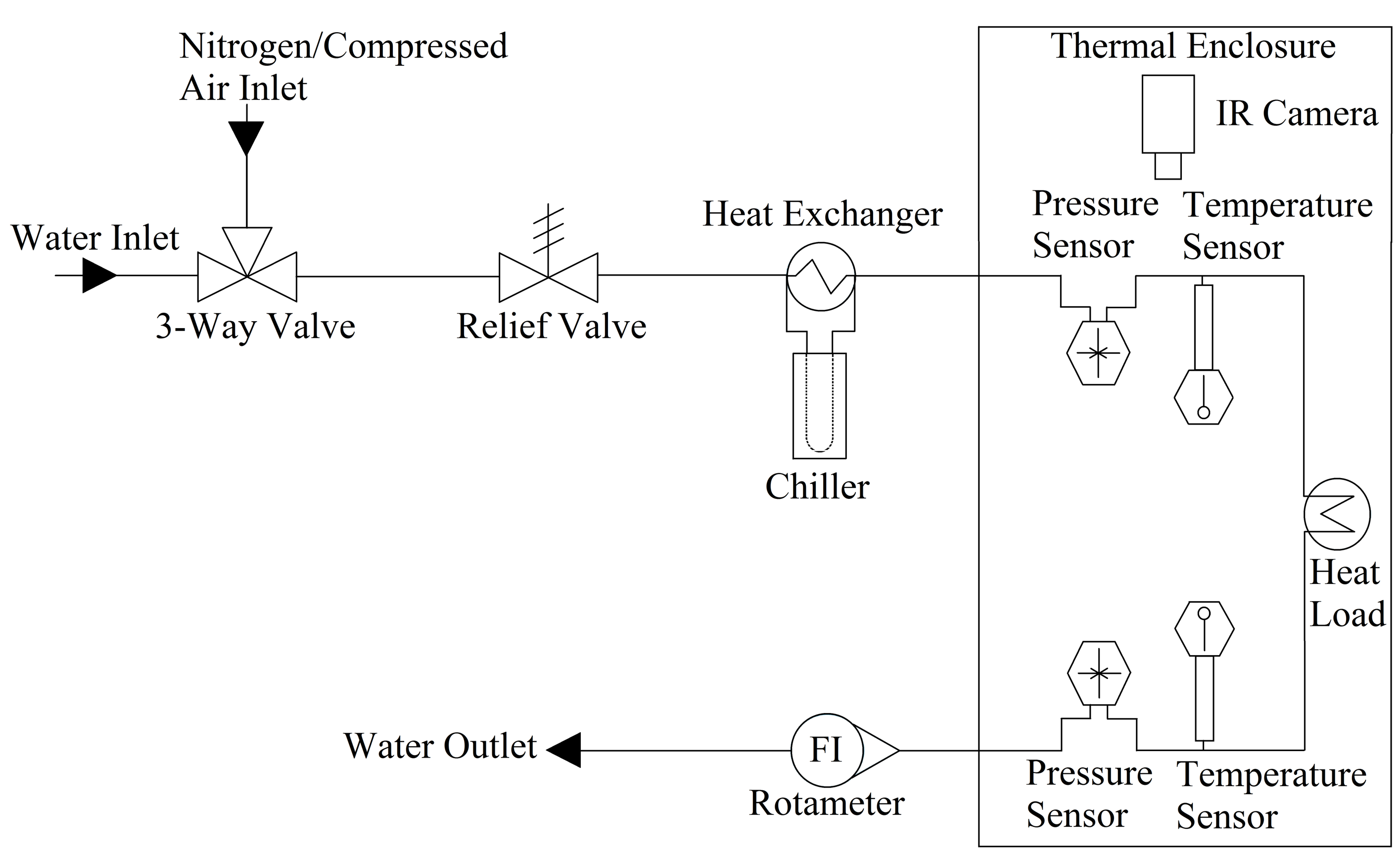

Figure 5: Experimental setup for thermal interface measurements with water

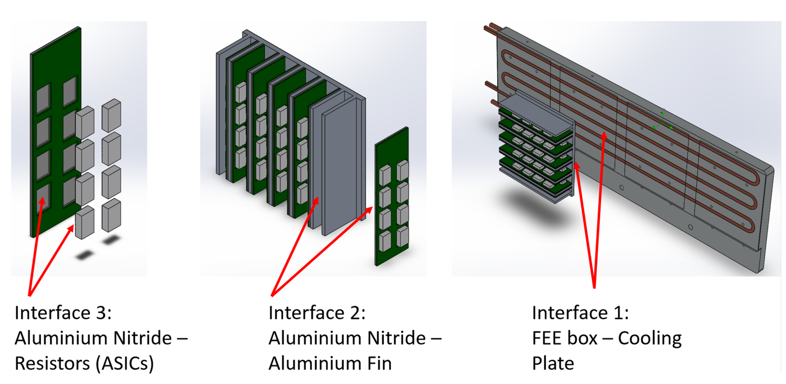

Figure 6: Thermal interfaces in the setup

- Input temp. = 15°C, Flow rate = 40lt/hr, Heat Load = 160W
- Interface 1: FEE Box – Cooling Plate
  Cases: Thermal Grease and Graphite Foil
- Interface 2: FEE Box Fin – AlN Plate
  Cases: Thermal Grease and Graphite Foil
- Interface 3: Resistor (ASIC) – AlN Plate
  Cases: Three different Thermal Glues

Results

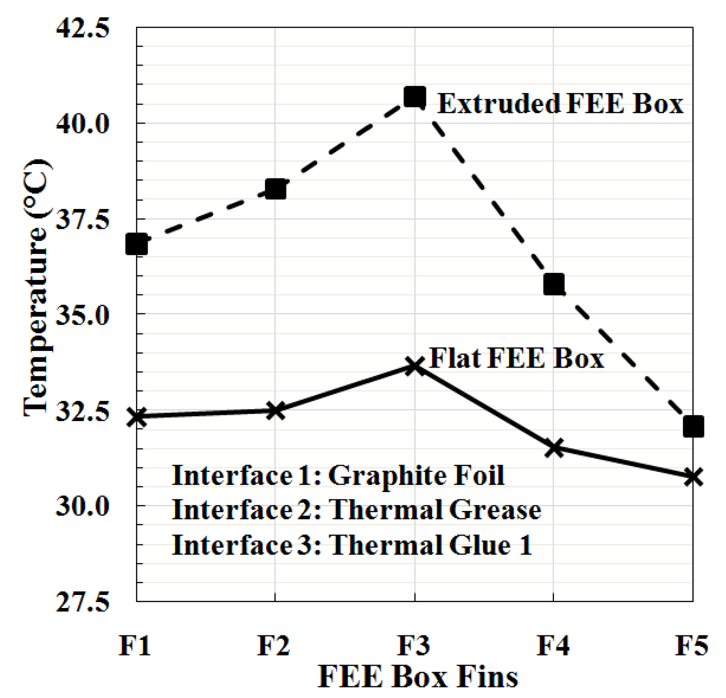

Figure 7: Effect of FEE box flatness on thermal interface measurements

- Since thermal conductivity of FEE box fin (aluminium), FEE base plate (aluminium nitride) and ASIC (silicon) is high and comparable, the temp. across all three materials is expected to be the same.
- Temp. as high as 40°C with an 'extruded' curve is observed for FEE box fins.
- Reason: Extruded botton surface of the FEE box (–110μm to +220μm with respect to centre).
- Flattening the bottom surface (+5μm to +30μm with respect to centre) improved the results by $\sim$5°C.

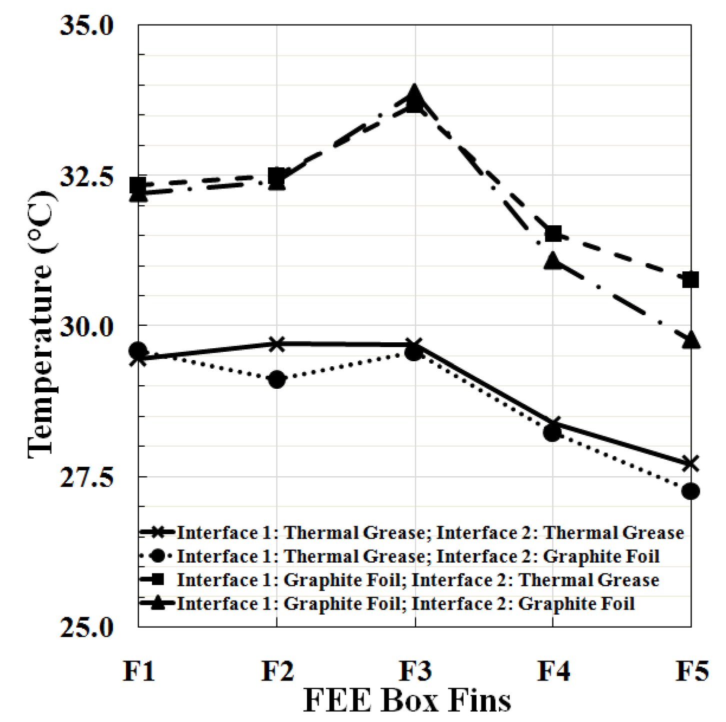

Figure 8: Temp. profile on the FEE box (flat) fins

- Fin temp. depend highly on the TIM used at Interface 1, where the max. fin temp. for thermal grease is $\sim$30°C and for graphite foil is $\sim$34°C.
- On the contrary, using graphite foil as Interface 2 minorly improves the result by $\sim$0.5°C irrespective of the TIM used as Interface 1.
- Reason: Imperfect contact at Interface 2 with graphite coil $\Rightarrow$ Lower fin temp. & higher ASIC temp.
- So for the coolant temp. = 15°C, max. fin temp. = 30°C $\Rightarrow$ ΔT = 15°C.

Interface 1	Interface 2	Interface 3	Max Fin Temp °C
Thermal Grease	Thermal Grease	Thermal Glue 1	29.7
	Graphite Foil		29.6
Graphite Foil	Thermal Grease		33.7
	Graphite Foil		33.9

Table 1: Summary of thermal interface measurements for Interface 1 & 2

- Using an aluminium cover for the FEE box encloses the FEE temp. such that it doesn't interact with the ambient environment.
- A minor change ($\sim$0.1°C) on FEE fin temp. is observed.

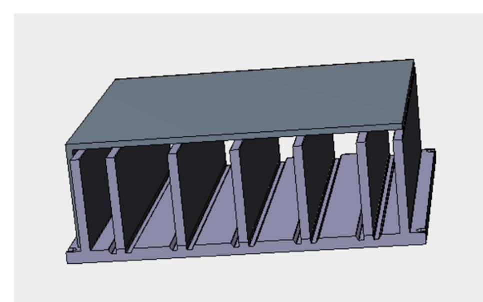

Figure 9: FEE box with aluminium cover

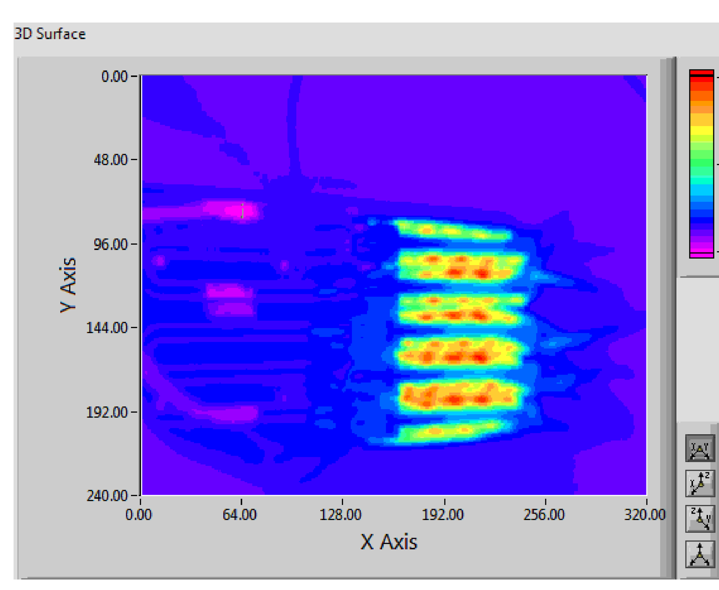

Figure 10: IR measurements without cover

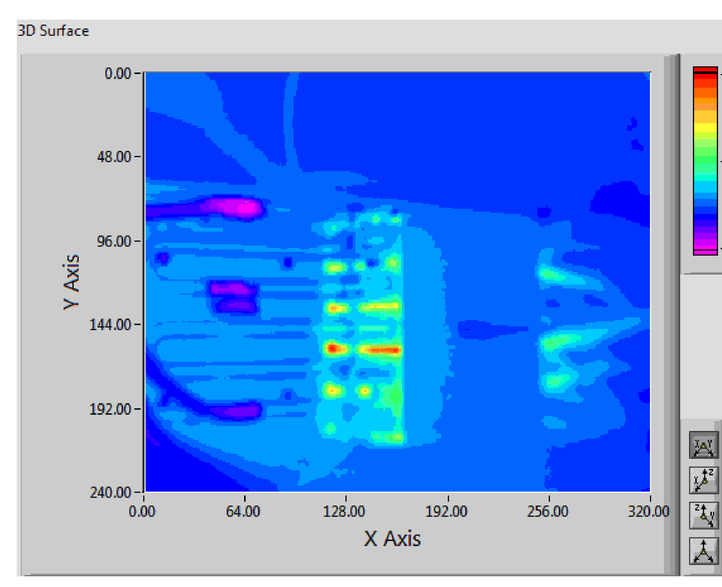

Figure 11: IR measurements with cover

Conclusion & Outlook

- All thermal interfaces should be flat & thermal grease is better for removable interfaces.
- For the eventual CO_2 temp. = -20°C, in principle it is possible to obtain the target -5°C max. temp. on FEE box, as ΔT = 15°C observed should be true over all coolant temp.
- Aluminium covers the higher FEE temp. from heating up the surroundings and is useful.
- Verification of results with bi-phase CO_2 at -20°C.

References

- S. Chattopadhyay *et al.*, arXiv:1607.01487 (2016)
- J. Heuser *et al.*, Technical Design Report for the CBM Silicon Tracking System (2013)
- L. Fältström, Masters Thesis (2014)

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