The ATLAS IBL CO₂ Cooling System

**International Workshop on Semiconductor
Pixel Detectors for Particles and Imaging
(Pixel 2016)**

(Sestri Levante, 5-9 September 2016)

On behalf of the ATLAS collaboration

VERLAAT, Bart (CERN), OSTREGA, Maciej (CERN), ZWALINSKI, Lukasz (CERN), BORTOLIN, Claudio (CERN), VOGT, Sven (MPI-München (DE)), GODLEWSKI, Jan (Polish Academy of Sciences (PL)), CRESPO-LOPEZ, Olivier (CERN), VAN OVERBEEK, Martijn (Nikhef), BLASZCZYK, Tomasz (CERN)

ATLAS IBL: A new 1st layer around a reduced beam pipe

IBL an extra pixel layer

Component (32 per stave)	Power (W/unit)	Power (W/stave)
FEI4 chip	1.12	35.84
Pixel sensor (after irradiation)	0.68	21.61
Stave flex	0.17	5.38
Type 1 cables	0.17	5.38
Total per stave		68.21
Total for 14 staves		954.94

IBL Carbon stave with cooling pipe

IBL Stave

Cooling temperature required: $<-35^{\circ}\text{C}$

1 round trip = 1 loop = 31m

PP1 connectors

Cooling plants in USA-15

IBL has **2 redundant CO₂ systems**, in case of failure it swaps transparent to the other system. **Detector is minimal affected** (small temperature fluctuation)

CO₂ plant commissioning

Junction box cooling tests (Detector by-passed)

8 hours

Simplified system schematics

- The cooling system is commissioned over a by-pass dummy load (3kW) and with the detector attached
- The cooling system is very stable ($\ll 1^\circ\text{C}$) over a large temperature range (from room temperature down to -35°C)

Detector temperature during commissioning

June 14

Days since 23 June 2014

Dec. 14

- The beam pipe bake-out was a crucial event for the IBL cooling
- The beam-pipe was heated in steps to 230°C, the cooling system prevented the IBL for overheating
- A 2 fault redundant operation of the cooling was established
  - 2 systems operated in parallel
  - System back-up by a bottle battery blow system
- Results and observations
  - Maximum recorded sensor temperature was -8°C @ 230°C beam pipe
  - Due to twice the flow (2 systems in parallel) => ca. 4x pressure drop, most staves stayed single phase for long time.
- No serious issues during bake-out, system run without problems

Beam pipe bake-out

25 minutes of stable 3kW cooling using blow system (3kW Test was stopped to save CO2)

IBL Cooling temperatures at bake-out

The IBL cooling heat loads

- The cooling system has to coop with several heat loads:
  - Detector electronics power
  - Ambient heat leak in the detector
  - Ambient heat leak of the system
- The detector power now is about ~30 Watt/stave (420 W total)
- The total absorbed heat load can be measured when both in and outlet of the plant are in liquid phase (occasionally present)
- The ambient heat leak in the detector, **is the same order as the electrical power**
- Total load for the cooling system (detector + ambient)
  - Current operation: 1.5 kW at low temperature
  - Expected EOL: 2 kW** at low temperature
  - Tests have been done with 3kW dummy load

Component (32 per stave)	Power (W/unit)	Power (W/stave)
FEI4 chip	1.12	35.84
Pixel sensor (after irradiation)	0.68	21.61
Stave flex	0.17	5.38
Type 1 cables	0.17	5.38
Total per stave		68.21
Total for 14 staves		954.94

From slide 2

End of commissioning steady state tests and comparison with simulations (Dec. 2014)

Manifold and junction box

IBL temperatures for set point -30°C ; Measured data and CoBra simulation results

Set point = -30°C

Ambient heat load from previous slide included in simulations

Steady state tests (Dec. 2014)

Overview of different set point temperatures

First modules show a larger and more irregular temperature offset (boiling onset issue)

Cooling performance during operation

Nick Dann

The cooling system is stable within $0.2\text{ }^{\circ}\text{C}$ ($<0.05\text{ }^{\circ}\text{C}$ RMS), Detector modules within a few degrees due to power fluctuations

Cooling pipe measured stability during M9 run

Module and cooling pipe temperatures

** Please note that the shown temperatures in 2015 show values which are not yet corrected with the calibration constants defined in April 2015. As a consequence cooling pipe sensors shown are $\sim 1.5^{\circ}\text{C}$ too high, Module temperatures $\sim 0.5^{\circ}\text{C}$

Antonio Miucci

Operational experience since LS1 (1.5 years of operation)

Period		CO ₂ System failure			Chiller or primary cooling issue	Software modification	System test	Plant recovery
		DSS Interlock	Automatic swap	Maintenance intervention				
Data taking	Beam		1x (<i>Flow meter failure</i>)		4x	5x		1x
	No beam	1x (<i>Initiated swap for maintenance followed by a trip of the 2nd system due to threshold conflict in the start-up stepper</i>)				6x		1x
TS				5x		6x	1x	1x
MD				1x	1x	3x	3x	1x

- The IBL CO₂ cooling system had an excellent track record: **0% downtime** during physics
- Only limited interventions were needed, of which most were done during safe periods (TS, MD)
- 2 incidents during detector operation
  - 1 hardware failure with a **successful back-up procedure**
  - 1 DSS interlock due to a threshold conflict in the stepper introduced for long term high temperature operation, interlock occurred during a controlled intervention
- We are getting positive feedback of the system operation and reliability by ATLAS
- Very good cooperation between the operator team (ATLAS+EN-CV) and development team (EP-DT)

Boiling onset problems

- Sometimes the boiling is not triggered, and a reduced cooling performance is observed (bad heat transfer)
- We are trying to understand what causes this phenomena and how we can improve it
- The non-boiling issue is annoying for the alignment due to stave bowing.
- A test set-up containing a real size stave pair including flex lines and its orientation is made in SR1 to investigate the phenomena

SR1 clean room

SR1 Level -1

Representative height difference

1st results from SR1 test

- 1st results from SR1 show the superheated liquid in the inlet tube
- Flow reduction looks promising
- Flow reduction needs a modification in the manifold to avoid manifold evaporation
  - Will be tried in SR1

Summary and conclusions

- The IBL CO₂ cooling system was successfully commissioned in 2014.
- The cooling system has been fully operational since LS1 for 1.5 years and has performed very **reliable with 0% downtime** for ATLAS physics.
- The cooling system **wide operational temperature range** has proven to be very convenient to solve the LV-current issue.
- The **high temperature stability** of the cooling is very advantage for the stave bowing issue.
- The boiling onset issue is studied in a real size cooling loop mock-up in SR1.
- The IBL cooling method and operational experience has proven to be a **good baseline for the ITk cooling**.