The ATLAS IBL CO_2 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

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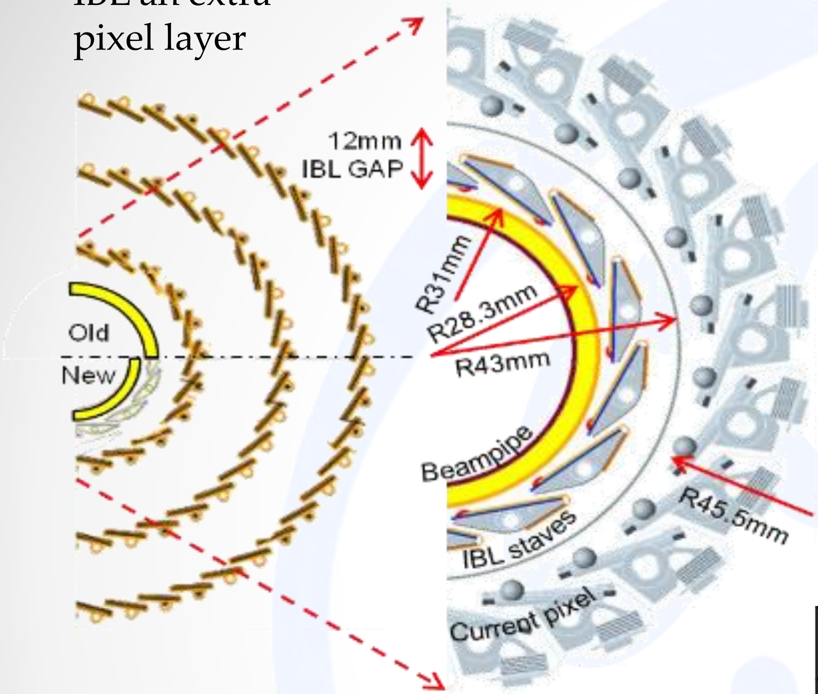
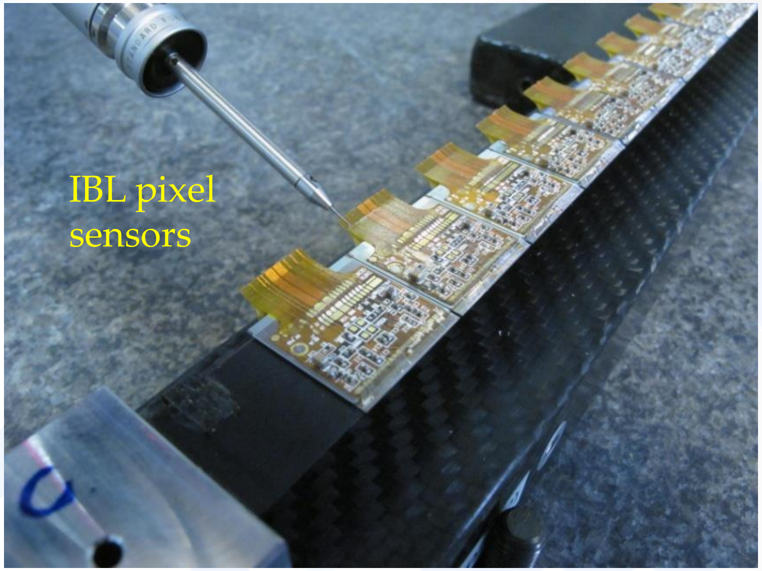
CERN EP-DT Detector Technologies

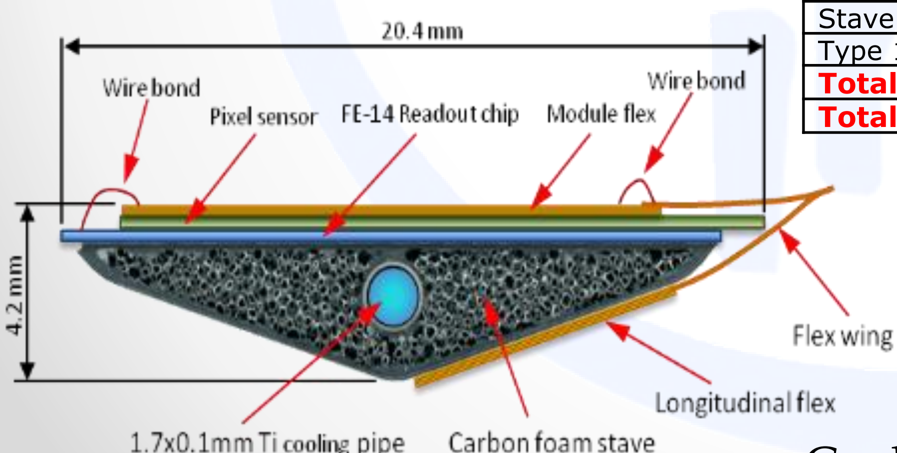
ATLAS IBL: A new 1st layer around a reduced beam pipe

IBL an extra pixel layer

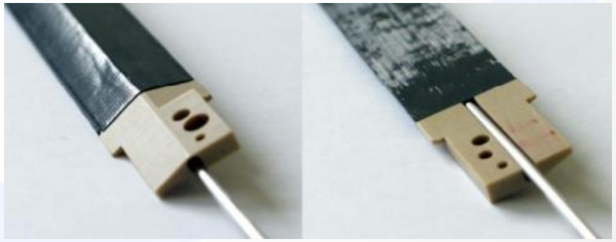




Component (32 per stave)	Power (W/unit)	Power (W/stave)
FEI4 chip	1.12	35.84
Pixel sensor (after irradiation)	0.68	21.61
Stave flex	0.17	5.38
Type 1 cables	0.17	5.38
Total per stave		**68.21**
Total for 14 staves		**954.94**



IBL Carbon stave with cooling pipe



IBL Stave

Cooling temperature required: <-35°C

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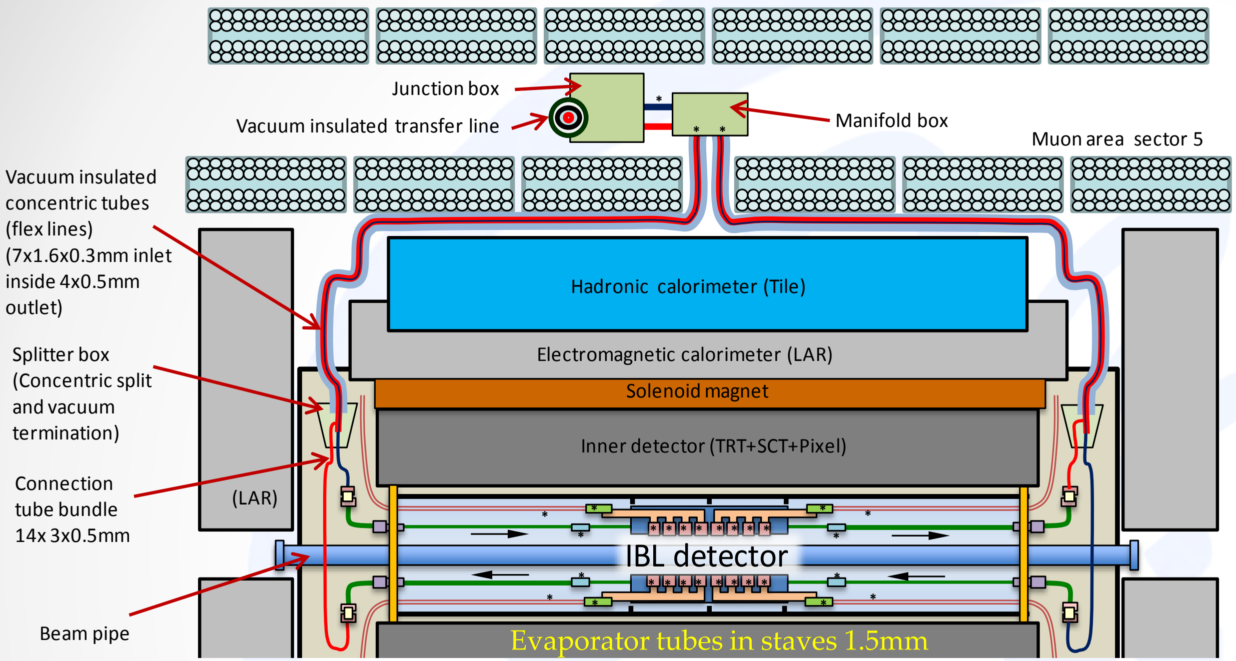
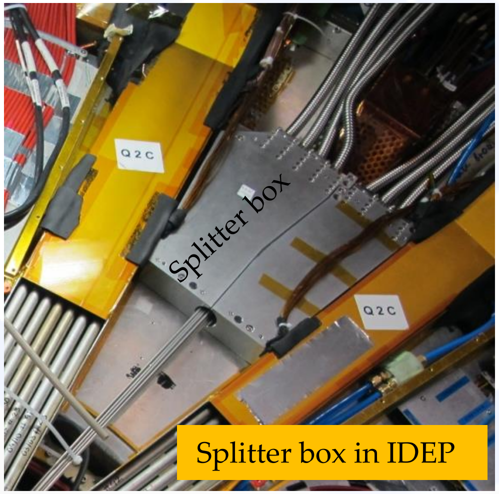
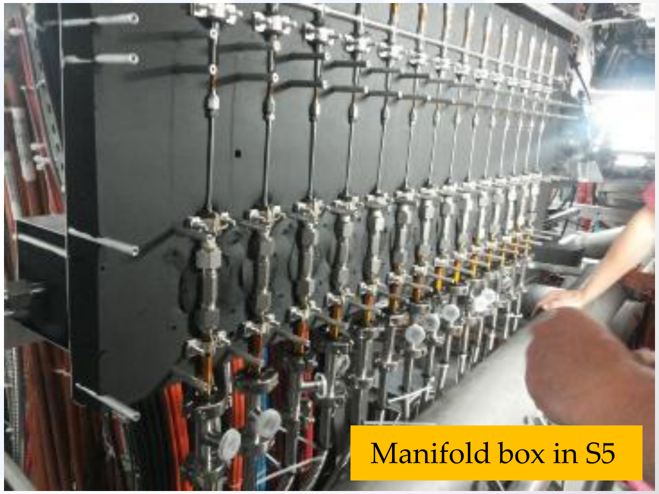
The IBL cooling loops



1 round trip = 1 loop = <u>31m</u>

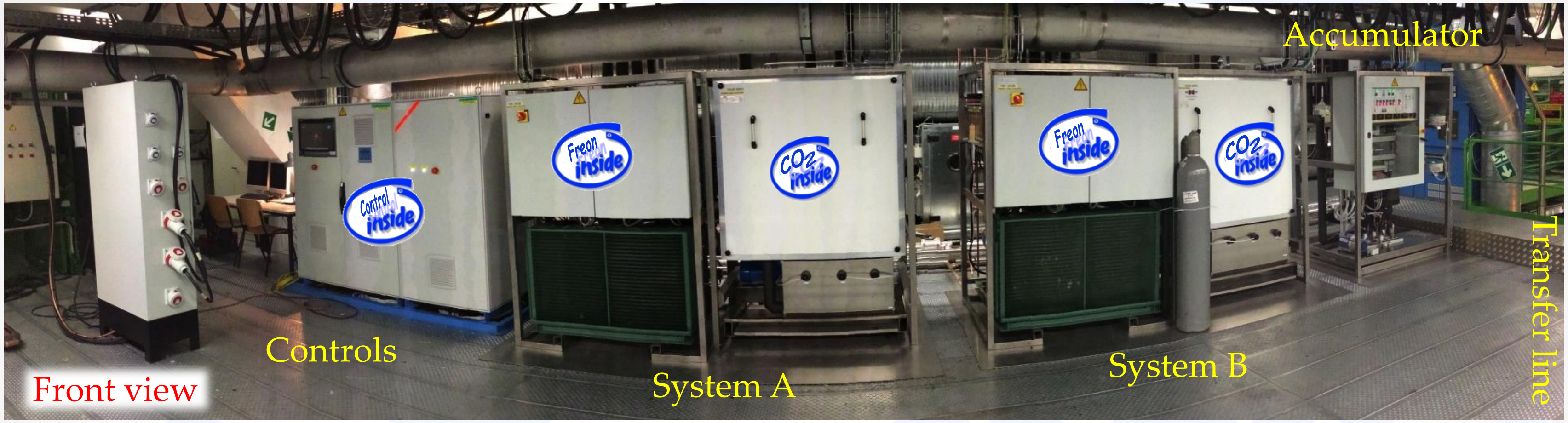
PP1 connectors

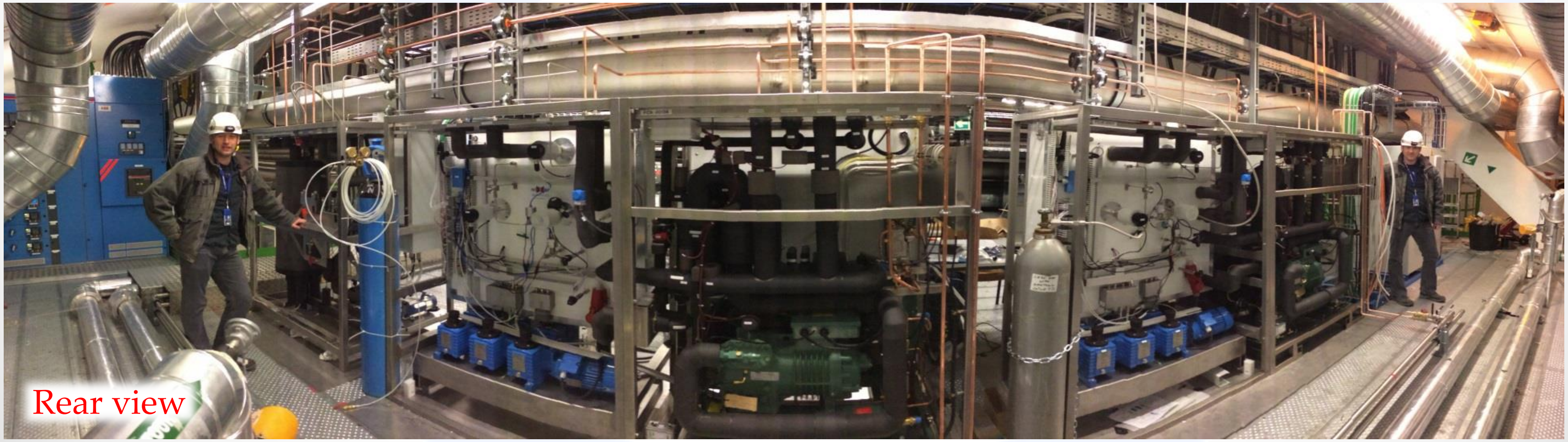




Cooling plants in USA-15

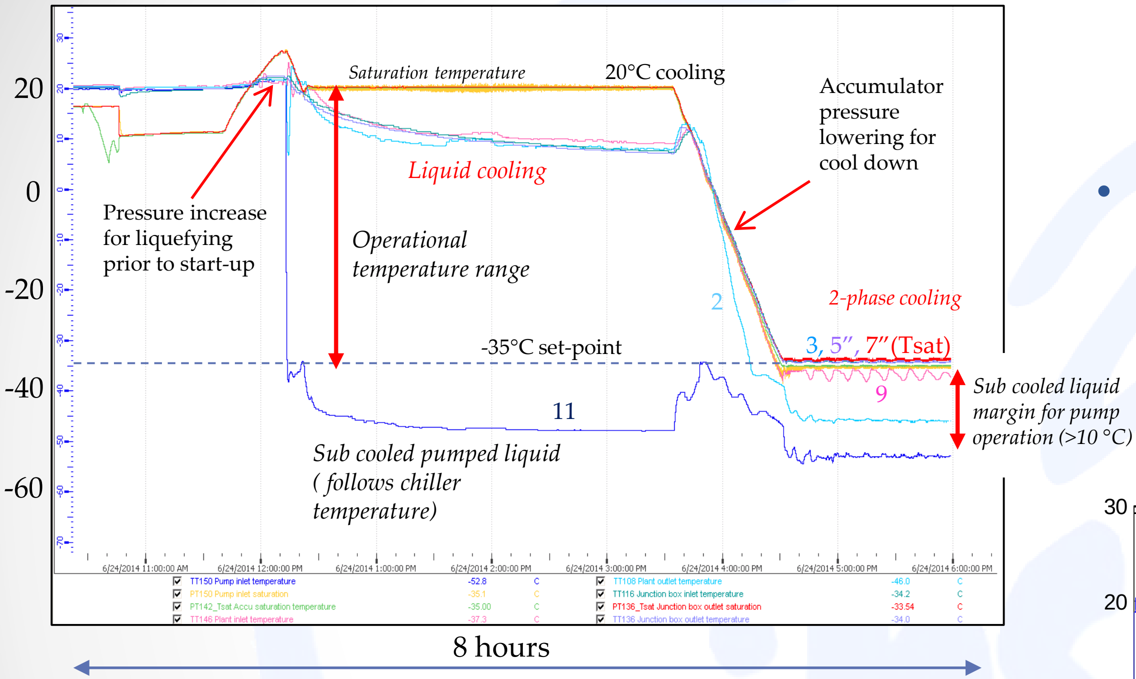
IBL has 2 redundant CO_2 systems, in case of failure it swaps transparent to the other system. Detector is minimal affected (small temperature fluctuation)

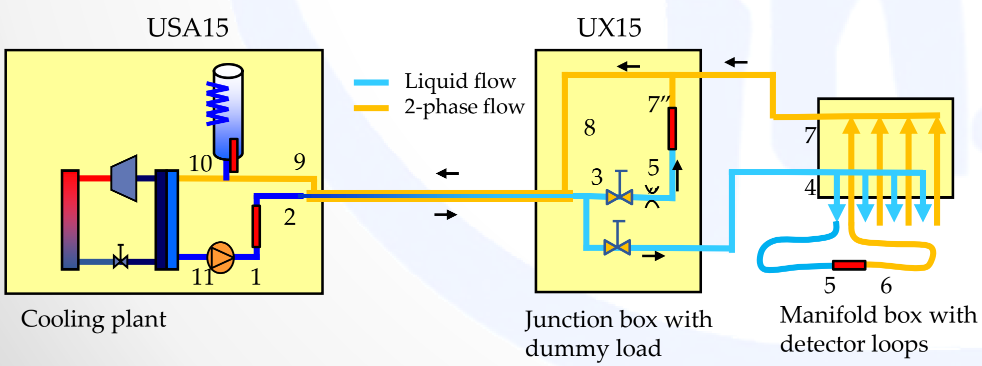




CO_2 plant commissioning

Junction box cooling tests (Detector by-passed)

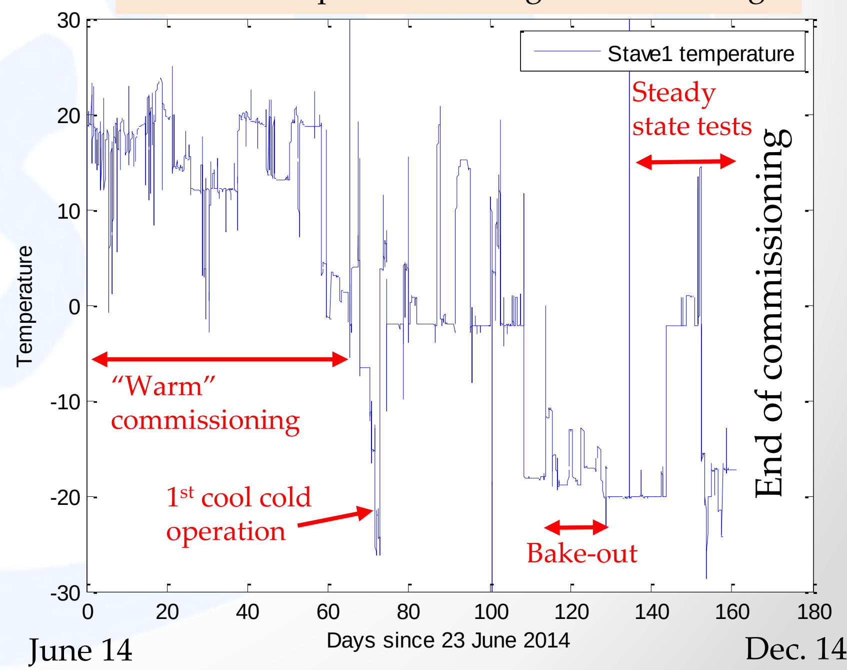




Simplified system schematics

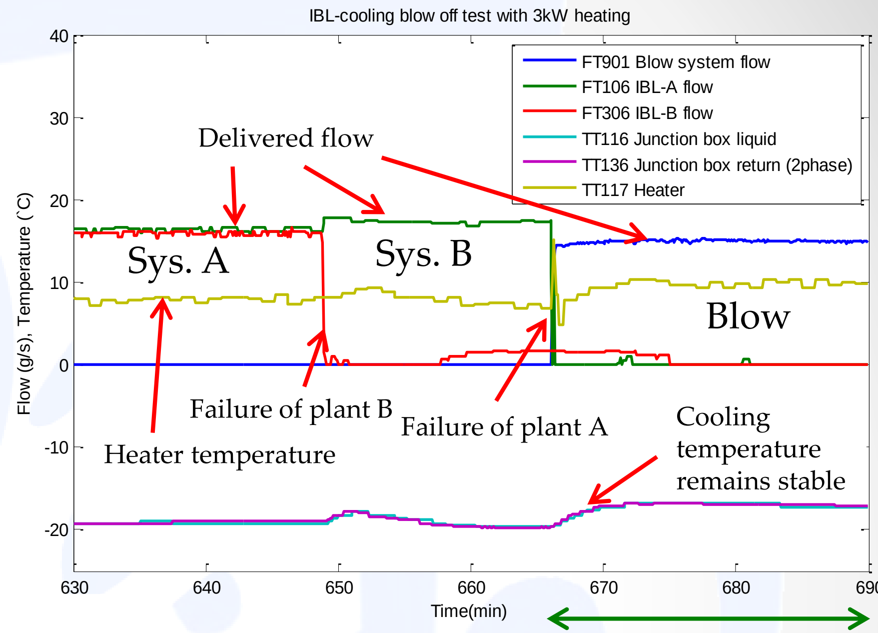
- The cooling system is commissioned over a by-pass dummy load (3kW) and with the detector attached
- The cooling system is very stable (<<1'C) over a large temperature range (from room temperature down to -35°C

Detector temperature during commissioning

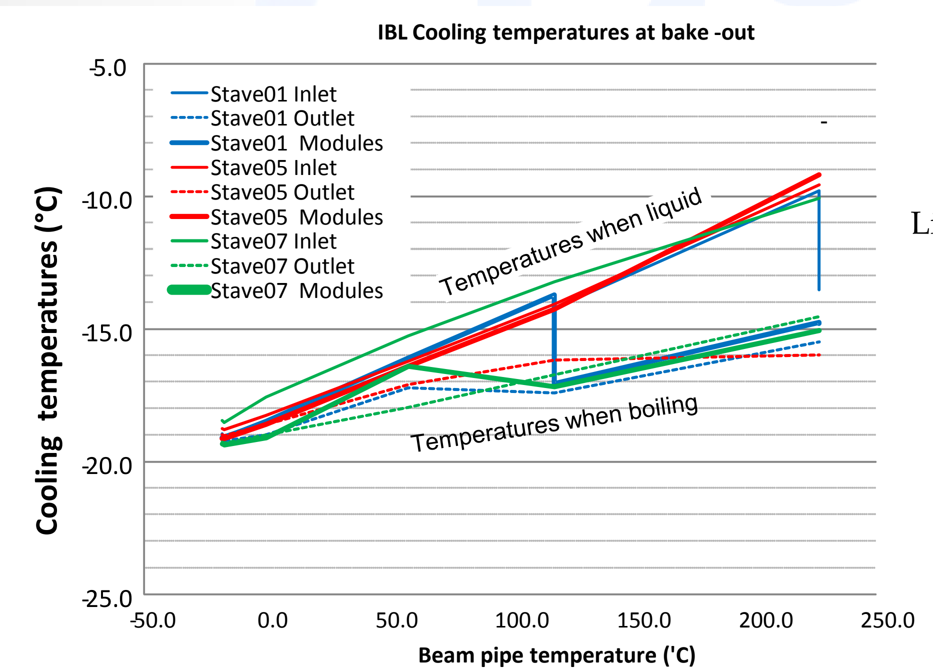


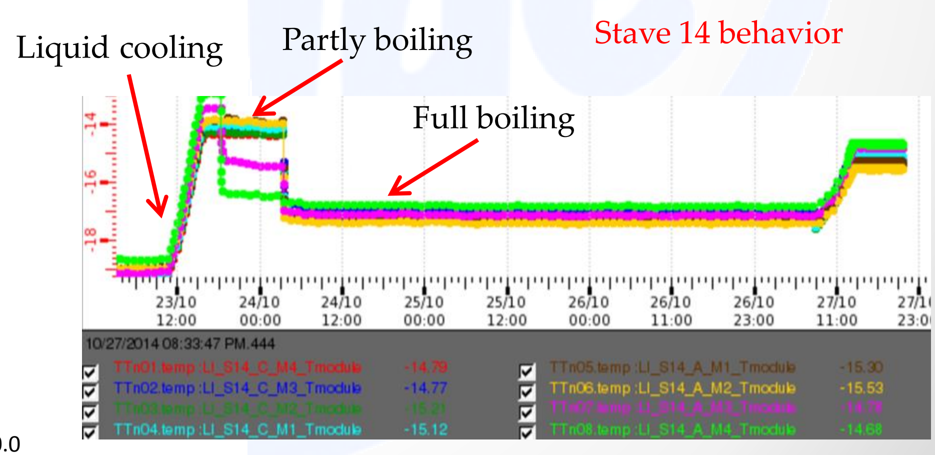
Beam pipe bake-out

- The beam pipe bake-out was a crucial event for the IBL cooling
- The beam-pipe was heated in steps to 230^{0}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^{0}C @ 230^{0}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



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





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

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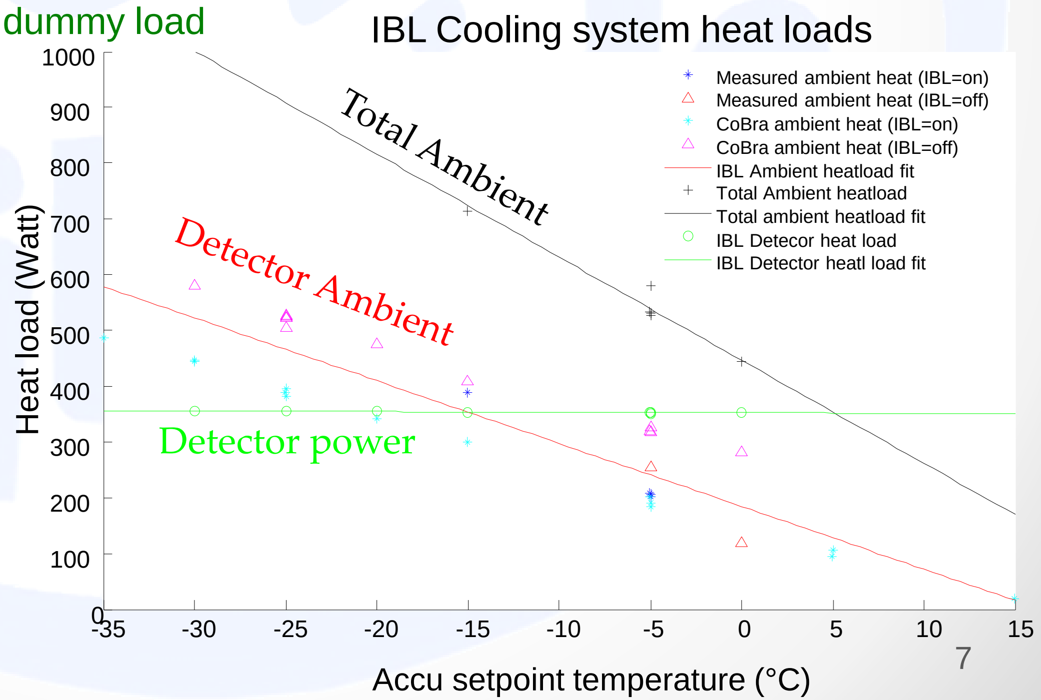
From slide 2



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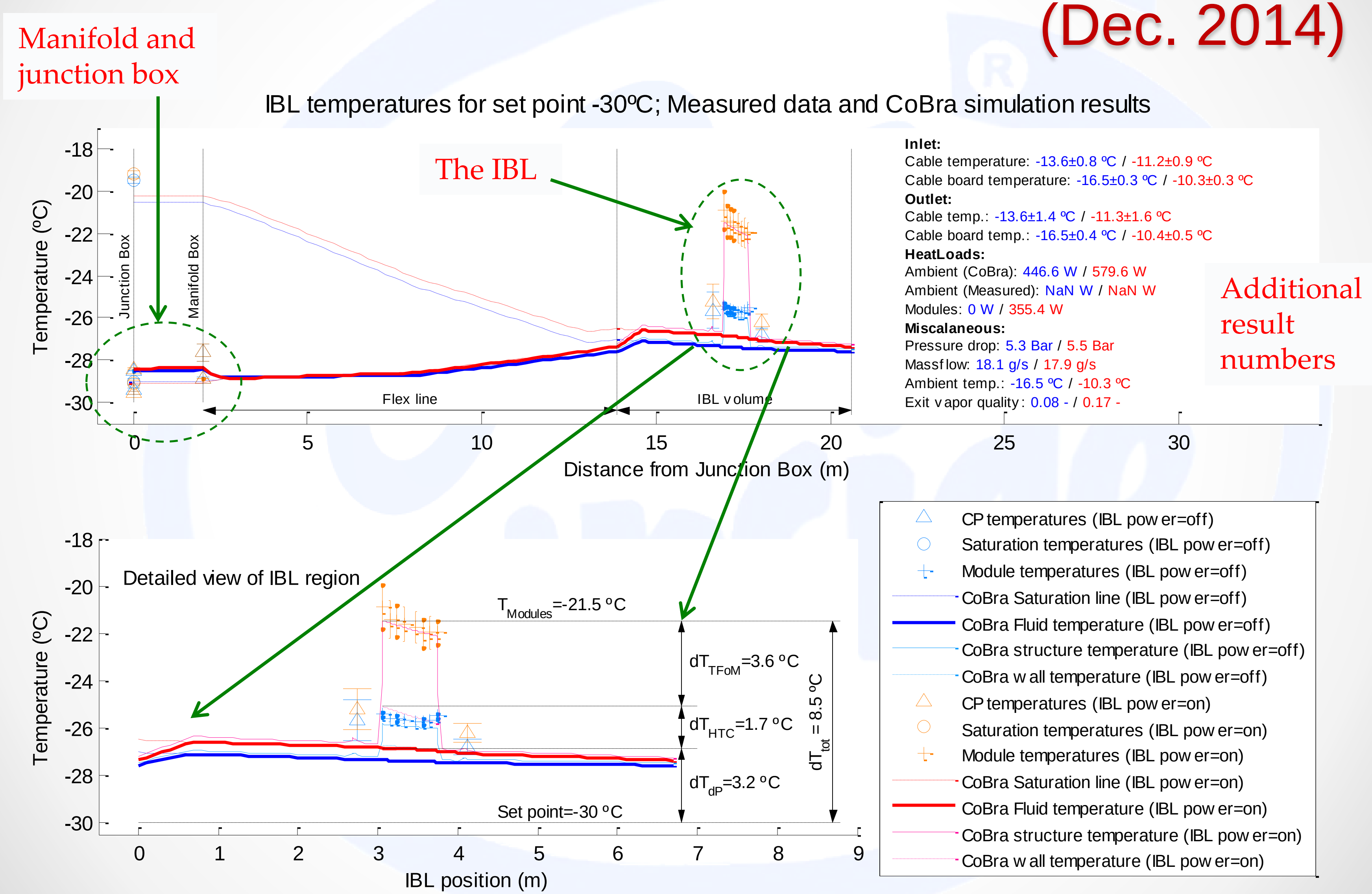
End of commissioning steady state tests and comparison with simulations (Dec. 2014)

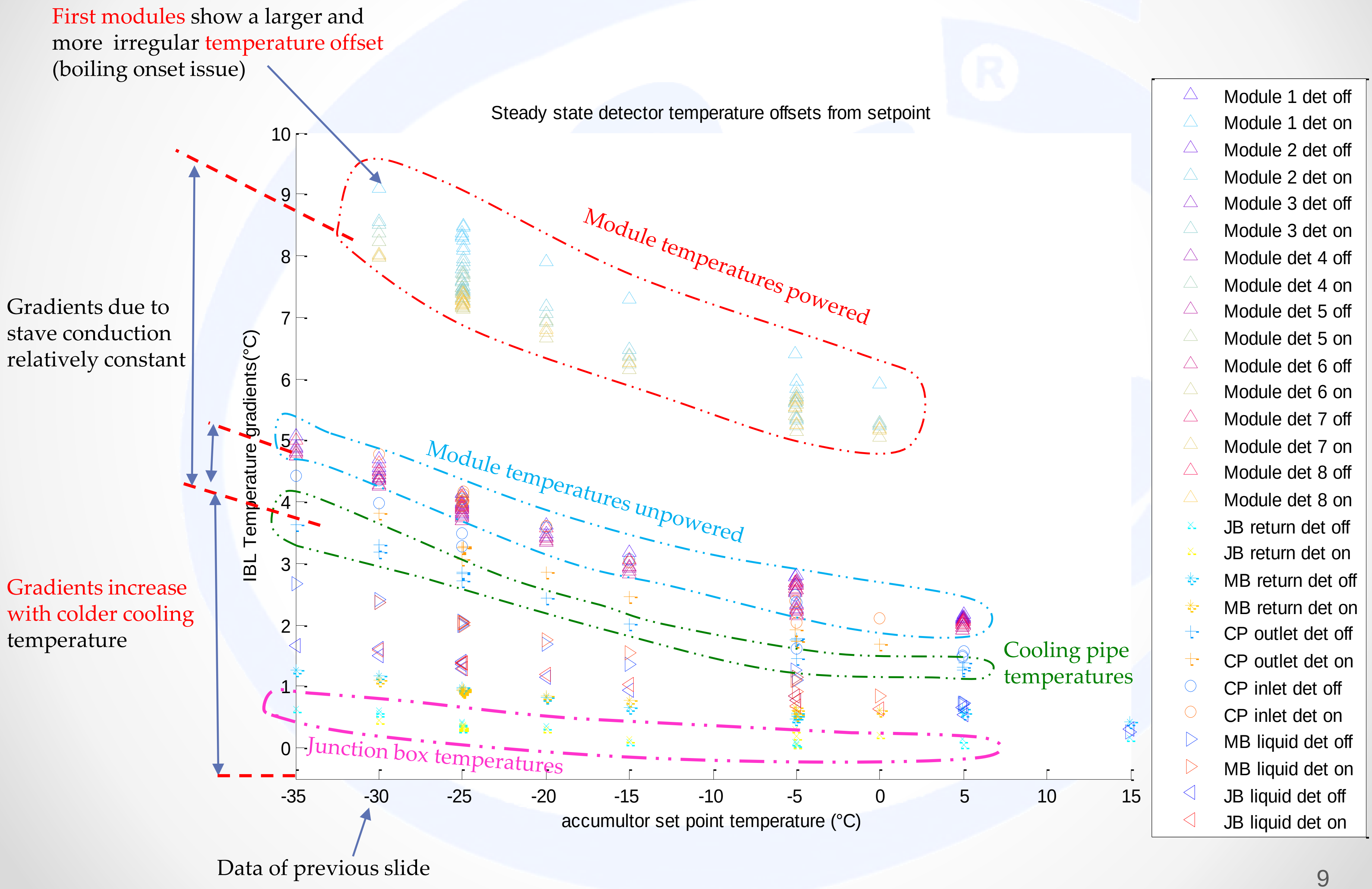


Set point = -30°C

Ambient heat load from previous slide included in simulations

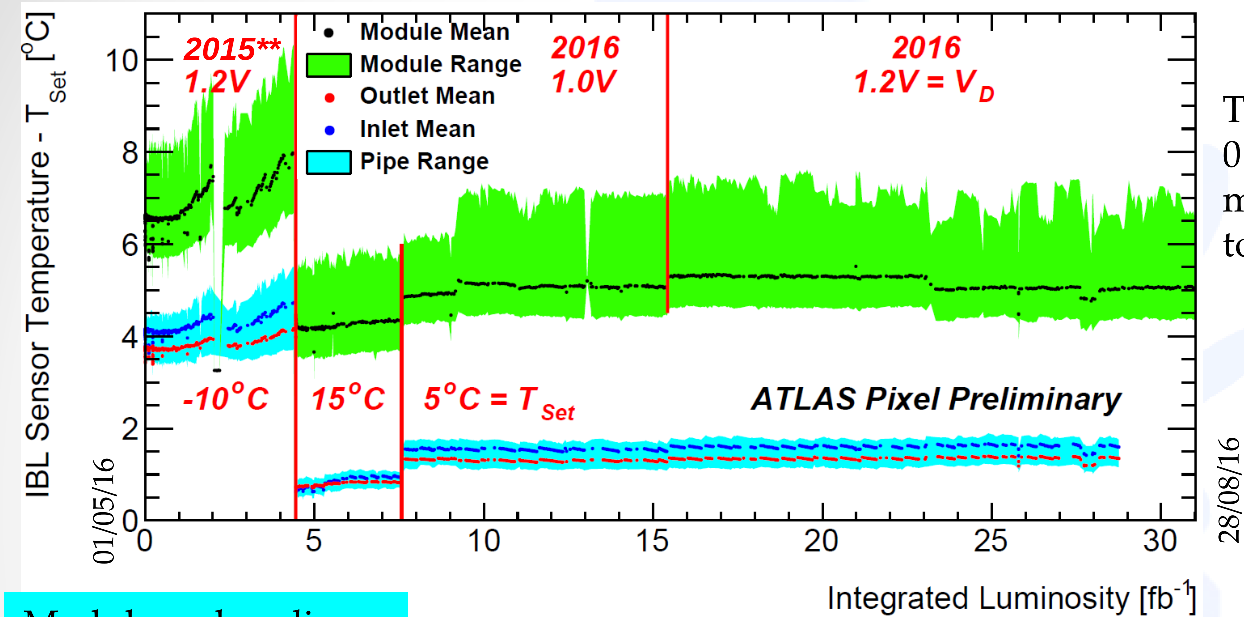
Steady state tests (Dec. 2014)

Overview of different set point temperatures



Cooling performance during operation

Nick Dann

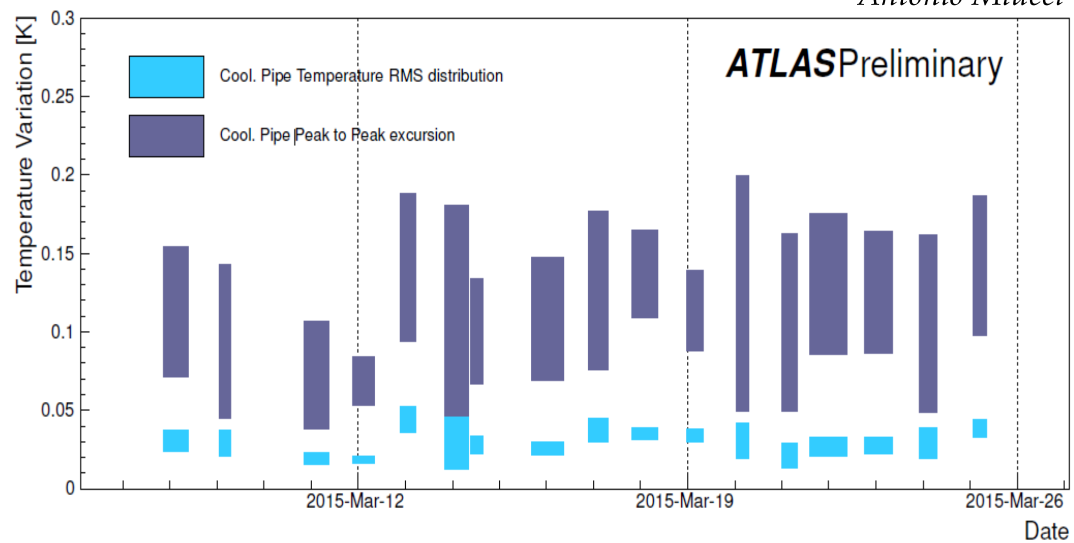


The cooling system is stable within 0.2 °C (<0.05 °C RMS), Detector modules within a few degrees due to power fluctuations

Module and cooling pipe temperatures

Cooling pipe measured stability during M9 run

Antonio Miucci



** 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 ˜1.5°C too high, Module temperatures ˜0.5°c

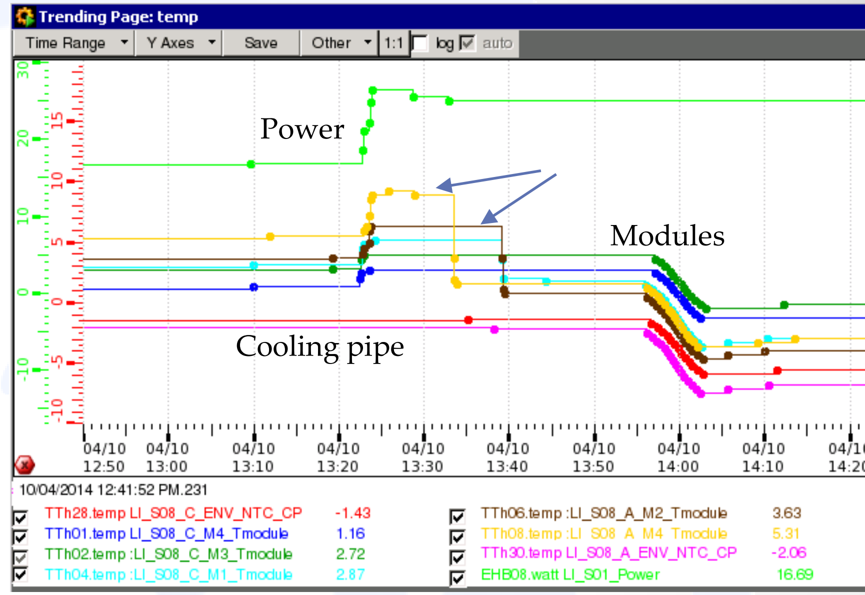
Operational experience since LS1 (1.5 years of operation)

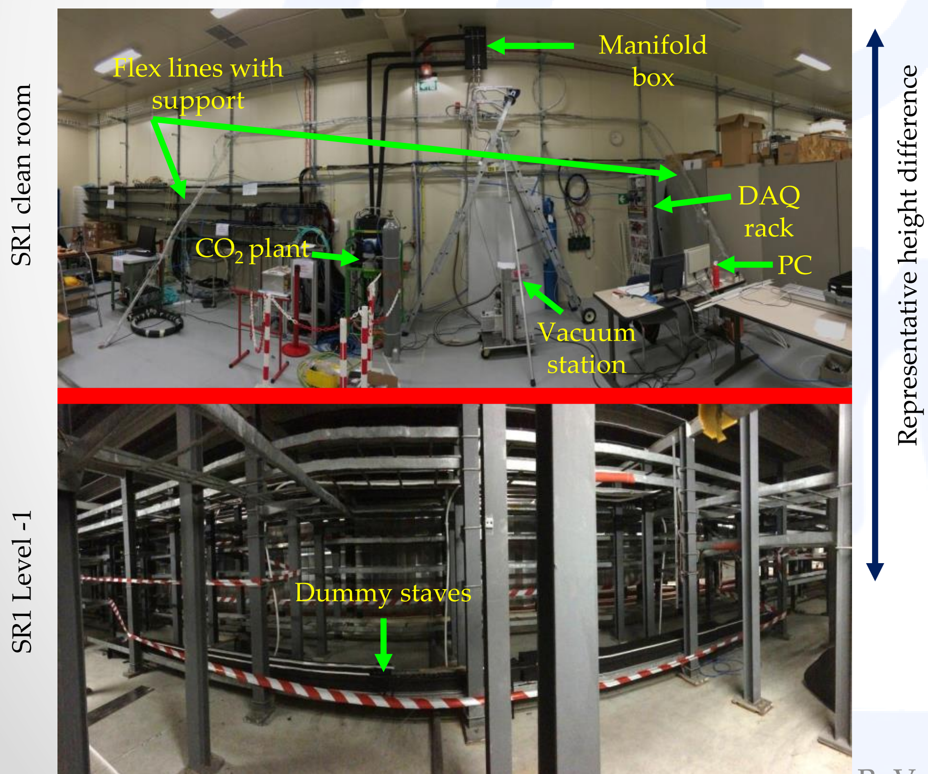
Period		CO_2 System failure			Chiller or primary cooling issue	Software modification	System test	Plant recovery
		DSS Interlock	Automatic swap	Maintenance intervention				
Data taking	Beam		1x *(Flow meter failure)*		4x	5x		1x
	No beam	1x *(Initiated swap for maintenance followed by a trip of the 2nd system due to threshold conflict in the start-up stepper)*				6x		1x
TS				5x		6x	1x	1x
MD				1x	1x	3x	3x	1x

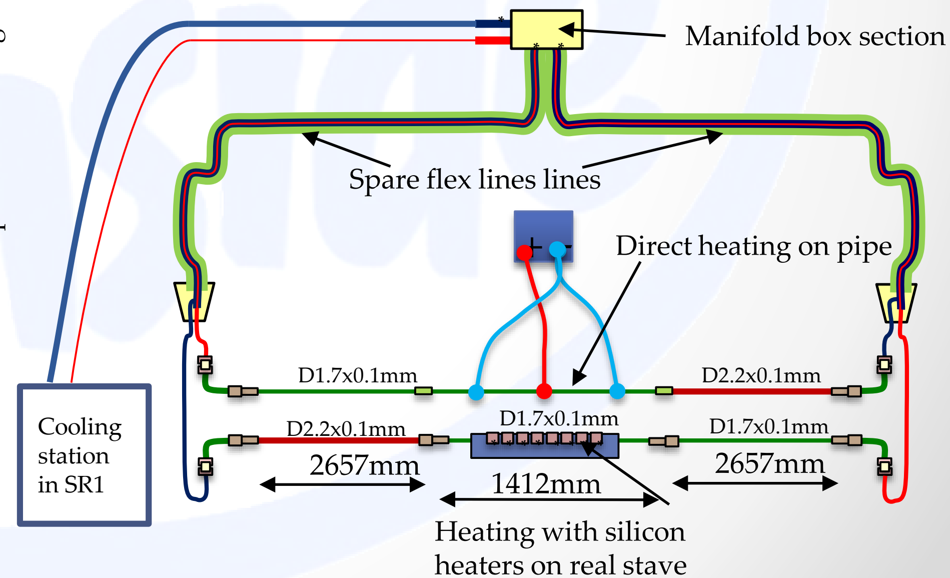
- The IBL CO_2 cooling system had an excellent track record: 0% downtime during physics
- Only limited interventions were needed, of which most were done during safe periods (TS, MD)
- 2 incidents during detector operation
  - 1 hardware failure with a successful back-up procedure
  - 1 DSS interlock 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

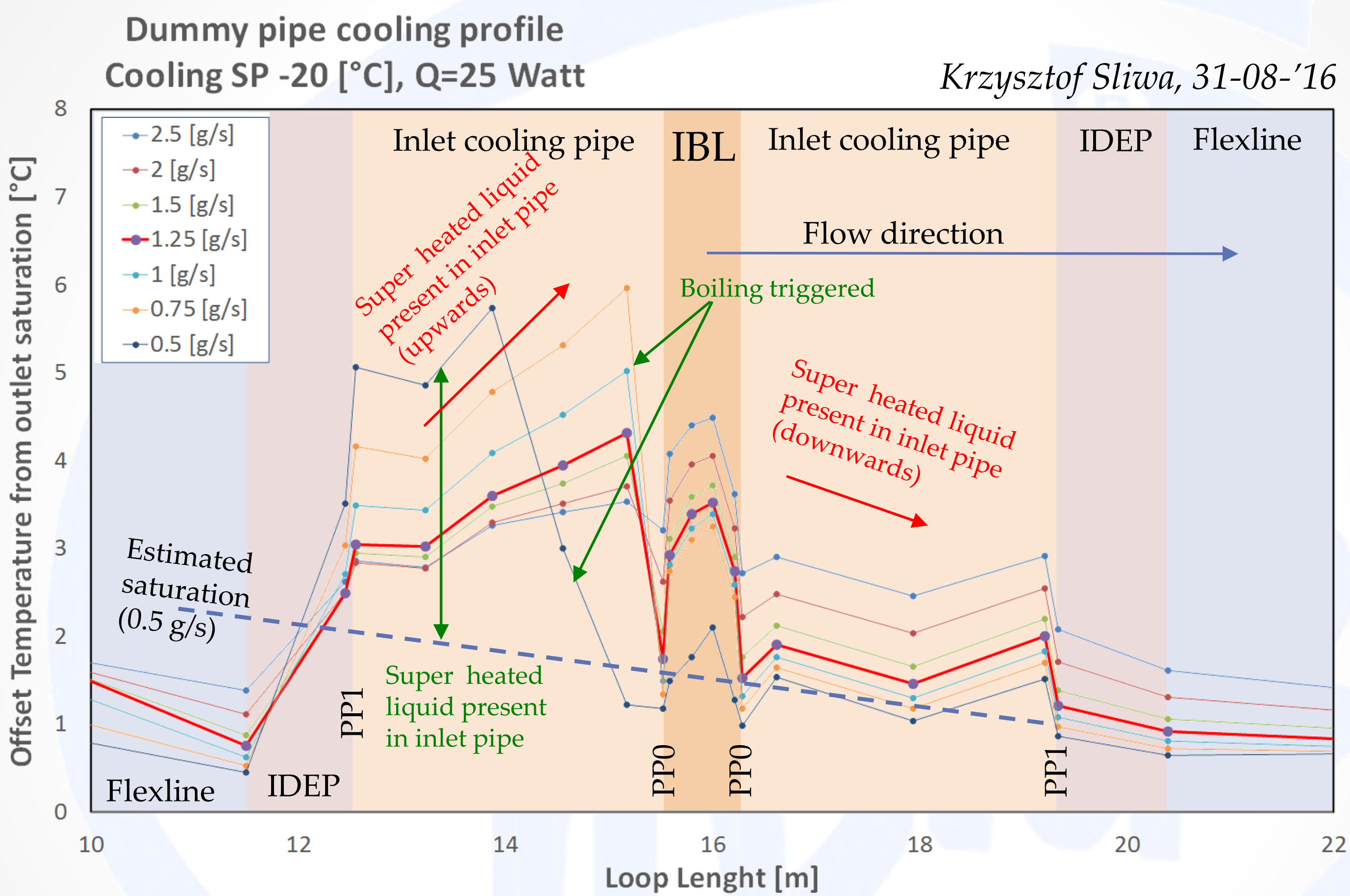
- Sometimes the boiling is not triggered, and a reduced cooling performance is observed (bad heat transfer)
- We are trying to understand what causes this phenomena and how we can improve it
- The non-boiling issue is annoying for the alignment due to stave bowing.
- A test set-up containing a real size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







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 CO_2 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.