CERN | PH-DT Detector Technologies

NIKHEF

Novel technologies and materials for thermal management

ECFA High Luminosity LHC Workshop

Session: Tracking Systems and Associated Electronics and Readout

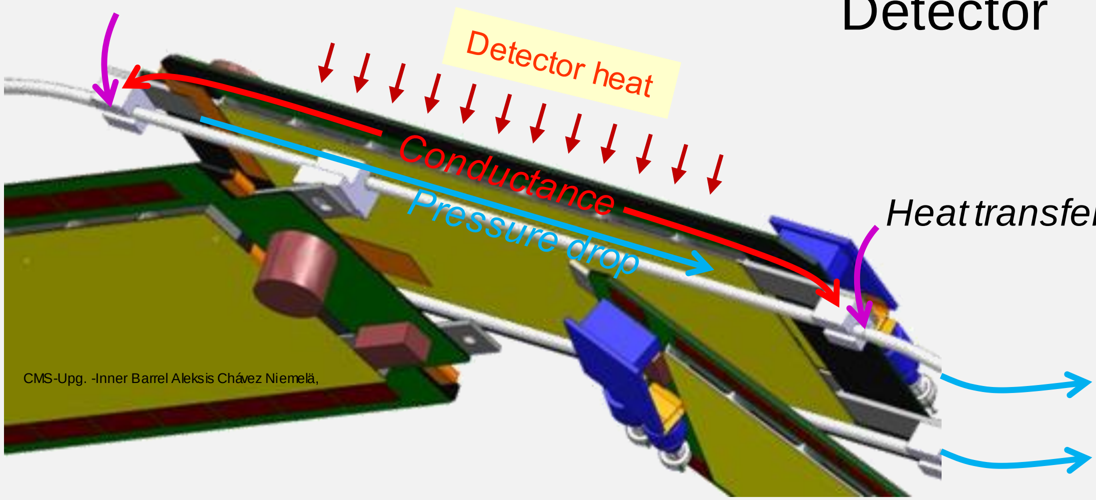
Aix les Bains, 2 October 2013

Bart Verlaat (Nikhef/CERN) on behalf of all my colleagues contributing to thermal management development in HEP

Introduction

- Thermal management is more important for HL-LHC detectors than ever before
- High radiation doses requires silicon detectors to be cold
  - To avoid thermal runaway
  - To avoid reversed annealing
  - General $T_{silicon} < -5^{o}C$
    - Cooling between -20ºC and -40ºC
- Whole thermal chain from detector towards cooling plant needs to be optimized
  - Construction materials with low radiation length and high thermal conductance
  - Reduced cooling pipe sizes and distribution piping

A typical Detector thermal path



Detector

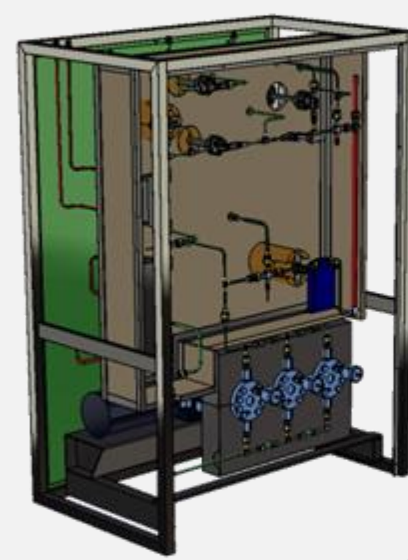
Transfer line

Cooling lines

- Thermal / Mechanical structure (Conductance)
- Evaporative Heat Transfer (Conductance)
- Cooling tube distribution (Pressure drop*)
- Cooling transfer line (Pressure drop*)

** Pressure drop in a 2-phase system changes the boiling pressure and is manifested as a temperature drop. Needs therefore to be accounted for in the design of the overall thermal chain together with the conductance in the structure.*

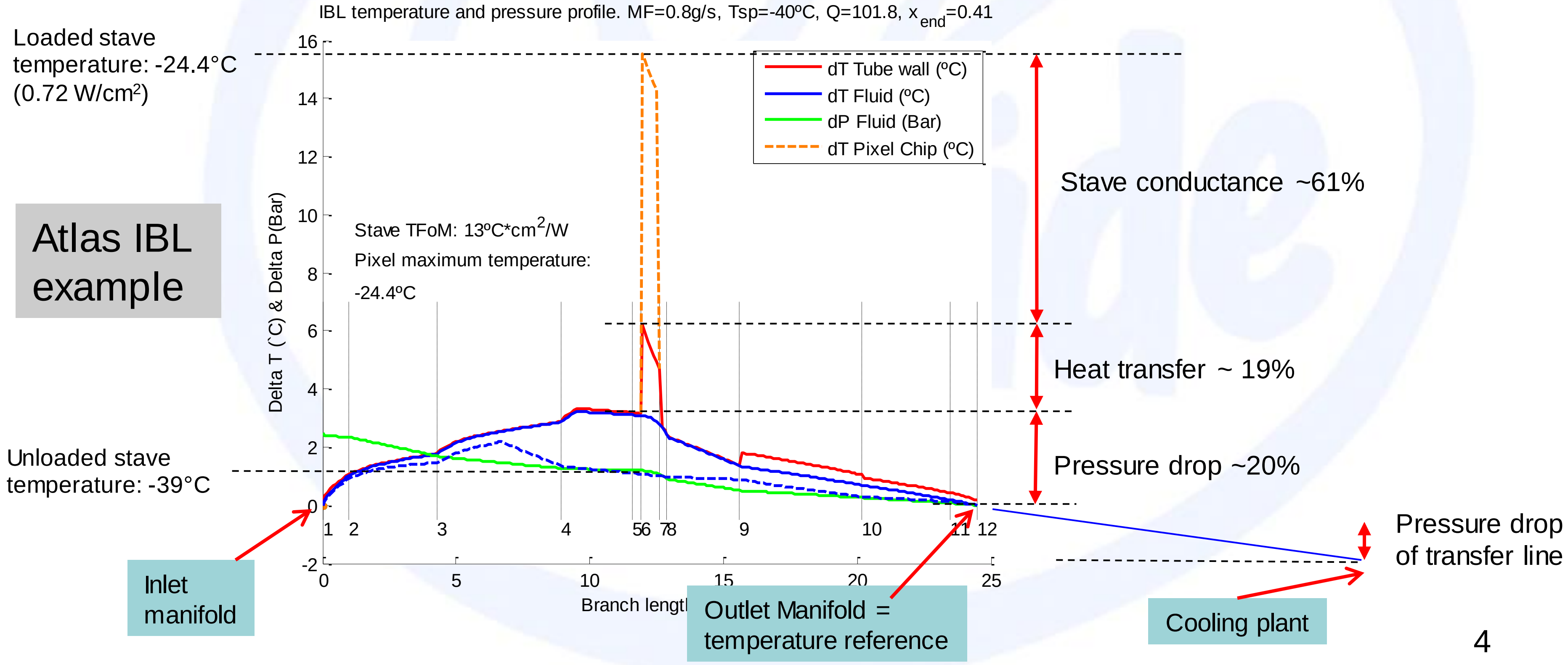
Cooling plant



Design of thermal structures: *From source to sink*

- Thermal management optimization is evaluating the whole thermal chain
  - Conductance of thermal-mechanical support structure towards cooling
  - Optimization of cooling pipe dimensions
  - Optimization of coolant transfer system (From detector to cooling plant)

Atlas IBL example



Thermal management of HEP detectors

- Thermal management is the optimization of the whole thermal chain
  - From source (silicon) to sink (cooling plant)
- Three area's of expertise can be distinguished:
  A. Thermal mechanical support structures design (mechanical and materials engineering)
  B. Geometry and lay-out optimization of the cooling lines (thermodynamics)
  C. Development of cooling stations including fluid transfer (thermodynamics)

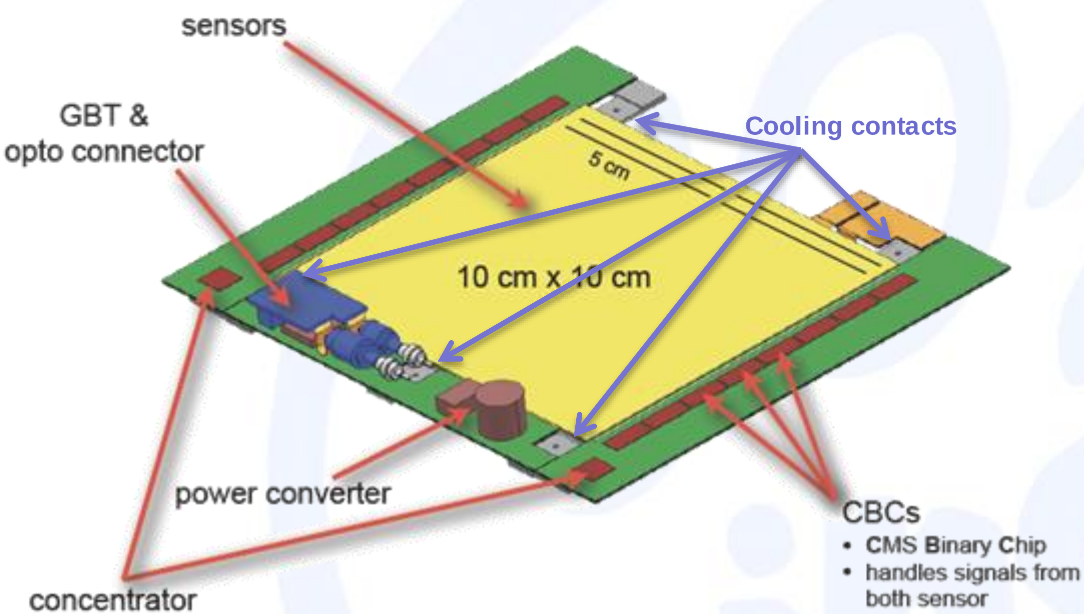
A. Thermal mechanical support structures design (1)

- Optimization of the thermal/mechanical support structures of the silicon detectors
- Materials engineeering focused on the following properties:
  - Low radiation length
  - High thermal conductivity
  - High stiffness
  - Low CTE (Coefficient of Thermal Expansion)
  - Radiation resistant
  - Low temperature resistant
- Examples of candidate materials fulfilling above properties
  - Carbon based materials in several appearances
    - Carbon foam
    - TPG (Thermal Pyrolytic Graphite)
    - Carbon-Carbon
    - Carbon fibers
    - Carbon fleece
    - Diamond
  - Titanium cooling pipes (Light weight / low CTE metal)
  - High conductive glues and resins
  - Silicon or polymer micro-channels plates

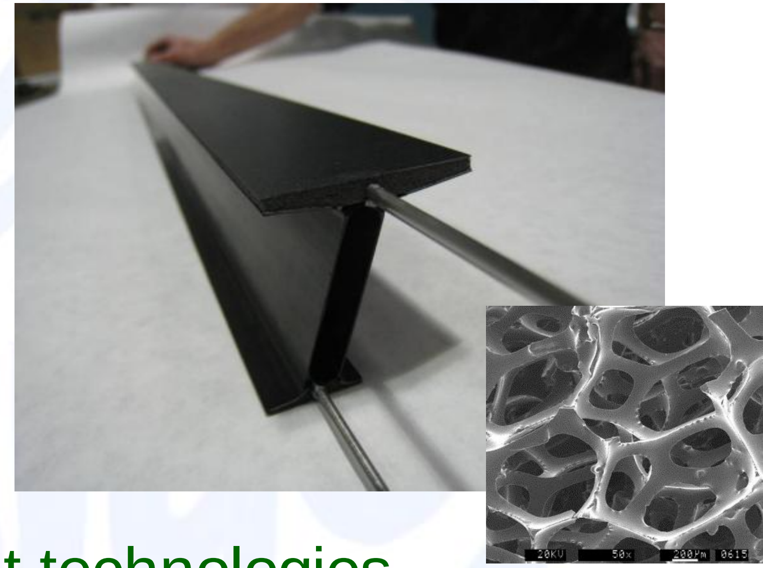
- Interesting new technologies are being explored; known technologies need to be re-qualified for higher radiation and lower temperatures
- These technologies are the core of the future detector structures; developments are carried out within the detector collaborations, in close connection with the specific details of the detector design

A. Thermal mechanical support structures design (2)

CMS-Thermal path oriented structures



Atlas- Carbon foam filled staves embedded in carbon fiber

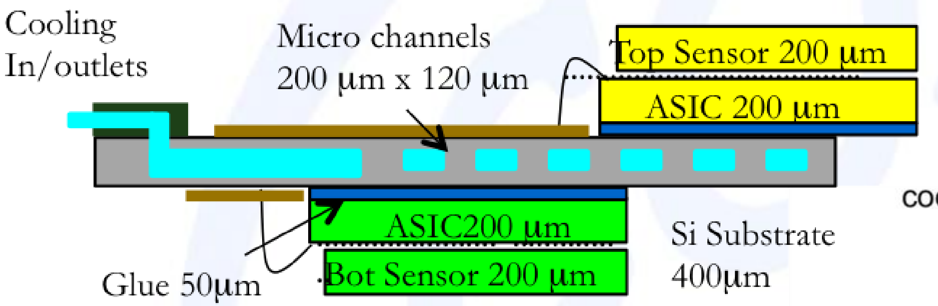


Different experiments with different technologies

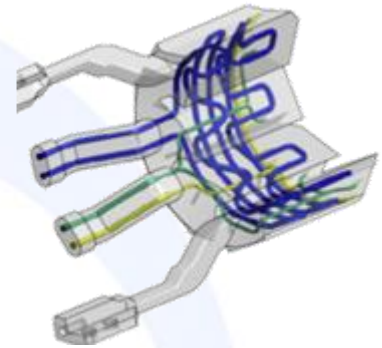
Alice: Very lightweight space frame structures

Very interesting new development: Micro-channel cooling

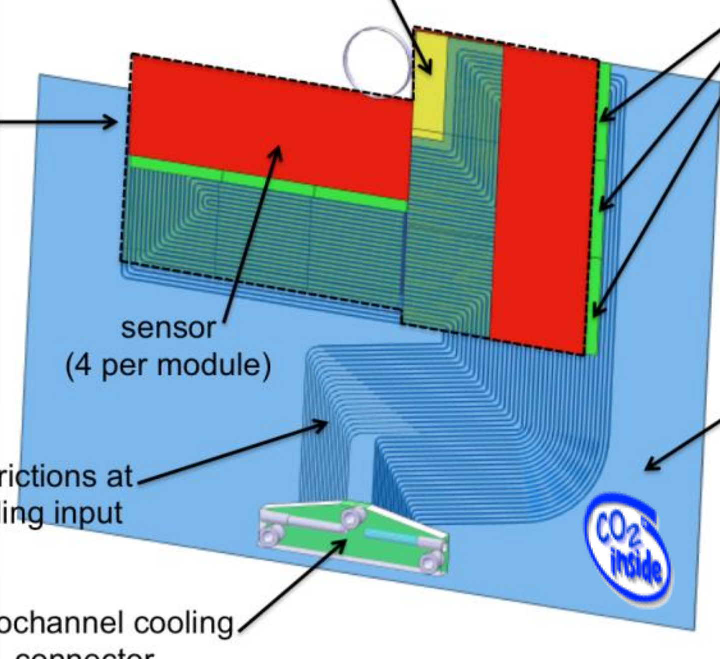
In silicon etched channel structure direct in contact with read-out chips of the silicon sensors



A different integrated channel technology: metal printed heat sinks (Belle-2)

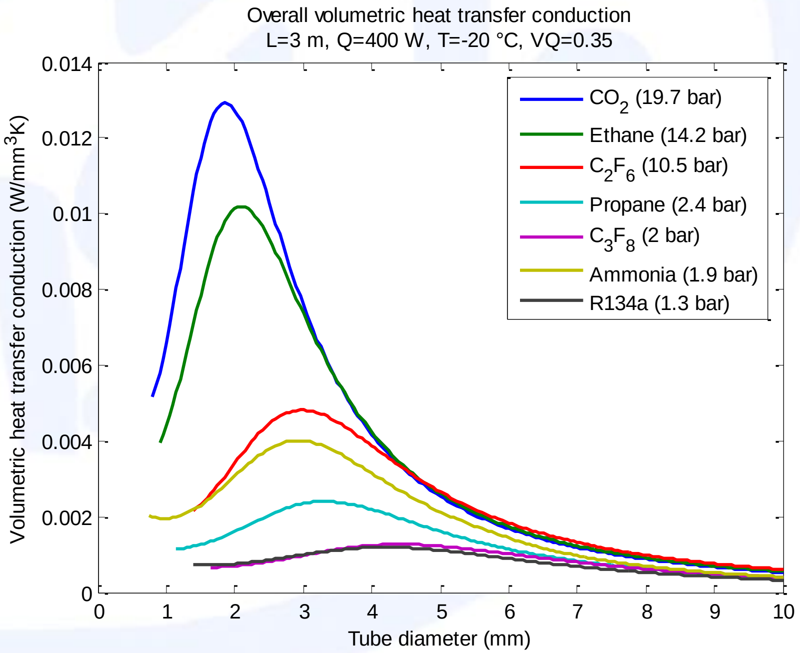


LHCb-Velo upgrade



B. Geometry and lay-out optimization of the cooling lines (1)

- Detectors require low mass cooling.
  - CO_2 has the best properties for efficient cooling in small tubes for the working temperature range of silicon detectors
    - +20°C (Commissioning) down to -40°C
  - What is the secret of CO_2?
    - Low viscosity, high pressure, high latent heat
- CO_2 cooling has been proven to work for AMS and LHCb-Velo.
  - CO_2 cooling foreseen for most new silicon detectors.



Volumetric heat transfer is also a good method to compare different fluids

How can we put a maximum amount of heat into the smallest possible cooling tube??

Interesting: Performance almost linear with fluid pressure.

PH-DT
Detector Technologies

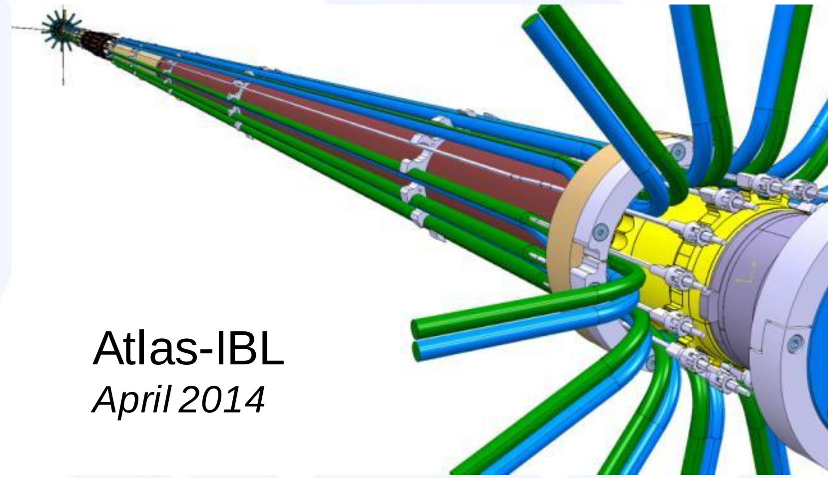
B. Geometry and lay-out optimization of the cooling lines (2)

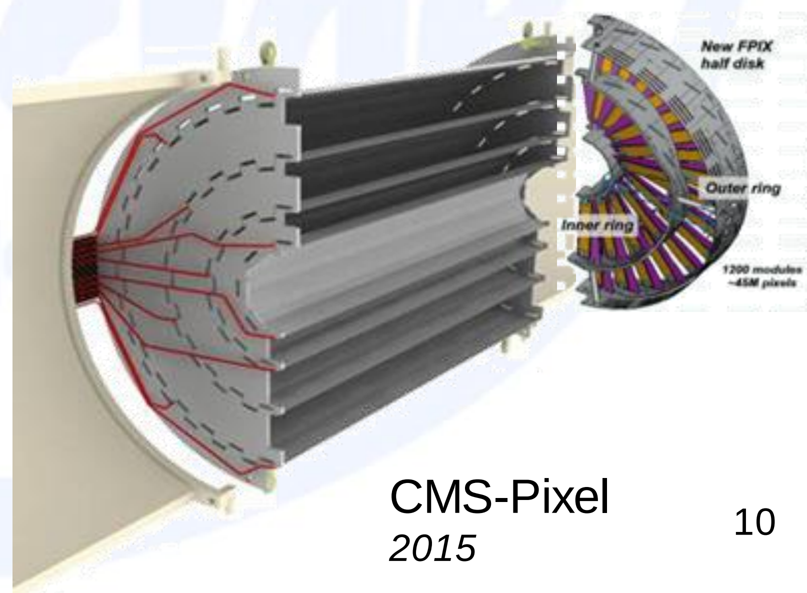
Operational CO_2 cooling
(With good track record)


AMS-Tracker
Since May 2011


LHCb-Velo
Since 2009

CO_2 cooling under construction:

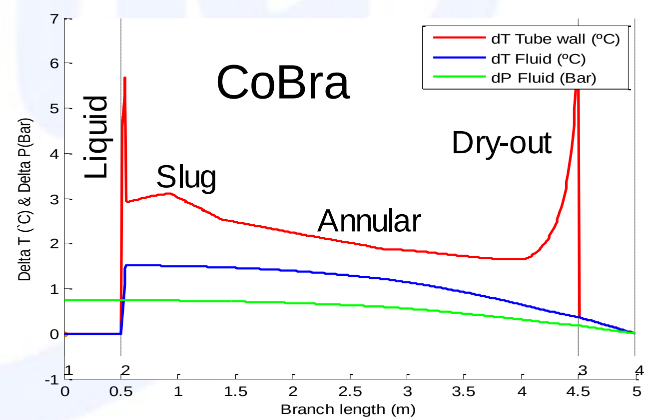

Atlas-IBL
April 2014



CMS-Pixel
2015

B. Geometry and lay-out optimization of the cooling lines (3)

- Future detectors have a complex cooling infrastructure inside.
  - Many different cooling lines (wrt power and geometry)
  - Good understanding of fluid flow behavior is needed
    - Development of calculation models is crucial
    - Verification of models by experiments
  - Cooling lines are part of the thermal/mechanical support structure design and optimization
    - The detector performance does not stop at the pipe wall!
  - This most complex part of the cooling system is in general under estimated
- Needs close collaboration between cooling experts and detector development groups
- Is important in the early stage of a detector design
  - Integration through the whole detector
  - Is related to the segmentation in the detector
- New promizing technologies
  - Flexible vacuum insulated cooling tubes
  - 2-phase flow modeling like CoBra
  - Special joining techniques
    - Brazing and orbital welding of new materials



C: Development of cooling stations including fluid transfer (1)

- Cooling plant development is based on LHCb-Velo cooling concept
  - Many new systems built based on LHCb design
  - Currently scaling from 1 kW (LHCb) to 15 kW (CMS)
  - In future scaling to 100 kW +
    - Modular approach of smaller systems, enhancing redundancy (E.G. 5x20kW)
- CO_2 cooling is developed for commercial refrigeration as a green refrigerant
  - Benefit from industry product development
  - But: the way we operate our systems is significantly different.
    - Need continuous development to satisfy our own specific needs.
- Standardization of design, control and maintenance for different experiments
- Centralized development ongoing in CERN PH-DT
  - Need to strengthen team to be ready for large future systems

C: Development of cooling stations including fluid transfer (2)

From LHCb to:


VTCS (1kW)


Traci (250 watt)


Atlas IBL(2kW)


Marco (1kW)


Cora (2kW)


CMS pixel (15kW)

Cloning LHCb-concept for new systems

C: Development of cooling stations including fluid transfer (3)

- A large demand from detector development groups for CO_2 test equipment.
- A compact CO_2 cooler called Traci is developed by CERN PH-DT & Nikhef
- User friendly system for non CO_2 experts.
- Currently suffering from an unreliable pump
  - Need vigorous R&D effort for the development of small CO_2 pumps
  - Small CO_2 pump not on the market
  - R&D is urgent
  - Lack of resources for development

Conclusions

- The development of detector cooling for the HL-LHC upgrades presents substantial challenges
  - To achieve optimal performance the thermal chain needs to be optimized with an integral perspective
- The design of mechanical structures and thermal contacts will profit from novel material and technologies
  - Promote initiatives to share knowledge and experience
    - E.g. Forum on Tracking Detector Mechanics http://www.physics.ox.ac.uk/forum2013/index.asp
- The realization of the cooling systems requires a common center of expertise for design, construction and operation
  - Ensure coherent and cost-effective developments, with standardized components
  - Maintain and evolve the necessary technical competencies
    - Simulation
    - Thermodynamics (materials, piping, fluids, plants)
    - System construction & operation (including controls)
  - The required competencies exist in the experimental teams in the collaborations and the CERN PH-DT cooling team
    - Further strengthen the common cooling project to build on current experience and the operation phase ahead, and to establish partnerships for future R&D
- Significant resources and funding needed for developments addressed above