EP-DT
Detector Technologies

Inżynier w CERN

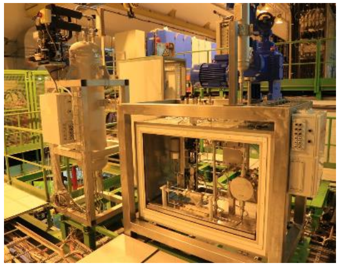
L. Zwalinski – CERN EP/DT
October 28th 2019

ATLAS Cooling Coordinator
EP-DT-FS leading control engineer

Professional path and educational background








AGH University of Science and Technology
Faculty of Physics and Applied Computer Science
Master degree

LHC Tunnel Cryogenics
all LHC sectors (ARC+LSS) & RF cavities

Detector cooling tests facilities

Detector cooling final systems

ATLAS cooling coordination
ATLAS Phase II upgrade coordination

New detector cooling team

2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016

ACR-IN / CRG-CE *PJAS* → PH-DT Detector Technologies **PH-DT-PO** *FELLOW* → EP-DT Detector Technologies **EP-DT-FS** *STAFF*

LHC Tunnel Cryogenic Control System
- PLC and SCADA software development
- Hardware commissioning

Test detector cooling systems development
- Controls HW & software
- **Evaporative CO_2 cooling R&D**
- Technical and safety documents preparation
- ATLAS ID Evaporative Cooling System operation

Final detector cooling systems development
- Control system development, commissioning and operation
- Controls standardization
- Evaporative CO_2 detector cooling R&D
- ATLAS cooling coordination
- Co-leading ATLAS ITk cooling effort for HL LHC upgrade

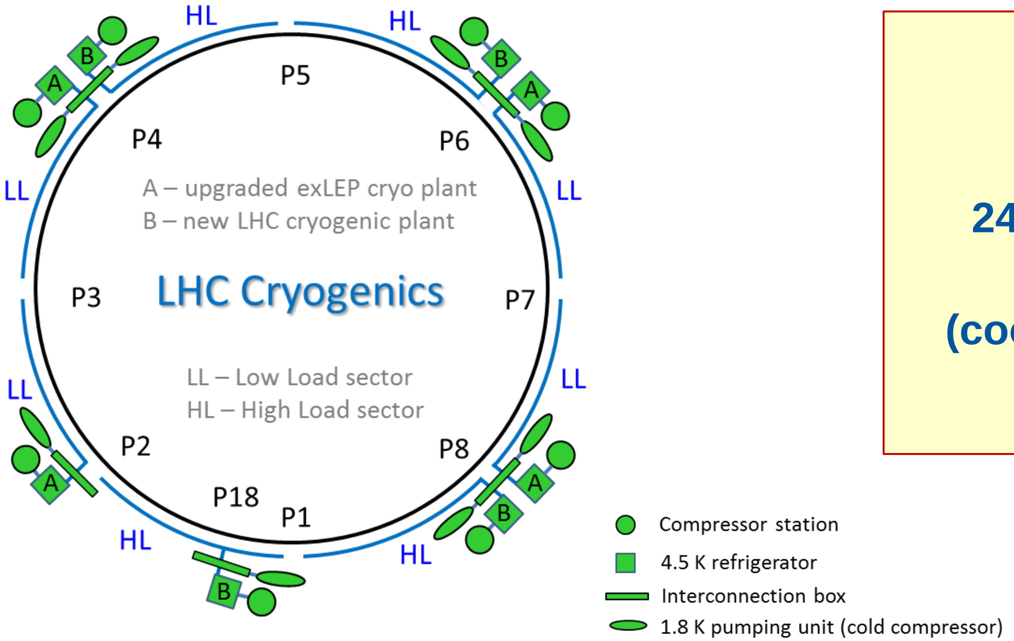
LHC tunnel cryogenics

Cryogenics

- Cryogenics is part of low temperature refrigeration science - below 150'C
- Cryogenics refrigeration -> superconductivity

➔ nadprzewodnictwo (bezoporowy przepływ prądu)

➔ przy przepływie wysokich prądów w cewkach magnesów generowane jest wysokie pole magnetyczne dla utrzymania trajektorii ruchu oraz geometrii wiązki.



8 x 18 kW = 144 kW at 4.5 K

1 800 sc magnets

24 km and 20 kW at 1.8 K (~-271 C)

37 000 t at 1.9 K

(cooled down with superfluid helium)

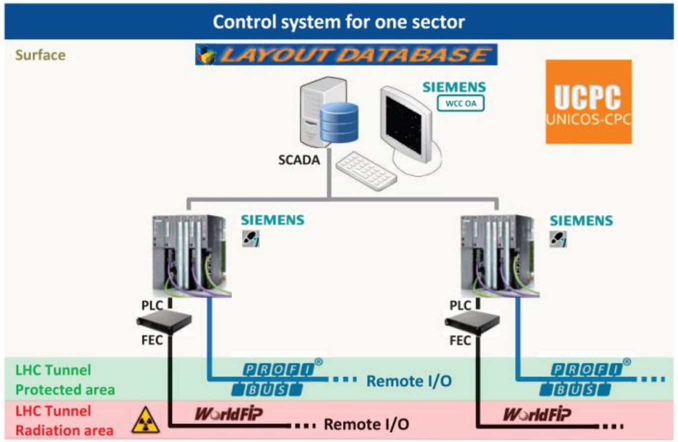
150 t He inventory

LHC tunnel cryogenics

Our role in LHC tunnel cryogenics

- Hardware commissioning
- Control system software development:
  - Process control implementation testing and upgrades
  - **PLC and SCADA programming**
  - Additional software tools development

Control System for LHC Tunnel Cryogenics [2005-2010]



Figures

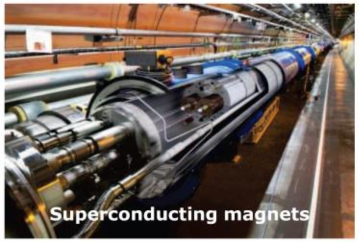
Layout Database
Conceptual objects: 30'000

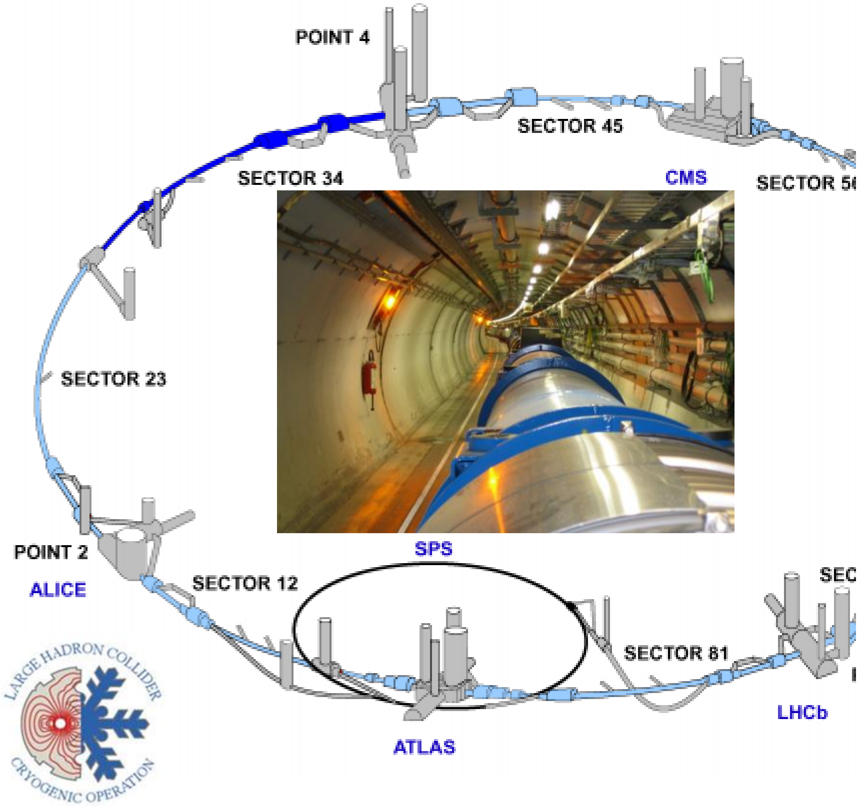
8 SCADA Data Servers
Panels: > 1'000

18 PLCs
code lines : 5'000'000

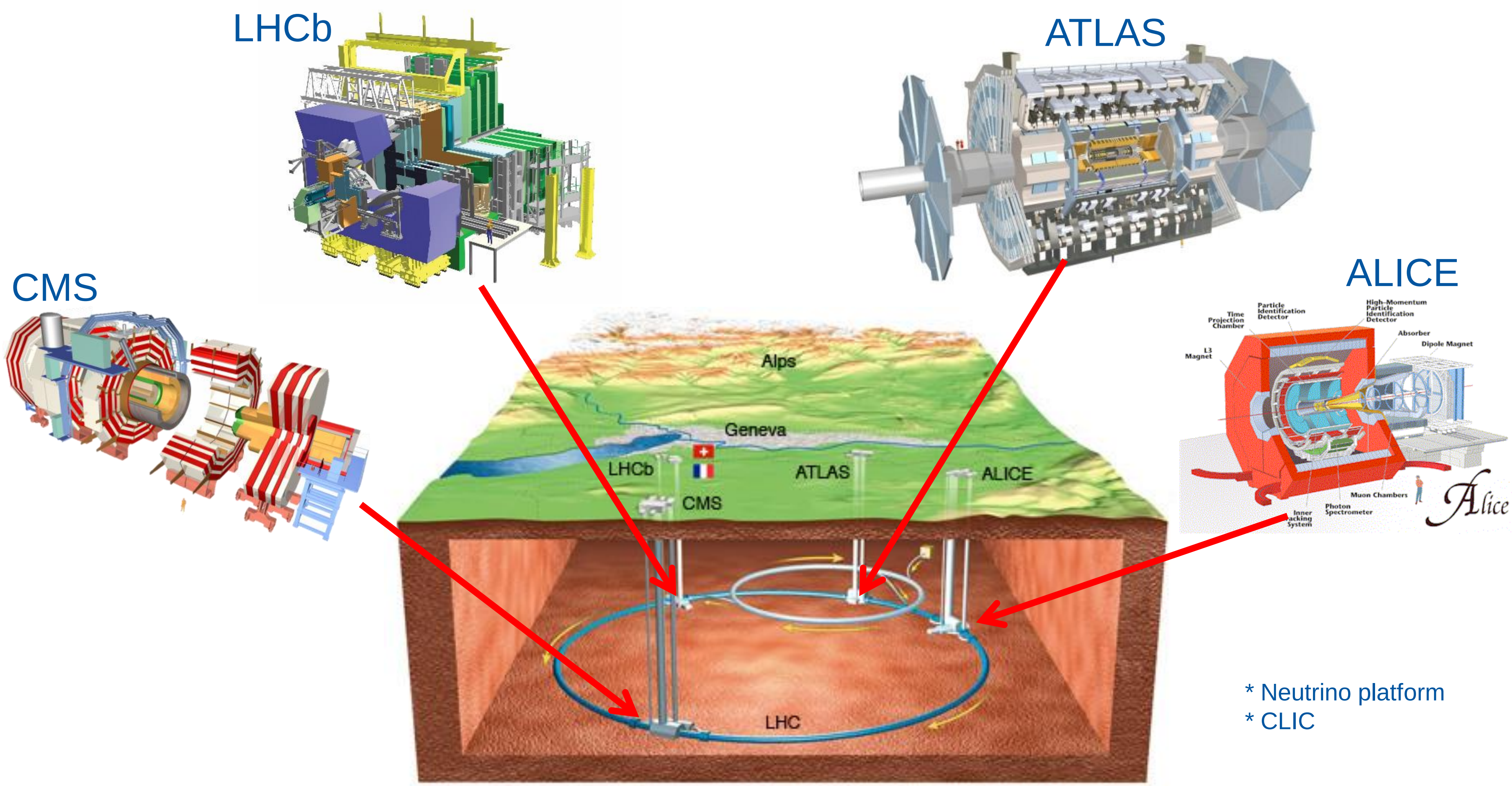
Profibus
Remote I/O stations: 150

Instrumentation
Sensor & Actuators: 15'000





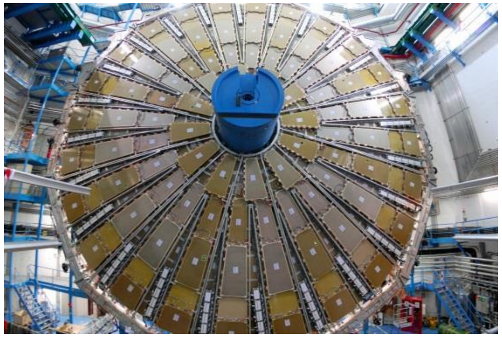
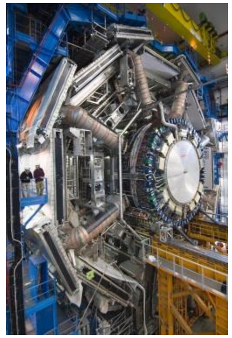
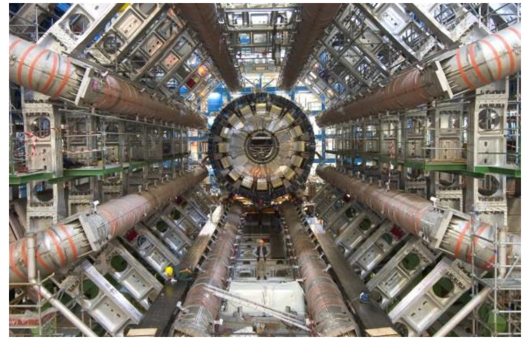
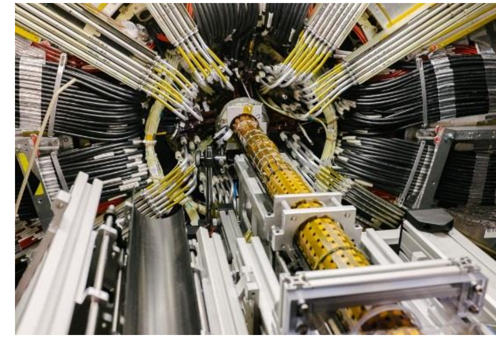
Eksperymenty LHC – technologie detektorów

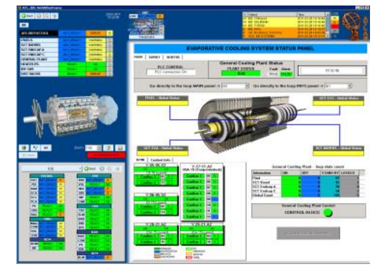


* Neutrino platform
* CLIC

Polskie zespoły brały oraz biorą czynny udział w projektowaniu, budowie i eksploatacji <u>wszystkich czterech największych eksperymentów LHC</u>.

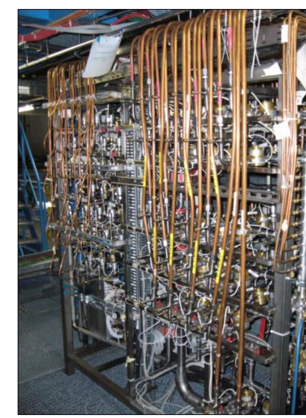
ATLAS i grupa technologii detektorowych



Zadania Polaków pracujących w eksperymencie ATLAS:

- Czynny udział w **koordynacji i budowie systemów gazowych i chłodniczych**;
- Prace nad odpornymi na promieniowanie krzemowymi detektorami i wyspecjalizowanymi układami scalonymi;
- Projekt, testy, układów sterowania i oprogramowanie systemu zasilaczy wysokiego napięcia;
- Znaczący wkład w stworzenie infrastruktury monitorującej, zabezpieczającej i zasilającej aparaturę elektroniczną detektora oraz systemy chłodnicze;
- Projektowanie wsporników pod kalorymetr i opracowanie metod instalacji komór mionowych.
- Koordynacja elektryczna i chłodnicza podczas normalnej pracy eksperymentu;
- Ciągły udział w rozwoju systemów monitorowania pracy detektorów;
- Aktywna partycypacja w pracach związanych z nowym detektorem śladowym oraz jego systemami chłodzenia.

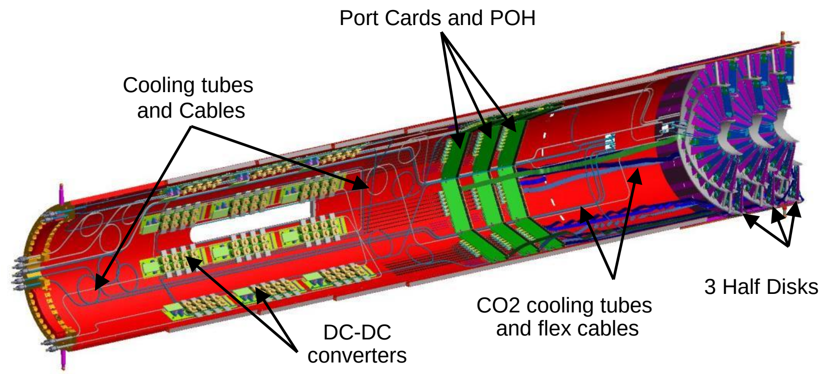


Wyzwania w ATLAS-ie
35 systemów o mocy chłodniczej
1kW – 260kW

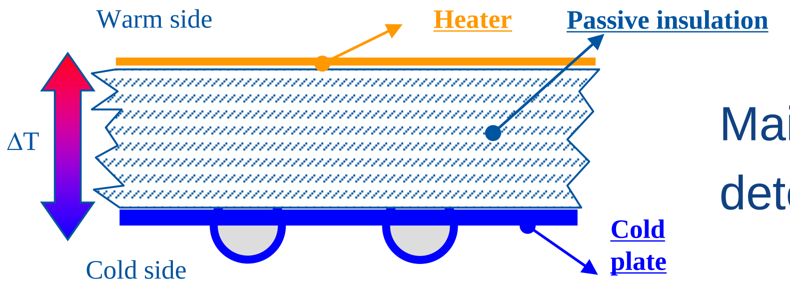
Detector cooling: why?

…many different reasons!

- Dissipate the heat produced by:
  - detector
  - electronics
  - cables

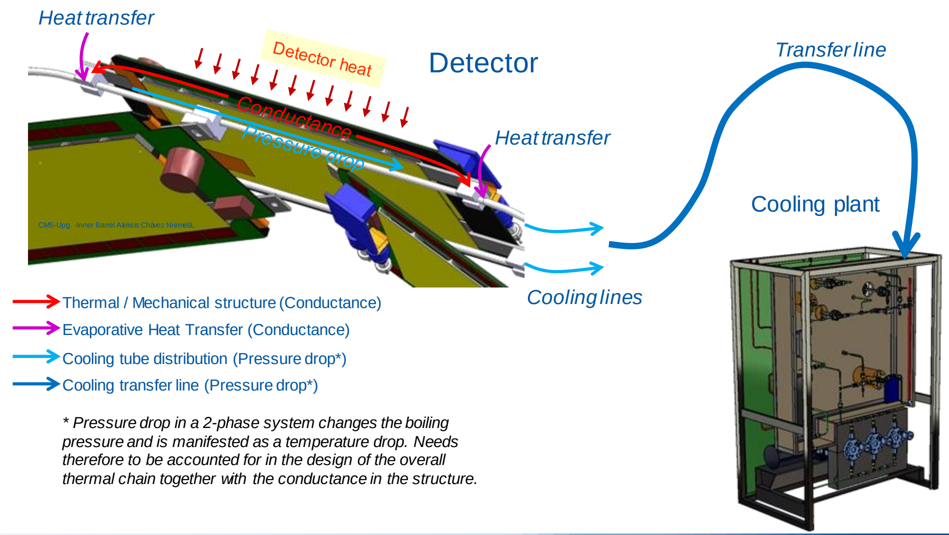


K. Arndt, CMS Phase I Pixel detector EDR (https://indico.cern.ch/event/278220/)

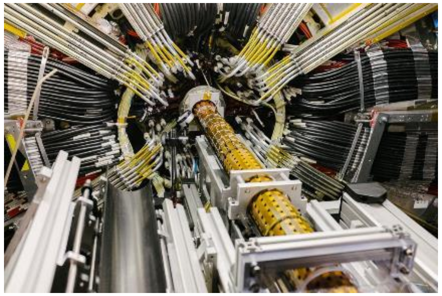


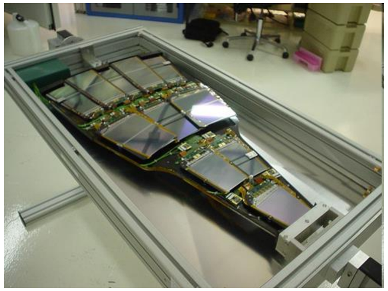
P. Petagna, Thermal enclosures & environmental management, 2008

Maintain a neutral environment between different detectors: active thermal screens



Guarantee detector lifetime !!!





Detector cooling classes

Cooling of LHC experiments – “room” T

Water, C_4F_{10}, C_6F_{14}

ALICE

SPD
2 phase C_4F_{10}
15 °C

HMPID, SSD & S DD, TPC, TRD, TOF & Calorimeters
Water
16-18 °C

ATLAS

Muons, LAr & Tile Calorimeters, Diffusion Pumps, Rod Racks
Demineralized or “treated” water
15-20 °C

TRT, CABLES
Liquid C_6F_{14}
15-20 °C

CMS

Muons, ECAL & HCAL calorimeters, Diffusion pumps & magnet Busbar
Demineralized water
16-18 °C

Racks, PC farm
Tap water
16-18 °C

LHCb

RICH1&2
Liquid C_6F_{14}
10 °C

Calorimeters, OT, Muons, Racks
Water
16-18 °C

Pretty well known technologies, still very challenging for the application!
Magnetic field, radiation, etc.
24/7 operation, reduced accessibility
No space/no time/no mass requirements



Cooling of LHC experiments – Low T

C_6F_{14}, CO_2, C_3F_8

ALICE

PHOS crystals
Liquid C_6F_{14}
-25 °C

ATLAS

Silicon detectors
Evaporative C_3F_8
-25°C

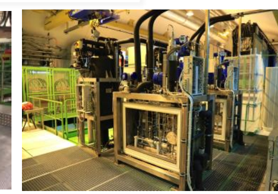
CMS

Tracker, Pixel, Preshower, Tracker/ECAL active thermal screen
Liquid C_6F_{14}
-25 °C

LHCb

VELO
Evaporative CO_2
-25 °C

Introducing further difficulties:
- Environmental management
- Insulation


Detector cooling examples

ATLAS PIXEL & SCT: 204 LOOPS, 60 KW, -25C

ATLAS Pix & SCT
Surface:

- Condenser
- Water circuit
- Low T chiller
- Brine circuit

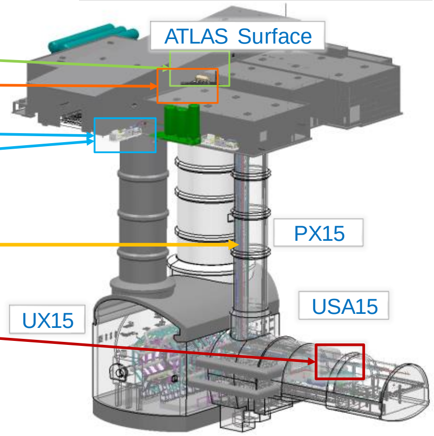
Surface-underground

- C_3F_8 piping

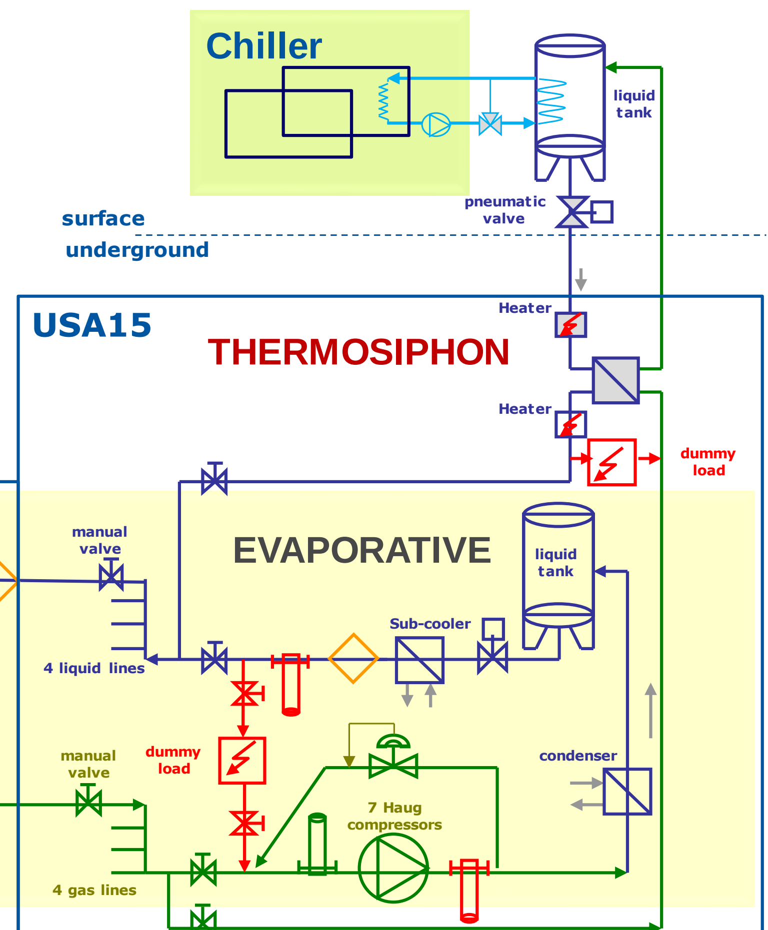
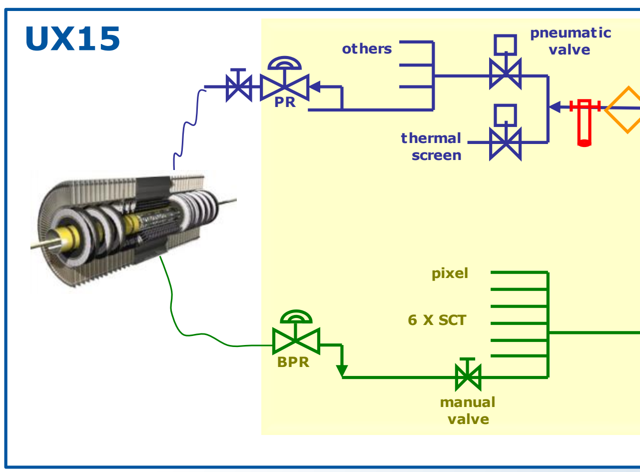
Underground

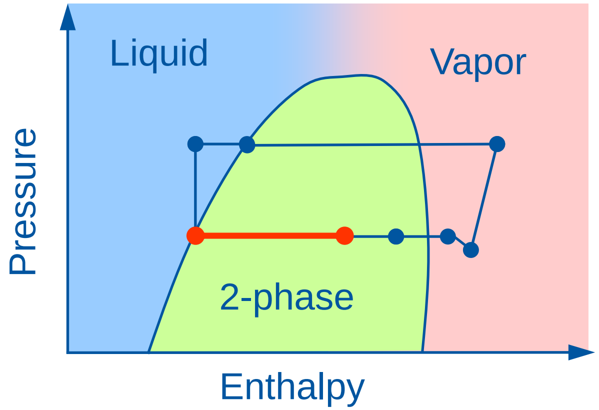
- USA15 by-pass unit
- Connection to existing ID evaporative cooling system

Pictures from: M. Battistin & all TS team ATLAS ID Week CERN October 2013



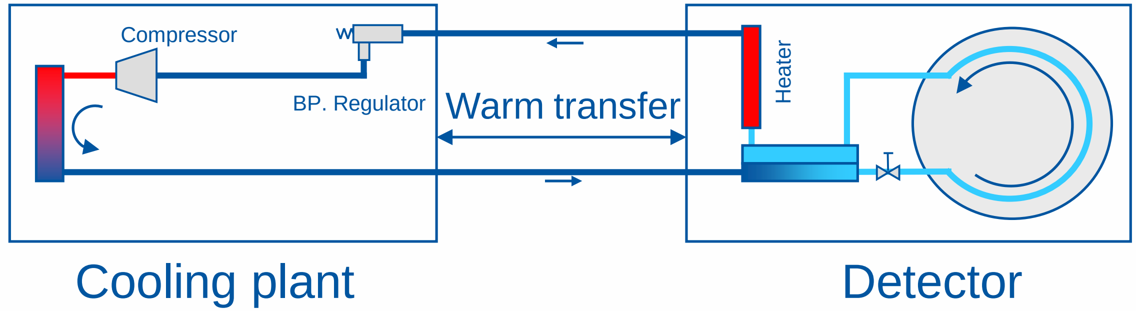
EN/CV & EP-DT

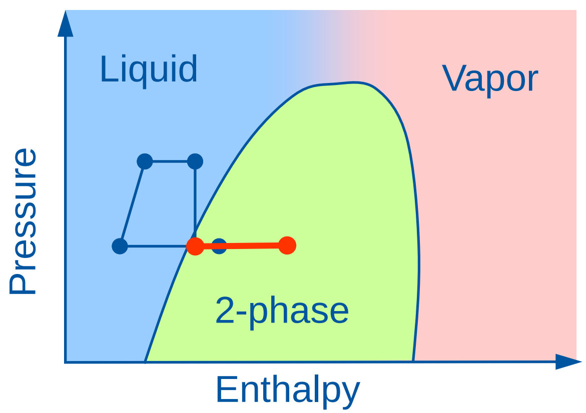





Refrigeration method:
(ATLAS Evap. Cool. Sys.)

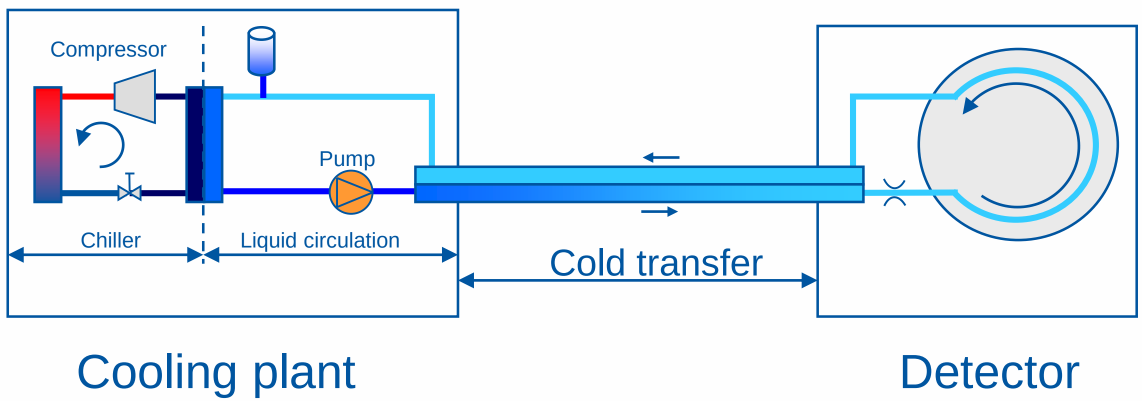
Vapor compression system





2-Phase Accumulator Controlled Loop method:
(LHCb)

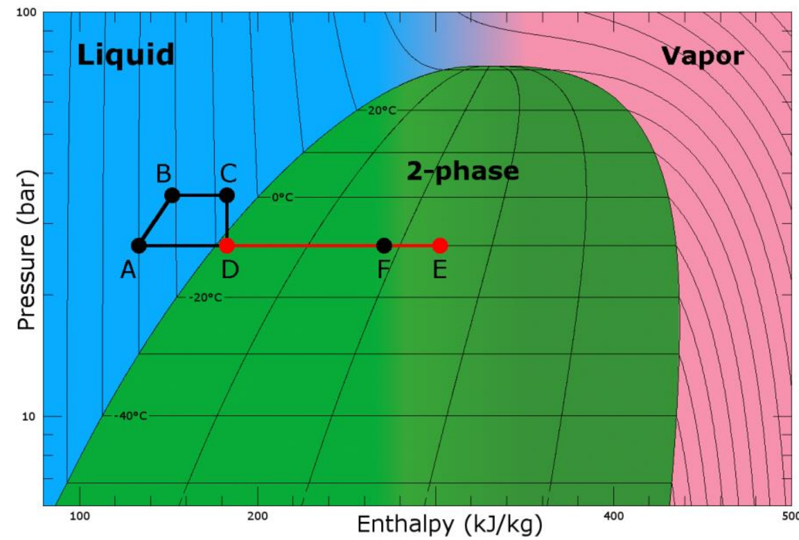
Pumped liquid system, cooled externally

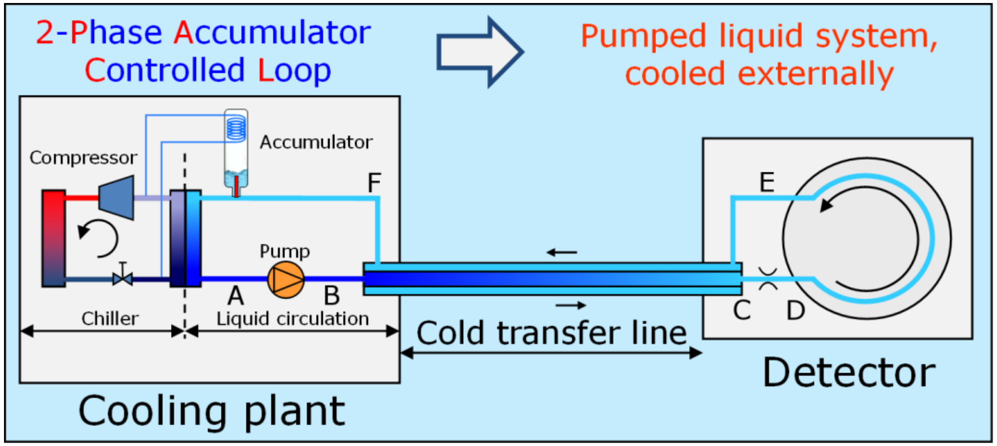


Evaporative CO_2 in pumping cycle

What is different?

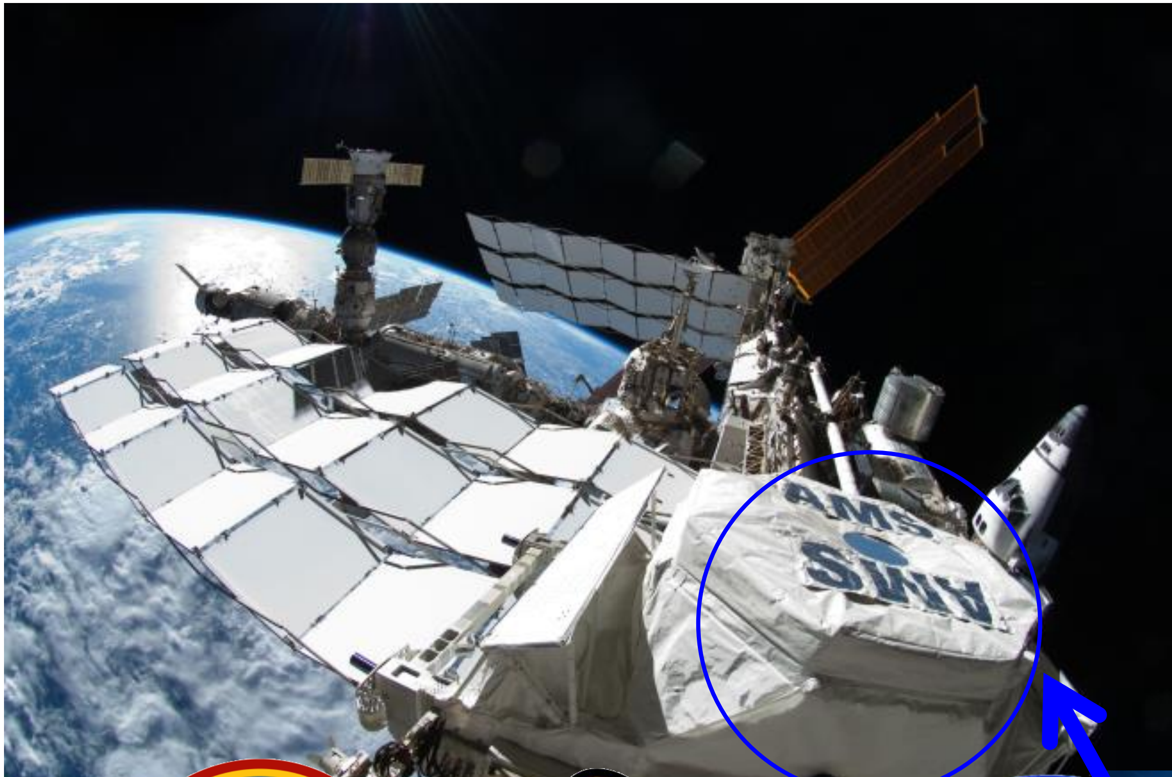
- **Significant saving of cooling hardware** (material budget) into the detector due to the physical properties:
  - large latent heat of evaporation
  - low liquid viscosity
  - high heat transfer coefficient
  - high thermal stability due to the high pressure
- Very practical fluid to work (environmental friendly, not activated)
- Practical range of the detector application -45^{0}C to +25^{0}C

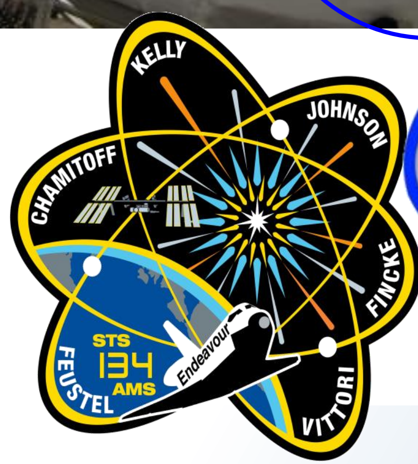




Pictures from: L.Zwalinski et al. THE CONTROL SYSTEM FOR THE CO2 COOLING PLANTS FOR PHYSICS EXPERIMENTS, ICALEPCS 2013, San Francisco CA

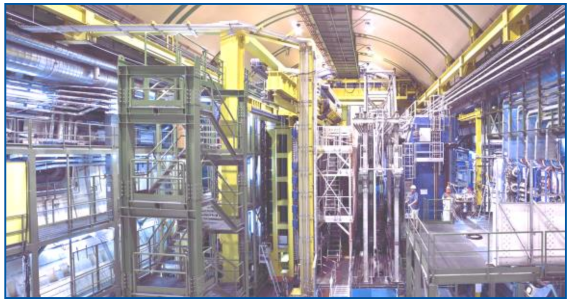
Alpha Magnetic Spectrometer

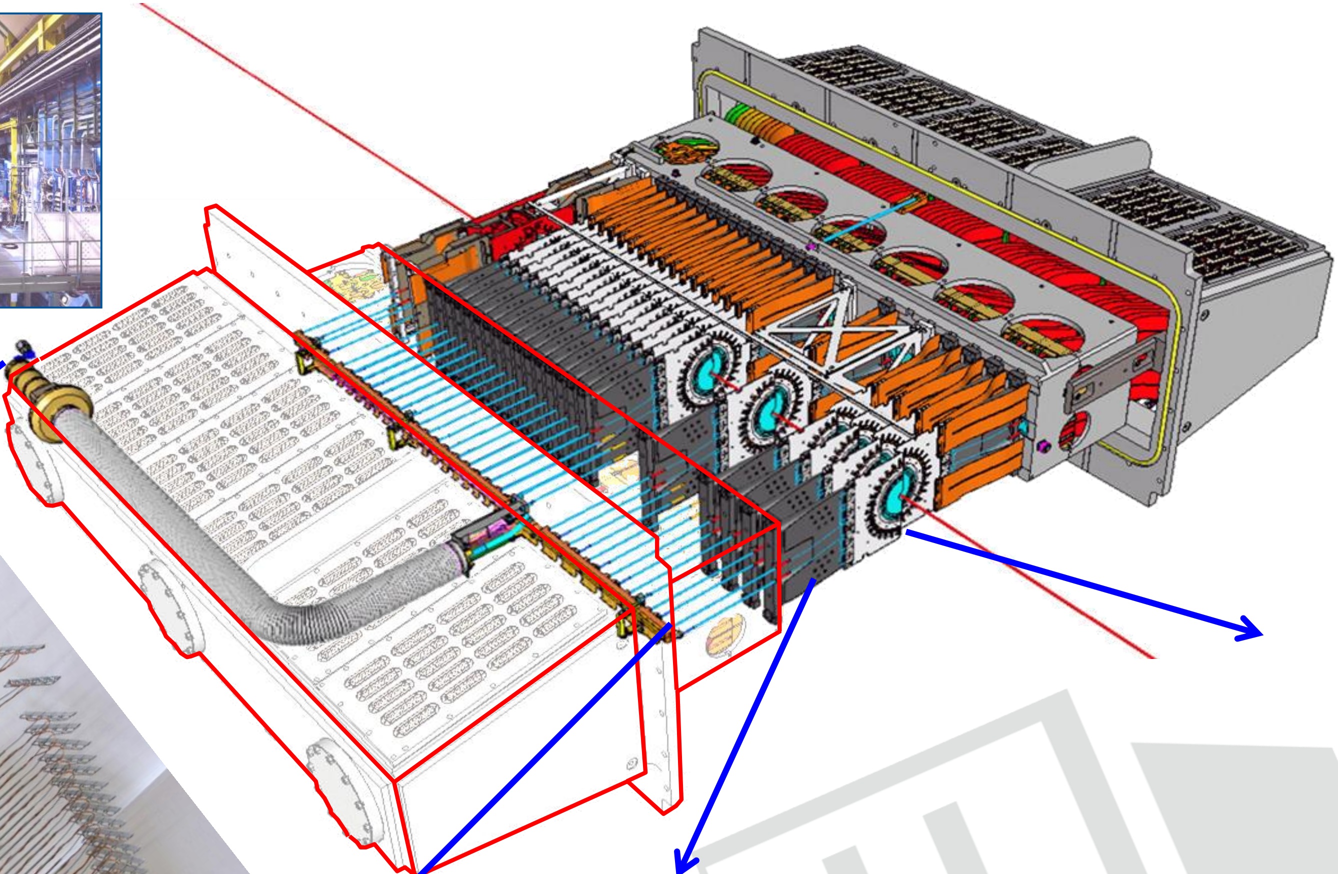


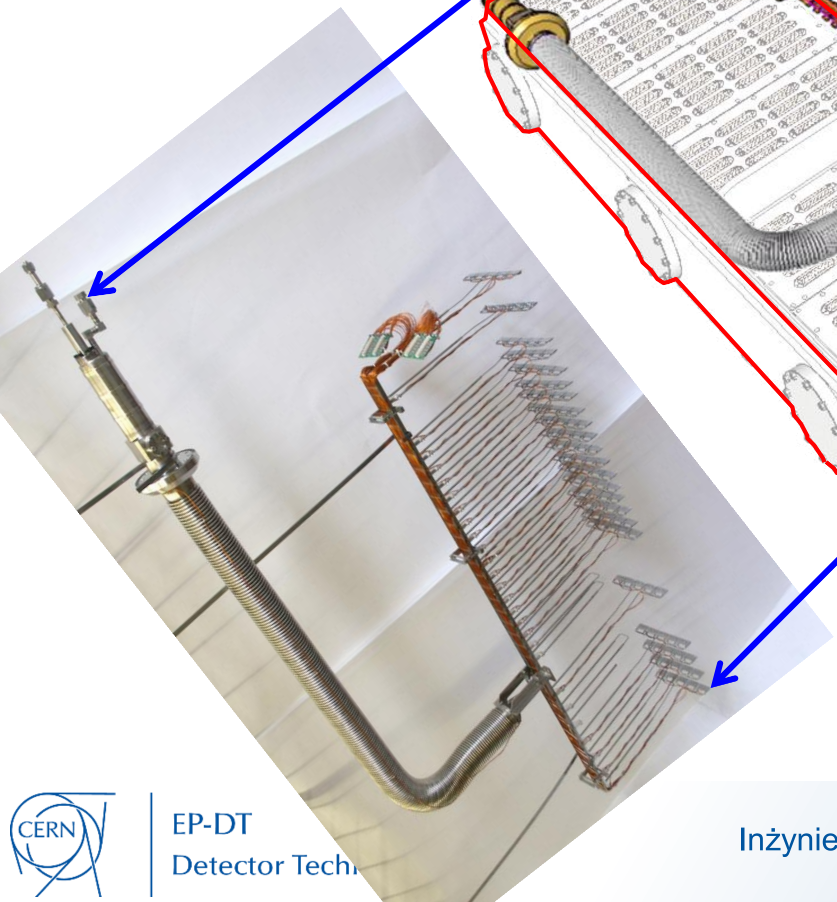


CO_2 inside

LHCb VELO detector







Detector cooling systems development

Detector cooling R&D roadmap towards HL-LHC

CMS Pixel-Ph1
(15kW, double redundancy)

Large capacity!

ATLAS IBL
(3.3kW, double redundancy)

Low temperature!

LUCASZ **4 units**
(2kW @ -30'C)

Portable cooling unit for surface detector tests (4@CERN+1@Cornell)

LHCb Velo & UT **2 units**
(2x7kW @ -30'C)

2 redundant systems

ATLAS NSW
(surf. test plant)

ATLAS NSW
(system upgrade)

Mono-phase system based on water

ATLAS ITk and CMS Phase II
ATLAS ITk (**~300kW!**)
CMS Phase II (**~534kW**)

Redundant systems **15+ units**

industrialization

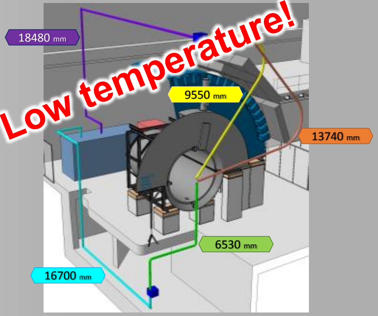
LS2 LS3

2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024

MARTA
(TRACI industrialization)

Portable cooling unit for low power detector tests

ATLAS ITk Baby-DEMO
(5kW @ -40'C or below)



Low temperature!

ATLAS ITk and CMS Phase II
DEMO pre-production plant
(100kW)

Large capacity & low temperatures

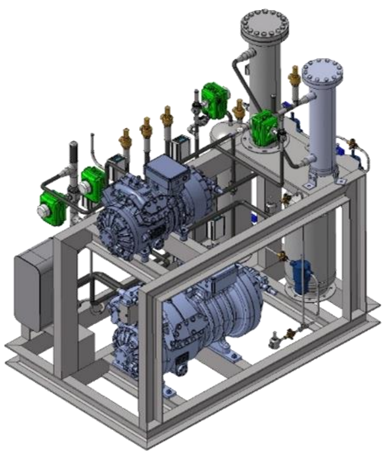
CMS HGC

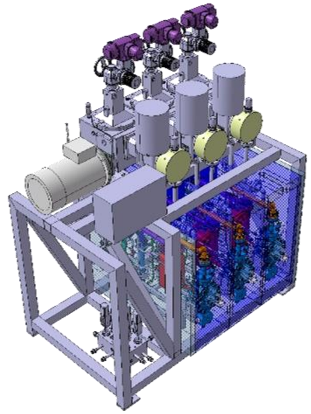
Evaporative CO_2 is the common development for all experiments.

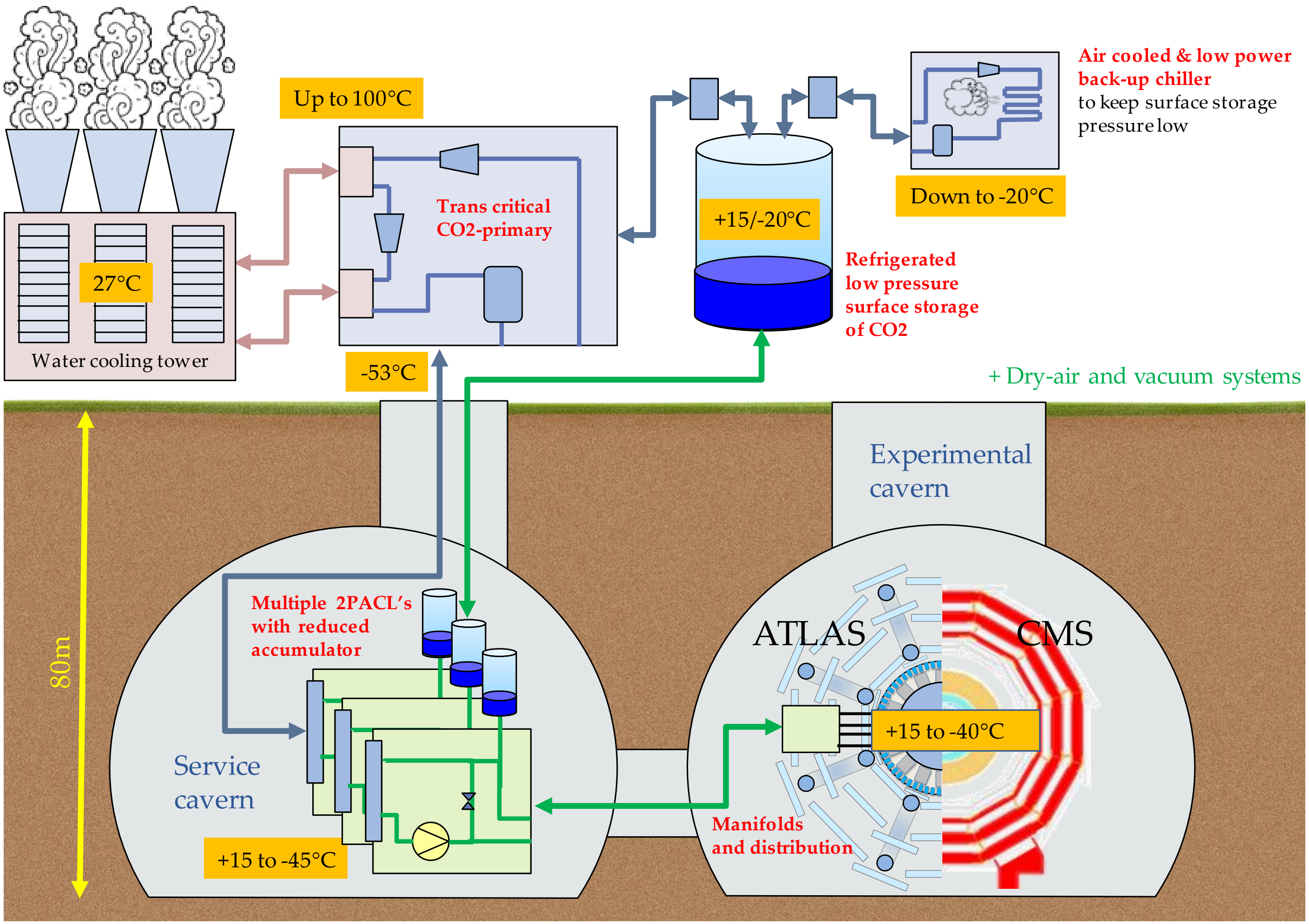
Production systems

R&D systems

ATLAS and CMS Phase II upgrades – R744 and 2PACL



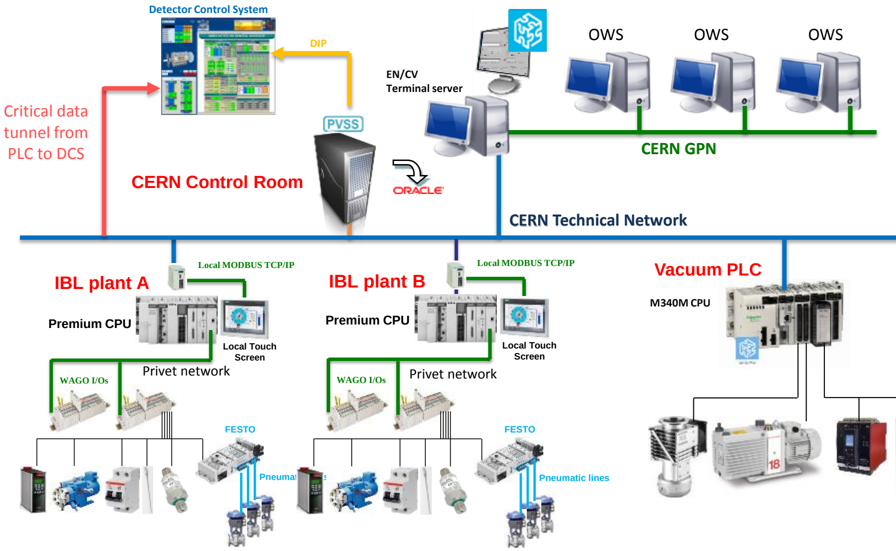




Detector cooling systems development

My role in detector cooling systems development

- Participate in the R&D and design of the evaporative CO_2 detector cooling systems for HEP detectors
- Lead control system design, commissioning and implementation for all the experiments:
    - Design of process control functional analysis
    - Supervise electrical design and assembly
    - Supervise PLC & SCAD programming
    - Lead standardization approach
    - Interface with detector operation and safety teams for communication paths and actions definition
- Provide maintenance and operation support
- Train students



Picture from: L.Zwalinski et al. The control system for the CO_2 cooling plants for physics experiments, ICALEPCS 2013, San Francisco CA

Achievements

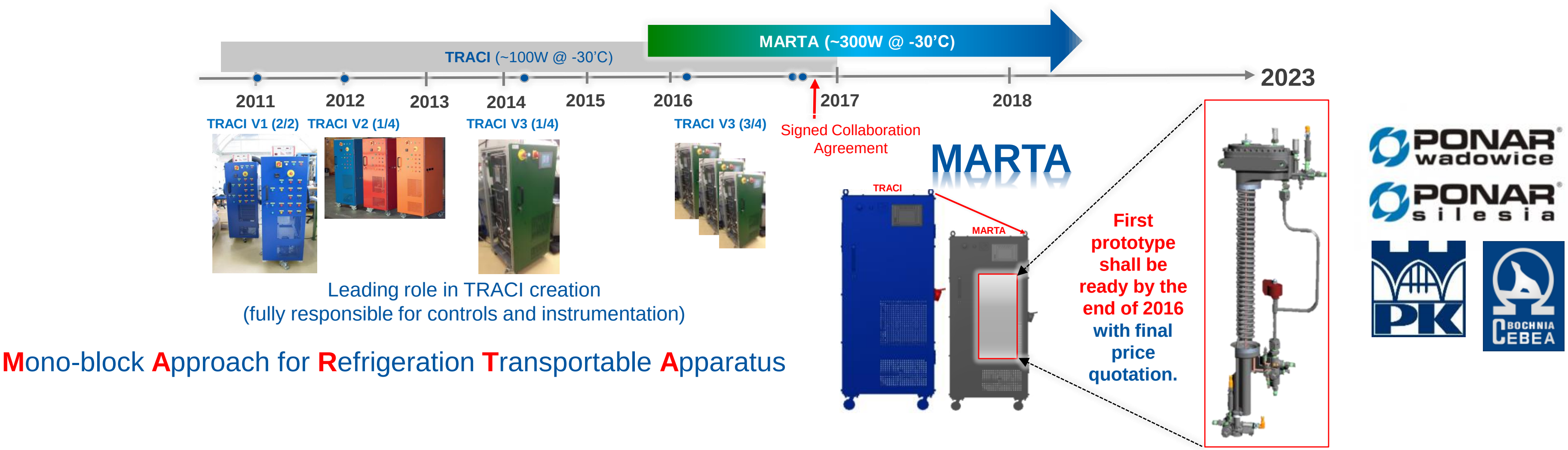
- **Control system development for 22 detector cooling applications** (based on Siemens, Schneider and National Instruments) that are currently in operation for various CERN experiments (ATLAS, CMS, LHCb).

Współpraca z Politechniką Krakowską i transfer technologii

- W grupie technologii detektorowych (EP-DT) przez ostatnie lata zatrudniliśmy ponad 70 studentów stażystów z PK, którzy zaangażowani byli w projekty związane z nowymi technologiami detektorowymi (ATLAS, CMS, LHCb).

- Cześć z nich pozostała w CERN (około 50% !!!) a cześć rozpoczęła swoje kariery zawodowe w Polsce, bogatsi o doświadczenia zdobyte w CERN-ie.

- Ostatnio podpisaliśmy transfer technologii z CERN-u do Polski (z konsorcjum naukowo-przemysłowym z Krakowa, Bochni i Wadowic) dotyczący produkcji laboratoryjnych chłodziarek, CO_2 do testów przyszłych detektorów śladowych.



Summary

Detector technologies at CERN require multidisciplinary competencies like:

- Mechanics
- 3D design
- Physics
- Automation
- Electricity
- Electronics
- Thermodynamics and fluidics
- Refrigeration
- …

Are you studying in one of this domains?

If so, CERN is a place for You to broaden your competencies! Join us!
https://careers.cern/

Share knowledge! THANK YOU!

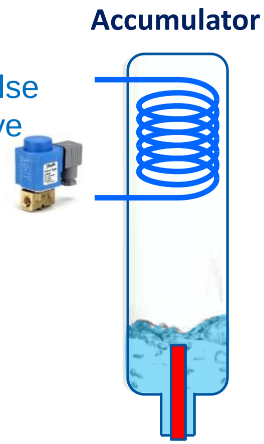
CERN

Selected publications and talks

- **Technology progress and R&D on detector cooling** ECFA 2017, Aix les Bains, France
- **Detector cooling systems at CERN experiments - CO2 cooling** HighRR Lecture Week, April 2016, Heidelberg, Germany;
- **CO2 cooling for particle detectors: experiences from the CMS and ATLAS detector systems at the LHC, and prospects for future upgrades** ICR 2015, Yokohama, Japan
- **CO2 evaporative cooling: the future for tracking detector thermal management**, FRONTIER DETECTORS FOR FRONTIER PHYSICS - 13th Pisa Meeting on Advanced Detectors, 2015,La Biodola, Isola d'Elba, Italy
- **Vacuum flex lines design, production, qualification and tests for the ATLAS IBL CO2 cooling system**, Forum on Tracking Detector Mechanics 2015, Amsterdam, Netherlands
- **CO2 cooling system for Insertable B Layer detector into the ATLAS experiment** TIPP 2014 Amsterdam
- **Design, construction and commissioning of a 15 kW CO2 evaporative cooling system for particle physics detectors, lessons learnt and perspectives for further development** TIPP 2014 Amsterdam
- **The Thermosiphon cooling system at ATLAS experiment at LHC;** 13th International Conference multiphase flow in industrial plants Sestri Levante
- **The control system for the Co2 cooling plant for physics experiments**, ICALEPCS 2013, San Francisco CA
- **Experimental infrastructure control systems development**; HEPTech Academia - Industry Matching Event on Technology of Controls for Accelerators and Detectors in Athens 2013
- **TRACI, a multipurpose CO2 cooling system for R&D** 10th IIR Gustav Lorentzen Conference on Natural Refrigerants, Delft, The Netherlands, 2012
- **The CORA CO2 cooling plant** 10th IIR Gustav Lorentzen Conference on Natural Refrigerants, Delft, The Netherlands, 2012 – to be presented in June
- **Recent developments for the evaporative fluorocarbon cooling system of the ATLAS Silicon Tracker at the CERN Large Hadron Collider** 92th Eurotherm Seminar on GRAVITATIONAL EFFECTS ON LIQUID-VAPOR PHASE CHANGE, Presqu'ïle de Giens, France, April 17-21, 2010
- **The Development of the Control System for the Cryogenics in the LHC Tunnel**; The 12th LSS 2010, Villeneuve d'Ascq, FRANCE
- **The Control System for the cryogenics in the LHC tunnel [First Experience and Improvements]**; ICALEPCS09, 12-16 October 2009, Kobe (Hyogo), Japan, WEP 061
- **The control system for the cryogenics in the LHC tunnel**; ICEC22 - ICMC2008, 21-25 July 2008 - Seoul, Korea, LHC-PROJECT-REPORT-1169,
- **Experience in configuration, implementation and commissioning of a large scale control system (based on LHC Cryogenic Control System)**; 9th International Carpatian Control Conference ICCC'2008, Sinaia, 25-28 May 2008
- **An automatic approach to PLC programming for a large scale slow control system (based on LHC Cryogenic Distribution Control System)**; 9th International Carpatian Control Conference ICCC'2008, Sinaia, May 2008

Accumulator – how does it work?

Cooling regulated by pulse modulated control valve



Heating – regulated by pulse modulated heater

Split range PID controller with dynamic limiters