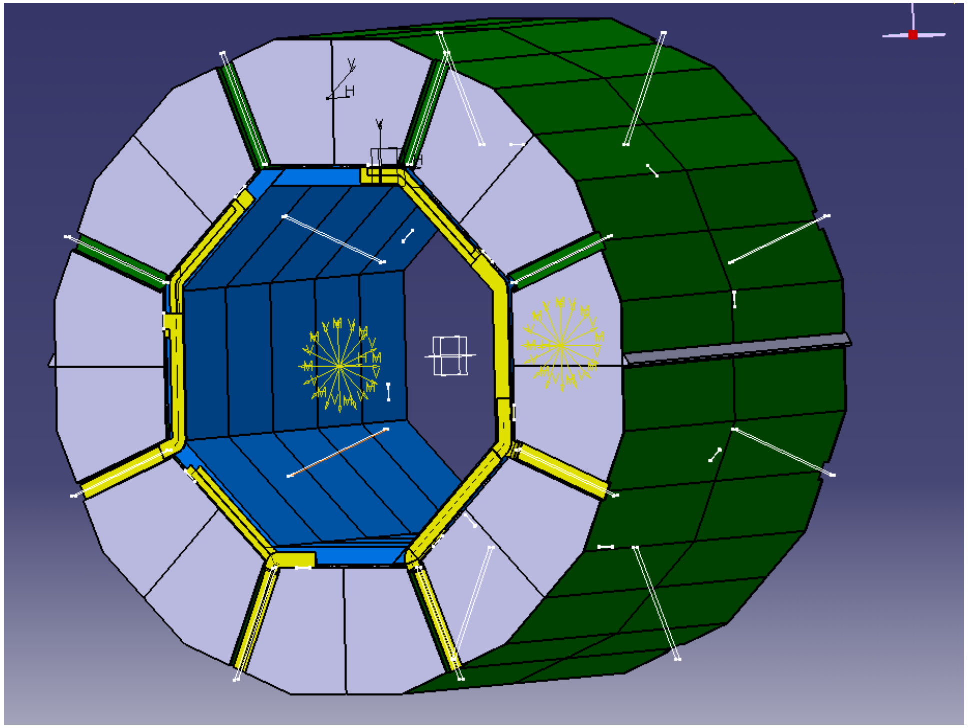
Cooling of ECAL and HCAL



Katja Krüger
CLICdp meeting
29 August 2017

with ECAL material
taken from presentations
by Denis Grondin

Cooling concept for ECAL and HCAL

- both ECAL and HCAL are designed for minimal cooling
  - allows to keep variations of dead material small
- (nearly) no cooling inside active layers
  - very limited power consumption of frontend readout ASICs
  - only reachable with power pulsing (1% duty cycle)
- interface electronics is significant source of heat
  - small area, limited amount of heat can be removed
  - limited power consumption also here

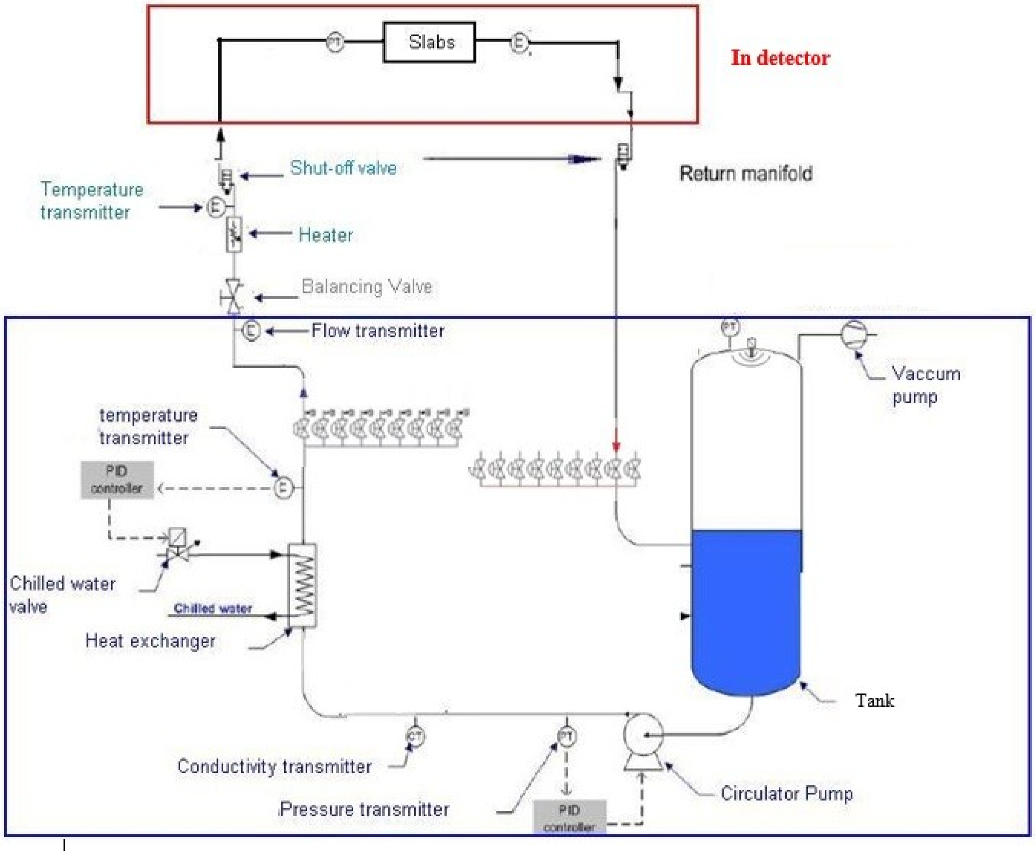
- ECAL and HCAL both plan “leakless cooling system”
  - part of cooling loop inside detector below atmospheric pressure
  - limited risk of spray
  - low water speed
  - small temperature gradient

Principle of leakless cooling

several areas:

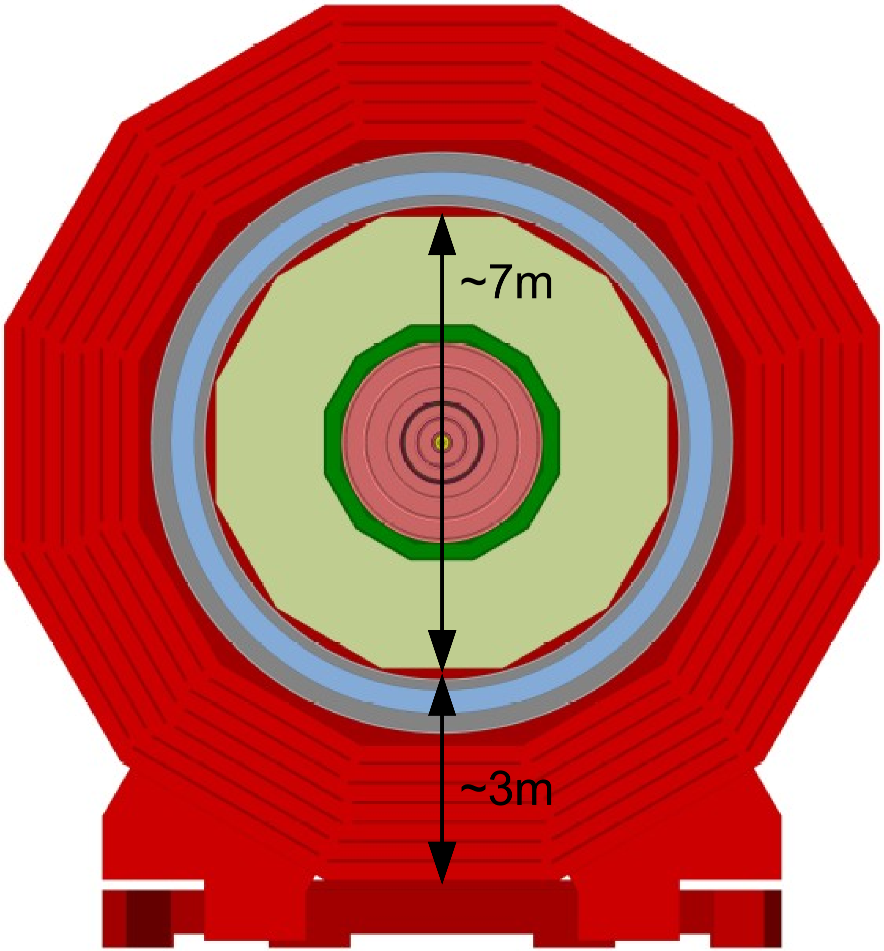
- pump and inlet: above atmospheric pressure
- inside detector: below atmospheric pressure
- return: below atmospheric pressure, non-stationary flow
- tank: below atmospheric pressure

- max. pressure drop inside detector ~800 mbar
  - height difference usually limited to ~2-3m → **design of global cooling system**
  - local pressure drops due to bends, valves, ... → **design of local cooling**

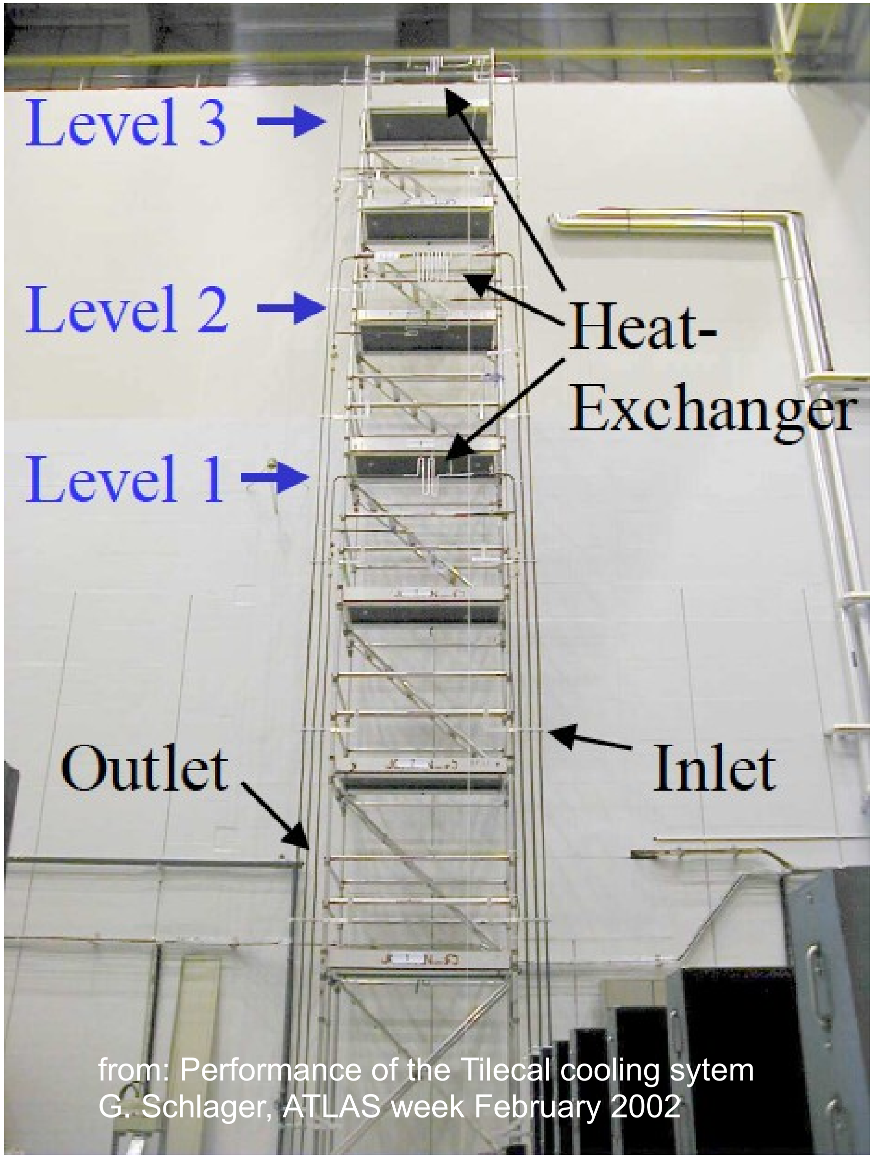


Leakless Cooling System in CLICdet and ILD

- total HCAL height
  - ~7m for CLICdet and ILD
- total ECAL height
  - ~3.5 m for CLICdet
  - ~4m for ILD
- additional height for inlet because of magnet and yoke
  - ~3m for CLICdet
  - ~4.5m for ILD
- need several cooling loops



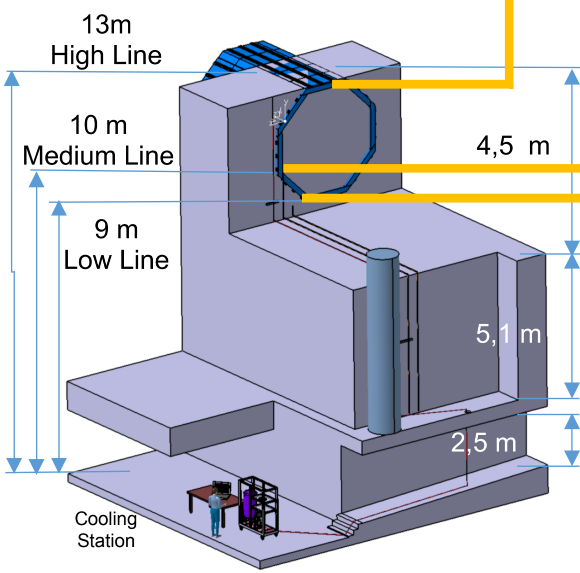
Leakless Cooling System v.2 for LHC experiments



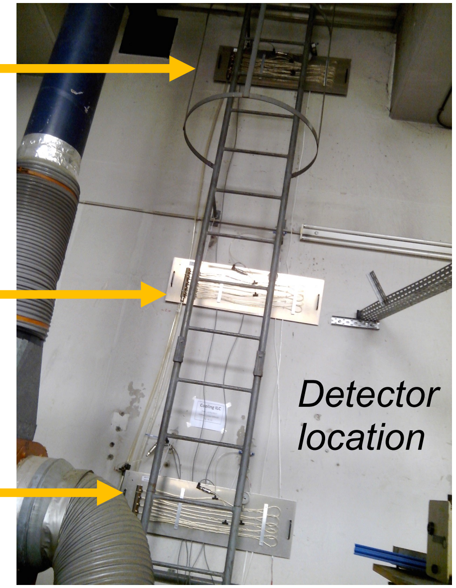
- leakless cooling systems are already in use, e.g. in ATLAS Tilecal
  - 3 loops with different heights up to 15 m
  - tested extensively with prototypes
- Tilecal cooling power:
  - 300 W per cooling channel
  - 77 kW in total
- can stabilize temperature to 0.3 K difference for 10 K ambient temperature change
  - depends strongly on insulation of inlet tubes

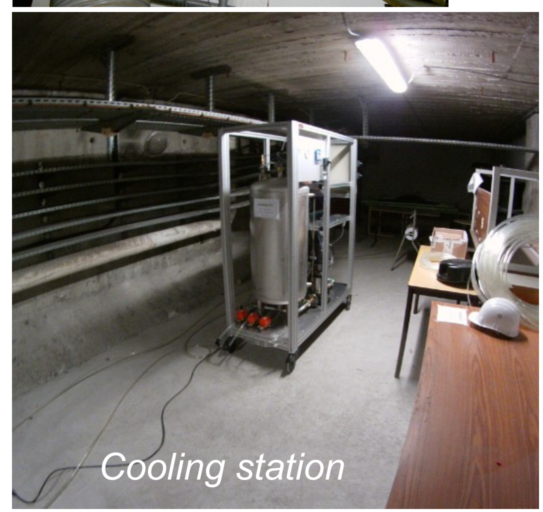
Leakless Cooling: full size cooling loop for ECAL

- demonstration and performance of a large leak-less cooling-loop on 3 levels (13m-10m-9m)
- results in line with simulations



LPSC cooling test area
with a drop of 13 m



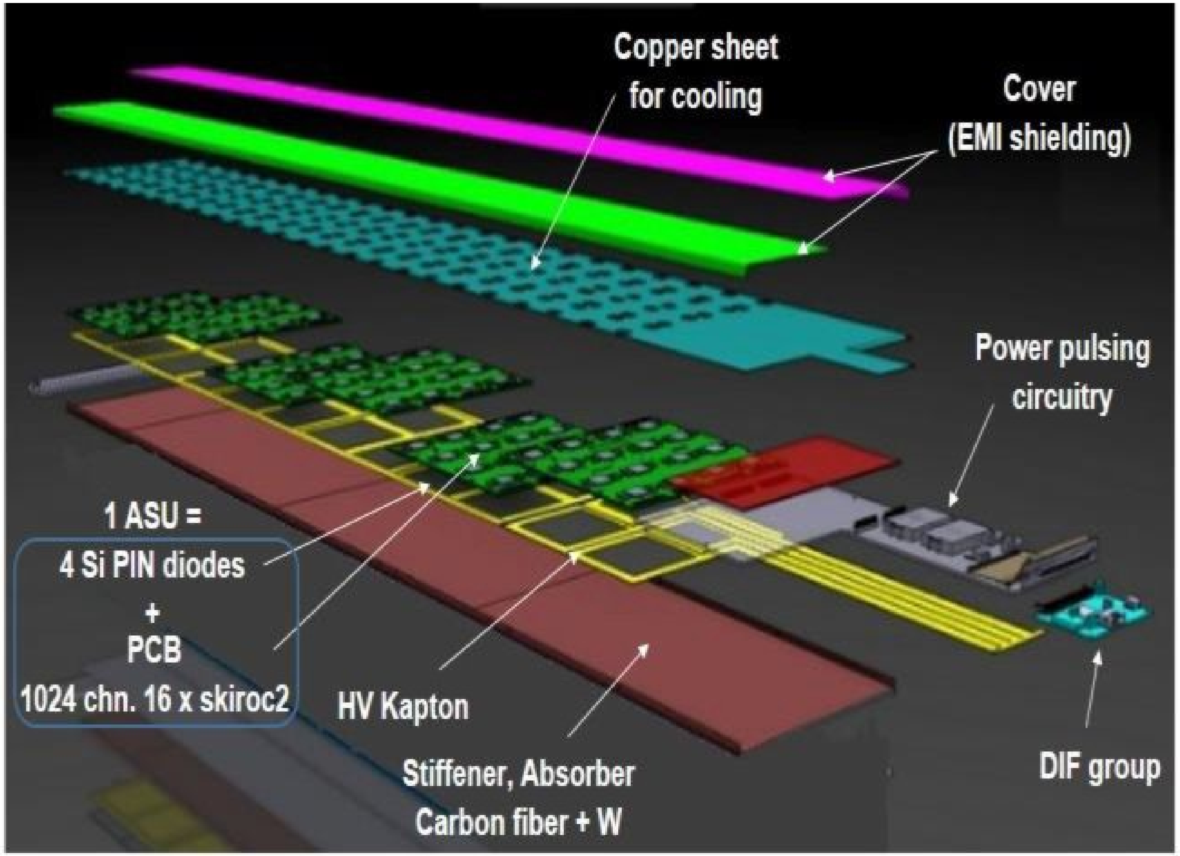


Local cooling system requirements

- numbers here are for ILD: SiECAL and AHCAL
- SiECAL: tungsten absorber in carbon fibre structure, silicon sensors
  - conditions:
    - temperature close to ambient, precision ±2.5 K acceptable
    - temperature difference of 20K within active layer acceptable
  - total ECAL power: 4.6 kW
  - very high channel density (~4 channels/cm²)
  - very strong space constraints
- AHCAL: steel absorber structure, scintillator with SiPM readout
  - conditions:
    - temperature close to ambient
    - temperature difference <0.5 K within active layer
  - total HCAL power:
    - inside layer: goal 40 µW per channel (SiPM+ASIC) → 320 W total
    - interfaces: measured ~9 W per layer, 28 kW in total → can be optimized
  - lower channel density (~0.1 channels/cm²)
  - less strong space constraints

Specification of local cooling: ECAL

- very high channel density & integrated readout electronics
  → large heat production inside active layers
- copper sheets to remove heat



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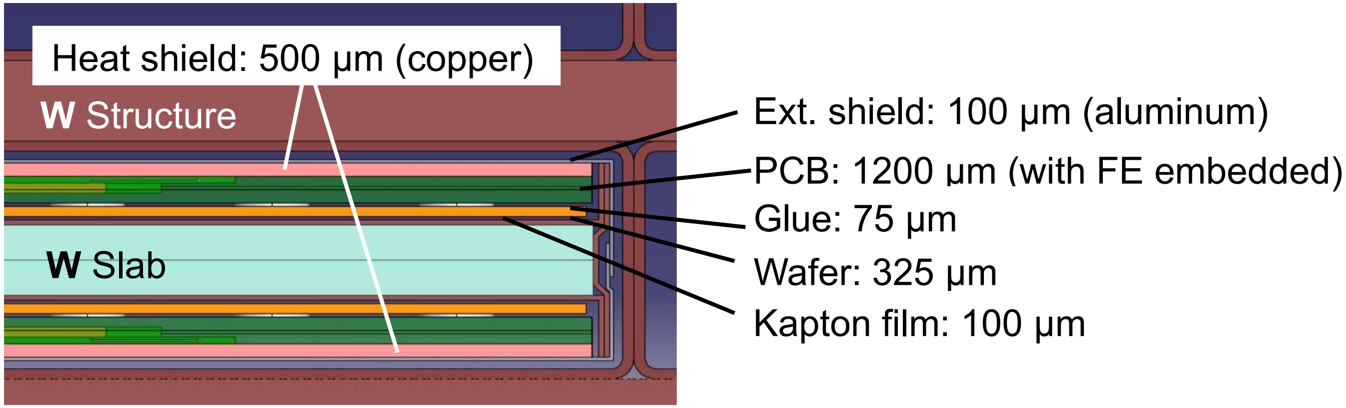
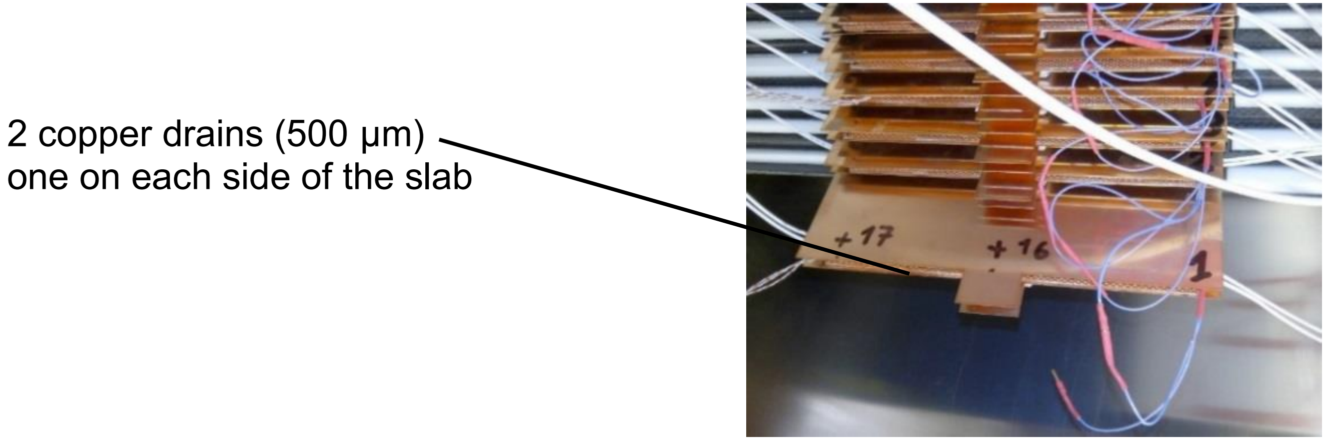
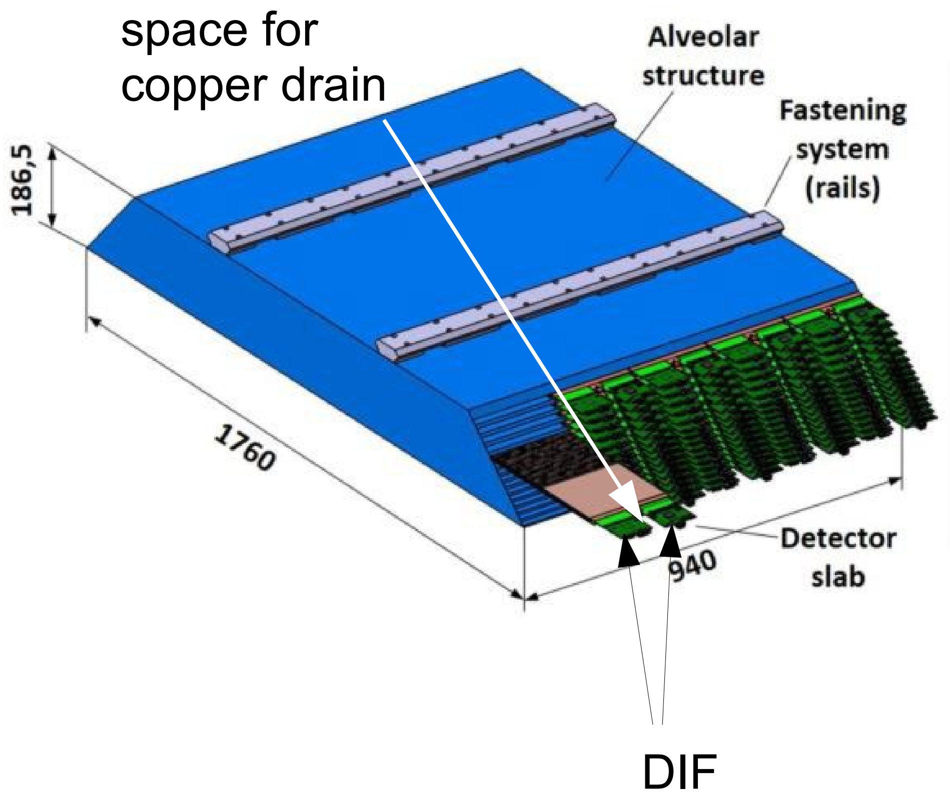
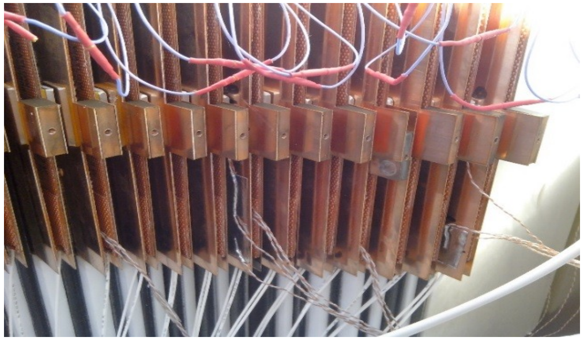


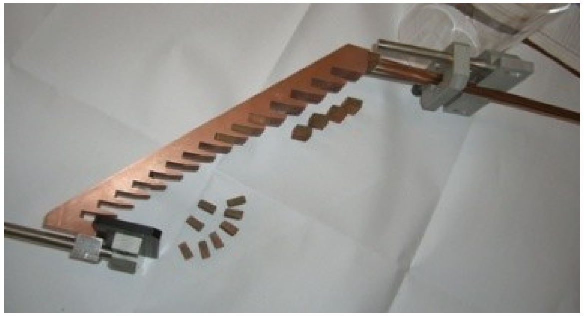


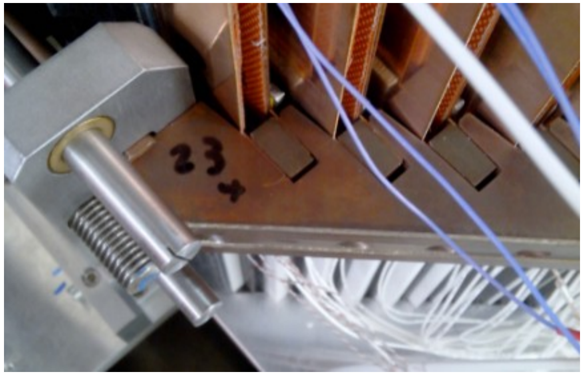
Specification of local cooling: ECAL

- connection of local cooling drains to cooling pipes



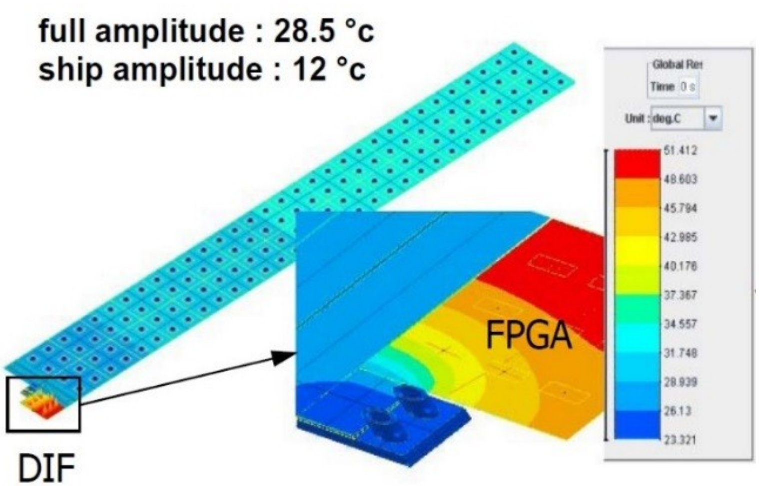






Specification of local cooling: ECAL

- thermal model developed to simulate temperature distribution within a slab and within a module
- expected temperature differences within a slab and a module well within acceptable limits



Ex. of numerical simulation of heat dissipation in one layer with a FPGA power of 2W

Thermal flux inside a column of 1 module

Power on PCB = 0,205 W (barrel) / 0,356 W (End-cap)
Boundary condition T = 23 °C

Results

Barrel : (1.5m)

Max T < 25,5 °C
ΔT = 2,2°C

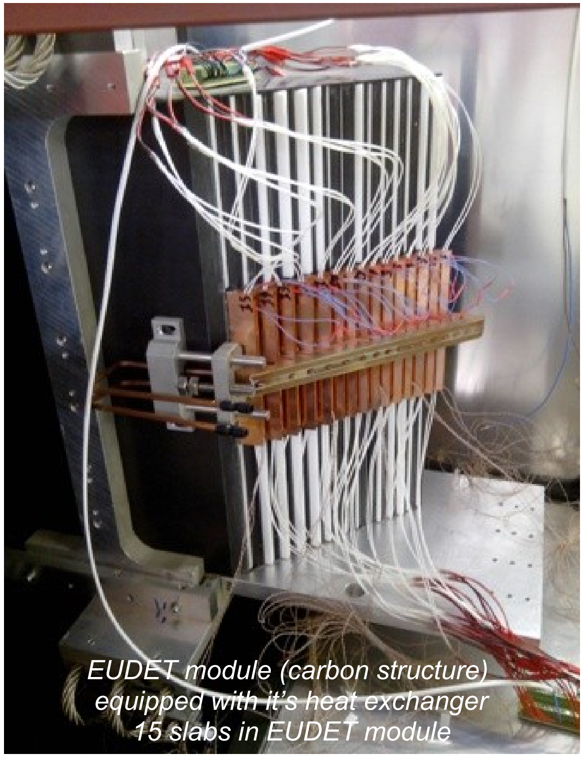
End Cap : (2.5m) → 2,1m if R_{Endcap} ≈1726mm

Max T = 29 °C
ΔT = 6°C

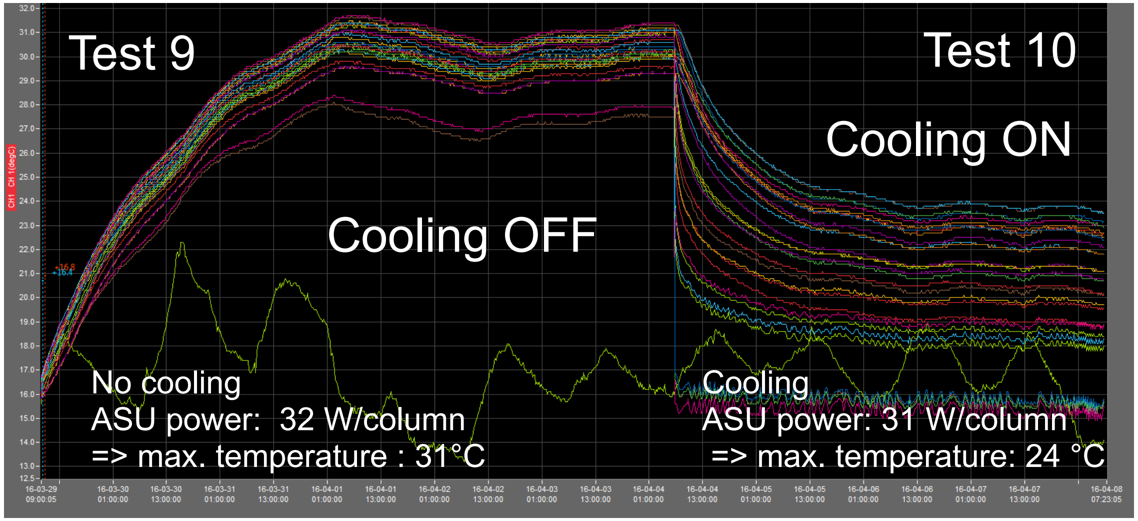
Power : 30*0,356 = 10,68 W

Specification of local cooling: ECAL

- demonstration of thermal model with dummy barrel module
- tested with 30 W per column (nominal is 15 W)
- first test results in line with expectation from simulation

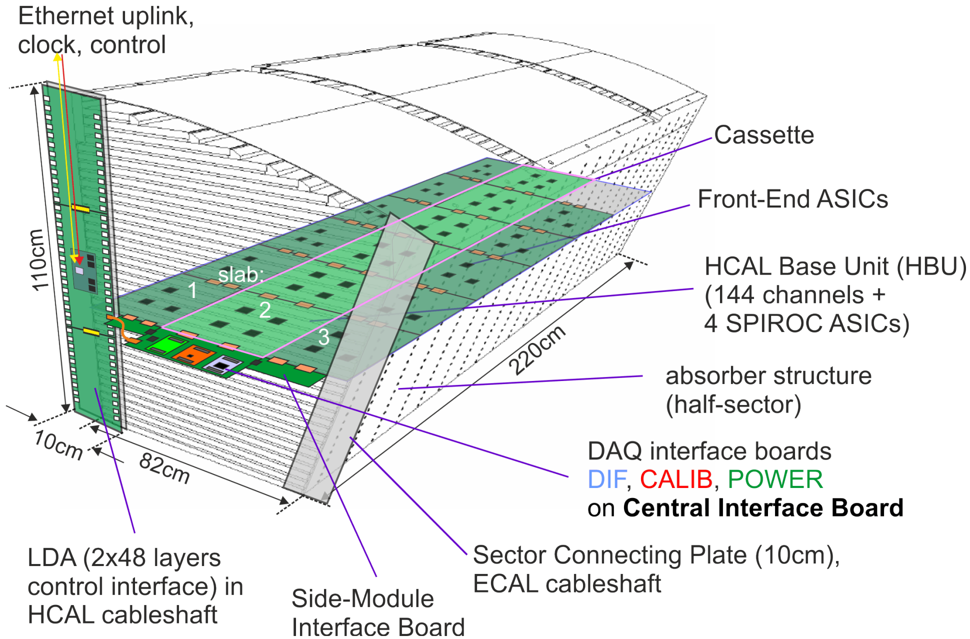


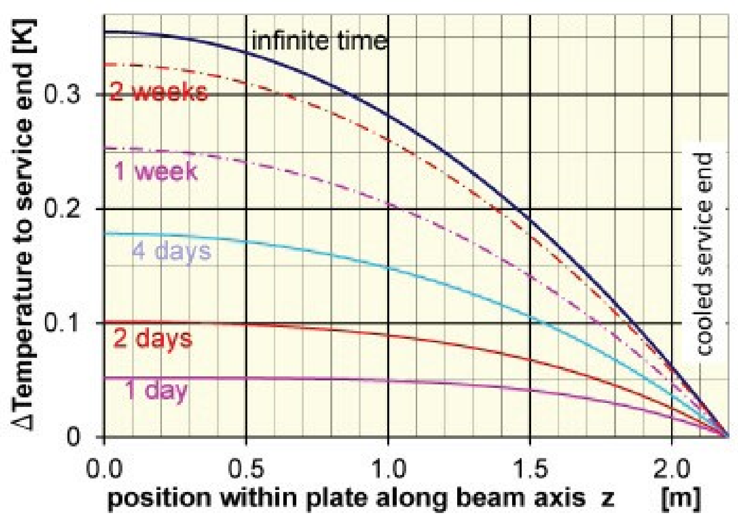
EUDET module (carbon structure)
equipped with it's heat exchanger
15 slabs in EUDET module



Specification of local cooling: HCAL

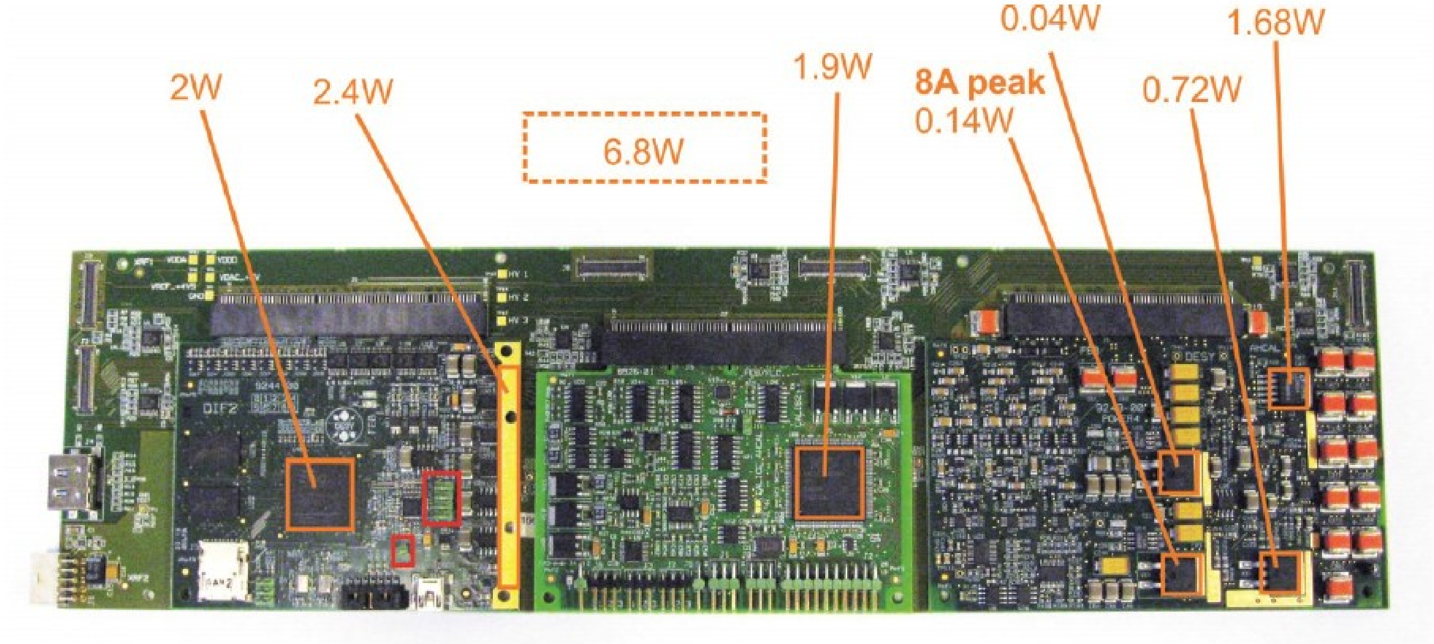
- also integrated readout electronics, but much smaller channel density than ECAL
- steel absorber structure can remove heat produced inside active layer
- temperature gradient along barrel expected from simulation: ~0.35 K → within goal of <0.5 K





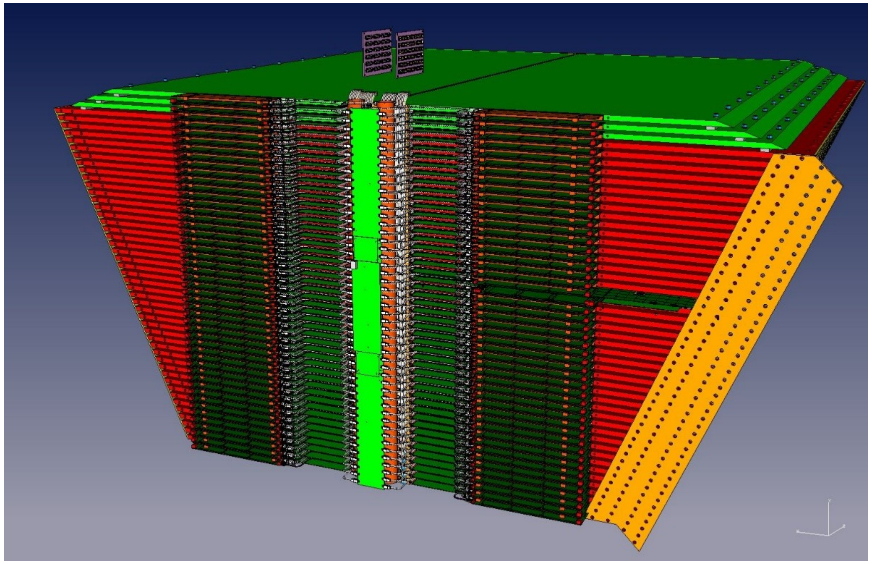
Specification of local cooling: HCAL

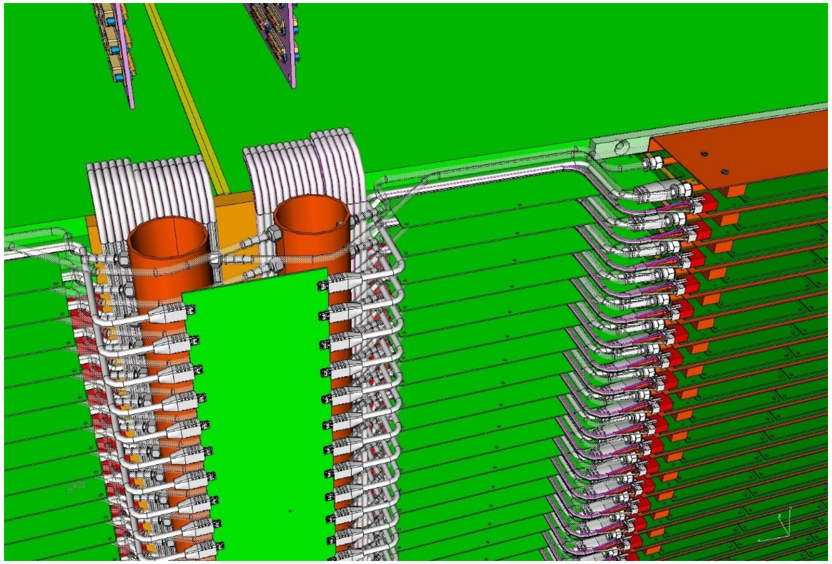
- DAQ interface boards are a significant source of heat
- measured values for current generation of interface boards: ~9 W for a full barrel layer (18 HBUs) with power pulsing (1% duty cycle)
  - not yet optimized
- adapt cooling plate to main heat sources



Specification of local cooling: HCAL

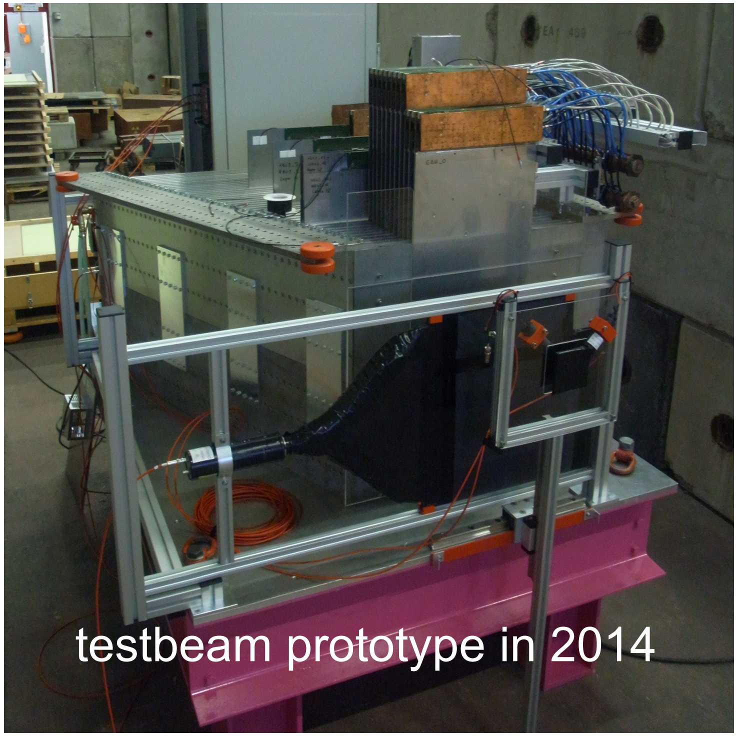
- careful design of cooling interfaces
  - cooling plates in thermal contact to DAQ interface boards
  - routing of cooling pipes connecting to each layer
  - large cooling pipes supplying a full sector
- must fit in available space:
  - ~2.7 cm layer pitch
  - ~10 cm gap between barrel and endcap, used for many services

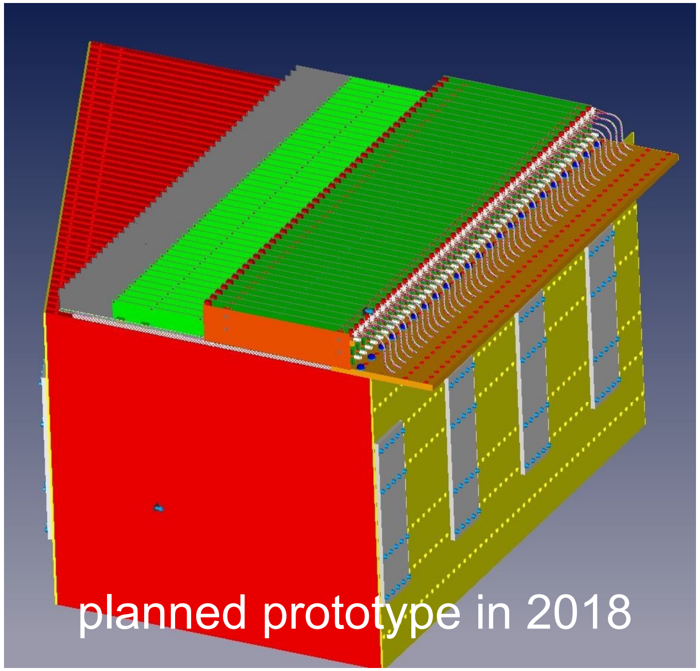




Specification of local cooling: HCAL

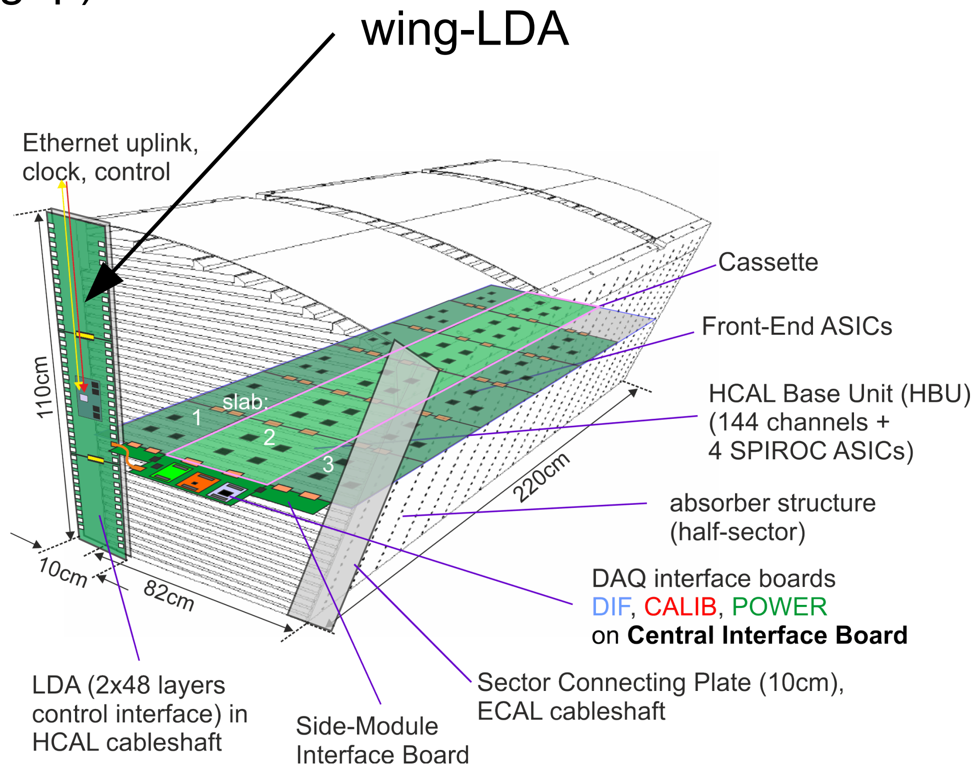
- EUDET steel stack follows ILD design, used for testbeams
- local cooling interfaces tested in testbeam prototypes
  - first experience gained in 2014&2015 with partly equipped system
  - working on fully equipped prototype (1/3 of barrel sector) for 2018
- important to gain experience with heat loads and pressure drops in realistic conditions


testbeam prototype in 2014


planned prototype in 2018

Specification of local cooling: data concentrators

- both ECAL and HCAL need additional data aggregation
- ECAL needs two stages
  - one stage close to the detector interfaces
  - one further out (e.g barrel/endcap gap)
- HCAL needs one stage
  - aggregation of a full barrel octant (~250.000 channels)
- these will probably need powerful FPGAs
- no numbers up to now
  - ECAL: no detailed design yet
  - HCAL: wing-LDA prototype exists, but improvements foreseen
- no cooling design yet!



Summary

- both ECAL and HCAL plan cooling systems based on Leakless Cooling
- global requirements (heights, total cooling power) comparable to existing Leakless Cooling systems like ATLAS Tilecal
- high number of channels, large channel density and integrated readout electronics challenging for local cooling design
  - ECAL: very high channel density, very limited space
  - HCAL: cooling of interfaces, space shared with other services
- within AIDA-2020 developed thermal models and demonstrators, first measurements in line with expectations
- cooling for testbeam prototypes provides important input for realistic modeling