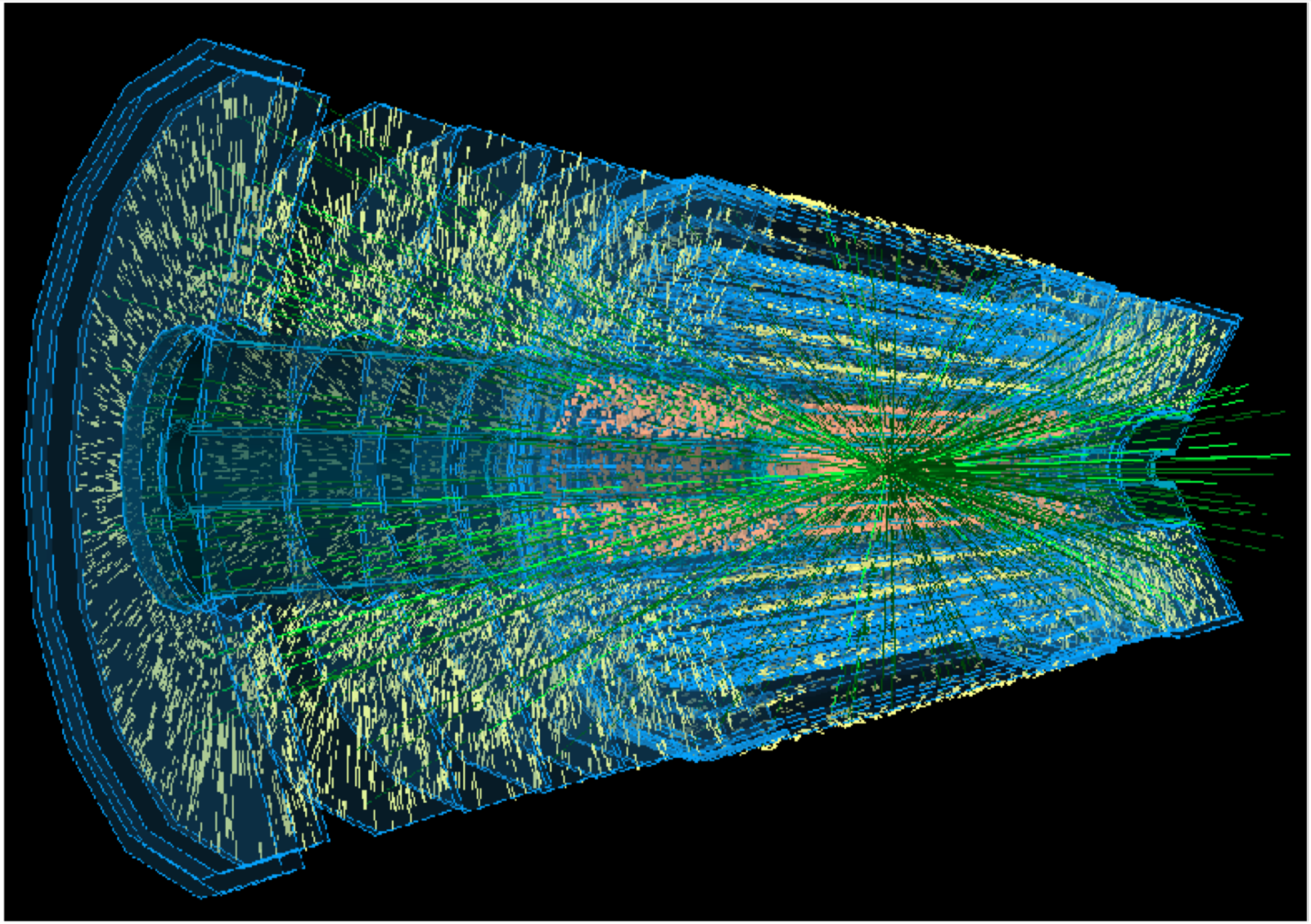
CO_2 based microchannel cooling

Marco Bomben – LPNHE & UPD

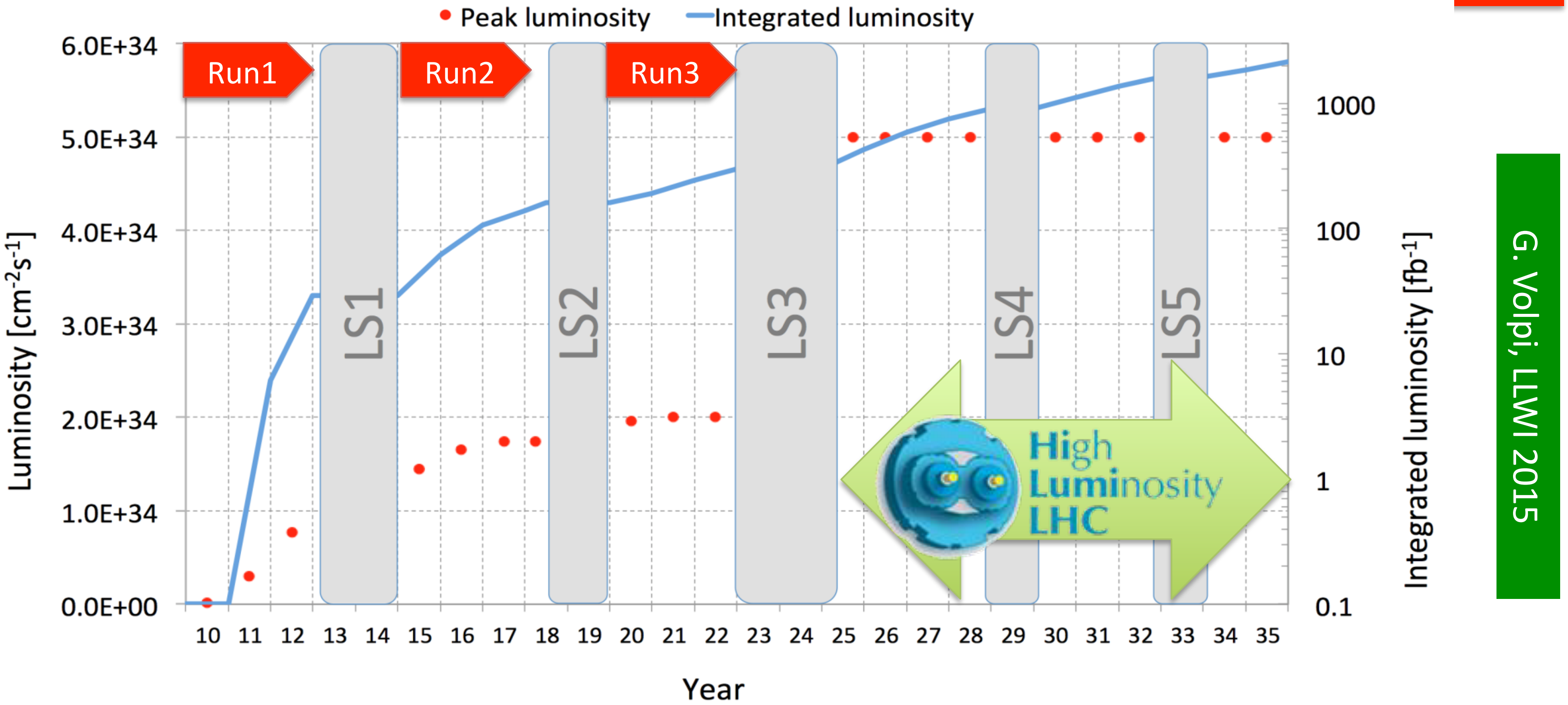
Outline

- The Phase-2 of the ATLAS program
  - The High-Luminosity LHC (HL-LHC)
  - The new ATLAS tracker: ITk
- Micro-channel based cooling for the ATLAS Phase-2 tracker
  - The ATLAS ITk cooling specifications
  - Micro-channels based cooling for the ATLAS ITk
  - Micro-channel cooling outside HEP
  - REFLECS & REFLECS2 project

The Phase-2 of the ATLAS program



From LHC to High-Luminosity LHC (HL-LHC)



LHC has brought 7-8 TeV p-p collisions, 50 ns bunch crossing, about 20 interactions / crossing

- LS1 consolidations will allow 13-14 TeV collision, 25 ns BC, nominal luminosity (TODAY)
- LS2 work will allow peak luminosities to reach 2-3x10^{34} $cm^{-2}s^{-1}$
    - 300 fb^{-1} expected for 2022 (x10 more than Run1)
- LS3 will make the instantaneous luminosity grow to 5-7 times the nominal luminosity

➢ Experiments are expected to collect up to 3000 fb-1 until 2035

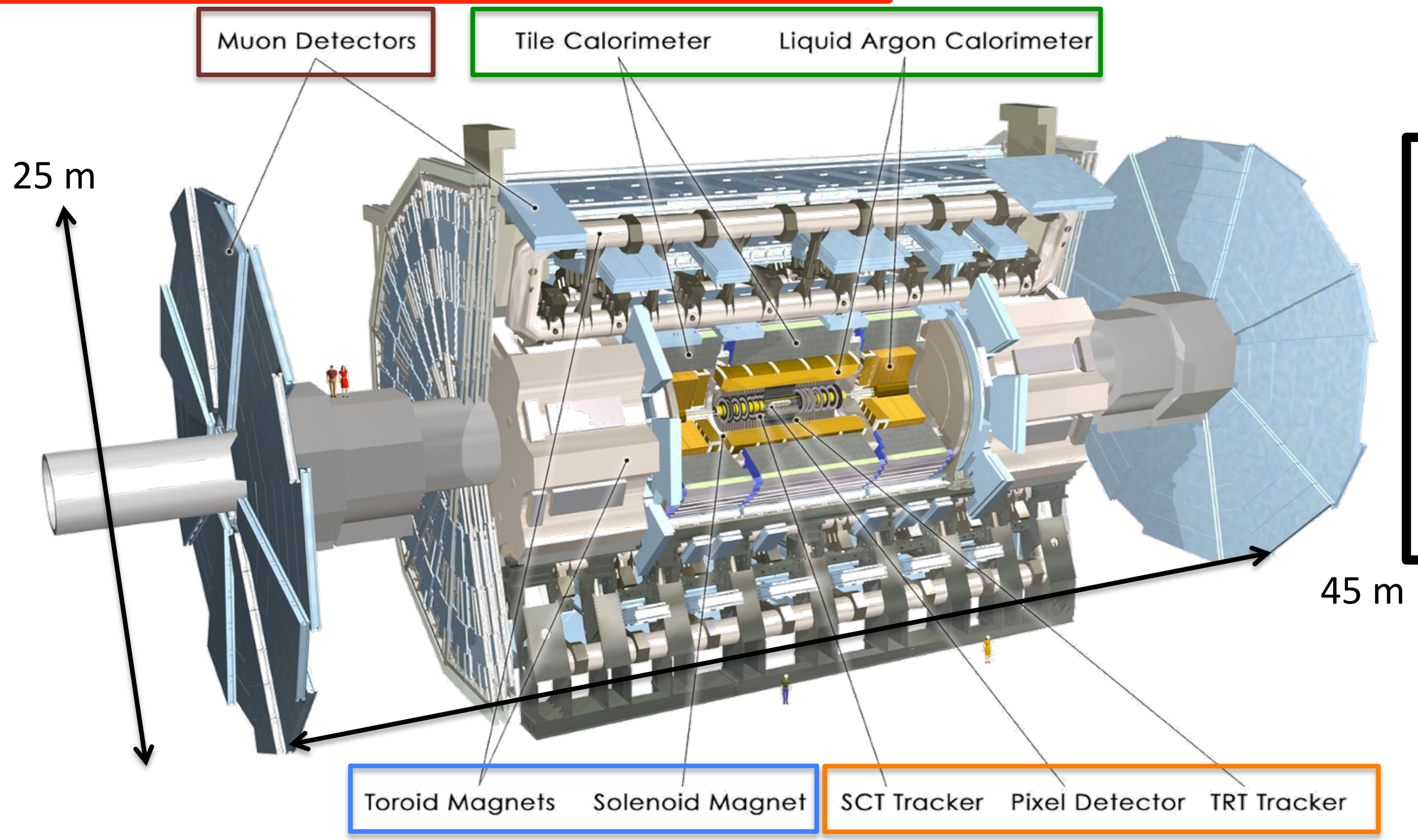
The ATLAS detector at the end of Run1

Multi-purpose, high resolution and hermetic detector

Magnets:	Central Solenoid +3 Toroids
Tracking:	Silicon (PIX & Strips) + TRT
Calorimeter:	EM (LAr), Had Cal
Muon:	Trigger + Precision Chambers

Three Level Trigger system

- L1 – hardware: 70 kHz, 2.5 μs latency
- L2 – software: 6.5 kHz, 10 ms latency
- EF – software: 600 Hz, 1-2 s latency



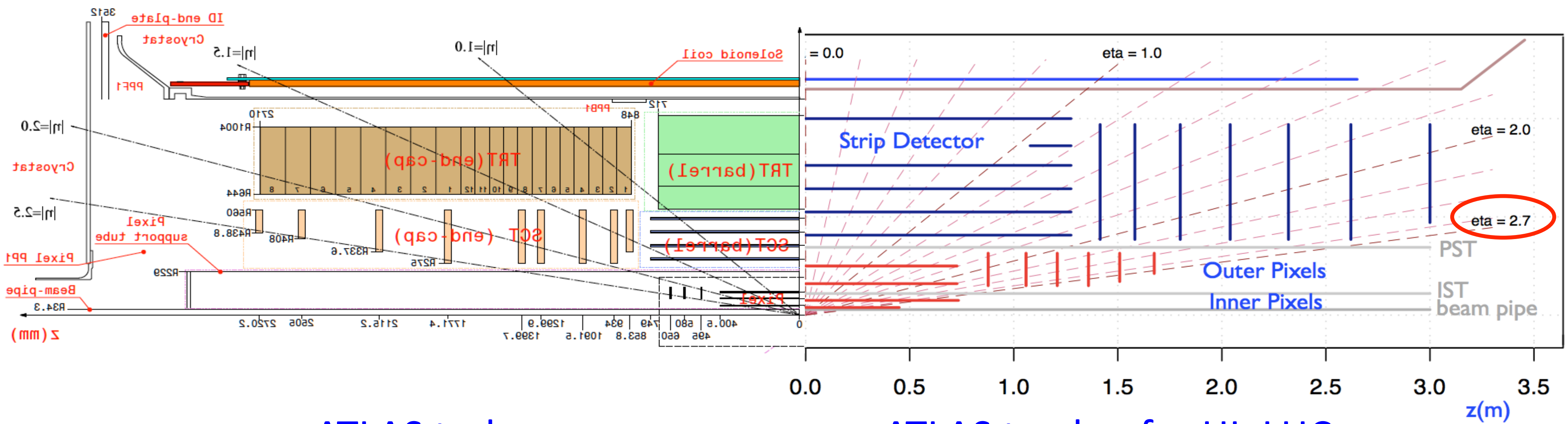
Reconstructed objects :

- **leptons (e,μ,τ)**
- **photons**
- **jets**
- **b-jets**
- **Etmiss**

ATLAS tracker upgrade: ITk

ATL-COM-UPGRADE-2014-029

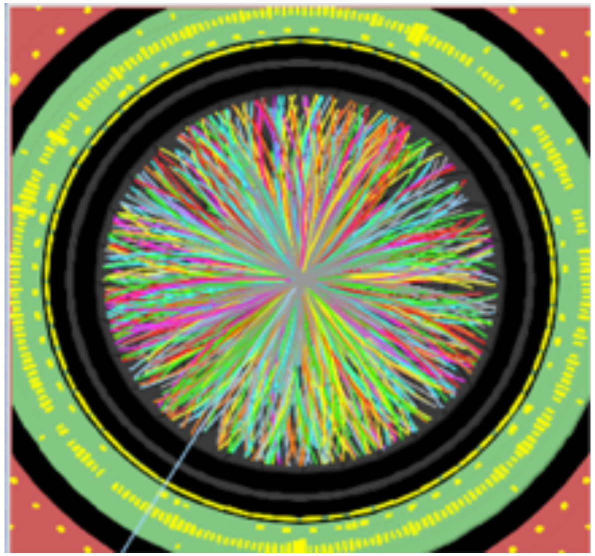
- Present tracker limitations for Phase-II
  - Accumulated radiation damage will make Pixels inefficient. Too large occupancy for Transition Radiation Tracker
  - Readout bandwidth limitation ➔ need for higher granularity and to operate at larger pile-up occupancies
- Complete replacement with an all-silicon tracker
  - Baseline layout proposed in the LoI provides tracking for |η|<2.7 (it was: |η|<2.5), with barrel cylinders and endcap disks
  - Very much work in progress! Several ideas to optimize and extend the layout being discussed – TDR due by 2017



ATLAS today ATLAS tracker for HL-LHC

A new tracker for ATLAS: requirements

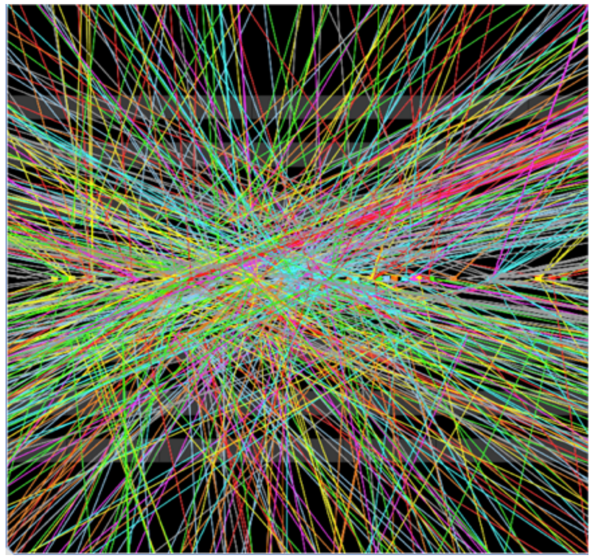
ATL-COM-UPGRADE-2014-029



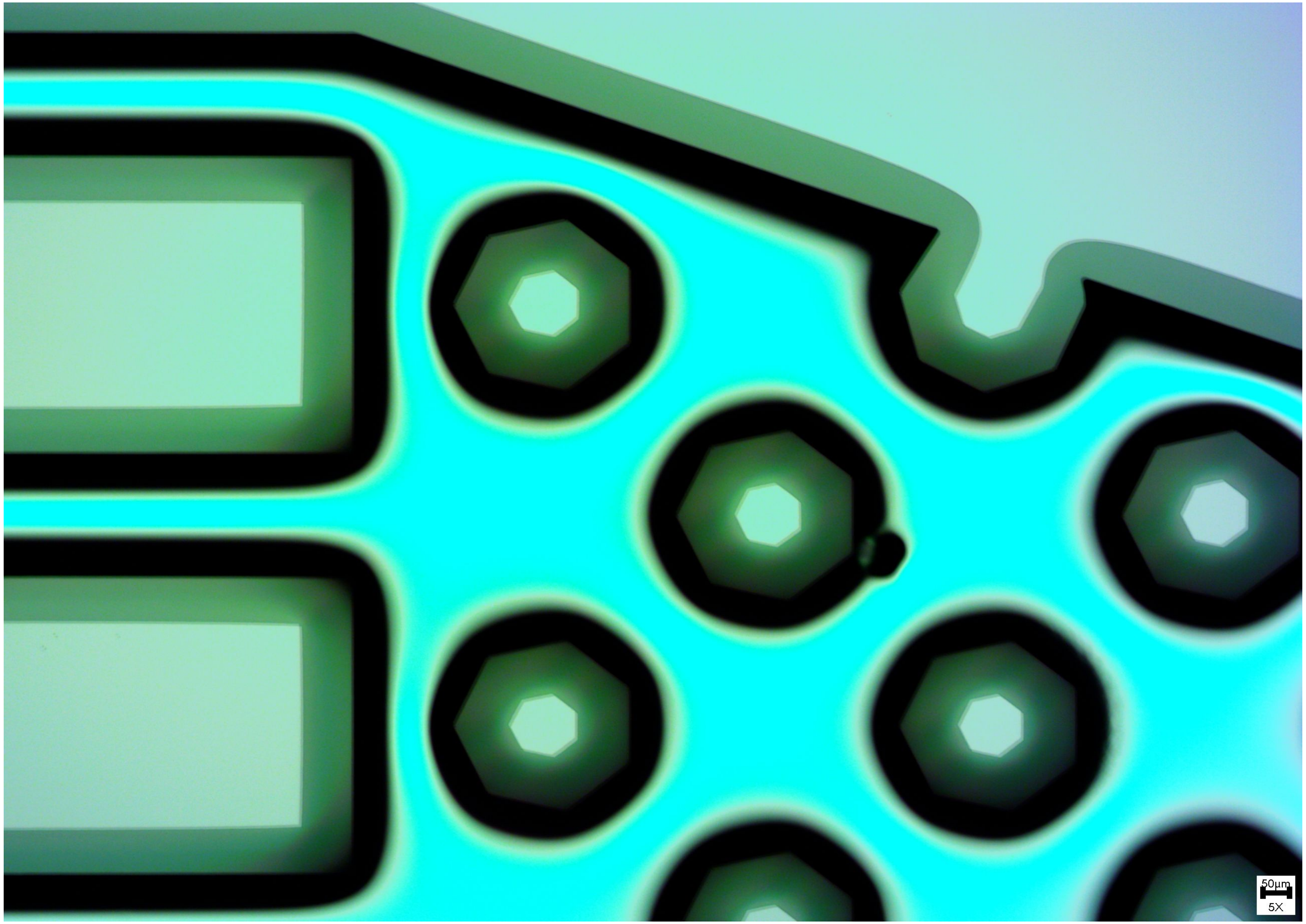
ttbar event with $\mu \approx 140$ (ATLAS simulation)

- Radiation hardness
  - Ultimate integrated luminosity ~ 3000 fb^{-1}
  - Radiation hard material required
  - New readout electronics required
- **Granularity**
  - Resolve 140-200 collisions per bunch crossing
  - Maintain detector occupancy below % level
  - Requires much higher granularity

- Improve tracking performance
  - Reduce material in the tracking volume
    - Improve performance at low p_T
    - Reduce rates of nuclear interactions, photon conversions, Bremsstrahlung…
  - Reduce average pitch
    - Improve performance at high p_T



Micro-channels based cooling



The ATLAS ITk cooling specifications

- To avoid negative annealing future sensors must be operated well below 0 °C ➔ ideally: -20 °C
- Sensor+chip will dissipate ~ W/cm^2
- A very efficient cooling system is needed
- Important constraint: very low material budget envisaged (< 1% X_0)

➢ Promising solution: micro-channel based cooling using CO_2

Micro-channels and 2-phase cooling features

Many modern devices are faced with two conflicting trends

- the need to dissipate increasing amounts of heat,
- and the quest for more compact and lightweight designs

Most present air cooling and single-phase liquid cooling solutions virtually obsolete

Paradigm shift from single-phase to two-phase cooling strategies to capitalize upon the coolant's sensible and latent heat rather the sensible heat alone

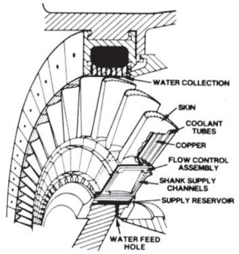
- CO_2 boiling into micro-channels!

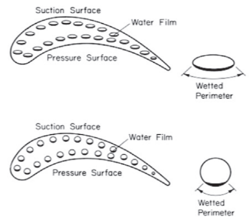
Sung-Min Kim, Issam Mudawar, International Journal of Heat and Mass Transfer 77 (2014) 74–97

μ-channels cooling applications

Sung-Min Kim, Issam Mudawar, International Journal of Heat and Mass Transfer 77 (2014) 74–97

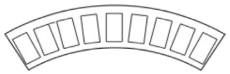
Water cooling of turbine blades

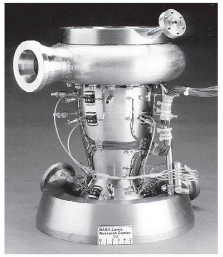


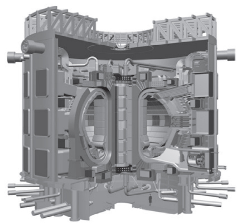


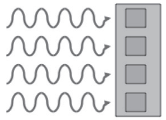
Computer data centres

Rocket engine noozle cooling



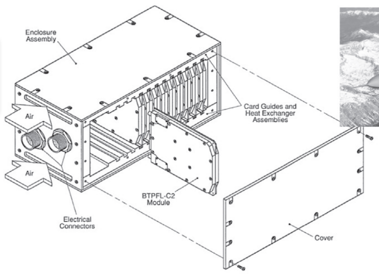


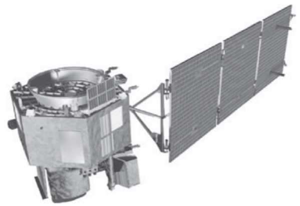




Fusion reactor blanket

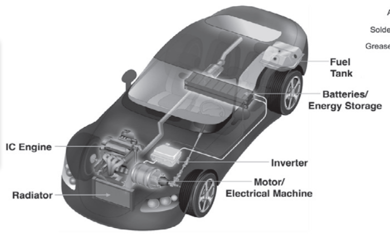
Avionics cooling

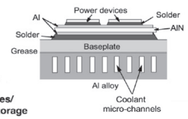


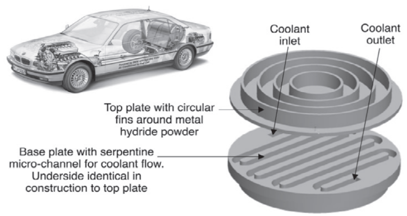


Cooling of satellite electronics (*e.g.* HEP: *AMS)*

Hybrid veichles data centres

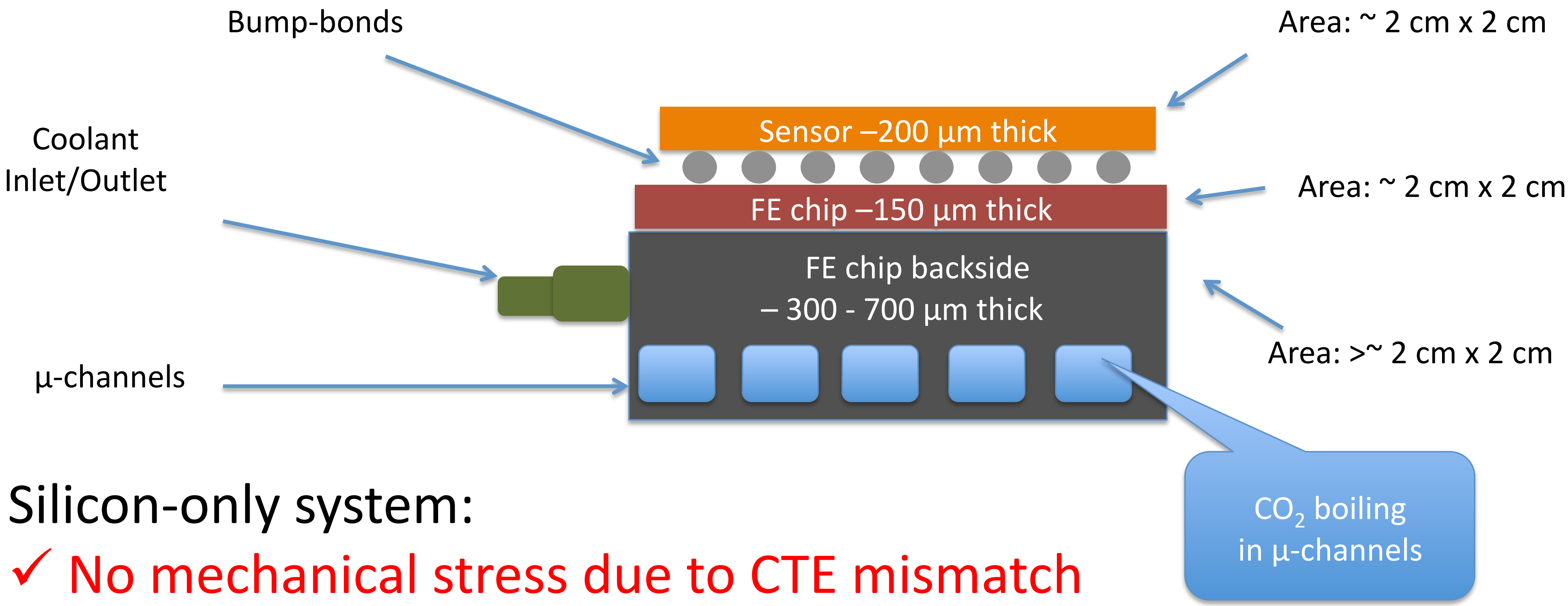






Heat exchange for hydrogen storage

The μ-channels solution



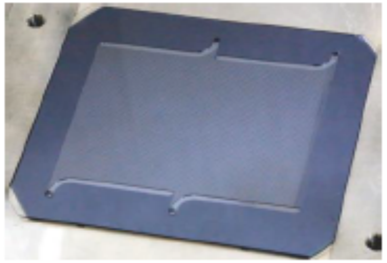
Silicon-only system:

- ✓ No mechanical stress due to CTE mismatch
- ✓ Low mass
- ✓ Customizable layout of the channels ➔ more efficient and uniform cooling
  - Very important to avoid thermal runaway after irradiation

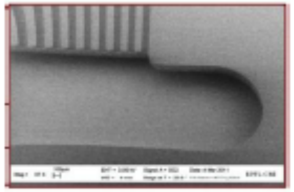
Micro-channle cooling: existing examples

NA62 GTK TDR

NA62 - GTK



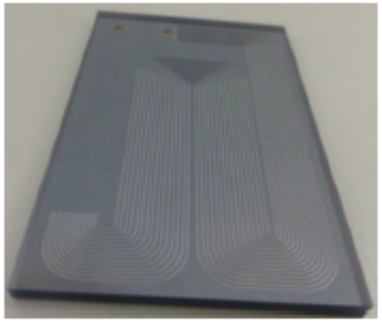
- Minimum material in beam area
- -20 °C
- C_6F_{14} single phase
- 2.5 W/cm^2
- Total power up to max 144 W



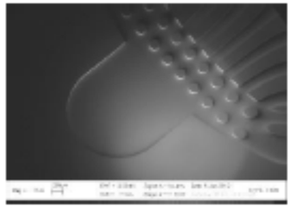
Approved by experiment

LHCb TDR 13

LHCb – Velo Upgrade

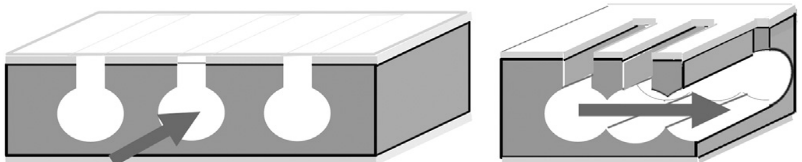


- Reduced material in beam area
- < -20 °C
- CO_2 two-phase
- 1.5 W/cm^2
- Total power 1.9 kW



Approved by experiment

FBK-CMM



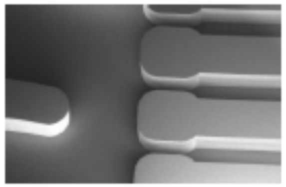
M. Boscardin et al.,
Nucl. Instrum. Meth. A718 (2013) 297-298

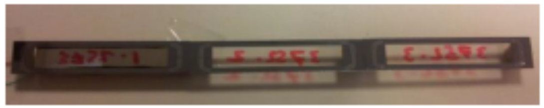
A. Petagna, 2013

ALICE - ITS

- No material in beam area
- 15 < T < 30 °C
- C_4F_{10} two-phase
- 0.3 W/cm^2
- Total power 600 W

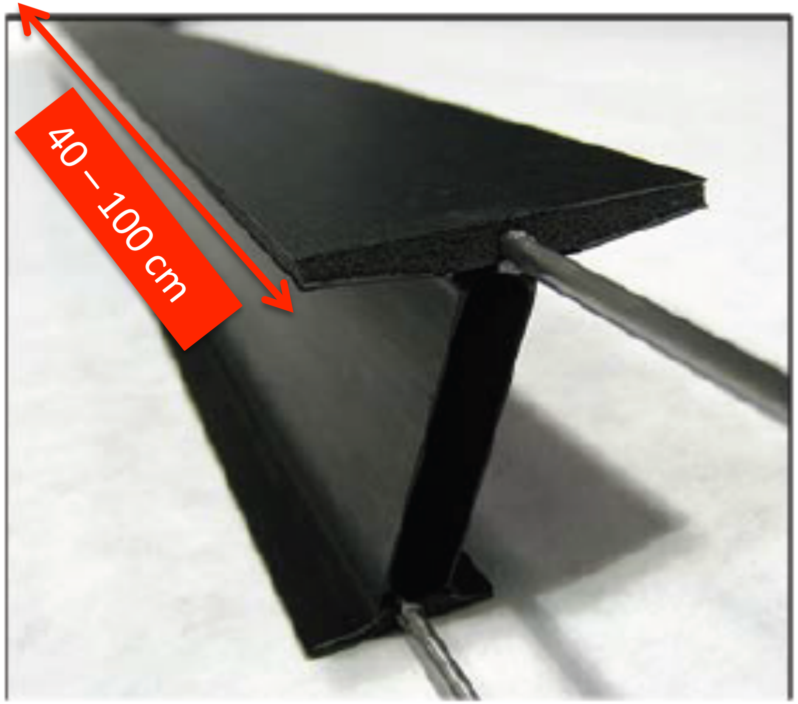
Under study

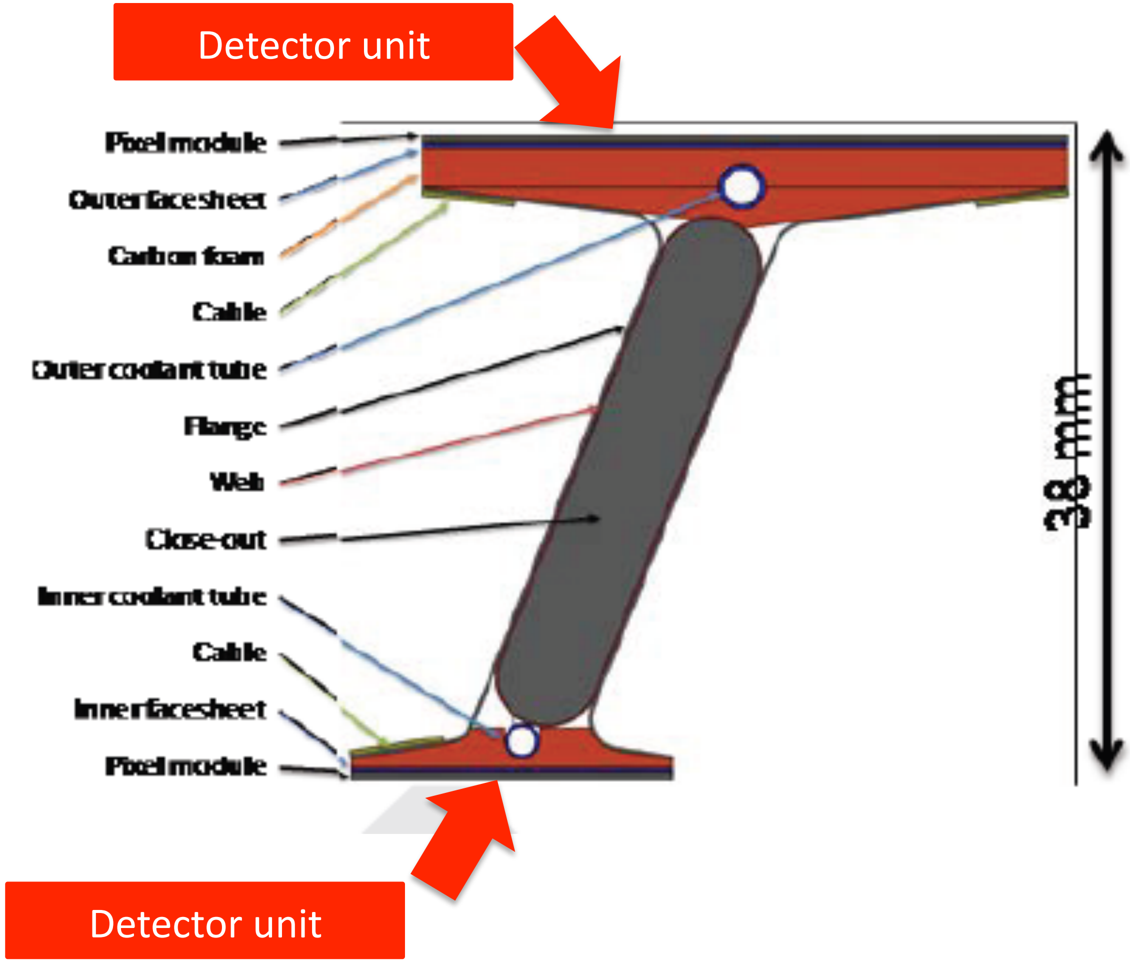




ATLAS ITk IDR stave

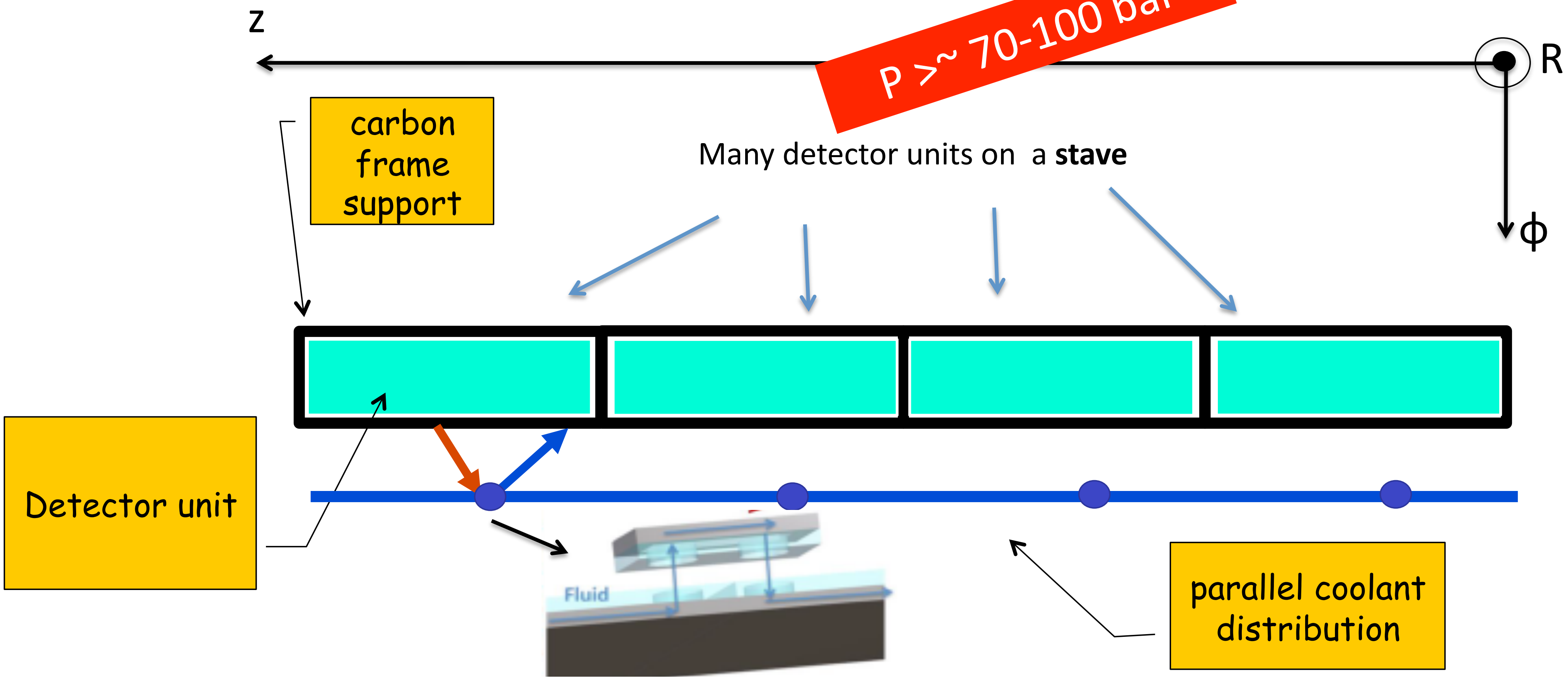
- Stave example





- 40-100 cm long

Micro-channels for the ATLAS ITk



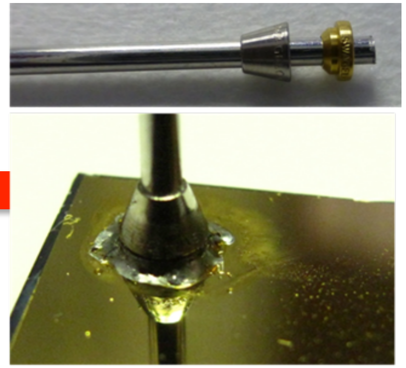
- How to deliver efficiently the coolant?

➢ Find suitable in plane connections

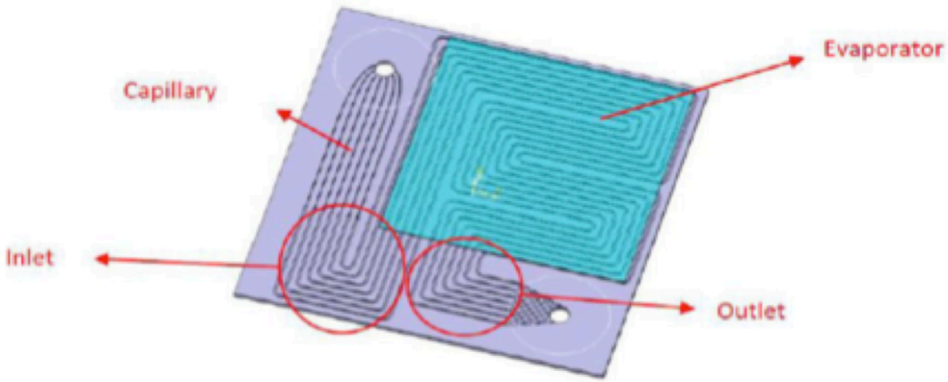
The REFLECS project

- ***REF**roidissement **L**éger au **C**O2 en **S**ilicium*
  - Project leader: M.B.
- Financed by CNRS (1 year)
  - *Defi instrumentation aux limites 2014*
- Goal: study a 2-phase CO_2 based cooling system for HEP trackers using μ-channels
- Partners: IEF (Paris Sud), MPI (Munich), CMM (Trento), PH-DT (CERN), DEI (Uni. Padua)
- μ-channels cooling plates being realized
  - Delivery: March 2015

REFLECS: designs



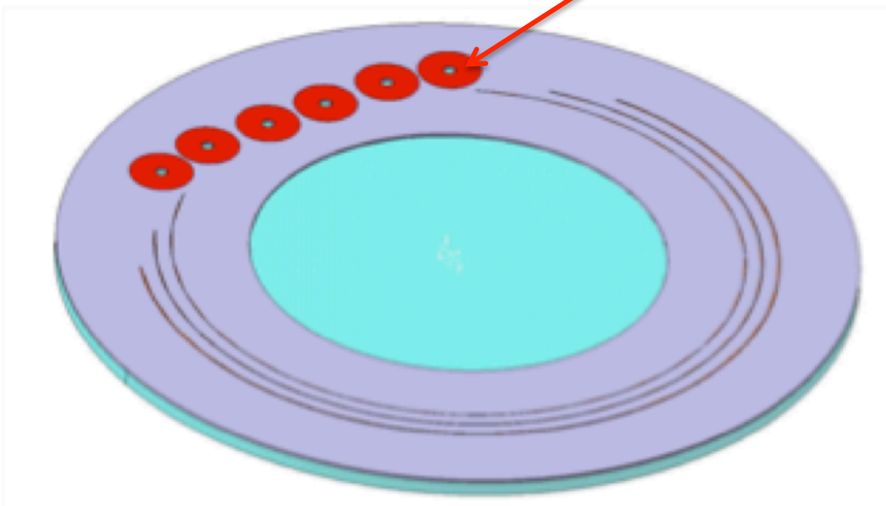
SNAKE design



•A real test-bench for CO_2 cooling based system

• Single-, Double- and Quad-chip modules being realized

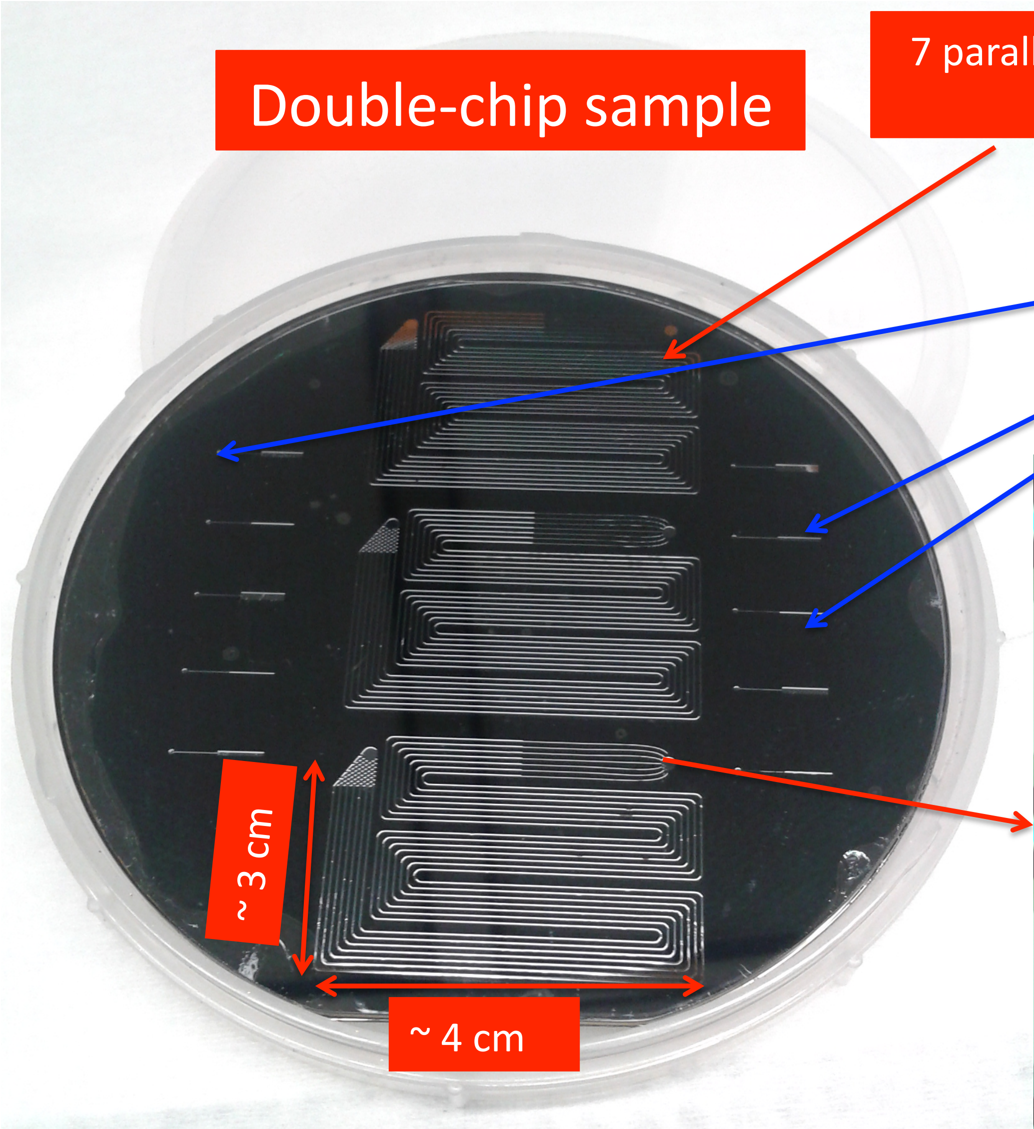
DOUGHNUT design

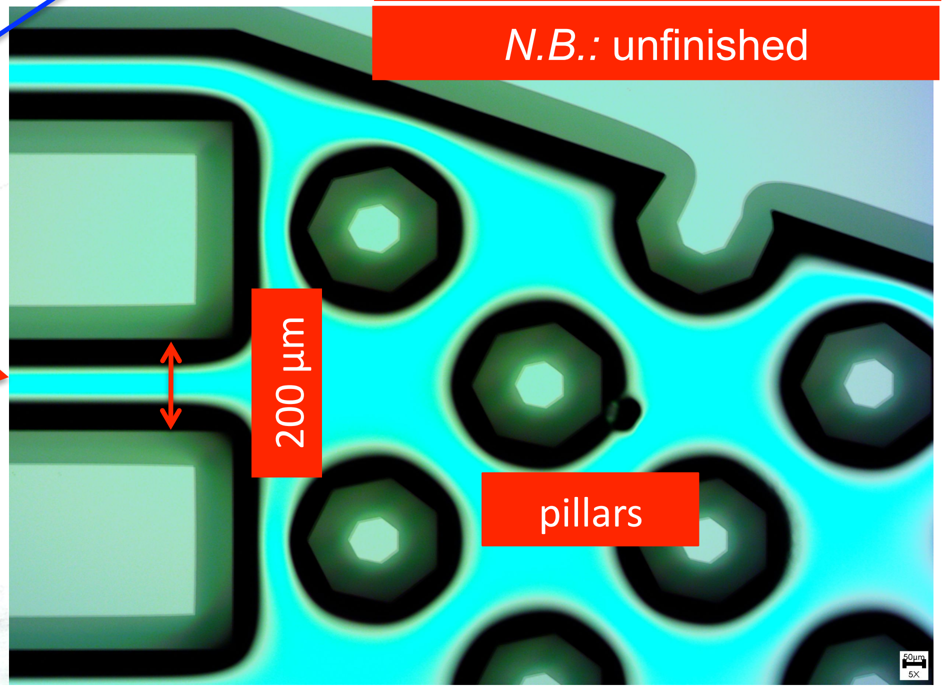


•To study high pressure CO2 flowing and boiling in µ-channels

• Production splits: different channel profiles, different walls roughness

REFLECS micro-channel samples





The REFLECS2 project

- Extension of the REFLECS project
- Goals:

1. Measure thermal performance of the REFLECS snake and doughnut samples
2. Develop a numerical model for the high-pressure CO_2 flowing/boiling in μ-channels
   - Lack of a reliable model for 2-phase microfluidic

- Partners: PH-DT (CERN), IEF (Paris-Sud) and DEI (Uni. Padua)
- Approved for 1 year

Conclusions & Outlook

- Micro-channel based cooling for ATLAS ITk looks very promising
  - High performance
  - High uniformity
  - No CTE
  - Very light (low X_0)
- What's next:
  - Test new (REFLECS) samples
  - Use data to model 2-phase flow in μ-channels
  - Link together many cooling units


THANK YOU FOR YOUR ATTENTION!
50µm

Backup

ITk schedule

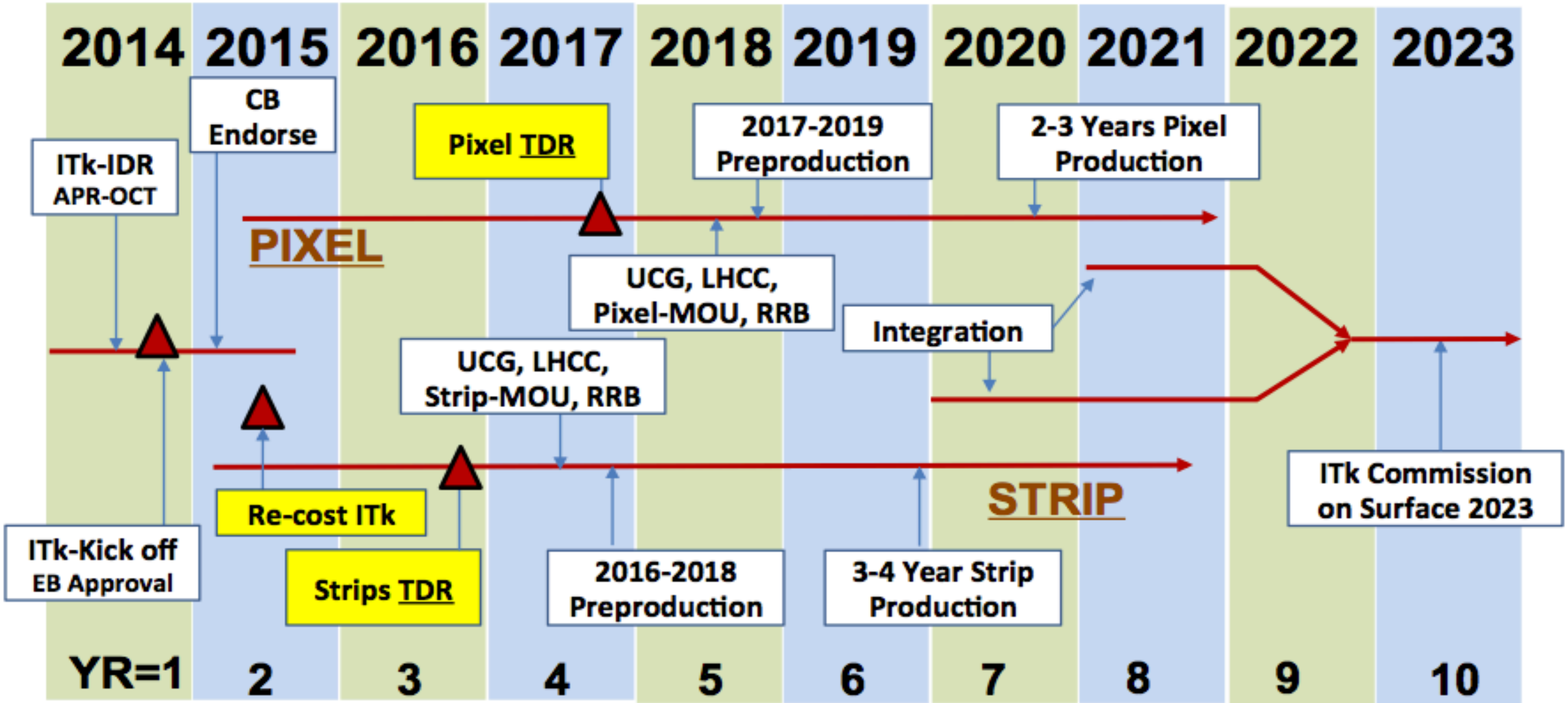


Figure 13.86. The construction schedule of the ITk.