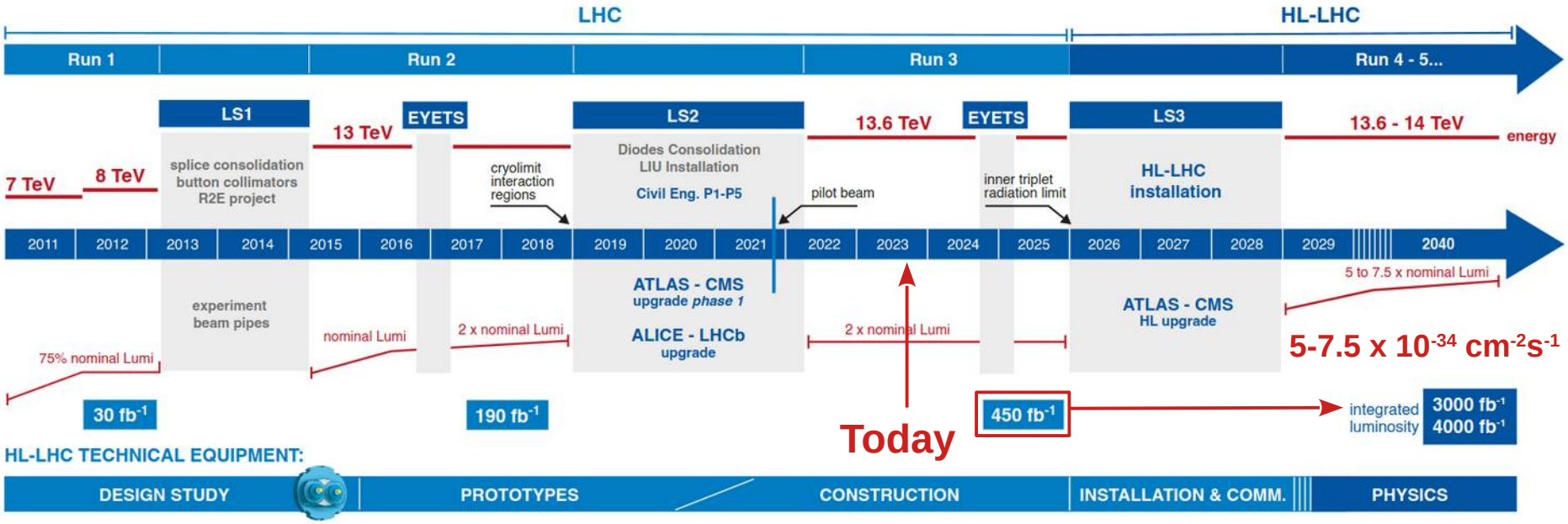
Laboratoire d'Annecy de Physique des Particules

The Inner Tracker of ATLAS

F. Costanza, on behalf of the ATLAS Collaboration

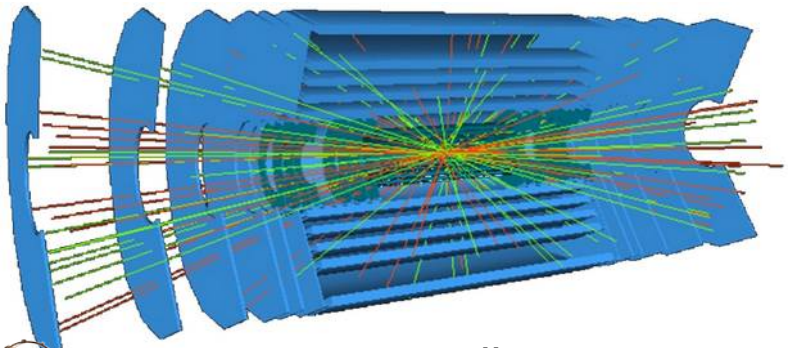
Intensity Frontier Workshop, GDR-InF
CPPM, September 19th-20th 2023

The High-Luminosity LHC Upgrade

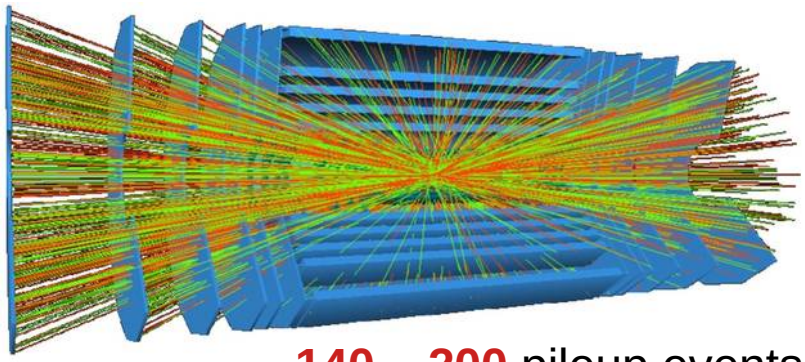


LHC: Inner Detector (ID), made of Pixels + Strips + TRT

HL-LHC: New all-silicon Inner Tracker (ITk), made of Pixels + Strips



19 – 55 pileup events

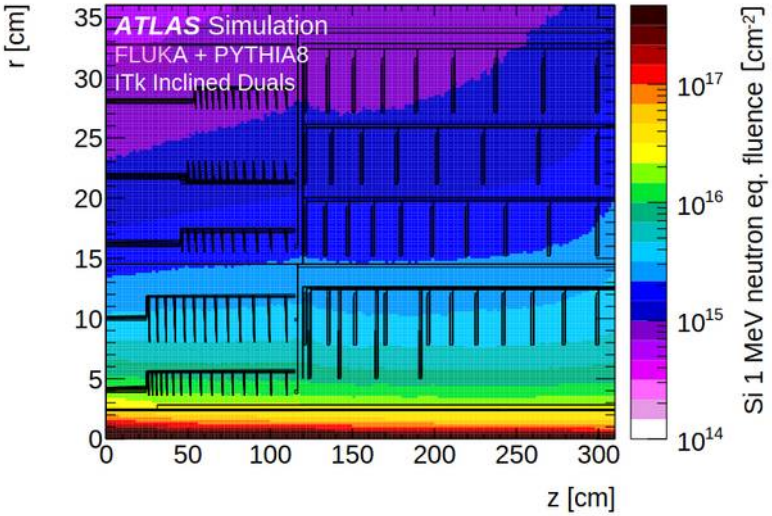


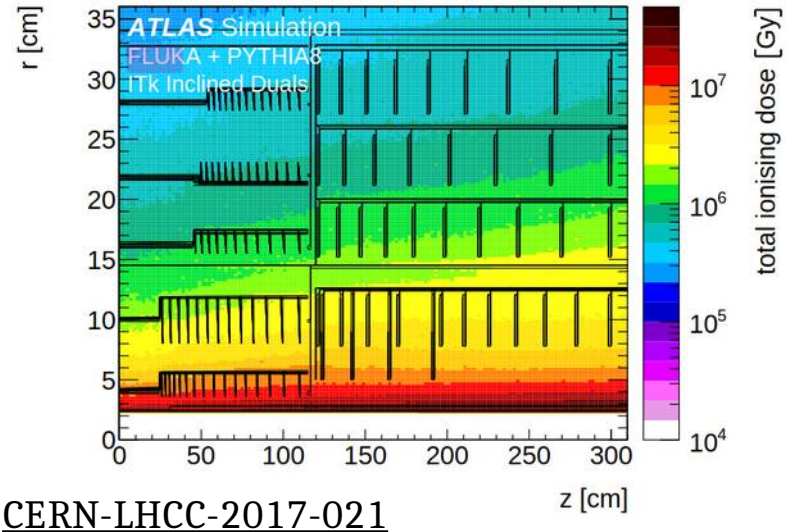
140 – 200 pileup events

- **Goal:** maintain (or improve) current ID tracking performance in the harsher HL-LHC environment.

- **Instantaneous conditions:**
  - Increased pileup, high event rate increased occupancy

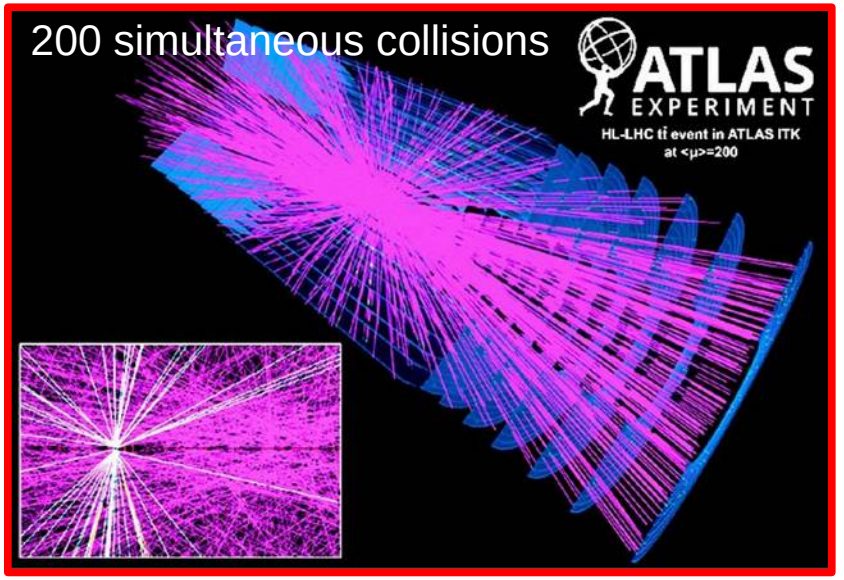
- **Integrated effects:**
  - x10 increase radiation damage.
  - Particle fluence up to **2×10^{16} n_{eq} cm^{-2}** and total ionizing dose (TID) up to **1MGy**.





CERN-LHCC-2017-021

- The Inner Tracker (ITk) @HL-LHC requires:
  - Increased radiation hardness.
  - Higher granularity (smaller pixels).
  - Faster readout.
  - Reduction of material.
  - Extended coverage up to $|\eta| < 4.0$.



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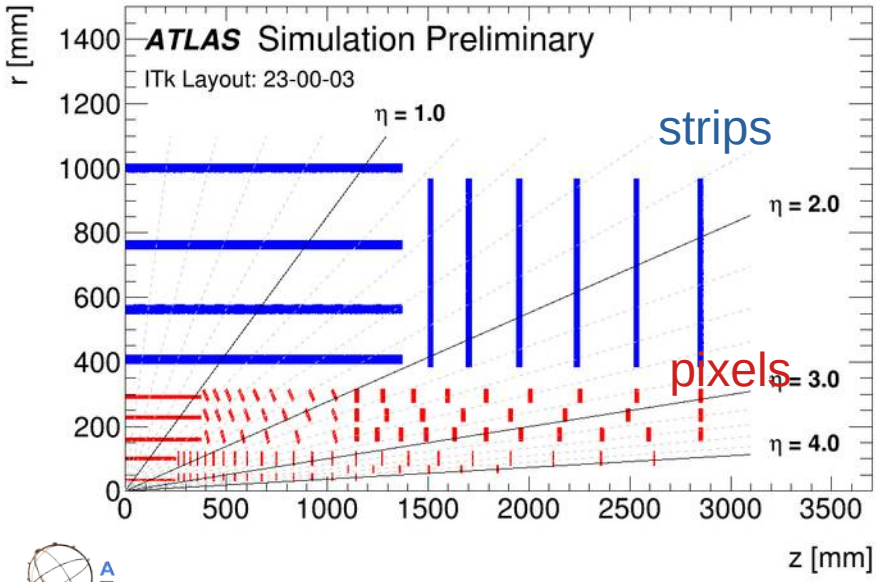

ITk-Pixel

- Reduced pixel pitch: *50x50 μm²*
- Five barrel layers with inclined sensors from $|\eta| > 1.4$ to reduce the material budget.
- Endcap rings to improve coverage.

ITk-Strip

- Four strip barrel layers and six endcap disks

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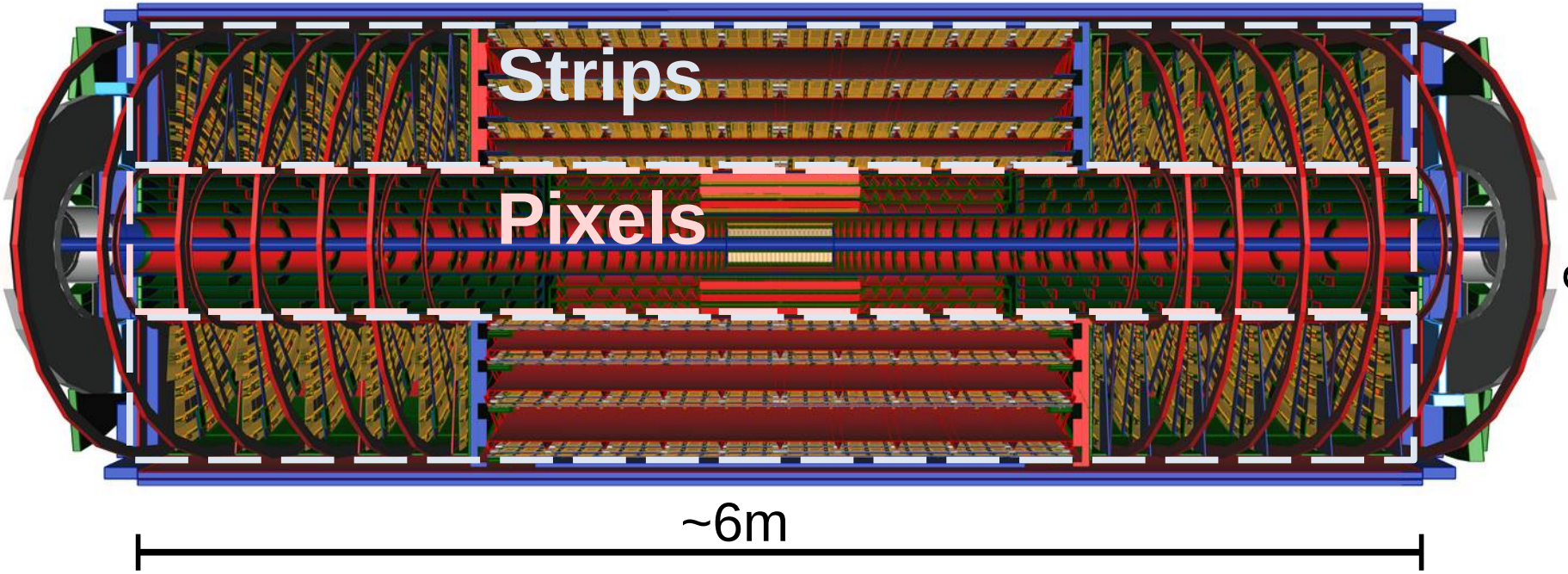

ITk (ID)	Area (m^2)	# Modules	# Channels (M)
Pixels	13 (1.6)	9164 (2000)	5100 (92)
Strips	165 (61)	17888 (4088)	60 (6.3)

- Lower material budget than ATLAS ID
  - **Advanced cabling:** serial powering for Pixels, data link sharing.
  - **Thin Sensors** and FE-chips, **inclined modules** for Pixels $|\eta| > 1.4$.
  - CO_2 titanium pipes for cooling, low-mass carbon local supports.

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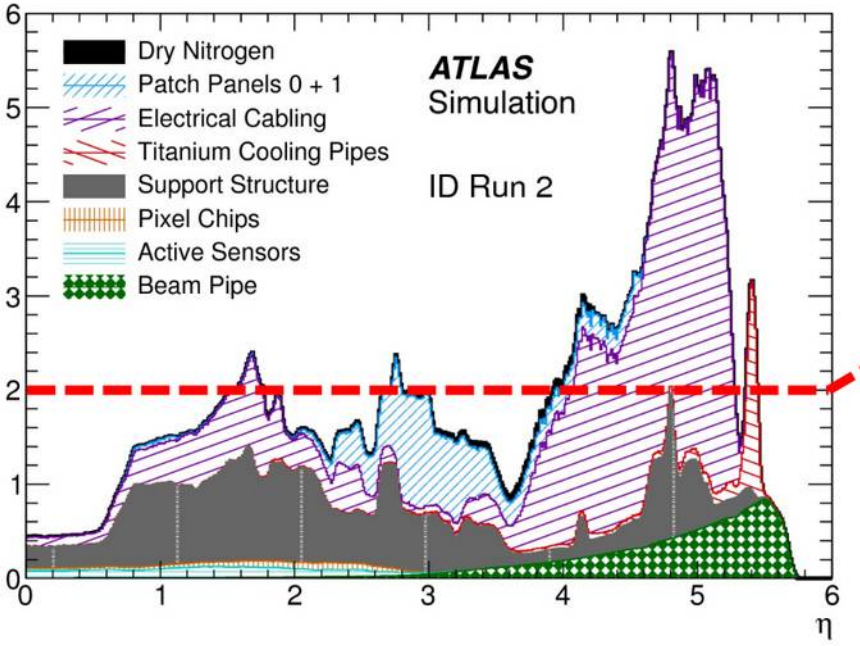

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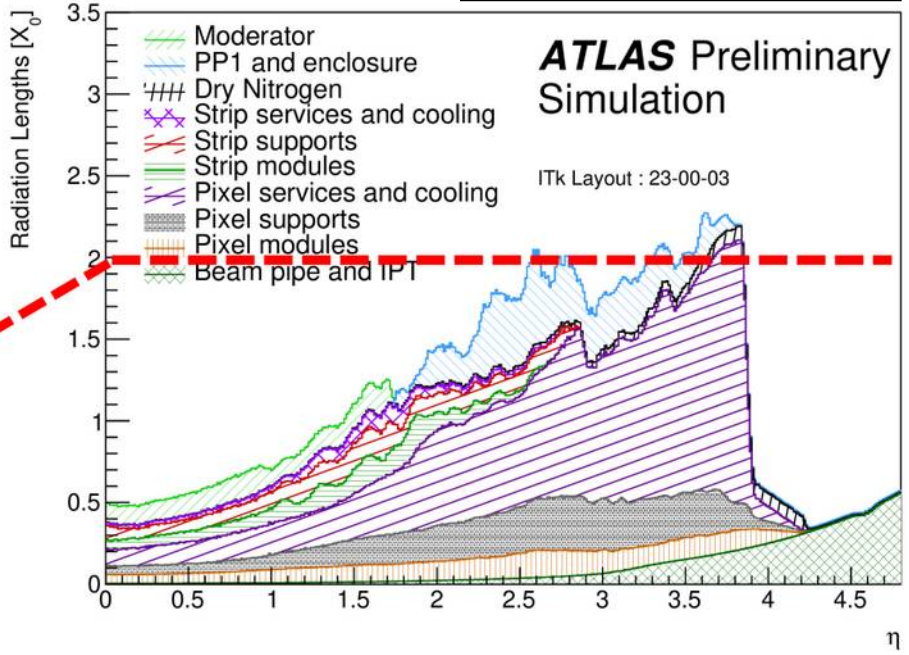
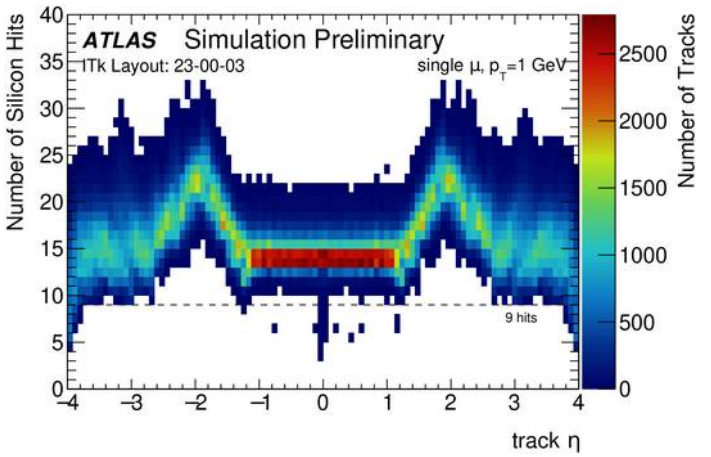


Tracking performance

- Minimum 9 hits on the full pseudorapidity range.
- Tracking efficiency pileup = 200 for ITk vs 38 for ID
  - Similar performance to Run-2 in the barrel.
  - Efficiency **above 85 % at high pseudorapidity**.

ATL-PHYS-PUB-2021-024



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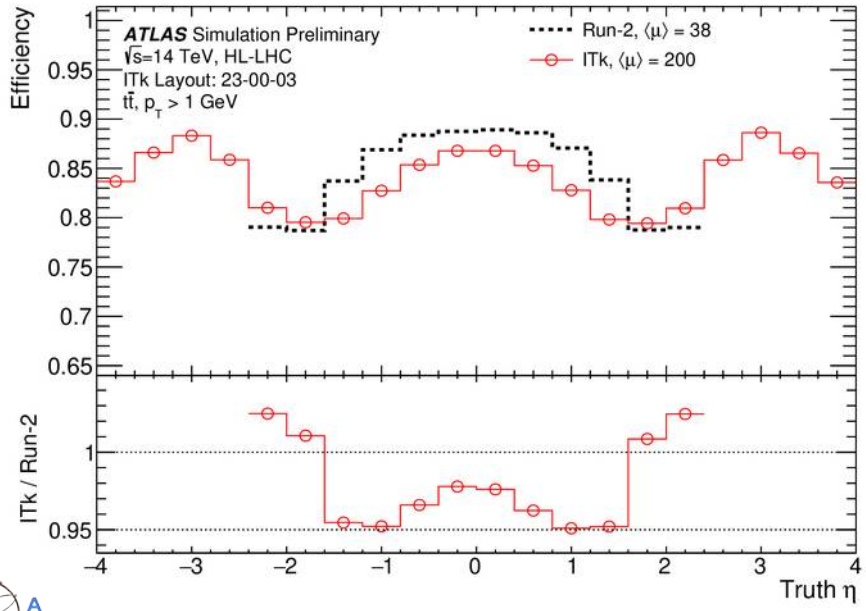

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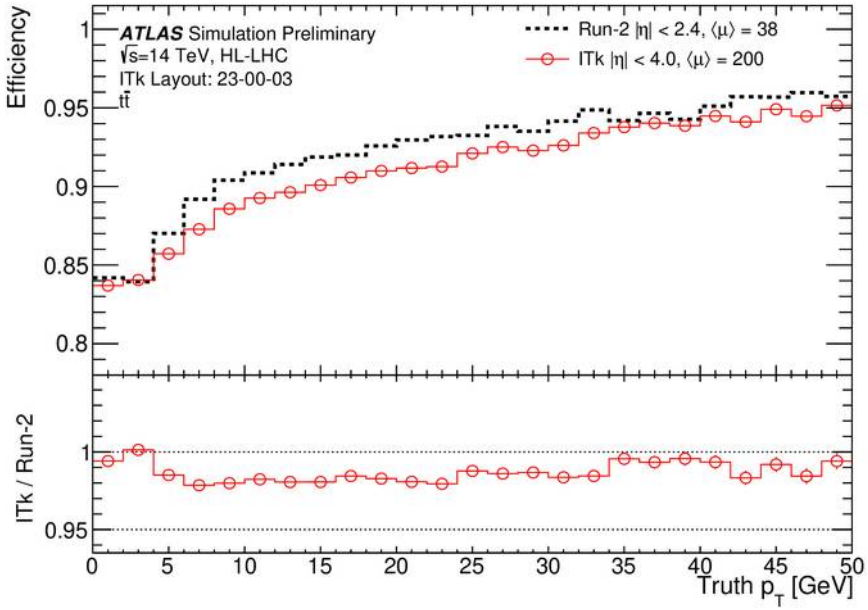
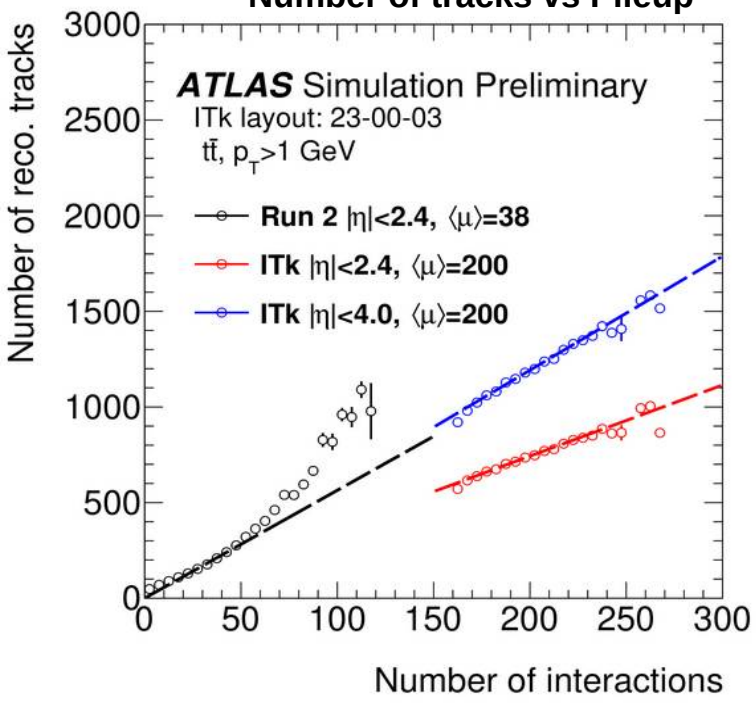
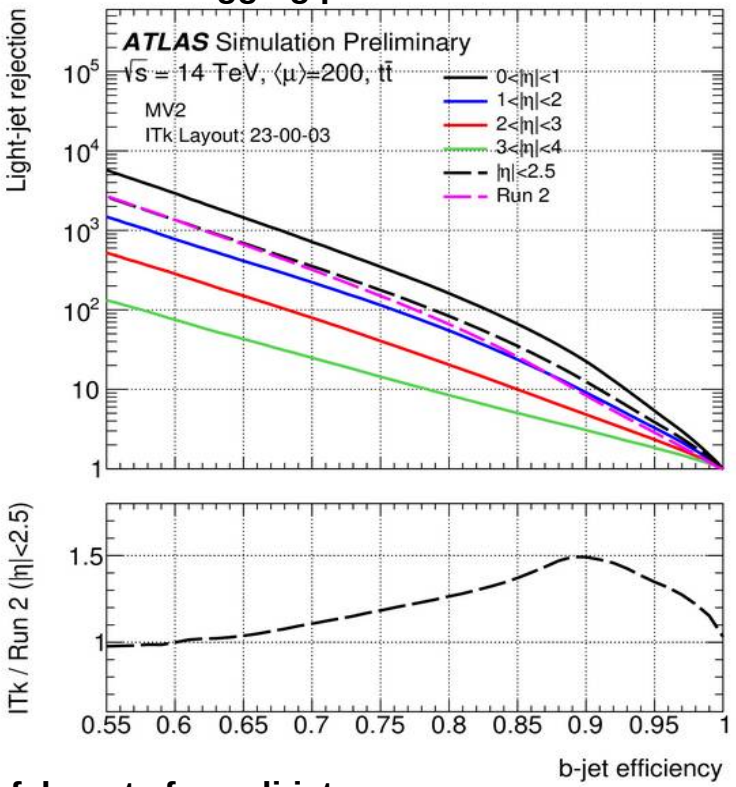


Physics performance

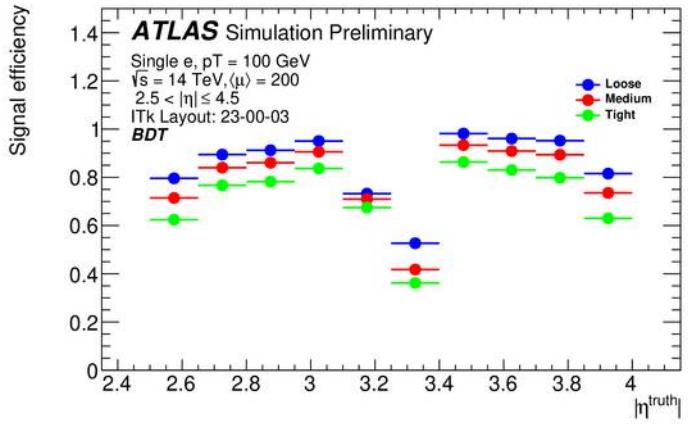
Number of tracks vs Pileup



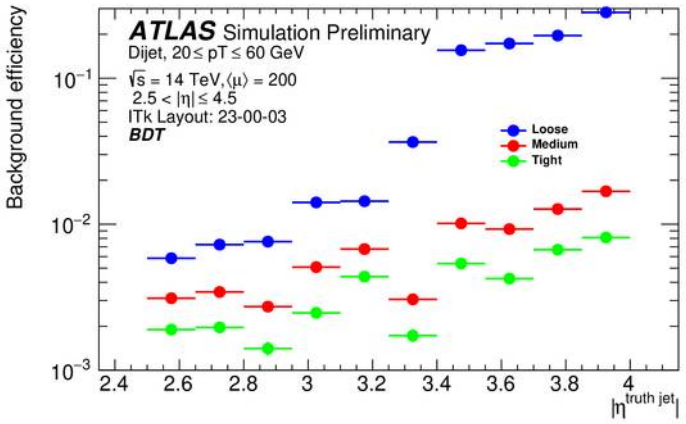
B-tagging performance



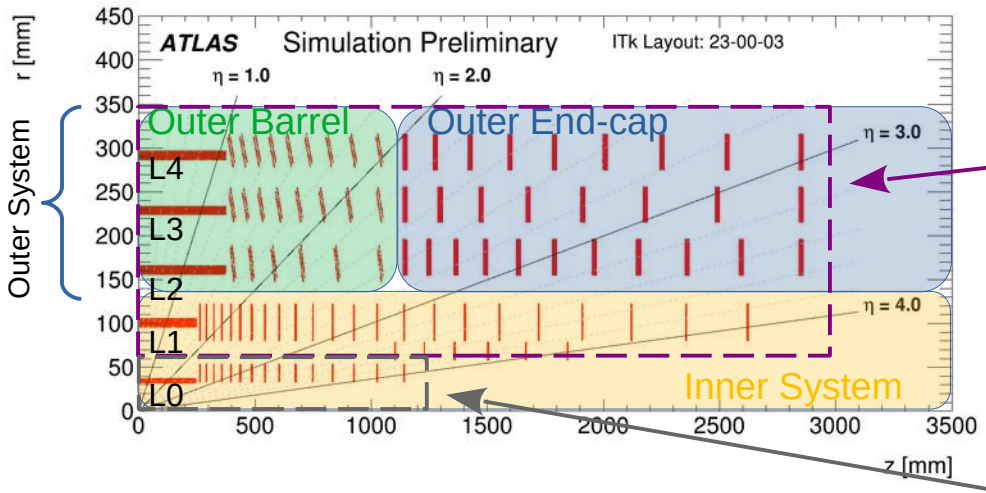
Forward Electron reconstruction Efficiency



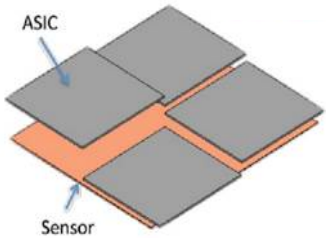
Forward Electron fake-rate from di-jets

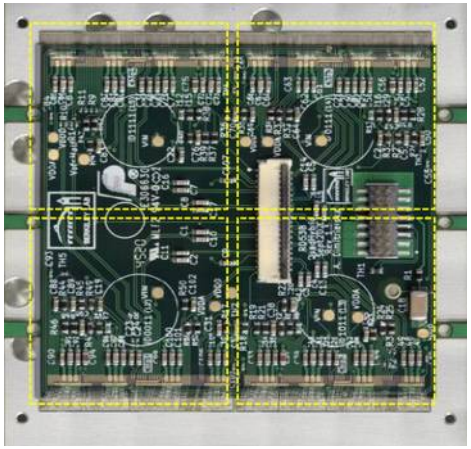


The Pixel Layout

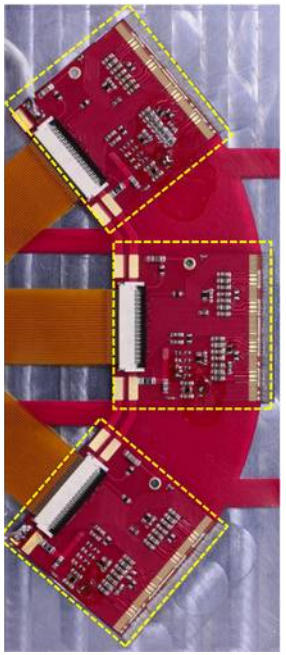


L1-4 planar quad module (single sensor)





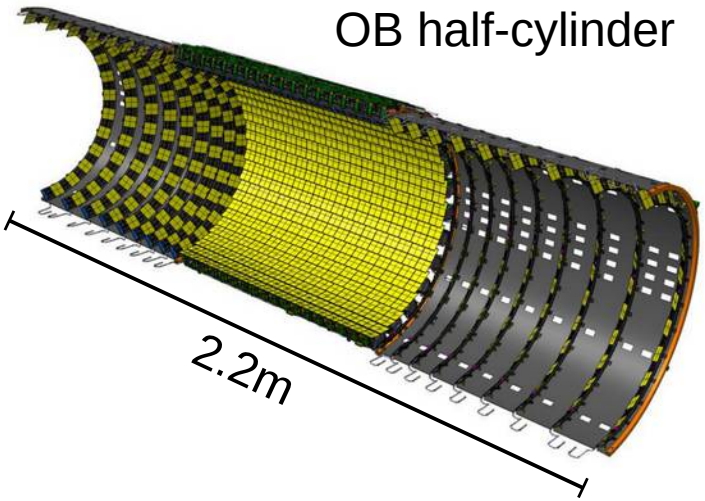
L0 3D single module (triplet PCB)



- Outer system
  - **3 layers** of flat staves and inclined rings.
  - **~7k planar quad modules** with 150µm thick sensor + 150µm thick ASIC, 50x50µm^2 pixel size.
- Inner system
  - **2 layers** of flat staves and rings.
  - L0: **~1.2k 3D single modules** (25x100µm^2 for flat, 50x50µm^2 for EC).
  - L1: **~1.2k planar quad modules** with 100µm thick sensor + 150µm thick ASIC, 50x50µm^2 pixel size.

- **Pixel outer barrel (OB), 3 coaxiales cylinders** :
  - ~50% of Itk-Pixel modules, ~5k modules.
  - International collaboration:
    CERN, Japon, **France**, Germany, Switzerland

OB half-cylinder

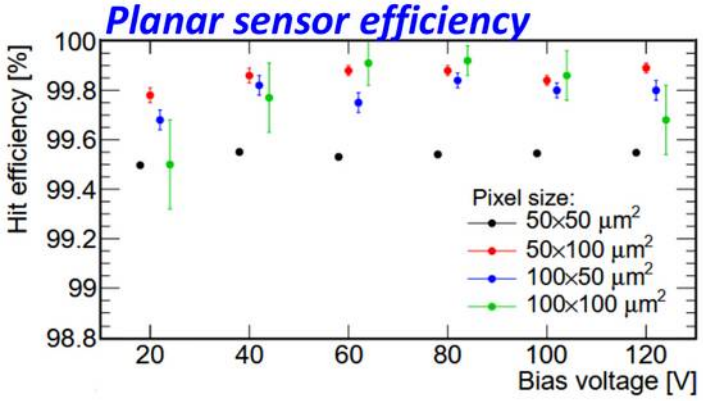


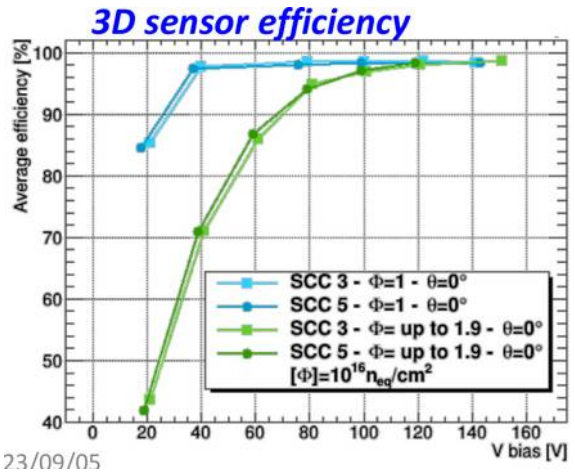
- **PIX-ILE** cluster : IJCLab/IRFU/LPNHE
  Module assembly.

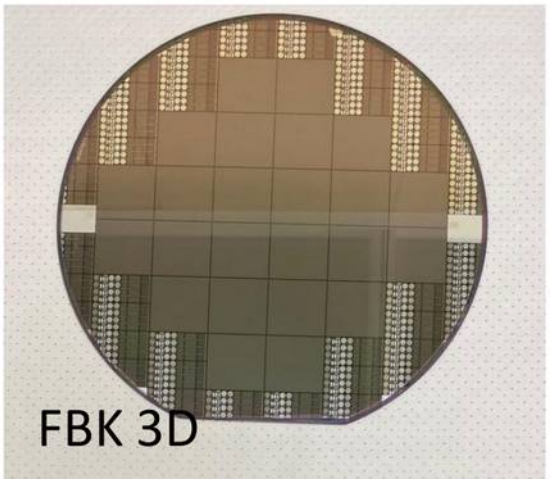
- **ALPACA** cluster : CPPM/LAPP/LPSC
  Cell loading and integration of 25% of local supports.

- Additionally, LAPP is responsible for the design and production of on-detector electrical services, aka type-0.
- And the tools needed for the integration of type-0 services.

- **Sensors:**
  - Pre-production (10% of required for installation) finished in ‘22.
  - Qualification for final production order almost completed (some producition sensors already received).

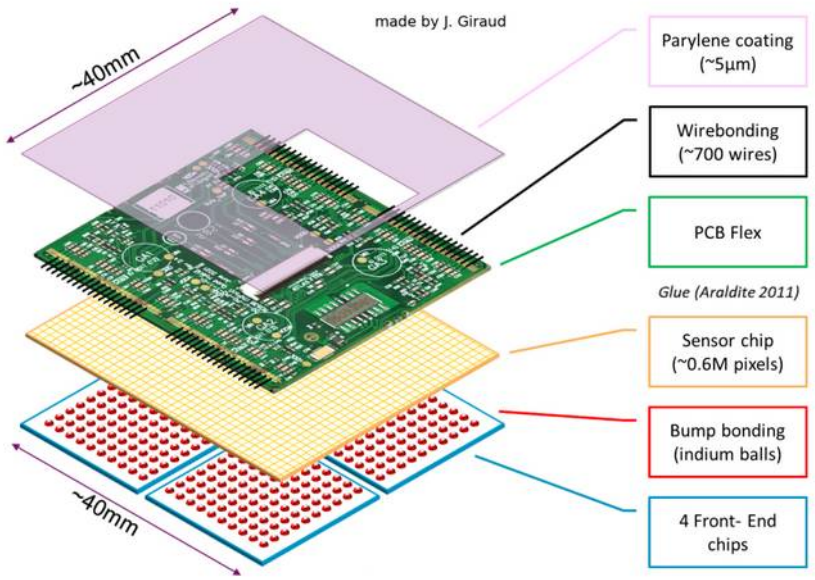






- **FE ASIC:**
  - RD53A and ITkpix-v1 used as prototype program.
  - **ATLAS approved final FE-chip (ITkpix-v2) submission on March 17th ‘23.**
    - First delivery of 20 wafers 26th June.
    - First checks show basic functions work as expected.

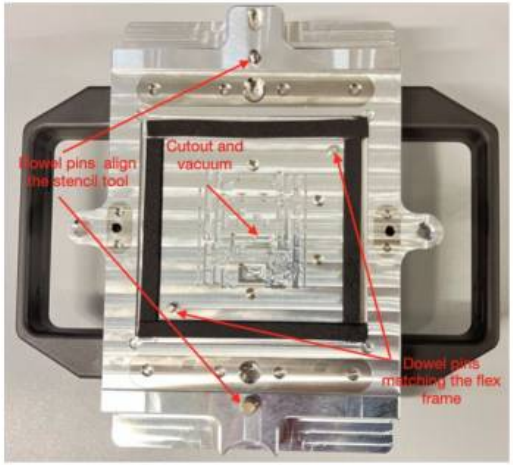
Modules production

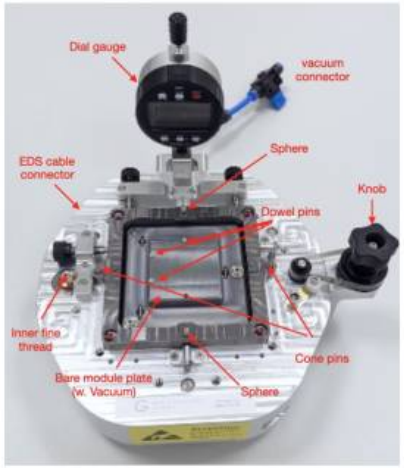


- Shared among over 20 institutes (CERN, France, Germany, Italy, Japan, UK, USA).
- 4 ITkpix flip-chip bump-bondend to one sensor tile
- Custom-designed flex PCB glued on sensor backside
  - Wirebonded to 4 ITkpix chips
- Wirebond protections

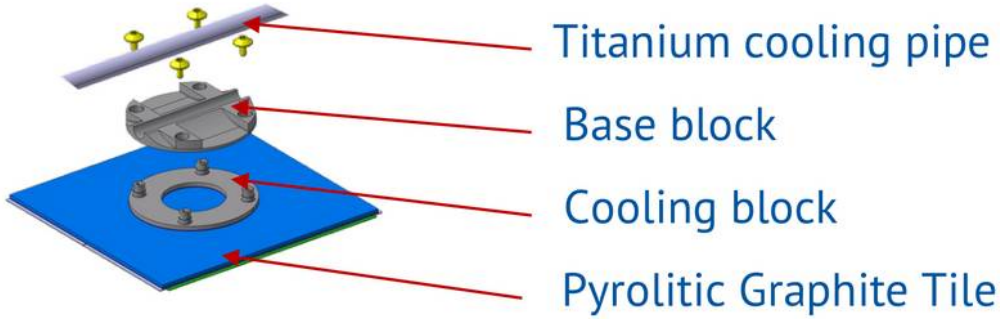
Quad module with wirebond mechanical protections

Common flex-attach tooling: flex PCB & bare module jig



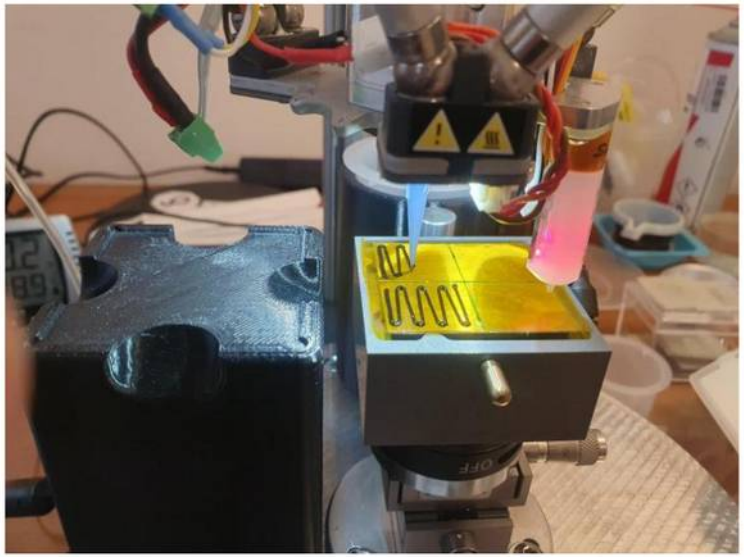


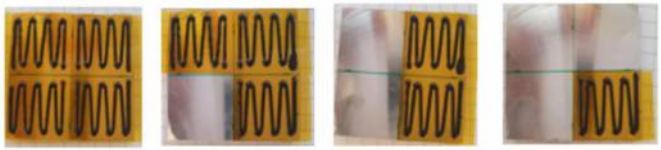
Cell integration tools



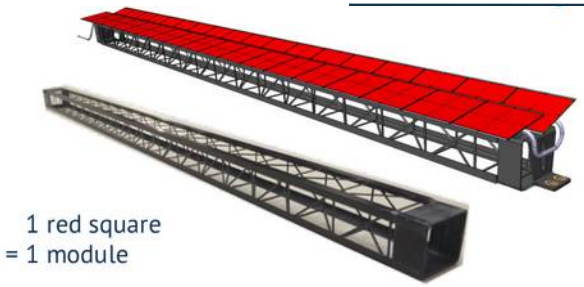
- In Outer barrel, cell concept to ease exchange of damaged modules mounted on LLS.
- Tests for optimisation and selection of pre-production glue patterns underway.
- QC test setup under commissioning.

Automatic glue dispenser





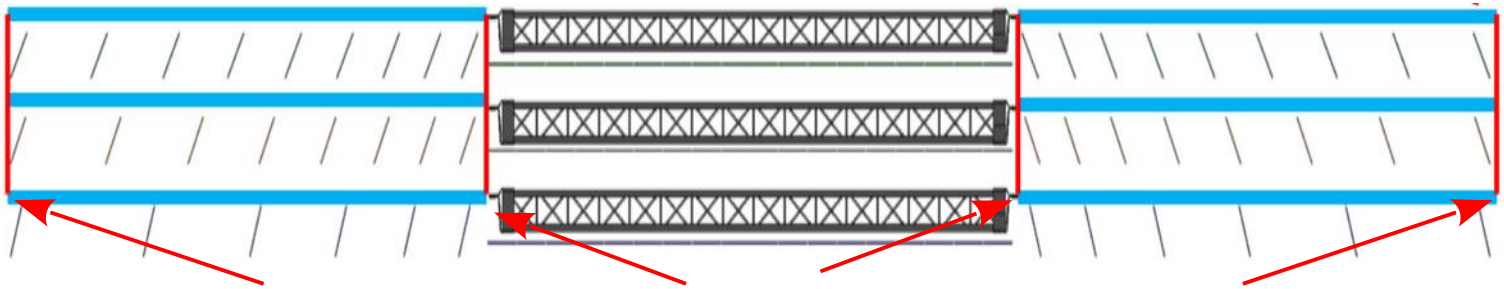
QC setup to test 4 cells in parallel with cold sycles down to -45°C



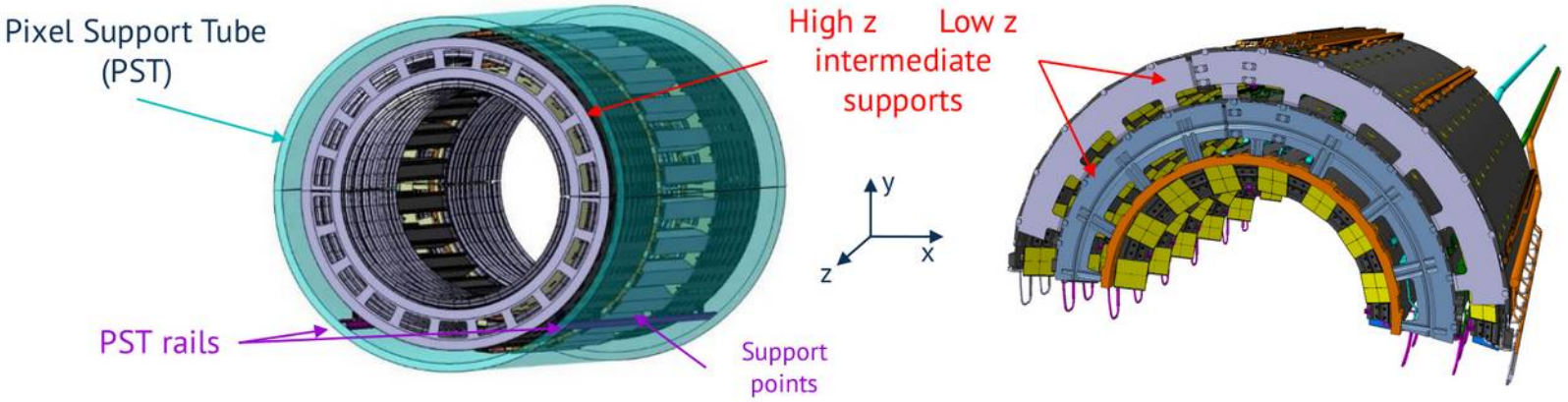
Flat section: Longerons

Inclined Half rings

Local supports: mechanical resistance with lowest possible mass → carbon-fiber.

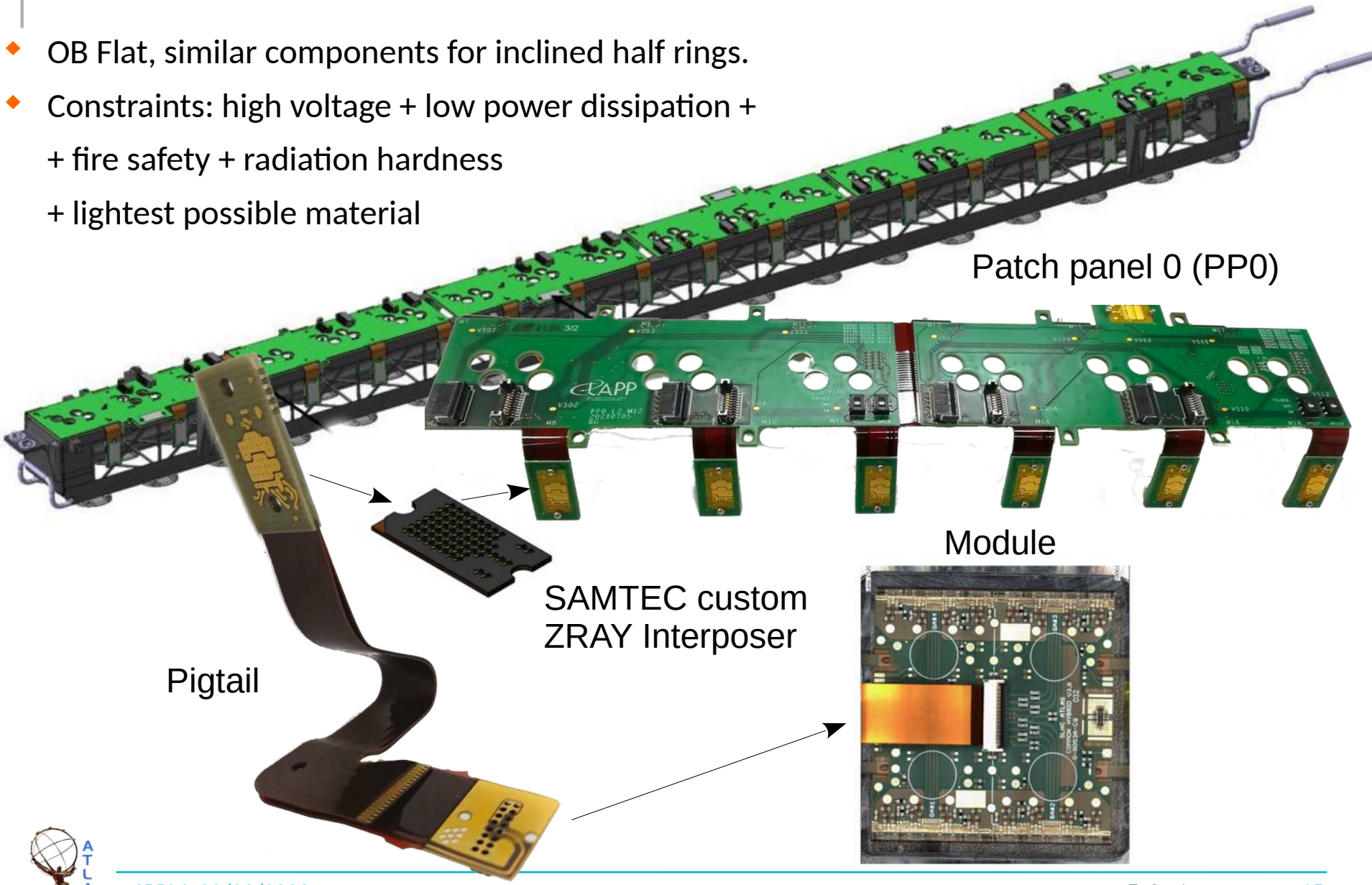


Global Mechanics: **Support points and intermediate supports**

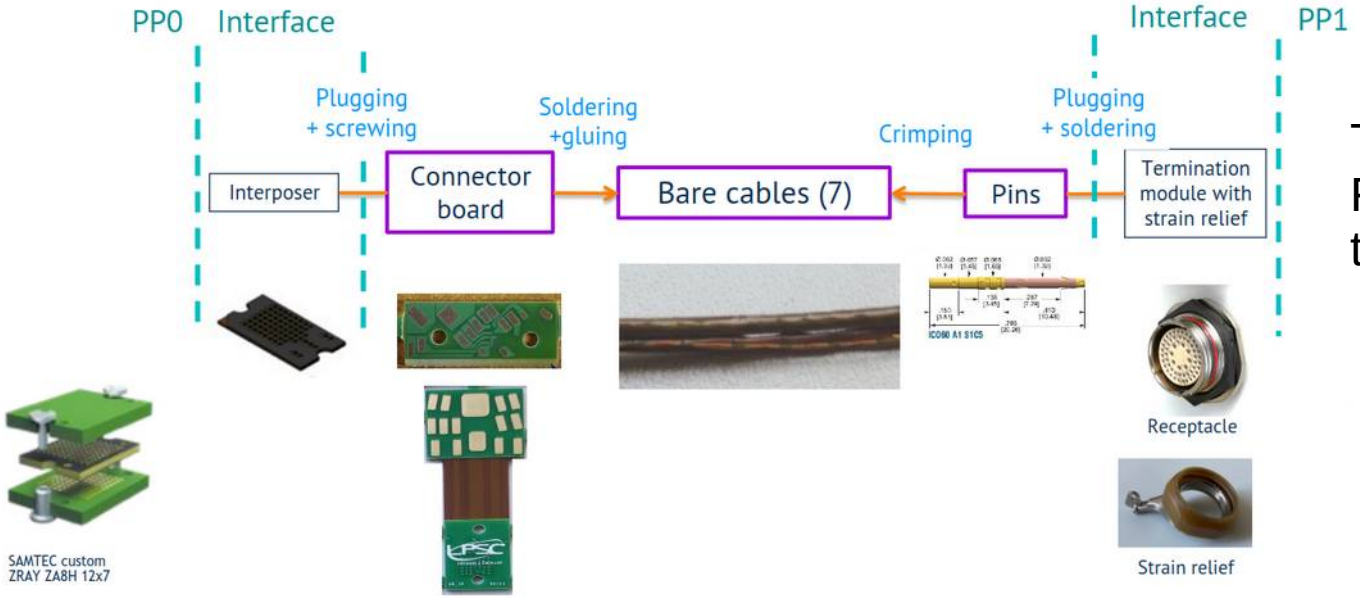


Type-0 services

- OB Flat, similar components for inclined half rings.
- Constraints: high voltage + low power dissipation +
  + fire safety + radiation hardness
  + lightest possible material



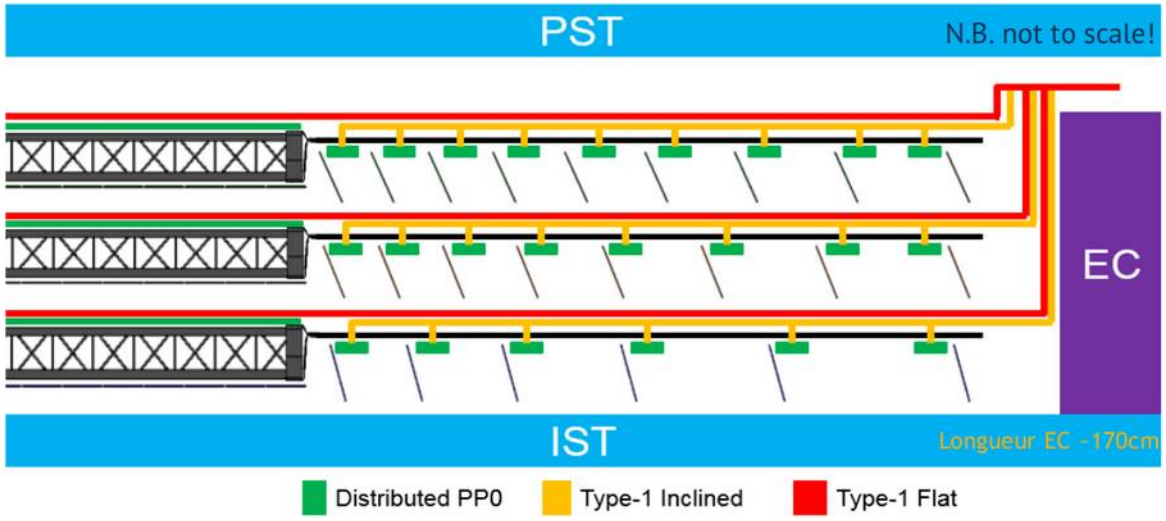
Type-1 services



Type-1 Power bundles. From distributed PP0 to the end of ITk.

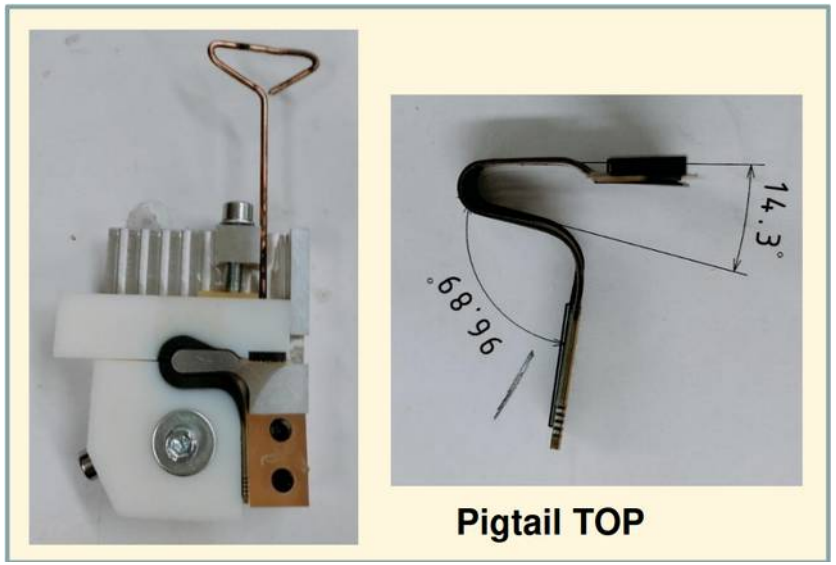
Similar requirements for type-0 services.

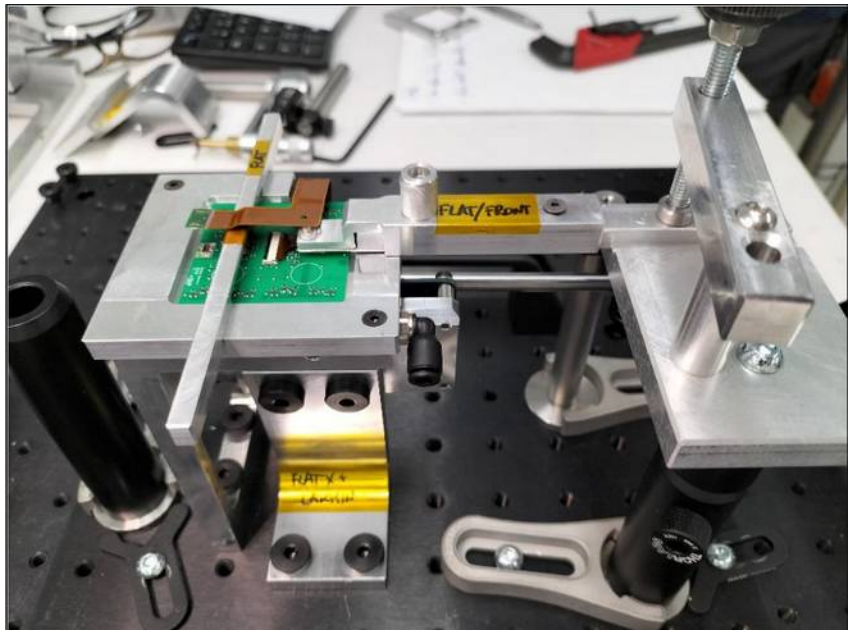
Very challenging space constraints.



Pigtail insertion tools

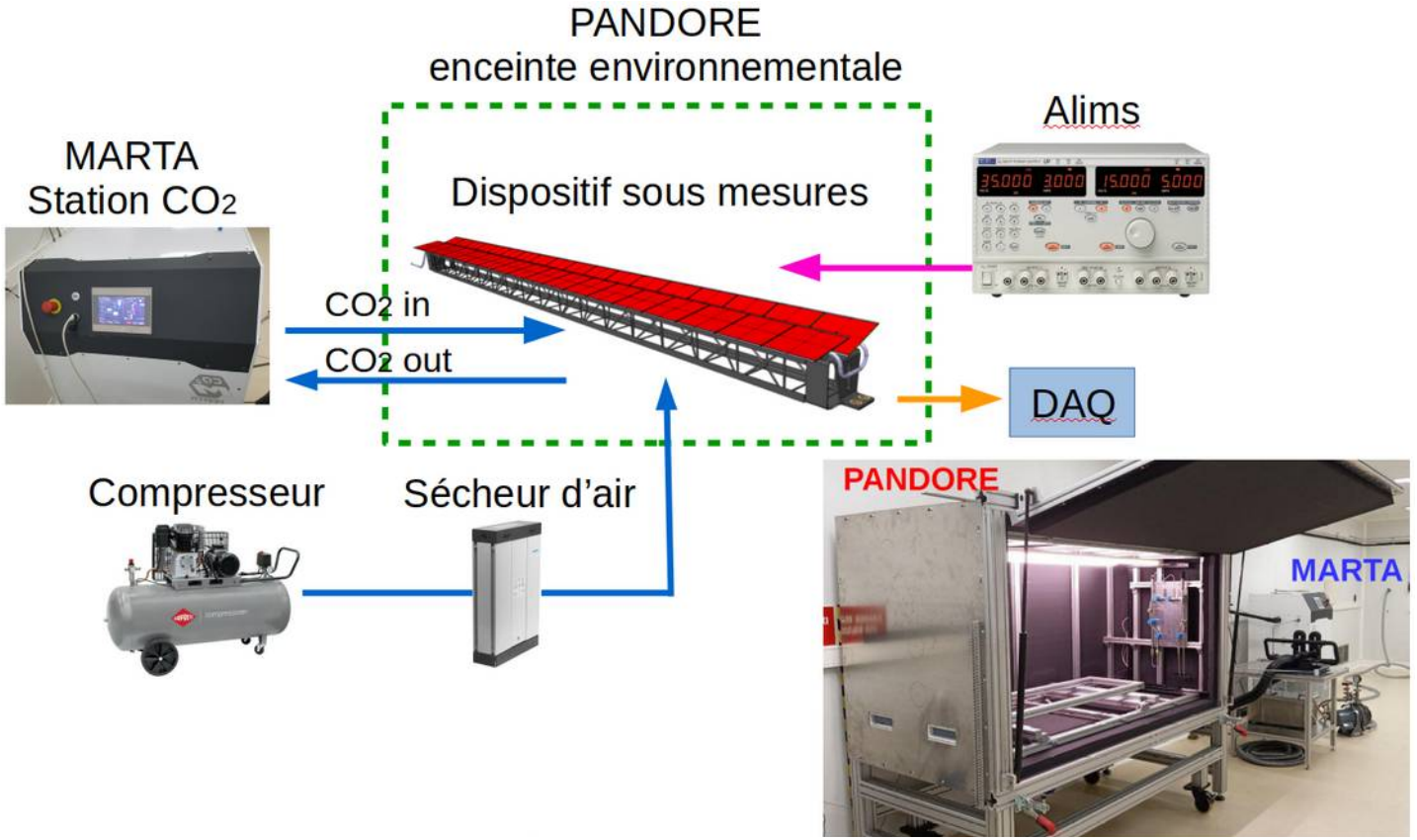
- Tools for **folding pigtails**: 4 flavors (2 for longerons and 2 for inclined half rings).
- Tools for **folding wings on PP0s**.
  - Folding requires **many prototypes** and **iterative process**, not easy to predict how the fold will relax. Heating while folded helps to preserve shape.
- Tools for **mounting pigtails on modules**, to be replicated for each integration site.





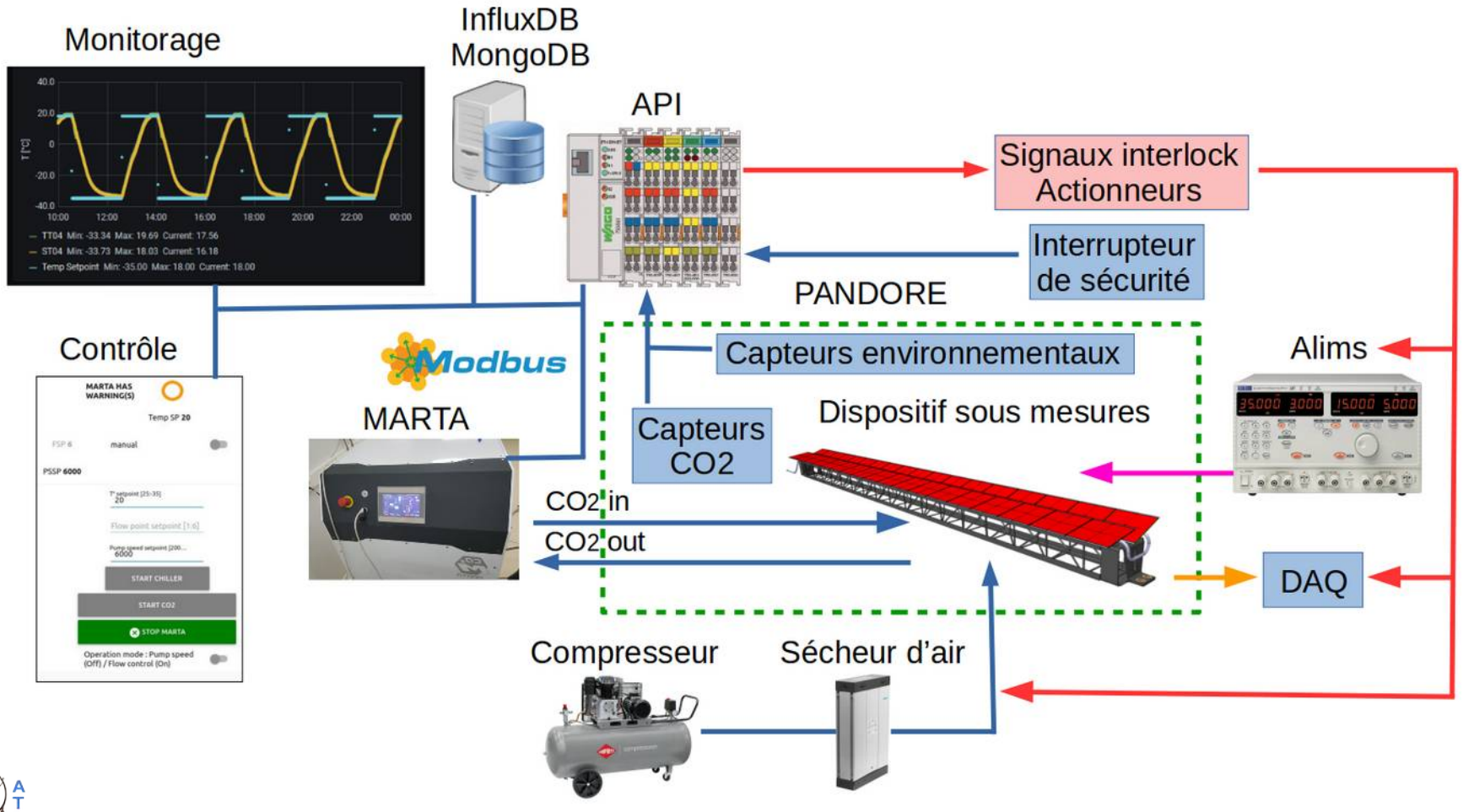
Quality control of loaded local supports

- Loading of local supports in 6 sites: Bonn Uni, CERN, CPPM, LAPP, LPSC, UniGe
- After integration, LLS will be tested in a controlled environment (temp, dew point, no light).
  - Thermal cycles with diphasic CO_2 plant MARTA: 300W cooling power @-30°C.
  - Electrical tests: current/voltage curve, module readout, …

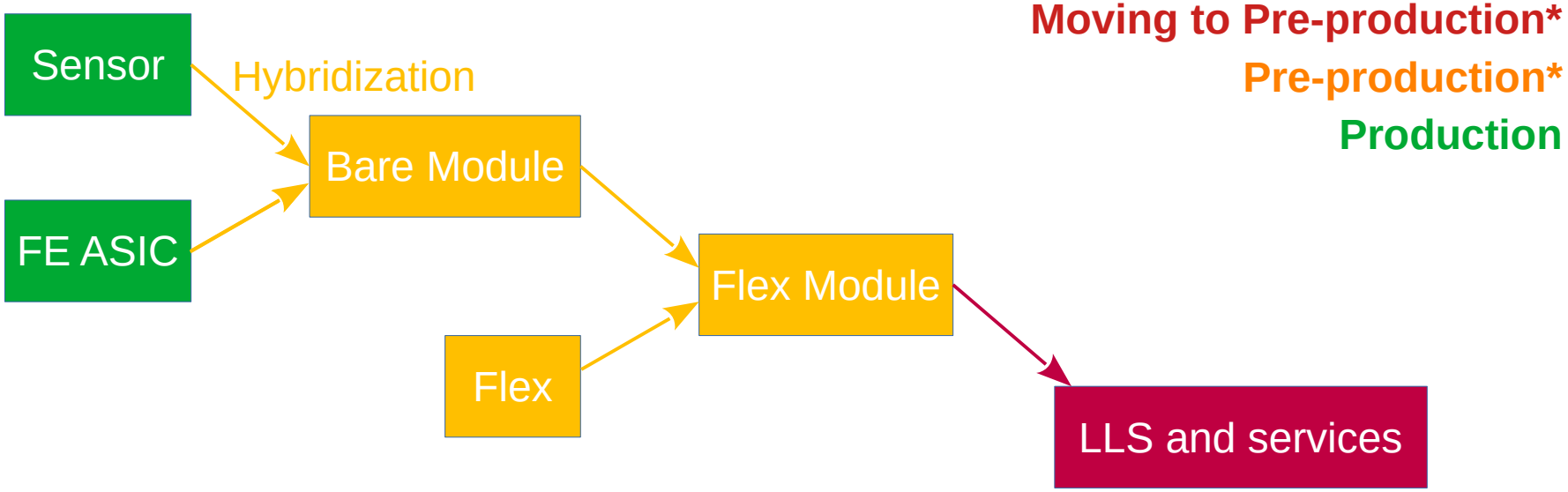


Quality control of loaded local supports

- Automatic interlock system to ensure safe operation for users and equipment.
- Human-machine interface for controling and monitoring (Node-RED + Grafana).
- Environmental data stored on local InfluxDB.



- ITk is a very challenging project and is crucial for successful Physics runs of ATLAS at HL-LHC.
- France institutes have a **primary role** in the design and construction of several key components of the ITk-Pixels Outer Barrel.
- **Coordination** among different parts of the project is essential.



*Pre-production = 10% required for installation