Construction the ITK IJC of ATLAS experiment for Phase 2 Upgrade

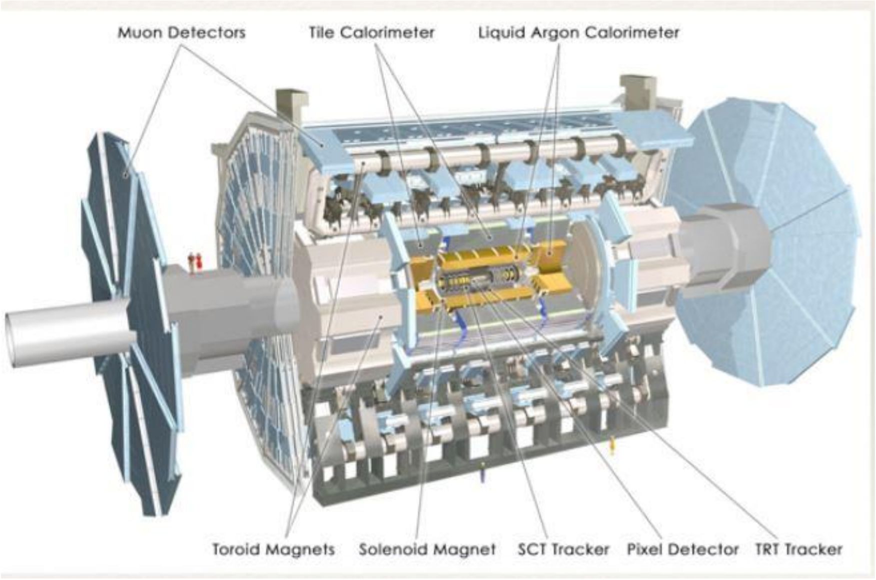
Abdenour Lounis

Outline

- Context of the Tracker Upgrade project
- The French Cluster contribution
- Infrastructure and equipments for Module production
- Calendar and Milestone
- Conclusions

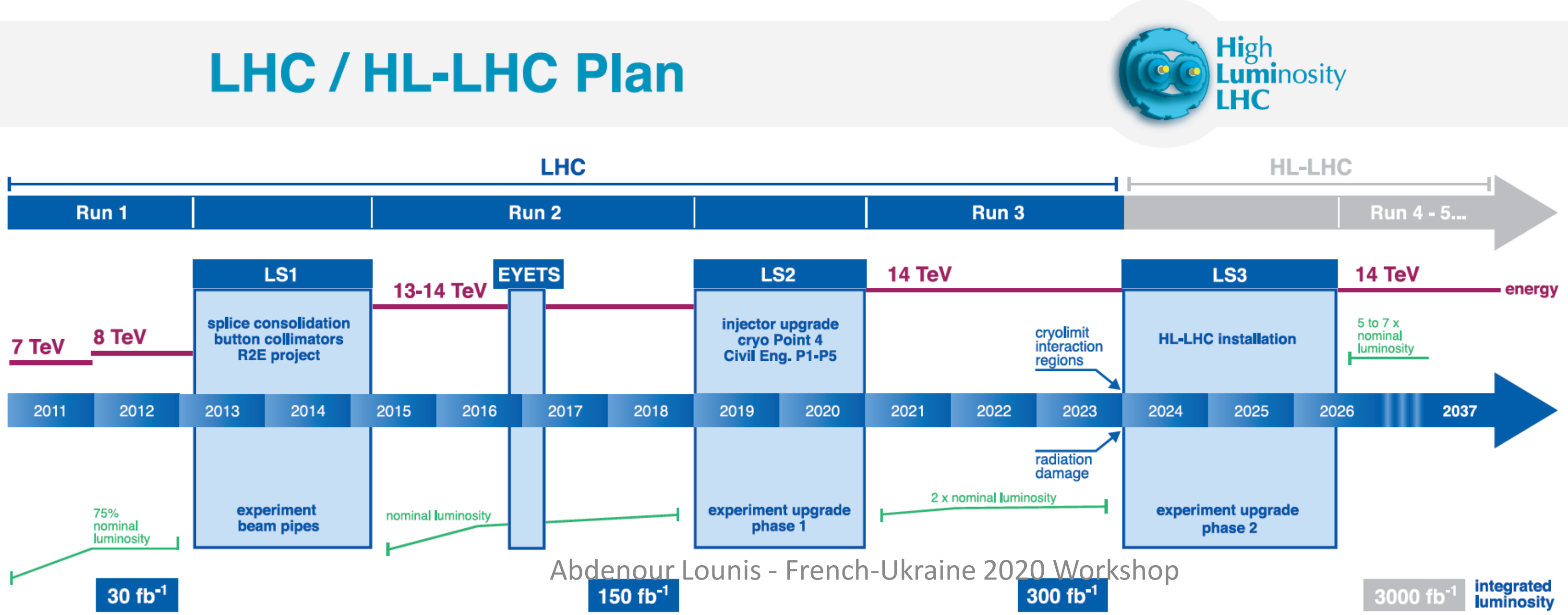
ATLAS Introduction

- Atlas Detector
  - 3 tracking detectors with Large number of channels (Pixels, semi-conductor tracker and Transition Radiation Tracker with particle discrimination capability).
  - 4 sampling calorimeter covering different regions(EM: Lead/liquid Argon; Tile Hadronic: iron/scintillators, Hadronic End caps : copper /liquid argon, Forward: cooper/tungsten/liquid argon)
  - Solenoid and toroid magnetics for charge and momentum measurements
  - 4 muon detectors with complementary measuring and triggering capabilities
  - Forward detectors
- Atlas view



Towards the upgrade

- The High Luminosity upgrade of the Large Hadron Collider (LHC) (HL-LHC) is currently expected to begin operations in the second half of 2026, with a nominal levelled instantaneous luminosity of $\mathcal{L} = 5\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ corresponding to an average μ, of roughly 140 inelastic pp collisions each beam-crossing, and delivering an integrated luminosity of around 250 fb^{-1} per year of operation.
- The ATLAS collaboration corresponding Phase-II up-grade of the detector, intended to take full advantage of the accelerator upgrade to achieve an ultimate luminosity of $\mathcal{L} = 7.5\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ corresponding an average μ=200 inelastic pp collisions per beam-crossing. This programme aims to provide a total integrated luminosity of 3000 fb^{-1} by 2035.



The detector upgrade to achieve physics objectives

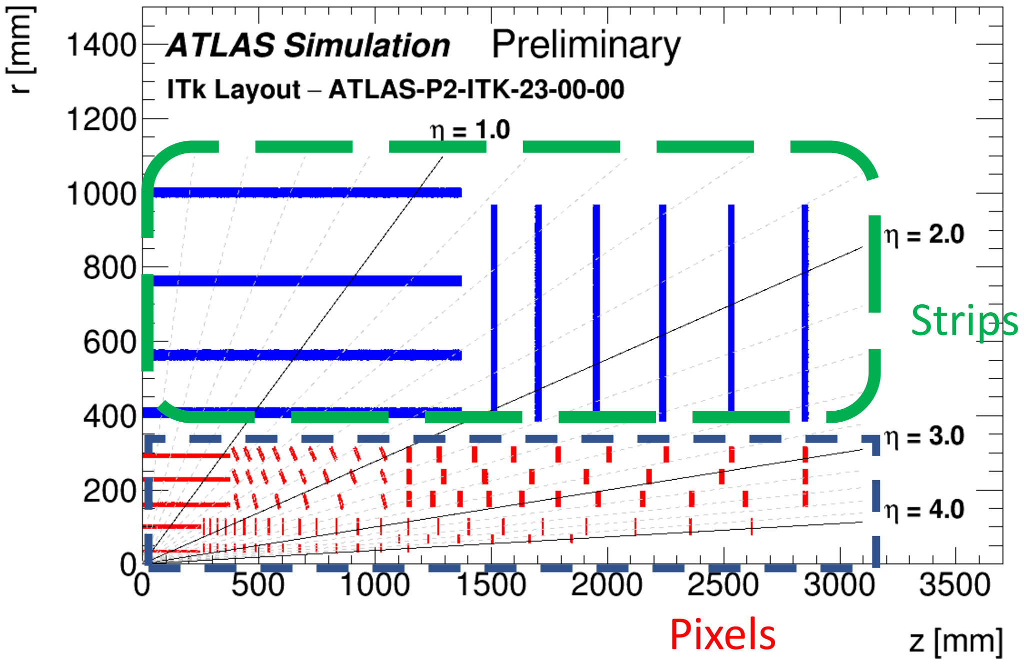
- LHC energy nominal limit (14 TeV).
- Precision measurements of the Higgs Boson properties at HL-LHC will be performed through all accessible production processes
- Complexity of the events is even larger : challenge, in particular for the inner detectors (radiation X10) and triggering.
- Some detectors won't survive the particle flu if no upgrade
- Experience with present detector helps to define main concerns in upgrade.

Detector system	Trigger–DAQ		Inner Tracker	Inner Tracker + Muon Spectrometer	Inner Tracker + Calorimeter		
Physics Process \ Object Performance	Efficiency/ Thresholds $\mu^{\pm}$	$e^{\pm}$	b-tagging	$\mu^{\pm}$ Identification/ Resolution	Pile-up rejection	Jets	E_T^{miss}
$H \longrightarrow 4\mu$	✓			✓			
VBF $H \to ZZ^{(*)} \to \ell\ell\ell\ell$	✓	✓		✓	✓	✓	
VBF $H \to WW^{(*)} \to \ell\nu\ell\nu$	✓	✓	✓	✓	✓	✓	✓
SM VBS ssWW	✓	✓		✓	✓	✓	✓
SUSY, $\chi_1^{\pm}\chi_2^{0} \to \ell b\bar{b} + X$	✓	✓	✓	✓	✓	✓	✓
BSM $HH \to b\bar{b}b\bar{b}$			✓			✓	

Overview of the physics analyses foreseen, and of the associated ATLAS sub-systems whose upgrades may impact the physics object performance

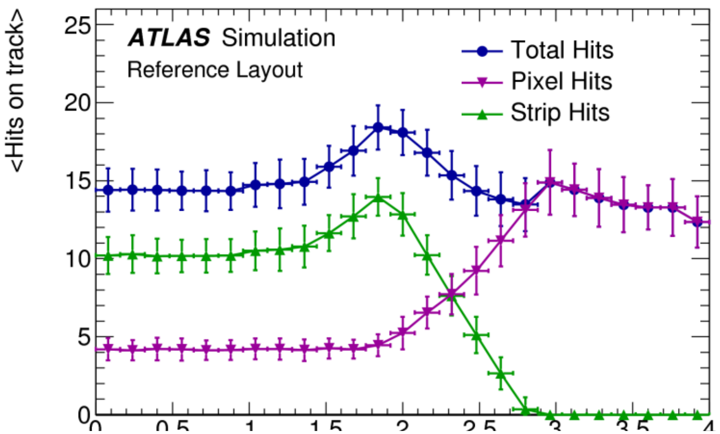
Focus on ITK

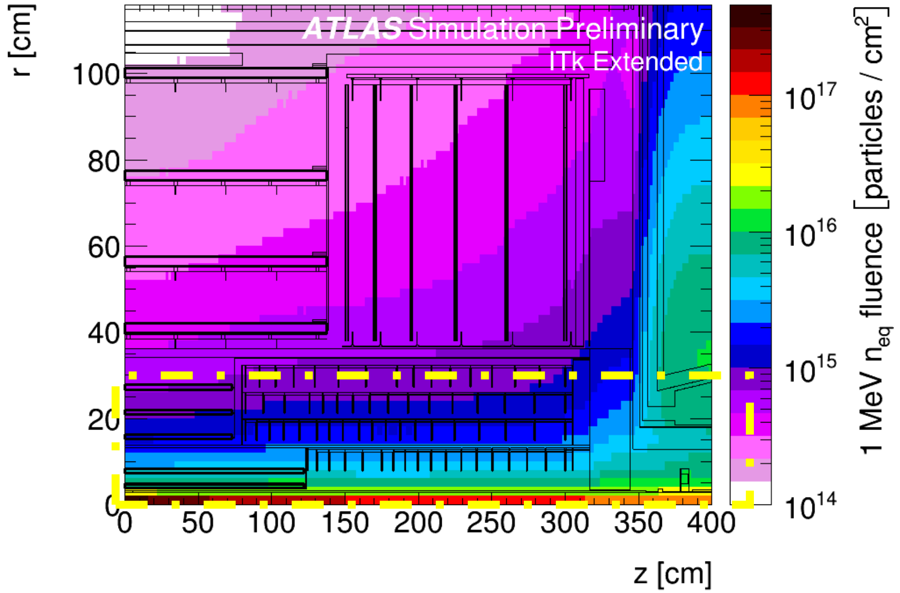
ATLAS Inner Detector will be replaced by Inner Tracker (ITk)
•ITk consists of silicon strip (outside) and pixel sensors (inside)
•One layer of 3D pixel sensors surrounded by layers of planar sensors
•Planar thickness:100μm in layer 1 and 150μm in layers 2-4
•Planar pixel size:50×50μm2 ; (25×100μm2_ Layer 0)



Internal Tracker

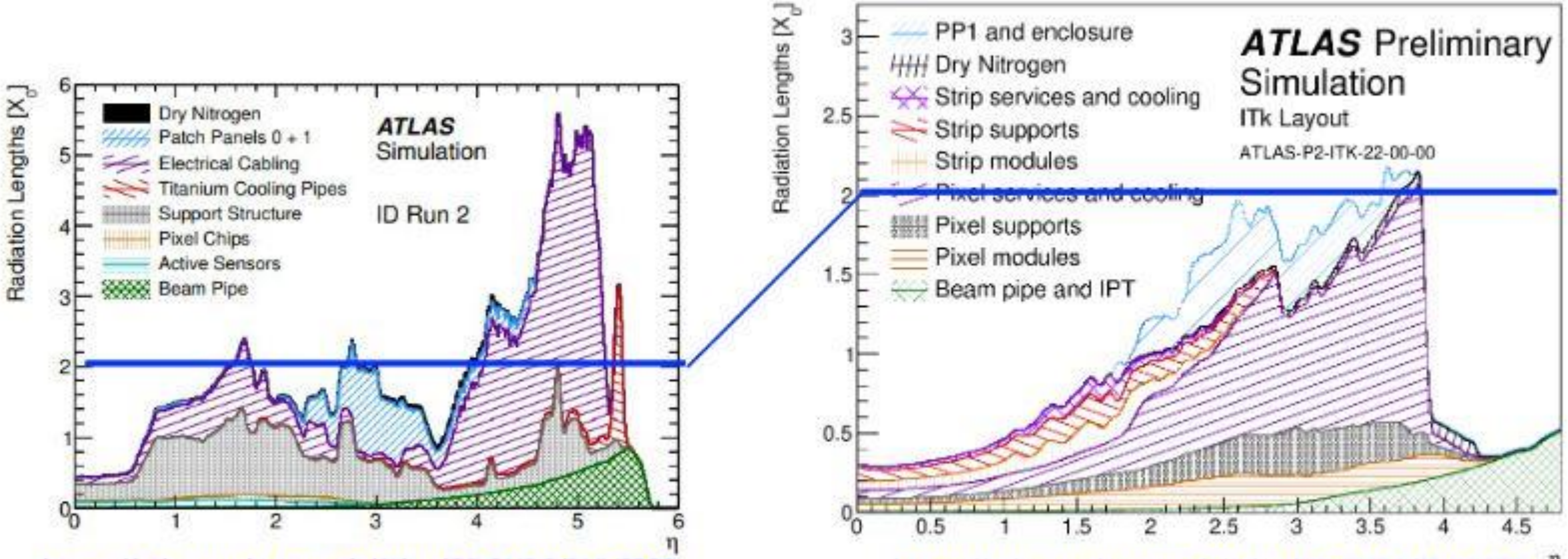
- *Hits in the tracker ~15 Hits*





Radiation fluences

Material Budget optimization

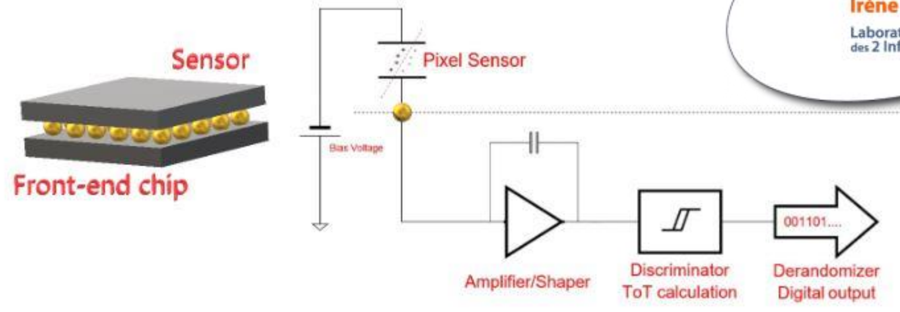


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/UPGRADE/CERN-LHCC-2017-021/

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2019-001/

Pixel Modules details (Outer Barrel)

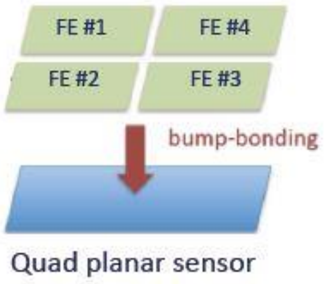
The working principle

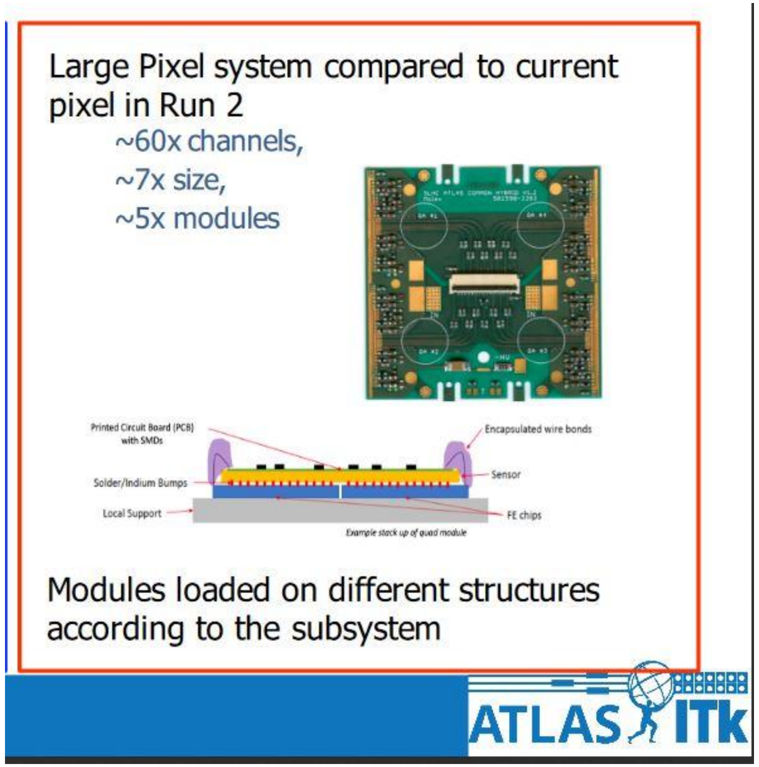


- Geometry & configuration

150 µm thick Si sensor for the outer barrel of approximate dimensions 4x4 cm^2

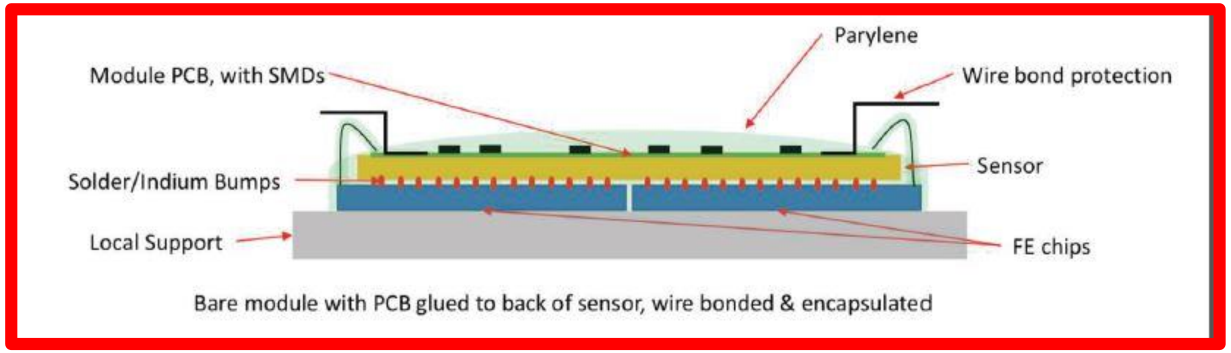
- Planar pixel pitch: 50x50 μm^2
- ITk pixel readout chip is foreseen to be 20x19.2 mm^2 relative to a matrix of 400 columns x 384 rows
- Planar sensors will be produced in a size compatible with 4-chip (quad)

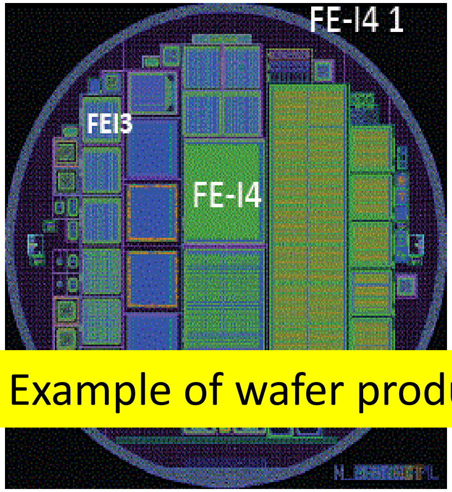


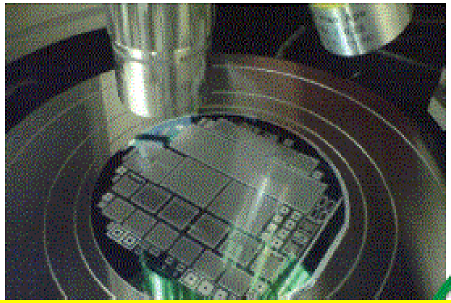


Components	Materia Budget X0
Front-end Chip, 150 um thick	0.19
Sensor, 150 um thick	0.17
Bumps	0.03
Module Flex	0.27
Flex adhesive	0.01
Total	0.67

Zoom on module

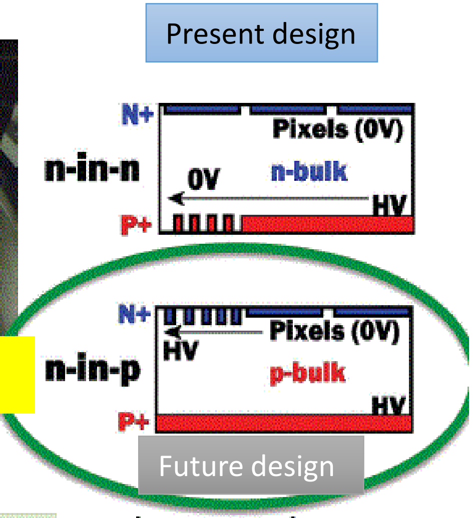




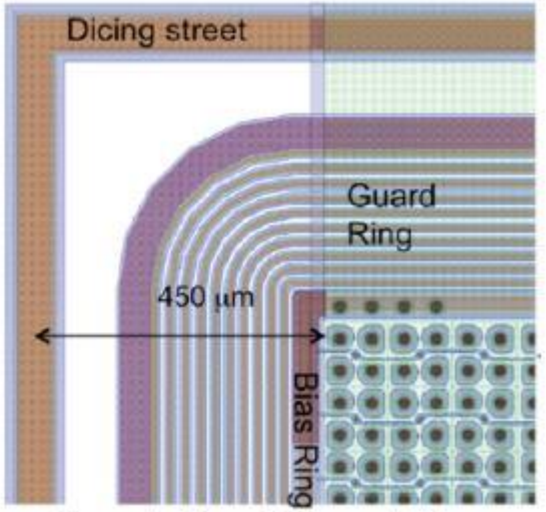


Example of wafer production

See: ATL-UPGRADE-PUB-2010-001; Nucl.Instrum.Meth. A730 (2013) 215



Cheaper and more rad-hard than n-in-n; 13

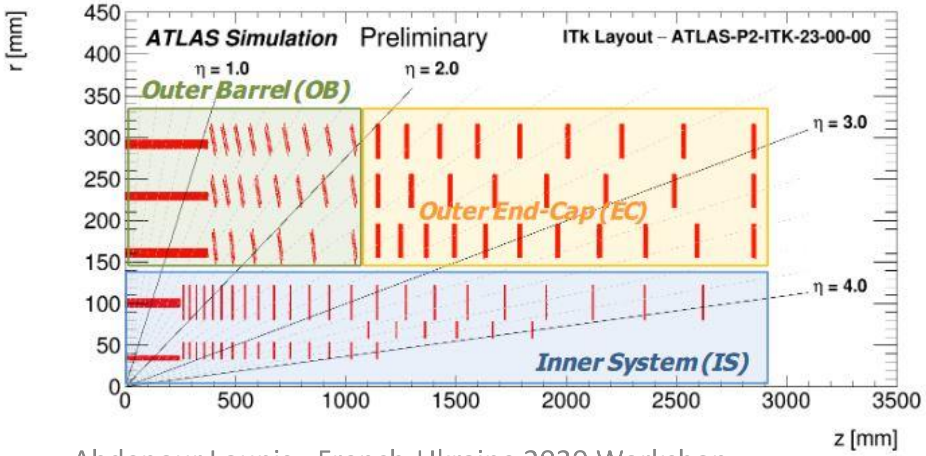


Example for a 150 µm thick sensor

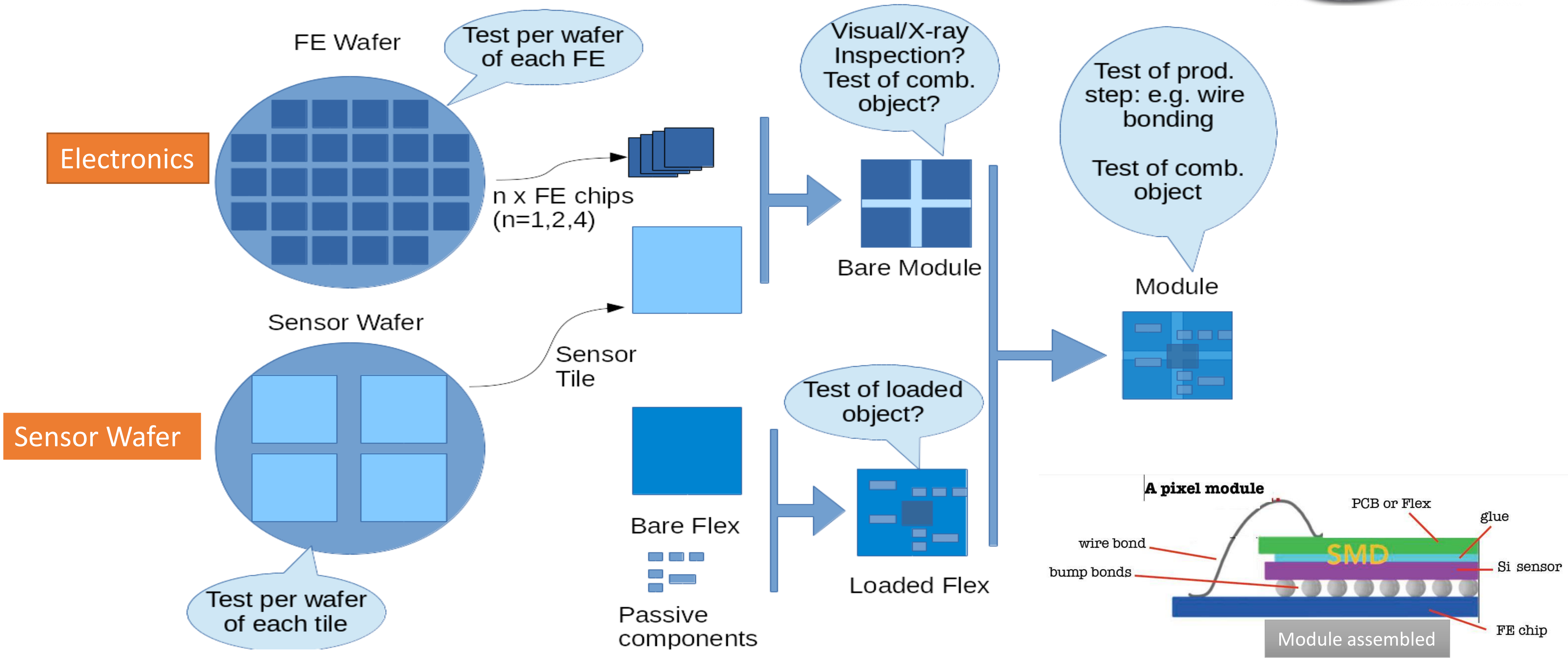
The Cluster Ile de France

- Joigned effort of three Laboratories
  - LPNHE (Université Pierre et Marie-Curie)
  - IJC Lab (Université Paris Saclay)
  - CEA-IRFU Saclay

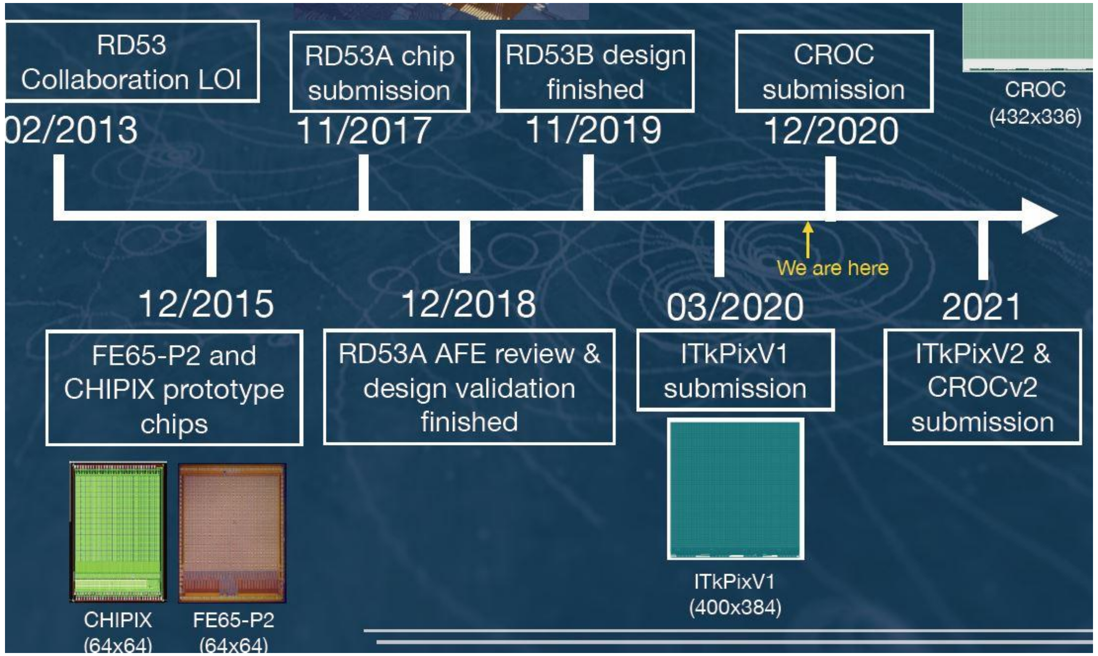
- Overall commitment to contribute to 33% of the ITK outer barrel Pixel Construction

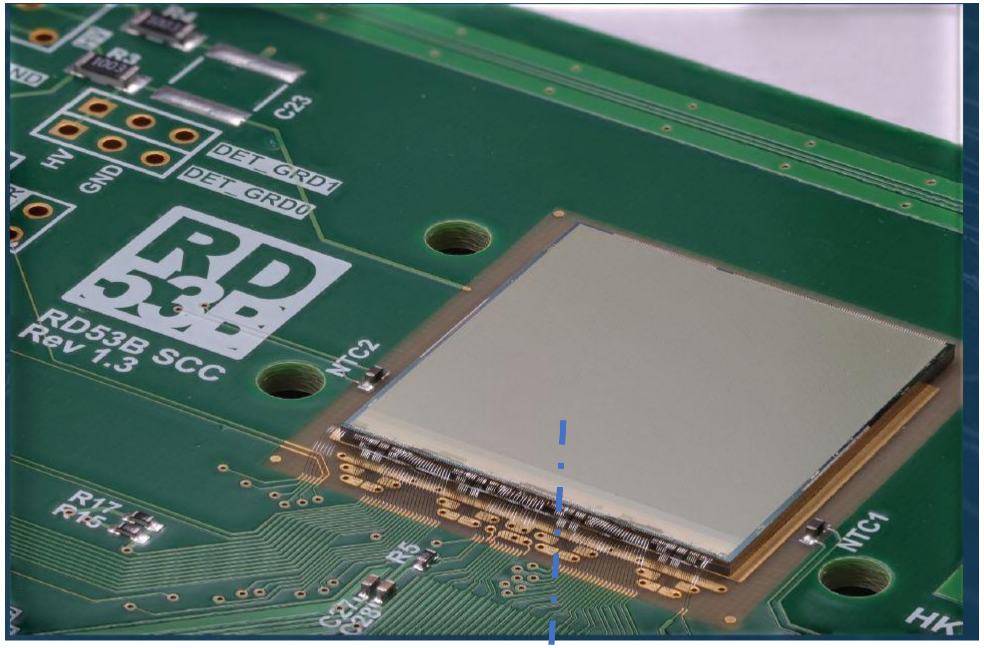


Overall strategy for Module Production



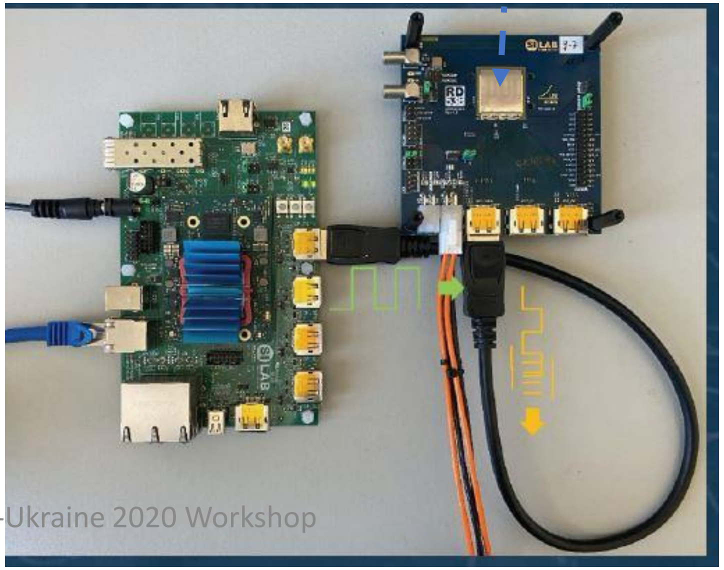
ATLAS Readout Chip developments (LPNHE & IJC are member of RD53 Collaboration)





ITKpixV1 properties

	RD53	Current Pixel
Chip Size	2x2 cm^2	2x2cm^2
Pixel Size	50x50 μm^2	50x250 μm^2
Pixel Hit Rate	3 GHz/cm^2	400 MHz/cm^2
Trigger rate	4/1 MHz	100 kHz
Trigger Latency	12.8 µs/51.2 µs	6.4 µs
Current consumption	<8 µA/pixel	20 µA/pixel
Radiation Tolerance	0.5 Grad	300 Mrad
Min. stable Threshold	600 e	1500 e



Quality Control & Assurance tasks

QC

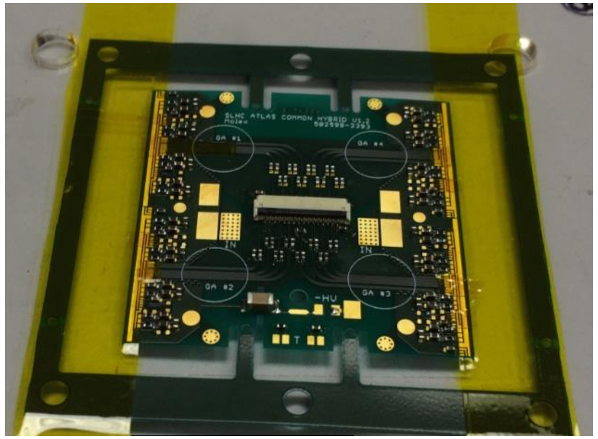
- QC aims at identifying defects in the finished sensor
- Its goal is to identifying and discard faulty sensors
- It is a reactive process
- Tests are made as much as possible on the final product

QA

- QA aims at preventing defects on the production process
- Its goal is to assure that the fault does not happen
- It’s a proactive process
- Tests can be made on other structures

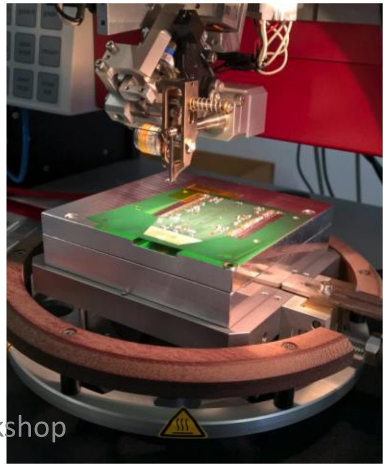
Working operation steps to follow

Planned Quality Control during production



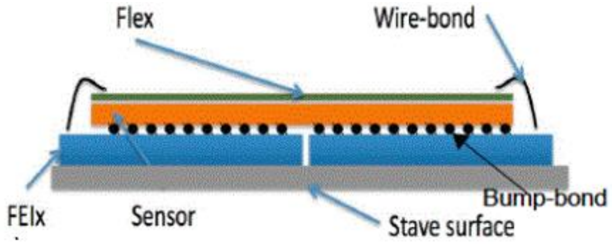
Tests are divided into Quality Control (QC) tests which are applied to all modules or their components and Quality Assurance (QA) tests, i.e. tests which are done on a subset of modules or their components.

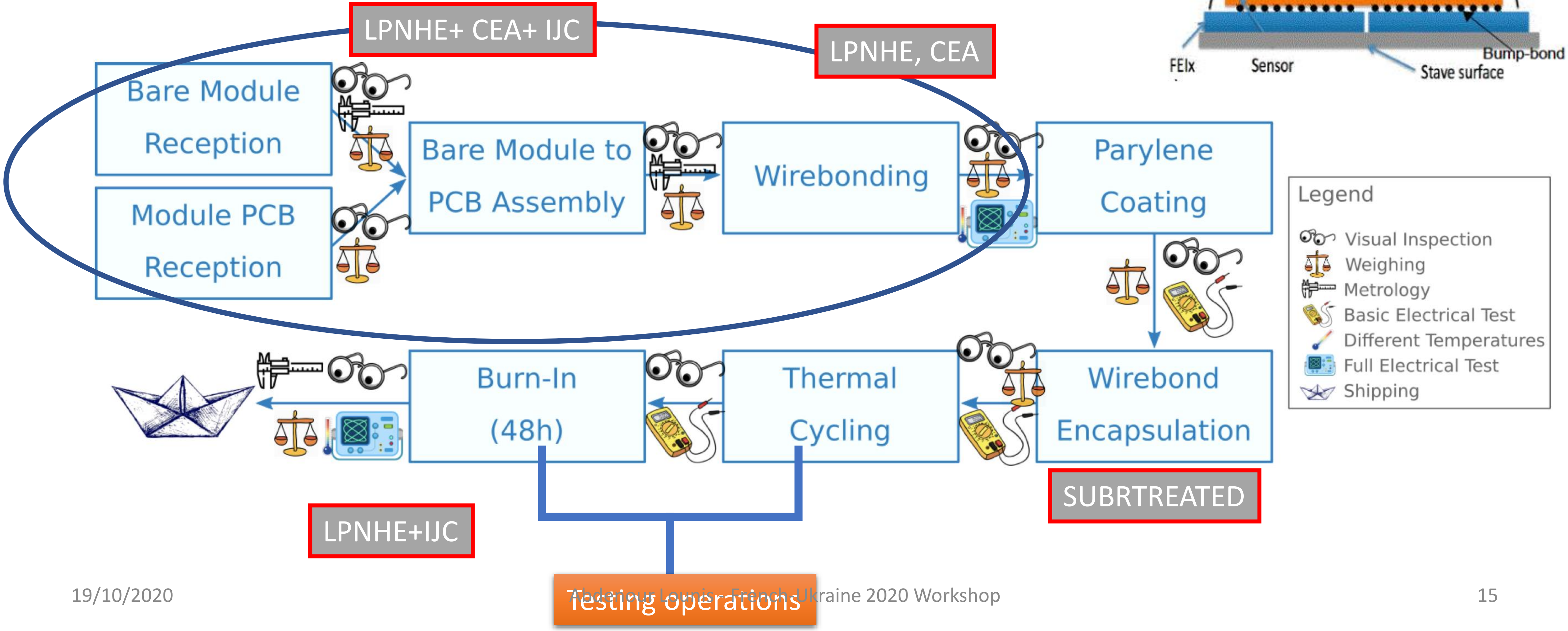
- Bare module reception tests (QC)
- Module flex reception tests (QC)
- ❖ Quality assurance tests to module flex (QA)
- Mass measurements and inspection of the fully assembled modules (QC)
- Wire bond pull testing (QC)
- Initial module tests (QC)
- Long term module tests (QC)
- ❖ Module tests beyond its operating range and destructive tests (QA)

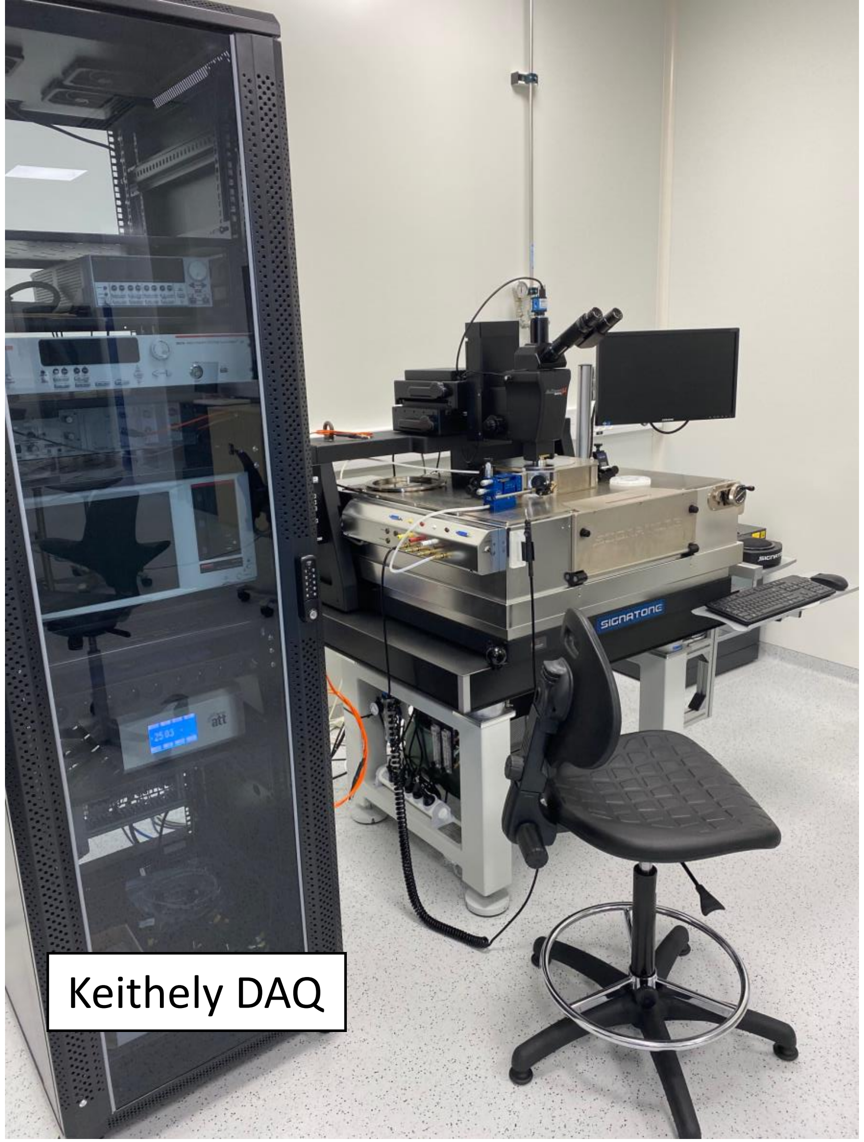


Module Quality Control/Qualitly Assurance- Organization in French Cluster

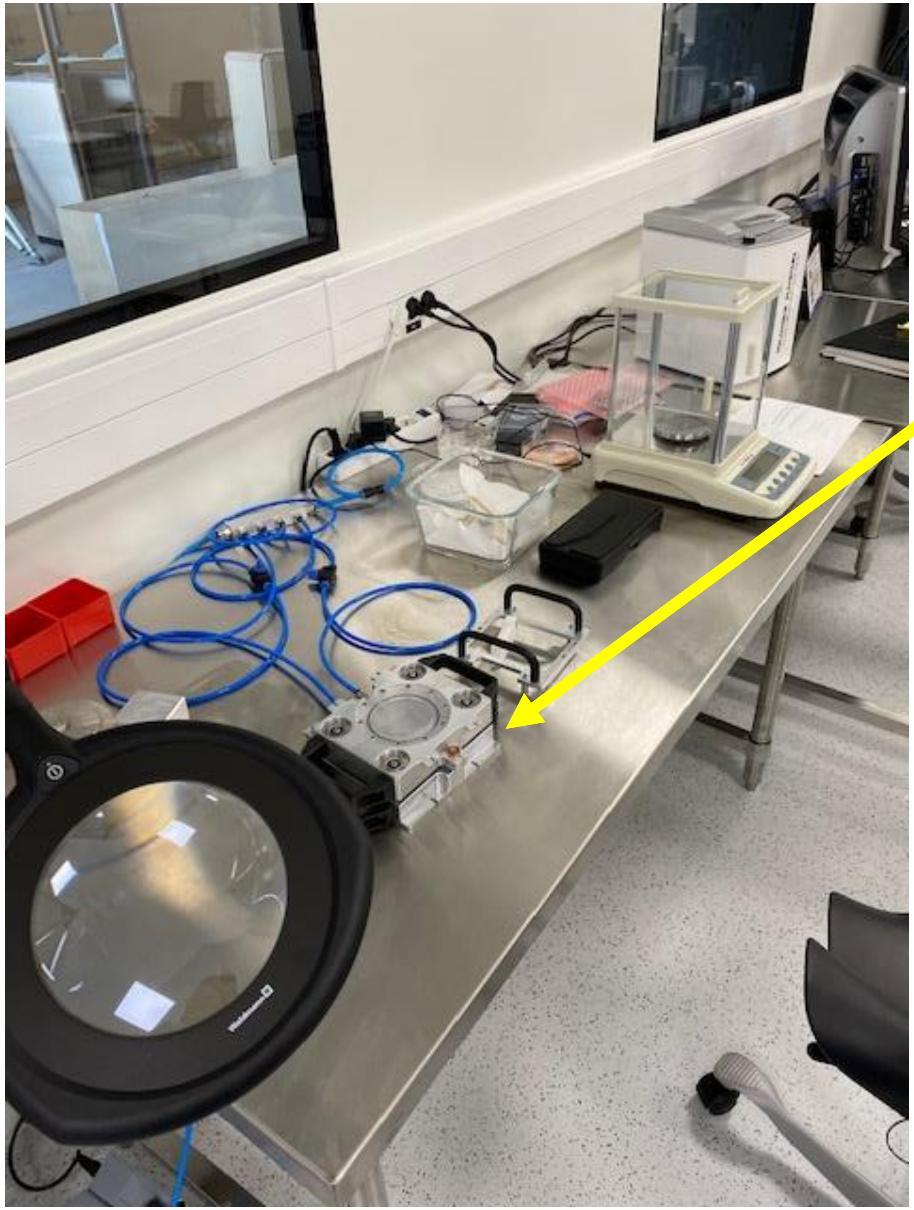
- Sequences for Module QA/QC operations



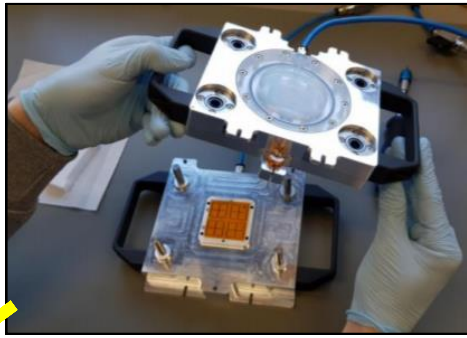


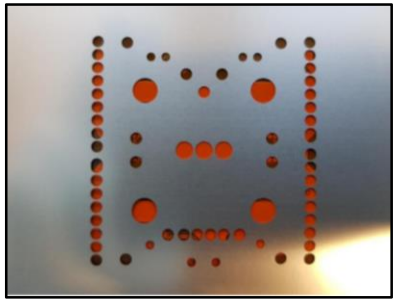


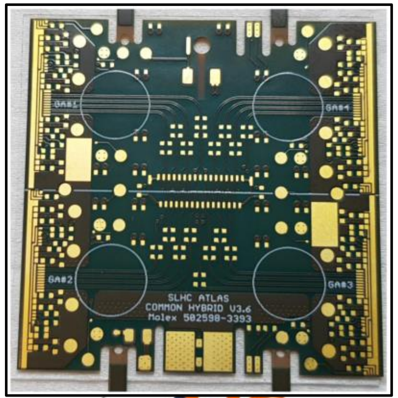
Sensor –wafers and ASIC probing and testing



Gluing and module assembly Setup



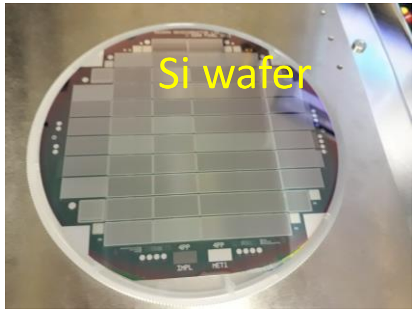


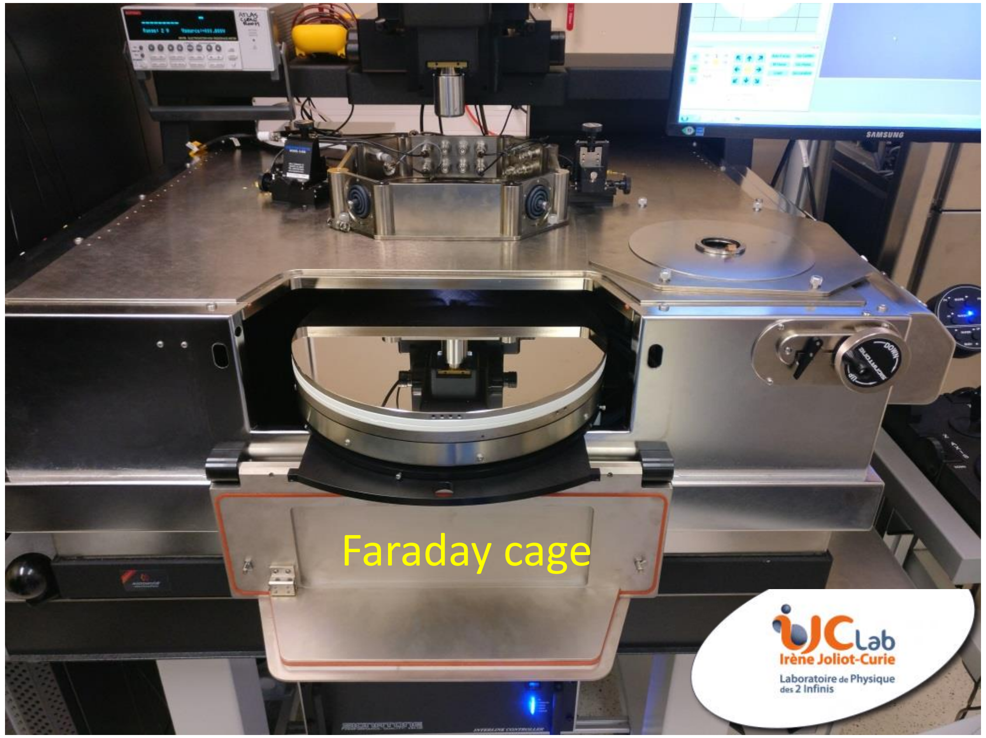


Sensor Probing as an initial step

- Powerfull probestations available

(Captinnov Plateform) and LPNHE Clean room

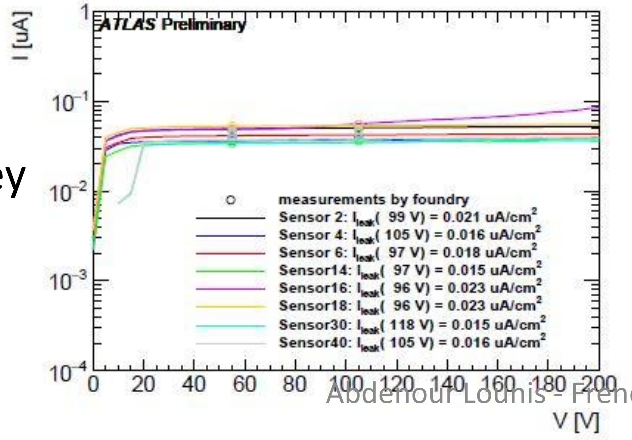


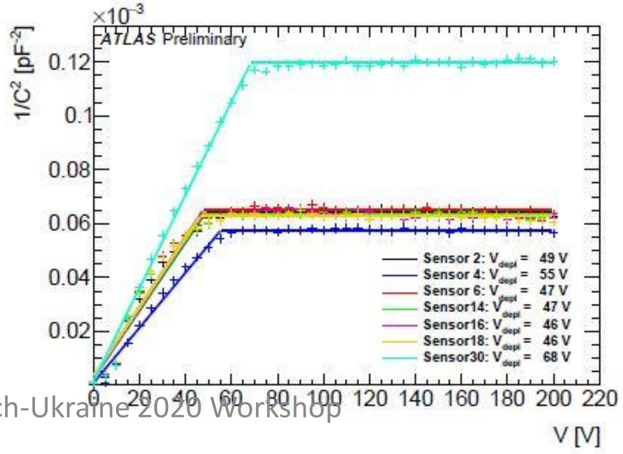


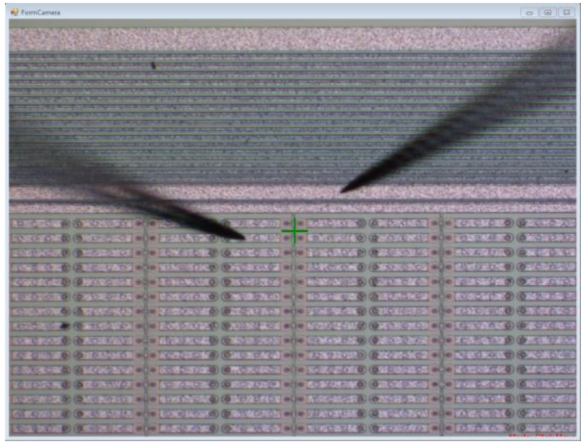
- Depletion voltage V_{dep} < 100 V
(for 150 μm sensors) measured at 1 kHz
- Leakage current I_{leak} < 0.75 μA/cm^2 at $V_{dep} \sim 50$ V
- Variation of leakage current
ΔI_{leak} ~ 25% measured over 48 h

- Breakdown voltage : $V_{break} > V_{dep}$+70 V

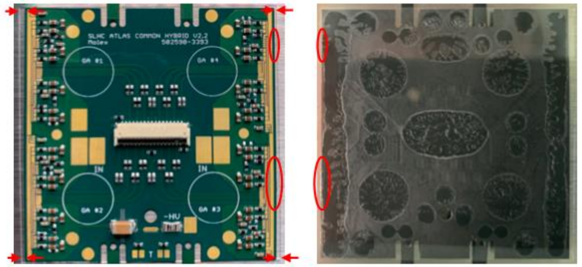
Data from Pixel Market survey



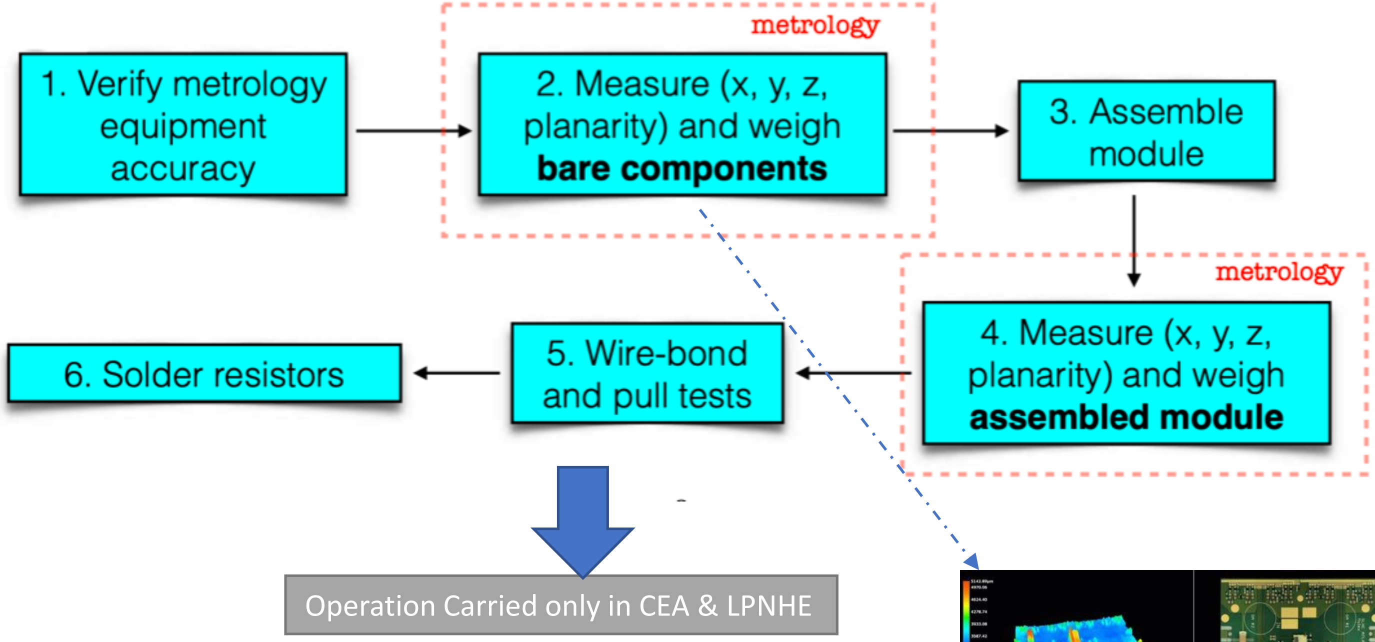


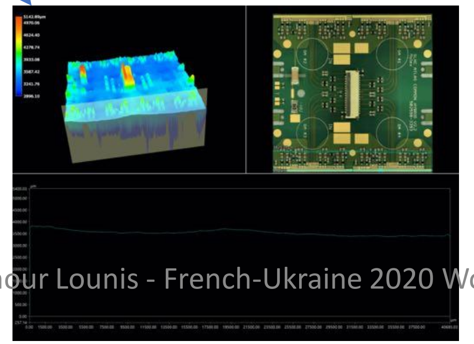


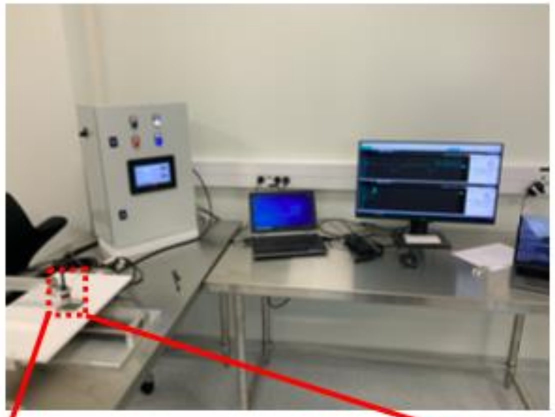
Contribution to module Assembly & QA/QC

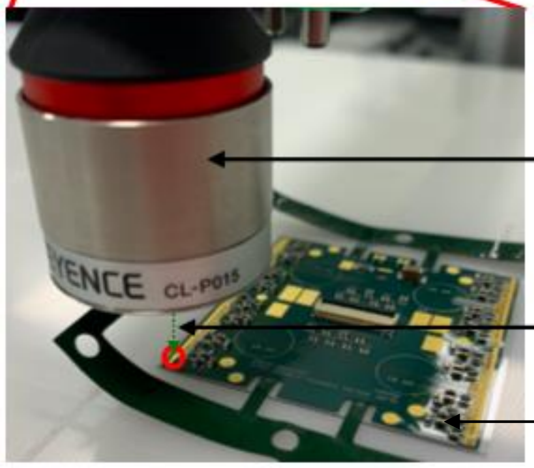


- Project carried inside the ITK Paris-Cluster (LPNHE-CEA-IRFU, IJCLab)







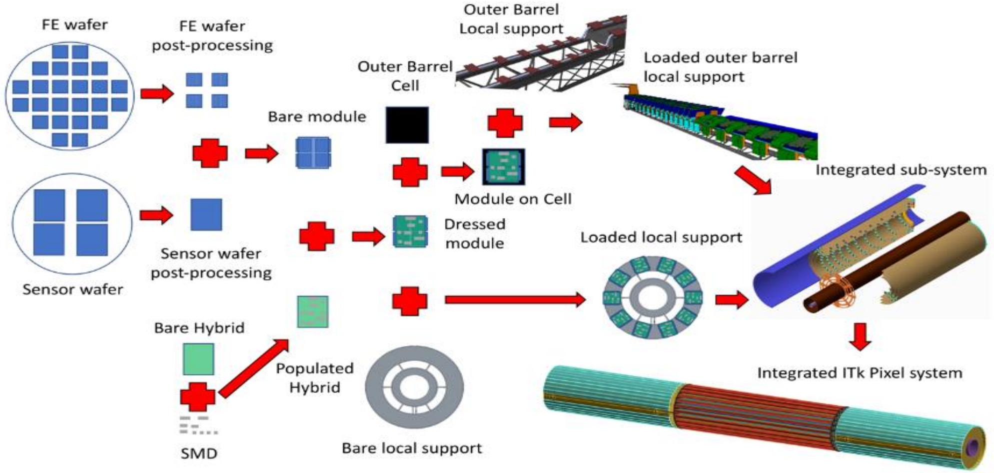


Database needed to share and retreive the full Production

All QC measurements; QC visual inspections, sensor bow, thickness, electrical tests

Module Id - Production testing/step -

Module ID	**Production Testing/step**	**Operator**	**Data**
Date & Time	Cluster Name	Institute name	DB Link



❖ <u>Photographic Documentation for module production:</u>

Modules should be imaged before and after each production testing step

(# 20 pictures/module according to QC recommendations);

Infrastructure and equipment for silicon module developments and production

Important Information

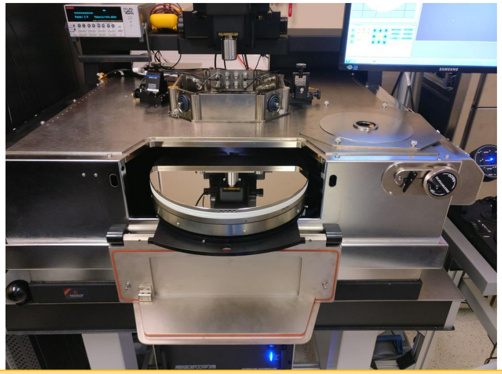
In Februray 2020
The ISO7 CAPTINNOV
Clean Room has been delivered
CPER-IJC Lab (Contrat Plan Etat Region)

*2 more clean rooms in LPNHE and CEA-IRFU

Overview of the actual infrastructure @IJC Lab

- Equipments state of the art

Tool for wafer and sensor Testing



Probe Station
Budget ~ 300 K€
(From Labex P2IO & SESAME Ile de France)
- HV Chuck*
- Compressor*

Module and Asic temp Cycling

Climate Chamber

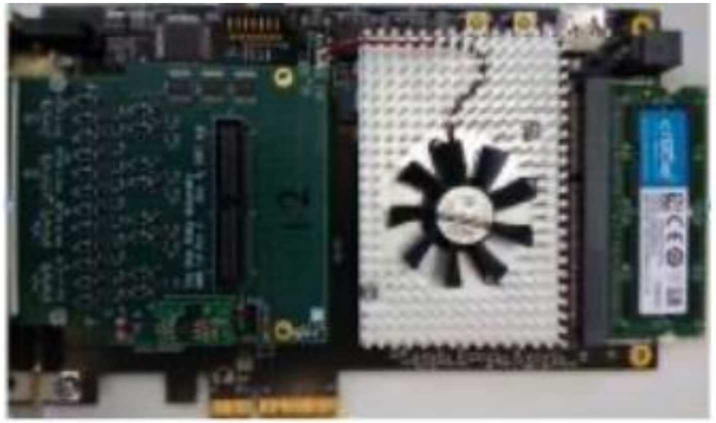
Tool for Visual Inspection

High resolution Microscope
KEYENCE VHX-7000

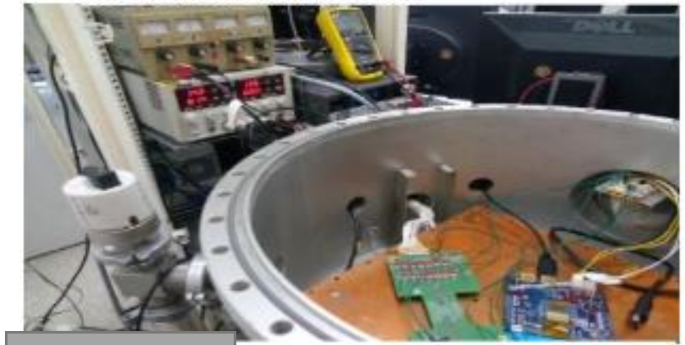
Test benchs for module testing and to radiation monitoring Electronics :

- Test benches for
  - Readout Chip ITKpixv1 (RD53) : BDAQ & YARR
  - Ring Oscillator & Systems

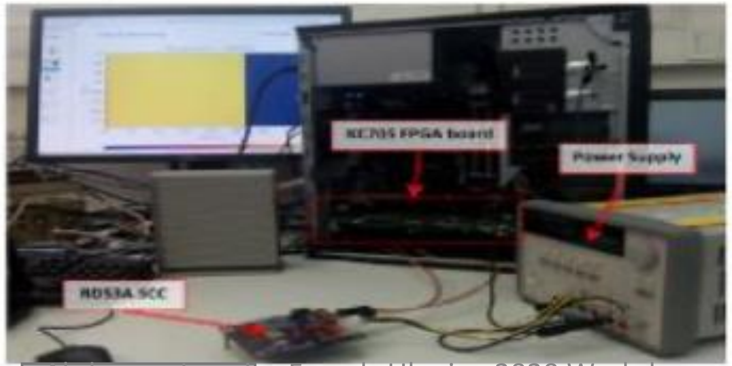
SETUP 1 : climate chamber with RD53A SCC inside.



PC-Board Xpressk7 board for data acquisition.



SETUP Open ROMIC (green chip) and RD53A (blue chip) inside the climate



ATLAS DAQ : BDAQ and RD53A

Ring Oscillator : Chip to monitor the Radiation dose

Designer : Maurice Cohen-Solal

- Embedded in ITKpixV1
- Performs mesurement of frequency Variations as function of Temperature, Radiation and charge particle radiation exposure,
- Can Provide a feedback correction loop for ITKpixV1 working voltages

Calendar and Milestone

Schedule

<u>Now - end of Nov. 2020</u>: Assemble and test ~10 quad modules

- Including , IV/CV/It probing of bare modules will be necessary before the assembly.

- <u>January 2021 - October 2021</u>: Sensors pre-production

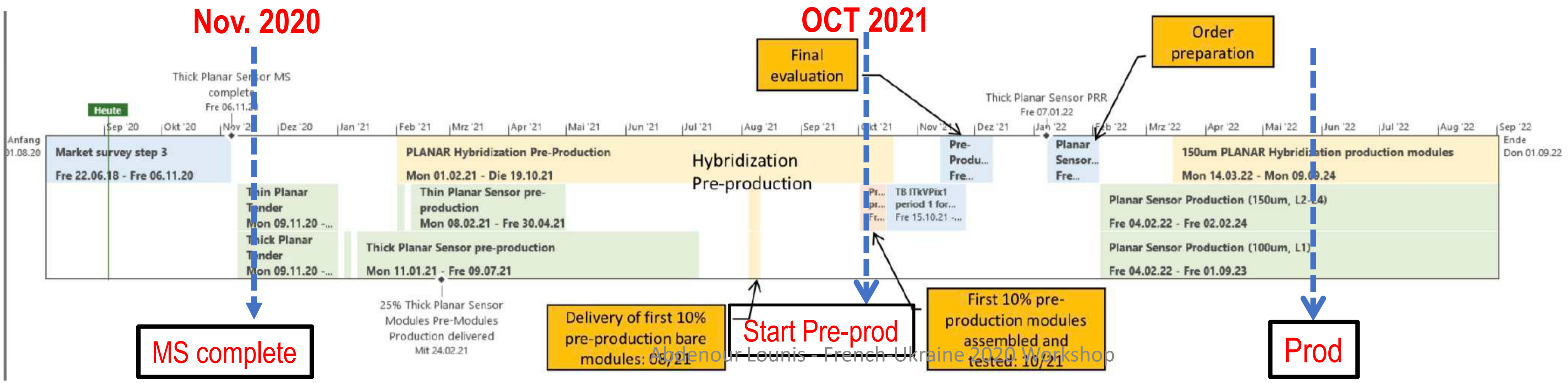
- Around 200 sensors allocated to Paris cluster. A good fraction of these will have to be tested using probe stations **(LPNHE + IJC)**

- <u>October 2021 - May 2022 : Modules pre-production</u>

- Paris cluster will have to assembly and qualify/test around **200 modules**

- <u>June 2022 - ~2024-2025 : Modules Production</u>

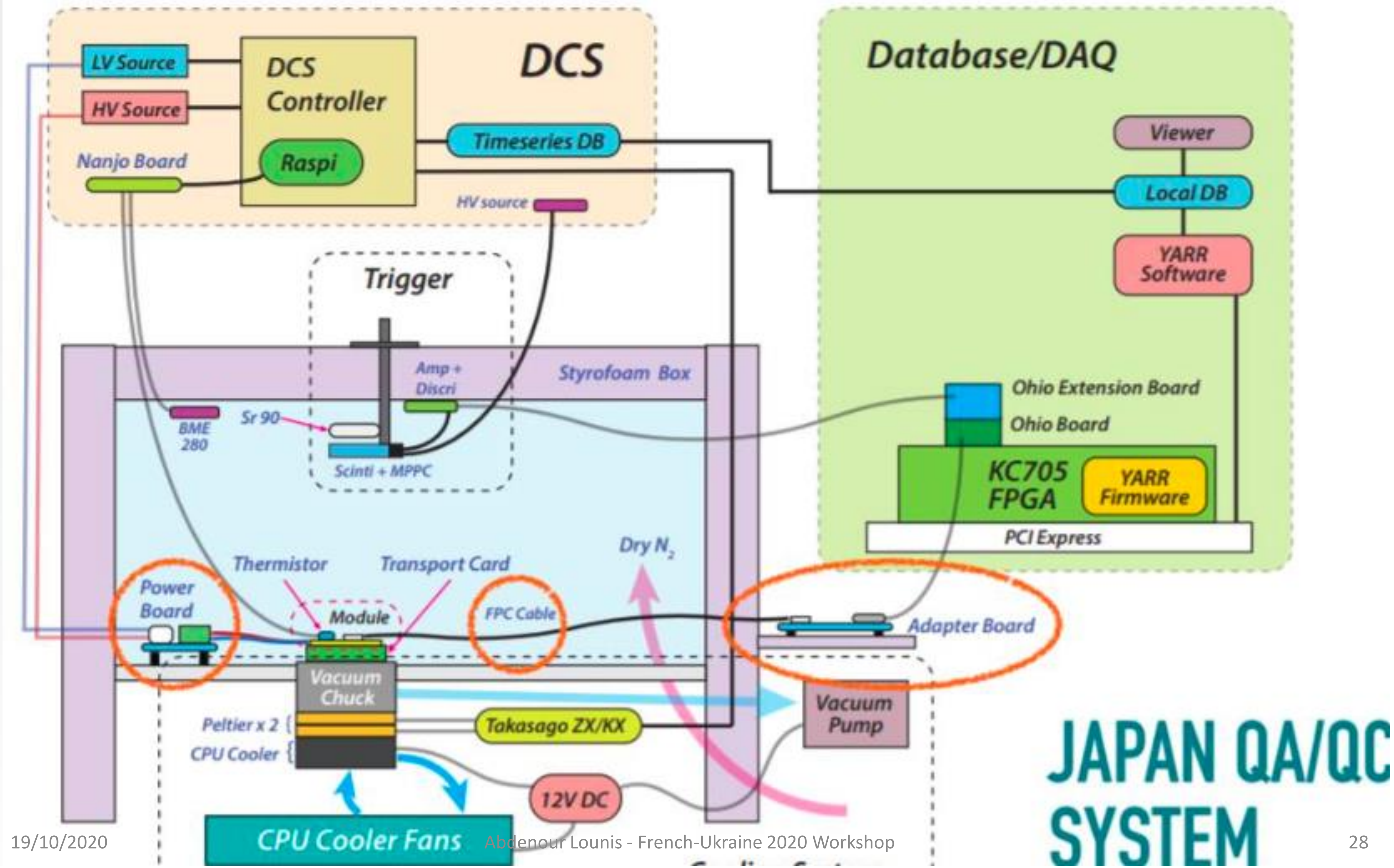
- Paris cluster will have to assembly and qualify around **2000 modules**



Conclusions

- The ATLAS French Cluster is committed in a very challenging detector construction program for HL-LHC program,
- High expertise in building complex systems of silicon Tracker will be acquired,
- A unique opportunity is given by such program to built in house a state of the art modern technological infrastructure “Si Lab”
- A beneficial valuable is gained through the close partnership within IN2P3 Labs and CEA-IRFU (exchange of expertise, open cooperation, sharing the efforts) to win this challenge.

End


DCS
LV Source
HV Source
DCS Controller
Raspi
Nanjo Board
Timeseries DB
HV source
Database/DAQ
Viewer
Local DB
YARR Software
Trigger
Styrofoam Box
Amp + Discri
Sr 90
BME 280
Scinti + MPPC
Ohio Extension Board
Ohio Board
KC705 FPGA
YARR Firmware
PCI Express
Dry N_2
Thermistor
Transport Card
Power Board
Module
FPC Cable
Adapter Board
Vacuum Chuck
Vacuum Pump
Peltier x 2
CPU Cooler
Takasago ZX/KX
12V DC
CPU Cooler Fans
JAPAN QA/QC SYSTEM