LAL KEK Tsukuba HEP

2019 Joint workshop of FKPPL and TYL/FJPPL

New project [D_RD_20]:

New challenge for Inner Pixel Tracker construction

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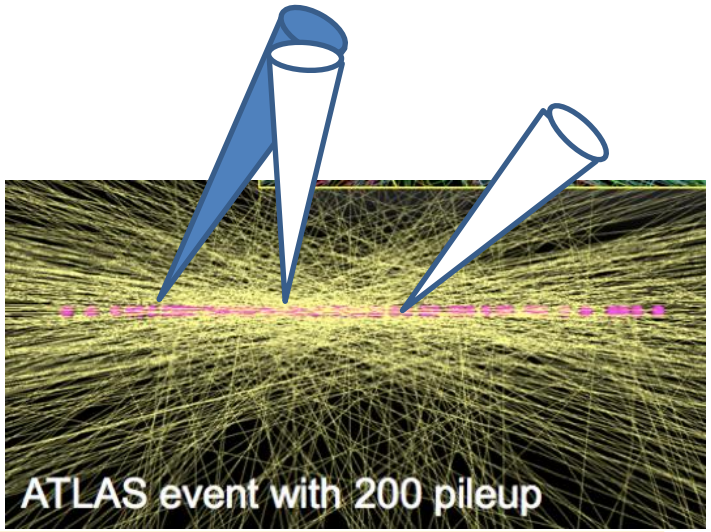
Framework : ATLAS Upgrade for HL-LHC

- **High Luminosity LHC (HL-LHC)**
  - Start around 2026- with new crab cavity in the interaction region.
  - Target : $\sqrt{s}$=14TeV L=5-7x10^{34}cm^{-2}s^{-1} $\int Ldt$=3000-4000fb^{-1}
  - Physics program focus on the precise measurements of the Higgs couplings (e.g. Y_τ, Y_b and λ_{HHH}) and BSM searches.
- **Tracking detector is key element**
  - To keep B/τ-tagging performance up to μ=200 pileup in an event.
  - Need to launch innovative solution for detectors, mechanics, efficient triggering and advanced analysis technics.

The ATLAS upgrade plans full replacement of Inner Tracker

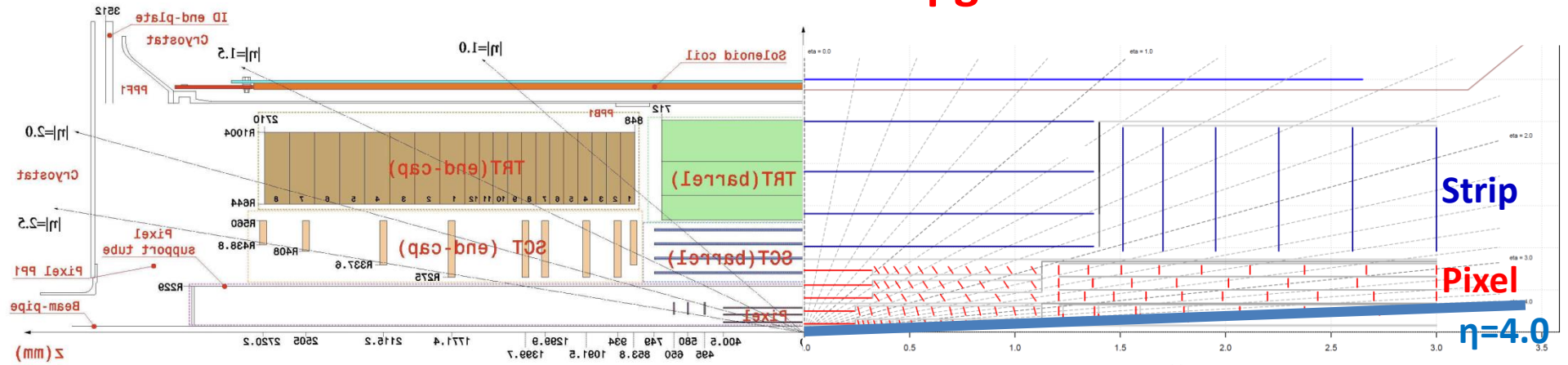
- All silicon tracker (Pixel & Microstrip)
- ***Requirements for Pixel detector***
  - Pixel Size : 50um x 50um (or 25um x 100um)
  - Radiation @ outer layer : 3x$10^{15}$$n_{eq}$/cm^2
  - Thickness : 100 or 150um
  - Low noise (<100e) → 600e stable threshold
  - High Readout Rate : 5.2Gbps (or 4x1.28Gbps)



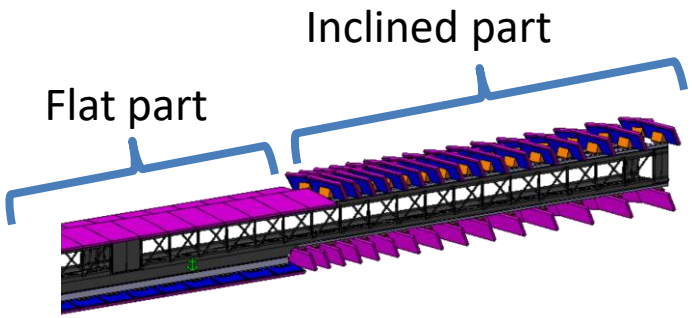
ATLAS inner tracker(ITK) project for HL-LHC

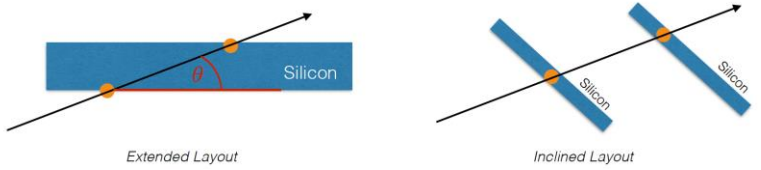
Current ATLAS Detector

ITK upgrade detector



- Larger coverage area
  - Pixel : current 2.7m^2 ➔**upgrade 8.2m^2**
  - Strip : current 34m^2 ➔upgrade 165m^2
- Higher Forward coverage
  - Current η<2.5 ➔ **upgrade η<4.0**
  - **Better Pileup removal**
- Mechanics : inclined
  - Reduce material
  - Higher tracking resolution.





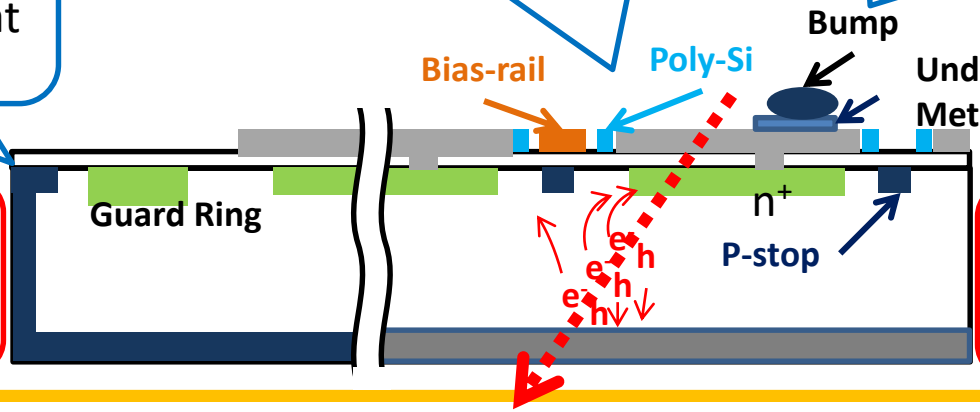
D_RD_15 program (2014-2018)

- ***Collaboration***
  - **Planar type Silicon Pixel detector R&D** for ATLAS detector upgrade in France-Japan collaboration
- ***Goals***
  - Performance : evaluate & improve sensor design for radiation tolerance up to $5x10^{15}n_{eq}/cm^2$ fluence.
  - Productions : work on common sensor productions

Biasing Structure
- Optimize Biasing structure
- Higher Efficiency at Pixel boundary

Bumpbonding
- Better UBM material
- Higher Flip-Chip Yield

Active Edge
- Smaller Edge size
- Higher Efficiency at Edge region

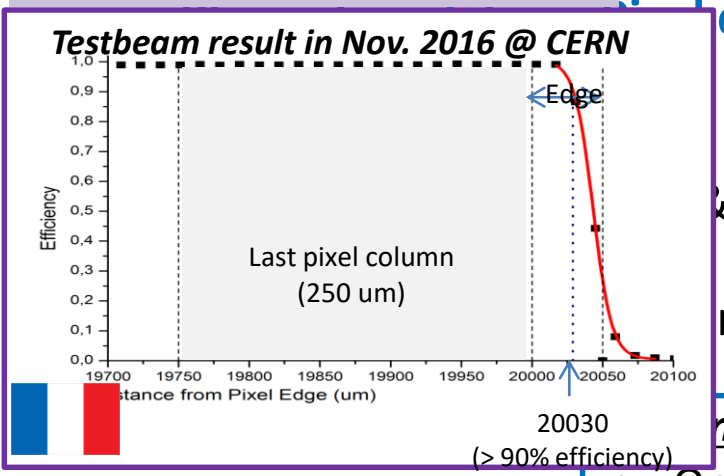


Simulation
- Doping concentration
- Charge collection

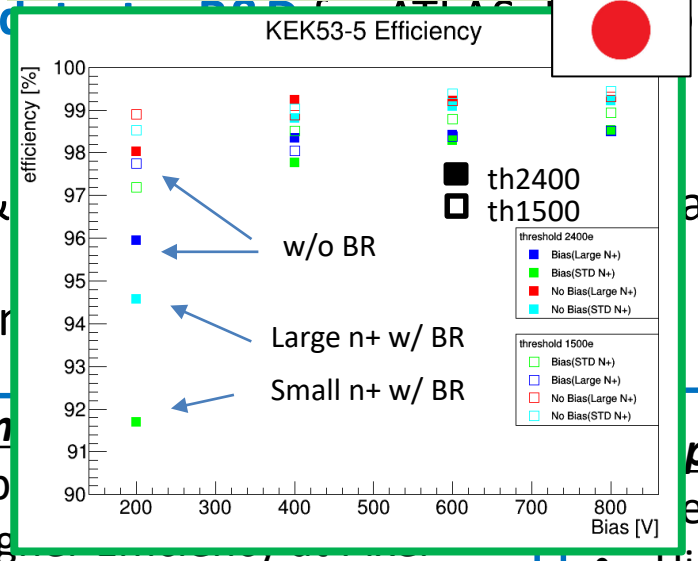
Radiation Tolerance
Assembly
Production…

D_RD_15 program (2014-2018)

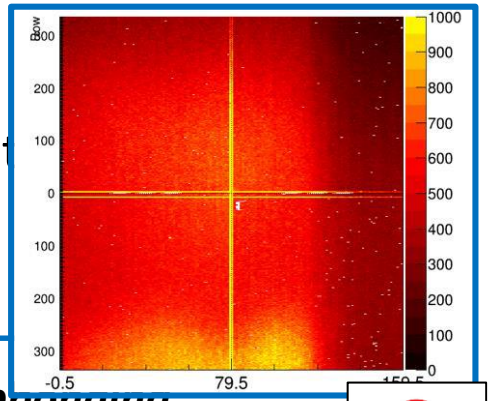
Higher Edge region Efficiency



>98% Efficiency after Irradiation



Good Bumpbond Yield

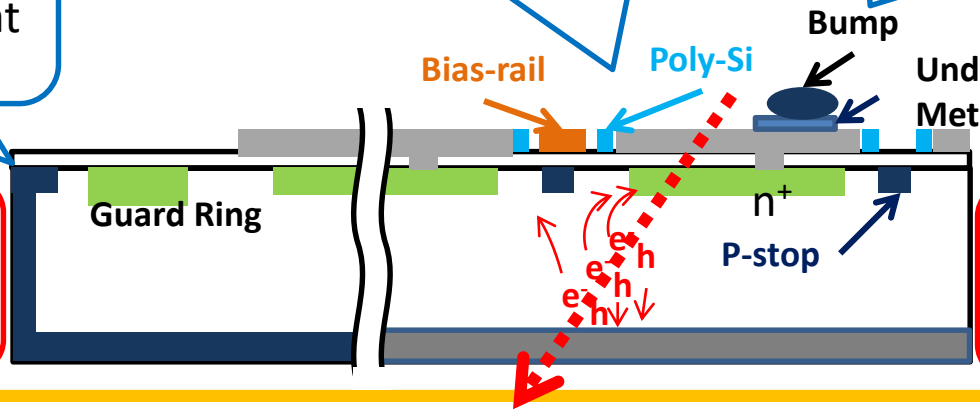


- Op
- Hig
  boundary

- Higher Flip-Chip Yield

Active Edge

- Smaller Edge size
- Higher Efficiency at Edge region



Simulation

- Doping concentration
- Charge collection

Radiation Tolerance
Assembly
Production…

D_RD_15 program (2014-2018)

- Project to build the demonstrator of the longeron.
- Both LAL and KEK are the contributors.
- Mainly : the electrical and heater modules provided.
- **These are the good joint effort towards the pixel detector construction.**

7 modules prototype

CERN official Facebook

Shared Effort *Both FR-JP teams are sharing their efforts*

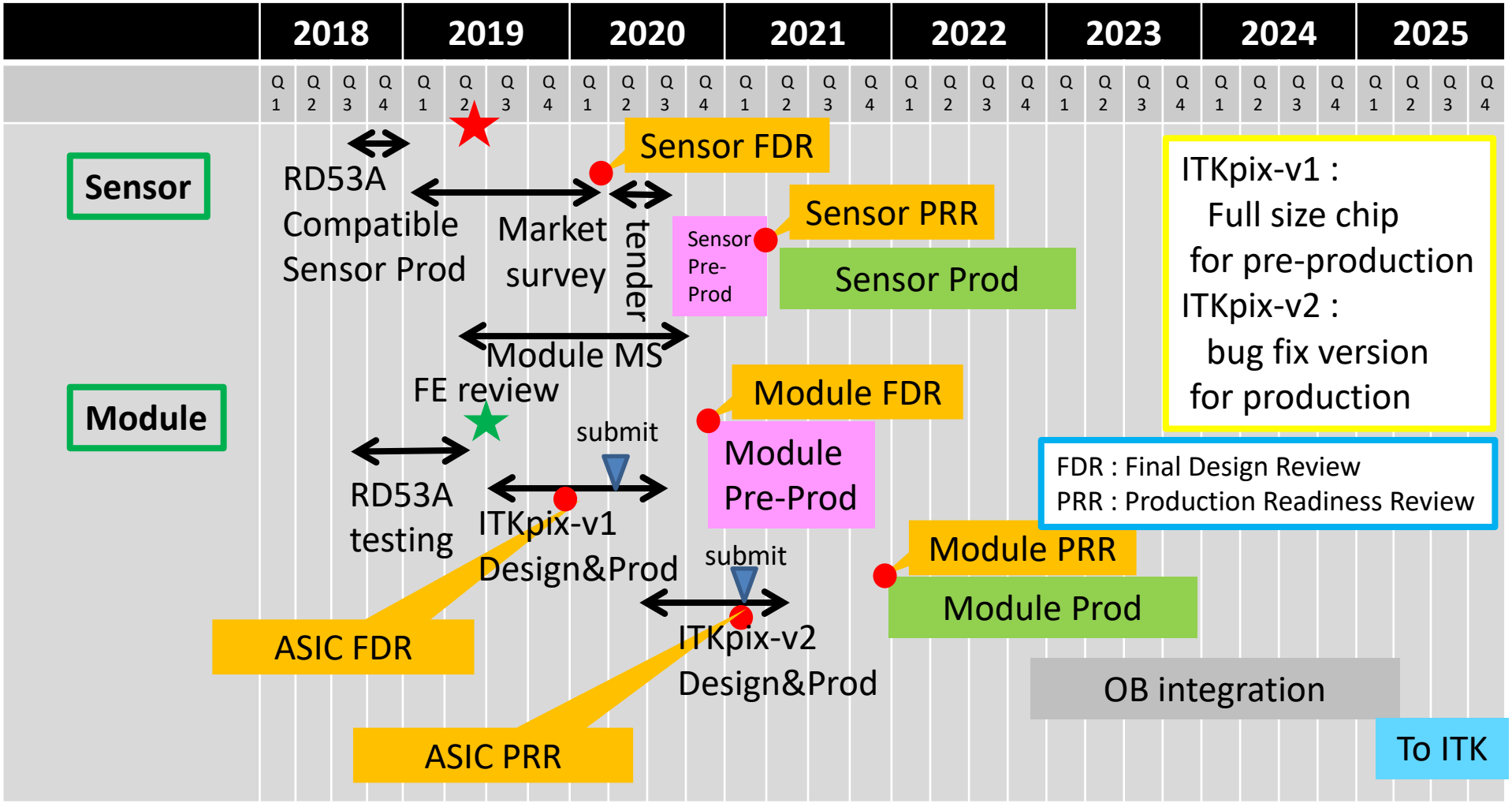
longeron
for layer 2 and layer 3 (1.6 m) 4 cooling lines
52 flat quad and 124 inclined double modules

D_RD_20 program proposal

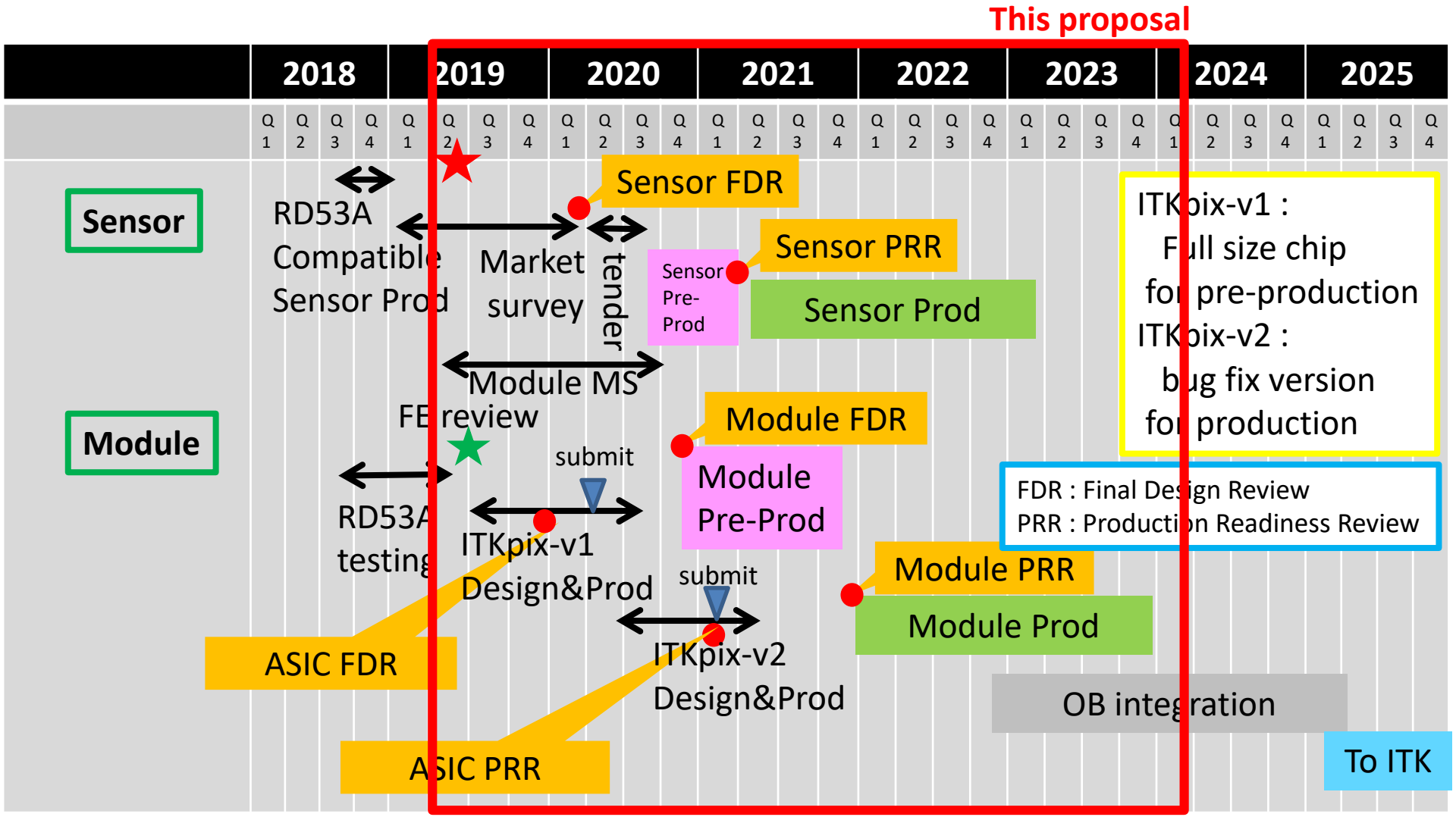
- Building production modules based on the developed pixel detector.
  - ***2019-2020 : preparation of production***
  - ***2021-2024 : Production of the modules***
- Constructing ITK pixel detectors is an extremely challenging project
  - **>10000 quad planar pixel modules to be produced. About 20% of modules are build by us.**
  - **Finalize the design and construction method.**
  - **Development of Quality Control and Quality Assurance.**

- **Mainly we ask funding for exchange people between FR-JP**
  - **Share experience/common development**

Production schedule



Production schedule



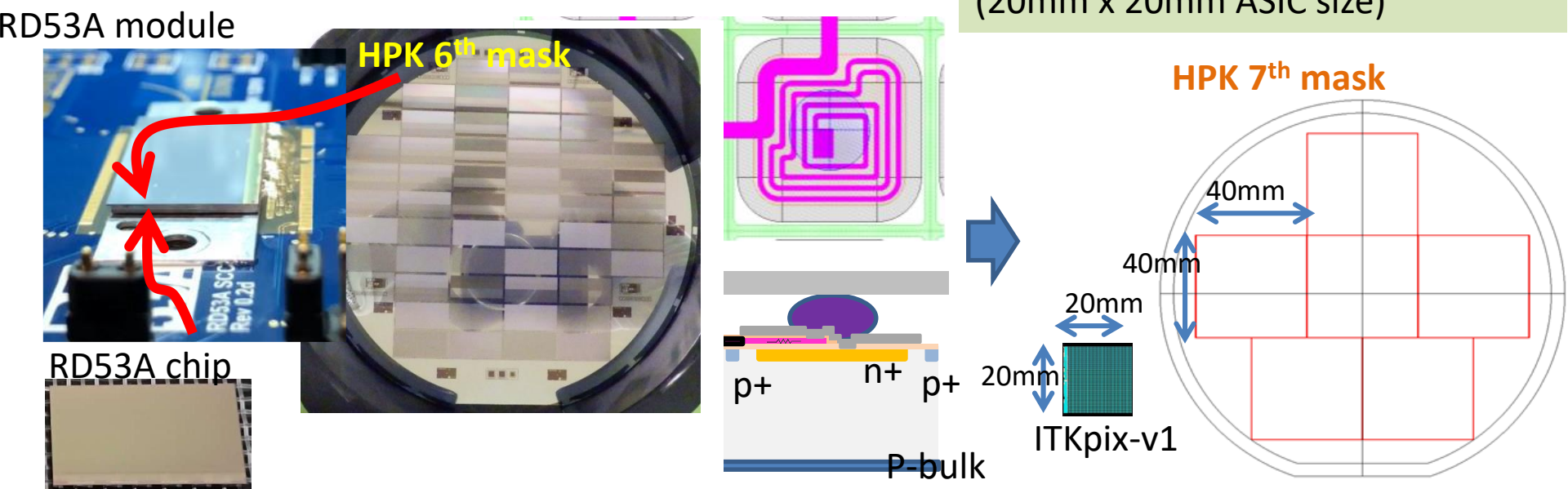
Finalize the design and construction method.

Final Sensor design

- Basic Sensor structure is almost final after years of development.
- Current fine pitch (50umx50um) pixel size sensors are attached to half size prototype ASIC (RD53A).
- Full size sensor and ASIC need to be produced in 2019.
  - RD53B (ITKpix-v1) and 7th HPK mask.

10mm x 20mm half size prototype modules

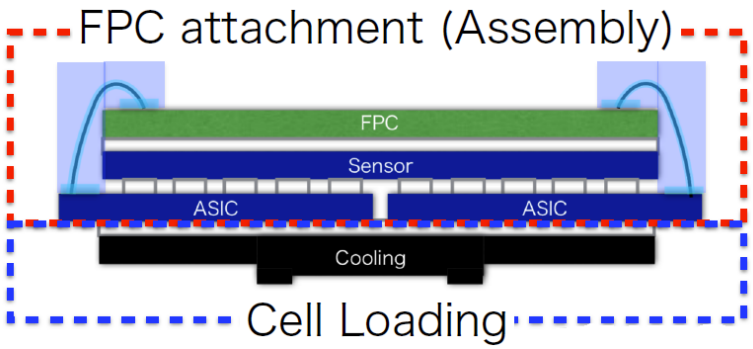
40mm x 40mm production modules (20mm x 20mm ASIC size)



Module Assembly

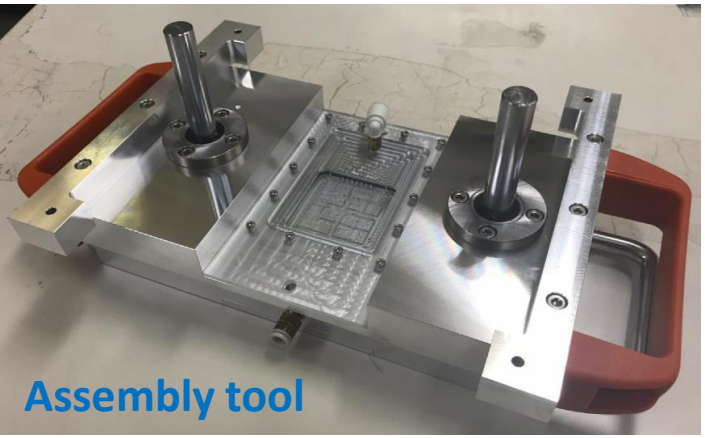
- Assembly of Quad module to the Flex Printed circuit.
  - Radiation hard glue choice
  - CTE matching to avoid stress for modules.
  - Cooling cell on the back side of modules

Module loading to support



Flex Printed Circuit

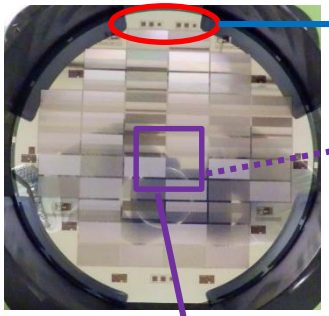
Cooling Cell



Development of Quality Control and Quality Assurance.

QC/QA flow for module production

Sensor from vender

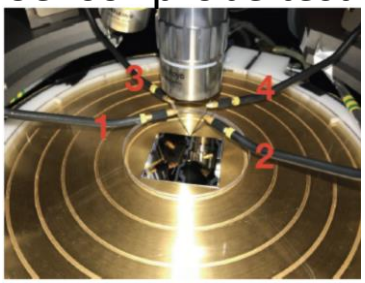


Test structure

1% of sensor

Sensor reception
Quality Assurance

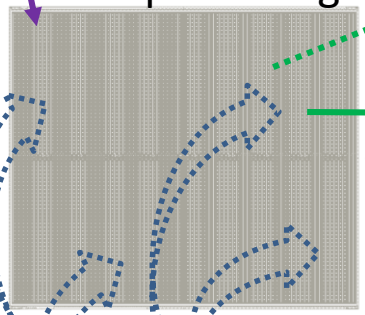
Sensor probe test



Bare module
Quality Assurance

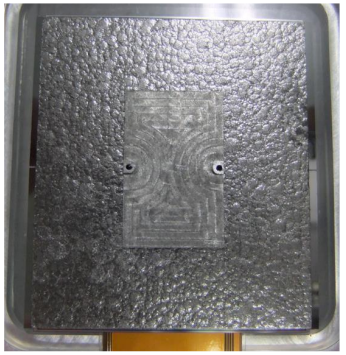
ASIC probing

Bump bonding



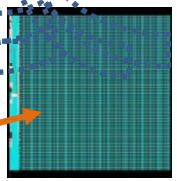
Module Assembly

Flex gluing
Wire bonding
Cooling cell gluing



ITKpix ASIC

Front End ASIC



1% of module

ASIC probe test
Quality Control

Module QA
Thermal Cycling
Irradiation/Testbeam

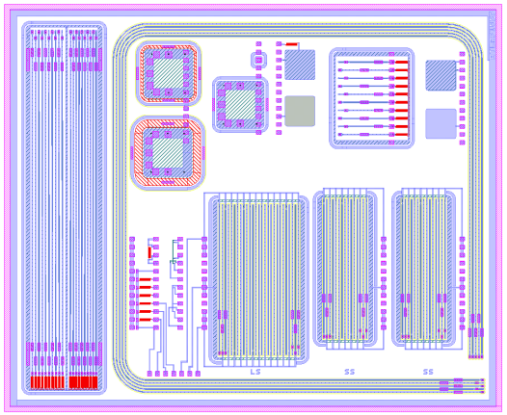
Module QC
Electrical test

loading to Local support.

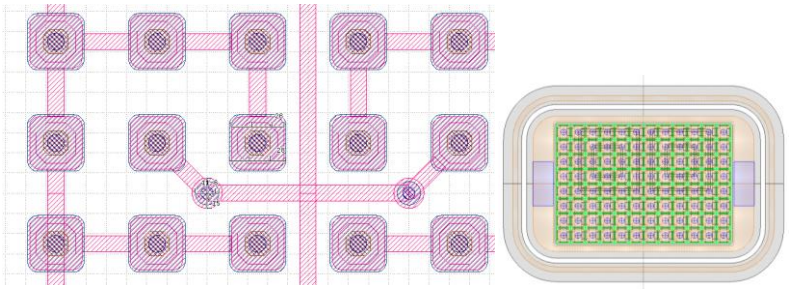
Sensor QC/QA preparation

- Most of the measurement : rely on the vender
- IV/CV measurement cross check
  - 1% of sensor will be re-measured by ATLAS ITK
- Test structure to control the quality of the wafer during production.
  - IV/CV measurement for Miniature diode
  - To measure inter-pixel capacitance, low noise probe station necessary.

Test structure

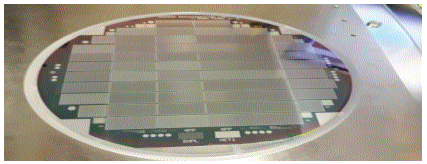


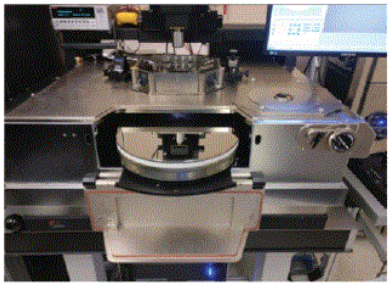
Inter-pixel cap/res test str.

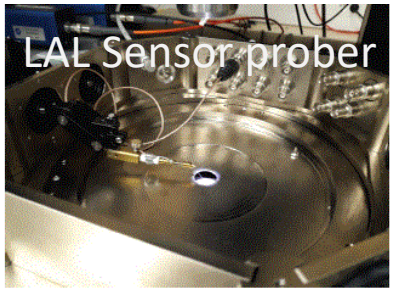


Contribution for ATLAS pixel Market survey

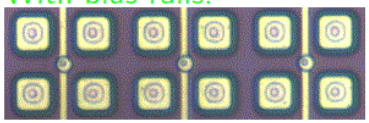
- Work carried within task force IN2P3 French Cluster (LAL+ LPNHE)
  - Characterization of pixel sensors of various designs through different actions, namely:
    - Visual Inspection
    - Planarity and bow evaluation
    - IV, CV measurements
- Outcome from MS measurement
  - Measurement consist with the values by foundry.
  - Infrastructure ready and operational for mass production



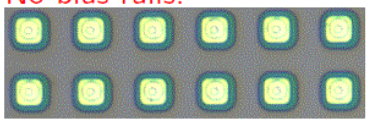




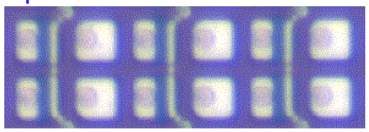
With bias rails:

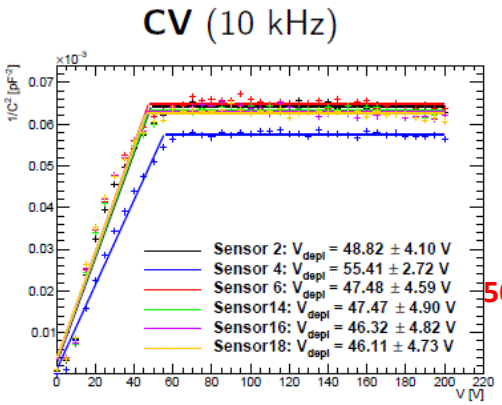


No bias rails:

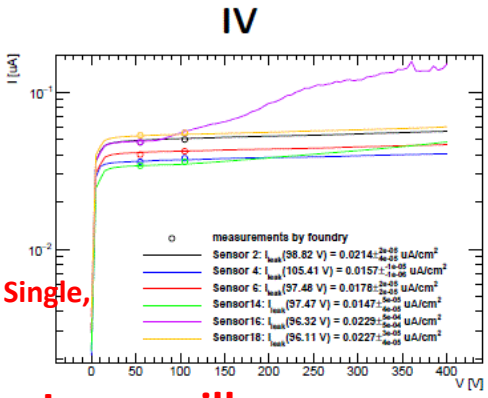


Special bias rails:





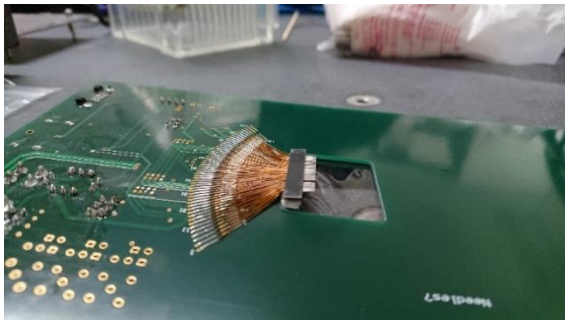
50x50 µm2 Single,

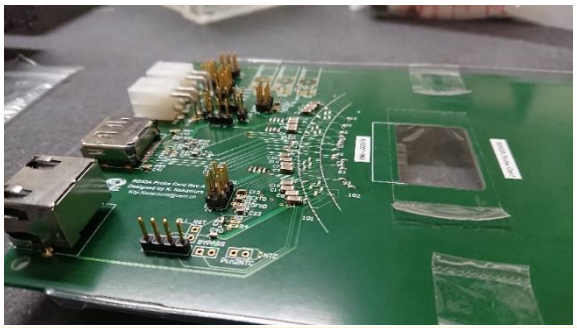


Japan will measure samples from the other vender who delivers samples later this year.

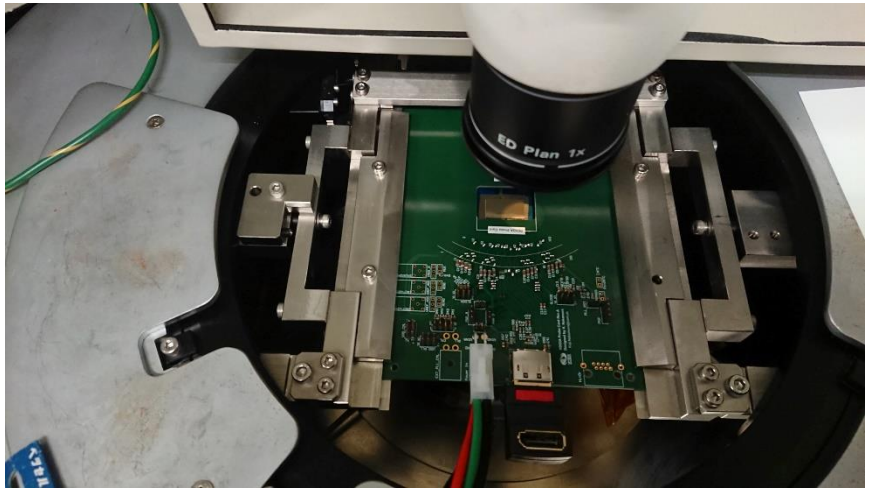
Module measurement

- Probe card for RD53A module has been developed in Japan.
  - **Immediate feedback of Bumpbonding quality in HPK.**
  - Highly needed tool that could be provided by KEK for the community for ASIC Chip testing.
- Test for RD53A module successfully done.
  - Will be tested modules for the local support demonstrator.
- **Probe card for Pre-production ASIC will be designed this year.**





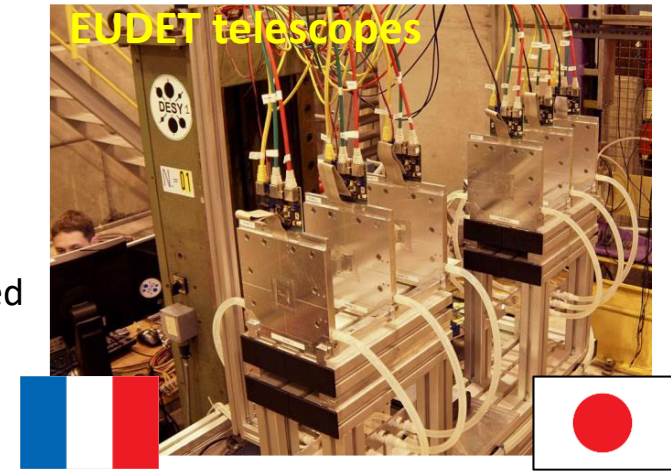
Probe station at KEK



Irradiation and Testbeam

- CYRIC@Tohoku Univ.
  - An irradiation facility with **70MeV proton beam** (~**1μA beam current**).
    - 3-5 hours for $3x10^{15} n_{eq}/cm^2$ irradiation with (600nA beam)
  - This allows 2-3 pixel modules with Al plate at the same time(3% E loss/module).
  - Operated at **-15°C temprature** with dry N_2 gas.
  - Scanning over full pixel surface at irradiation.

- **Testbeam**
  - **Extremely important to test device performance**
  - Efficiency/Noise monitoring during production
  - Testbeam facility
    - **CERN SPS : 120GeV π+ beam**
    - DESY : 4-5GeV e+ beam
    - FNAL : 120GeV proton beam
  - Telescope planes (Track pointing to device)
    - EUDET based on MIMOSA26 monolithic CMOS detector placed in beamline at CERN/DESY/SLAC (**~3um pointing resolution**).
    - Huge experience of the testbeam operation as having testbeam 3-4 times a year



Funding request

Exchange Experience(D_RD_15)

Visit Versailles in 2017

Junki Suzuki, Hitomi Tokutake, and K.N. + Tasneem Rashid

To perform SIMS measurement @ Versailles

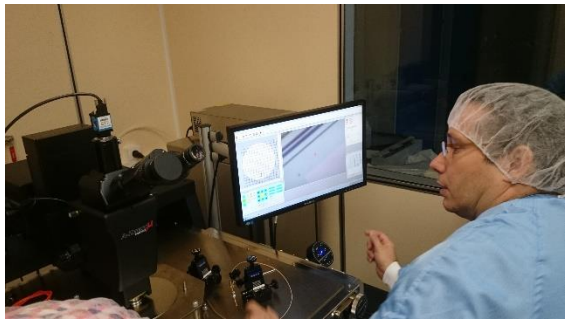
Thanks to Fraçois Jomard for help and the operation of measurement

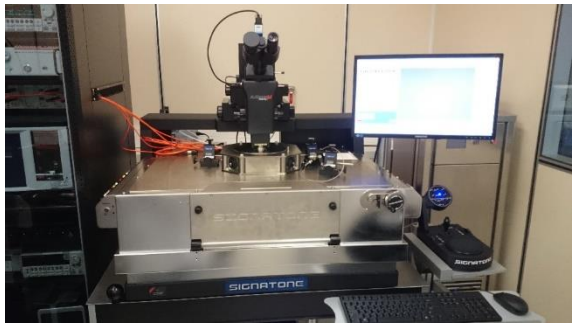
Visit LAL in 2016

Kazuyuki Sato, Junki Suzuki, Hitomi Tokutake, Hiromi Sawai and K.N.

Original aim is to perform SIMS measurement @ Versailles but it was temporary broken unfortunately.

Visiting probe-station, SMD lab etc.

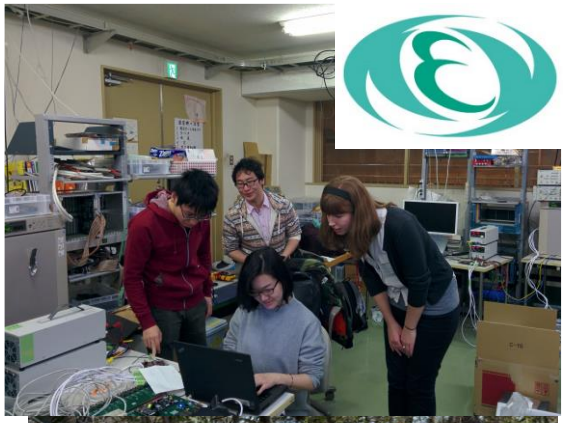




Visit KEK in 2015

Clara Nelist

After irradiation of LAL's module in Japan, testing of the devices as well as visiting J-park @ Tokai



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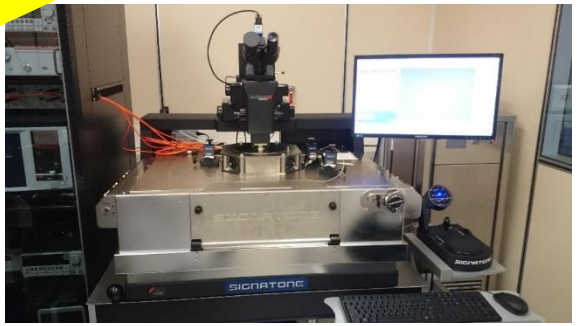


Very good opportunity to share expertise and effort. Huge help for the phase of production & QA/QC

Visit KEK in 2015

Clara Nelist

After irradiation of LAL's module in Japan, testing of the d es as well as ark @ Tokai

Budget request 2019

Funding Request from France

Description	€/unit	Nb of units	Total (€)	Requested to
Visit to KEK/Tsukuba	150 / day	5 day	750	LAL
Visit to Japan	1000	1	1000	Uni. Paris Saclay
Students in KEK/Tsukuba	650/month	12 weeks	7800	Uni. Paris Saclay
Student Stay in KEK/Tsukuba	1500	1	1500	KEK/Tsukuba
Student Travels	800	1	800	Uni. Paris Saclay
Total			**4400**	

Funding Request from Japan

Description	k¥/unit	Nb of units	Total (k¥)	Requested to
Visit to LAL (3 seniors), per diem	45/day	5days	225	KEK
Student (1) Stay at LAL, per diem	150/month	2 months	300	KEK
Travels	160	4	640	KEK
Total			**1165**	

Additional Funding from France

Provided by / requested to	Type	€
LAL/ATLAS PIXEL/IN2P3	TCADSIM licence	1500
LAL/ATLAS/PIXEL /IN2P3	DAQ Front board For Irrad tests	1500
LAL/ATLAS PIXEL/IN2P3	New DAQ PC	1000
Total		**4000**

Additional Funding from Japan

Provided by / requested to	Type	k¥
Tsukuba/ATLAS	Quality Control setup	800
KEK/ATLAS	CYRIC irradiation	450
Tsukuba/ATLAS	Test beam	800
Total		**2050**

backup

Strategy for ITK pixel module construction scenario within IN2P3 French Cluster.

Clean room

Point tests

- SI WAFER OPTICAL RECEPTION-INSPECTION TEST - INDIVIDUAL SENSORS OR WAFERS TESTS

Location: LAL LPNHE

connexion

- PIXEL MATRIX WITH INDIUM BALLS SENSORS PIXEL FLIP-CHIP on ASIC CHIP

Flip Chip

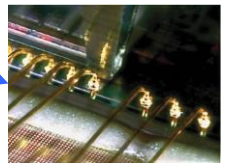
INDUSTRY

Point test machine at LAL

Construction module

- CONNECTION OF THE MODULE ON THE READOUT CARD (WIRE BOND)

LAL LPNHE+ IRFU



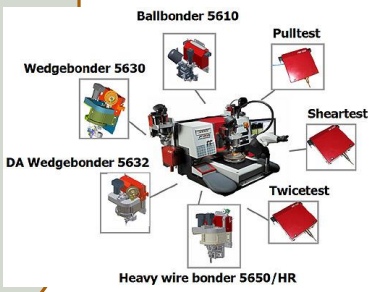
Ultrasonic weldingIC WELDING

- FLEXIBLE CABLE GLUING FOR HV AND CLOCK SIGNALS

LAL LPNHE+ IRFU

Module test bunch with béta source, …

DEBUG



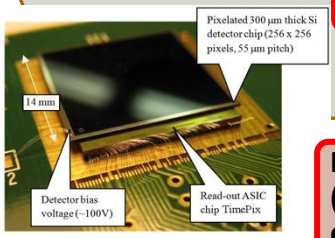
Ultrasonic welding machine (CEA/IRFU)

COMPLETE CARACTERISATION AND SELECTION OF MODULES ACCORDING TO PERFORMANCES

LAL LPNHE

OK

Module Pixel

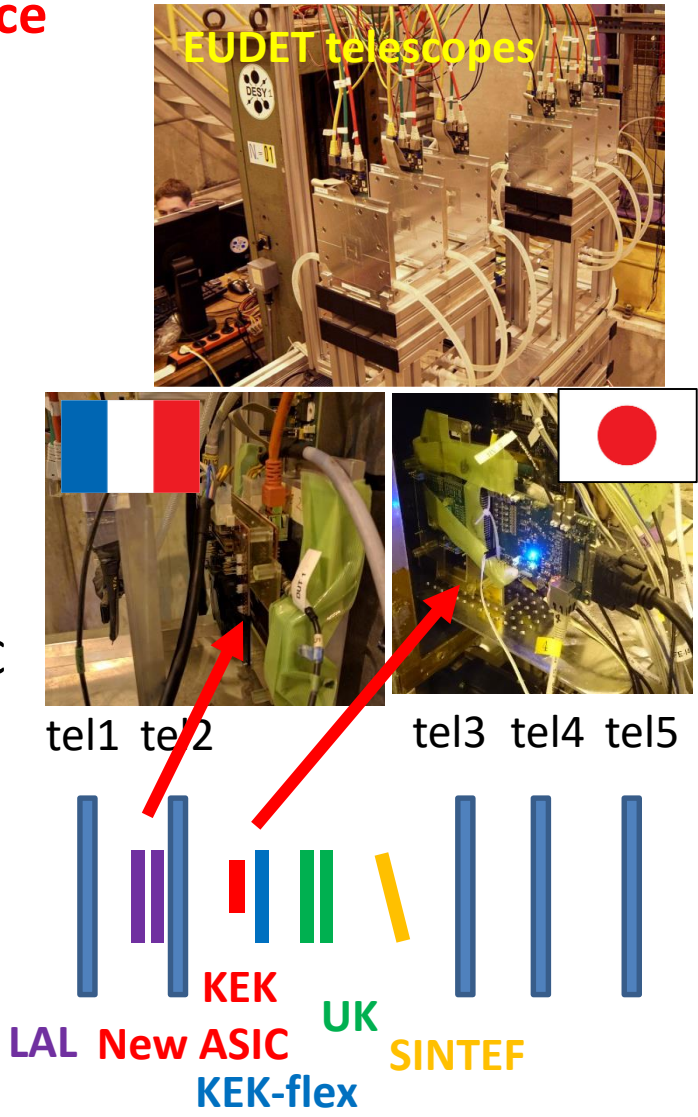


MODULE EXPEDITION towards integrating centers (CERN, CPPM, etc..) TO built the full tracker detector

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Testbeam campaign

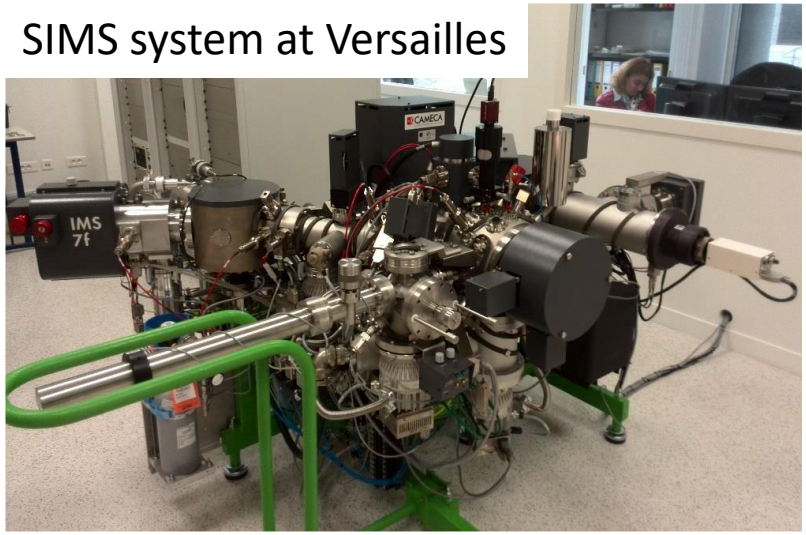
- **Extremely important to test device performance**
  - DAQ and operation
  - In-pixel and/or Edge efficiency
- Testbeam facility
  - **CERN SPS : 120GeV π+ beam**
  - DESY : 4-5GeV e+ beam
  - SLAC : 5-13GeV e- beam
  - FNAL : 120GeV proton beam
- Telescope planes (Track pointing to device)
  - EUDET based on MIMOSA26 monolithic CMOS detector placed in beamline at CERN/DESY/SLAC (**~3um pointing resolution**).
  - Huge experience of the testbeam operation as having testbeam 3-4 times a year
- ***Example*** : November testbeam @CERN
  - LAL&KEK devices are in the same runs together with UK, Norway's samples.
  - Excellent data taking was achieved.

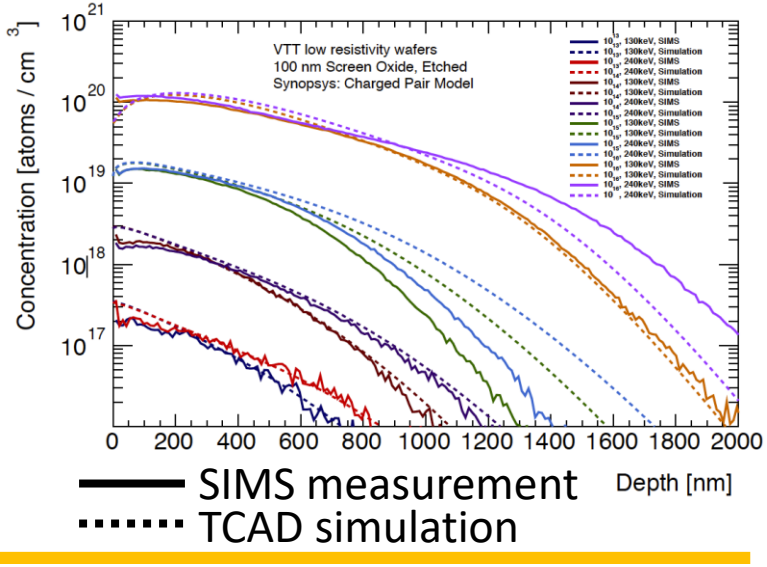


Secondary Ion Mass Spectrometry and Simulation

- SIMS measurement
  - Analytical technique to characterize the impurities near surface(<30um) by ionized secondary particles.
  - Good detection sensitivity for **B, P, Al, As, Ni, O, Si** etc down to 10^{13} atoms/cm^3 with 1-5nm depth resolution.
- Synopsys TCAD simulation
  - Process simulation:
    - Simulate implantation and resulting concentrations.
    - **Can compare to SIMS result.**
  - Device Simulation :
    - Simulate Electric field to understand the performance of silicon device.
    - Possible to perform simulation of charge correction of MIP signal.

SIMS system at Versailles





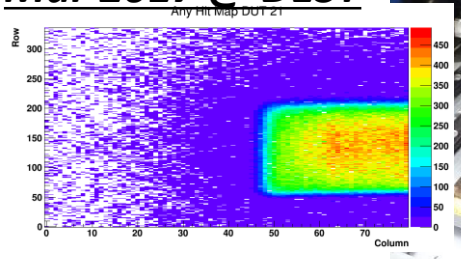
CYRIC : Irradiation Facility in Japan

- CYRIC@Tohoku Univ.
  - An irradiation facility with **70MeV proton beam** (~**1μA beam current**).
    - 3-5 hours for $3x10^{15} n_{eq}/cm^2$ irradiation with (600nA beam)
  - This allows 2-3 pixel modules with Al plate at the same time(3% E loss/module).
  - Operated at **-15°C temprature** with dry N_2 gas.
  - Scanning over full pixel surface at irradiation.
- LAL's Active Edge Pixel Modules
  - Irradiated LAL's module twice in 2016 and 2017.
  - First irradiation, observed disconnection of bumps after irradiation.
  - **Second irradiation, it was successfully done and measured the device at DESY testbeam in March 2017.**

Feb 2017

LAL's Pixel Mod. (Active Edge)

Mar 2017 @ DESY

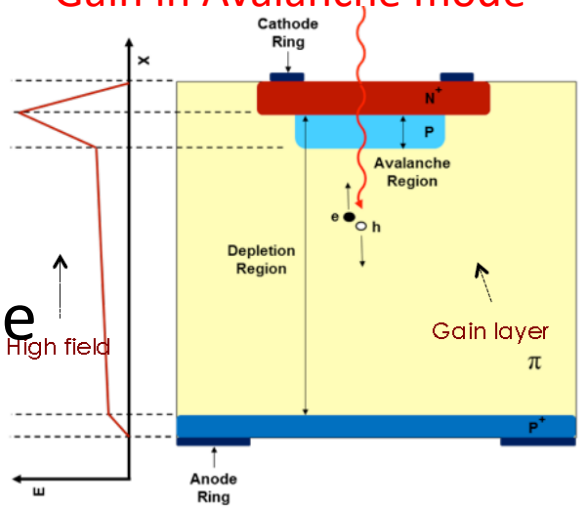


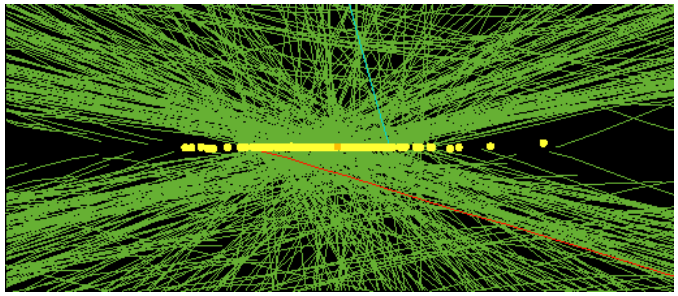
Another layer of Collaboration? : LGAD

Low Gain Avalanche Detectors

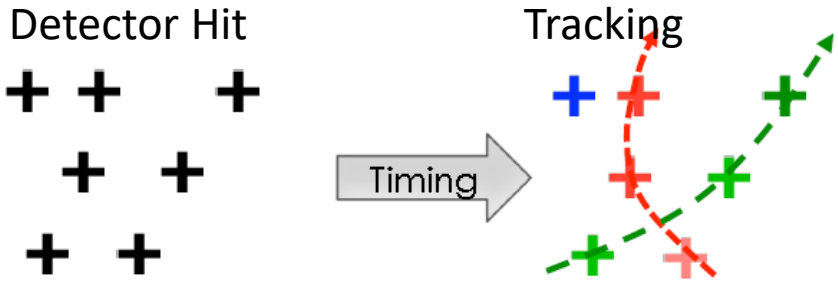
- To solve pileup issue in future high luminosity hadron collider, good time resolution detector is important.
- The **~50ps** time resolution makes it possible to identify each collision in an event.

Gain in Avalanche mode





- Time resolution
  - Smaller time walk (higher field)
  - Smaller time jitter (low noise)
- p+ layer beneath n+ implant creates ~300kV/cm electric field (Gain ~ 10)



CNM/FBK/HPK produced devices

- **LAL group : Simulation&Testing CNM device**
- **Tsukuba group : Testing HPK device**