LAL KEK Tsukuba HEP

Workshop on France-Japan and France-Korea Particle Physics Laboratories

Continuation of the D_RD_15 project:

Innovative design concepts in P-bulk Planar Pixel Sensor R&D project

Koji Nakamura (KEK)

Yoichi Ikegami, Koji Nakamura, Yoshinobu Unno (KEK)
Kazuhiko. Hara, Hideki Okawa (Tsukuba)
Evangelos Gkoukgoussis, Abdenour Lounis, Clara Nelist, Pierr Petroff
Dmytro Hohov, Tasneem Rashid, Reisaburo Tanaka (LAL)

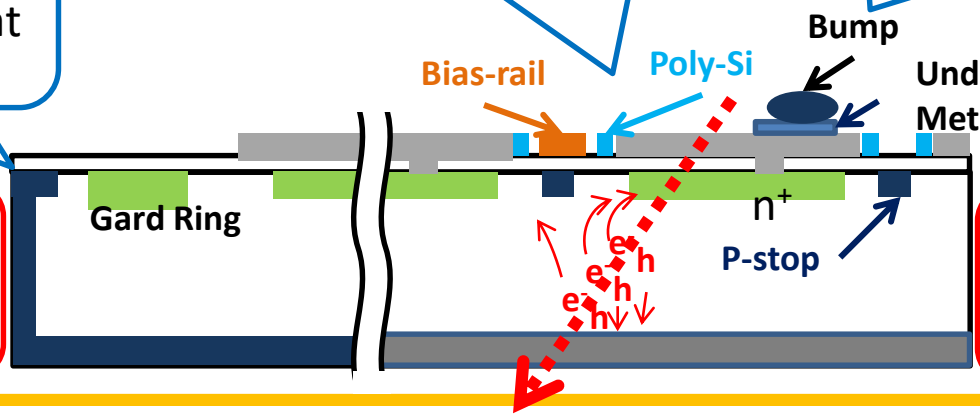
Introduction

- ***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 $3x10^{15}n_{eq}/cm^2$ 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

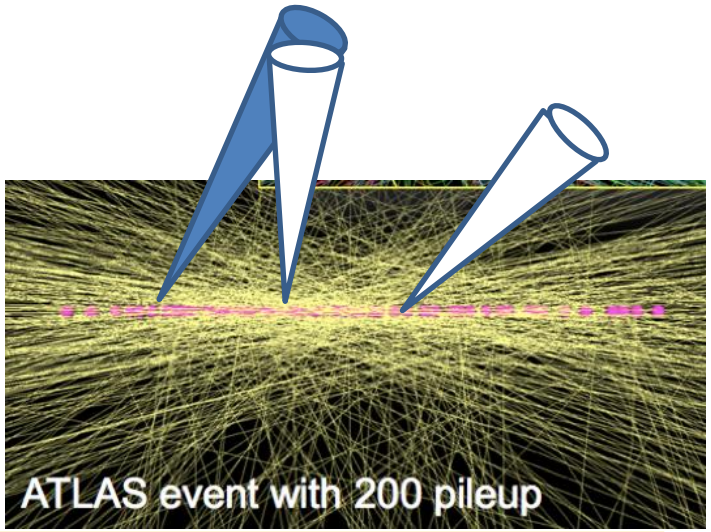
Radiation Tolerance
Assembly
Production…

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=5x10^{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

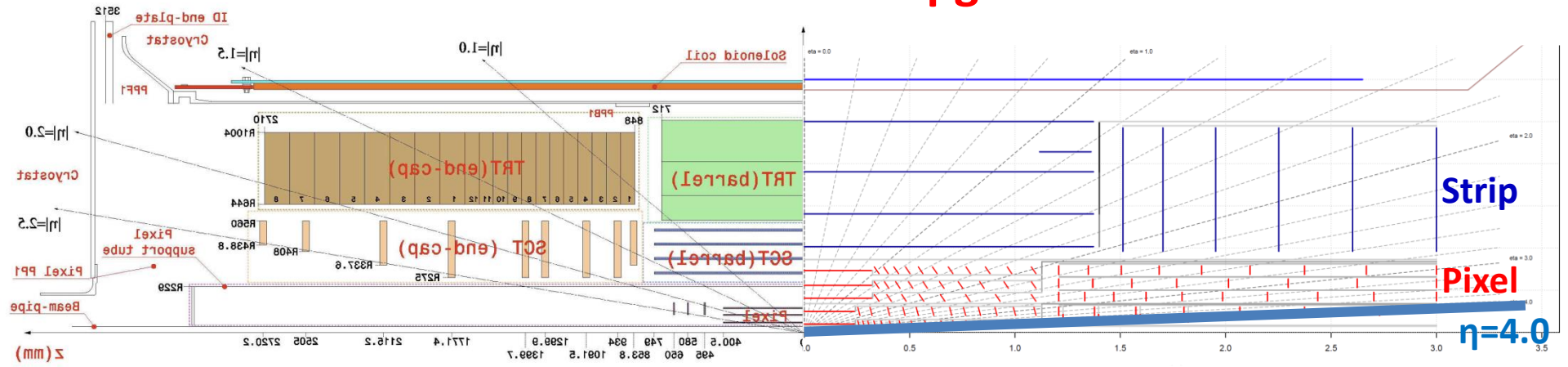
- All silicon tracker (Pixel & Microstrip)
- ***Requirements for Pixel detector***
  - Pixel Size : 50um x 50um (or 25um x 100um)
  - Radiation @ outer layer : 3x10^{15}n$_{eq}$/cm^2
  - Thickness : 100 or 150um
  - Low noise (<100e) → 600e stable threshold
  - High Readout Rate : 5.2Gbps (or 4x1.28Gbps)



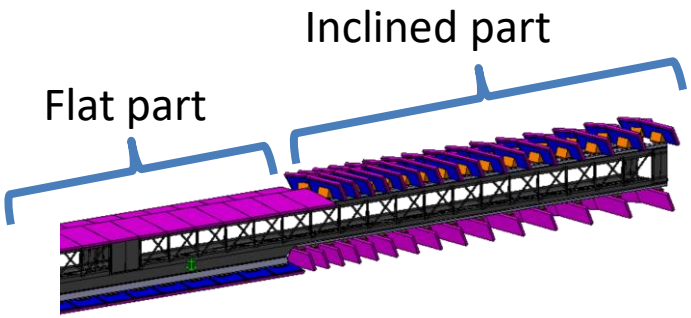
ATLAS inner tracker(ITK) project for HL-LHC

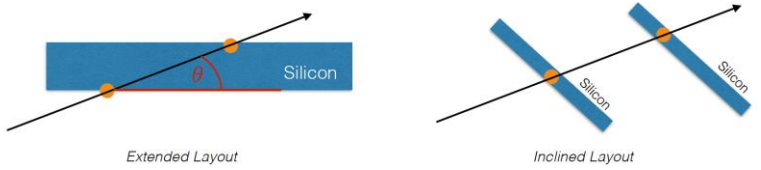
Current ATLAS Detector

ITK upgrade detector



- Larger coverage area
  - Pixel : current 2.7m^2 ➔**upgrade 8.2m^2**
  - Strip : current 62m^2 ➔upgrade 193m^2
- Higher Forward coverage
  - Current η<2.5 ➔ **upgrade η<4.0**
  - **Better Pileup removal**
- Mechanics : inclined
  - Reduce material
  - Higher tracking resolution.

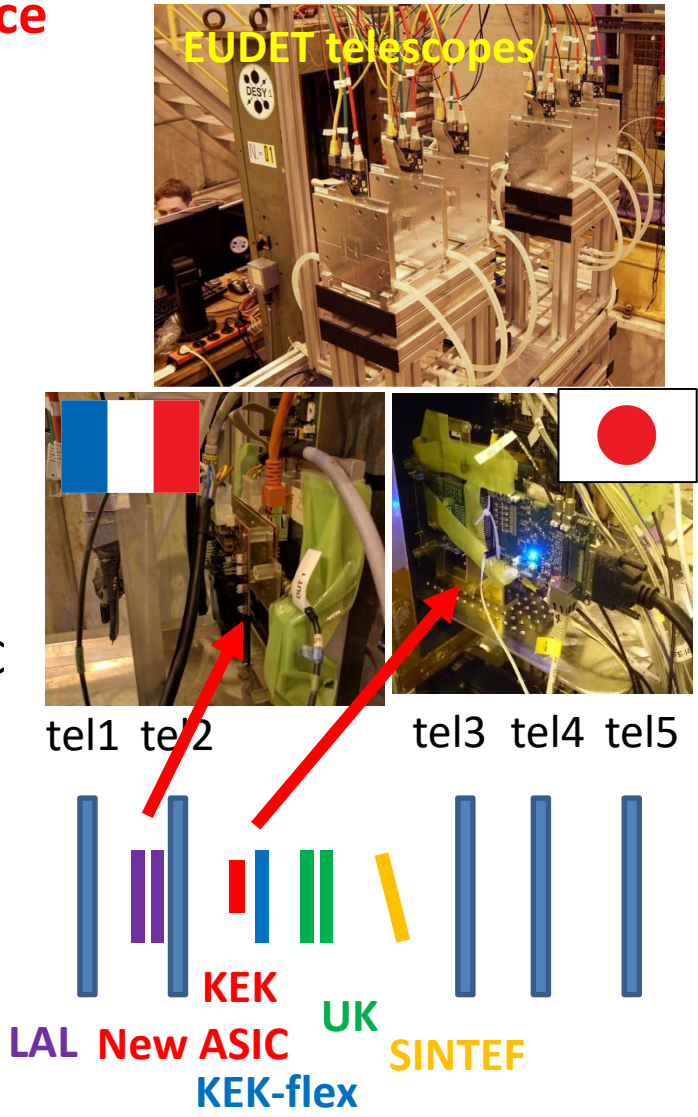




Facility and expertise

Testbeam campaign

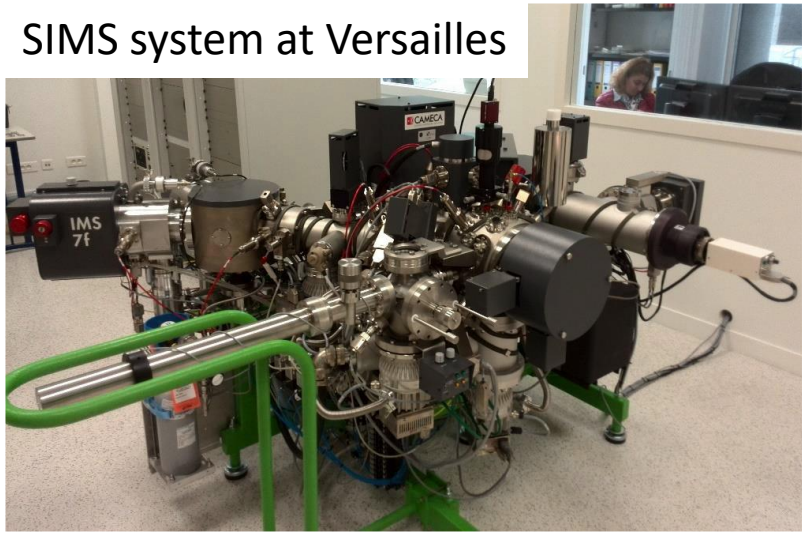
- **Extremely important to test device performance**
  - DAQ and operation
  - In-pixel and/or Edge efficiency
- Testbeam facility
  - **CERN SPS : 120GeV π+ beam**
  - DESY : 4-5GeV e+ beam
  - SLAC : 5-13GeV e- beam
  - FNAL : 120GeV proton beam
- Telescope planes (Track pointing to device)
  - EUDET 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.

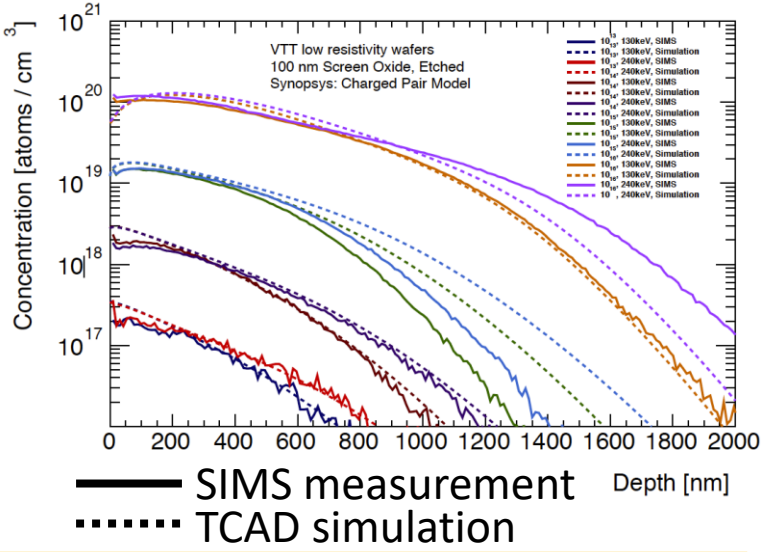


Secondary Ion Mass Spectrometry and Simulation

- 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 for charge correction of MIP signal.

SIMS system at Versailles





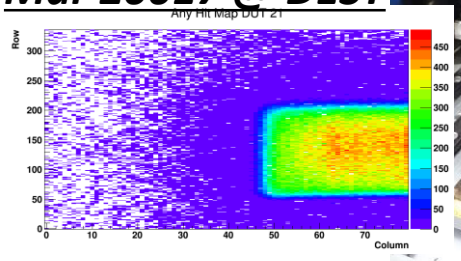
CYRIC : Irradiation Facility in Japan

- 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 range during 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)

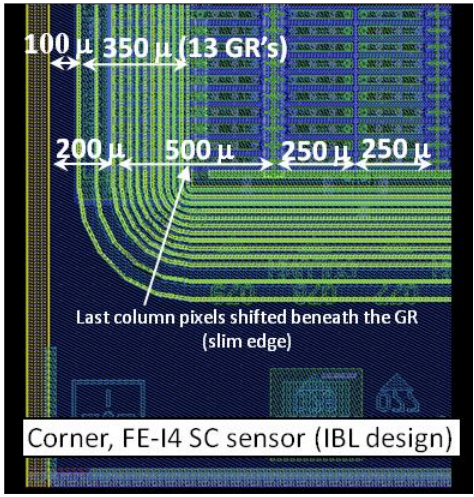
Mar 20017 @ DESY

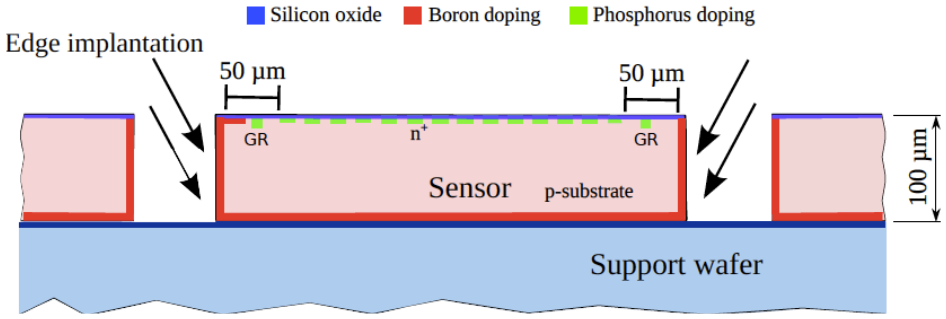


Sensor technology improvement

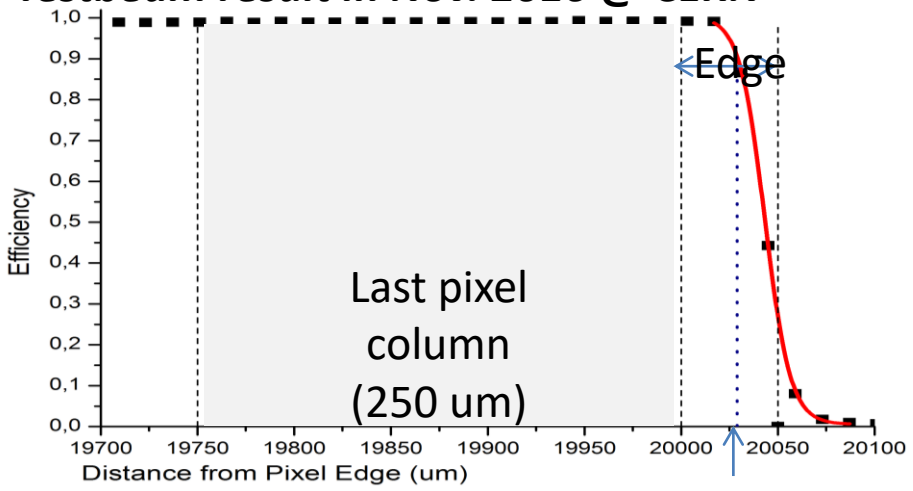
Active Edge

- Active edge designs for planar pixels.
  - To decrease the Edge inefficiency, active edge process has been developed over 4 years with VTT.
  - To achieve a fully efficient and slim edge sensor, edge implantation (Boron) is performed.
  - 100-200um thick sensor with this active edges makes it a veryattractive candidates for the inner layer(s).
  - Guard ring types are optimized.





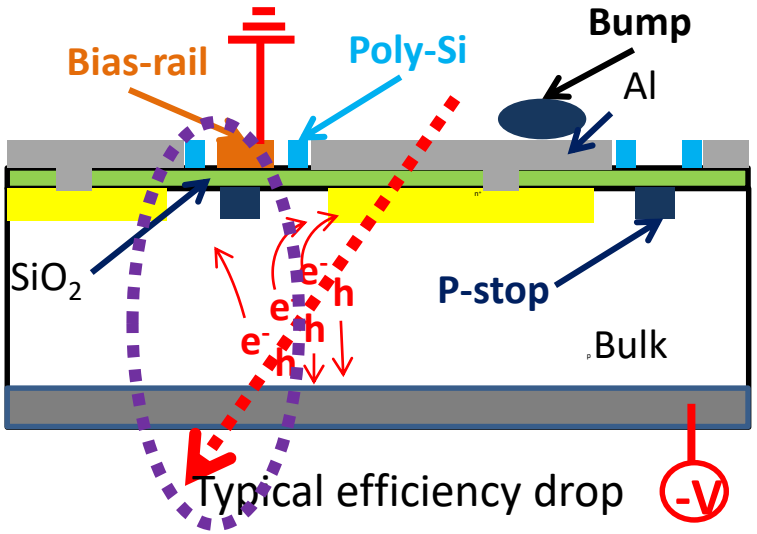
Testbeam result in Nov. 2016 @ CERN



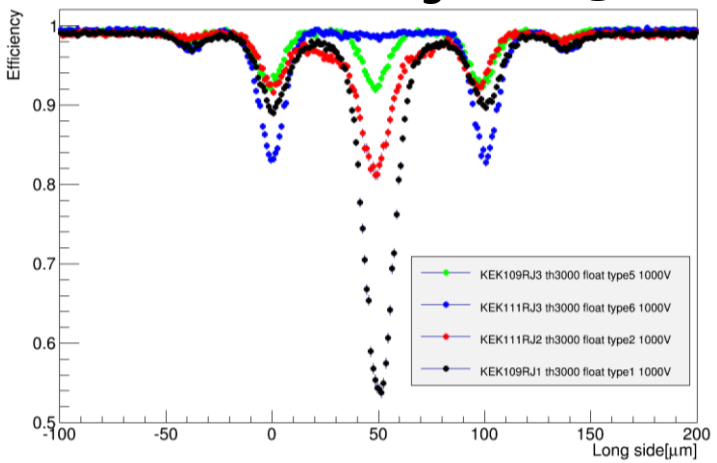
20030
(> 90% efficiency)

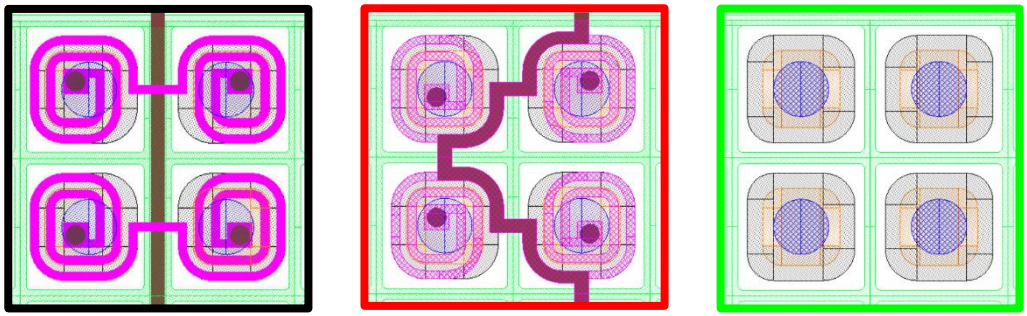
Biasing structure optimization

- Biasing Structure
  - To apply bias voltage before bumpbonding biasing structure (bias rail and resistor/punch through) to each pixel is necessary to make it GND.
  - **On the other hand we observed Efficiency drop under the structure due to field effect.**
- Charge sharing
  - On the corner of pixel MIP charge sprit to 4 pixels resulting lower efficiency.
- Biasing structure optimization and lower noise readout chip (TSMC 65nm) are tested.
  - **Better Efficiency with optimized bias rail path.**
  - Trying to figure out low threshold data with new chips.



Testbeam result in Aug. 2016 @ CERN

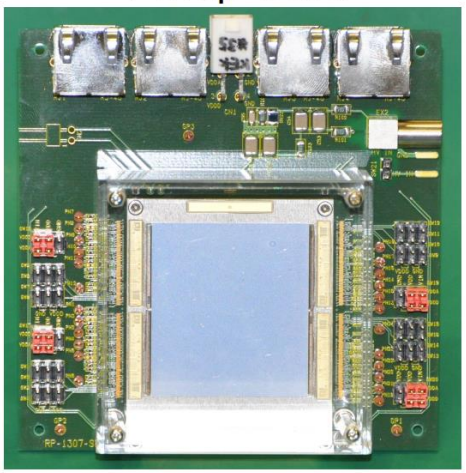


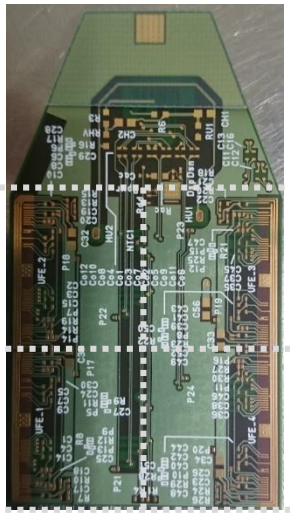


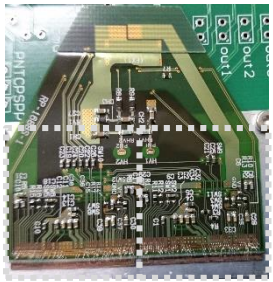
Module Assembly

- Bump Bonding Technology has been developed.
  - Optimized under bump metallization (UBM)
  - Optimization of parameters for flip-chip.
  - **Yield of bump bonding is almost 100% for last 2 years(>60 ASICs).**
  - **Stability against thermal cycling (-40,40°C) performed w/o bump disconnection.**
- Towards Integration, Flex readout circuits have been developed.
  - **Quad(4 ASICs) and double(2 ASICs) module flex have been designed and produced in Japan.**
  - Alignment tools for gluing and wire bonding are in development.

4 Chip Card



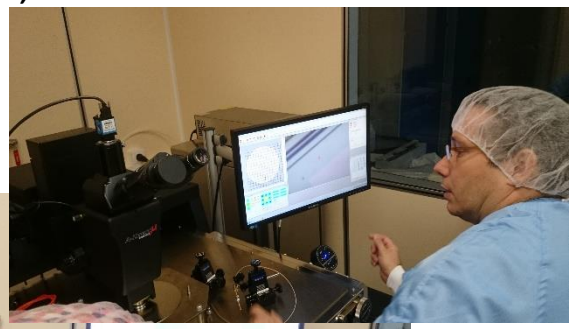




Exchange Experience

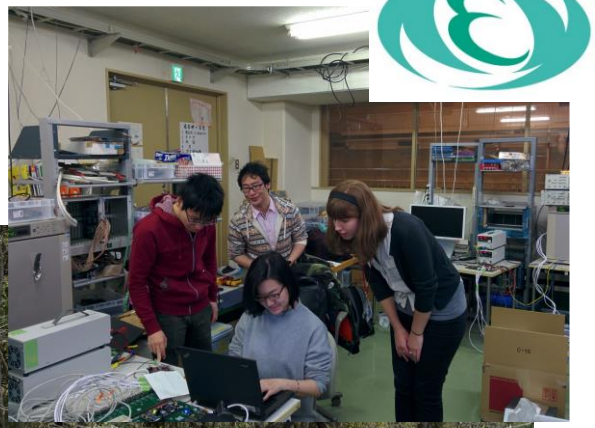
Visit LAL in 2016

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 for the device as well as visiting J-park @ Tokai

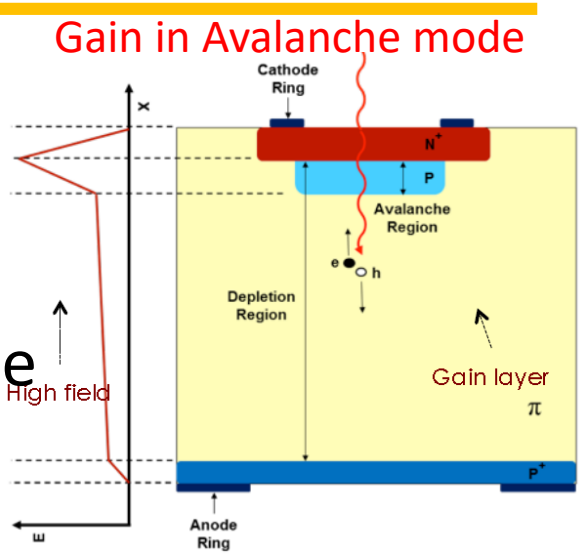


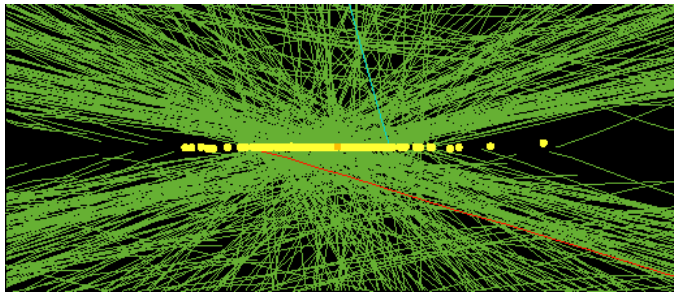
Good opportunity to share expertise and effort.

Another layer of Collaboration? : LGAD

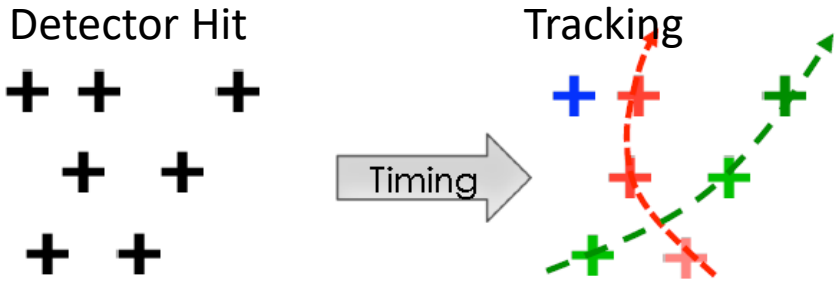
Low Gain Avalanche Detectors

- 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.





- 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**

Sharing of the work

Conclusion

- **French and Japanese Groups are committed in an ambitious R&D program inside the ATLAS ITK effort for HL-LHC, where we will face challenging issues:**

  Major issue is to Built an innovative granular thin pixel planar detector.
  - Find the best sensor layout ingredients for high charge collection efficiency.
  - Explore productions with active edge and optimized biasing structure which will exhibit the best performance.
  - Develop robust radiation hard solutions to cope with HL-LHC irradiation fluences.

- **Thus our aim is to enhance and reinforce LAL-FR/Japan collaboration to built the future P bulk Planar Pixel Sensors for ATLAS tracker for HL-LHC. We intend to increase the :**
  - Synergy in terms of P bulk sensor design, characterization and testing (Clean room, Test-Beam, irradiation facility)
  - Understand the behavior of heavily irradiated Planar Pixel Sensors
  - Share expertise and efforts (TCAD simulation, SIMS, Irradiation etc…).
- **Now in application of Japanese funding program for "Advancing Strategic International Networks to Accelerate the Circulation of Talented Researchers." LAL is also partner other such Japanese research program.**

Budget request 2017

Funding Request from France				
Description	€/unit	Nb of units	Total (€)	Requested to
Visit to KEK/Tsukuba (2 seniors)	150 / day	5 day	1500	FJPPL
Student Stay in KEK/Tsukuba	1000/month	2 weeks	500	KEK/Tsukuba
Travels	900	2	1800	FJPPL
Total			**5850**	

Funding Request from Japan				
Description	k¥/unit	Nb of units	Total (k¥)	Requested to
Student Stay at LAL	100 / week	4 weeks	400	FJPPL/LAL
Travel+per-diem (Japan-CERN)	400	1	400	FJPPL
Travel+per-diem (CERN-LAL)	50	4	200	FJPPL
Total			**1000**	

Additional Funding from France			Additional Funding from Japan		
Provided by / requested to	Type	€	Provided by / requested to	Type	k¥
LAL / ATLAS PIXEL	TCAD SIM license	400	Tsukuba / ATLAS PIXEL	Travel to CERN	2100
LAL / ATLAS PIXEL	Silicon wafer production	4000	Tsukuba / ATLAS PIXEL	Various expenditure	600
LAL / ATLAS PIXEL	Readout card	1500			
Total		**5900**	**Total**		**2700**

backup

Members

FJPPL (TYL) application 2016-2017

Fiscal year April 1st 2016– March 31st 2017

Please replace the red examples by the appropriate data in black

ID[1]:	Title: Innovative design concepts in P Bulk Planar Pixel Sensors					
	French Group			Japanese Group		
	Name	Title	Lab./Organis.[2]	Name	Title	Lab/Organis.[3]
Leader	Leader : A. Lounis	Dr.	LAL/IN2P3	Leader : K. Hara	Dr.	U. Tsukuba
Members	P. Petroff	Dr.	LAL/IN2P3	K. Nakamura	Dr.	KEK
	R.Tanaka	Dr.	LAL/IN2P3	Y. Unno	Dr.	KEK
	D. Varouchas	Dr	LAL/IN2P3	Y. Ikegami	Dr.	U. Tsukuba/KEK
	D. Hohov	PhD	LAL/IN2P3	H. Okawa	Dr.	U. Tsukuba

Budget request in 2017

Funding Request from France				
Description	**€/unit**	**Nb of units**	**Total (€)**	**Requested to[4]:**
Visit to KeK/Tsukuba (2 seniors)	150/day	5 days	1500	FJPPL
Student Stay in KeK/Tsukuba	1000/month	2 weeks	500	KEK /TSUKUBA
Travels	900	2	1800	FJPPL
Total			5850	

Funding Request from KEK				
Description	**k¥/Unit**	**Nb of units**	**Total (k¥)**	**Requested to:**
Student Stay at LAL	100/week	4 weeks	400	FJPPL/LAL
Travel+ per-diem (Japan-CERN)	400	1	400	FJPPL
Travel+ per-diem (CERN-LAL)	50	4	200	FJPPL
Total			1000	

Additional Funding from France			Additional Funding from Japan		
Provided by/Requested to[5]	**Type**	**€**	**Provided by/Requested to[6]**	**Type**	**k¥**
LAL/ATLAS PIXEL	TCAD SIM licence	400	Tsukuba/ATLAS PIXEL	Travel to CERN	2100
LAL/ATLAS PIXEL	Silicon wafer production	4000	Tsukuba/ATLAS PIXEL	Various expenditure	600
LAL ATLAS PIXEL	Readout card	1500			
Total		5900	Total		2700