IJC/IN2P3

KEK Tsukuba HEP

2024 Joint Workshop of FKPPN and TYL/FJPPN

Date: 2024. 5.22~24
Place: KISTI, Daejeon, Korea

2024 Joint workshop of FKPPL and TYL/FJPPL

Development of precision timing silicon detector (LGAD) for future collider experiments

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Beng-Yun Ky, Arzoo Sharma (IJC/IN2P3)
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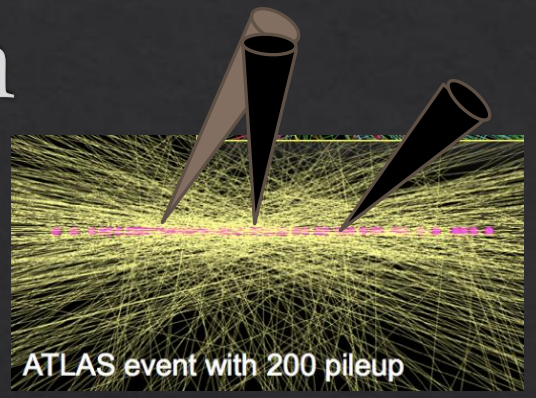
History of collaboration

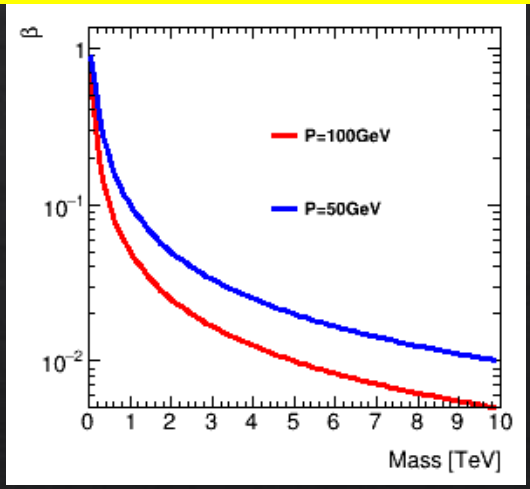
- Structured collaboration in JPY2022 and approved as D_RD_23 project
  - JPY2022 and JPY2023 we had effective collaboration for AC-LGAD R&D.
  - Exchanged staff and students to exchange expertise.
- This year is 3rd year of the project.
  - Newly included ASIC experts who are working on Electron Ion Collider (EIC) experiment
  - Strong collaboration with Omega lab in France.

Impact for tracker with time resolution



- **Collider experiment gets high energy and high intensity.**
  →Future Tracking detector should have timing information for all hits!
- **Tentative Requirement**
  - **30ps timing resolution &~o(10)um spatial resolution**
  - **(hadron collider) ~o(10^{16})n_{eq}/cm^2 radiation tolerance**

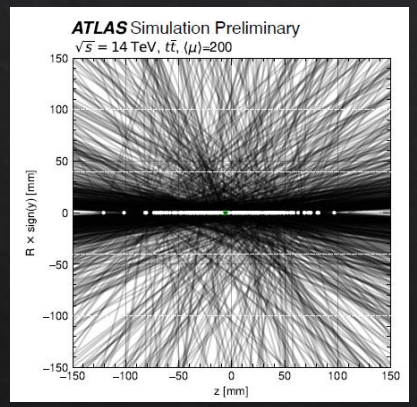
Mass spectrum for new particle

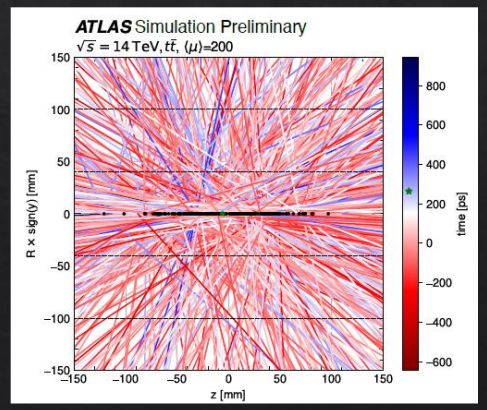


β measurement to obtain mass

e.g. Mass measurement for Long lived chargeno

4D tracking !





Solve pileup hits in an event

Particle identification

β = 1 β = 0.95

150ps difference at R=1m

K+ π+ separation

Operating and Planning Collider Experiment

World highest energy collider !

2011～ **Large Hadron Collider (LHC experiment)**

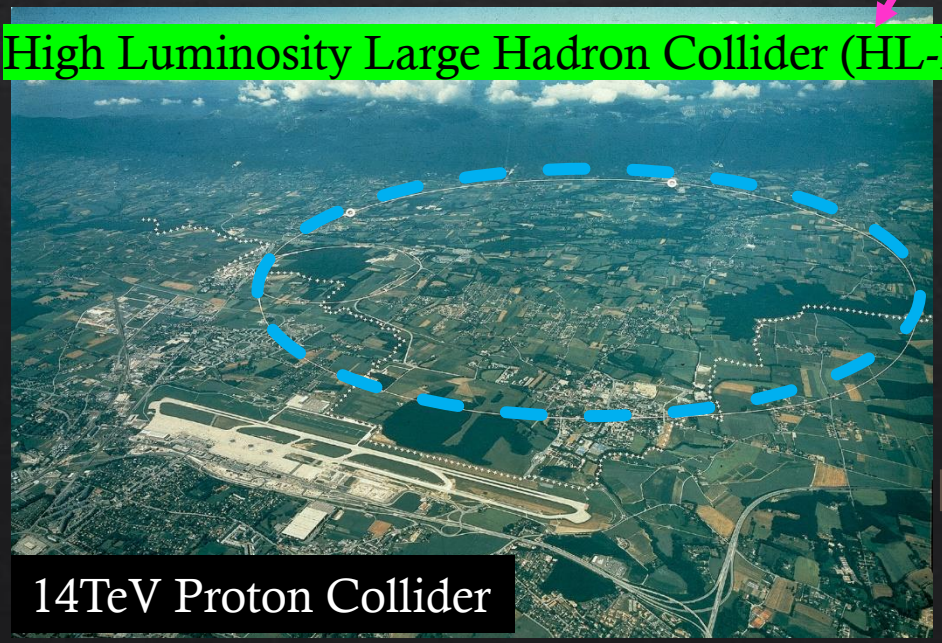
13.6TeV Proton collider

x10 Luminosity

2029～

Approved & constructing

High Luminosity Large Hadron Collider (HL-LHC)



14TeV Proton Collider

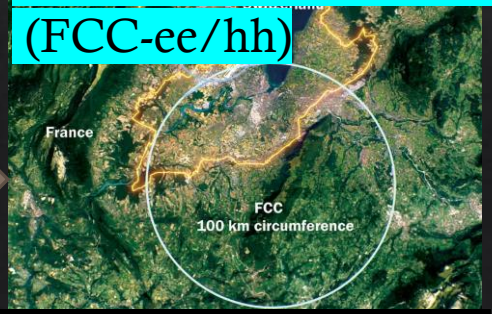
Planning Experiment

High Energy LHC

Twice Energy

7 times Energy

Future Circular Collider (FCC-ee/hh)

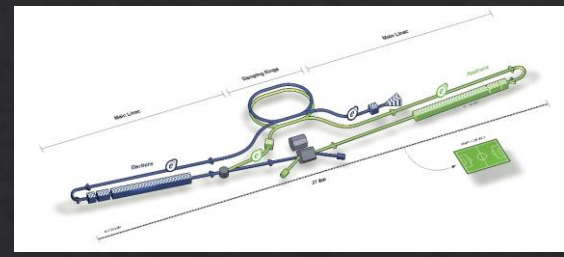


100TeV Proton Collider

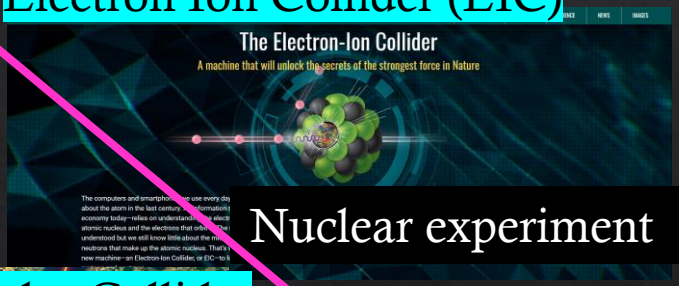
Preparing construction

International Linear Collider (ILC)

Focusing on Higgs measurement (e+e-)

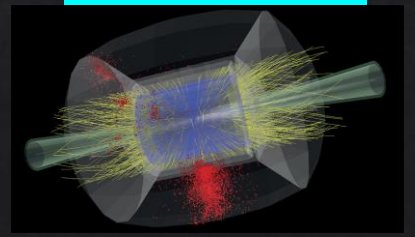


Electron Ion Collider (EIC)



Nuclear experiment

Muon Collider



Operating and Planning Collider Experiment

World highest energy collider !

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13.6TeV Proton collider

x10 Luminosity

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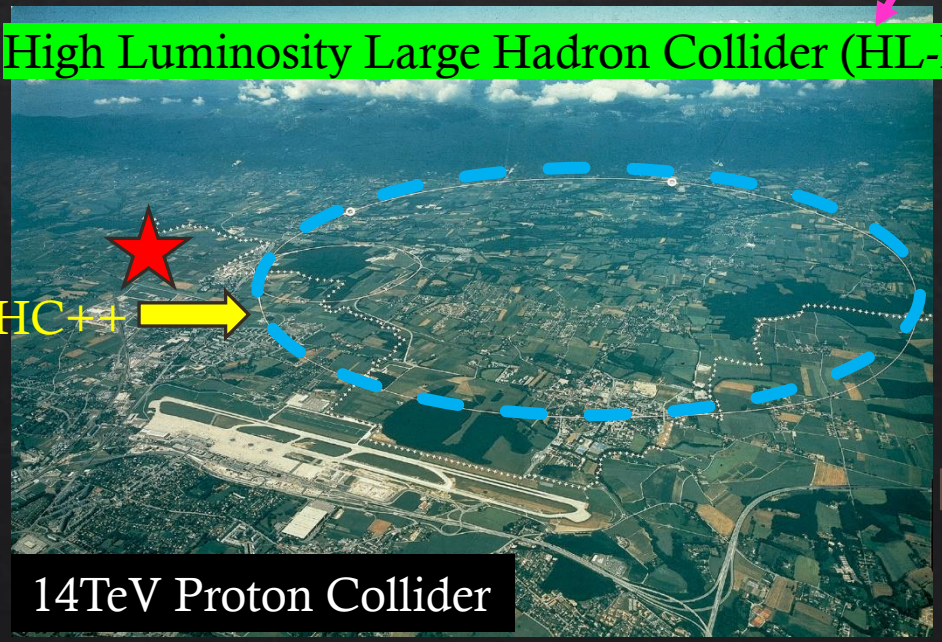
High Luminosity Large Hadron Collider (HL-LHC)



2034?
HL-LHC++

14TeV Proton Collider

Approved & constructing

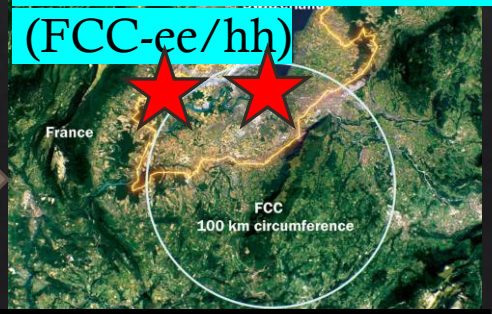
Planning Experiment

High Energy LHC

Twice Energy

7 times Energy

Future Circular Collider (FCC-ee/hh)



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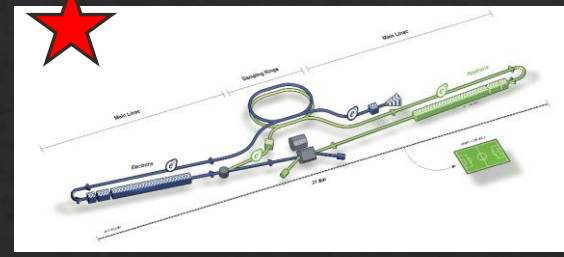

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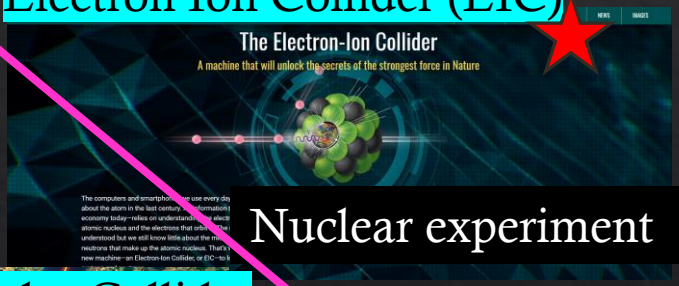
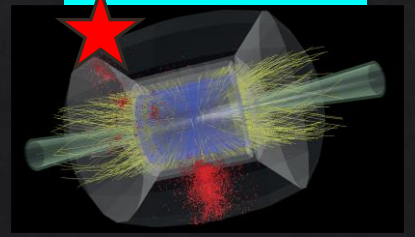


Nuclear experiment

Muon Collider

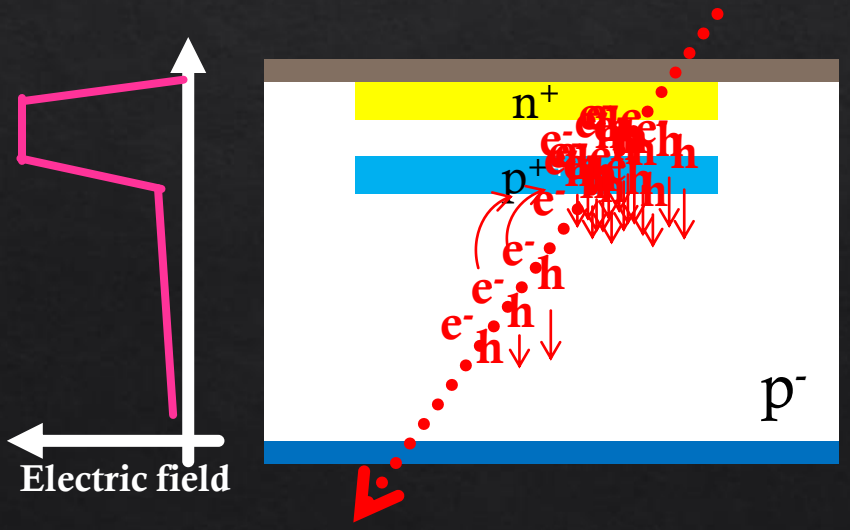


Timing Tracker is necessary for all of these colliders

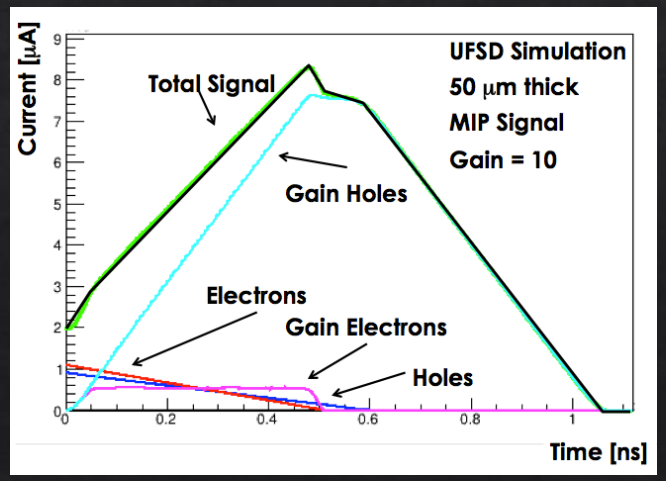
Low Gain Avalanche Diode (LGAD)

- Low gain Avalanche Diode (LGAD)
  - General n^+-in-p type sensor with p^+ gain layer under n^+ implant to make very high Electric Field at the surface.

    → Good timing resolution.
  - **30ps timing resolution achieved already in 2015.**

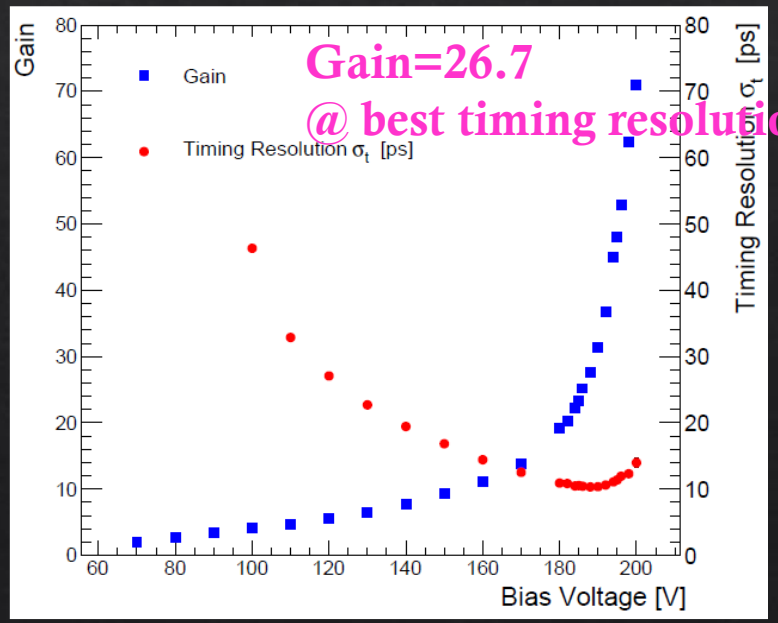


Signal drivers : **Gain Holes**



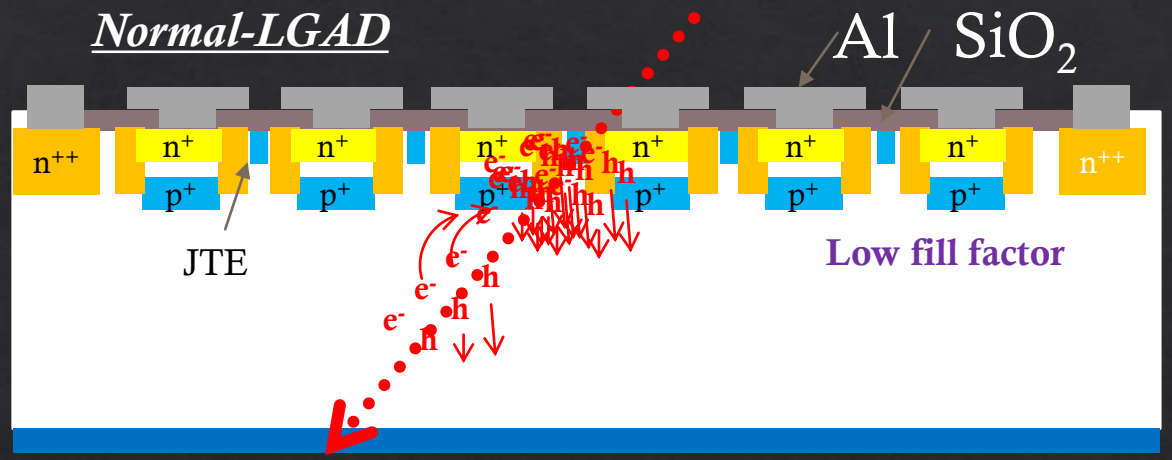
Cartiglia et al., NIMA 796, p141-148, 2015

Gain measurement (AC-LGAD):



Spatial resolution of LGAD

- Segmented LGAD :
  - To have spatial resolution, strip sensors has been processed.
  - Need **Junction termination extension(**JTE) and p-stop structure to have individual gain layer →**Low fill factor (20% for 80um strip)**



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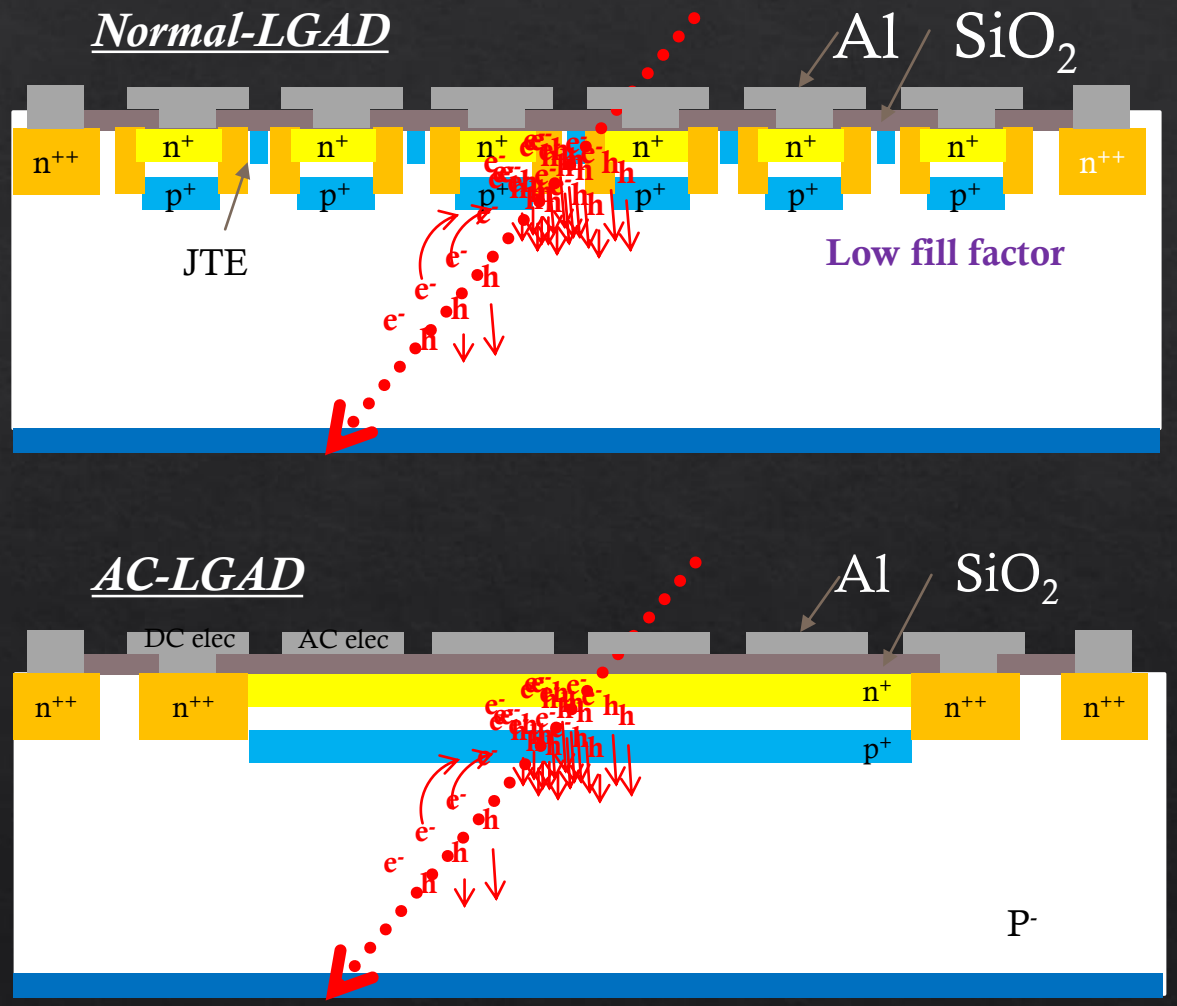
  - To have spatial resolution, strip sensors has been processed.
  - Need **Junction termination extension(**JTE) and p-stop structure to have individual gain layer →**Low fill factor (20% for 80um strip)**
- **Uniform gain layer with AC-Coupled electrode. (AC-LGAD)**
  - **In principle, 100% fill factor.**
  - **Signal shared on neighboring electrodes.**
    - Need optimization of n+ resistivity



Achievement : Spatial resolution

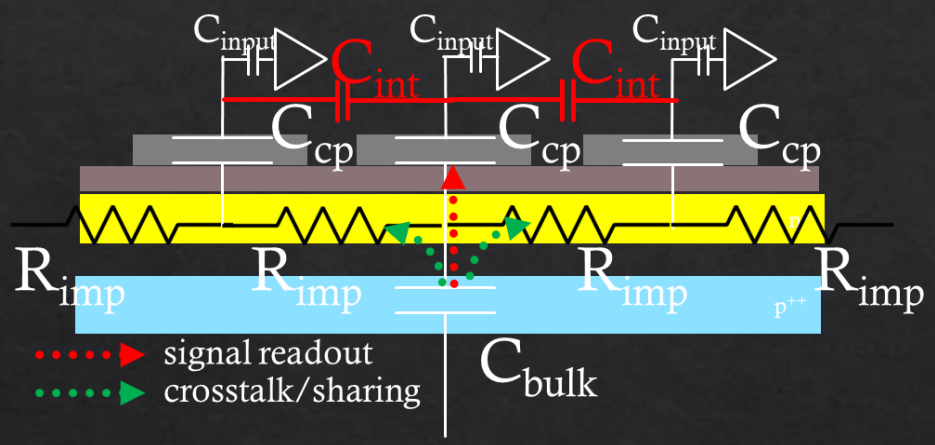
- Charge split : Impedance ratio

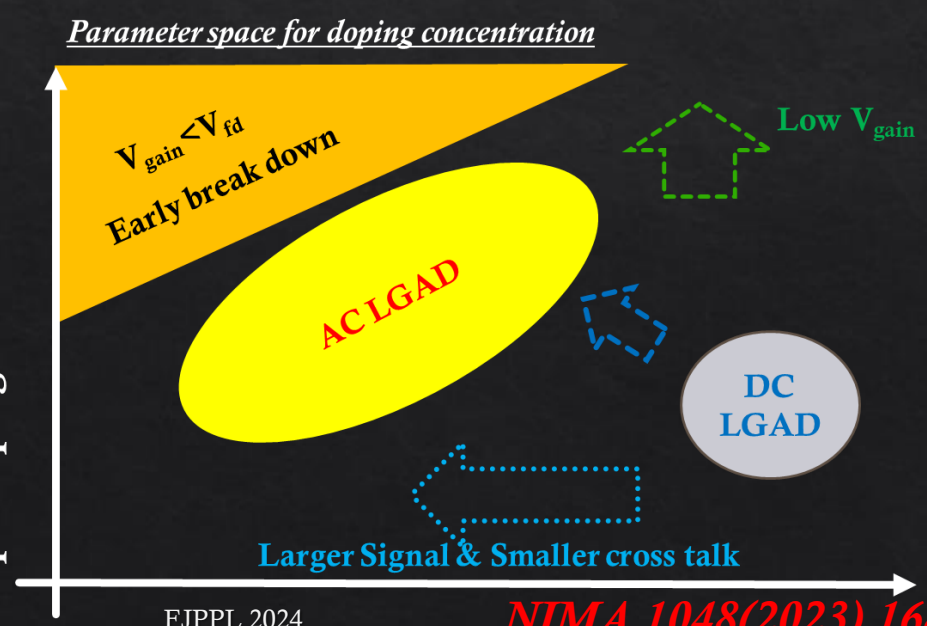
$$Q = \frac{Z_{R_{imp}}}{Z_{R_{imp}} + Z_{C_{cp}}} Q_0$$

Assuming Z_{Cbulk},Z_{cint}>>Z_{Ccp}…

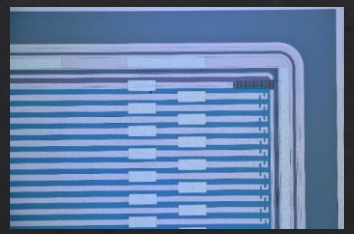
- Amount of produced charge:Q_0
- Readout Charge :Q

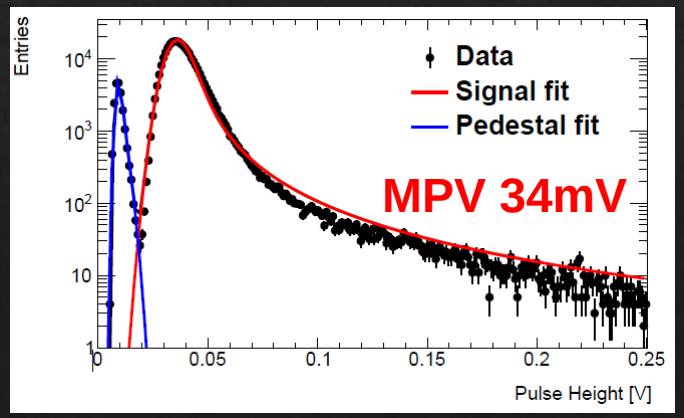
Read out principle of AC-LGAD



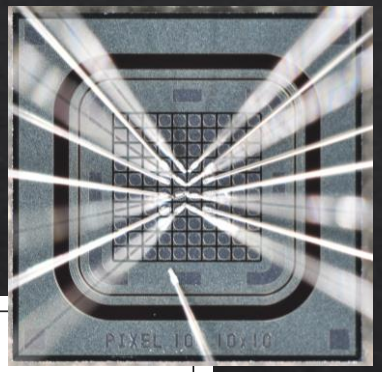


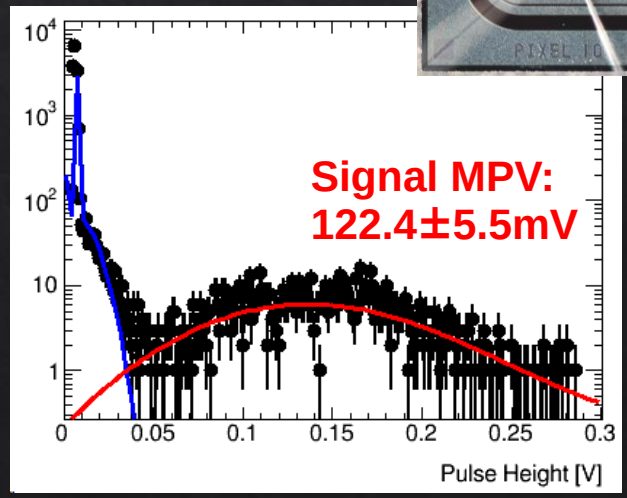
Strip type 80um pitch (10mm)





Pixel Type 100um pitch





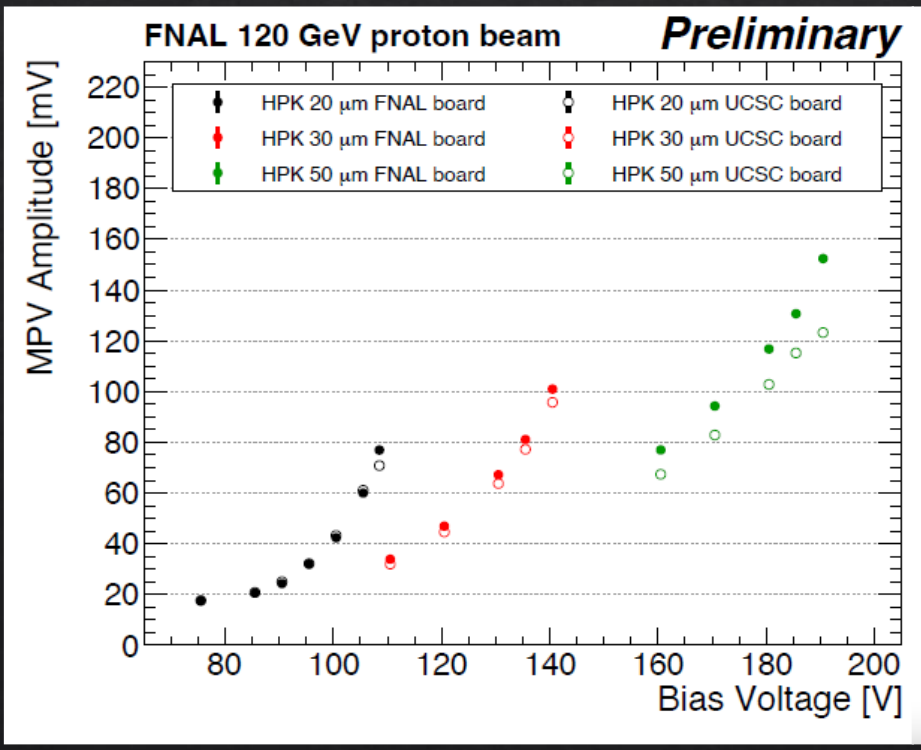
First fine segment AC-LGAD detector !

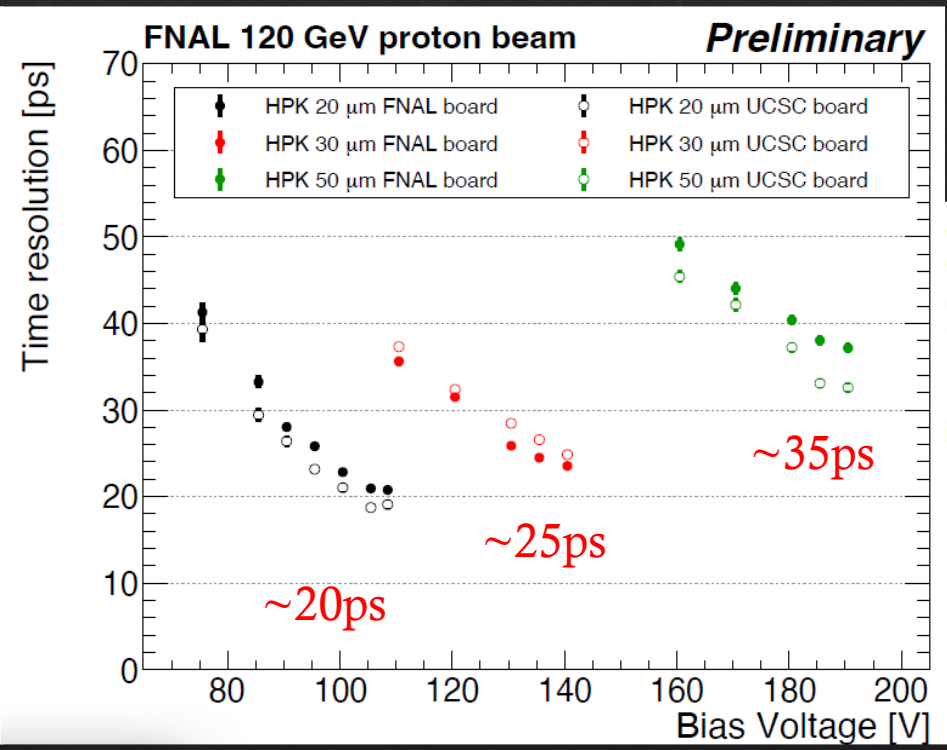
NIMA 1048(2023) 168009

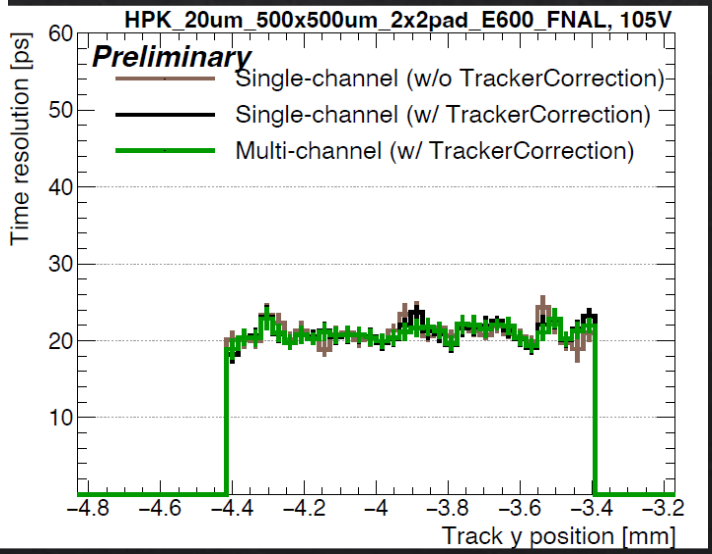
VERTEX2022(arXiv:2305.12355)

Improvement of timing resolution

- To reduce Landau noise : Fabricated 50um, 30um and 20um thick sensors
  - Signal size (amplitude) is smaller in thinner sensors.
  - **20um thick sensor has the best timing resolution : ~20ps**
  - **Uniform timing resolution at the gap region as well.**







Readout ASIC development

- HL-LHC upgrade : ATLAS High Granular Timing Detector (HGTD)
  - Insert 2 disks of HGTD detector between Inner Tracker and Calorimeter.
- ALTIROC ASIC
  - Targetting a 25ps time resolution

Plan : Application this technology to AC-LGAD readout ASIC

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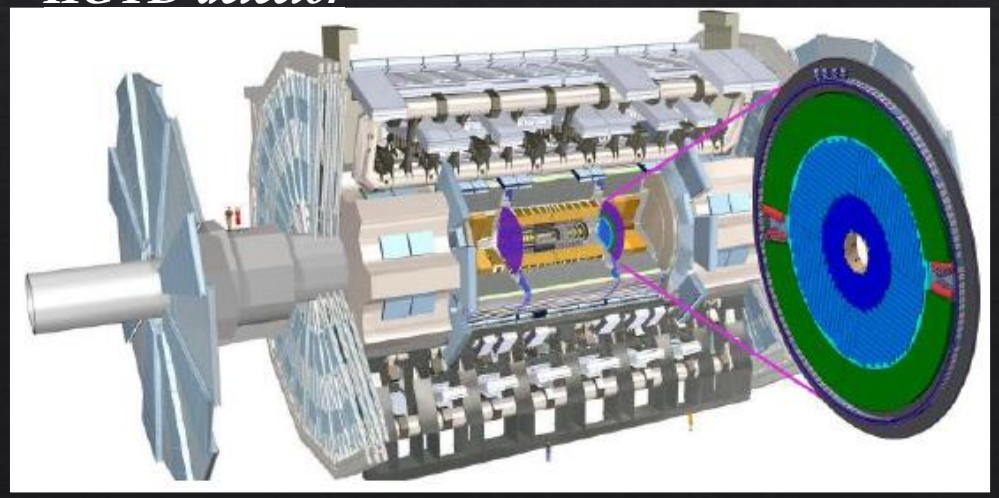
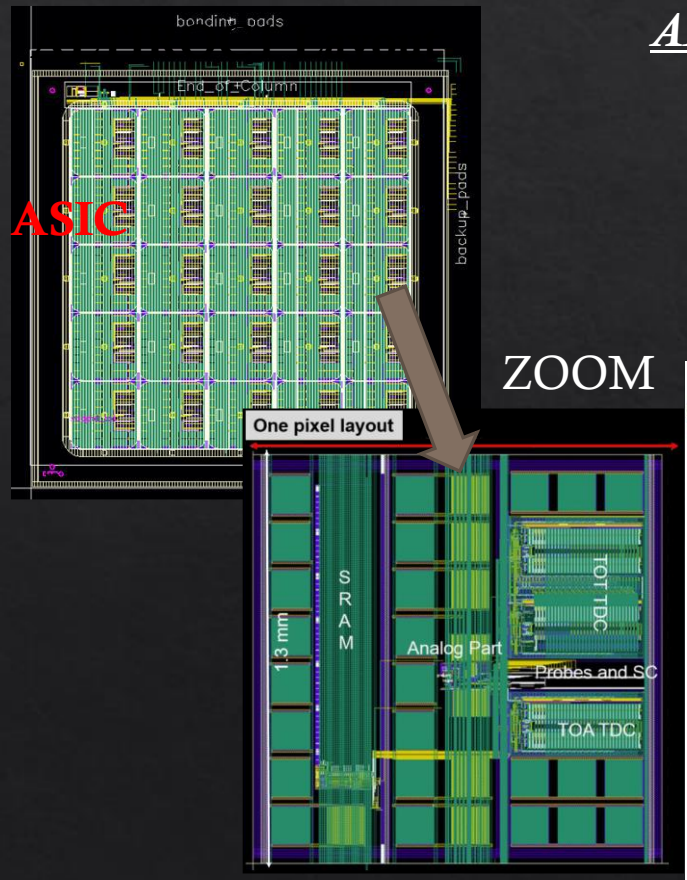
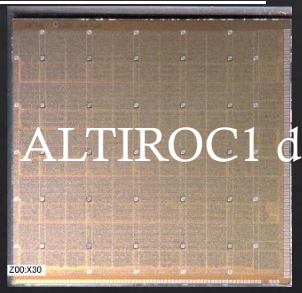
HGTD detector



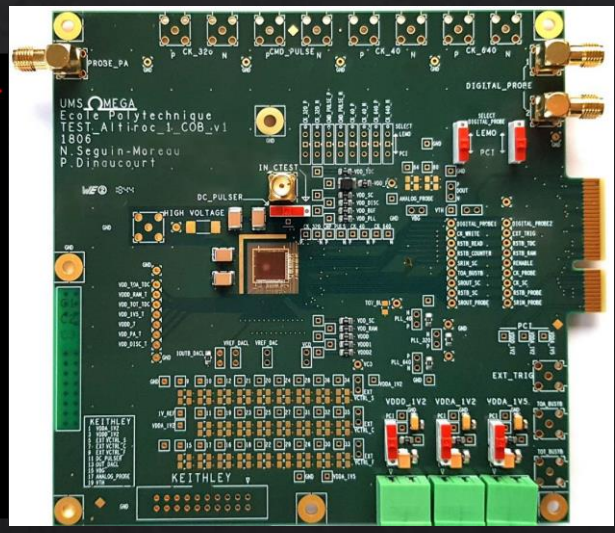


ZOOM

ALTIROC1 ASIC



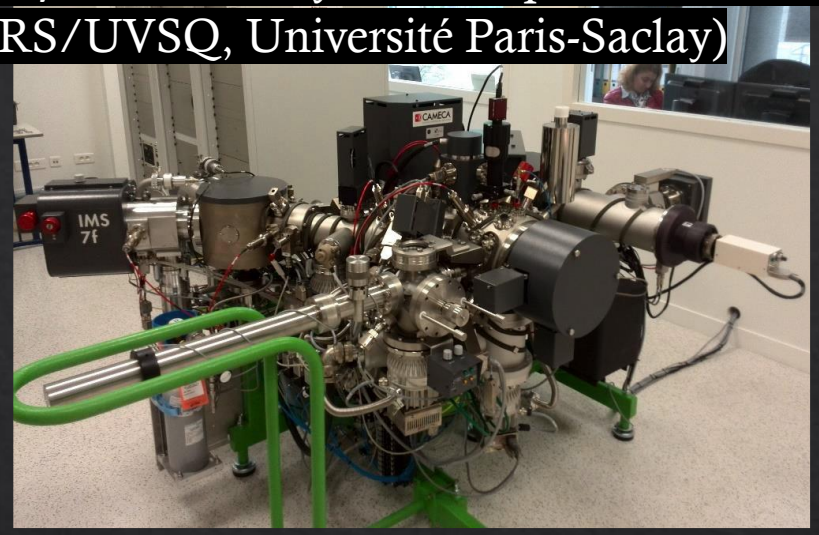
ALTIROC1 die

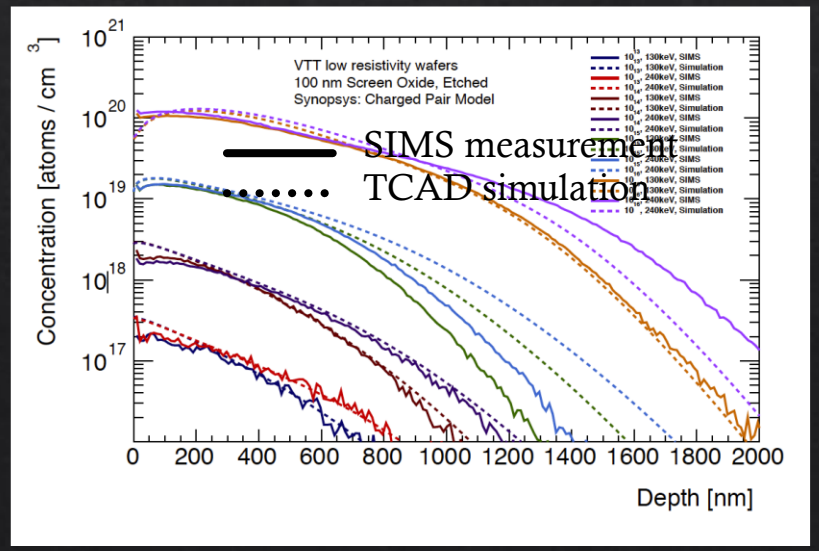


Secondary Ion Mass Spectrometry and Simulation

- 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 Analyseur ionique du GEMaC (CNRS/UVSQ, Université Paris-Saclay)

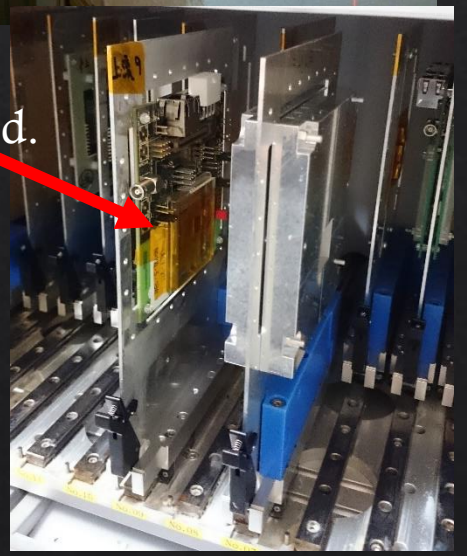




CYRIC : Irradiation Facility in Japan

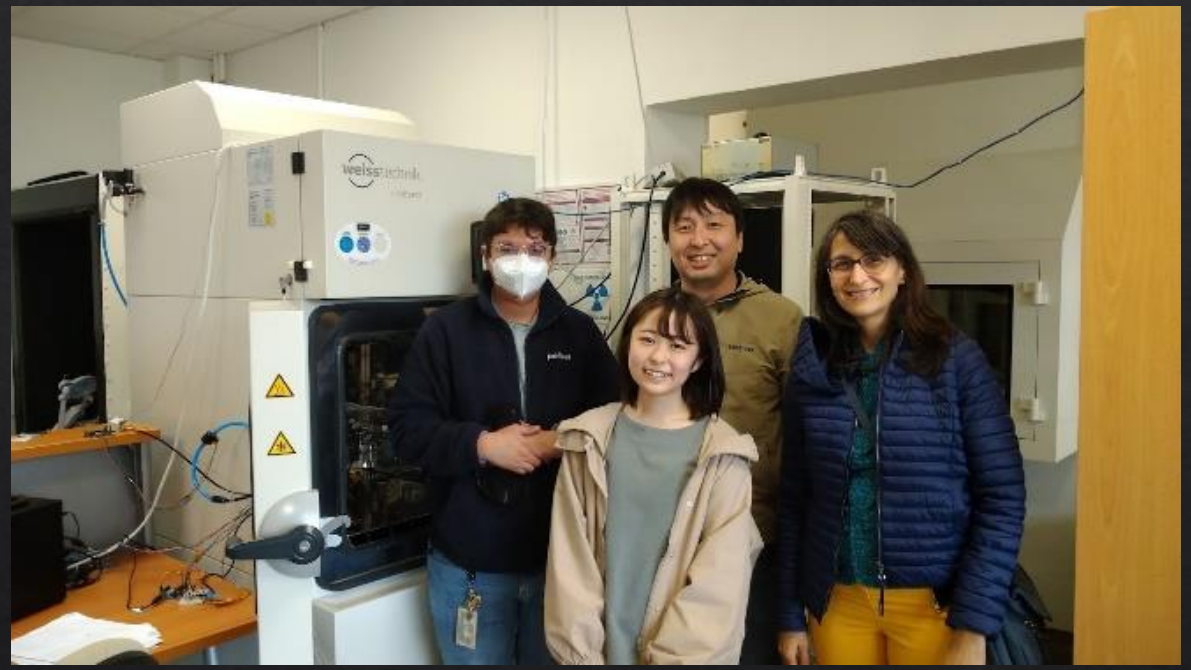
- CYRIC@Tohoku Univ.
  - An irradiation facility with 70MeV proton beam (~1μA beam current).
    - 3-5 hours for $3x10^{15}n_{eq}/cm^2$ irradiation with (600nA beam)
  - This allows 2-3 pixel modules with Al plate at the same time(3% E loss/module).
  - Operated at -15°C temprature with dry N_2 gas.
  - Scanning over full pixel range during irradiation.
  - Historically French prototype samples have been tested at CYRIC as a collaborative work.
- Facility for AC-LGAD development
  - Using this facility by sensor development very often (KEK)
  - In future, ASIC and module radiation tolerance test will be performed to develop AC-LGAD module (i.e. with sensor and ASIC)

Feb 2017
LAL's Pixel Mod.
(Active Edge)

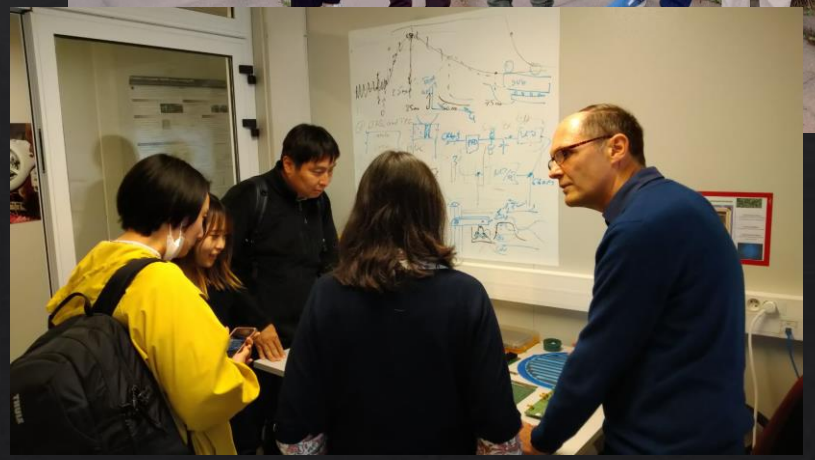


Exchange people and experience

Japanese team visiting IJClab to discuss plan
and to exchange experience. 2022.9



Japanese team visiting IJClab and Omega lab
to learn and discuss electronics (ASIC) 2023.11



Summary

- Silicon tracking detector with **spatial and timing resolution** is promising to improve physics performance for future collider experiment.
  - **AC-LGAD** developed by HPK/KEK should be a strong candidate
    - Need improvement especially for radiation tolerance
    - Laser setup to test general LGAD is in preparation at IJClab
  - **ALTIROC ASIC** developed for ATLAS HGTD detector
    - This technology will help to readout AC-LGAD signal.

  → **Synergy of these activities will make extremely effective R&D**
- Existing collaboration with following Facility and expertise
  - Secondary Ion Mass Spectroscopy (SIMS)
  - CYRIC proton irradiation facility

Mainly we request funding for

1) **Exchange people between FR-JP share experience.**
2) **SIMS measurement to understand AC-LGAD**

Backup

AC-LGAD collaboration