IJC/IN2P3

KEK Tsukuba HEP

2021 Joint workshop of FKPPL and TYL/FJPPL

New Project of FJPPL (D_RD_23):

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

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Next generation of Collider experiment

- **Need "Higher Luminosity" and/or "Higher Energy"**
  - ***High Luminosity LHC (HL-LHC)***
    - 20 times more data (~3000-4000fb^{-1}) at **14TeV**
    - Plan : Start at 2027

Coming soon

  - ***High Energy LHC (HE-LHC)***
    - Use Super Conducting Magnet with Higher Magnetic field(16T)
    - **28TeV** collider in the same tunnel as LHC.

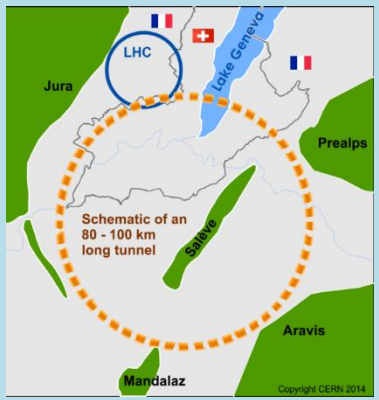
Discussion Started

  - ***Future Circular Collider (FCC-hh)***
    - Use Super Conducting Magnet with Higher Magnetic field(16T)
    - **100TeV** collider with 100km tunnel at CERN.

Discussion Started

  - ***International Linear Collider (ILC)***
    - 250GeV e+ e- collider in Japan

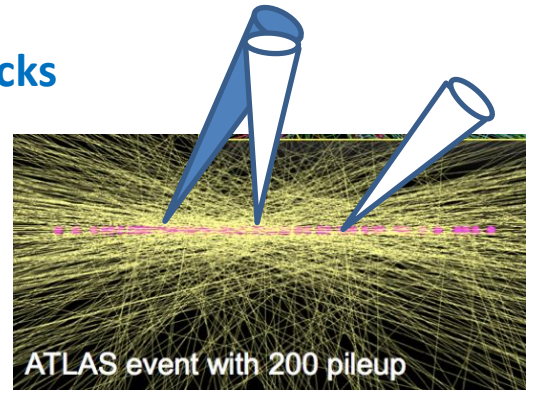
Final decision soon



Inner Tracking system

Very high density tracks

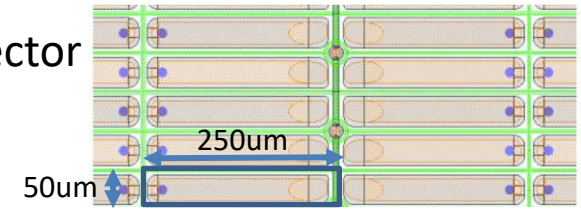
140 pileup @ HL-LHC
1500 pileup @ FCC-hh



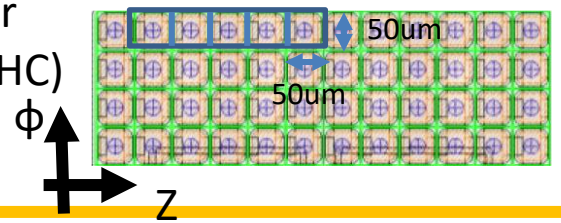
Only way to solve this so far…

finer pixel pitch

Current detector
(ATLAS IBL)



New detector
(Pixel @HL-LHC)

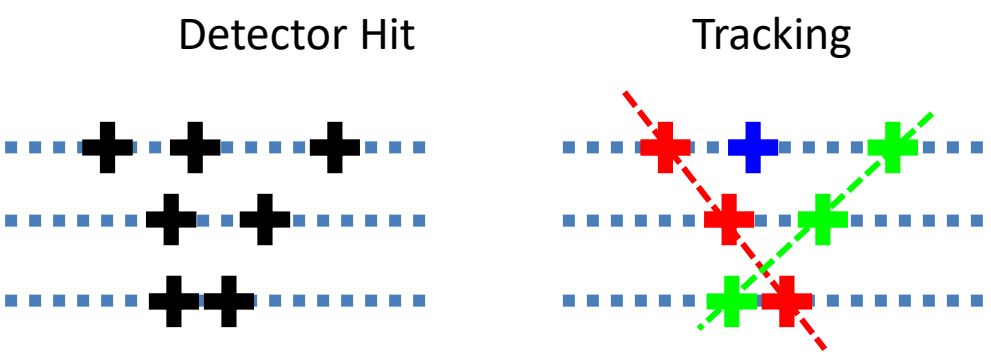


Future Semi-conductor Tracking Detectors

- **Further finer pitch pixel detector → Limited by front end Electronics (min : 50x50um^2)**
  - In addition to spatial resolution, **Timing resolution helps!**

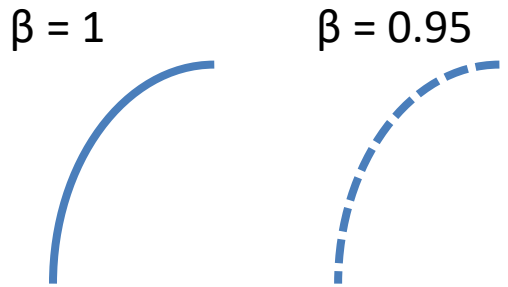
  →New generation of Tracking detector should have timing information for all hits!
- **Tentative Requirement**
  - **30ps timing resolution**
  - **~o(10)um spatial resolution (Pixel type).**
  - **(hadron collider) ~o(10^{16})n$_{eq}$/cm^2 radiation tolerance**

4D tracking !



Solve pileup hits in an event

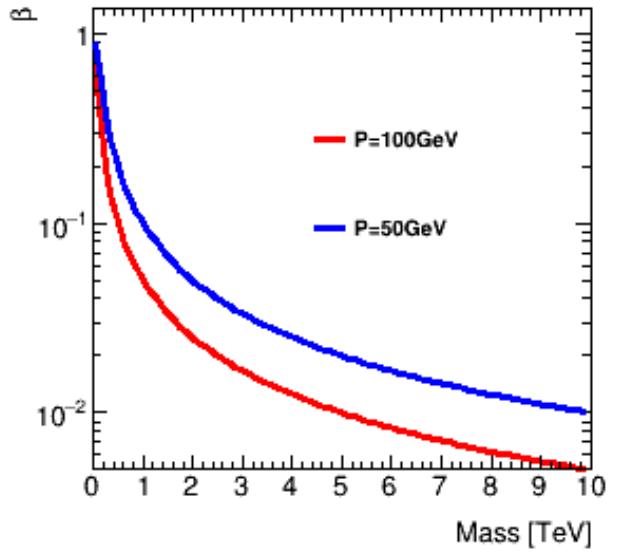
Particle identification



150ps difference at R=1m

K+ π+ separation

Mass spectrum for new particle

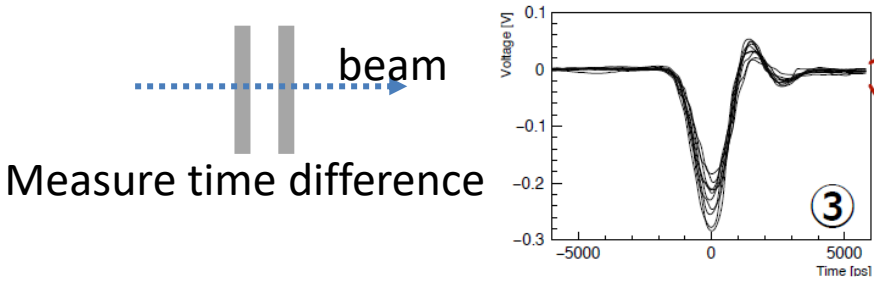


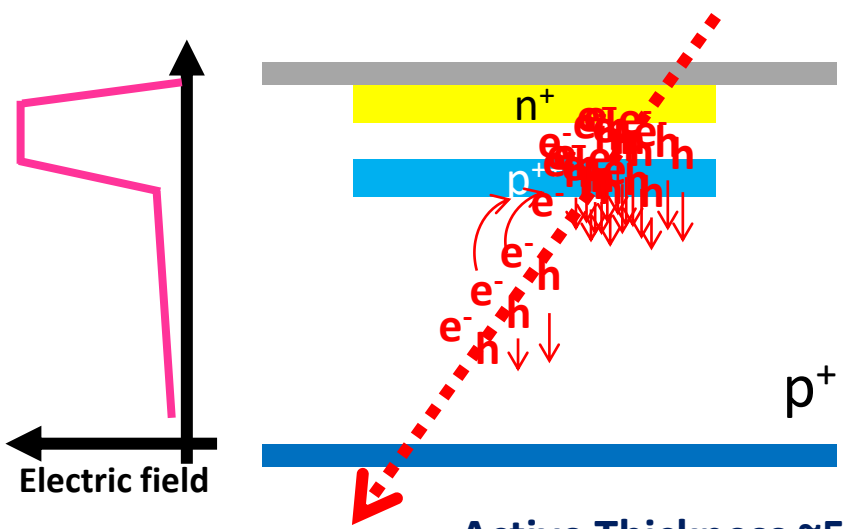
β measurement to obtain mass

e.g. Mass measurement for Long lived chargeno

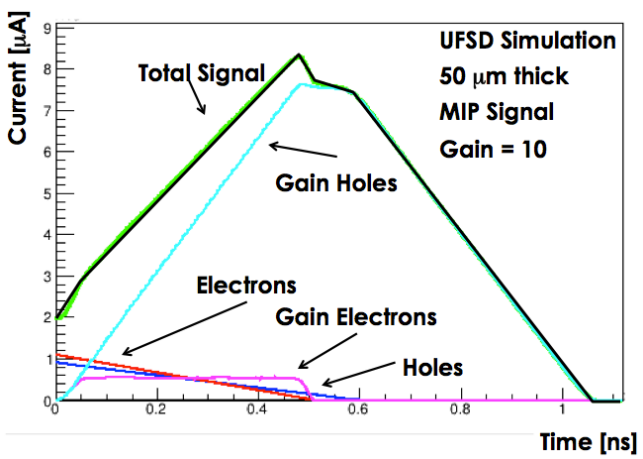
Low gain Avalanche Diode (LGAD)

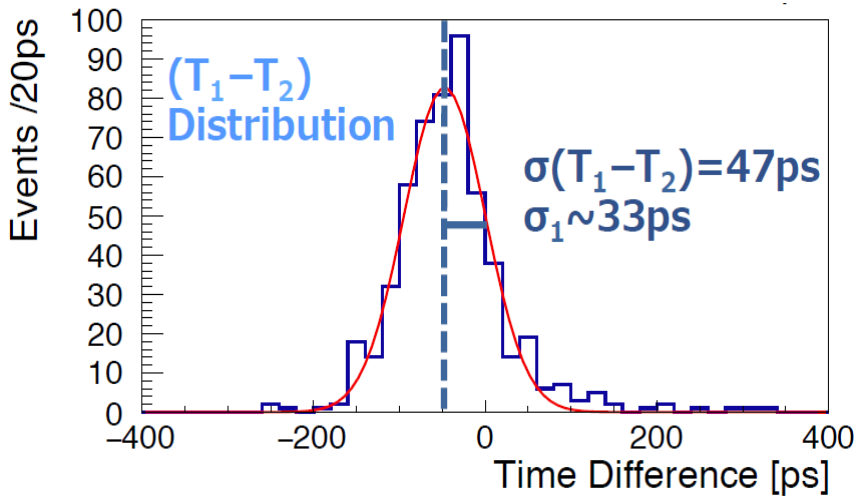
- Low gain Avalanche Diode (LGAD)
  - General n^+-in-p type sensor with p^+ gain layer under n^+ implant to make higher Electric Field → Good timing resolution.
  - **30ps timing resolution achieved already.**
  - Next development
    - **Finer electrode separation for spatial resolution**
    - **Radiation tolerance**





Signal drivers : **Gain Holes**

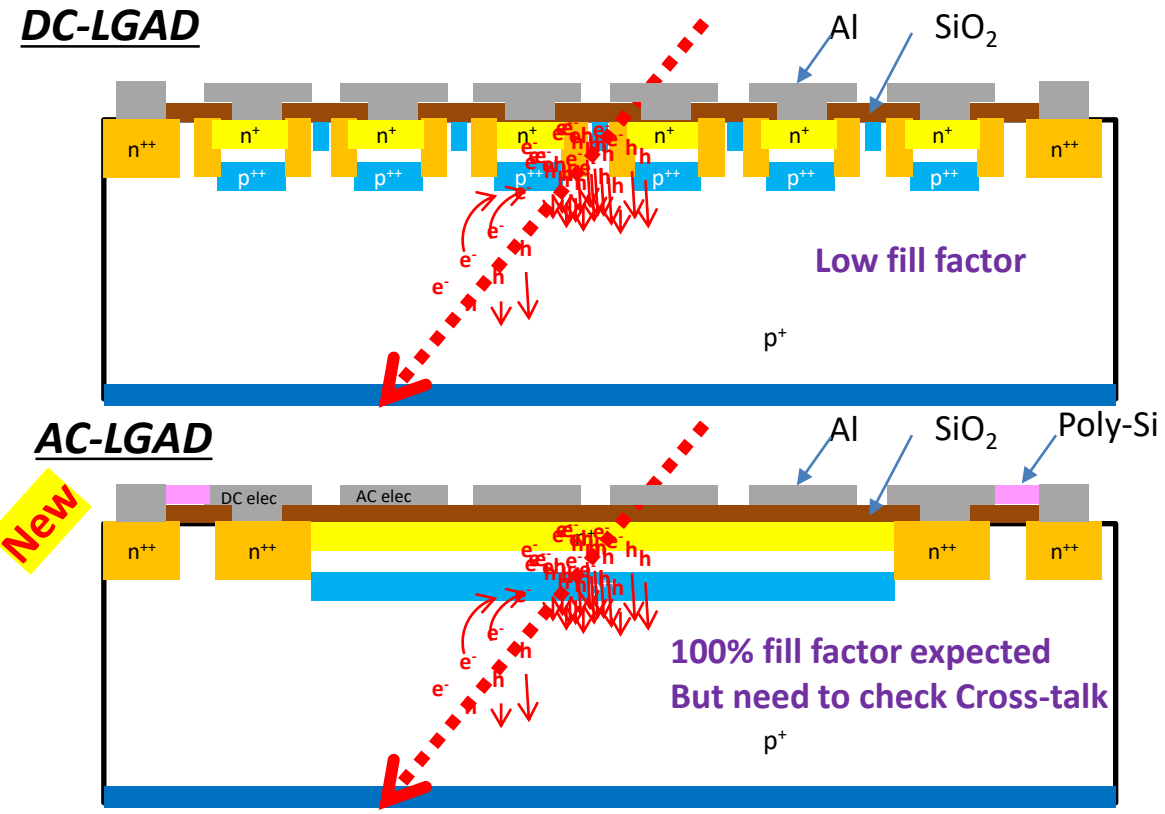


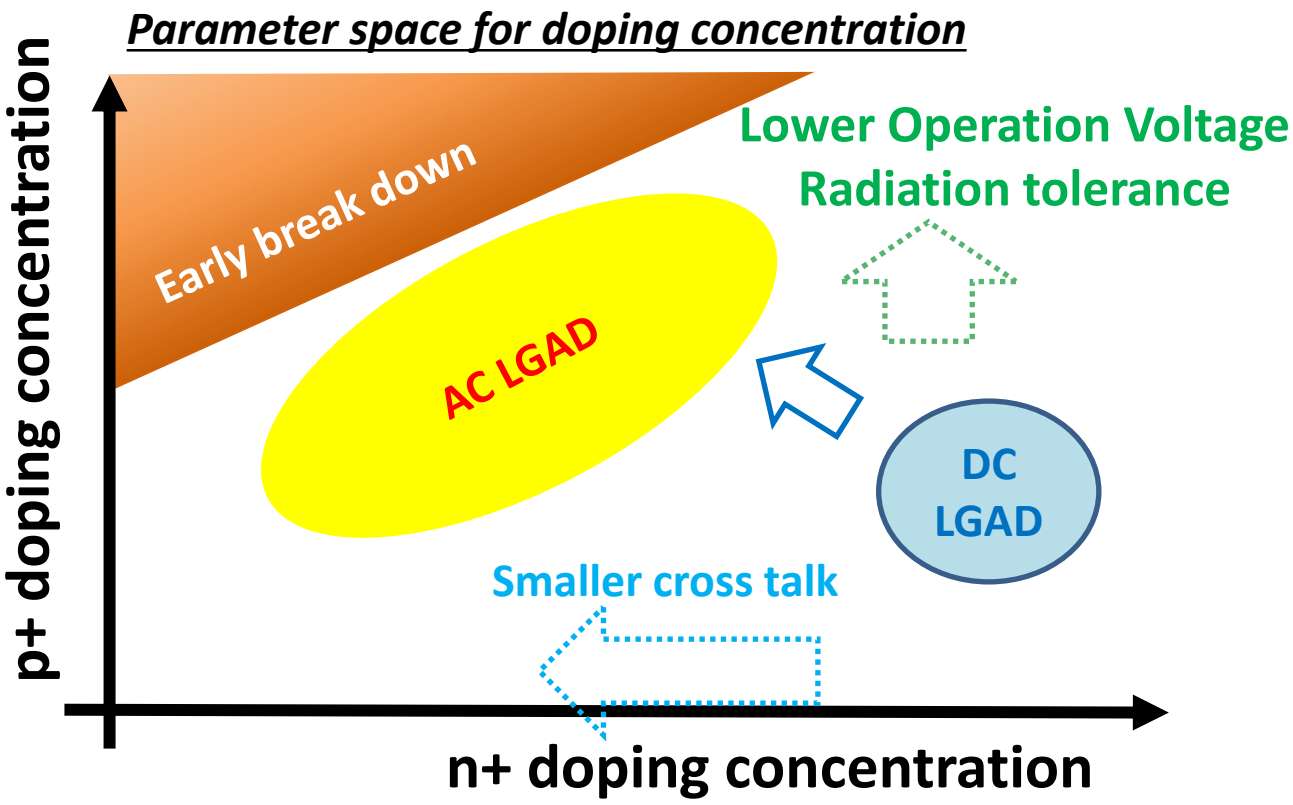


Active Thickness ~50um

Detector with both spatial and timing resolution

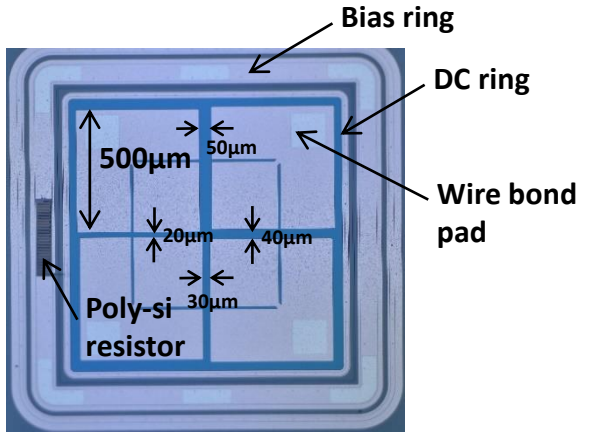
- First prototype with 80um pitch strip (DC-LGAD)→**Only 20% of active area has gain**
- Common gain layer with AC-coupled readout (AC-LGAD) → **Uniform gain expected!**
  - **Cross talk expected in the n^+ implant → Increase resistivity of n^+ implant**



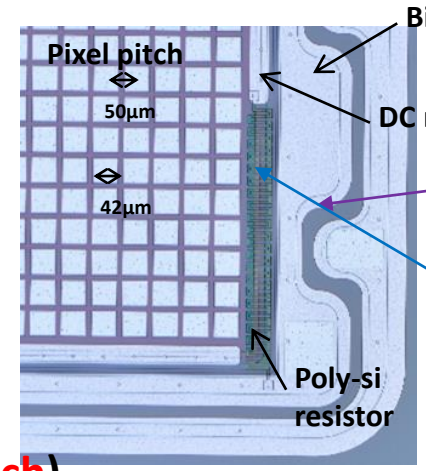


First AC-LGAD by KEK/HPK

Pad type sensor (4x 500umx500um)



Pixel type sensor (14x14 50umx50um)



Active Thickness : 50um

GNDed DC ring via Poly-si

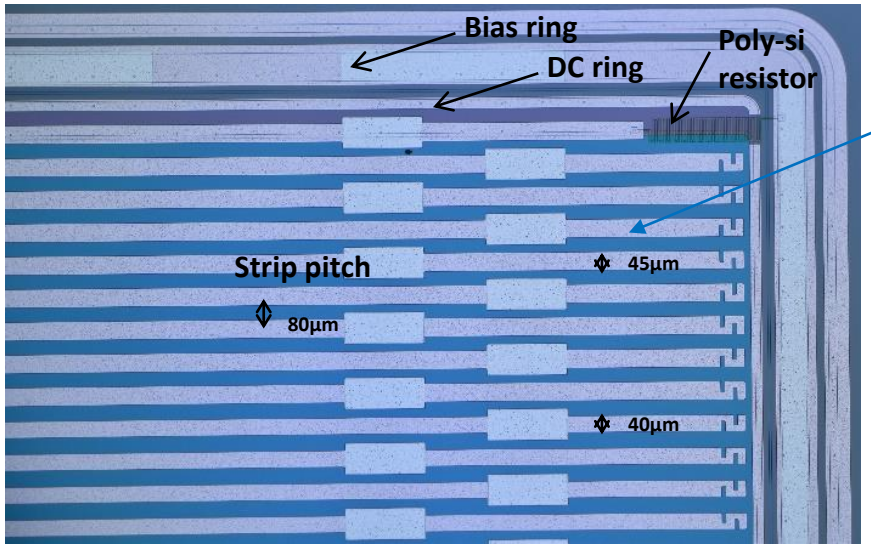
→ To remove charge in n+

Varied Al size (AC coupling capacitance)

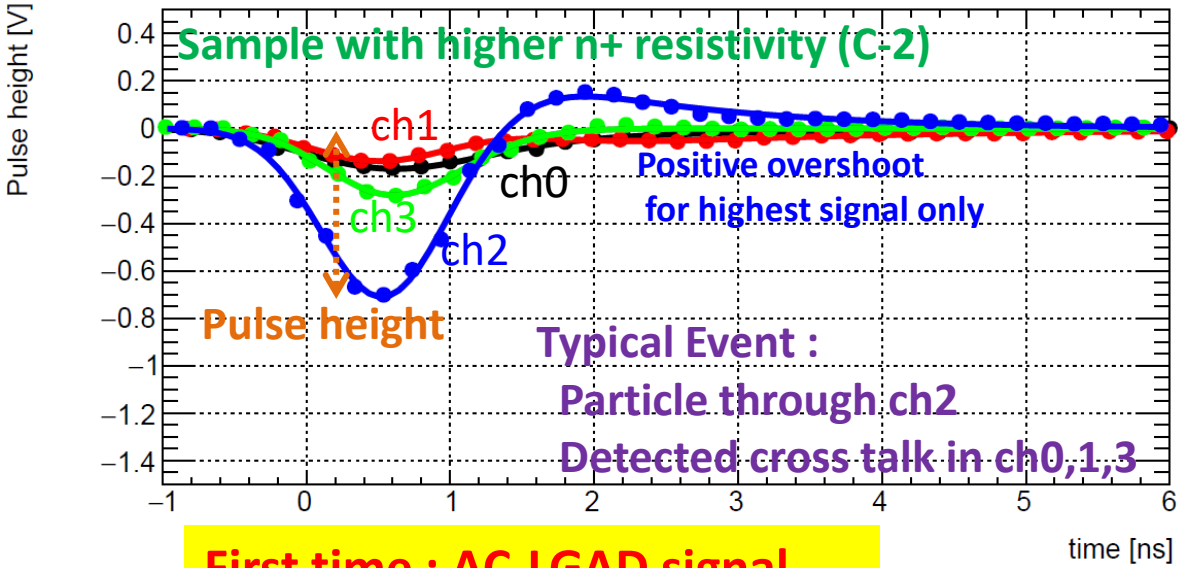
Pixel : 42/38/34/30 um width/length

Strip : 45/40/35/30 um width

Strip type sensor (16x 80um pitch)



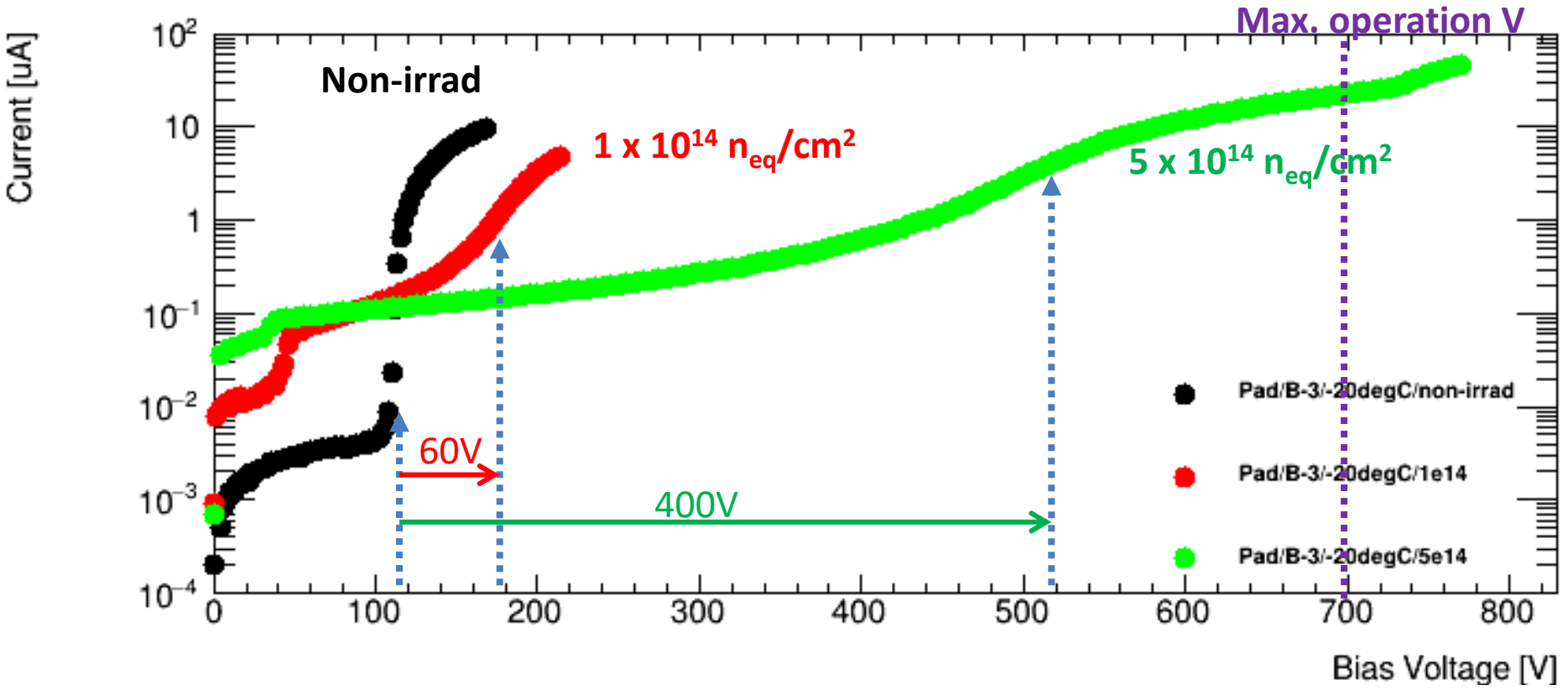
HV : 170V



First time : AC-LGAD signal observed with small crosstalk

IV performance after irradiation

- Irradiated sensors at CYRIC (Tohoku university) with 70MeV Proton.
- Operation/Gain voltage get higher by irradiation (almost linearly)
  - **Current sensor does not work after 1x10^{15}n$_{eq}$/cm^2 fluence or more.**



Signal Size

Fluence	Signal MPV
Non-irrad	35±2 mV
1x10^{14}n$_{eq}$/cm^2	39±1 mV
5x10^{14}n$_{eq}$/cm^2	30±2 mV

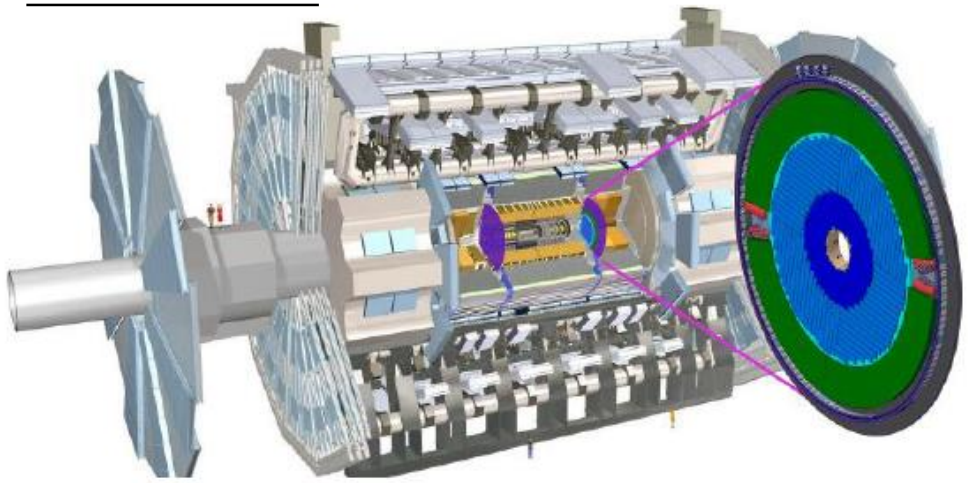
5x10^{14}n$_{eq}$/cm^2 may have slight decrease of signal (But keep at least ~75%)

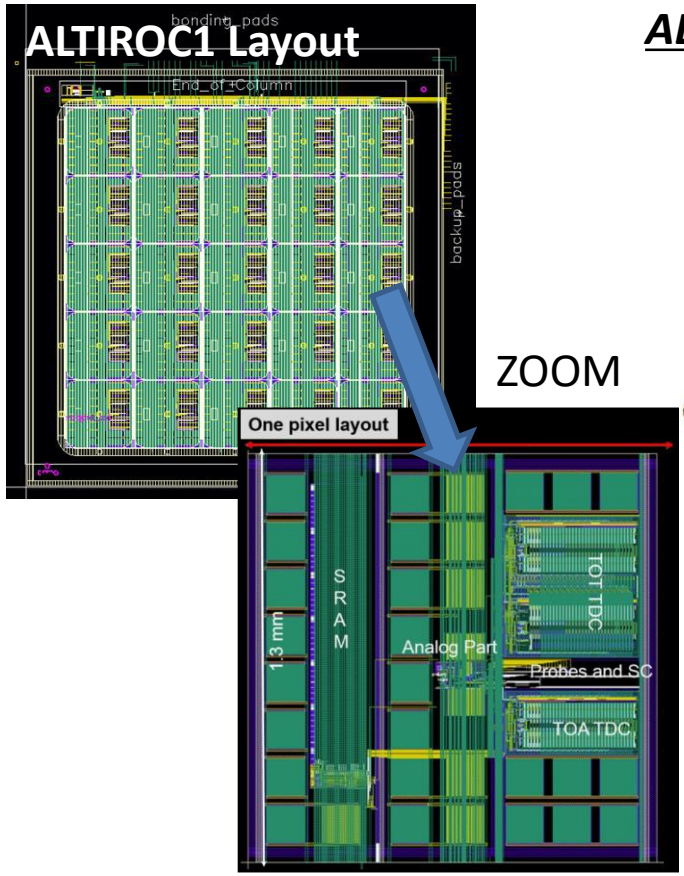
Readout ASIC development

- 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

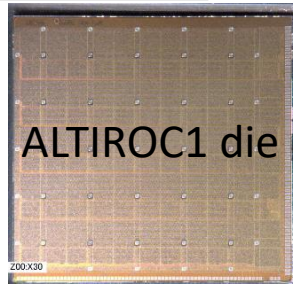
HGTD detector

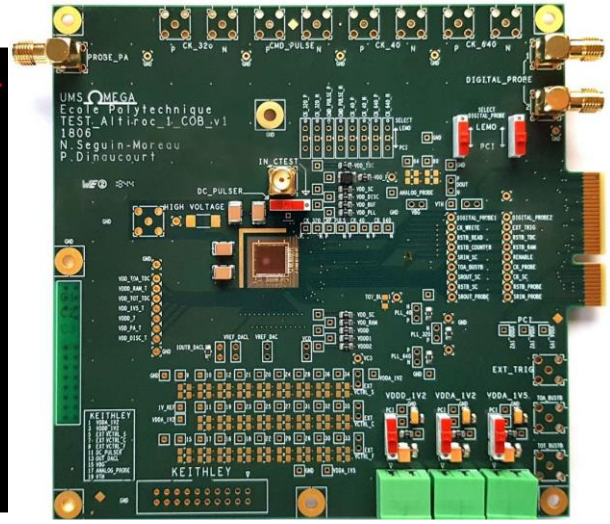




ZOOM

ALTIROC1 ASIC





Summary

- Silicon tracking detector with **spartial 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
  - **ALTIROC ASIC** developed for ATLAS HGTD detector 
    - This technology will help to readout AC-LGAD signal.

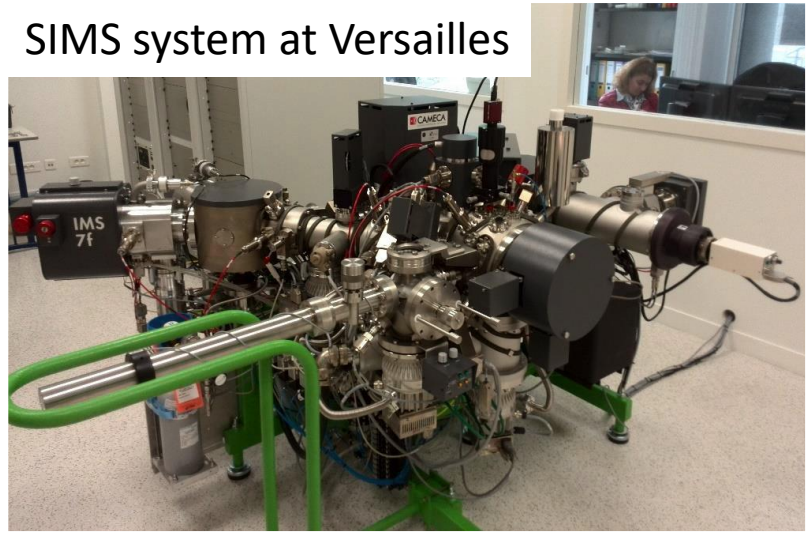
  → Synergy of these activities will make extremely effective R&D
- Existing collaboration with following Facility and expertise
  - Secondry Ion Mass Spectroscopy (SIMS) 
  - CYRIC proton irradiation facility 

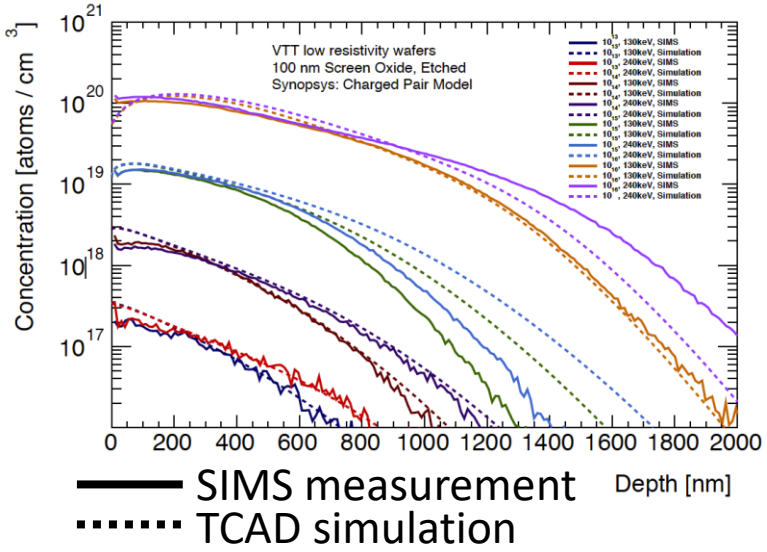
Mainly we ask funding for exchange people between FR-JP
Share experience/common development

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

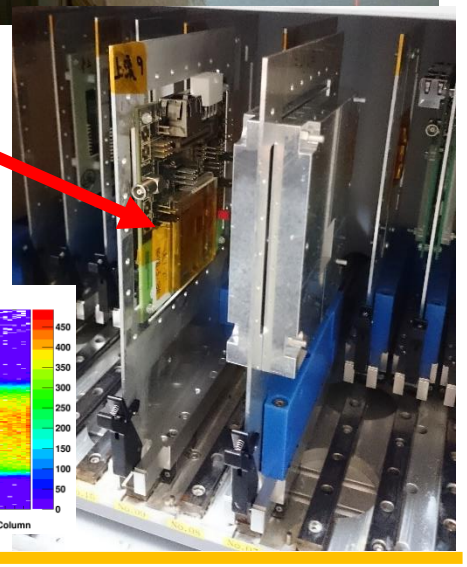




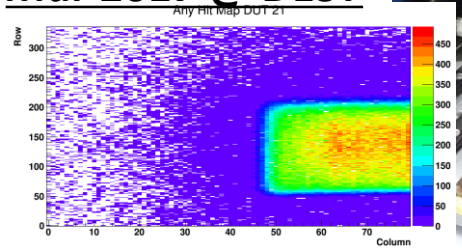
CYRIC : Irradiation Facility in Japan

- 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)



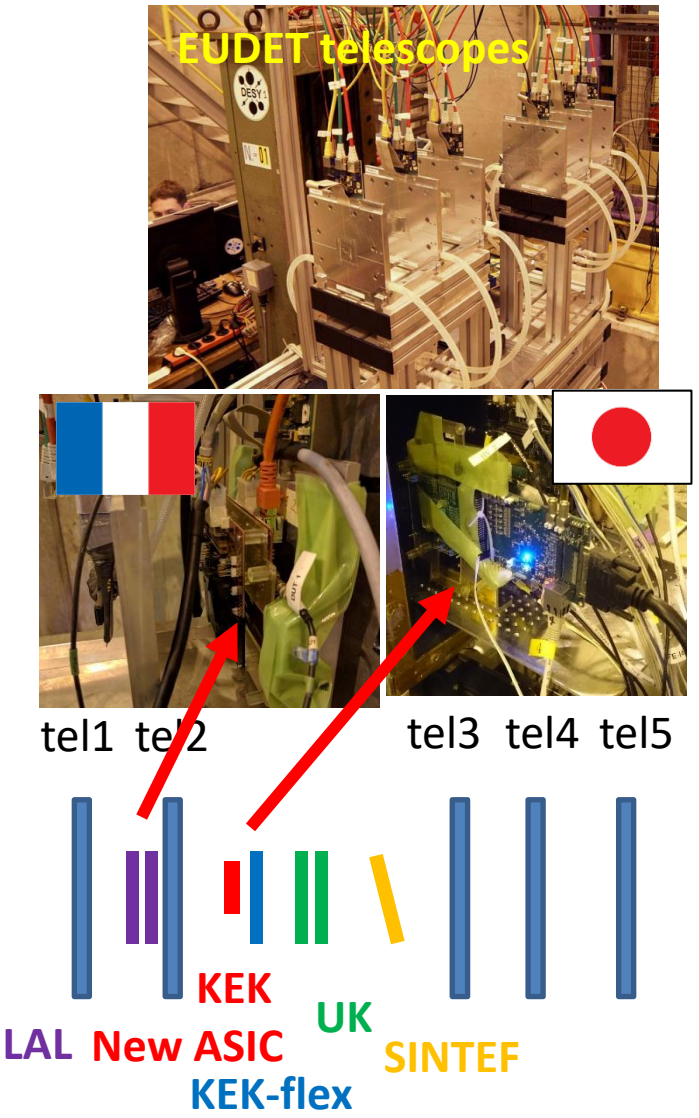
Mar 2017 @ DESY



backup

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.

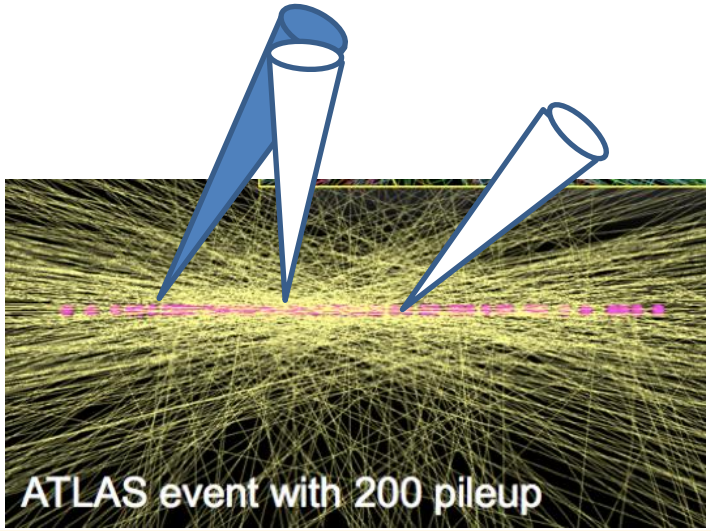


Framework : ATLAS Upgrade for HL-LHC

- **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)



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**