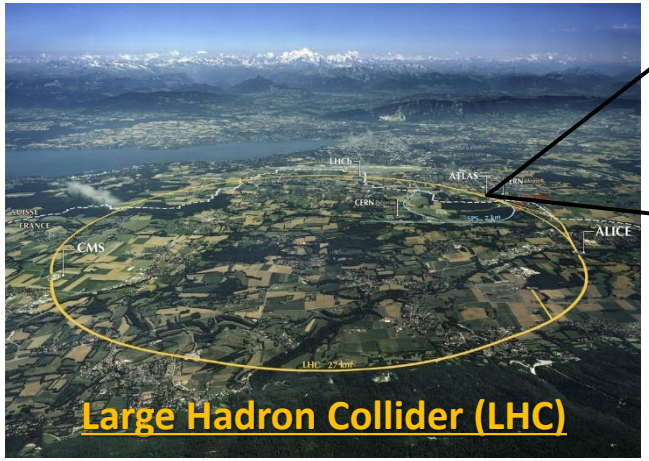
Production of microstrip silicon sensors for HL-LHC ATLAS ITk

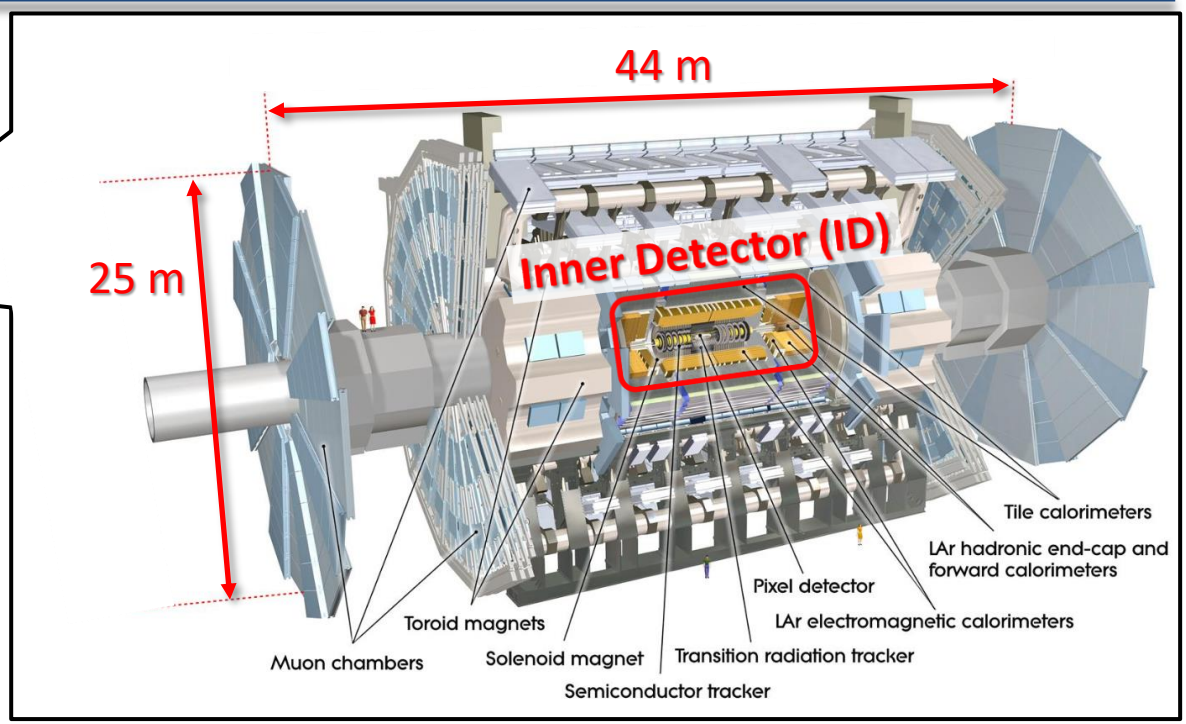
22 March 2022, TCHoU Workshop

Shigeki Hirose (U. Tsukuba)

K. Kuramochi (Tsukuba), K. Hara (Tsukuba), Y. Hiemori (Tsukuba),
T. Ishii (Tsukuba), K. Nakamura (KEK), K. Saito (Tsukuba), K. Sato (Tsukuba)
and the ATLAS ITk Strip Sensor team

ATLAS experiment at LHC



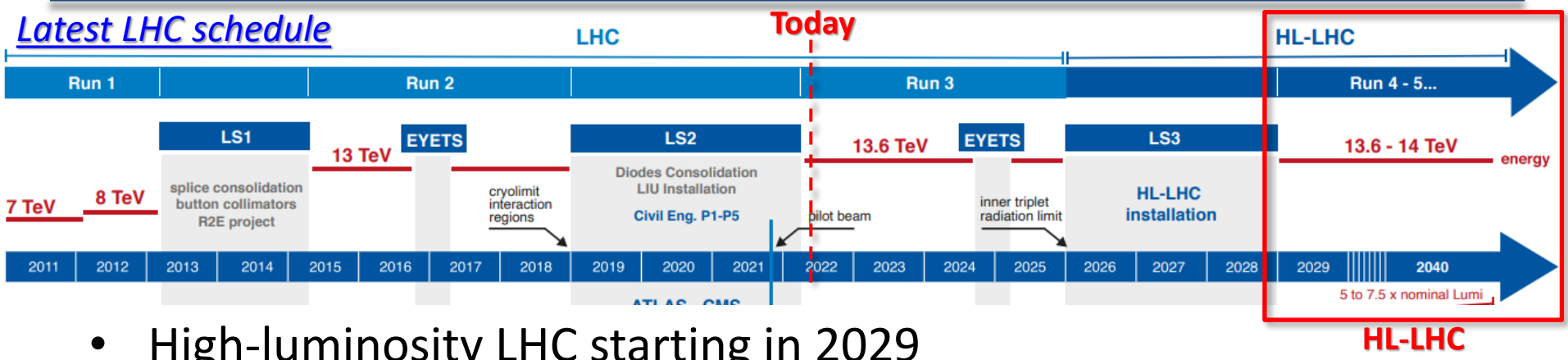


- Circumference = 27 km
- pp collision at $\sqrt{s}$ = 13 TeV
- Bunch per 25 ns

- ATLAS detector
  - Targets high-p_{T} objects from decays of heavy particles
  - Severe environment of pp collisions due to QCD

  → Track finding performance of ID is essential for any physics analyses

Upgrades for HL-LHC



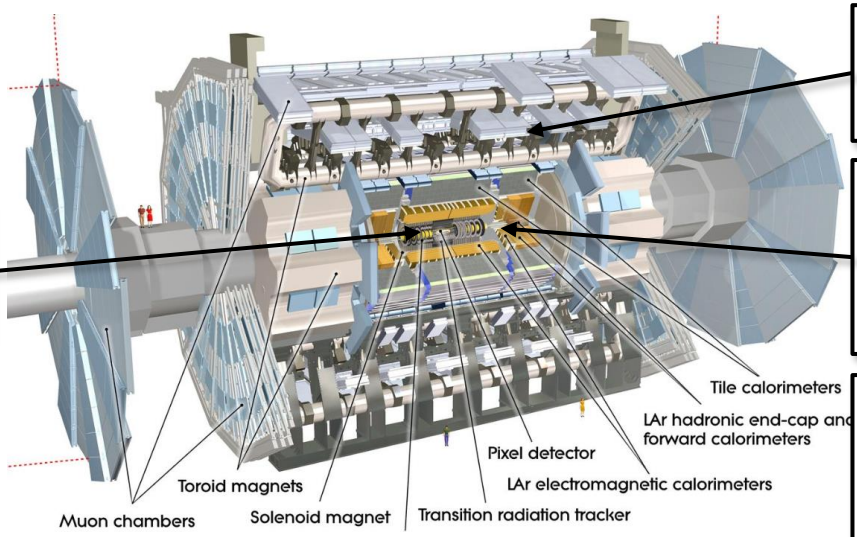
- High-luminosity LHC starting in 2029
  - Collect ~10x more data with ~3x higher instantaneous luminosity
  - The schedule was delayed by two years to allow all LHC experiments to absorb delays in upgrade projects (largely due to COVID-19)

Our contributions

All-silicon inner tracker (pixel + strip)

My talk

Next talk by K. Nakamura

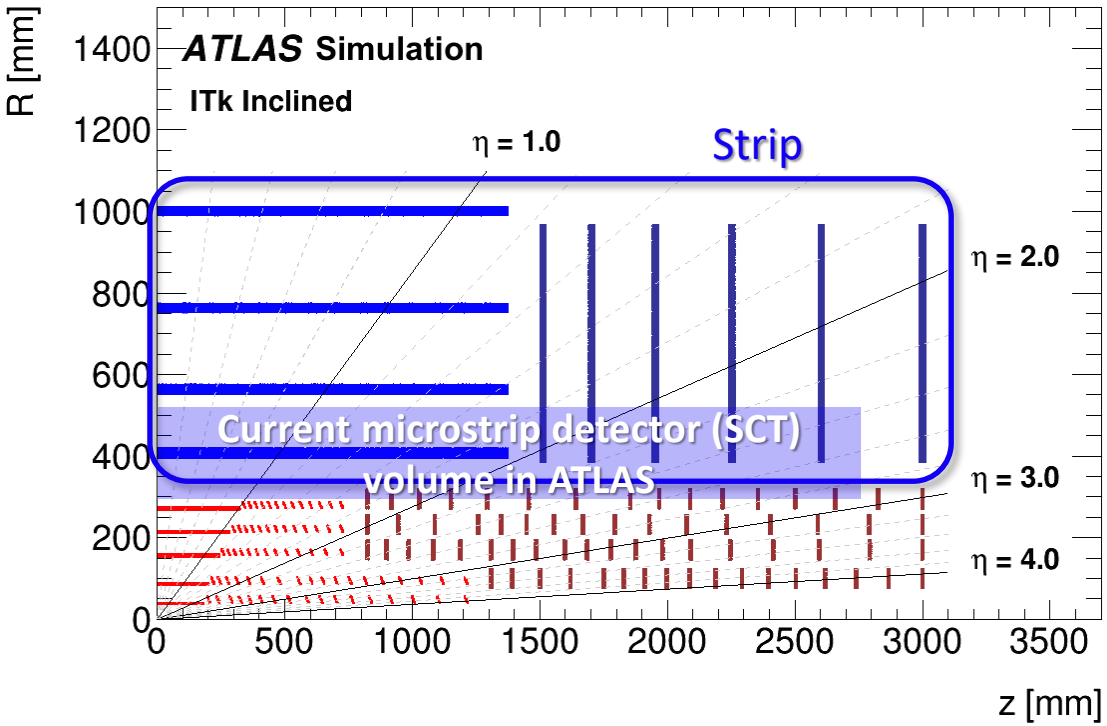


New muon chambers in the inner barrel region

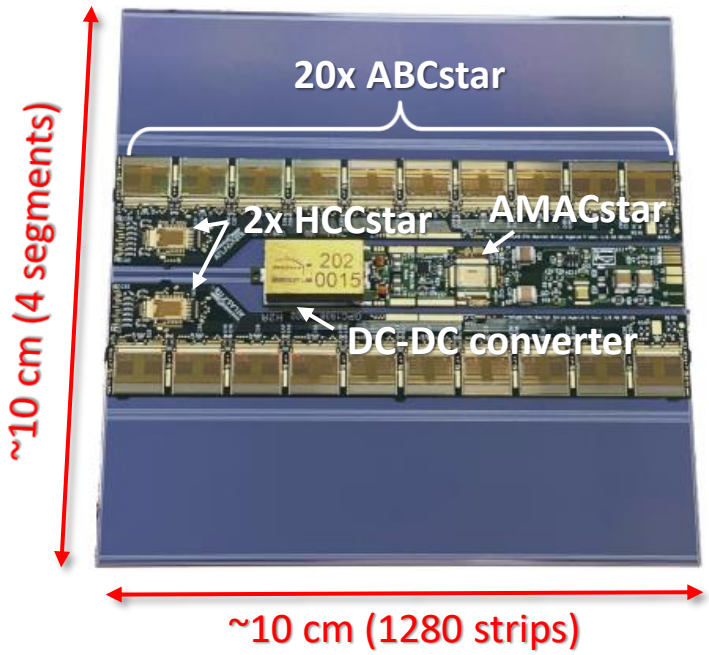
High Granularity Timing Detector with LGAD (σ_t~50 ps)

Better performance trigger DAQ & electronics systems

ATLAS ITk Strip



Short-strips
(Inner two barrel layers)

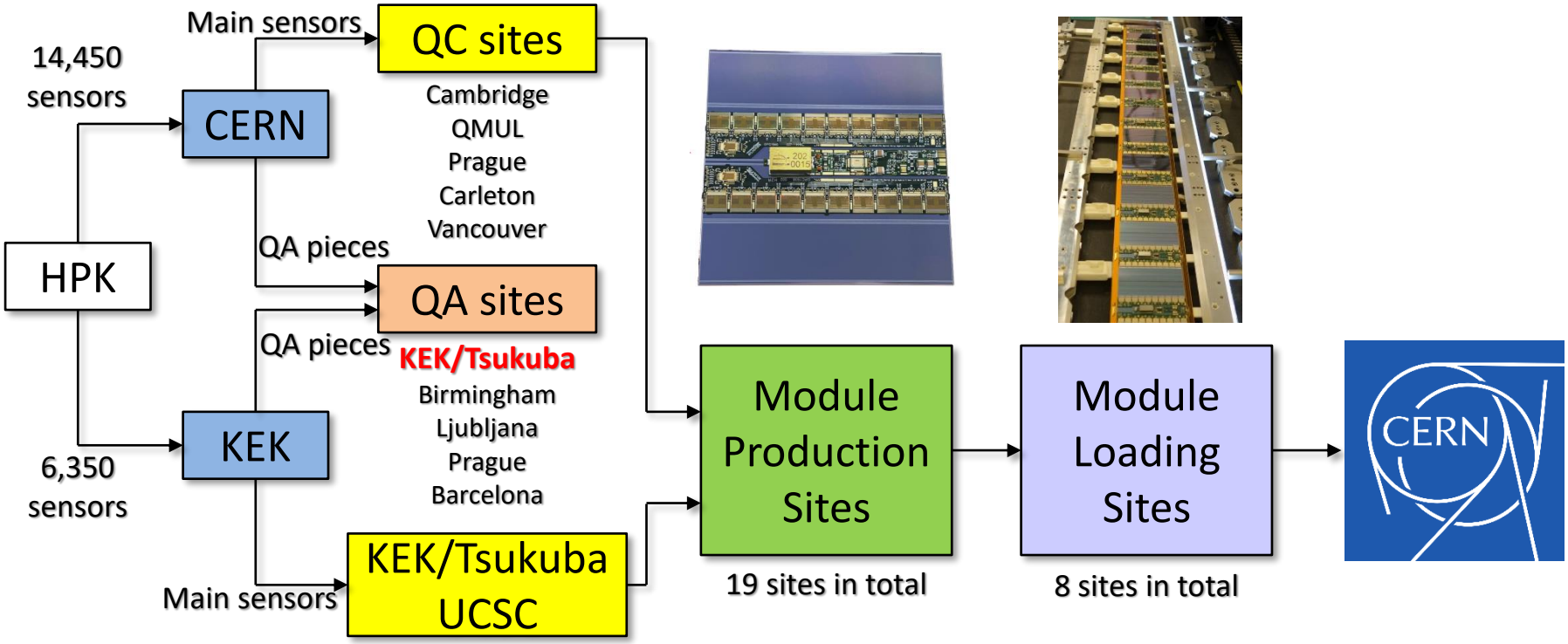


	SCT	ITk Strip
Surface	63 m^2	165 m^2
# modules	4,088 (8,196 sensors)	17,888
# channels	6.3M	60.2M

- Huge silicon detector system!

Strip sensor production

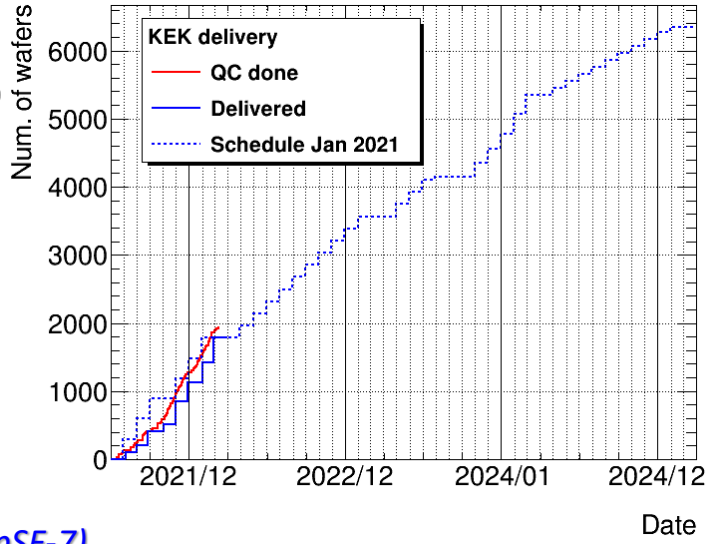
- 20,800 sensors are produced with 6-inch wafers
  - All strip sensors are produced by Hamamatsu Photonics K.K.



- Sensors must pass all quality checks
  - Quality control (QC): basic inspection for all sensors
  - Quality assurance (QA): monitoring of radiation hardness
- Tsukuba is in charge of both QC and QA in collab. with KEK

Strip sensor QC

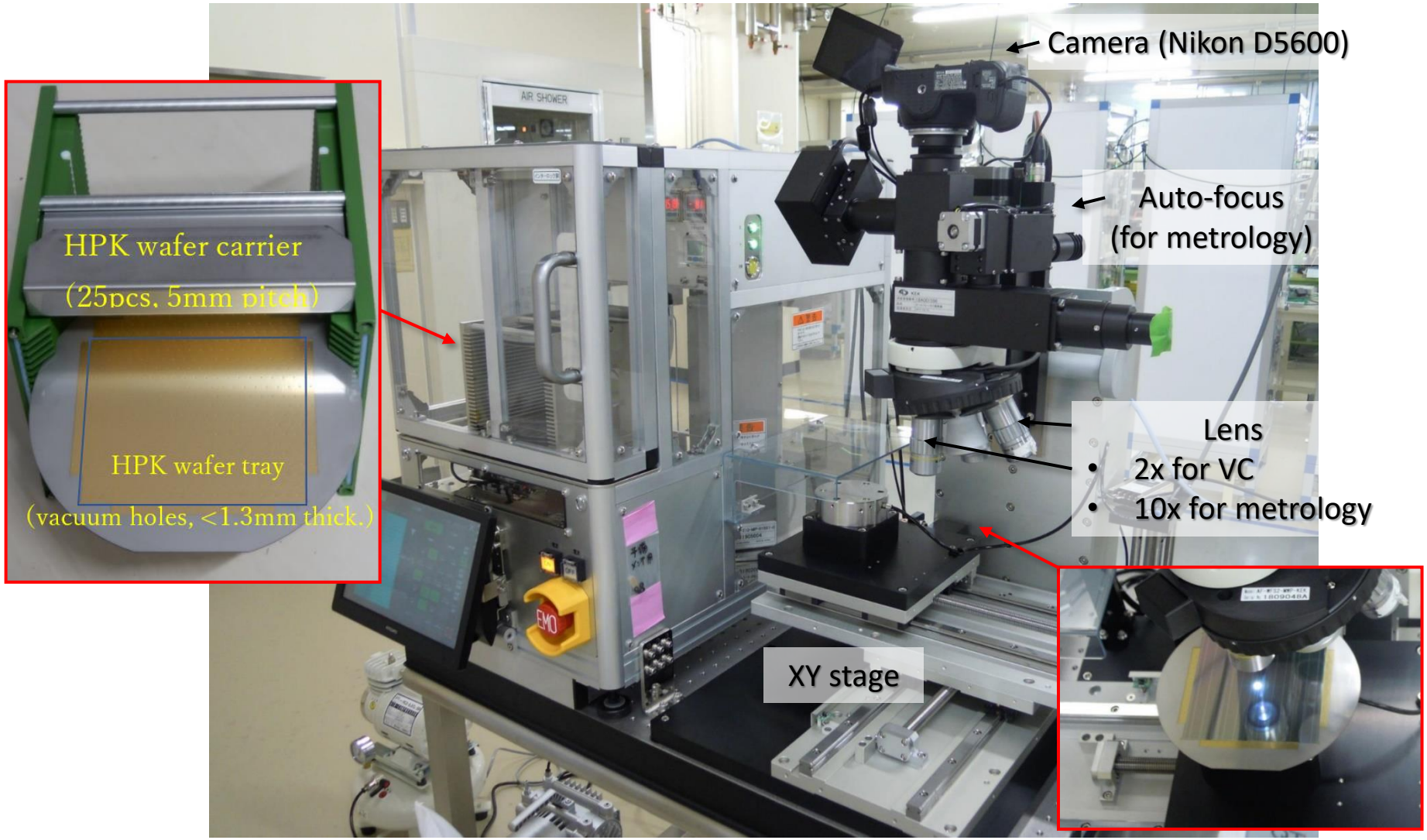
- Items to be measured in QC tests
  - **KEK Tsukuba**
    - Visual inspection (taking high-reso. photos)
    - Metrology (height measurement)
    - Electrical tests on strips
  - **UCSC**
    - IV stability
    - Sensor thickness



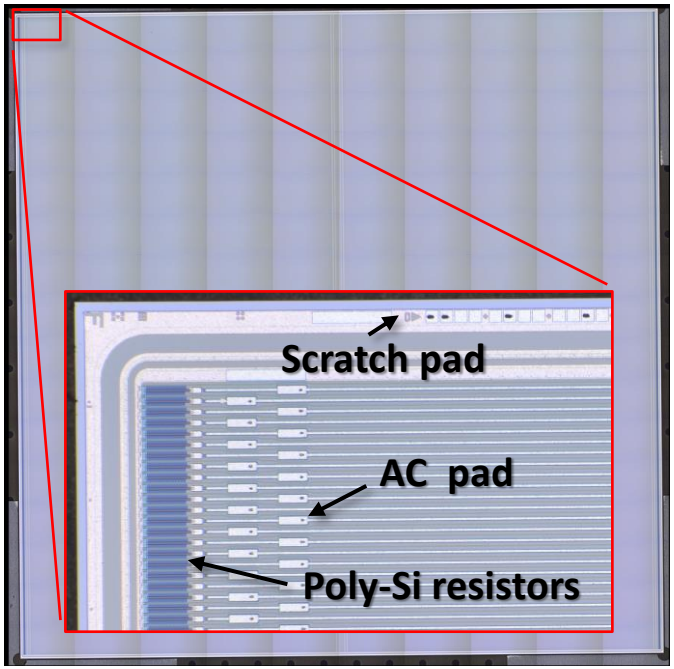
- QC procedures established during pre-production in 2020 *K. Saito, JPS Fall 2020 (14pSF-7)* *T. Ishii, JPS Spring 2021 (13aT3-3)*
  - Our measurements are done at HPK
    →Sensors are delivered to UCSC for further tests
- Sensor production has started in July 2021
  - About 30% of the sensors have been measured / delivered
- Measurements are done at the rate of ~20 sensors per day
  - Establishing stable "routine flow" was a key in the first year

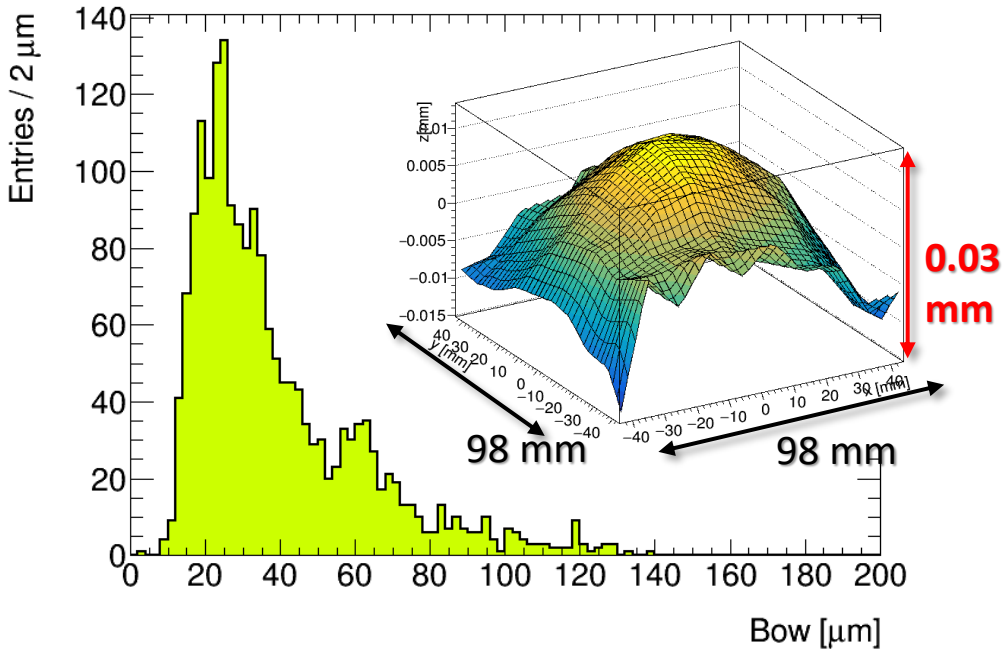
■ QC machine at HPK

- VI / metrology machine located at HPK



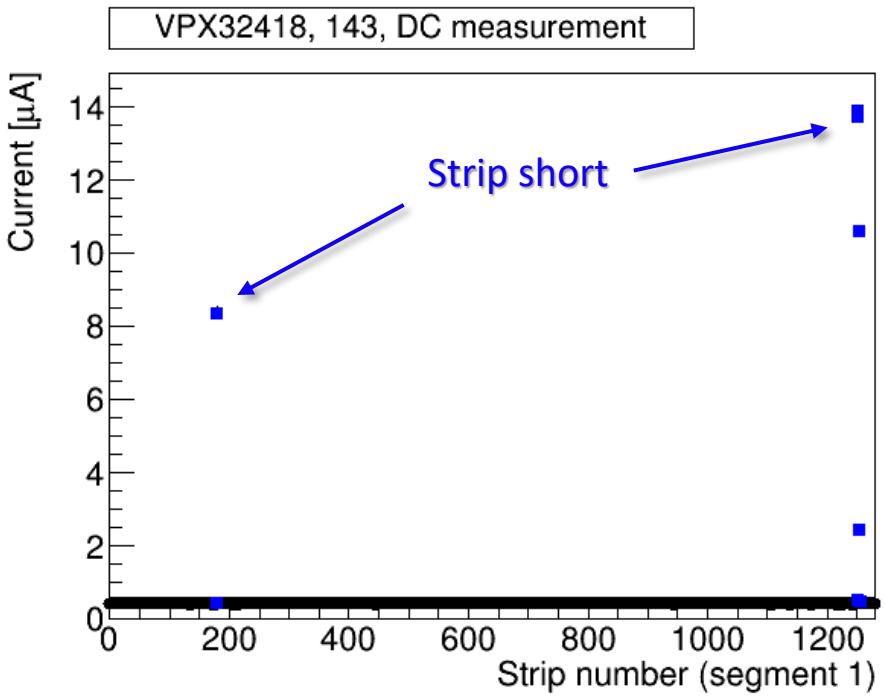
Results from pre-production

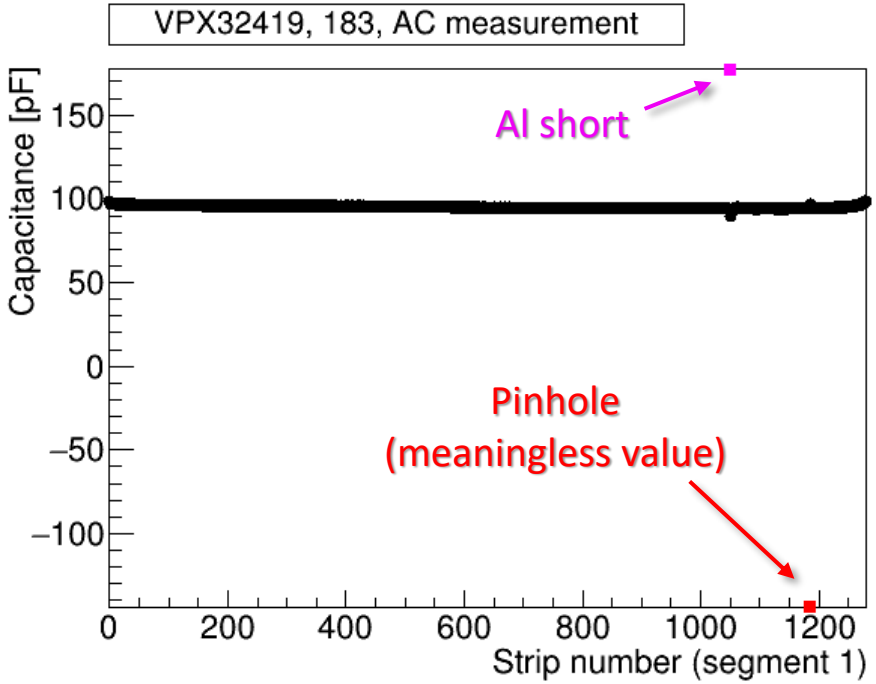




- Sensor photo for visual inspection
  - Possible to catch images of very fine structures
- Metrology
  - Bowing is at most ~100 µm while < 200 µm is required

Electrical performance tests

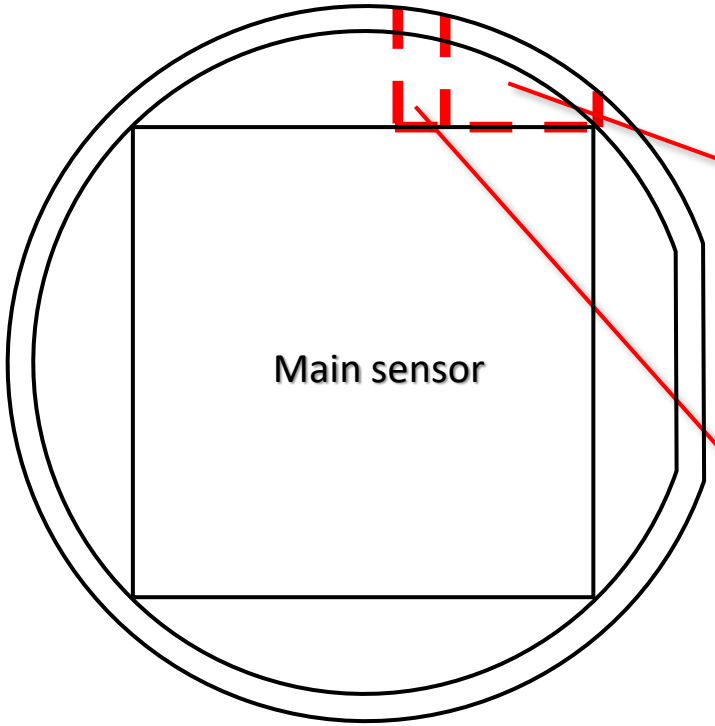


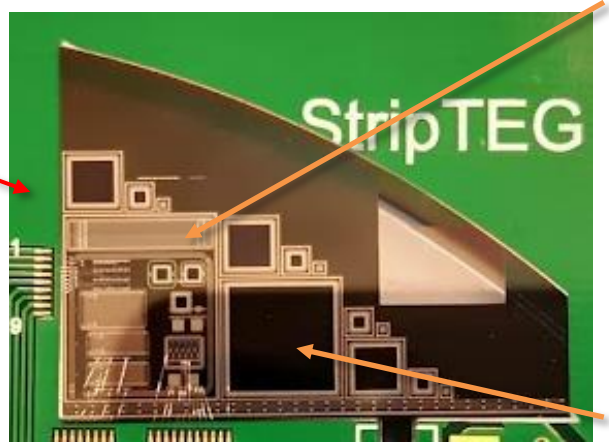


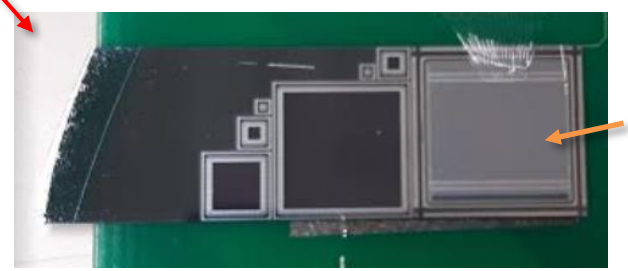
- Electrical performance checks for every strips
  - DC test: measure interstrip currents
  - AC test: measure coupling capacitance

  → Tests are done by HPK
- Good performance in general: defect rate is ~0.01%

Strip sensor QA







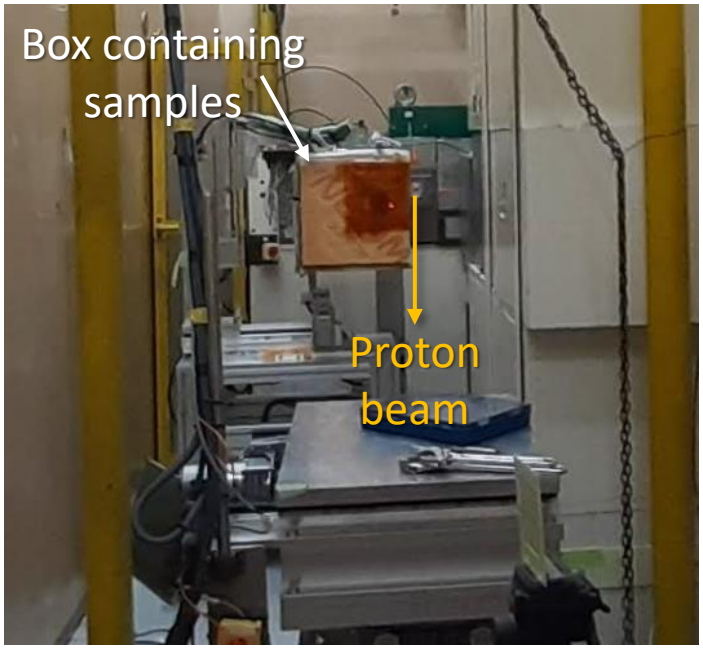
Test chip
- Bias resistance
- Interstrip characteristics
- Coupling capacitance
- Punch-through protection
- Oxide thickness

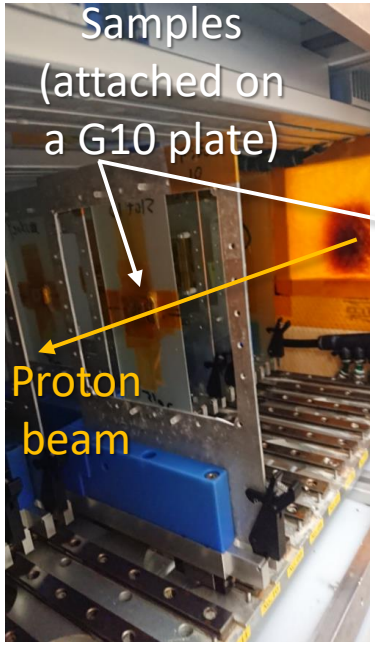
8 × 8 mm^2 diode
- I-V and C-V characteristics

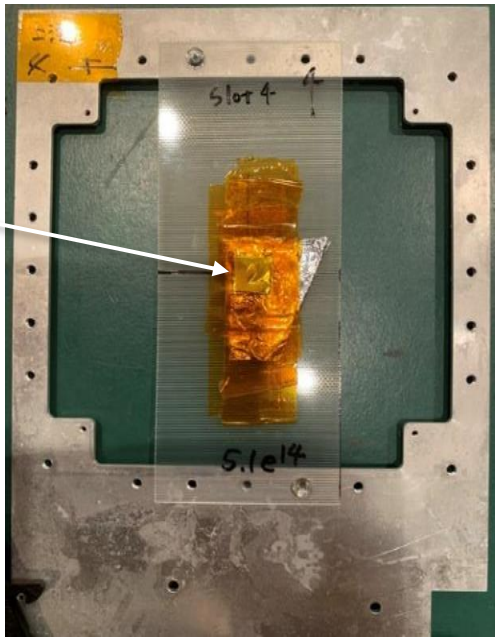
Mini sensor (1 × 1 cm^2)
- Charge collection

- Inspection for basic silicon properties after irradiation
  - Several structures (QA pieces) are formed on the wafer
  - Three structures are used for sensor production QA
- We are in charge of proton irradiation
  - Irrad. up to 1.6×10^{15} n_{eq}/cm^2 ← 1.5 × [total fluence at HL-LHC]

Irradiation @ CYRIC



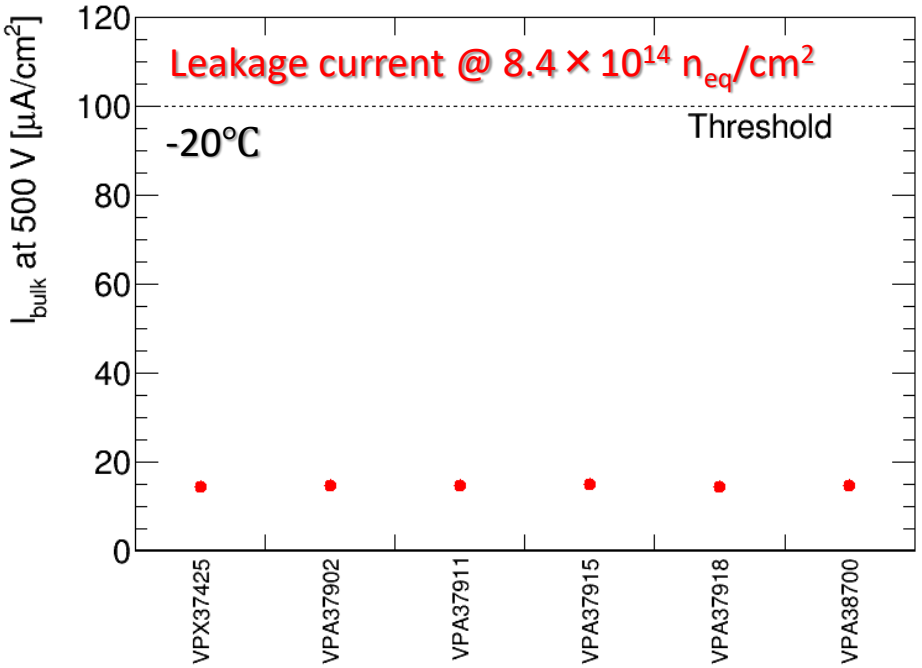


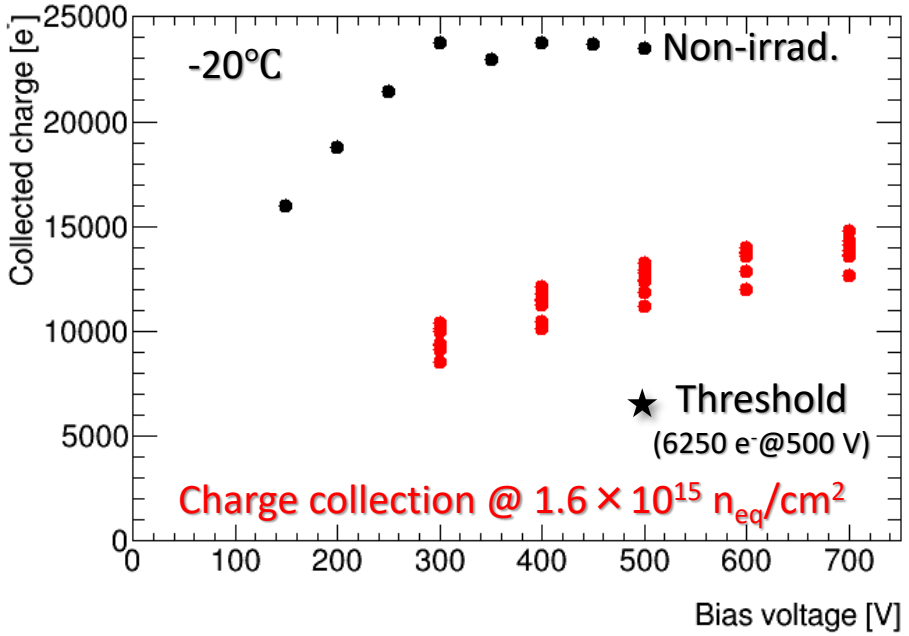


- Irradiation at CYRIC, Tohoku U.
  - 70 MeV proton beam up to ~1000 nA
  - 10-20 QA pieces every ~6 months
- Procedures well established
  - Hold samples on a G10 plate → Put them in the box (movable XY)
  - After irradiation, attach a sample onto the PCB with wire-bonding

    → Measure basic parameters at KEK

Irradiation tests





- 13 samples were irradiated at CYRIC in 2021 *T. Ishii, JPS Fall 2021 (17aT3-6)*
- Overall good performance was confirmed
  - All parameters are very stable (same for results from other QA sites)
  - Occasional issues such as early breakdowns are attributed to our handling and measurements

→ Accumulating experiences to achieve more stable "routine"

Summary

- ITk Strip is a key for successful physics programs at HL-LHC ATLAS
  - Huge silicon tracker with 165 m^2
  - Production for >20,000 sensors has been launched in July 2021!
  - U. Tsukuba is strongly contributing to sensor QC/QA

- Strip module production is also progressing
  - Many module sites have been qualified → Starting pre-production modules

- The entire ITk will be ready by the middle of 2027