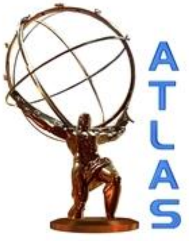
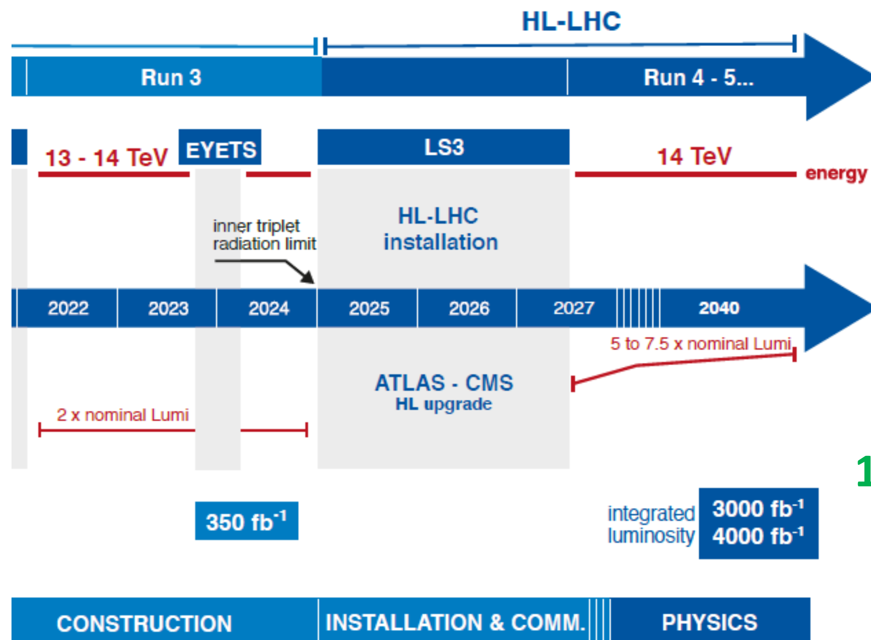


Preparation of pixel module production for the HL-LHC ATLAS ITk

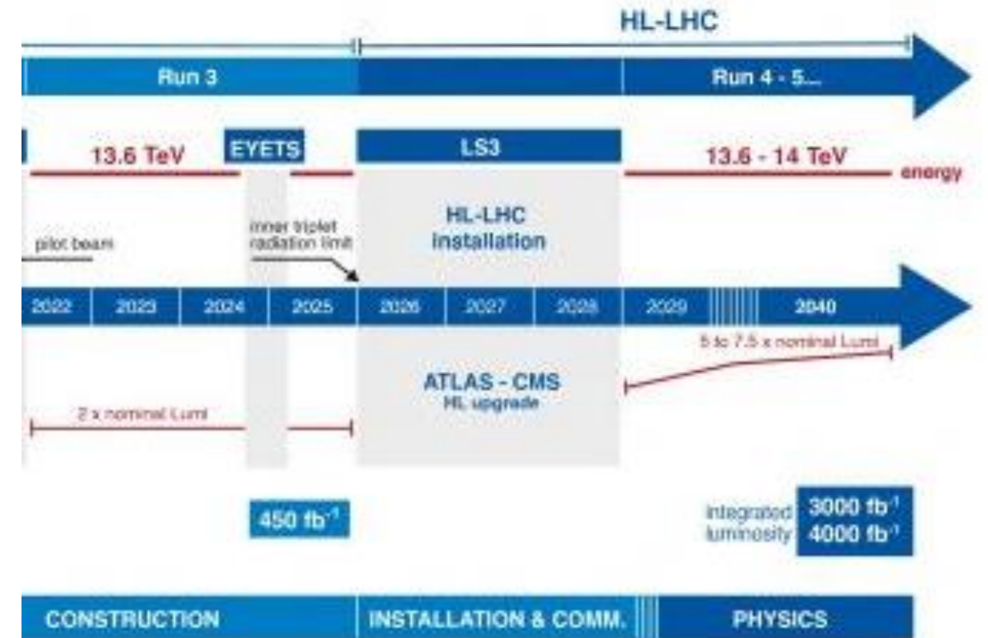
Koji Nakamura (KEK)

on behalf of ATLAS Japan Itk group

High Luminosity LHC (HL-LGC) -- schedule update

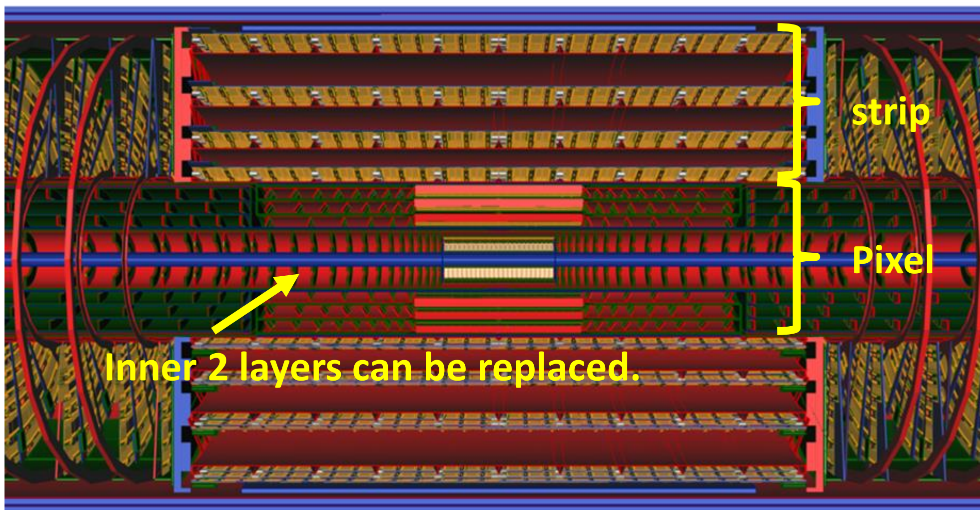


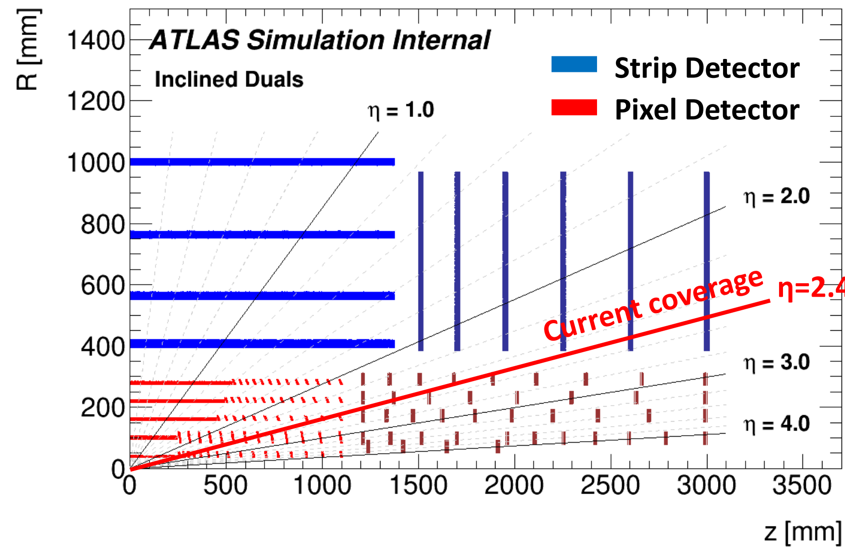
1 year longer Run 3
1.5 year delay of HL-LHC



- High Luminosity LHC (HL-LHC) start in 2029 to take 10 times higher integrated luminosity (**3000-4000fb^{-1}**) in 10 years.
  - Center of Mass Energy will be 14TeV
  - Instantaneous luminosity after leveling is **~5x10^{34}cm^{-2}s^{-1}**
    - **Requirement : No major degradation of performance upto 7.5x10^{34}cm^{-2}s^{-1} instantaneous luminosity with 200 multiple interaction per bunch crossing.**

Inner Tracker (ITk) Layout

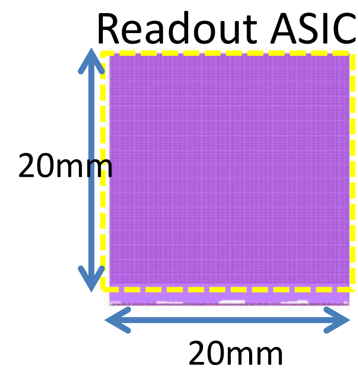




	Type of sensors
Layer 0	3D type
Layer 1	Thin planar(100um)
Layer 2-4	Thick planar(150um)

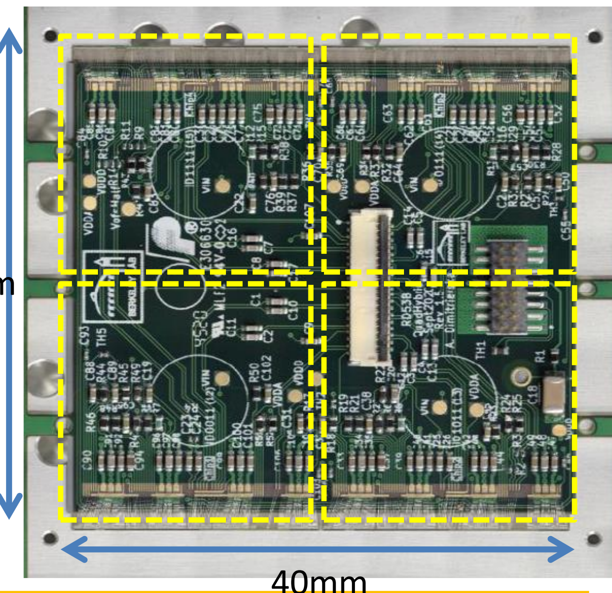
- Larger coverage area
  - Pixel : current $2.7m^2$ ➔ **upgrade $8.2m^2$**
  - Strip : current $34m^2$ ➔ upgrade $165m^2$
- Higher Forward coverage
  - Current η<2.5 ➔ **upgrade η<4.0**
  - **Better Pileup removal & background rejection**
- For Layer 1-4, constructing Quad module
  - Size : 40mm x 40mm
  - Single sensor with 4 Front End ASIC bonded.

Readout ASIC



Layer 1-4

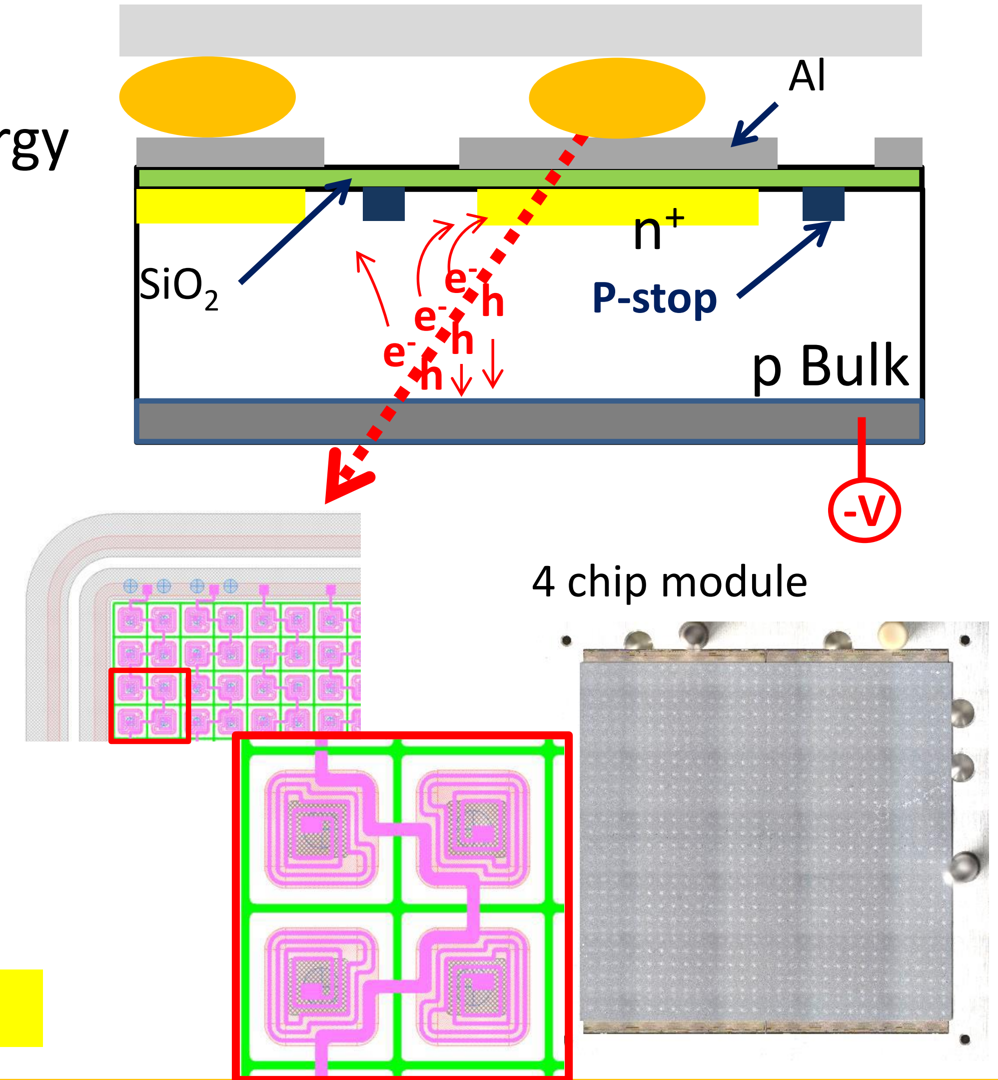
Planar : Quad module (single sensor)



Sensor and module design

- ***Basic principle :***
  - Backside is negative bias and n+ is ground.
  - Detect electron-hole pairs created by ionizing energy loss from MIP particle.
- Strip detector
  - **n+ can easily ground at the end of strip.**
  - Readout usually via **"wire bonding"** strips to the readout ASIC.
- ***Pixel detector***
  - **Electrode placed two dimensionally.**
  - To ground all pixels, high resistivity biasing grid is necessary. (important for testing sensor alone)
  - Readout ASIC is connected by **"bump-bonding"**.

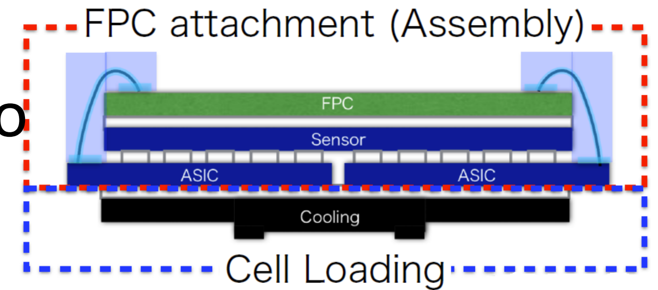
Our development is together with Hamamatsu Photonics K.K (HPK)

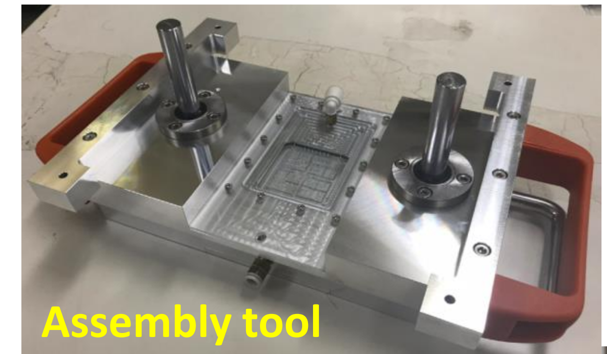


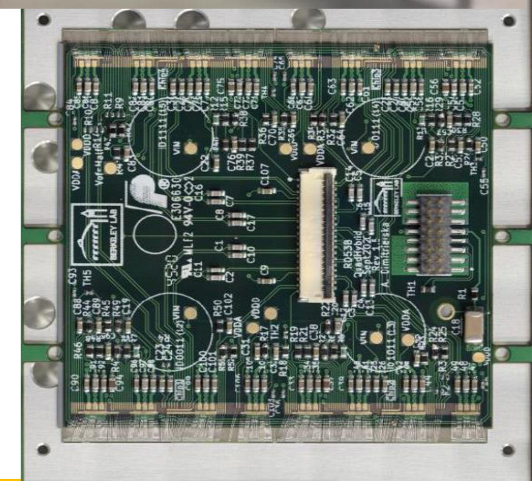
Flex assembly and CTE mismatch

- Module - Flex assembly
  - To read signal from ASIC, Flex Printed Circuit (FPC) is glued to the module by Araldite 2011.
  - Cooling TPG/CFRP will attach to the backside of ASIC.
  - Then wire bond ASIC pad to FPC.
- CTE mismatch issue
  - Coefficient of Thermal Expansion (CTE) is different for silicon/copper/Carbon.
    - E.g. Silicon 2.6ppm/°C Copper 16.7ppm/°C
  - Huge bump stress during thermal cycling.
    - **During 10 years operation, expected 400 times TC from -45°C to 40°C**
    - Qualification : 100 cycle with -55°C to 60°C Temp range

This issue could be solved by "Parylene coating" of assembled module.



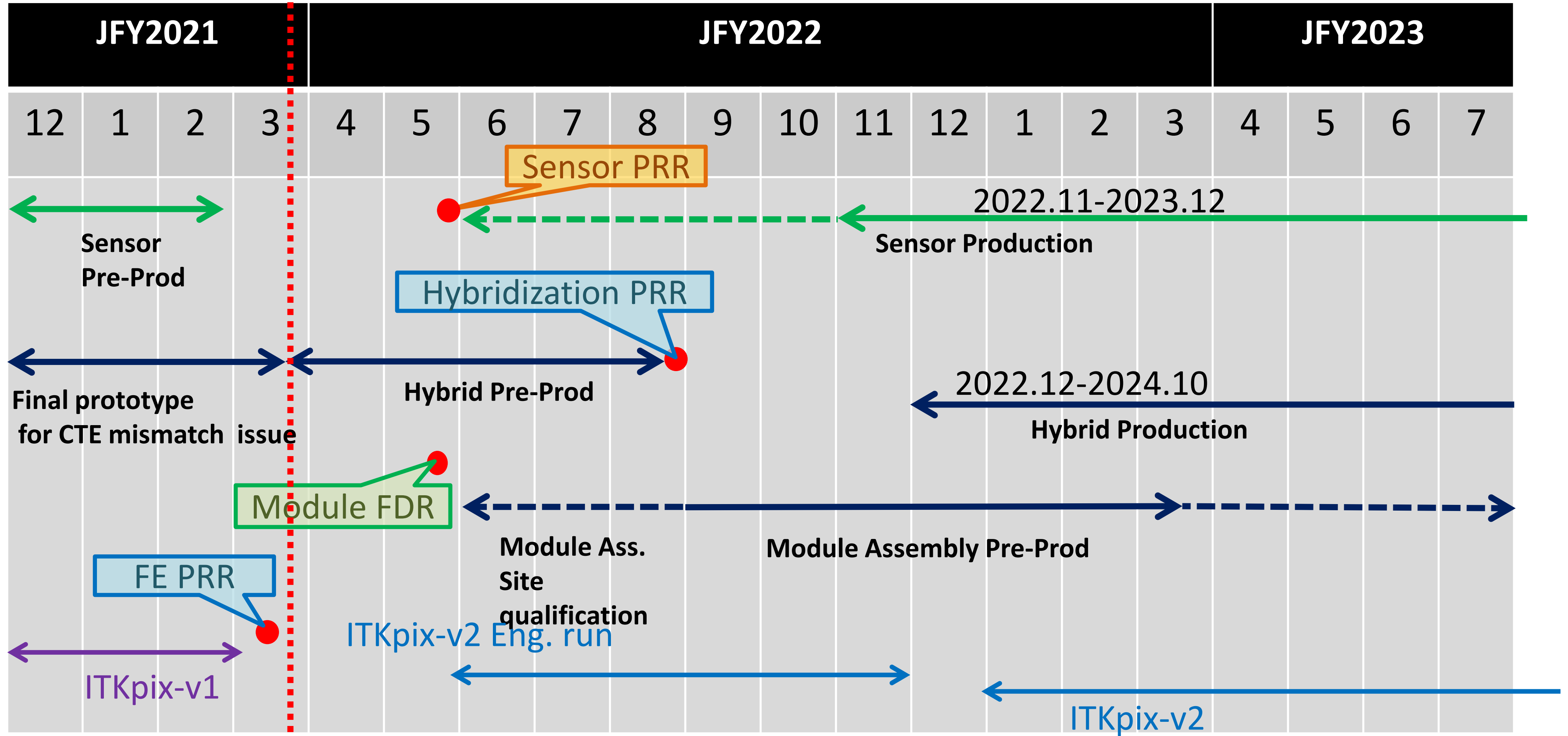




Schedule of Production

- Production has already started.

PDR : Preliminary Design Review
FDR : Final Design Review
PRR : Production Readiness Review



Schedule of Production

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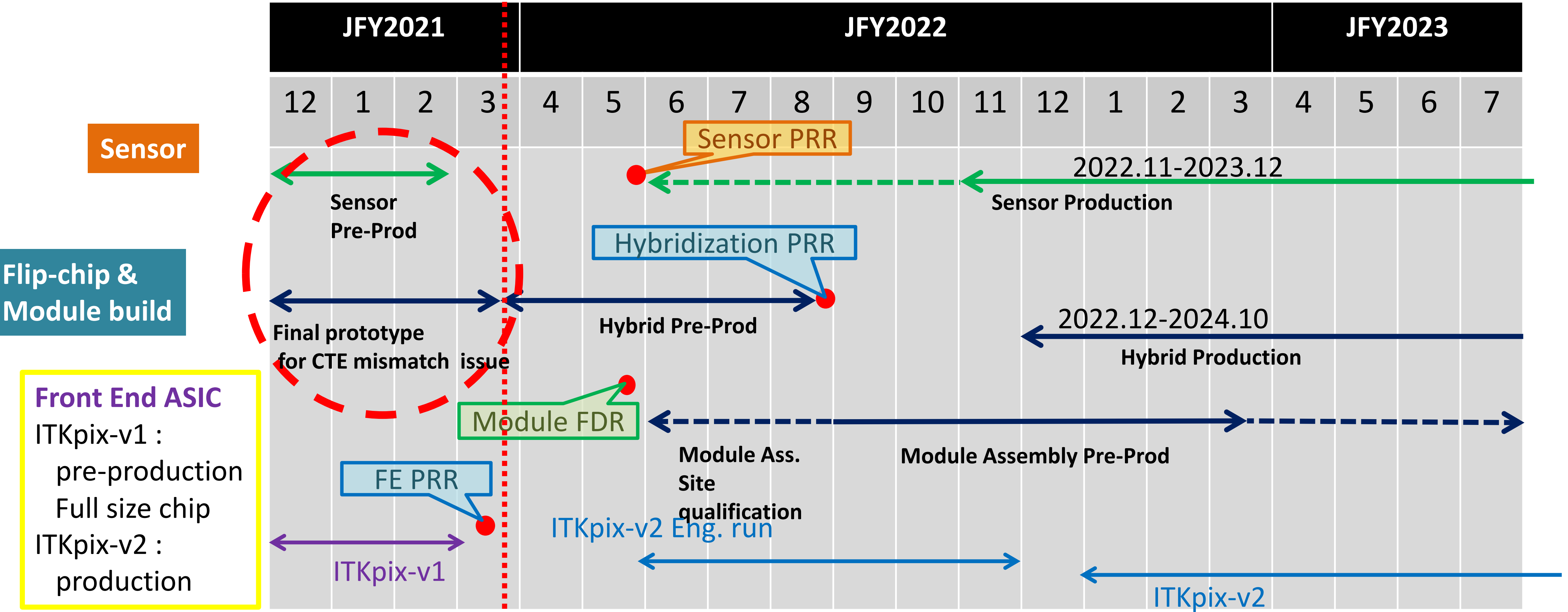
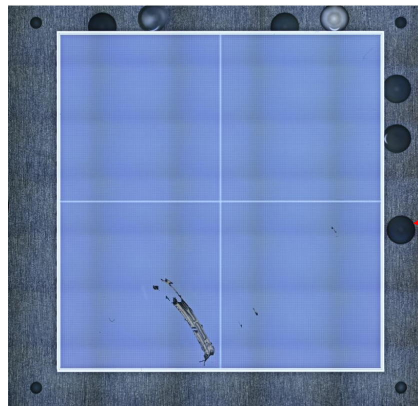


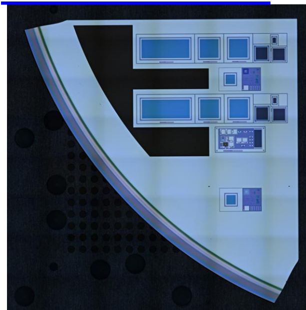
Delivery of HPK Pre-production sensors

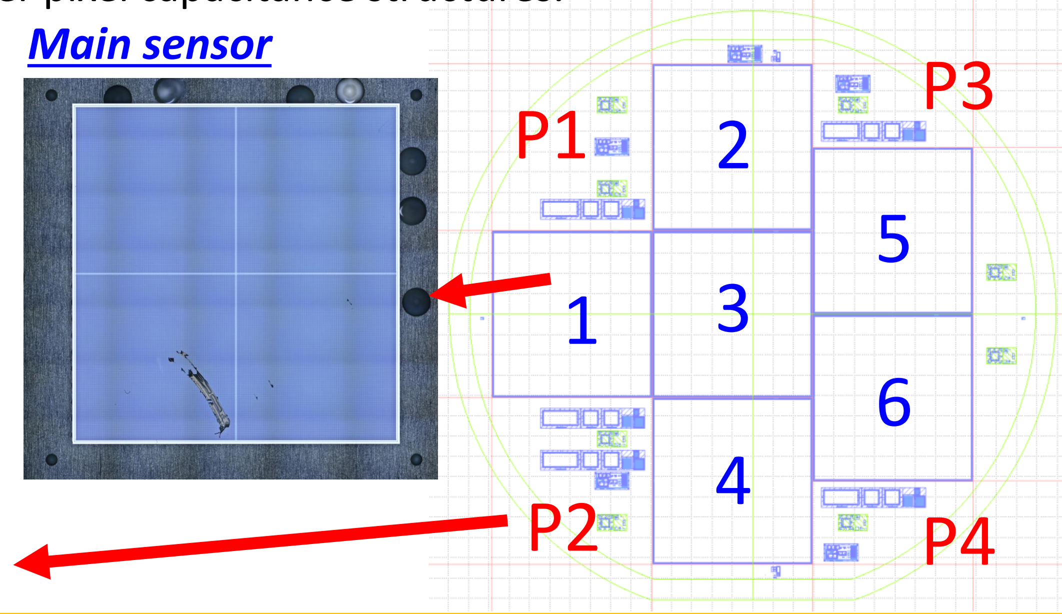
- Delivered 124 good sensors by the end of Feb.
  - First 20 good sensors have been diced.
  - Remaining 104 sensor as wafer.
- In wafer :
  - 6 main quad sensor
    - 40mm x 40mm sensor for actual module
  - Test structure
    - Structure for quality assurance contains diodes, baby pixel, Strip and inter pixel capacitance structures.

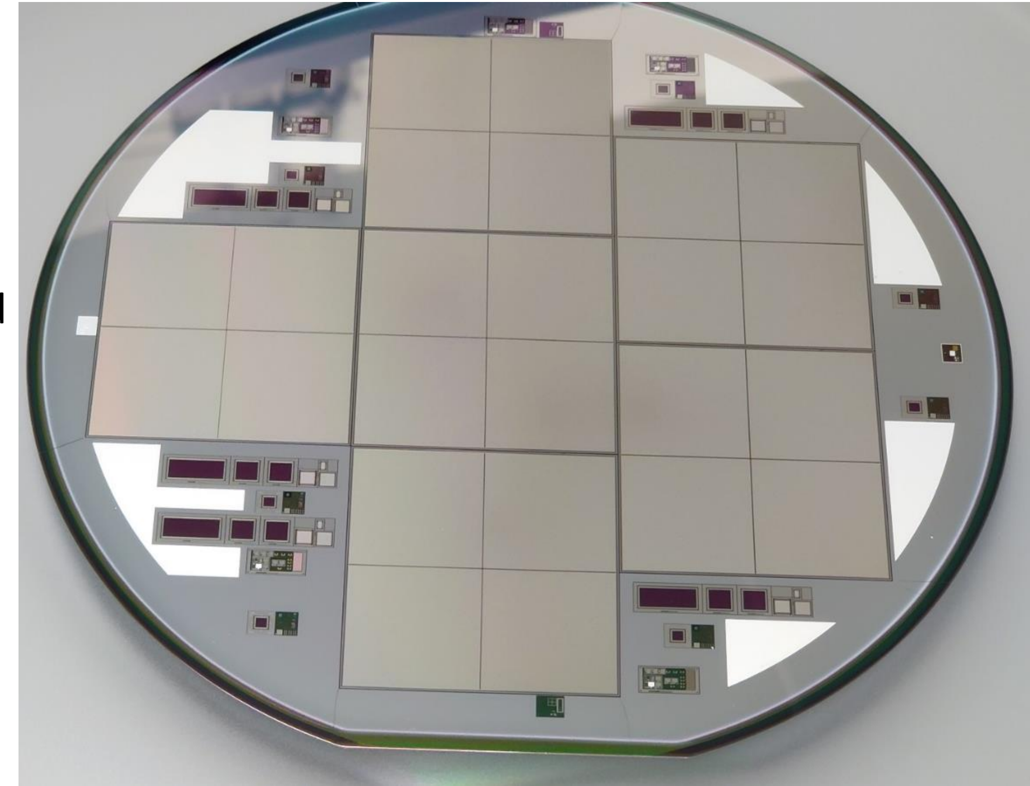
Main sensor



Test structure





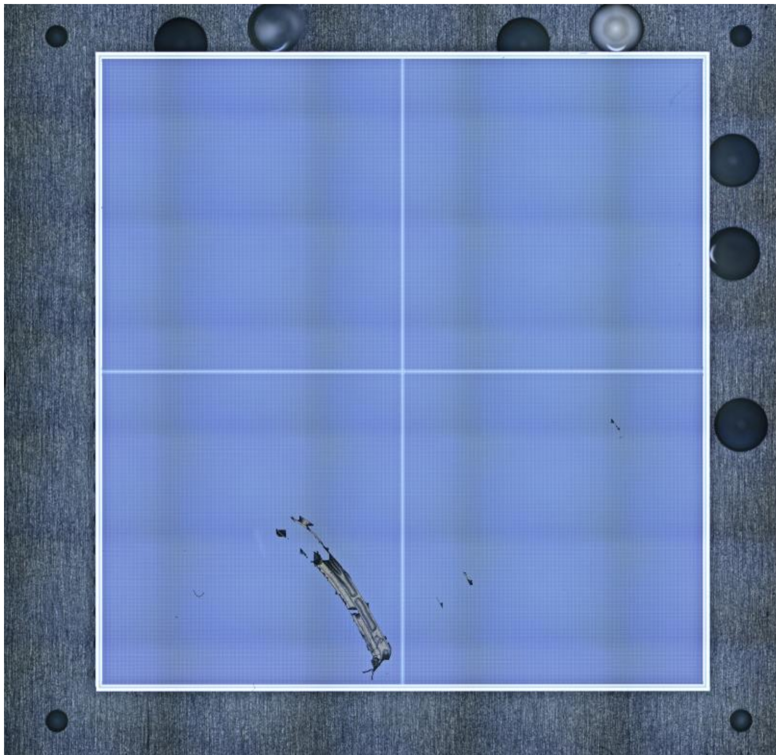


Main sensor – Visual inspection

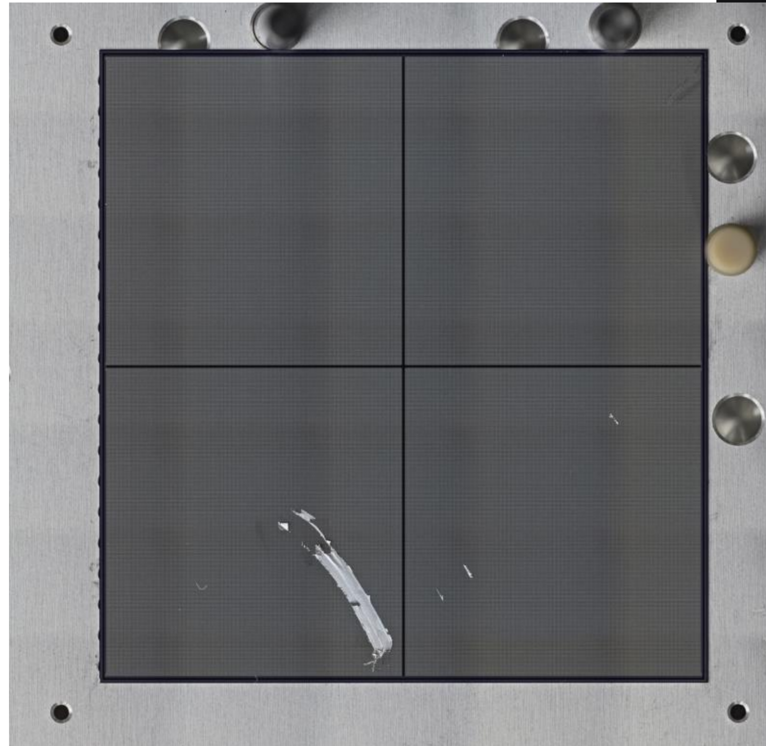
Karin Kuramochi

- Visual capture
  - Example of a sensor with defect

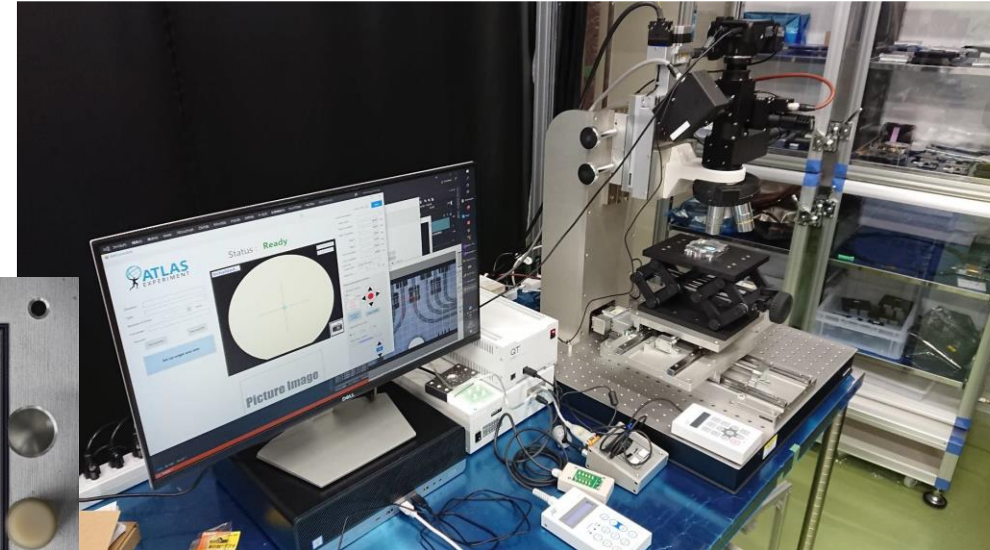
With LED via micro scope



Without LED



Metrology machine @ KEK



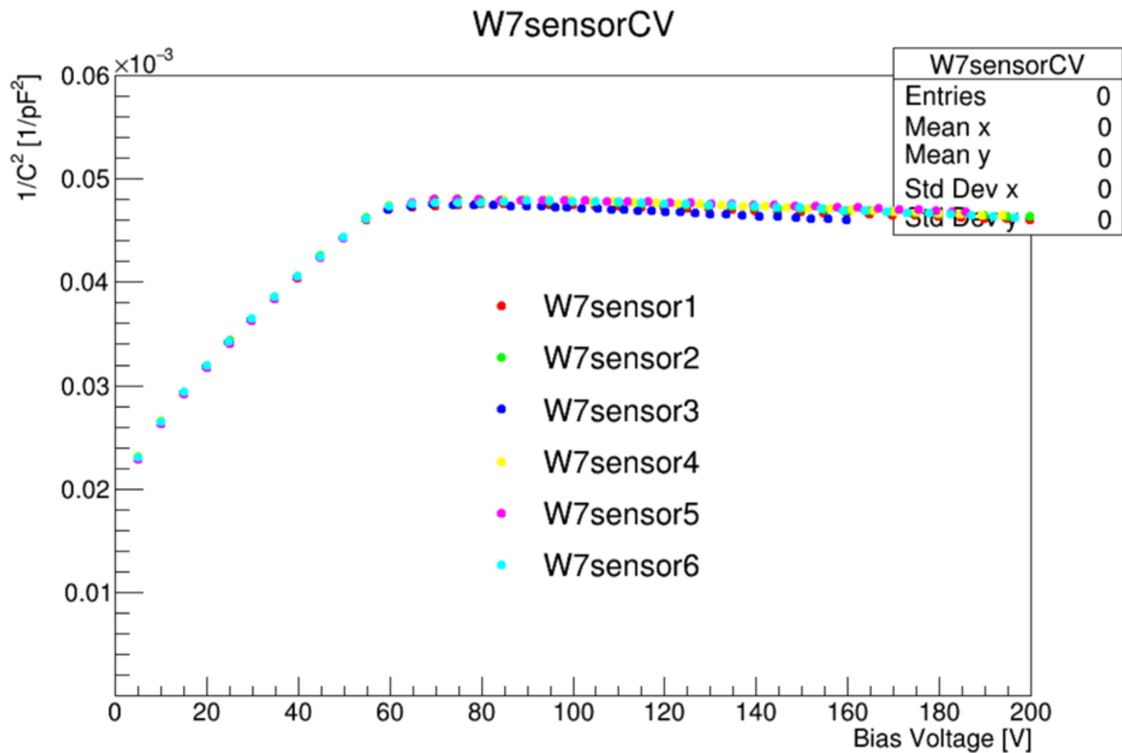
Took pictures of all 6 sensors. (without LED on)

Main sensor – IV/CV measurement

Shunsuke Iizaka

- CV measurement
  - 6 main sensors has been measured.
  - KEK: 20°C RH<5%

Requirement : V_{dep}<100V

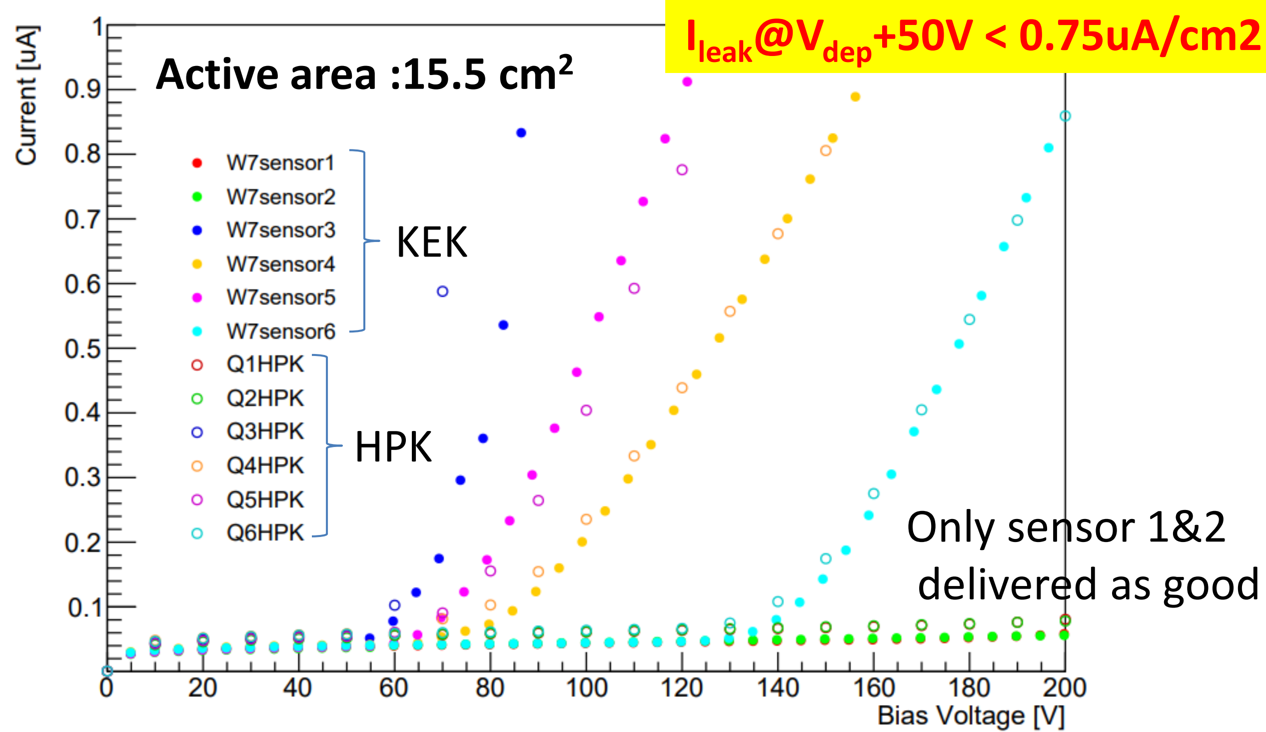


Analysis and comparison to HPK data still on going.
(but V_{dep} is clearly satisfied the requirement)

- IV measurement
  - 6 main sensors has been measured and compared with HPK measurement
  - KEK: 20°C RH<5%   HPK : 23°C RH~40%

Requirement : V_{bd}>V_{dep}+70V

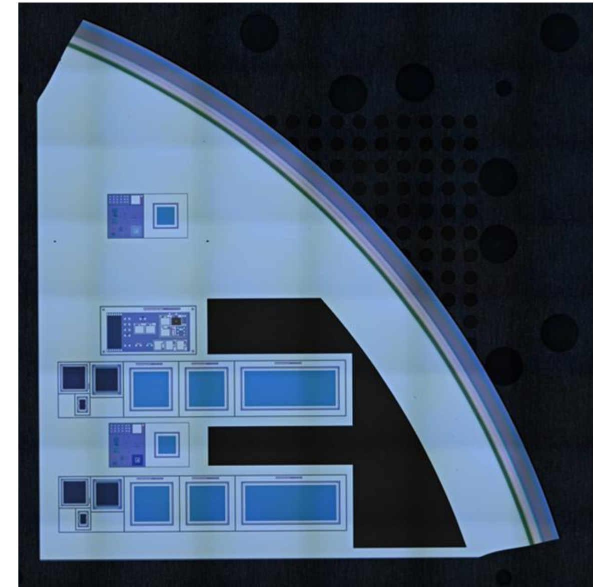
I_{leak}@V_{dep}+50V < 0.75uA/cm2



Leakage current and V_{bd} agreed well   **2.8-2.9 nA/cm²**

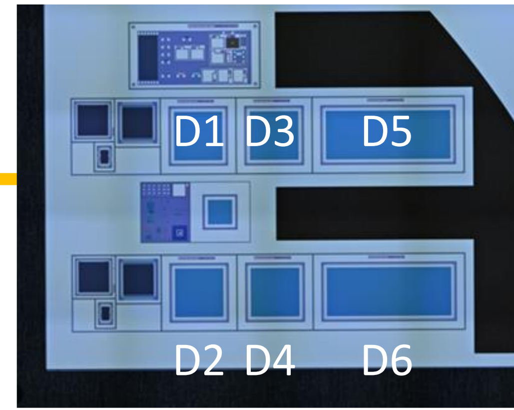
Test structure – Visual capture

- Not required but took high resolution picture.
  - Found that no-scratch mark in Test structure…
    - Made feed back to HPK and will be improved in production

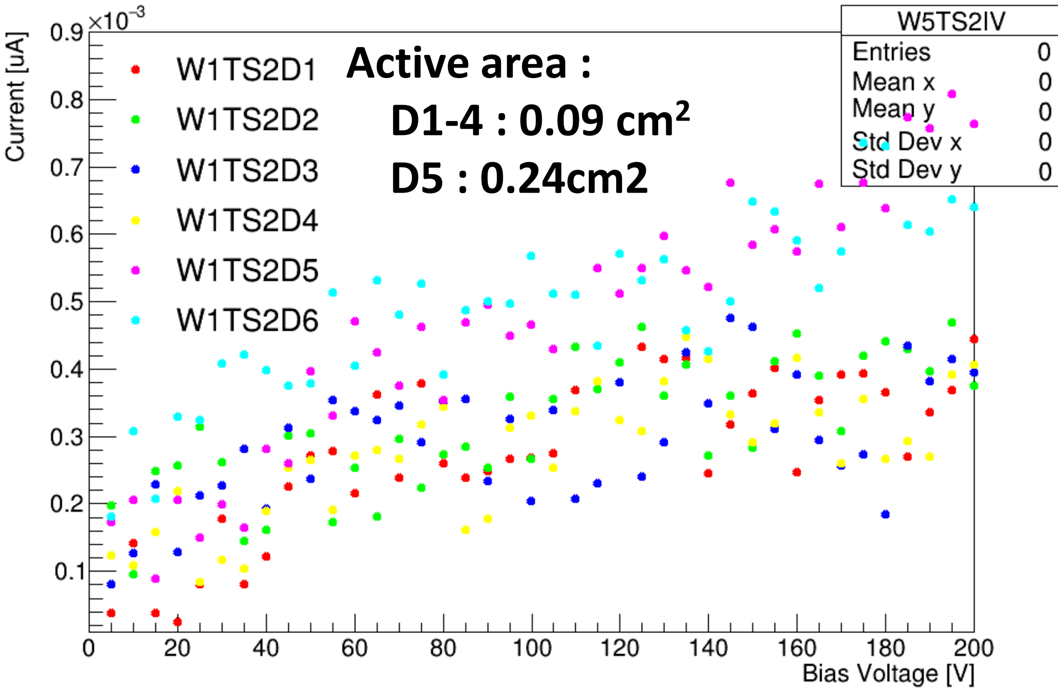


Baby pixel TS
Strip TS
Inter pixel TS
Diode 5x5mm^2
Diode 5x5mm^2
Diode 5x10mm^2

Test structure – IV/CV measurement



- IV measurement

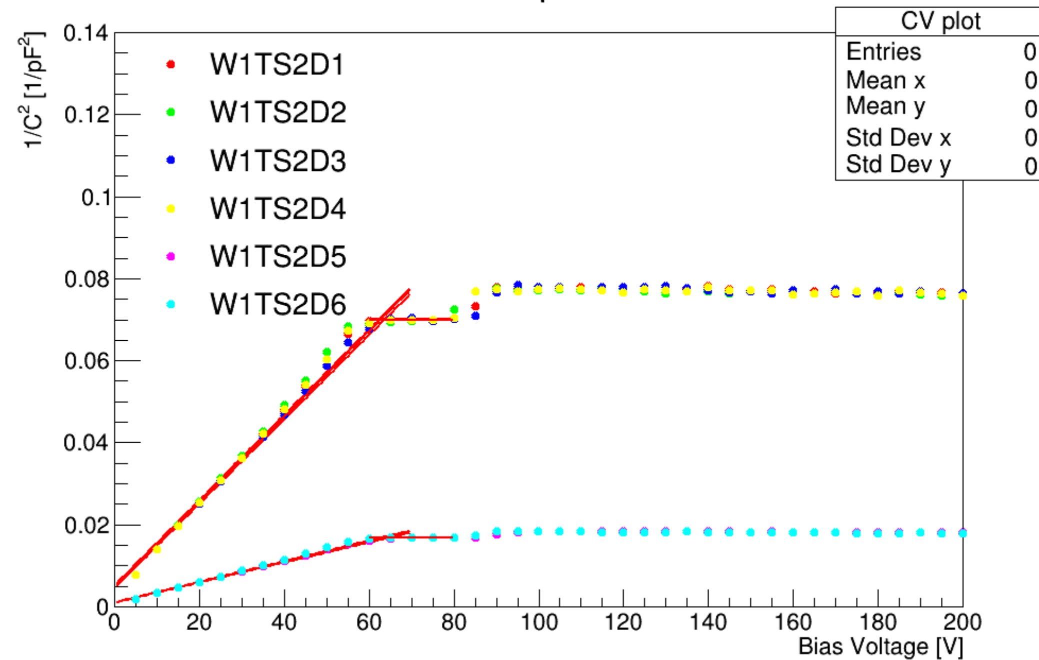


Leakage current is extremely low (~0.5nA)

May not be sufficient measurement…

3.5-4.4 nA/cm²

- CV measurement



Shunsuke Iizaka

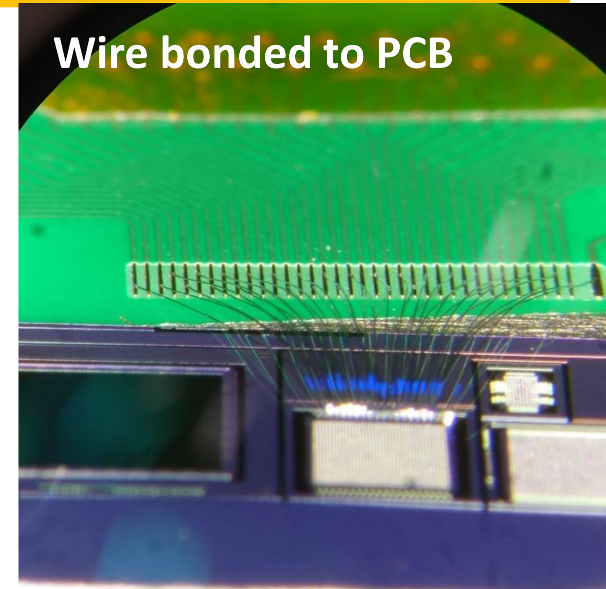
Strange step at shoulder (probably due to edge effect?)

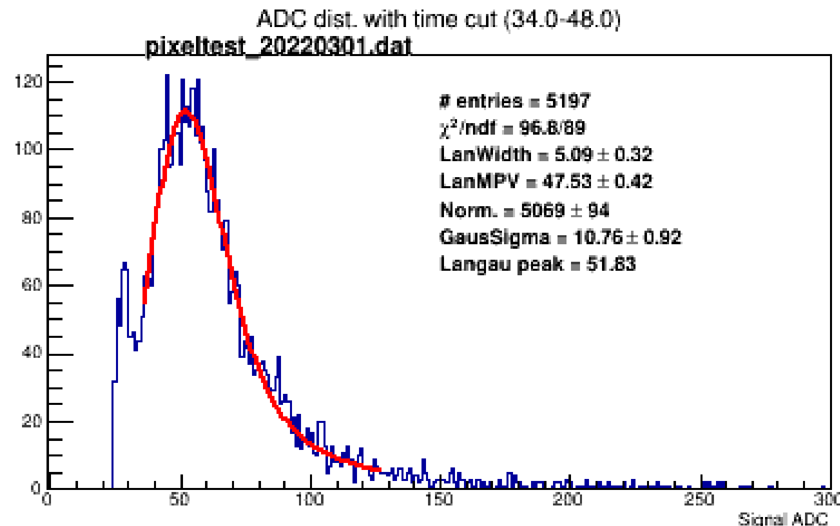
A bit hard to conclude Full Depletion voltage from this measurement.

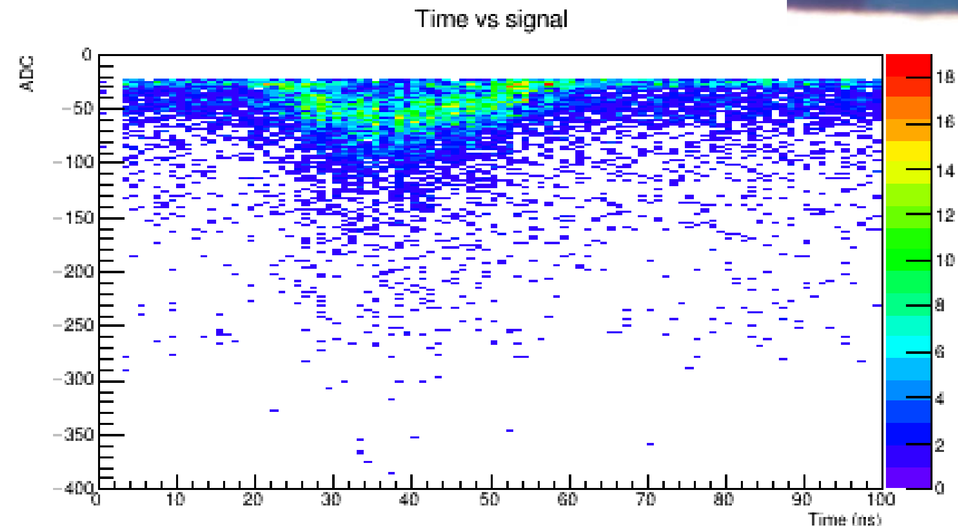
Test structure – First CCE measurement

Tatsuya Ishii

- Measured one of strip TS by Alibava setup.
  - Used ^{90}Sr source with scintillator trigger.
  - LandauMPV=47.53±0.42 ADC count ~**8570±76 e**
  - Smaller than expected. (due to inter strip capacitance?)



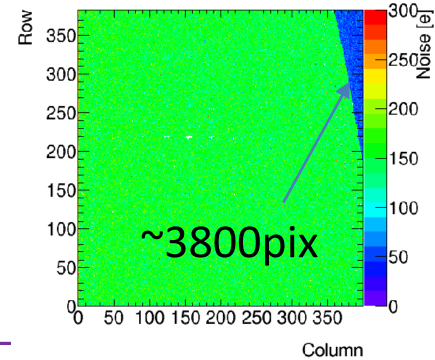




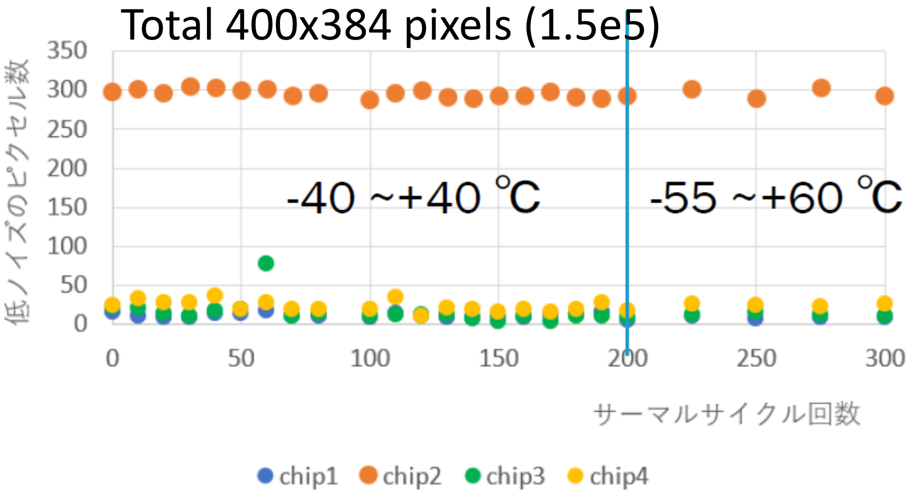
Bump stress during thermal cycling

Yuta Hiemori
Kota Saito

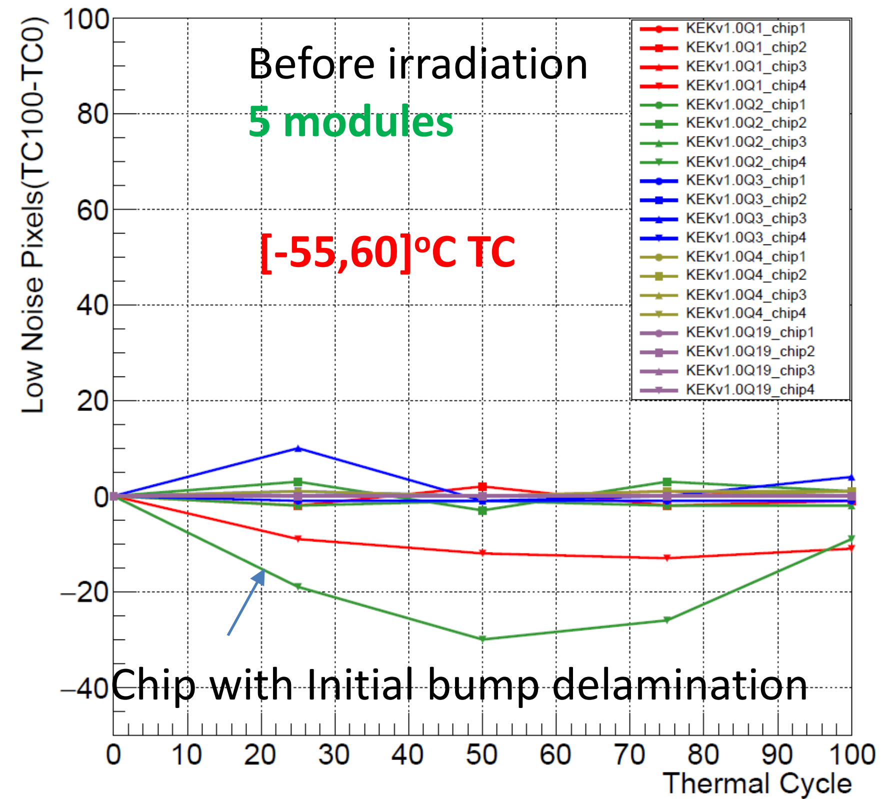
- CTE mismatch introduce stress to the Bump
- Checked bump connectivity after thermal cycle
  - Checked number of disconnected bumps as a function of number of cycle. (subtracted initial failure)
  - Additional 5 modules are tested to increase statistics.
  - **No visible increase of bump delamination observed.**



Only one module has been tested at the time of Nov



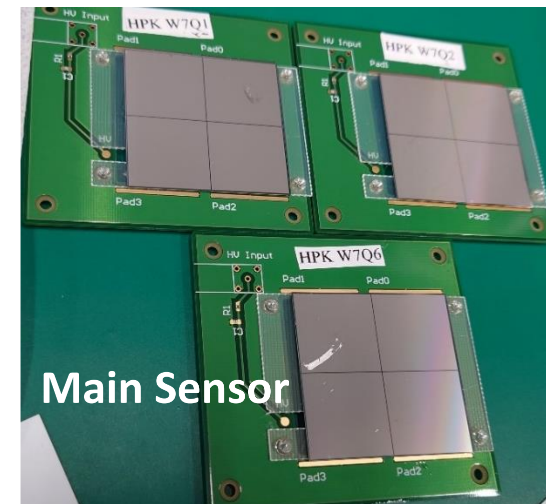
Additional 5 modules

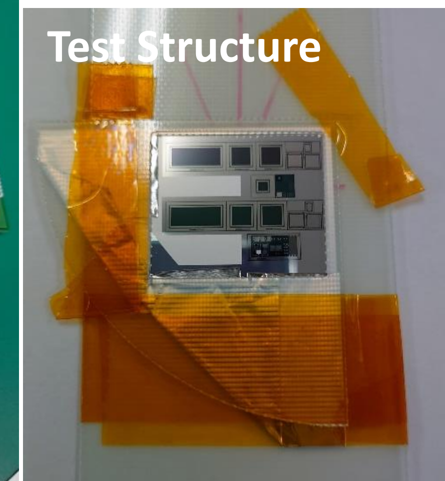


Irradiation test in March

Yuta, Karin, Shunsuke

- 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.
- We had irradiation beginning of this month 28th Feb – 4th Mar)
  - **Sensor Pre-production Quality assurance**
    - Three main sensors and 4 test structures are irradiated.
  - **Final module level testing before pre-production**
    - Four modules are also irradiated
      - To check bump stress issue after irradiation
      - Especially Parylene performance after irradiation
    - One of 4 modules are irradiated with chip operation
      - We should know the radiation effect to the CMOS FET
      - Checked stability of regulator/reference voltage/ring oscillator



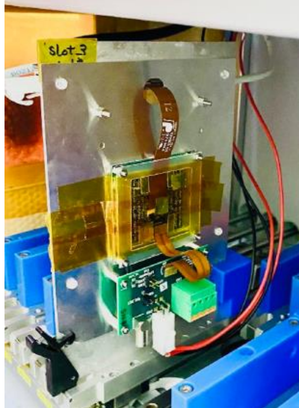


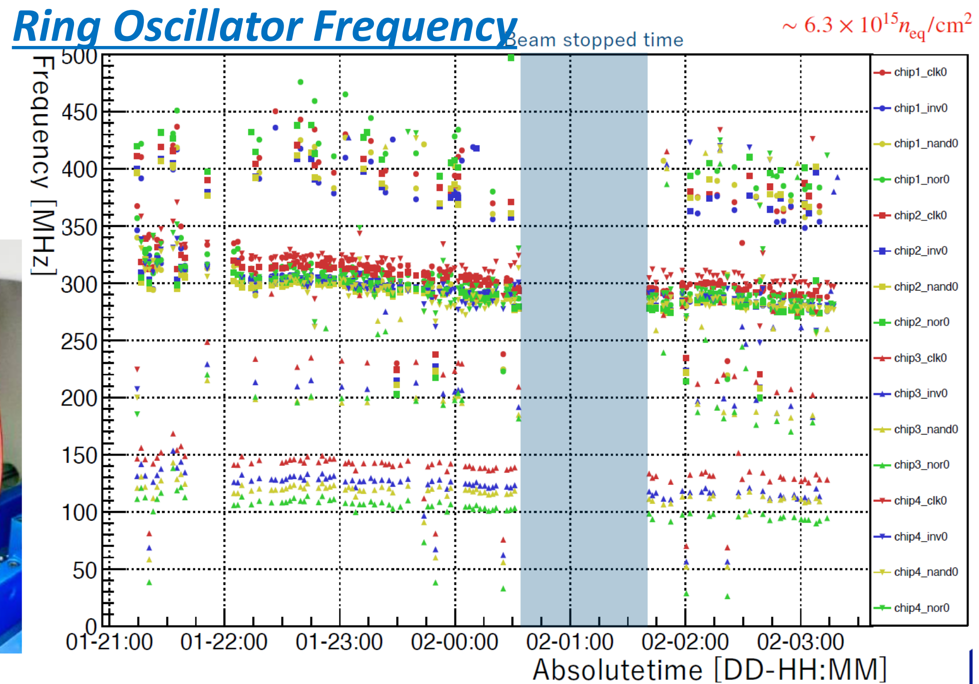
Some fresh results of module irradiation

Yuta Hiemori

- Irradiated module with proper cooling system.
  - Kept module temp ~-15°C
- During irradiation chip was operated and measured various parameters.
  - Ring Oscillator Frequency went down (15%)
  - Reference voltage going up (5%)

Module on cooling plate





~ $6.3 \times 10^{15} n_{eq}/\mathrm{cm}^2$

Beam off

Regulator output voltage

Regulator input voltage

Reference voltage

Module and box temperature

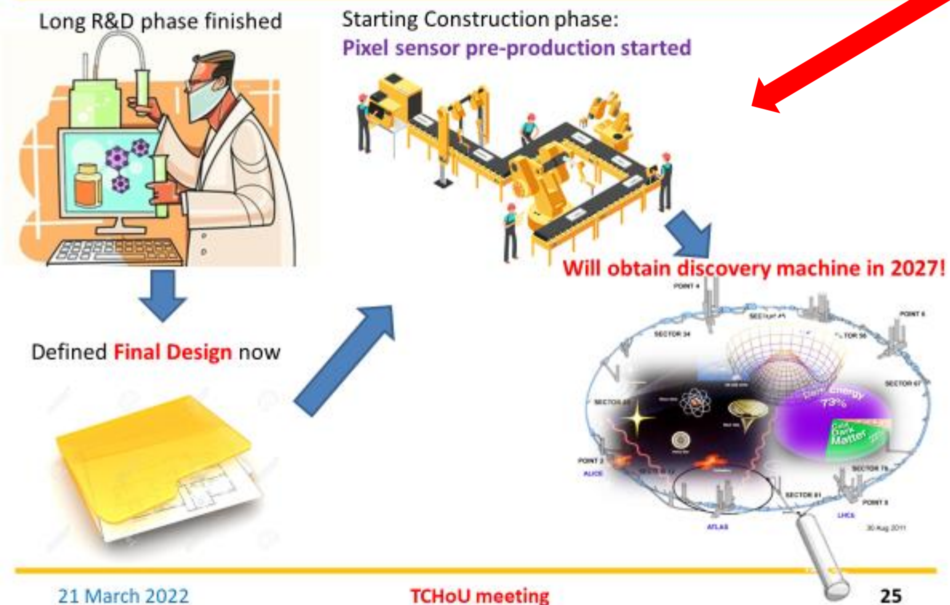
v1.1 temperature

Box temperature

Time [dd:mm:hh]

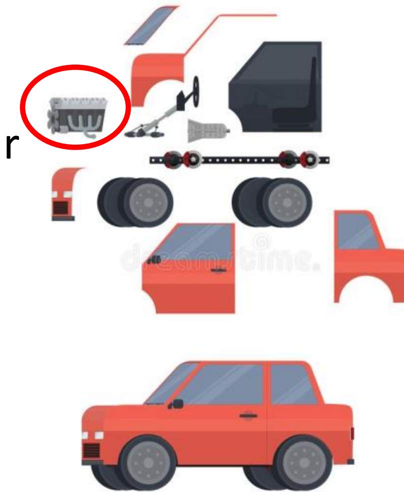
Conclusion

Conclusion in November last year



- Pre-Production has started already
  - Production needs several parts to construct modules.
  - 7% of Sensor production as first important parts have available for quality check.
  - Pre-production for the other parts and assembly start soon.

Like engine of a car

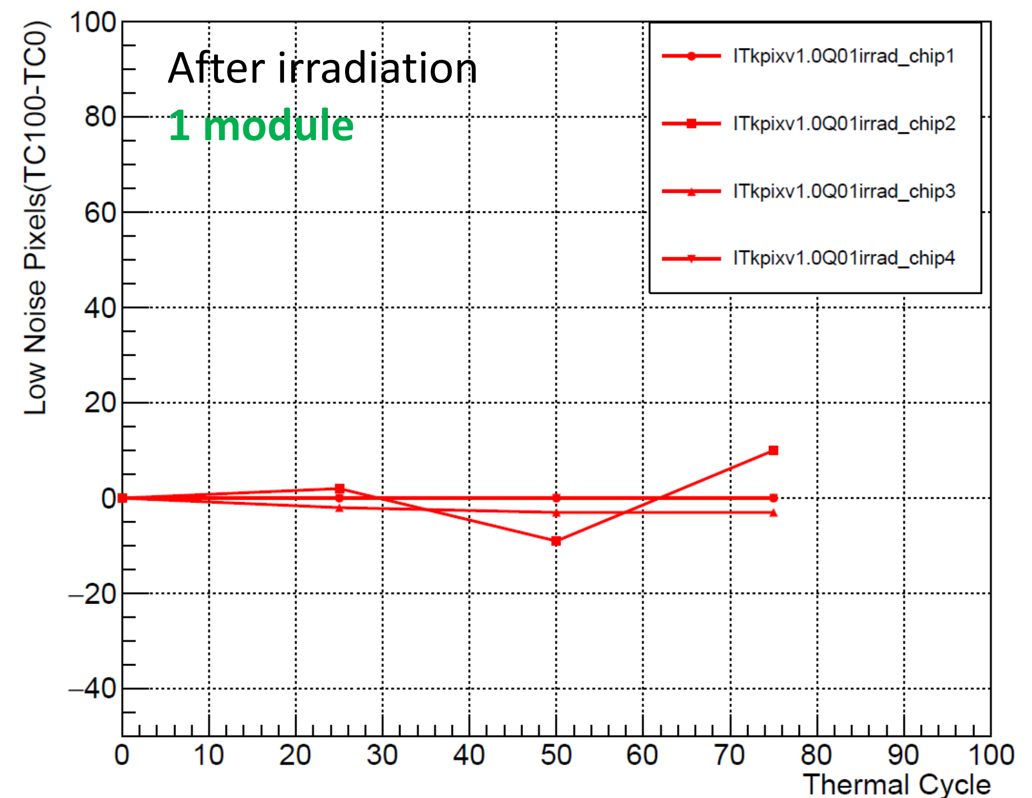


JFY2022 will be busy year for full pre-production and assembly

backup

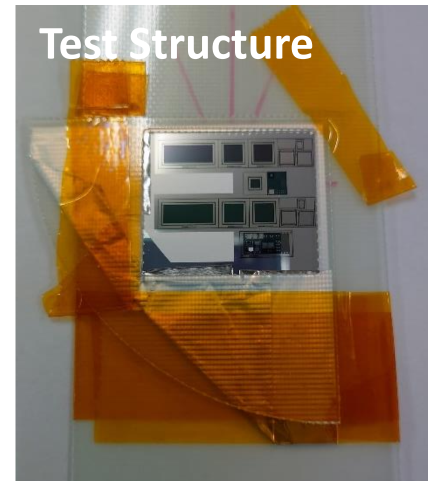
Thermal Cycle after irradiation

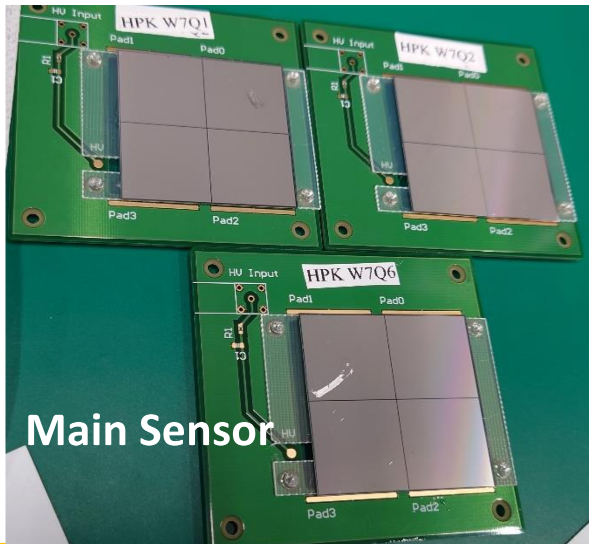
- Only one module has performed thermal cycle after irradiation so far.
  - The number of disconnected bump have not increased after TC
  - The result confirmed Parylene coating effect is not changed even after irradiation.
  - Need to increase statistics of the test.



Irradiation at CYRIC (28th Feb-)

- ***Irradiation samples***
  - Test structure (2x 2e15 and 2x 5e15)
    - $2x10^{15}$: w5-TS-P2, w7-TS-P2
    - $5x10^{15}$: w1-TS-P2, w3-TS-P2
  - Main Quad sensor (3x 5e15)
    - $5x10^{15}$: w7-P1, w7-P2 and w7-P3
  - 3D Test structure (2x 1e16 and 2x 1.7e16)
    - $1x10^{15}$: w9-PCM117, w13-PCM117
    - $1.7x10^{15}$: w9-PCM634, w13-PCM634
  - 3D Single sensor (2x 1.7e16)
    - $1x10^{16}$: w9-I34, w13-S22
    - $1.7x10^{16}$: w9-P43, w13-U42





No way to handle
without touching surface soft UBM…
Glued to PCB.

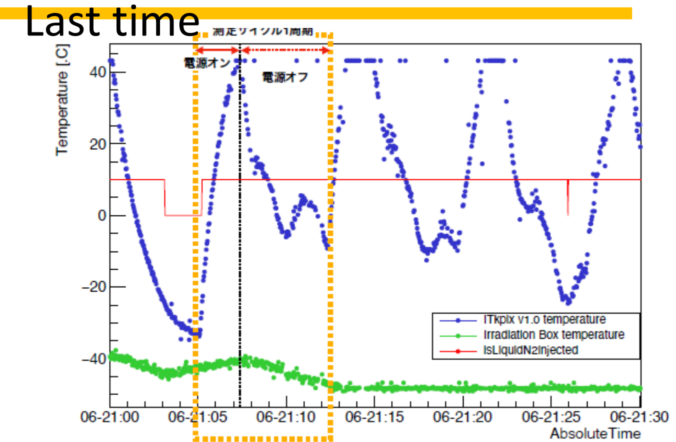
Irradiated successfully except $2x10^{15}$ Test structure
➔ Irradiation box broken and couldn't continue irradiations.

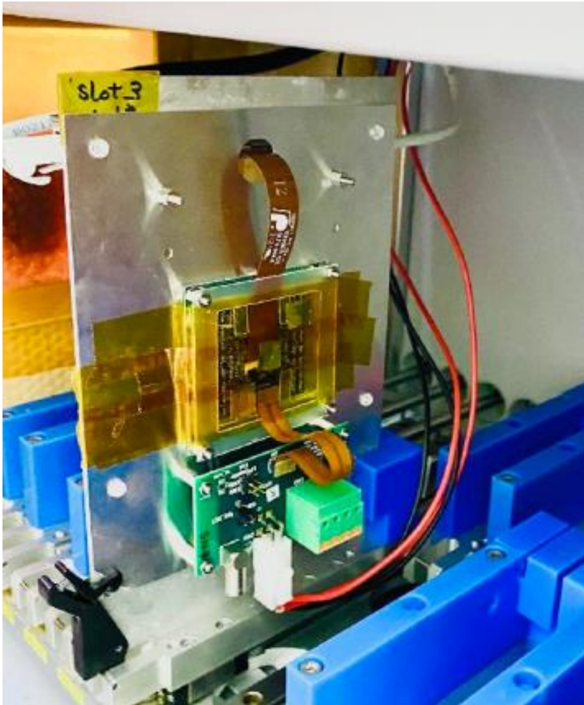
Samples will be ready to pickup around 22nd March

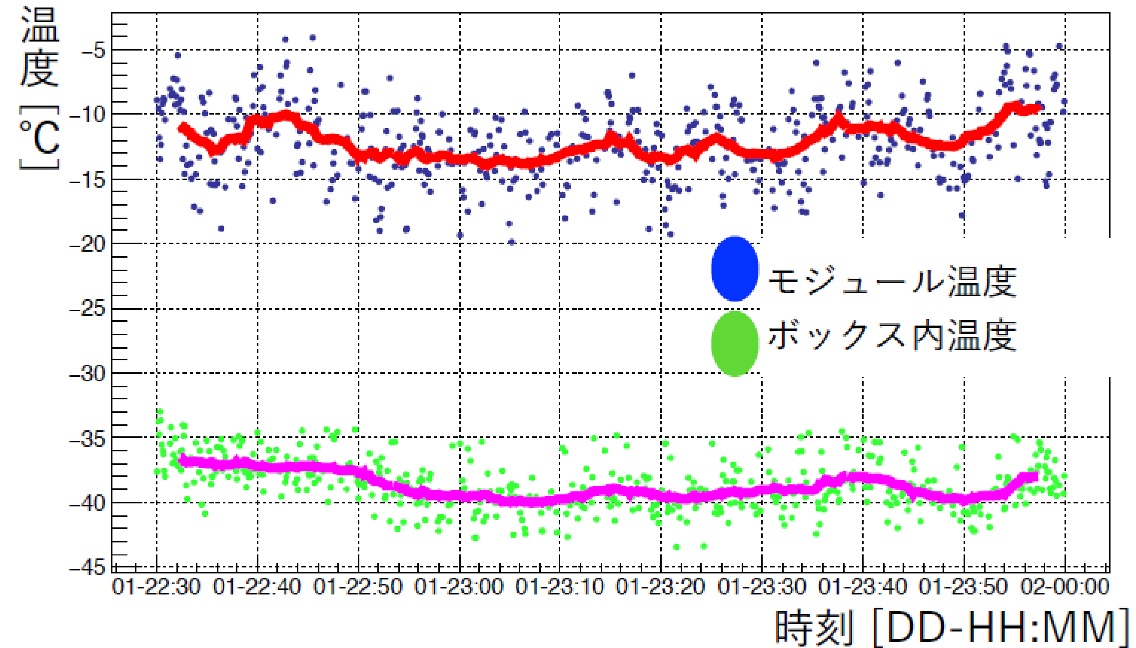
Itkpix-v1.1 irradiation with chip operation

- Cooling
  - In previous irradiation we observed rapid temperature ramp when chip LV turned on. →LV off after measurement.
  - Better cooling system has been developed and successfully operated with [-15,-10]^{o}C temperature range!

Last time







MUX monitoring and Ring Oscillator frequency

ビーム停止時間帯

chip1_VddA, chip2_VddA, chip3_VddA, chip4_VddA, chip1_VddD, chip2_VddD, chip3_VddD, chip4_VddD

chip1_VinA, chip2_VinA, chip3_VinA, chip4_VinA, chip1_VinD, chip2_VinD, chip3_VinD, chip4_VinD

chip1_VrefA, chip2_VrefA, chip3_VrefA, chip4_VrefA, chip1_VrefD, chip2_VrefD, chip3_VrefD, chip4_VrefD

Ratio

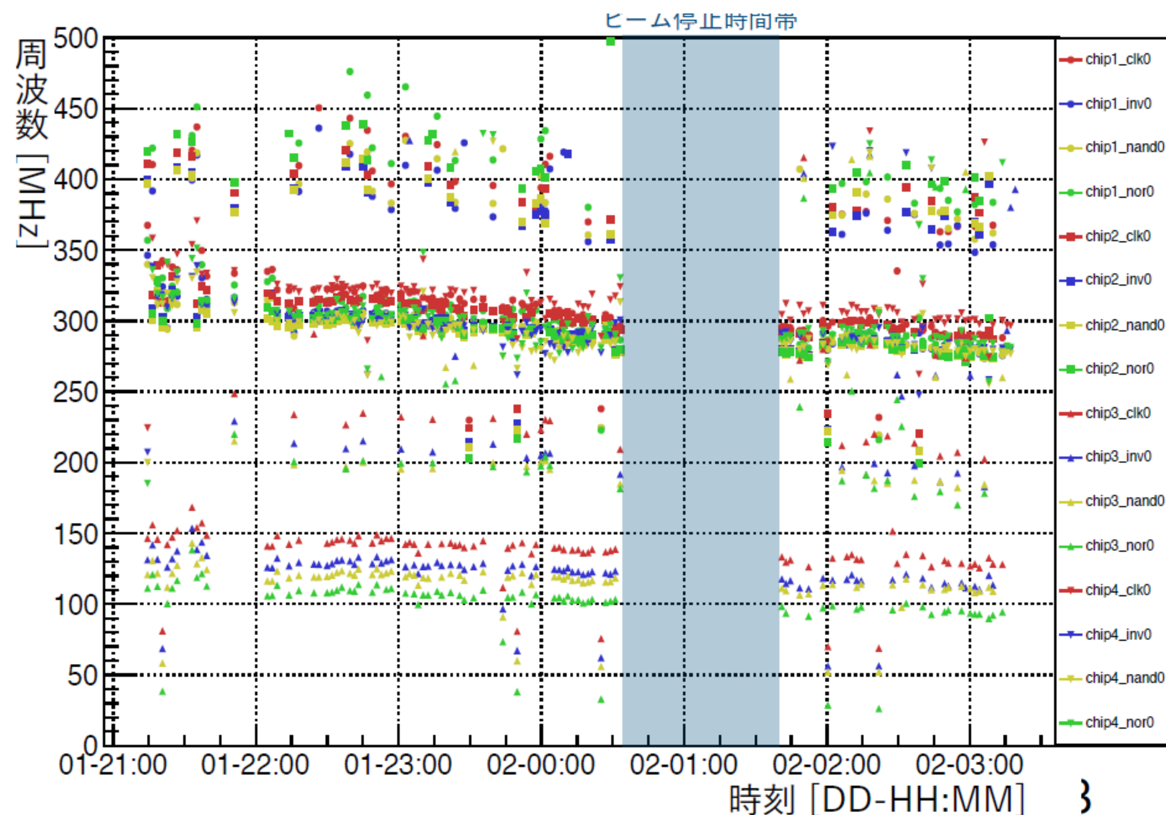
温度[°C]

モジュール温度

照射ボックス温度

時刻 [DD-HH:MM]

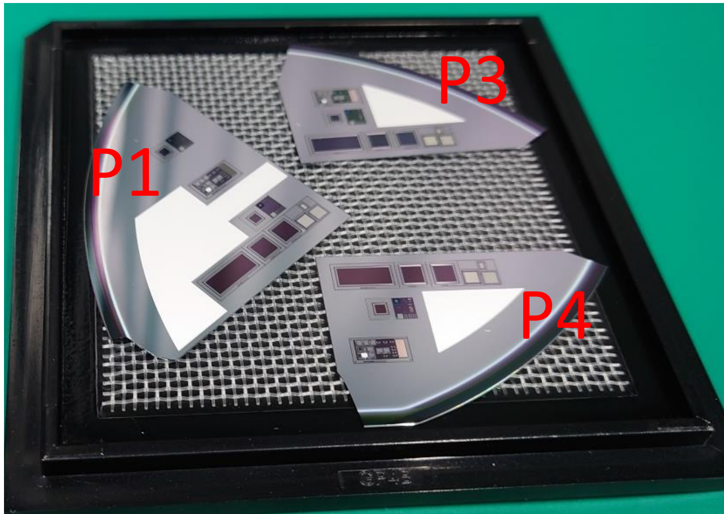
- VDDD/A rising due to Vref change.
- RO frequency going down. (50MHz/500Mrad)
  - C.f. in Xray irrad (about twice reduction..)
  - Quite consistent to what Maria saw in Birmingham irradiation.

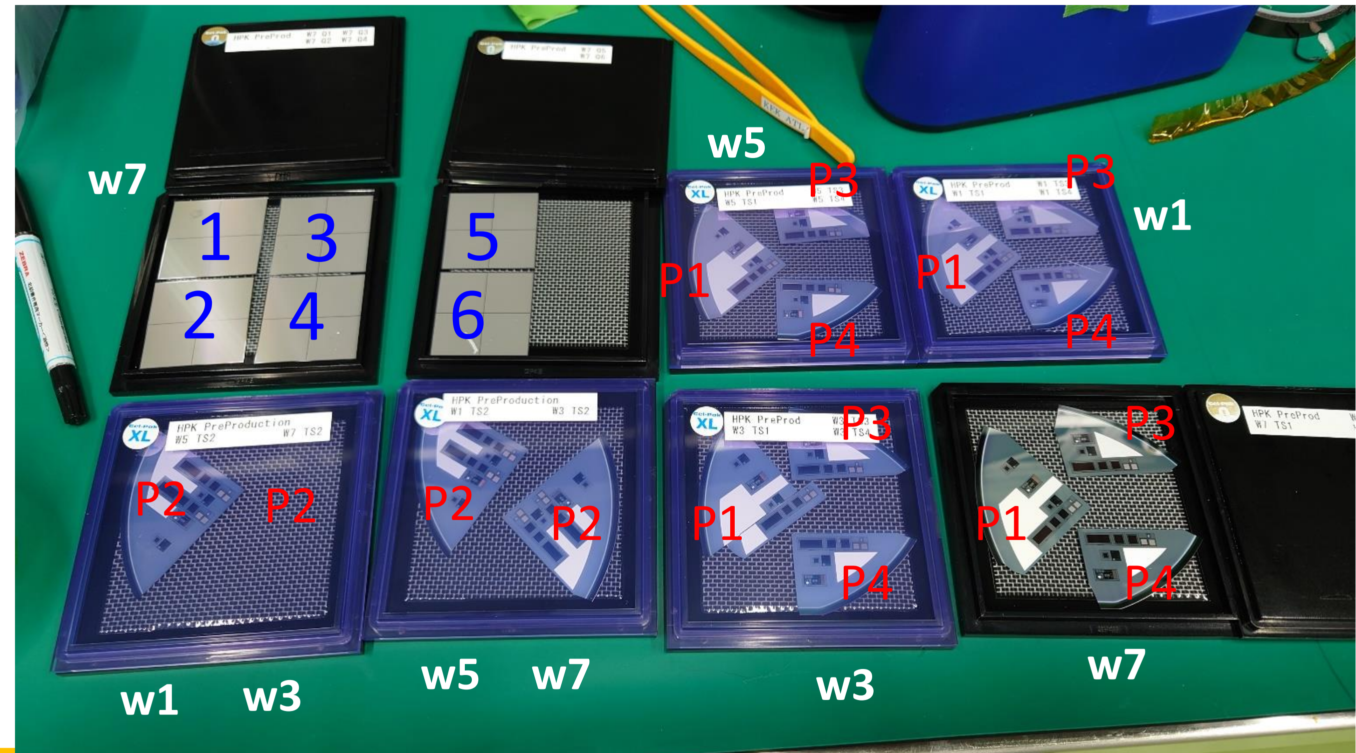


Pick up

- Picked up all Test structures from w1, 3 ,5 and 7.
- Picked up all Quad sensors from w7.
- All are stored to gel-packs

Package send to institute



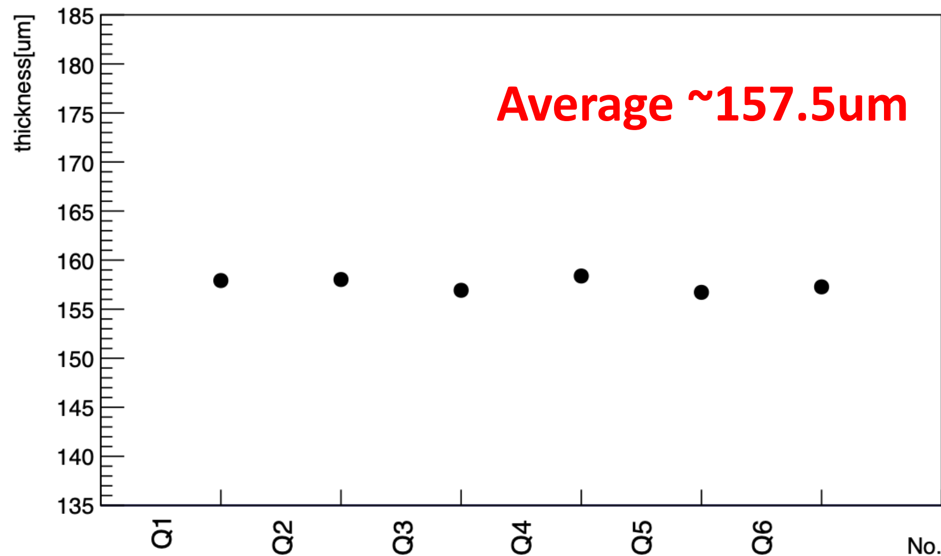


Shipment TS to testing institutes

- each gel-pack contain P1,P3,P4
  - To Goettingen : w5-P1,P3,P4
  - To Dortmund : w1-P1, P3, P4
  - To IJC lab : w7-P1, P3, P4
  - Keep one at KEK : w3-P1, P3, P4

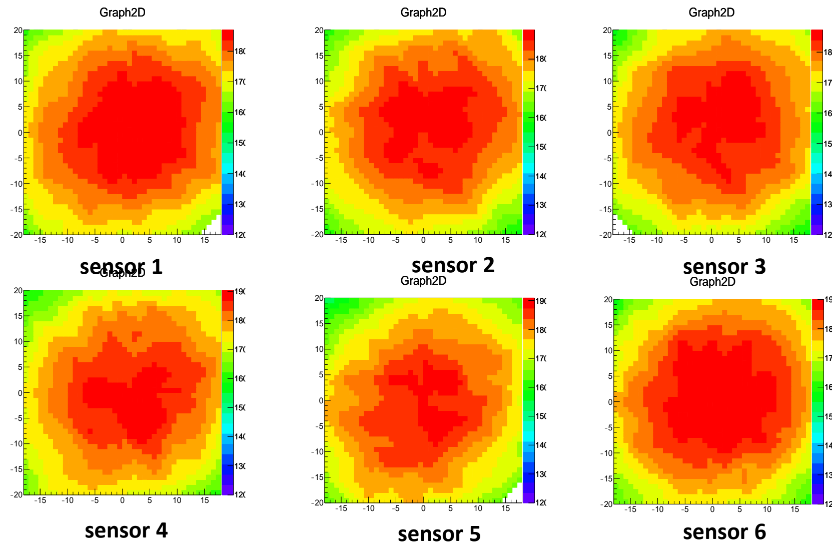
Main sensor – Thickness and bow

- Thickness
  - Hight measurement with Vacuumed chuck on
  - Take average of height for points scanned with 2mm steps (2D)



Matching to Specification : 150±15um

- Bow
  - Hight measurement without Vacuumed chuck on



All sensors have quite similar shape

Height differences are 20-35um after slope correction

Not within <25um specification(?) → may be ok since FC by HPK

bow measurement results (height diff in um)

	Q1	Q2	Q3	Q4	Q5	Q6
Max – top right	22.1	**34.1**	**31.4**	**31.3**	**27.3**	**32.7**
Max – bottom right	18.2	**26.4**	23.3	22.5	**28.2**	22.4
Max – top left	**28.7**	**31.9**	**33.8**	**32.8**	**39.5**	**33.9**
Max – bottom left	**29.2**	**31.7**	**27.1**	**26.8**	**28.4**	**25.5**