Hands-on Lab: FDSOI pixel detector

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with help from SOIPIX community

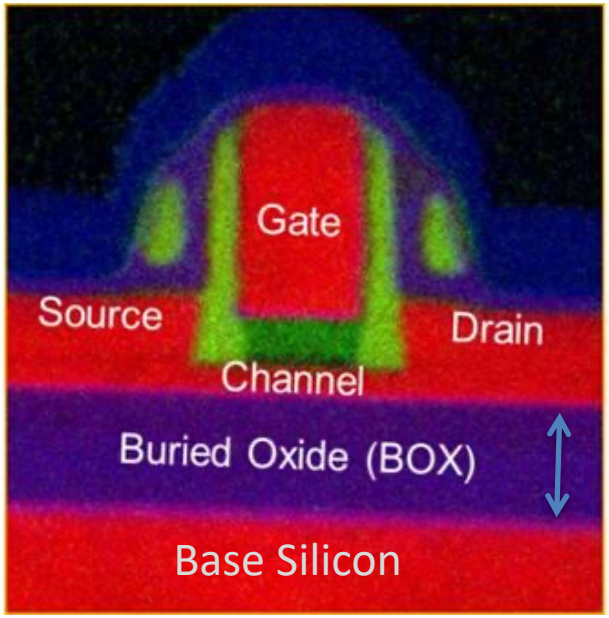
Hands-on Lab: Schedule

1) Run "Cosmic ray events collection"
   - while going through the lab lecture
2) Go through the "Lab lecture"
3) Check-out of "Cosmic ray events collection"
4) Go through the operation instruction
5) Run Hands-on Lab with laser lights

Hands-on Lab: lecture

FD-SOI

- Fully-depleted (FD)-Silicon-On-Insulator (SOI)
  - ref. "Learn More About FD-SOI – STMicroelectronics"

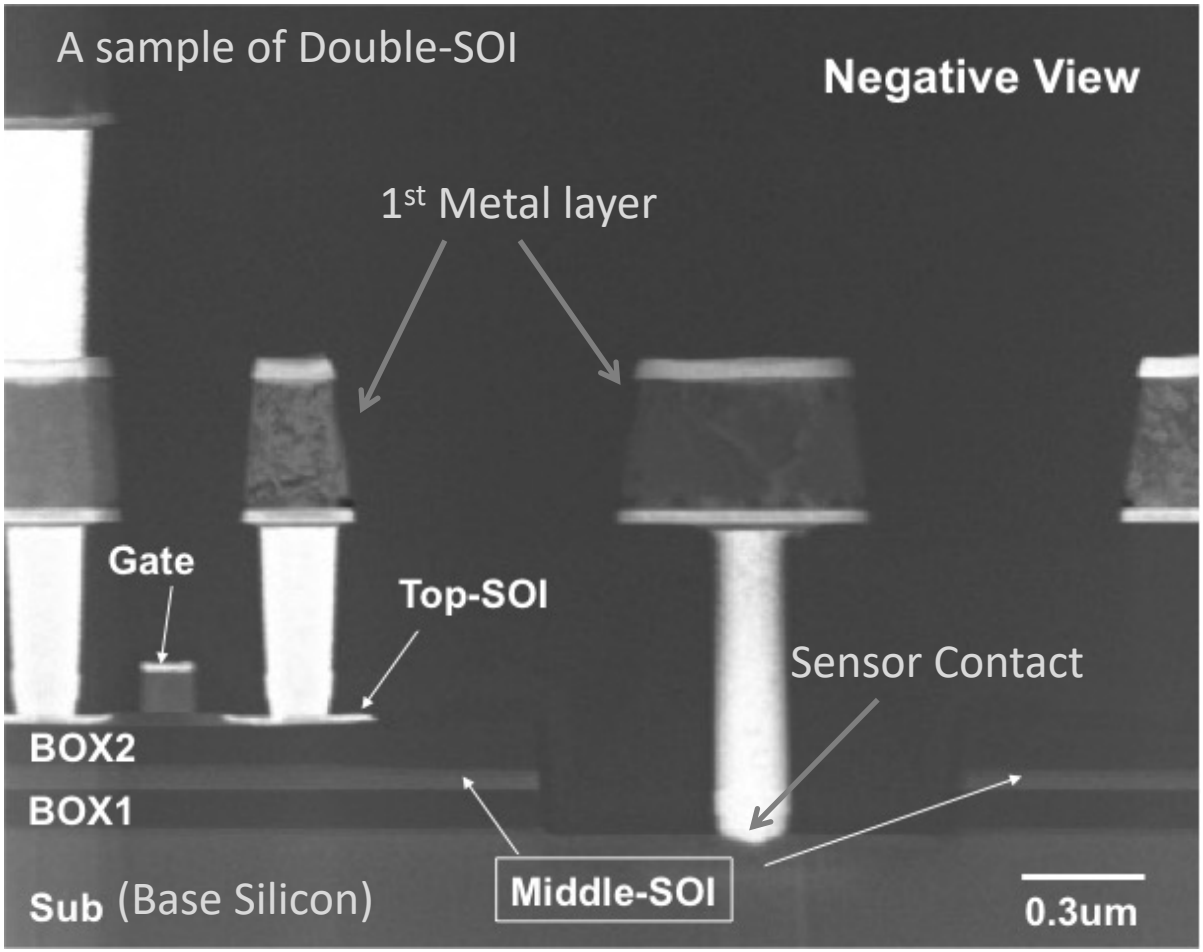


<100 nm

- FD-SOI is a planar process technology that relies on two primary innovations
  - An ultra-thin layer of insulator, called the buried oxide, is positioned on top of the base silicon.
  - A very thin silicon film implements the transistor channel, thus making the transistor Fully Depleted.

- FD-SOI enables much better transistor electrostatic characteristics versus conventional bulk technology.
  - The buried oxide layer lowers the parasitic capacitance between the source and the drain.
  - It efficiently confines the electrons flowing from the source to the drain, dramatically reducing performance-degrading leakage currents.

FD-SOI Pixel Detector (SOIPIX)

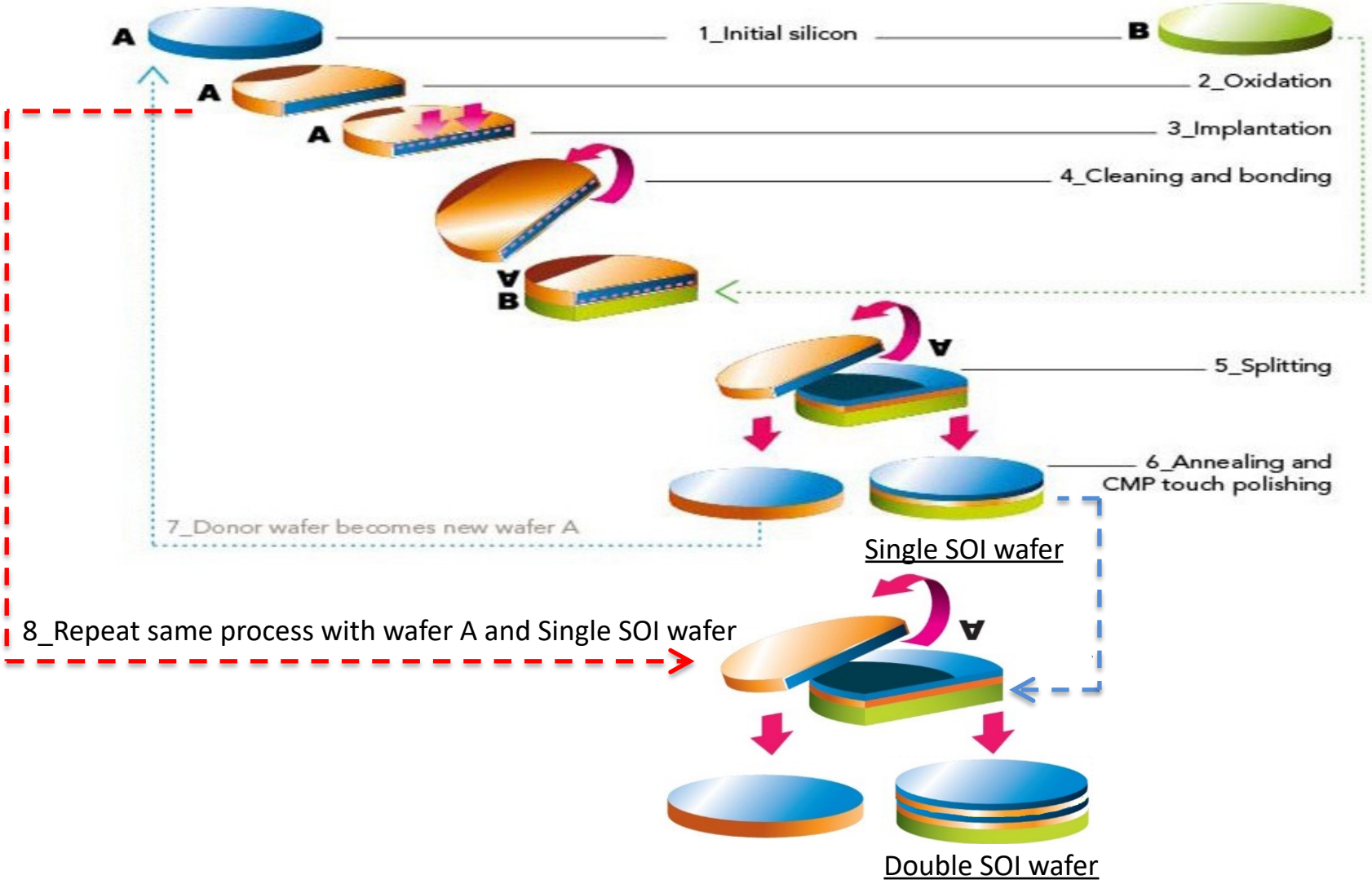


- Utilizing the Base Silicon as charge-collection medium, by making
  - a though-hole through BOX layer
  - an electrode in the Base Silicon with Sensor contact from external metal trace
- Monolithic
  - Less material
- Separated function
  - compared with bulk-CMOS MAPS
  - Electronics in FD-SOI layer
  - Sensor in Base Silicon with capability of high voltage operation (>100V)

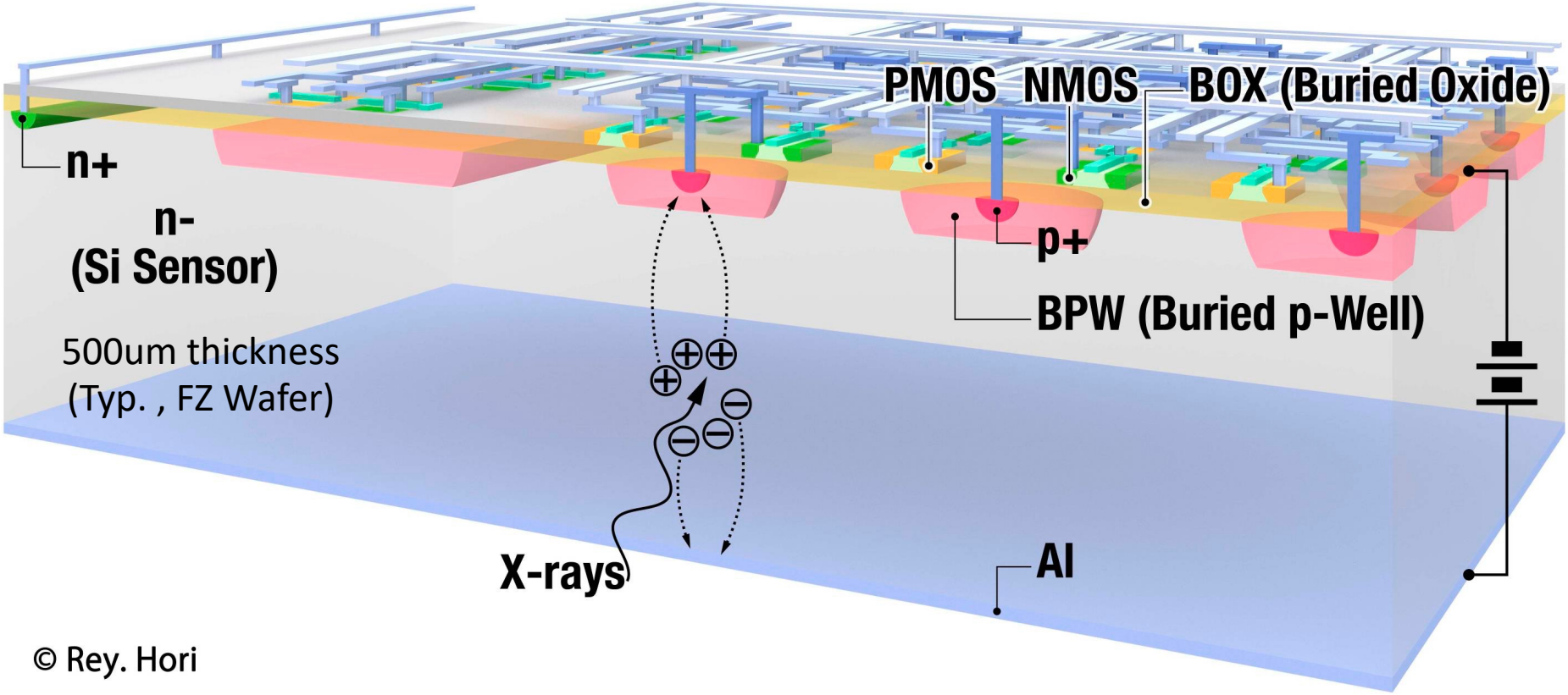
SOIPIX – A type of Monolithic Active Pixel Sensor (MAPS)

How to make SOI Wafer – SmartCut®

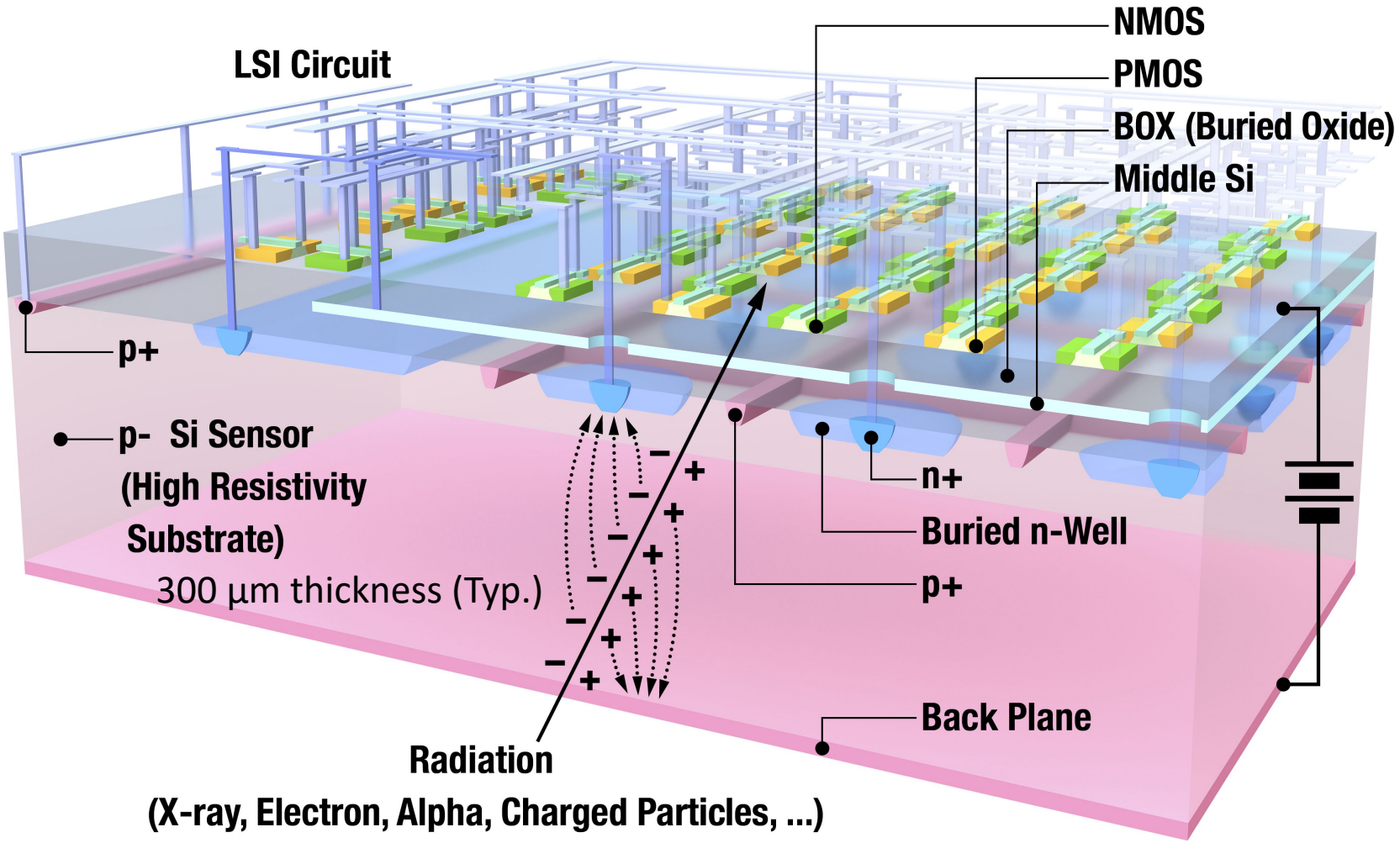
soitec



Single SOI (ex. INTPIX4)



Double SOI
(Recent Detectors, ex. CPIXTEG3b)



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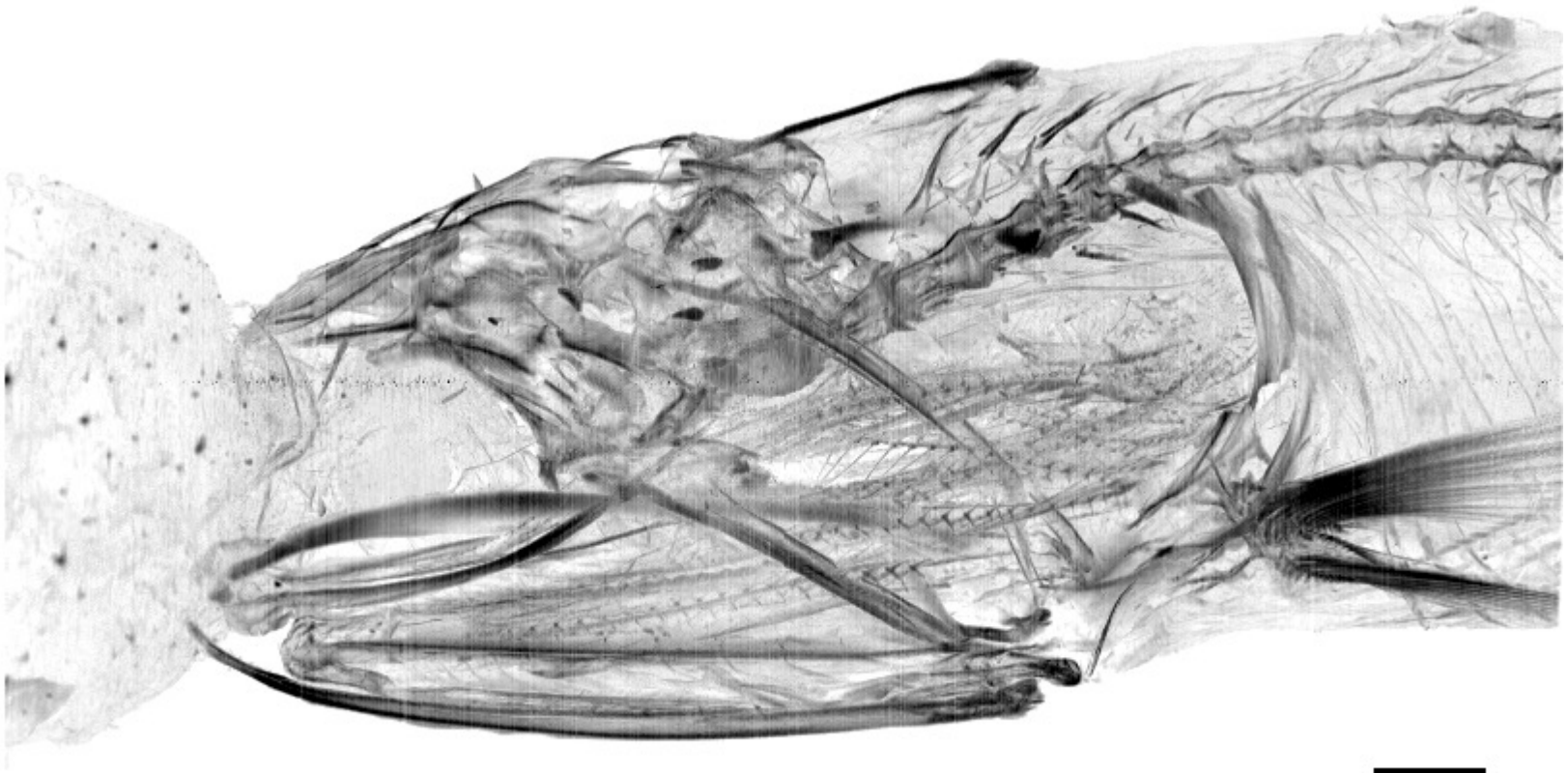
Lapis 0.2 µm FD-SOI Process Spec.

Process	0.2 µm Low-Leakage Fully-Depleted SOI CMOS 1 Poly, 5 Metal layers, MIM Capacitor (1.5 fF/μm2), DMOS Core (I/O) Voltage = 1.8 (3.3) V
SOI wafer	Top Si : Czochralski, ~18 Ω-cm, p-type, ~40 nm thick Buried Oxide : 200 nm thick Handle wafer : Czochralski (n-type) ~700 Ω-cm, Floating Zone (n-type) ~7k Ω-cm, Floating Zone (p-type) ~25k Ω-cm etc.
Backside process	Mechanical Grind, Chemical Etching, Back side Implant, Laser Annealing and Al plating
Transistors	Normal and low threshold transistors are available for both core and IO transistors. Three types of structures (body floating, source-tie and body-tie) are available.
Optional process	Buried p-well formation Vertical integration with μ-bumps

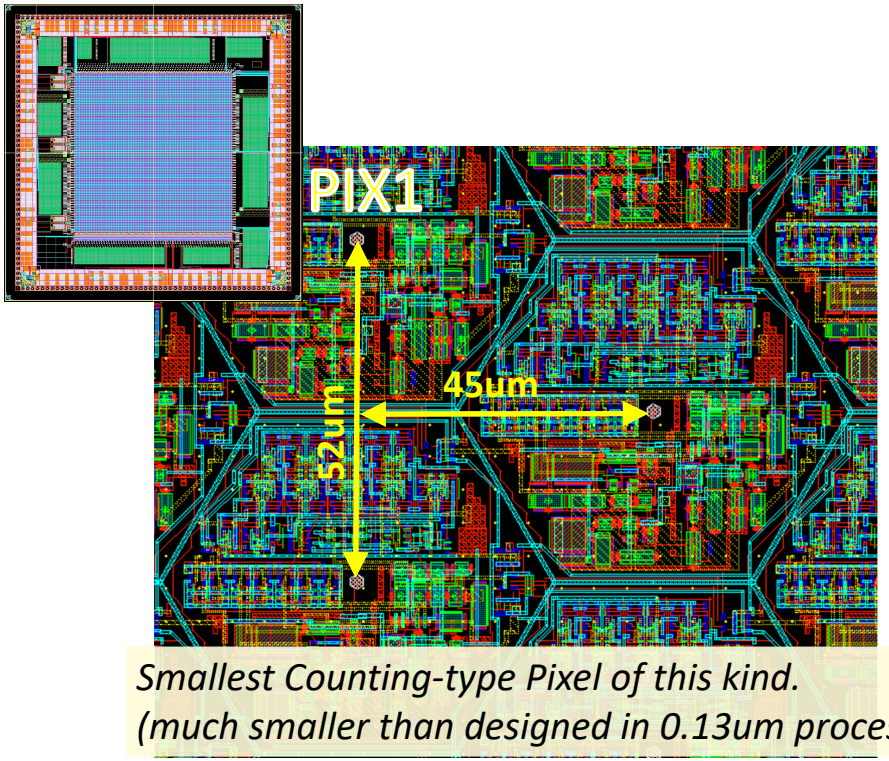
SOI Device performance example
(3D micro-CT taken by INTPIX4 at PhotonFactory BL-14B)

Sample : Small dried sardine (Niboshi)

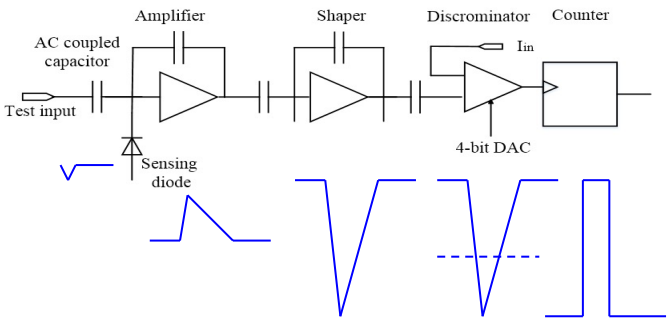


By R. Nishimura (KEK)

FD-SOI pixel detector - Device

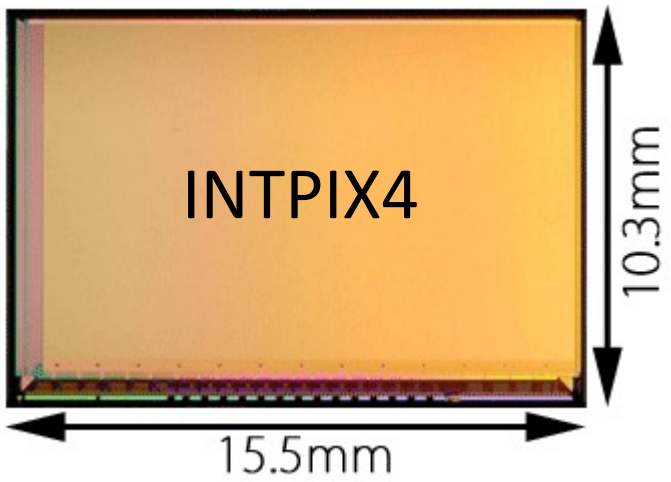


Smallest Counting-type Pixel of this kind.
(much smaller than designed in 0.13um process)

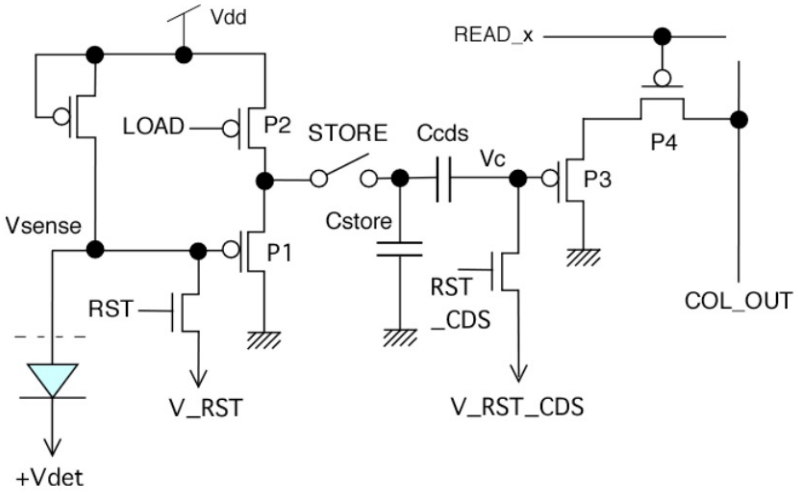


- A counting type SOI pixel detector (CPIXTEG3b)
  - 0.2 µm CMOS process
  - The prototype measures 6 × 6 mm^2, with the sensitive area of 3.2 × 3.2 mm^2.
  - 64 × 64-pixel matrix with 50 µm pixel pitch
- SOI pixel sensor
  - Double SOI process
  - 300 µm thickness
- On-chip electronics
  - Charge sensitive amplifier(charge to electronic pulse)
  - Discriminator
  - Counter (registered the X-ray photon number)

FD-SOI pixel detector - Device

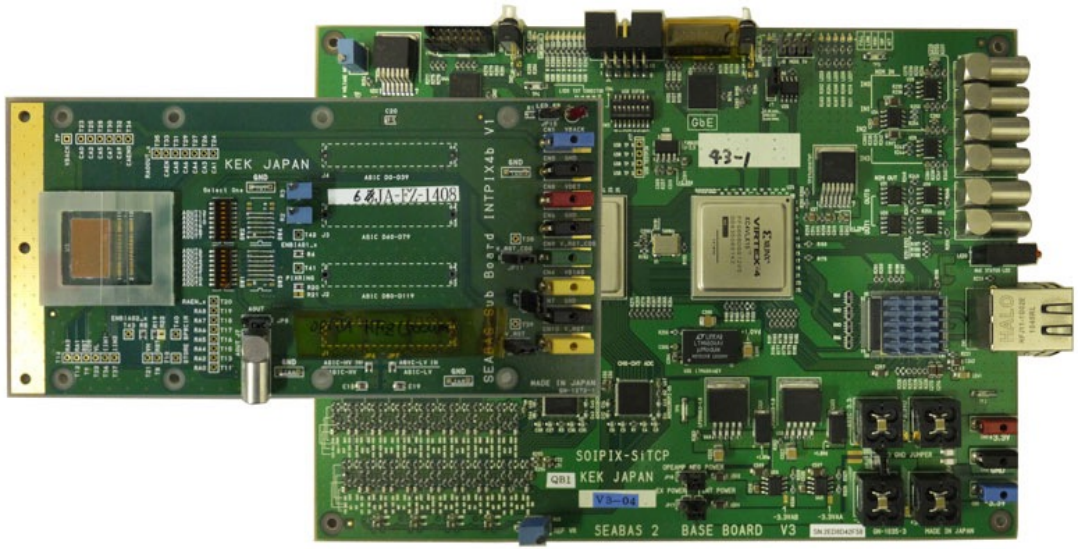


In-pixel circuit

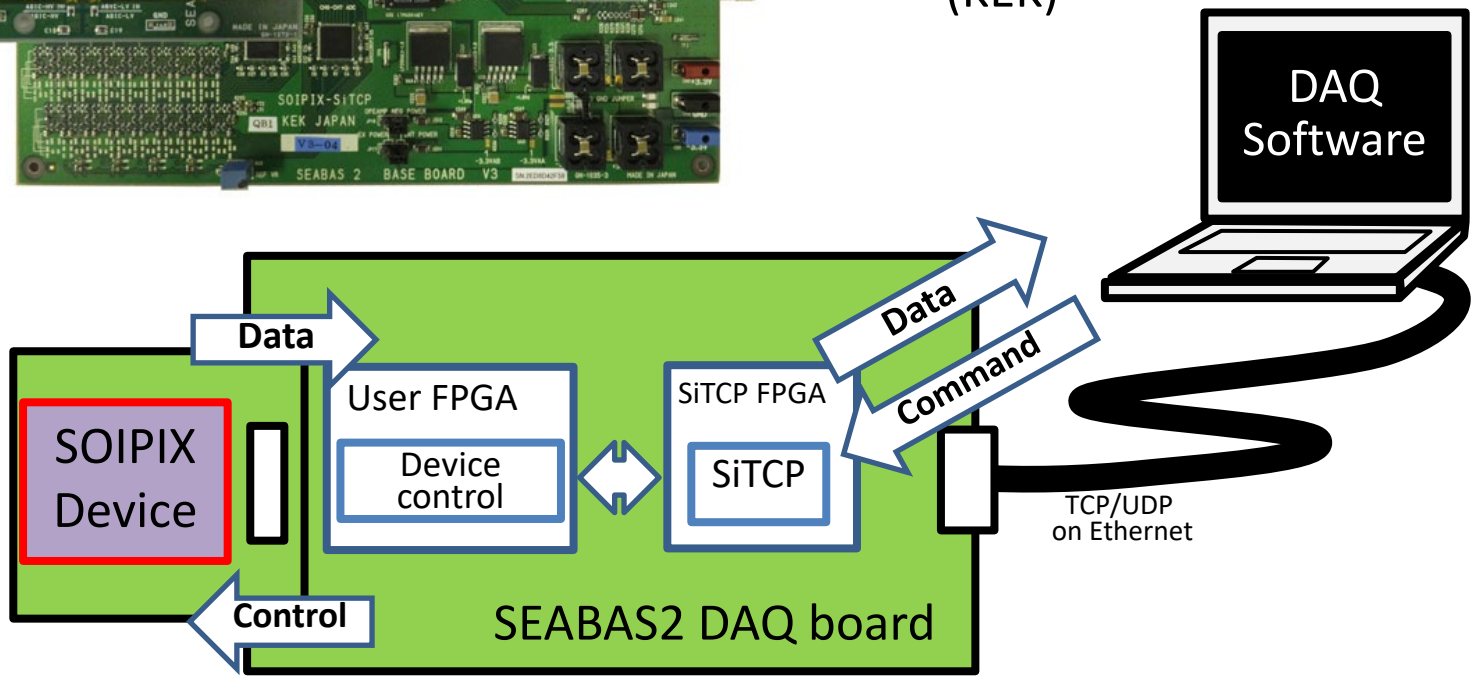


- An integration type SOI pixel detector (INTPIX 4)
  - 0.2 um CMOS process
  - Measures 15.5 × 10.3 mm^2, with the sensitive area of 14.1 × 8.7 mm^2.
  - 832 × 512-pixel matrix with 17 µm pixel pitch
- SOI pixel sensor
  - Single SOI process
  - 500 µm thickness
- On-chip electronics
  - PMOS Source Follower Amp
  - In-pixel Correlated Double Sampling
  - 13 channels parallel readout

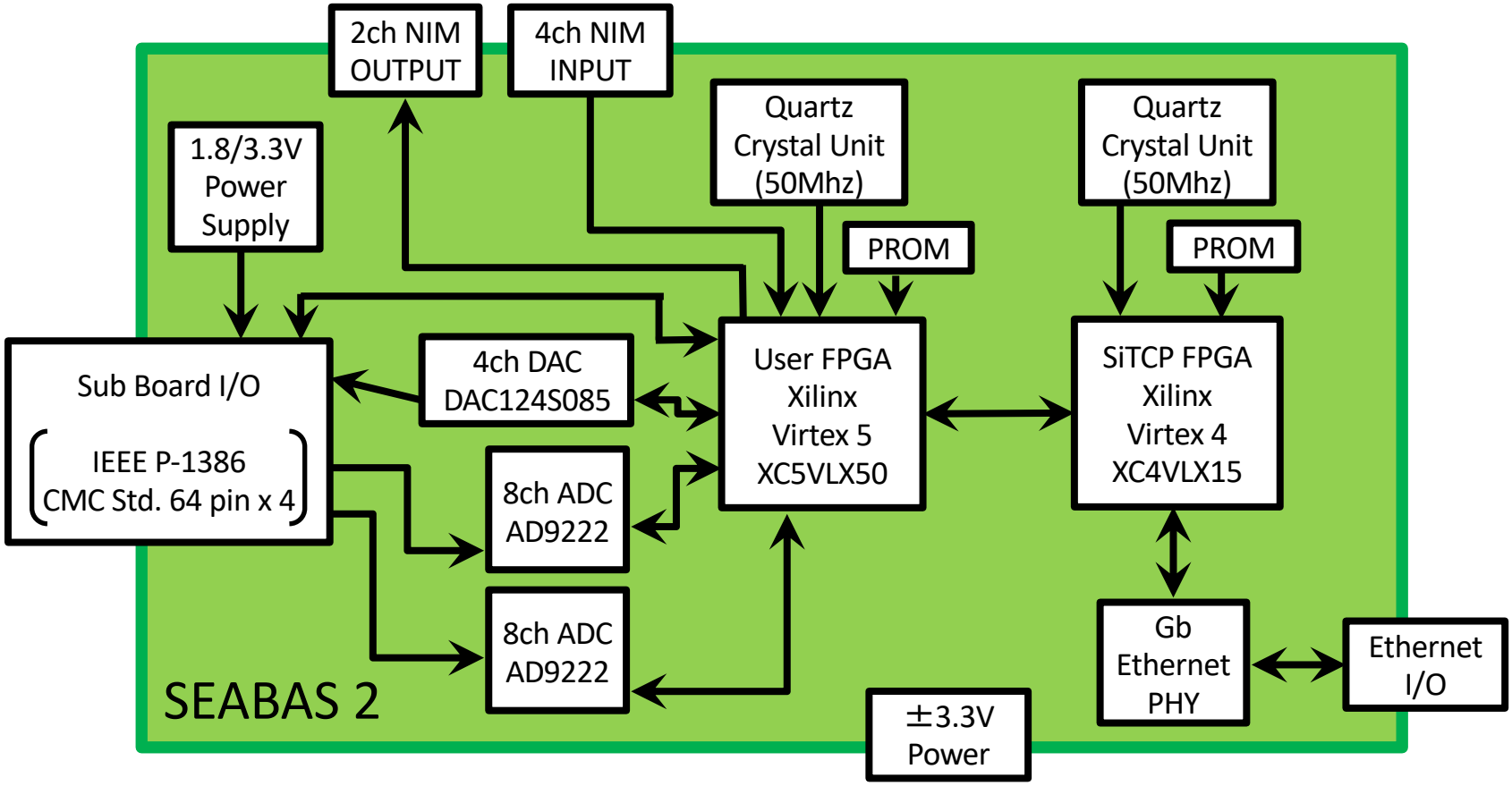
FD-SOI pixel detector - Setup



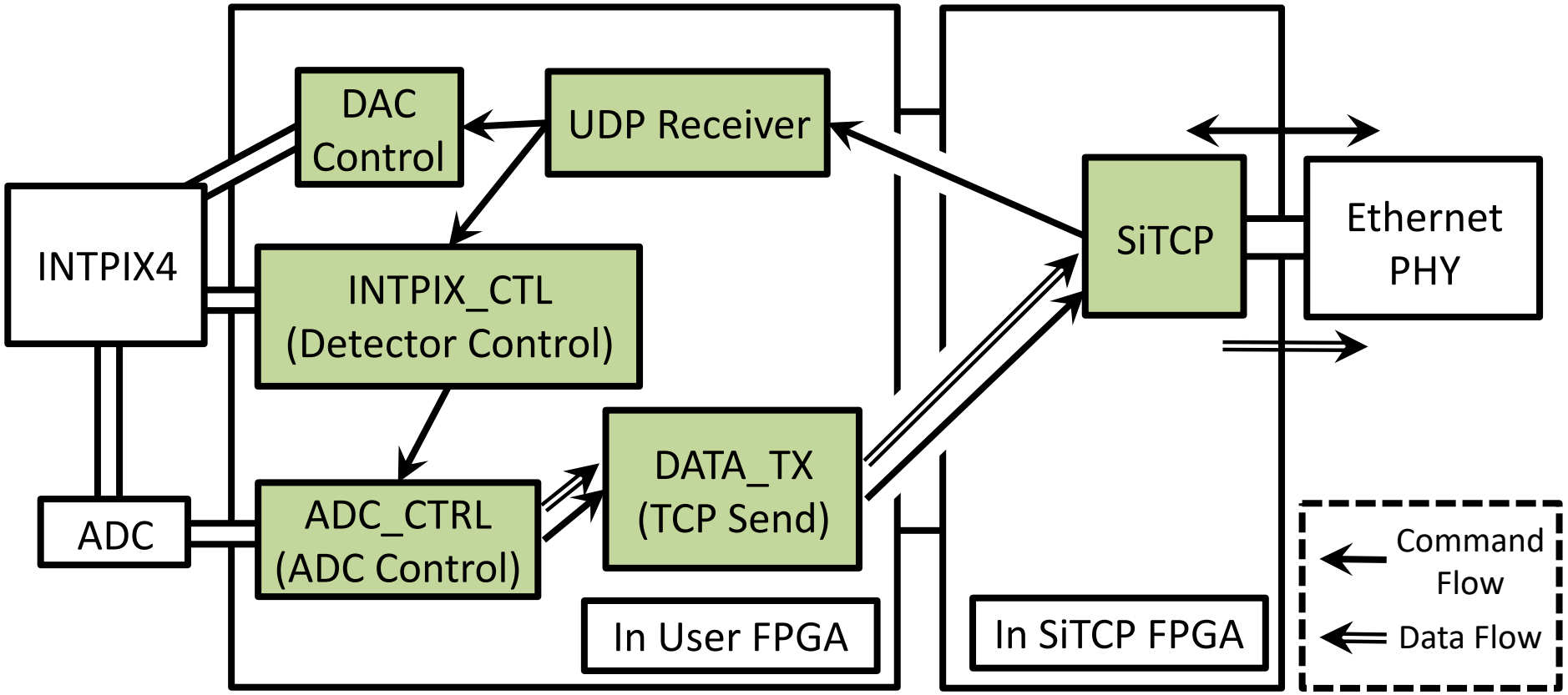
- SOIPIX Device board
  - piggy-backing on
- SEABAS DAQ board
  - developed by KEK
- DAQ Software
  - developed by R. Nishimura (KEK)



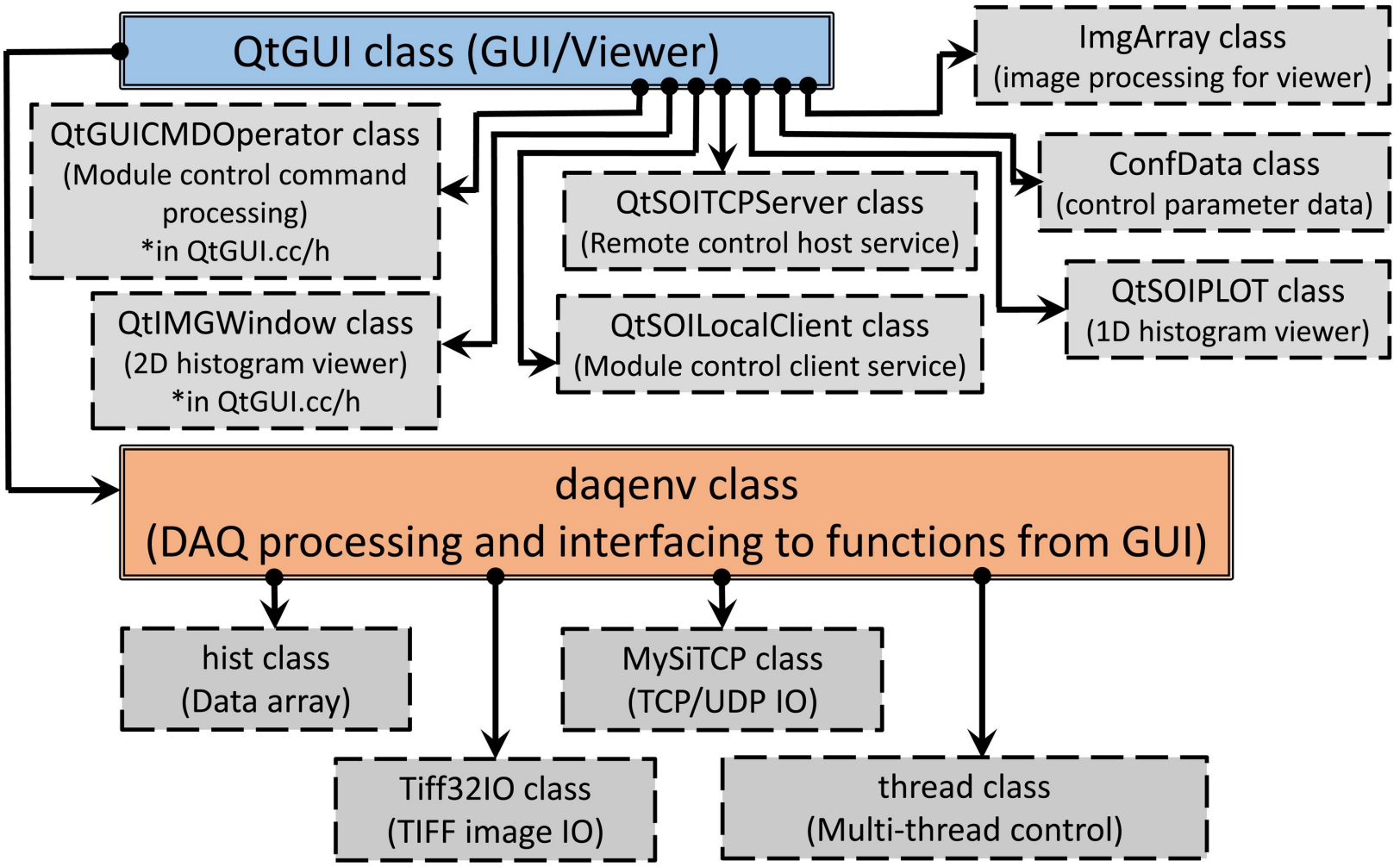
Detail of DAQ system Modules on SEABAS



Detail of DAQ system Structure of Firmware on SEABAS FPGAs (INTPIX4 case)



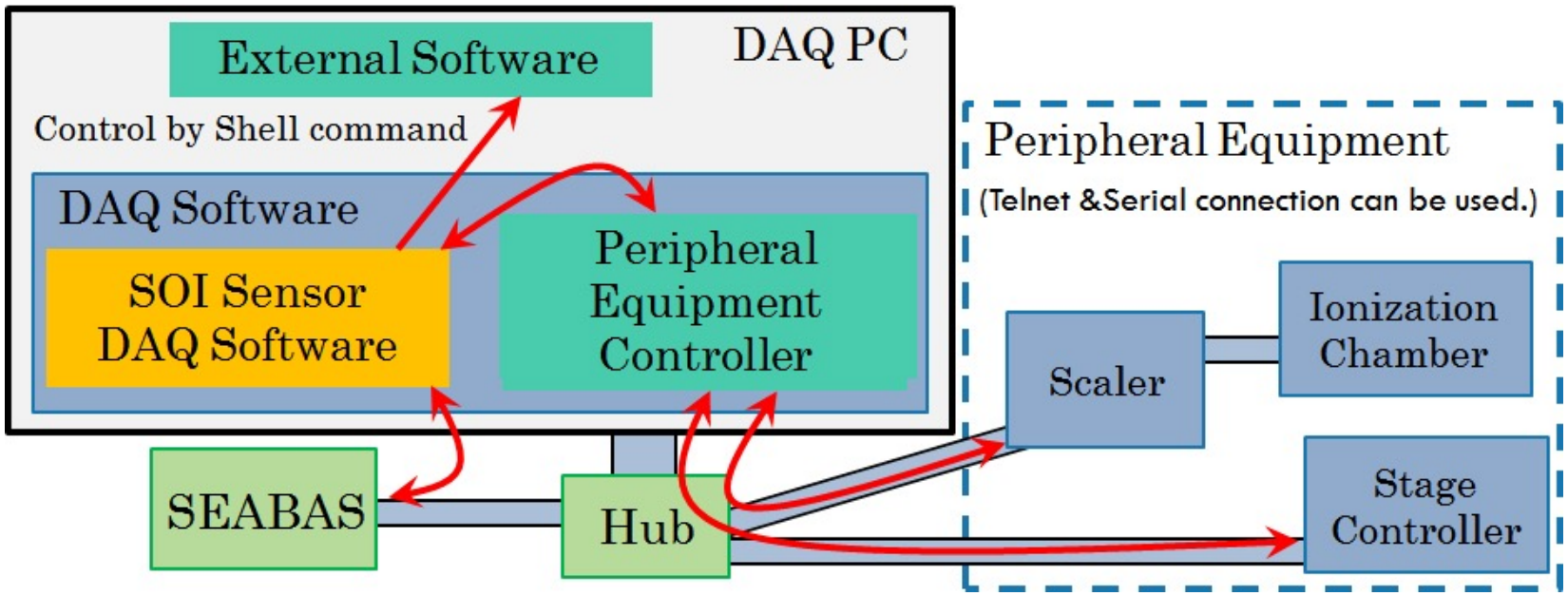
Detail of DAQ system
Structure of SOI Sensor DAQ Software



All Software module were written by C++11 and support recent Windows and Linux.
Using OpenCV, Qt, ROOT, picojson and qcustomplot libraries.

Detail of DAQ system
DAQ Framework

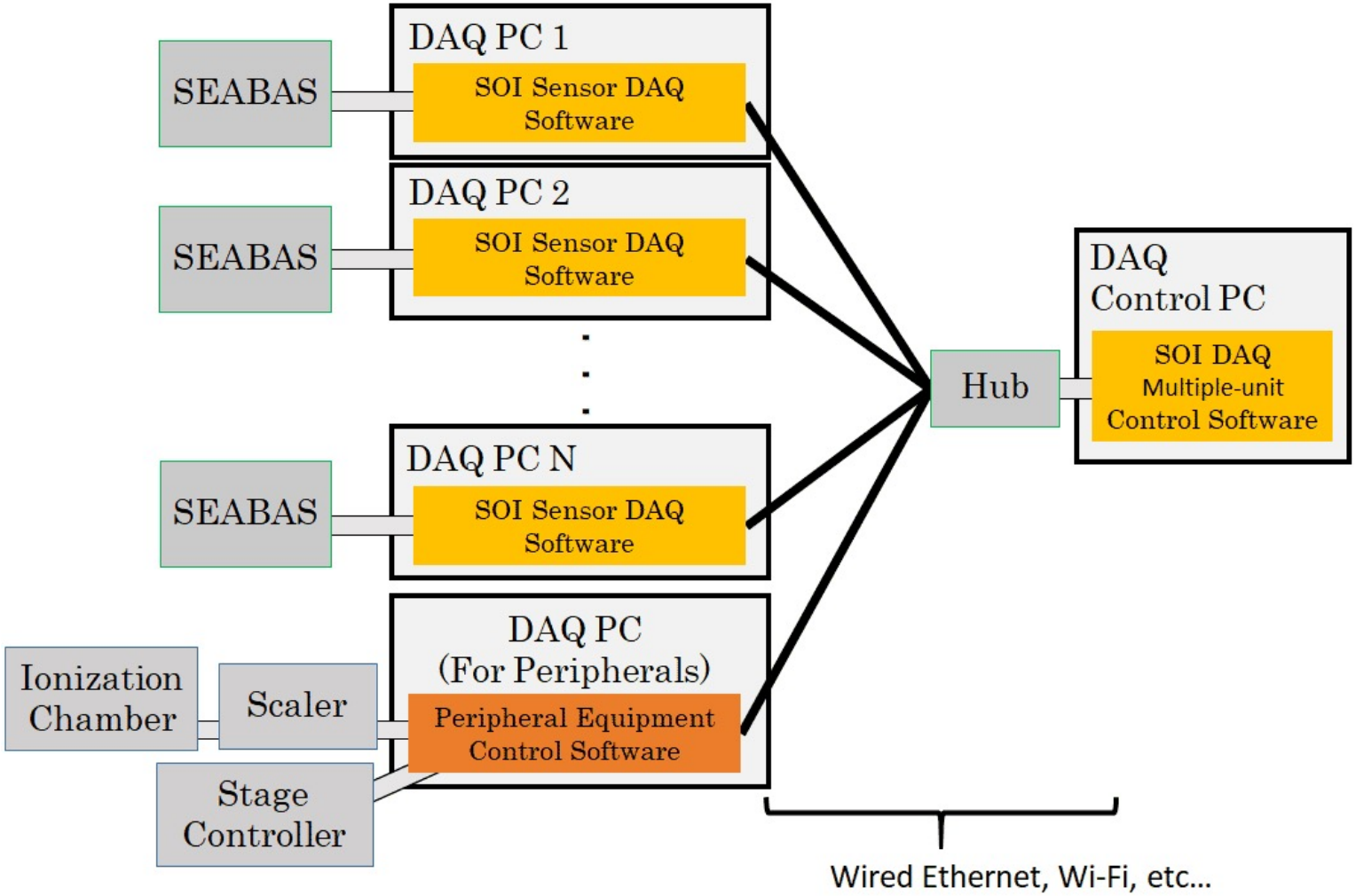
Case 1. 1 SOI device with peripherals controlled from 1 DAQ PC.



Small setup is OK.

Detail of DAQ system
DAQ Framework

Case 2. Several SOI devices with peripherals controlled from several DAQ PCs.



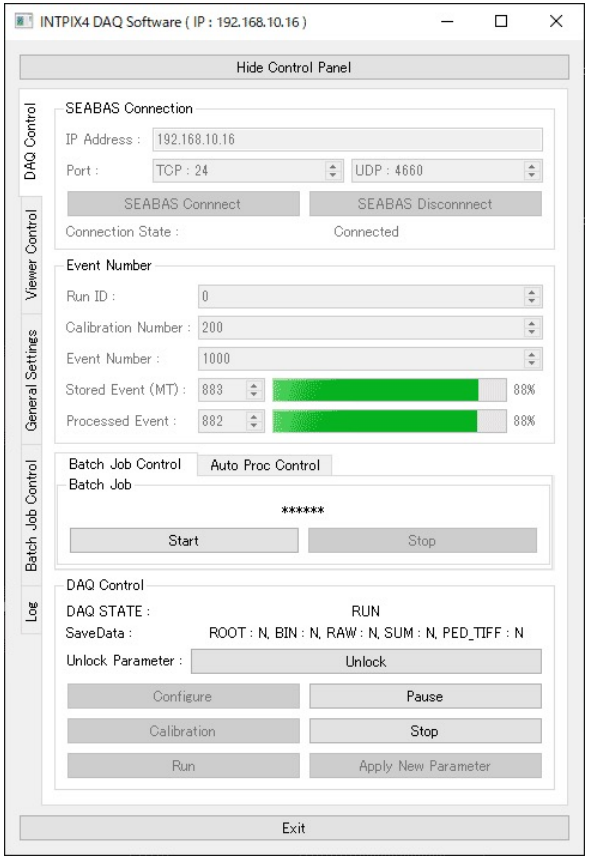
Larger setup is also OK.

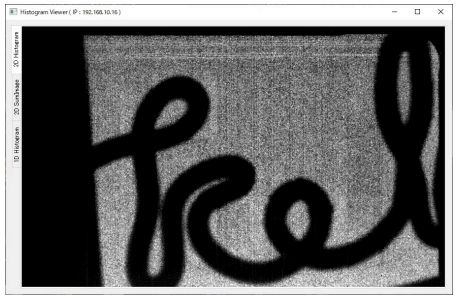
Detail of DAQ system
DAQ Framework

Case 3. This Lecture.

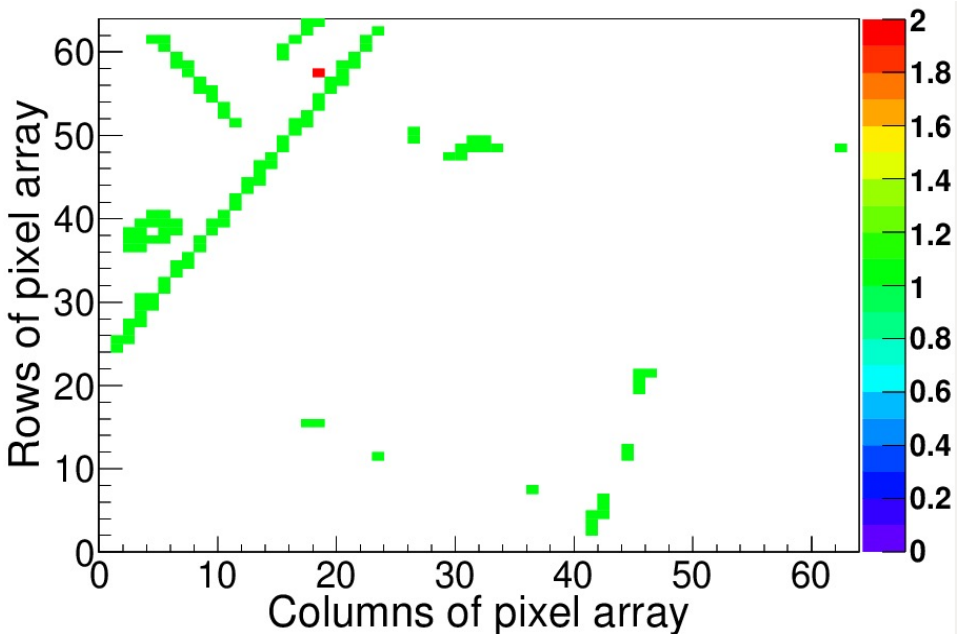
Very simple. ☺

Hands-on Lab: Training





- Operation of Data Acquisition (DAQ)
- Cosmic ray events collection
  - Event accumulation for 1 hour
- Response to laser light
  - with a laser pointer
  - Charge/Signal vs Bias voltage
  - Transparency of Silicon



Hands-on Lab: Operation of DAQ

How to Use SOI Device and DAQ Software

Prepare below before DAQ Software hook up. (1)
(Already done in today's setup.)

1. Connect SEABAS and SOI Detector.
2. Connect Power cables for SEABAS/SOI Detector.
3. Hookup SEABAS and PC by Ethernet cable.
4. Power On.
   Supply +3.6V(3.3V+0.2V for drop-down) for SEABAS2,
   +5.0V for SEABAS 1.
5. Apply Bias Voltage. (Apply + for Ntype, - for Ptype)
   Typical value is +150..200 V for INTPIX4, but +15V is enough for this training setup.

* If you want to know the detail of DAQ Software, please contact to R. Nishimura (ryunishi@post.kek.jp).

How to Use SOI Device and DAQ Software

Prepare below before DAQ Software hook up. (2)
(Already done in today's setup.)

6. Startup PC and set IP configuration for wired Ethernet shown below.

IP Address	192.168.10.30 (1-254 without 16)
NetMask	255.255.0.0
Default gateway	(leave blank)

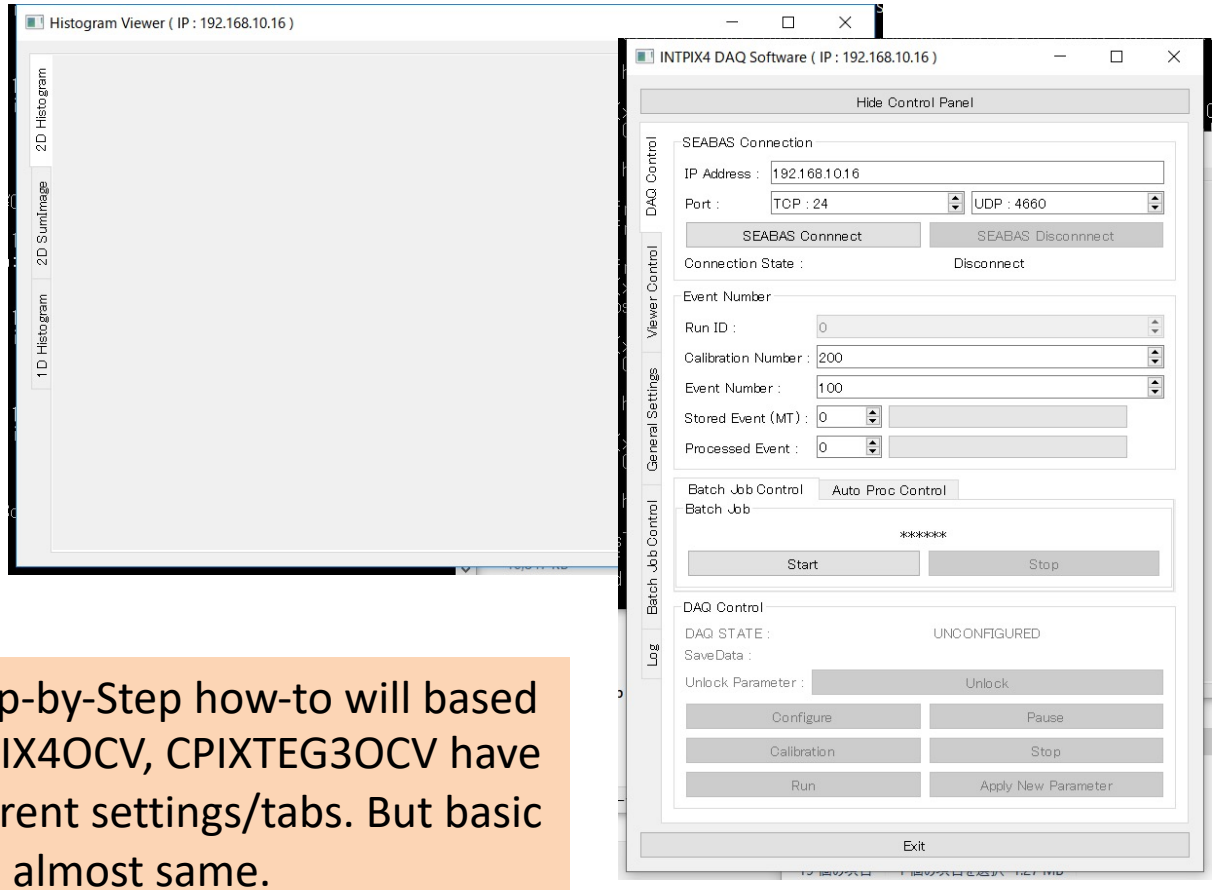
7. Ping to 192.168.10.16 (or 0.16 for SEABAS1) and check reply.

* If you want to know the detail of DAQ Software, please contact to R. Nishimura (ryunishi@post.kek.jp).

How to Use SOI Device and DAQ Software

1. Execute DAQ Software.

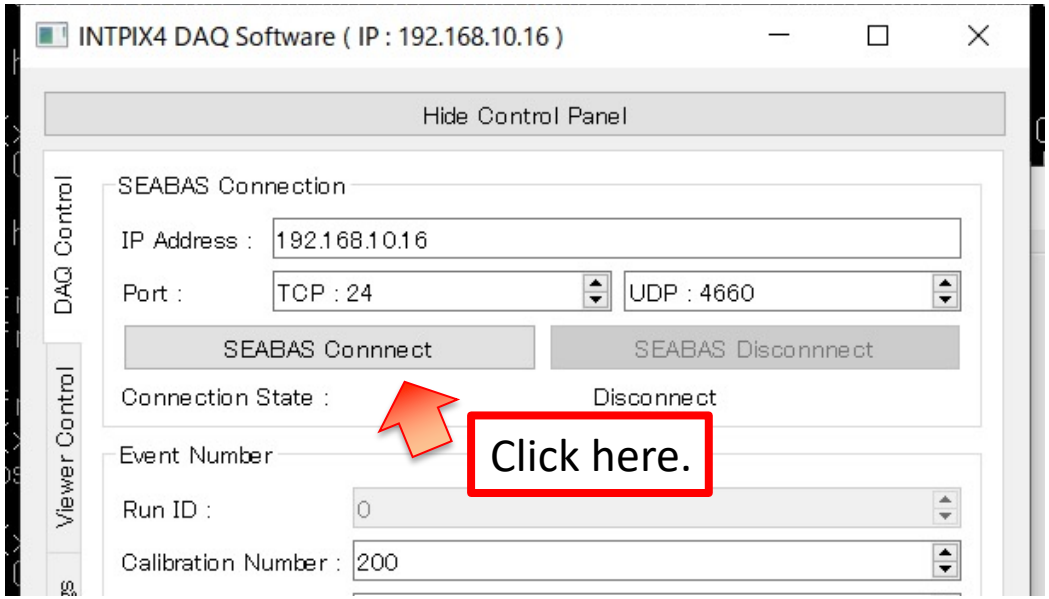
(INTPIX4 : INTPIX4OCV , CPIXTEG3b : CPIXTEG3OCV)



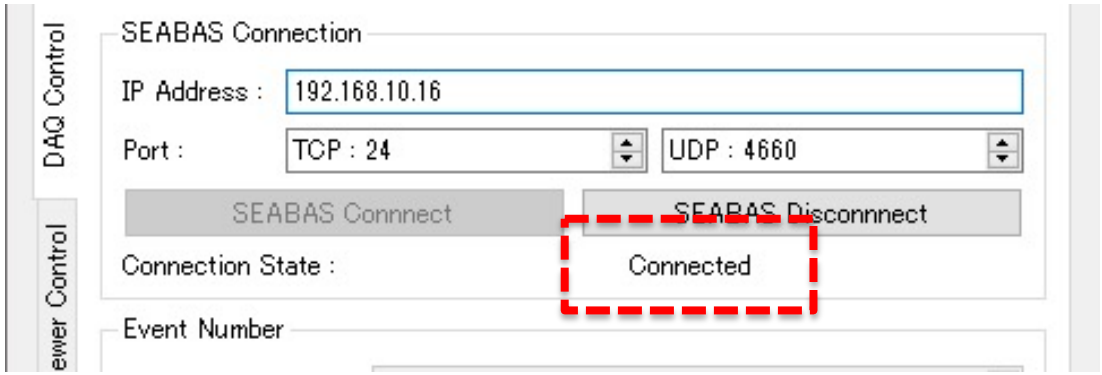
* This Step-by-Step how-to will based on INTPIX4OCV, CPIXTEG3OCV have bit different settings/tabs. But basic usage is almost same.

How to Use SOI Device and DAQ Software

2. Make a Connection to SEABAS.

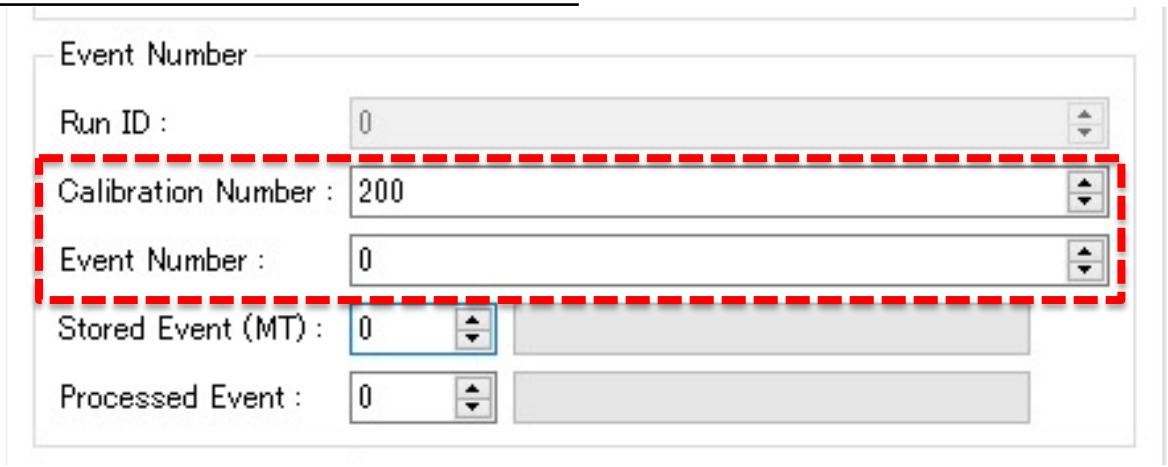


If connection was successful, Connection State will be changed to “Connected”.



How to Use SOI Device and DAQ Software

3. Set Frame number.

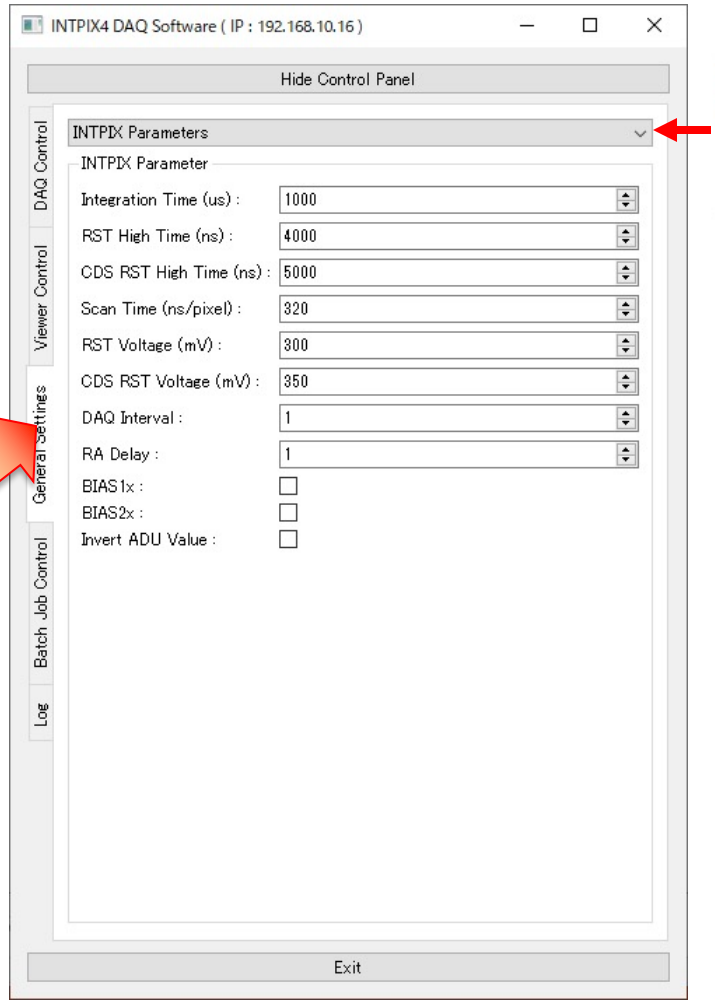


Calibration Number	Frame number to use to make Pedestal data. Pedestal data = Avg. of [ADC offset + BG + Noise] Calibration data taking will stop automatically when frame count reached to this number.
Event Number	Frame number of real event data (ex. MIP tracks, X-rays image etc). Event data taking will stop automatically when frame count reached to this number. “0” means ∞. (Have to stop manually.)

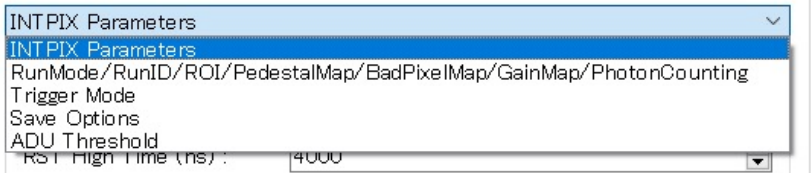
This time we set “200” for Calibration Number and “0” for Event Number.

How to Use SOI Device and DAQ Software

4. Switch to “General Settings” tab.



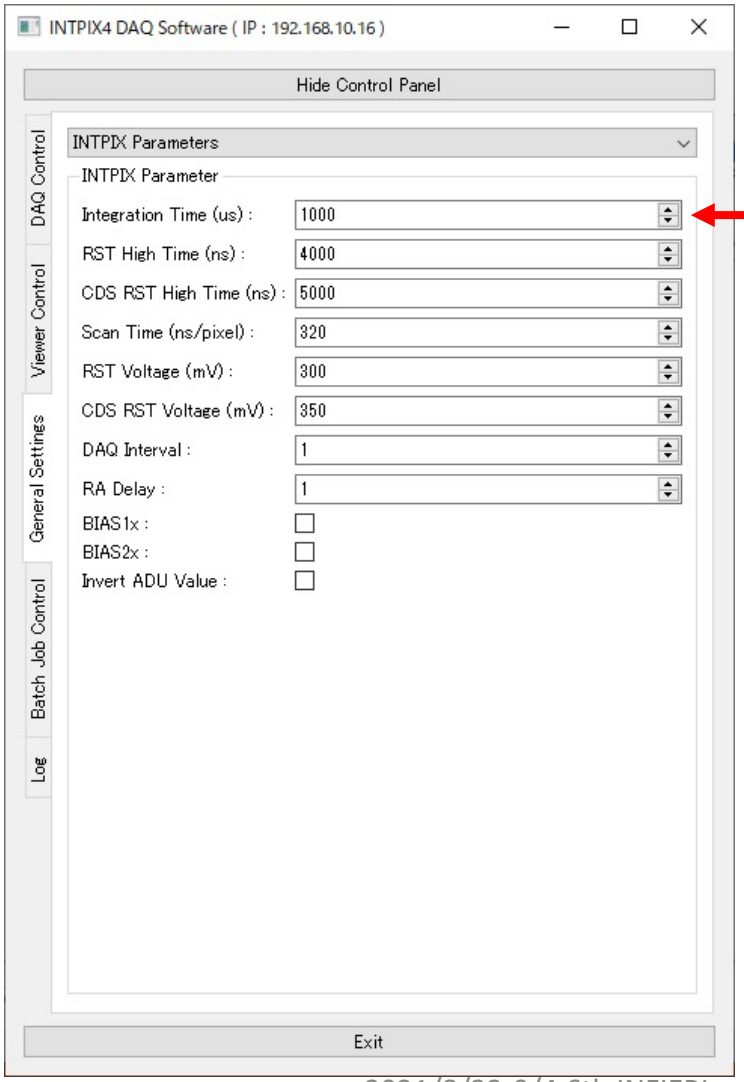
Click here.

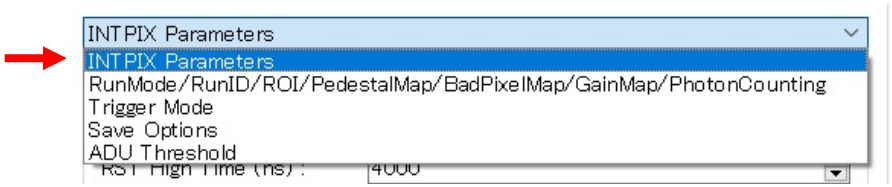


Upper dropdown box has several list shown above.

How to Use SOI Device and DAQ Software

5. Set INTPIX Parameters.

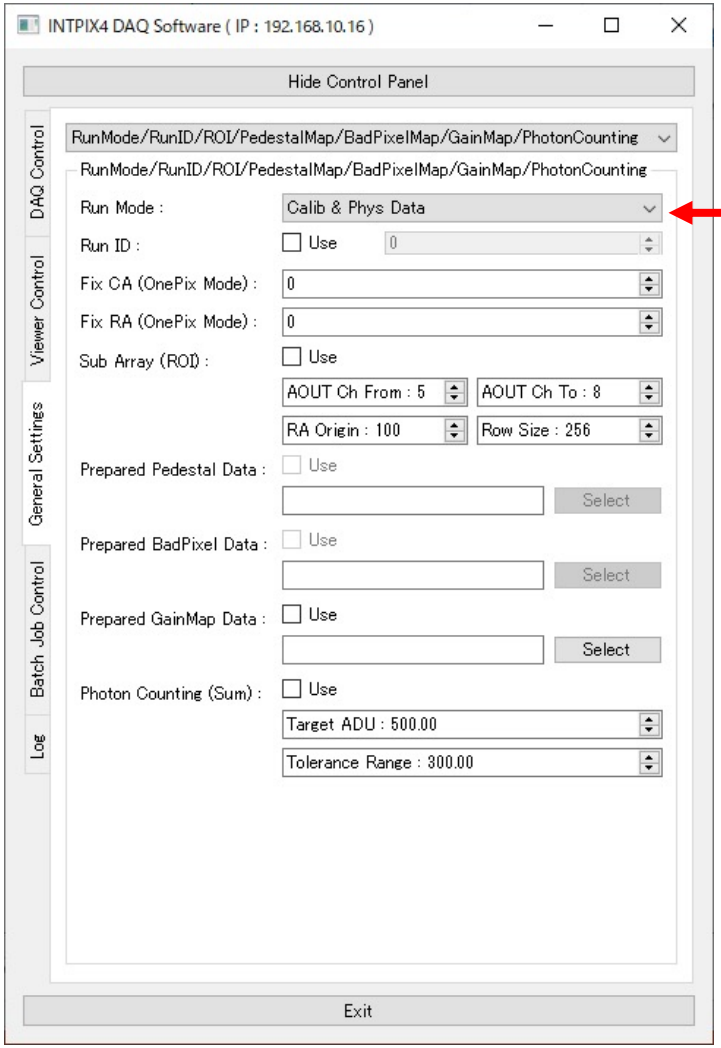


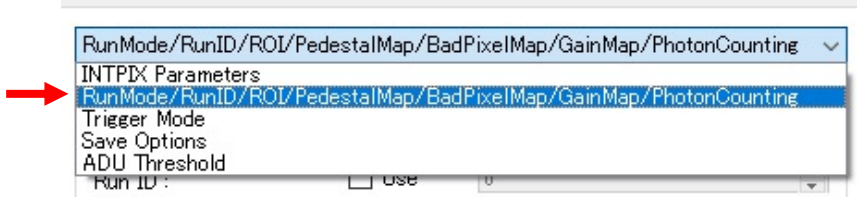


You can set several parameters,
but this time you should modify only Integration Time (Exposure time of each frames).
500us..1000us is better.

How to Use SOI Device and DAQ Software

6. Set Run Mode.





Run Mode is the behavior setting of Data taking.
Behavior available on INTPIX4 DAQ is shown below.

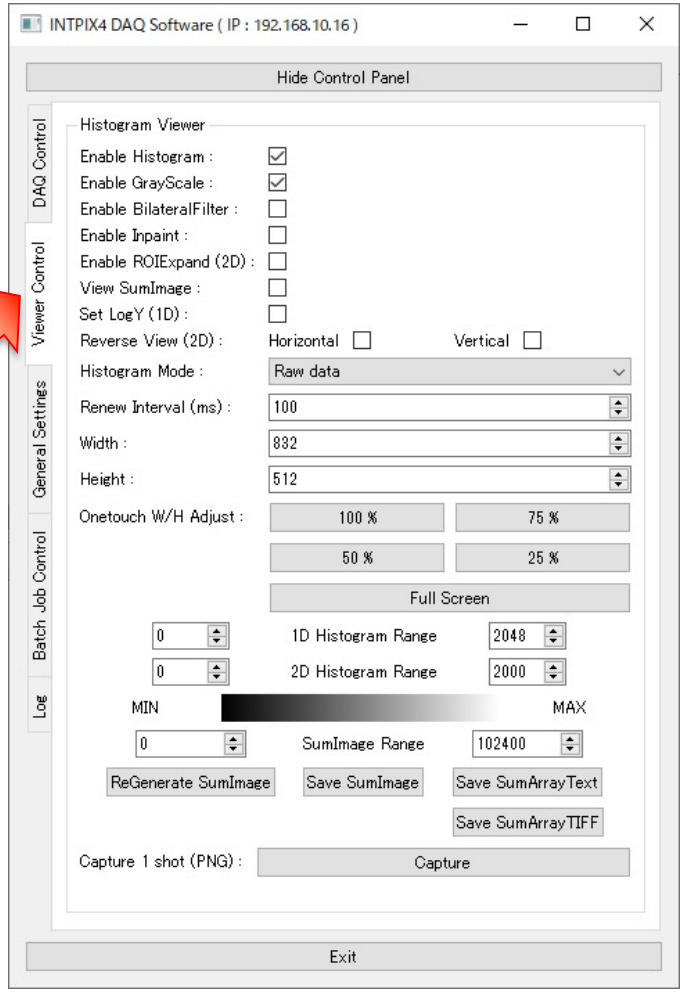
Calib Data Only	Take Calibration (Pedestal) data and Stop. Can be used for Pedestal data preparation.
Calib & Phys Data	Take both Calibration data and Event Data. Calibration data will used for some process of Event Data taking such as viewer image, sum data creation.
Data Only	Take Event Data only. Prepared pedestal data created by “Calib Data Only” can be used with this mode.
One Pixel Mode	Readout specified 1 pixel with “Data only” behavior.

This time we choose “Calib & Phys Data”.

How to Use SOI Device and DAQ Software

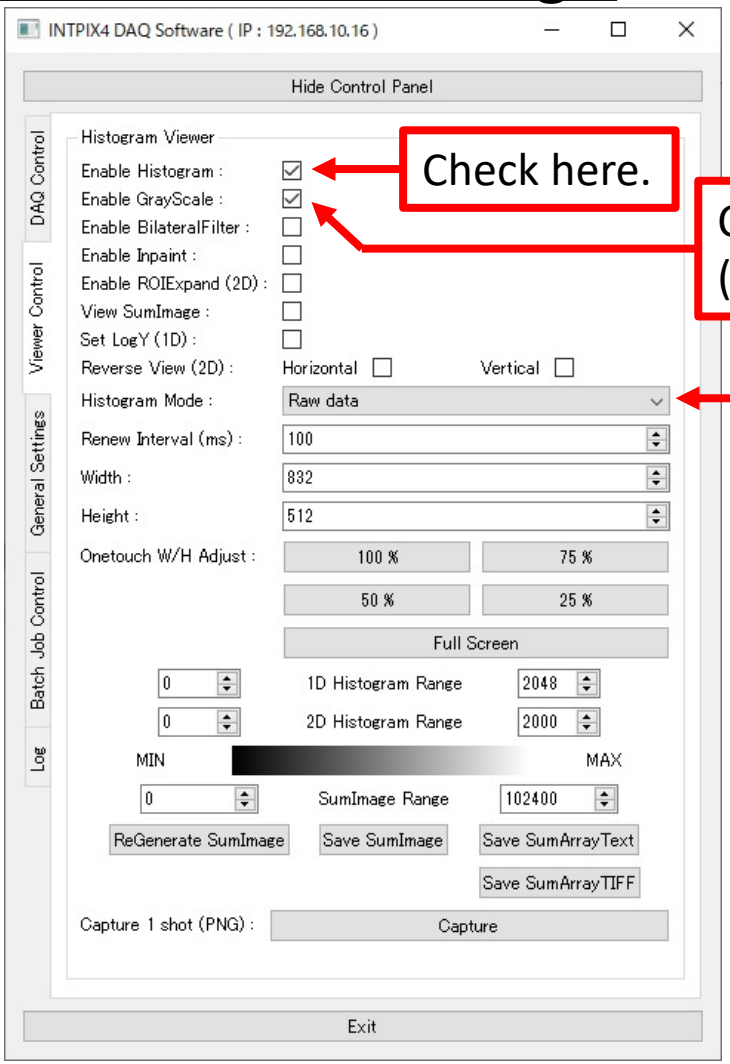
7. Switch to “Viewer Control” tab.

Click here.



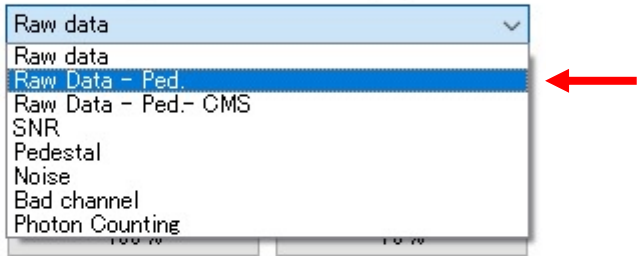
How to Use SOI Device and DAQ Software

8. Set Viewer settings.



Check here.

Check here if you want to use gray scale view.
(Default is Pseudo color (Red is higher side).)



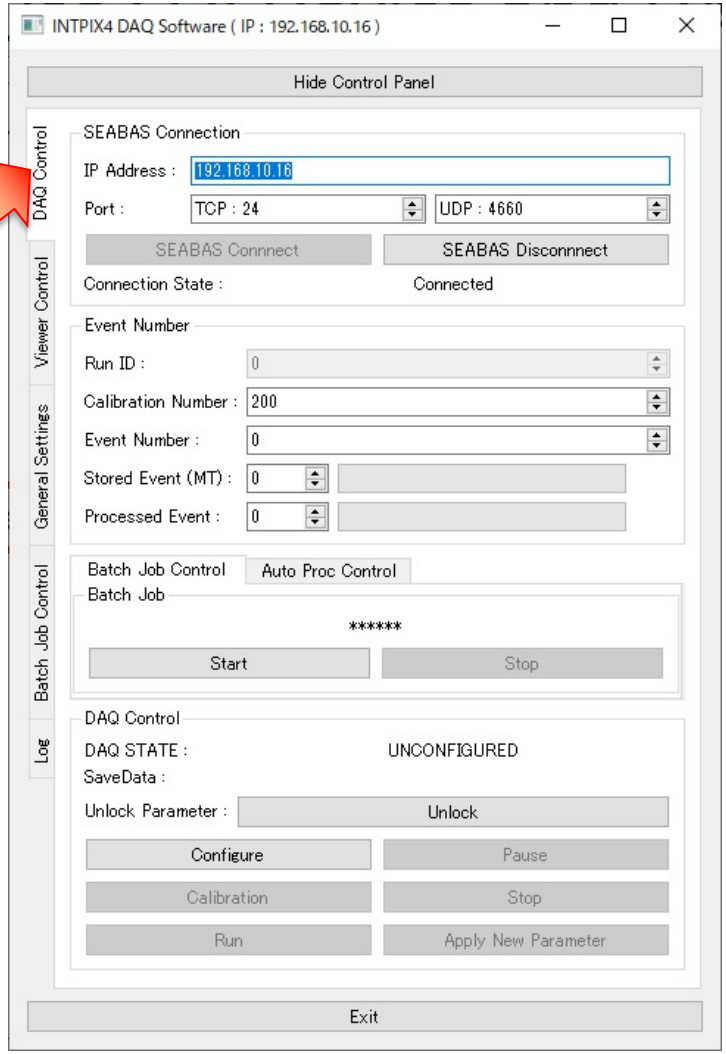
You can set viewer paramters.
(Enable options, set ranges, etc…)

This time we choose “Raw Data - Ped.”.
(This means “Subtract pedestal”)

How to Use SOI Device and DAQ Software

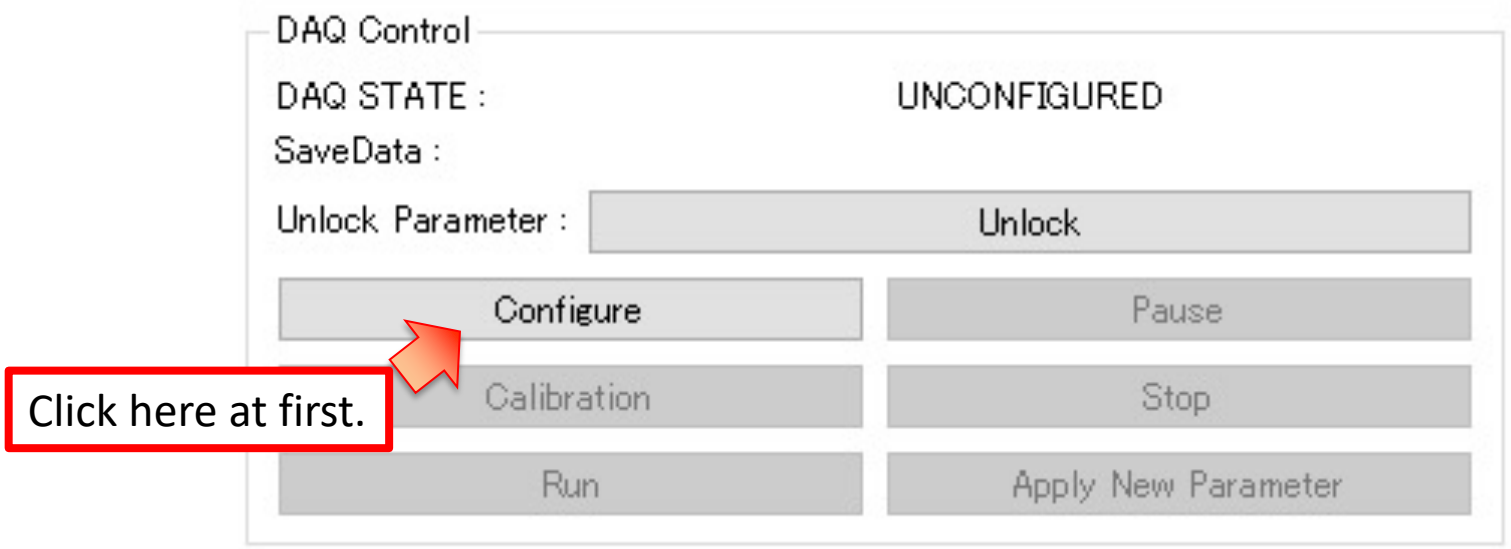
9. Switch to “DAQ Control” tab.

Click here.



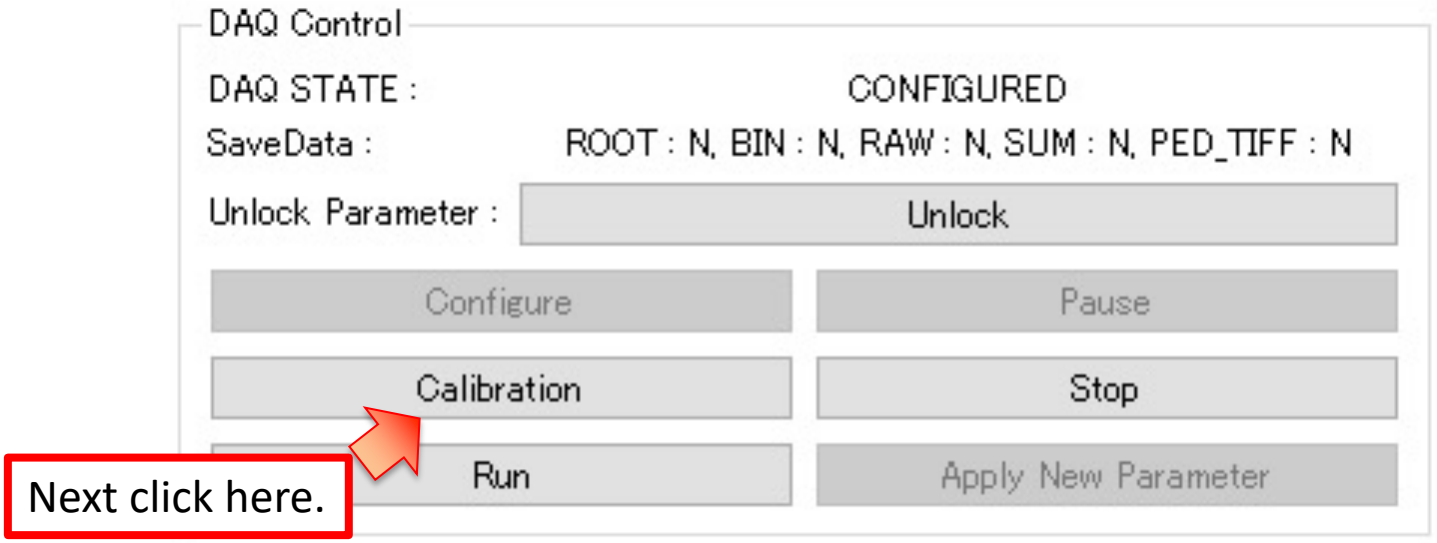
How to Use SOI Device and DAQ Software

10. Do Data acquisition (1).



How to Use SOI Device and DAQ Software

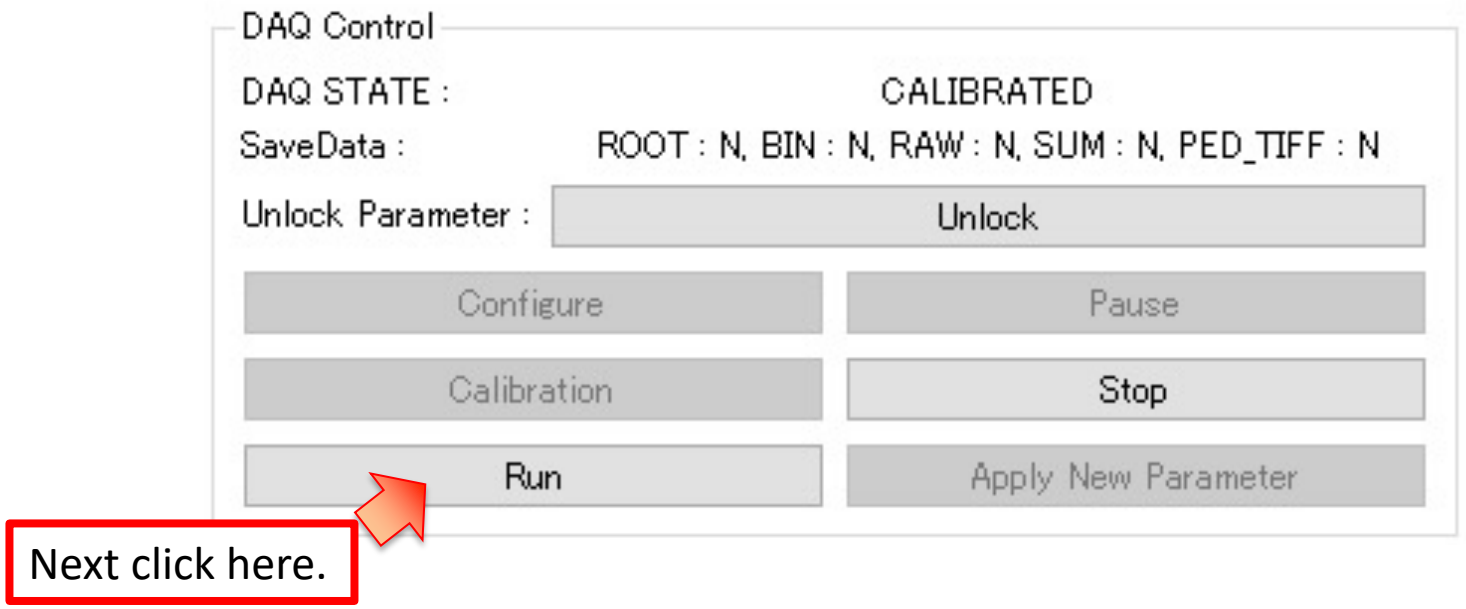
10. Do Data acquisition (2).



Don’t input Laser light to detector while this calibration data taking !

How to Use SOI Device and DAQ Software

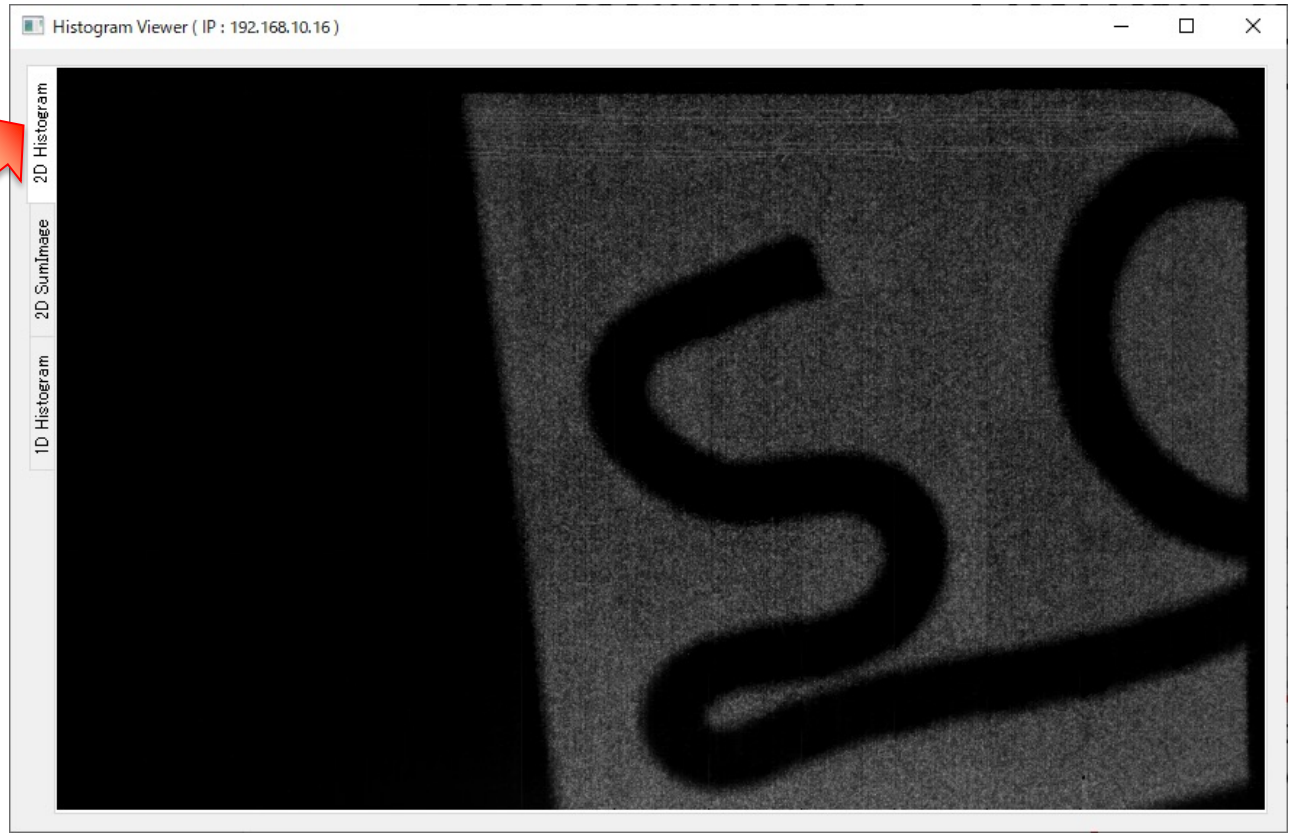
10. Do Data acquisition (3).



How to Use SOI Device and DAQ Software

10. Do Data acquisition (4).

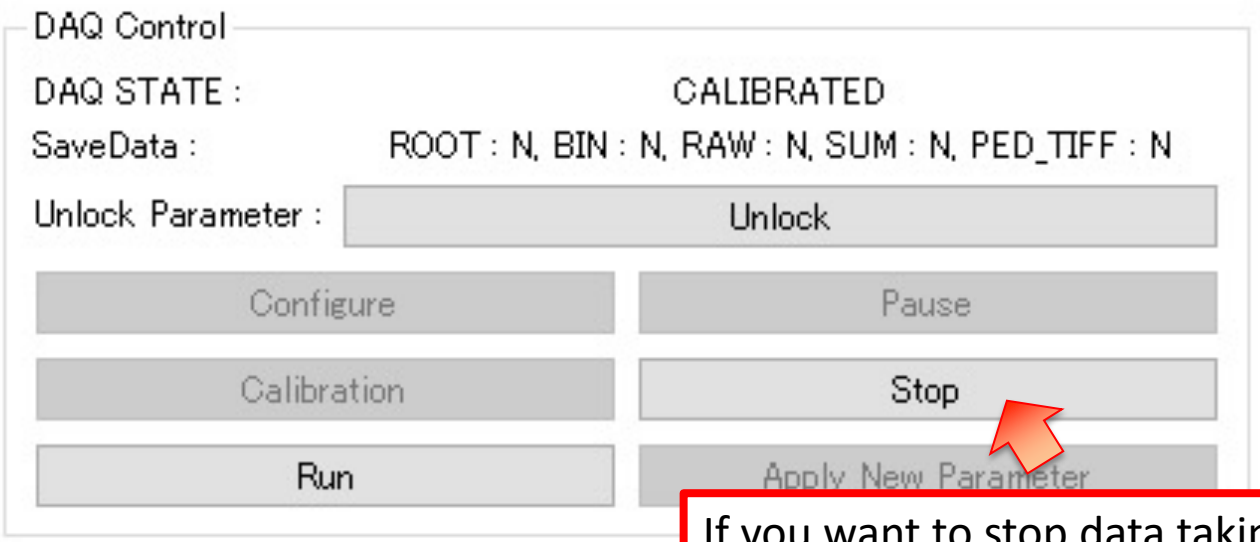
Select this tab.



Input Laser light to detector, you can see laser's spot by this viewer.

How to Use SOI Device and DAQ Software

10. Do Data acquisition (5).



If you want to stop data taking, click here.

* You have to “Stop” manually in the end because now Event number is “0(=∞)”.

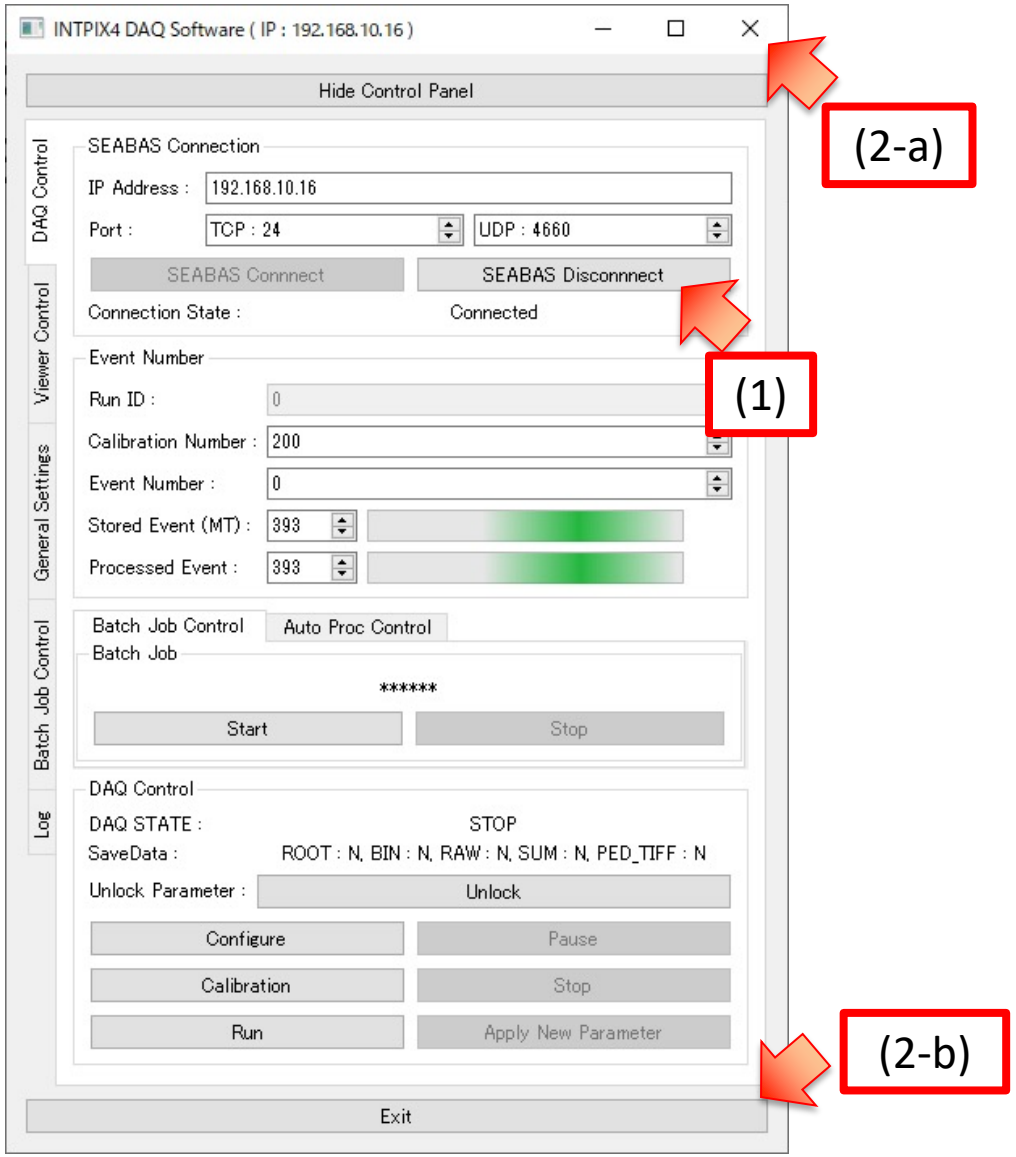
How to Use SOI Device and DAQ Software

11. Exit.

At first, Do
(1) Click “SEABAS Disconnect”.
(2) Exit DAQ Software by Close button (2-a) or Exit button (2-b).

* If you forget (1), it’s automatically done when Software’s exit. No problem. ☺

Finally Turn off all devices & equipment.



Hands-on Lab: Training

Cosmic ray events collection

- Run the device for 1 hour
  - Apply a bias voltage of 100 V
  - Accumulate cosmic ray events
  - Observe the different shapes of the events
  - Q: Why are there different shape of events?
  - If no events were observed explain why.

Response to laser lights

- Use "green" and "red" laser pointers
- Signals with the bias voltage
  - Apply voltages from 0 to a few 10's V
    - up to 50 V for safety to the device
  - Shine a laser pointer (red) from top and observe the spread of signals in the display
- Transparency of silicon
  - Apply voltage of 10 V
    - to leave non-depleted silicon thickness
    - Q: Estimate the un-depleted thickness
  - Shine lasers from backside
    - Observe signals for the "green" and "red" light
    - Q: Which light generates more signals and why?