Hands-on Lab: FDSOI pixel detector

Y. Unno (KEK) / <u>K. Androsov</u> (EPFL and ETHZ) with help from SOIPIX community

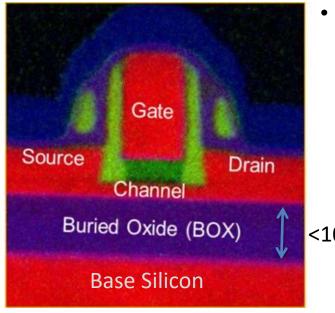
Hands-on Lab: Schedule

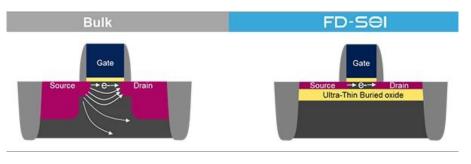
- 1) Run "Cosmic ray events collection"
 - while going through the lab lecture
- 2) Go through the "Lab lecture"
- 3) Check-out of "Cosmic ray events collection"
- 4) Go through the operation instruction
- 5) Run Hands-on Lab with laser lights

Hands-on Lab: lecture

FD-SOI

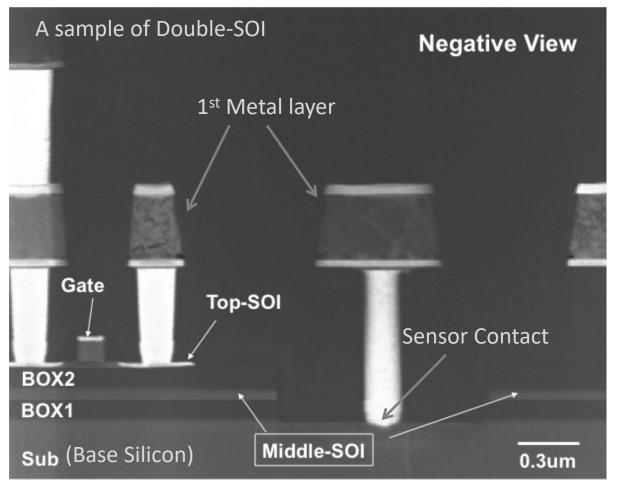
- Fully-depleted (FD)-Silicon-On-Insulator (SOI)
 - ref. "Learn More About FD-SOI STMicroelectronics"





- 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.
- <100 nm
- 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 performancedegrading leakage currents.

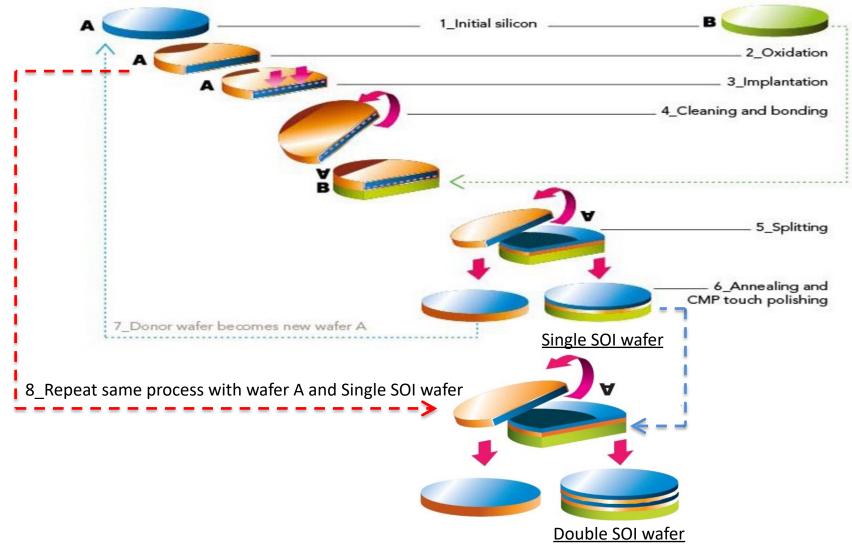
FD-SOI Pixel Detector (SOIPIX)



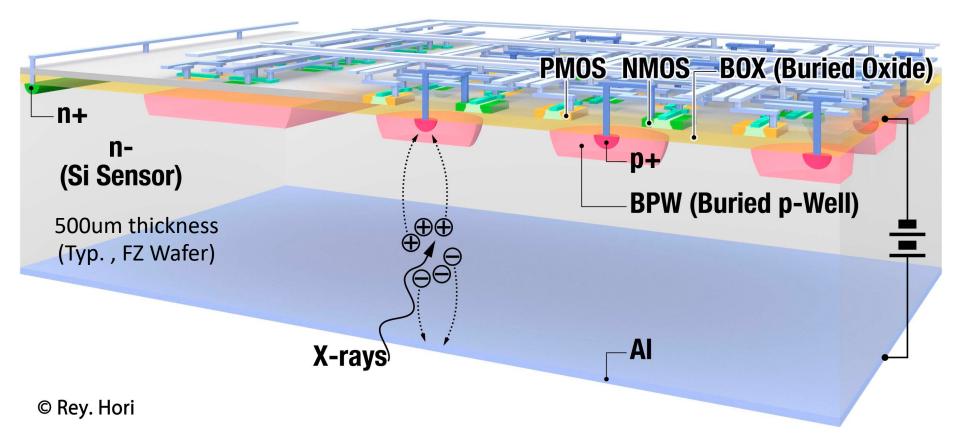
SOIPIX – A type of Monolithic Active Pixel Sensor (MAPS)

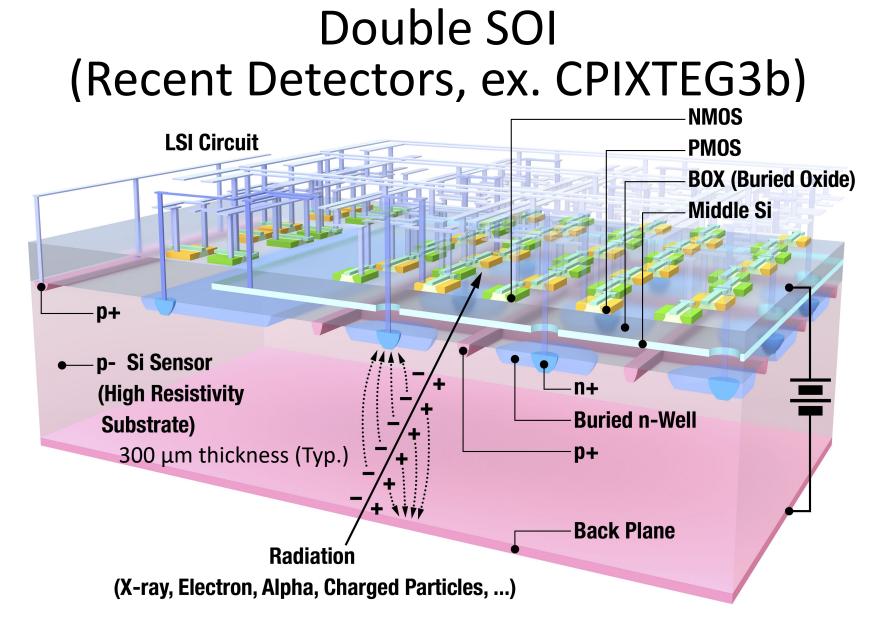
- Utilizing the Base Silicon as charge-collection medium, by making
 - a though-hole through BOX layer
 - an electrode in the Base Silicon with Sensor contact from external metal trace
- Monolithic
 - Less material
- Separated function
 - compared with bulk-CMOS MAPS
 - Electronics in FD-SOI layer
 -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

How to make SOI Wafer – SmartCut[®] spitec



Single SOI (ex. INTPIX4)





[©] Rey. Hori

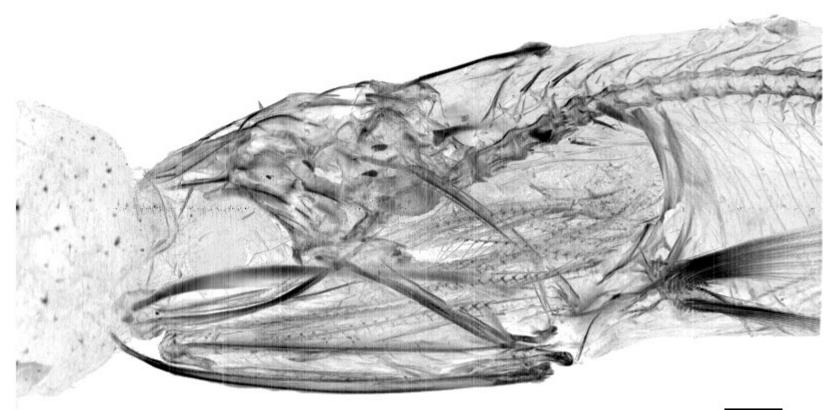
Lapis 0.2 µm FD-SOI Process Spec.

Process	0.2 μ m Low-Leakage Fully-Depleted SOI CMOS 1 Poly, 5 Metal layers, MIM Capacitor (1.5 fF/ μ m2), 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)



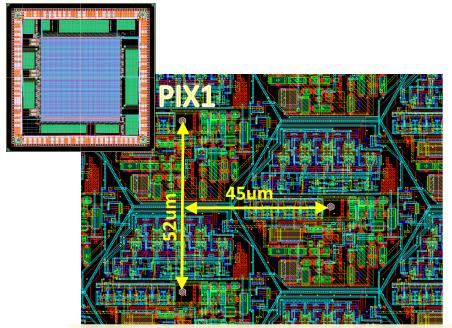
Sample : Small dried sardine (Niboshi)



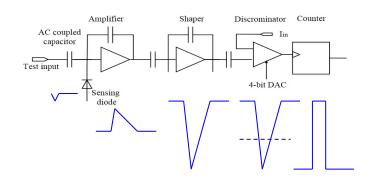
By R. Nishimura (KEK)



FD-SOI pixel detector - Device

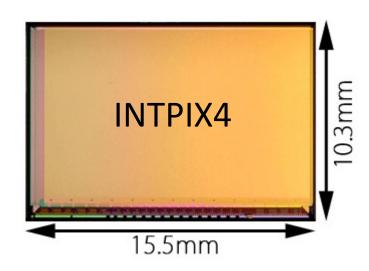


Smallest Counting-type Pixel of this kind. (much smaller than designed in 0.13um process)

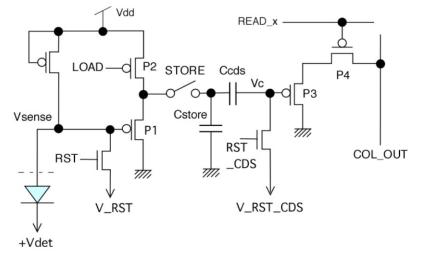


- A counting type SOI pixel detector (CPIXTEG3b)
 - 0.2 µm CMOS process
 - The prototype measures 6 × 6 mm², with the sensitive area of 3.2 × 3.2 mm².
 - 64×64 -pixel matrix with 50 μ m pixel pitch
- SOI pixel sensor
 - Double SOI process
 - 300 μ m thickness
 - **On-chip electronics**
 - Charge sensitive amplifier(charge to electronic pulse)
 - Discriminator
 - Counter (registered the X-ray photon number)

FD-SOI pixel detector - Device

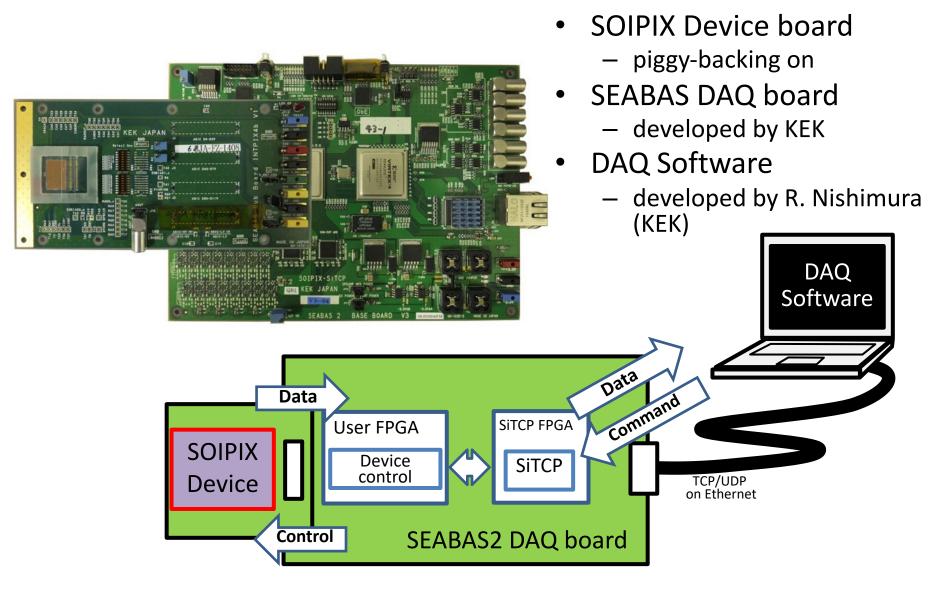


In-pixel circuit



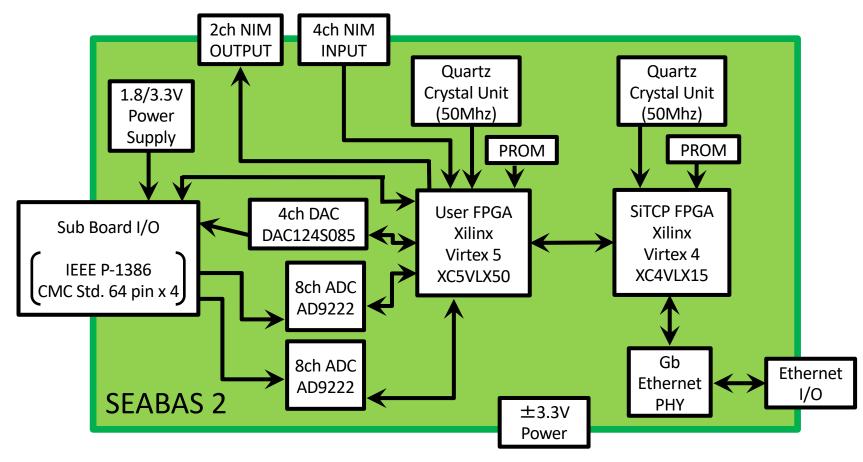
- An integration type SOI pixel detector (INTPIX 4)
 - 0.2 um CMOS process
 - Measures $15.5 \times 10.3 \text{ mm}^2$, with the sensitive area of $14.1 \times 8.7 \text{ mm}^2$.
 - 832 \times 512-pixel matrix with 17 μm pixel pitch
- SOI pixel sensor
 - Single SOI process
 - 500 μm thickness
 - On-chip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

FD-SOI pixel detector - Setup

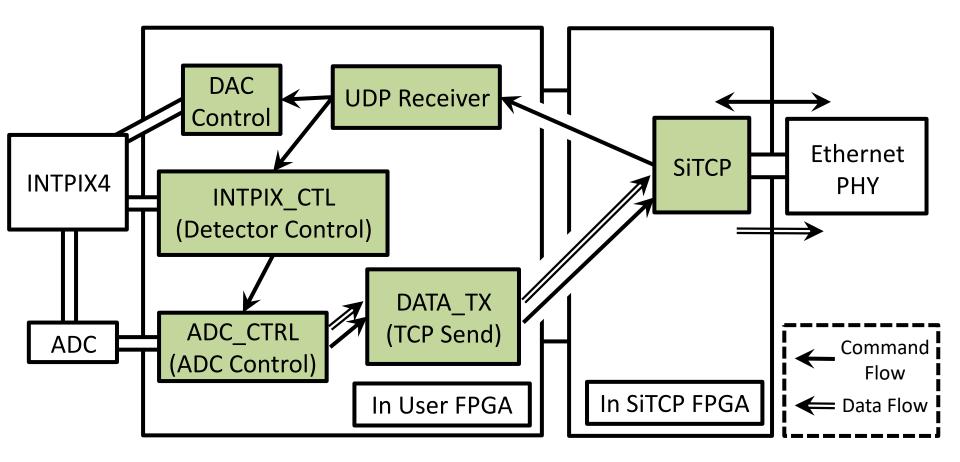


^{2021/8/23-9/4 6}th INFIERI school: Hands-on Lab: FD-SOI pixel detector

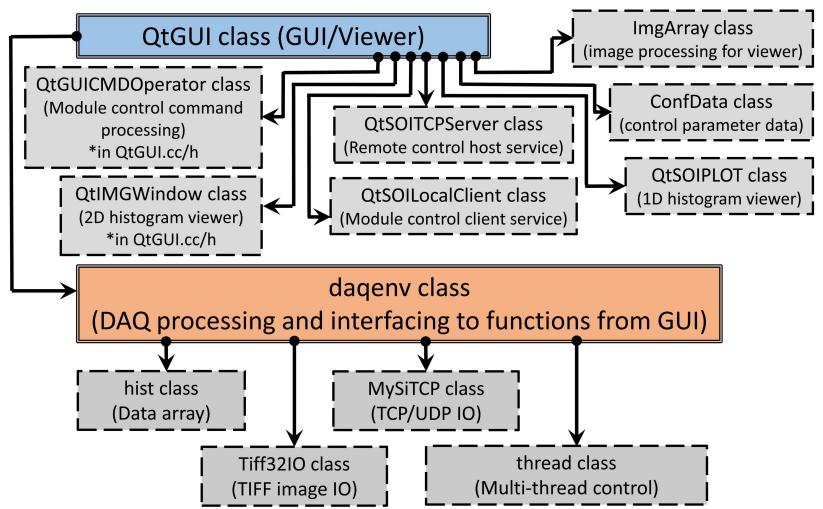
Detail of DAQ system Modules on SEABAS



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



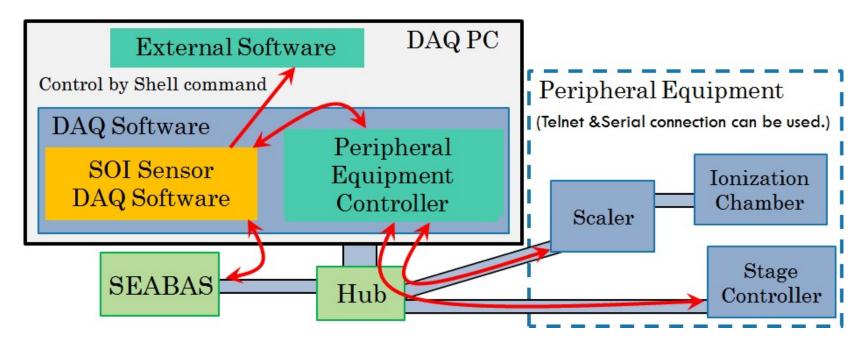
Detail of DAQ system Structure of SOI Sensor DAQ Software



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

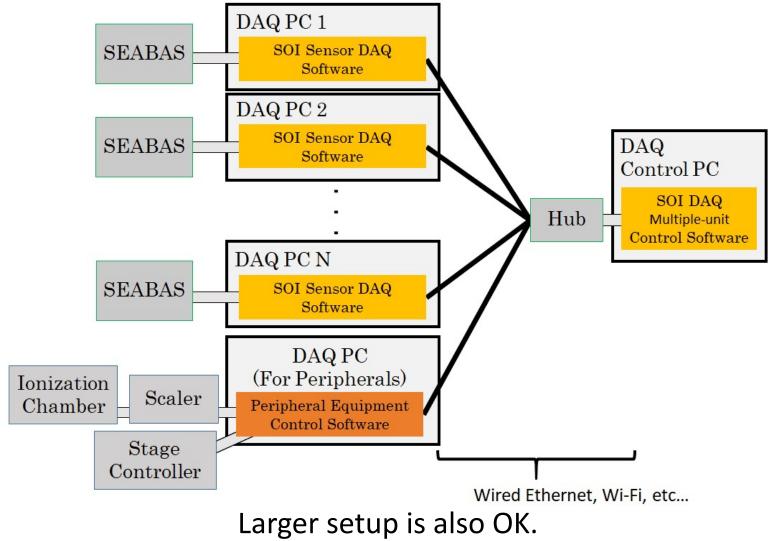
Case 1. 1 SOI device with peripherals controlled from 1 DAQ PC.



Small setup is OK.

Detail of DAQ system DAQ Framework

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



Detail of DAQ system DAQ Framework

Case 3. This Lecture.



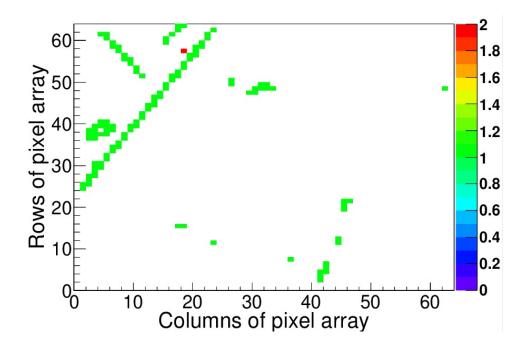
Very simple. 🙂

Hands-on Lab: Training

			Hide Cont	rol Panel			
ē	SEABAS Connection						
	IP Address :	192.168.10	1.16				
240	Port :	TOP:24		♣ UDP: 4660	4		
_	SEABAS Connect		SEABAS Disco	nnnect			
ontro	Connection Sta	ite :		Connected			
Viewer Control	Event Number						
Vie/	Run ID :	0			4		
22	Calibration Nur	nber: 20	0		4		
General Settings	Event Number :		00		4		
n D	Stored Event (MT) :		3 🗘		88%		
nene	Processed Event :		2		88%		
ontrol	Batch Job Control Batch Job		iuto Proc Cor	itrol			
8	*****						
	Start			Stop			
l dich J		Start					
	DAQ Control	Start					
	DAQ Control DAQ STATE : SaveData :		OOT : N, BIN	RUN : N, RAW : N, SUM : N, P	ED_TIFF : N		
	DAQ STATE :	F	oot : n, bin		ED_TIFF : N		
	DAQ STATE : SaveData : Unlock Parame	F	OOT : N, BIN	: N, RAW : N, SUM : N, P	ED_TIFF : N		
	DAQ STATE : SaveData : Unlock Parame	F ter:		: N, RAW : N, SUM : N, P Unlock	ED_TIFF : N		
Log Batch Job Control	DAQ STATE : SaveData : Unlock Parame	F ter:		: N, RAW : N, SUM : N, P Unlock Pause			



- 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

Prepare below <u>before</u> 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. (<u>Apply + for Ntype, - for Ptype</u>) 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).

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

6. Startup PC and set IP configuration for <u>wired</u> <u>Ethernet</u> shown below.

IP Address	192.168.10. <u>30</u> (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).

1. Execute DAQ Software. (INTPIX4 : INTPIX4OCV , CPIXTEG3b : CPIXTEG3OCV)

Histogram Viewer (IP : 192.168.10.16)	- 🗆 X			
E	■ INTPIX4 DAQ Software (IP : 192.168.10.16)			
Historia Boot	Hide Control Panel			
2D Sumitmage 2D Histogram 2D Sumitmage 2D H	SEABAS Connection IP Address : 192.168.10.16 Port : TCP : 24 UDP : 4660 SEABAS Connect SEABAS Disconnect Connection State : Disconnect Event Number Run ID : 0 Calibration Number : 200 Event Number : 100 Stored Event (MT) : 0 Stored Event (MT) : 0 Stored Event (MT) : 0 Stored Event (MT) : 0 Calibration State : Disconnect Stored Event (MT) : 0 Calibration State : Disconnect Stored Event (MT) : 0 Calibration State : Disconnect Connect Calibration State : Disconnect Connect Calibratic : Disconnec			
	Processed Event (III) Batch Job Control Auto Proc Control Batch Job Control Auto Proc Control Stath Job Start Stop			
	the second secon			
	B DAQ Control DAQ STATE : UNC ONFIGURED SaveData :			
hy Stop how to will based	Unlock Parameter : Unlock			
o-by-Step how-to will based	Configure Pause			
X4OCV, CPIXTEG3OCV have	Calibration Stop			
	Run Apply New Parameter			
rent settings/tabs. But basic				
0,	Fxit			





* This St on INT bit diff usage is almost same.

2. Make a Connection to SEABAS.

		Hide Con	trol Panel		
2	SEABAS Cor	nection			
DAQ Control	IP Address :	ss : 192.168.10.16			
DAQ	Port :	TCP : 24	UDP : 4660		
	SE/	ABAS Connnect	SEABAS Disconne	ect	
nta	Connection	State : 💦 🚬	Disconnect		
Viewer Control	Event Numbe	r C	lick here.		
View	Run ID :	0		* *	
ı ور	Calibration N	umber: 200		▲ ▼	

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

IP Address	: 192.168.10.16	
Port :	TGP : 24	UDP: 4660
S	EABAS Connnect	SEABAS Disconnec
~ · · ·	State :	Connected

3. Set Frame number.

Event Number	
Run ID :	0
Calibration Number :	200
Event Number :	0
Stored Event (MT) :	0 ≑
Processed Event :	0

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.

4. Switch to "General Settings" tab.

	INTPIX4 DAQ Software (IP : 192.168.10.16) - X Hide Control Panel - - -				
					INT PIX Parameters
Click here.	Log Batch Job Control General Settings Viewer Control DAQ Control	INTPIX Parameters INTPIX Parameter Integration Time (us) : RST High Time (ns) : CDS RST High Time (ns) : Scan Time (ns/pixel) : RST Voltage (mV) : CDS RST Voltage (mV) : DAQ Interval : RA Delay : BIAS1x : BIAS2x : Invert ADU Value :	1000 4000 5000 320 300 350 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1		INTERX Parameters RunMode / RunID/ROI/PedestalMap/BadPixelMap/GainMap/PhotonCounting Trigger Mode Save Options ADU Threshold Roi Trigger dropdown box has several list shown above.

		Hide Control Panel		
Viewer Control DAQ Control	INTPIX Parameters INTPIX Parameter Integration Time (us) : RST High Time (ns) : CDS RST High Time (ns) : Scan Time (ns/pixel) :	1000 4000 5000 320	÷ ;	
Viewe	RST Voltage (mV):	300	÷	
Log Batch Job Control General Settings	CDS RST Voltage (mV) : DAQ Interval : RA Delay : BIAS1x : BIAS2x : Invert ADU Value :		÷	
Loe Ba				

INTPIX Parameters	~
INTPIX Parameters	
RunMode/RunID/ROI/Peo	lestalMap/BadPixelMap/GainMap/PhotonCounting
Trigger Mode	n na sana ang Barten na ang ang sana ang ang sana ang sa
Save Options	
ADU Threshold	
RSI High Lime (ns):	4000

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

		Set Run Mode. INTPIX4 DAQ Software (IP : 192.168.10.16) × Hide Control Panel			INTPIX Par	RunID/ROI/PedestalMap/BadPixelMap/GainMap/PhotonCounting ode ons			
DAQ	Control DAQ Cont		estalMap/BadPixelMap/GainMap/PhotonCounting v destalMap/BadPixelMap/GainMap/PhotonCounting Calib & Phys Data Use 0 ÷ 0 ÷		Run Mode is the behavior setting of Data taking. Behavior available on INTPIX4 DAQ is shown below Calib & Phys Data Calib & Phys Data Calib & Phys Data Data Only One Pixel Mode				
	al Settings	Prepared Pedestal Data :	AOUT Ch From : 5 AOUT Ch To : 8 RA Origin : 100 Row Size : 256 Use		Calib Data Only	Take Calibration (Pedestal) data and Stop. Can be used for Pedestal data preparation.			
	Batch Job Control General	Prepared BadPixel Data : Prepared GainMap Data :	Select	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.				
	Loe Ba	Photon Counting (Sum) :	Use Target ADU : 500.00		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.				
		Exit			This time we ch	oose "Calib & Phys Data".			

7. Switch to "Viewer Control" tab.

	IN IN	TPIX4 DAQ Software (IP : 1	92.168.10.16)	- [x נ
			Hide Control Panel		
Click here.	Log Batch Job Control General Settings Viewer Control DAQ Control	Histogram Viewer Enable Histogram : Enable GrayScale : Enable BilateralFilter : Enable ROIExpand (2D) : View SumImage : Set LogY (1D) : Reverse View (2D) : Histogram Mode : Renew Interval (ms) : Width : Height : Onetouch W/H Adjust : 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Horizontal Raw data 100 832 512 100 % 50 % Full S 1D Histogram Range 2D Histogram Range SumImage Range	Vertical	×t

<u>8.</u>		et View		<u>tings.</u> - • ×	You can set viewer paramters. (Enable options, set ranges, etc)
	Log Batch Job Control General Settings Viewer Control DAQ Control	Histogram Viewer Enable Histogram : Enable GrayScale : Enable BilateralFilter : Enable Inpaint : Enable ROIExpand (2D) : View SumImage : Set LogY (1D) : Reverse View (2D) : Histogram Mode : Renew Interval (ms) : Width : Height : Onetouch W/H Adjust : 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	Horizontal Horizontal Raw data 100 832 512 100 % 50 % Full 1D Histogram Range 2D Histogram Range SumImage Range se Save SumImage		Check here if you want to use gray scale view. (Default is Pseudo color (Red is higher side).) Raw data Raw Data - Ped. Raw Data - Ped. Raw Data - Ped. Noise Bad channel Photon Counting This time we choose "Raw Data - Ped.". (This means "Subtract pedestal")
			Exit		

9. Switch to "DAQ Control" tab.

		NTPIX4 DAQ Software (IP : 192.168.10.16) -	×
		Hide Control Panel	
Click here.	Batch Job Control General Settings Viewer Control DAQ Control	SEABAS Connection IP Address : IP Address : Port : TCP : 24 UDP : 4660 SEABAS Connect SEABAS Disconnect Connection State : Connected Event Number Run ID : 0 Calibration Number : 200 Event Number : 0 Stored Event (MT) : 0 Processed Event : 0 Batch Job Control Auto Proc Control Batch Job	÷
	Log Batch	DAQ Control DAQ STATE : UNCONFIGURED SaveData :	
		Unlock Parameter : Unlock	
		Configure Pause	
		Calibration Stop	
		Run Apply New Parameter	
		Exit	

10. Do Data acquisition (1).

	Control CTATE : ata :	UNCONFIGURED	
Unlock	: Parameter :	Unlock	
	Configure	Pause	
Click here at first.	Calibration	Stop	
	Run	Apply New Parameter	

10. Do Data acquisition (2).

DAQ Control DAQ STATE : SaveData :	CONFIGURED ROOT : N, BIN : N, RAW : N, SUM : N, PED_TIFF : N	
Unlock Parameter :	Unlock	
Configu	ure Pause	
Calibrat	tion Stop	
Next click here.	Apply New Parameter	

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

10. Do Data acquisition (3).

DAQ Control DAQ STATE : SaveData :	CALIBRATED ROOT : N, BIN : N, RAW : N, SUM : N, PED_TIFF : N		
Unlock Parameter :	Unlock		
Config	ure Pause		
Galibra	tion Stop		
Run	Apply New Parameter		
Next click here.			

10. Do Data acquisition (4).



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

10. Do Data acquisition (5).

DAQ Control DAQ STATE :		CALIBRATED
SaveData : ROOT : N, E		N, RAW : N, SUM : N, PED_TIFF : N
Unlock Parameter :		Unlock
Config	ure	Pause
Calibra	ition	Stop
Rur	1	Apply New Parameter
		 If you want to stop data taking, click here. * You have to "Stop" manually in the end because now Event number is "0(=∞)".

<u>11. Exit.</u>

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.

	Hide Con	trol Panel	
DAQ Control	SEABAS Connection IP Address : 192.168.10.16 Port : TCP : 24	↓ UDP : 4660	(2-a)
	SEABAS Connnect	SEABAS Disconnect	
ontro	Connection State :	Connected	
Viewer Control	Event Number Run ID : 0		(1)
General Settings	Calibration Number : 200 Event Number : 0 Stored Event (MT) : 393 + Processed Event : 393 +		
Batch Job Control	Batch Job Control Auto Proc Con Batch Job	ntrol	
tch Jo	Start	Stop	
Log Ba	DAQ Control DAQ STATE : SaveData : ROOT : N. BIN	STOP N:N, RAW:N, SUM:N, PED_TIFF:N	
	Unlock Parameter :	Unlock	
	Configure	Pause	
	Calibration	Stop	
	Run	Apply New Parameter	(2-b)

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?