Evaluation of on-chip ADC installed on the X-ray SOI pixel detector

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Outline

- Introduction : Astronomy and Detector

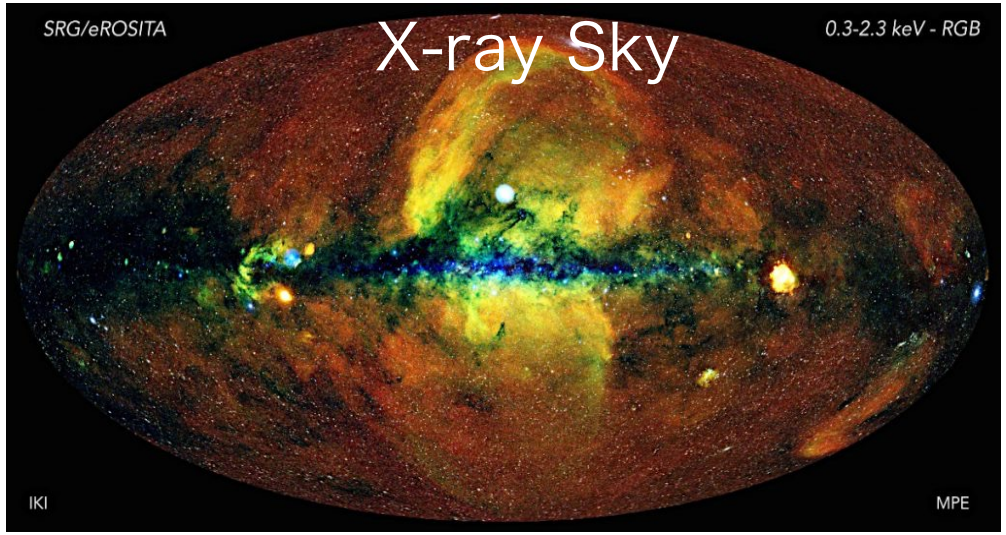
- About XRPIX
  —. What is the XRPIX?
  —.XRPIX's current status
  —.Purpose of on-chip ADC
  —.Overview of on-chip ADC

- Evaluation
  —.Evaluation of on-chip ADC only
  —.Evaluation of XRPIX + on-chip ADC

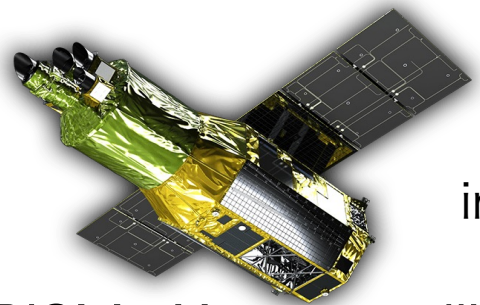
Introduction : X-ray Astronomy and Detector

What can we see ?

X-ray Band : High Energy Star (Black Holes , Galaxy , Neutron Star …)



Problem :
X-rays need to be observed from space
→ Observe X-rays using a satellite



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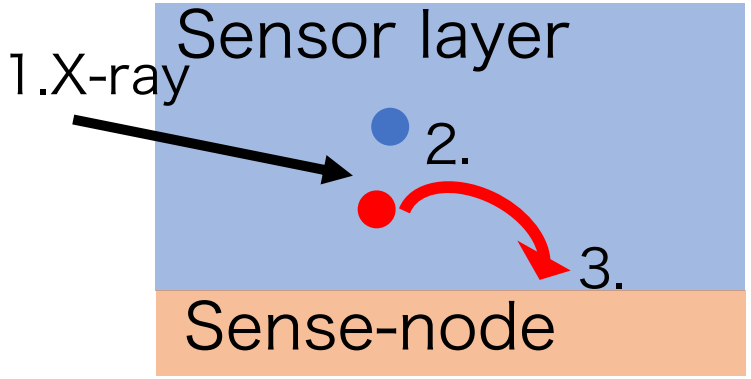
XRISM : X-ray satellite

<X-ray Detector>



1.Irradiation X-ray on Sensor layer

2.Electron-hole pairs occur at Sensor layer(Si)

3.Sense-nodes catch the hole
and evaluate Energy of X-ray

What is the XRPIX?

Aiming to be installed on a future X-ray satellite as X-ray Detector

X-Ray SOI-CMOS detector

- Combine CMOS circuits and high-ρ Si sensor with SOI technology

Each pixel has trigger function

- Read pixels above threshold

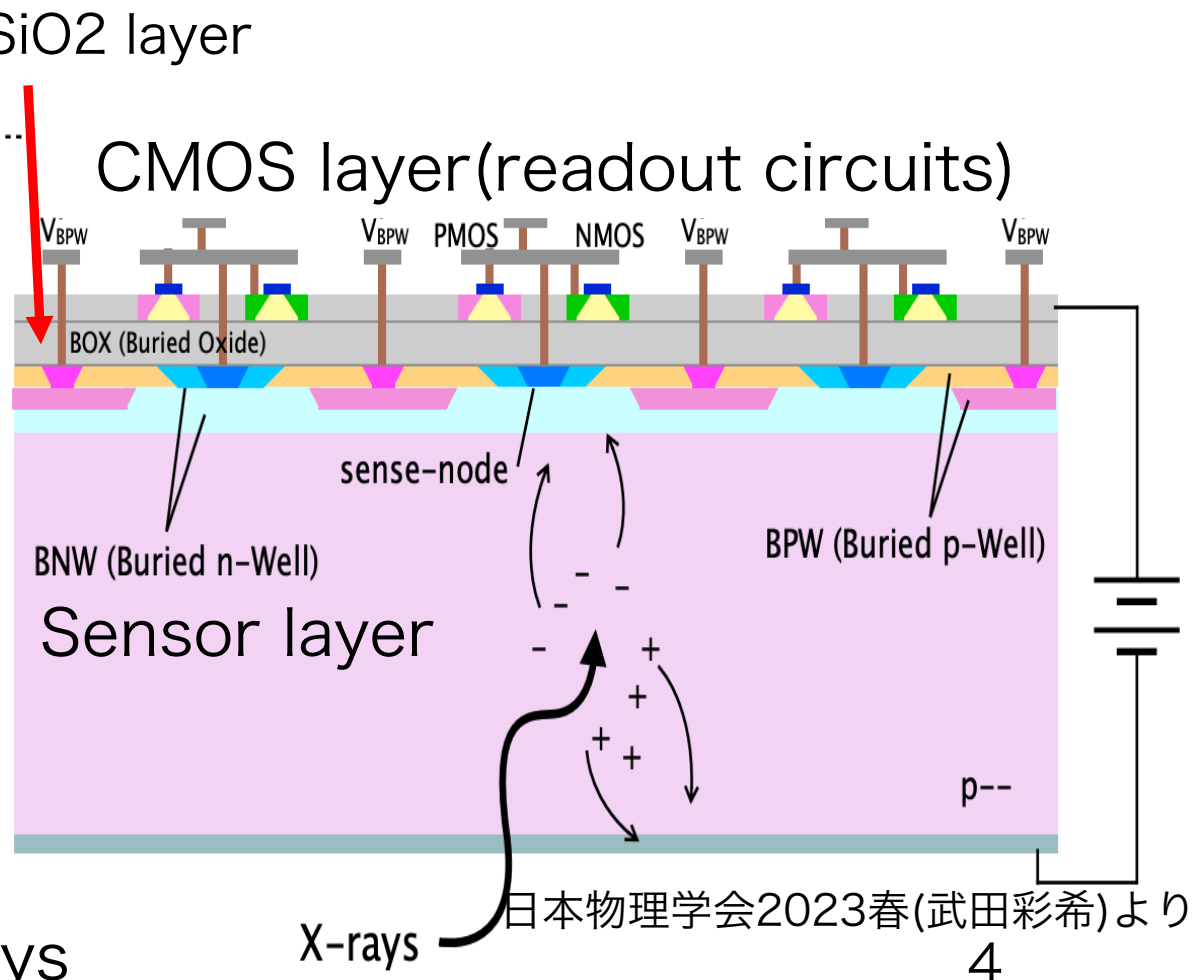
→ fast readout time(<10 μsec)

Energy resolution

- Require : $\Delta E < 300$ eV(@6.0 keV)

Thick Sensor Layer

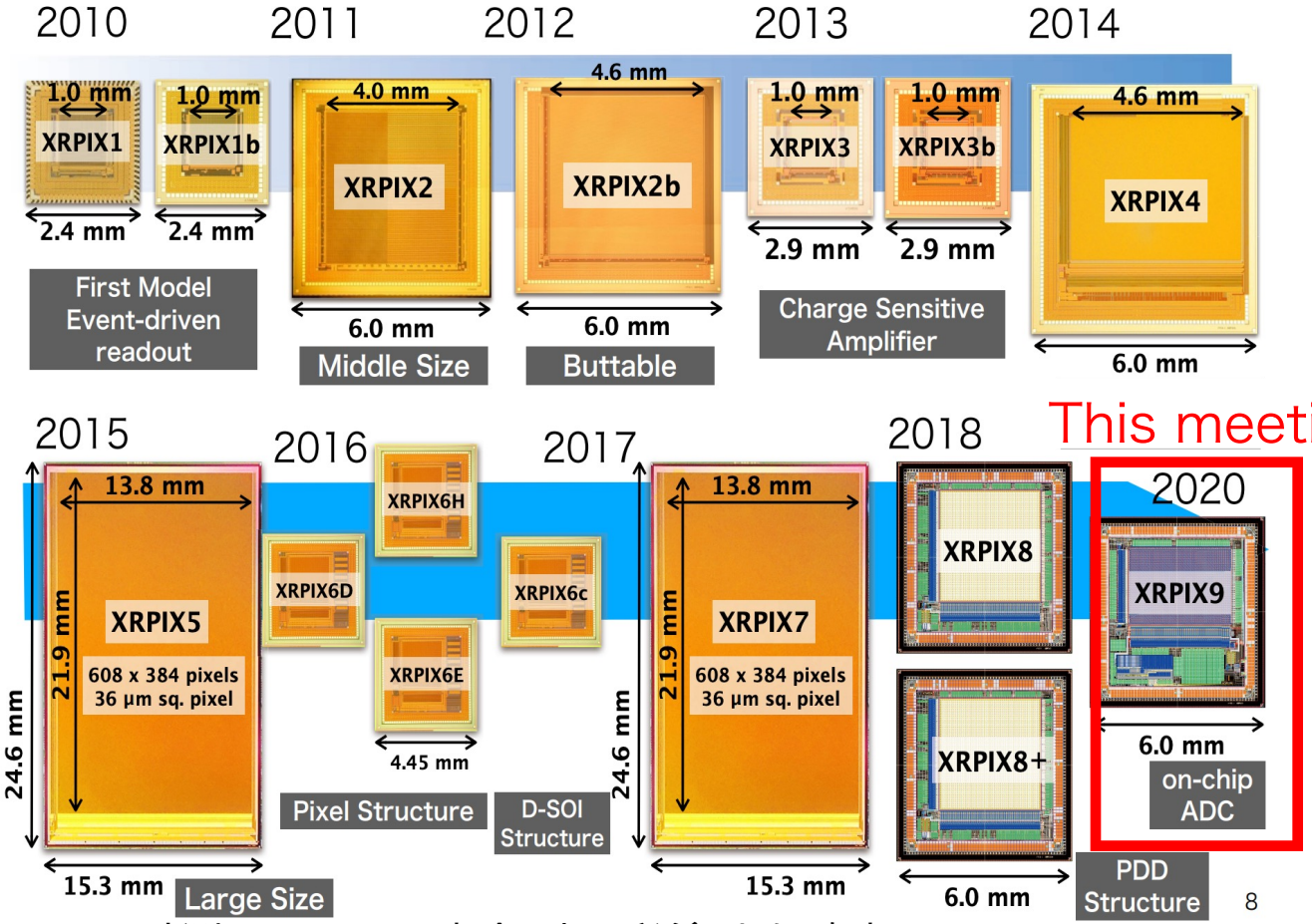
- High detection efficiency for hard X-rays



日本物理学会2023春(武田彩希)より

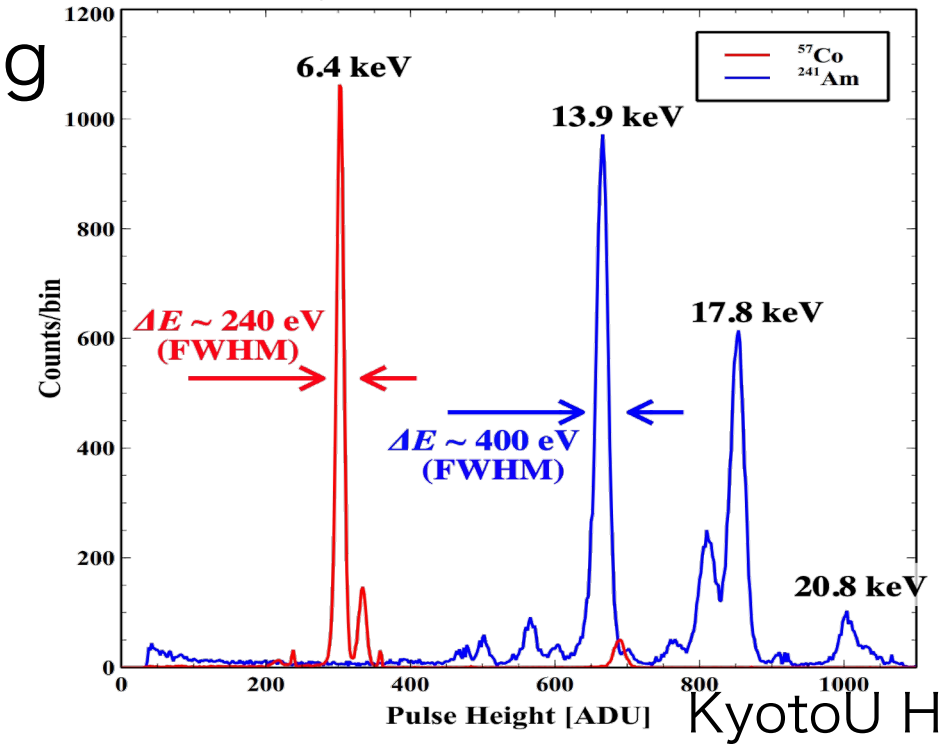
XRPIX's current status

We've been researching and developing



From計測システム研究会(武田彩希)より改変

XRPIX6E
FWHM~240 eV at 6.0 keV



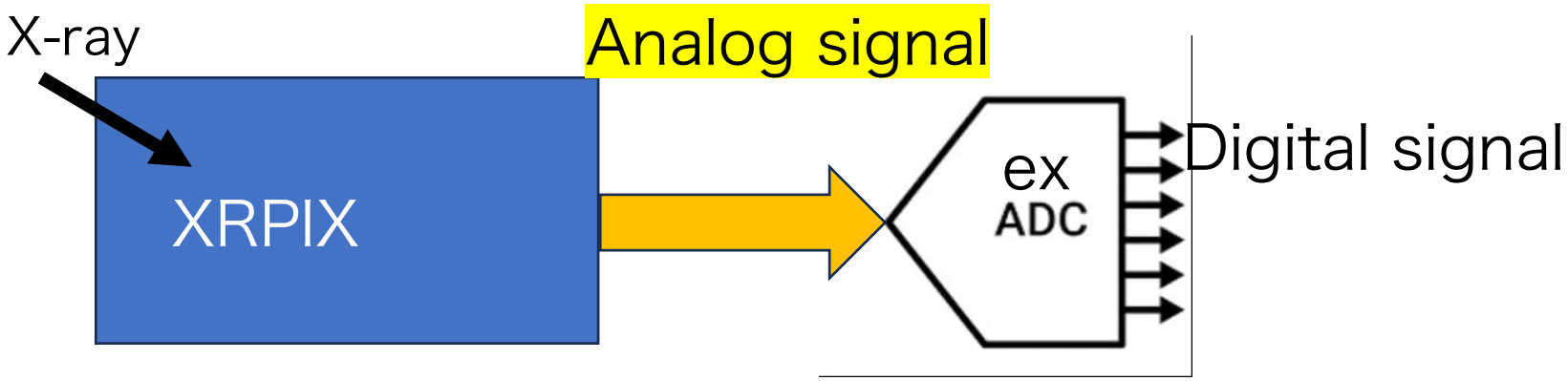
KyotoU Harada

Sensor : Good spectral performance

Future task : Digitalization

Purpose of on-chip ADC

Previous XRPIX： Converts analog signals with external ADC

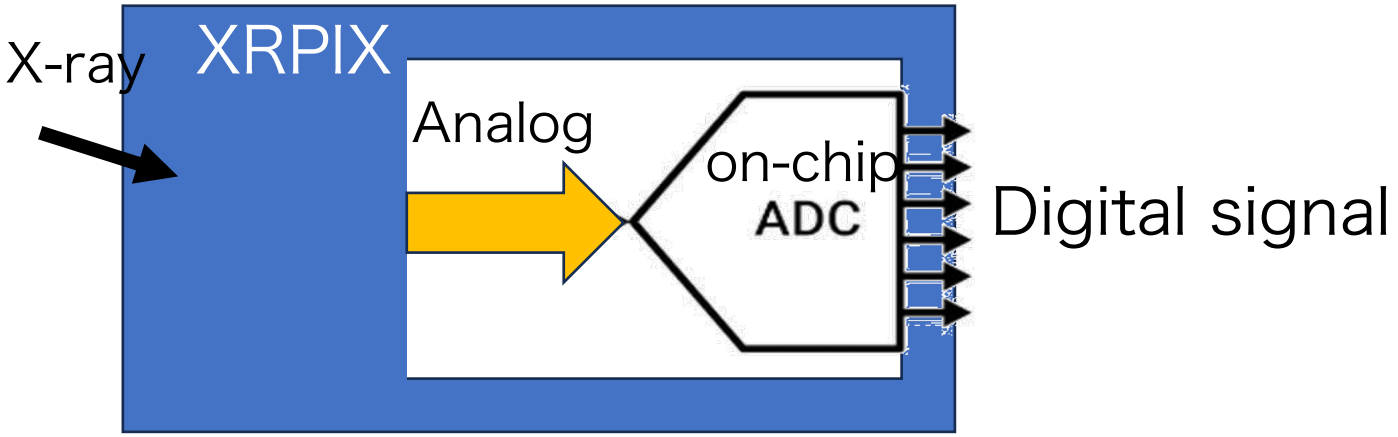


Problem : X-ray satellites require a large imaging area in a limited space

ADC mounted on XRPIX for compactness(on-chip)

Overview of on-chip ADC

We developed XRPIX with on-chip ADC
Then XRPIX can output digital signal



Summary of on-chip ADC
- Type : Cyclic ADC
- Number of bits : 14 bits
- Voltage range : 0.4-1.5 V
- Total Units : 16 units

Goal : Evaluate on-chip ADC performance

Evaluation Contents

Evaluation of on-chip ADC only

1. Integral non-linearity
2. Differential non-linearity
3. Noise

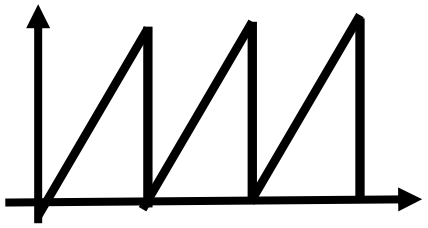
Evaluation of XRPIX+on-chip ADC

4.comparison on-chip ADC with external one.

Set Up : Evaluation of on-chip ADC

Input Ramp wave into ADC

Function Generator



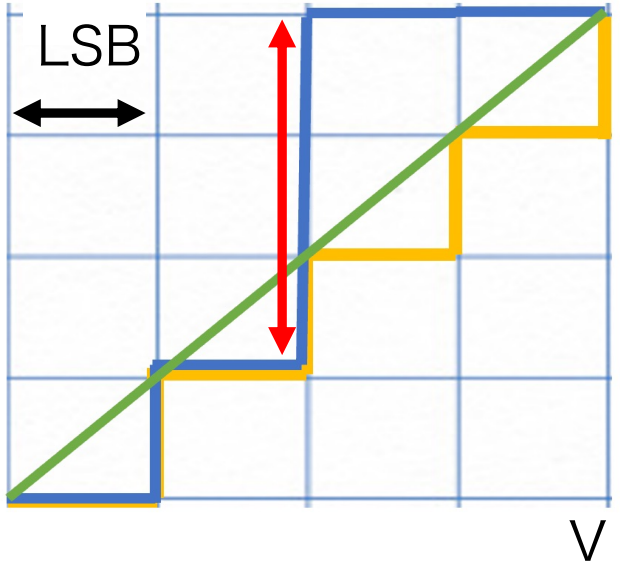
Analog Signal

14 bits Digital Signal

on-chip
ADC

Analysis

Result1:Integral Non-Linearity



Input Ramp wave(100 mHz) into on-chip ADC

Ideal ADC steps one at a time

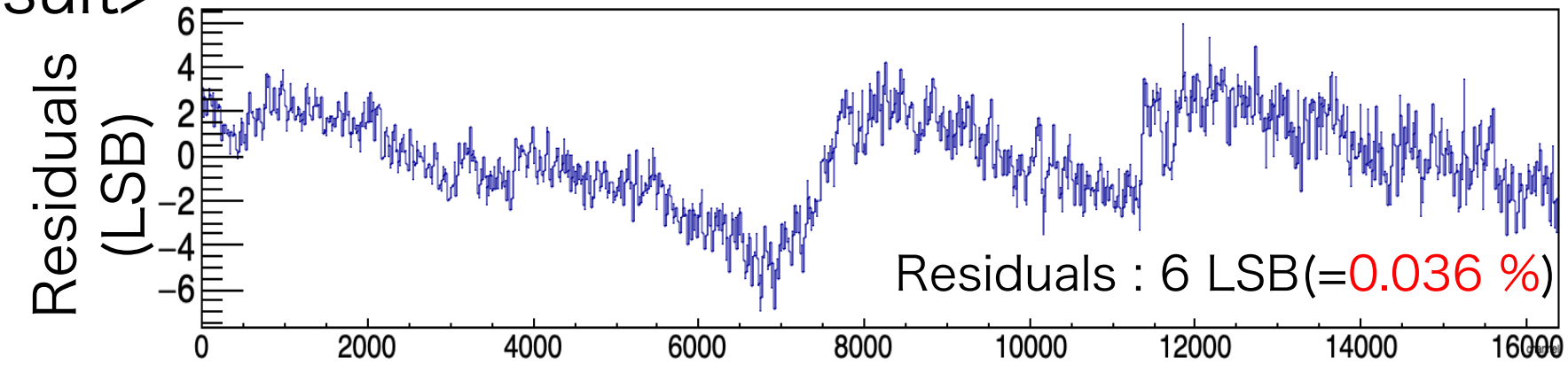
Actual ADC : Vertical deviation occurs

<Methods>

Fitted actual ADC outputs with Straight line

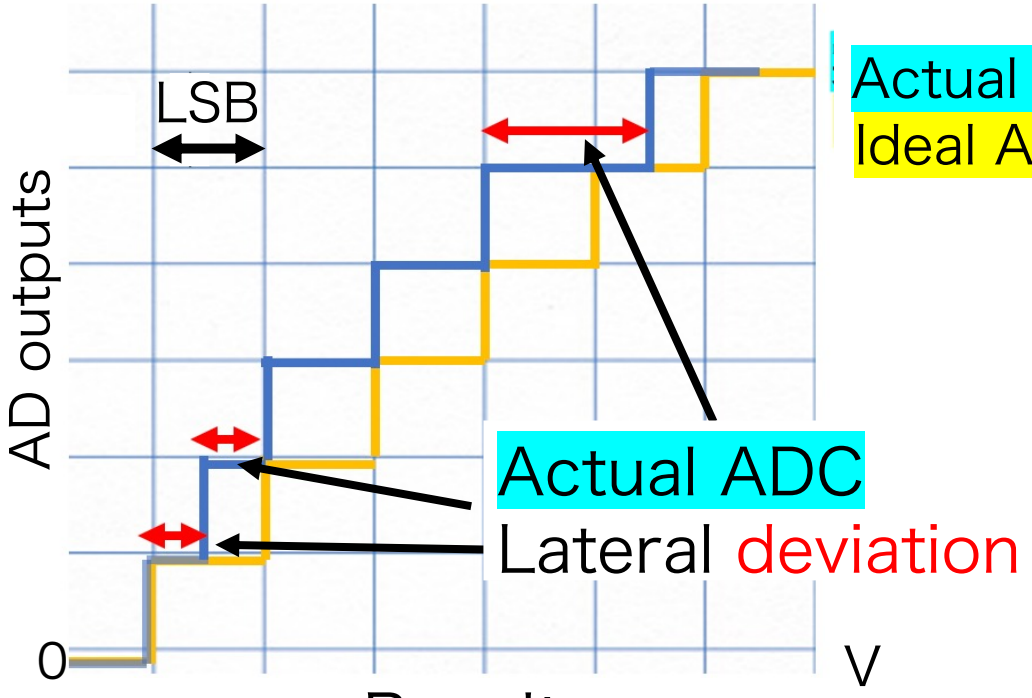
calculated residuals between the line and ADC outputs

<Result>

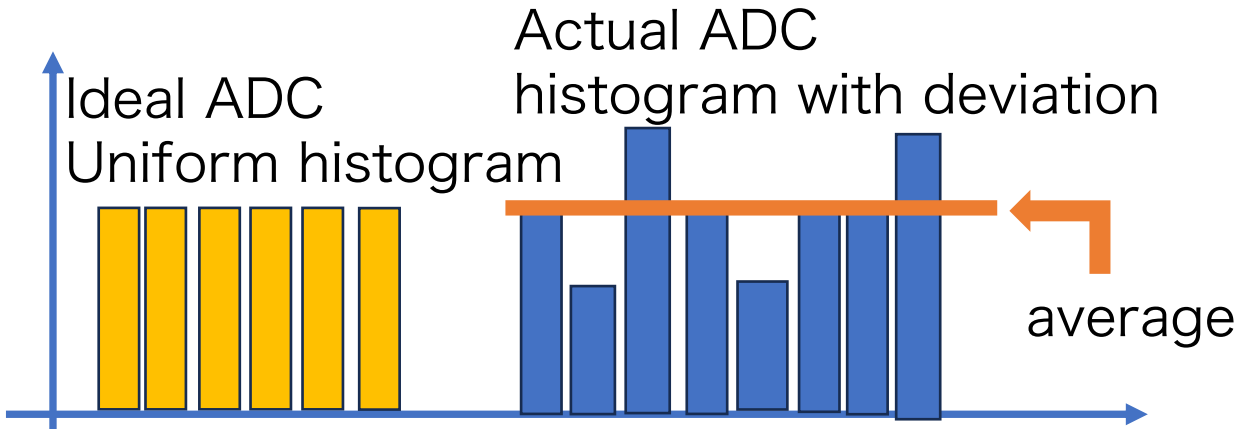


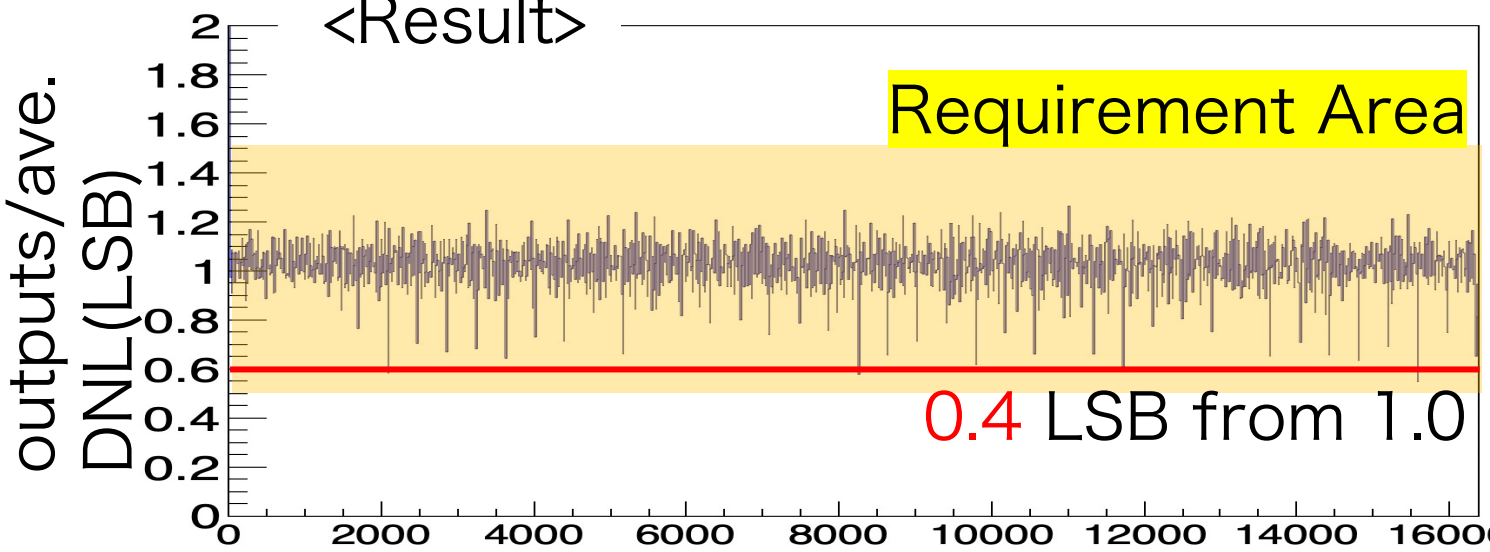
No effect level for resolution 300 eV

Result2:Differential Non-Linearity



Methods :
Histogram the number of AD outputs
Divide each histogram by the average

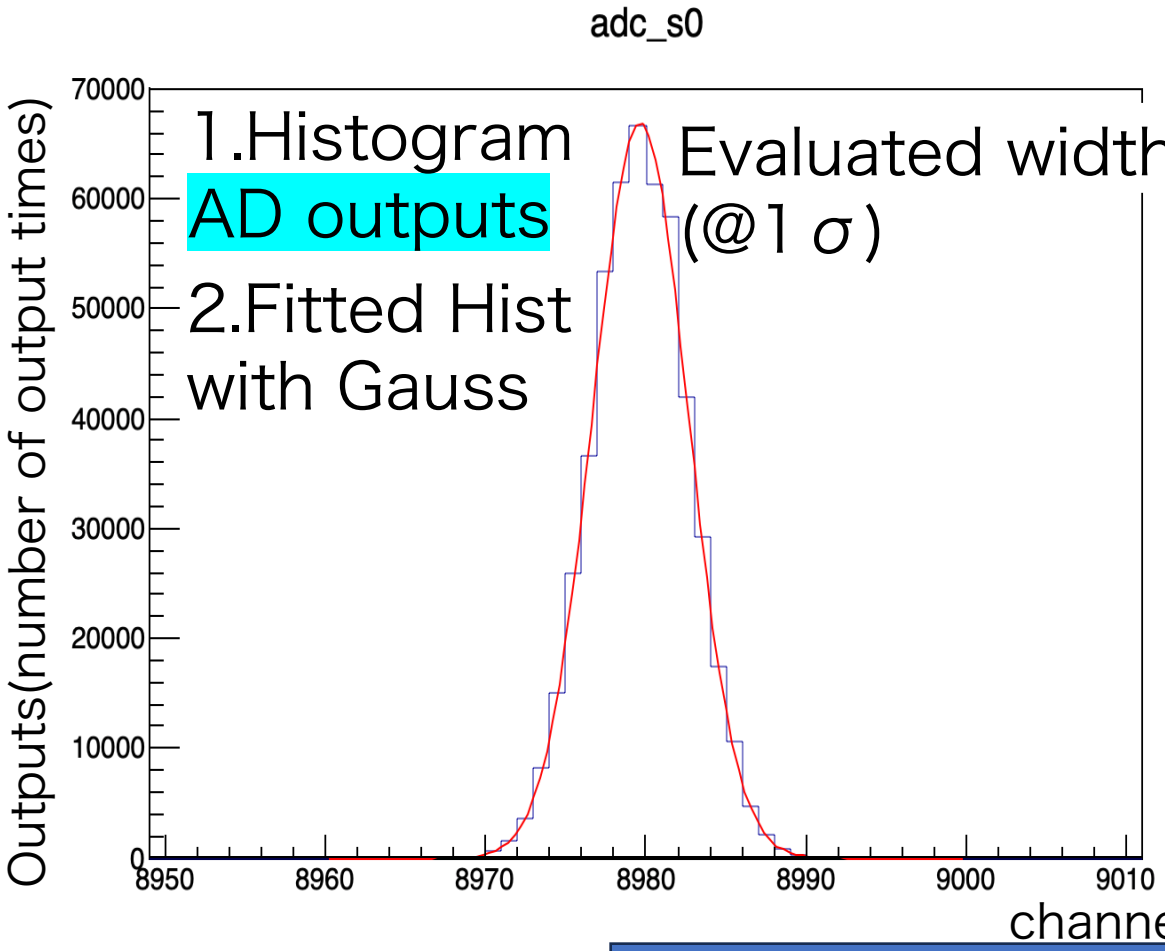


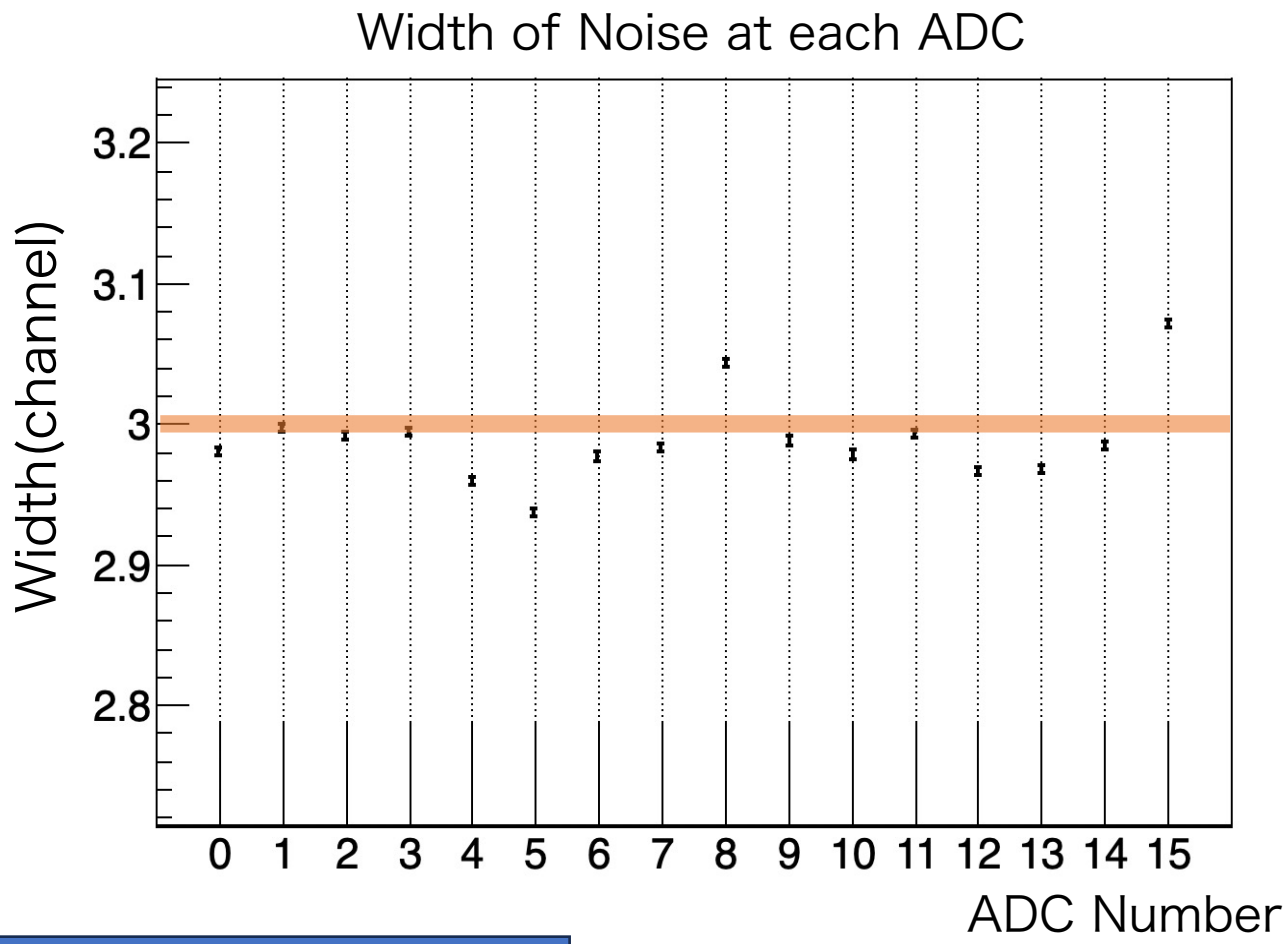


ADC's Requirement <0.5 LSB
Measurement : 0.4 LSB
→ Meets requirements

Result3:Evaluation of Noise

Methods：Inputs constant voltage into on-chip ADC



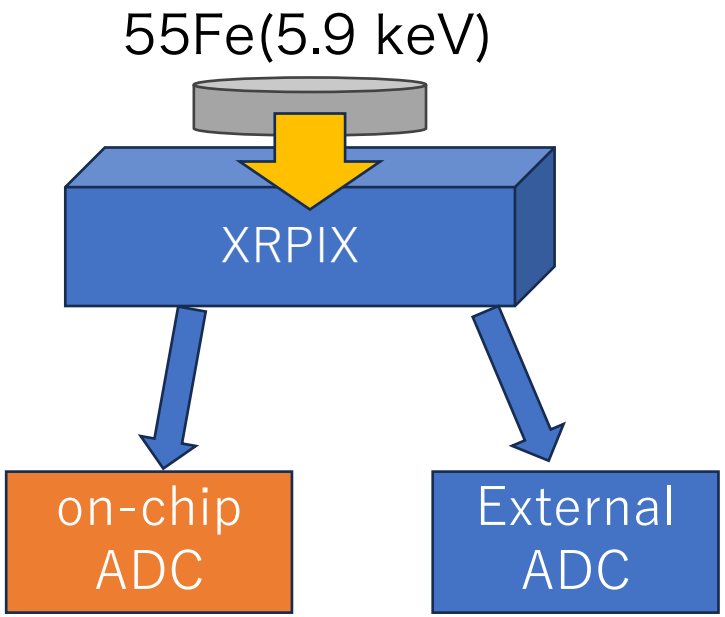


Noise width ~ 3 channel (=0.2 mV)

⟹ Meets the requirements

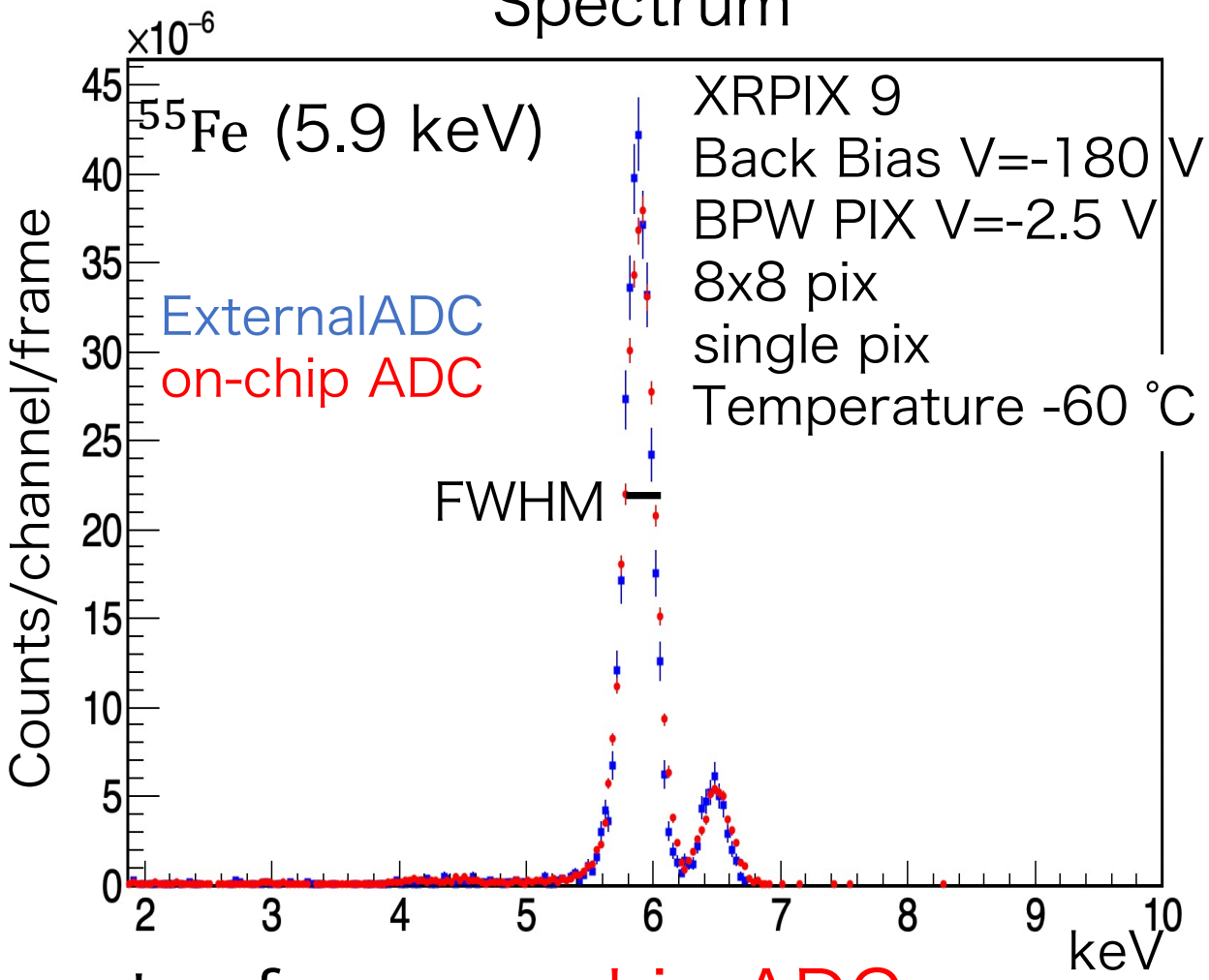
Evaluation of XRPIX + on-chip ADC

Irradiated X-rays on XRPIX



Comparison on-chip ADC with external

Spectrum

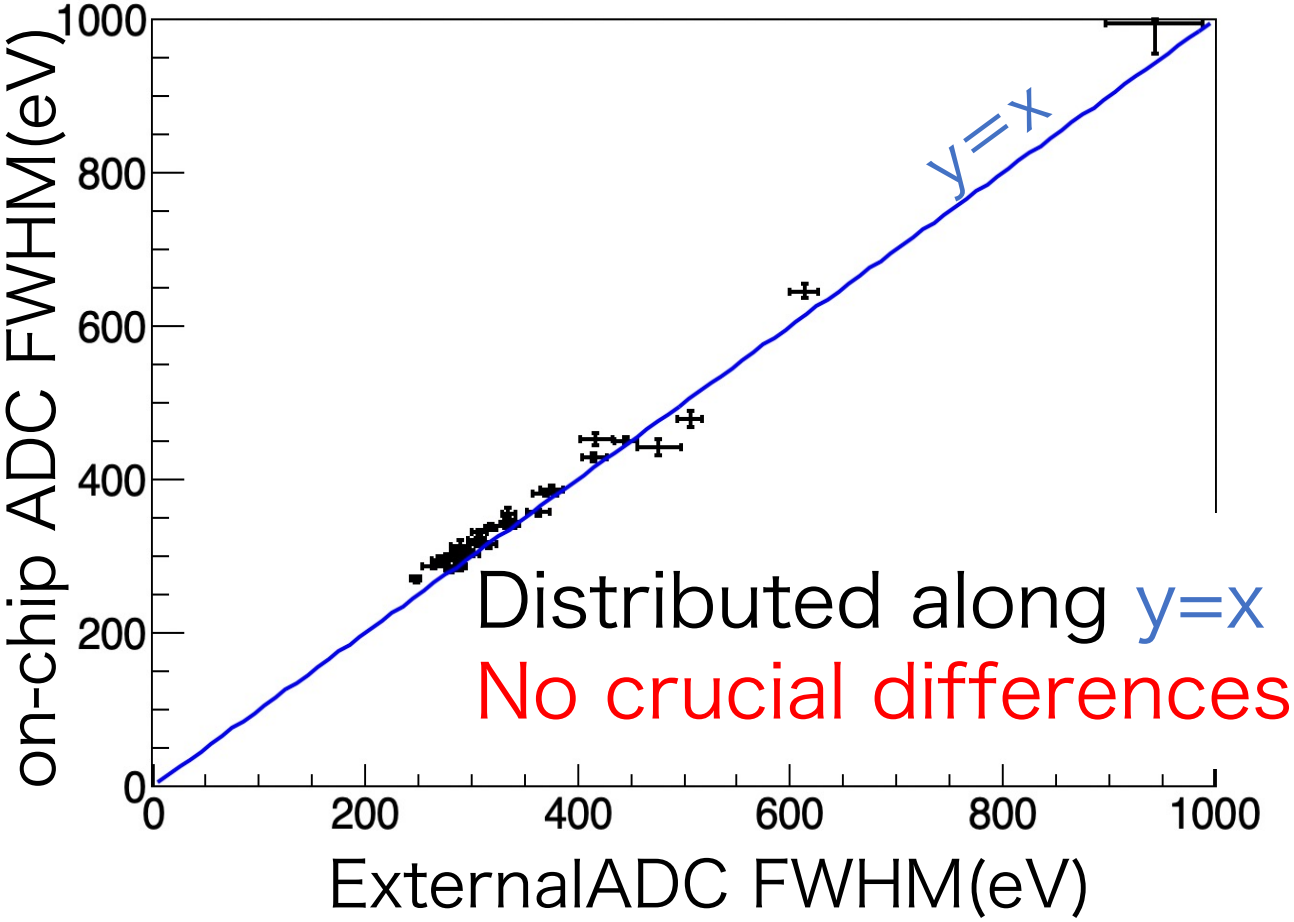


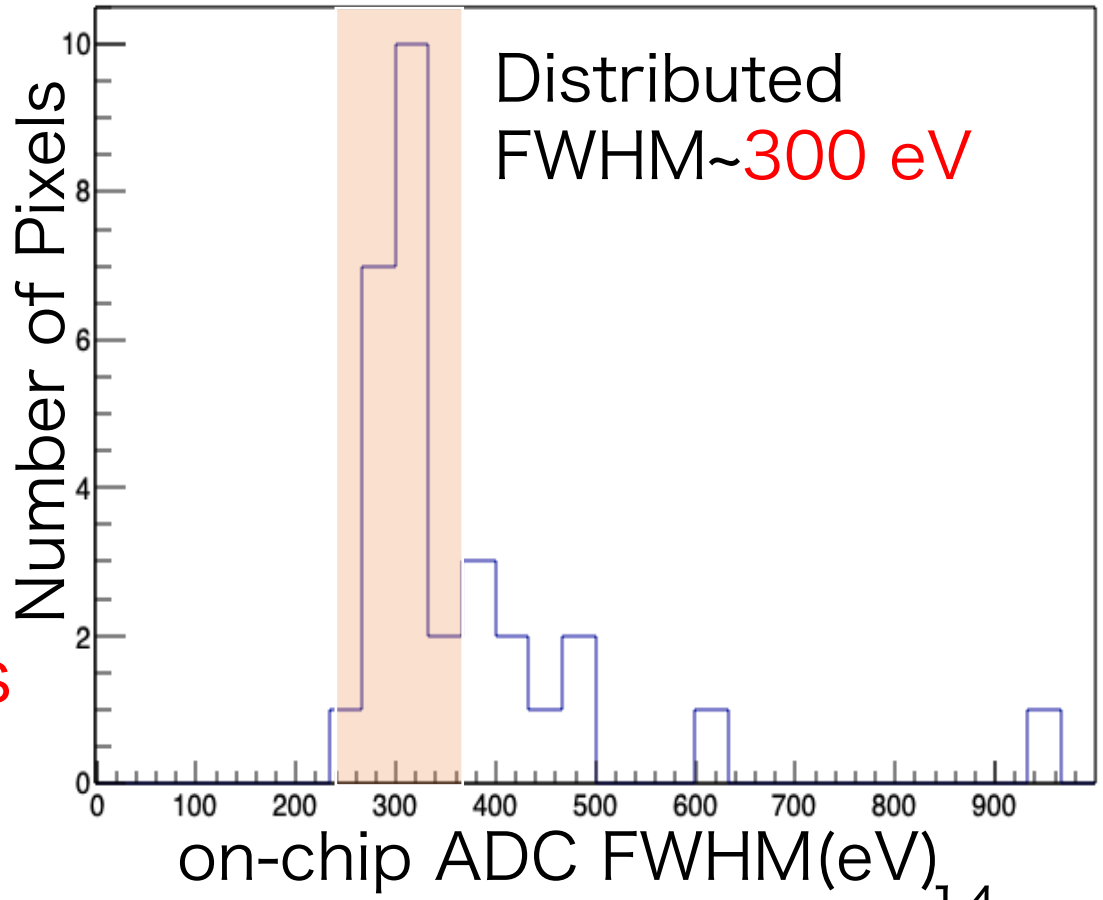
Successfully obtained spectra from on-chip ADC

investigate performance difference

Result4:Compared on-chip with external

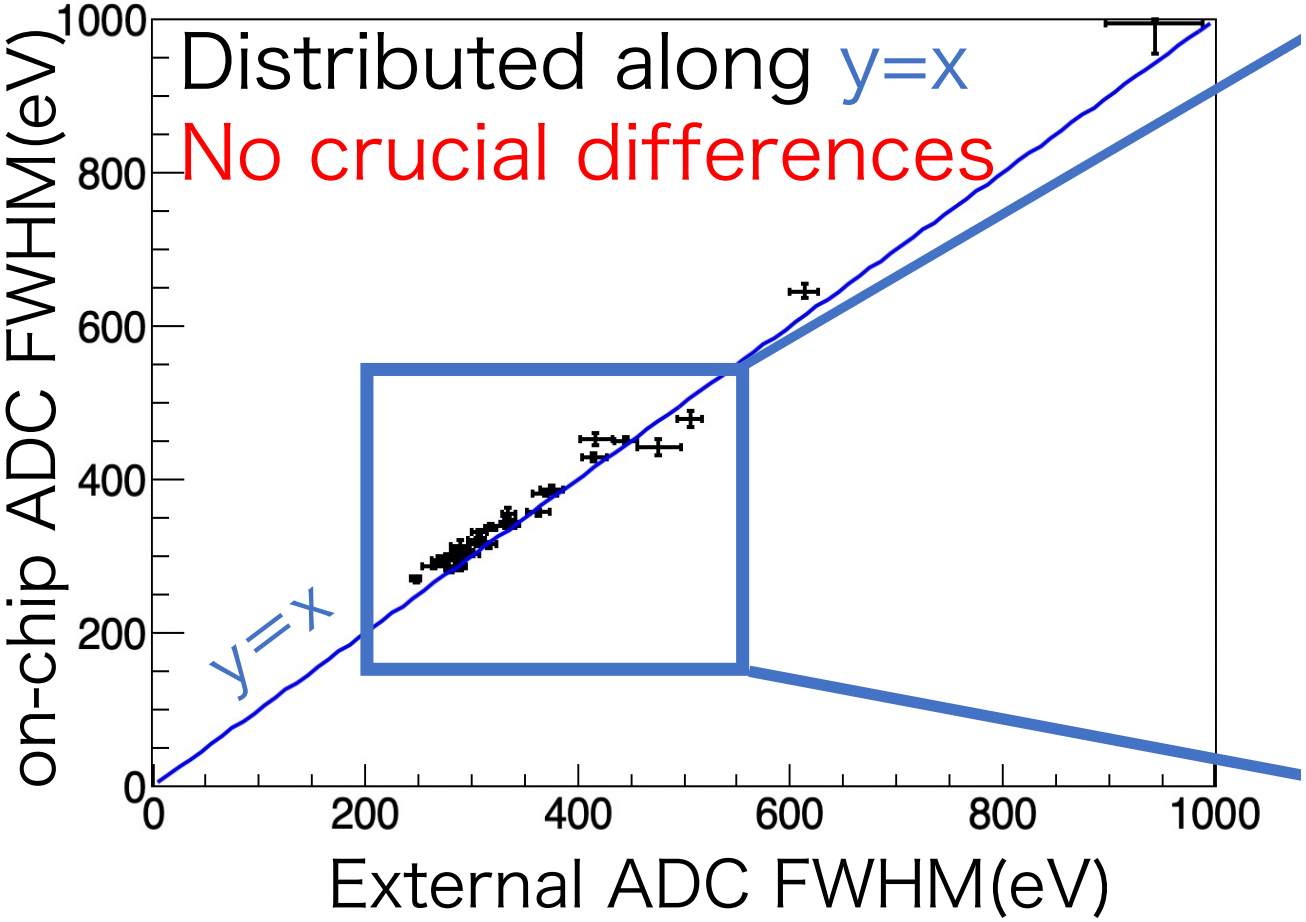
FWHM of external ADC and on-chip ADC compared at each pixel



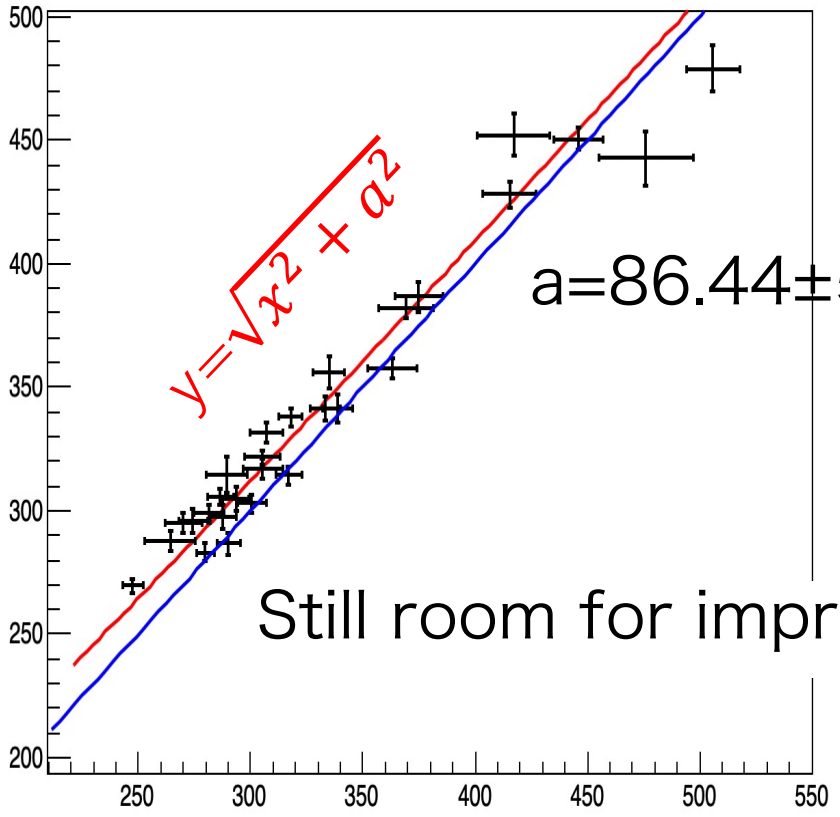


Result4:Compared on-chip with external

FWHM of external ADC and on-chip ADC compared at each pixel



Fitted with $\sqrt{x^2 + a^2}$



a=86.44±5.59 eV

Still room for improvement

Summary

<Objective>

XRPIX aims to be installed on a future X-ray satellite as detector

Its Sensor : Good spectral performance(previous work)

⇒Future task: Digitalization

Detector needs to be compact ⇒ We developed on-chip ADC

＜Result : Evaluation of on-chip　ADC>

1. Integral Non-Linearity:0.036 %
2. Differential Non-Linearity:0.4 LSB (Requirement < 0.5 LSB)
3. Noise :0.2 mV

<Result : Irradiated X-Rays on XRPIX9>

We successfully obtained spectrum from on-chip ADC.

No crucial differences between on-chip and external