VCI2022 – The 16th Vienna Conference on Instrumentation

WASEDA University
早稲田大学

Performance demonstration of a novel Photon-counting CT for preclinical application

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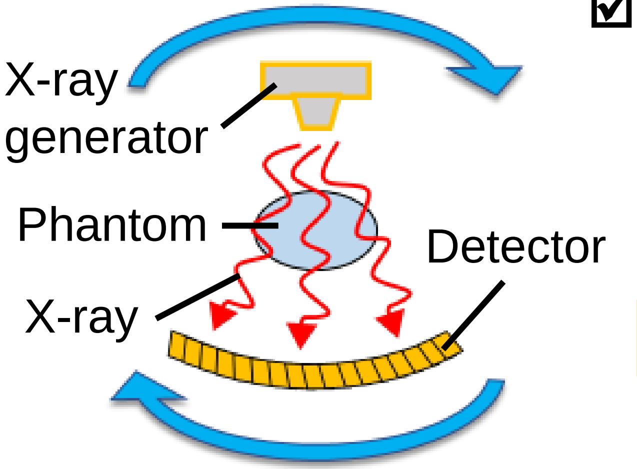
Introduction

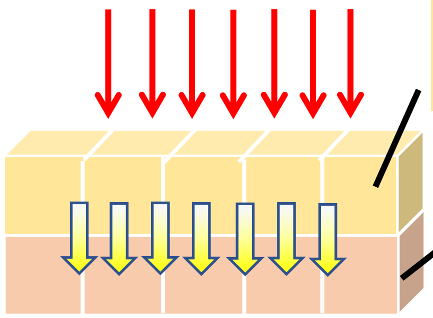
～ Energy integrated CT (EiCT) ～

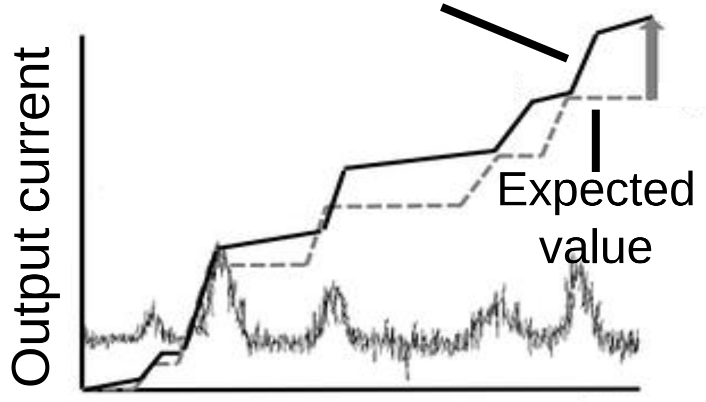
➢ The problems of energy integrated CT

❍ X-ray CT is a powerful medical diagnostic device in medical imaging



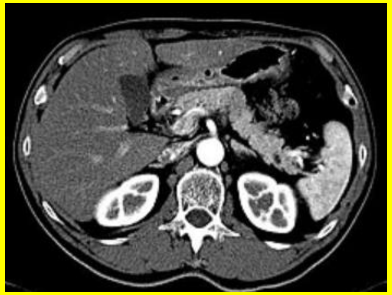
☑ **Readout methods**





Problems

- ✓ **Irradiation with「High radiation dose」(100Mcps/mm²)**
- ✓ **The lack of individual X-ray energy information**
  - ⇒ Occurrence of artifacts
  - ⇒ The obtained images is「monochrome」

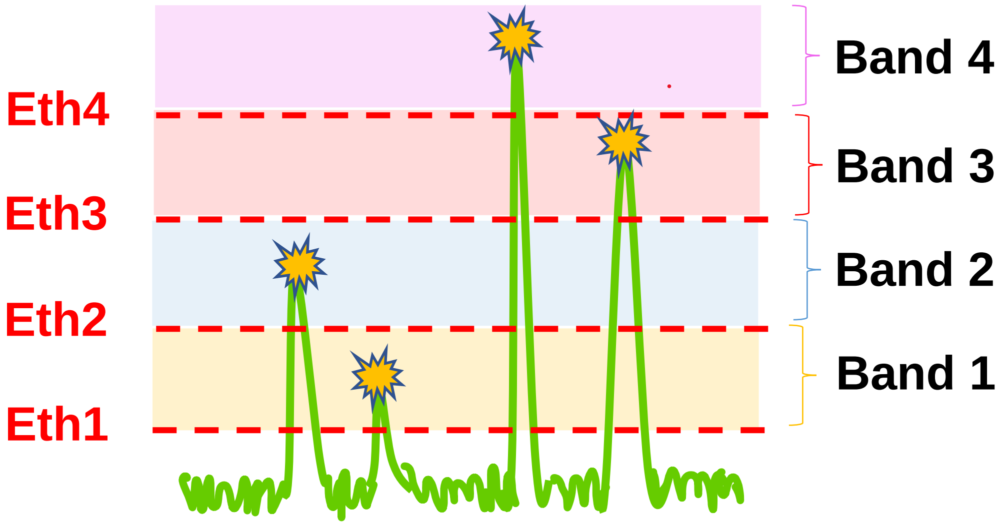


Introduction

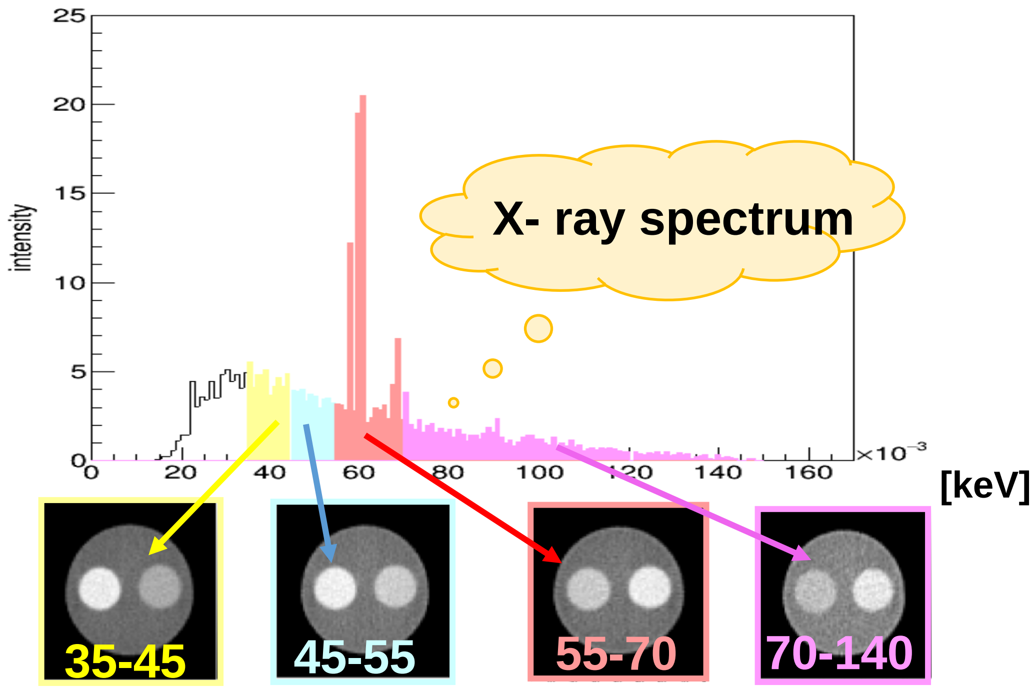
～ Photon counting CT ～

➢ Photon-counting CT(PC-CT) system

Readout of pulse mode



Read individual pulse



Imaging in each energy band

Benefit of PC-CT

- Setting the threshold ⇒「Cut noise components」such as dark current
- Obtain energy information of individual X-ray photons

⇒ Imaging of「each energy band」is possible

Direct and indirect conversion-based PC-CT

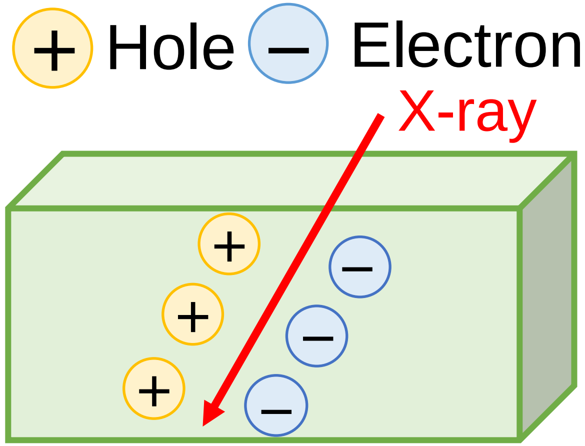
Direct conversion-based PC-CT

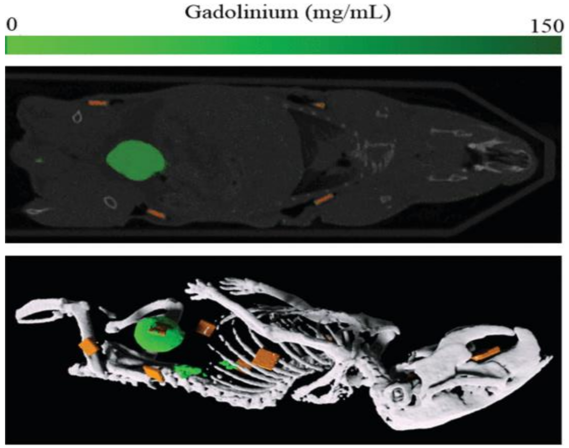
➢ **Semiconductor-based PC-CT**

- ✓ Excellent energy resolution
- ✓ Detector : CdTe, CZT

Problems

- ❍ CSA and shaper are required for each channel
  ⇒ System is complex and expensive
- ❍ Difficult to make a large area





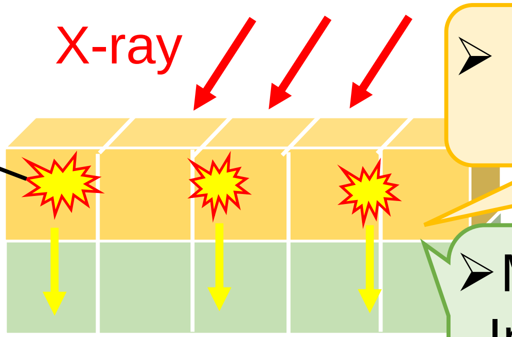
E. Marfo et al. (2020)

Indirect conversion-based PC-CT

➢ **Scintillator coupled with MPPC**

Benefits

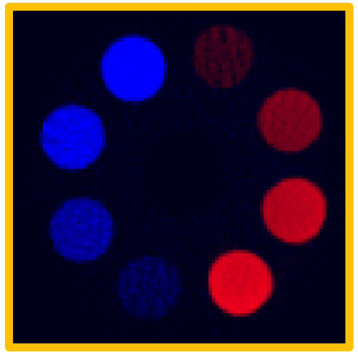
- ❍ Feasible at low cost
- ❍ Simple system
- ❍ Use knowledge of conventional CT



➢ High speed scintillator
Decay time : ~ 70 ns

➢ MPPC
Internal gain : M ~ 10^6
Rapid temporal : ~ 10 ns

(Gadolinium, Iodine)



Density image

Limitation of PC-CT

～ the lack of statistics ～

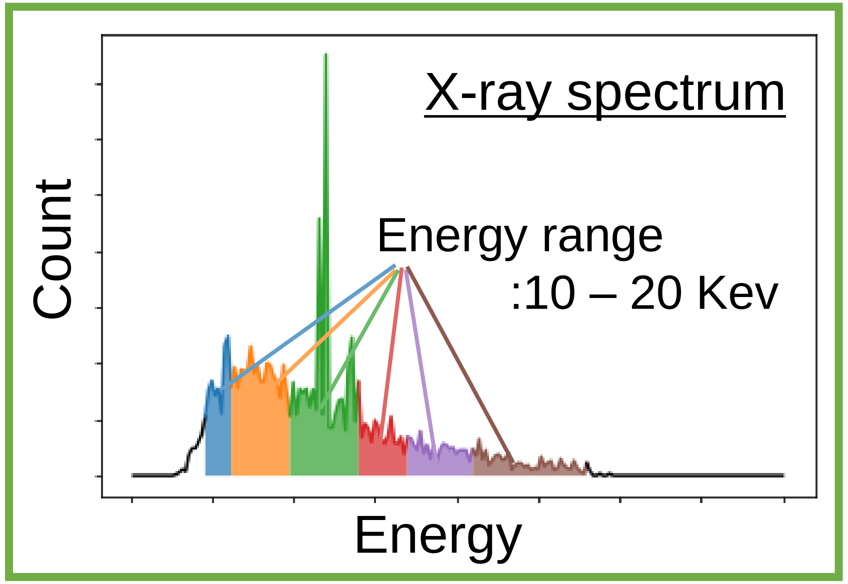
➢ Image quality deterioration

❍ PCCT system in general, the lack of statistics results in image deterioration

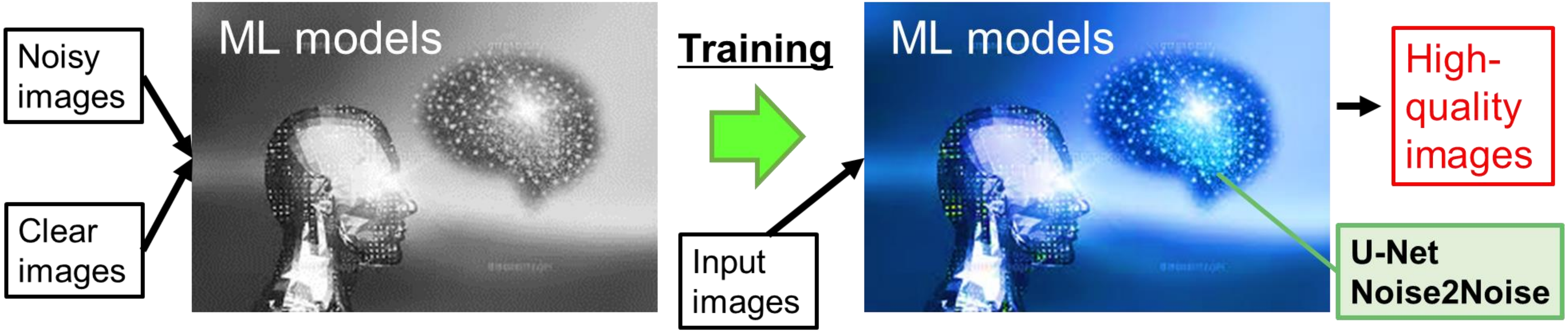
✓ Image reconstruction in a narrow energy band (Typically, 10 – 20 Kev)

⇩

The photon statistics are severely limited



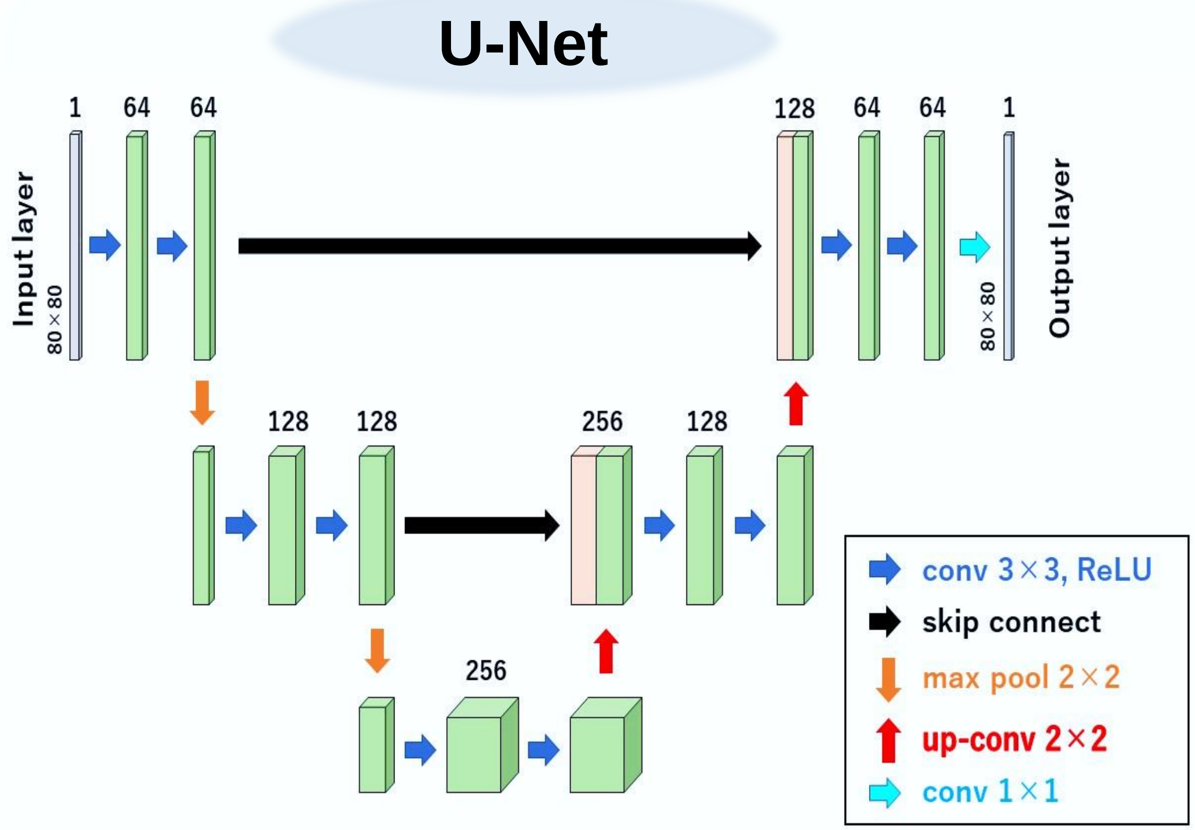
◆ Applying machine learning (ML) models



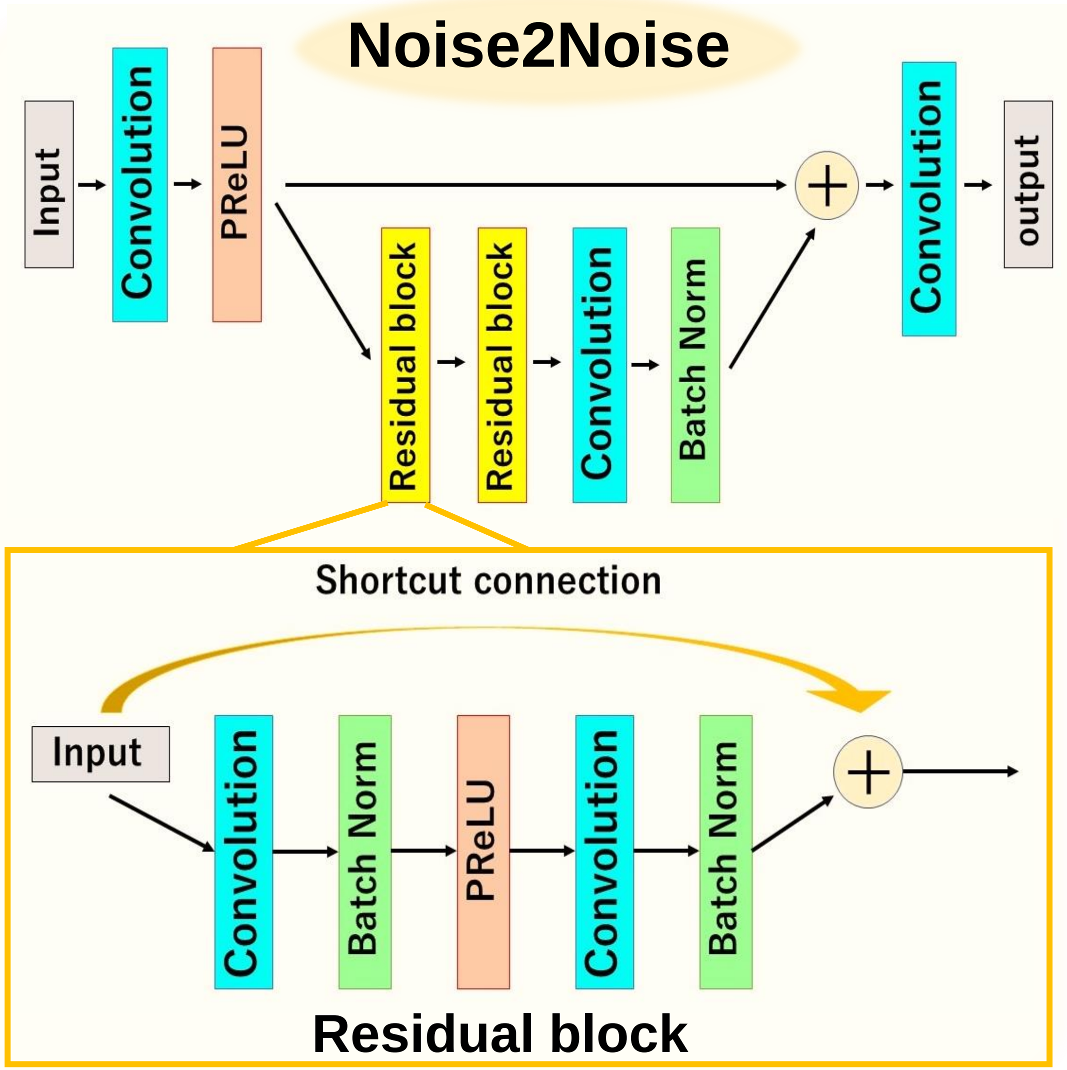
ML models

～ Architecture of ML models ～

➢ Overview of Architecture *(T. Toyoda et al. Jinst 2021)*



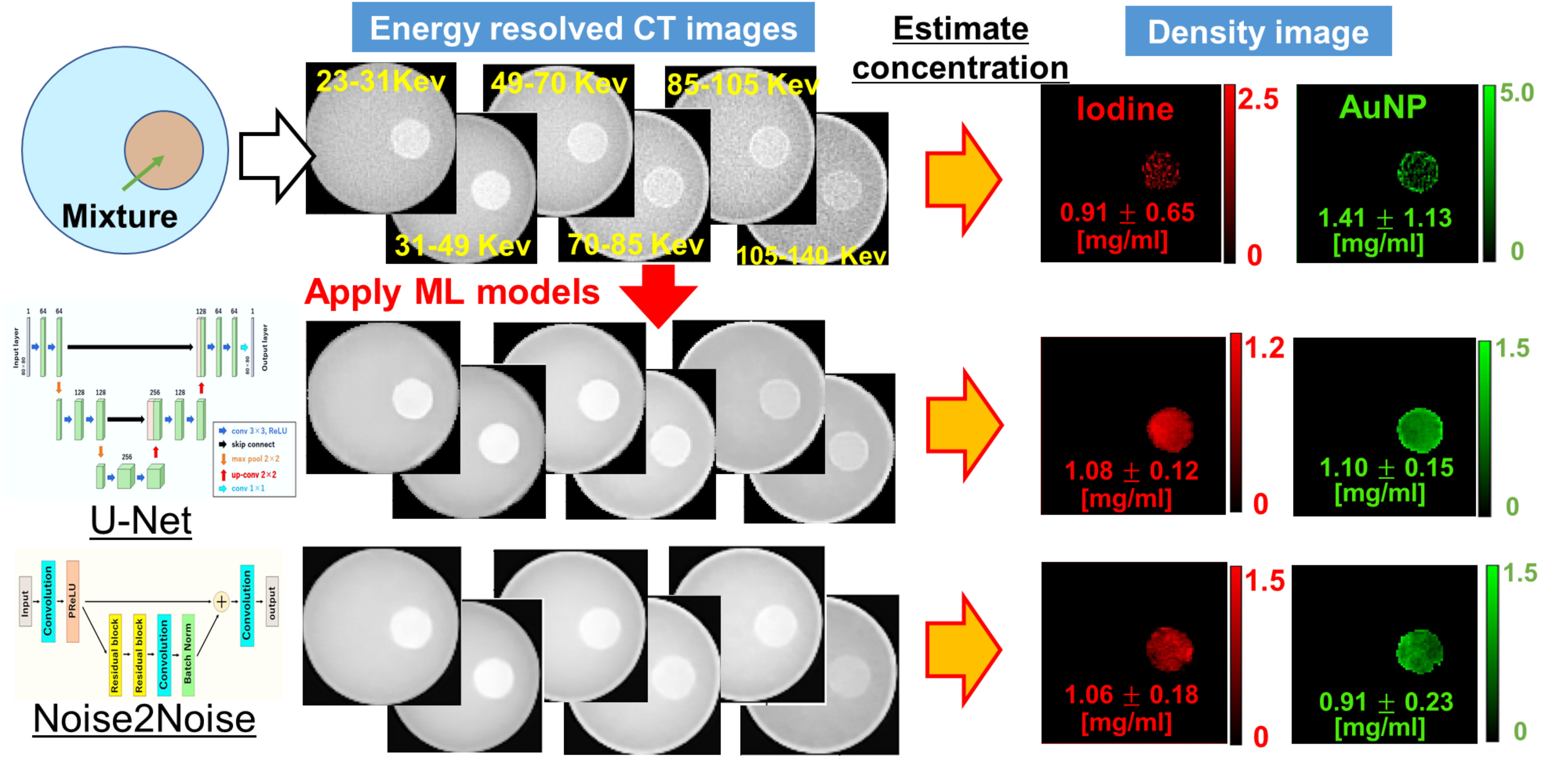
- Training data : 1200 pairs
- Validation data : 100 images
- Test data : 100 images



Results

~ Applying ML models to mixed phantom images ~

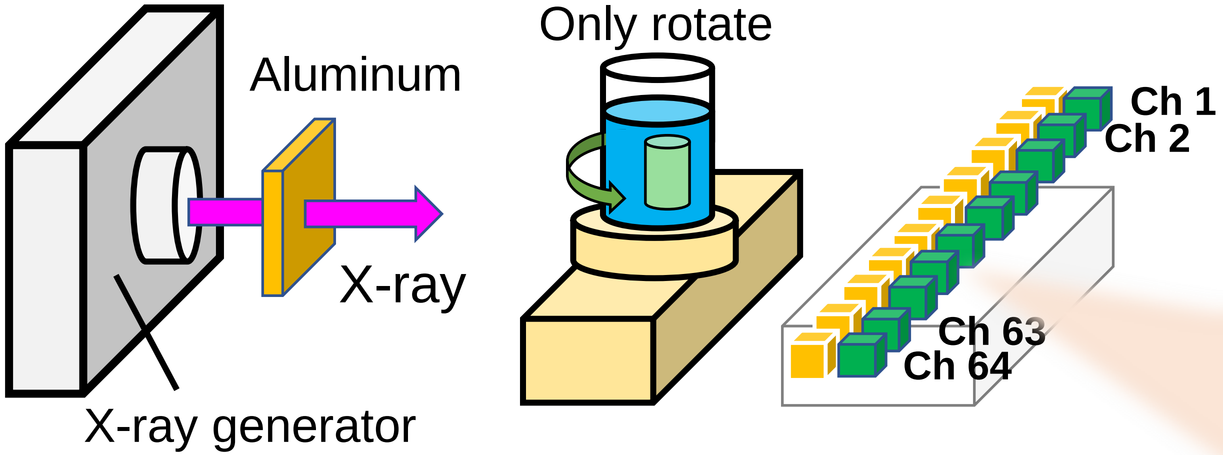
➢ Results of applying ML models



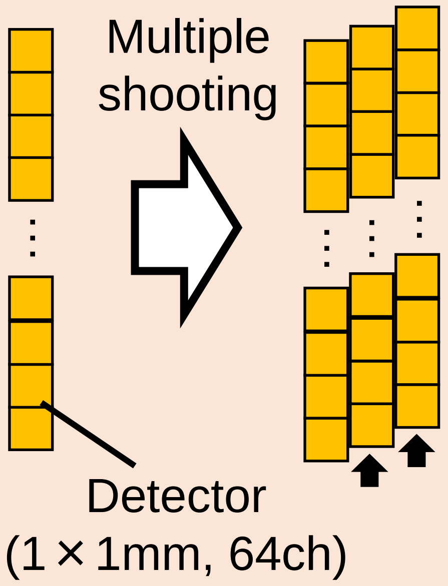
Super-resolution PC-CT images ～ Experimental setup ～

➢ Experimental setup

❍ The third-generation X-ray CT



◆ Generate virtual 128ch or 192ch detector



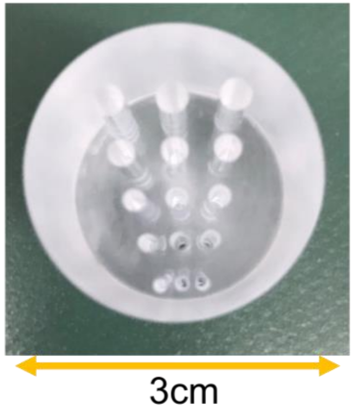
In the case of 128ch

Shooting as usual
⇒ move the detector 0.5 mm
⇒ shooting again
⇒ combine the both of two projection data
⇒ image reconstruction
⇒ obtain 128×128 pixel image

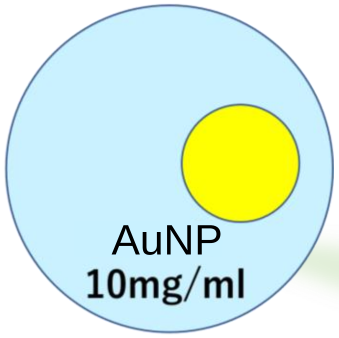
❍ Phantom condition

(A)

Hole size
・4mm
・3mm
・2mm
・1.5mm
・1mm



(B)



(A) Acrylic phantom with several holes
The hole sizes were 4, 3 , 2, 1.5, 1 mm

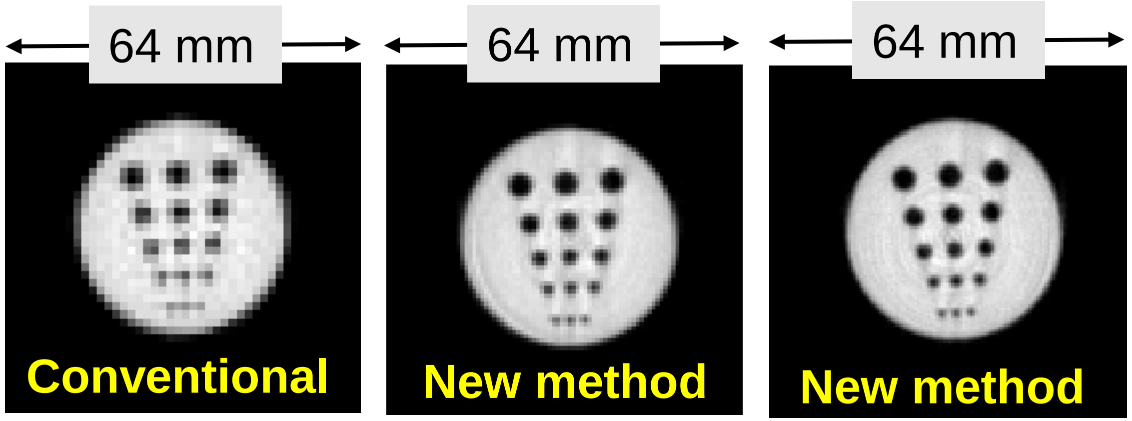
(B) Gold nanoparticles phantom in the water
The concentration was 10 mg/ml

Super-resolution PC-CT images

～ Experimental setup ～

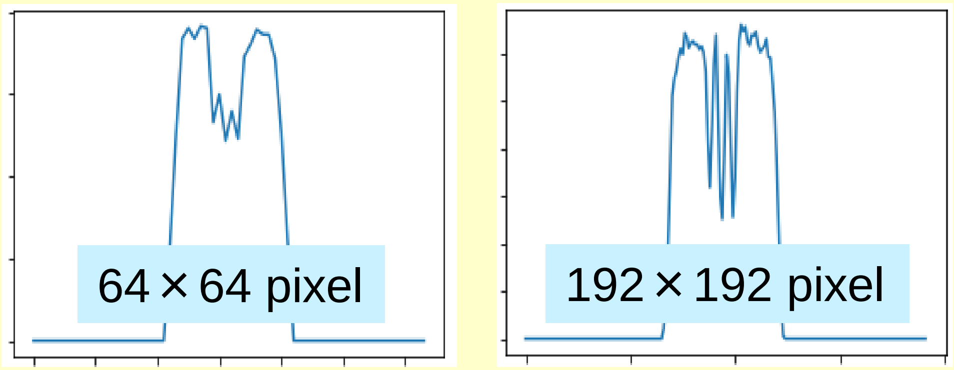
➢ Results of MTF evaluation

(A) Results of hole phantom



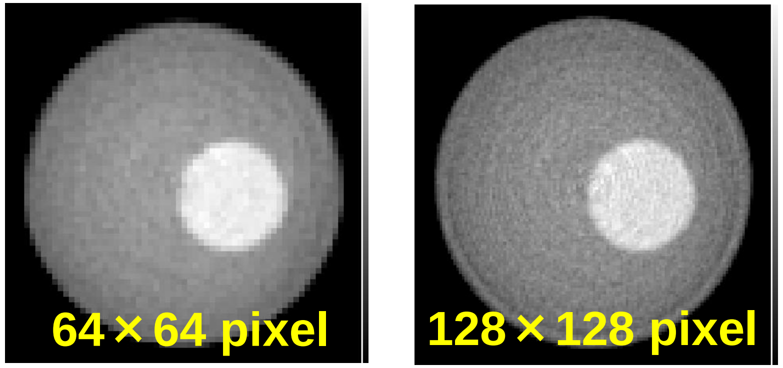
64×64 pixel | 128×128 pixel | 192×192 pixel

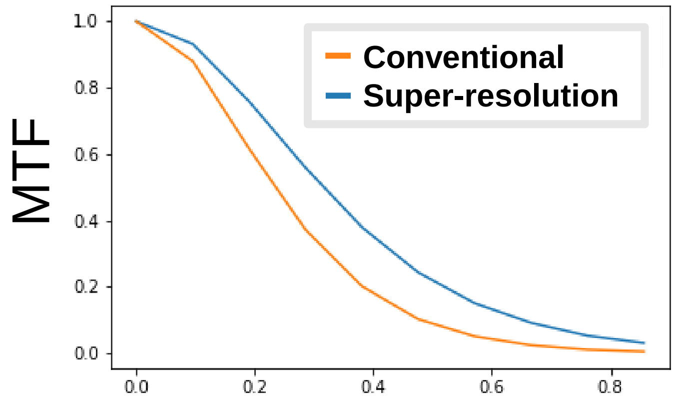
1D projection on the 1 mm hole



Successfully distinguished 1 mm holes

(B) Results of AuNP phantom





	MTF	Resolution
Conventional	0.48	1.04 mm
High resolution	0.65	0.77 mm

MTF & resolution of CT images using new method were better

Successfully improved resolution with new imaging method

Application to in vivo imaging

~ Next target of PCCT ~

◆ Previous performance of PCCT

・Only phantom-based PCCT imaging (Contrast Agents, nanoparticles, etc..)

next → The challenge of *in vivo* imaging for clinical applications (rat, mouse, etc..)

Before *in vivo* imaging …

☑ Mouse imaging with indirect conversion PCCT is unprecedented

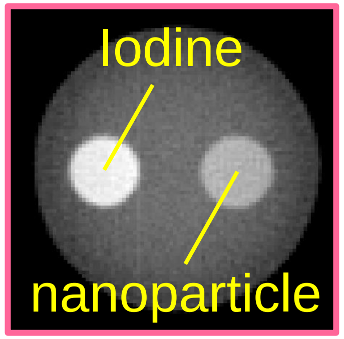
However…

Mouse shooting takes much time to prepare

↓

Imaging validation in plants before in vivo imaging of mouse

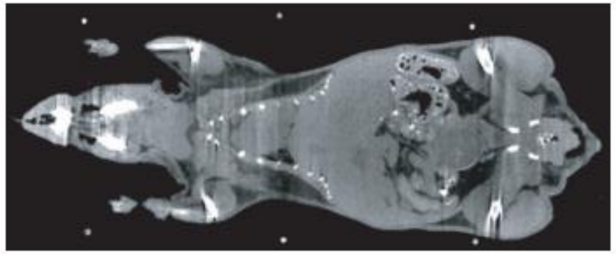
Previous works



Phantom

(Our PCCT imaging)

Next target of PCCT



(Belma Dogdas et al 2007)

Challenging PCCT imaging in plants as a preliminary validation for in vivo imaging

Visualization of dynamics in plants

～ Experimental setup ～

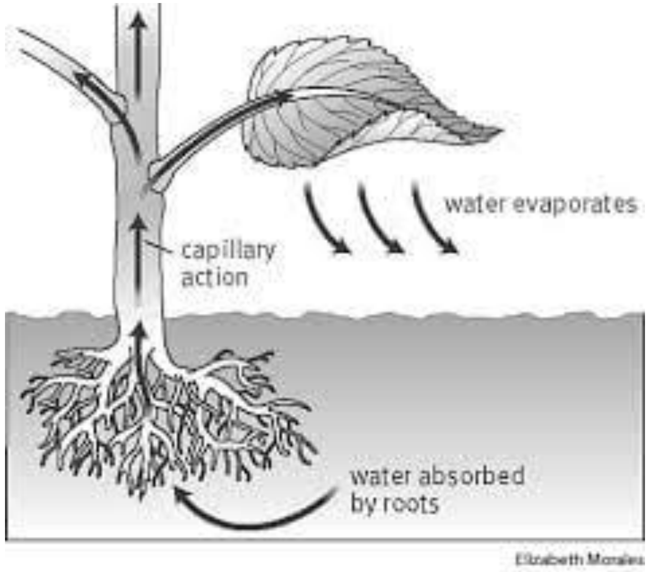
➢ Application of PCCT to botany

- PCCT allows flexible imaging
  - ⇒ because PCCT can provide multiple sets of energy information
- PCCT Enables non-invasive observation of structures internal to plants
- Verifying whether K-edge imaging can be performed in plants

Measurement Condition

- Tube voltage : 140 kV
- Tube current : 0.7 mA
- Exposure time : 700 ms/pixel
- Energy thresholds
  23 , 31, 49, 70, 85, 105 keV

❑ Using the mechanism of water uptake by plants



Imaging phantom

(A)

(B)

(A)

Water + Green food coloring

(B)

Iodine 30 mg/ml + Green food coloring

Visualization of dynamics in plants

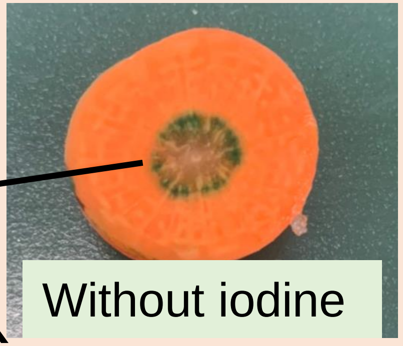
～ Imaging results ～

➢ Comparison between with and without iodine

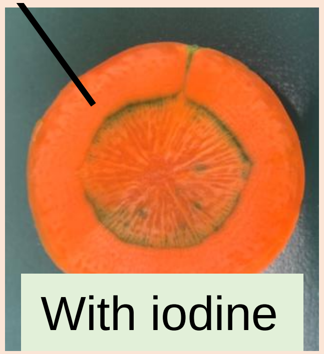
◆ Without iodine (only water absorption)

・Green part is the area that has absorbed water

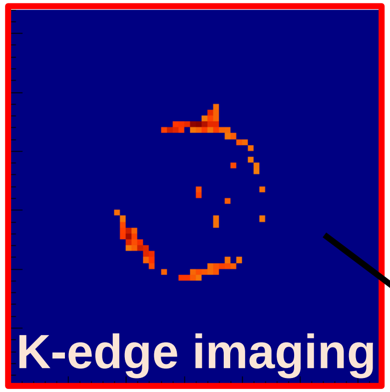
・No changes in CT images



Actual sectional view



◆ With iodine



Succeeded in highlighting the iodine absorption part

Successful visualization of contrast agents in plants by K-edge imaging

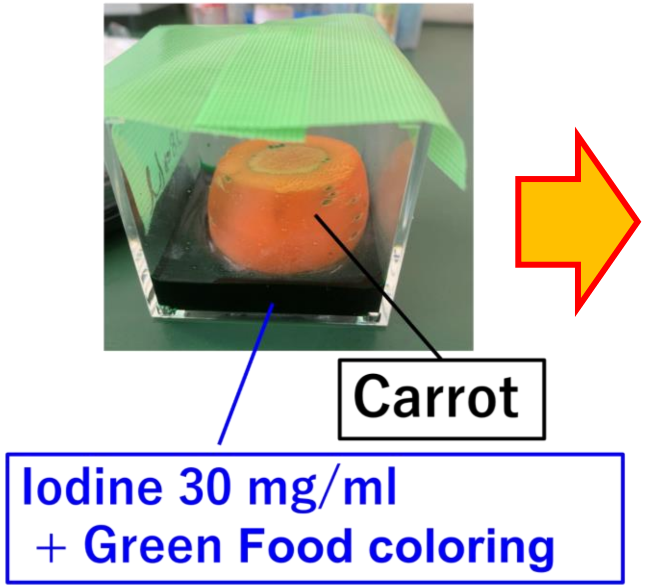
Visualization of dynamics in plants

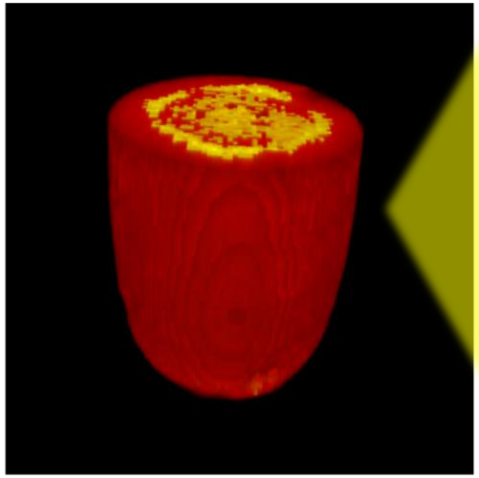
～ imaging results ～

➢ 3D imaging of carrot

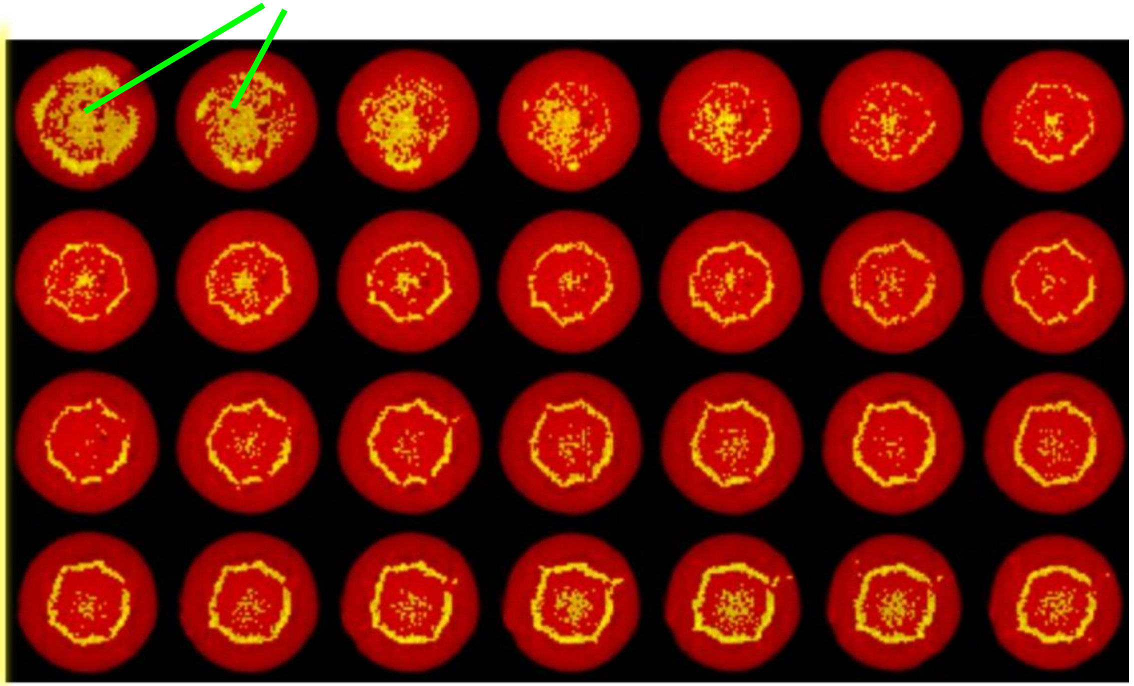
- ✓ Challenging 3D Reconstruction of carrot absorbing iodine Using PCCT
- ✓ Use energy information to distinguish between iodine and the rest

➡ Iodine : yellow, the other part : red





3D reconstruction



2D slices of 3D reconstruction

Successful material decomposition in 3D reconstruction image

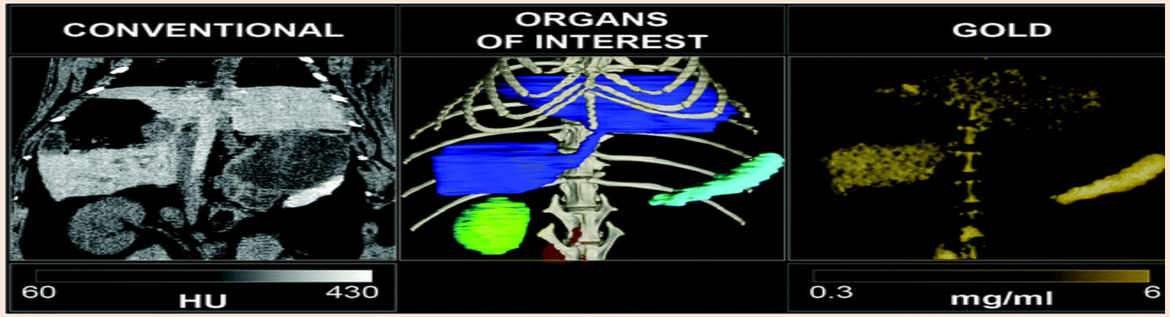
Conclusion & Future works

Conclusion

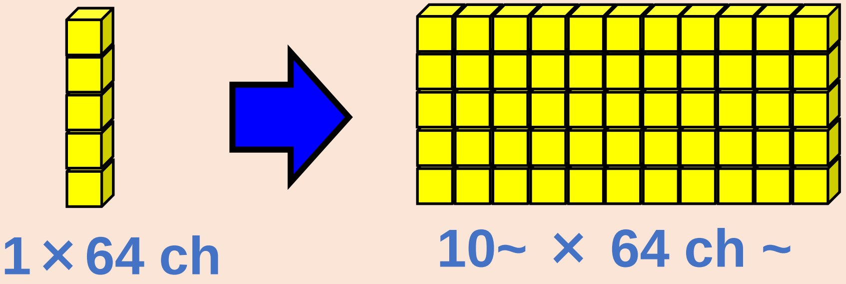
- *Confirmed SN improvement of CT images by machine learning models*
- *Super-resolution CT images were successfully acquired*
- *Demonstrated contrast agent visualization in plants*

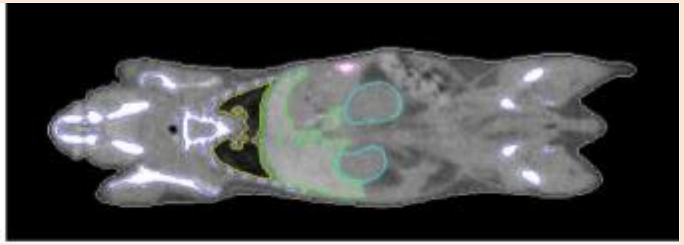
Future works

- *Construction of a larger detector*
- *Challenge for in vivo imaging*
- *Applying ML models to in vivo images*



S. Si-Mohamed et al. (2017)





H. Wang et al. (2012)