# Evaluation of Timepix ASIC for particle detection and X-ray imaging
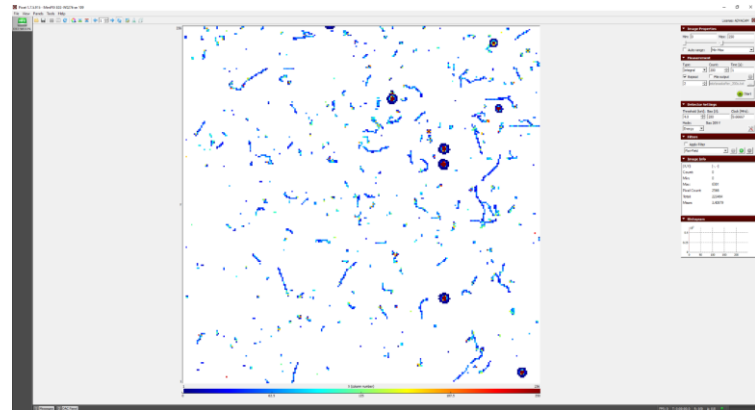
Eden Chung, Laura Lardi
29.10.2021

# What is [Medipix](#)/Timepix?

- Collaboration between many centers and universities
- Family of ASICs (Application-Specific Integrated Circuit)
- Pixel detectors were originally created to measure particles from the LHC and similar projects at CERN
- Evolved to have many different applications now
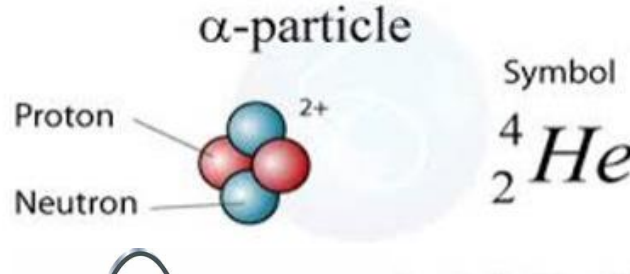- 256 x 256 pixels that can measure ionizing radiation
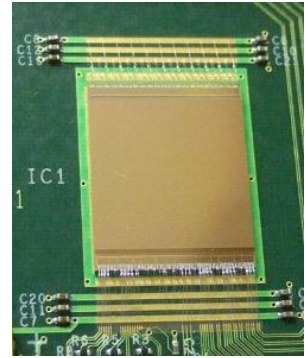
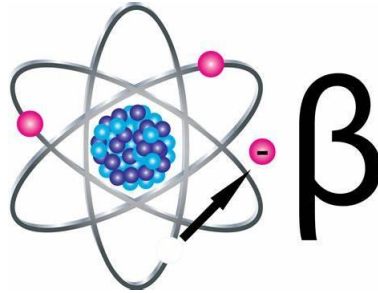Pixet (program used to record data from the sensor)
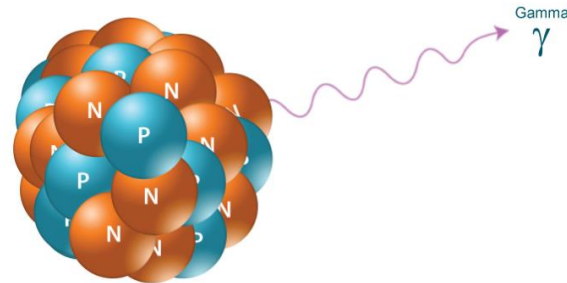
# Radioactive particles

α particles = helium nucleus

α-particle

Proton — 2+
Neutron —

Symbol
$^4_2He$

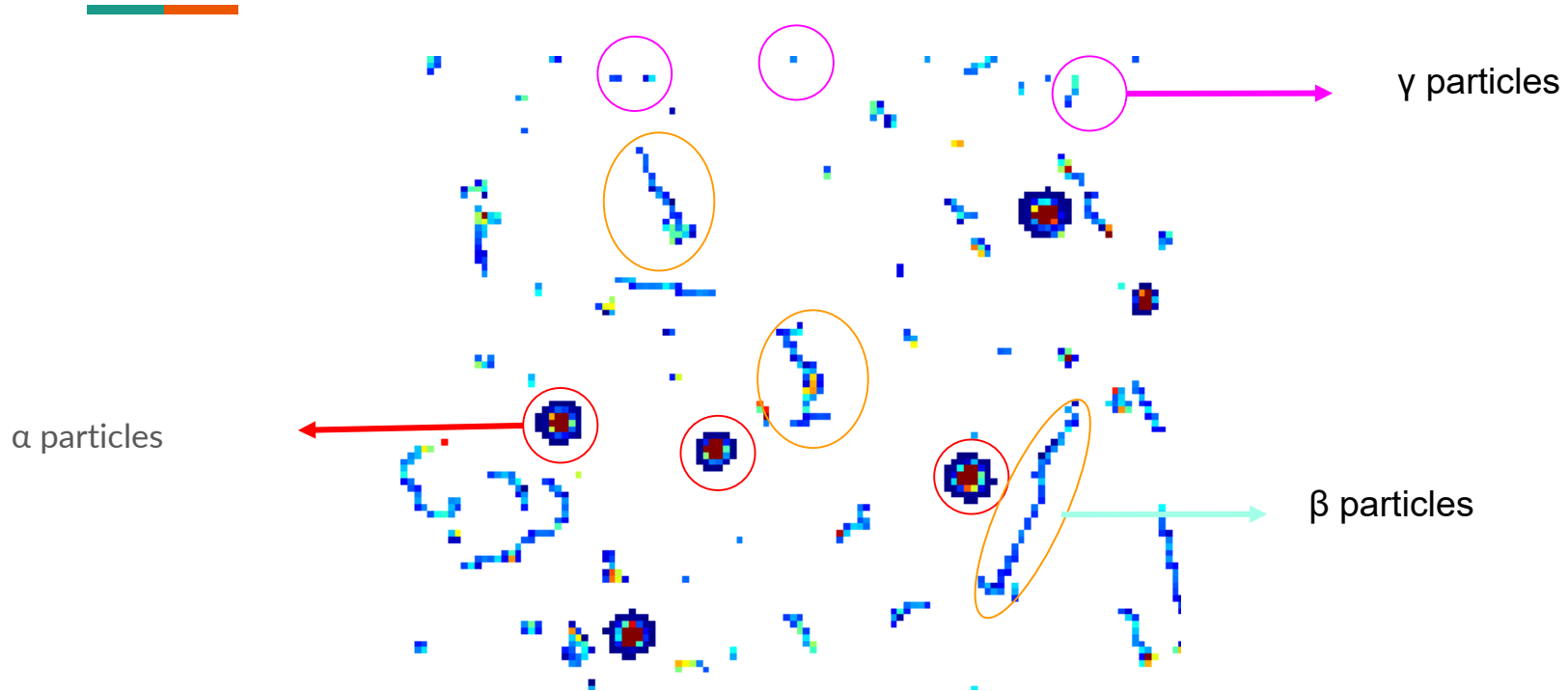β particles = electrons or positrons

β

γ particles = photons

Gamma
γ

# Radioactive particles from background radiation

(close up of a section on the 256x256 matrix)



γ particles

α particles

β particles

Cluster shapes can be used to identify radioactive species (Alphas, beta, ...)

# How do Medipix and Timepix work?

- Ionizing radioactive particles deposit charge in the sensor (for example for a single 10 keV photon 2800 electron-hole pairs are deposited locally)
- An electric field is applied to the sensor so the electrons move to one side and the holes to another
- An electric signal is induced in the sensor pad, which can be measured by the chip
- Silicon material is used in high energy physics because it is uniform, cheap and doesn't interfere with the radioactive particles
- Each pixel has its own electronics, so 65000+ individual electronics
- The electronics of each pixel detects pulses of charges above a certain threshold (for example the threshold may be ~700 electrons. As the electronic noise is ~100 electrons all hits are detected but no noise hits are created)
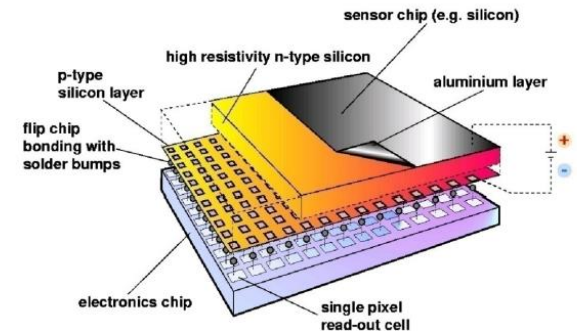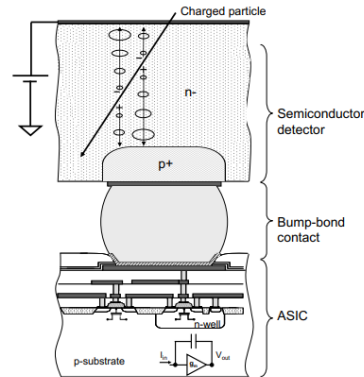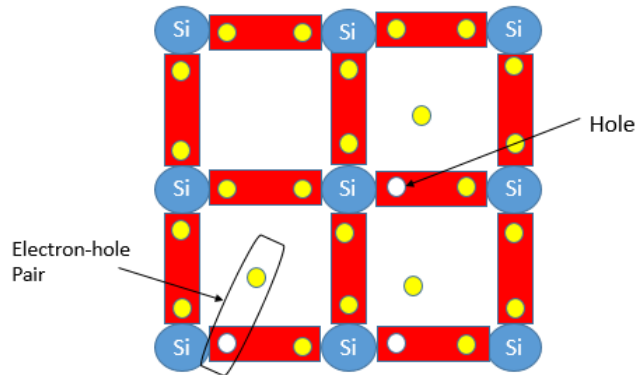
# Modes of Operation

- Photon Counting (PC) - only shows 0 (no count) or 1 (count) → x-ray imaging
- Time over Threshold (ToT) → tracking, energy measurements
- Time of Arrival→ tracking

Time over Threshold

Threshold

Time of Arrival

Shutter
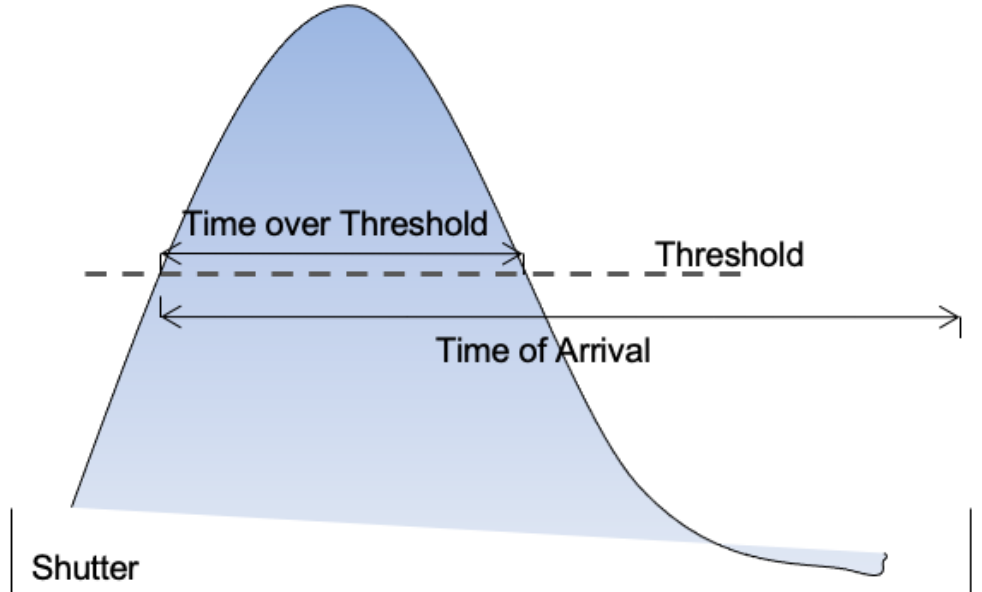
# File output (ToT)

# Python

We must convert the numbers into a colormap using Python:

```python
#1000 seconds balloon
%matplotlib widget
import numpy as np
import matplotlib as mat
import matplotlib.pyplot as plt
from matplotlib.colors import ListedColormap, LinearSegmentedColormap
from matplotlib.backends.backend_pdf import PdfPages

#custom colormap
jet = plt.get_cmap('jet', 256)
newcolors = jet(np.linspace(0, 1, 256))
white = np.array([255/256, 255/256, 255/256, 1])
newcolors[:5, :] = white
newcmp = ListedColormap(newcolors)

#colormap before
plt.close('all')
dataBefore = np.loadtxt('/eos/user/m/mpix/SWAN_projects/Medipix_Students_2021/Timepix/Data/1000s_balloonbefore_thl5_5kev__r0.txt', dtype=float)
plt.imshow(dataBefore,interpolation='none', cmap=newcmp, origin='lower',vmax=250)
plt.colorbar(orientation ='vertical')
plt.title("1000 seconds balloon before")

#colormap after
plt.close('all')
dataAfter = np.loadtxt('/eos/user/m/mpix/SWAN_projects/Medipix_Students_2021/Timepix/Data/1000s_balloonafter_thl5_5kev__r0.txt', dtype=float)
plt.imshow(dataAfter,interpolation='none', cmap=newcmp, origin='lower',vmax=250)
plt.colorbar(orientation ='vertical')
plt.title("1000 seconds balloon after")
plt.xlabel('ToT')
pp.savefig()
```
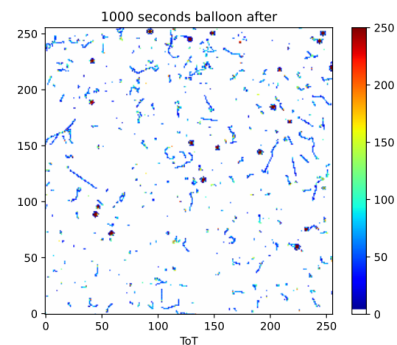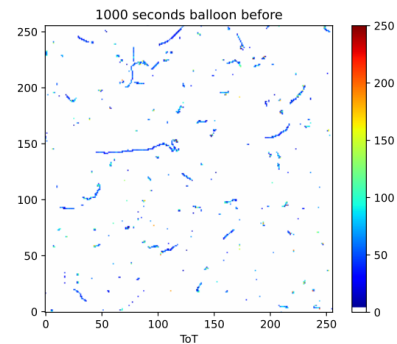
Saved to PDF →



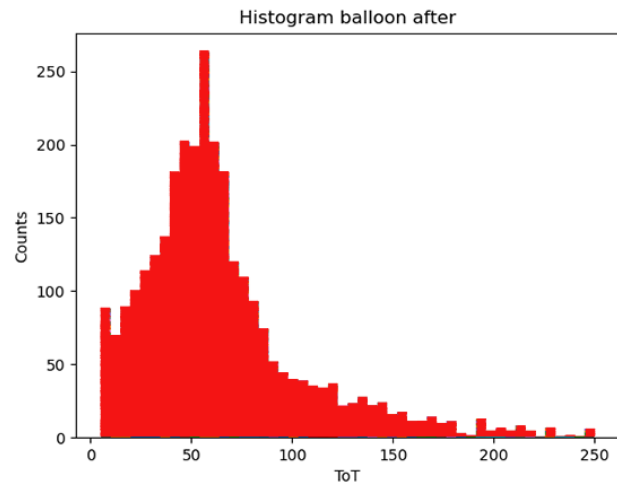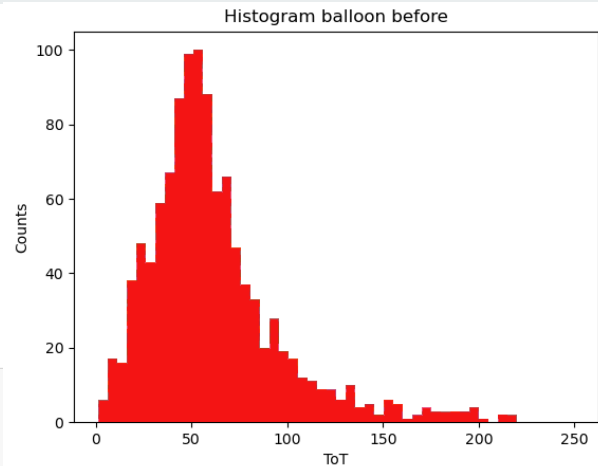1000 seconds balloon before



1000 seconds balloon after

# Python

We can also use the data to create histograms

```python
#histograms
dataBefore = np.loadtxt('/eos/user/e/edchung/SWAN_projects/Medipix_Students_2021/Timepix/Data/1000s_balloonbefore_th15_5kev__r0.txt', dtype=float)
dataAfter = np.loadtxt('/eos/user/e/edchung/SWAN_projects/Medipix_Students_2021/Timepix/Data/1000s_balloonafter_th15_5kev__r0.txt', dtype=float)

#histogram before
plt.close('all')
plt.hist(dataBefore, range=(1, 250), bins=50,histtype='barstacked')
plt.title("Histogram balloon before")
plt.xlabel('ToT')
plt.ylabel('Counts')
plt.show()

#histogram after
plt.close('all')
plt.hist(dataAfter, range=(5, 250), bins=50,histtype='barstacked')
plt.title("Histogram balloon after")
plt.xlabel('ToT')
plt.ylabel('Counts')
plt.show()
```
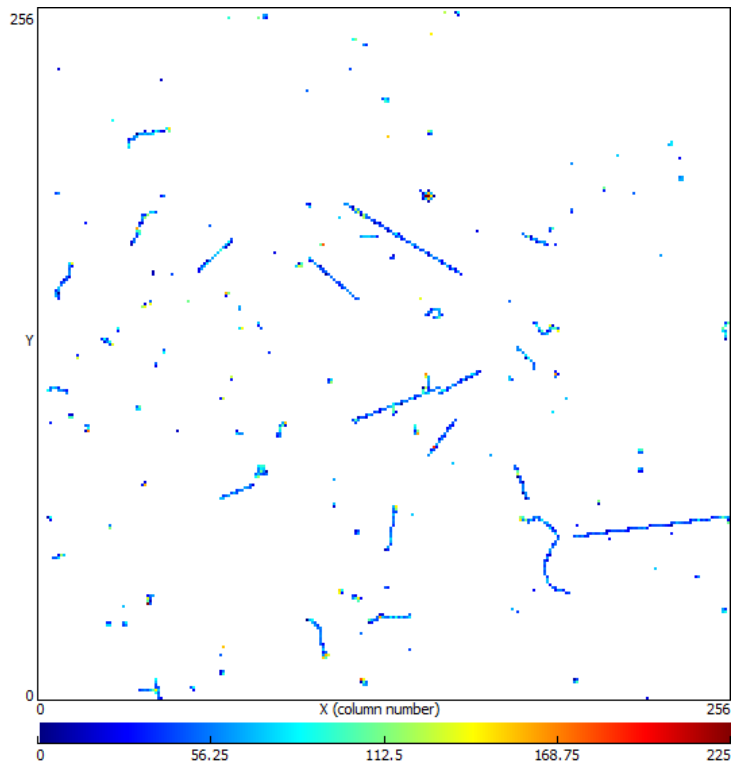


Histogram balloon before



Histogram balloon after

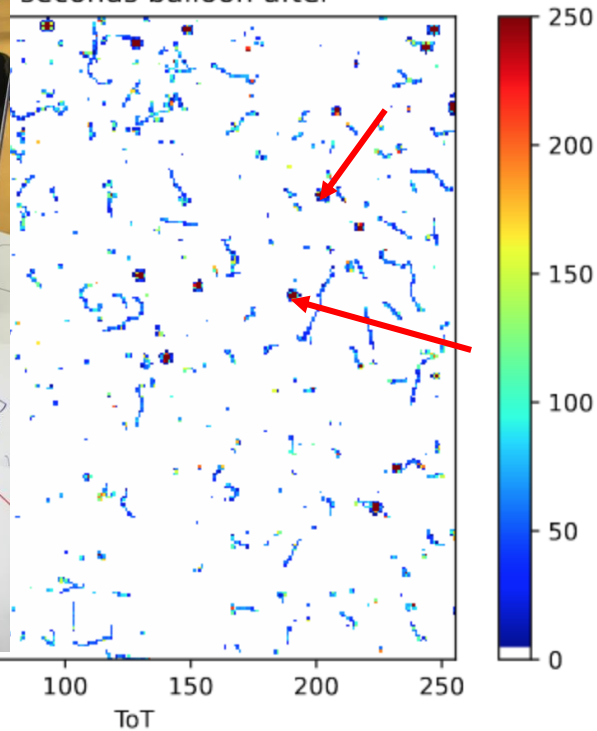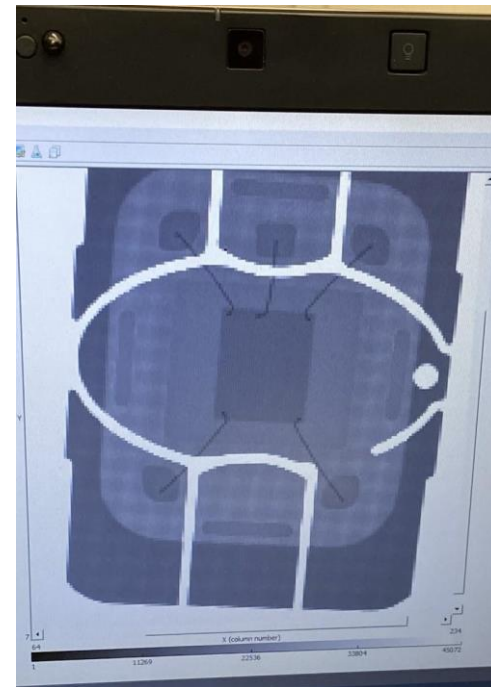# Test: How exposure time affects the results

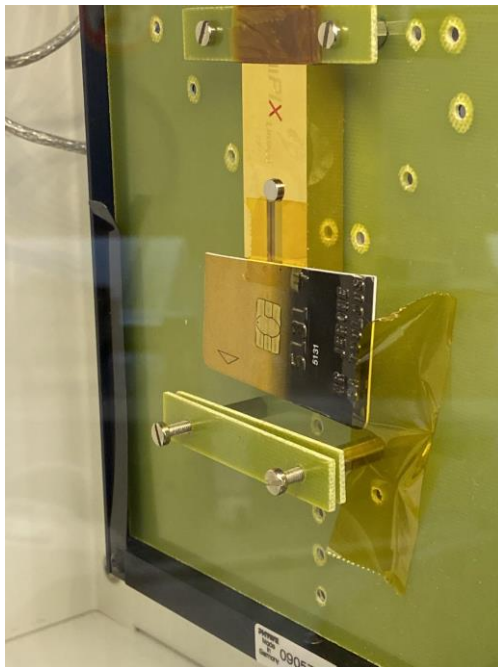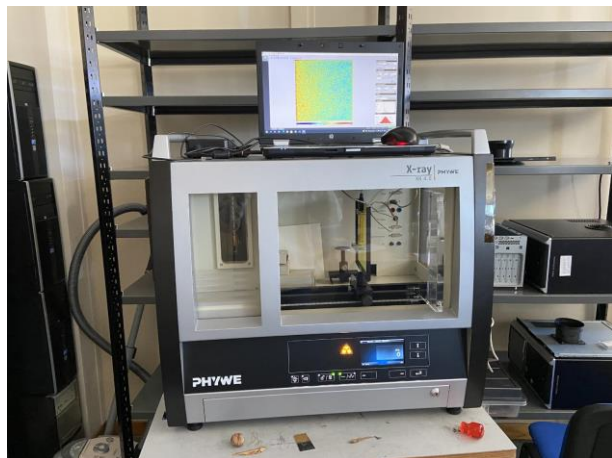10000 seconds



Muon
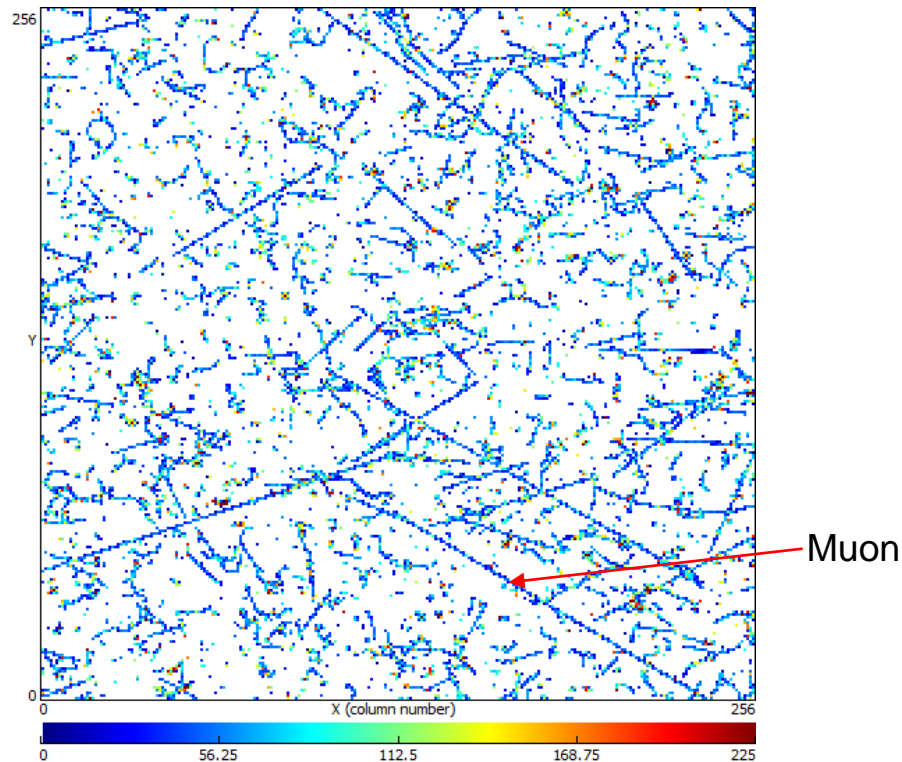
# Test: using a balloon
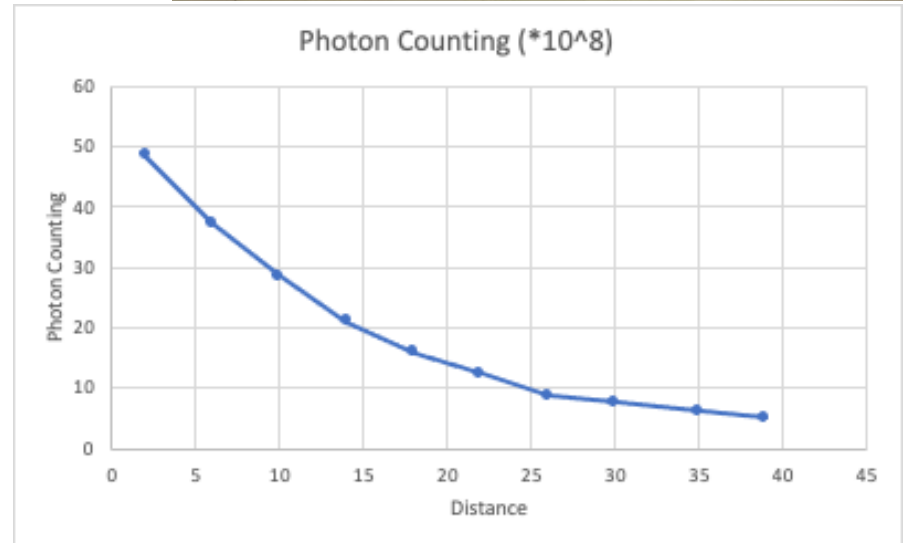


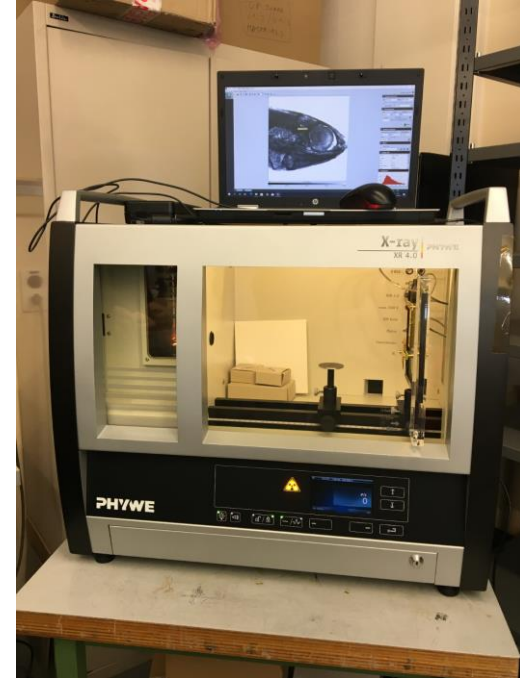1000 seconds balloon before
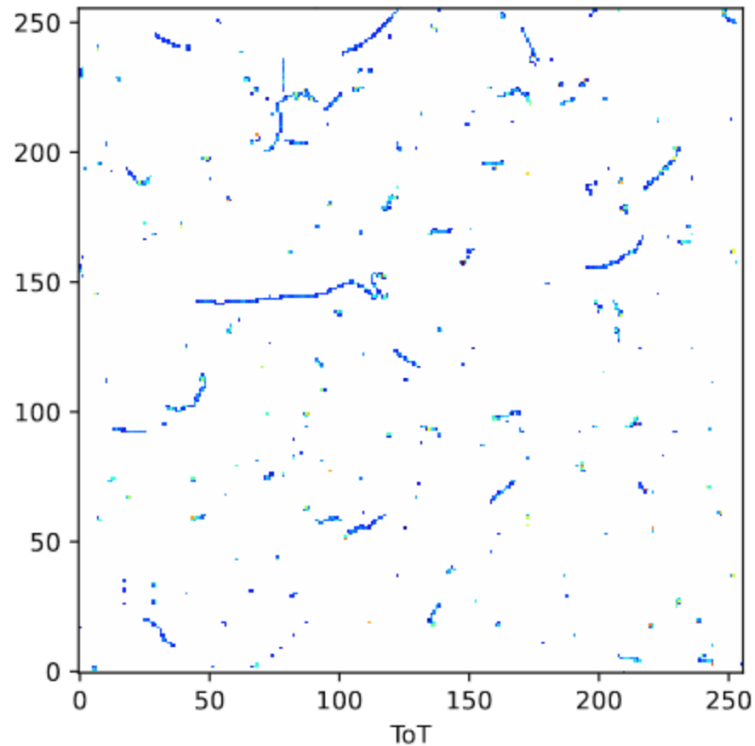
seconds balloon after

# X-ray scanning

# Test: PC with changing distance

| Distance (cm) | Photon Counting (*10^8) |
|---|---|
| 39 | 4.963 |
| 35 | 6.108 |
| 30 | 7.693 |
| 26 | 8.713 |
| 22 | 12.4 |
| 18 | 15.84 |
| 14 | 21 |
| 10 | 28.43 |
| 6 | 37.36 |
| 2 | 48.51 |



Photon Counting (*10^8)
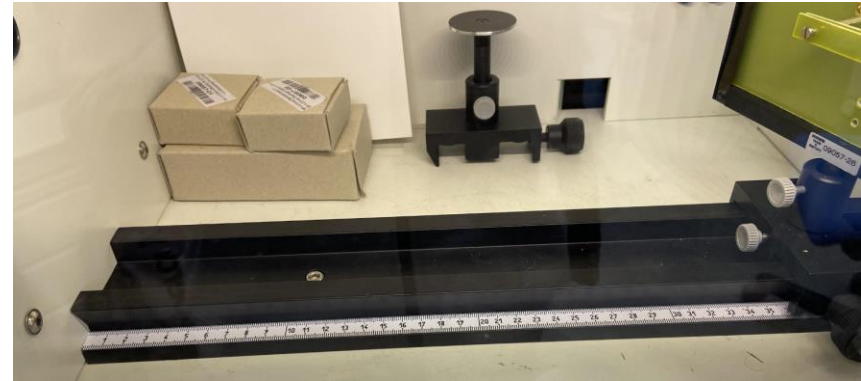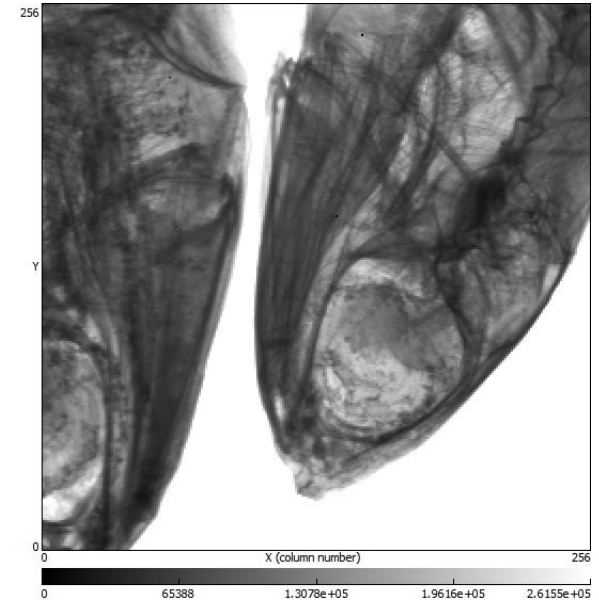
# X-ray Scanning with dried fishes (Bob and Bonnie)

# X-ray depending on time



0.001 seconds

0.05 seconds

30 seconds

# Applications



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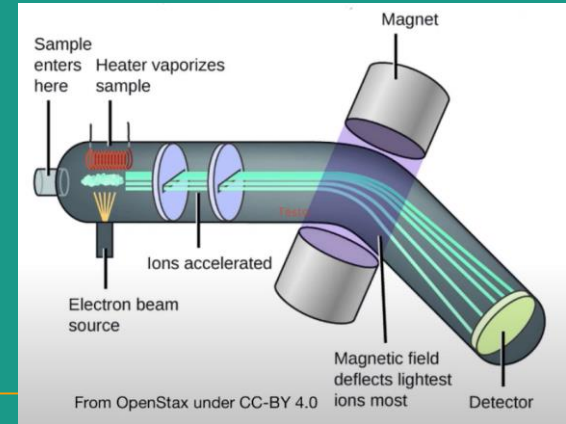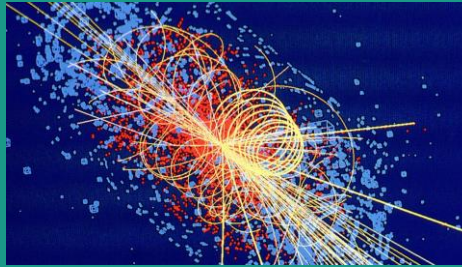
- Medical Imaging
- Space Dosimetry
- Material Analysis
- Education
- High-energy Physics (Charged particle tracking with Timepix 3)
- Cryo- electron- microscopy (instead of x-ray Cristallography)
- Mass spectrometry (Isotopes measurements)
- ...
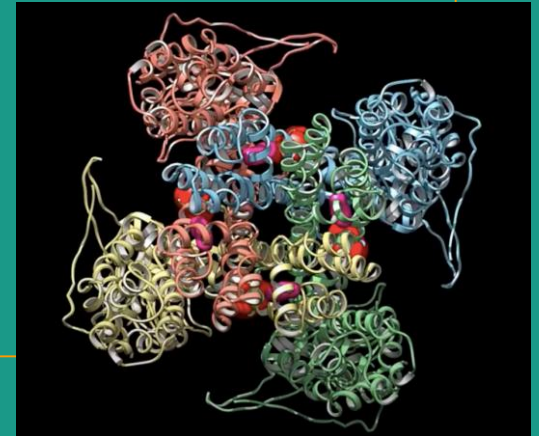
# X-Ray Histology

- Photon counting, PC
- Multiple frames are combined to form a 3D reconstruction
- High resolution images possible because PC is noise free
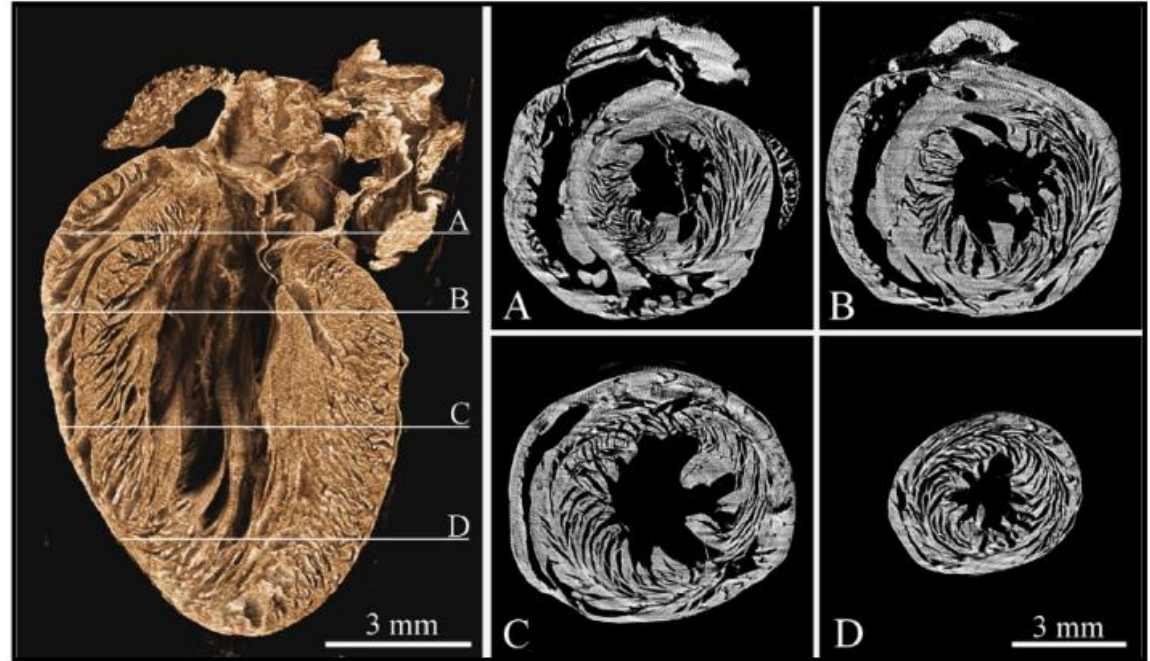
# Comparison: normal vs. spectral CT

- Different images are taken using different kVp (keV Peaks) → Medipix3 just needs a single shot
- The detector classifies the photons according to their energy
- Lower radiation (ALARA-principle)
- In normal CTs, any metal implants or parts create artefacts (unusable shots)→ not with Medipix3
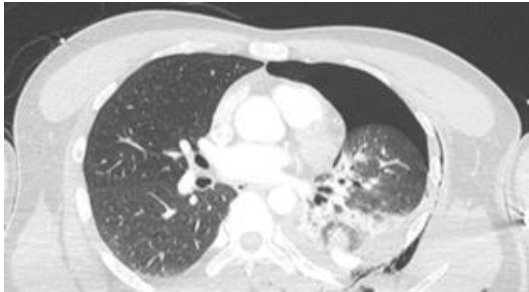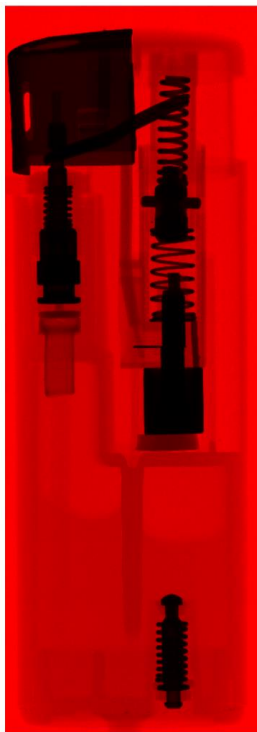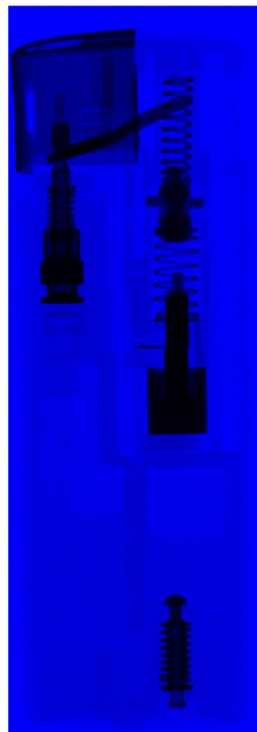
Plastic and casing clear, but springs and mechanical parts are too dark (for better contrast at lower density -> low energy threshold)
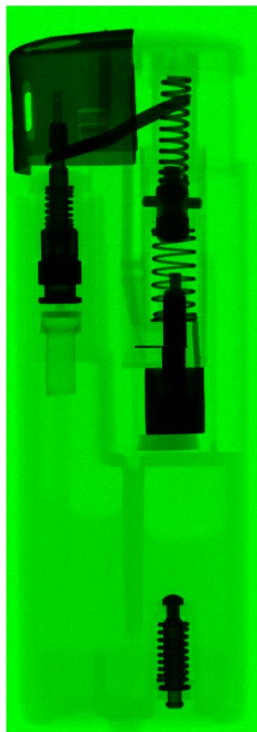
The mechanical parts are more clear, but the plastic is less clear (for better contrast at high density -> high energy threshold)
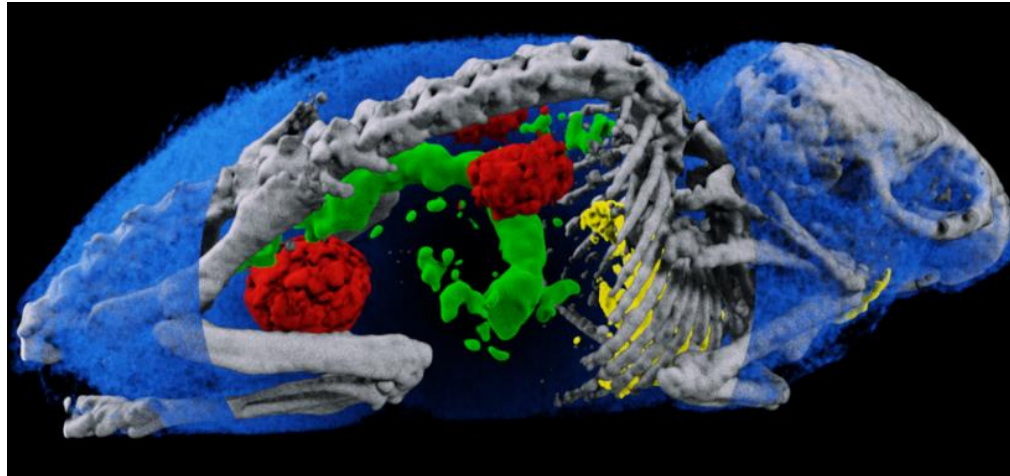
Combine the 3 images to create the clear image while optimizing dose

# Medical imaging with Medipix3

- Colored CT scans (spectral imaging) → clearer pictures for a better diagnosis
- Different colours to represent different materials in the object
- Material identification is possible because the energy information is available
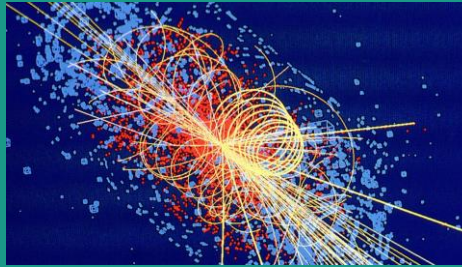
# MARS, New Zealand

- Photon counting
- Currently tested in New Zealand and CHUV, Lausanne (doctors, physicists, radiologists)
- Only scans arms or legs, not the hole human body (full body scanner is still in development)
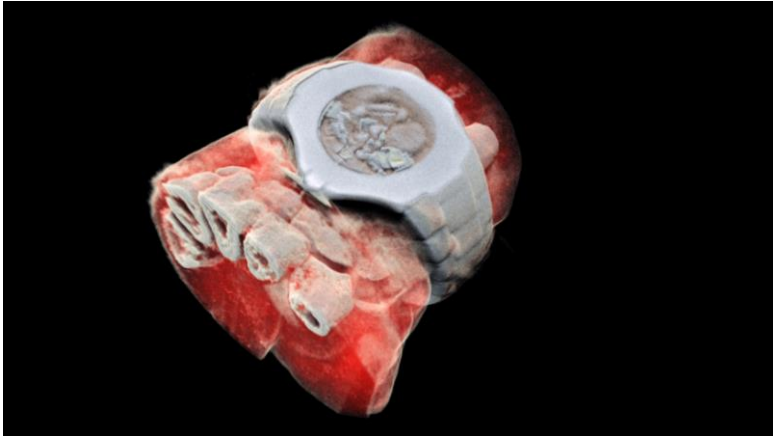
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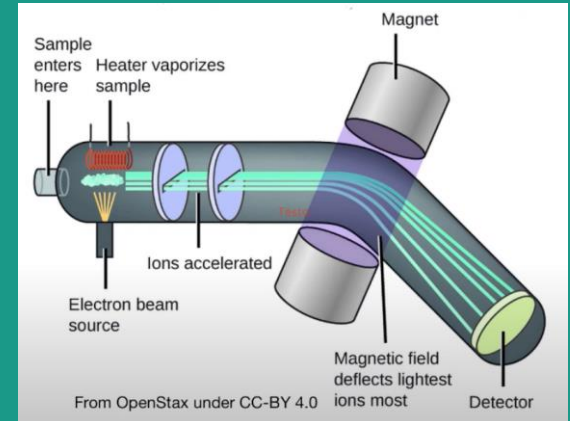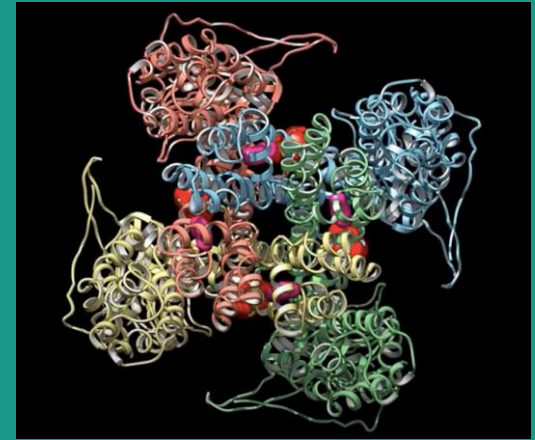
# Timepix Used in Space Dosimetry

Monitors the radiation environment of the station, measures the dose absorbed by the human body
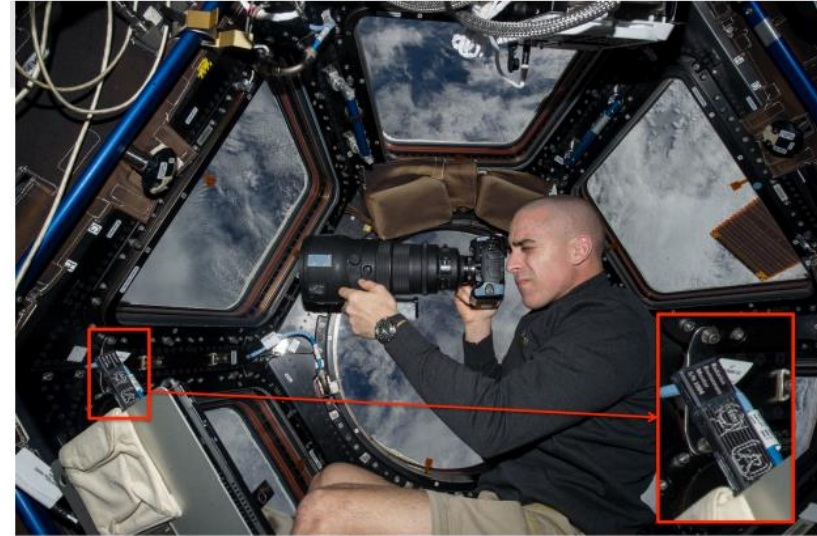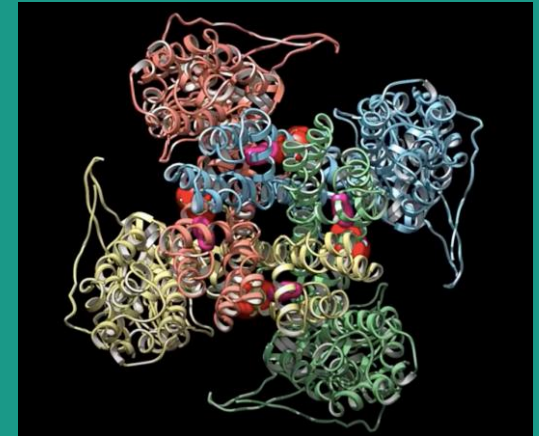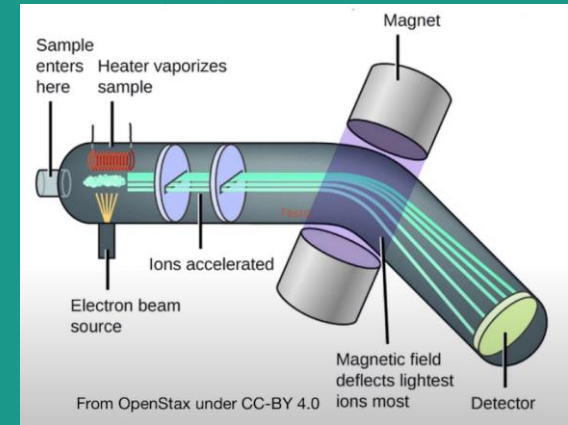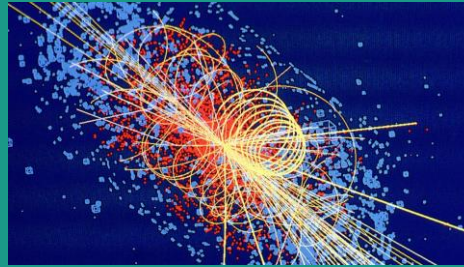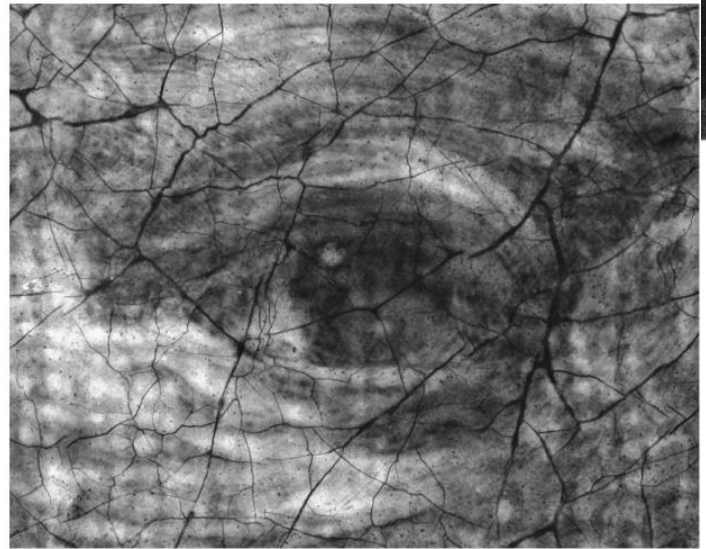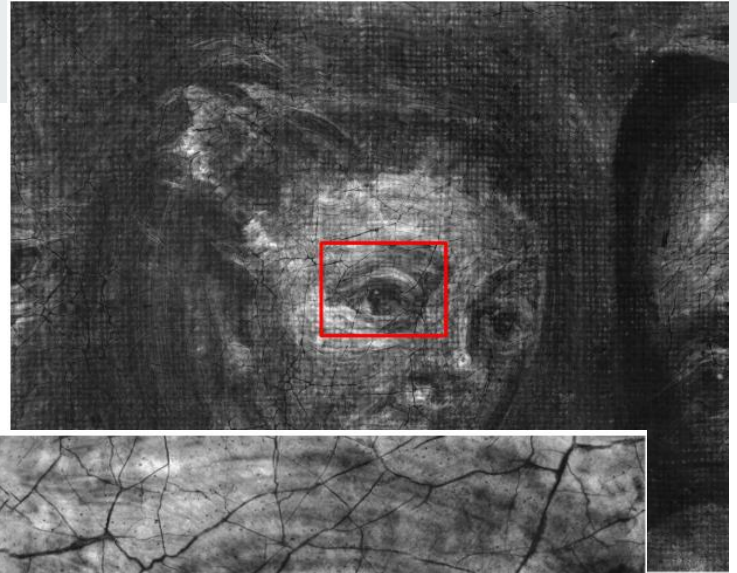
→ ISS and NASA's Orion rocket





Image of the astronaut Chris Cassidy working near the Timepix USB on the International Space Station (Courtesy of NASA, photo ref. no. iss036e006175)

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# Applications

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# Material Analysis in Art

Thank you!