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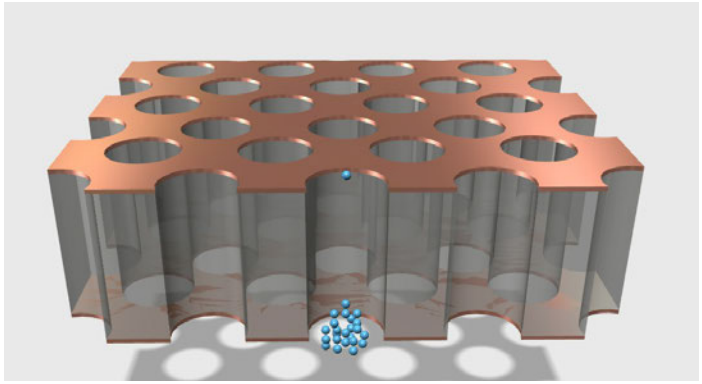

Gas scintillation Glass GEM detector for high-resolution X-ray imaging and CT

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5th International Conference on Micro-Pattern Gas Detectors (MPGD2017)

Summary of this work

1. Developing X-ray imager for low energy X-rays (5 keV ~ 40keV)

- For imaging low Z material
- Deposits small energy to detector

2. Using gas for medium to detect X-rays.

- Large in volume, cost effective
- Low detection efficiency, low spatial resolution

*3. Using **"Glass GEM (gas electron multiplier)"** for electron multiplication.*

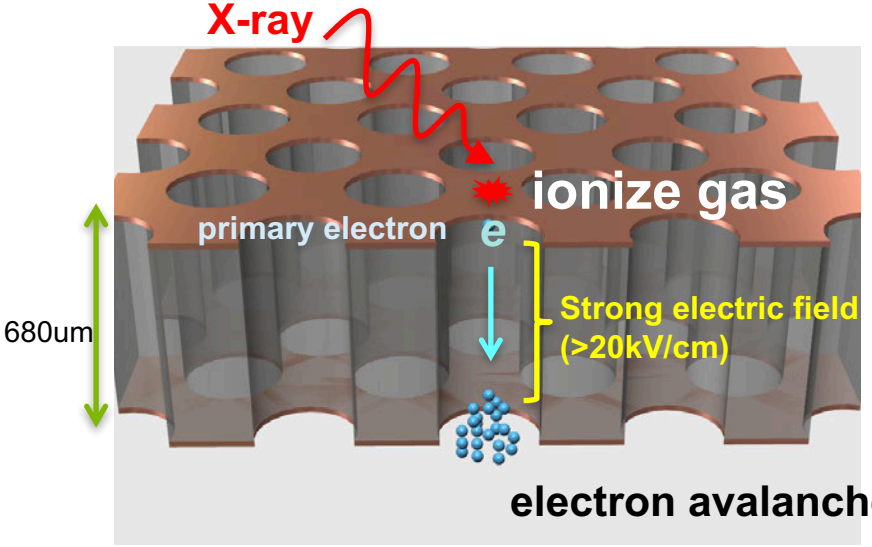
- High gain
- Enables rapid imaging (≈image intensifier, MCP)

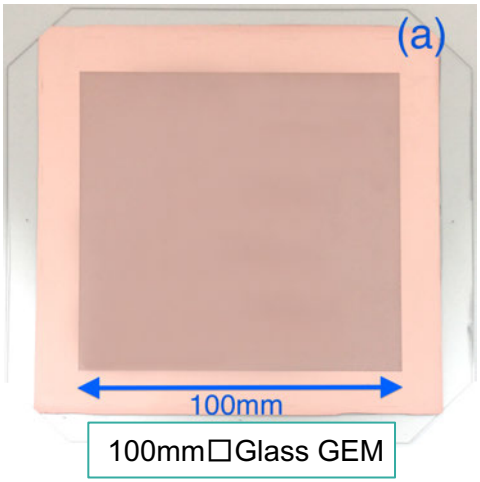
4. Optical readout with scintillating gas.

- Simple and powerful.

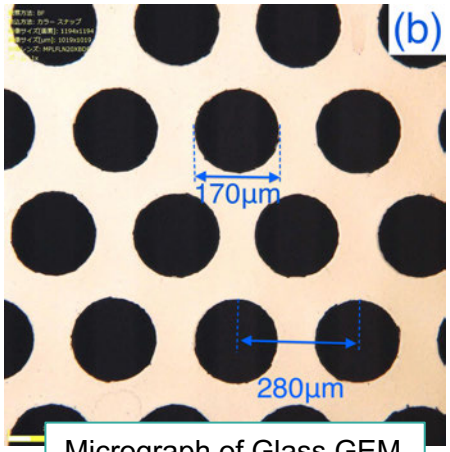
New digital imaging device based on gaseous detector
"Scintillating Glass GEM"

X-ray detection scheme with Glass GEM



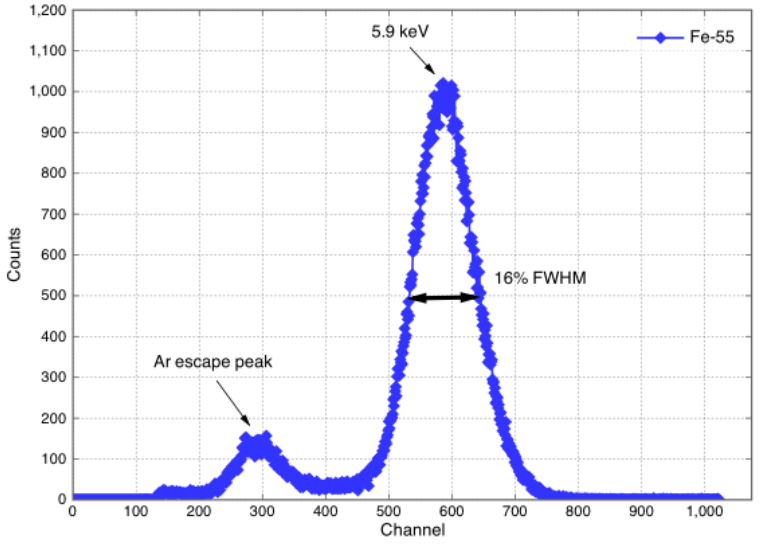


100mm□Glass GEM



Micrograph of Glass GEM

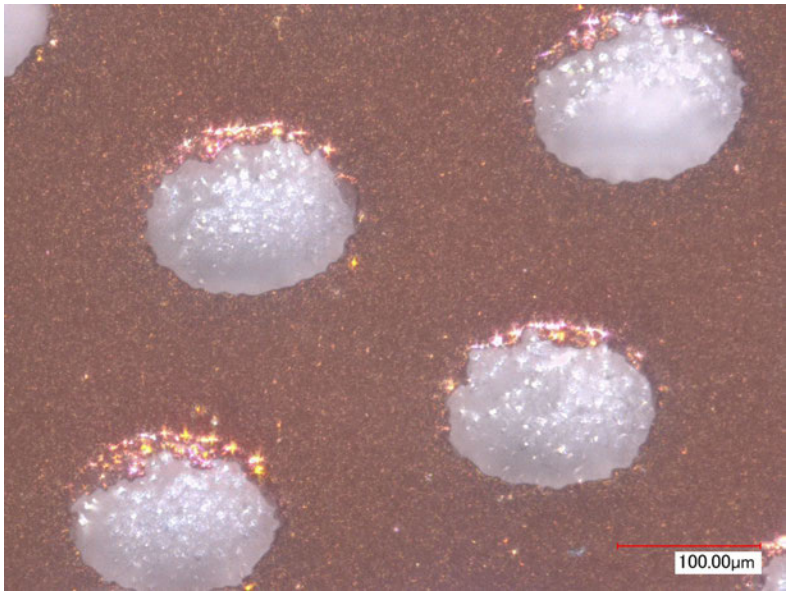
- We fabricated a new type of Gas Electron Multiplier (GEM)[1] with “glass substrate” (Glass GEM)[2]
- Electron multiplication in each tiny holes
- Gas is used for medium to detect X-rays
- Small amount of primary charge are multiplied to 10^3 ~ 10^5
- Able to detect low energy depositing radiation
- Gas is cost effective, uniform, and easy to fabricate large in volume



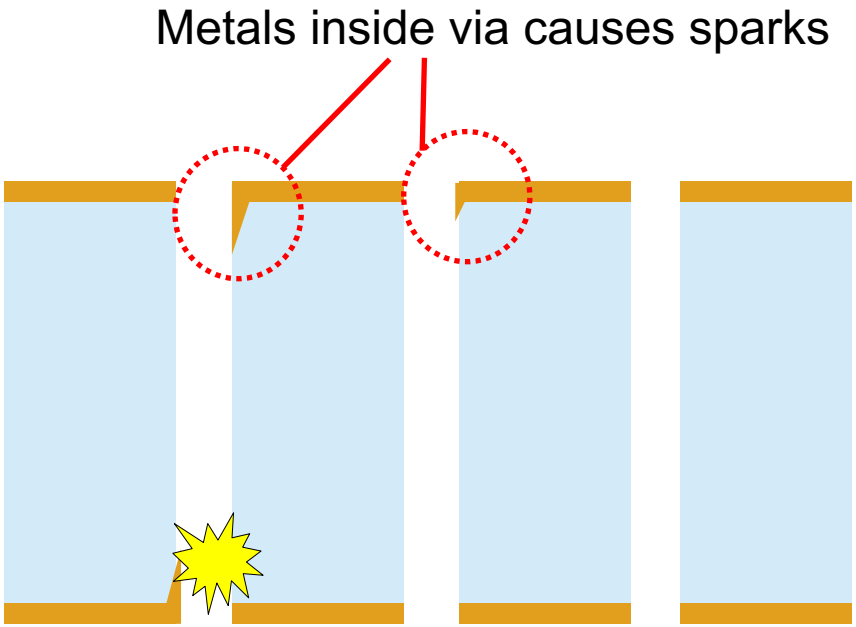
5.9keV Energy spectrum obtained with Glass GEM
Energy resolution was 16% (FWHM) with uniform irradiation (gas gain = 1 × 10^4)[3]

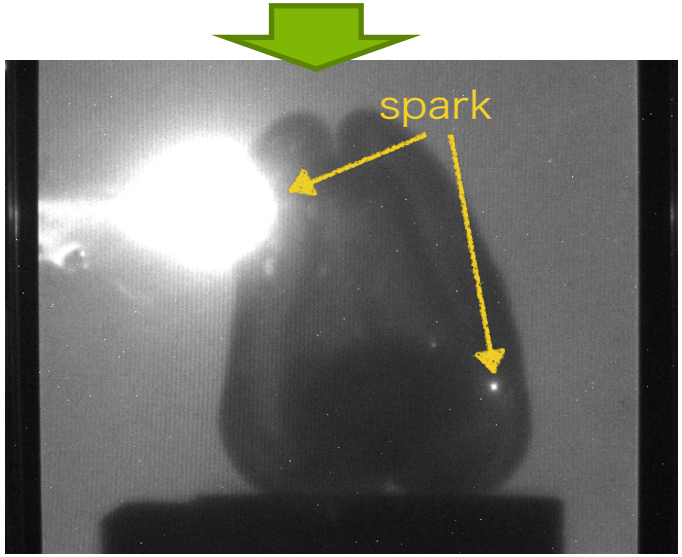
[1] F. Sauli, NIM A, vol. 386, no. 2, pp. 531–534, (1997)
[2] H. Takahashi, et al., NIM A, vol. 724, pp. 1–4, (2013)
[3] T. Fujiwara, et al., JINST, vol. 9, pp. 11007 - 11007, (2014)

Avoid sparks



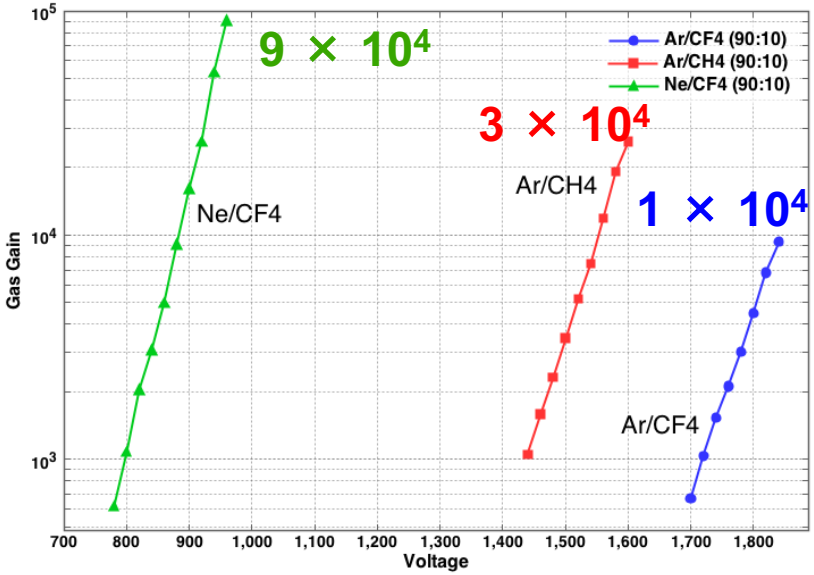
Micrograph of early Glass GEM.





Burnt electrode

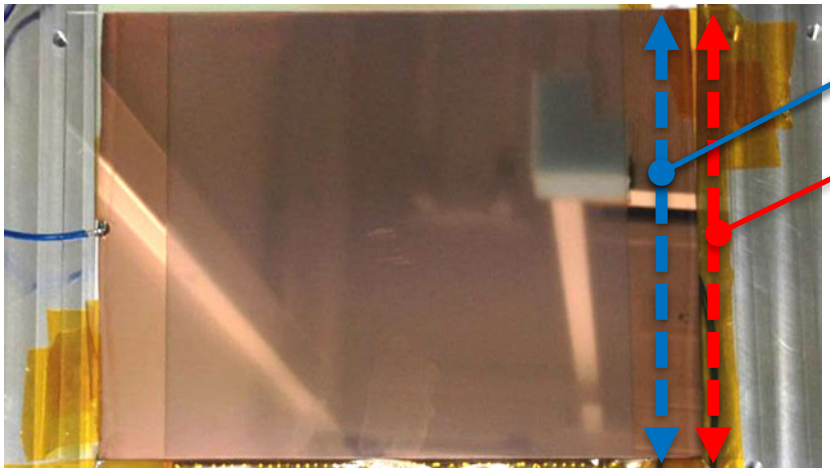
High gas gain of Glass GEM[5]



Gain curve of single Glass GEM

- Succeed in operating Glass GEM in various gas mixtures
- Effective size: 100 * 100mm^2
- **High gain is achievable with single Glass GEM**
  - Gas gain : 3 × 10^4 @Ar/CH_4 (90:10, 1bar)
  - Gas gain : 1 × 10^4 @Ar/CF_4 (90:10, 1bar)
  - Gas gain : 9 × 10^4 @Ne/CF4 (90:10, 1bar)
- Energy resolution: 18% to 23%

Cross-sectional view of single via



Gapless Glass GEM (easily tiled)

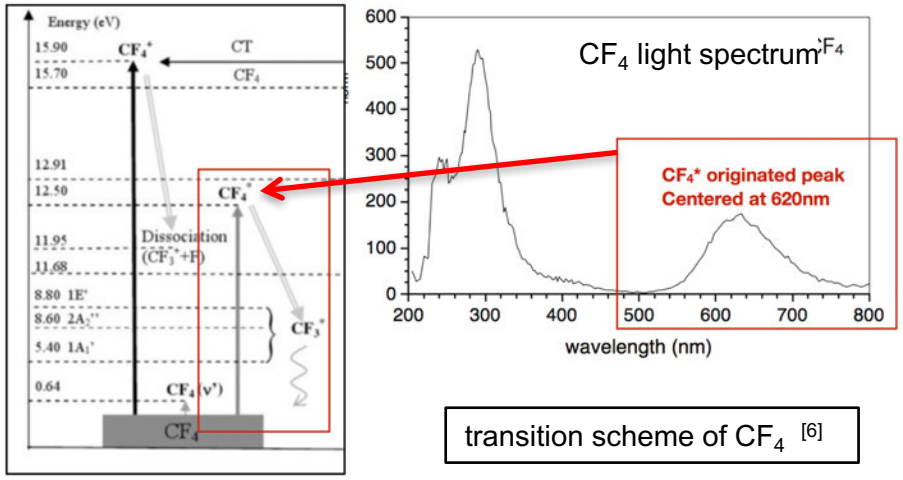
Effective area 100mm

Substrate 101mm

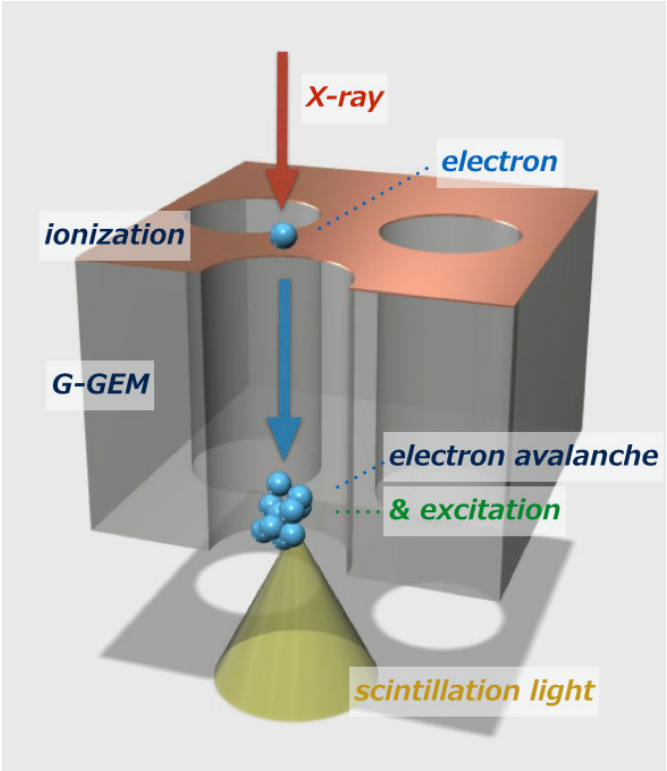
- **high gain** with single GEM
- **rigid assembly (needs no support)**
- minimize charge spread, high spatial resolution
- Cylindrical hole
- Spark tolerance

[5] T. Fujiwara, et al., JINST, vol. 9, pp. 11007 - 11007, Nov. 2014

Scintillation gas with Glass GEM



transition scheme of CF_4 [6]

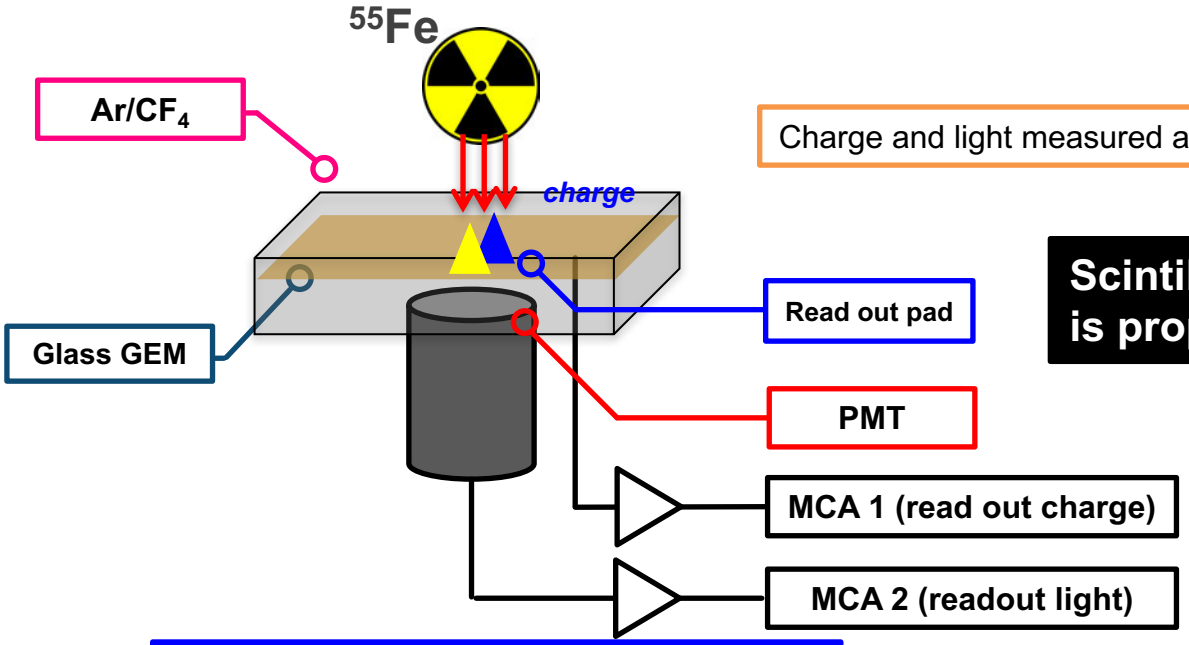


- CF_4 molecules are excited with electron avalanche
- Emits UV and 620nm peak centered visible photons during the dissociation process $CF_4^* \rightarrow CF_3^*$

- **CH_4 and CO_2 are popular gas for quenching gas.**
- **CF_4 is known as a good scintillation gas** *[6] and more (Fraga etc.)*
- **Large amount of scintillation photons would be produced during Glass GEM's high gain avalanche process**
- **Develop a radiation imager with scintillation gas × Glass GEM**

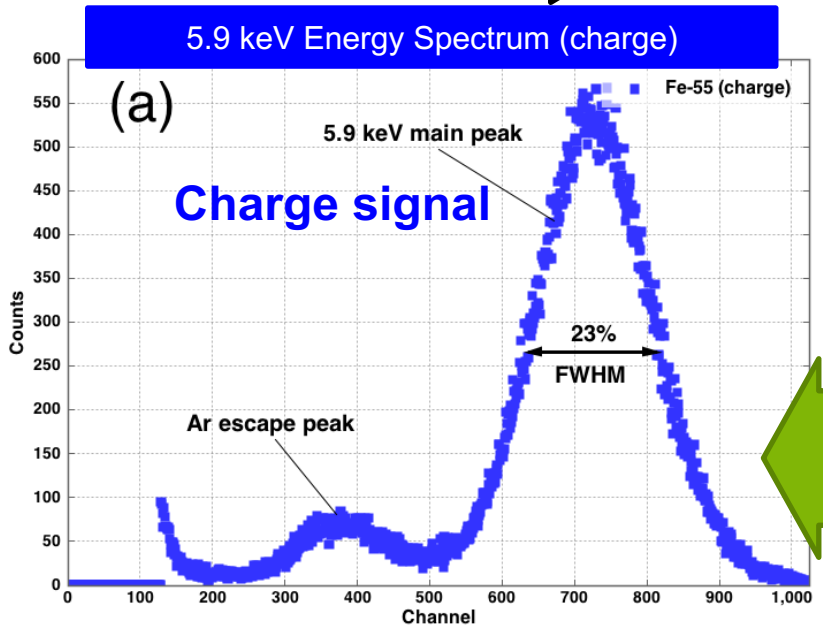
[6] E. Seravalli, Delft University Press (2008)

Initial experiment : ^{55}Fe (5.9keV X-rays) & PMT[7]

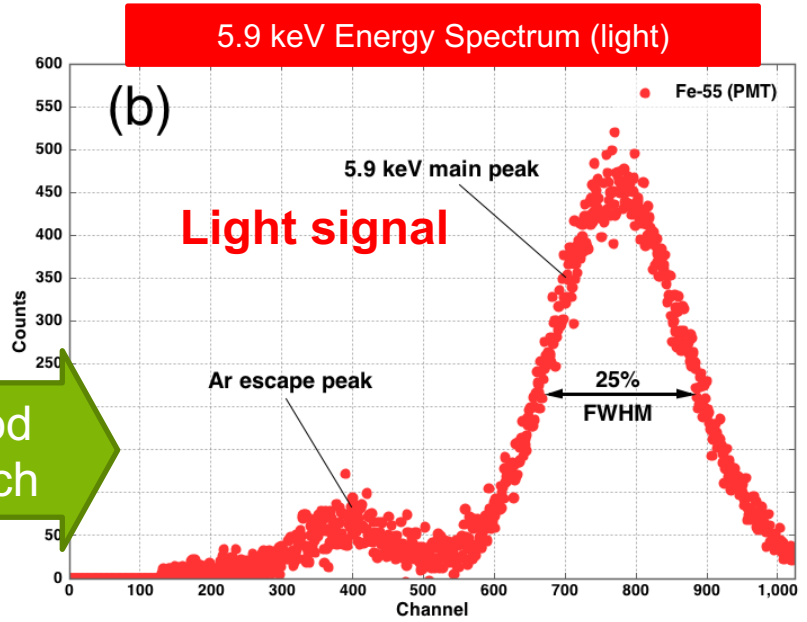


Charge and light measured at same time

Scintillation light from Glass GEM is proportional to charge

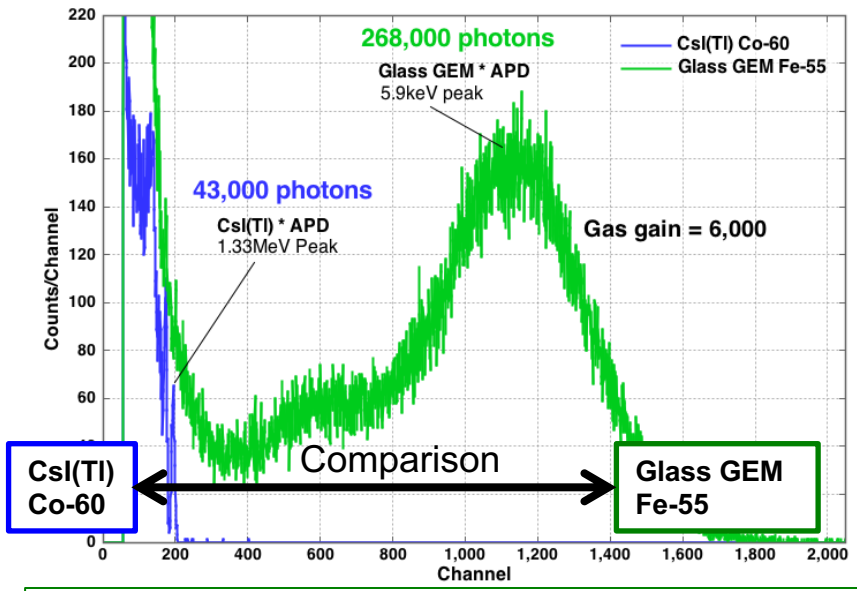


Good match



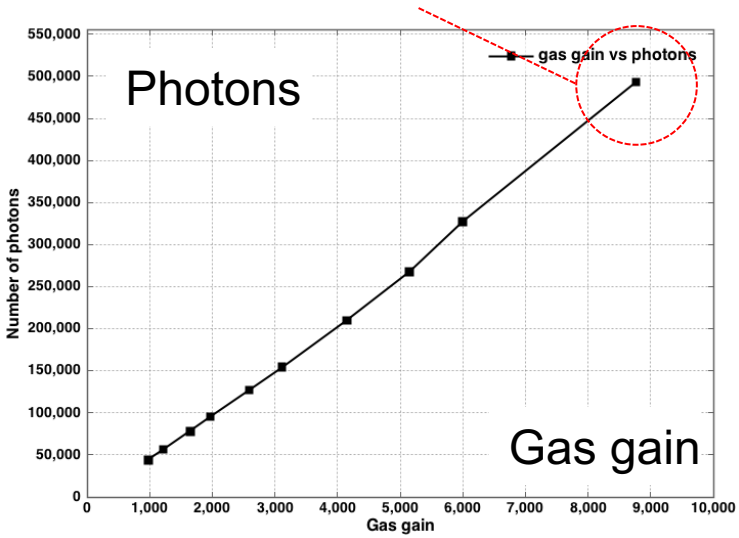
[7] T. Fujiwara, et al.,Jpn. J. Appl. Phys., vol. 55, no. 10 (2016)

How bright is it?[7]



Comparison with calibrated CsI(Tl) (energy spectrum with APD)*

Max: 500,000 photons @5.9keV



Photons vs gas gain

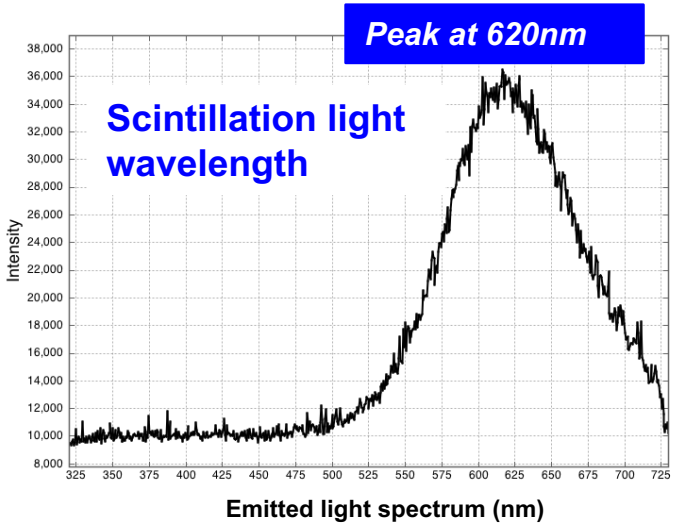


Table 1. Comparison with inorganic scintillators

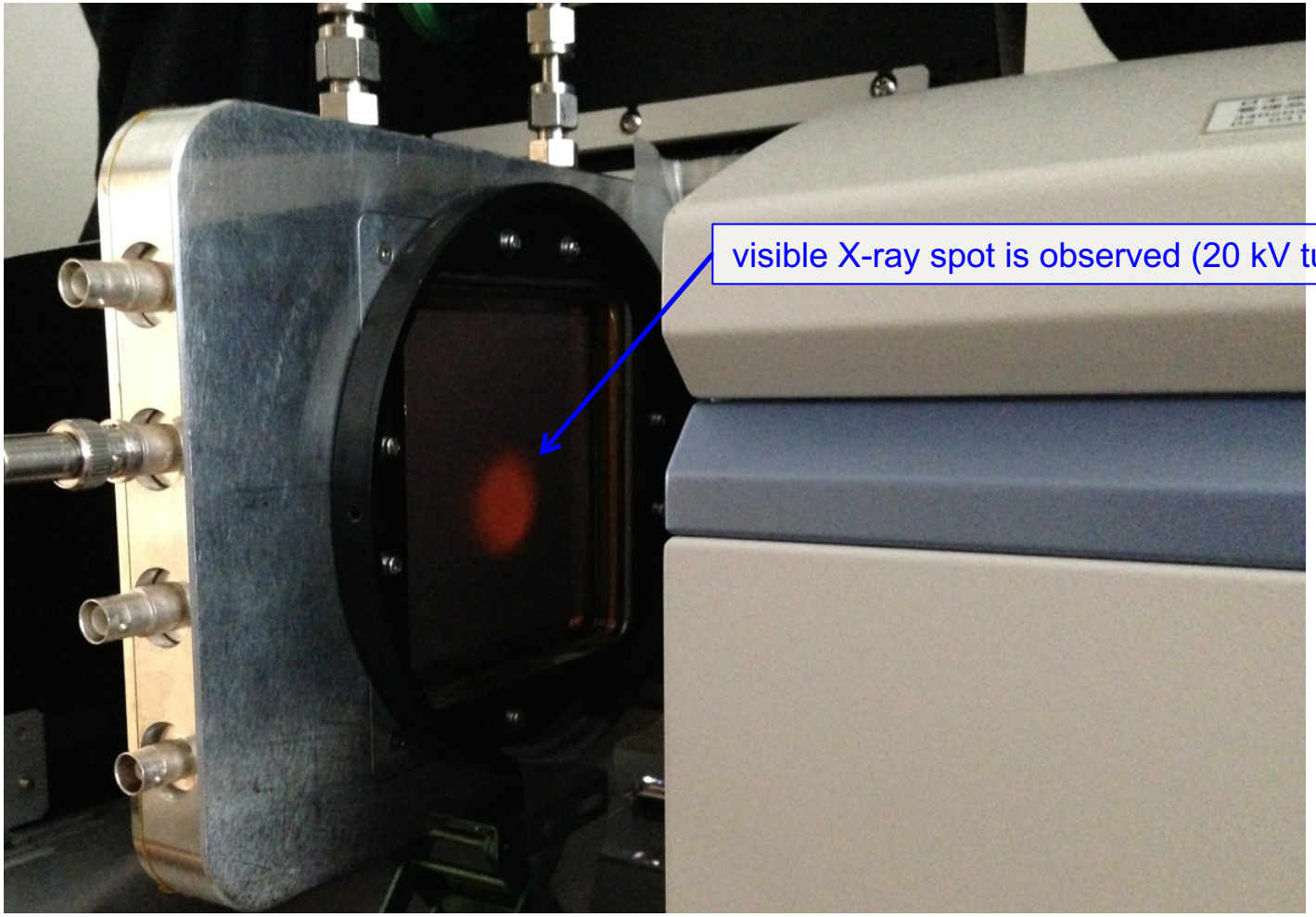
Scintillator	Photons
CsI(Tl)	59,000 ph/MeV
NaI(Tl)	38,000 ph/MeV
SrI	115,000 ph/MeV
Glass GEM + Ar/CF_4	**85,000 ph/keV**

Ultra high yield (orders of three)

high photon yield with low energy depositing radiation

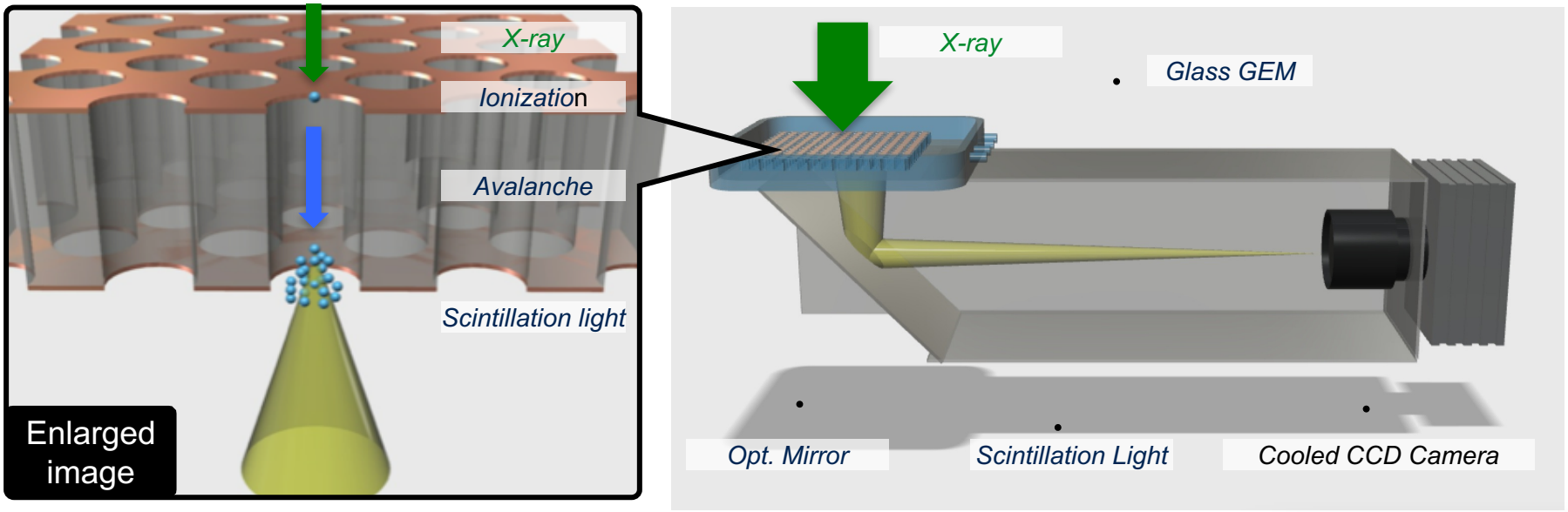
[7] T. Fujiwara, et al.,Jpn. J. Appl. Phys., vol. 55, no. 10 (2016)

How bright is it?

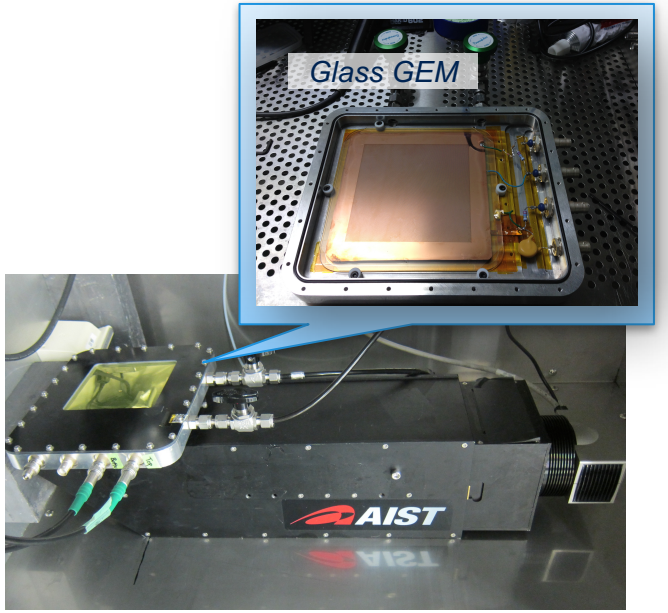


Looking from backside of chamber

The detector design[8]

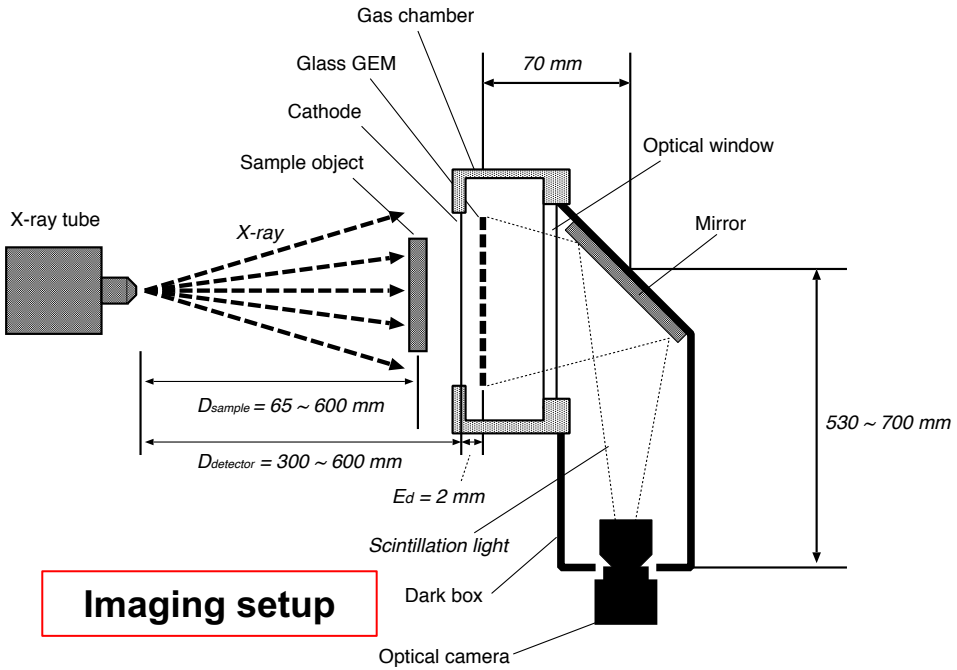


- Glass GEM × scintillation gas × mirror × optical camera
- Convert radiation into visible light
- Optical mirror to prevent the CCD from irradiated directly with X-rays
- ITO coated transparent electrode were used as an anode & optical window



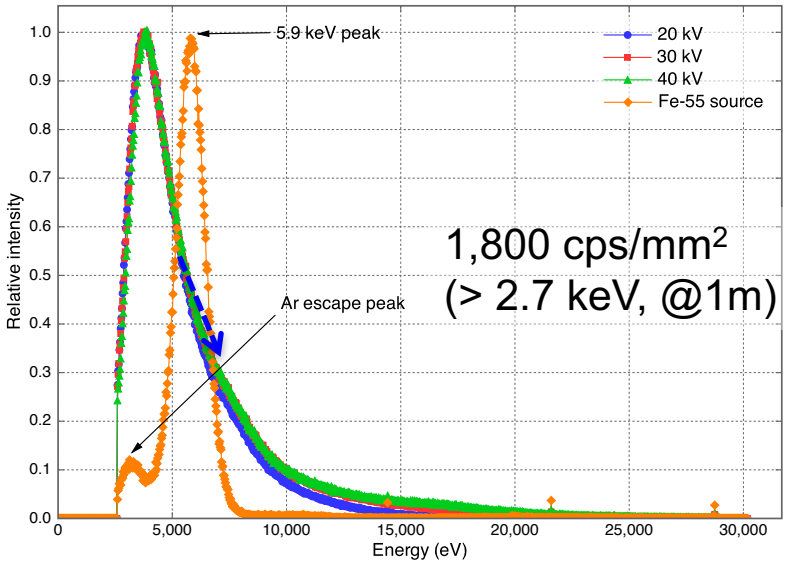
[8] T. Fujiwara, et al., JINST, Vol. 8, No. 7 (2013)
[9] T. Fujiwara, et al., NIM A, 850 (2017)

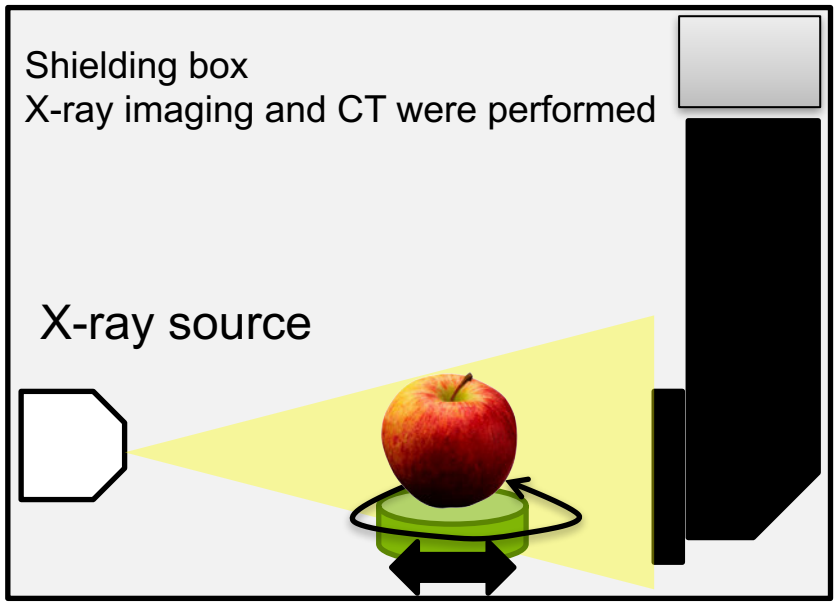
Imaging setup & result



Imaging setup

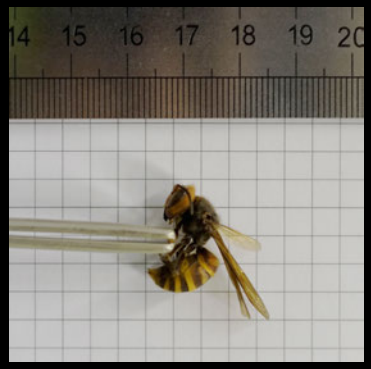
Detected energy spectrum



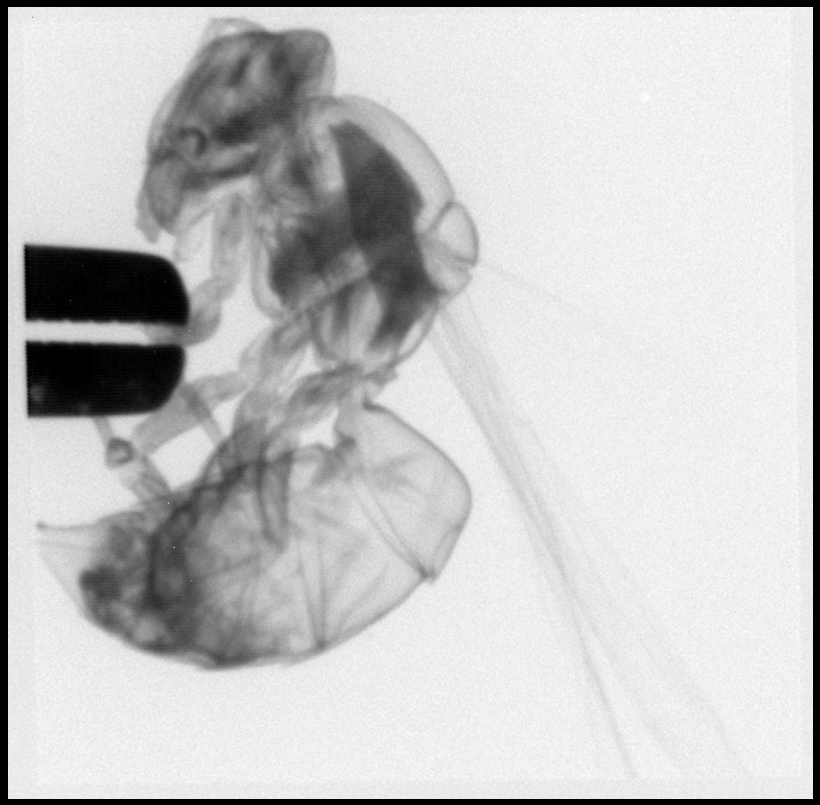


Gas multiplier	**Glass GEM (phi=180 um hole, 280 um pitch, 680 um thick)**
Scintillation Gas	**Ar/CF_4 (90:10)**
Sensitive area	**100 × 100 mm**
Camera	**Cooled CCD Camera BITRAN BU-52LN 16bit 4M pixels**
Lens	**Nikon 50mm F1.4**
X-ray source	**Micro-focus X-ray tube Hamamatsu L9631 20~30 kV 450uA**

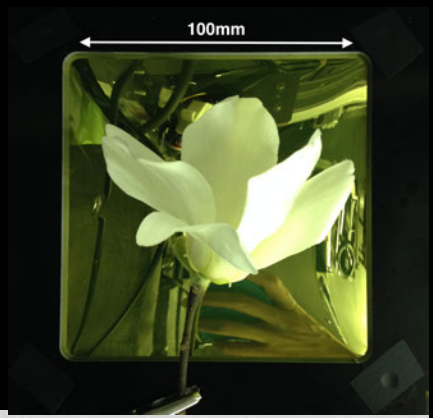
Imaging performance of Glass GEM



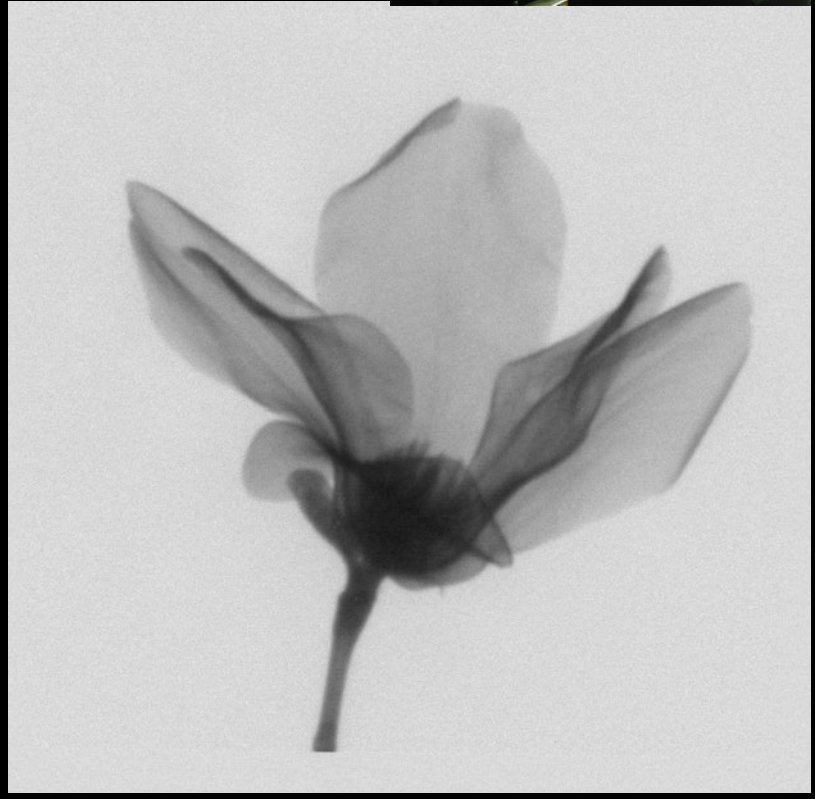
100 × 100 mm



Bee (×3 enlarging)



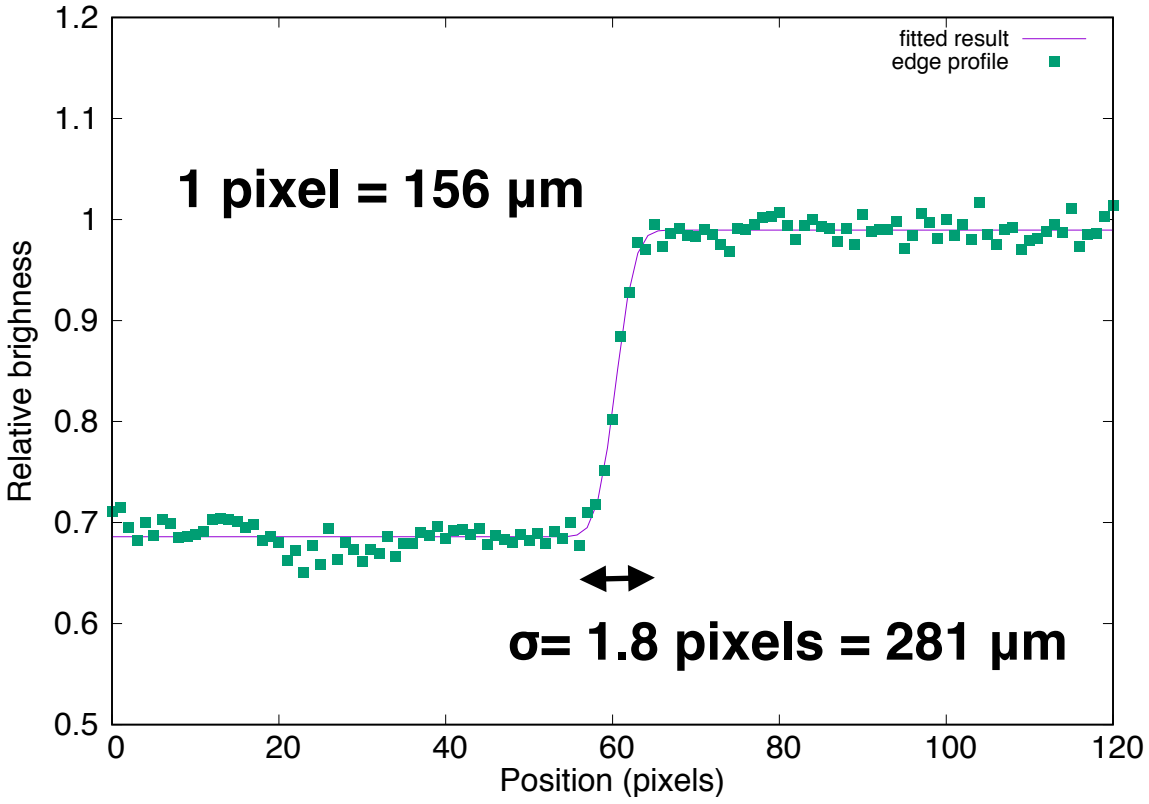
100 × 100 mm

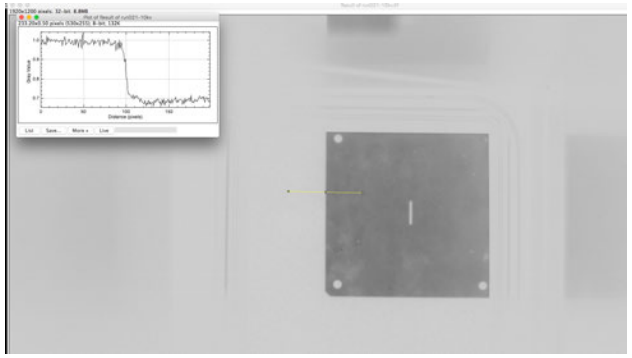


Flower (without enlarging)

[9] T. Fujiwara, et al., NIM A, 850 (2017)

Spatial resolution





Spatial resolution: 281 um (rms)

Fitting with error function

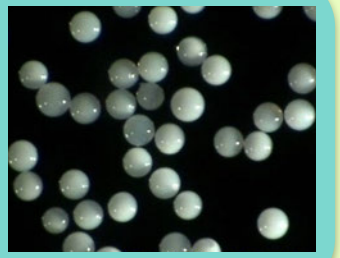
$$a \cdot erf\left(\frac{x-\mu}{\sqrt{2}\sigma}\right) + c$$

Spatial resolution evaluation
Edge of aluminum plate imaging with X-ray tube : 20 kV)
Analyzed with *ImageJ*

3D CT of medicine tablet

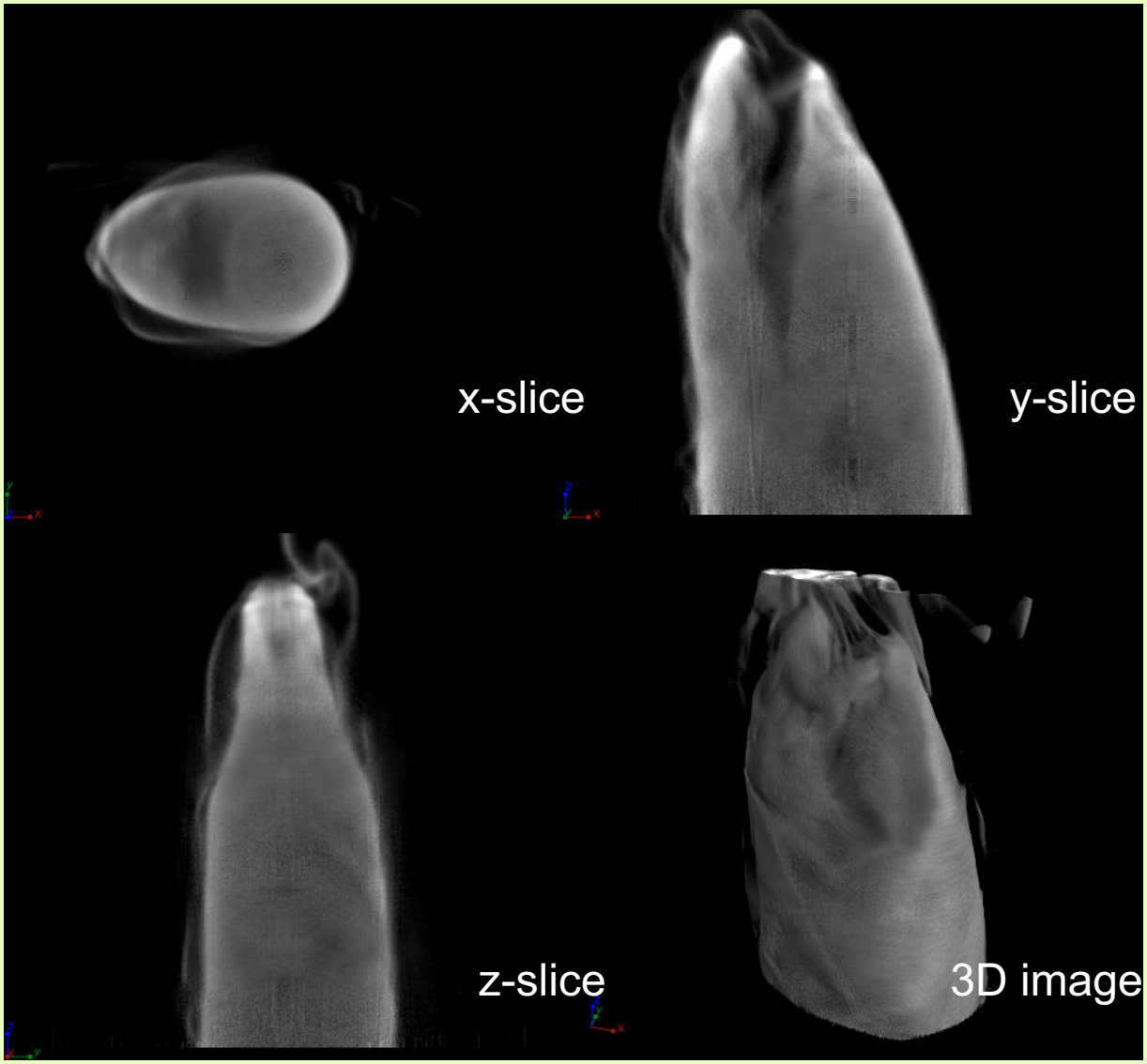
Micro-sphere medicine tablet

Micro-spheres medicine inside the medtab



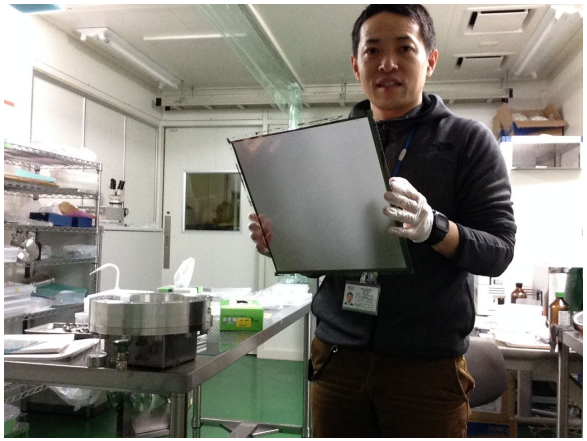
Using 20kV micro-focus X-ray source
Taken in 30 minutes. (360° scan, 0.5 pitch°)
Reconstructed with filtered-back-projection algorithm
High contrast achieved with low Z number materials

3D CT of fish head

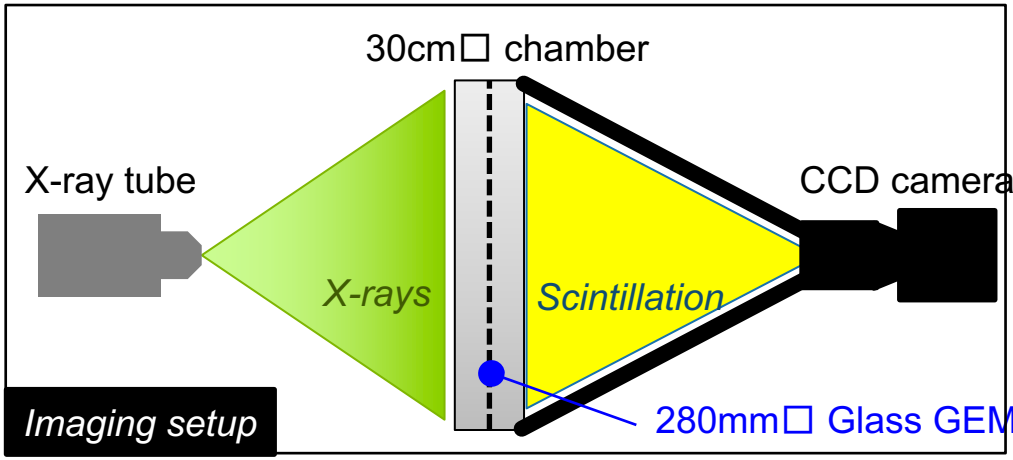


Large area: 280mm□ Glass GEM

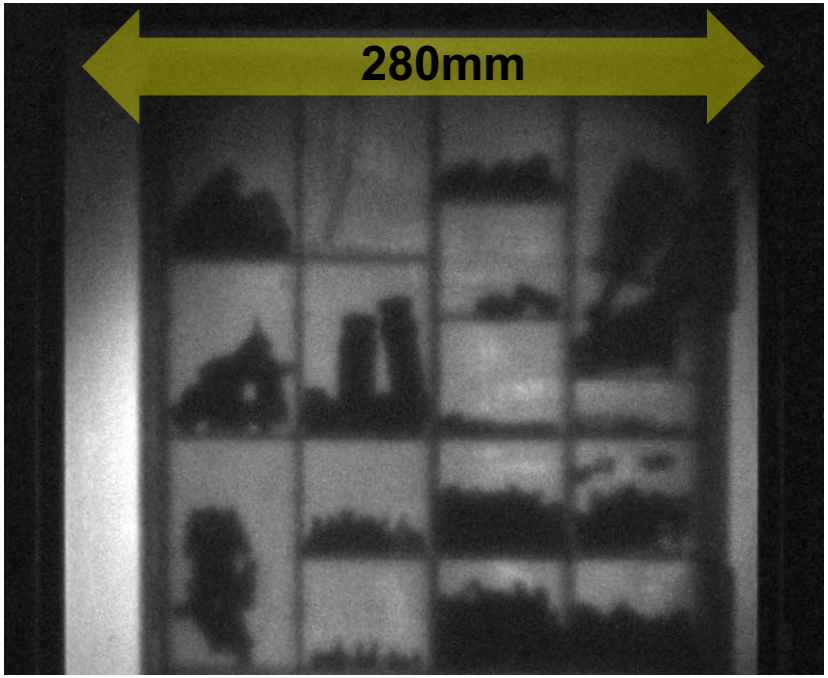
preliminary



300mm□ Glass GEM (1,154,423 holes)



Toolbox



X-ray transmission image of a toolbox

Imaging with Kr/CF4 gas filling

Preliminary

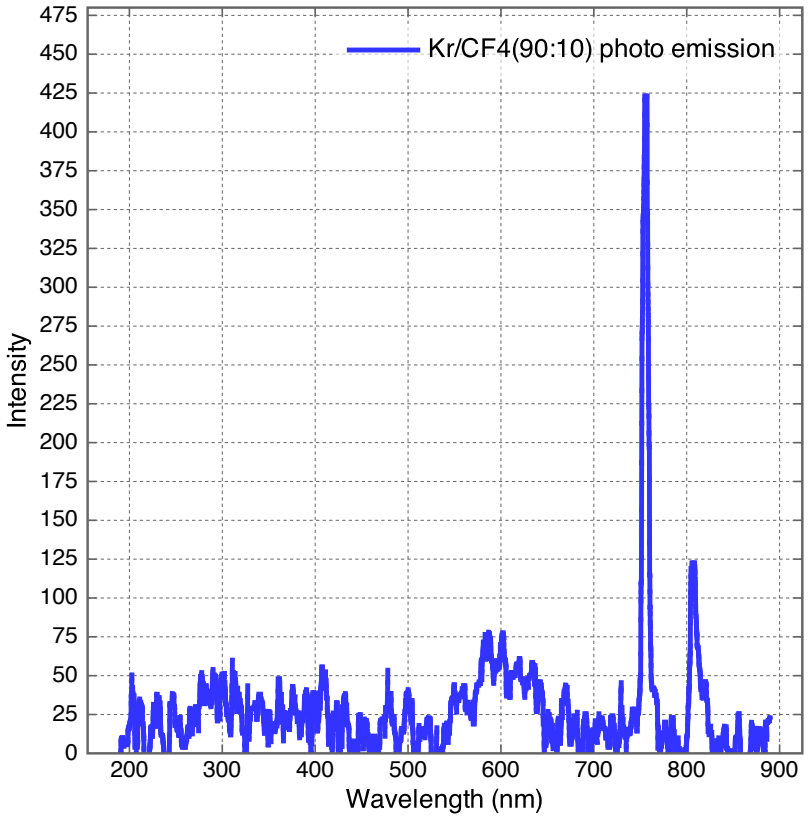
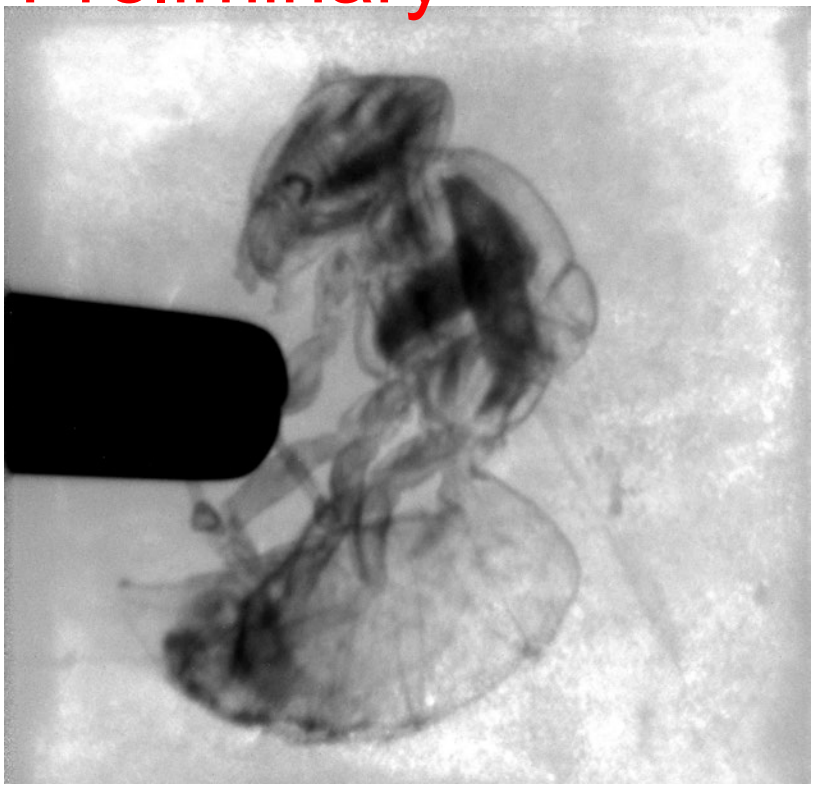


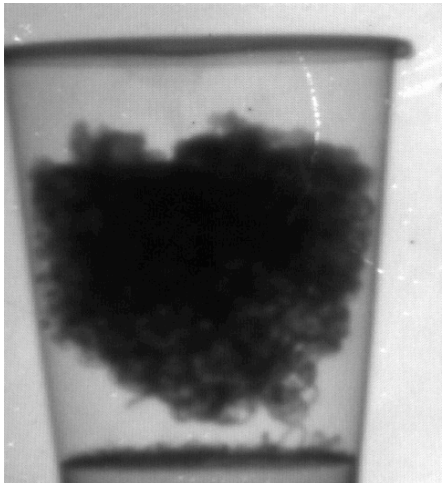
Photo emission spectrum of Kr/CF4 gas filled Glass GEM



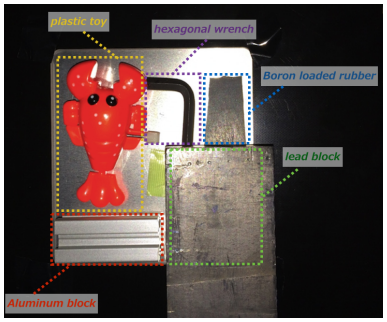
Radiograph taken with 40 kV, 200 uA x-ray tube

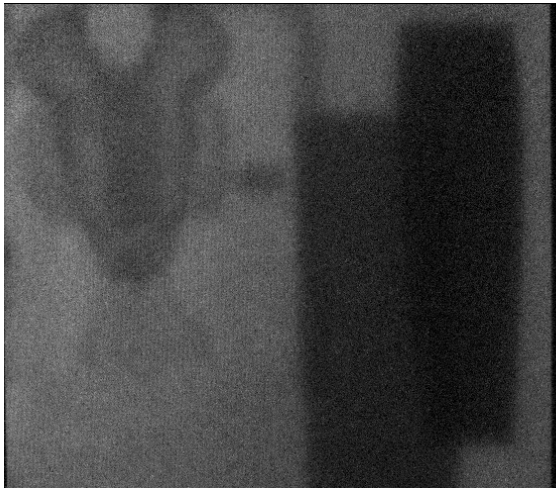
- Photons emitted from Kr/CF4 is much less than Ar/CF4.
- Spatial resolution did not significantly improved.
- Strange pattern appeared around the sample.

Succeed in taking radiograph with various radiation

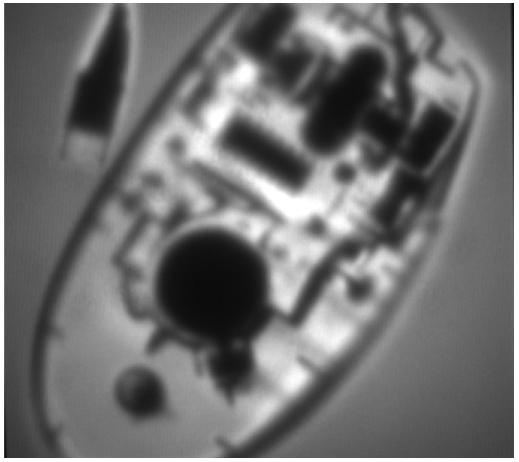


X-rays

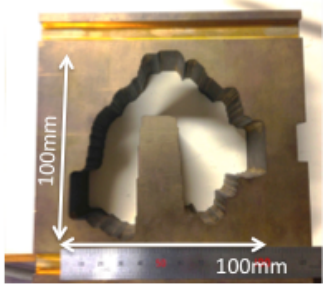




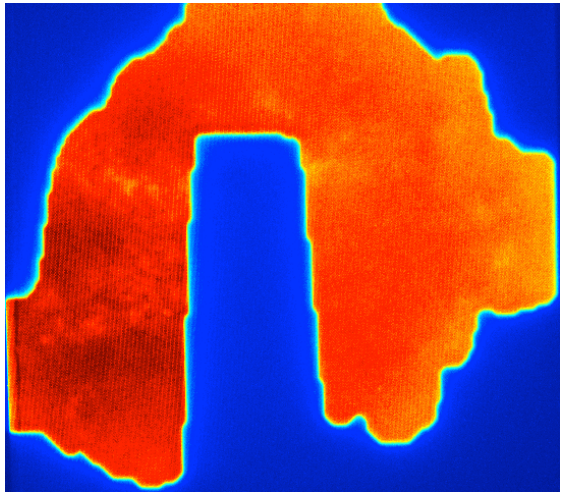
Neutrons[9]
(Coupling with B-10 foil)



80MeV
proton beam



290 MeV
Clinical
Carbon beam



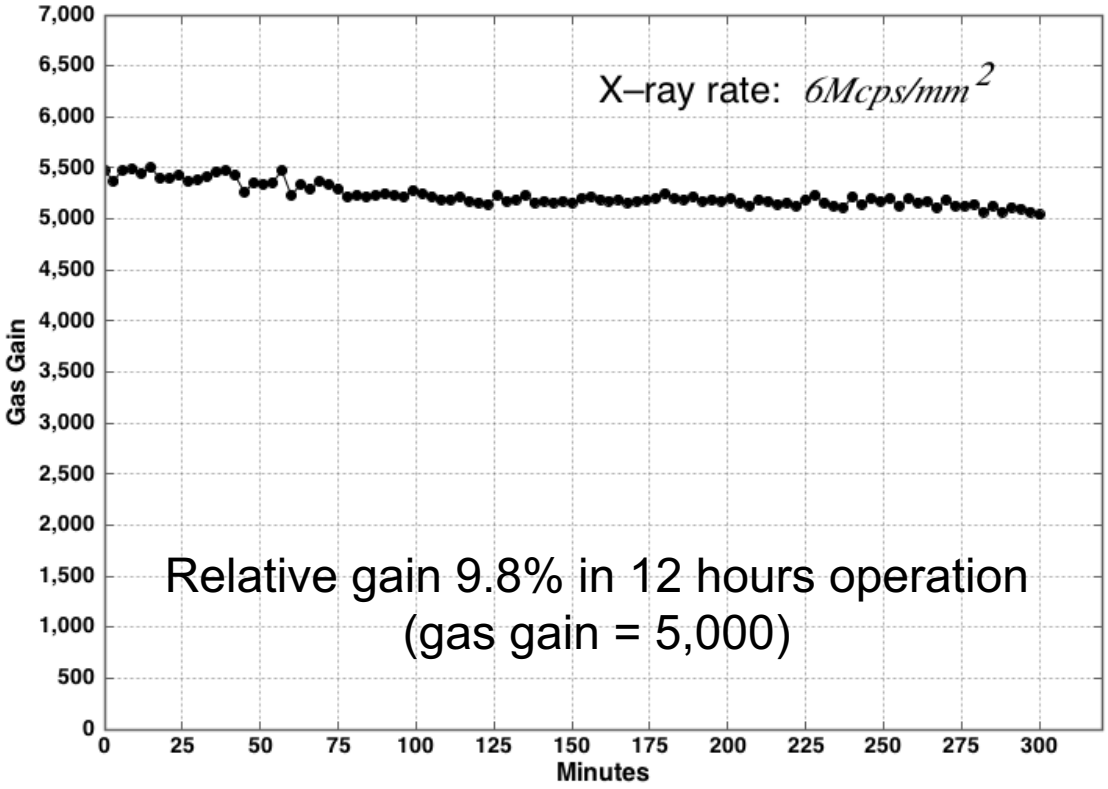
[9] T. Fujiwara , et al., NIM A, vol. 838,(2016)

Summary

- X-ray imaging and X-ray CT were performed with ***"Scintillating Glass GEM"***
- **85,000 photons (per keV)** (ex. CsI:Tl = 59,000 ph/MeV)
- **Ultra high yield photons enables rapid imaging with low energy depositing X-rays**
  - **High speed imaging and high contrast with low Z materials**
  - **May results to minimize the dose for medical imaging**
- 280mm□ Glass GEM imager is now being developed
- Glass GEM can also be used for imager for neutron and proton/carbon beam therapy.

Thank you for your kind attention.

Gain stability in high intensity X-ray source



Tested in synchrotron radiation (6 Mcps/mm²)

Low volume resistivity of the substrate enables stable operation in high count rate.
(<u>no charge-ups</u>)

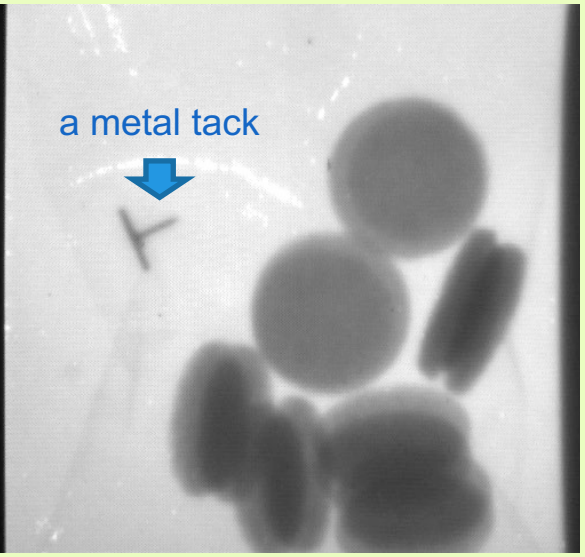
Item	**PEG3**	**Polyimide**	**Glass**
Volume resistivity (*W cm*)	8.5 x 10^{12}	~10^{18}	~$10^{15\sim20}$

X-ray image of earphone

40kV Micro-focus X-ray tube

X-ray images with Scintillating Glass GEM

20kV:Oreos

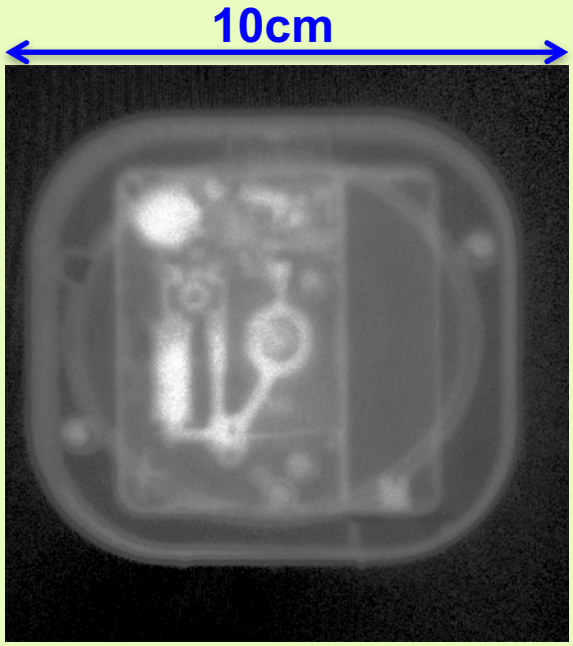


20kV: noodle

X-ray transmission image

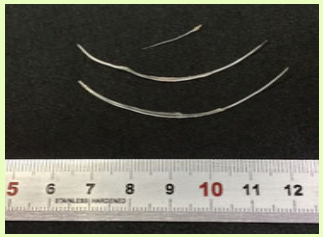
Non-destructive inspection

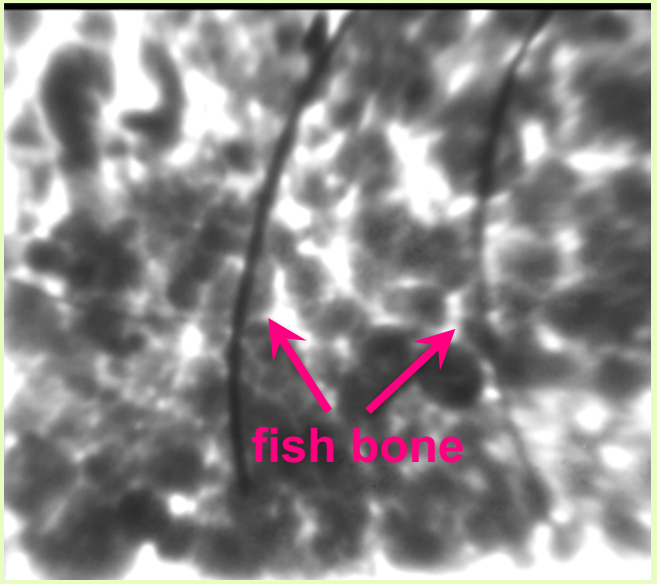
clock@30kV



X-ray transmission image of a clock

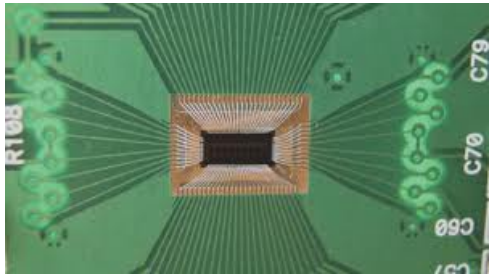
Food inspection





Inspecting fish bones

Scintillating GlassGEM × Optical camera



ASIC

Needs 40000 channels of amps and ADCs to readout 100mm × 100mm effective area in 0.5 mm spatial resolution.

Creating thousands of feed-throughs to a chamber is an issue.

- Development of optical camera is rapid
- CMOS technology is not suitable for large size
- Optical lens would be a solution

2003

Sensor: 22.7 × 15.1mm APS-C CMOS Sensor
Pixels: 6.5M
ISO:100～1600

Higher sensitivity
More pixels
Low pirce

2014

Sensor：36.1 × 24.1mm full size CMOS
Pixels: 12M
ISO：50～**409600**