



Development of μ -PIC with glass substrate aiming at high gas gain

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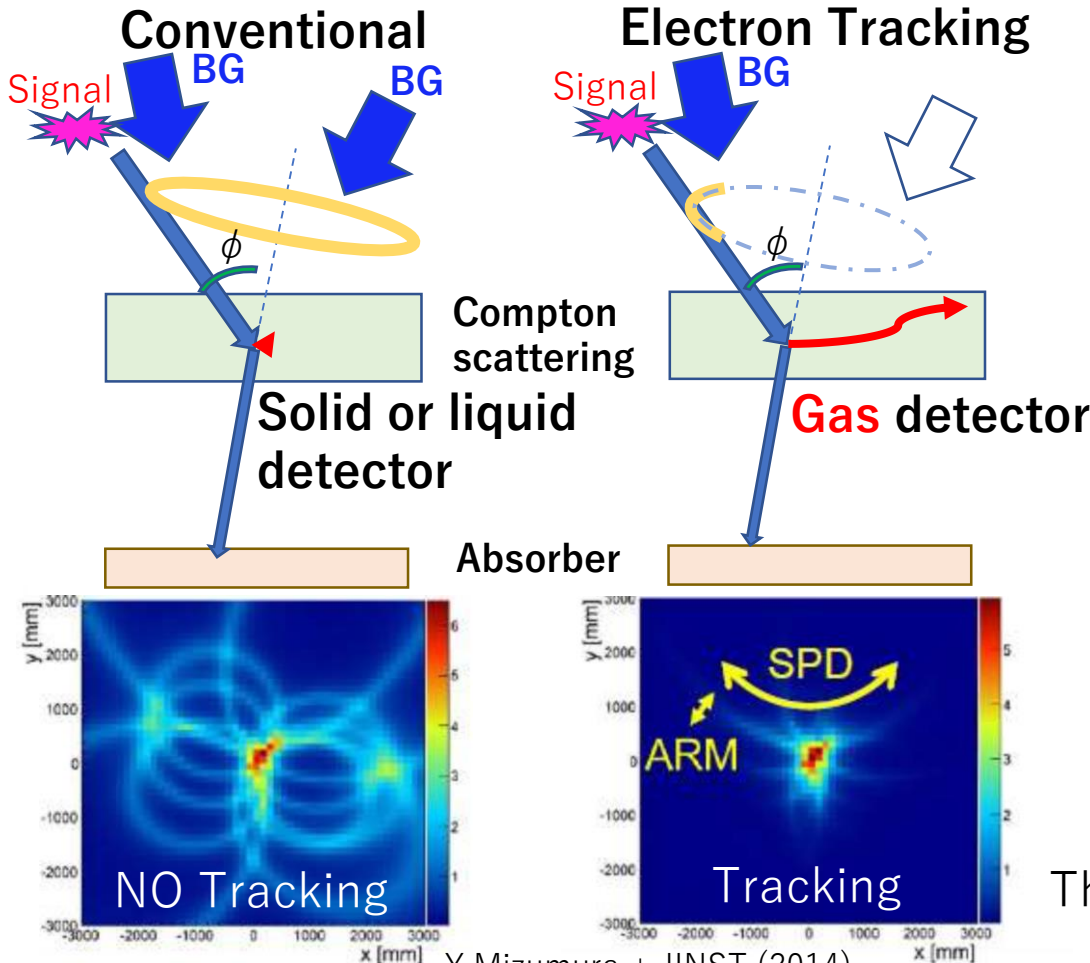
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MeV γ ray telescope

Directly investigate the existence and generation of RIs in the universe

Electron-Tracking Compton Camera (ETCC)



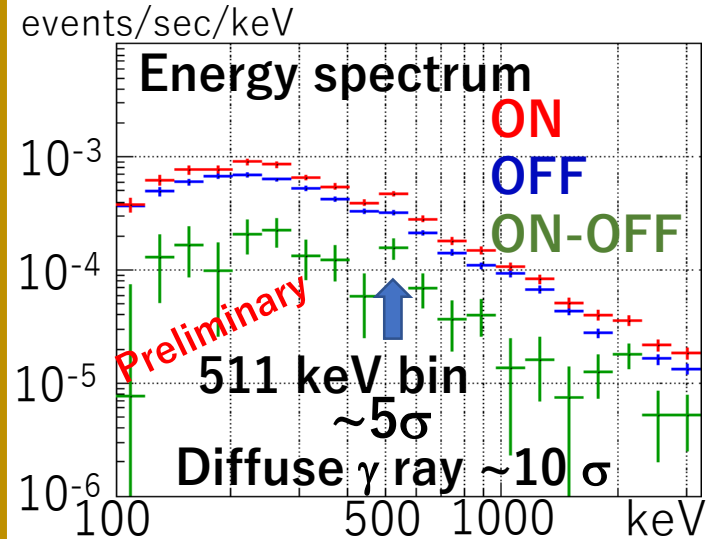
2019/5/6

MPGD2019 La Rochelle, France

Balloon experiment in 4/2018



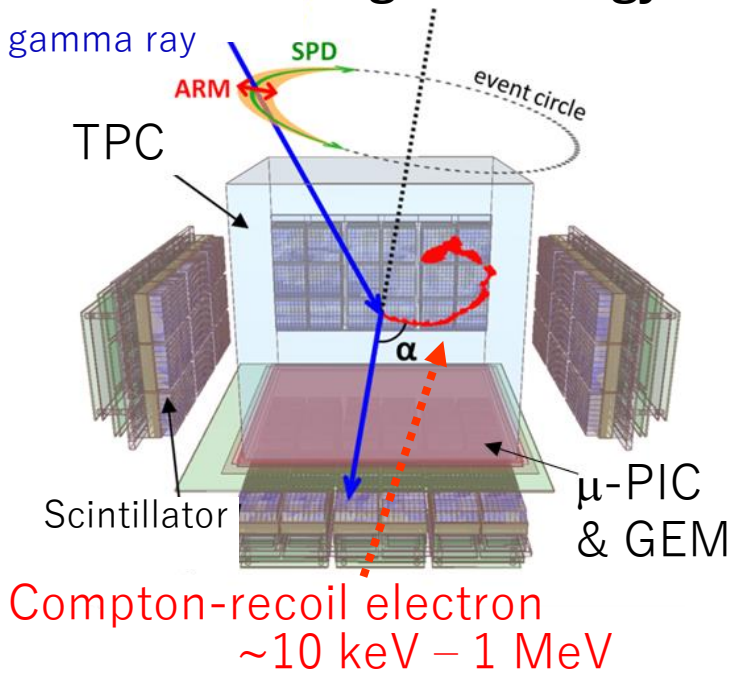
Galactic diffuse & 511 keV



The superiority of the ETCC method is proven in space

μ -PIC

Requirements from ETCC :
3D tracking low energy e^-

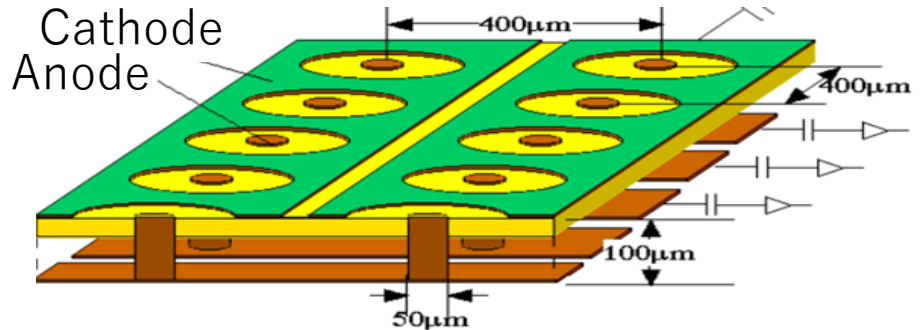


short track (~cm)
↑
sub mm sampling

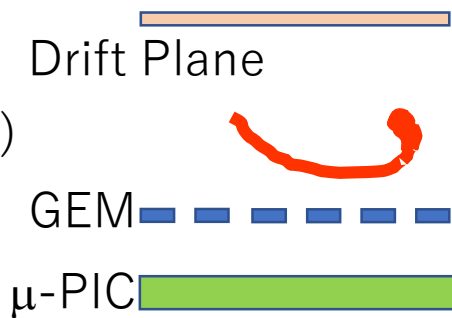
MIP-like
↑
To detect,
gain of ~15,000
(Ar based gas, 1atm)

Feature of μ -PIC

- ✓ A gaseous 2D imaging detector with strip read out
- ✓ **Manufactured with printed circuit board (PCB) technology**
- ✓ Each pixel is place with a pitch of $400 \mu\text{m}$
- ✓ Fine position resolution (RMS - $120 \mu\text{m}$)
- ✓ Large detection area : $10 \times 10, 30 \times 30 \text{ cm}^2$
- ✓ Gas gain : $\sim 15,000$ (MAX, a moment)
 $\sim 6,000$ (stable, 1month)

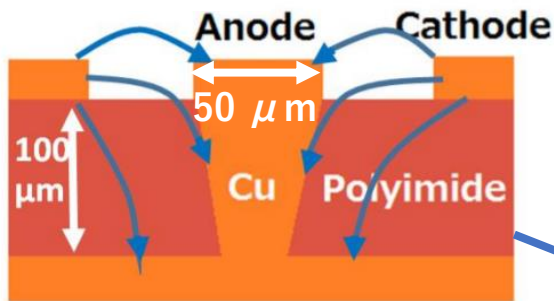


We temporary adopt
 μ -PIC+GEM
(Gain_{GEM} < 10)
↓
Only μ -PIC

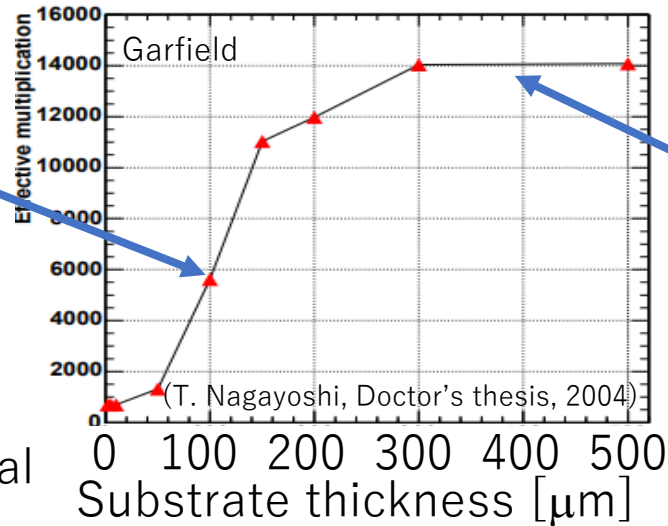


The more thickness, the more gain

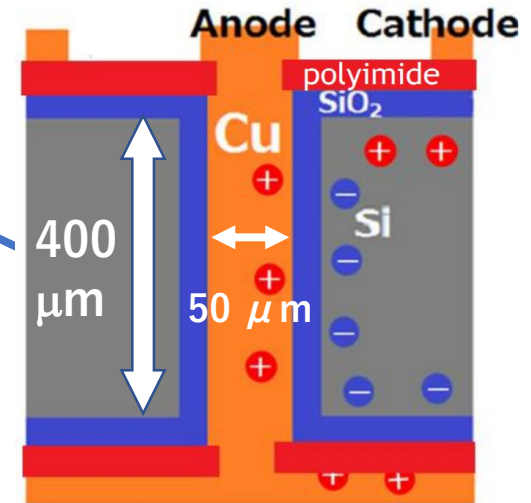
PCB(Printed Circuit Board) μ -PIC



Gain VS Substrate thickness



TSV(Through Silicon Via) μ -PIC



(T. Takemura et al, 2018)

Anode aspect ratio
(Thickness/Anode ϕ)
is limited by PCB technical
restrictions.

Up to $\sim 300 \mu\text{m}$,
Thickness \uparrow , Gas gain \uparrow

we focus on a glass substrate

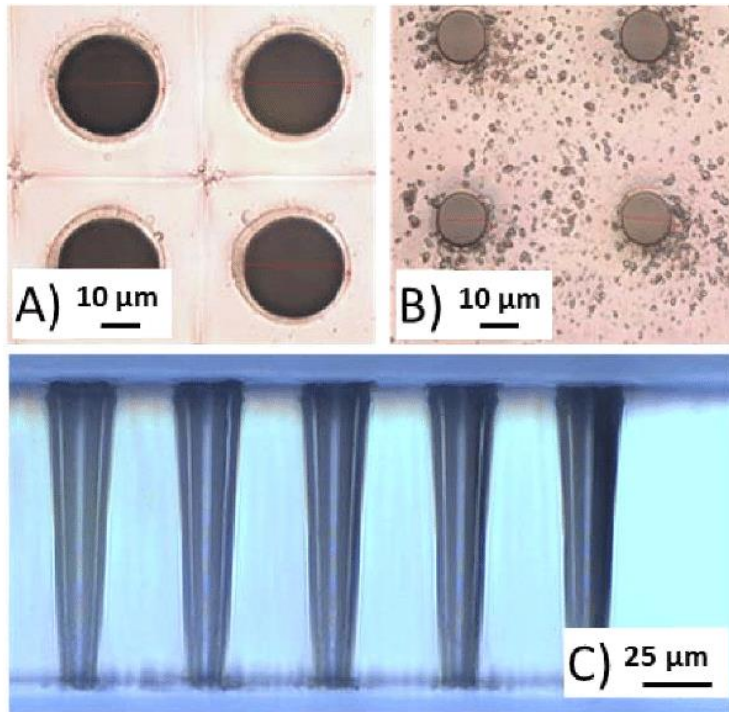
- ✓ Insulator
- ✓ Inorganic
- ✓ capable of forming **high aspect ratio** anode via

but TSV operation had
instability

- charge transfer inside
the silicon substrate.
- Thickness of SiO_2 film
on side of anode via

TGV μ -PIC

Through **G**lass **V**ia



- ✓ Able to form **high aspect** ratio via
- ✓ Good **accuracy** ($\sim\mu$ m) thanks to MEMS processing technologies
- ✓ (Potentially) Having a **scalability**

(R. Delmdahl & R. Paetzel, "Laser Drilling of High-Density Through Glass Vias (TGVs) for 2.5D and 3D Packaging", 2014)

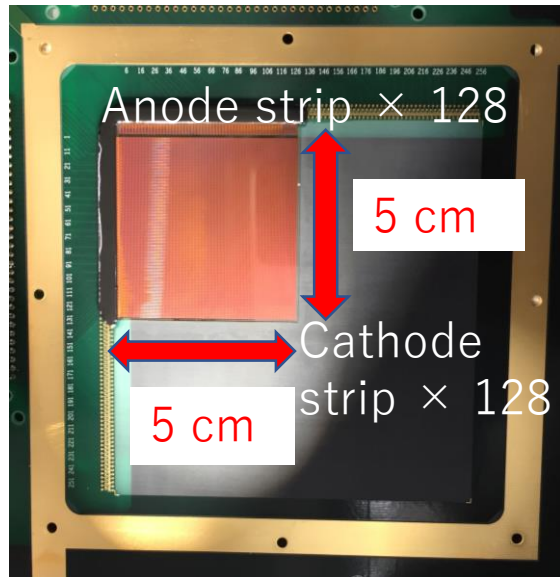
✘ Not a train



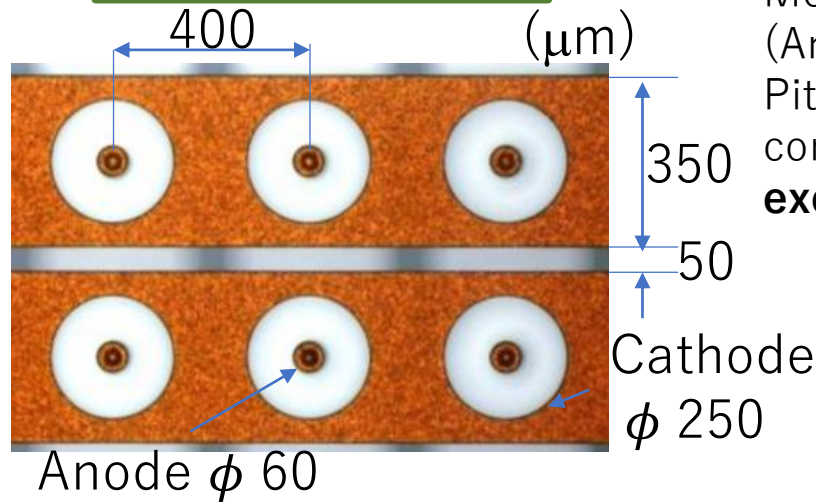
Train à Grande Vitesse

First prototype TGV μ -PIC

- Developed with DNP (Dai Nippon Printing Co., Ltd.)

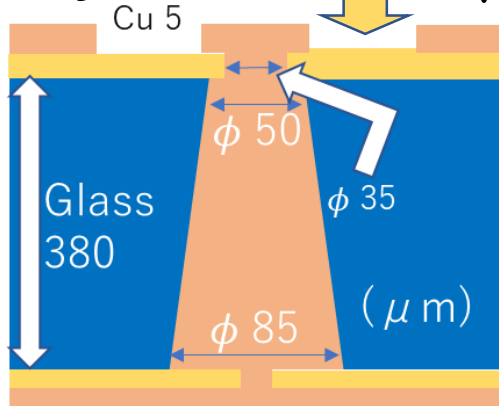


Microscope image



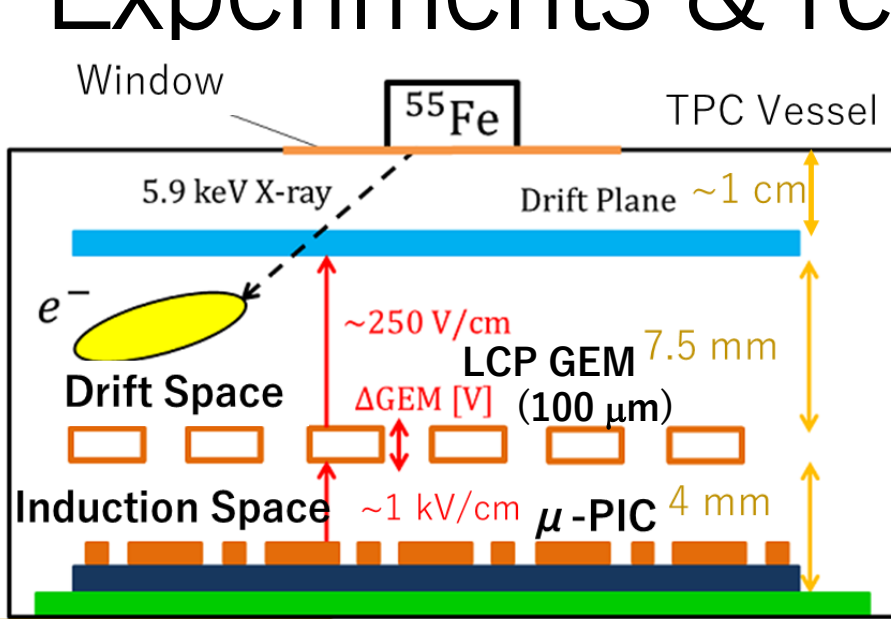
Most geometry parameters (Anode ϕ , Cathode ϕ , Pitch, ...) are **same** as for conventional μ -PIC, **except for the thickness.**

Polyimide thin film 5 μm

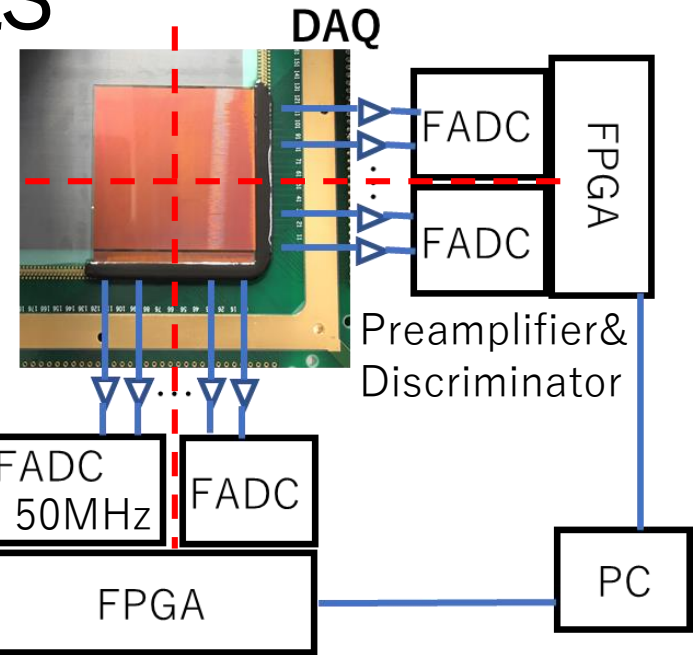


	PCB μ -PIC	TSV μ -PIC	TGV μ -PIC
Substrate material	Polyimide	Silicon	alkali-free glass
Dielectric constant	3.2 [1 MHz]	Si : 11 SiO ₂ : 4.5	5.8 [1 MHz]

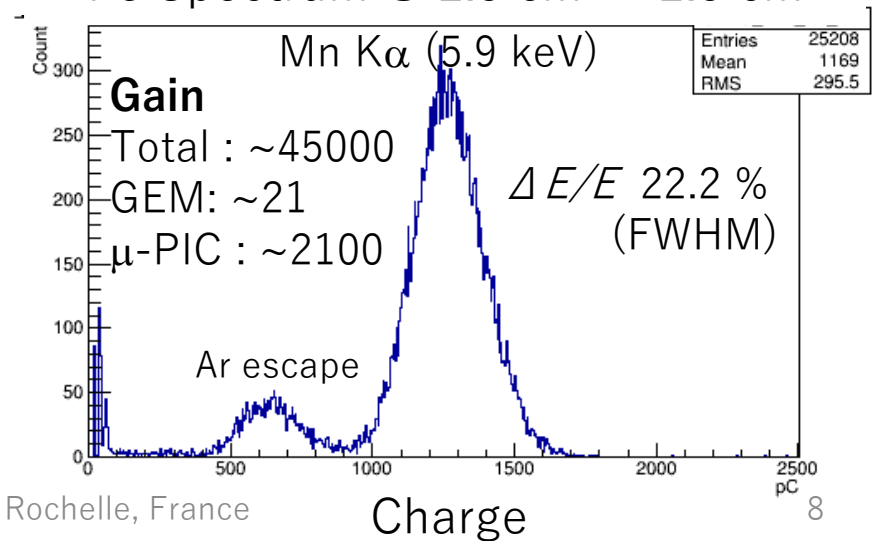
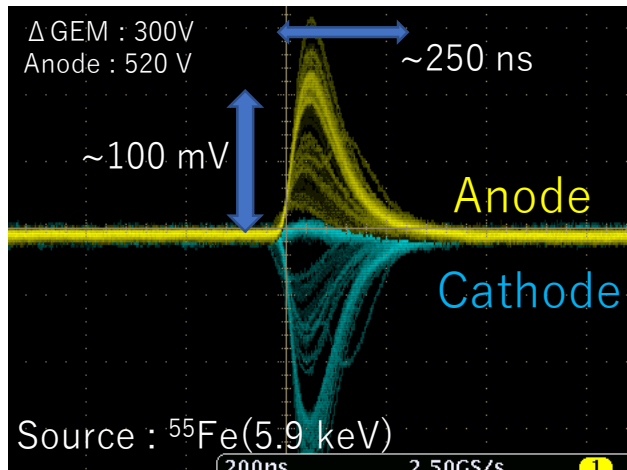
Experiments & results



HV supply & read out $\text{Ar} : \text{C}_2\text{H}_6 = 90:10 (1\text{atm})$

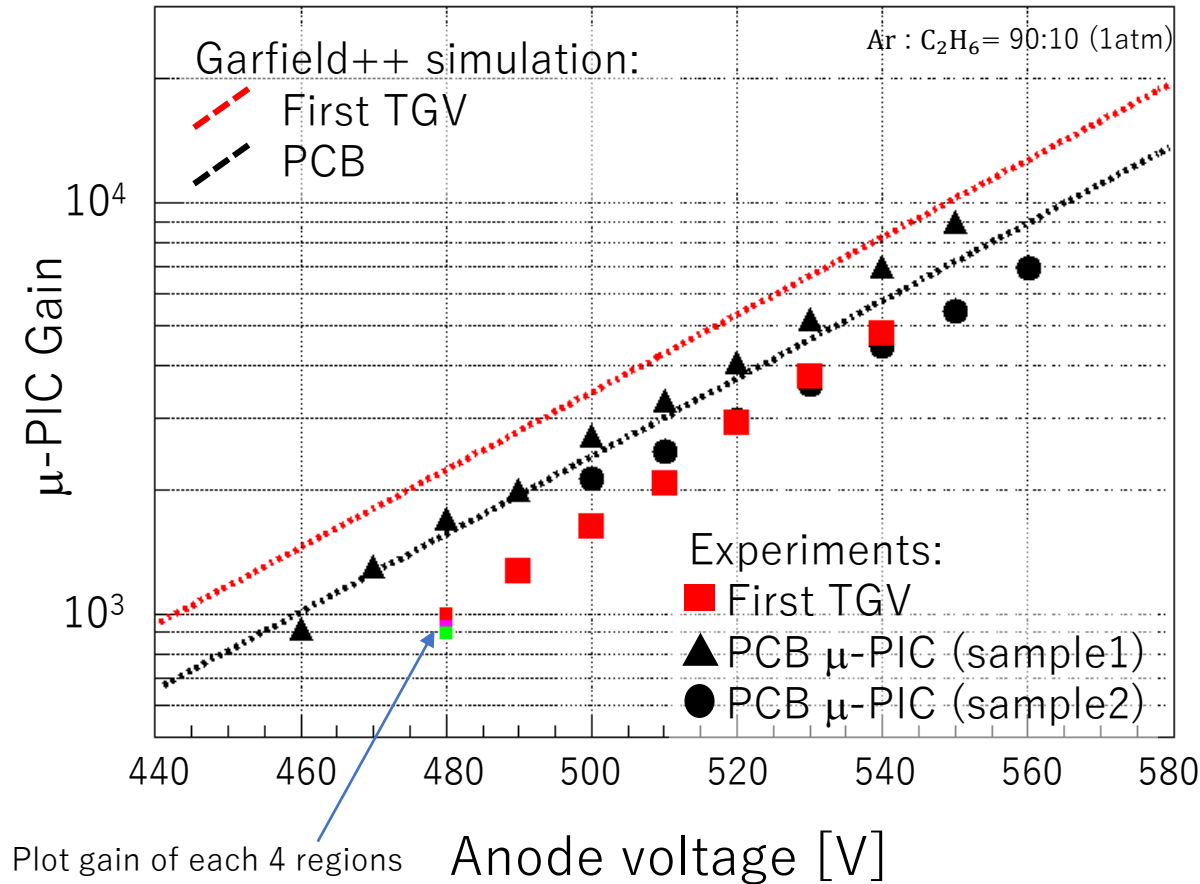


^{55}Fe Spectrum @ 2.5 cm \times 2.5 cm



Gain curve

Gain of μ -PIC ($\text{Gain}_{\text{Total}}/\text{Gain}_{\text{GEM}}$)



- The gain of TGV and PCB was **comparable**.
- In the first TGV, The experimental gain value was **$\sim 50\%$ lower** than the simulated gain value.

Why ?

Something that decreases the gain

Reference the product catalog

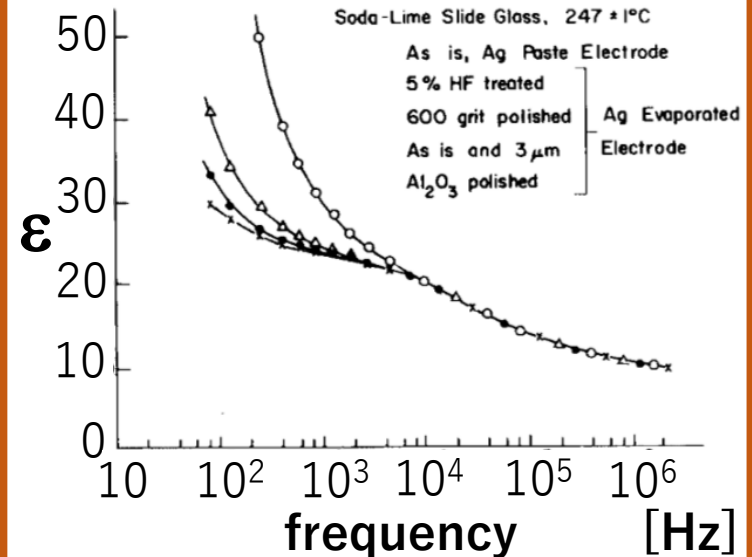
$\epsilon_{\text{alkali-free glass}}$: 5.8 [@1MHz]

Reflect reality??

It is difficult to measure ϵ at DC

Hypothesis : Effective dielectric constant > 5.8

Dielectric constant VS frequency



Electrode polarization at low frequency in a Soda lime glass
(C. Kim & M. Tomozawa, 1975)

Something that decreases the gain

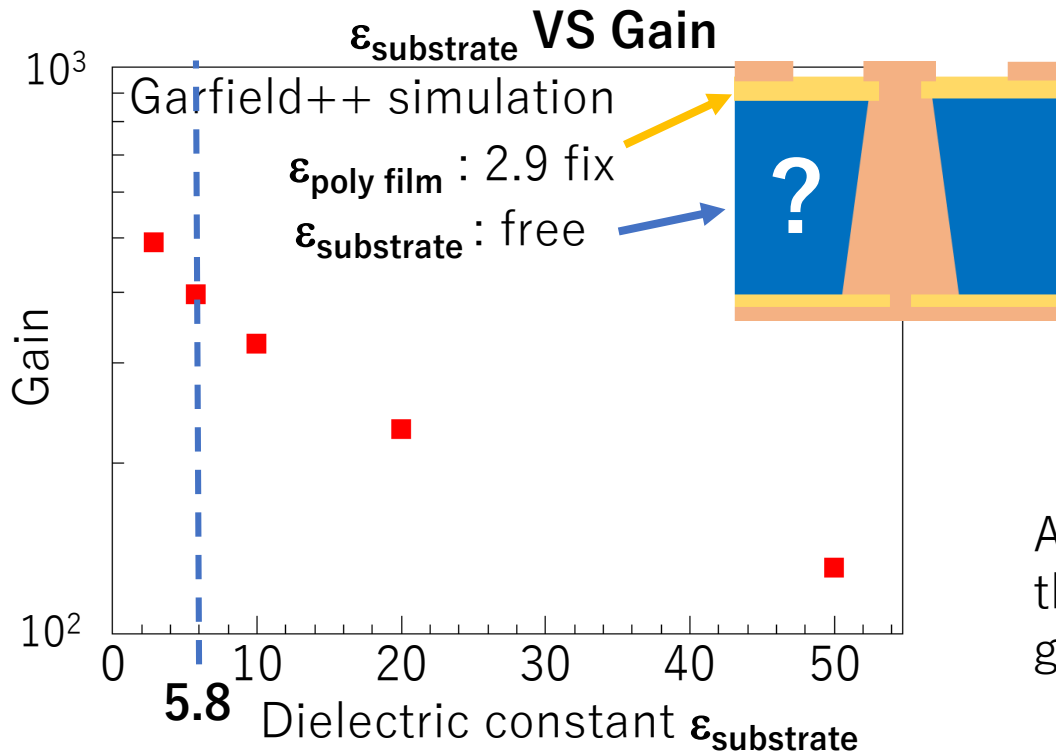
Reference the product catalog

$\epsilon_{\text{alkali-free glass}} : 5.8$ [@1MHz]

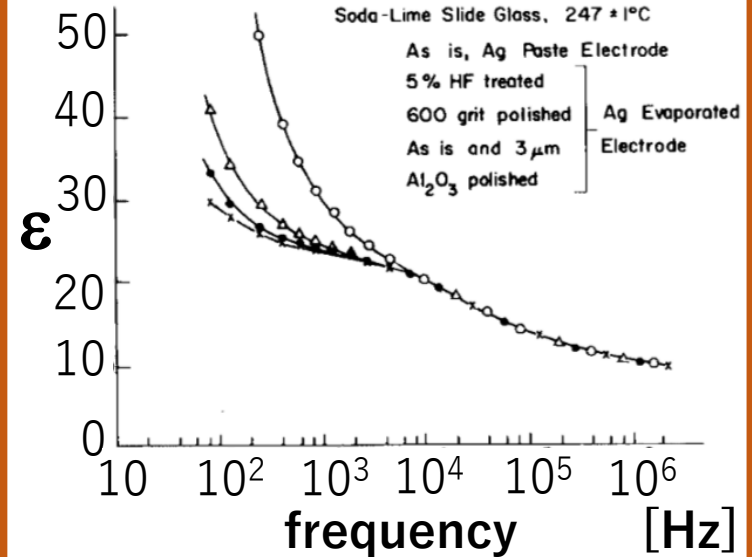
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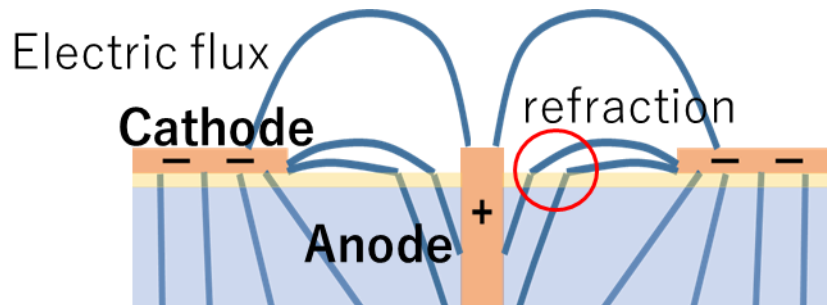
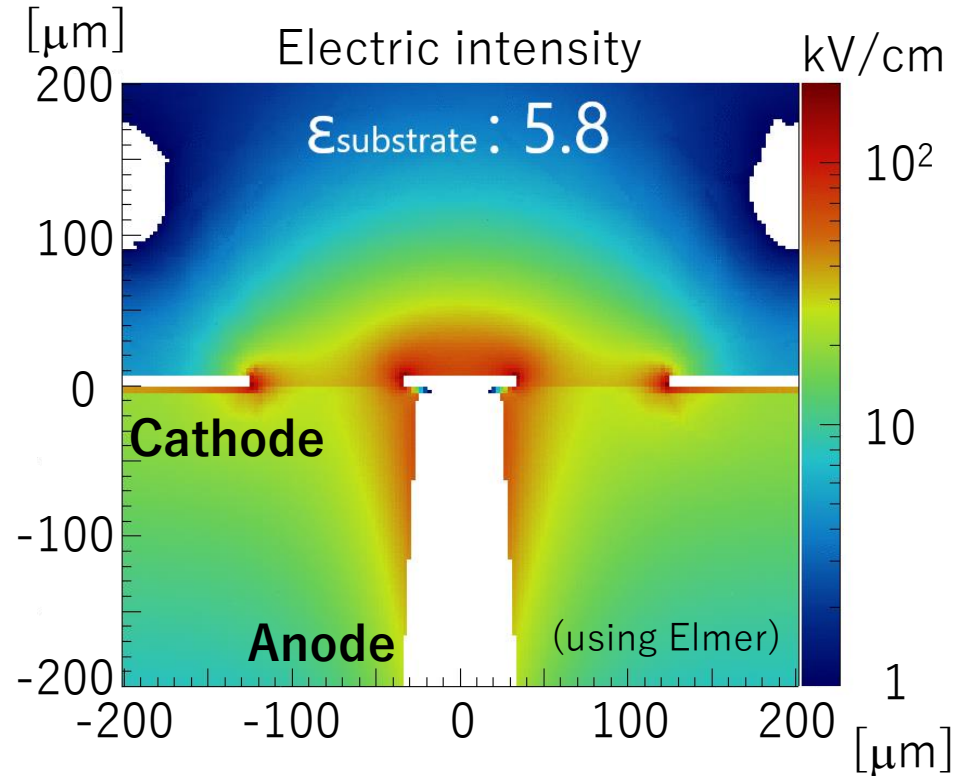
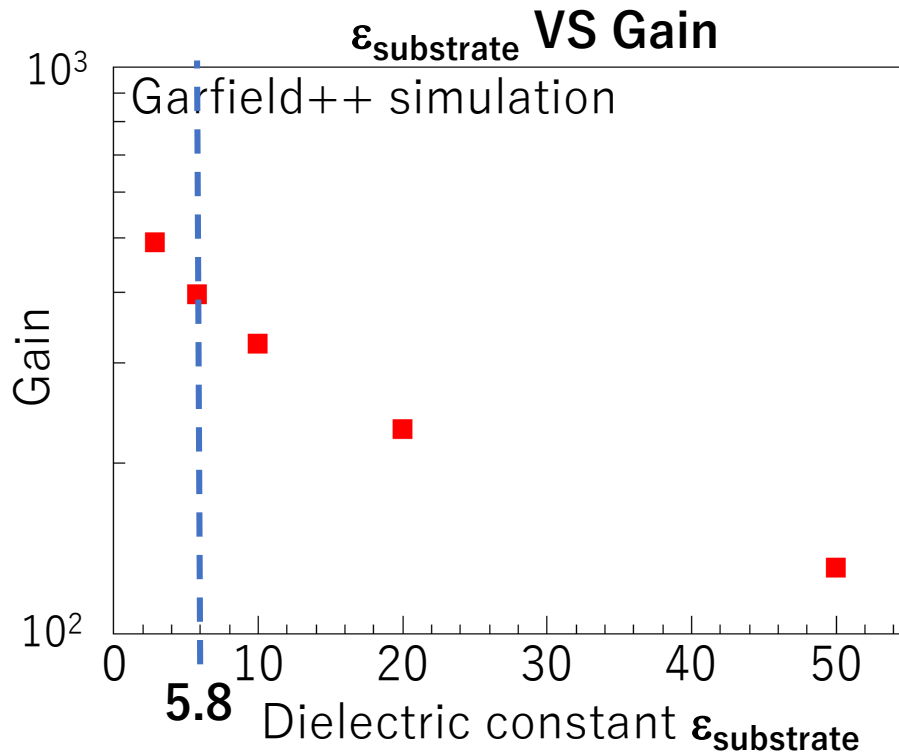
Dielectric constant VS frequency



Electrode polarization at low frequency in a Soda lime glass
(C. Kim & M. Tomozawa, 1975)

As the dielectric constant of the substrate **increases**, the gas gain tends to **decrease**.

E field around the anode



$$\epsilon_{\text{Gas}} \sim 1$$

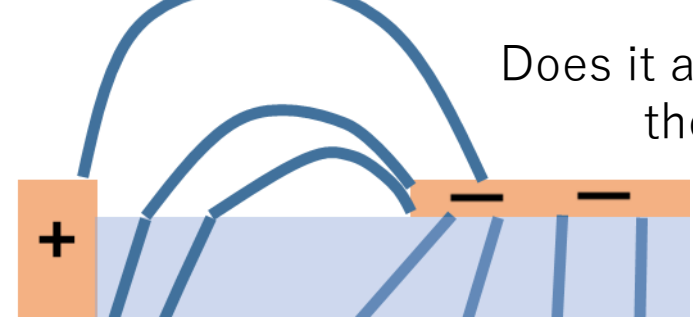
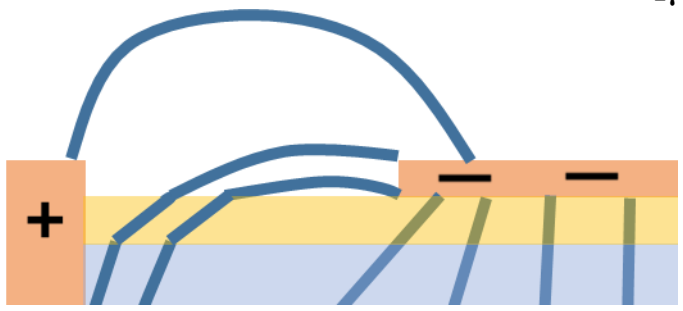
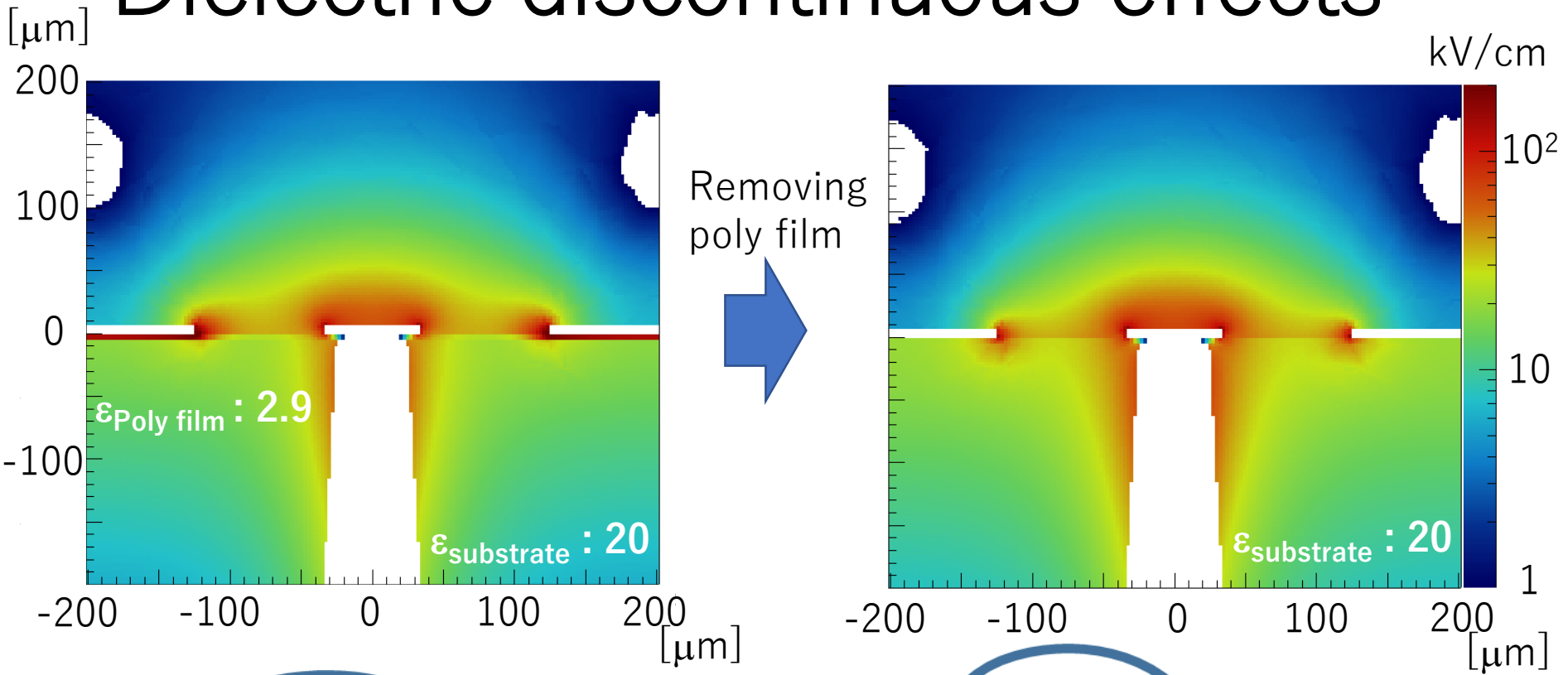
$$\wedge$$

$$\epsilon_{\text{poly film}} \sim 2.9$$

$$\wedge$$

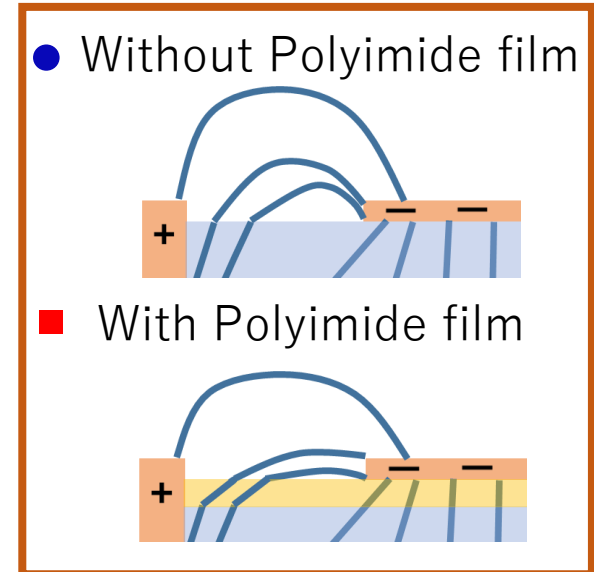
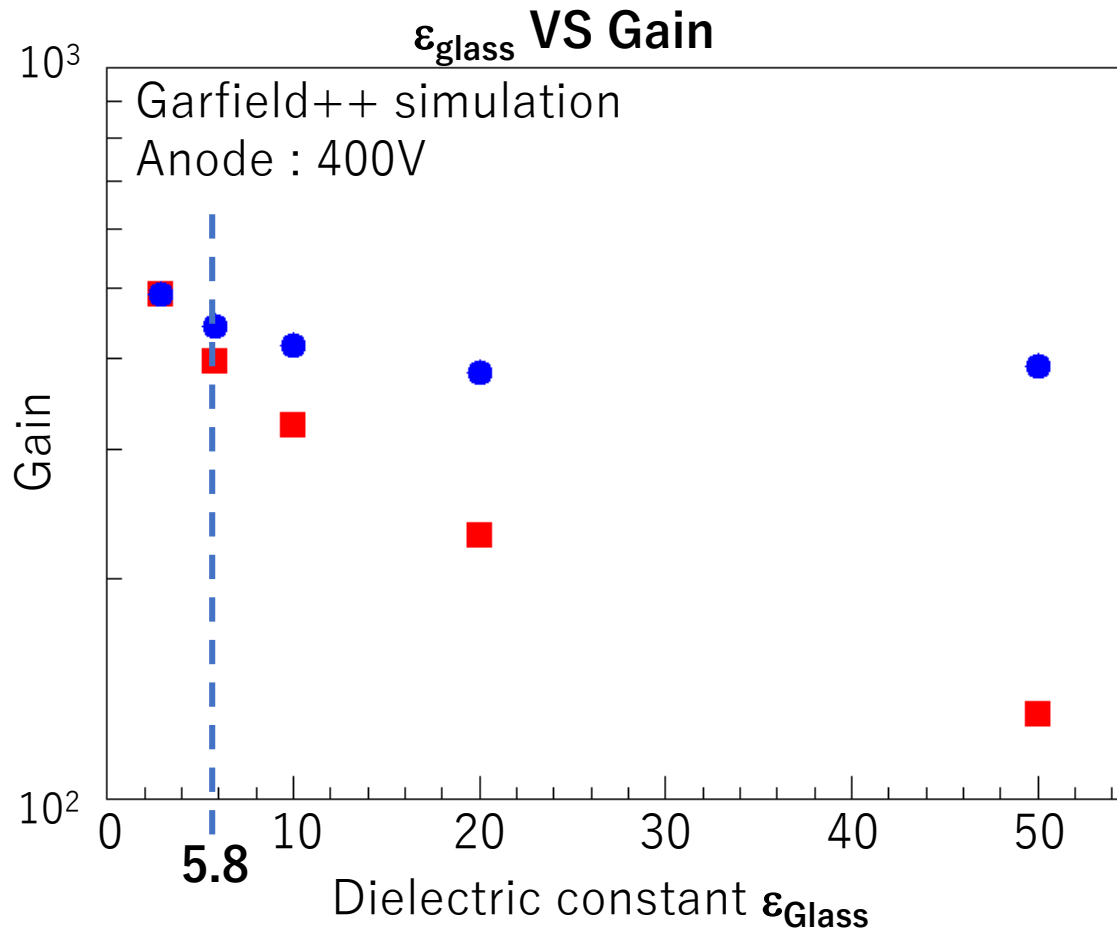
$$\epsilon_{\text{substrate}}$$

Dielectric discontinuous effects

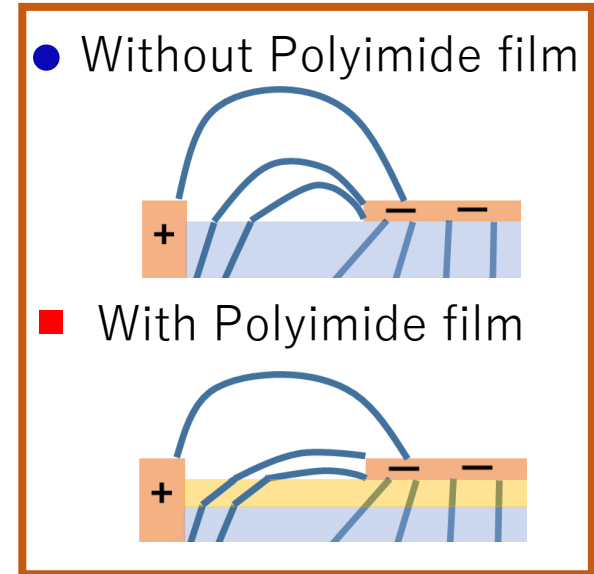
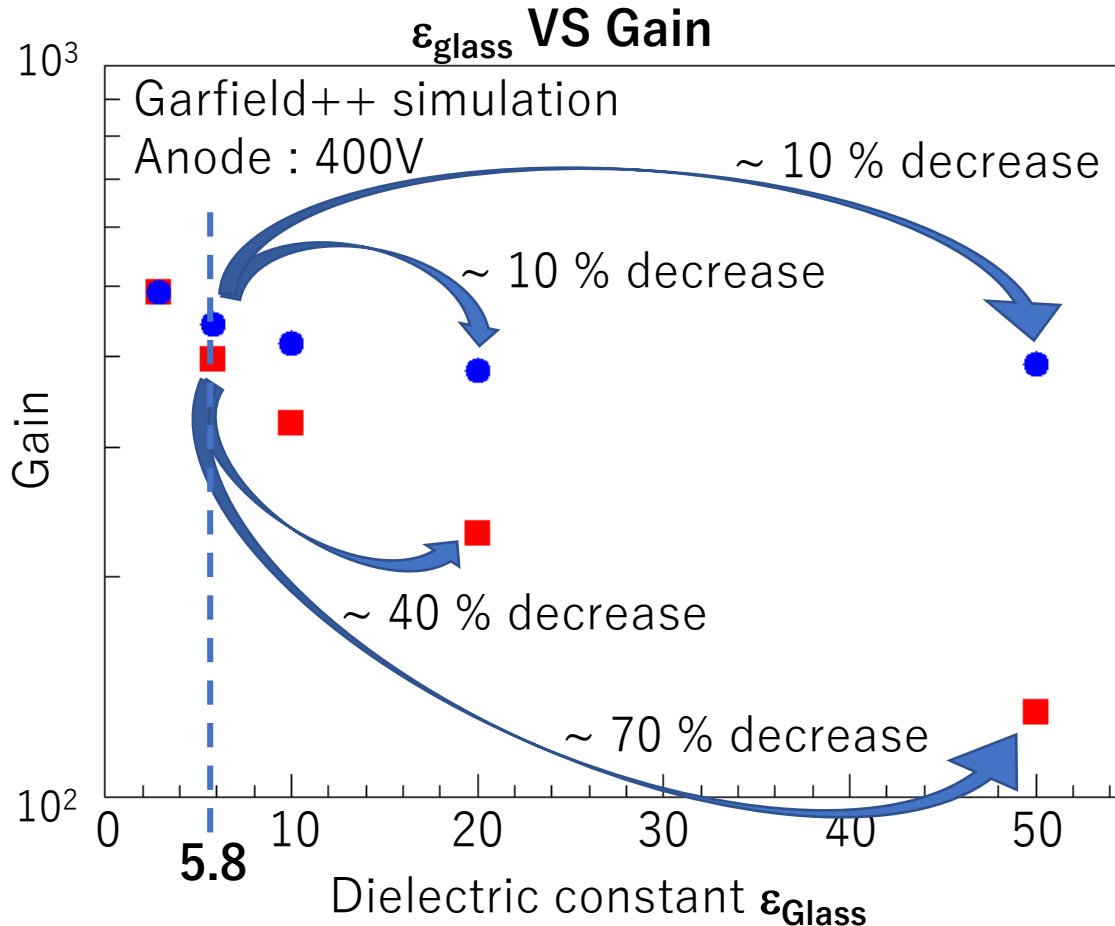


Does it affect the gain?

Dielectric discontinuous effects



Dielectric discontinuous effects



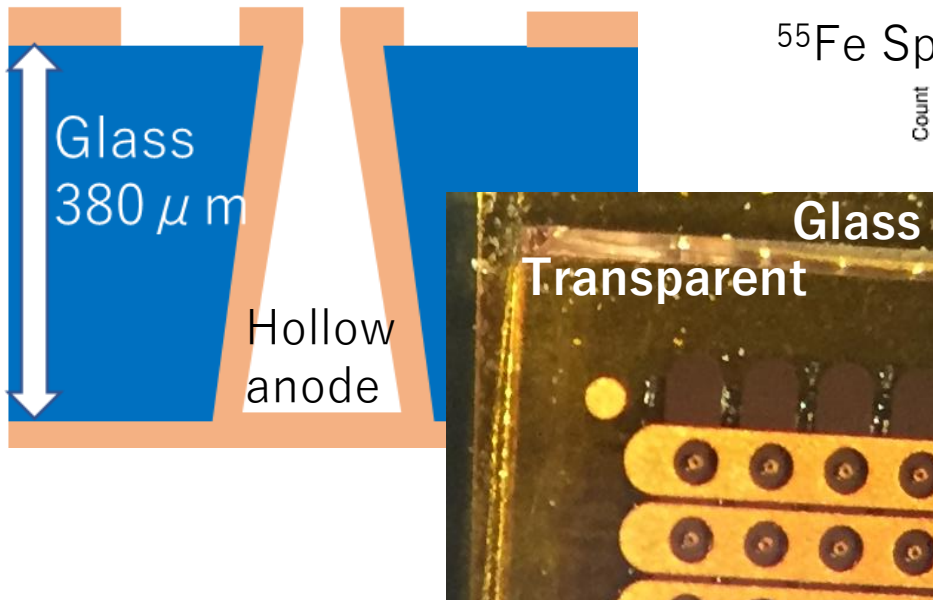
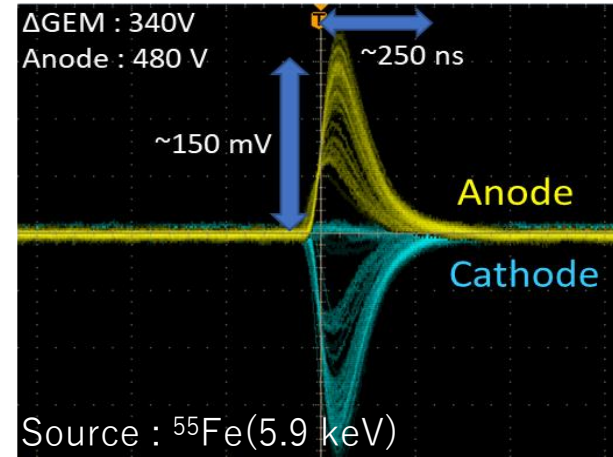
Trends found from simulation studies

- As the dielectric constant of the substrate **increases**, the gas gain tends to **decrease**.
- The **dielectric discontinuous** makes the gas gain **sensitive** to the value of the dielectric constant.

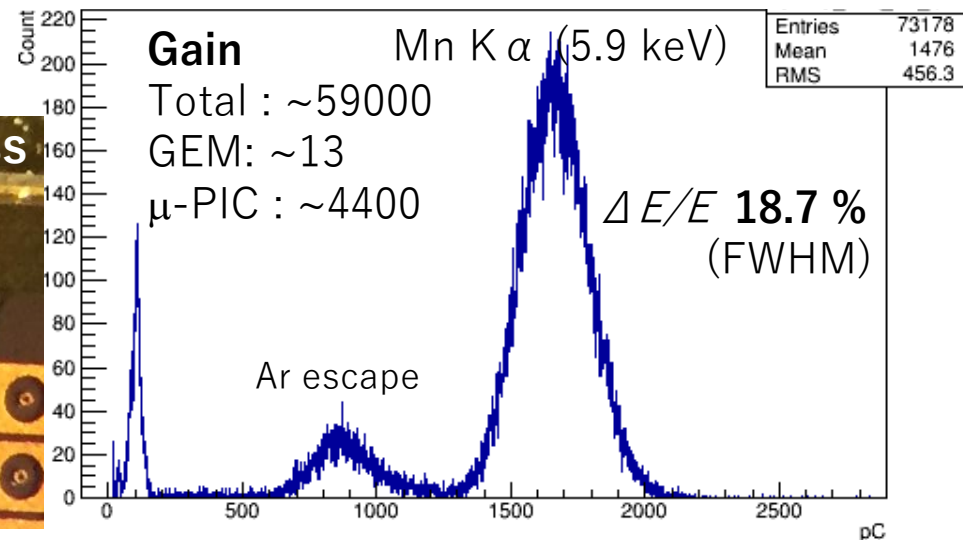
Let's remove the polyimide film!

TGV μ -PIC without polyimide film

- We fabricated second TGV μ -PIC without polyimide film.
- Geometry parameters (Anode ϕ , Cathode ϕ , Pitch, Detective area, ...) are same as for the first prototype TGV.
- Hollow anode vias do not affect the gas gain, that is confirmed by past experiments and simulation studies in TSV.



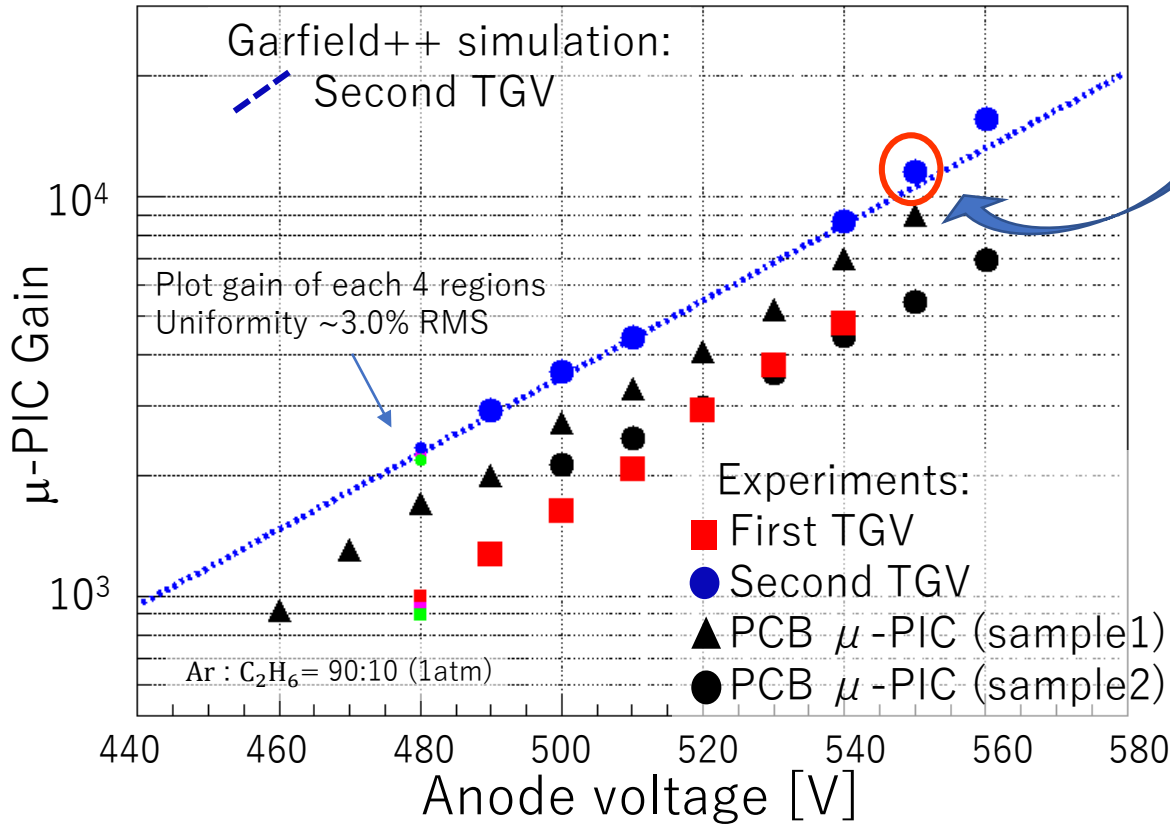
^{55}Fe Spectrum @ $2.5 \text{ cm} \times 2.5 \text{ cm}$ (~ 3100 pixel)



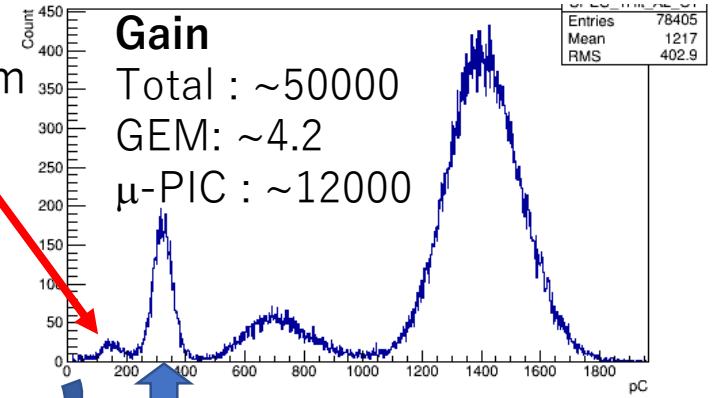
Gain curve

^{55}Fe Spectrum @ 2.5 cm × 2.5 cm

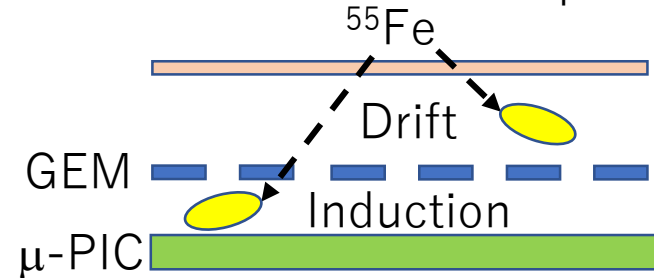
Gain of μ -PIC ($\text{Gain}_{\text{Total}}/\text{Gain}_{\text{GEM}}$)



Clearly confirm
Ar escape



Absorbed in induction space



- The gain of the second TGV is about twice that of the first TGV.
- In the second TGV, the experimental and simulation gain values are consistent.

Summary

- We are developing a μ -PIC for the MeV gamma-ray telescope
- We manufactured two types of the μ -PIC using a glass substrate with DNP aiming at high gas gain
- The gain of the second TGV μ -PIC without the polyimide film was about twice as high as the first TGV with the polyimide film.
- The gain of the second TGV μ -PIC reached $\sim 15,000$ (discharges rates ~ 1 / several min)
- It was found from Garfield++ simulation study that the dielectric constants discontinuous makes the gas gain sensitive to the value of the dielectric constant.

Thanks to DNP for the development and manufacturing

Future works

- Feasibility study of manufacturing large detection area ($> 30 \times 30 \text{ cm}^2$) TGV μ -PIC using a glass panel
- Long term modulation & Charge-up on substrates by irradiation of high intensity radiation
- Study of μ -PIC + mesh (mesh selection, stable operating voltage setting, gain uniformity, ...)