# **Upgrade to Glass GEM**
# for the GEM-based TPC “HypTPC” at J-PARC

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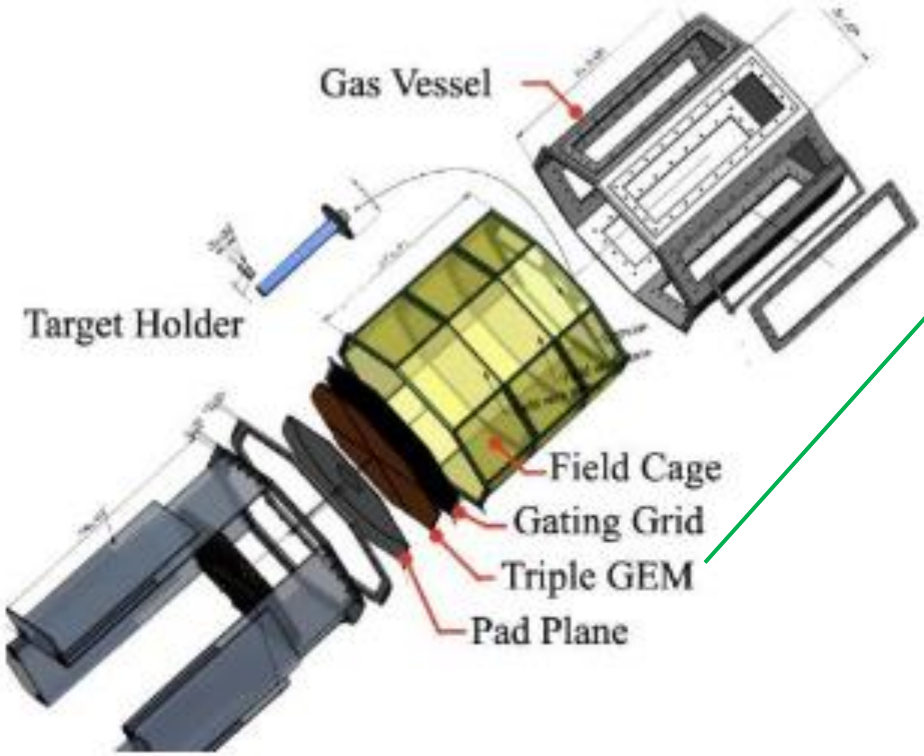
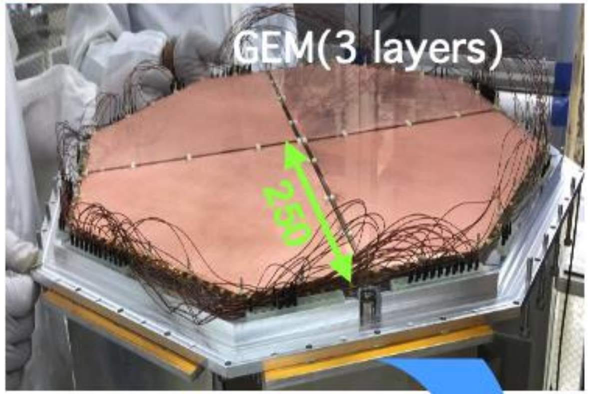
# GEM-based TPC for hadron experiments at J-PARC

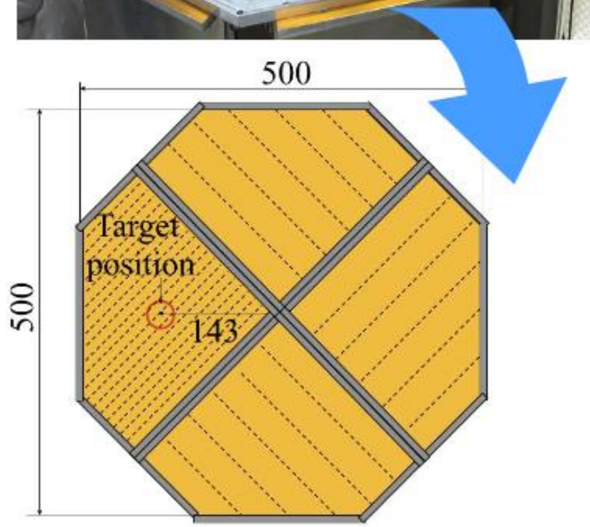
Hyperon-Time-Projection-Chamber "HypTPC"




→ $\pi/K$ Beam Intensity ~ 500 k/spill

Triple GEM (**G**as **E**lectron **M**ultiplier)



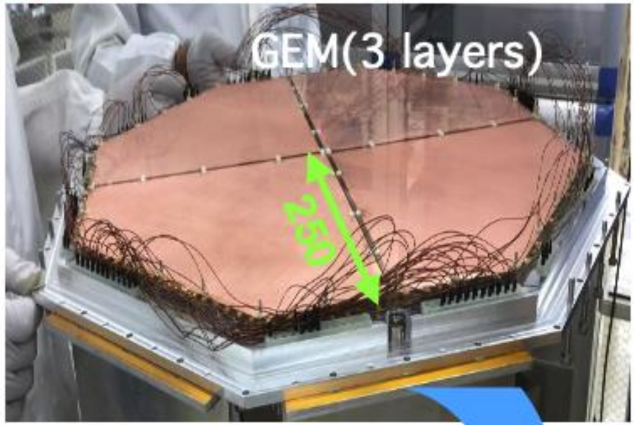

[top view]

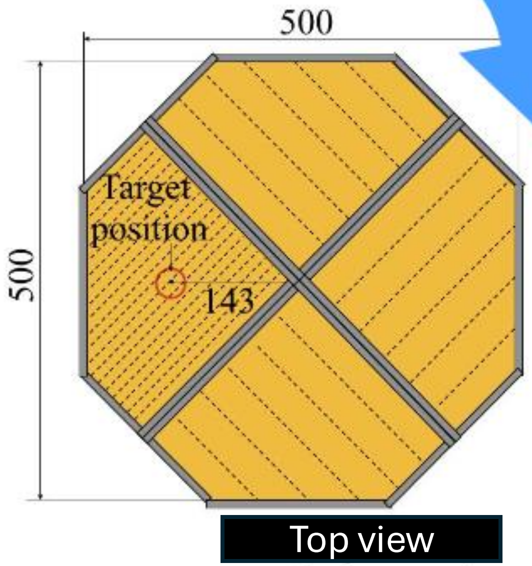
- **Triple** GEM layers

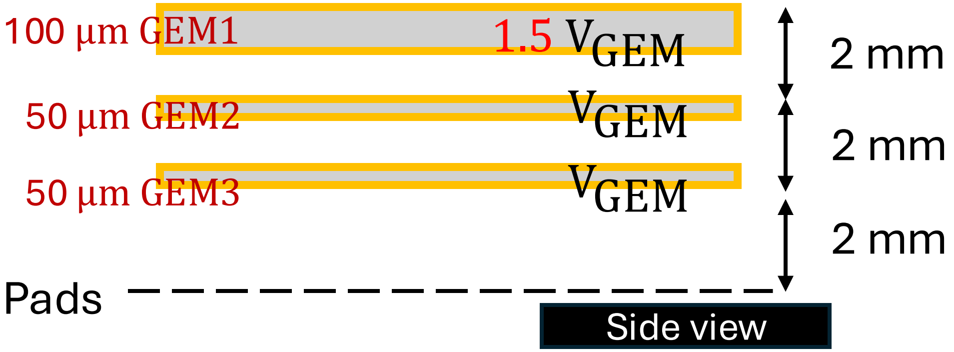
( 100 + 50 + 50 um)

- **Low ion back flow rate**
- Gain ~ $10^4$
- **Segmented electrodes**

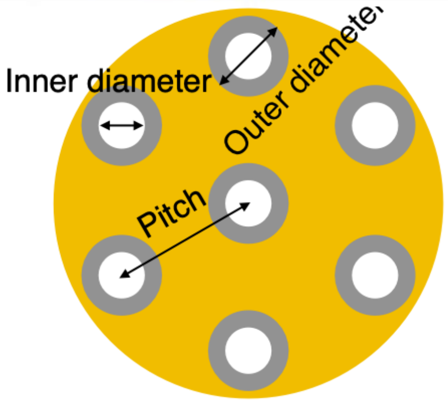
# Triple GEM

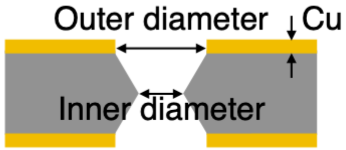



| Property | 50 $\mu m$ GEM | 100 $\mu m$ GEM |
|---|---|---|
| Manufacturer | Raytech | Raytech |
| Insulator material | Polyimide (PI) | Liquid Crystal Polymer (LCP) |
| Etching method | Wet | Laser |
| Cu thickness | 4 $\mu m$ | 9 $\mu m$ |
| Pitch ($d$) | 140 $\mu m$ | 140 $\mu m$ |
| Inner diameter ($r$) | $25 \pm 10$ $\mu m$ | $35 \pm 10$ $\mu m$ |
| Outer diameter ($R$) | $55 \pm 5$ $\mu m$ | $65 \pm 5$ $\mu m$ |



# Issues with conventional GEMs

**Sagging** up to 1 mm observed.
→ This had a significant impact on the spark rate.

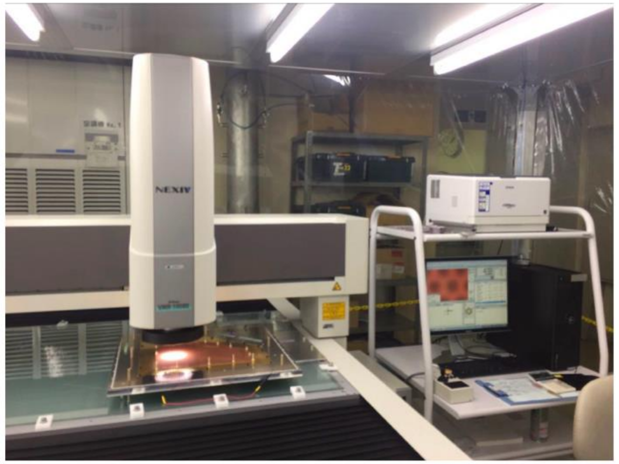
Reinforced with **a supporting frame.**
→ Reduced sagging and the spark rate.

Operated with spark rate ≤ 6/hour.

→ The supporting frame introduces a **dead area**.

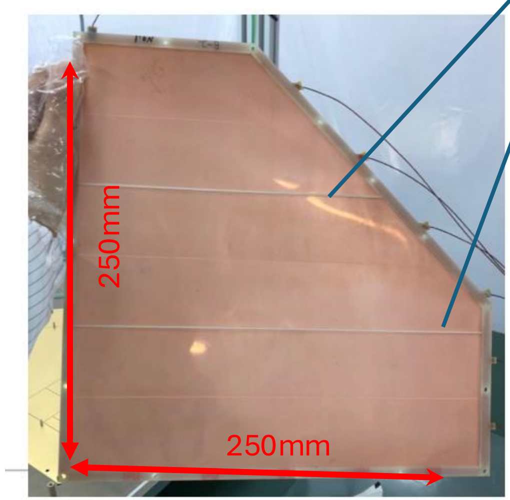
& A spark can carbonize the plastic, making it **conductive**.

GEM height measurement

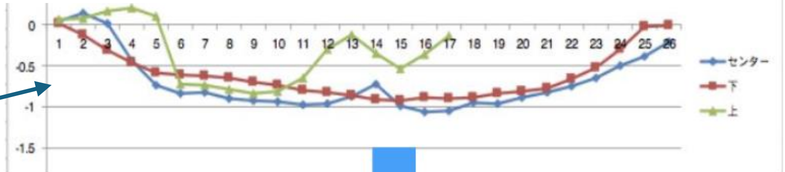


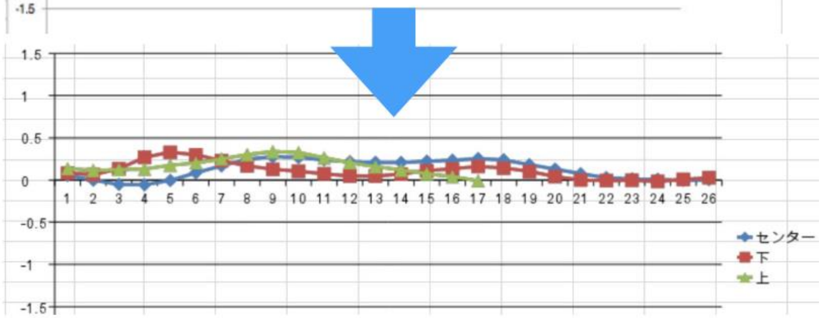
@H-REPIC

Supporting frame



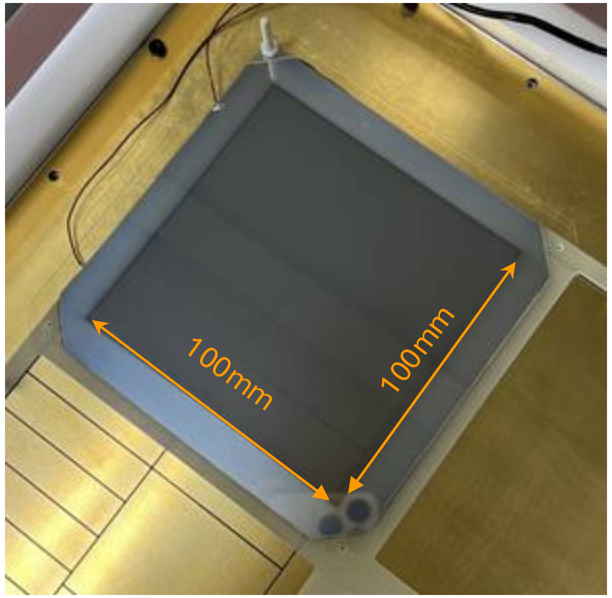

Sagging of up to 1 mm



# Glass GEM

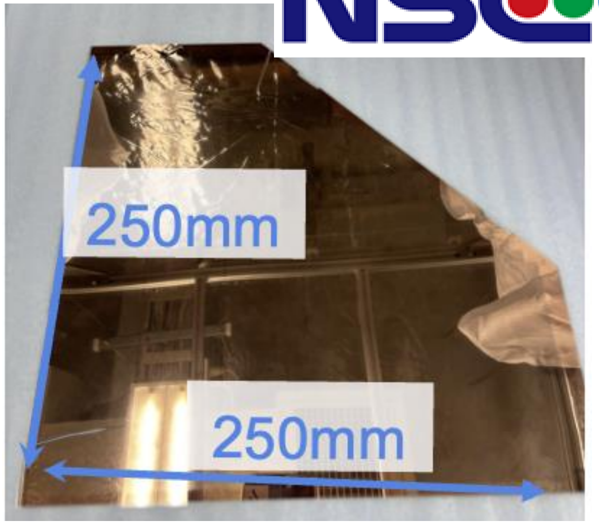
## The conventional glass GEM




Developed by AIST

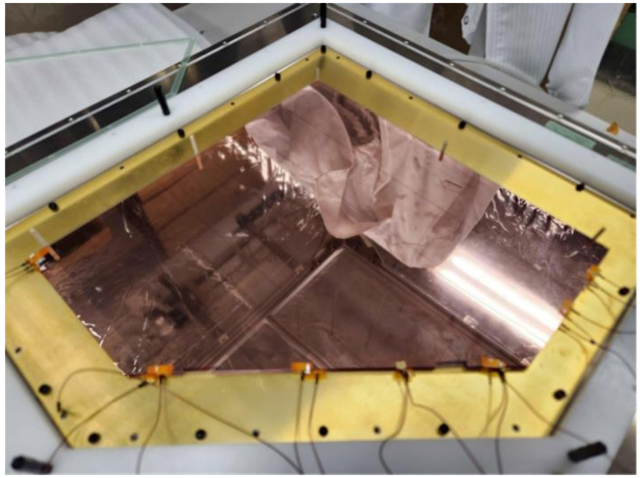
- ✅ Small : 100 mm x 100 mm.
- ✅ Thick : 570 μm.

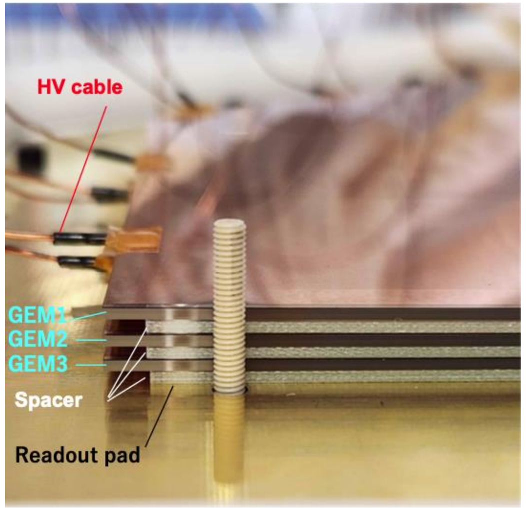
## The newly developed glass GEM




- ✅ Large: 250 mm x 250 mm.
- ✅ Thin : 100 μm.

→ Large enough for **TPC coverage.**
→ **Segmented** into six parts.





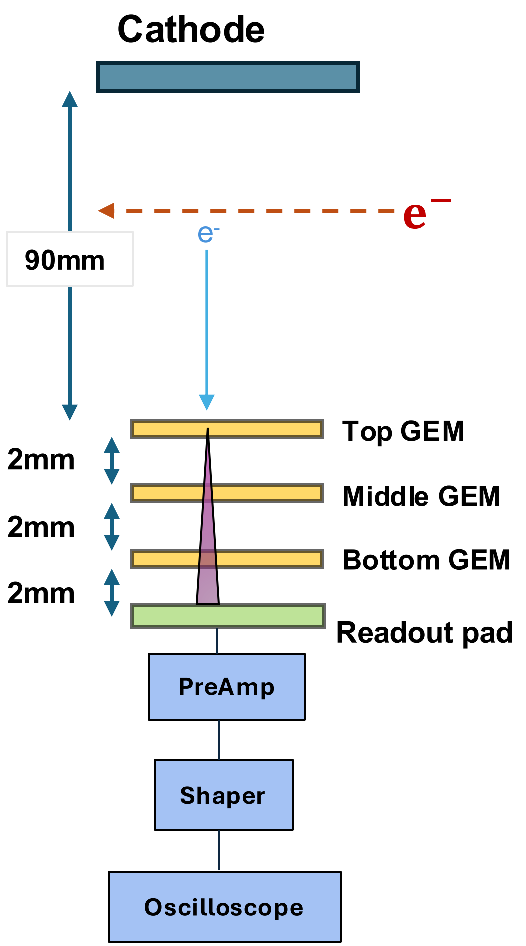
# Glass GEM

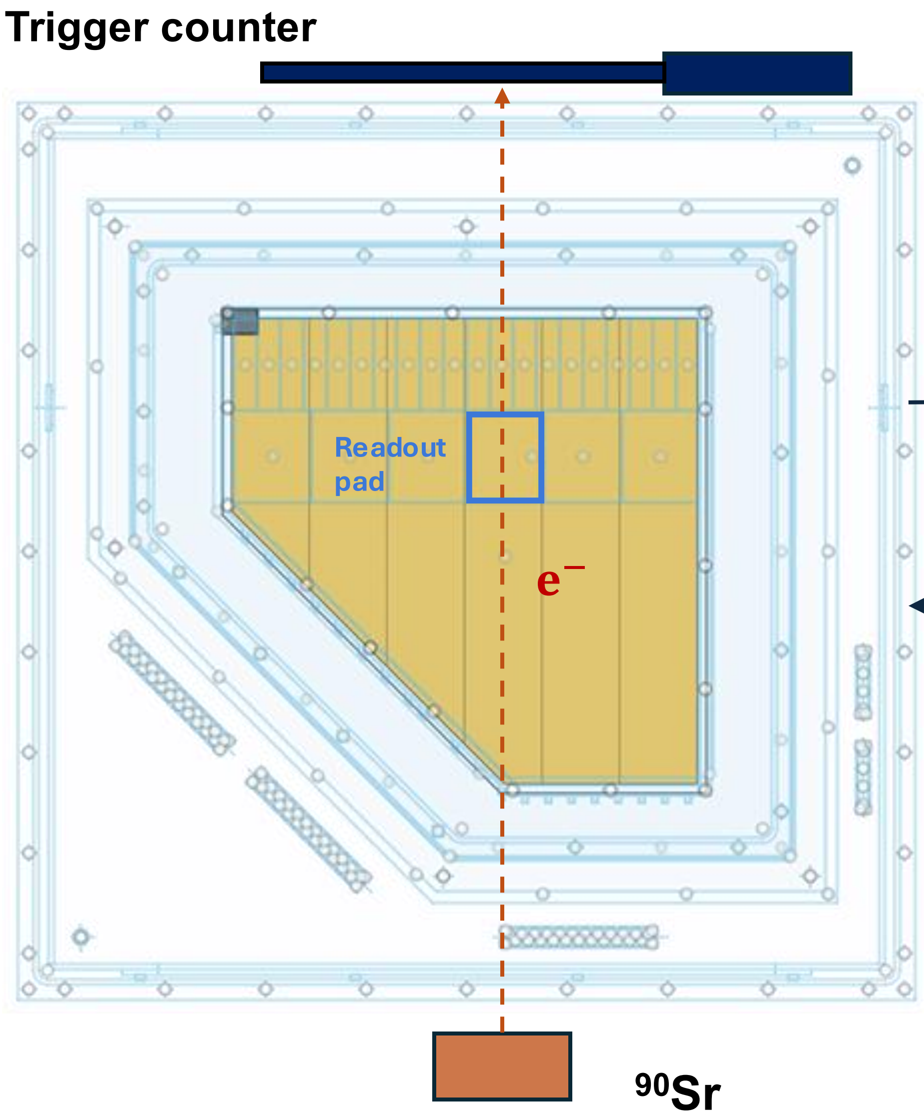
Comparison of GEM Specifications

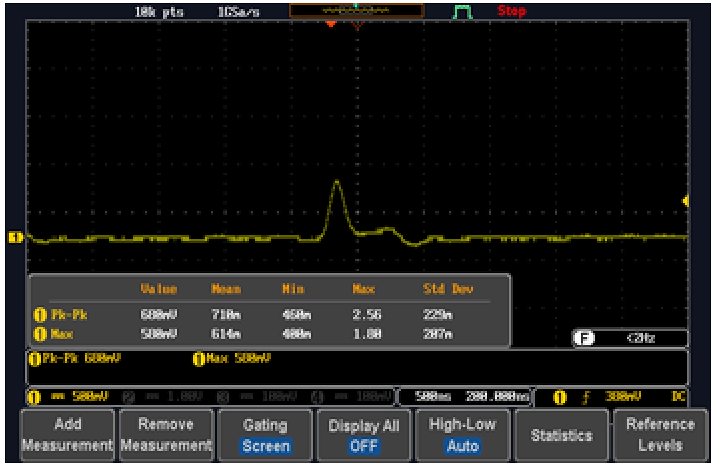
| | PI/LCP GEM | Glass GEM (AIST) | New Glass GEM (NSC) |
|---|---|---|---|
| **Thickness [μm]** | 50 / 100 | 570 | 100 |
| **Cu thickness [μm]** | 4/9 | 3-4 | 0.17 |
| **Hole shape** | Double conical | Through hole | Double conical |
| **Inner diameter [μm]** | 25/35 | 170 | 38 |
| **Outer diameter [μm]** | 55/65 | 170 | - |
| **Pitch [μm]** | 140/140 | 280 | 104 |
| **Segmented** | Yes (6 divisions) | No | Yes (6 divisions) |

# Test bench for Glass GEM

[side view]



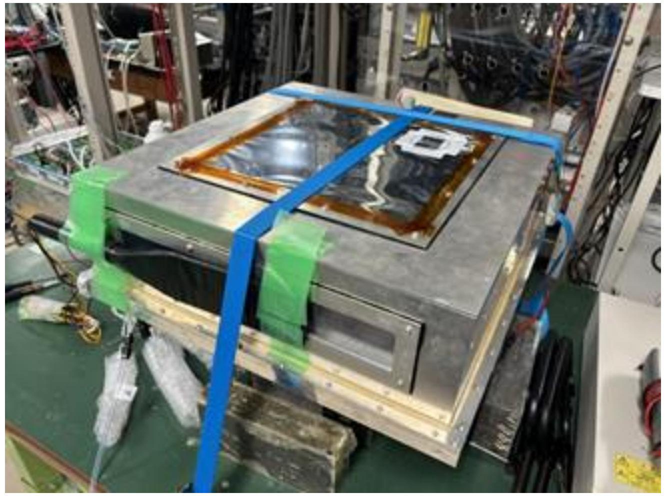




21.5℃Td | 17.3ppm

Moisture Sensor — Oxygen Sensor — Pump

Mass flow controller

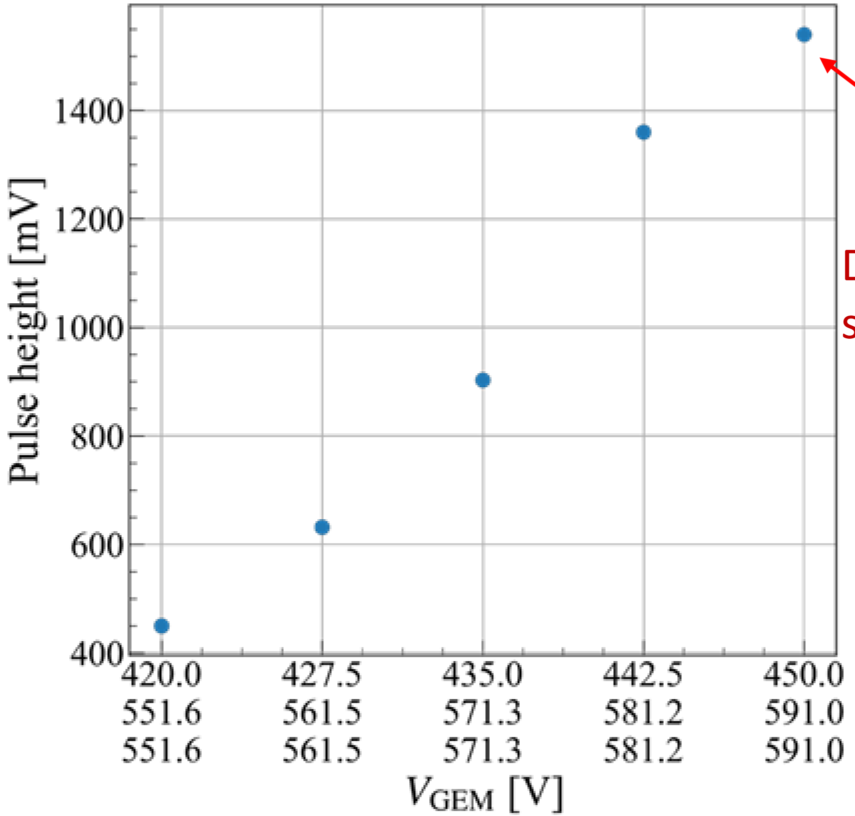
P10 gas
1 atm



# Glass GEM

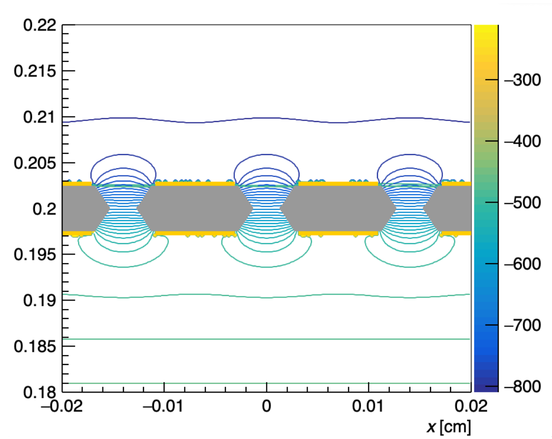
A [90]Sr source was installed, and the signal peak from the Glass GEM was measured.

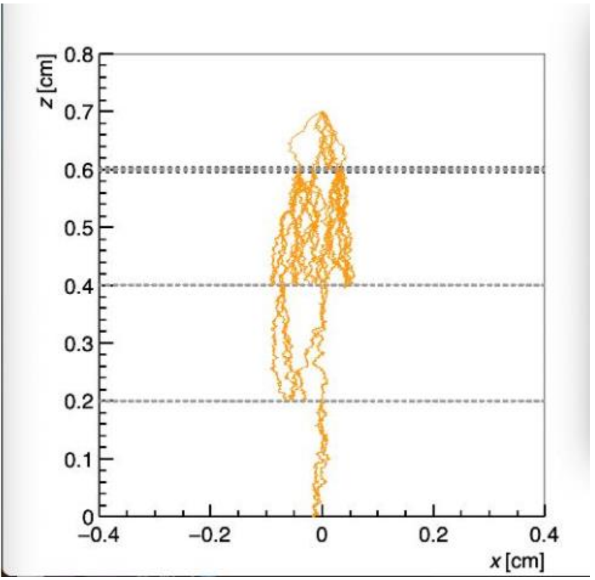
| $I_{GEM}$ [uA] | Spark rate [/min] | Height [mV] |
|---|---|---|
| 280 | **0**<br>**0(w/Sr)** | **450** |
| 285 | **0**<br>**0(w/Sr)** | **632** |
| 290 | **1**<br>**1(w/Sr)** | **903** |
| 295 | **2**<br>**5(w/Sr)** | **1360** |
| 300 | **1**<br>**6(w/Sr)** | **1540** |




Due to the pre-amp saturation

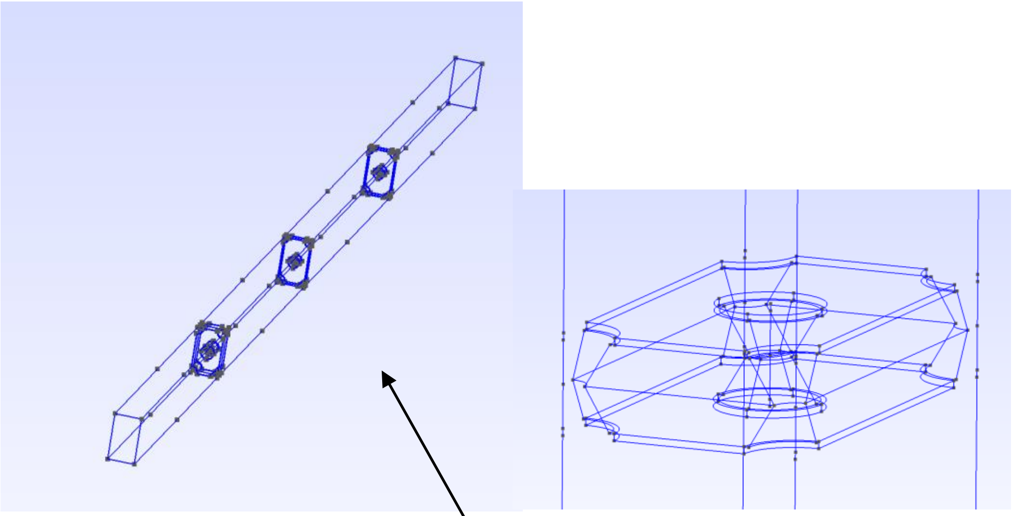
# GEM simulation using Garfield++

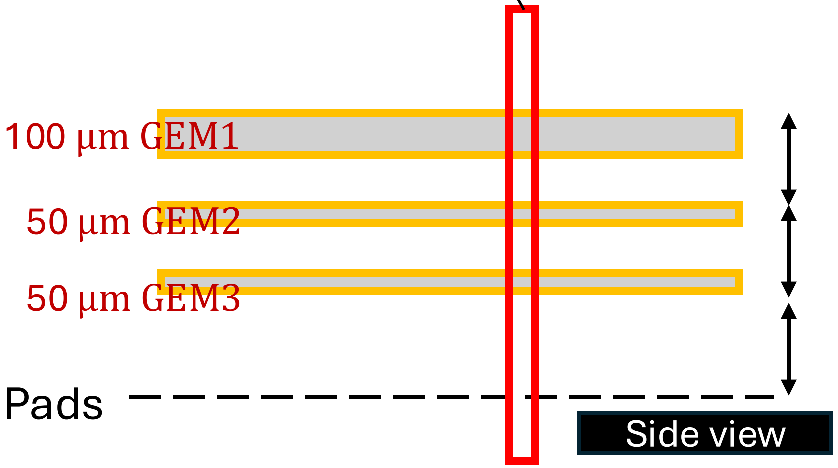



As an initial step in the simulation, we decided to model the well-studied **Polyimide/LCP GEM**, for which abundant experimental data is available.

# GEM simulation using Garfield++: Polyimide/LCP GEM



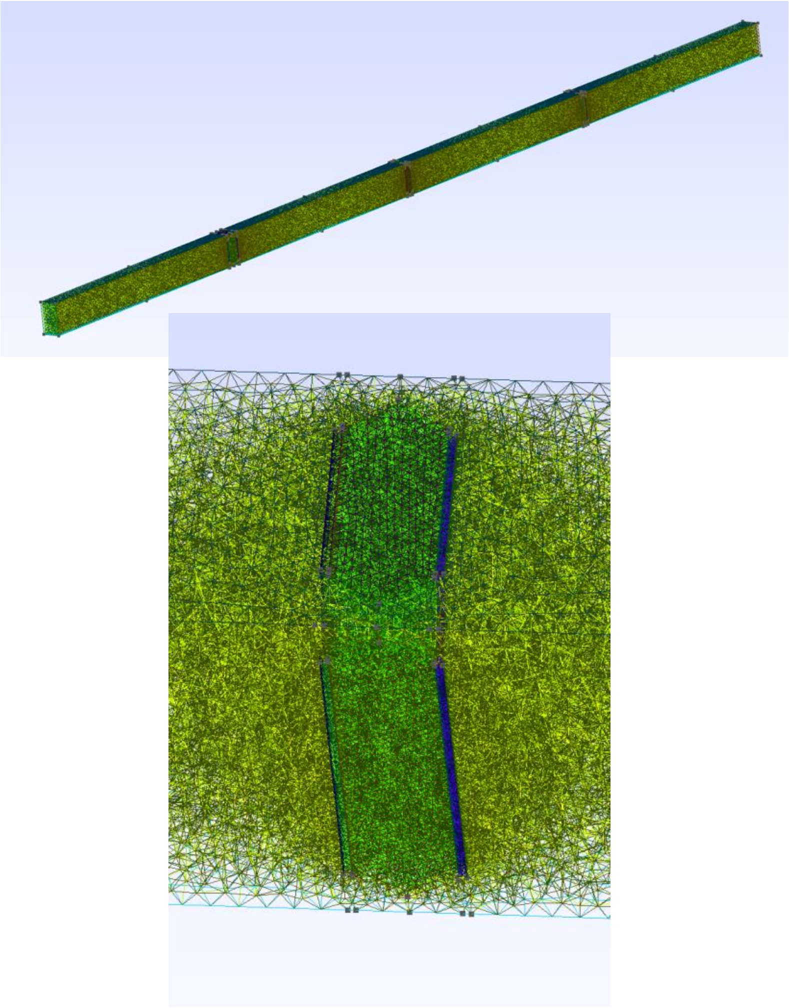



**Modeling the GEM structure with Gmsh**

**Calculating the electric field using Elmer**

**Avalanche simulation with Garfield++**

# **GEM simulation** using Garfield++: **Polyimide/LCP GEM**

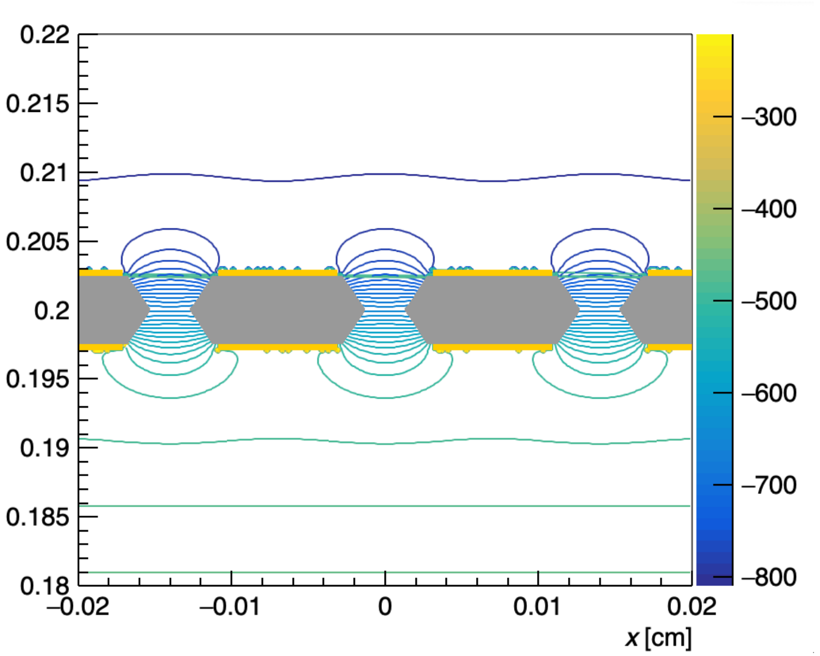


**Modeling the GEM structure with Gmsh**

**Calculating the electric field using Elmer**

**Avalanche simulation with Garfield++**

# **GEM simulation** using Garfield++: **Polyimide/LCP GEM**




**Modeling the GEM structure with Gmsh**

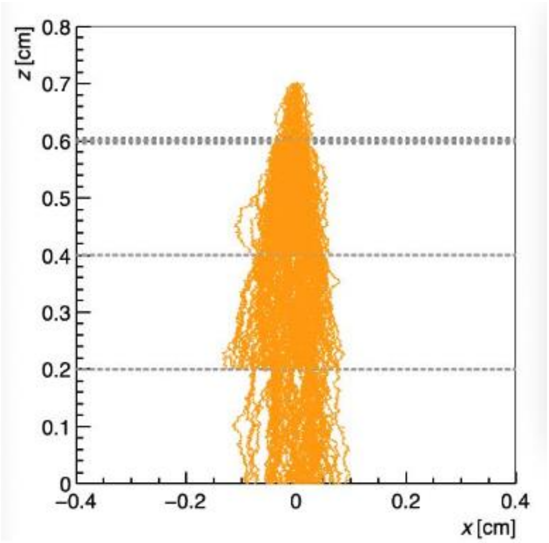
**Calculating the electric field using Elmer**

**Avalanche simulation with Garfield++**

# **GEM simulation** using Garfield++: **Polyimide/LCP GEM**

- **Input:** Single electron.
  **Output:** Number of electrons reaching the pads.

- A **Penning transfer ratio** of 0.212 was used for **P10**, as reported in [Cortesi et al., JINST 15 P07020 (2020)].



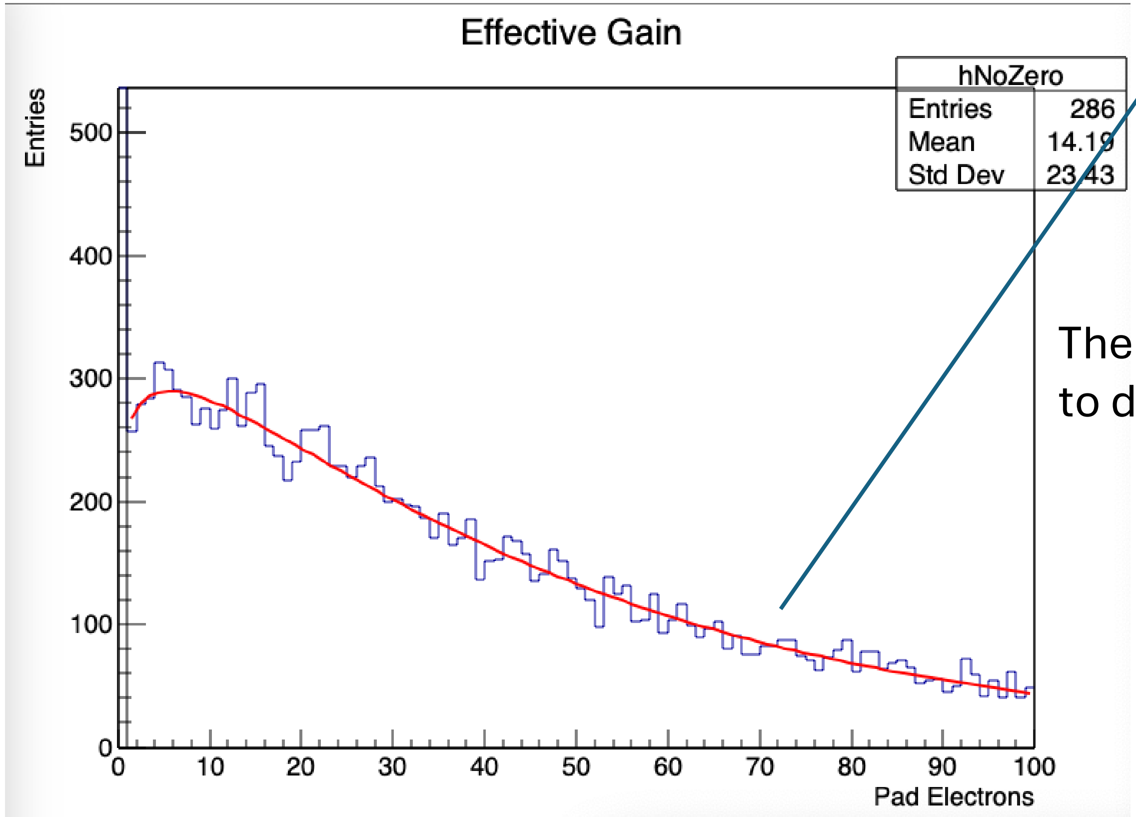

**Modeling the GEM structure with Gmsh**

**Calculating the electric field using Elmer**

**Avalanche simulation with Garfield++**

# GEM simulation using Garfield++: Polyimide/LCP GEM

| | |
|---|---|
| Total event | 38900 |
| **Effective gain** | **46.85** |
| Time per 100evt | 8 min |




**Fitted with a Polya distribution.**

$$P(G) = C_0 \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{G}{\bar{G}}\right)^{\theta} \exp\left[-(1+\theta)\frac{G}{\bar{G}}\right]$$

$\bar{G}$: Mean avalanche gain
$G$: Gain (Number of electrons in the avalanche)
$\theta$: Related to gain variance $f = 1/(1+\theta)$

The **Polya function** is an **empirical formula** that has been widely used to describe **avalanche fluctuations** in gaseous detectors.

(M. Hauschild, *Study of Avalanche Fluctuations in Gaseous Detectors with Micromegas and GEM*, CERN-THESIS-2015-268.)

# **GEM simulation** using Garfield++: **Polyimide/LCP GEM**

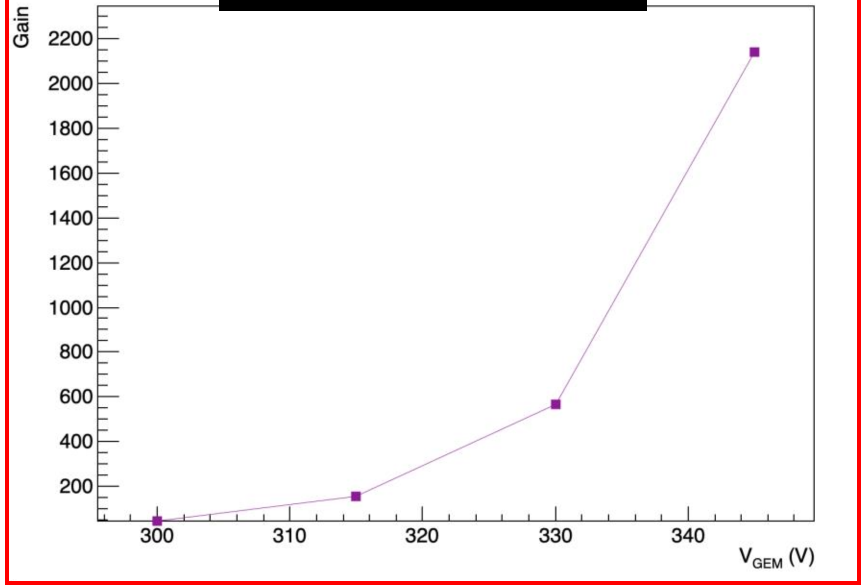
| GEM2,3 (V) | GEM 1(V) | Transfer(V/cm) | Induction(V/cm) | Effective gain |
|---|---|---|---|---|
| 300 | 450 | 1995 | 2550 | 46.85 |
| 315 | 472.5 | 2094.75 | 2677.5 | 152.78 |
| 330 | 495 | 2194.5 | 2805 | 568.042 |
| 345 | 517.5 | 2294.25 | 2932.5 | 2139.84 |

An exponential trend in the simulated gain is observed as the voltage increases.

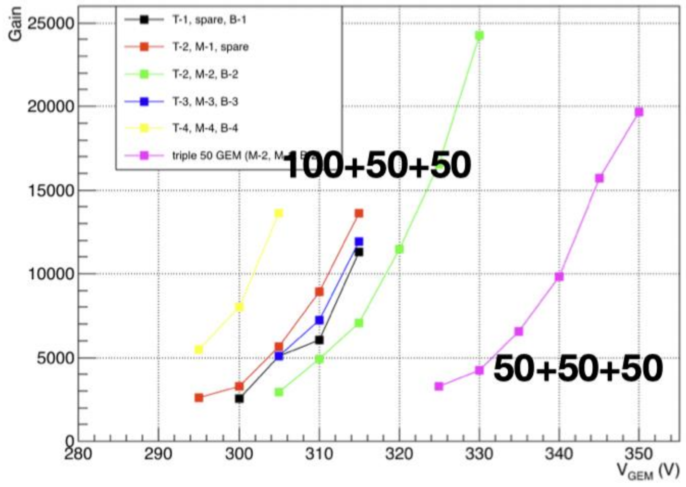
The gain seen in simulations is lower than in experiments.

One possible explanation for the lower gain observed in simulations is their limited temporal resolution, which may fail to capture fast avalanche processes accurately, resulting in an underestimation of gain. *(Ref: NIM A 936 (2019) 364–366)*

Simulated Gain




Experimental Gain



# Summary

1. We are developing glass GEMs for next-generation HypTPC experiments.

2. A triple-layered 100 μm-thick glass GEM was developed in collaboration, with fabrication support from NSC, and successfully tested using an Sr-90 source.

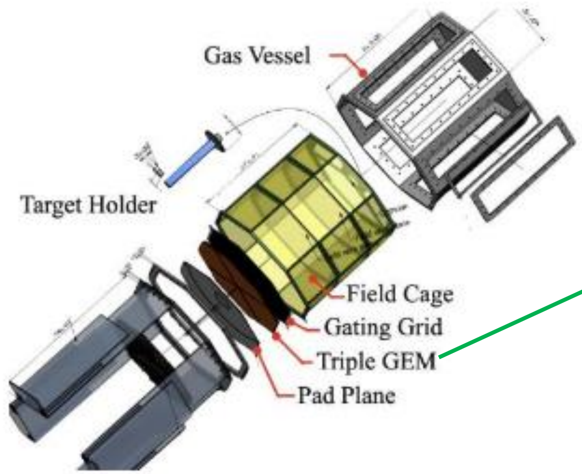
3. GEM geometry optimization is currently underway using Garfield++ simulations.

4. A new glass GEM setup, **produced in collaboration with Toray**, the manufacturer of the original HypTPC GEMs, is planned to be installed at Kyungpook National University.

# Back up

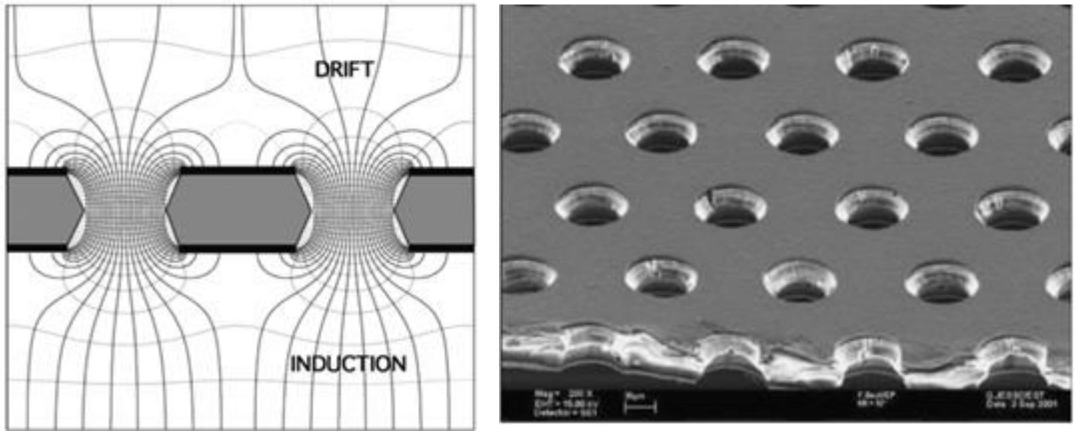
# GEM-based TPC for hadron experiments at J-PARC

Hyperon-Time-Projection-Chamber "HypTPC"




→ $\pi/K$ Beam Intensity ~ 500 k/spill

GEM (Gas Electon Multiplier)




→ Copper-coated insulator with holes.

→ High voltage creates strong electric field in the holes, amplifying electrons.

# A **Penning transfer ratio** of 0.212 was used for **P10**

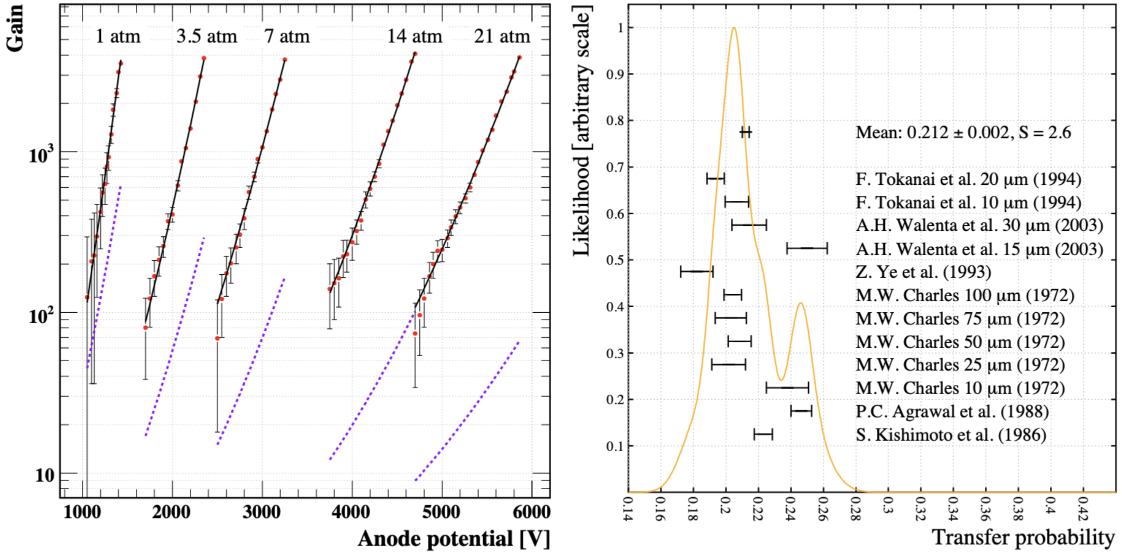



**Figure 11**. Left: Gas gain in Ar 90% $CH_4$ 10% measured by Z. Ye et al. [94], fitted with eq. (3.1) to obtain the Penning transfer probabilities. Red circles show the data, dashed purple lines show the gas gain computed from uncorrected Townsend coefficients and solid black lines show the fit with adjusted Townsend coefficients. Right: Compilation of transfer probability measurements in Ar 90% $CH_4$ 10% at atmospheric pressure. The spread of the transfer fraction measurements in 10% $CH_4$ at atmospheric pressure is $S = 2.6$ with $S^2 = \chi^2/(\text{ndf} - 1)$. No excessive spread is seen in the 2% $CH_4$ atmospheric pressure data. In model fits, the weighted average and the error bar shown are used instead of the individual measurements.

**M. Cortesi et al., JINST 15 P07020 (2020)**

DOI: 10.1088/1748-0221/15/07/P07020

# Polya distribution

### 3.4.3 Avalanche fluctuations

For the single-electron avalanche distribution, a simple model can be carried out by assuming that the probability of ionization by an electron depends only on the electric field strength without any influence of its path traveled already in the gas. It can therefore be predicted by *Furry distribution*:

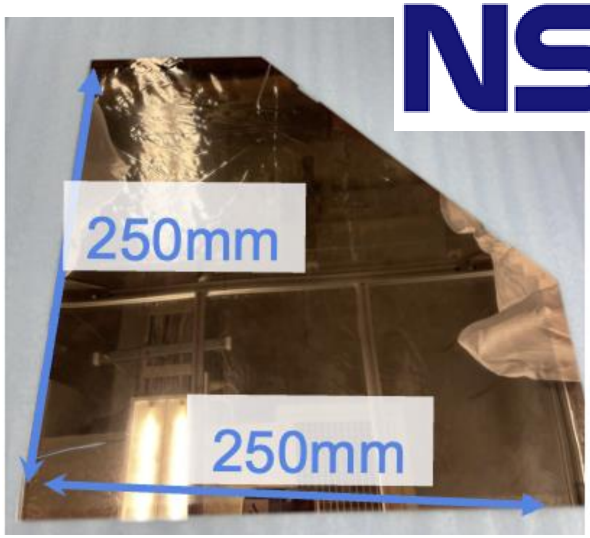
$$P(G) \cong \frac{e^{-G/\overline{G}}}{\overline{G}} \tag{3.26}$$

where $\overline{G}$ is the mean value of multiplication and $G$ the number of electrons in the avalanche. As the field gets stronger, the probability of ionization by an electron can no longer be treated as totally independent of its path already traveled inside the gas and the conditions leading to the exponential distribution for single electrons are violated. Therefore the Furry distribution can no longer describe the avalanche by a single electron and another distribution called *Polya* is used [6]. The Polya distribution is expressed like:

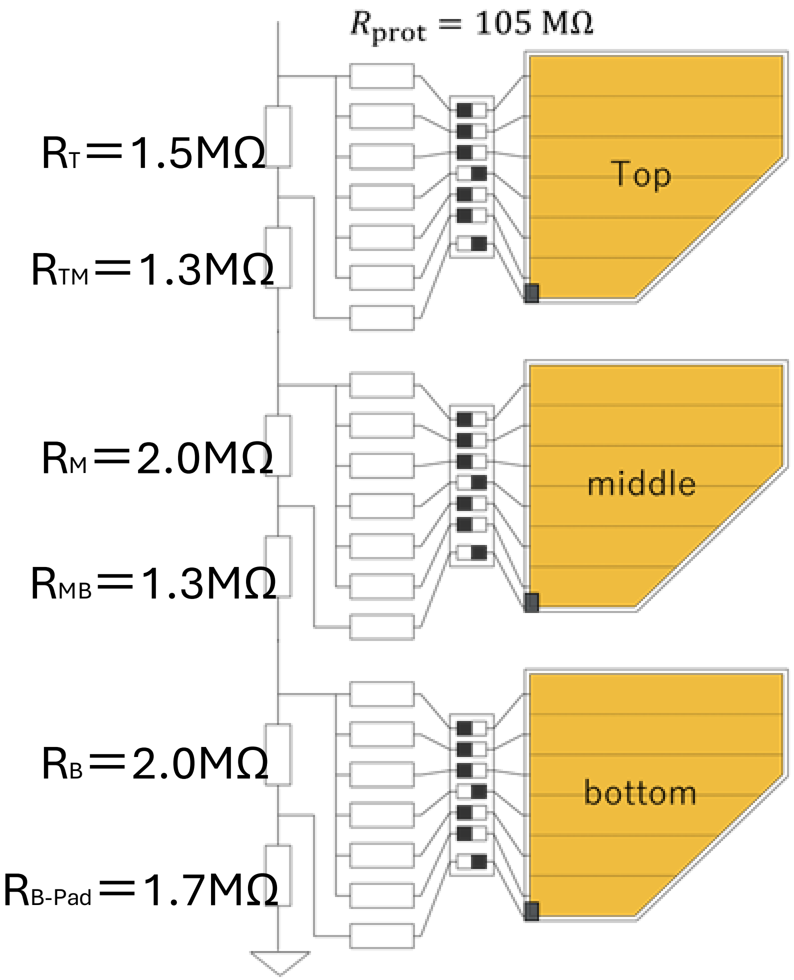
$$P(G) = C_0 \frac{(1+\theta)^{1+\theta}}{\Gamma(1+\theta)} \left(\frac{G}{\overline{G}}\right)^{\theta} \exp\left[-(1+\theta)\frac{G}{\overline{G}}\right] \tag{3.27}$$

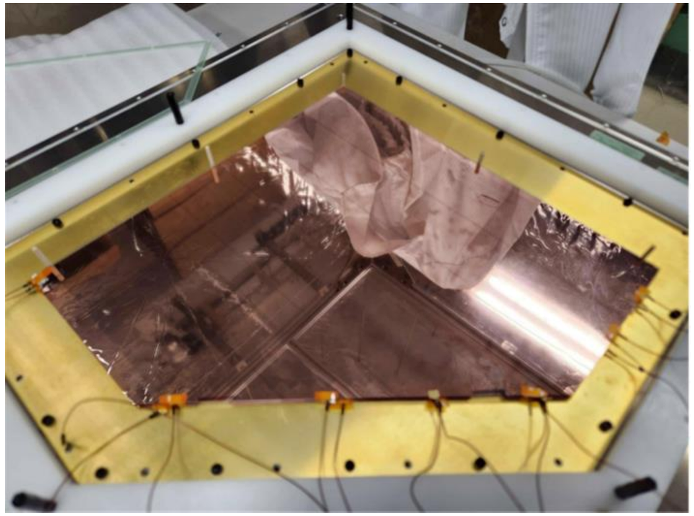
where $\theta$ is the parameter related to the relative gain variance $f = 1/(1+\theta)$. Frequently, Polya distribution is used to describe the avalanche fluctuations in homogeneous fields. Although Polya distribution describes the avalanche pretty well, it lucks any physical interpretation.

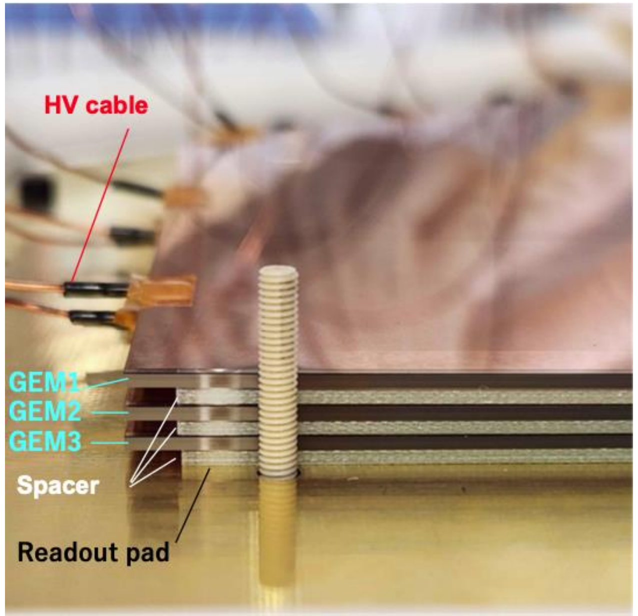
# Glass GEM




100 µm Glass GEM

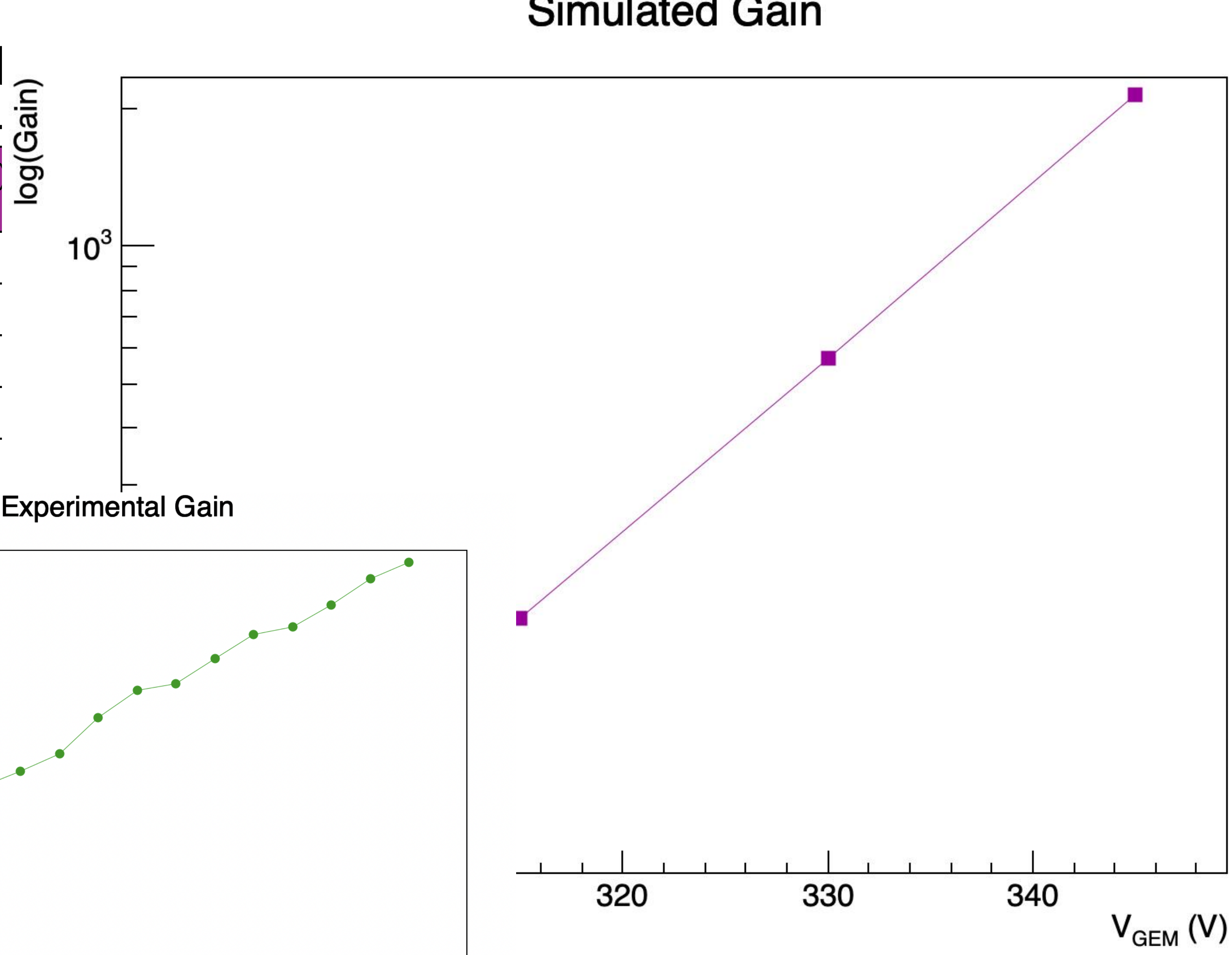


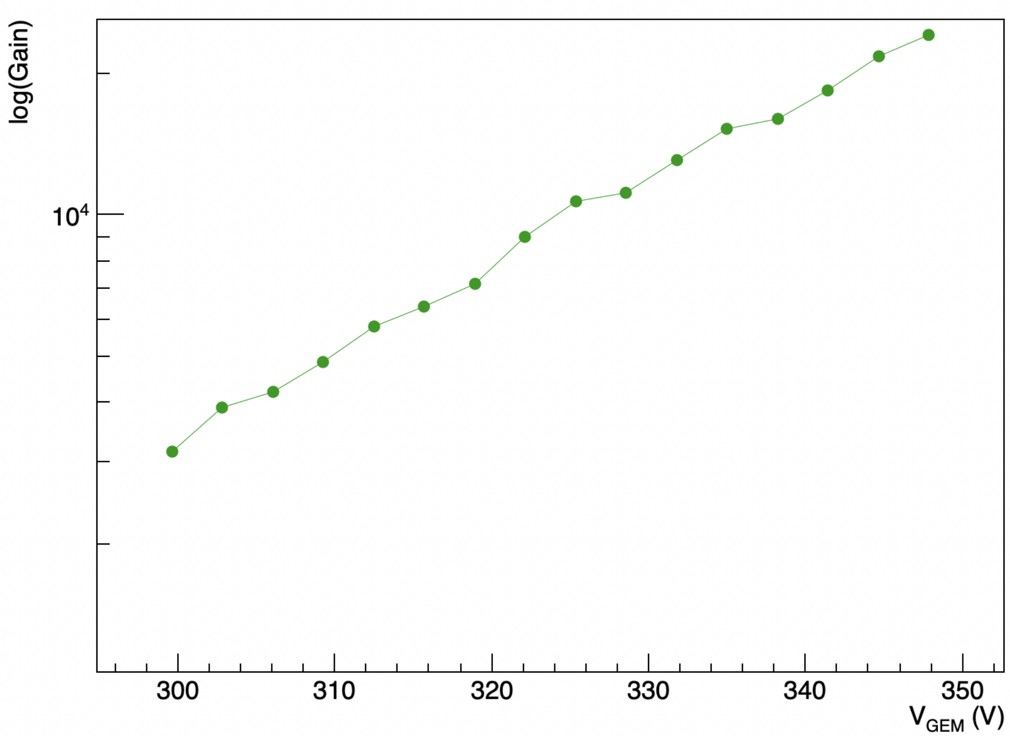





# GEM simu … P GEM

| GEM2,3 (V) | GEM 1(V) |
|---|---|
| 300 | 450 |
| 315 | 472.5 |
| 330 | 495 |
| 345 | 517.5 |

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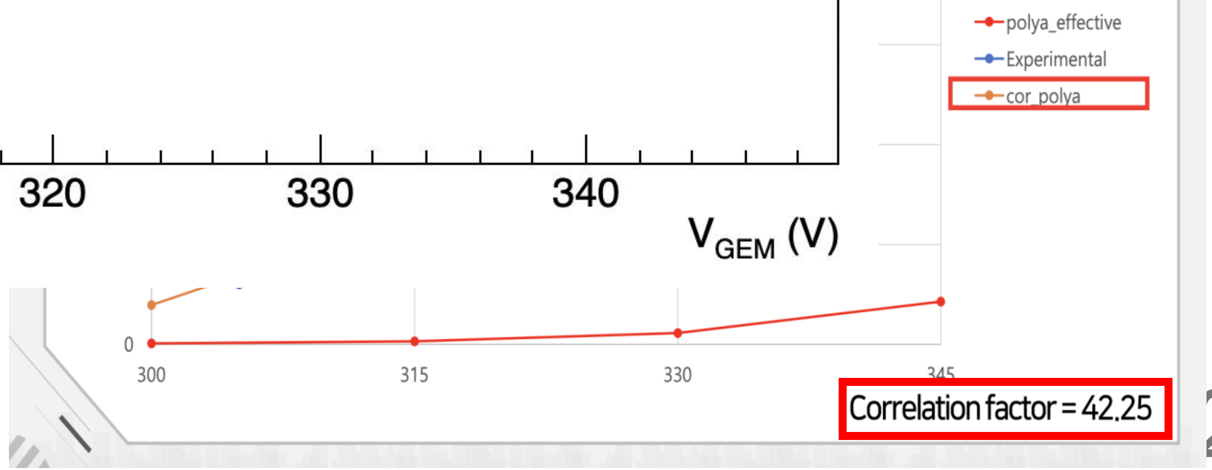

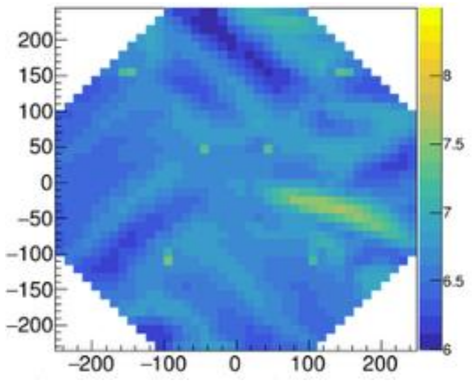


②Flatness(Sagging)

Higher spark rate

**So we're developing Glass GEMs — stronger and with fewer sparks!**