Studies on Diamond-like Carbon Coated GEMs and Ceramic GEMs

RD51 Collaboration Meeting
CERN

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PHYSICS AT THE TERA SCALE Helmholtz Alliance

Center for Particle Physics Siegen

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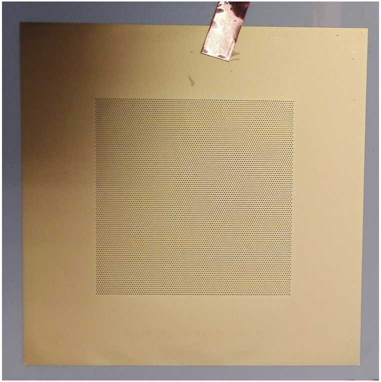
Outline

Ceramic GEMs

A Time Projection Chamber for a Future Linear Collider

- Motivation for the use of ceramic: **Higher tolerance for discharges.**
- Produced by a Japanese Company named "KOA Corporation"
- Holes made by tipping



Ceramic GEM

- Two batches of GEMs
  - First batch: **Without rim** around the holes. Caused discharges at low voltages
  - Second batch: **Rim included.** Decreased probability of discharges. Only the second batch of GEMs are characterized.

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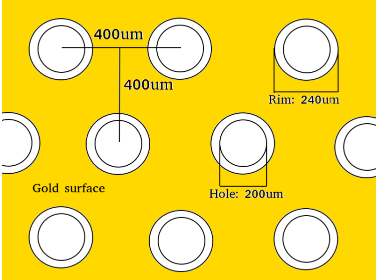
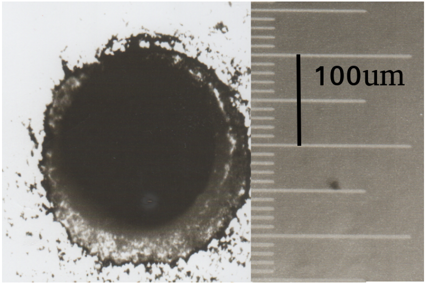
Ceramic GEMs

A Time Projection Chamber for a Future Linear Collider



Sketch of a ceramic GEM



A picture of a hole in a ceramic GEM

Properties	ceramic	CERN
Size	$50mm \times 50mm$	$50mm \times 50mm$
Thickness	$120\mu m$	$50\mu m$
Conductor	Silver, Nickel and Gold	Copper
Insulator	**Ceramic**	**Kapton**
Holes diameter	$200\mu m$ (**straight**)	$50 - 70\mu m$ (**conic**)
Pitch	$400\mu m$	$140\mu m$
Ceramic body	Glass-Alumina composite	n/a

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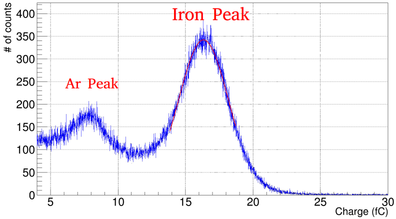
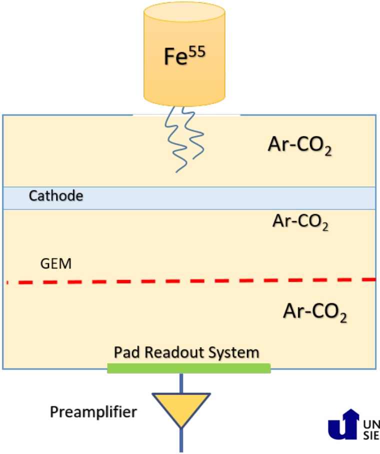
Test Chamber in Siegen

- Small chamber **(120 mm × 184 mm)**to measure the gain of GEMs.
- Gas mixture: **Ar – CO_2 (80% – 20%)** mixture.
- 5.9 keV **X-ray source (^{55}Fe)** for primary ionization.
- Drift field: **0.5 kV/cm**, induction field: **2kV/cm**.
- Pressure: **Air pressure**
- Temperature: **Room temperature**
- Multi Channel Analyzer (MCA) Spectra

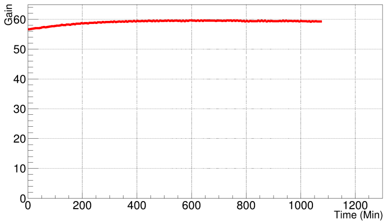


Signal with 2 peaks (Argon escape peak and ^{55}Fe peak).

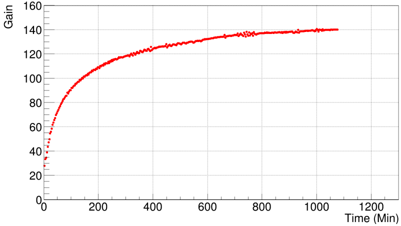


Long Time Stability

A Time Projection Chamber for a Future Linear Collider



Long time measurement with CERN GEM



Long time measurement with ceramic GEM

- The first important result of ceramic GEM: **Charge up effect**.
  - CERN GEM gain starts already from 95% of maximum gain
  - Gain stabilization of a ceramic GEM takes hours.

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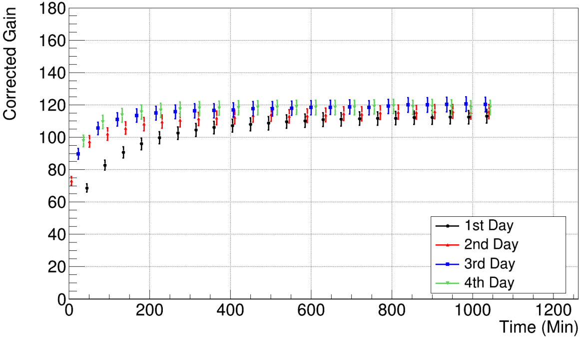
Repeatability

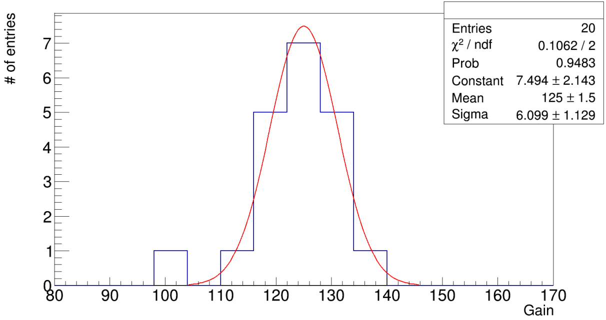


Long time measurements **after T/P correction** at 1 atm and 300 K.

Time required for	1st Day	2nd Day	3rd Day	4th Day	3 Days Later
90% of max gain	258 min	132 min	93 min	69 min	189 min
95% of max gain	414 min	276 min	192 min	117 min	297 min

- Second important result: **Conditioning**
  - Increase of gain stabilization with consecutive measurements

Repeatability

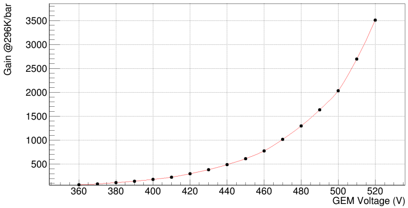


Distribution of gains from different measurements taken for 4 months of period

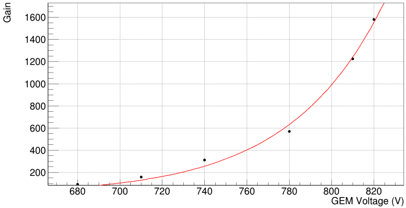
- Mean of the distribution of the corrected gains (at 1 atm and 300 K) from different measurements: **125**
- Relative width: $\sigma/\mu = 4.9\%$

Achievable Maximum Gain

A Time Projection Chamber for a Future Linear Collider



CERN GEM voltage vs gain.
1 atm and 300 K



Ceramic GEM voltage vs. gain
∼1 atm and ∼300 K

- Achievable maximum voltage without discharges
  - for CERN GEM: **520 V**
  - for ceramic GEM: **820 V**
- Gain at achievable maximum voltage without discharges
  - for CERN GEM: ∼**3500**
  - for ceramic GEM: ∼**1600**

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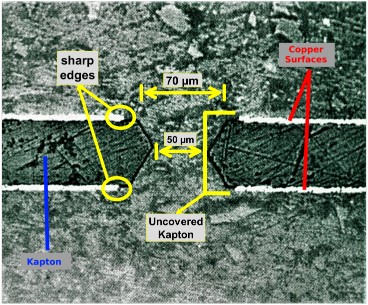
Summary of Ceramic GEMs

- CERN GEM and ceramic GEM measurements have been performed.
- Repeatability check of ceramic GEMs
  - $<5\%$ deviation between different measurements within 1σ
- **Charging up effect observed.**
- **Conditioning observed.**
- **Lower maximum safe gain.**
- Ceramic GEM studies have been terminated.

Diamond-like Carbon (DLC) Coated GEM

- Motivation
  - Reduce of discharge probability by coating sharp edges and kapton inside the holes
  - Establishment of well defined electric field within the hole
  - Increase of maximum safe gain voltage (and gain)
- Four batches of coating with different thicknesses and speeds
  - **50 nm fast**, **50 nm**, **100 nm**, **300 nm**



Cross section of a GEM

GEM	C. Speed	Thickness (nm)
SICON50f	fast	50
SICON50	normal	50
SICON100	normal	100
SICON300	normal	300

The list of DLC coated GEMs. There are four coated GEMs for each type of coating.

DLC Coating Procedure

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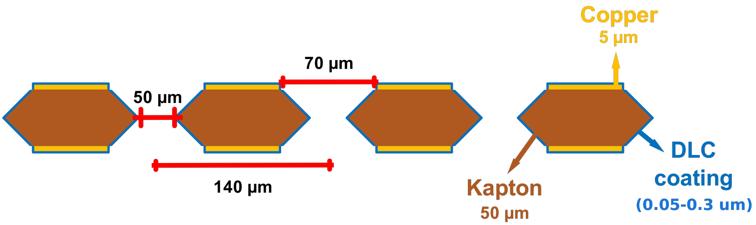
- Coatings done by **Fraunhofer-Institut für Schicht- und Oberflächentechnik** using Plasma assisted Chemical Vapor Deposition (PACVD) procedure.
  - **Hexamethyldisiloxane (HMDSO)** for **a-C:H:Si:O (SICON)** coating
  - High electric field to break HMDSO into fragments to grow diamond-like bonding
- Thickness control by deposition time

Coating material	Chemical deposition	Element Concentration			
		C	H	Si	O
HMDSO	a-C:H:Si:O	41-43	22-23	23-24	10-11



Schematic Cross section of a DLC GEM*

Thickness Measurements (on the Surface)

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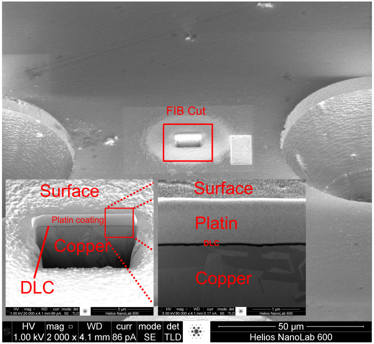
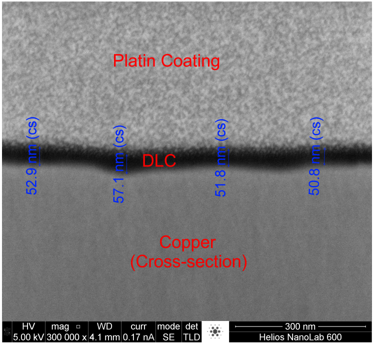
- **FIB (Focused Ion Beam)** analysis by Micro- and Nanoanalytics at Uni Siegen (Prof. Dr. Butz)
  - Coating of **platin-organic compounds** to increase contrast
  - Confirmed **the thickness** on surface of the GEM: **∼50nm**



FIB image from surface of the GEM.



FIB image with thickness measurement.

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Thickness Measurements (in the Holes)

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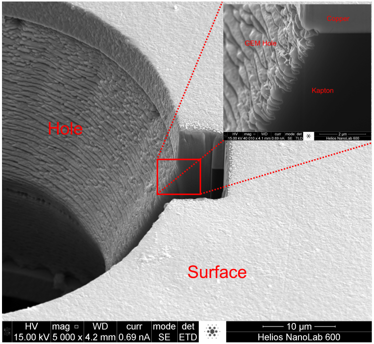
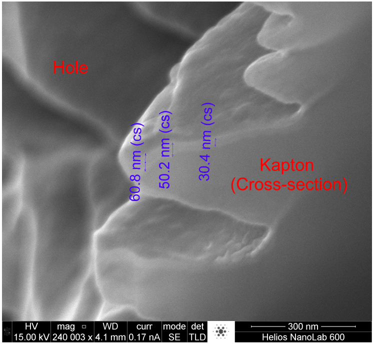
- The coating thickness measurement not possible due to **non-homogeneity of the inner wall of the hole**
- Rough surface inside the hole due to etching of the holes
- Confirmed **the existence of the DLC** on the wall of the hole by EDX



FIB image from a hole of the GEM.



FIB image inside the GEM hole with a presumable coating.

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Thickness Measurements (in the Holes)

- The coating thickness measurement not possible due to **non-homogeneity of the inner wall of the hole**
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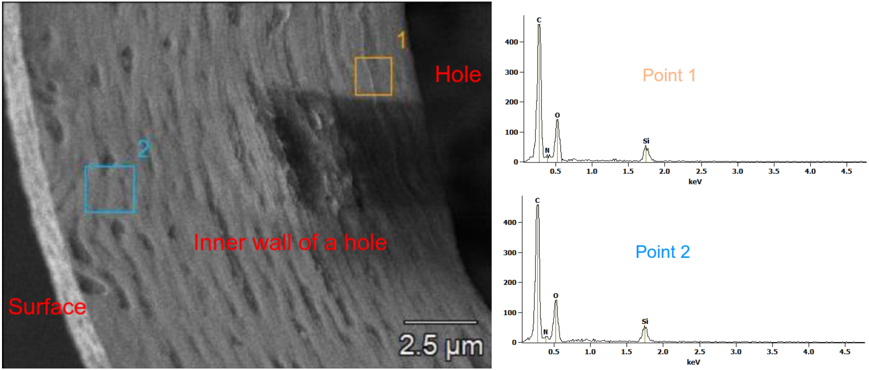
- Confirmed **the existence of the DLC** on the wall of the hole by EDX

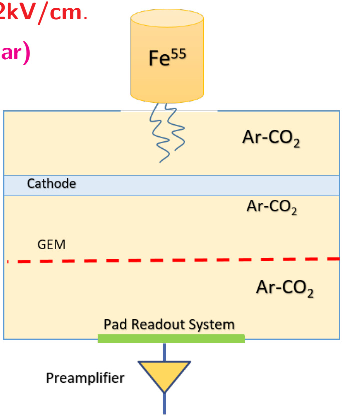


SEM image with EDX analysis

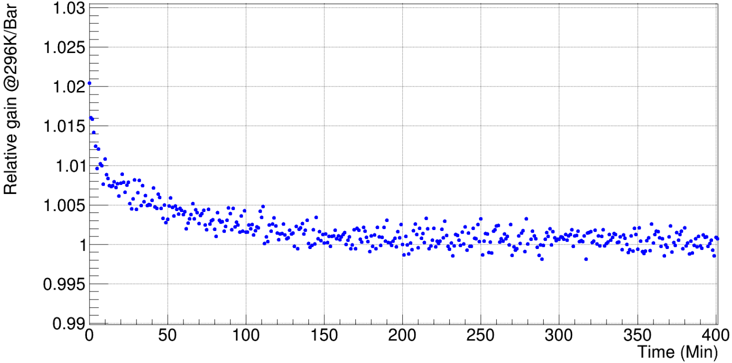
Test Chamber in Siegen

- Small chamber (**120 mm × 184 mm**)to measure the gain of GEMs.
- Gas mixture: **Ar – CO_2 (80% – 20%)** mixture.
- 5.9 keV **X-ray source** (**^{55}Fe**) for primary ionization.
- Drift field: **0.5 kV/cm**, induction field: **2kV/cm**.
- Pressure: **1 atm (1013.25 mbar ±1 mbar)**
- Temperature: ∼ **300K ±1K**
- **Corrected gain** for small T/P deviations

A scheme of the arrangement of the GEM inside the test chamber.



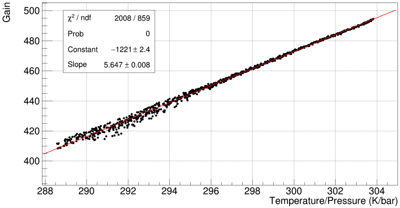
Charge up effect



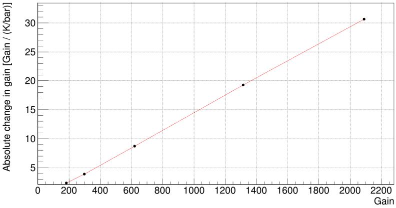
Gain vs. time

- MCA spectra with **1 minute-intervals**
- 2% overshooting of gain after 10V V_{GEM} increase
- Cut of first 150 minutes to get rid of charge up effects

Temperature/Pressure Correction



GEM gain vs. T/P at constant voltage

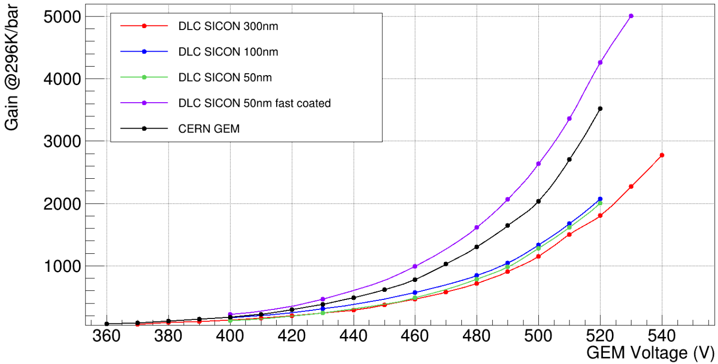


Absolute change in gain per 1 K/bar vs gain

GEM	Coating speed	Thickness nm	Change in gain % / (K/bar)
CERN	–	0	1.39
SICON50f	fast	50	1.49
SICON50	normal	50	1.19
SICON100	normal	100	0.87
SICON300	normal	300	0.78

- Aim to get same conditions to compare the measurements.
- A simple T/P correction coefficient for each type of GEM independent on other parameters around 1 atm and 300 K

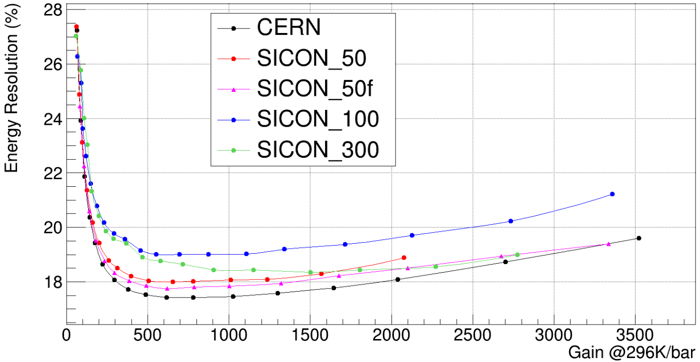
Comparison of Gains



Gain vs. GEM Voltage for SICON GEMs.

- Each point: **Gaussian mean** of the distribution of at least 90 MCA spectra.
- With DLC coating, **lower gain than in CERN GEM is achieved at same voltage**, except **50nm fast coated DLC GEMs**.

Energy Resolution



Energy Resolution vs. gain for 50nm fast coated SICON GEMs.

- Each point: **Gaussian mean** of the distribution of at least 90 MCA spectra
- Similar energy resolutions with respect to CERN GEMs

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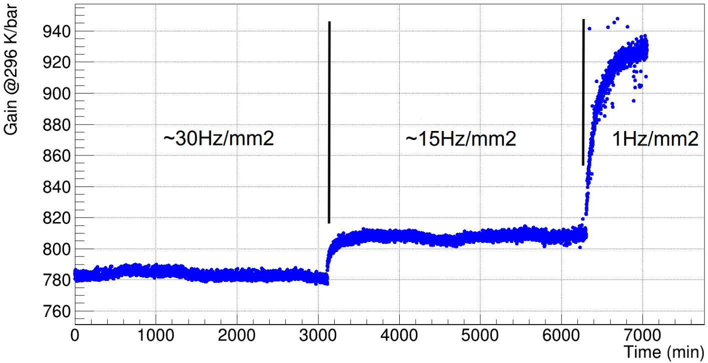
Rate Dependency of Gain



Gain vs. time with different rates for 50nm fast coated SICON GEMs.

- SICON GEM gain depends on the rate.
- The higher the rate, the lower the gain.
- Q:Typical behoviour of GEMs at lower rates??

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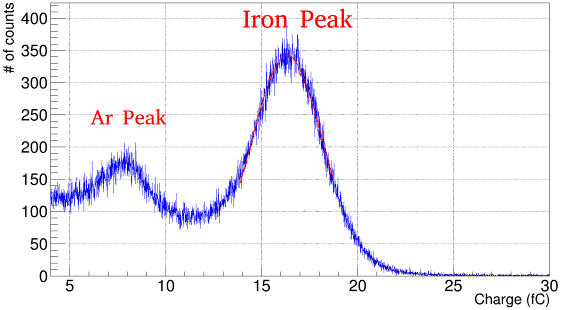
Summary of DLC GEMs

- CERN GEMs have been DLC coated by PACVD method with 3 different thicknesses and 2 different coating speeds **(50nm fast coated, 50nm, 100nm, 300nm)**.
- FIB analysis predicts the thickness for 50nm fast coated DLC GEMs as ∼**50nm on the surface**
- Existence of the DLC coating is confirmed **the inner wall of the holes** by EDX analysis
- Gains are corrected for **environmental parameters (pressure and temperature)**
- With DLC coating, **lower gain than in CERN GEM is achieved at same voltage**, except **50nm fast coated DLC GEMs**.
- **The thicker the coating, the lower the gain at same voltage**.
- SICON GEM gain depends on rate at lower values. (under investigation)

Backup

Gain Calculation



Signal with 2 peaks (Argon escape peak and ^{55}Fe peak).

- Number of primary electrons:
  $n_p = \frac{5900\ eV}{25\ eV} \times 0.80 + \frac{5900\ eV}{34\ eV} \times 0.20 = 223$
  - $25eV$ and $34eV$: Average energy per ionization for Ar and CO_2 respectively.
- Thus, the gain: ratio of total (n_t) to primary (n_p) electron number
  $G = n_t \times \frac{1}{n_p} = \frac{Q_t}{e} \times \frac{1}{223}$

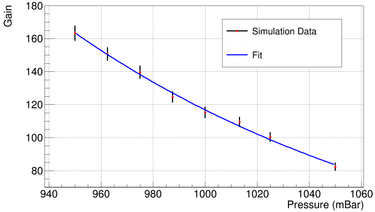
Pressure Adjustment

- Assumption for gain adjustment:
  - $G = e^{\alpha x}$ is valid
  - $\alpha = Ape^{-Bp/E} \propto p$ is valid
- Pressure adjustment fit function: $G = e^{sp+c}$
  - s: slope
  - c: constant

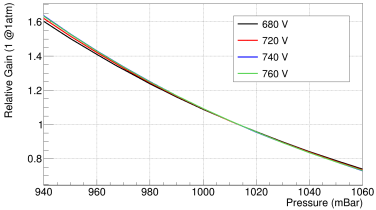
- Gain adjustment (at 1 atm):

$$G_{corr} = \frac{G_{meas}(p)}{e^{sp+c}}$$

V_{GEM} (V)	slope (Bar^{-1})	constant
680	**-6.44±4.5%**	6.53±4.5%
720	**-6.59±4.4%**	6.68±4.4%
740	**-6.72±4.5%**	6.81±4.5%
760	**-6.69±4.8%**	6.78±4.8%



Fit on simulations of ceramic GEM at 740 V



Fits on simulations of ceramic GEM at different V_{GEM}

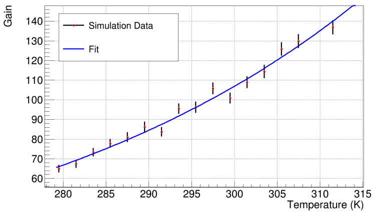
Temperature Adjustment

- Adjustment function by fitting simulation data
- Temperature adjustment fit function: $G = e^{sT+c}$
  - s: slope
  - c: constant

- Gain adjustment (at 299.5 K):

$$G_{corr} = \frac{G_{meas}(T)}{e^{sT+c}}$$

V_{GEM} (V)	slope ($10^2 K^{-1}$)	constant
680	**2.11±2.2%**	-6.32±2.2%
720	**2.2±2.1%**	-6.59±2.1%
740	**2.35±3%**	-7.03±3%
760	**2.39±5.4%**	-7.15±5.4%



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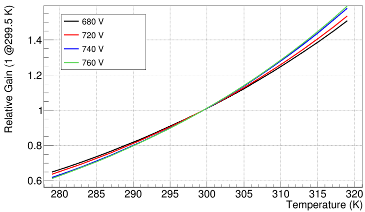

Fits on simulations of ceramic GEM at different V_{GEM}

Gas System in Siegen

A Time Projection Chamber for a Future Linear Collider

- The gas system includes a gas mixing system with desired percentages and a small chamber to monitor gas stabilization inside the experimental chamber
- After mixing process, gas mixture flows through the test chamber and/or the TPC prototype
- Later, the gas mixture flows to another chamber where we can monitor gas stabilization before it is released to air.

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