Gain and Stability Behaviour of Carbon Coated GEMs

RD51 Mini-Week
CERN

Serhat Atay Amir Alfarra Ivor Fleck

Department of Physics
University of Siegen

4 December 2018

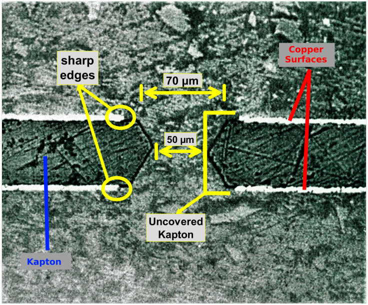
SPONSORED BY THE

Outline

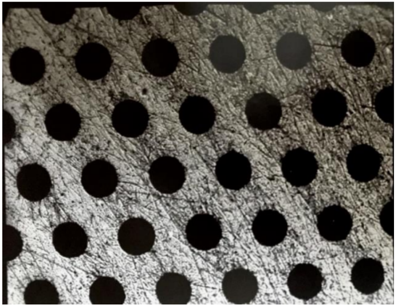
Diamond-like Carbon (DLC) Coated GEM

A Time Projection Chamber for a Future Linear Collider

- 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)
- Three batches of coating with different thicknesses
  - **50 nm**, **100 nm**, **300 nm**



Cross section of a GEM*



Surface of a DLC GEM*

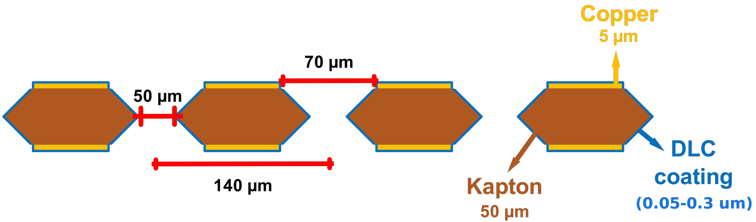
UNIVERSITÄT SIEGEN

*A. Alfarra, Master Thesis, October 2018

Coating Procedure

- Coatings done by **Fraunhofer Institut für Oberflächentechnik** using Plasma assisted Chemical Vapor Deposition (PACVD) procedure.
  - In a vacuumed chamber
  - **Hexamethyldisiloxane (HMDSO)** for **a-C:H:Si:O (SICON)** coating
  - High electric field to break HMDSO into fragments
- 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



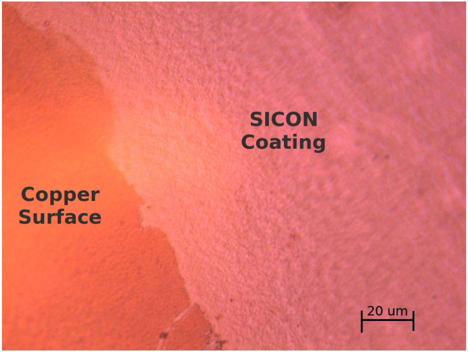
Schematic Cross section of a DLC GEM*

*A. Alfarra, Master Thesis, October 2018

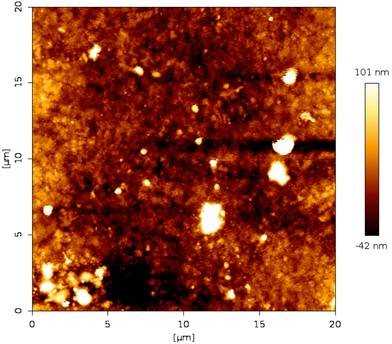
AFM Analysis (Preliminary)

A Time Projection Chamber for a Future Linear Collider

- Samples for analysis
  - **Additional coated GEMs** in the same coating process of DLC GEMs for AFM analysis
  - Coating **roughness is ∼5-10nm**
  - Coating **thickness** measurement is under study



Surface of a 50nm SICON GEM



AFM picture of 50nm sicon GEM surface

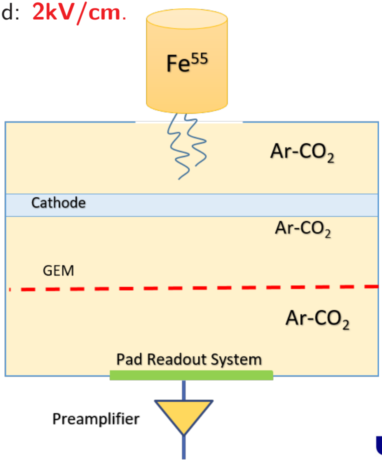
UNIVERSITÄT SIEGEN

Test Chamber in Siegen

A Time Projection Chamber for a Future Linear Collider

- Motivation: **Smaller drift distance, higher drift fields**.
- 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: **Absolute air pressure**
- Temperature: **Room temperature**

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



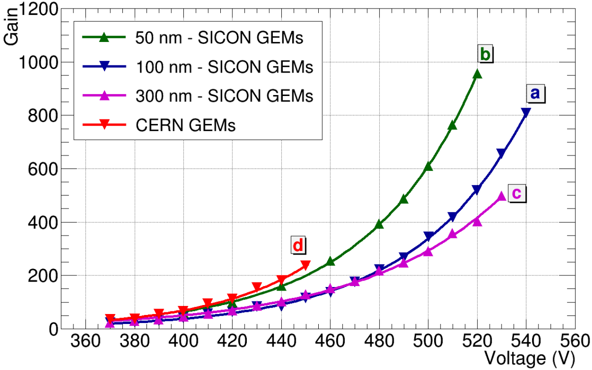
*Amir Alfarra.

UNIVERSITÄT SIEGEN

Gain of DLC GEMs

A Time Projection Chamber for a Future Linear Collider

Gain comparison of all coated and CERN GEMs*



- Gains corrected to **1 atm** and **300K** by coefficients from Garfield++ simulation
- **Lower gain at same voltage** for coated GEMs
- Highest gain **(>1000 w/o correction)** with **50nm coated GEMs**.
- **The thicker the thickness**, **the lower the gain** at same voltage.
- Maximum safe gain voltage for all coated GEMs: **510V**

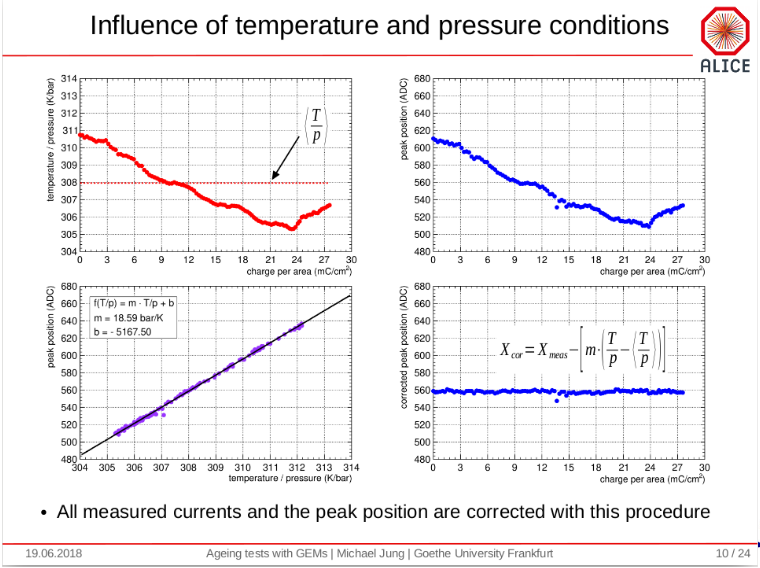
UNIVERSITÄT SIEGEN

*A. Alfarra, Master Thesis, October 2018

Environmental Parameters

A **T**ime **P**rojection **C**hamber
for a **F**uture **L**inear **C**ollider

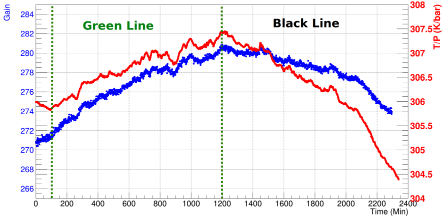
- Environmental parameter correction: **Simulations**→**Measurements**



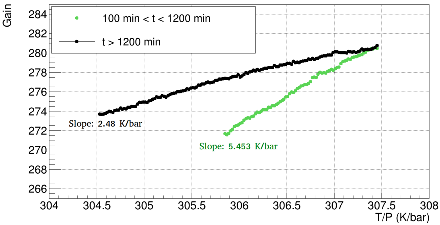
UNIVERSITÄT SIEGEN

Effects of Environmental Parameters

A Time Projection Chamber for a Future Linear Collider



100nm SICON GEM @480V



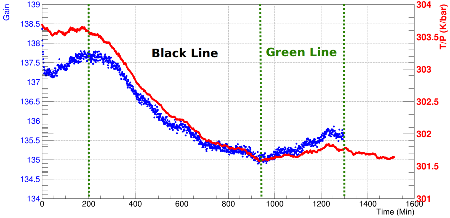
100nm SICON GEM @480V

- Results from **100nm SICON GEM @480V**
- 2 different slopes depending on T/P trend.
  - **Low slope when T/P decreases**
  - **High slope when T/P increases**
- Why different slopes of T/P vs. gain?

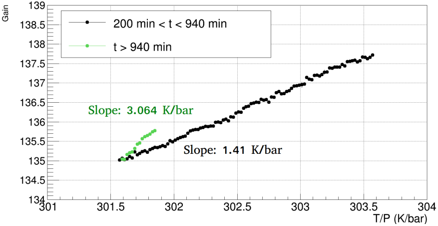
UNIVERSITÄT SIEGEN

Effects of Environmental Parameters

A Time Projection Chamber for a Future Linear Collider



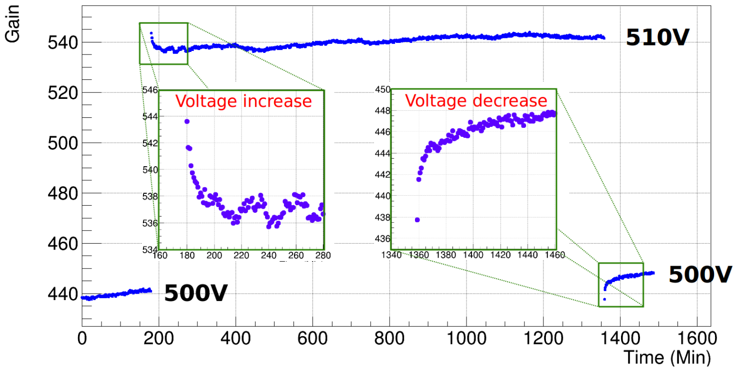
CERN GEM @430V



CERN GEM @430V

- Results from **CERN GEM @430V**
- 2 different slopes depending on T/P trend.
  - **Low slope when T/P decreases**
  - **High slope when T/P increases**
- Why different slopes of T/P vs. gain?

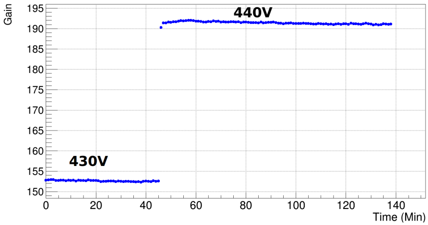
Turn on effect



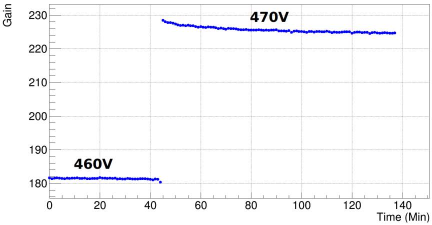
Gain during voltage change 100nm SICON GEM

- Each point is 1 minute of spectrum
- When voltage is
  - increased, gain increases higher than its new equilibrium then stabilizes.
  - decreased, gain decreases lower than its new equilibrium then stabilizes.
- Is this behaviour expected for GEMs?

Turn on Effect



CERN GEM



100nm SICON GEM

- Turn on effect comparison for **CERN GEM** and **100nm SICON GEM** after voltage change
- **CERN GEM doesn't have** turn on effect
- **SICON GEM has turn on effect** $\sim 2\%$ for 10V change

UNIVERSITÄT SIEGEN

Summary

- CERN GEMs have been DLC coated by PACVD method with 3 different thicknesses **(50nm, 100nm, 300nm)**.
- **Roughness is ∼5-10nm.**
- **Thickness measurement** of coatings is under investigation.
- With DLC coating, **lower gain is achieved at same voltage**, but **higher voltages are accessible to reach x5 gain than in CERN GEM**.
- **The thicker the coating, the lower the gain at same voltage**.
- Enviromental parameters (temperature and pressure) **affect the gain differently** (even for CERN GEMs) during increase and decrease of T/P. Gain changes slower when T/P is decreasing.
- After voltage change, **gain of the SICON GEM instantly overshoots and undershoots, then stabilizes**.

Backup

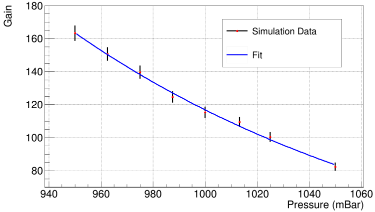
Pressure Adjustment

- 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

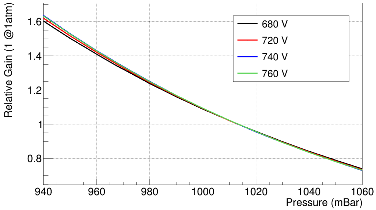
- Gain adjustment (at 1 atm):

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

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}

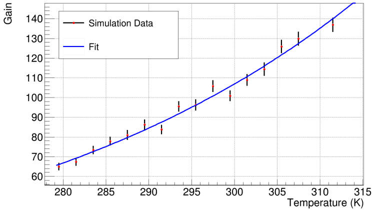
Temperature Adjustment

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

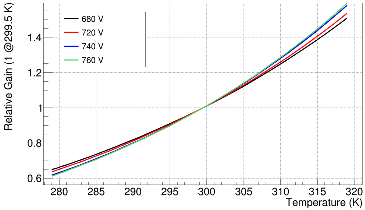
- Gain adjustment (at 299.5 K):

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

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%



Fit on simulations of ceramic GEM at 740 V



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.

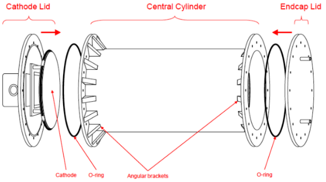
UNIVERSITÄT SIEGEN

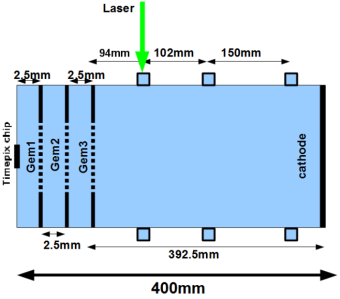
TPC Prototype in Siegen

A Time Projection Chamber for a Future Linear Collider

In Siegen we have a cylindirical TPC prototype with 240mm diameter and 400mm length

- As readout detector, it has a TimePix chip which has 256×256 pixel resolution with $55\mu m \times 55\mu m$ pixel size
- The TimePix chip is controlled via FPGA card and signal is recorded in a matrix form which inludes possible tracks of electrons
- To be able to start primary ionization, a UV laser and beta-ray source are used in 3 entry holes.

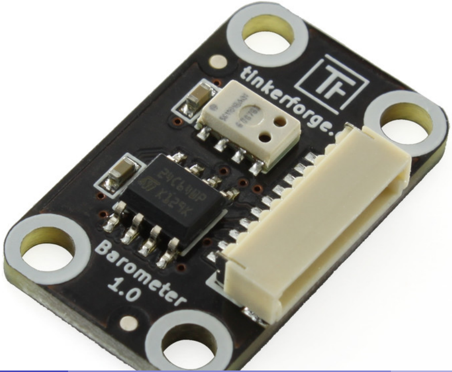




UNIVERSITÄT SIEGEN

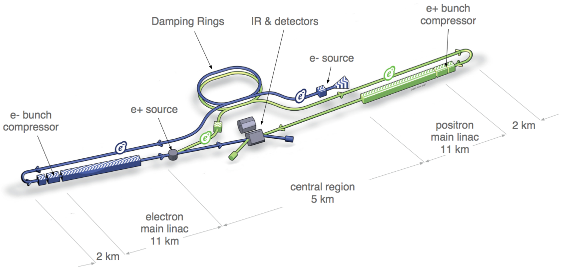
Pressure and Temperature Measurements

–Pressure of the gas mixture is slightly higher than absolute air pressure.
–Thus, absolute air pressure can be used as gas pressure since pressure difference is negligible
–Absolute air pressure is measured by a pressure sensor (MS5611-01BA01)
–Temperature is measured built-in temperature sensor of the pressure sensor



International Linear Collider (ILC)

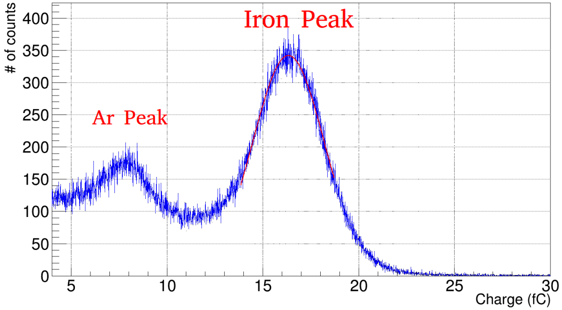
- Electron - positron collider
- Foreseen length: 31 km*
- Center of mass energy: 250 GeV to 500 GeV (1 TeV)
- Two foreseen detectors, one of them being the International Large Detector (ILD)
- Time Projection Chamber (TPC) as the tracker for the ILD
  - One of the candidates for electron multiplication: Gas electron multiplier (GEM)



*R. Diener, *Physics Procedia*, 00 (2012) 1-8

Gain Calculation

A Time Projection Chamber for a Future Linear Collider

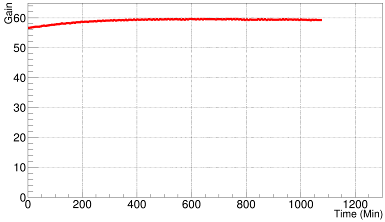


Signal with 2 peaks (Argon escape peak and ^{55}Fe peak).

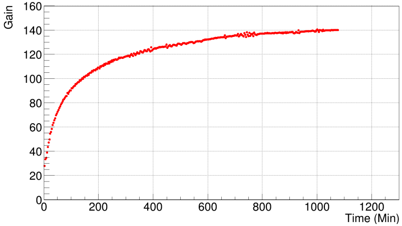
- Number of primary electrons:
  $n_p = \frac{5900\ eV}{26\ eV} \times 0.80 + \frac{5900\ eV}{34\ eV} \times 0.20 = 216$
  - $26eV$ and $34eV$: Average energy per ionization for Ar and CO_2 respectively.
- Thus, the gain: ratio of total (n_t) to primary (n_p) electron number
  $G = n_t \times \frac{1}{n_p} = \frac{Q_t}{e} \times \frac{1}{216}$

UNIVERSITÄT SIEGEN

Long Time Stability



Long time measurement with CERN GEM at V_{GEM}=390 V.



Long time measurement with ceramic GEM at V_{GEM}=740 V.

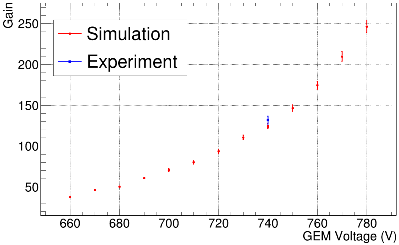
- The first important result of ceramic GEM: **Charge up effect**.
  - CERN GEM gain starts already from 95% of maximum gain
  - Gain stabilization of a ceramic GEM takes hours.

UNIVERSITÄT SIEGEN

Garfield++ Simulations

A Time Projection Chamber for a Future Linear Collider

- Field maps from ANSYS.
- Simulation with GEM specifications and geometries.
- Agreement within uncertainties (for the gains after stabilization)
- Pressure and temperature adjustment to compare measurements



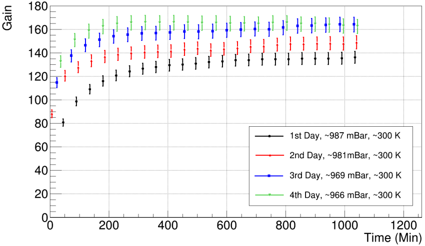
V_{GEM} vs. gain for ceramic GEM

GEM	data	V_{GEM} (V)	P (Bar)	T (K)	Gain	G_{sim}/G_{meas}
CERN	experiment	390	0.987	298	**59.64±2.17**	
CERN	simulation	390	0.987	298	**60.56±1.15**	**1.015±0.056**
Ceramic	experiment	740	0.9875	299.5	**131.2±4.91**	
Ceramic	simulation	740	0.9875	299.5	**124.6±3.13**	**0.95±0.059**

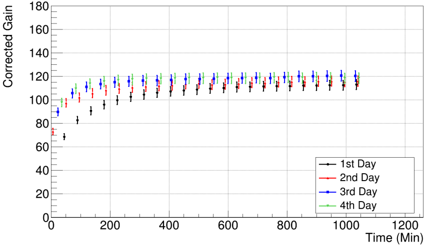
UNIVERSITÄT SIEGEN

Repeatability

A Time Projection Chamber for a Future Linear Collider



Long time measurements **before adjustment** for 4 consecutive days with ceramic GEM at 740 V.



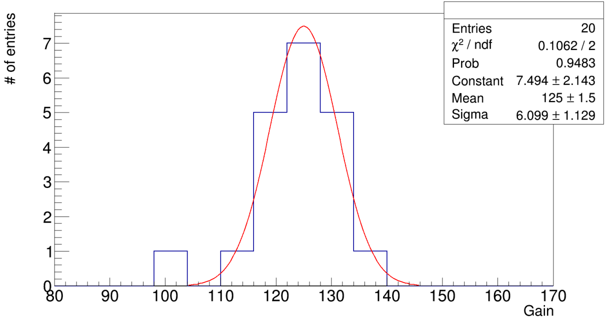
Long time measurements **after adjustment** at 740 V, 1 atm and 299.5 K.

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

- Pressure and temperature adjusted to **1 atm** and **299.5 K**,
- Second important result: **Conditioning**
  - Increase of gain stabilization with consecutive measurements

UNIVERSITÄT SIEGEN

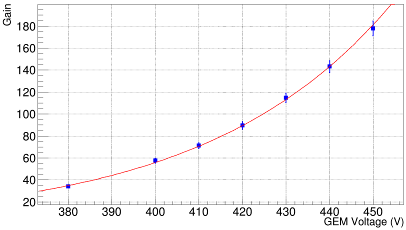
Repeatability



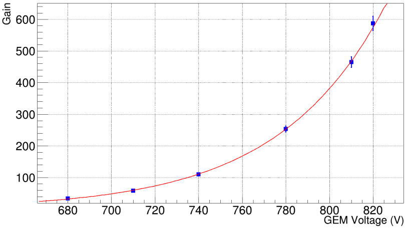
Distribution of gains from different measurements taken for 4 months of period

- Mean of the distribution of the adjusted gains (at 1 atm and 299.5 K) from different measurements: **125**
- Variation within 68% inclusion area: $\sigma/\mu = 4.9\%$

Achievable Maximum Gain



CERN GEM voltage vs gain.
976 mBar and 301-302 K



Ceramic GEM voltage vs gain.
982-985 mBar and 300-301 K

- Achievable maximum voltage without discharges
  - for CERN GEM: **450 V**
  - for ceramic GEM: **820 V**
- Gain at achievable voltage without discharges
  - for CERN GEM: **178**
  - for ceramic GEM: **586**

Ceramic GEM Characterization

- Long time stability measurements
  - Operation stability
  - Gain stability
- Repeatibility of measurements
  - Comparison of measurements
    - Challenges in comparison due to varying pressure and temperature
    - Adjustment of the gain to a chosen pressure and temperature using Garfield++ simulation data
- Achievable maximum voltage and gain