Characterization of Ceramic GEM for The International Large Detector

RD51 Collaboration Meeting and the "MPGD Stability" Workshop Münich

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Outline

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

1. Introduction
   - International Linear Collider (ILC)
2. LCTPC Lab at Siegen
   - Ceramic GEM
   - Test Chamber
3. Measurements and Characterization
   - Long Time Stability
   - Repeatability
   - Maximum Gain
4. Summary

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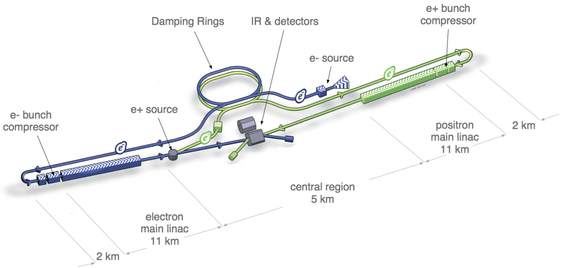
International Linear Collider (ILC)

A *Time Projection Chamber* for a *Future Linear Collider*

- 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)



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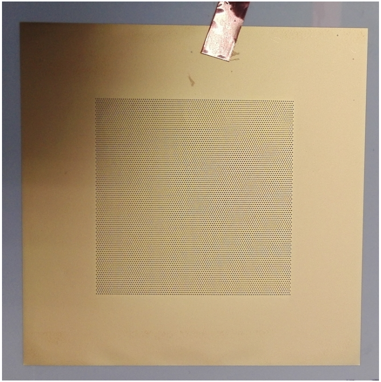
*R. Diener, *Physics Procedia*, 00 (2012) 1-8

Ceramic GEM

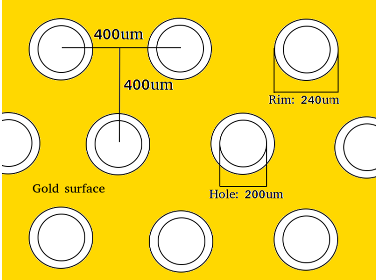
- Motivation of use of ceramic: **Resistance against melting**.
- Avoid melting of the insulator with the heat emerging by discharges
- Produced by a Japanese Company named "KOA Corporation"
- Holes made by tipping



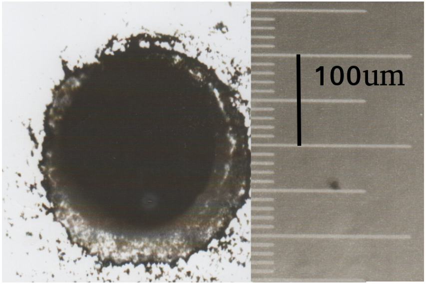
Ceramic GEM

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

Ceramic GEM



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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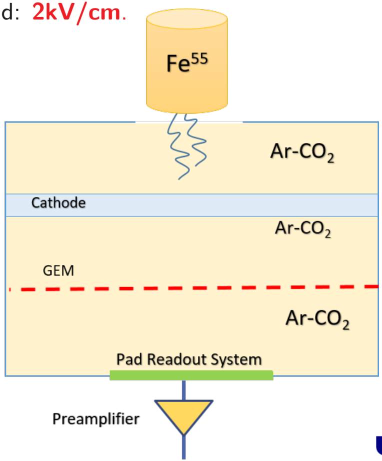
Test Chamber in Siegen

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*



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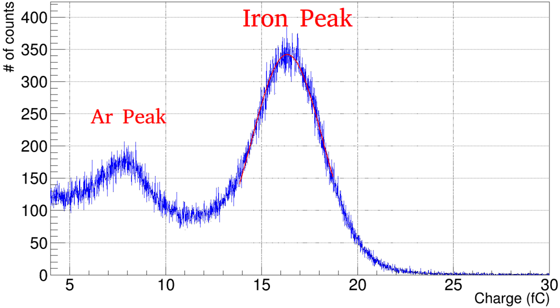
*Amir Alfarra.

Gain Calculation



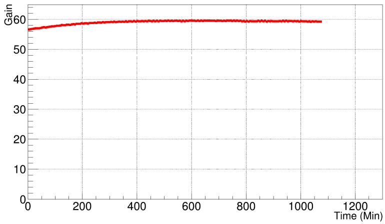
Signal with 2 peaks (Argon escape peak and ^{55}Fe peak).

- 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
  $$G = n_t \times \frac{1}{n_p} = \frac{Q_t}{e} \times \frac{1}{216}$$

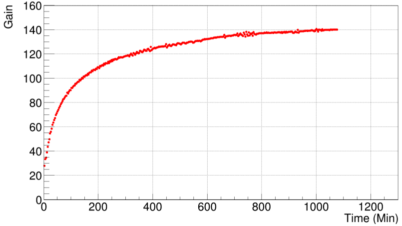
Ceramic GEM Characterization

- 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

Long Time Stability



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

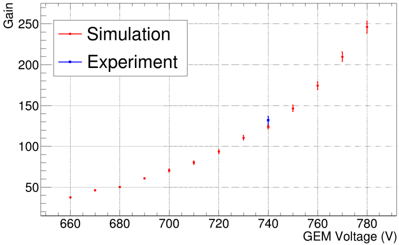


Long time measurement with ceramic GEM at V_{GEM}=740 V.

- 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.

Garfield++ Simulations

- 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**

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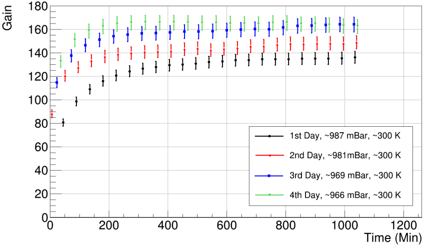
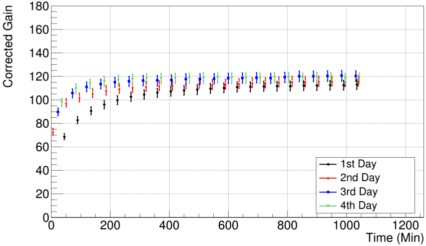
Repeatability



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

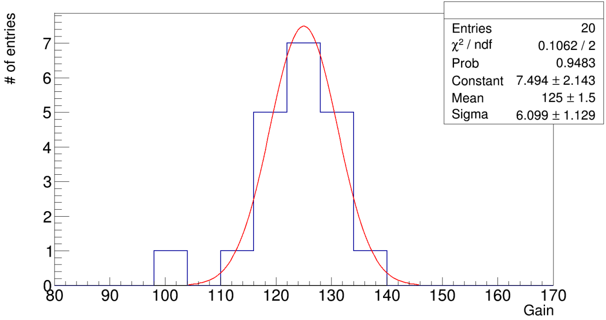


Long time measurements **after adjustment** at 740 V, 1 atm and 299.5 K.

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

Repeatability

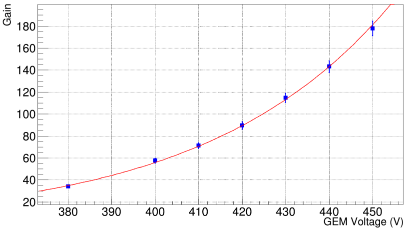


Distribution of gains from different measurements taken for 4 months of period

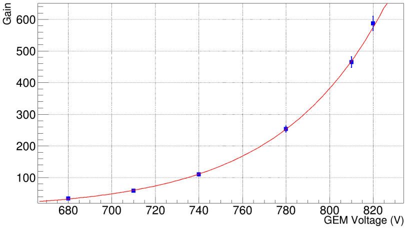
- Mean of the distribution of the adjusted gains (at 1 atm and 299.5 K) from different measurements: **125**
- Variation within 68% inclusion area: $\sigma/\mu = 4.9\%$

Achievable Maximum Gain

A Time Projection Chamber for a Future Linear Collider



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**

Summary

- CERN GEM and ceramic GEM measurements have been performed.
- Measurements have been compared to Garfield++ simulations.
- Pressure and temperature adjustments for repeatability check of ceramic GEMs
  - $<5\%$ deviation between different measurements within 1σ
- **Charging up effect observed.** The gain of the ceramic GEM requires hours to become stabilized
- **Conditioning observed.** The ceramic GEM has a memory. Early reach of maximum gain if consecutive (HV) ramp-up and ramp-down performed.
- **Higher maximum safe gain.** The ceramic GEM has higher achieavable gain than in CERN GEM

Backup

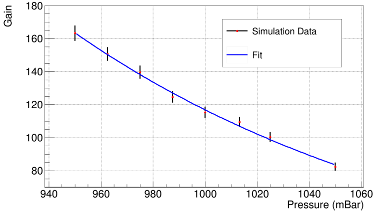
Pressure Adjustment

- 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

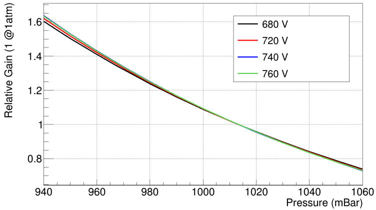
- Gain adjustment (at 1 atm):

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

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}

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Temperature Adjustment

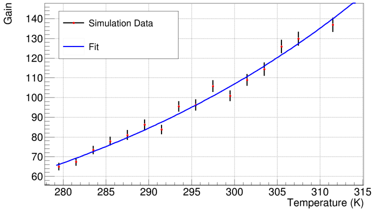
A Time Projection Chamber for a Future Linear Collider

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

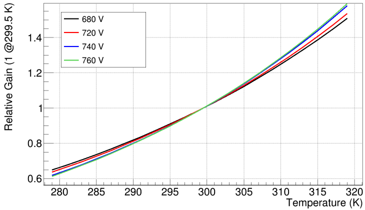
- Gain adjustment (at 299.5 K):

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

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}

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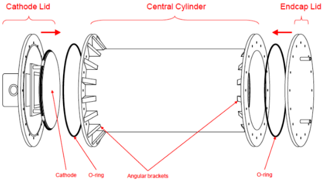
Gas System in Siegen

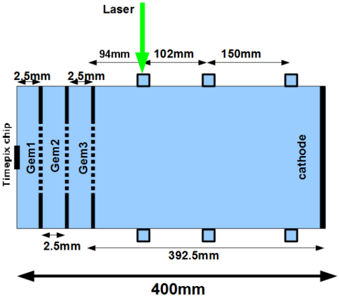
- The gas system includes a gas mixing system with desired percentages and a small chamber to monitor gas stabilization inside the experimental chamber
- After mixing process, gas mixture flows through the test chamber and/or the TPC prototype
- Later, the gas mixture flows to another chamber where we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

TPC Prototype in Siegen

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.





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