Characterization of Ceramic GEM for The International Large Detector

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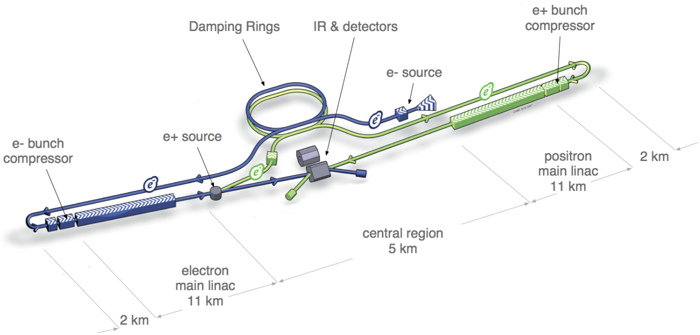
Outline

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 International Large Detector (ILD)



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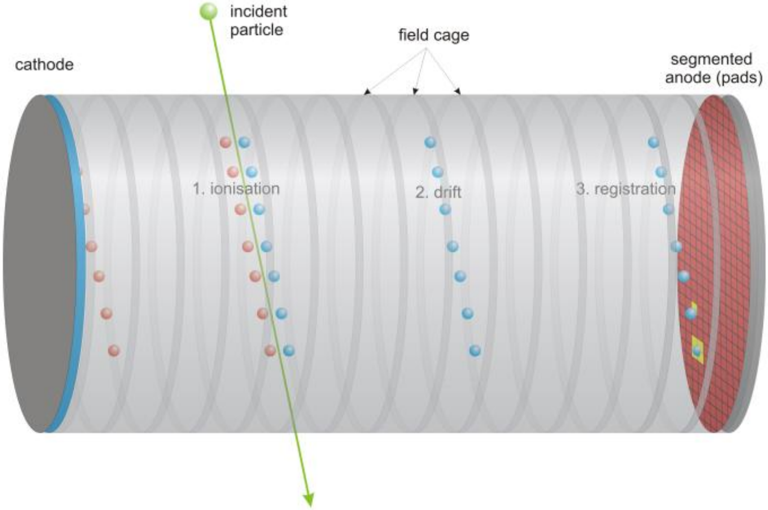
*R. Diener, *Physics Procedia*, 00 (2012) 1-8

Time Projection Chamber (TPC)

A Time Projection Chamber for a Future Linear Collider



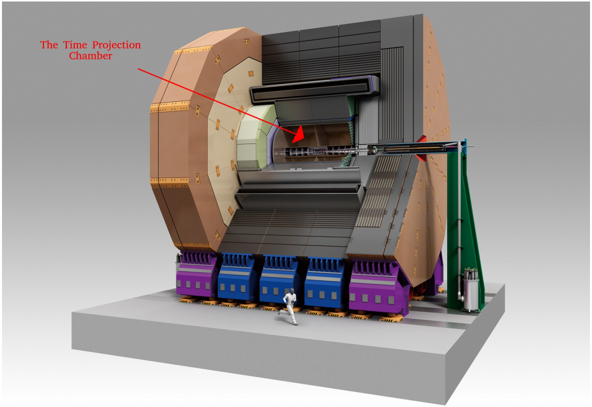
An illustration of a TPC.*

*LCTPC webpage, lctpc.org

Time Projection Chamber (TPC)

ILD tracking detector should have;

- good track separation,
- low material budget,
- and a very good pattern recognition.



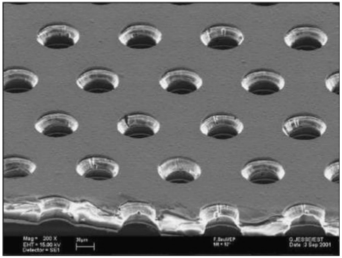
An illustration of ILC ILD.*

The ILD TPC can achieve all these requirements

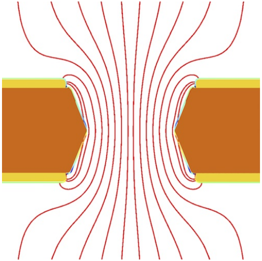
*LCC webpage, linearcollider.org

Gas Electron Multipliers

- A candidate device for electron multiplication in ILD TPC.
- Proven method for amplification developed by F. Sauli at CERN in 1997.
- Two conducting layers (mostly copper) around a non-conducting substrate (mostly kapton) with a thickness around 50 μm.
- Holes through insulator and conductor layers.



Electron microscope picture of a section of typical GEM electrode, 50 μm thickness.*

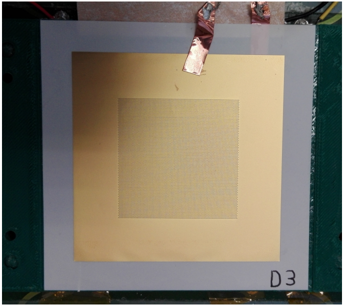


Electric field in the region of the holes of a GEM electrode.

*F. Sauli, *Nuclear Instruments and Methods in Physics Research A* 805 (2016) 2-24

Ceramic GEM

- Motivation of use of ceramic: **Resistance to electrical discharge**, higher heat capacity and hardness.
- Ceramic GEMs developed for Uni Siegen
- Higher gain due to larger avalanche path (thickness).



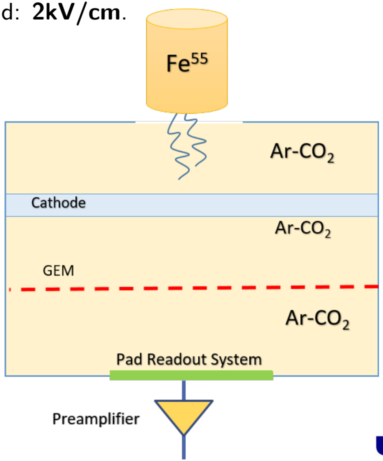
Ceramic GEM.

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

Test Chamber in Siegen

- Motivation: **Smaller drift distance, higher drift fields**.
- Small chamber (**120 mm** $\times$ **184 mm**) to measure the gain of GEMs.
- Gas mixture: $\mathbf{Ar - CO_2}$ ($\mathbf{80\% - 20\%}$) 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.

Gain Calculation

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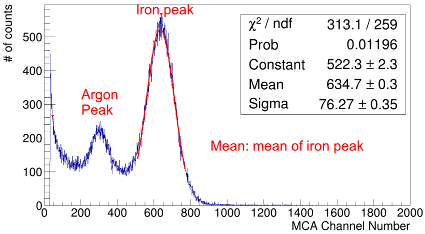
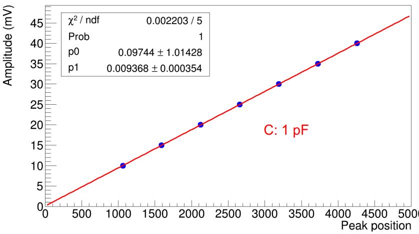


Signal with 2 peaks (Argon escape peak and ^{55}Fe peak).



Calibration fit with a pulse generator.

- Total charge: $Q_t = (p_0 + p_1 \times Mean) \times C$.
- 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
  $G = n_t \times \frac{1}{n_p} = \frac{Q_t}{e} \times \frac{1}{216}$

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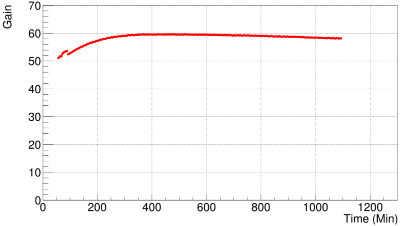
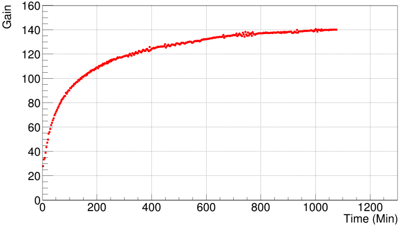
Long Time Stability



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

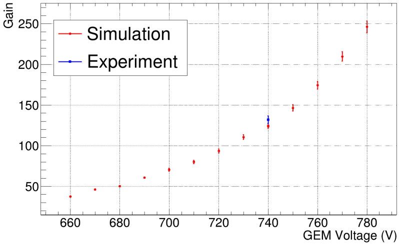


Long time measurement with ceramic GEM at V_{GEM}=740 V.

- The first important result of ceramic GEM: **Charge up effect**.
- Gain dependance: **Pressure, temperature,** electric field and nature of gas.
- First Townsend coefficient and gain: $\alpha = Ape^{-Bp/E}$, $G = e^{\alpha x}$
  - A and B: phonemenological constant of the gas,
  - p: pressure of the gas,
  - E: electric field,
  - x: thickness of GEM,

Garfield++ Simulations

- Field maps from ANSYS.
- Simulation with GEM specifications and geometries.
- Verification of test setup by CERN GEM gain simulation.
- Less gain in ceramic GEM simulation than in measurements



V_{GEM} vs. gain for ceramic GEM

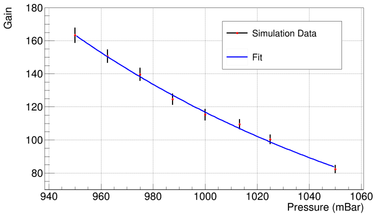
GEM	data	V_{GEM} (V)	P (Bar)	T (K)	G	G_{sim}/G_{meas}
CERN	experiment	390	0.987	298	**59.64±2.17**	
CERN	simulation	390	0.987	298	**60.56±1.15**	**1.015±0.056**
Ceramic	experiment	740	0.9875	299.5	**131.2±4.91**	
Ceramic	simulation	740	0.9875	299.5	**124.6±3.13**	**0.95±0.059**

Pressure Correction

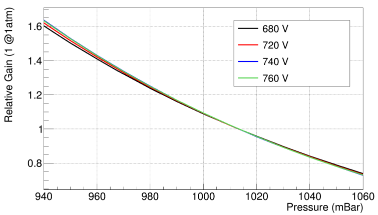
- Assumption for gain correction:
  - $G = e^{\alpha x}$ is valid
  - $\alpha = Ape^{-Bp/E} \propto p$ is valid
- Pressure correction fit function: $G = e^{sp+c}$
  - s: slope
  - c: constant

- Gain correction 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 Correction

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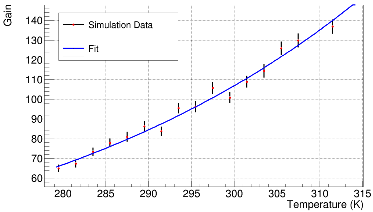
- Correction function by fitting simulation data
- Temperature correction fit function: $G = e^{sT+c}$
  - s: slope
  - c: constant

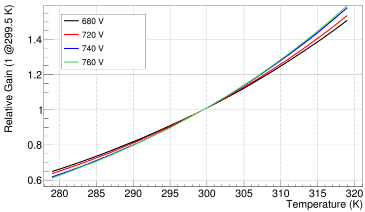
- Gain correction at 299.5 K:

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

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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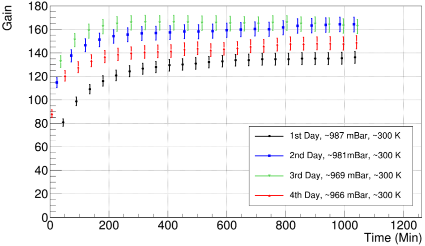
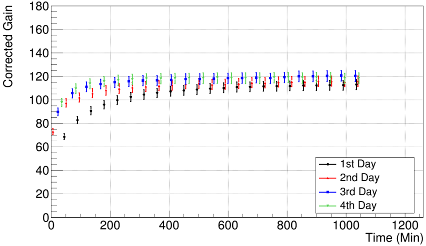
Results



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



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

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

- Gain at 1 atm, 299.5 K and 740 V: ∼117
- Second important result: **Conditioning**
  - Increase of gain stabilization with consecutive measurements

Summary

A Time Projection Chamber for a Future Linear Collider

- CERN GEM and ceramic GEM measurements have been performed.
- Measurements have been compared by Garfield++ simulations.
- Pressure and temperature corrections for repeatability check
  - **Repeatable within uncertainties**
- **Charging up effect observed.** The gain of the ceramic GEM becomes stabilized after first hours as in the CERN GEM
- **Conditioning observed.** It has a memory. Early reach of maximum gain if consecutive (HV) ramp-up and ramp-down performed.

Backup

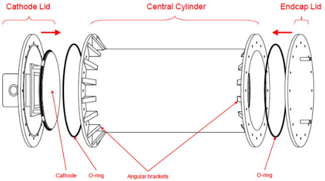
Gas System in Siegen

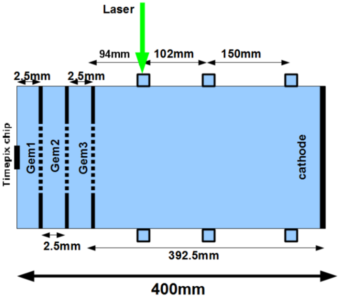
- The gas system includes a gas mixing system with desired percentages and a small chamber to monitor gas stabilization inside the experimental chamber
- After mixing process, gas mixture flows through the test chamber and/or the TPC prototype
- Later, the gas mixture flows to another chamber where we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





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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