Simulation of multi-layer GEM detectors

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- Motivation and Method
- Simulation results of single, double and triple GEMs
- Simulation results of quadruple GEMs
- Summary

Contents

- **Major advantage:** With a multi-GEM layer structure, a very high effective gain (up to 10^6 with some gases) can be attained with each GEM layer working at an individually much lower gain thus avoiding discharge problems.

- **Our group's simulation motivation:**
  - Single, double and triple GEMs:

    - There is not enough information to compare and understand the differences between single, double and triple GEMs seen in experiments and simulations.

    - There are consistently seen difference in gain between simulation and experiment results.

  - Quadruple GEM:

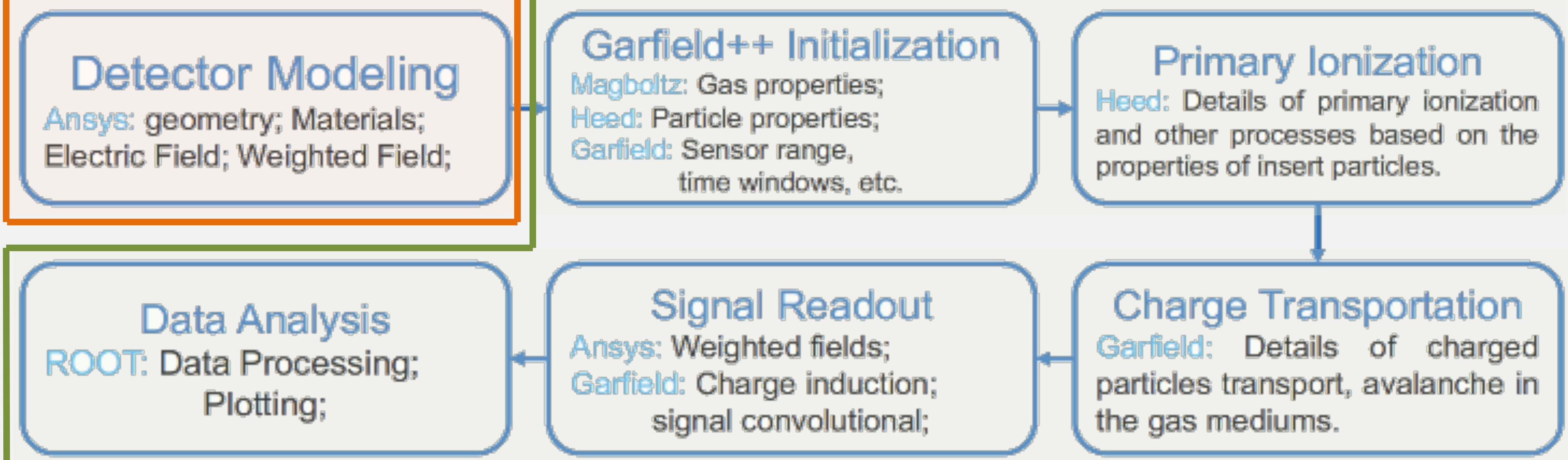
    - Lower operating voltage, low discharge probability and low IBF make it more attractive for high radiation environments

01 Simulation steps (characteristics of the detector)

- **Commercial software ANSYS + free software GARFIELD++**

ANSYS : https://www.ansys.com/

design the detector geometry, set boundary conditions and optimize the mesh of the structure for the electric potential calculation of each finite element

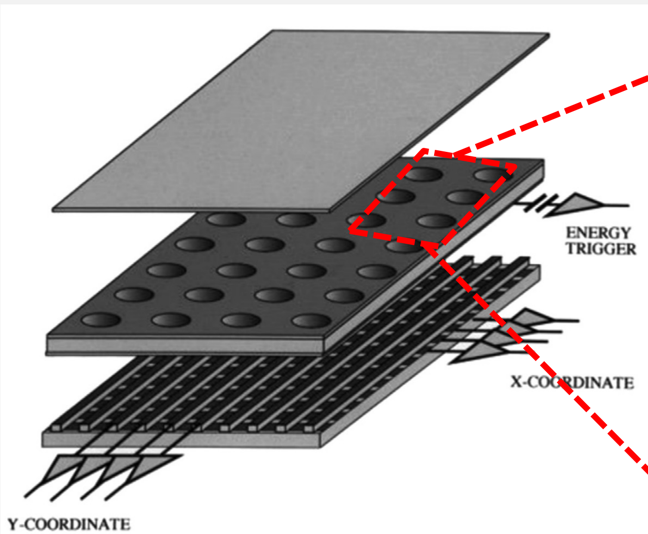


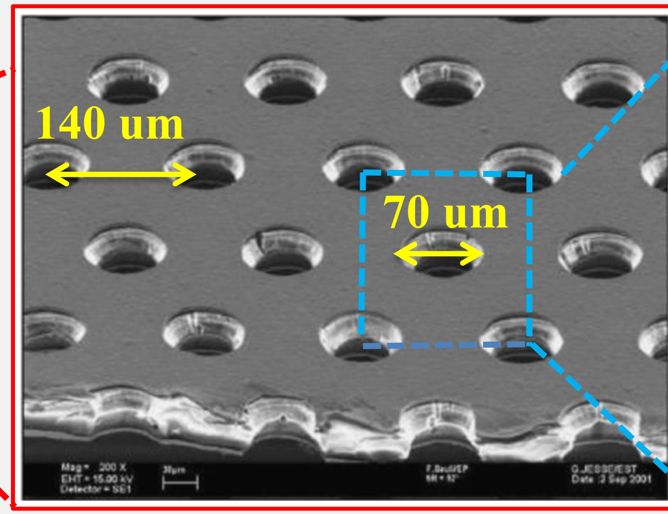
Garfield++: https://garfieldpp.web.cern.ch/garfieldpp/

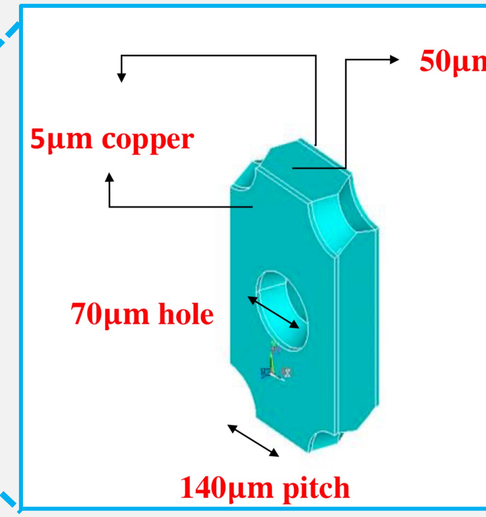
simulation of the electron motions

01 Simulation model – GEM foil geometry and gas

- **Schematics of single GEM detector**
- **Microscope view of GEM foil**
- **Standard hexagonal GEM foil**





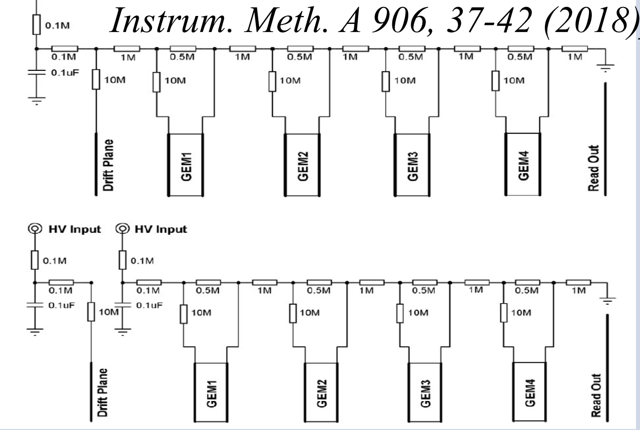


Fabio Sauli, The gas electron multiplier (GEM): Operating principlesand applications, Nuclear Instruments and Methods in Physics Research A 805 (2016) 2-24

https://garfieldpp.web.cern.ch/garfieldpp/examples/triplegem/

- The foil (e.g. 50 um thick kapton) is metalized on both sides (e.g. 5 um copper) and has a pattern of holes (e.g. 70 um with a 140 um pitch).
- Gas: Single, double and triple GEMs - 70% Ar + 30% CO_2
  triple and quadruple GEMs - 70% Ar + 30% CO_2 and 90% Ar + 10% CO_2

01 Simulation model – detector configuration in the simulation

<table>
<tr><th rowspan="2"></th><th rowspan="2">drift distance [mm]</th><th rowspan="2">transfer distance [mm]</th><th rowspan="2">induction distance [mm]</th><th colspan="3">HV divider</th><th rowspan="2">readout shape</th></tr>
<tr><th>drift field [kV/cm]</th><th>transfer field [kV/cm]</th><th>induction field [kV/cm]</th></tr>
<tr><td>single</td><td>3</td><td>1 / 2</td><td>1 / 2</td><td>2</td><td>3.5</td><td>3.5</td><td>plate</td></tr>
<tr><td>double</td><td>3</td><td>1 / 2</td><td>1 / 2</td><td>2</td><td>3.5</td><td>3.5</td><td>plate</td></tr>
<tr><td>triple</td><td>3</td><td>1 / 2</td><td>1 / 2</td><td>2</td><td>3.5</td><td>3.5</td><td>plate</td></tr>
<tr><td>quadruple</td><td>4.8</td><td>2</td><td>2</td><td colspan="3">[Rajendra Nath Patra, et al., Nucl. Instrum. Meth. A 906, 37-42 (2018)]

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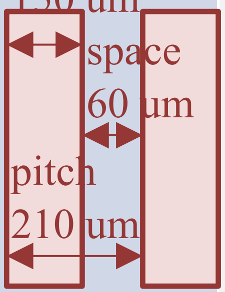
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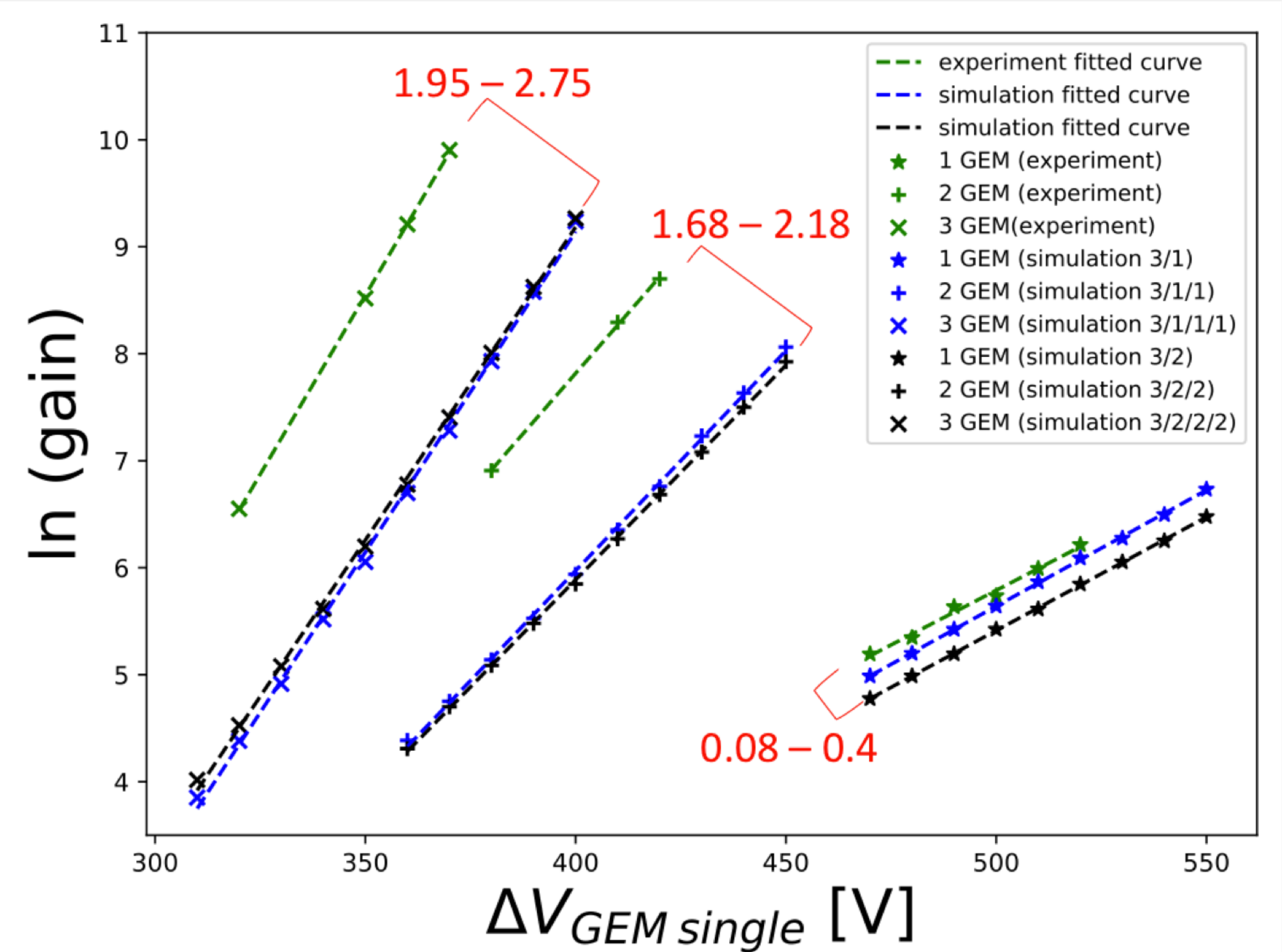
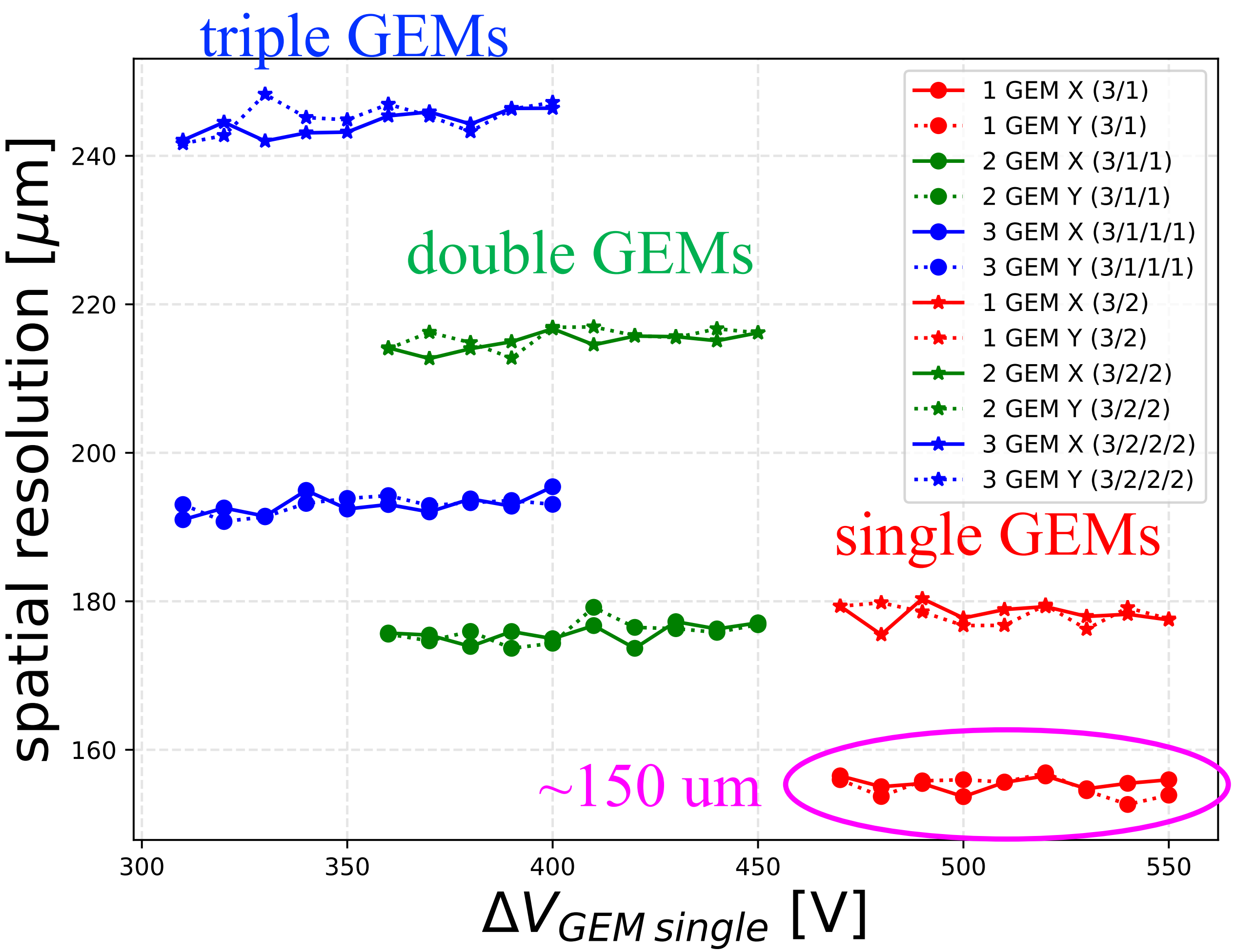
Simulation results

- **Gain:** given by the number of electrons created by each primary electron that reaches the anode



The experimental data (green) originally from Bachmann's paper *[S. Bachmann, et al., Nucl. Instrum. Meth. A 479, 294-308 (2002)]*

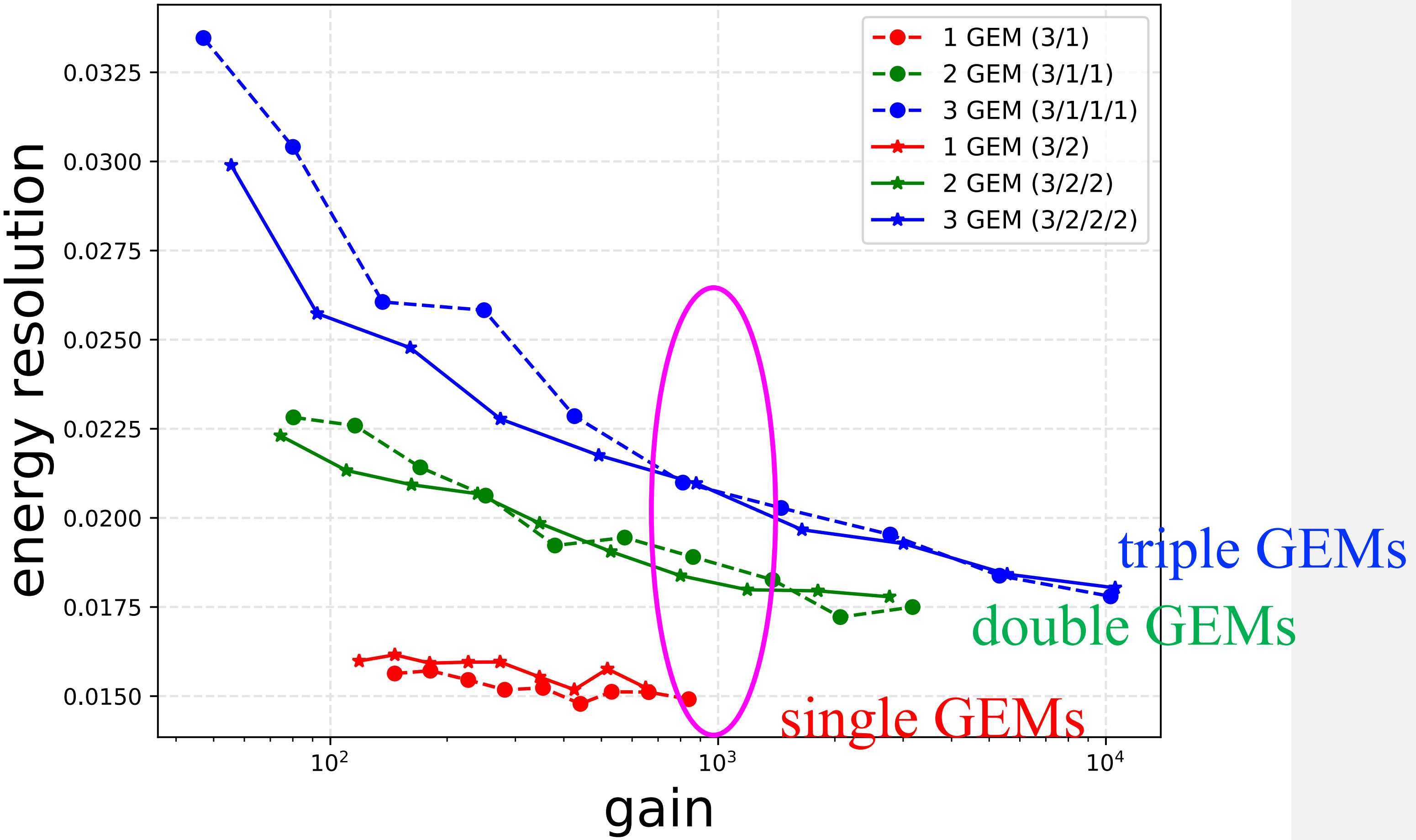
- **Spatial resolution:** key parameters for tracking systems and extracted from the **width of the residual distribution reached on the anode/readout plate**



- distance from the first GEM to the readout plate increases by about **15 um/mm**

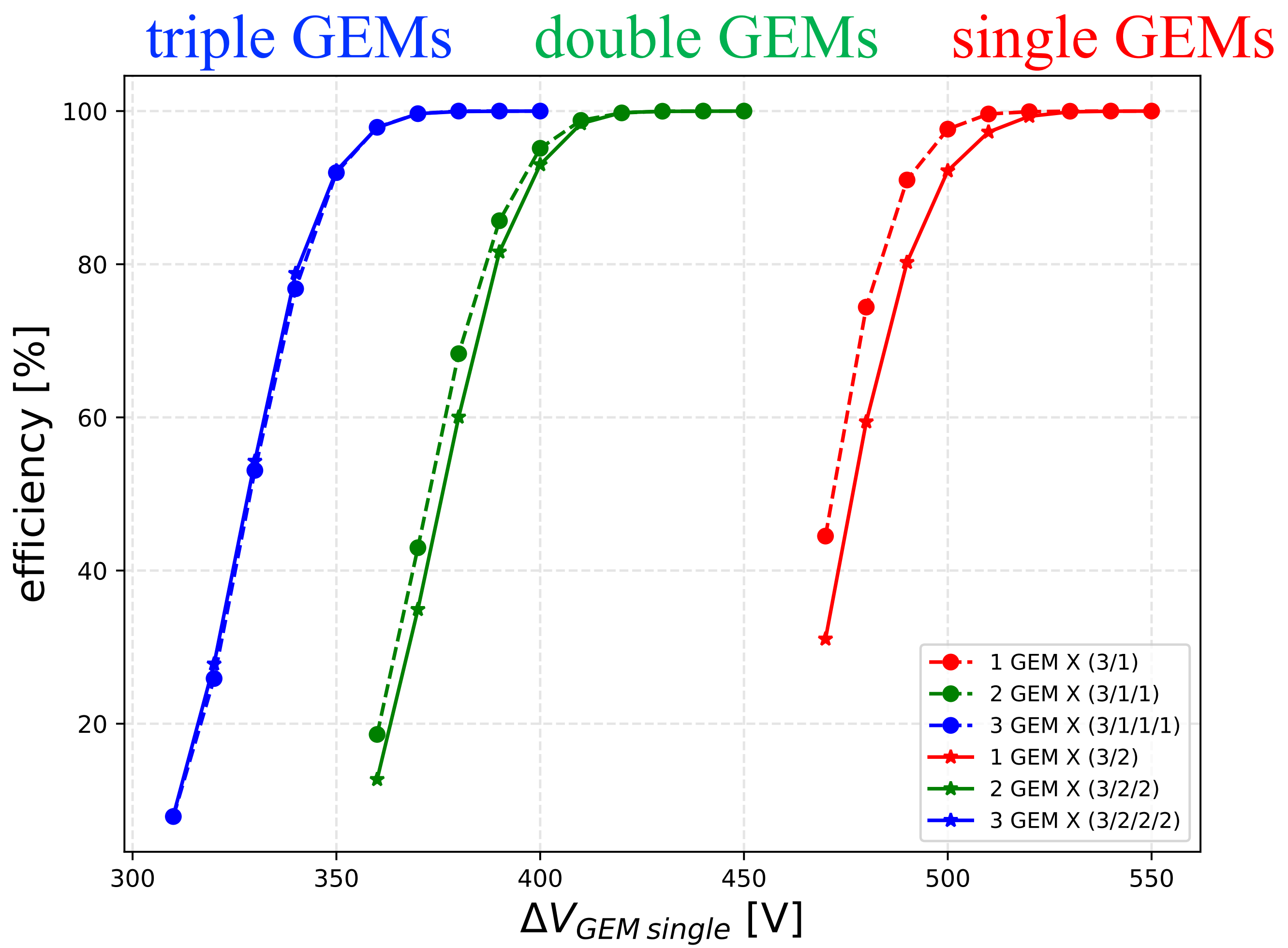
- e.g. triple GEM (3/2/2/2) has a spatial resolution of ~240 um (=150 + 15 x 6)

- **Energy resolution:** central for GEM detectors working in proportional mode and other devices aiming for a measurement of the deposited energy



Simulation results

- **Efficiency:** the probability of a trespassing particle to yield the expected signal and, if applicable, to overcome a threshold value needed have this signal recognized



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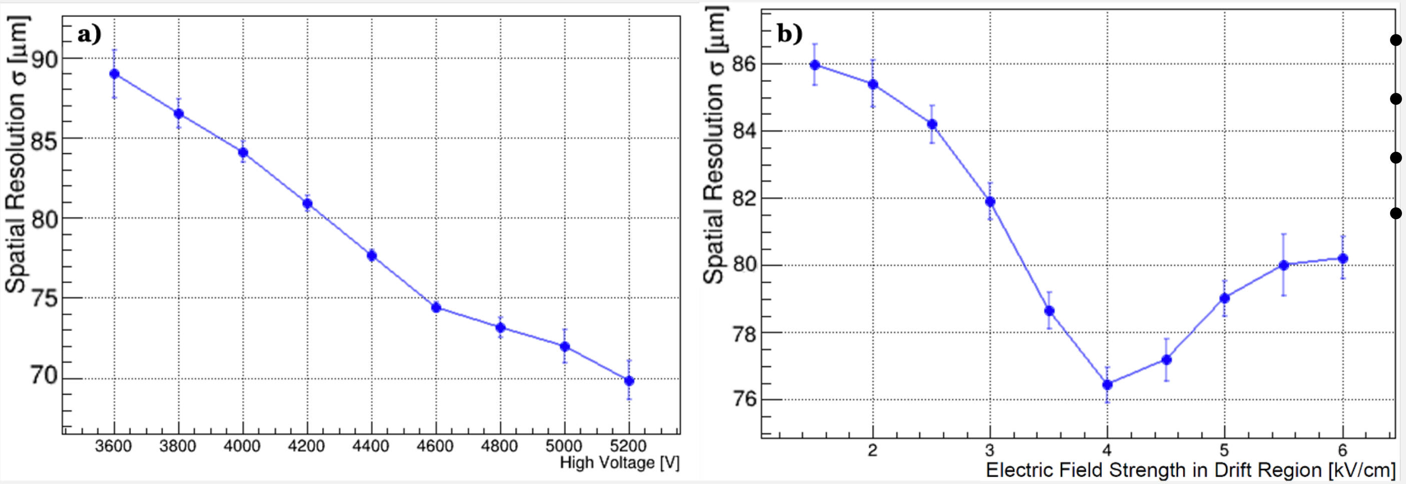
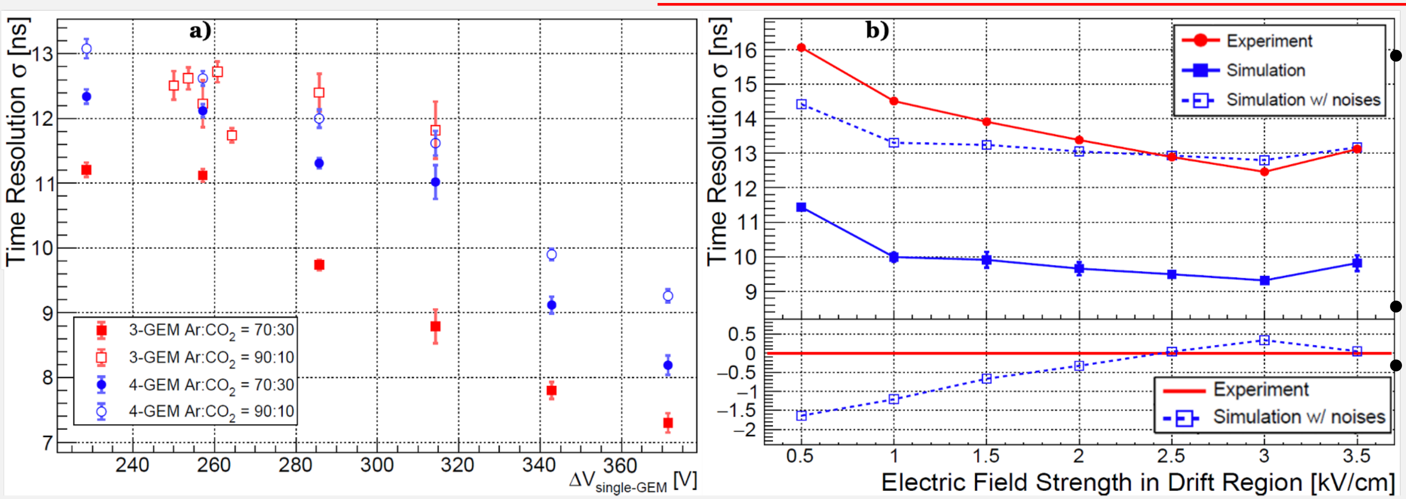
Simulation results

- **Spatial resolution:** calculated by the Center of Gravity (COG) method



- 70% Ar + 30% CO2
- 150 GeV muon beam
- Strip: 150 um
- Space: 60 um

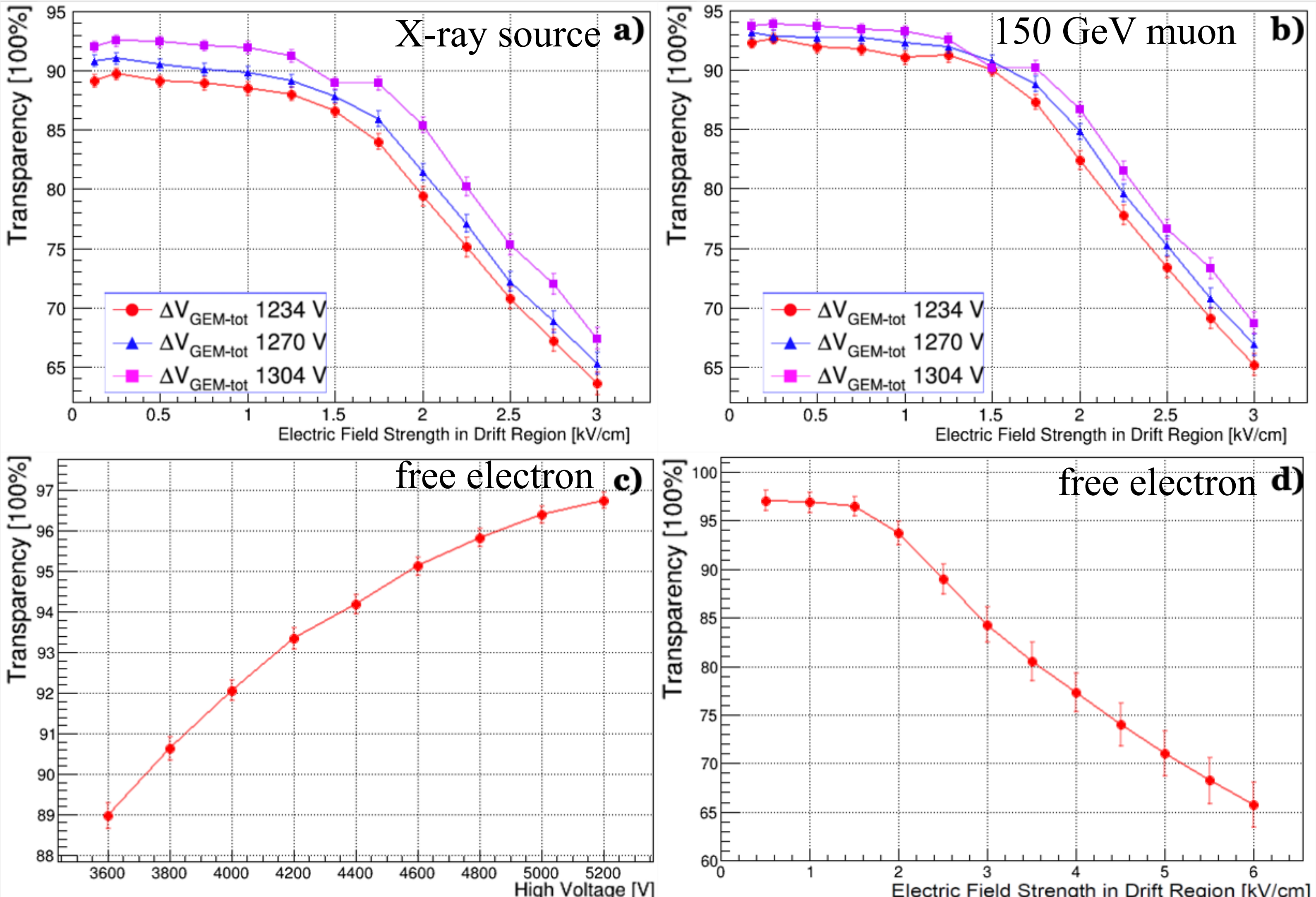
- **Time resolution:** used a Constant Fraction Discriminator (CFD) method



- 70% Ar + 30% CO_2 and 90% Ar + 10% CO_2
- Triple GEM better
- 70:30 gas better

Experiment data originally from
[Rajendra Nath Patra, et al., Nucl. Instrum. Meth. A 906, 37-42 (2018)]

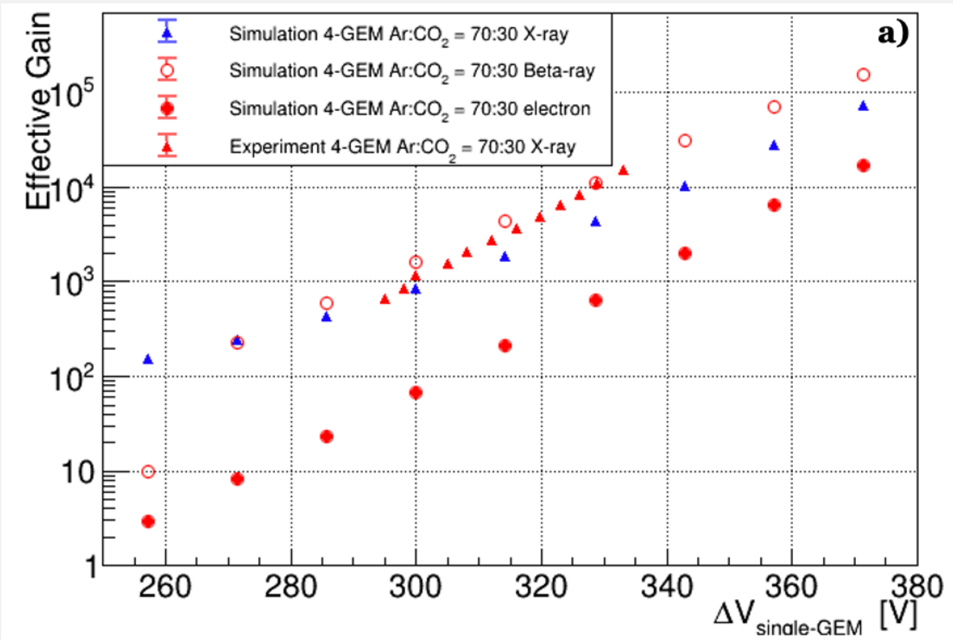
- **Primary electron transparency:** defined as the fraction of electrons that go through the first GEM foil
- Gas: 70% Ar + 30% CO_2

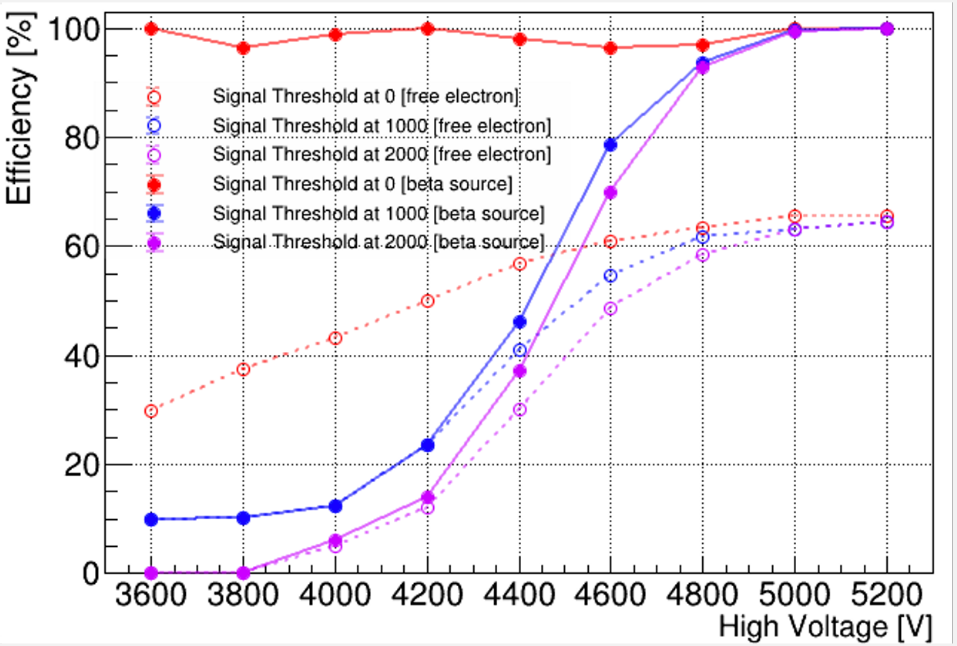


- As the E_{drift} increases, primary electron transparency decreases

- **Effective gain**
  - Gas: 70% Ar + 30% CO_2
  - Input particle
    - X-ray
    - free electron
    - beta source

- **Efficiency**
  - Gas: 70% Ar + 30% CO_2
  - Input particle
    - free electron
    - beta source





Experiment data originally from
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- **Single, double and triple GEMs**
  - Energy resolution deteriorates with more GEM layers
  - Spatial resolution becomes poorer as the distance between the first GEM and the anode increases
  - Efficiency is not so relevant to the number of GEM layers at appropriate HV

- **Quadruple GEM**
  - Time resolution, spatial resolution, effective gain, efficiency and transparency are studied. Simulation and Experimental data are consistent.
  - On going study: optimization of quadruple GEM structure design, Ion Back Flow rate, discharge effect….