UNIVERSITEIT GENT

FACULTY OF SCIENCES

Gas gain in a single GEM: parameter space

Sven Dildick

Department of Physics and Astronomy
Ghent University
CMS Collaboration

23-11-2011, RD51 mini-week

Objectives

Objectives: Understanding the gain in standard GEMs

- To investigate various influences on the gain
  - Penning effect: r_{P}
  - GEM voltage: V_{GEM}
  - Drift field: E_{D}
  - Induction field: E_{I}
  - GEM hole diameter: D/d
- To find the actual value of r_{P} for Ar/CO$_2$ $(70\%/30\%)$
- To make an animation of an electron avalanche in a single GEM

Method

Software

- ANSYS: to model & mesh the GEM
- Magboltz 8.9.6: contains all relevant cross sections of electron-matter interactions
- Garfield++: to simulate electron avalanches
- ROOT and C scripts: to analyse the data

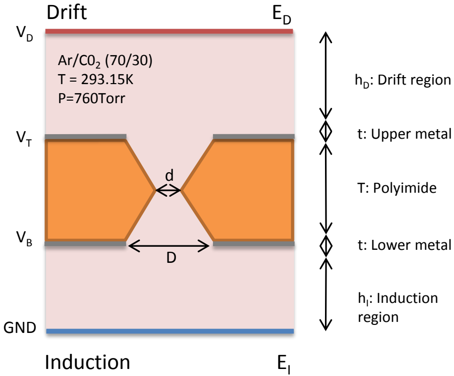
Compare simulations with experimental data

- PhD thesis G.Croci (2010)
- S. Bachmann et al. NIM A 438 (1999) 376-408
- Ö.Şahin et al. (2010) JINST 5 PO5OO2

Standard simulation setup I

Standard GEM

- $V_{\mathrm{D}} = -V_{\mathrm{T}} - E_{\mathrm{D}} \times h_{\mathrm{D}}$
- $V_{\mathrm{I}} = V_{\mathrm{B}} + E_{\mathrm{I}} \times h_{\mathrm{I}}$
- $V_{\mathrm{T}} = -V_{\mathrm{B}} = -\frac{1}{2} V_{\mathrm{GEM}}$
- $\varepsilon_{r,\mathrm{polyimide}} = 3.5$
- $\rho_{r,\mathrm{metal}} = 0$
- $h_{\mathrm{D}} = 3\mathrm{mm},\ h_{\mathrm{I}} = 2\mathrm{mm}$
- $D = 70\mu\mathrm{m},\ d = 50\mu\mathrm{m}$
- $T = 50\mu\mathrm{m},\ t = 5\mu\mathrm{m}$
- $P = 140\mu\mathrm{m}$



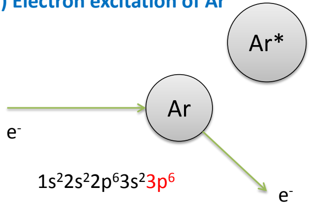
Standard simulation setup II

Extra information and conventions

- G_{tot}: Total number of electrons produced in the simulation
- G_{eff}: Electrons that reach at least the imaginary plane $50\mu\mathrm{m}$ below the lower metal
- $f = \mathrm{RMS}/\mu$: measure for the avalanche size fluctuations
- $N_{\mathrm{avalanches}} = 1000$ (3-4% statistical error on the (eff/tot) gain)
- Avalanche size maximum $N_{\max}$ is not yet implemented

The Penning effect: explanation I

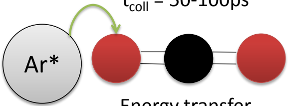
1) Electron excitation of Ar



$1s^2 2s^2 2p^6 3s^2 3p^6$

$1s^2 2s^2 2p^6 3s^2 3p^5 4s$
$1s^2 2s^2 2p^6 3s^2 3p^5 4p$
$1s^2 2s^2 2p^6 3s^2 3p^5 3d$
...

2) Energy transfer Ar-C0$_2$

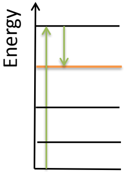


t_{coll} = 50-100ps

t_{Ar*} = O(ns)

Energy transfer
@ 10^{10} collisions/s

3) Ionisation of C0$_2$



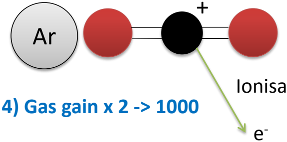
$1s^2 2s^2 2p^6 3s^2 3p^5 3d$

Ionisation energy of CO_2

$1s^2 2s^2 2p^6 3s^2 3p^5 4p$

$1s^2 2s^2 2p^6 3s^2 3p^5 4s$

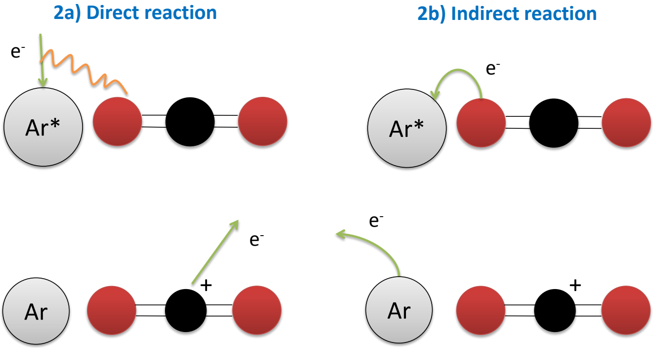
Ground level



Ionisation

4) Gas gain x 2 -> 1000

The Penning effect: explanation II



The Penning effect: explanation III

Different implementations yield same results (checks were performed)

- Garfield (`FORTRAN`)

$$\alpha_{\text{eff}} = \alpha\left(1 + r\frac{\nu_{exc}}{\nu_{ion}}\right)$$

- Garfield++: Probability r that excited state transforms into ionised state

The Penning effect: Setup

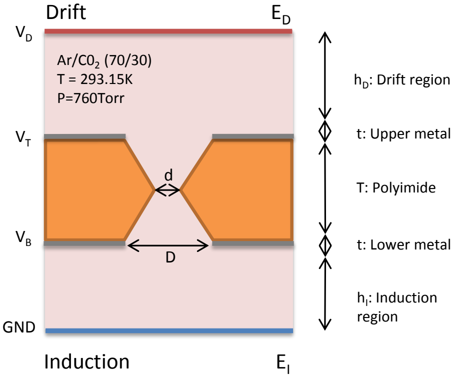
Simulation setup:

- Standard GEM
- $E_D = 1$ kV/cm
("Influence of the E_D and E_I")
- $E_I = 3$ kV/cm
- $V_\mathrm{GEM} = 200, ..., 500$ V;
$\Delta V = 50$V
- $r_\mathrm{P} = 0.0, ..., 1.0$

Experimental setup:

Data from PhD thesis G.Croci

- $E_\mathrm{D} = 2$ kV/cm,
$E_\mathrm{I} = 3$ kV/cm



The Penning effect: Results

- Gain increases with r_P
- Notice that none of the r_P sim. data agrees with the exp. data
- Therefore it was necessary to scale the exp. data accordingly

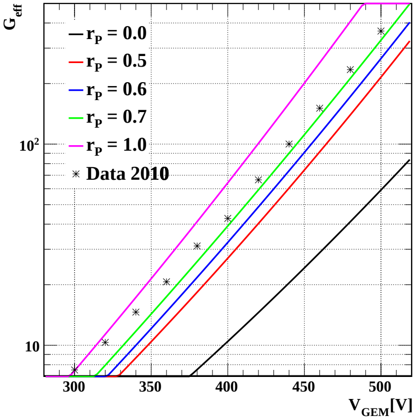


Figure: G_eff as function of V_GEM for various r_P.

Determination of r_{P} I

1. Complications
   - No error bars for exp. data (?)
   - Systematic effects
     (Calibration, definition W,...)
   - No simulated data for $320\ \mathrm{V}, 340\ \mathrm{V}, 360\ \mathrm{V}, \ldots$
2. Fit exp. data to function: $G_{\mathrm{exp}} = \exp(a + bc + cv^2)$
3. Fitting methods:
   - Constant absolute uncertainty of 10.5 on the effective gain
   - Constant relative uncertainty of 1.6% $(\chi^2/\mathrm{ndf} = 1)$
4. Simulated data was fitted to G_{fit} (a': scaling parameter)

$$G_{\mathrm{fit}} = a' G_{\mathrm{exp}} = a' \exp\left(a + bc + cv^2\right)$$

Determination of r_P II

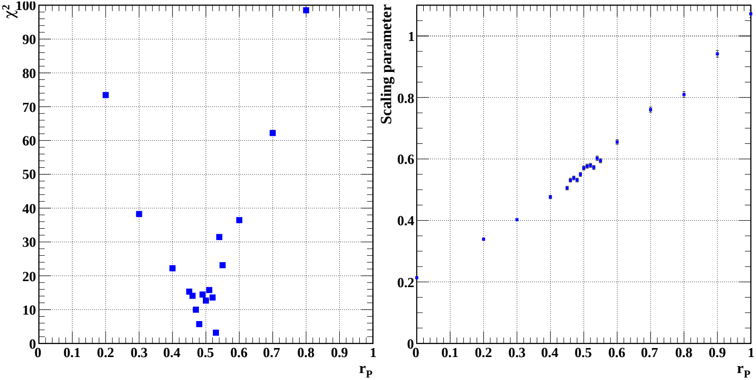


Figure: Plot of the χ^2 (left) and the scaling parameter a' (right) as a function of the Penning transfer parameter. Compare to the value extracted from Ö.Şahin et al. (2010) JINST 5 PO5OO2: $r_P = 0.56 \pm 0.03$ (after correcting for P and T).

Avalanche size fluctuations I

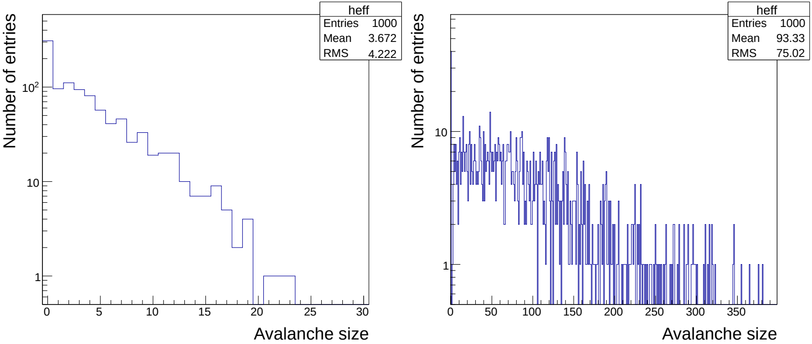


Figure: Avalanche shape for 1000 avalanches at $300V$ (left) and $460V$ (right).

Avalanche size fluctuations II

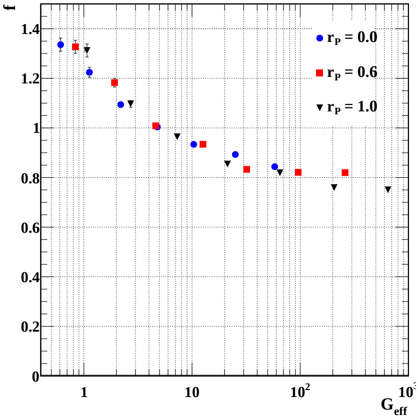


Figure: $f = \mathrm{RMS}/\mu$ as function of G_{eff} for various r_{P}.

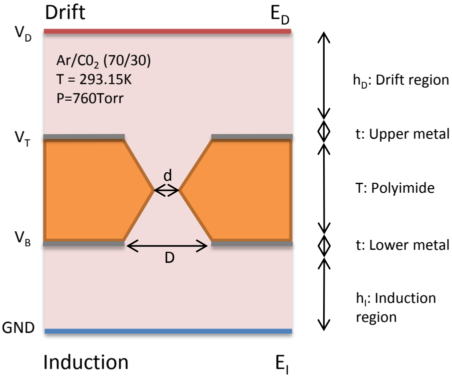
Influence of the E_D and E_I: setup

Simulation setup:

- Standard GEM geometry
- $E_D = 1, ..., 5$ kV/cm
- $E_I = 1, ..., 5$ kV/cm
- $V_\mathrm{GEM} = 300,\ 400,\ 500,\ 550$ V
- $r_\mathrm{P} = 0.55, 0.6, 0.7$

Experimental setup:

Data from S. Bachmann et al.
NIM A 438 (1999) 376-408



Influence of the E_{D} and E_{I}: Results I

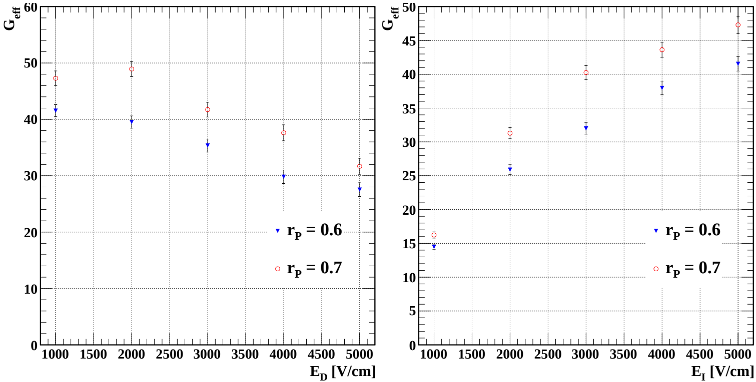


Figure: Plot of G_{eff} as a function of the E_{D}, $E_{\mathrm{I}} = 5\ \mathrm{kV/cm}$ (left) and as a function of E_{I}, $E_{\mathrm{D}} = 1\ \mathrm{kV/cm}$ (right) for various r_{P}.

Influence of the E_D and E_I: Results II

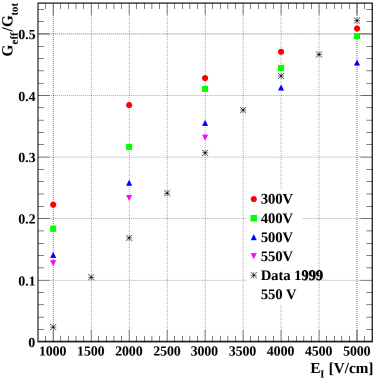
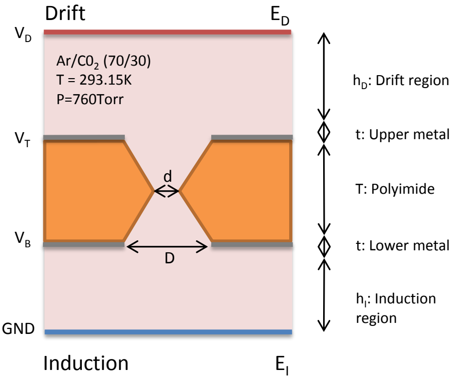


Figure: Plot of $G_\mathrm{eff}/G_\mathrm{tot}$ as a function E_I, $E_\mathrm{D} = 1\ \mathrm{kV/cm}$ for simulated and experimental data ($r_\mathrm{P} = 0.55$).

Influence of the hole diameter: Simulation setup

In cooperation with Mythra Varun Nemallapudi

- $D = 30, ..., 120\ \mu\text{m}$
  $\Delta D = 10\ \mu\text{m}$
- $d = \frac{D \times 50}{70} = \frac{D}{1.4}$
- $E_D = 1\ \text{kV/cm}$
- $E_I = 3\ \text{kV/cm}$
- $V_{\text{GEM}} = 400\ \text{V}$
- $r_{\text{P}} = 0.6$



Influence of the hole diameter: Results I

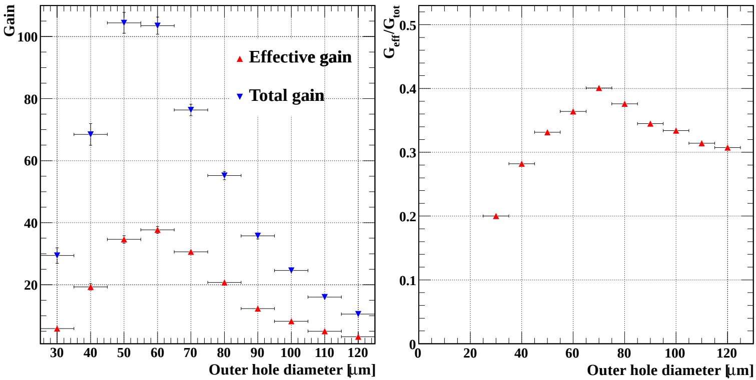


Figure: Effective and total gas gain (left) and $G_{\text{eff}}/G_{\text{tot}}$ (right) for various GEM hole diameters.

Influence of the hole diameter: Results II

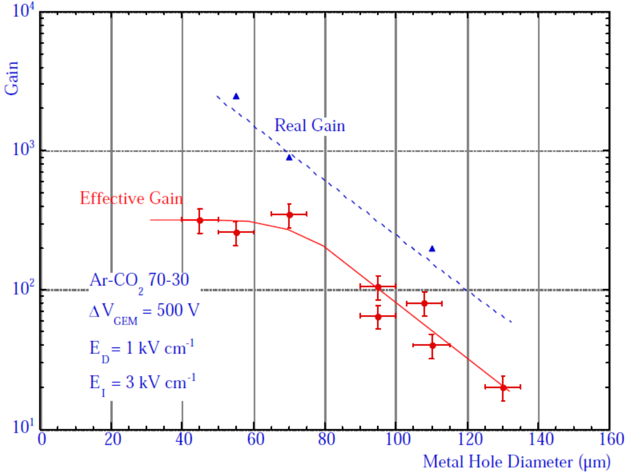


Figure: [...] *The gain increases considerably with decreasing diameter until around* $70\mu\mathrm{m}$, *and reaches a plateau for lower values.* [...] (S. Bachmann et al. NIM A 438 (1999) 376-408)

Influence of the hole diameter: Results III

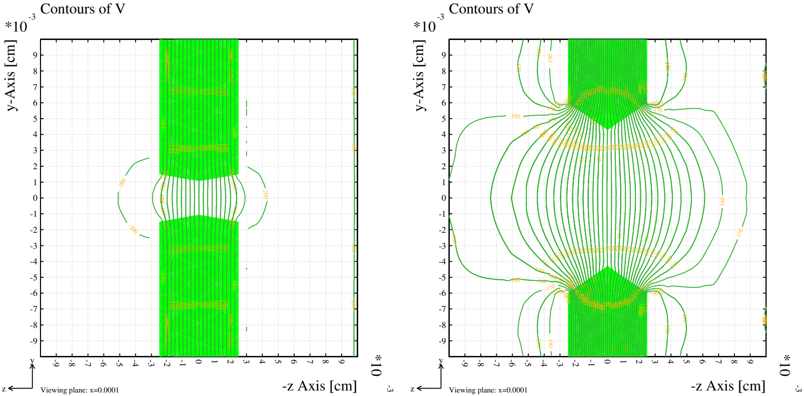


Figure: E_z field configuration for $D = 30\mu\mathrm{m}$ (left) and $D = 120\mu\mathrm{m}$ (right). For large GEM holes electrons have less difficulty in finding the hole.

Influence of the hole diameter: Results IV

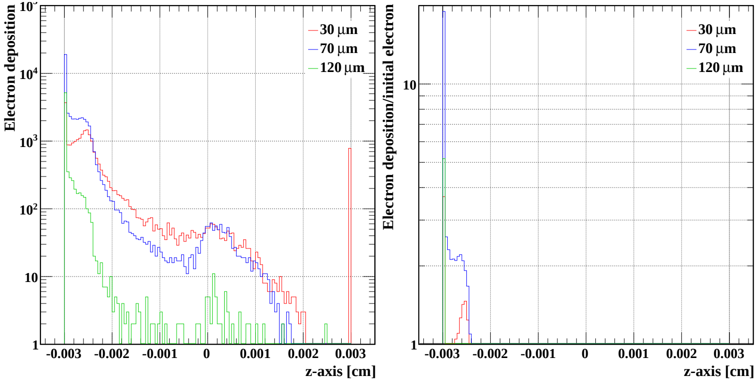


Figure: Total electron deposition (left) and electron deposition per initial electron (right).

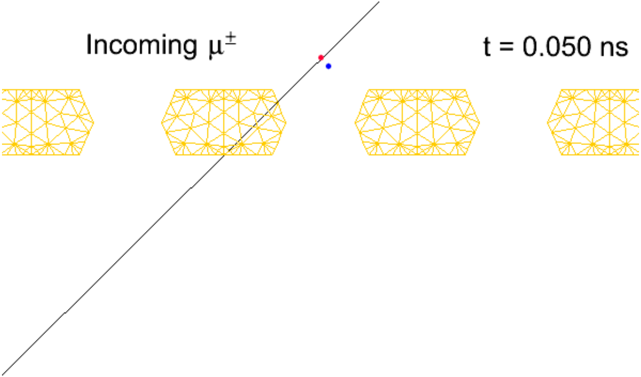
Animation of an electron avalanche I

In cooperation with Heinrich Schindler (LHCb)

In the simulation:

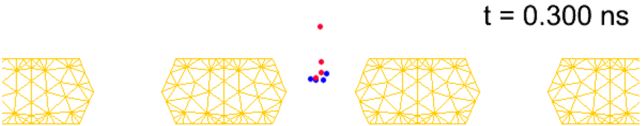
- Conformal mapping
- Electrons are blue dots
- Ions are red dots
- Polyimide (meshed) is shown in orange
- Traversing muon is the black line (upper left)
- No metal layers are shown (absence of electric field)

Animation of an electron avalanche II



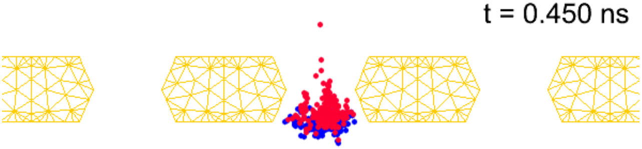
Phase 1: High energy muon enters the gas and ionizes a molecule.

Animation of an electron avalanche III



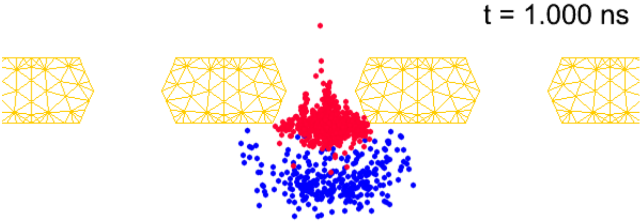
Phase 2: After some time the primary electron drifts towards the GEM hole and starts ionizing the molecules in the Ar/CO_2 mixture.

Animation of an electron avalanche IV



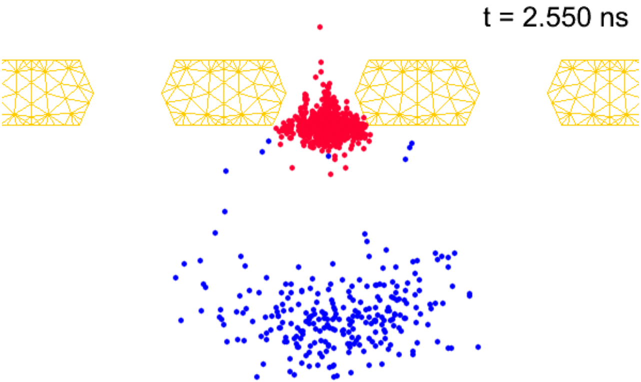
Phase 3: Avalanche develops exponentially through the GEM hole. Most of the electrons are produced at the bottom where the electric field is strongest.

Animation of an electron avalanche V



Phase 4: Avalanche reaches maximal size.

Animation of an electron avalanche VI

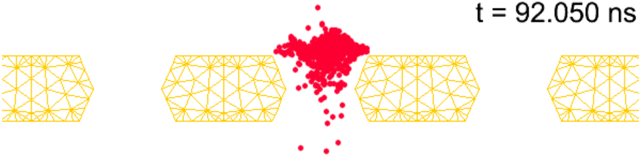


Phase 6: Electrons drift towards the anode.

Animation of an electron avalanche VII

Phase 7: Electrons have 'left the building'. Ions start drifting towards the kathode.

Animation of an electron avalanche VIII

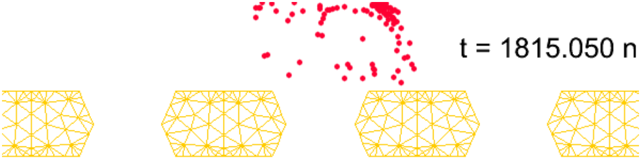


Phase 8: Ions get attached to the top metal electrode.

Animation of an electron avalanche IX

Phase 9: Ions remain around the top electrode for a long time...

Animation of an electron avalanche X



Phase 9bis: ... for a really long time...

Work in progress...

- Complete investigation of r_{p} and compare with current experiments
- Simulations with various gasmixtures
- Investigate charging-up effects
- ...

Gas gain in a single GEM

Thank you!

The author would like to acknowledge

Mythra V. Nemallapudi, Rob Veenhof, Leszek Ropelewski
Ankit D. Mohapatra, Heinrich Schindler,

`http://garfieldpp.web.cern.ch/garfieldpp/examples/gemgain/`