Avalanche simulation
in noble gas + isobutane mixtures

Fabian Kuger[1], Ö. Sahin, R. Veenhof, T. Zerguerras,
B. Genolini, M. Imré, M. Josselin, A. Maroni, T. Nguyen Trung,
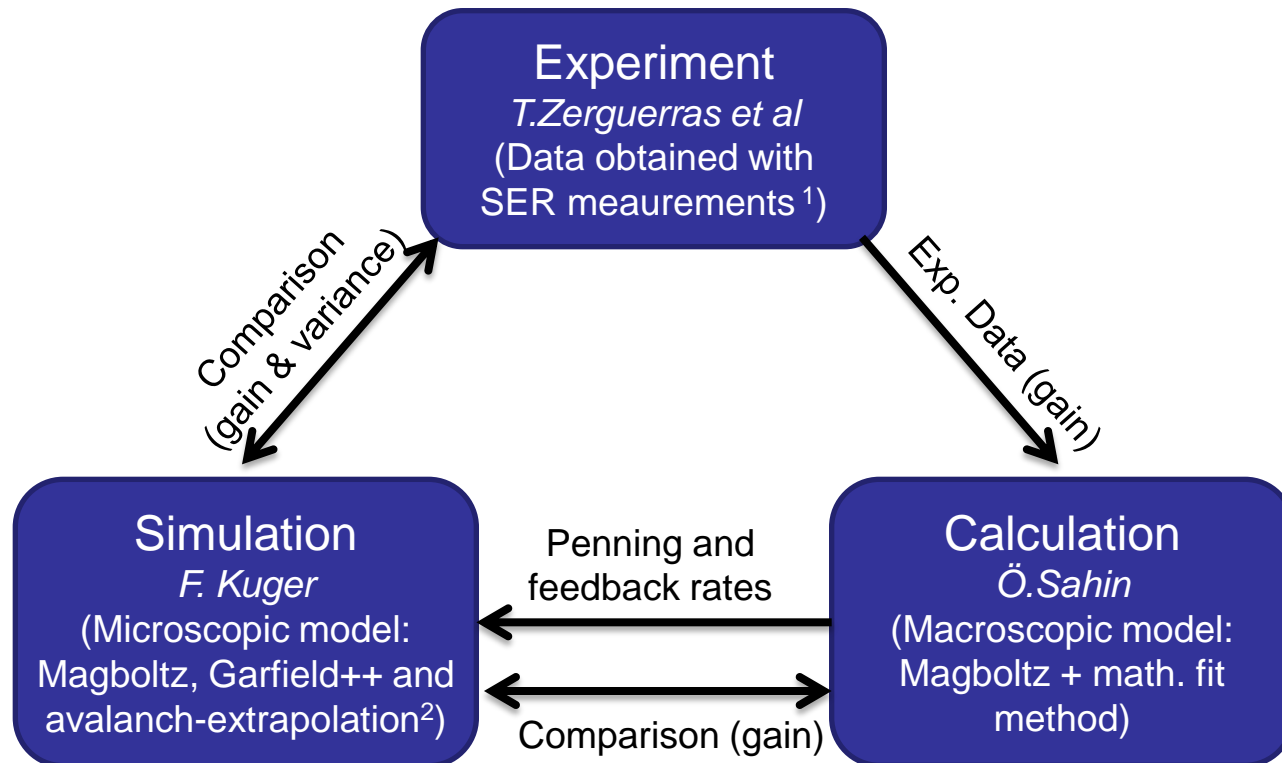J. Pouthas, E. Rindel, P. Rosier, L. Séminor, D. Suzuki, C. Théneau

[1]University of Würzburg, Germany

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13th RD 51 Collaboration Meeting 2014 (WG4) - CERN

Studies on penning transfer and feedback in electron avalanche formation, gas gain behavior and gain variances using a comparison between


[1]T. Zerguerras et al: *New results on gas gain fluctuations in a Micromegas detector,* MPGD Conference- July 2013 – Zaragoza
[2] F. Kuger et al*: Simulation of gas gain variance in noblegas + isobutane mixtures,* 12th RD51 Collaboration Meeting – Oct 2013 – CERN.

As reported during the 12th RD51 Collaboration Meeting (Oct 2013) huge differences in gas gain have been observed between the results yielded by the macroscopic and the microscopic model.
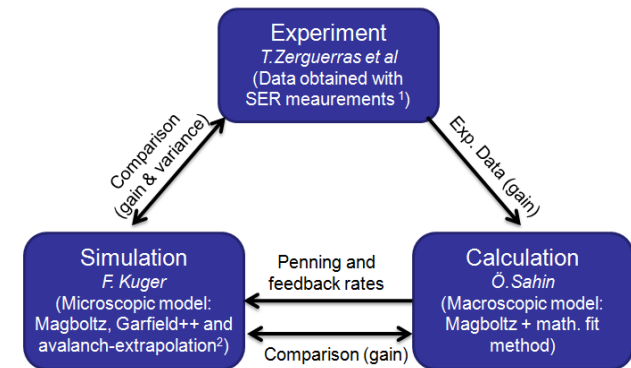
→ Further investigation on the used methods
  (e.g. FEM field maps vs. analytic fields, avalanche extrapolation)

→ Enhanced understanding of the fundamental differences between microscopic treatment in Garfield++ and macroscopic model calculation

→ Better agreement between gain data from simulation and experiment, necessary premise to trust in variance comparison which is not accessible in the calculation method.
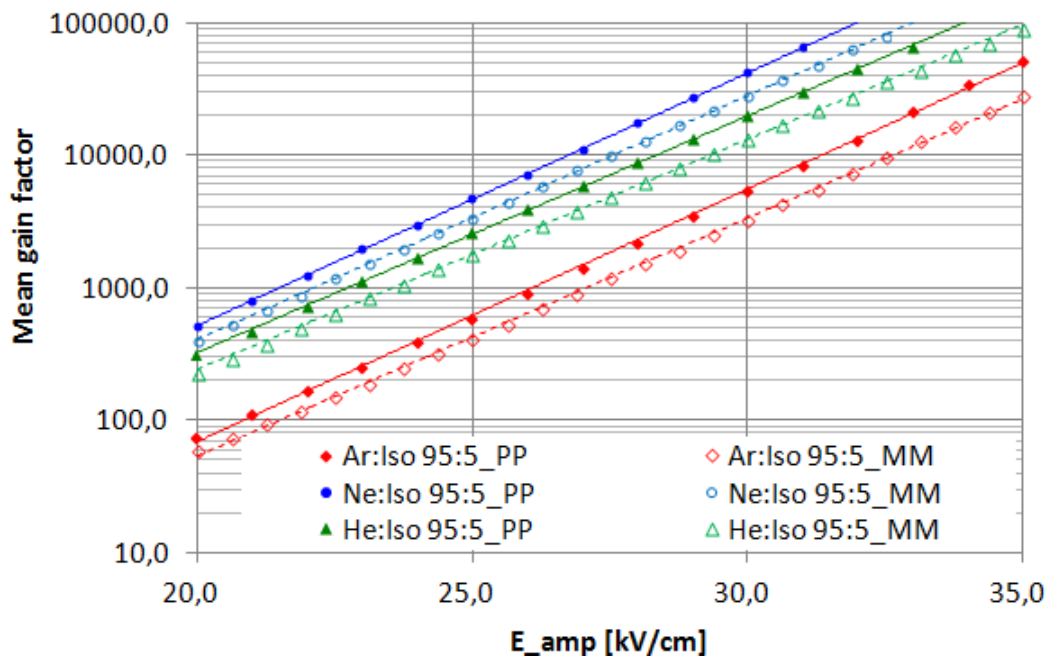
MM vs. PP approach

Simulation

using FEM field maps modeling a Micromegas (MM)

Calculation

based on a homogeneous field assumption (like a parallel plate setup - PP)

→ Switching to analytic field setup in Garfield, modeling the homogeneous field in a PP

→ PP leads to significant higher gain values than the MM layout.

→Using PP for further investigation

+ much faster / less CPU intensive

+ avoiding introduction of new errors

- less realistic model

→ For further studies both methods should be adopted to a MM approach

Coping with large avalanches using a mathematical extrapolation.

Simulation

The problem:

- ⚡ full avalanche simulation is limited towards high gain due to CPU limits
- ⚡ the larger the avalanche grows, the more statistic becomes dominant
- → Full simulation for the first (physical significant) part of the avalanche + mathematical extrapolation yields valid results using less CPU

The model:

- The avalanche development can be divided into independent steps.

- During the first step, a single starting electron is amplified into n electrons, with a probability $p_1(n)$, which depends (mostly) on the spatial step length and the electric field.

- Each following step is identical as long as the step length and the electric field are equal.

Mathematical derivation yields: Mean   RMS

$$\bar{p}_n = \bar{p}_1^{\,n}, \qquad \mathrm{RMS}(p_n) = \mathrm{RMS}(p_1)\sqrt{\bar{p}_1^{\,n-1}\sum_{i=0}^{n-1}\bar{p}_1^{\,i}}$$

Avalanche extrapolation method (How to use)

Steps of the simulation:

- Full simulation of the avalanches (gap = 160µm) in control region (20-28 kV/cm) → $\bar{g}_{full}$
- Simulation of the first step avalanches (gap = 80µm) in the full region (20-35 kV/cm) → $\bar{g}_{step}$
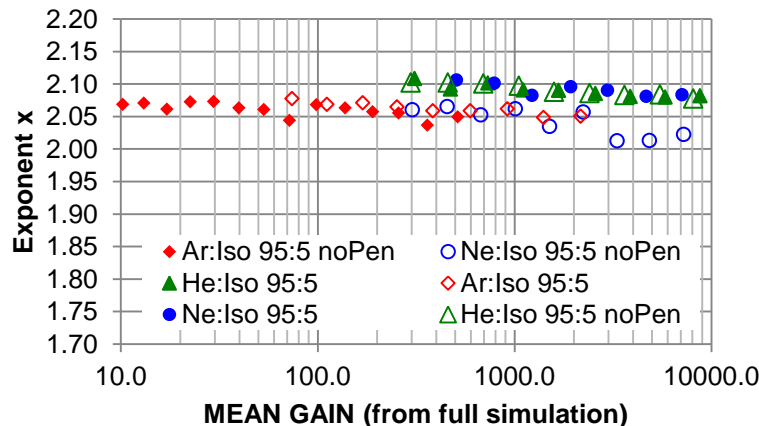- 'Verification' of the step size and the extrapolation exponent x:

$$x = \frac{\lg \bar{g}_{full}}{\lg \bar{g}_{step}}$$

- Calculation of mean gain and RMS, using x, $\bar{g}_{step}$ and the formula shown above

Simulation

full (physics) simulation

mathematical extrapolation
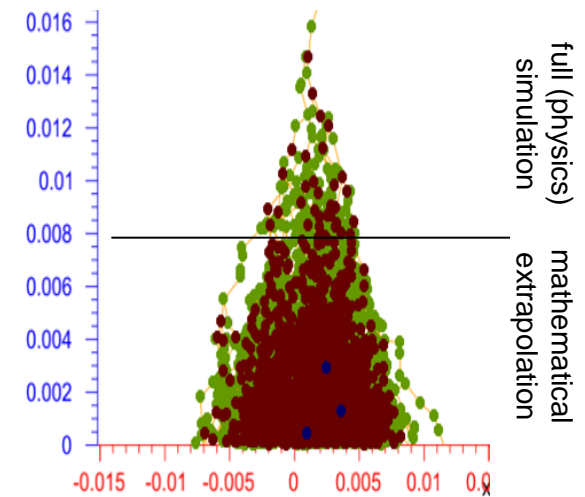
Calculated Exponents for Extrapolation over MEAN GAIN- half Step

⚡ Exponents do not fit the expectation of

x =160µm / 80µm = 2

⚡ Systematic effect visible: first step seems to be underestimated /second overestimated.

⚡ Effect seems to depend on the gas mixture

Avalanche extrapolation method (Understanding discrepancies)

What is the difference between one full step and two half steps?

Simulation

➢ Constraints on the 'half-way-plain', like the starting energy of the electron E_0

Full simulation:	*Step simulation:*
No restrictions, 'random' energy after previous steps	Reset of each electron to starting conditions
→ E_0 is distributed	→ E_0 is fixed

Mean_Electron_Energie

htemp	
Entries	10000
Mean	12.55
RMS	5.275
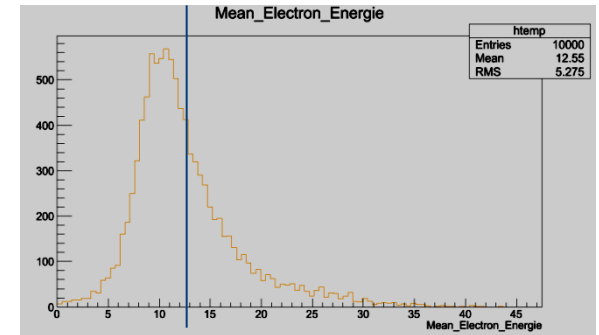
→ Variation of electron starting energy verifies this assumption:

Calculated Exponents for Extrapolation over Electron Starting Energy
(Ar+Isob 95:5, E_amp=25kV/cm)
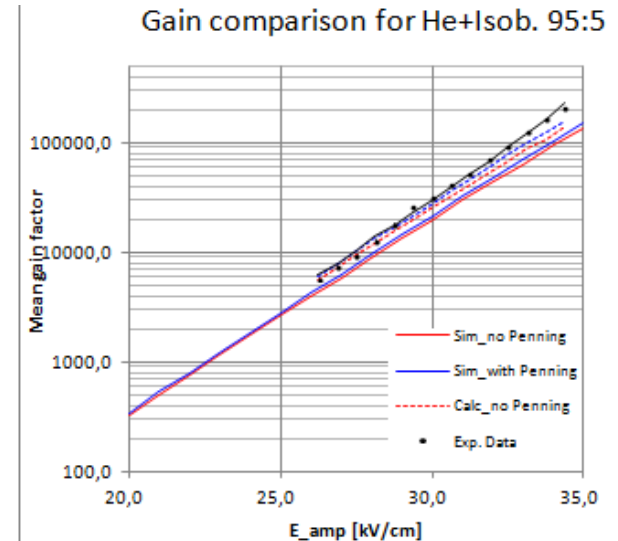
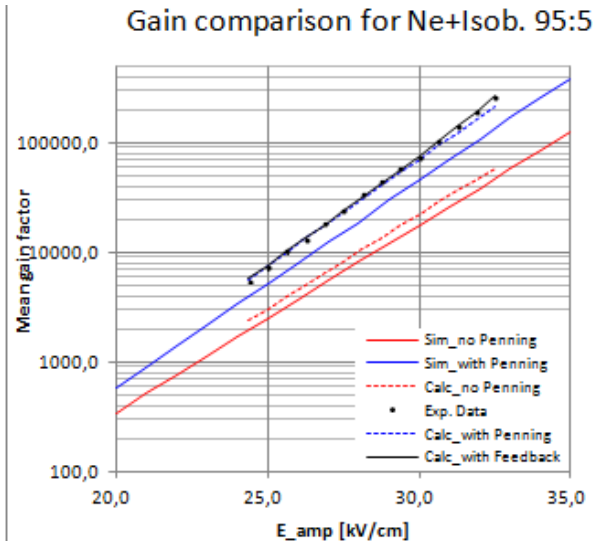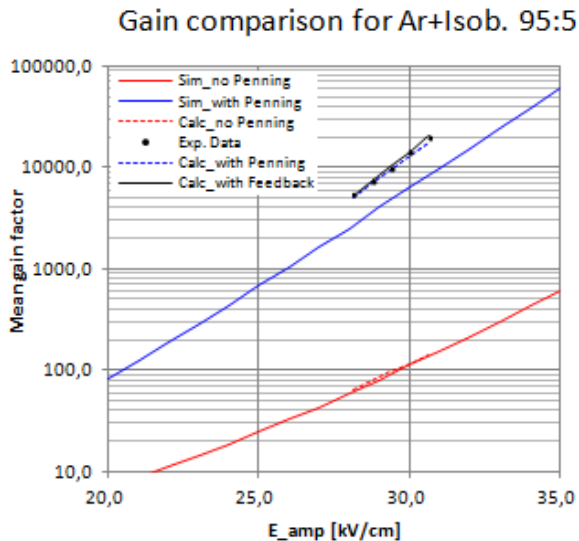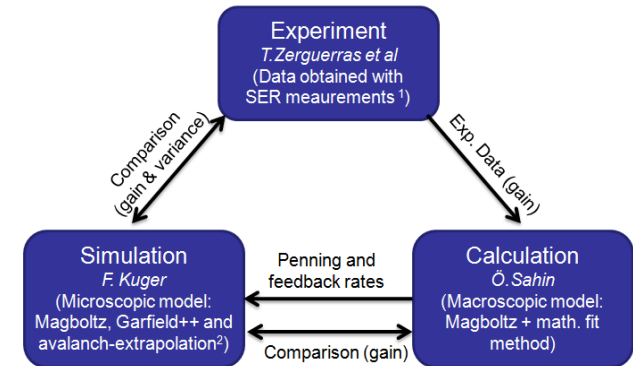◆ Ar:Iso 95:5 noPen
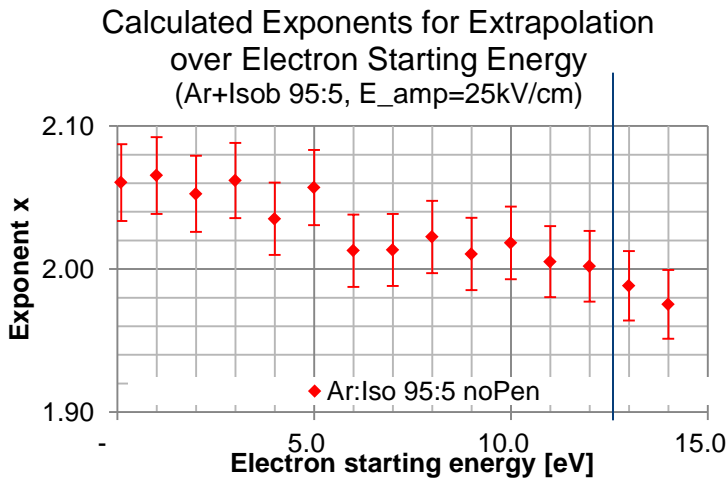
→ Reason for x ≠ 2 is perfectly understood

→ Forcing E_0 to obtain x = 2 is not necessary and would introduce an error in gain values

→ E_0 is set accordingly to simulated energy-distribution at the end of a drift process (simulation fitting to exp. drift circumstances)

Comparison of simulation and calculation

Results comparison after parameter alignment (pressure, temperature, gas input parameter like excitation levels…):

- Still discrepancies in the 'without penning effect – data' (Ar: 2%, Ne: ~20%, He: ~25%)

- Differences in the effect of penning transfer using the same penning transfer rates! (most pronounced in Ar)

Experiment
T.Zerguerras et al
(Data obtained with SER meaurements [1])

Comparison
(gain & variance)

Exp. Data (gain)

Simulation
F. Kuger
(Microscopic model:
Magboltz, Garfield++ and
avalanch-extrapolation[2])

Penning and
feedback rates

Calculation
Ö.Sahin
(Macroscopic model:
Magboltz + math. fit
method)

Comparison (gain)

Gain comparison for Ar+Isob. 95:5

Gain comparison for Ne+Isob. 95:5

Gain comparison for He+Isob. 95:5
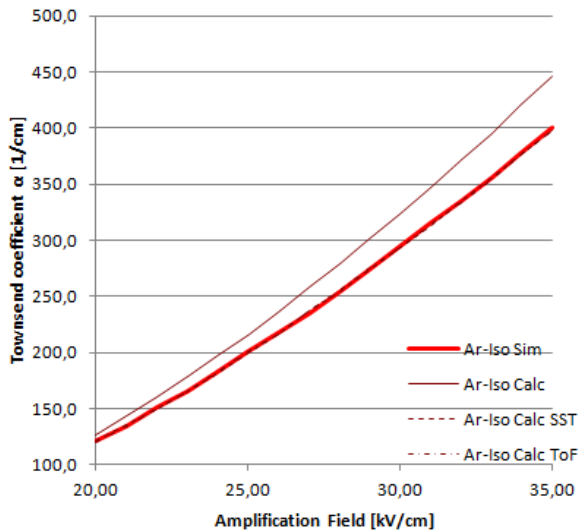
Discrepancies in 'without penning effect data'

Both methods (Sim and Calc) use the same Magboltz input!
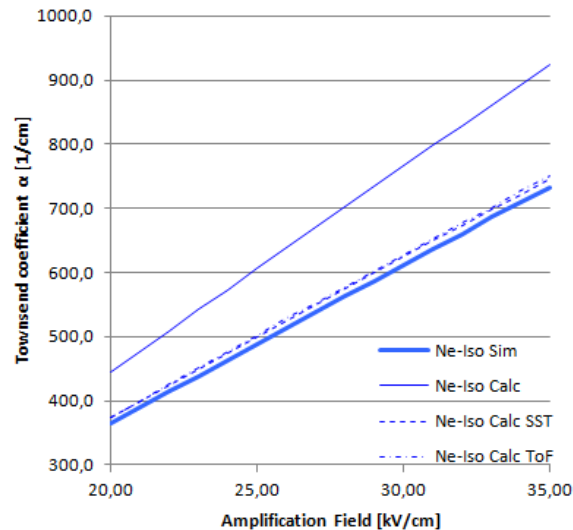→Nevertheless the 'raw' data differs

→Comparison of the Townsend coefficients yield
(Input parameters in calculation, extracted by magboltz;
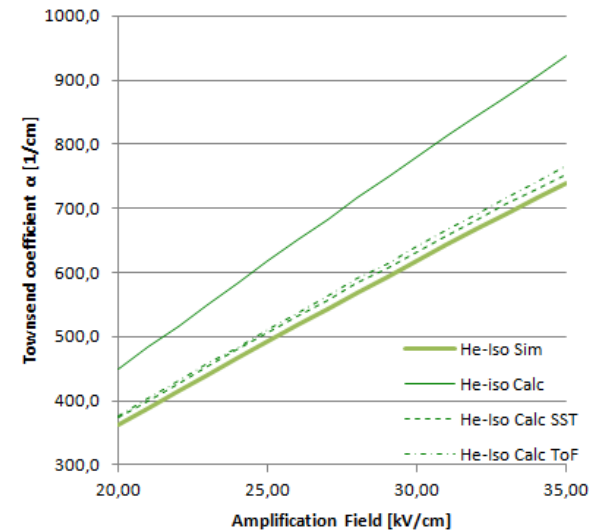Results derived from microscopic simulation in Garfield++)
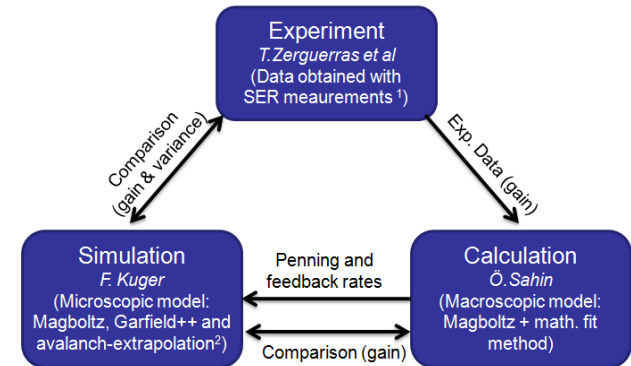
* SST = Steady State Townsend, ToF = Time of Flight

Calculation

The mean gain depends on the spatial length of the avalanche development

→ Gain is a steady function in d.

$$G_0 = e^{\alpha d}$$

Simulation

Gain depends on the number of fully finished amplification processes

→Gain has the characteristic of a step function in d, with steps every mean free path length λ.

→Steps are less pronounced if d/λ >> 1 .

Short example assuming fixed interaction length between ionisation and d = 3.5 λ

Calc G_0 = 2^3.5 = 11,3

Sim G_0 = 2^3 = 8 + energy distribution

When calculation Townsend coefficients with Magboltz: d/λ >> 1 is fullfilled.

Running Garfield++ simulations in a 'half step method' (80µm):

$$d/\lambda_{Ar} \sim 19 > d/\lambda_{Ne} > d/\lambda_{He}$$

Which fits to the observed discrepancies. Numerical validation is in progress.

Discrepancies in 'penning effect impact'

Although a lot of aspects have been under study, no satisfying explanation has been found.

Calculation		Simulation

Gain value
generation

$$G_1 = e^{\alpha_{Penning} d}$$

$$\alpha_{Penning} = \alpha \left(1 + r_p \frac{f_{exc}}{f_{ion}} \right)$$

Garfield ++ algorithm:

If excited state with energy > lowest ionisation threshold occures, ionisation takes place with propability r_p.

Excitation levels &
Cross sections

Checked for all noble gases! One isobuthane state @ 14.0eV not included in Garfield++ Sim – to check if included in Calc. (min. influence)

Electrons energy
after ionisation

?

Energy difference transfered to electron starting energy

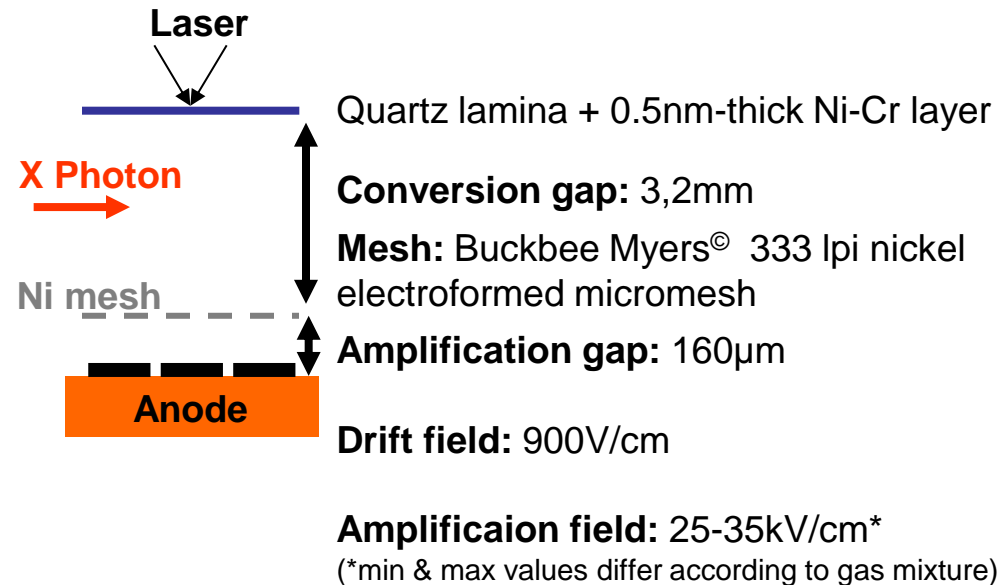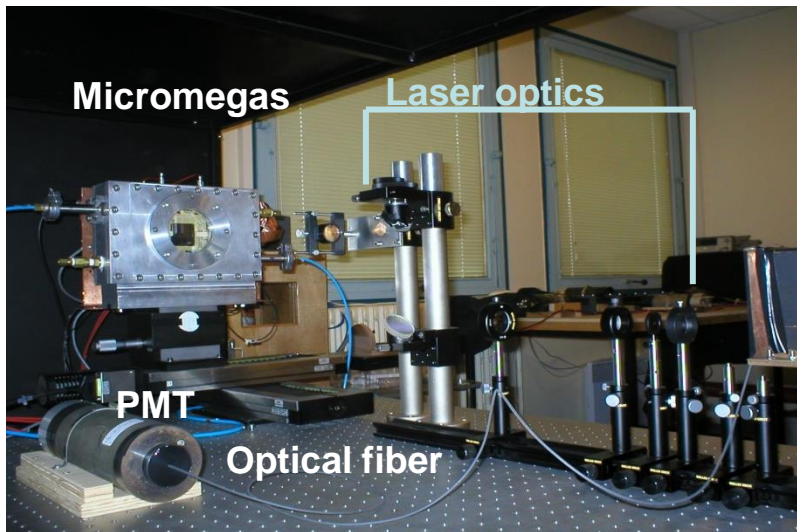→ Investigation work on this topic is in progres.

→ Ideas, remarks and contributions are highly welcome!

➢ The detailed inquiry in the simulation method provided a satisfying level of understanding in the avalanche extrapolation method and reviled some error sources (MM vs. PP, starting energy, measurement conditions…)

➢ Simulation and Calculation still differ significantly:

   ➢ Difference on 'without-penning-data' is understood but not jet proven

   ➢ Different impact of penning transfer is not yet understood

➢ Comparison to experimental data is on a satisfying level. (results to be presented soon). Work will go on relying on the microscopic approach.

Thank you for your attention!

Experimental Setup - SER (Orsay)[1]

MPGD characterization with a point-like electron source (<100 µm) of variable intensity produced by a 337nm UV laser. Single electrons can be produced at the cathode and their sprectra measured with low noise background.

Micromegas   **Laser optics**

X Photon

Ni mesh

PMT

Optical fiber

Laser

Quartz lamina + 0.5nm-thick Ni-Cr layer

Conversion gap: 3,2mm

Mesh: Buckbee Myers© 333 lpi nickel electroformed micromesh

Amplification gap: 160µm

Anode

Drift field: 900V/cm

Amplificaion field: 25-35kV/cm*
(*min & max values differ according to gas mixture)

Gas mixtures: 95% Ar/He/Ne + 5% iC$_4$H$_{10,}$ 1atm

« Comparisons with calculations are needed […] and could help quantifying Penning effect in the three tested mixtures. »[1]   T. Zerguerras – MPGD 2013

[1]T. Zerguerras et al: *New results on gas gain fluctuations in a Micromegas detector,* MPGD Conference- July 2013 – Zaragoza.

# (Dis-)Agreement on gas gain calculation
- Simulation Parameters -

OLD

Calculation of the **electrical field** with *FEM* in **ANSYS 14** using the *smart meshing* with finest granularity.

Layout describes a micromegas with an electroformed mesh (thickness: 5µm, pitch: 76µm, window-size: 64µm), in fixed 160µm distance to the anode.

Voltages:

U_{anode}=0V, U_{mesh}:-320V to -560 V, $U_{cathode}$=U_{mesh}- 288V,
→ Amplification fields: 20-35 kV/cm *
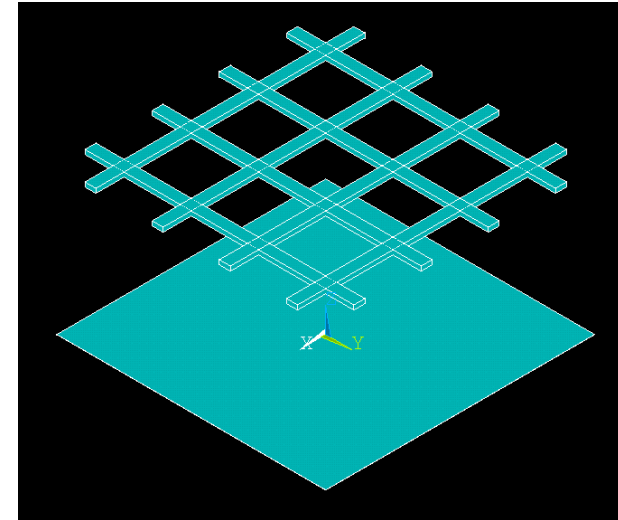
Calculation of the electrical field of a **parallel plate** setup.

NEW

Using *FEM* in **ANSYS 14** in the first approach, including drift of the electron along 300µm in a fixed driftfield.

The *analytic component* - class in **Garfield++** has been used in the second approach, neglecting the drift region, starting the electron at the upper border of the amplification region.

* Calculation assumes a homogeneous field (E=ΔU/d).
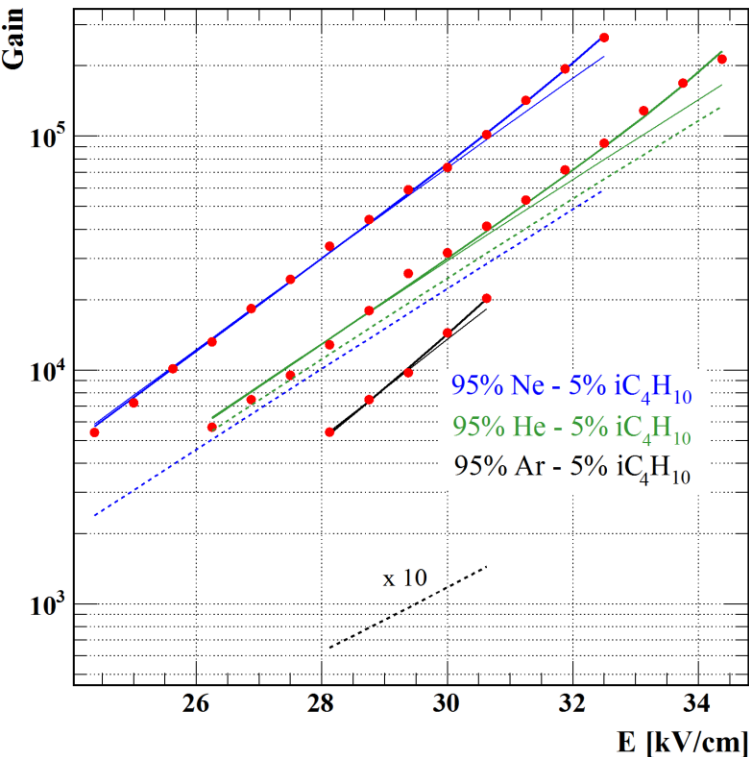
Macroscopic calculation model (Formulas and fit results)

Gain without penning effect:

$$G_0 = e^{\alpha d}$$

Gain with penning effect:

$$G_1 = e^{\alpha_{Penning} d} \qquad \alpha_{Penning} = \alpha \left(1 + r_p \frac{f_{exc}}{f_{ion}}\right)$$

Gain with penning effect and feedback term:

$$G_2 = \frac{G_1}{1 - \beta G_1}$$

Mixture	r_P	β
He i-C$_4$H$_{10}$	0.044 ± 0.012	$2.01 \pm 0.36 \; 10^{-6}$
Ne i-C$_4$H$_{10}$	0.3223 ± 0.0054	$0.99 \pm 0.18 \; 10^{-6}$
Ar i-C$_4$H$_{10}$	0.2659 ± 0.0022	$7.6 \pm 3.4 \; 10^{-6}$