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Mesh transparancy and gas gain studies in micromegas detectors

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Outline

- Simulation of a micromegas
- Experimental setup
- Macroscopic Results:
  - Transparency
  - Gas gain curves
  - Temperature behavior
- Microscopic Results:
  - Development time of an avalanche
  - Spatial extent of an avalanche
- Statistics of gas amplification

- *Simulation of a micromegas*

- Experimental setup

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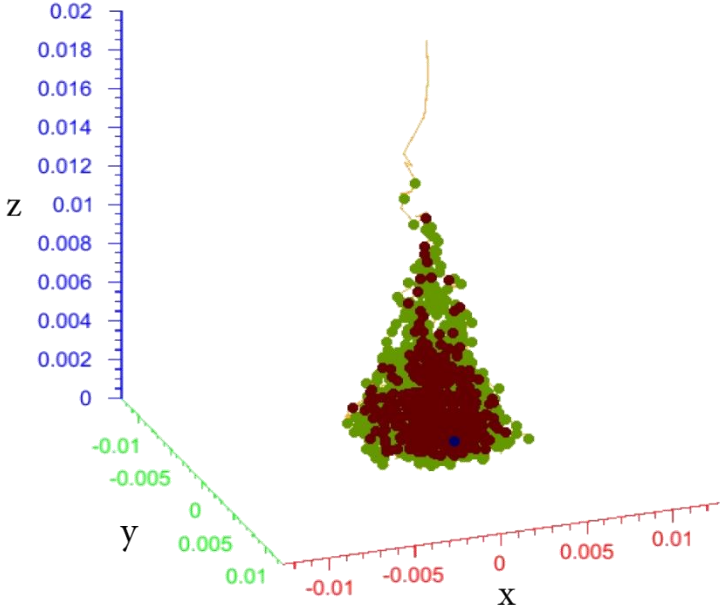
Simulation of the micromegas - Garfield++ Simulation

Simulation of electron drift, scattering processes and avalanche formation is

- done by using the *microscopic avalanche* method in **Garfield++**,
- interfacing **Magboltz 9** for gas properties (Ar CO_2 93:7, 1 atm, 20°C),
- taking into account penning-transfer
  [Sahin, Ö. ; et al: Penning transfer in argon-based gas mixtures. In: Journal of Instrumentation 5 (2010)]
- Using field maps computed with **ANSYS 12.1**

1-5 10^3 avalanches have been simulated per run, relevant information:



- number of electrons per avalanche n_e
- starting z- coordinate of secondary electrons
- end coordinates: Center of gravity, total width, gauss-fit parameters, z_{min}
- timing information of the electrons

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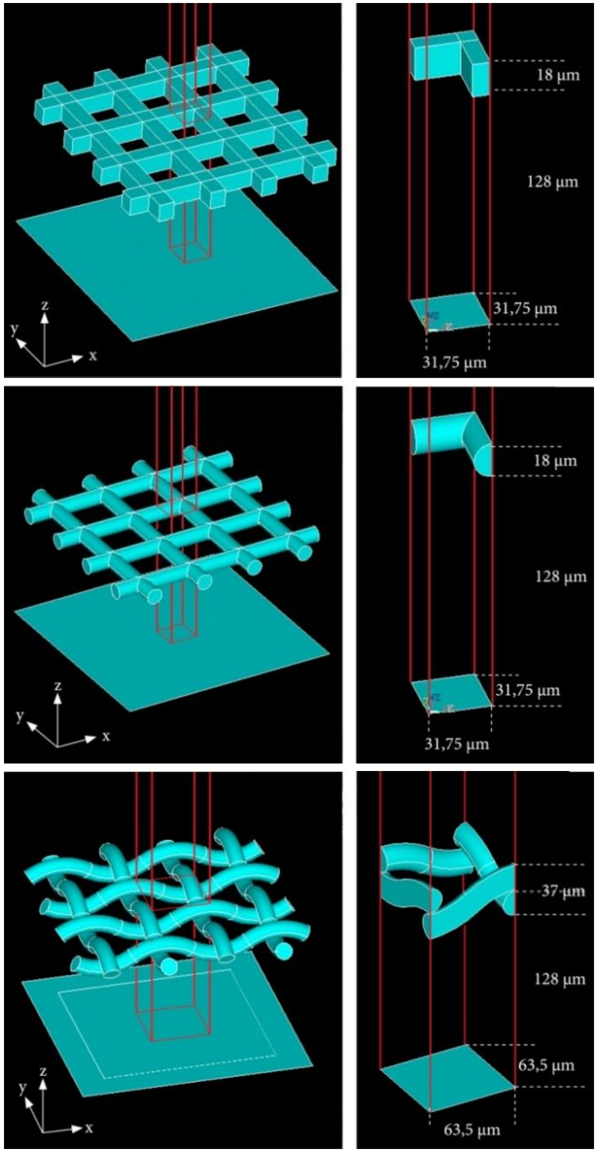
Simulation of the micromegas - fieldmap calculation in ANSYS

Approximation of the electrical field is done by using a *FiniteElementMethod (FEM)*, utilizing the *smartmeshing* option of **ANSYS 12.1**.

- Only unit cell is calculated, with mirror conditions on all vertical borders applied.
  - ✓ Periodicity of the mesh
  - X Periodicity of the readout and pillars
- 3 different layout with rising complexity have been under study.
  - – Layout 1 (L1): flat, rectangular wires
  - – Layout 2 (L2): flat, cylindrical wires
  - – Layout 3 (L3): woven, toroidal wire-pieces
  - ✓ Cylindrical wires and woven structure
  - X Calendering of the mesh

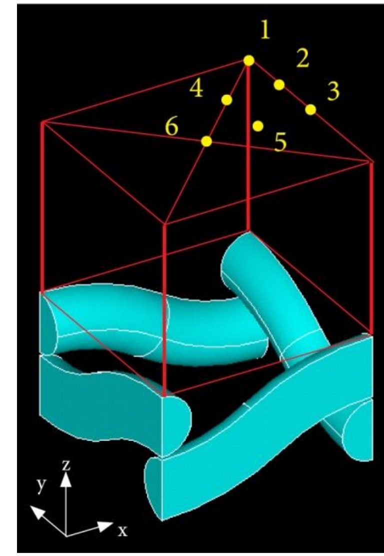


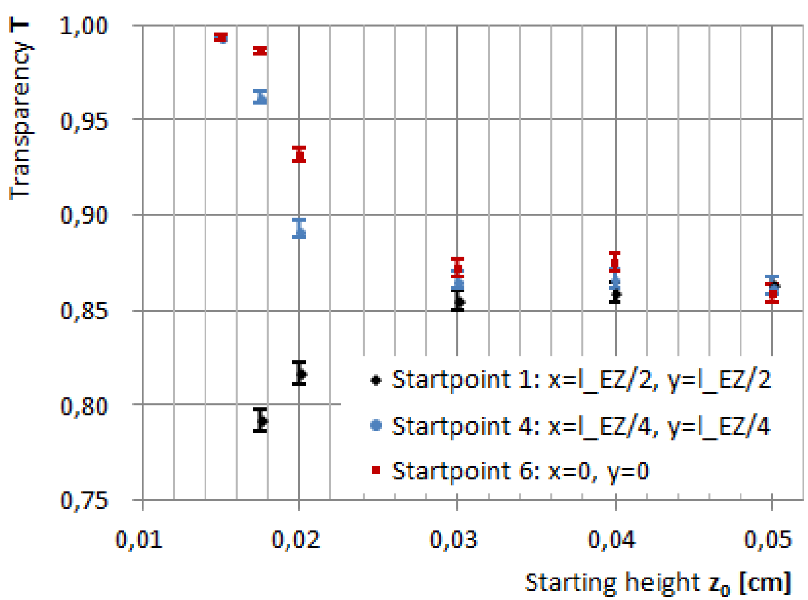
Simulation of the micromegas - starting position adjustment

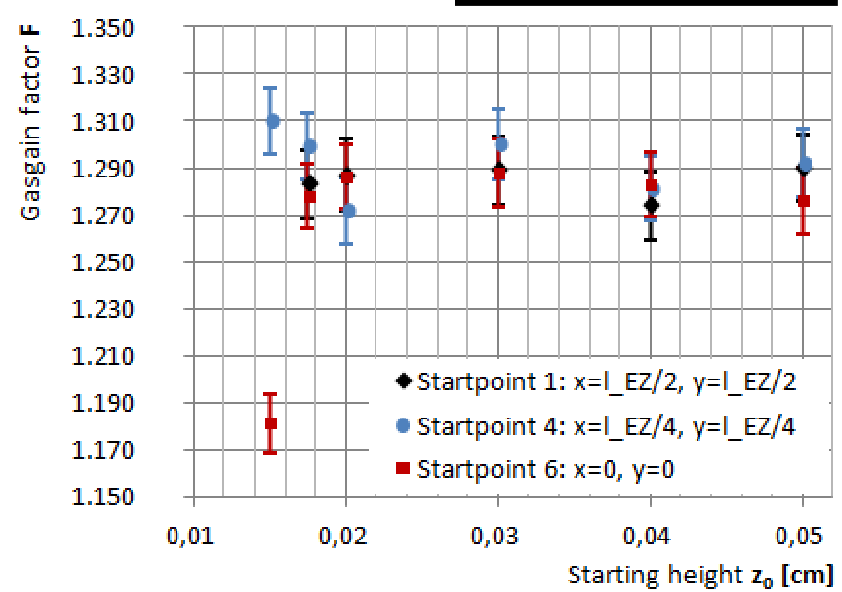
Elimination of systematic errors due to starting position:

- x-y coordinates at random
- precedent study on starting height dependence for transparency and gas gain.

→ z_0=400 µm (~250 µm above mesh upper border)







- Simulation of a micromegas

- *Experimental setup*

- Macroscopic Results:
  - Transparency
  - Gas gain curves
  - Temperature behavior

- Microscopic Results:
  - Development time of an avalanche
  - Spatial extent of an avalanche

- Statistics of gas amplification

Measurement of the mesh transparancy & the mean gas gain

Measurements taken in February 2013 in collarboration with the experimental partical physics group at the LMU Munich.

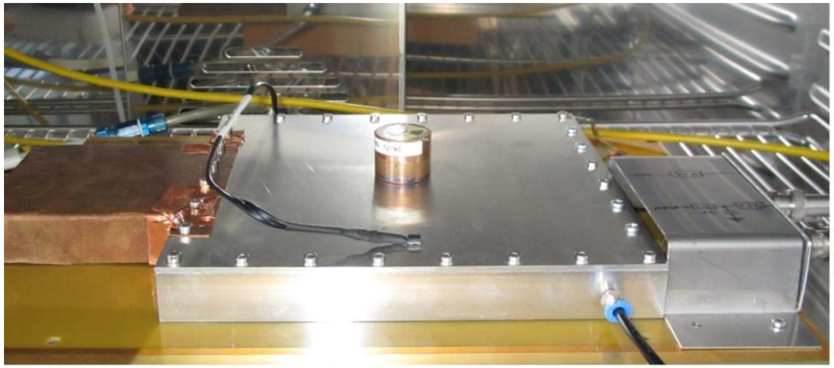
- two chambers tested:
  Standard (STD) & Resistive (RES)

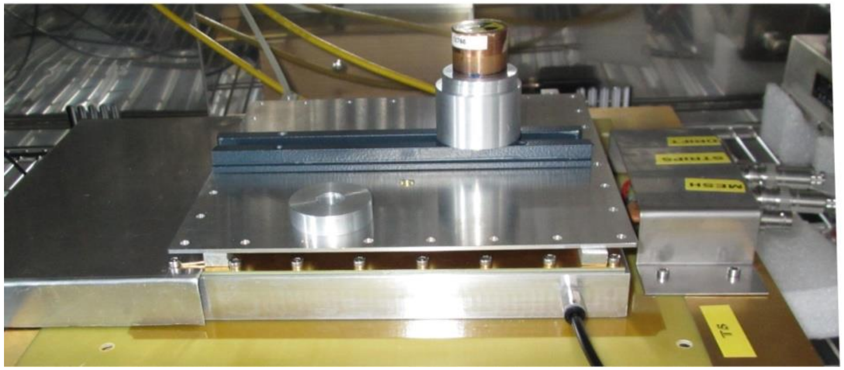
- using an ^{55}Fe source

- temperature controlled measurement

- pressure controlled to ±0,3 mbar,
  self mixed Ar-CO_2 93:7 gas

- accumulated charge on 18 readout strips has been measured

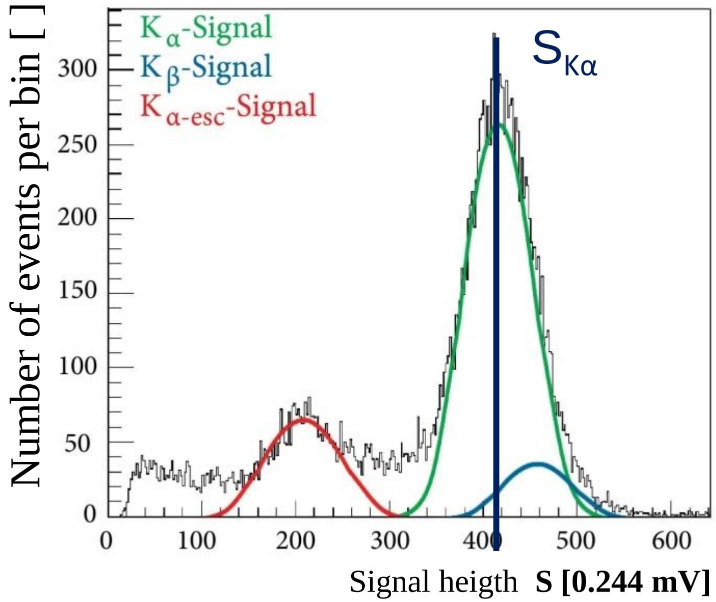




Measurement of the mesh transparancy & the mean gas gain

Measure the gas gain: Spectra of the ^{55}Fe source was recorded using ~20K events.

Signal Position of the K_α-Peak $S_{K\alpha}$ is related to the signal of $n_{K\alpha}$≈230 primary electrons produced by the 5,9 keV photon.



The mean gas gain F can be calculated by:

$$F(E_{amp}) = \frac{Q_{real}}{n_T \cdot e} = \frac{S_{K\alpha}(E_d, E_{amp}) \cdot \frac{1}{f_{Cor}}}{n_{K\alpha} \cdot T(E_d, E_{amp}) \cdot e}$$

Simulate the gas gain: Avalanche size of single primary electron.

$$F = \overline{n_e}$$

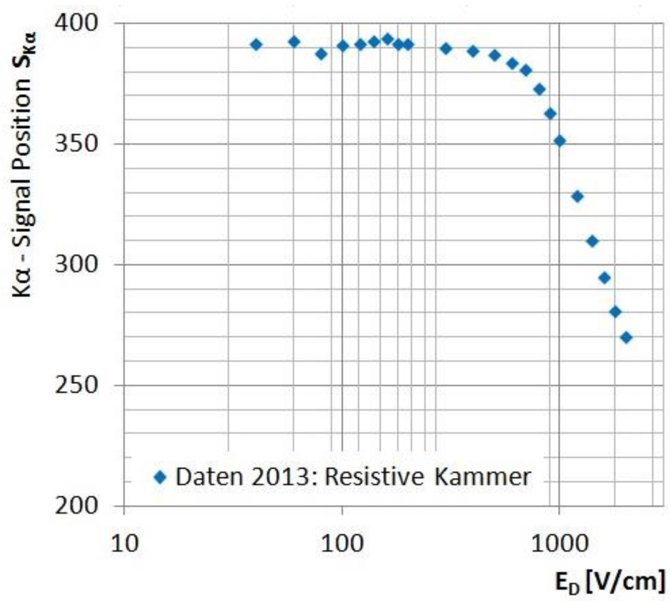
f_{Cor} refers to studies in:

[Bortfeldt, J.: Development of Micro-Pattern Gaseous Detectors - Micromegas, LMU Munich, Diplomarbeit, 2010].

Measurement of the mesh transparancy & the mean gas gain

Measure the transparency T: indirectly by observation of the shift in the peak-Position ($S_{K\alpha}$) under variation of E_d at constant E_{amp}, assuming $\lim_{E_d \to 0} T = 100\,\%$.

$$F(E_{amp}) = \frac{Q_{real}}{n_T \cdot e} = \frac{S_{K\alpha}(E_d, E_{amp}) \cdot \frac{1}{f_{Cor}}}{n_{K\alpha} \cdot T(E_d, E_{amp}) \cdot e}$$



Normalization of the Data to 99%-100% at

E_{drift} < 400 V/cm

Simulate the transparency T:

$$T = \frac{n_T}{n_T + n_A}$$

n_T = Number of events with z_{min} < 120 µm, n_A = Number of events with z_{min} > 120 µm *

*(other definition of n_T and n_A has been tested using the number of electrons per event, yielding the same transparancy at < ‰ – Level.)

- Simulation of a micromegas

- Experimental setup

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  - *Transparency*
  - *Gas gain curves*
  - *Temperature behavior*

- Microscopic Results:
  - Development time of an avalanche
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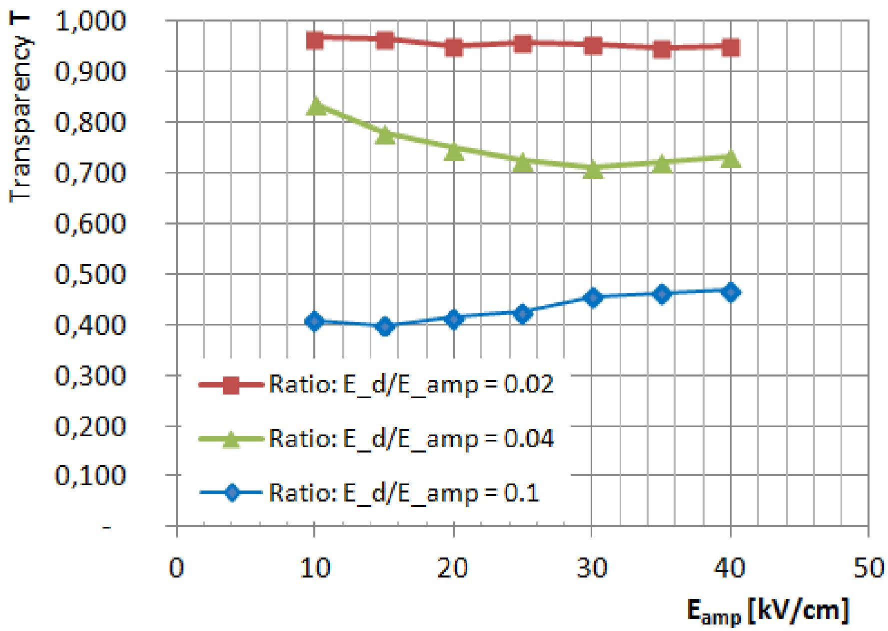
Macroscopic results – Transparency of the mesh

Transparency depends on various parameters:

- mesh geometry (woven & calendared or electroformed, wire diameter, wire periodicity, optical transparency)
- gas mixture
- gas parameters (pressure, temperature)
- electric configuration (voltages)

In literature, often you can find T (E_d/E_{amp}) without any theoretical or experimental justification for this parameter reduction.

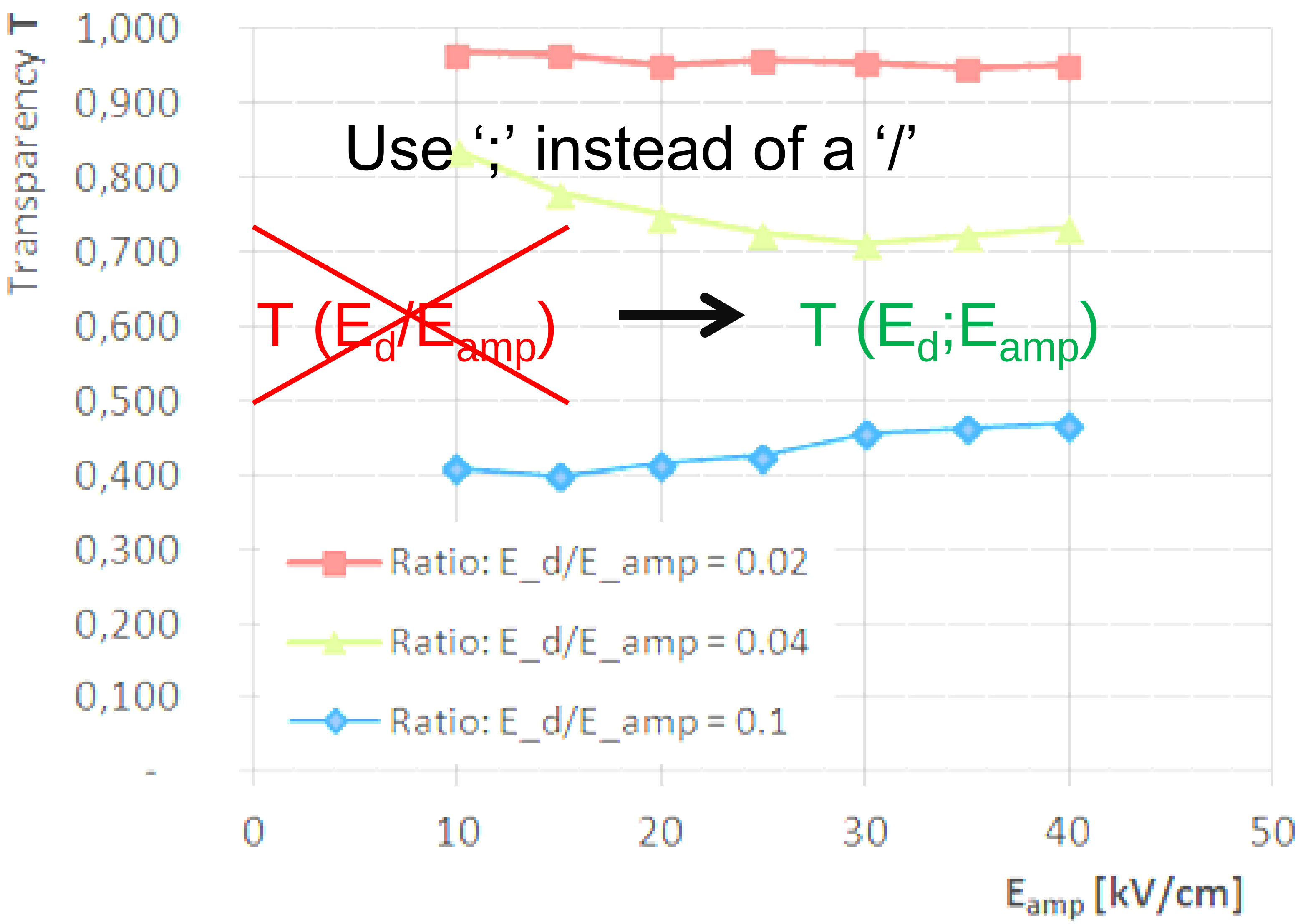
→ Simulation study with fixed Ratio E_d/E_{amp} = 0.1; = 0.04; = 0.02



First message of my talk

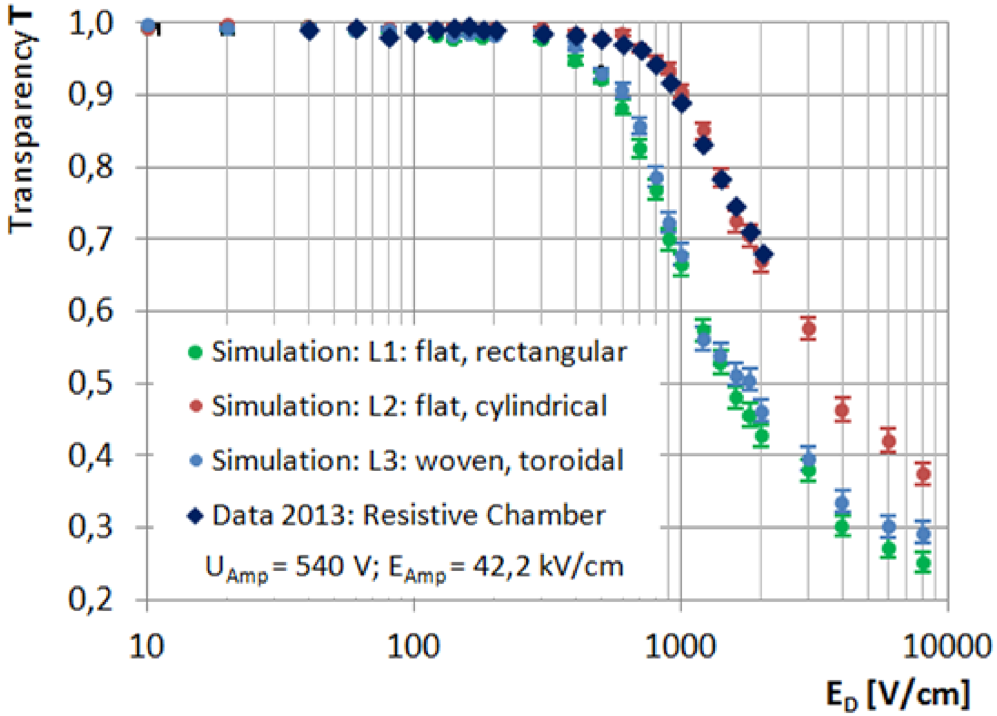
Use ‘;’ instead of a ‘/’

~~$T\,(E_d/E_{amp})$~~ → $T\,(E_d;E_{amp})$



Macroscopic results – Transparency of the mesh

Comparison of the measured and simulated transparency with constant amplification field and variated drift field.

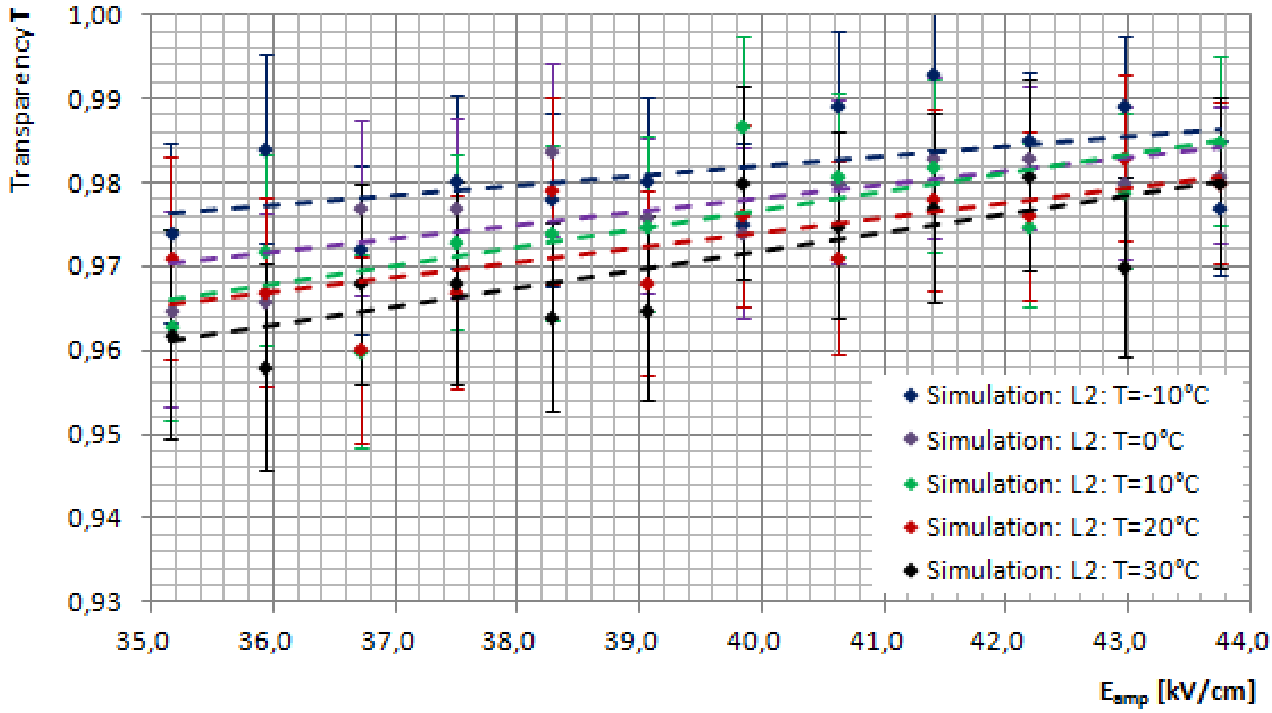


- Experimental and simulation data are in very good agreement for Layout 2
- Layout 3 shows a reduced transparency compared to L2 simulation and data
- Layout 1 transparency underestimates data, in agreement with previous studies

[K. Nikolopoulos, et al: *Electron transparency of a Micromegas mesh;* Journal of Instrumentation 6 (2011)]

Macroscopic results – Transparancy of the mesh

The simulated transparancy of the mesh with constant driftfield and variated amplification field is shown for different temperatures (-10°C to 30°C). (including linear fits as dashed lines)



- Increase of the transparency with the amplification voltage can be observed
- Decrease of the transparency with growing temperature is noticeable

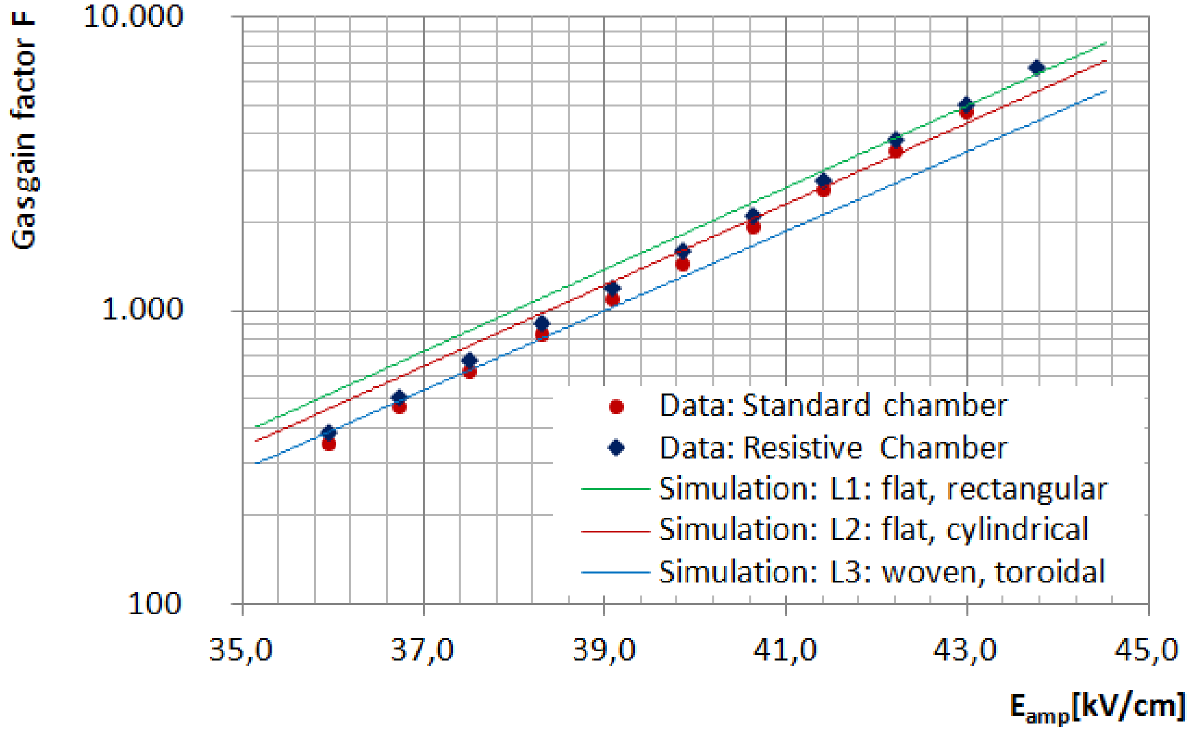
Macroscopic results – Transparency of the mesh

Gas gain also depends on a set of parameters:

- electric configuration: $\mathbf{E_{amp}}$; (E_d)
- gas mixture
- gas parameters (pressure, temperature)
- heigth of the amplification gap
- ? mesh geometry ?

Macroscopic results – Gas gain dependancy on amplification voltage

The amplification factor for a single electron F, the gas gain, with exponential fit:



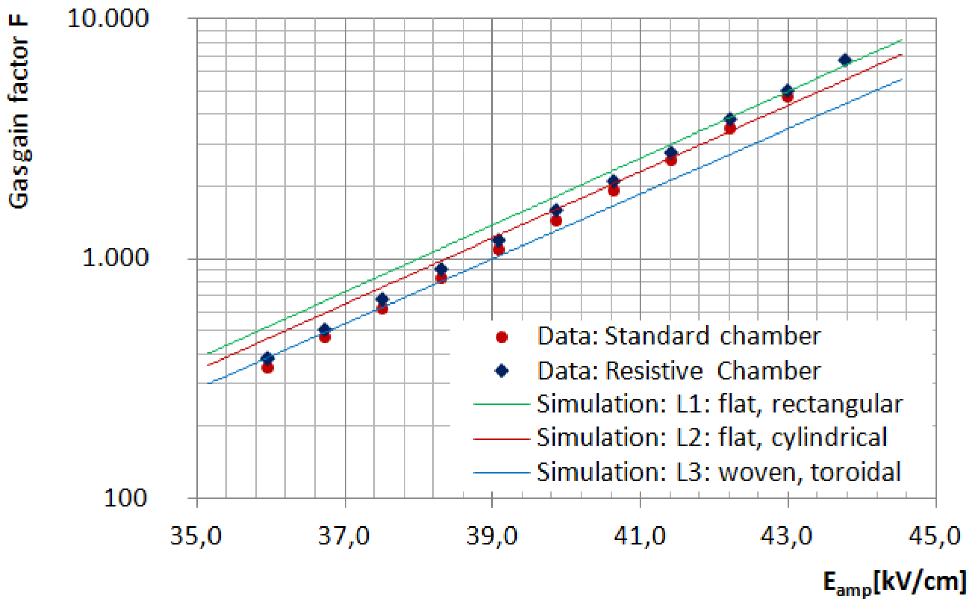
- All data (simulated and experimental) show the exponential behavior
- Good agreement in order of magnitude between simulation and experiment
- Experimental data grow faster

Macroscopic results – Gas gain dependancy on amplification voltage

Experimental data:

- Resistive chamber shows an slightly higher amplification behavior of approx. 8,5 %

→ Unexpected behavior, signal loss due to resistive strips would be expected



→ But: Comparison of the lines assumes equal thickness of the amplification gap ($d_{amp}=128\,\mu m$), which is used to determine $E_{amp} = \dfrac{U_m - U_a}{d_{amp}}$

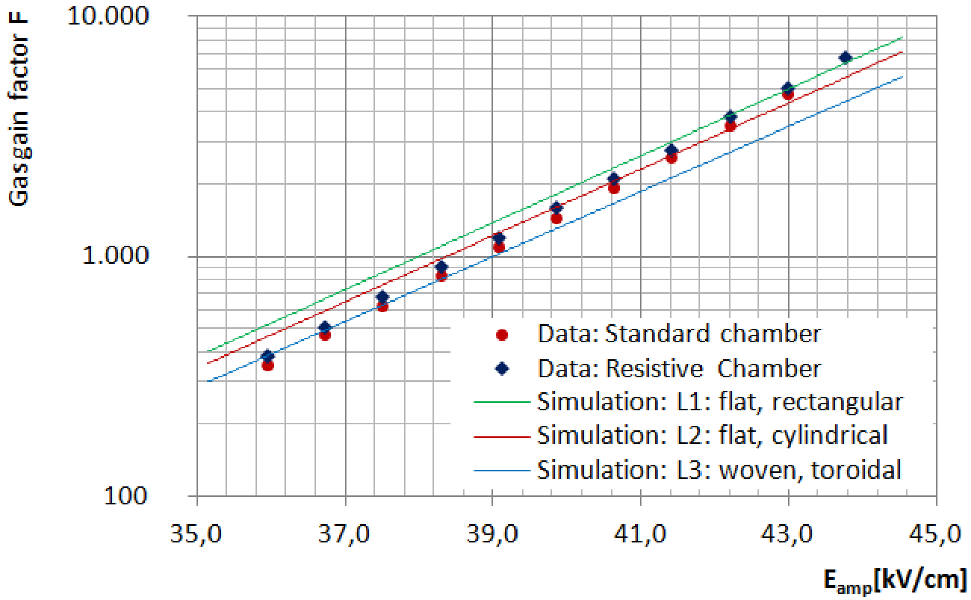
→ Only a deviation of ±1 µm in this thickness leads to an agreement of the data.

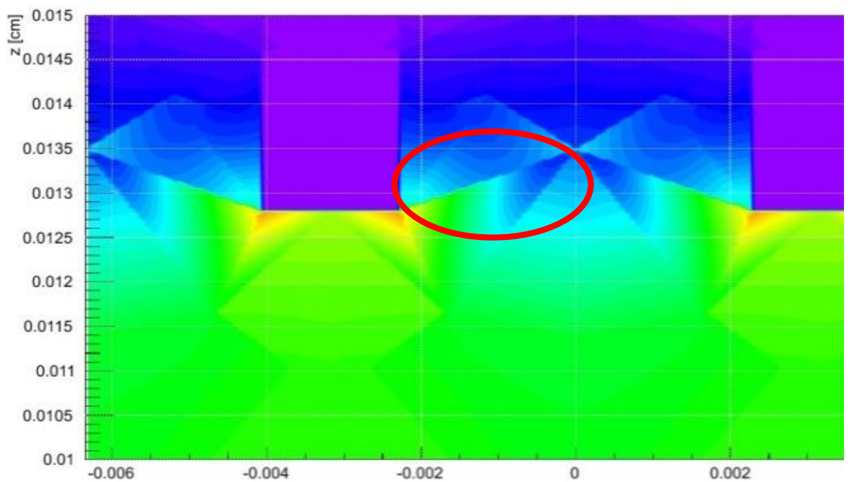
Macroscopic results – Gas gain dependancy on amplification voltage

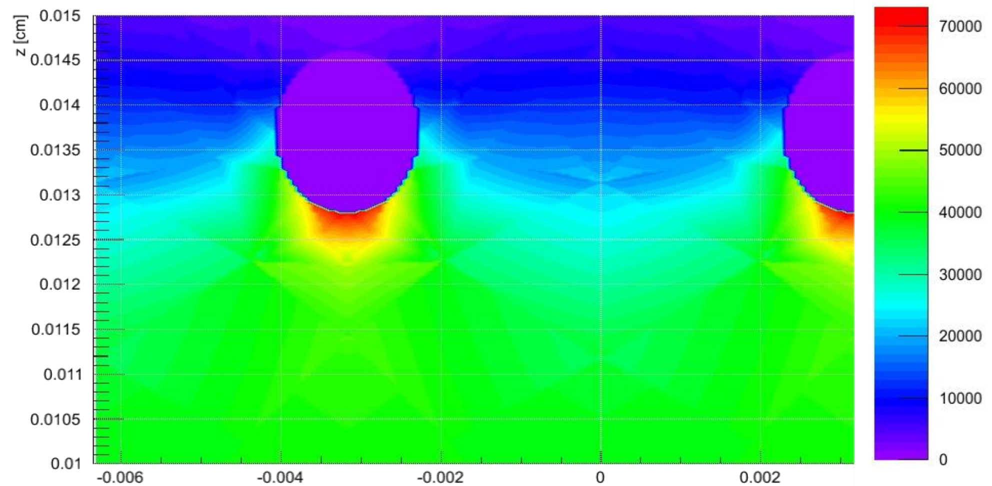
Simulated data:

- **Layout 1** simulation results show the highest gas gain.

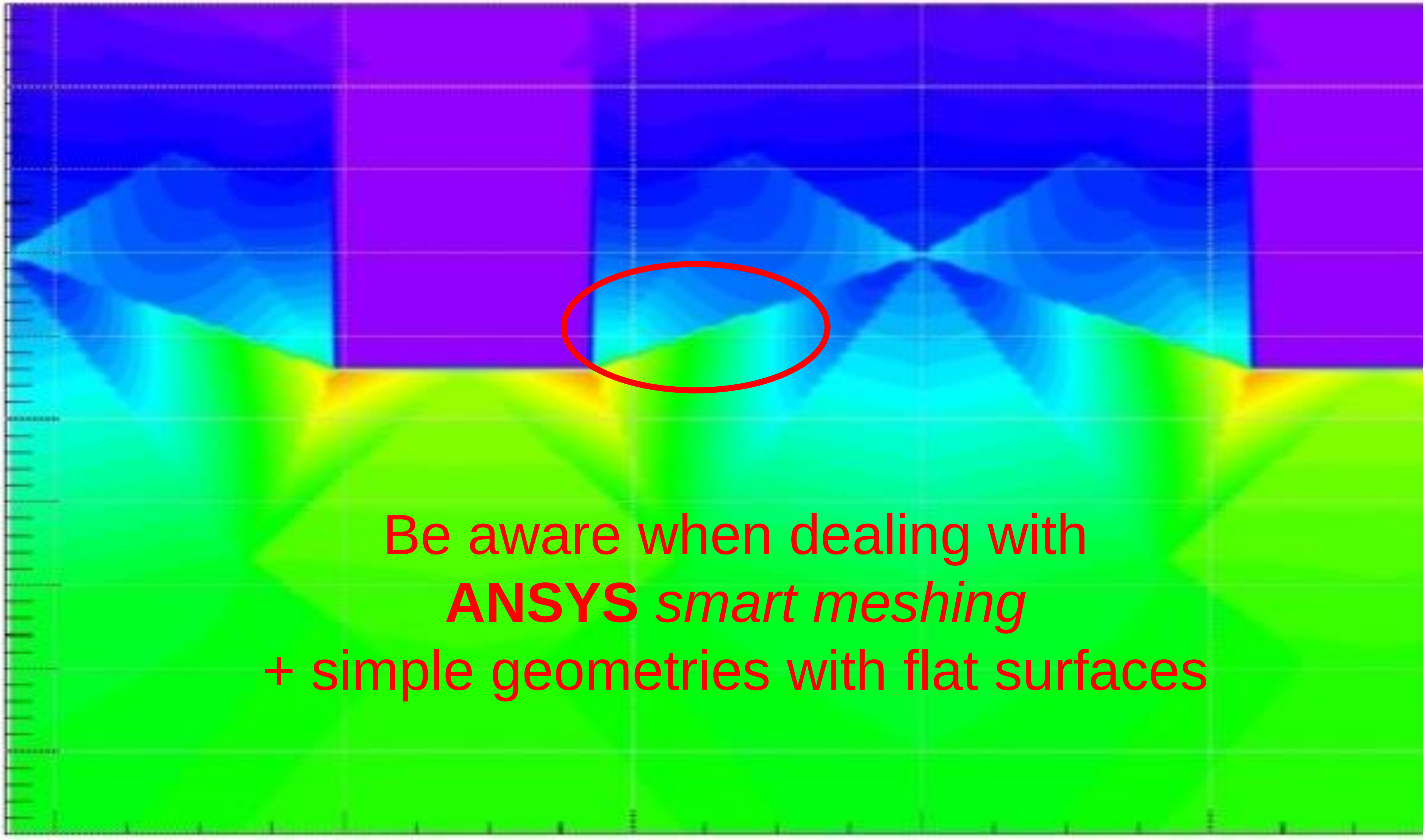
→ This results from an artifact in the field maps, created by the FEM using the ANSYS *smartmeshing.*







Very important message



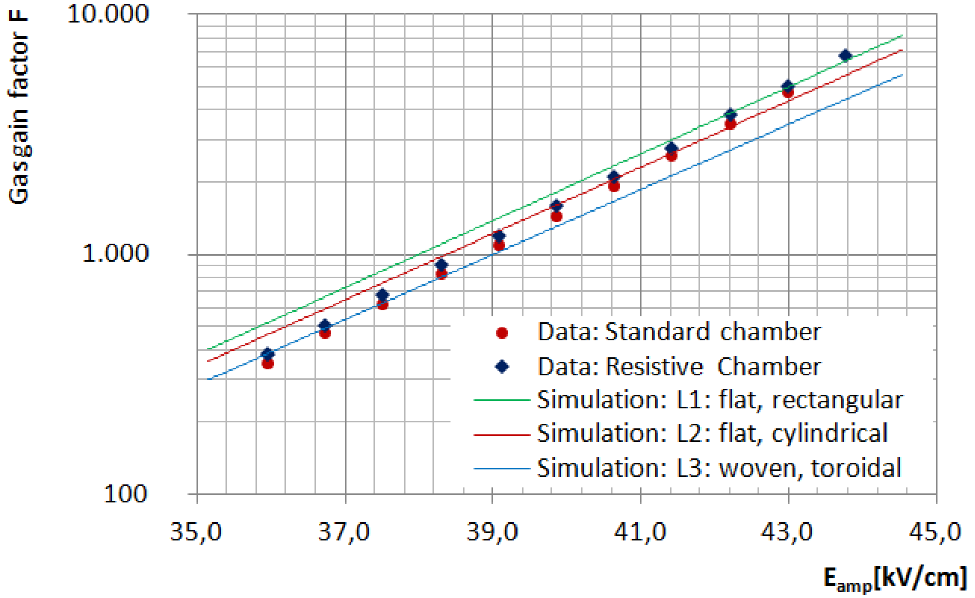
Be aware when dealing with
ANSYS *smart meshing*
+ simple geometries with flat surfaces

Macroscopic results – Gas gain dependancy on amplification voltage

Simulated data:

- **Layout 3** simulation results show the lowest gain values

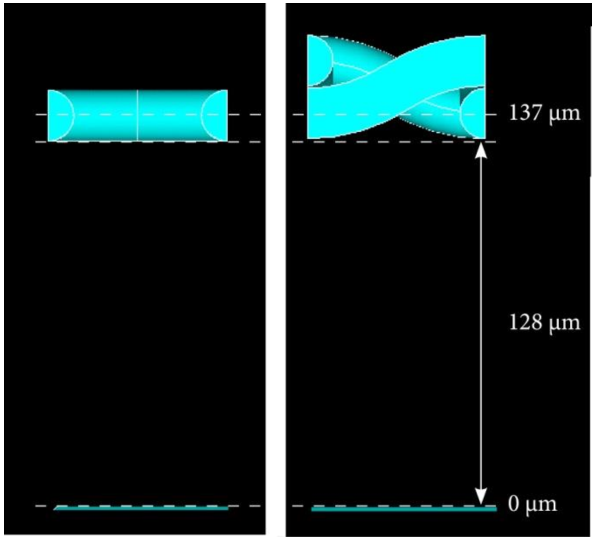
→ This discrepancy again results from the calculation of E_{amp} .



→ Using the ‚flat' Layout 1 and 2 the lower edge of the mesh is fixed at 128 µm above the anode.

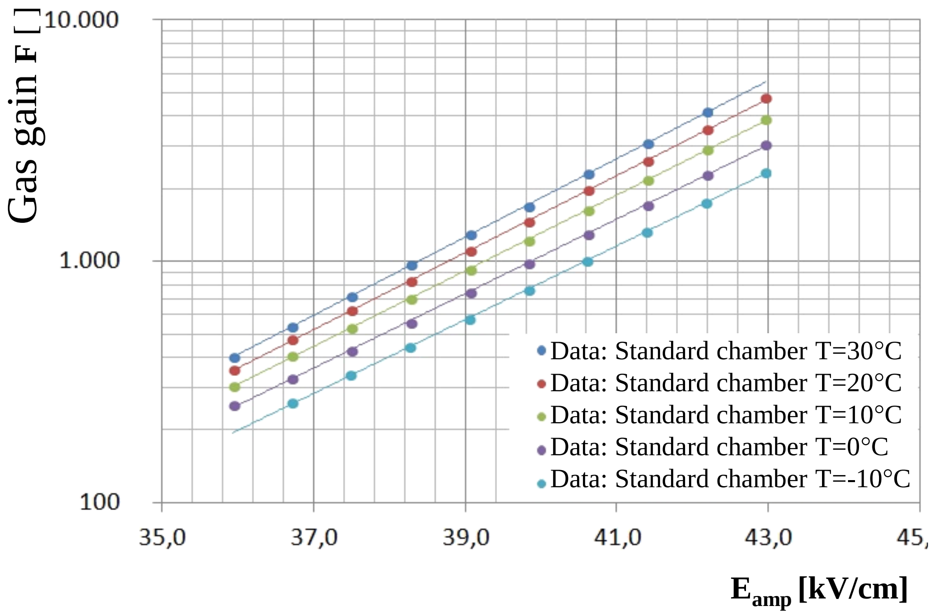
→ In Layout 3 only the lower edge of the curved wire is between 128 to 137 µm, thus the mean height of the gap is >128 µm.

→ Electric field is overestimated by $E_{amp} = \frac{U_m - U_a}{d_{amp}}$



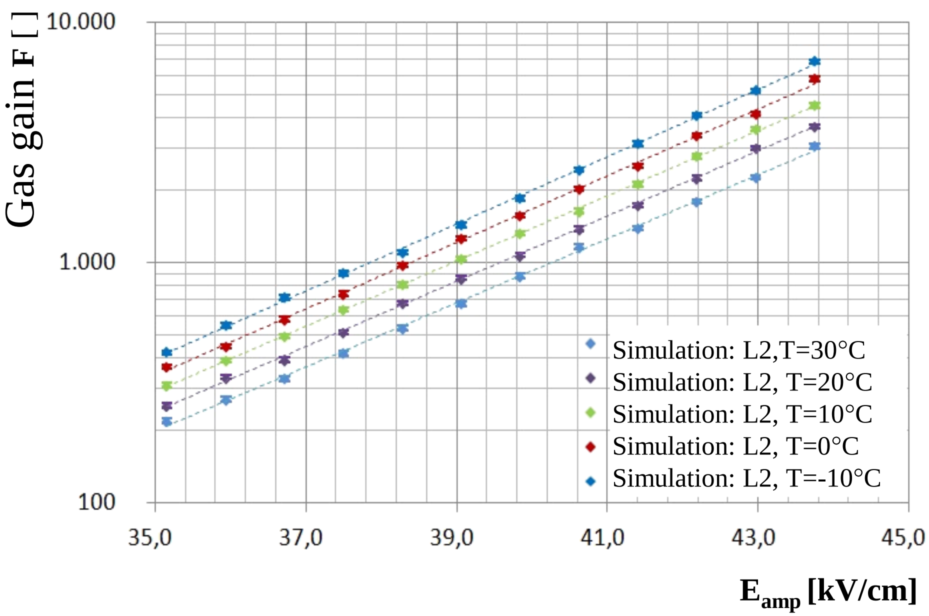
Macroscopic results –
Gas gain dependancy on temperature

Gas gain ‚voltage scan‘ for different temperatures in a range from -10°C to 30°C.



Experiment

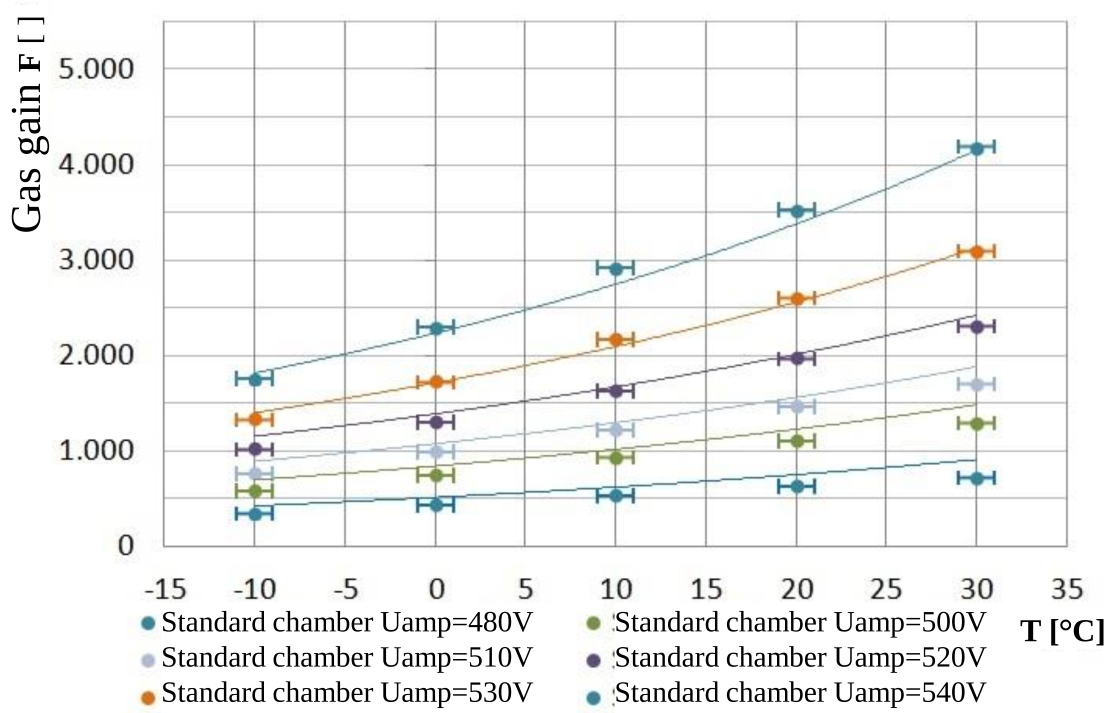
Simulation



→ Same behavior for different chambers / layouts at all temperatures

Macroscopic results – Gas gain dependancy on temperature

Agreement between STD chamber data and L2 simulation:



Comparison between gain factors in simulation (lines = exponential fit to simulated data) and experimental data (dots + errors) over growing temperature for different amplification voltages.

- Simulation of a micromegas

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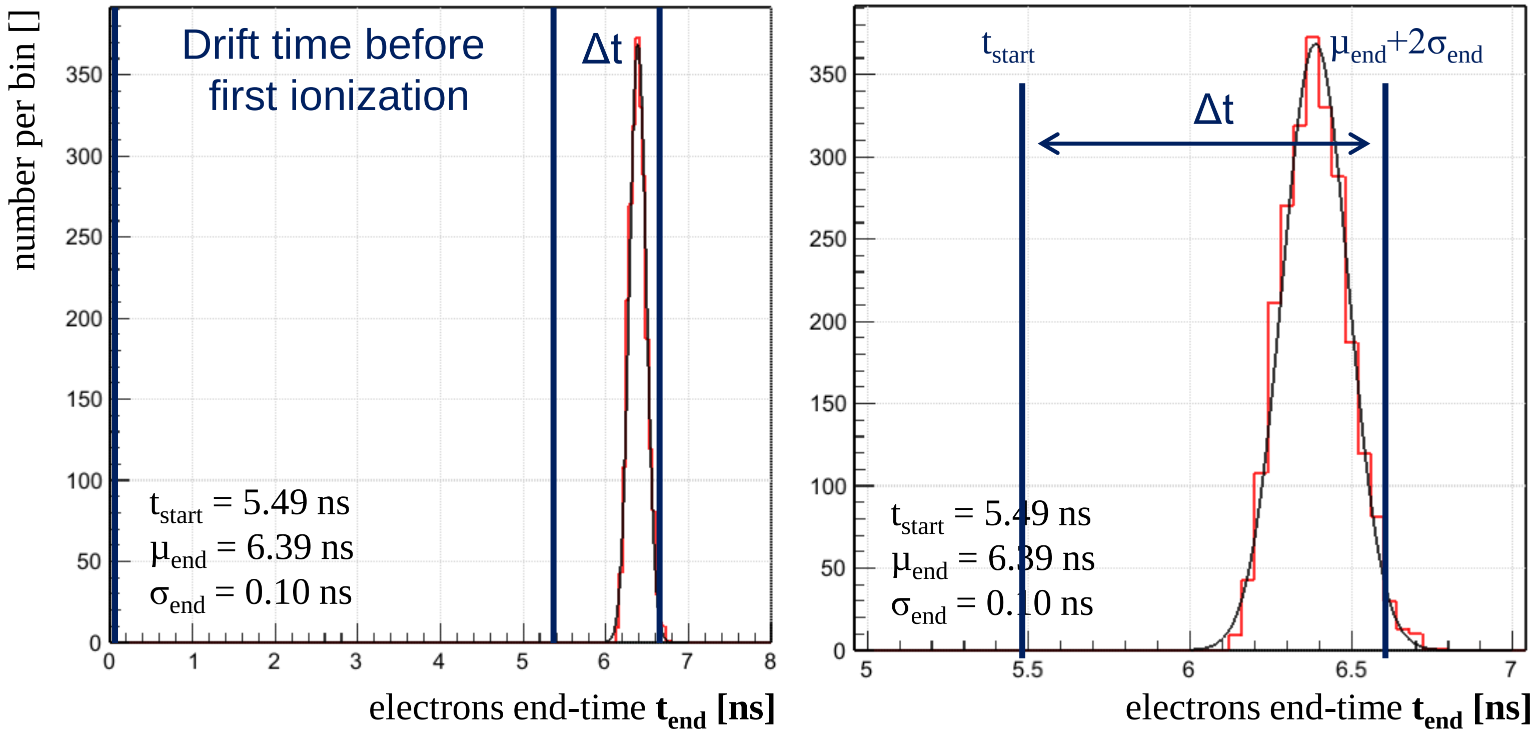
- ***Microscopic Results:***
  - *Development time of an avalanche*
  - *Spatial extent of an avalanche*

- Statistics of gas amplification

Microscopic results – Development time of an electron avalanche

Calculation of the development time of an electron avalanche Δt:

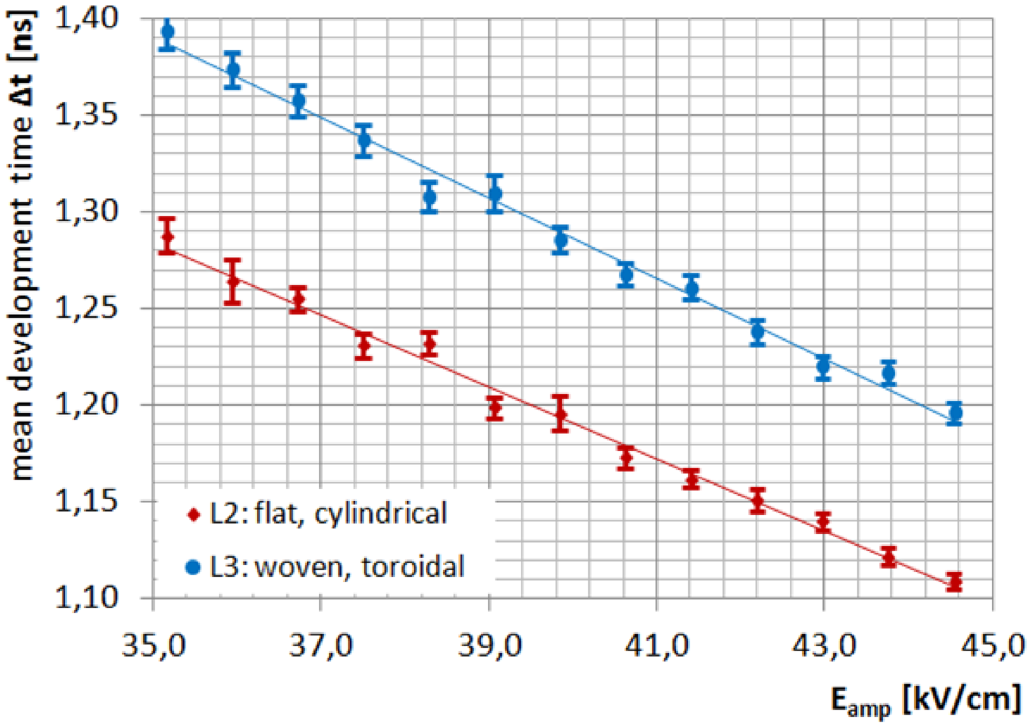
$$\Delta t = \mu_{end} + 2\,\sigma_{end} - t_{start}$$



Time span from the production of the first secondary electron (=first ionization) until 97,5% of the avalanche-electrons reached the anode.

Microscopic results – Development time of an electron avalanche

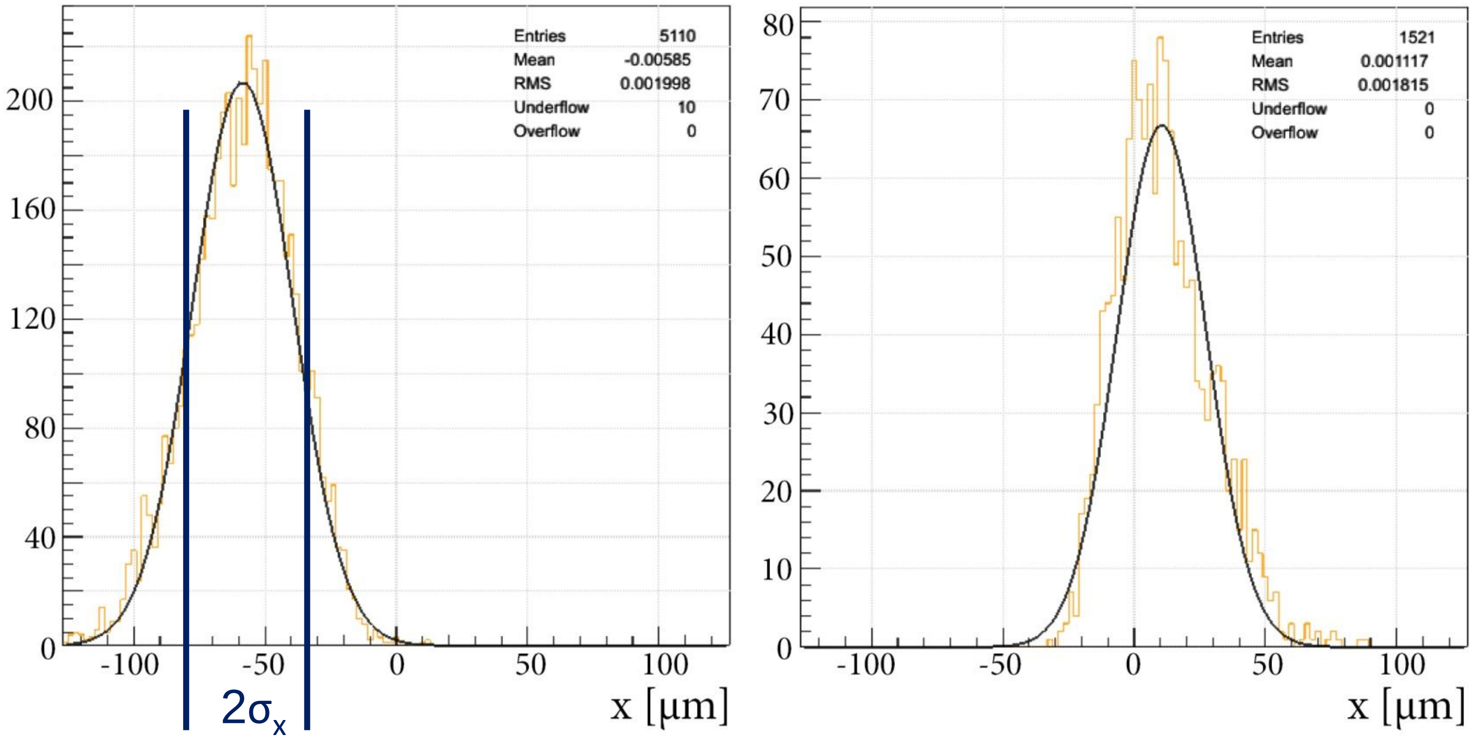
Dependency of the development time of an electron avalanche Δt on the electric field in the amplification gap.



- Linear decrease of Δt with growing E_{amp}, due to higher mean electron velocity
- Systematical greater Δt for the toroidal Layout (L3), due to greater distance between anode and location of first amplification process

Microscopic results –
Spatial extent of an electron avalanche

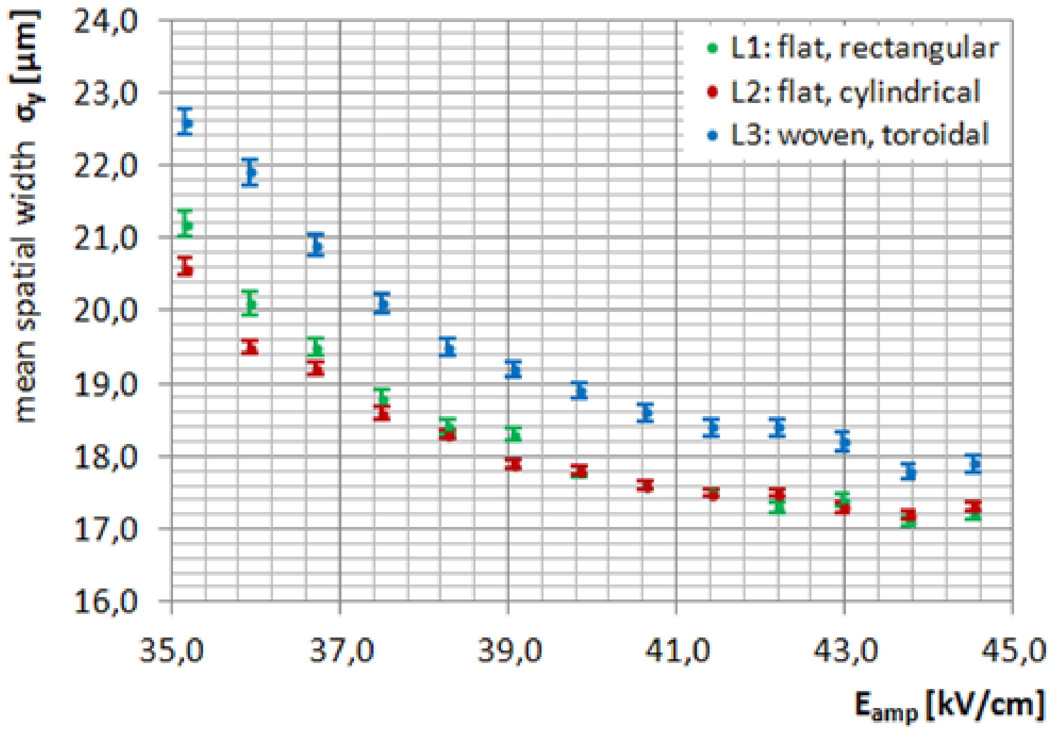
Gauss-function fit proved to be a good form-estimator for large avalanches, less good for small avalanches. Mean spatial extent measured by the sigma along the direction σ_x. (y – direction yields similar results)



The extent of 68% of the electrons can be estimated by $2\sigma_x$.

Microscopic results – Spatial extent of an electron avalanche

Electric field dependancy of the mean spatial extent measured by fitting a gauss-function, shown is the sigma along the x-direction σ_x.



- Decrease of spatial extent as expected, due to transversal diffusion $\sigma_x = \sqrt{2D\,\Delta t}$
- ~ 50% results from the decrease of Δt, thus ~ 50% influence on $D(E_{amp})$
- Again systematic offset for L3, according to longer diffusion time

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- *Statistics of gas amplification*

Statistic of single electron amplification

The number of electrons n_e in one avalanche is statistically distributed.
For the parameterization of amplification often the Polya-distribution is used:

$$P(n_e) = \frac{1}{\bar{n}} \frac{(\Theta+1)^{\Theta+1}}{\Gamma(\Theta+1)} \left(\frac{n_e}{\bar{n}}\right)^{\Theta} e^{-(\Theta+1)\frac{n_e}{\bar{n}}}$$

Normalized two parameter function with mean electron number $\bar{n}$ and form parameter Θ , which e.g. yields the most probable number of electrons:

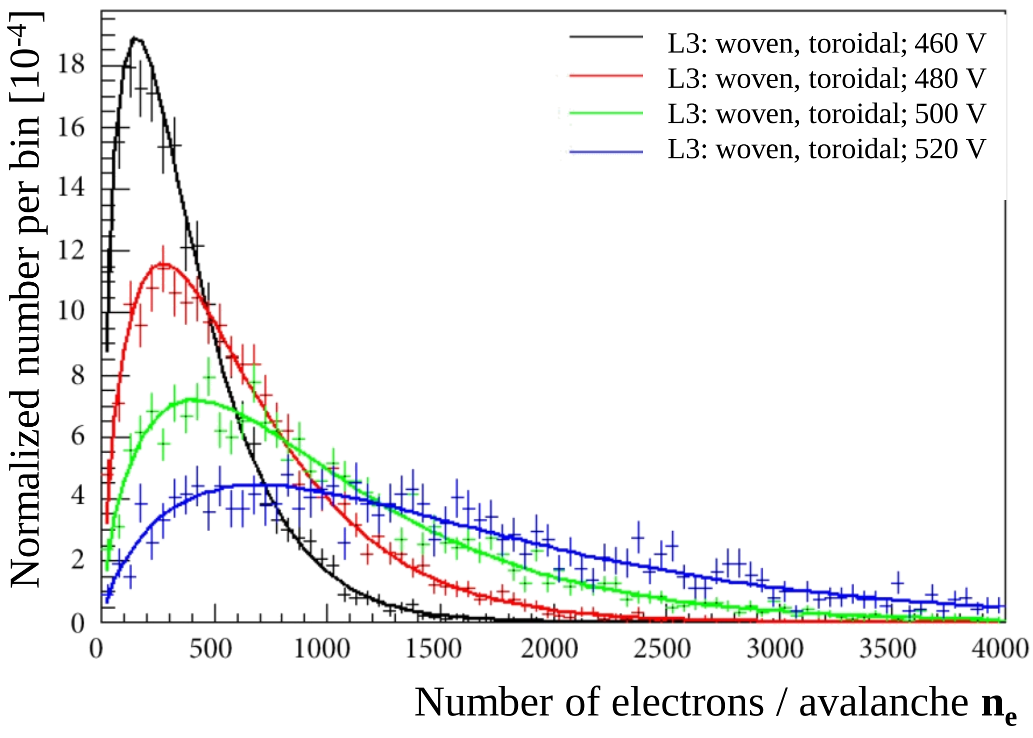
$$n_{mp} = \frac{\bar{n}\,\Theta}{\Theta + 1}$$

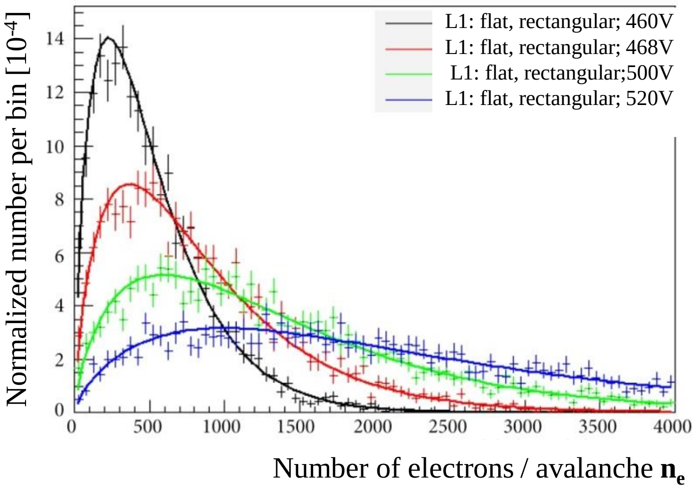
And the width of the distribution:

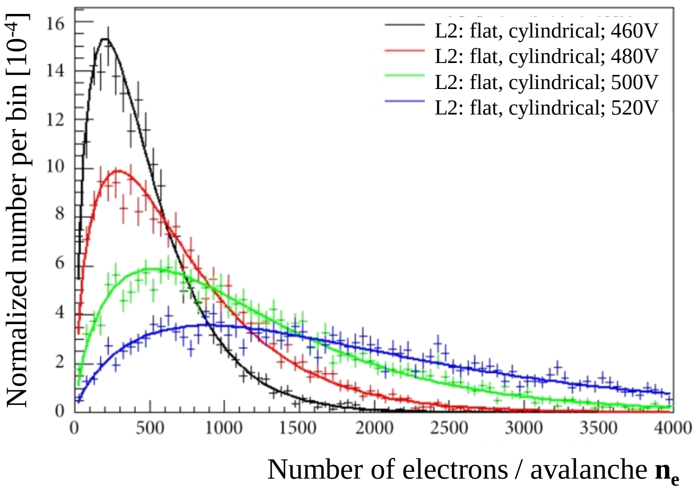
$$f = \frac{1}{\theta + 1}$$

Statistic of single electron amplification

Using Polya distribution to discribe gain fluctuations in micromegas simuliation

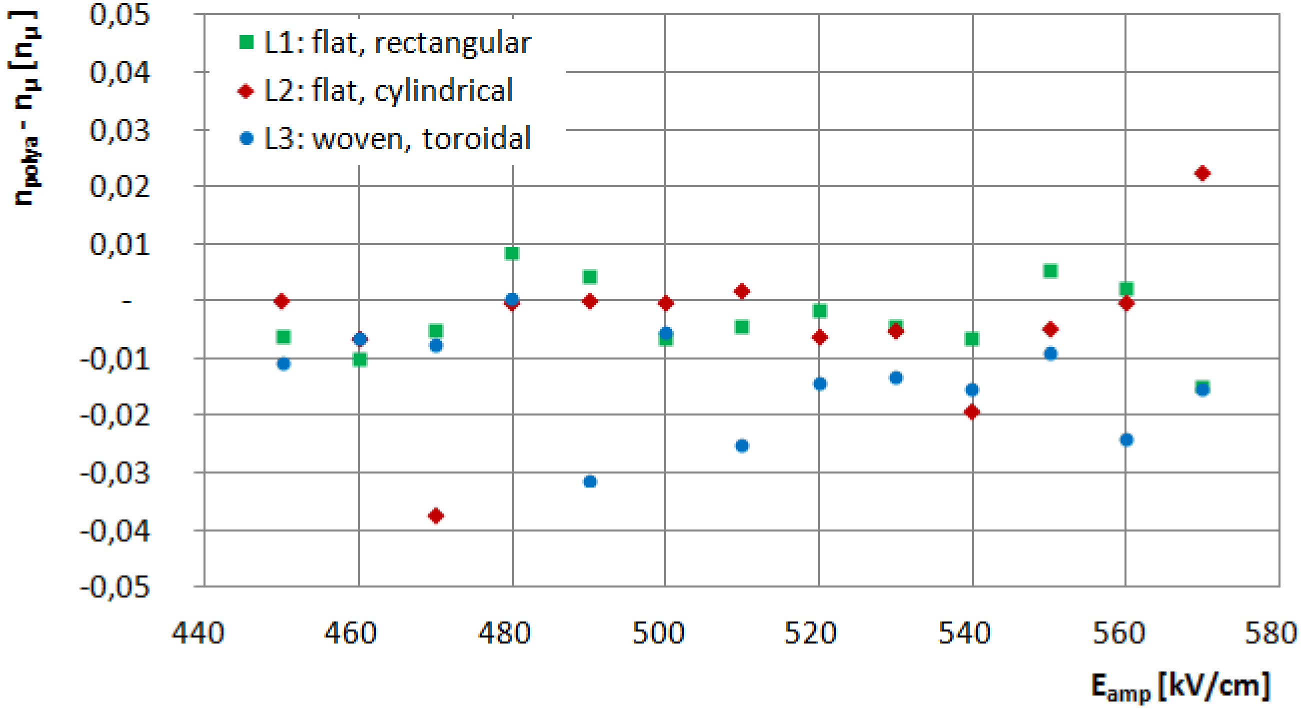






Statistic of single electron amplification

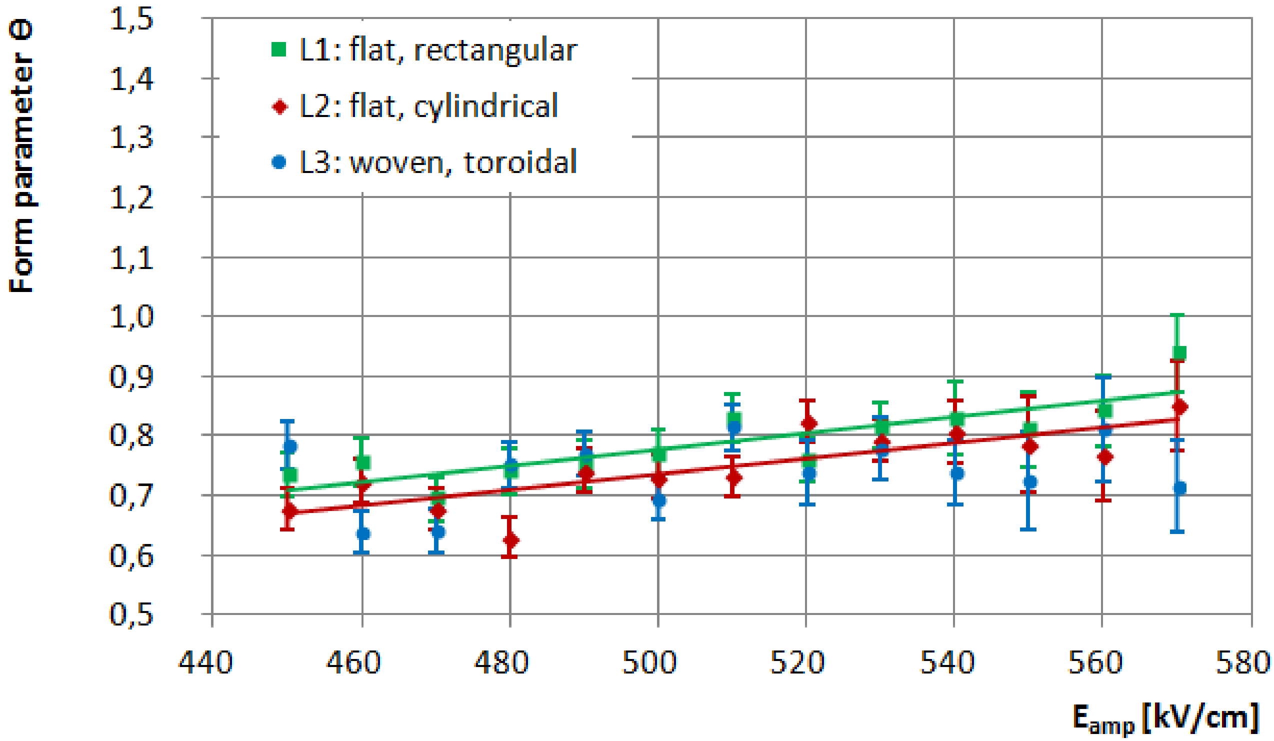
Comparison of mean electron numbers from raw-simulation results n_μ and the numbers taken from the polya fits n_{polya} for different amplification voltages.



This yields a very small underestimation of the ‘real‘ value by the fit in Layout 1 (0,3%) and Layout 2 (0,4%) and a noticeable underestimation for the results simulated with Layout 3 (1,4%).

Statistic of single electron amplification

Observation of the form parameter Θ within typical parameter range.



The data produced by L1 and L2 favor a slight growth in Θ

→ Study has to be optimized to reduce to errors

Statistic of single electron amplification - Summary-

- The mean electron number seems to be slightly underestimated by the Polya-fit function (not significant for L1 and L2).
- The form parameter shows a slight growth with the amplification voltage, further studies on dependencies on gas parameters are to be done.
- A list of parameters ($\bar{n}$ and Θ) for different amplification voltages with the given gas mixture and environmental conditions has been provided for further use.

Conclusion and Outlook

- All experimental accessible macroscopic results (Transparency, Gas gain incl. temperature scan) are in good agreement with the simulation, favoring Layout 2 results.

- Microscopic values of the avalanche process have been studied and guide values could be derived. (Δt = 1,2 – 1,4 ns; $2\sigma_x$ = 35 – 45 µm).

- The statistic of single electron amplification has been successfully described by using Polya-distribution, Form parameter shows a slight dependence on the amplification voltage.

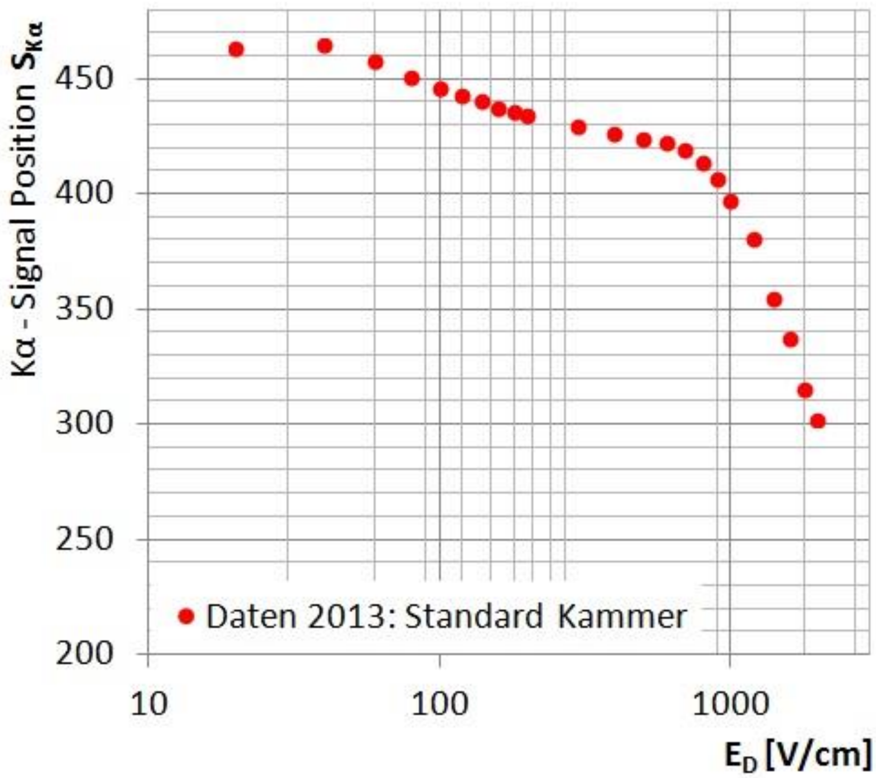
- Layout 3, taking the woven structure of the mesh into account, did not yield better simulation results, since the mesh thickness is clearly overestimated.

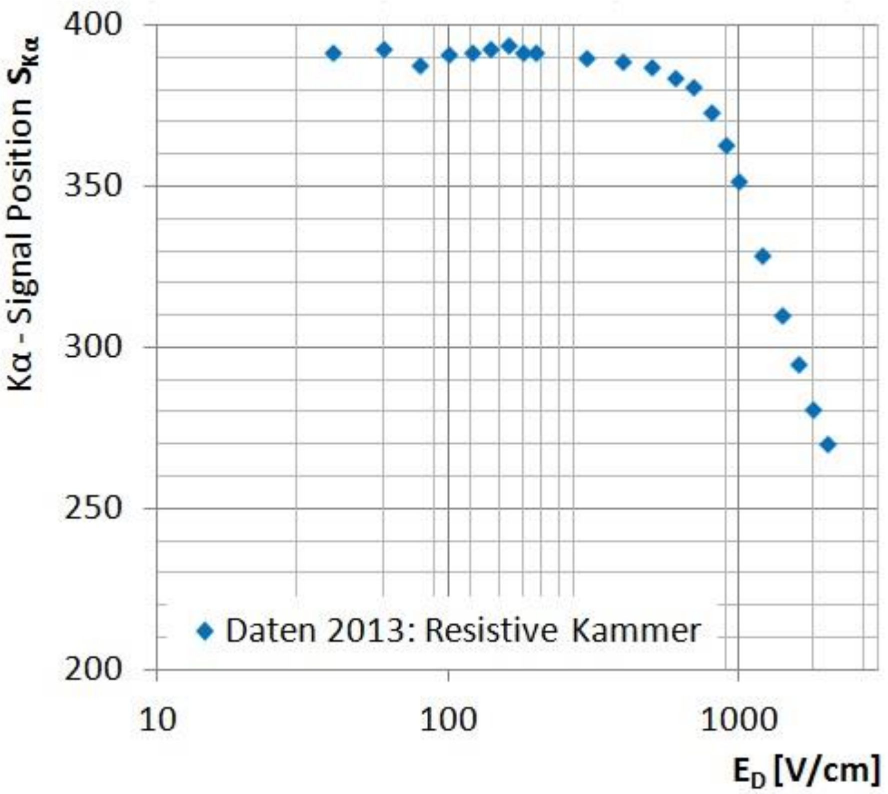
- The validated simulation could be use to study different gas mixtures and / or pressure behavior.
- A further improved Layout, taking the calendering process into account, should be studied and compared to Layout 2.

Thank you for your attention!

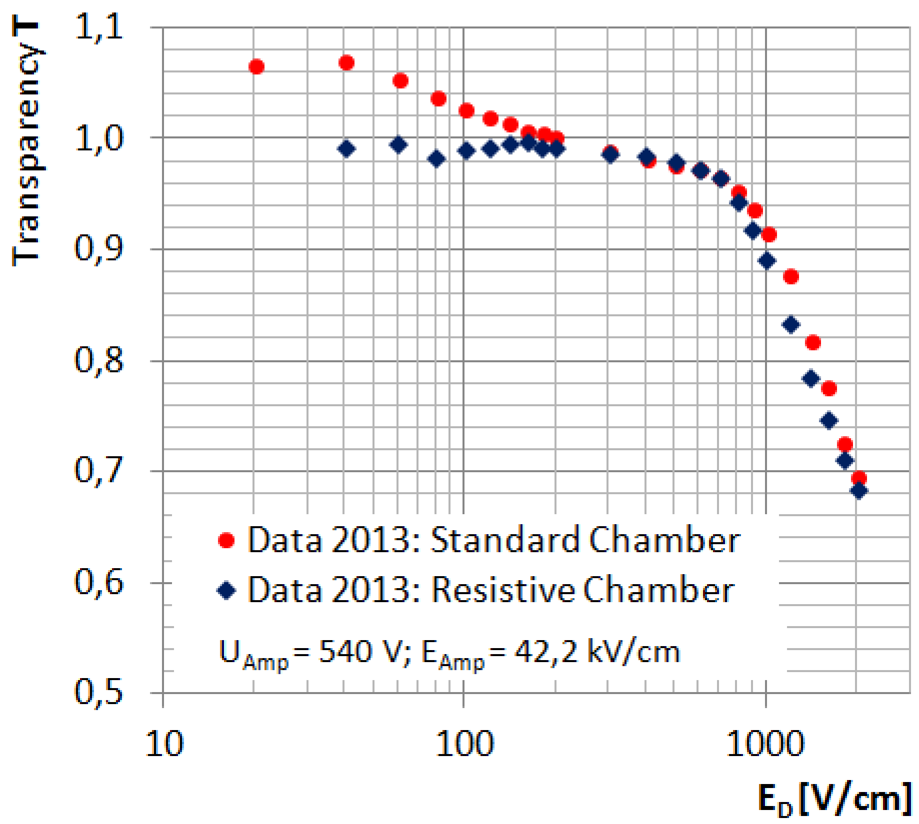
Questions, remarks and comments are highly welcome.

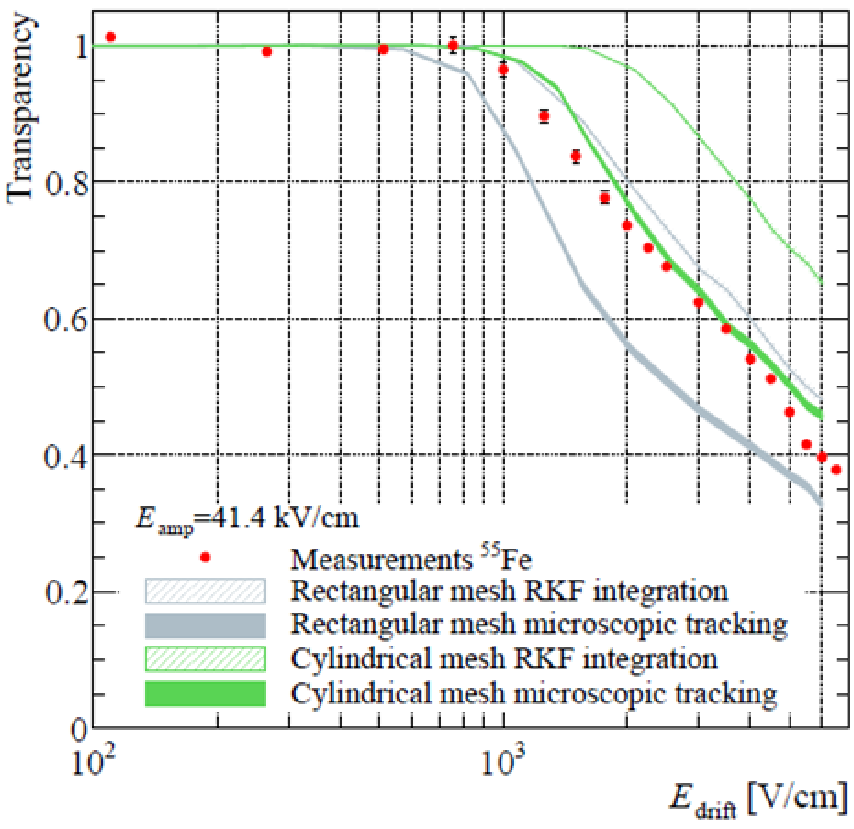
Backup-
Transparency measurements





Backup- Transparency measurements





Backup – Parameter of the micromegas in experiment

Merkmal	**Symbol**	**Standard MM**	**Resistive MM**
Innere Abmessungen			
Höhe des Driftbereichs	d_D	$5,0\,\mathrm{mm}$	$5,0\,\mathrm{mm}$
Höhe des Verstärkungsbereichs	d_V	$128\,\mu\mathrm{m}$	$128\,\mu\mathrm{m}$
Parameter des Netzes			
Drahtdruchmesser	$\oslash_{Draht}$	$18\,\mu\mathrm{m}$	$18\,\mu\mathrm{m}$
Drahtdichte	n_{Draht}	$400\,\mathrm{lpi}$	$400\,\mathrm{lpi}$
Periodizität	p_{Netz}	$63,5\,\mu\mathrm{m}$	$63,5\,\mu\mathrm{m}$
Optische Transparenz	T_{Opt}	$51,3\,\%$	$51,3\,\%$
Parameter der Streifenelektrode			
Streifenlänge	$l_{Streifen}$	$100\,\mathrm{mm}$	$100\,\mathrm{mm}$
Streifenbreite	$b_{Streifen}$	$150\,\mu\mathrm{m}$	$250\,\mu\mathrm{m}$
Streifenperiodizität	$p_{Streifen}$	$250\,\mu\mathrm{m}$	$400\,\mu\mathrm{m}$
Gesamte aktive Fläche	A_{gesamt}	$90\,\mathrm{cm}^2$	$100\,\mathrm{cm}^2$
# der ausgelesenen Streifen	$\#_{Streifen}$	18	18
Parameter der Pfeilerstruktur			
Pfeilerdurchmesser	$\oslash_{Pfeiler}$	$300\,\mu\mathrm{m}$	$300\,\mu\mathrm{m}$
Pfeilerperiodizität	$p_{Pfeiler}$	$2,5\,\mathrm{mm}$	$2,5\,\mathrm{mm}$
Inaktiver Flächenanteil	$A_{Pfeiler}$	$1,1\,\%$	$1,1\,\%$

Backup – Capaticity Correction Factor

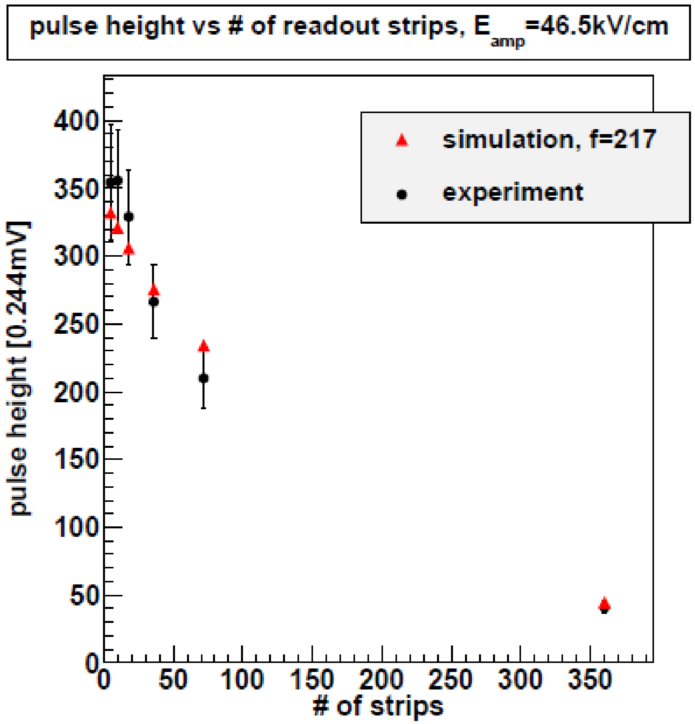


Figure 8.11: Pulse height of 5.9 keV X-rays as a function of the number of read out strips.

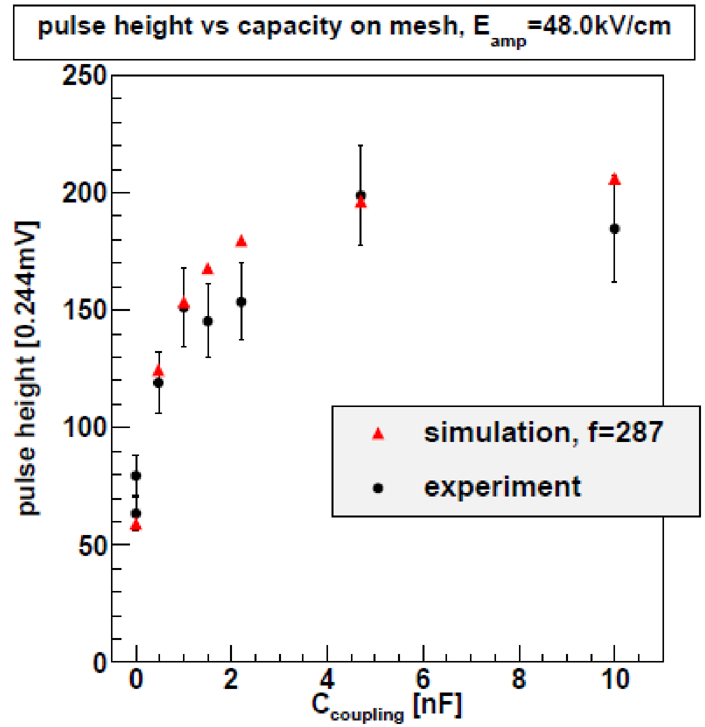


Figure 8.12: Pulse height of 5.9 keV X-rays as a function of the additional capacitor between mesh and ground.

Number of strips	5	10	18	36	72	360
$Q_{\mathrm{preamp}}/Q_{\mathrm{total}}$	0.88	0.85	0.81	0.73	0.62	0.12

taken from [Bor11]

Backup – Penning transfer rates

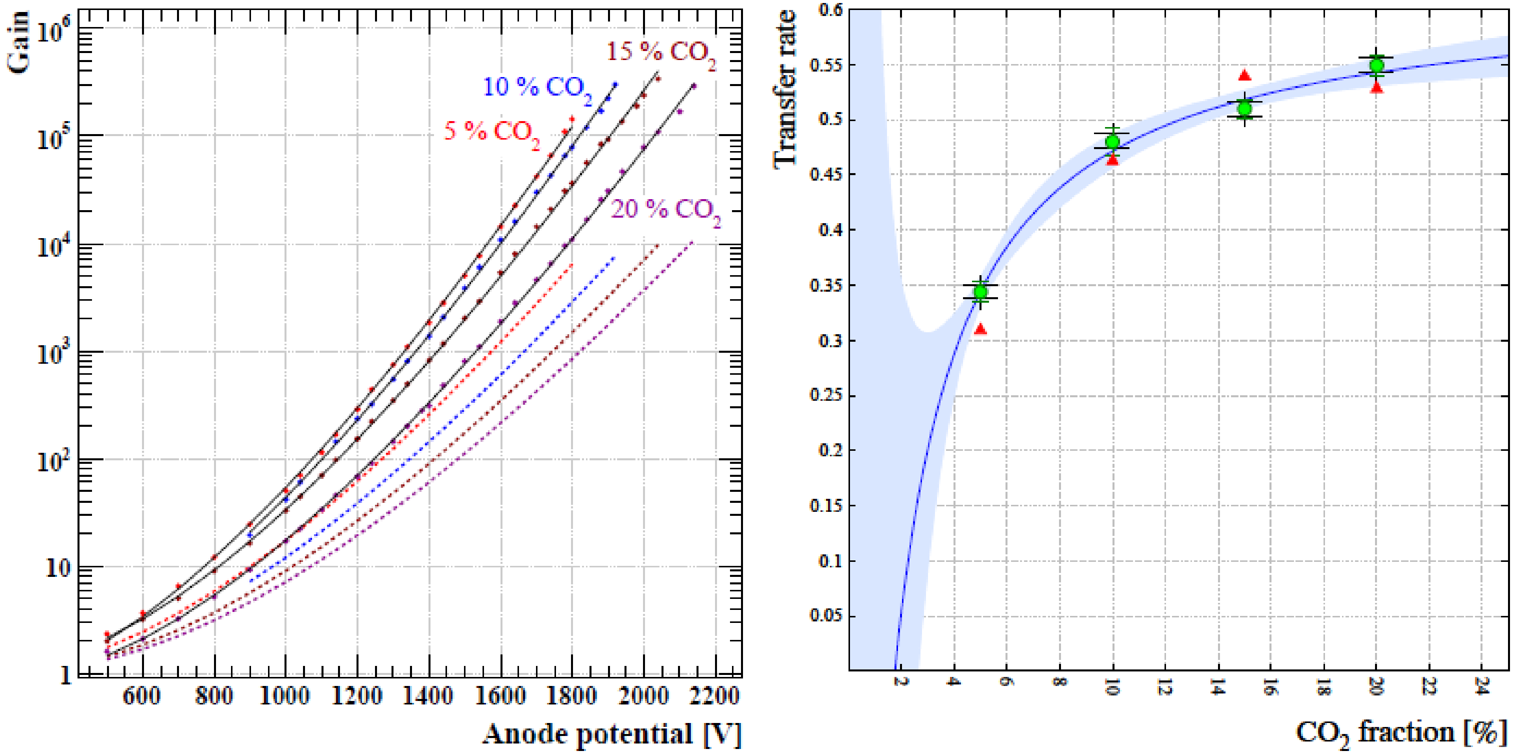


Figure 10. Left: Measured gain curves for Ar-CO_2 mixtures from T.Z. Kowalski et al. [58] (red dots) with fits of the transfer rates (black lines). For comparison, dashed purple lines show the calculated gain curves without transfer. Right: Transfer rates fitted with $(a_1c+a_3)/(c+a_2)$ (blue curve) and the uncertainty on this parametrisation (blue error band). The a_3 parameter is outside the physical range (by 1.2σ). The larger error bars are obtained leaving gain scalings and transfer fractions free, while the broader and smaller error bars correspond to fits with fixed gain scalings. The triangles indicate the transfer rates found when using the weighted average of the gain scaling factor in all fits.

taken from [Sah11]