13th Pisa Meeting on Advanced Detectors – May 2015, Elba

Mesh geometry impact on Micromegas performance with an Exchangeable Mesh prototype

The reconstruction precision of gaseous detectors is limited by losses of primary electrons during signal formation. In addition to common gas related losses, like attachment, Micromegas suffer from electron absorption during e⁻ transit through the micro mesh. This study aims for a deepened understanding of electron losses and its dependency on the mesh geometry.

Signal formation in a Micromegas

In a Micromegas (micro mesh gaseous structure) detector, a precisely positioned metallic mesh divides the gas volume into a drift- or conversion region and a very thin amplification region.

A traversing charged particle ionizes the gas in the conversion region ❶ and freed electrons drift in the low electrical field ❷ towards the mesh. Here they are either conducted through the mesh or end up on its surface ❸ due to scattering. Once entering the strong electrical field in the amplification gap, each electron triggers an e^- avalanche ❹, introducing a signal on the Micromegas readout structure ❺.

The resulting signal is described by:

$$S = \underbrace{n_e}_{❶} \cdot \underbrace{(1 - A)}_{❷} \cdot \underbrace{T}_{❸} \cdot \underbrace{G}_{❹} \cdot \underbrace{c_{r/o}}_{❺}$$

n_e: statistically distributed number of primary electrons	**A**: fraction of electrons lost to gas attachment during drift	**T**: fraction of electrons conducted through the mesh (Transparency)	**G**: statistically distributed amplification of one electron	$c_{r/o}$: read-out constant, converting charge to digital signal

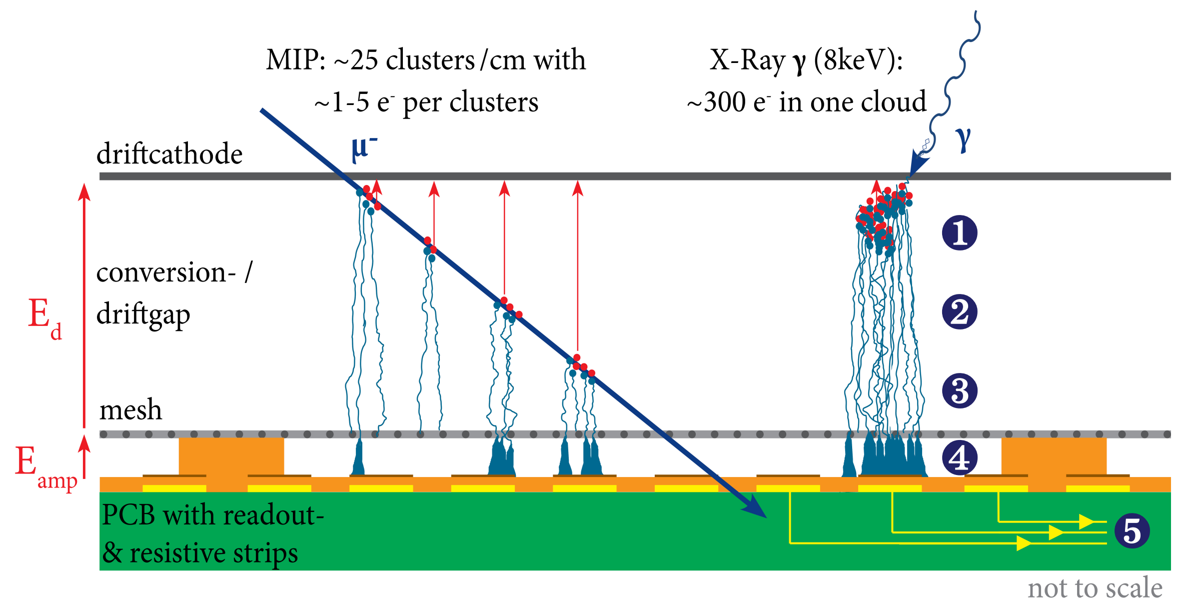

Fig 1: Structure of and signal formation in a Micromegas Detector

Experiment

The Exchangeable Mesh Micromegas build at CERN is the first chamber permitting measurements with different meshes maintaining otherwise exact similar geometrical conditions:

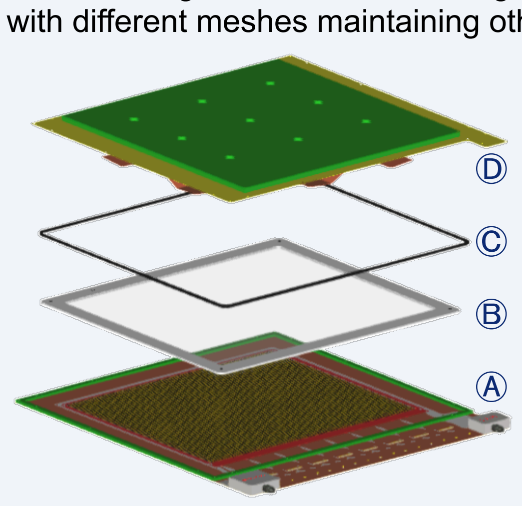

Fig 2: Schematic view of the Exchangeable Mesh Micromegas components

Ⓐ: The readout panel comprises a PCB with a 450μm pitch copper strip pattern covered by a Kapton® foil carrying a <1μm resistive carbon layer for spark protection and a Pyralux® structure of 128μm high pillars.

Ⓑ: Exchangeable frames position the tensioned mesh on the pillars, assuring a precise amplification gap thickness.

Ⓒ: A flexible o-ring pressed between drift and readout panel secures gas tightness.

Ⓓ: The drift panel carries a copper drift cathode and brass springs, tensioning the mesh frame toward the readout. HV vias and gas conduits are embedded in the panel.

Measuring the signals induced by a Cu X-Ray, the signal strength S is obtained as position of the 8keV K_α-Peak in a >500k events spectrum (Fig 3 top). It corresponds to a stable, statistically distributed number of primary e^-. (❶)

Changing only the drift voltage U_D ensures stability of the gain (❹) and the read-out constant (❺), but effects electron drift (❷) and mesh-approximation behavior (❸):

$$S \propto [1 - A(U_D)] \cdot T(U_D)$$

This change in absolute signal strength (Fig 3 middle) is associated with a loss of electrons before amplification.

Normalizing these signal strength curves (Fig 3 bottom) corrects for all proportional factors from ❶, ❹ and ❺.

- The congruence proves the independence of electron losses from the amplification voltage, within the Micromegas working range, where $E_A \gg E_D$.

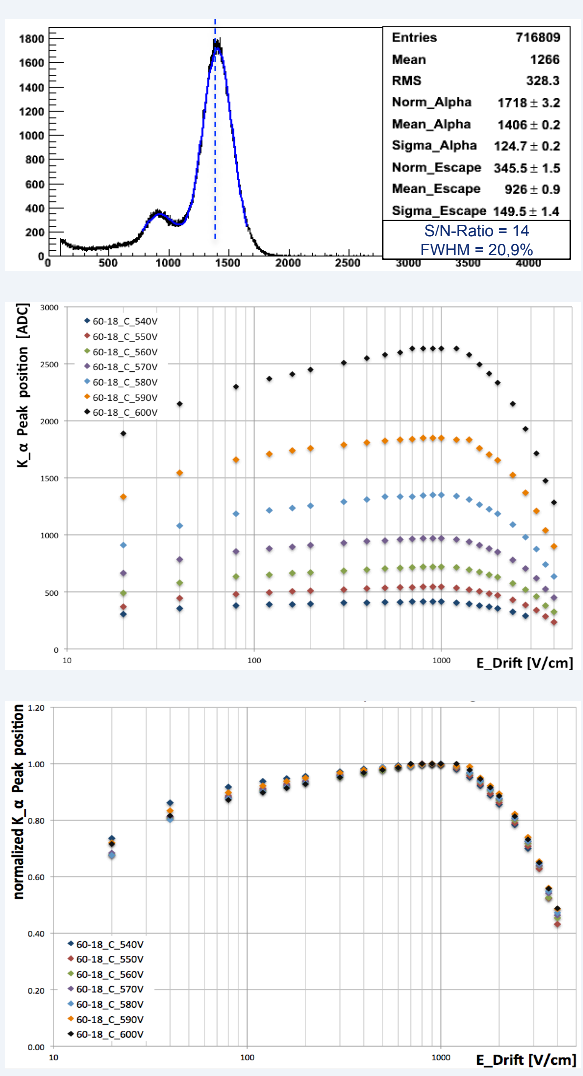

Fig 3: Evolution of experimental data: X-Ray spectra (top), absolute (middle) and normalized (bottom) signal strength

Acknowledgments

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Simulation

The geometry and electrostatic configuration of a Micromegas with different mesh geometries was simulated using a finite element method (FEM) in ANSYS 15.0. A Monte-Carlo based simulation of electron drift on a microscopic-step-level was carried out in Garfield++ referring to scattering cross-sections from Magboltz 10.6.

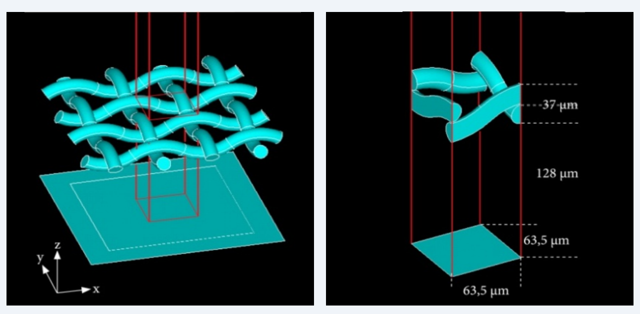

Fig 4a: Input-geometry for FEM calculation as extended mesh (left) and unit cell (right)

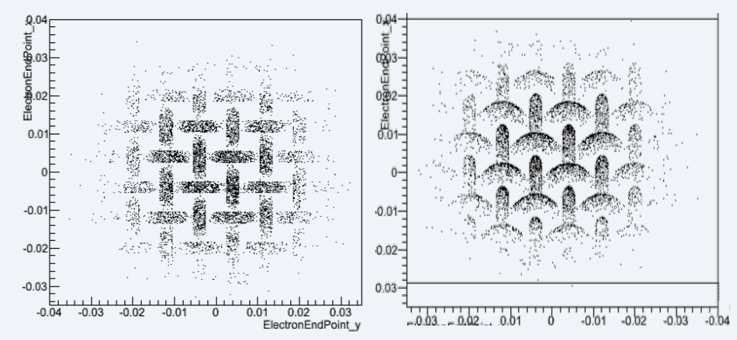

Fig 4b: Simulation-output: endpoints of mesh-absorbed electrons in top (left) and inclined view(right)

Sets of 10k single electron events per geometry, voltage setting and/or gas composition were simulated. This resulted in a quantitative understanding of two main sources of electron losses:

➢ **Attachment to gas molecules during electron drift (❷)**

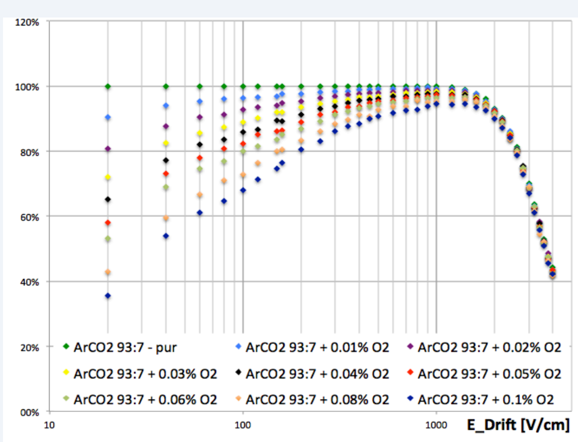

Fig 5: Fraction of non-attached electrons after 5mm drift in $ArCO_2 + O_2$ contamination

- CO_2 attachment for high E_D:
  At higher drift field strength, the probability for a higher electron scattering energy grows.
  → Attachment to CO_2 molecules becomes dominant
- O_2 attachment at low E_D:
  In lower electrical fields the electrons drift velocity is reduced and scattering rates (per length) increase.
  → Attachment to O_2 yields significant electron losses

➢ **Absorption at the mesh surface (❸)**

- Approaching the mesh with higher velocity, electrons are more likely scattered onto the wire-surface.
  → Rising drift field strength reduces mesh transparency
- Electron loss probability depends on the ratio of exposed wire-surface and mesh opening.
  → Transparency increases with larger open area (Fig 6)
- Comparison of mesh geometries with 18μm and 30μm wires (Fig 6) reveals lower transparencies for finer structures of comparable open area.

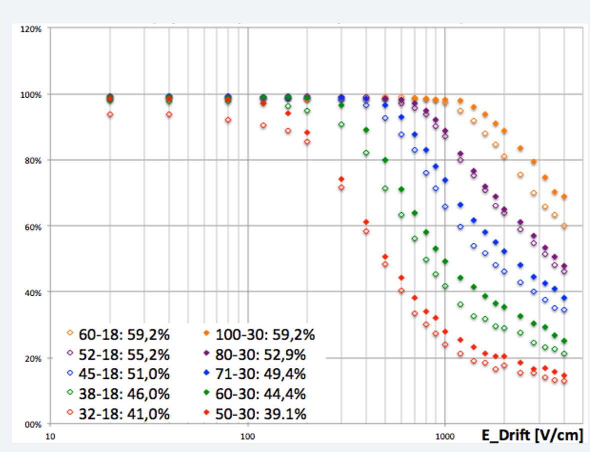

Fig 6: Simulated electron transparency of different mesh geometries

Combined results

Comparison between experimental data and simulation results (Fig 7) illustrates the impact of attachment processes on the total electron loss and the importance of adjusted normalization.

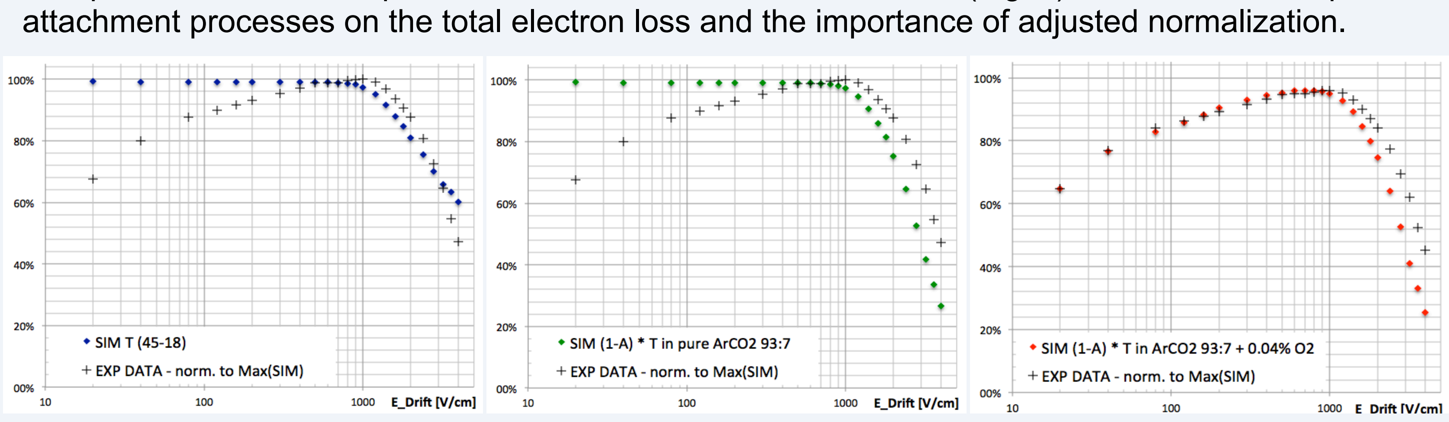

Fig 7: Comparison of normalized signal strength (EXP) and model prediction of e^- losses (SIM) for mesh transparency (left), including attachment in $ArCO_2$ 93:7 (center) and 0,04% O_2 contamination (right)

The good congruence confirms the validity of the simulation-model in respect to the experimental approach. Remaining challenges are:

- Gas-contaminations bias the experimental results
  → Upgrade of the setup to improve gas purity and monitoring is under construction
- Remaining discrepancies need to be understood
  → Different simulation approaches (FEM, neBEM) are developed further for cross-checking
  → Other sources of electron losses are probed
- Further effects of changing mesh geometry (e.g. gain or reconstruction efficiency) will be investigated

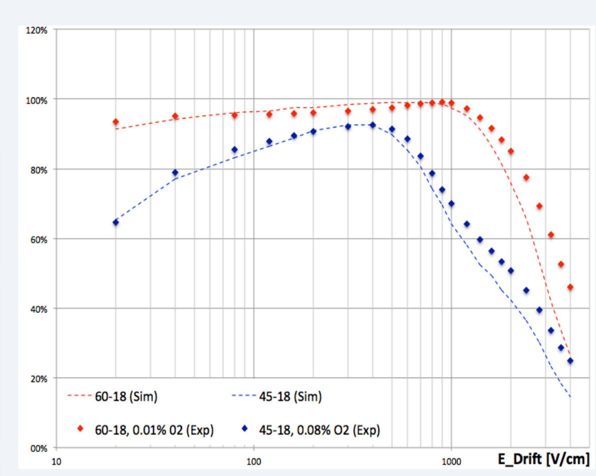

Fig 8: Electron losses in the MM with two different meshes (SIM and EXP)

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