Physical modeling of the Malter effects in GEM-based detectors: implications in spark formation and dark currents

IX Reunião Geral - Projeto Especial FAPESP

"Física e Instrumentação de Altas Energias com o LHC-CERN"

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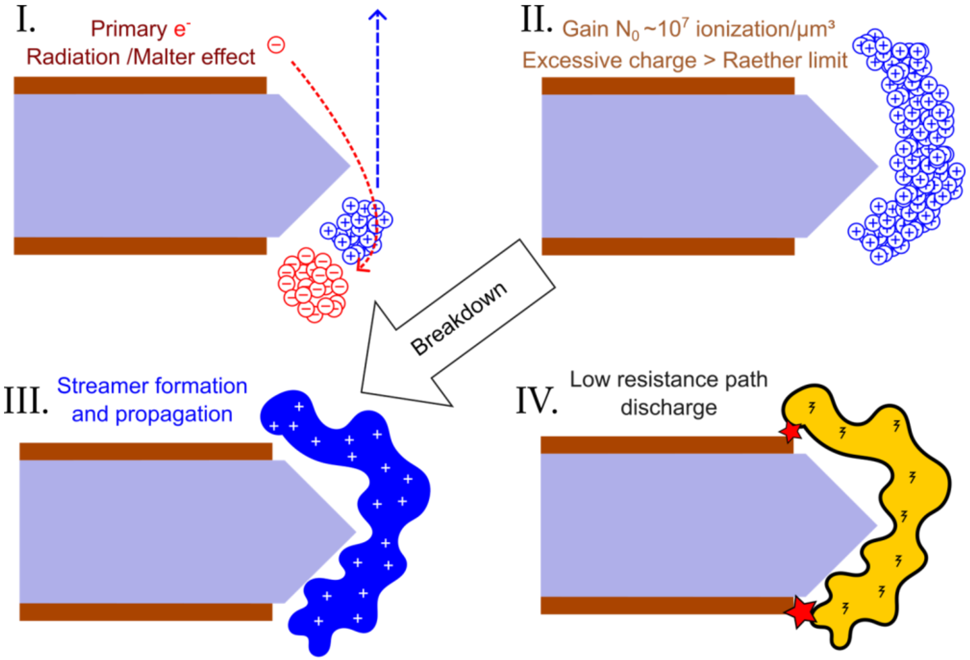
Bruna B. Tizoni Francisco[12] Tiago Fiorini da Silva[1].

1-High Energy Physics and Instrumentation Center @ IF-USP (Brasil)
2- Mestrado FAPESP vinculado ao PI "Detectores gasosos microestruturados de radiação e suas aplicações

The long-term performance of GEMs can be affected by cumulative degradation effects. One such issue is the formation of insulating layers on the metallic surfaces of GEM foils, resulting from chemical interactions with the gas mixture or residual contaminants.



These layers can lead to local charge buildup and induce undesired electron emission, a phenomenon known as the Malter effect. The emitted electrons may drift into GEM holes, generating spurious currents, premature gain saturation, and, in severe cases, electrical discharges.

Ionic current model:

- Number of collisions/cm²/pC in the readout obtained from Garfield++ simulations
- Parametric curve fitted to the ion collisions distribution
- The readout charge is modeled as $Q_{read} = 4.0x10^{-5} f G_{eff}$, where f is the event rate and G_{eff} is the effective gain (for 6 keV photons).

Dielectric layer model:

- Can be treated as a leaky capacitor ($CdV/dt + V/R = i_{ionic}$);
- Polymer resistivity 10^{13} - 10^{15} Ωm
- $\rho = \rho_0 \exp(-A/(E_b-E))$, where E is the electric field and E_b is the breakdown electric field of the polymer (may spark > 300 MV/m)
- Electric field given by: $\frac{E}{\rho_0} \cdot \exp\left(\frac{A}{E_b - E}\right) = J_0$

Field Emission model:

- Fowler-Nordheim equation:
  $J(F) = (A_{FN} F^2 / \Phi) \exp(-B_{FN} \Phi^{3/2} / F)$

  where $A_{FN} \approx 1.5414 X10^{-6} [AeVV^{-2}]$ and $B_{FN} \approx 6.830 X10^{9} [Vm^{-1}eV^{-3/2}]$.
- The electric field F is given by $F = \beta E$, where β is a local enhancement factor due to surface roughness.

The Malter effect:

- Field emitted electrons propagated using Garfield++
- Initial energy of 7 eV (Copper Fermi energy)
- Varying distances to the GEM hole

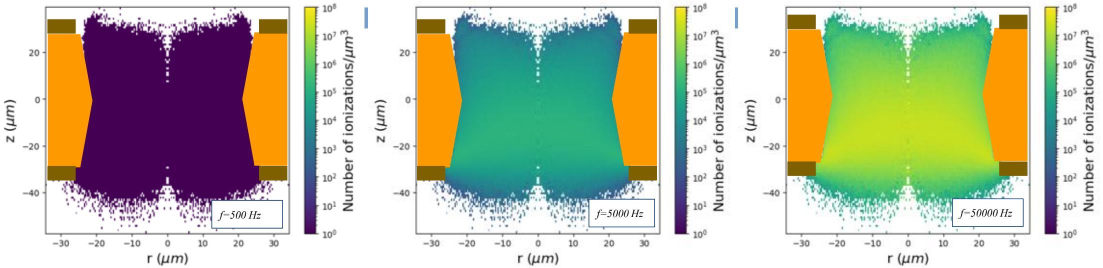


Figure 3 – Simulation of particle trajectory and ionizations of emitted electrons from Malter Effect assuming a bulk electrical resistivity ρ = 1×10¹³ Ωm and *β=100*.

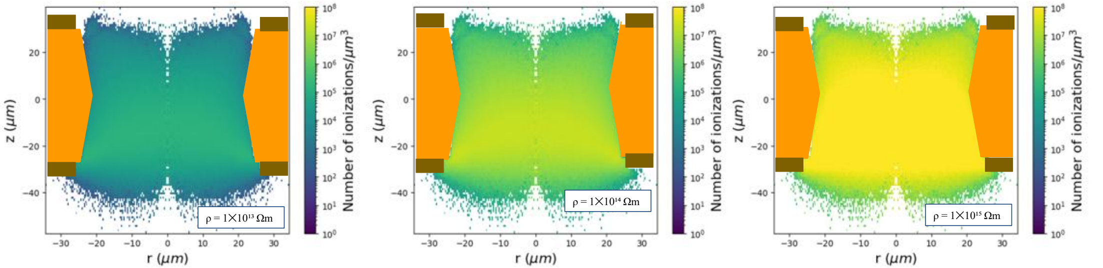


Figure 4 – Simulation of particle trajectory and ionizations of emitted electrons from Malter Effect assuming a initial event rate *f = 5000 Hz* and *β=100*.

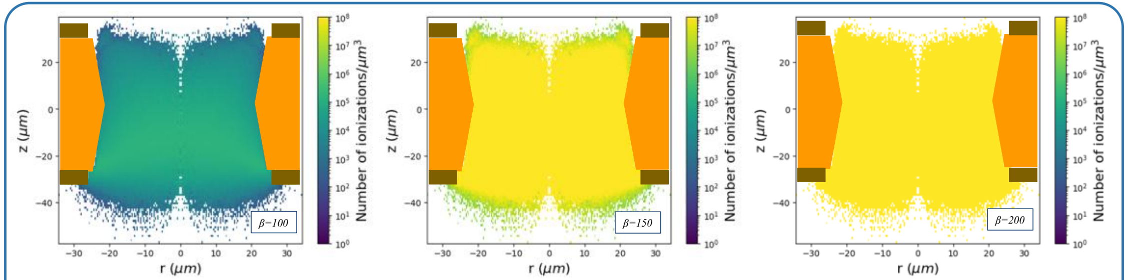


Figure 5 – Simulation of particle trajectory and ionizations of emitted electrons from Malter Effect assuming a initial event rate *f = 5000 Hz* and bulk electrical resistivity *ρ = 1×10¹³*.

Figure 6 – Calculation of the dark current as a function of the event rate, considering the electrons emitted by the Malter effect.

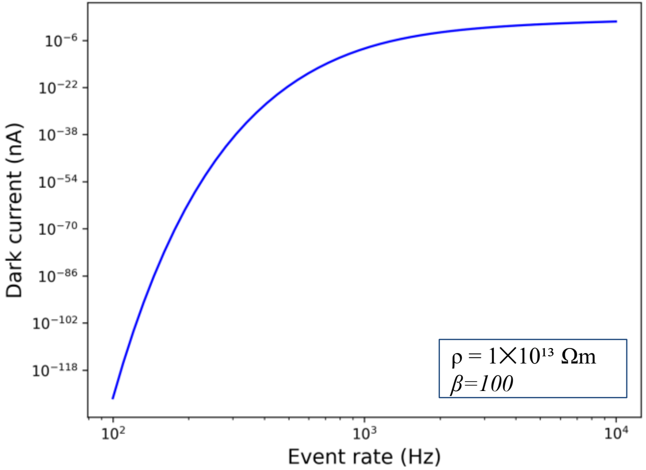
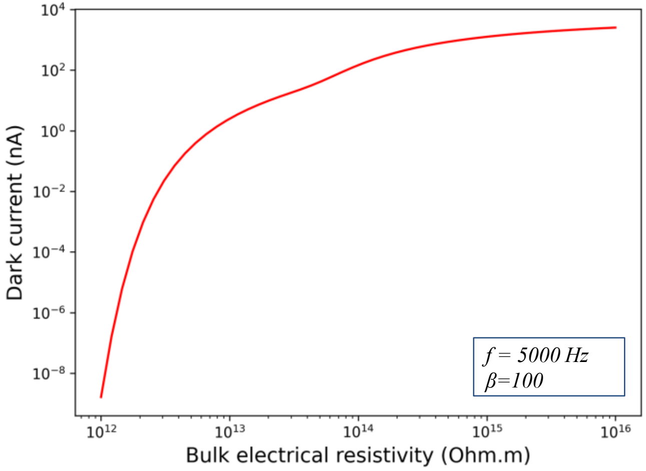


Figure 7 – Calculation of the dark current as a function of the bulk electrical resistivity, considering the electrons emitted by the Malter effect.



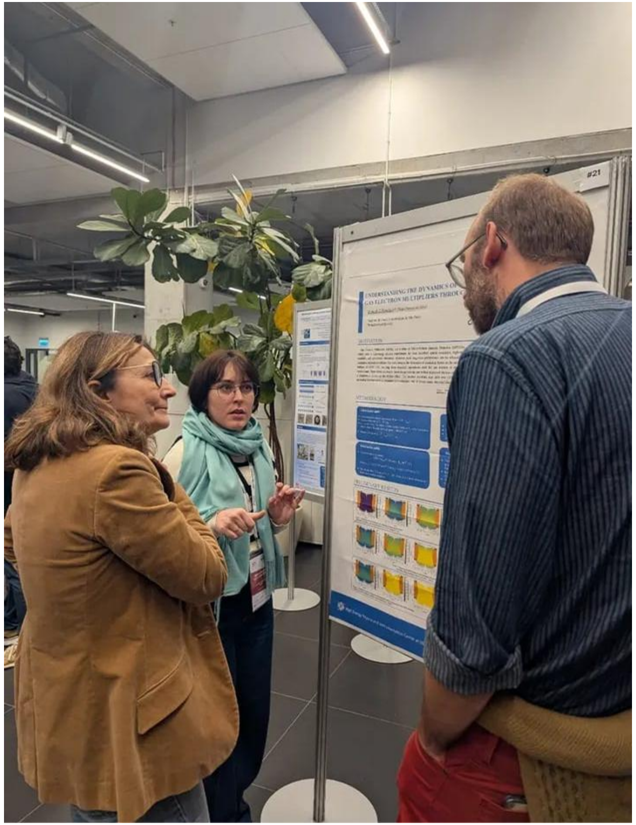
CONCLUSIONS

- Increased ionizations as the dielectric electrical resistivity increases.
- Increased ionizations as the field enhancement factor (surface roughness) increases.
- Dark current from Malter-effect ionizations increases with dielectric resistivity and event rate.

NEXT STEPS

- Attempt to evaluate how the dark current affects the readout sensitivity.
- Try to measure the space charge distortions caused by the Malter effect–induced charge.

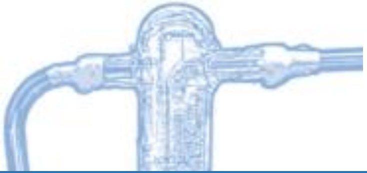
Poster presentation at the 6th DRD1 Collaboration Meeting



Research presented at the 6th DRD1 related to my work

FAIR GSI TUM

Impact of trace amounts of water on the stability of MPGDs measured in Ar-CO_2 (90-10)



H. Fribert[1], P. Gasik[2], B. Ulukutlu[1], L. Fabbietti[1]

[1] TUM School of Natural Sciences, Technische Universität München
[2] GSI Helmholtzzentrum für Schwerionenforschung GmbH (GSI), Da
[3] Facility for Antiproton and Ion Research in Europe GmbH (FAIR), D

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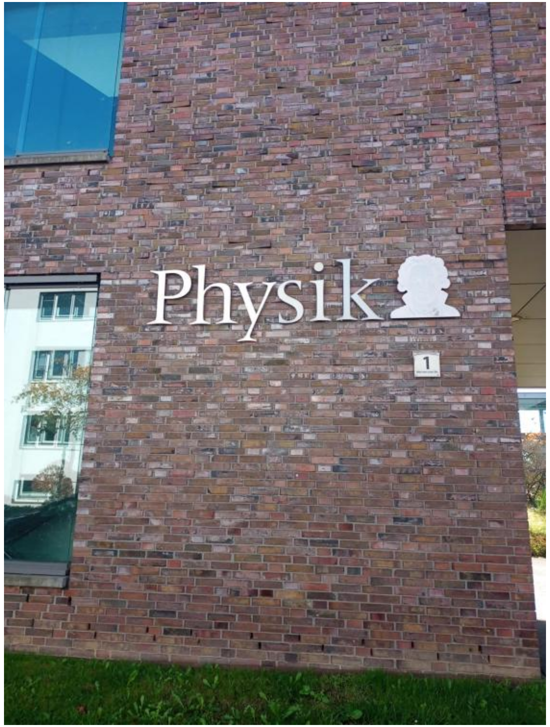
DRD Collaboration Meeting 06-10 October 2025

Results related to the Malter Effect:
Under conditions without a radioactive source, adding water reduced spurious discharges, possibly by mitigating charging effects on insulating surfaces and local defects.

Meeting with the Frankfurt group in Germany:
Dr. Jens Wiechula and Dr. Matthias Kleiner (both Research Associates)



Drift-Field Distortions and
Specific Energy Loss Calibration of the
ALICE TPC in LHC Run 3

Dissertation
zur Erlangung des Doktorgrades
der Naturwissenschaften

vorgelegt beim Fachbereich Physik
der Johann Wolfgang Goethe-Universität
in Frankfurt am Main
von

Matthias Kleiner

Summary of the meeting with the Frankfurt group

Context (Frankfurt group work):

- Correction of distortions from Ion Backflow (IBF)
- Modeling using Poisson equation + Pb–Pb simulations
- 3D time-dependent corrections (IDCs) implemented in O2
- Significant improvements in tracking precision

Planned collaboration:

- Replace IBF input with Malter-induced dark current in distortion models
- Use existing O2 correction codes for implementation
- Investigate its impact on drift field distortions and readout performance

Obrigada!

Perguntas?

Contato: brunabeatriztf@usp.br / tfsilva@usp.br