THE OPERATIONAL PRINCIPLES OF MICROMEGAS GAS DETECTORS AT LOW PRESSURE: A COMPREHENSIVE EXPLORATION

Istituto Nazionale di Fisica Nucleare
Sezione di Pisa

G. ANTONELLI, C. AVANZINI, G. BALESTRI[a], G. BIGONGIARI[a,b], R. CAROSI[a], A. FORESI[a], F. FRASCONI[a], P. MAESTRO[a,b], M. MASSA[a], A. MOGGI[a], F. MORSANI[a], F. PILO[a,*], G. TERRENI[a]

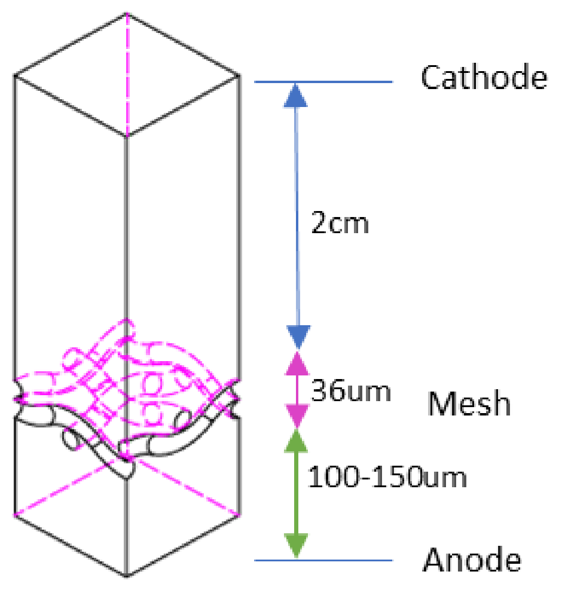
[a] *INFN Pisa,* [b] *Department of Physical Sciences, Earth and Environment, University of Siena, via Roma 56, 53100 Siena, Italy*

INTRODUCTION

Our research group at the INFN Pisa Laboratory is developing a gas detector operating in a low-pressure regime below 100 mbar. Our objective is to detect atoms at energies of 1-100 keV and measure their energy and direction through a compact instrument. The MICROMEGAS (MM) technology has proven to be inherently well-suited for low-pressure operations, offering tunable avalanche volume to achieve the desired signal amplification. Working at low pressures implies the relevance of physical phenomena that are normally negligible at NTP conditions and therefore the need to model them in the MC simulation software.

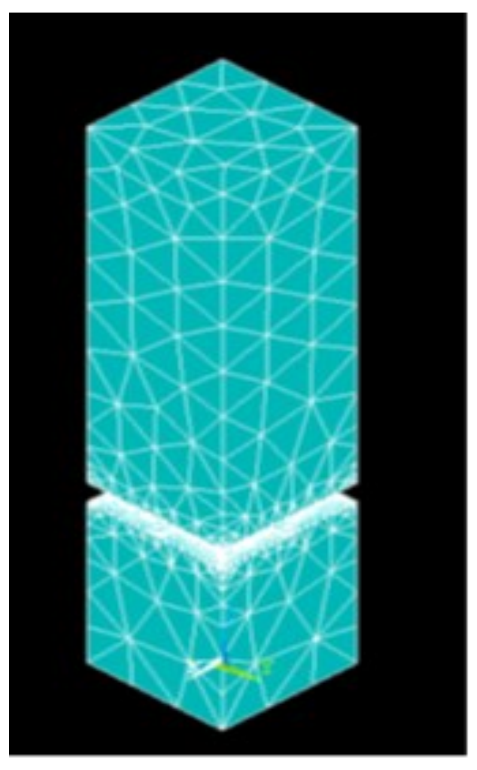
MICROMEGAS SET-UP

- Two 20 mm drift height MM: BULK MM with nominal 128/192 µm avalanche gap (MM128/MM192). Actual gaps were estimated to be 100 µm and 150 µm respectively
- Mesh is a 18 µm thick Nickel interlaced grid (woven mesh)
- Gas mixture: Ar / CO_2 (93% / 7%)
- At low pressures (100mbar) typical electric fields are 25 V/cm (drift) and 18 -40KV/cm (avalanche)
- Measurements with X-rays source: number of electrons generated by one X-ray interaction calculated as mesh current/event rate



MC SIMULATIONS SET-UP

GOAL: identify and quantify physical processes relevant to the overall gain (M), energy and tracking resolution and investigate their relationships with gas mixture, pressure, temperature and avalanche gap



Drift Region

- Geant4 fast simulators
- Degrad for X-rays
- SRIM for atoms
- Garfield++/Magboltz for electron drift
- Electric field: uniform field

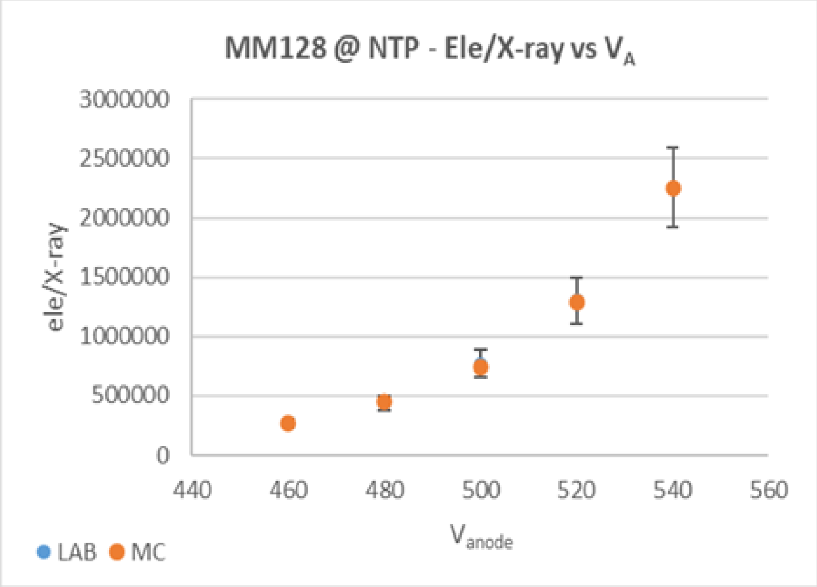
Avalanche Region

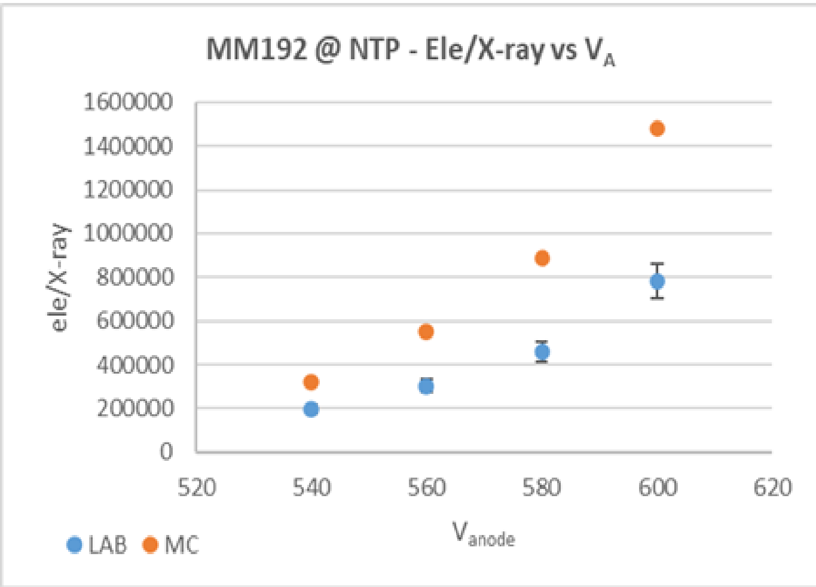
- Garfield++ & Magboltz
- Electric field: ANSYS123

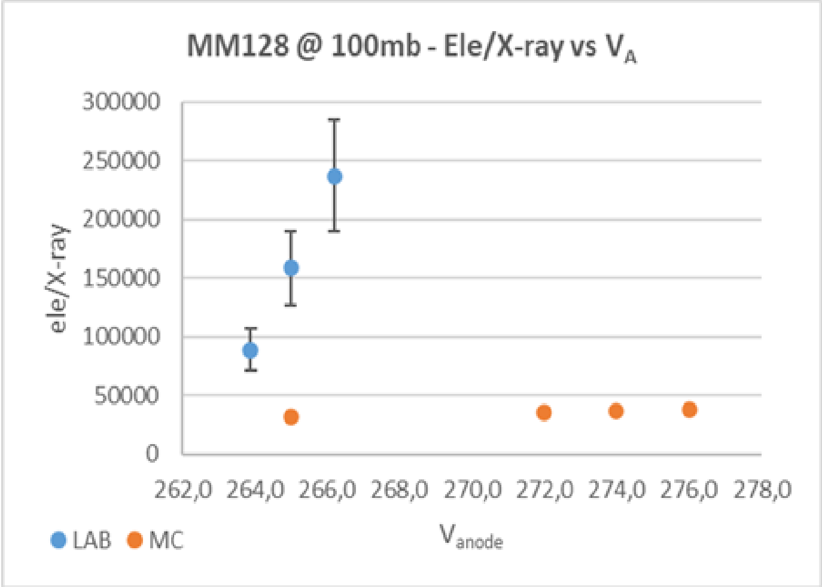
At low pressures the basic MC model is not able to account for measured gains

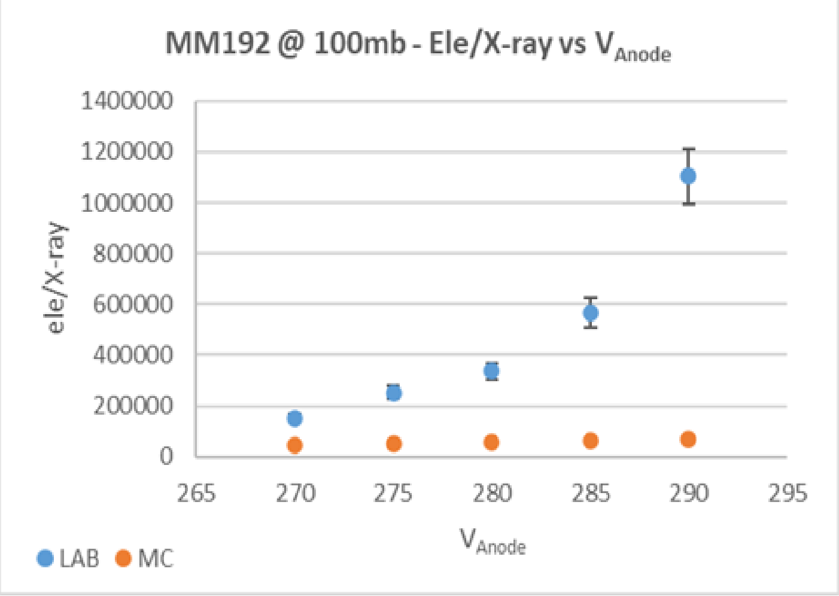
The simulation of the usual avalanche phenomena (ionization, penning, …) as implemented by Garfield++ predicted a **very low gain** for low pressure interval.

@100 mbar both MM show a **low multiplication factor** and **low mesh transparency** compared to LAB measures









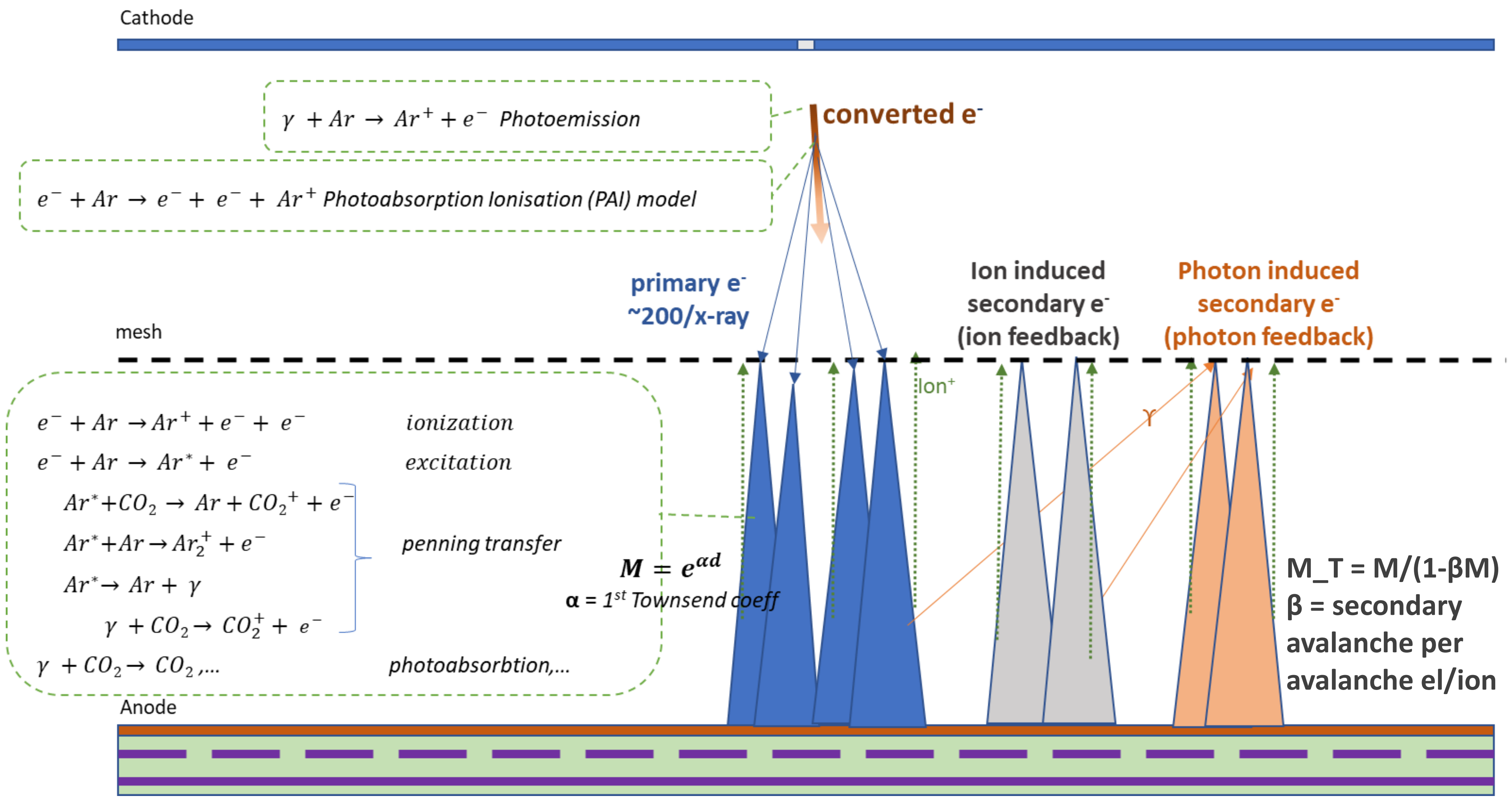
The first Townsend coefficient (α) calculated in the last part of the avalanche gap (where E is uniform) and calculated by Magboltz are close and significantly lower than LAB:

$\alpha_{MC} = 497\ cm^{-1}$ (last 50um) , $\alpha_{Magboltz} = 530\ cm^{-1}$ (via generated gas table) VS $\alpha_{Lab} = 600\text{-}630\ cm^{-1}$ (estimated with MM128 $V_{Anode} = 265V$)

AT LOW PRESSURES ADDITIONAL PHYSICAL PROCESSES MUST BE TAKEN INTO ACCOUNT

Through an extensive modelling and tuning of the MC software driven by the X-ray test results we have now acquired a better understanding of the additional processes relevant to the detector performance as a function of gas pressure. The main finding are related to processes at the mesh surface: photon induced and ion induced secondary electron emission that in turn generate secondary avalanches. Other MC improvements in the area of microscopic collision technique led to a better modelling of the paths followed by electrons around the mesh and therefore a better simulation of the mesh transparency. The overall result is a gain which is in line with a Secondary Townsend Effect [1], rather than with a simple First Townsend Effect.

Further investigations are still in progress to refine the parametrization of processes related to photo emission and absorption and the chance to intercept any scintillation.


Cathode

$\gamma + Ar \rightarrow Ar^{+} + e^{-}$ *Photoemission*

$e^{-} + Ar \rightarrow e^{-} + e^{-} + Ar^{+}$ *Photoabsorption Ionisation (PAI) model*

converted e^{-}

primary e^{-}
~200/x-ray

Ion induced secondary e^{-} (ion feedback)

Photon induced secondary e^{-} (photon feedback)

mesh

$e^{-} + Ar \rightarrow Ar^{+} + e^{-} + e^{-}$ *ionization*

$e^{-} + Ar \rightarrow Ar^{*} + e^{-}$ *excitation*

$Ar^{*} + CO_2 \rightarrow Ar + CO_2^{+} + e^{-}$
$Ar^{*} + Ar \rightarrow Ar_2^{+} + e^{-}$
$Ar^{*} \rightarrow Ar + \gamma$
$\gamma + CO_2 \rightarrow CO_2^{+} + e^{-}$
penning transfer

$\gamma + CO_2 \rightarrow CO_2, \ldots$ *photoabsorbtion,…*

$M = e^{\alpha d}$
α = 1st *Townsend coeff*

Ion+

γ

M_T = M/(1-βM)
β = secondary avalanche per avalanche el/ion

Anode

Photon Induced Secondary Emission

Mean free path of photons may be enough to hit mesh and energy can be greater than Nickel ϕ => Photoelectric emission.

Modelling in our MC

- $E_\gamma > 5$ eV (Nickel work function), $E_e = E_\gamma - 5$
- Yield on Nickel surface from [2];
- E_γ: 11 - 15 eV => Yield: 0.02 – 0.13

Quencher % is relevant: more CO_2 less feedback. LAB measurements with different gas mixtures indicate that Photon Feedback is the **largely prevalent process** of secondary emission (@50mbar CO_2 8% halves the gain obtained with 7% CO_2).

Ion Induced Secondary Emission

Ions at mesh may have enough energy and field may be large enough to give rise to the ion enhanced field emission process.

Modelling in our MC

- Literature on this topic is difficult to apply to our context: the process which seems applicable is the ion enhanced field emission
- Yield on Nickel surface from [3]

$$\text{Yield} = kT/E_F\ e^{-W/kT}$$

where W (work function) = 5 eV, E_F (Fermi energy) = 13.97 eV, kT = ion energy (around 1 eV @ 50-100mbar). At kT = 1 eV => Yield ≈ 0.0005

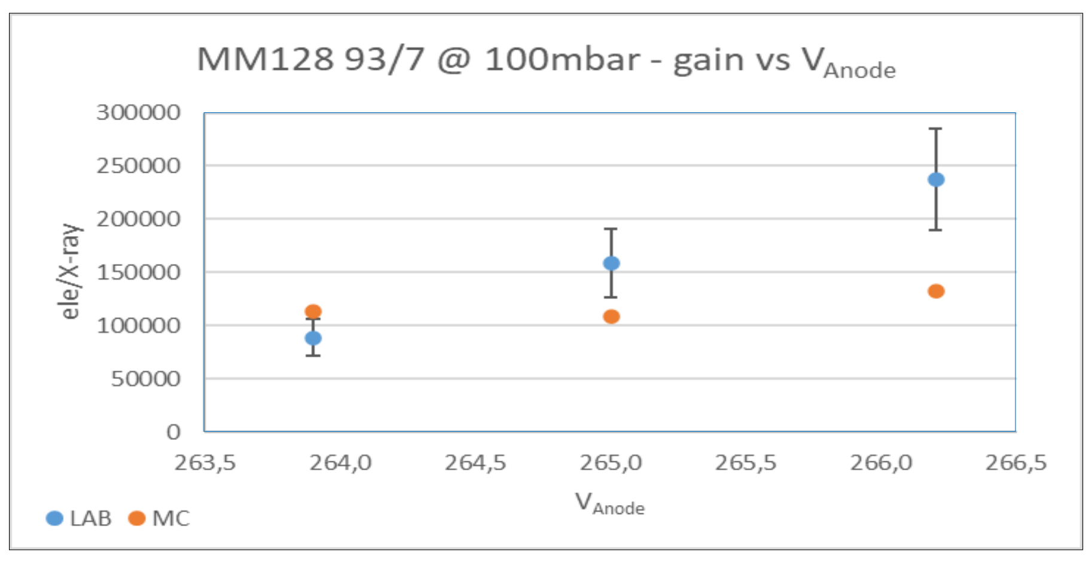
NEW MC vs MEASURES @ 100mbar

- Photoelectric and ion induced secondary emission
- Penning adjustment (resulting rpen ≈ 0.25 - 0.26)
- Reduced collision frequency of discrete absorption lines
- Increased photoelectric emission Yield

GAIN

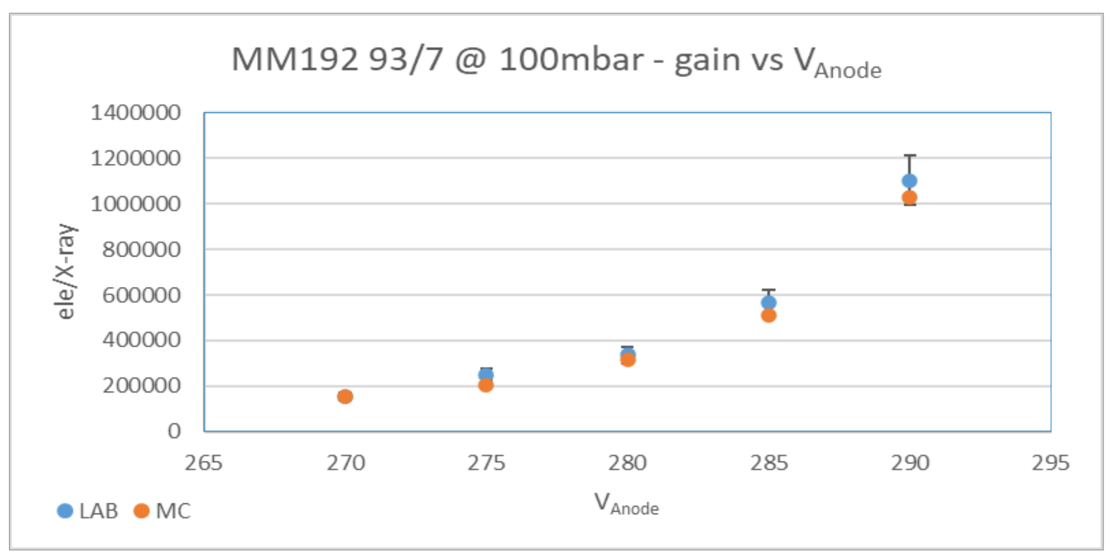
MM128

⇒ Reasonable agreement MC vs Measures
⇒ Transparency ≈ 95%, FWHM ≈ 30-40%
⇒ β ≈ 0.0026



MM192

⇒ Good agreement MC vs Measures
⇒ Transparency ≈ 85-90%, FWHM ≈ 30-50%
⇒ β ≈ 0.0013



MESH TRANSPARENCY (% electrons through the mesh)

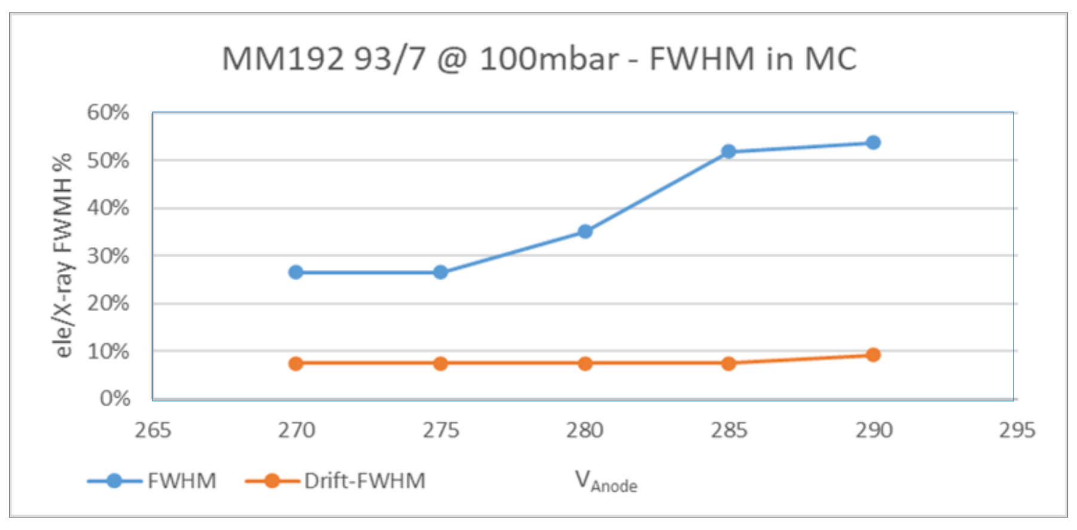
		Old MC	New MC
MM128	93-98% (Eaval/Edrift ~100) @NTP	55% (Eaval/Edrift ~ 700) @100mbar	95% (Eaval/Edrift ~ 700) @100mbar
MM192	87-89% (Eaval/Edrift ~90) @NTP	55% (Eaval/Edrift ~ 500) @100mbar	85% (Eaval/Edrift ~ 500) @100mbar

MC changes made in the area of the collision step handling provided a more realistic transparency estimate at 100mbar

^{55}Fe Main Peak FWHM

MM192

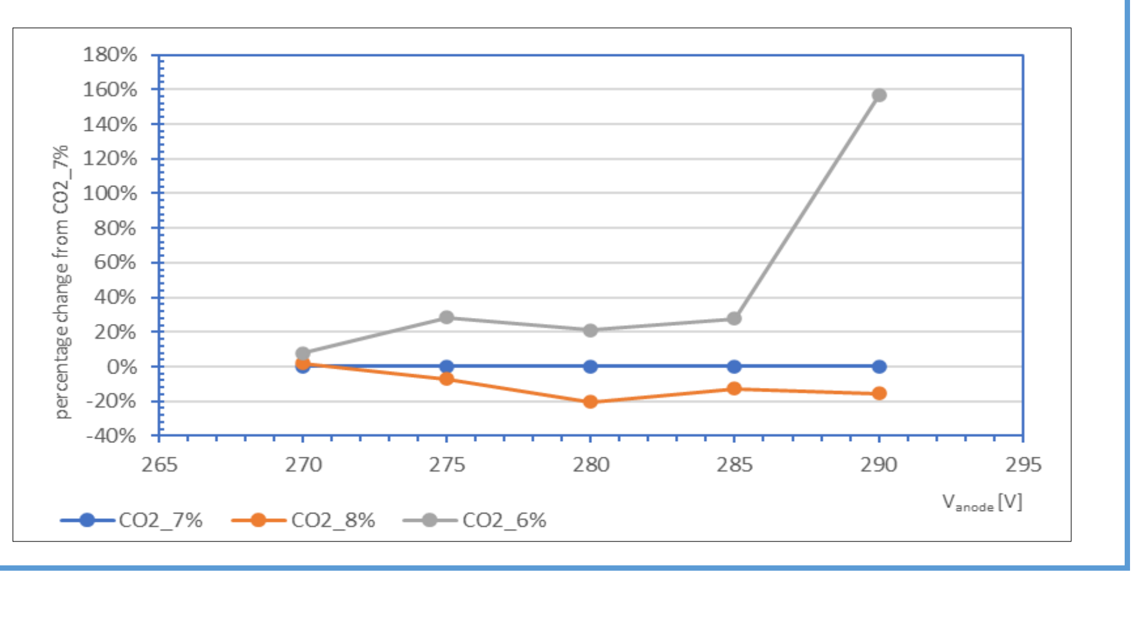
⇒ FWHM significatively grows up to 50%



QUENCHER FRACTION

MM192

⇒ Gain rapidly decreases with the increment of CO_2 % as observed in LAB



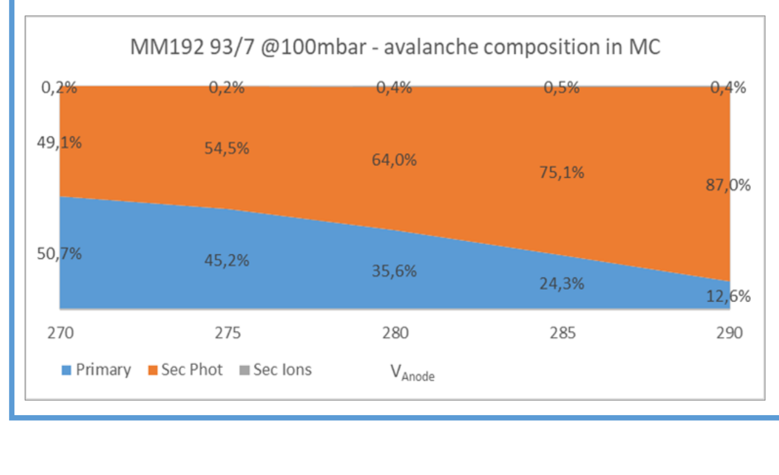
ACKNOWLEDGMENTS

The SWEATERS team is grateful for all these activities to the INFN Pisa technical staff, the CERN Micro-Pattern Technologies Workshop as well as to the CERN GDD laboratory

REFERENCES

[1] O.Sahin et al. - Secondary Avalanches in gas mixtures — Nuclear Instruments and Methods A 718 (2013) 432-433
[2] R.Cairnis – Journal of the optical society of America 56/11, 1578-1573(Nov 1966)
[3] L.Burm - Contrib. Plasma Phys. 47/3, 177-182 (2007)

SECONDARY CONTRIBUTION WEIGHT



MM192

- Contribution of photoelectric secondary emission grows with V_{Anode}
- Ions induced secondary emission on mesh doesn't seem relevant
- Regarding the relative weight of secondary effects things may change at even lower pressures

---

[*] Corresponding author at: INFN, Pisa, Italy.
e-mail address: federico.pilo@pi.infn.it (F. Pilo).