Analysis of Gas Gains for ATLAS MM Mixtures

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ATLAS MM Mixtures (Ar-CO_2-iC_4H_{10})

- **Paolo Iengo** asked data for ATLAS mixtures (Ar-CO_2-iC_4H_{10})
  - *In ATLAS Ar:CO_2 93:7 is the baseline gas mixture for Micromegas, however we are now considering to add a small fraction of iC_4H_{10} and have started test with Ar:CO_2:iC_4H_{10} 93:5:2 (October 2020).*

- **Tadeusz Kowalski** made the first systematic gas gain measurements with a single wire proportional counter (November 2020)

- Preliminary calculation results were shared at the weekly CERN GDD meeting (December 2020)
  - **Recalculated** with more sensible Penning adjustment method (thanks to Rob)

- **Stefano Franchellucci** shared the gas gain measured with ATLAS MM prototypes (March 2021):
  - *Ar-CO_2 (93/7) and Ar-CO_2-iC_4H_{10} (93/5/2)*
  - DLC20 MM and PAD3 MM

Penning Energy Transfers

$e^- + A \rightarrow A^+ + 2e^-$: ionisation → Townsend coefficients

$e^- + A \rightarrow A^*$: excitation → **what happens ? Michel Penning explains**

1. F.M. Penning, *The starting potential of the glow discharge in neon argon mixtures between large parallel plates: II. Discussion of the ionisation and excitation by electrons and metastable atoms,* *Physica, Volume* **1** (1934).
2. M.J. Druyvesteyn and F.M. Penning, *The Mechanism of Electrical Discharges in Gases of Low Pressure,* *Rev. Mod. Phys.,* **12** (1940).

- Assume a gas mixture ($A - B$)
  - A : noble gas (Ar, Xe, Ne, He ...)
  - B : mostly a molecular gas (CO_2, CH_4, C_2H_6, C_3H_8, iC_4H_{10} ...)
- The following can happen for an excited atom (A^*):
  - $A^* + B \rightarrow A + B^+ + e^-$: collisional ionisation,
  - $A^* + A \rightarrow A_2^+ + e^-$: homonuclear associative ionisation,
  - $A^* \rightarrow A + \gamma$: radiative decay
    - $\gamma + B \rightarrow B^+ + e-$: photo-ionisation
- **The list can be extended for other processes depending on the mixture**

Townsend coefficient adjustment

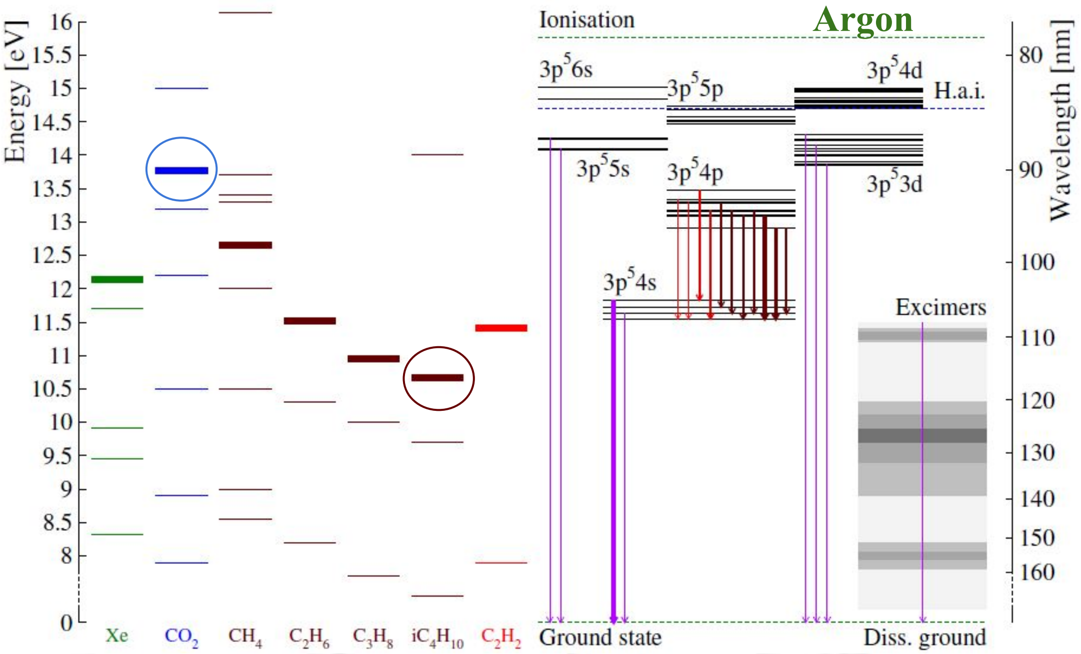
$$\alpha_{Pen} = \alpha\left(1 + r_{Pen}\frac{\nu^{exc}}{\nu^{ion}}\right) \Longrightarrow G = e^{\int \alpha_{Pen}(E(r))\,dr}$$

Penning corrected gas gain

- ❖ **α** : uncorrected Townsend coefficients;
- ❖ **α_{Pen}** : corrected Townsend coefficient including Penning transfers;
- ❖ **v^{ion}** : production rates of the direct ionisations in the mixture;
- ❖ **v^{exc}** : production rates of the excitations of the noble gas atoms;
    - ❖ only excited states of noble gas which are eligible to ionise ;
- ❖ **r_{Pen}** : Penning transfer probabilities:
    - ❖ assuming α proportional to the sum of v_{ion},
    - ❖ the gain curves are fitted using the same r_{Pen}
        - ❖ impossible to separate them, strong correlations
- ❖ α, v^{ion}, v^{exc} depend on gas properties (pressure, temperature) and **Magboltz calculates them**

Penning Correction in Ar-CO_2-iC_4H_{10} mixtures

- **$Ar^* + CO_2 \rightarrow Ar + CO_2^+ + e^-$**
  - ➢ Ar^* $3p^53d$ (13.8 eV) and higher excitations can ionise CO_2 (IP: 13.77 eV)
- **$Ar^* + iC_4H_{10} \rightarrow Ar + iC_4H_{10}^+ + e^-$**
  - ➢ All excited Argon atoms can ionise iC_4H_{10} (IP: 10.67 eV)
  - ➢ The lowest excited Argon 11.55 eV

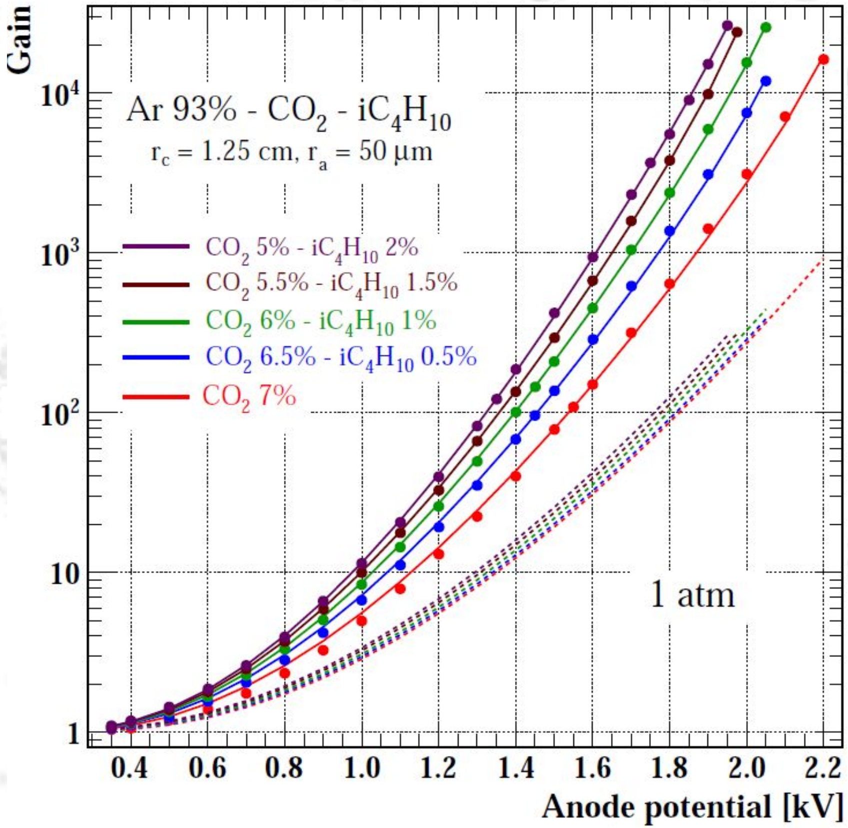


- **Concentration of the admixtures should be taken account while Penning calculation**

$$\alpha_{Pen} = \alpha\left(1 + r_{Pen}\,\frac{c_1 \cdot \nu_{3d}^{exc} + c_2 \cdot \nu_{all}^{exc}}{\nu^{ion}}\right)$$

- ❖ c_1: fraction of CO_2
- ❖ c_2: fraction of iC_4H_{10}

Gas Gains in Ar-CO_2-iC_4H_{10} mixtures (wire chamber)

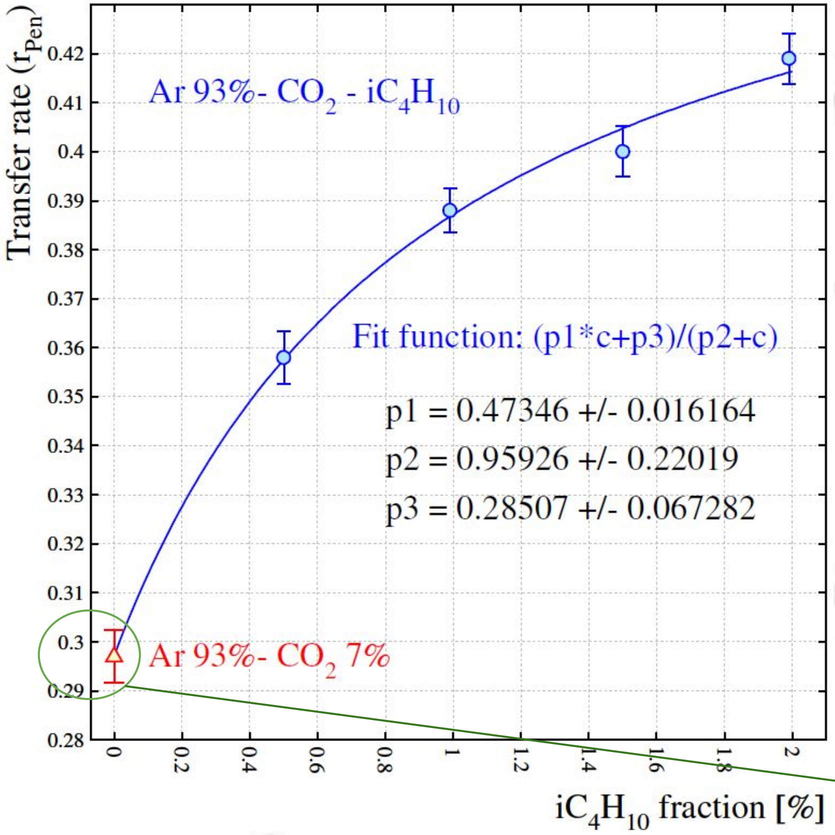


- ❖ Points are the measurements
- ❖ Dashed lines without any correction
- ❖ Full lines with Penning and feedback corrections
  - ➢ Feedback correction for the over-exponential increases in gas gain

$$G_{total} = G/(1-\beta G)$$

- ❖ Higher gains are reached with more iC_4H_{10} at the same anode potential
  - ➢ The lowest gas gain in Ar 93% - CO_2 7%

Energy Transfer Model for Ar-CO_2-iC_4H_{10} mixtures



- ❖ Concentration dependence of the energy transfers
  - ➢ c: fraction of the iC_4H_{10}
- ❖ Clear evidence of the rise with the increase of iC_4H_{10} concentration

$$r_{Pen}(c) = \frac{p1 \cdot c + p3}{c + p2}$$

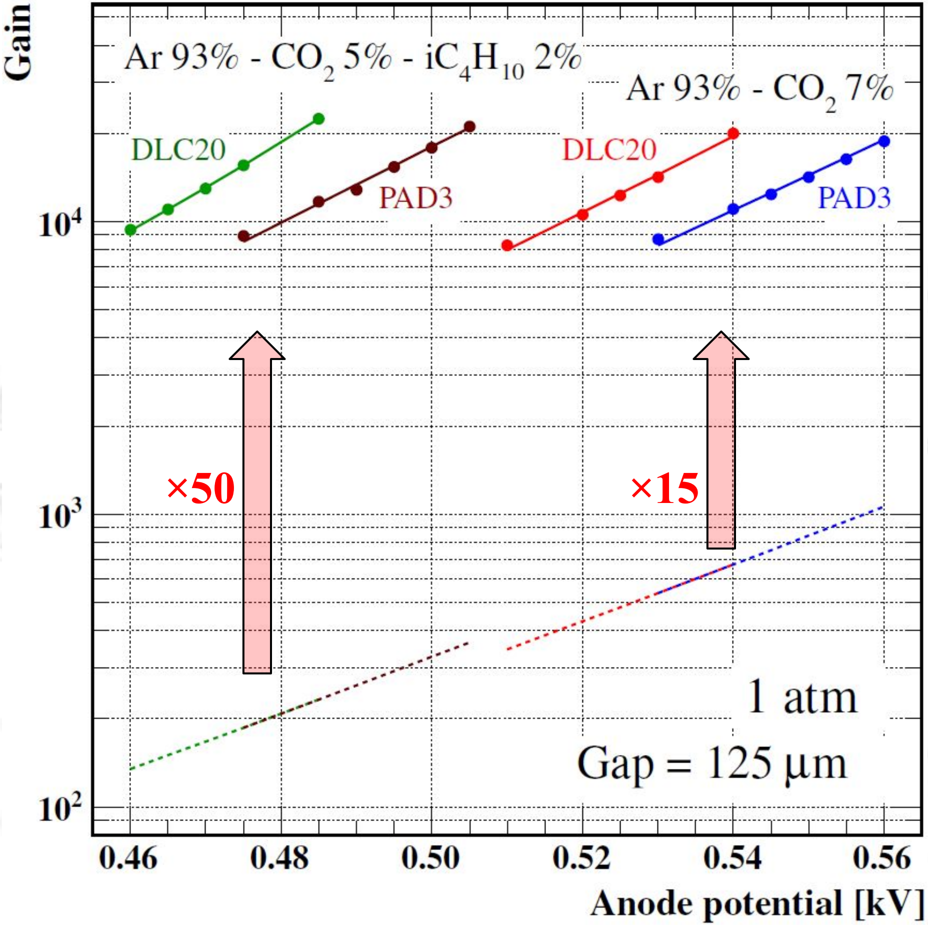
1) Collosional ionizations (p1 ≈ 47 %)

- ➢ $Ar^* + B \rightarrow Ar + B^+ + e^-$
  - ■ B: CO_2 or $CO_2 + iC_4H_{10}$

2) c = 0 refers to transfer rate in Ar 93 %-CO_2 7 %

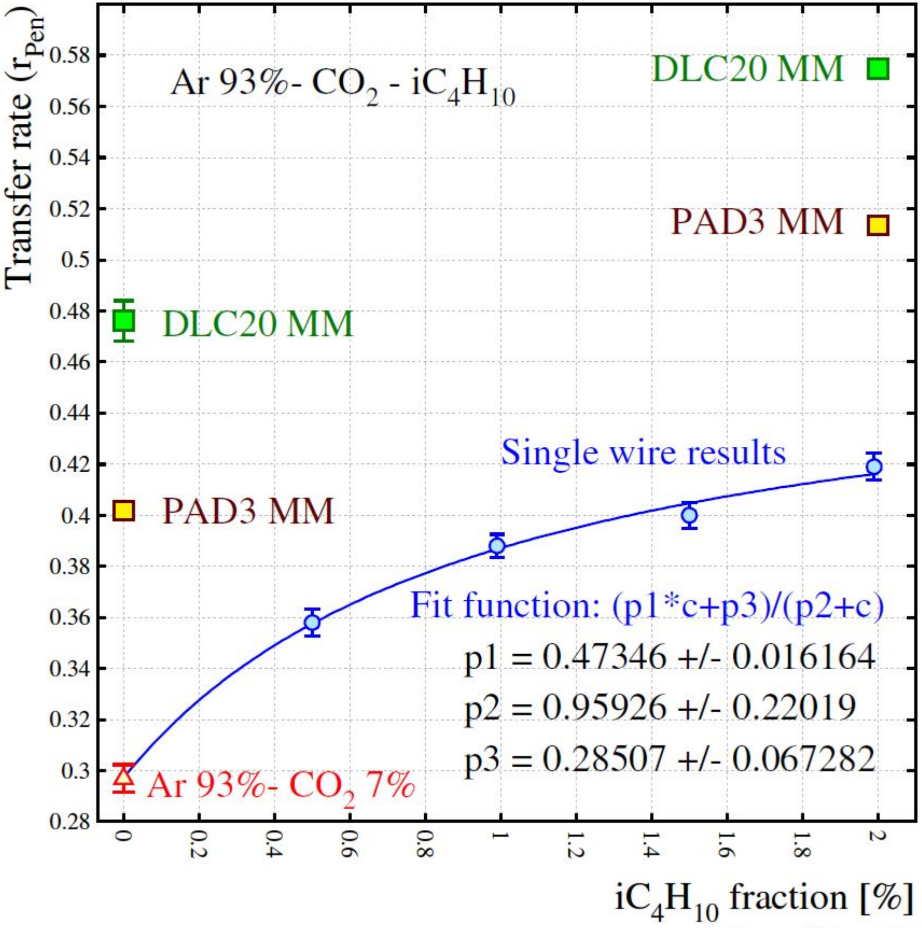
p3/p2 ≈ 30 % is comparable with earlier data

Gas Gain Fits for ATLAS MM Prototypes



- Higher gains with DLC MM
  - Almost 2 times bigger at the same anode potential!
    - Why ?
- Gain fits: considering the MM geometry as parallel plate
- Feedback correction needed only for DLC20 gas gain data
- Maximum of the gas gains are similar with wire chamber limits (Tadeus data)
- Penning effect is stronger in the mixture with iC_4H_{10}

Energy Transfers Driven from ATLAS MMs and Wire Chamber



- ❖ Higher energy transfer rate with MM data compared to single wire results:
  - ➢ 17% for DLC20 MM
  - ➢ 10% for PAD3 MM
- ❖ Gas gains with DLC MM give higher rates
  - ➢ Reason: bigger gas gains with DLC MM
- ❖ For the same mixture we **expect to have similar transfer rates** from MMs with the single wire results
  - ➢ Penning transfers are related with the gas properties rather than the geometry
  - ➢ **Other corrections or assumptions ?**

Assumptions to Have Similar Transfer rates

- Both the DLC20 and PAD3 MM have the same GAP distance: d = 125 μm
  - Gain Fits: the electric field is defined with the same approach; E = V/d
  - In any case both the MMs and single wire results for the transfer rates should be the same

- **Electric Field Scaling (z)**
  - The electric field scaling: E = **z** (V/d)
  - DLC20 : z = 1.086
  - PAD3 : z = 1.052

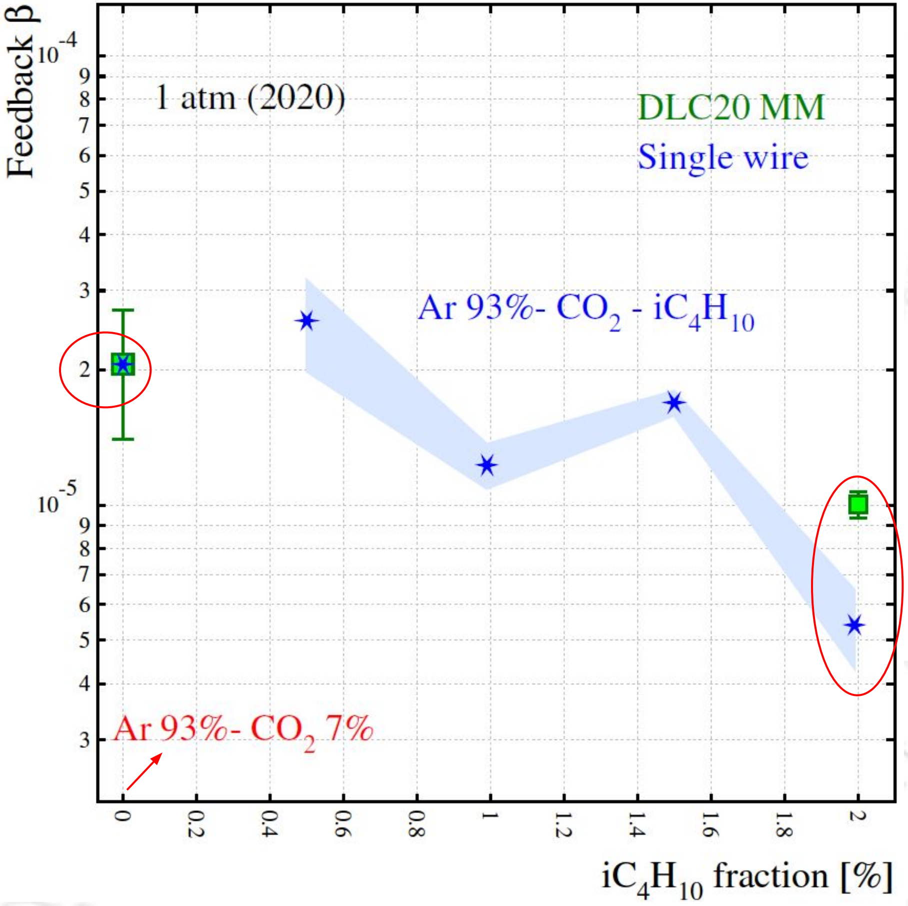
- **Gas Gain Scaling (h)**
  - The gas gain scaling: $G = \mathbf{h}\,(G_{measurement})$
  - DLC20 : h = 3.1
  - PAD3 : h = 2.1

- Thanks to these corrections, the **energy transfer probabilities** extracted from ATLAS MM gain data (DLC20 and PAD3) and the results obtained from the single-wire proportional counter **quite well match**.

Feedback Parameters

- Feedbacks terms tend to decrease with the increase of iC_4H_{10} concentration
- iC_4H_{10} is better quencher than CO_2 molecules
  - The maximum obtainable gas gain increase
- MM and single wire gain data give similar results for the feedback parameter
- The feedback parameter in Ar 93% - CO_2 7% confirms our previously published data

Özkan Şahin, Tadeusz Z.Kowalski, Rob Veenhof, *High-precision gas gain and energy transfer measurements in Ar–CO_2 mixtures*, Nucl. Instrum. Meth. **A 768** (2014) 104 (see plot 12).



Summary

- Surveys of the ATLAS mixtures (Ar 93% - CO_2- iC_4H_{10}) continue
  - Started with single wire counter gas gain data, thanks to Tadeusz Kowalski
    - Energy transfer rates tend to increase with increasing iC_4H_{10} fraction
    - The rate seems to reach a saturation at high iC_4H_{10} fractions
  - ATLAS MM gas gains give higher energy transfer rates compared to single wire results
    - Surely, there are experts among us who can explain the gain differences between the DLC20 and PAD3 MM ???
    - Possible to get consistent with the single wire transfer results introducing some correction factors
      - Electric field and gas gain scalings
- New ideas will welcome to investigate these discrepancies for the transfer rates

Thanks and ???