Modelling of Energy Transfer Drops in $Ne\text{-}CO_2$ mixtures

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Systematic gas gain measurements and Penning energy transfer rates in Ne-CO_2 mixtures

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ABSTRACT: In Ne-CO_2 mixtures, excitation energy of Ne atom can be used to ionize CO_2 molecule by the mechanisms called Penning transfers. In the present work, we have measured the gas gain systematically in various Ne-CO_2 mixtures (Ne + 0.6-60 % CO_2) at 0.4, 0.8, 1.2, 1.8 atm. The experimental data have been fitted to investigate the Penning energy transfer rates and the secondary processes playing a role in avalanche formations.

CO_2 percentage

1) 0.6%
2) 1%
3) 2%
4) 4%
5) 5%
6) 7%
7) 10%
8) 15%
9) 20%
10) 30%
11) 40%
12) 50%
13) 60%
14) 74%

Pure Ne

Pure CO_2

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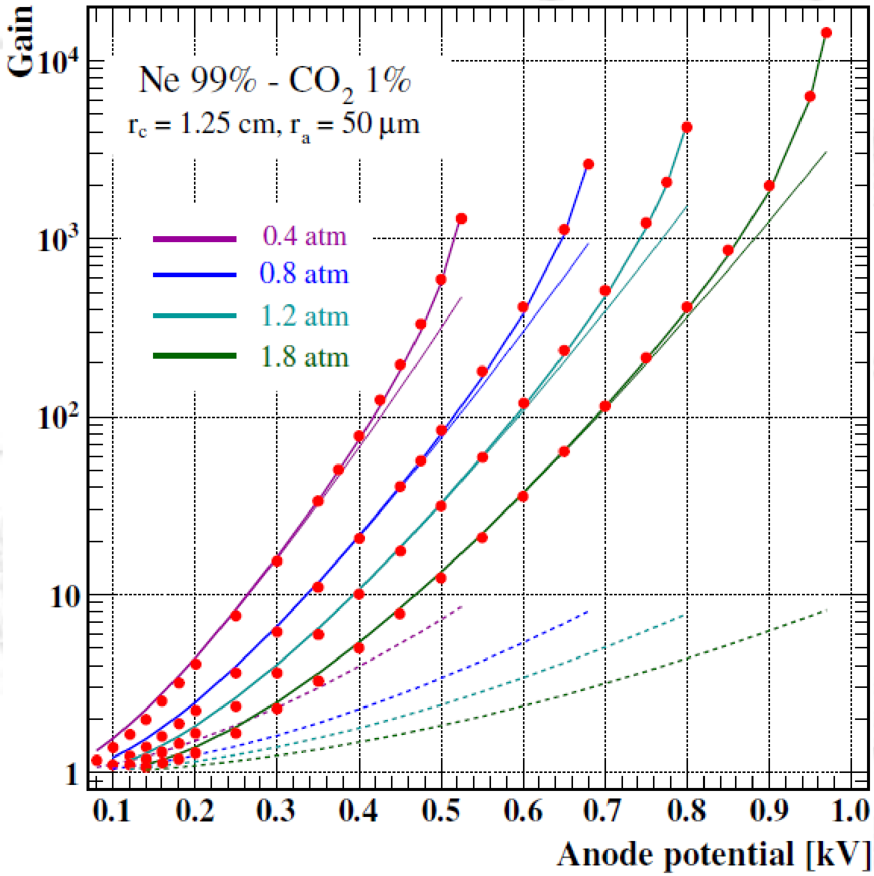
Ne – CO_2 gas gain calculations



Penning correction

- ❖ Ne* + $CO_2 \rightarrow$ Ne + CO_2^+ + e^-
- ❖ All of the excited Ne atoms can ionise CO_2

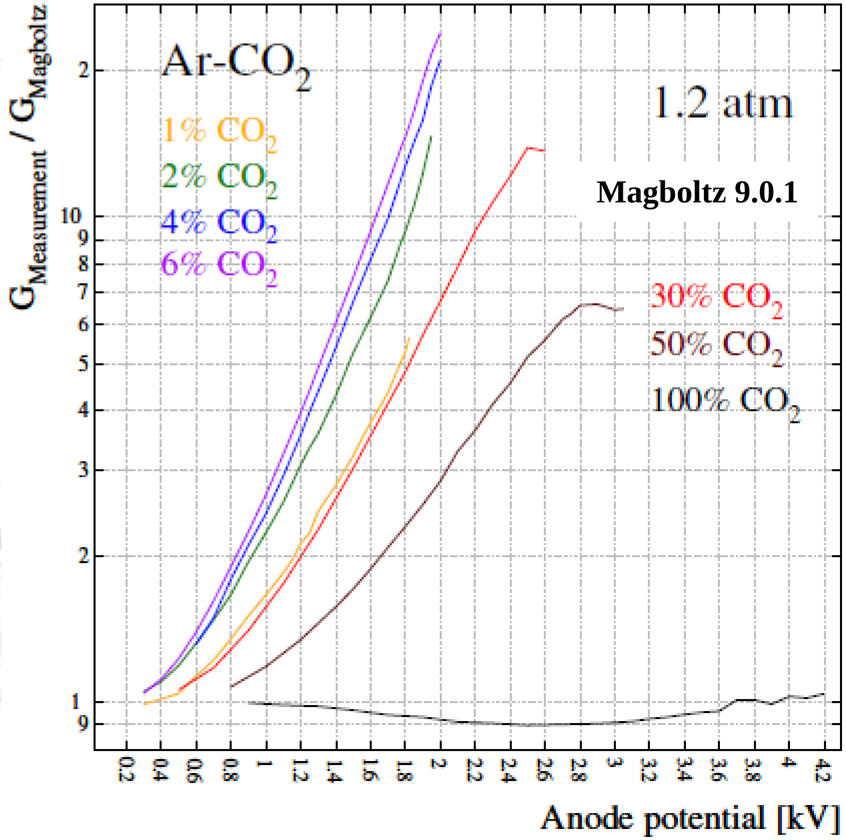
$$\alpha_{Penning} = \alpha \frac{\sum \nu_i^{ion} + \sum r_i \nu_i^{exc}}{\sum \nu_i^{ion}}$$

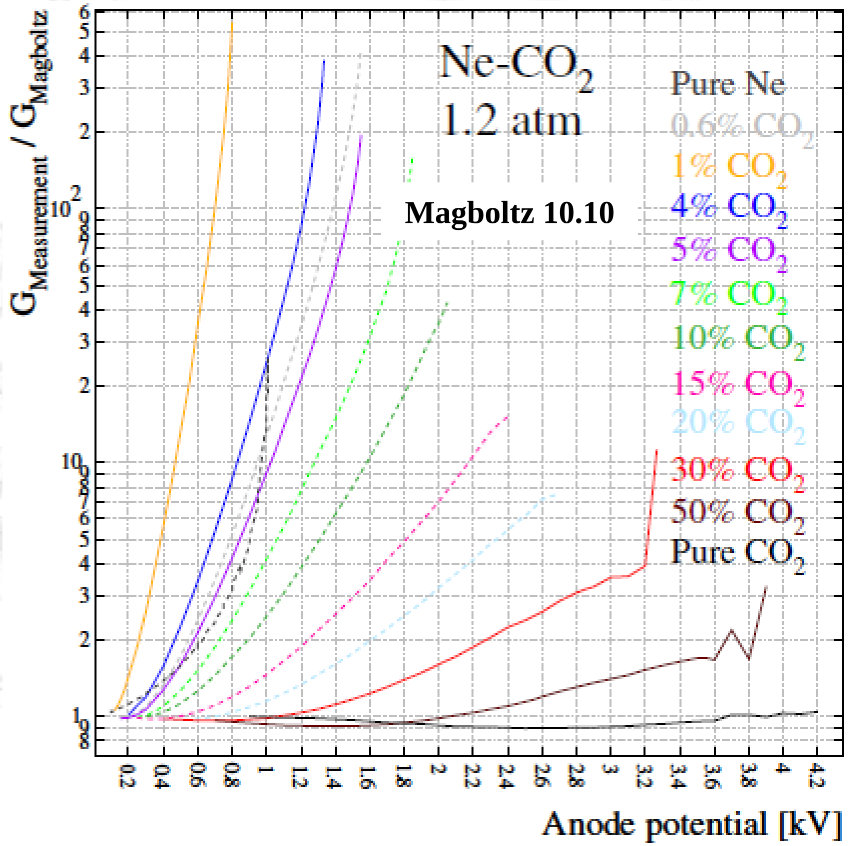
Photon feedback $G' = G/(1 - \beta G)$

Production frequencies of the ionisations and excitations with **Magboltz 10.10**

- ❖ Dashed lines: **without** corrections (Penning, feedback),
- ❖ Thin lines: with Penning, **without** feedback corrections ,
- ❖ Thick lines: final fits **with** Penning and feedback corrections.

Gain ratio: measured vs calculated without Penning





❖ Ratio increases with CO_2 fraction up to 6 %

❖ Decrease for 30% and upper CO_2 fractions

❖ Approaches unity in pure CO_2

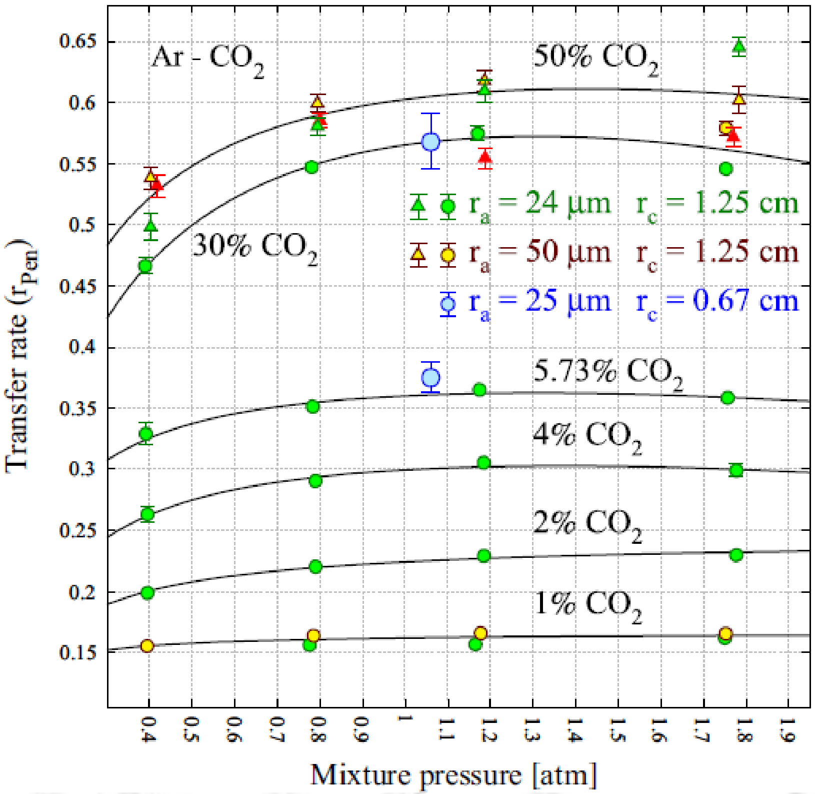
❖ No gain data yet in pure Ar

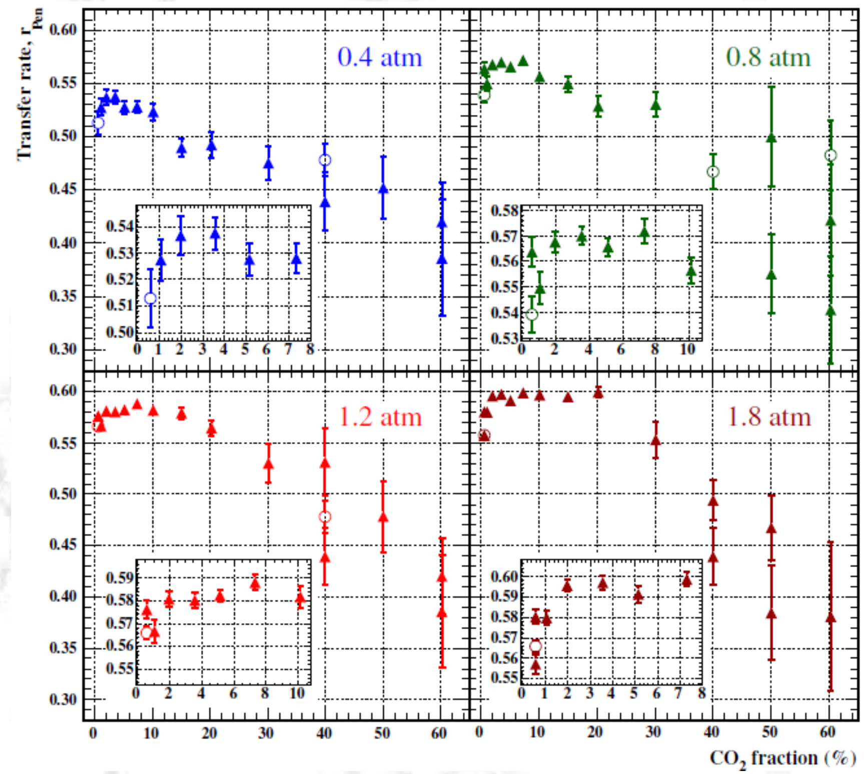
❖ Ratio increases from pure neon to 1% CO_2 and becomes smaller at high CO_2 fractions

❖ **So, almost the same trend for the ratio as seen in Ar – CO_2 mixtures !**

❖ Better agreement in pure CO_2

Penning rates derived from the gain fits





❖ Bigger rates at higher CO_2 concentrations and mixture pressures

❖ shorter collision time of excited Ar atoms

❖ Ar 2p and higher levels are included

Plot: Ö. Şahin, T.Z. Kowalski and R. Veenhof, *High-precision gas gain and energy transfer measurements in Ar-CO_2 mixtures*, Nucl. Instrum. Meth. **A 768** (2014) 104.

❖ The transfer rate increases with pressure

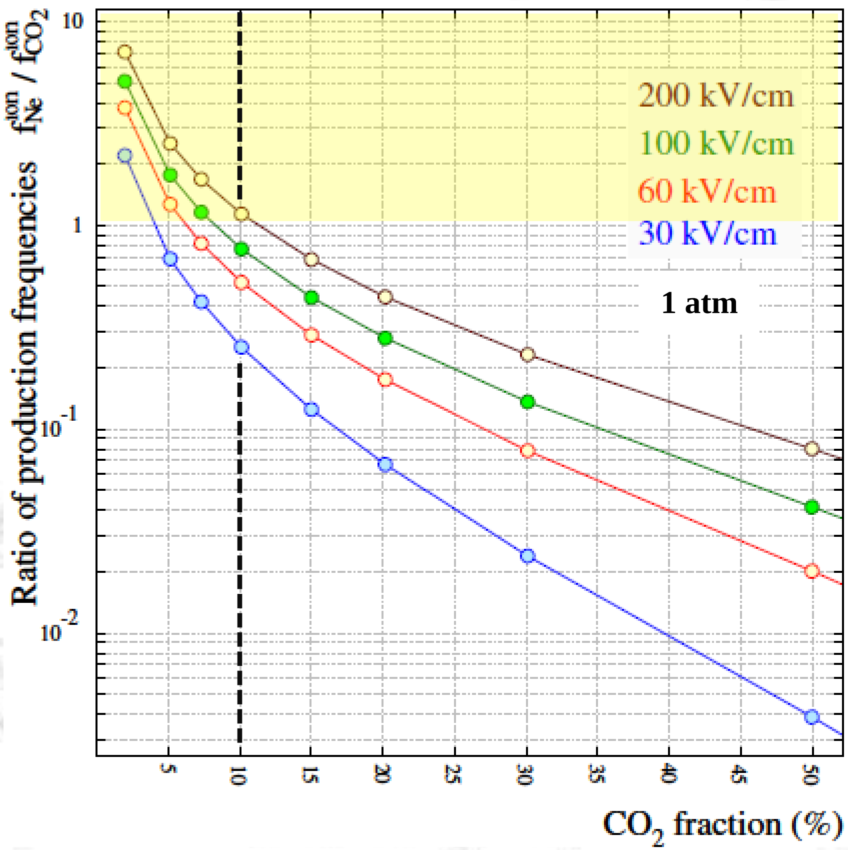
❖ shorter collision time

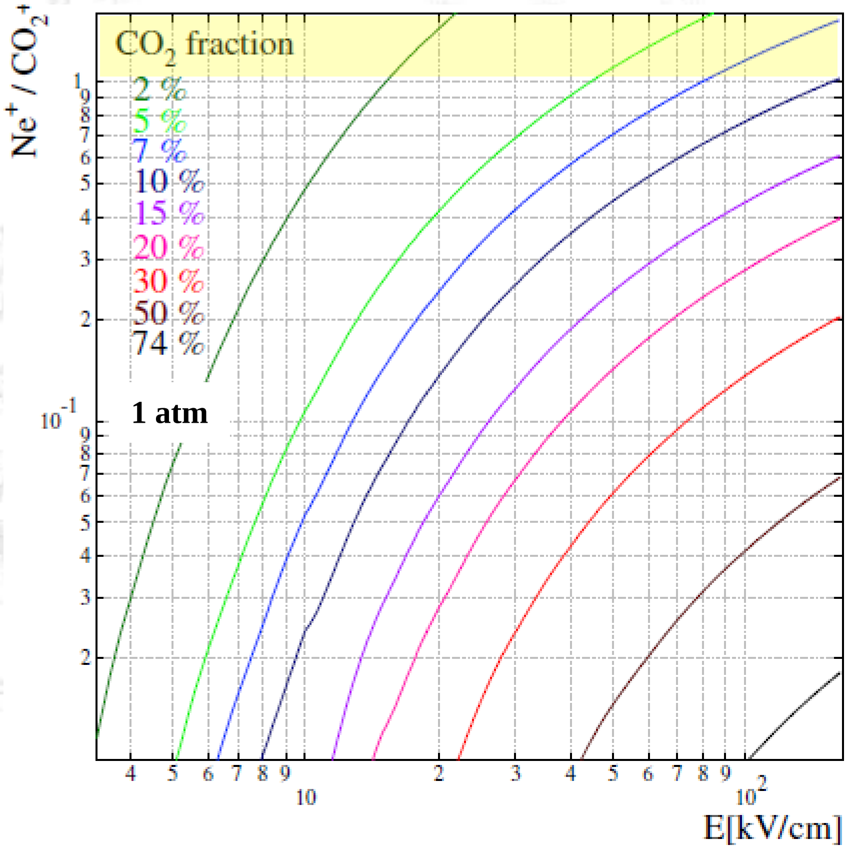
❖ **BUT, drops at high CO_2 fractions !!!**

❖ Although the gain ratio descends with CO_2, the rate is expected to be high since excited Ne atoms will find more CO_2 molecules to transfer

Plot: Ö. Şahin, T.Z. Kowalski and R. Veenhof, *Systematic gas gain measurements and Penning energy transfer rates in Ne − CO_2 mixtures*, 2016 *JINST* **11** P01003.

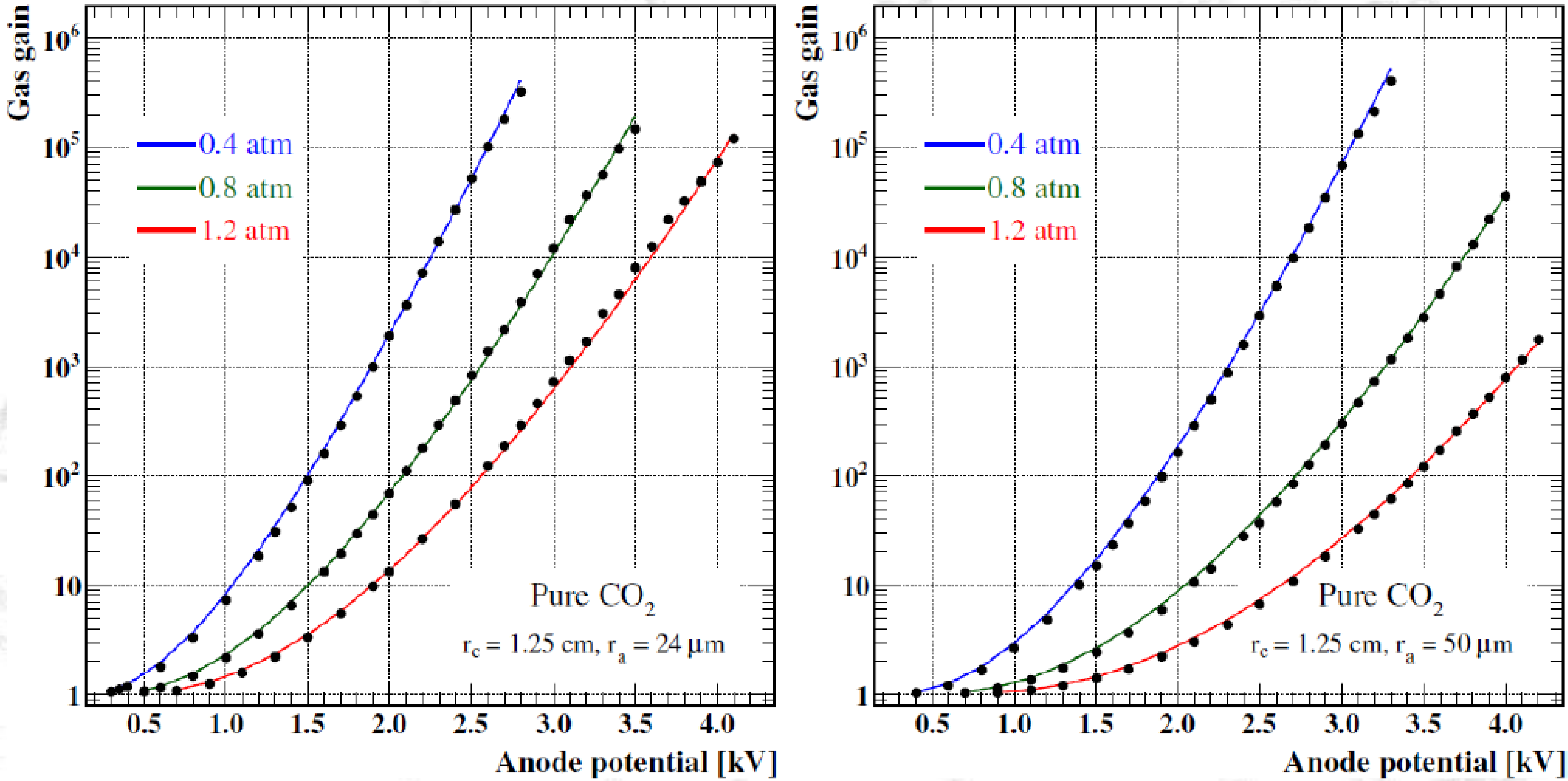
Production ratios of the direct ionisations





- Direct ionisation of neon is dominant in the mixtures filled with higher than 90 % Ne,
  - particularly at high electric fields (ionisation potentials: CO_2^+ 13.78 eV, Ne^+ 21.56 eV)
- Beyond 10% CO_2, **the largest part of the gain comes from CO_2 ionisations,**
- In 50% and 74% CO_2 mixtures the contribution of Ne^+ downs much lower than10 %

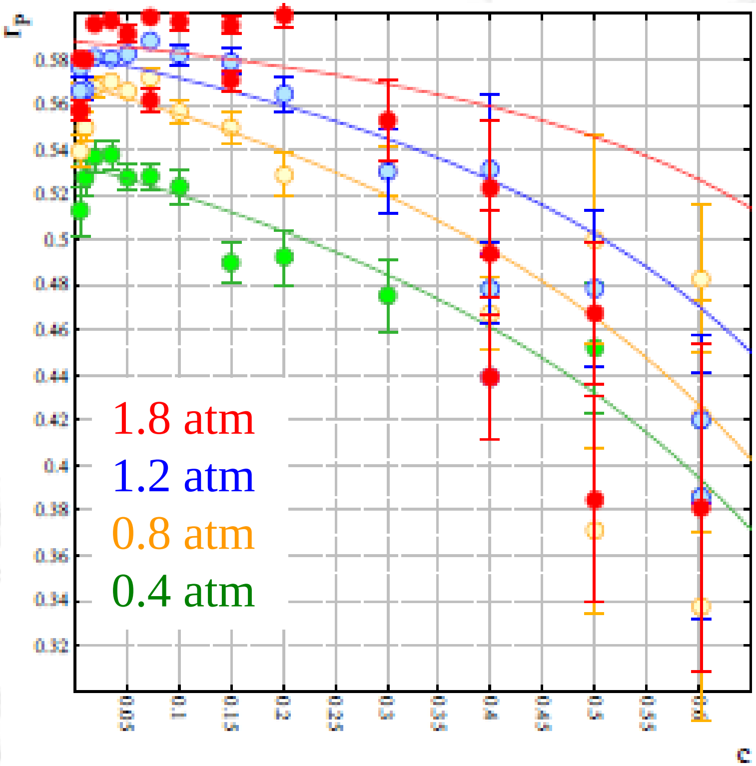
Are CO_2 ionisation cross sections wrong in Magboltz ???

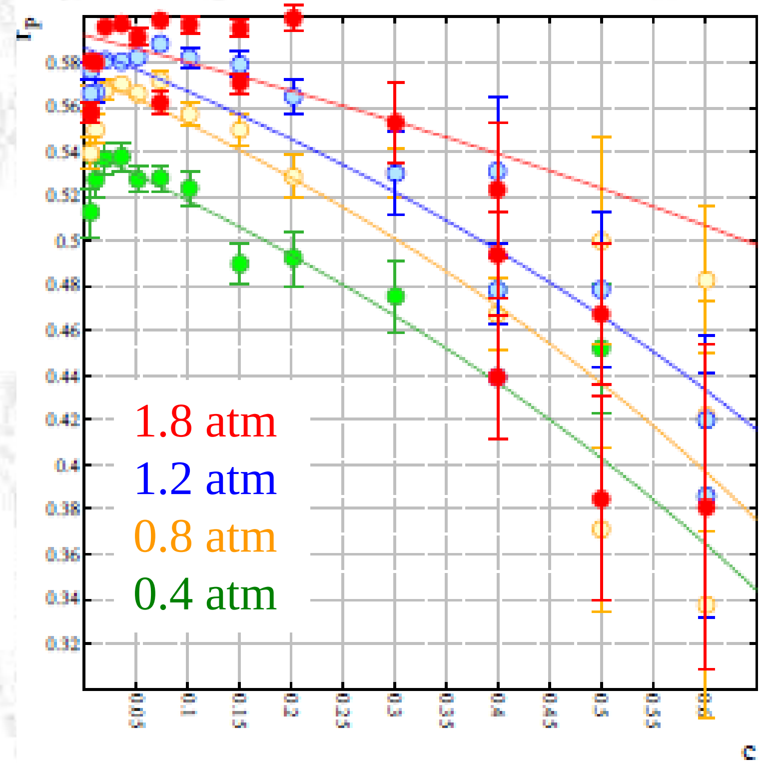


❖ Magboltz calculates the measured gain in pure CO_2 accuratelty without using any correction factor; direct ionisation cross sections of CO_2 in Magboltz are correct.

❖ **There should really be other physical processes leading the transfer rate drops**

Separate fits for the pressures

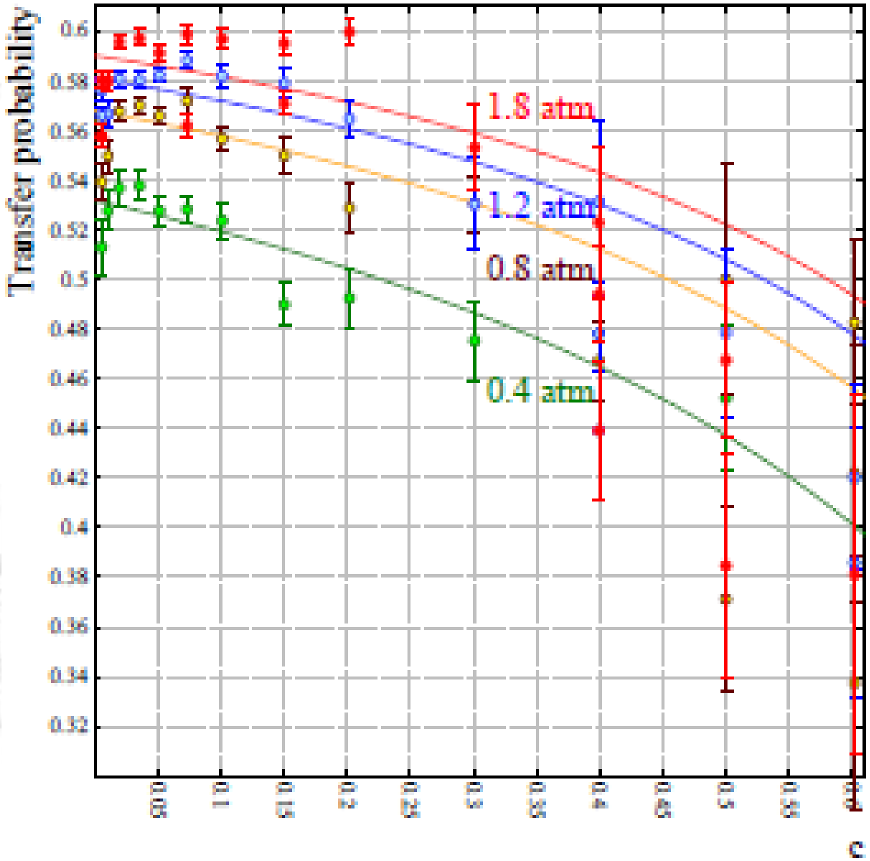




- ❖ Hornbeck-Molnar ionisation is assumed to be dominant process ($Ne^* + Ne \rightarrow Ne_2^+ + e^-$)
- ❖ Collisional ionisation of CO_2 takes 0 value
  - ❖ $Ne^* + CO_2 \rightarrow Ne + CO_2^+ + e^-$
- ❖ Collisional losses of Ne^* to Ne or CO_2 are included
- ❖ Decay is not considered

- ❖ Collisional ionisation of CO2 is **not** included
- ❖ Collisional losses of Ne^* are **not** included
- ❖ For the loss only decay is included
- ❖ So, Hornbeck-Molnar ionisation (included) is one of the process that can lead to decrease of the transfer rate with increasing CO_2 fraction

Combined fits for the pressures

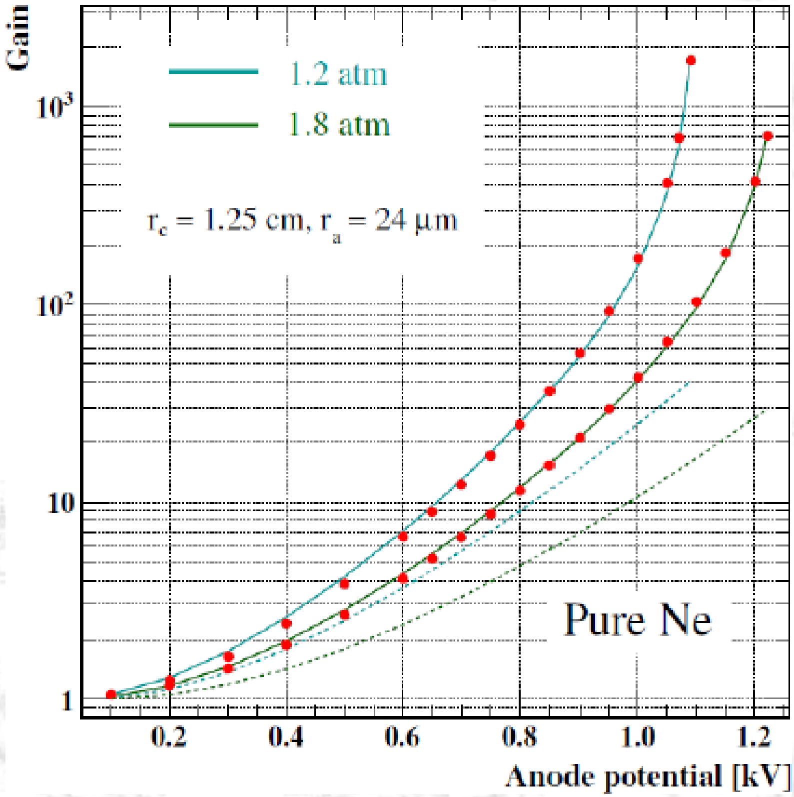


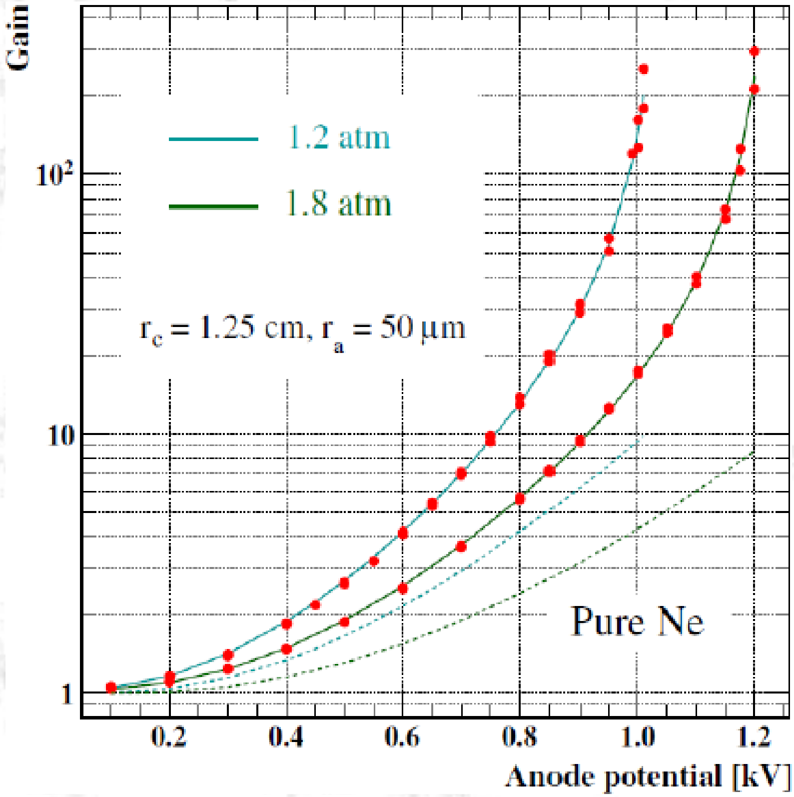
- ❖ Separate fits do not allow to distinguish between Hornbeck-Molnar and decay processes
- ❖ Combined fit over the 4 pressures is needed:
  - ❖ no visible collisional transfer to CO_2
  - ❖ there are losses due to Ne and CO_2
  - ❖ Hornberck-Molnar is dominant mechanism
  - ❖ a decay term is necessary to fit the rates
- ❖ Physically meaningful fit parameters

- ❖ There are some articles in literature that supports to above fitting results:
  - ❖ Hornbeck-Molnar process could be responsible for the high gain in Ne
  - ❖ Experimental data: excited (metastable) neon efficiently is quenched by CO_2

- ❖ Continue to search mechanisms that can be important to explain collisional loss reactions for excited Ne; e.g. ion clustering may lead to drop of the transfer rates

Gain calculations in pure Ne





❖ Considering the neon excitation levels above **20 eV** fits the experimental data with the transfer rates varying between $\mathbf{r_p = 40 – 65\ \%}$

❖ Hornbeck-Molnar ionisation threshold is 20.9 ± 0.2 eV

- ❖ If the levels above this threshold are used then we get unphysical large values, r_p

❖ **Contamination of other gases (like O_2, N_2 etc.) even in purified neon can play an important role and may lead to Penning ionisations**

Summary

- ❖ Increase of the rates below 3% CO_2 indicates the typical Penning transfer to CO_2 molecules (excited neon will find more CO_2 to ionise)

- ❖ Hornbeck-Molnar ionisation seem to be dominant mechanism that explains the transfer drops at high CO_2 fractions ($Ne^* + Ne \rightarrow Ne_2^+ + e^-$)
  - ❖ But why excited neon does not prefer to collisional ionisations at large CO_2 fractions ($Ne^* + CO_2 \rightarrow Ne + CO_2^+ + e^-$)
    - ❖ Losses of the excited metastable neon atoms (quenched by CO2) may have an effect

- ❖ Many-body losses to CO_2 can also be responsible for the drops
  - ❖ Clustering ions should be worked

Thanks and ???