Gain Ar-CO_2 mixtures

Özkan ŞAHİN & Tadeusz KOWALSKI

Uludağ University, Physics Department,
Bursa – TURKEY

Faculty of Physics and Applied Computer Science, AGH University of Science and Technology,
Krakow – POLAND

Nuclear Instruments and Methods in Physics Research A 768 (2014) 104–111

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

High-precision gas gain and energy transfer measurements in Ar–CO_2 mixtures

Özkan Şahin [a,*], Tadeusz Z. Kowalski [b], Rob Veenhof [a,c]

[a] Department of Physics, Uludağ University, 16059 Bursa, Turkey
[b] Faculty of Physics and Applied Computer Science, AGH University of Science and Technology, Kraków, Poland
[c] RD51 collaboration, CERN, Genève, Switzerland

ARTICLE INFO

Article history:
Received 31 May 2014
Received in revised form
20 September 2014
Accepted 23 September 2014
Available online 2 October 2014

Keywords:
Gas detectors
Penning transfer
Excited states
Photon feedback

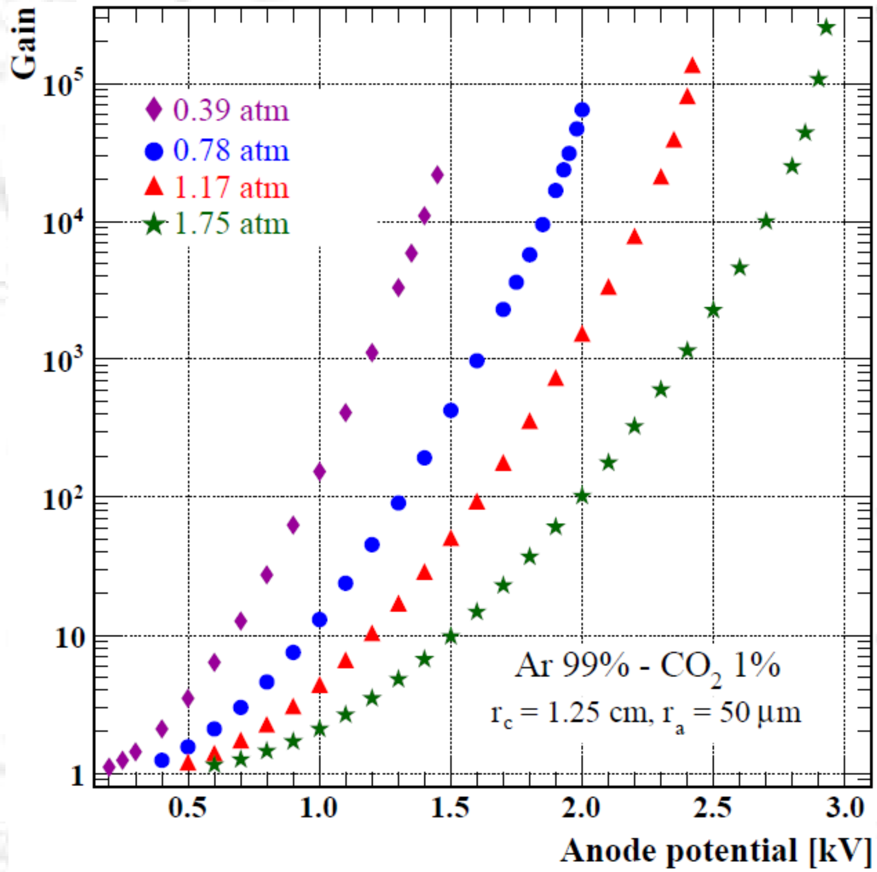
ABSTRACT

Ar–CO_2 is a Penning mixture since a fraction of the energy stored in Ar $3p^5 3d$ and higher excited states can be transferred to ionize CO_2 molecules. In the present work, concentration and pressure dependence of Penning transfer rate and photon feedback parameter in Ar–CO_2 mixtures have been investigated with recent systematic high-precision gas gain measurements which cover the range 1–50% CO_2 at 400, 800, 1200, 1800 hPa and gas gain from 1 to 5×10^5.

http://dx.doi.org/10.1016/j.nima.2014.09.061

Gain measurements

- Gains for 6 admixture concentrations: Ar + 1%, 2%, 4%, 5.73%, 30%, 50% CO_2
- Single wire cylindrical tubes: r_c = 1.25 cm; r_a = 24 μm, 50 μm
- Current method
- A special grid of guard rings protecting the node
- Radiation source: mono – energetic X-rays
- Very carefully calibrated equipments
  - less than 5% error on gas gain
  - **no need to use gain scaling** (see next slides: gain fits)
- Wide gain regime: 1 – 10^5
- Photon feedback: visible G > 10^4
- Measured by Tadeusz KOWALSKI



Calculation method

❖ Ar 3d and higher excitations included (transport parameters using Magboltz)

$$G = \exp \int_{\text{tube}}^{\text{anode}} \mathrm{d}r\, \alpha \frac{\sum \nu_i^{\text{ion}} + \sum r_i \nu_i^{\text{exc}}}{\sum \nu_i^{\text{ion}}}$$

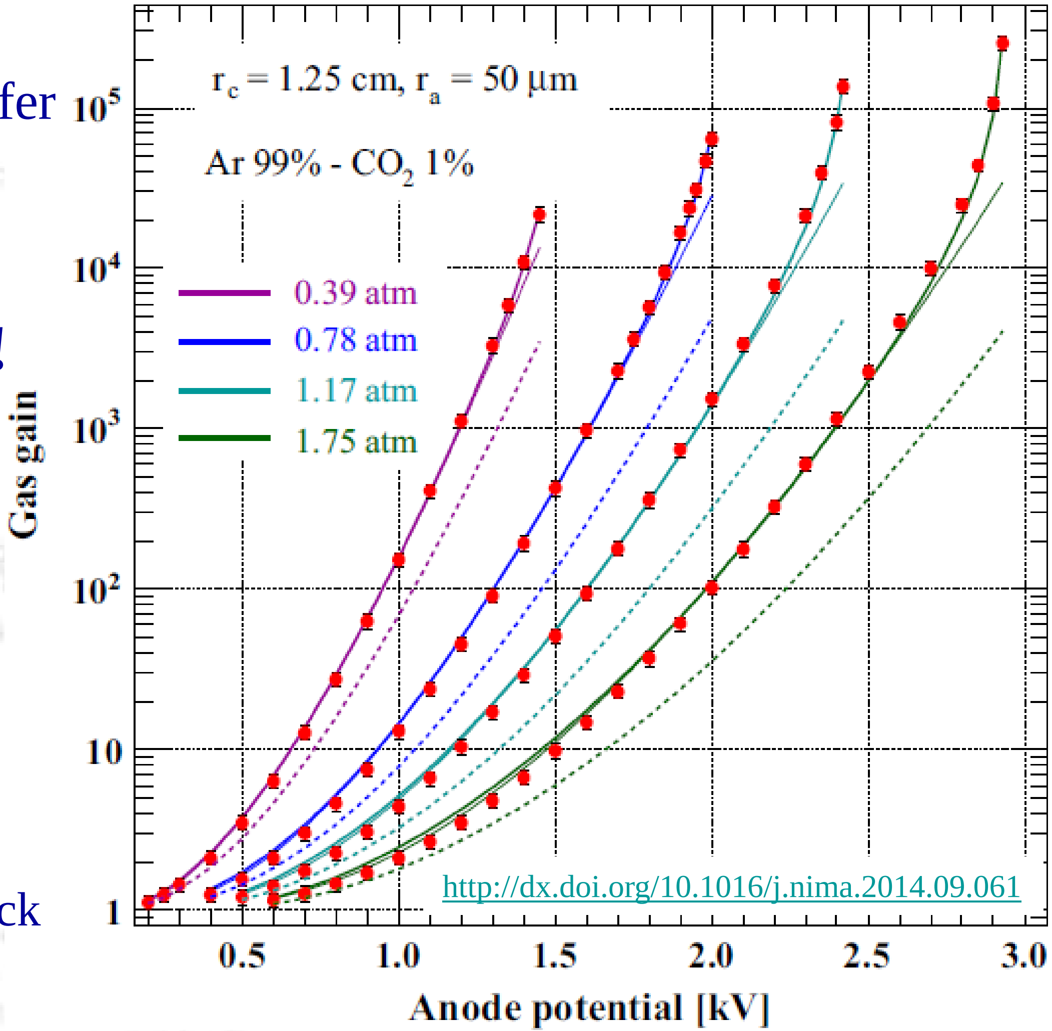
❖ r_i : Penning energy transfer probability

❖ **No** gain scaling factor needed

❖ **proof quality of the calibration !**

❖ Photon feedback parameters (β)

$$G' := G/(1-\beta G)$$



❖ without any correction

❖ with Penning transfer

❖ with Penning and feedback corrections

Transfer mechanisms

$e^- + A \rightarrow A^+ + 2e^-$: ionisation

$e^- + A \rightarrow A^*$: excitation

- 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

$$r = \frac{pc\,\frac{f_{B^+}}{\tau_{A^*B}} + p(1-c)\,\frac{f_{A^+}}{\tau_{A^*A}} + \frac{f_{rad}}{\tau_{A^*}}}{pc\,\frac{f_{B^+} + f_{\overline{B}}}{\tau_{A^*B}} + p(1-c)\,\frac{f_{A^+} + f_{\overline{A}}}{\tau_{A^*A}} + \frac{1}{\tau_{A^*}}}$$

A*- B ***A*- A*** ***A*- γ***

Modeling of the transfer rates

❖ Some measurements are repeated

❖ Fit function for 1%, 2% CO_2

$$r(p) = \frac{b_1 p}{p + b_2}$$

❖ Some transfer rates drop at the highest pressure !!!

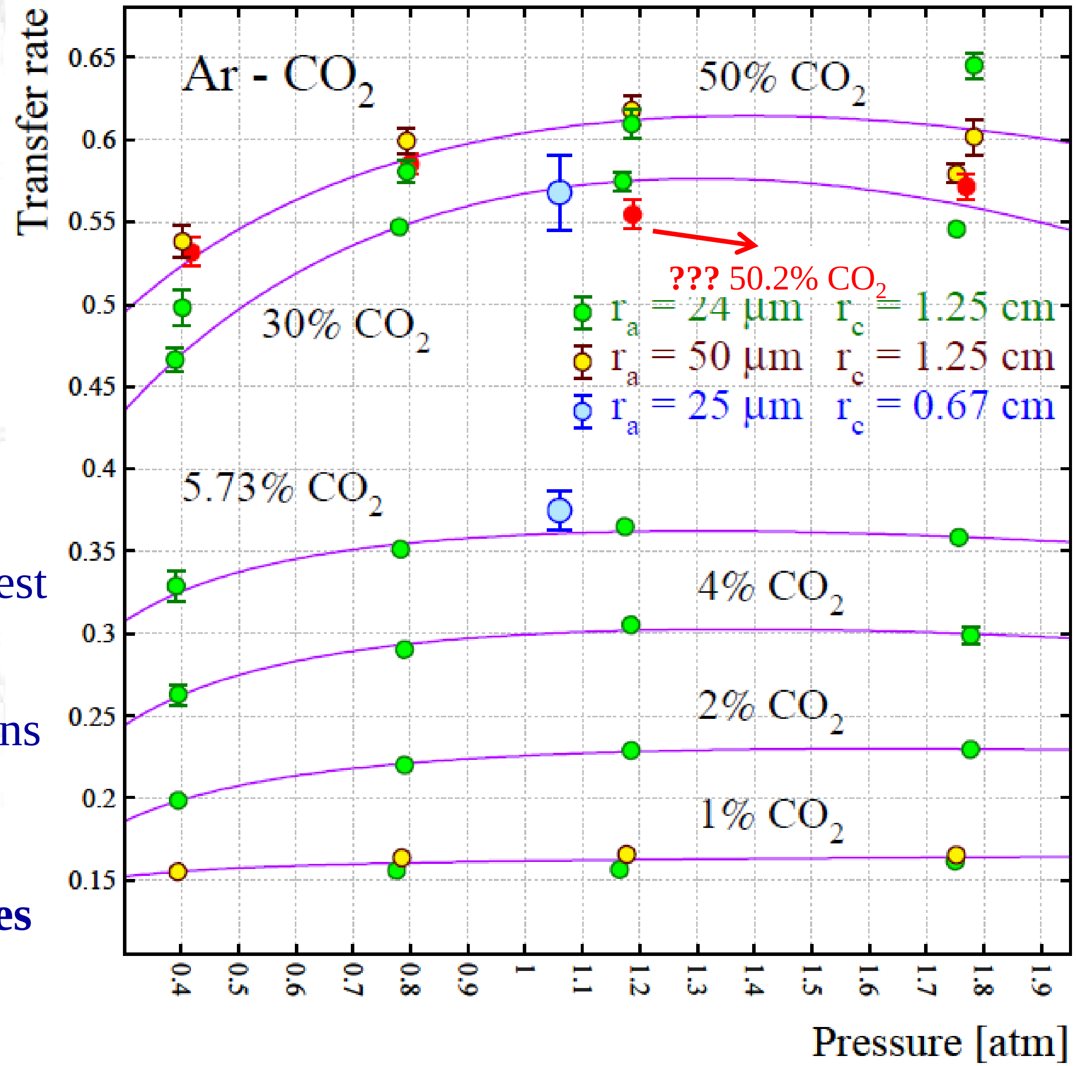
❖ excited argon molecule formations

$$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar$$

destruction of the excited states in 3–body reaction

❖ Fit function for higher CO_2 fractions

$$r(p) = \frac{b_1 p + b_3}{p + b_2} + b_4 p^2$$



❖ p^2 dependence:

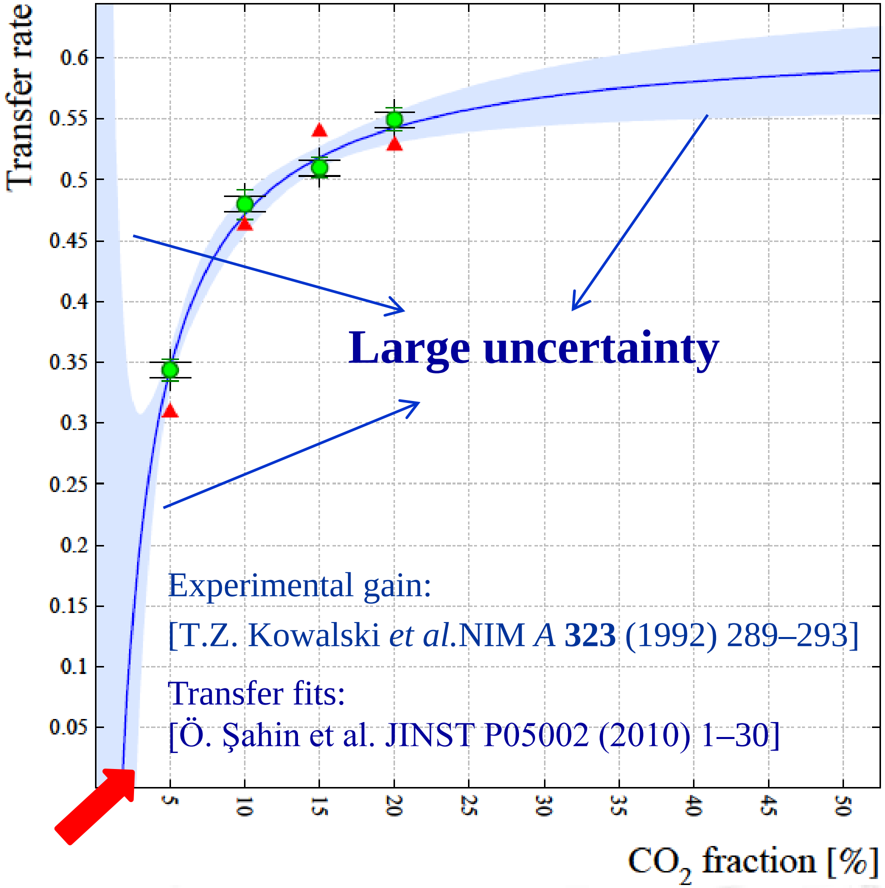
evidence of 3–body interactions

Fit parameters of the transfer curves

CO_2 (%)	b_1	b_2	b_3
1	0.1667 ± 0.0031	0.0287 ± 0.0156	–
2	0.2434 ± 0.0032	0.0858 ± 0.0119	–
4	0.3432 ± 0.0179	0.1208 ± 0.0341	-0.0068 ± 0.0044
5.73	0.3999 ± 0.0217	0.0898 ± 0.0398	-0.0070 ± 0.0045
30	0.7046 ± 0.0708	0.1970 ± 0.0786	-0.0235 ± 0.0142
50	0.6974 ± 0.0507	0.1324 ± 0.0488	-0.0134 ± 0.0119

http://dx.doi.org/10.1016/j.nima.2014.09.061

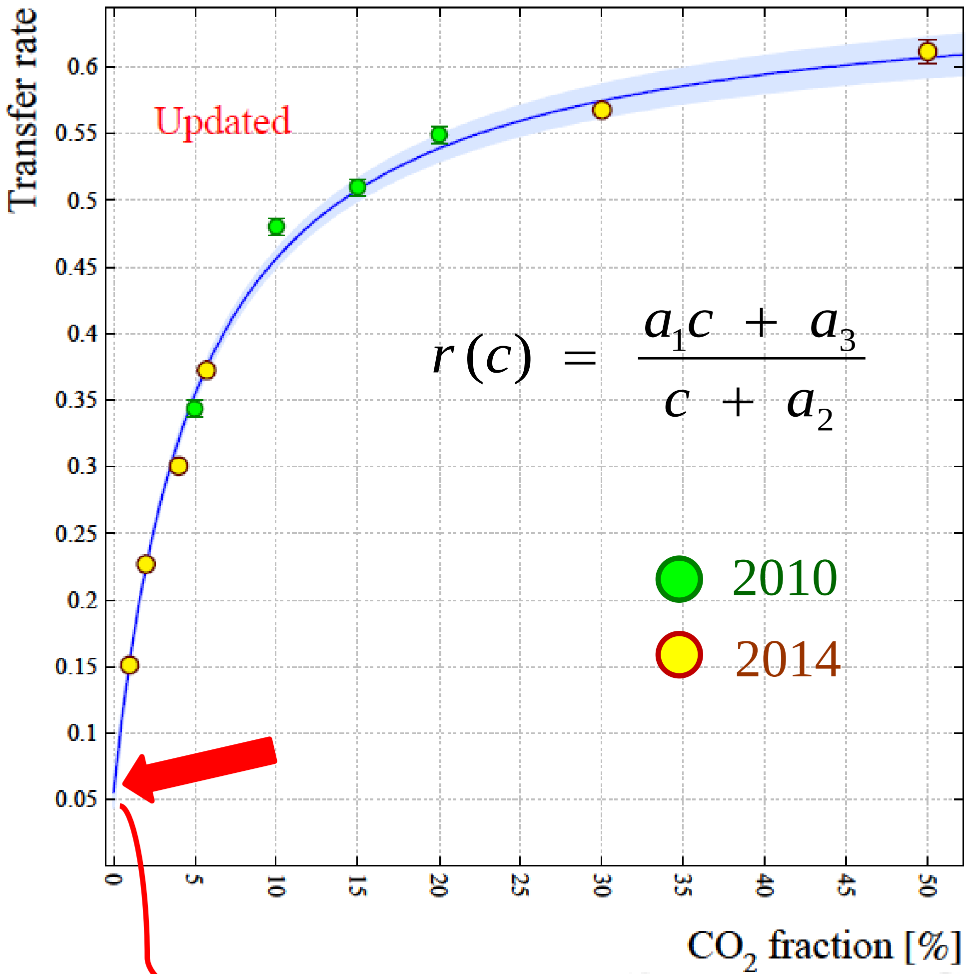
Transfer rates at 1070 hPa extracted from earlier data



- **PUBLISHED DATA**
- Gain curves : Ar + 5%, 10%, 15%, 20% CO2
- Pressure: 1070 hPa
- 1x1 cm^2 Square tube with 25 μm radius single anode wire,
  - Cylindrical approximation $r_c = 0.67$ cm
- Transfer rates found: Ö. Şahin et al.,
- Wide error band, lack of experimental data for <5% and >20% CO_2 fractions !!!

- Extended version of published plot,
- 1.06 gain scaling factor were used, $G = g\, G_{meas}$
- **Negative radiative term (a_3/a_2) ???**

Transfer rates at 1070 hPa with the present data



$$r(c) = \frac{a_1 c + a_3}{c + a_2}$$

- Joint fit gives transfer rates at1070 hPa,
- Narrow error band both at low and high CO_2 percentages,
- **All the fit parameters are physical**, relevant to learn about radiative transfers.

Parameter	This work
a_1	0.6643 ± 0.0208
a_2	0.0518 ± 0.0056
a_3	0.0028 ± 0.0009

http://dx.doi.org/10.1016/j.nima.2014.09.061

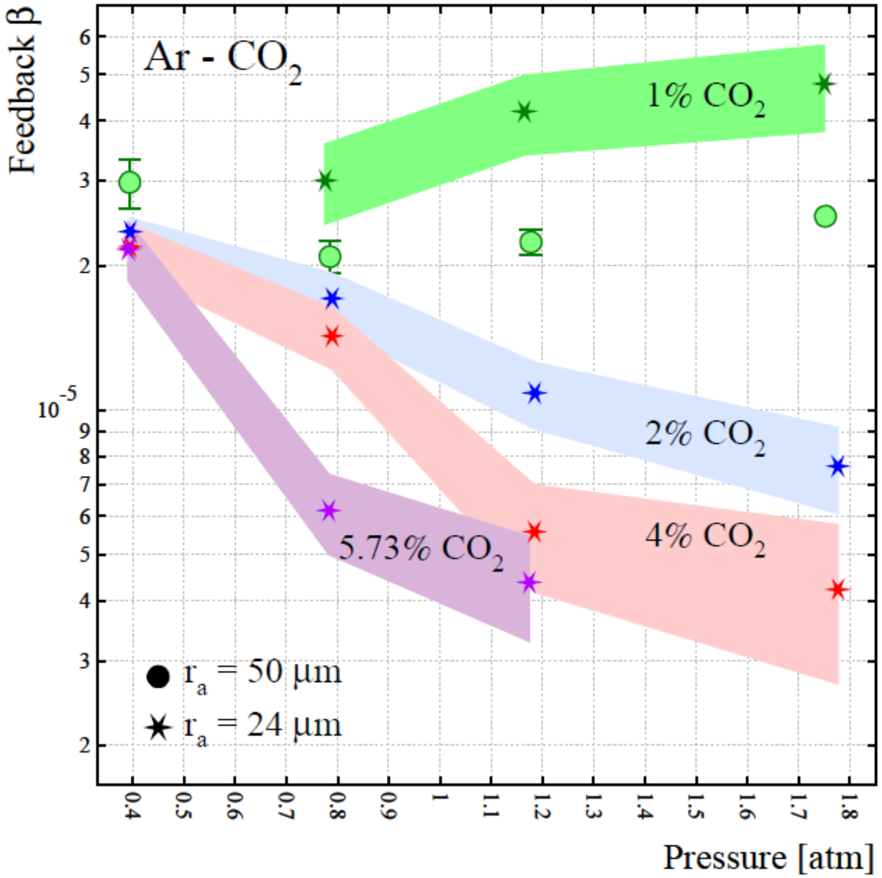
Positive radiative term !!!

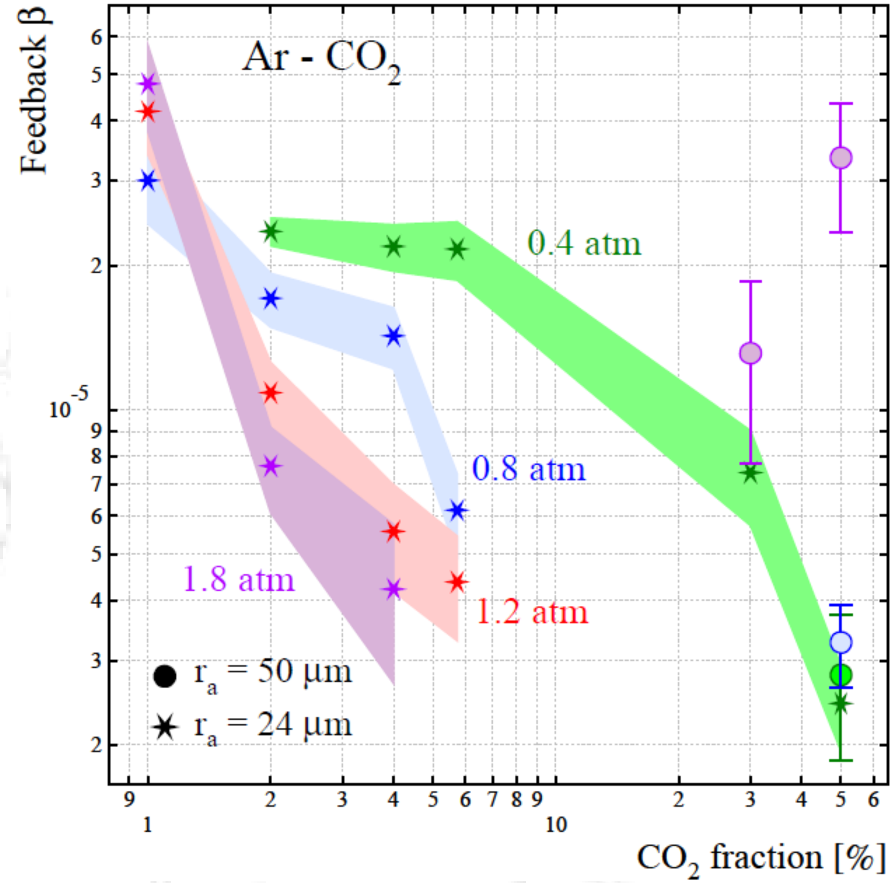
a3/a2 = 0.0541 +/- 0.0183

$Ar^* \rightarrow Ar + \gamma$

$\gamma + CO_2 \rightarrow CO_2^+ + e^-$

Pressure and concentration depence of feedback





❖ 1% CO_2 : increase with gas pressure
❖ higher β for 24 µm anode radius

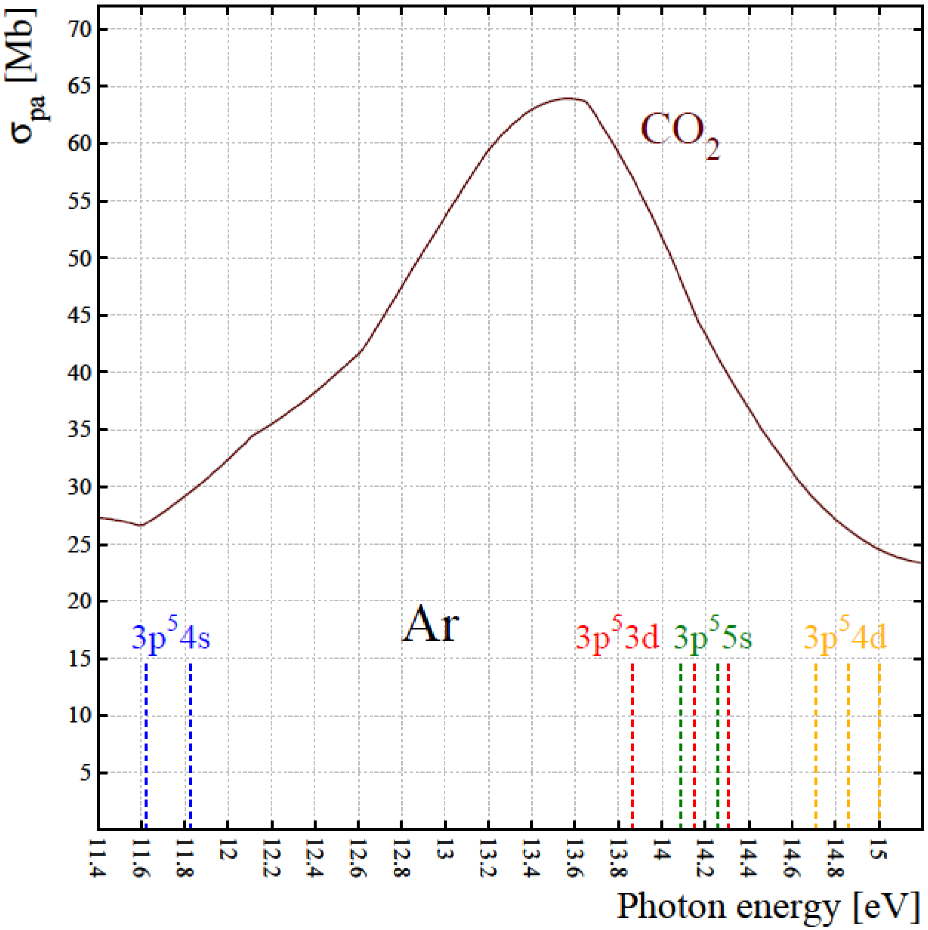
❖ 2%, 4%, 5.73% CO_2 : decrease on β with pressure

❖ 0.4 atm: almost flat β for the mixtures with 2%, 4% and 5.73% CO_2

❖ 0.8 atm – 1.2 atm: β decrease with CO_2 concentrations

Decreases of β easy to explain in terms of photon mean free path **!!!**

Photo – absorption cross section of CO_2



Cross section compiled from J. Berkowitz, *Atomic and Molecular Photoabsorption*, Chapter 5, p. 189–197, Academic Press (2002)

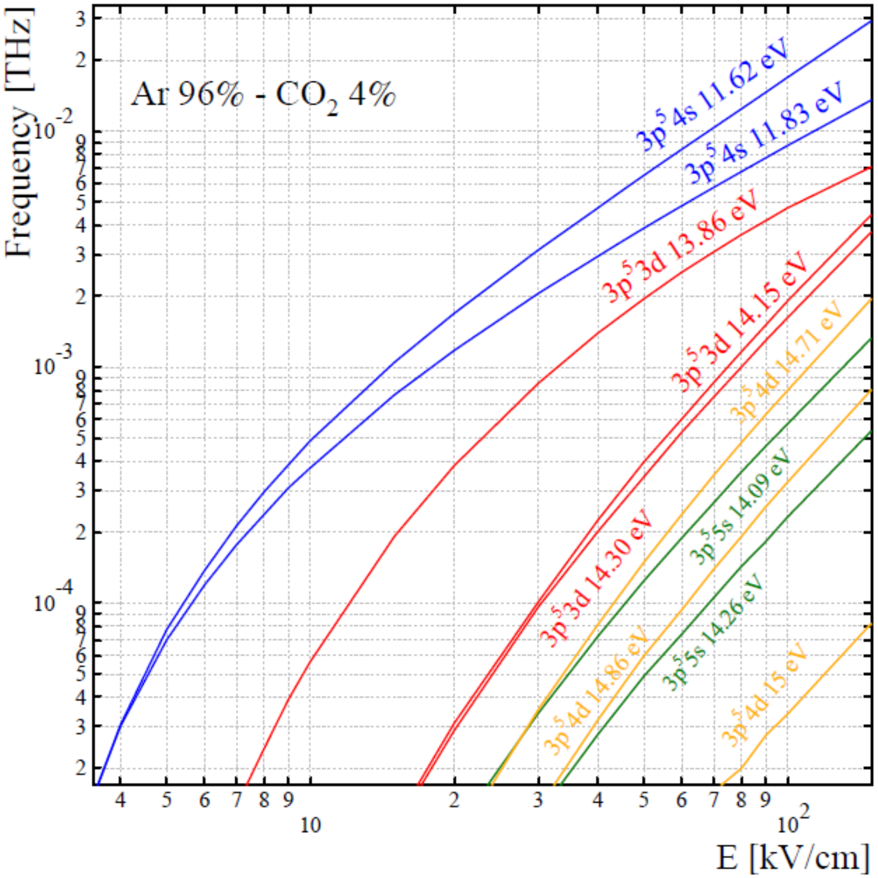
❖ photons from 3d and higher radiative levels can ionise CO_2

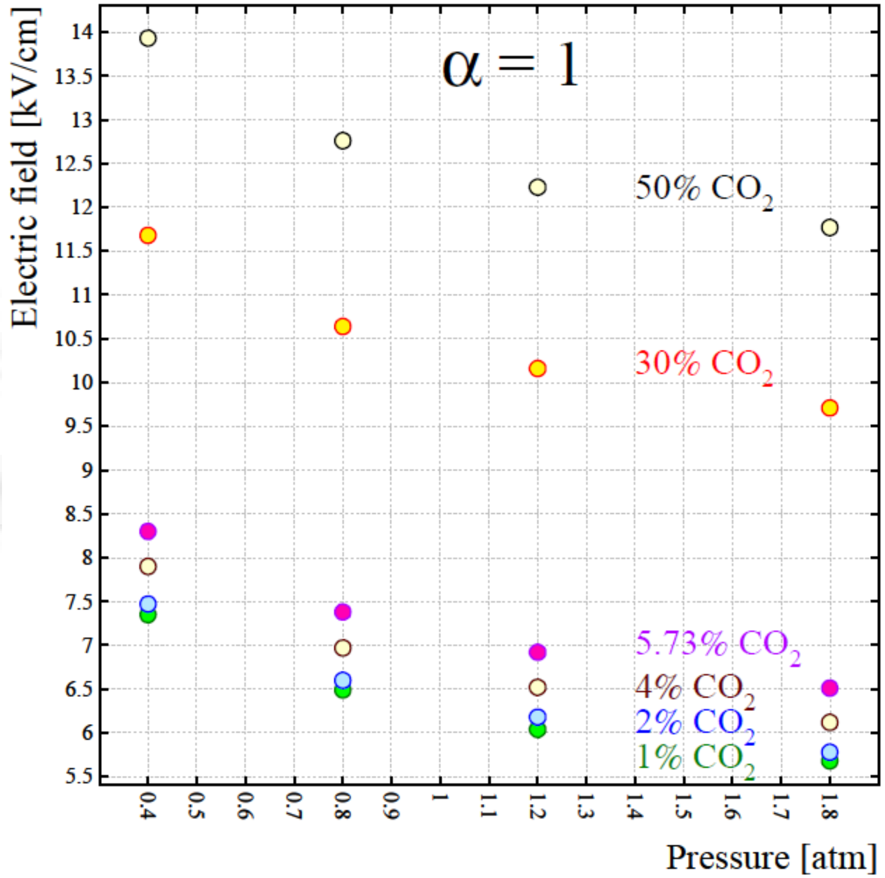
❖ 4s photons produce photo – electron if they arrive the cathode but they can not ionise CO_2

❖ non – radiative states decays to intermediate states; they have not enough energy to ionise CO_2 or to extract electron from cathode

❖ σ_{pa} : 3d, 5s > 4s > 4d

Production rates and avalanche region



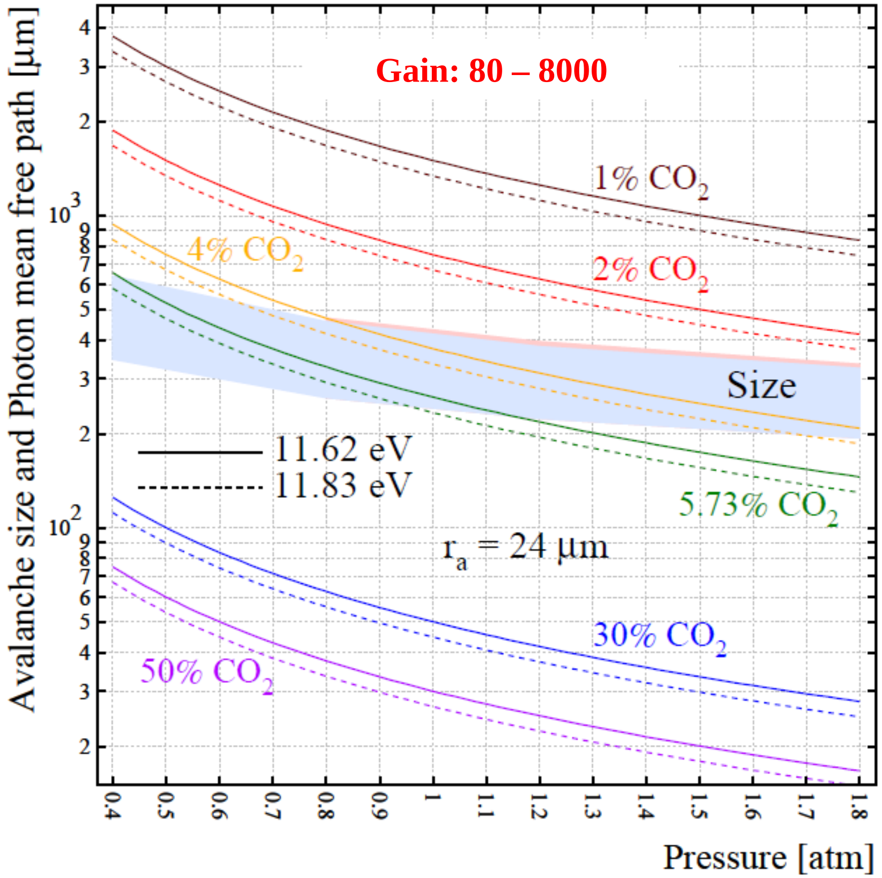


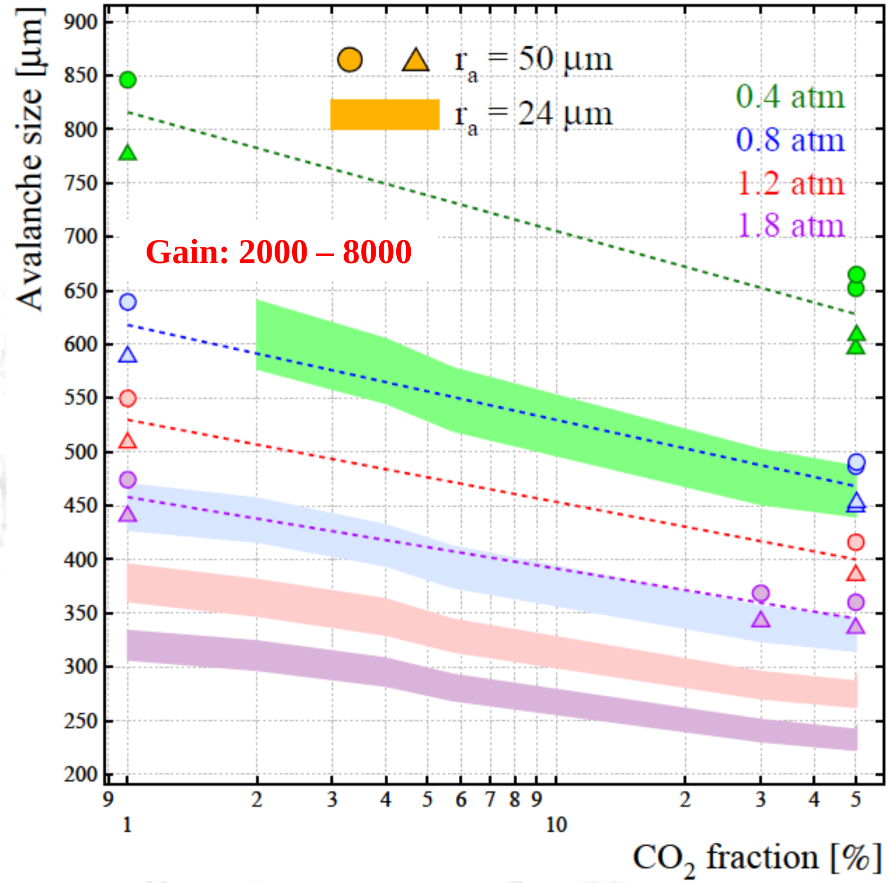
- 4s levels are the most abudantly produced
  - they are not lost in Penning transfers
  - they can contribute to feedback effectively by arriving the cathode **???**

- α = 1 used to define avalanche sizes

$$r_{size} = \frac{V_{anode}(gain\,curves)}{E(\alpha = 1,\ Magboltz)\ \log(r_{tube}/r_{anode})}$$

Absorption distance of the excited states

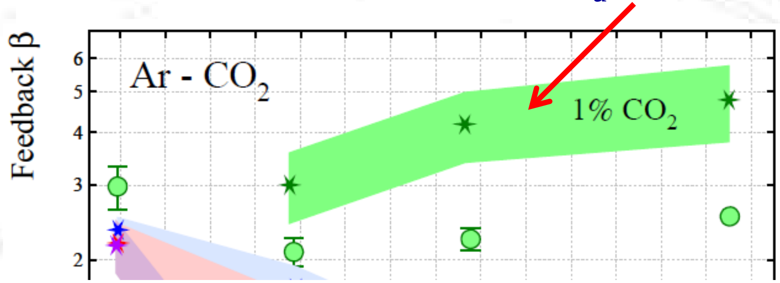




❖ Both avalanche sizes and photon mean free path decreases with pressure and size reduction is smaller than the mean free path

❖ photons in 1% and 2% CO_2 stopped outside the avalanche (still in gas) while the rest are absorbed in the avalanche

❖ Size in the tube with thinner anode wire is smaller: explains bigger beta for r_a = 24 µm



SUMMARY

❖ Energy transfer mechanisms in Ar – CO_2 mixtures enlightened from the fits of the recent high–precision gain measurements,

❖ Calculated transfer rates confirm the published data [Ö. Şahin et al. JINST P05002 (2010) 1–30],

❖ Diminish of the rates at the highest pressure indicates that 3–body interaction losses of excited argon states (excimer formation),

- ❖ The drop on the rate is modelled with a reduction parameter,

❖ Ar 4s excited state is the dominant feedback source,

❖ Feedback parameters implies that argon excimers, high level excited states of argon and ions are other potantial feedback sources.

Next:

❖ We hope to publish the results for Ne – CO_2 mixtures, soon (measured data by Tadeusz KOWALSKI in Krakow)

- ❖ Important mixture for ALICE-TPC.

Thanks and ???