Penning transfers:

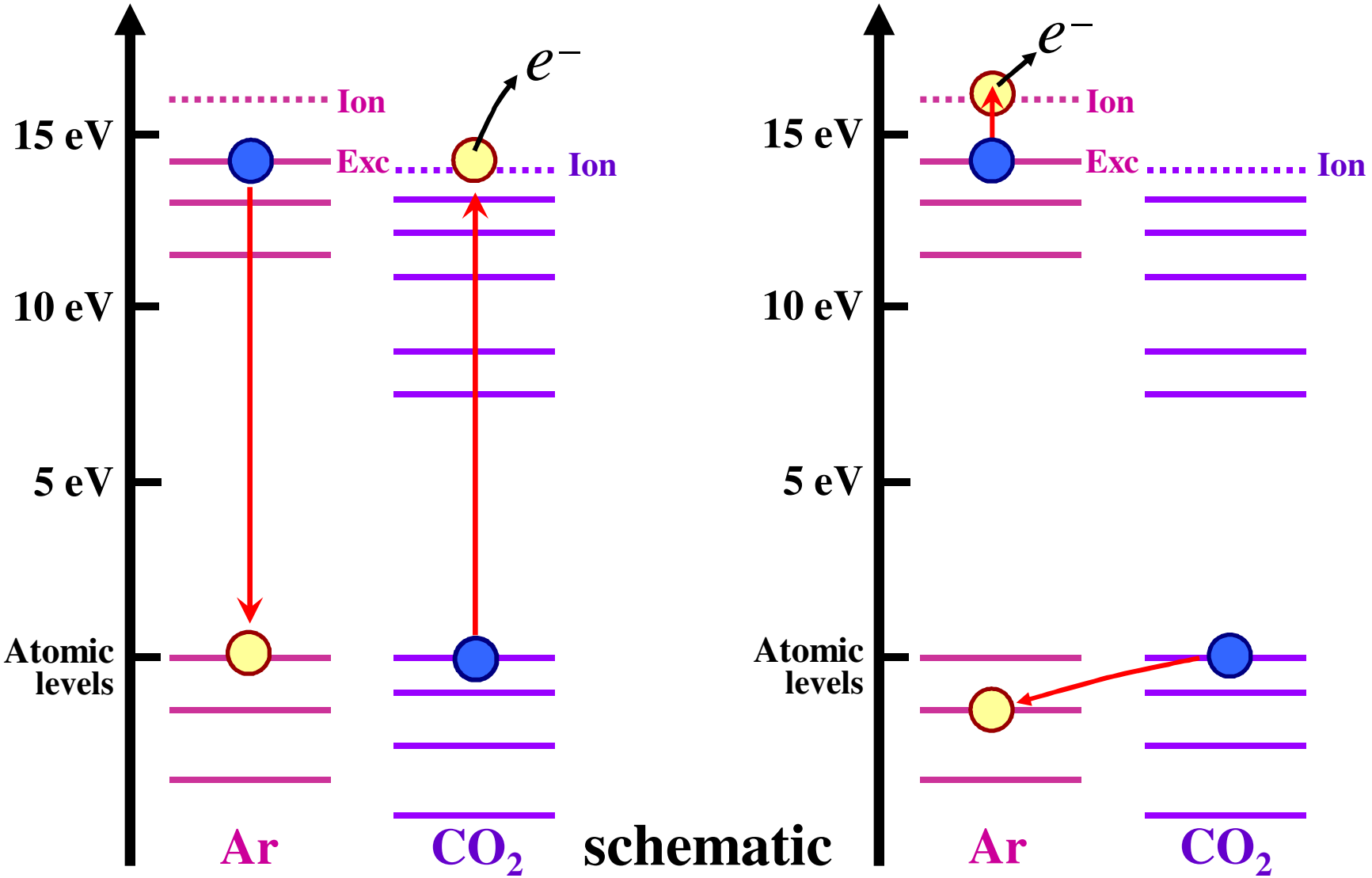
learning about the mechanism from gain curves

Özkan ŞAHİN
Uludağ University Physics Department
Bursa -TURKEY

Energy transfer mechanisms

Direct ("dipole-dipole")

Exchange ("Auger")



Measuring the transfer probabilities

- Townsend coefficient adjustment

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

- r_i transfer probabilities: assuming α proportional to the sum of ν^{ion},
- α, ν_i : gas properties (pressure, temperature …)
- calculated by Magboltz [S.F. Biagi, *NIM A* **421** (1999) 234–240.]

- Corrections:
  - Gain calibration,
  - Photon feedback.

Gain calibration

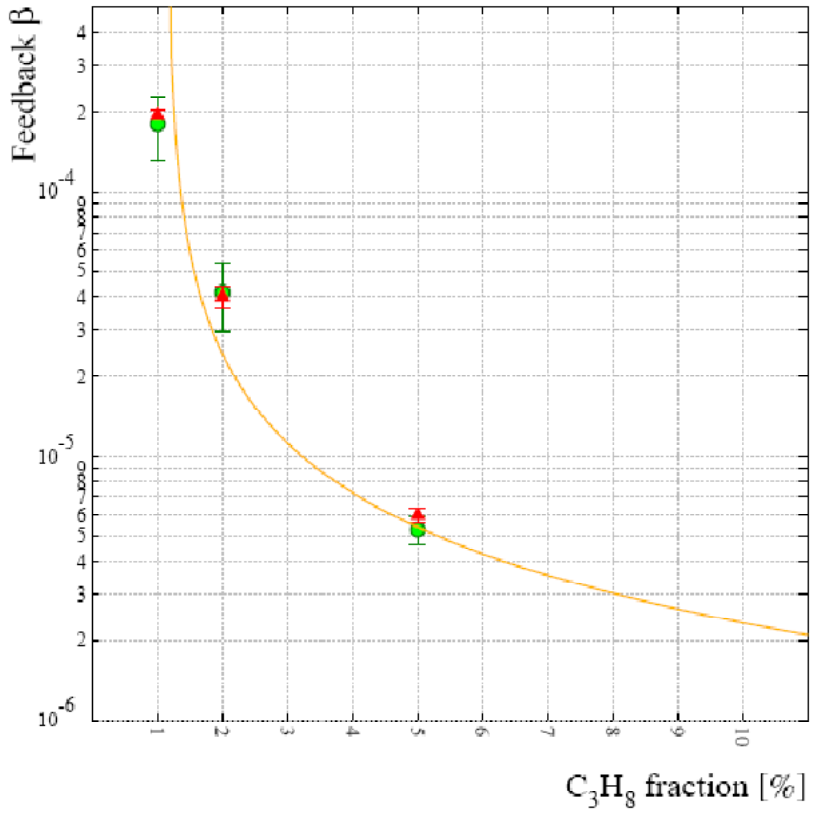
- uncertainty on the absolute gain:
  - work function,
  - calibration of the equipment
- in most datasets we allow gain calibration,
- error bars on r_i take this into account.

$$G := g\,G$$

Photon feedback

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

- secondary avalanches:
- at high gain,
- 1/β linear in admixture concentration,
- almost uncorrelated, free parameter.



- Example for C_3H_8.
- More effective photo absorbtion C_3H_8 than C_2H_2, ≈ 30% higher electric fields.

Model of the transfer probabilities

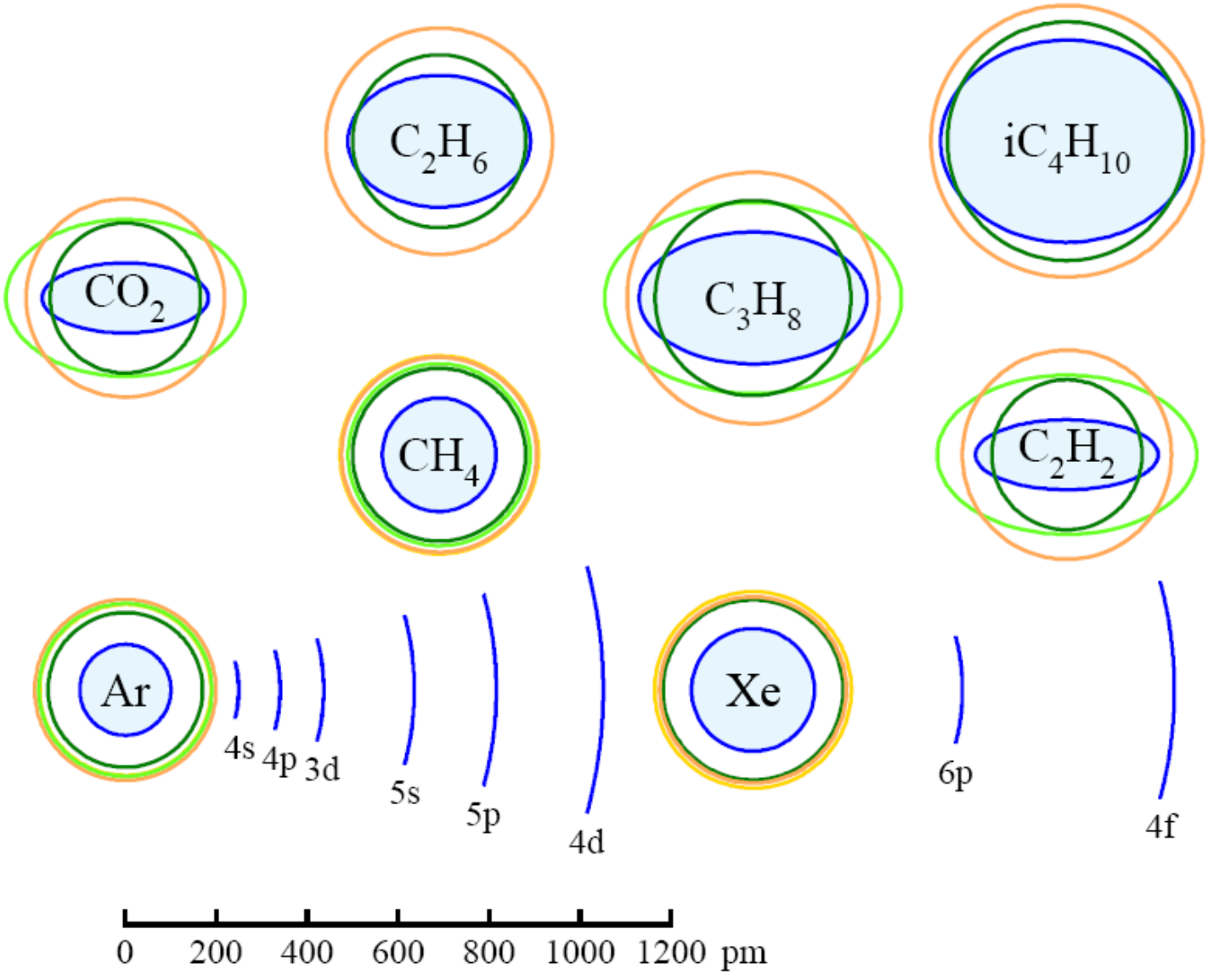
- A* is followed through a series of small time steps.
- The following can happen:
  - $A^* + B \rightarrow A + B^+ + e^-$: collisional ionisation,
  - $A^* + A \rightarrow A_2^+ + e^-$: homonuclear associative ionisation,
  - $A^* \rightarrow A + \gamma$: radiative decay
- Total transfer probability is given by:

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

A^*- B A^*- A A^*- γ

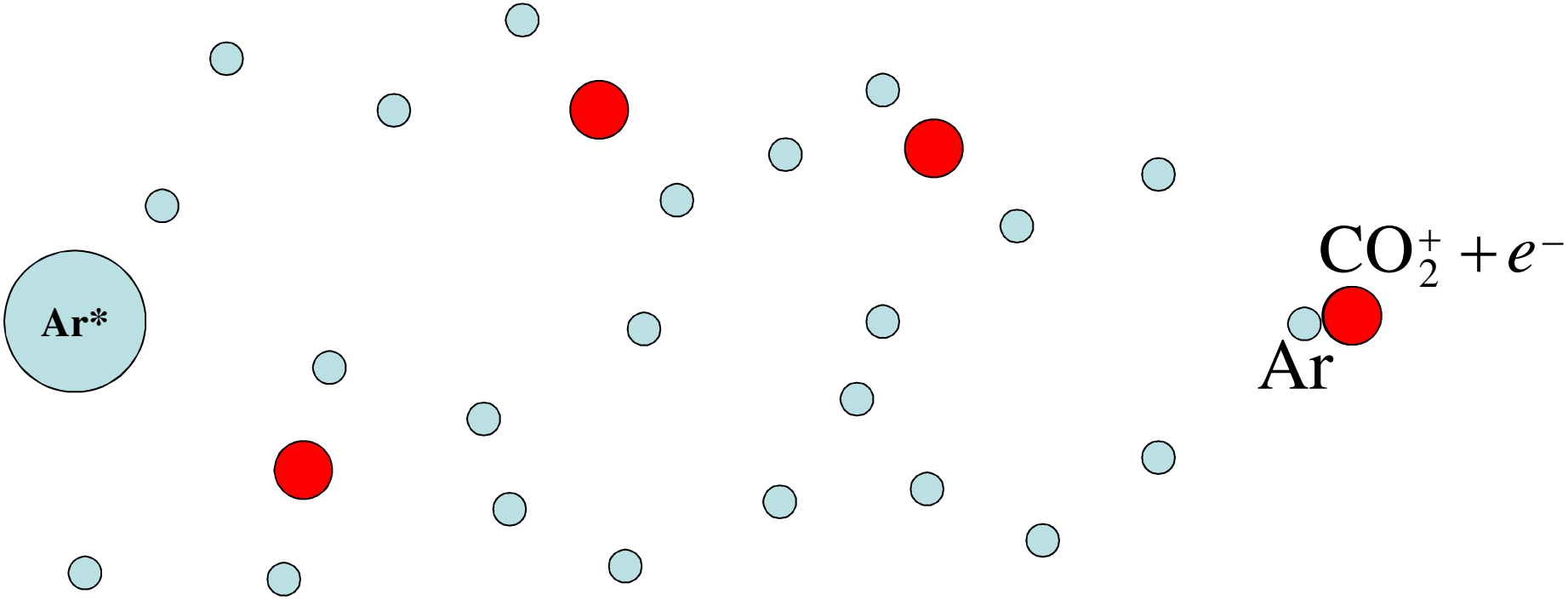
- Note the pressure and concentration dependence!

Diameters

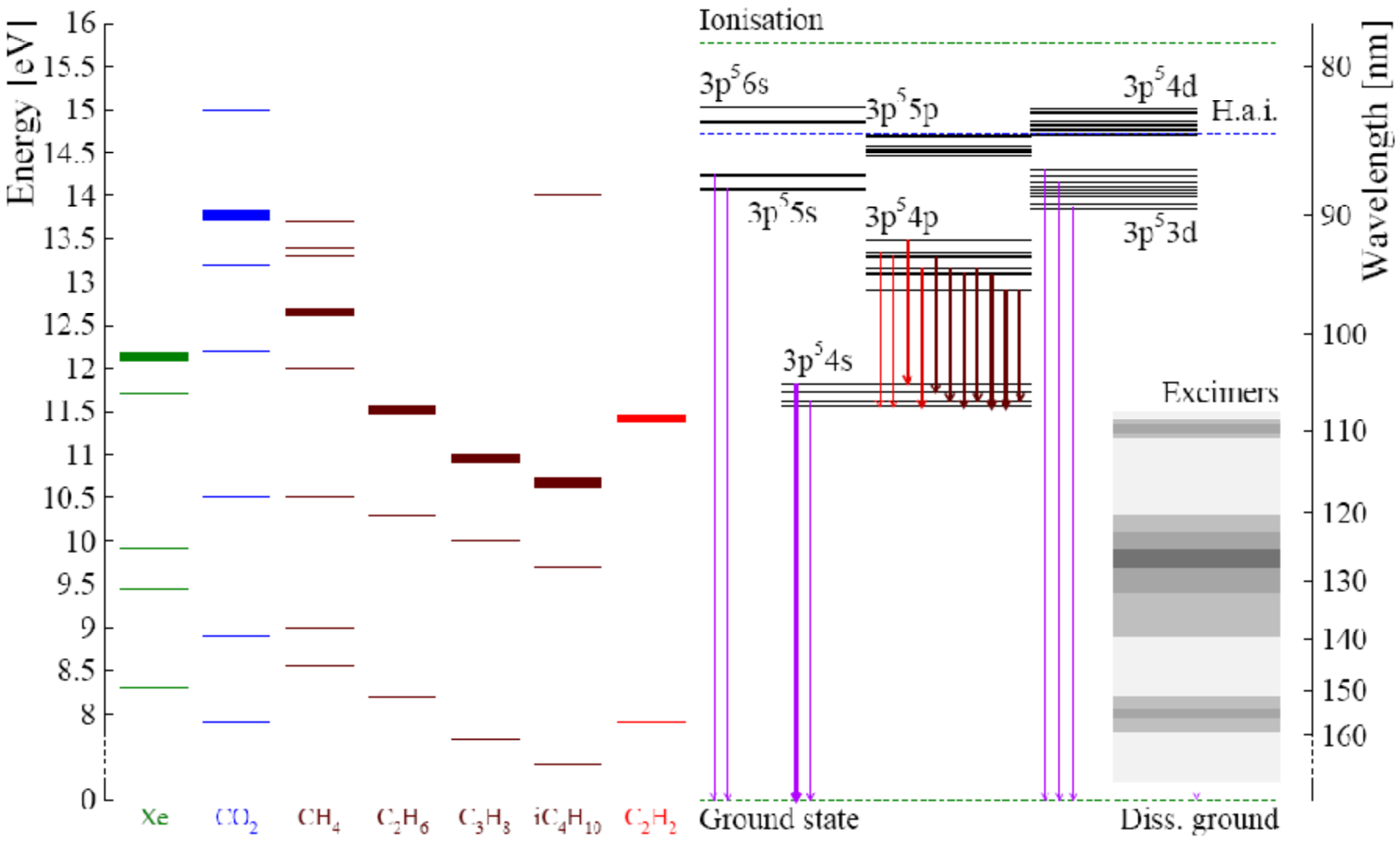

C_2H_6
iC_4H_{10}
CO_2
C_3H_8
CH_4
C_2H_2
Ar
Xe
4s
4p
3d
5s
5p
4d
6p
4f
0
200
400
600
800
1000
1200
pm

Collision times

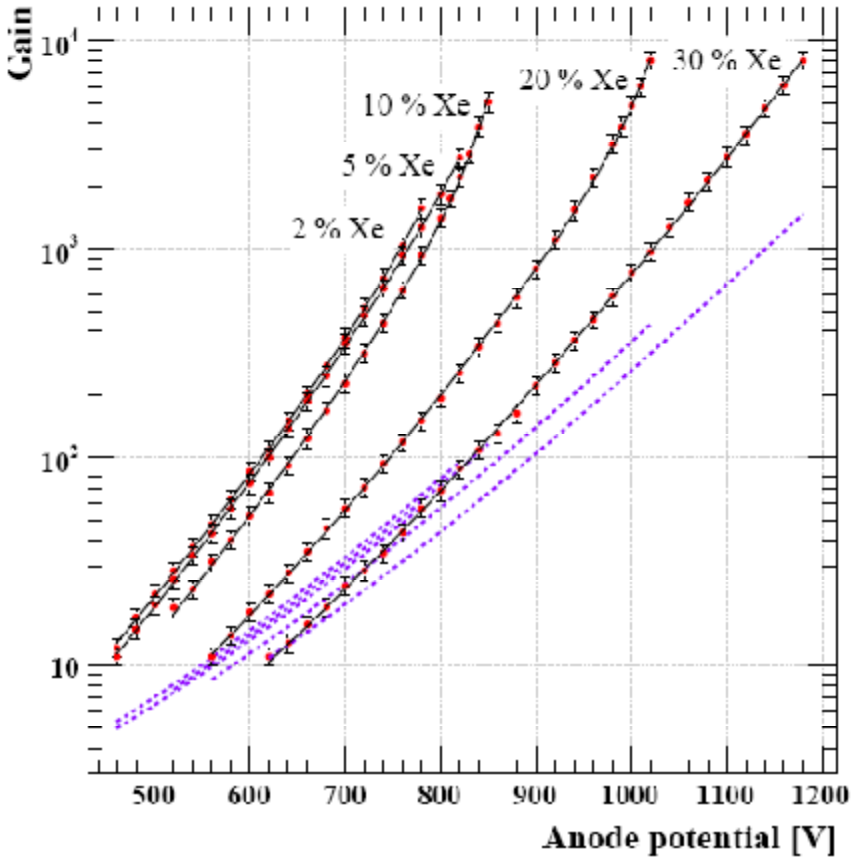
- Ar 90% - CO_2 10%
- Duration: 2 ns

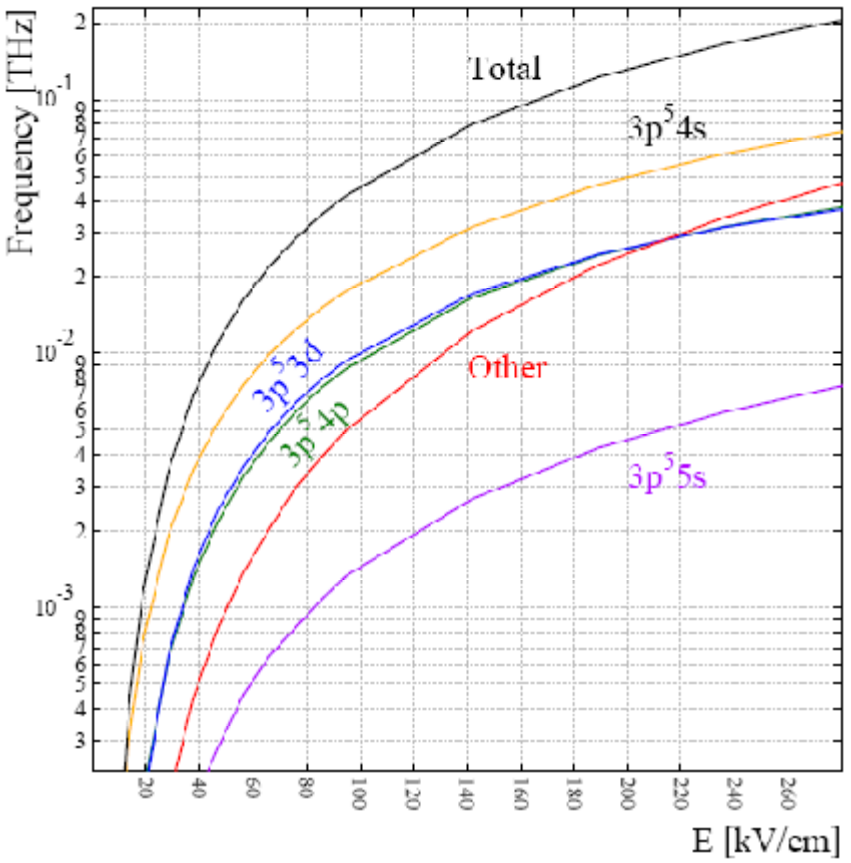


Argon spectroscopy



Argon-xenon mixtures



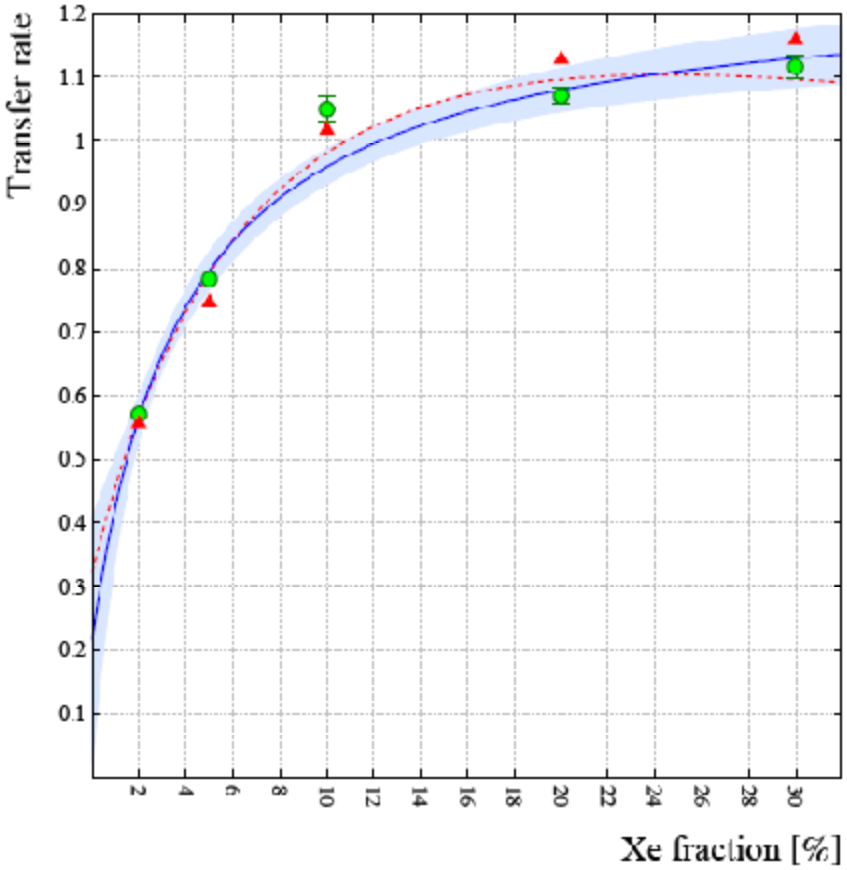


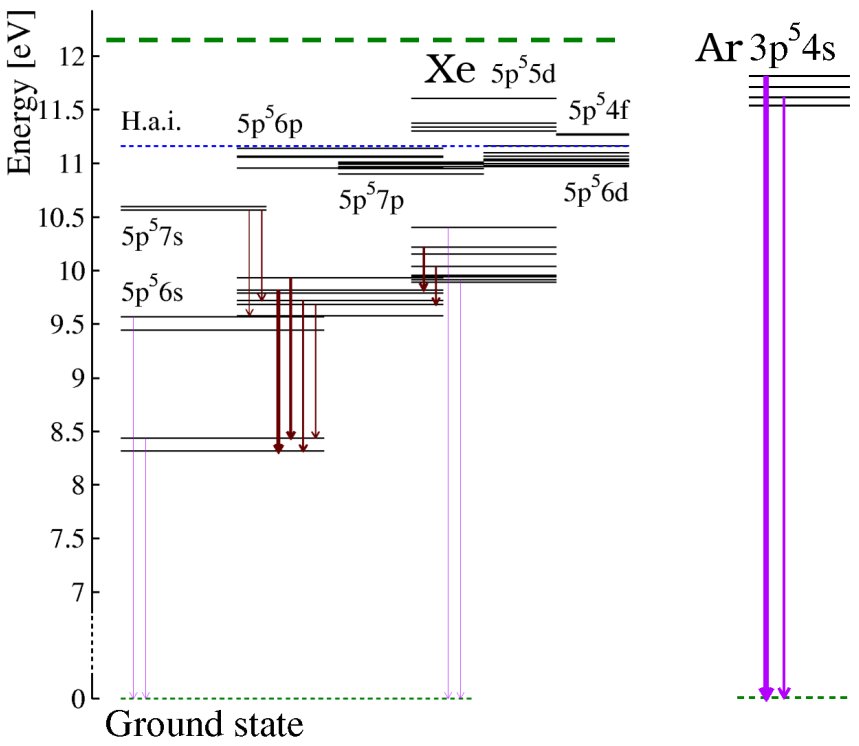
- 1×1 cm^2, 25 μm diameter wire, 1 atm
- Photon feedback,

- $\varepsilon_{4s} < IP_{Xe}$ (12.13 eV) $< \varepsilon_{4p}, \varepsilon_{3d}$ …

[P.C. Agrawal *et al.*NIM *A* **277** (1989) 557–564.]

Argon-xenon mixtures





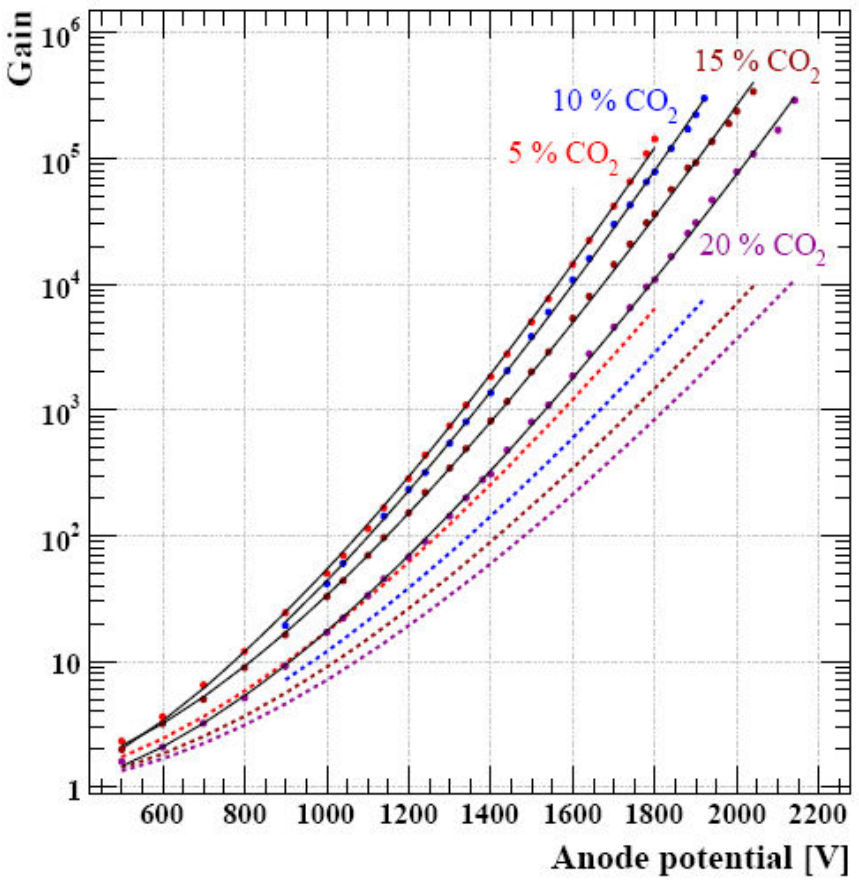
- collisional energy transfers ≈ 0.1
- no inelastic collisions,
- (Xe ionisation cross sections ?)

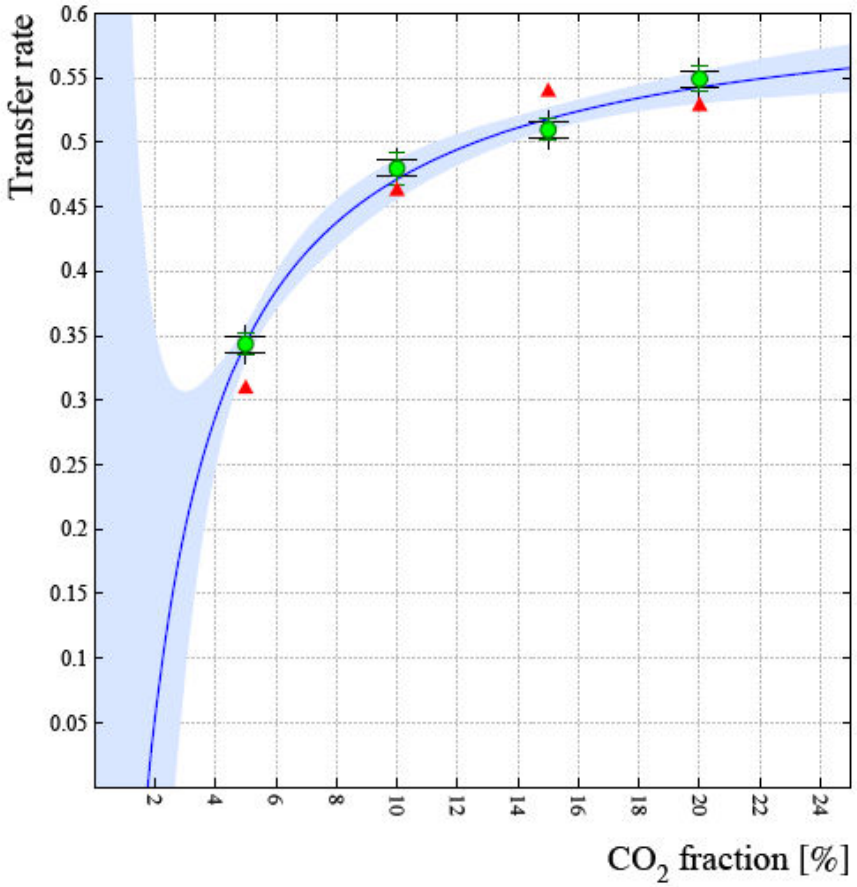
- homonuclear associative ionisations of **Xe**

$$Ar^* + Xe \rightarrow Ar + Xe^*$$

$$Xe^* + Xe \rightarrow Xe_2^+ + e^-$$

Argon-carbon dioxide mixtures

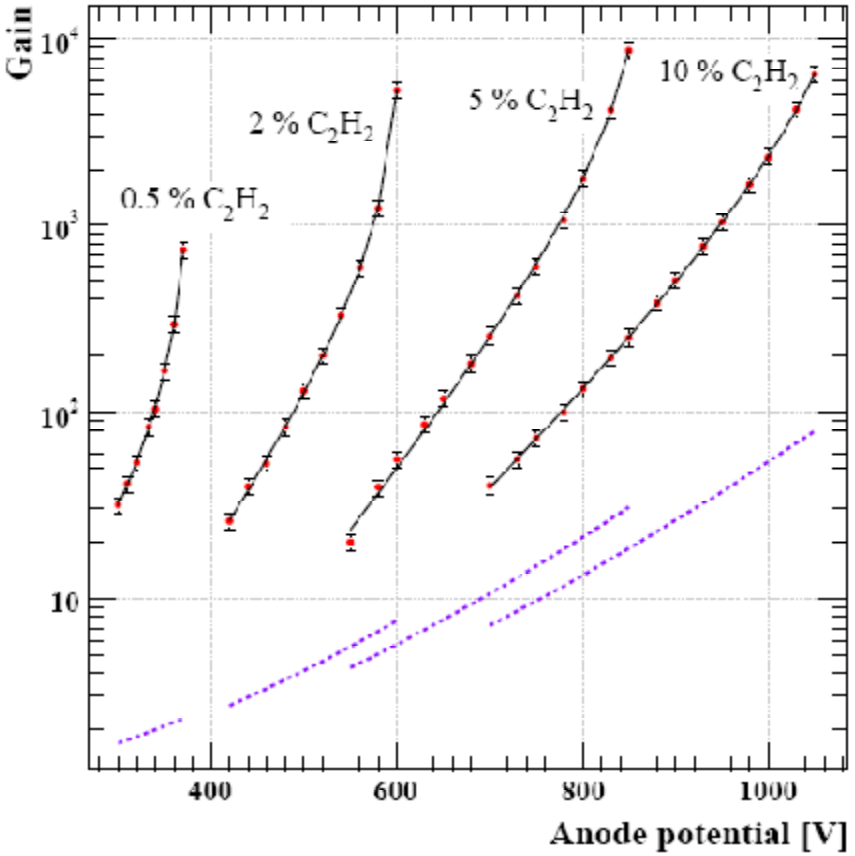


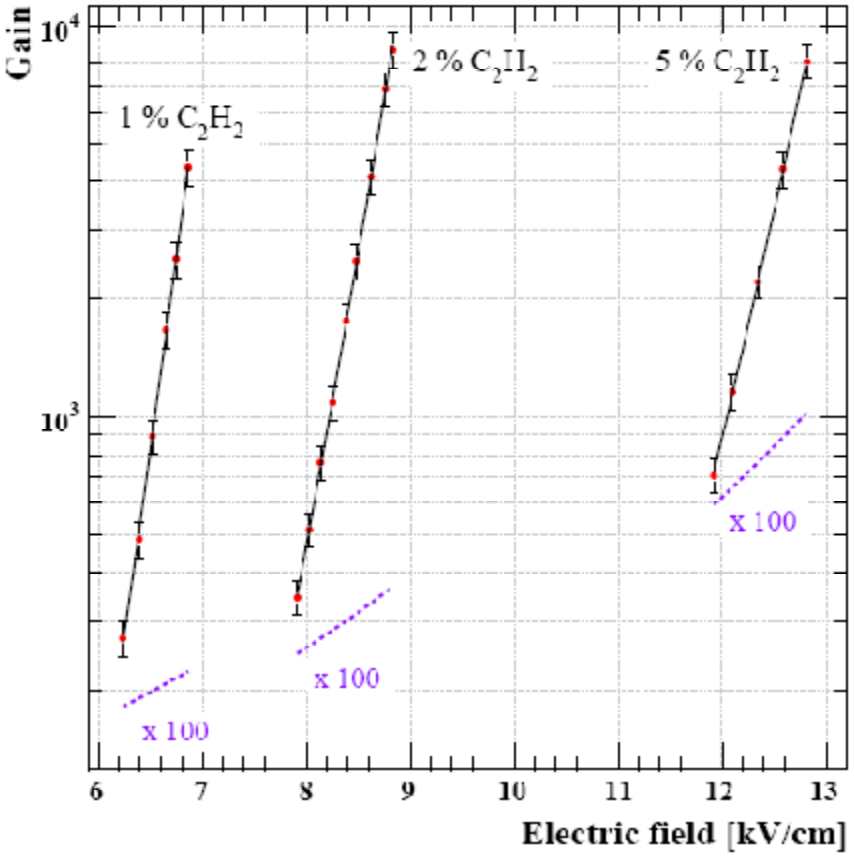


- 1×1.16 cm^2, 50µm anode diameter, p_{gas} = 1070 hPa
- no photon feedback,
- [T.Z. Kowalski *et al.*NIM *A* **323** (1992) 289–293.]

- $\varepsilon_{4s}, \varepsilon_{4p} < IP_{CO2}$ (13.77 eV) $< \varepsilon_{3d}$ …
- loss of Ar* via inelastic collisions,
- collisional ion. + loss prob. < 0.04

Argon-acetylene mixtures



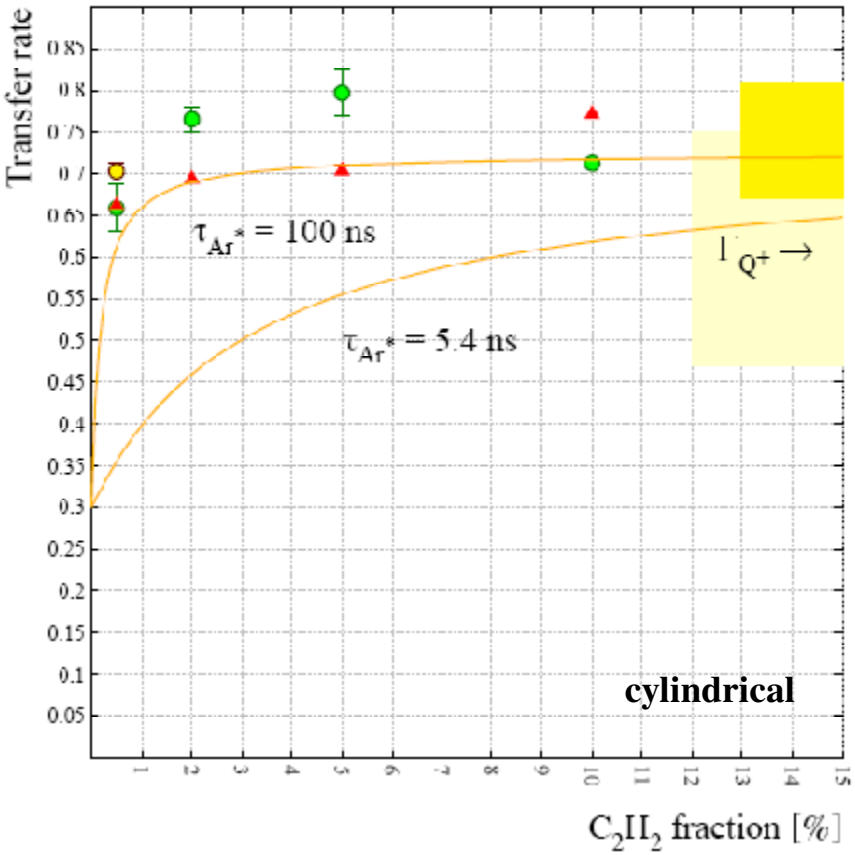


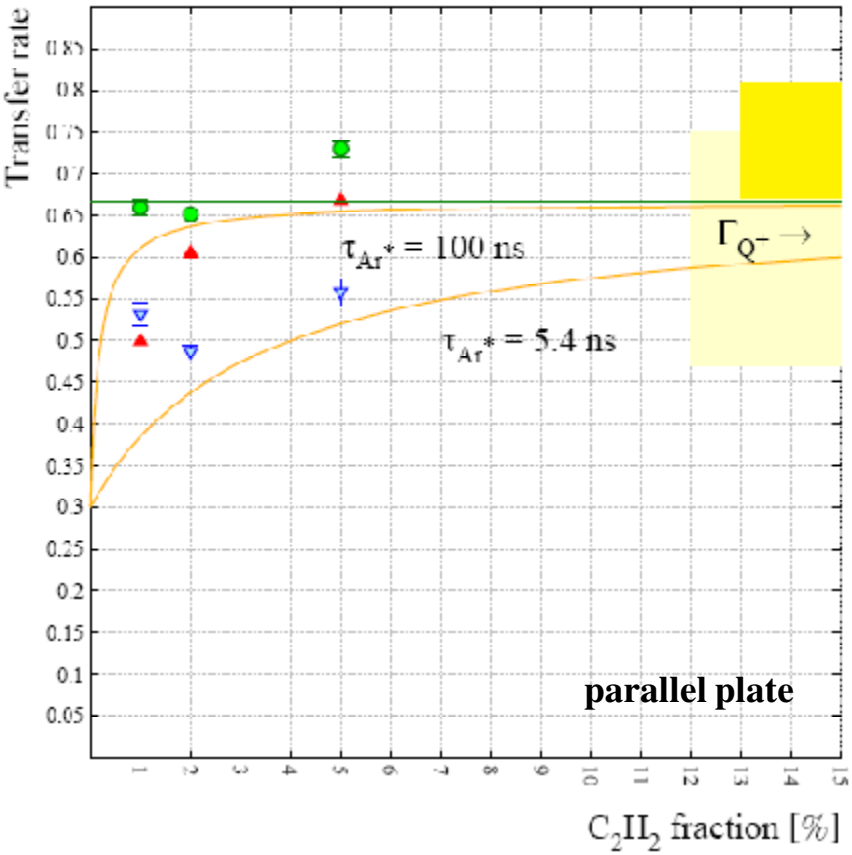
- ❖ cylindrical geometry,
- ❖ massive photon feedback,

- ❖ 1.07 mm gas gap,
- ❖ no photon feedback,
- ❖ huge Penning effect ,

[P.C. Agrawal *et al.*NIM *A* **277** (1989) 557–564.]

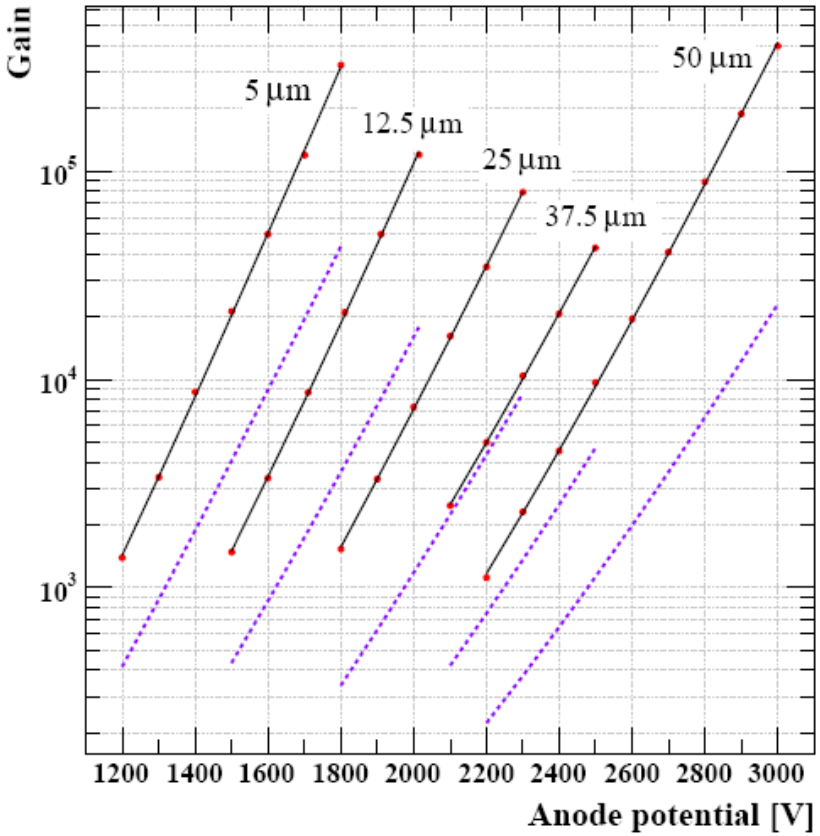
Argon-acetylene mixtures

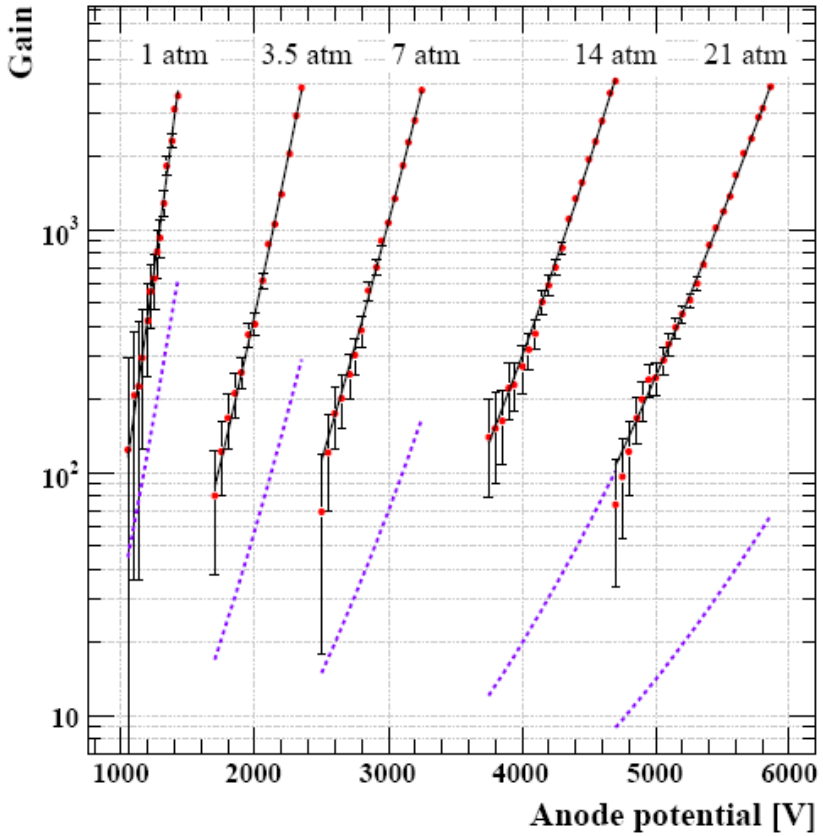




- IP_{C2H2} (11.42 eV) < ε_{4s}, ε_{4p} ε_{3d} …
- Almost **flat** transfer probabilities: $3p^5 4s$ radiation trapping.
- Average transfer rate; 0.72 (cylindrical chamber), 0.67 (parallel plate), cf. $\Gamma_{Q^+} = 0.61, 0.74$ [Michael T. Jones *et al.*, *J. Phys. Chem.* **89** (1985) 4501– 4517.]

Argon-methane mixtures

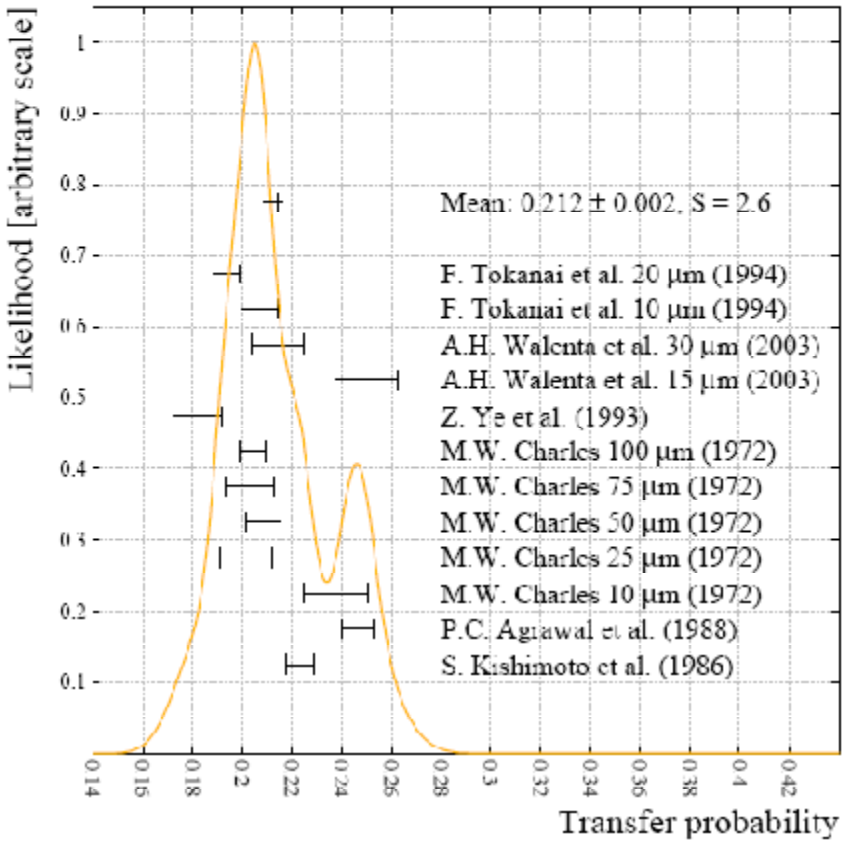


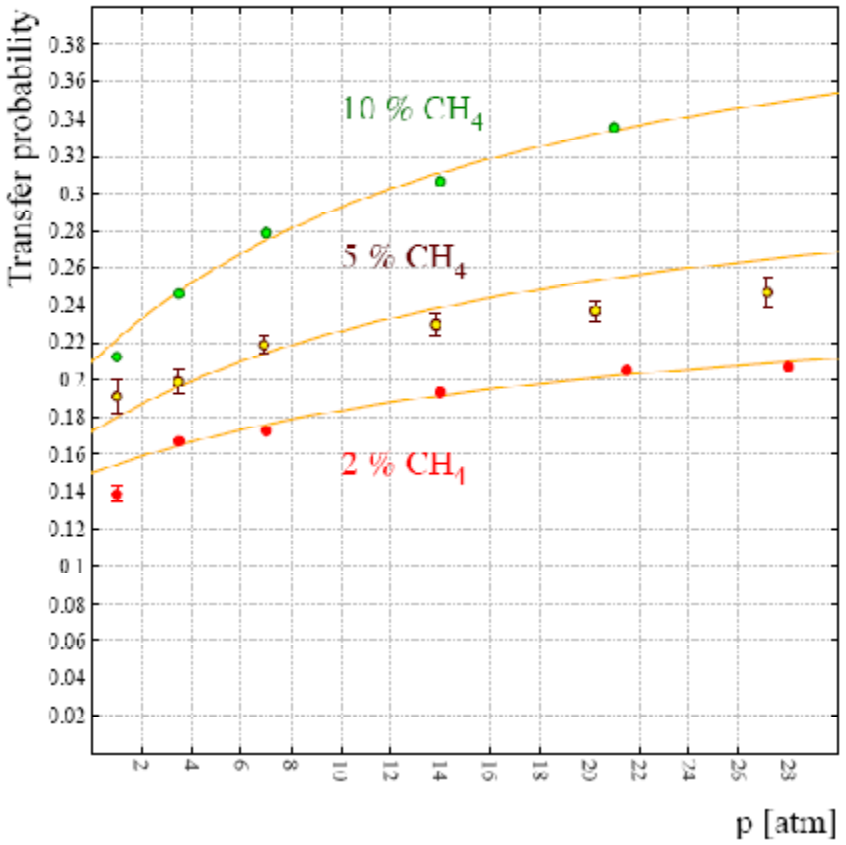


- Ar 90 % - CH_4 10 %,
- r_{anode}=5-50 µm, r_{tube}=2.845 cm, 1 atm,
- no photon feedback,
- [M.W. Charles, *J. Phys. E: Sci. Instr.* **5** (1972) 95–100.]

- Ar 90 % - CH_4 10 %,
- r_{anode}=12.5 µm, r_{tube}=1.5 cm, 1-21 atm,
- no photon feedback (except at 1 atm),
- [Z. Ye *et al.*, NIM *A* ***329*** (1993) 140–150.]

Argon-methane mixtures

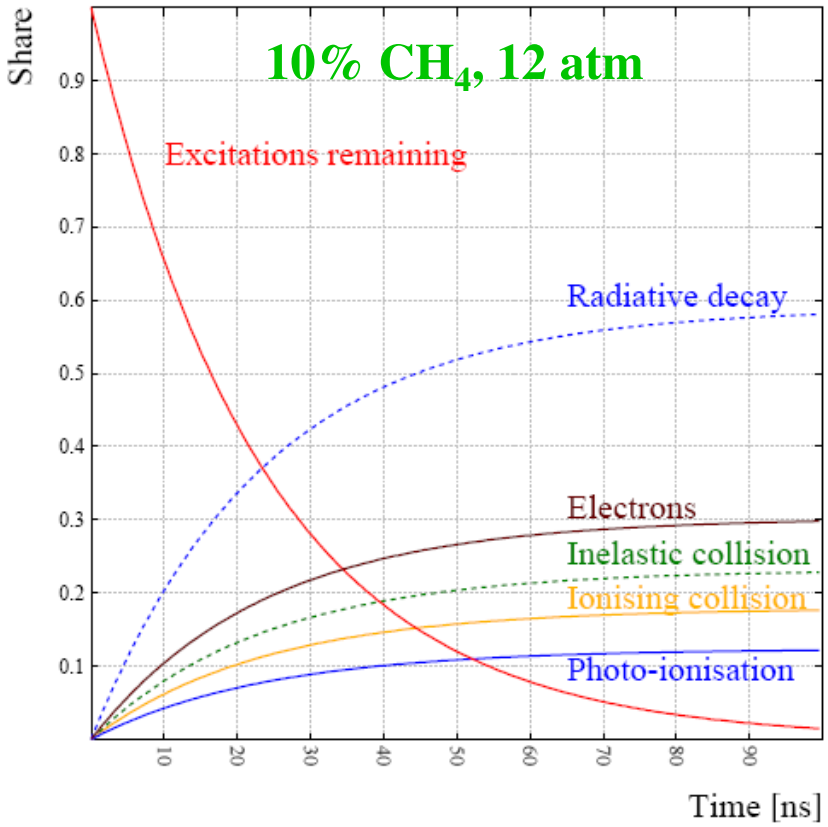


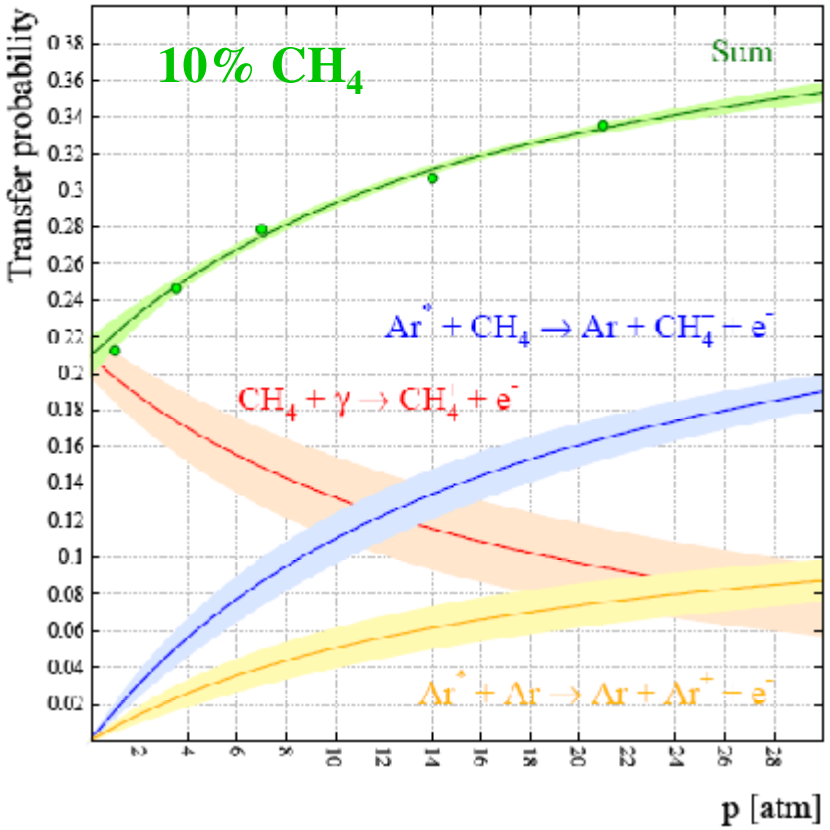


- $\varepsilon_{4s} < IP_{CH4}$ (12.65 eV) $< \varepsilon_{4p}\ \varepsilon_{3d}$ …
- more than 30 experimental data,

- combined fit of 2 %, 5 % and 10 %;
  - homonuclear associative ionisations,
  - f_{rad} assumed linear in CH_4 fraction.

Argon-methane mixtures



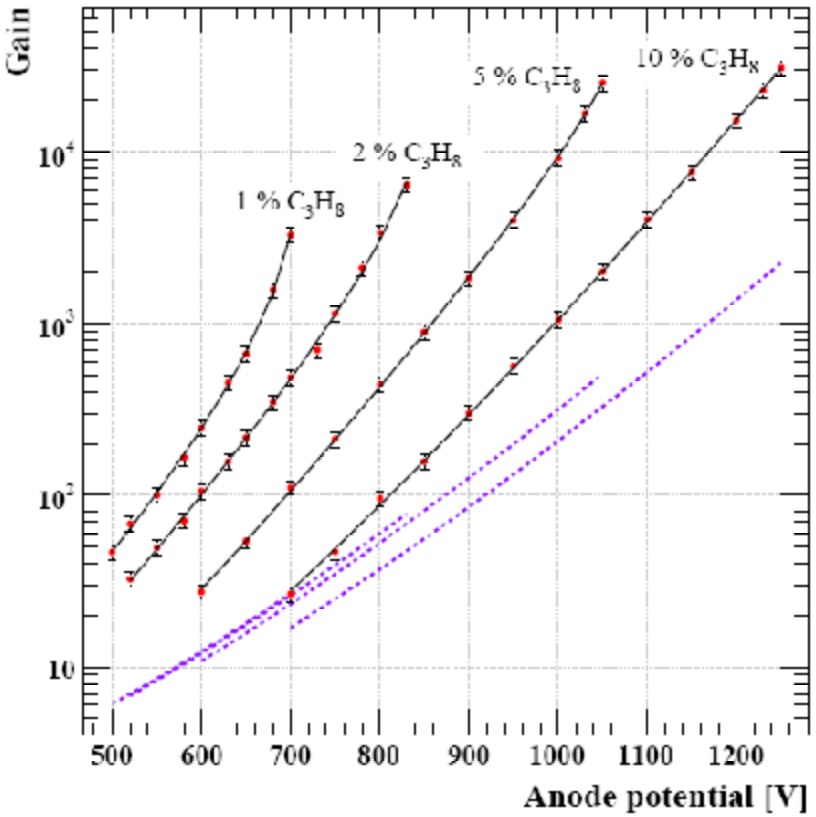


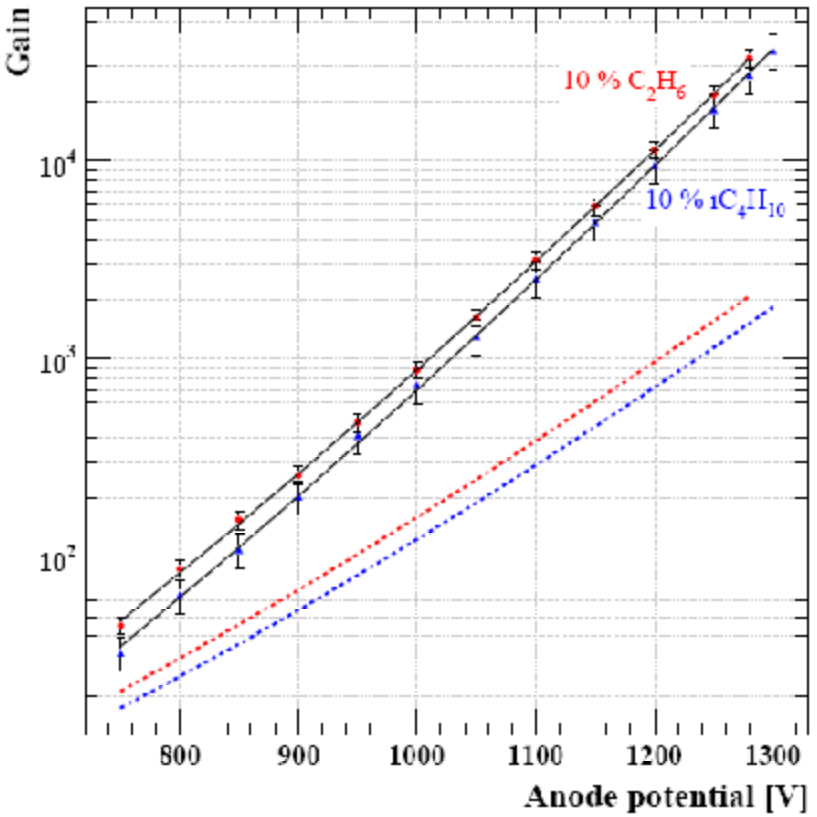
- Time evolution of the Penning transfer processes.
- Calculated from fit parameters, collision times and decay times.

- Contributions to the transfer rates:
  - Collisional ionisation Ar*-CH_4,
  - Radiative ionisation
  - Hint of Ar*-Ar ≈ 1 % upper limit at 1 atm: 1.5-2 %

[E. Eggarter, J. Chem. Phys. 62 (1975) 833–847, S.F. Biagi, Private communication.]

Argon-ethane, propane, isobutane mixtures

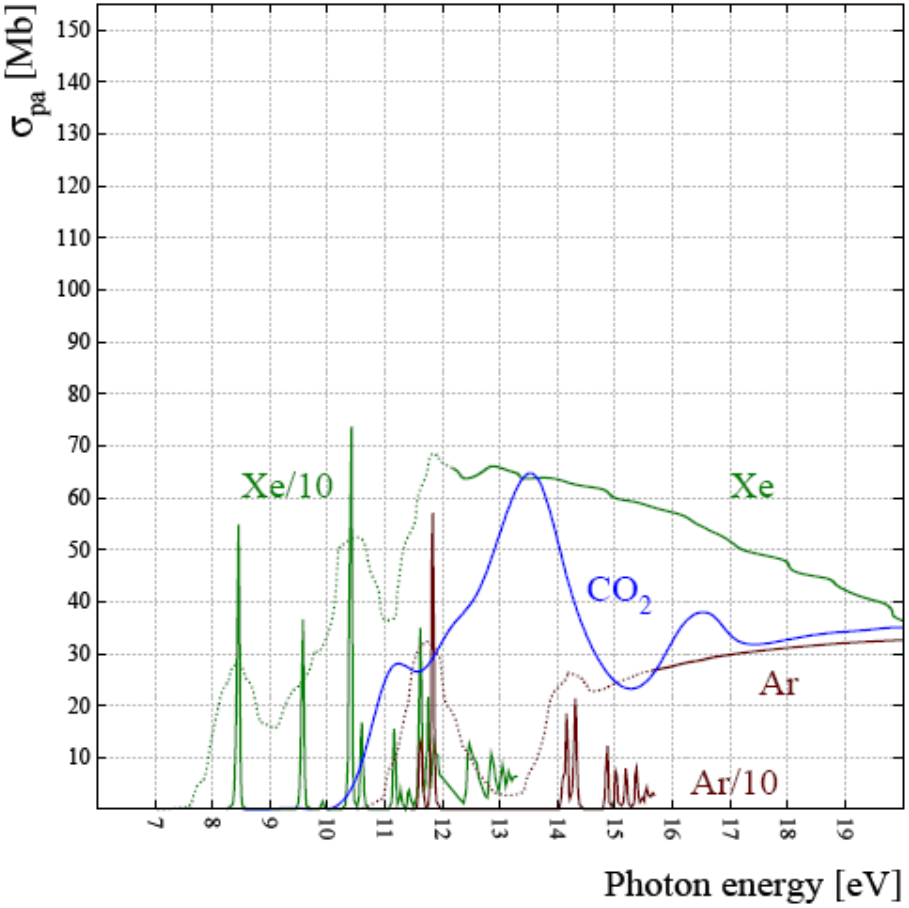


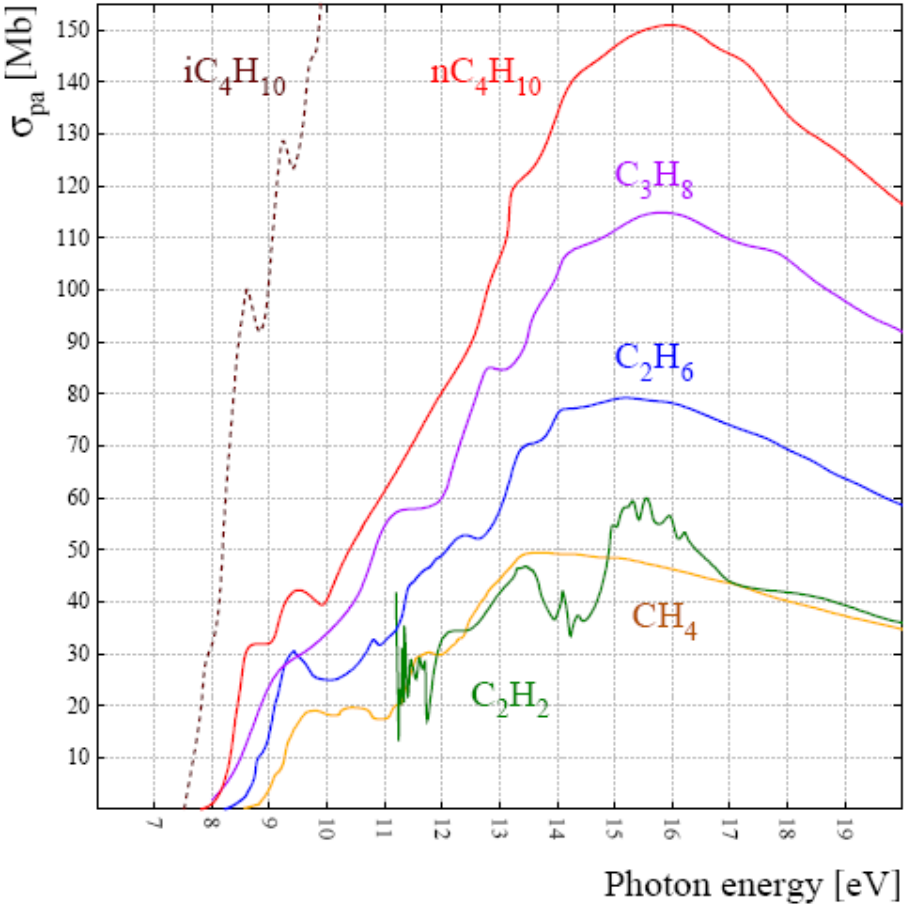


- $IP_{C2H6,\ C3H8,\ iC4H10}$ (11.56 eV, 10.95 eV, 10.67 eV) < ε_{4s} ,ε_{4p}, ε_{3d} …
- Photon feedback for lower concentrations of C_3H_8,

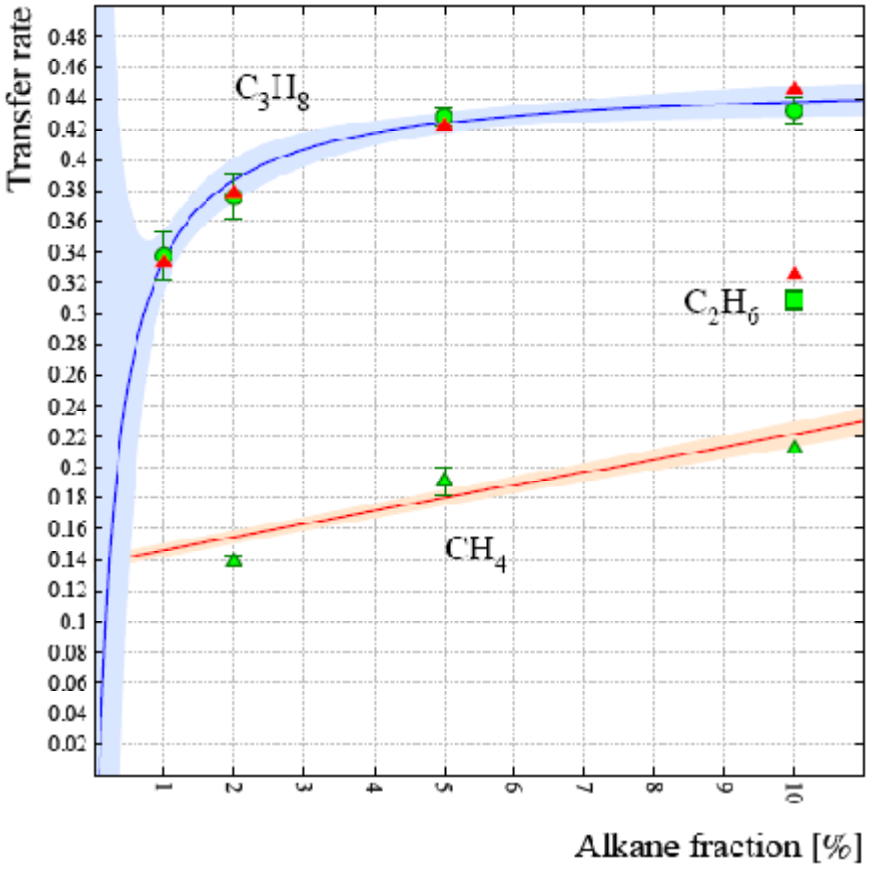
- [P.C. Agrawal *et al.*NIM *A* **277** (1989) 557–564.], [P.C. Agrawal and B.D. Ramsey NIM *A* **273** (1988) 331–337.]

UV absorption





Argon-ethane, propane, isobutane mixtures



- While moleculer weight increases:
  - transfer probability increases,
  - UV absorbtion cross section increases,
  - ionisation yield treshold lowers.

Conclusion

- Energy transfer mechanisms: microscopic model.
- Distinguish the mechanisms: pressure and concentration dependence.