Feedback mechanisms

Özkan ŞAHİN
Uludağ University Physics Department
Bursa -TURKEY

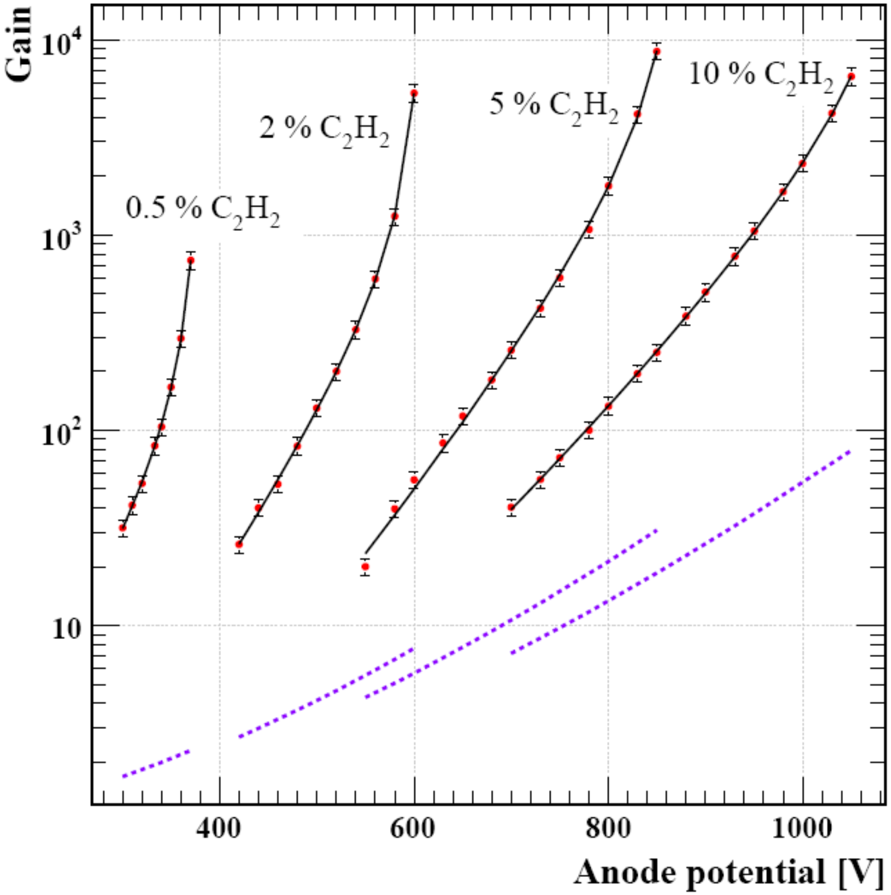
Photon feedback

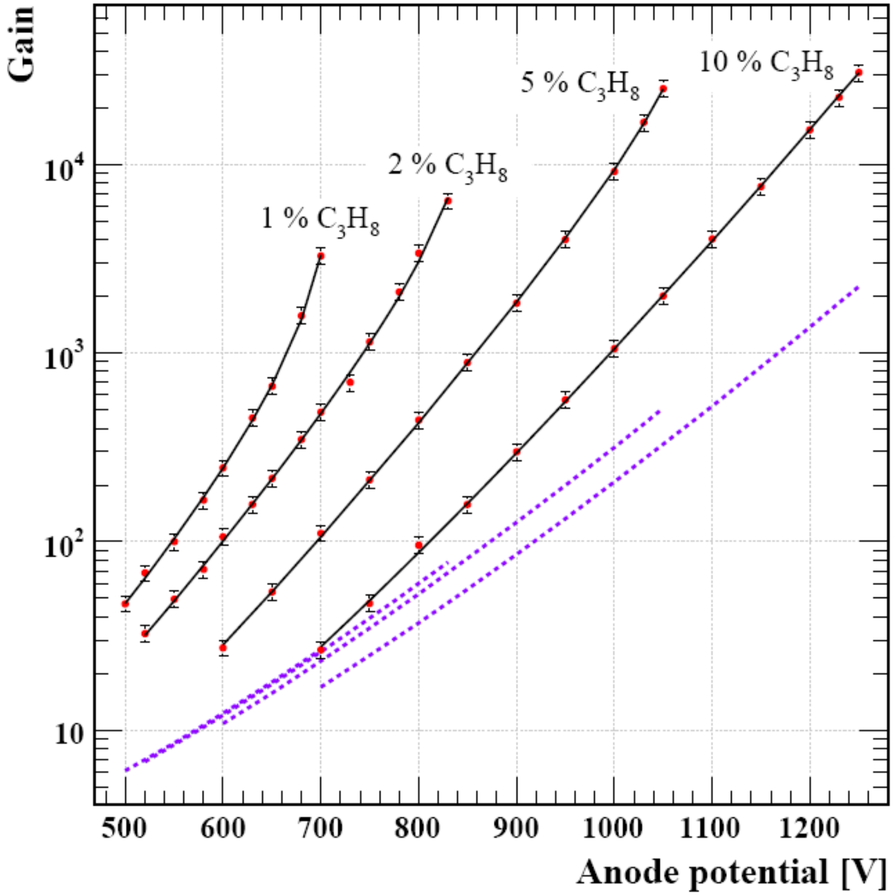
- Excited states (A^*) $\Rightarrow$ radiative decay ($A^* \rightarrow A + \gamma$),
- Photons $\Rightarrow$ photo-electrons (from cathode and in gas itself),
- Secondary, delayed avalanches $\Rightarrow$ over exponential increases at high gains:
  - $G \Rightarrow$ average avalanche size without feedback,
  - $\beta \Rightarrow$ the number of secondary avalanches started by one avalanche electron,
    - electrons: 1th step $\Rightarrow \beta G$, 2nd step $\Rightarrow \beta G^2$, 3th step $\Rightarrow \beta G^3$, …
    - Summing over each step:

$$G + \beta G^2 + \beta^2 G^3 + \ldots = G / (1 - \beta G)$$

Examples

Ar + quencher



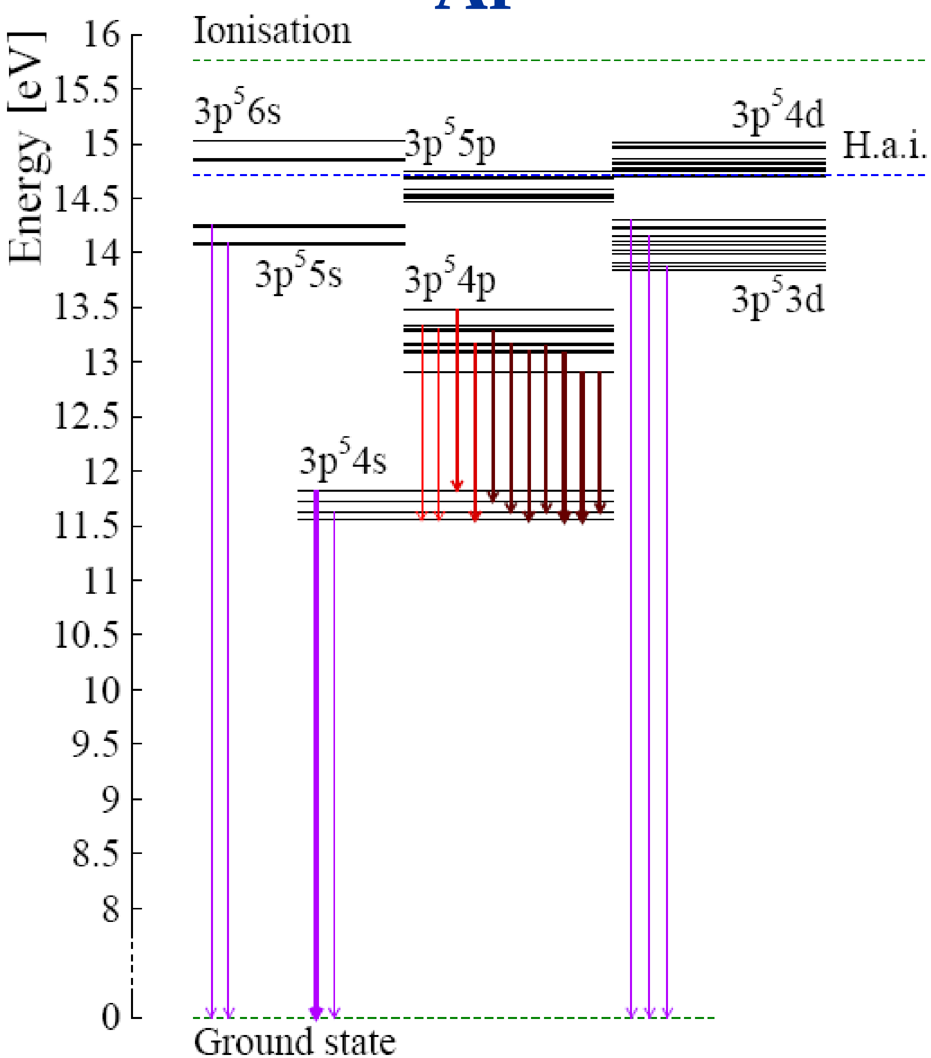


Exp. data: P.C. Agrawal et al., *Study of argon-based Penning gas mixtures for use in proportional counters, Nucl. Instrum. Meth.* **A 277** (1989) 557.

Plots: Ö. Şahin, İ. Tapan, E. N. Özmutlu and R. Veenhof, *Penning transfer in argon-based gas mixtures*, 2010 *JINST* **5** P05002.

Energy of photons

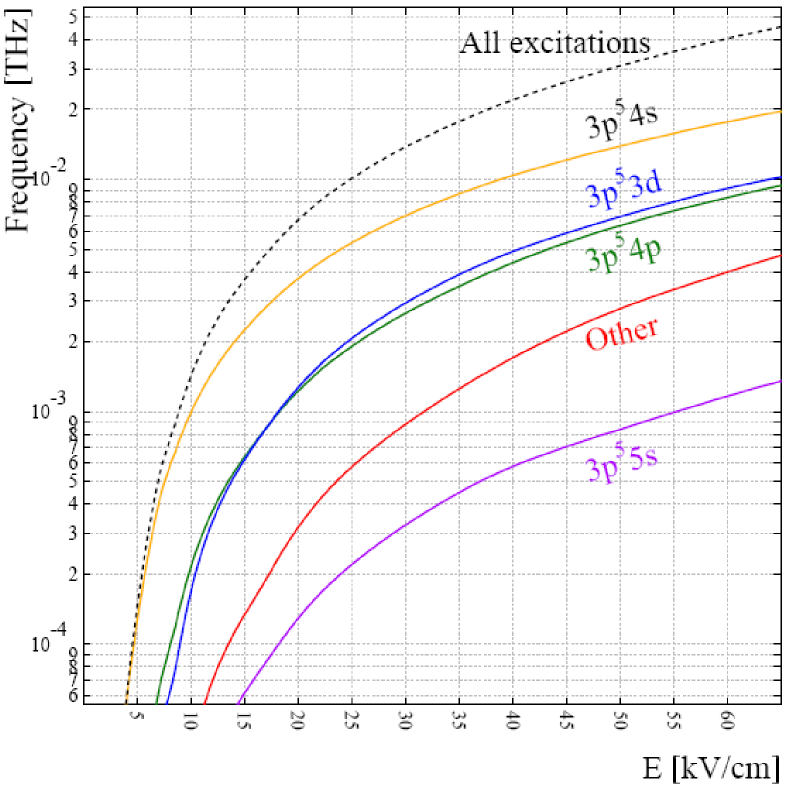
Ar

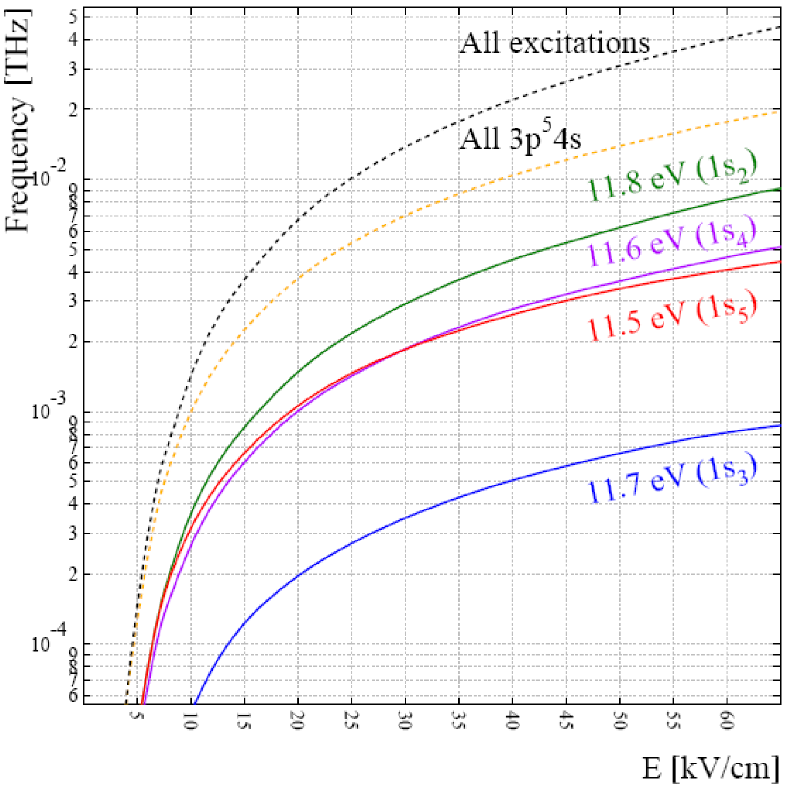


- **3*p*^{5}4*s***
  - Ar*($^3P_0$), Ar*($^3P_2$)
    11.55 eV, 11.72 eV ⇒ Metastables
    τ ⇒ lifetime of seconds
  - **Ar*($^3P_1$), Ar*($^3P_3$)**
    11.62 eV, 11.83 eV ⇒ UV photons
    τ ≈ 8.6 0.4 ns, τ ≈ 21 2 ns
- **3*p*^{5}4*p***
  - predominantly decays ⇒ 3*p*^{5}4*s*
    red or infrared light (≈ 2 eV)
    τ ⇒ 21.7 – 40.5 ns
- **3*p*^{5}3*d***
  - threshold energy of 13.85 eV
    τ ≈ 50 ns
- **higher levels**
  - less frequently excited in avalanches
    τ ⇒ 100 – 300 ns

Production rates of excited states

Ar 99 % - C_2H_2 1% mixture, at 1 atm





- ❖ Dominant excitations ⇒ ***3p⁵4s***
- ❖ ***3p⁵4s*** ⇒ the least produced levels are metastables

A simple model of β

$$\beta = n_\gamma \exp(-d/\lambda)$$

- n_γ : number of photons emitted per avalanche electron,
  - Penning transfer probabilities,
  - Rates of excited states (Magboltz)
- d : avalanche sizes,
  - Townsend coeefficients (Magboltz)
- λ : mean free path of photons
  - Absorption cross sections (literature)

Number of photons (n_γ)

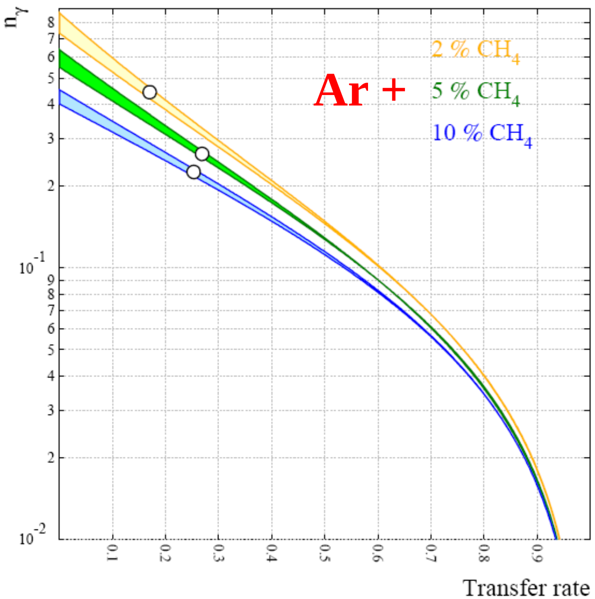
$$n_\gamma = \frac{total\ number\ of\ \ photons}{total\ number\ of\ \ electrons}$$

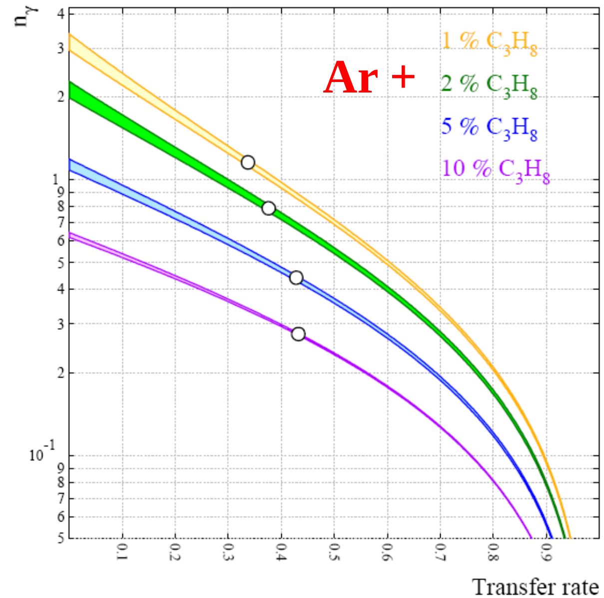
$$n_\gamma = \frac{\exp \int_{\text{tube}}^{\text{anode}} \mathrm{d}r\, \alpha(E(r)) \frac{\sum \nu_i^{\text{ion}}(E(r)) + \sum k_i\ \nu_i^{\text{exc}_{\text{all}}}(E(r))}{\sum \nu_i^{\text{ion}}(E(r))} \left(r\ \ \alpha(E(r)) \frac{\sum (1-k_i)\ \nu_i^{\text{exc}_{\text{rad}}}(E(r))}{\sum \nu_i^{\text{ion}}(E(r))} \right)}{\exp \int_{\text{tube}}^{\text{anode}} \mathrm{d}r\, \alpha(E(r)) \frac{\sum \nu_i^{\text{ion}}(E(r)) + \sum k_i\ \nu_i^{\text{exc}_{\text{all}}}(E(r))}{\sum \nu_i^{\text{ion}}(E(r))}}$$

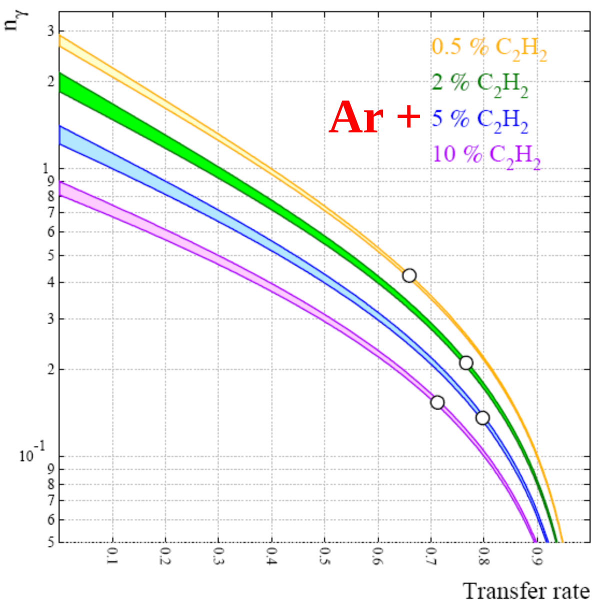
- α, ν_i : gas properties (pressure, temperature …)
- k_i transfer probabilities:
  - $A^* + B \rightarrow A + B^+ + e^-$: collisional ionisation,
  - $A^* + A \rightarrow A_2^+ + e^-$: homonuclear associative ionisation,
  - …

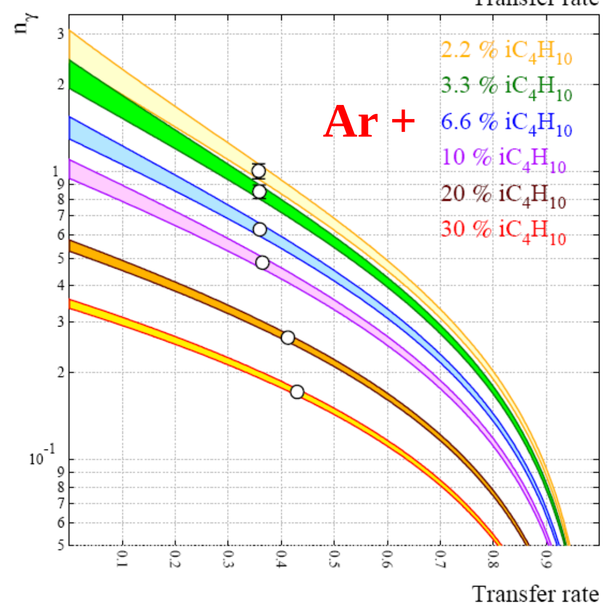
For detail: Ö. Şahin, İ. Tapan, E. N. Özmutlu and R. Veenhof, *Penning transfer in argon-based gas mixtures*, 2010 *JINST* **5** P05002.

Number of photons (n_γ)

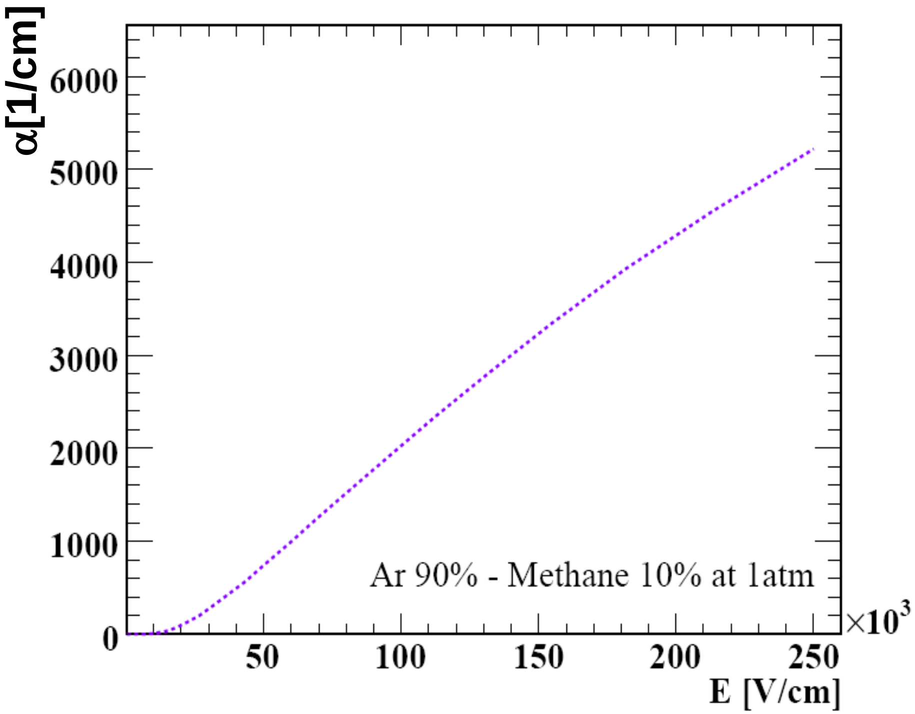








Avalanche sizes (*d*)



Example

r_{wire}=0.00125 cm r_{tube}=0.539 cm

Ar 98% - CH4 2%

===================

Alpha = 20/cm E = 10.5 kV/cm

V_{max} = 1300 V d_{min} = 100 μm (min. avalanche size)

V_{min} = 750 V d_{max} = 200 μm (max. avalanche size)

Ar 95% - CH4 5%

===================

Alpha = 20/cm E = 11 kV/cm

V_{max} = 1400 V d_{min} =120 μm (min. avalanche size)

V_{min} = 800 V d_{max} = 210 μm (max. avalanche size)

Ar 90% - CH4 10%

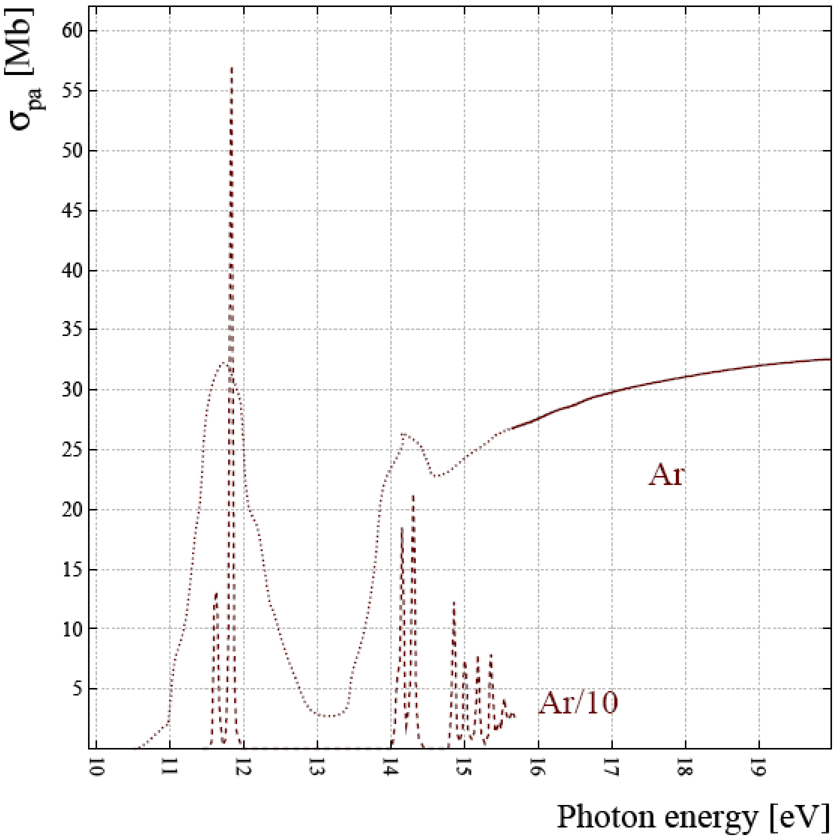
===================

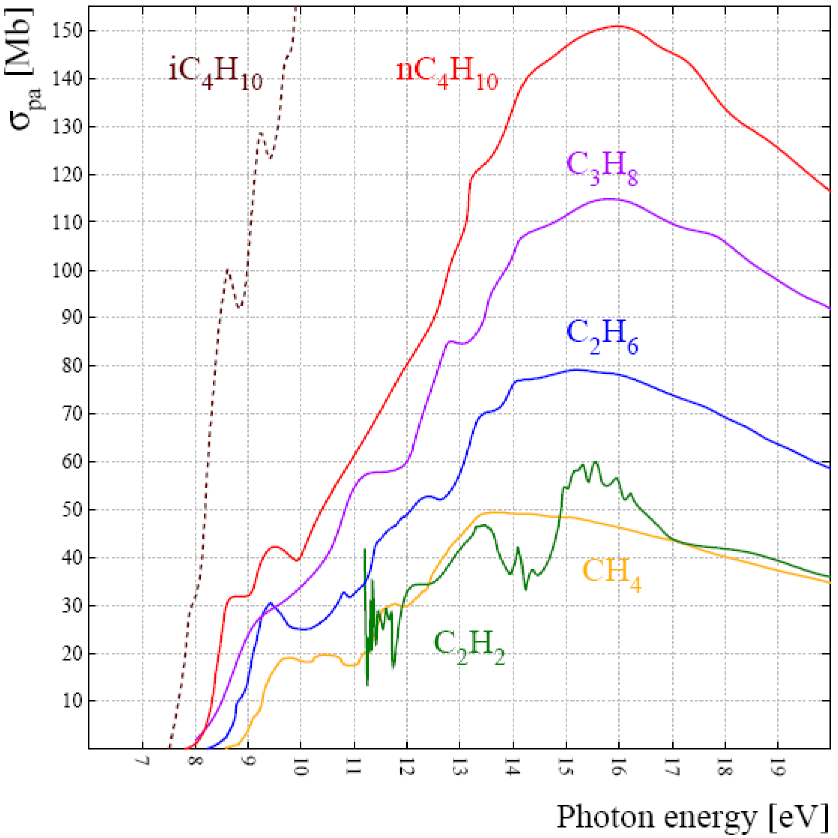
Alpha = 20/cm E = 12 kV/cm

V_{max} = 1475 V d_{min} = 110 μm (min. avalanche size)

V_{min} = 800 V d_{max} = 200 μm (max. avalanche size)

Photo-absorption cross sections (σ_{pa})

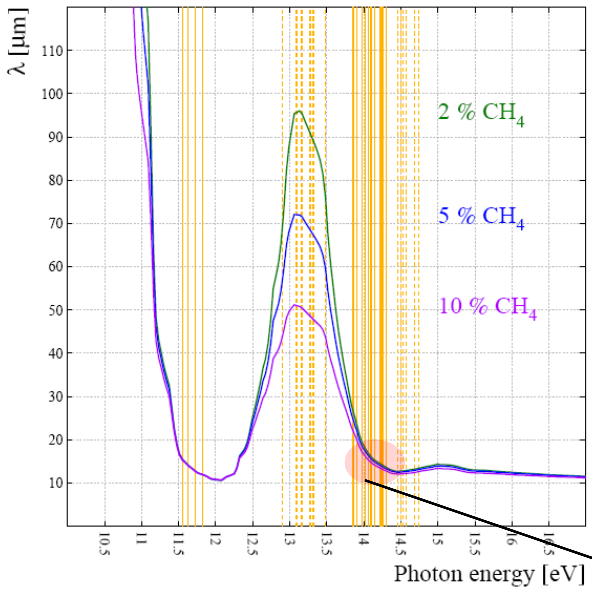




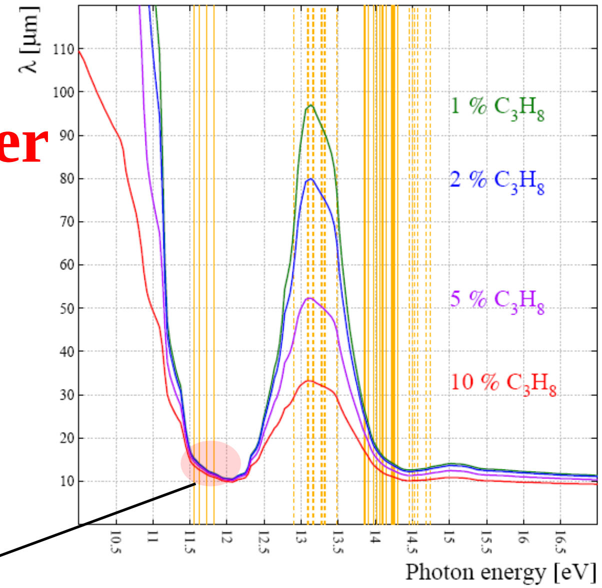
❖ Large σ_{pa} for Ar below the ionisation,

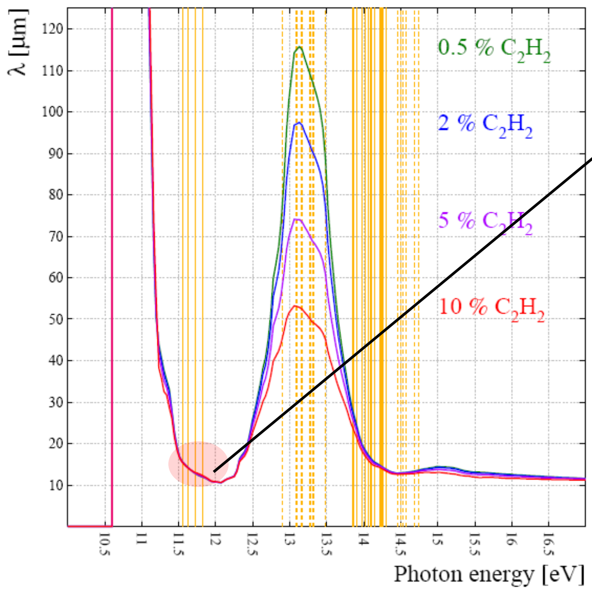
❖ Increase on σ_{pa} for bigger molecules,

Mean free path of photons (λ)



Ar + quencher

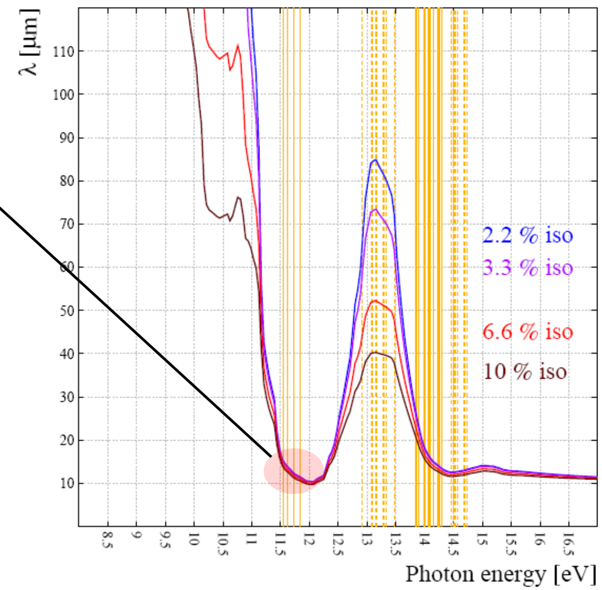




$\lambda \approx 12\ \mu m$

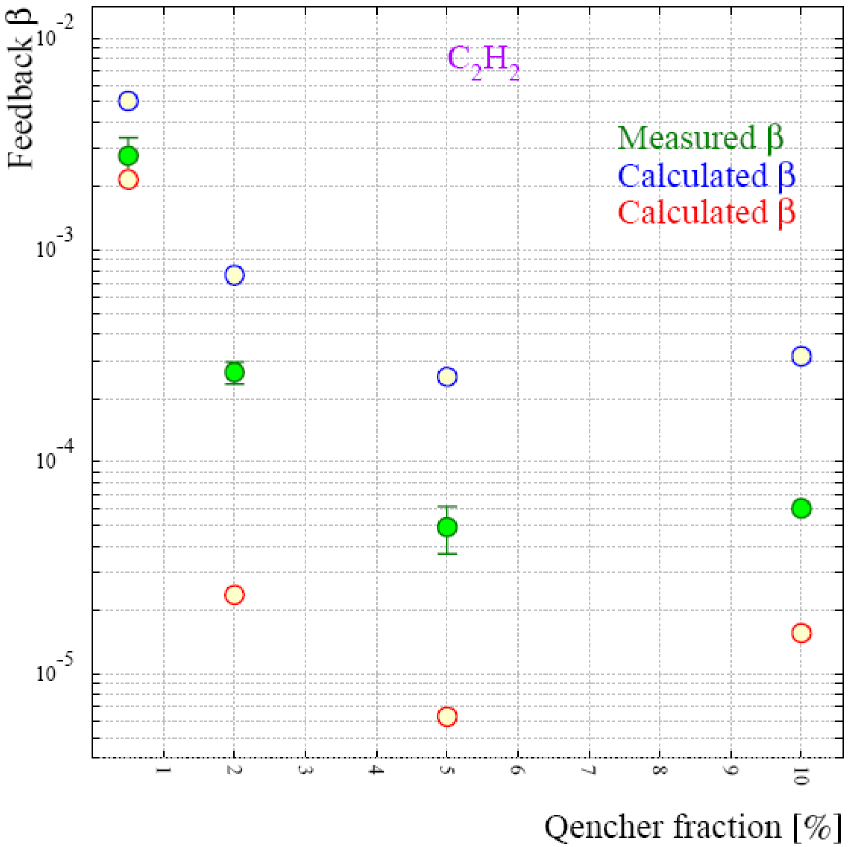
$\exp(-d/\lambda)$

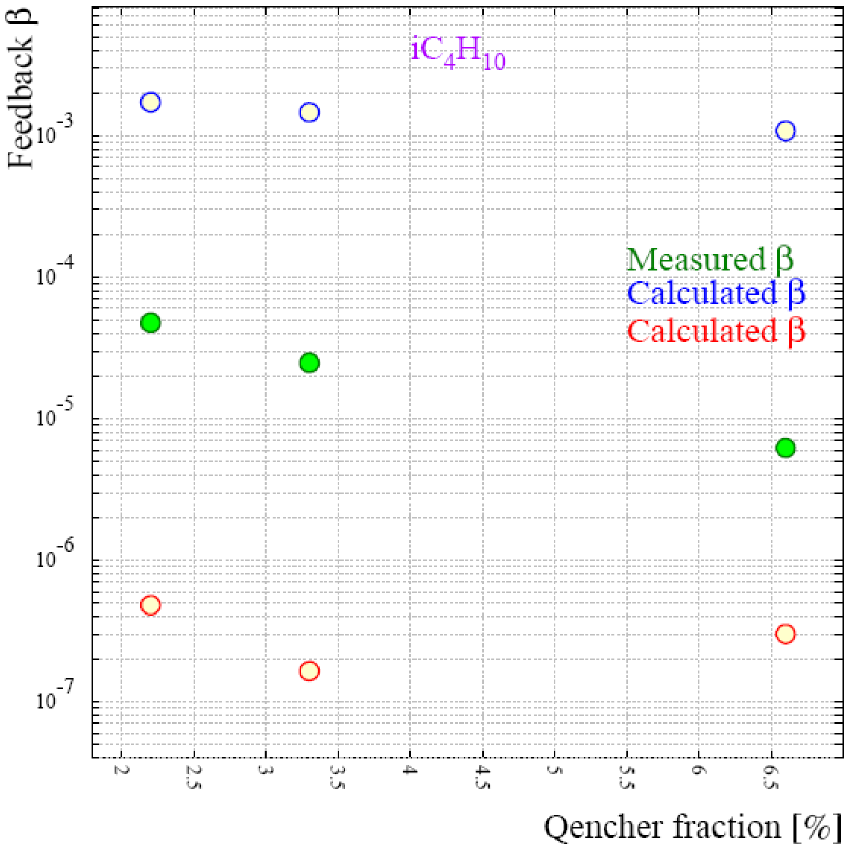
Photons will be outside the avalanche



Estimated feedback probabilities

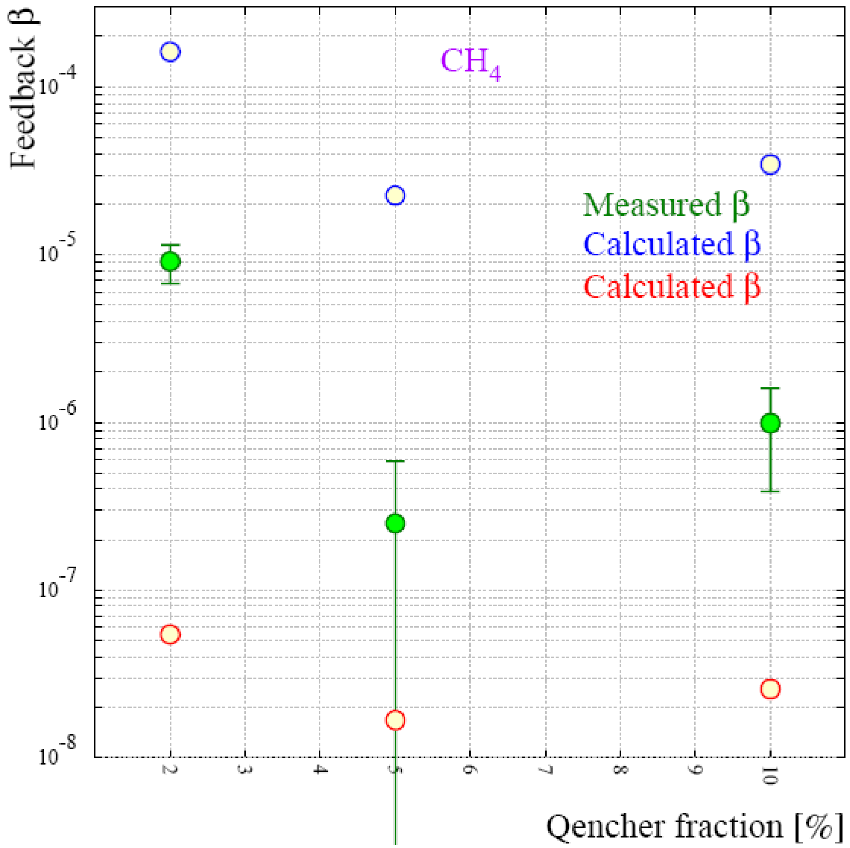
Ar + quencher

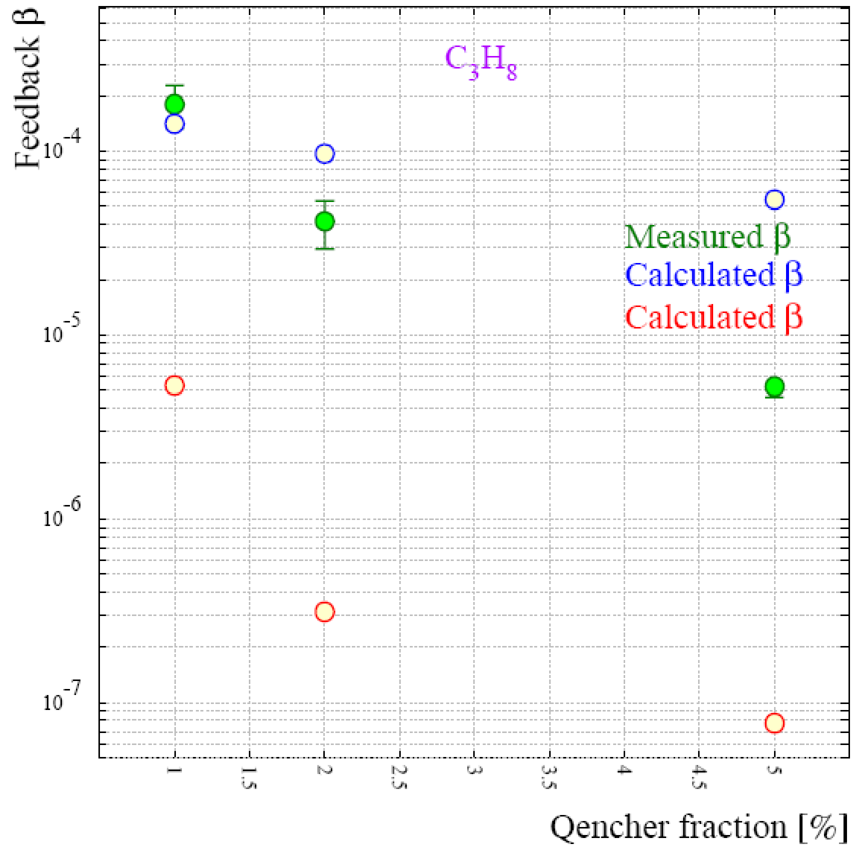




Estimated feedback probabilities

Ar + quencher





Summary

- We can learn about the feedback mechanisms considering;
  - Mean free paths,
  - Avalanche sizes,
  - Number of photons produced per avalanche electron,
    - Penning transfer probability from the gain fits.

- A microscopic model is needed to understand the mechanisms in detail.

Thank you …

???