Penning Effect on Gas Amplification Factor

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Micro-Pattern Gas Detectors (RD-51) Workshop
Nikhef, Amsterdam, April 16-18 2008

Introduction

Energy resolution is one of the fundamental counter parameters and it depends on both the number of produced ion pairs by an incident ionizing particle (W) and Fano factor (F) values

It is expected that Penning mixtures would improve the detector energy resolution because of lower W and F values.

Penning gas mixtures consist of a rare gas (in most cases Ar) and an admixture, usually molecular gases, which is present in a relatively low concentration.

Introduction

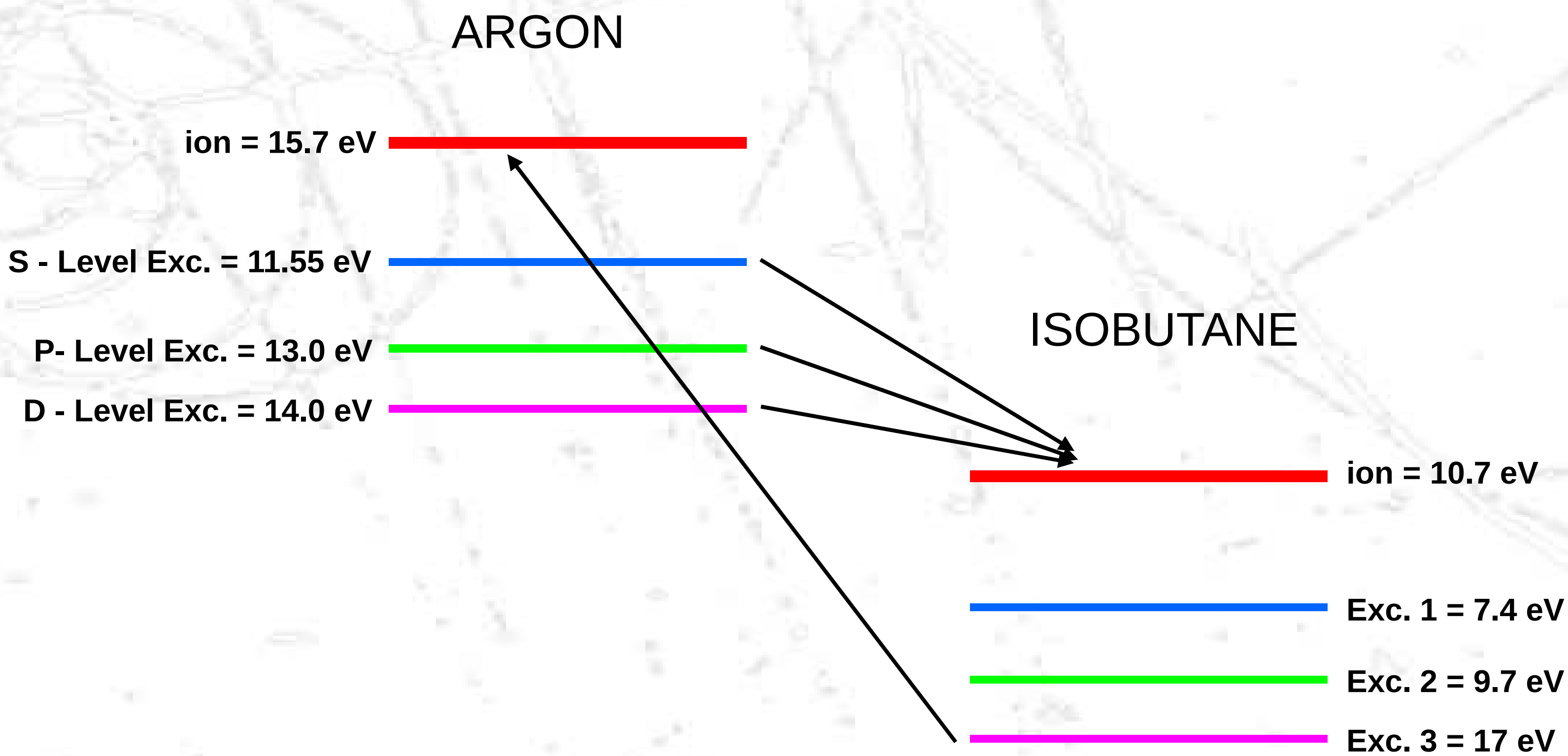
The excitation energy of a metastable state of a rare gas should be higher than the ionization potential (I) of the admixture to enable an effcient transfer of energy stored in excited metastable state to ionization of the admixture.

As a result of the energy transfer, the number of electron- ion pairs produced in the mixture increases, lowering thus the mean energy required to form an ion pair, and the Fano factor.

We were interested mostly in low admixture concentrations because the possible Penning transfers are more efficient under such conditions.

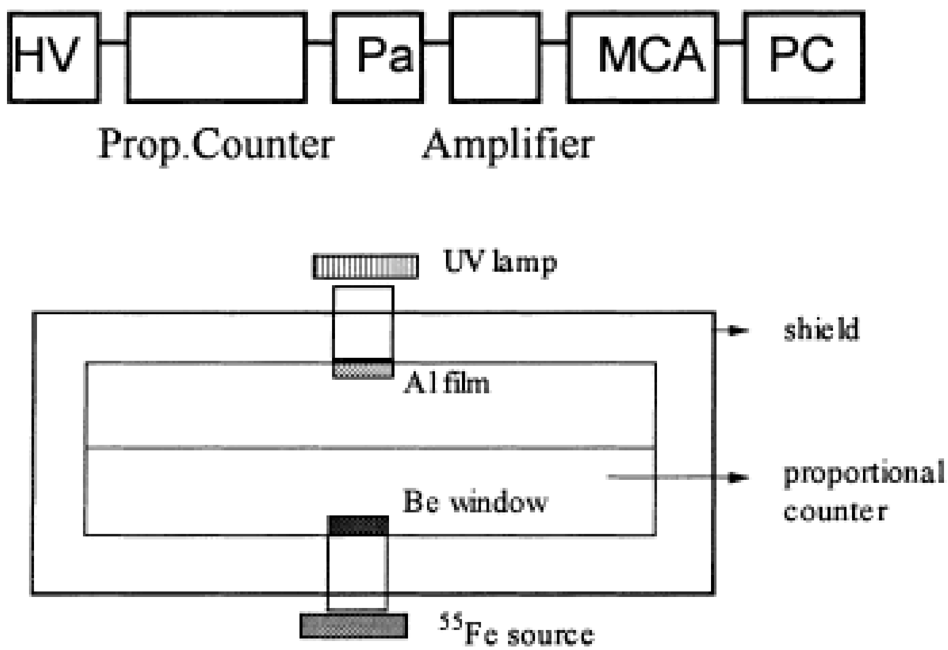
Excitation and ionization levels for Ar and iC_4H_{10}

As the energies of the argon metastable states are 11.55, 13.0 and 14.0 eV only molecular gases having I less than 11.55 eV can make a good Penning mixture with argon as the main gas. Isobutane (I =10.70 eV) added to argon forms one of the most effcient Penning mixtures.



Gas gain measurement

The measurements of the gas gains were made in argon based mixtures in a proportional counter at different total gas pressures *.

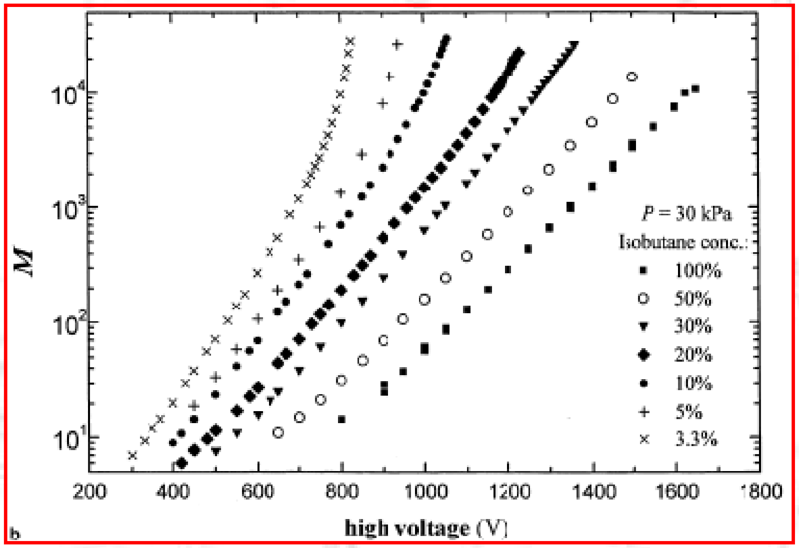


A schematic view of the experimental setup and proportional counter

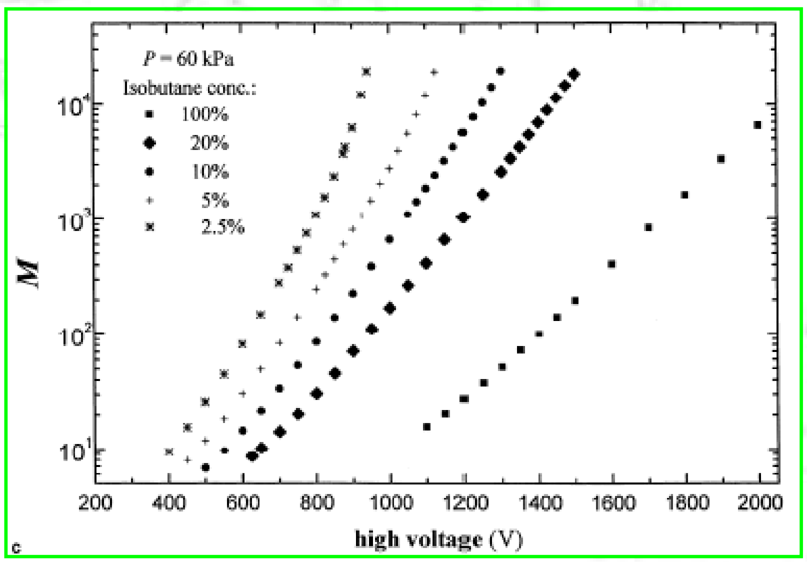
The inner diameter of the stainless-steel counter is 5 cm, the length is 15 cm, and it was placed in a copper shield, 8 cm in diameter. The anode was a stainless-steel wire of 25 μm in diameter.

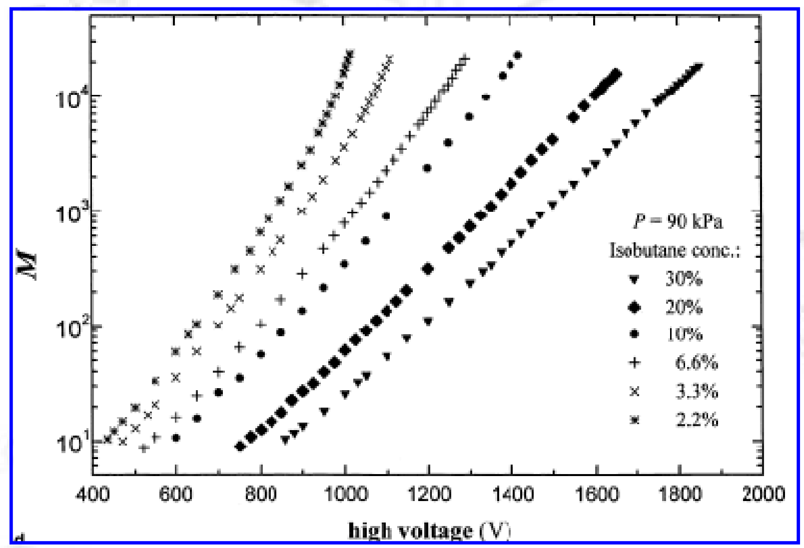
* I. K. Bronic, B. Grosswendt NIM B 142 (1998)

Gas gain measurement

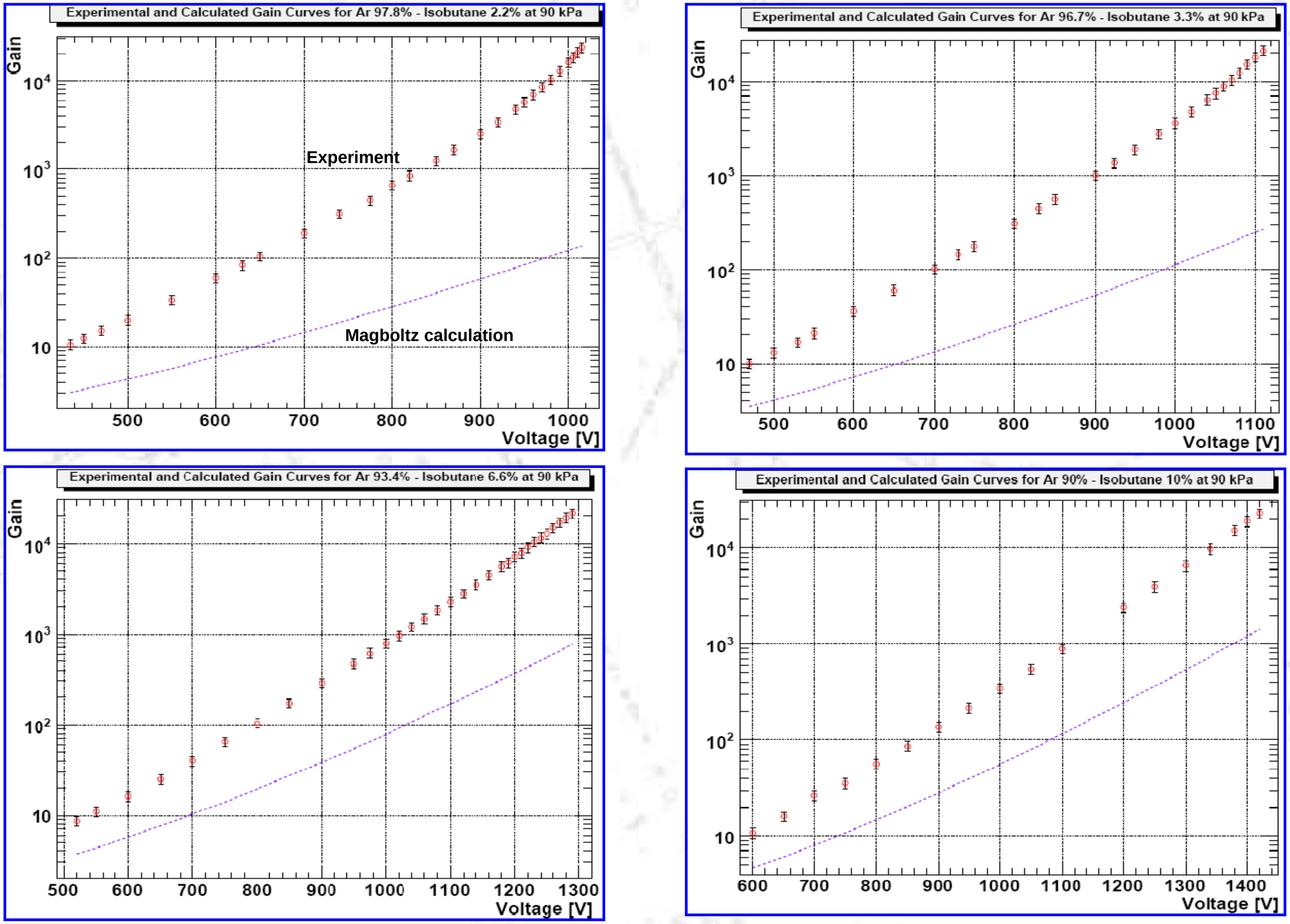


Measurements of the mean gas gains in argon-isobutane mixtures performed at total gas pressures of 30, 60 and 90 kPa.

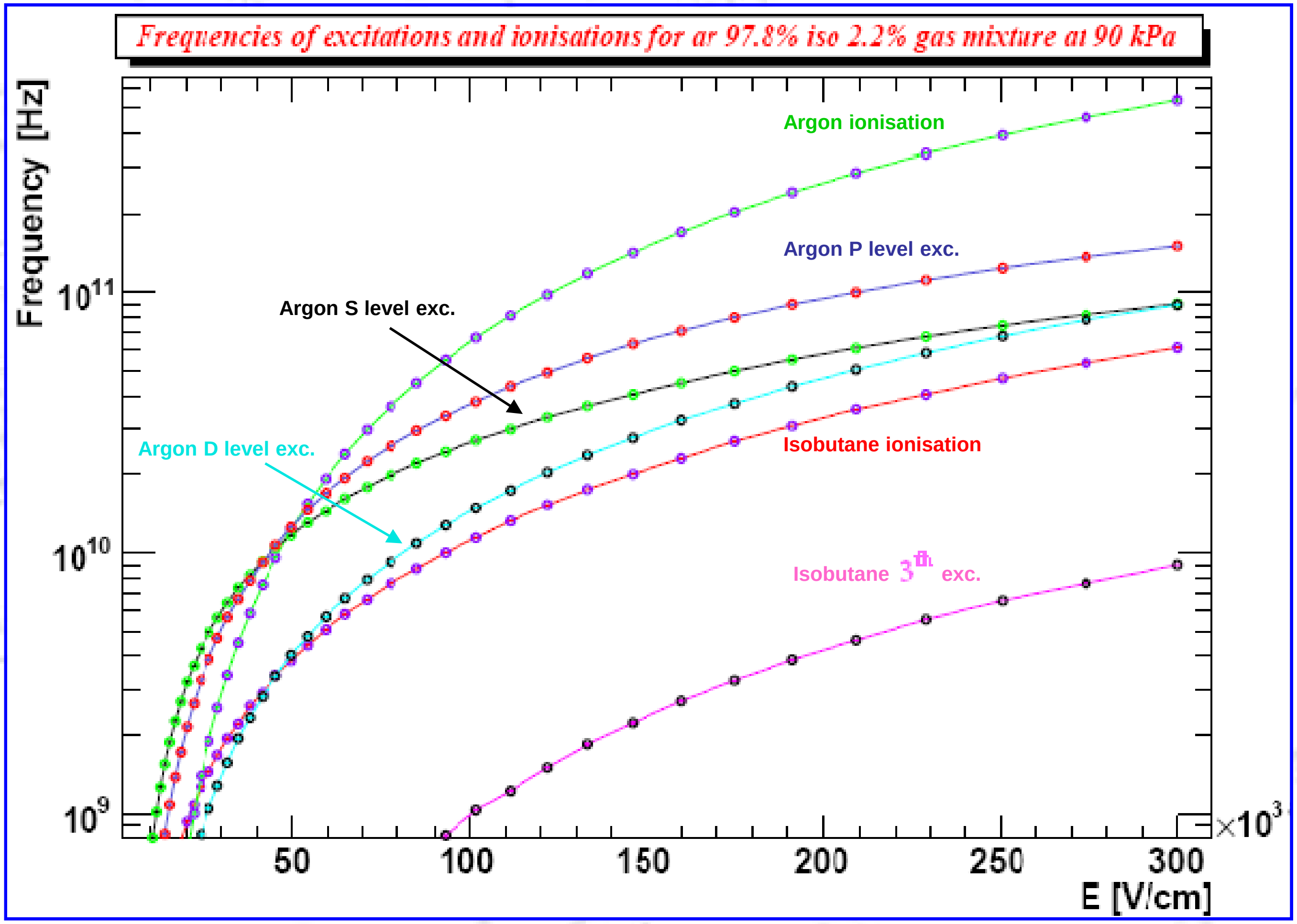




Measured and calculated (without Penning effect) gas gains



Excitation and ionization frequencies of Ar and iC_4H_{10}



Calculation

The first Townsend coefficients including Penning transfers

$$\alpha_{penning} = \alpha \frac{(f_{ion(Ar)} + f_{ion(iC_4H_{10})} + prob1 * f_{exc(iC_4H_{10})} + prob2 * f_{exc(Ar\ S-level)} + prob3 * f_{exc(Ar\ P-level)} + prob4 * f_{exc(Ar\ D-level)})}{(f_{ion(Ar)} + f_{ion(iC_4H_{10})})}$$

The probabilities of Penning transfers have been calculated by fitting experimental data using Minuit in Root.

$$G = e^{\int_{r_a}^{r_b} \alpha_{Penning}(E(r)) * dr}$$

G ⟶ **Main gain**

$$G_{photon} = \frac{G}{1 - \beta * G}$$

G_{photon} ⟶ **Gain including photon term**

β ⟶ **Photon term**

Transfer probabilities

// ar-96.7-iso-3.3 at 30kPa

NO.	NAME	VALUE	ERROR	
1	prob1	1.68699e-04	8.78757e-06	// photon term
2	prob2	2.94871e-01	4.57158e-03	// including all transfers → ~29.5%

// ar-95-iso-5 at 30kPa

NO.	NAME	VALUE	ERROR	
1	prob1	1.29981e-04	1.10423e-05	// photon term
2	prob2	1.89403e-01	7.34301e-03	// including all transfers → ~18.9%

// ar-90-iso-10 at 30kPa

NO.	NAME	VALUE	ERROR	
1	prob1	4.20120e-05	2.52955e-06	// photon term
2	prob2	2.57732e-01	4.13671e-03	// including all transfers → ~25.8%

// ar-80-iso-20 at 30kPa

NO.	NAME	VALUE	ERROR	
1	prob1	1.04907e-05	2.55348e-06	// photon term
2	prob2	1.87887e-01	5.87415e-03	// including all transfers → ~18.8%

// ar-70-iso-30 at 30kPa

NO.	NAME	VALUE	ERROR	
1	prob1	1.46482e-01	8.79637e-03	// including all transfers → ~14.6%

Transfer probabilities

```
// ar-97.5-iso-2.5 at 60kPa
 NO.  NAME      VALUE        ERROR
  1  prob1     1.44574e-04  1.14384e-05  //  photon term
  2  prob2     2.94483e-01  4.80416e-03  //  including all transfers      ~29.4%

// ar-95-iso-5 at 60kPa
 NO.  NAME      VALUE        ERROR
  1  prob1     5.83176e-05  7.49674e-06  //  photon term
  2  prob2     2.54128e-01  5.37397e-03  //  including all transfers      ~25.4%

// ar-90-iso-10 at 60kPa
 NO.  NAME      VALUE        ERROR
  1  prob1     2.36581e-05  6.34143e-06  //  photon term
  2  prob2     2.39938e-01  7.76290e-03  //  including all transfers      ~24.0%

// ar-80-iso-20 at 60kPa
 NO.  NAME      VALUE        ERROR
  1  prob1     2.63341e-01  8.44710e-03  //  including all transfers      ~26.3%
```

Transfer probabilities

```
// ar-97.8-iso-2.2 at 90kPa
 NO.  NAME      VALUE          ERROR
  1  prob1     6.82880e-05  6.26363e-06  //  photon term
  2  prob2     3.76835e-01  4.00320e-03  //  including all transfers
```

→ ~37.7%

```
// ar-96.7-iso-3.3 at 90kPa
 NO.  NAME      VALUE          ERROR
  1  prob1     3.45401e-05  5.46933e-06  //  photon term
  2  prob2     3.83965e-01  4.40361e-03  //  including all transfers
```

→ ~38.4%

```
// ar-93.4-iso-6.6 at 90kPa
 NO.  NAME      VALUE          ERROR
  1  prob1     1.15584e-06  4.14069e-06  //  photon term
  2  prob2     4.25030e-01  5.43375e-03  //  including all transfers
```

→ ~42.5%

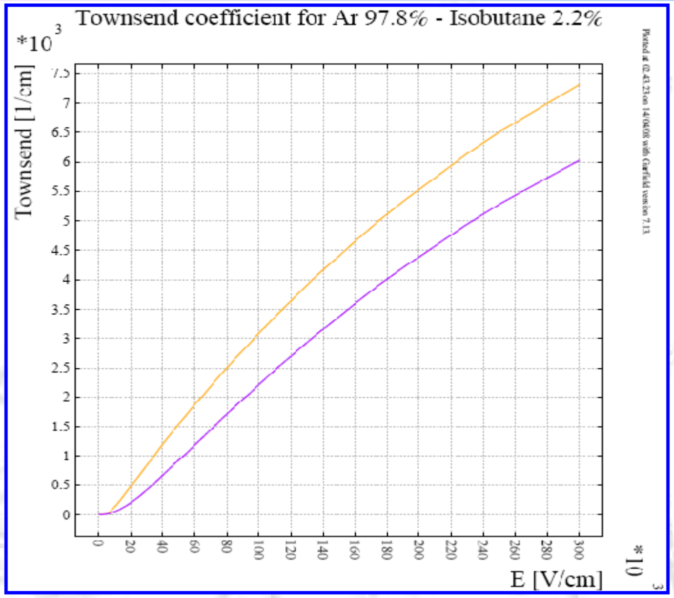
```
// ar-90-iso-10 at 90kPa
 NO.  NAME      VALUE          ERROR
  1  prob1     4.58055e-01  6.31163e-03  // including all transfers
```

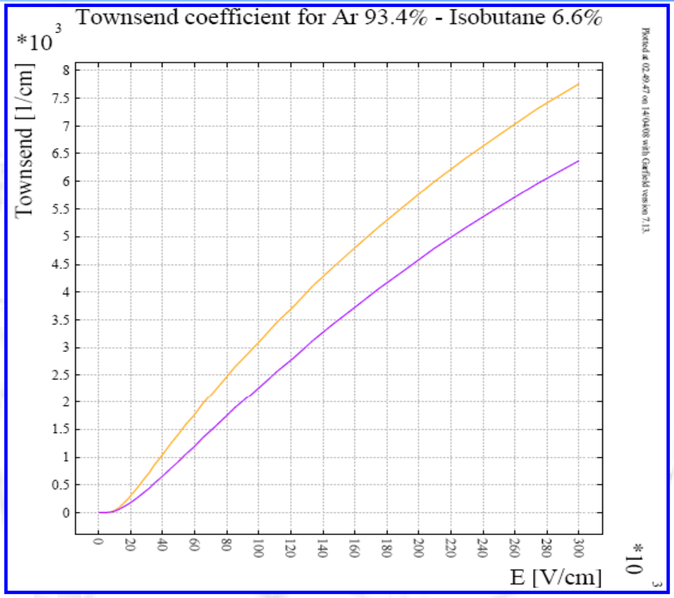
→ ~45.8%

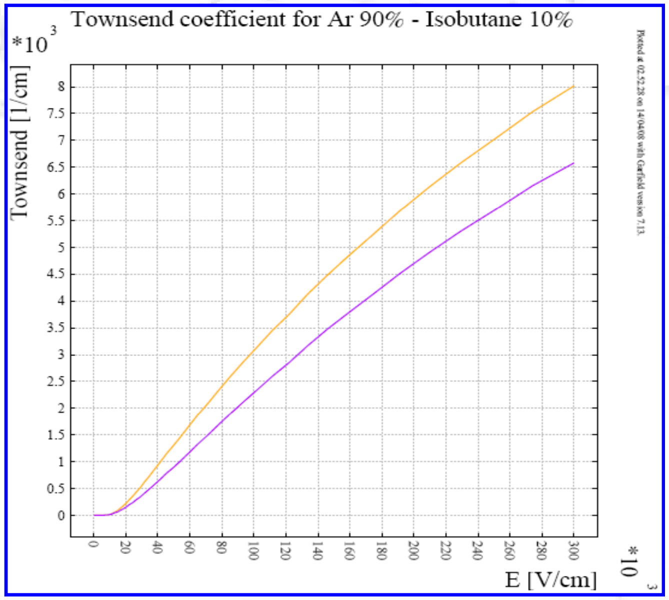
```
// ar-80-iso-20 at 90kPa
 NO.  NAME      VALUE          ERROR
  1  prob1     4.73030e-01  7.42292e-03  // including all transfers
```

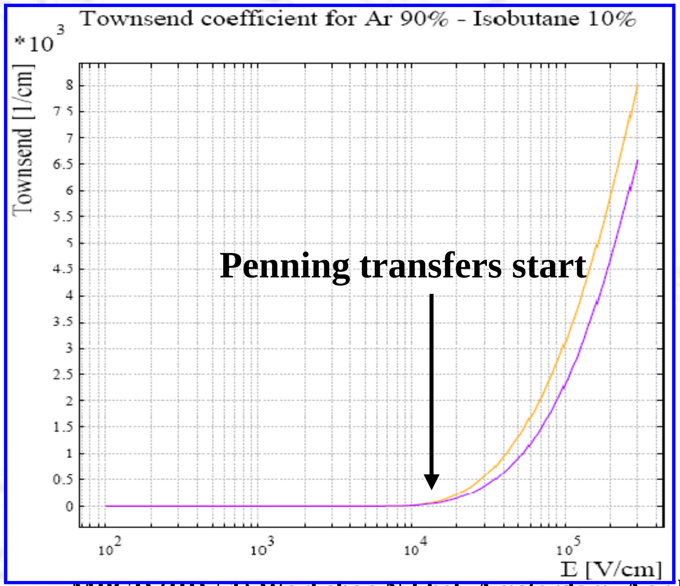
→ ~47.3%

Townsend coefficient versus E field (with and without Penning effect)

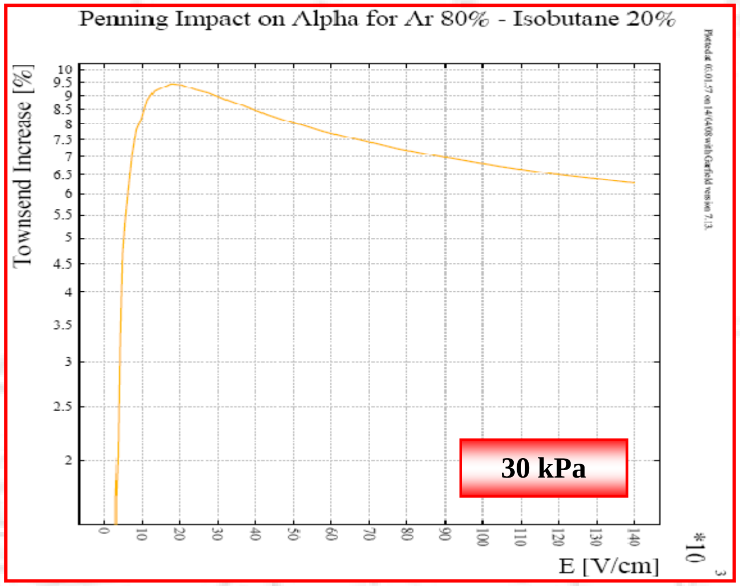


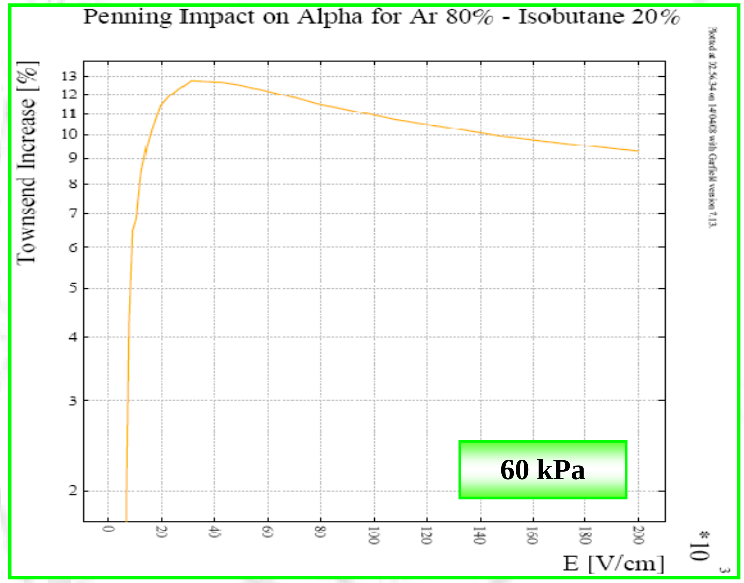


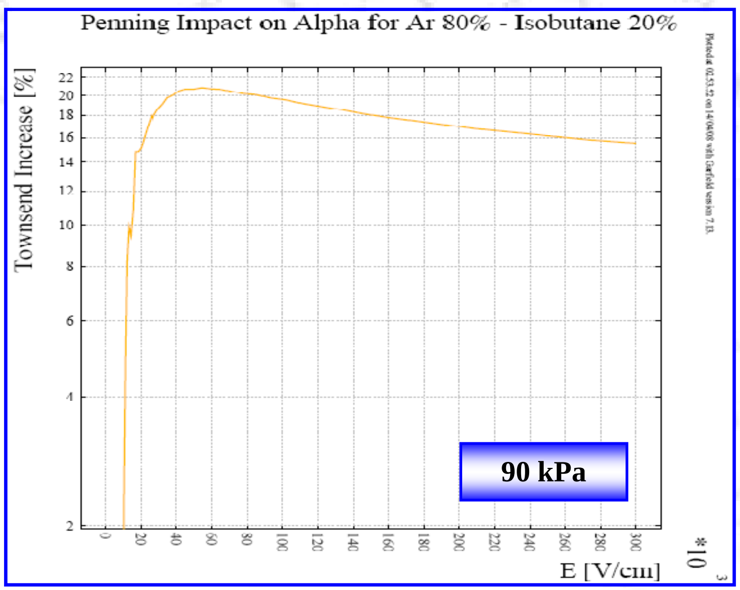




Variation of Penning impact on Alpha with E field

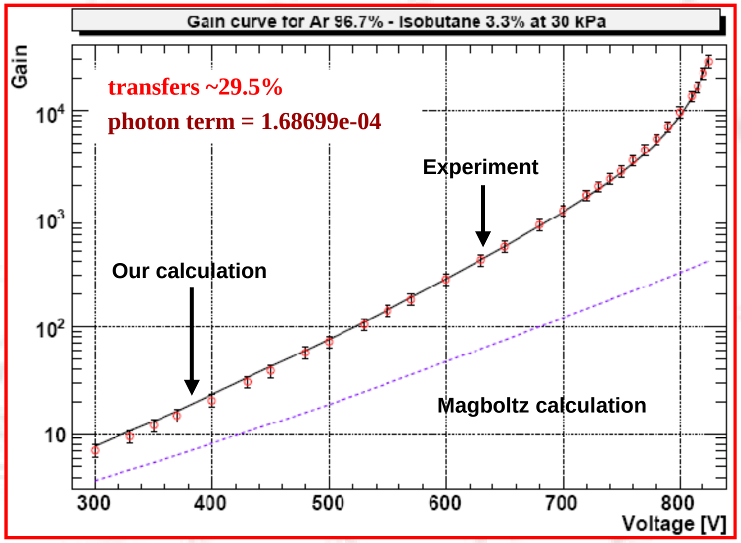


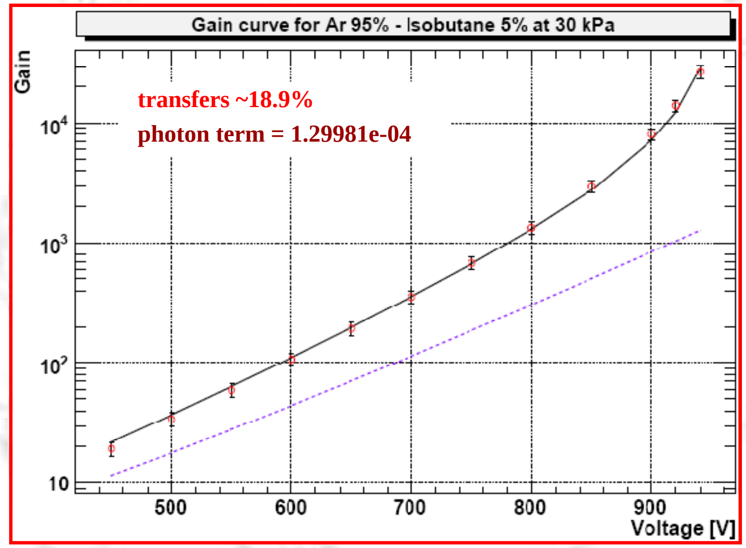


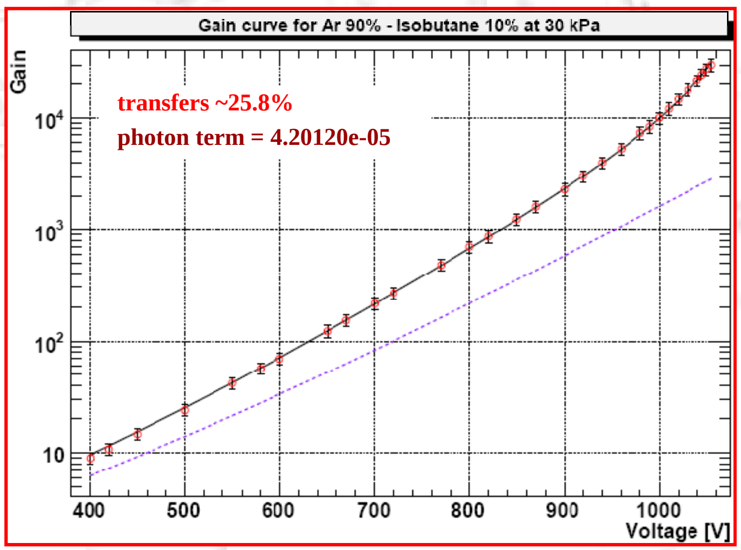


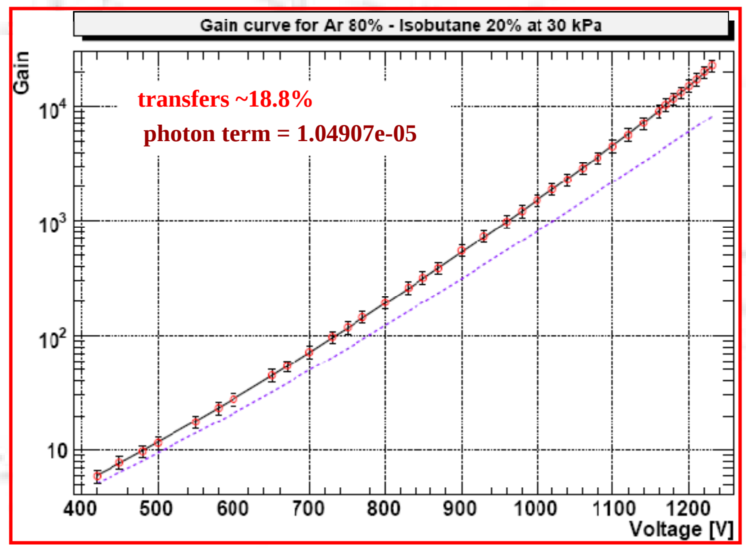
Increasing pressure increase Penning transfer probabilities

Measured and calculated (with Penning effect) gas gains at 30 kPa

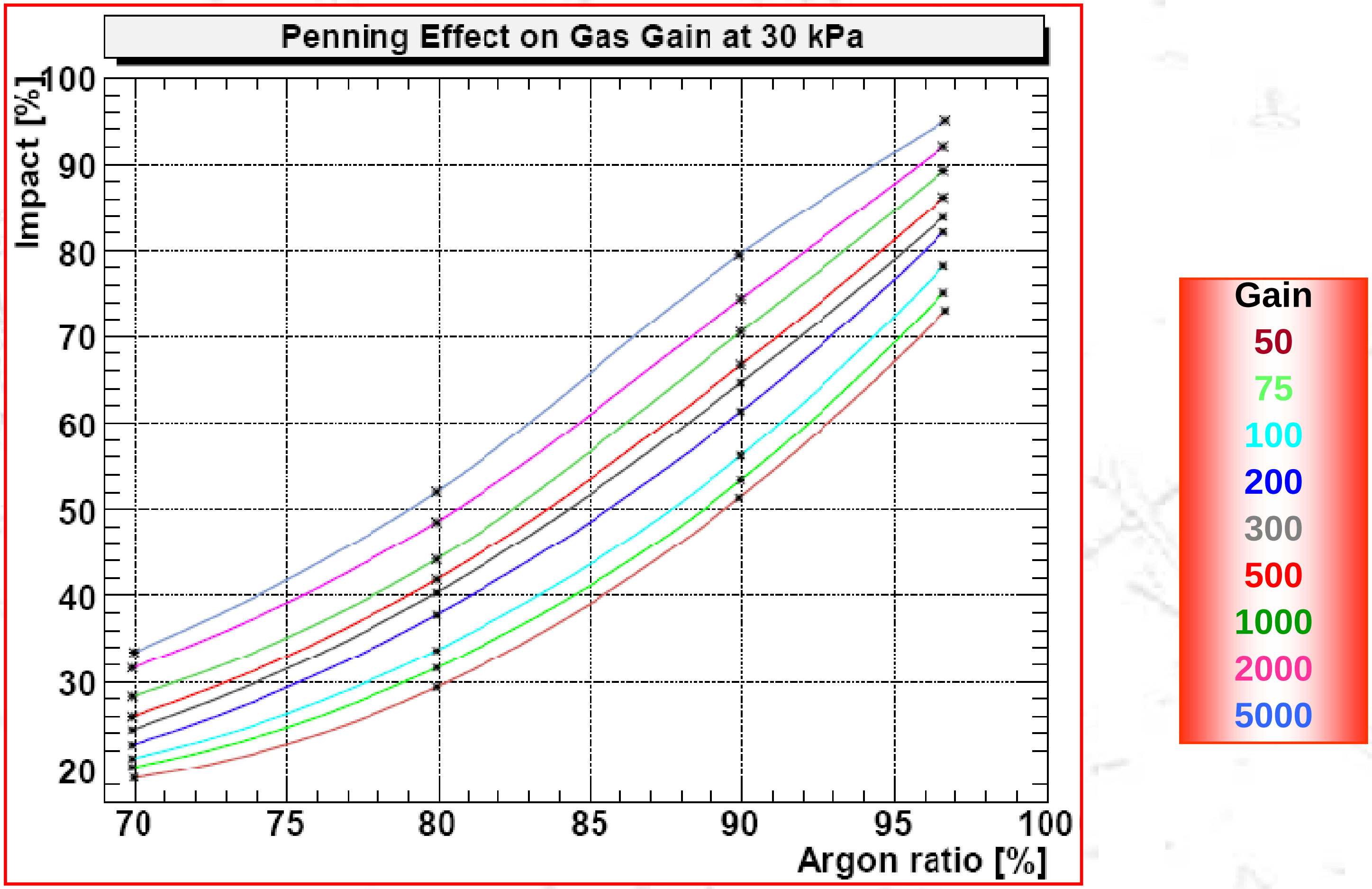




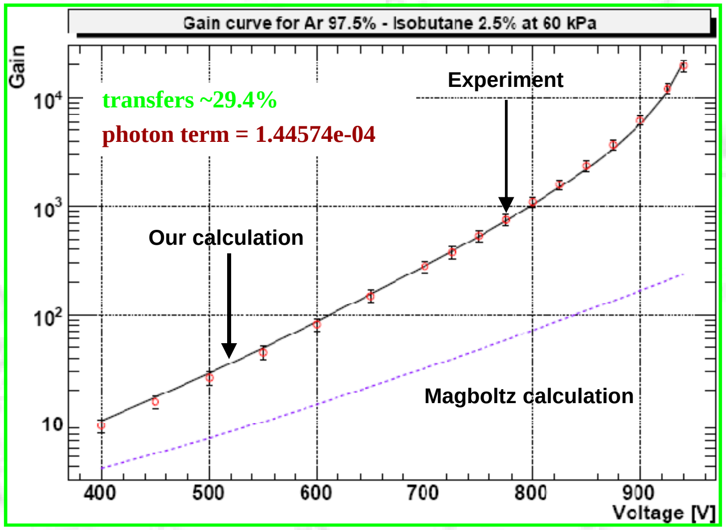


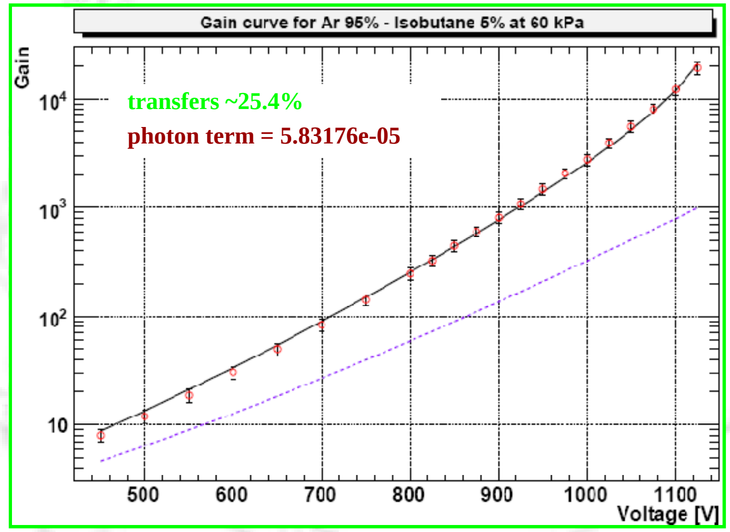


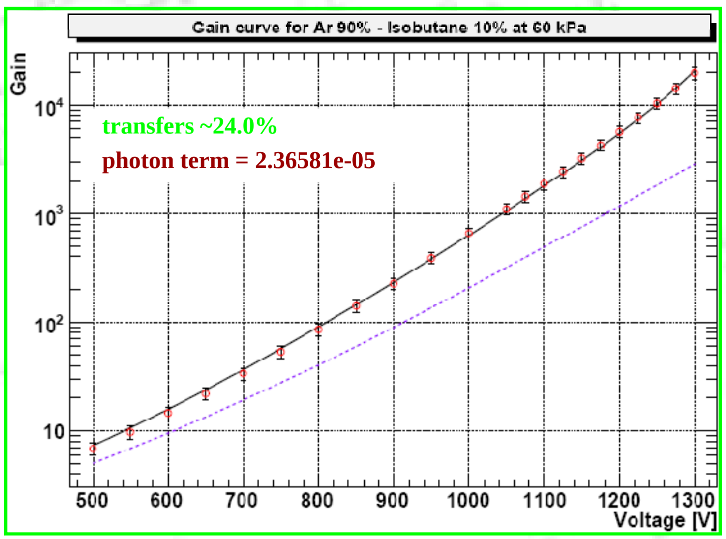
Penning impact on gas gains at 30 kPa

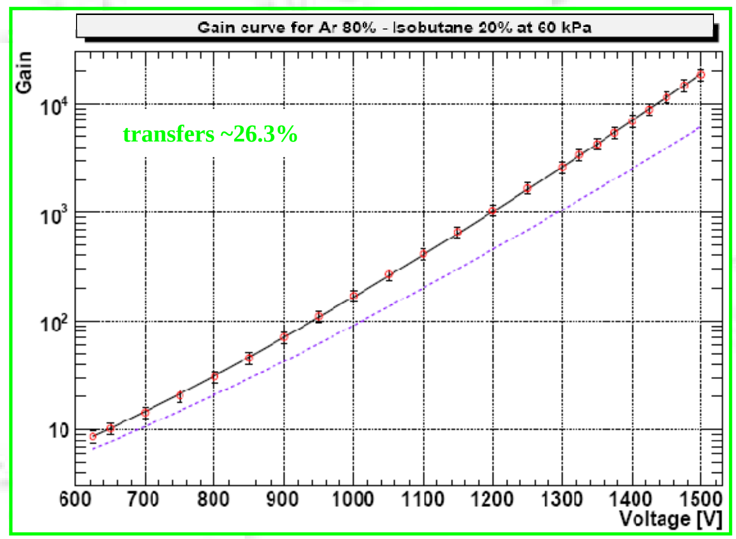


Measured and calculated (with Penning effect) gas gains at 60 kPa

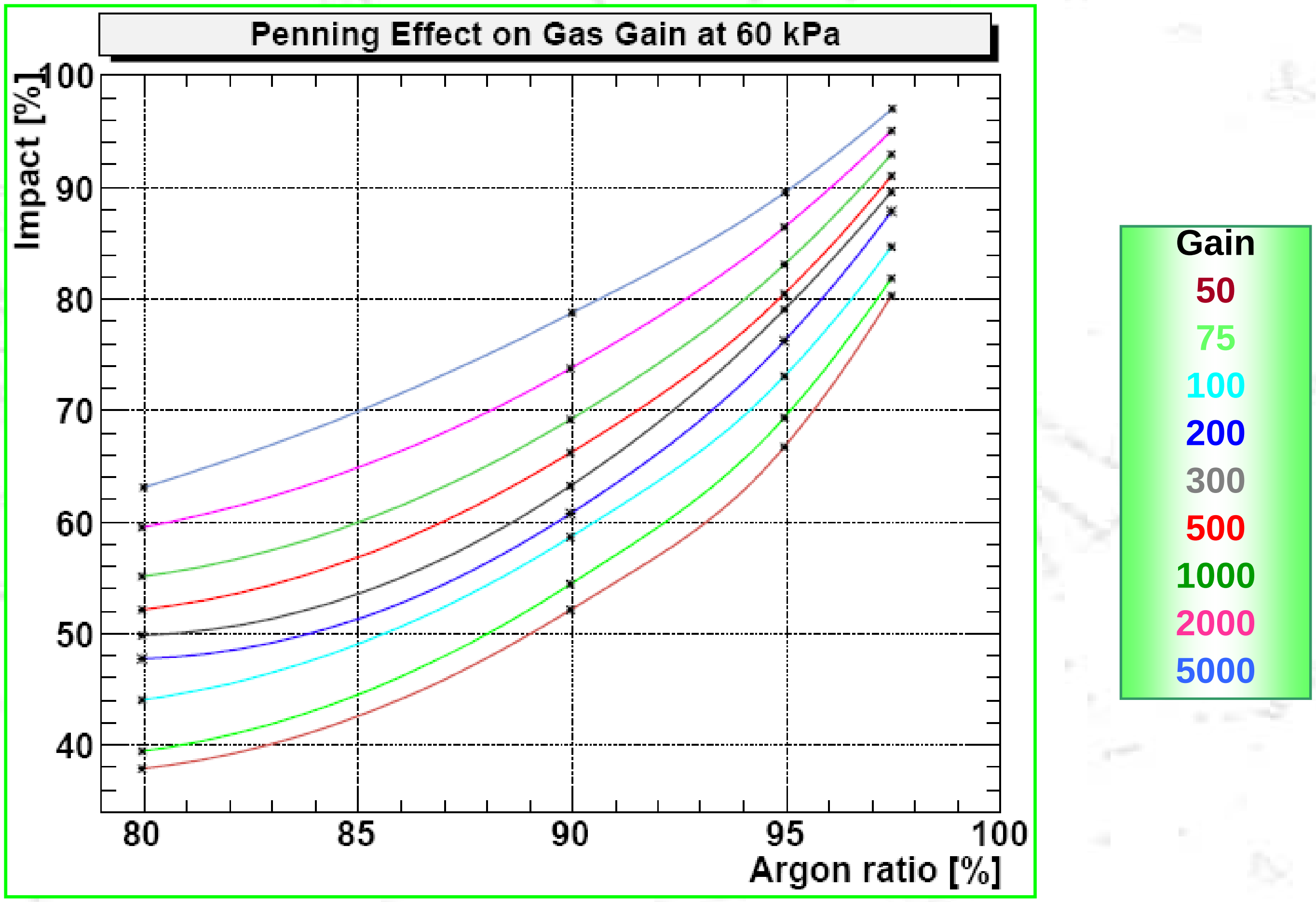




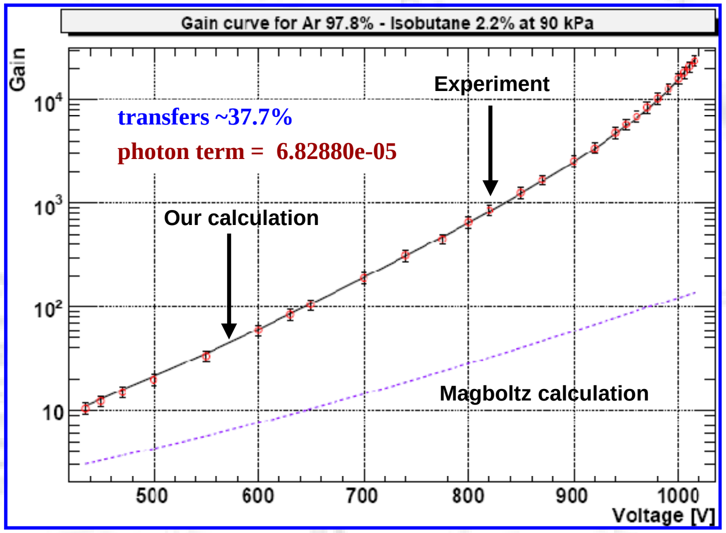


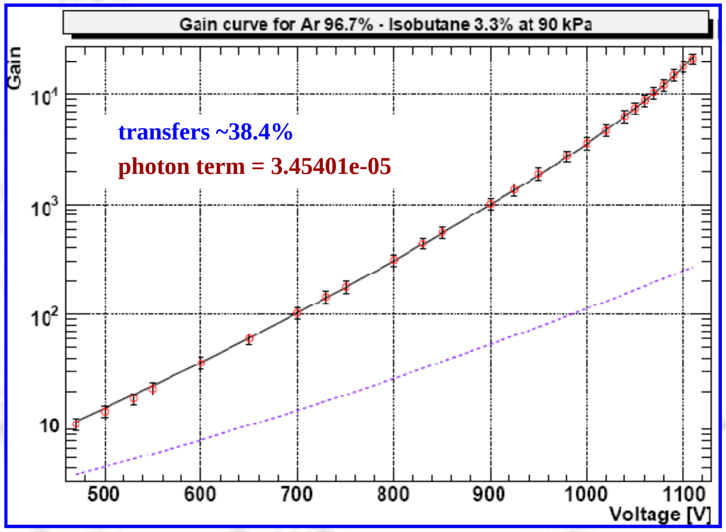


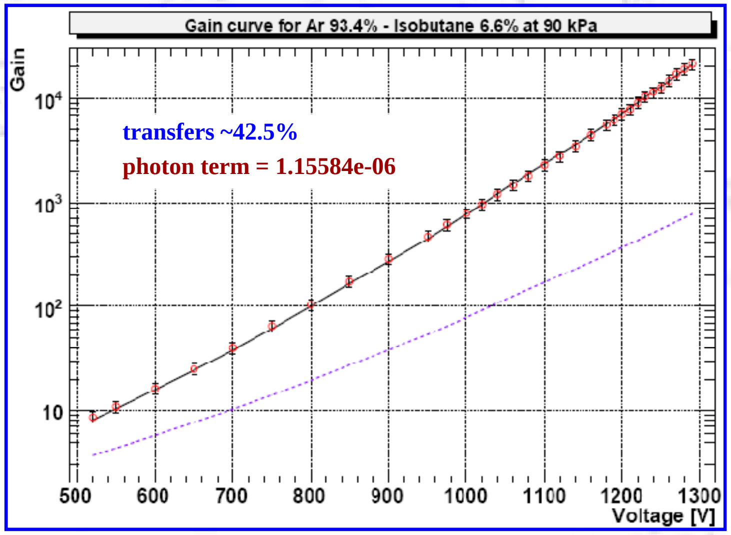
Penning impact on gas gains at 60 kPa

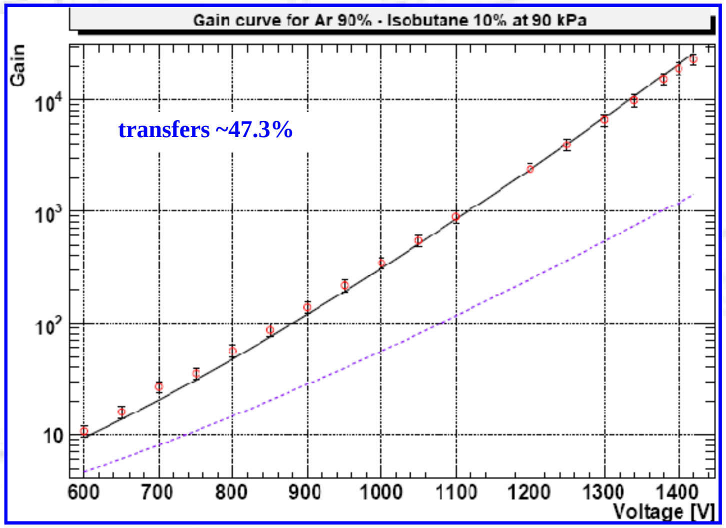


Measured and calculated (with Penning effect) gas gains at 90 kPa

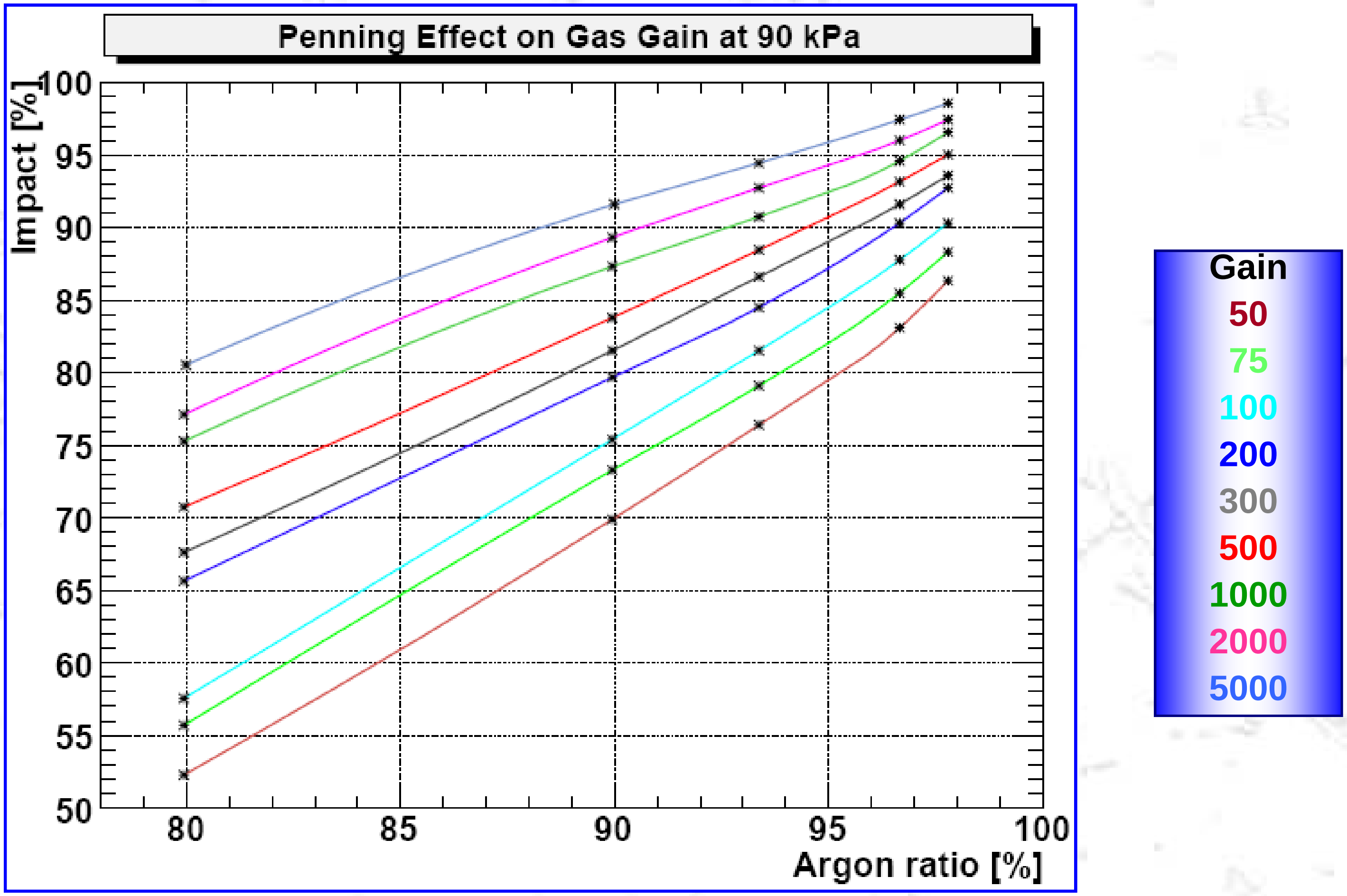




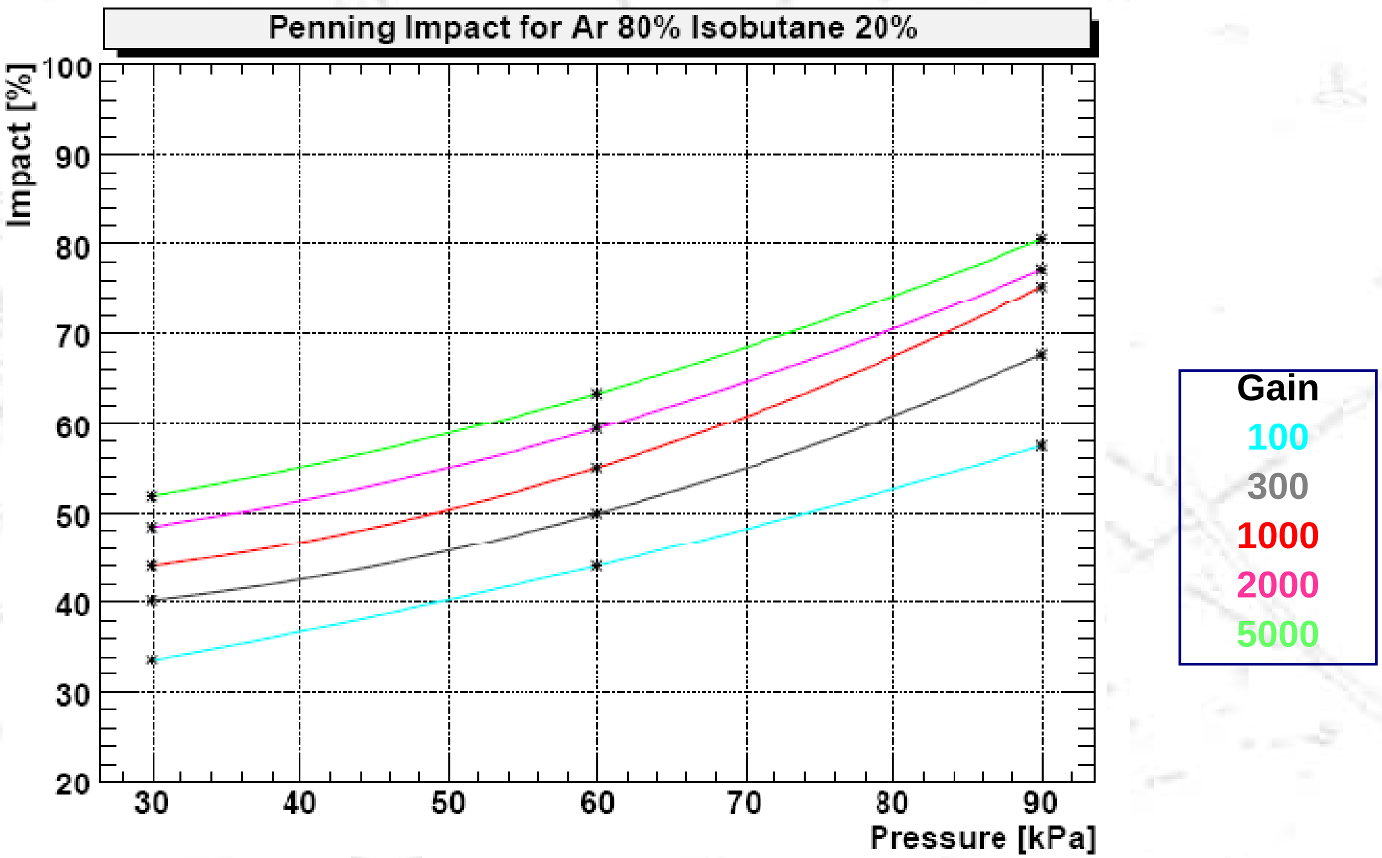




Penning impact on gas gains at 90 kPa



Variation of Penning impact on gas gains with pressure



Conclusion

- Penning transfers on first Townsend coefficients and gas gain factors are important at lower admixture concentrations.

- Systematics calculation on Penning transfer probabilities are going on.

- Calculations will be performed for other Penning mixtures..