Measurements and calculations of gas gain in tissue equivalent gases

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

inst

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

RECEIVED: *September 30, 2014*
ACCEPTED: *October 22, 2014*
PUBLISHED: *December 2, 2014*

10th INTERNATIONAL CONFERENCE ON POSITION SENSITIVE DETECTORS
7–12 SEPTEMBER 2014,
UNIVERSITY OF SURREY, GUILDFORD, SURREY, U.K.

Gas gain limitation in low pressure proportional counters filled with TEG mixtures

T.Z. Kowalski

AGH, University of Science and Technology,
30-057 Krakow, Al. Mickiewicza 30, Poland

E-mail: Tadeusz.Kowalski@fis.agh.edu.pl

ABSTRACT: Proportional counters filled with tissue equivalent gas mixtures (TEPC) can be used to simulate interactions and energy transferred to small tissue volumes. One criteria which allows to use TEPC as the dose meter is that the particle ranges are larger compared to the gas volume. TEPC achieve this by operating at low gas pressures. Single ionization events dominate the distribution of low-LET radiation at low gas pressure and therefore their detection is of primary importance, a high gas gain is necessary. Therefore gas gain factor has been measured for Methane- and Propane-based tissue equivalent gas mixtures. The highest stable gas gains, second ionization Townsend coefficient and electron avalanche dimensions have been determined.

JINST **9** C12007 doi:10.1088/1748-0221/9/12/C12007

Application areas of tissue equivalent gas (TEG) mixtures

Especially essential mixtures in Medical Physics !!!

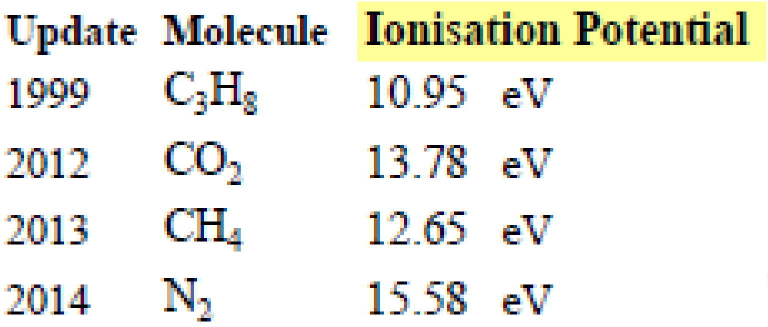
- ❖ energy deposited in the volume is required for microdosimetry in radiotherapy,
- ❖ practical use in radiation monitoring and protection,
- ❖ low **L**inear **E**nergy **T**ransfer (LET) radiation.

Measurements

- ❖ Propane and Methane TEG mixtures,
- ❖ Single wire cylindrical tubes: r_c = 1.25 cm; r_a = 24 μm, 50 μm,
- ❖ Pressure: 0.02 – 0.5 atm,
- ❖ Gas gain: $1 - 3.2\times10^5$ with current method,
- ❖ A special grid of guard rings protecting the node,
- ❖ Radiation source: mono – energetic X-rays,
- ❖ High precision: error on gas gain < 5%

Calculation method

- Townsend coefficients from Magboltz 10.5
    - oldest update for propane



Update	Molecule	Ionisation Potential
1999	C_3H_8	10.95 eV
2012	CO_2	13.78 eV
2013	CH_4	12.65 eV
2014	N_2	15.58 eV

- **No** gain scaling factor needed

$$G := g\,G$$

- **proof quality of the calibration !**

- Photon feedback parameters (β) needed

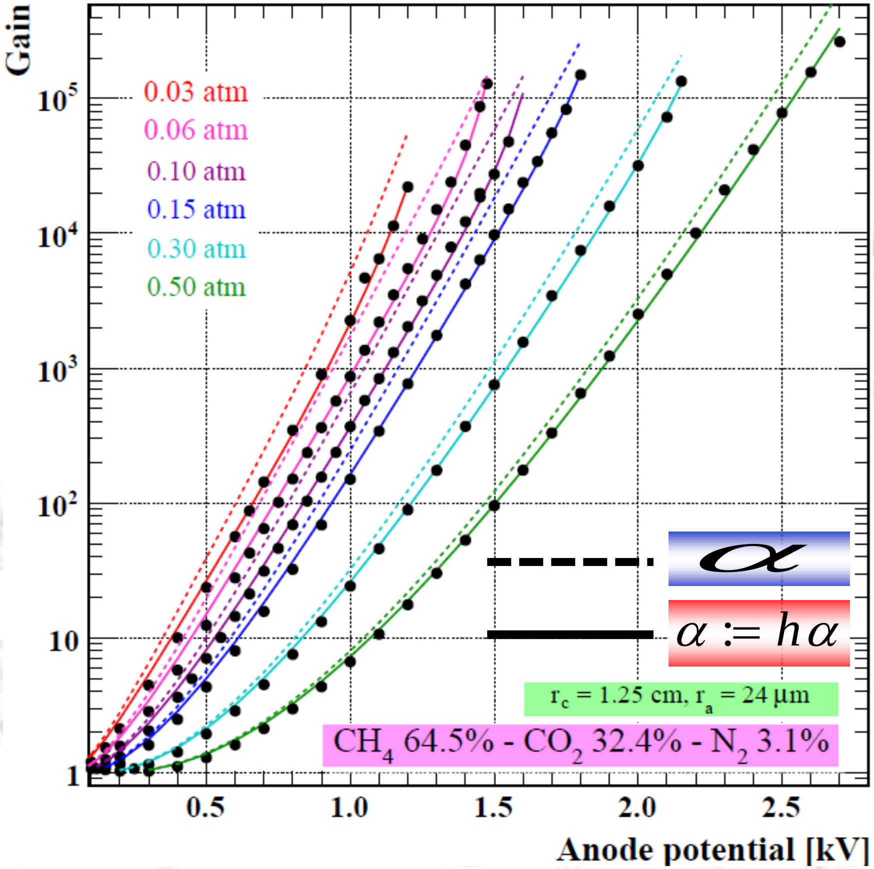
$$G := G/(1-\beta G)$$

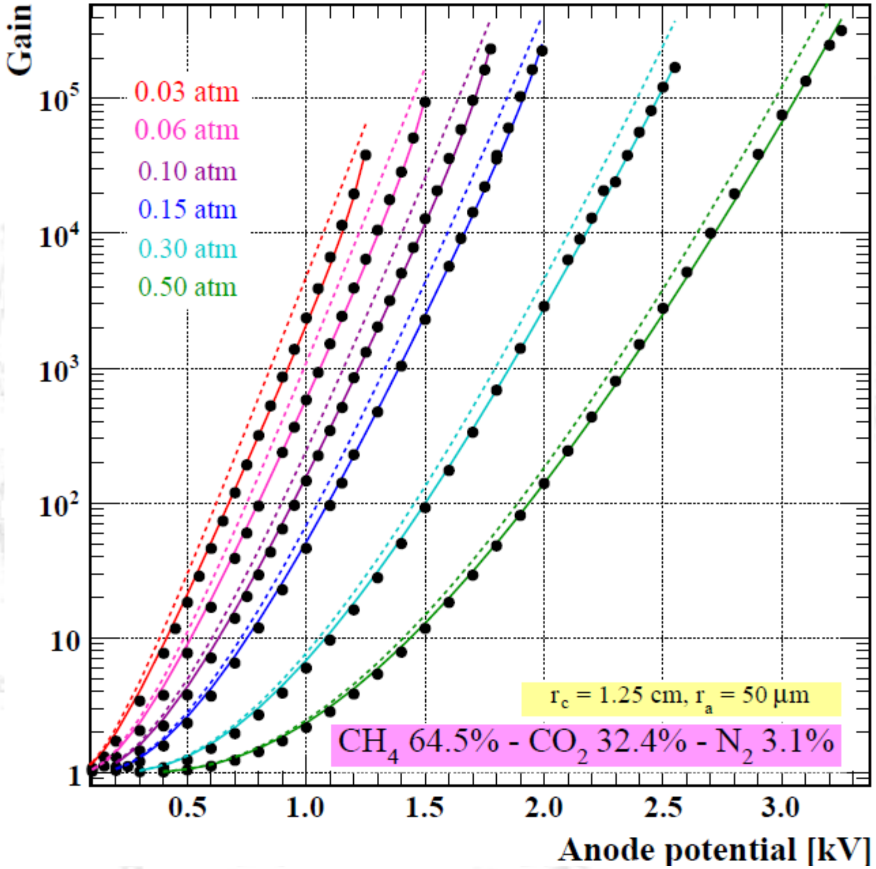
- **Townsend coefficient (α) scaling used for the gain simulations !!!**

$$\alpha := h\alpha$$

- h is the alpha scaling factor

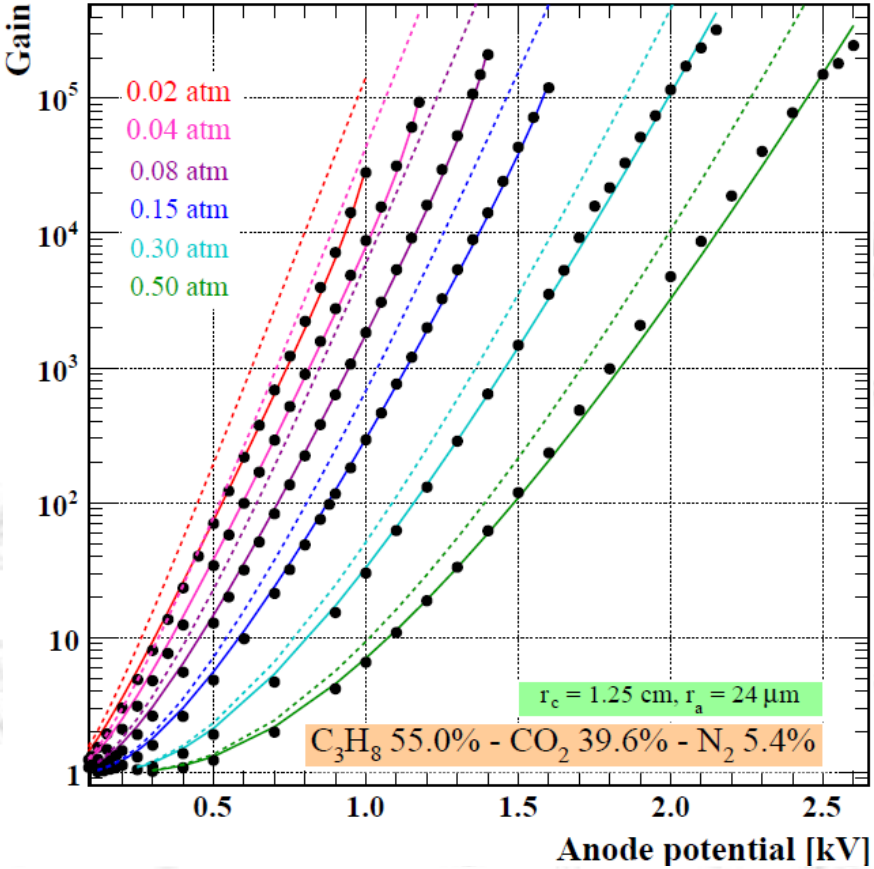
Methane-based tissue equivalent gas (TEGCH$_4$)

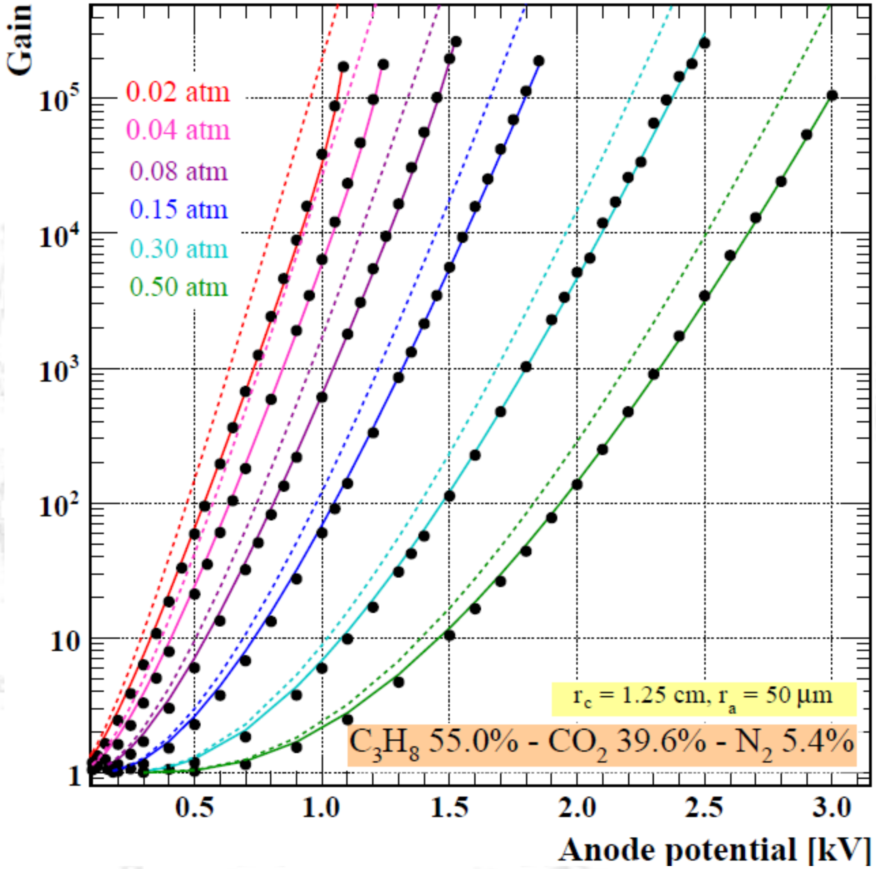




CH$_4$ 64.5% CO$_2$ 34.2% N$_2$ 3.1% (TEGCH$_4$)								
	r_a = 24 micron				r_a = 50 micron			
Pressure [atm]	alpha scal	err_alp_scal	beta	err_beta	alpha scal	err_alp_scal	beta	err_beta
0.50	0.9534	0.0027	no	no	0.9485	0.0023	no	no
0.30	0.9396	0.0034	2.2048E-06	7.3196E-07	0.9408	0.0032	6.1528E-08	4.9878E-07
0.15	0.9250	0.0039	3.0381E-06	8.0538E-07	0.9320	0.0032	1.9595E-06	4.1901E-07
0.10	0.9104	0.0041	1.0774E-05	2.4599E-06	0.9194	0.0031	3.2237E-06	4.6102E-07
0.06	0.9076	0.0047	1.3382E-05	1.4822E-06	0.9109	0.0034	7.1440E-06	1.1658E-06
0.03	0.8949	0.0068	1.2075E-05	7.0330E-06	0.8969	0.0052	2.4006E-05	4.0930E-06

Propane-based tissue equivalent gas ($TEGC_3H_8$)

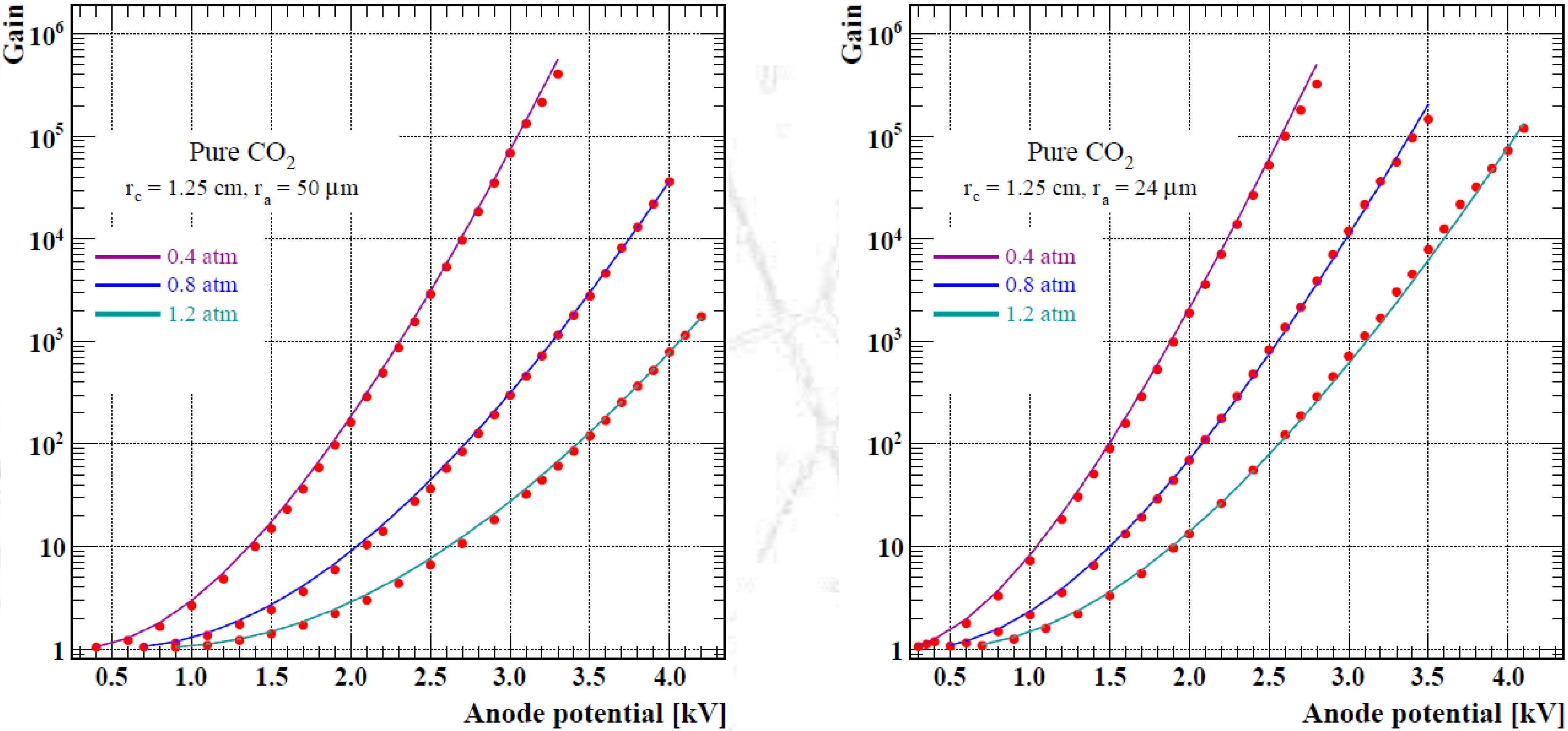




C_3H_8 55% - CO_2 39.6% - N_2 5.4% ($TEGC_3H_8$)

	r_a = 24 micron				r_a = 50 micron			
Pressure [atm]	alpha scal	err_alp_scal	beta	err_beta	alpha scal	err_alp_scal	beta	err_beta
0.50	0.8735	0.0045	no	no	0.8787	0.0026	no	no
0.30	0.8892	0.0029	no	no	0.8792	0.0024	no	no
0.15	0.8743	0.0030	2.7342E-06	7.6444E-07	0.8806	0.0027	no	no
0.08	0.8596	0.0033	3.9374E-06	5.5731E-07	0.8683	0.0038	2.0071E-06	4.5224E-07
0.04	0.8338	0.0045	9.8440E-06	1.6944E-06	0.8505	0.0047	4.7553E-06	9.1479E-07
0.02	0.8146	0.0056	2.9705E-05	6.4132E-06	0.8336	0.0046	8.3367E-06	1.1056E-06

Gain measurements and fits for Pure CO_2 (unpublished)



❖ Perfectly fine overlaps with all experimental gain curves,

❖ the first time that we ever have such a successful agreement for pure gases without using any scaling or correction factor:

- ❖ confirmation of the high precision measurements (thanks to Tadeusz),
- ❖ correctness of the cross sections used in Magboltz (thanks to Steve),
- ❖ our calculation method is sufficient enough to reproduce the measured gain curves.

Our earlier calculations on alpha scaling

J. Phys. D: Appl. Phys. 32 (1999) 3179–3187. Printed in the UK

PII: S0022-3727(99)04748-8

Ionization coefficient in propane, propane-based tissue equivalent and dimethyl-ether in strong non-uniform electric fields

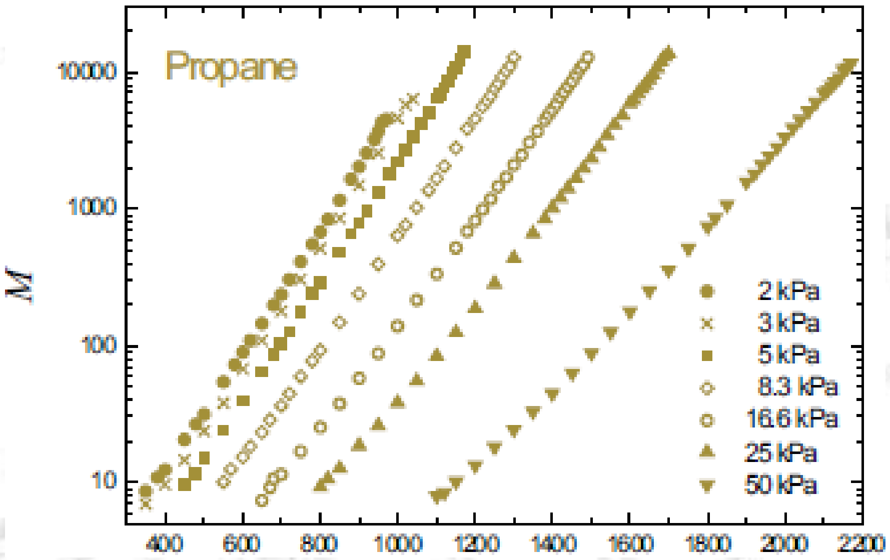
Ines Krajcar Bronić†§ and Bernd Grosswendt‡

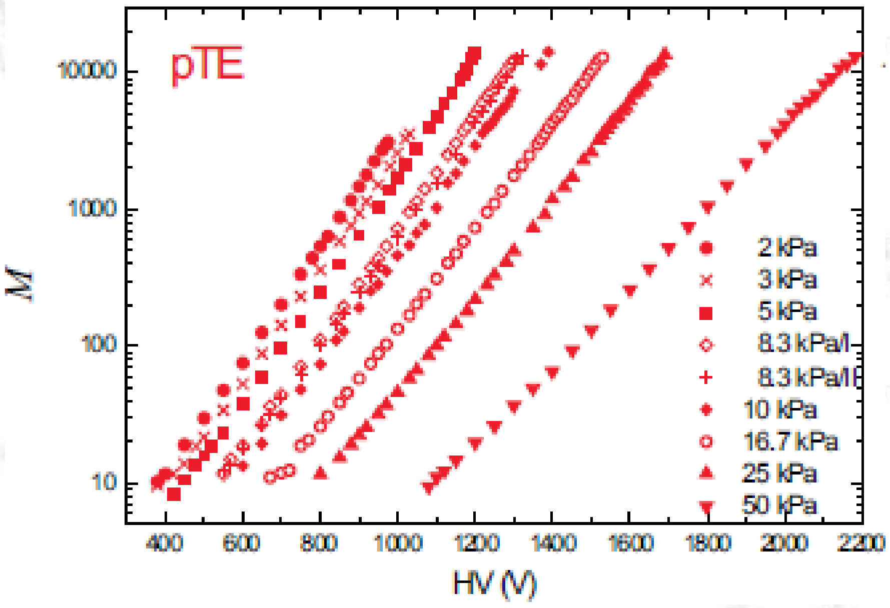
† Department of Physics, Rudjer Bošković Institute, PO Box 1016, 10001 Zagreb, Croatia
‡ Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany

E-mail: `krajcar@rudjer.irb.hr`

Received 2 June 1999, in final form 1 October 1999

Fit results for pure propane and propane based TEG





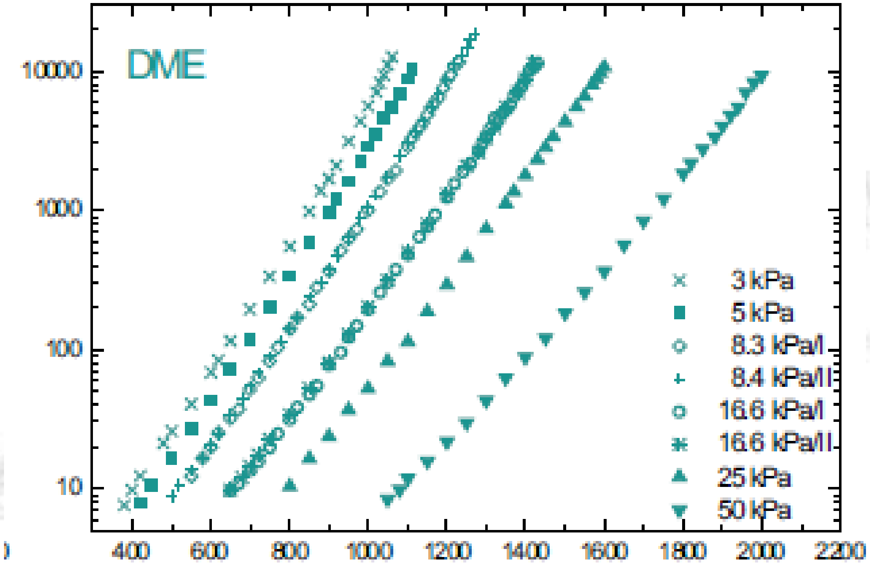
Pure C_3H_8

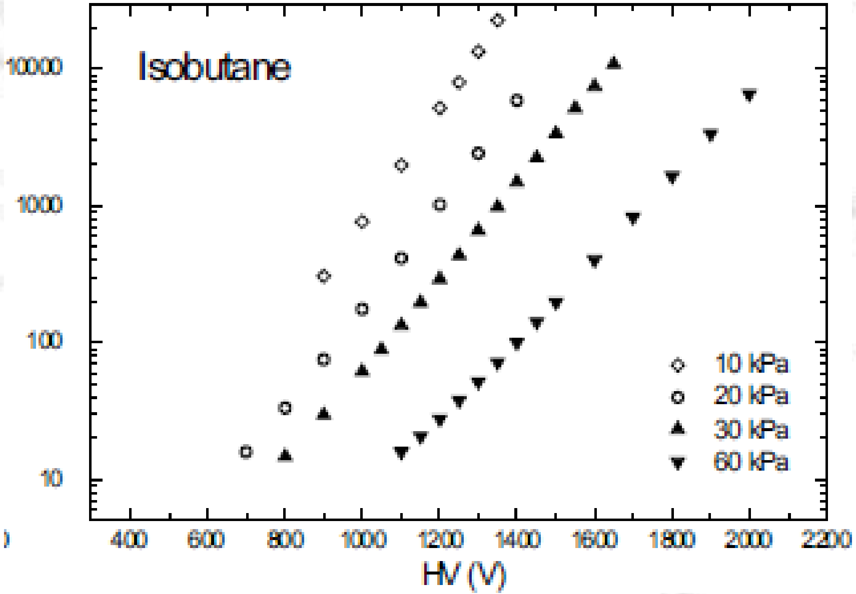
	r_a = 12.5 micron	
Pressure [atm]	alpha scal	gain scal
0.49	0.96	0.54
0.25	0.94	0.55
0.16	0.93	0.54
0.08	0.88	0.49
0.05	0.88	0.53
0.03	0.86	0.51
0.02	0.84	0.51

C_3H_8 55% - CO_2 39.6% - N_2 5.4% (TEGC_3H_8)

	Alpha scaling		
Pressure [atm]	Kowalski 2014		Bronic 1999
0.50	0.8735	0.8787	---
0.49	---	---	0.8631
0.30	0.8892	0.8792	---
0.25	---	---	0.9022
0.15	0.8743	0.8806	---
0.16	---	---	0.8842
0.10	---	---	0.8816, 0.8789
0.08	0.8596	0.8683	0.8928, 0.8823
0.05	---	---	0.8819
0.04	0.8338	0.8505	---
0.03	---	---	0.8478
0.02	0.8146	0.8336	0.8406

Fit results for pure DME and Isobutane





Pure DME

	r_a = 12.5 micron	
Pressure [atm]	alpha scal	gain scal
0.49	1.06	0.36
0.25	1.02	0.40
0.16	1.00	0.43, 0.47
0.08	0.95	0.48, 0.44
0.05	0.93	0.48
0.03	0.93	0.40

Pure iC4H10

	r_a = 15 micron	
Pressure [atm]	alpha scal	gain scal
0.59	1.18	1.57
0.30	1.05	1.45
0.20	1.02	1.13
0.10	0.92	1.06

Ar – CF$_4$ mixtures

ELSEVIER

Available online at www.sciencedirect.com

ScienceDirect

Nuclear Instruments and Methods in Physics Research A 572 (2007) 184–186

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

Gas multiplication process in mixtures based on Ar, CO$_2$, CF$_4$

M. Deptuch, T.Z. Kowalski*

Faculty of Physics and Computer Science, AGH University of Science and Technology, Krakow, Poland

Single wire chamber

❖ r_a = 25 µm, r_c = 0.9 cm

Gas

❖ 1000 hPa pressure, 20 °C temperature

Gain

❖ Order of 10^5

Error on gain

❖ < 10%

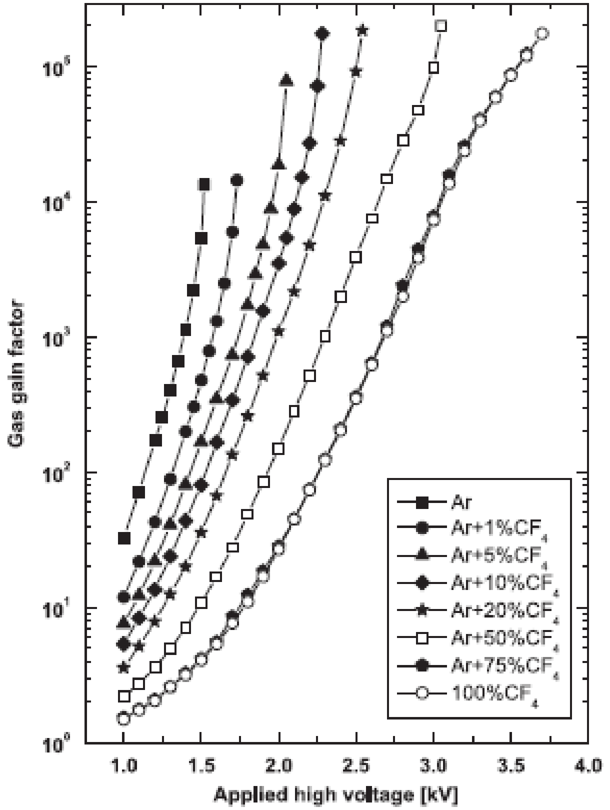
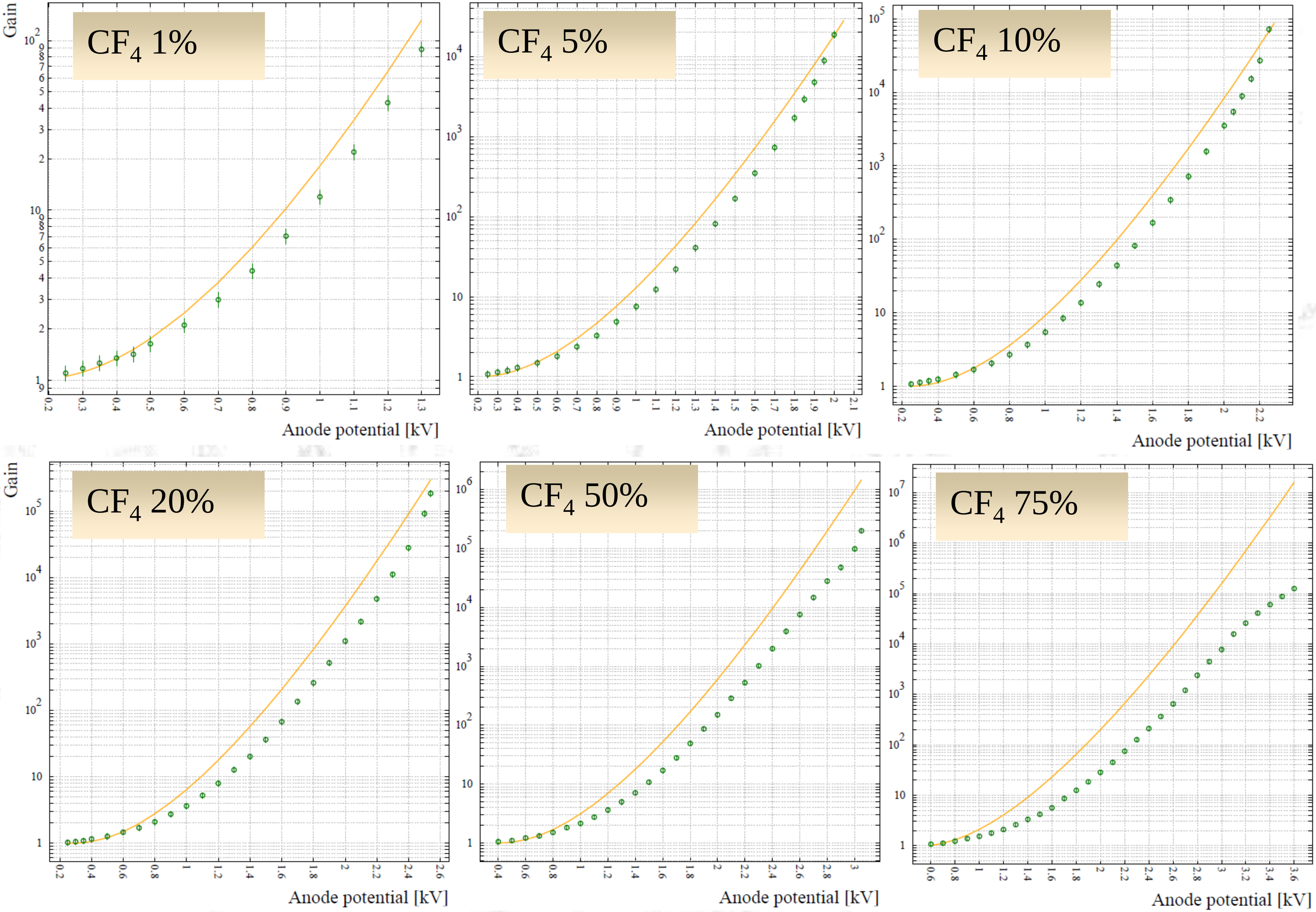
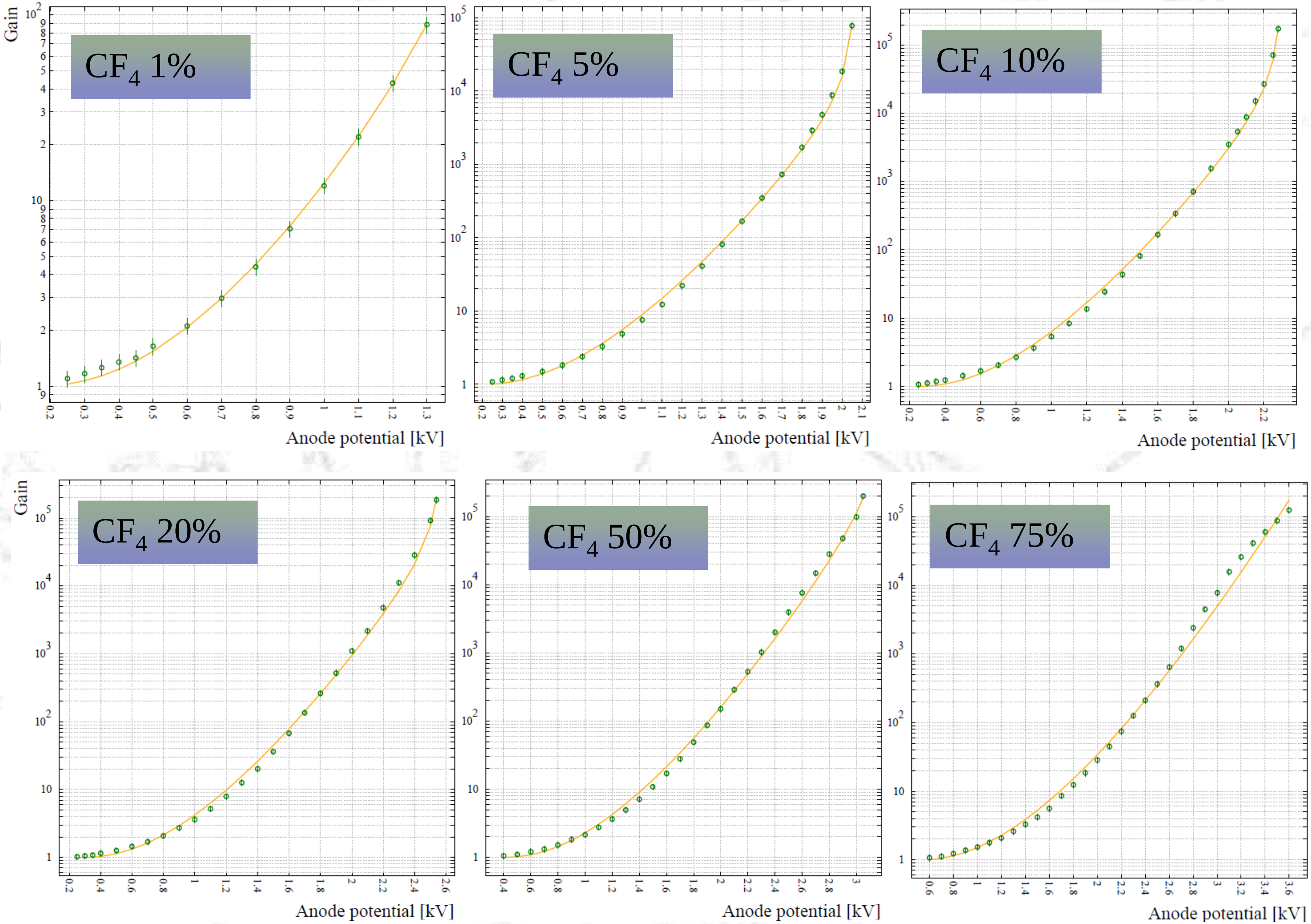


Fig. 1. Gas gain as the function of applied high voltage for Ar + CF$_4$ mixtures.

Fit results for Ar – CF_4 (without dissociative exc.)



Fit results for Ar – CF_4 (with dissociative exc.)



SUMMARY

- Magboltz calculates bigger gas gain than the measured data for TEG mixtures,
- The measurements for pure CO_2 mixtures confirm correctness of the ionisation cross sections used in Magboltz,
- Disagreement with calculation also seen for pure gases (C_3H_8, DME, iC_4H_{10}) and Ar – CF_4 mixtures,
- Dissociative excitations may lead decrease on Townsend coefficients (Ar – CF_4),
  - this is not enough to explain whole picture at the moment,
- Natural radicals like CH_2, CH_3 can be produced in the avalanche (proposed by **T.Z. Kowalski**),
  - they are very reactive; other quenchers too CH_4, C2H$_4$, C_2H_6, C_2H_2 also be present in counter volume,
  - propane has more channels; may be the reason of worse agreement.

NEXT

❖ In very soon, exact dissociative ionisation breakup channels will be introduced in Magboltz 10 (***private com. 4 December 2014,* Steve Biagi**),

- ❖ by January: for CH_4 (CH_4^+, CH_3^+, CH_2^+, CH^+, C^+, H^+ and H_2^+), probably for iC_4H_{10}, CO_2 and CF_4 , too,
- ❖ by summer: C_3H_8 and C_2H_6 may be ready,

❖ And more detailed and accurate information will be ready for excitation channels,

❖ Although we do expect minor effect of N_2 (percentage is low) for TEG mixtures, systematic gas gain measurements in pure N_2 would be very useful (seems manageable by T.Z. Kowalski),

❖ Similarly, systematic measurements for pure C_3H_8 and CH_4 would also be very useful since in literature it is very difficult to find data with **sufficient calibration** for these gases (we need gain calibration for the present measurements**!!!**).

Thanks and ???