SUMMARY OF PROFESSIONAL ACCOMPLISHMENTS

WORKING MIXTURES USED IN GASEOUS DETECTORS IN HIGH ENERGY PHYSICS EXPERIMENTS AND IN MICRO-DOSIMETRY

Tadeusz Kowalski, PhD

Faculty of Physics and Applied Computer Science

AGH University of Science and Technology

30-059 Kraków

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1. Personal Details

Name and surname:

Tadeusz Kowalski

Position:

AGH University of Science and Technology
Faculty of Physics and Applied Computer Science
Al. Mickiewicza 30
30-059 Kraków

Phone:

+48 12 617 33 75

Email:

Tadeusz.Kowalski@fis.agh.edu.pl

1.1 Academic degrees

1977 – Master of Science (technical nuclear physics)

University of Mining and Metallurgy
Faculty of Electrical Engineering, Automatics and Electronics
Thesis "Long living proportional counters filled with Ne based mixtures for X-rays of energy up to 6 keV"
Supervisor doc. dr Kazimierz W. Ostrowski

1983 - PhD in technical science (nuclear technical physics)

University of Mining and Metallurgy
Faculty of Electrical Engineering, Automatics and Electronics
Thesis "Analysis of gas gain coefficient in the mixtures of gases and vapours in the function of selected parameters"
Supervisor doc. dr Kazimierz W. Ostrowski

1.2 Employment record

1977-1978

Faculty of Electrical Engineering, Automatics and Electronics, Institute of Physics and Nuclear Techniques – assistant trainee.

1978-1980

Doctoral studies UJ-AGH, stationary studies.

1980-1983

Doctoral studies UJ-AGH, part-time study.

1980- 1993

Faculty of Electrical Engineering, Automatics and Electronics, Institute of Physics and Nuclear techniques – a science and technology specialist.

1986 -1987

European Space Research and Technology Center, ESTEC, Nordwijk aan Zee, The Netherland, under the fellowship of International Atomic Energy Agency in Venna

1993 - present

AGH University of Science and Technology
Faculty of Physics and Applied Computer Science
Assistant professor

2. Indication of the scientific achievement constituting the author's significant contribution to the development of the given scientific discipline

Pursuant to Article 16(2) of the Act of March 14th, 2003 on university degrees and university titles in arts (Journal of Laws No 65, item 595, as amended), the scientific achievement is a series of thematically related publications.

2.1 Title of the scientific achievement

"Working mixtures used in gaseous detectors in high energy physics experiments and in micro-dosimetry".

List of publication that are the basis of the proposal:

[H1] **T. Kowalski**, *Manifestation of the Penning effect in gas proportional counters,* Nuclear Instruments and Methods in Physics Research A 735(2014)528-531 (IF = 1,216).
I am the only author of the work. My percentage is 100%.

[H2] Ö. Şahin, **T.Z. Kowalski** , R. Veenhof, *High-precision gas gain and energy transfer measurements in Ar-CO_2 mixtures,* Nuclear Instruments and Methods in Physics Research A 768(2014)104-111 (IF = 1,216).
My contribution to the creation of this work consists in: developing the concept of work, making detectors, filling them with the mixture of the desired composition, performing all the presented measurements, determining the gas gain cefficient, interpreting the results obtained. I participated in preparing the text of the publication and in discussions with the reviewers. My percentage is estimated at 51%.

[H3] Ö. Şahin, **T.Z. Kowalski** , R. Veenhof, *Systematic gas gain measurements and Penning energy transfer rates in Ne – CO_2 mixtures,* Journal of Instrumentation, 2016 JINST 11 P01003 (IF = 1,310, 2015 year).

My contribution to the creation of this work consists in: developing the concept of work, preparing detectors for measurements, determining the concentration of extinguishing agent, filling the detectors with the desired composition and pressure, performing all presented measurements, determining the gas gain, interpreting the results obtained. I participated in preparing the text of the publication and in discussions with the reviewers. My percentage is estimated at 60%.

[H4] Ö. Şahin, **T.Z. Kowalski**, *Measurements and calculations of elektron avalanche growth in ternary mixture of Ne – CO_2 – N_2*, Journal of Instrumentation, 2016 JINST 11 P11012 (IF = 1,310 2015 year).

My contribution to the creation of this work consists in: the development of the concept of work, the performance of all presented measurements, the determination of gas gain, the interpretation of the results obtained, the determination of the constant characteristic of the mixture. I have prepared the text of the publication and have a discussion with the reviewers. My percentage is estimated at 75%.

[H5] Ö. Şahin, **T.Z. Kowalski**, A comprehensive model of Penning energy transfers in Ar – CO_2 mixtures, Journal of Instrumentation, 2017 JINST 12 C01035 (IF = 1,310, 2015 year).

My contribution to this work consists in: measuring gas gain for different concentrations of CO_2 and different pressures of the mixture, modeling of energy transfer in the Penning effect, physical interpretation of the obtained constants, preparing the text of the publication. My percentage is estimated at 50%.

[H6] **T.Z. Kowalski,** *Gas gain limitation in low pressure proportional counters filled with TEG mixtures, Journal of Instrumentation*, 2014 JINST 9 C12007 (IF = 1,399).

I am the only author of the work. My percentage is 100%.

[H7] **T.Z. Kowalski**, *Microdosimetric response of proportional counters filled with different tissue quivalent gas mixtures,* Journal of Instrumentation, 2015 JINST 10 C03006 (IF = 1,310).

I am the only author of the work. My percentage is 100%.

[H8] **T.Z. Kowalski,** *Gas gain limitation in low pressure proportional counters filled with TEG mixtures – part II,* Journal of Instrumentation, 2016 JINST 11 P01009 (IF = 1,310 2015 rok).

I am the only author of the work. My percentage is 100%.

[H9] **T.Z. Kowalski,** *Factors limiting the linearity of response of tissue equivalent proportional counters used in micro- and nano-dosimetry*, Journal of Instrumentation, 2017 JINST 12 C01075 (IF = 1,310 2015 rok).

I am the only author of the work. My percentage is 100%.

In the works [H1] - [H5], a dual approach to physical phenomena occurring in gas detectors has been presented. One can be called an "analog approach". We create a model of physical phenomena with a number of simplifying assumptions. We obtain the formula for Townsend's first ionization coefficient, α / p, and the corresponding formula for gas gain. In the appropriate coordinate system, the measurement results should be in a straight line. The linearity range determines the suitability of a given formula for describing physical phenomena in a detector. Based on the measurements, we can determine certain constants characteristic for a given mixture such as the effective ionisation potential, the average energy value the electron gains from the field between successive ionic collisions, the field strength at which avalanche multiplication begins, the average free ionization path, the radius of electrons avalanche. These constants give an average information about the phenomena in the detector. The formulas obtained can be applied to each mixture and whether or not they are useful. The second approach would be called a "digital approach." Using the MAGBOLTZ program, one can trace the movement of a single electron in a given gas mixture at a given distribution of electric field. This requires, however, knowledge of the cross sections on the interaction of electrons with the individual components of the detector operating gas. Calculations can only be made for those mixtures for which these cross-sections are known. In the works [H1] - [H5] characteristic constants for mixtures were determined using both analogue and digital approaches. In the case of determination of the second Townsend ionization coefficient, β, the values obtained [H4] in "analog" and "digital" approach were compared. These are two complementary methods.
Gas counters are one of the basic types of detectors used in micro- and nano-dosimetry. According to ICRU recommendations, the dose should be measured with accuracy below 5%. In papers [H6] - [H9], there are presented factors limiting the use of gas detectors in micro- and nano-dosimetry. Factors resulting from the physics of phenomena occurring in the detector, limiting the minimum and maximum measured dose of radiation, as well as limiting the size of the simulated by the detector biological object.

2.2 Introduction

Much of our knowledge about the nature of nuclear radiation, atomic structure, elements of the structure of matter, natural and artificial isotopes of elements and their applicability, we owe the fact that the methods of detection and counting of individual particles, in the years following the discovery of radioactivity became more and more accurate. Single particles of nuclear radiation were initially observed by scintillation, which consisted of the fact that when the α particle hit the crystal, for example a zinc or diamond blend, it produced such an intense light effect that it could be observed with the naked eye. With this method, it was possible to detect only α particles or at most protons, the light effects of individual electrons were too weak to be observed in such a simple way. The use of this method was cumbersome and subjective, but thanks to it the basic information about the existence of

atomic nucleus was obtained. In 1908, Rutherford and Geiger described the first gas ionisation counter for α particles. It consisted of a cylindrical metal tube in which an axially thin wire was attached. The ends of the tubes were closed, the inside was air or another gas at a lower pressure. There was a voltage between the cylinder and the wire that there was no spontaneous discharge. When α particles passing through a thin window parallely to the axis of the cylinder, a ionization current was generated which could be recorded. The primary ionisation generated by α particles in the gas filling the tube was amplified about a thousand times. In the gas gain mode, the pulse size was already many times greater than the original ionization but still proportional to it. In the geiger mode, minimal primary ionization produces a discharge in which the pulse height no longer depends on the size of the primary ionization. Particularly interesting and mostly study is the proportional mode (with gas gain) and Geiger's mode. These two modes have been specifically studied for different mixtures, working gas pressures and detector geometry. The possibility of detecting neutrons using a boron trifluoride counter in the mixed field of radiation with the β and γ using the proportional mode of the BF_3 counter was used. Counters were initially filled with clean gases, such as noble gases, but in these meters the values of the gas gains obtained were not high. Huge advances in gas detectors technology have been attributed by Trost (1935) to the fact that adding a few percent alcohol to the filling gas significantly changes the properties of the counters. This has significantly improved energy and time resolution. It took many years for the work of numerous researchers to at least learn to understand the processes taking place in the counters. Interest has mainly turned to proportional counters because they allow not only the detection of particles but also to measure their energy, ionization density and time correlation (coincidence measurements).
For gas detectors, the filling gas mixture is of particular important because its determines detectors properties and their fields of application.

2.2.1 Gas mixtures in high energy physics experiments

The harsh working conditions of gas detectors in high energy physics experiments place high demands and significant limitations on the choice of working gas:

- The gas must provide a high radiation recording efficiency of over 95%;
- The gas must be fast to minimize the overlapping of pulses over time, the charges generated by the resulting particles from the previous and next beams collisions. The gas mixture must contain the highest possible concentration of fast gas molecules such as CF_4, O_2 so that the detector can operate at frequencies of the order of MHz;
- The gas must provide stable detector performance over a wide range of supply voltage, long detector life time counted by the value of the collected charge per unit length of the anode, eg 5C / cm, for high radiation intensities reaching up to 200 kcps / (cm anode length);
- The gas mixture should be non-flammable, non-toxic, non-explosive, ecological and cheap one, if possible.

As the base gas most commonly used is Ar, and Xe in the transition radiation detectors. Adding to the main gas CF_4 pairs significantly increases the speed of the mixture, but does not ensure stable operation of the detector. In this mixture the spark discharges are observed. Another components are added to quench them. It can be CO_2, N_2, DME or other organic vapours. Most often, working mixtures are two- or three-component and sporadically four-component.

Charge collection time is a critical parameter for gas detectors working in high energy physics experiments. It is determined by the electron drift velocity, its dependence on the electric field strength in the detector and on the direction of the external magnetic field. The detectors may be located in parallel or perpendicular to the lines of external magnetic field. The presence of the magnetic field extends the collection time and the amount of elongation depends on the mutual orientation of the electric and magnetic fields. In practice, the total collection time depends on the component of the drift velocity parallel to the electric field lines, which is difficult to measure directly but can be calculated from the MAGBOLTZ program. This component decreases violently in the presence of a magnetic field, with an electrical field strength of less than 4 kV / cm. Such fields are present in the detector at a distance of more than 1 mm from the anode wire. Even for straw detectors with a radius of 2 mm, the influence of the external magnetic field is considerable. In HEP experiments, where we have several hundred thousand or even several million read-out channels, the cost of a single electronic read-out channel is important. We expect for gas detectors to work with the highest gas gain possible to achieve a good signal to noise ratio. This also makes it possible to lower the cost of single read-out electronic channel, so with so much numbers of channels gives one high cost-effectiveness. The value of the working gas gain is limited by the planned detector life time (the value of the charge collected per unit length of the anode). For higher values of gas gains, the effect of space charge in a single electron avalanche as well as the secondary phenomena described by the second Townsend ionization coefficient give a significant nonlinearity of the detector response. In the gas detectors, based on the above mentioned limits, the range of gas gain variation from ~ 10^4 to 7×10^4 was determined. The lower value is due to the noise of the read-out electronic and the upper nonlinearity of the response is due to the physical phenomena occurring in the detector.

Performance of proportional counters at high gas gain is often accompanied by a SQS-Self Quenching Streamer discharge, whose probability of occurring is increasing very rapidly with increasing detector voltage (gas gain). The charge generated in the SQS discharge is approximately 10 times greater than the charge generated in the proportional mode. Fast electronic component of this discharge has an amplitude of approximately (100-200) times greater than that of the analogue in the proportional discharge. Such a large signals lead to reloading of the reading electronics, inducing dead time in the preamplifier. To keep the dead time of the electronic measuring circuit to be below (1-2%), the probability of SQS discharge should be less than 10^{-3}. This is another factor limiting the maximum gas gain.

When the working gas gain is already established, factors that may change them should be taken into account, because they can degrade the parameters of the whole detector. These factors may be atmospheric pressure changes (in the flow systems the working gas pressure is several millibars higher than the atmospheric pressure), temperature gradients in the detector area, change in the composition of the working gas. Changes in pressure and composition of the mixture can easily be corrected by changing the supply voltage so that the gas gain is constant. Temperature compensation is often not possible because different parts of the detector may have different temperatures.

The detectors record both minimal ionizing particles depositing about 3 keV/cm, as well as particles from hadronic cascades that deposit several MeV / cm energies, so the energy is about 1000 times higher than for the minimum ionizing energy. For a such large energy deposits, the detector work in proportional mode only to the gas gain of about 100. Above this value there are sparks.

Detectors work at radiation rates up to 15 MHz. With such a large streams of recorded particles we observe a phenomenon called transient /temporary aging. This causes the pulse amplitude to drop by up to 10%. This effect appears very soon after the detector's exposure starts and reaches saturation in a few minutes. The temporary ageing effect is caused by radicals generated in electron avalanche, fragments of extinguishing vapors that change the composition of the working gas locally. This effect limits the highest count rate and the lowest gas exchange rate.

The quality of the anode wire used, the quality of the cathode surface, the centering of the anode wire are the factors that significantly affect the stability of the detector performance. Unfavourable working environments impose strict requirements on gas detectors especially for the selection of working mixture and technology of detector manufacturing.

2.2.2 Position sensitive gas detectors for high energy physics experiments.

In high energy physics experiments (HEP), gas detectors are widely used. The Multi Wire Proportional Chamber (MWPC), the Drift Chamber (DC), the Straw Tube (ST), the Time Projection Chamber (TPC) and the Resistive Plate Chambers(RPC). Their use is best demonstrated by the currently working experiments on the LHC accelerator.

In the CMS experiment [1], **drift Chambers** with rectangular drift cells (42 x 13 mm^2) filled with a mixture **of 85% Ar-15% CO_2** with a position resolution of ~ 100 μm with 172000 read-out channels are used to detect miuons in the central part. 468 Cathode Strip Chambers are used in the CMS Endcap Muon system to provide 220000 cathode strip read-out channels and 180000 anode wire read-out channels. The Trigger system in this experiment is based on a resistive cathode chambers (RPC) filled with 96,2% $C_2H_2F_4$ – 3,5% iC_4H_{10} - 0,3% SF_6 with a total area of 2400 m^2 and the number of read-out strips of 80640.

In the LHCb experiment [2], the external tracker is a 4.9 mm array of **gas straw tube detectors**, filled with a mixture of **70% Ar-30% CO_2**, with a position resolution of 200 μm and 55,000 read-out channels. The internal tracking system is based on 12 chambers of triple GEMs gas detectors with 2300 read-out channels. The muon detection system is a multi-wire proportional chamber (rectangular in cross section) filled with a mixture of 40% Ar-55% CO_2-5% CF_4 giving 3×10^6 read-out channels with a total area of 435 m^2.

TOTEM Experiment [3] employs **Cathode Stripe Chambers** (11100 anode read-out channels, 16000 cathode stripe read-out channels, **50% Ar-50% CO_2** as the working gas) and 40 **triple-GEM** type detectors filled with **70%Ar - 30% CO_2,** having 3176 read-out channel, in total.

In the ALICE experiment [4] the **Time Projection Chamber** with the volume of 90 cubic-meter, filled with a mixture of **90% Ne - 10% CO_2 - 5% N_2** is the main tracking detektor of the central barrel and is optimised to provide charge-particle momentum measurements with good two-particle separation, particie identification and vertex determination. As a read-out system of this chamber, the multi wire proportional chambers with cathode pads have been selected. The drift gas **Ne/CO_2/N_2** was optimised for drift speed, low diffusion, low radiation length, small space-charge effect, and ageing and stability properties. TPC has 558000 channels of electronic readout.

Drift chambers with the multi wire proportional chamber with pad readout have been selected to provide electron identification in the central barrel (1.2×10^6 reading channels, 85% Xe - 15% CO_2 working mixture, 27 m^3 working gas volume). Multi-gap Resistive Plate Chambers (171m^2, 17.5 m^3 and 157,000 readout channels) were used for particle identification in the intermediate momentum range by the time-of –flight method.

The sensitive element of the **photon multiplicity detector** consists of large arrays of gas proportional counters in a honeycomb cellular structure filled with a mixture of **70% Ar-30% CO_2** and having 221000 readout channels.

Cherenkov counters, **charge particle veto detectors** and **muon spectrometers** have a multi- wire pad chambers filled with CH_4 or **80% Ar - 20% CO_2**, respectively, giving another million readout channels, hundreds of square meters of detector surface.

One of the component of the ATLAS internal detector [5] is a system of 350000 **cylindrical straw tubes** with a diameter of 4 mm, filled with a mixture 70% Xe - 27% CO_2 - 3% O_2. A mixture containing **70% Ar – 30% CO_2** has been used during straw quality control and cosmic ray studies. It fulfills a double role, gives an average of 36 measurement points on a particle track and is used to identify electrons. ATLAS Muon Detection Systems include Monitored Drift Tubes (MDTs), Cathode Strip Chambers (CSC), Resistive Plate Chambers (RPCs) and Thin Gap Chambers (TGC).

The basic element of the **monitored drift tube** chambers is a pressurized drift tube with a diameter of 30 mm, operating with **97% Ar – 7% CO_2** at 0,3 Mpa. The total area of this component is of 5500 m^2. The chambers work at a gas gain of $\sim 2 \times 10^4$, giving a spatial resolution of ~ 80 μm. The number of readout channels is 340000.

In the front part of the detector, for pseudorapidity greater than 2, the MDTs have been replaced by **multi-wire cathode-strip tubes** which combine high spatial (~ 60 μm) time and double track resolution with high-rate capability, filled with a mixture of **80% Ar-20% CO_2**, working at gas gain 6×10^4. The total number of readout channels is 30720.

The Resistive Plate Chambers (RPCs) are a gaseous parallel electrode-plate detector. RPC's can be operated both in avalanche and streamer mode. RPCs in the ATLAS experiment contain 14 m^3 of the working gas.

Thin gap chambers are multi-wire proportional chambers with the characteristic that the wire-to-cathode distance is smaller than the wire-to-wire distance. They work in quasi-saturated mode, i.e. with a gas gain of $\sim 3 \times 10^5$, working gas is 55% CO_2 - 45% n-$C5H_{12}$. The volume of these chambers is 16 m^3.

The total number of readout channels from gas detectors in the ATLAS experiment is about 1.4×10^6.

The above mentioned gas detectors are used in high energy physics experiments only on one accelerator. Design diversity, GEM micro type detectors, cylindrical detectors 4 mm and 30 mm in radius, cylindrical or hexagonal (honey comb) in cross section, single- and multi-anodes, working in proportional mode, in quasi-saturation mode or in SQS mode. Number of read-out channels counted in millions show the very good condition of gas detectors. In all experiments, multi wire proportional chambers with stripped or pad cathode are used. Under this name are detectors with different thicknesses of the gas layer, different distances between anode wires, different widths of cathode strips and pad dimensions as well as filled with various gas mixtures. The spatial resolution of gas detectors is not as good as semiconductor detectors, but they provide much more measurement points on the particle track, up to several dozen. They are used wherever large areas are required to be covered by the detectors. In the above text, the detectors filled with mixtures which were studied in H2, H3, H4 and H5 are bolded.

2.2.3 RD51 Collaboration ”Development of Micro-Pattern Gas Detector Technologies”

The culmination of work on gas detectors was awarded to Prof. Georges Charpak Nobel Prize in Physics in 1992 for his invention of particle detectors, in particular the multi wire proportional chamber. Developed by Prof. G. Charpaka's multi wire proportional chamber made it possible to measure high radiation intensity (~ 10^6 cps), providing a spatial resolution of ~ 300-400 μm. Furthermore, the information from the chamber was electronically ready for further processing (from previously used bubble chambers the photos of particle traces had to be scanned for useful information for further calculations.) For some time it seemed that with the Nobel Prize and with the departure of Prof. G. Charpaka's retired gas detectors will also be retired.

The development of photolithography, plastic etching, and demand from detector users has led to the development of micro-type gas detectors like MSGC (Micro Strip Gas Chamber), MICROMEGAS [7] (MICROMEGAS - Micro Mesh Gaseous Structure) or GEM [8] (GEM - Gas Electron Multiplier). Micro-detectors provide high gas gain, high detection efficiency, very good spatial and energy resolutions, long life-time and the ability to operate in very high radiation streams.

The work on the development of gas detectors of the micro type and classical one gas detectors is carried out and coordinated within the framework of the RD51 Collaboration at CERN. It should be stressed that the RD51 collaboration was developed as a response to the demands of detector users, for example, the GEM electron multiplier was developed as a "lifebuoy" for the HERA B experiment on the HERA accelerator at the DESY research center in Hamburg. The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research. The development of gas microstrip detectors (MPGDs), gas electron duplicators (GEMs) or micro mesh detectors (MICROMEGAS) offers the potential for industrial construction of new types of gas detectors, particularly interesting if the detectors have to cover a large area.

Advances in particle physics have always been enabled by parallel advances in radiation-detector technology. Radiation detection and imaging with gas-avalanche detectors, capable of economically covering large detection volumes with a low material budget, have been

playing an important role in many fields. Besides their widespread use in particle-physics and nuclear-physics experiments, gaseous detectors are employed in many other fields: astro-particle research and applications such as medical imaging, material science, and security inspection. While extensively employed at the LHC, RHIC, and other advanced HEP experiments, present gaseous detectors (wire-chambers, drift-tubes, resistive-plate chambers and others) have limitations which may prevent their use in future experiments. Present techniques will not be capable of coping with the expected high-flux and high-repetition rates, and often will not provide the needed space point resolution. For example, point resolution in large-volume TPCs based on wire read-out will suffer from high fluxes of back flowing
ions and from the limited granularity of the readout; particle-trackers will not withstand the high fluxes and will require large-area high-resolution localization; calorimeters will need better and faster sampling elements; Cherenkov detectors in particle and astro-particle experiments will require more efficient and robust large-area photon detectors; rare-event cryogenic noble-liquid detectors for dark matter, neutrino-physics double-beta decay and other searches will require large-volume detectors with adequate economic low-radioactivity readout elements. Besides resolutions - radiation hardness, rate capability and economic aspects related to production costs are of major concern. The possibility of producing micro-structured semi-conductor devices (with structure sizes of tens of microns) and corresponding highly integrated readout electronics led to the success of semi-conductor (in particular silicon) detectors to achieve unprecedented space-point resolution. Micro-structured gas amplification structures now open the possibility to apply the same technology to gaseous detectors and enable a plethora of new detector concepts and applications. Particle detection through the ionization of gas has large fields of application in future particle, nuclear and astro-particle physics experiments with and without accelerators. For these reason the formation of a world-wide collaboration, RD51, for R&D on MPGDs aiming at efficient
coordinated effort to advance the development of MPGDs and associated technologies was proposed. The RD51 collaboration involves 450 authors, 75 Universities and Research Laboratories from 25 countries in Europe, America, Asia and Africa. All partners are already actively pursuing either basic- or application-oriented R&D involving a variety of MPGD concepts. The collaboration established common goals, like experimental and simulation tools, characterization concepts and methods, common infrastructures at test beams and irradiation facilities, and methods and infrastructures for MPGD production. An intensified
communication between the cooperating teams will be fostered in order to better understand and solve basic and technical issues and to solve common problems connected e.g. to detector optimization, discharge protection, ageing and radiation hardness, optimal choice and characterization of gas mixtures and component materials, availability of adequate simulation tools, optimized readout electronics and readout integration with detectors, as well as detector production aspects. Summarizing, the main objective of the R&D programme is to advance technological development and application of Micropattern Gas Detectors.

Collaboration RD51 started its activities in 2008, the founding group covered 298 authors from 57 universities and research laboratories. Currently, as I mentioned, the collaboration includes 450 authors (up 51%) and 75 universities (up 32%). At the collaboration meeting in February, 2017, two further groups from the University of Mainz and the Instituto Gallego de Fisica de Altus, University of Santiago de Compostela were accepted for cooperation. Collaboration is working intensively on the next generation of gas detectors and electronic readings that meet the requirements of the modernized LHC.

I am an active member of this collaboration. I am a co-author of a number of talks at working meetings (RD51 Mini-Week). My experimental data is the basis for simulating the development of an electron avalanche in any detector geometry. Works H2 to H9 were created within this collaboration.

2.3 Penning effect

F. M. Penning [9], measuring the starting potential of the glow discharge in the Ne + Ar mixtures between large parallel platter, has seen a significant reduction in its value for argon concentrations below 0.01%. In dedicated measurements using polonium alfa particles (5,298 MeV) W.P. Jesse and J. Sadauskis [10] received a significant reduction in the W value for tracer argon concentration , in mixtures He + Ar and Ne + Ar. For pure spectral He obtained W = 41.3 eV / (ion pair) and for He + 0.13% Ar only 29.7 eV / (ion pair), while for spectral pure Ne and Ne + 0.12% Ar respectively 36.3 eV and 26.1 eV / (ion pair). During the interaction of the measured radiation with the detector gas mixture, in addition to ionizing the atoms of the mixture, we have excited them to the metastable levels, M^m, or to the resonance levels, M*. The return of the excited atoms of the main gas of the mixture to the ground state without photon emission can be due to collisions with atoms or molecules of dopants if the energy of the metastable or excited states is higher than the dopant ionization potential

$M^m + B \rightarrow M + B^+ + e^-$ (Penning effect) (1)
$M^* + B \rightarrow M + B^+ + e^-$ (Jesse effect). (2)

In Penning's effect the production of additional electrons is effected by the interaction of the atoms of the main gas excited to metastable levels with the atoms/moleculars of the quenching admixture while in Jesse the atoms are excited to the optical (resonant) levels [11, 12]. At present, both processes (1) and (2) are known as Penning effects respectively on metastable and resonant levels [13, 14]. The Penning effect (Jesse effect) has a significant impact not only on primary ionization but also on the development of electron avalanche in the proportional counter.

2.3.1 Development of electron avalanche in the mixtures of gases and vapors.

The electrons produced in the primary ionization process are diffused and drifted in the electric field. As a result of interaction with the electric field, the distribution of electrons energy is so wide that they can excite to metastable states, M^m, resonant levels, M *, and ionize the atoms/molecules of the mixture in collisions:

$$e^- + M \rightarrow e^- + M^m \quad (3)$$
$$e^- + M \rightarrow e^- + M^* \quad (4)$$
$$e^- + M \rightarrow e^- + M^{*+} + e^- . \quad (5)$$

Atoms or molecules of gas excited to resonance levels, M *, have a short lifetime of the order of ~ ns and after that they are de-excitated to their basic state by photon emission:

$$M^* \rightarrow M + h\nu. \quad (6)$$

Atoms in metastable states, M^m, have a life time of ~ μs. During this time, they can create so-called excimers in three body collisions,

$$M^m + M + M \rightarrow M_2^* + M . \quad (7)$$

Excimers are an excited molecules that return to its base state emitting continuous-spectrum of photons:

$$M_2^* \rightarrow M + M + h\nu. \quad (8)$$

Created in process (5) excited ion can de-excite by emitting a photon or passing an excitation energy to another atom:

$$M^{*+} \rightarrow M^{+} + h\nu, \tag{9}$$

$$M^{*+} + M \rightarrow M^{*} + M^{+}. \tag{10}$$

So in the zone of electron multiplication we have electrons, ions, photons and excited atoms. If the gas filling the detector is a mixture of gases and vapours, then the process (1) may additionally occur, and if the ionization potential of the dopant B is lower than the ionization potential of the main atom M, then the process (2) will also take place with high probability. In addition, photons produced in processes (6), (8) and (9) can ionize dopant B:

$$h\nu + B \rightarrow B^{+} + e^{-} . \tag{11}$$

The basic development of the electron avalanche occurs through collision ionization (5). The processes (1), (2) and (11) are the source of additional electrons modifying the gas multiplication process.

2.4 Description of the scientific objectives of the achievement forming the basis for habilitation proceeding.

2.4.1 Manifestation of Penning effect in gas gain curves.

The gas gain factors in the range from 1 to 8×10^{3} were measured for the Ar + iso-pentane mixtures, starting from spectroscopically pure argon to 5% dopant content as a function of detector supply voltage, for a total mixture pressure of 880 hPa. A cylindrical proportional counter of cathode radius r_k = 14,5 mm with an axially placed anode of radius r_a = 50 μm, was used for measurements. The counter was connected to a vacuum system, enabling rapid changes in counter filling. The value of the gas amplification factor was measured using the current method. The gas gain, A, has been determined as the ratio I/I_0, where I and I_0 are the measured current intensities at constant intensity of the incoming photons of X-rays for the applied voltage and for the ionization chamber regime, respectively. ^{55}Fe radioisotope, of X-rays 5,9 keV or ^{90}Sr, (β source of maximal energy of 2,3 MeV)were used as the radiation sources. To minimize the error in I_0 and the dark current a special grid of guard rings protecting the anode has been constructed. Value of current I was always below 2 nA to eliminate the so called space charge effect. The accuracy of measurements of the gas amplification factor is limited by the error of measuring the current I0 in the ionization chamber regime, and of measuring the current intensity, I, for different voltages ($\Delta I_0/I_0 \sim 2{,}5$ % and $\Delta I/I \sim 2$ %). The concentration dependence of the gas gain coefficient, A(c), for a fixed high voltage is presented in Fig. 1, where a wide maximum at concentrations $10^{-4} - 10^{-2}$ is seen. This maximum is due to increase of the first Townsend ionization coefficient α induced by the generation of additional electrons by the Penning effect in the electron avalanche multiplication region. For admixture concentration $c \leq 5 \times 10^{-3}$ the increase of the gas gain is due to increase of the probability of process (1), on the other hand, the increase of c cools the electrons leading to decrease of A. Energy levels of metastable and resonant states of argon are 11.55; 11.72; 11.62 and 11.83 eV, the ionization potential of iso-pentane is 10.45 eV, so the energy condition of the process (1) is fulfilled.

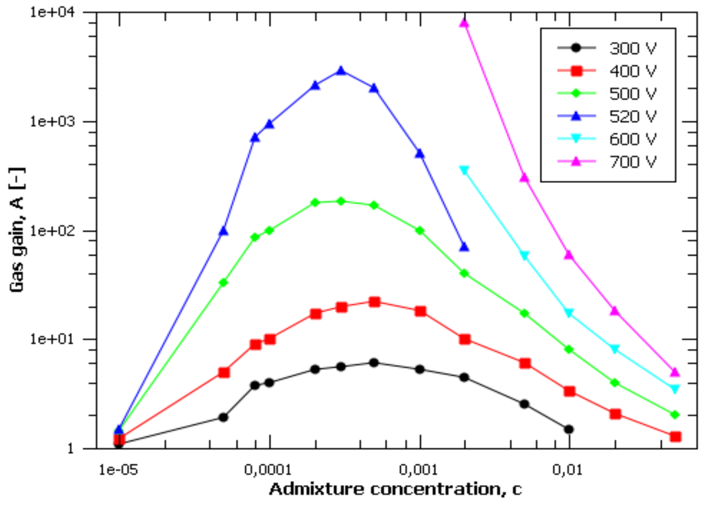

Fig.1 Concentration dependence of gas gain coefficient A, for Ar – isopentane mixtures for fixed applied high voltage. The occurrence of Penning effect is manifested by the wide maximum. Spectoscopically pure Ar is marked as admixture concentration of 10^{-5} [H1, 15].

2.4.2 Manifestation of the Penning effect in concentration dependence on effective ionization potential [H1]

The basic factor describing the development of electron avalanche is the first Townsend ionization coefficient α, which represents the amount of ion-electron pairs generated by the electron moving in the direction of the electric field per unit length. α depends on the type of gas, its molecular properties and the electric field strength. Aoyama [14] proposed and obtained that:

$$\frac{\alpha}{p} = K\, S^{m} \exp(-L/S^{1-m}), \qquad 0 \le m \le 1 \tag{12}$$

and derived for gas gain A:

$$\frac{\ln A}{p\, r_a\, S_a} = \frac{1}{1-m}\,\frac{1}{V_i} \exp(-L\, S_a^{m-1}), \tag{13}$$

where: K, L and m – characteristic constants for the gas mixture, S_a - reduced electrical field strength on anode surface and V_i - effective ionization potential, p – working gas pressure.

The V_i was defined as:

$$e \int_{r}^{r+\lambda_i} E\, dr + \varepsilon_0 = e\, V_i\,, \tag{14}$$

where: r – any point in the counter, λ_i - the mean path length for an electron to travel in the field direction to ionize a gas molecule, ε_0 - initial electron energy, energy which electron has immediately after the scattering by a gas molecule averaged in the field direction, e –

elementary charge and E - electrical field strength. The left side of eq. (14) is just the sum of the energy that an electron gained from the electric field and, ε_0 , so eV_i is just the energy of electron just before next ionizing interaction. Equation (13) can be reduced to the linear relation between S_a^{m-1} and *ln [lnA/ (p* r_a S_a*)]:*

$$ln\left(\frac{lnA}{p\, r_a\, S_a}\right) = - L\, S_a^{m-1} - lnD, \qquad (D = (1 - m)\, V_i). \tag{15}$$

This formula in reality contains three unknown parameters *L, D* and *m*. For the measured, experimental data of gas gain, *A*, using the method of least square, for *m* varying from 0.05 to 0.95 in step of 0.01, the values of *L* and *M* were calculated. On the base of correlation coefficient the best fit was selected, thus giving the proper value of *L, D* and *m*. As *D = ln[(1 – m)* V_i*]*, the value of V_i was re-counted. Values of V_i for Kr + cyclohexane, Kr + ethanol and Kr + isopentane as function of admixture concentration are shown in Figs. 2, 3 and 4. Energy values of metastable and resonant levels of krypton are 9,915; 10.56 and 10.03; 10.64 eV and ionization potential of dopants respectively: 10.3; 10.49 and 10.6 eV. Ionisation potentials of dopants were selected so that processes (1) and (2) could only take place at certain excited levels. A wide minimum in $V_i(c)$ dependence (Figs. 2 and 3) for concentration from 3×10^{-5} to 6×10^{-3} is due to process (1) and much smaller but clearly seen (Figs. 2, 3 and 4) for admixture concentration *c* ~ (2 – 3) % is due to process (2). The time constant, τ, the disappearance of the number of excited atoms depends on many factors, formula (16),

$$\tau^{-1} = k_1 p_M^2 + k_2 p_B^2 + k_3 p_M + k_4 p_B + k_5 p_M p_B + \tau_0^{-1}, \tag{16}$$

where k_1 - k_5 are the constants of the different collisional reaction rates, p_M and p_B are respectively the partial pressures of the component M and B and τ_0 is the life time of the excited levels. Excited levels can be de-excited both in three body collisions ($\sim p_M^2, p_B^2, p_M p_B$) as well as two body collisions ($\sim p_M, p_B$), and the Penning effect is only one of the possible channels of de-excitation; therefore, the minimum of V_i potential is a function of the dopant type and pressure of the mixture .

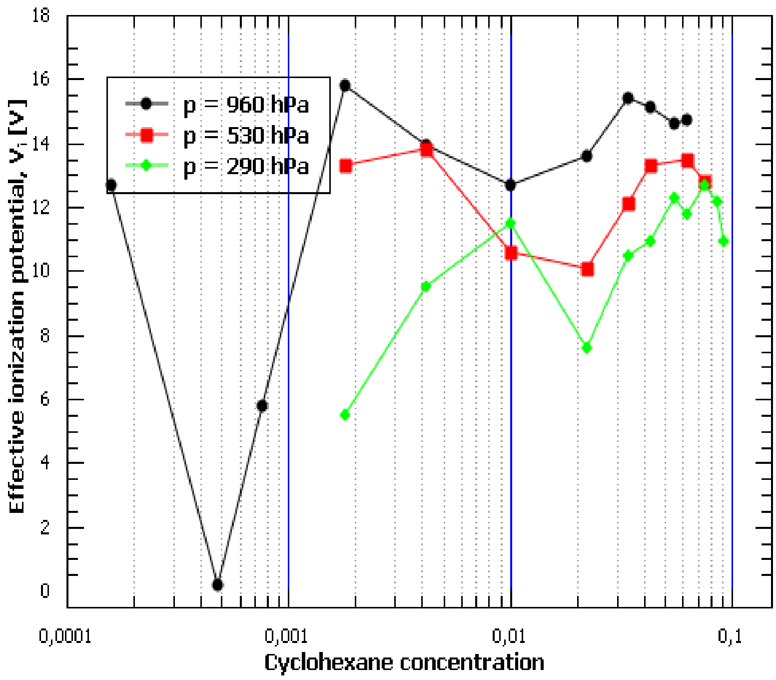

Fig. 2. Concentration dependence of V_i for Kr + cyclohexane mixtures. Concentration 10^{-5} means spectroscopically pure Kr. Concentration, c (near 1-3%), for which V_i reach minimum is proportional to $c \sim 1/p$. This implies that the life time of the resonance states does not depend on p for the studied range of pressures. $V_i \approx 0$ ($c = 4.8\times10^{-4}$) means that there is no direct ionization, electron multiplication is only via the Penning effect, process (1) [H1].

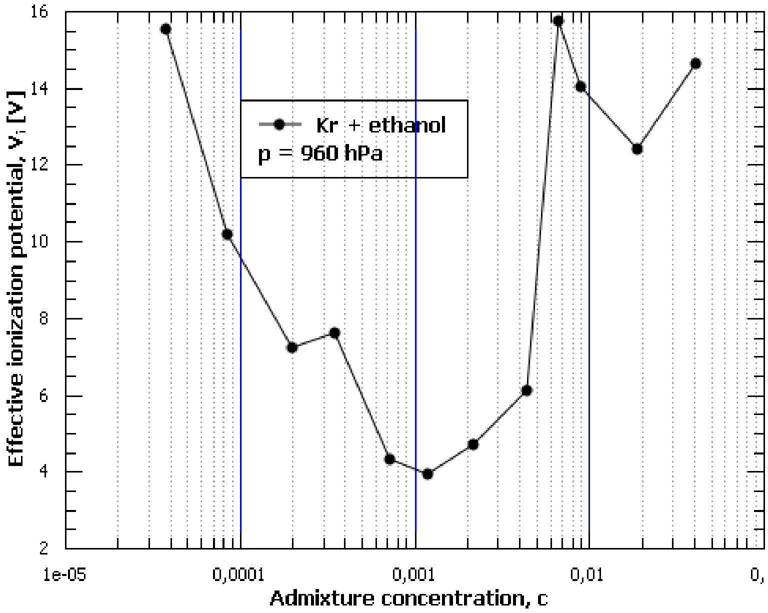

Fig. 3. Effective ionization potential V_i, as function of ethanol concentration in Kr. Due to the value of ethanol ionization potential (10.49 eV), the Penning effect is only for one metastable level (10.56 eV) and one resonance level (10.64 eV) [H1].

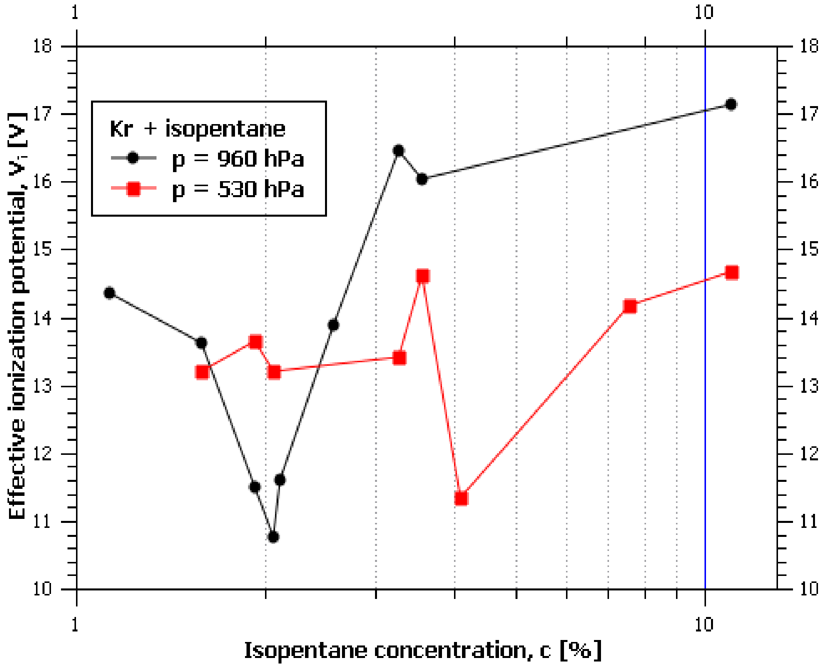

Fig. 4. Effective ionization potential V_i, as function of isopentane concentration. There is only one minimum for admixture concentration c ~ (2-4)%, caused by the process (2) [H1]. Penning effect is only on one krypton resonance level with energy of 10.64 eV.

2.4.3 Manifestation of the Penning effect in the α/p concentration dependence

Zastawny [17] points out that in counter of cylindrical geometry, the expression

$$\frac{\ln A}{p\, r_a\, S_a} = \int_{S_0}^{S_a} \frac{\alpha}{p} \times \frac{dS}{S^2} = F(S_a)\,. \tag{17}$$

is unique function of reduced electrical field strength at the anode surface S_a. Knowing the geometrical dimensions of the counter (r_a - anode radius and r_k - cathode radius) and the filling gas pressure, p, we can calculate S_a and by measuring the dependence of the gas gain coefficient, A, on the voltage applied between the anode and the cathode one can calculate the function $F(S_a)$. Using the semi-empirical formula of Townsend for α/p, eq. (18),

$$\frac{\alpha}{p} = C_1 \cdot e^{-\frac{C_2}{S}}\,, \tag{18}$$

the gas amplification coefficient can be expressed as, eq. (19),

$$\frac{\ln A}{p\, r_a S_a} = F(S_a) = \frac{C_1}{C_2} \cdot e^{-\frac{C_2}{S_a}}\,. \tag{19}$$

The constants C_1 and C_2 are determined from the measurements of the gas amplification factor, *A*. Using the formula (18) and experimentally determined constants, C_1 and C_2, α/p has been calculated and displayed in Fig. 5 as the function of CO_2 concentration for fixed reduced electrical field. Peak in α/p is observed for CO_2 concentration near 20% for high value of reduced field strength, higher than 80 [V m^{-1} Pa^{-1}]. The increase in the α/p can be explained by the Penning effect. The excited Ar atoms to 3D levels in the reaction, eq. (2) provide to production of additional electrons.

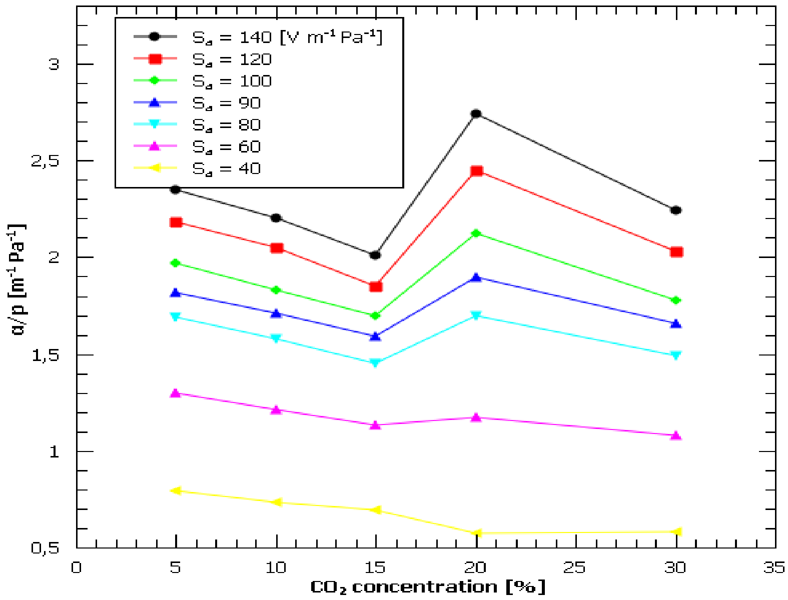

Fig. 5. Dependence of α/p on CO_2 concentration in Ar. Reduced electrical field strength on anode surface S_a, is the curves parameter. The ionization potential of CO_2 is 13,79 eV. In this mixture the Penning effect occurs on the 3D resonance levels of 14.09 and 14.26 eV [H1].

2.4.4 Penning adjustment of α/p in Ar – CO_2 mixture [H2]

The gas gain, A, including Penning adjustment for a single wire tube can be written as:

$$A = \exp \int_{r_m}^{r_a} \alpha_{Pen} E(r) dr \qquad (20)$$

here, r is the radial distance from the anode wire, r_m is the starting point of the multiplications ($\alpha > 0$) and E(r) is the electric field at point r for the given voltage. Adjusted Townsend coefficient α_{Pen} is defined with the following expression [H2, H3, H4, H5]:

$$\alpha_{Pen} = \alpha \times (1 + r_{Pen} \frac{f_{Ar}^{exc}}{f_{mix}^{ion}}), \qquad (21)$$

where, f_{mix}^{ion} is the total frequencies (production rates) of the direct ionisations Ar^+ and CO^+_2, f_{Ar}^{exc} is the sum of the production rates for the excited argon states which have larger energy than the ionization threshold of CO_2 (13,77 eV) and r_{Pen} is Penning transfer rate, the probability that an excited argon atom ionizes a CO_2 molecule. In the calculations, it is assumed that f_{mix}^{ion} is proportional to α. The production rates of the first lowest argon excited states ($3p^5 4s$), located at 11.55 eV (metastable), 11.62 eV (resonance), 11.72 eV (metastable) and 11.83 (resonance), are not taken into account in the fits as their energies are below ionization threshold of CO_2. We assume the same value of r_{Pen} probability for all excited argon levels of the $3p^5 3d$ and higher. Calculated values of r_{Pen} as the function of mixture pressure and CO_2 concentration are displayed in Figs 6 and 7.

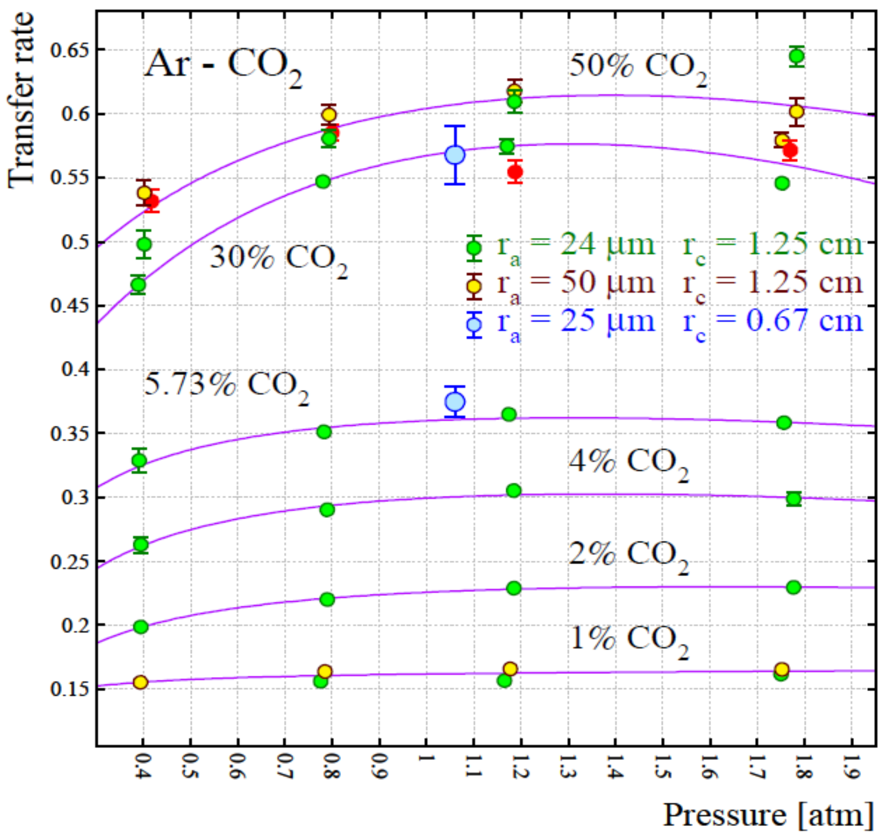

Fig. 6. Energy transfer probabilities for different counters parameters as the function of mixture pressures.

As seen from Fig. 6, the energy transfer rate, r_{Pen}, always increases with the CO_2 concentration at the same gas pressures. This is simply results of the decreasing time between collisions of the excited argon atoms with quencher molecules of CO_2. The lifetime of the argon excited states remains constant and they find greater number of recipients for Penning transfers at higher percentages of CO_2 in the mixture. Pressure dependence of the transfer curves for 1% CO_2 and 2% CO_2 mixtures can be described with a two parameters fit function [H2],

$$r_{Pen}(p) = \frac{b_1 \times p}{p + b_2} \tag{22}$$

here, p dimensionless pressure is related to the gas pressure by $p_{gas} = p \times 1$ atm, b_1 indicates the asymptotic value of the energy transfer and b_2 gives the collisional energy transfer efficiency ($Ar^* + CO_2 \rightarrow Ar + CO_2^+ + e^-$). At higher concentrations than 2% CO_2, r_{Pen} initially rises with increasing pressure reaching their maximum at 1200 hPa for the mixtures with 4% of CO_2 and more. Surprisingly, there are hints that the transfer rate actually drops at the highest pressures for the same CO_2 fraction. Such a drop indicates the processes by which excited argon atoms (Ar*)are lost. For instance, excited argon molecules formations (Ar_2^*, argon ecimer) led destruction of Ar* by the following process,

$$Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar, \tag{23}$$

especially since the probability of process (23) is proportional to $\sim p^2$.
Ar excimers can decay by emitting VUV photons,

$$Ar_2^* \rightarrow Ar + Ar + \gamma. \tag{24}$$

They can also excite and ionize some quencher atoms/molecules, B,

$$Ar_2^* + B \rightarrow Ar + Ar + B^* \tag{25}$$

$$Ar_2^* + B \rightarrow Ar + Ar + B^+ + e^-. \tag{26}$$

The highest energy level of argon excimers have a peak at 11.3 eV [18]. Because of the high ionization potential of CO_2 (13,77 eV) none of the argon excimers have capable of ionizing CO_2 molecules through the photoionization, by photons from process (24), nor with the mechanism given in eq. (26). Since the excimers develop in three-body interaction [19, 20], the process (23) is proportional to the square of the gas pressure. So, the Ar_2^* formation become increasingly likely with increasing pressure [21]. Under these considerations the reduction of the transfer rate at the highest pressure can be modelled with a b_3 parameter [H2],

$$r_{Pen}(p) = \frac{b_1 \times p}{p + b_2} + b_3 \times p^2 . \tag{27}$$

2.4.5 Transfer curve at atmospheric pressure as the function of CO_2 concentration

Concentration dependence of the transfer rate shown in Fig. 7 was defined by the following fit function,

$$r_{Pen}(c) = \frac{a_1 \times c + a_3}{c + a_2} \ , \quad (28)$$

the parameter a_1 is the asymptotic transfer rate and a_3/a_2 ratio gives the ionization probability of CO_2 by the decayed photons, γ, from Ar $3p^5 3d$ and higher states:

$$Ar^* \rightarrow Ar + \gamma$$

$$\gamma + CO_2 \rightarrow CO_2^+ + e^- . \quad (29)$$

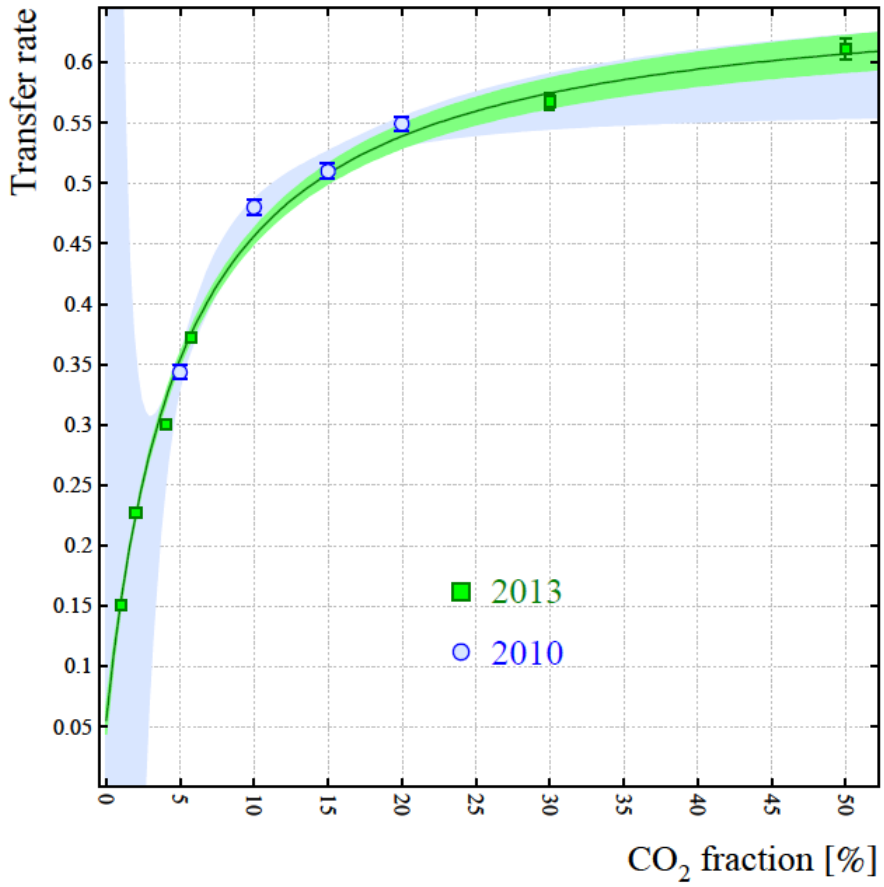

Fig. 7. Transfer rate, r_{Pen}, in Ar – CO_2 as the function of CO_2concentration at mixture pressure of 1070 hPa. The blue points (2010) indicate the r_{Pen} values determined in [22] based on the results presented in [23]. Green point (2013) marked r_{Pen} determined from my dedicated measurements. Colored fields indicate uncertainty ranges for r_{Pen} [H2].

Extrapolation of the transfer curve to pure argon gives a positive radiative transfer probability, a_3/a_2 =0.0541, for the mechanism represented by eq. (29).

A comprehensive model of energy transfer in Penning effect in the Ar-CO_2 mixture, taking into account both changes in CO_2 concentration and pressure change of the mixture is presented in [H5].

2.4.6 Penning effect in Ne –CO_2 mixture [H3]

The lowest excited state of Ne ($2p^5 3s$, 16,619 eV) has larger energy than the ionization potential of CO_2 (13.773). Therefore, all the excited states of neon located below the ionization threshold are eligible for transferring energy to ionize CO_2 molecules. The energy transfer rates (r_{Pen}) calculated from the fits of the gas gain measurements using eq. 21 are shown on Fig. 8.

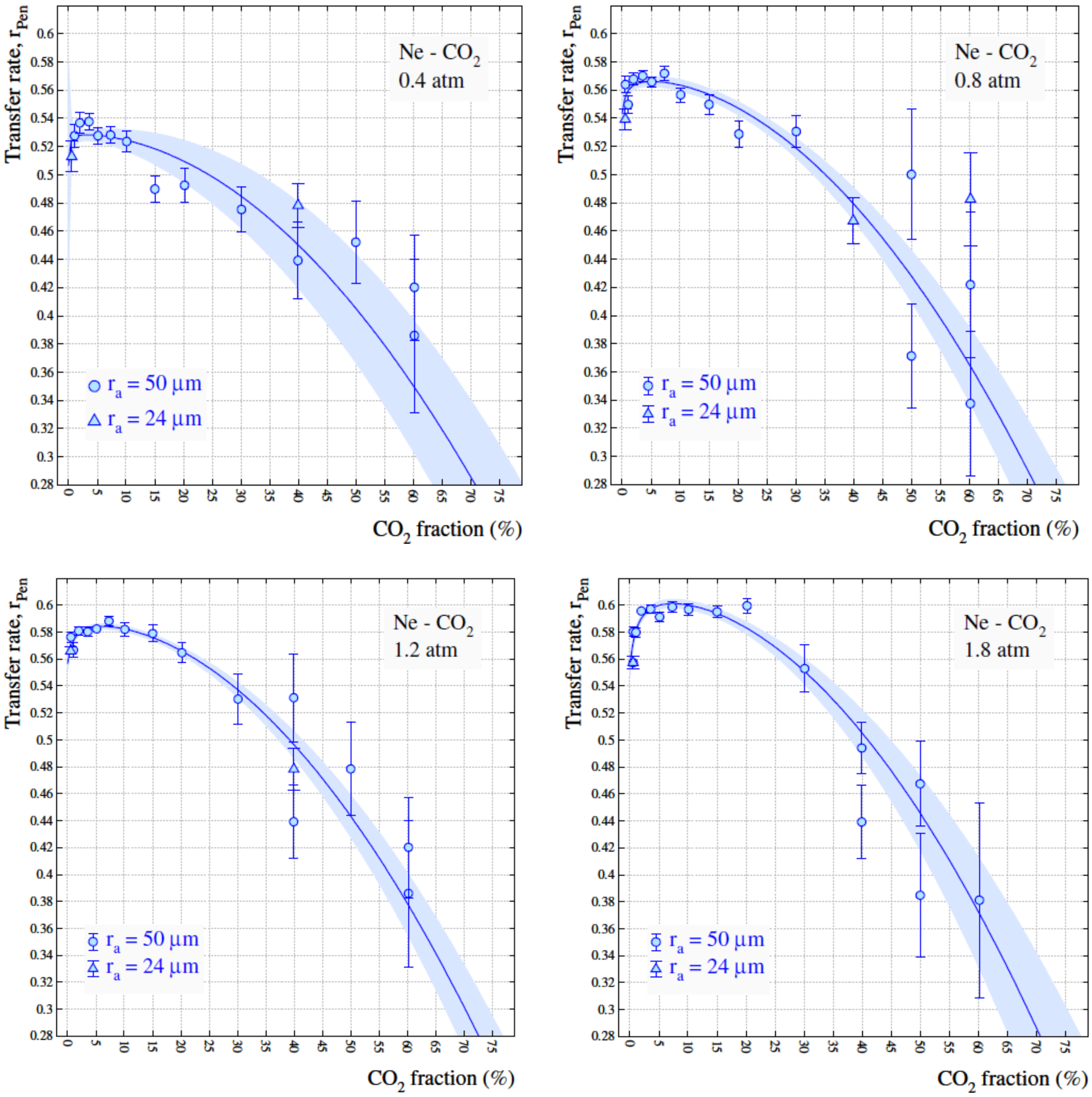

Fig.8. Penning energy transfer rates, r_{Pen}, in Ne – CO_2 as the function of CO_2 at mixture pressures of 0.4, 0.8, 1.2, 1.8 atm [H3, 24].

It should be pointed out that for all pressures, for concentration below 7,5% of CO_2, rPen increases with increasing concentration, reaching a maximum at c ~ (5 - 10)%. For higher CO_2 concentrations, r_{Pen} rapidly decreases. In addition, r_{Pen} at maximum for the same mixture has a lower value for lower pressure. r_{Pen} in the function of concentration can be described by following function [24],

$$r_{Pen}(c) = \frac{a_1 \times c + a_3}{c + a_2} - a_4 c^2 \qquad (30)$$

a_1 : asymptotic values of the transfer rates, a_2 : collisional energy transfer probability, $Ne^* + CO_2 \rightarrow Ne + CO_2^+ + e^-$, a_3/a_2: radiative transfer and homonuclear associative ionisation of neon ($\gamma + CO_2 \rightarrow CO_2^+ + e^-$, $Ne^* + Ne \rightarrow Ne_2^+ + e^-$) and a_4 : reduction parameter of the rates for higher CO_2 concentration.

The following processes are possible leading to Ne * de-excitation,

$$Ne^* + Ne + Ne \rightarrow Ne_2^* + Ne \,, \qquad (31)$$

$$Ne_2^* + CO_2 \rightarrow Ne + Ne + CO_2^*, \qquad (32)$$

$$Ne_2^* + CO_2 \rightarrow Ne + Ne + CO_2^+ + e^-, \qquad (33)$$

$$Ne_2^* \rightarrow Ne + Ne + \gamma \;\; (\gamma \sim 17{,}7 \text{ eV}), \qquad (34)$$

$$\gamma + CO_2 \rightarrow CO_2^+ + e^-. \qquad (35)$$

CO_2 * can dissociate into neutral fragments of CO, O and C. As the concentration of CO_2 increases, the probability of the process (31) decreases. The probability of the process (32) is increasing with increasing CO_2 concentration but because of the smaller number of excimers the efficiency of process (32) decreases. The processes (33) and (35) provide additional electrons. Therefore, processes (32) - (35) can not cause a reduction in energy transfer, r_{Pen}, with an increase in CO_2 concentration.

The following three-body collisions may be responsible for the reduction of r_{Pen}, with high CO_2 concentration,

$$Ne^* + Ne + CO_2 \rightarrow NeCO_2^* + Ne \qquad (36)$$

$$Ne^* + CO_2 + CO_2 \rightarrow NeCO_2^* + CO_2 \,. \qquad (37)$$

The probability of the processes (36) and (37) increases with the increase of concentration (partial pressure)of CO_2 and de-excitation of Ne*states by the formation of $NeCO_2$* complexes can explain the rapid decrease of r_{Pen}, with the increase in CO_2 concentration.

2.4.7 Penning effect in Ne – CO_2 – N_2 mixture [H4]

The ionization potentials of the components of the studied mixture are: N_2 – 15.59 eV, CO_2 – 13.776 eV and Ne – 21.56 eV. The lowest excitations levels of Ne are: 16.62 eV($^3P_0$), 16.72 eV ($^1P_0$), 16.616 eV ($^3P_1$) and 16.844 eV ($^1P_1$). Therefore, Penning effect can occur for all electronically excited states of Ne. Determined values of r_{Pen} are shown on Fig. 9.

As can be seen from Fig. 9, r_{Pen} grows with increasing pressure. This is consistent with the decrease in time between collisions of excited neon atoms with CO_2 or N_2 molecules. The life time of the excited neon atoms remains constant and the density of the molecules of CO_2 and N_2 increases with pressure, thereby increasing their chance of interacting with the dopant molecules.

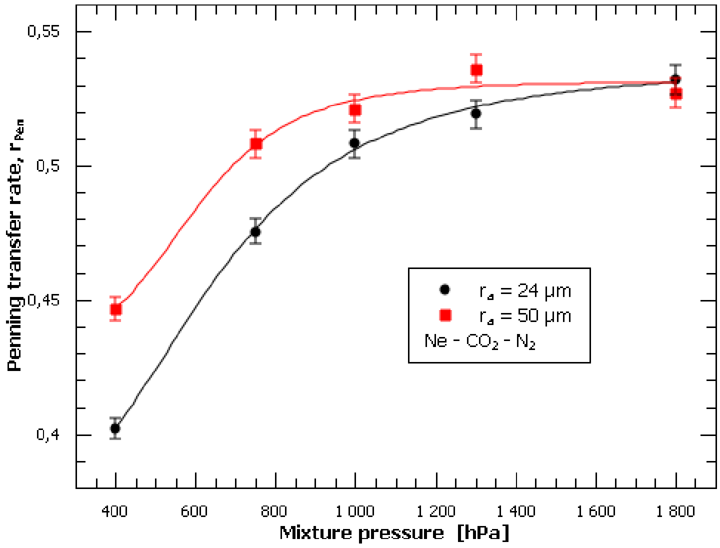

Fig. 9. Energy transfer probabilities extracted from gas gain curves for different anode radii as functions of mixture pressure [H4].

2.4.8 Data analysis method

There are two fit parameters that are extracted from the fits of the gas gain measurements, Penning transfer rate probability and the second Townsend ionisation coefficient, β. The Magboltz [25] software is used for the calculation. The Magboltz code performs a Monte Carlo simulation to compute the transport properties of electrons in the gas by solving the Boltzman transport equation. The program use excitation, ionization, attachement, elastic and inelastic scattering cross-sections to determine collision parameters with a random generator while tracking the electrons step by step under the influence of the electric field. The input file of the program consists of electric and magnetic field, gas pressure and temperature, the fractions of the each gas type in the mixture. The output file contains all needed transport parameters for the gas gain fits such as Townsend coefficients α, collision frequencies of excitations and ionizations with varying electric field strengths in the given range. Magboltz 9.0.1 version was used for the gas gain simulations. The excitation rates for 44 different levels of argon can be computed with this version. Since the Penning transfer rates are not known a priori, the special tool first reads the measured gas gain data and the output file of Magboltz software. Then, it proceeds a numerical integration of the Townsend coefficients written in the Magboltz output file to simulate gas gain. A fitting procedure has been added into the simulation program which iterates using a non-linear least squares method to find both the transfer rates, r_{Pen}, and photon feedback parameters, β. An example of measured and calculated gas gain curves are shown on Fig. 10.

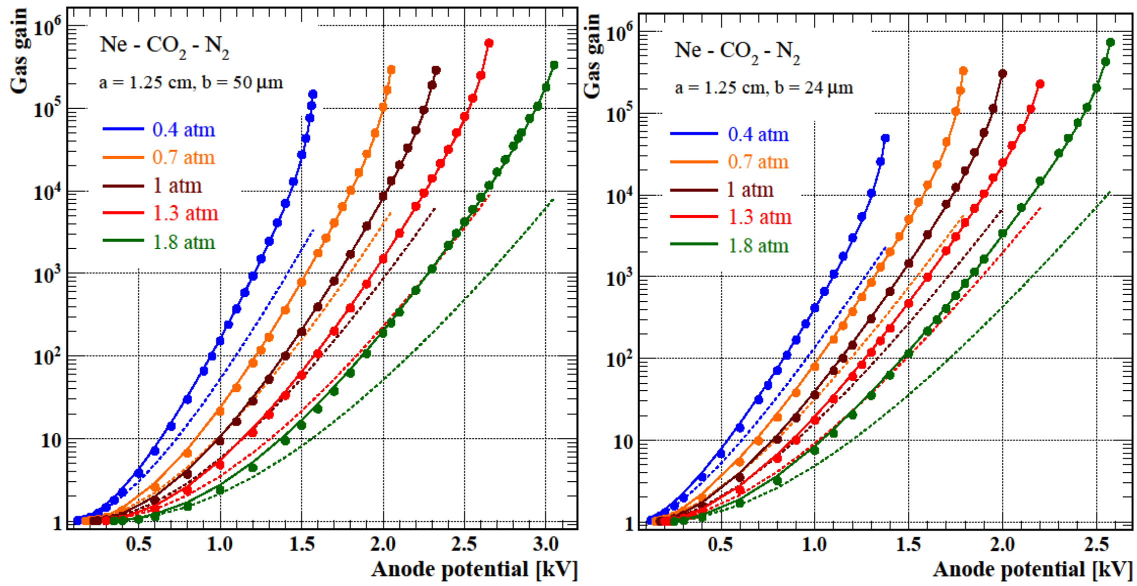

Fig. 10. The measured and calculated gas gain curves for the ternary mixture of 85% Ne-10% CO_2-5%N_2. Dashed lines – calculated without any corrections; straight lines – both Penning transfer and secondary effects included; points – measured data, [H4].

2.5 Microdosimetric mixtures

The ideal detector, which can be used in microdosimetry for determining the energy transferred by radiation and its distribution in biological objects should satisfy the following requirements:

- Measurements of the distribution of energy transferred by radiation should be measured in the material from which the biological object is built,
- The detector should be useful for determining the distribution of the energy in biological objects of varying size,
- The measuring range of the detector should be equal to the total range of transferred energy,
- The signal obtained from the detector should be proportional to the energy transferred by the radiation being measured,
- The signal from the detector corresponding to the smallest registrable energy transferred by radiation should be free of any instability caused by the performance of the detector,
- The detector response should be independent on type of measured radiation.

The materials used for the construction of microdosimetric counters and the gas mixtures filling them should meet a number of requirements in relation to the pattern of tissue. A number of constructions that meet the conditions of tissue equivalency can be found in the literature. Most often, in their construction, particular attention is paid to the type of material, its thickness, and often overlooked aspect that " the proportional counter should be proportional." In the work [H6] - [H9] particular attention was paid to the physical processes taking place in the detectors filled with tissue equivalent gas mixtures and the limitation in their use resulting from the mechanism of their work.

2.5.1 Microdosimetric response of proportional counters [H7]

Changes in diameter of the simulated biological object can be done by changing the pressure of the detector filling gas or the physical dimensions of the detector. Microdosimetric measurements were made with the usage of four cylindrical counters with different cathode diameter. Counters were filled with the standard TEG (tissue equivalent gas) mixtures based on both methane (64.4% CH_4 – 32.5% CO_2 – 3.1% N_2) and based on propane (55.0% C_3H_8 – 39.6% CO_2 – 5.4% N_2). Measurements were made for ^{109}Cd (X-ray, 22 keV), ^{137}Cs (γ – ray, 661 keV) and ^{90}Sr (β – ray, max. energy – 2,3 MeV), at 200, 100, 40 hPa for methane based TEG and 116, 58, 23 hPa for propane based TEG.

Comparisons of detectors response were made in three ways:

- for the same detector, the same size of the simulated object (constant mixture pressure), but a variety of radiation sources (Fig. 11);
- the same detector, the same radiation source but different sizes of simulated object, different mixtures pressure (Fig. 12);
- the same radiation source, the same value of equivalent gas pressure but for different counters (the size of the simulated object was changed by the change of detector diameter) (Fig. 13).

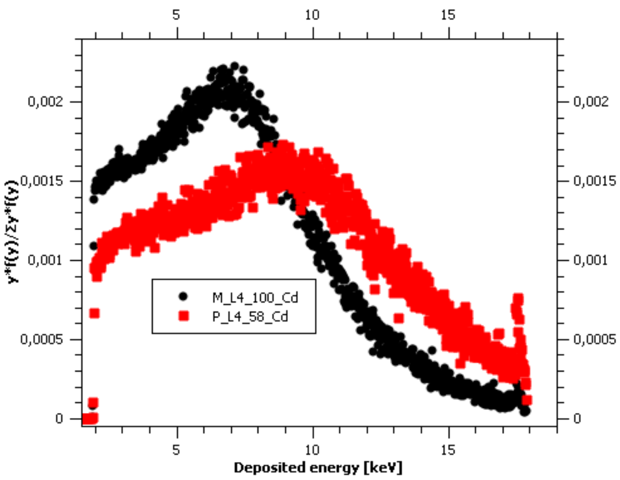

Fig. 11. The distributions of dose depositions (y*f(y)/∑y*f(y)) for events measured in proportional counters, having the cathode diameter of 8mm, filled with TEG mixtures (M - methane based TEG mixture of 100 hPa, P – propane based TEG mixture of 58 hPa) for ^{109}Cd source. Diameter of simulated biological object is 1.01 μm. Maximal deposited dose are clearly shifted.

Measurements have been made for three different counters, for three different radiation sources, for three values of working gas pressures and for two TEG mixtures, some measurements were repeated few times to check the reproducibility so in total near 150 spectra were collected. Final conclusions are based on all collected spectra, not only presented in the paper. Here only selected examples of spectra are shown.

• The biggest differences in the response of TEG filled counters were observed for intermediate equivalent mixture pressure (Methane based – 100 hPa, Propane based – 58 hPa) for ^{109}Cd source.
• Only for small deposited energy, below 2 keV, the ambiguity of detectors responses were obtained for ^{137}Cs radiation source.
• The univocal function of response for used counters and for all spectra have been got for ^{90}Sr source.

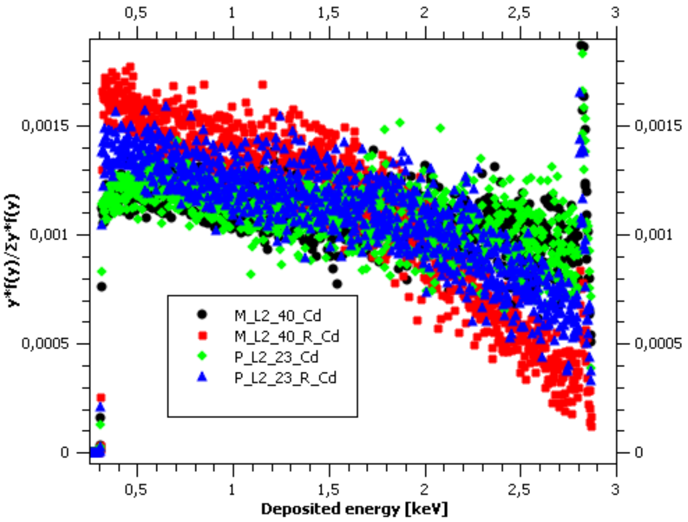

Fig. 12. The distributions of doses depositions (y*f(y)/∑y*f(y)) for events measured in proportional counter (cathode diameter 5.9 mm)filled with TEG mixtures (M – methane based of pressure 40 hPa, P – propane based of pressure 23 hPa) for ^{109}Cd radiation source. Simulated site size diameter 0.31 μm.

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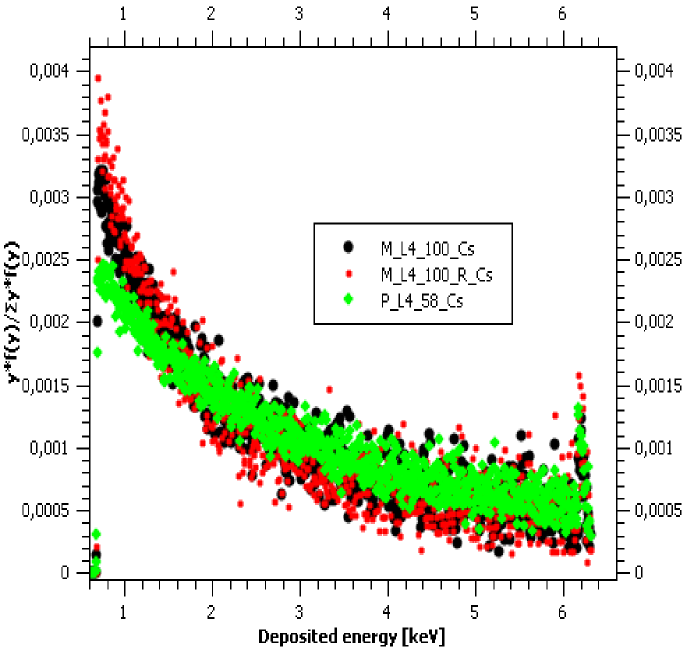

Fig. 13. The distribution of doses depositions (y*f(y)/∑y*f(y)) for events measured in proportional counter (cathode diameter 8 mm) filled with TEG mixtures (M – methane based of pressure 100 hPa, P – propane based of pressure 58 hPa) for ^{137}Cs radiation source. Simulated site size diameter 0.76 μm. There is difference in deposited dose only for the smallest deposited energy.

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

Tissue equivalent proportional counters are commonly used for radiation monitoring especially in areas where a mixture of radiations may be present. Based on radiobiological observations, the correlation between the energy distribution absorbed by the detector and the radiation-induced biological effects has been observed. The phenomena related to radiation damage in biological objects occur in areas of a size significantly smaller than 1 µm, probably in size of several nanometers. Hence, there is a need to build counters with a nanometer simulated diameter. This can be achieved by lowering the pressure of the mixture in the detector or by miniaturizing the detector. At low pressure of the mixture, avalanche multiplication of electrons begins at a great distance from the surface of the anode and the volume of the avalanche region can not be neglected as compared to the volume of the full detector. It is assumed that the lower limit of the simulated tissue diameter below which the results obtained with proportional gas detectors of centimeter cathode diameter are no longer reliable is about 0.3 µm. Miniaturization of counter geometric dimensions allows to make the measurements for higher filling gas pressure and to simulate the biological target of the order of tens of nm.

Furthermore, the limitation of the use of gaseous detectors to measure the biological effects of radiation-to-matter interaction is that the proportional counter only records those effects that result in the formation of free electrons and ions and does not record those effects resulting in the creation of atoms / molecules excited to higher energy levels. Gas amplification factors were measured for Methane- and Propane- based TEG mixtures for different mixture pressures, p, in the range from 20 hPa to 500 hPa (details are given in Figs 14 and 15). A cylindrical proportional counters of cathode diameter 25 mm and anode of diameter 100 µm and 48 µm, respectively, were used for measurements. The measured gas gain curves are shown in Fig. 14.

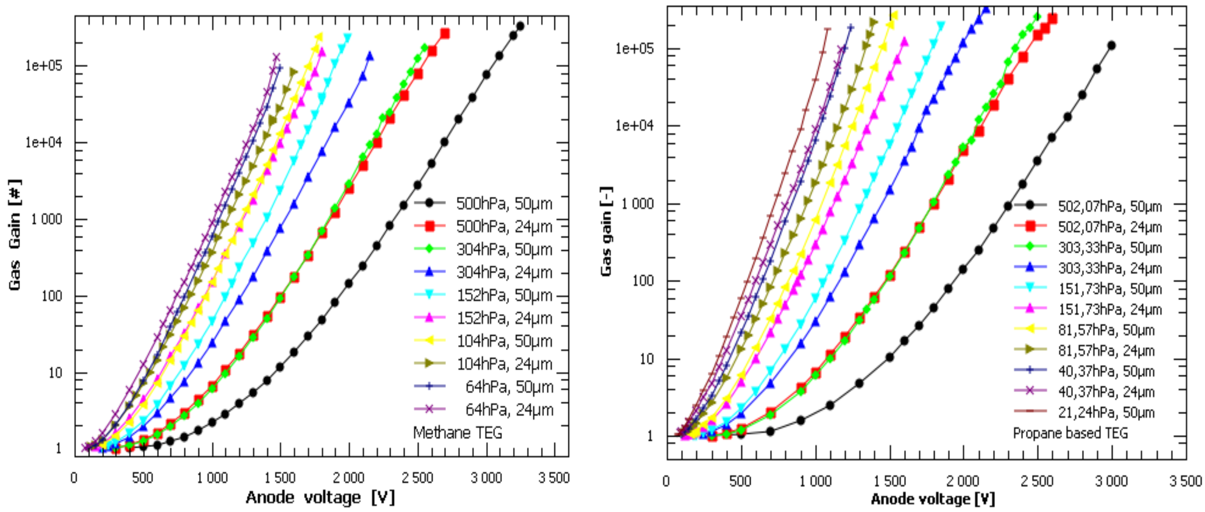

Fig. 14. The gas gain as a function of applied HV for CH_4-based (left) and C_3H_8-based TEG mixtures. The mixtures pressures and radius of anodes are given on the figures, [H5].

Above experimental data in the notation of Zastawny [26], equation 17, are shown in Fig. 15.

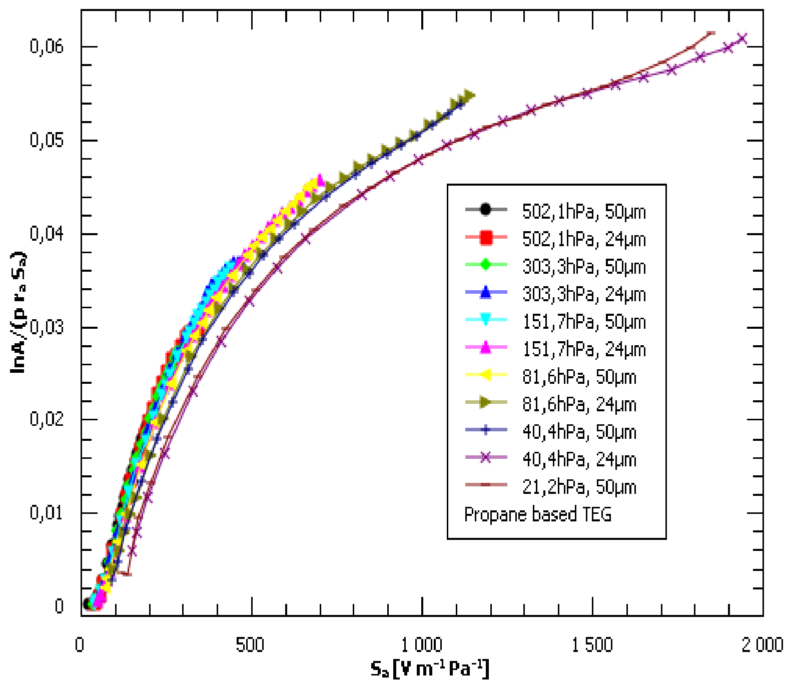

Fig. 15. Amplification factors, A, given as lnA/($p \times r_a \times S_a$) measured for Propane-based TEG mixture displayed vs S_a. In this coordinates data point for different pressure and radius of anode should lie on one curve.

It is seen from Fig. 15 that for mixture pressures below 100 hPa and for low radius of anode the measured point are not placed on the same curve. The measured gas gains seem to be too low. Between the multiplication region and drift volume, there is an ionization region in which the electric field is such that an electrons reach enough energy between two collisions to excite the gas atoms rather than to ionize them in this way reducing the dimension of electron avalanche, decreasing the distance from the anode at which the multiplication starts. The number of such collisions of the primary electrons increases with decreasing mixture pressure and leads to a lower overall gas gain. For the employment of this counters in microdosimetry it means that for the same deposited energy of radiation, the measured dose depends on the simulated tissue target diameter.

2.5.3 Electron avalanche dimension

Diethorn [27] obtained the relationship between the gas gain and the parameters describing the detector and gas mixture in the form of:

$$\frac{lnA}{p\, r_a\, S_a} = \frac{ln2}{\Delta E}\, lnS_a - \frac{ln2}{\Delta E}\, lnH \,, \qquad (37)$$

where ΔE & H are characteristic constants for the gas mixture. ΔE is the average kinetic energy obtained by the electron from the electrical field between two successive ionizing collisions and H is the reduced electric field strength at whichelectron multiplication starts. Experimental points in coordinates lnA=(pra Sa) vs. lnSa should lie on straight lines. From the slope and intercept of the approximated straight line the constants ΔE and H can be determined. Using the formula of Diethorn, (constant H), the size of electron avalanche can be calculated as function of both gas gain, A, and mixture pressure for fixed gas gain factor, Figs 16 and 17.

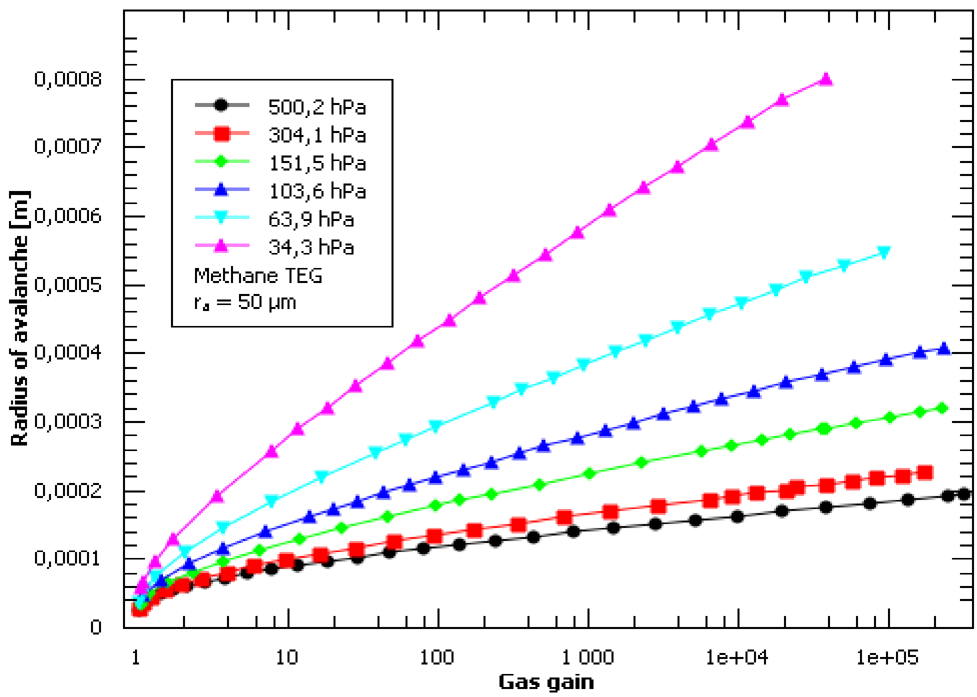

Fig. 16. Radius of electron avalanche as the function of gas gain for Methane-based TEG mixture, for different mixture pressure, r_a = 50µm. Attention should be paid to the significant increase of electron avalanche for low pressure mixtures with constant gas gain.

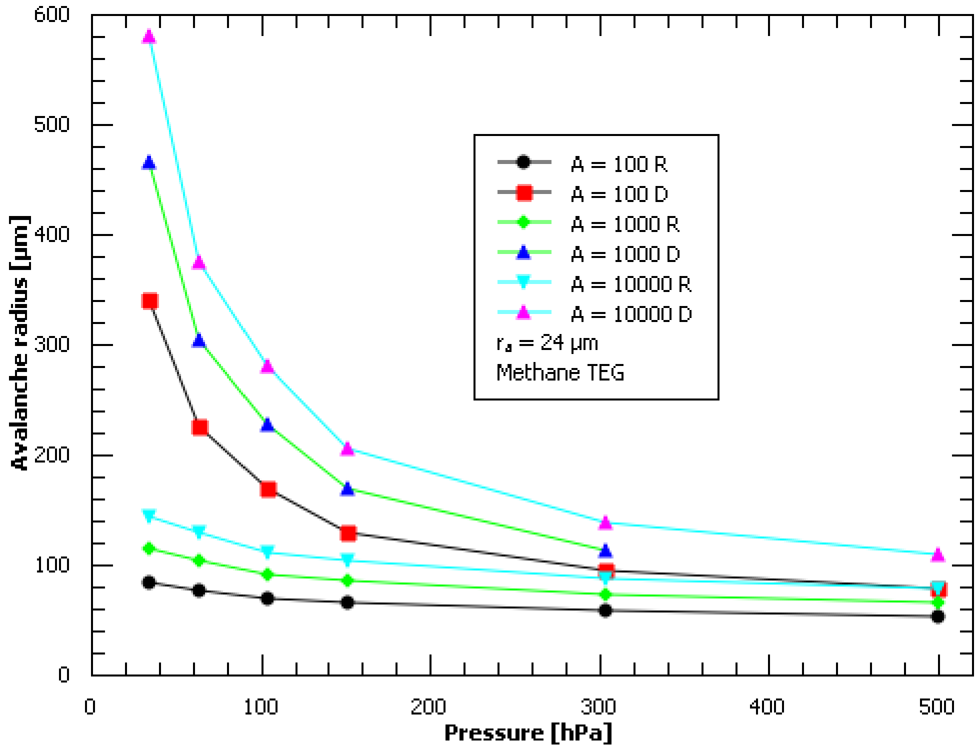

Fig. 17. Full (D, from A = 1) and reduced (R, from A = 2) radius of electron avalanche as the function of methane based TEG mixture pressure, for counter having anode of radius r_a = 24 µm. Final value of gas gains are also given. Attention should be paid to the significant increase of the intermediate zone between the electron drift area and the gas multiplication area for low working gas pressures.

For the working gas pressure p ~ 500 hPa, the volume ratio of the gas multiplication zone to the volume of the counter is ~10^{-6}, for a mixture pressure of ~ 30 hPa this ratio is of the order of ~ 10^{-3}. Further lowering the pressure to simulate a smaller diameter of biological object will result in loss of proportionality of the detector response.

2.5.4 Performance at high count rate, linearity in dose

The total space charge effect includes the cumulative effect of positive ions created from many different avalanches [28, 29, 30]. The presence of slowly moving positive ions in the avalanche multiplication region reduces the electric field simultaneously decreasing the gas amplification factor. The gas gain has been measured as a function of the applied voltage for a low (below 2 nA) and high (above 2 nA) count rate by means of the current method.
For any count rate there is always a critical voltage indicated by the arrow in figure 18, which divides the operation range of the counter into two regions [31, 32]. In the region below the arrow no changes in the gas gain with a count rate are observed. Above the arrow there is already an influence of the space charge of positive ions in the avalanche multiplication region, which reduces the gas gain.
The current, I, flowing through the counter can be expressed by the following expression:
.

$$I = \frac{\Delta E}{W} \times A \times R \times e, \tag{38}$$

where ΔE is the deposited energy by a single registered particle, W is the energy required to produce an ion-electron pair, R is the count rate in cps and e is the elementary charge. Thus, $\Delta E \times R$ is the energy deposited by radiation per second, i.e. it is in fact the radiation dose rate, P.
From equation (38)

$$P = \frac{I \times W}{A \times e} , \tag{39}$$

and

$$P_{max} = \frac{I_{cr} \times W}{A \times e} , \tag{40}$$

is the maximal measurable radiation dose rate and I_{cr}, is the values of currents over which a 5% reduction in gas gain is observed. Gas gain, A, is a free parameter in eq. (40).

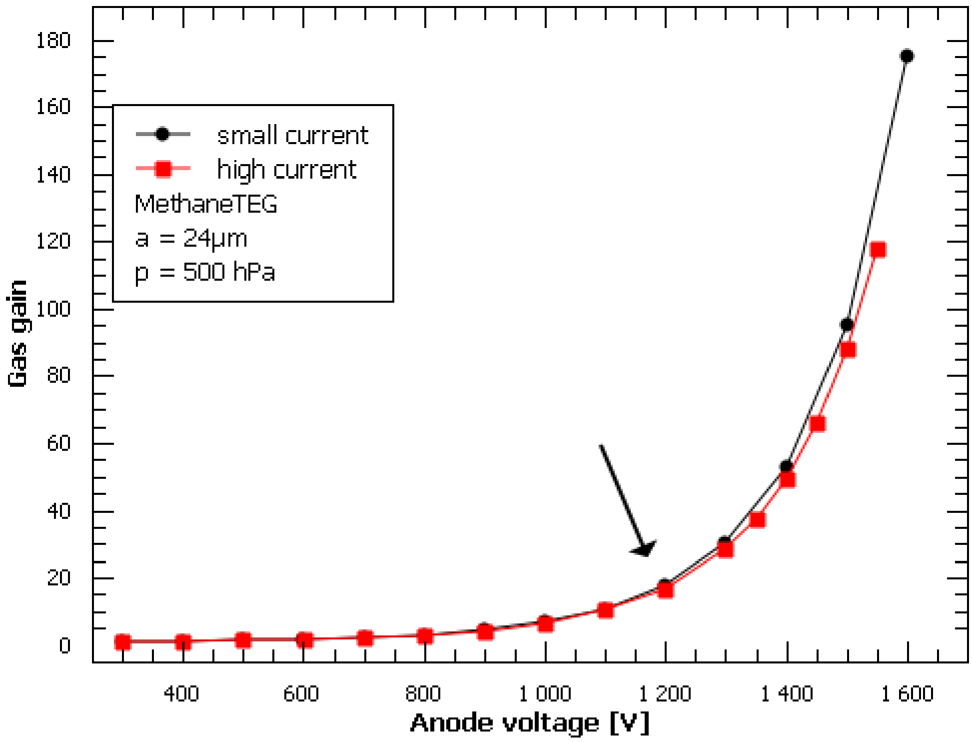

Fig. 18. Gas gain as the function of the anode voltage for a low and high count rate. The arrow indicates the start of the gas gain curves separation, the start of the total space charge effect manifestation.

2.5.5 Performance at high gas gain, linearity of response in gas gain

To obtain a high signal-to-noise ratio and to reduce the cost of the readout electronics, it is important to work at high gas multiplication factors, but one should remember to avoid potential losses of energy resolution and of the gas gain caused by space charge effects within the avalanche. In the measurements of radiation using the proportional counter energy linearity is lost at a high gas gain. In the electron multiplication process, which takes place in proportional counters, both electrons and positive ions are created. The electrons reach the anode very quickly, while the positive ions move much more slowly to the cathode. When the gas gain is sufficiently high, the created positive ions in a given avalanche can alter the field and reduce the gas gain within the same avalanche. It is the so-called self-induced space charge effect (limited proportionality) [32, 33, 34]. Gas gain is an exponential function of the applied anode voltage. The slope of the gas gain curve as a function of the anode voltage is a voltage increasing function. The slope ($\Delta \ln A/\Delta U$) was determined by graphical differentiation of the measured gas gain curves. The Diethorn equation in the form proposed by Zastawny was also applied to the measured gas gain curves. Analytic functions depending of the gas gains from the supply voltages were received. The derivatives of these functions with respect to the anode voltages were calculated. Example of such obtained slope is shown in Fig. 19. For a low gas gain ideal agreements between the graphical differentiation and the Diethorn equation differentiation is observed. For an intermediate mixture pressure (Fig. 19) both a reduction in the gas gain due to the self-induced space charge (between the arrows) and an increase in the gas gain due to the secondary effects described by the second Townsend ionisation coefficient, β, are observed [14, 34]. So the highest value of gas gain, A_{max}, in proportional counters are determined either by the self induced space charge effect or by secondary effect described by β factor. The values of the gas gains over which nonlinearity due to the field distortion within the electron avalanche, or due to the secondary effects described by β, are not manifested were determined as the function of the working gas pressure and are shown in Fig. 20. For a high mixture pressure (~ near atmospheric) the energy linearity is lost at a high gas gain by the self induced space charge. For an intermediate mixture pressure (~ 300 hPa) the linearity is lost due to both space charge within the single avalanche and the secondary effects described by *β* and for the lowest pressure (below 200 hPa) *β* coefficient limits the applicability of proportional counters in radiation dose measurements.

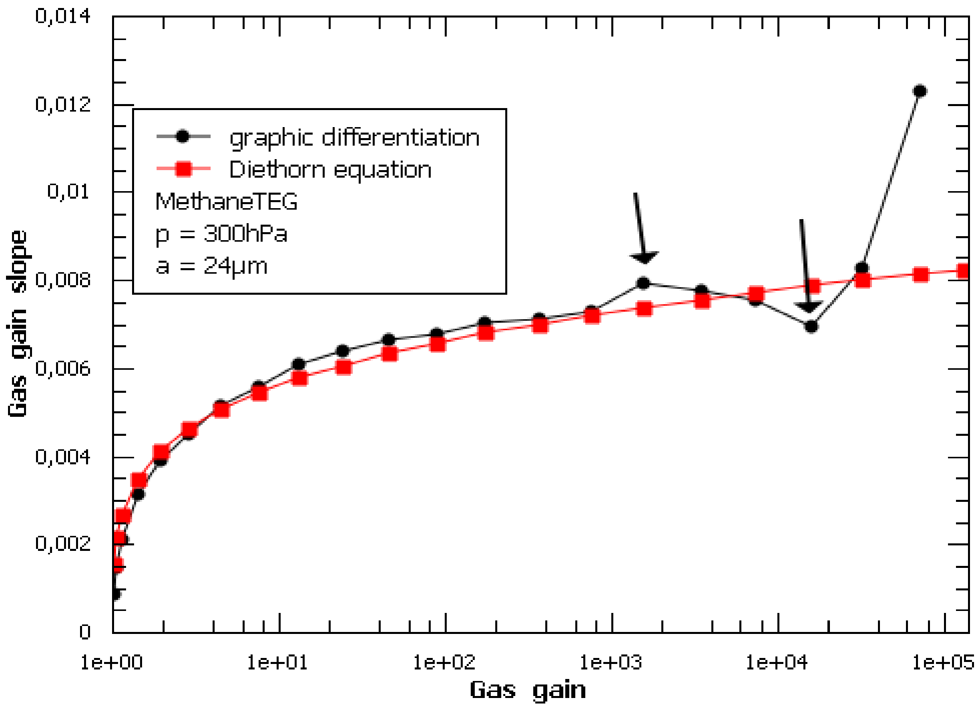

Fig. 19. The slope of the gas gain curve as the function of the gas gain obtained from the graphical differentiation and from the Diethorn equation. The decrease in the slope indicated by the arrows is due to the electric field deterioration within the electron avalanche volume. The rapid increase is due to the secondary effects described by β.

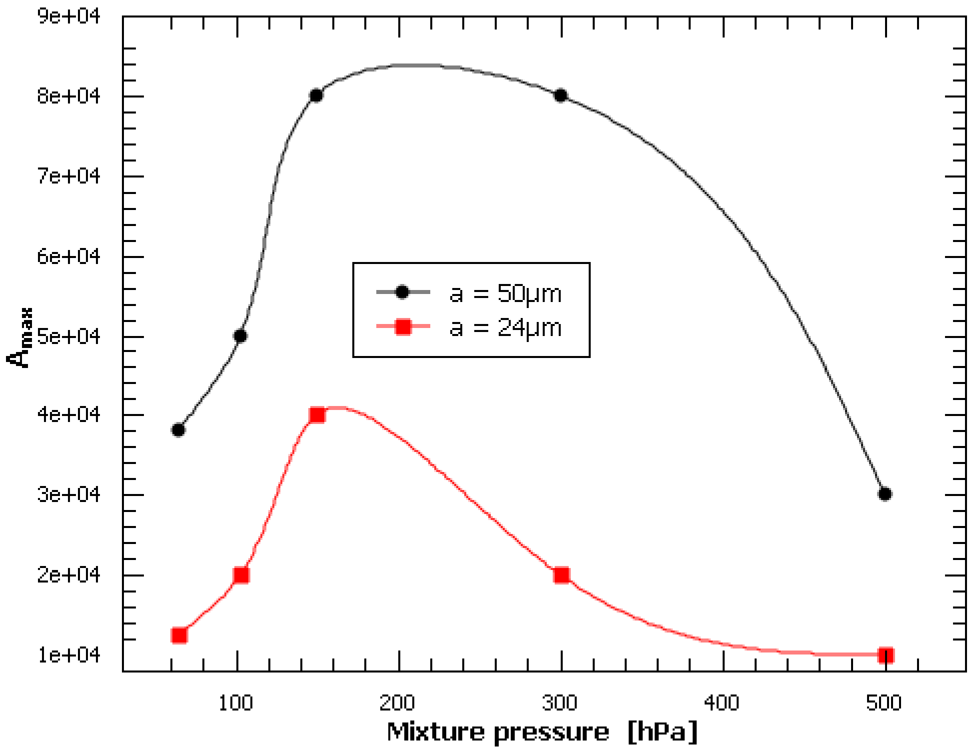

Fig. 20. The maximal gas gain, not affected by self-induced space charge effect or by secondary effects as the function of the mixture pressure for methane based TEG mixture.

2.6 Summary

The issue connecting the work [H1 - H9] is the physical phenomena taking place in gas detectors, knowledge which is necessary to determine their usefulness in experiments of high energy physics and dosimetry. Knowledge of physical phenomena allows to determine limitations in the use of gas detectors.
The most important achievements in [H1 - H9] include:

• Measurement of gas gain curves for mixtures Ar + CO_2, Ne + CO_2, Ne + CO_2 + N_2 in a wide range of changes in quenching agent concentration and wide range of mixtures pressures.

• Measurement of gas gain curves for TEG mixtures based on methane or propane in a wide range of pressure variations of the mixture and thus within a wide range of diameters of the simulated biological target.

• Determination of the probability of energy transfer in the Penning effect, r_{Pen}, as a function of the mixture pressure and of the concentration of the quenching agent.

• Creation of a comprehensive model of energy transfer in Penning effect involving variability of r_{Pen} as a function of the concentration of the quenching agent and as a function of the total pressure of the mixture.

• Determine the second Townsend ionization coefficient and creation of a model of secondary phenomena for the above mixtures.

• Gas gains values measured and calculated with the MAGBOLTZ program perfectly agree, what means that the proposed models are correct.

• Both analog formulas (equations of Diethorn, Aoyamy, Williams, and Sary) describing the gas multiplication process and the Monte Carlo method for simulating electron transport in gas were used for the analysis of the mixture properties. These are two complementary approaches, for the first time simultaneously applied.

• For the studied mixtures, the basic parameters characterizing the development of the electron avalanche were determined, α / p - the first Townsend ionization coefficient, ΔE - the electron energy increase between successive collisions, H - the reduced field strength at which the electron multiplication begins, V_i – effective ionization potential, electron avalanche radius and its dependence on gas gain and working gas pressure.

• For aTEG mixture based on methane-, the upper limit for the measured dose was determined and its dependence on the pressure of the mixture and maximum gas intensities limiting the minimum measured energy deposited in the detector.

• It has been shown that the responses of detectors filled with different tissue mixtures are different only for low energy deposits in the simulated biological target.

These characteristic gas constants were determined for a single anode detector of cylindrical geometry but determined constants can and are used in avalanche simulations in other geometries e.g. for GEM or MicroMegas detectors.

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3. Discussion of other scientific and research achievements

3.1 Before obtaining the PhD degree (years 1977 – 1983)

My diploma work (Supervisor doc. dr. Kazimierz W. Ostrowski,) under the title "Long – lived X-ray proportional counters with neon filling for energy up to 6 keVs" was defended with honors in 1977. I have done my work in the Gas Detector Laboratory of the Institute of Nuclear Physics and Techniques. Since then I am associated with this laboratory, due to changes in the organizational structure of the Institute, the creation of the Faculty, currently the laboratory is part of the Department of Particle Interaction and Detection Techniques of Faculty of Physics and Applied Computer Science AGH. I actively participated in works conducted in the Gas Detector Laboratory concerning the development of new detector constructions:

- end windows, cylindrical proportional counters,
- proportional counters with aluminized mica windows for detection of low energy X – rays for astrophysics application,
- counters of pill – box type for X – rays fluorescence,
- box-type side window counters for fluorescence analysis of copper content at various stages of flotation,
- Geiger-Mueller counters for cosmic ray burst study,
- box – types counters for Mossbauer effect study filled with Kr based mixture.

The work concerned not only the mechanical construction of the detector but also the appropriate selection of the gas mixture filling it. For this purpose, I conducted measurements of energy resolution, gas gain, count rate and temperature effects for proportional counters filled with neon, argon and krypton as primary gases with various quenching agents.

3.1.1 List of publications and reports from this period.

1. B. Bednarek, W. Jagustyn, K. Jeleń, **T. Kowalski**, K.W. Ostrowski, E. Rulikowska i T. Zabagło, *New solutions for proportional X-ray counters for industrial applications*, RWPG Symposium on the application of radioisotope methods in industry including control and steerage, Lipsk 1979 (in polish).
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3. B. Bednarek, K. Jeleń**, T. Kowalski**, K.W. Ostrowski, E. Rulikowska-Zarebska, *X-ray Detectors*, Conference Proceedings, Physics for Industry, Kraków 1980 (in polish).
4. **T.Z. Kowalski**, *The gas amplification factor in Kr + isopentane filled proportional counters*, Nucl. Instr. and Meth. in Phys. Res. 216(1983)447.
5. B. Bednarek, W. Jagusztyn, K. Jeleń, **T.Z. Kowalski**, K.W. Ostrowski, E. Rulikowska-Zarębska, P. Turkowski, J. Zajac, *Some problems in the development of proportional counters for X-ray fluorescencje analysis*, Conference Proceedings DET'84, Warszawa 1984, Raport INT 188/I, Kraków 1984.

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7. **T.Z. Kowalski**, E. Rulikowska-Zarębska, *Studies of elektron avalanche multiplication In non- equilibrium weakly ionized gases with Kr as a main ga*s, 7th ESCAMPING, Bari, Italy, 1984, page 74.8.
8. B. Bednarek, K. Jeleń, **T. Kowalski**, K.W. Ostrowski, E. Rulikowska-Zarębska, J. Zajac, *Miniature proportional counters for the detection of X-ray radiation in the energy range 1,3 - 50 keV*, Nauczpribor SEV'84, Plovdiv, Bułgaria, 1984 (in russian) . Summary in polish appeared in AND 5,12(1984).
9. B. Bednarek, W. Jagusztyn, K. Jeleń, **T. Kowalski**, K. Ostrowski, E. Rulikowska-Zarebska, P. Turkowski, J. Zając, *Selected issues in the field of X-ray proportional counters for fluorescence analysis*, Institute of Physics and Nuclear Techniques AGH, Report INT 188 / I.

3.2 List of academic achievements after the PhD degree (years 1984-1986).

Various authors have tried theoretically to determine the dependence of the gas gain coefficient on the anode voltage of the detector, its geometry and the type of gas mixture. This requires knowledge of the function describing α/p from the reduced electric field strength at the anode surface, E/p. Assuming that the space charge of positive ions does not deform the distribution of the electric field in the gas multiplication zone, the diffusion and recombination phenomena of charge carriers, and the secondary phenomena described by the second Townsend ionization coefficient can be omitted, making further simplifying assumptions different authors receive different equations for α/p in function of E/p and different formulae for gas gain. Ten different formulae were received, including two received by me. Each of these formulas contains two or three constants, which can be experimentally determined for a given mixture. These constants are related to microscopic phenomena occurring in the detector. By presenting the gaseous gas gain in a suitable coordinate system, it is possible to determine the range of gaseous gas gains (reduced electric field strength) within which the given formula can be used. Determined constants are characteristic for a given mixture and they tell us about the process of physical phenomena occurring in the counter, of course, this information is averaged information, for instance, average increase in electron energy between two successive ionizing impacts. During this period of my scientific career (years 1984-1986) I was dealing with the measurement of gas gain curves and determining characteristic constant for counter mixtures, their dependence on the concentration of admixture and the total mixture pressure. The results are summarized in the following publications.

3.2.1 List of publications and reports from this period (years 1984 - 1986)

1. **T.Z. Kowalski**, *Measurements and parametrisation of the gas gain in proportional counters*, Nucl. Instr. and Meth. in Phys. Res. A234(1985)521-526.

2. **T.Z. Kowalski**, *The influence of the concentration of the quench gas on the count rate effect in proportional counters*, Nucl. Instr. and Meth. in Phys. Res. A239(1985)551-555.
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10. **T.Z. Kowalski**, J. Zając, *Noble gases ionization formulae,* XVII Int. Conf. on Phenomena in Ionized Gases, Budapest 8-12 July, 1985, Contr. Papers vol 1 p. 400-401.
11. **T.Z. Kowalski**, J. Zając, *Krypton-cyclohexane total ionization formula*, XVII Int. Conf. on Phenomena in Ionized Gases, Budapest 8-12 July, 1985, Contr. Papers vol 1 p. 402-403.
12. **T.Z. Kowalski**, J. Zając, *Temperature effect of proportional counters filled with Ne-based mixtures*, ISRP-3, Ferrara, Sept. 30, Oct. 4, 1985, Abstract Book, p. 115.
13. **T.Z. Kowalski**, *Performance of Kr-isopentane proportional counter under extreme operating conditions*, ISRP-3, Ferrara, Sept. 30, Oct. 4, 1985, Abstract Book, p. 114.
14. **T.Z. Kowalski**, K.W. Ostrowski, J. Zając, *Proportional needles counter*, The Third Int. Conf. on Low-Level Counting Low Radioactivites'85, 21-25 October 1985, Bratislava, AbstractVI/21.
15. **T.Z. Kowalski**, K.W. Ostrowski, J. Zając, *Parametrization of gas gain in proportional counter for low radioactivites measurements,* The Third Int. Conf. on Low-Level Counting Low Radioactivites'85, 21-25 October 1985, Bratislava, AbstractVI/24.
16. B. Bednarek, K. Jeleń, **T.Z. Kowalski**, K.W. Ostrowski, E. Rulikowska-Zarebska, J. Zając, *Proportional counters for Mössbauer spectroscopy*, Abstracts of invited and contributed papers of the Int. Conf. on the Appl. of the Mössbauer effect, September 16-20, 1985, Leuven, p. 12.34.
17. The Patent Office of the Polish People's Republic, the authors of the invention, **Tadeusz Kowalski** and K. Ostrowski performed the invention entitled *"Sealed*

counter of X and β ionizing radiation", patented by the Patent Office of the Polish People's Republic No. 147541, 1989.

3.3 Stay at the European Space Research and Technology Center, ESTEC (1986).

From January 1986 to January 1987 I was on a fellowship of the International Atomic Energy Agency at the European Space Research and Technology Center, ESTEC at Nordwijk aan Zee in the Netherlands. ESTEC is the main technology center of the European Space Agency (ESA). At this time in the Netherlands there were three scholarships for all kinds of fellowships. During my stay at ESTEC, I was involved in the development and research of GSPC (Gas Scintillation Proportional Counter) for astrophysics applications. The schematic of the GSPC detector is shown in Fig. 21.

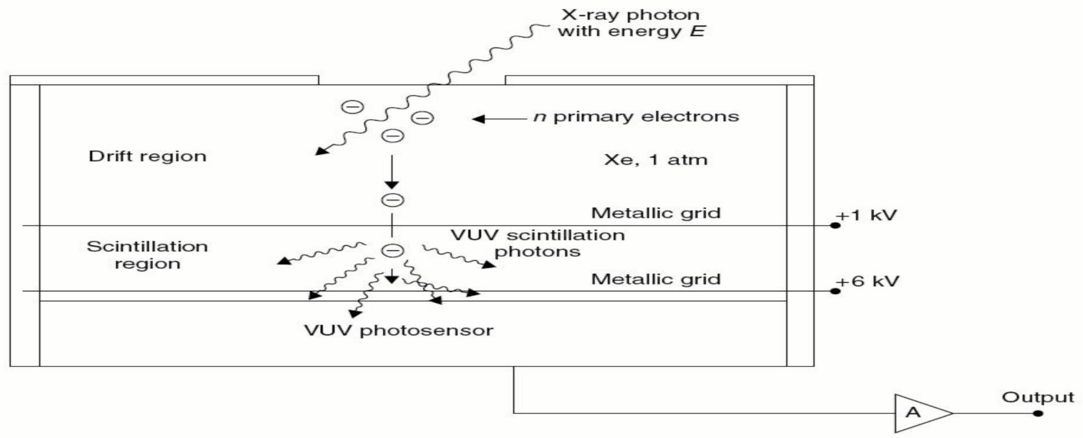

Fig. 21 Schematic view of GSPC counter

In this type of detector, in the drift zone, the measured X-ray of energy, E, produces n = E/W of the primary electrons (W-energy required to produce one ion-electron pair in the gas filling the counter). The resulting primary ionization electrons drift towards the scintillation area (field intensity in the drift area is ~ 0.5 - 1 kV / cm). In the scintillation area, the electric field strength is ~ 5 kV / cm. In this field, electrons gain enough energy to excite gas,

$e^- + Xe \rightarrow e^- + Xe^*$, which gives rise to another reaction

$Xe^* + Xe + Xe \rightarrow Xe_2^* + Xe$,

$Xe_2^* \rightarrow Xe_2 +$ photon VUV.

We measure VUV photons from Xe_2* de-excitation. The GSPC detector is a slow detector, the pulse duration is ~ μs, the pulse shape is very regular, the short rise and fall time and long duration time. This allows for a very thorough analysis of its shape. Based on analysis of the pulse shape, background events can be rejected. The ratio of the amount of Xs photons we want to measure to the total number of particles entering the detector in astrophysical measurements is ~ 1: 200. The ability to analyze the shape of the pulse greatly increases the effectiveness of rejecting background events.

At ESTEC I stayed twice, in the fall of 1987 for six weeks and in the fall of 1988 for four weeks as an expert in the SAX program (Satellite for Astronomy in X-rays). SAX Satellite was an Italian space mission aimed at measuring soft galactic X-rays from 0.1 keV to 200 keV. The satellite was equipped with three GSPC-based spectrometers with beryllium window for measuring X-radiation in the energy range of 1 keV to 10 keV and one GSPC-based spectrophotometer with polypropylene window for measuring X-radiation in the energy range of 0.1 keV to 10 keV. I participated in the testing of this spectrometer. As the first in ESTEC I measured the CK_α line (0,3 keV). I consider it to be my great success that the spectrometer in testing of which I was actively involved was approved as a payload of the satellite. Based on the measurements made by the SAX satellite, about 1500 publications have been produced.

In ESTEC I stayed in the late 80's, this is a period of strong political and social changes in Poland, the Berlin Wall still stood and to be invited as a mission expert I had the agreement of two Directors of the European Space Agency (ESA), the Director of Science and the Humane Resource Director and the ESTEC industrial guards did not hide that I was "a person under special supervision".

3.3.1 List of publications and reports related to my stay at ESTEC

E1. A. Smith, A. Peacock, **T.Z. Kowalski**, *A gas scintillation proportional counter for the X-ray astronomy satellite SAX*, IEEE Trans. Nucl. Sci. NS-34(1987)57-60.

E2. **T.Z. Kowalski**, A. Smith, A. Peacock, *Fano factor implications from gas scintillation counter measurements*, Nucl. Instr. and Meth. in Phys. Res. A 279(1989)567-572.

E3. A. Smith, F. Favata, **T.Z. Kowalski**, *Gas pressure and reduced electric field effects in gas scintillation proportional counters*, Nucl. Instr. and Meth. in Phys. Res. A 284(1989)375-380.

E4. F. Favata, A. Smith, M. Bavdaz, **T.Z. Kowalski**, *Light field as a function of gas pressure and electric field In gas scintillation proportional counters*, Nucl. Instr. and Meth. in Phys. Res. A 294(1990)595-601.

E5. **T.Z. Kowalski**, A. Peacock, B.G. Taylor, J.J. Valero, A. Smith, *Energy dependence of the F*W product*, XVIII Int. Conf. on Phenomena in Ionized Gases, 13-17 July 1987, Swansea, Contributed Papers, p. 74-75.

E6. **T.Z. Kowalski**, *Mechanism of proportional scintillation in Xenon*, Booklet of Abstracts, VIIIth Int. Conf. on Hyperfine Interactions, Prague, August 14-19, 1989, C-16.

E7. **T.Z. Kowalski**, A. Smith, A. Peacock, *Fano factor implications from gas scintillation proportional counter measurements*, ESTEC, Eslab 89/29.

E8. **T.Z. Kowalski**, A. Smith, A. Peacock, *Some remarks on the secondary scintillation output of Xe in GSPC*, Contributed paper in Int. Conf. on Phenomena in Ionised Gases XIX, Belgrade 10-14 July 1989.

3.4 Cooperation with the ZEUS experiment, 1988 - 2006

Cooperation with the ZEUS experiment, I began by taking part in tests of the BAC Calorimeter prototype on the H1 beam at CERN. During preparation for the tests, I made measurements of the Ar-CO2 mixture properties (gas gain, temperature effect, pressure effect). In addition, I made components of the gas system necessary for tests.

3.4.1 BAC Calorimeter prototype tests on the H1 beam.

Within the tests I was responsible for:

- design, construction and assembly of a gas system that supplies the BAC Calorimeter prototype with a suitable gas mixture,
- the gas supply system was divided into three branches, at the inlet and outlet of each branch were gas proportional counters of my construction monitoring the quality of the gas being fed the BAC prototype,
- the gas system was an open flow one, which resulted in changes in the working gas pressure, the temperature in the measurement room also changed, based on the output of the gas quolity control counters, I determined the correction coefficients of both the pressure and working gas temperature change, necessary to determine the linearity of the BAC calorimeter response,
- I also participated in the assembly and testing of multi-cell proportional chambers of BAC calorimeter used in the tests.

3.4.2 Gas system of BAC Calorimeter, general information

The working group called "BAC gas system" operated within the Department of Physics of Elementary Particle and Detectors of the Faculty of Physics and Nuclear Techniques. The task of this group was to design, to build, to operate and to service the system during its operation. The layout of the gas system was based on certain assumptions. The system was supposed to be an open one that would allow the regulation and control of the concentration of the quenching agent in the range of 10 to 15%. The calorimeter chambers were planed to work at a slight overpressure relative to atmospheric pressure. The gas system was supposed to reconstruct the high voltage power supply structure. All chambers were to be connected in parallel so that in case of leakage it was possible to disconnect a single chamber from the gas supply system. The gas system consisted of a ground part and a part located in the ZEUS experiment hall. The ground part consists of a container of liquid argon and of a container of liquid carbon dioxide and a machine mixing these two gases. The most important components of the mixer were electronically controlled valves and flowmeters, a CO_2 concentration gage and proportional gas quality control counters. The mixer had a capacity to produce a mixture of Ar-CO_2 up to 240 m^3/day which allowed for four gas exchanges per day in the calorimeter multi-cell chambers. In the ZEUS experiment hall was a gas distribution system. The gas distribution system was divided into 79 independent branches. There was a valve in each gas branch to determine the flow of the mixture in the branch, two electronic flowmeters measuring the amount of the flow in and flow out of the mixture (the difference was the leakage information in the branch) and the gas quality control counters at the input and output of each branch. The gas flow rate of the mixture in the branch was selected according to the number of chambers in the branch and to the required number of gas exchanges per day. The design of the gas system allowed the individual gas flow to be determined for each branch independently.

3.4.3 My contribution in building of BAC calorimeter gas system

1. I was the coordinator for the design, construction and operation of the BAC calorimeter gas system.
2. I conducted laboratory study of the avalanche multiplication process in the final Ar-CO_2 working mixture as a function of the admixture concentration in the geometry of the multi-cell chamber.
3. I conducted systematic laboratory measurements of both aging effects in multicell BAC calorimeters chambers in conditions similar to those in detectors and of detectors aged under real conditions of the experiment.
4. At the entrance and exit of each gas branch were control counters. I was the constructor of these detectors. I participated in their assembling, testing and annual inspection during gas system operation.
5. At the input and output of each branch were gas flowmeters. I have developed a procedure for their calibration and I participated in their annual re-calibration.
6. I participated in the project, selecting components, building and testing a gas mixing machine.
7. I participated in the measurement and analysis of homogeneity of the gas flow into the individual chambers in the gas branch.
8. Of all 158 gas quality control counters, Fe-55 spectra were collected. The spectra were archived, for each of them the peak position and the energy resolution were determined. I participated in the analysis of the results obtained, with particular emphasis on the aging effects.
9. The gas system was open and the gas density in the chambers varied with the change in temperature and in atmospheric pressure. The appropriate sensor system allowed the measurement of the temperature distribution in the iron yoke of the calorimeter and the variation of the working gas pressure. I participated in determining the correction coefficients of temperature and pressure changes.
10. Before the installation in the calorimeter , each chamber was tested. Counting characteristics were determined, the homogeneity of the chamber response along the anode wire and the leakage current were measured. The tester decided to install the

chamber in the calorimeter, repair it or reject it. I have been very active in testing chambers, even 16 hours/day.

11. As a member of the ZEUS ćollaboration, in addition to the current maintenance of the BAC calorimeter gas system, I participated in data collection of the ZEUS experiment, as a person responsible for the safety of the detector (safety shift officer) and as Deputy to Shift Leader. I estimate that I participated in approx. (60-70) blocks of shifts, one block is 4 shifts, 8 hours each.

12. For a short period of time (about 1 year) I worked with the straw tube tracker (STT). My obligation was to select a gas mixture for this detector and to determined the operating voltage of the straw detectors.

3.4.4 List of publications and reports related to my cooperation with the ZEUS experiment

Z1. H. Abramowicz et al. (**T.Z. Kowalski**), *Intercalibration of the ZEUS high resolution and backing calorimeters*, Nucl. Instr. and Meth. in Phys. Res. A 313(1992)126-134.

Z2. **T.Z. Kowalski**, A.R. Stopczyński, *The gas gain process in Ar-CO_2 filled proportional tubes*, Nucl. Instr. and Meth. in Phys. Res. A 323(1992)289-293.

Z3. M. Bobrowski, K. Jeleń, S. Koperny, **T.Z. Kowalski**, W. Machowski, E. Rulikowska-Zarębska, J. Zając, *Proportional counters as monitoring detectors of BAC Chambers at the ZEUS experiment*, Nucl. Instr. and Meth. in Phys. Res. A 313(1992)309-313.

Z4. B. Bednarek, K. Jeleń, S. Koperny, **T.Z. Kowalski**, J. Zając, *A study of aging effects in gas proportional detectors at the BAC calorimeter of the ZEUS experiment*, Nucl. Instr. and Meth. in Phys. Res. A 348(1994)228-231.

Z5. B. Bednarek, K. Jeleń, S. Koperny, **T.Z. Kowalski**, E. Rulikowska-Zarębska, J. Zając, *Anode wire ageing in proportional detectors at the BAC calorimeter of the ZEUS experiment*, Nucl. Instr. and Meth. in Phys. Res. A 392(1997)51-54.

Z6. **T.Z. Kowalski**, B. Mindur, *Manifestation of aging effects in gas proportional counters*, Nucl. Instr. and Meth. in Phys. Res. A 515(2003)180-184.

Z7. **T.Z. Kowalski**, B. Mindur, *A study of aging effects in gas monitoring proportional counters of BAC calorimeter in the ZEUS experiment*, Nucl. Instr. and Meth. in Phys. Res. A 515(2003)60- 64.

Z8. ZEUS Collaboration, *The ZEUS Detector Technical Proposal*, DESY, 1986.

Z9. ZEUS Collaboration, *The ZEUS Detector Status Report 1993*, DESY, 1993.

Z10. H. Czyrkowski, at al. (**T. Kowalski**), *Tests of the BAC prototype*, ZEUS Note 90-099, 1990.

Z11. M. Deptuch, S. Koperny, **T.Z. Kowalski**, B. Mindur, *The temperature coefficient of the gas gain in the chamber of BAC Calorimeter*, Internal Report, DESY, ZEUS Note 03-025, 2003.

Z12. B. Bednarek, K. Jeleń, S. Koperny, **T.Z. Kowalski**, J. Zając, *Control of Gas Flow in BAC Calorimeter at the ZEUS Experiment,* Internal Report, DESY, ZEUS Note 93-093, 1993.

Z13. B. Bednarek, K. Jeleń, S. Koperny, **T.Z. Kowalski**, E. Rulikowska-Zarębska, J. Zając, *The Temperature Distribution in the Iron Yoke at the ZEUS Experiment,* Internal Report, DESY, ZEUS Note 95-033, 1995.

Z14. M. Deptuch, K. Jeleń, S. Koperny, **T.Z. Kowalski**, B. Mindur, *Some remarks on Ageing Effects in ZEUS – BAC Multicell Chambers*, ZEUS Note 02-003, 2002.

Z15. B. Bednarek, K. Jeleń, S. Koperny**, T.Z. Kowalski**, J. Zając, *A study of Aging Effect in Gas Proportional Detectors at BAC calorimeter of the ZEUS Experiment*, ZEUS Note 93-100, 1993.

Z16. B. Bednarek, K. Jeleń, S. Koperny, **T.Z. Kowalski**, J. Zając, *Monitoring Proportional Counters in BAC Gas System at the ZEUS Experiment*, ZEUS Note 93-095, 1993.

Z17. H. Abramowicz, et al., (**T.Z. Kowalski***), Intercalibration of the ZEUS High Resolution and Backing Calorimeters*, DESY 91-081, 1991.

Z18. H. Abramowicz et al. (**T.Z. Kowalski**), *Tests of the BAC prototype*, ZEUS Note 90-099, 1990.

Z19. H. Abramowicz et al. (**T.Z. Kowalski**), *New metod of pulse height and time reconstruction for BAC*, ZEUS Note 90-91, 1990.

Z20. H. Abramowicz et al. (**T. Kowalski**), *Intercalibration of the ZEUS Backing Calorimeter with the Uranium Calorimeter*, ZEUS Note 90-88, 1990.

Z21. B. Bednarek, M. Deptuch, S. Koperny, **T.Z. Kowalski**, B. Mindur, *BAC gas system-general information and instruction for safety officer,* ZEUS Note 01-052, 2001.

Z22. B. Bednarek, K. Jeleń, S. Koperny, **T.Z. Kowalski**, E. Rulikowska-Zarębska, J. Zając, *The Temperature Distribution in the Iron Yoke at the ZEUS Experiment*, ZEUS Note 95-033, 1995.

3.5. Collaboration with the ATLAS experiment

At the beginning I collaborated with the EAGLE experiment. The EAGLE experiment merged with the ASCOT experiment and created the ATLAS experiment. Gas microstrip detectors were one of the proposals of the inner detector in EAGLE. In EAGLE collaboration

I coordinated work on the construction of a gas system that supplies micro strips detectors. Micro stripes detectors by ATLAS collaboration have not been adopted for implementation. Then I went to the Transit Radiation Tracker (TRT). The literature review of this period of time includes both the work on micro-strips detectors and on the, TRT, transition radiation detector.

3.5.1 General comments on the ATLAS experiment and on the TRT transition radiation detector

There are two basic tasks before the TRT (Transition Radiation Tracker) detector. The first is the registration of tracks of ionizing particles passing through the detector. It is estimated that during the detector operation a track reconstruction will be possible by recording about 35 hits per track. The second, very important task is the identification of electrons with transverse momentum of approximately 40 GeV, by recording the transition radiation generated by them, which is emitted during the transition of the charged particle across the material of different electrical constants. The TRT detector of transition radiation is a very complex system. It has about 300,000 proportional straw tubes. The transient radiation tracker is one of the components of the inner detector located in the very center of the ATLAS experiment. It was designed to operate in a 2T magnetic field produced by a solenoid coil surrounding the whole inner detector. The transition radiation detector has a modular construction. The central part of the transition radiation detector consists of three concentric cylindrical rings. Each of the rings contains 32 fully independent modules in which 144 cm long straw tubes are arranged side by side, parallelly to the beam axis. End-capes are side modules of the transient radiation detector. In this section straw proportional detectors are positioned radially to the beam axis. Each end-cap consists of a set of identical and independent wheels. The straws are 39 cm in length. Straw detectors used in the experiment have cylindrical geometry. They are constructed from a conductive cathode with a diameter of 4 mm (hence the name of the straw) and a centered anode with a diameter of 30 μm. One of the tasks of the TRT component is to identify the electrons by recording the transition radiation generated by them. To maximize this task, the system stabilizing the gas gain in TRT straws is needed. It was assumed that for correct operation of the whole TRT system the fluctuations in gas gain values can not be higher than 5%. It was established that the maximum permissible temperature gradient in TRT can not exceed 10°C. The simulation showed that a larger temperature gradient could cause mechanical damage to the detector. It should be pointed out that the temperature has a strong influence on the value of the gas gain. This is due to the change in the density of gas flowing through the straws at change in temperature. During accelerator operation all parts of the TRT are in a strong field of ionizing radiation. The gas filling the counters will therefore be subjected to continuous irradiation, as a result of which the dissociation of the components of the mixture may lead to a change in its chemical composition resulting in a fluctuation in the value of the gas gain. Any change in the composition of the working gas mixture, in the atmospheric pressure and in temperature values significantly affect the gas gain in the detectors, and especially in the quasi- flow system like we have in TRT sub-detector. In order to obtain sufficiently stable operation of the whole TRT detector and the functionality of electron identification, it is necessary to keep the gas gain constant. For this purpose, Gas Gain Stabilization System (GGSS) was designed and built.

3.5.2 My participation in the construction of the TRT transition radiation detector of the ATLAS experiment.

1. Design, construction, testing and coordination of work related to the construction of Gas Gain Stabilisation System (GGSS).
2. Study of gas mixtures for TRT detector, Ar-CO_2-CF_4, Xe-CO_2-CF_4, Xe-CO_2-O_2.
3. Test the homogeneity of detector responses along the anode wire (very important for straw detectors in the central barrel part where the straw length is ~ 140 cm).
4. Measurement of counting characteristics of straw detectors.
5. Measurement of the dependence of the energy resolution on the anode supply voltage.
6. Measurement of the influence of working gas pressure on gas gain, determination of pressure coefficient of gas gain.
7. Measurement of the influence of temperature on the gas gain, determination of the temperature coefficient of the gas gain.
8. Study of diffusion of gases through the walls of straws, to determine gas losses due to diffusion through the walls and to determine change in composition of working gas mixture.
9. Study of outgassing of whole straw and straw elements, measuring the minimal amount of working gas change.
10. Measurement of the temporary aging effect.

3.5.3 Publications and reports related to my collaboration with the ATLAS TRT detector

A1. D. Gingrich et al. (**T. Kowalski**), ATLAS – *Letter of Intent for a General-Purpose pp Experimental at the large Hadron Collider at CERN*, Raport CERN/LHCC/92-4, Genewa, 1992.

A2. W.W. Armstrong et al. (**T. Kowalski**), *ATLAS –Technical Proposal for a General-Purpose pp Experiment at the Large Hadron Collider at CERN*, Raport CERN/LHCC/94-43, LHCCIP2, 1994.

A3. F.E. Bakker et al. (**T. Kowalski**), *ATLAS-MSGC, Support Document for the Micro Strip Gas Counter Sub-system which is part of the Inner Detector for the ATLAS experiment at CERN*, ATLAS Internal-Note, INDET-NO-076, 1994.

A4. B. Bednarek, K. Jeleń, **T.Z. Kowalski**, E. Rulikowska-Zarębska, J. Zając, *Overview of MSGC studies at Cracow*, ATLAS MSGC Meeting at Coseners House, Anglia, January 18-19, 1994.

A5. B. Bednarek, K. Jeleń, **T.Z. Kowalski**, E. Rulikowska-Zarębska, J. Zając, *Review of gases used in MSGC – towards baseline gas mixture, ATLAS+MSGC Meeting*, Prague, May 23-24, 1994.

A6. R. Bouclier et al. (**T. Kowalski**), *RD-28 Collaboration, Development of micro-strip gas chambers for radiation detection and tracking at high rates*, RD-28 Status Report, CERN/DRDC/93-94, Genewa, 1993.

A7. A. Airapetian et al. (**T. Kowalski**), *ATLAS calorimeter performance, Technical Design Report*, CERN-LHCC-96-40 (Dec 1996)189p.

A8. A. Airapetian et al. (**T. Kowalski**), *ATLAS computing technical propos al*, CERN-LHCC-96-43 (Dec 1996) 100p.

A9. F. Sauli et al. (**T. Kowalski**), *Development of microstrip gas chambers for radiation detection and cracking at high rates,* RD-28 Collaboration, CERN-DRDC-94-45 (Jan 1995) 54p.

A10. T. Akesson et al. (**T. Kowalski**), *Particle identification using the time-over-threshold metod in the ATLAS Transition Radiation Tracker*, Nucl. Instr. and Meth. in Phys. Res. A 474(2001)172-187.

A11. E. Abat, et al. (**T.Z. Kowalski**), *The ATLAS TRT barrel detektor*, Journal of Instrumentation, 2008 JINST 3 P02014.

A12. E. Abat, et al. (**T.Z. Kowalski**), *The ATLAS Transition Tracker (TRT) proportional drift tube:design and performance*, Journal of Instrumentation, 2008 JINST 3 P02013.

A13. T. Akesson, et al. (**T.Z. Kowalski**), *Aging studies for the ATLAS Transition Radiation Tracker (TRT),* Nucl. Instr. and Meth. in Phys. Res. A 515(2003)166-179.

A14. T. Akeson, et al. (**T.Z. Kowalski**), *Status of design and construction of the Transition Radiation Tracker (TRT) for the ATLAS experiment at the LHC*, Nucl. Instr. and Meth. in Phys. Res. A 522(2004)131-145.

A15. M. Capeans, et al. (**T.Z. Kowalski**), *Recent aging studies for the ATLAS transition radiation tracker*, IEEE Trans. On Nucl. Science 51,3(2004)960-967.

A16. T. Akesson, et al. (**T.Z. Kowalski**), *ATLAS Transition Radiation Tracker test-beam results*, Nucl. Instr. and Meth. in Phys. Res. A 522(2004)50-55.

A17. M. Deptuch, **T.Z. Kowalski**, *Gas multiplication process in mixtures based on* Ar, CO_2, CF_4, Nucl. Instr. and Meth. in Phys. Res. A 572(2007)184-186.

A18. T. Akesson, et al. (**T.Z. Kowalski**), *An X-ray scanner for wire Chambers*, Nucl. Instr. and Meth. in Phys. Res. A 507(2003)622-635.

A19. K. Jeleń, S. Koperny, **T.Z. Kowalski**, et al. *Gas gain in MSGCs with* $Ar/CO_2/CF_4$ *mixtures*, Nucl. Instr. and Meth. in Phys. Res. A 392(1997)80-82.

A20. St. Koperny, **T.Z. Kowalski**, *Operation of proportional counters under high gas gain, high working gas pressure in mixed field of radiatio*n, Nucl. Instr. and Meth. in Phys. Res. A 718(2013)575-576.

A21. M. Deptuch, **T.Z. Kowalski**, *Performance of Ar/CO_2 filled proportional counters under high gas gain at high working gas pressure*, Nucl. Instr. and Meth. in Phys. Res. A 572(2007)181-183.

A22. M. Deptuch, **T.Z. Kowalski**, B. Mindur, *Change in detektor properties caused by electronegative impurities,* Nuclear Physics B-Proceedings Suppl. 150(2006)398-401.

A23. M. Deptuch, **T.Z. Kowalski**, B. Mindur, *Performance of Xe-filled counters under high gas gain*, Nucl. Instr. and Meth. in Phys. Res. A 518(2004)579-581.

A24. M. Deptuch, **T.Z. Kowalski**, B. Mindur, *Performance of straw proportional tubes under high gas gain, transition to self-quenching streamer mode and corona dis charge,* Nuclear Physics B-Proceedings Suppl. 125(2003)390-393.

4. Total Impact Factor of the publications in accordance to Journal Citation Reports

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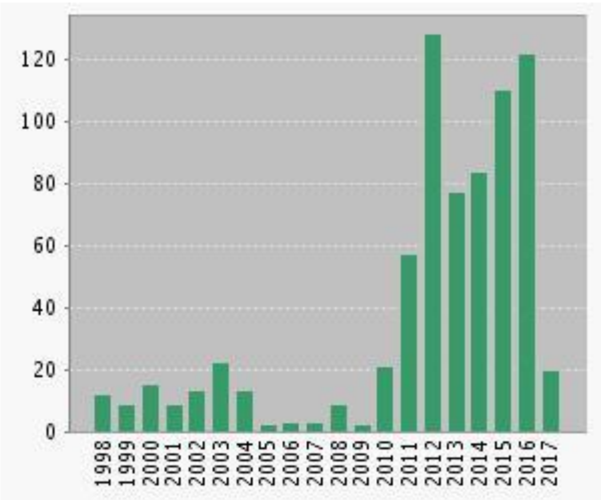

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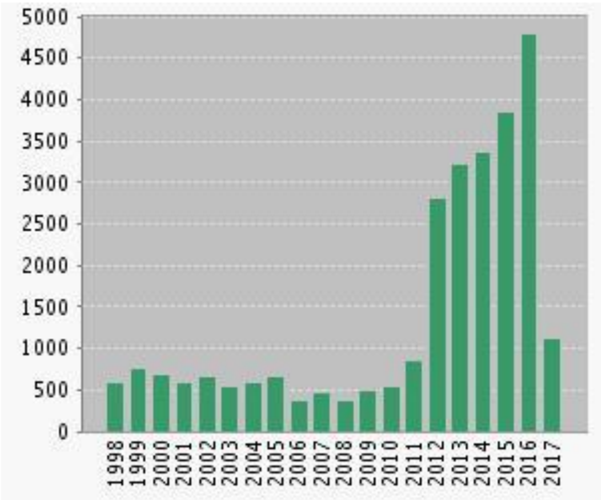

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Citing Articles :	14230
Citing Articles without self-citations	13483
Average Citations per Item	35.69
h-index	74

List of all my publications is attached as separate appendix.

4.1 Total Impact Factor (For the publications that have been published in 2016,[H4, H8], and 2017 [H5, H9], I adopted IF from 2015):

11,65

4.2 Number of all publications: (Web of Science dated as of 15.06.2017)

808

Sum of Times Cited:

28834

Sum of Times Cited without self-citations:

26047

h-indeks:

74

Most of my publications are signed by the ZEUS Collaboration and ATLAS Collaboration. I did not participate directly in the analysis of data from these experiments, but I am sure that my participation in the publication of these papers is significant. I participated in the construction of the component of both experiments, in their ongoing maintenance, repair and performance quality control. Ultimately, the quality of the data collected from the experiments is determined by the correct work of the detectors in the building and testing of which I actively participated. The GGSS system, in the ATLAS experiment, the construction of which I have coordinated is a small part, but its incorrect operation makes all data from the TRT component useless for further analysis. The same applies to the correct functioning of the ZEUS BAC Calorimeter gas supply system. I participated also in current experiment handling as ACRDQ (ATLAS Control Room Data Quolity Shifter), whose main task was to control the quality of collected data of all components. I played a similar role in the ZEUS experiment as Deputy Shifter. There were a number of verification procedures to be co-authored of the papers assigned by the Collaboration and the appearance on the list of authors is not accidental.

The list of publications [H1] to [H9] involves gas detectors and physical phenomena occurring in them, so I have excluded from all my publication those directly related to gas detectors and physical processes occuring in gas counters.

Number of publications without publications affiliated by ZEUS and ATLAS:
55

Sum of Times Cited without publications affiliated by ZEUS and ATLAS:
284

Sum of Times Cited without self-citations without publications affiliated by ZEUS and ATLAS:
243

h-index without publications affiliated by ZEUS and ATLAS:
12

4.3 Training and post-doc trips

The Netherlands, Nordwijk aan ZEE, ESTEC, European Space Research and Technology Centre, January 1986 – January 1987. Research scholarship of International Atomic Energy Agency in Vienna.

Germany, Hamburg, DESY, 1992 – 2006.
Multiple trips, during construction and collection of data by the ZEUS experiment on average about 6 months per year (until 2003), then about 3 months per year (until 2006).

Switzerland, Geneva, CERN, 1988 – up to now.
Multiple trips averaging about 4 months per year during the BAC prototype tests (1988 - 1990), than about 1 – 4 months per year.

The Netherlands, ESTEC, 1987 year, six weeks, ekspert of SAX satelite project(SAX - Satellite for Astronomy of X-rays).

The Netherlands, ESTEC, 1988 year, four weeks, ekspert of SAX satelite project.

Germany, Hamburg, DESY, 1995 year, three months, scholarship of European Union.

4.4 Prizes and awards

1. Team Award of the Polish National Atomic Energy Agency (third degree) for development of beryliumless proportional counters, 1985.
2. Team Award of Ministry of Science and Higher Education (second degree) for the development of new types of proportional counters, 1986.
3. Award of the AGH – UST Rector for scientific research activity, 1983.
4. Award of the AGH – UST Rector for participation in research work, 1984.

5. Team Award of the AGH – UST Rector (third degree) for scientific activity, 1990.
6. Team Award of the AGH – UST Rector (second degree) for scientific achievements, 1997.
7. Team Award of the AGH – UST Rector (second degree) for scientific achievements, 2002.
8. Team Award of the AGH – UST Rector (first degree) for scientific achievements, 2005.
9. Team Award of the AGH – UST Rector (first degree) for scientific achievements, 2012.
10. Team Award of the AGH – UST Rector (first degree) for scientific achievements, 2013.
11. Team Award of the AGH – UST Rector (first degree) for scientific achievements, 2014.
12. Team Award of the AGH – UST Rector (second degree) for scientific achievements, 2015.
13. Team Award of the AGH – UST Rector (second degree) for didactic achievements, 2016.
14. Team Award of the AGH – UST Rector (first degree) for scientific achievements, 2017.
15. Silver Cross of Merit awarded by the President of the Republic of Poland, 2003.

4.5 Active participation in international conferences

1. The International Conference on Position Sensitive Detectors, PSD, a regular three-yearly conference in the first half of September in England, a multiple participation.
2. Topical Seminar on Innovative Particle and Radiaton Detectors, Siena, Italy, a regular two- or three – yearly conference, a multiple participation.
3. Frontier Detectors for Frontiers Physics, Pisa Meeting on Advanced Detectors, Isola D'Elba (La Biodola), a regular three – yearly conference, a multiple participation.
4. Vienna Wire Chamber Conference (currently Vienna Conference on Instrumentation), a regular three – yearly conference, a multiple participation.
5. Multiple presentations in ZEUS BAC Gas System, ATLAS TRT (until August 2013 I was coordinator of the work provided by the Cracow Group) and CERN RD 51 Collaborations.

At each conference in which I participated, I presented the results of my work.

5. Didactic and organizational activities

5.1 Didactic activities

I am responsible for three complex course syllabi for students:

- Genaral physics, Faculty of Drilling, Oil and Gas, AGH – UST.
- Radiation detectors, Faculty of Physics and applied Computer Science, AGH – UST.
- Detection of radiation in medicine, Faculty of Physics and applied Computer Science, AGH – UST,

5.2 Didactic clases

- General Physics – lectures, classes, laboratory classes,
- Radiation Detectors – lectures, laboratory classes,
- Detection of Radiation in Medicine – lectures, laboratory classes,
- Nuclear Engineering – Accelerators – lectures, classes.

5.3 External lectures:

- Lectures on "Methods of Radiation Detection and Dosimetry" at postgraduate studiem in specialization in medical physics organized by the Center of Oncology, Instytut im. Maria Skłodowska-Curie, Cracow Department, 30 hours, 2014.
- Lectures on "Radiation Detectors" within the framework of the Radiation Protection Project - specialists for modern and safe economy, Pedagogical University of Cracow, 30 hours, 2013.

5.4 Scientific assistance to students as scientific supervisor of Master thesis

1. **Dominika Czudek**, *Study of gas gain in mixtures with small ageing effect*, 1996 year.
2. **Marek Pietrzyk**, *Long term stability of the straw detectors*, 1999 year.
3. **Rafał Dziekanowski**, *Influence of electronegatives impurities on proportional counters performance,* 1999 year.
4. **Anna Pietrzyk**, *Gas gain in the straw detectors*, 1999 year.
5. **Dorota Karsznia**, *Ageing effects in gas detectors*, 2000y.
6. **Jakub Wojtaszewski**, *Gas multiplication process in Ar based gas mixtures in proportional counters in straw geometry of ATLAS and ZEUS experiment*, 2001year.
7. **Sabina Płoskonka**, *Performance ofd proportional counters under high gas gain*, 2000 year.
8. **Monika Puchalska**, *Electron multiplication in proportional counters filled with Xe - CF_4 - CO_2 mixture*, 2001year.

9. **Damian Kabat**, *Influence of proportional counter geometry on the speed of their aging*, 2003y.

10. **Michał Miska**, *Straw detectors in high energy physics experiments*, 2004y.

11. **Klaudia Hajder**, *Performance of gas detectors under high count rate. Temporary ageing effect*, 2004y.

12. **Tomasz Śpilski**, *Temperature effect in flow proportional counters*, 2006y.

13. **Miłosz Podlaszewski** *Flat ionisation chamber for dose measurements in hadronic therapy. Design and preliminary studies*, 2006 y.

14. **Michał Bochenek**, *Gas gain stabilisation system in transition radiation tracker of the ATLAS experiment*, 2007y.

15. **Paweł Radeberg**, *Performance of proportional counters under high gas gain and the mixture pressure above 0,1 MPa*, 2008 y.

16. **Rafał Ochman**, *Performance of micro-dosimetric counters in mixed field of radiation*, 2016 y.

17. **Paweł Haduch**, *Measurements of the Bragg curve for alfa particle*, 2016 y.

5.5 Scientific assistance and co – supervision to Ph.D. students

n/a

5.6 Membership in international scientific societies

1. Member of the ZEUS Experiment at HERA accelerator from 1988 to 2006, Group Leader gas BAC system.
2. Member of ATLAS Collaboration, from 1992 up to now, Group Leader of Gas Gain Stabilisation System for TRT up to 2013 year.
3. Member of CERN RD-28 Collaboration, Development of micro strip gas chambers radiation detection and cracking at high rates, 1992 – 1996.
4. Member of CERN RD-51 Collaboration, Development of Micro-Patern Gas Detectors Technologies, from 2012 up to now.

5.7 Organizational activity

1. Reviewer of the scientific journal: Nuclear Instrument and Method in Physics Research A.
2. Reviewer of the scientific journal: Applied Radiation and Isotopes.
3. Member of the faculty recruitment commission at the Faculty of Physics and Applied Computer Science, AGH – UST, Krakow.
4. Head of the student laboratories (organized by me), Radiation Detectors and Radiation Detection in Medicine.

5.8 Participation in international research projects

1. Special Research Project, applies to the ZEUS Experiment at HERA accelerator at DESY from 1988 to 2006, next editions of the grants.
2. Special Research Project, applies to the ATLAS Experiment at LHC accelerator at CERN from 1992 to 2013, next editions of the grants.

3. Harmonia, grant of National Science Centre, applies to RD – 51 Collaboration at CERN, from 2012 up to now.

6.0 Final remarks

My diploma work on " Long living proportional counters filled with Ne based mixtures for X-rays of energy up to 6 keV” refers to proportional counters. My Ph.D. thesis entitled " Analysis of gas gain coefficient in the mixtures of gases and vapours in the function of selected parameters " also referred to gas proportional counters and phenomena occurring in them. All my professional life is connected with radiation detection, especially with gas proportional counters. My interests have always been twofold, (1) to understand the physical phenomena taking place in the detector, (2) to build a properly functioning detector fullfeeling the expectation of the user. Execution of (2) is impossible without (1). In order to understand the physical phenomena occurring in the detector, I made measurements of the gas gain curves and determined the constants characteristic for the mixture. Comparison of the measured gas gain curves and calculated from the MAGBOLTZ program has allowed us to determine the probability of Penning effect, a process that significantly changes the evolution of the electron avalanche in the detector. Measurements of energy resolution, of count rate effect, and of detector performance at high gas gain have been used to determine the maximum stable gas gain, maximum measured radiation intensity and the range of anode voltages, parameters relevant to understand the physical phenomena in the detector and for their applications. A separate issue on the borderline of physics and plasma chemistry is the aging effect of detectors. I have studied the aging effect of detectors in laboratory conditions but I also studied detectors aged in their natural working conditions. Here I mean on the measurements of gas quality control counters and multi-cel BAC calorimeter chambers before mounting in the experiment and after the experiment. The second stream of my interest is the construction of detectors for the specific requirement of users. This concerns the construction and testing of counters for the Mossbauer effect study, for X-ray fluorescence analysis, for the detection of cosmic ray bursts, for the measurements of soft X-rays in astrophysics, counters for the control of gas quality in BAC Calorimeter or dedicated straw detectors for the gas gain stabilization system in the TRT transition radiation detector in the ATLAS experiment.

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Special thanks to Professor Kazimierz Jeleń for introducing me into the world of radiation detection.

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Tadeusz Kowalski