Results from Prototypes of Some Environmental and Health Related Alarm Devices Based on Gaseous Detectors Operating in Air in Counting Mode

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There are some commercial devices/sensors based on gaseous detectors operating in air in ionization chamber mode

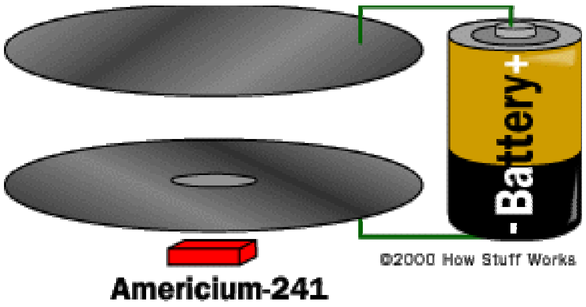
PID

Smoke detector

PID

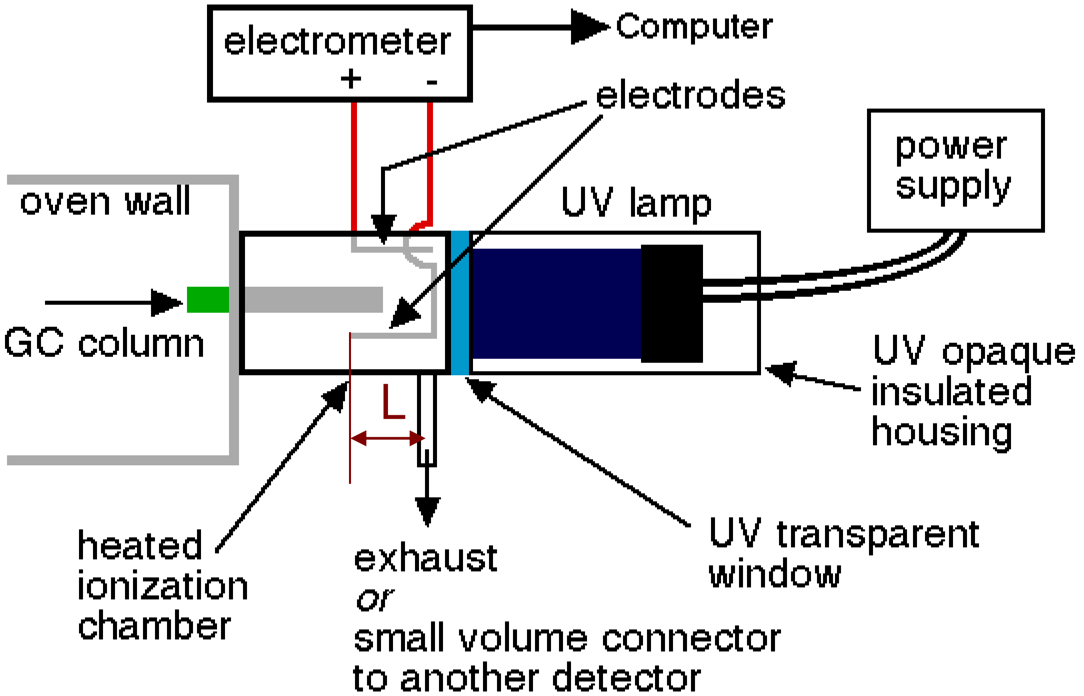
Atmos Rn deetcpr

The most useable gaseous detector operating in open air



Smoke detectors are one of those amazing inventions that, because of mass production, cost practically nothing. You can get a smoke detector for as little as $20. And while they cost very little, smoke detectors save thousands of lives each year. In fact, it is recommended that every home have one smoke detector per floor.

Commercial photoionization detector of dangerous gases /flammable , combustive, toxic):



<u>Sensitivity</u>: in some cases up to 100 ppb (stationer devices)
<u>Gases</u>: benzene, toluene and others

The main advantages of gaseous detectors operating in air (recall: they all are running in ionization chamber mode) are simplicity and low cost

What limits their sensitivity?

The minimum current which can be reliably measured with modern compact electronics

~πA

The <u>aim</u> of this work was to investigate if gaseous detectors can be exploited in avalanche mode

(in this case the gaseous detector will be a natural preamplifier for the picoammeter and this will <u>increase its sensitivity</u>)

The presentation will consists from three parts:

I) **Study** of operation of various gaseous detectors in air in avalanche mode

II) **A prototype** of the dangerous gases detector based on photoionization principle and operating in avalanche mode

III) **A prototype** of a Rn detector operating in air in avalanche mode

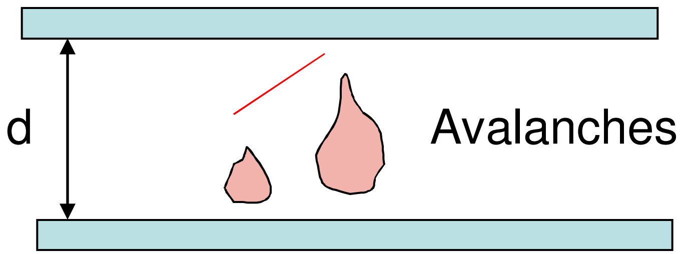
Part I.

Study of operation of various gaseous detectors in air in avalanche mode

Can they operate in air?

Avalanches in air were carefully studied a long time a ago, however these studied did not lead to any practical detector operating in air at some gain due to unstable behavior

Example: a parallel –plate detector in air at gains close to breakdown



Important feature of this detector geometry: free electrons start the avalanches:

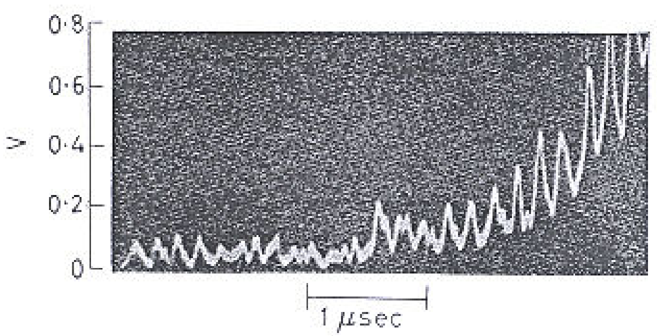


Figure 5.22. Series of avalanches in room air at $U_{stat.}$ which lead to breakdown; $E/p = 37{\cdot}7$, $p_{20} = 760$ Torr, $d = 2{\cdot}5$ cm. The growth of the current in generations can be observed up to current amplitudes ten times higher than the mean amplitude reproduced here[43]

$$n_e = \exp\,[(\alpha-\eta)d]$$

The discharge occurs via a photon feedback mechanism.
<u>This is very similar to noble gases</u>

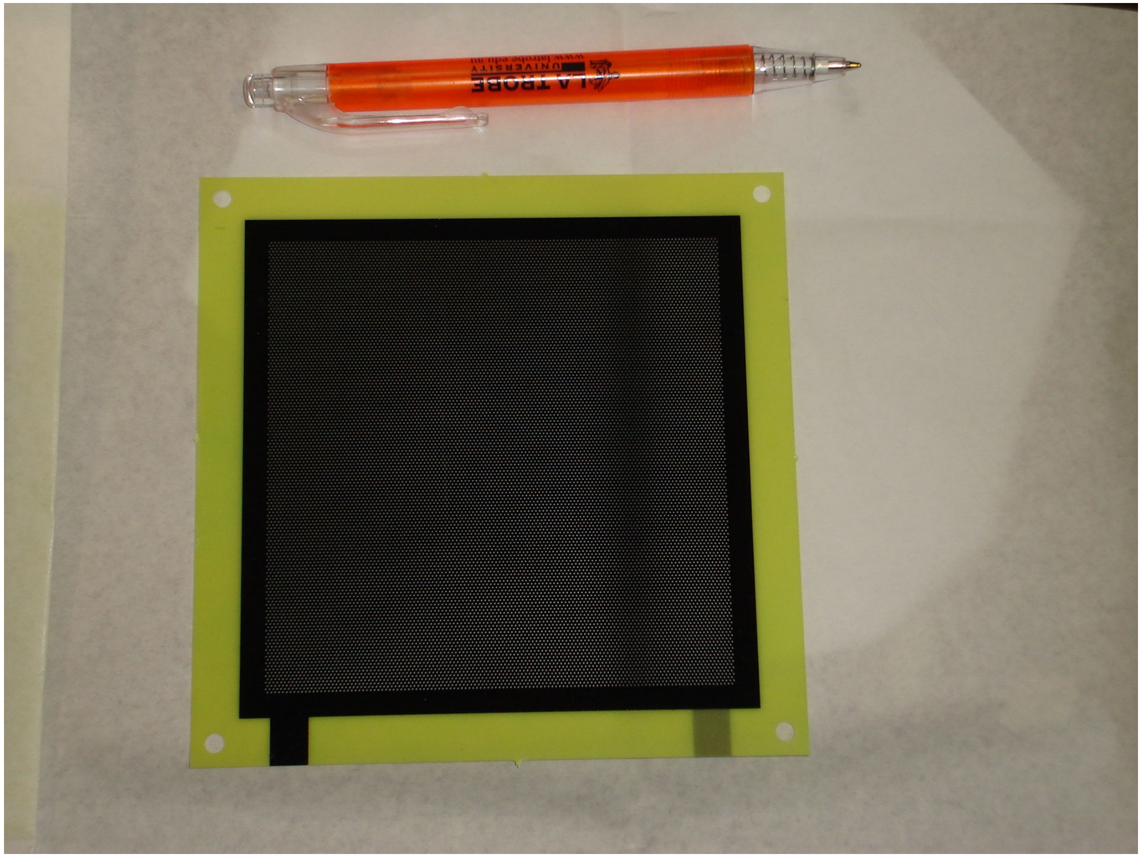
H. Raether, "Electron avalanches and breakdown in gases" London : Butterworths, 1964.

Air is a bad quencher gas. "Classical" gaseous detectors operating in in air meet the same problems as in badly quenched gases, for example in noble gases.
However, it is known that hole-type structures (capillaries or GEM-like) can operate stably in noble gases

Hence, very probably hole-type detectors will stably operate in air too (?)

10x10cm^2 RETGEM-

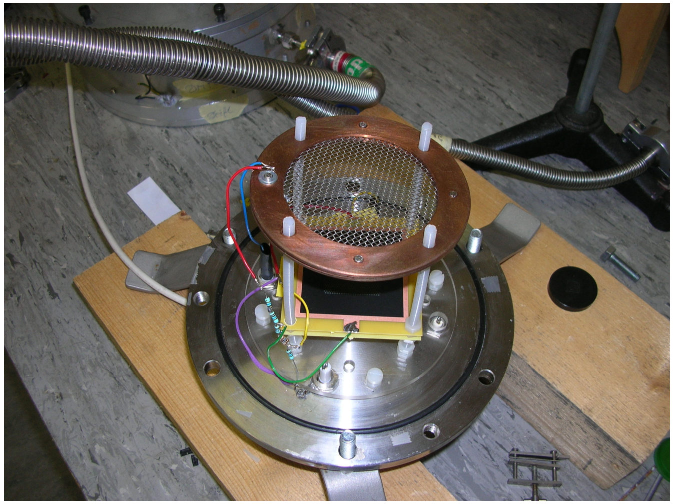
-robust spark-protected thick GEM (TGEM) with resistive electrodes



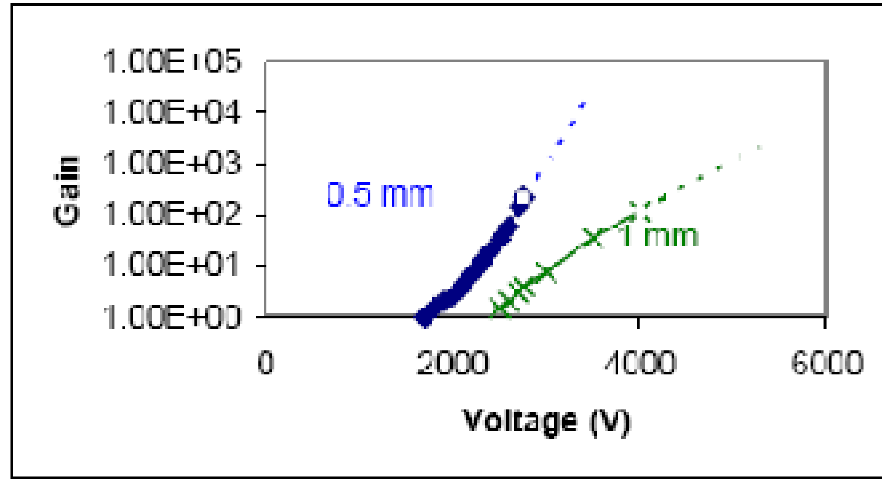
RETGEM *was first presented at the previous Vienna conference on Instrumentation (see report of V. Peskov et al there)*

TGEM *was first described in papers: L. Periale et al., NIM A478,2002,377and J. Ostling et al., IEEE Nucl. Sci 50,2003,809*

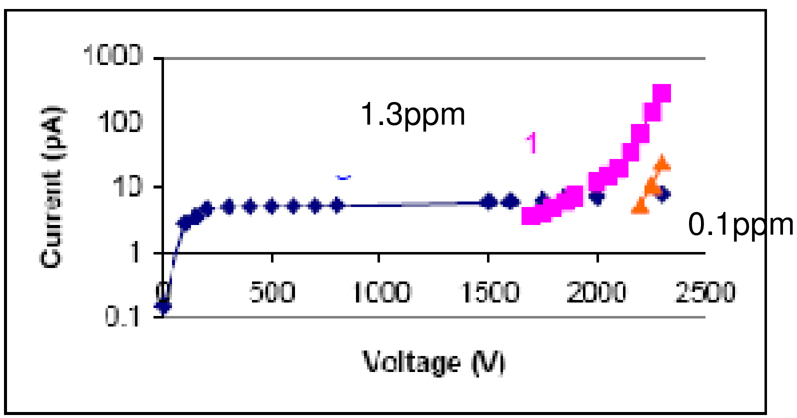
Some results obtained with RETGEM after the previous Vienna Conference



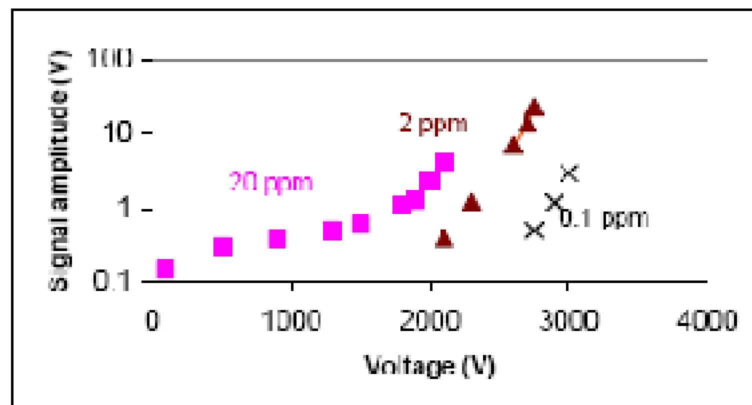
RETGEM-based prototype



Gain curves in air (CsI photocathode)



Ethylferrocene in air (current and pulse mode)

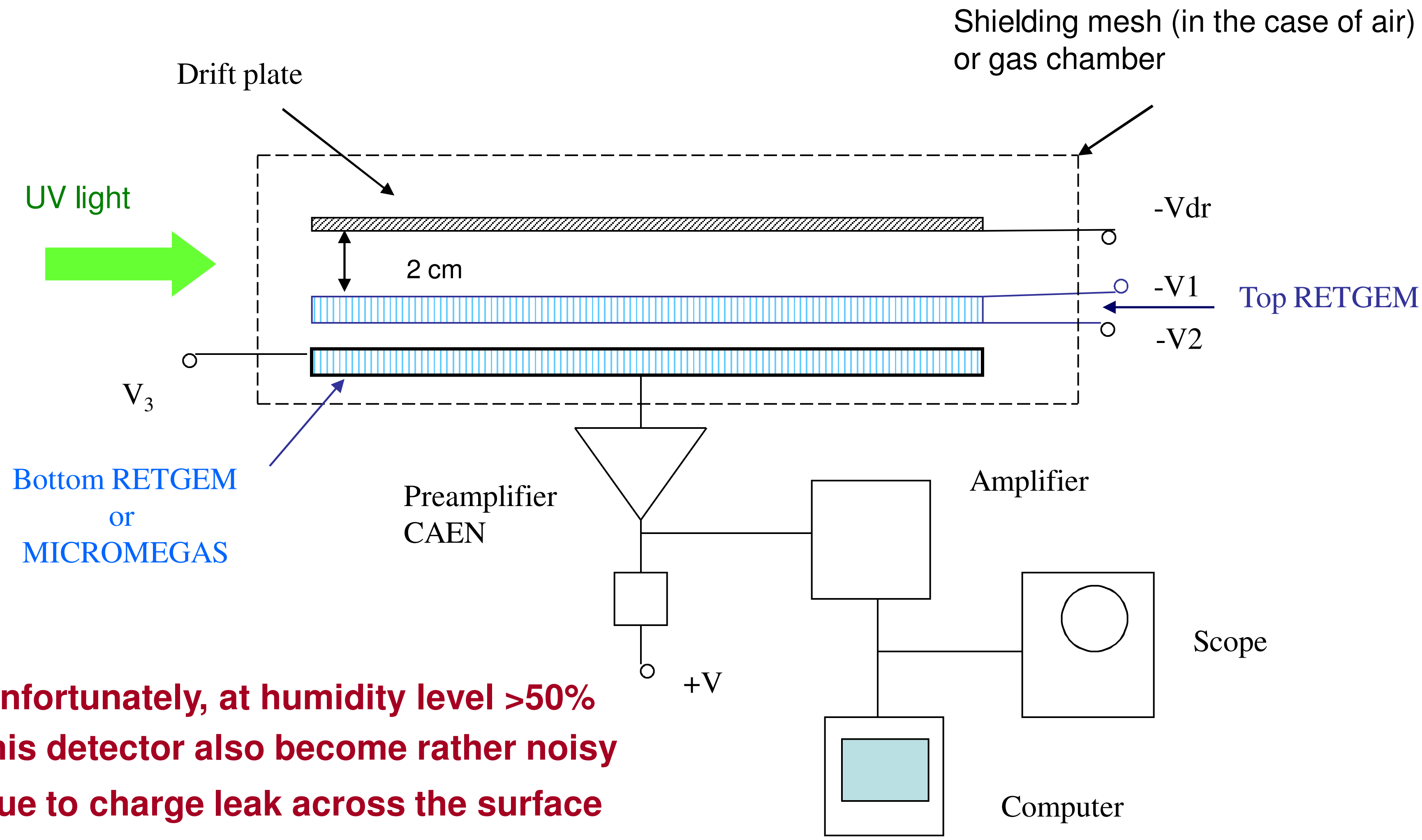


Benzene in air (current and pulse mode). Max gain~10^4

G. Charpak et al., IEEE Trans. Nucl. Sci 55 , 2008 , 1657

Problems at air humidity >50%

Double RETGEM and RETGEM+MICROMEGAS were also tested



Unfortunately, at humidity level >50% this detector also become rather noisy due to charge leak across the surface

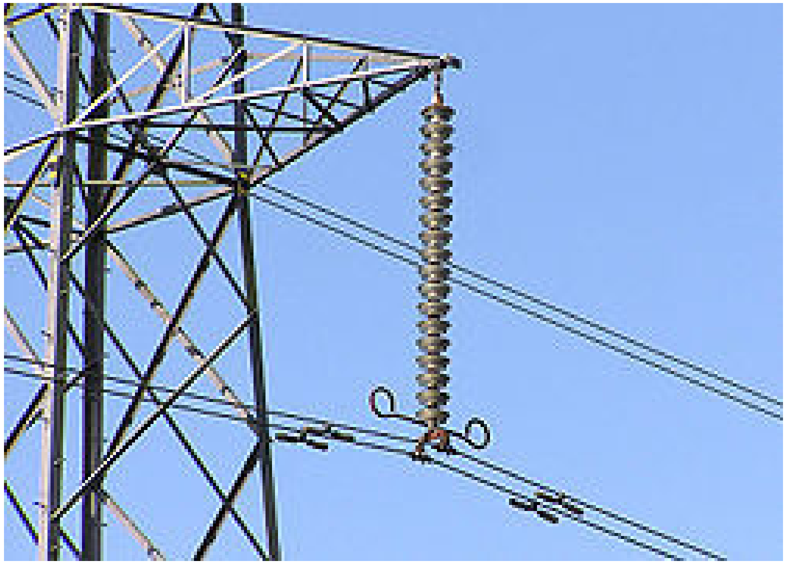
G. Charpak et al., IEEE Trans. Nucl. Sci 55 , 2008 , 1657

…PPAC cannot, but

can single-wire counter operate
in air and especially in humid air?

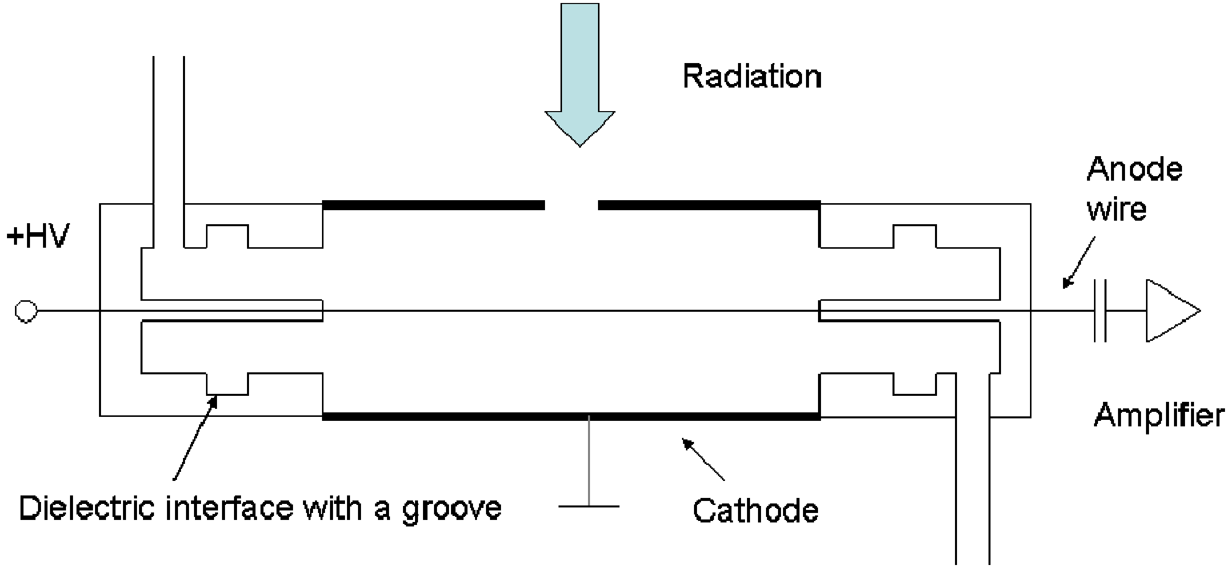
Yes…if its design is optimized…

Step-by step
solution of the problems

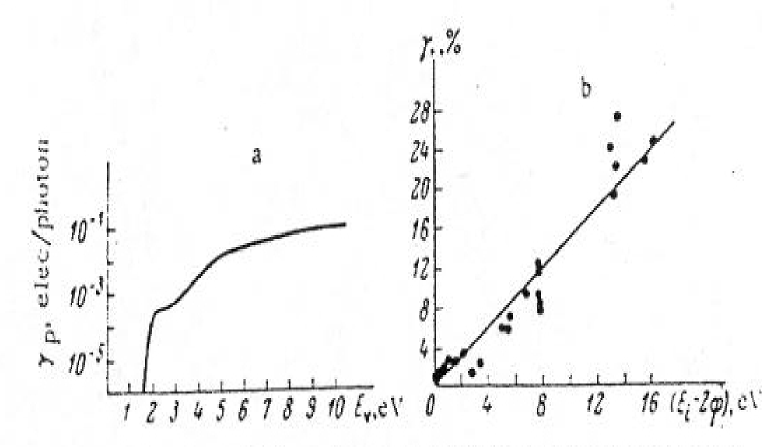


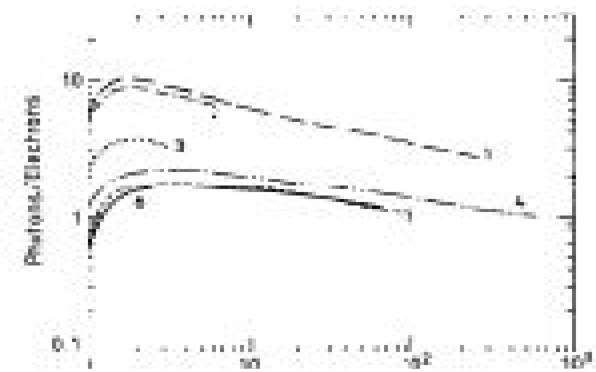
1) Solution of the “humidity” problem:

well developed anode- cathode dielectric interface
(similar to industrial HV isolation)



2) Feedback problem

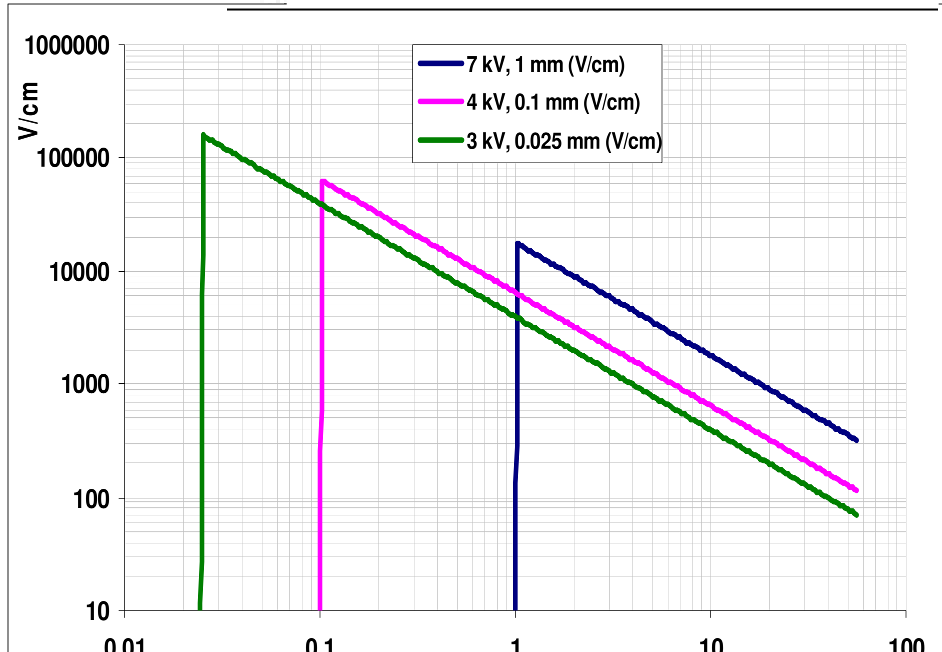




Light emission*

$\gamma_{ph}(E)=\int Q(E, E_v)S(E)\exp(-kL)dE_v$ (1)

$\gamma_{+}=k(E)(E_i-2\varphi)$ (2)



Electric field in a single-wire counter

Recommendations:
1) large cathode diameter
(low E and absorption in air
2) small anode diameter

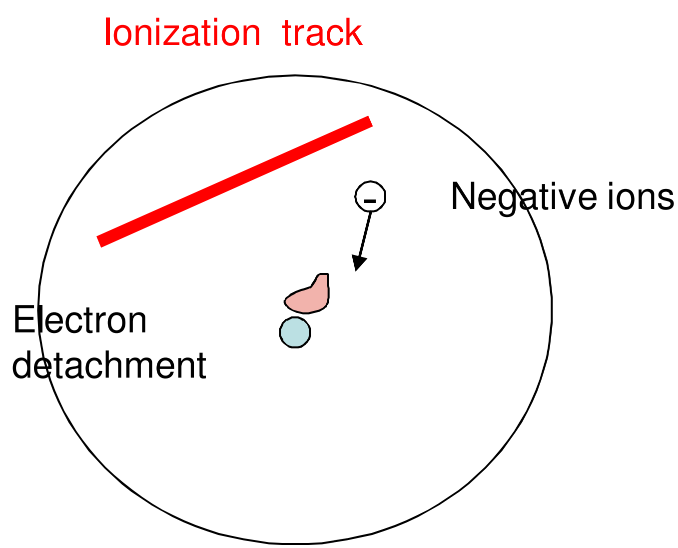
For details see:

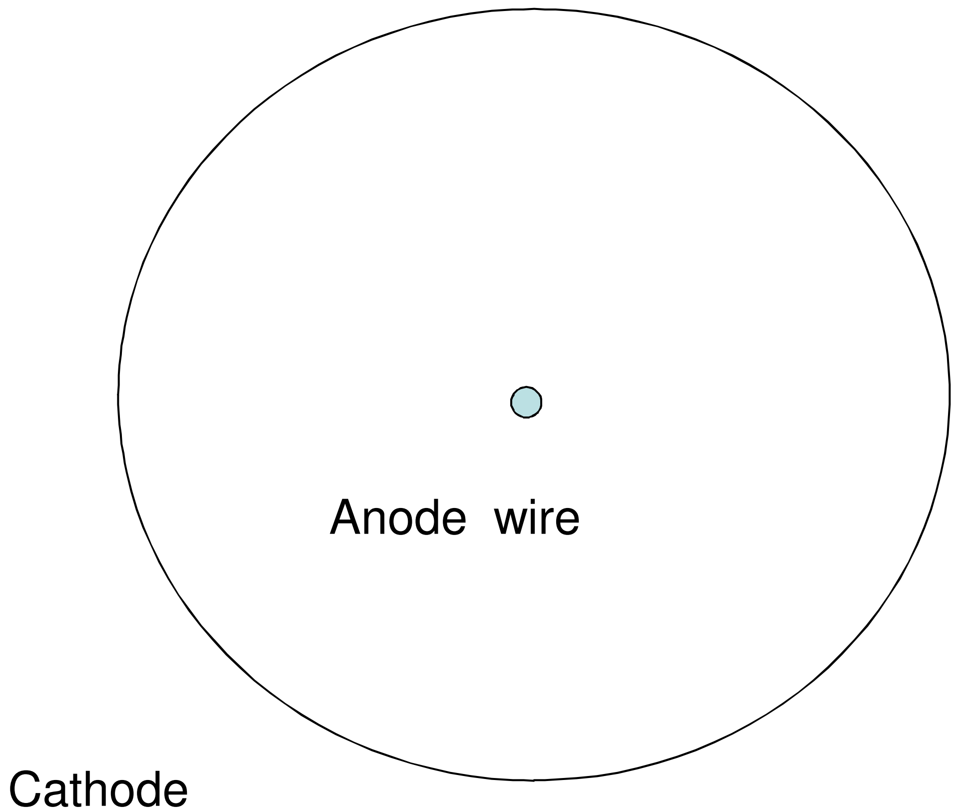
V. Peskov et al., arXiv:0911.0463, 2009

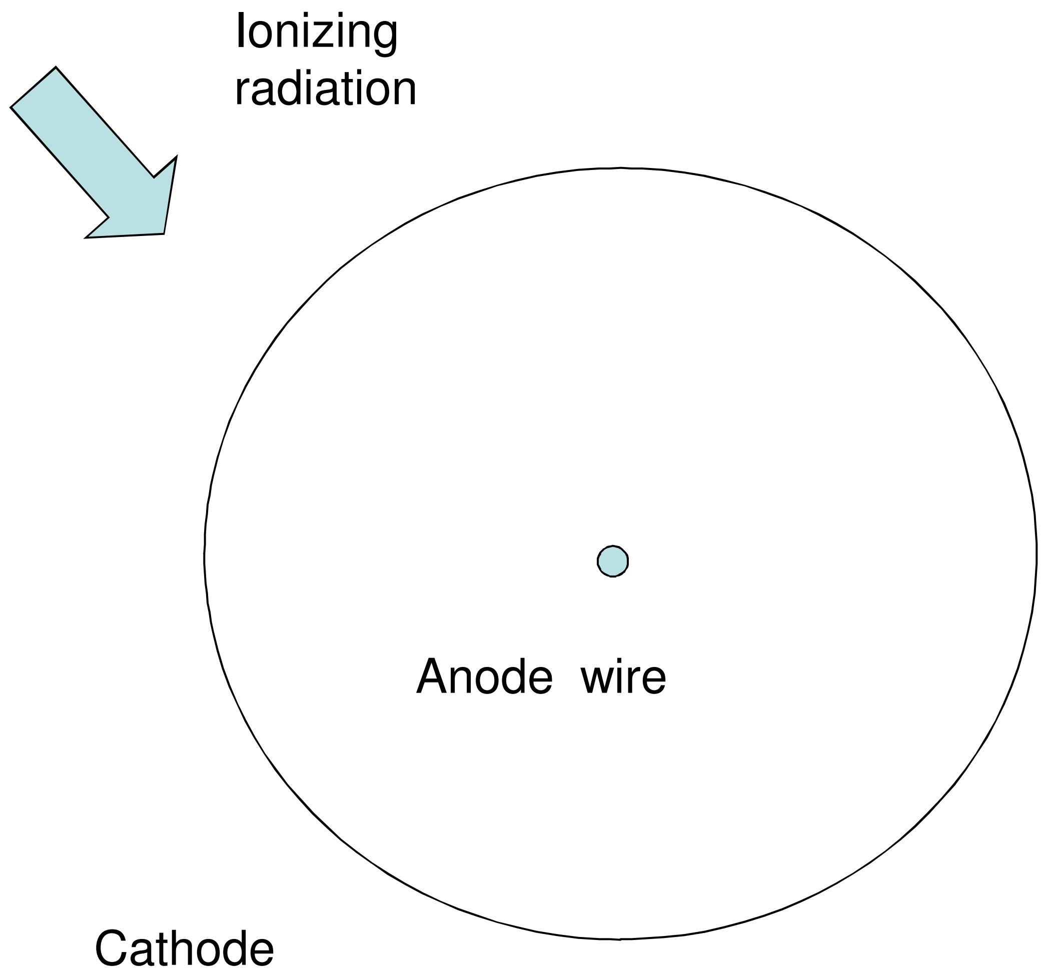
V. Peskov, J. Tech. Phys, 45, 1974, 1268 and 47, 1977, 556,

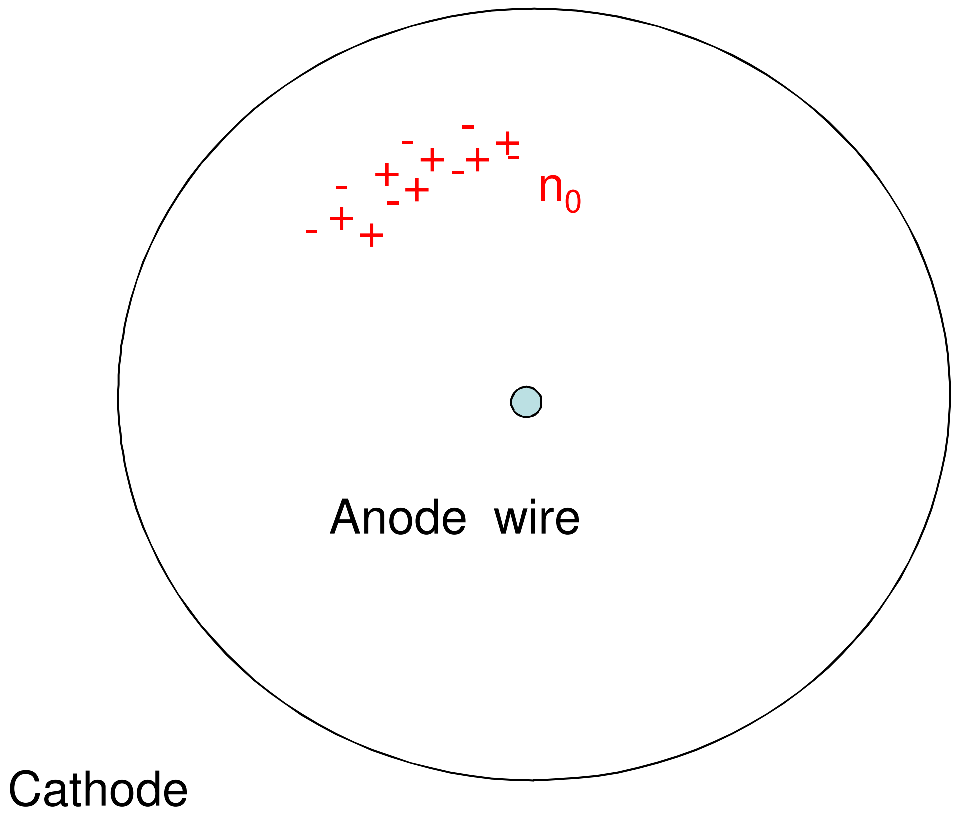
**V. Peskov et al., NIM 277,1989,547*

Attachment - detachment processes

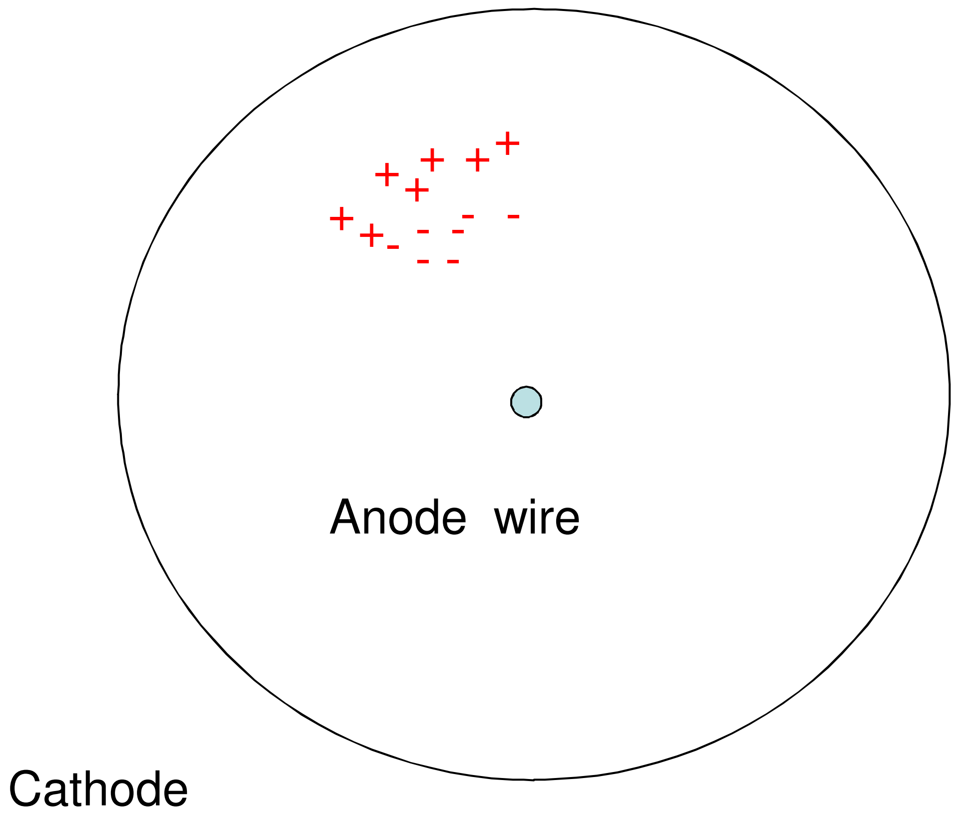



Anode wire
Cathode

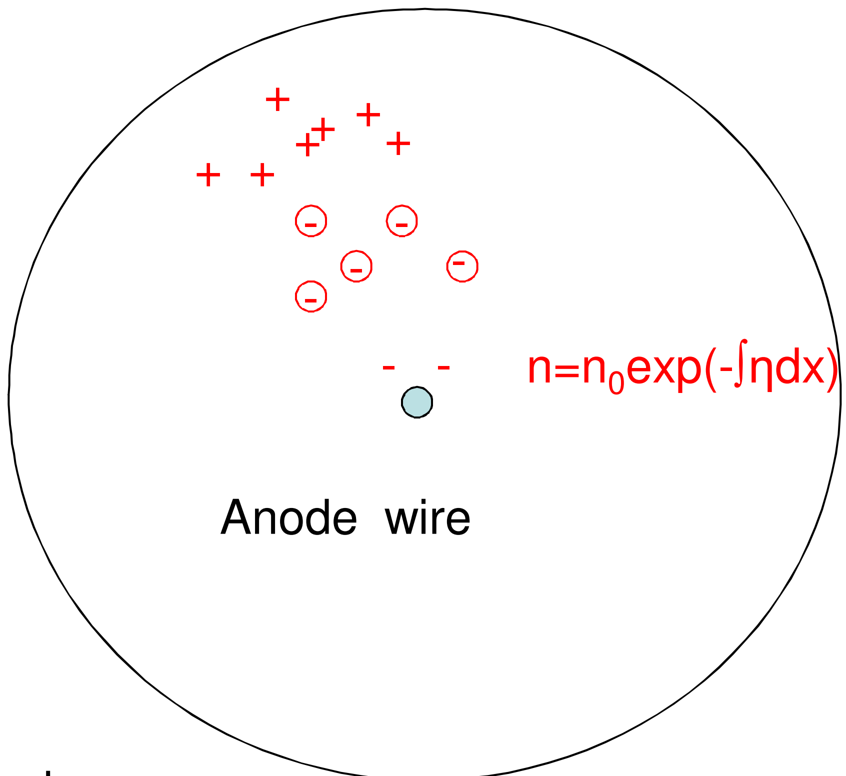

Ionizing radiation
Anode wire
Cathode



n_0
Anode wire
Cathode



Anode wire
Cathode



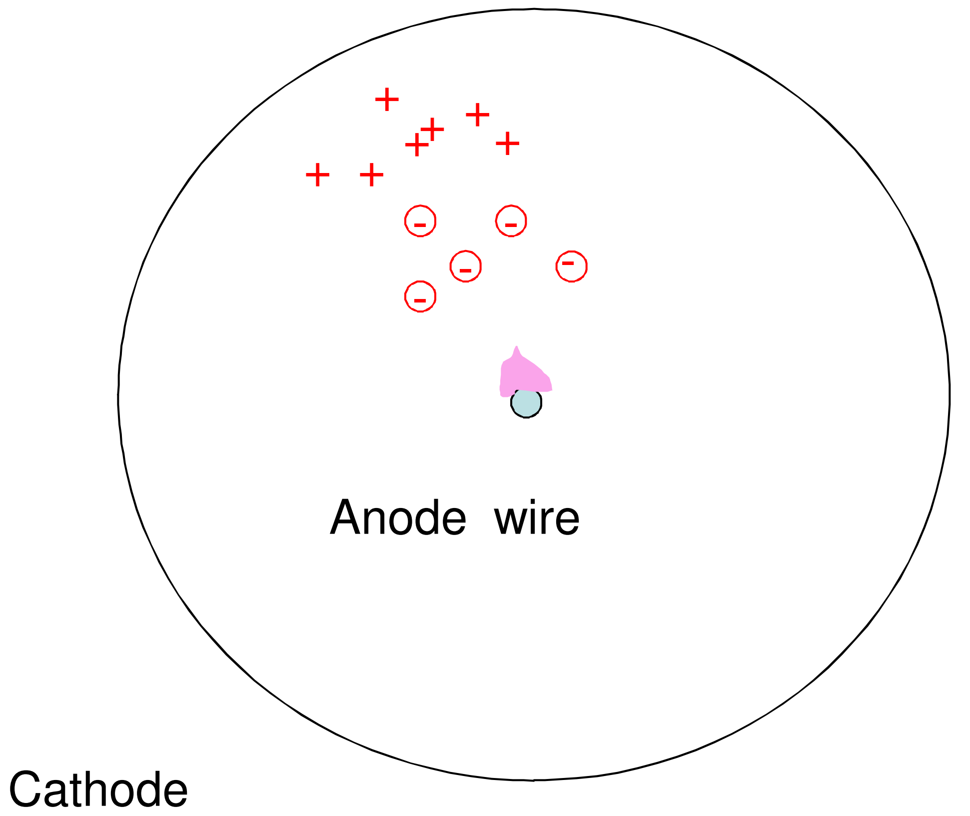
Cathode

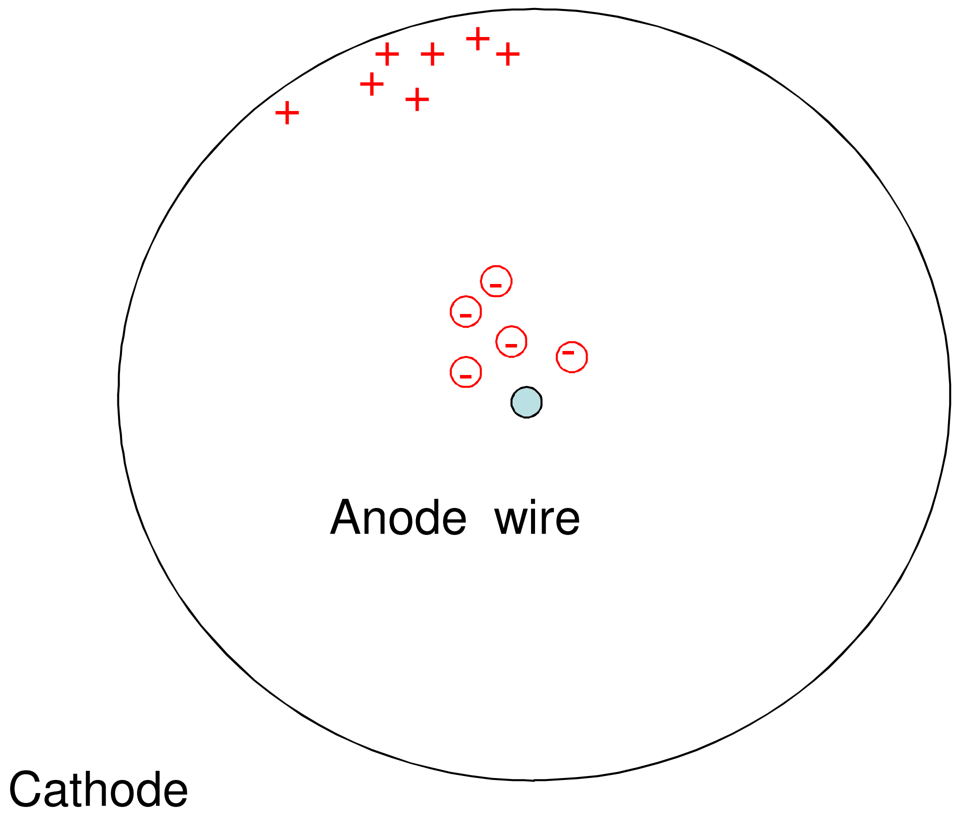
At pressure below 1000Torr

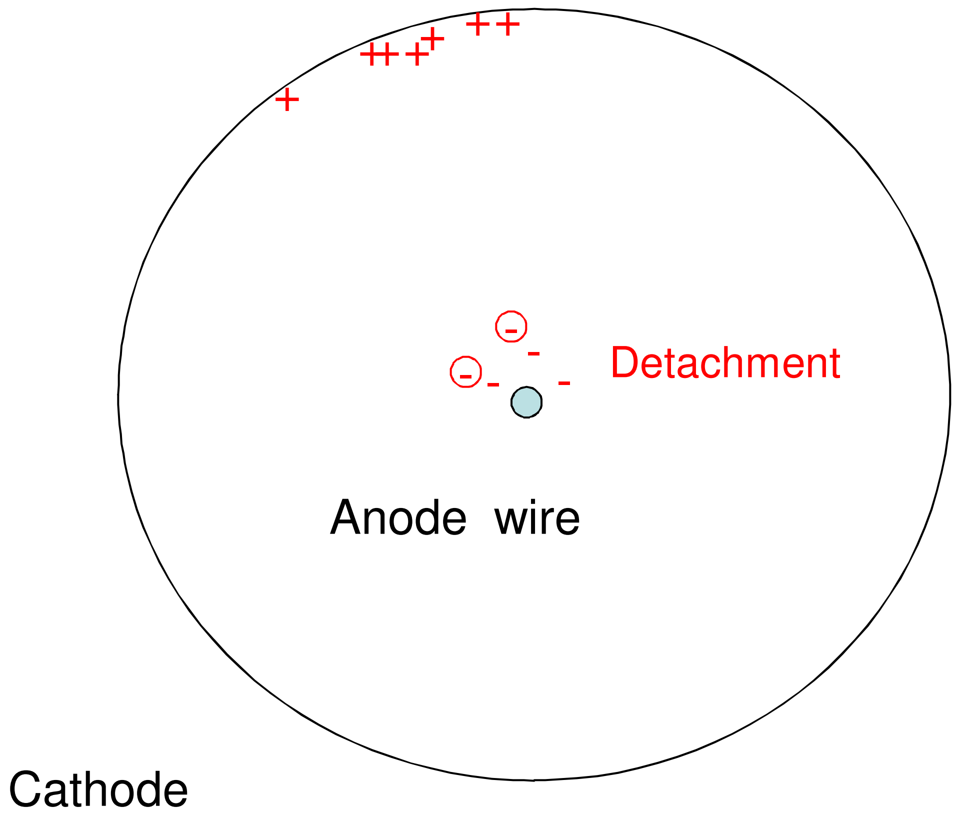
$e+O_2=O+O^-$

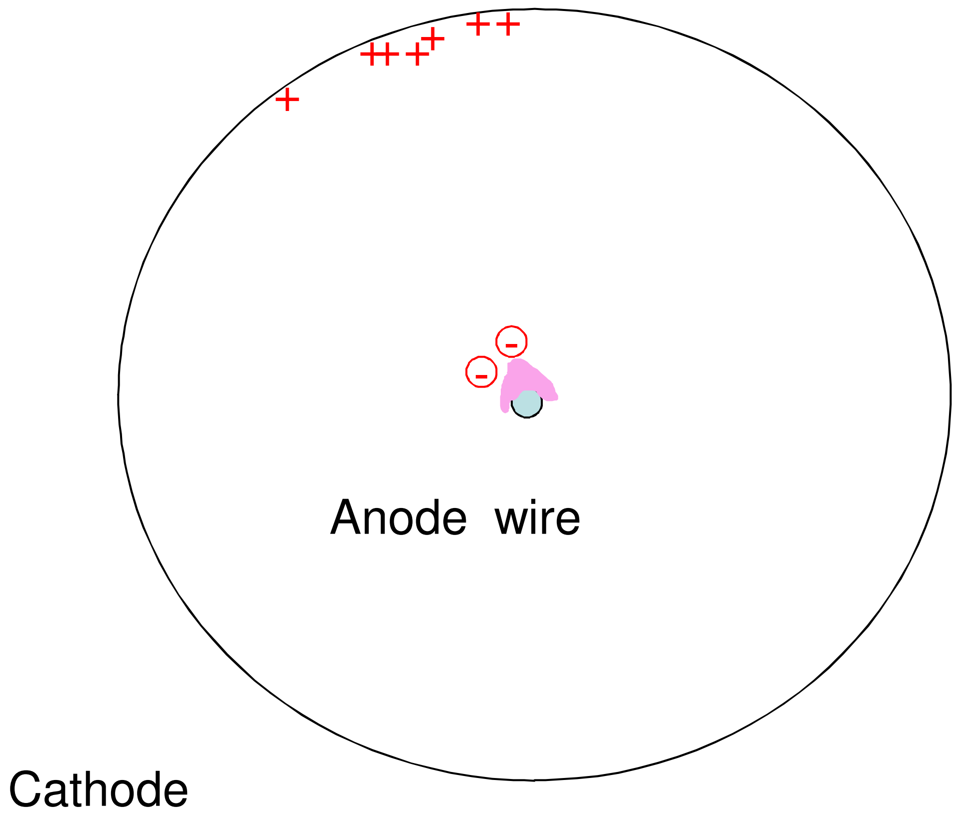
$O^-+O_2=O_2^-+e$

Formation-affinity: 0.14-0.5 eV


Anode wire
Cathode


Anode wire
Cathode


Detachment
Anode wire
Cathode


Anode wire
Cathode

Calculation of the electron survival probability: $n=n_0\exp(-\int\eta dx)$ for a single-wire counter

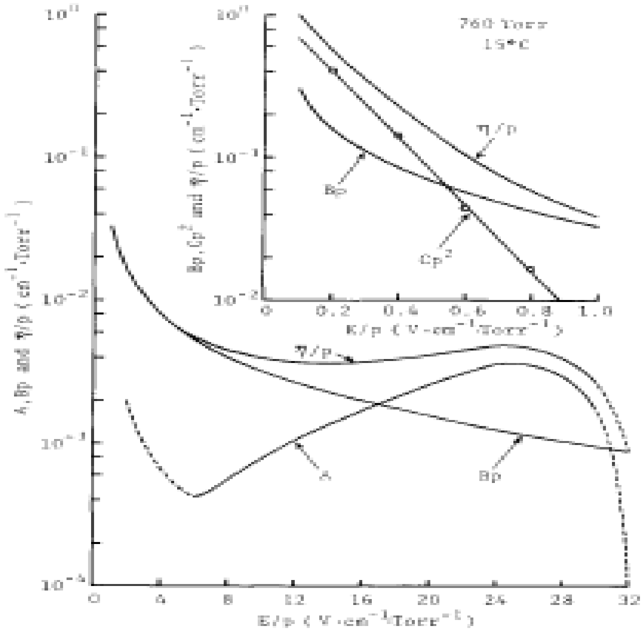


Fig. 1. Attachment coefficients as a function of E/p in air at atmospheric pressure. A, Bp, Cp^2 and η/p represent, respectively, the dissociative, three-body four-body and total attachment coefficients per unit pressure.

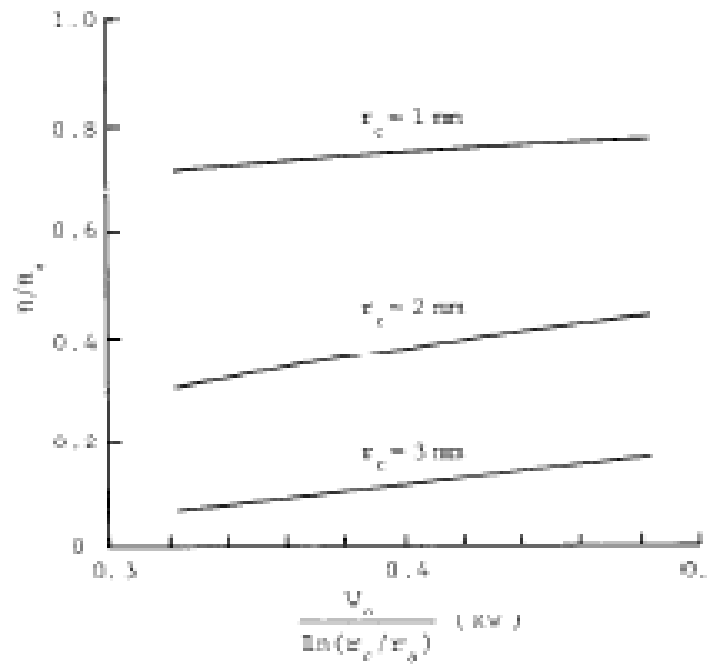


Fig. 7. Electron surviving probability n/n_0 as a function of $V_0/\ln(r_c/r_a)$. $r_a = 25$ µm, $p = 760$ Torr.

P.A. Chaterlon et al., Proc.Phys. Soc 85 (1965) 355,
J. Dutton et al., Proc. Phy.Soc, 82 (1963) 581
G.C. Hurst et al.,Phy. Rev 114(1959) 116

3) Detachment

Field detachment

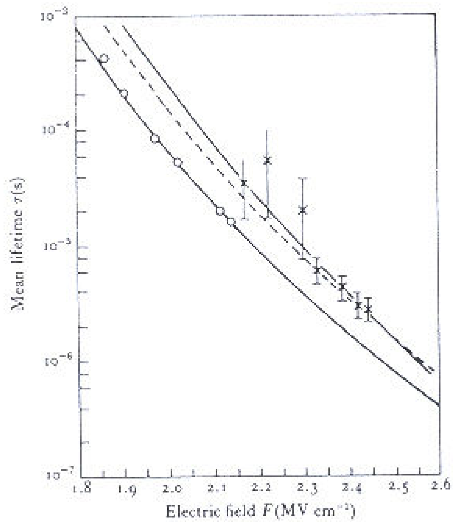
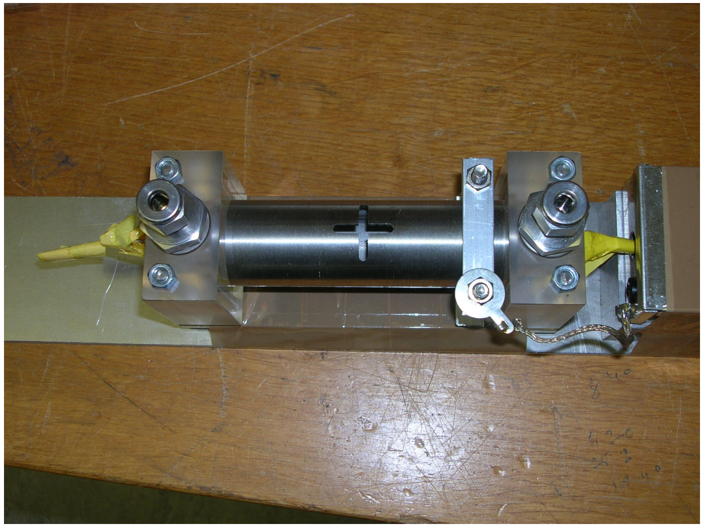
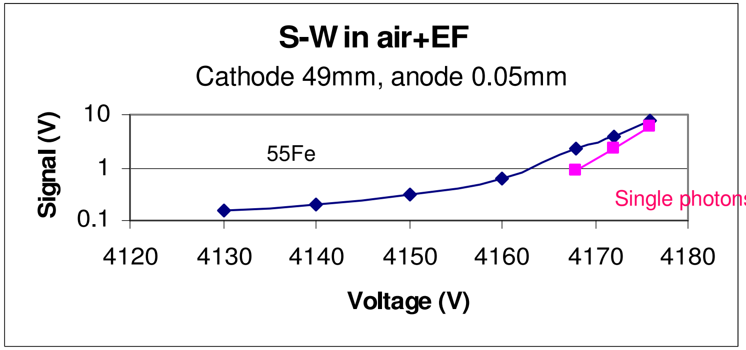


Fig. 11.43. Mean lifetime of H⁻ ions as a function of the applied steady electrostatic field. Observed –○– Stinson *et al.* (1969), × Cahill *et al.* (1966). Calculated —— Hiskes (1962), ---- Mullen and Vogt (1968).





<u>Detachment by collisions:</u>

$M^- + e = M + e + e$

$M^- + A = M + A + e$

$M^- + A = MA + e$

$M^- + A^* = M + A + e$

Our measurements show that in single wire detector <u>>10%</u> of negative ions experience the detachment

H. Massey, "Negative ions", 1976

B.M. Smirnov, Negative ions (in Russian), Atomizdat, Moscow

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

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Negative ion drift and diffusion in a TPC near 1 bar

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Dark matter TPC

[UB01.02] **DRIFT: A Negative-Ion Drift Chamber for the Detection of Dark Matter**

Juan Burwell (Mount Holyoke College, South Hadley, MA 01075), Daniel P. Snowden-Ifft, Tohru Ohnuki, Nathan Villaume (Occidental College, Los Angeles, CA 90041), C. J. Martoff (Temple University, Philadelphia, PA 19122), Matthew J. Lehner, Niel J. C. Spooner (University of Sheffield, Sheffield S3 7RH UK)

The Weakly Interacting Massive Particle (WIMP) is a persuasive candidate for solving the dark matter problem. We are pursuing a new technique for detecting WIMPs: a low-pressure TPC (Time Projection Chamber) which drifts electronegative ions rather than electrons; hence a NIDC (Negative Ion Drift Chamber).

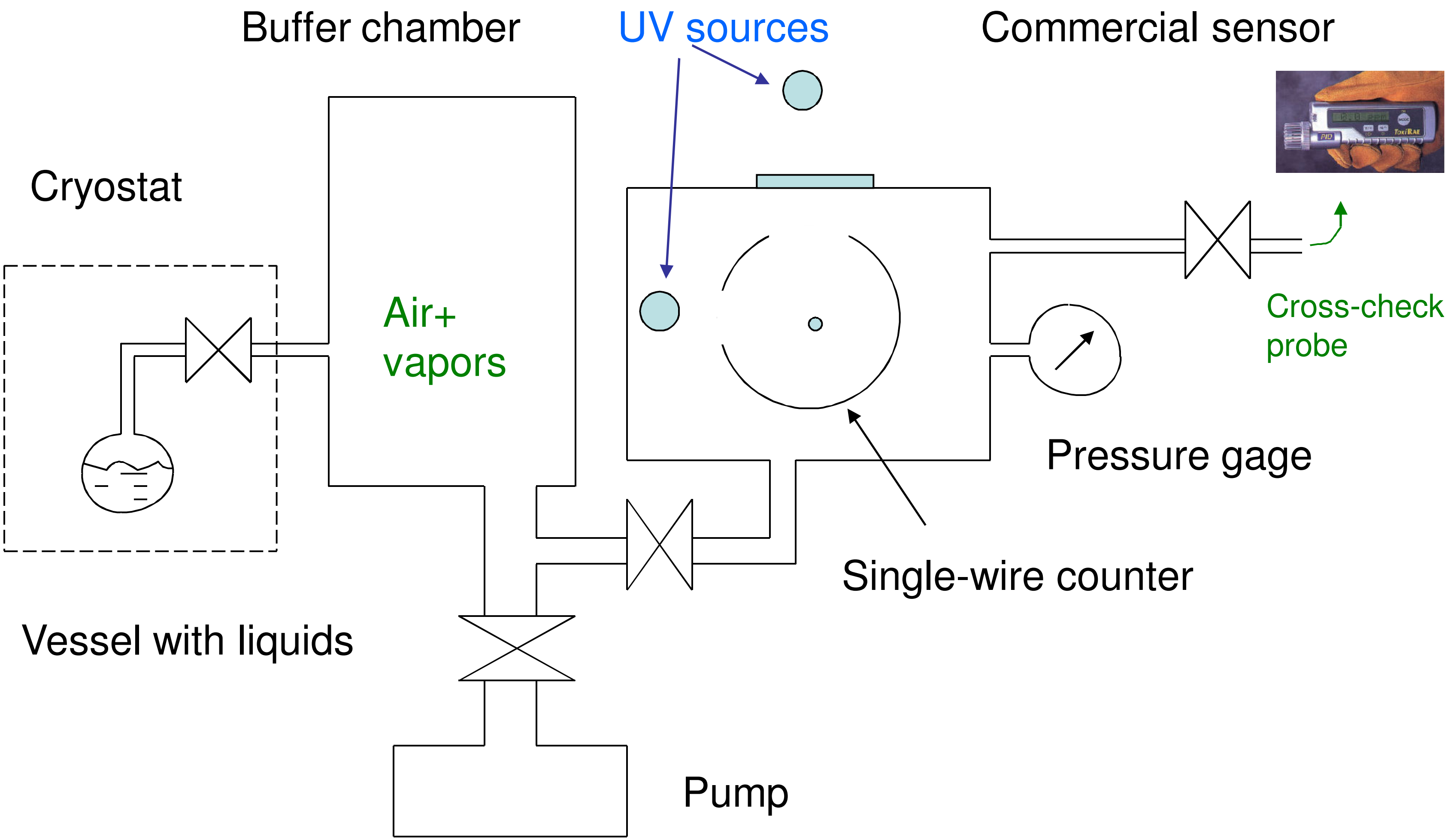
The DRIFT (Direction Recoil Identification From Tracks) chamber can record range components, and ion pair production information allowing for high background rejection. Current predictions based on Monte Carlo simulations indicate unrejected background levels below 0.05 events/kg/day. In addition, DRIFT offers a powerful signature to determine the presence of WIMPs. This signature arises by measuring range components and track angles, which vary based on the diurnal (sidereal) modulation of the WIMP signal.

We also report completion of test of a prototype detector measuring neutron scattering, and confirmation of the electronegative ion drift technique. Construction of a 1 m^3 DRIFT chamber is underway. In short, DRIFT is capable of setting scattering cross section limits better than current experiments, is not background limited, and offers a strong signature to confirm the presence of WIMPs.

Part II.

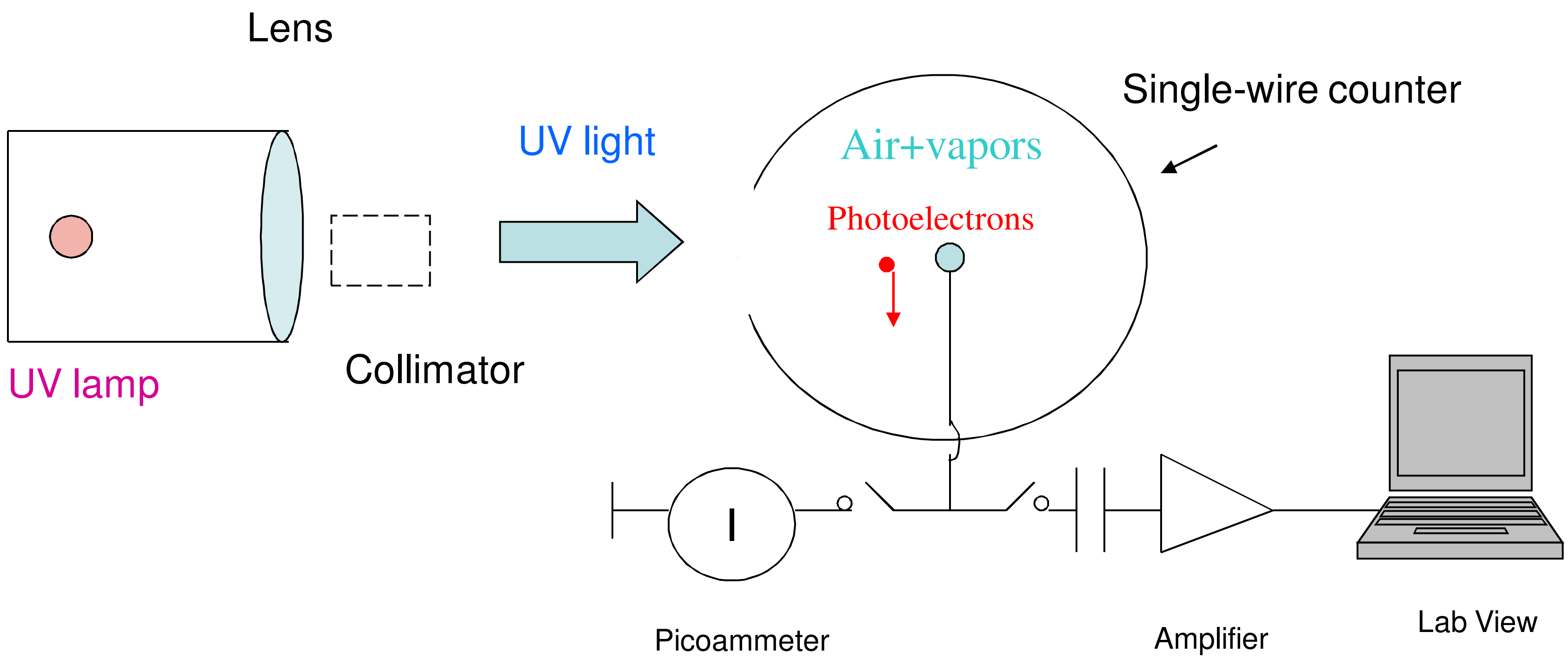
A prototype of the dangerous gases detector based on photoionization principle and operating in avalanche mode

The setup for the study a photoionization detector based on a single-wire counter operating in avalanche mode



Calibration by : 1) “volume” dilution, 2) low temperature vapours

A more detailed picture of the photosensitive single –wire counter



<u>Lamps tested:</u>

Hg
H_2
D_2 pulsed
Ar pulsed

<u>Gases testes:</u>

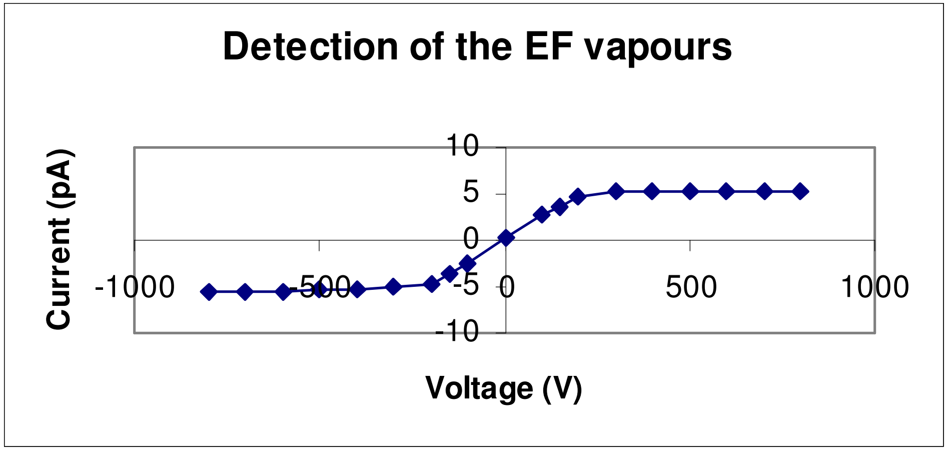
TEA, TMAE, EF

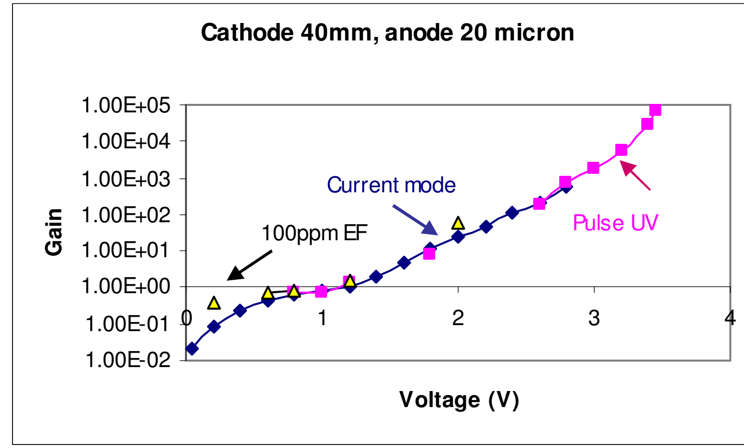
benzene

For correct comparison
with commercial devices
(to <u>be independent</u> on the UV
lamp intensity) single-wire detector
were first was run in current and
then in avalanche mode

New features implemented in this setup:

- Pulse lamp (to suppress a constant current)
- Simultaneous ionization and absorption measurements
- Measurements below the absorption edge of air





Ionization chamber mode(≥10-100ppm)

Surface photoeffect:

$J=N_{ph}$ [1-exp(-σnL)]QE {-exp(kL)} (3)

At small n:

$J=N_{ph}$ σnLQE{-exp(kL)} (4)

Volume photoeffect

$J=N_{ph}$ σnLQE (5)

Avanche mode(below 10ppm)

Surface photoeffect:

Δq $=N_{ph}$ [1-exp(-σn_0L)]QE {-exp(kL)}A (6)

At small n_0:

Δq $=N_{ph}$ σn_0LQE{-exp(kL)} A(7)

Volume photoeffect:

Δq $=N_{ph}$ σn_0LQEA (8)

Δq=n_0A, so one have to know A

G.Charpak et al., Electrical Insulation, IEEE Transactions on 26 , 1991 , 623

The vapor pressure of most of the liquids is well known:

Antoine's fit function:

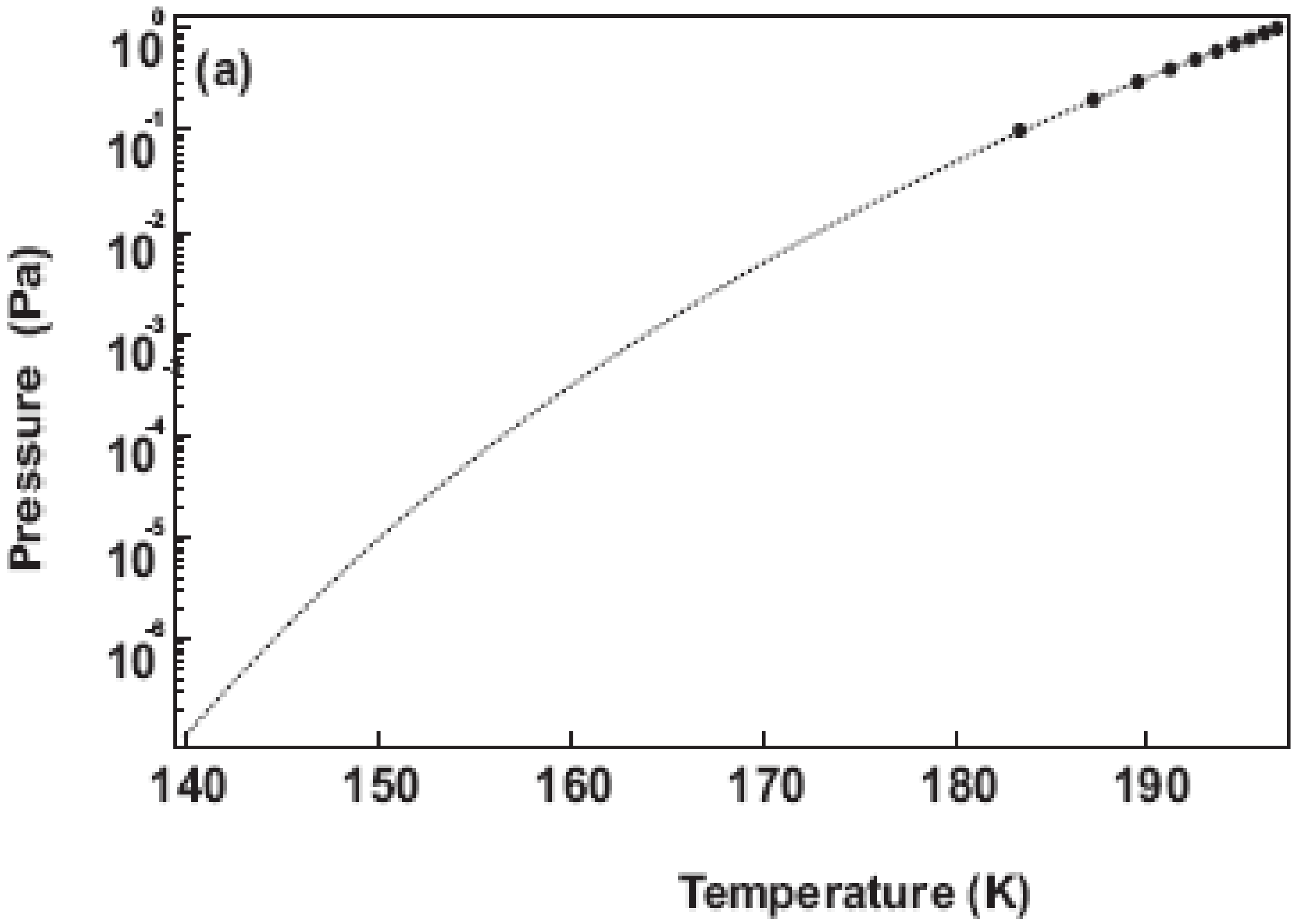
$$\ln[p(T)] = A - \frac{B}{T + C},$$

where A, B and C are fit coefficients. Table A.1 displays the fit parameters A, B and C. In Fig. A.1, the literature vapor pressure data of PAH molecules and the

Table A.1.: Compilation of Antoine's fit coefficients

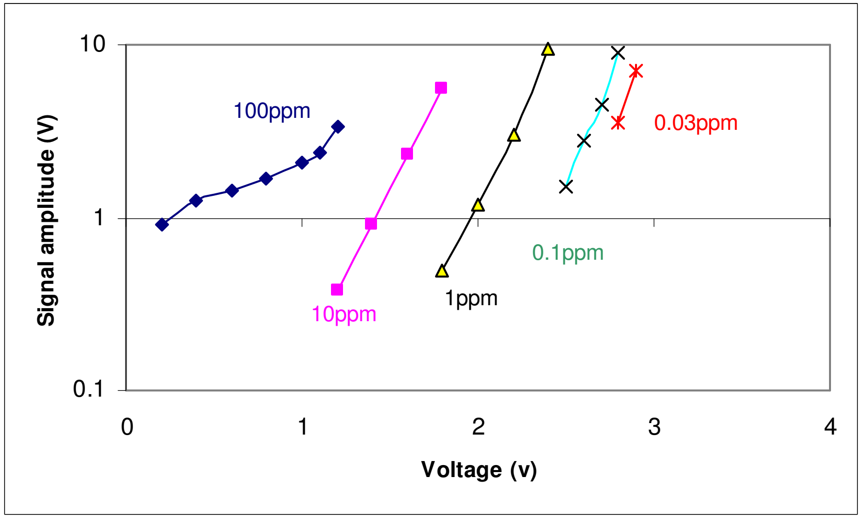
Molecule	A	B (K)	C (K)
Benzene	26	7640	30
Naphthalene	43	20100	124
Coronene	37	30400	184

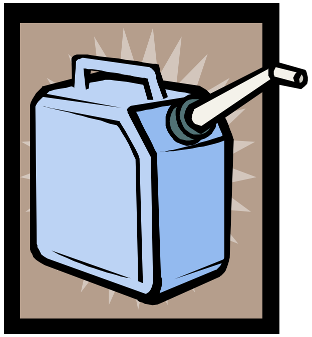
Low temperature method:



Typical results:

(in the given case with different concentration of benzene)

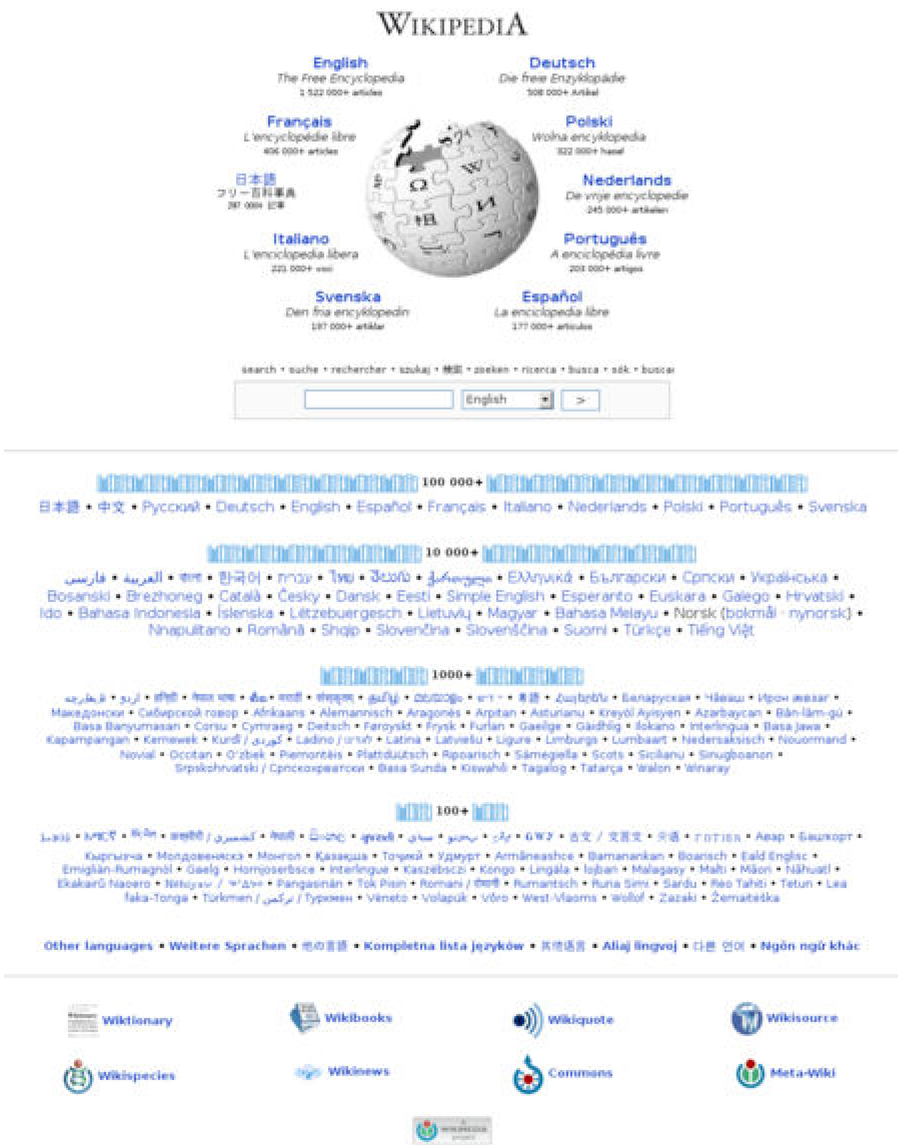




Gain calibration was done by a pulse UV lamp, but it could be also performed with ^{55}Fe or ^{241}Am

Part III

A prototype of a Rn detector operating in air in avalanche mode



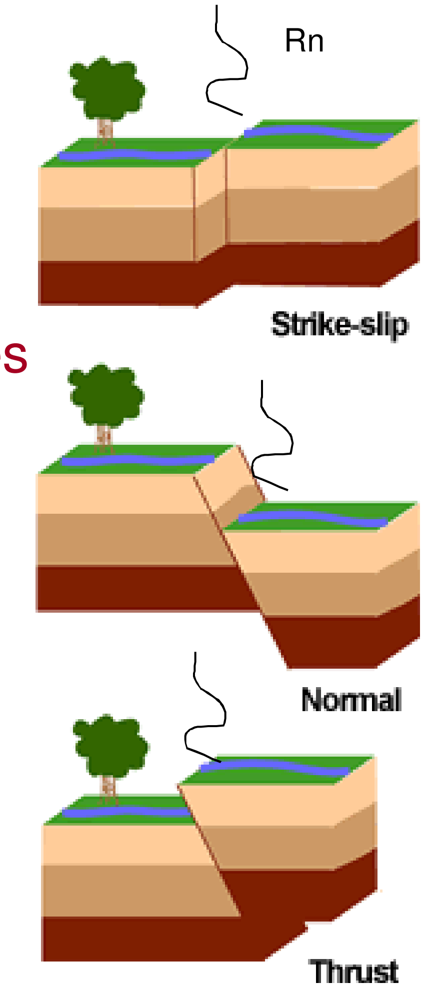
Based on studies carried out by the National Academy of Sciences in the United States, radon is the second most common cause of lung cancer after cigarette smoking, accounting for 15,000 to 22,000 cancer deaths per year in the US alone according to the National Cancer Institute.

In this work, however, the main focus will not be on the application to health safety (which is quite well covered with the existing detectors), but on the possibility to investigate the presence of <u>anomalous Radon concentrations in case of forthcoming earthquake events</u>

Haiti Earthquake building damage

In the last decade, some studies have shown the possibility to correlate elevated concentrations in the soil of gas Rn, or rapid changes in soil or groundwater

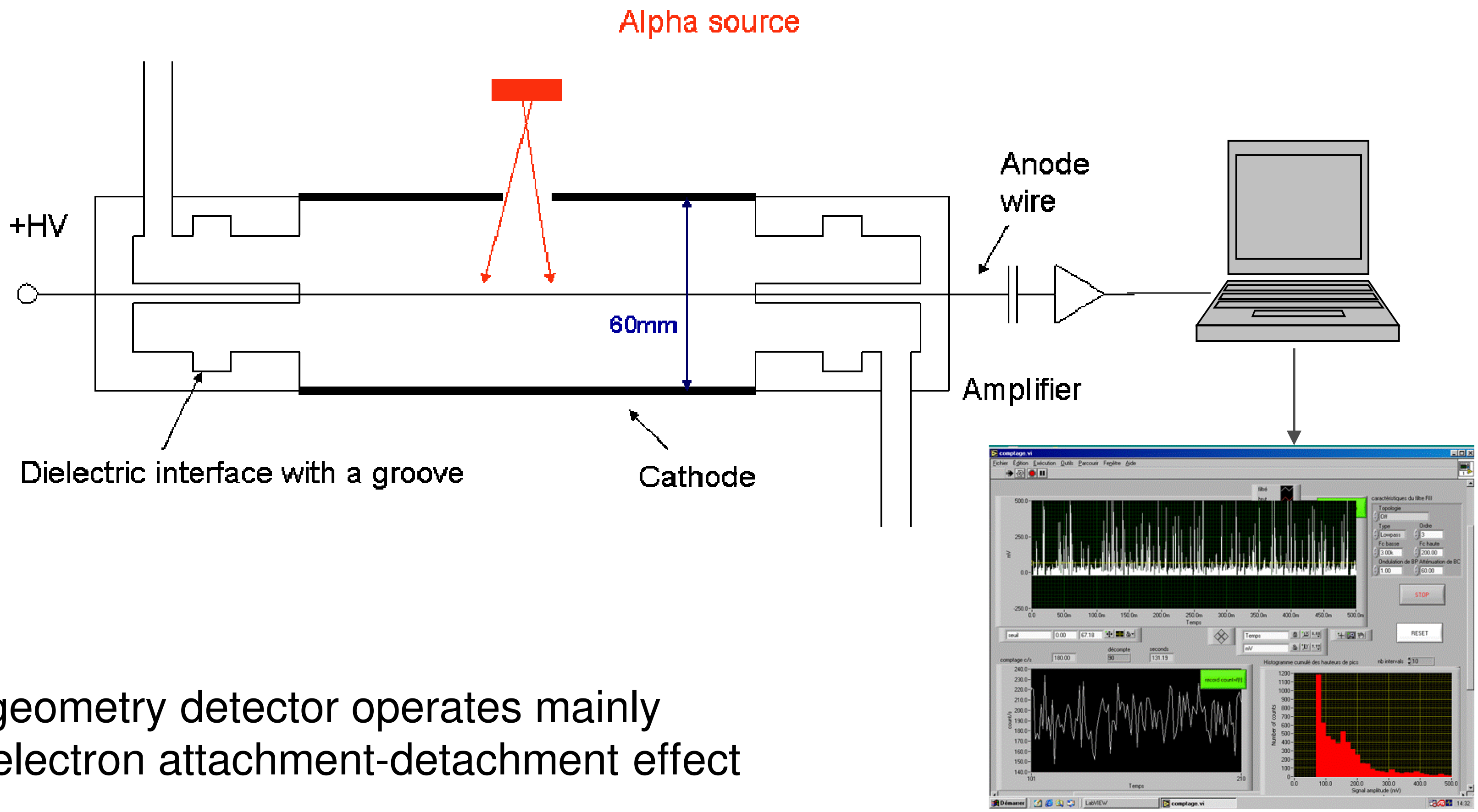
radon concentration, to the early prediction of earthquakes



<u>To the aim of verifying such studies</u> on a more solid statistical ground one has to create a wide network of cheap, compact and high sensitivity Rn detectors

Commercial detectors exist but are **too expensive** for this application

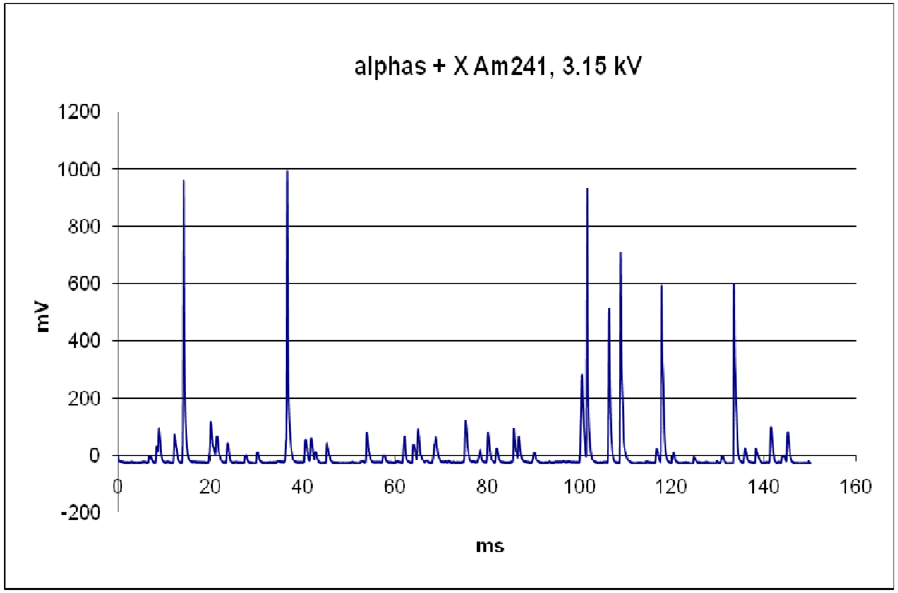
A single- wire prototype of the Rn detector operation in air in <u>on line mode</u>



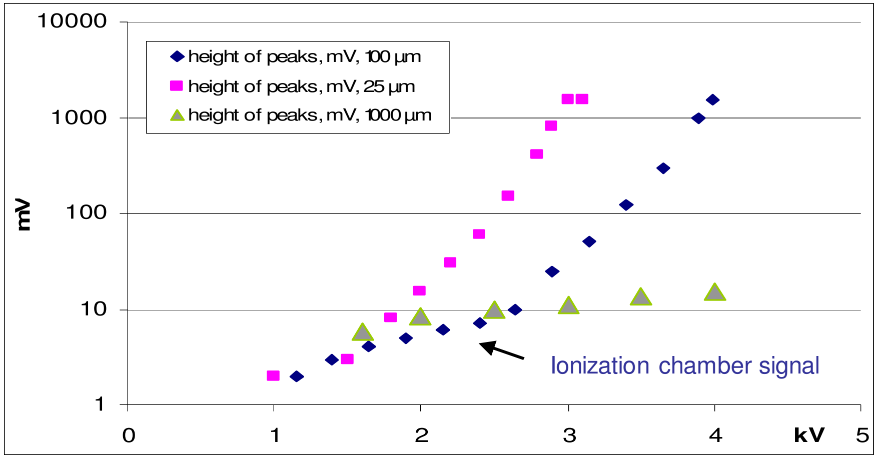
In this geometry detector operates mainly
on the electron attachment-detachment effect

(<u>PS.</u>Our earlier efforts to detect Rn were done
with RETGEMs and described in: *G. Charpak et al., 2008 JINST **3** P02006, 2008)*

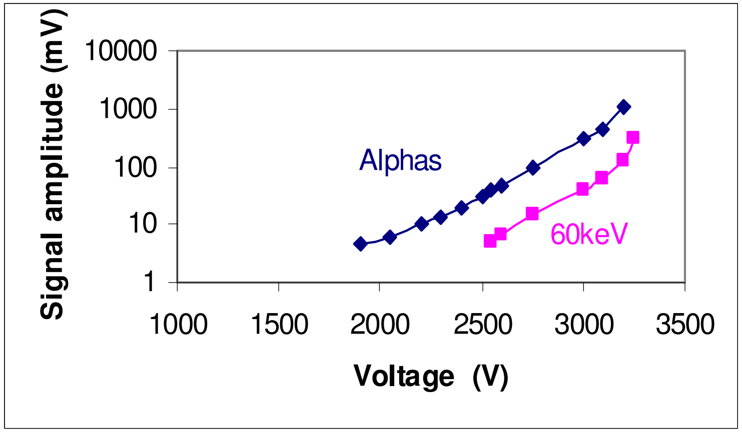
1) Results obtained with Am:



Typical signals measured with a single –wire counter (basic lay-out) operating in air and irradiated by ^{241}Am source

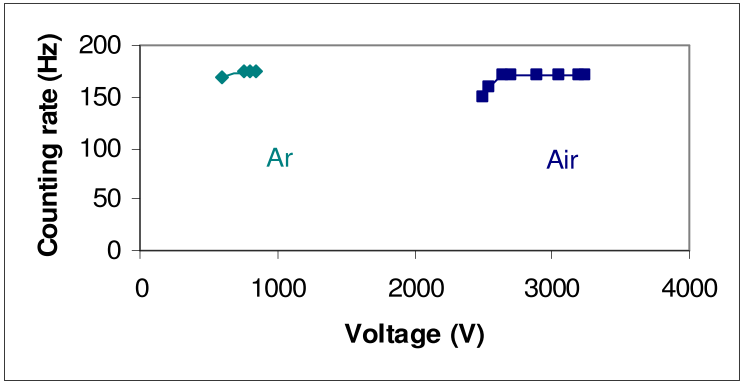


Mean signal amplitude produced by alpha particles vs. the voltage applied to detectors having a cathode diameter of 60 mm and different anode wires

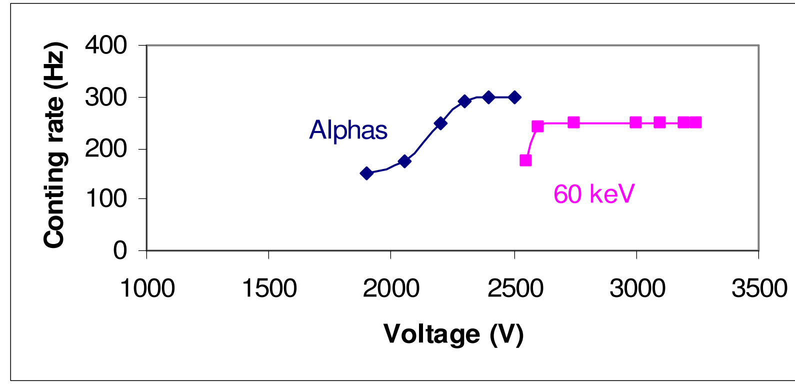


The pulse amplitudes vs. the voltage measures with a single-wire counter having

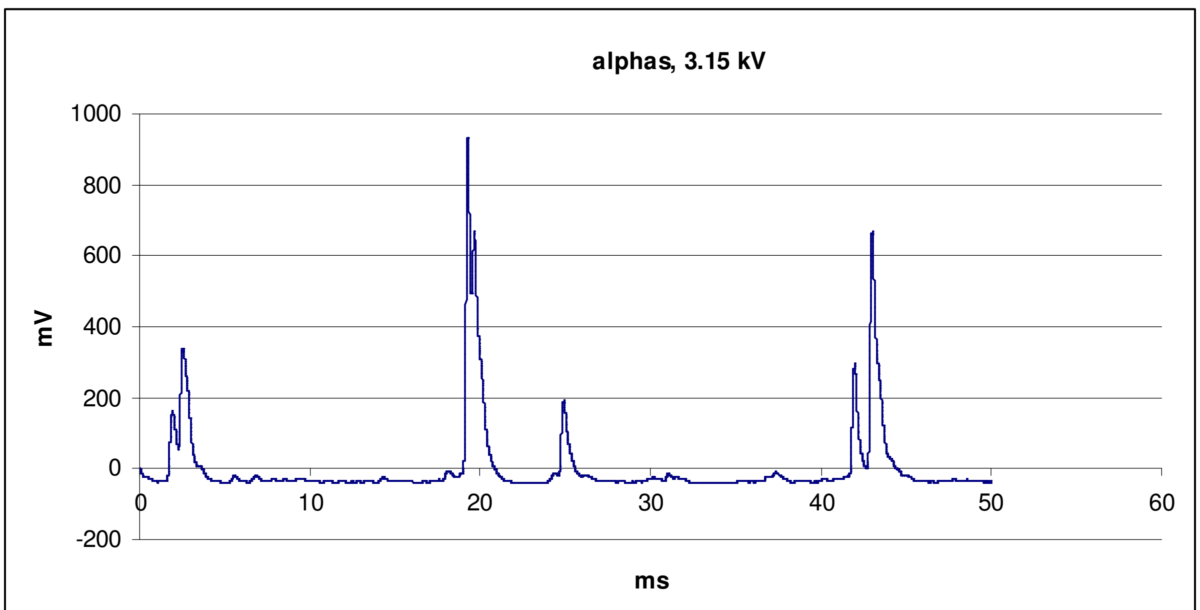
Efficiency of alpha particles detection is ~100%



Counting rates vs. the applied voltage measured in Ar and in air at the same conditions (alpha particles, D=60mm, da=100 μm)



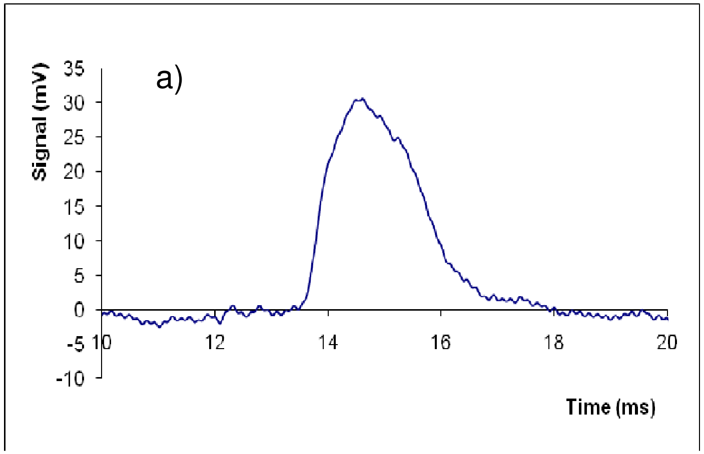
Counting rate vs. Vd for alpha particle (blue) and for 60 keV photons (rose) measured with a basic design of the single wire counter

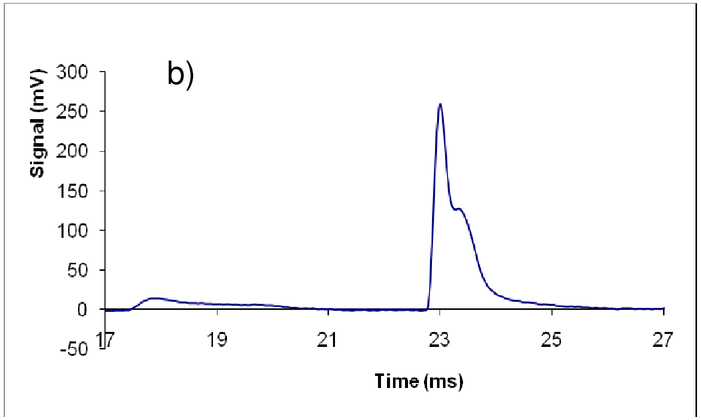


Oscillogramm of pulses produced by ^{241}Am measured in 100% humid air

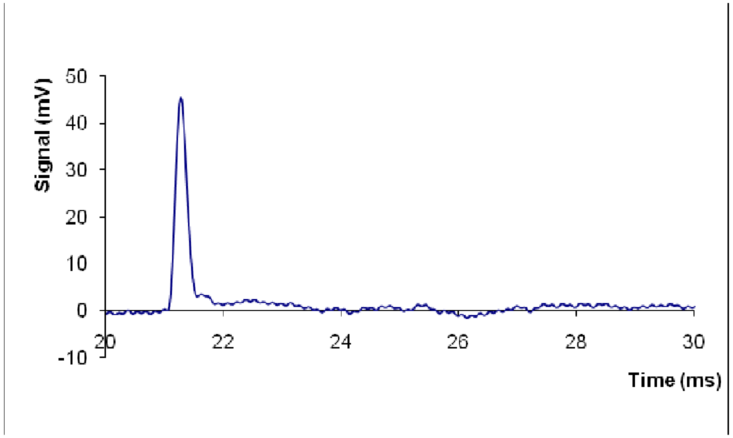
2) Basic studies with ^{220}Rn (Thoron)

High sensitivity can be achieved only if the noise pulses rate is suppressed almost to zero

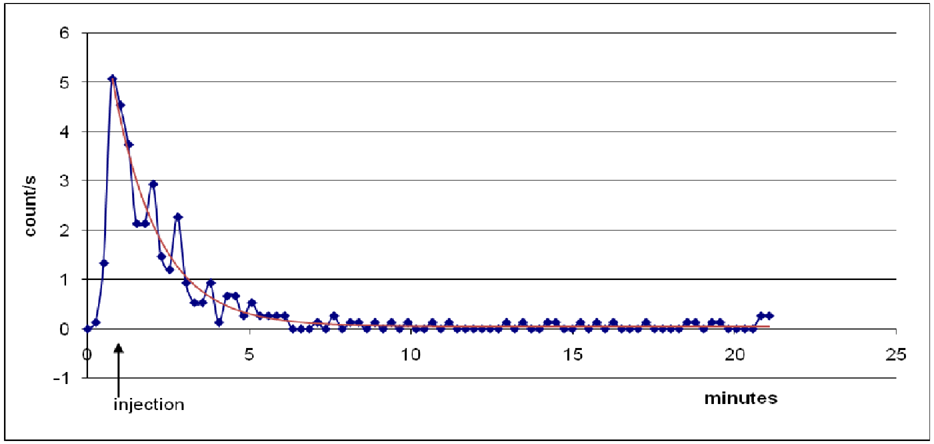




Typical shape of pulses produced in the single-wire counter by Thoron: a) smooth pulses, b) pulses containing 1-2 peaks

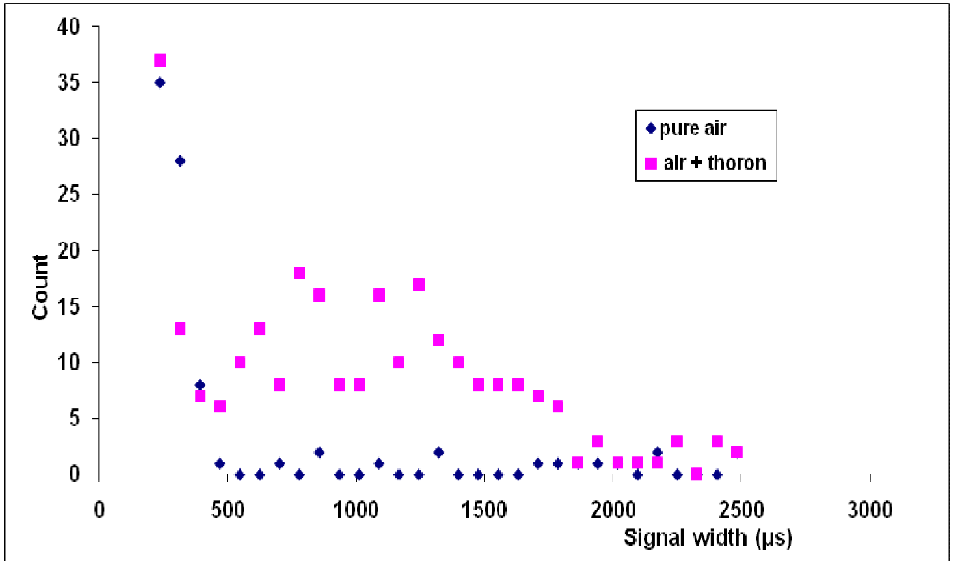


Typical pulse shape of noise pulses



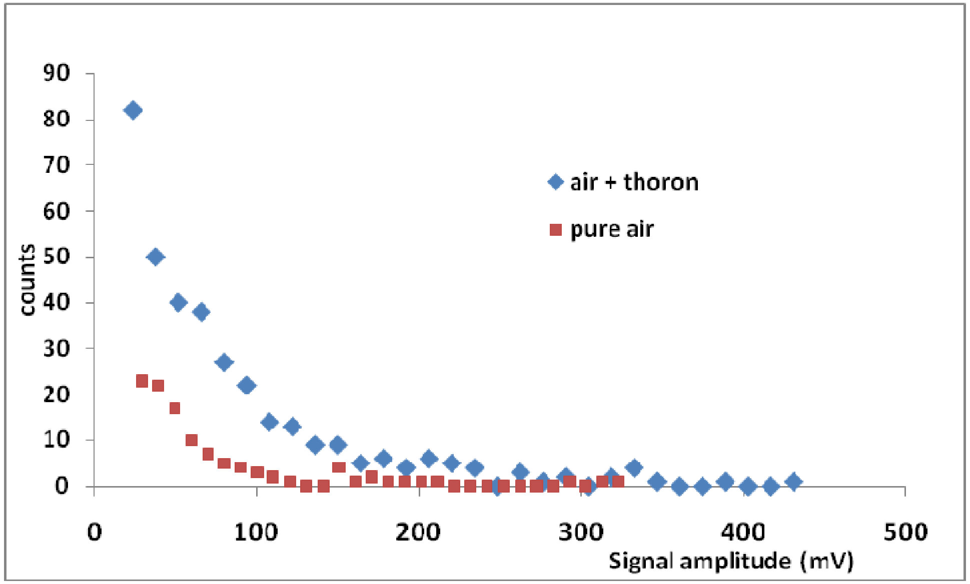
Counting rate vs. time as measured by the single-wire counter in which air contaminated with Thoron was injected(T_0=56sec).

Noise pulses rejection technique:

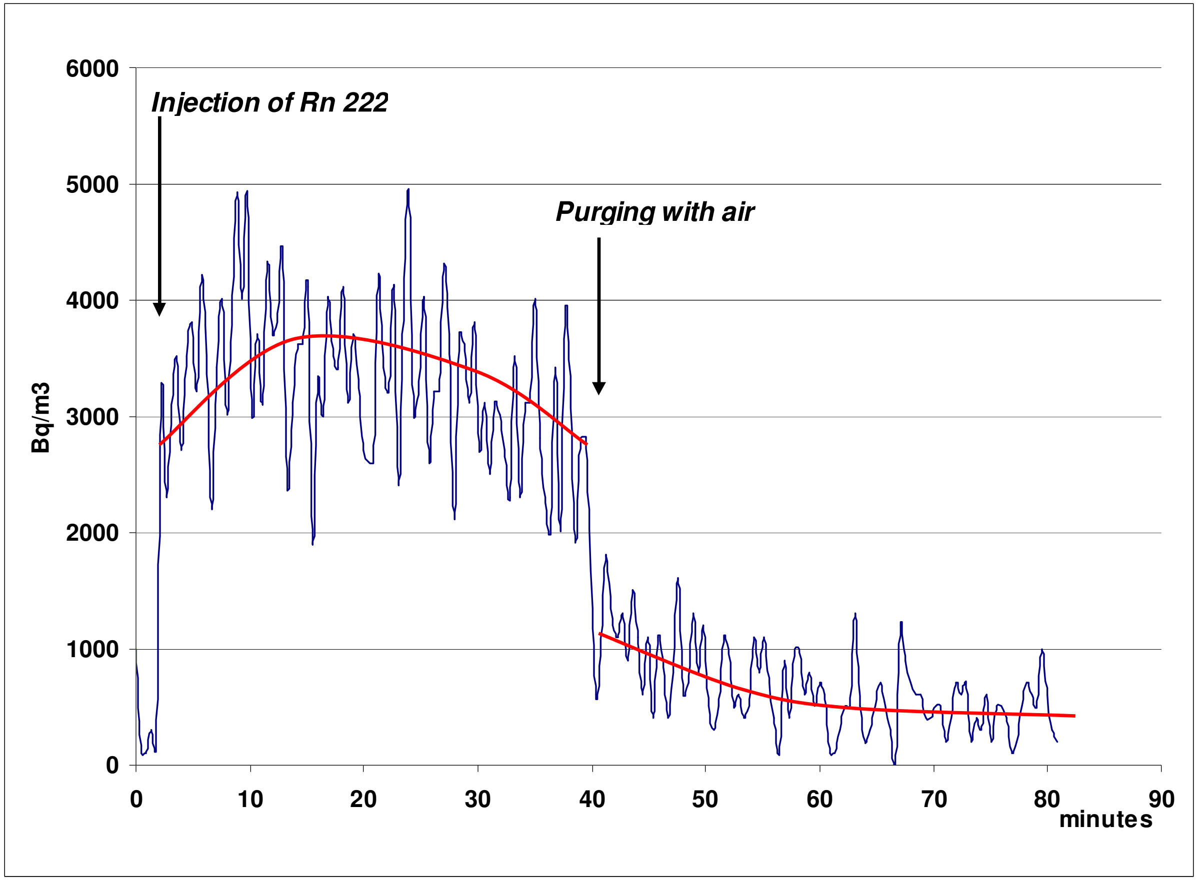


Distribution of the noise width and Thoron induced pulses
(Lab View program)

Pulse height spectrum of Thoron and noise pulses
(Lab View program)



3) Measurements with ^{222}Rn

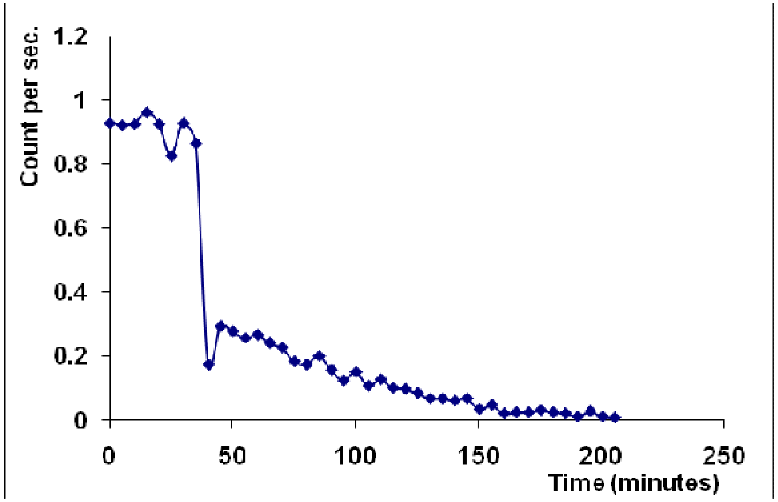


In case of measurements of the ^{220}Rn or ^{222}Rn the air having traces of these radioactive elements was introduce in to the detector. Their concentration was evaluated from the counting rate produced by alpha particles. samples of air containing Rn were also <u>independently</u> measured by the experts from the French company **ALGADE**

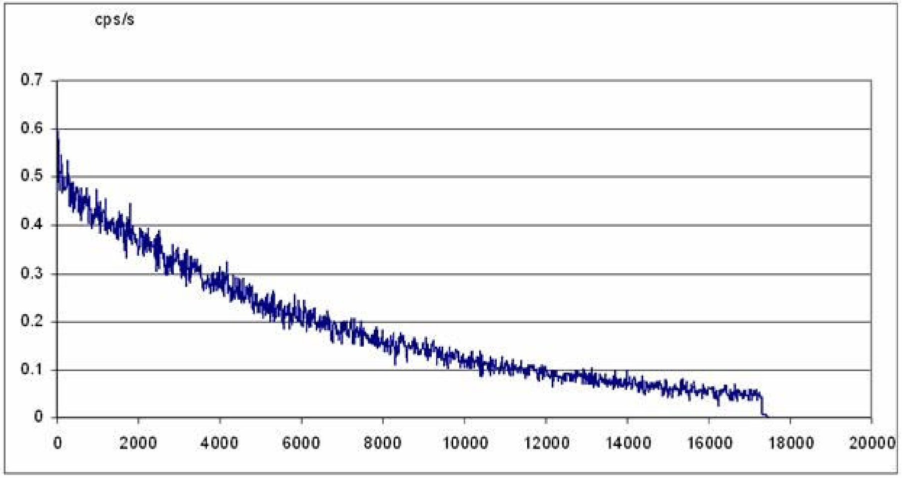
Counting rate vs. time after injection into the basic design (at t=2min) air contaminated with ^{222}Rn.

At t=40 min the detector for a few second was flushed with a clean air

Comparative measurements with a single-wire counter operating at low voltages (plateau region):



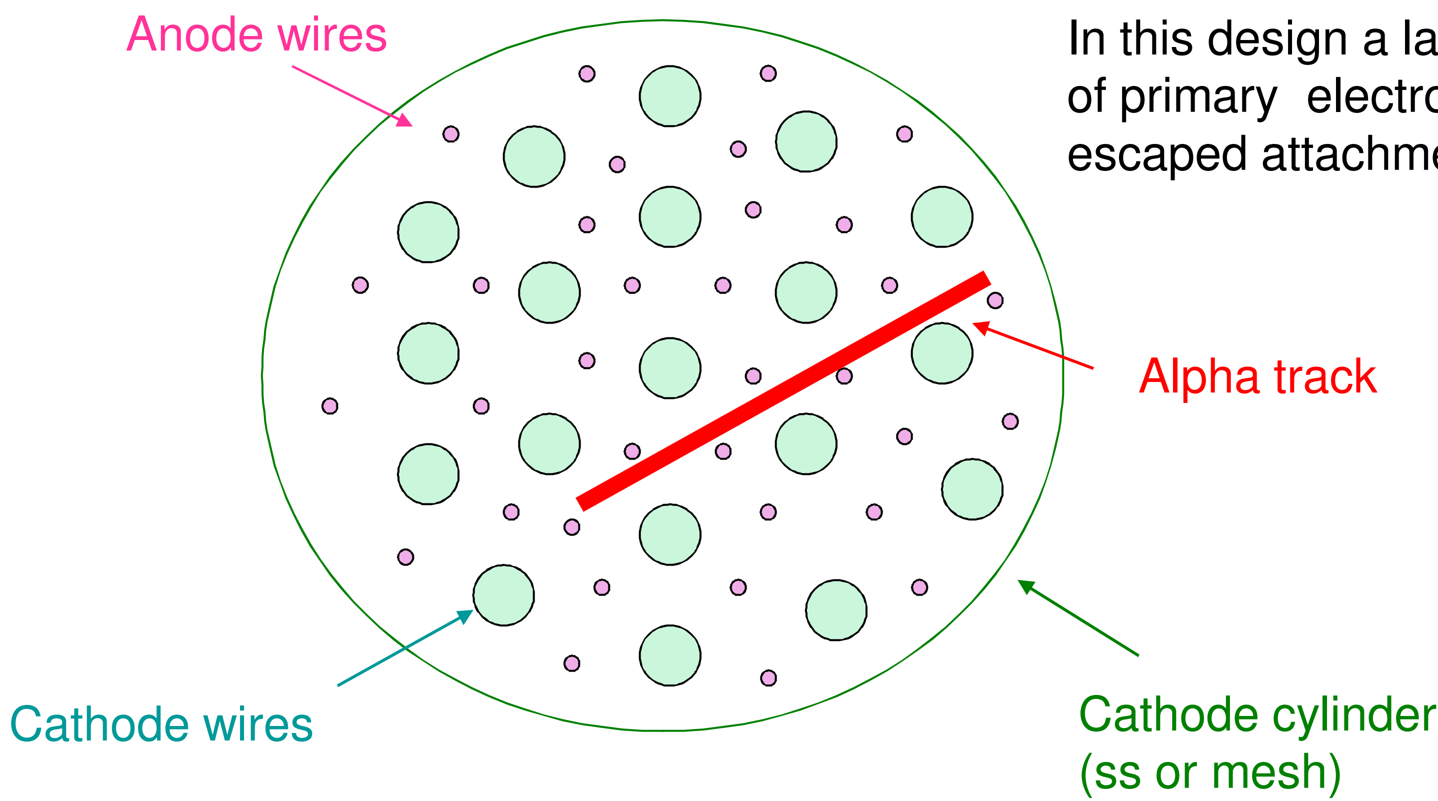
Counting rate vs. time when the radon contaminated air was introduces (at t=0sec) into the ionization chamber and at t=40sec it was flushed with clean air. The fast decrease of the counting rate is mainly due to the Po decay



Long-term measurement performed with the ionization chamber: the counting rate decrease with a good accuracy corresponds to the decay of the 222Rn (T_0=5500min)

However, the <u>most efficient</u> suppression of noise pulses was achieved with <u>MWPC</u>

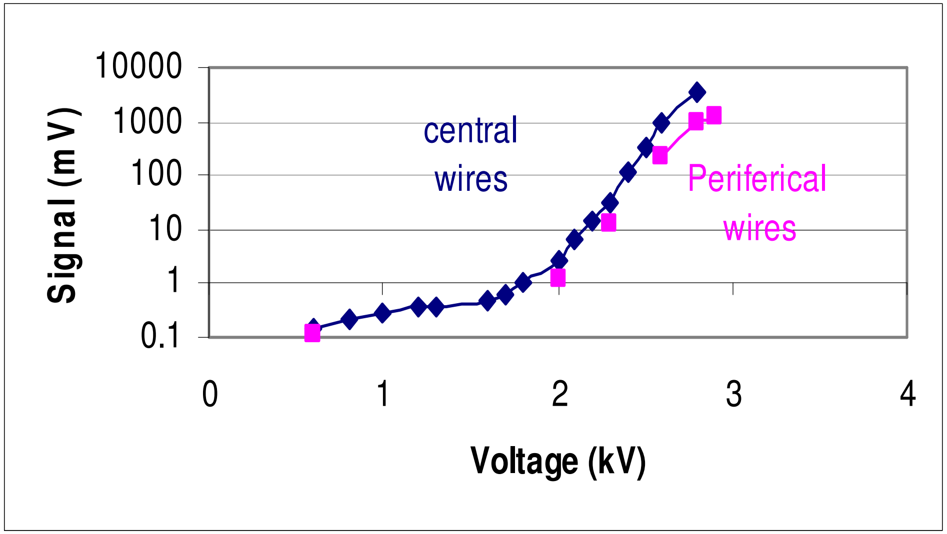
(*a copy of Sauli drift tube**)



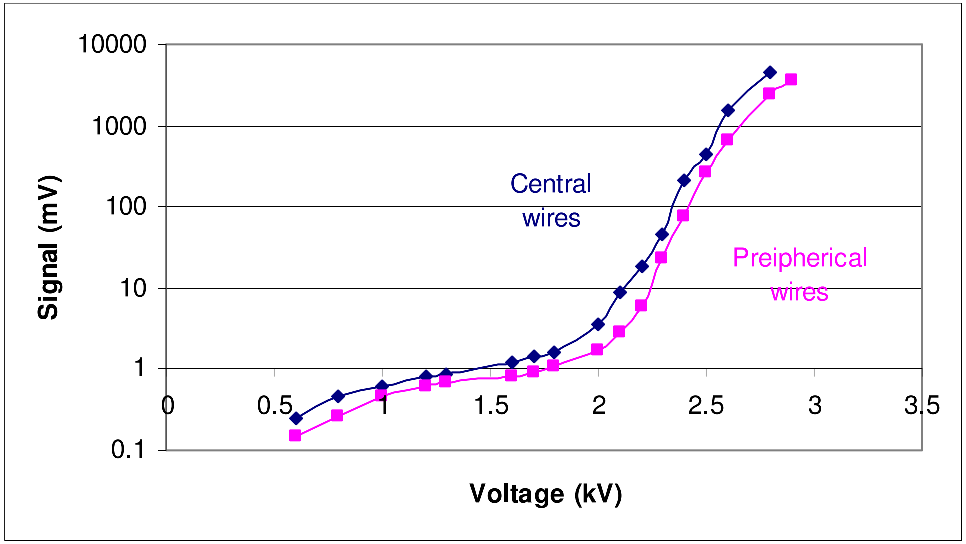
Standard electronics: each anode wire was connected to its own amplifier which after the amplitude discrimination produces a standard square pulse 1μs long. These pulses were sent in parallel to a simple "majority" unit which generate an output pulse it there was two or more coinciding input signals. These generated pulses were counted by a standard scaller.
In measurements with alpha particlesonly those event were chosen and counted when two or more wires produce signals within a few μs gate.

**R. Bouclier et al., NIM A2521986,393*

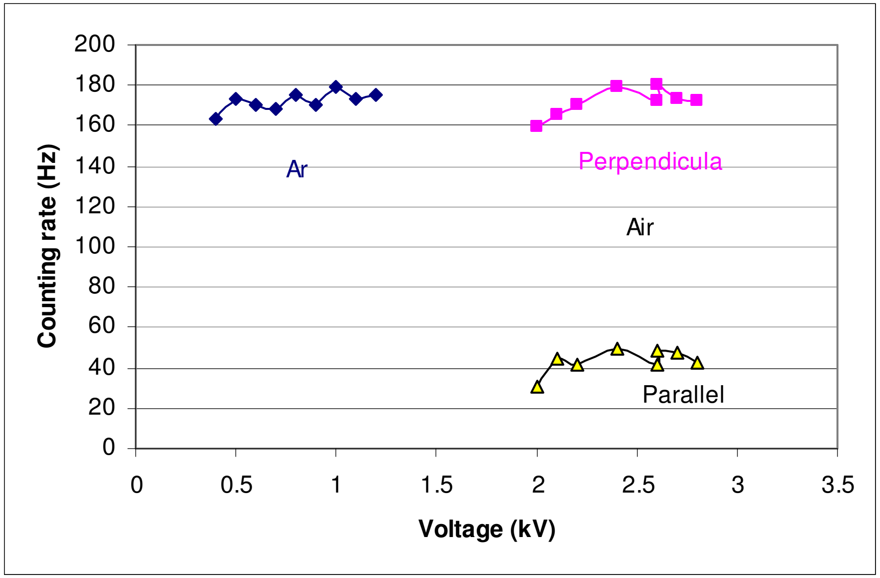
a)



b)

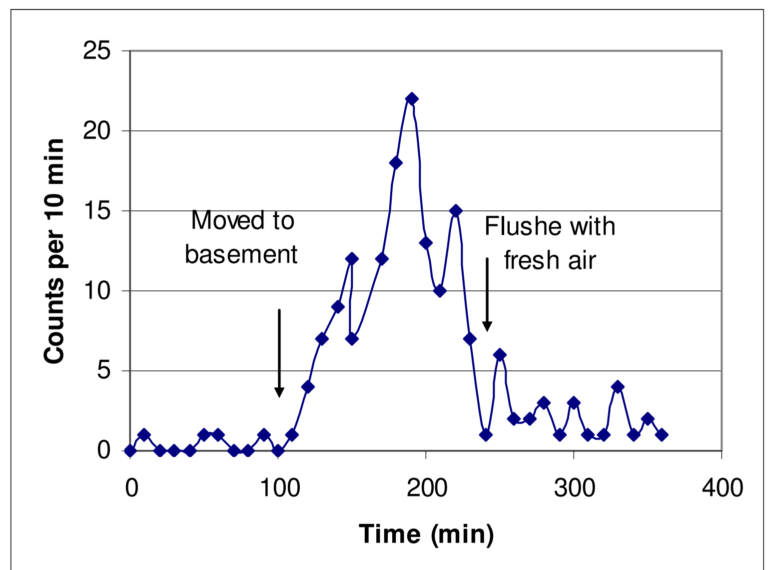


MWPC gain vs. the voltage curves measured with alpha particles oriented perpendicular to anode wires(a) and parallel to them (b)



Counting characteristics of the MWPC measured in Ar (all wires were connected to one amplifier) and in air for alpha tracks oriented perpendicular and parallel to the anode wire

Results of detection a small concentration of Rn in a basement. In the time interval of 0-100min the MWPC operated in fresh air. At T=100min it was moved in to the basement. At T=240min the chamber was flushed with fresh air and removed from the basement



Summary of results:

	Single -wire proportional counters	Single- wire ionization chamber	MWPC
Noise Bq/m3	76	24	1.2(air from a cylinder) 2 (ambient air)
Efficiency	1	0.15	1

Table 1 Noise and efficiency of various types of wire detectors operating in air and tested in this work

Time of counting (min)	Single -wire proportional counters MDA	Single -wire ionization chamber MDA	MWPC MDA	**Atmos MDA** (the best on the market)
0.2	1300	6830	625	
1	420	1960	**140**	**150**
2	270	1200	75	
4	175	760	43	

Table 2 Minimum detectable activity of our detectors (in Bq/m3) to Rn alpha particles for various time intervals of measurements Δt

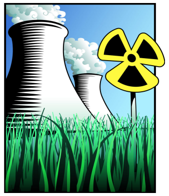
To verify our measurements some samples of air containing Rn were also independently measured by the experts from the French company **ALGADE**_

Conclusions:

1) Operation of various gaseous detectors (*wire –type and micropattern*) in air in avalanche mode was investigated and conditions for their stable operation were found

2) Based on these studies laboratory prototypes of photoionozation detectors of dangerous gases were build an successfully tested. Due to the avalanche multiplication they are 100-1000 more sensitive than any commercial devices currently available on the market

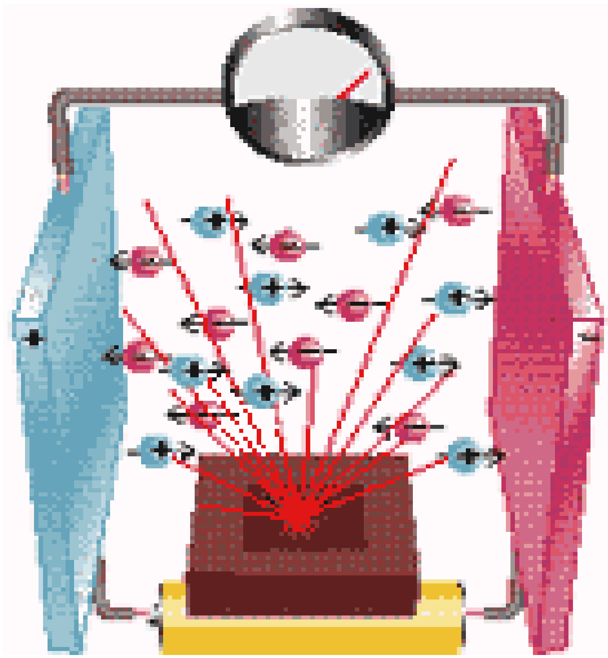
3) We also constructed and tested a prototype of a Rn detector operating in air in avalanche mode. It has sensitivity as high as the best commercial Rn detectors, however *much* simple and cheaper. Its features make it suitable for massive applications, such as a continuous Rn monitoring for possible earthquake prediction or continuous monitoring of Po contaminations



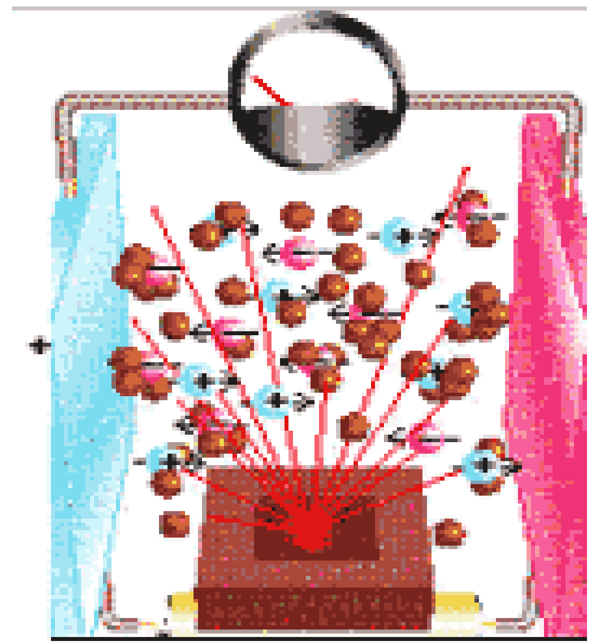
Spare

Principle of operation

Constant current-O'K



Current drop-alarm



PID detector

What determines the detection sensitivity?

$$J=N_{ph}\,[1-\exp(-\sigma n L)]QE\,\{-\exp(kL)\}\ (1)$$

$$J=N_{ph}\,\sigma n L QE\{-\exp(kL)\}\ (2)$$

In portable devices:

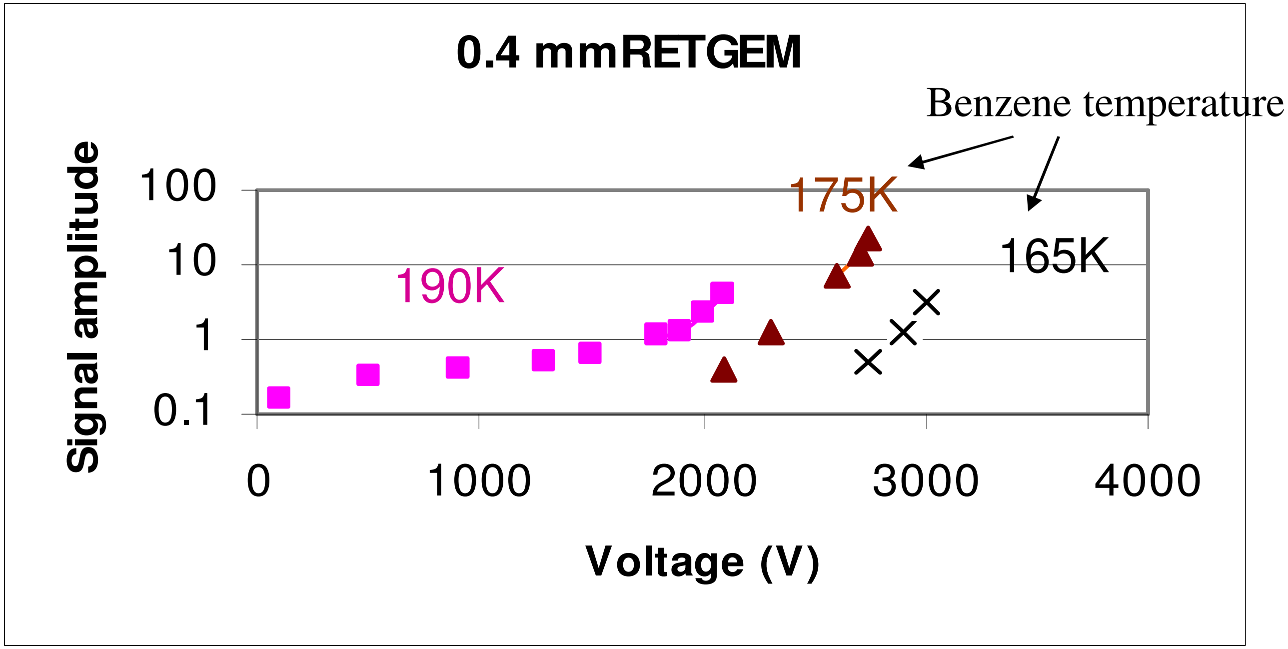
Typically lamps give <10^{12} phot/sec

Minimum current which can be measured ~πA

↓

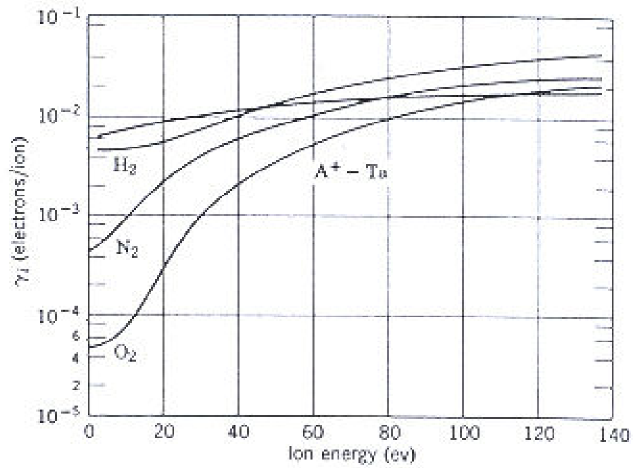
Sensitivity 1-100 ppm

<u>Preliminary:</u> detection of benzene vapors by RETGEM operating in pulse mode



187K~20 ppm
175~2 ppm
165-0.1 ppm → **order of magnitude higher than with the ordinary ionization chamber**

γ+ and γph also depend on the cathode surface conditions



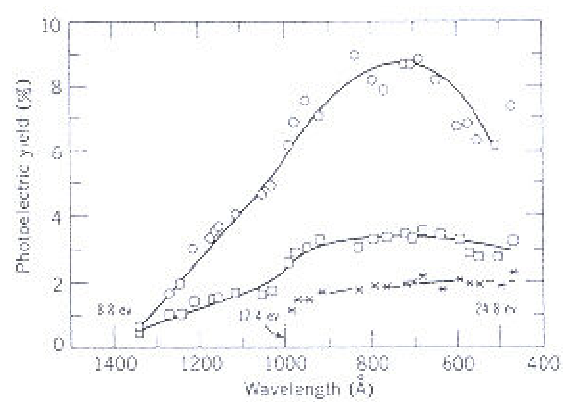
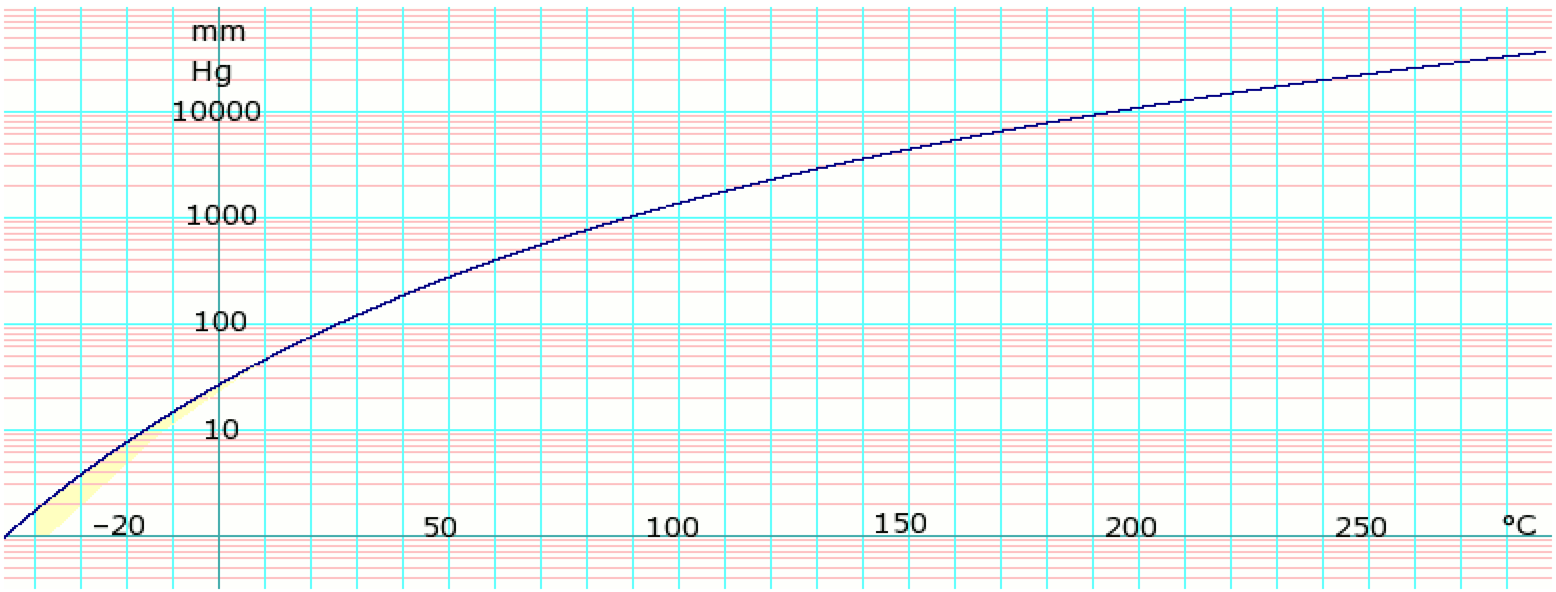


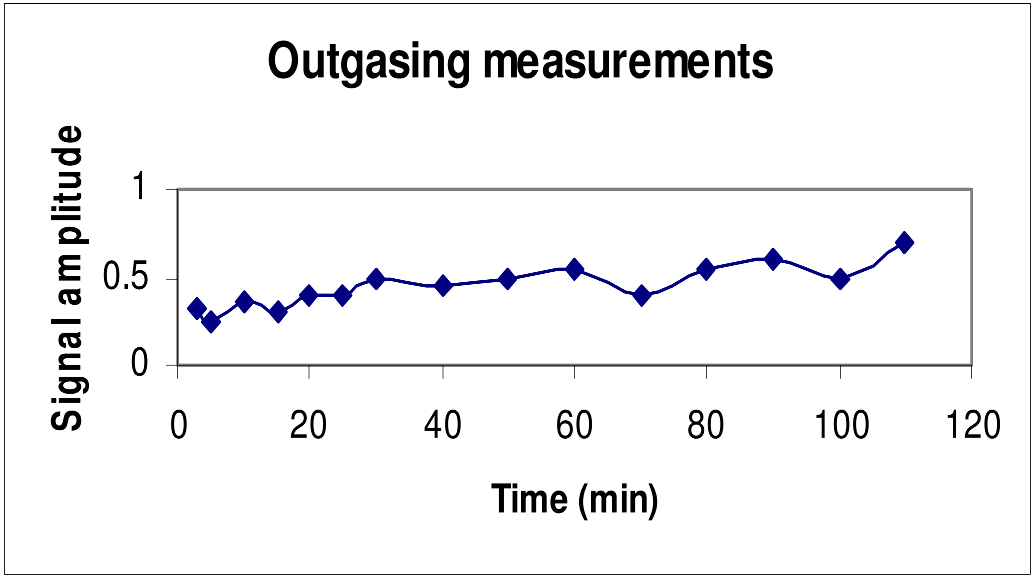
FIG. 13-4-10. Photoelectric yield of Cu. ○ Untreated cathode. □ Heat treated cathode in equilibrium with residual gases at about 10^{-5} mm Hg. * Cathode maintained a 500°C in a vacuum of 10^{-5} mm Hg.

E. McDaniel, "Collision phenomena in gases", 1964

Benzene as an example

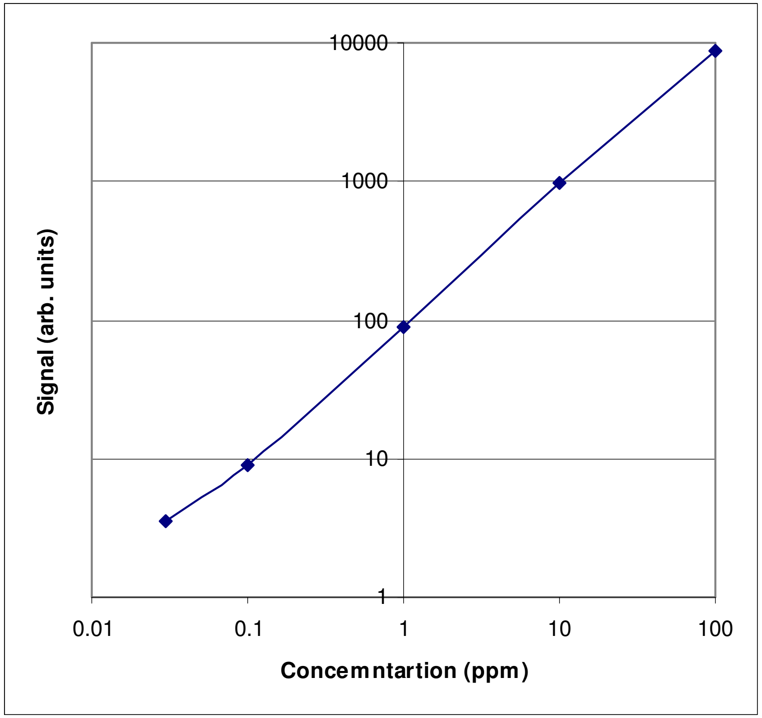


Volume dilution method

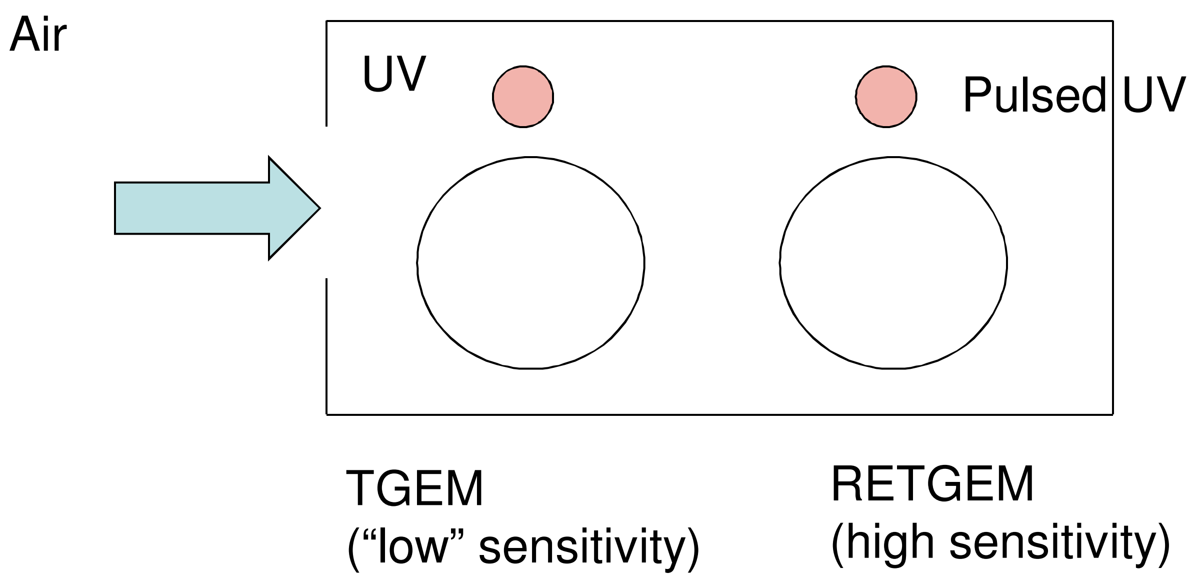


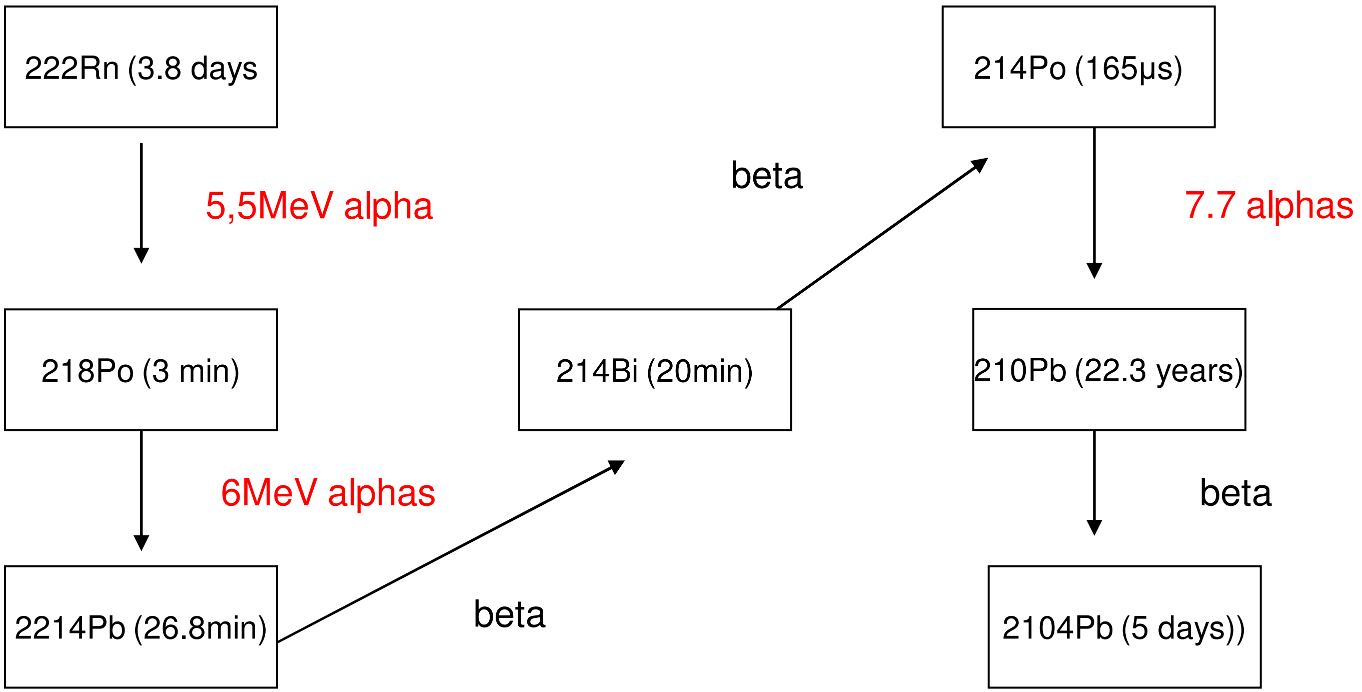
10ppm benzene

Detector response for the V=const



A wide - range device (under developments)




222Rn (3.8 days
5,5MeV alpha
218Po (3 min)
6MeV alphas
2214Pb (26.8min)
beta
214Bi (20min)
beta
214Po (165µs)
7.7 alphas
210Pb (22.3 years)
beta
2104Pb (5 days))

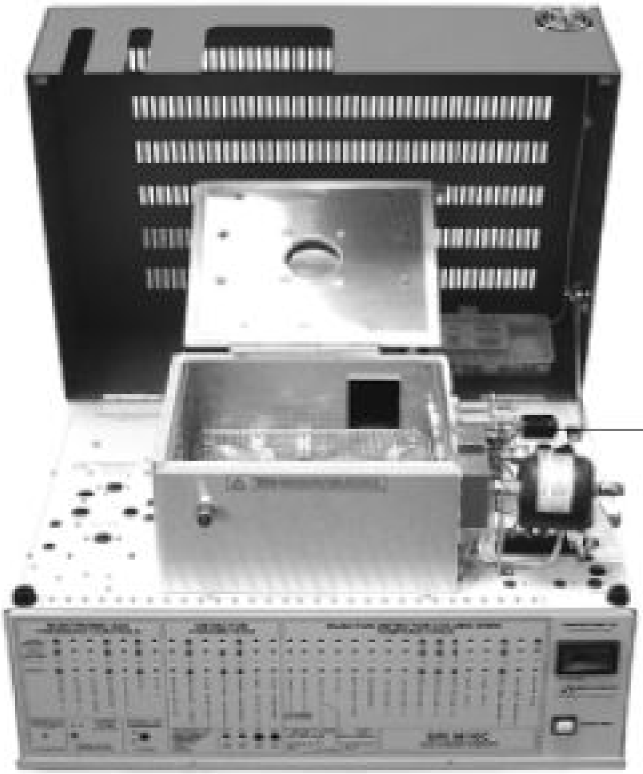
Thoron was obtained by the following way: a sealed metallic box was filled with towel paper preliminarily impregnated with solution of thorium nitrate and dried. Thoron was generated via so called “Thorium series” of radioactive decays:

^{232}Th>^{228}Rn> ^{228}Ac> ^{228}Th> ^{224}Ra> ^{220}Rn…

Air with some trace of ^{222}Rn was produced in the sealed metallic box containing about 50g of sandy loom with 1550 ppm of Uranium (obtained from one of the St. Etienne mines). The Rn was generated via the so called “uranium series”:

^{238}U>^{234}Th> ^{234}Pa>^{234}U>^{230}Th>^{226}Ra>^{222}Rn

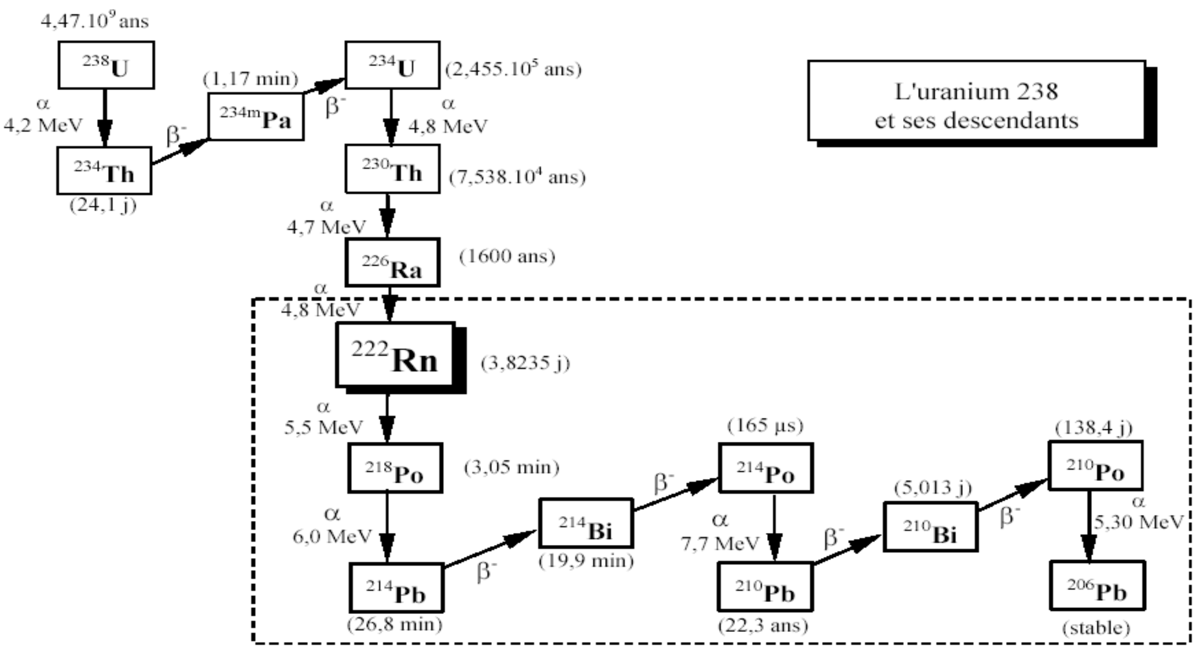
In case of measurements of the ^{220}Rn or ^{222}Rn the air having traces of these radioactive elements was introduce in to the detector. Their concentration was evaluated from the counting rate produced by alpha particles. To verify our measurements some samples of air containing Rn were also independently measured by the experts from the French company **ALGADE**



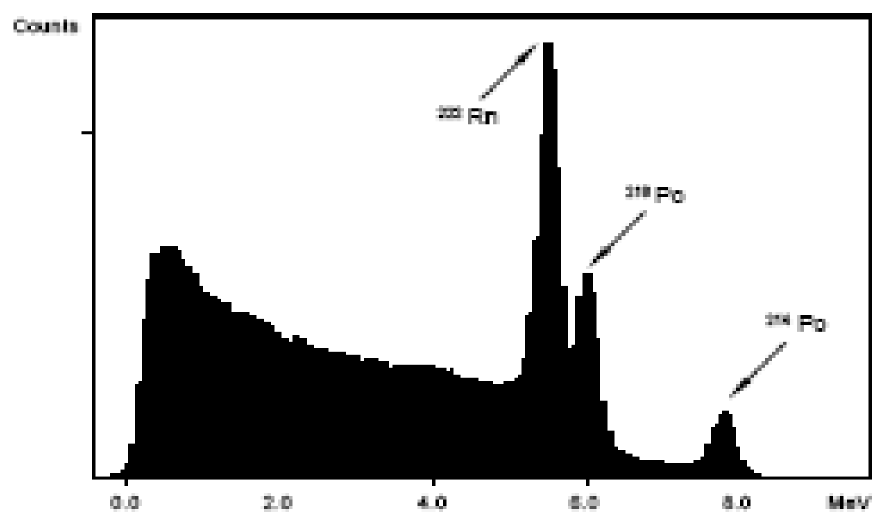
PID in series
with a DELCD
and an FID on
an SRI 8610C
chassis

http://www.srigc.com/PIDman.pdf

Commercially available Rn detectors



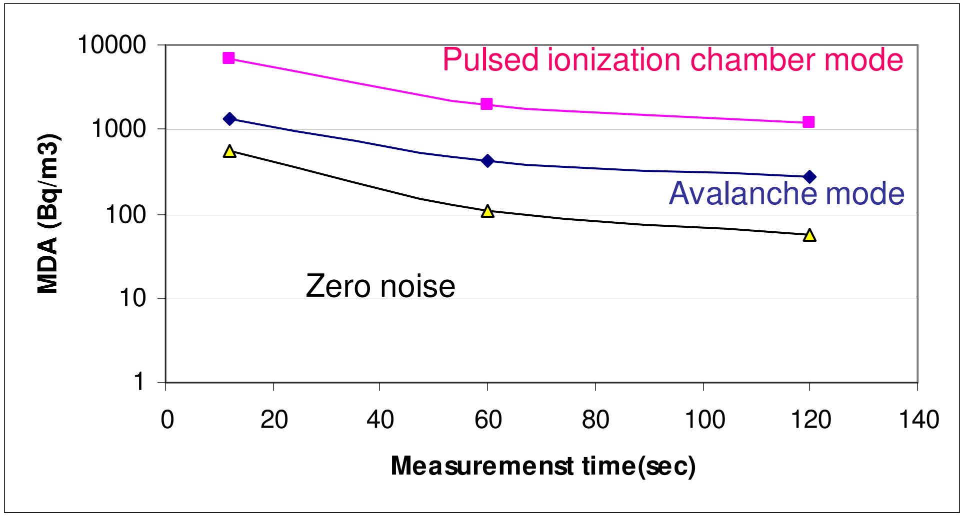
Atmos 12px



Energy spectrum obtained with the ATMOS 12 prx.

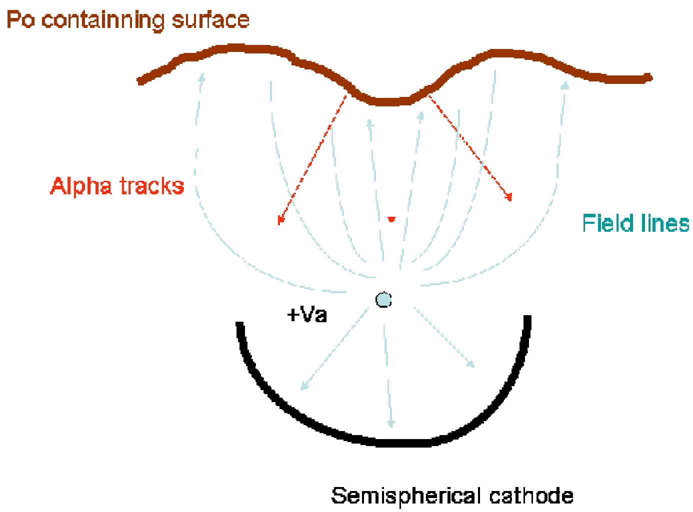
$$L = \frac{4\left(1 + \sqrt{2 B_0 . V . \Delta T}\right)}{\lambda . V . \Delta T}$$

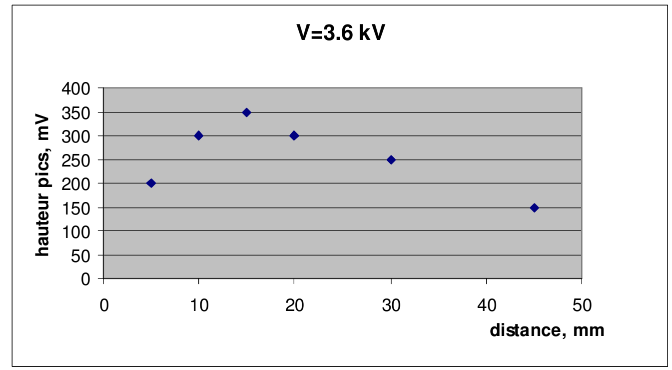
	détecteur amplifié	ancien détecteur	Atmos 12dpx
bruit bq/m3 B0	76	24	~0
rendement lambda	1	0.15	1
volume L	0.5	0.5	0.6



Po detection:

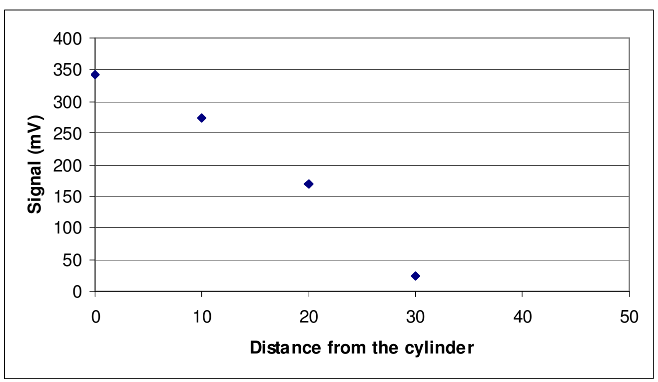
Single -wire

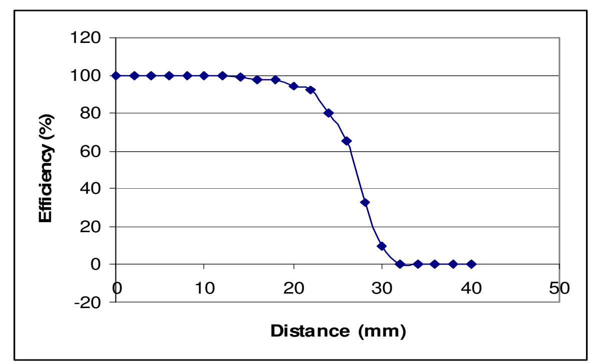




Alpha particles signal amplitude as a function of the distance from the single-wire counter

MWPC





Signal amplitude vs. the distance from the cathode of the MWPC measured with alpha particles oriented perpendicular to the cylinder axis. In these particular measurements all wires were connected to one amplifier

Efficiency of alpha particles detection vs. the distance from the cathode cylinder when MWPC operated in signal coincidence mode