Photon and ion induced breakdown

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I’ll start from what is known and generally accepted and then will move to new facts and new points of views

Classical point of view

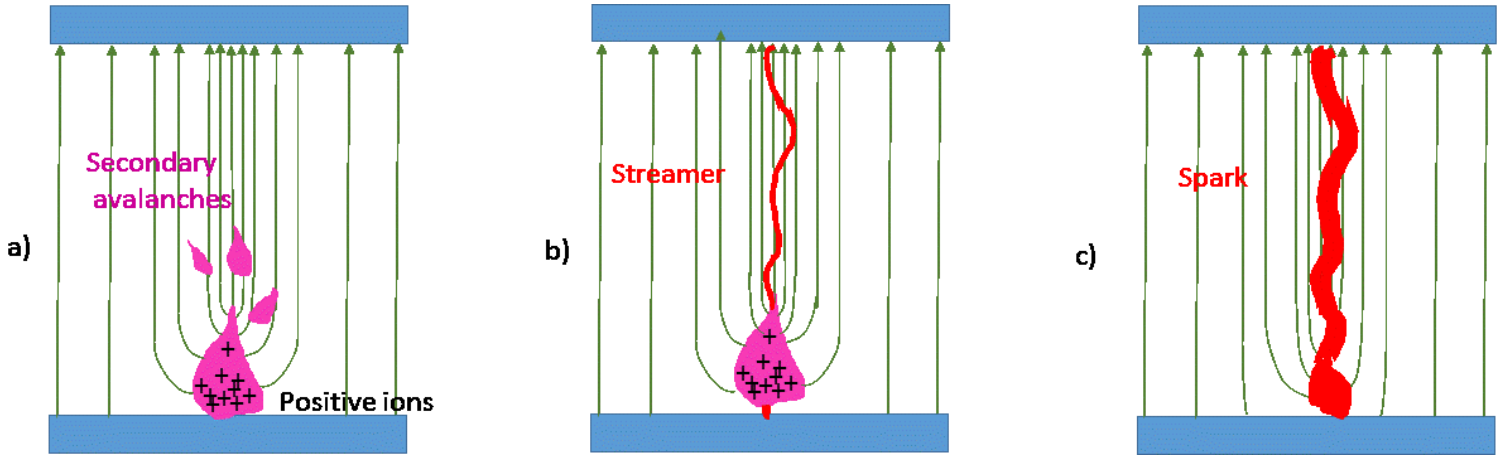
(“fast” and “slow” breakdowns)

A few notes about fast breakdown

Typical time ≤ ns

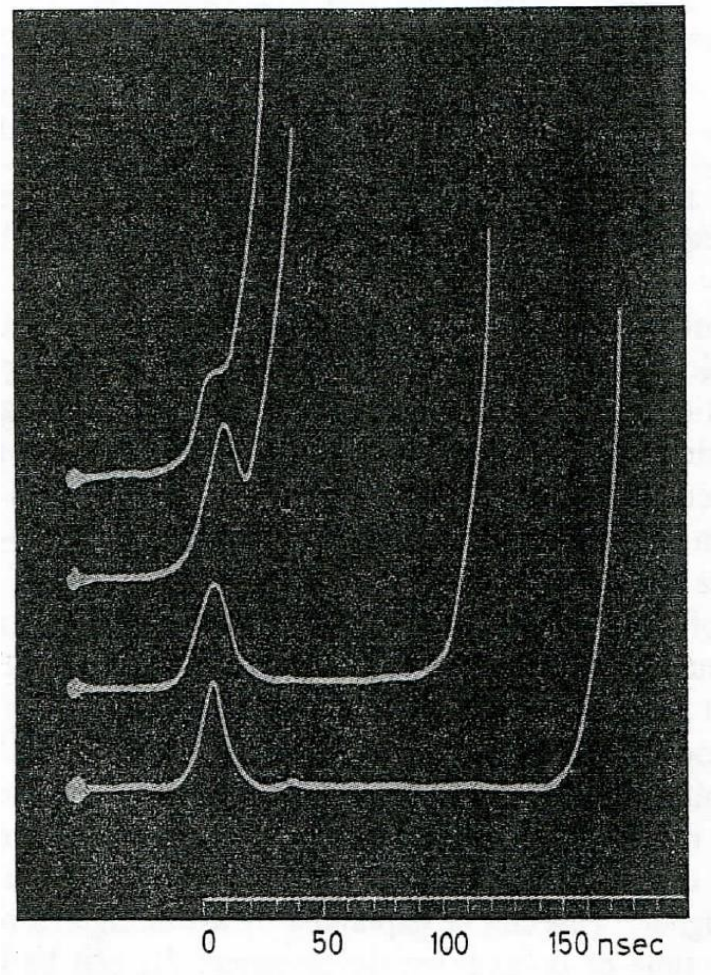
$An_0 \sim 10^8$ electron-Raether limit

(A –gas gain, n_0-primary ionization



Animation of spark development when the total charge in the avalanche reaches the Raethet limit:

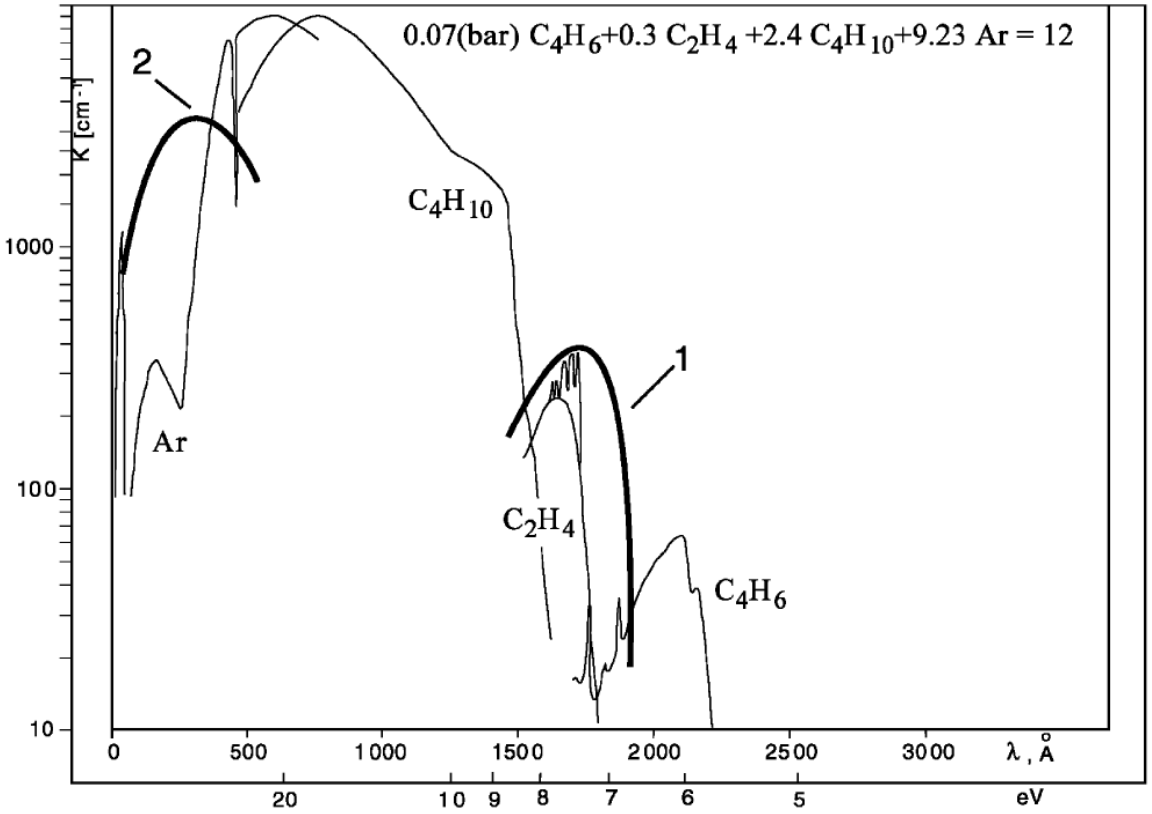
a) filed lines close to the avalanche experience a focusing effect and some secondary avalanches start
b) moving towards the positive ions “body”, b) a thin plasm filament-a streamer- is formed,
c) c) when the streamer reaches the electrodes, a spark happens



Current oscillograms of static breakdown in methylal at various overvoltages increased from the lowest to upper curves (from Raether book)

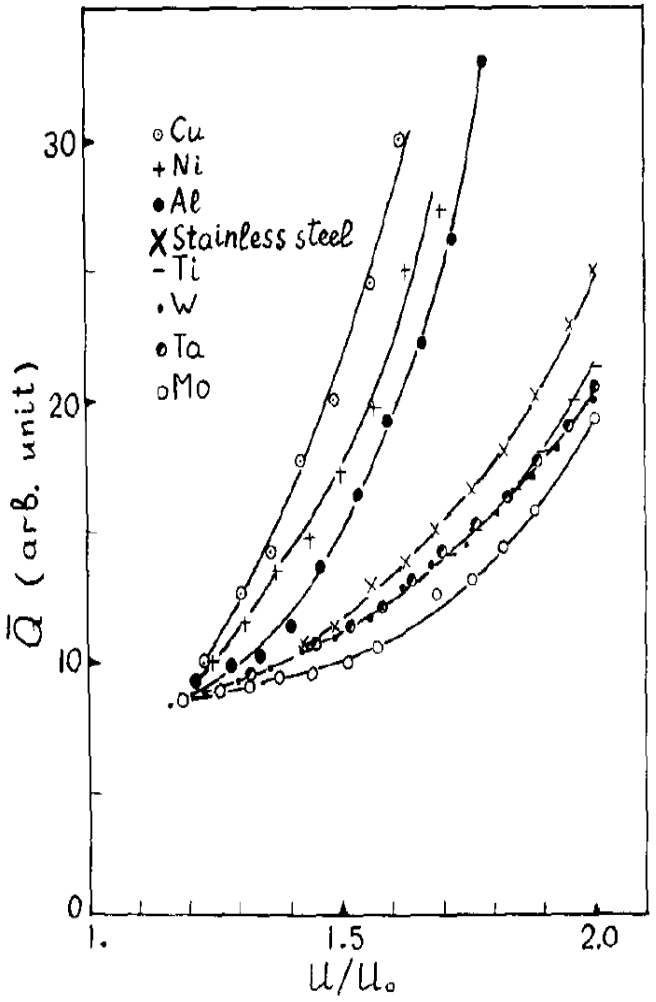
In case of metallic electrodes breakdown disable the detector for some time

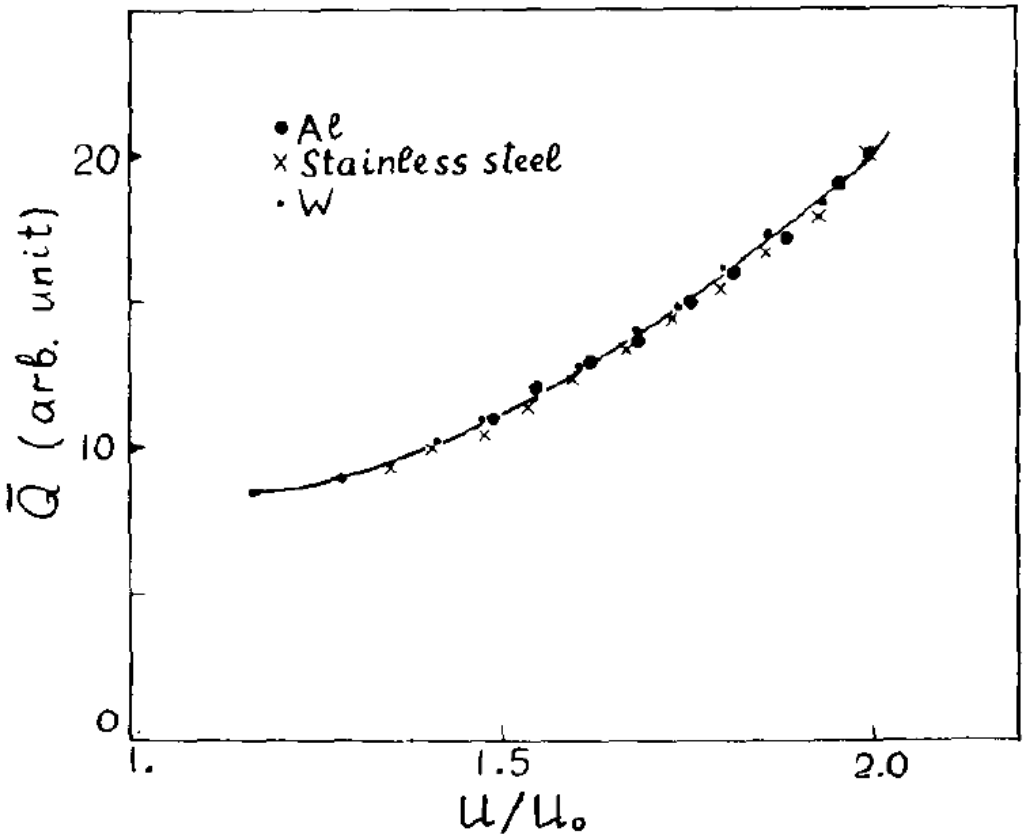
Many researches belief in a strong role of avalanche and streamer emission in the detector operation,.. although with some reservations



Linear absorption coefficient for the components of gas mixture used in high-pressure Pestov counters (corresponding to their quantity). The corves 1 and 2 correspond to propylene (C3H6) and neon respectively

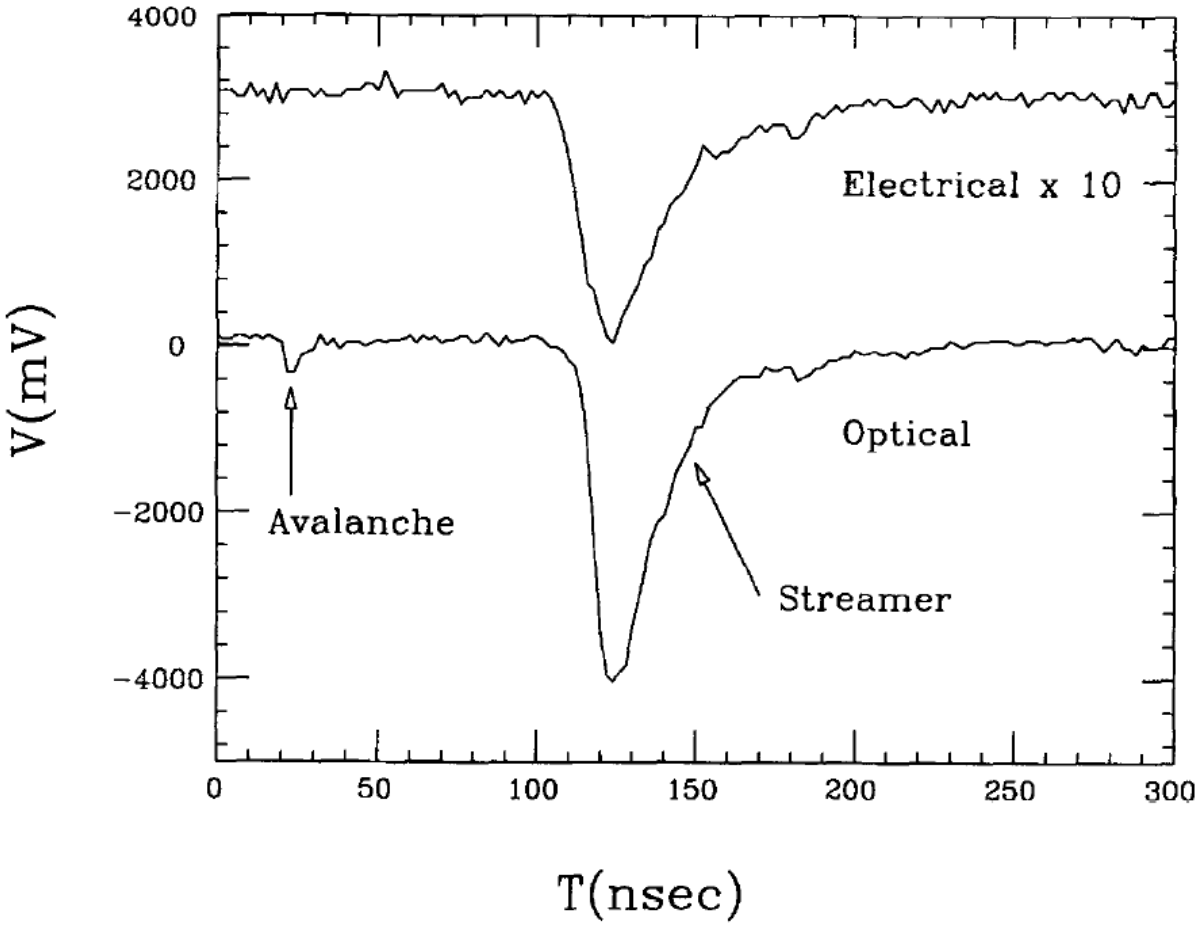
In case of dielectric electrodes (in contrast to metallic electrodes) a breakdown disable only some part of the detector and one can observe “the consequence of photon emission on the discharge development”(Pestov)



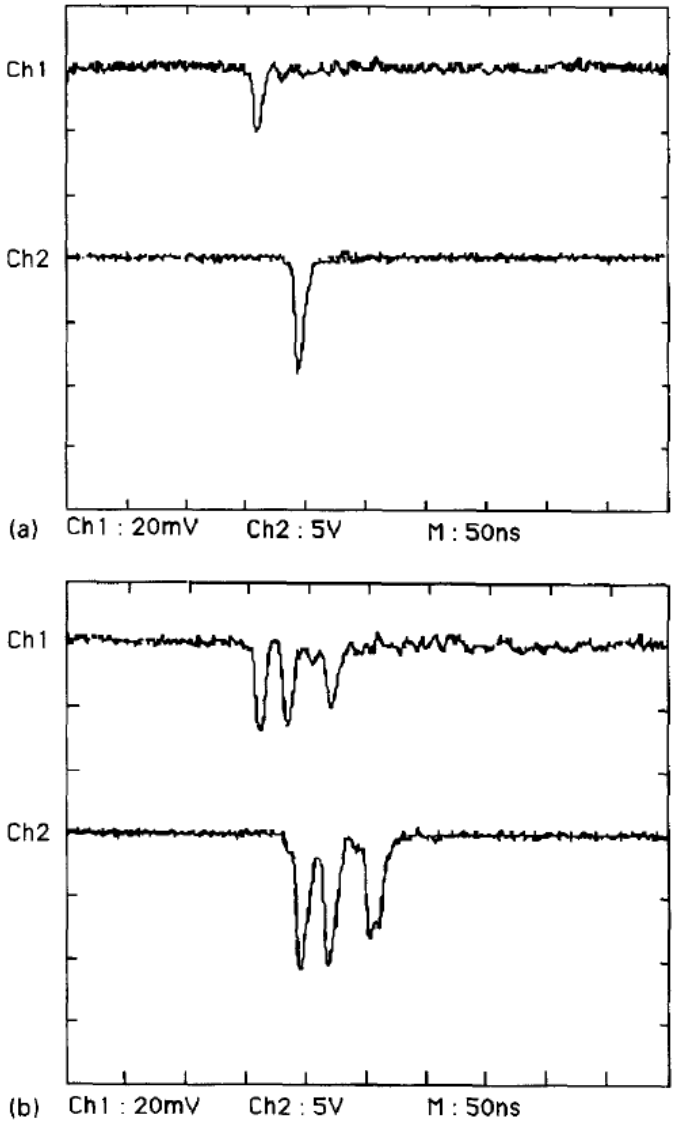


…However, alternative explanation is also possible-
Ion induced emission properties of the cathodes

Details of discharge development in RPC



Y. Inoue et al., NIM, A394, 1997,65



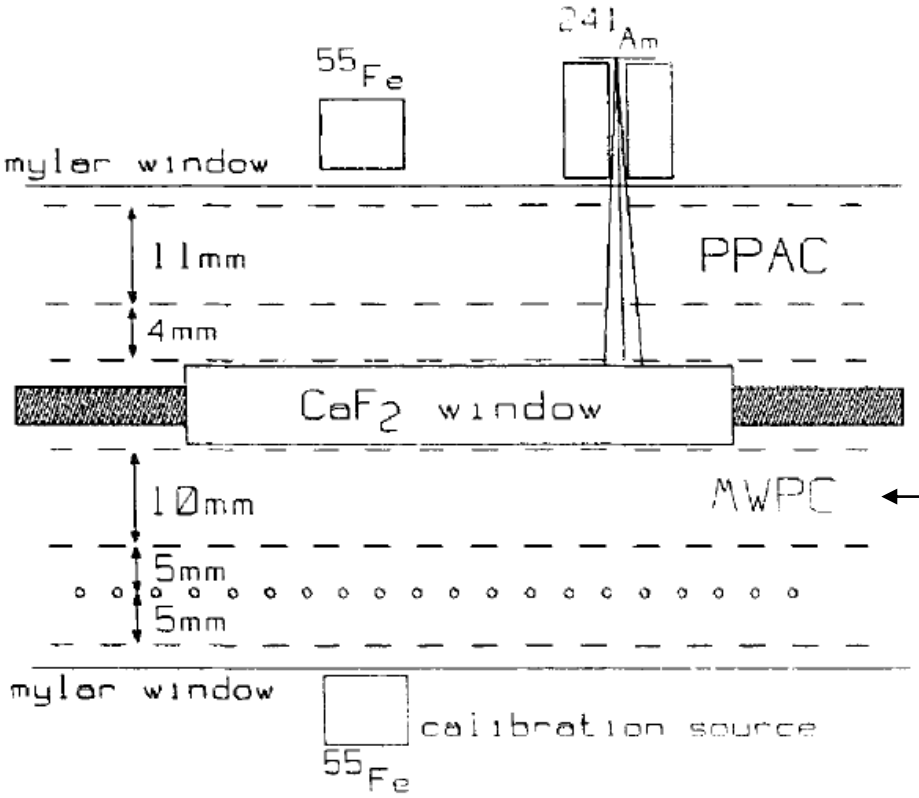
Visual observations

Large distance (2-3 mm) between consequent streamers is difficult to explain without photon mechanism

A puzzle…

From the “theoretical” point of view, not in all gases the UV emission of avalanches are capable to ionize its own gas

Some related studies



Filtering region

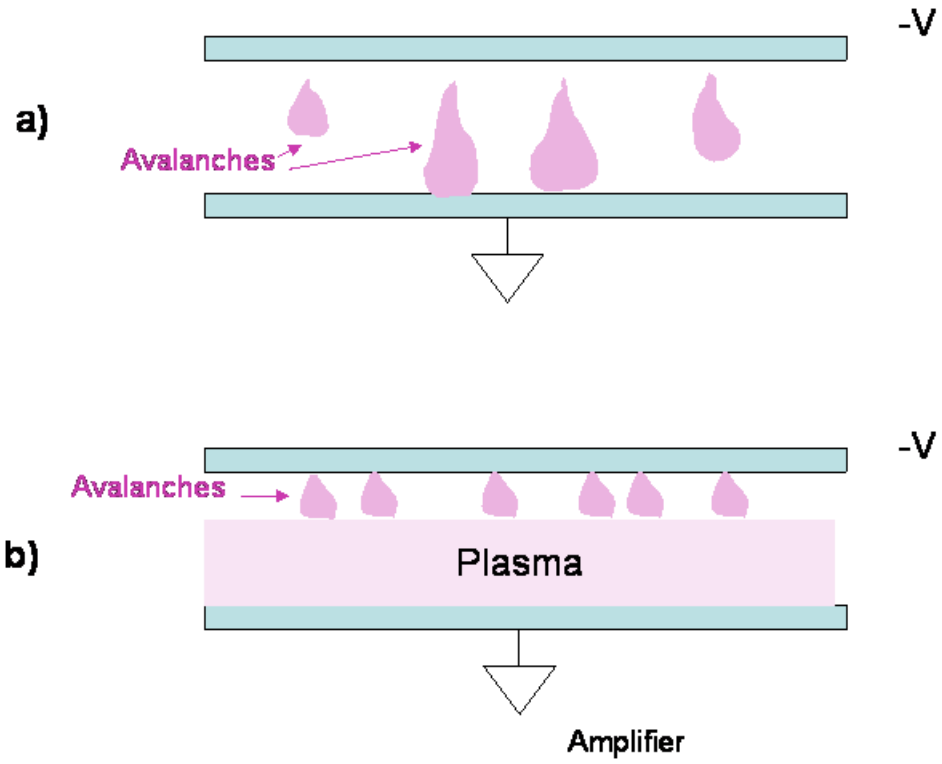
P. Fonte et al., NUM A310, 1991, 140

Our results allow us to put forward a hypothesis about the origin of the emission. For example, in the case of an Ar + TEA mixture in the PPAC we can assume that the molecular emission of TEA cannot ionize TEA molecules in the MWPC. On the other hand, the measurements with the CH_4 gas filter show that the first and second continua of Ar* emission (which exist mainly below 140 nm) do not contribute noticeably, so the observed emission can be either third Ar_2^* emission at $\lambda > 140$ nm [10] or fragment emission of TEA, which leads to the emission of atomic lines: C*, H*, N*, etc. The third continuum of argon corre-

By using CH_4 as a gas filter we could separate the sensitive band into two subbands: 120–140 and 140–170 nm. For mixtures containing hydrocarbons the emission is concentrated in the band 140–170 nm, whilst for pure Ar the emission is concentrated in the 120–140 nm band as should be expected from argon excimer emission. These results suggest that for the mixtures containing hydrocarbons the emission is mainly due to fragment emission and not to noble gas excimer or molecular emission.

A few notes about slow breakdown

Typical time…up to ms or even more

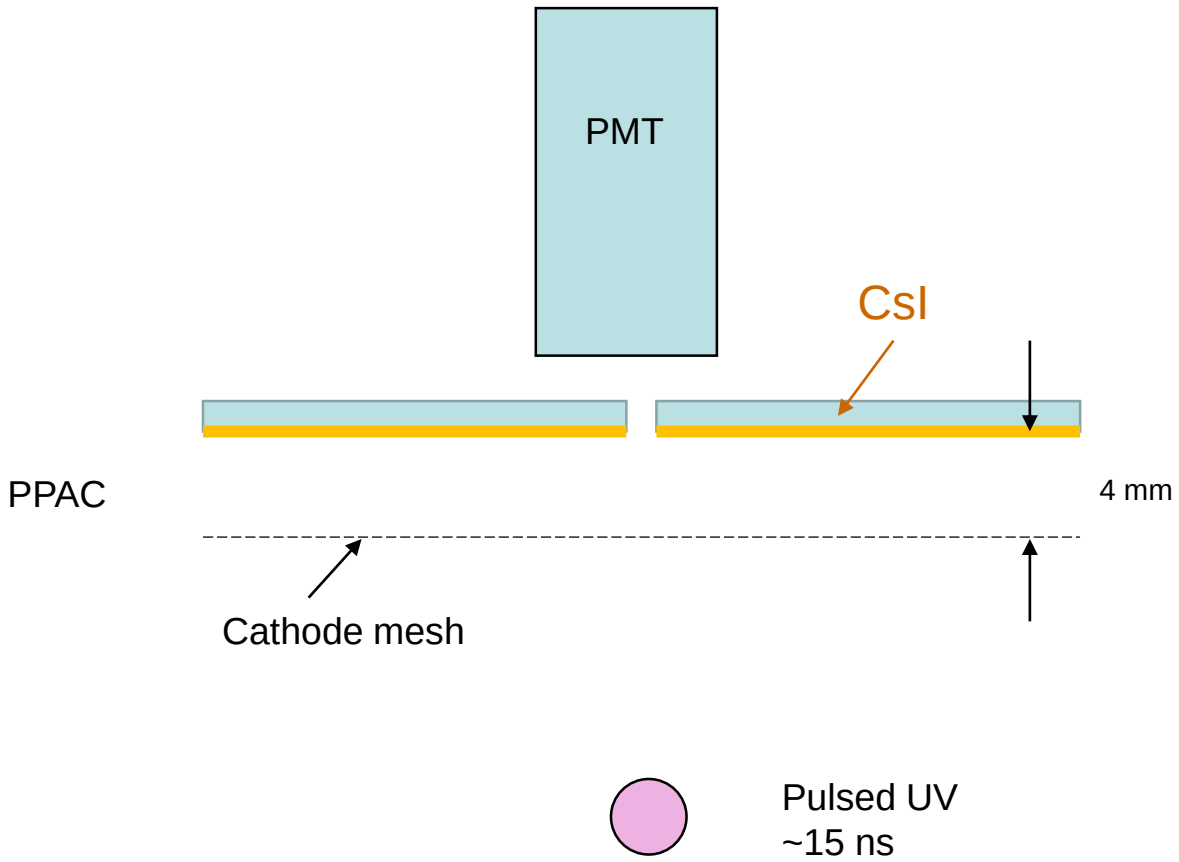


Conditions:

$A\gamma_{ph}=1$
or
$A\gamma_{+}=1$

Free electron can be emitted from the cathode as a result of the ion recombination with a probability γ_{+}
or due to the photo processes- γ_{ph}

An example of a slow breakdown studies



G. Charpak et al., NIM A307,1991,63

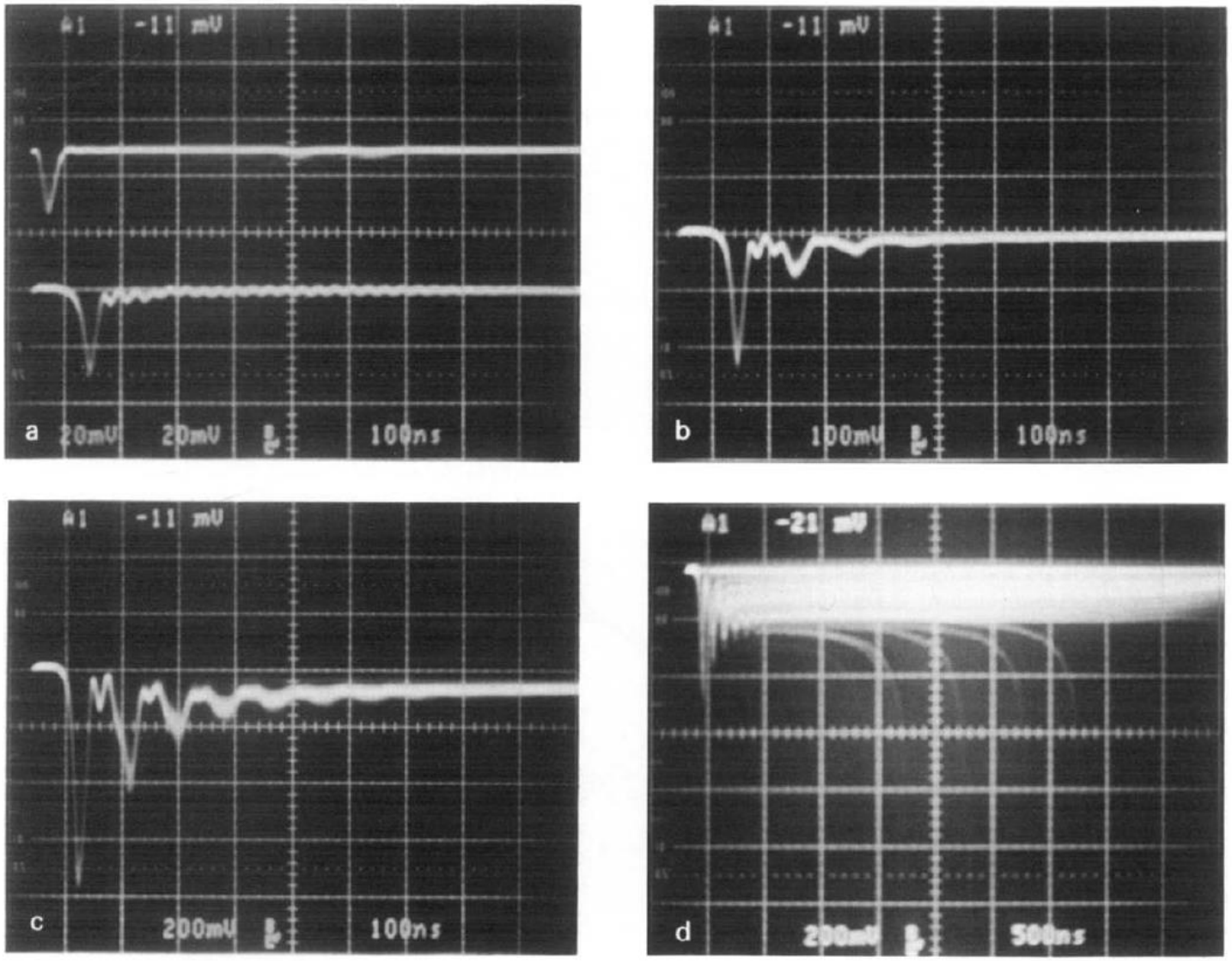


Fig. 2. Typical chamber signals, as detected with a fast current preamplifier: (a) chamber signal delayed after the PM signal (top) by the avalanche time, (b) ~25% feedback – our standard level for feedback measurements, (c) many feedback successors, (d) slow breakdown.

In both cases (fast and slow breakdowns) the main contribution comes from the VUV and UV avalanche photons

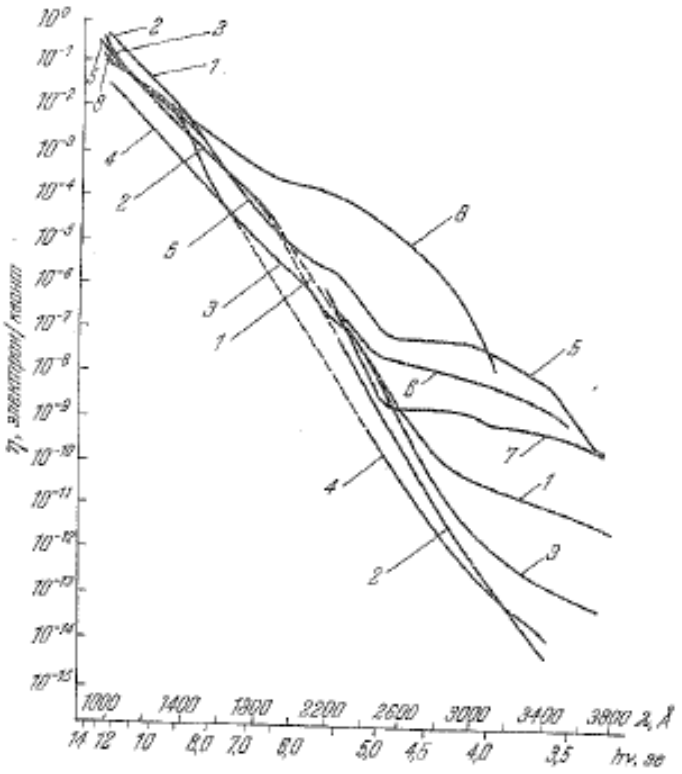
Ionization Potentials for Common Industrial Gases

Many compounds not appearing in this list with an ionization potential of 11.7 eV or less may also be detectable.

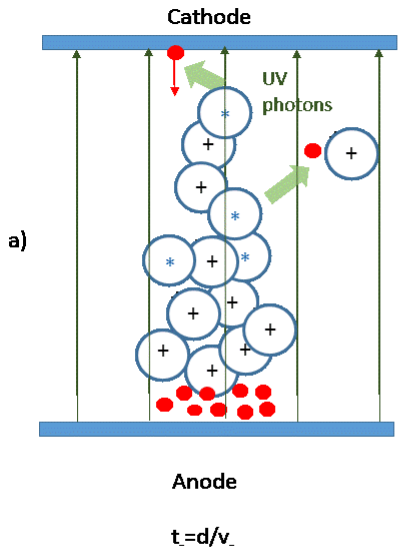
Other sources of ionization potential data:
CRC Handbook of Chemistry and Physics
NIOSH Pocket Guide to Chemical Hazards
HYPERLINK http://webbook.nist.gov/

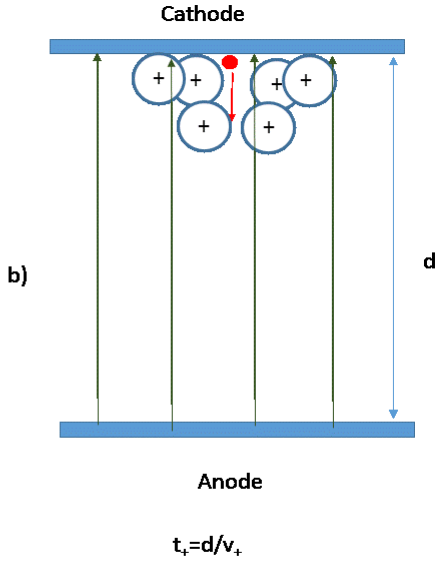
Chemical Name	IP (eV)	Chemical Name	IP (eV)
Acetaldehyde	10.22	1-Bromopropane	10.18
Acetic Acid	10.66	2-Bromopropane	10.08
Acetone	9.69	1-Bromo8propene	9.30
Acetylene	11.40	2-Bromopropene	10.06
Acrolein	10.13	3-Bromopropene	9.70
Acrylonitrile	10.91	2-Bromothiophene	8.63
Allene	9.83	o-Bromotoluene	8.79
Allyl Alcohol	9.63	m-Bromotoluene	8.81
Allyl Chloride	10.05	p-Bromotoluene	8.67
Aminoethanol	9.87	1,3-Butadiene	9.07
2-Amino Pyridine	8.00	2,3-Butadione	9.23
Ammonia	10.18	n-Butanal	9.83
Aniline	7.70	s-Butanal	9.73
Arsine	9.89	n-Butane	10.63
Benzaldehyde	9.53	n-Butanol	10.04
Benzene	9.24	s-Butanol	10.23
Benzenethiol	8.33	t-Butanol	10.25
Bromobenzene	8.98	2-Butanone	9.54
1-Bromobutane	10.13	1-Butene	9.58
2-Bromobutane	9.98	cis-2-Butene	9.10
1-Bromobutanone	9.54	3trans-2-Butene	9.13
1-Bromo-2-Chloroethane	10.63	n-Butyl Acetate	10.00
Bromoethane	10.28	s-Butyl Acetate	9.91
Bromoethene	9.80	t-Butyl Acetate	9.90
Bromoform	10.48	n-Butyl Alcohol	10.04
1-Bromo-3-Hexanone	9.26	n-Butylamine	8.71
Bromomethane	10.53	s-Butylamine	8.70
Bromomethyl Ethyl Ether	10.08	t-butylamine	8.64
1-Bromo-2-Methylpropane	10.09	n-Butylbenzene	8.69
2-Bromo-2-Methylpropane	9.89	t-Butylbenzene	8.68
1-Bromopentane	10.10	Butyl Cellusolve	8.68

27



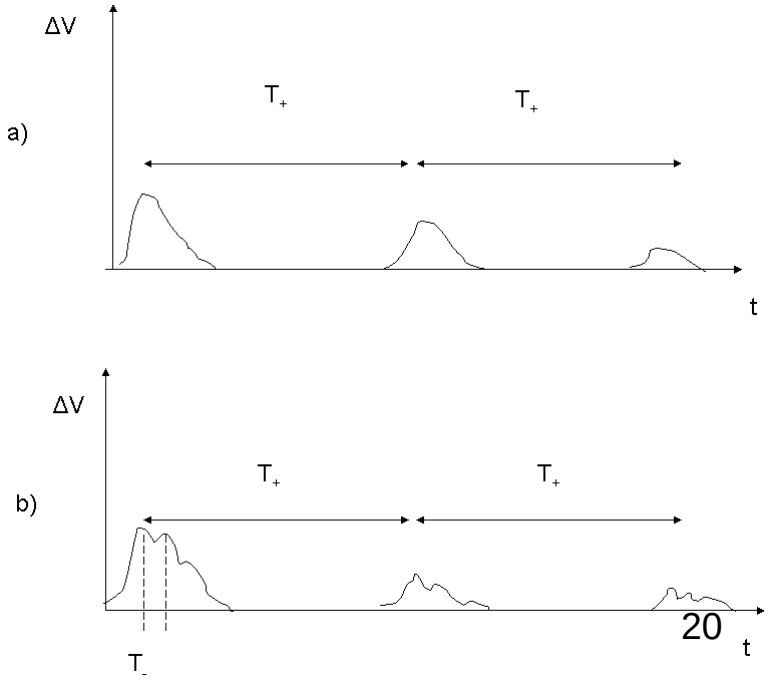
Ion induced breakdowns





$$\gamma_+ = k_{gas}\,(E/p)\,(E_i - 2\varphi)$$

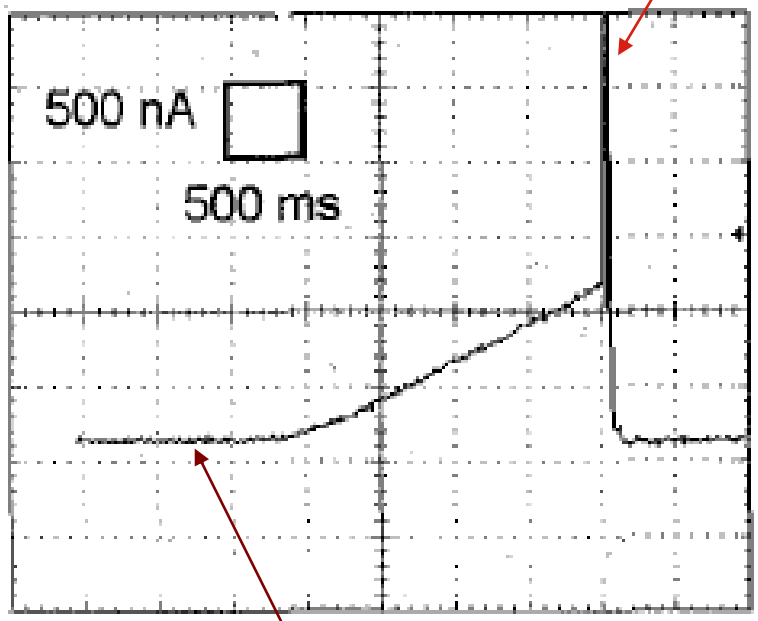
V. Peskov, Zh.Tekh Fiz, 45, 1975,1268



Beside these ”classical” ion feedback mechanism there are also observed “exotic” mechanisms called : breakdown preparation/cathode excitation/memory effect and electron jets

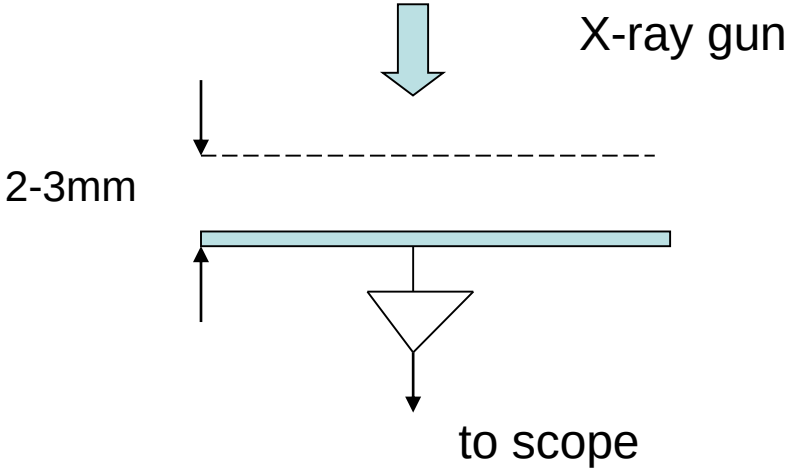
Preparation mechanism

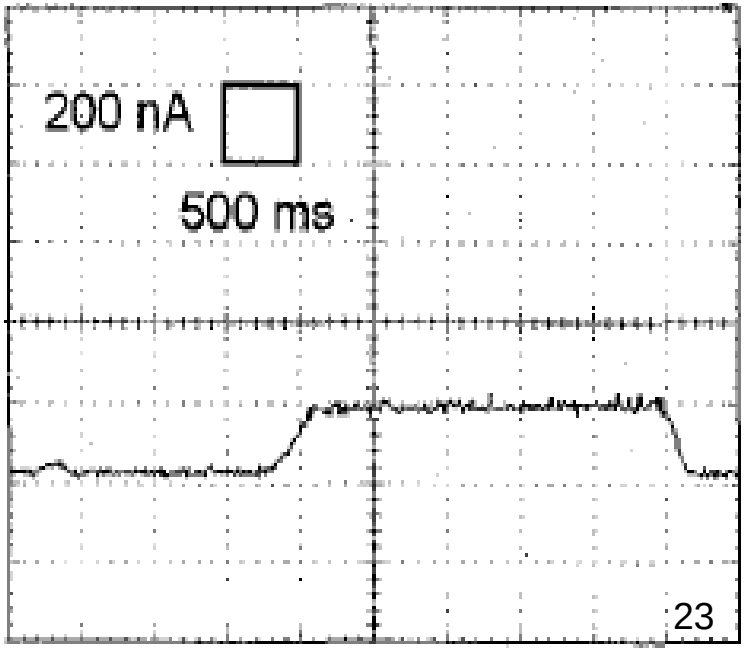
Breakdown



X-ray current

I. Ivanchenkov et al, IEEE, 45,1998, 258

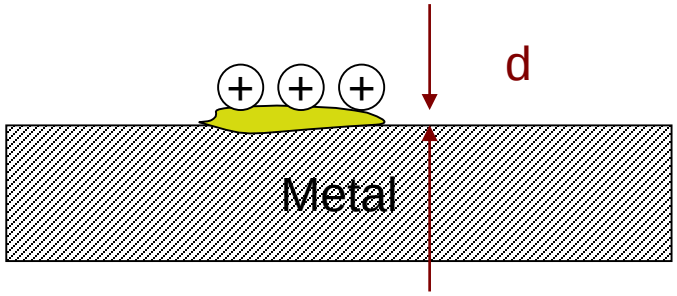




Similar effect is often describes in aging papers

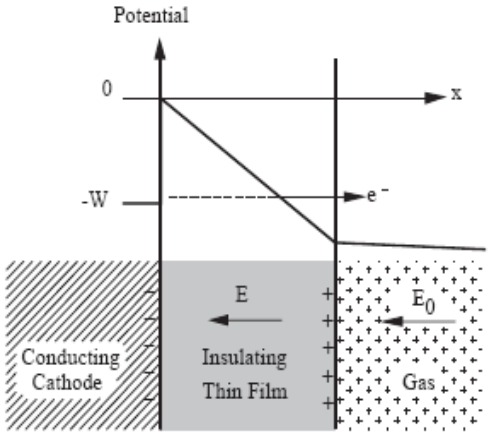
(see for example *Aging Workshop*, *NIM A515, 2003*)

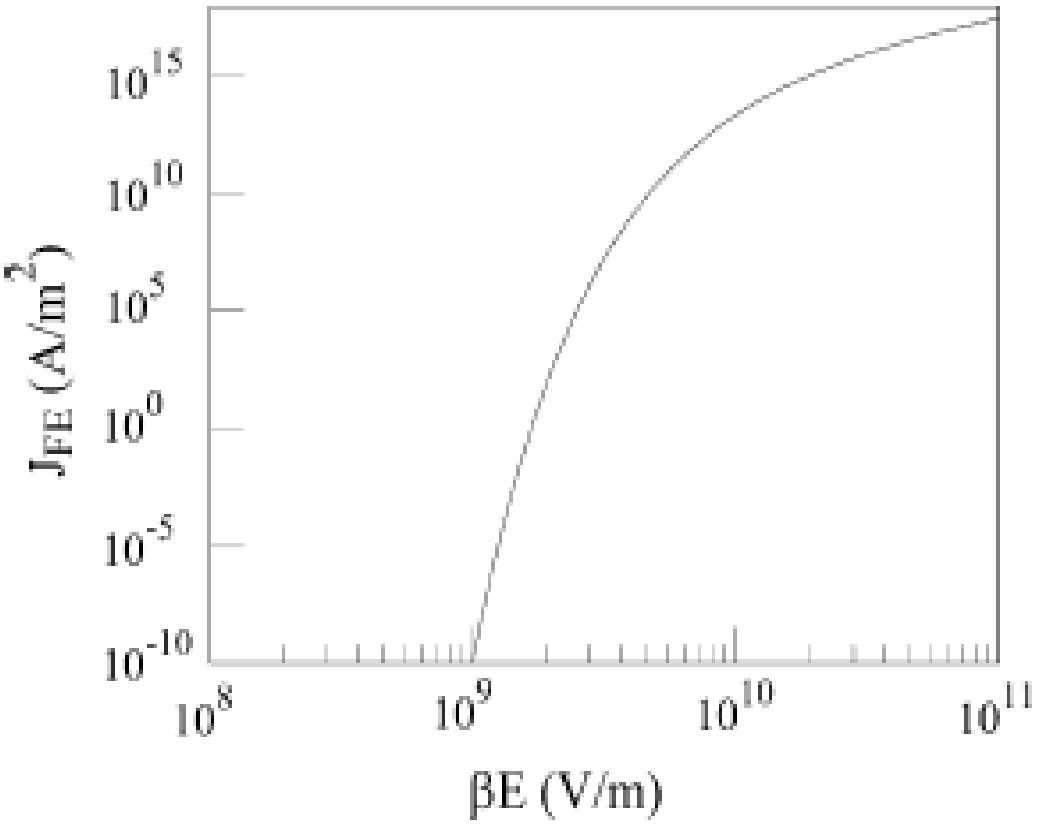
Usual explanation is via Malter effect..



$Jfe=5.4x10^{-5}(\beta E)^2 exp(-5.43x10^{10}/\beta E)$

$E=\sigma/d$



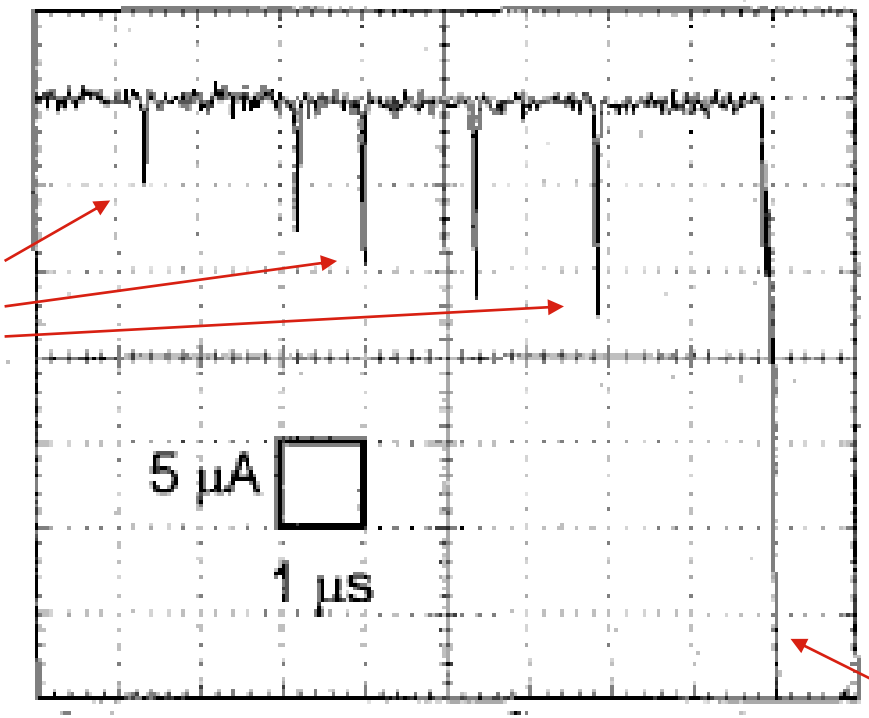


But it is not so simple…

Classical Malter effect predicts single electron emission

(see L. Malter , Phys. Rev, 49,1936, 478)

However, in most cases a slow current increase is just an integral of high amplitude pulses *I. Ivanchenkov et al, IEEE, 45,1998, 258* :



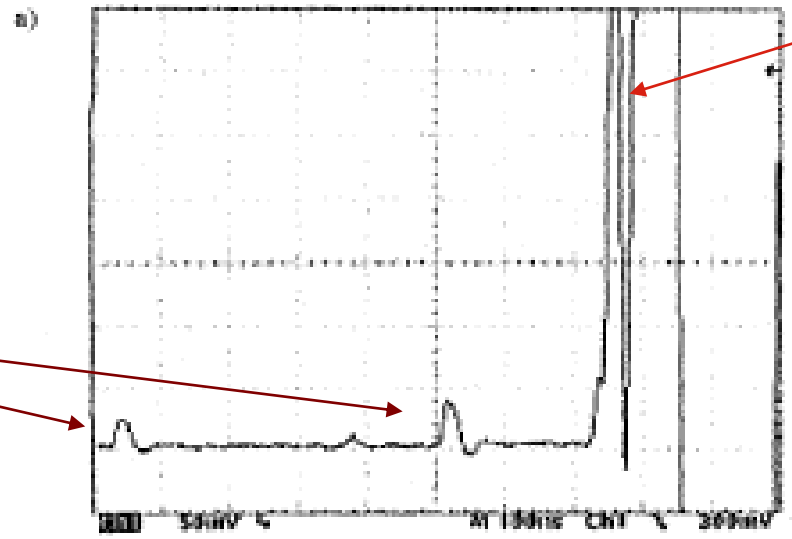
"preparation" pulses, each contains a huge number of electrons-jets

Breakdown

This strongly contradict to classical Ma;ter effect

More detailed studies reveal that the preparation mechanism may exhibit not only as current pulses but also as a short-term current growth

This was called a cathode excitation effect



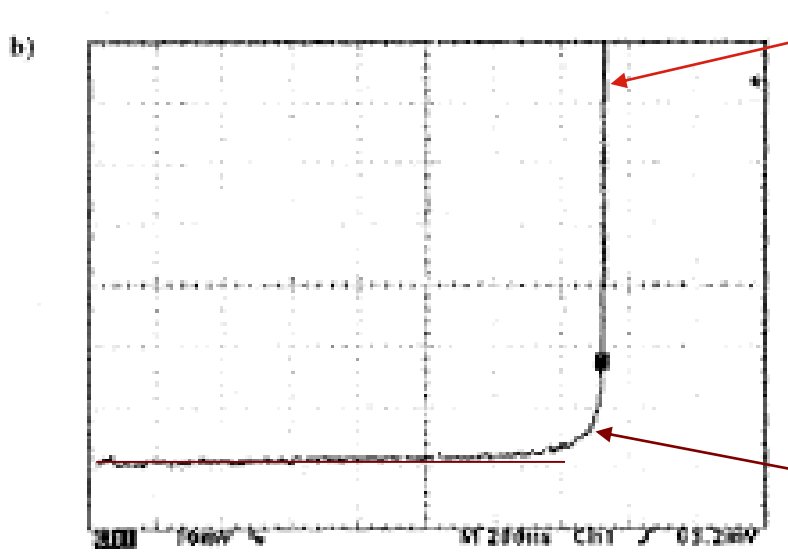
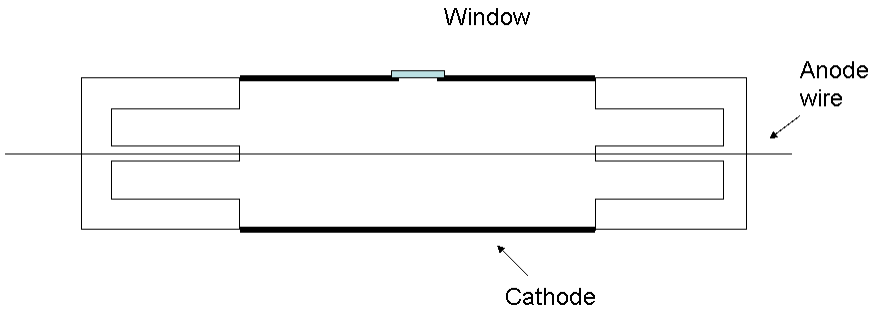


Figure 2a), b): Two typical oscillograms showing a preparation mechanism immediately preceding a high-rate breakdown.

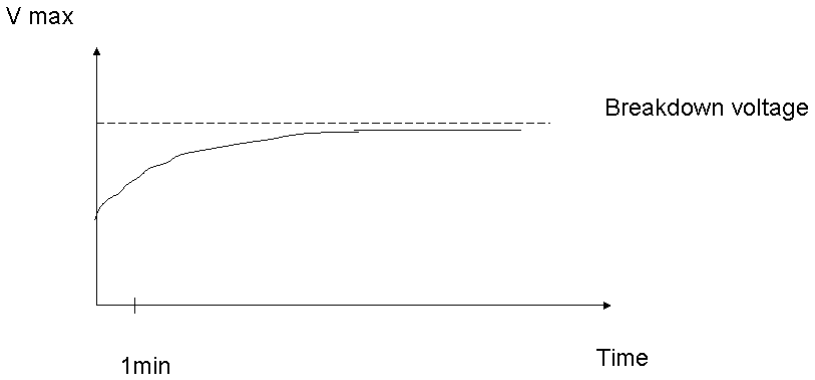
P. Fonte etal., IEEE Nucl Sci,46,1999,321

Measurements with single wire counters:

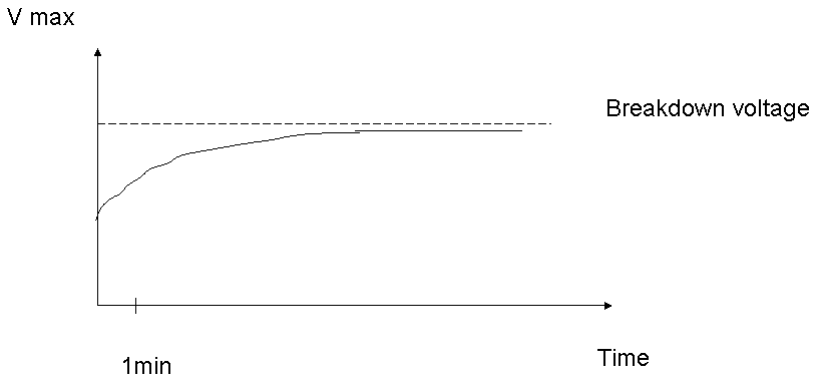


It is well known that
In single wire counters:

$A\gamma=1$

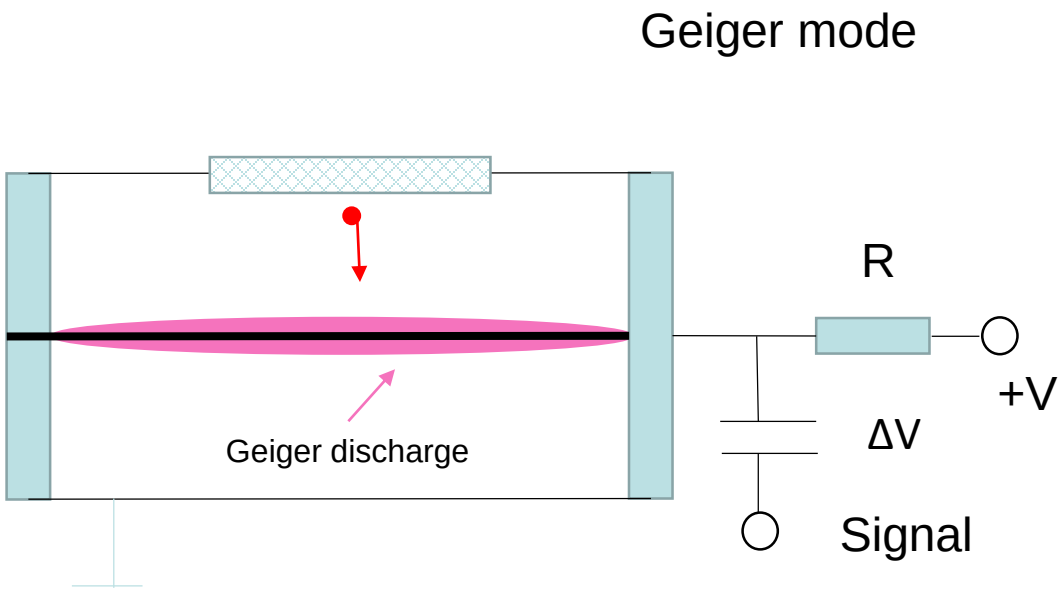


V. Peskov, PhD Thesis , 1976



This curve is typical for many gaseous detectors, including MPGDs (check with your experience!)

Early studies of the cathode excitation effect (Karabadjak Thesis)



In self-quenchd mode ion emission does dot contribute to the γ_+studies

More detailed studies

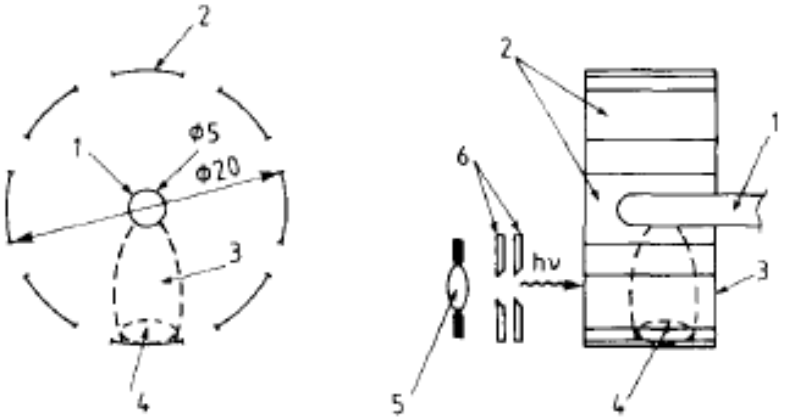


Fig. 8. Sketch of a multisection gas counter for γ_+ measurements. 1 – Cylindrical anode; 2 – multisectional cylindrical cathode; 3 – glow-discharge; 4 – cathode spot of the glow-discharge; 5 – external VUV radiation source; 6 – collimating system for the VUV radiation.

Glow discharge at elevated pressures

G. F. Karabadzhak and V. D. Peskov

S. I. Vavilov Institute of Physics Problems, Academy of Sciences of the USSR, Moscow

(Submitted July 22, 1985; resubmitted January 15, 1986)

Zh. Tekh. Fiz. **57**, 891–895 (May 1987)

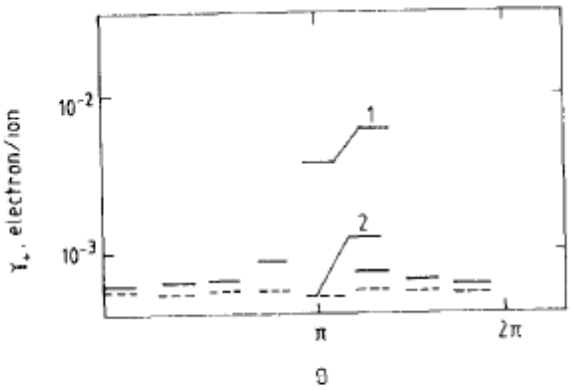
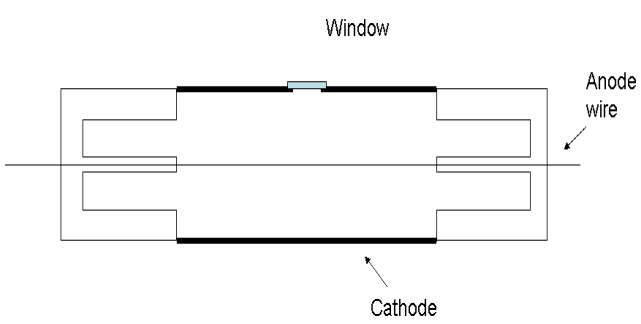
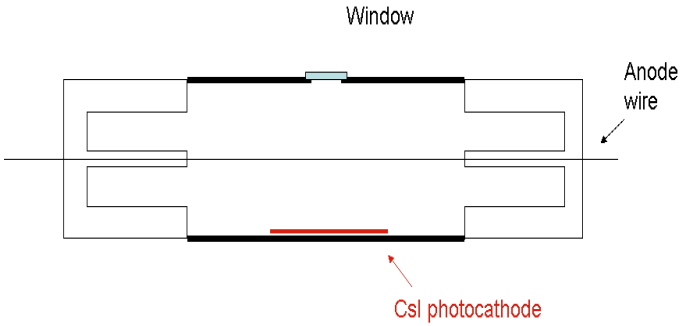


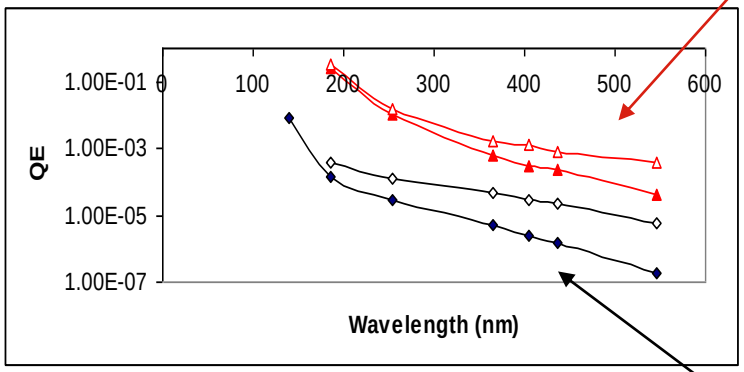
Fig. 9. Values of γ_+ as a function of the angle Θ between the upper section (see fig. 8) and investigated one and for different time delays τ after turning off the glow-discharge. 1 – $\tau = 9$ μs; 2 – $\tau = 10$ ms.

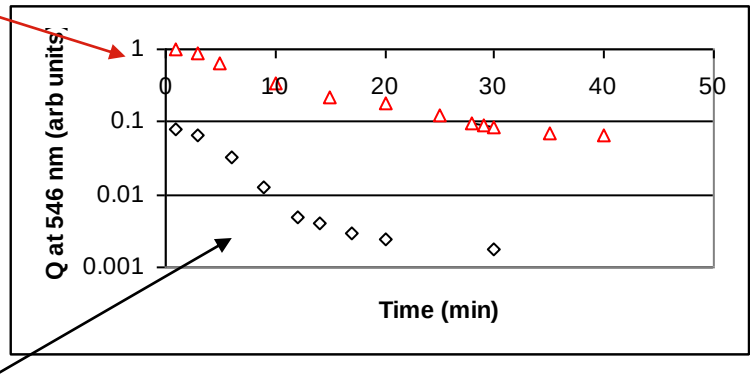
Changes in QE after intense ion bombardment





CsI





SS

P. Fonte , V. Peskov, ArXive

So it was clearly observed that after intense ion bombardment the QE temporally increase as well as γph and γ+

Therefore , the feedback loop Aγ=1 will appear at lower A

Further studies

JINST

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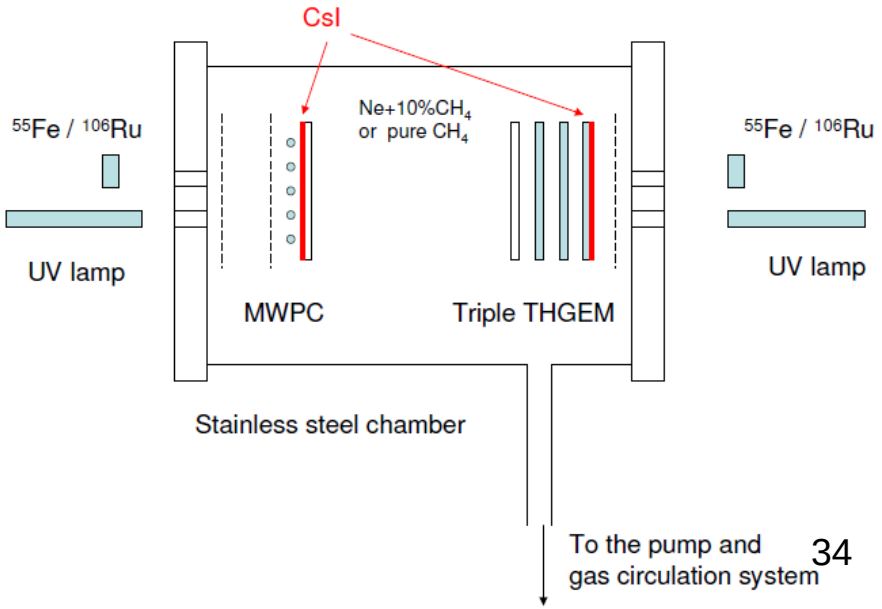
Further evaluation of a THGEM UV-photon detector for RICH – comparison with MWPC

V. Peskov,[a,b,1] M. Cortesi,[a] R. Chechik[a] and A. Breskin[a]



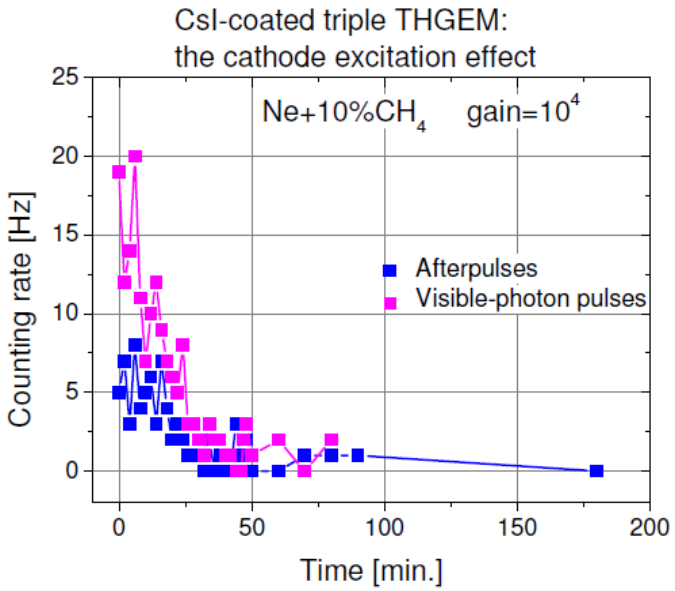


Figure 10. Counting rate of spurious pulses and visible-light induced pulses vs. time after induction of the cathode excitation effect; CsI-coated triple THGEM; gas mixture: Ne+10%CH_4; gas gain ~10^4.

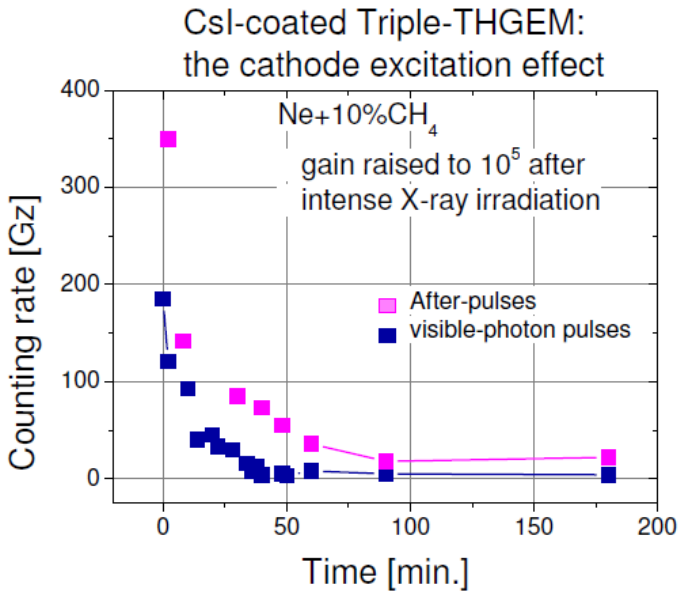
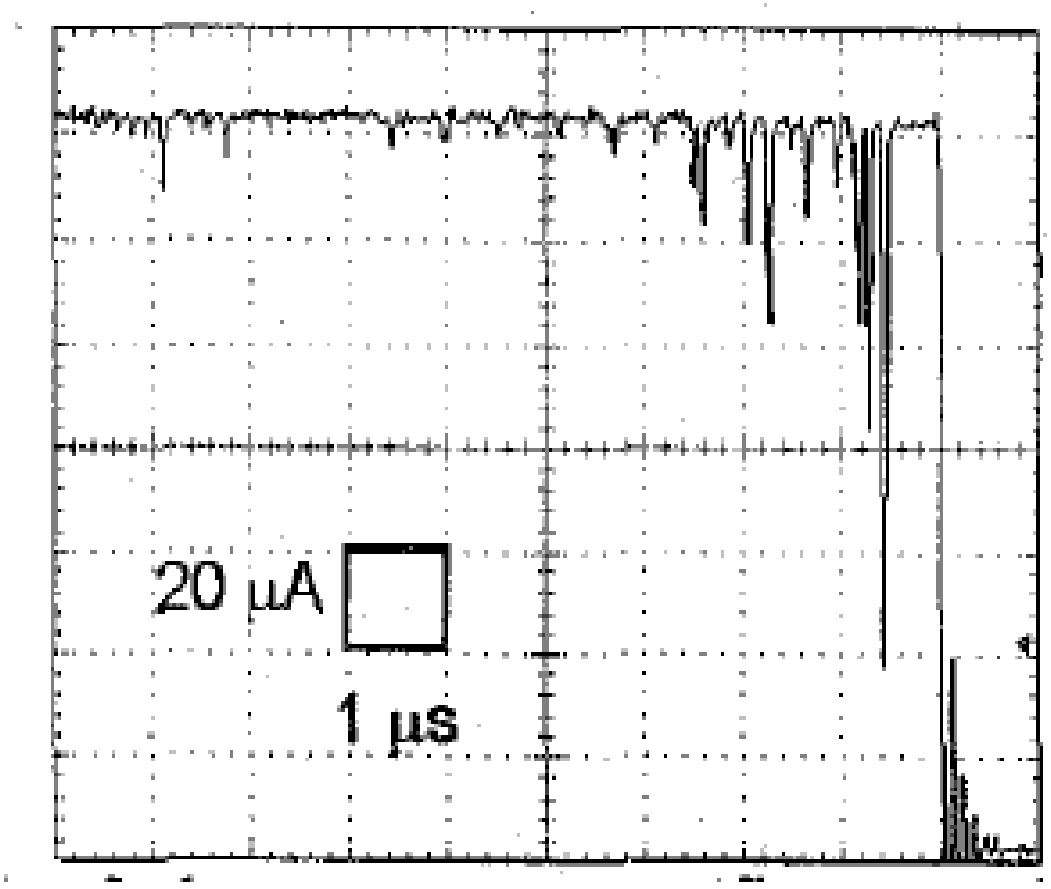


Figure 11. Counting rate of spurious pulses and visible-light pulses vs. time after cathode excitation induction at gain 10^4, followed by a 10-fold gain increase. CsI-coated triple THGEM, Ne+10%CH_4 mixture, gas

We also succeed to reproduced COMPASS problems

Jets

What is the origin of these gigantic pulses?



Explosive field emission

Besides classical field emission calculated by Zommerfeld and others there is another phenomena -explosive field emission

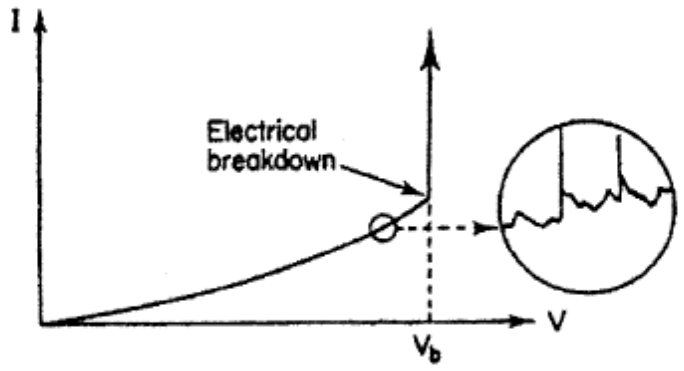
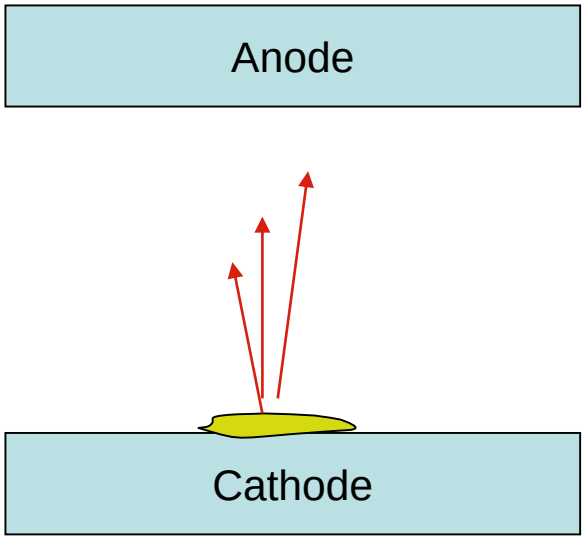
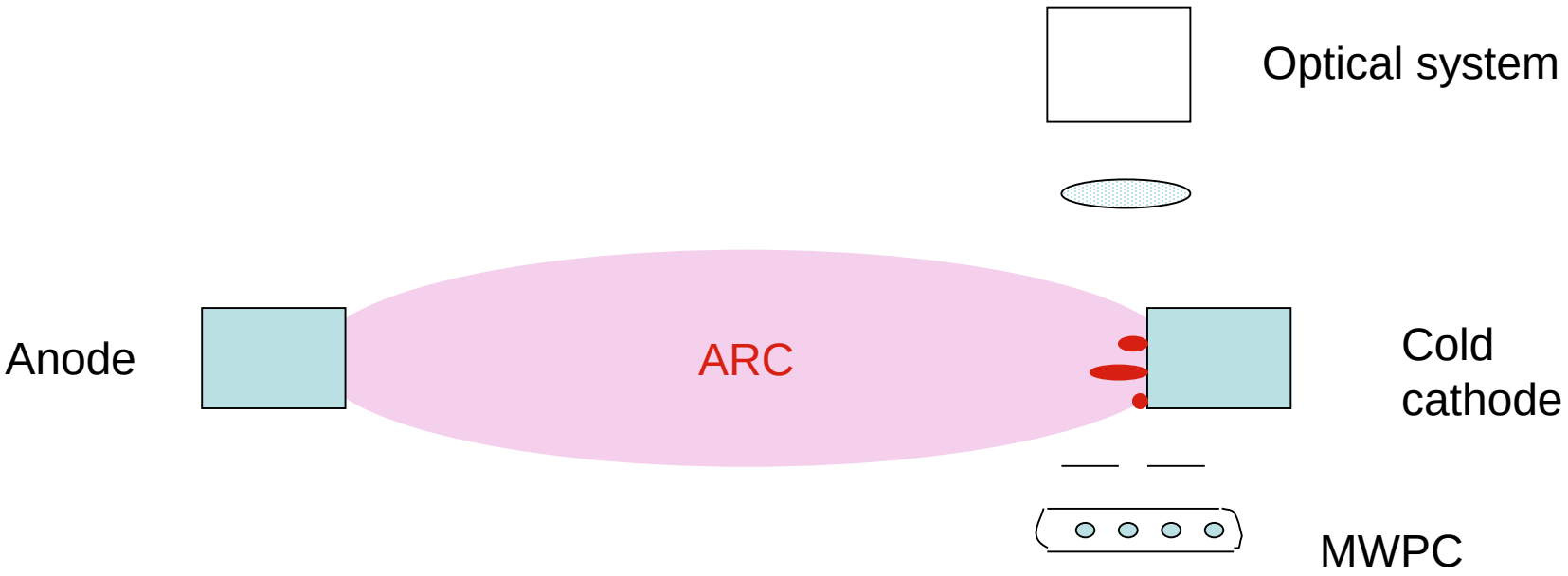


Fig. 14. Current–voltage curve in the case of electrical breakdown in vacuum (from [17]). Enlargement shows pulses due to the explosive field emission.



R. Latham, "High voltage vacuum insulation", new Yoork,1995

Explosive electron emission was also observed from cold cathodes of some gaseous discharges, for example arcs (*Rachovski phenomena*)



See: G.A. Lubimov, V.I. Rahovski, Uspekh. Phys. Nauk, 125, 1978, 665,

V. Peskov Journ, de Physique Coll. C7, suppl#7, 1979,C7-333

A proposed mode of electrons jets in gaseous detectors:

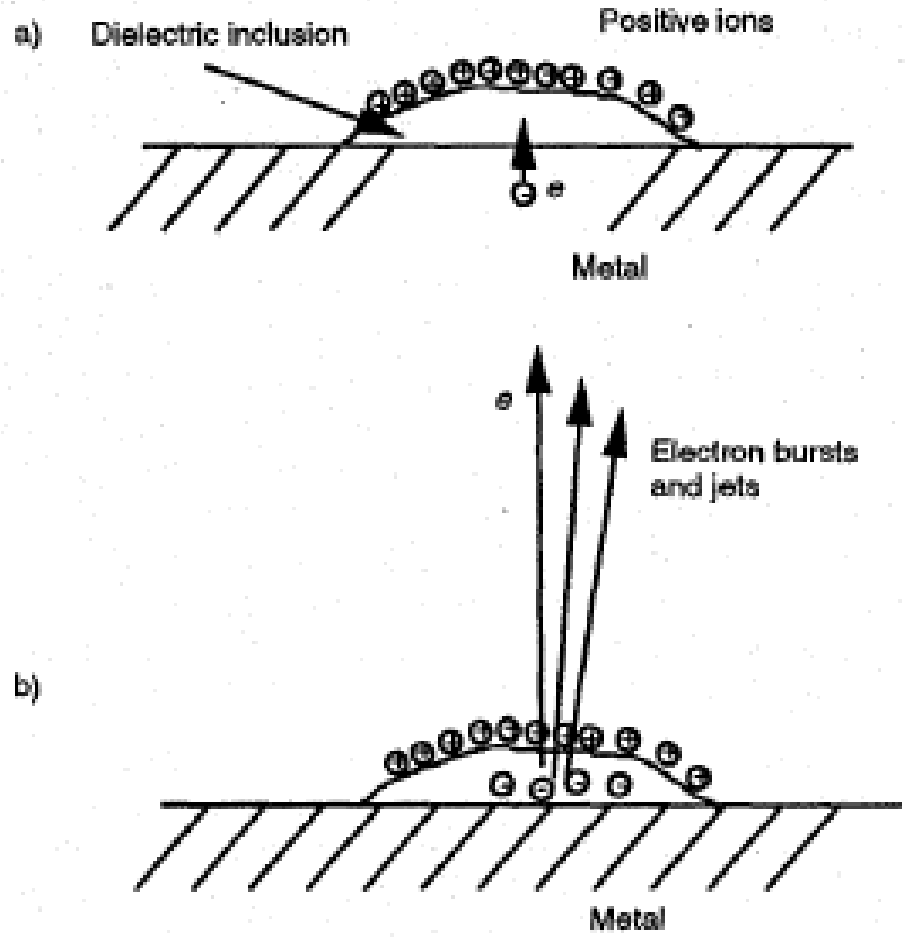


Figure 3: Schematic illustration of a two-step process which leads to emission of jets and bursts from thin dielectric films.

P. Fonte et al., IEEE Nuc. Sci 46,1999,321

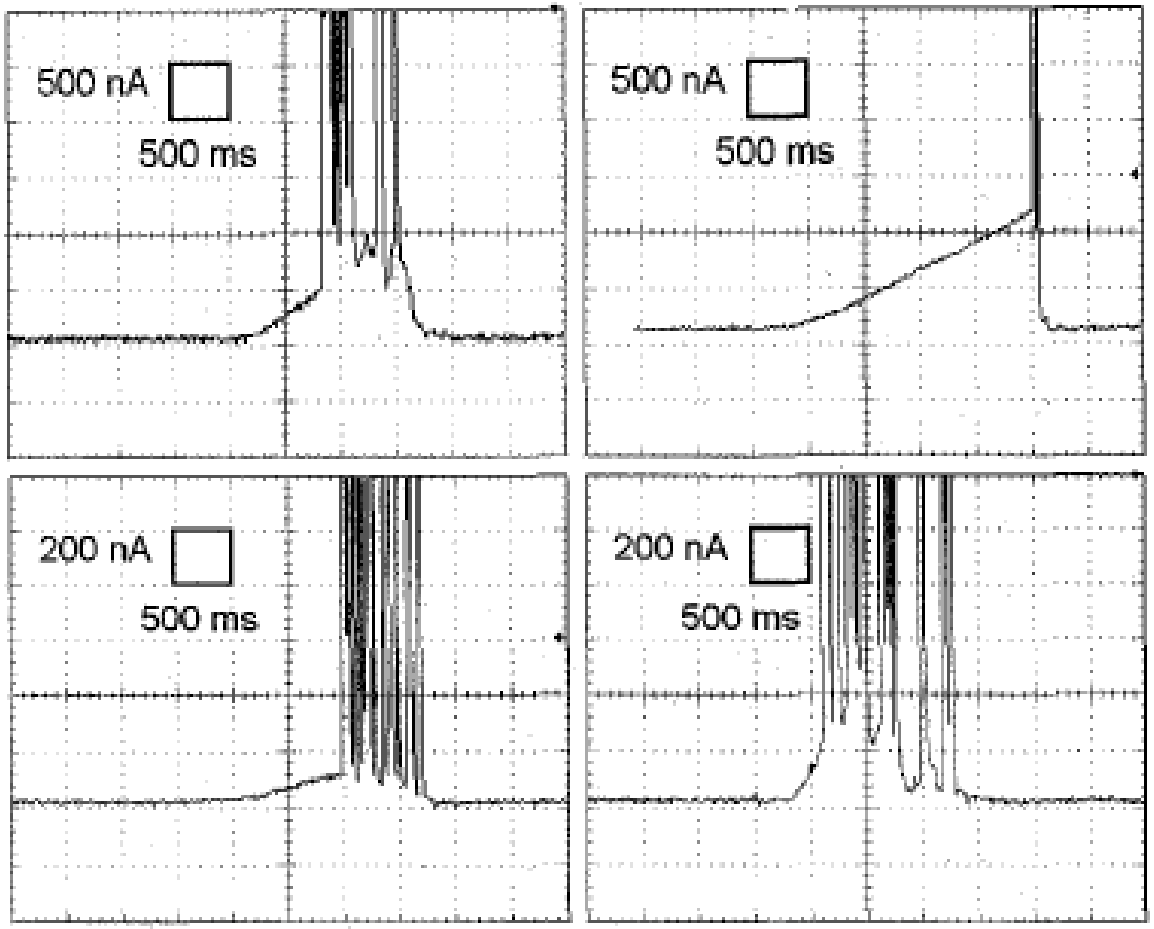


Figure 3 - Gap current as a function of time in the vicinity of a rate-induced spark at low gas gain. A linear increase in current is visible for about one second before breakdown, followed by several large pulses that coincide with a spark.

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Model of high-current breakdown from cathode field emission in aged wire chambers☆

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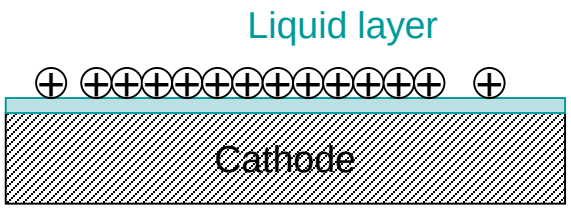
Some of the results presented in this paper were interpreted via the jets mechanism

Role of adsorbed layers?



If Ei<2φ –no ion recombination

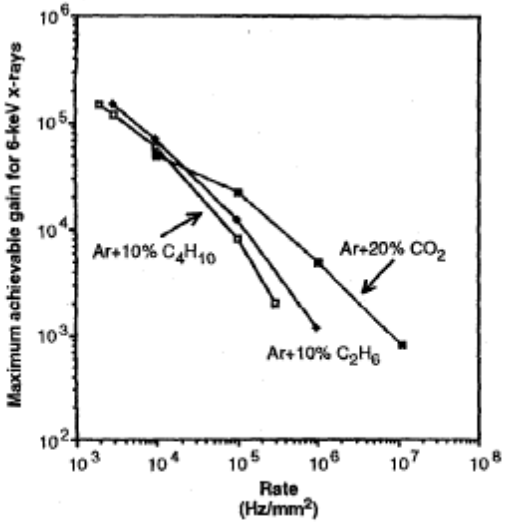
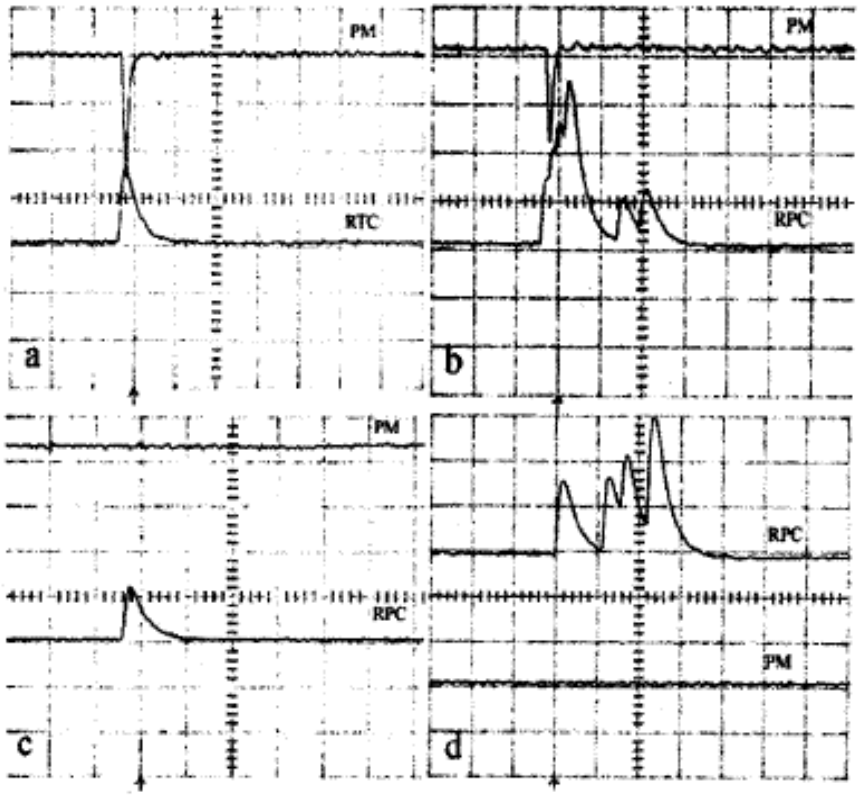


Figure 4: Improvement in the rate characteristics of a PPAC by optimizing the gas mixture.

Observations of jets and cathode excitation effect in operation of some gaseous detectors

Examples:

Glass RPC



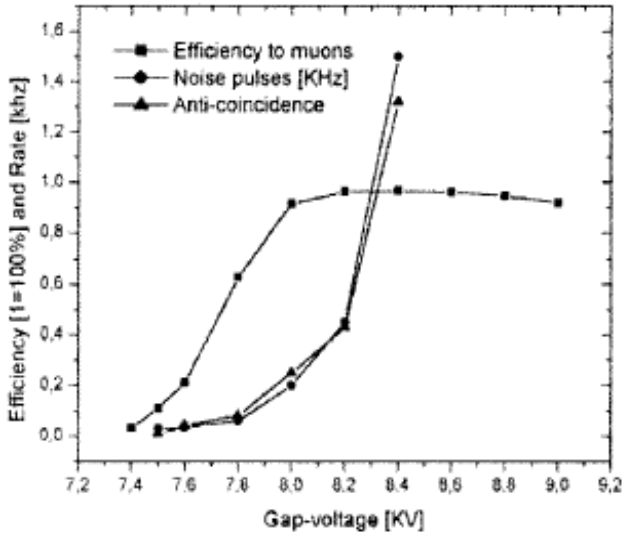


Fig. 5. The efficiency and the rate of noise pulses versus the voltage applied on the RPC [4]. The curve with the triangle symbols correspond to measurements done in anti-coincidence with the signals from the scintillators, respectively. Gas mixture Ar/Isobutane/Freon (R134) in the ration 48/4/48.

C. Iacobaeus et al., IEEE Trans Nucl. Sci, 49, 2002, 1622

High rate Si and GaAs RPCs

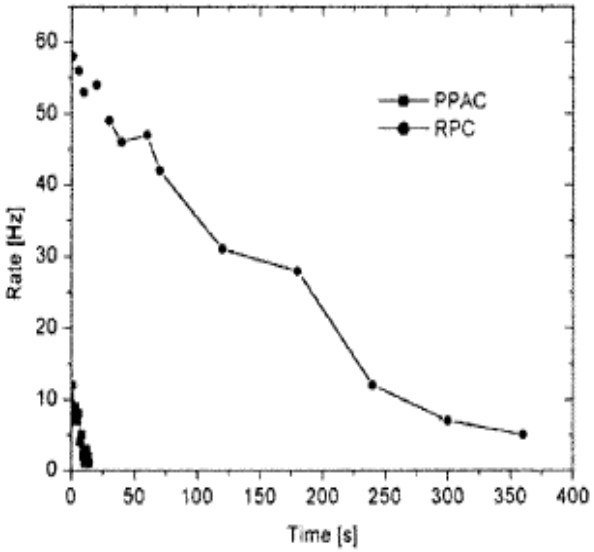


Fig. 11. The rate of the afterpulses for the PPAC (Cu-electrodes) and the RPC (Si). Gas mixture Xe (20%)+Kr (40%)+CO_2 (20%) at 1 atm.

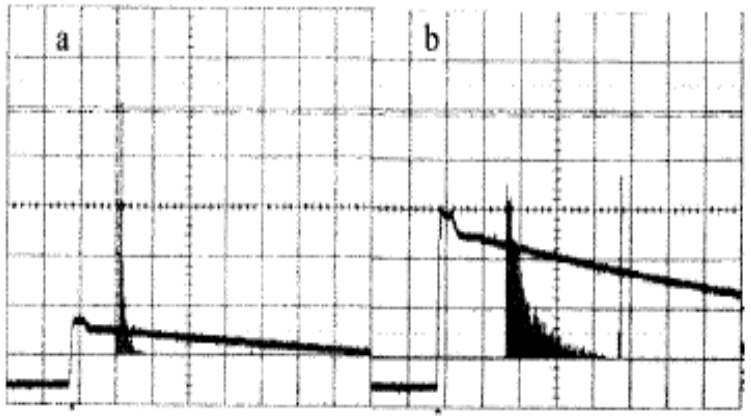


Fig. 6. Pulse-height spectra of signals from RPCs measured in the case of single primary electrons produced from the cathode by (a) UV emission and (b) in the case of noise pulses. The gas mixture Xe (40%)+Kr (40%)+CO_2 (20%) was used (1 atm).

C. Iacobaeus et al., IEEE Trans Nucl. Sci, 49, 2002, 1622

GEM at extreme counting rates

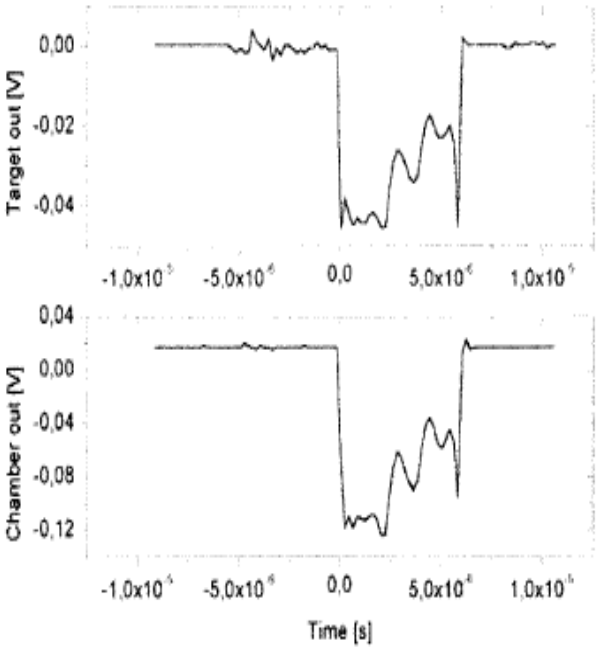


Fig. 12. The current from the GEM (at 350 V) recorded directly on a 50-Ω input of the oscilloscope when the GEM was exposed to a pulsed gamma radiation, producing $\sim 10^7$ counts/mm^2 on the 2.5 cm × 2.5 cm GEM area. No other resistors (except the 50-Ω input of the scope) were connected. The upper figure shows the current pulse from a racetrack current monitor. The lower figure shows the corresponding current pulse from the GEM readout. The gas mixture Ar+20%CO_2 was used for the measurement (1 atm).

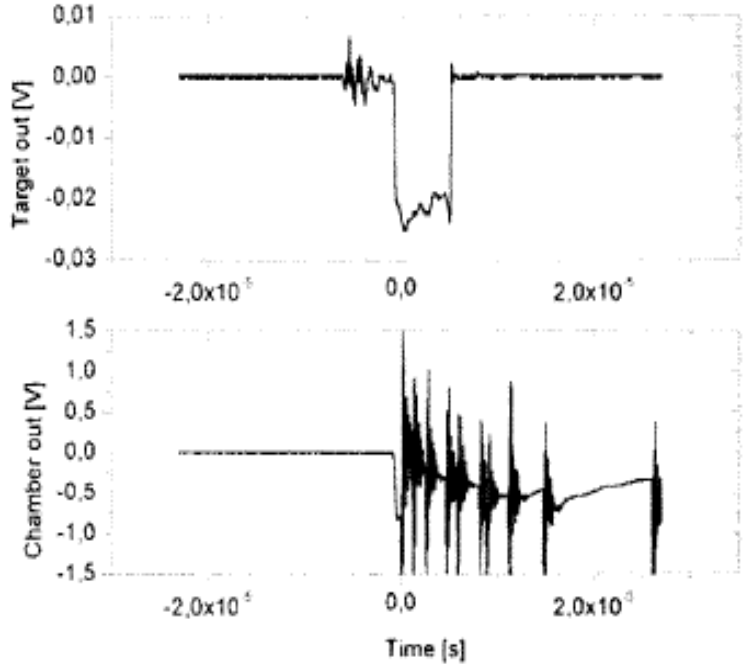


Fig. 13. The same setup as in Fig. 12, but 420 V applied over the GEM electrodes. The upper oscillogram shows the current pulse from the racetrack current monitor, the lower shows the current from the GEM readout. One can clearly see current pulses of large amplitudes, corresponding to a large number of primary electrons $> 10^5$.

C. Iacobaeus et al., IEEE Trans Nucl. Sci, 49, 2002, 1622

Delayed discharge propagation between GEMs

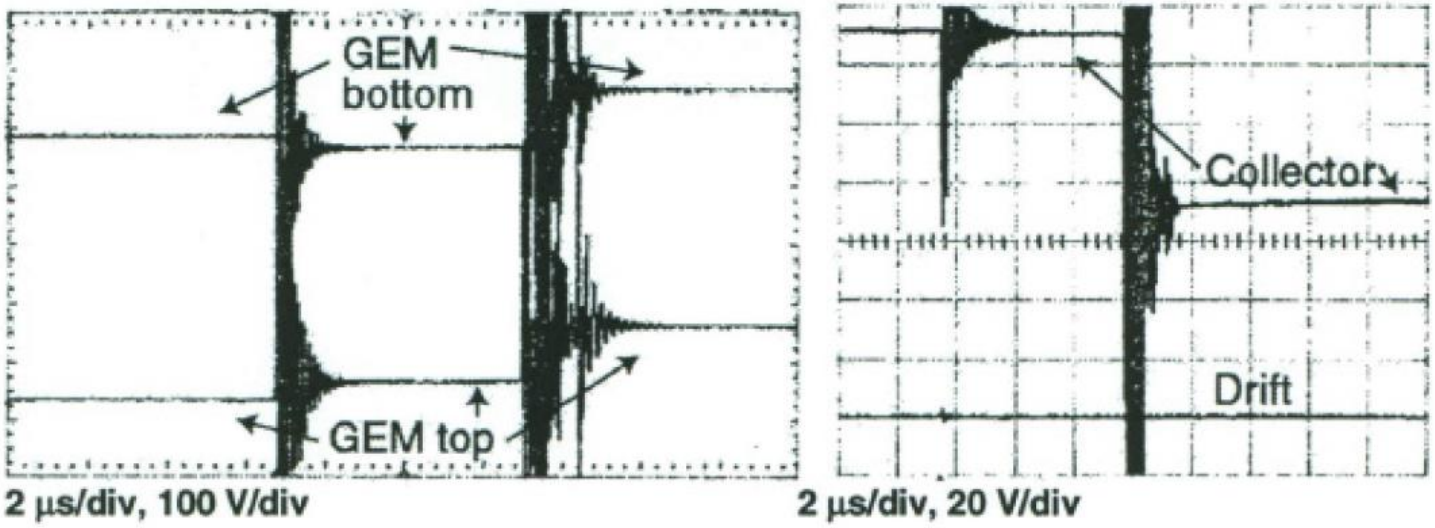


Fig. 41. Two breakdowns following each other: the breakdown in the GEM was followed with some delay by discharge propagation to the collector

See: V. Peskov. "Discharge propagation between GEMs," WG-2 meeting

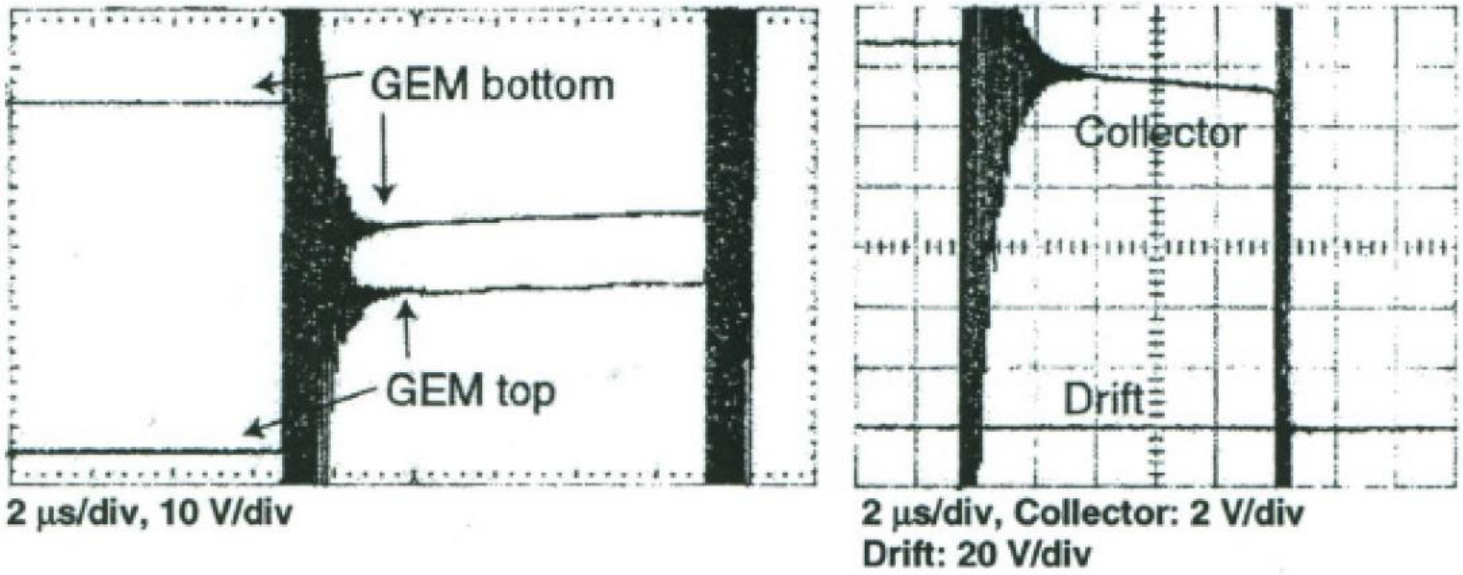


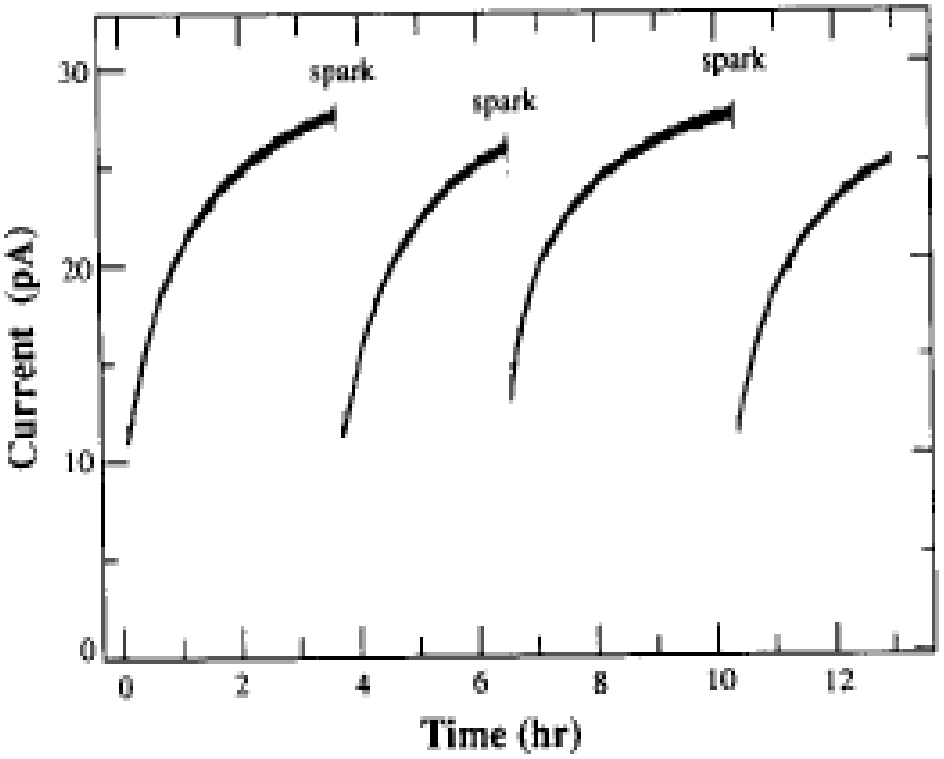
Fig. 42. In a more sensitive scale one can see a steady current increase before the second breakdown happens

This phenomena resembling the current growth before breakdown mentioned earlier

Conclusions

- Besides well established breakdown mechanisms- streamer and feedback related -it was also observed another one: “memory/cathode excitation-jets”
- This mechanism mainly show up at high counting rates. For example COMPASS RICH already experience in the memory effect and some tests of RPCs at GIF also reveal this effect too
- Very often cathode excitation and jets mechanism are mixed
- It will be important to further study these effects , because they can cause problems at future MPGDs applications in LHC experiments.

Backups


spark
spark
spark
30
20
10
0
Current (pA)
0
2
4
6
8
10
12
Time (hr)