A cathode excitation effect and jets induced breakdown

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Discharge physics in MPGDs was already reviewed during Paris Workshop and WG2 meeting in December

The main focus in these presentations which were made by *P. Fonte and myself* was on a Raether limit and a high rate effect to which in some cases the Raether limit can be also applied

Raether limit for MPGDs:

It was recently discovered* that in micropattern detectors: GEMs, MICROMEGAS and others breakdowns appear at the following conditions:

$A_{max}n_0=Q_{max}=10^6\text{-}10^7$ electrons,

where n_0 is the number of primary electrons created in the drift region of the detector

(Q_{max} depends on the detector geometry and the gas composition)

*(*see Y. Ivanchenkov et al., NIM A422,1999,300 and V. Peskov et al., IEEE Nucl. Sci. 48, 2001, 1070)*

Therefore:

With single primary electrons gains up to 10^6-10^7 in principle are possible

With ^{55}Fe (n_0~230 electrons) the maximum achievable gain is $<10^5$

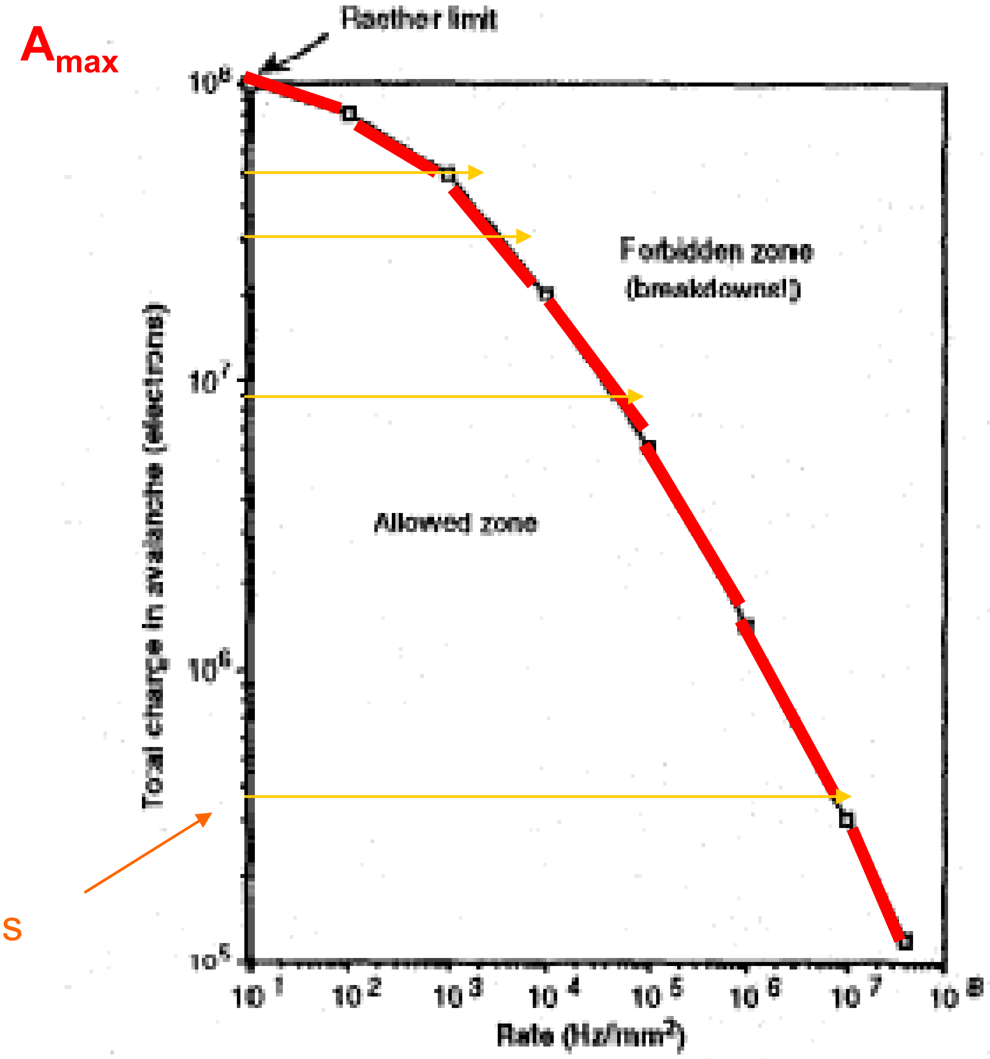
With alphas ($n_0=10^5$) the maximum achievable gain <100

Feedbacks related breakdowns can be in the case of MPGDs operating in noble gases or combined with photocathodes)

$A_f\gamma=1(A_f\gamma_+=1$ or $A_f\gamma_{ph}=1)$-"slow" mechanism of discharges

The probabilities γ_+ and γ_{ph} are increasing with the increasing the photocathode QE and it's sensitivity to visible light and
with electric field near the cathode

Parallel plate detector (PPAC)



Amplitudes

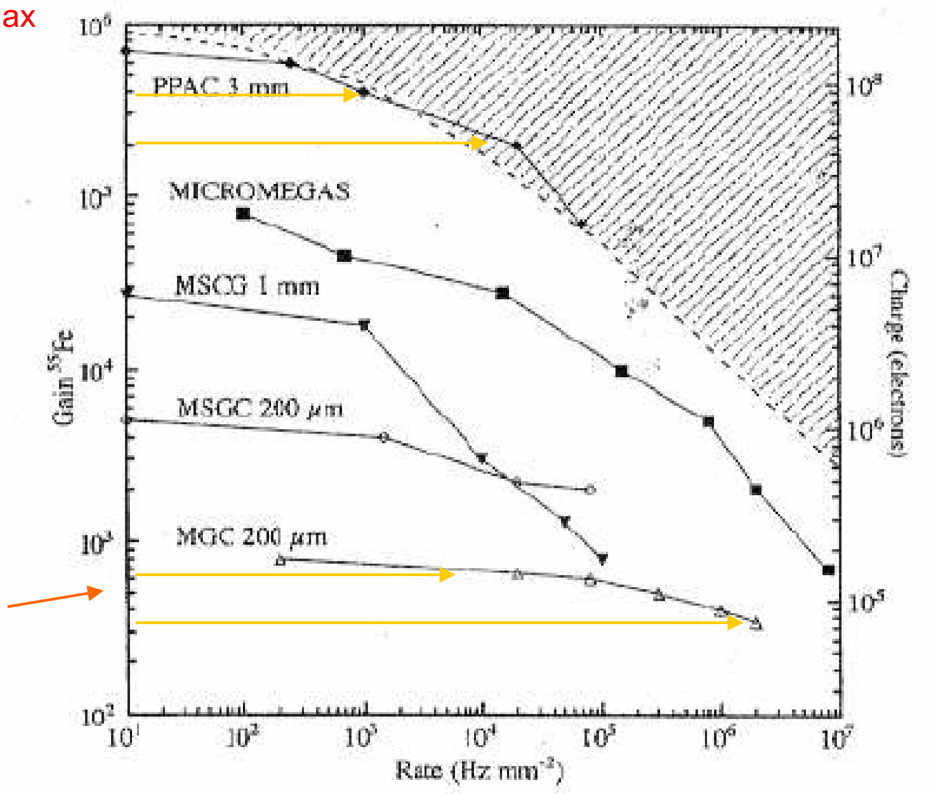
P. Fonte et al IEEE Nucl. Sci 46,1999,321

Figure 1: General curve reflecting gain limitation with rate for gaseous detectors.

Signal amplitude does <u>not drop with rate</u>, however there is a <u>rate limit</u> for each amplitude

Rate limit of micropattern gaseous detectors

A_{max}

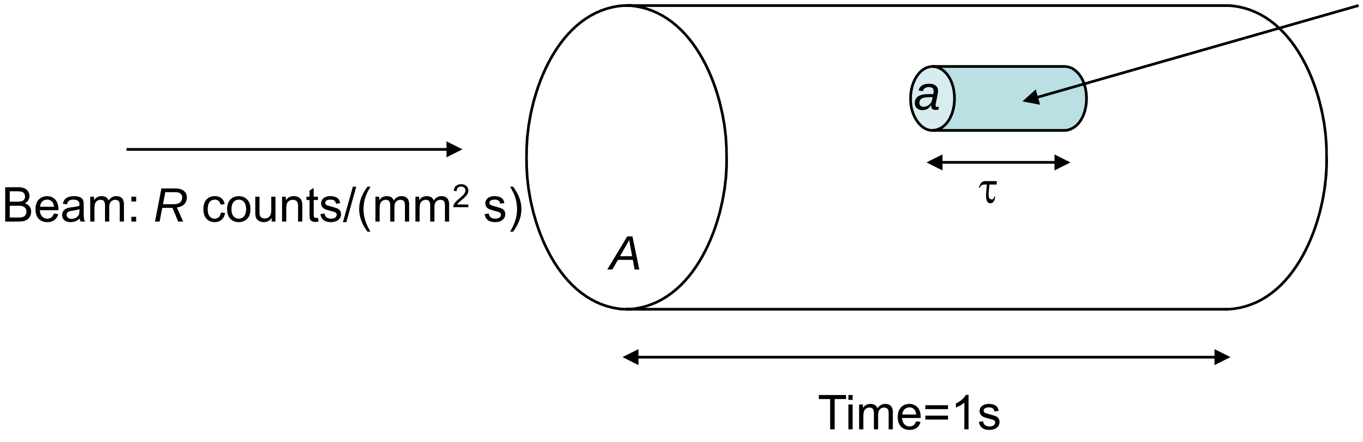


Amplitudes

P. Fonte et al,
NIM A419,1998,405

For each micropattern detector the amplitude remains unchanged with rate, however the maximum achievable gain drops with rate

Breakdown statistics via superimposition and Raether limit



Superimposition cell

For instance:
$A = 1\ cm^2$
$a = 1\ mm^2$
$\tau = 1\ \mu s$ (ions)

P(spark in a cell)=p
λ= *average # avalanches/cell*

There are $N=A/a\times(1s)/\tau$ superimposition cells: $N=10^8$.

We want to observe a relatively low absolute spark rate $P(spark)=S\sim10^{-2}$ /s

$S=1-P(not\ spark)=1-(1-p)^N \Rightarrow p\approx S/N$: $p=10^{-10}$.

The number of avalanches n in each cell is Poisson-distributed with average $\lambda=Ra\tau$: $\lambda=R\times1\times10^{-6}$.

There will be a spark if $nq>Q_R$, q=is the average avalanche charge and Q_R the Raether limit.

Then, the required gain reduction owing to superimposition is *1/ñ*, with *ñ* the percentile *1-p* of the Poisson distribution with average λ.

Rate-induced breakdown? – experimental evidence

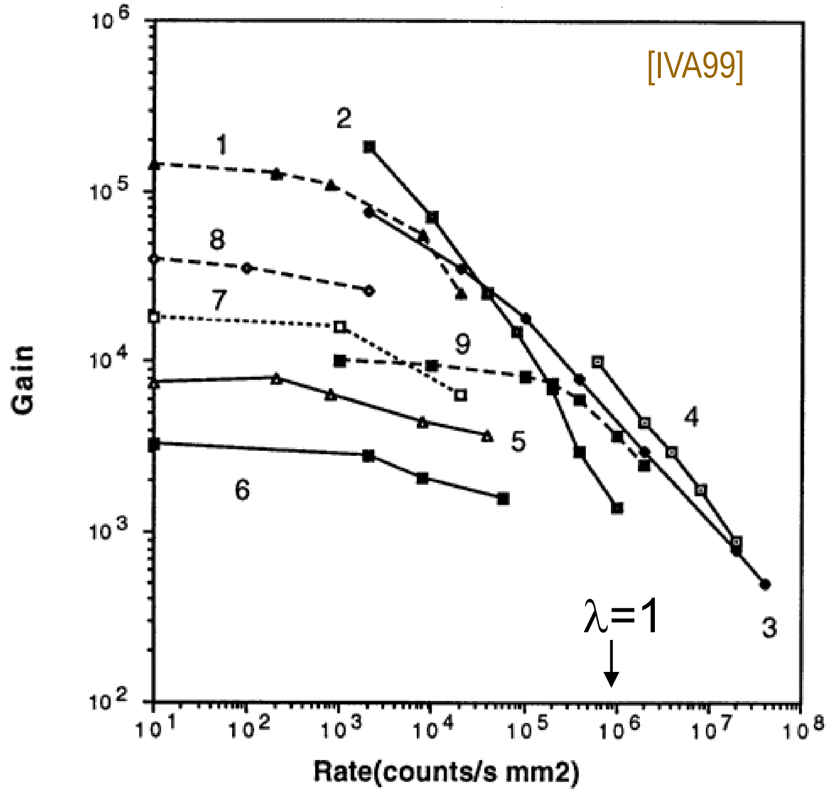
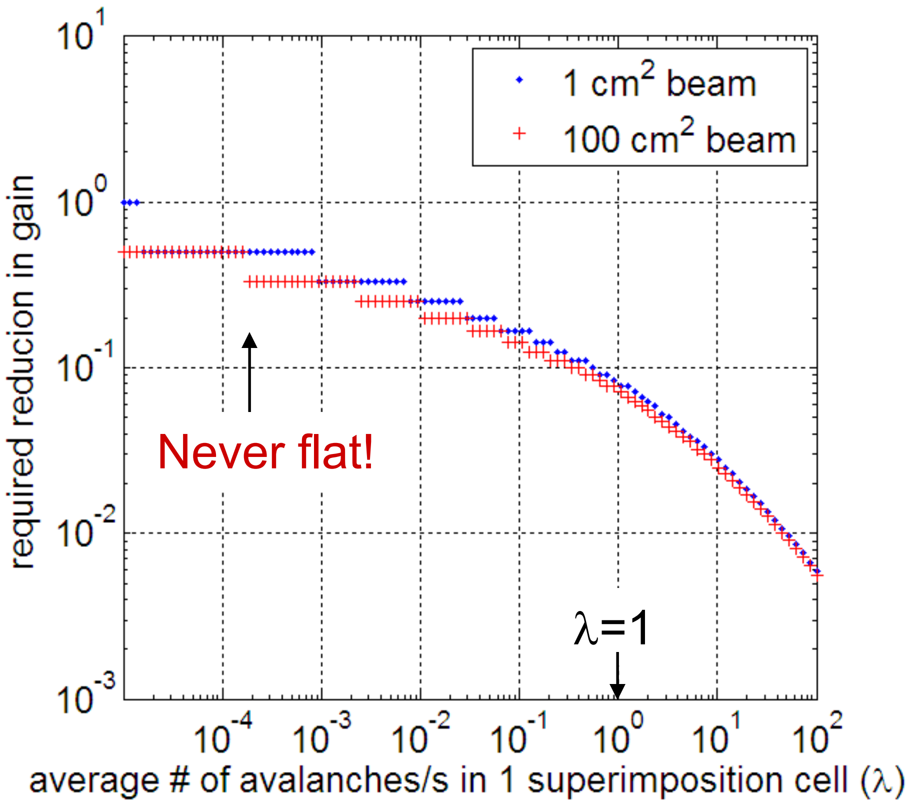


Fig. 1. The maximum achievable gain (curves 1–6), as a function of X-ray flux for various detectors: (1) thick-wire MWPC, (2) PPAC with 3 mm gap, (3) PPAC with 0.6 mm gap, (4) MICROMEGAS (from Ref. [13]), (5) CAT, (6) GEM. (7–9) Space-charge gain limit as a function of rate for other MWPCs: (7) "standard" MWPC, (8) MWPC replotted (from Ref. [14]), (9) thin-gap MWPC (from Ref. [15]).



Never flat!

Mere statistics seem to qualitatively reproduce the data!

BUT…

Puzzle…?

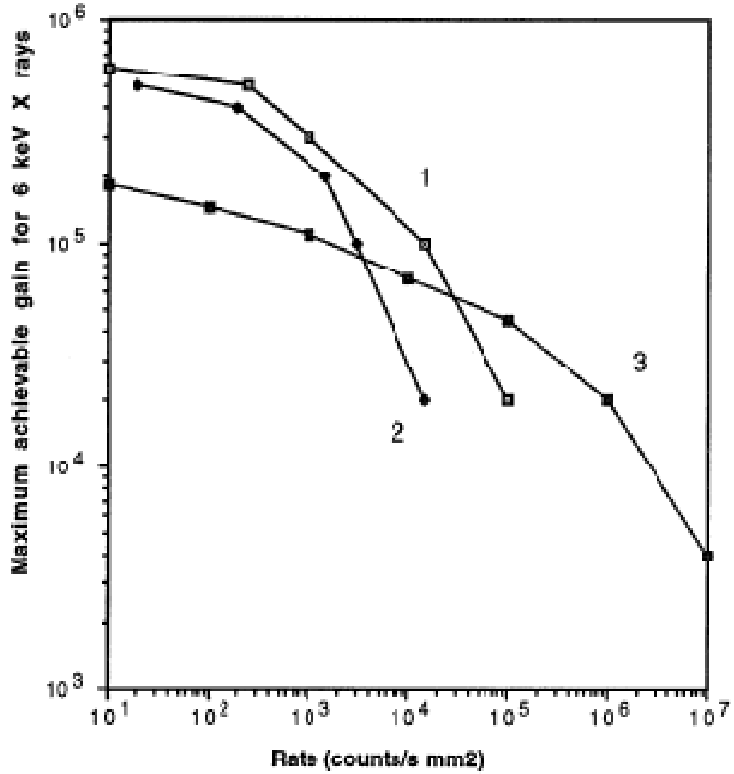


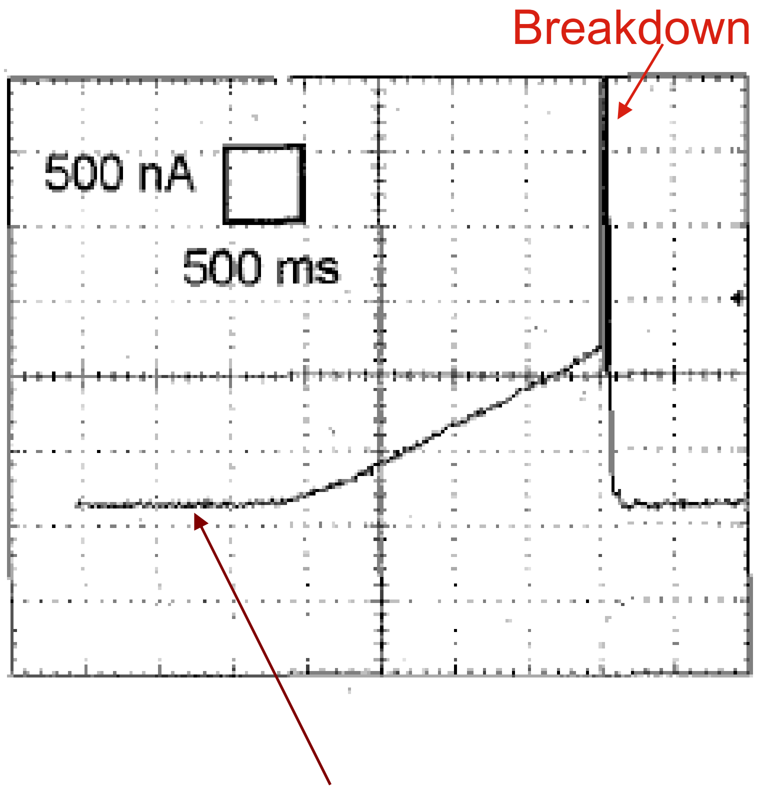
Fig. 3. The maximum achievable gain as function of rate (6 keV X-rays) for the 3 mm-gap PPAC (1,2), and for MICROMEGAS (3) (from Ref. [6]). Curve (1) corresponds to a beam diameter of 2 mm and curve (2), to a beam diameter of 20mm. The gas mixture was Ar + 5% isobutane at 1 atm.

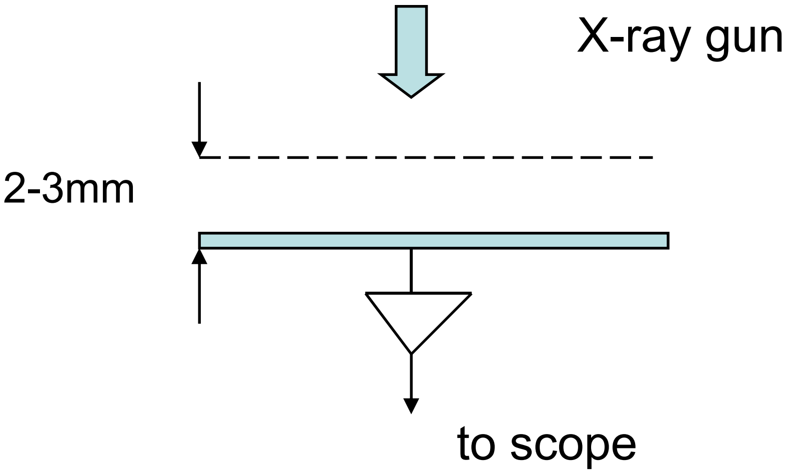
Beside these ”classical” mechanisms there were mentioned exotic mechanisms: “preparation”, “cathode excitation/memory” effect and electron jets

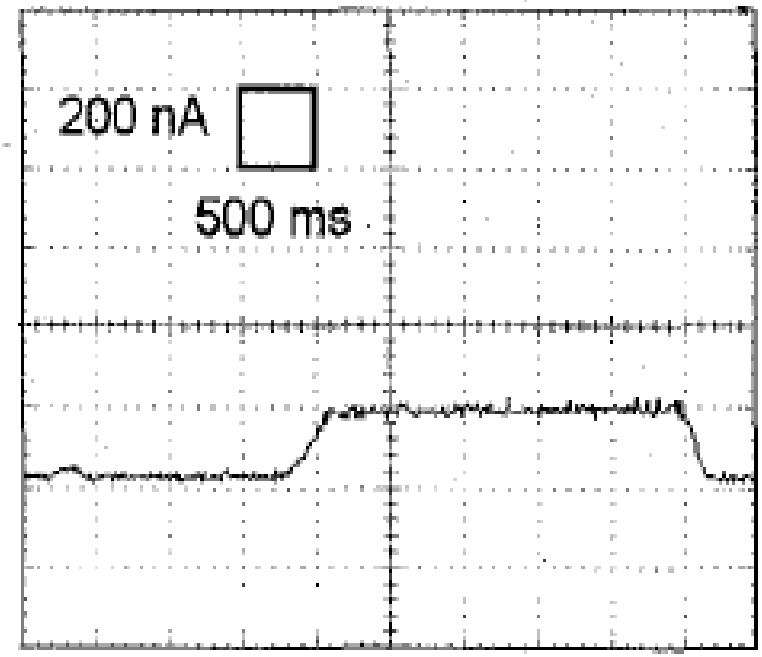
In this reports I’d like to focus on these exotic breakdown mechanism and demonstrate that they exist in MPGDs

Preparation mechanism

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



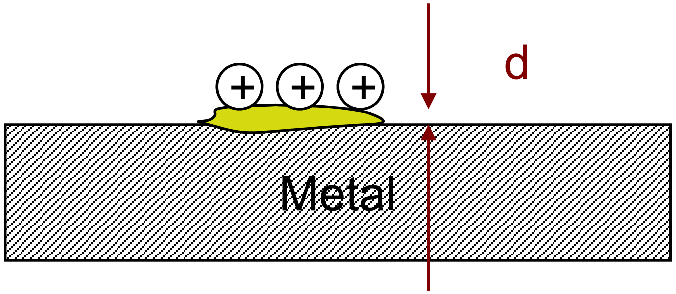




Similar effect is often describes in aging papers

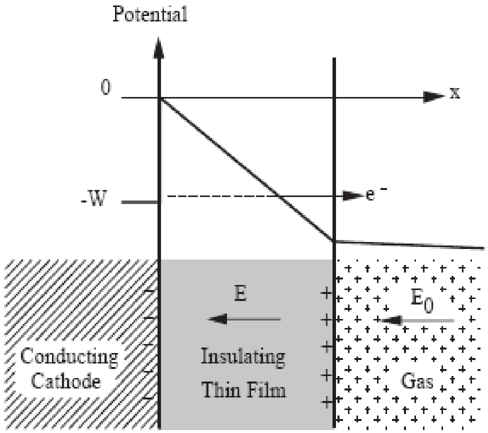
(see for example *Aging Workshop, NIM A515, 2003*)

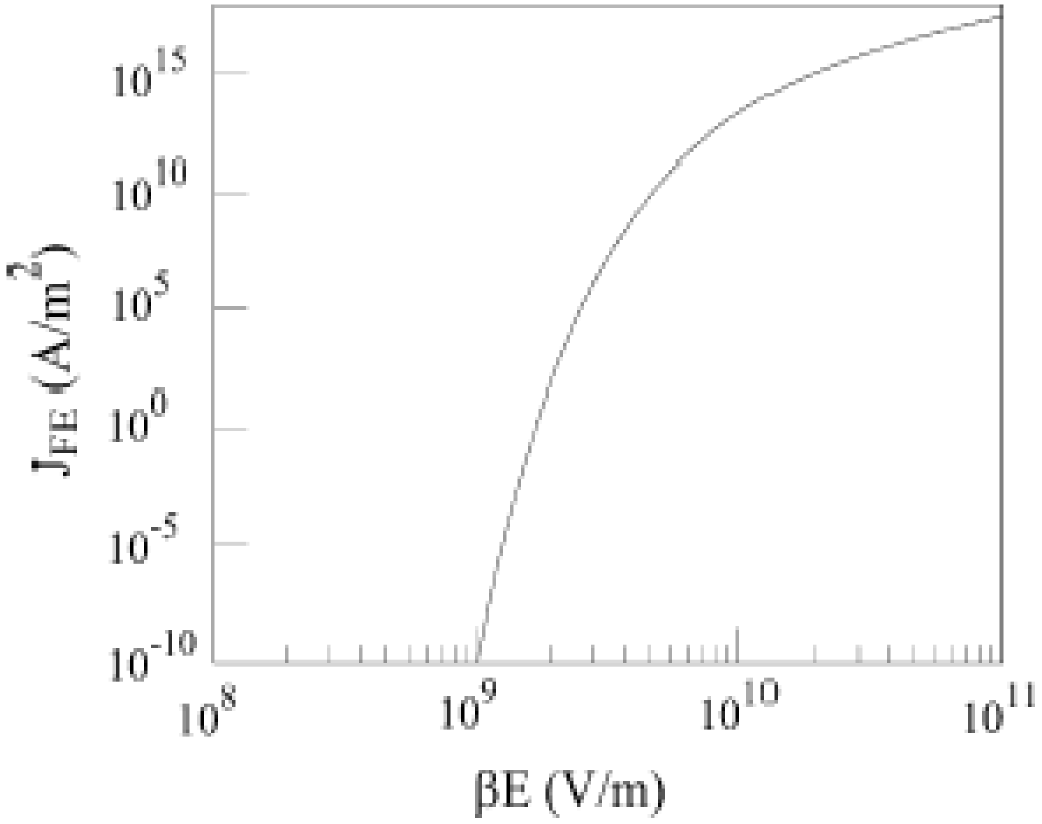
Usual explanation is via a Malter effect..



$$J_{fe}=5.4\times10^{-5}(\beta E)^2\exp(-5.43\times10^{10}/\beta E)$$

$$E=\sigma/d$$





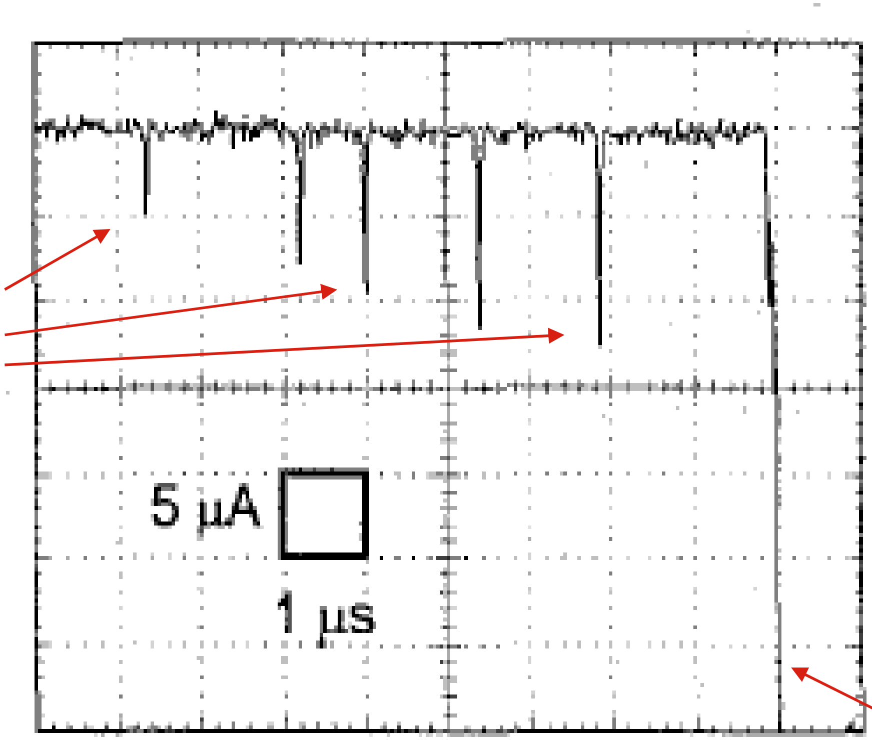
But it is not so simple…

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*

:



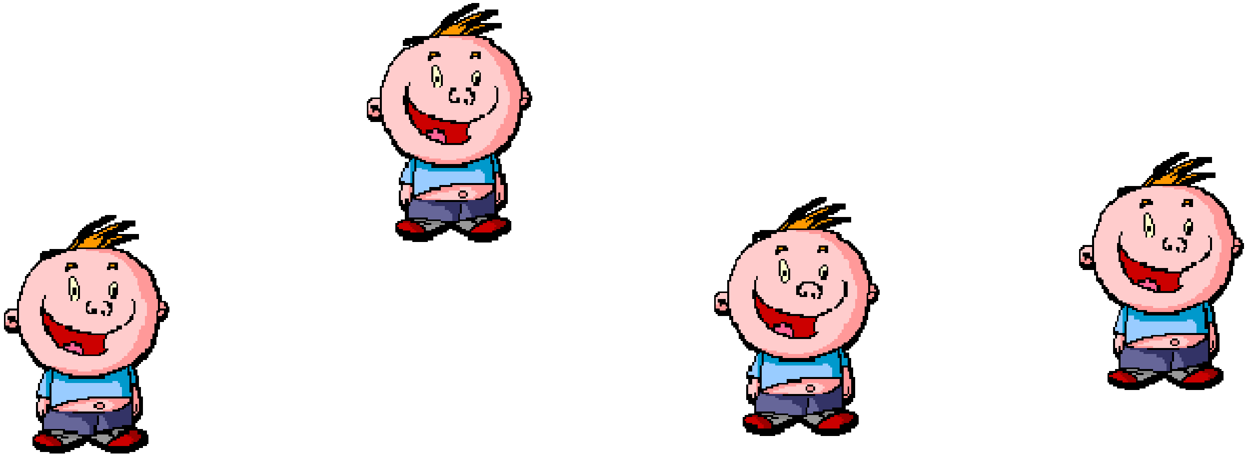
“preparation” pulses, each contains a huge number of electrons-jets

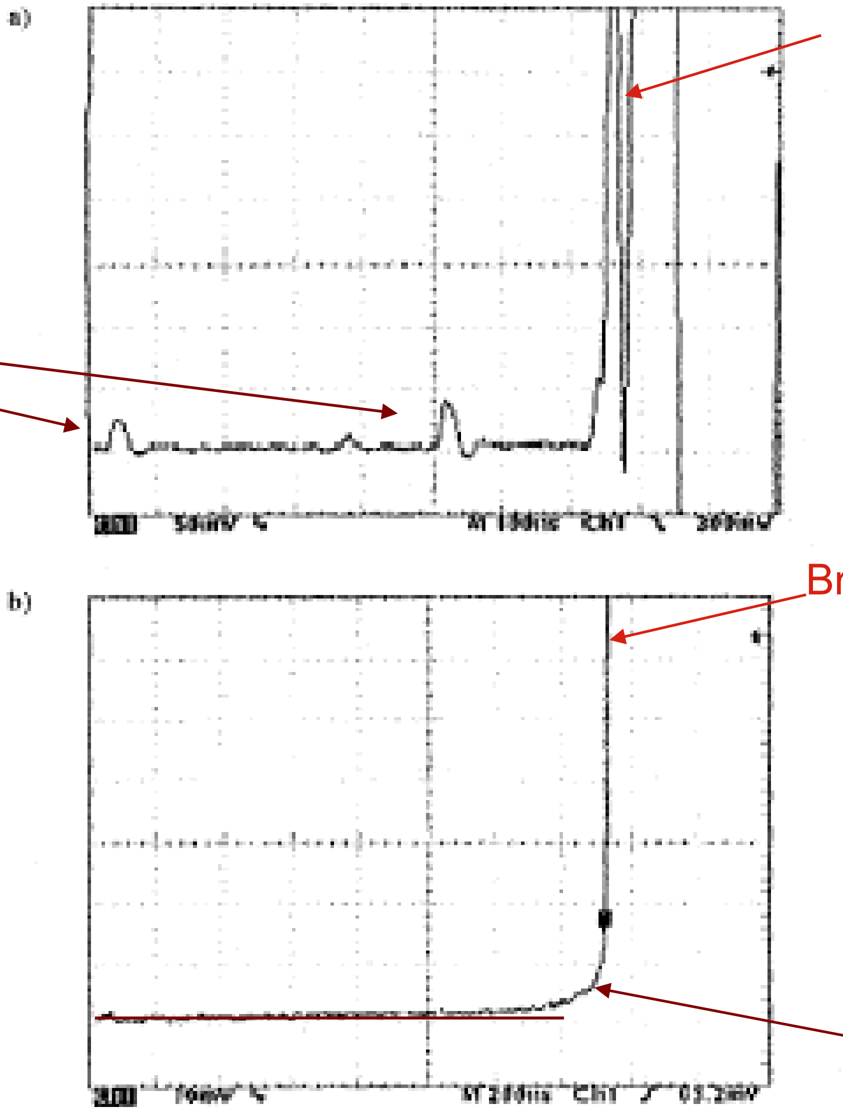
Breakdown

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

Cathode excitation





Breakdown

jets

Breakdown

True 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

Early studies of the cathode excitation effect

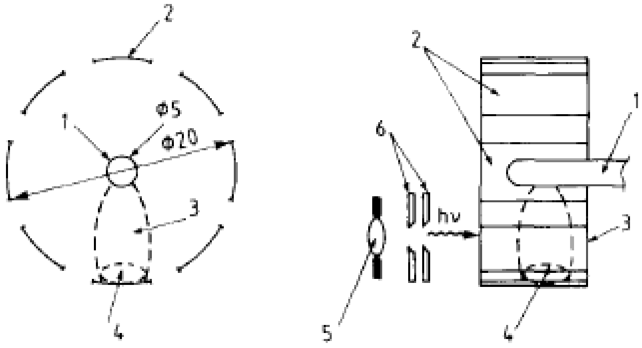


Fig. 8. Sketch of a multisection gas counter for γ_+ measurements. 1 – Cylindrical anode; 2 – multisectional cylindrical cathode; 3 – glow-discharge; 4 – cathode spot of the glow-discharge; 5 – external VUV radiation source; 6 – collimating system for the VUV radiation.

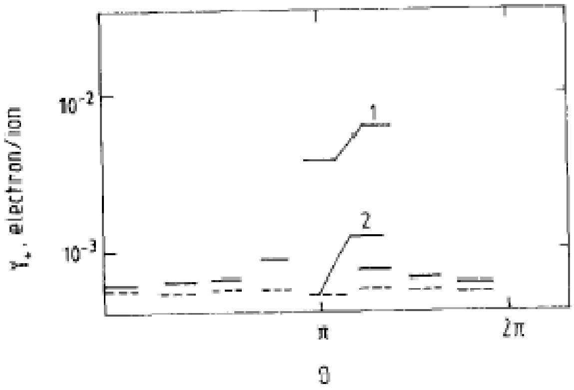
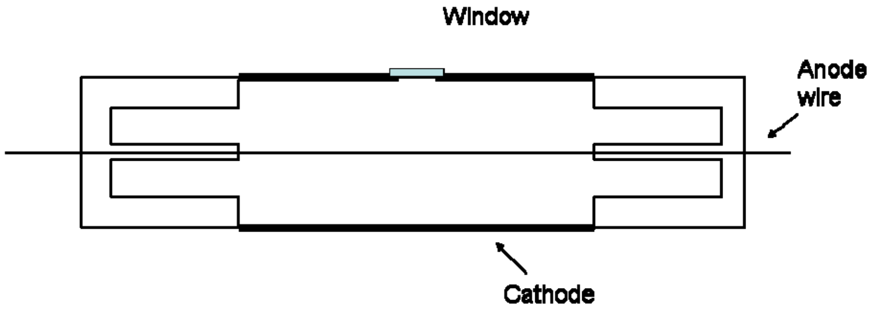


Fig. 9. Values of γ_+ as a function of the angle Θ between the upper section (see fig. 8) and investigated one and for different time delays τ after turning off the glow-discharge. 1 – τ = 9 μs; 2 – τ = 10 ms.

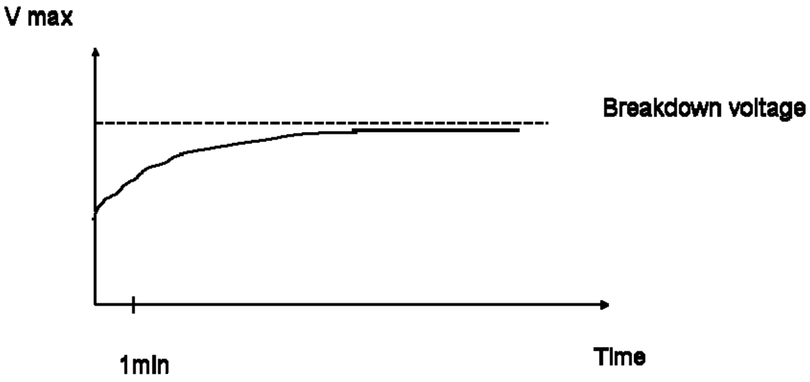
G.F. Karabadjak et al., NIM 217, 1983, 56

Measurements with single wire counters:

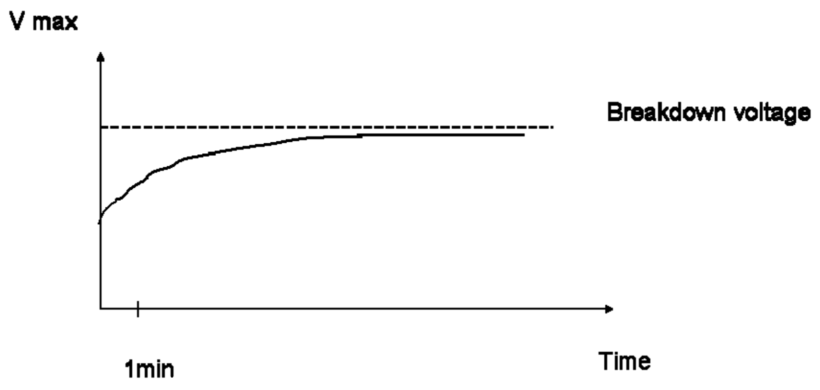


It is well known that
In single wire couters:

$A_f \gamma = 1$

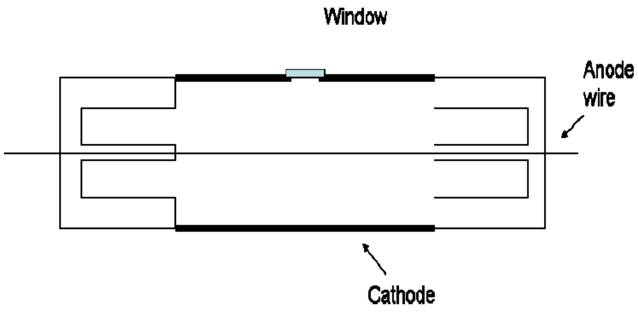


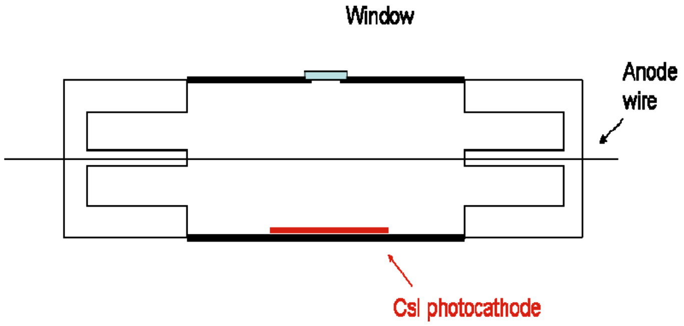
V. Peskov, PhD Thesis , 1976



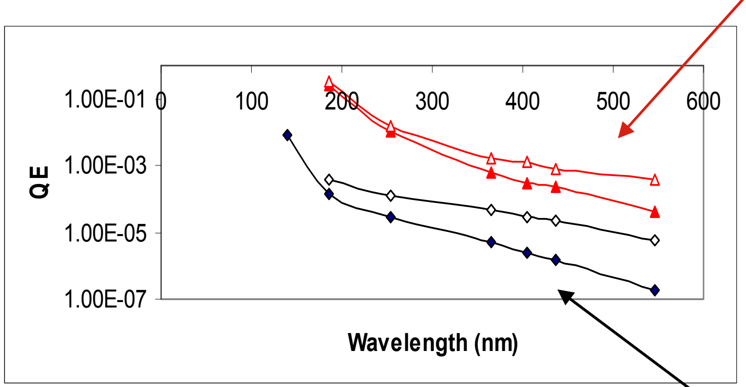
This curve is typical for many gaseous detectors, including MPGDs (check with your experience!)

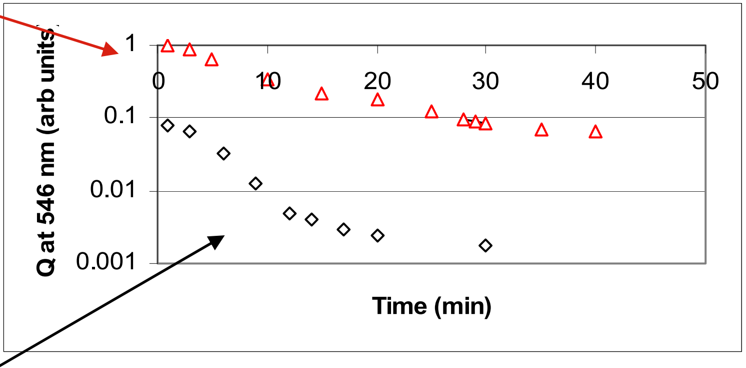
Changes in QE after intense ion bombardment





CsI





SS

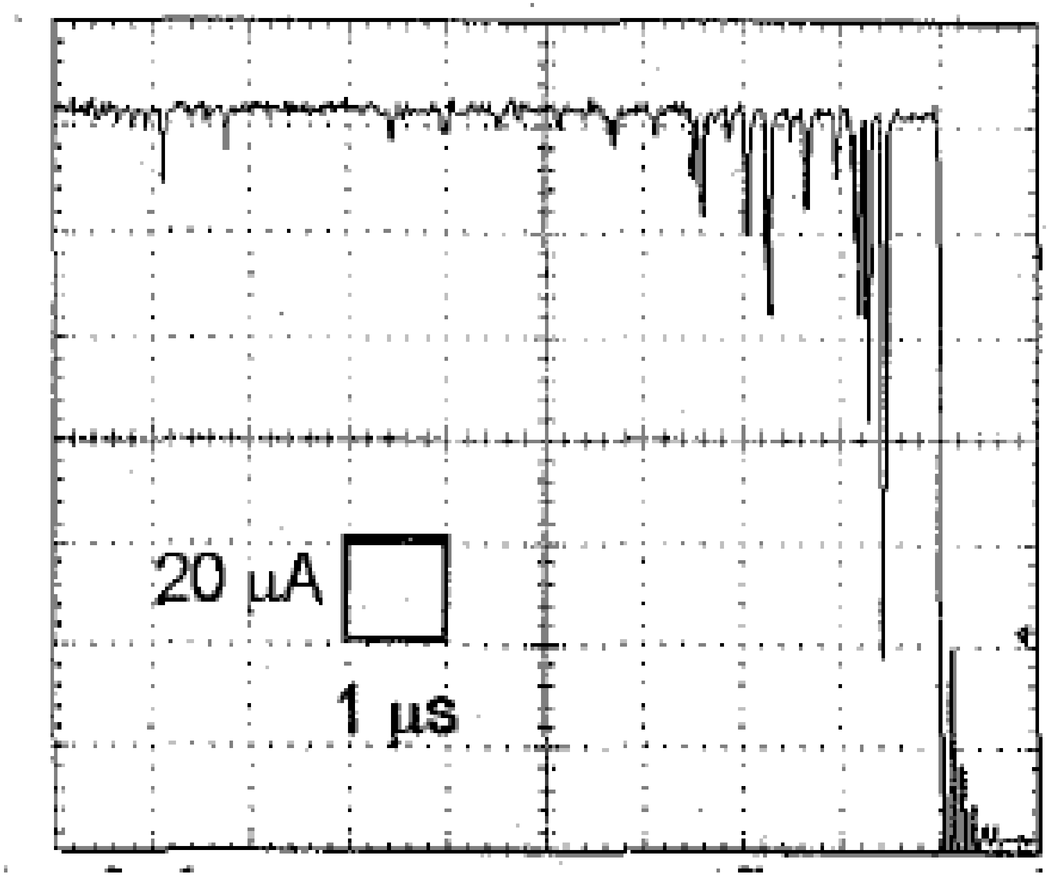
P. Fonte , V. Peskov, paper in preparation

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

Therefore , the feedback loop $A\gamma=1$ will appear at lower A

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

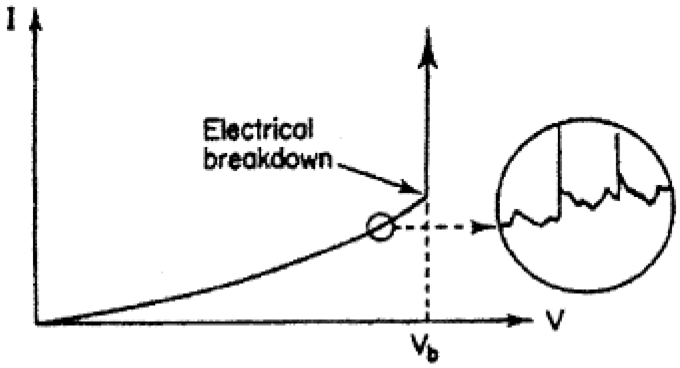
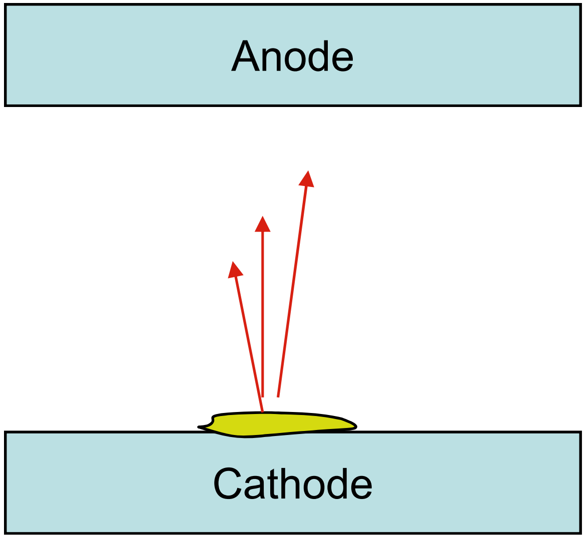


Fig. 14. Current–voltage curve in the case of electrical breakdown in vacuum (from [17]). Enlargement shows pulses due to the explosive field emission.

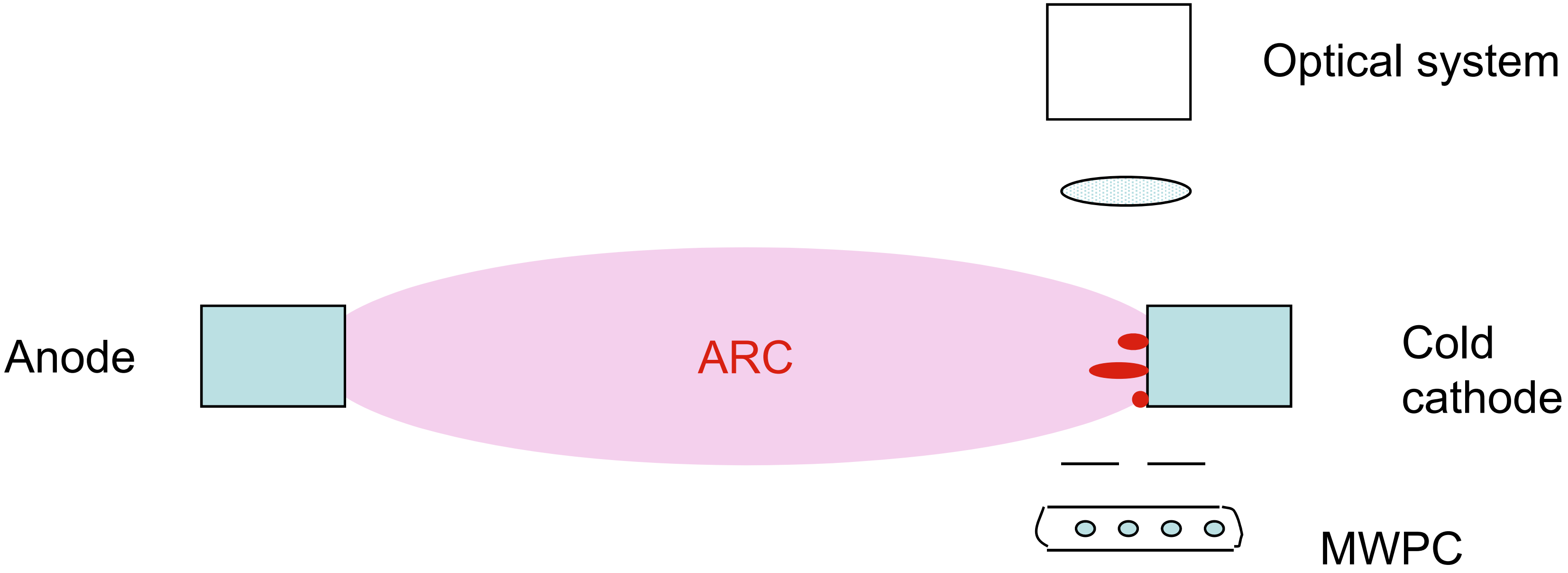


Anode

Cathode

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:

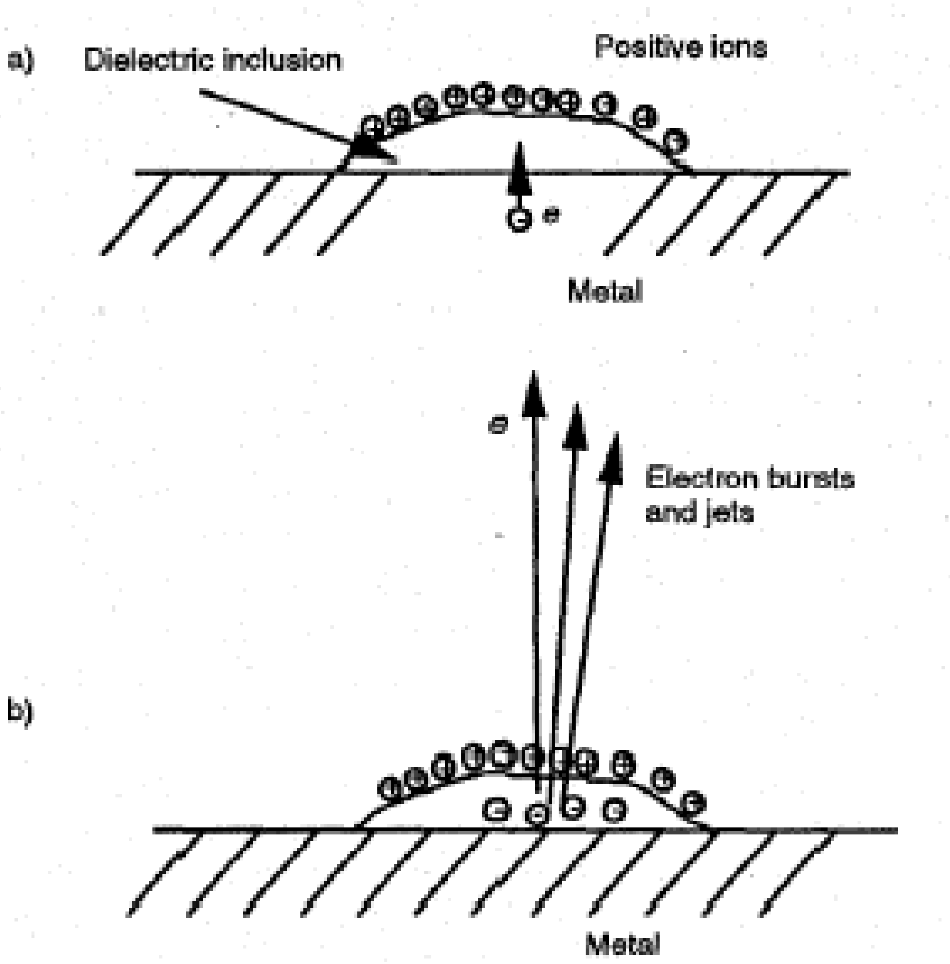


Figure 3: Schematic illustration of a two-step process which leads to emission of jets and bursts from thin dielectric films.

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

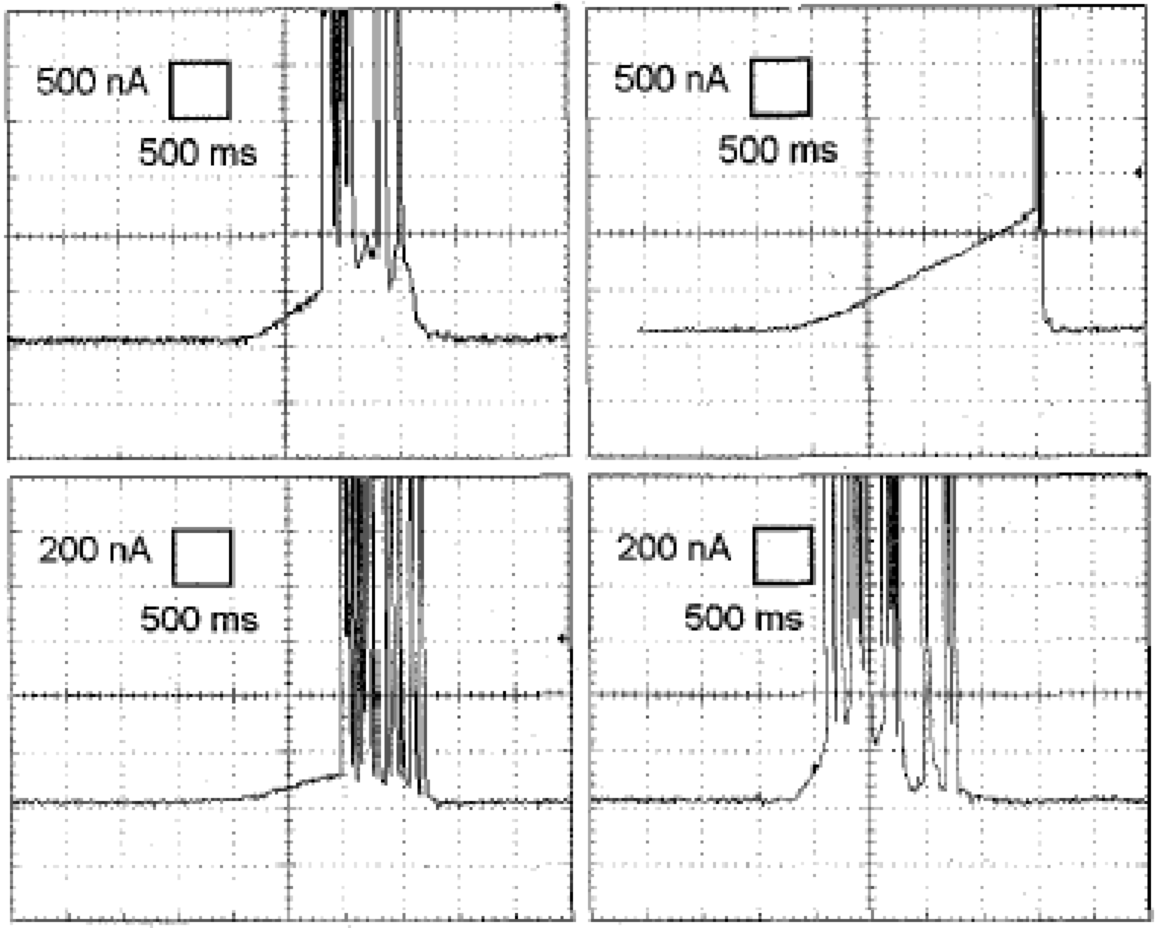


Figure 3 - Gap current as a function of time in the vicinity of a rate-induced spark at low gas gain. A linear increase in current is visible for about one second before breakdown, followed by several large pulses that coincide with a spark.

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

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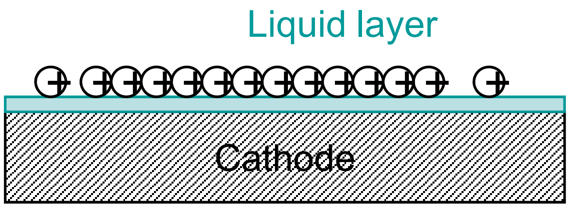
Some of the results presented in this paper were interpreted via the jets mechanism

Role of adsorbed layers?



If Ei<2φ –no ion recombination

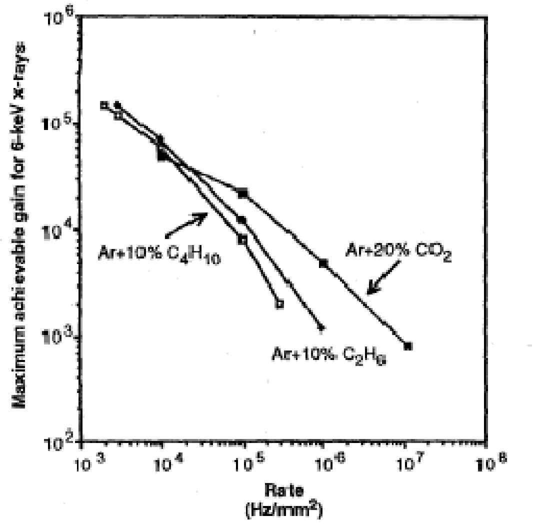
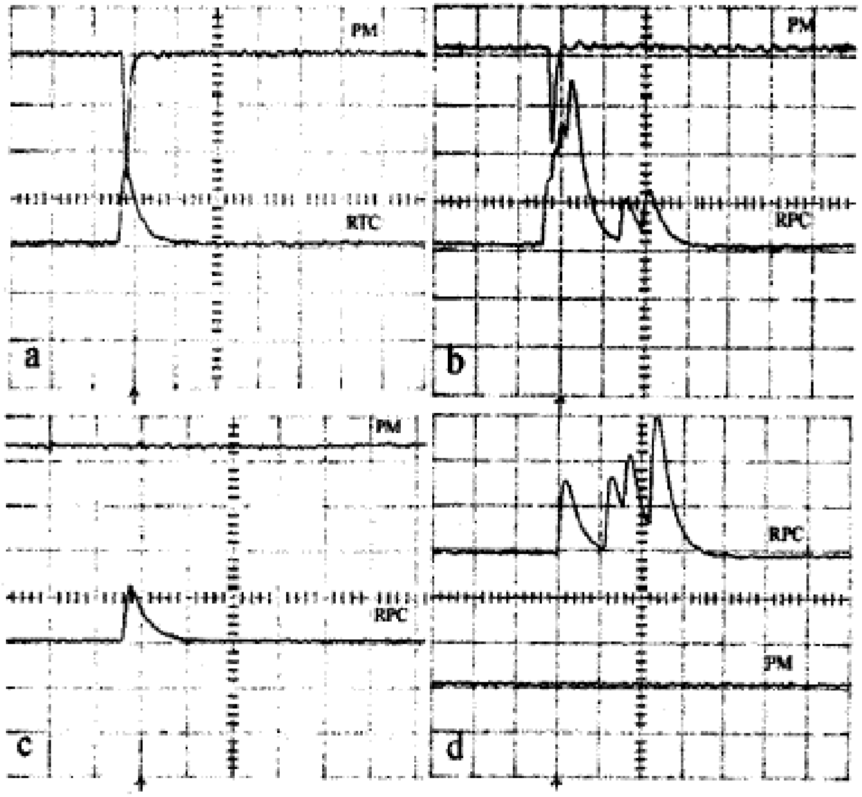


Figure 4: Improvement in the rate characteristics of a PPAC by optimizing the gas mixture.

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

Examples:

Glass RPC



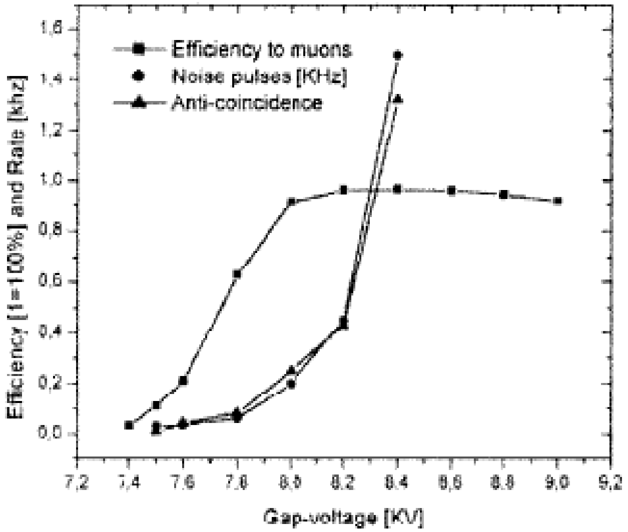


Fig. 5. The efficiency and the rate of noise pulses versus the voltage applied on the RPC [4]. The curve with the triangle symbols correspond to measurements done in anti-coincidence with the signals from the scintillators, respectively. Gas mixture Ar/Isobutane/Freon (R134) in the ration 48/4/48.

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

High rate Si and GaAs RPCs

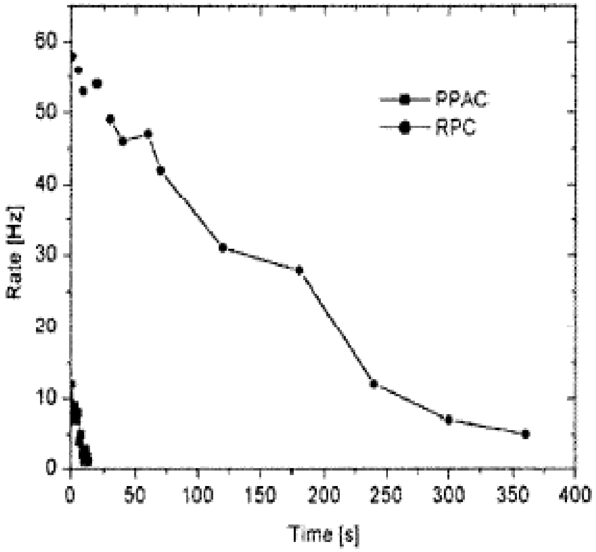


Fig. 11. The rate of the afterpulses for the PPAC (Cu-electrodes) and the RPC (Si). Gas mixture Xe (20%)+Kr (40%)+CO_2 (20%) at 1 atm.

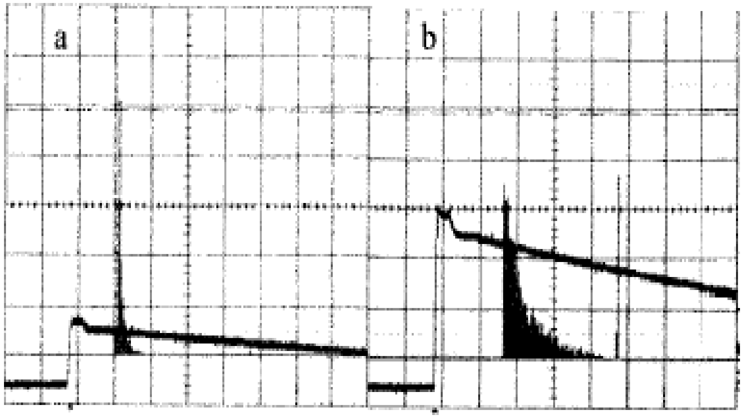


Fig. 6. Pulse-height spectra of signals from RPCs measured in the case of single primary electrons produced from the cathode by (a) UV emission and (b) in the case of noise pulses. The gas mixture Xe (40%)+Kr (40%)+CO_2 (20%) was used (1 atm).

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

GEM at extreme counting rates

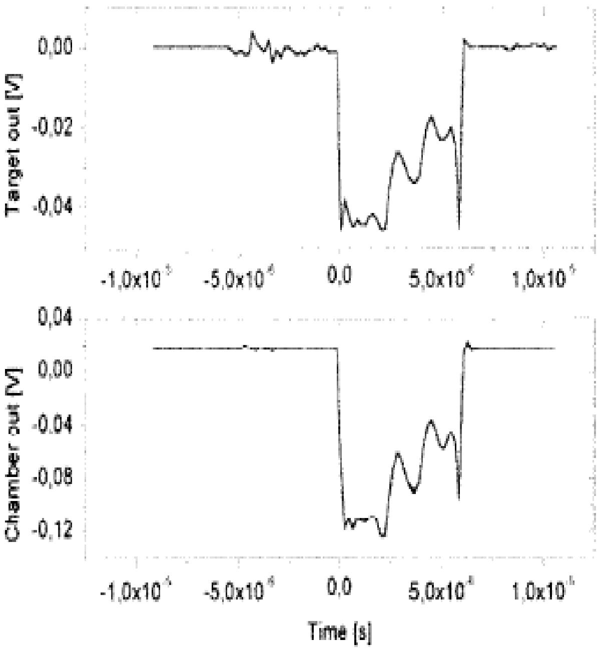


Fig. 12. The current from the GEM (at 350 V) recorded directly on a 50-Ω input of the oscilloscope when the GEM was exposed to a pulsed gamma radiation, producing ~10^7 counts/mm^2 on the 2.5 cm × 2.5 cm GEM area. No other resistors (except the 50-Ω input of the scope) were connected. The upper figure 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).

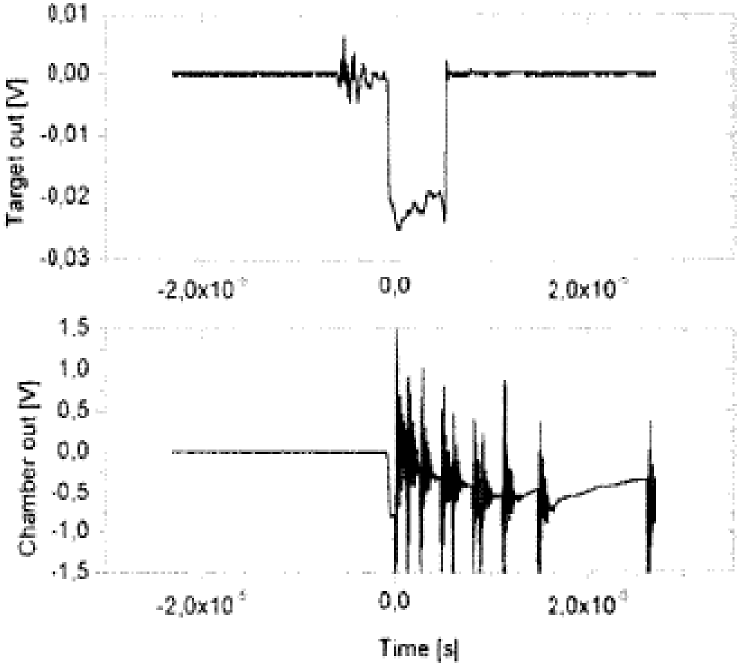
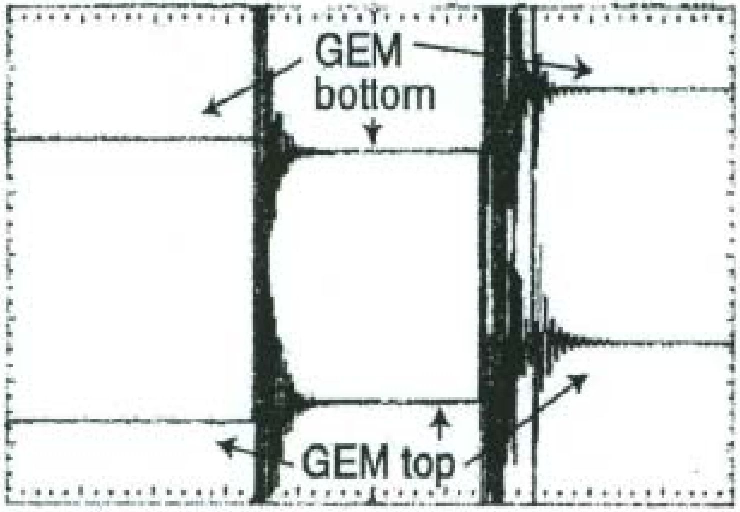


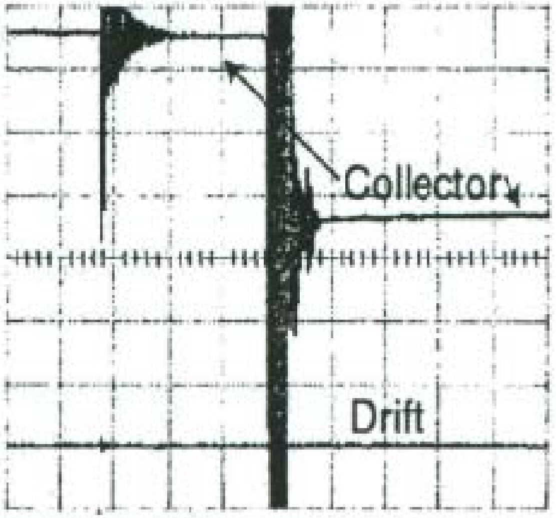
Fig. 13. The same setup as in Fig. 12, but 420 V applied over the GEM electrodes. The upper oscillogram shows the current pulse from the racetrack current monitor, the lower shows the current from the GEM readout. One can clearly see current pulses of large amplitudes, corresponding to a large number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

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

Delayed discharge propagation between GEMs



2 µs/div, 100 V/div

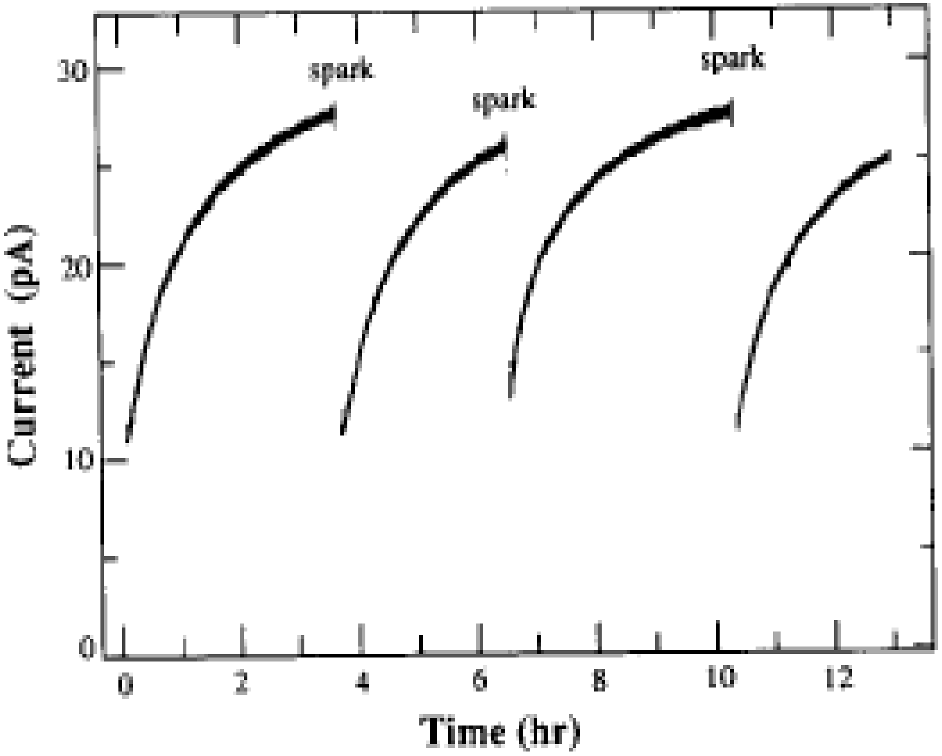


2 µs/div, 20 V/div

See: V. Peskov. “Discharge propagation between GEMs,” this WG-2 meeting

Conclusions

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


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