Discharge propagations between GEMs

V. Peskov

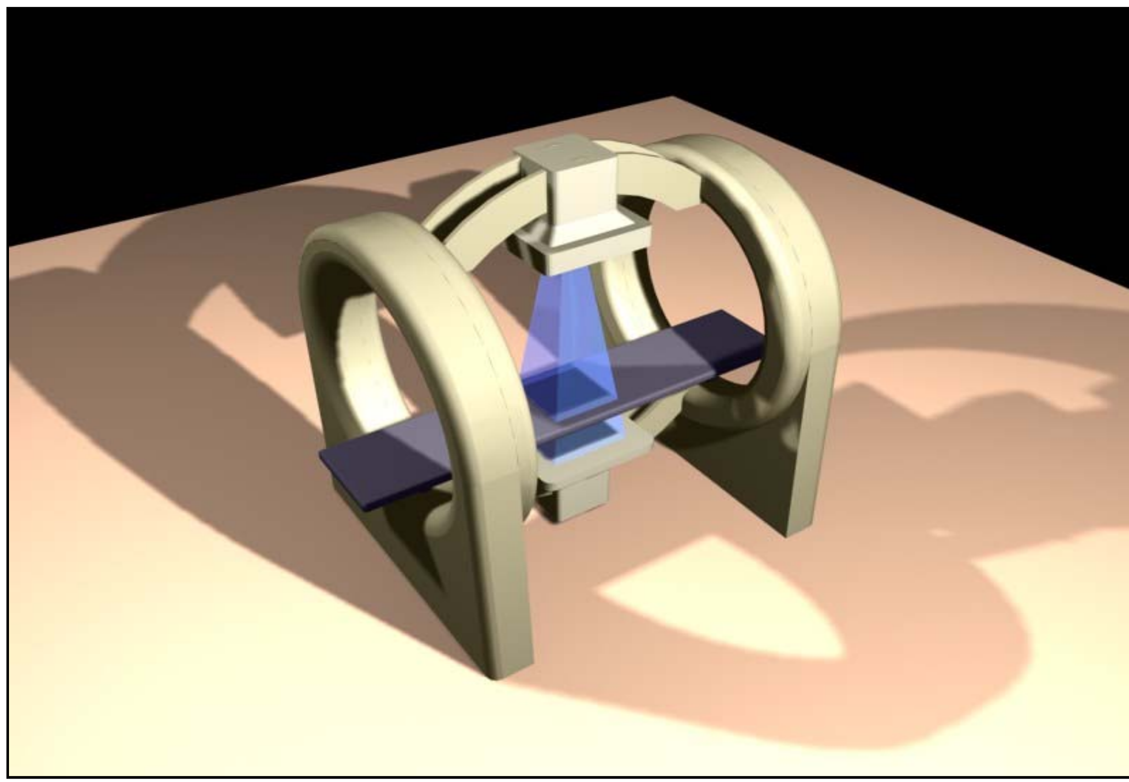
Background:

…to our best knowledge the study of discharge propagation between GEMs was triggered by development of high-rate gaseous detectors for medical application

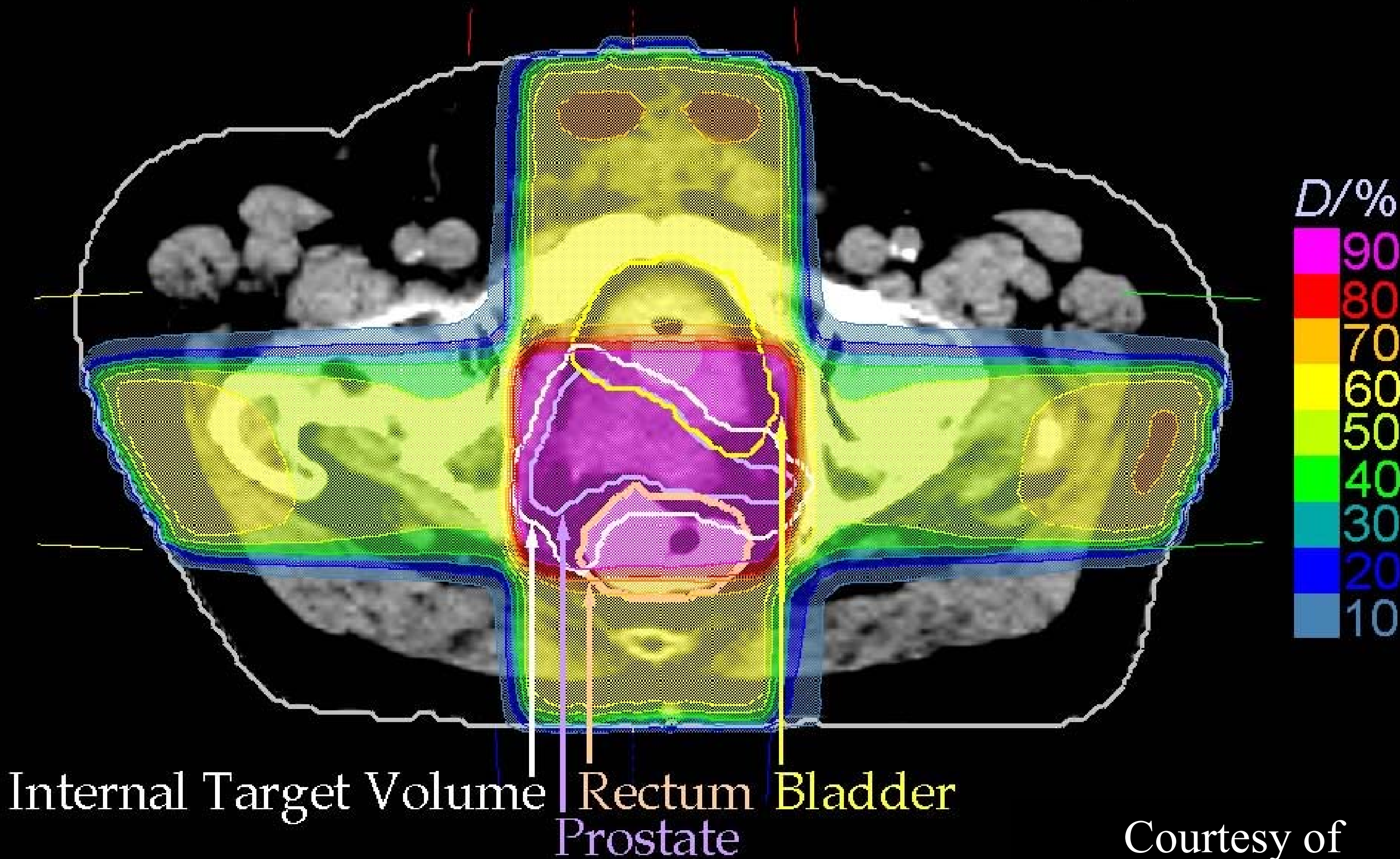
The Portal Imaging Project

RayVision AB, Sweden.

Patient setup

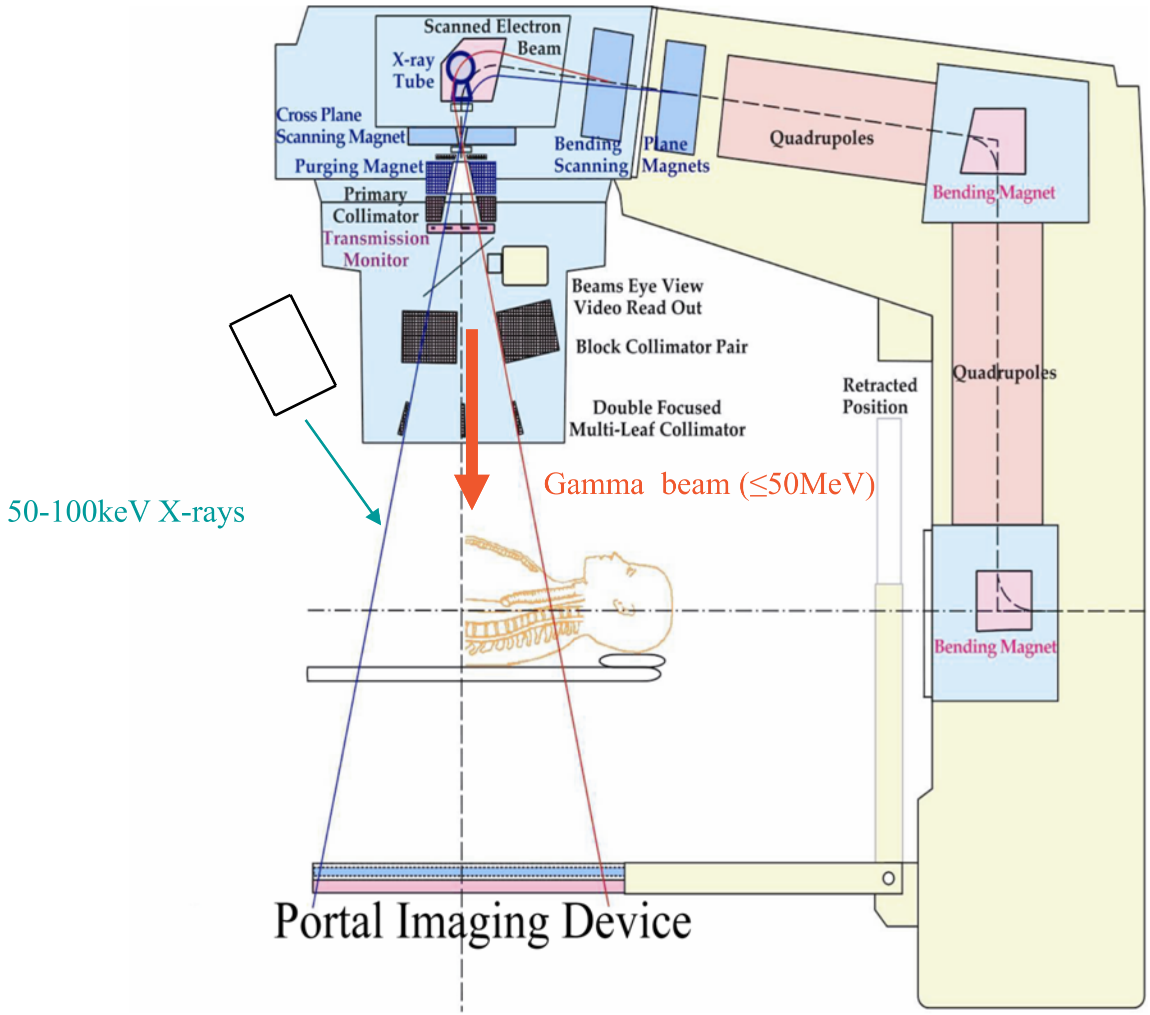


Conventional Radiation Therapy

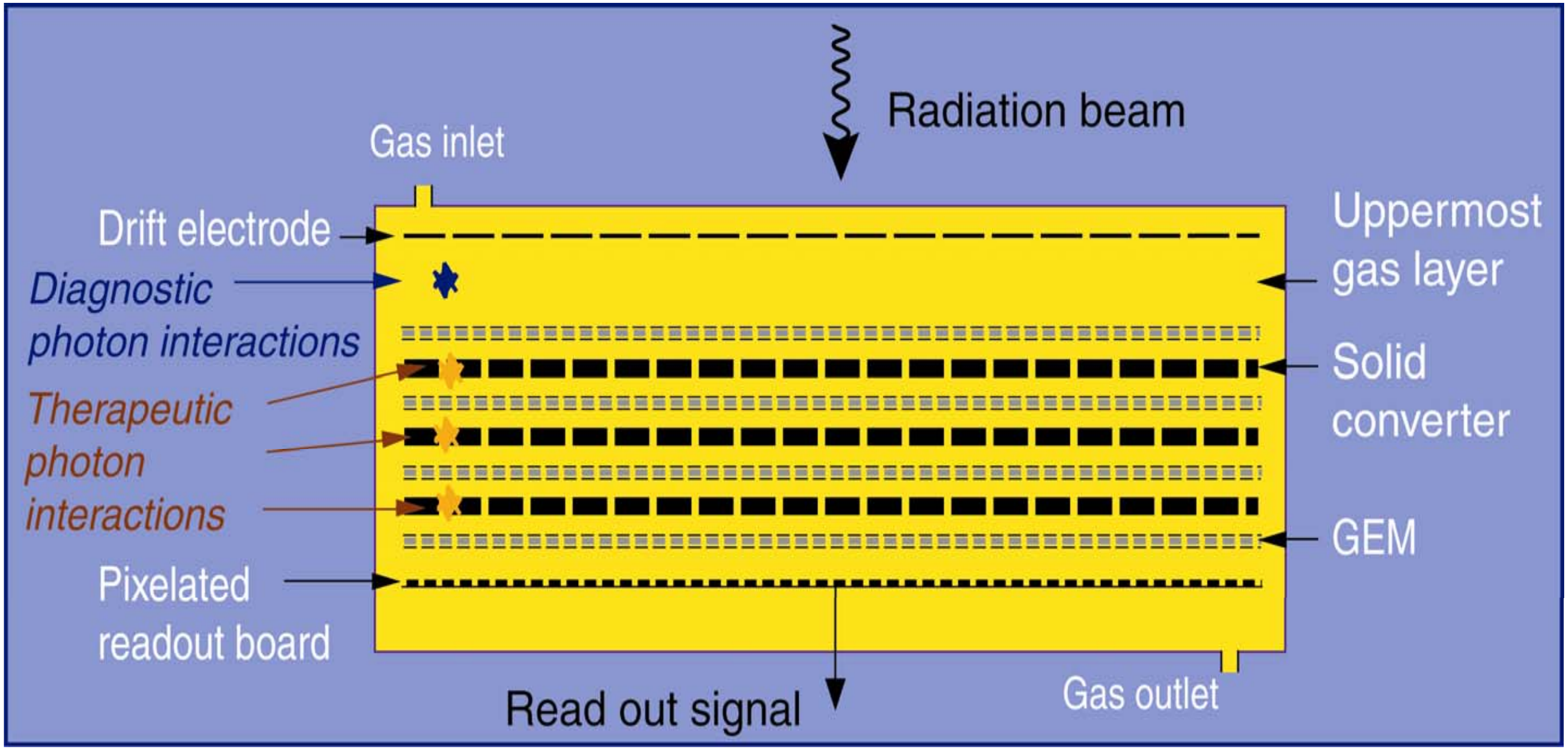


Courtesy of
RaySearch
Laboratories AB

A cancer treatment facility at Karolinska hospital(Stockholm)



The new detector

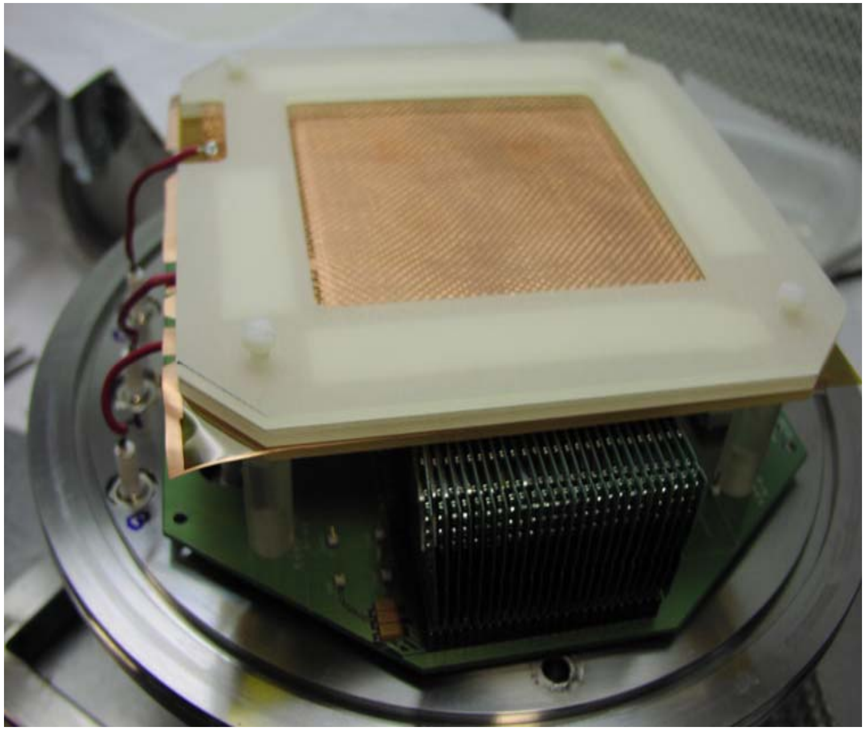


A. Brahme et al., NIM A454,2000,136

A similar concept/detector is under study by CERN-Trieste group

(see G. Croci et al., NIMA582,2007,693)

New electronic readout

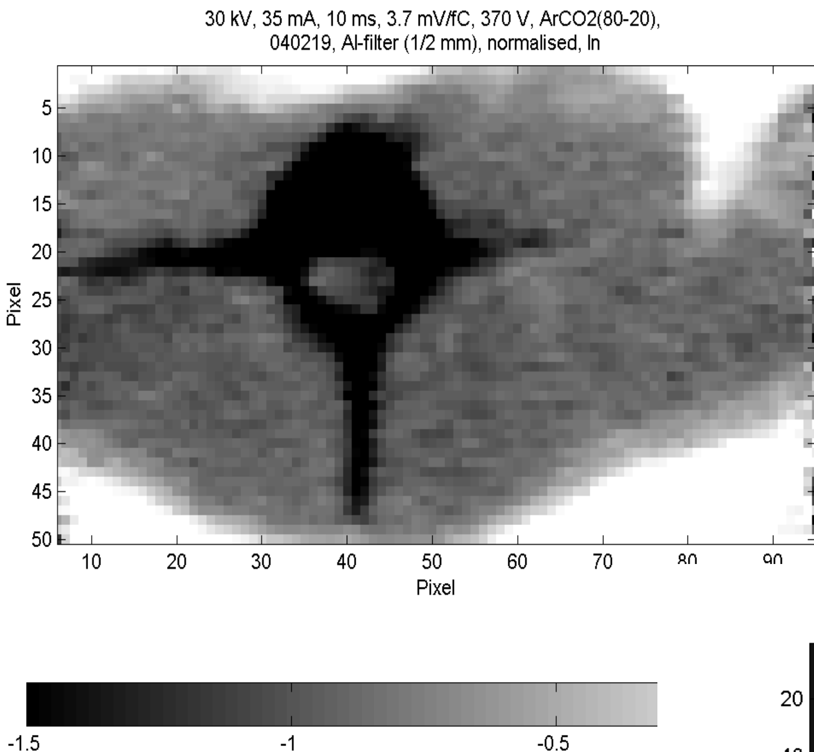


Test setup:
1 GEM installed
Distance: 130 cm between x-ray source and object imaged

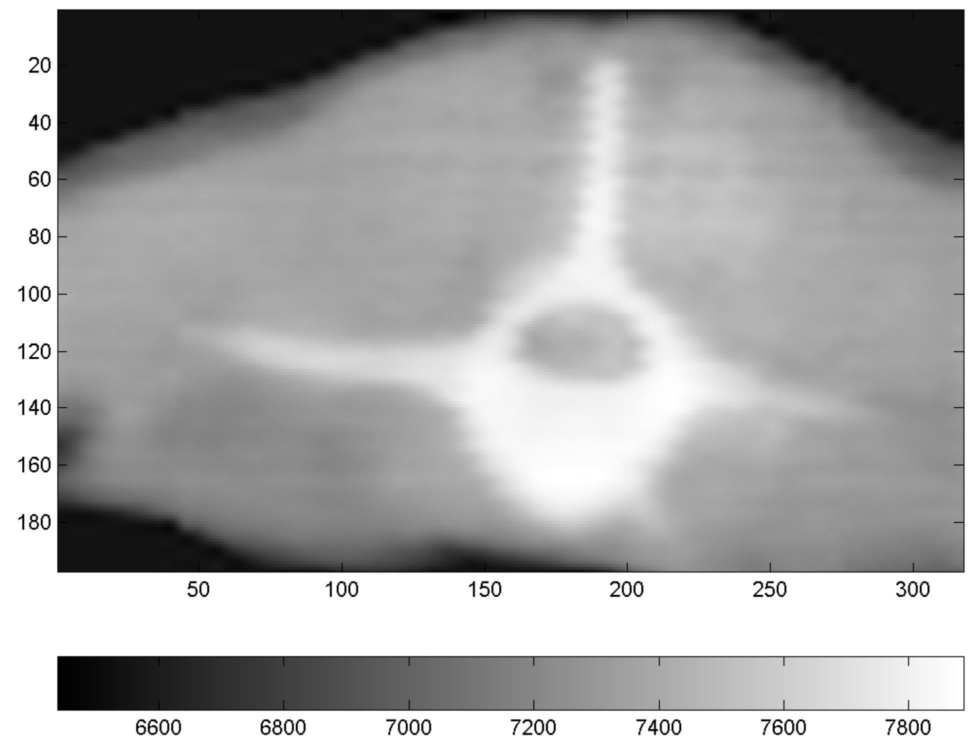
Lamb chop (thickness 15 mm)

Front side

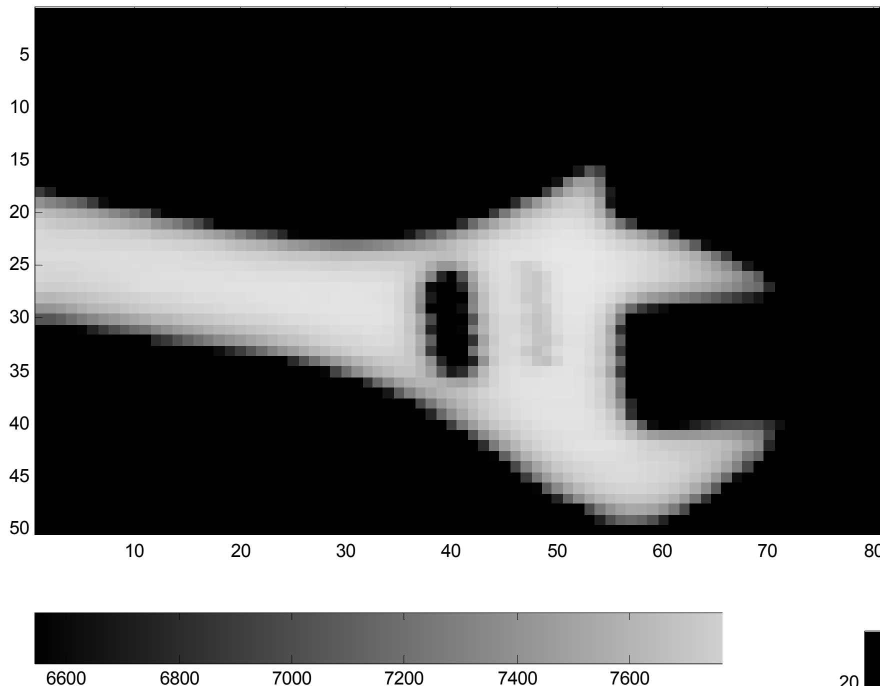
Back side



The **black** surface shows total absorption of x-rays



The **white** surface shows total absorption of x-rays



5
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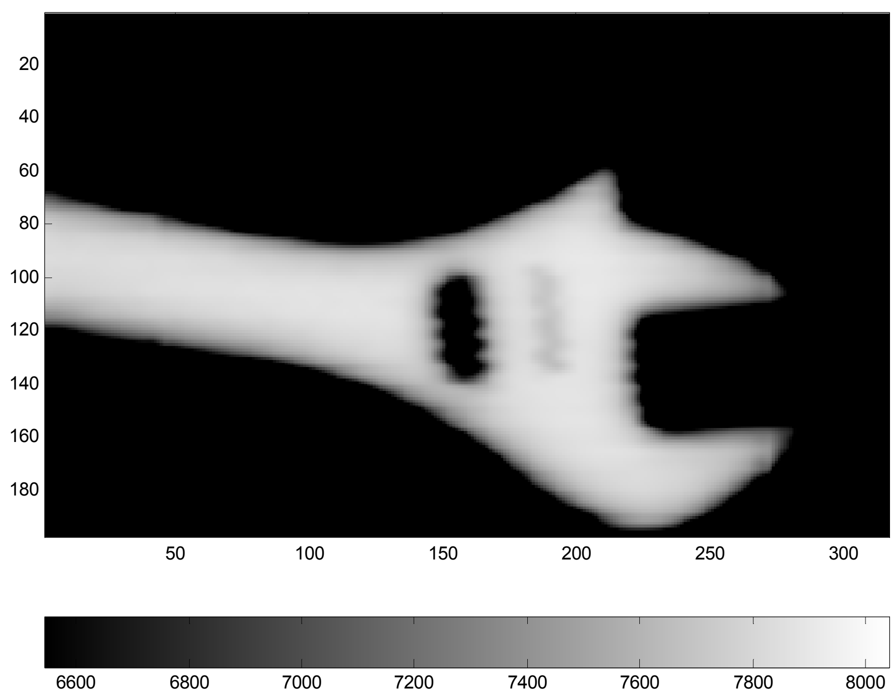
6600 6800 7000 7200 7400 7600



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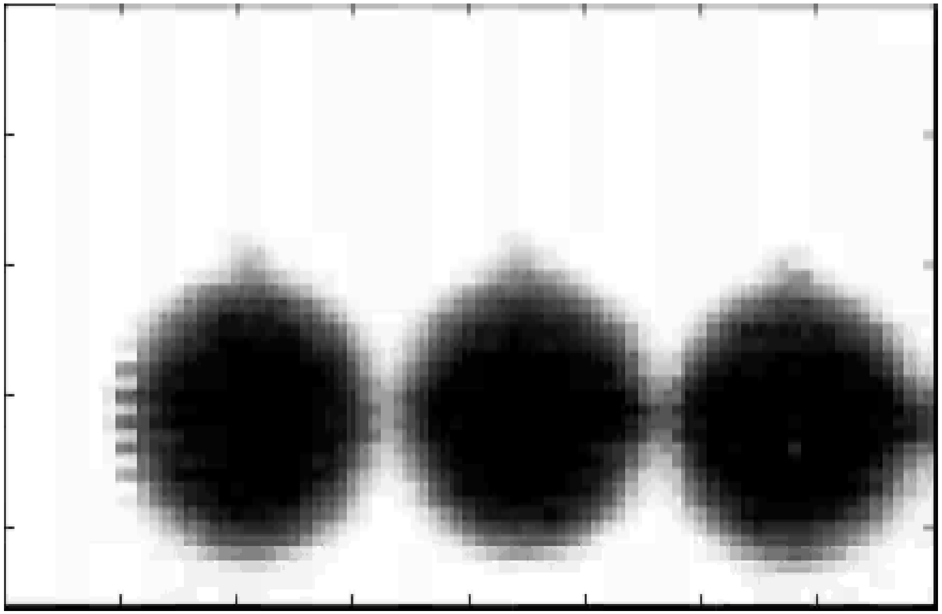
6600 6800 7000 7200 7400 7600 7800 8000

Digital camera video clip



In this environment the GEMs operated at extreme counting rates caused by x-rays, gammas (~2Gy/min~10^{10}ph/mm^{2}s) and also in presence of alphas (due to neutrons)

So we had the most difficult case: high rate + heavily ionizing particles

(see my previous report at this WG-2 meeting)

This was actually test almost in LHC environment!

Of course at the beginning the GEMs sparked a lot, we had some problems with discharge probation and so on

So our aim was to find a safe zone of GEMs operation

Our studies of discharge propagation were published in several papers, see for example:

C. Iacobaeus et al., IEEE Nucl. Sci. 48. 2001, 1496,
M. Walmarked at al., NIM A471, 2001, 151

and in more detail are described in Thesis

M. Wollmark, "Operational Range of gas electron multiplier for Portal Imaging", Karoliska Inst, Stockholm, May 2000

There are not too much studies from other authors

There were some studies from the HERA-B collaboration
(see C. Richter presentation at the International Workshop on micro-pattern gaseous detectors, Orsay, France, 1999

and

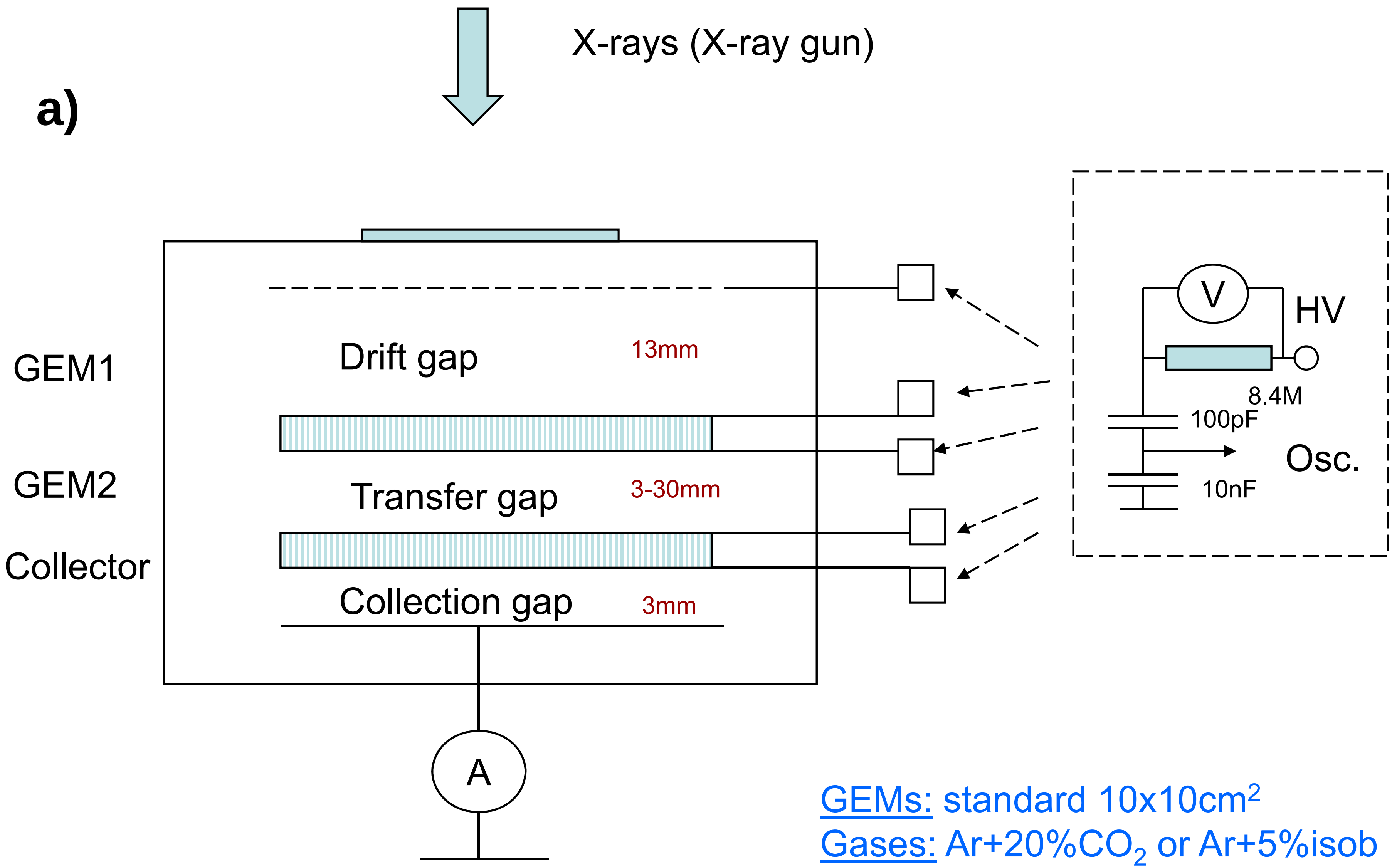
some studies made in Sauli group:
(see for example S. Bashmann et al NIM A 479, 2002 294
and in Thesis M. Ziegler, Zurich, 2002

I'll try today review these works

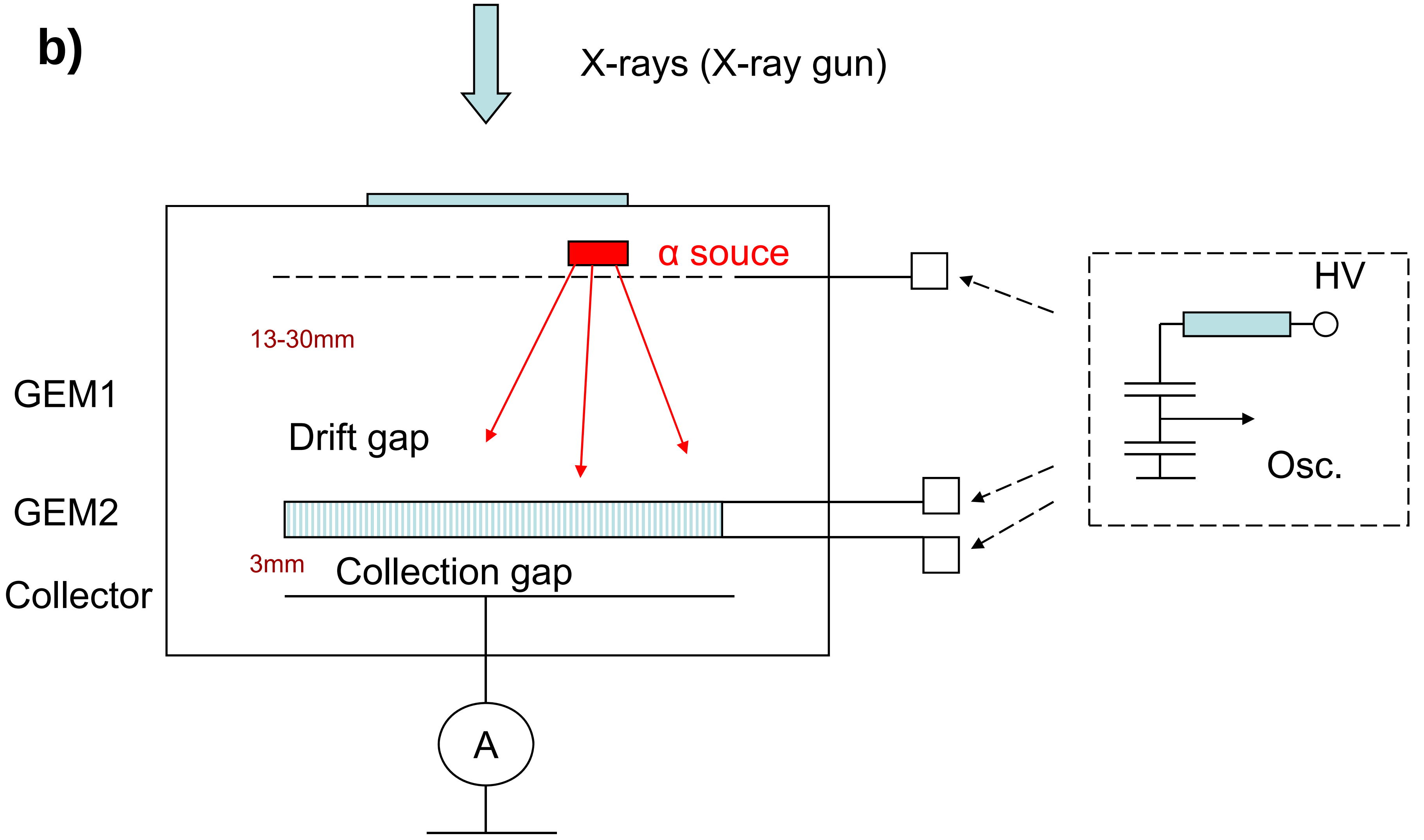
The maim intriguing question is: what type of discharges are when they propagate: streamers, feedback …or?

Two setups were used: one for studies with x-rays, the other one –with x-rays and alphas

a)

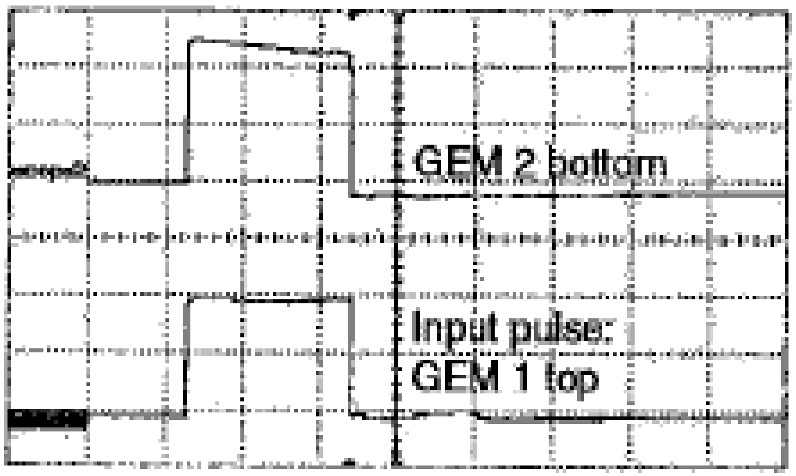


GEMs: standard 10x10cm^2
Gases: Ar+20%CO_2 or Ar+5%isob at 1atm

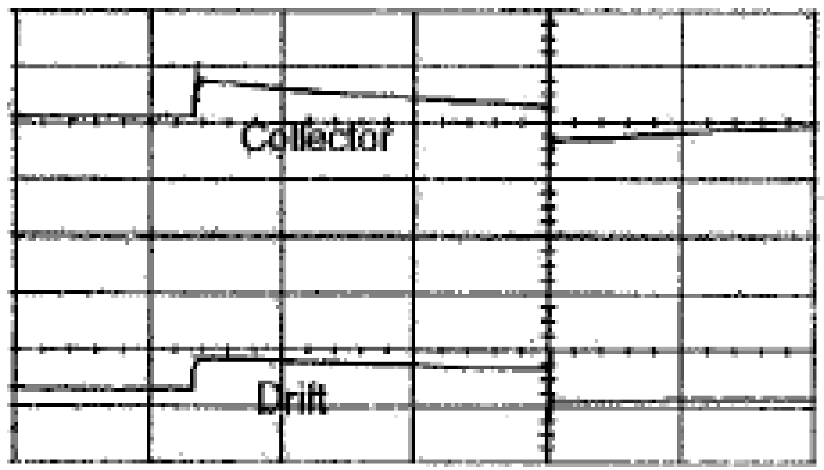


b)
X-rays (X-ray gun)
α souce
HV
13-30mm
GEM1
Drift gap
Osc.
GEM2
3mm
Collection gap
Collector
A

Pick up signals studies:



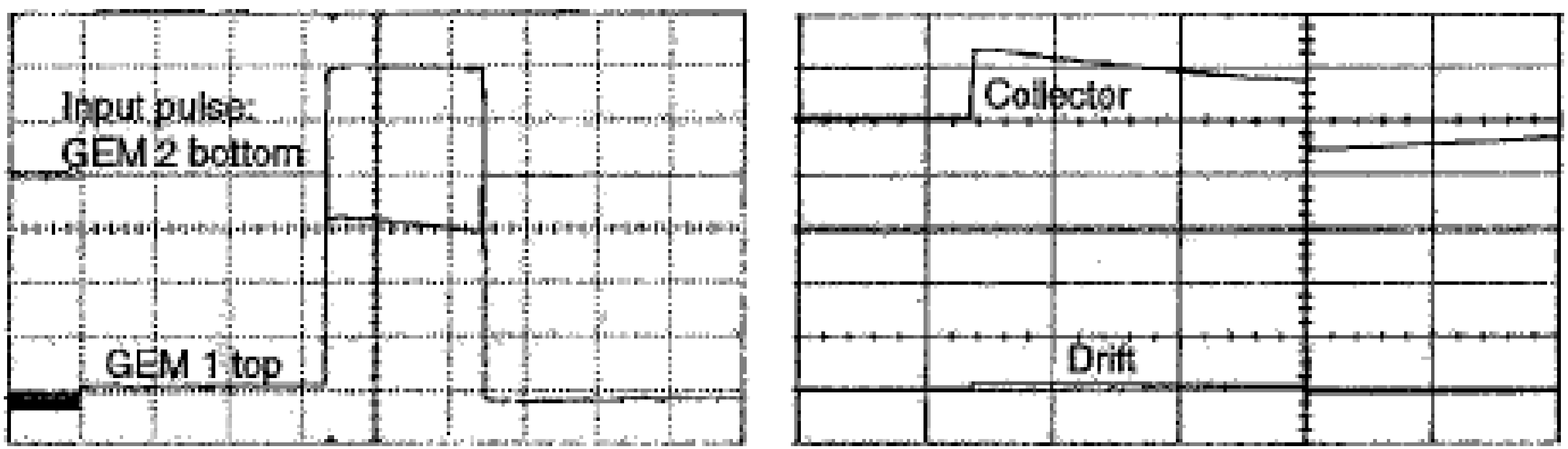
50 µs/div (x-axis)
GEM 1 top: 2 V/div (y-axis)
GEM 2 bottom: 0.1 V/div (y-axis)



40 µs/div (x-axis)
Collector: 0.1 V/div (y-axis)
Drift: 0.2 V/div (y-axis)

Figure 5-4 A square pulse of 4 V was applied to GEM 1 top. Pickup signals from GEM 2, the collector and the drift electrode are seen on the oscilloscopes. The time is seen on the x-axis and the voltage on the y-axis.

Pick up signals studies:



50 μs/div, GEM 2 bottom: 2 V/div
GEM 1 top: 0.1 V/div

40 μs/div, Collector: 0.2 V/div
Drift: 0.2 V/div

Figure 5-5 Pickup signals from GEM 2. Time on the x-axis.

Results of pick up signals studies

GEM 1 TO GEM 2	0.063
GEM 1 to Drift	0.03
GEM 1 to Collector	0.0013
GEM 2 to GEM 1	0.075
GEM 2 to Drift	0.005
GEM 2 to Collector	0.0063

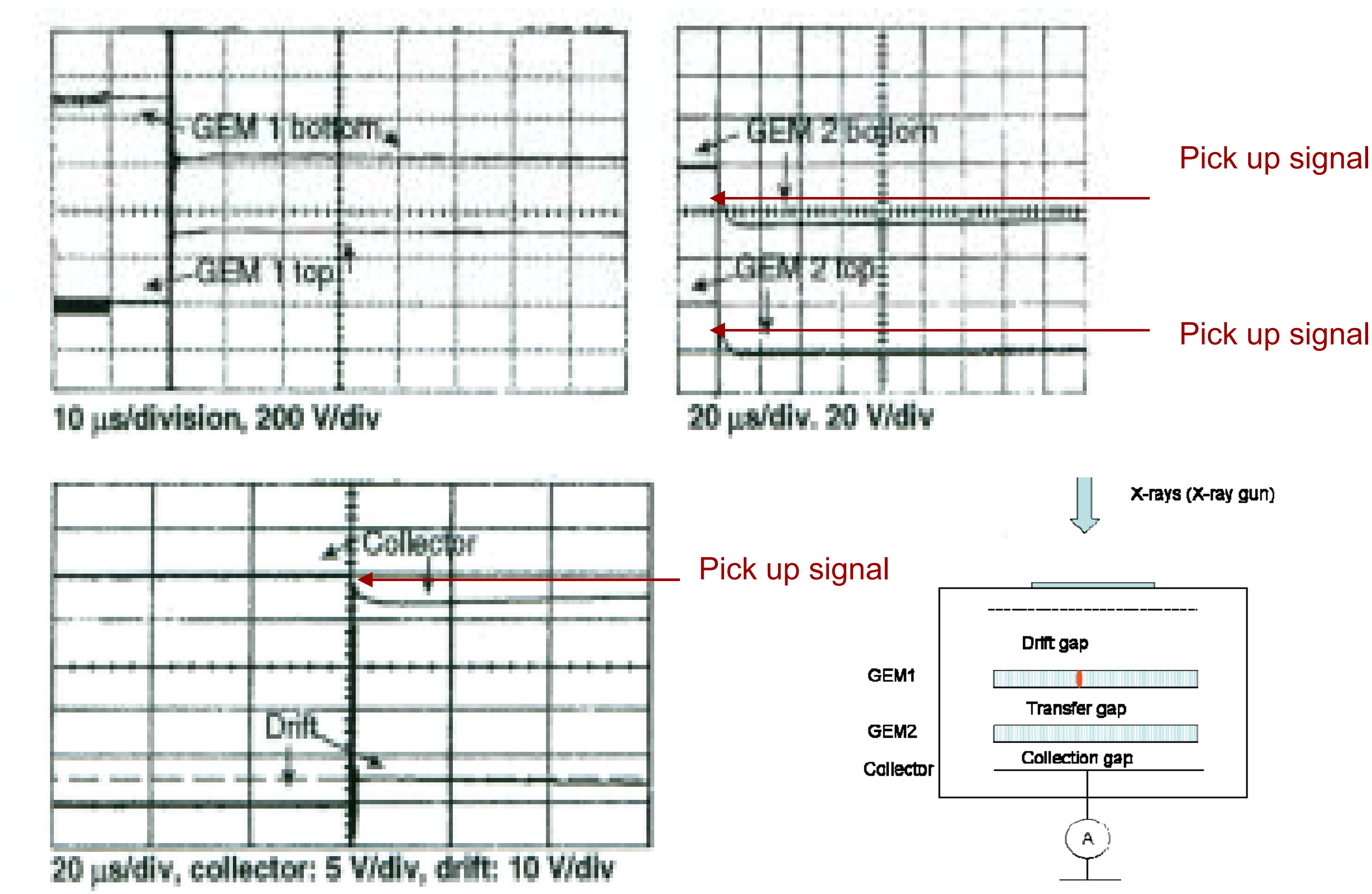
Table 5-1 Ratio of pickup signal to input signal, 3 mm transfer gap.

GEM 1 TO GEM 2	0.011
GEM 1 to Drift	0.086
GEM 2 to GEM 1	0.011
GEM 2 to Drift	0.006
GEM 2 to Collector	0.036

Table 5-2 Ratio of pickup signal to input signal, 26 mm transfer gap.

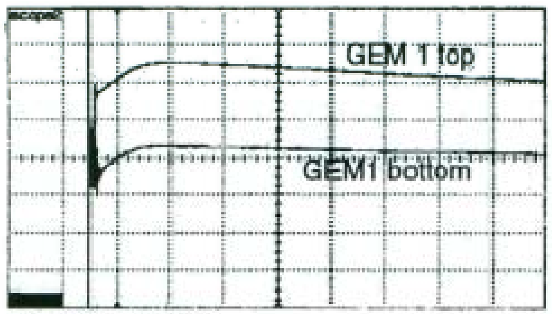
1. Results with X-rays

Discharge in one GEM: what signals it induces on other electrodes?

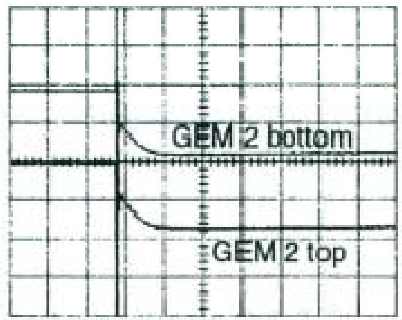


Signals measured simultaneously from all electrodes of the double GEM detector in Ar+20%CO2 gas mixture at p=1atm, when breakdown happened in GEM1

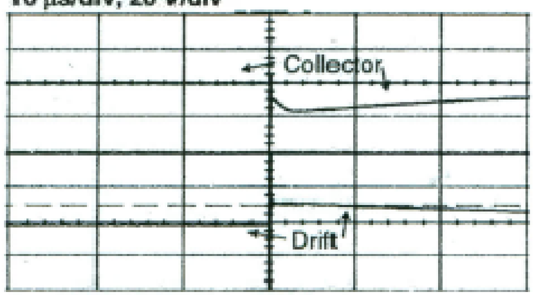
In expanded scale:



10 µs/div, 20 V/div

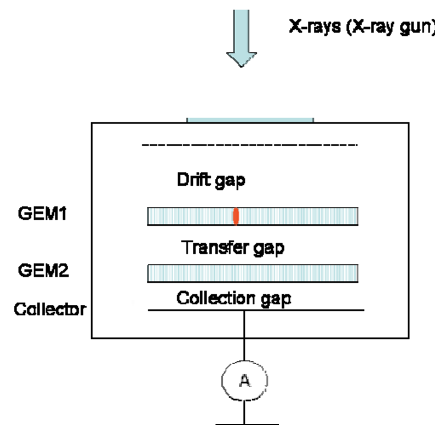


10 µs/div, 20 V/div



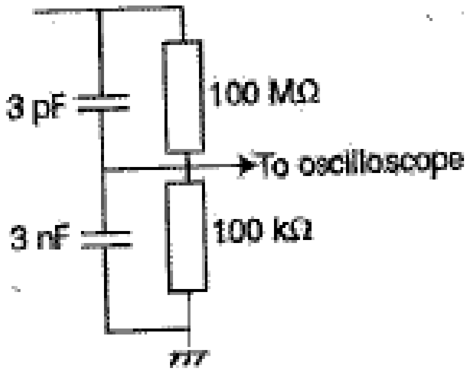
40 µs/div, collector: 2 V/div
Drift: 10 V/div

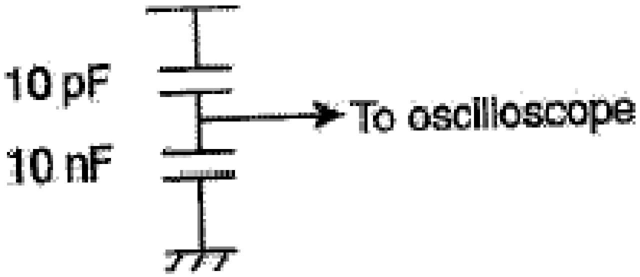
Signal have two components: fast and the slow one

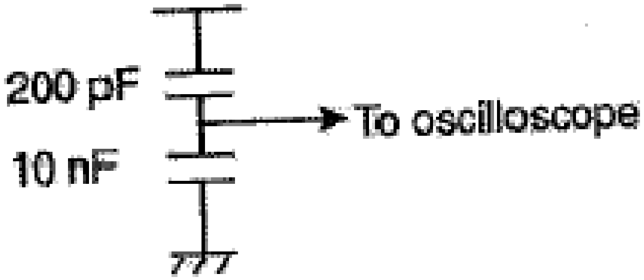


At the increased sensitivity of the scope one can see slow rise signals from GEM electrodes as well.
Gas mixture: Ar+20%CO2 at p=1atm

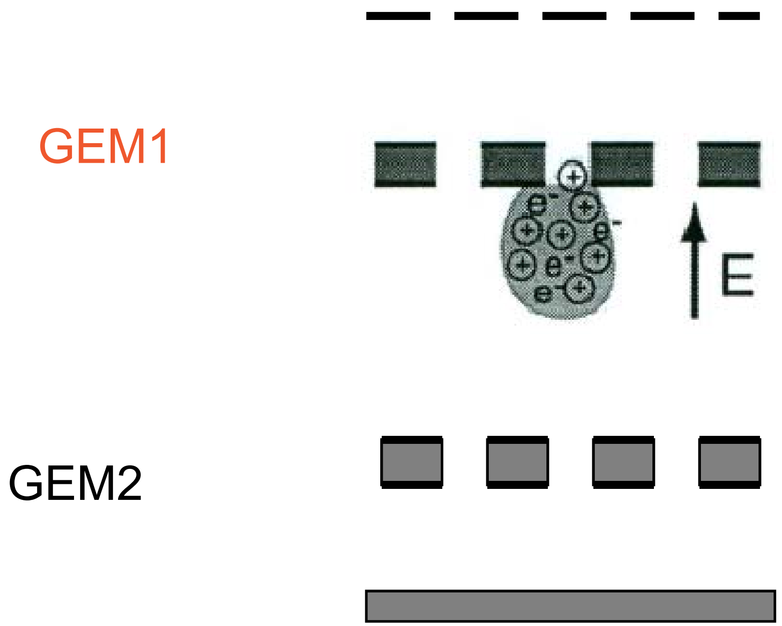
Verifications that the slow rise signals are not connected the circuit







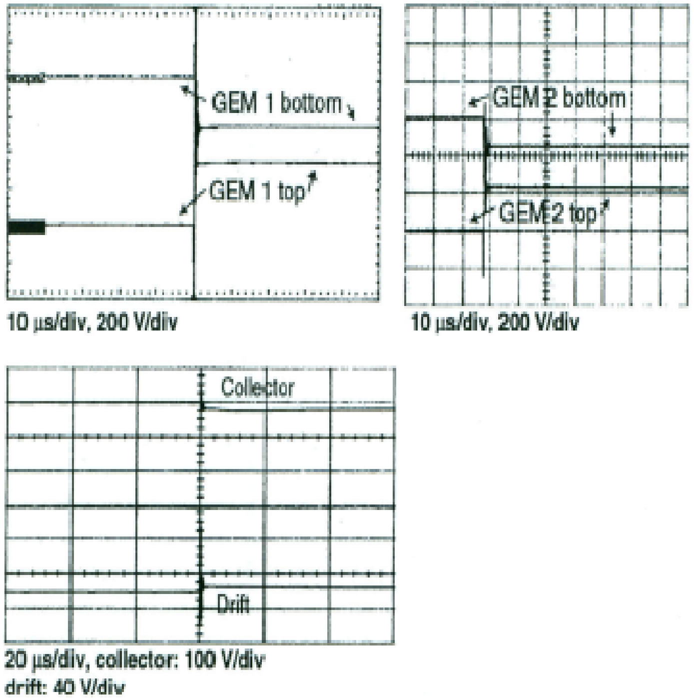
The conclusion is:
the slow signal is due to the ion movement

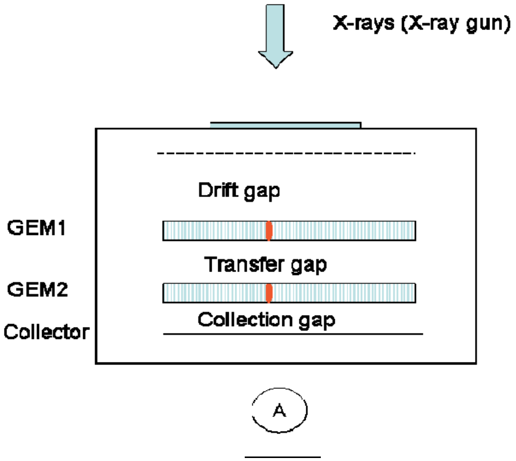


Plasma bulb
(see F. Fraga,
report Micropattern Workshop
in Orsay, 1999

The size of the “ion” signal increased with transfer field

Discharge propagation from GEM to GEM





Oscillogramms of signals from all electrodes of the double GEM detector when a breakdown propagated from one GEM to another. In this case the “breakdown” signals were seen on both GEM1 and GEM2. Gas mixture: Ar+20%CO2 at p=1atm

It was found that breakdown propagation is independent on the electric strength between the GEMs. For example, in several occasions the propagation could occur at reversed fields between the GEMs, i.e. a larger negative potential on GEM2 top than on GEM1 bottom.

Also, when the distance between the GEMs was small, for example 3mm, a breakdown could propagate upwards, to GEM1 if the discharge was initiated in GEM2.

However, this propagation from GEM2 to GEM1 never occurred in the case of large transfer gap, for example 26mm and more.

Delay time measurements

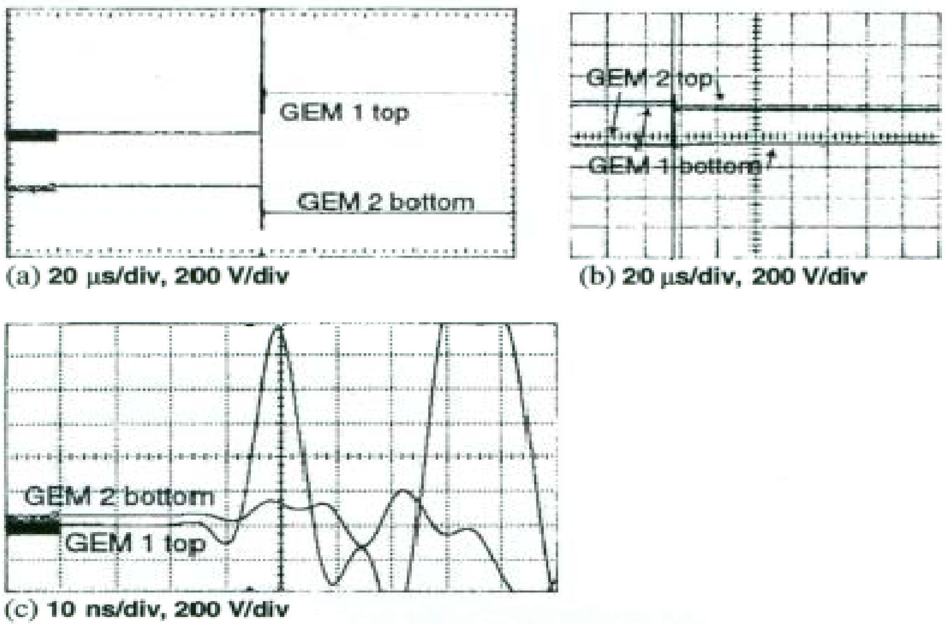


Figure 5-12 A breakdown occurs both in GEM 1 and in GEM 2. (c) is an enlarged version of (a). Since signals from both the GEMs are shown on the same oscilloscope in (c) it is

With an accuracy ~10ns no delay between breakdowns was observed.

This offers photon assistance mechanism for the discharge propagation

Confirmation from Sauli group (S. Bachmann et al, NIM A479,2002,294)

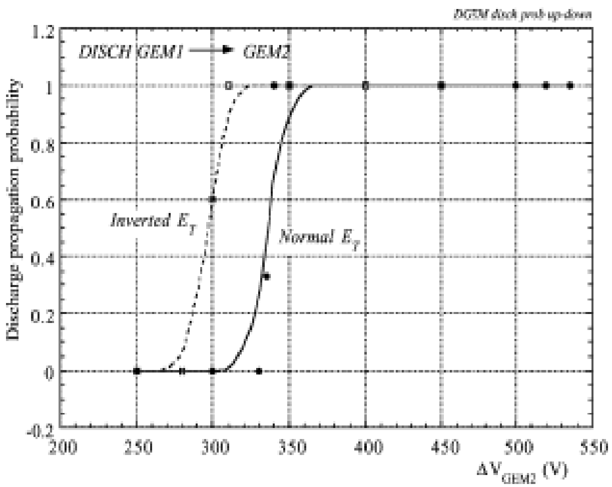


Fig. 13. Discharge propagation probability between first and second GEM in a cascade, as a function of voltage on the second, for normal and inverted transfer fields.

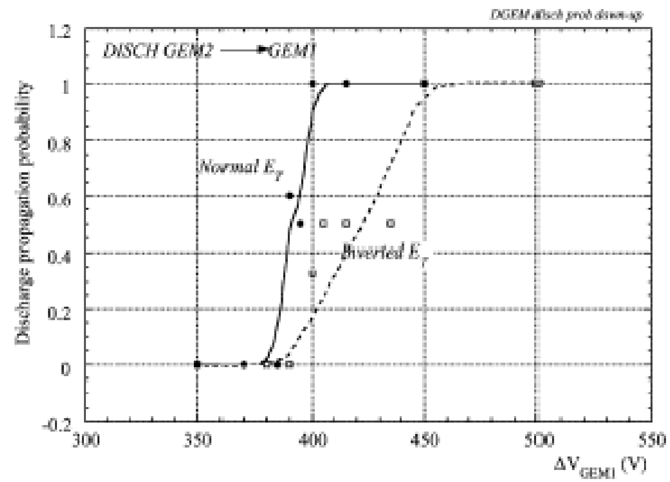


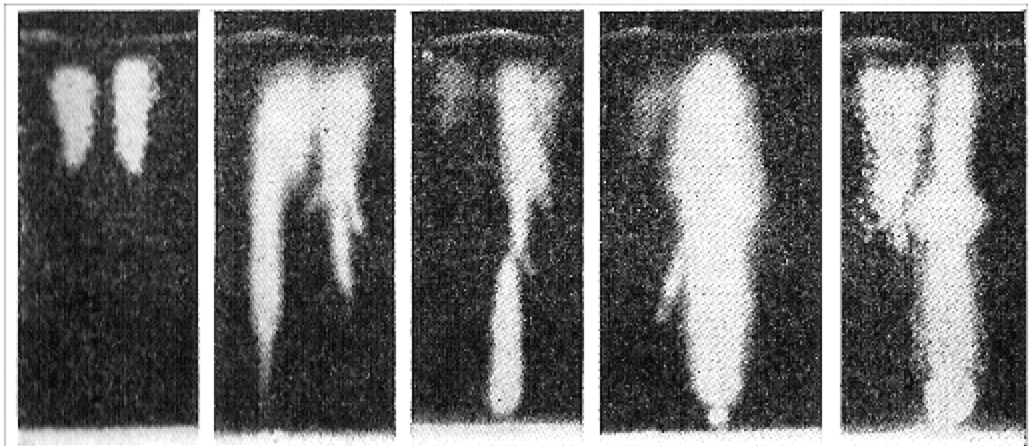
Fig. 14. Discharge propagation probability between second and first GEM in a cascade, as a function of voltage on the first, for normal and inverted transfer fields.

the predominance of a fast propagation mechanism between GEMs is confirmed by the observation that discharges can propagate between two multipliers, even if the electric field is inverted in the transfer region..

Fast breakdown - experimental evidence

Lower gain – only cathode streamer

From avalanche head near the anode starts the cathode stremaer	Cathode streamer almost at anode +streamer branches	Cathode streamer reaches anode	Channel established	Channel established



(a) (b) (c) (d) [RAE64] (e)

Figure 5.10. Development of the cathode directed streamer (with increasing pulse length). From the head of the avalanche (near the anode) (a) starts the cathode directed streamer ((b) (c)) till a plasma channel connects cathode and anode (d, e). These branched streamers resemble the discharge figures going out from a positive point, see *Figure 5.12*[18]

Is it relevant for detectors?

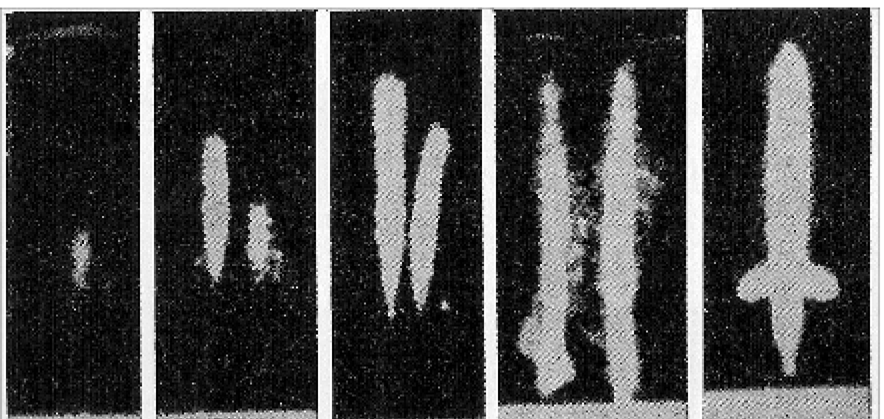
P. Fonte tak in Paris

Fast breakdown - experimental evidence

Cloud chamber observations (vapours, ~1cm gap)

High gain – anode and cathode streamers

Avalanche head	Anode streamer almost at anode	Anode streamer almost at anode	Cathode streamer develops	Channel established



(a) (b) (c) (d) [RAE64] (e)

Figure 5.9. Development of one avalanche into a streamer, photographed in the cloud chamber (air, 270 Torr). The expansion ratio was reduced, so that in (a) only the head of the avalanche, as the region of the highest ion density, is visible as a track. If the voltage is slightly raised (at constant voltage pulse duration), an 'anode directed' streamer develops out of the avalanche head (b, c). Further increase of the voltage produces the development of the 'cathode directed' streamer, so that a plasma channel bridges the two electrodes. Therein occurs the spark. The same stages pass, if the voltage pulse height remains constant and the pulse duration is increased[16]

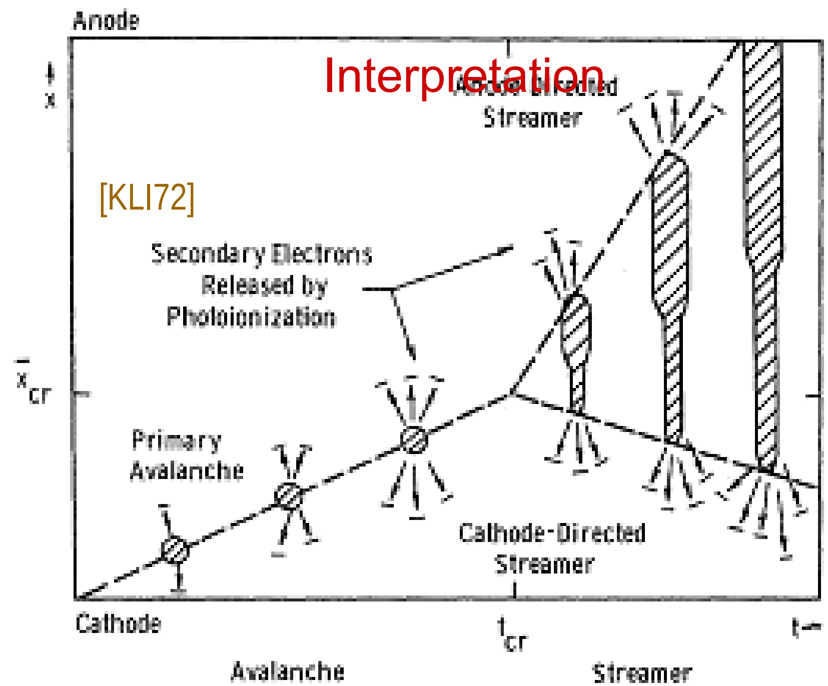
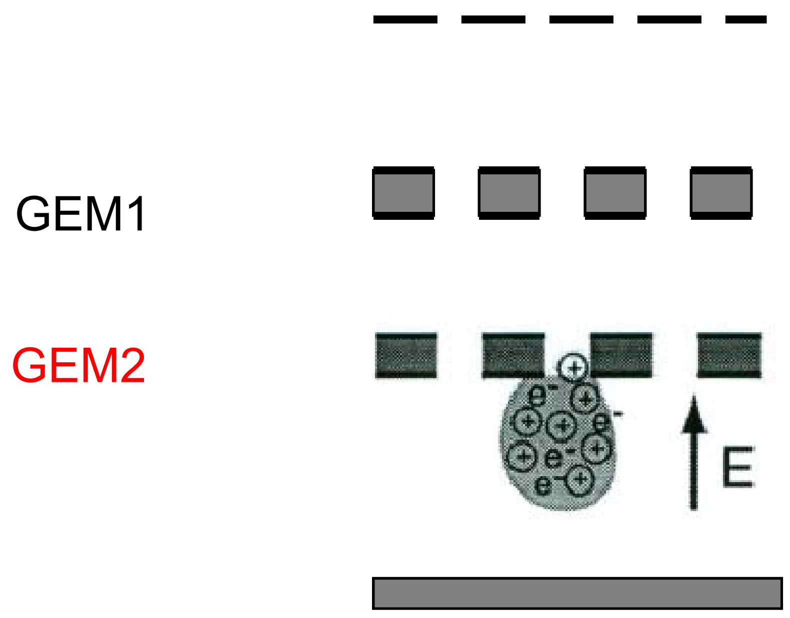


FIG. 6. Schematic representation of the qualitative description of streamer development given by Wagner. (Based on Figs. 22 and 27 of Ref. 11.) Anode- and cathode-directed streamer propagation begins at $t_{critical}$ when the avalanche position equals $\bar{x}_{critical}$.

P. Fonte tak in Paris

Is the streamer mechanism applicable?

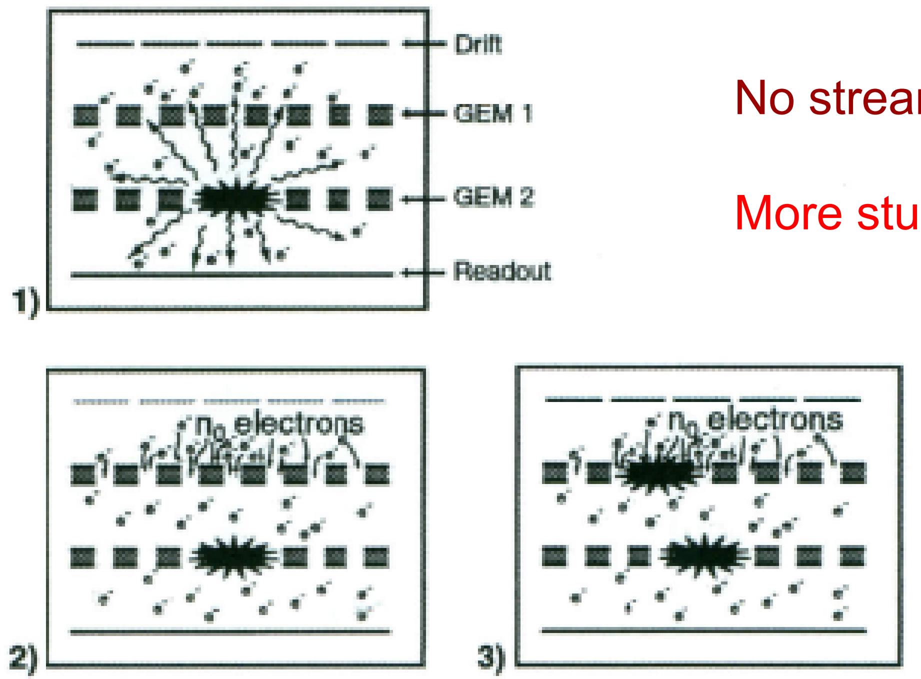


Field is too low for the cathode streamer (or for any streamer)

It looks like a classical streamer mechanism is no applicable for the explanation the discharge propagation between GEMs.

May be we do not know all about streamers?

Photon mechanism of discharge propagation(??)

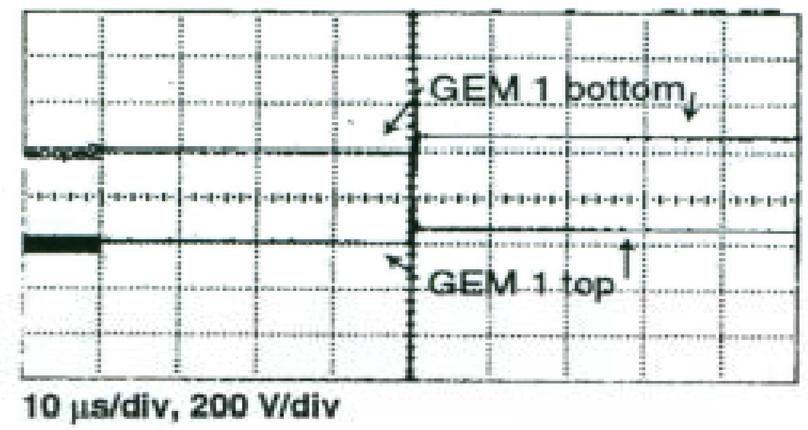


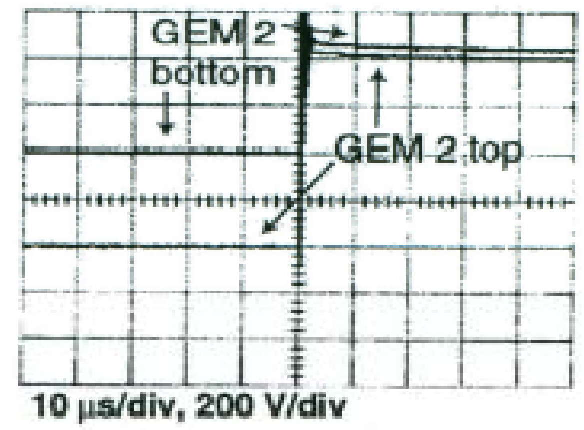
No streamers?

More studies should be done!

A schematic drawing illustrating discharge propagation from GEM2 to GEM1. The UV photons from the discharge in the GEM2 photoionize gas in the entire detector, including the drift region. The secondary electrons trigger a breakdown in GEM1

Discharge propagation to the collector



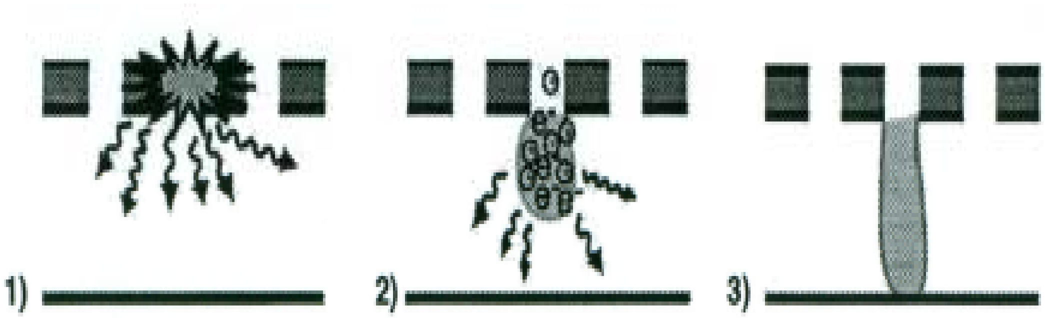


Oscillograms of signals when a breakdown in GEM2 that propagates down to the collector plate. On GEM1 pick up signals are seen. The signal from GEM2 top was large and had the same polarity as the signal from the GEM2 bottom

The condition for the breakdown propagation to the collector was that the electric field between GEM2 bottom and the anode is above <u>10kV/cm</u>

When the field strength was lower than this, the discharge stayed confined inGEM2 and did not propagate to the collector

Breakdown propagation to the collector with X-rays



Breakdown propagation from the GEM to the collector with X-rays: according to this model the breakdown produce photons and a dense cloud of electrons and ions under the GEM and this creates a streamer

2. Results with X-rays and alphas

A new phenomena was observed in presence of alpha particles: a semi-propagation to the collector

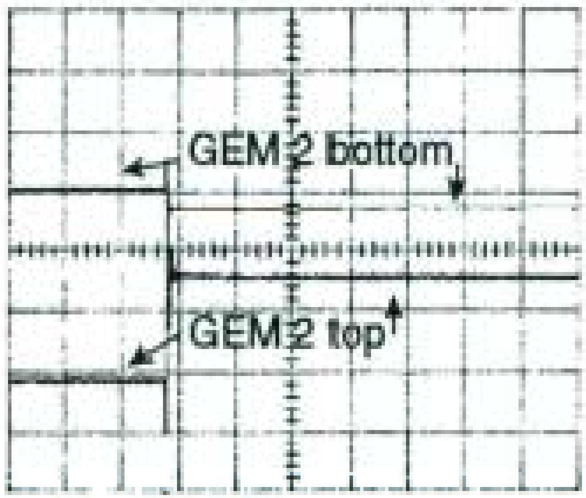
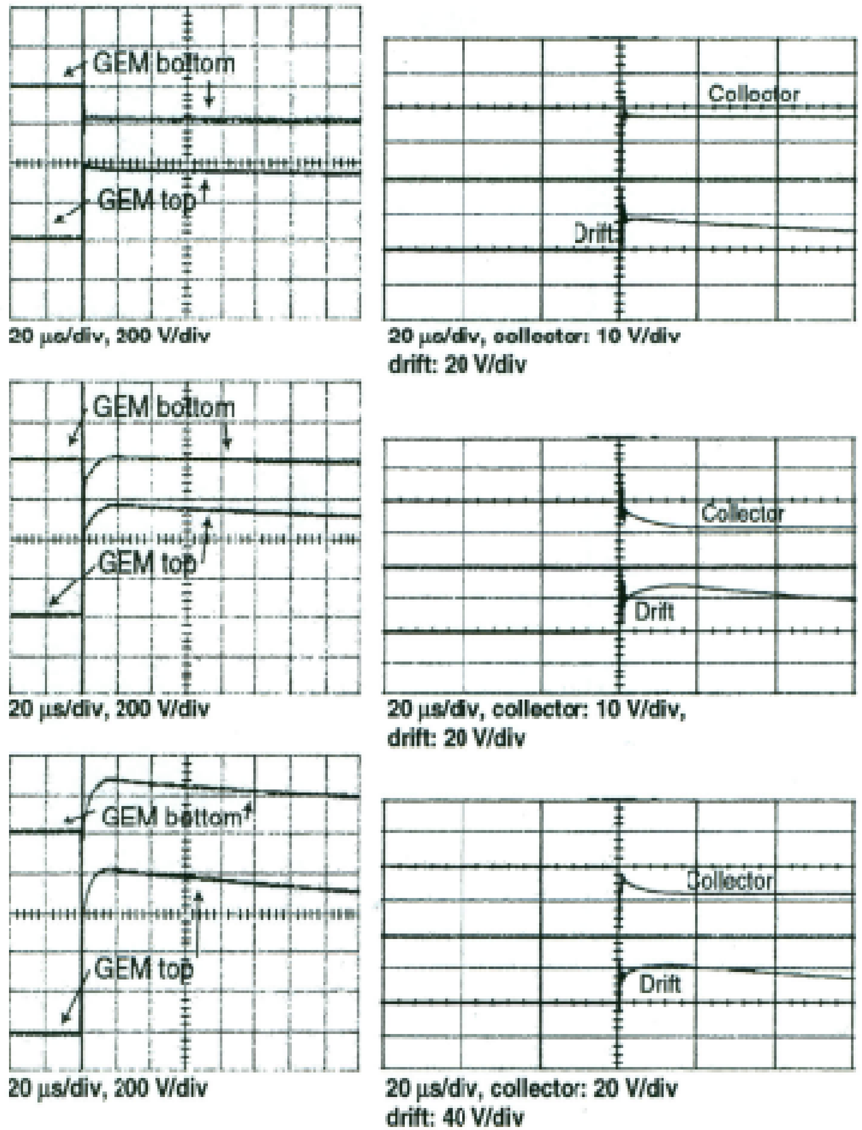


Figure 5-10 The steps seen on GEM 2 top and GEM 2 have different size. The anode and cathode do not share the voltage evenly. Time on the x-axis.



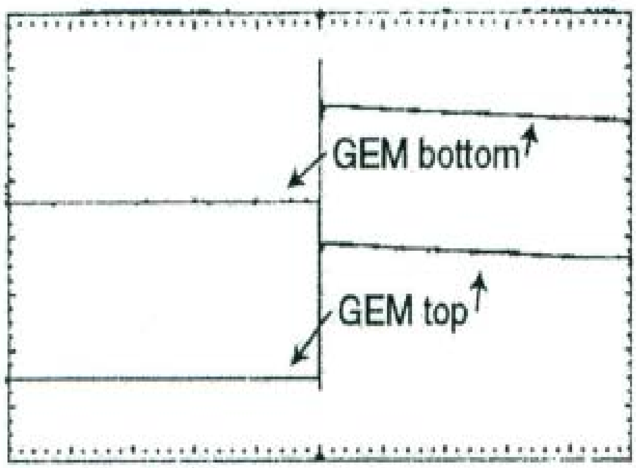
400V

600V

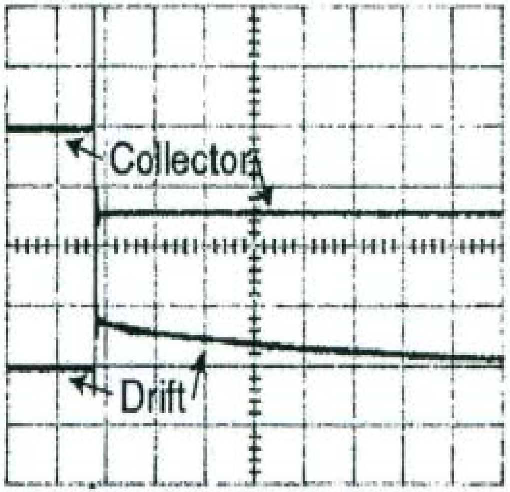
800V

Oscillograms from all detector electrodes for various collection fields illustrating a semi-propagation of the dischagre from the GEM to the collector

Only at high enough electric field there was a full propagation to the collector



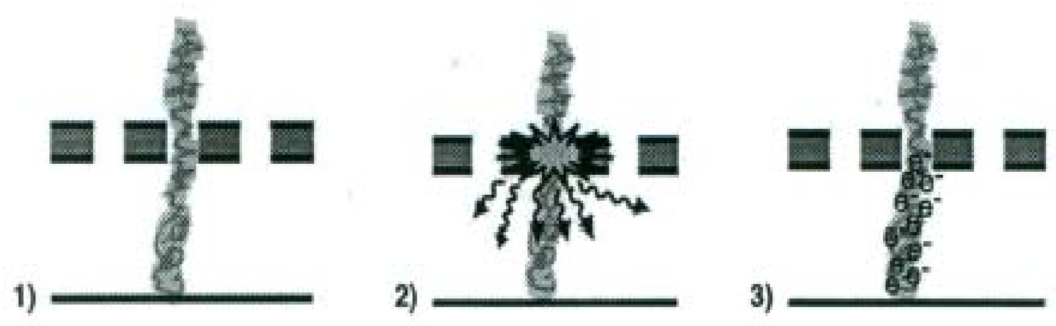
20 µs/div, 5 V/div



20 µs/div, Collector: 20 V/div
Drift: 100 V/div

During the full propagation the potential on both GEM electrodes goes to ground

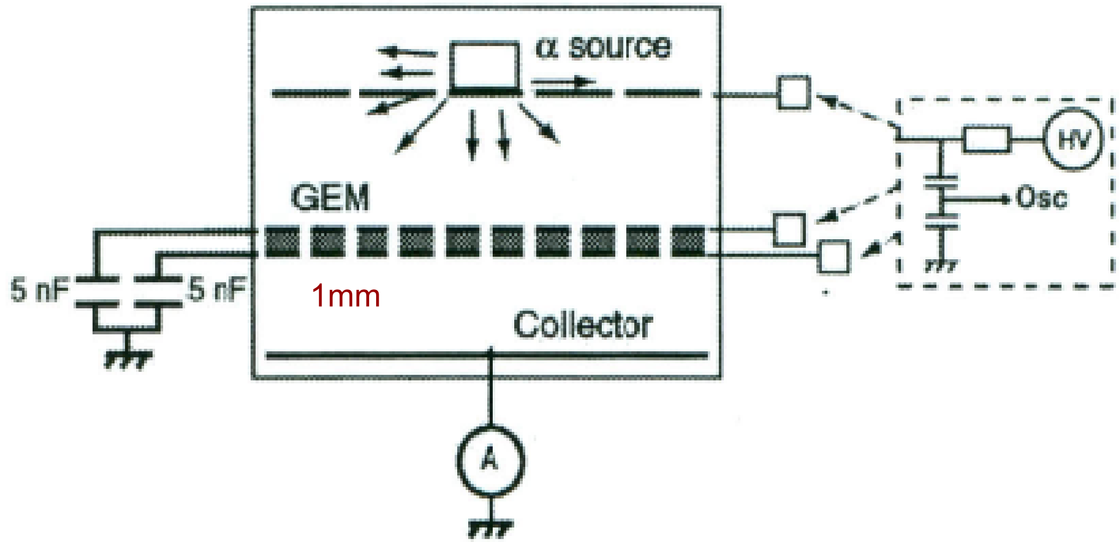
Semi-propagation and full breakdown propagation to the collector with alpha particles



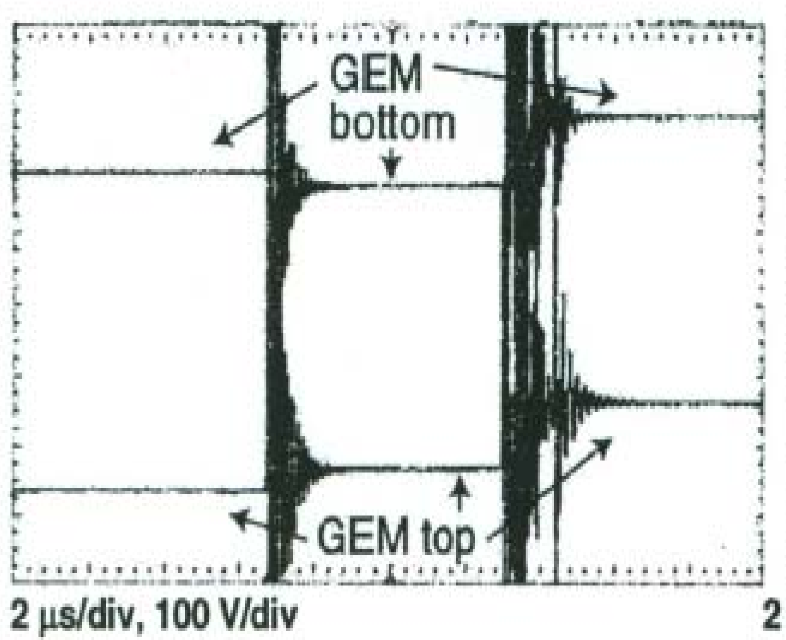
An illustration of semi-propagation of a discharge from the GEM to the collector with alpha particles. Alpha particles moving through the gas in the detector create dense ionised tracks. When the discharge appears, the electrons can easily move down to the collector through this pre-ionized channel and cause a discharge

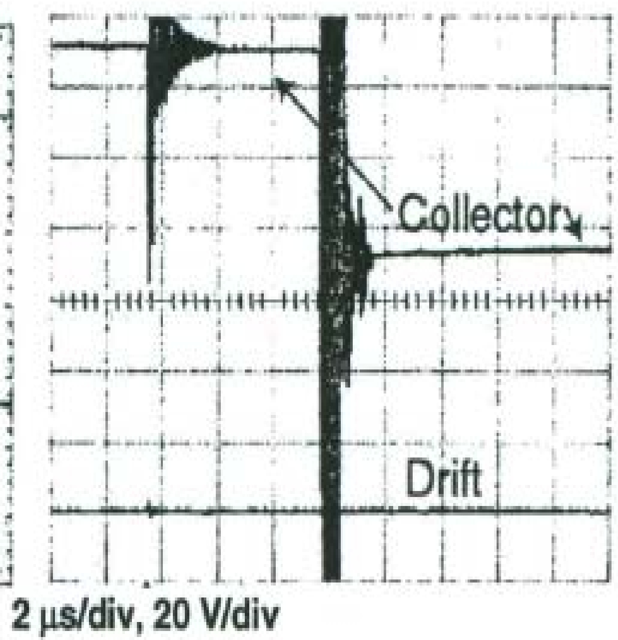
Another interesting phenomena-
delayed breakdowns

To observe this phenomena a large discharge energy is required, so capacitors were connected



A set up for studies of breakdown propagation when GEM electrodes were connected to ground via 5nF capacitors



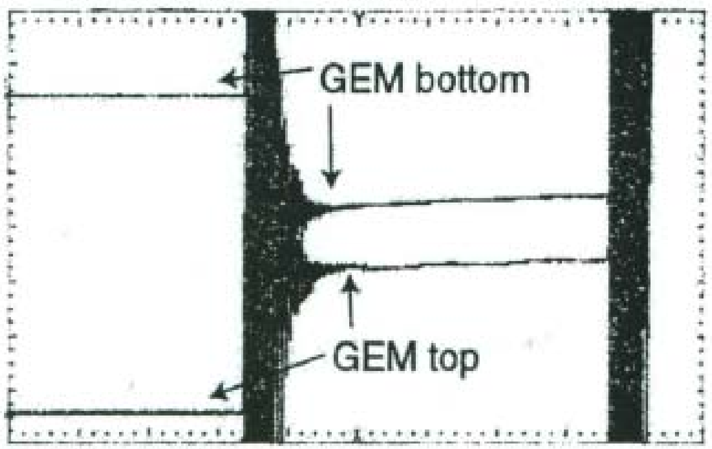


Delay time varied between 1.5 to 25μs

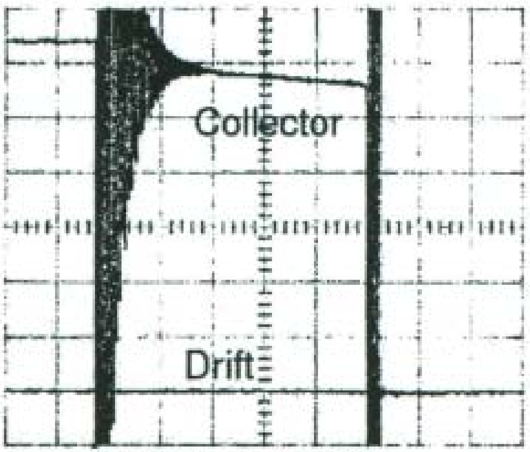
Note that electron drift time was~15ns and full ions collection time 6-9μs

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

Close inspection reveal some similarity to the cathode excitation effect

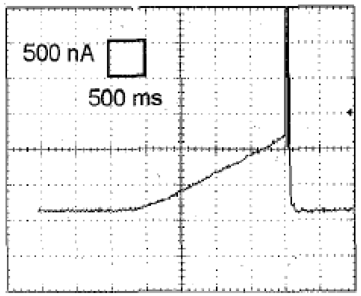


2 µs/div, 10 V/div

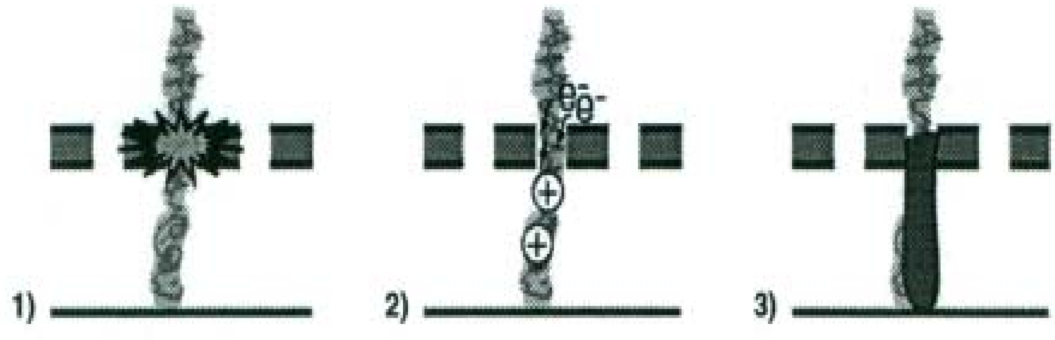


2 µs/div, Collector: 2 V/div
Drift: 20 V/div

(See my previous talk)



A possible explanation of the breakdown with delay



“Preparation” activity- cathode excitation

Finally-streamer

A schematic illustration of the delayed breakdown. When there is a spark in GEM triggered by alpha particles, the cathode will emit for some tile electrons due to the slow collected ions from the alpha track. This may cause another breakdown in the space between the GEM and the collector due to the combination of two effects: ion feedback and jets

Conclusions:

- Physics of discharge propagation is interesting and somehow quite unusuall:

Photo propagation

Semi-propagation

Delayed breakdown

- Practical way to avoid propagations:

between GEMs-distance increase

between GEM and collector-field decrease

- More studies should be done in connection to the LHC experiment and for cryogenic and RICH detectors

Any volunteers inside the WG-2?