Development of innovative micropattern gaseous detectors with resistive electrodes and first results of their applications

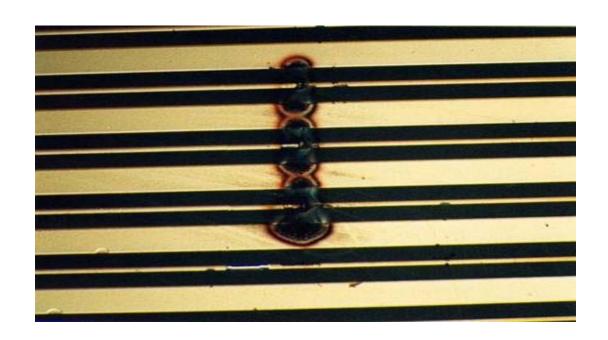
A. Di Mauro¹, B. Lund-Jensen², P. Martinengo¹, E. Nappi¹, 3, R. Oliveira¹, V. Peskov¹, L. Periale^{1,4}, P.Picchi^{1,5}, F. Pietropaolo^{1,6}, I.Rodionov⁷, J.C. Santiard¹

> ¹CERN, Geneva, Switzerland, ²KTH, Stockholm, Sweden ³INFN, Bari, Italy, ⁴INAF, Turin, Italy ⁵INFN, Frescati, Itali ⁶INFN, Padova, Italy ⁷Reagent Research Center, Russia

Rapid developments are currently taking place in the area of gaseous detectors of charged particles and photons. Parallel plate-type and wire-type detectors which dominated for years in high energy and space flight experiments are now being replaced by recent invented micropattern gaseous detectors.

The main advantage of these new detectors is that they are manufactured by means of a microelectronic technology which offers high granularity and hence a very good position resolution.

However, they are very fragile and could be easily damaged by sparks

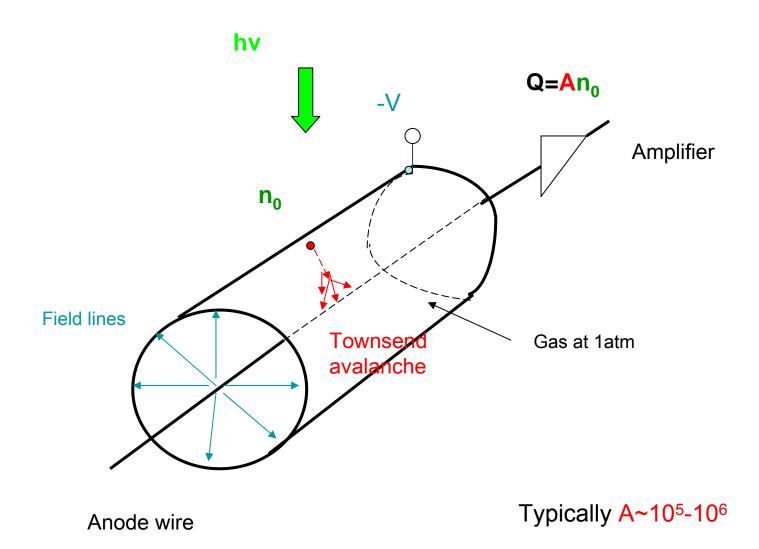


A photo of an MSGS damaged by sparks (L. Ropelewski, CERN detector seminar)

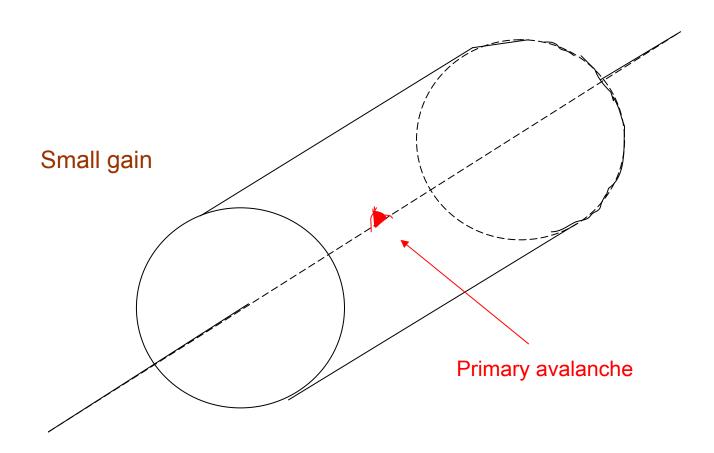
Physics of discharges

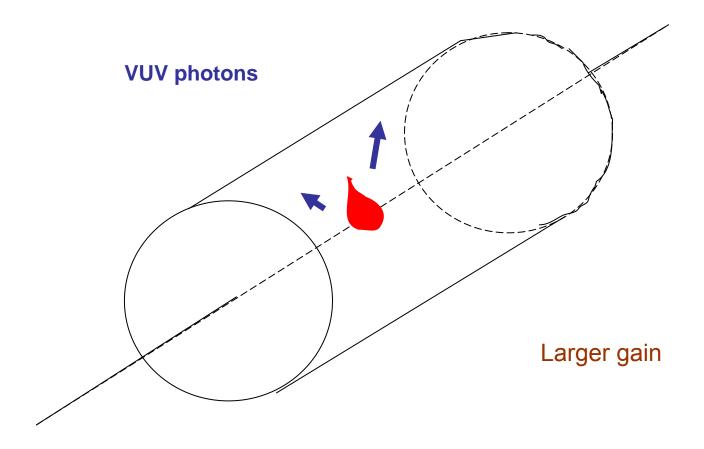
A simplified picture

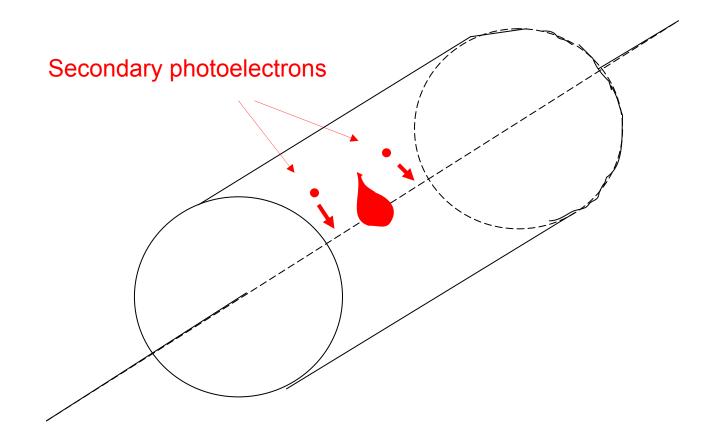
Example of a traditional gaseous detector - a single wire counter

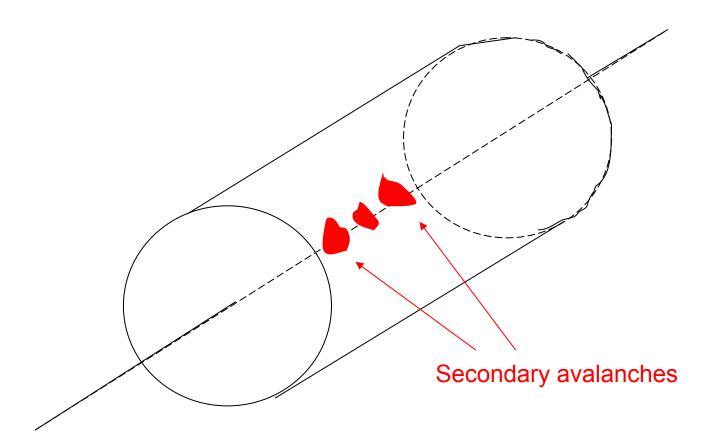


Discharges in thin wire detectors

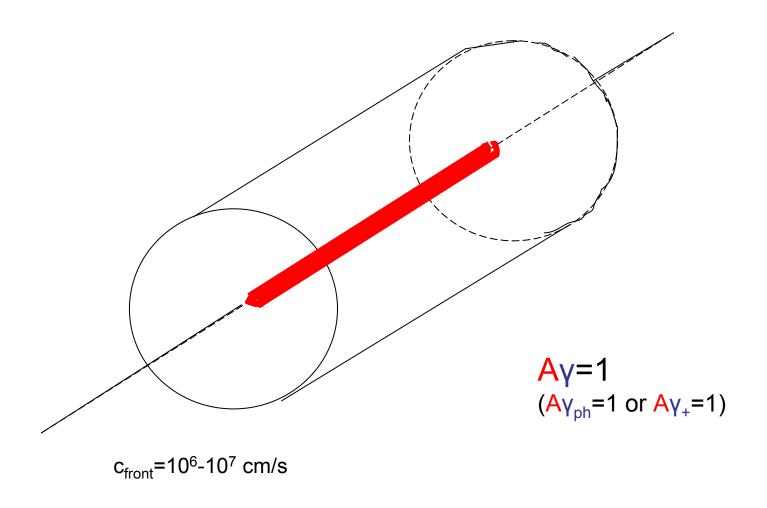






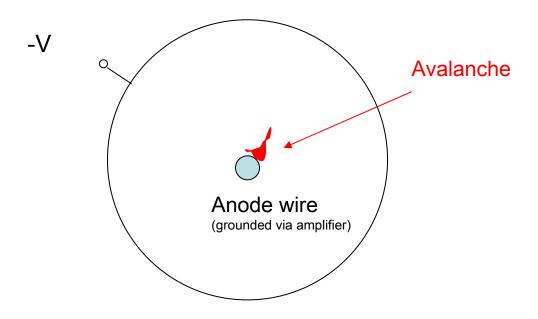


Geiger mode in quenched gases



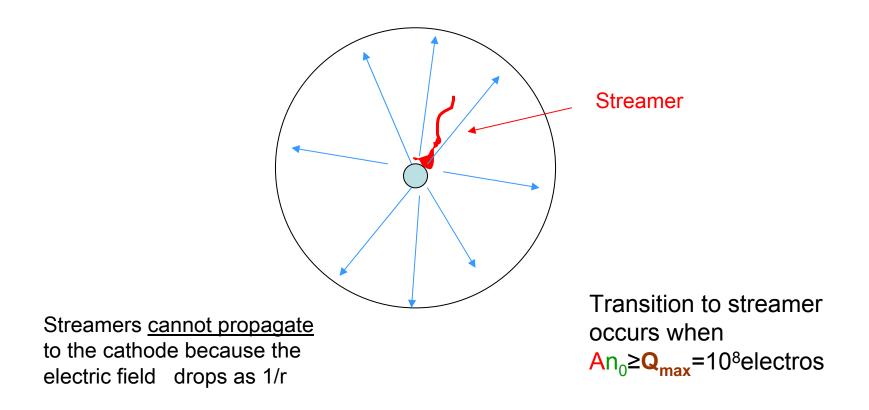
Geiger discharge is not damaging. One can observed signals~1V directly on $1M\Omega$ input of the scope (no amplifier is needed)

Discharges in thick wire detectors



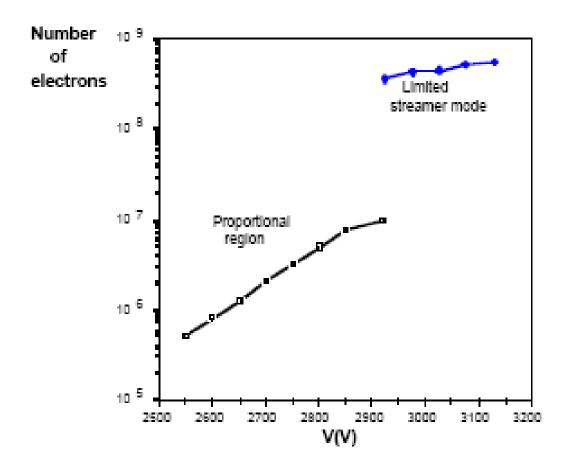
Cylindrical cathode

Self-quenched streamer



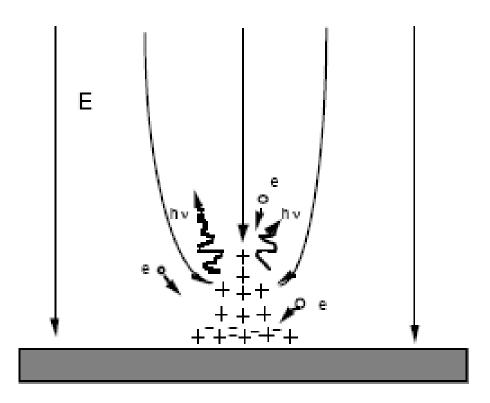
Strimers give huge amplitudes but the are not harmful as well

Signal's amplitude in proportional and streamer modes



P. Fonte et al., INFN Insrum. Bull, SLAC-Journal ICFA-15-1, 1997

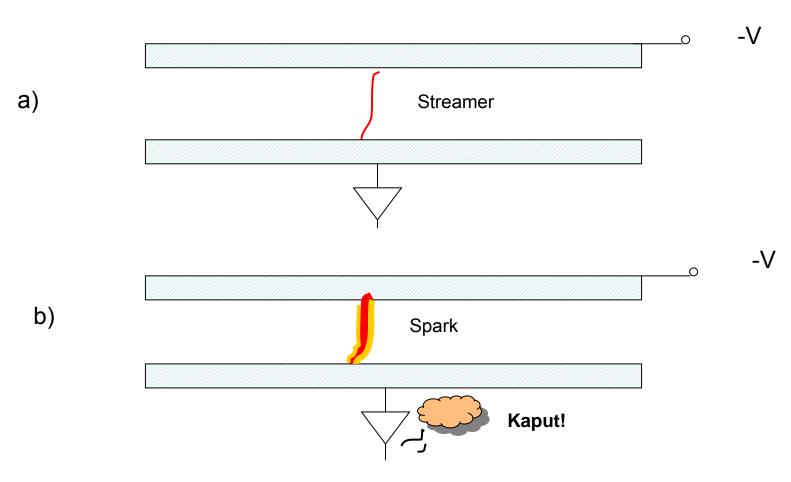
Discharges in parallel-plate geometry



 $An_0 \ge Q_{max} = 10^8$ electrons - so called Raether limit.

P. Fonte et al., INFN Instrum. Bull, SLAC-Journal ICFA-15-1, 1997

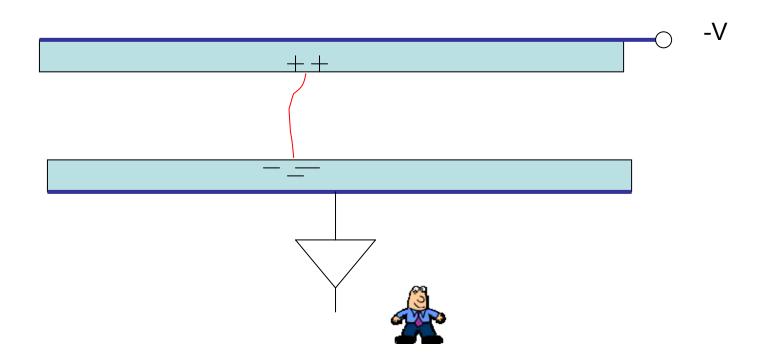
Streamer to spark transition in parallel-plate geometry: in the geometry with parallel field lines streamer propagated to the cathode and cause the spark



This discharge is <u>harmful</u>: all electric energy stored in the detector capacitance is released in the spark

There are limited number of ways to restrict the the discharge energy

One of them is the use resistive electrodes instead of metallic



Summary:

Ay=1(Ay₊=1 or Ay_{ph}=1)-slow mechanism $An_0=10^8 \text{ electrons-fast mechanism}$

What type of breakdown dominates in micropattern gaseous detectors?

Studies performed by P. Fonte et al., show that in most cases it is a fast breakdown (see: *IEEE Trns Nucl Sci 45,1998,244 and IEEE 46,1999,321*)

If it is a fast mechanism, will be Raether limit valid for micropattern gaseous detectors as well?

Actually the answer was unknown.

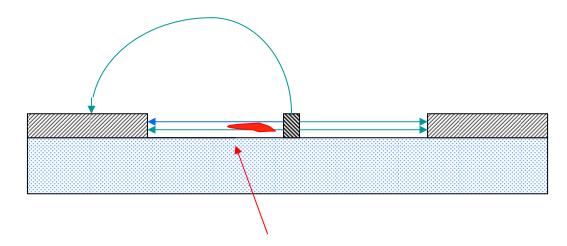
Note that Raether limit was established empirically by Raether for parallel-plate avalanche detectors with large amplification gaps (>a few mm) and for a few specific gas mixtures only.

What was well known that almost any type of micropattern gaseous detectors has maximum achievable gain of ~10⁴(with ⁵⁵Fe) and all attempts to overcome this limit failed

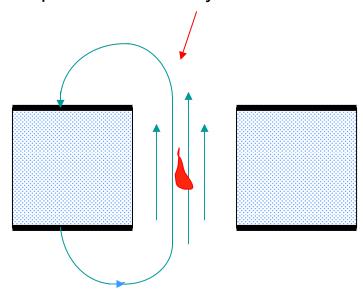
Only in ~1998 it was established that there is a charge limit in avalanche (similar to Raether limit), see: *Y. Ivanchenkov et al., NIM A422,1999,300.* If the total charge in avalanche overcome this limit $An_0 > q_{max} \sim 10^7$ electrons breakdowns occur.

It was an important new result

Why there are sparks in micropattern gaseous detectors?



Regions with parallel fields lines where any streamer, if appear, is unquenched and may reach the cathode

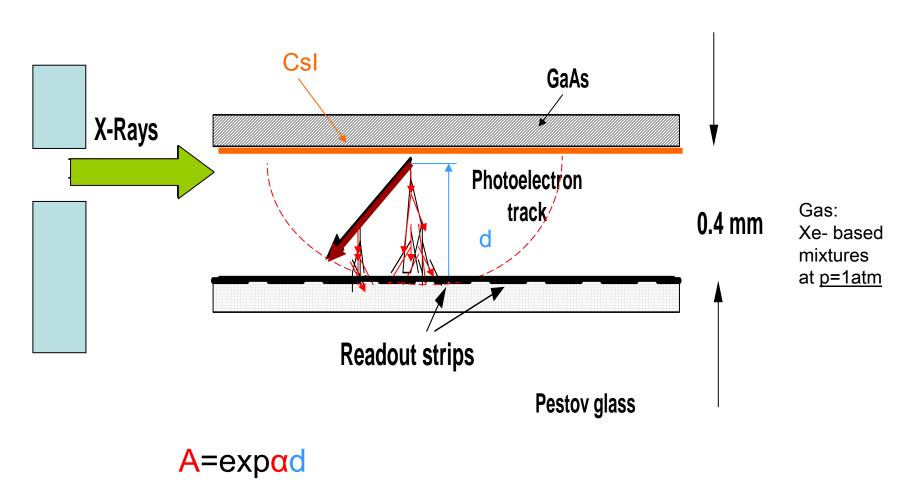


Because there are regions with parallel field lines, so streamers develop there by the same mechanism as in PPAC

First spark- protected micropattren gaseous detector-microgap RPC

Note: resistive (GaAs) cathode protects electronics in the case of occasional sparks

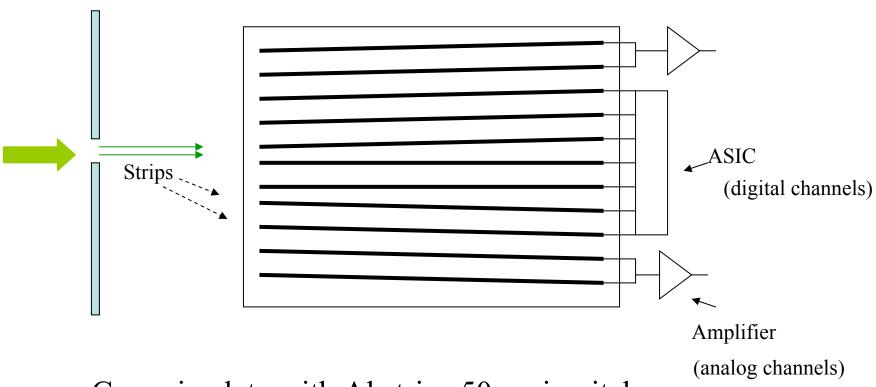
Collimator



There are several XCounter patents on this subject as well as on resistive electrodes micropattern gaseous detectors for X-ray imaging

Readout plate

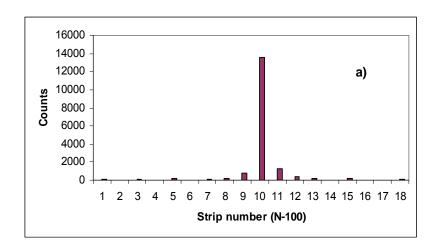
(Developed in collaboration with XCouner AB, Sweden)

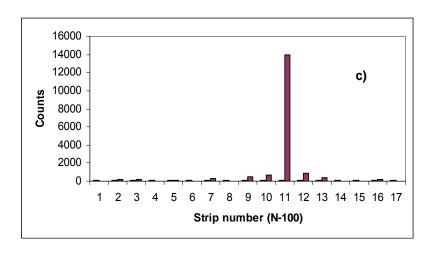


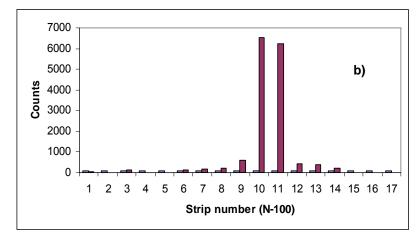
Ceramic plate with Al strips 50µm in pitch

(« focused » on 78 cm distance)

Position resolution of ~50 µm was achieved in digital mode at counting rate of 10⁵ Hz/ strip

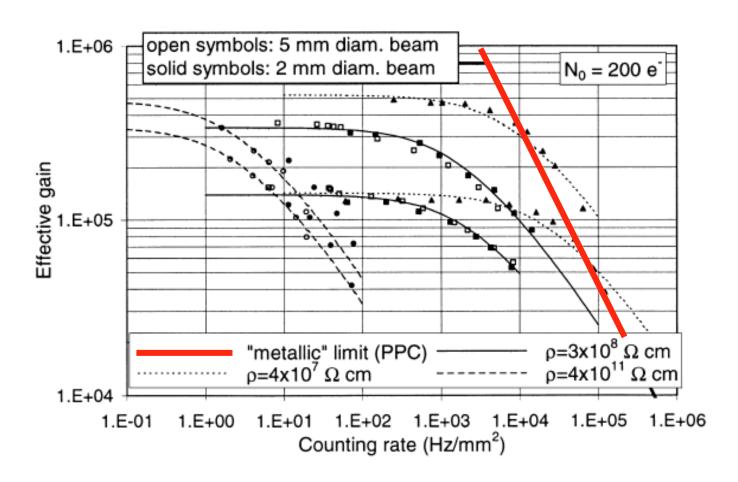




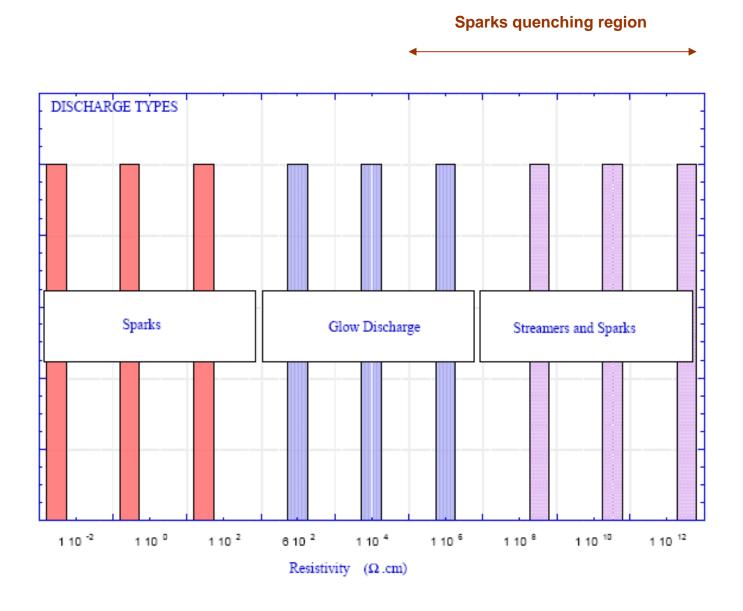


 Figures a,b,c show results of scanning a collimated x-ray beam (~30 µm) in the direction perpendicular to strips -the number of counts from various strips accumulated during 0.1 sec)

Optimization of the RPC electrodes resistivity



P. Fonte et al., NIM A413,1999,154



T. Francke et al., NIM A508, 2003,83

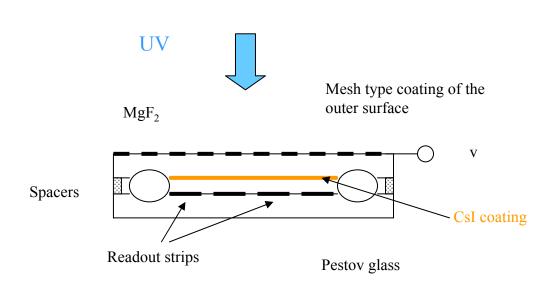
To demonstrate that resistive electrode approach dramatically improves the robustness of various micropattern gaseous detectors several different designs were constructed and tested in this work:

various microgap RPCs, Micropins detectors, CATs and GEM-like.

Depending on a particular designs the resistive electrodes were made from one of the following materials:

MgF₂, GaAs, graphite paint, Cu and Cr oxides

Photosensitive RPCs combined with Csl photocathodes



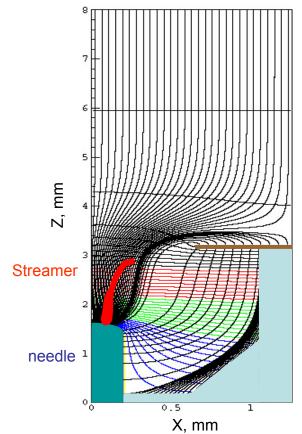
•This detector allows one at the same time high gains and high position resolutions to achieve

P. Fonte et al., NIM A553, 2005,30

The cathode was made from a 2 mm thick MgF₂ plate with an area of 40×40 mm². The inner surface, facing the anode, was coated by a 20 nm thick photosensitive CsI layer. The outer surface was in contact with a 0.2 µm thick Al mesh, manufactured by a microelectronic technology, forming cells with an open area of $23\times23 \,\mu\text{m}^2$ at $30 \,\mu\text{m}$ pitch. The anode of the RPC was made of Pestov glass covered by Cr strips placed at 30 µm pitch and the gas gap was 0.4 mm wide.

Array (5x5cm²) of needle-CuO electrodes-operating in gas volume (self-quenched streamer mode)

 Coupling of a TGEM with a needle array and oxided-Cu (or resistive) layer



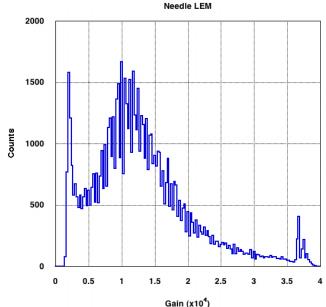
- Advantages:
 - much longer discharge path along hole walls
 - Streamers selfquenched by geometry
 - Resistive coating additionally ensures spark protection

- Disadvantages:
 - Critical adjustment of needle height and shape: affecting gain uniformity

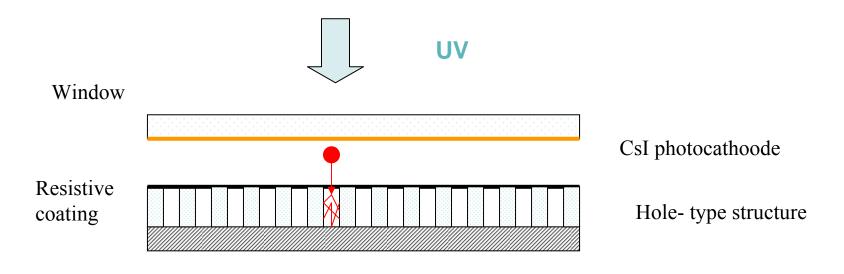
Top electrode (CuO)

Preliminary results: gains >> 10⁴ were easily reached before transition to the selfquenched streamers Poor resolution (~50%FWHM)

Vetronite



Resistive electrode "CAT"



Metallic readout plate

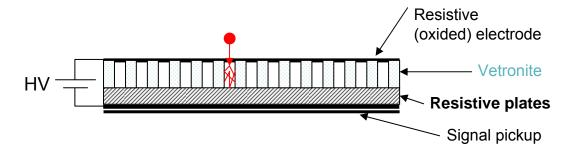
As a hole type structures we have tested were G-10 pate 1 –2 mm thick with drilled holes (0,3 –1 mm in diameter, depending on a design). The Cu coating of the G-10 was almost fully removed and both surfaces were covered with graphite paint used in the usual RPCs.

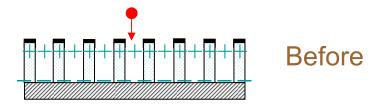
I. Rodionov et al., Presented at the IEEE Nucl. Sci., 2005

Hybrid CAT detector: CuO coating combined with true resistive electrodes for ensuring the streamer mode of operation

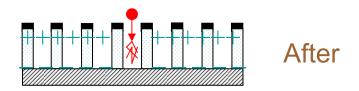
- Hybrid RPC concept:
 - Resistive layer "quenches" the electron avalanche
 - Vetronite holes "limit" the photon propagation and afterpulses
- Disadvantages
 - Choice of resistive material critically depending on rate and gain (resistive materials from Quadrant Technology, ranging from 10⁵ to 10¹⁵ Ω-cm, under investigation)

Preliminary results: gains > 10⁴ easily reached in a single step before the transition to a streamer mode





A charged particle entering the hole induces an avalanche, which develops into a spark. The discharge is quenched when all of the locally (~1 hole) available charge is consumed.

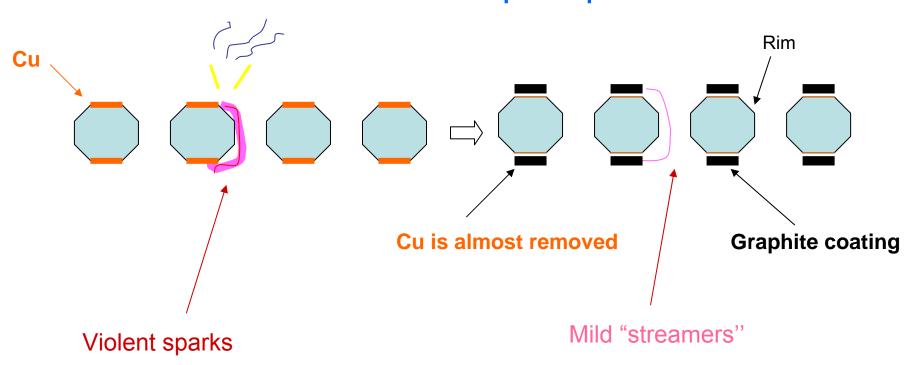


The discharged area recharges slowly through the high-resistivity plates.

A. Di Mauro et al., presented at the IEEE Nucl. Sci. 2006

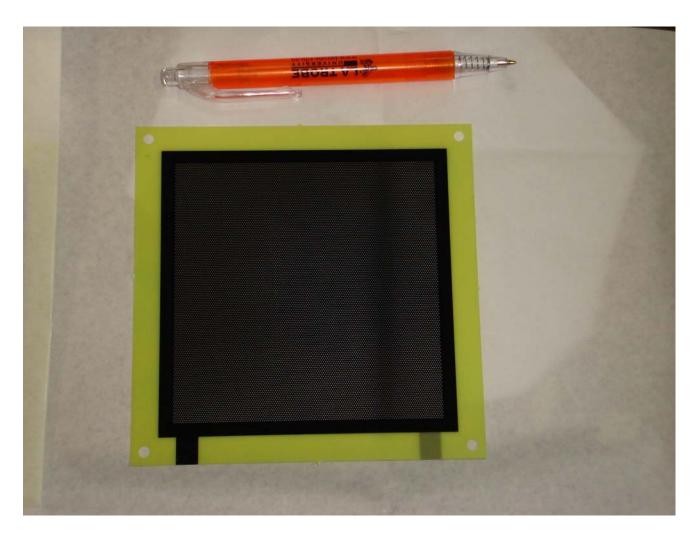
Resistive coating of the TGEM electrodes (RETGEM)

can make detector spark protected:



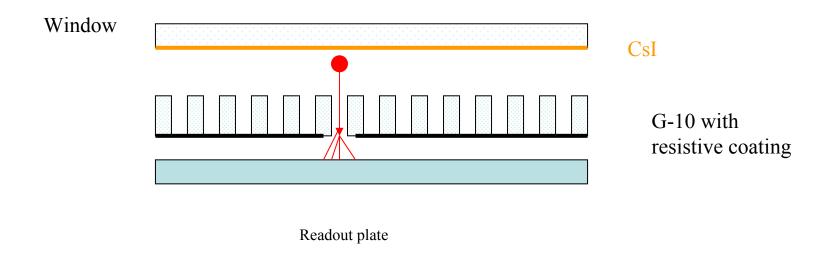
Surface resistivity: graphite coating ~500kΩ/□, CuO and CrO- ~a few GΩ/□

Photo of 10x10 cm² prototypes



Design feature: coating around the holes was removed

« Hybrid RPC »



As a readout plate we used either a ceramic plate $40x40 \text{ mm}^2$ covered with Al strips $50 \mu \text{m}$ in pitch (see above) or a pixelizd readout plate (see next fig). The readout plate was placed 0,4-1 mm below the anode of the G-10. Gas multiplication could take place either in the holes of the G-10 plate or in the gap between the G-10 anode and the readout plate. The advantage of this approach is that the photocathode is geometrically shielded from the light produced by the avalanches and this allows better suppression of feedback pulses and as a result higher avalanche gains ($>10^6$) were achieved. The resistive coating in turn protected the device and amplifiers from the occasional discharges.

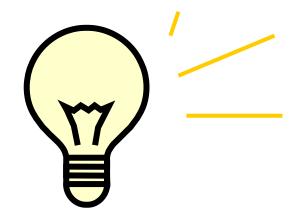
J. M. Bidault et al., Nucl. Phys. B (proceedings supplements) 158, 2006, 199

Conclusions from these studies:

Thin (< 3 µm) resistive coating (CuO, CrO) makes detector more robust, but do not quench sparks to a "streamer" level.

Thick resistive coating (>10 µm) provides full spark protection

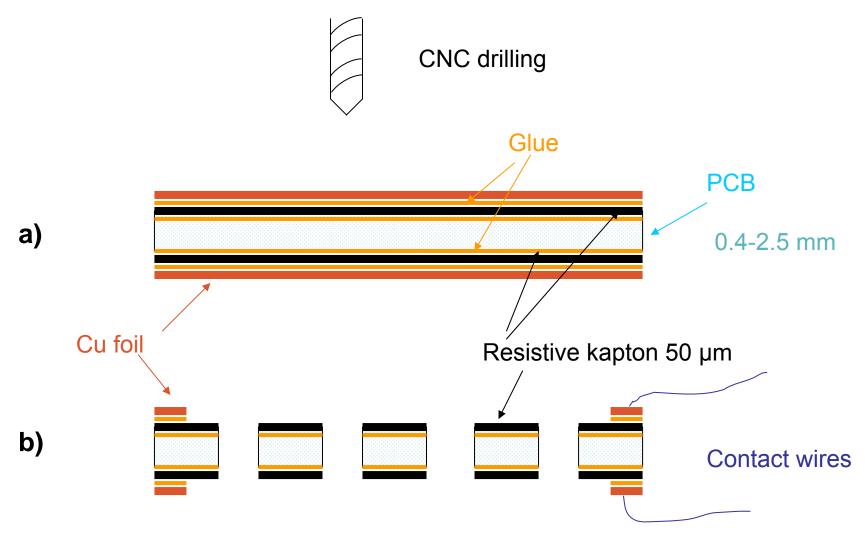
Certainly, no only the graphite coating but also many other resistive layers could be used to achieve the same effect. The most important issue in the production of such types of detector is to use a technology which ensures high quality and reproducibility of resistive coatings during the mass production.



New (last months) developments:

Thick GEM with kapton resistive electrode

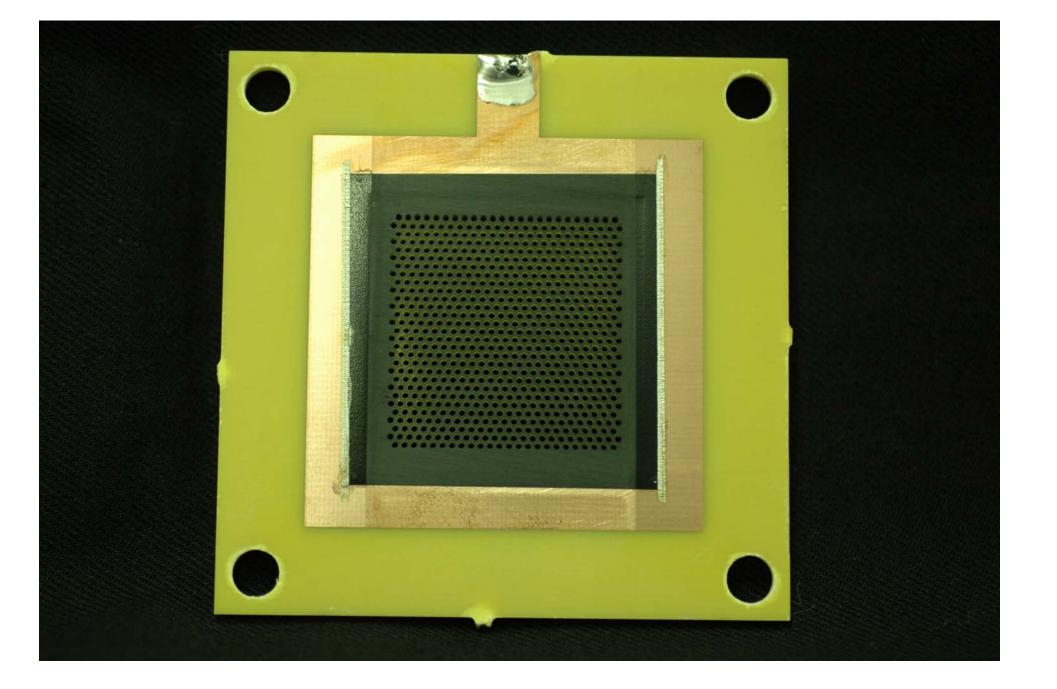
For more details see: R. Oliveira et al., Preprint/Physics/0701154, Jan. 2007

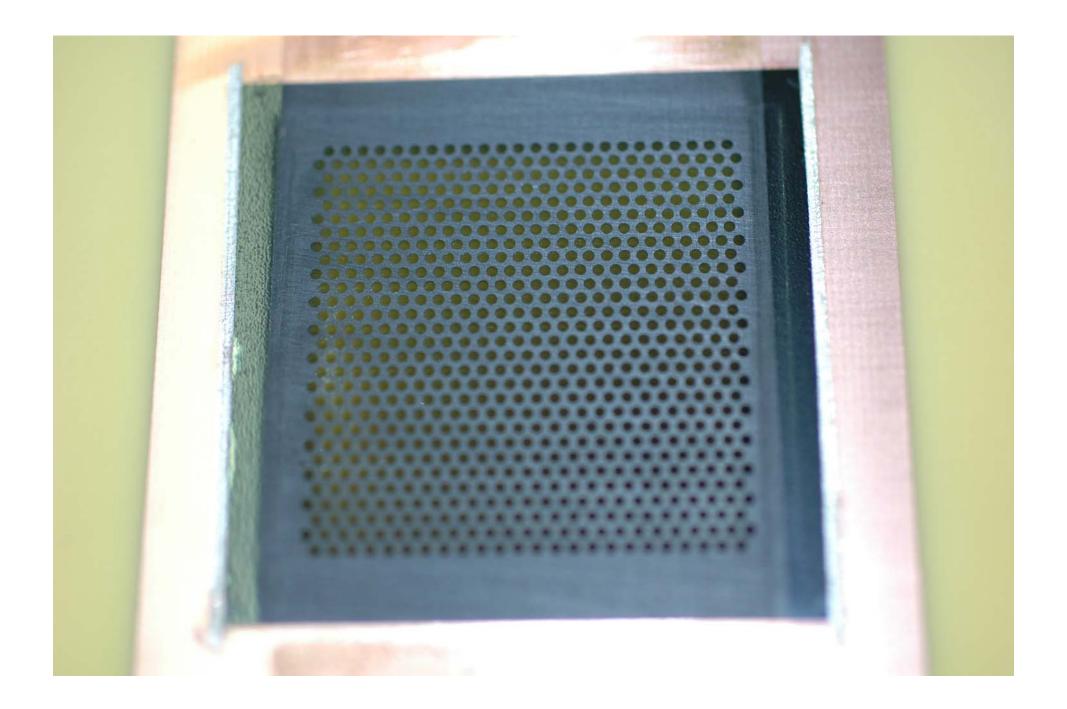


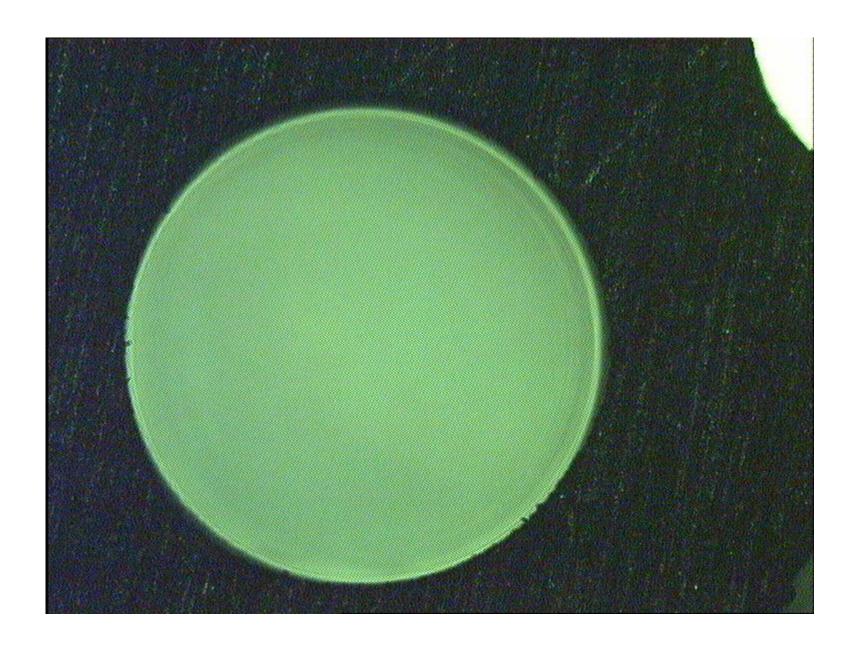
Diameter of holes :0.3-0.8 mm, pitch 0.7-1.2 mm Active area 30x30 and 70x70 mm²

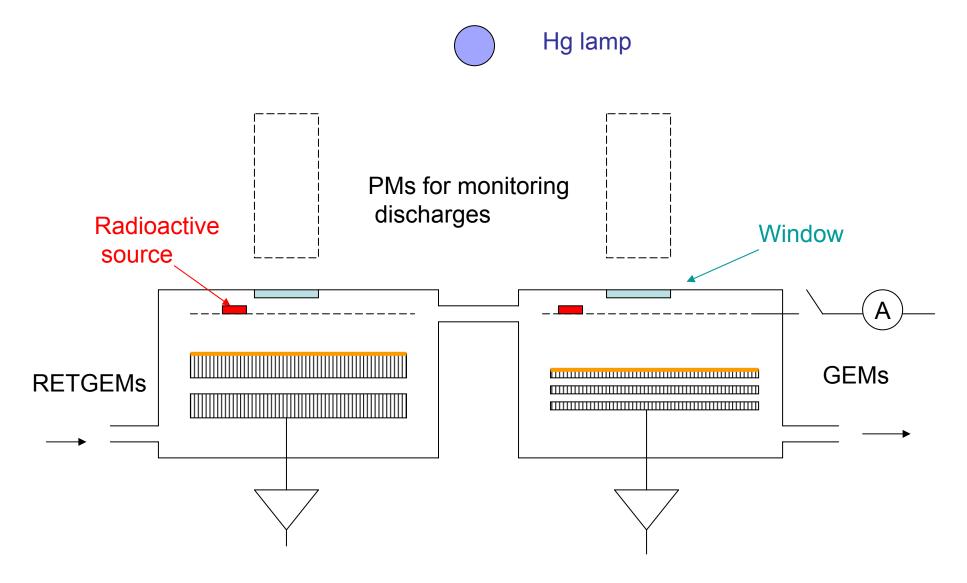
<u>Important feature</u>: for the first time the resistive electrodes have not any metallic substrate

Surface resistivity 200 - 800 kΩ/□ (100XC10E5)



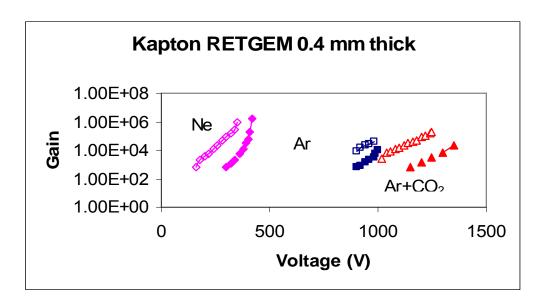




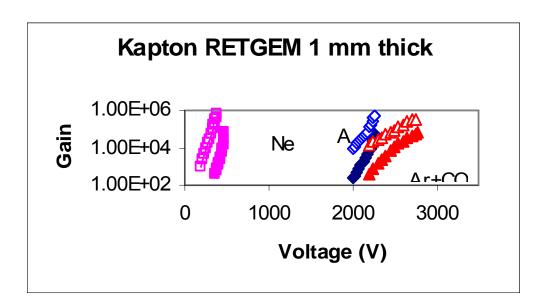


Charge- sensitive or current amplifiers

Gains of single (solid symbols) and double (open symbols) kapton RETGEMs

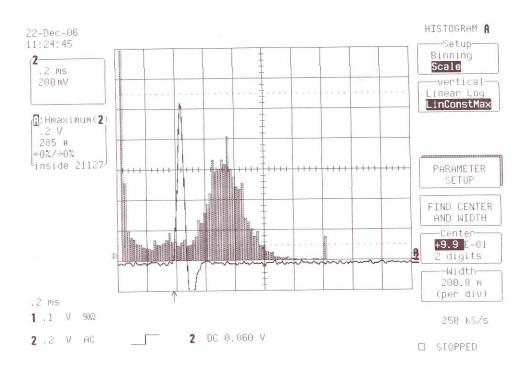


Holes 0.3 mm in diameter on a 0.7 mm pitch.



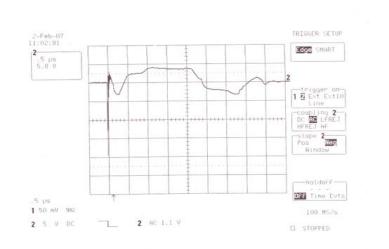
Holes 0.8 mm in diameter with a 1.2 mm pitch

With double RETGEMs Raether limit for "macroscopic" detectors was reached: An₀~10⁸ electrons



Energy resolution of ~33% FWHM was achieved for uncollimated ⁵⁵Fe at gains of 10³-10⁴. At higher gains the detector may lose the proportionality and sometimes even works in "Geiger" mode

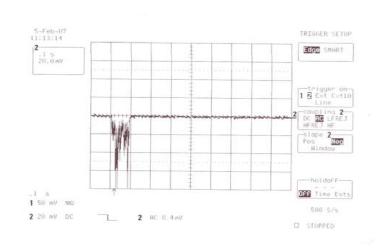
Measurements relative sparks energies with a current amplifier

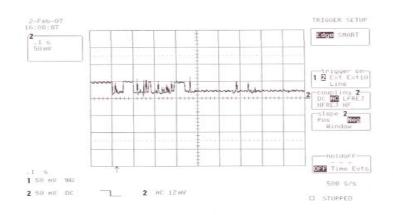


Metallic TGEM 1mm thick, 100 Ω resistor

Conclusions:

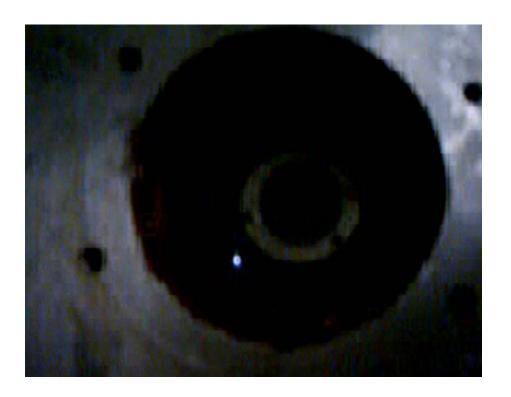
- 1) In Ar spark current in kapton RETGEM is almost 1000 times less
 2) In kapton RETGEM initial "sparks"/'streamers" with further increase of the voltage may transit to glow discharge
- 3) Either sparks or streamers damage the detector or electronics





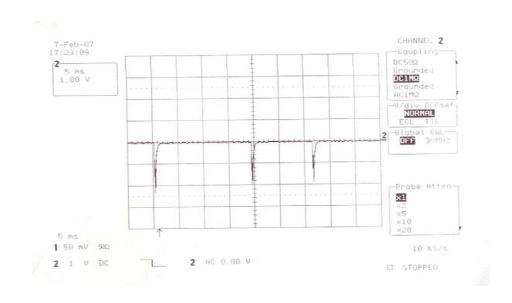
Kapton RETGEM 1 mm thick, I $k\Omega$ resistor

A photo of a continuous discharge in RETGEM

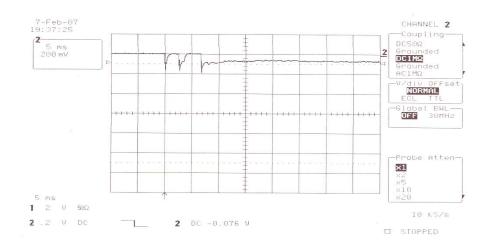


In several cases, we initiated continuous glow discharges in the RETGEM for a total duration of 10 minutes. After the discharge was stopped (by reducing the voltage on the detector's electrodes), the RETGEMs continued to operate without any change in their characteristics, including that of the maximum achievable gain.

Signals from PM detecting light from sparks



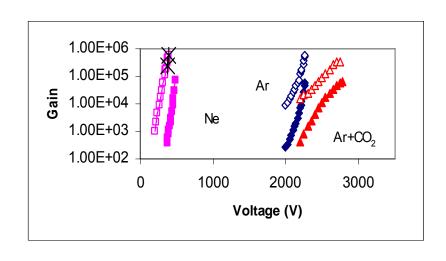
The best CrO RETGEM



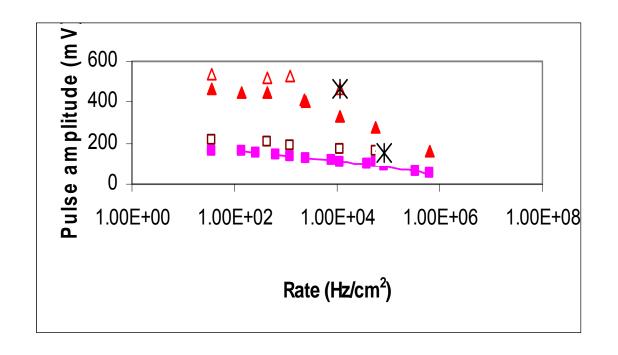
Regular Kapton RETGEM

RETGEM with kapton electrodes coated with a CsI layer

We discovered that a kapton RETGEM with the cathode coated by a CsI layer can operate stably at high gains and the QE at λ=120 nm was ~30%



Rate characteristics



Open symbols: CrO RETGEM Filled symbols: kapton RETGEM

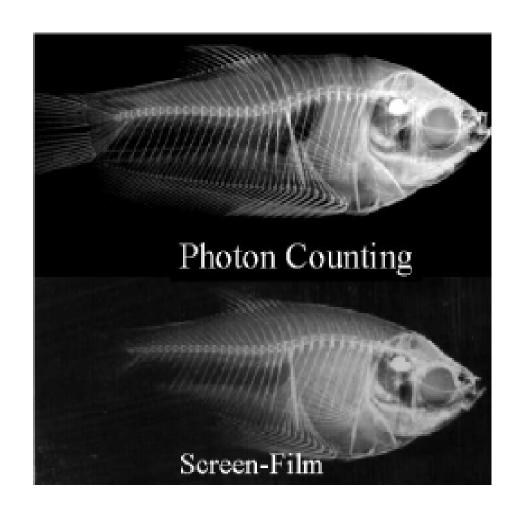
<u>Conclusions</u>: in the case of the CrO RETGEMs sparks may appear at high rate. In contrast, the kapton RETGEMs never went to discharges at high rates; charging up effect plays a stabilization role

Applications

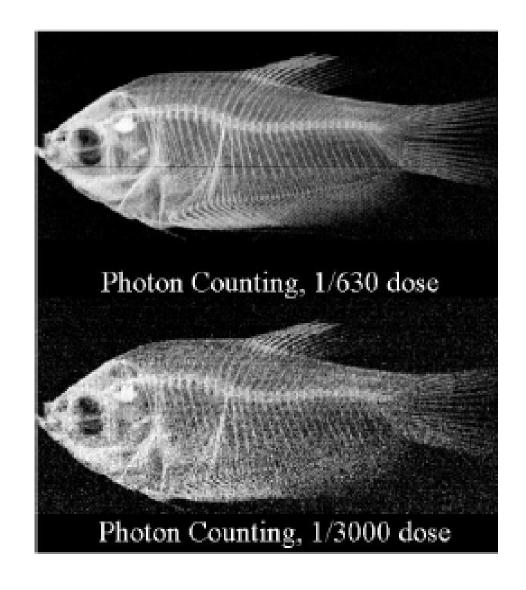
A modified version of parallelplate micropattern detector was developed for X-ray imaging

T. Francke et al., NIM A471,2001,85

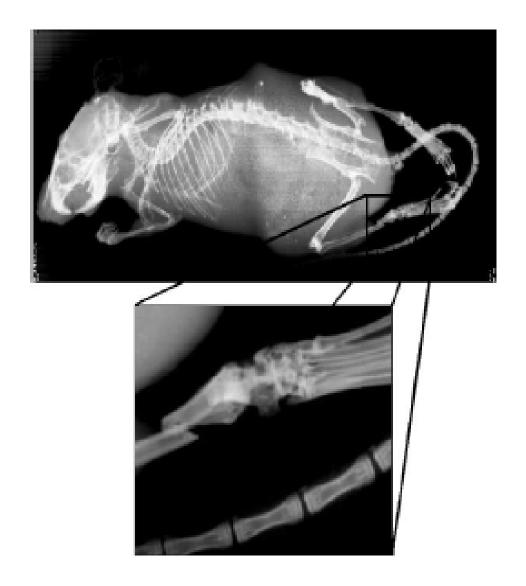
XCounter images



T. Francke et al., NIM A471, 2001, 85

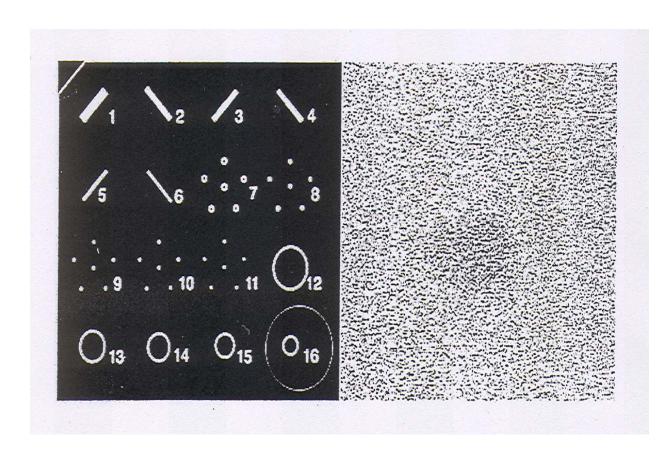


T. Francke et al., NIM A471, 2001, 85

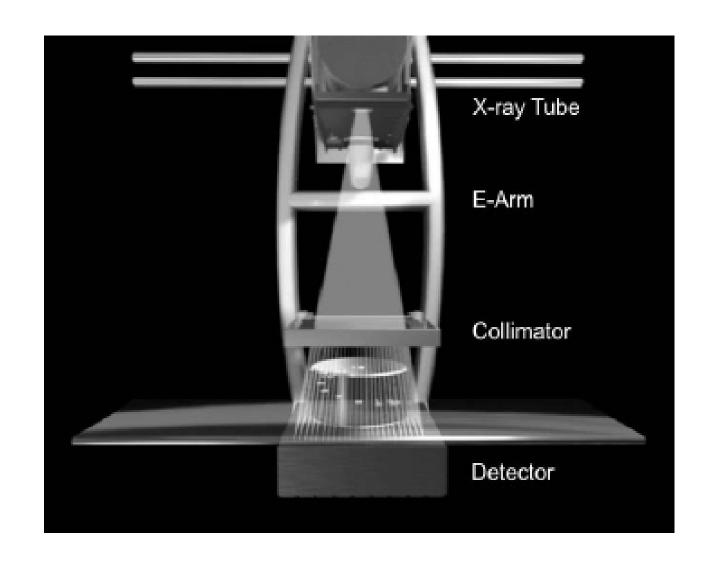


For more images see XCounter web page: http://www.xcounter.se/

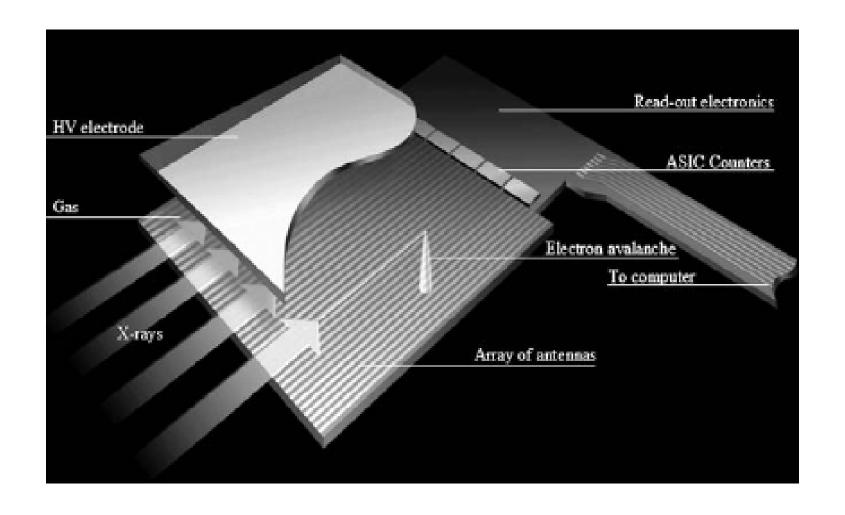
Mammographic phantom



Low contrast object # 16 was possible to resolve



A. Maidment et al., Proc. of SPIE's International Symposium on Medical Imaging 2006, 11-16 February 2006, San Diego, USA

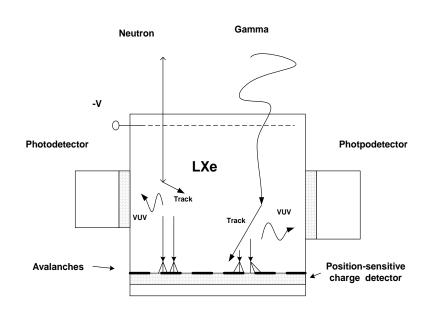


A. Maidment et al., Proc. of SPIE's International Symposium on Medical Imaging 2006, 11-16 February 2006, San Diego, USA

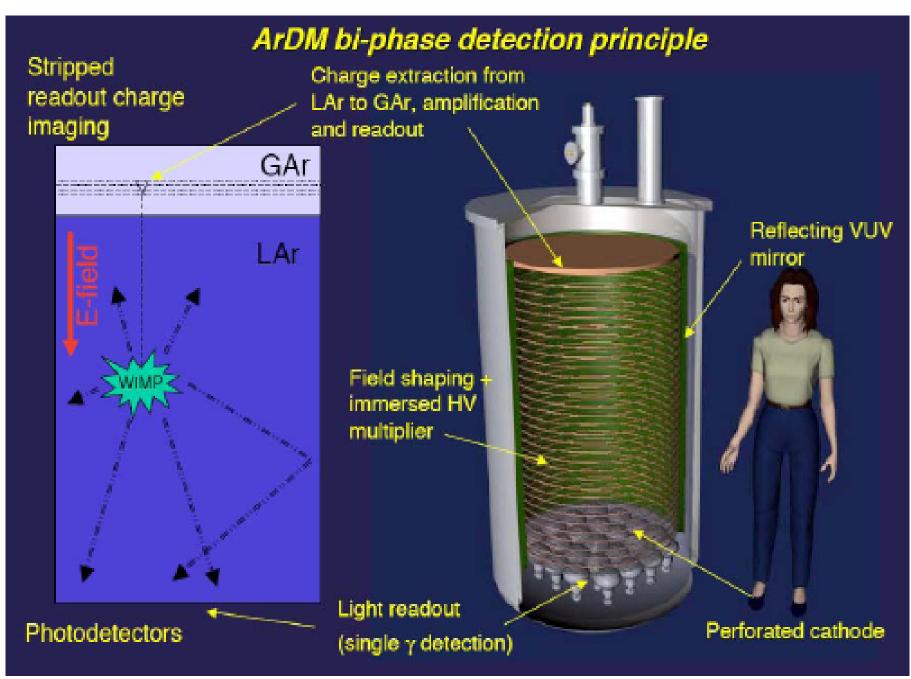
Photosensitive RETGEMs

A special focus in our further developments was directed towards detectors that are sensitive to UV and visible light, which, in the case of single photon detection, should operate at exceptionally high gains≥10⁵ and thus have an elevated risk of sparks.

The principle of the LAr/Xe TPC

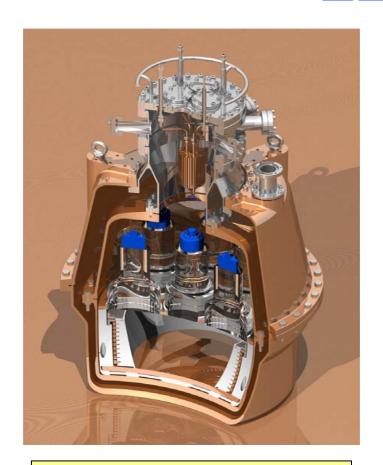


• The detection of primary scintillation light in combination with the charge or secondary scintillation signals is a powerful technique in determining the events "t=0" as well as particle/photon separation in large mass TPC detectors filled with noble gases and/or condensed noble gases.



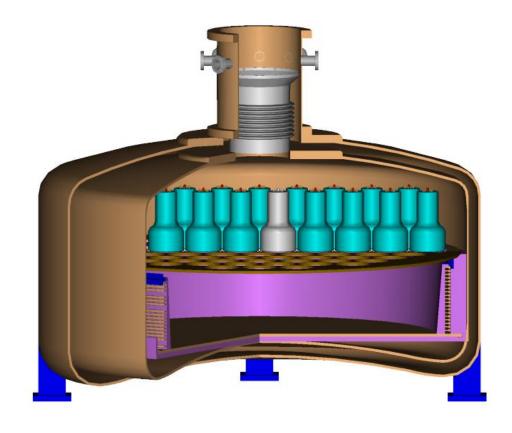
A. Rubbia detector

ZEPLIN II → ZEPLIN IV



The latest design as at DM2002

 $30 \text{ kg} \rightarrow 1000 \text{ kg}$



FYI:

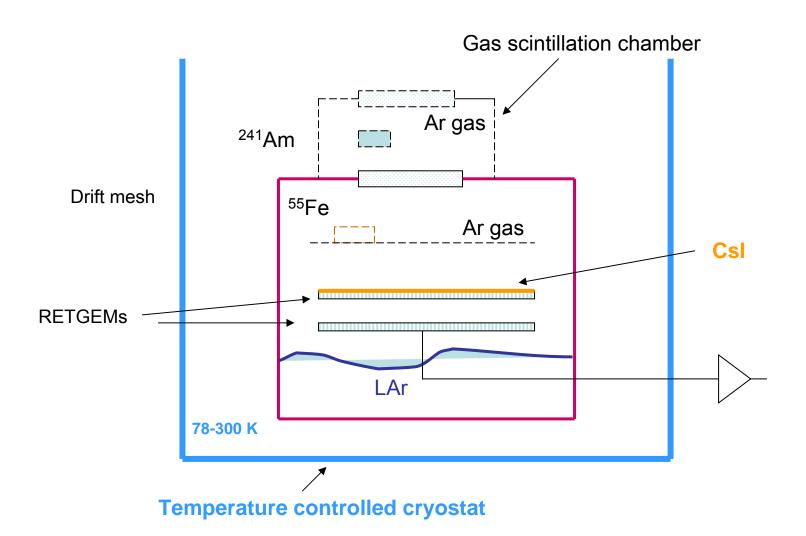
Our earlier results on operation of GEMs, CPs and TGEMs coated with CsI layer at cryogenic temperatures can be found in:

- L. Periale et al., IEEE Nucl. Sci., 52, 2005, 927
- L. Periale et al., NIM, A535, 2004, 517
- L. Periale et al., NIM, 56, 2006, 381 as well as in several Phyis. Preprints

We heard today about the first attempt of Novosibirsk group to operate CsI coated GEM at LAr temperatures. So these developments are going well

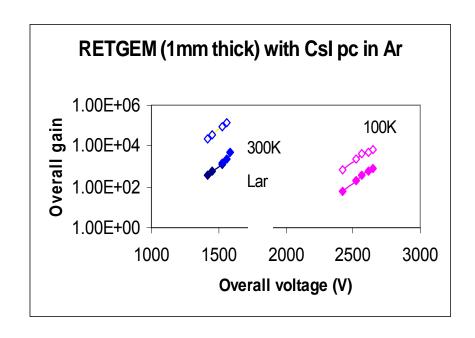
However, the typical problem is that at high gas densities the maximum achievable gain of these detectors dropped and thus <u>risk of sparks increased</u>

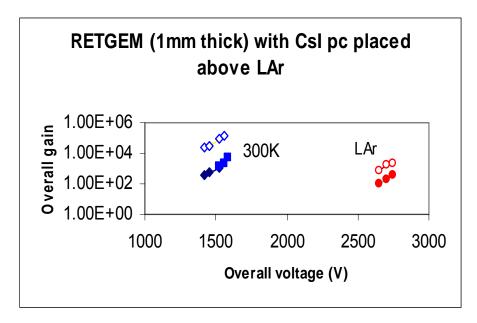
Chamber design for study of operation of RETGEMs at cryogenic temperatures (CERN, ICARUS group)



For more details see: Preprin/Physics/0612166, Dec.2006

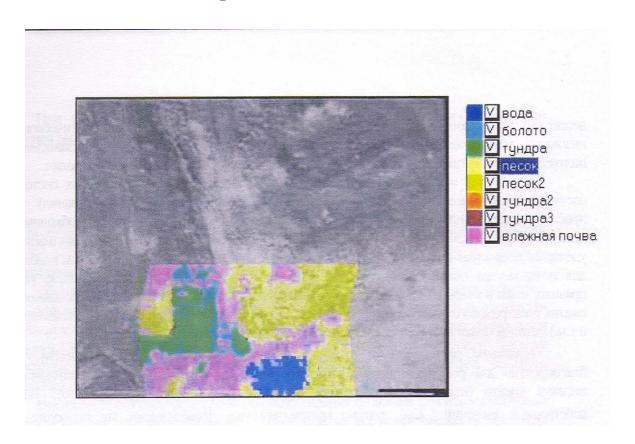
Gains of single and double RETGEM operating at cryogenic temperatures





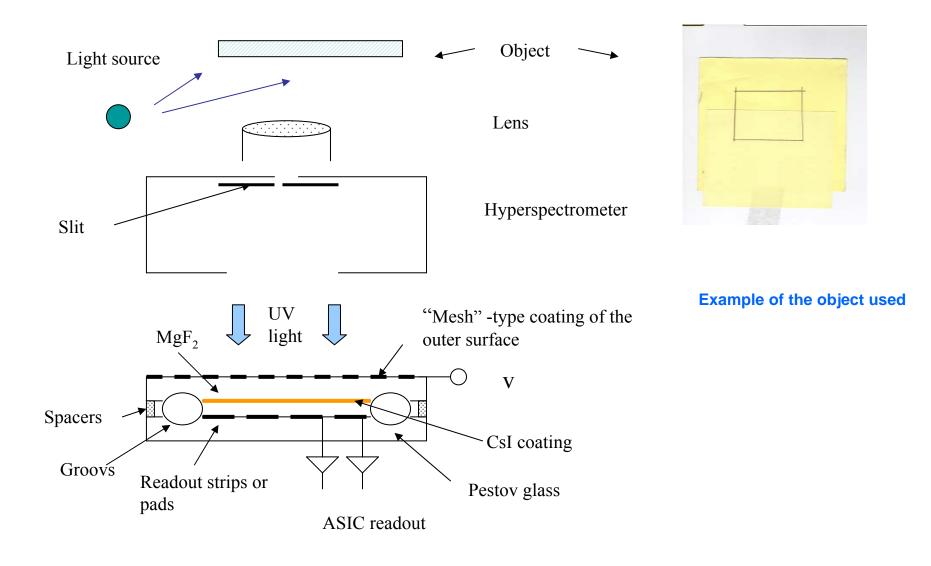
More info about operation of RETGEMs coated with CsI layer at cryogenic temperatures could be find in: *Preprint/Physics/0612166 Dec.2006*

Environmental applications: results in IR and visible spectra obtained with MCPs



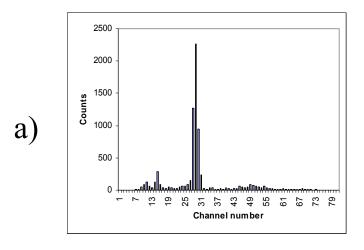
- •The Reagent Research Center in Moscow developed and used this method for the analysis of earth surface.
- For example, it is used now for Gasprom Inc. tasks: observation of oil pipes and spills from planes and helicopters

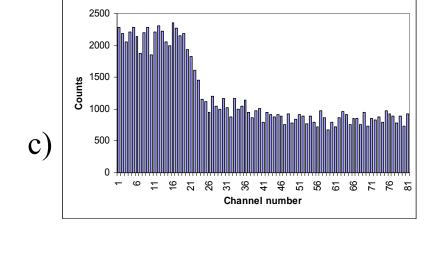
N.N. Khrenov et al., Science and Technique in Gas industry, 2-3, 2001, 37

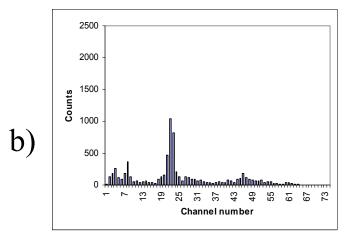


J.-M. Bidault et al., Preprint/Physics/0612014, Dec. 2006

1D hyperspectroscopic images





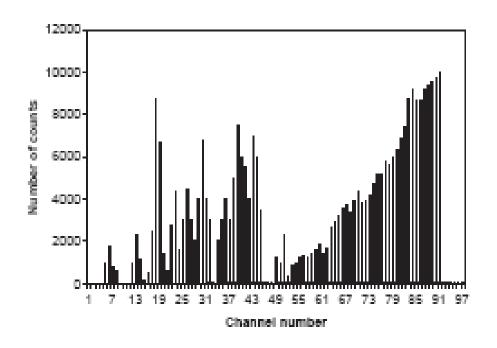


c) a scan across the dark and light sticker (the RPC was turned on 90°).

Note: with a solar blind PMs it was impossible to detect this radiation due to the long wavelength background

a) "dark " yellow sticker, b) " light " yellow sticker

Spectra of H₂ lamp (105-150 nm) recorded with a microgap RPC



T. Francke et al., NIM A533, 2004, 163

UV imaging in daylight conditions

Industrial applications: visualisation of corona discharges and sparks at day-light conditions

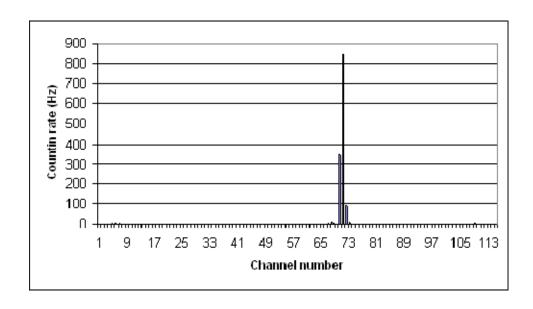


Example: a UV image of the HV corona discharge obtained with image intensifies combined with a narrow band filters. During the day time this corona is practically undetectable in the visible region of spectra

In spite of impressive UV images which one can obtain with image intensifiers combined with narrow-band UV filters these detectors have several drawbacks, for example: small size of the MCPs used, high noise(bialkali photocathodes), bad transmission of narrow band filters for UV (typically only 10%)

See: http://www.daycor.com

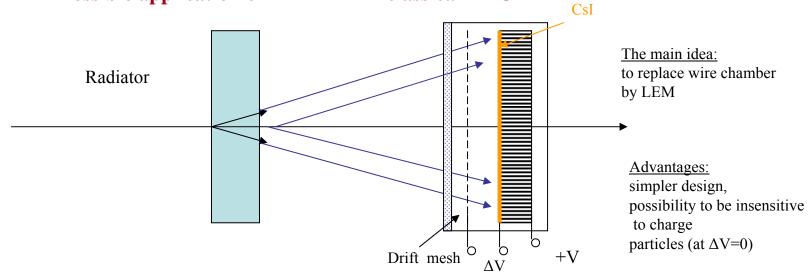
Recent results obtained with photosensitive RETGEMs



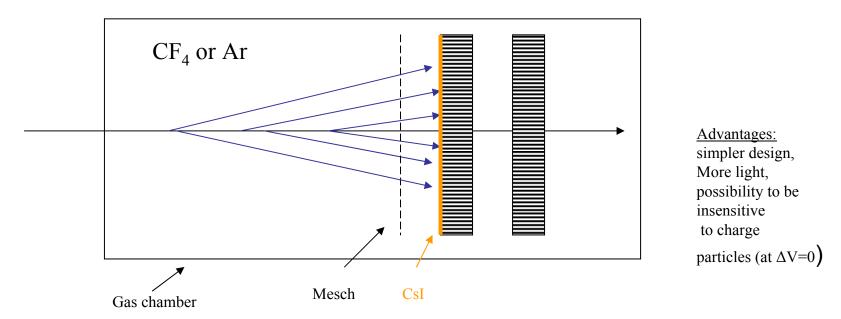
Digital image (number of counts vs. readout strip number) of the candle placed 15 m away from the photosensitive RETGEM combined with an optical system. Small counting rate at the channel # 5-7 was caused by 100W lamp placed close to the candle.

Recently with RETGEMs filled with photosensitive vapours we succeeded to obtain images of small flames (~ 5x5x5 cm³) placed 70 m away from the detector in open air on a sunny day (*Preprint/Physic/0612014, Dec. 2006*)

Possible application of RETEM in "classical' RICH



New idea: radiator and the detector are placed in the same gas volume



Conclusions:

- We have developed and successfully tested several designs of micropattern gaseous detectors with resistive electrodes
- Resistive electrodes make detectors spark- protected and thus very robust and reliable in operation
- We discovered that all resistive layers used in these studies (including kapton), that are coated with photosensitive layers, such as CsI, can be used as efficient photocathodes for detectors operating in a pulse counting mode.
- The detectors were already used for several applications, for example RETGEMs coated with CsI layer were used for detection of the scintillation light from noble liquids
- Arising from our results, we believe that micropattern gaseous detectors with resistive electrodes will open new avenues in future developments and applications.