Gaseous Photo-Multipliers: Lessons from the past

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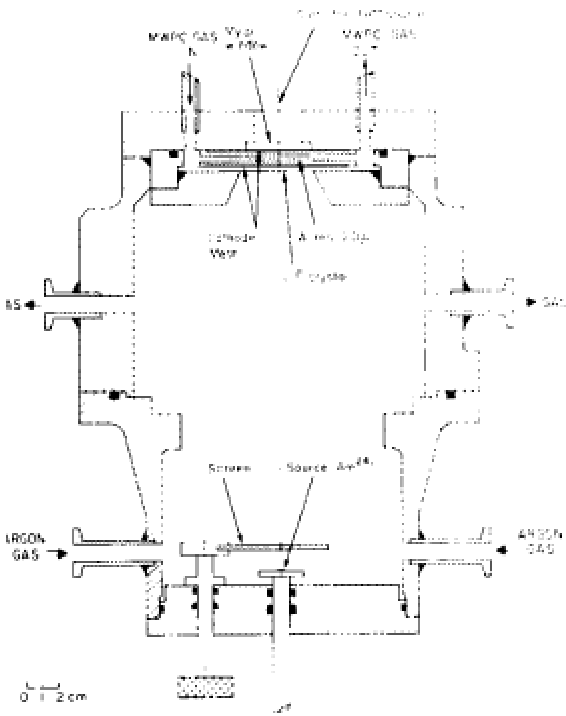
Photosensitive MWPC and PPAC were used for the detection of photons since a long time

Efforts to develop gaseous PMs started a at the end on 70's, they were triggered by an invention of MWPC

The motivation was
to develop:
large-area (no mechanical constrains on the window size),
cheap and
position- sensitive (at this time position sensitive vacuum or solid state PMs did not exist!) photodetectors

First photosensitive MWPC were developed at the same time by J. Seguinot, T Ypsilantis (*NIM 142,1977,377*) and G.Bogomolov, Yu. Dubrovski, V. Peskov (*Instr. Exp. Tech. 21,1978,779*)

Photosensitive MWPC for **RICH applications** (benzene vapors, λ<135nm)



(Submitted in December 1976)

Photosensitive MWPC for **plasma applications** (toluene vapors , λ<146nm)

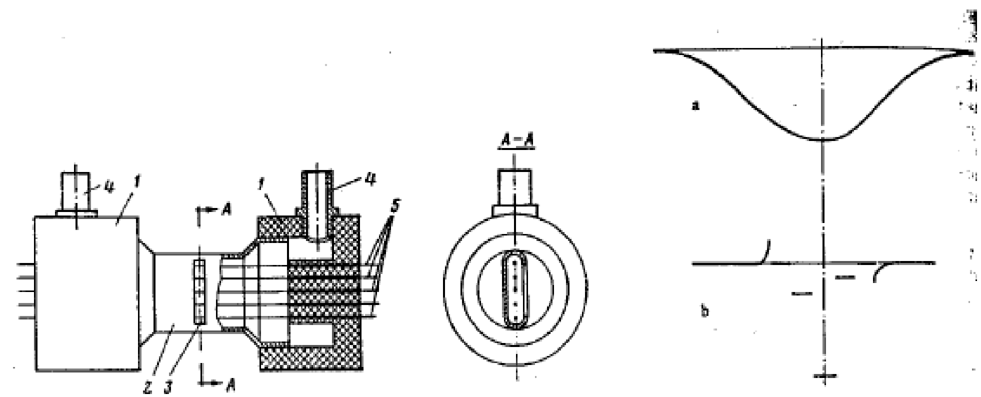


Fig. 1

Fig. 2

Fig. 1. Schematic sketch of a five-wire counter. 1) Plastic insulators; 2) copper anode; 3) window of the counter; 4) fitting for injection of working mixture; 5) anodes.

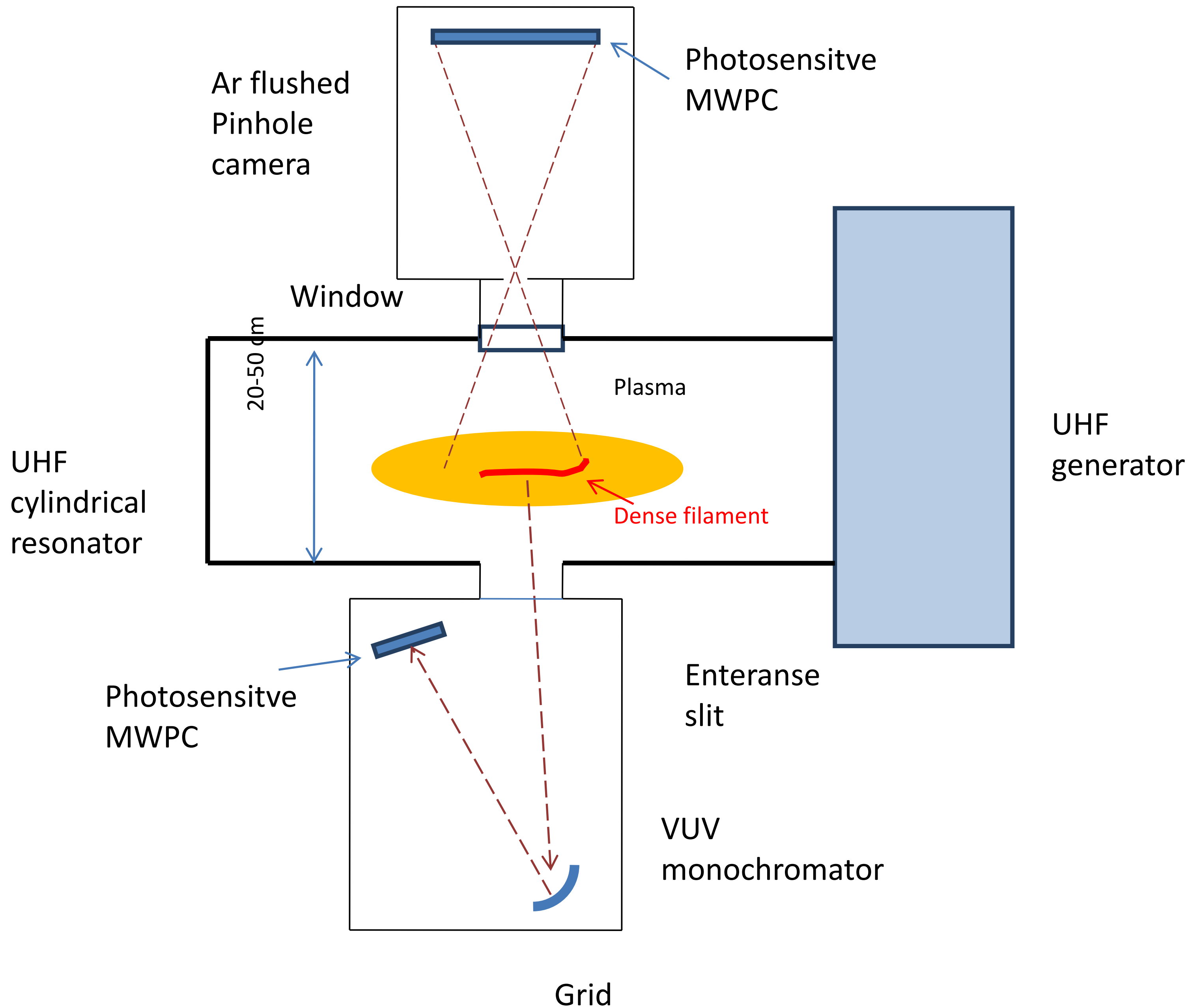
Fig. 2. Oscillograms of signals from the dissector (a) and counter (b).

(Submitted January 1977)

These two papers open new possibilities in experimental techniques and applications

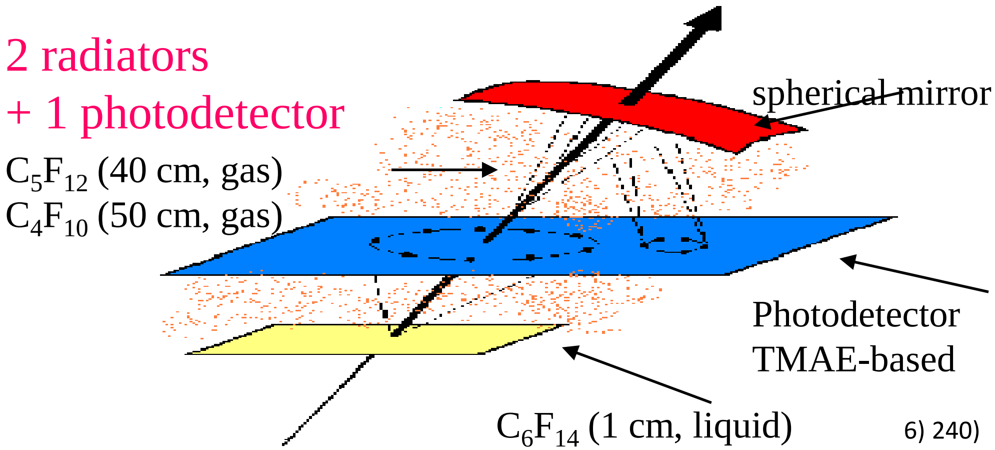
Moscow group used photosensitive MWPCs for spectral measurements and for plasma visualization in the UV region.

P.L. Kapitza plasma



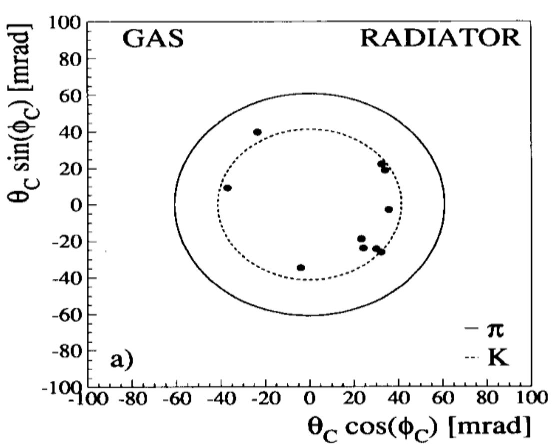
On a much more large scale photosensitive MWPCs were used in in Cherenkov detectors

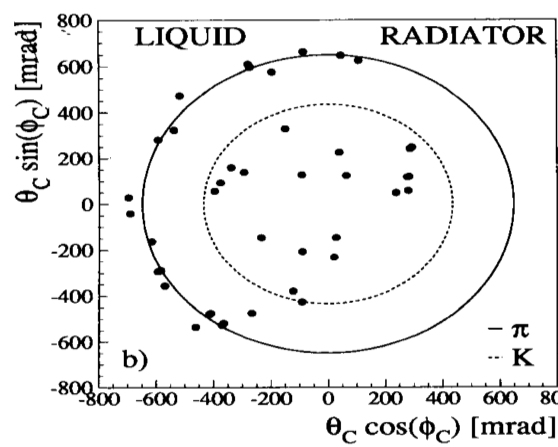
DELPHI RICH



A RICH with two radiators to cover a large momentum range. π/K/p separation 0.7 - 45 GeV/c: DELPHI and SLD

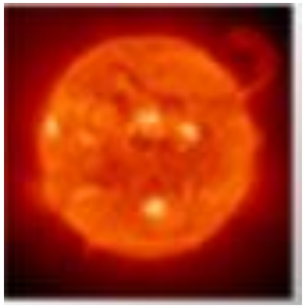
Two particles from a hadronic jet (Z-decay) in the DELPHI gas and liquid radiator + hypothesis for π and K



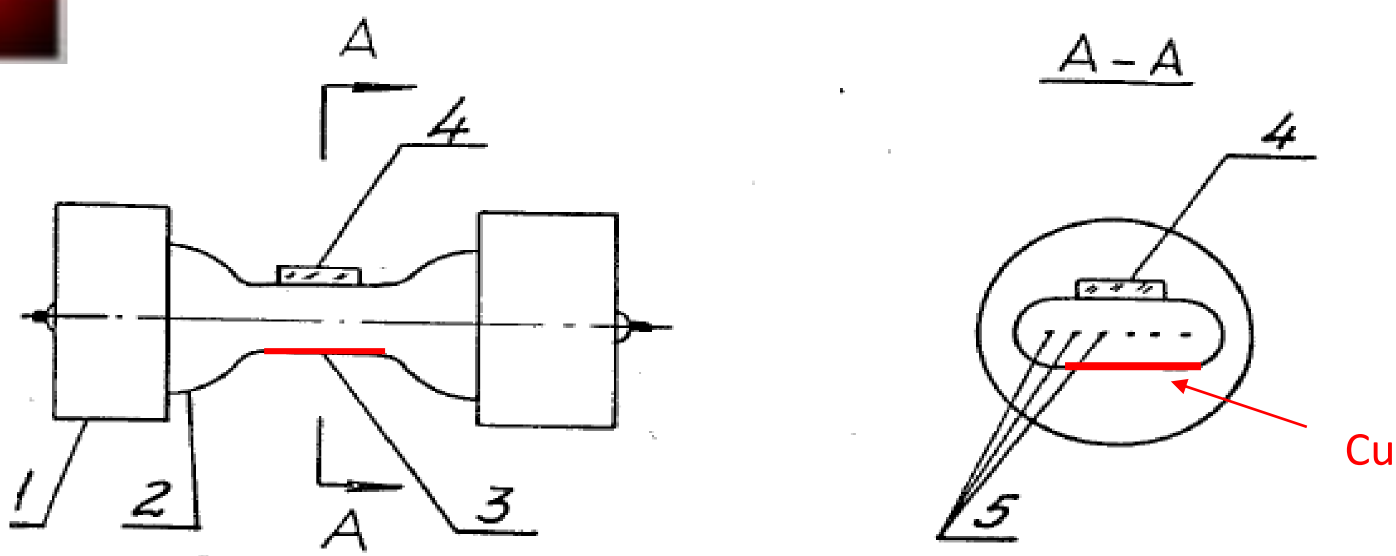


Next important step: gaseous detectors combined with solid photocathodes.

This allowed to extend their sensitivity to longer wavelengths .
These detectors also had much better time resolutions (min. jitter in photoelectron creations)



For example, MWPC with : CuI photocathodes were used for **plasma diagnostics**



V. Peskov, Doctror of Sci. Thesis, 1981

Later other
solid photocathodes were investigated,

(see for example: *V. Peskov,NIM269.1988,149,V. Peskov, NIM 283,1989, 786,J. Séguinot et al, NIM 297,1990,133, G. Charpak et al., NIM 310,1991, 128, D. C. Imrie et al.,.,NIM 310,1991,122, V. Peskov, NIM 315,1992,77,D. C. Imrie et al., NIM317,1992,92,*

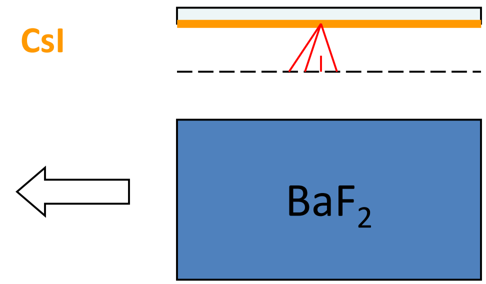
G. Malamud et al, NIM 348,1994,275 and reference there in)

however,

the greatest success was achieved with **CsI** photocathodes

Starting chain of works on CsI photocathodes:

G. Charapak, V Peskov and D. Scigocki,
Proc. Symp. on. Particle Identification
at High Luminosity Hadron Colliders,.
Fermilab. Batavia. 5-7 April 1989. p. 295

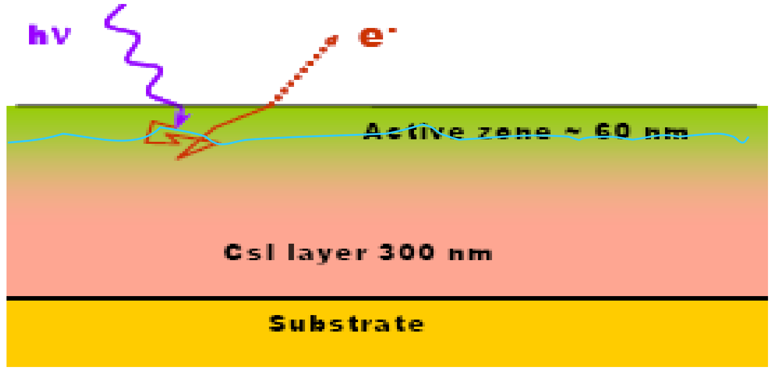


J. Seguinot et al., NIM, 1990

A. Breskin et al, NIM,1990

(see review paper A. Breskin, NIM 371,1996,116)

Advantages of CsI photocathodes: high quantum efficiency, tolerate a short contact with air, and, of course, potential for high time resolution



Importance of an absorbed layer

Two major effects:

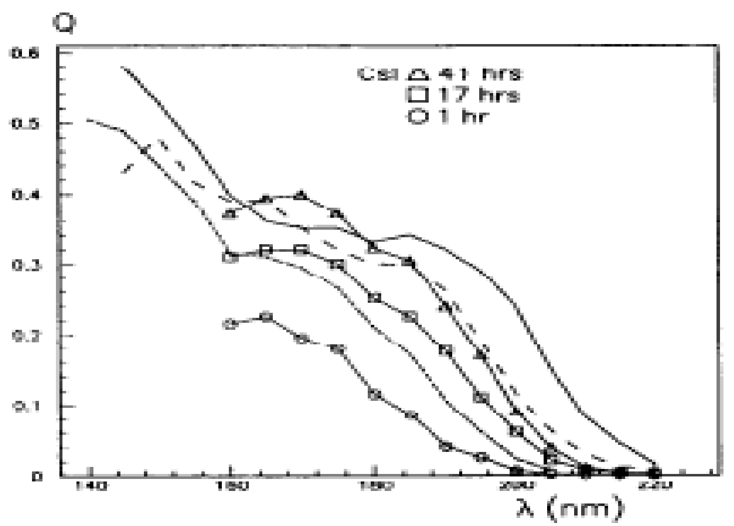


Fig. 5. The measured quantum yields versus the photon wavelength of a 500 nm thick CsI photocathode after 1, 17, and 41 h of methane gas-flow through the chamber. The solid line without data points is the TMAE gas-phase yield, and the dash-dotted line is the Carruthers vacuum photocathode yield [22].

1. Improvement with time

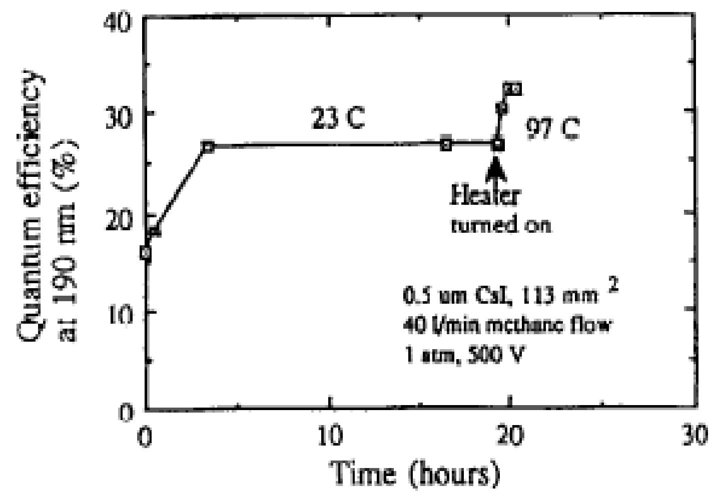


Fig. 6. QE as a function of time of a freshly deposited, 0.5 nm thick CsI photocathode, with a 40 l/min flow of methane. At 20 h the photocathode is heated to 97°C, resulting in the enhancement of the photoyield [38].

2. QE efficiency enhancement by heating

CsI RICH

…it was not se easy…

Chain of proposals to the CERN committee

Development of a high-efficiency gaseous detector for the localization of photons from scintillators and Cherenkov radiators
Charpak, Georges; Giomataris, Yu; Peskov, V (et al.)
1991

Declined

↓

Development of a high-efficiency gaseous detector for the localization of photons from the Scintillator and a new generation of Cherenkov counters
A.Braem, André; Charpak, Georges; Peskov, V; et al
1992

Declined

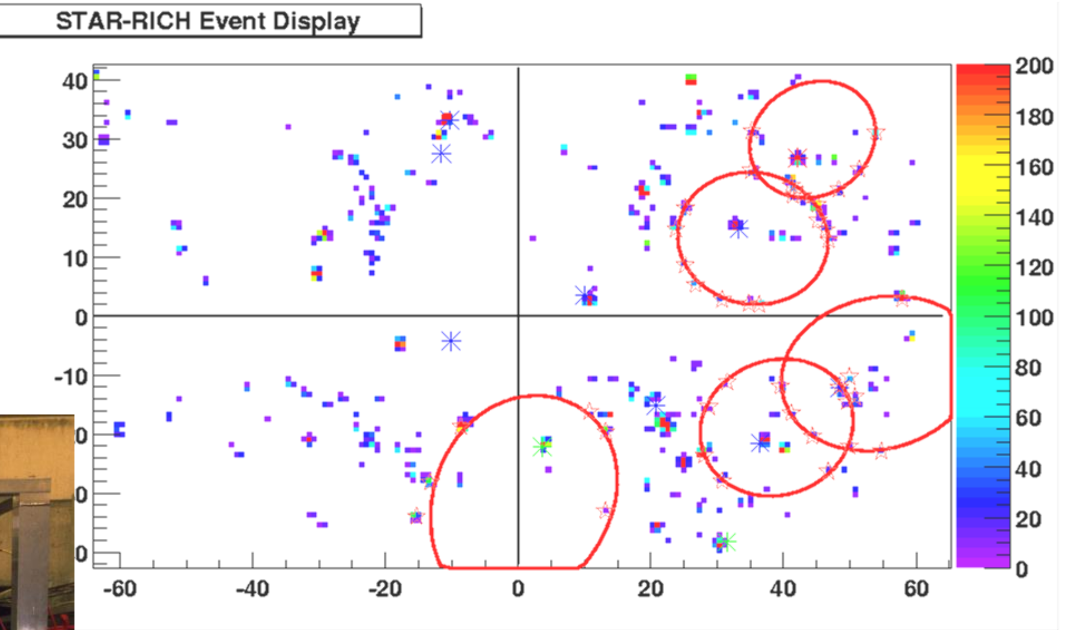
↓

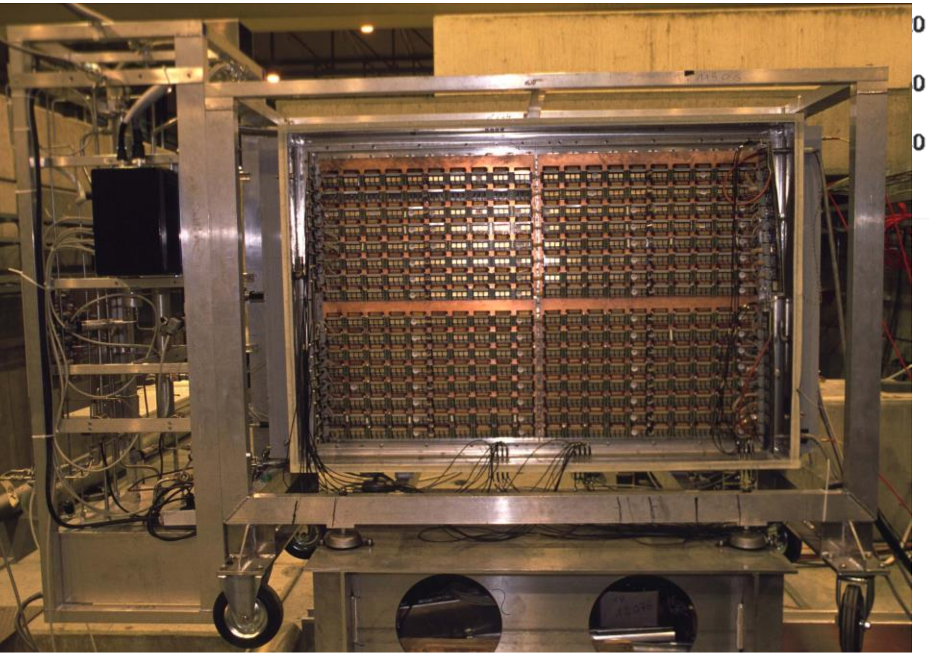
Development of a large area advanced fast rich detector for particle identification at the Large Hadron Collider operated with heavy ions
Nappi, E*et al.*
1992

Approved!

The STAR-RICH detector

- Charged particles multiplicity: 10 m^{-2}
- Interaction rate: 10^4
- PID:
  - $1 < p < 3$ GeV/c π K
  - $2 < p < 5$ GeV/c p

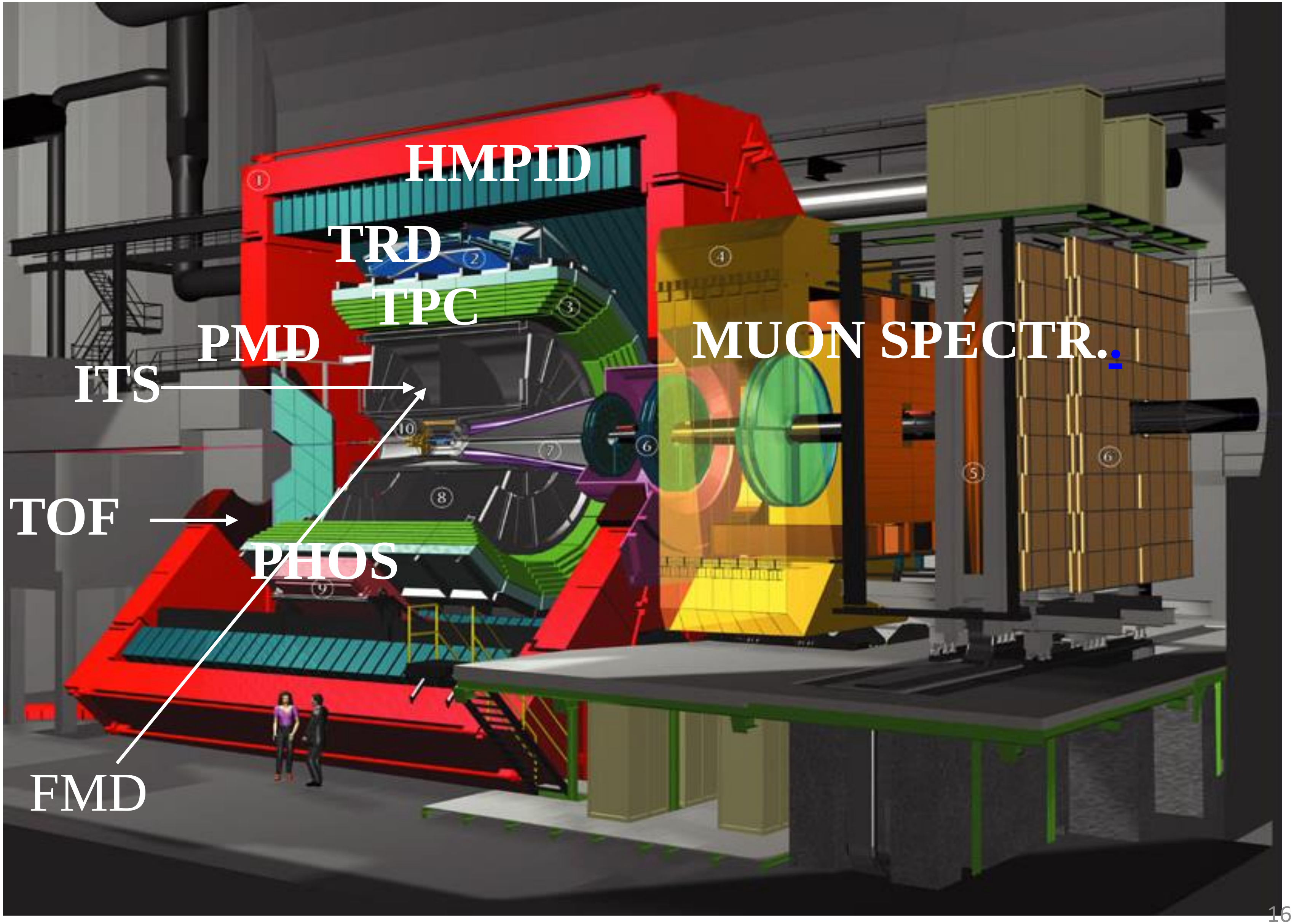




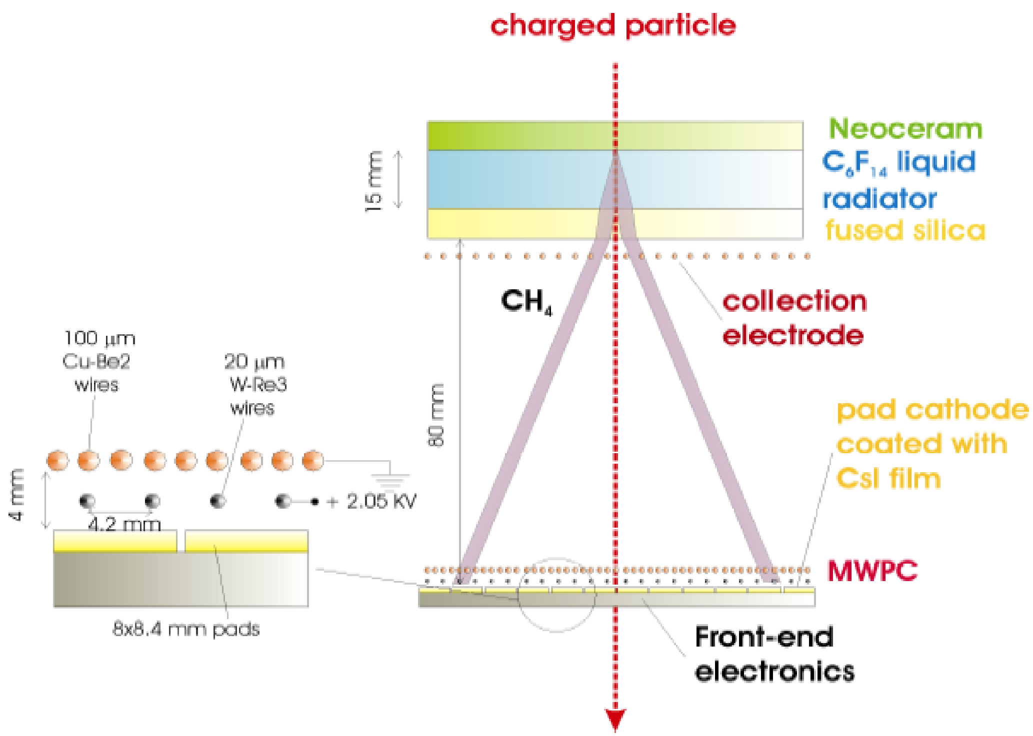
- ALICE HMPID proto-2 (1 m^2 active area): proximity focusing (80 mm gap), 10 mm C_6F_{14} radiator, 4 CsI PC of 60x40 cm^2
- FEE: Gassiplex 1.5 μ, noise 1000 e^-

New: First use of a CsI RICH detector in a collider experiment

Now several experiments have CsI RICH: ALICE, HADES, COMPASS, STAR and others



The ALICE/HMPID Detector



$\beta > 1/n$

$\cos\theta = 1/(n\,\beta)$

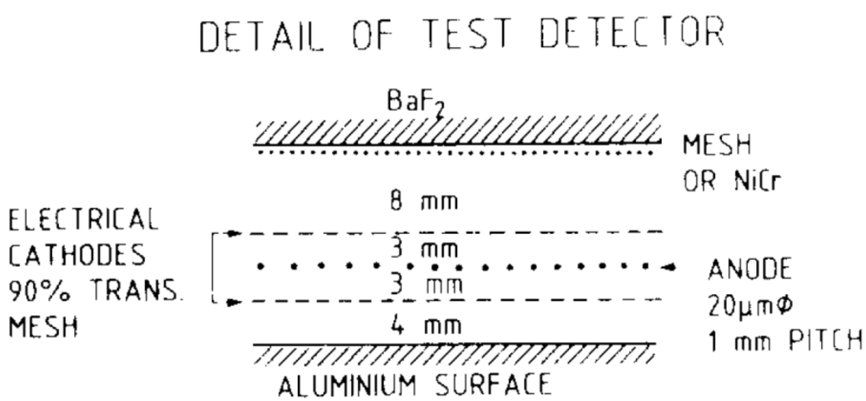
$N_{ph}[cm^{-1}eV^{-1}] = 370Z^2(1-1/n^2)$

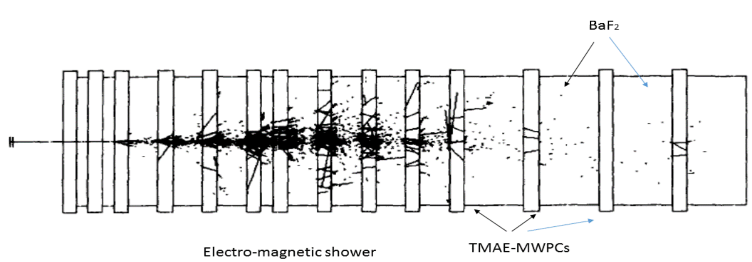
Concept: proximity focussing CsI RICH

- liquid C_6F_{14} radiator
- MWPC
- cathode pads coated with CsI
- 3840 pads (8x8 mm^2) per PC with individual analogue readout

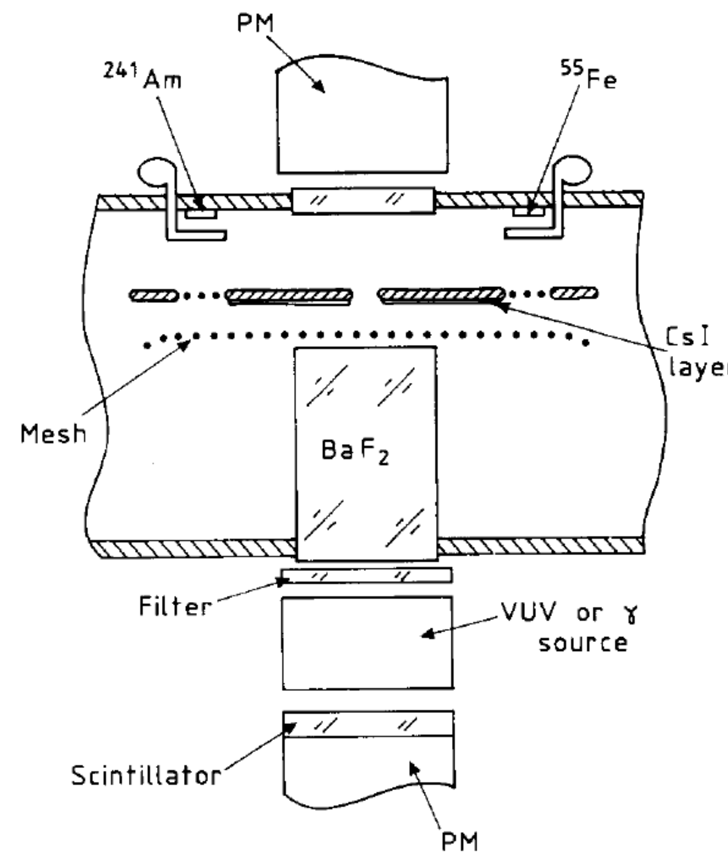
- 7 modules: total area 11 m^2 largest application so far
- 42 PCs (64 cm x 40 cm) in total (6 per module)

Photosensitive gaseous detectors were also used for detection gammas and charged particles





Anderson, et al.NIMA 217, 983, 217-223



Charpak, et al. *NIM.* A307,1991, 63-68

Those gaseous PMs were sensitive to VUV and UV light only

However, let's recall that at the time when vacuum and solid state position-sensitive detectors did not exist, so the gases PM were really unique:

they had efficiency to UV as the best PMT,

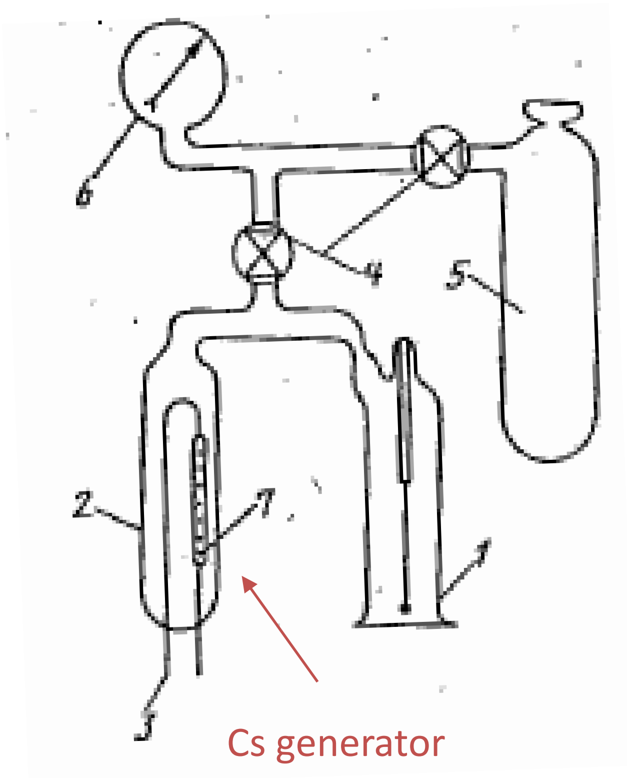
were position sensitive,

rather cheap and sensitive.

Even nowadays they can compete with other detectors in many applications

Attempts to develop gaseous PMs with Cs-based photocathodes in order to extend the sensitivity close to visible light

Cesiates Cu photocathode



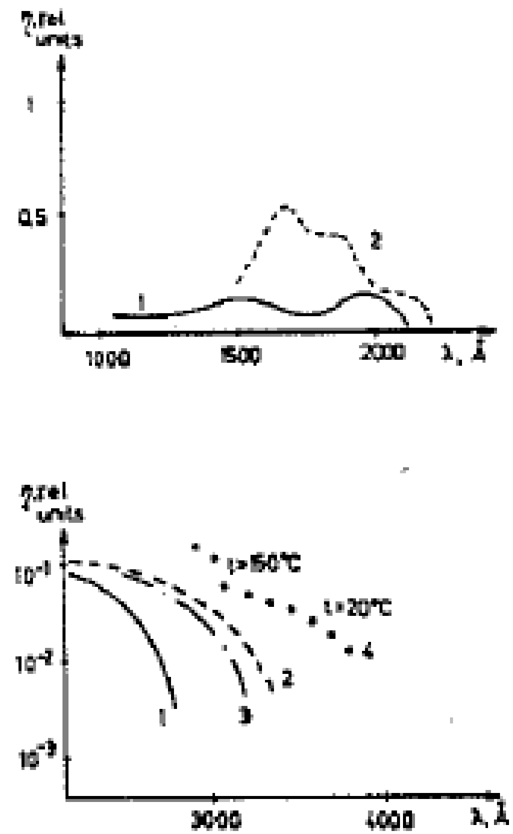
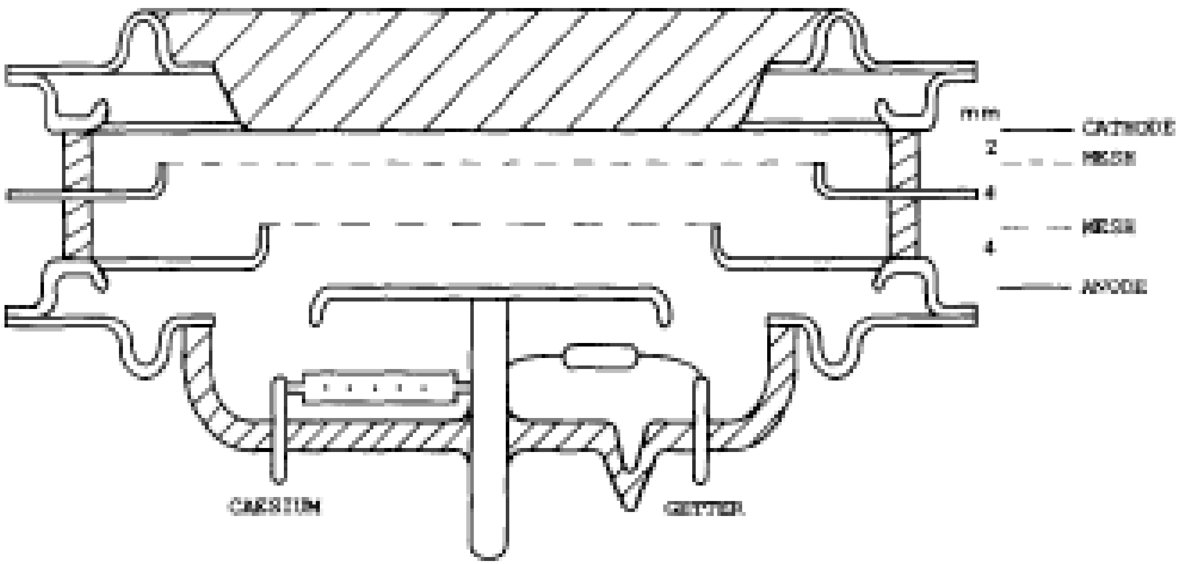


Fig. 2. Efficiencies, φ, of radiation from copper-cathode counters filled with ethyl-ferrocene (1) and TMAE (2). Efficiencies measured for CuI (3) and Cs (4) photocathodes are also given.

V. Peskov , Jour Spectr, 48, 1988,316

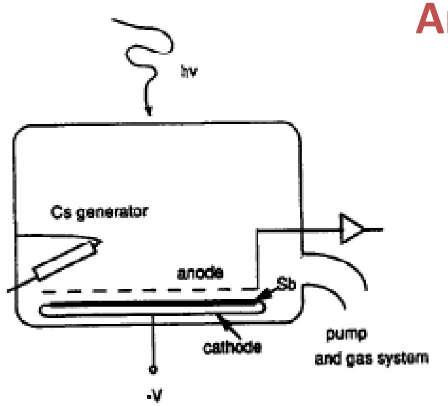
V. Peskov, NIM, 252,1986, 465

Cesiates Sb photocathode



J.S Edmens NIM A 273, 1988, 145 (in cooperation with a photonic company)

Another cesiated photocathdes



<u>Three main difficulties</u>:

Cleanness,

QE,

feedbacks

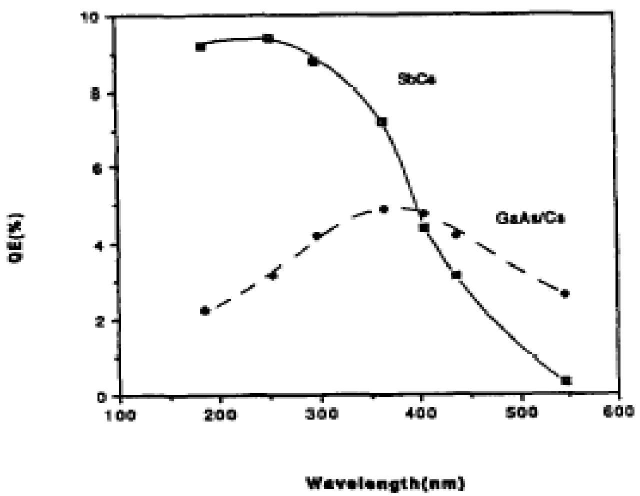


Fig. 2. Typical QE of SbCs and GaAs/Cs photocathodes fabricated inside the glass chamber.

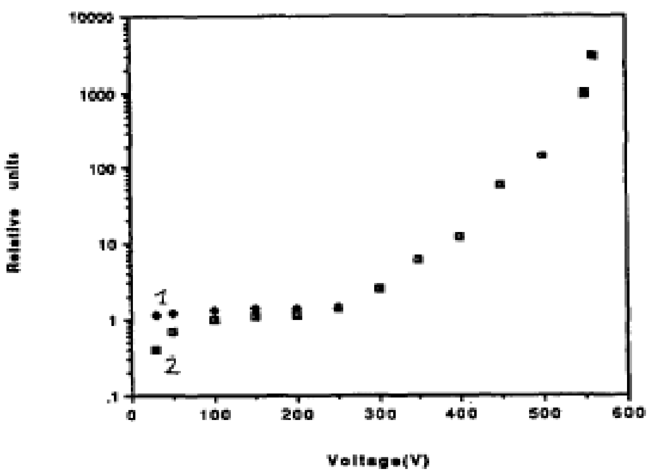
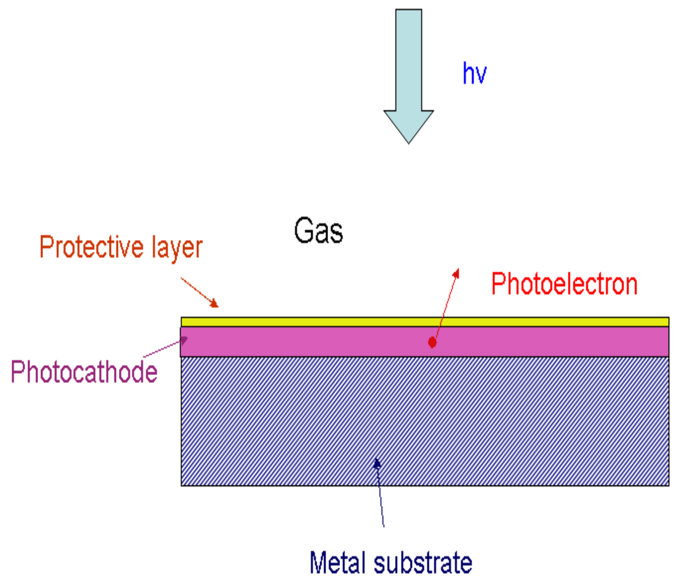


Fig. 3. Photocurrent in relative units versus voltage for the SbCs photocathode fabricated inside the stainless steel chamber. 1 – results in vacuum, 2 – results in CH_4 at 80 Torr.

G. Charpak et al, NIM 323, 1992,445, A. Borovick-Romanov et al, NIM348,1994,269, V. Peskov, NIM 353, 1994, 184, V. Peskov, NIM 367,1995, 347

Photocathode protection by on over coating



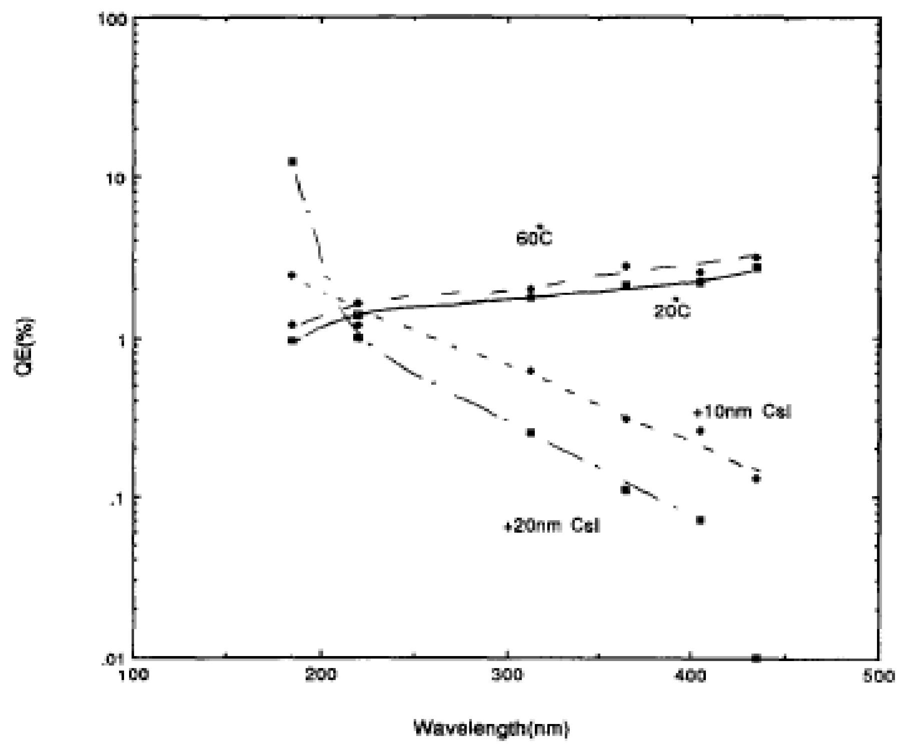
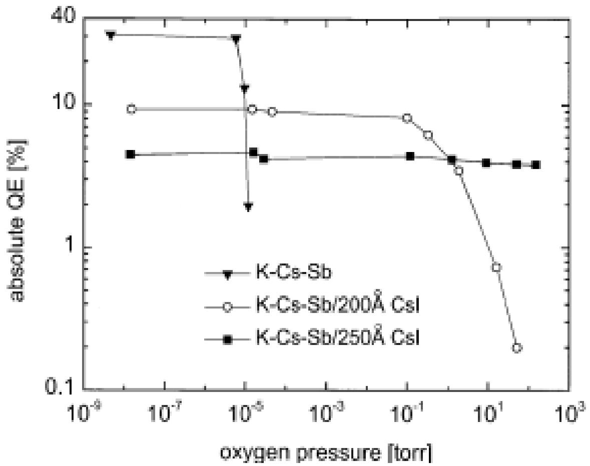


Fig. 2. The QE of the SbCs photocathodes vs the wavelength under different conditions: room temperature (20°C), 60°C and without and with CsI protective layers. One can see that heating to 60°C helped to increase the QE. A similar effect was observed earlier in the case of a CsI photocathode [20].

V. Peskov et al. NIM A353,1994,184

A new momentum was obtained when Breskin group joined to these developments

This group learn how to manufacture high efficient photocathodes and made a lot of studies on photocathode protection



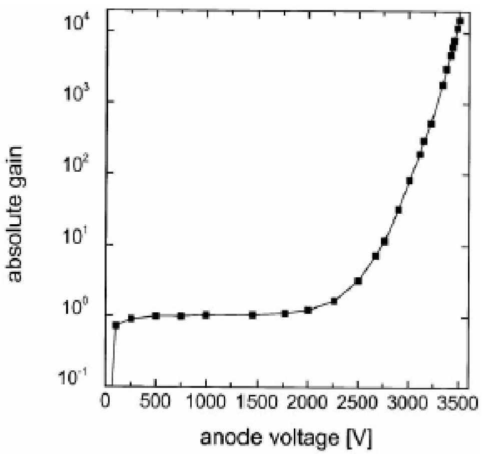


Fig. 3. Absolute gain as a function of anode voltage of a 1 mm gap parallel-plate electron multiplier coupled to a semitransparent K–Cs–Sb photocathode coated with 300 Å thick CsBr film, at 1 atm of methane.

However, the maximum reachable gains were<10^3 with high efficient photocathodes

See for example: NIMA3871997,176,E. Shefer et al., NIMA411,1998,383, E. Sheferet al.,A433,1999,502

What limit the gain? Feedbacks

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

or ,

$$A\gamma_{+}=1 ,$$

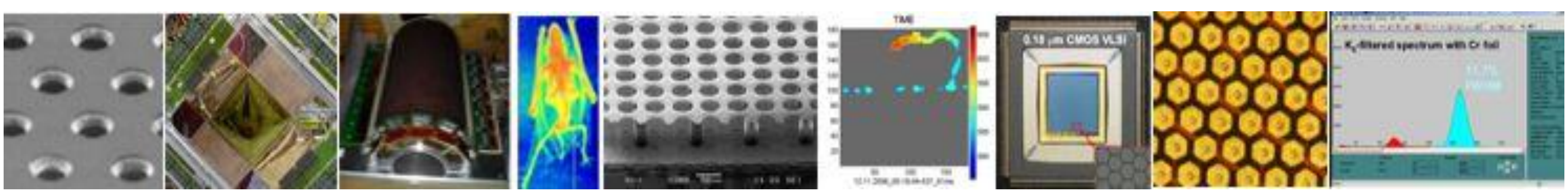
where

$$\gamma_{ph}=K_{back\ scat}(E, E_v)\int Q(V, E_v)S(V,E_v)dE_v,$$

$$\gamma_{+}= K_{back\ scat}(E, E_{i-2\phi})k_g(V)\ (E_i-2\phi)$$

Conclusion: with "open geometry (PPAC) we reached the limit

New breakthrough: photomultipliers based on **micropattern gaseous detectors**



MPGDs open new possibilities in feedback suppression:

$Ab\gamma_{ph}=1$ $b<<1$

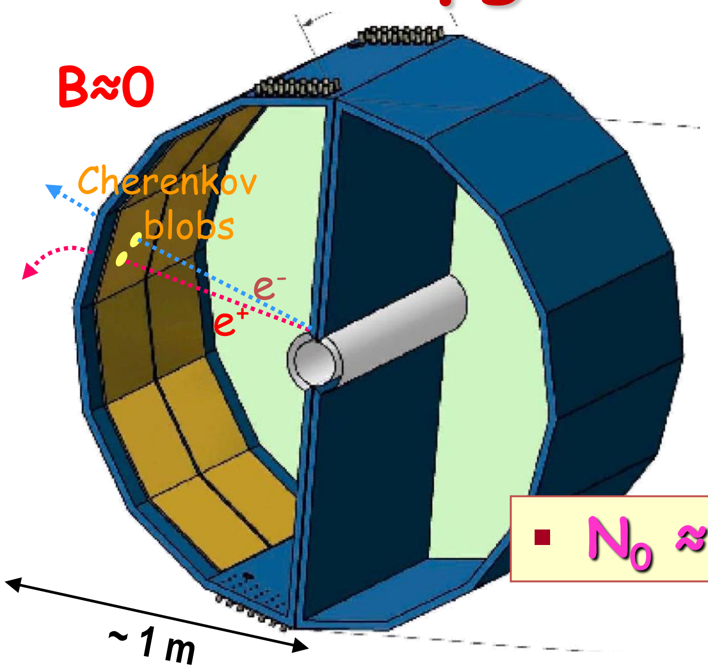
or

$Ac\gamma_{+}=1$ $c<1$

b and c are coefficients appearing due the geometry and ion flow splitting

PHENIX Upgrade (PHENIX HBD)

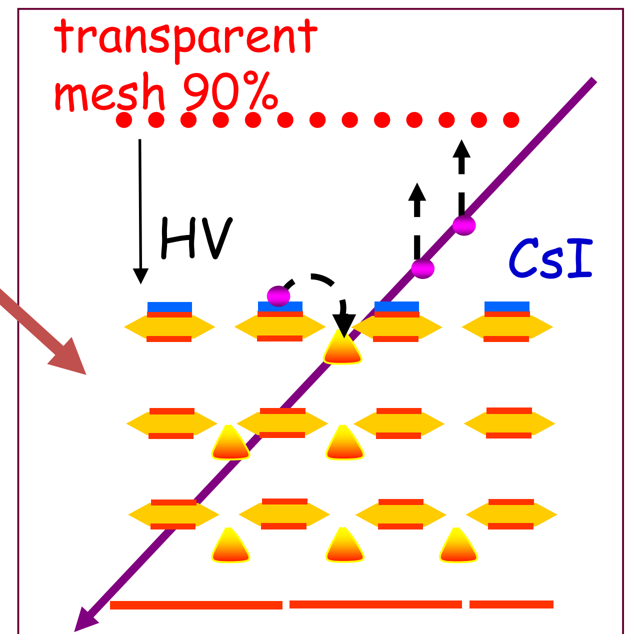
A. Milov et al.
J. Phys. G34, S701 2007



RICH added around the interaction region.
Goal: identify low-mass e⁻-pairs (π^0, γ) to reduce X300 combinatorial BG.
But: limited to 50 cm length.
Solution: Radiator gas = Working gas = CF_4.
Proximity=> Radiating particles produce blobs, diameter ~ 3.6 cm.

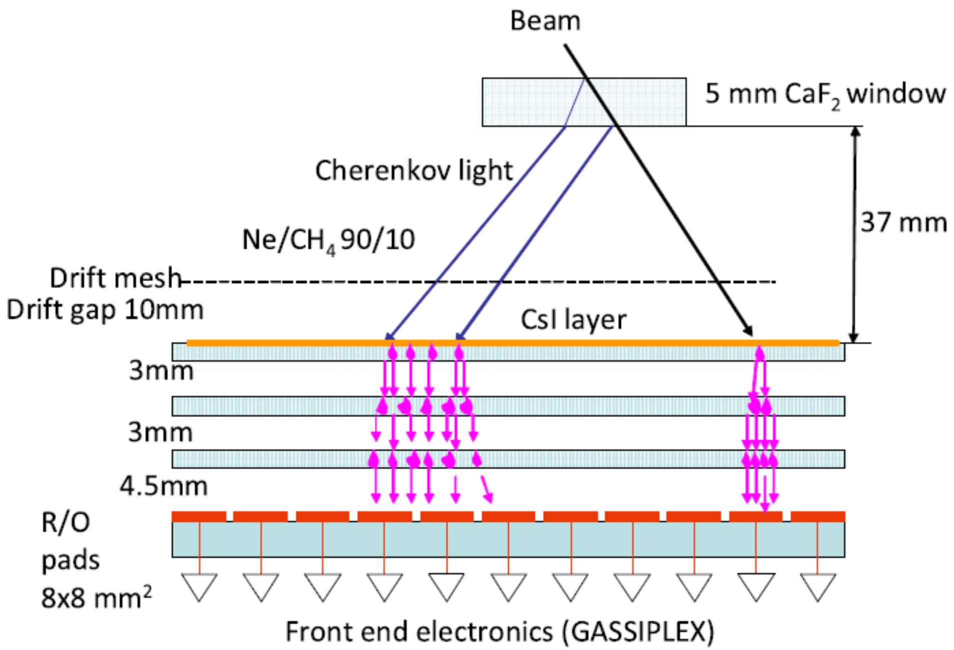
- **$N_0 \approx 840$ cm^{-1} (x6 larger than any e/π RICH)**

- The GPD of choice is a multi-GEM +REF PC
- Relies on CsI preparation knowledge and techniques from CERN:
  Gold-coated GEM,
  in-situ QE monitoring, QE enhancement,
  PC transport and storage.
- CsI QE match to CF_4

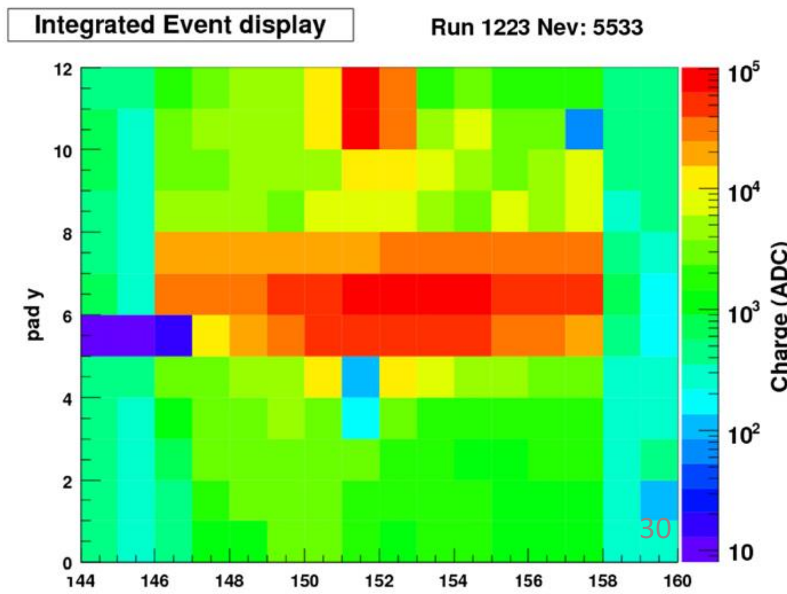


(From R. Chechik presentation ar RICH Conf.)

Studies for the ALICE upgrade

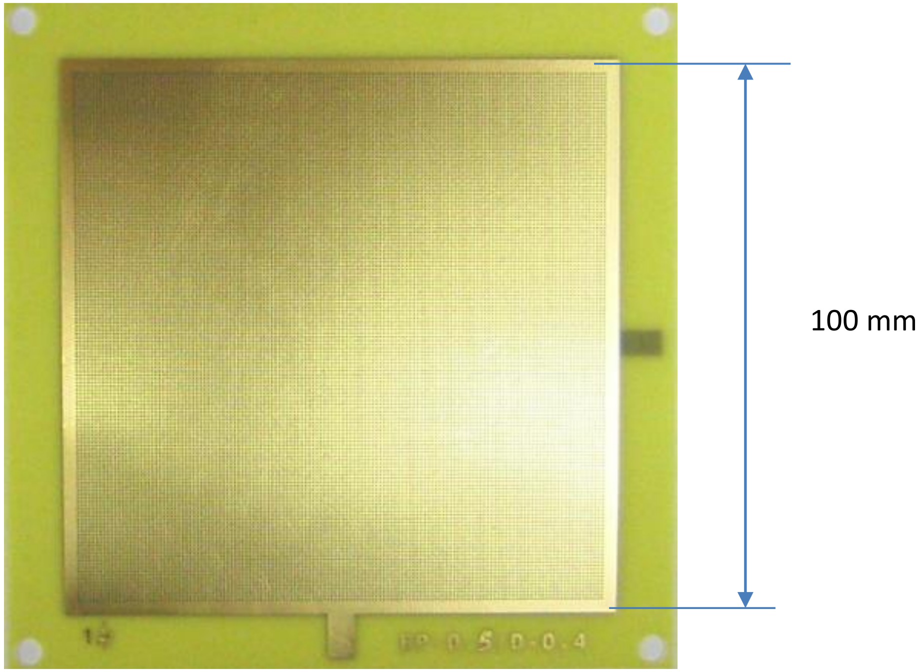


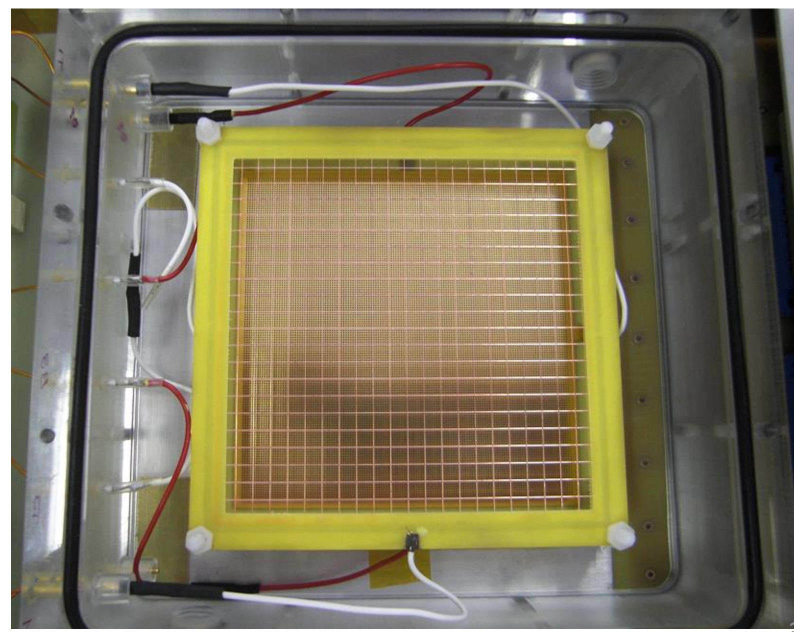
Solid radiator

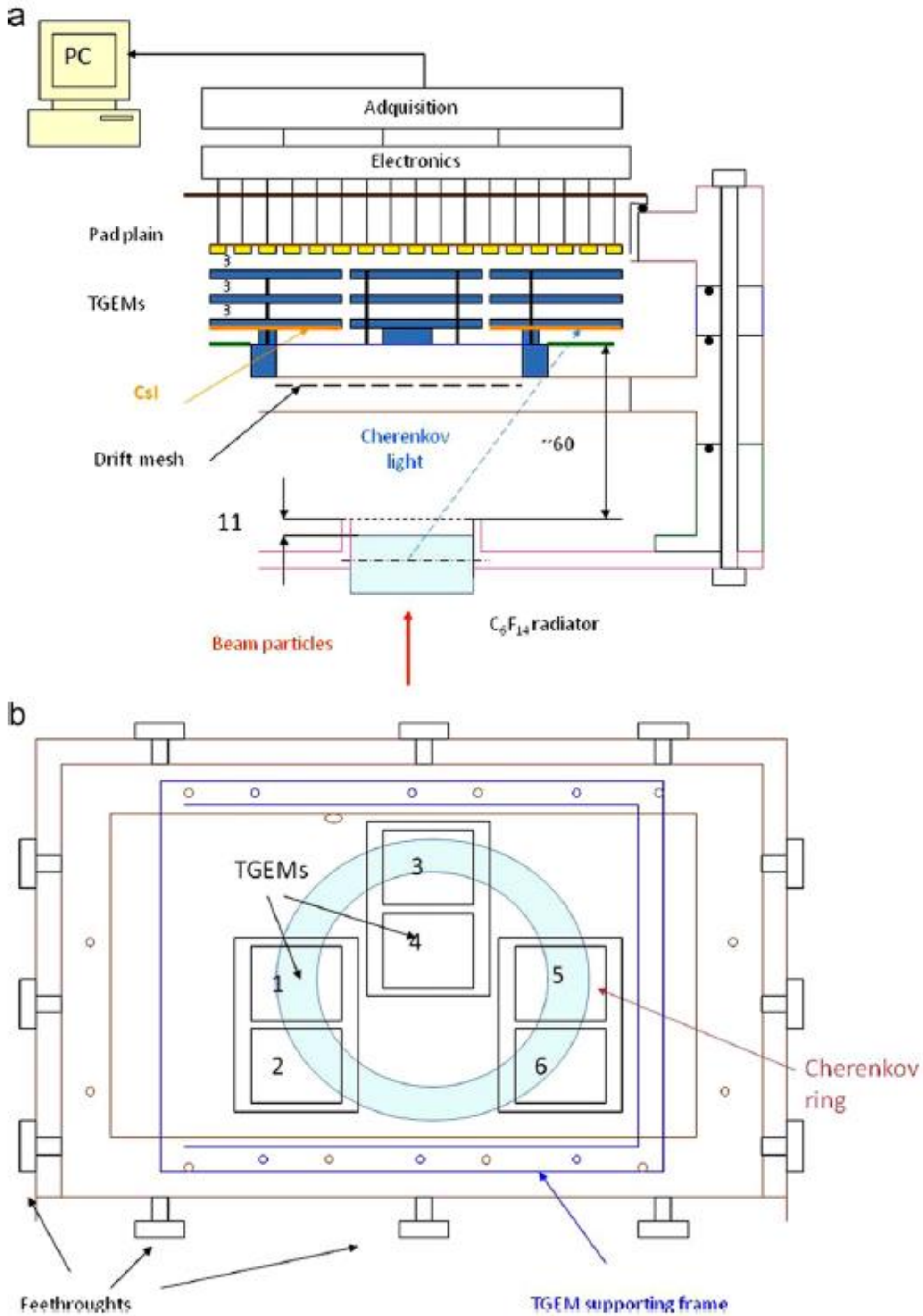


P. Martinengo et al., NIM, A639(2011)126

CsI coated TGEMs



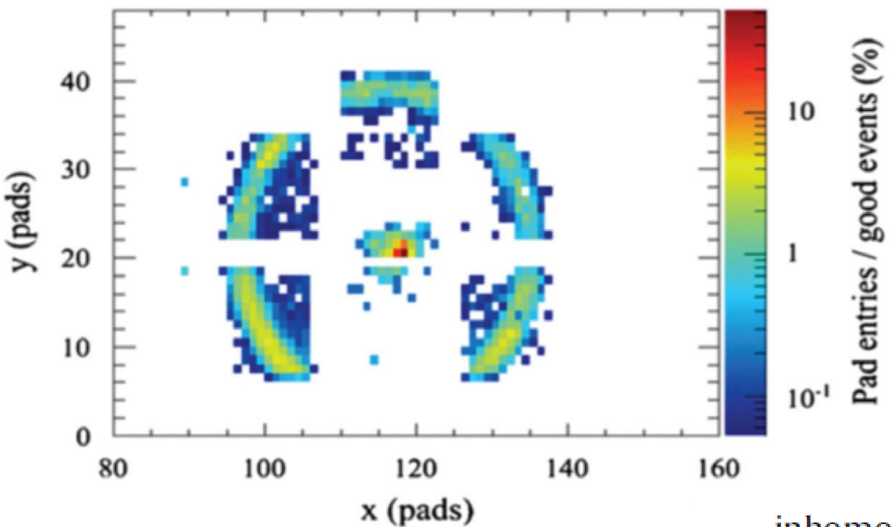




Liquid radiator (the same as in currently running ALICE RICH)

V. Peskov et al., NUM, A 695 (2012) 154

The main results:

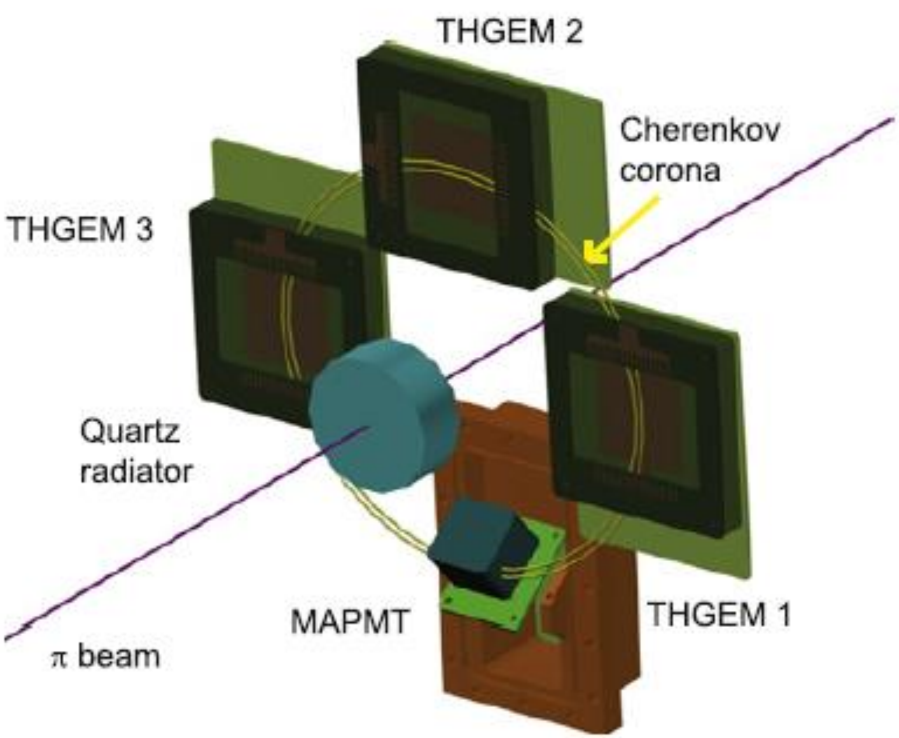


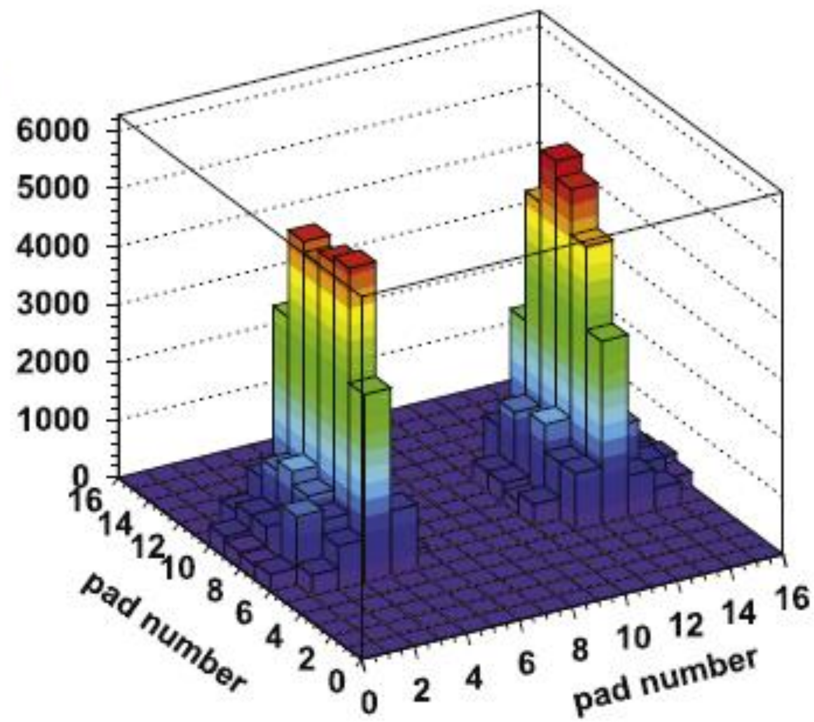
The main conclusions:

An inhomogeneity correction factor of ~0.78 has been calculated for the two TGEMs now under discussion bringing to ~9 raw clusters per event. Note that in the case of the ALICE MWPC operating in CH_4 it was ~15 per MIP [14]. From these data one can draw some conclusion about the QE of the CsI layer deposited on the top of TGEMs. For example, in Ne+10%CH_4 the extraction efficiency of photoelectrons from the CsI layer at the voltage drop across TGEM 650–750V is about $\eta_{rel}=0.9$ compared to the same value for pure CH_4 [15]. The collection efficiency of the photoelectrons into the TGEM holes when the CsI coated TGEM operated at a gas gain of ≤ 100 is $\varepsilon_{col} \leq 0.95$. Keeping in mind that the active area of the TGEM is $A_{eff}=75\%$ of the total active area (15% are holes), the total correction factor will be: $K_{tot}=\eta_{rel}\varepsilon_{col}A_{eff} \approx 0.9\times 0.95\times 0.75=0.64$. Thus in the case of the hypothetical photodetector operating in CH_4 and having no holes (let us call this "an ideal condition") the expected number of the photoelectrons will be 9/0.64=14 p.e., which is very close to the best CsI-MWPC data [14].

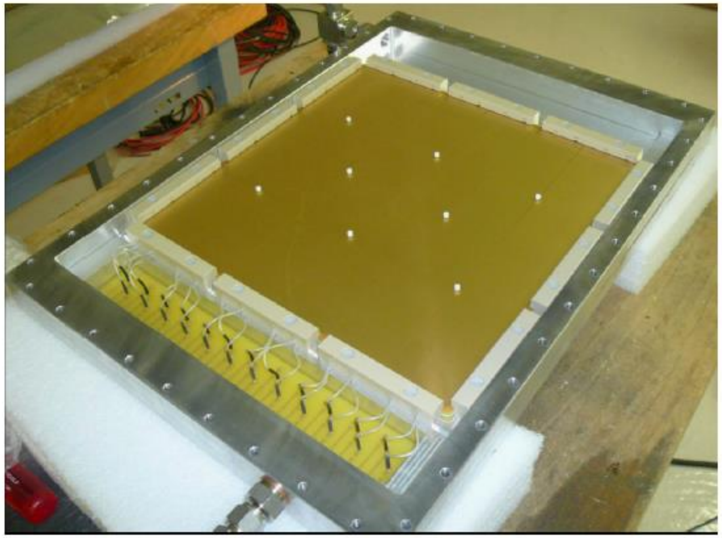
V. Peskov et al., NUM, A 695 (2012) 154

These developments were successfully continued by the COMPASS RICH group

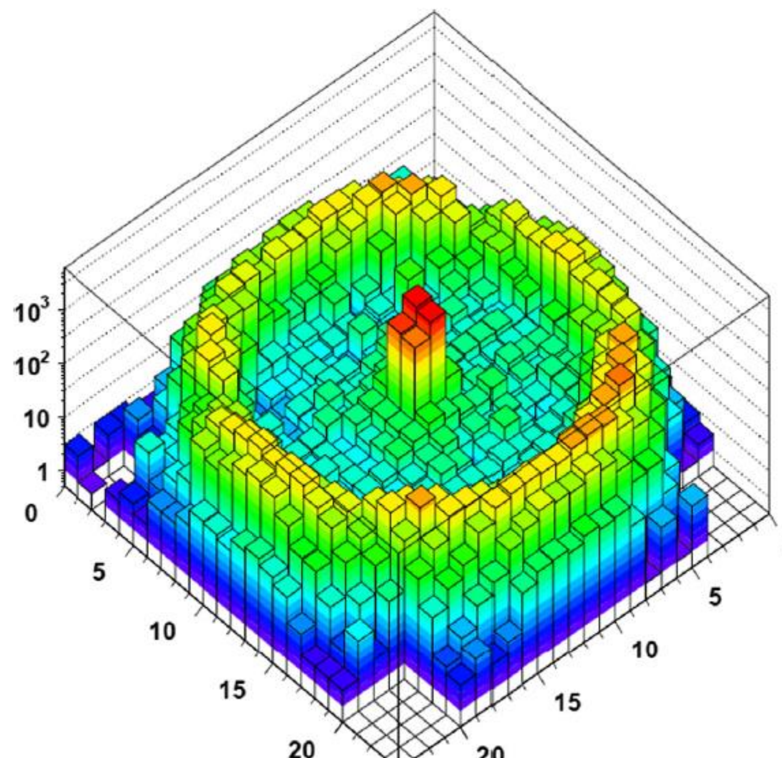




M. Alexeev et al., NIM A695 (2012) 159

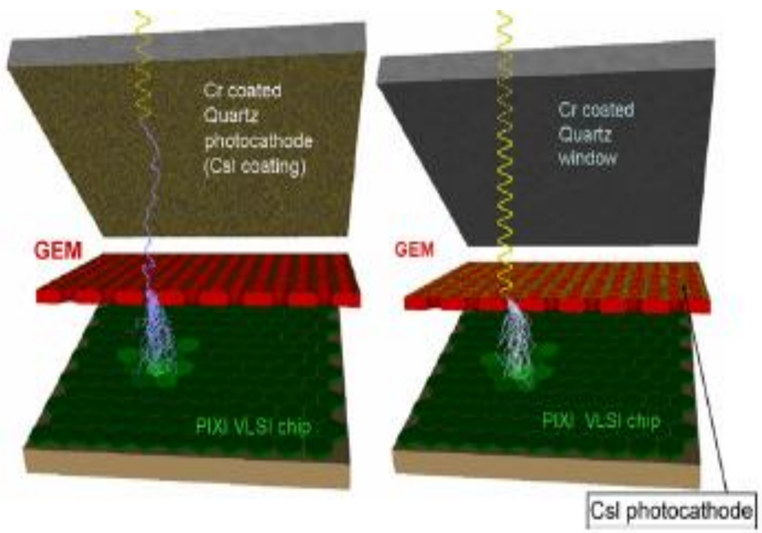


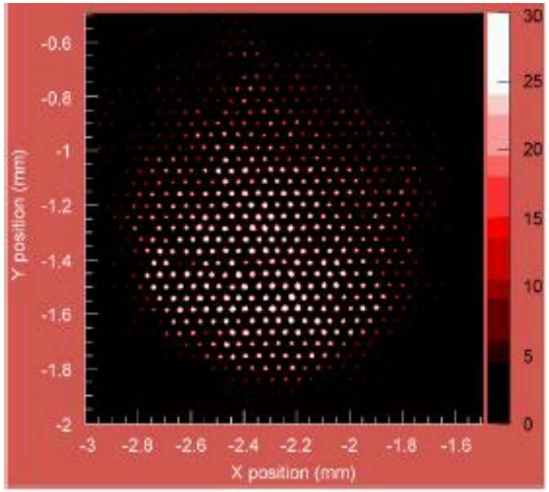
30x30 cm2 TGEM



M. Alexeev et al., NIM A732 (2013)264

Latest tendency : micropatten gaseous detectors combined with CsI photocathode (for the exhausting review see *R. Chechik, et al., NIM A595,2008,116)*





Example: an impressive work from *R.Bellazzini et al., , NIM A581,2007246*

Micropattern detectors sensitive to visible light

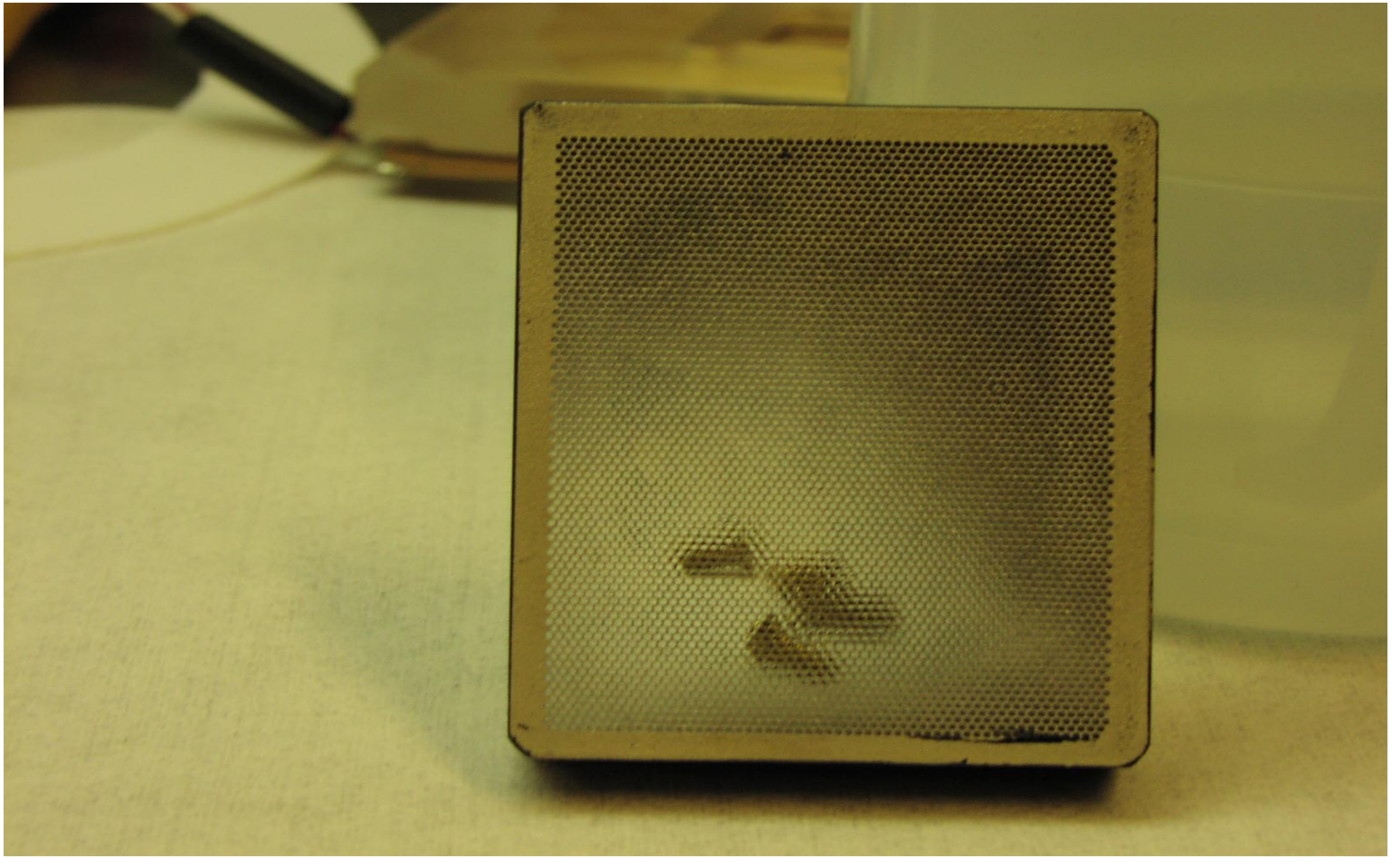
Main difficulties

Very clean materials: glass, ceramics

Cascaded micropattern detectors to supress feedback,

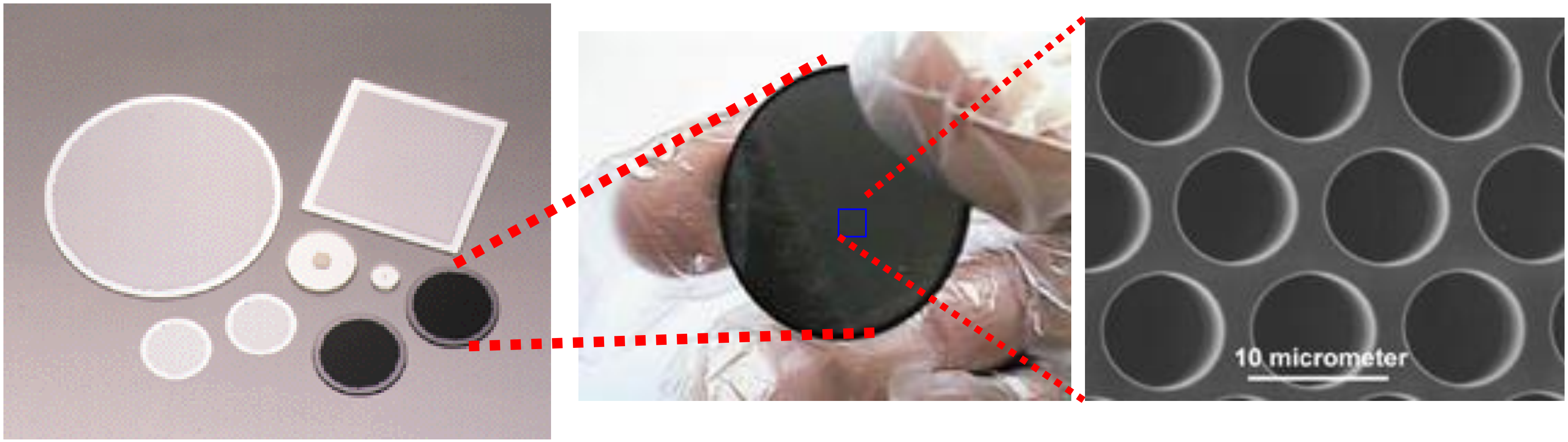
Sealed detectors

Photo of a glass capillary plate



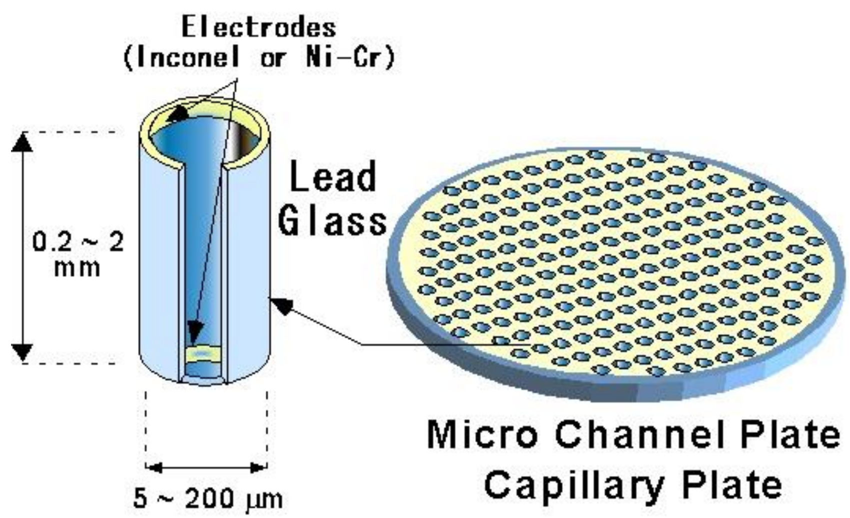
A. Del Guerra et al., NIM A257,1987, 609

Micro Channel Plate / Capillary Plate



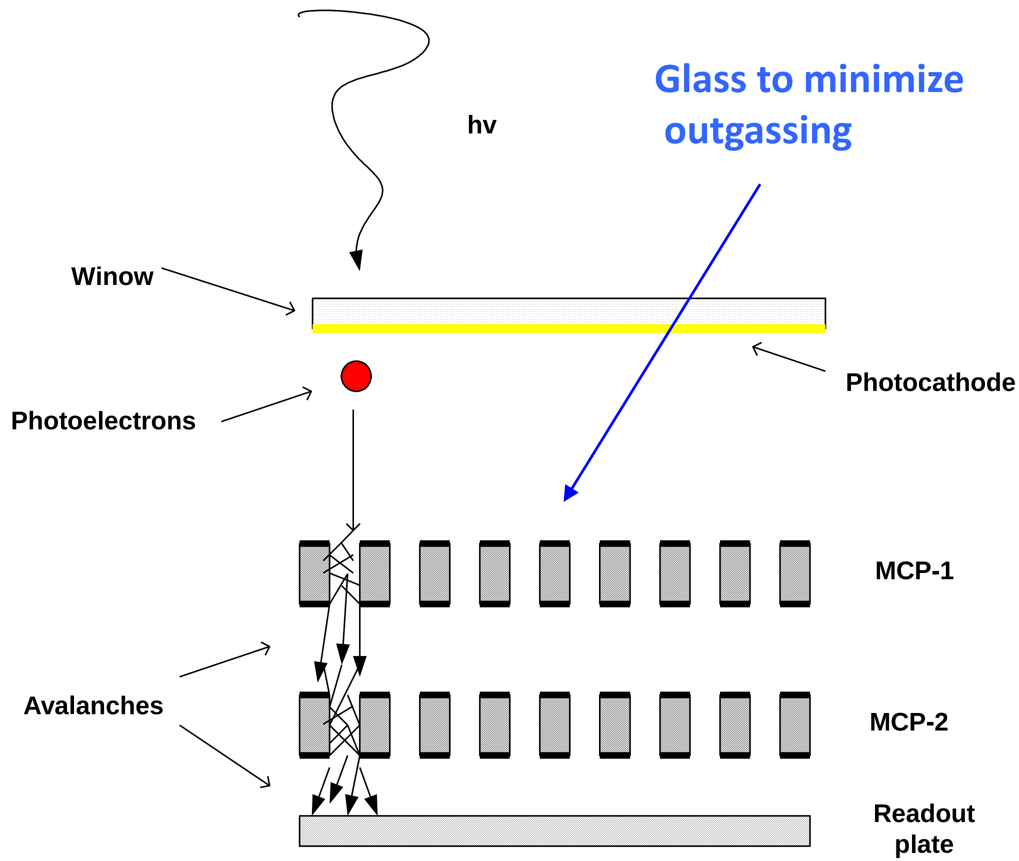
Physical Parameter of MCP and CP

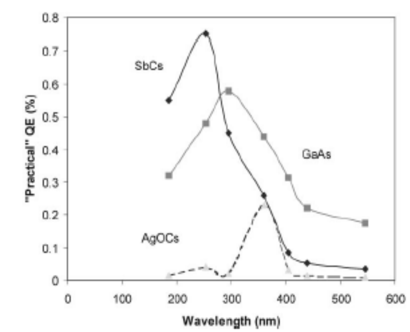
Material	Lead Glass
Outer Diameter (mm)	10~100
Package Density (cm^{-2})	~10^6
Thickness (mm)	0.2~2
Channel Diameter (μm)	5~200
Electrode Material	Inconel or Ni-Cr
Resistivity (Ω)	10^6~10^{10} : 10^{15}
Bias Angle (degree)	5~15 : 0

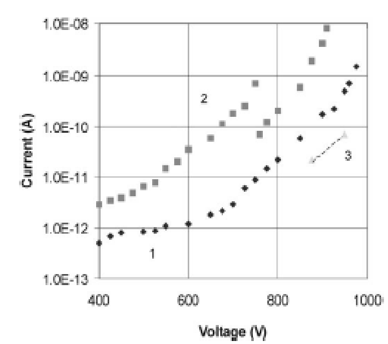


H. Sakurai et al., NIM A374, 1996,341

A schematic view of two capillary plates operating in cascade mode



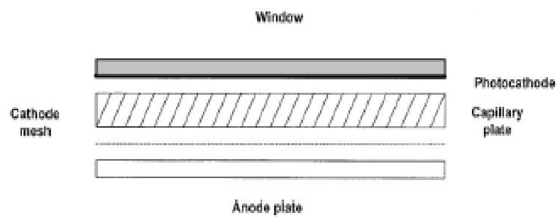




Gains >10^4 were possible to achieve

See: *Peskov et al, NIM A433,1999,492*

Several other designs :



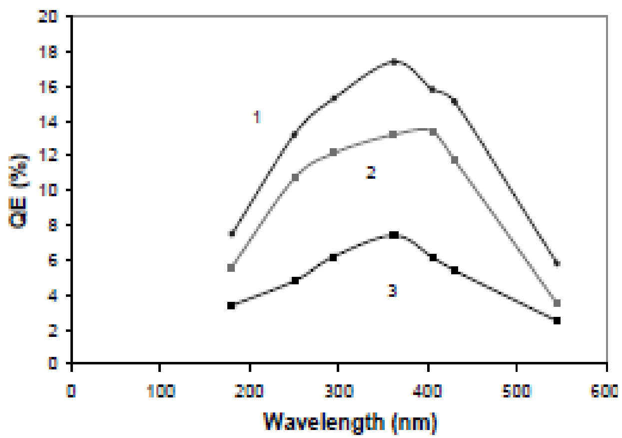
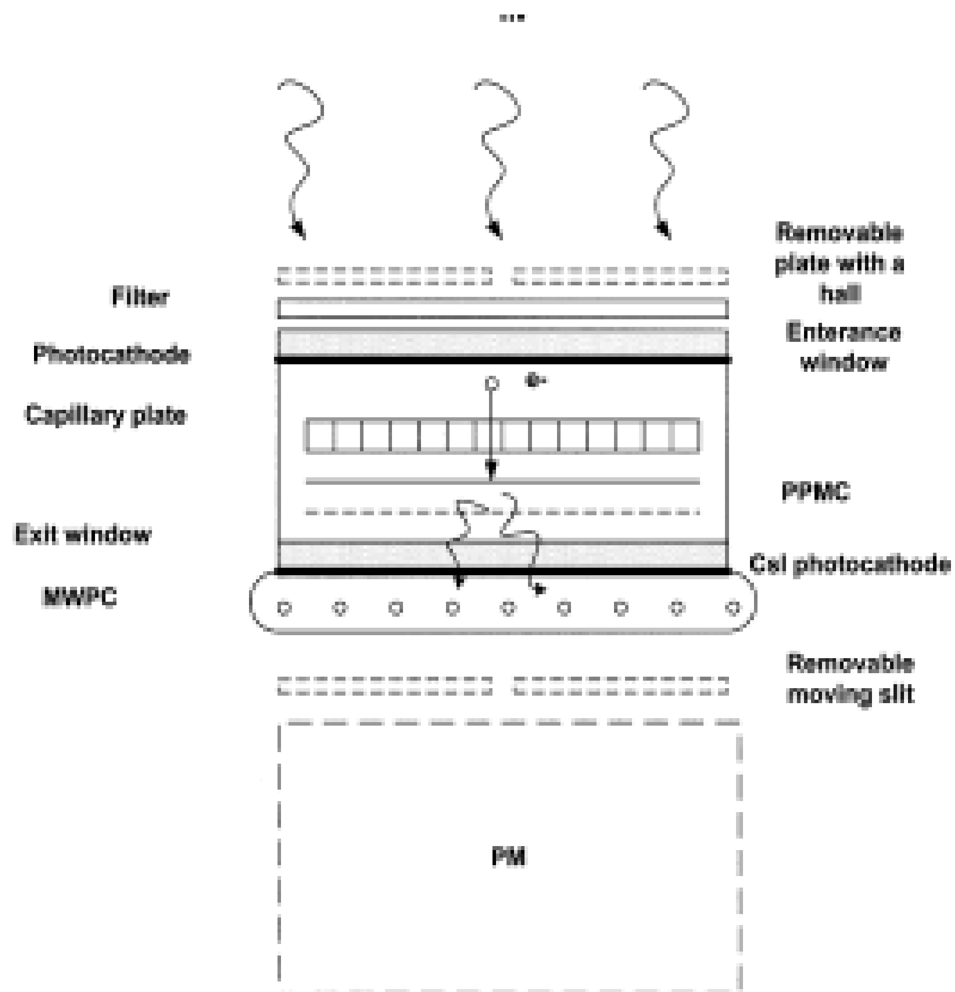


Fig. 1. QE efficiency of a bialkali photocathode, measured i vacuum (1), and in Ar + 5% CH_4 (2) in collection mode; (3 "practical" [11] QE measured in amplification mode.



S. Guinji et al, NIMA477,2002,8
V. Biteman et al., NIMA471,2001,205

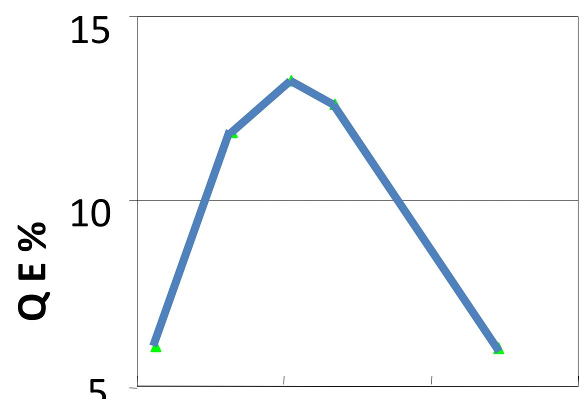
I. Rodionov et al., NIMA478,2002,384

Later very impressive results in this direction were obtained by Breskin group

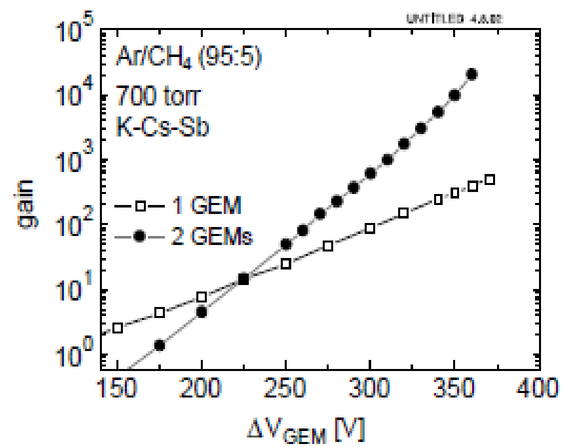
Sealed detector package

Sealing of 3 Kapton-GEMs + K-Cs-Sb photocathode

(Instead of capillaries)



13% = best QE measured after sealing.

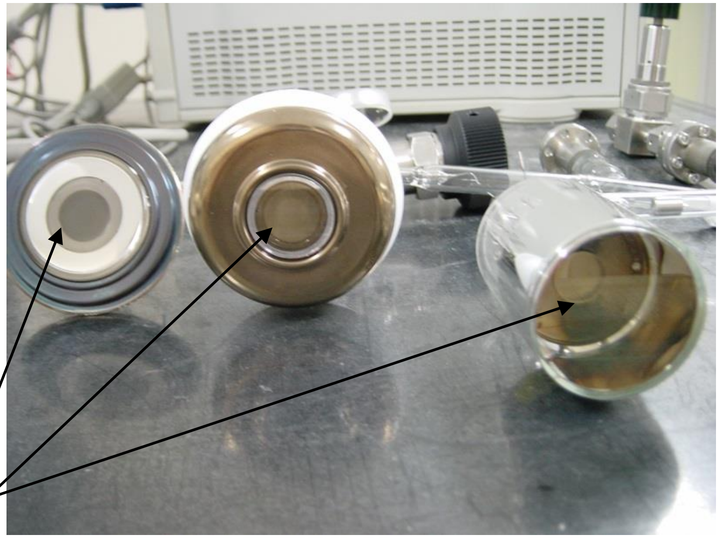


Gain about 10^4

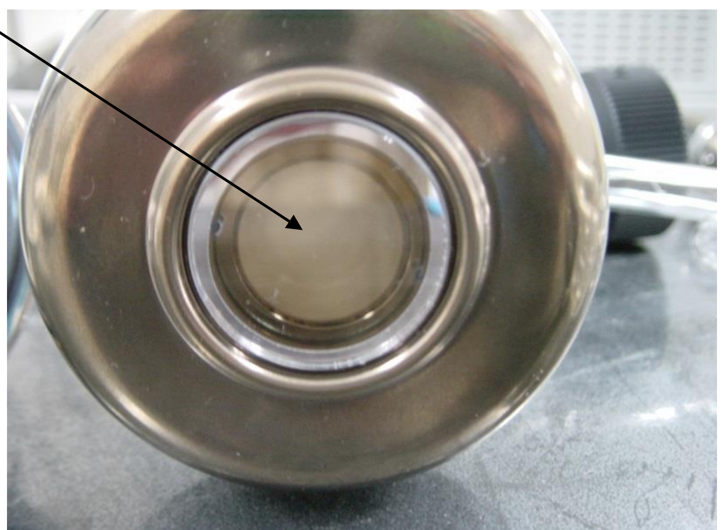
Sealing technique in gas: In/Sn; 130-150^{0}C

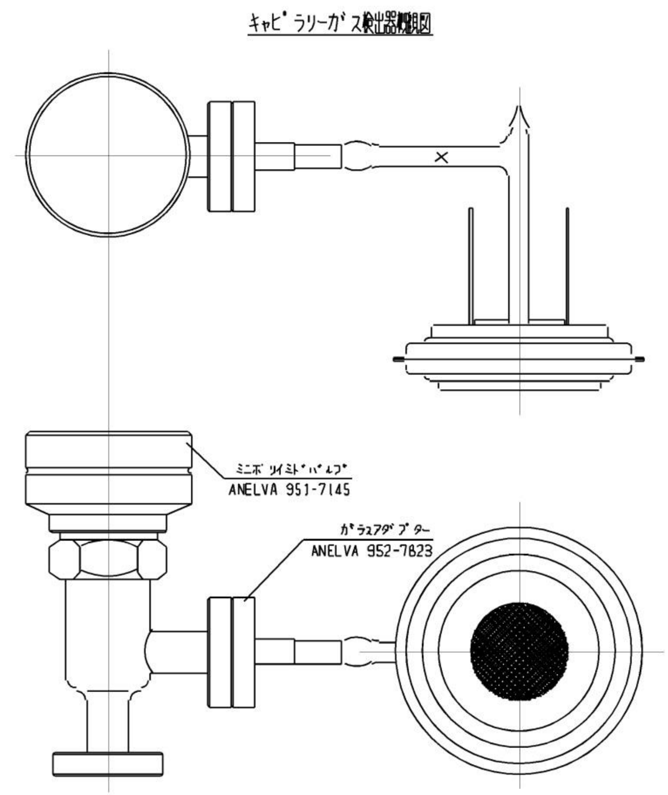
R. Chechik et al., NIMA502,2003,195

H. Sakurai et al., Gas Photo-Multipliers. Made by Hamamatsu



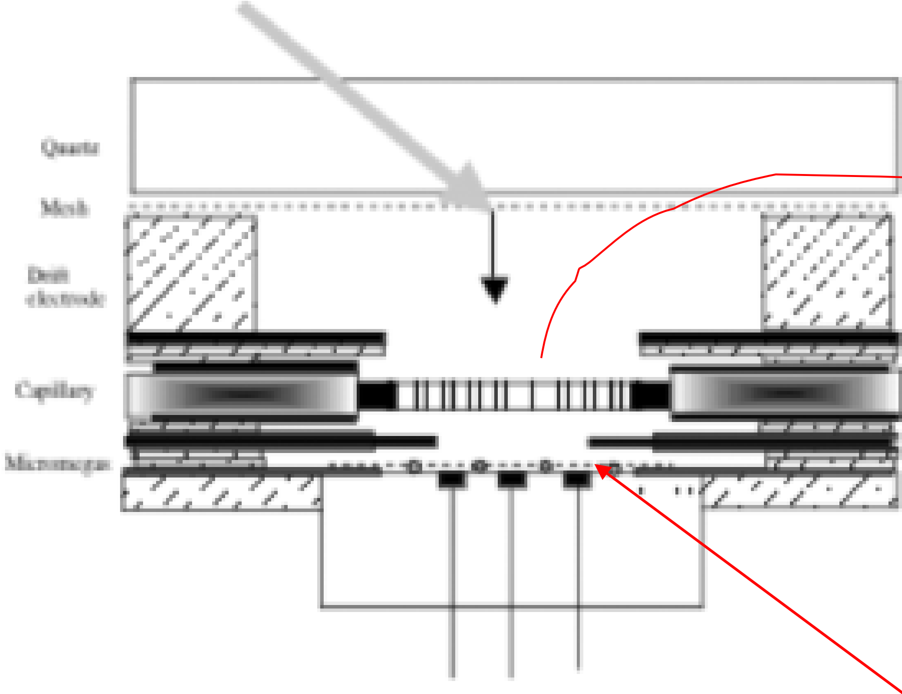
Capillary plates



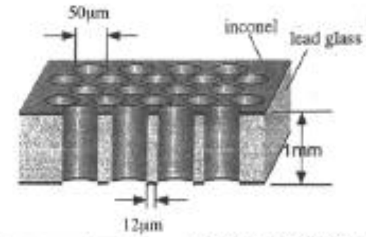


Presented at the Imaging Conf 2003

Capillary+MICROMEGAS



Capillary plate



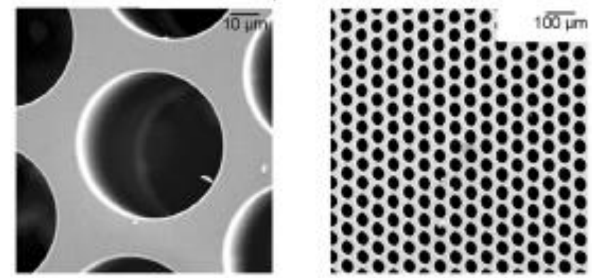


Fig. 2. Our detector is made by a combination of a single MCP and a single Micromegas. The Micromegas has a 100-μm gap, and the capillary has a 50-μm hole diameter. The Micromegas gap is held by 100-μm-diameter nylon lines in this particular test. Single electrons are produced by a UV light striking a dense s.s. mesh located at the entrance of the drift region.

MICROMEGAS

J. Va'vra et al IEEE trans. Nucl. Sci,51,2004,2262

Beside Breskin team several other groups tried to develop PMs based on MPGDs:, Tokanai, Va’vara, Gorodecki-Giomataris

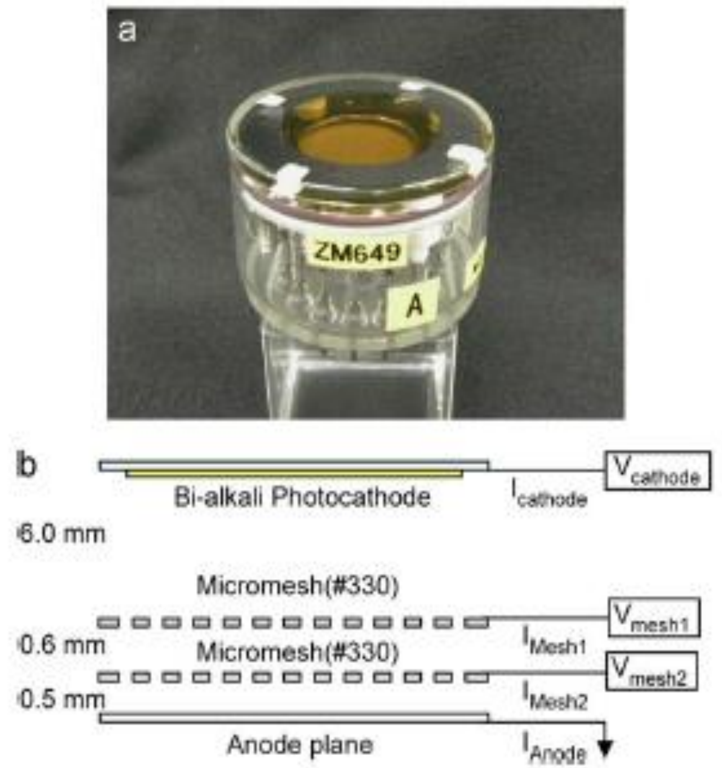
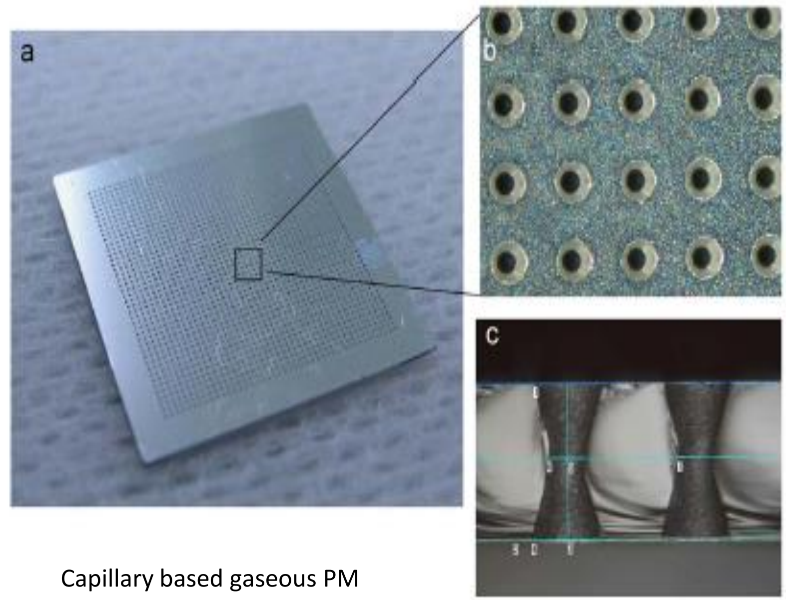
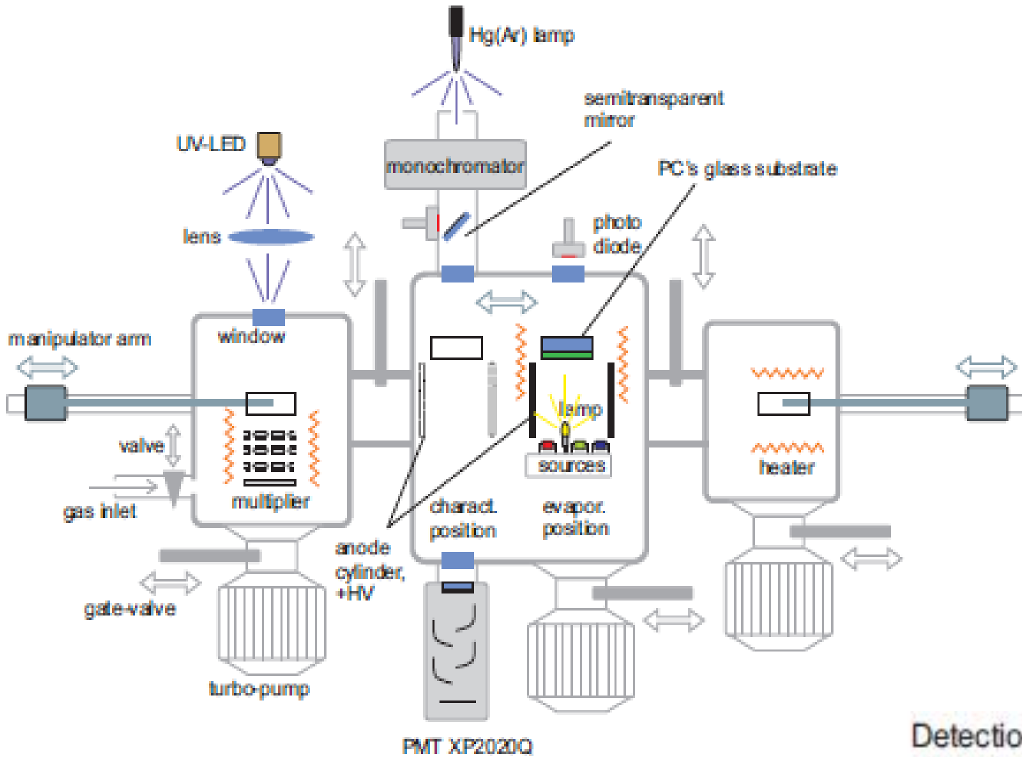


Fig. 1. Photograph (a) and schematic view (b) of the sealed gaseous PMT with a bialkali photocathode and double Micromegas detector.

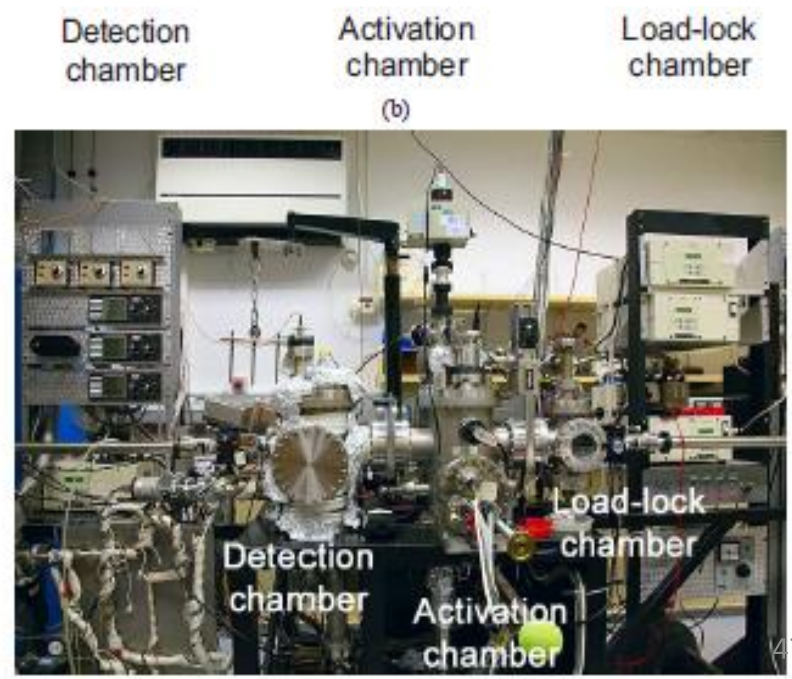


Capillary based gaseous PM

F. Tokanai et al, NIM A610,2009,164

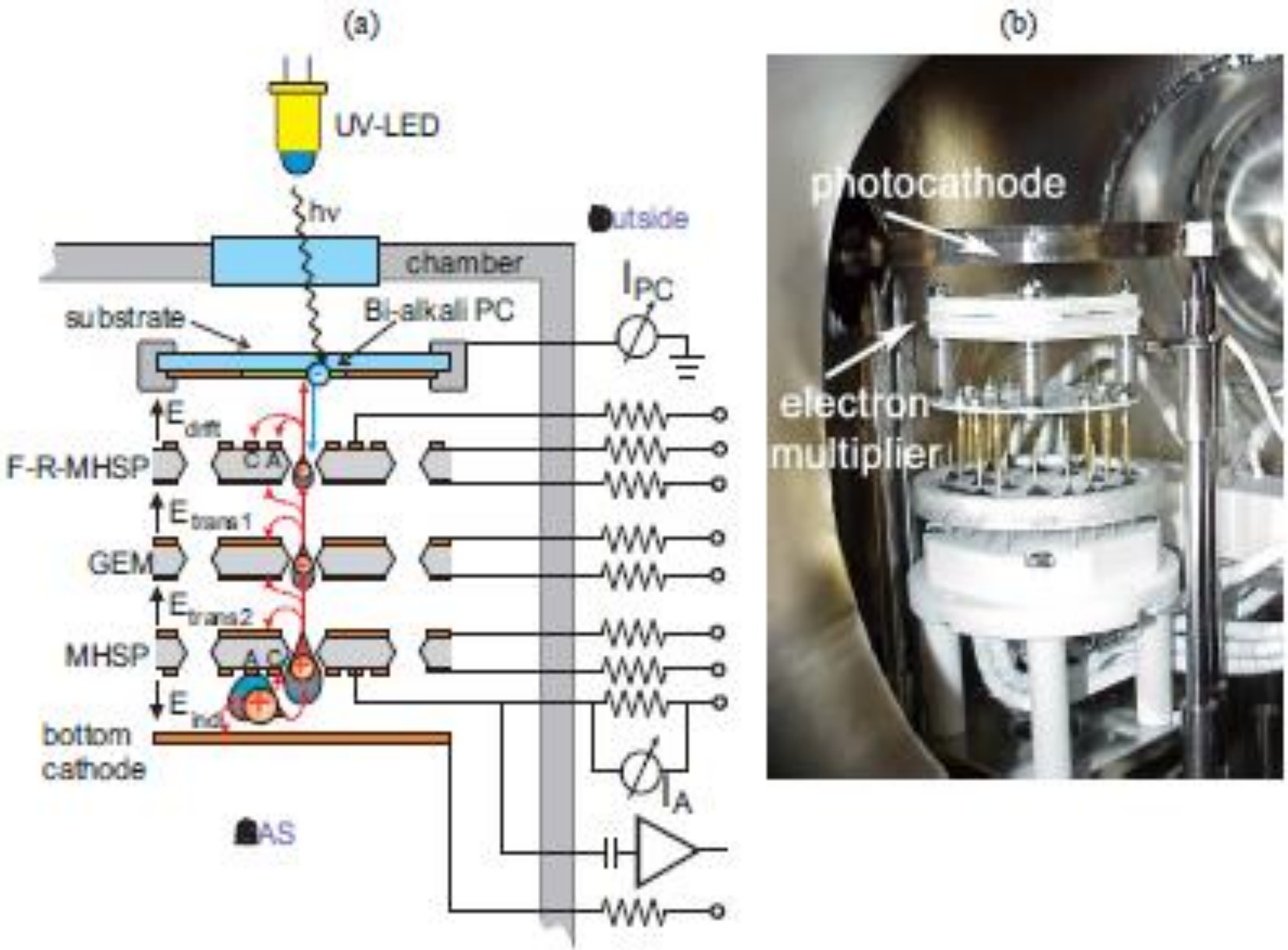


The set up is complicated and expensive



A. Lyashenko et al., JINST 4 P07005, 2009

State of art gaseous PMT based on MPGDs



A. Lyashenko et al., JINST 4 P07005, 2009

Detailed information about gaseous PMs can be found in the review: *R. Chechik, et al., NIM A595,2008,116*

MPGDs sensitive to visible light may have a great future: the main advantage is the possibility to build a large–area detectors

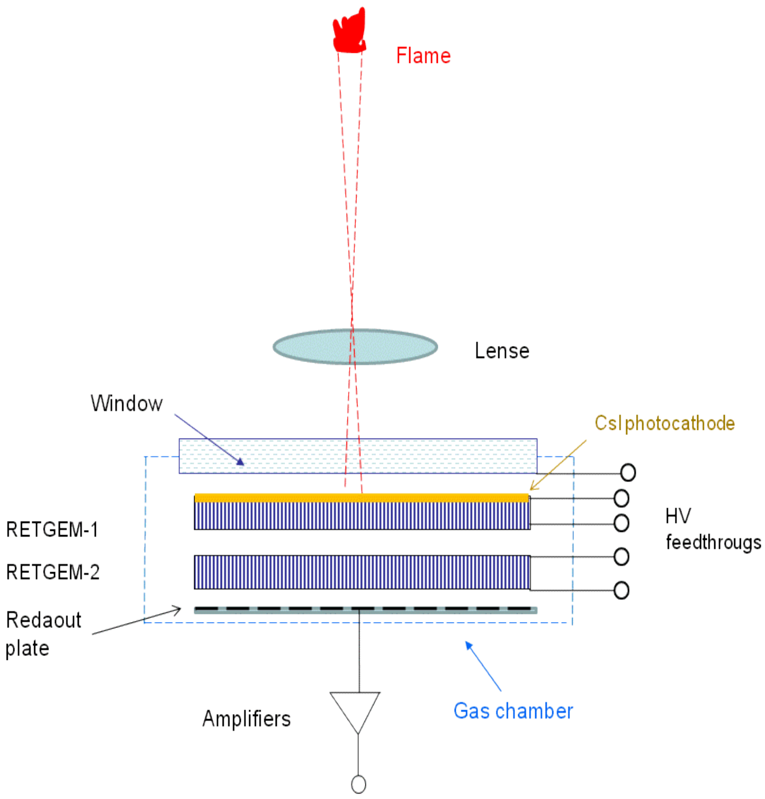
Applications of gaseous photomultipliers beyond RICH

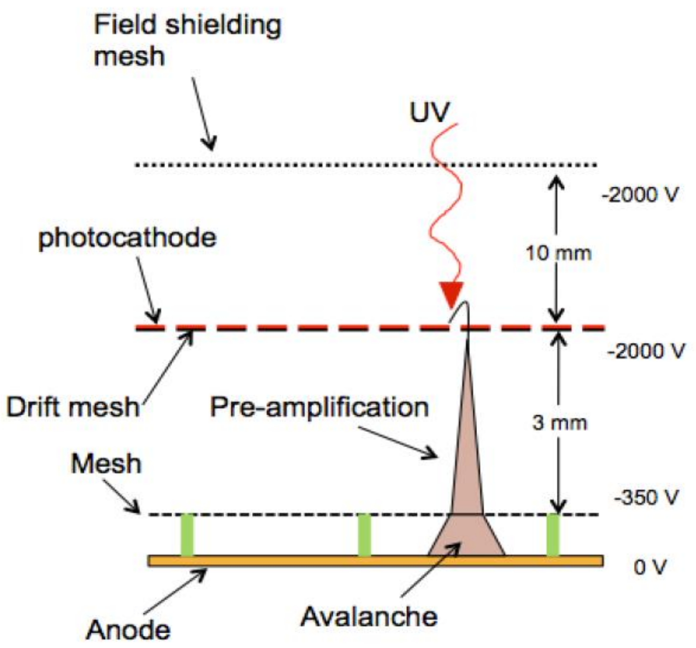
Flame detectors

Non position-sensitive gaseous PM

The main advantage:
100-1000 <u>times more sensitive</u>
than the best commercial
Flame detectors

Position-sensitive flame detectors

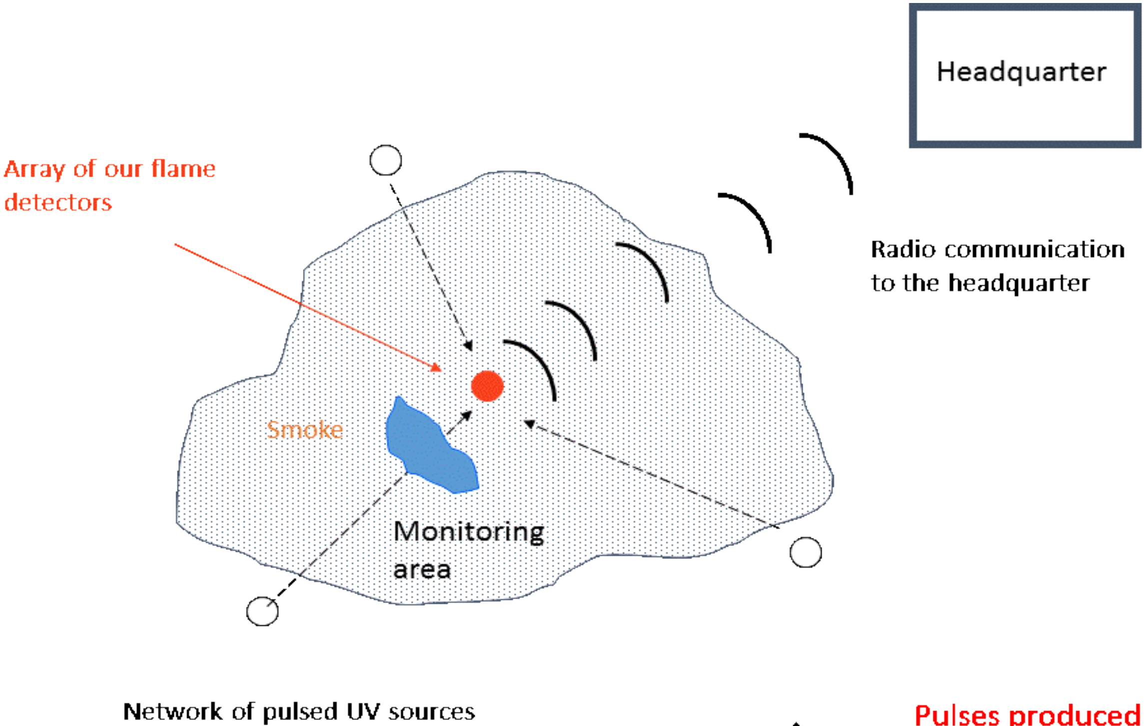


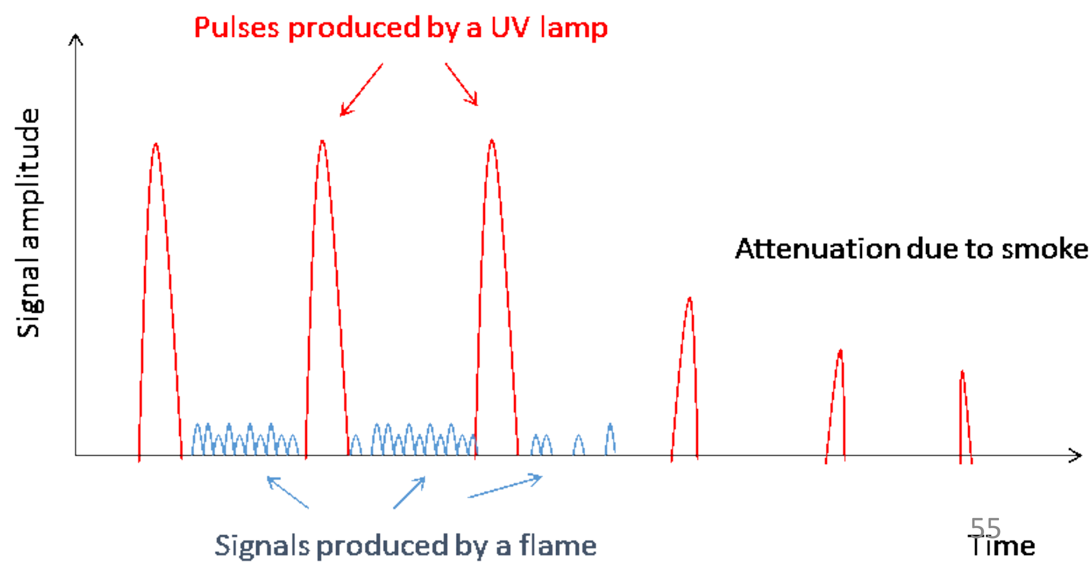


See for example:
Bidault et al.,Nucl.Phys B (Proc. Suppl.), 58 (2006) 199

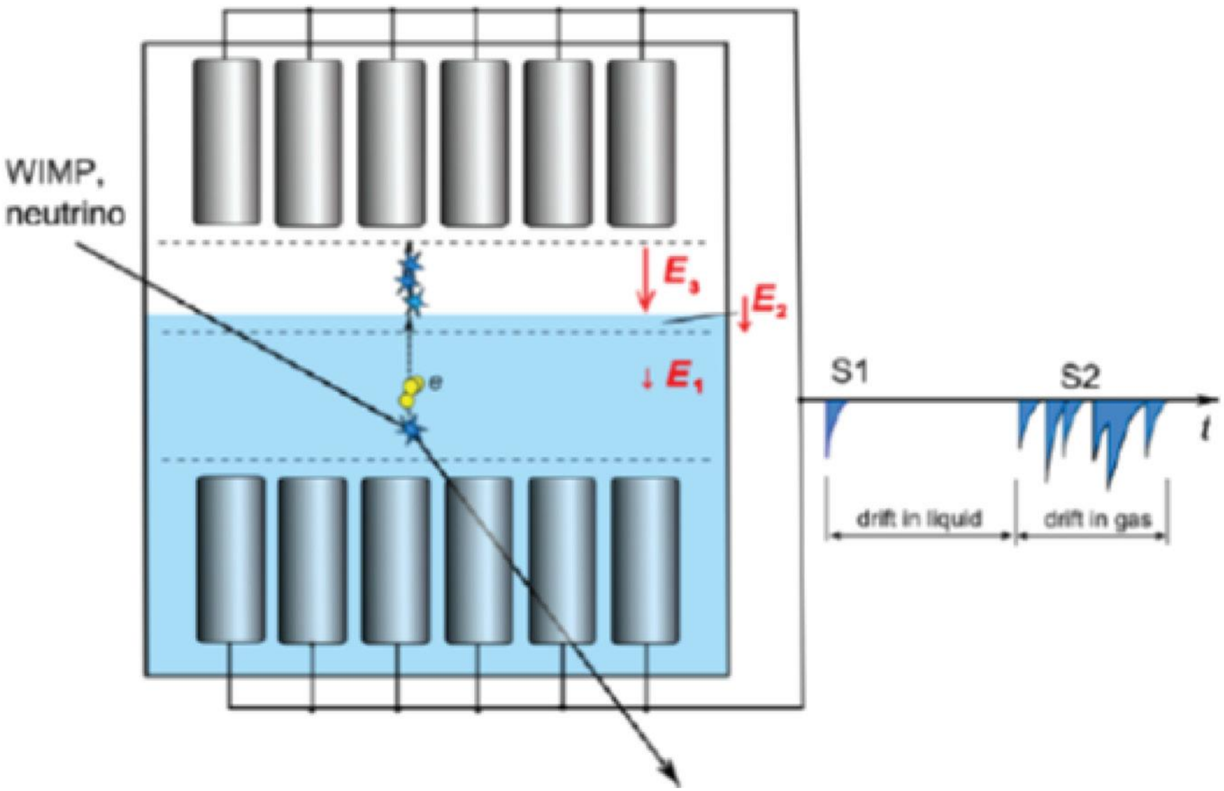
Peyaud et al., NIM, 787 (2015) 102

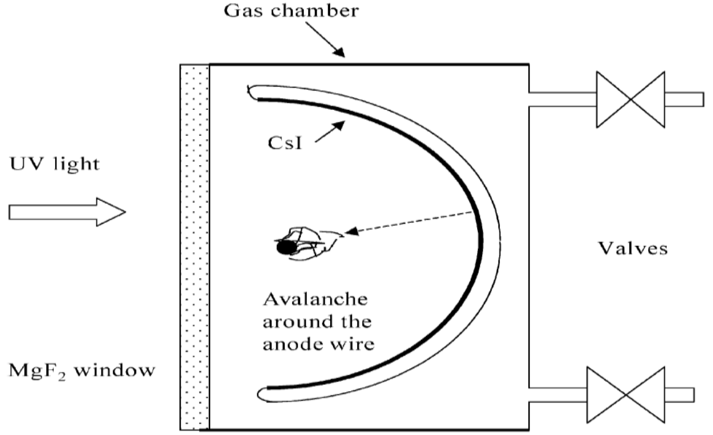
Flame and smoke detectors

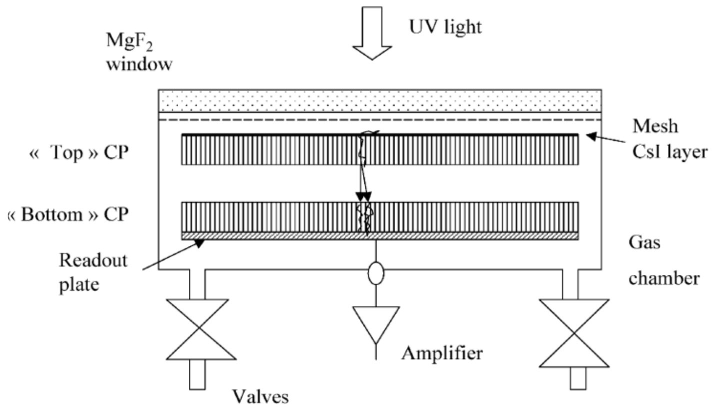


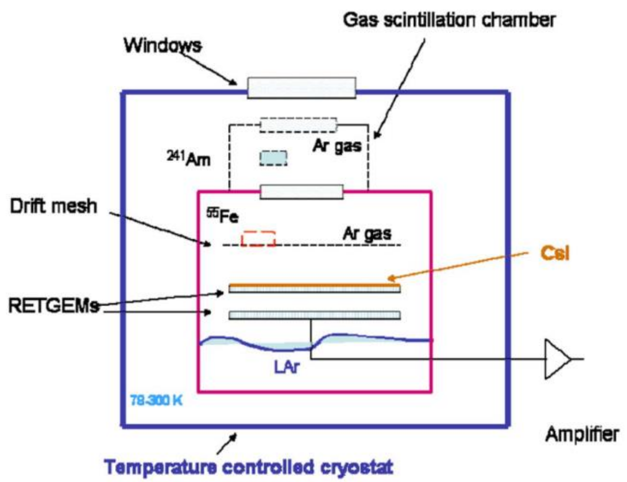


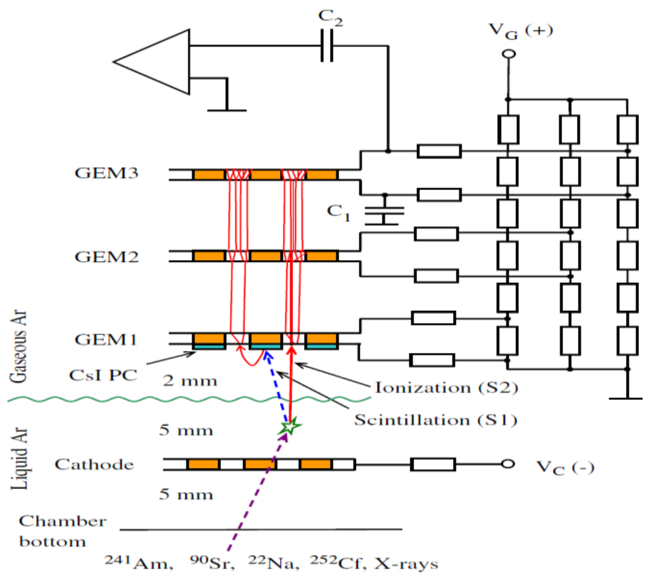
Noble liquids







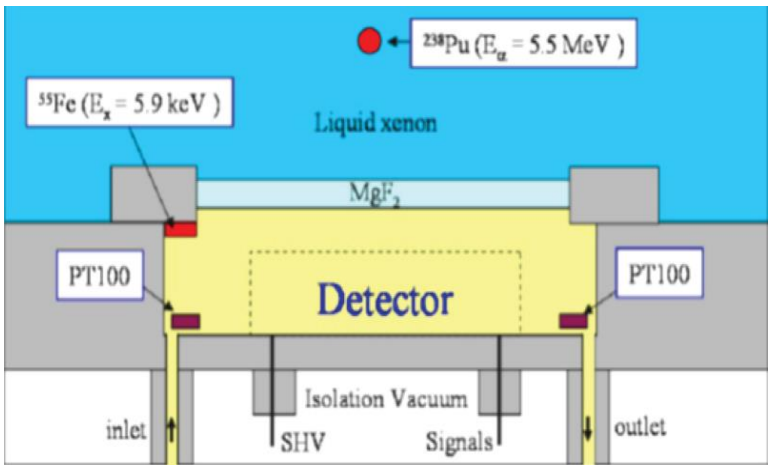


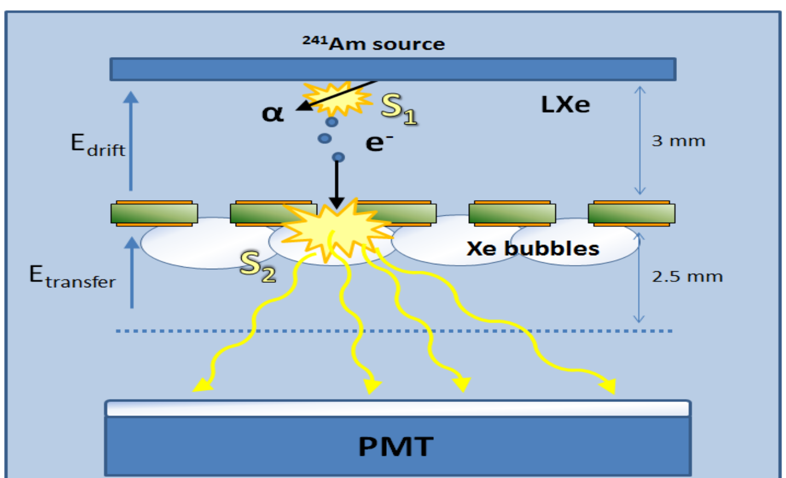


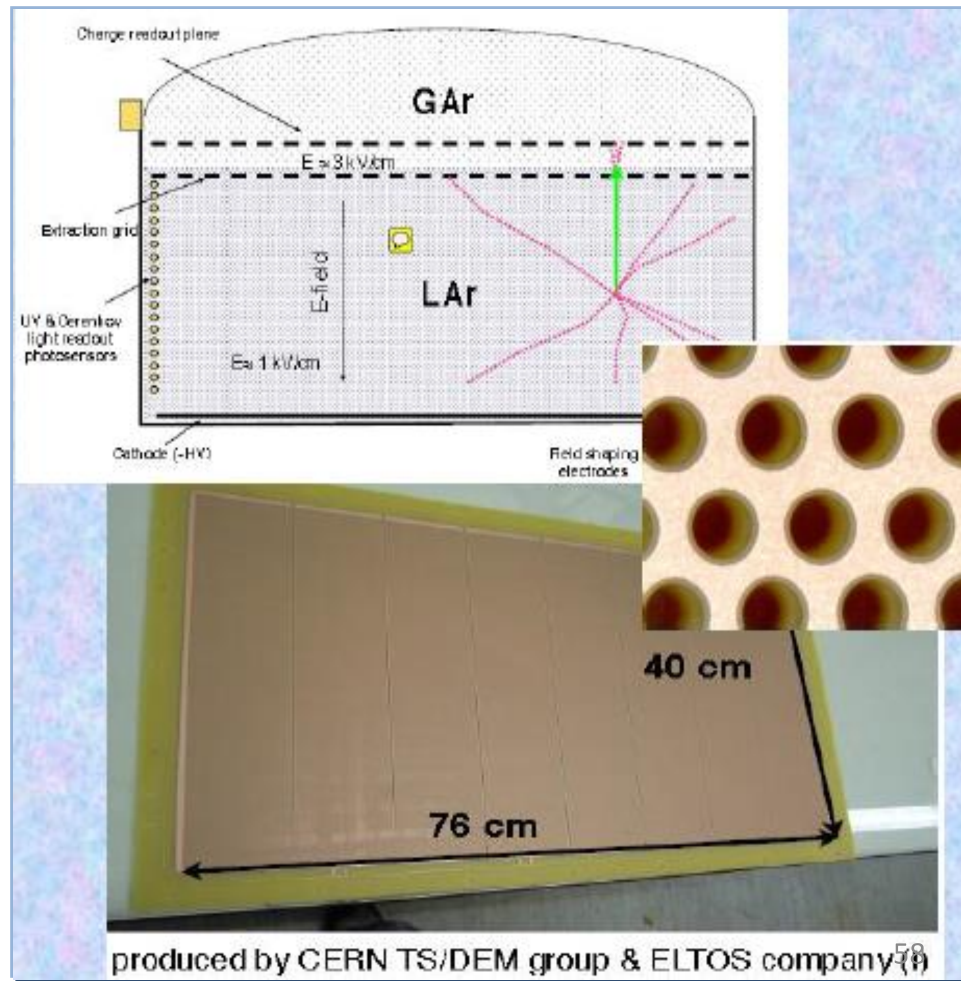
Periale et al., NIM A535, (2004) 517, IEEE Nucl. Sci.52 (2005), 927, NIM A567 (2006)381, NIM A572 (2007), 189, NIM 573 (2007) 302

Bondar et al., NIM A581(2007) 241

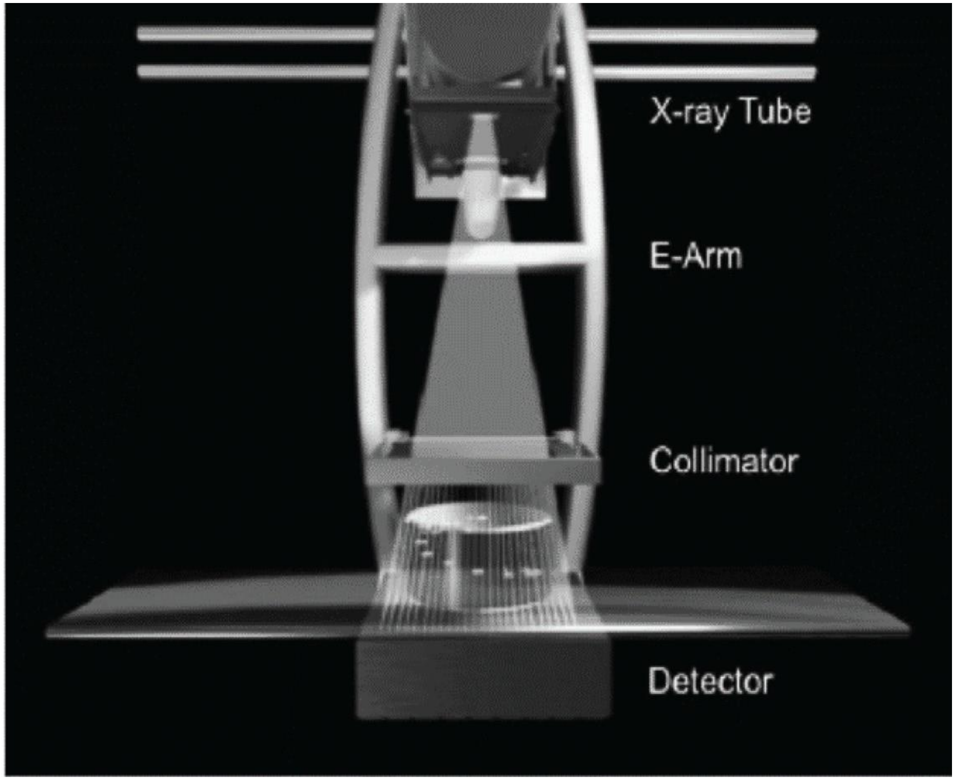
These studies were successfully continued by several groups



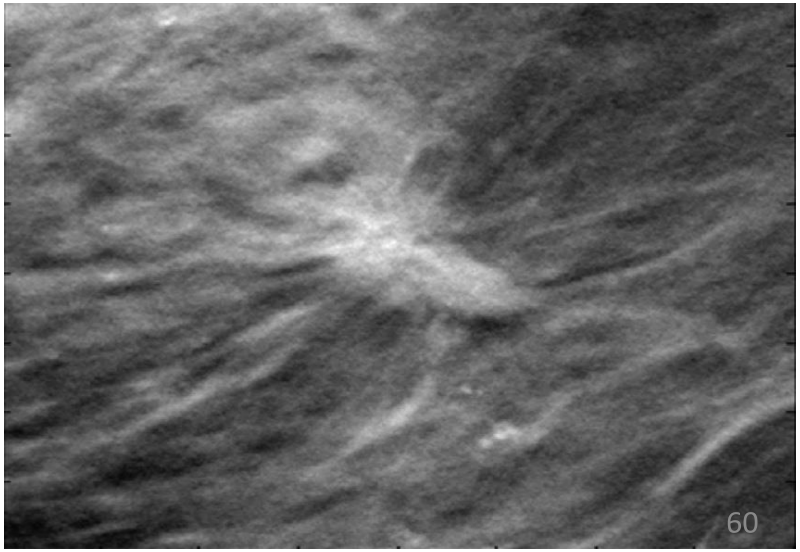




Micropattern detectors can be used not only fro the detection of UV and visible photons, but also fo the detection of x-ray gamma rays



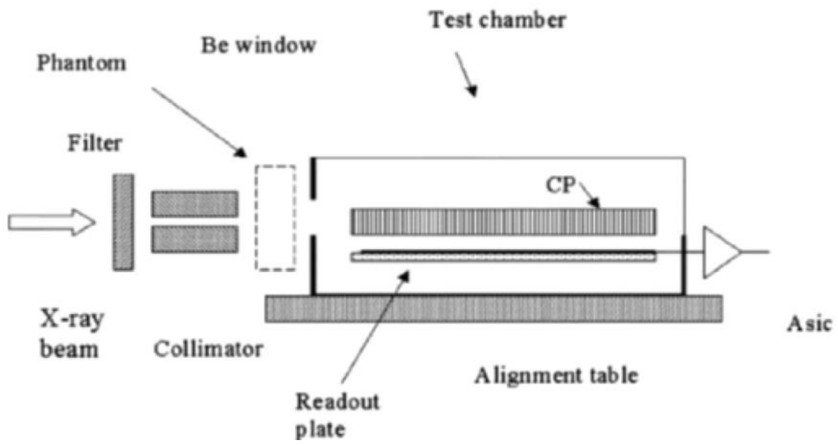
Low dose mammographic scanner

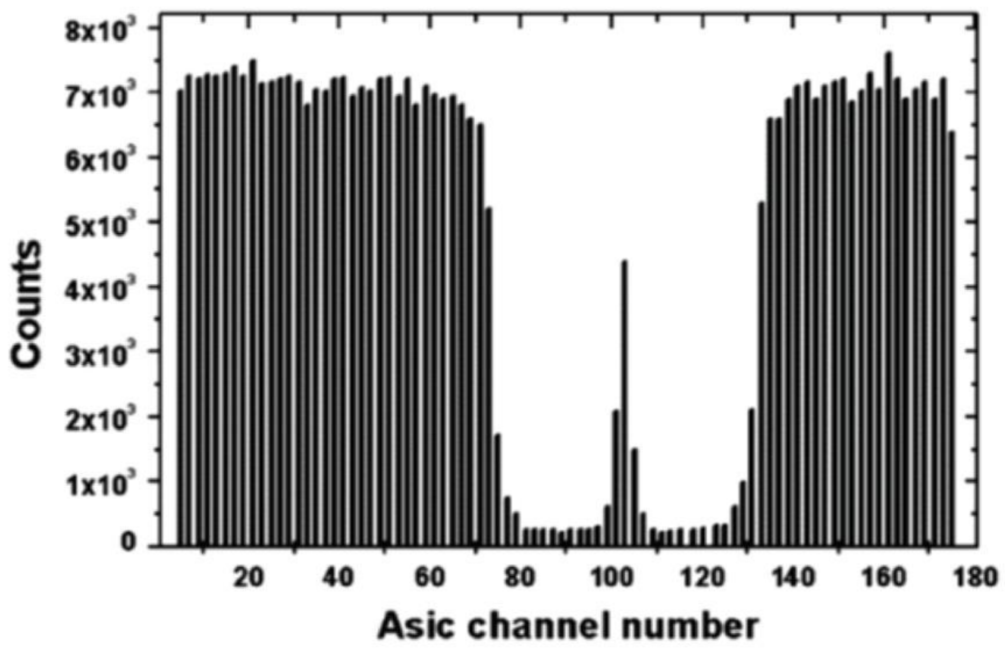


Microgap RPCs with a CsI convertor for detection of X-ray

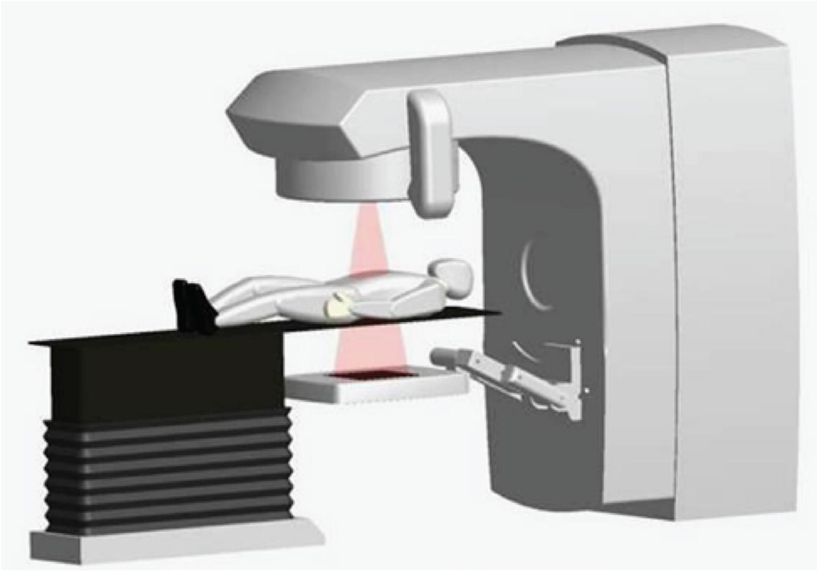
Maidment et al., Proc. of SPIE, 2006

Glass capillary-based X-ray scanner



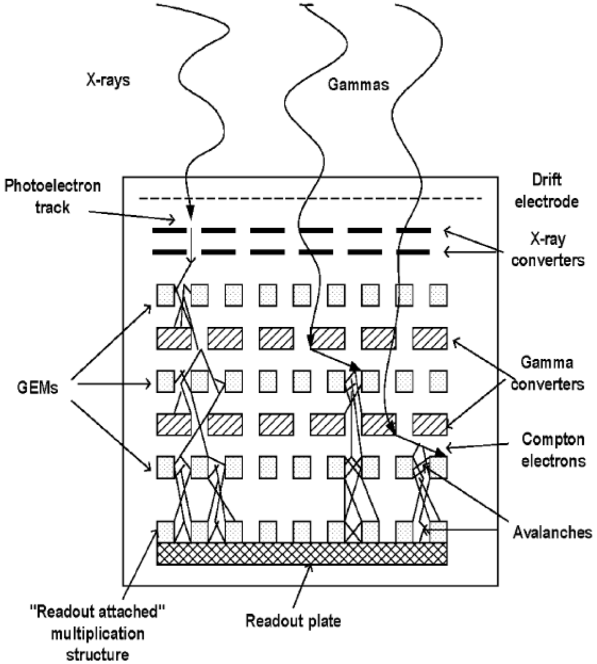


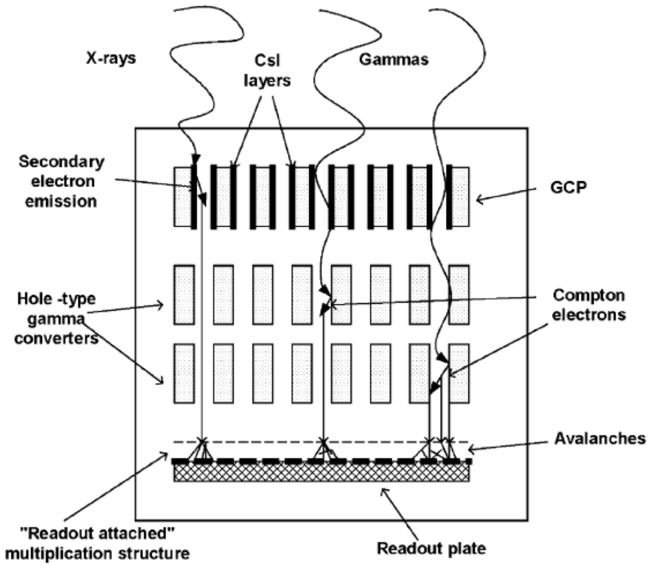
Iacobaeus, et al., IEEE Trans Nucl. Sci, 55 (2006) 554



Simultaneous monitoring of a therapeutic beam and an X-ray image of the patient

Iacobaeus et al., IEEE Tran Nucl. Sci 8 (2001)1496





Danielsson, NIM A 515 (2004) 406

Conclusions:

- Long-term experience of many groups show that gaseous PM are reliable and competitive devices
- Micropattern gaseous detector offer new possibilities: suppression of feedbacks (high gains) and excellent position and time resolution
- Gaseous PM will be used in COMPASS RICH and my have many other applications: in detection of scintillation light from noble liquids, UV visualization, flame detection and etc.

New momentum in developmets:
micropatter gaseous detectors

Detection of x-ray gamma rays

X rays Tom + capillaries

Gamm danileson

Ostling