A New Generation of GEM Detectors and their Applications

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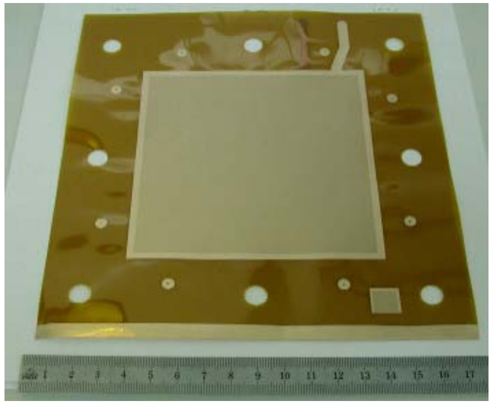
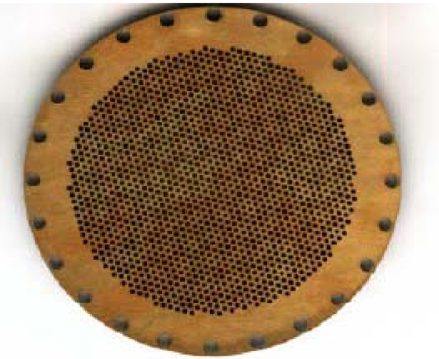
Recently developed hole-type gaseous detectors have opened new possibilities in the detection of photons and charged particles.

Capillary plate
H.Sakuria et al.,NIM,A374,1996,341



GEM
F. Sauli,NIM, A386,1997,531



TGEM
L.Periale et al., NIM, A478,2002,377

Hole-type gas avalanche amplifiers were introduced by I. Fijueda et al., (IEEE Nucl.Sci.NS-33,1986,587) a long time ago

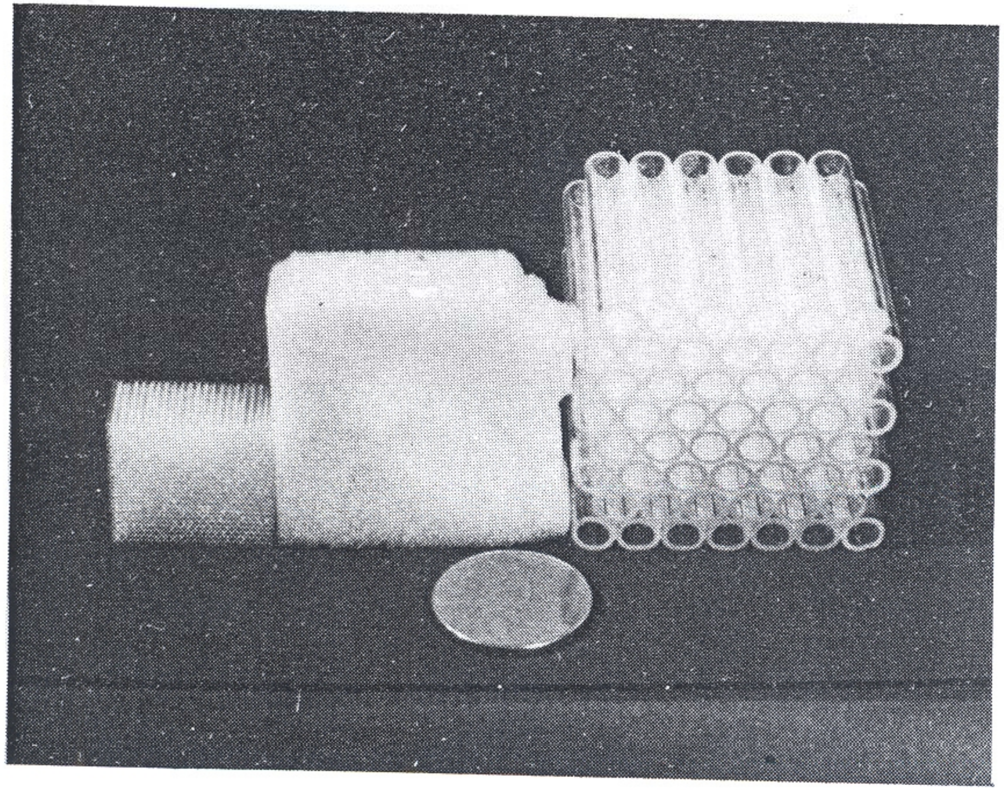
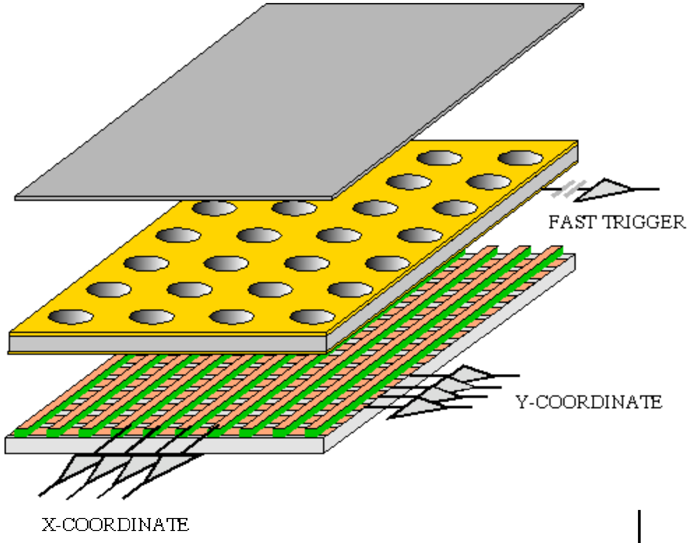
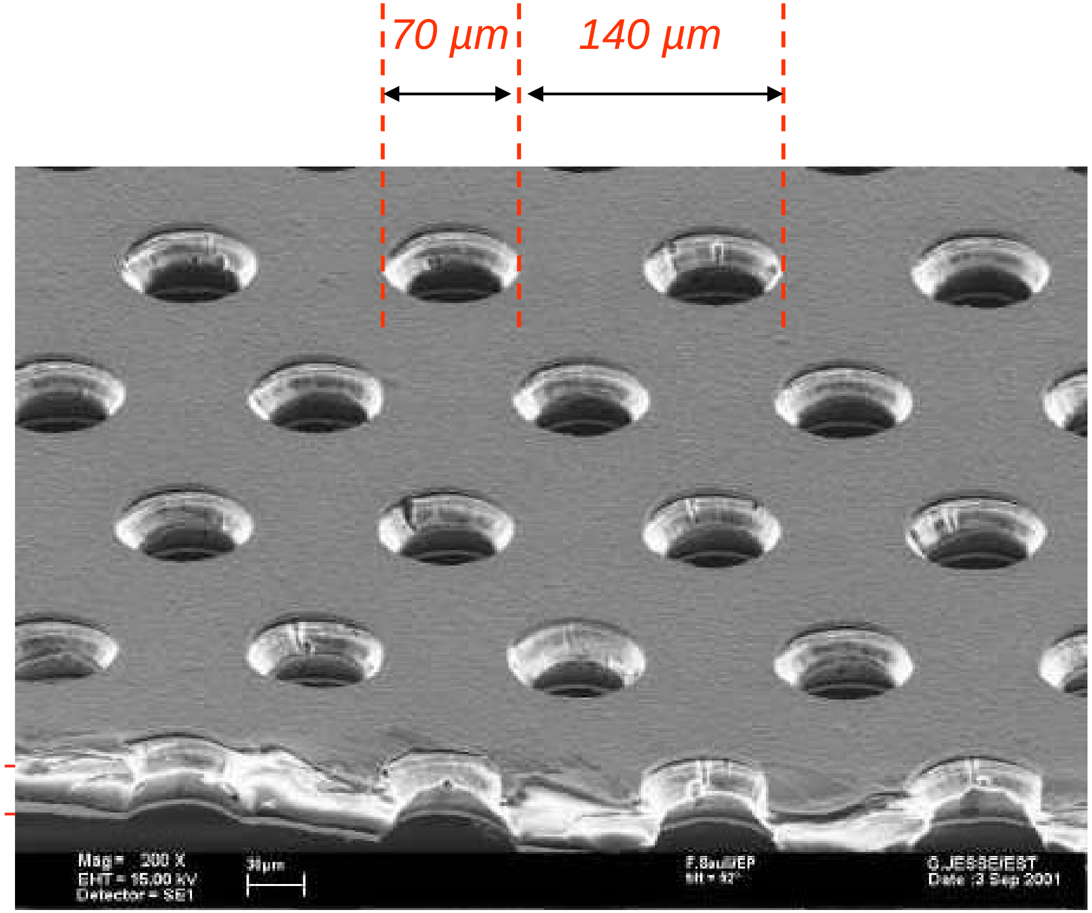


Fig. 2. Three samples of lead glass arrays (before H_2 treatment). From left to right: for RICH, PET and electromagnetic calorimeter applications. (Tubing diameters as from table 1.)

Nowadays, the most popular hole-type detector is the so-called Gas Electron Multiplier (GEM)





F. Sauli,
NIM A386,1997, 531

One should admit however, that the GEM is a rather fragile detector and could easily be damaged by sparks, almost unavoidable at high gains of operation.

Thus, the main problems appears at single photon/electron counting mode

Difficulty:

single photon detection → thus high gain

→ high risk of discharges

Want cause the breakdowns?

1) In bad quality detectors - imperfections

2) In good quality detectors - there is a fundamental reason- a so called Raether limit

Raether limit:

It was discovered recently that the maximum achievable gains of bare hole –type structures A_{max} are governed by the so-called Raether limit (first empirically established by H. Raether for parallel-plate chambers):

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

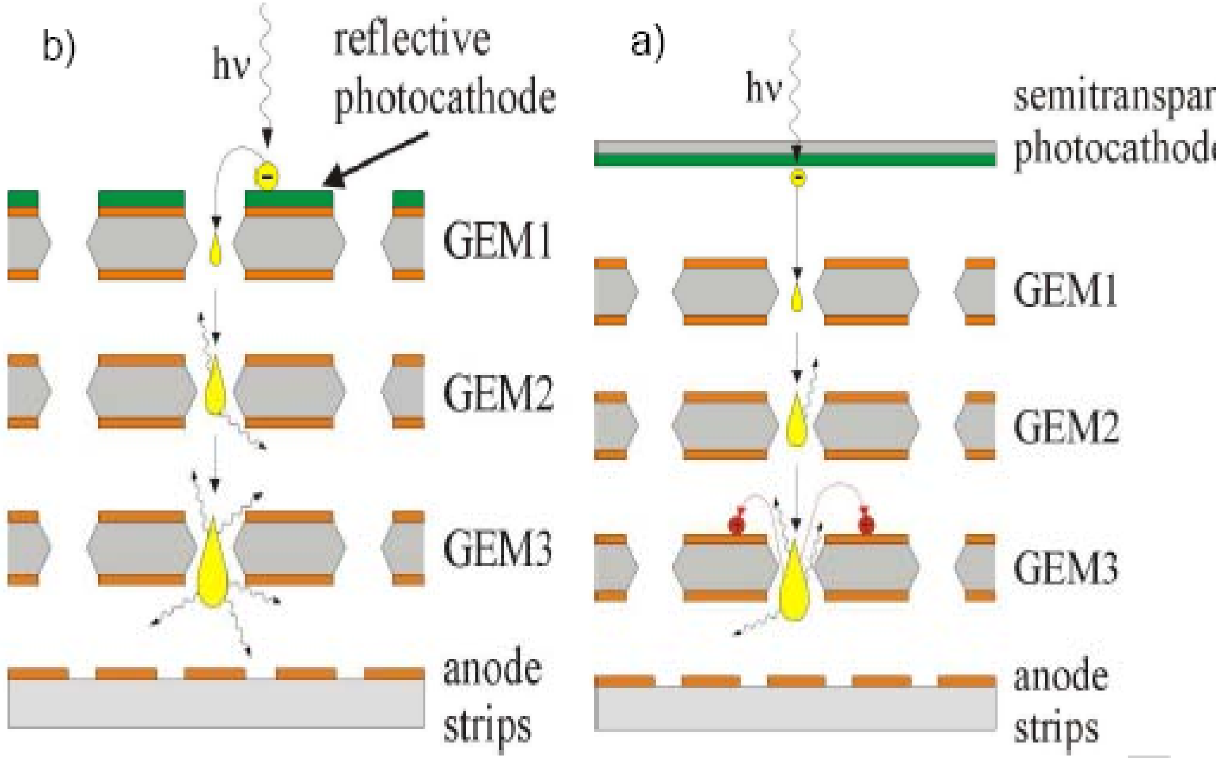
where n_0 is the number of primary electrons created in the drift region of the detector

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

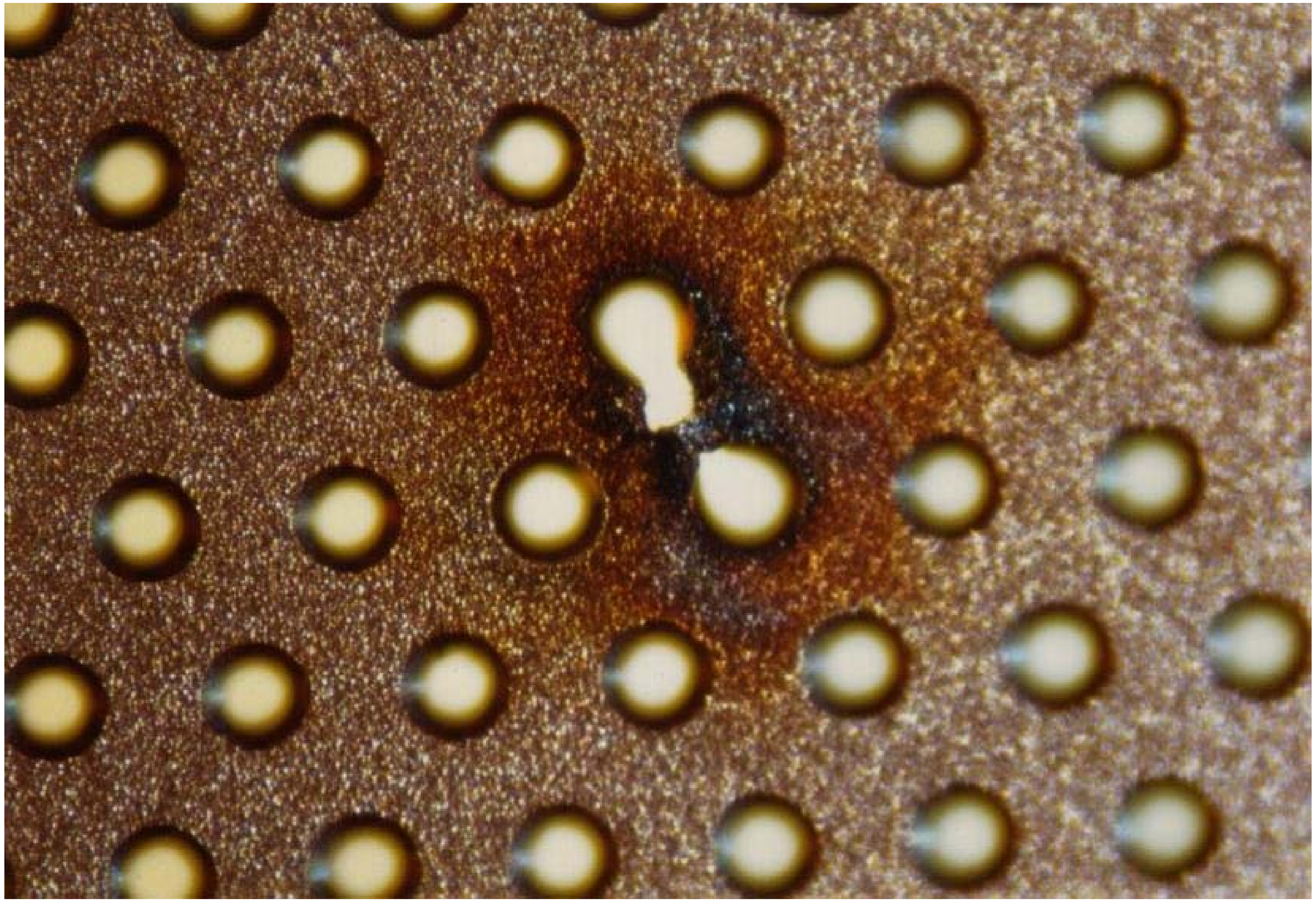
(see Y. Ivanchenkov et al., NIM A422,1999,300 and
V. Peskov et al., IEEE Nucl. Sci. 48, 2001, 1070)

Therefore, at gas gains $\geq 10^5$ (necessary for single electron detection) any radioactive background, natural or created during the high energy physic experiment, if it produces more than 100 primary electrons (heavily ionizing particles, showers and in some cases even minimum ionizing particles) will trigger occasional discharges

There are several standard measures to lower the sparking rate and the subsequent damage caused by using either segmented GEMs, or many GEMs (up to 4-5) in a cascaded mode



However, Phenix experience shows that in spite of all these measures photosensitive GEMs can be damaged..



...so sparks are unavoidable

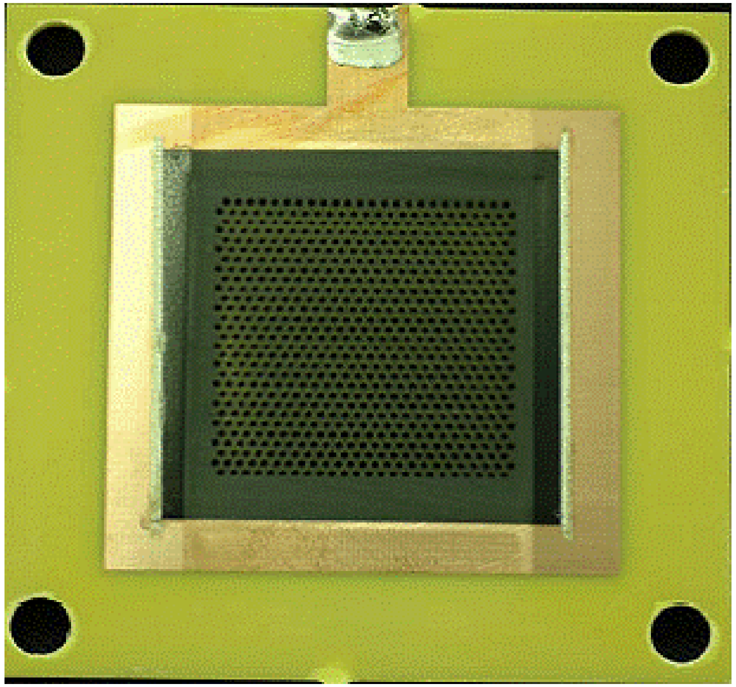
This is why choose another direction:

we have developed Resistive Electrodes GEM (RETGEM)

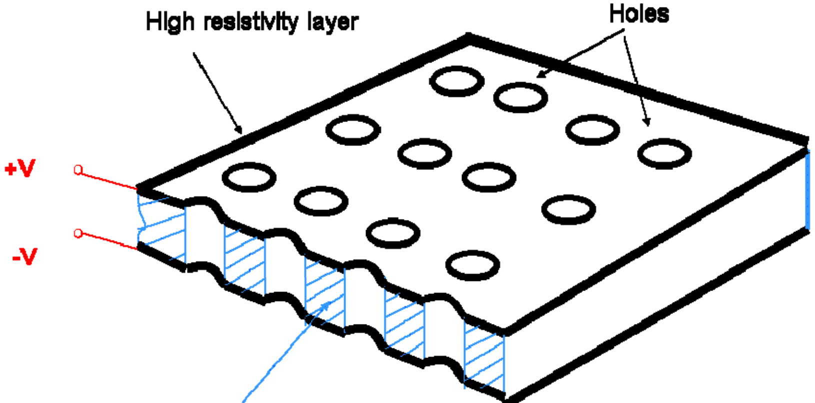
What is RETGEM?

Thick GEM with resistive electrodes (RETGEM)- a fully spark protected detector

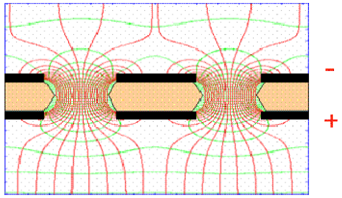
TGEM



RETGEM



Principle of operation

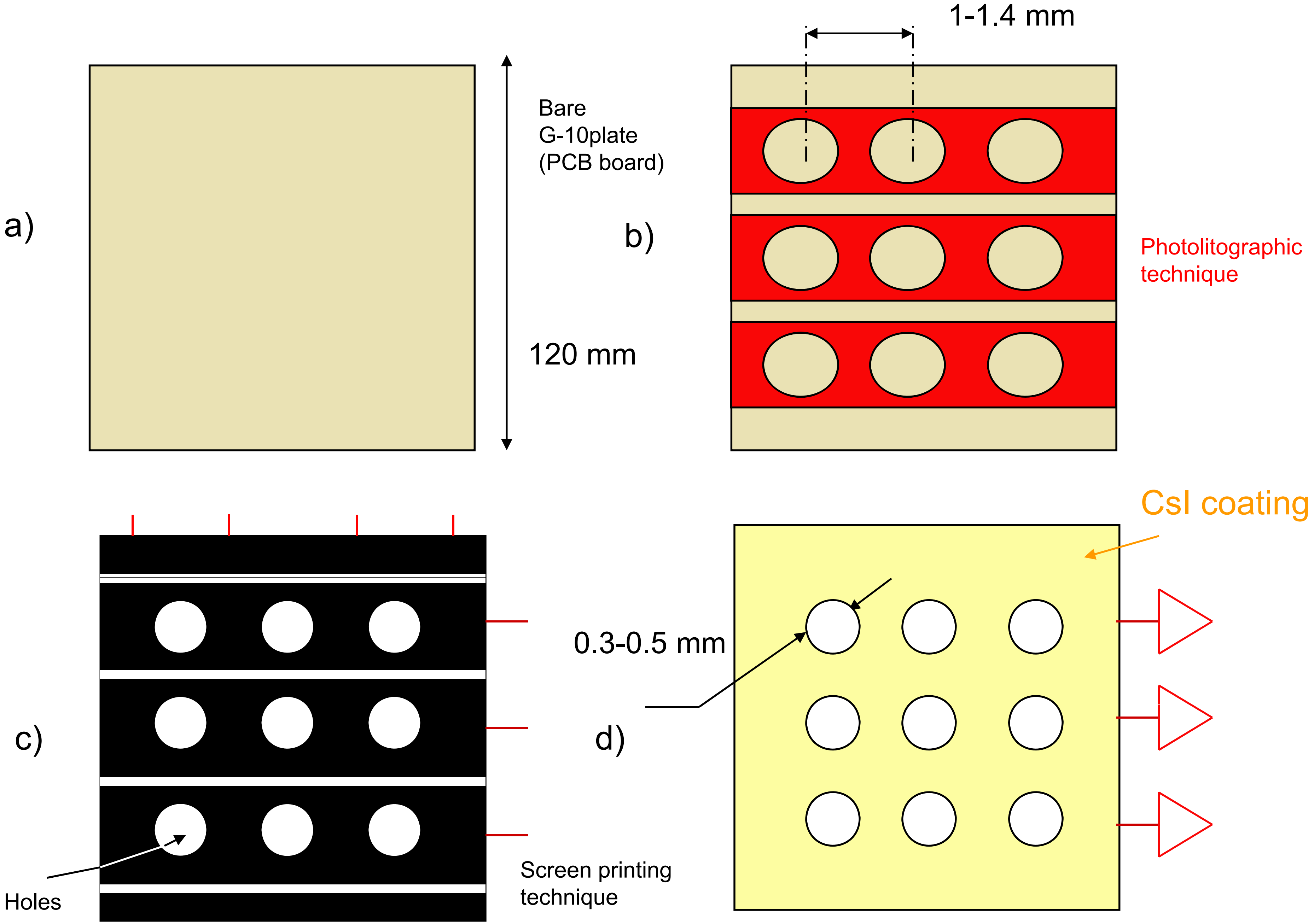


More about TGEM see in:
L. Periale et al., NIM A478,2002,377
J. Ostling et al., IEEE Nucl. Sci 50,2003,809
R. Chechik et al., NIM A553, 2005, 35
C. Chalem et al, NIM A558, 2006, 475

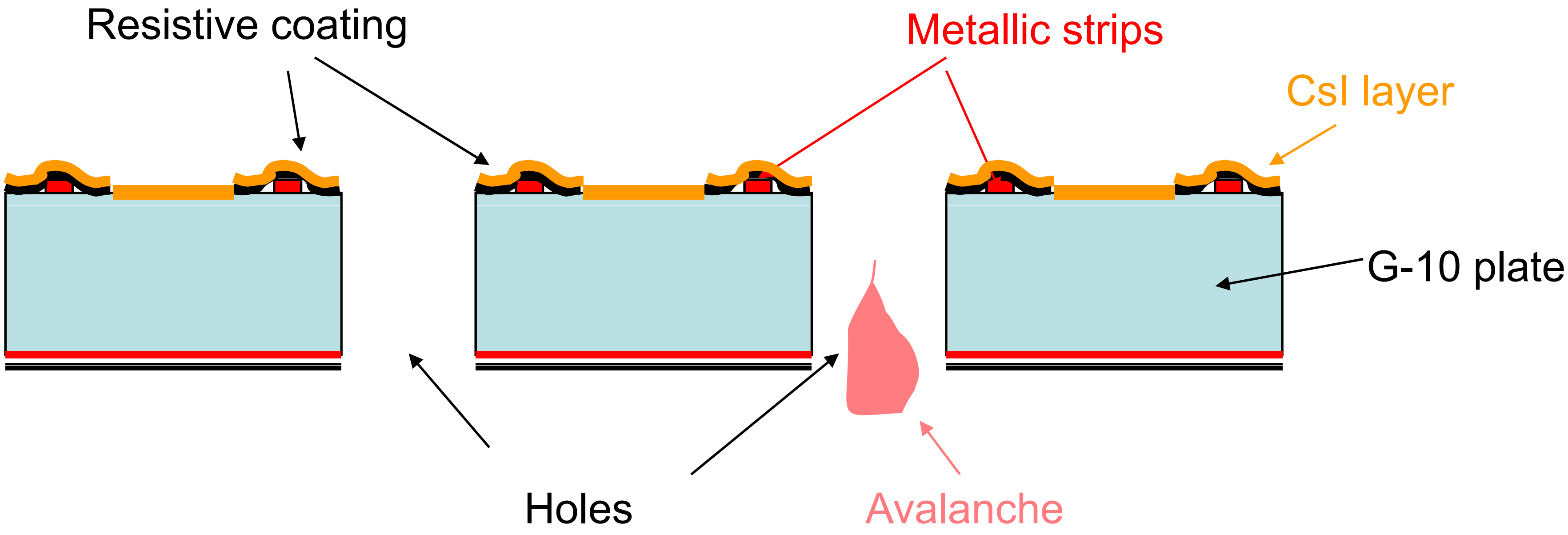
Geometrical and electrical characteristics:
Holes diameter 0.3-0.8 mm, pitch 0.7-1.2 mm, thickness 0.5-2 mm. Resitivity:200-800kΩ/□
Kapton type: 100XC10E
or a resisive layer made by a screen printed technology

New advanced design:
“Strips “ RETGEM
(S-RETGEM)

Top view


1-1.4 mm
a)
Bare
G-10plate
(PCB board)
120 mm
b)
Photolitographic
technique
CsI coating
c)
0.3-0.5 mm
d)
Holes
Screen printing
technique

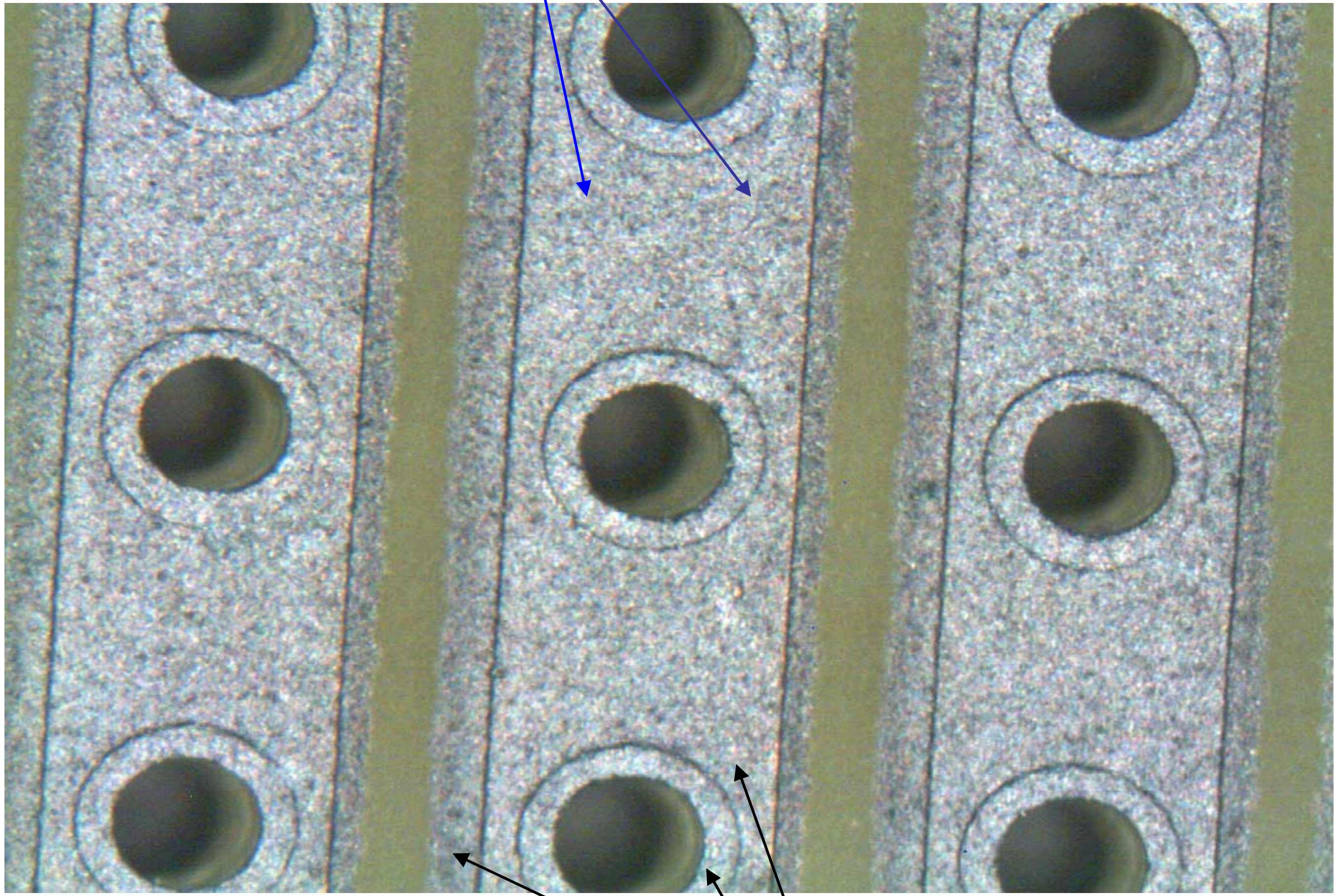
Side view:



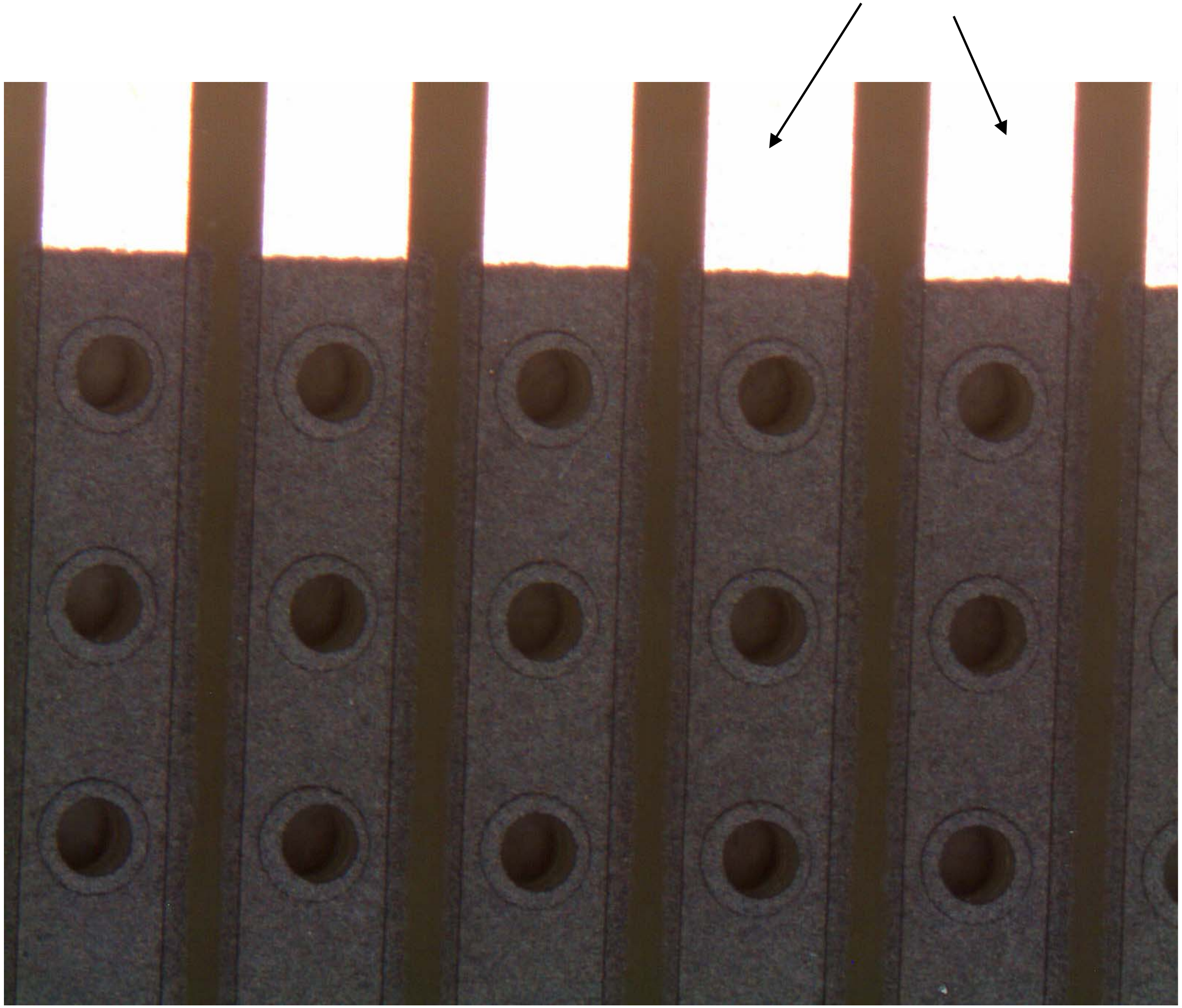
Metallic strips allow position- sensitive readout

Resistive coating provides spark-protection

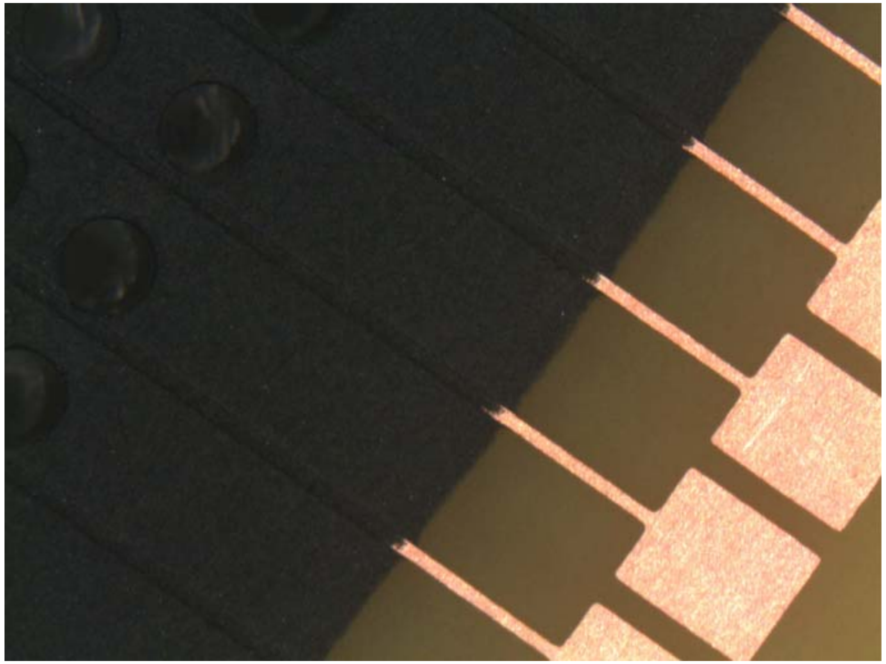
Inner metallic strips



Resistive strips on the top of metallic strips

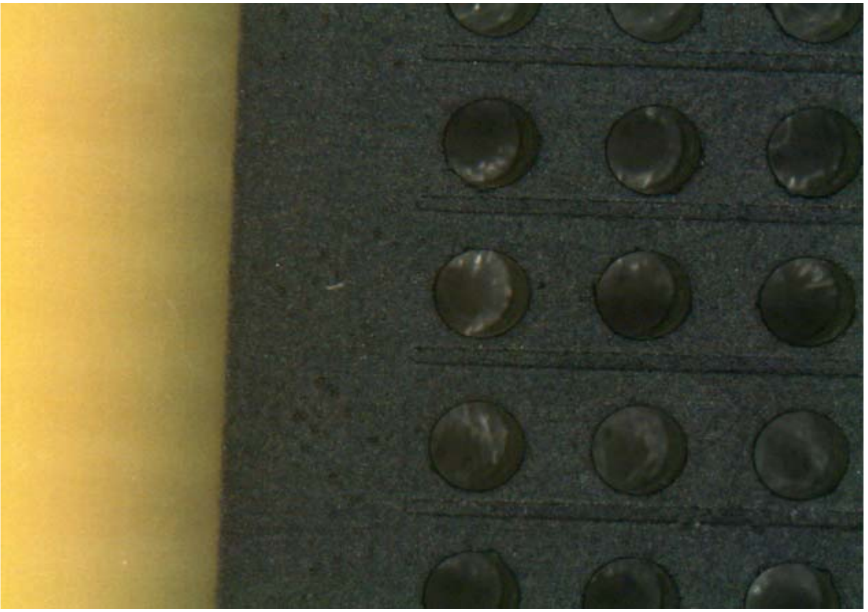

Cu pads for contacts

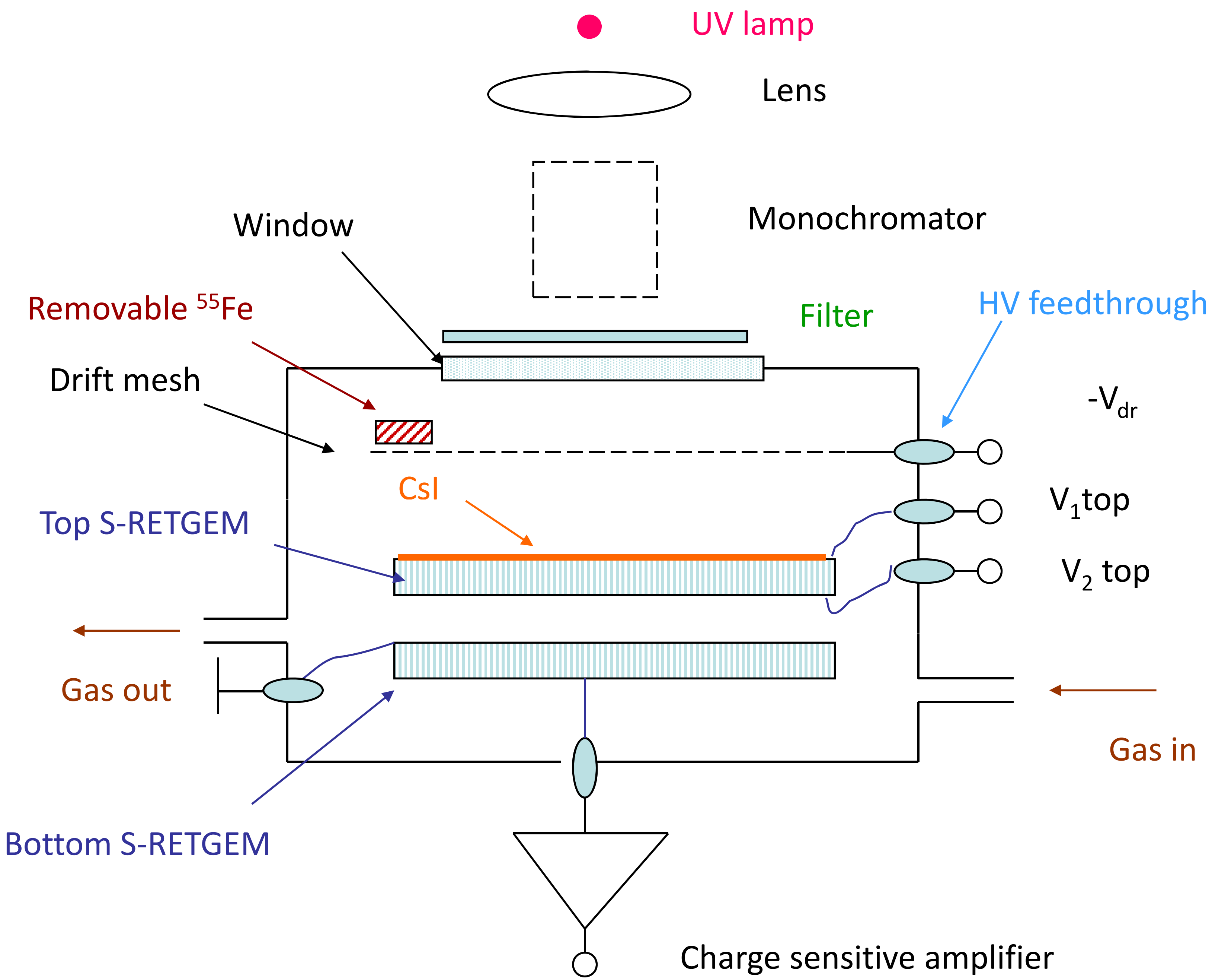
Design with perpendicular strips on both sides of the G-10



Photos of the S- RETGEM with perpendicular strips

Resistive coating-15μm
Strips thickness ~13μm




UV lamp
Lens
Monochromator
Window
Removable ^{55}Fe
Filter
HV feedthrough
Drift mesh
$-V_{dr}$
CsI
V_1top
Top S-RETGEM
V_2 top
Gas out
Gas in
Bottom S-RETGEM
Charge sensitive amplifier

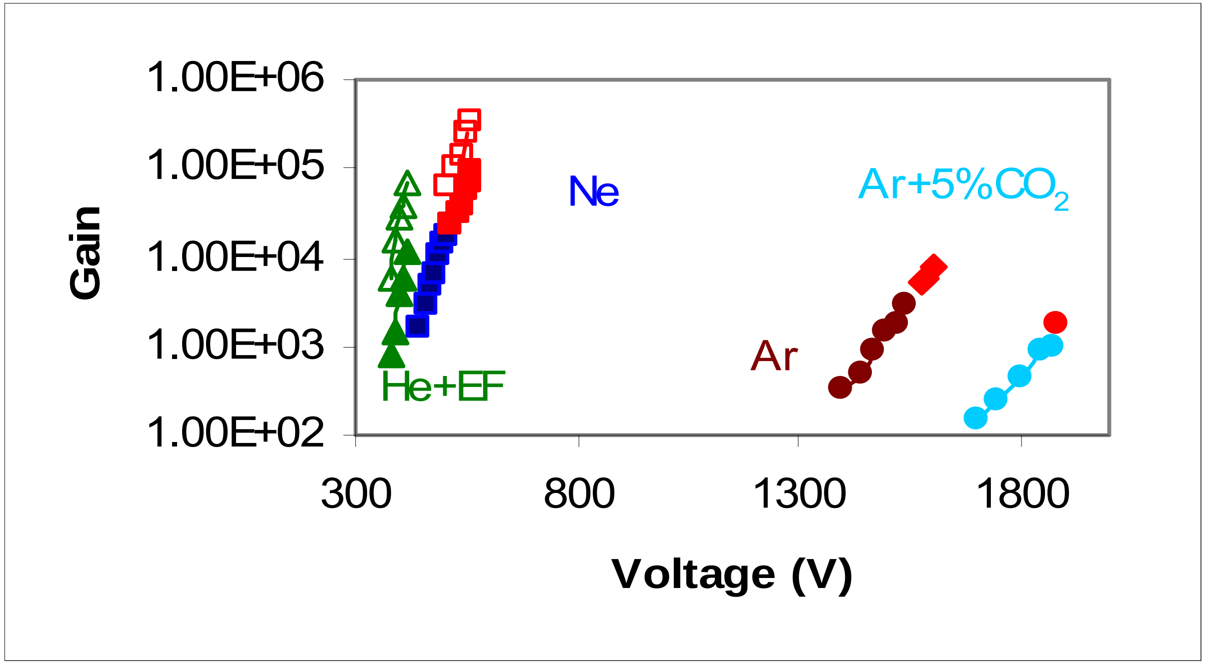
We discovered that S-RETGEMs being coated with CsI layers gain high efficiency to UV:

quantum efficiency 13-15% can be achieved at 185 nm

Gains in various gases (UV only):

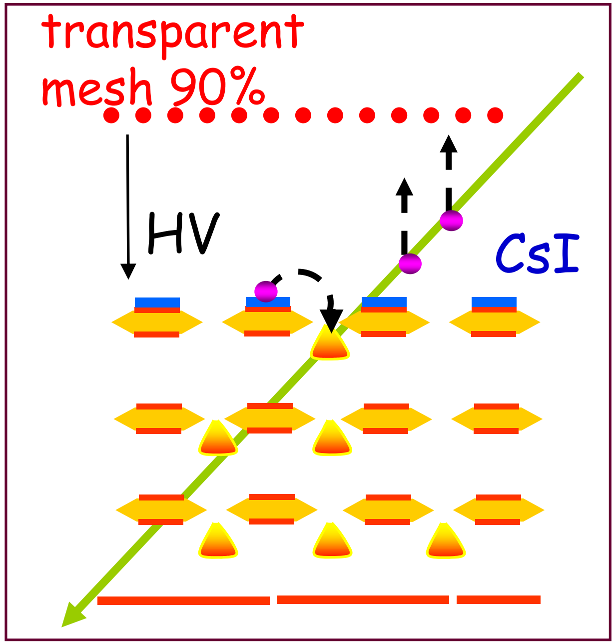
Filled symbols-single S-RETGEM

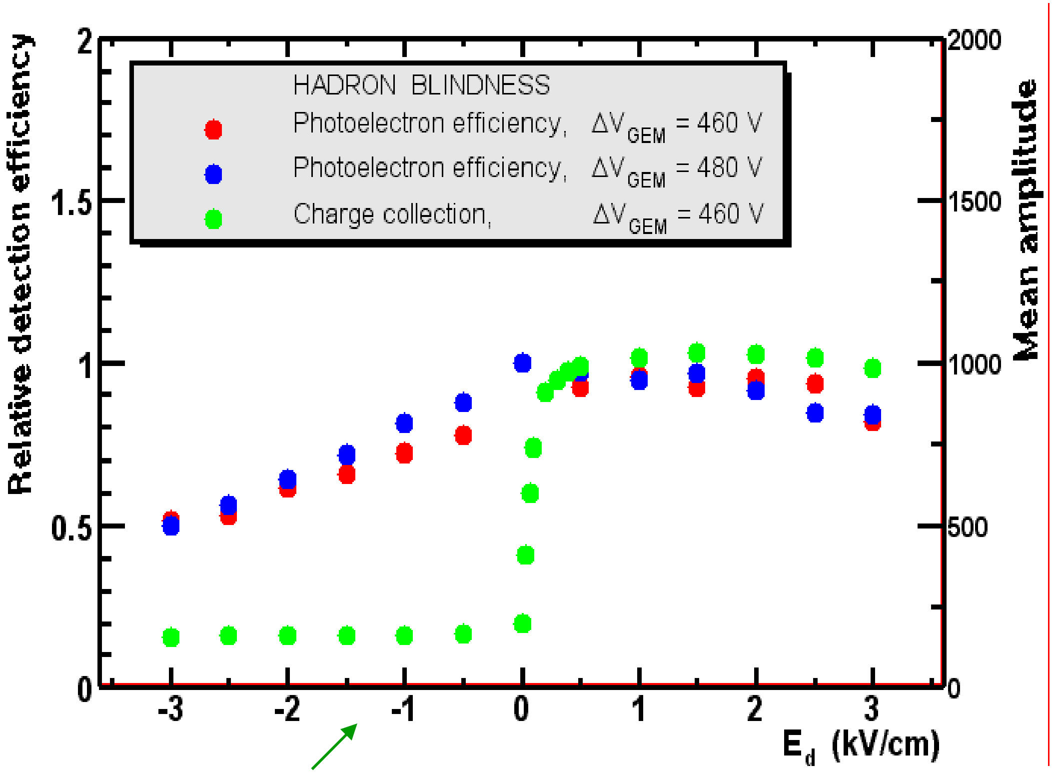
Open symbols-double S-RETGEM



We discovered that in He- and Ne-based gases and in the case of the inverted drift filed the S-RETGEM can operate at 10-20 times higher gains than in the case of Edr=-250V/cm reaching the values of 10^5 and 10^6 with a single and double S-RETGEM, respectively. Such high gains allowed detecting single photoelectrons even with one S-RETGEM.

Phenix Hadron Blind detector: UV photons vs α particles

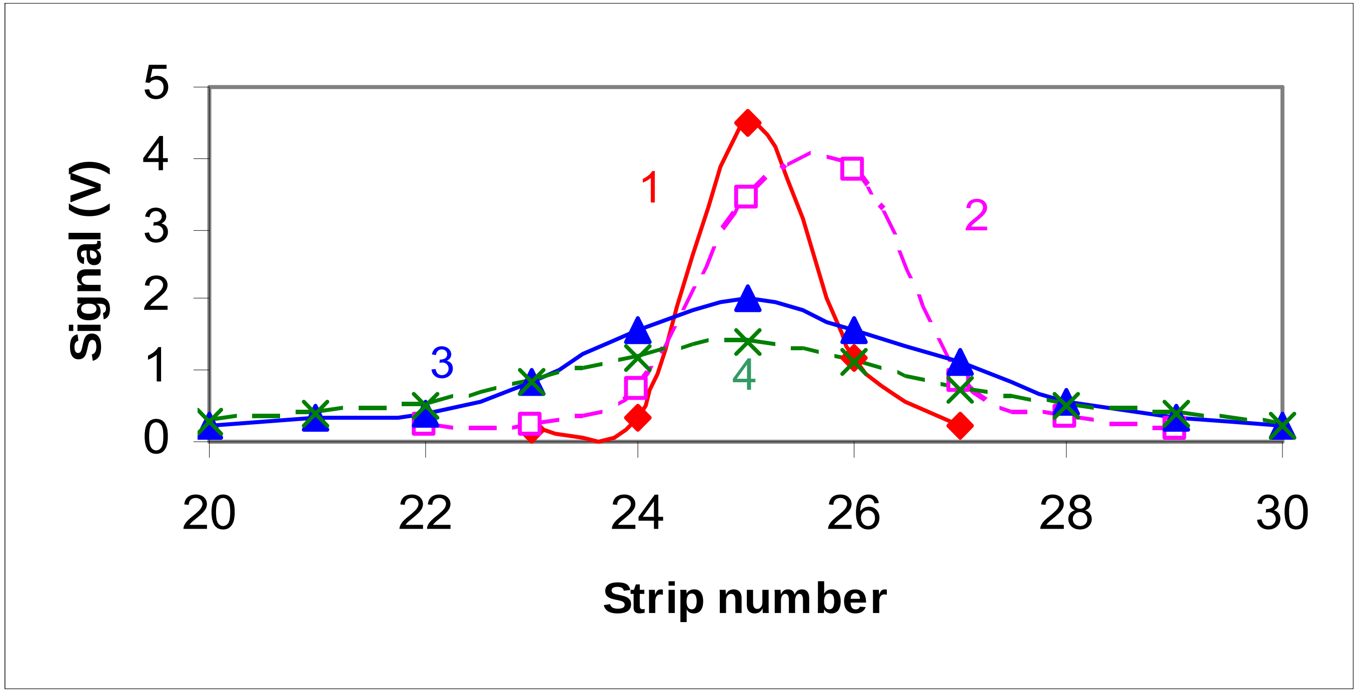




Inversed drift field

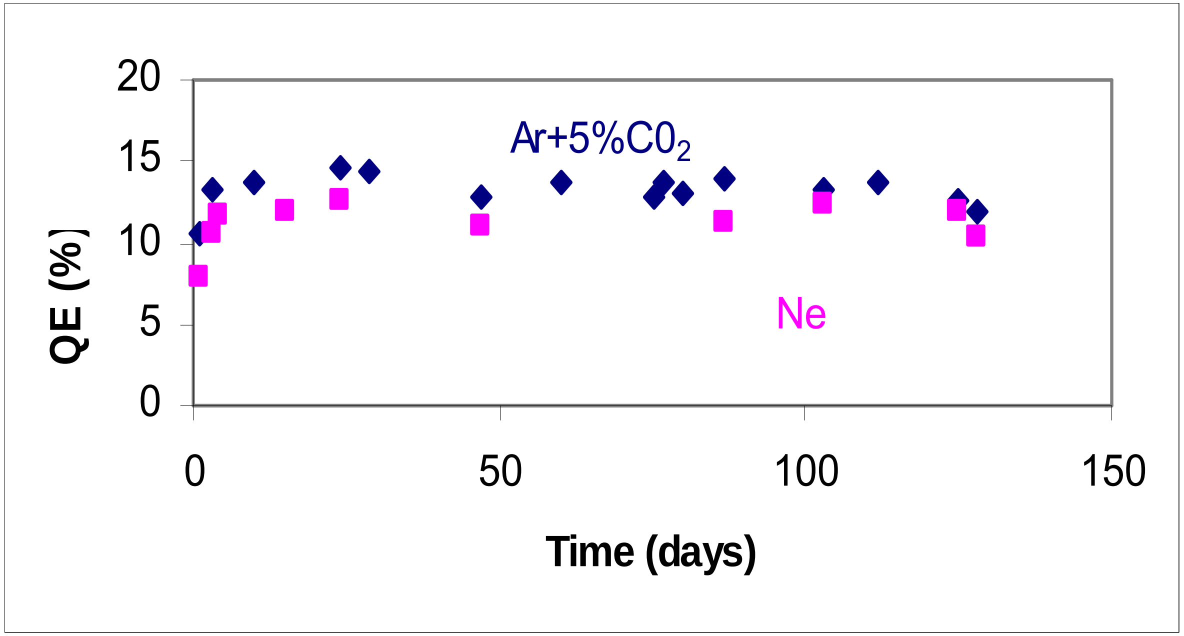
At slightly negative E_d, photoelectron detection efficiency is preserved whereas charge collection is largely suppressed.

Position resolution:



Thus, after optimization of the drift voltage and the gas composition we were able to reach remarkable high gas gains with S-RETGEM detectors allowing to detect single photoelectrons and make position measurements even with a single S-RETGEM!

Stability with time:



Unique features of S-RETGEMs:

1) With reverse drift field, due to high achievable gains ~10^5,one can use a single–plate UV detector (instead of three stage+ readout plate as it is in the case of GEM-based detectors)

2) S-RETGEM is intrinsically spark protected

Note also that due to the low strip capacity and the protective resistive coating, the discharges happing at gains >10^5-10^6 were exceptionally weak- their energy was almost 10 times less than n the case of the ordinary RETGEMs.

Strip design offers the possibility to disconnect bad channels

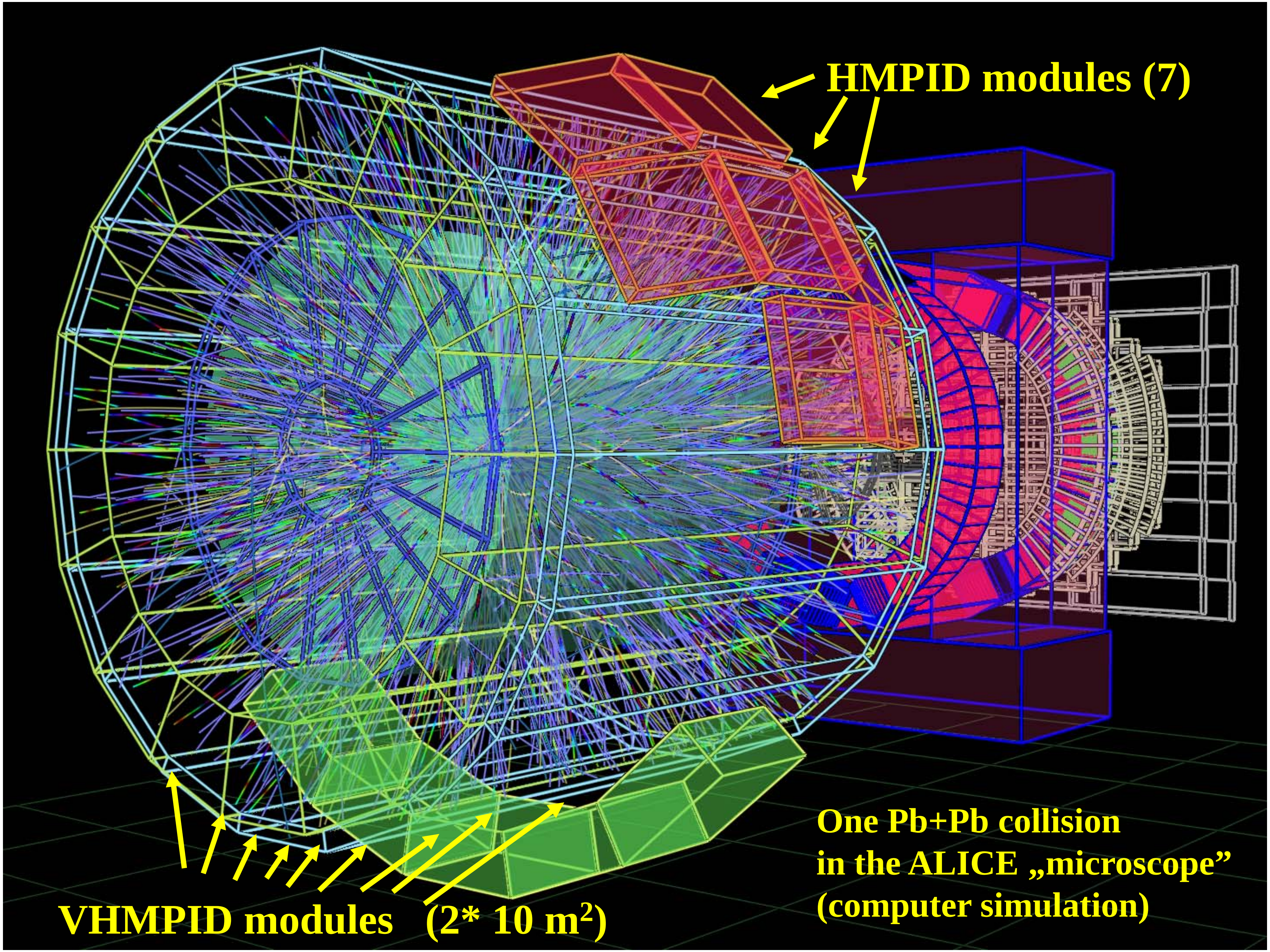
Among several tested S-RETGEMs we had one which “sparked” (very mild discharges) in Ar+CO_2 mixture at rather low gains~10^2. By identifying the strips at which the discharges happened and applying the -200V negative voltage on these strips (thus lowering the voltage across the S-RETGEM in the troubled region) we were able to operate the rest of the detector area at “nominal” gas gains shown in one of the Fig. above. We consider this experience as a possible practical method to operate detectors at high gains even if several holes have defects.

It also offers the possibility of position measurements by strips readout (no needs in traditional readout plate!)

Possible applications of singe-step S-RETGEM:

Could be many, as examples we will focus on upgraded ALICE RICH and dark matter noble liquid detectors

RICH



HMPID modules (7)

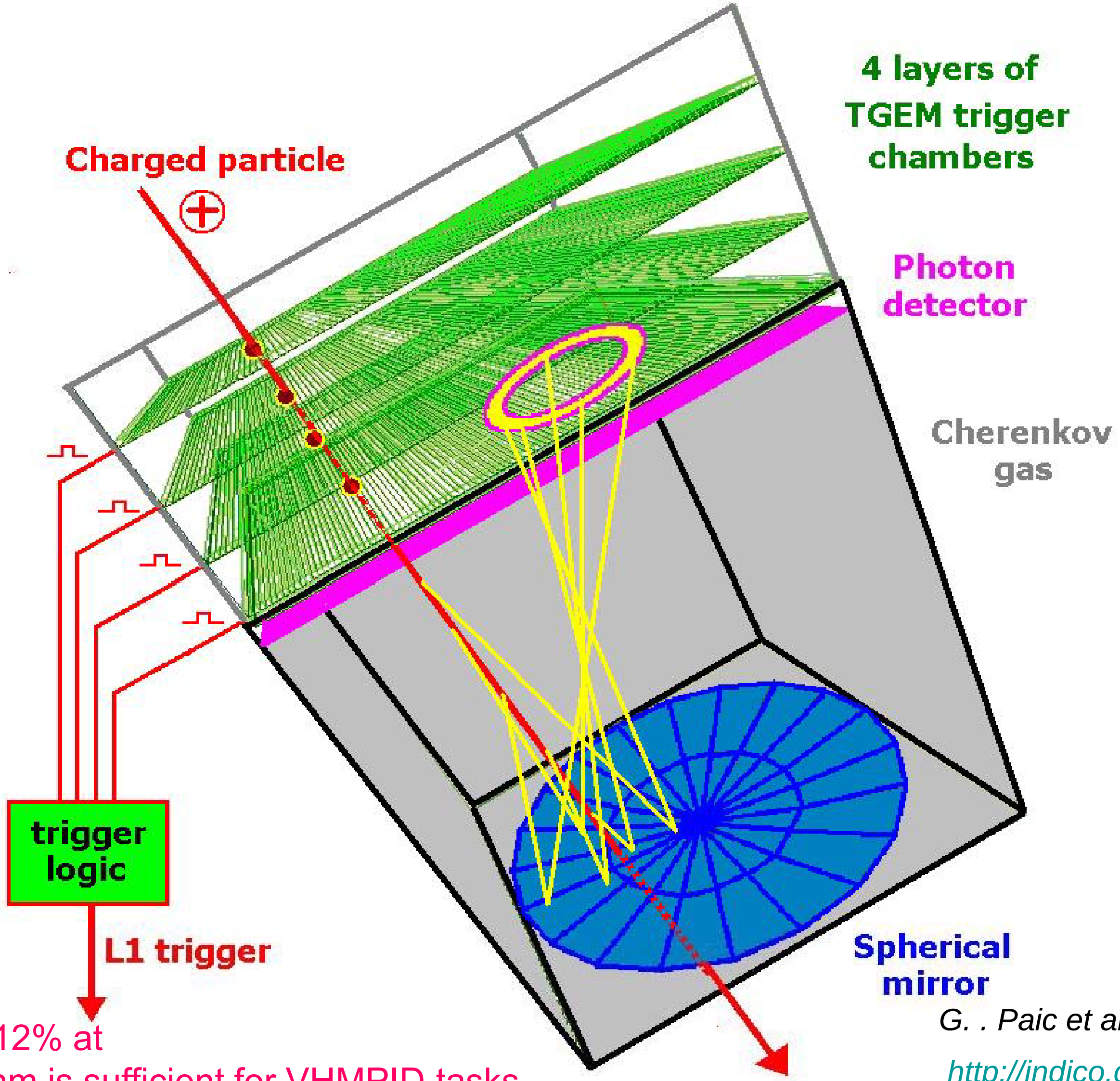
VHMPID modules (2* 10 m^2)

One Pb+Pb collision
in the ALICE „microscope"
(computer simulation)

LOI in preparation

VHMPID

(Very High Momentum Particele Identification Detector)



Triggering and identifying charged hadrons in $5\text{GeV} < p_T < 20\text{GeV}$

Separation between π, K, p using Cherenkov effect.

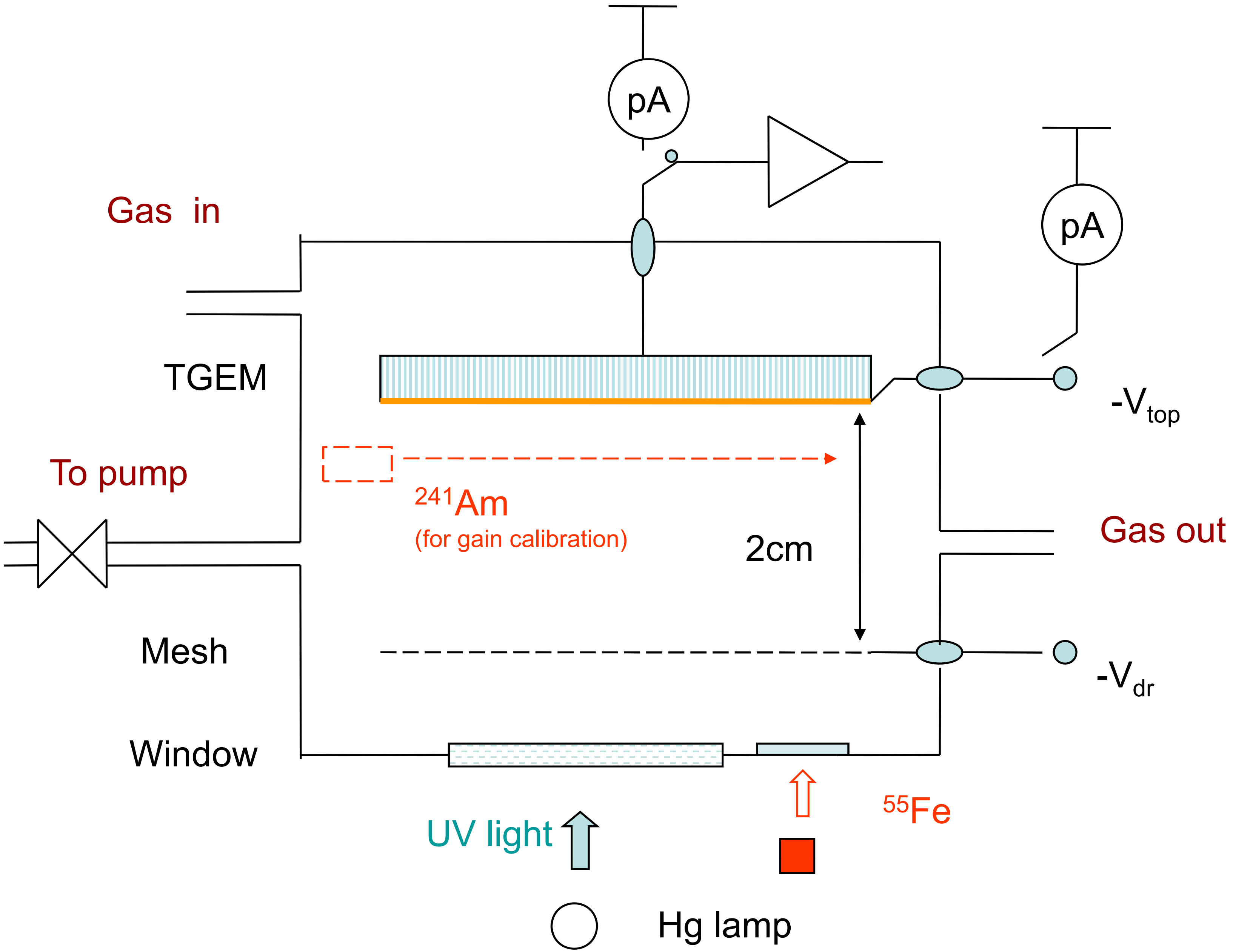
Using gas → n small → large gas space

QE~12% at 185 nm is sufficient for VHMPID tasks

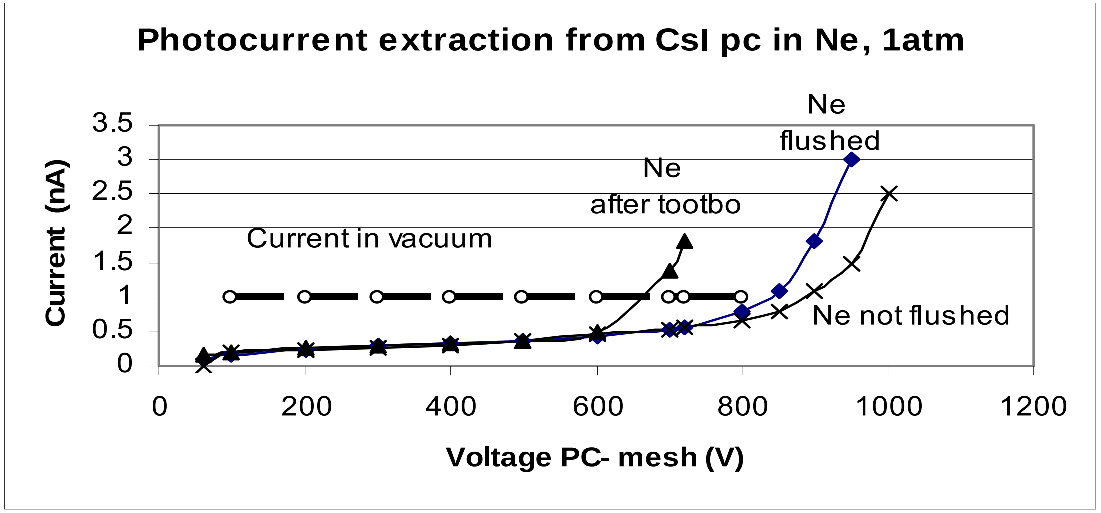
G. . Paic et al., , Report at the ALICE Physics Forum,

http://indico.cern.ch/conferenceDisplay.py?confId=26371

Gas optimization for VHMPID design with window


pA
pA
Gas in
TGEM
To pump
^{241}Am
(for gain calibration)
2cm
-V_{top}
Gas out
Mesh
-V_{dr}
Window
^{55}Fe
UV light
Hg lamp

Photoelectron extraction from the CsI photocathode in Ne (low fields)



← ~50% extraction

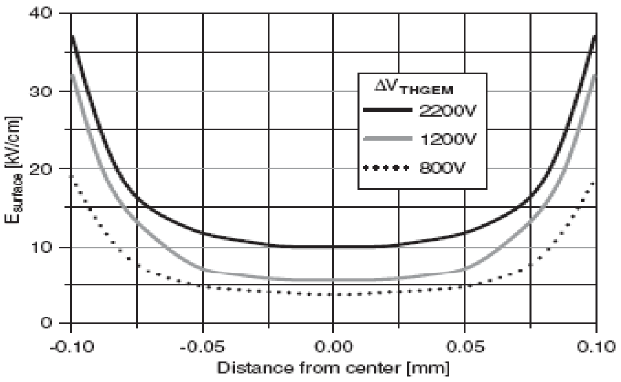
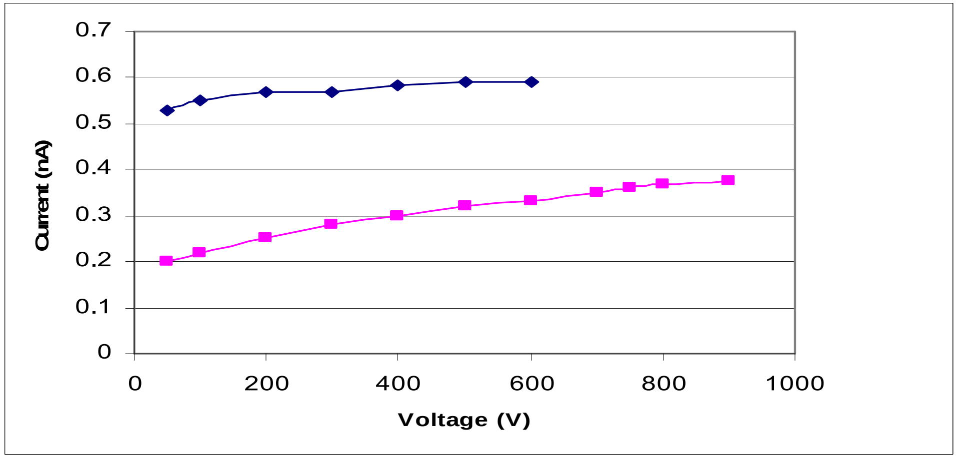


Fig. 8. The electric field on THGEM#9 top surface, E_{surface}, calculated by MAXWELL along the line interconnecting two hole centers. The electric field magnitude is above 3 kV/cm, even at $\Delta V_{\text{THGEM}} = 800$ V.

In reality could be larger!

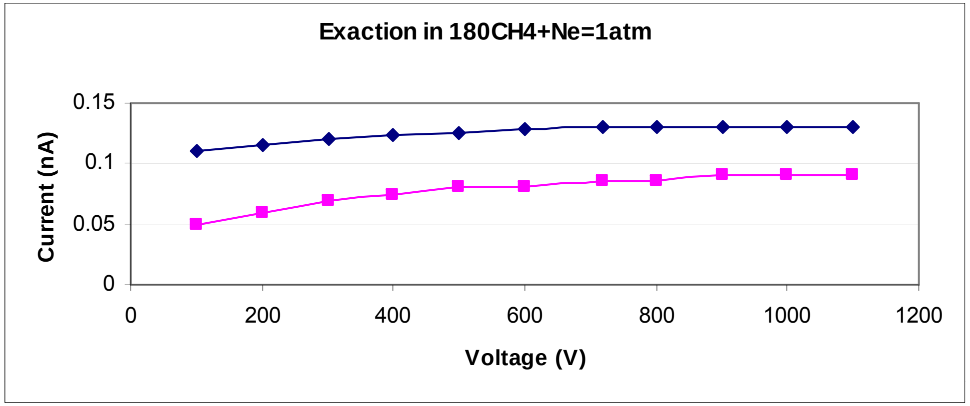
A. Breskin, V. Peskov, presented at the Gaseous Detectors group seminar at CERN, August 2008

Extraction in Ne +5%CH_4



← ~63%

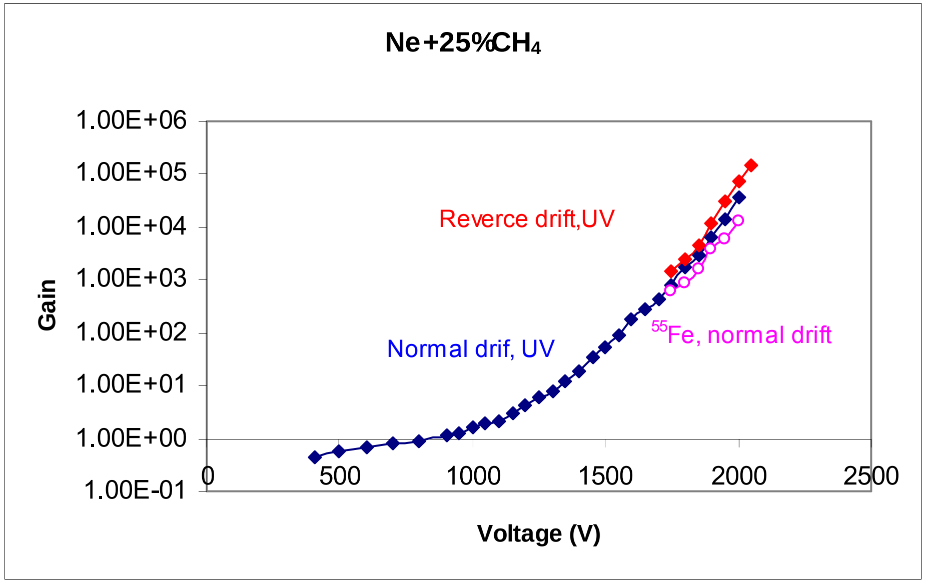
Extraction in Ne +23%CH_4



← ~70%

A. Breskin, V. Peskov, presented at the Gaseous Detectors group seminar at CERN, August 2008

Ne+25% CH_4 is an optimum gas mixture for RICH applications (?)



<u>Advantages:</u>

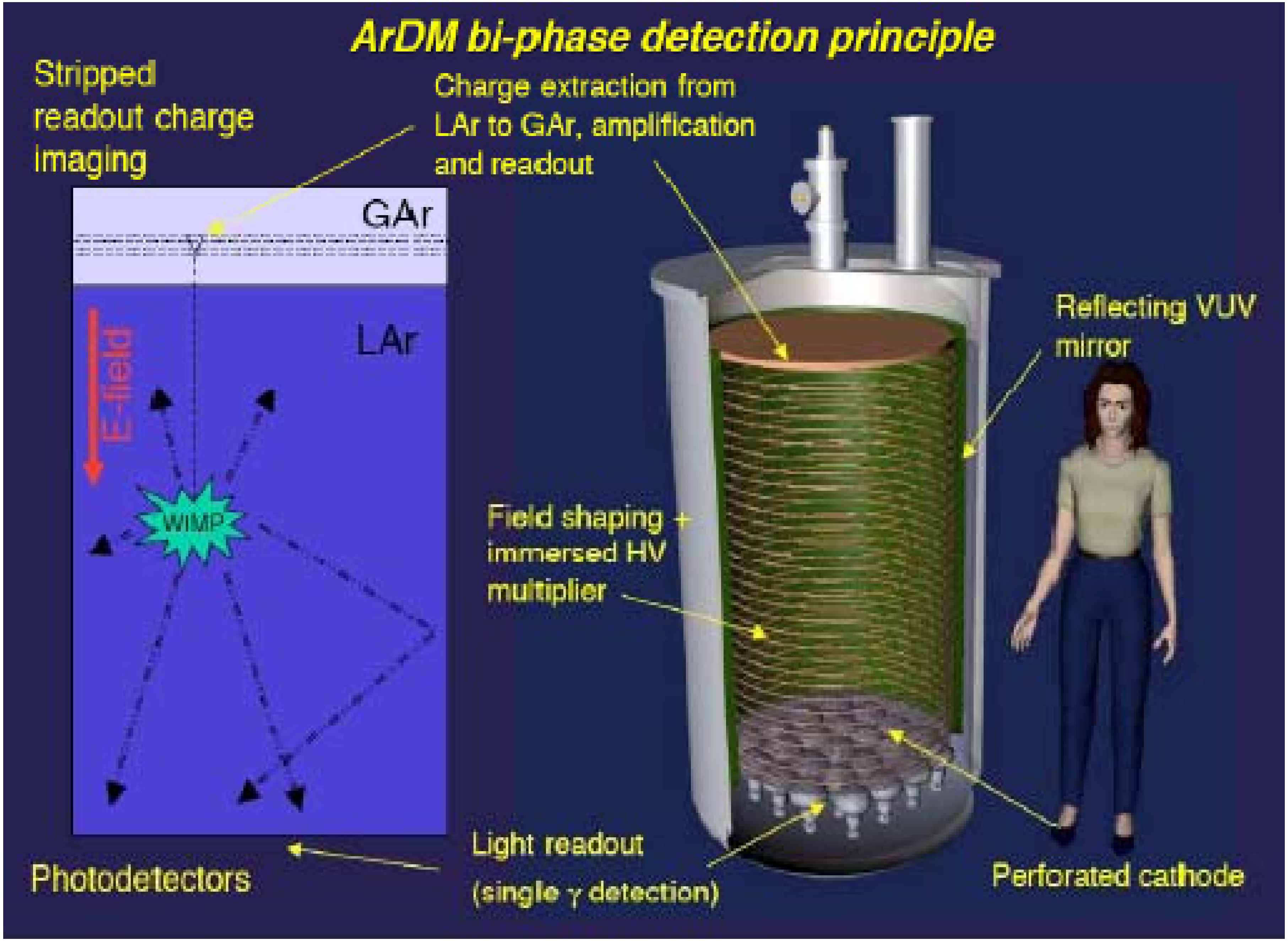
High gains

High quantum efficiency ~15% at 185 nm

Preliminary Conclusions:

- For RICH detector with window optimal are Ne –based mixtures.
- The exact quencher additives could be optimized

Noble liquid dark matter detectors



ArDM bi-phase detection principle

Stripped readout charge imaging

Charge extraction from LAr to GAr, amplification and readout

Reflecting VUV mirror

Field shaping + immersed HV multiplier

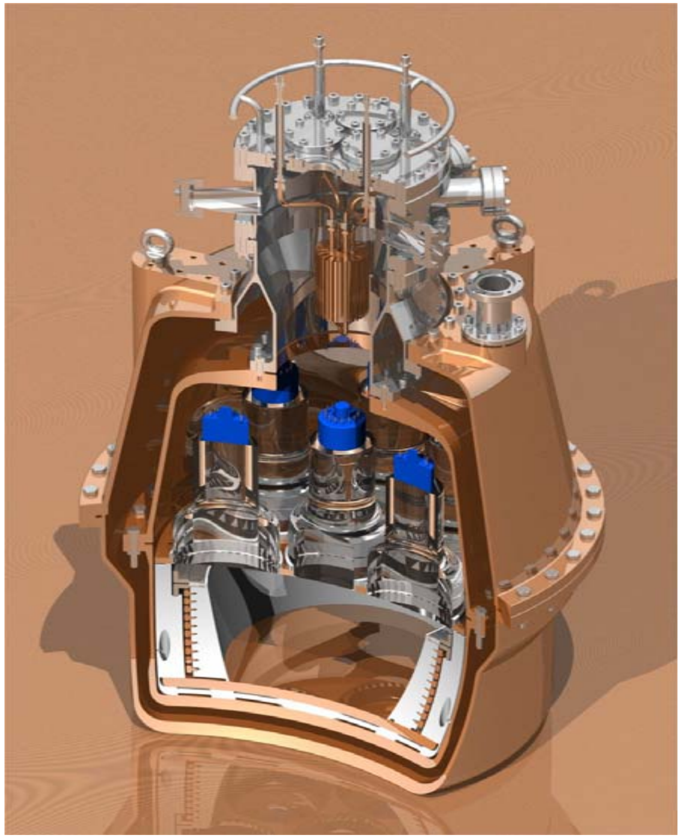
Photodetectors

Light readout (single γ detection)

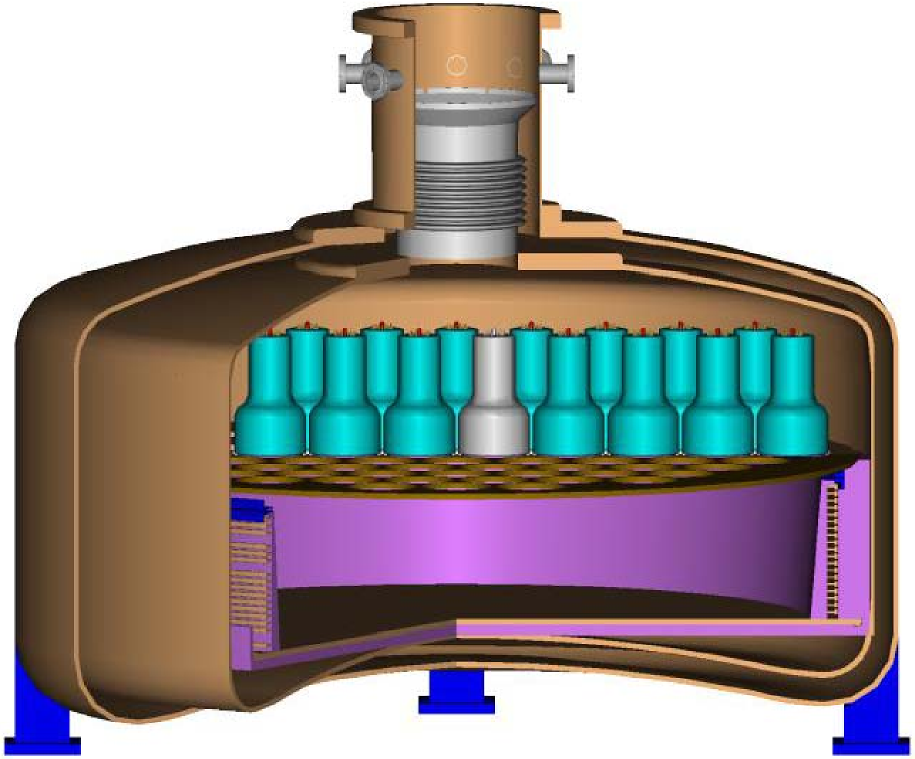
Perforated cathode

A. Rubbia detector

ZEPLIN II → ZEPLIN IV



30 kg → 1000 kg



The latest design as at DM2002

One of the ideas is to replace PMs by photosensitive hole-type structures

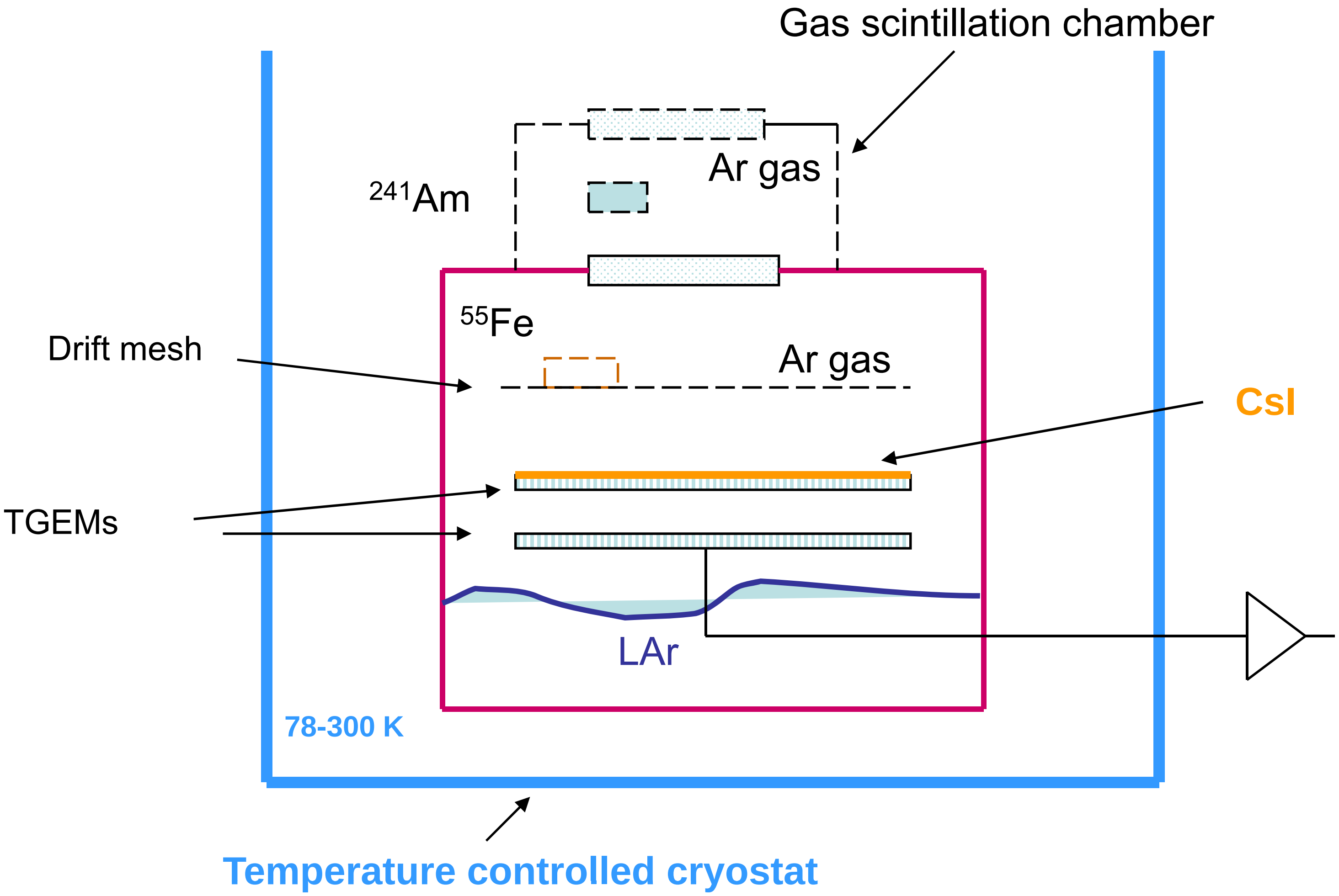
On this subject we are in a healthy competition with a Novosibirsk group (A. Bondar et al., INP, Novosibirsk, Russia)

They were the first who discovered that GEM can operate at cryogenic temperatures

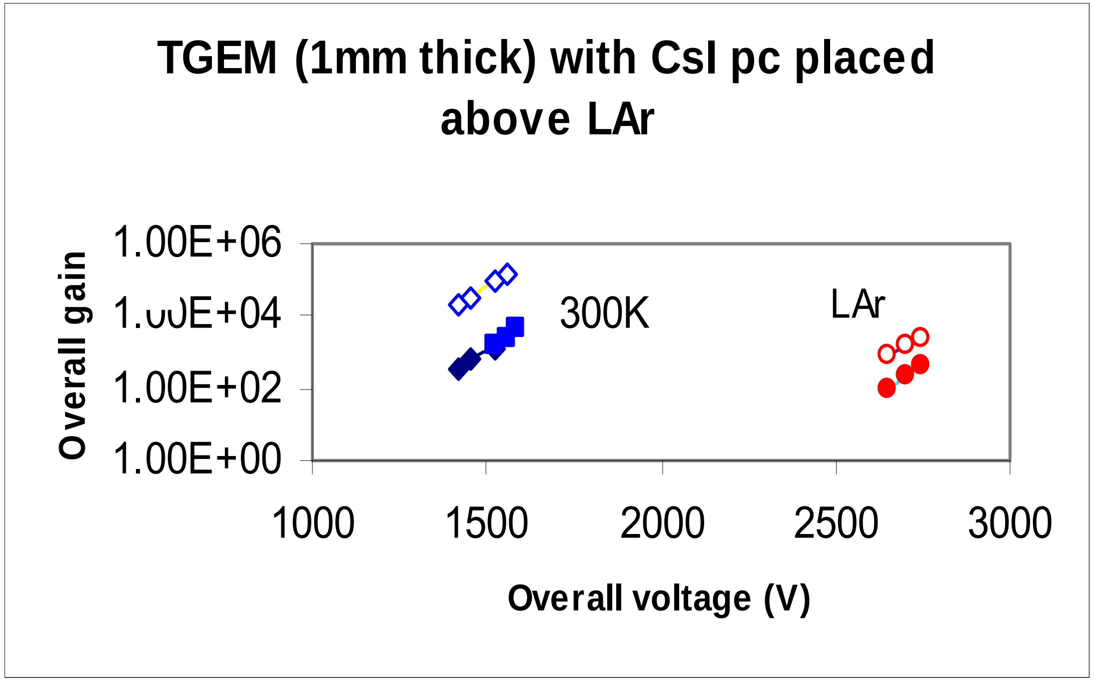
↓

We were the first who demonstrated that various photosensitive hole-type detectors (GEMs , capillary plates, TGEMs coated with CsI layers) can operate at cryogenic temperatures

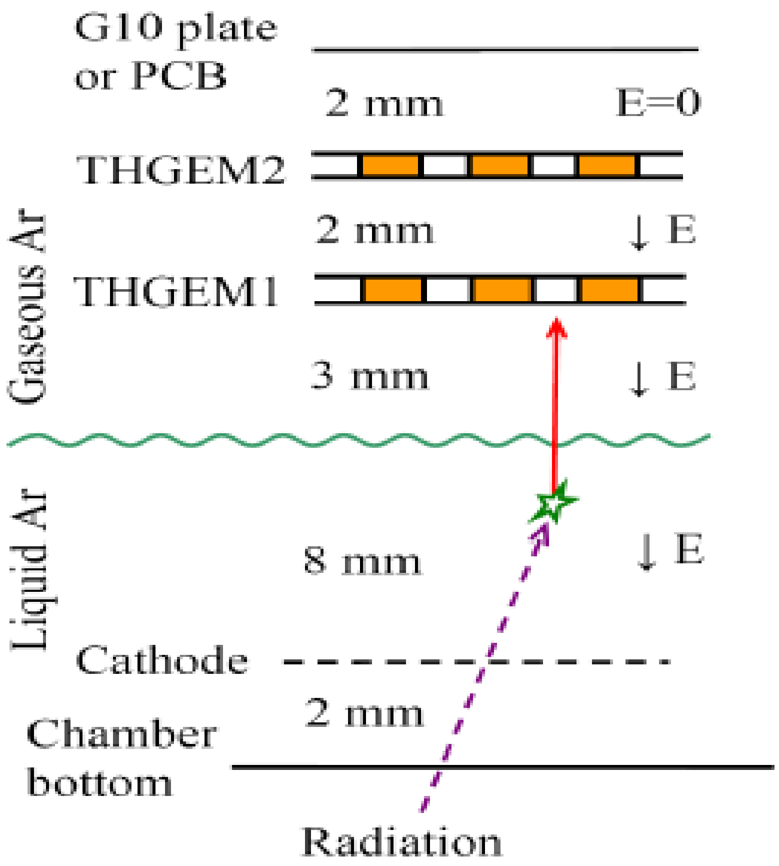
Chamber design for study of operation of TGEMs at cryogenic temperatures (CERN, ICARUS group)



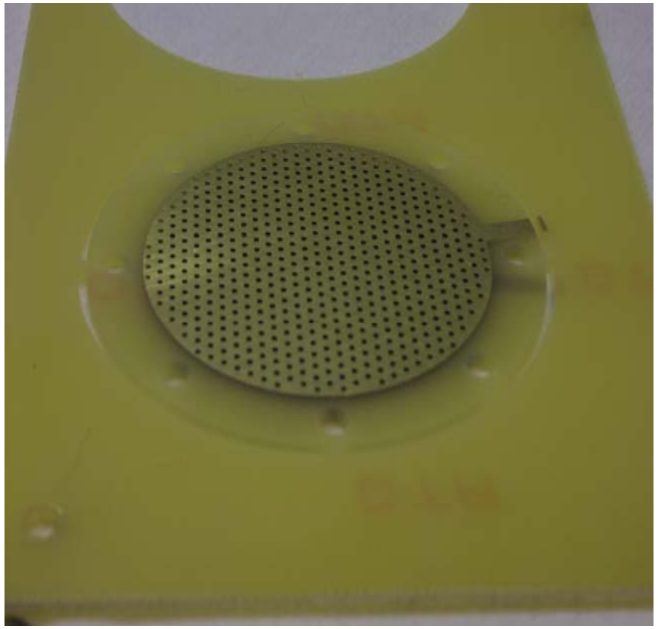
Gains of single and double steps TGEM operating at cryogenic temperatures



Novosibirsk group recently confirmed our results with photosensitive GEMs and with bare TGEMs



A. Bondar et al.,JINST, 3 P07001,2008

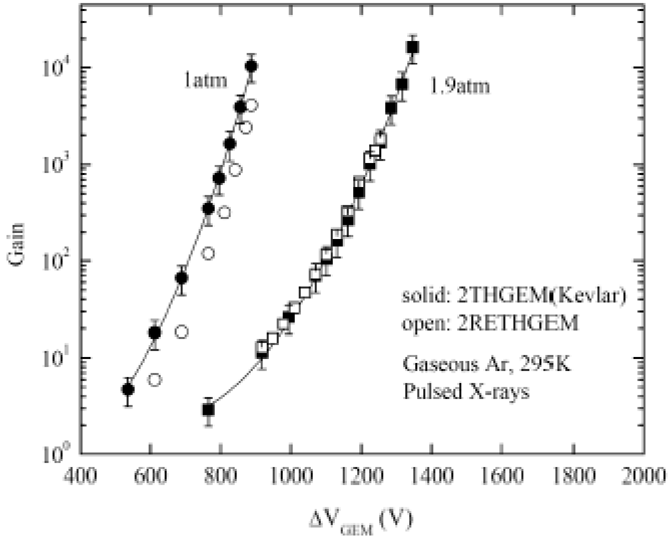


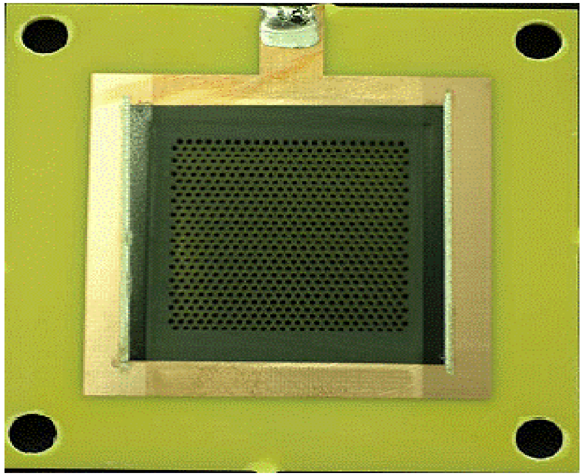
More about TGEM see in:

L. Periale et al., NIM A478,2002,377
J. Ostling et al., IEEE Nucl. Sci 50,2003,80
R. Chechik et al., NIM A553, 2005, 35
C. Chalem et al, NIM A558, 2006, 475

They also tested RETGEM and confirmed our results obtained at room temperature.

However, at cryogenic temperatures, especially close to 80K some instability was observed





RETGEM used by the Novosibirsk group

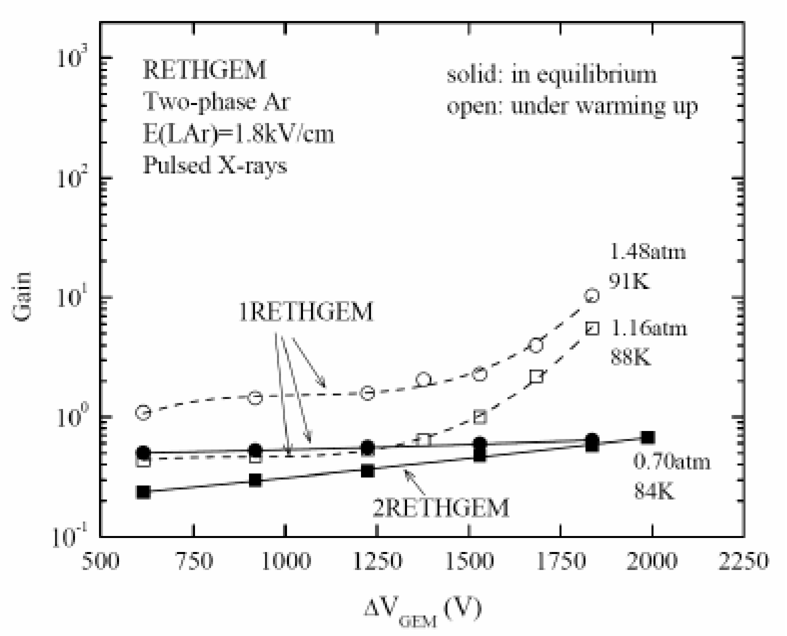
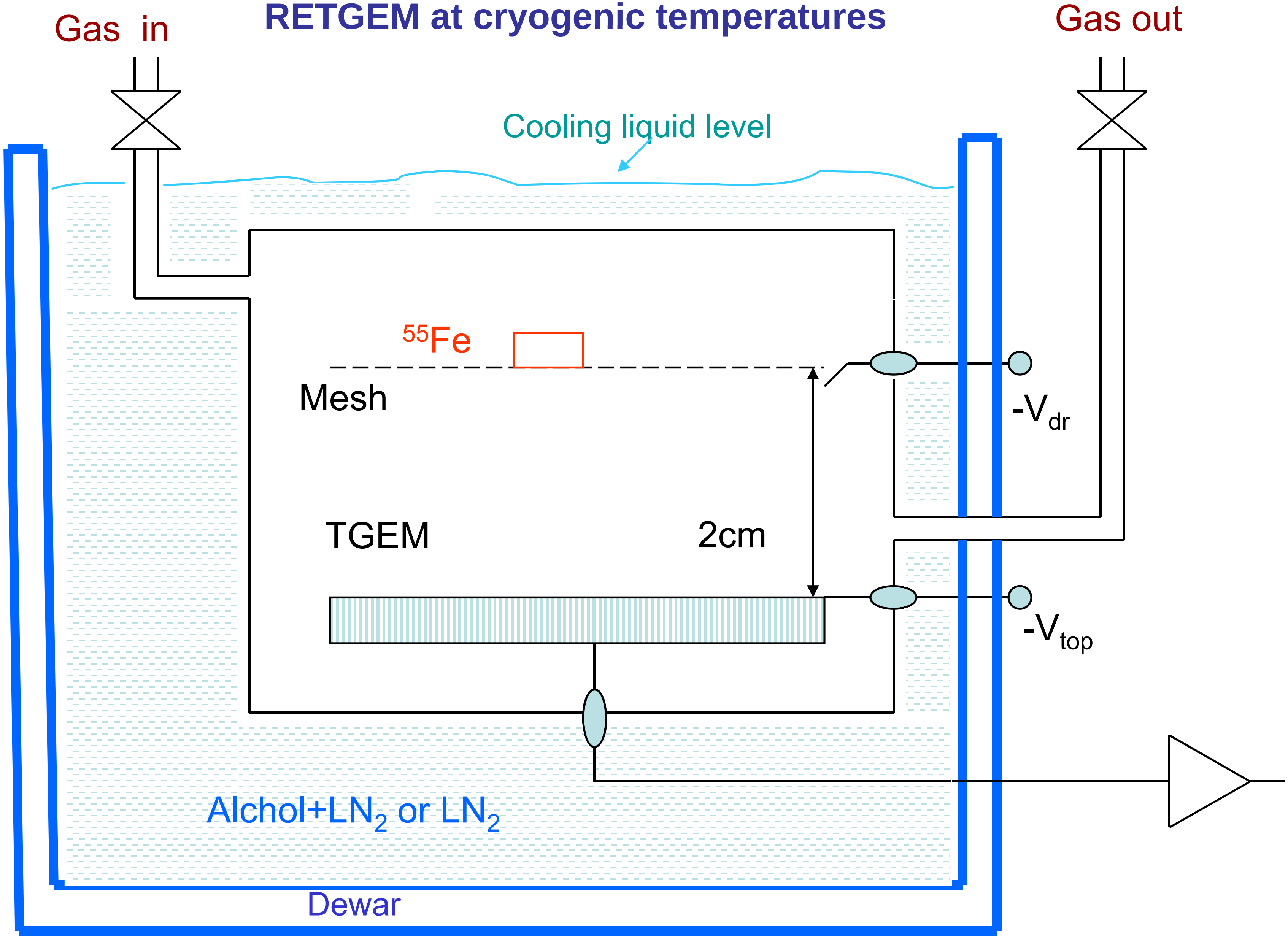
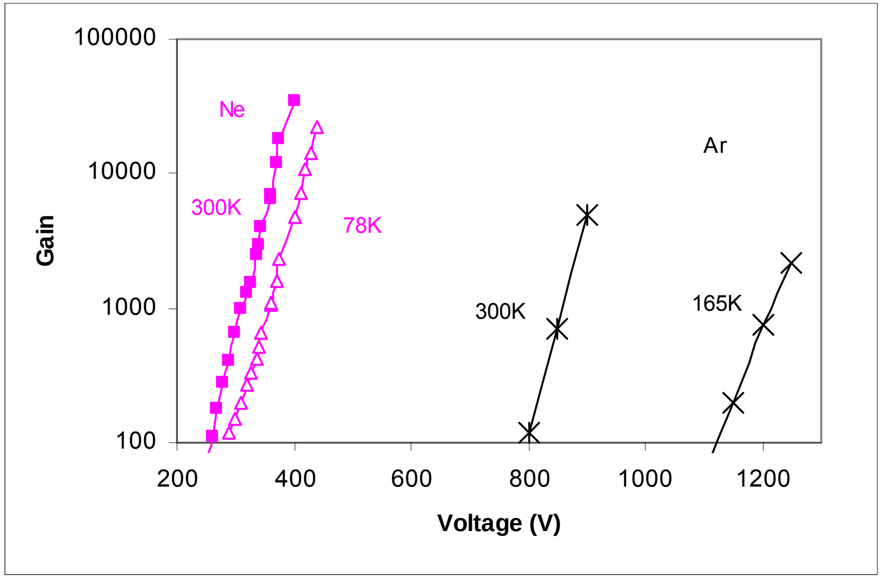


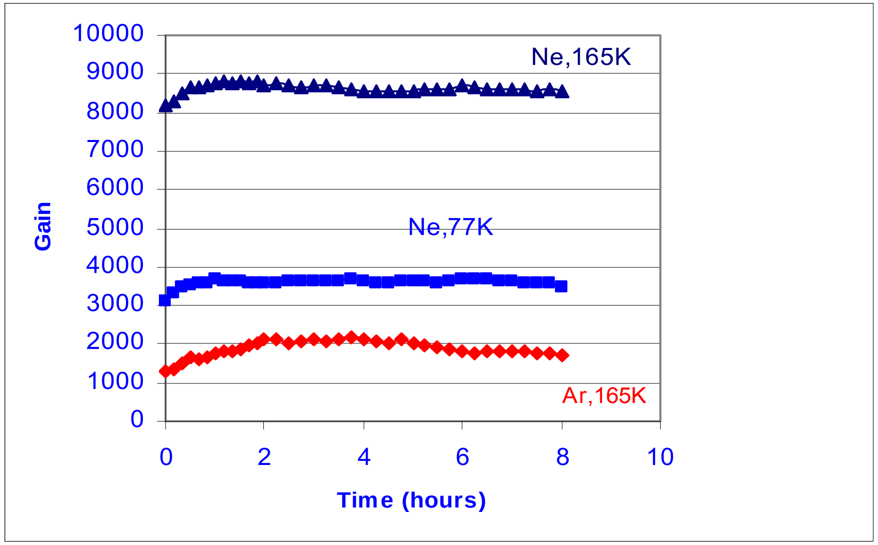
Fig. 7. Gain-voltage characteristics of single- and double-RETHGEM multipliers in two-phase Ar in electron emission mode in equilibrium and under warming-up, measured with pulsed X-rays. The maximum gains were limited by discharges. The pressures and temperatures are indicated in the figure.

Experimental setup for tests of S-RETGEM at cryogenic temperatures





Gains at various temperatures



Stability measurements at various temperatures

Thus, <u>in contrast</u> to old RETGEM, S-RETGEM exhibit stable operation at cryogenic temperatures

Conclusions:

- We presented an innovative photosensitive gaseous detector: S-RETGEM having metallic strips electrodes coated with resistivity strips
- Coated with CsI layers such S-RETGEMs has QE of 12-14% at 185nm

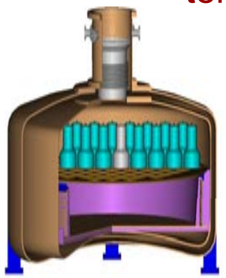
and operate stably (4 months observation)

- This approach allows:

1) to build large-area (ether the whole detector or consisting from mosaic) and fully spark-protected detectors

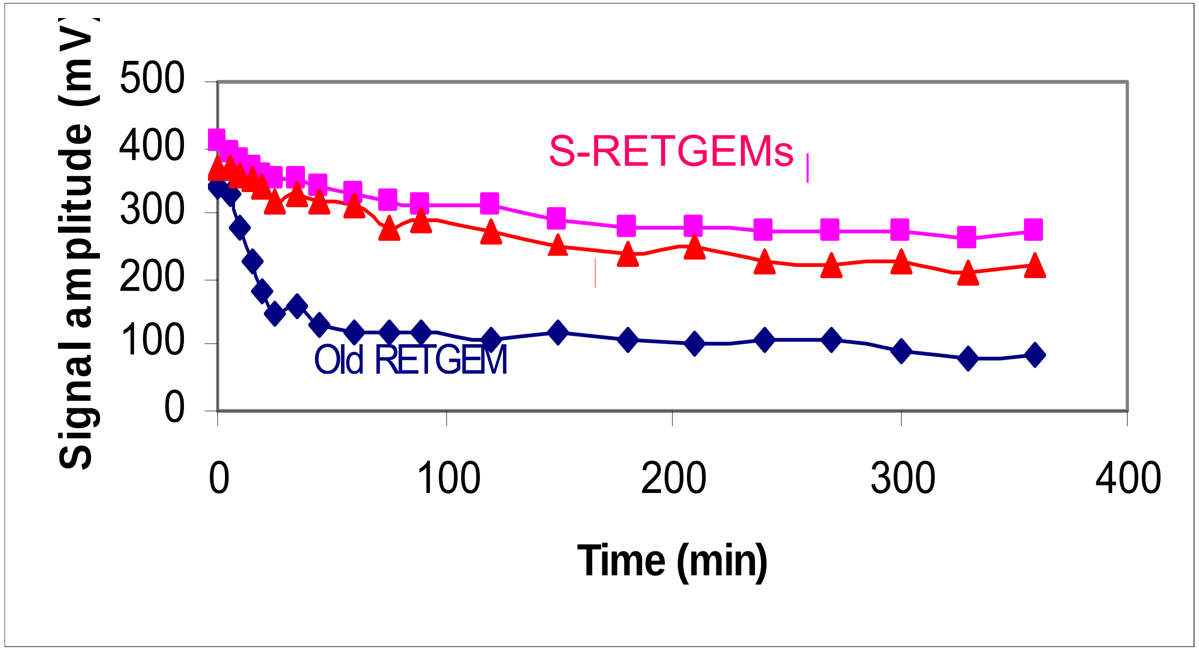
2) to obtain position information about avalanches directly from the RETGEM electrodes

- After optimization of drift voltage and the gas composition we were able to reach remarkable high gas gains with S-RETGEM detectors allowing to detect single photoelectrons and make position measurements even with a single S-RETGEM
- We believe that S- RETGEMs will find a lot of applications, for example, we are considering their use for the ALICE VHMPID
- First encouraging results were obtained with S-RETGEM operating at cryogenic temperatures



Backup

Rate characteristics



Possible explanation of Why the Raether limit is “easier” in Ne?

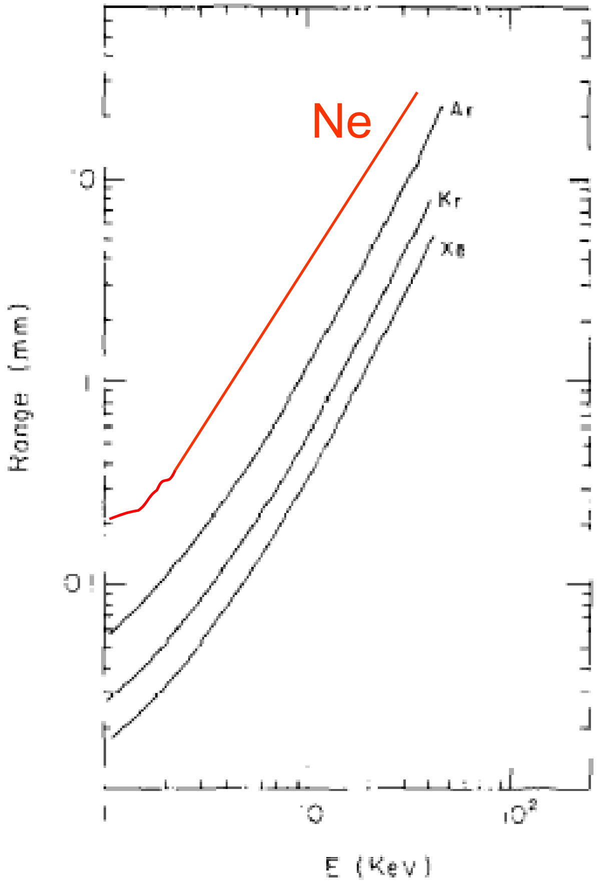


Fig 2 Electrons range-energy relationship in some gases

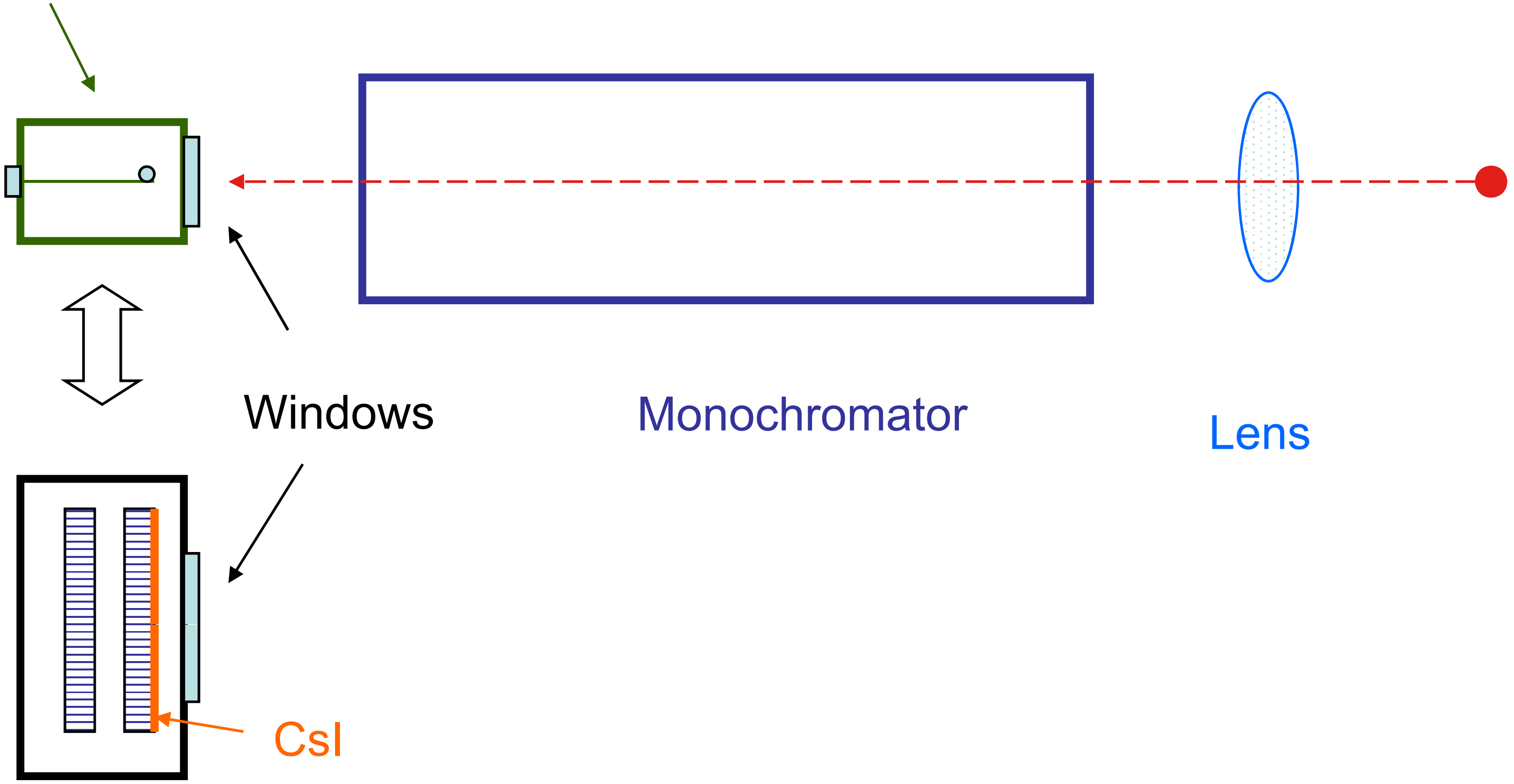
Mean free path of Fe photoelectrons is about 1 mm

Nowadays, the most popular hole-type detector is the so-called Gas Electron Multiplier (GEM) [3]). In this detector for position measurements part of the avalanche charge should be extracted to the readout plate placed a few mm apart from the GEM. Cascaded GEM structures combined with such readout plates have been implemented in the layout of several large scale high energy physics experiments.

The advantage of hole-type gas multipliers:

In contrast to traditional gas amplification structures such as parallel-plate or wire type, the hole–type detectors due to their geometric features offer strong photon and some ion feedback suppression which is essential for reaching high gas gains when the detectors are combined with photocathodes

QE measurements



Hg lamp

TMAE filled single-wire gas counter

Windows

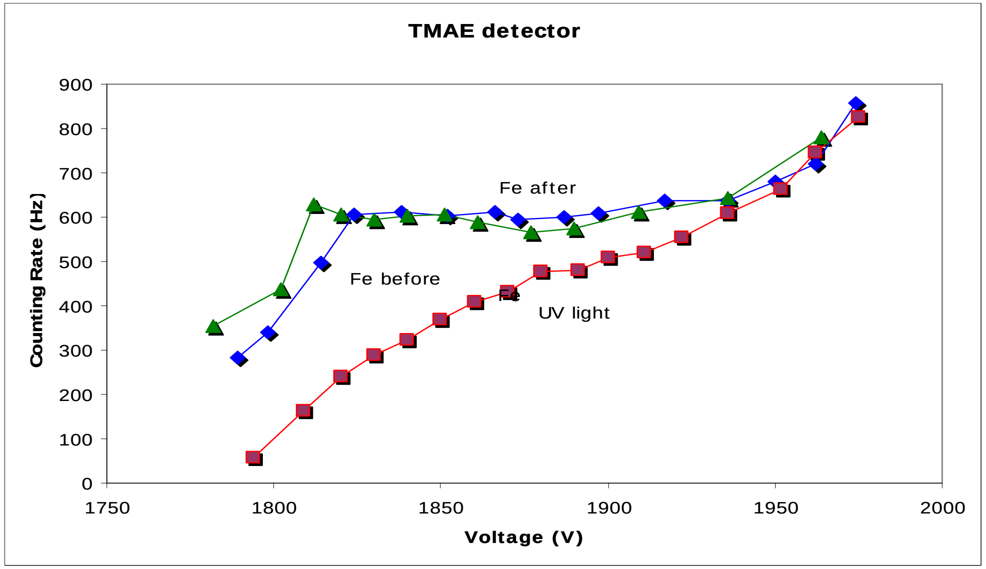
Monochromator

Lens

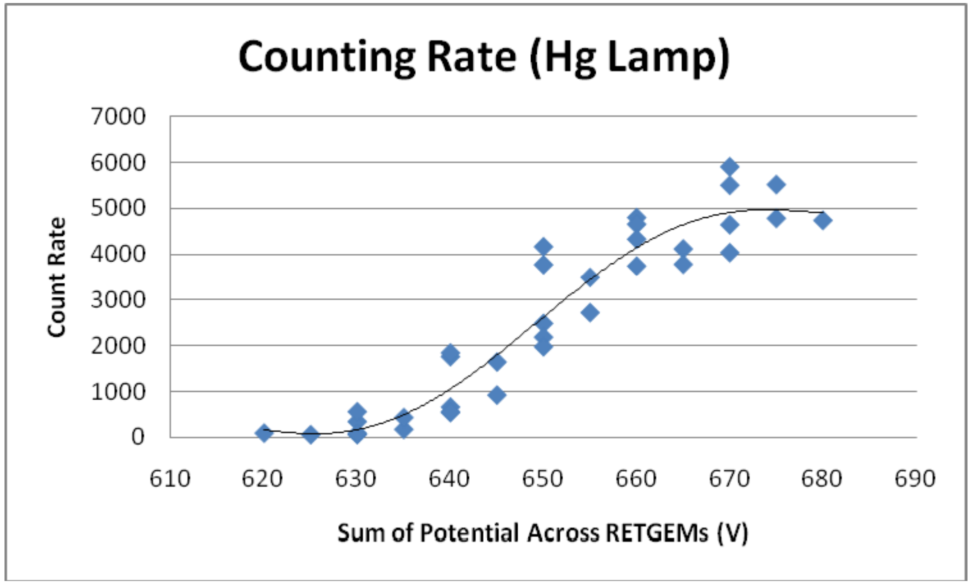
CsI

Double-step RETGEMs
with **CsI** photocathode

Counting plateau



TMAE detector

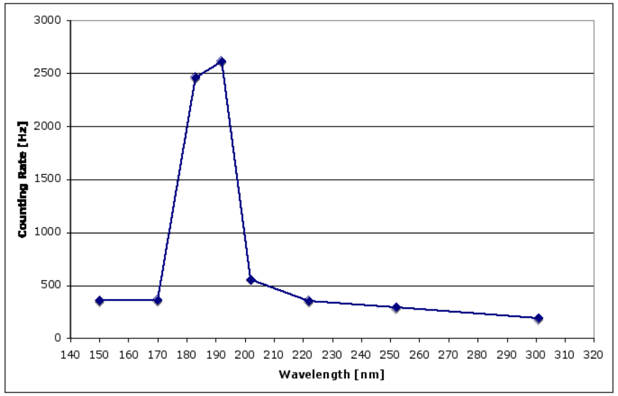


Double RETGEM

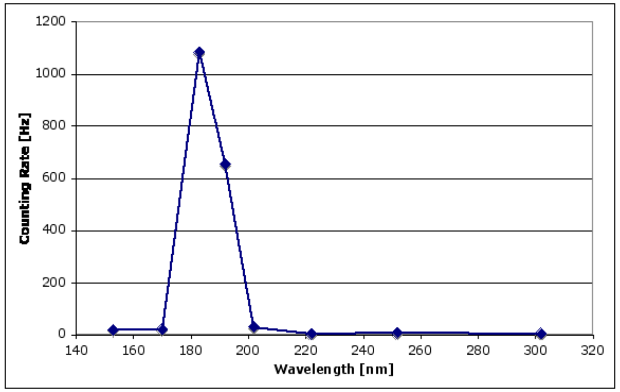
Hg lamp spectra, measured with
TMAE (a) detector and RETGEM (b)

TMAE QE vs. wavelength (c)

a)



b)



c)

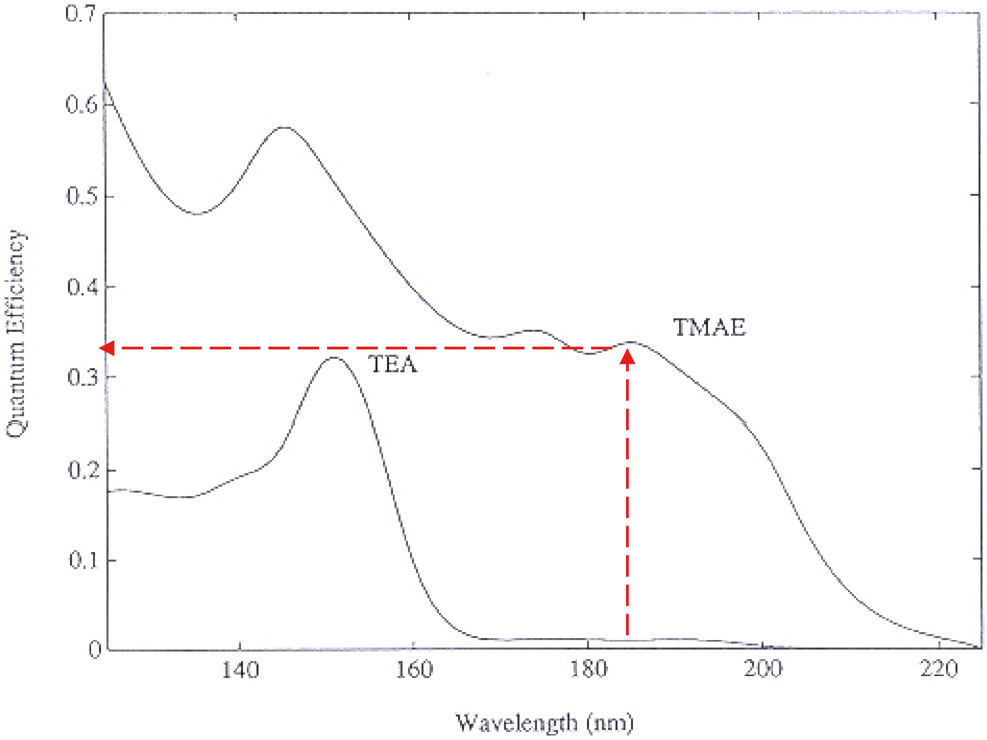
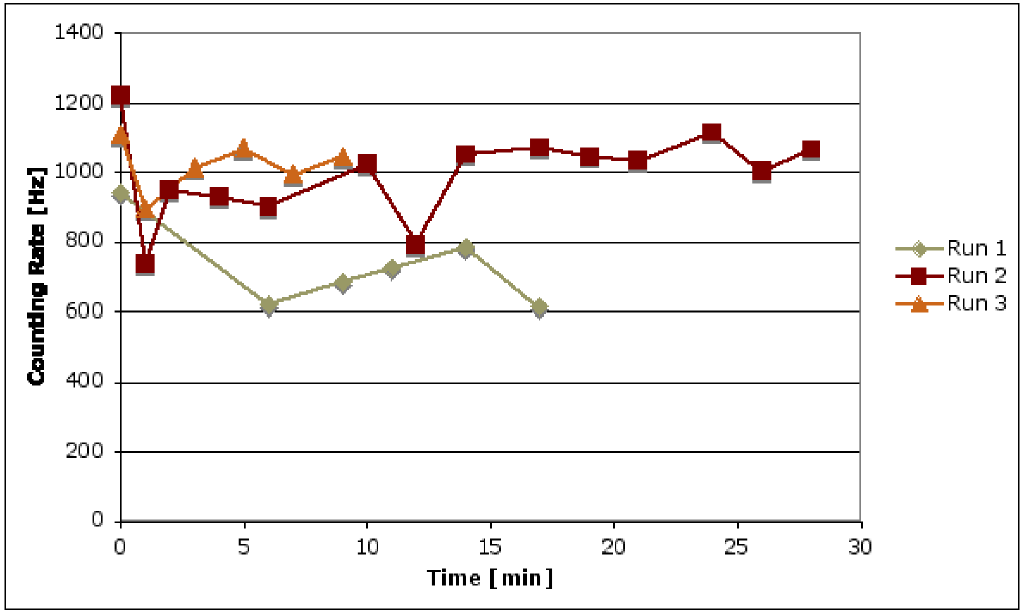


Figure 4.4. Quantum efficiency of TMAE and TEA as a function of wavelength, according to measurements by Holroyd et al [4.6].

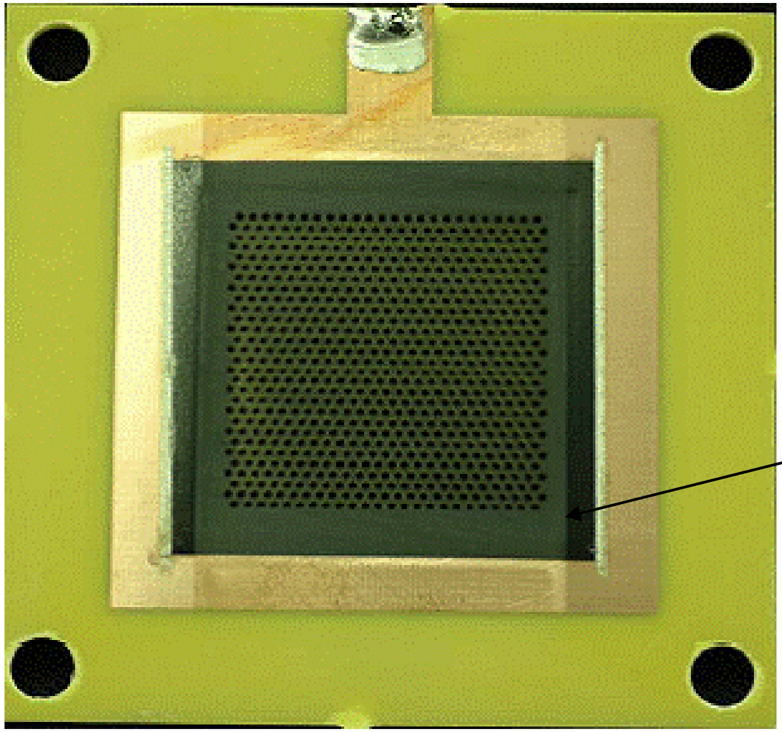
$Q_{CsI}=33\%N_{CsI}/N_{TMAE}\sim$ 14.5%

“Focused” beam



Measurements of the stability of the RETGEM, using Hg as a source, at 185nm. The light is concentrated on a small slit. About 30min without light have passed between each run.

These first prototypes were built just to demonstrate the principle.
Certainly their design should be optimized for use in real life.



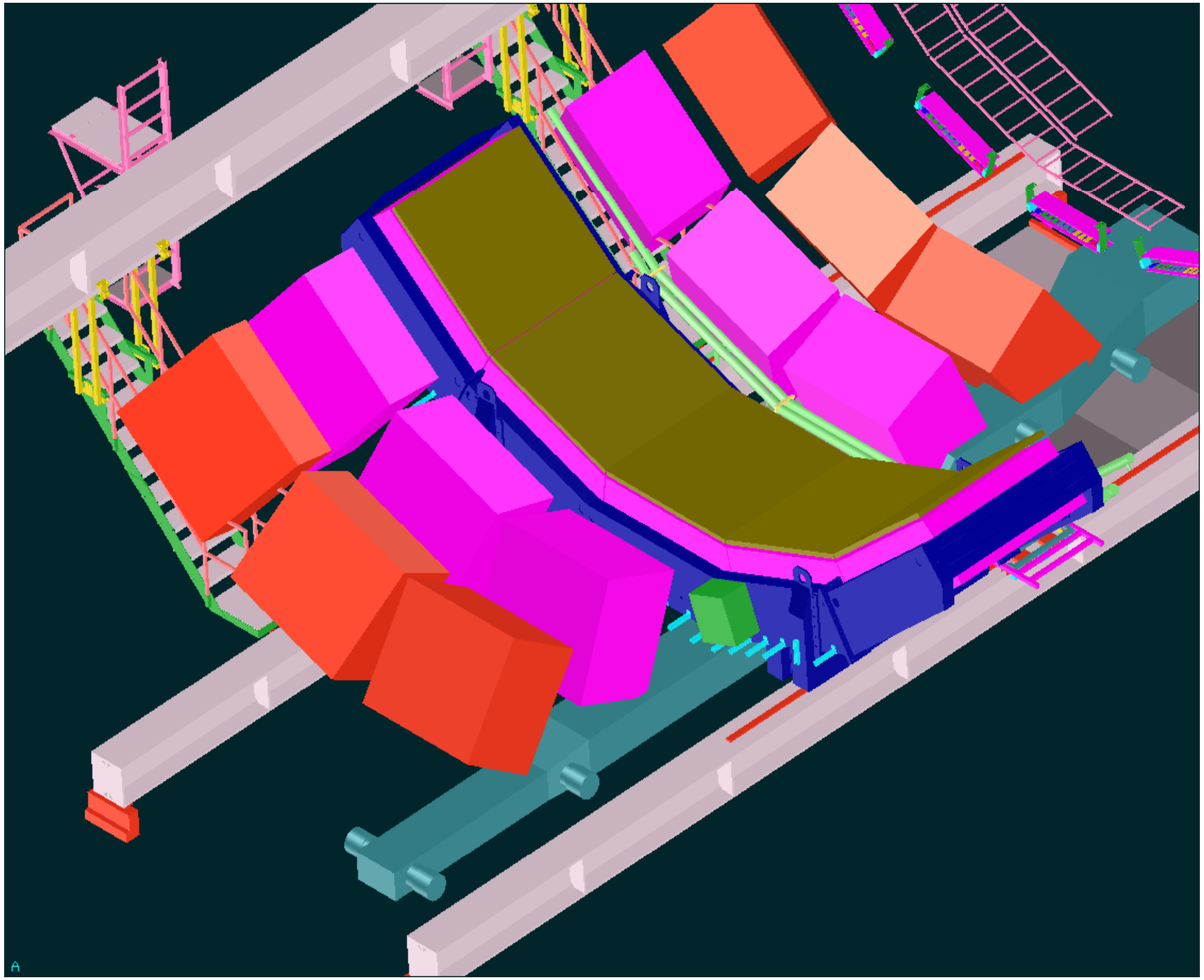
Drawbacks of the old designs:

Current flow along the surface.
To avoid surface streamers we
have to create “dead” zones.

So, one cannot build an efficient
large-area detector based on mosaic
of these detectors

This is why our further goal was to develop an approach allowing to build large-area photodetectors

Free space for the VHMPID



Free space near the
PHOS detector

12 modules could be
inserted
Maximal extension
of a module:
90x140 cm^2 x 120cm

Opposite side of
the **EMCal**:
away side jet
correlations
would become
measurable, too!