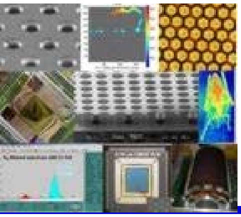
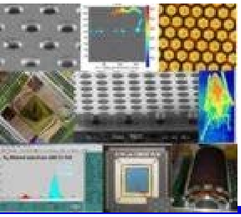


Photon Detection with MPGDs

S. Dalla Torre



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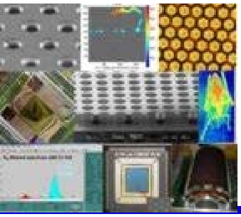
- MPGD-based PDs
  - Basic principles and architectures
    - Gaseous PDs with sensitivity in the visible range
    - Cryogenic MPGD-based PDs
    - Detecting electroluminescence produced in avalanche processes for frontier research and applications
- Conclusions



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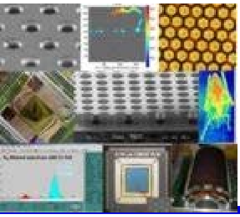
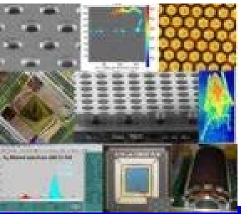


WHY GASEOUS PDs ?

- the most effective solution for what concerns the cost of large detector area application (a cheap approach)
- operation in magnetic field (low sensitivity to B)
- minimum material budget when the photon detectors have to seat in the experiment acceptance (advantages for experiment architectures)

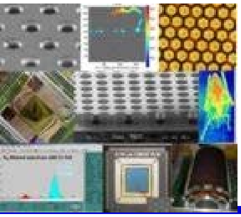


DETECTION GOALS

- Historically, the development has been guided by the requirements of the Cherenkov imaging counters for PID, namely the goal has been the challenging detection of SINGLE PHOTONS

- Detection of scintillation light, mainly in rare-event noble liquid counters

- The relevance of generating/detecting ELECTROLUMINESCENCE PHOTONS by MPGDs for fundamental research and applications has become evident more recently



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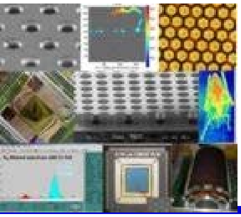
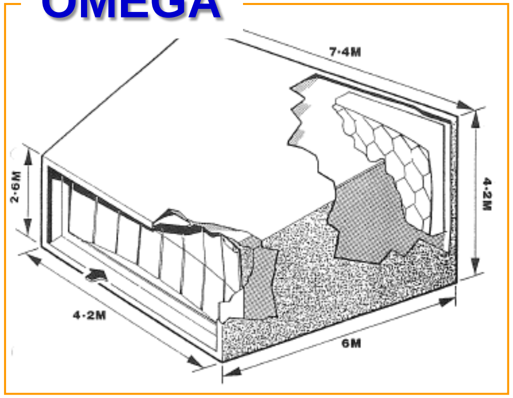
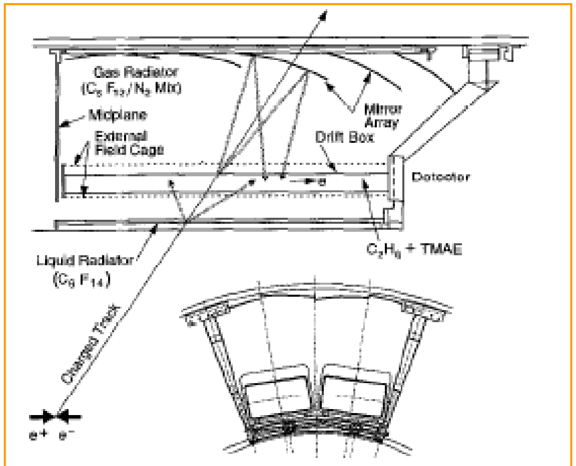


GASEOUS PDs, I GENERATION

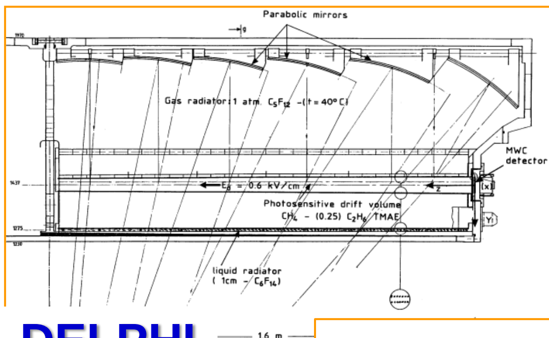
Gaseous photon detectors, the first generation: converting vapours

OMEGA





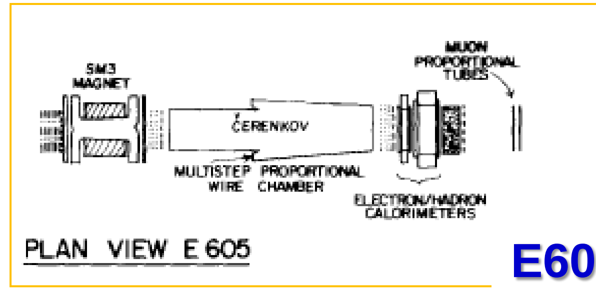
SLD - CRID



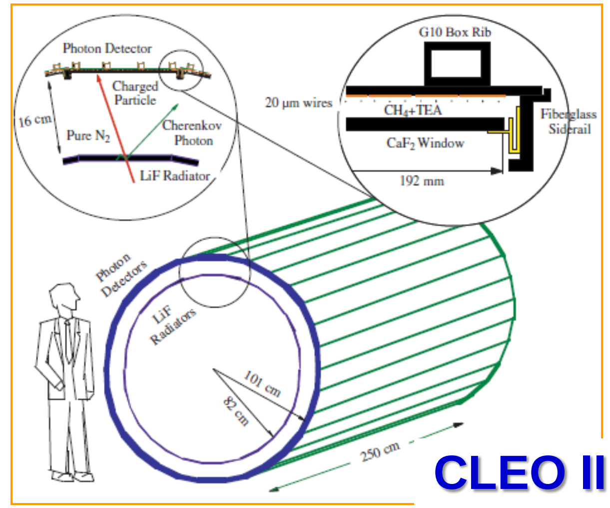
DELPHI

TMAE

(Tetrakis-Dimethylamine-Ethylene)



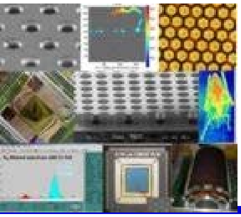
E605



CLEO III

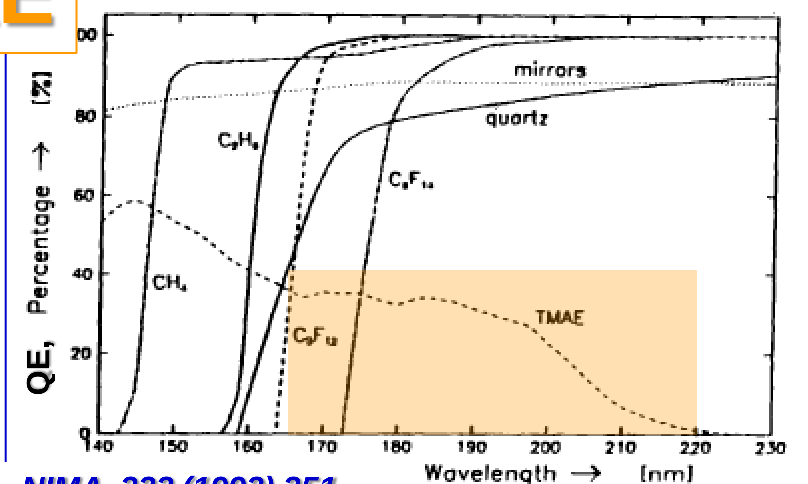
TEA

(Tri-Ethyl-Amine)

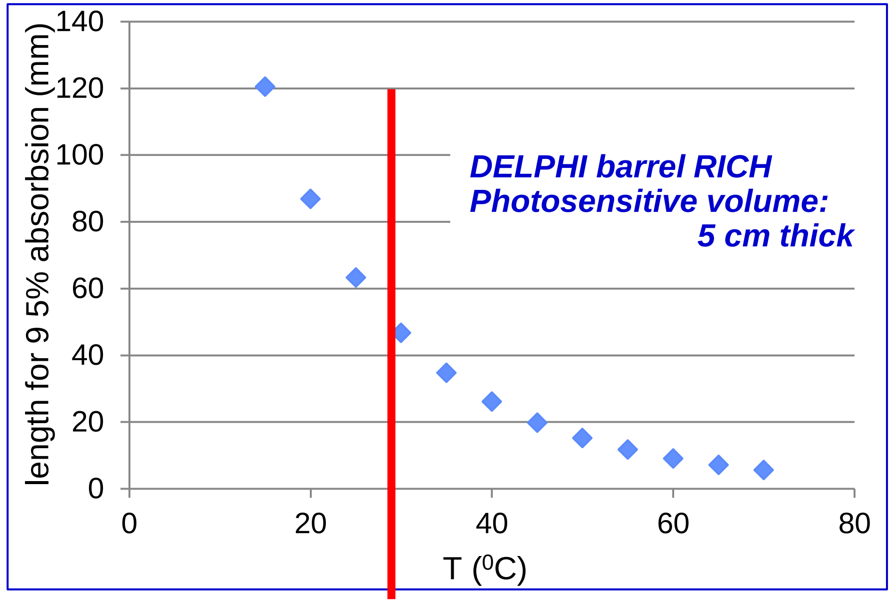


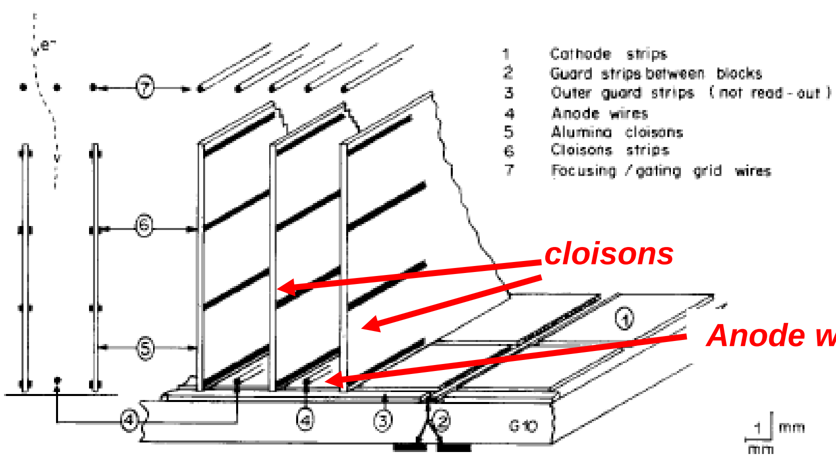
GASEOUS PDs, I GENERATION

TMAE



NIMA 323 (1992) 351



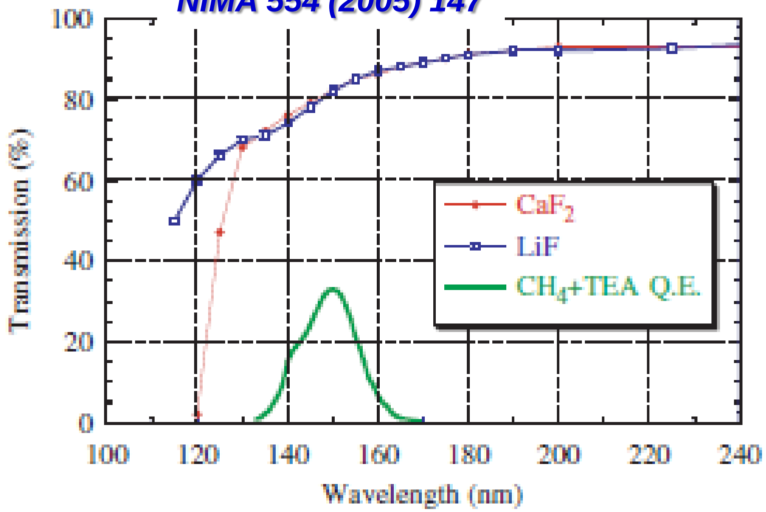


DELPHI barrel RICH, NIMA 273 (1988) 247

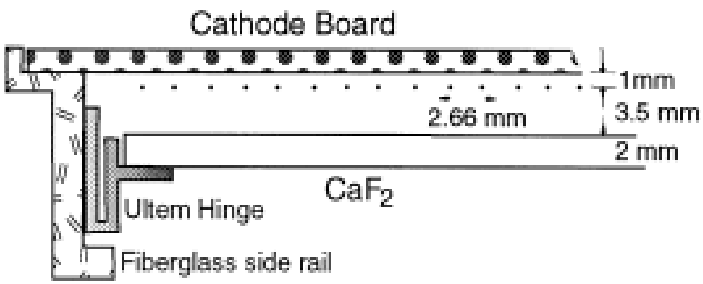
- thick photosensitive volume (slow photon detectors, parallax error)
- heating and temperature control (T _bubbling <T_operation)
- photon feed-back from amplification region (protections)
- chemically extremely reactive

TEA

NIMA 554 (2005) 147

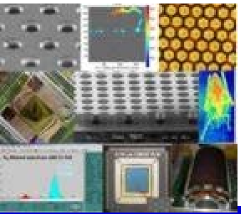


CLEO III, NIMA 441 (2000) 374



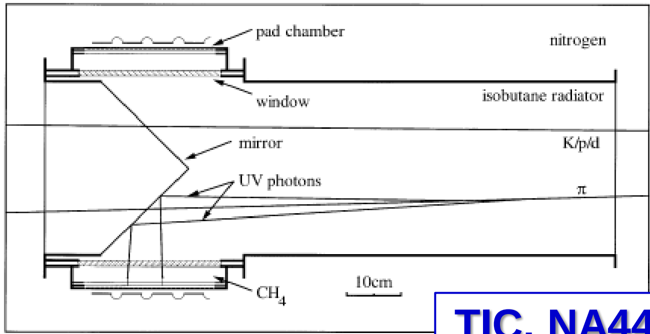
•technical challenges of the far UV domain

• <u>large chromatic dispersion</u> in far UV region:
  - •Proximity focusing (the Chromatic dispersion is not the major resolution limitation)
  - •He, a radiator gas with extremely reduced chromatic dispersion

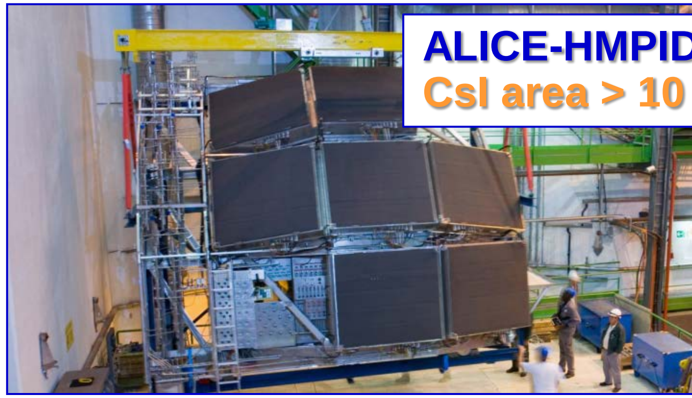


GASEOUS PDs, II GENERATION

- MWPCs with solid state photocathode (the RD26 effort)

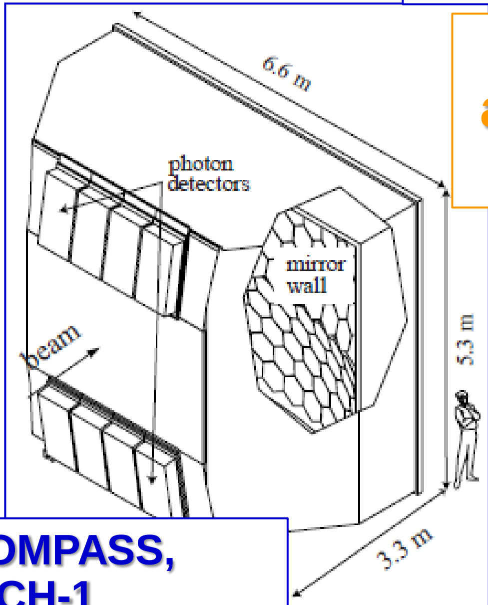


TIC, NA44



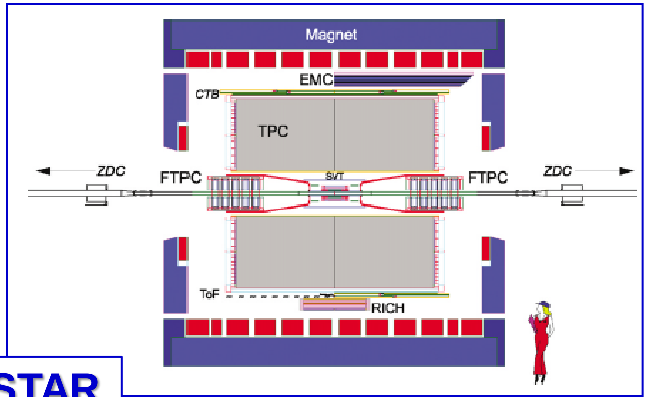
ALICE-HMPID
CsI area > 10 m²

JLAB-HALL A

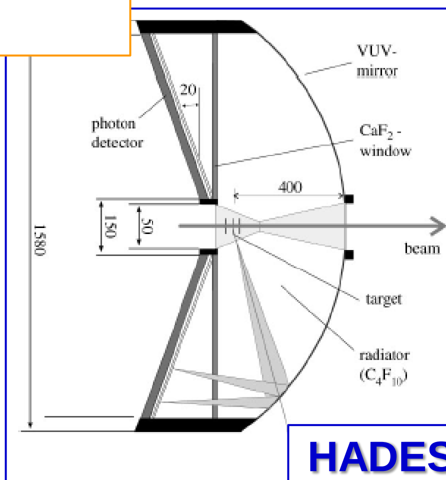


COMPASS, RICH-1
CsI area > 5 m²

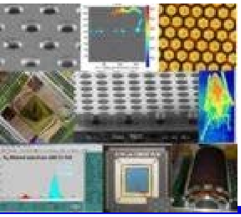
A solid state photocathode exposed to a gaseous atmosphere in an effective PD: a success !



STAR



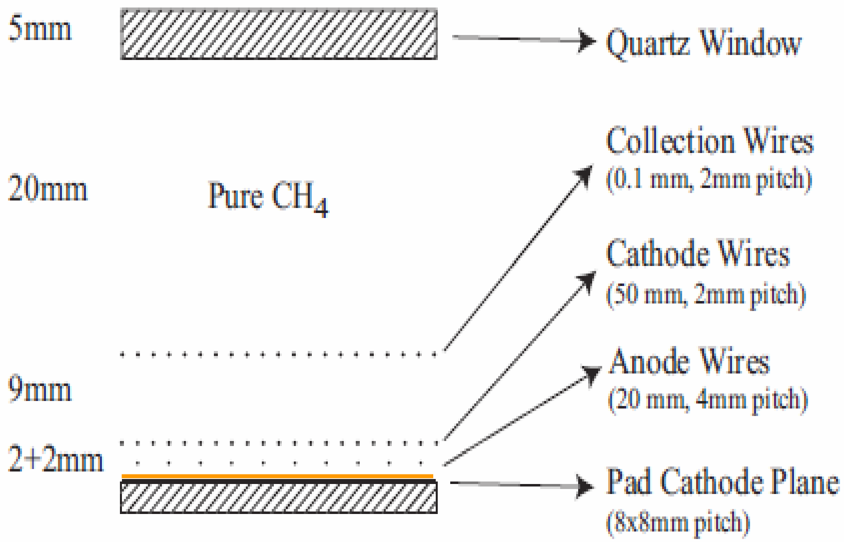
HADES



GASEOUS PDs, II GENERATION

Structure of the PDs

COMPASS, RICH-1 PDs



P. Abbon et al, NIM A 577 (2007) 455.

@ 2 kV (typical):

E (CsI surface) ~ 7 kV/cm

Photocathode - the most robust one in gaseous atmosphere: CsI

The best quartz cuts here

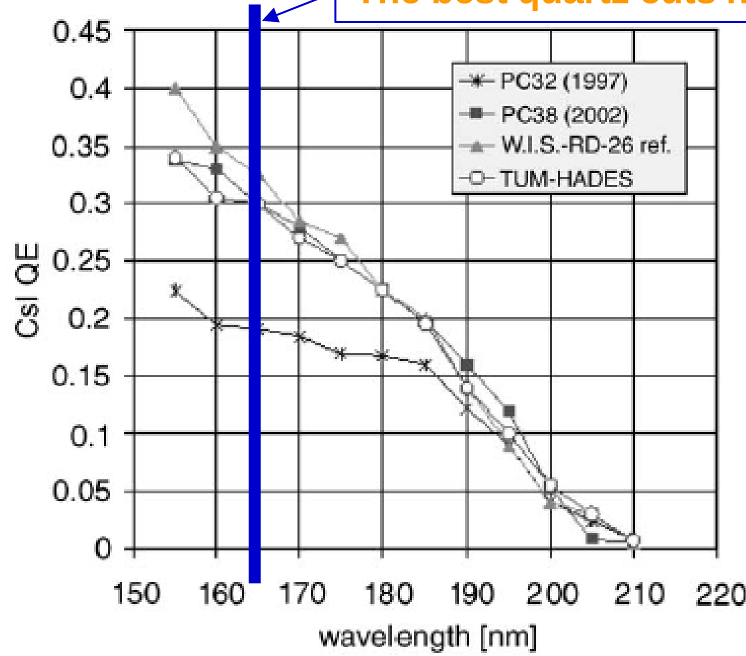
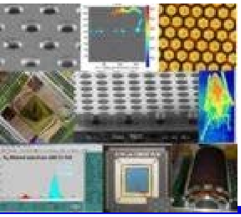


Fig. 1. The QE of CsI PCs produced at CERN for ALICE and at TUM for HADES, compared to that measured at the W.I.S. on small samples (reference for RD-26). PC32 is one of the four PCs equipping the ALICE-RICH prototype used in STAR at BNL.

A. Di Mauro, NIM A 525 (2004) 173.



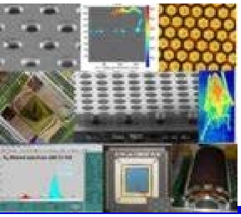
PCs, WHICH CONFIGURATION ?

Reflective versus semi-transparent photocathodes

- REFLECTIVE - larger photoelectron collection :
  - Semitransparent photocathode - the application of a thin metallic film, which absorbs photons, on the entrance window is required
  - the probability of photoelectron absorption is lower in a reflective photocathode than in a semitransparent one as the conversion probability is the highest at the entrance surface of the photo-converter

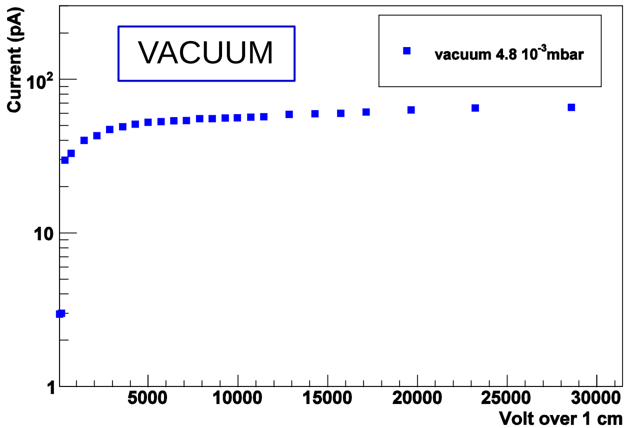
- the thickness of the photo-converter layer is non critical in the reflective configuration, contrary to the semitransparent one:

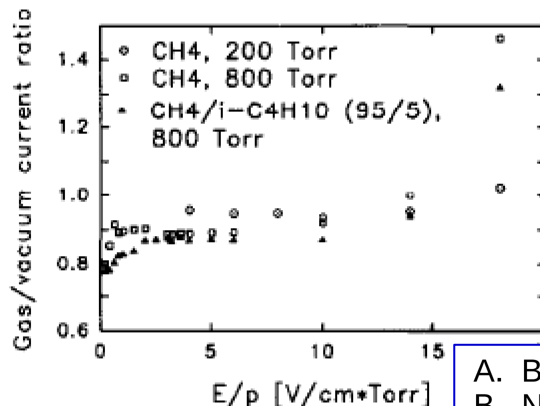
  this aspects is very relevant for large area detectors



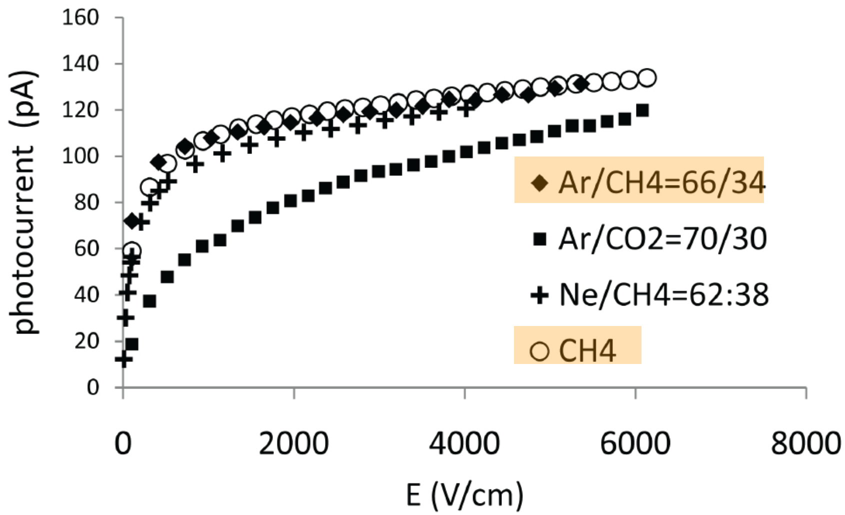
PHOTOELECTRON EXTRACTION

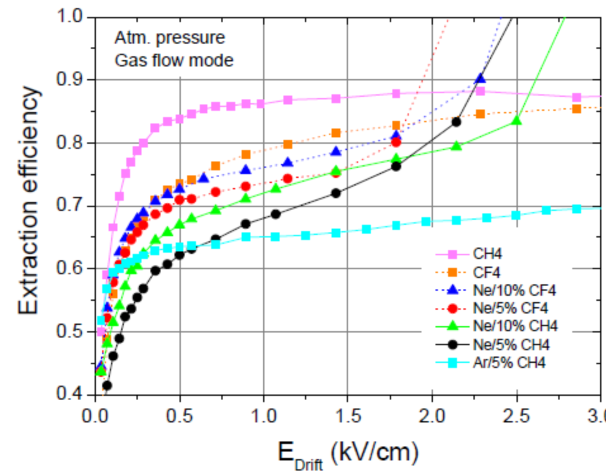
- Photoelectron extraction from a CsI film, the role of gas and E





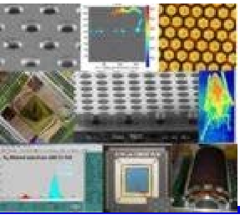
A. Breskin et al.,
B. NIM A 367 (1995) 342





M. Alexeev et al., NIM A (2010) in press

C. D. R. Azevedo et al., 2010 *JINST* 5 P01002



GASEOUS PDs, II GENERATION

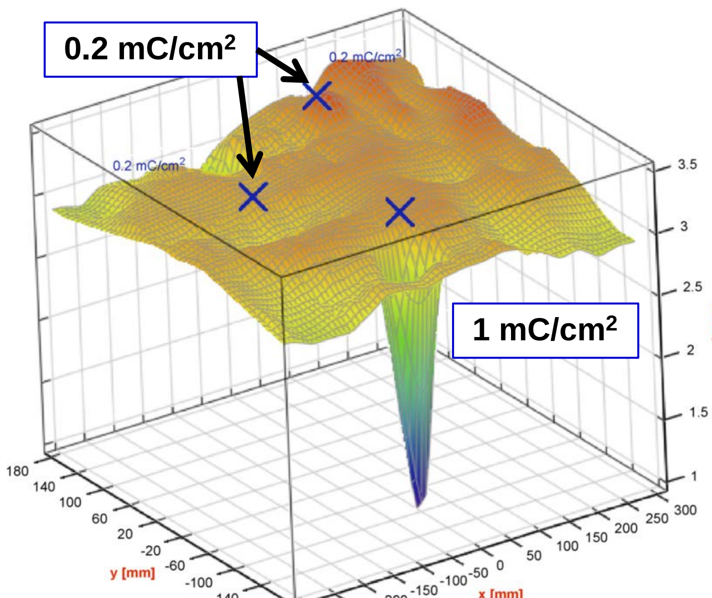
MWPCs with CsI photocathode, the limits

- **Severe recovery time (~ 1 d) after detector trips**
  - *Ion accumulation at the photocathode*
- **Feedback pulses**
  - *Ion and photons feedback from the multiplication process*
- **Aging after integrating a few mC / cm^2**
  - *Ion bombardment of the photocathode*

moderate gain: < 10^5

(effective gain: < 1/2)

not fast



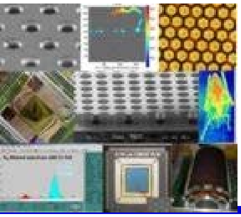
H. Hoedlmoser et al., NIM A 574 (2007) 28.

MWPCs → slow signal formation

+ low gain → "slow" electronics (signal integration, low noise level)

- *Gassiplex FE : integration time ~ 0.5 μs, time res> 1 μs*
- *APV (COMPASS RICH-1 upgrade) : resolution ~ 400 ns*

→ Detector memory, i.e. not adequate for high rates

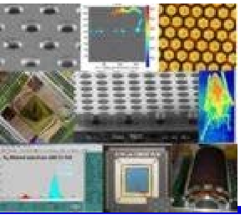


TOWARDS THE FUTURE

TWO REQUESTS

- Reduced photon and Ion BackFlow (IBF)
  - Reduced ageing
  - High gain → high photoelectron detection efficiency
- Intrinsically fast gaseous detectors (signal due to electron motion)
  - Short integration time
  - High rate environments

MICROPATTERN GASEOUS DETECTORS



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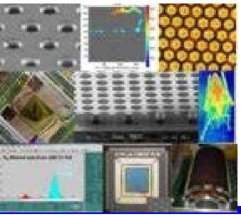


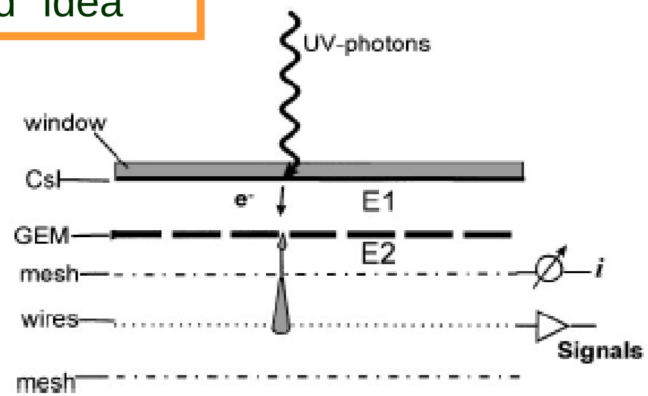
ION & PHOTON BLOCKING GEOMETRIES

First developments …

GEM-based PDs

NO photon feedback
Reduced ion feedback

An "old" idea

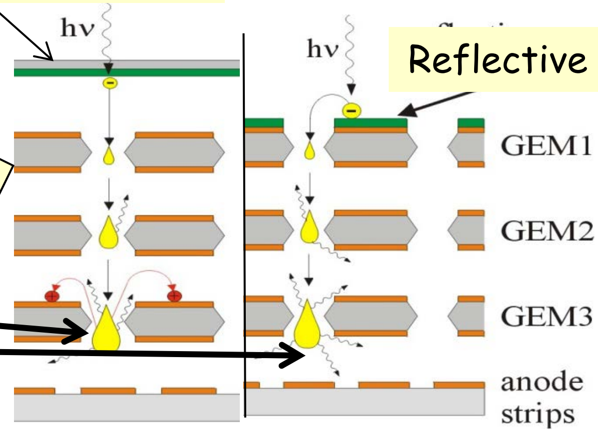


R. Chechwik et al., NIM A 419 (1998) 423

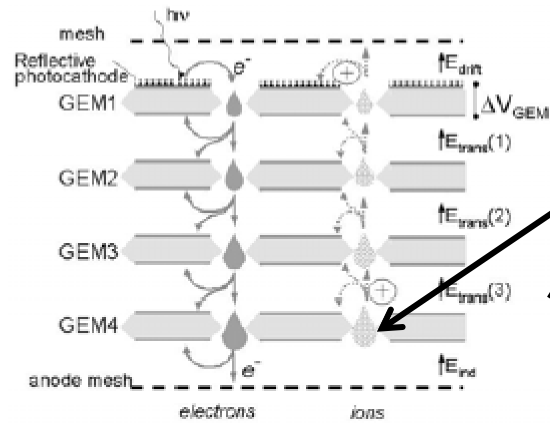
Semi-transparent PC

Reflective PC

e⁻ avalanche

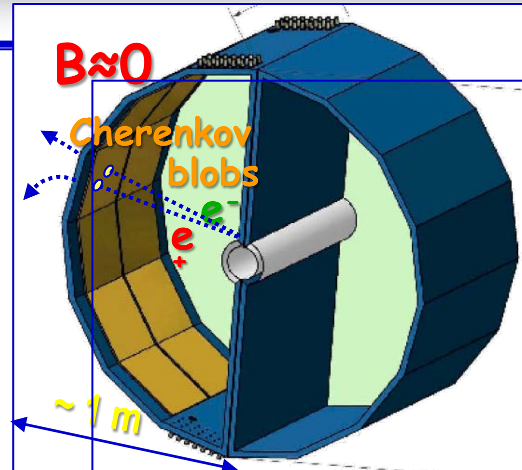


ion avalanche



A. Breskin and R. Chechwik, NIM A 595 (2008) 116

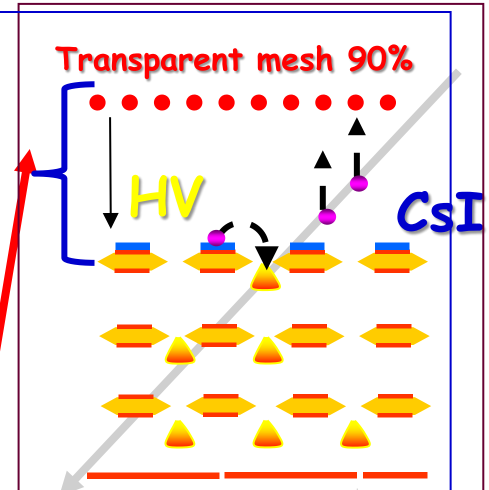
… and applications:



PHENIX HBD,

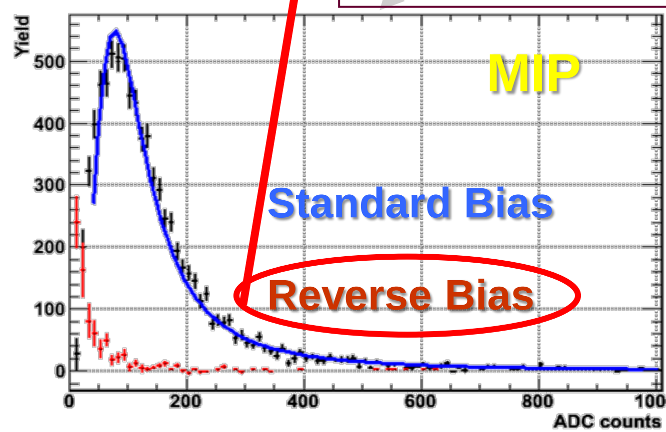
a threshold Cherenkov counter

(window-less)



Central message for any similar application

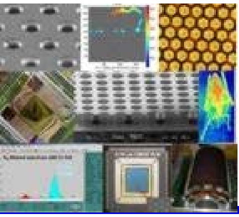
- Reversed bias cuts the MIP signal !



W. Anderson et al., NIMA 646 (2011) 35

Aspects non exportable to imaging devices:

- detection of >> 1 photon per pad: low gain (5000)
- non negligible noise level (~20% single photon signal)
- detect photons with λ down to ~110 nm: chromaticity !



GEM-based PDs and IBF

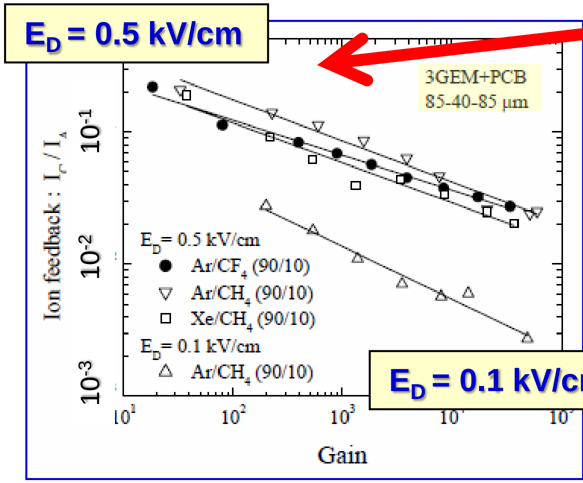
rich literature about IFB in GEM-based detectors

here examples with semi-transparent PC

- strong dependence from gain and E_{DRIFT}
- poor dependence from pressure and gas type

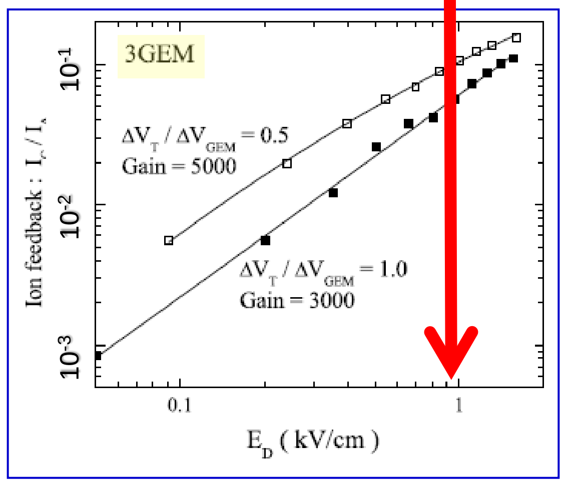
E ~ 1 kV/cm needed for good photoelectron extraction

E_D = 0.5 kV/cm

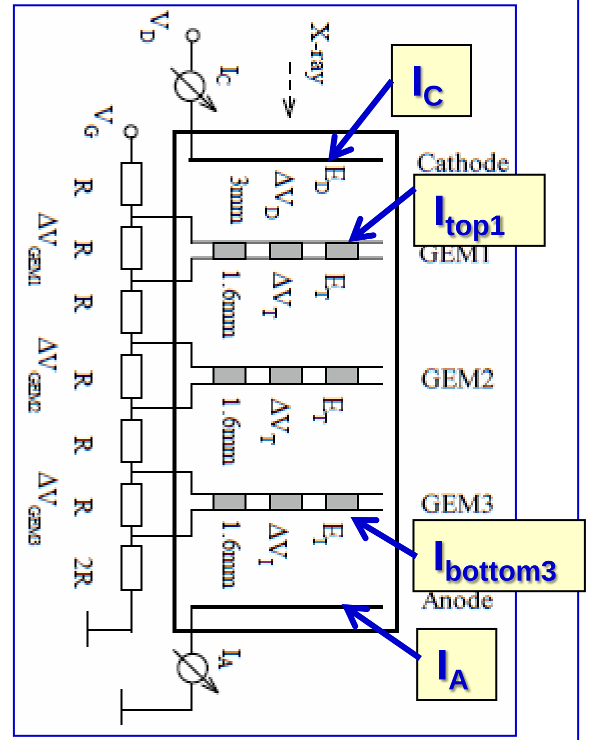


E_D = 0.1 kV/cm

A. Bondar et al., NIMA 496 (2003) 325

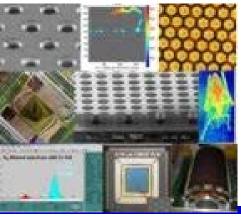


A. Breskin et al., NIMA 478 (2002) 225d



The same for reflective PCs : small and reversed E_D is needed

IBF: a few % level in effective GEM-based photon detectors

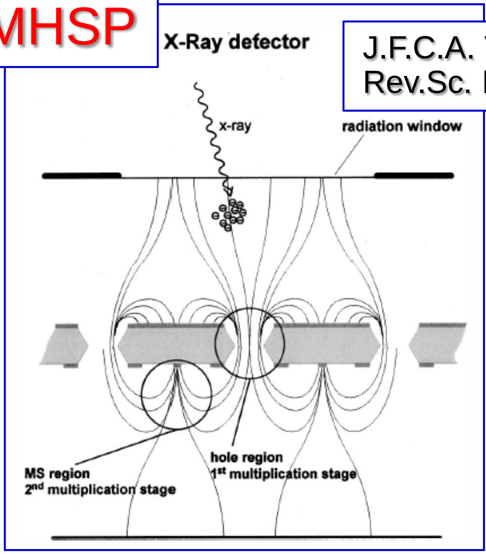


OVERCOMING IBF

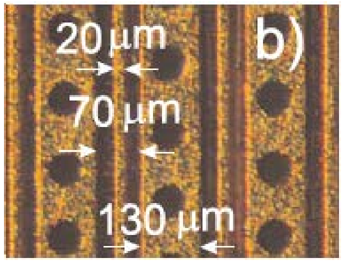
More complex geometries needed with extra electrodes to trap the ions:

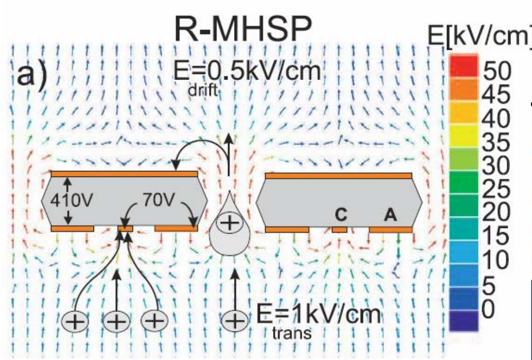
Micro-Hole & Strip Plate (MHSP), COBRA

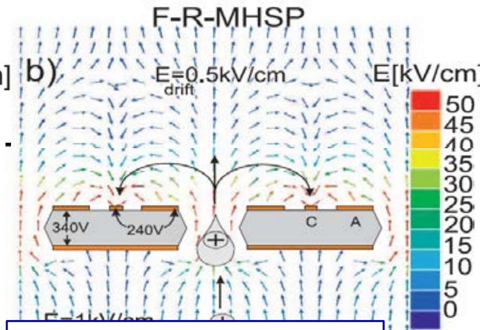
MHSP



J.F.C.A. Veloso et al.,
Rev.Sc. Instr. 71 (2000) 2371

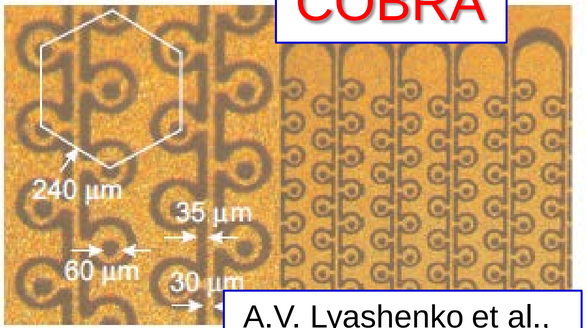




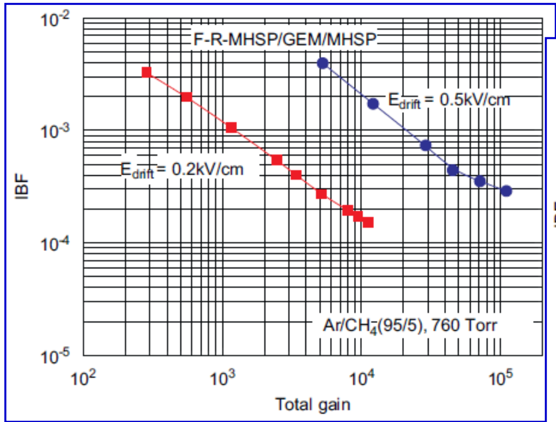


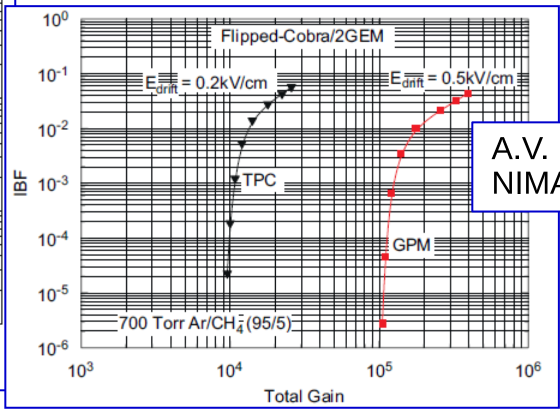
A.V. Lyashenko et al.,
JINST 2 (2007) P08004

COBRA

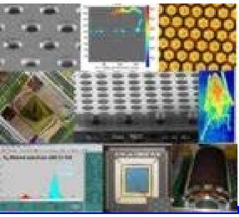


A.V. Lyashenko et al.,
NIMA 598 (2009) 116





A.V. Lyashenko et al.,
NIMA 598 (2009) 116



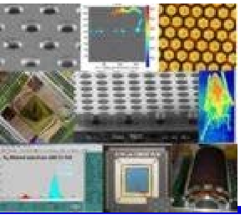
GEM-based PDs and GAIN

LARGE GAIN RELEVANT FOR SINGLE PHOTON DETECTION

- GEM-based PDs in laboratory studies
  - for single photoelectron detection, they have been operated at gains > 10^5 (see, for instance, the plots of the previous slides)

- GEM-based detectors in experiments
  - Always a MIP flux and small rates of heavily ionizing fragments crossing the detectors (even when the detectors are used as photon detectors)
    - At COMPASS: G ~ 8000 (B. Ketzer, private comm.)
    - At LHCb: G ~ 4000 (M.Alfonsi NIMA 581 (2007) 283)
    - At TOTEM: G ~ 8000 (G. Catanesi, private comm.)
    - Phenix HBD: G ~ 4000 (W. Anderson et al., NIMA 646 (2011) 35)

→ In experiments, small chances to operate GEM-based PDs at gains > 10^4



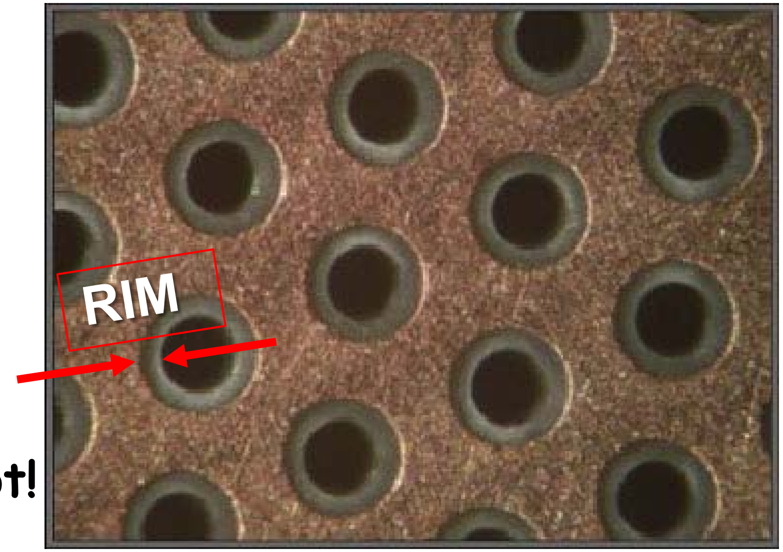
THGEM-based PDs, why ?

PCB technology, thus:

- robust
- mechanically self supporting
- industrial production of large size boards
- large gains have been immediately reported (rim !)

About PCB geometrical dimensions:

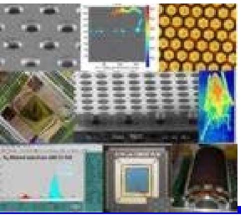
Hole diameter :	0.2 - 1 mm
Pitch :	0.5 - 5 mm
Thickness :	0.2 - 3 mm



Comparing to GEMs

- Geometrical dimensions X ~10
  - But e^- motion/multiplic. properties do not!
  - Larger holes:
    - dipole fields and external fields are strongly coupled
    - e^- dispersion plays a minor role

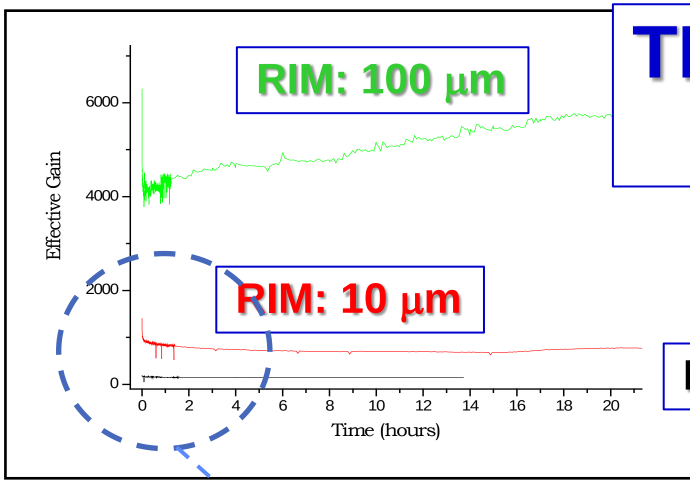
introduced in // by different groups:
L. Periale et al., NIM A478 (2002) 377.
P. Jeanneret, PhD thesis, Neuchatel U., 2001.
P.S. Barbeau et al, IEEE NS50 (2003) 1285
R. Chechik et al, .NIMA 535 (2004) 303



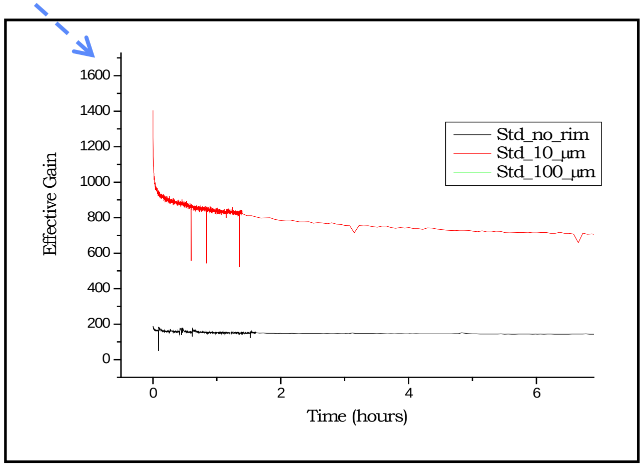
ABOUT THE RIM

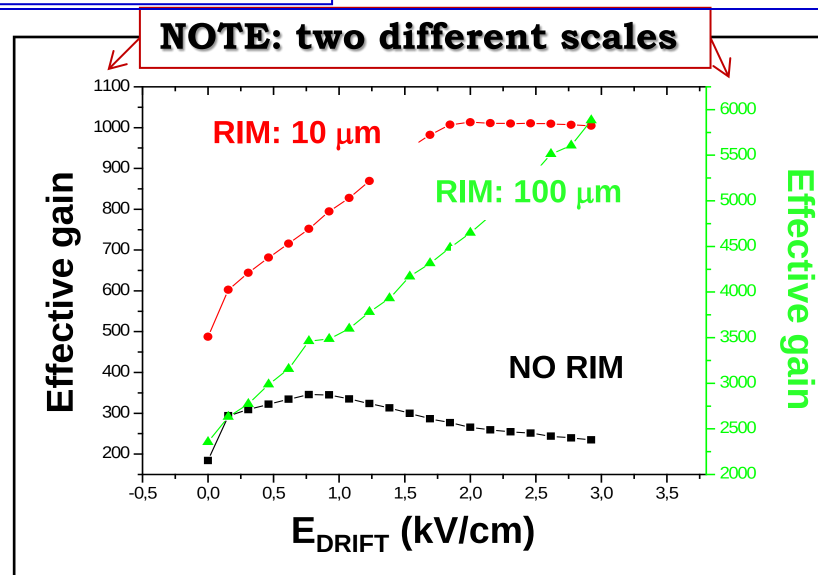
X-ray measurements

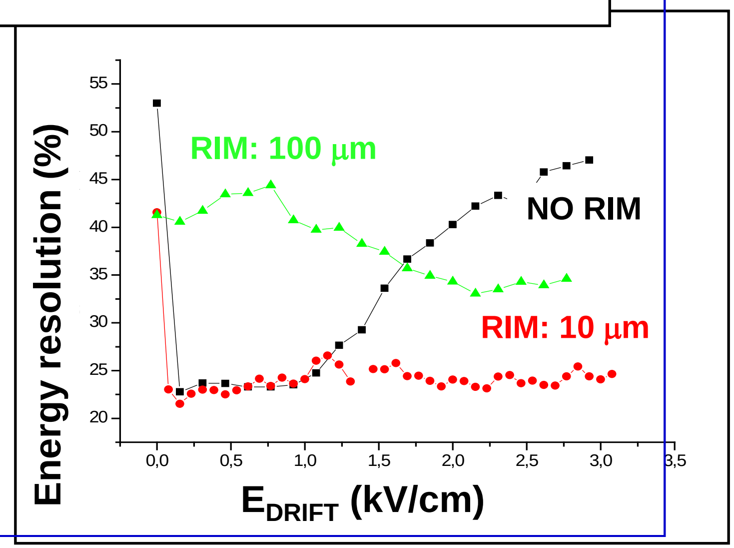
THGEM & RIM



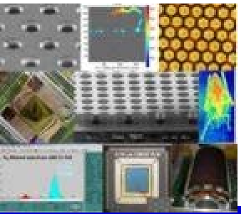
zoom





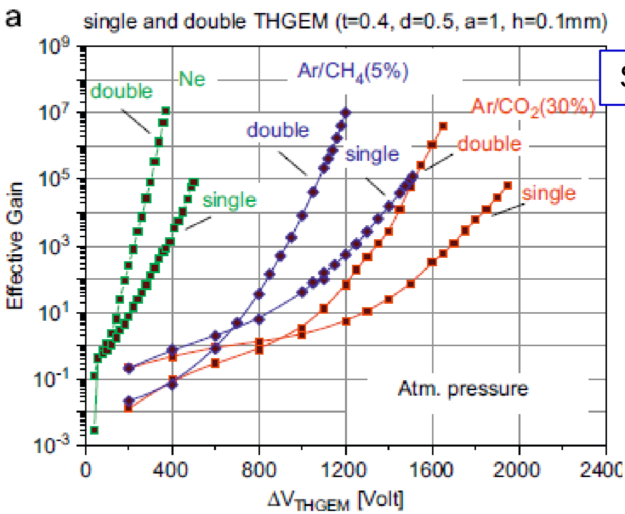


S. Dalla Torre et al.,
IEEE – NSS 2008 , Dresden 19-25/10/2008

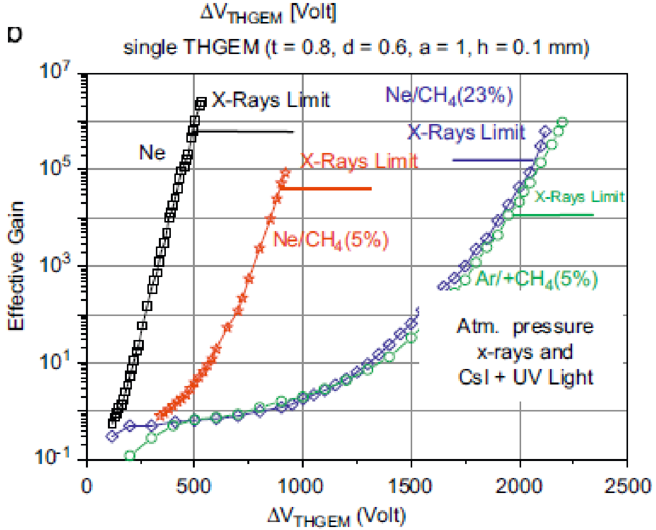


THGEM GAIN & RIM

employing large rim (100 μm)

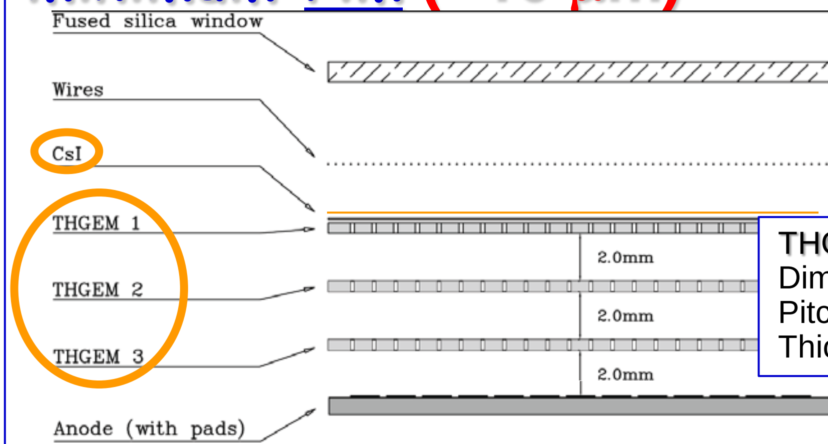


Single photons

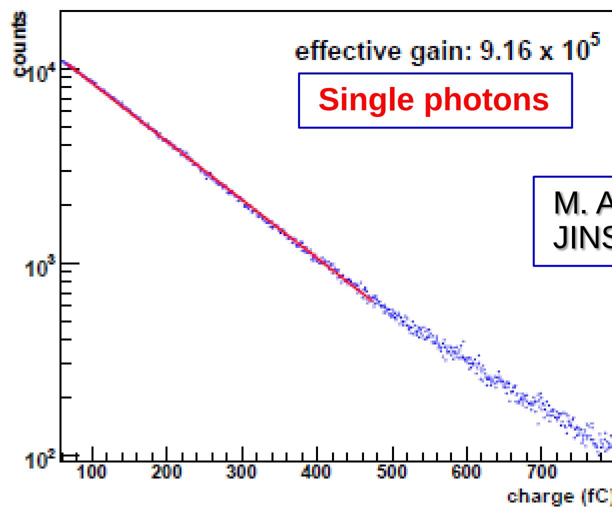


A. Breskin et al., NIMA (2010) in press

minimum rim (<10 μm)



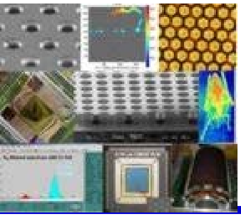
THGEMs
Dim: 0.4 mm
Pitch: 0.8 mm
Thickn.: 0.4mm



Single photons

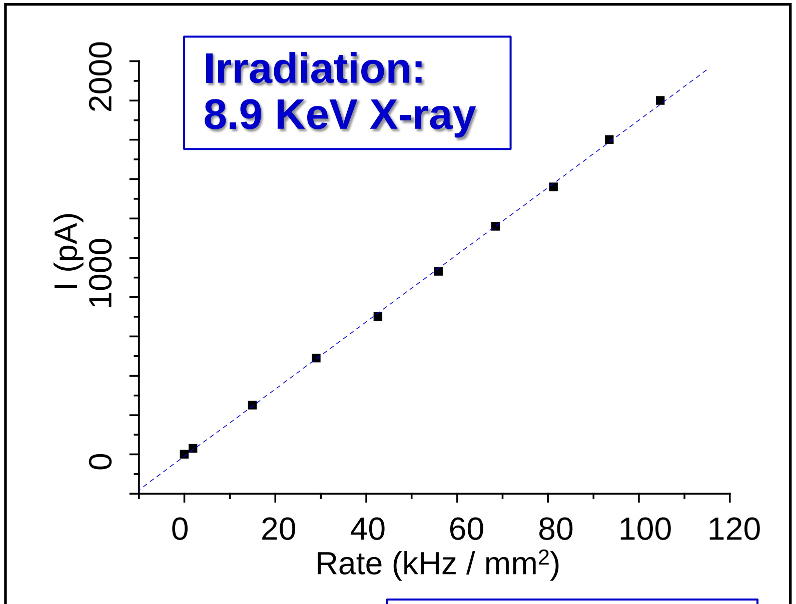
M. Alexeev et al., JINST 5 (2010) P08009

Gain limited to ~10^5 in test beam



More about THGEMs

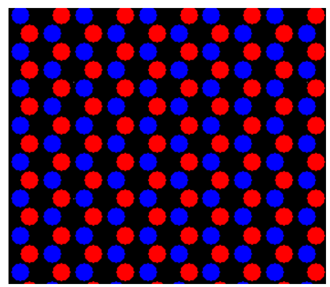
High rate device

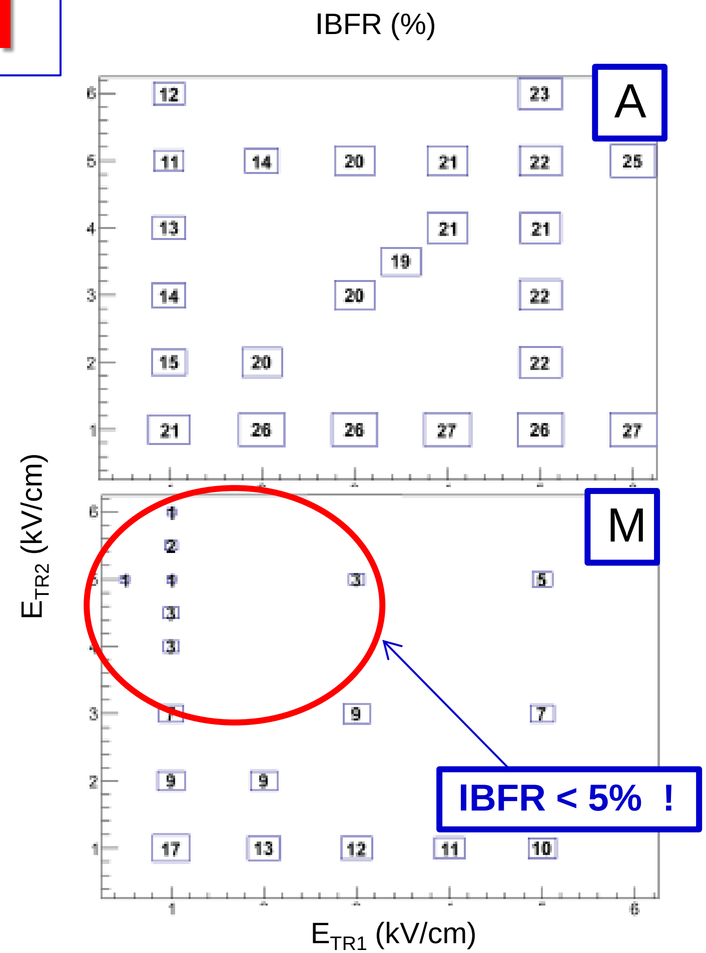


single THGEM, no RIM

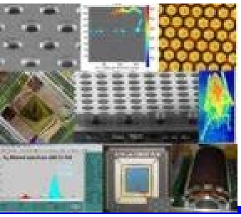
IBF control

Tripple THGEM:
Ion Back Flow
reduction by
staggering plates





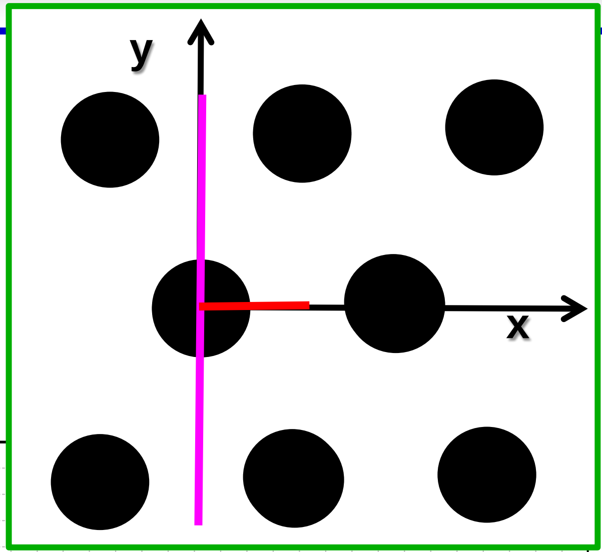
M. Alexeev et al., JINST 7 (2012) C002014



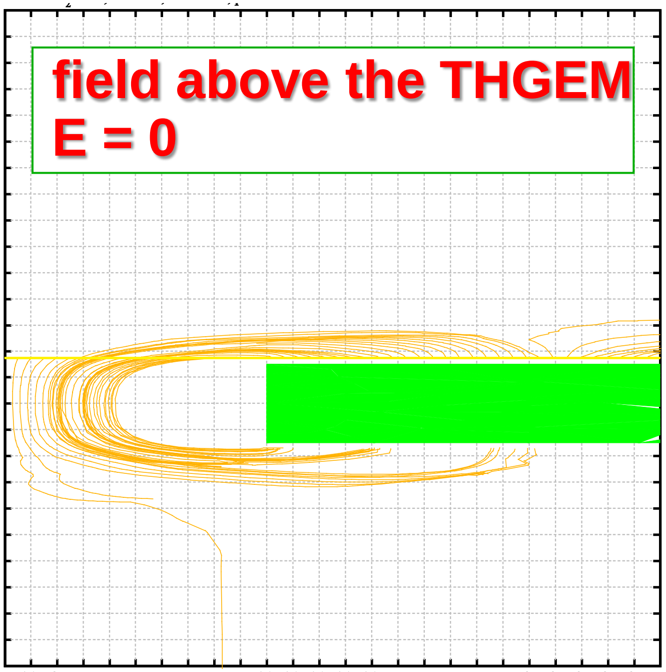
PHOTOELECTRON EXTRACTION

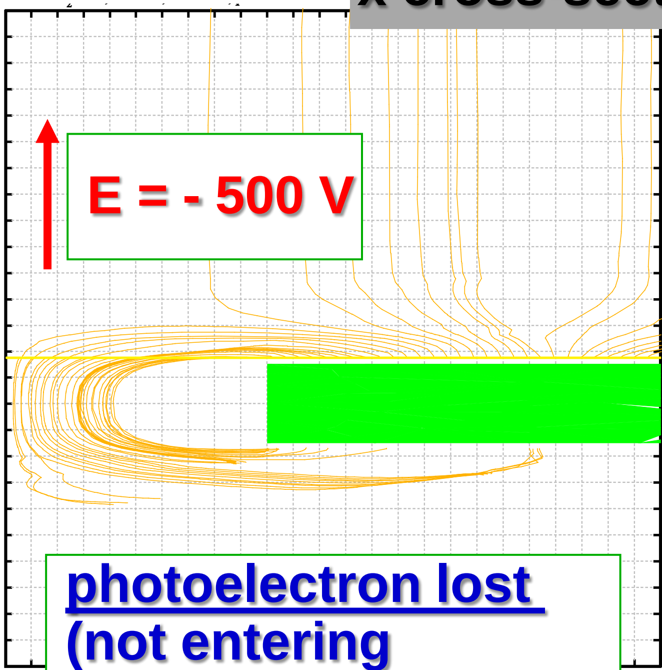
photoelectron trajectories from
a THGEM photocathode, simulation,
multiplication switched off

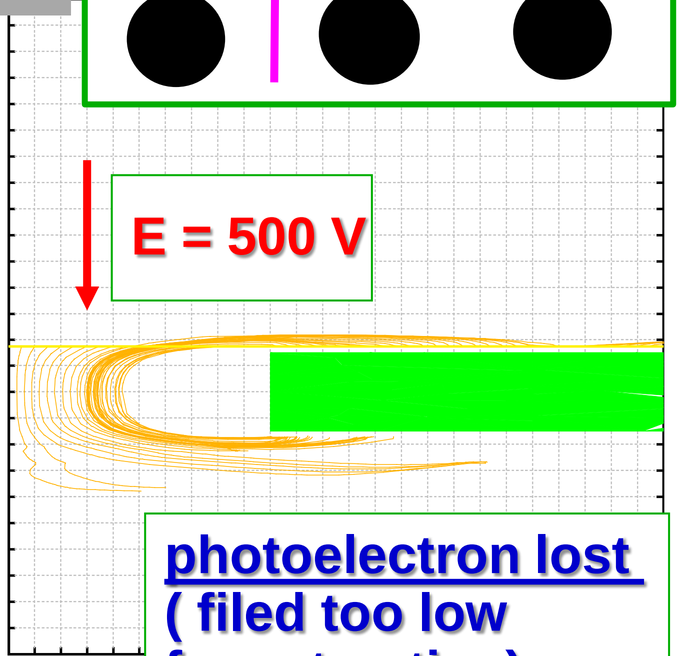
thickness 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, ΔV = 1500 V



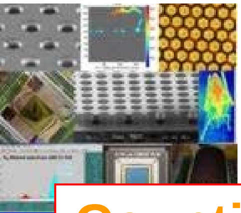
x cross-section



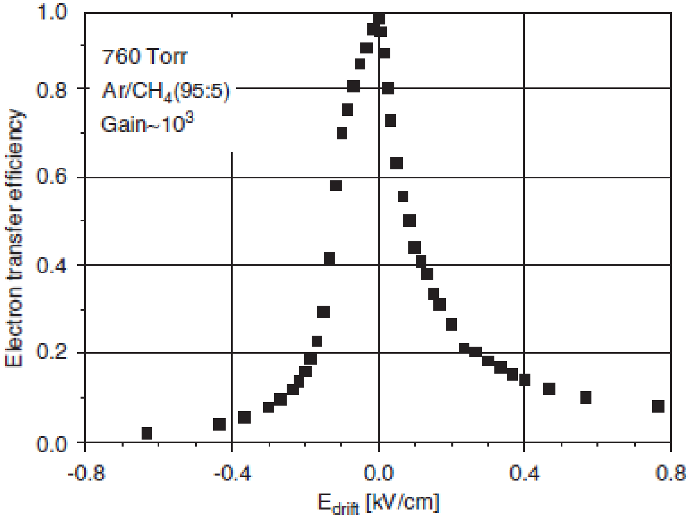


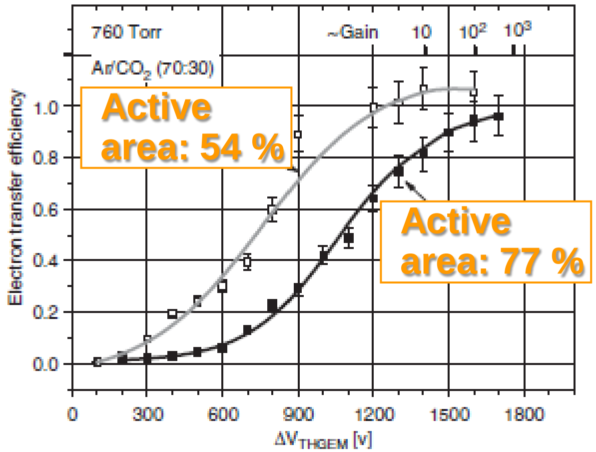


PHOTOELECTRON EXTRACTION

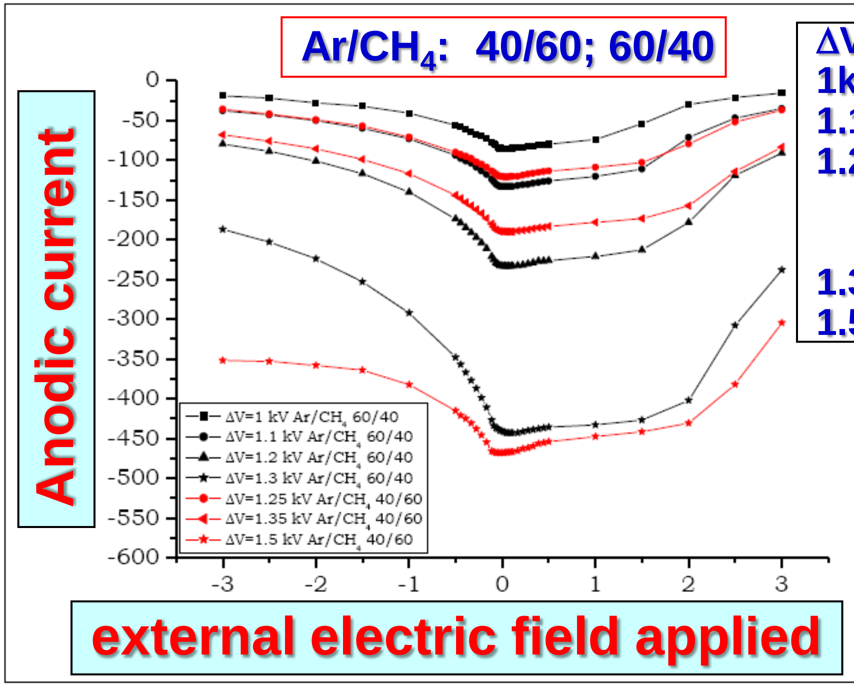


Counting mode technique





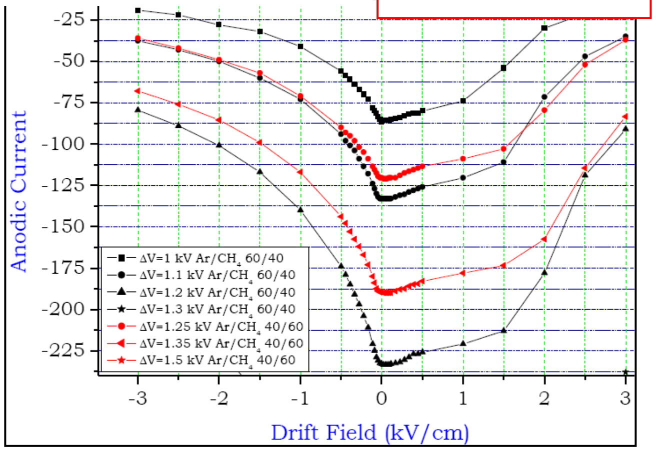
C. Shalem et al., NIMA 558 (2006) 475



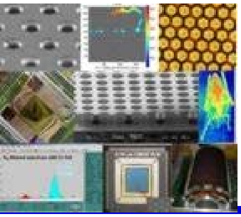
ΔV =
1kV
1.1, 1.2
1.25, 1.3

1.35
1.5

ZOOM



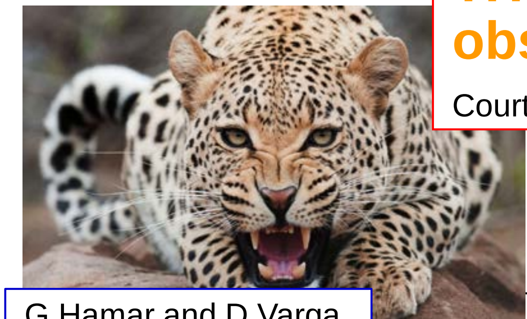
S. Dalla Torre et al., TIPP09 - Tsukuba, Japan 11-17/3/2009



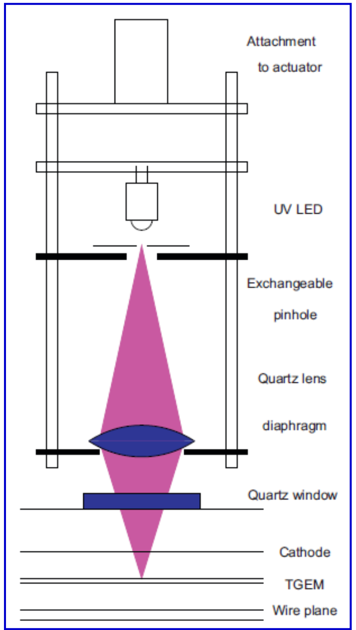
PHOTOELECTRON EXTRACTION

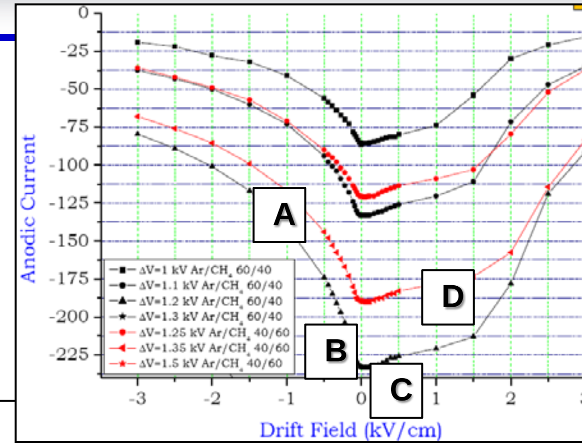
Photoelectron extraction from THGEM PC fully confirmed by direct observation with "Leopard"

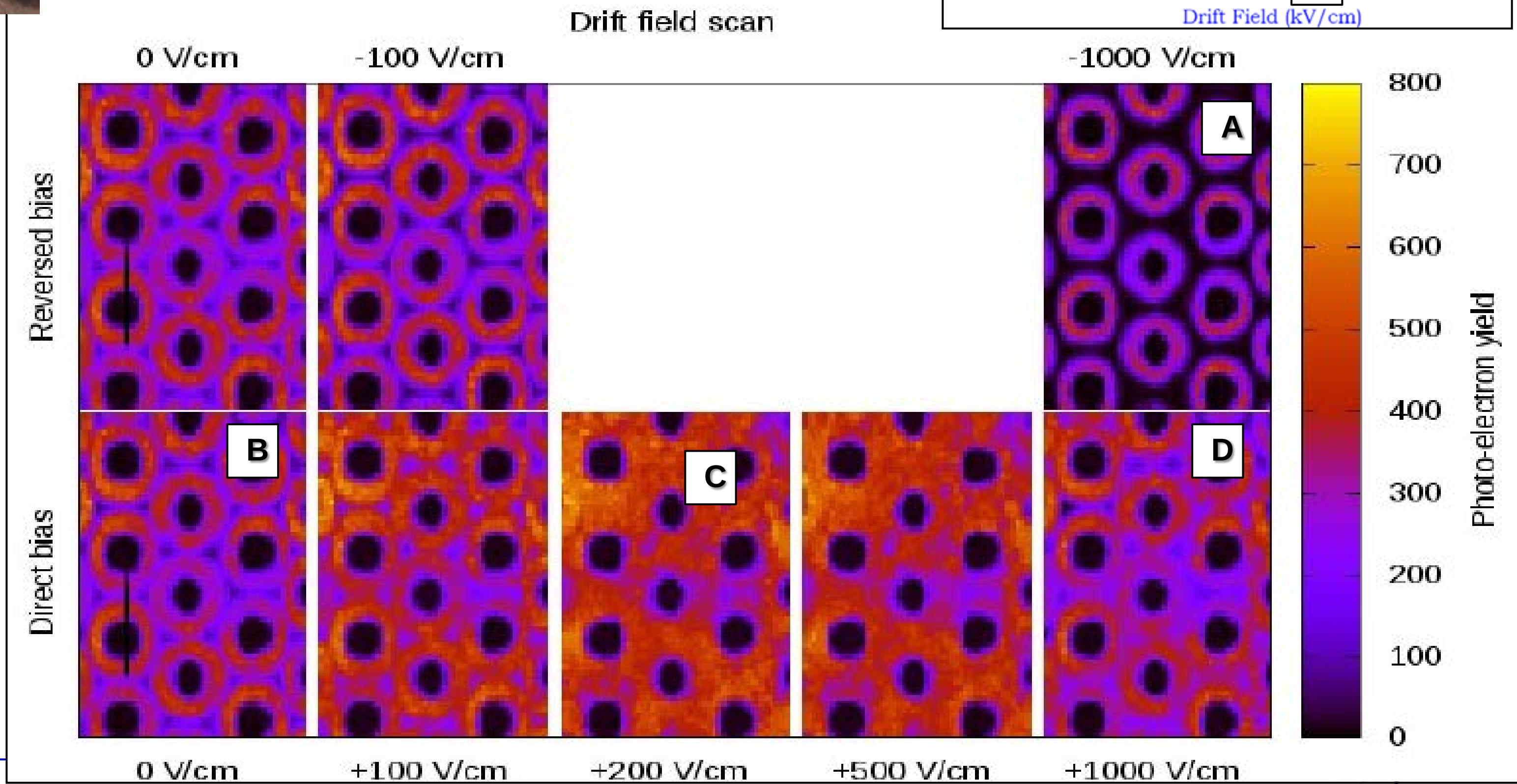
Courtesy of the Budapest and Trieste THGEM groups



G.Hamar and D.Varga, NIMA 694(2012) 16

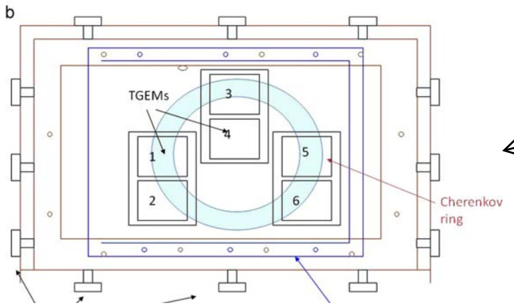




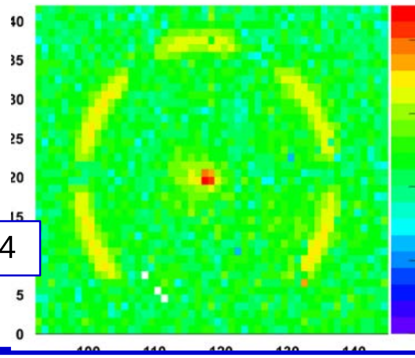


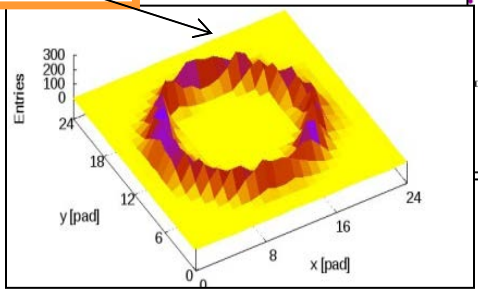
THGEM R&D for RICHes

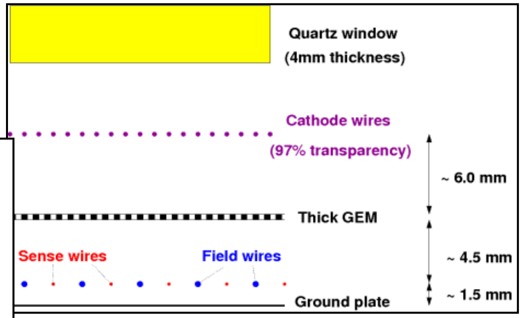
ALICE VHPID THGEM & HYBRID



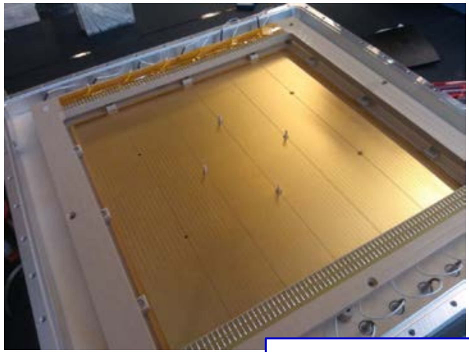
V.Peskov et al., NIMA 695 (2012) 154



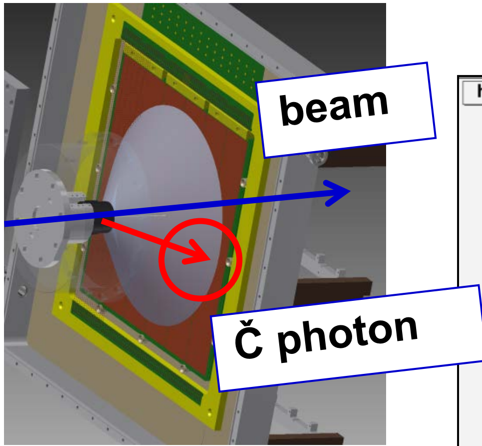


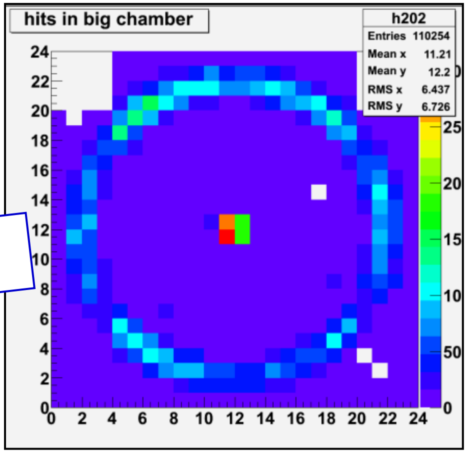


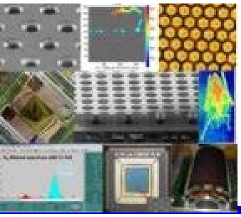
COMPASS, RICH-1 upgrade by Triple THGEM detectors



300 x 300 mm^2 active surface







NUMBER OF DETECTED PHOTONS

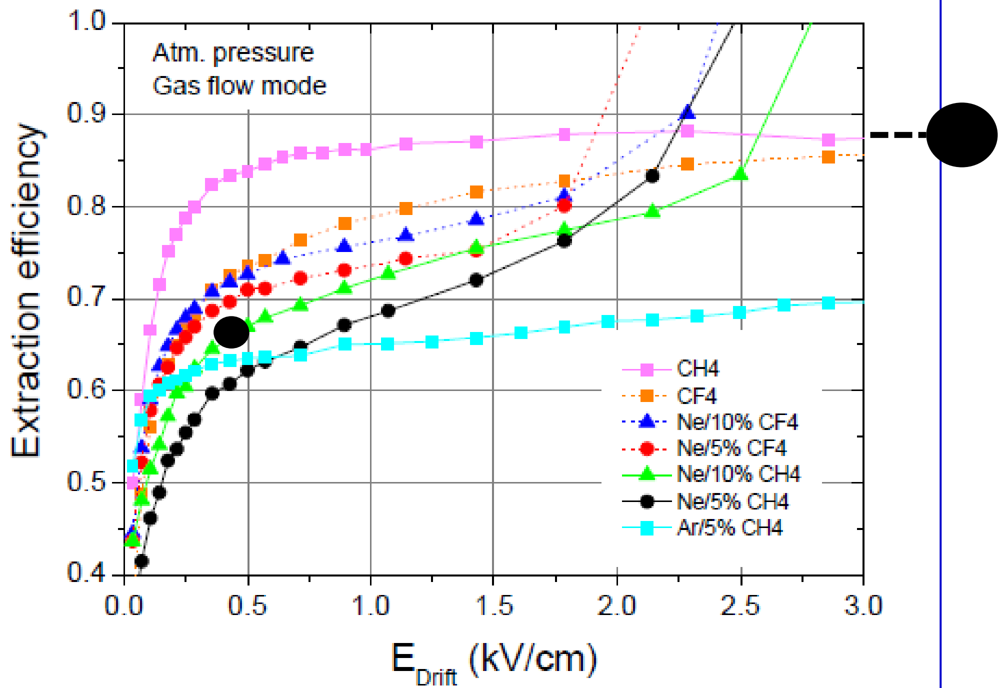
V.Peskov et al., NIMA 695 (2012) 154

N of detected photons is ~60-70% of MWPCs with CsI

- Ne+10%CH_4, used with ΔV at 650-750 V

5. Conclusions and Outlook

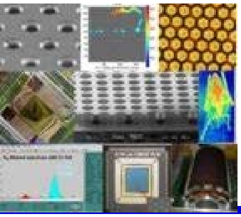
We report the first successful implementation of a set of CsI-TGEMs with a liquid radiator where a Cherenkov ring has been observed. The results obtained are encouraging and suggest that the present performance could be improved in the future by optimizing elements of the design. We are launching now systematic studies on TGEM geometry optimization allowing increasing the value of η_{rel}, ε_{col} and A_{eff}. We also are planning to investigate



→ Relative extraction efficiency Respect to pure methane at E ~ 7kV/cm ~ 75% (my estimate)

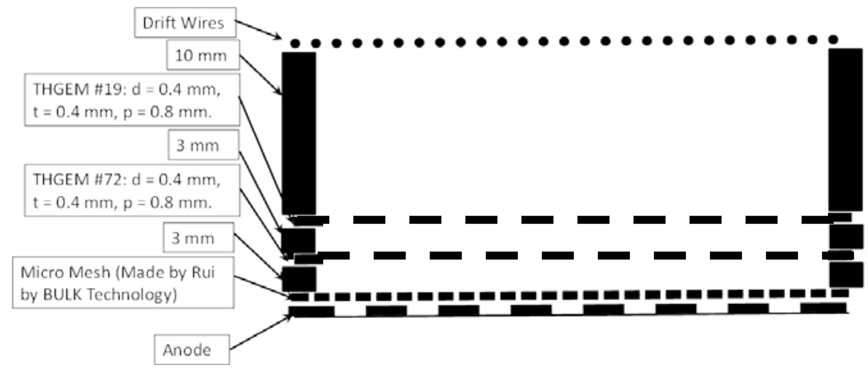
C. D. R. Azevedo et al., 2010 *JINST* 5 P01002

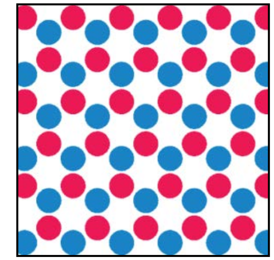
HYBRID MPGD PDs (THGEM + …)



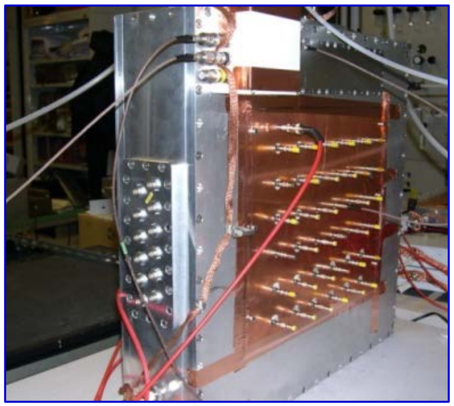
- The 1st THGEM forms the PC
- The 2nd THGEM (staggered) forces the electron diffusion
- The MM provides large gain, made larger by the diffusing the impinging electron cloud

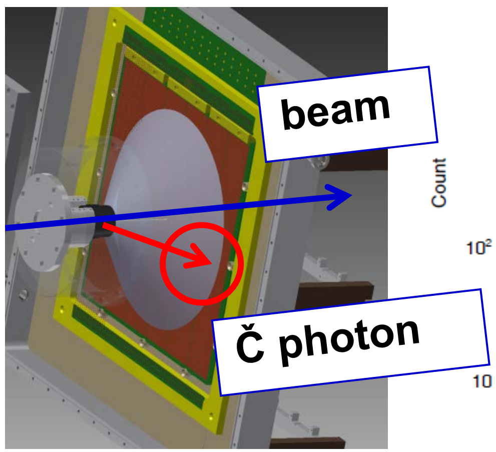
Setup Hybrid (300 X 300 mm^2) with double THGEM





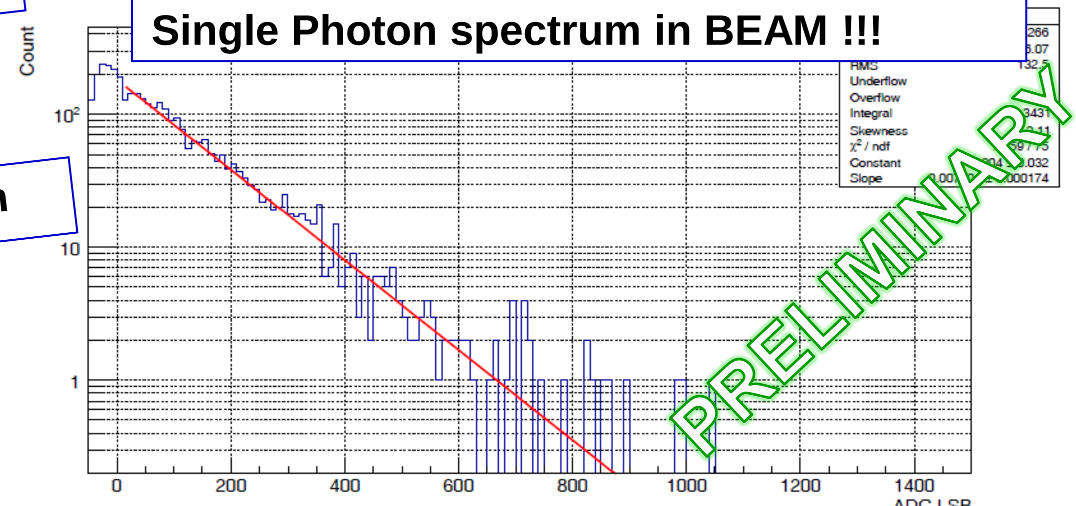
THGEM staggered !





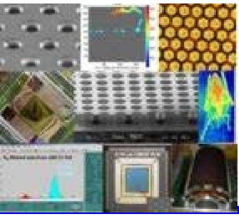
Gain ~ 130K

Single Photon spectrum in BEAM !!!



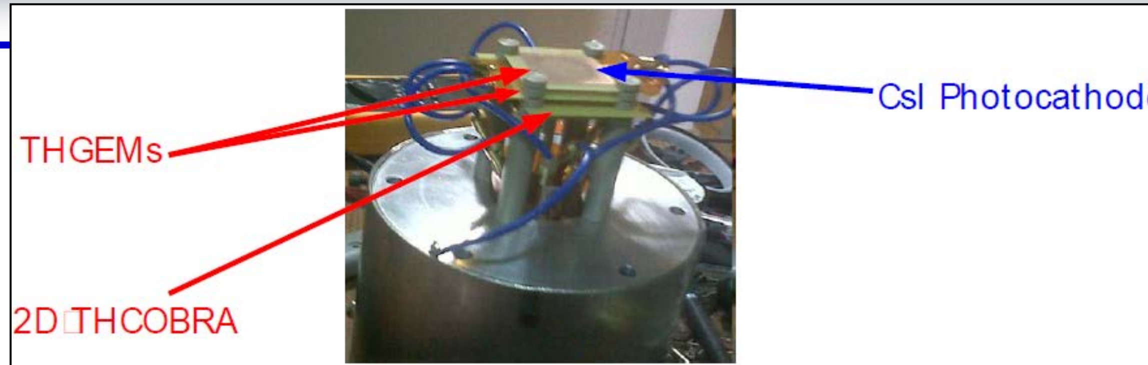
Courtesy of the COMPASS-THGEM group

The same architecture independently studied in parallel as GPM for DM searches (see later)

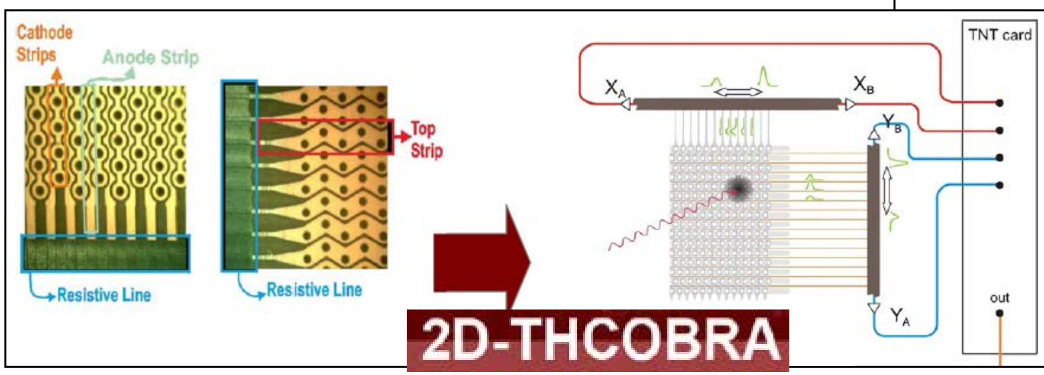


HYBRID MPGD PDs (THGEM + ...)

- 2 THGEMs
- a THCOBRA with 2 d R-O structure

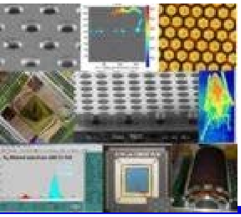


Parameters			
Structure	Hole Diameter (µm)	Pitch (µm)	RIM (µm)
THGEM 1	400	800	5
THGEM 2	700	1300	100
2D THCOBRA	400	1000	80



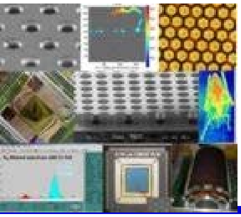
- Gas Photomultiplier (GPM) : 2D-THCOBRA
  - Good Performance
    - Gain of 10^6
    - IBF values of about: 20%
  - 2D THCOBRA adequate to obtain image
  - Position Resolution: FWHM= 300 µm, σ= 128µm
  - Count rate of 100kHz

T. Lopes 2013 JINST 8 P09002



OUTLINE

- Introductory considerations
- Gaseous PDs, historical overview
  - I generation - photoconverting vapours
  - II generation – MWPCs with solid state CsI PC
- MPGD-based PDs
  - Basic principles and architectures
  - Gaseous PDs with sensitivity in the visible range
  - Cryogenic MPGD-based PDs
  - Detecting electroluminescence produced in avalanche processes for frontier research and applications
- Conclusions



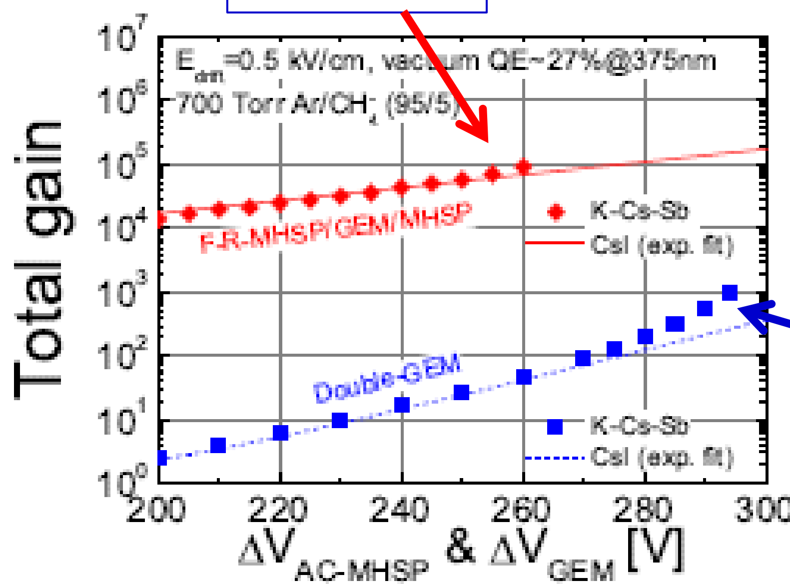
- photocathodes for visible light
  - Chemical reactivity (gas purity better than ppm level needed → UHV materials and sealed detectors)
  - PC stability under ion bombardment - work function lower than CsI one
  - AGEING CsI: -16% QE at 25μC/mm²
    Bilkaly: -20% QE at 0.4μC/mm²

F.Tokanai et al., NIMA 628 (2011) 190

T.Moriya et al., NIMA 732 (2013) 263

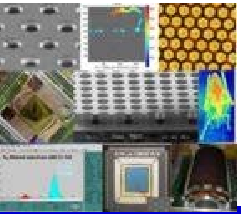
F-R-MHSP,
IBF: 3 x 10 $^{-4}$

K-Cs-Sb vs CsI

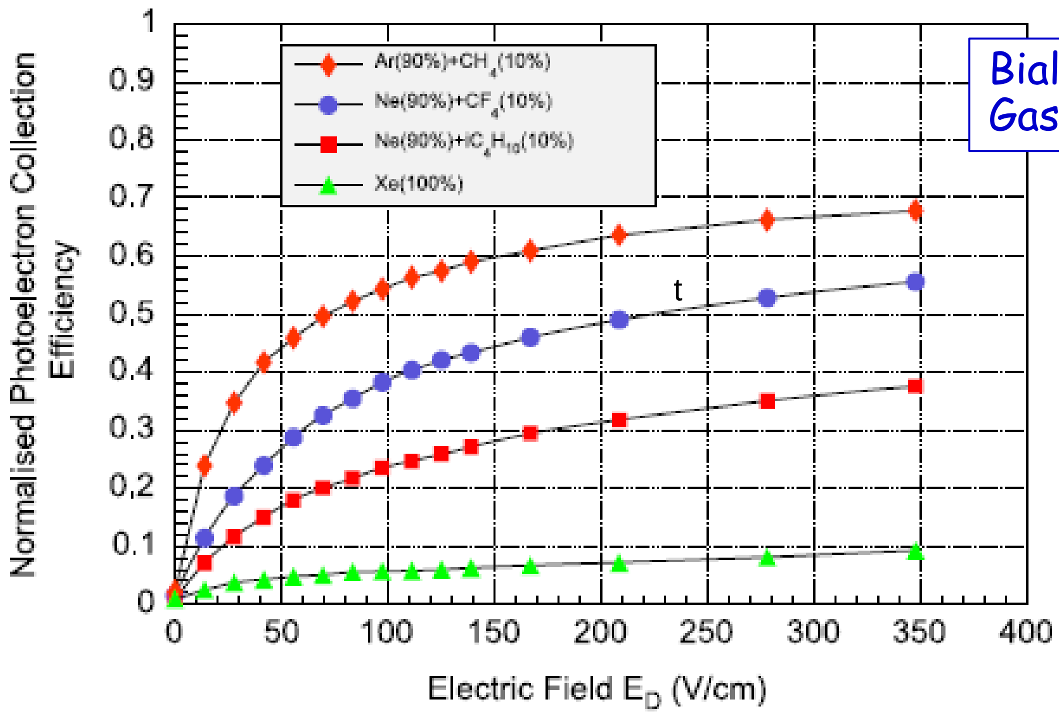


Doulble GEM,
IBF: ~ 10 $^{-2}$

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

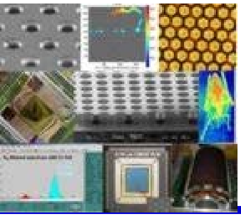


- **Dedicated photoelectron extraction studies**

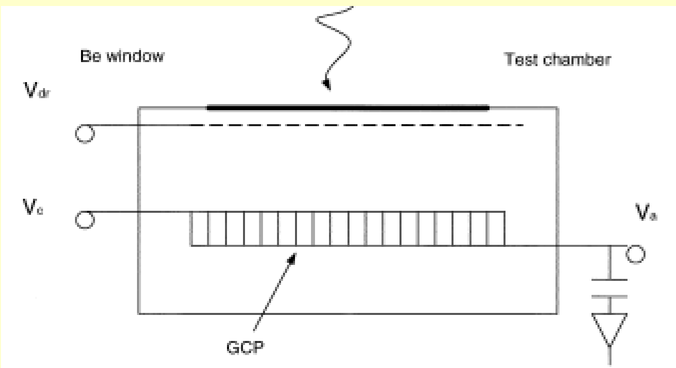


Bialkali,
Gas P 675 torr

F. Tokanai et al., NIMA 610 (2010) in press



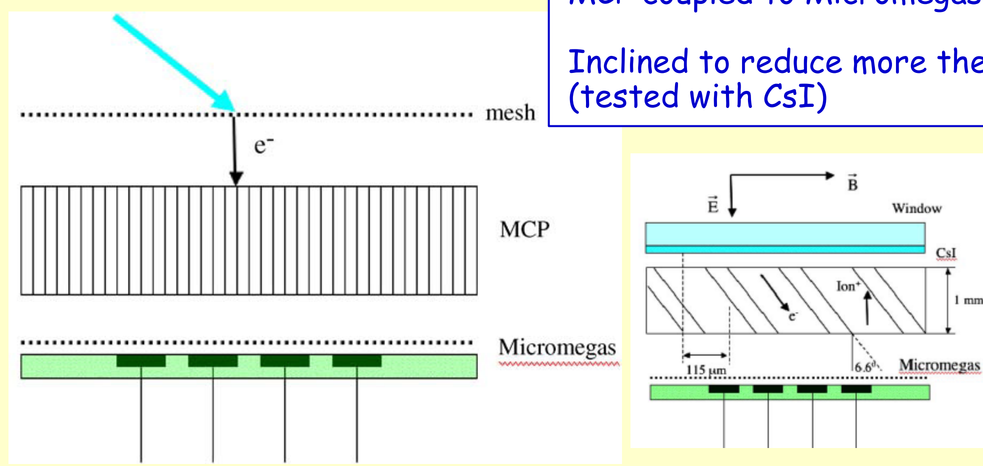
The Capillary Plate (CP) approach



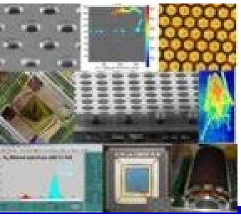
V. Peskov et al., NIMA 433 (1999) 492

MCP coupled to Micromegas

Inclined to reduce more the IBF (tested with CsI)



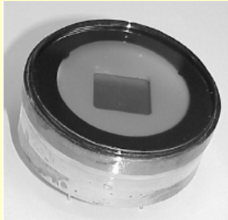
J.Va'vra and T. Sumiyoshi, NIMA, 435 (2004) 334



the GEM approach

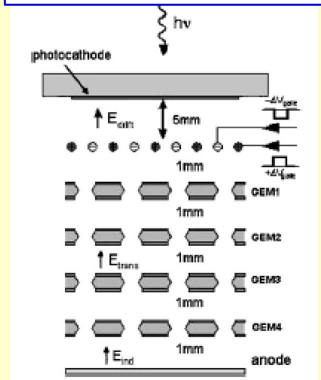
TIME LINE

Multiple GEM sealed



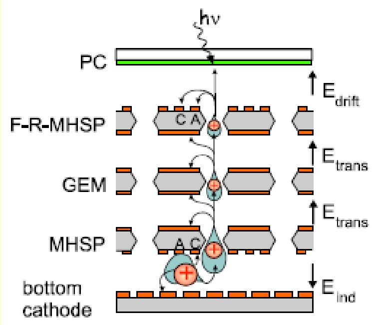
R.Chechik et al., NIMA 502 (2003) 195

Pulsed ion gating



A. Breskin et al.,
B. NIMA 553 (2005) 46

K-Cs-Sb - Continuous mode, not a sealed PD

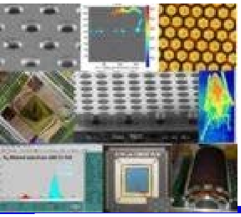


A.V.Lyashenko et al., 2009 JINST 4 P07005

Poor compatibility of bialkali and GEM material ?

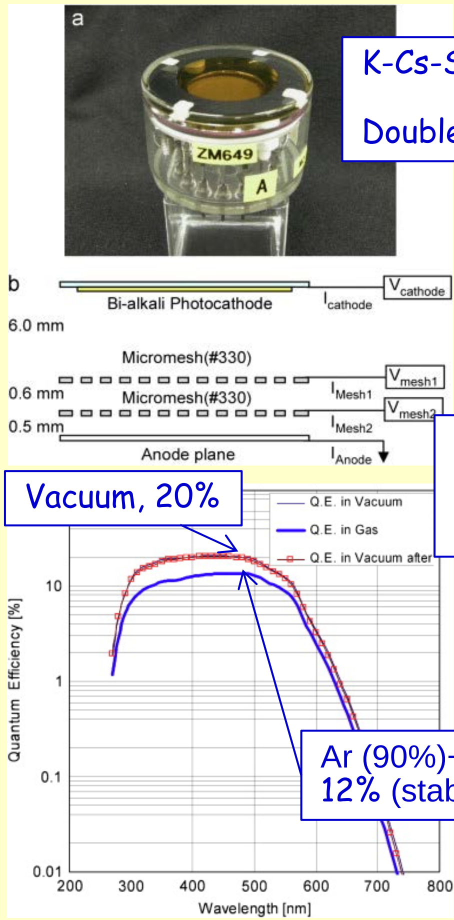
Extremely poor QE of the bialkali PC:
the material of the GEM chemically reacts with the bialkali metals

F. Tokanai et al., NIMA 610 (2009) 164



GASEOUS DETECTORS FOR VISIBLE LIGHT

the MicroMega approach



K-Cs-Sb

Double MM, Ni mesh

IBF : <2.5×10^{-3}

Gain < 10^4

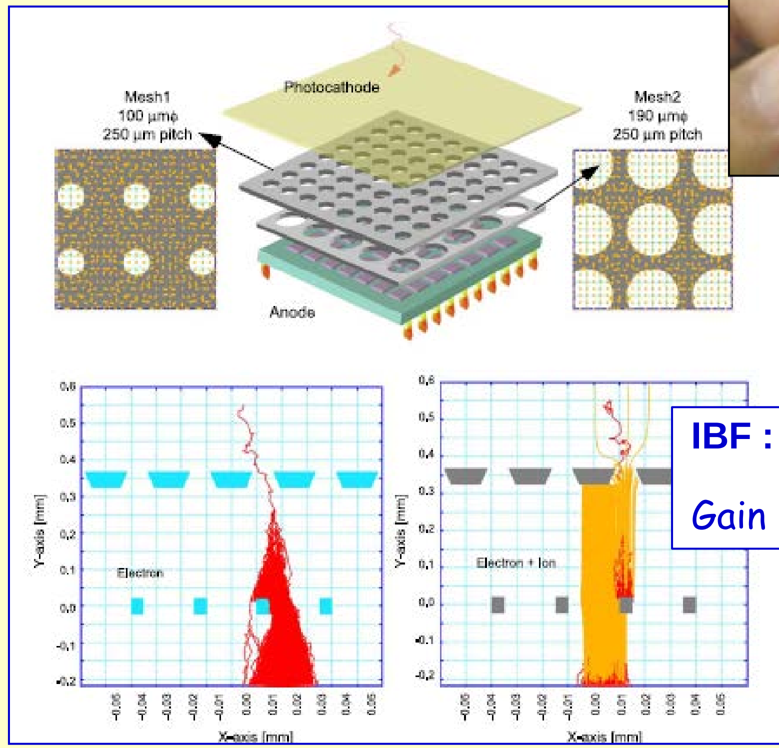
Vacuum, 20%

Ar (90%)+CH_4 (10%)
12% (stable) after 1.5 y

F. Tokanai et al., NIMA 610 (2009) 164

More recently: 2 staggered MM layers to enhance ion trapping

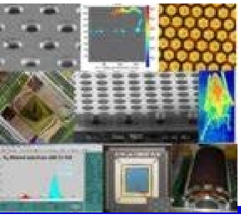
In collaboration with HAMAMATSU



IBF : 6 ×10^{-4}

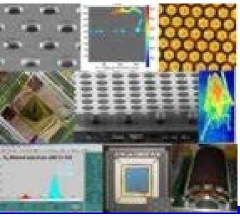
Gain : 10^4

F. Tokanai et al., NIMA (2014) in press



OUTLINE

- Introductory considerations
- Gaseous PDs, historical overview
  - I generation - photoconverting vapours
  - II generation – MWPCs with solid state CsI PC
- MPGD-based PDs
  - Basic principles and architectures
  - Gaseous PDs with sensitivity in the visible range
  - Cryogenic MPGD-based PDs
  - Detecting electroluminescence produced in avalanche processes for frontier research and applications
- Conclusions

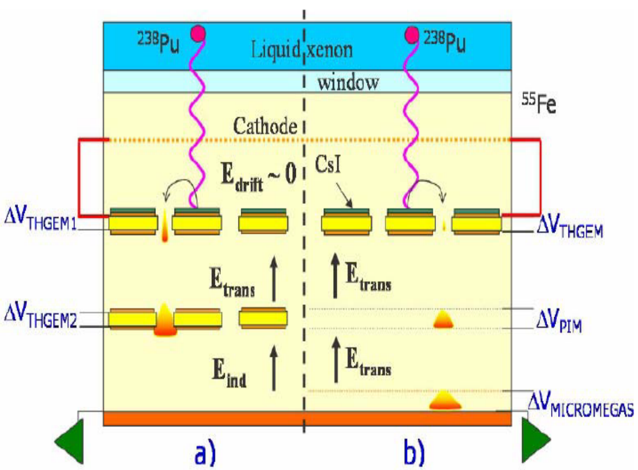


CRYOGENIC MPGD-PDs

Two-Phase Photoelectric Gate

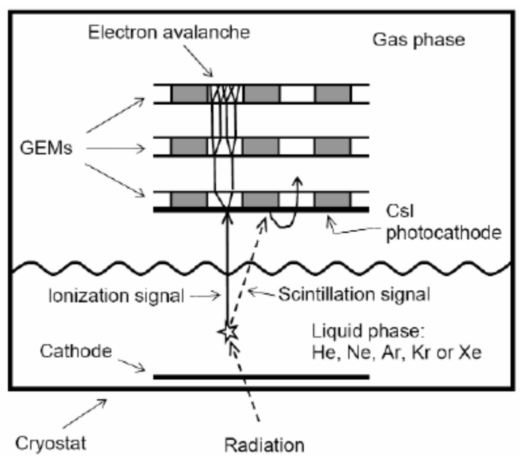
- **Read-out elements of cryogenic noble liquid detectors**
  - **Rear event detectors (ν, DM)**
  - **Detecting the scintillation light produced in the noble liquids**
  - **Options of scintillator light and ionization charge detection by a same detector !**

with WINDOW



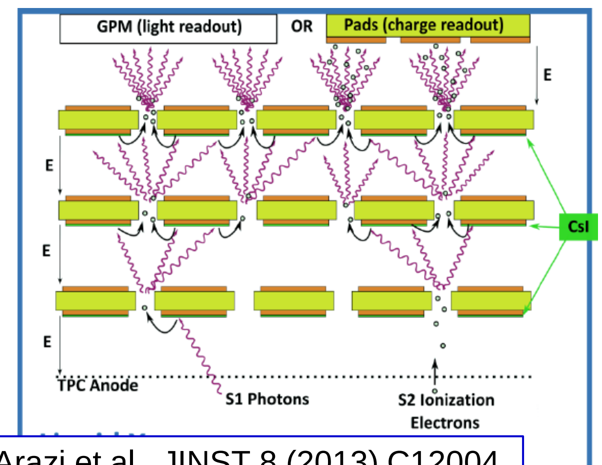
S.Duval et al., JINST 6 (2011) P04007

WINDOWLESS (2-PHASES)

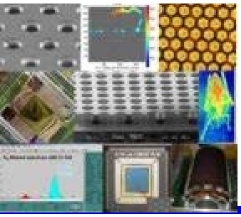


A. Bondar et al., NIMA 556 (2006) 273

OPERATED IN THE CRYOGENIC LIQUID



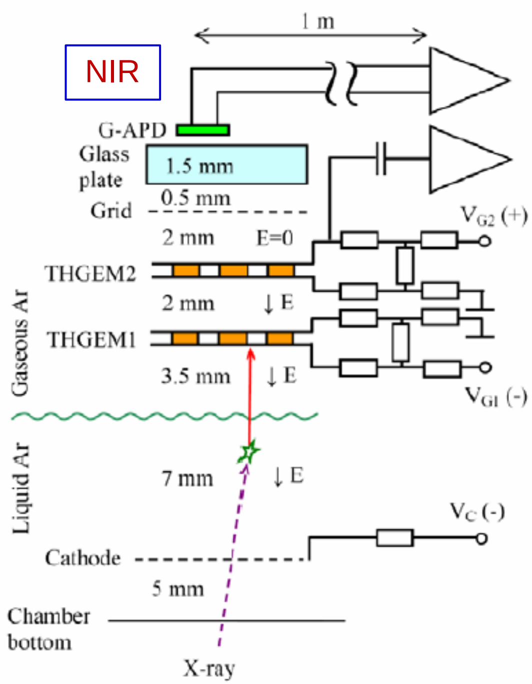
L.Arazi et al., JINST 8 (2013) C12004



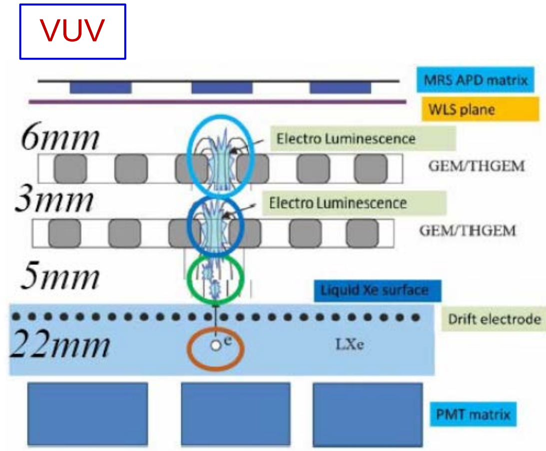
ELECTROLUMINESCECE

MPGDs are source (and detection) of electroluminescence

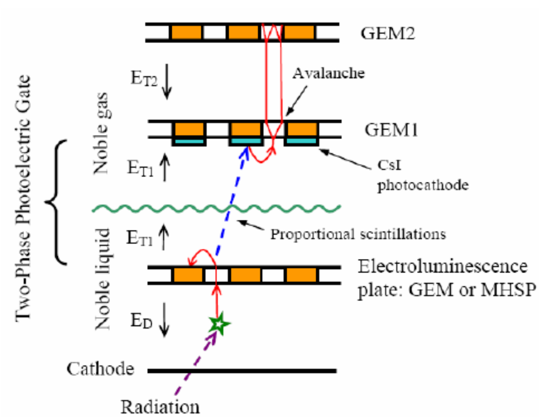
- Fast, no ion distortion



A. Bondar et al., JINST 5 (2010) P08002

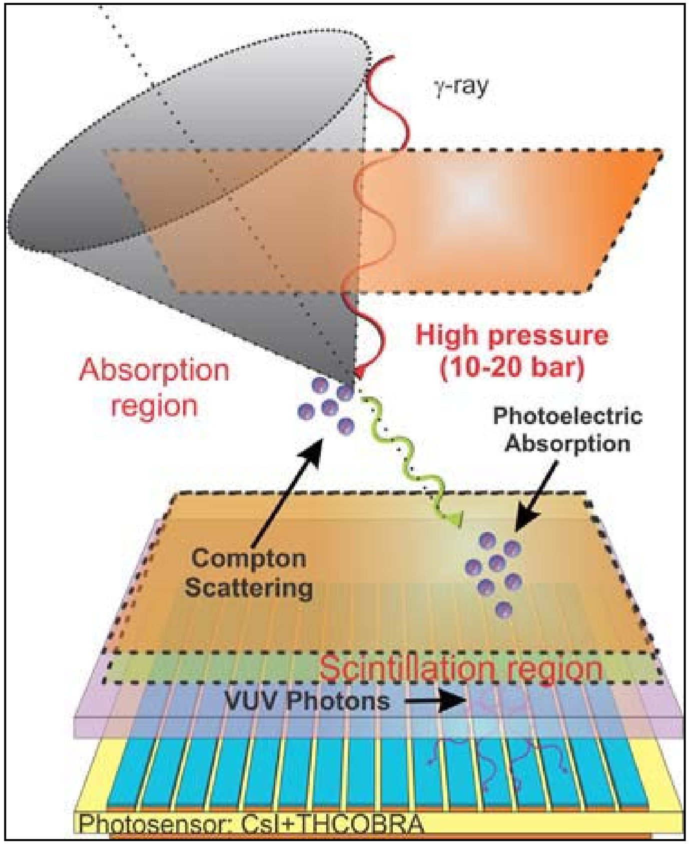


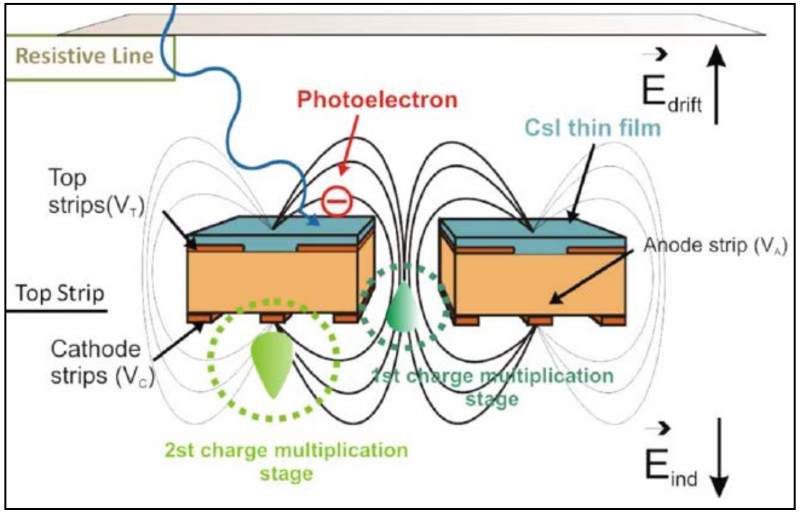
A. Akimov et al., NDIP2011

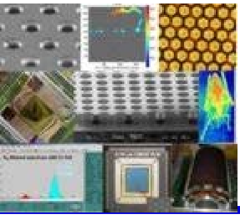


A. Buzulutskov et al., JINST 1(2006) P08006

- **Gaseous Compton camera for medical applications**
  - Electroluminescence light is detected by THCOBRA with 2D R-O
  - Drift time provides the third coordinate







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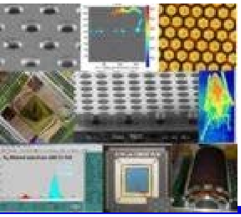
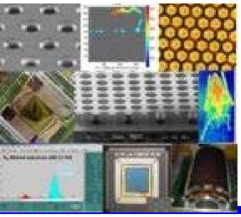


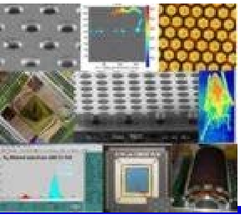
SUMMARY / CONCLUSIONS

- **GASEOUS PHOTON DETECTORS**
  - Still no other approach to instrument large surfaces at affordable costs
- **MPGD-BASED PHOTON DETECTORS**
  - The handle to overcome the limitations of open geometry gaseous PDs
  - R&D in the context of MPGDs: dedicated developments needed for photon detection
  - A wide R&D effort (wider than what I could present) !
- **APPLICATIONS OF MPGD-BASED PHOTON DETECTORS**
  - From PID to ν, DM, medical applications …



THANK YOU

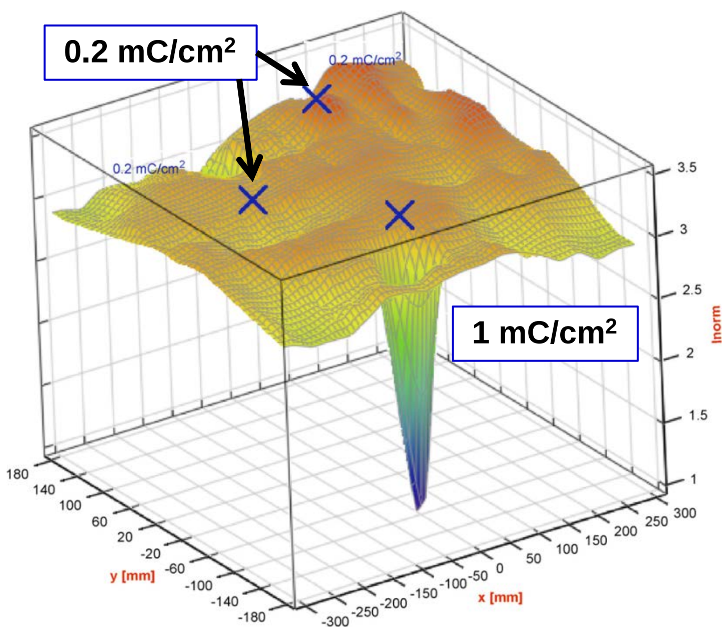
SPARE SLIDES



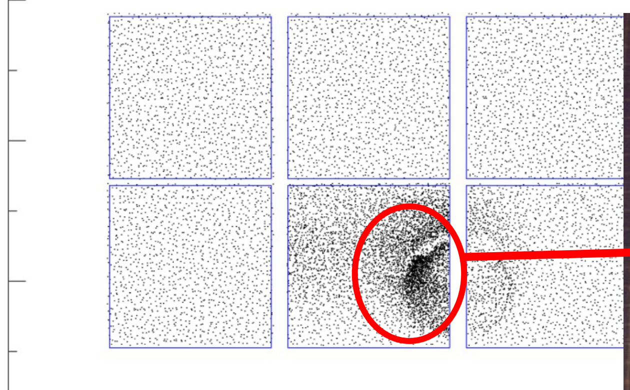
MWPCs with CsI photocathode, the limits

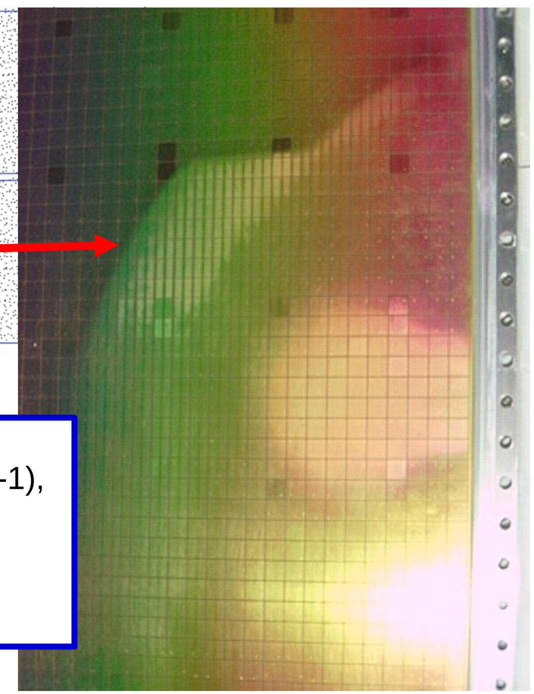
- Severe recovery time (~ 1 d) after detector trips
- Feedback pulses
  - *Ion feedback and photons from the multiplication process*
- Aging after integrating a few mC / cm^2
  - *Ion bombardment of the photocathode*

moderate gain: < 10^5
(effective gain: <1/2)
not particularly fast

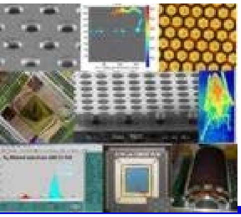


H. Hoedlmoser et al., NIM A 574 (2007) 28.





Proof of the CsI film degradation thanks to an accident (COMPASS RICH-1), chamber contaminated by air: water absorption is largely enhanced where the ion bombardment has been more intense

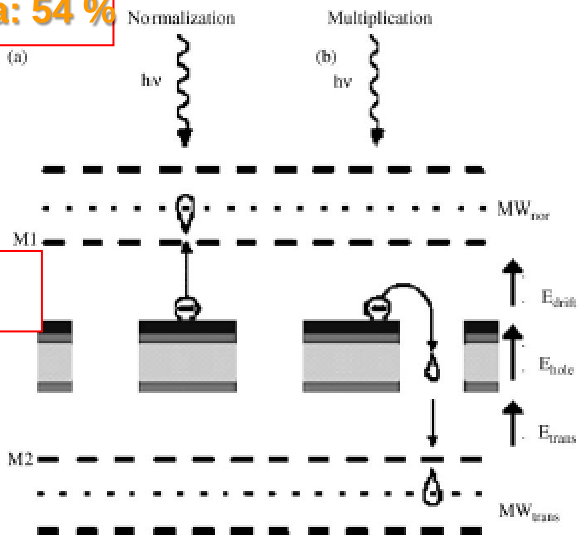


PHOTOELECTRON EXTRACTION

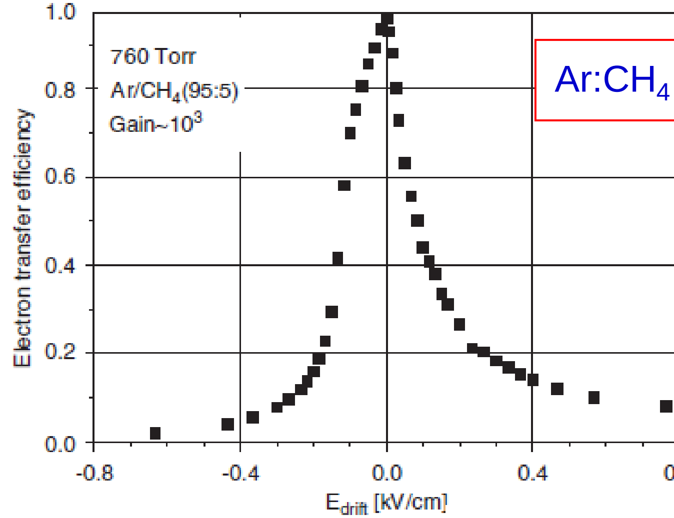
" the ETE includes also the extraction efficiency from the PC into the gas "

Counting mode technique

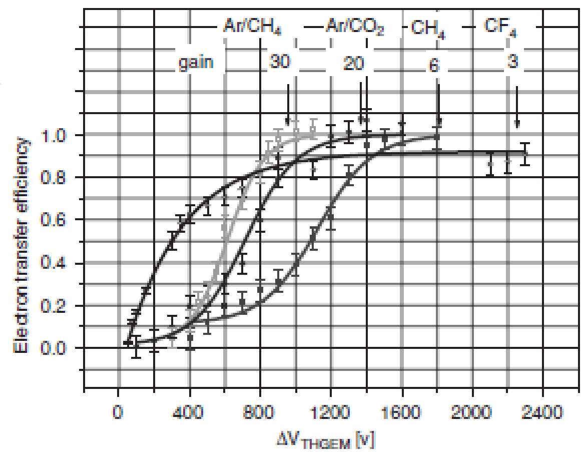
THGEM
Tick 0.4 mm
diam. 0.3 mm
Pitch 0.7 mm
Rim: 0.1 mm
Active area: 54 %

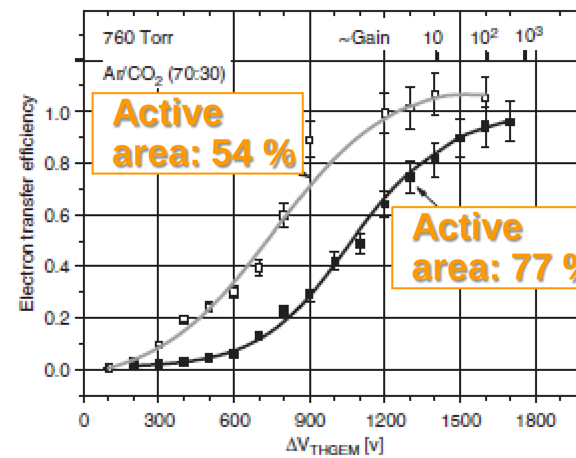


Normaliz.
E=3 kV/cm



$Ar:CH_4$ = 95 : 5





Active area: 54 %

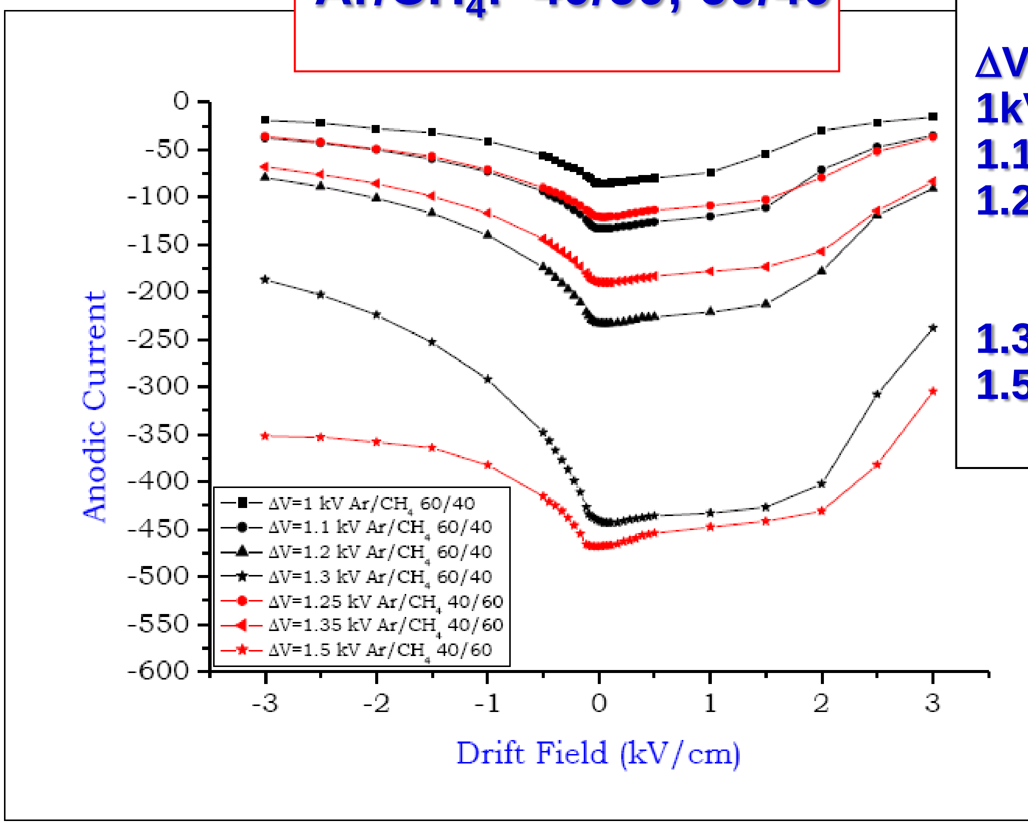
Active area: 77 %

C. Shalem et al., NIMA 558 (2006) 475

PHOTOELECTRON EXTRACTION 5/5

Anodic current in a THGEM detector versus the external electric field applied , a measurement

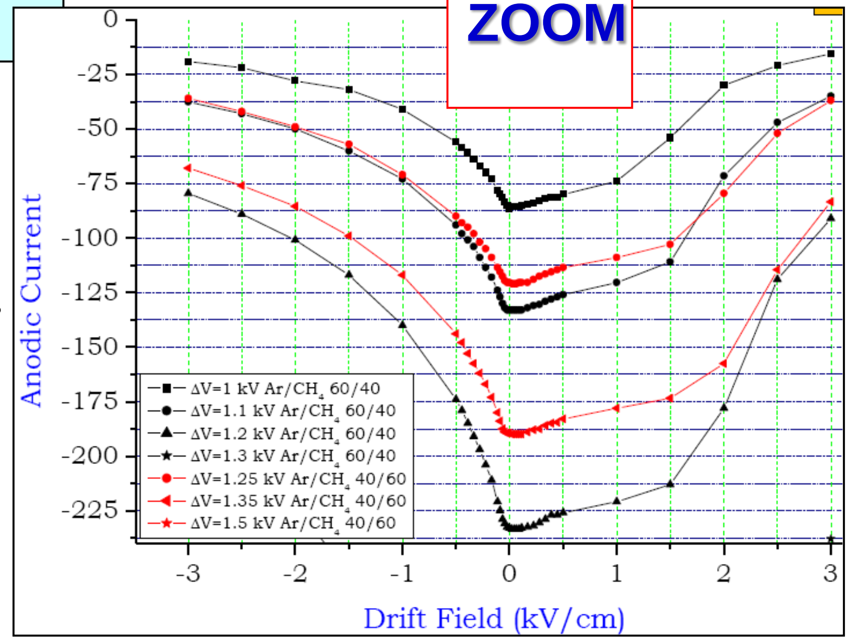
Ar/CH_4: 40/60; 60/40



ΔV = 1kV 1.1, 1.2 1.25, 1.3

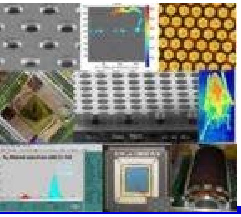
1.35 1.5

ZOOM



The behaviour predicted by the simulation is confirmed!
→A clear suggestion to optimise the detector design

S. Dalla Torre et al., TIPP09 - Tsukuba, Japan 11-17/3/2009



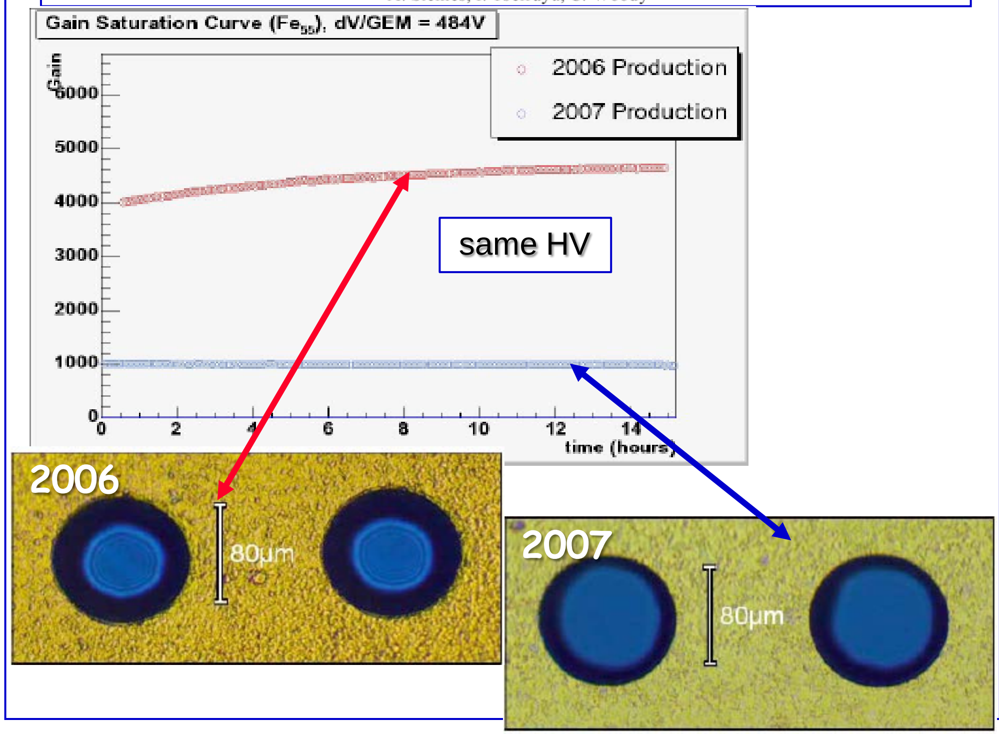
ABOUT THE RIM

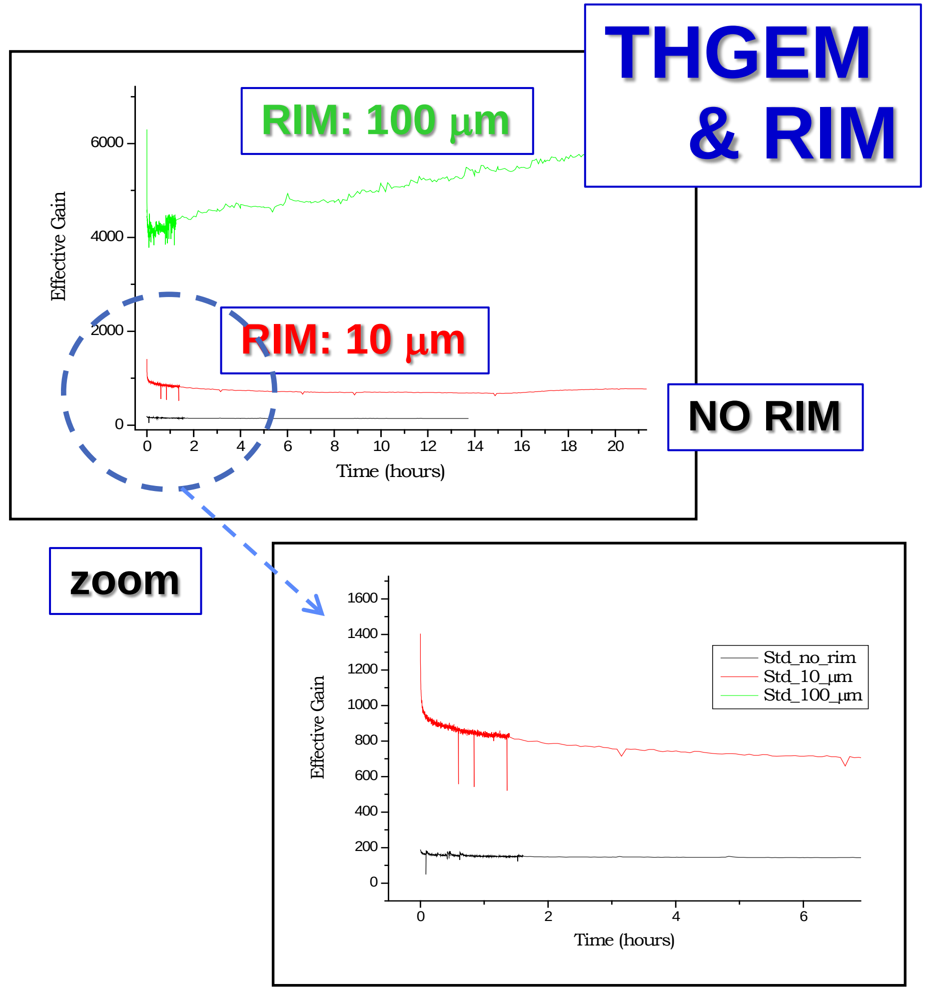
RIM - analogous to the GEM conical hole profile

2007 IEEE Nuclear Science Symposium Conference Record MP5-3

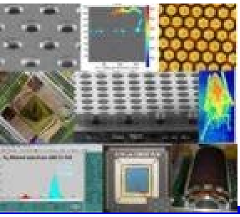
Understanding the gain characteristics of GEMs inside the Hadron Blind Detector in PHENIX.

W. Anderson, B. Azmoun, C.-Y. Chi, Z. Citron, A. Dubey, J. M. Durham, Z. Fraenkel, T.Hemmick, J. Kamin, A. Kozlov, A.Milov, M. Naglis, R. Pisani, I. Ravinovich, T. Sakaguchi , D. Sharma, A. Sickles, I. Tserruya, C. Woody

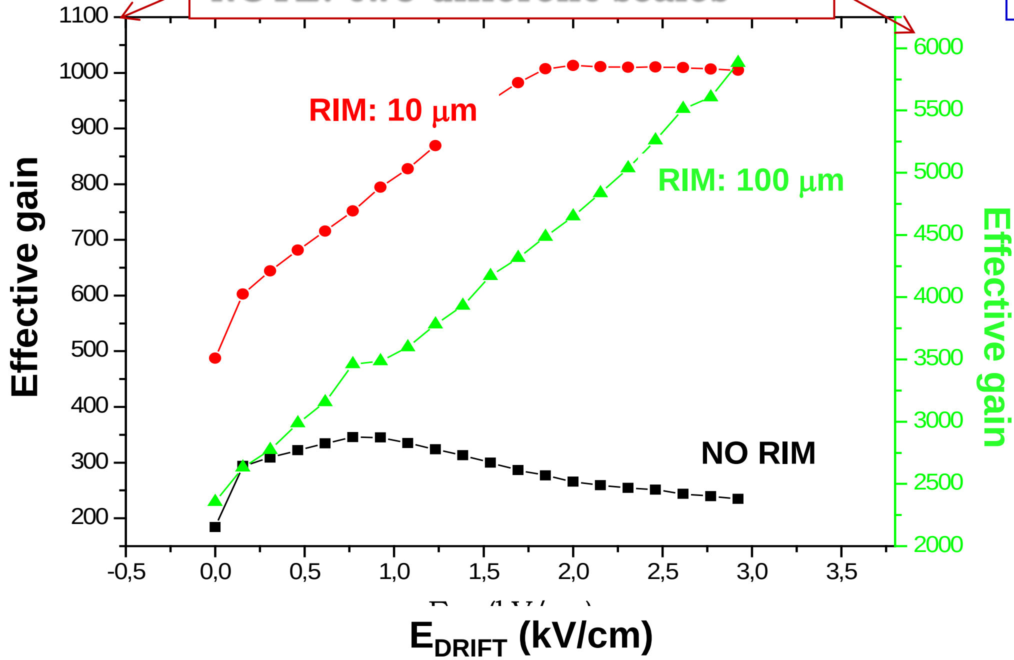




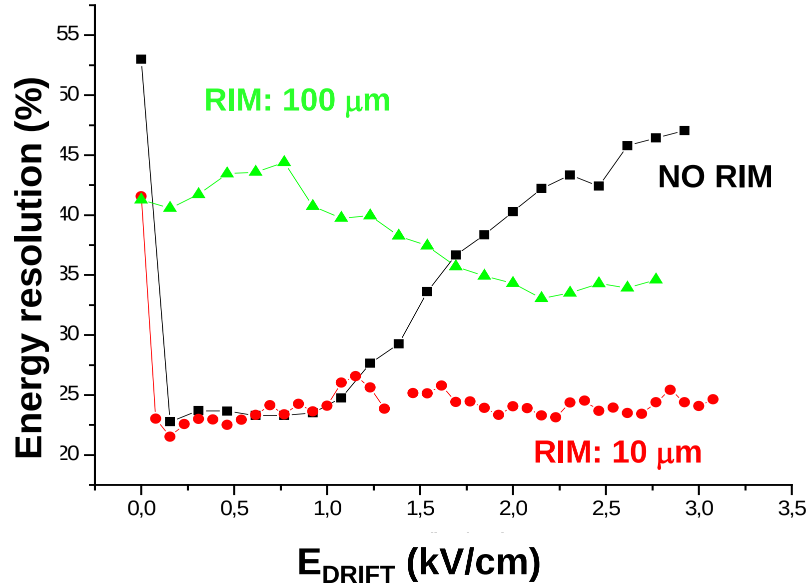
S. Dalla Torre et al.,
IEEE – NSS 2008 , Dresden 19-25/10/2008



MORE ABOUT THE RIM



X-ray measurements



Diam (mm)	Pitch (mm)	Rim (μm)	Thick (mm)
0.3	0.7	0	0.4
0.3	0.7	10	0.4
0.3	0.7	100	0.4

the charge accumulation at the dielectric surface that allows to obtain much larger gains

- **makes it difficult to have complete charge collection**

S. Dalla Torre et al.,
IEEE – NSS 2008 , Dresden 19-25/10/2008