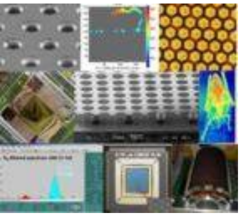


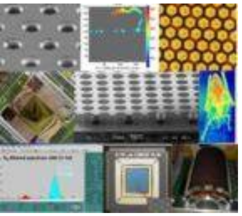
3rd RD51 - Academia-Industry Matching Event "Detecting Photons with MPGDs"

Status of Photon Detection by MPGDs and needs in fundamental research

Fulvio Tessarotto
INFN - Trieste

Review: material mostly from A. Breskin, S. Dalla Torre, J. Va'vra, etc.

far from complete … essential aspects are covered in other talks

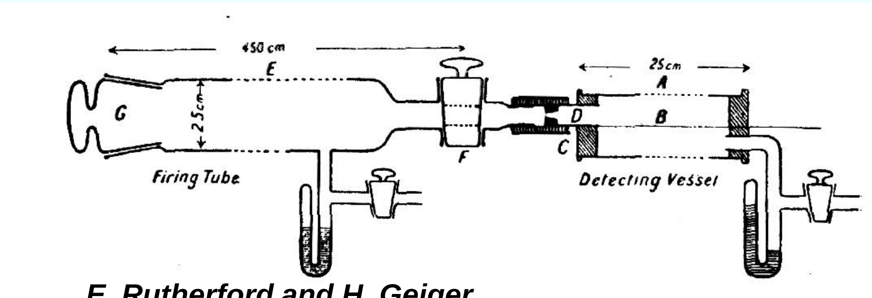


OUTLINE

- Historical overview
- MWPCs with CsI Photocathodes
- GEM-based PDs
- THGEM-based PDs
- Other architectures
- Gaseous detectors for visible light
- Cryogenic applications,
- Conclusions

Glorious tradition: 100 years of gaseous detector developments

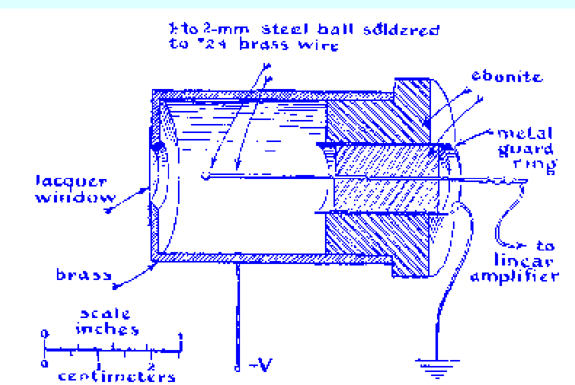
1908: FIRST WIRE COUNTER
USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY



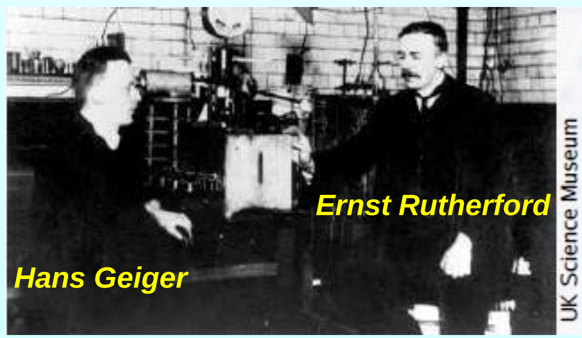
E. Rutherford and H. Geiger ,
Proc. Royal Soc. A81 (1908) 141

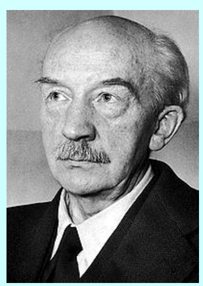
Nobel Prize in Chemistry in 1908

1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY



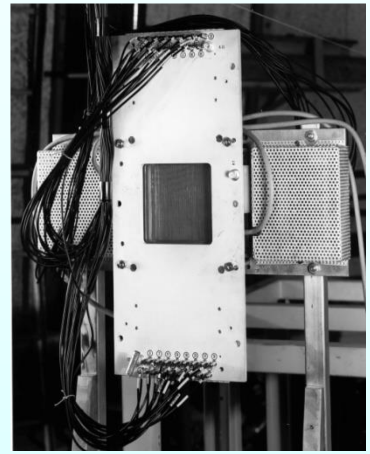
H. Geiger and W. Müller,
Phys. Zeits. 29 (1928) 839

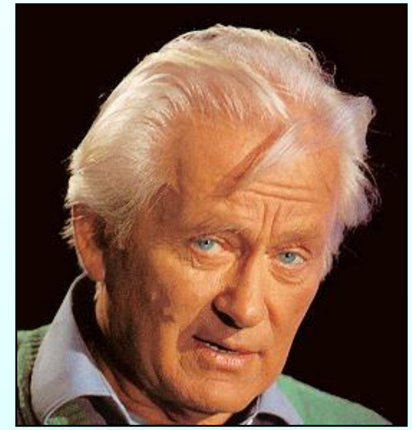




Walther Bothe
Nobel Prize in 1954 for the "coincidence method"

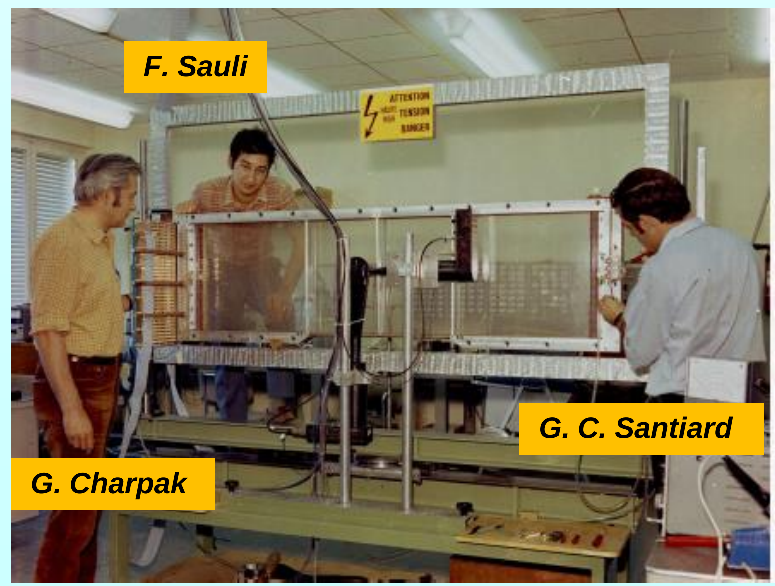
1968: MULTIWIRE PROPORTIONAL CHAMBER





Nobel Prize in 1992

G. Charpak, Proc. Int. Symp. Nuclear Electronics
(Versailles 10-13 Sept 1968)

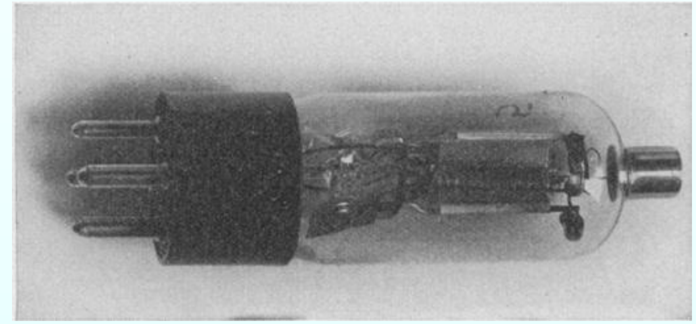


photon detection and Cherenkov light

John Sealy Townsend

Heinrich Rudolf Hertz
photoelectric effect, 1887

A. Einstein, Nobel Prize in 1921



Iams, H. E. and B. Salzberg, "The secondary emission phototube," Proc. IRE **23**, 55 (1935).

Pavel Cherenkov 1904-1990

Ilya Frank ***and***

Igor Tamm

Nobel Prize in 1958

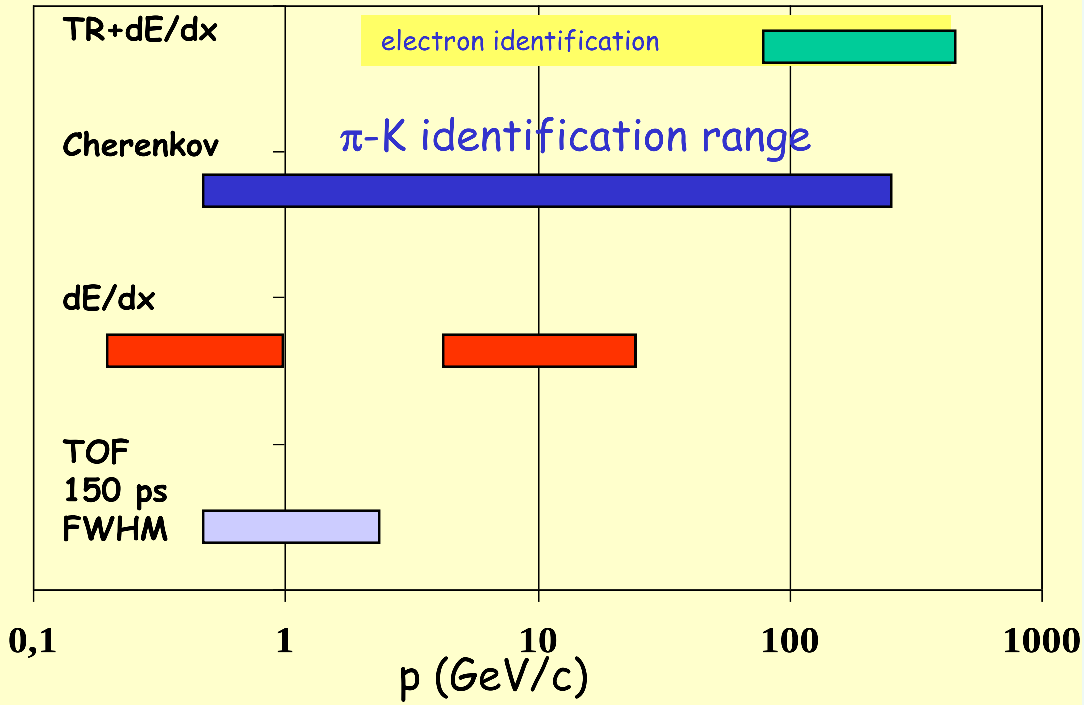
Arthur Roberts 1912-2004

Tom Ypsilantis 1928-2000

Needs in HEP fundamental research

- Driving force: <u>need for π-K identification from HEP Experiments</u>
- Large momentum acceptance → Cherenkov angle measurement technique
- Large angular acceptance → large area of efficient single photon detection

Particle Identification Techniques:



- 1970s: large area position sensitive gaseous detectors available

- Suitable photo-ionizing agent:

  benzene: Seguinot-Ypsilantis NIM 142 (1977) 377,
  TEA (7.6 eV) NIM 173 (1980) 283,
  TMAE (5.3 eV) NIM 178 (1980) 125.

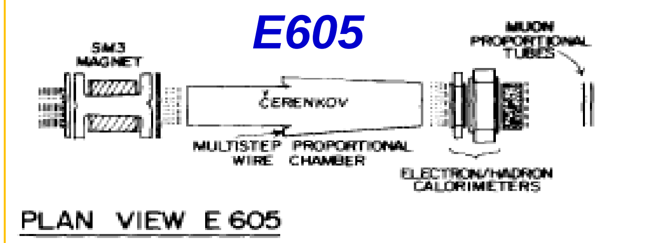
- a gas gain high enough to detect single photoelectrons

→ **conflicting requirements because of the copious UV emission by the multiplication avalanche.**

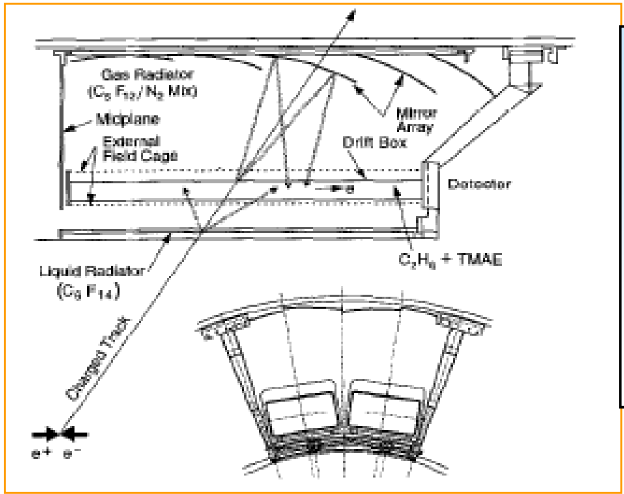
- **solution: multistep avalanche chamber** (Charpak-Sauli Phys. Lett. B 142 (1977) 377) **or TPC**

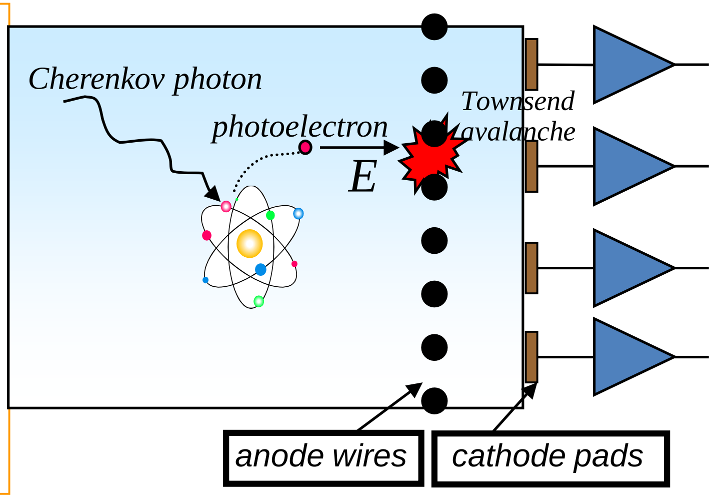
Advantages wrt PMTs: 1) cheap, 2) magnetic insensitive, 3) low material budget

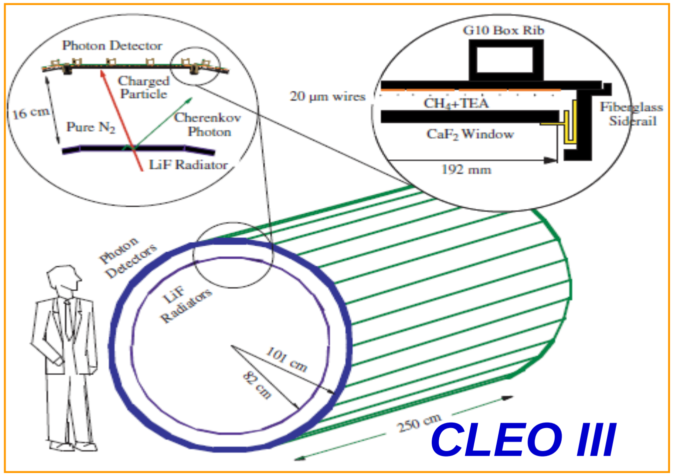
RICH with large area gaseous PD's
1st generation: photoconverting vapours



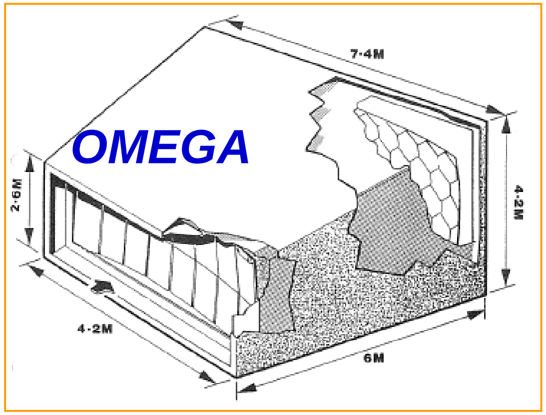
SLD - CRID

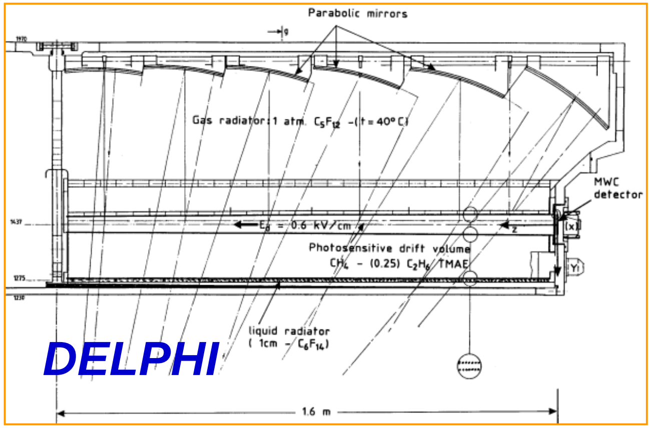


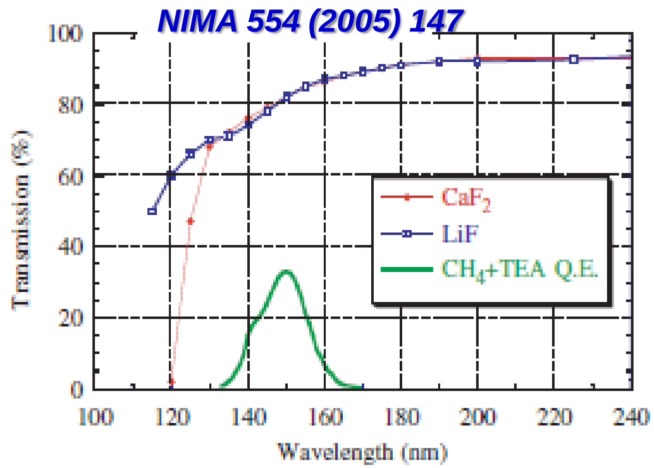




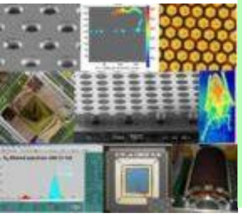
TEA (Tri-Ethyl-Amine)



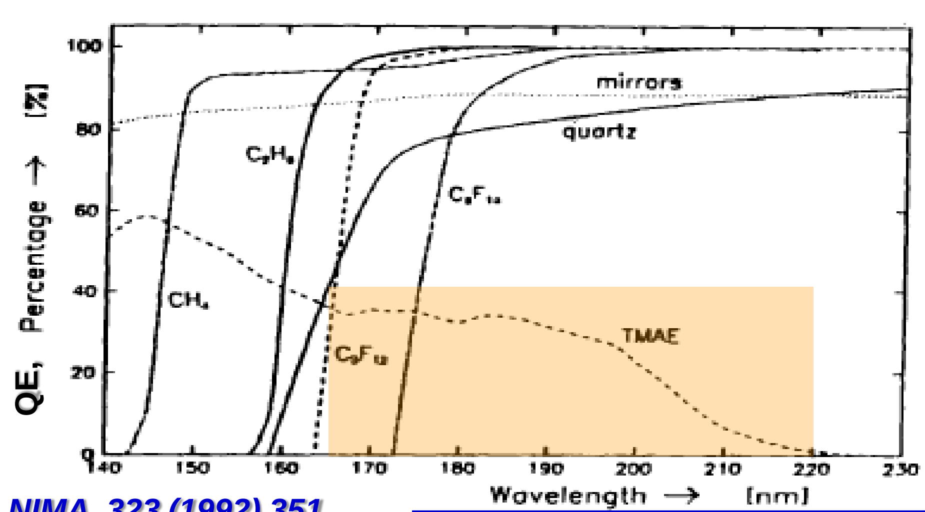




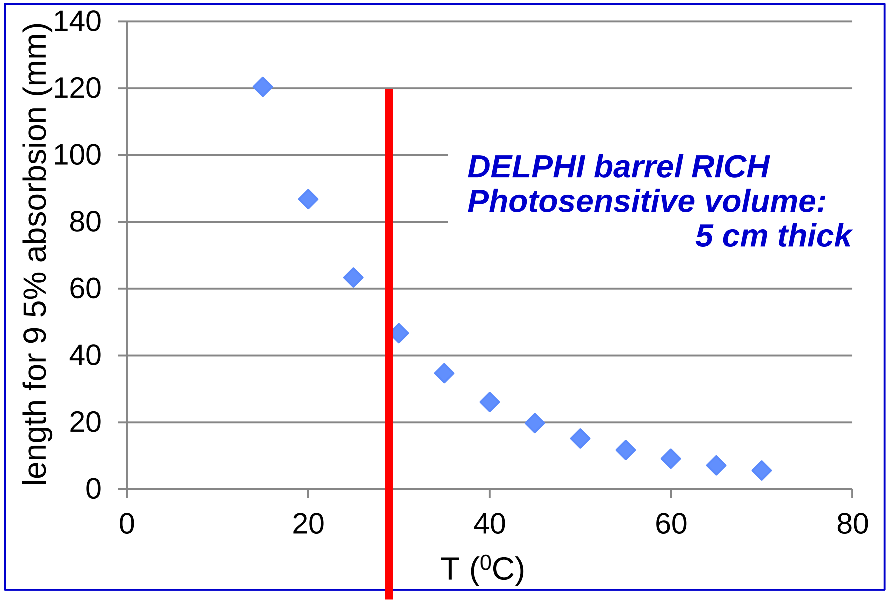
TMAE (Tetrakis-Dimethylamine-Ethylene)

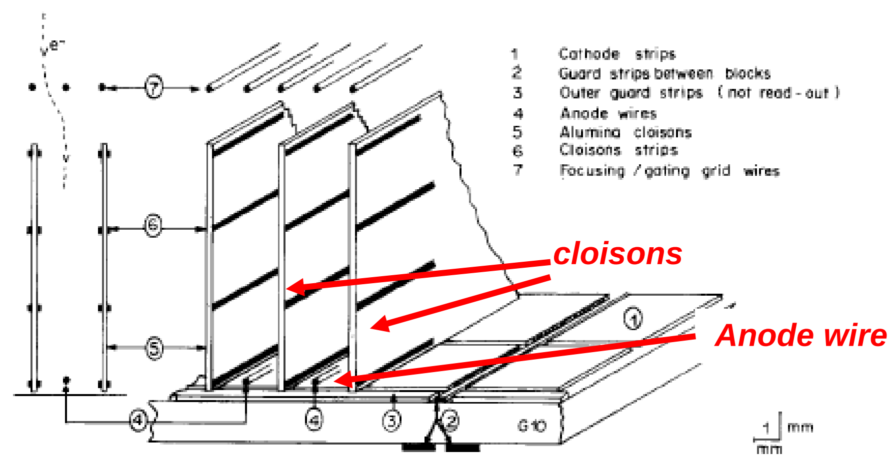


TMAE



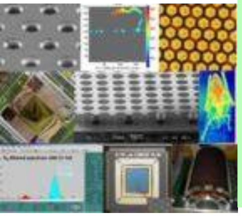
NIMA 323 (1992) 351





DELPHI barrel RICH, NIMA 273 (1988) 247

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



Thin CsI film

1956:
CsI layer has large QE for photons with hν > 6 eV (Philipp and Taft)

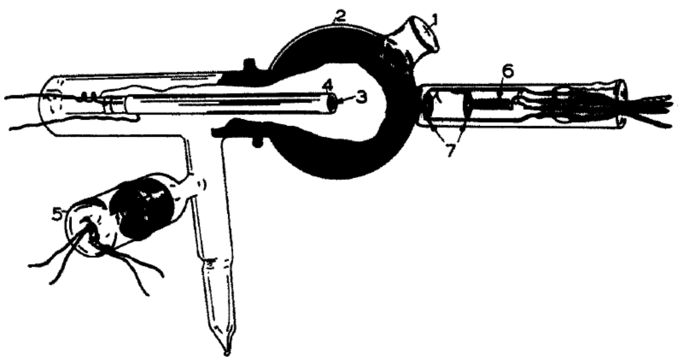


FIG. 1. Cutaway sketch of phototube; (1) 9741 glass bubble window, (2) graphite coated collector sphere 4 inches in diameter, (3) ⅜ inch glass tube, platinum painted, (4) nickel sleeve insulated from tube by glass beads, (5) ion gauge, (6) evaporating cylinder and helical platinum heater, (7) collimating shields.

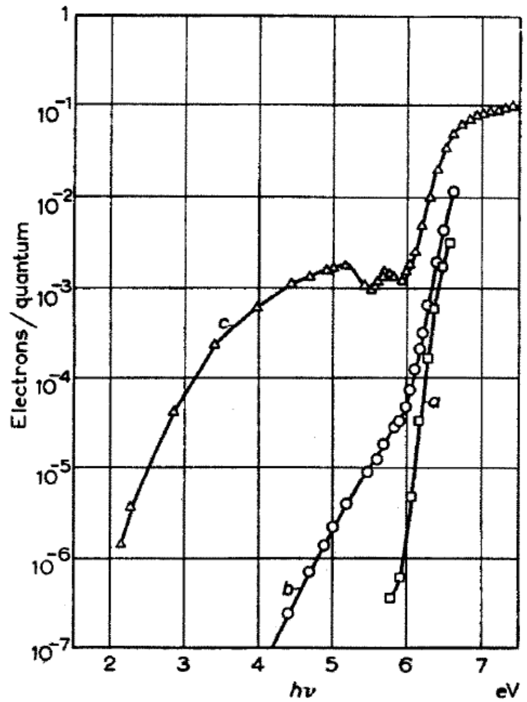


FIG. 2. Spectral distribution of the photoelectric yield for CsI surfaces: (a) thick film, (b) single crystal, (c) thin film evaporated in presence of excess Cs.

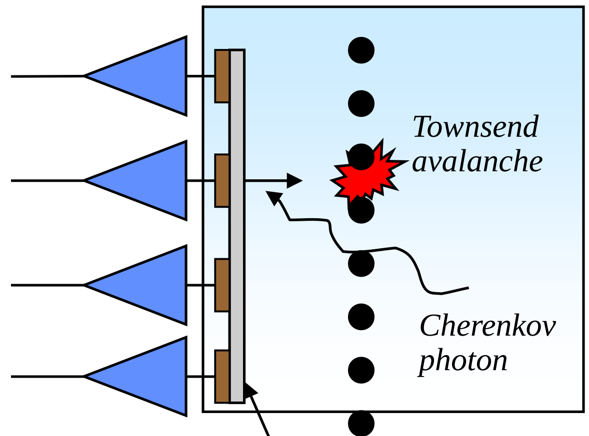
J. Phys. Chem. Solids. Pergamon Press 1956. Vol. 1. pp. 159–163.

PHOTOELECTRIC EMISSION FROM THE VALENCE BAND OF CESIUM IODIDE

H. R. PHILIPP AND E. A. TAFT

General Electric Research Laboratory, Box 1088, Schenectady, New York

CsI is highly reactive with water and oxygen: it took many years to develop appropriate substrate preparation, deposition method, handling technology for high QE gaseous PDs



thin layer (300 - 500 nm) of CsI on a cathode pad plane

RD26: the technology of MWPCs + CsI

1992, F. Piuz et al. Development of large area advanced fast-RICH detector for particle identification at LHC operated with heavy ions

TO ACHIEVE HIGH CsI QE:

Substrate preparation:

Cu clad PCB coated by Ni (7 µm) and Au(0.5 µm), surface cleaning in ultrasonic bath, outgassing at 60 ºC for 1 day

Slow deposition of 300 nm CsI film:

1 nm/s (by thermal evaporation or e⁻-gun) at a vacuum of ~ 10^{-7} mbar, monitoring of residual gas composition

Thermal treatment:

after deposition at 60 ºC for 8 h

Careful Handling:

measurement of PC response, encapsulation under dry Ar, mounting by glove-box.

The best fused silica cuts here

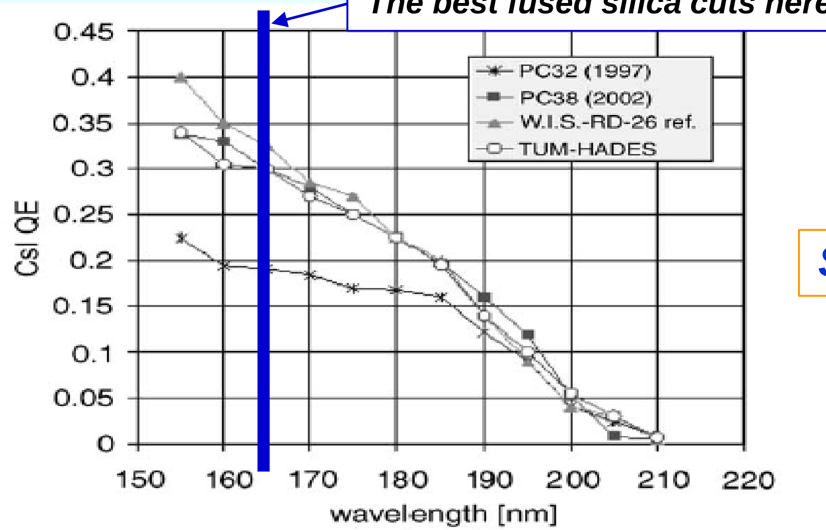
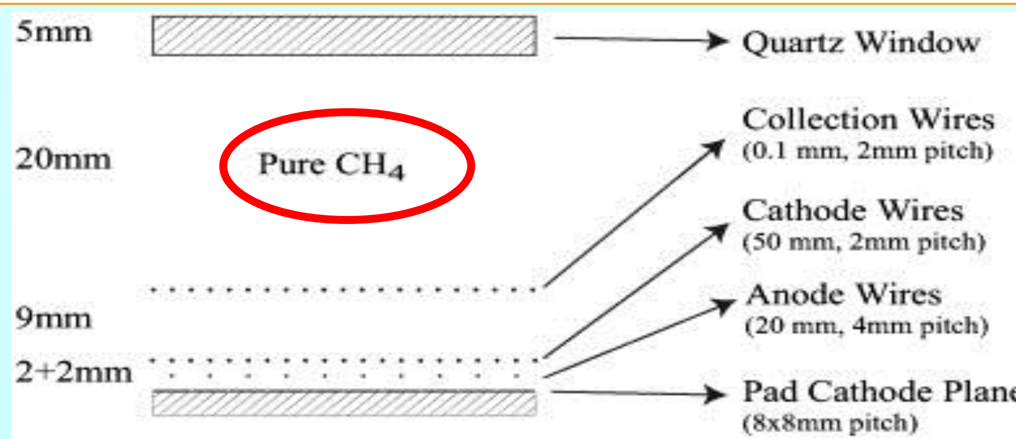
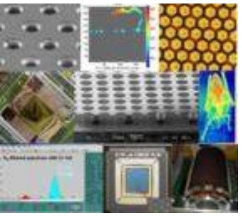


Fig. 1. The QE of CsI PCs produced at CERN for ALICE and at TUM for HADES, compared to that measured at the W.I.S. on small samples (reference for RD-26). PC32 is one of the four PCs equipping the ALICE-RICH prototype used in STAR at BNL.

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

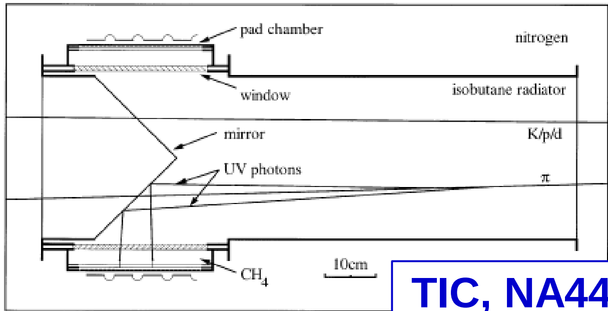
Schematic structure of the COMPASS Photon Detector:



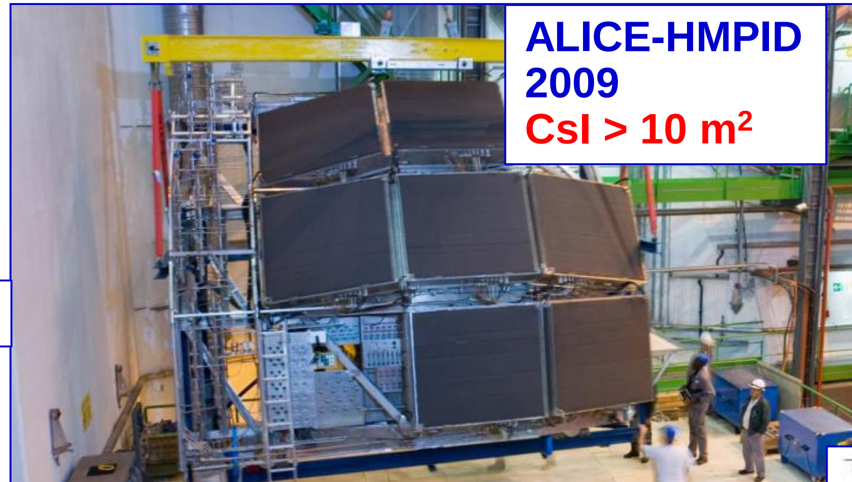


RICH with large area gaseous PD's
2nd generation: MWPC's + CsI

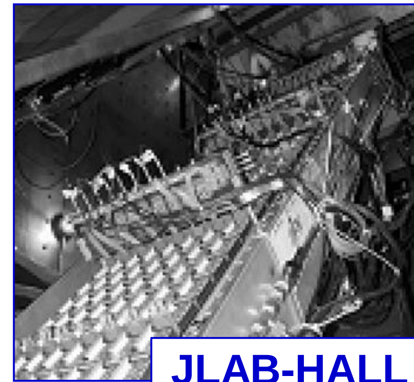
- **MWPCs with solid state photocathode (the RD26 effort)**



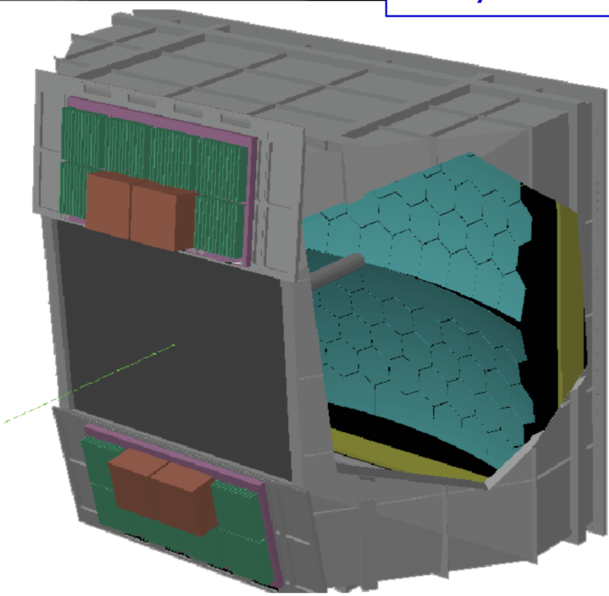
TIC, NA44



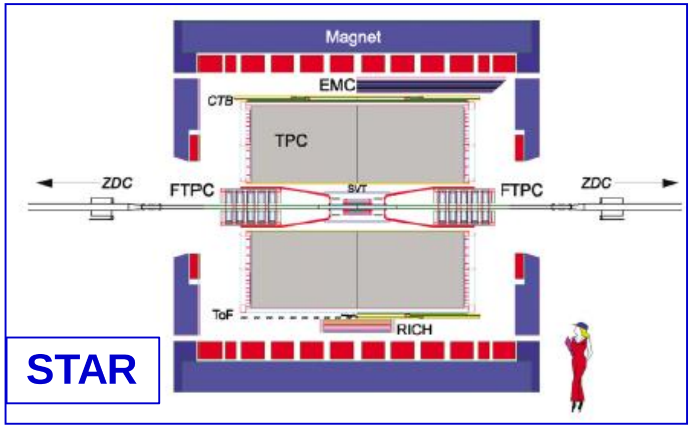
ALICE-HMPID 2009
CsI > 10 m²



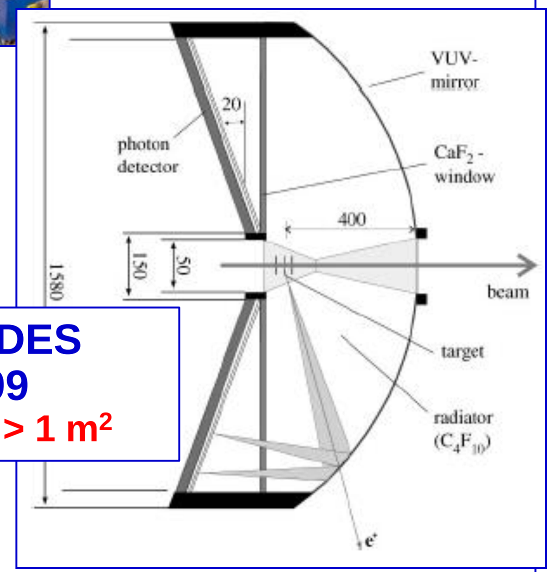
JLAB-HALL A



COMPASS RICH-1 2002
CsI > 5 m²



STAR



HADES 1999
CsI > 1 m²

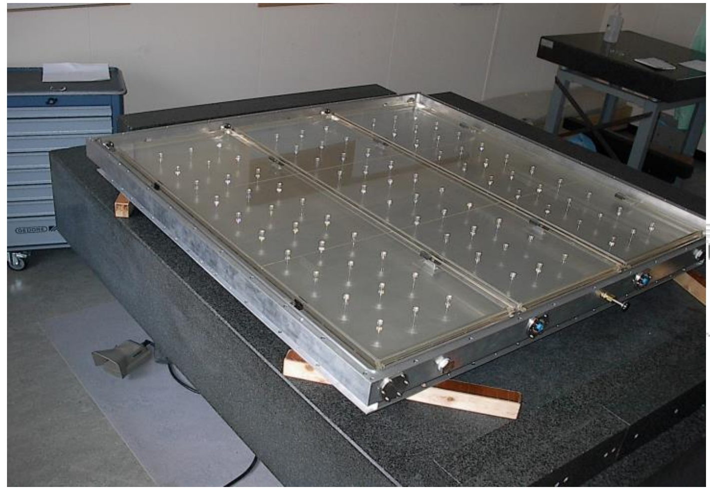
ALICE HMPID

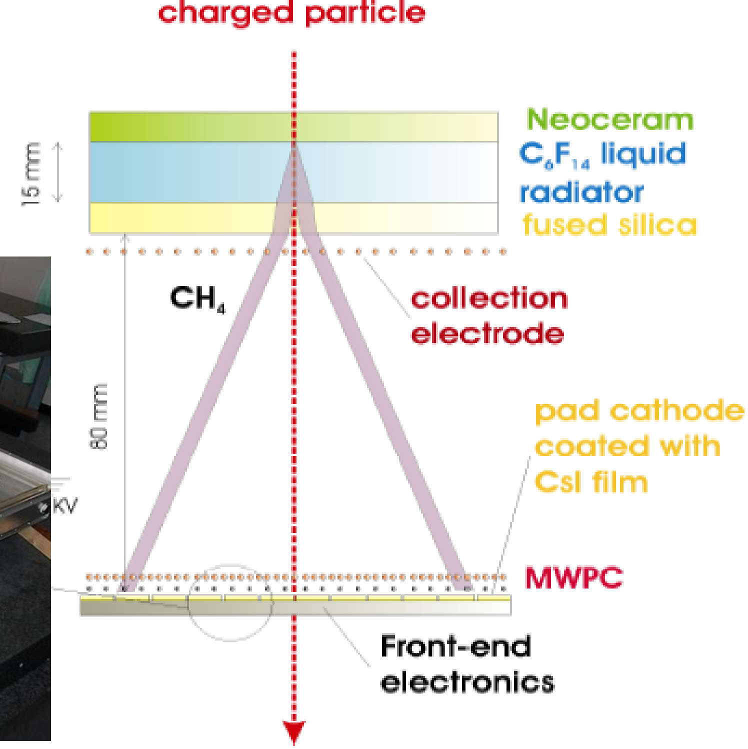
RADIATOR: 15 mm liquid C_6F_{14},
n ~ 1.2989 @ 175nm, β_{th} = 0.77

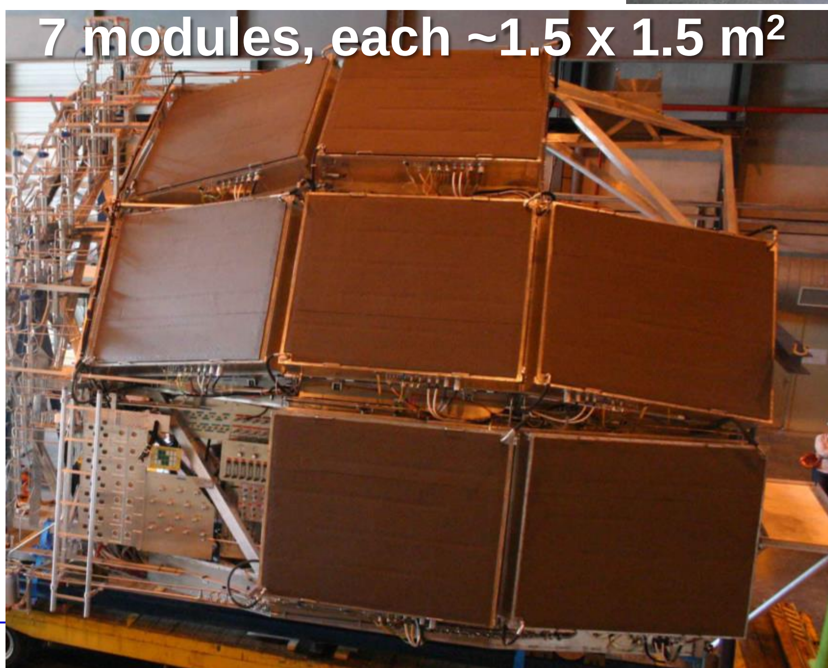
PHOTON CONVERTER: Reflective layer of CsI (QE ~ 25% @ 175 nm)

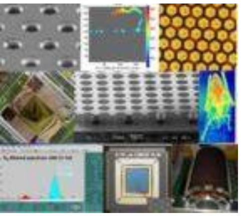
PHOTOELECTRON DETECTOR:
MWPC with CH_4 at atmospheric pressure (4 mm gap) **HV = 2050 V**.

- Analogue pad readout

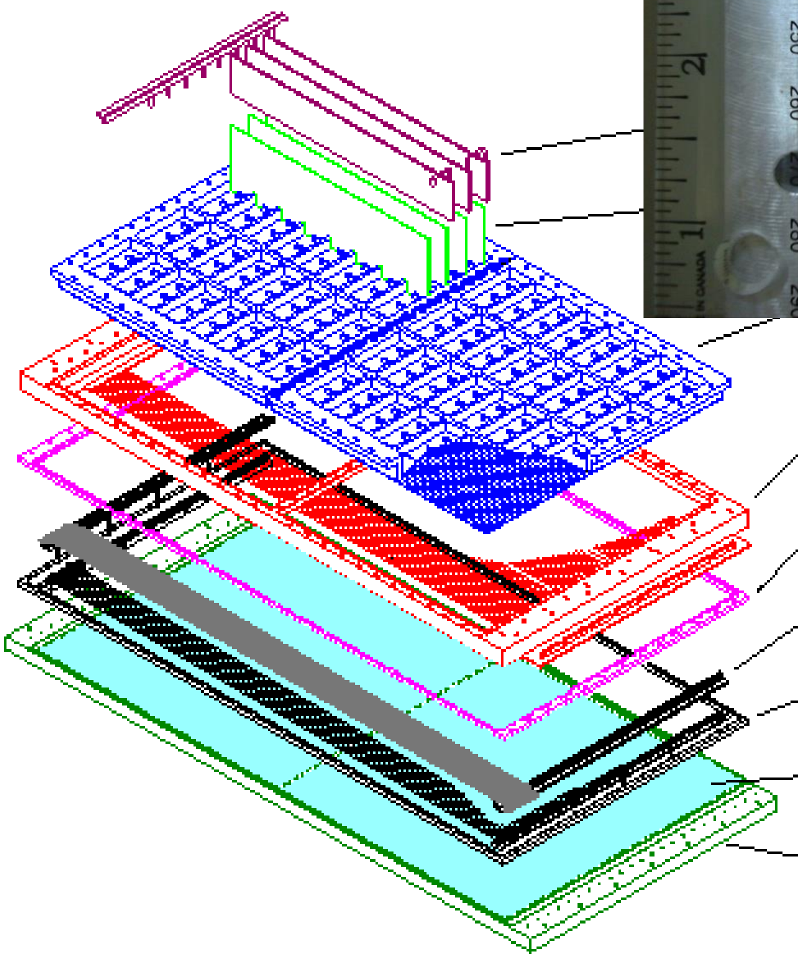


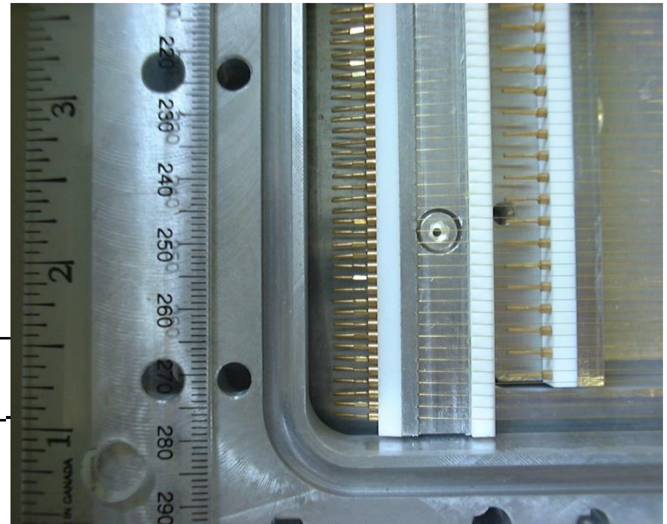


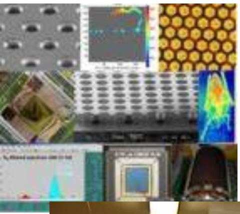




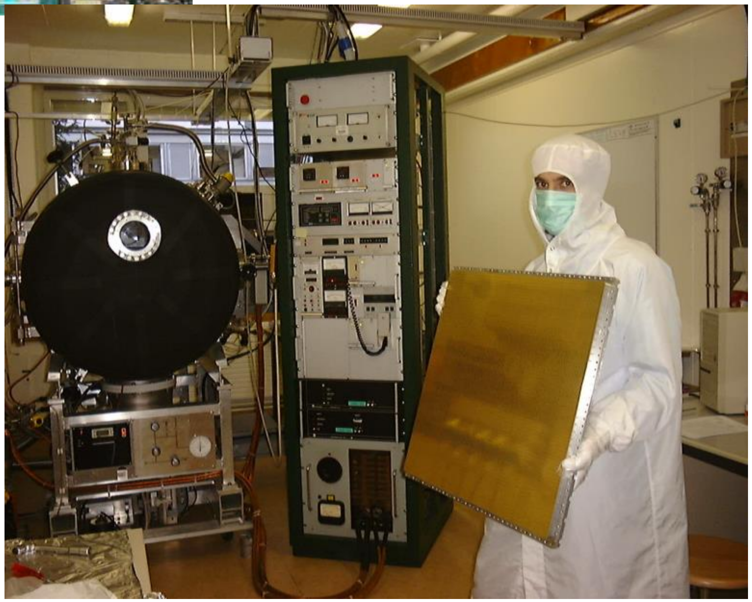
COMPASS RICH-1 MWPC's with CsI

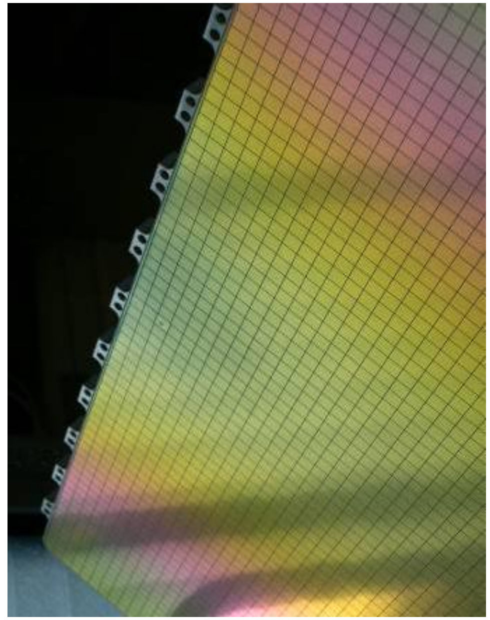


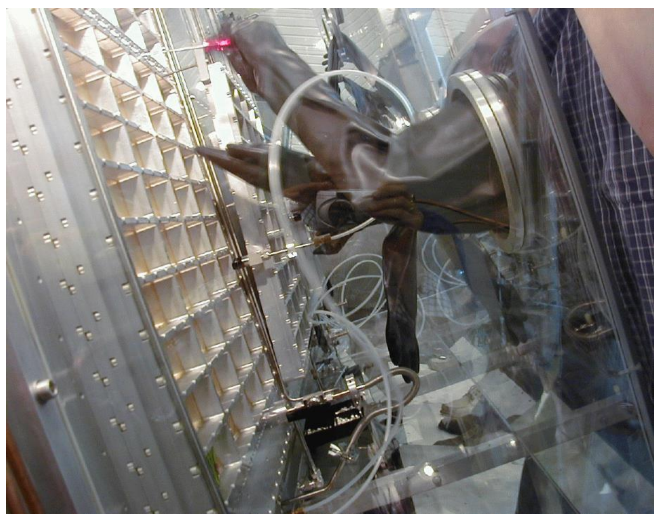


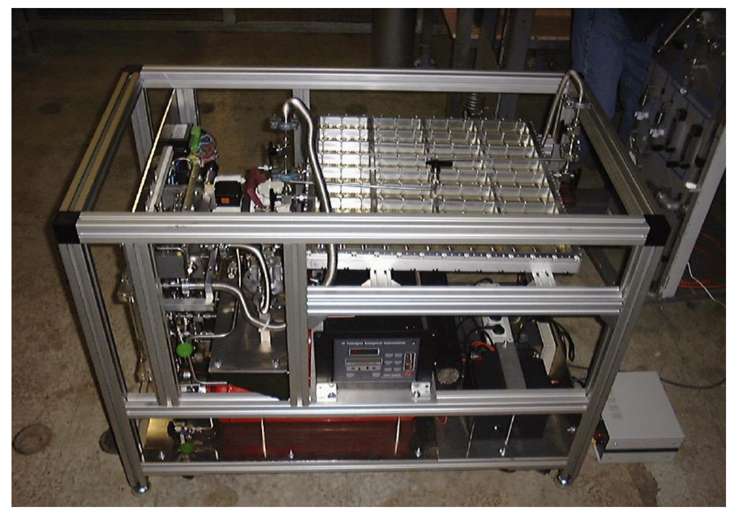


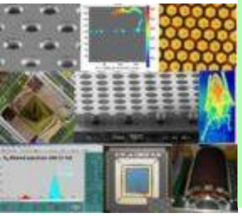
photocathodes





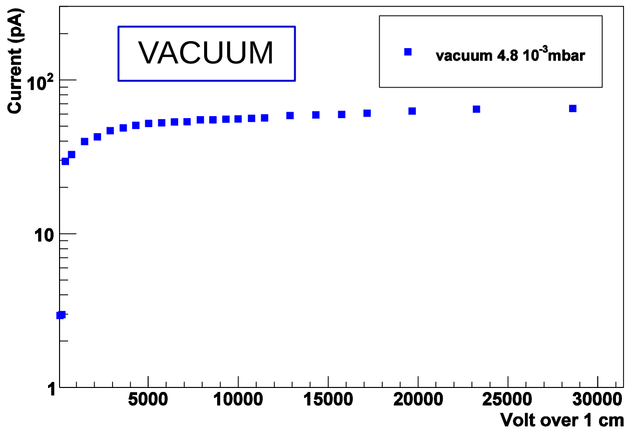


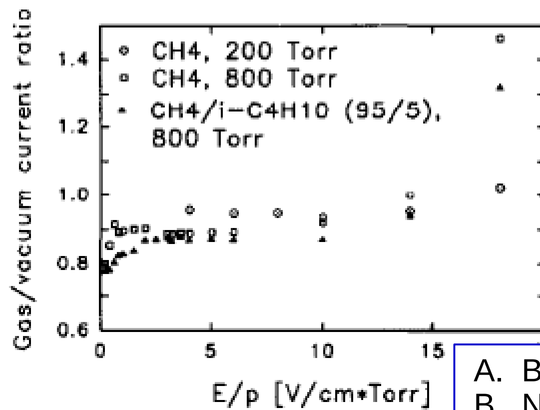




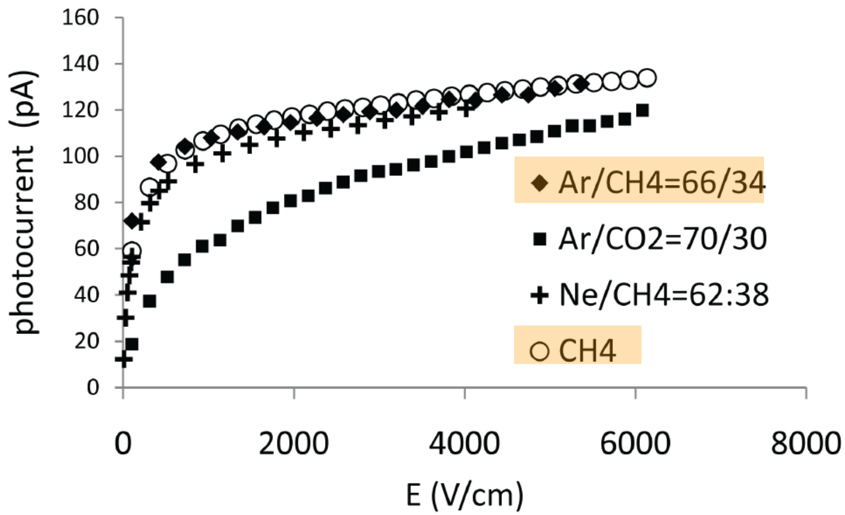
PHOTOELECTRON EXTRACTION

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

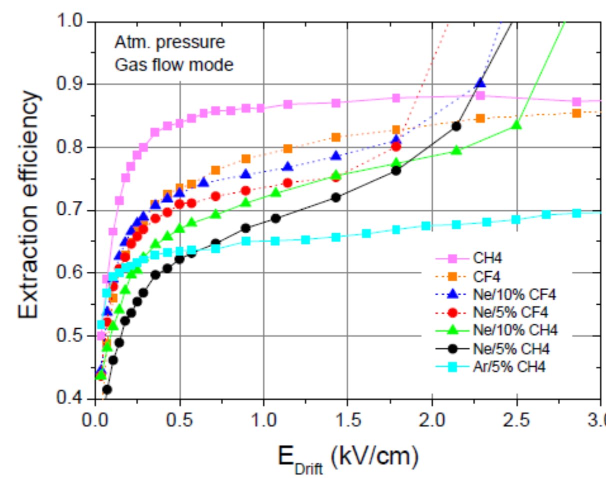




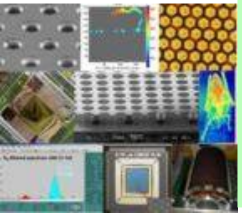
A. Breskin et al.,
B. NIM A 367 (1995) 342



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



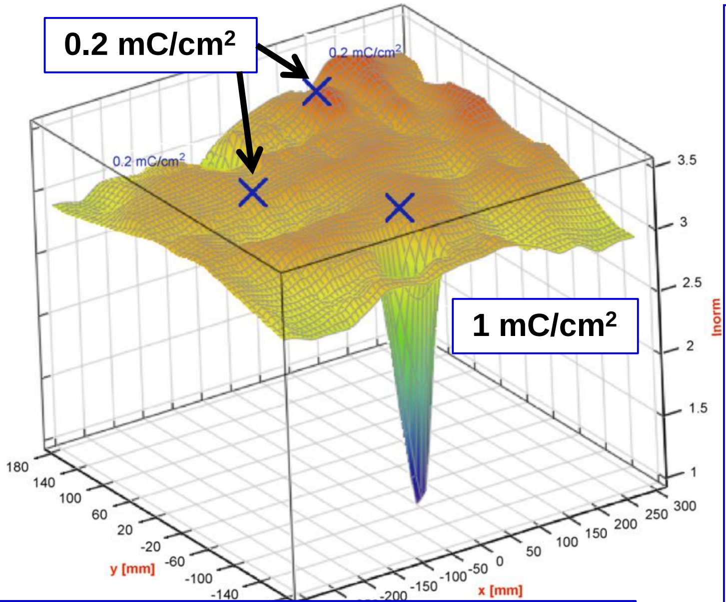
C. D. R. Azevedo et al., 2010 *JINST* 5 P01002



MWPCs with CsI: 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 / cm²
  - *Ion bombardment of the photocathode*

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



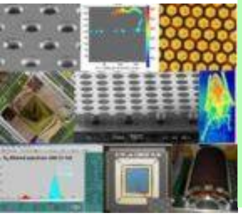
H. Hoedlmoser et al., NIM A 574 (2007) 28.

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*

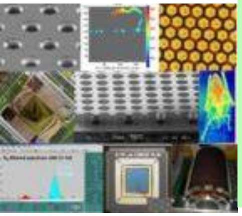
→ Detector memory, i.e. not adequate for high rates



WHY MPGD-BASED PDs

- 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**



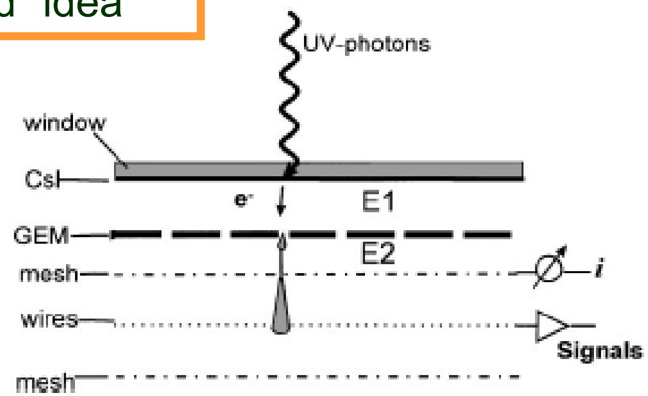
ION & PHOTON BLOCKING GEOMETRIES

First developments …

GEM-based PDs

NO photon feedback
Reduced ion feedback

An "old" idea

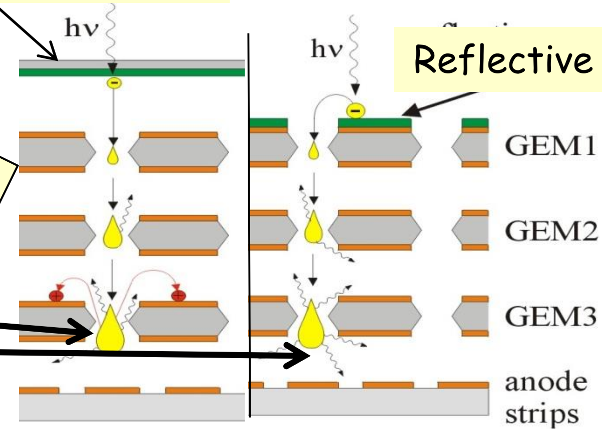


R. Chechik et al., NIM A 419 (1998) 423

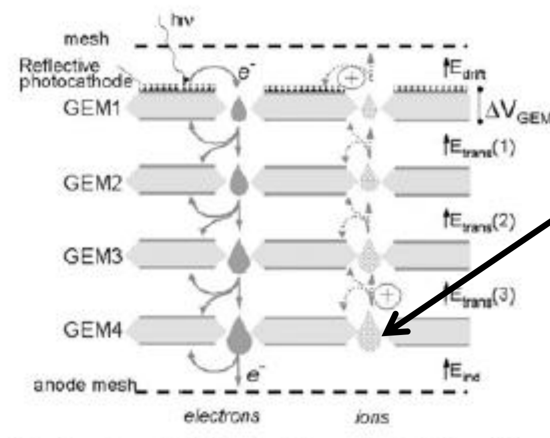
Semi-transparent PC

Reflective PC

e⁻ avalanche



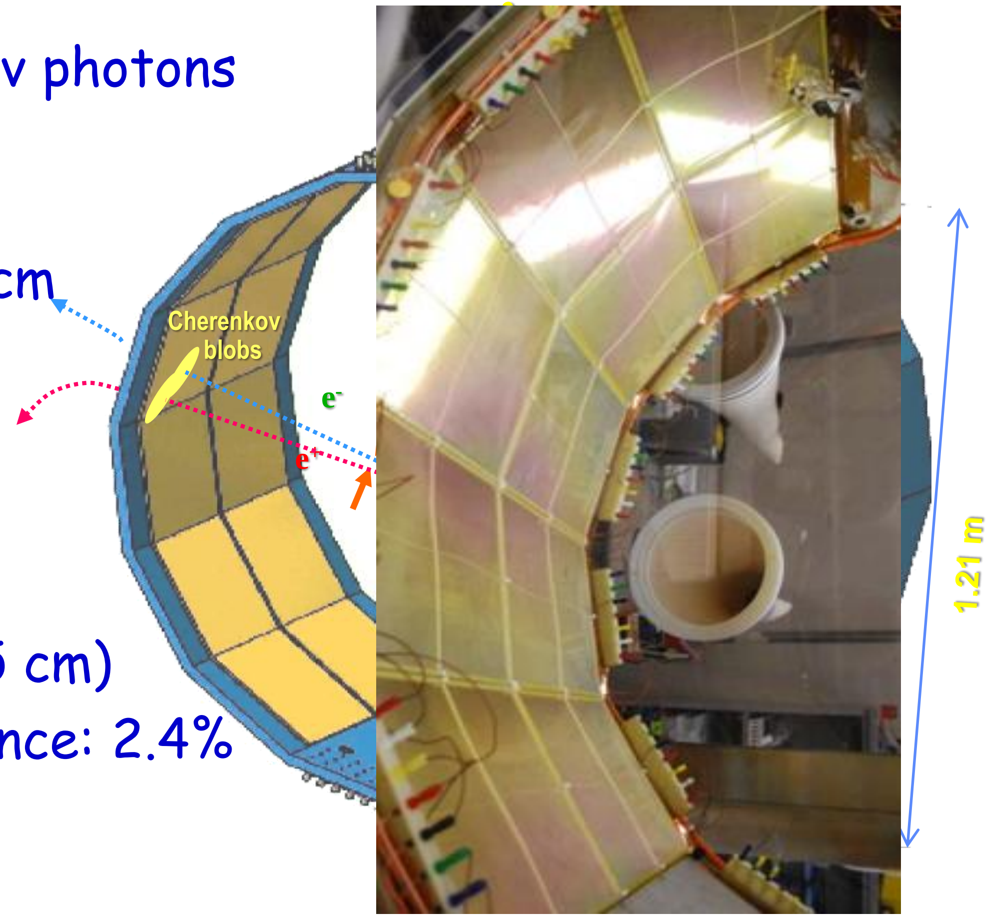
ion avalanche



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

HBD- Cherenkov detector with GEMs +CsI

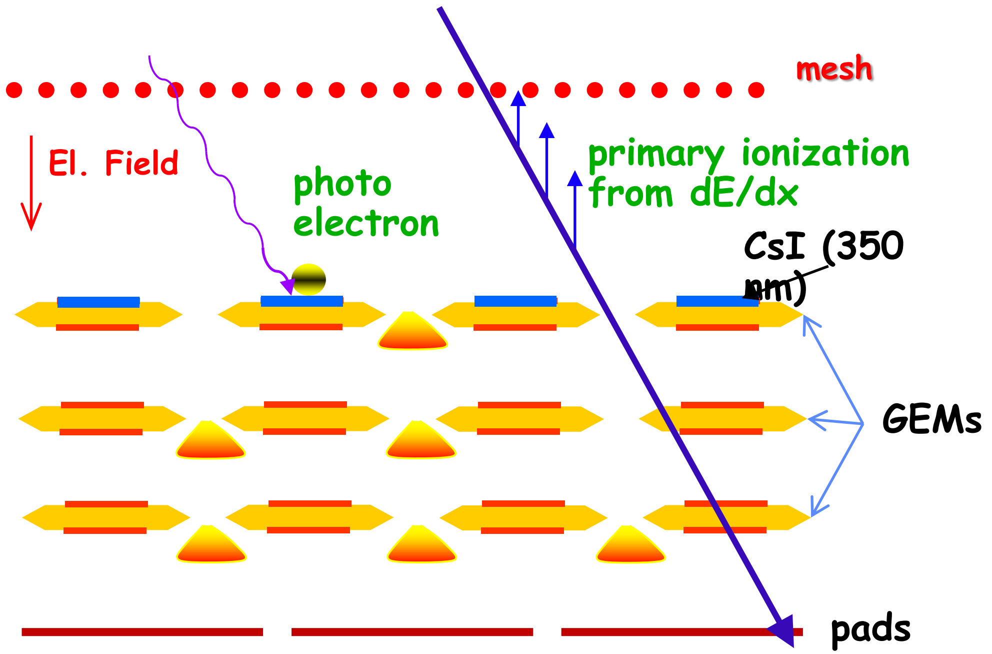
- ✓ The PHENIX HBD detects Cherenkov photons
- ✓ Proximity focus configuration
  no window, no mirror
- ✓ CF_4 radiator and active gas. L_{rad}=50 cm
- ✓ Very large bandwidth 108 - 200 nm
  (6.2 - 11.5 eV)
- ✓ triple GEMs for signal multiplication
- ✓ CsI photocathode
- ✓ hexagonal pad readout (pad side 1.55 cm)
- ✓ total radiation length within acceptance: 2.4%

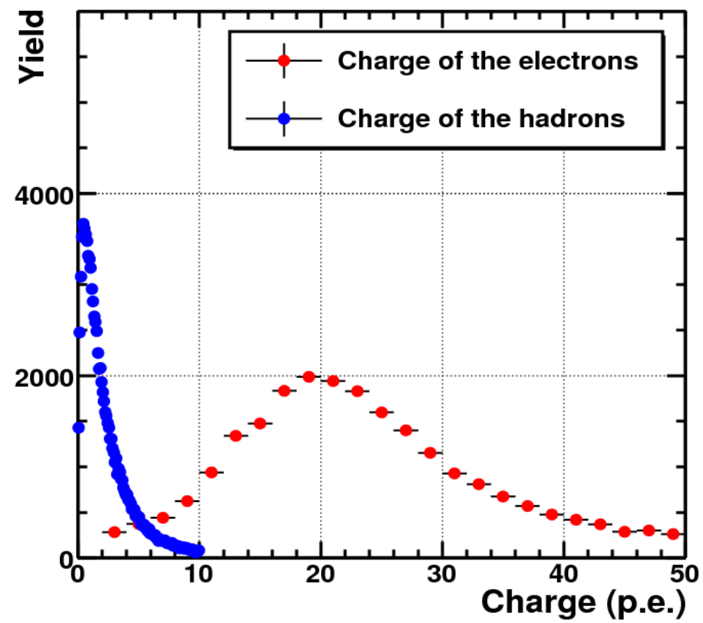


W. Anderson et al., NIM A 646 (2011) 35

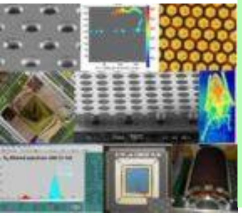
HBD – hadron blindness

❖ Electron signals are relatively rare (compared to hadrons)





a. Detector operated in reverse bias mode to repel the ionization charge from dE/dx
b. Cherenkov light is formed only by e^+ or e^-
c. Successfull operation at PHENIX since seversl years
d. <u>It is not a detector of single photons</u>



GEM-based PDs and IBF

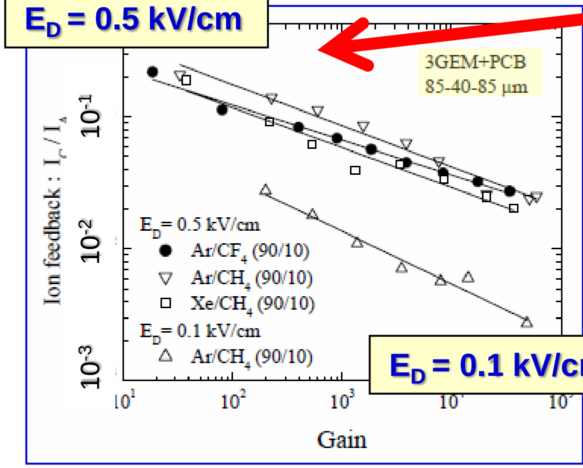
rich literature about IFB in GEM-based detectors

here examples with semi-transparent PC

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

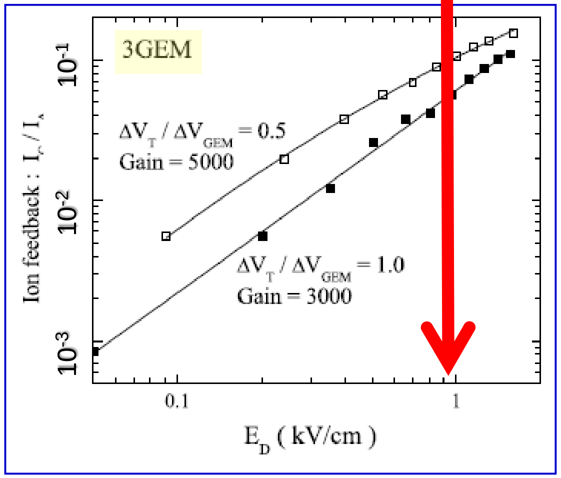
E ~ 1 kV/cm needed for good photoelectron extraction

E_D = 0.5 kV/cm

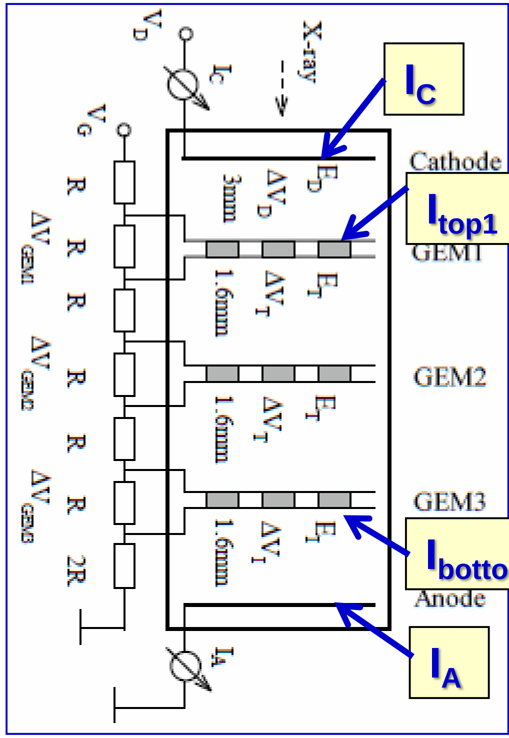


E_D = 0.1 kV/cm

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

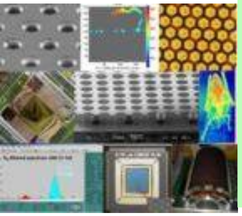


A. Breskin et al., NIMA 478 (2002) 225d



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

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

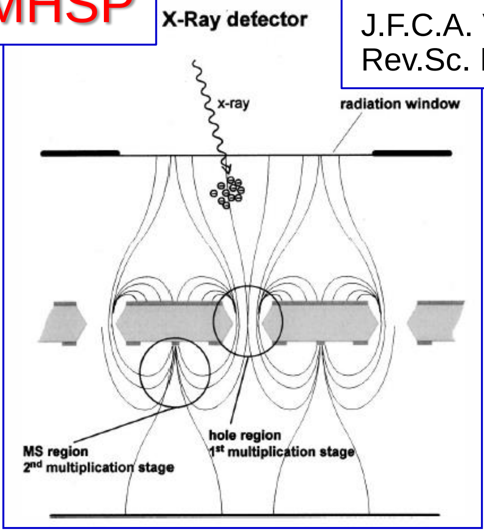


OVERCOMING IBF

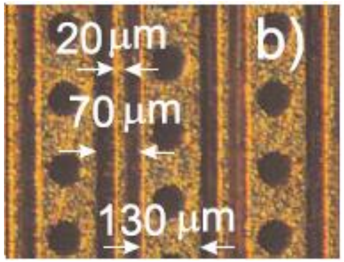
More complex geometries needed with extra electrodes to trap the ions:

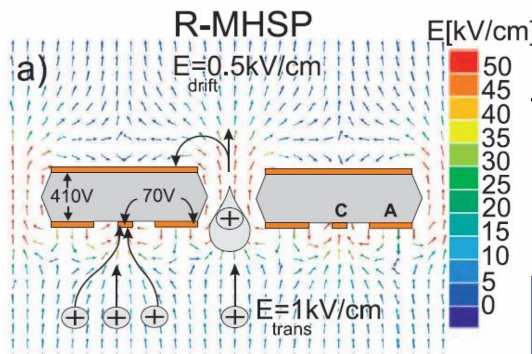
Micro-Hole & Strip Plate (MHSP), COBRA

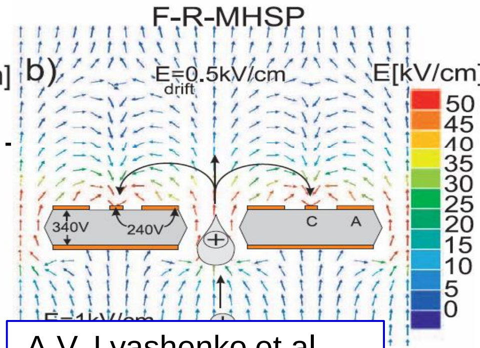
MHSP



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

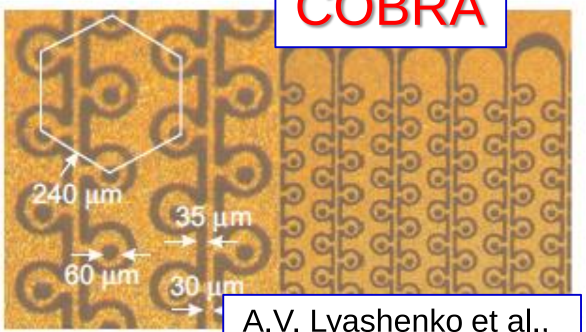




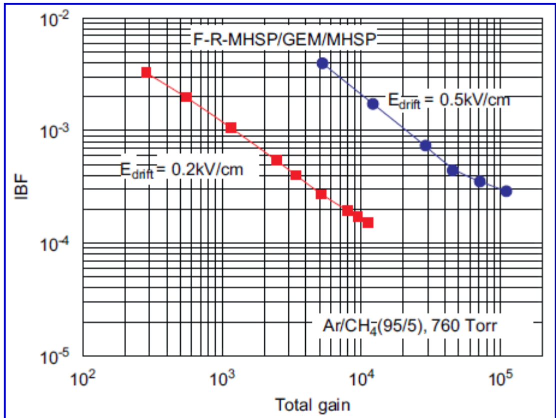


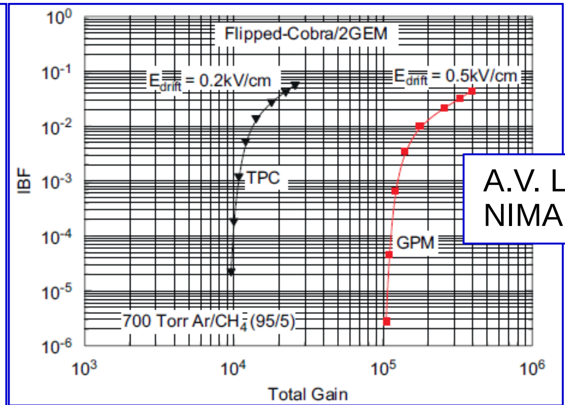
A.V. Lyashenko et al.,
JINST 2 (2007) P08004

COBRA

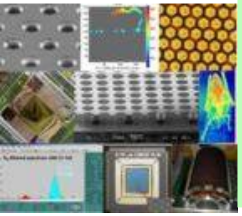


A.V. Lyashenko et al.,
NIMA 598 (2009) 116





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



GEM-based PDs and GAIN

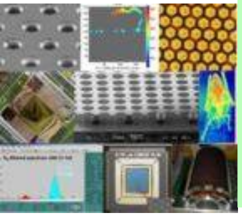
LARGE GAIN RELEVANT FOR SINGLE PHOTON DETECTION

- 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



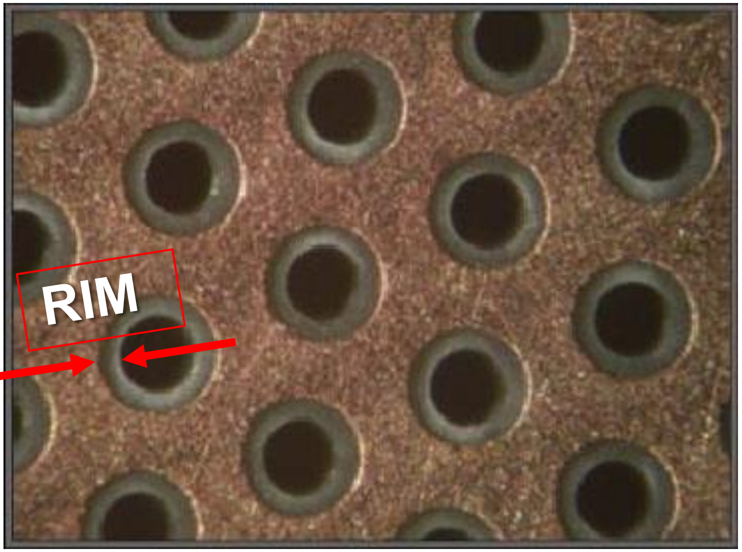
THGEM-based PDs, why ?

PCB technology, thus:

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

About PCB geometrical dimensions:

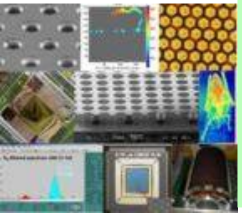
Hole diameter :	0.2 - 1 mm
Pitch :	0.5 - 5 mm
Thickness :	0.2 - 3 mm



Comparing to GEMs

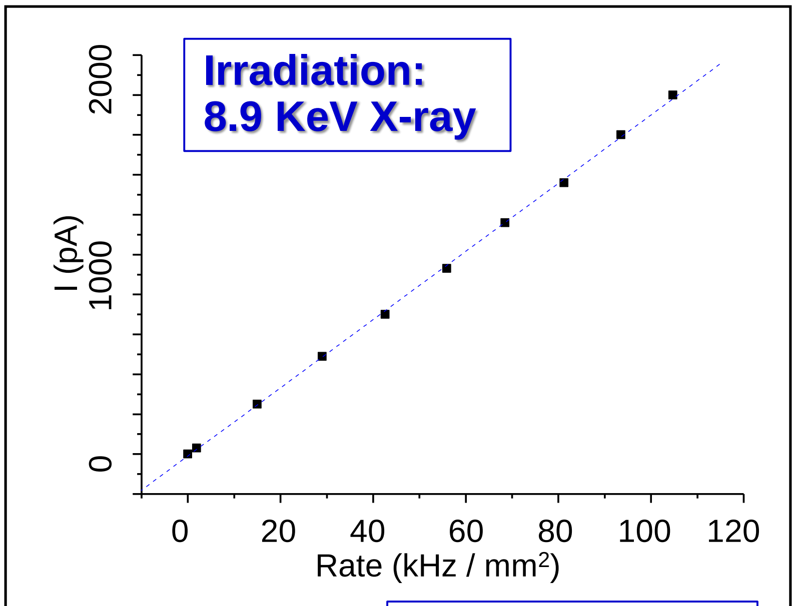
- Geometrical dimensions X ~10
  - But e^- motion/multiplic. properties do not!
  - Larger holes:
    - dipole fields and external fields are strongly coupled
    - e^- dispersion plays a minor role

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



More about THGEMs

High rate device



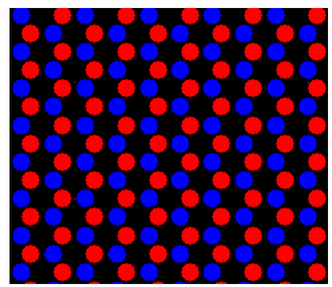
single THGEM, no RIM

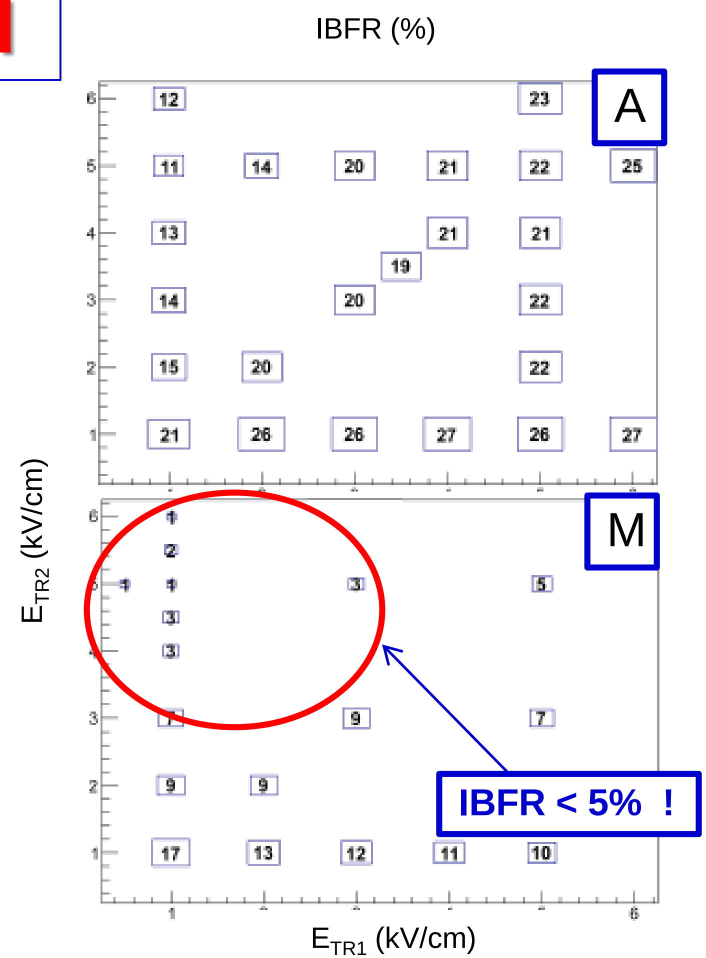
M. Alexeev *et al.* *JINST* 10 (2015) P03026

The gain in Thick GEM multipliers and its time-evolution

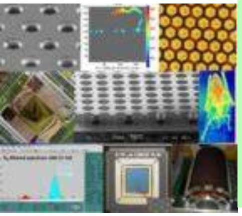
IBF control

Triple THGEM:
Ion Back Flow
reduction by
staggering plates





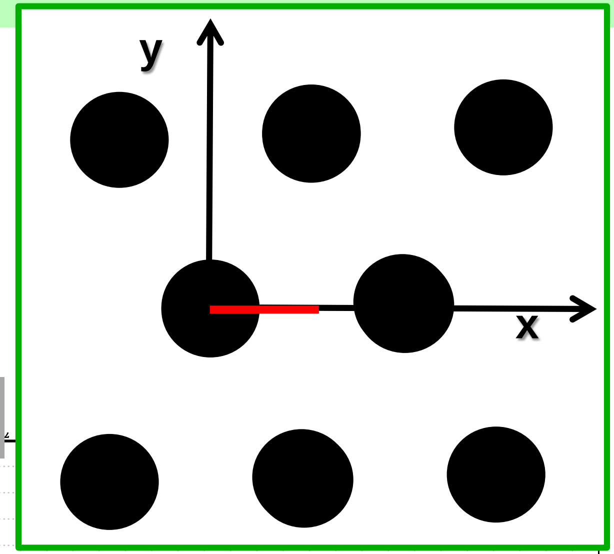
M. Alexeev et al., JINST 7 (2012) C002014



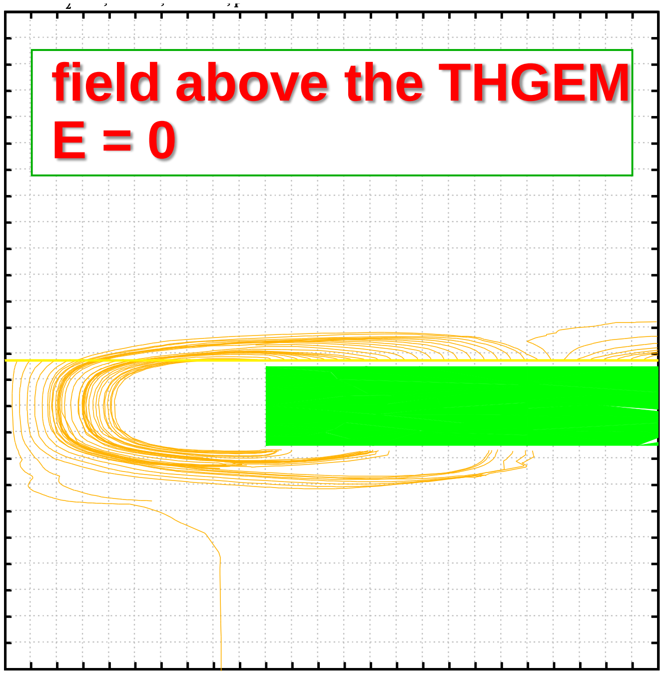
PHOTOELECTRON EXTRACTION

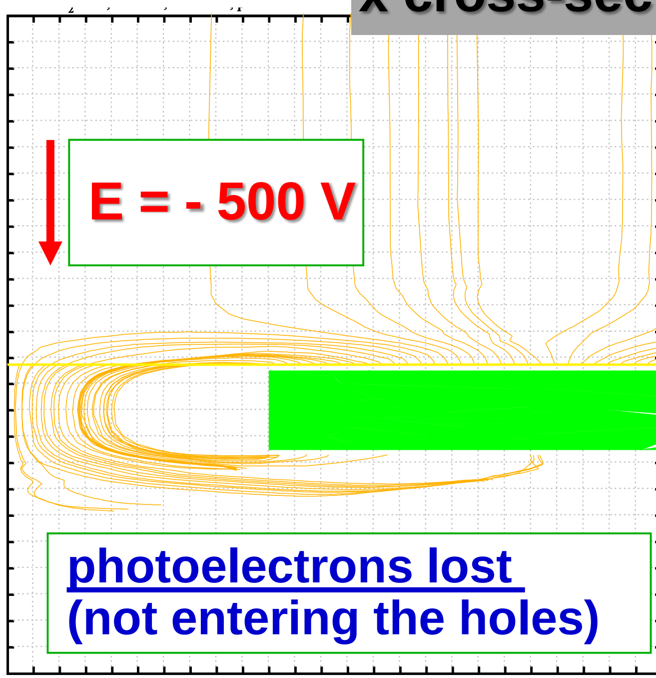
photoelectron trajectories from a THGEM photocathode, <u>simulation,</u> multiplication switched off

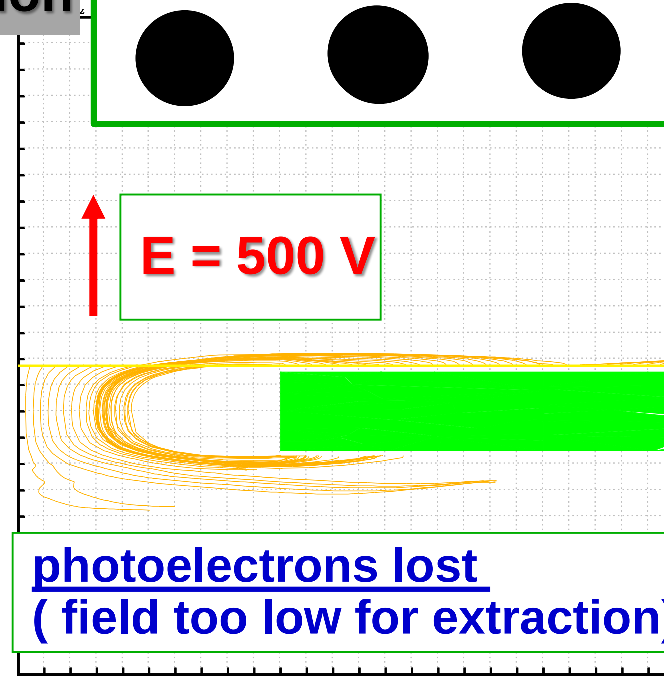
thickness 0.6 mm, diam. 0.4 mm, pitch: 0.8 mm, ΔV = 1500 V

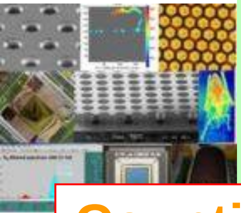


x cross-section



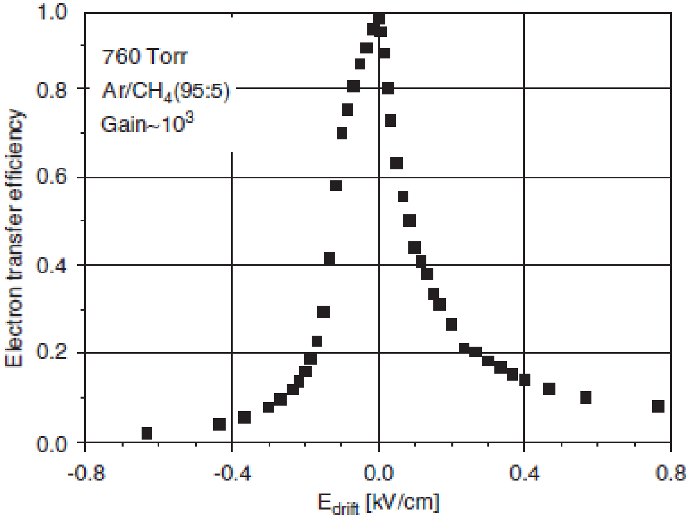


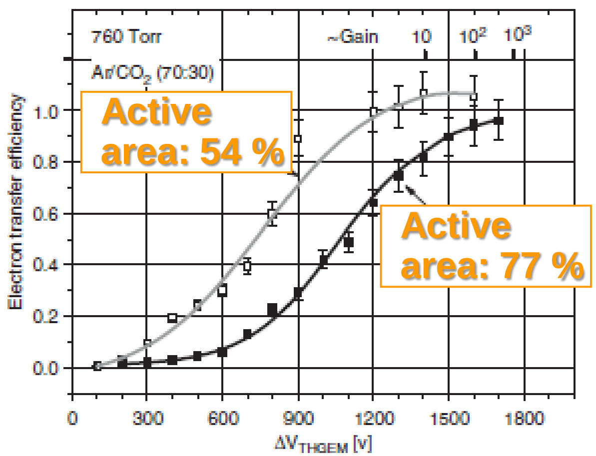




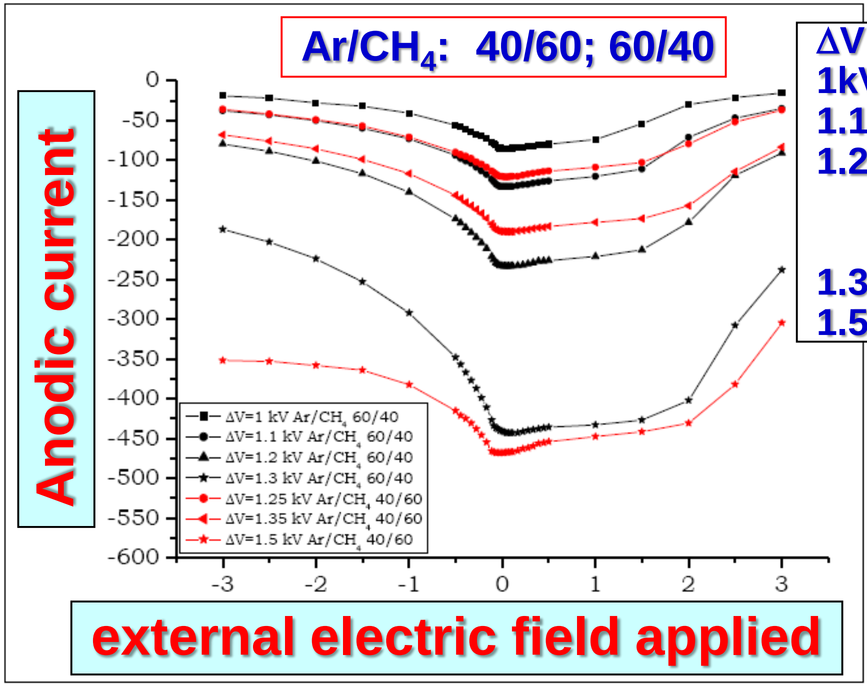
PHOTOELECTRON EXTRACTION

Counting mode technique

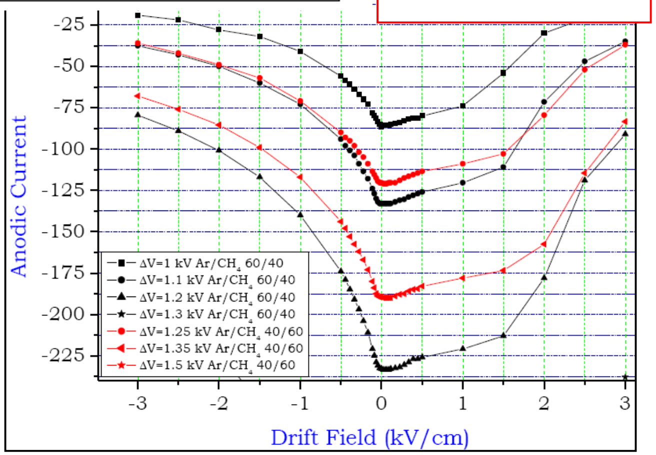




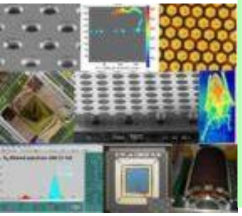
C. Shalem et al., NIMA 558 (2006) 475



ZOOM



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

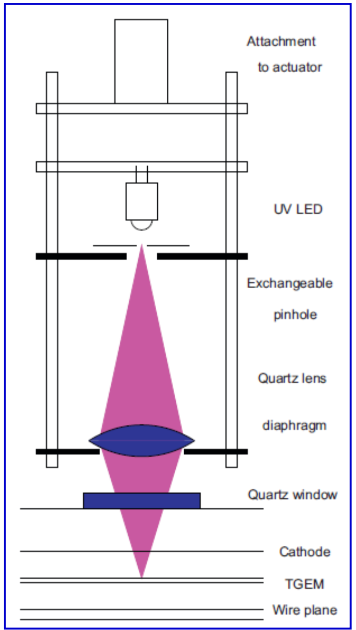


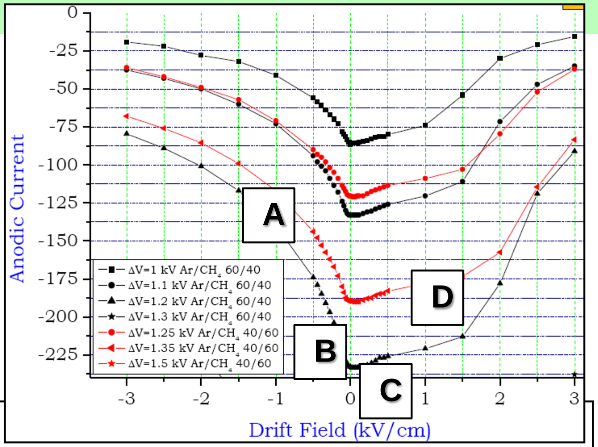
PHOTOELECTRON EXTRACTION

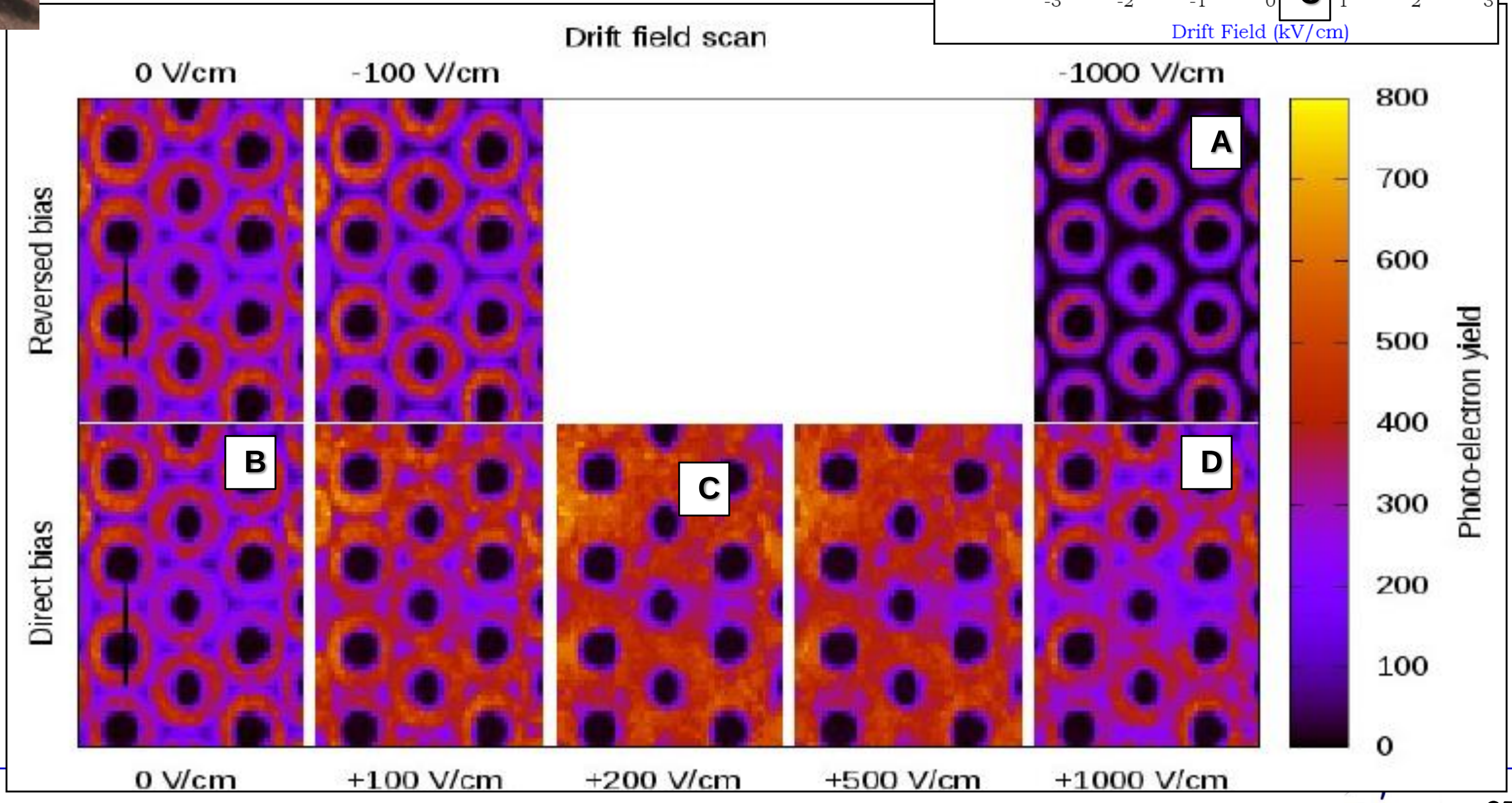
Photoelectron extraction from THGEM PC fully confirmed by direct observation with "Leopard"

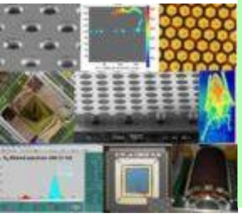
Courtesy of the Budapest and Trieste THGEM groups

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



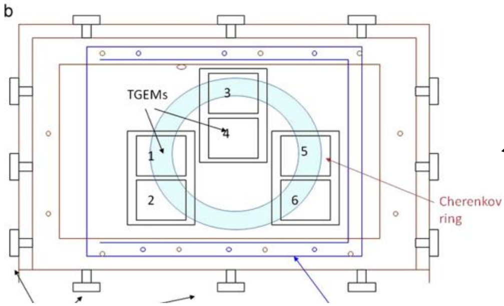




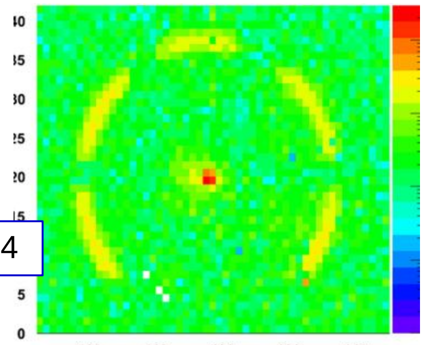


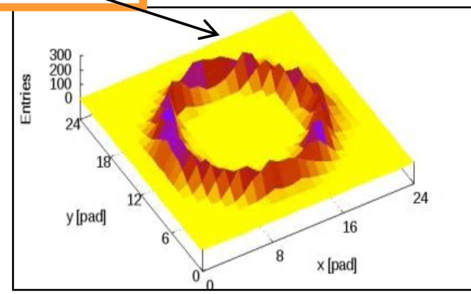
THGEM R&D for RICHes

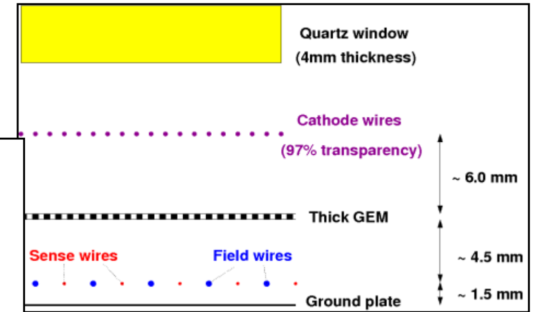
ALICE VHPID
THGEM &
HYBRID



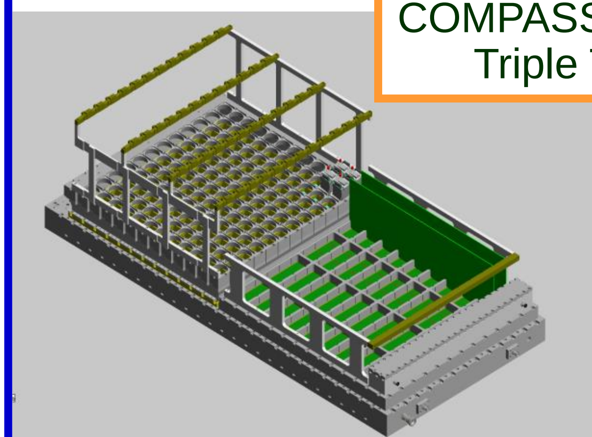
V.Peskov et al., NIMA 695 (2012) 154

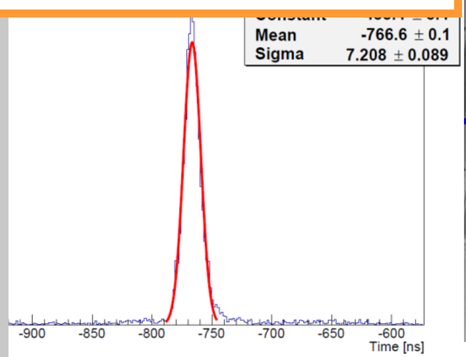


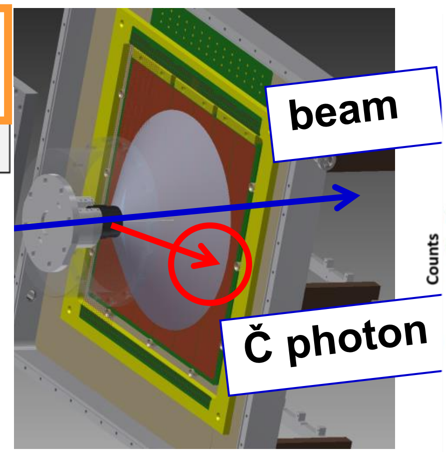


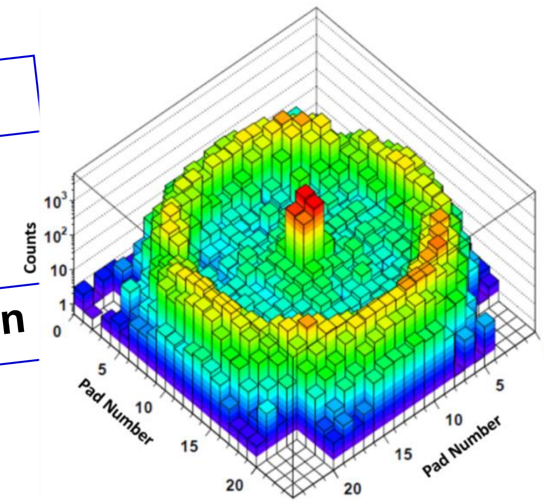


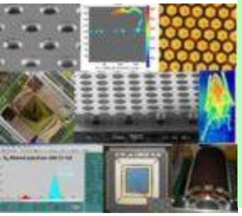
COMPASS, RICH-1 upgrade by
Triple THGEM detectors











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%CH4, used with ΔV at 650-750 V

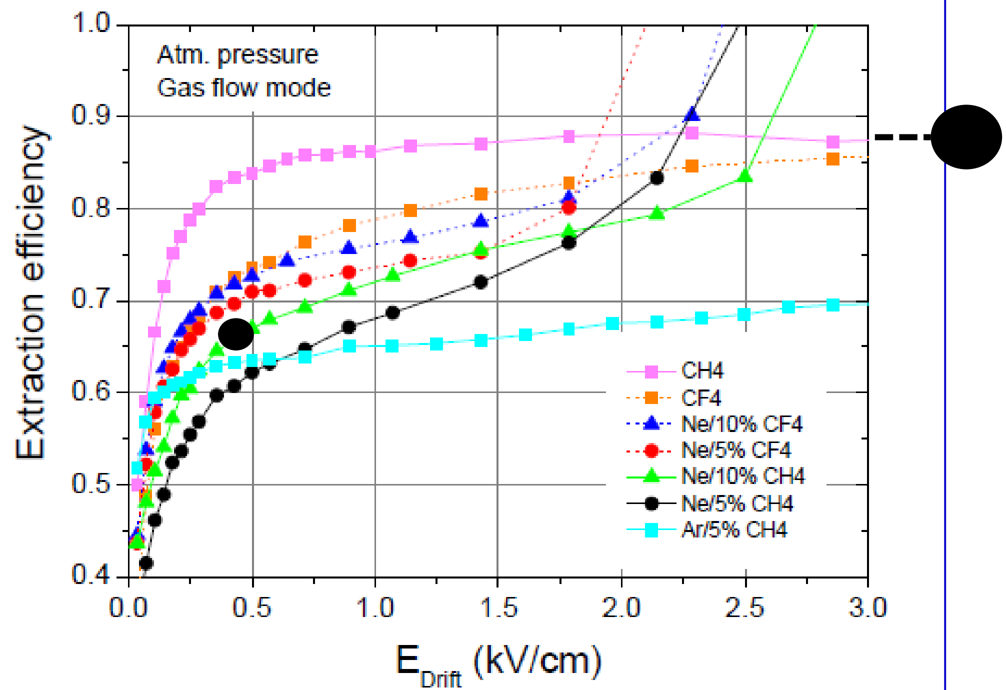
5. Conclusions and Outlook

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

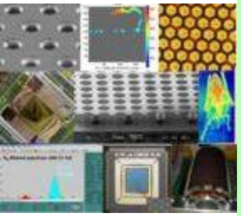
→ Relative extraction efficiency

Respect to pure methane at

E ~ 7kV/cm ~ 75% (my estimate)



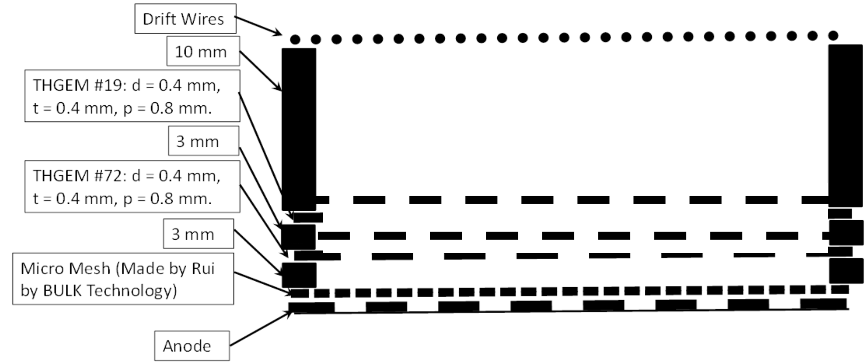
C. D. R. Azevedo et al., 2010 *JINST* 5 P01002

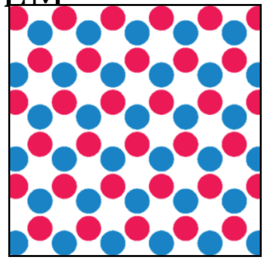


HYBRID MPGD PDs (THGEM + MM)

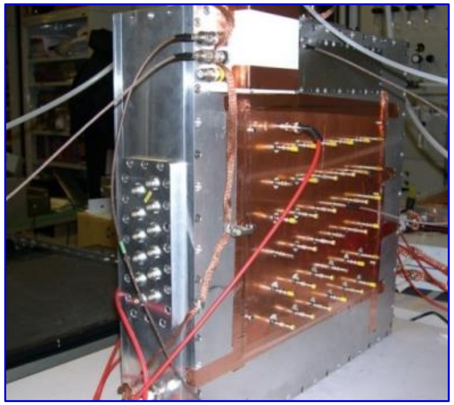
- The 1st THGEM forms the PC
- The 2nd THGEM (staggered) forces the electron diffusion
- The MM provides large gain, made larger by the diffusing the impinging electron cloud

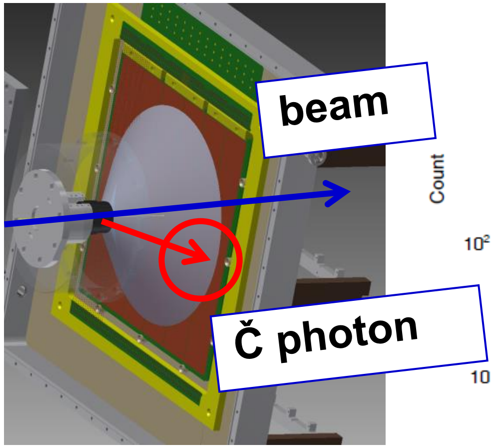
Setup Hybrid (300 X 300 mm^2) with double THGEM





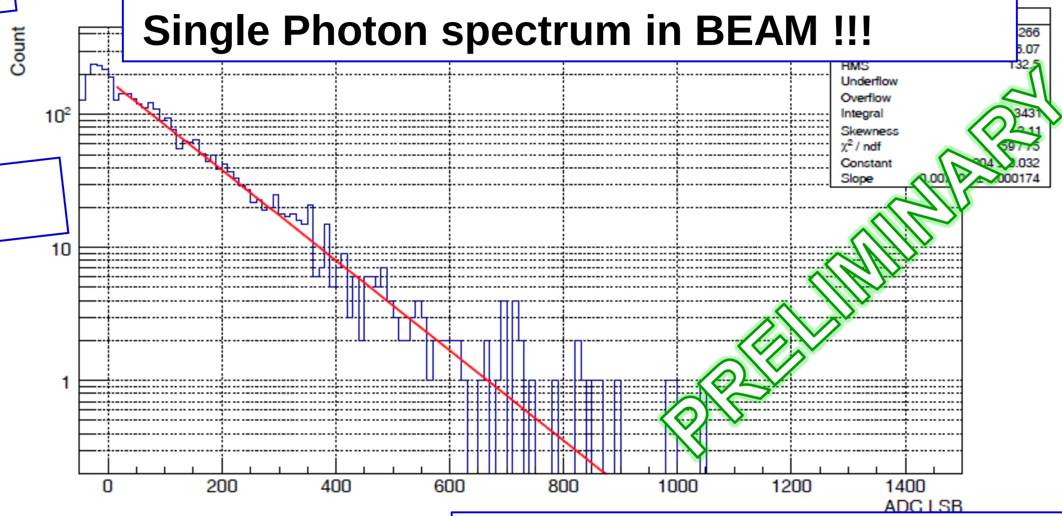
THGEM staggered !





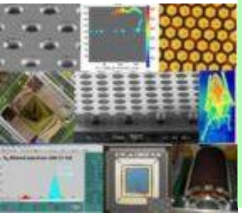
Gain ~ 130K

Single Photon spectrum in BEAM !!!



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

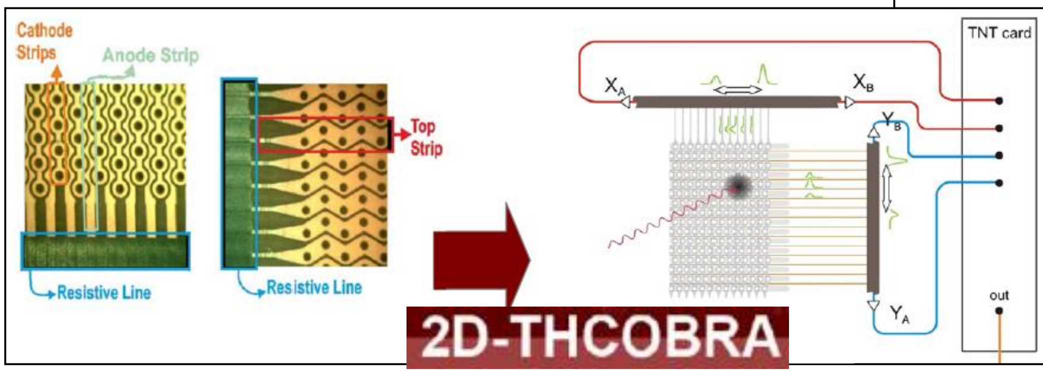
Courtesy of the COMPASS-THGEM group



HYBRID MPGD PDs (THGEM + THCOBRA)

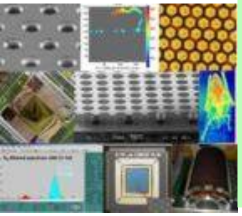
- 2 THGEMs
- a THCOBRA with 2 d R-O structure

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



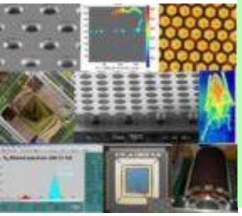
GASEOUS DETECTORS FOR VISIBLE LIGHT

- **Investigated since long time**
  - <u>Chemical reactivity</u> (gas purity better than ppm level needed → UHV materials and sealed detectors)
  - <u>PC stability under ion bombardment</u> - work function lower than CsI one
  - AGEING CsI: -16% QE at 25μC/mm^2
    Bilkaly: -20% QE at 0.4μC/mm^2

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

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

Investigation of prototype gas-filled Photomultiplier
J.S. Edmends, D.J. Miller and F. Barlow, NIM A 273 (1988) 1



GASEOUS DETECTORS FOR VISIBLE LIGHT

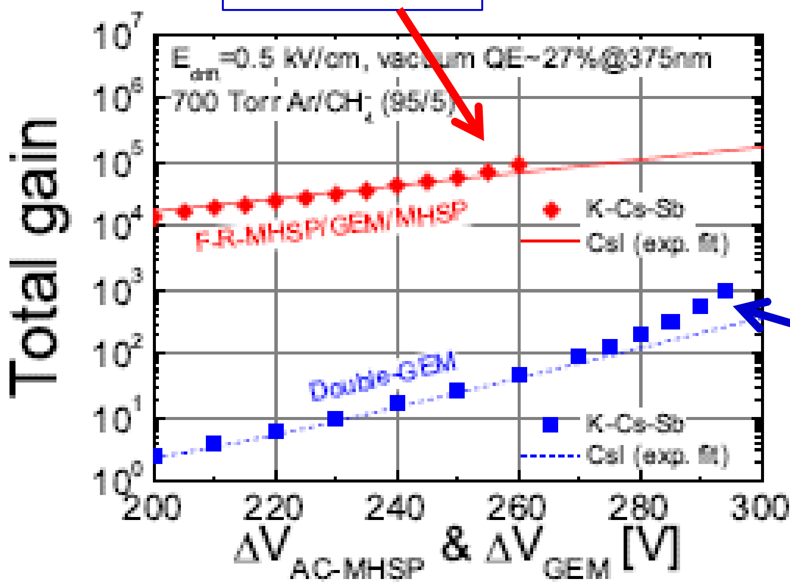
- **photocathodes for visible light**
  - Chemical reactivity (gas purity better than ppm level needed → UHV materials and sealed detectors)
  - PC stability under ion bombardment - work function lower than CsI one
  - AGEING CsI: -16% QE at 25μC/mm²
    Bilkaly: -20% QE at 0.4μC/mm²

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

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

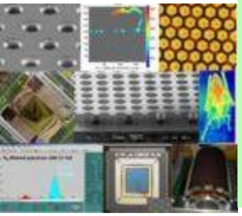
F-R-MHSP, IBF: 3 x 10^{-4}

K-Cs-Sb vs CsI



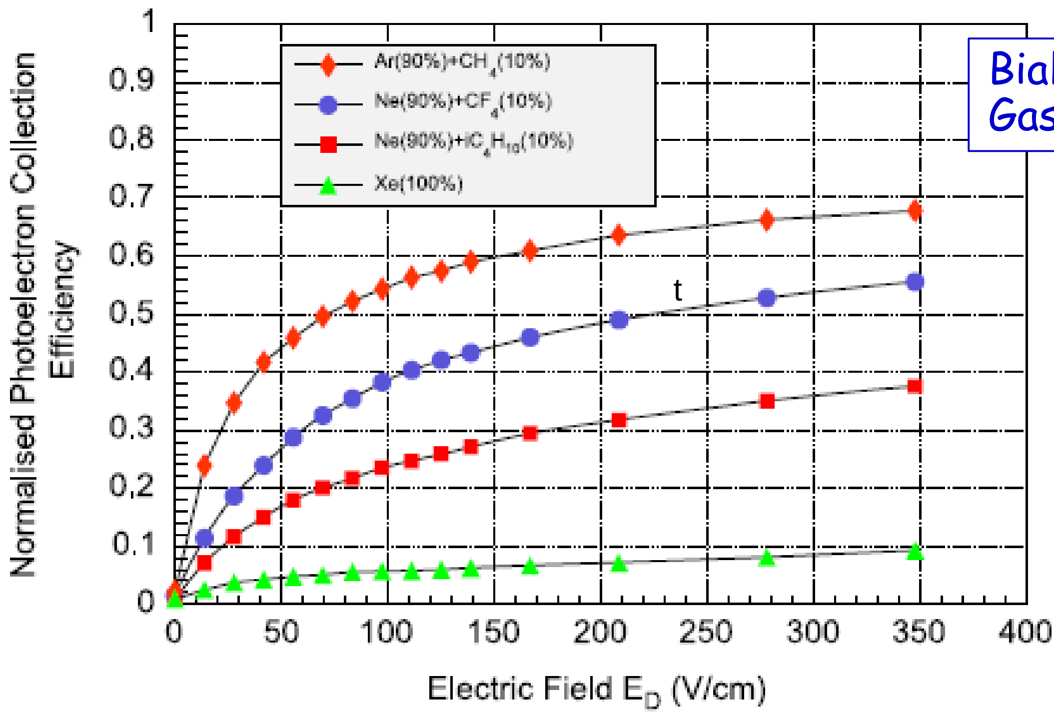
Doulble GEM, IBF: ~ 10^{-2}

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



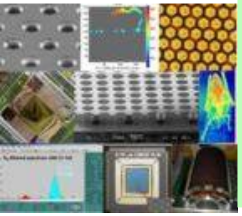
GASEOUS DETECTORS FOR VISIBLE LIGHT

- **Dedicated photoelectron extraction studies**



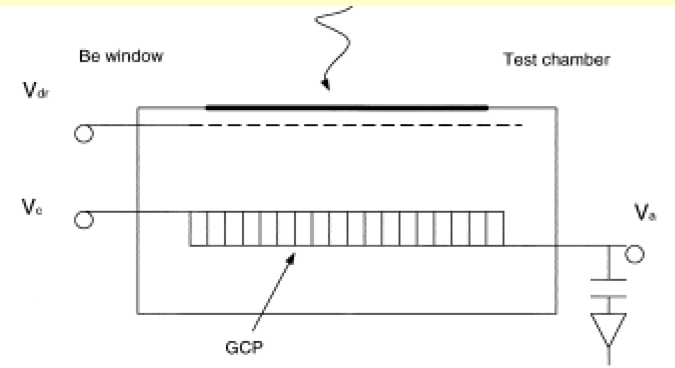
Bialkali,
Gas P 675 torr

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



GASEOUS DETECTORS FOR VISIBLE LIGHT

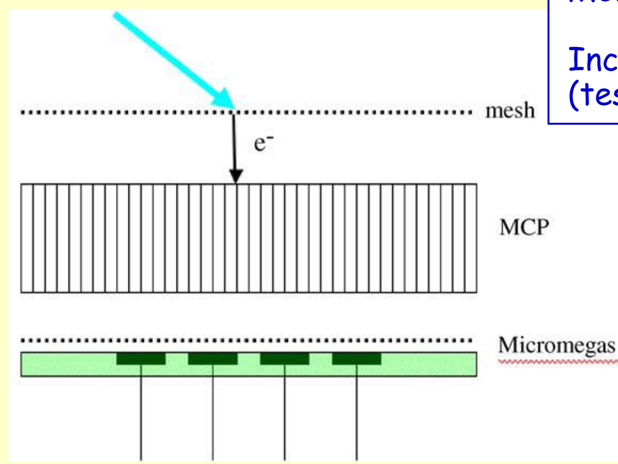
The Capillary Plate (CP) approach

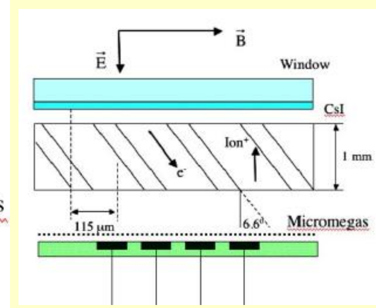


V. Peskov et al., NIMA 433 (1999) 492

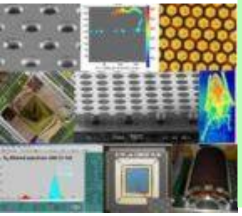
MCP coupled to Micromegas

Inclined to reduce more the IBF (tested with CsI)





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

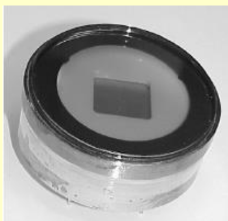


GASEOUS DETECTORS FOR VISIBLE LIGHT

the GEM approach

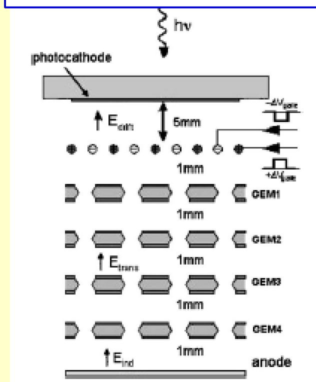
TIME LINE

Multiple GEM sealed



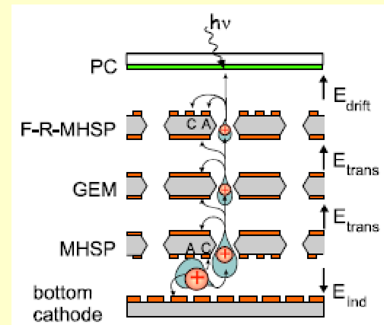
R.Chechik et al., NIMA 502 (2003) 195

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

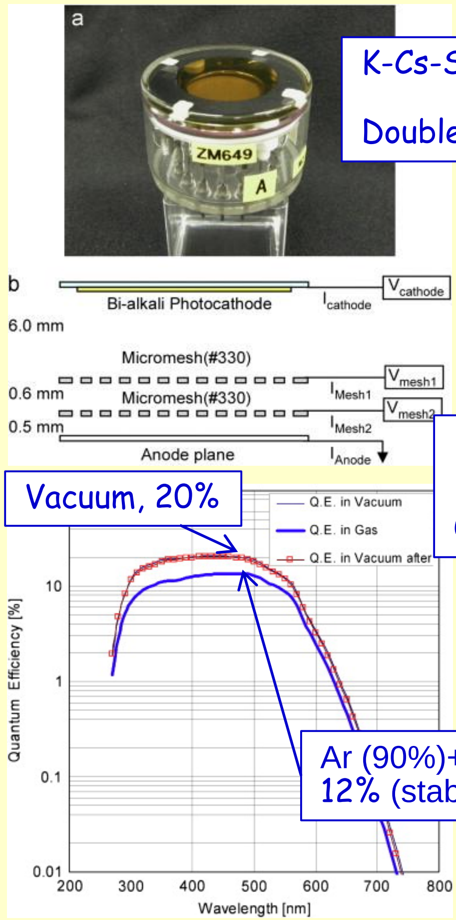
Poor compatibility of bialkali and GEM material ?

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

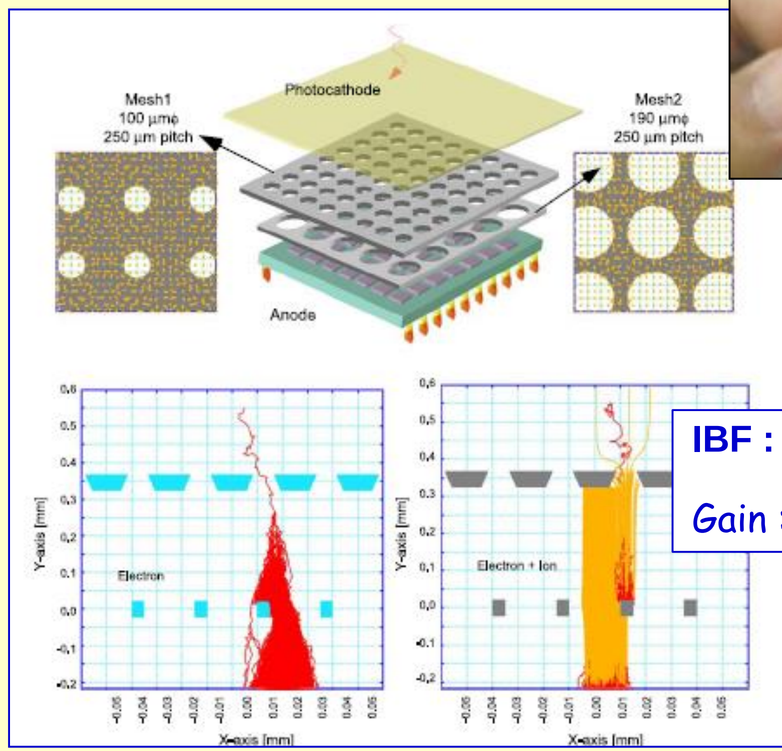
Vacuum, 20%

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

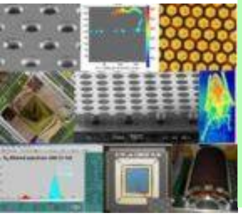
In collaboration with HAMAMATSU



IBF : 6 ×10^{-4}

Gain : 10^4

F. Tokanai et al., NIMA 766 (2014) 176

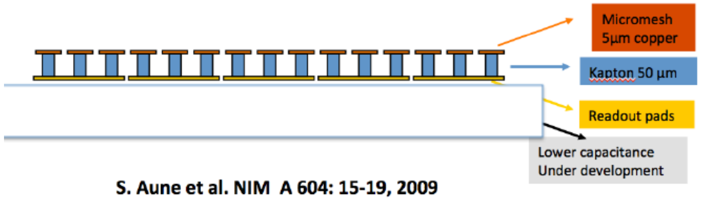


PHOTONS FOR SUB-NANOSECOND TIMING

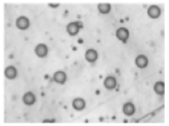
Sub-100 picosecond charged particle timing with MicroMegas

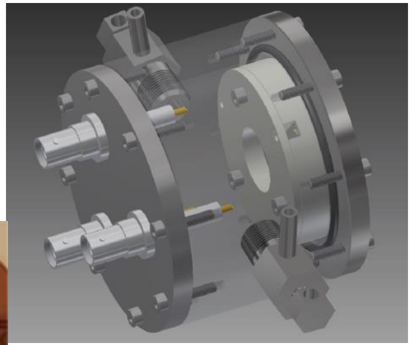
Very promising rewcent development presented at RD51 Mini-Week

Microbulk technology

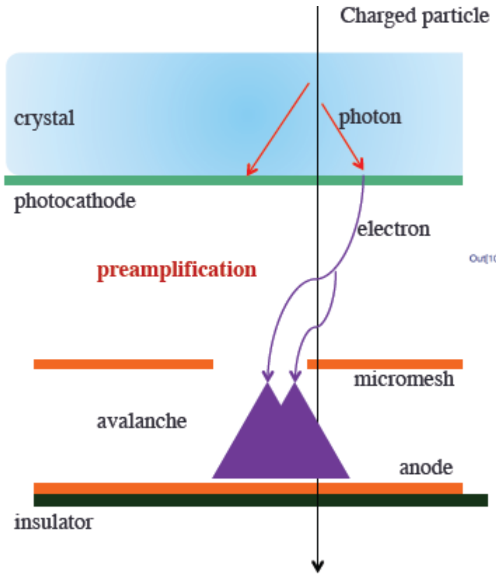


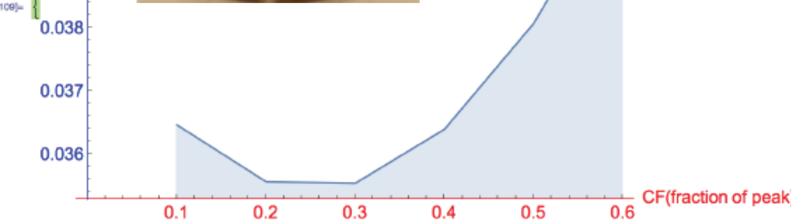
Pitch 100 µm, Holes 30 µm





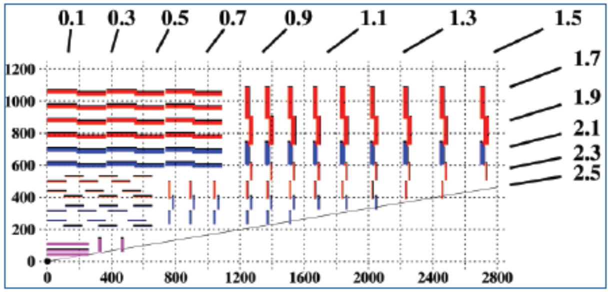
S. Aune et al. NIM A 604: 15-19, 2009
S. Andriamonje et al. JINST, 2010



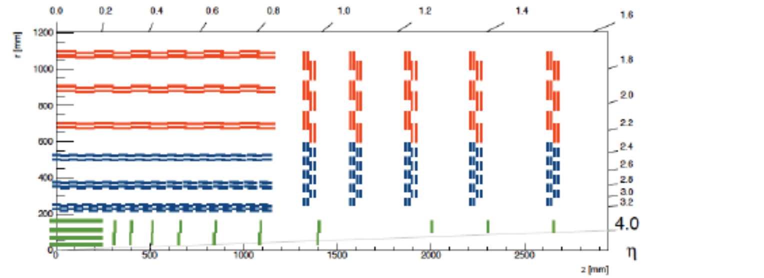


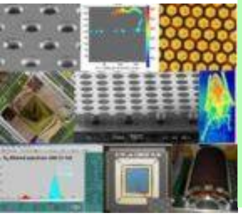
~20 pe: 36 ps rms time jitter observed

current model in CMSSW matched to:



if tracker extended in Phase2, complementary role?

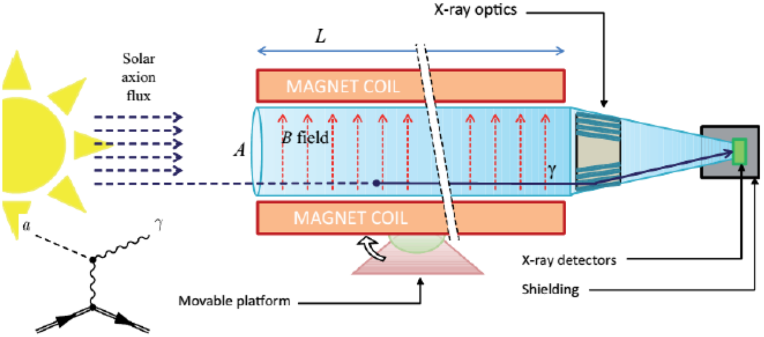




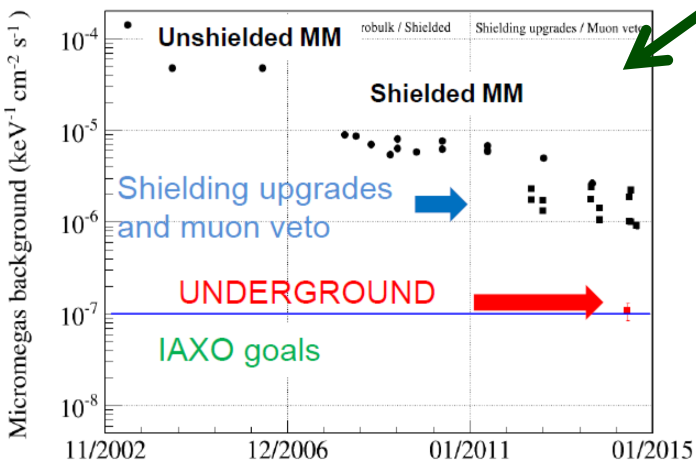
AXION search: low bkg. X-ray detection

Micromegas as Low Background x-ray detectors in axion searches: CAST & IAXO

- High power to discriminate x-rays signals from other type of events. Event topology.
- Intrinsically radiopure, very low radioactivity budget ***(Astr. Part. 34 (2011) 354)***.
- Shielding techniques from low background experiments are also applied.



Detection: *inverse Primakoff* (Sikivie 1983)
Axions in a magnetic field convert to photons.
Expected x-ray excess when the magnet points to the Sun.

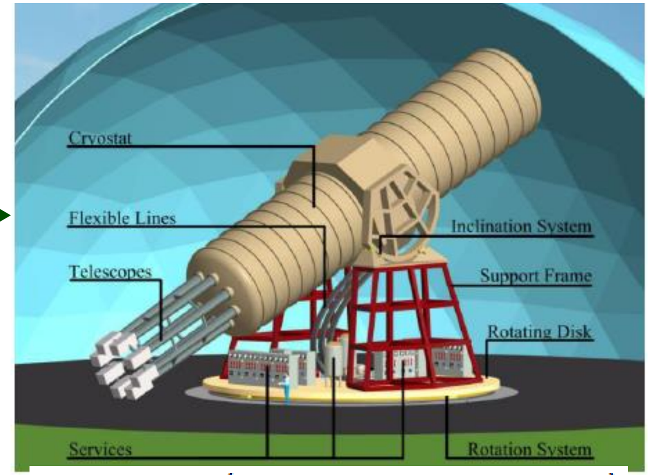


JINST 9 (2014) P01001:
Low background x-ray detection with Micromegas for axion research

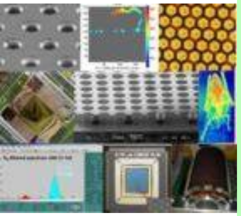
JINST 8 (2013) C12042
X-ray detection with Micromegas with background levels below 10^{-6} $keV^{-1}cm^{-2}s^{-1}$

CAST: CERN Axion Solar Telescope

IAXO: International AXion Observatory

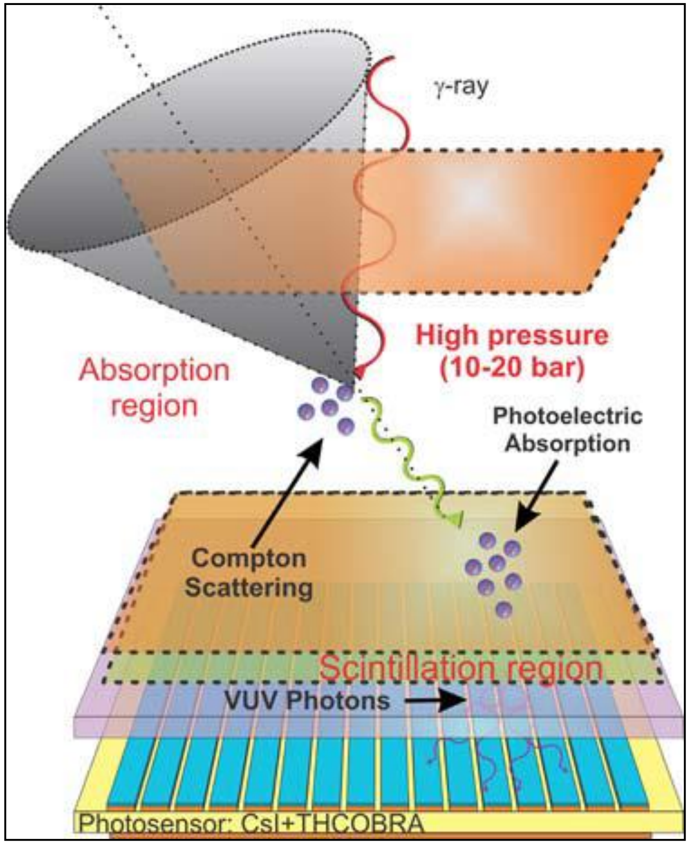


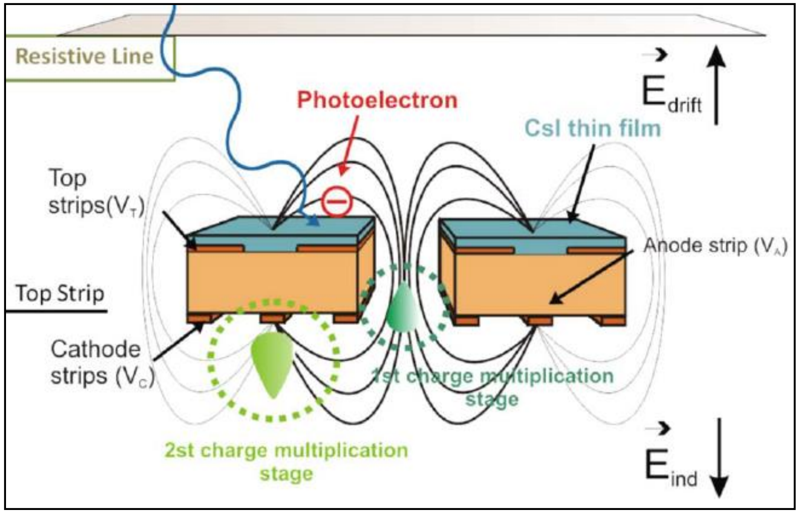
IAXO-CDR (**2014 JINST 9 T05002**)

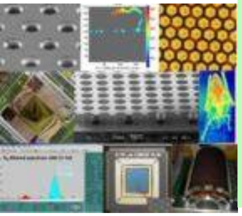


MPGD PDs for medical imaging → Gabriela Llosa Llacer talk

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



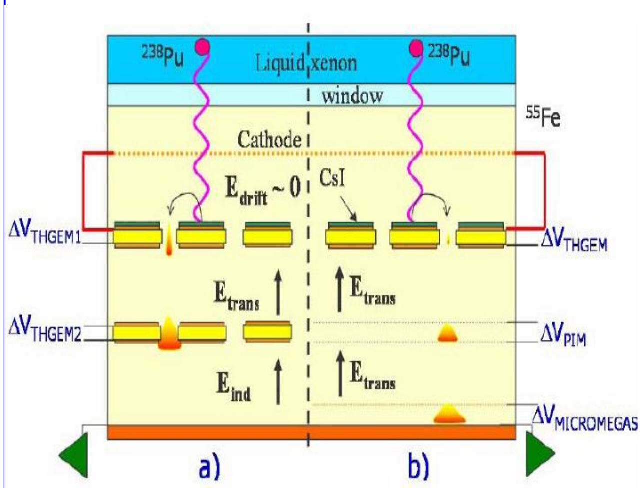




CRYOGENIC MPGD-PDs

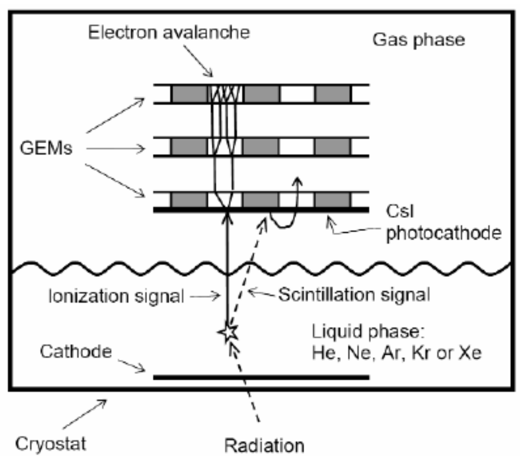
- **Read-out elements of cryogenic noble liquid detectors**
  - **Rear event detectors (ν, DM)**
  - **Detecting the scintillation light produced in the noble liquids**
  - **Options of scintillator light and ionization charge detection by a same detector !**

with WINDOW



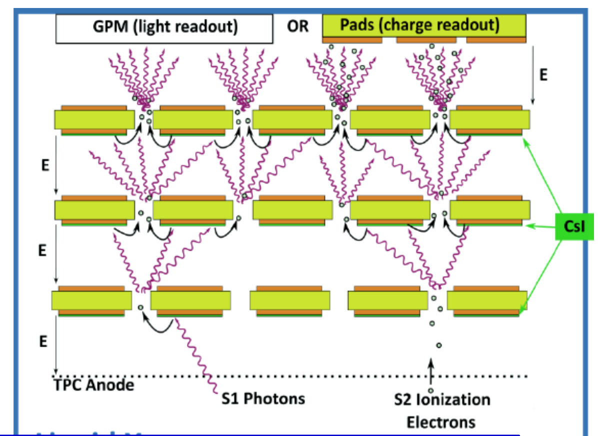
S.Duval et al., JINST 6 (2011) P04007

WINDOWLESS (2-PHASES)

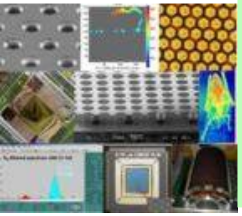


A. Bondar et al.,
NIMA 556 (2006) 273

OPERATED IN THE CRYOGENIC LIQUID

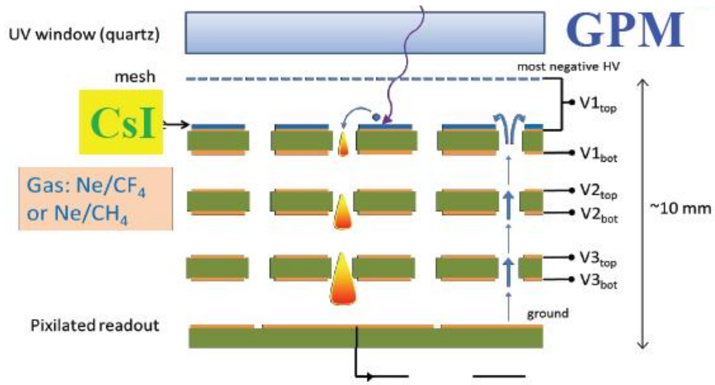


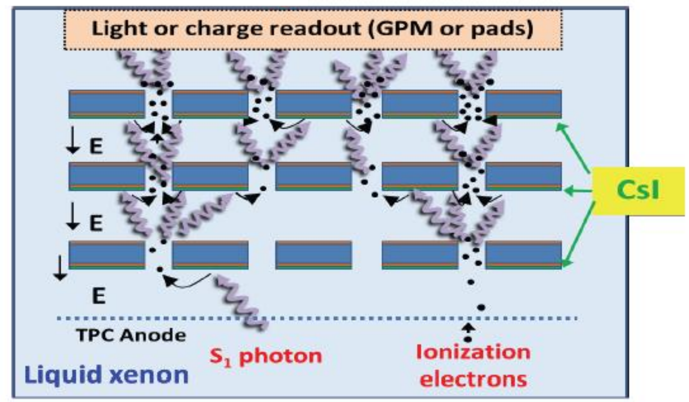
L.Arazi et al., JINST 8 (2013) C12004



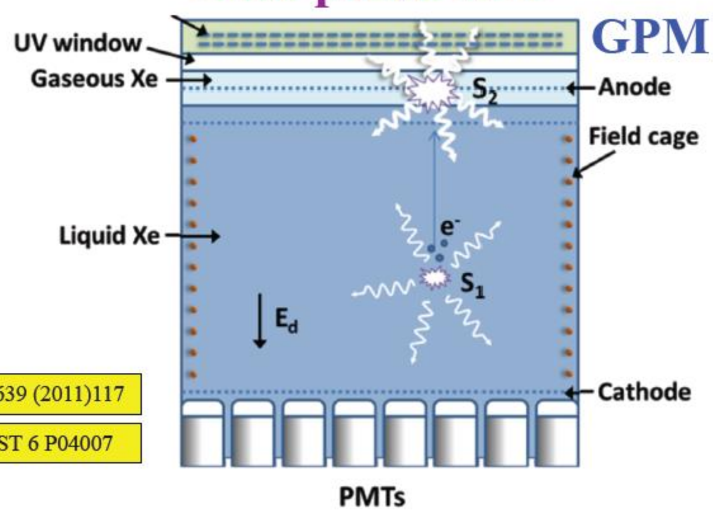
Cryogenic: → Lior Arazi talk

Low T THGEM in noble-liquid TPC (DM etc.)

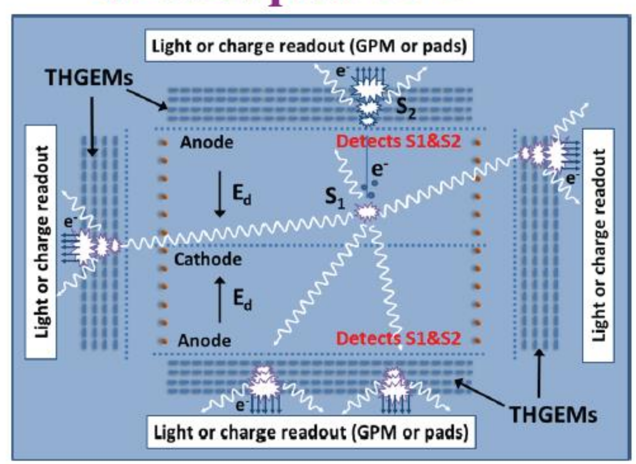




Dual-phase TPC



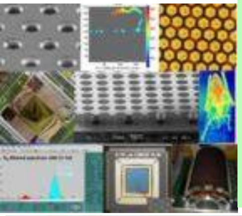
4π all-liquid TPC

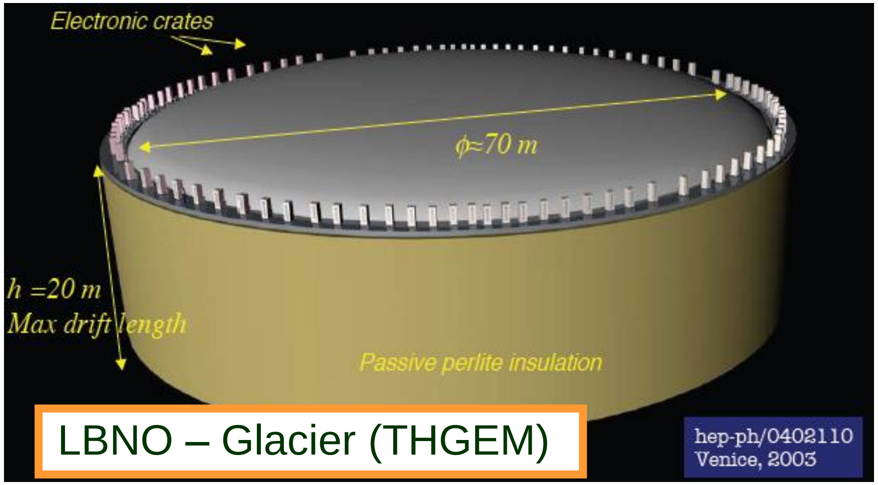


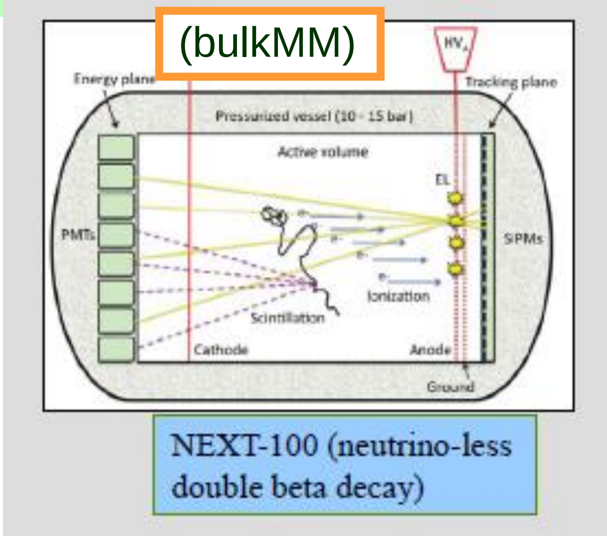
Breskin NIM A639 (2011)117

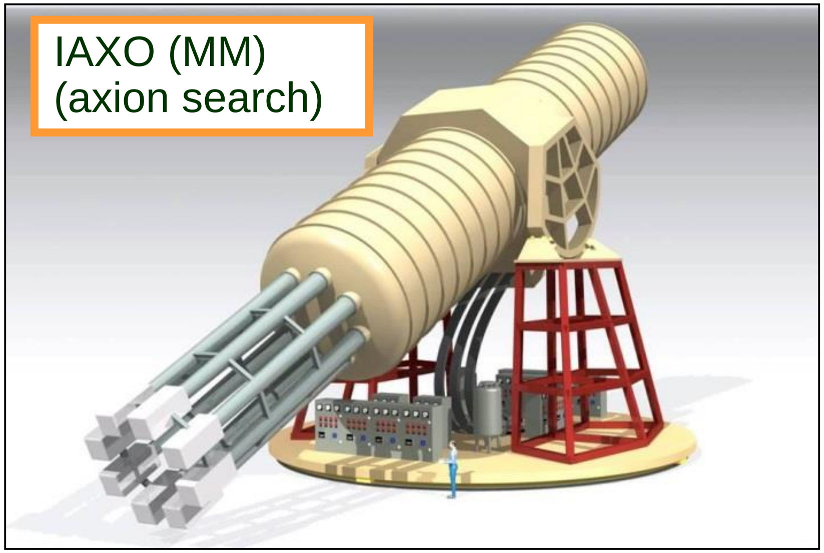
Duval 2011 JINST 6 P04007

LARGE SIZE PROJECTS



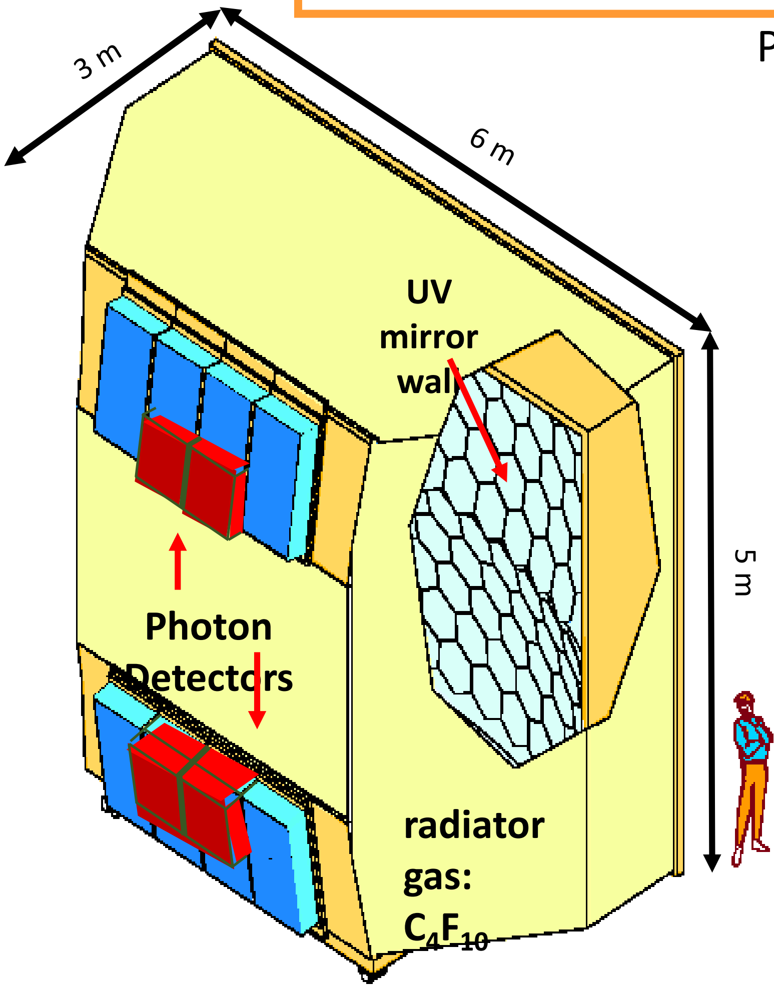




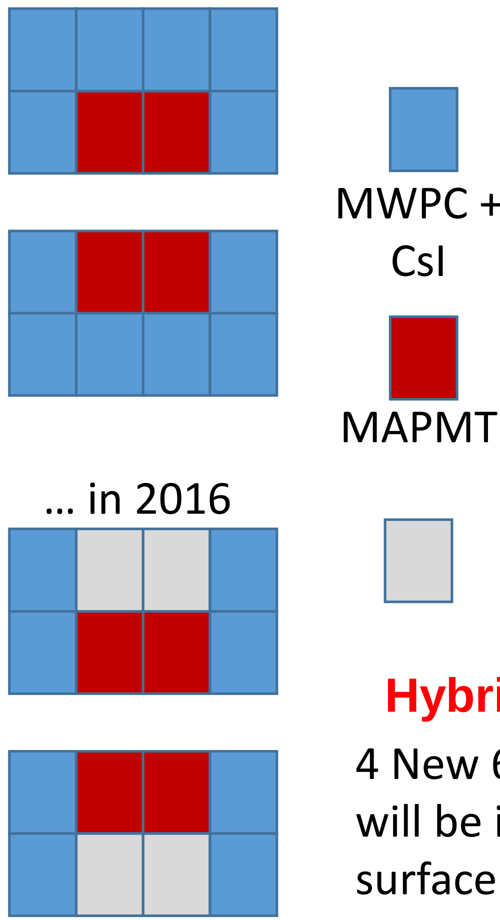


FIRST STEP TOWARD LARGE SIZE

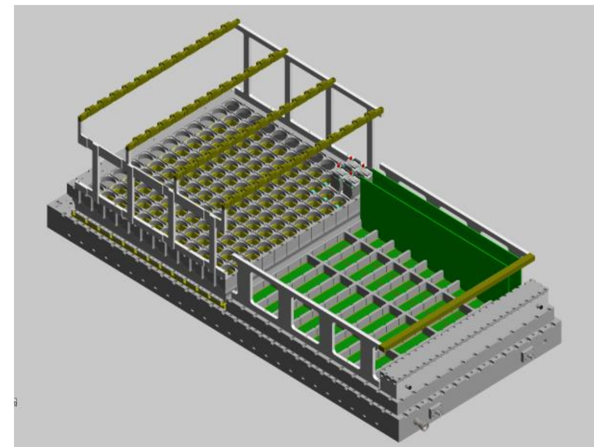
COMPASS RICH-1 UPGRADE IN 2016



Photon detectors system now:

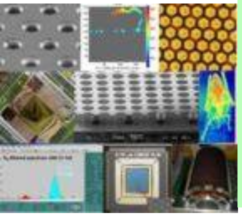


- 12 MWPC + CsI 600 x 600 mm^2
- 4 MAPMT 600 x 600 mm^2 (2006)



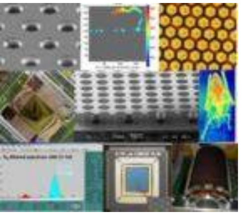
Hybrid Detector (2 THGEM + MM)

4 New 600 x 600 mm^2 MPGD based PDs will be installed for a total sensitive surface of ~ 1.1 m^2



SUMMARY / CONCLUSIONS

- GASEOUS PHOTON DETECTORS
  - Most effective approach to instrument large surfaces at affordable costs
- MPGD-BASED PHOTON DETECTORS
  - Allow to overcome the limitations of open geometry gaseous PDs
  - recent R&D advancements → MPGD photon detectors are a reality
  - A wide effort to refine and consolidate the technology
- MANY APPLICATIONS OF MPGD-BASED PHOTON DETECTORS
  - From PID to ν, DM, medical applications …



THANK YOU