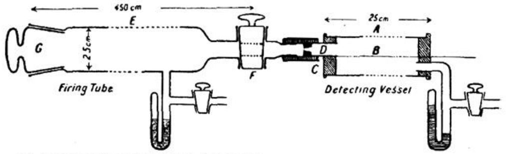
"Single Photon Detection with gaseous detectors"

Stefano Levorato

Limited to the PID applications of gaseous photon detectors………

Single photon detection with gaseous detector: a beautiful marriage

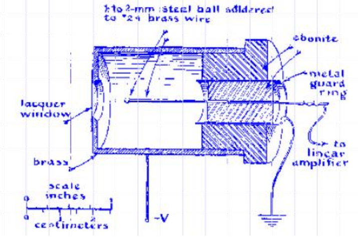
1908: FIRST WIRE COUNTER
USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY



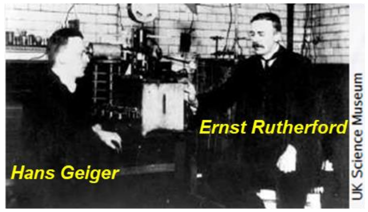
E. Rutherford and H. Geiger ,
Proc. Royal Soc. A81 (1908) 141

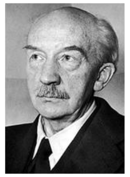
Nobel Prize in Chemistry in 1908

1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY



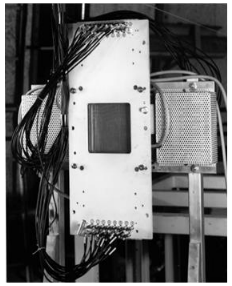
H. Geiger and W. Müller,
Phys. Zeits. 29 (1928) 839

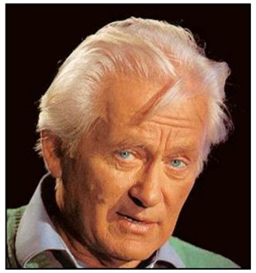




Walther Bothe
Nobel Prize in
1954 for the
“coincidence
method”

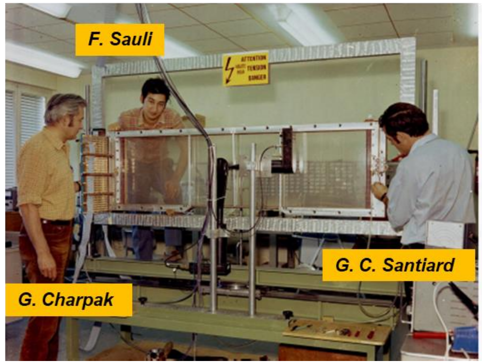
1968: MULTIWIRE PROPORTIONAL CHAMBER





Nobel Prize in 1992

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

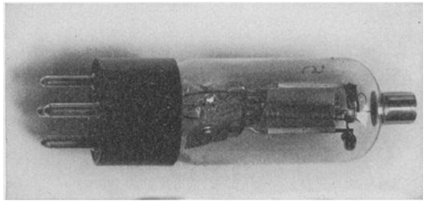


More than 100 years of tradition on gaseous detectors development and operation

John Sealy Townsend

Heinrich Rudolf Hertz
photoelectric effect, 1887

A. Einstein, Nobel Prize in 1921



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

…the discovery and the exploit of the photoelectric phenomenon and the Cherenkov effect ….

Pavel Cherenkov 1904-1990 *Ilya Frank* *and* *Igor Tamm*

Nobel Prize in 1958

Arthur Roberts 1912-2004

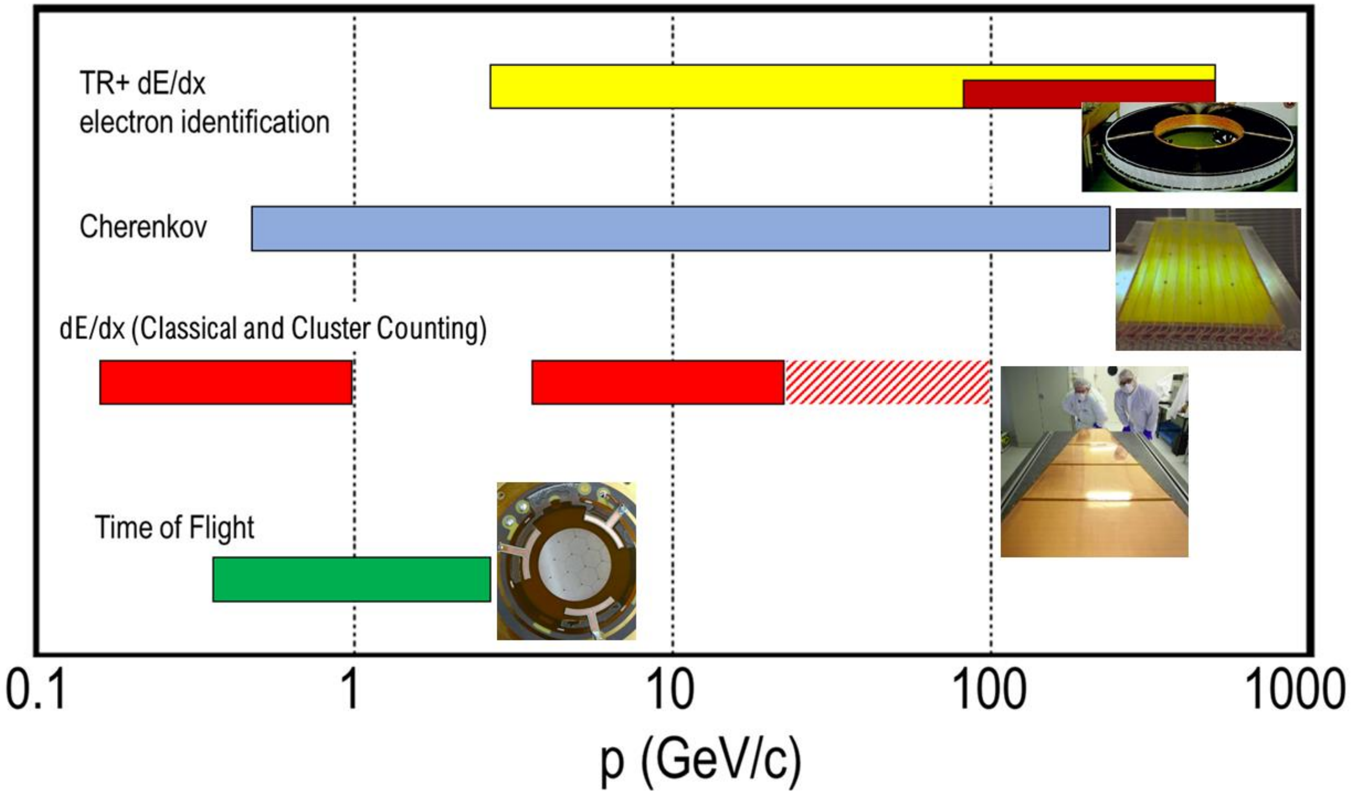
Tom Ypsilantis 1928-2000

The motivation

Needed for π-K identification from HEP Experiments

Large momentum acceptance → Cherenkov angle measurement technique

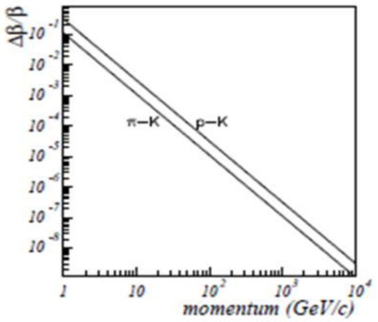
Large angular acceptance → large area of efficient single photon detection



Gaseous detectors: 1) cheap, 2) magnetic insensitive, 3) low material budget

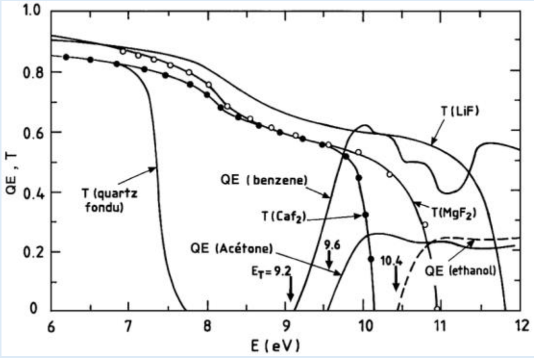
$$\cos(\theta) = \frac{1}{n\beta}$$

$$\left(\frac{dm}{m}\right)^2 = \left(\gamma^2\frac{d\beta}{\beta}\right)^2 + \left(\frac{dp}{p}\right)^2$$



10^{-5} $\Delta\beta/\beta$ ~ 80 GeV/c π/K separation

- 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

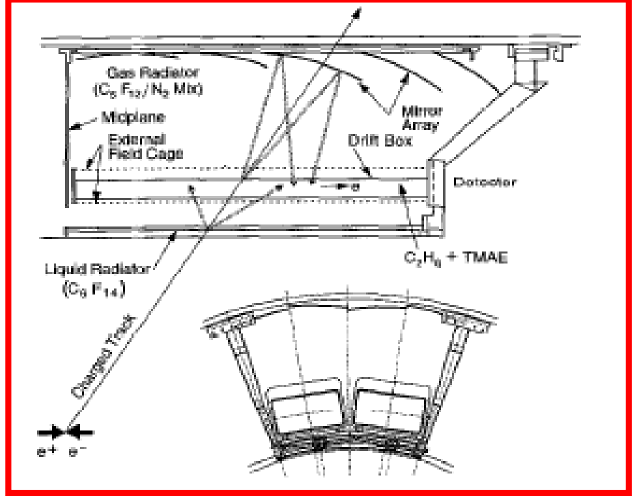
→ conflicting requirements because of the copious UV emission by the multiplication avalanche.

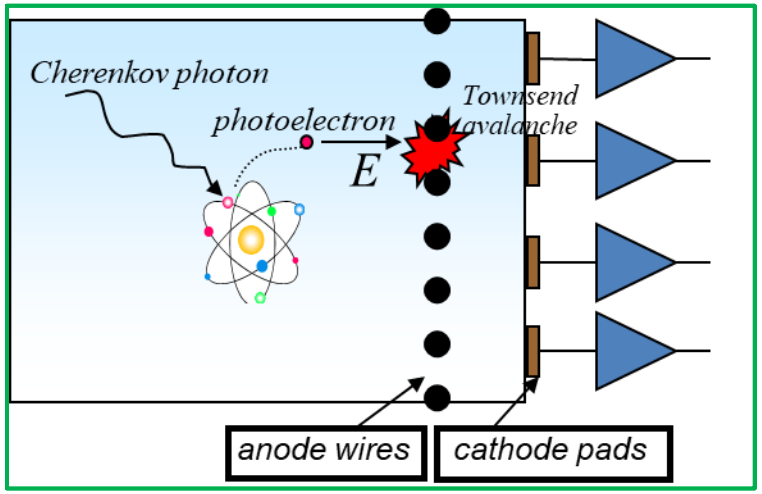
- solution: multistep avalanche chamber

(Charpak-Sauli Phys. Lett. B 142 (1977) 377) or TPC

Photoconverting Vapor based RICH coupled to large MWPC: the first generation

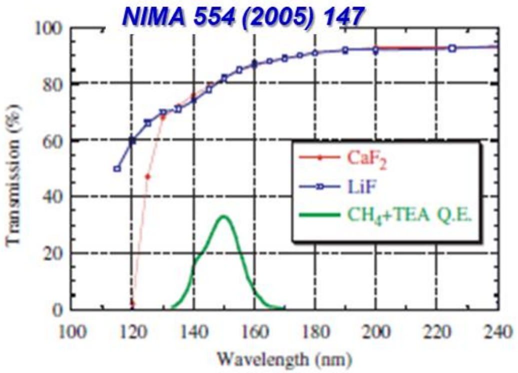
SLD - CRID



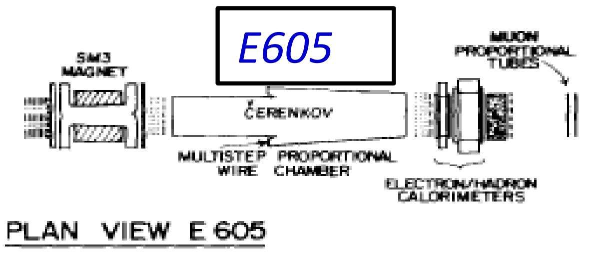


photosensor	E_{th}(eV)	vapour pression (torr)	l_{abs}(mm)	operational issues
TMAE	5.6	0.3	30	hazardous material, strong anode wire ageing
TEA	7.2	52	0.6	operation in the far UV: CaF_2+ultrapure gas mixture, high chromat.

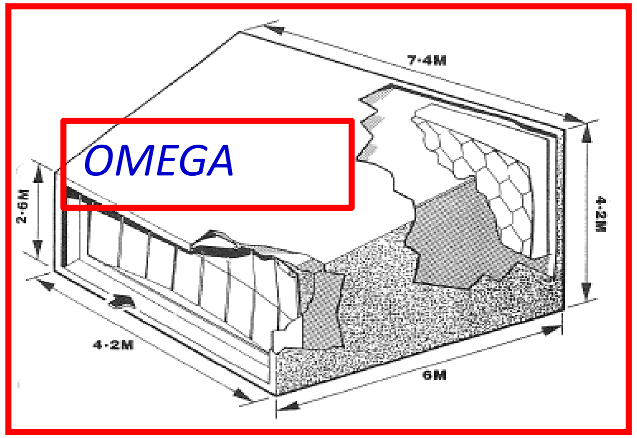
NIMA 554 (2005) 147



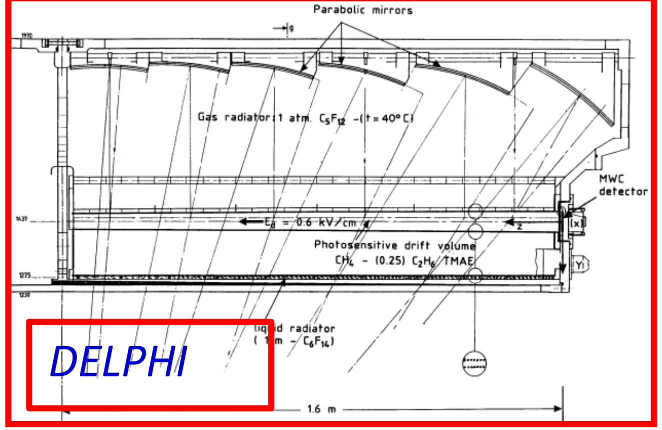
E605



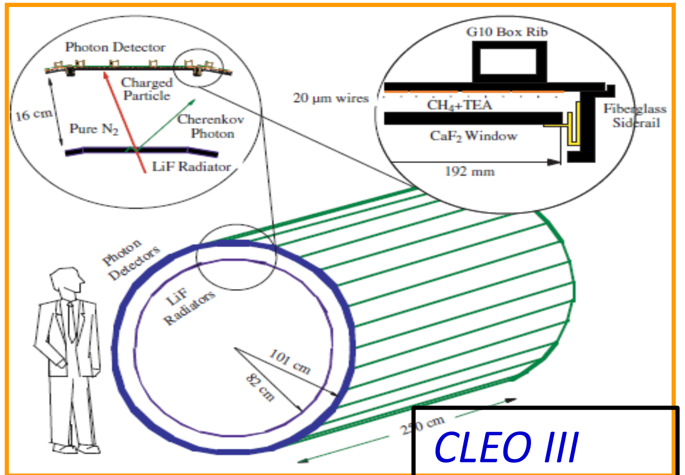
OMEGA



DELPHI



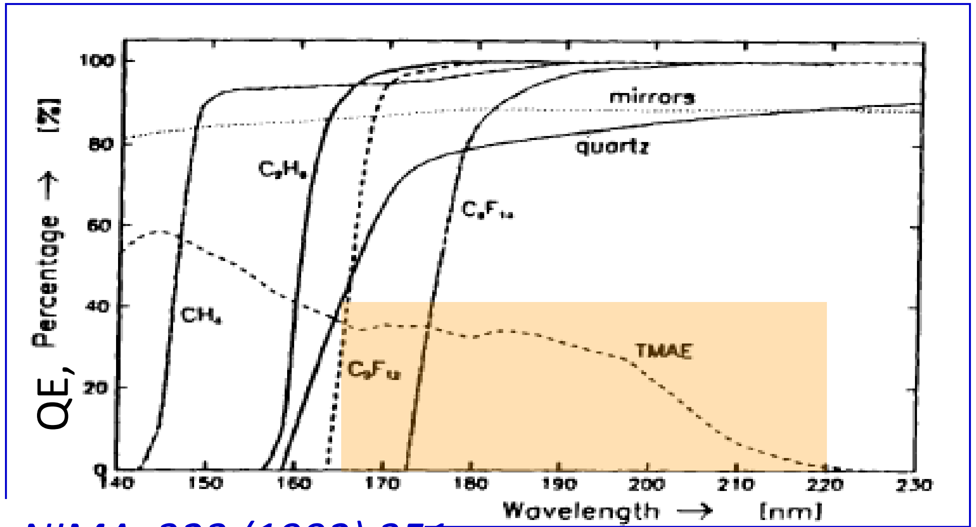
CLEO III



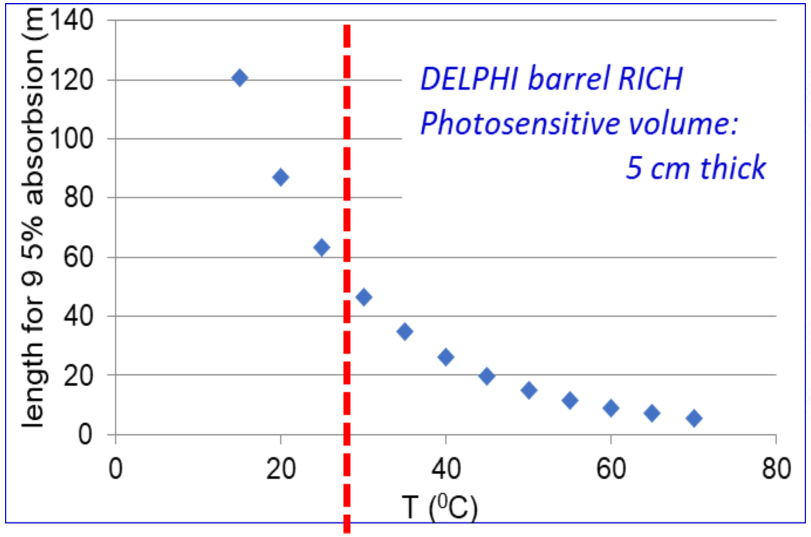
TMAE *(Tetrakis-Dimethylamine-Ethylene)*

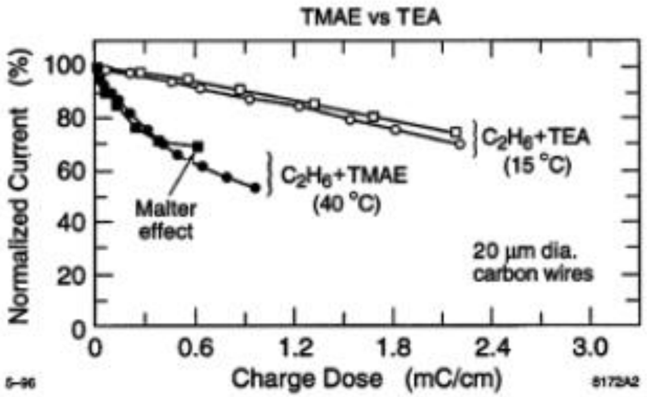
TEA *(Tri-Ethyl-Amine)*

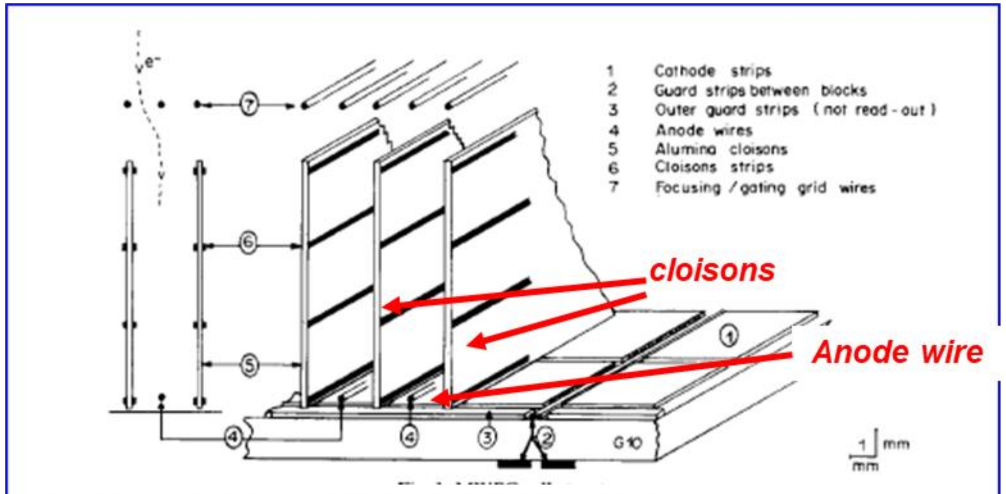
TMAE gas



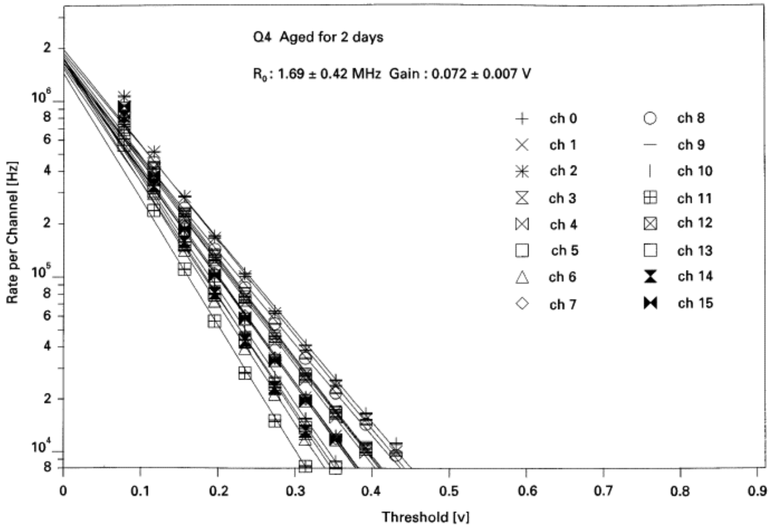
NIMA 323 (1992) 351







DELPHI barrel RICH, NIMA 273 (1988) 247



NIMA Volume 433, Issues 1–2, 21 August 1999, Pages 92-97 (HERA-B RICH)

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

The revolution of the CsI, the conversion on solid photocathode

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

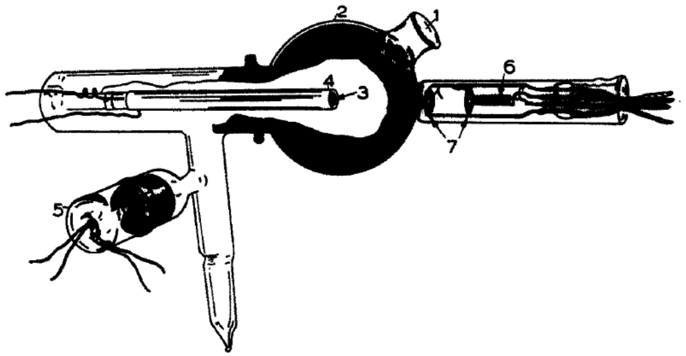


FIG. 1. Cutaway sketch of phototube; (1) 9741 glass bubble window, (2) graphite coated collector sphere 4 inches in diameter, (3) ⅜ inch glass tube, platinum painted, (4) nickel sleeve insulated from tube by glass beads, (5) ion gauge, (6) evaporating cylinder and helical platinum heater, (7) collimating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

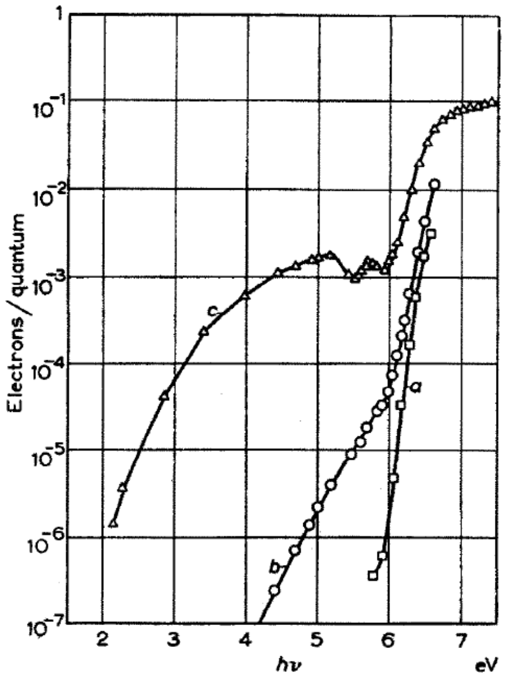


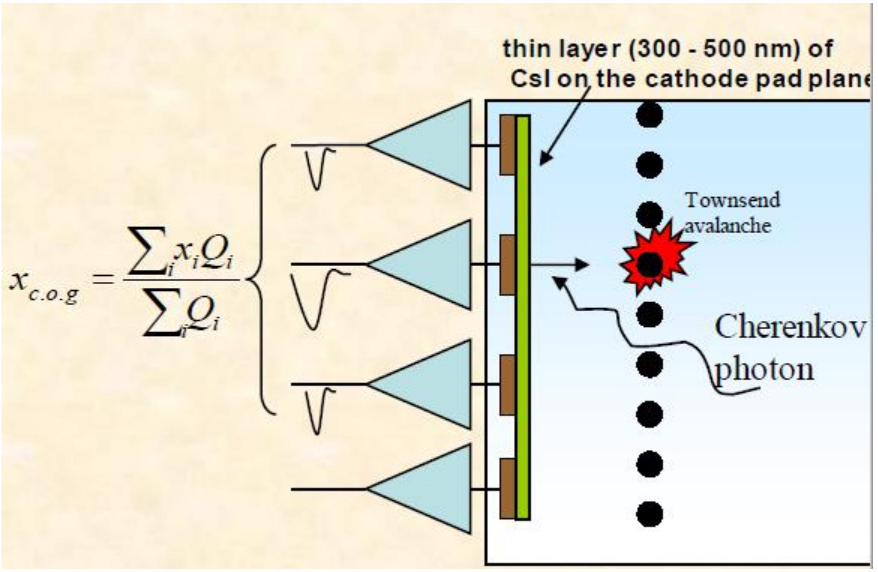
FIG. 2. Spectral distribution of the photoelectric yield for CsI surfaces: (a) thick film, (b) single crystal, (c) thin film evaporated in presence of excess Cs.

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

PHOTOELECTRIC EMISSION FROM THE VALENCE BAND OF CESIUM IODIDE

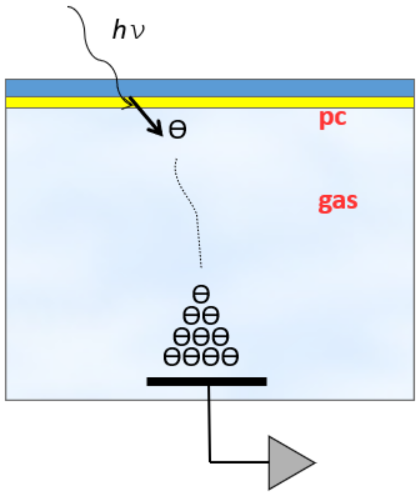
H. R. PHILIPP AND E. A. TAFT

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

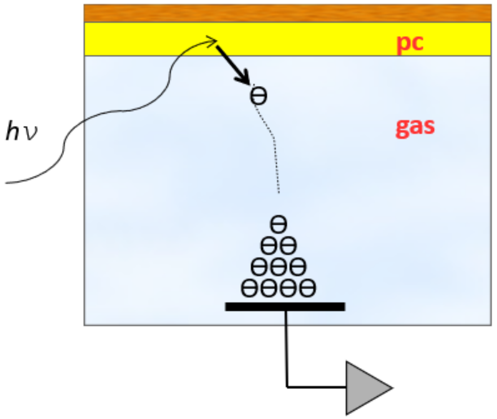


$$x_{c.o.g} = \frac{\sum_i x_i Q_i}{\sum_i Q_i}$$

semi-transparent



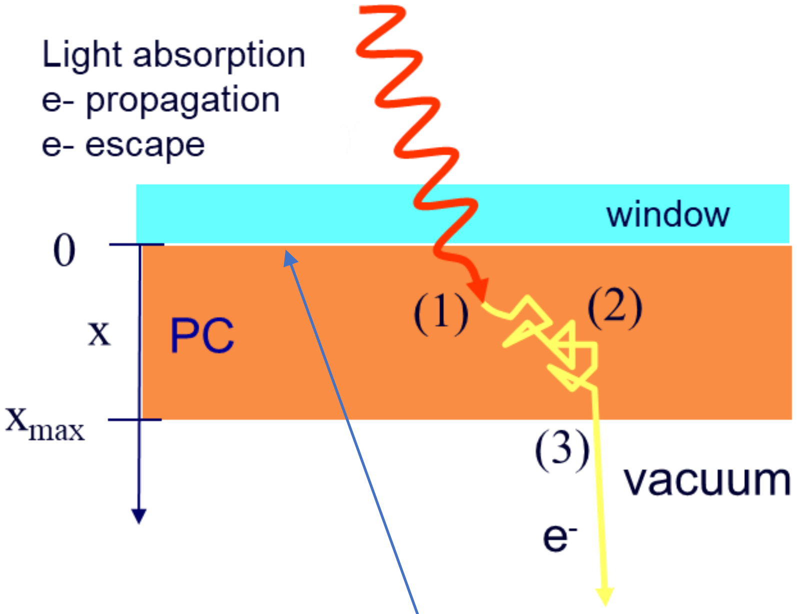
opaque/reflective

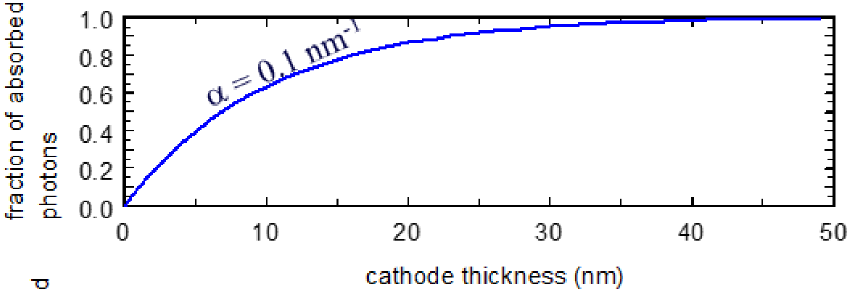


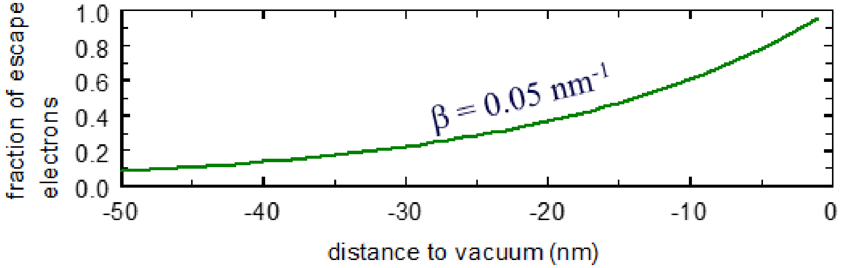
Semitransparent and reflective mode, photoelectron escape probability from thin film photocathodes

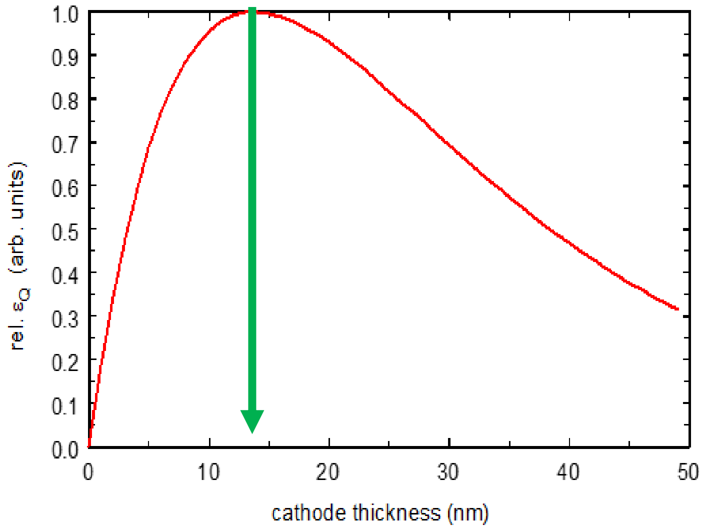
Semitransparent photocathode:

(1) Light absorption
(2) e- propagation
(3) e- escape

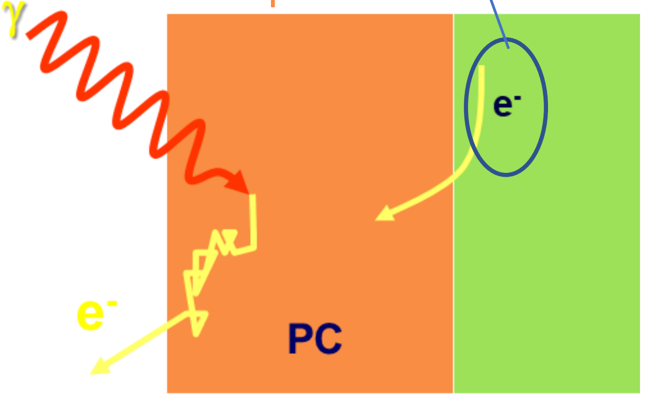


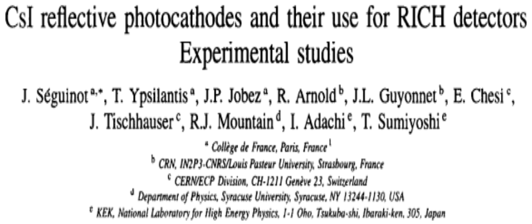






Reflective photocathode:





CsI reflective photocathodes and their use for RICH detectors
Experimental studies

J. Séguinot[a,*], T. Ypsilantis[a], J.P. Jobez[a], R. Arnold[b], J.L. Guyonnet[b], E. Chesi[c], J. Tischhauser[c], R.J. Mountain[d], I. Adachi[e], T. Sumiyoshi[e]

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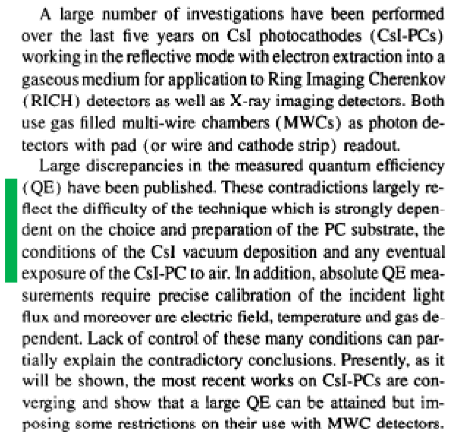
[b] CRN, IN2P3-CNRS/Louis Pasteur University, Strasbourg, France
[c] CERN/ECP Division, CH-1211 Genève 23, Switzerland
[d] Department of Physics, Syracuse University, Syracuse, NY 13244-1130, USA
[e] KEK, National Laboratory for High Energy Physics, 1-1 Oho, Tsukuba-shi, Ibaraki-ken, 305, Japan



A large number of investigations have been performed over the last five years on CsI photocathodes (CsI-PCs) working in the reflective mode with electron extraction into a gaseous medium for application to Ring Imaging Cherenkov (RICH) detectors as well as X-ray imaging detectors. Both use gas filled multi-wire chambers (MWCs) as photon detectors with pad (or wire and cathode strip) readout.

Large discrepancies in the measured quantum efficiency (QE) have been published. These contradictions largely reflect the difficulty of the technique which is strongly dependent on the choice and preparation of the PC substrate, the conditions of the CsI vacuum deposition and any eventual exposure of the CsI-PC to air. In addition, absolute QE measurements require precise calibration of the incident light flux and moreover are electric field, temperature and gas dependent. Lack of control of these many conditions can partially explain the contradictory conclusions. Presently, as it will be shown, the most recent works on CsI-PCs are converging and show that a large QE can be attained but imposing some restrictions on their use with MWC detectors.

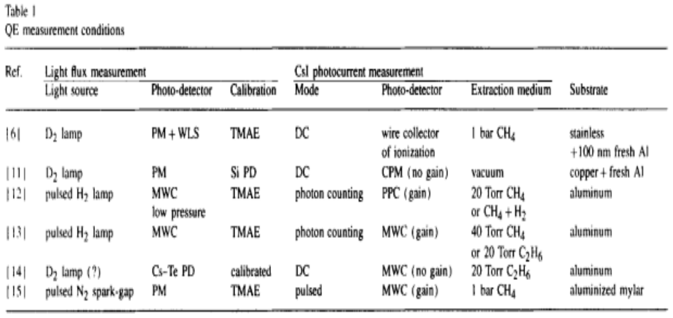


Table 1
QE measurement conditions

Ref.	Light flux measurement			CsI photocurrent measurement			
	Light source	Photo-detector	Calibration	Mode	Photo-detector	Extraction medium	Substrate
[6]	D_2 lamp	PM + WLS	TMAE	DC	wire collector of ionization	1 bar CH_4	stainless +100 nm fresh Al
[11]	D_2 lamp	PM	Si PD	DC	CPM (no gain)	vacuum	copper + fresh Al
[12]	pulsed H_2 lamp	MWC low pressure	TMAE	photon counting	PPC (gain)	20 Torr CH_4 or $CH_4 + H_2$	aluminum
[13]	pulsed H_2 lamp	MWC	TMAE	photon counting	MWC (gain)	40 Torr CH_4 or 20 Torr C_2H_6	aluminum
[14]	D_2 lamp (?)	Cs-Te PD	calibrated	DC	MWC (no gain)	20 Torr C_2H_6	aluminum
[15]	pulsed N_2 spark-gap	PM	TMAE	pulsed	MWC (gain)	1 bar CH_4	aluminized mylar

RD26: MWPC coupled to CsI for the large area fast rich detectors

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

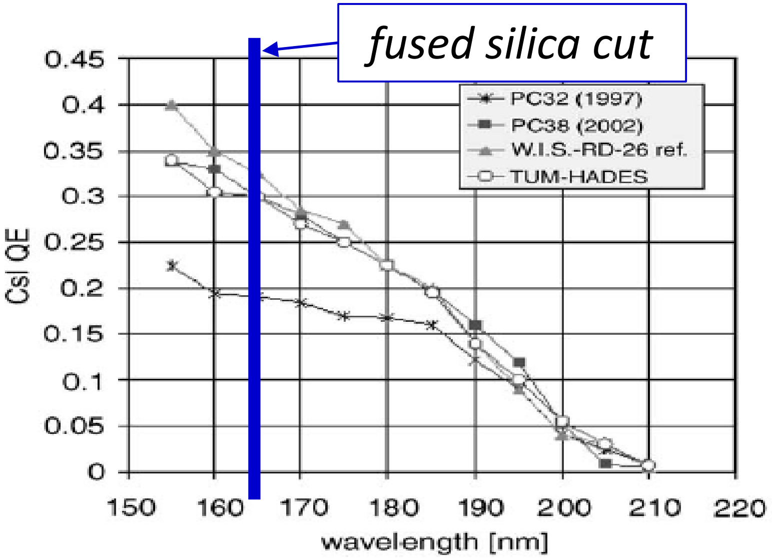


Fig. 1. The QE of CsI PCs produced at CERN for ALICE and at TUM for HADES, compared to that measured at the W.I.S. on small samples (reference for RD-26). PC32 is one of the four PCs equipping the ALICE-RICH prototype used in STAR at BNL.

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

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 °C 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

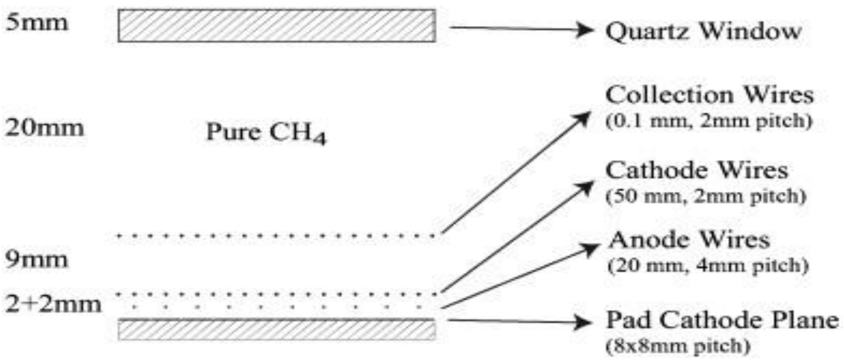
Thermal treatment:

after deposition at 60 °C for 8 h

Careful Handling:

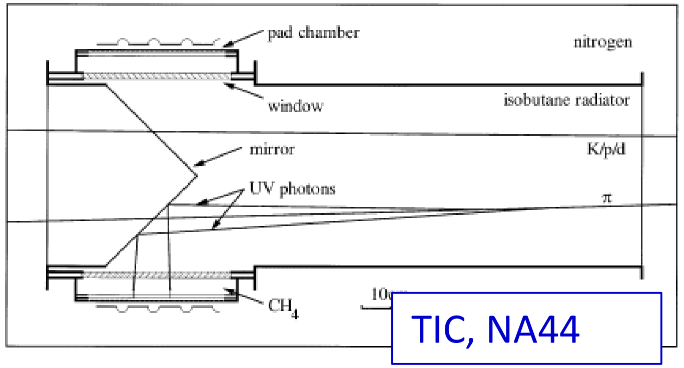
measurement of PC response, encapsulation under dry Ar, mounting by glove-box.

Schematic structure of the Photon Detector:



RICH with large area single photon detector based on CsI and MWPC, the second generation

MWPCs with solid state photocathode (the RD26 effort)

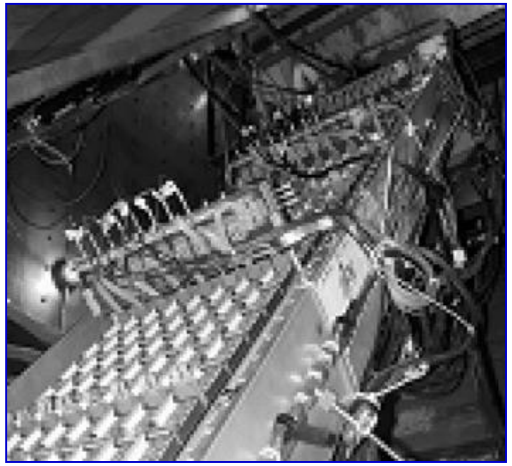


TIC, NA44

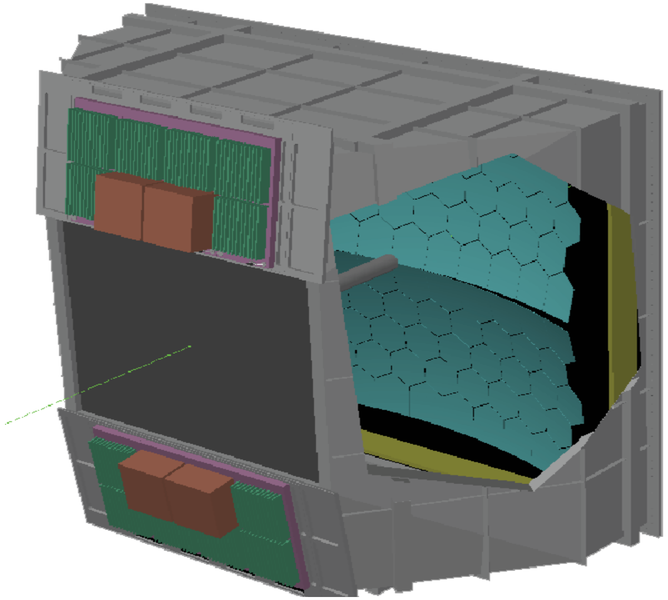
Table 1: Technical specifications for the TIC photon detection chambers

Active area	78 × 19 cm^2
Number of pads	96 × 24
Pad size	8 × 8 mm^2

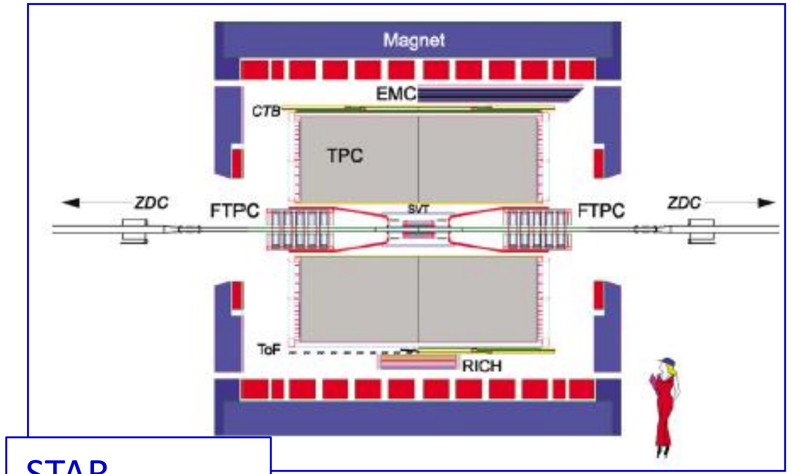
ALICE-HMPID
2009
CsI > 10 m^2



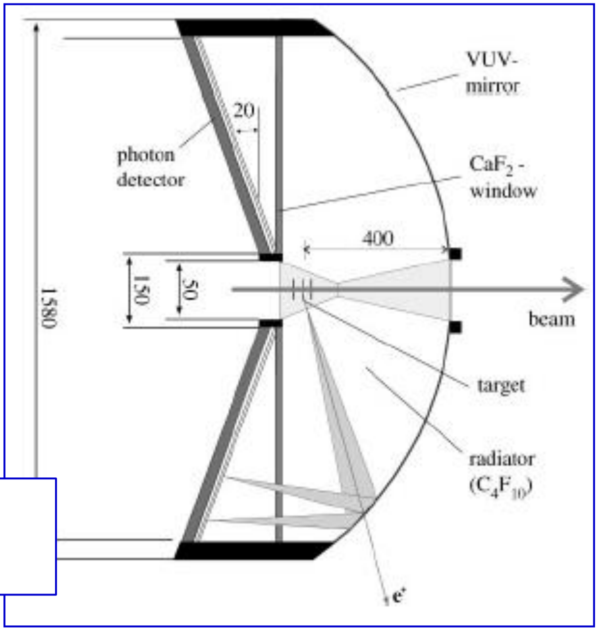
JLAB-HALL A



COMPASS RICH-1 2002 CsI > 5 m^2

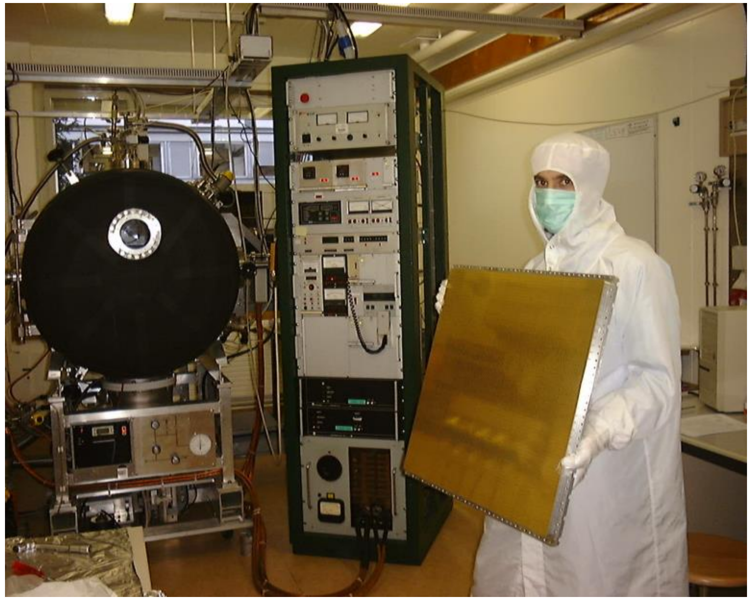


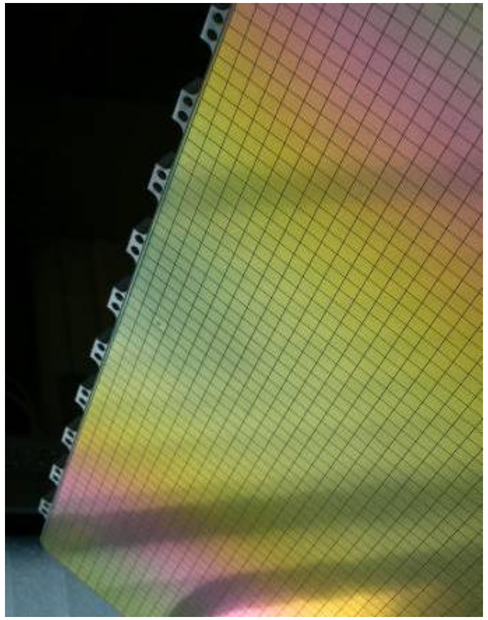
STAR
CsI ~ 1 m^2

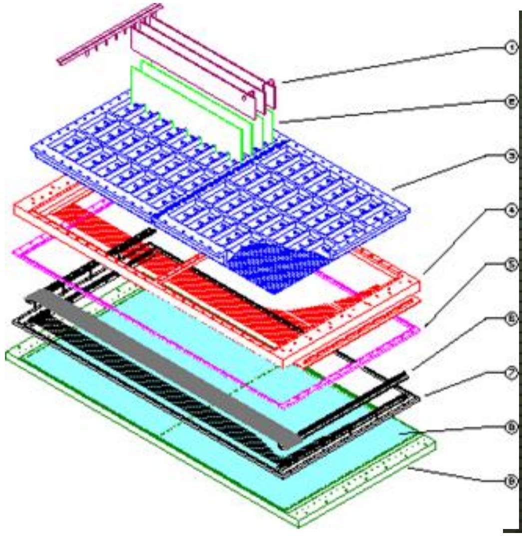


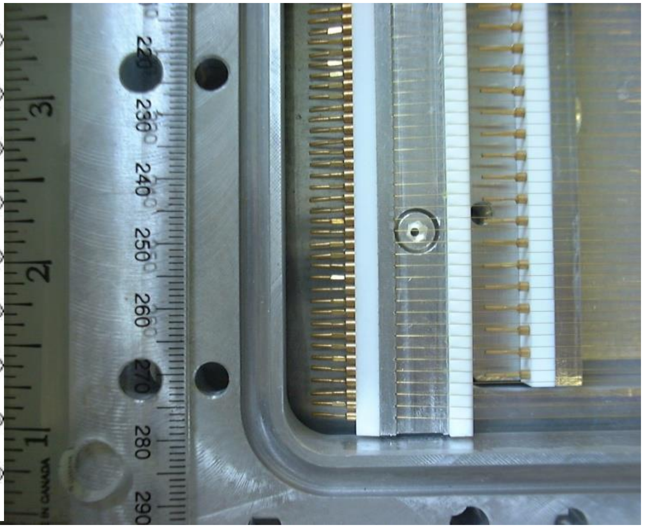
HADES 1999
CsI > 1 m^2

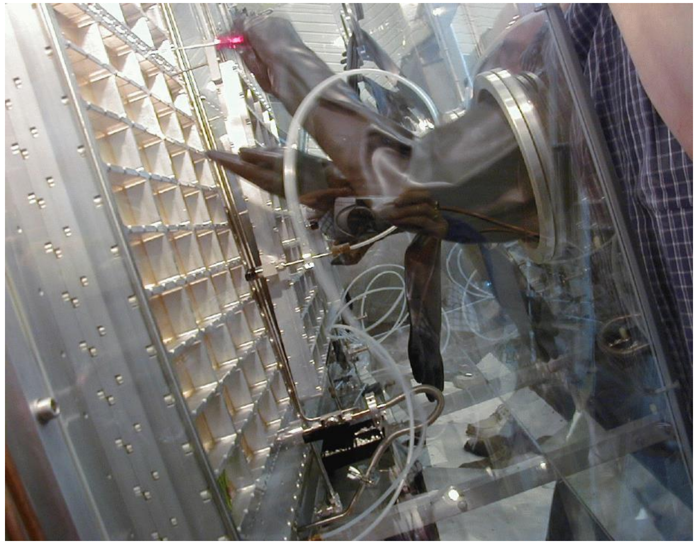
The COMPASS RICH photodetectors











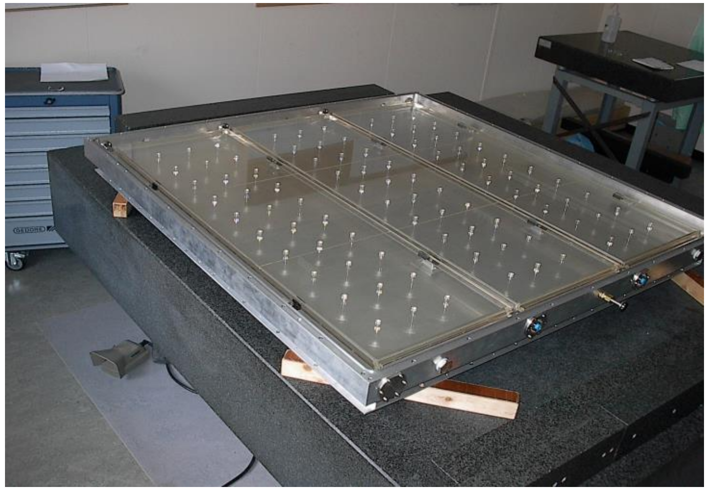
The ALICE RICH photodetectors

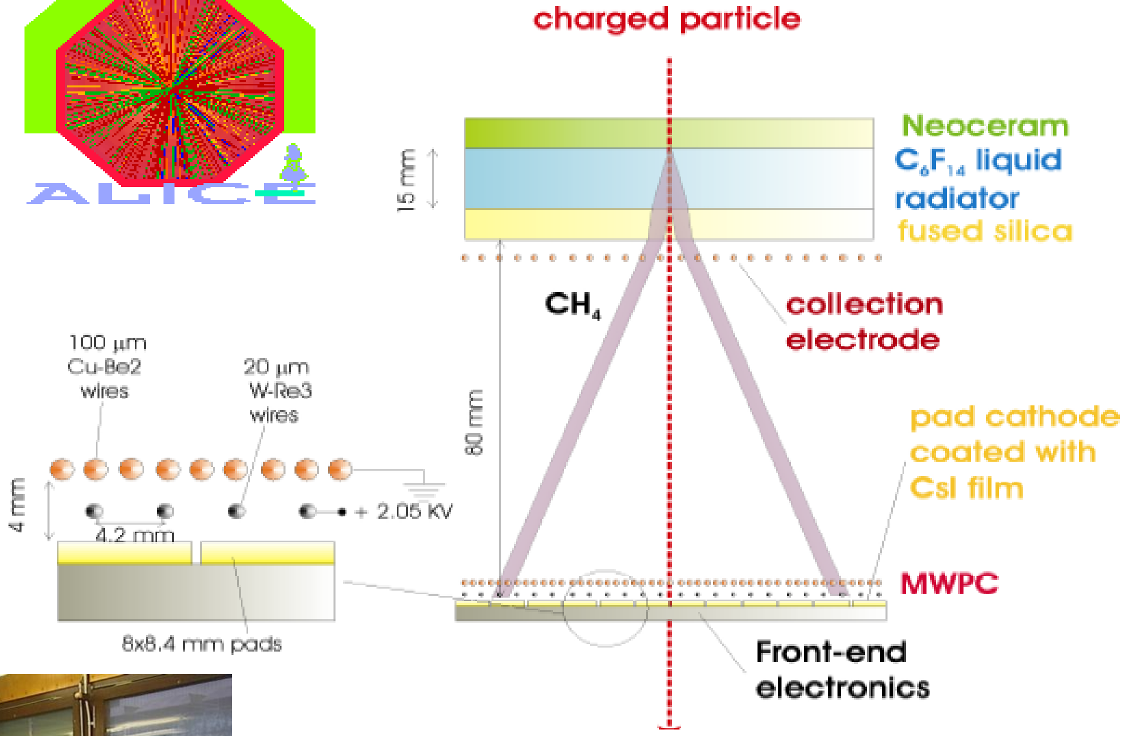
RADIATOR: 15 mm liquid C_6F_{14},
n ~ 1.2989 @ 175nm, $\beta_{th} = 0.77$

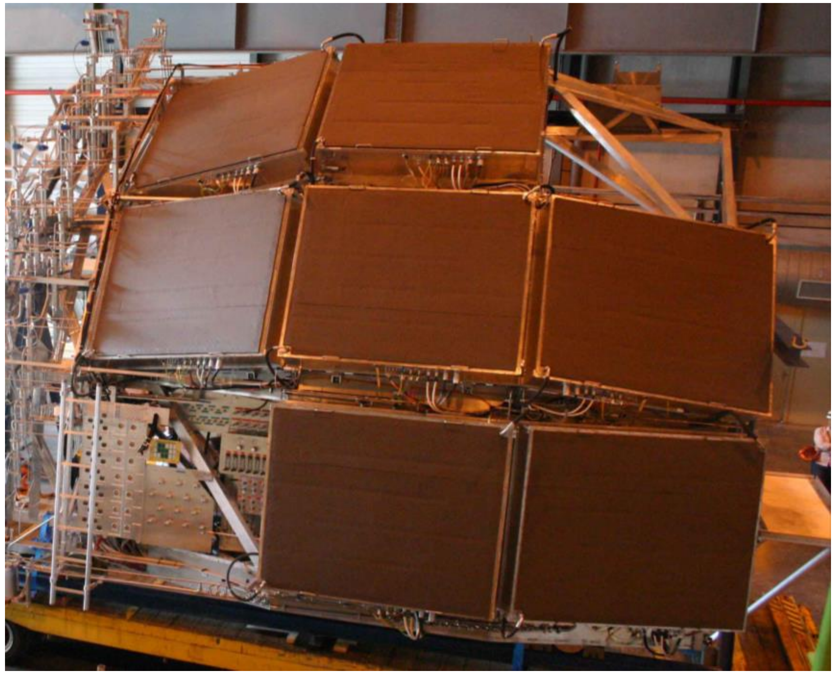
PHOTON CONVERTER: Reflective layer of CsI (QE ~ 25% @ 175 nm)

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

- Analogue pad readout







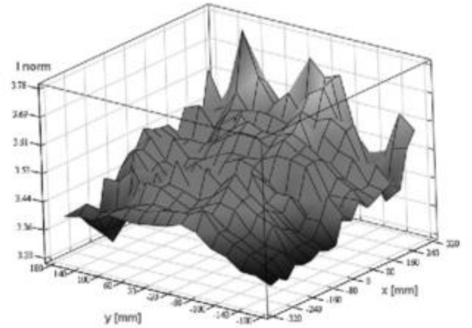
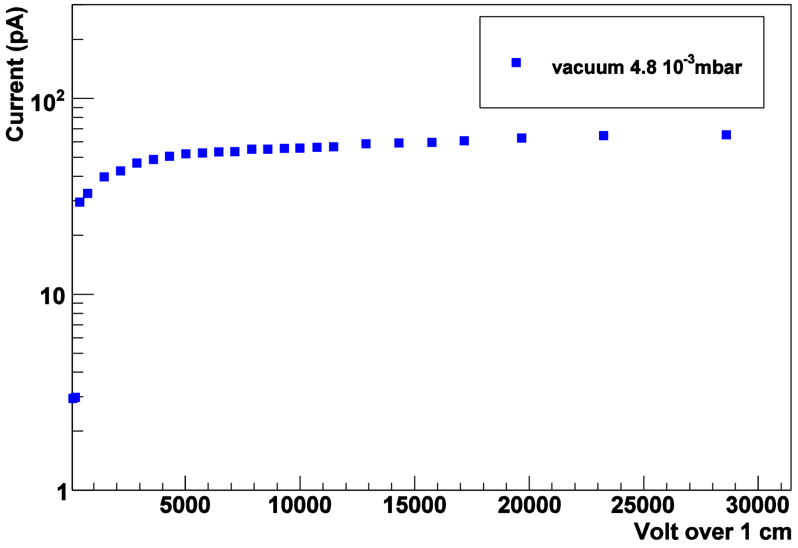
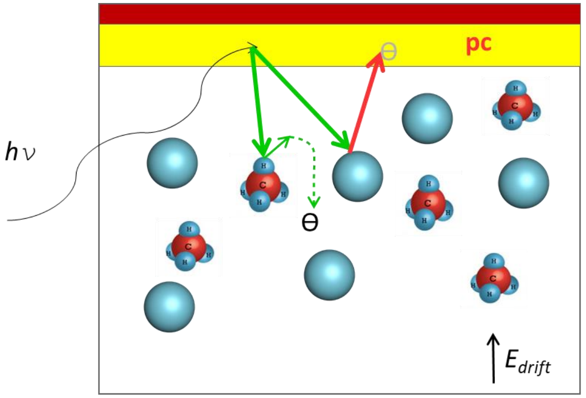


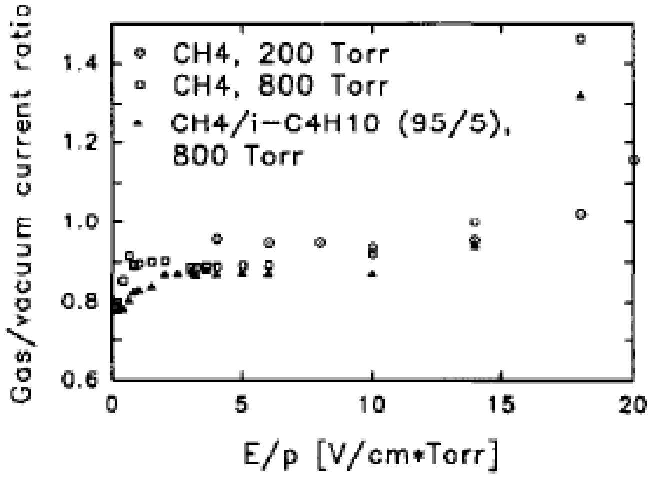
Fig. 4. The normalized photocurrent response mapping of PC45 characterized by an average of 3.5 over the full sensitive area.

Full QC of the Photon detector

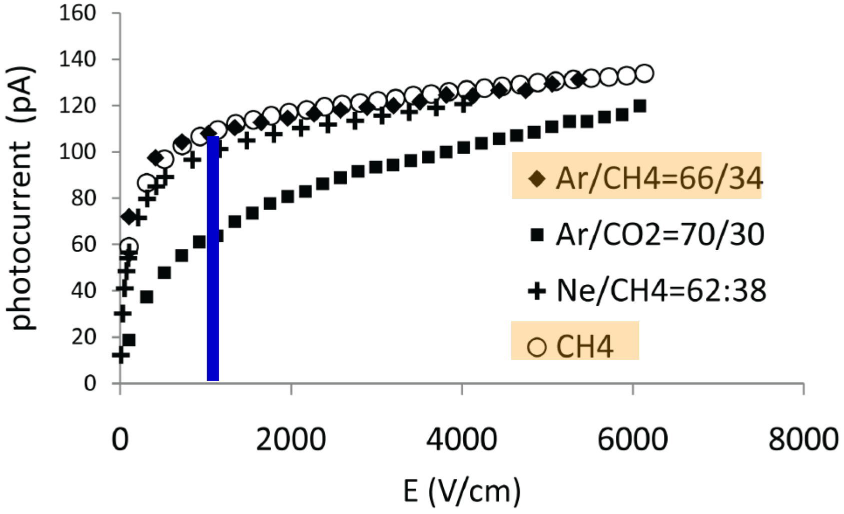
Photoelectron extraction from a CsI film, the role of gas and E





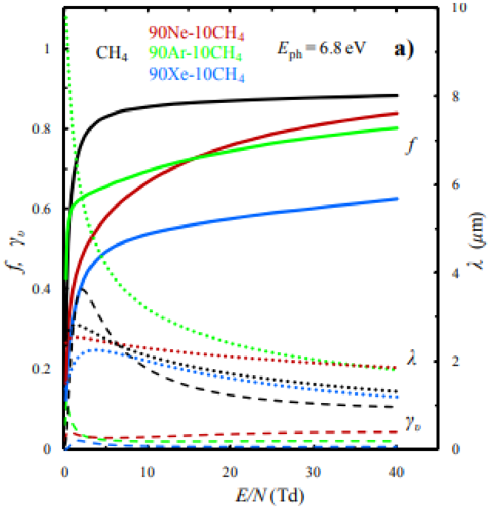


A. Breskin et al., NIM A 367 (1995) 342

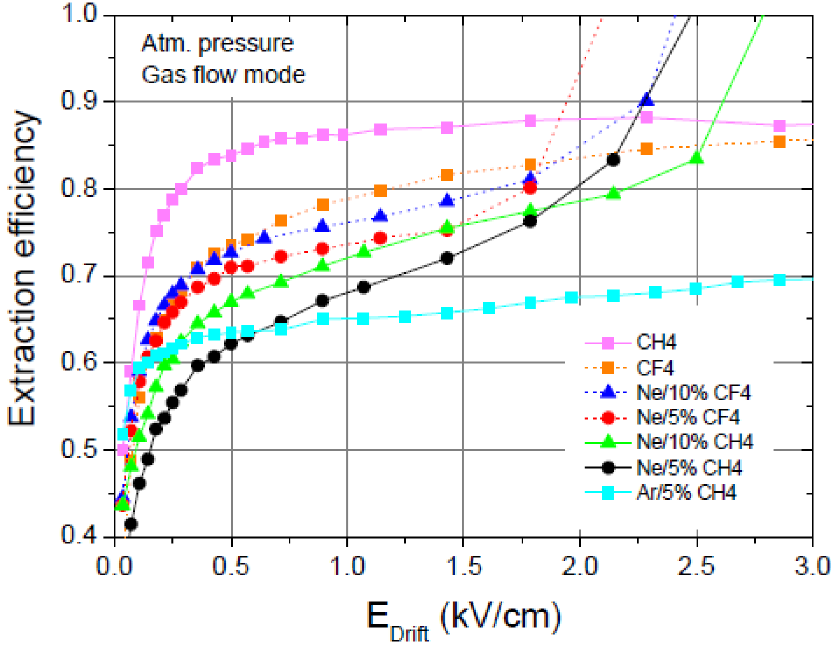


M. Alexeev et al., NIM A (2010)

Backscattering of photoelectrons in the gas medium → QE degradation



Escada et al., J. of Physics D 43(2010)65502



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

The limits of the CsI and MWPC technology

Severe recovery time (~ 1 d) after detector trips

Ion accumulation at the photocathode

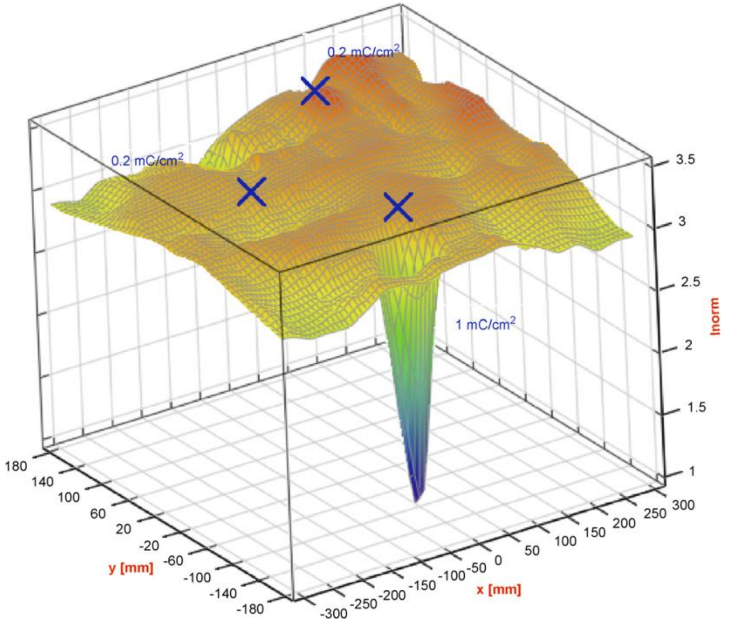
Feedback pulses

Ion and photons feedback from the multiplication process ***2pi → 50%***

Aging after integrating a few mC / cm^2

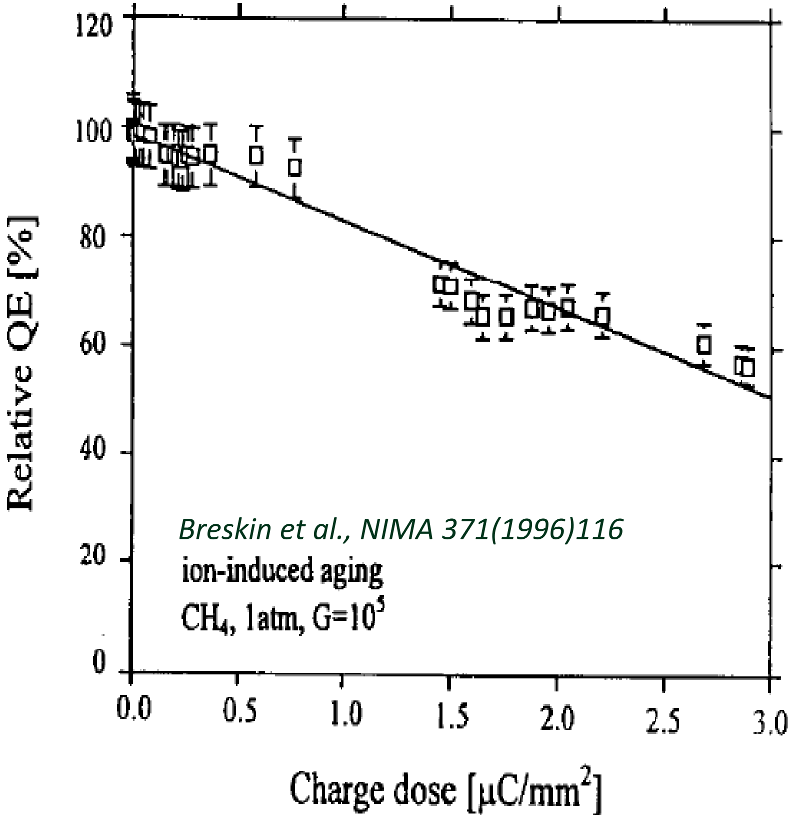
Ion bombardment of the photocathode 50, 60 %

Operation at moderate gain < 10^5



Degradation not well understood – physical and chemical mechanisms competing? Evaporation? Cesiation?..

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



Breskin et al., NIMA 371(1996)116

MPWC based signal

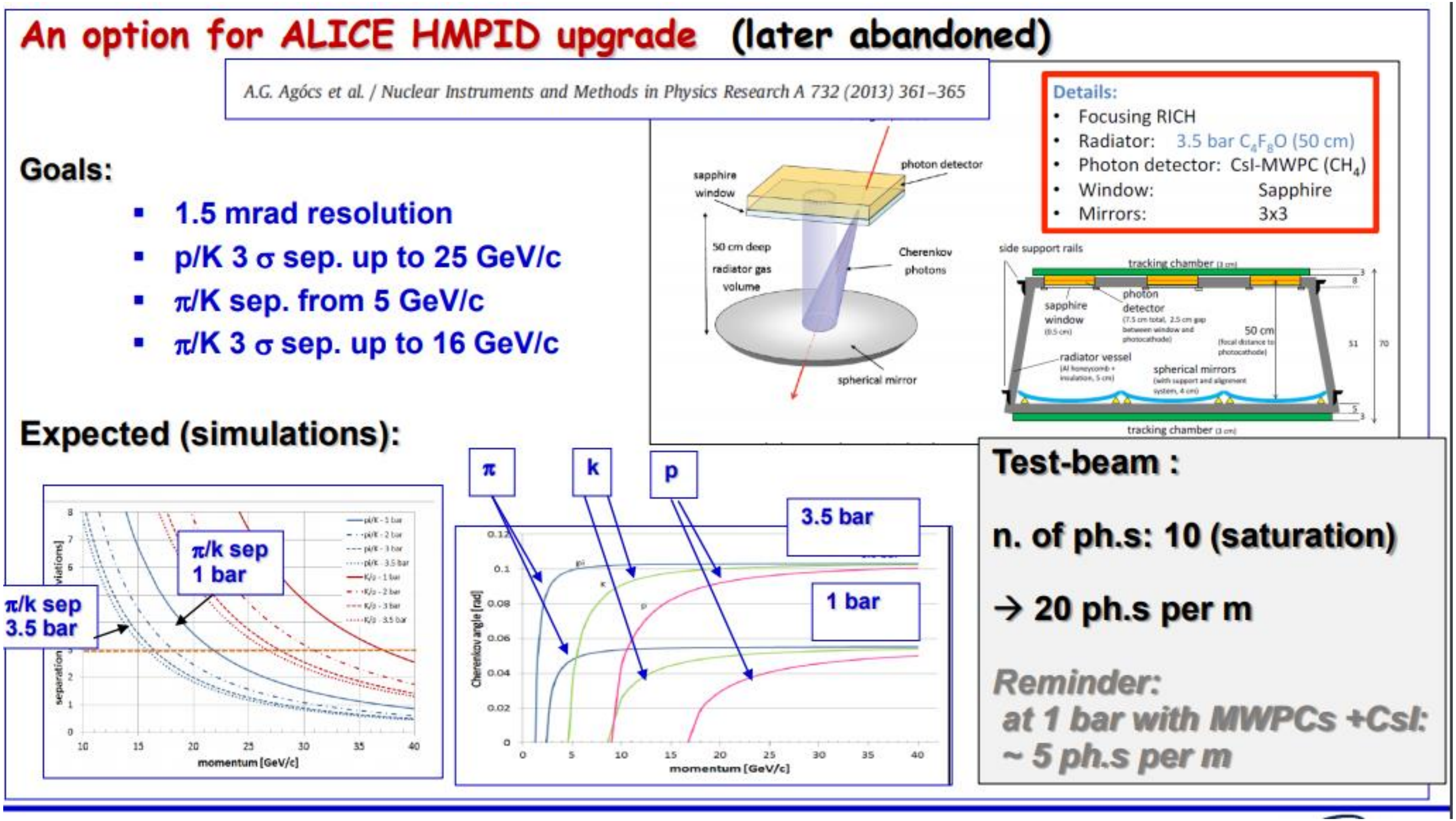
slow signal formation μs and low gain

→ "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

An option for the ALICE HMPID upgrade



An option for ALICE HMPID upgrade (later abandoned)

A.G. Agócs et al. / Nuclear Instruments and Methods in Physics Research A 732 (2013) 361–365

Goals:

- 1.5 mrad resolution
- p/K 3 σ sep. up to 25 GeV/c
- π/K sep. from 5 GeV/c
- π/K 3 σ sep. up to 16 GeV/c

Details:

- Focusing RICH
- Radiator: 3.5 bar C_4F_8O (50 cm)
- Photon detector: CsI-MWPC (CH_4)
- Window: Sapphire
- Mirrors: 3x3

Expected (simulations):

Test-beam :

n. of ph.s: 10 (saturation)

→ 20 ph.s per m

Reminder:
at 1 bar with MWPCs +CsI:
~ 5 ph.s per m

The MPGD era

The Micro Pattern Gaseous Detector technology triggered new possibilities for Gaseous PD performance

Intrinsic mitigation of the photon feedback

Strategies for Ion backflow reduction

High gain

High position resolution

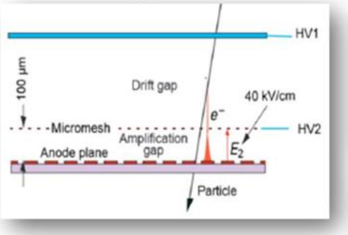
Fast signals

Visible sensitivity

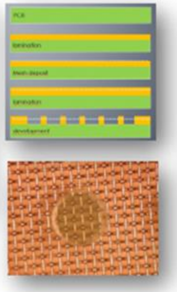
Nano/Pico second resolution

- High Rate Capability
- High Gain
- High Space Resolution
- Good Time Resolution
- Good Energy Resolution
- Excellent Radiation Hardness
- Good Ageing Properties
- Ion Backflow Reduction
- Photon Feedback Reduction
- Large Size
- Low Cost

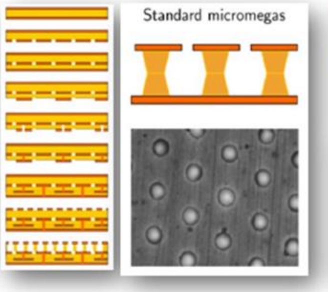
Micromegas



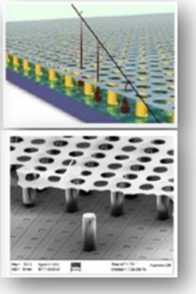
Bulk



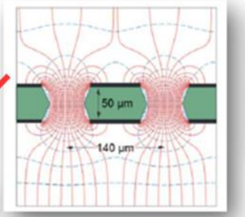
Micro bulk



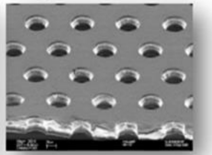
InGrid



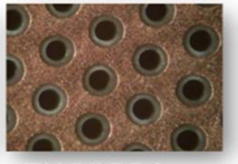
GEM



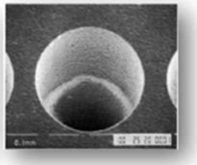
50µm GEM



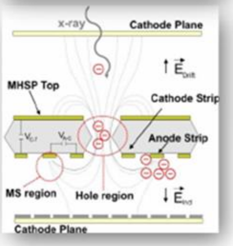
THGEM

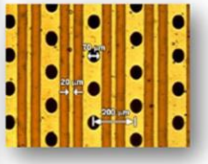


GLASS GEM

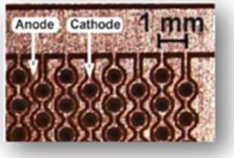


MHSP

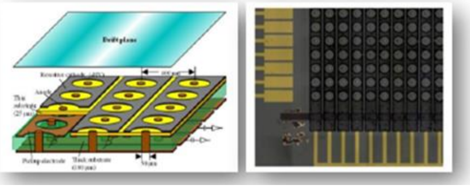




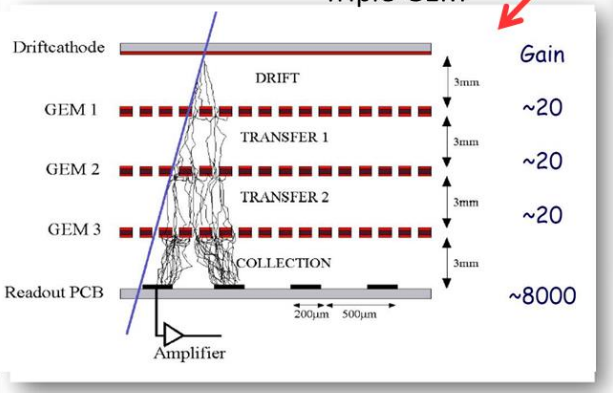
THCOBRA



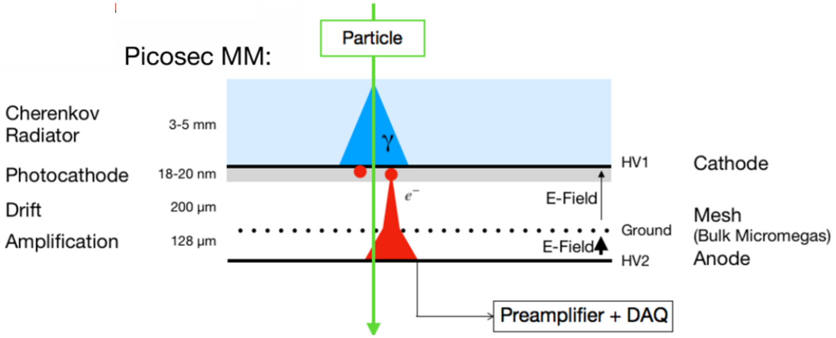
µPIC



Triple-GEM



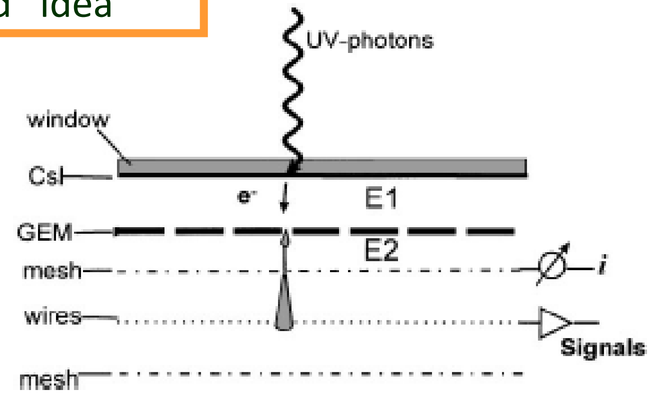
Picosec MM:



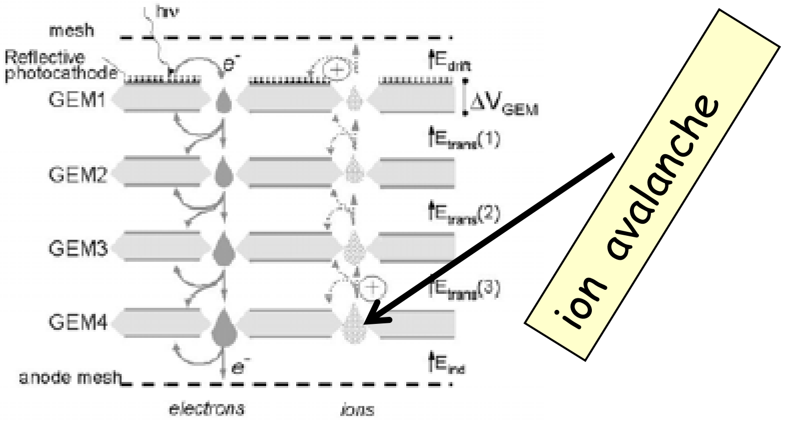
The MPGD ion and photon feedback suppression

No photon feedback, reduced ion feedback

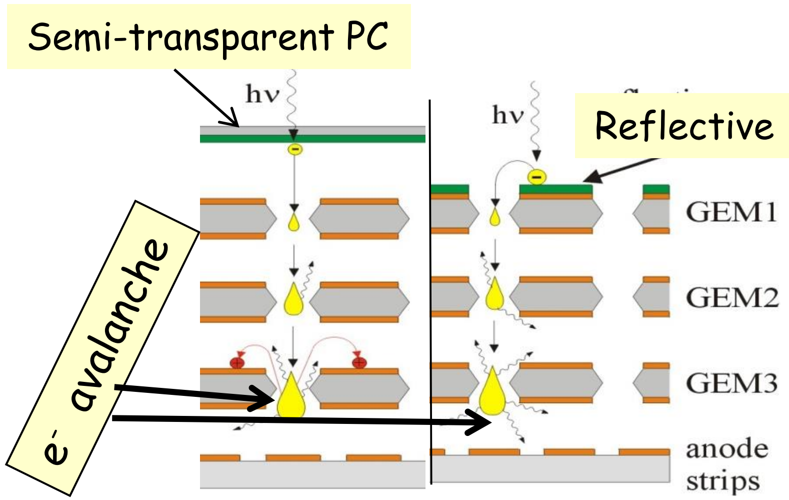
An “old” idea



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



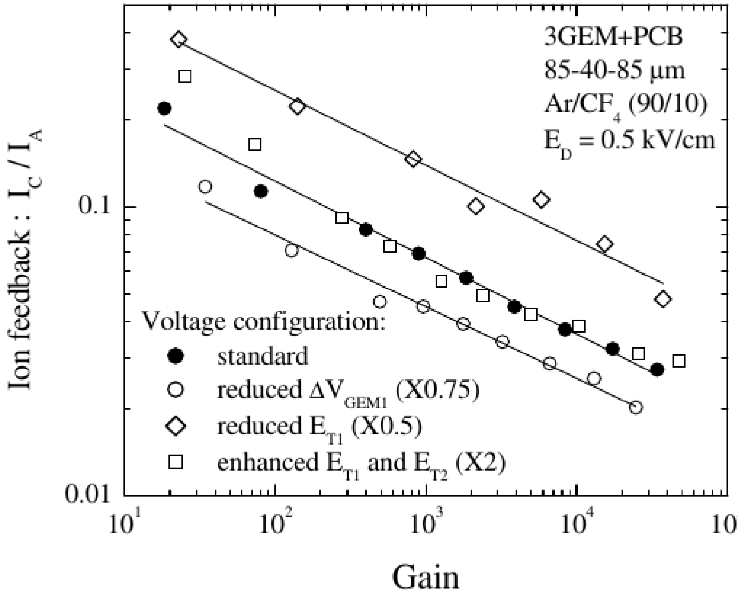
A. Breskin and R. Chechik, NIM A 595 (2008) 116



3% IBF @ 0.5 kV/cm
Gain ~ 10^5

- **triple gem with CsI pc**
- **semi-transparent vs reflective pc**
- **typical stable gains ~ 10^5**
- **large area > 1 m^2 can be produced**

Bachman et al. NIMA 438(1999)376
Breskin et al. NIMA 478(2002)225
Bondar et al. NIMA 496(2003)325
Chechik and Breskin NIMA 595(2008) 116



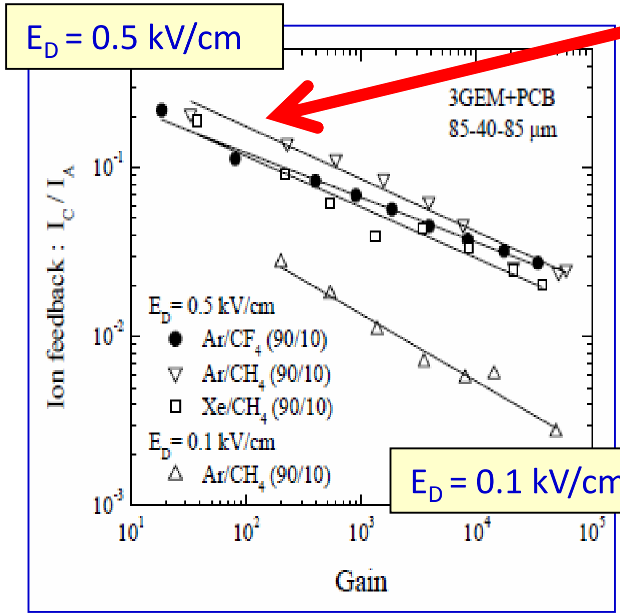
IFB in GEM-based detectors

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

semi-transparent PC

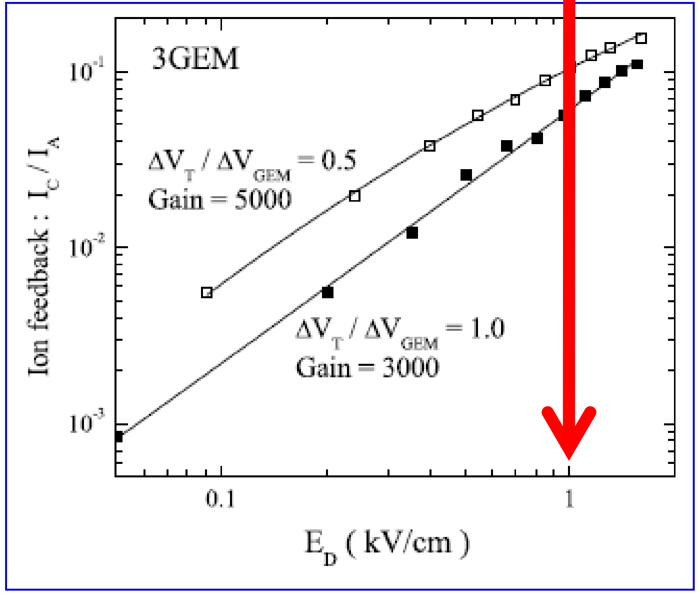
E ~ 1 kV/cm needed for good photoelectron extraction

E_D = 0.5 kV/cm

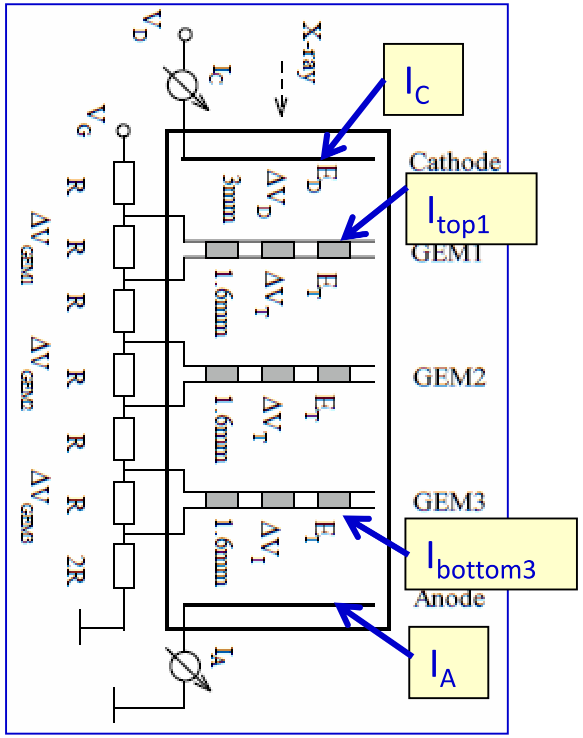


E_D = 0.1 kV/cm

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

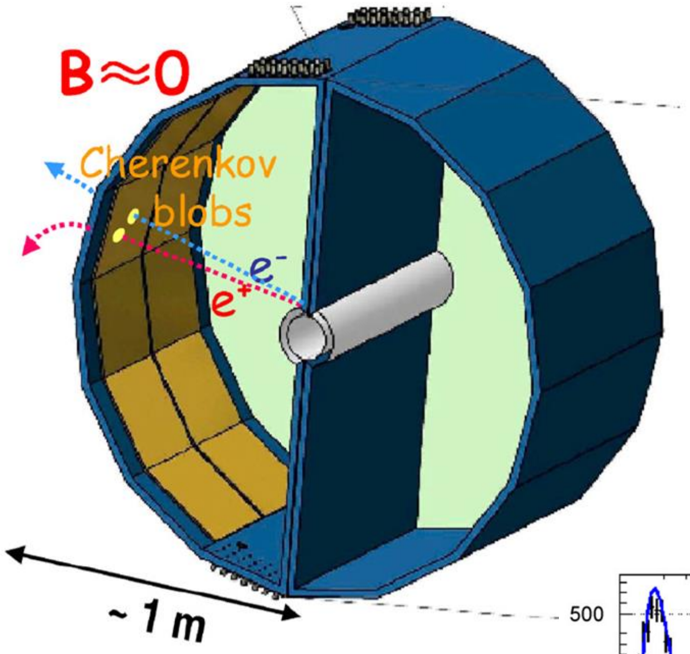


A. Breskin et al., NIMA 478 (2002) 225d

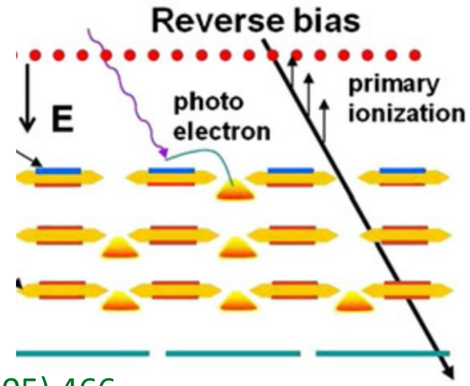


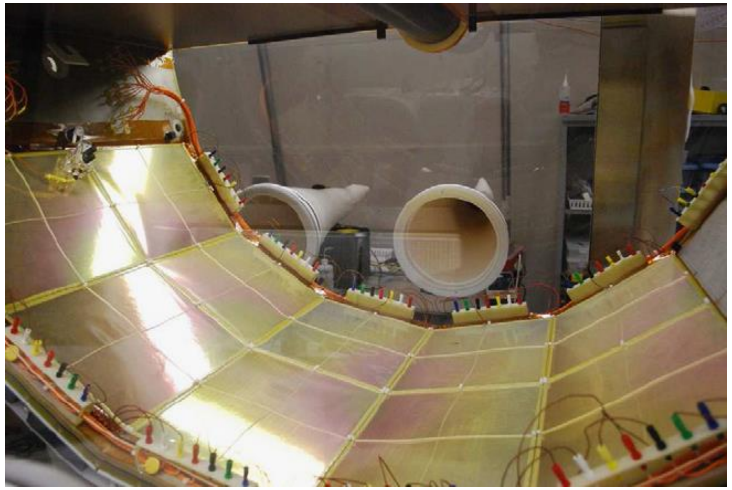
IBF: a few % level in effective GEM-based photon detectors

Hadron-Blind detector (HBD) at RHIC-PHENIX reflective mode



- Triple GEM
- CsI reflective pc
- G~10^4





Anderson et al., NIMA 546 (2005) 466.

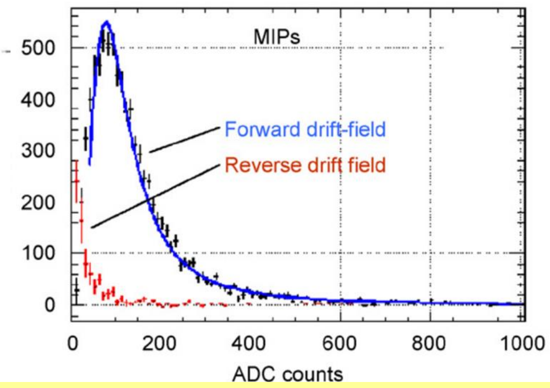
S. Milov, et al., J. Phys. G: Nucl. Part. Phys. 34 (2007) S701

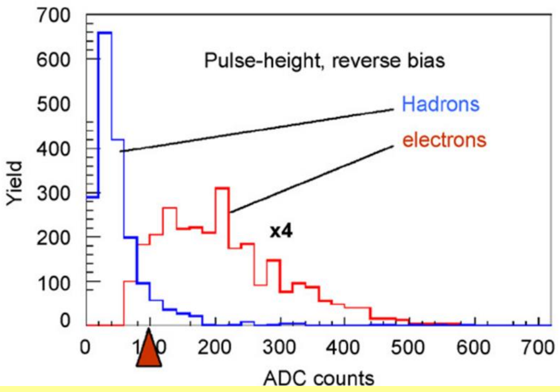
Z. Fraenkel, et al., NIMA 546 (2005) 466.

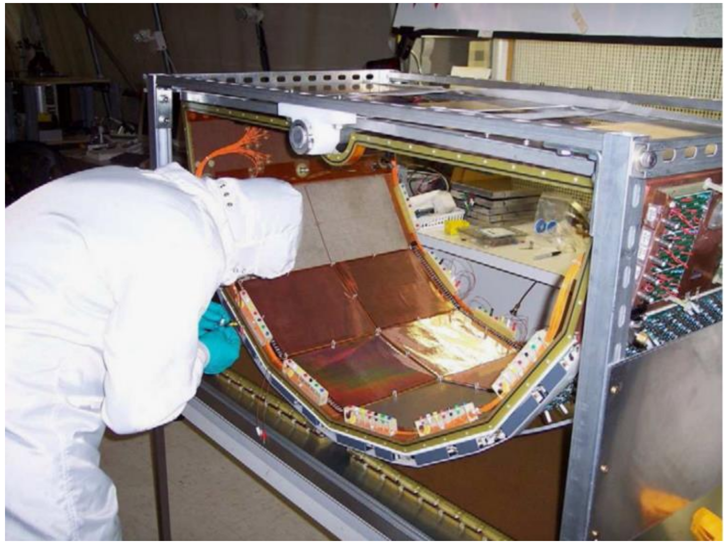
-Proximity focus configuration, no window, no mirror

-CF4 radiator and active gas.

-Lrad=50 cm Very large bandwidth 108 – 200 nm







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 several years

d. <u>It is not a detector of single photons</u>

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

PCB technology, thus:

robust

mechanically self supporting

industrial production of large size boards

large gains can be easily achieved (rim !)

Gain stability is challenging

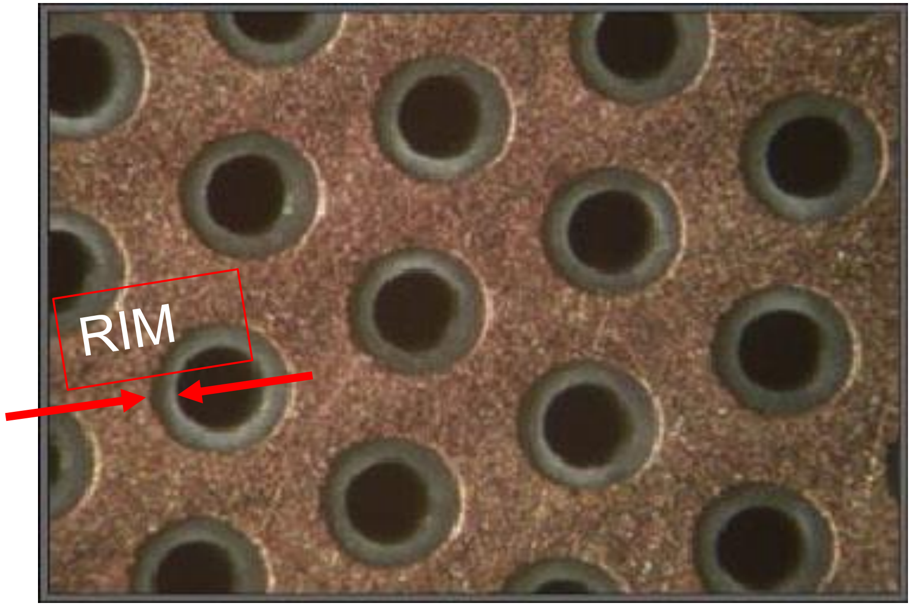
Comparing to GEMs

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

About PCB geometrical dimensions:

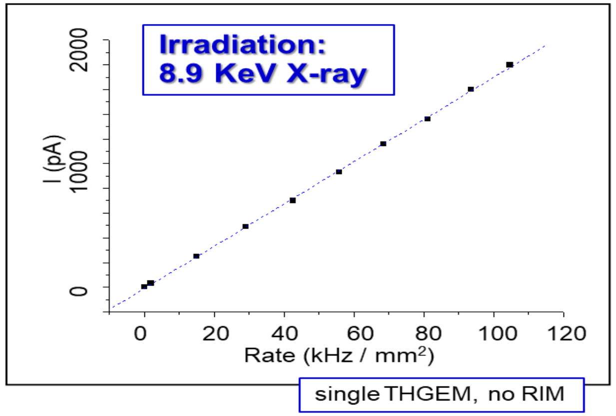
Hole diameter : 0.2 – 1 mm
Pitch : 0.5 – 5 mm
Thickness : 0.2 – 3 mm



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

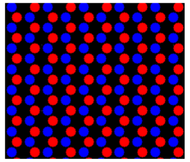
THGEM-based PD

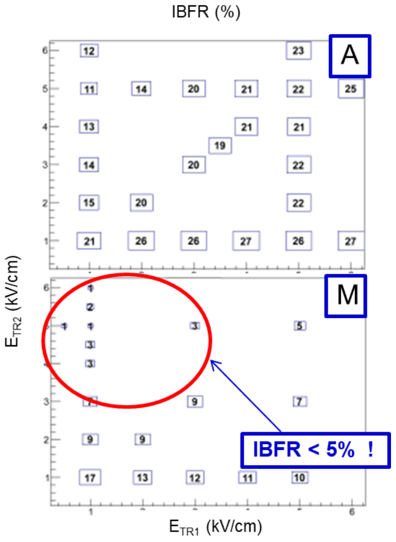
High-rate device



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

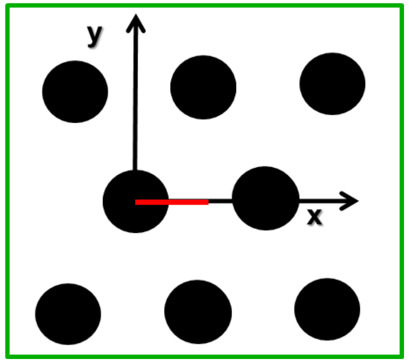
Triple THGEM:
Ion Back Flow
reduction by
staggering plates

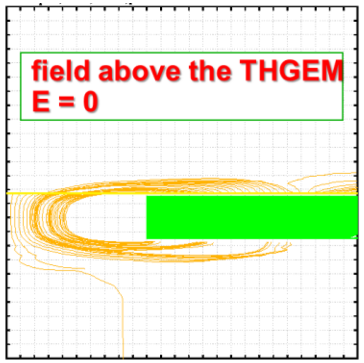


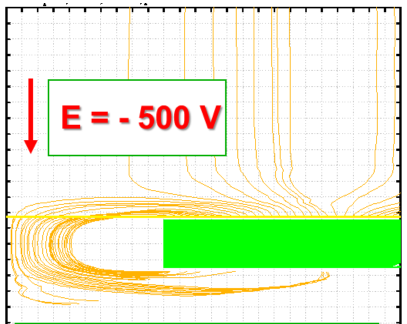


M. Alexeev et al., JINST 7 (2012) C002014

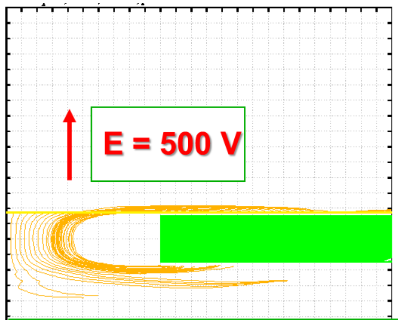
photoelectron trajectories from a THGEM photocathode,simulation, multiplication switched off
thickness 0.6 mm, diam. 0.4 mm,
pitch: 0.8 mm, ΔV = 1500 V





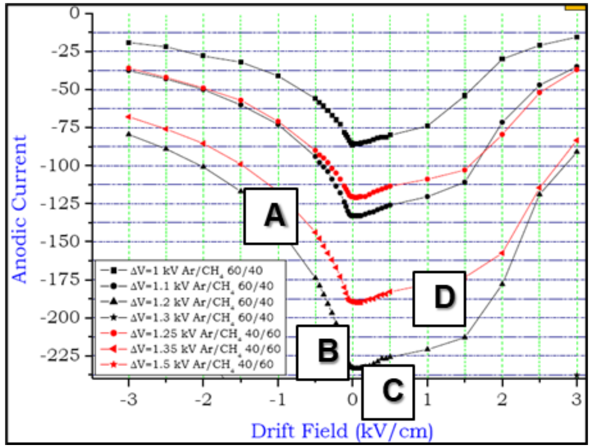


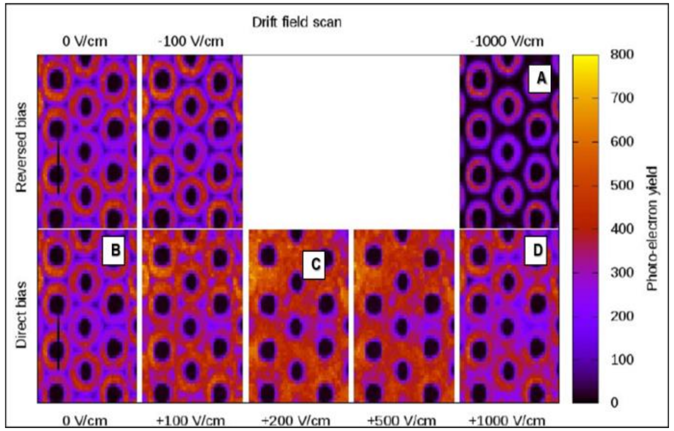
photoelectrons lost
(not entering the holes)

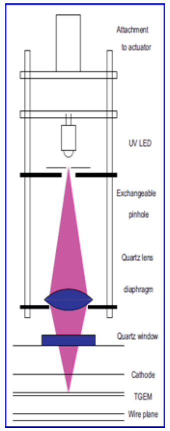


photoelectrons lost
(field too low for extraction)

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

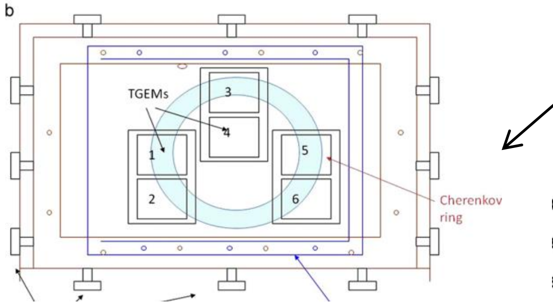






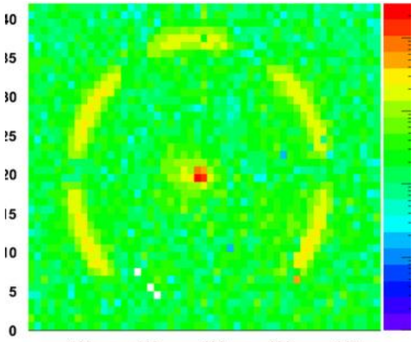
G.Hamar and D.Varga,
NIMA 694(2012) 16

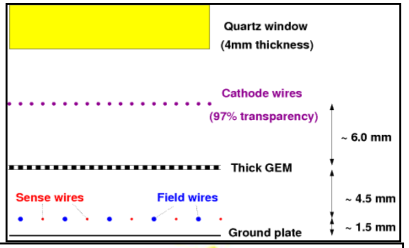
Ne+10%CH4, used with ΔV at 650-750 V

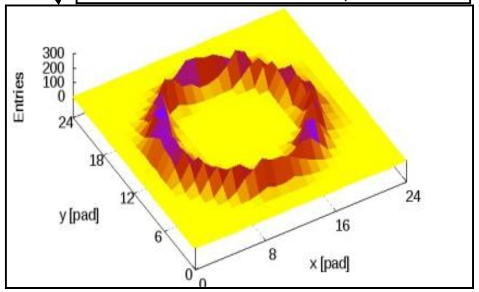


V.Peskov et al., NIMA 695 (2012) 154

ALICE VHMPID
THGEM & HYBRID



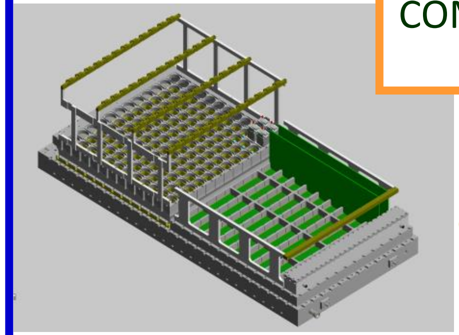




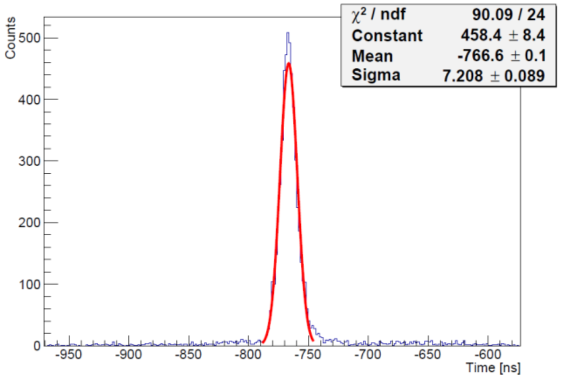
N of detected photons is ~60-70% of MWPCs with CsI

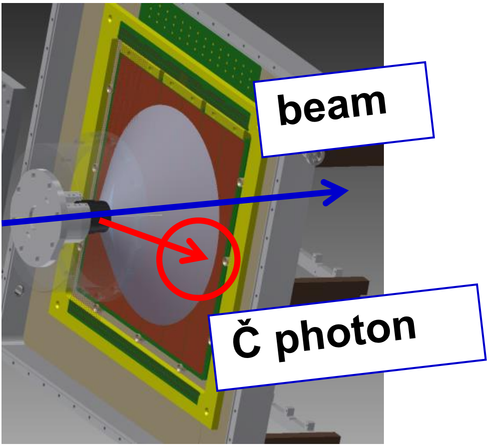
5. Conclusions and Outlook

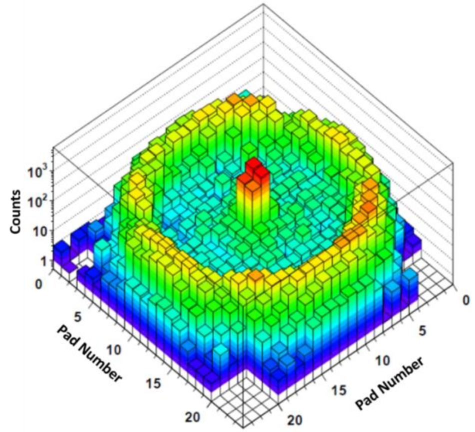
We report the first successful implementation of a set of CsI-TGEMs with a liquid radiator where a Cherenkov ring has been observed. The results obtained are encouraging and suggest that the present performance could be improved in the future by optimizing elements of the design. We are launching now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



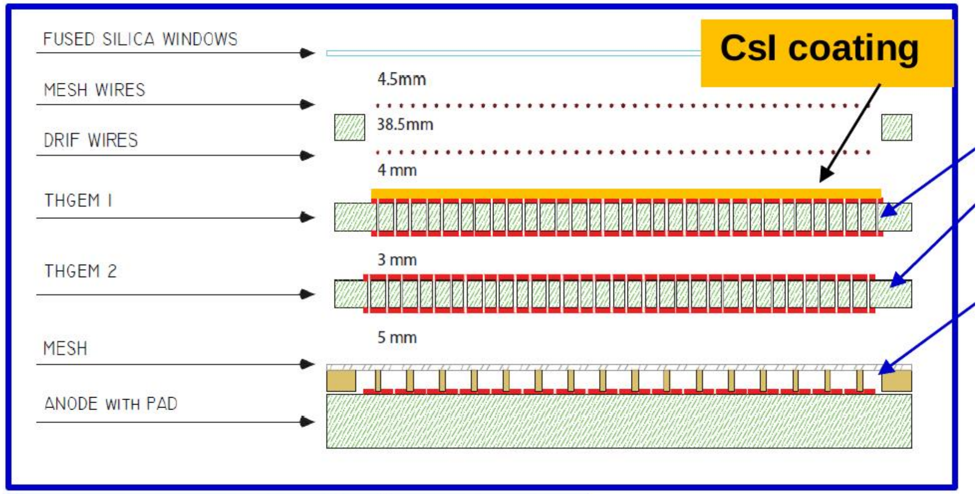
COMPASS, RICH-1 upgrade by Triple THGEM detectors







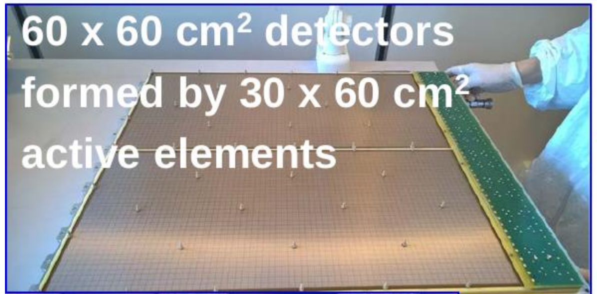
THGEMs+Resitive Micromegas combination



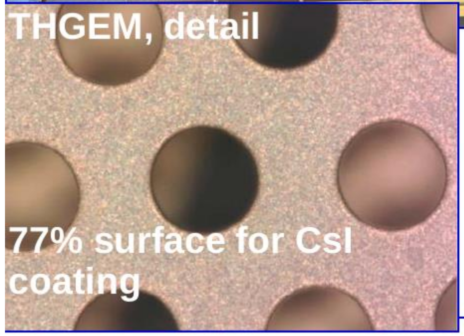
THGEM 1- provide support for the CsI *pc*, gain and partial block of ions and photons

THGEM 2 -extra gain and extra ion blocking and **charge splitting**

Micromegas – discrete element approach efficient for ion trap and provide extra gain and spark mitigation



60 x 60 cm² detectors formed by 30 x 60 cm² active elements

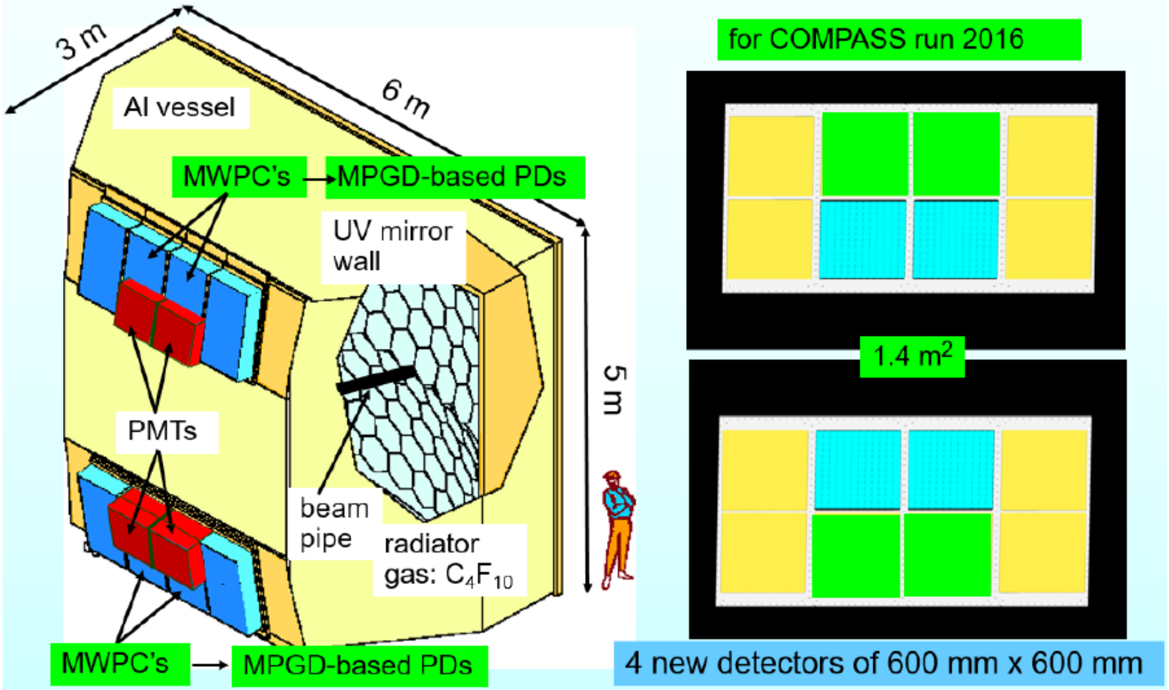


THGEM, detail

77% surface for CsI coating

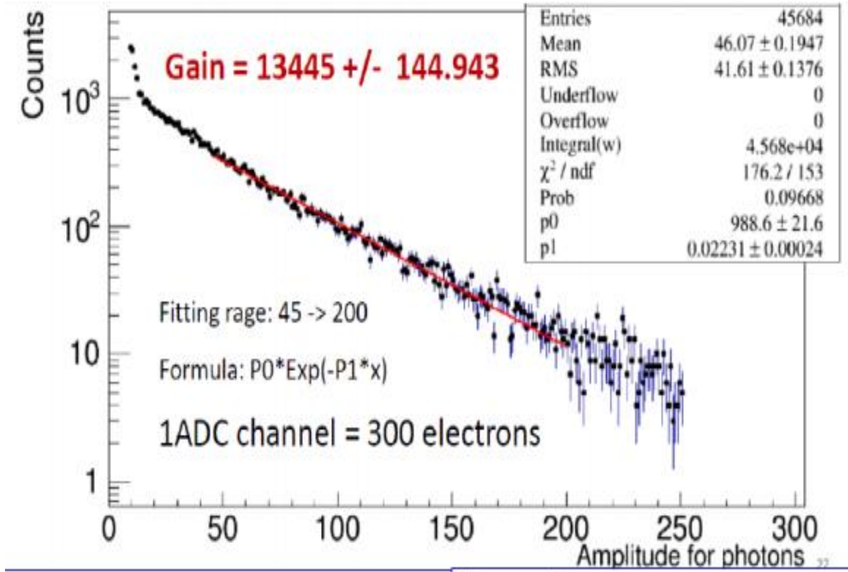
Bulk MICROMEGAS, detail

Micromesh support pillars (diam. 0.4 mm, pitch 2 mm → 8‰ dead area)



4 new detectors of 600 mm x 600 mm

THGEMs+Resitive Micromegas combination, performance

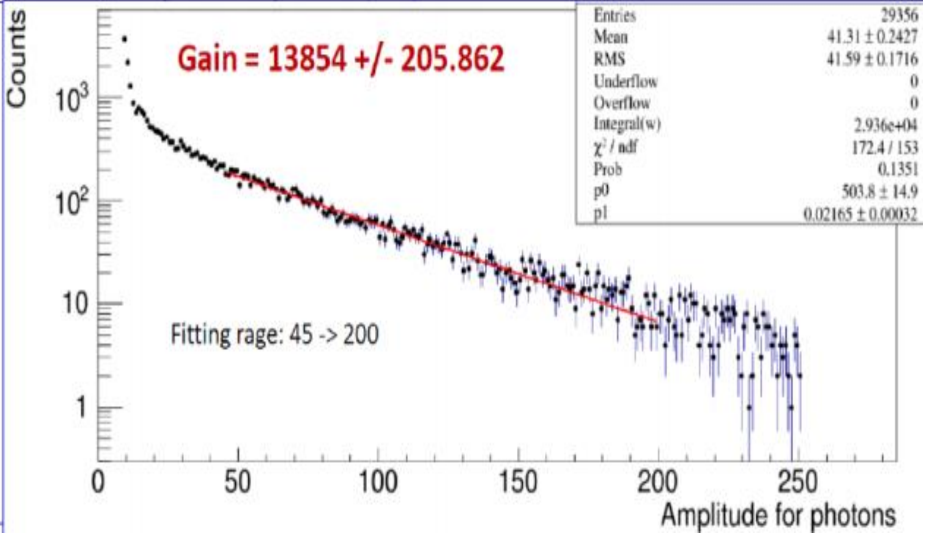


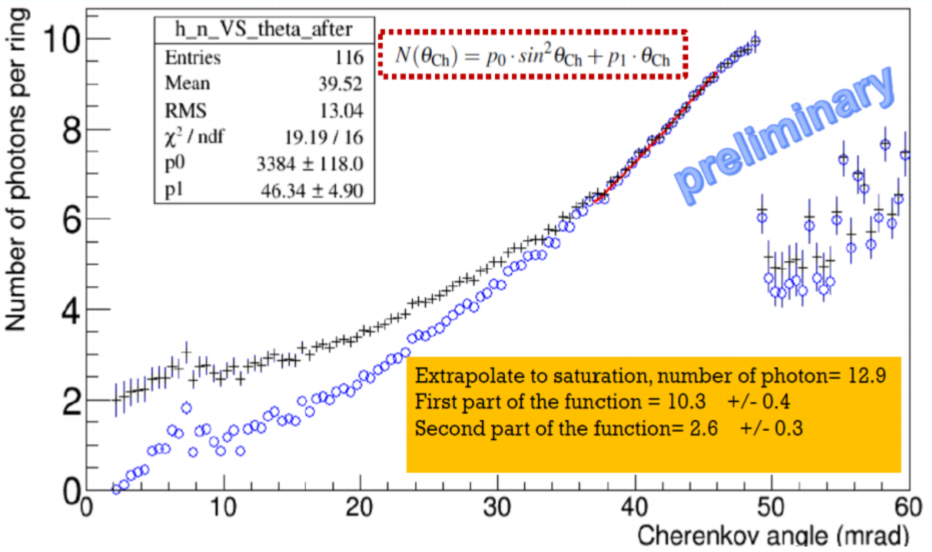
From electronic noise → Threshold

From threshold & gain → **photoelectron detection (effective) efficiency > 80%**

For comparison, in MWPCs: ~50-60%

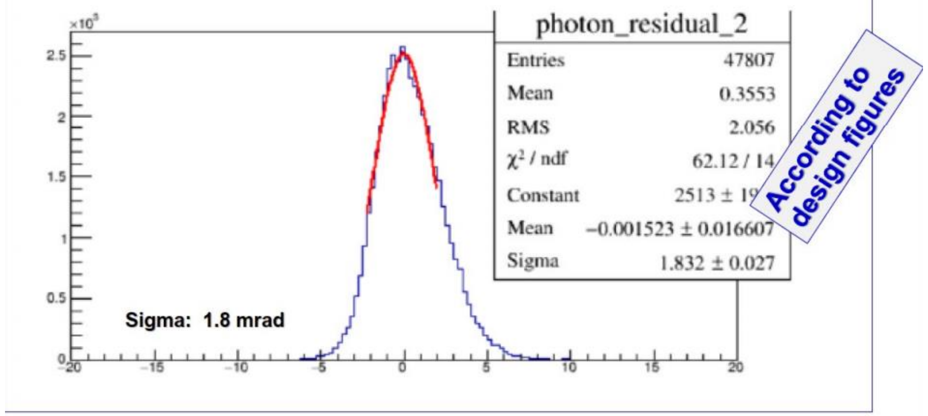
from the extrapolated exponential an estimate of the **noise level under the signal: ~10%**





Extrapolate to saturation, number of photon= 12.9
First part of the function = 10.3 +/- 0.4
Second part of the function= 2.6 +/- 0.3

Residual distribution for individual photons (preliminary):
$\theta_{calculated} - \theta_{photon}$

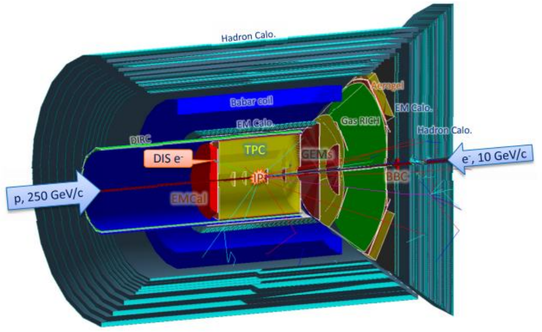


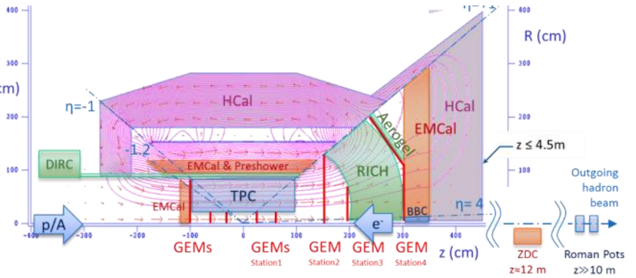
Sigma: 1.8 mrad

According to design figures

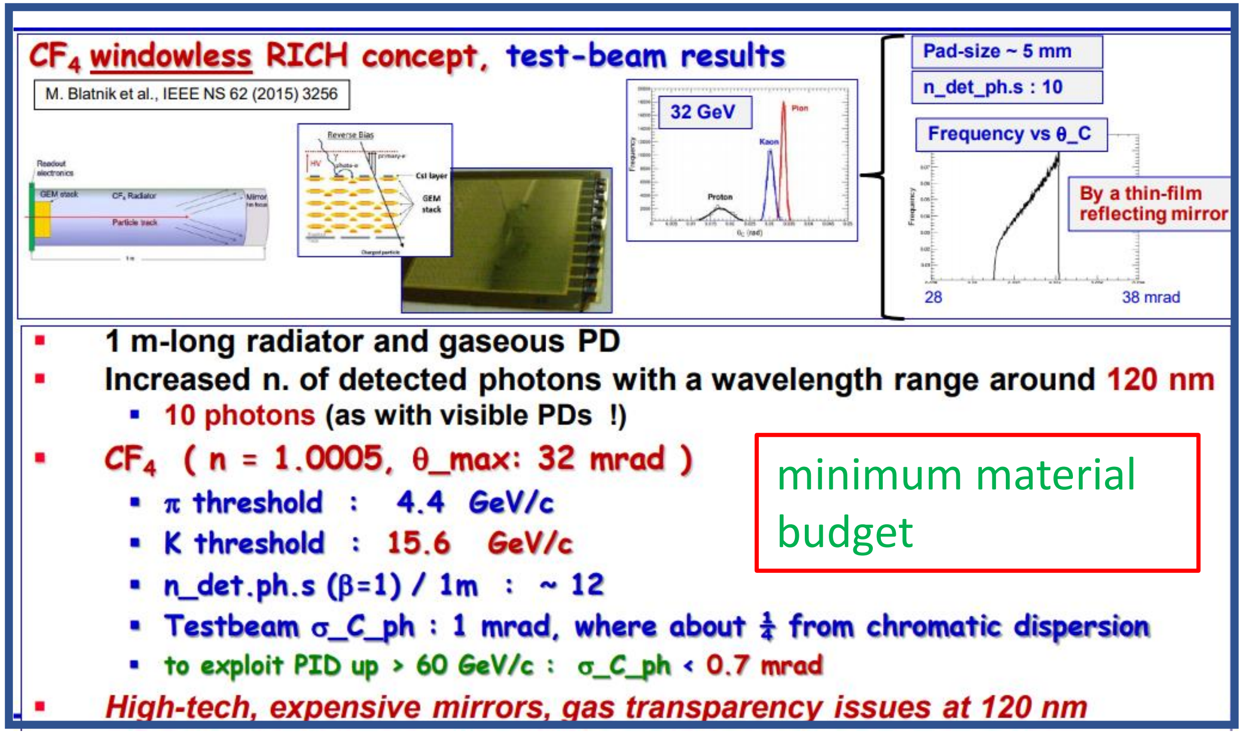
The future...

RICH at the EIC, exploiting the COMPASS hybrid PD upgrade





- -1<η<+1 (barrel) : sPHENIX + Compact-TPC + DIRC
- -4<η<-1 (e-going) : High resolution EM calorimeter + GEM trackers
- +1<η<+4 (h-going) :
  - 1<η<4 : GEM tracker + Gas RICH
  - 1<η<2 : Aerogel RICH
  - 1<η<5 : EM Calorimeter + Hadron Calorimeter
- Along outgoing hadron beam: ZDC and roman pots



CF$_4$ windowless RICH concept, test-beam results

M. Blatnik et al., IEEE NS 62 (2015) 3256

Pad-size ~ 5 mm

n_det_ph.s : 10

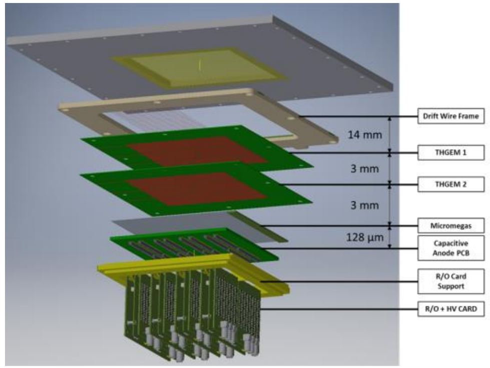
Frequency vs θ_C

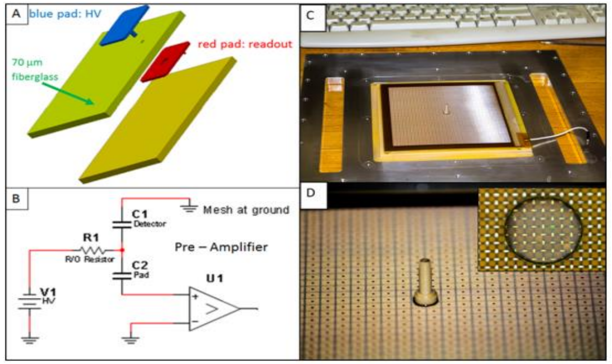
By a thin-film reflecting mirror

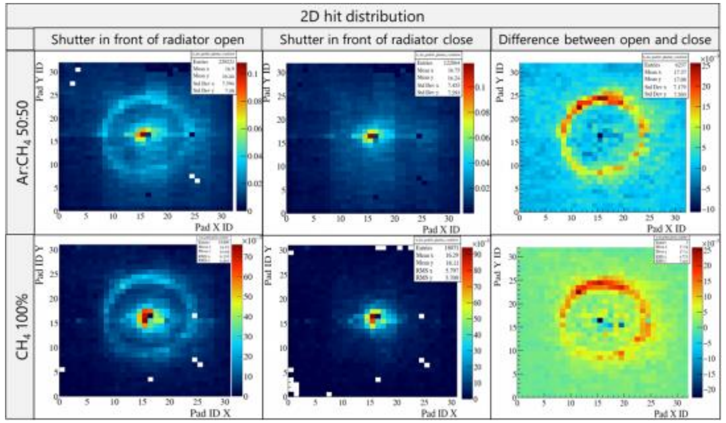
- 1 m-long radiator and gaseous PD
- Increased n. of detected photons with a wavelength range around 120 nm
  - 10 photons (as with visible PDs !)
- CF$_4$ (n = 1.0005, θ_max: 32 mrad)
  - π threshold : 4.4 GeV/c
  - K threshold : 15.6 GeV/c
  - n_det.ph.s (β=1) / 1m : ~ 12
  - Testbeam σ_C_ph : 1 mrad, where about ¾ from chromatic dispersion
  - to exploit PID up > 60 GeV/c : σ_C_ph < 0.7 mrad
- *High-tech, expensive mirrors, gas transparency issues at 120 nm*

minimum material budget

Different lever arm w.r.t. COMPASS requires pads of small size to improve the space resolution(3mmx3mm)



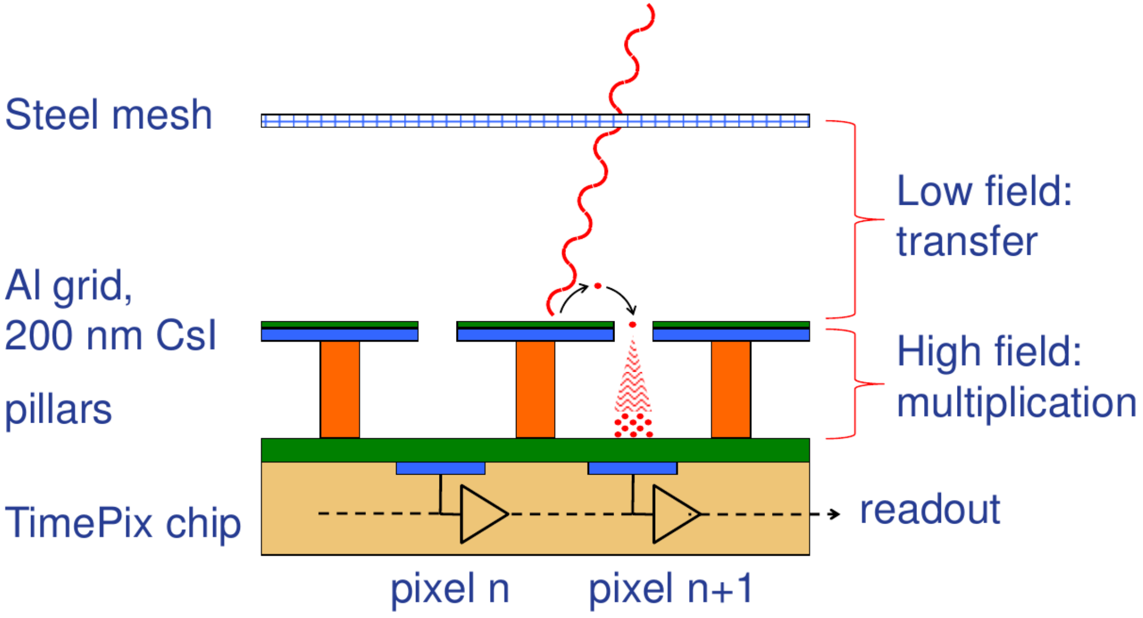




Studies performed with Ar/CH4 mixtures, towards a windowless approach using CF4 → *Chandradoy Chatterjee* and different photoconverters → *Daniele D'Ago*

Innovative approaches to single photon detection with GPD, R&D

InGrid – Micromegas integrated in a Timepix



Steel mesh

Al grid,
200 nm CsI

pillars

TimePix chip

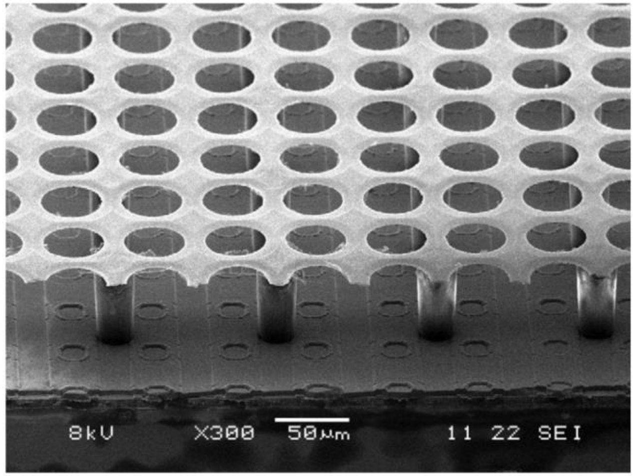
Low field:
transfer

High field:
multiplication

readout

pixel n

pixel n+1



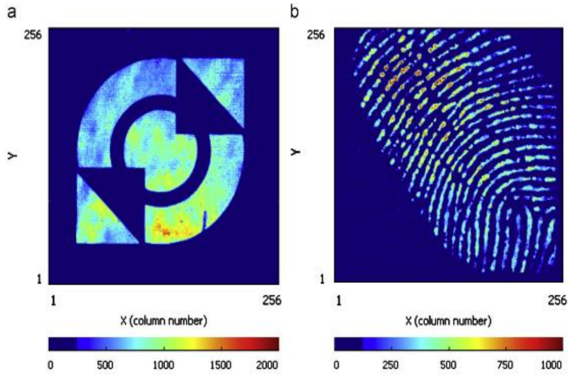


Fig. 8. (a) Image of the logo of the University of Twente and (b) image of a fingerprint left on the detector window.

- Very interesting performance for imaging (high granularity)
- Compact system with integrated electronics
- Limited to small detection areas – timePix limitation

Melai et al., NIMA 628 (2011)133

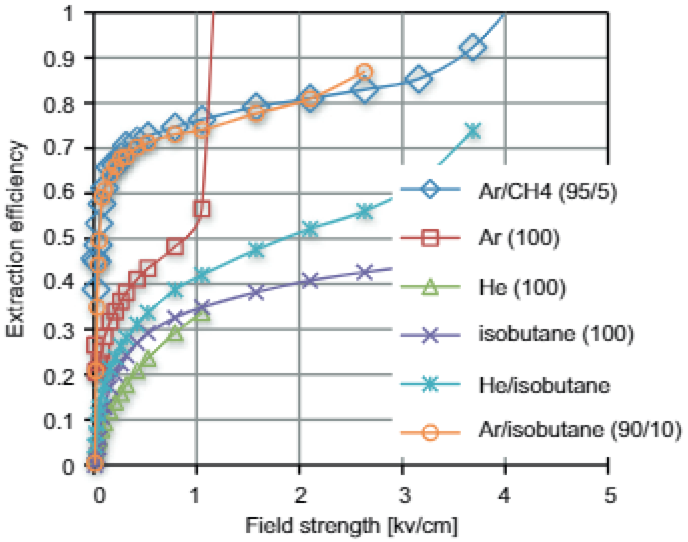
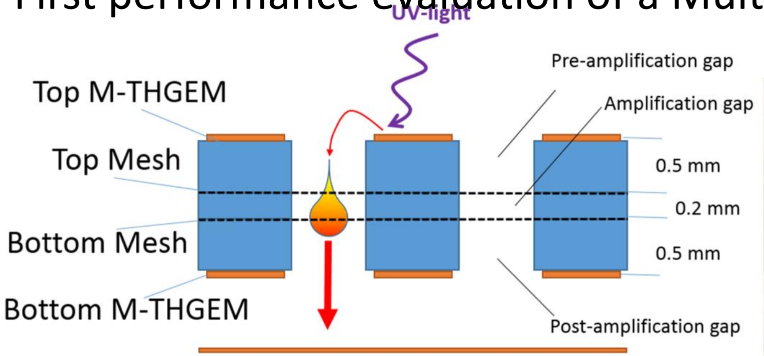
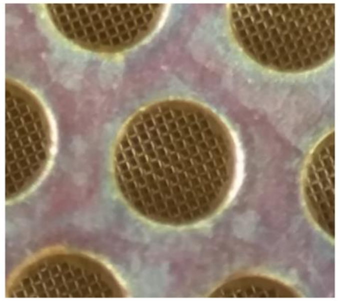


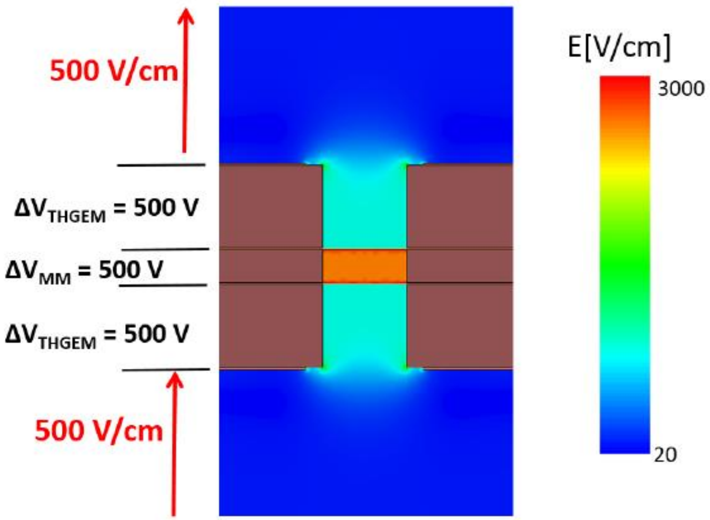
Fig. 3. Extraction efficiency of photoelectrons from a CsI photocathode into various gas mixtures (reference to vacuum). All gases were maintained at 1 atm.

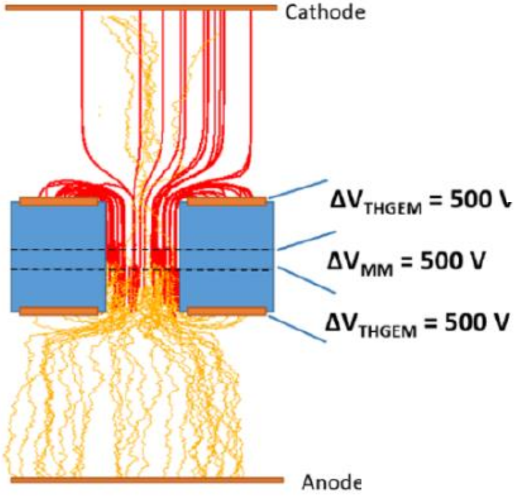
MM-TGHEM – Multi-Mesh

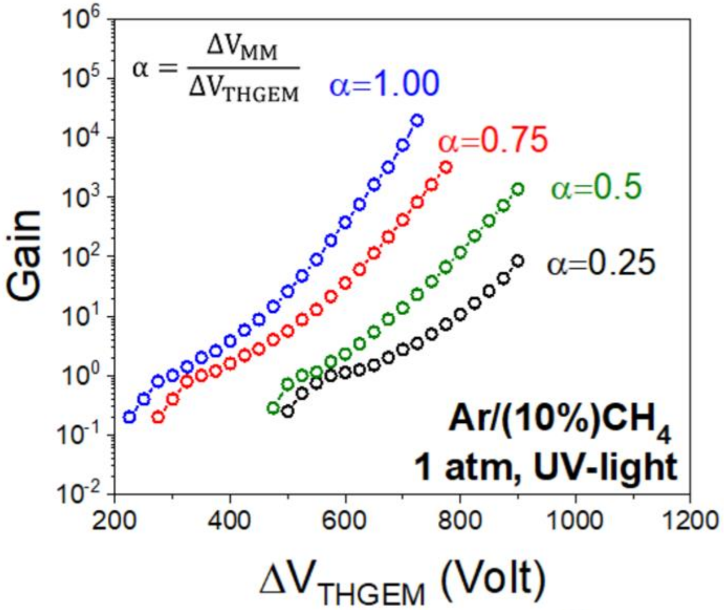
First performance evaluation of a Multi-layer Thick Gaseous Electron Multiplier with in-built electrode meshes—MM-THGEM

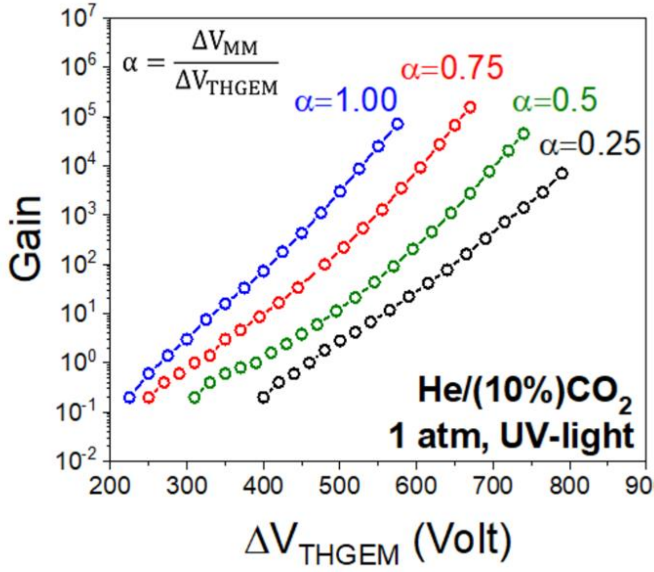








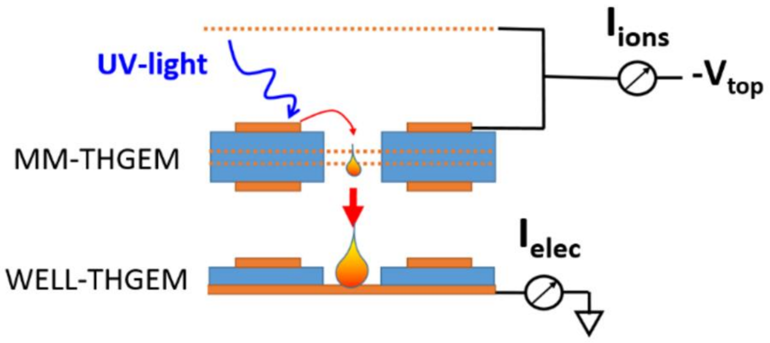


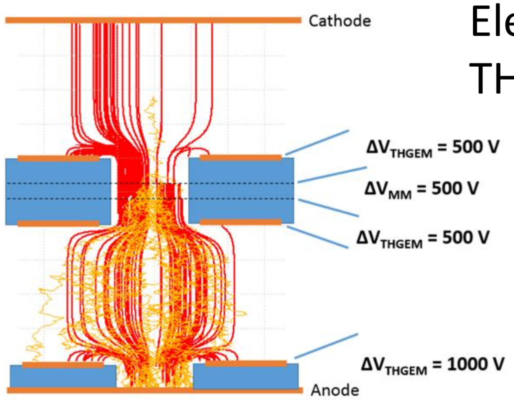


Oliveira and Cortesi., JINST 13 (2018) P06019

MM-TGHEM + RWELL – Multi-Mesh

MM-THGEM/WELL-THGEM detector

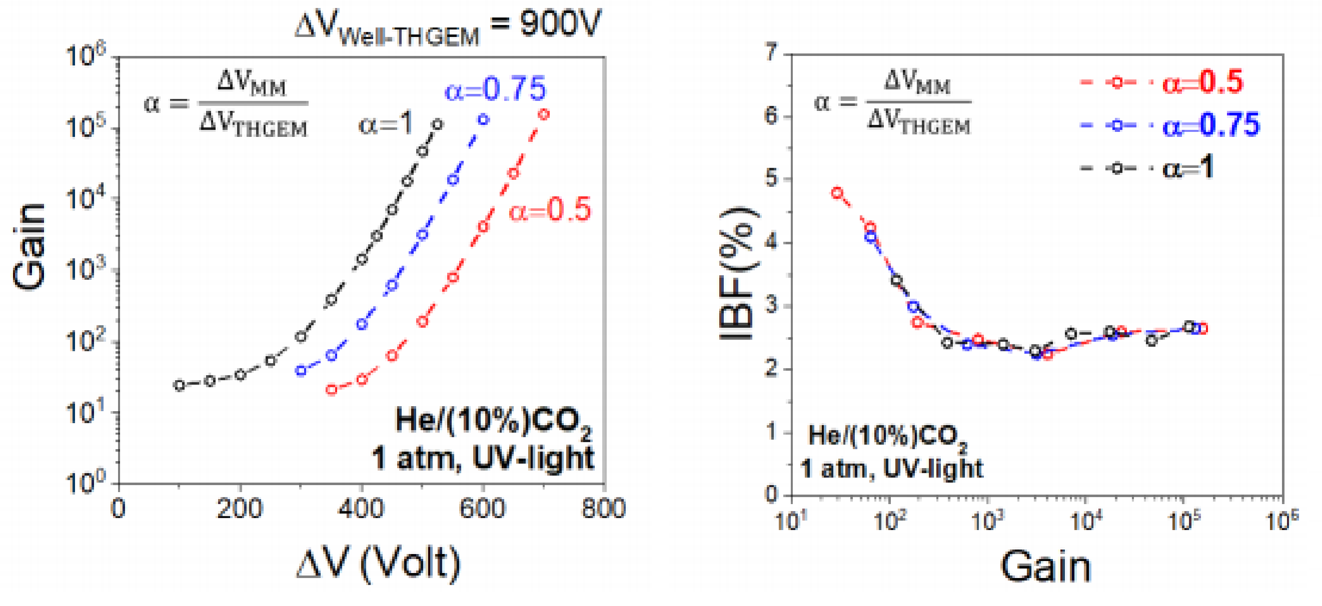




First performance evaluation of a Multi-layer Thick Gaseous Electron Multiplier with in-built electrode meshes—MM-THGEM

- Gain ~10^6
- Fair IBF for CsI pcs

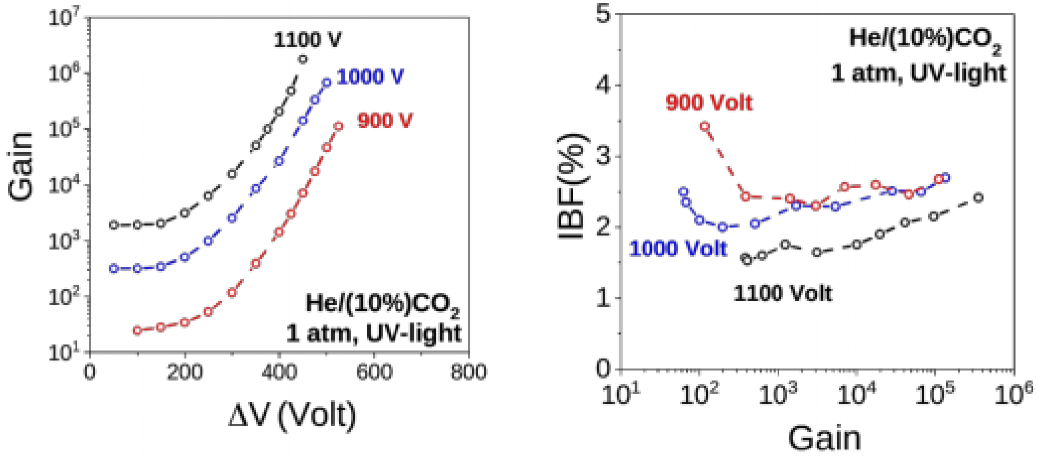
IBF ~2-3%



(a) (b)

Oliveira and Cortesi., JINST 13 (2018) P06019

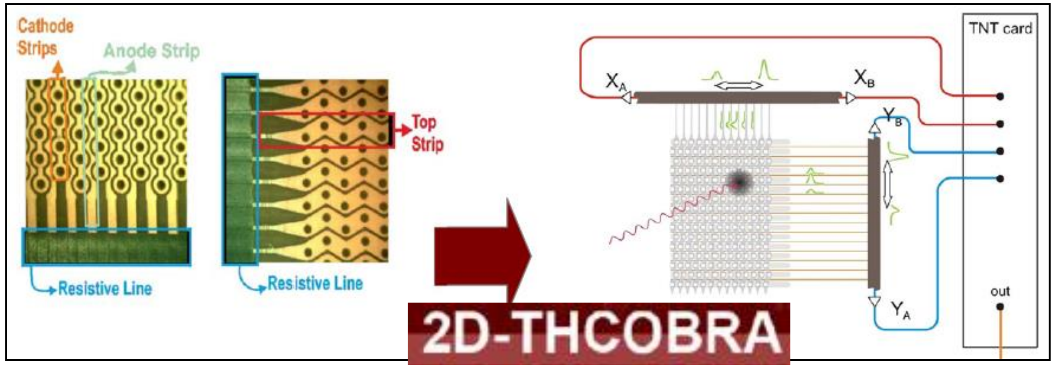
Low IBF contribution when the WELL-THGEM electrode contribution to the total gain is high

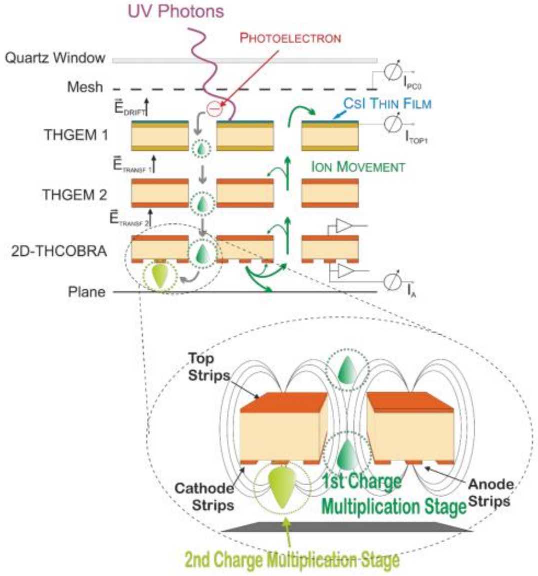


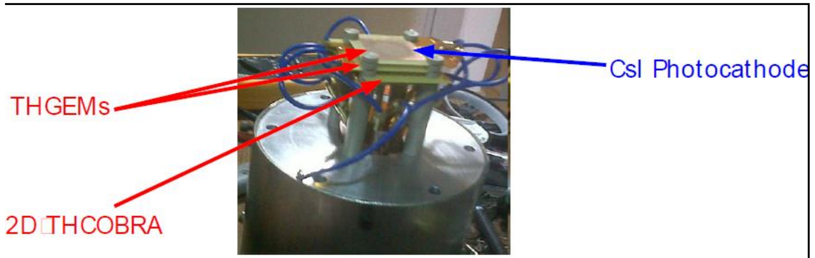
HYBRID MPGD PDs (THGEM + THCOBRA) a low rate application

2 THGEMs

a THCOBRA with 2 d R-O structure



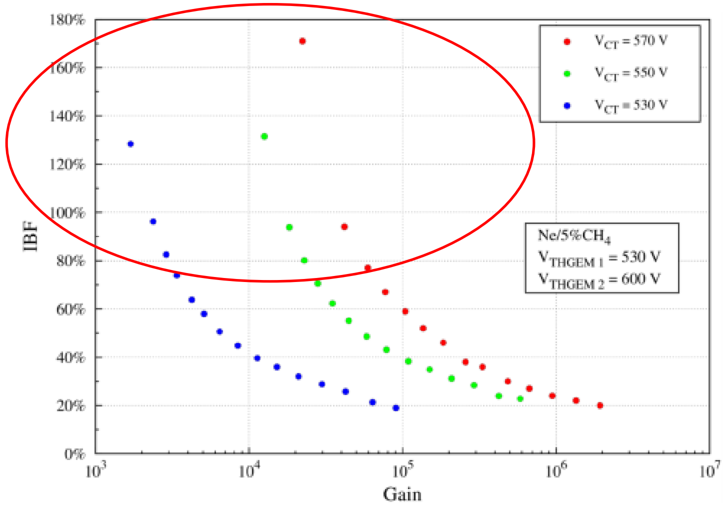




Parameters			
Structure	**Hole Diameter (µm)**	**Pitch (µm)**	**RIM (µm)**
THGEM 1	400	800	5
THGEM 2	700	1300	100
2D THCOBRA	400	1000	80

T. Lopes 2013 JINST 8 P09002

- 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



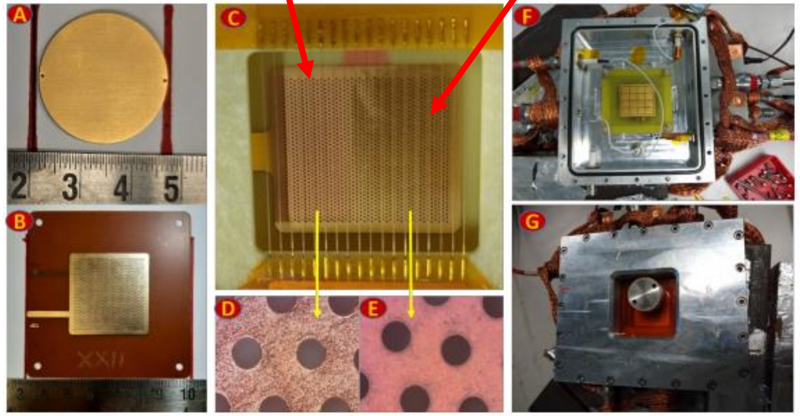
IBF high but

Carbon based photocathodes coupled to Gaseous Detectors, HND and THGEMS

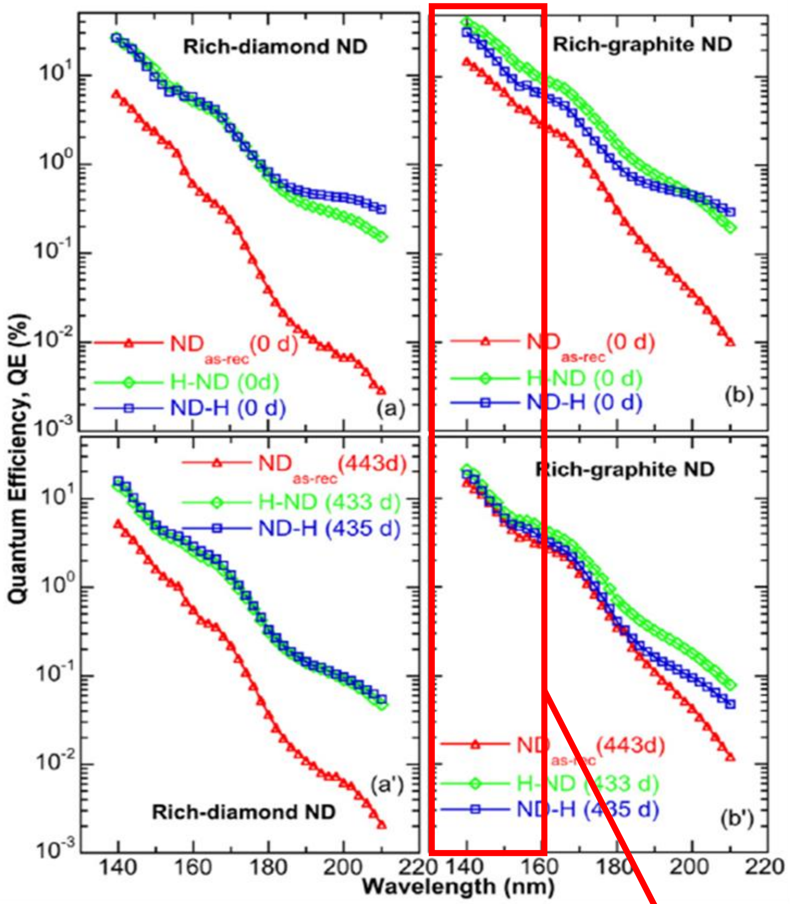
- .Very promising photocatode for VUV
- - very interesting QE
- - high radiation hardness
- - spray technique – hidrogenated ND powder

Uncoated THGEM

Coated THGEM



→ Daniele D'Ago Talk



Below Quartz cutoff
Windowless approach for
RICH

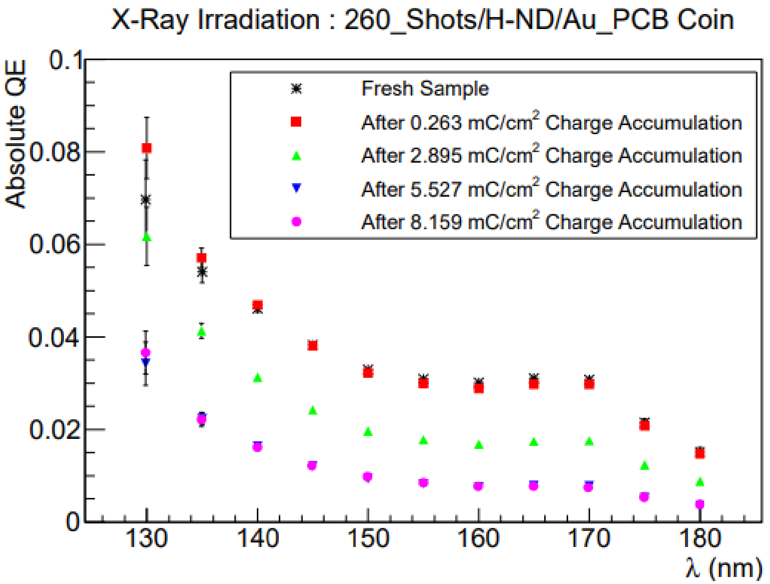


Figure 6. Quantum efficiency as a function of wavelength for fresh and various charge accumulations ($0.263mC/cm^2$, $2.895mC/cm^2$, $5.527mC/cm^2$and $8.159mC/cm^2$) due to ion bombardment on H-ND coated Au_PCB substrate.

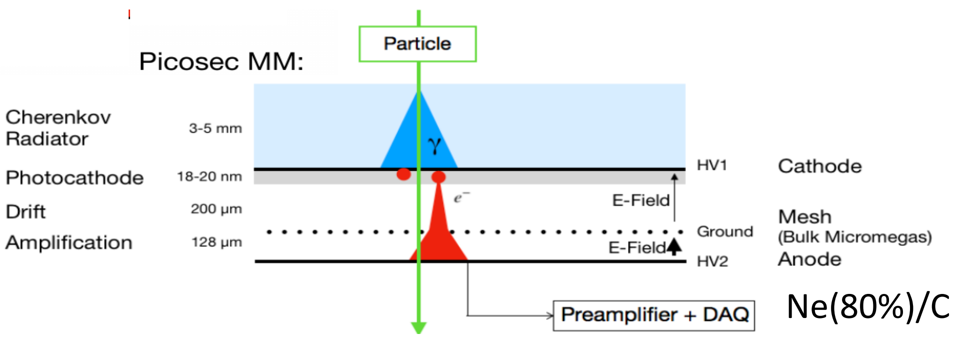
.Still presenting some ageing →

.Ion bombardment resistance !

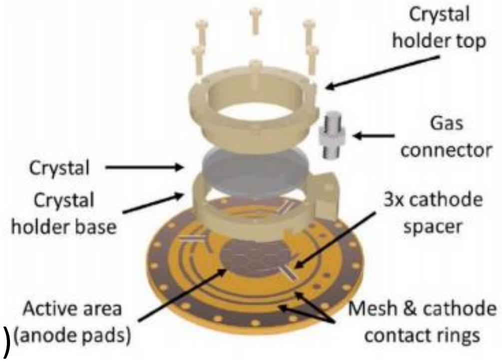
.Compatible with MPGD operation !

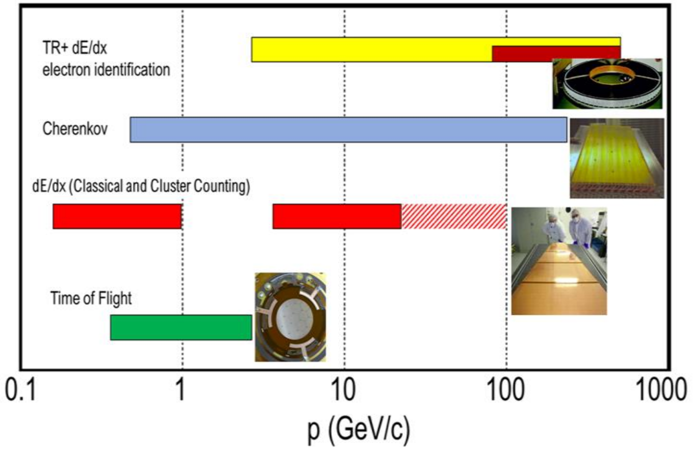
Velardi et al., Diamond & RM 76(2017)1 ; Valentini et al. Patented

PICOSEC Collaboration aims for the development of a Micromegas based detector coupled to a photocathode for time resolution in the **ten pico second** time scale, not single ph.

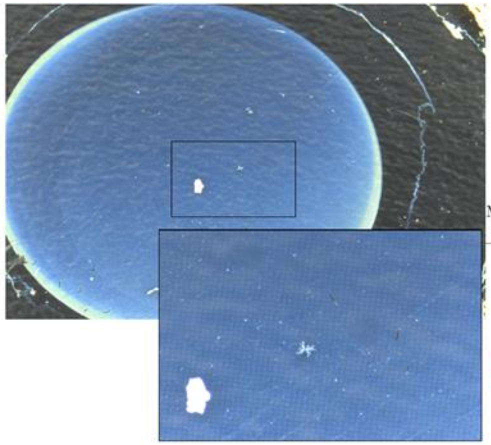


Ne(80%)/CF4(10%)/C2H6(10%)

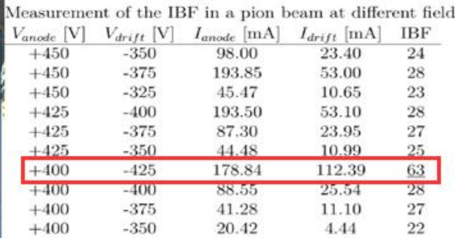




Lukas Sohl et al. For the PICOSEC Collab., presented in RD51 collaboration meeting, Munich, June 2018
Papaevangelou et al, Fujiwara et al., EPJ Web Conf., 174(2018)02002

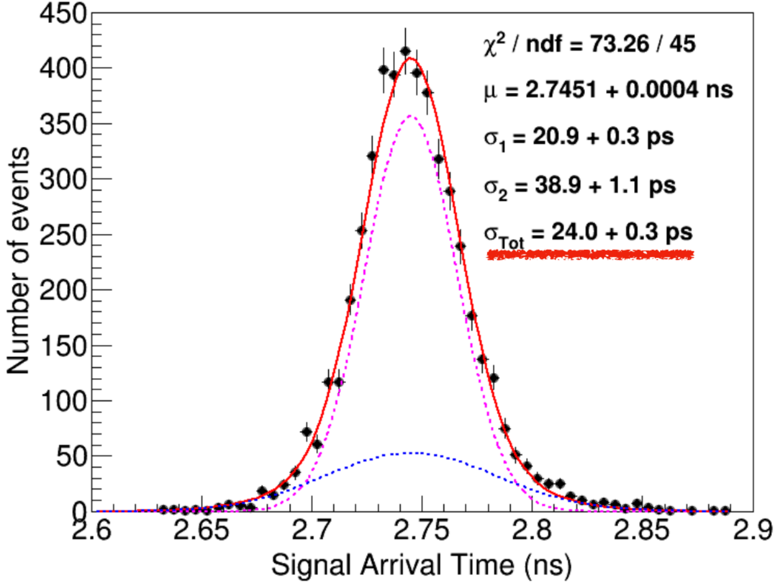


- **Ion back flow damages CsI photocathode under higher particle flux**
- **IBF > 60 % at high detector gain**
- **Robust photocathodes needed**

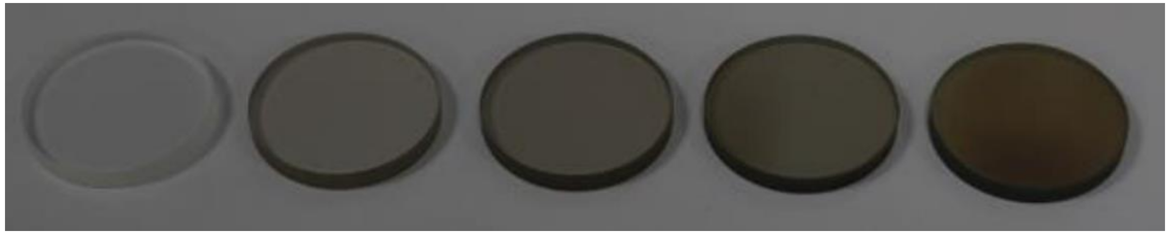


Measurement of the IBF in a pion beam at different field

V_{anode} [V]	V_{drift} [V]	I_{anode} [mA]	I_{drift} [mA]	IBF
+450	-350	98.00	23.40	24
+450	-375	193.85	53.00	28
+450	-325	45.47	10.65	23
+425	-400	193.50	53.10	28
+425	-375	87.30	23.95	27
+425	-350	44.48	10.99	25
+400	-425	178.84	112.39	63
+400	-400	88.55	25.54	28
+400	-375	41.28	11.10	27
+400	-350	20.42	4.44	22



Advances in DLC films triggered the possibility of producing photocathodes to operate in gas medium for MPGDs



- **DLC – Diamond-like carbon**

–Widely used in industry as a solid lubricant

–Recently introduced to the MPGD field as excellent resistive electrodes

–Tested with success in the **PICOSEC** Collaboration

- A breakthrough in **carbon based photocathodes** would favour:
- GPMs performance in general
- RICH detectors for PID for future NP/HEP experiments: i.e. **HND nanodiamonds**

Innovative approaches to single photon detection with GPD, R&D , visible range

Chemical reactivity (gas purity better than ppm level needed → UHV materials and sealed detectors

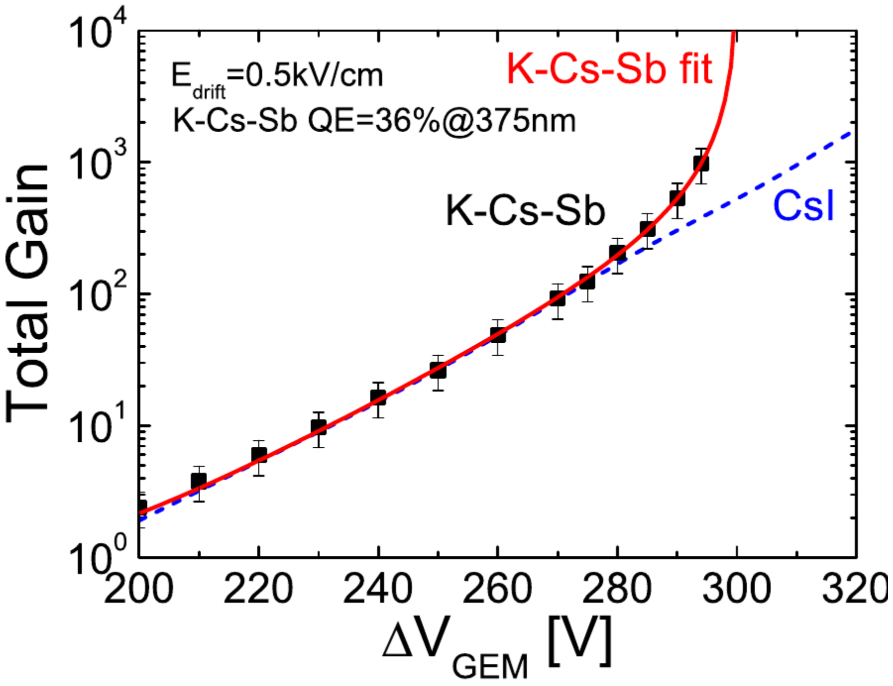
PC stability under ion bombardment - work function lower than CsI one

AGEING CsI: -16% QE at 25mC/mm^2

Bilkaly: -20% QE at 0.4mC/mm^2

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

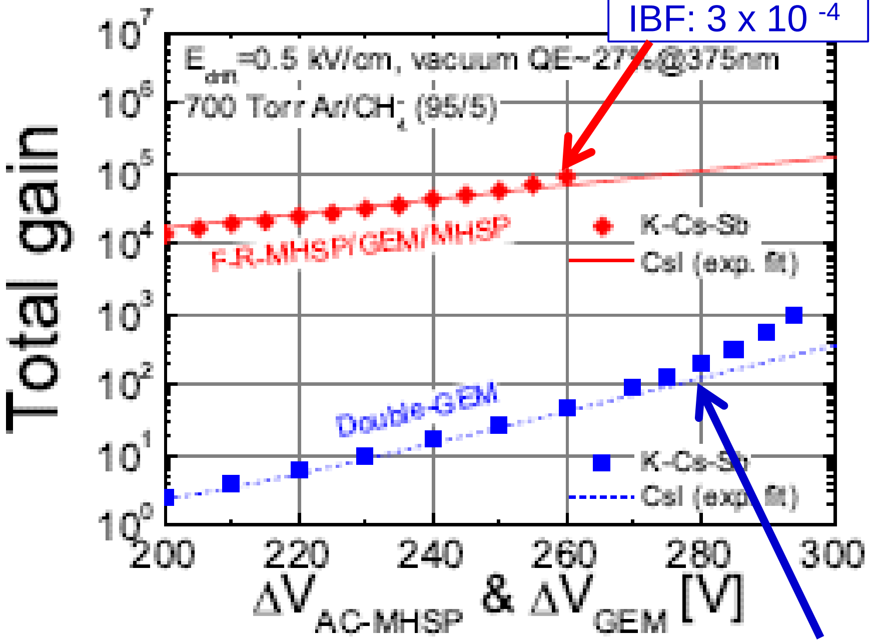
F.Tokanai et al., NIMA 628 (2011) 190



Ion induced secondary emission in CsI is negligible

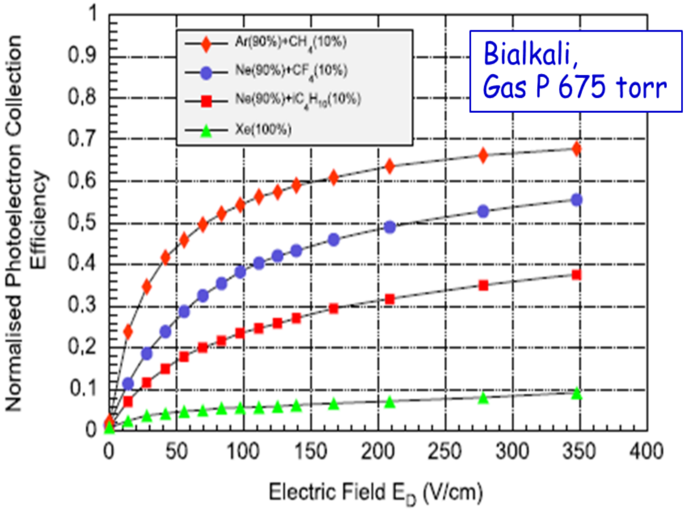
K-Cs-Sb vs CsI

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



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

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



Bialkali, Gas P 675 torr

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

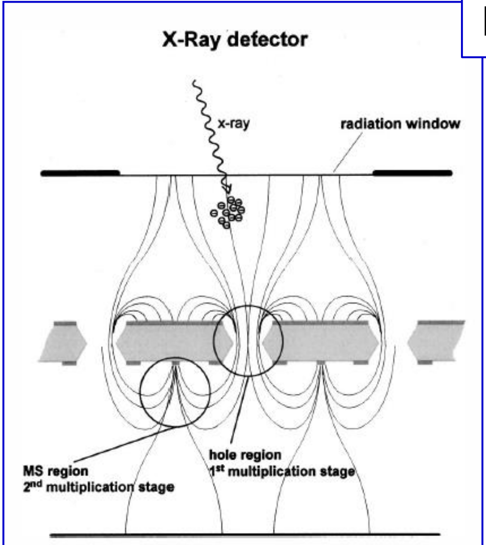
More complex geometries needed with extra electrodes to trap the ions:

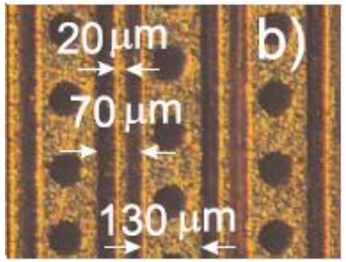
Micro-Hole & Strip Plate (MHSP), COBRA

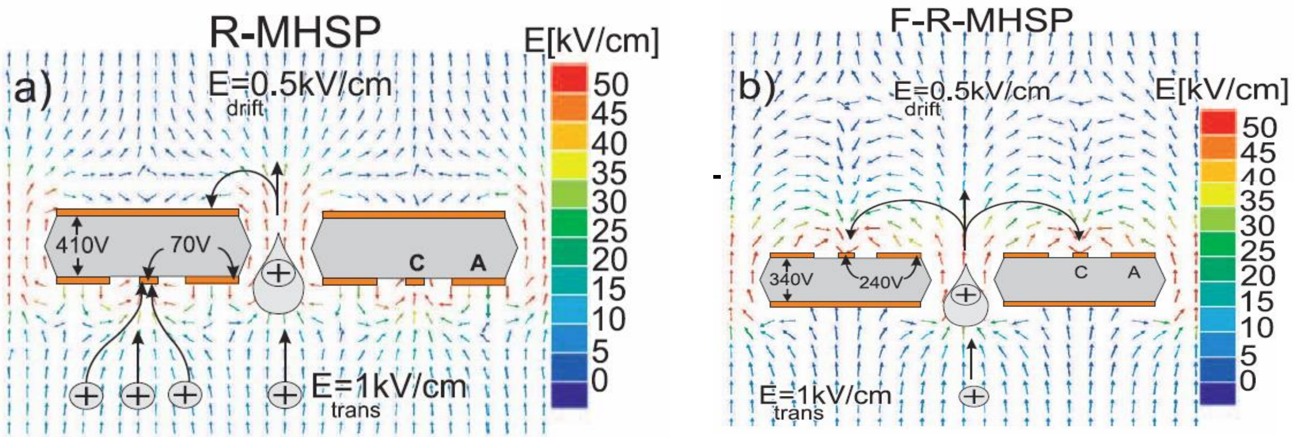
A.V. Lyashenko et al.,
JINST 2 (2007) P08004

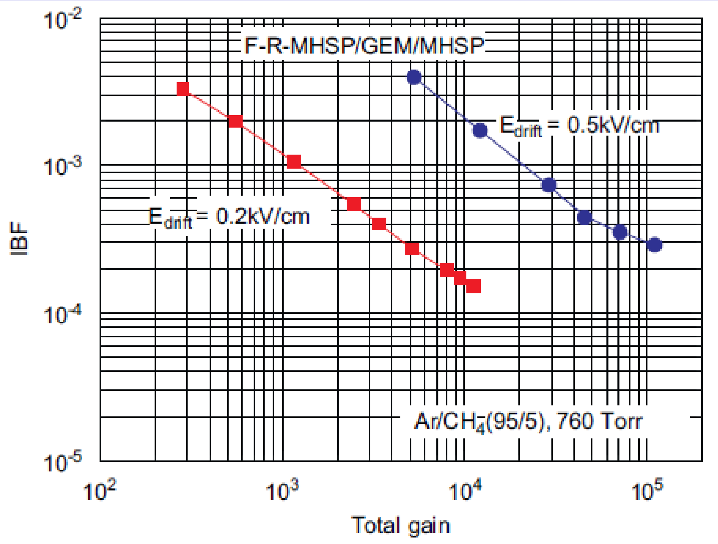
MHSP

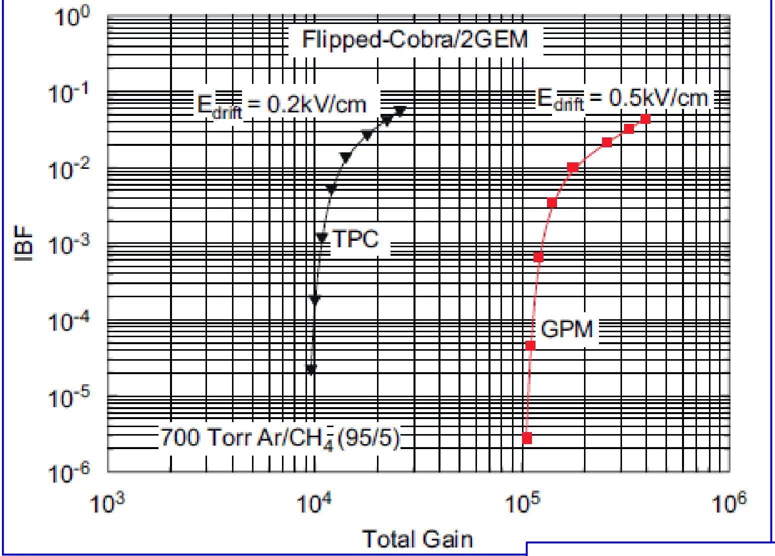
J.F.C.A. Veloso et al.,
Rev.Sc. Instr. 71 (2000) 2371



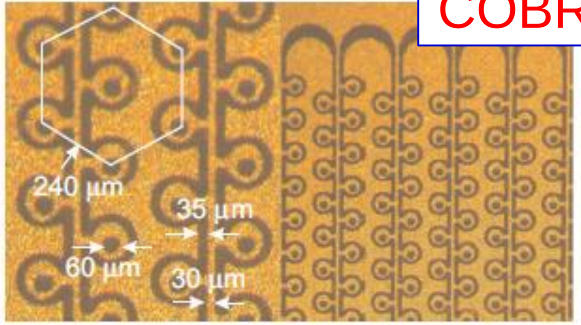








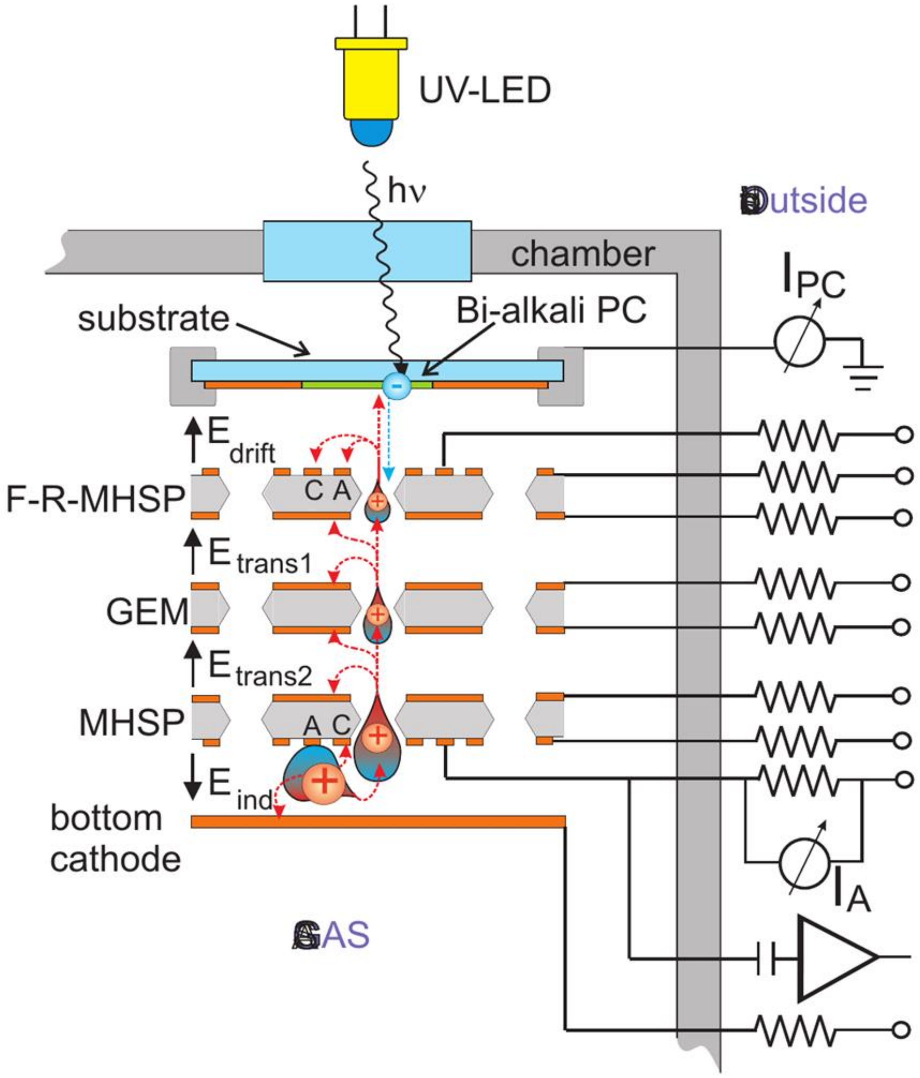
COBRA

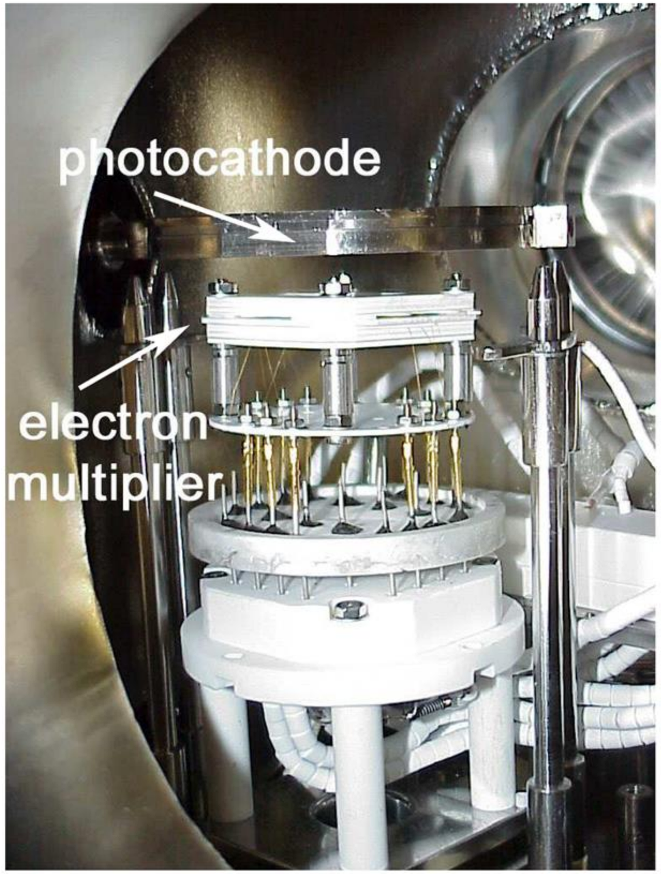


A.V. Lyashenko et al.,
NIMA 598 (2009) 116

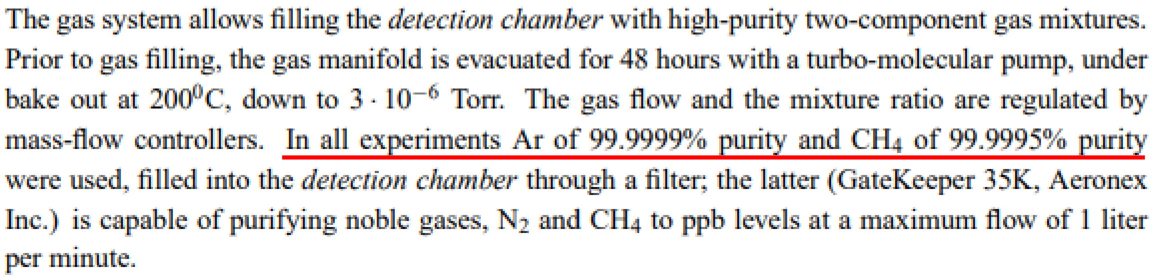
A.V. Lyashenko et al.,
NIMA 598 (2009) 116

Visible range single photon detection, GEM approach



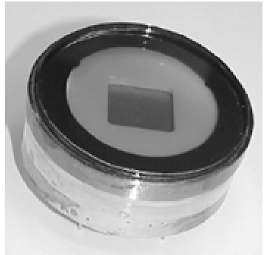


Lyashenko et al., JINTS 4(2009)P07005


The gas system allows filling the *detection chamber* with high-purity two-component gas mixtures. Prior to gas filling, the gas manifold is evacuated for 48 hours with a turbo-molecular pump, under bake out at 200^0C, down to $3 \cdot 10^{-6}$ Torr. The gas flow and the mixture ratio are regulated by mass-flow controllers. In all experiments Ar of 99.9999% purity and CH_4 of 99.9995% purity were used, filled into the *detection chamber* through a filter; the latter (GateKeeper 35K, Aeronex Inc.) is capable of purifying noble gases, N_2 and CH_4 to ppb levels at a maximum flow of 1 liter per minute.

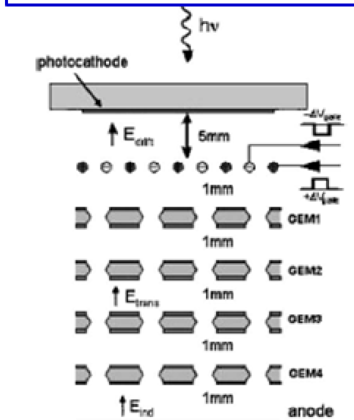
the GEM approach

Multiple GEM sealed



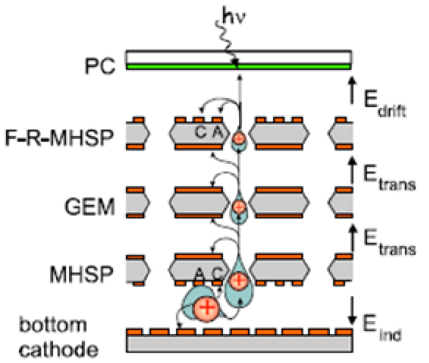
R.Chechik
et al., NIMA
502 (2003) 195

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

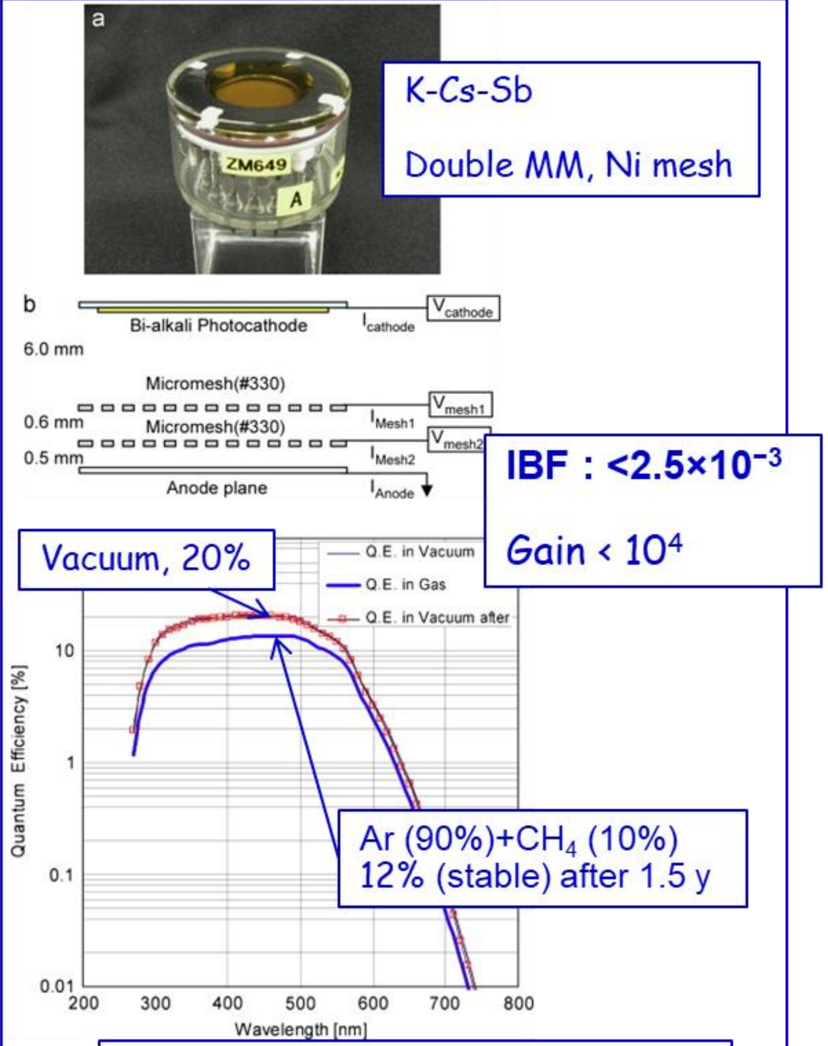
Poor compatibility of Bialkali and GEM material ?

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

Visible range single photon detection, Micromegas approach

the Micromegas approach



K-Cs-Sb

Double MM, Ni mesh

IBF : <2.5×10^{-3}

Gain < 10^4

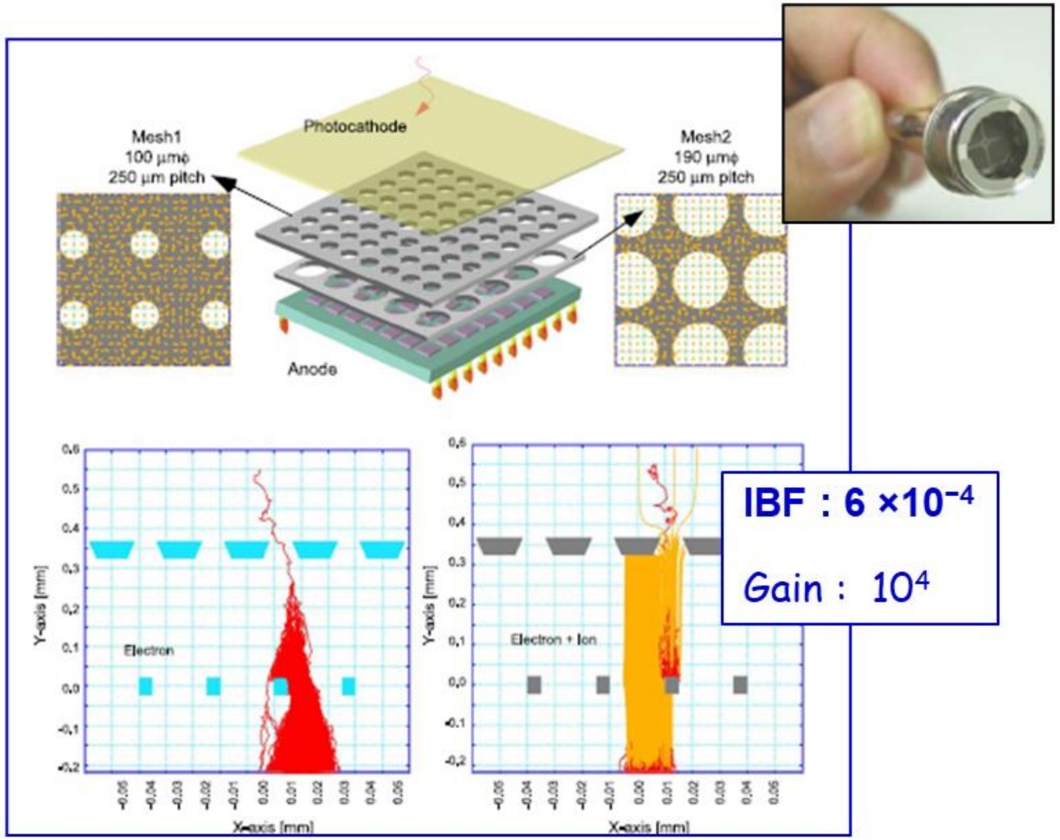
Vacuum, 20%

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

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

2 staggered MM layers to enhance ion trapping

In collaboration with HAMAMATSU



IBF : 6 $\times10^{-4}$

Gain : 10^4

Nicely working!

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

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

A wide effort to refine and consolidate the technology

MANY APPLICATIONS OF MPGD-BASED PHOTON DETECTORS

From PID to ν, DM, medical applications …

First step toward large area: Hybrid THGEM+MM for COMPASS

BRIGHT FUTURE FOR:

Inventions: new ideas, new techniques

Technology consolidation, new applications

Large scale projects