Status and Perspectives of the Gaseous Photon Detectors Technologies

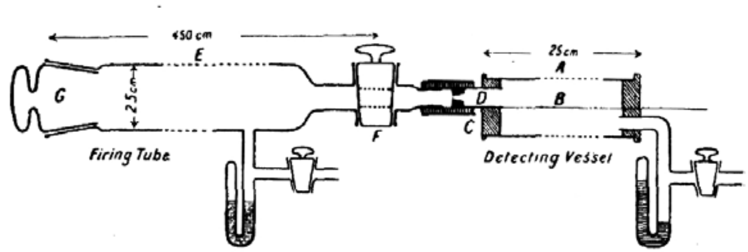
Fulvio Tessarotto (INFN – Trieste)

Gaseous Photon Detectors

- Historical overview of gaseous detectors
- MWPCs with CsI Photocathodes
- GEM-based PDs
- THGEM-based PDs
- Other architectures
- Gaseous detectors for visible light
- Cryogenic gaseous photon detectors
- Large area coverage

Glorious tradition: 100 years of gaseous detector developments

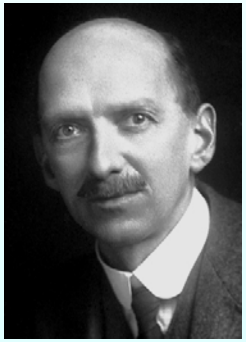
1908: FIRST WIRE COUNTER
USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY



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

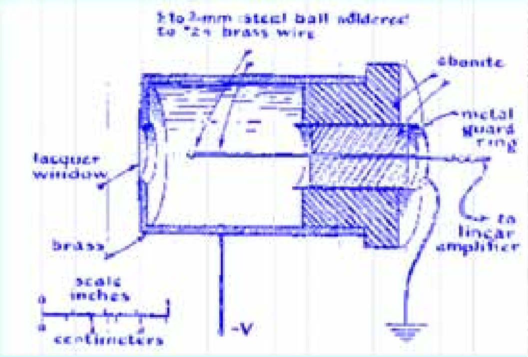
Nobel Prize in Chemistry in 1908

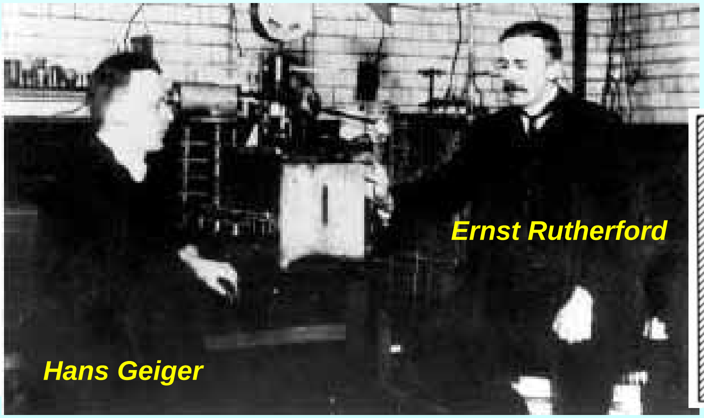
1911: CLOUD CHAMBER



Charles T.R. Wilson
Nobel Prize in 1927

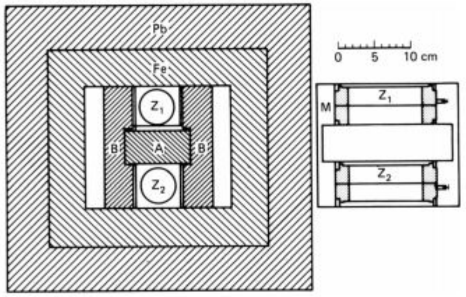
1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY

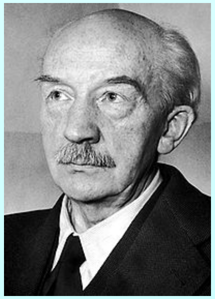




H. Geiger and W. Müller,
Phys. Zeits. 29 (1928) 839

COINCIDENCE METHOD

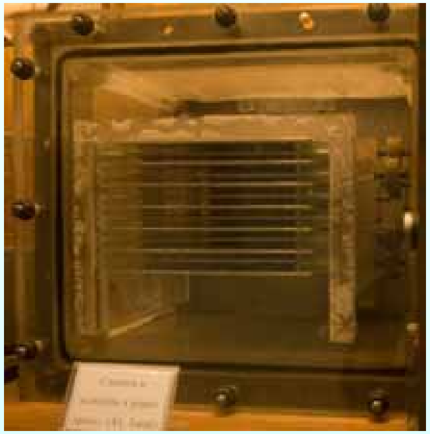




Walther Bothe
Nobel Prize in 1954

Glorious tradition: 100 years of gaseous detector developments

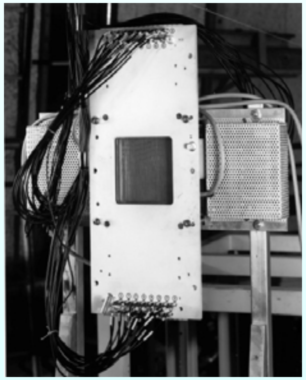
SPARK CHAMBER

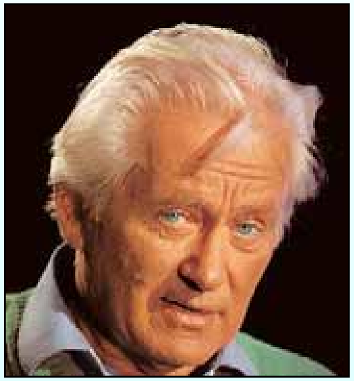


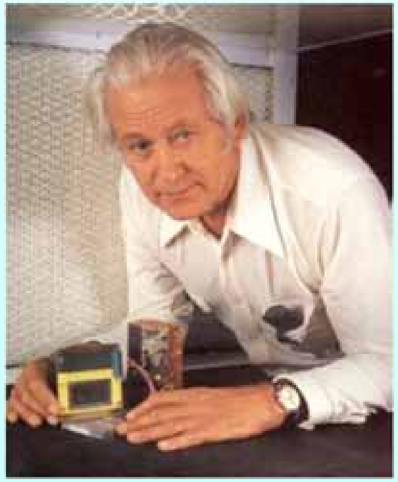
1952: BUBBLE CHAMBER

Donald A. Glaser
Nobel Prize in 1992

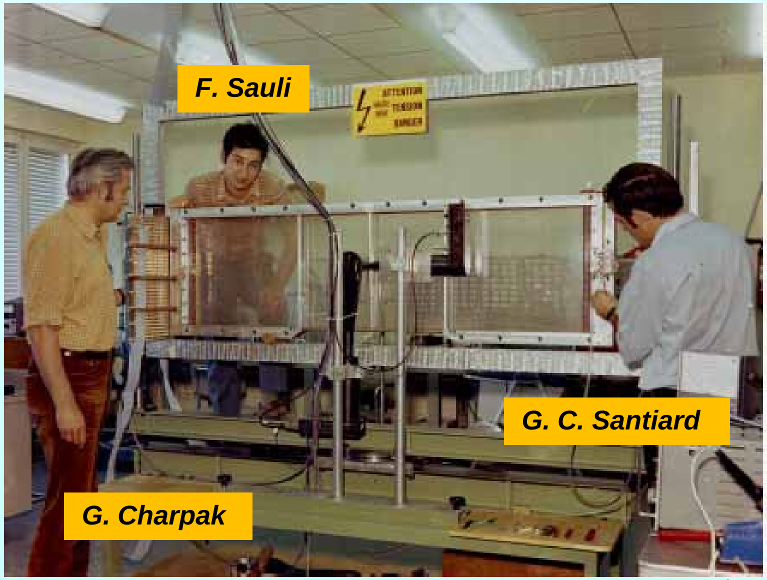
1968: MULTIWIRE PROPORTIONAL CHAMBER



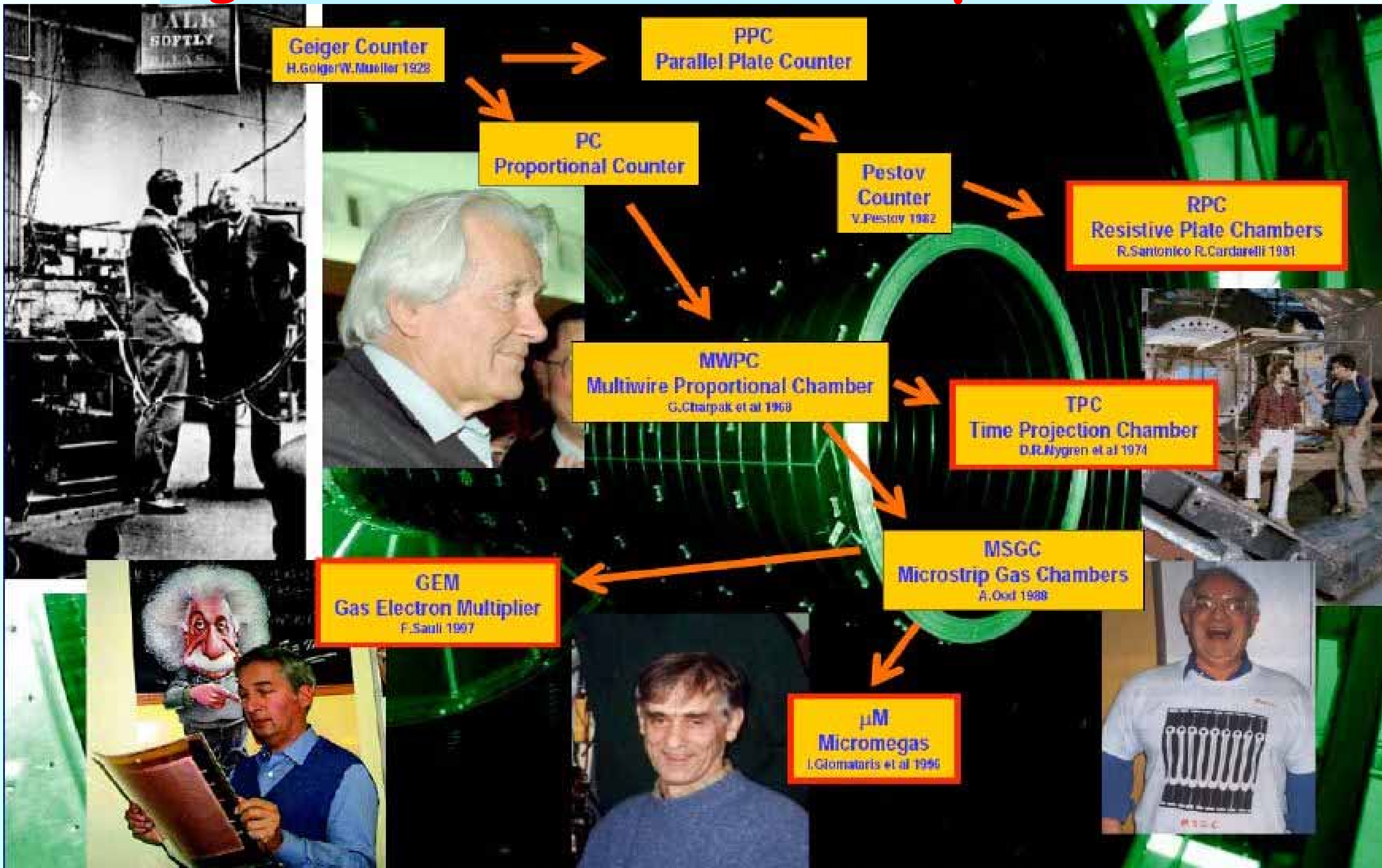




George Charpak
Nobel Prize in 1992

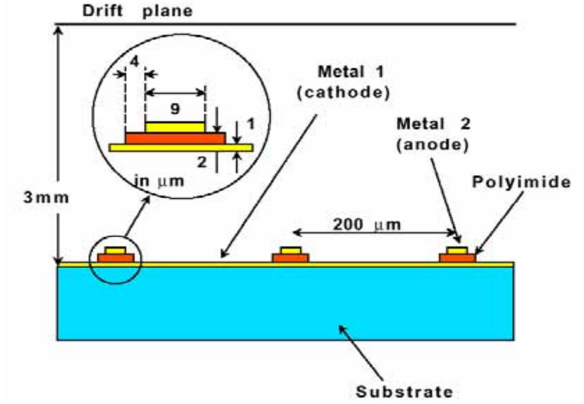


Glorious tradition: 100 years of gaseous detector developments

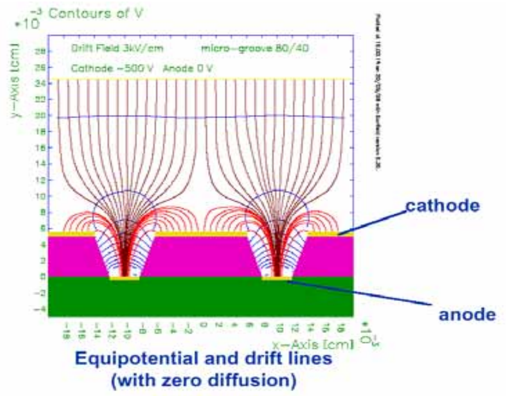


Many different MPGDs have been developed

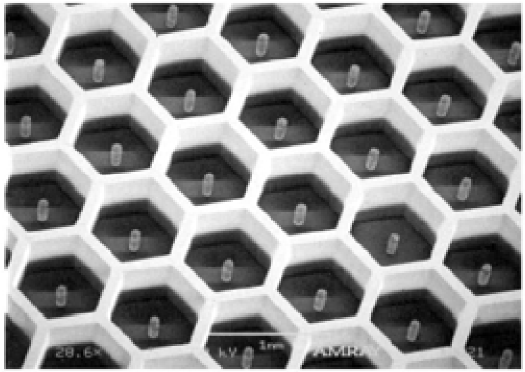
MICRO-GAP CHAMBER



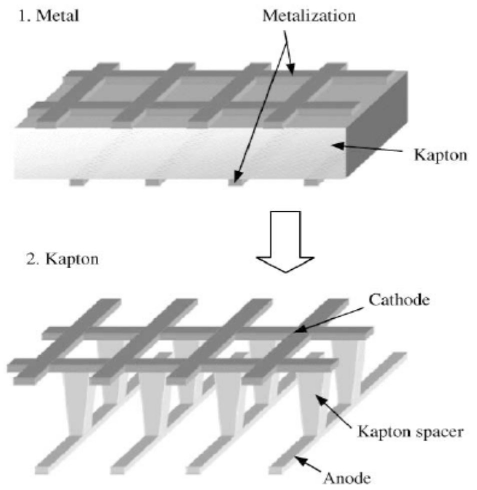
MICRO-GROOVE CHAMBER



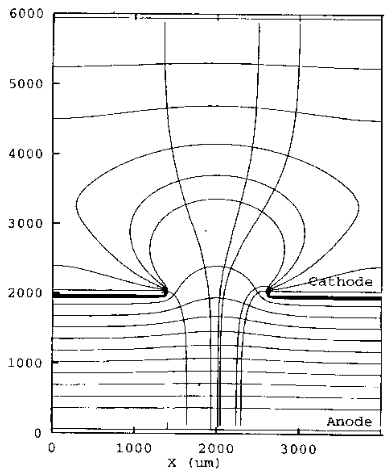
MICRO-PIN ARRAY



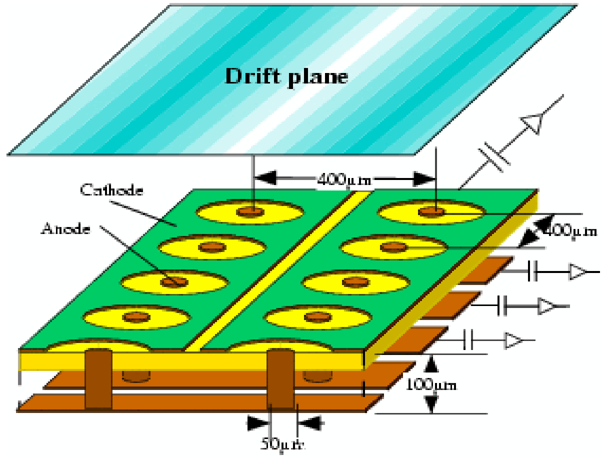
MICRO-WIRE CHAMBER



COMPTEUR A TROUS



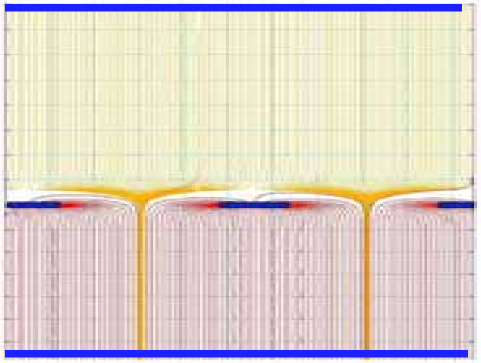
MICRO-PIXEL CHAMBER

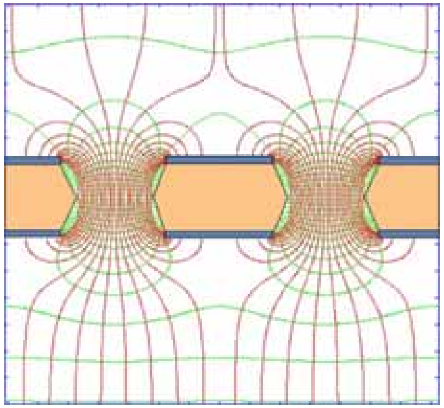


2 very solid, fully established technologies:

MICRO MEsh GAseous Structure (MICROMEGAS)
Thin gap Parallel Plate Chamber: micromesh stretched over readout electrode.

Y. Giomataris et al., Nucl. Instr. and Meth. A376(1996)29





GAS ELECTRON MULTIPLIER (GEM)
Thin, metal-coated polymer foil with high density of holes, each hole acting as a proportional counter.
F. Sauli, Nucl. Instrum. Methods A386(1997)531

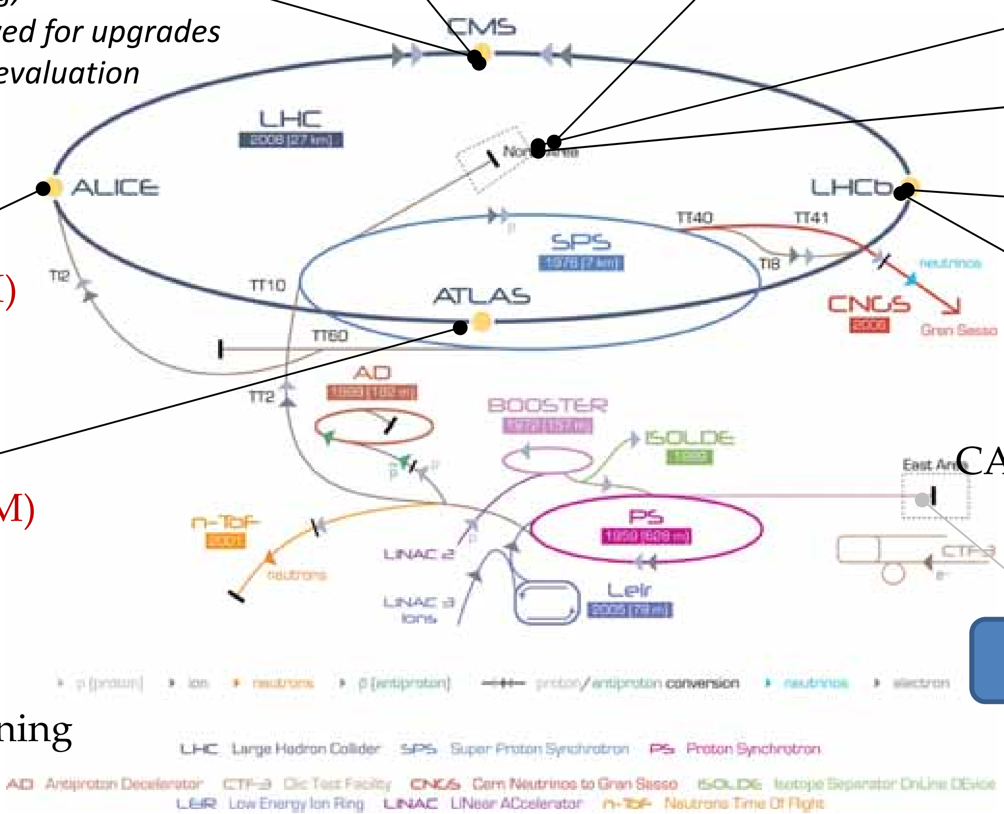
HIGHER LUMINOSITIES, HIGHER PRECISION EXPERIMENTS

1. **MPGDs allow for**
   - **High rates (granularity & occupancy, signal formation time)**
   - **Fine space resolution**
2. **Technological maturity and accurate engineering FUNDAMENTAL for successful MPGDs**

MPGDs at CERN Experiments

Despite original MSGC discharge problems, MPGDs have been chosen for all LHC upgrades (mostly for muon systems)

Some of them running,
Some of them approved for upgrades
Some of them under evaluation



TOTEM (GEM)

CMS (GEM, uRWELL)

COMPASS (2TGEM+MM, MM, GEM)

GLACIER(LEM)

NA48 (MM)

LHCb (GEM)

LHCb (uRWELL)

ALICE(GEM)

ATLAS (MM)

CAST (MM,InGrid)

DIRAC (MSGC-GEM)

E. Oliveri

RED = LHC

- running

MPGDs and RD51

- **MPGDs exist thanks to a few genial inventors**
- **Great progress due to engineering for the use in experiments**

- **Recently, a fundamental boost thanks to RD51:**

  "RD51, aims at facilitating the <u>development of advanced gas-avalanche detector technologies</u> and associated electronic-readout systems, for <u>applications in basic and applied research</u>."

RD51 serves as an access point to MPGD "know-how" for the world-wide community

Unique in providing:

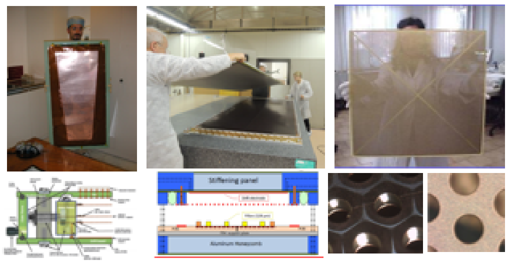
- **Space and resources for non – project related R&D**
- **tools for the word-wide MPGD community <u>AND BEYOND</u>**

~ 80 Institutes from 4 continents: Europe, Nord and South America, Asia, Africa
~ 450 physicists

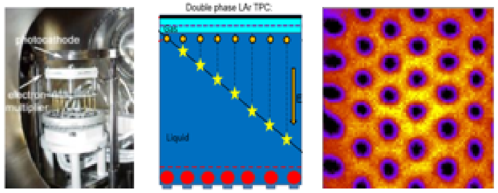
RD51 Working groups

RD51

WG1: Technological Aspects and Development of New Detector Structures

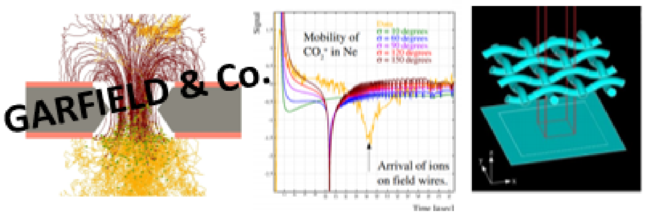


WG2: Common Characterization and Physics Issues

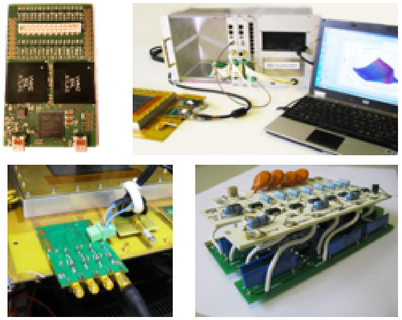


WG3/NEW WG: Academia-Industry Matching Events, Training, Education

WG4: Simulations and Software Tools

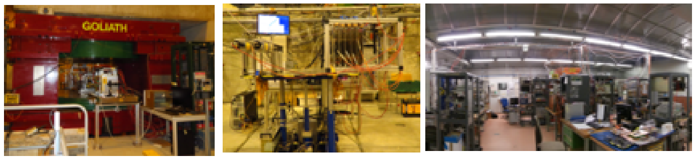


WG5: MPGD Related Electronics



WG6: Production, quality control, industrialization

WG7: Common Facilities : Test Beam and Laboratory

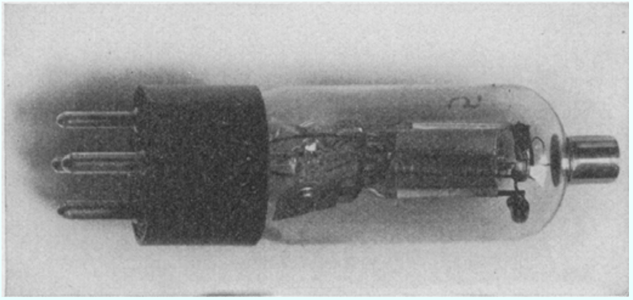


photon conversion and Cherenkov light

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

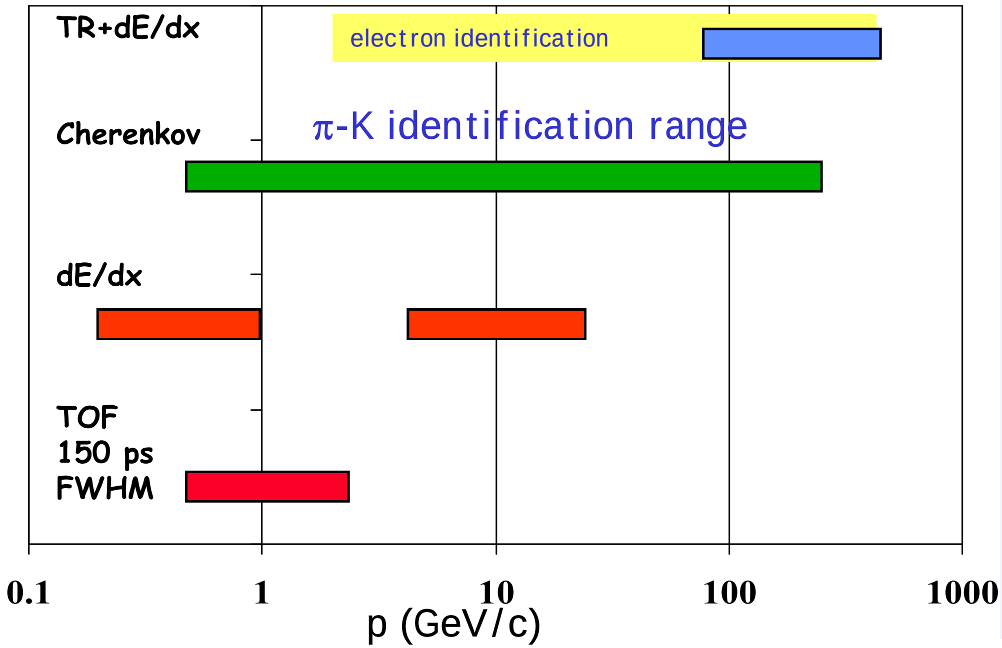
Arthur Roberts 1912-2004

Tom Ypsilantis 1928-2000

Motivation

- *need for π-K identification from HEP Experiments*
- 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.

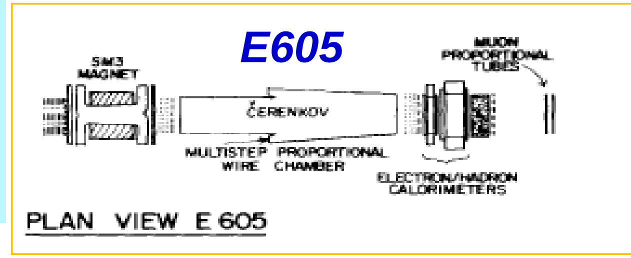
- **a gas gain high enough to detect single photoelectrons**

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

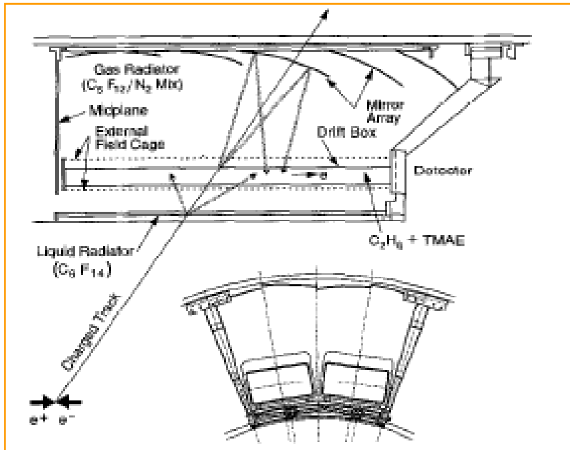
- **solution: multistep avalanche chamber**
  (Charpak-Sauli Phys. Lett. B 142 (1977) 377) *or TPC*

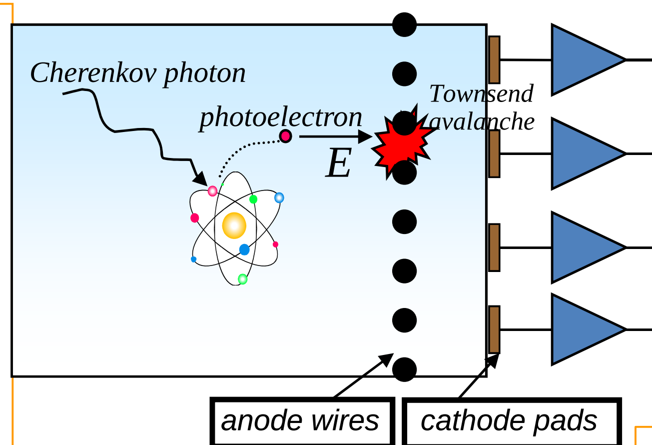
Gaseous detectors: 1) cheap, 2) magnetic insensitive, 3) low material budget

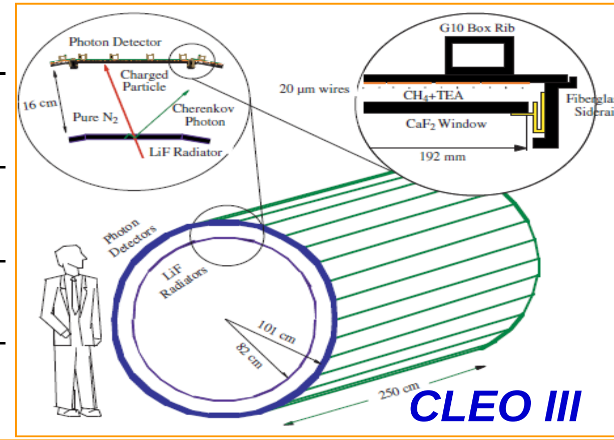
RICH with large area gaseous PD's
1^{st} generation: photoconverting vapours



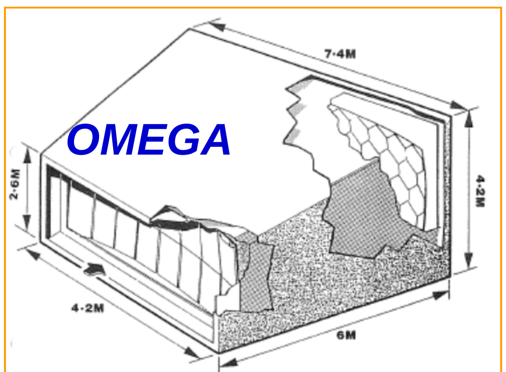
SLD - CRID

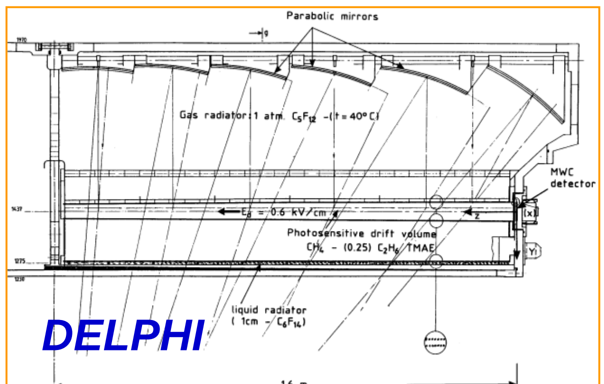


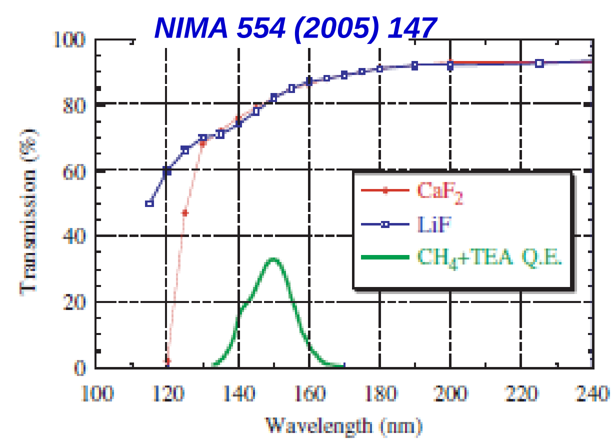




TEA(*Tri-Ethyl-Amine*): E_i=7.6 eV

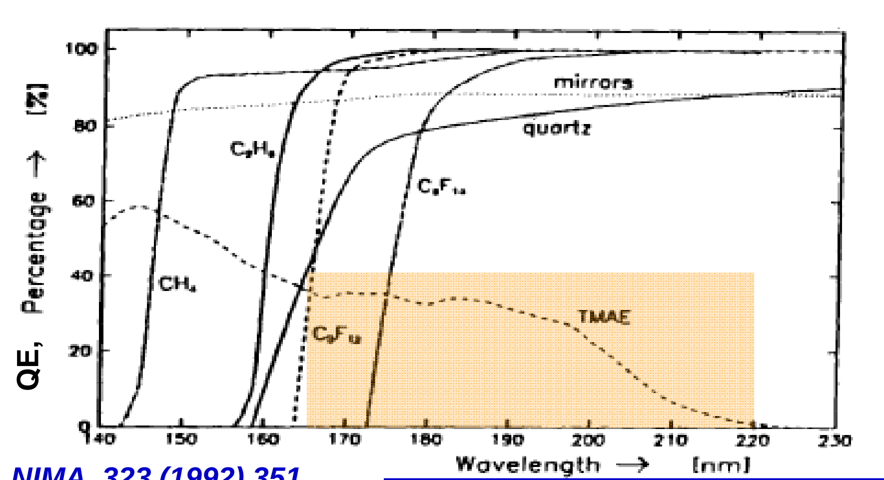




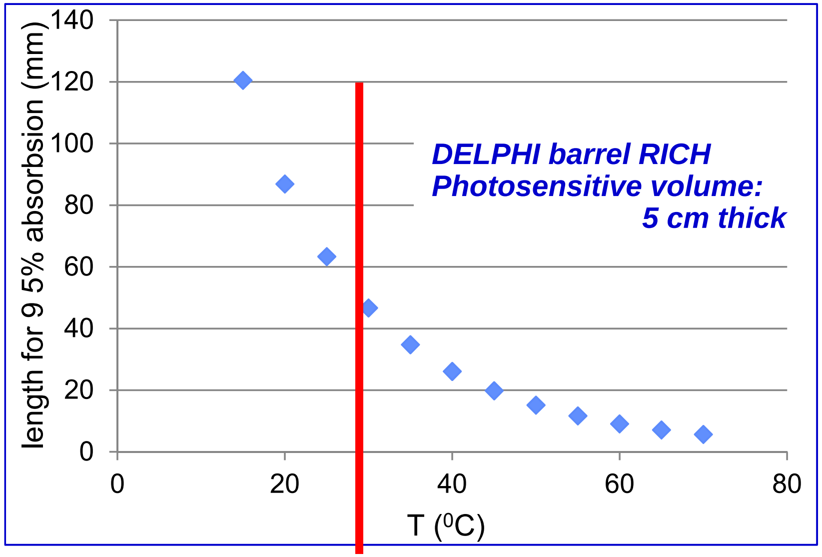


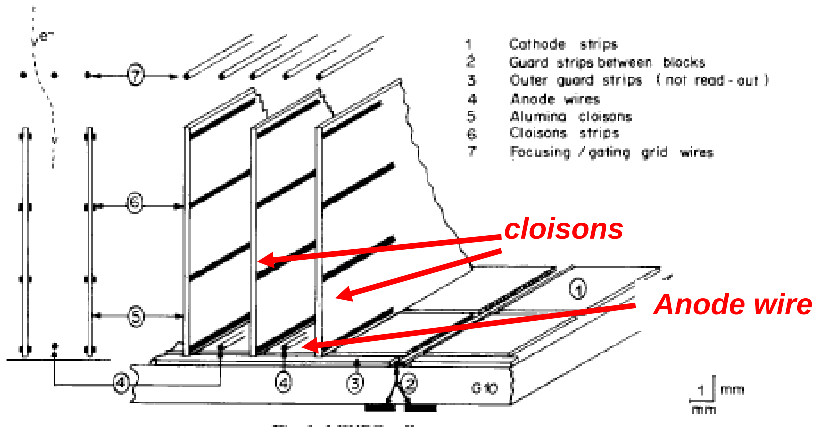
TMAE(*Tetrakis-Dimethylamine-Ethylene*): E_i=5.3 eV

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 provides UV photoconversion

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

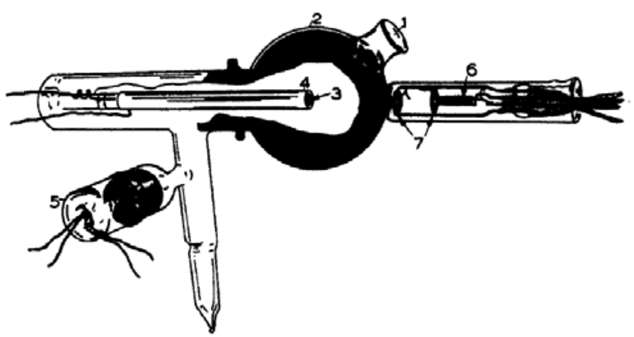


FIG. 1. Cutaway sketch of phototube; (1) 9741 glass bubble window, (2) graphite coated collector sphere 4 inches in diameter, (3) ⅜ inch glass tube, platinum painted, (4) nickel sleeve insulated from tube by glass beads, (5) ion gauge, (6) evaporating cylinder and helical platinum heater, (7) collimating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

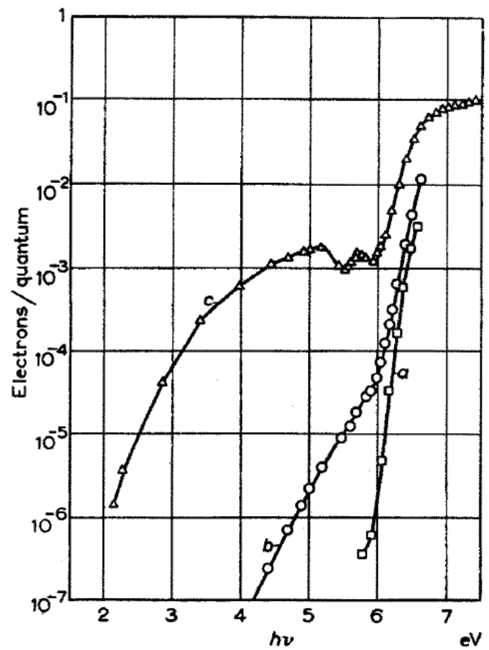


FIG. 2. Spectral distribution of the photoelectric yield for CsI surfaces: (a) thick film, (b) single crystal, (c) thin film evaporated in presence of excess Cs.

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

vacuum operated photocathodes were developed for space astronomy:

G.R.Carruthers,
Appl. Opt. 8 (1969) 633
Appl. Opt. 12 (1973) 2501
Appl. Opt. 14 (1975) 1667

The first position sensitive gas detectors with CsI photocathodes were developed at the end of the 80s:

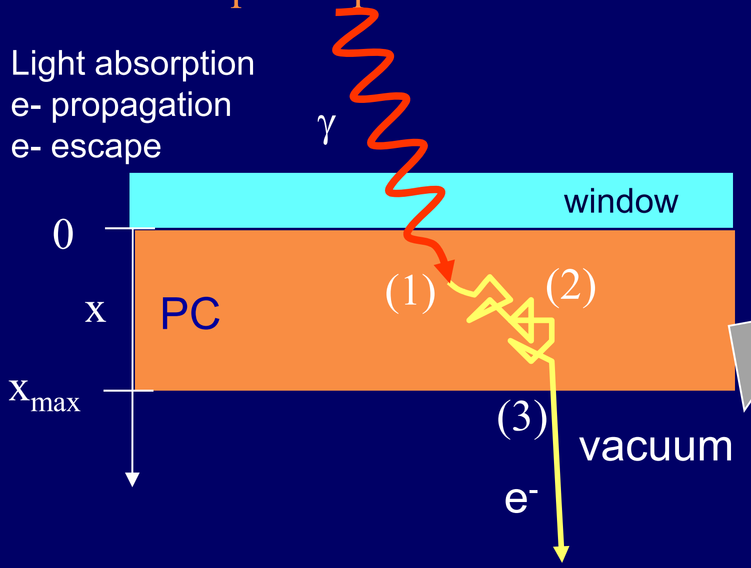
G.Charpak et al., Proceedings of Symposium on Particle Identification at High Luminosity Hadron Colliders, Fermilab, Batavia, IL, 1989, p. 295.

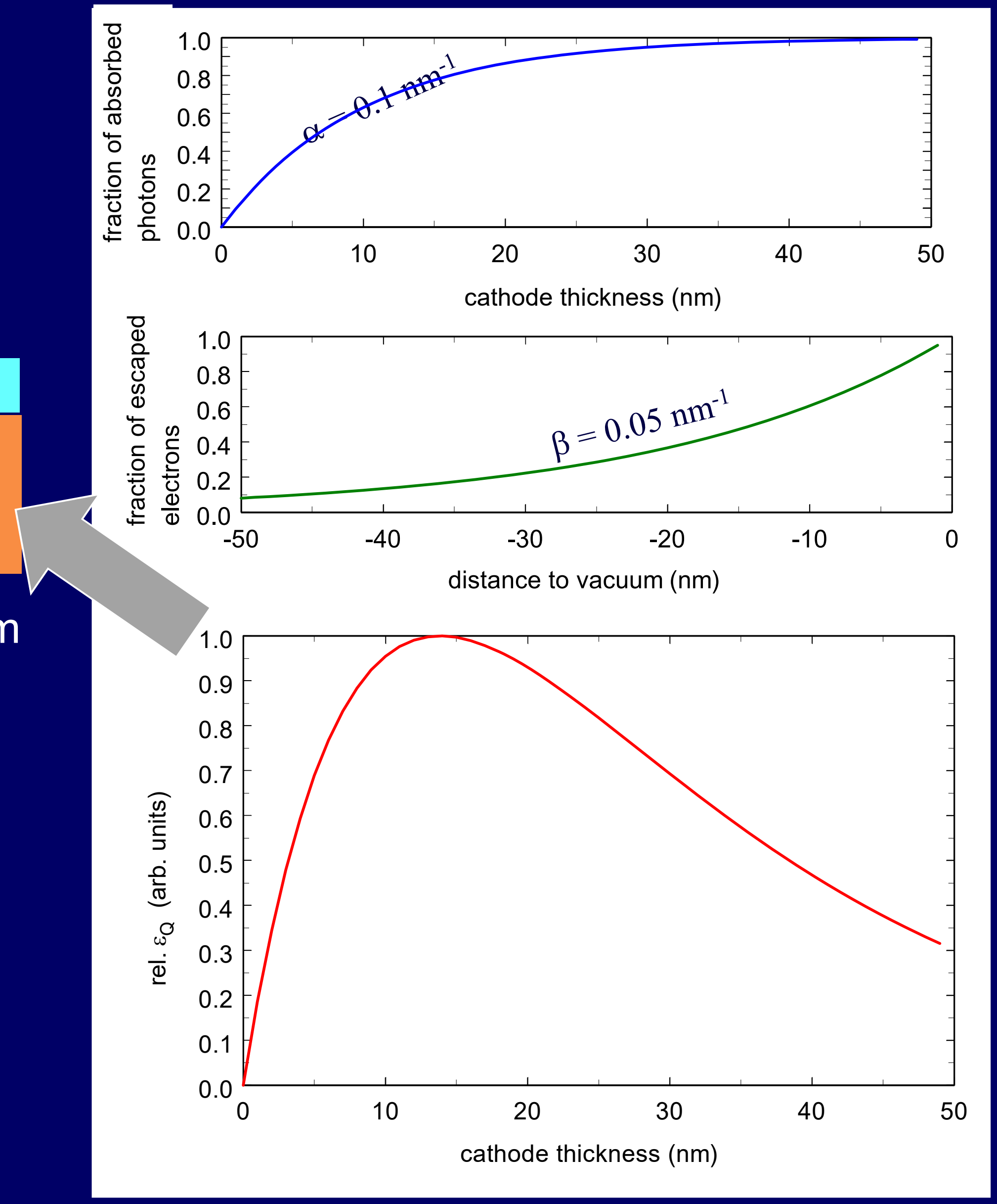
J.Séguinot et al., Nucl. Instr. and Meth. A 297 (1990), p. 133

Thin film photo cathodes

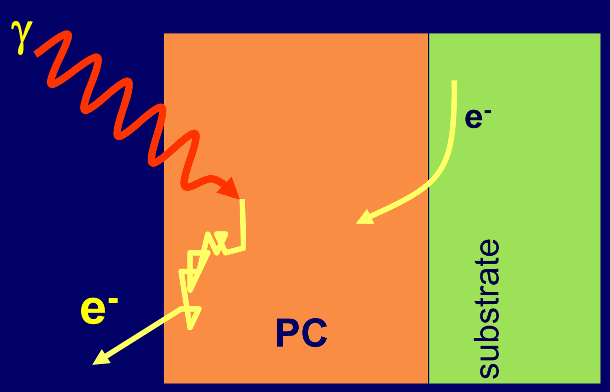
Semitransparent photocathode:

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





Reflective photocathode:



Reflective CsI photocathodes

70 J. Séguinot et al. / Nucl. Instr. and Meth. in Phys. Res. A 371 (1996) 64–78

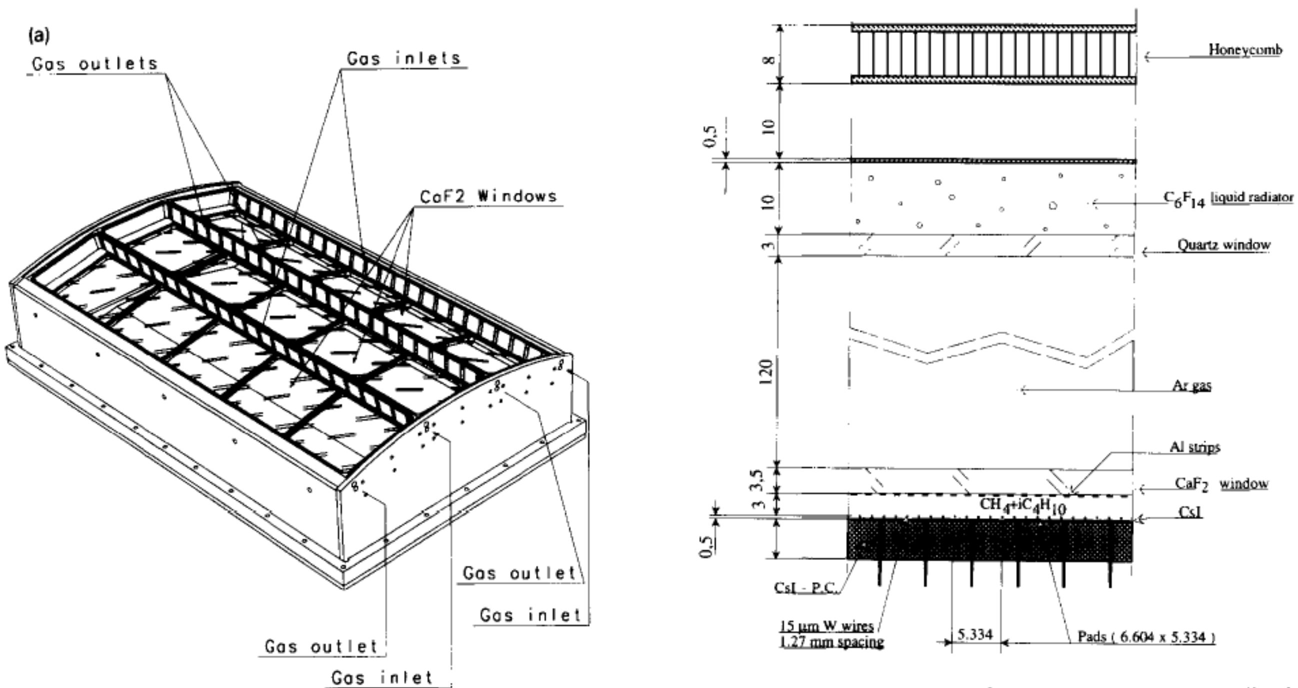
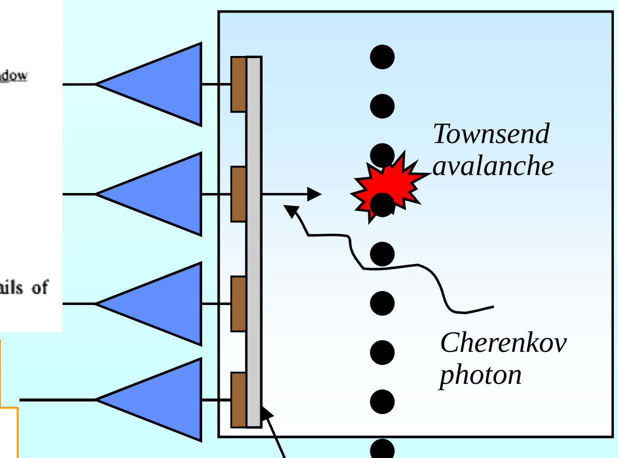


Fig. 9. Cross section on the Fast-RICH Prototype showing the details of radiator and detector geometry.

CsI is highly reactive with moisture:
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

J.Séguinot et al., Nucl. Instr. and Meth. A 371 (1996), p. 64.

This technique was pioneered by T. Ypsilantis and J. Séguinot, who built an extraordinary prototype and correctly concluded the technology was not adequate for the extreme time performance they needed

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 °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.

The best fused silica cuts here

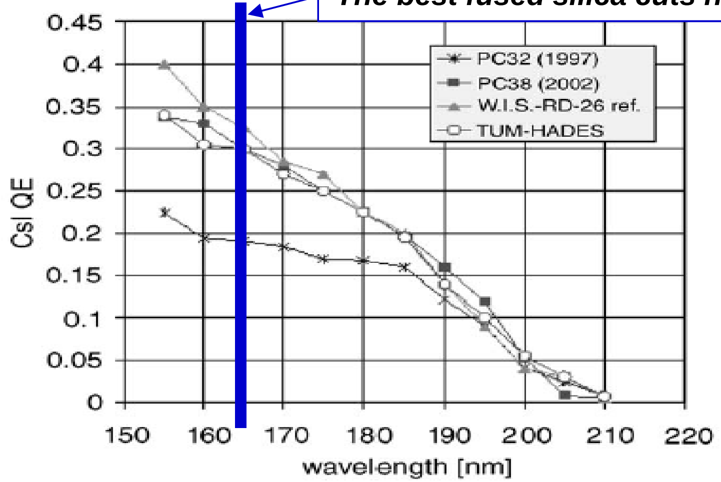
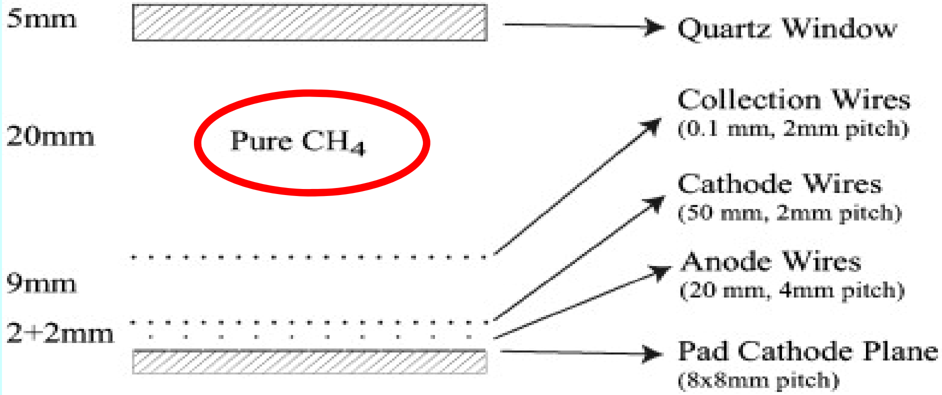


Fig. 1. The QE of CsI PCs produced at CERN for ALICE and at TUM for HADES, compared to that measured at the W.I.S. on small samples (reference for RD-26). PC32 is one of the four PCs equipping the ALICE-RICH prototype used in STAR at BNL.

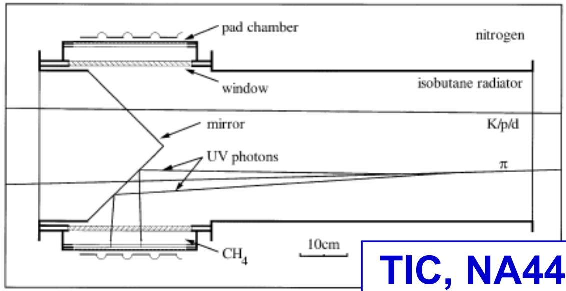
A. Di Mauro, NIM A 525 (2004) 173.

Schematic structure of the COMPASS Photon Detector:



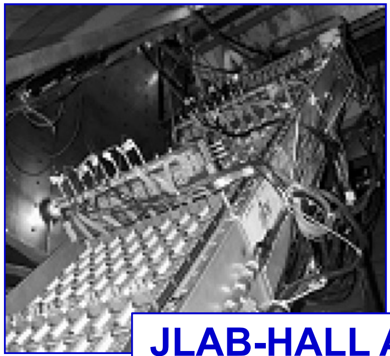
RICH with large area gaseous PD's
2nd generation: MWPC's + CsI

- MWPCs with solid state photocathode (the RD26 effort)

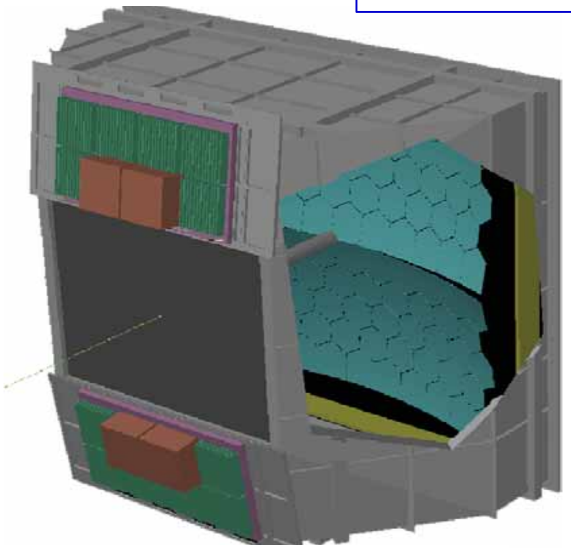


TIC, NA44

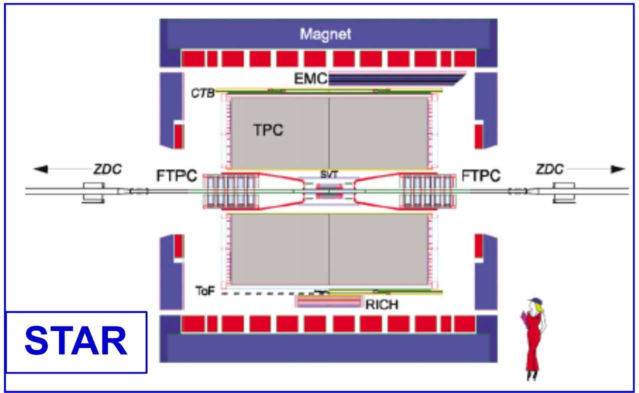
ALICE-HMPID 2009
CsI > 10 m²



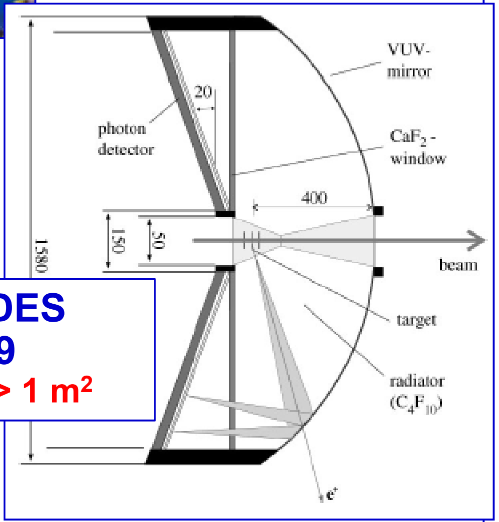
JLAB-HALL A



COMPASS RICH-1 2002
CsI > 5 m²



STAR



HADES 1999
CsI > 1 m²

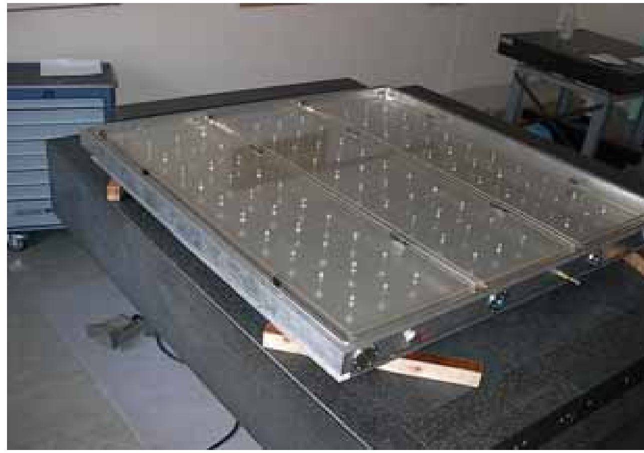
ALICE HMPID

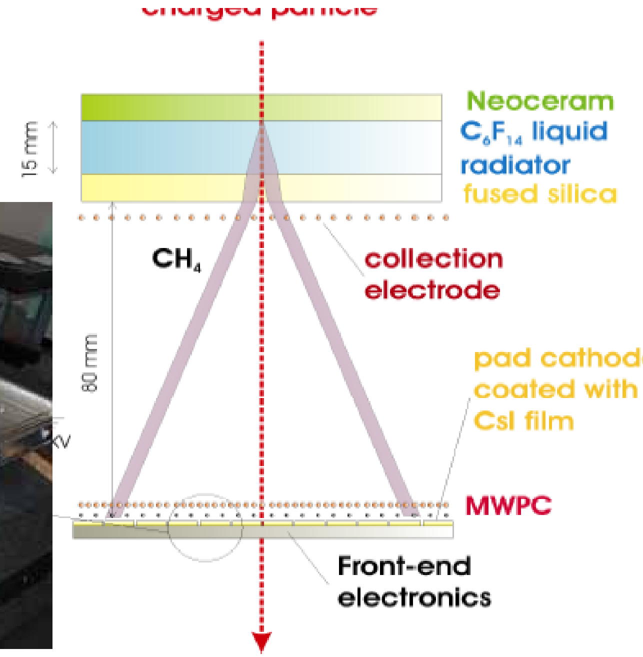
RADIATOR: 15 mm liquid C_6F_{14}, n ~ 1.2989 @ 175nm, β_{th} = 0.77

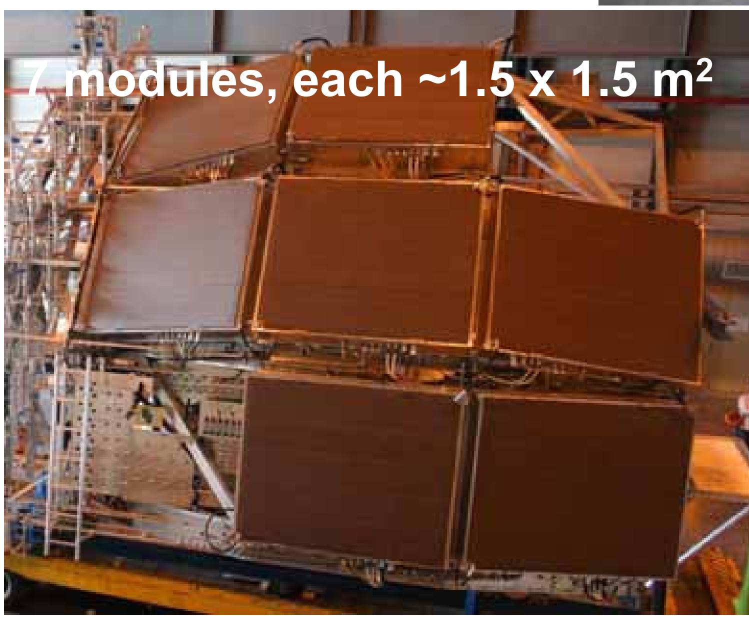
PHOTON CONVERTER: Reflective layer of CsI (QE ~ 25% @ 175 nm)

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

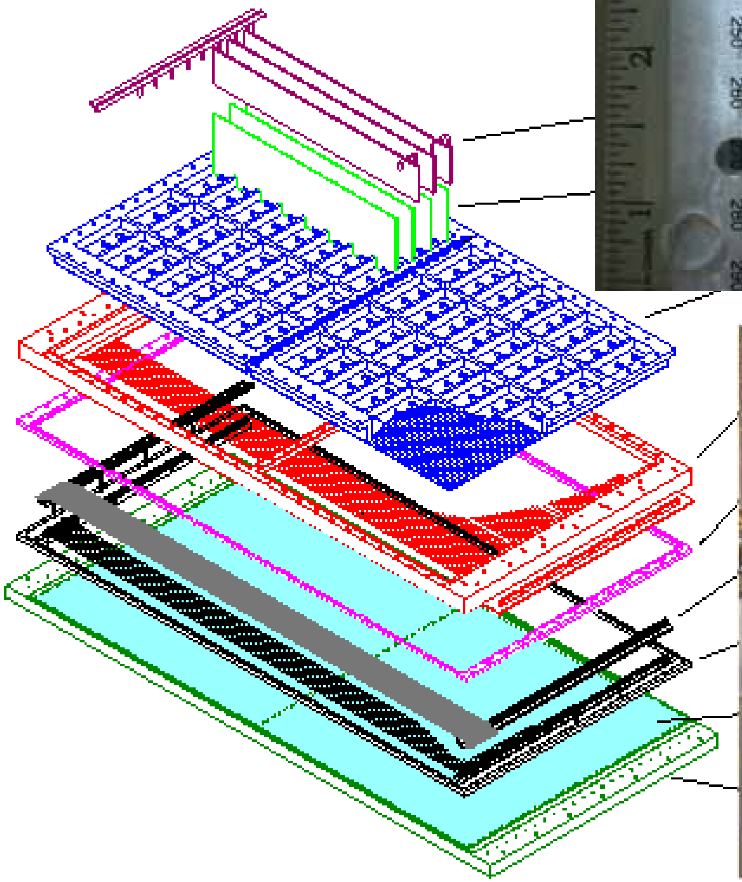
- Analogue pad readout

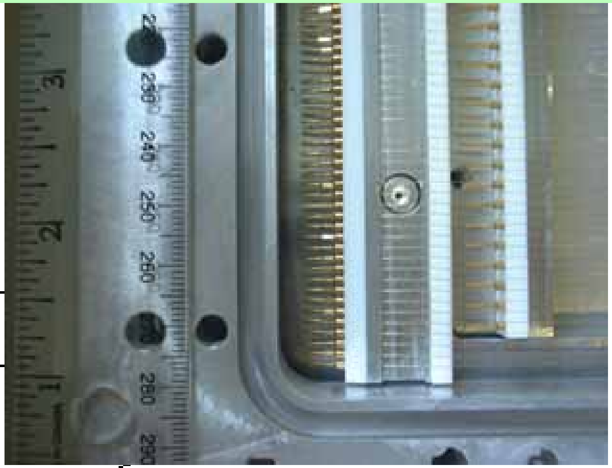




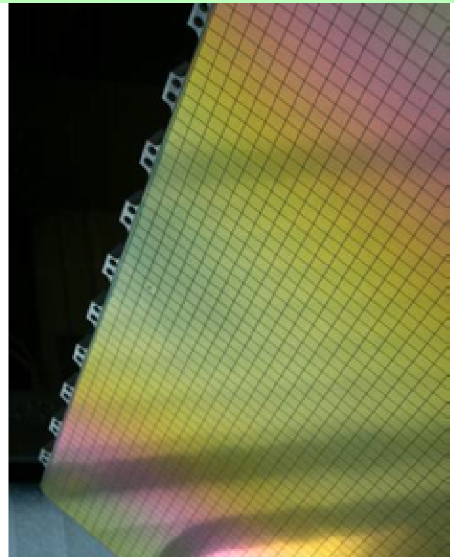


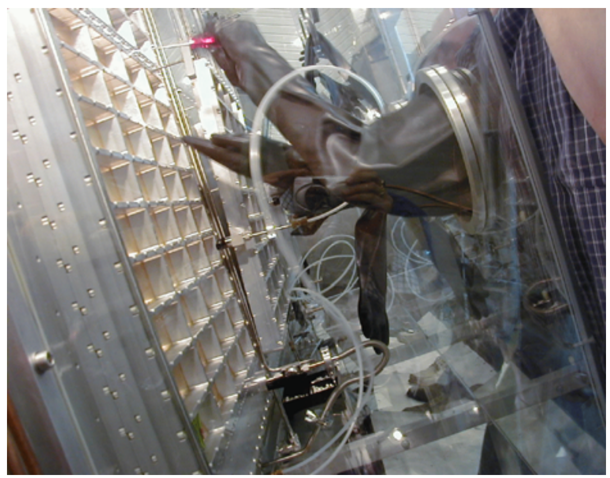
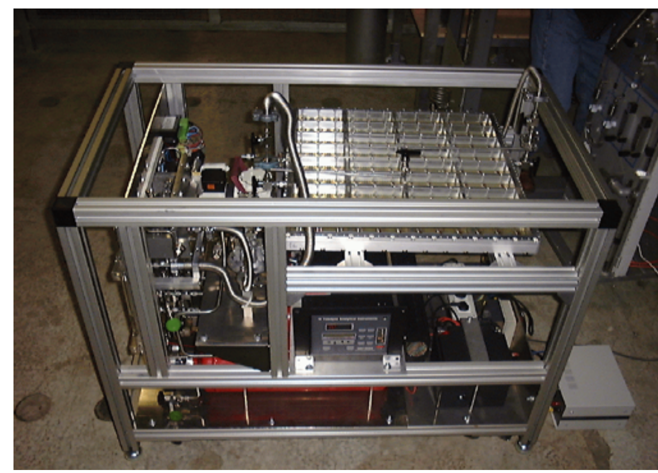
COMPASS MWPC's with CsI





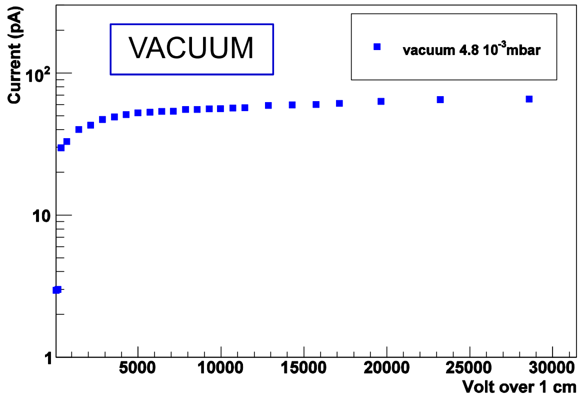
COMPASS photocathodes

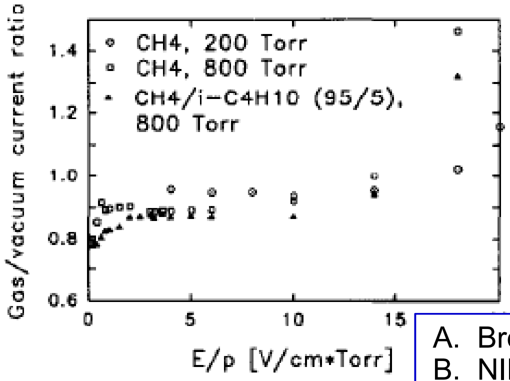



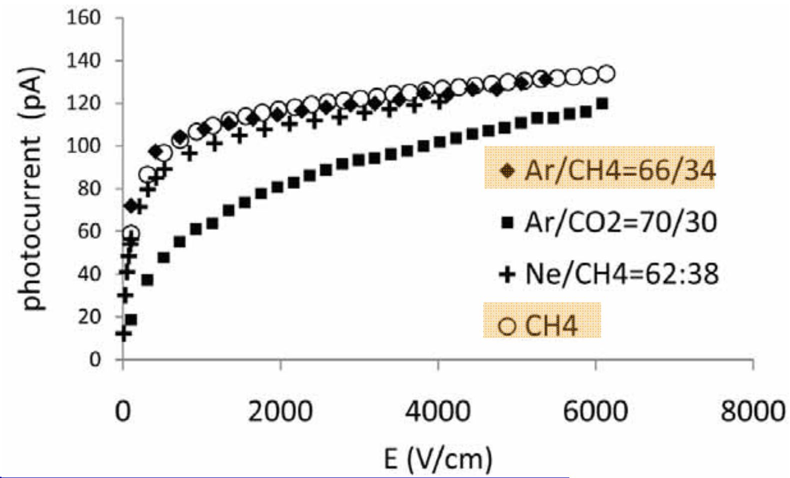
PHOTOELECTRON EXTRACTION

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

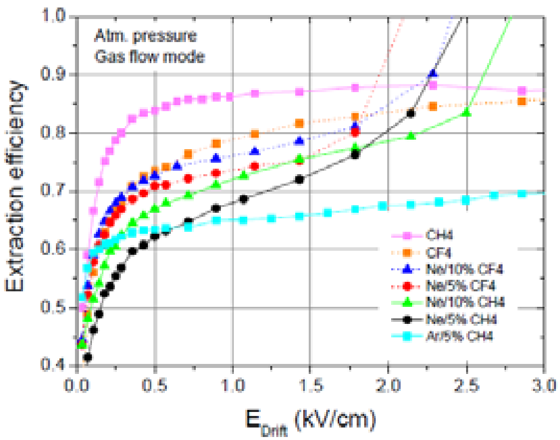




A. Breskin et al.,
B. NIM A 367 (1995) 342



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

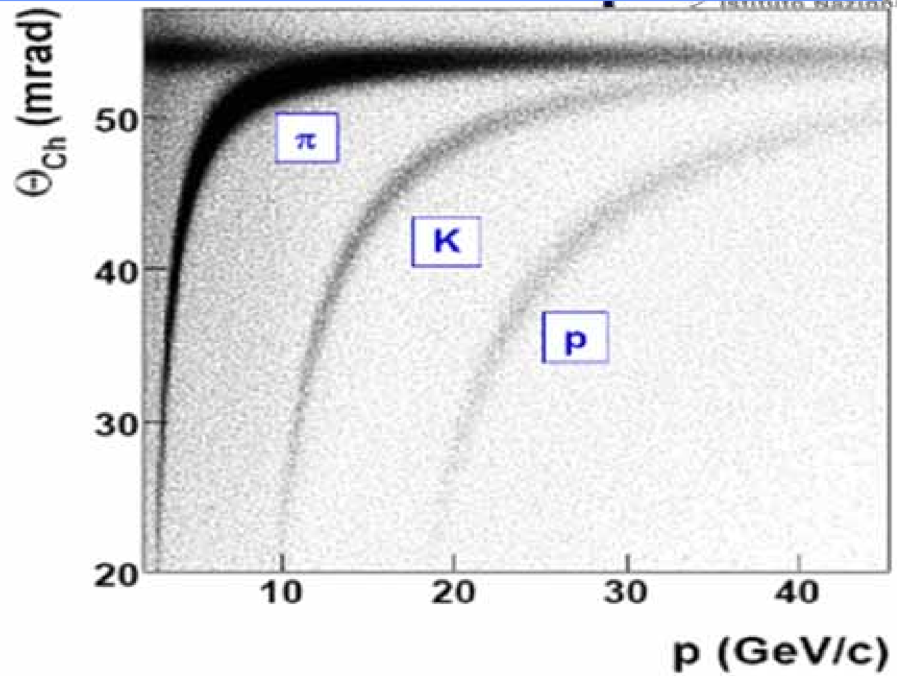


C. D. R. Azevedo et al., 2010 *JINST* 5 P01002

MWPCs with CsI have good performance

- photons / ring ($\beta \approx 1$, complete ring in acceptance) : **14**
- $\sigma_{\theta\text{-ph}}$ ($\beta \approx 1$) : **1.2 mrad**
- σ_{ring} ($\beta \approx 1$) : **0.6 mrad**
- 2σ π - K separation @ **43 GeV/c**
- PID efficiency **~ 95%** for θ_{Ch} > 30 mrad

except for the very forward region



After a long fight for increasing electrical stability at high m.i.p. rates and systematic studies at the CERN GIF we came to the same conclusion as Ypsilantis and Seguinot:

J. Seguinot et al., NIM A 371 (1996), 64:

CsI-MWPC with 0.5 mm gap to minimize ion collection time, fast front-end electronics (20 ns int. time):

stable operation is not possible at 10^5 gain because of photon feedback, space charge and sparks

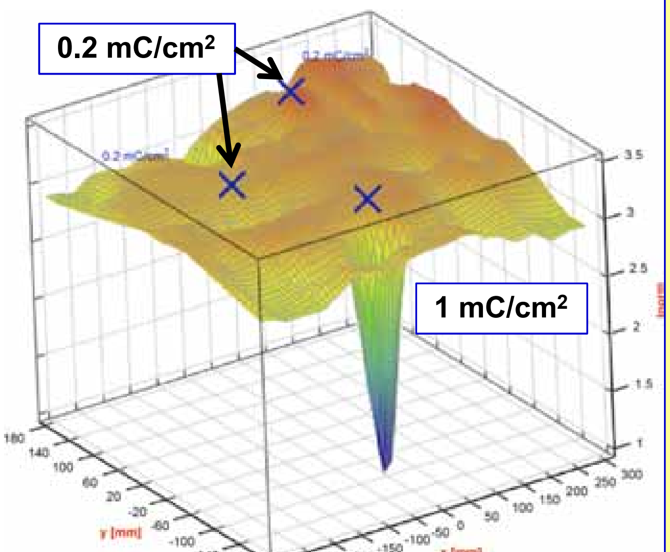
MWPCs with CsI: the limits

- 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 / cm^2
  - *Ion bombardment of the photocathode (IBF > 50%)*

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*

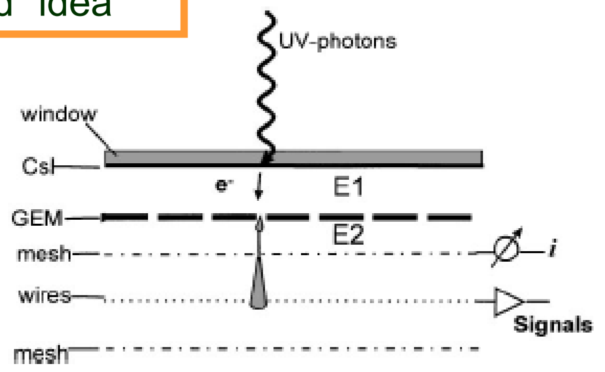
MPGD technologies are needed to overcome these limits

ION & PHOTON BLOCKING GEOMETRIES

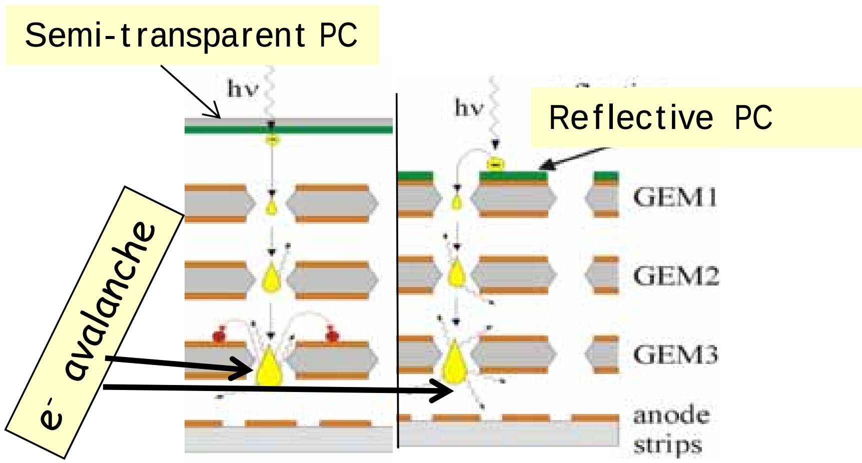
GEM-based PDs

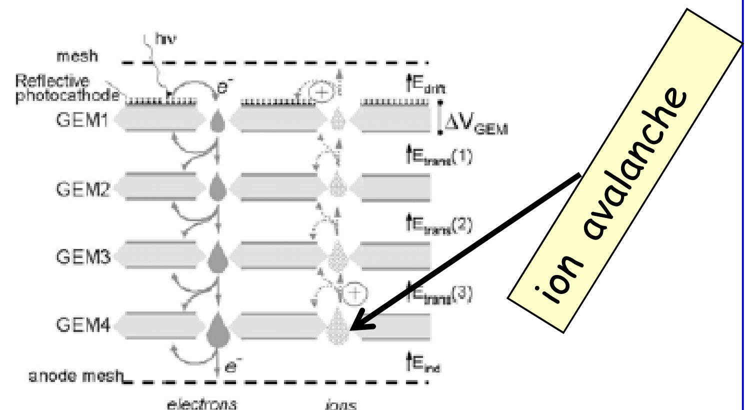
NO photon feedback
Reduced ion feedback

An "old" idea



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

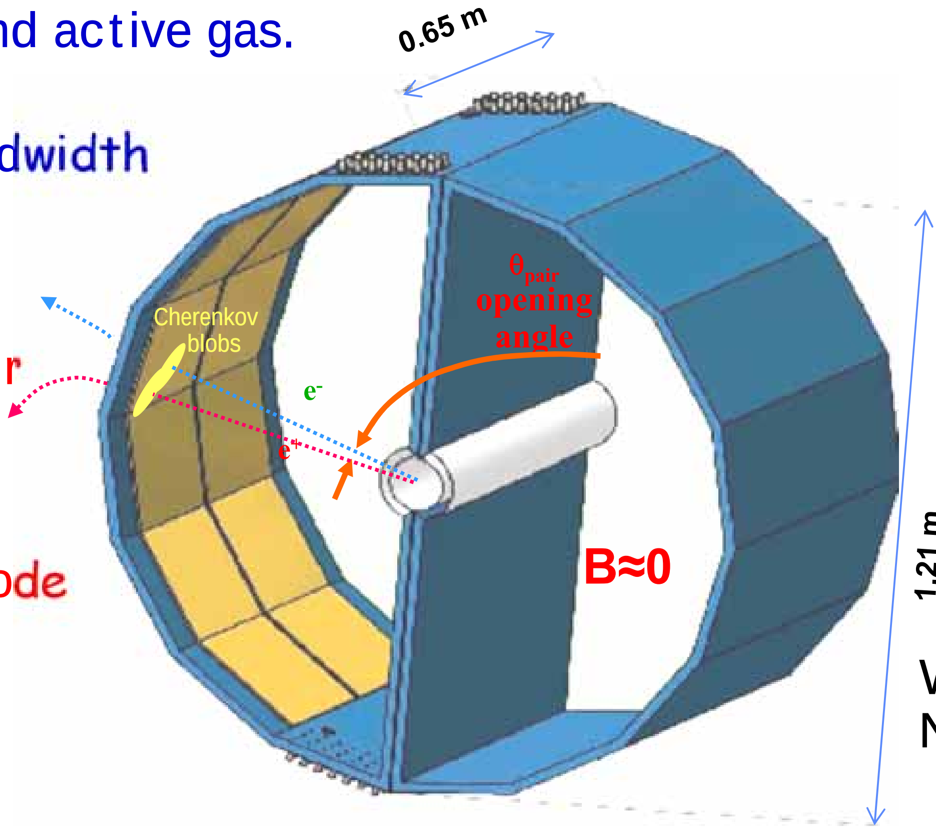


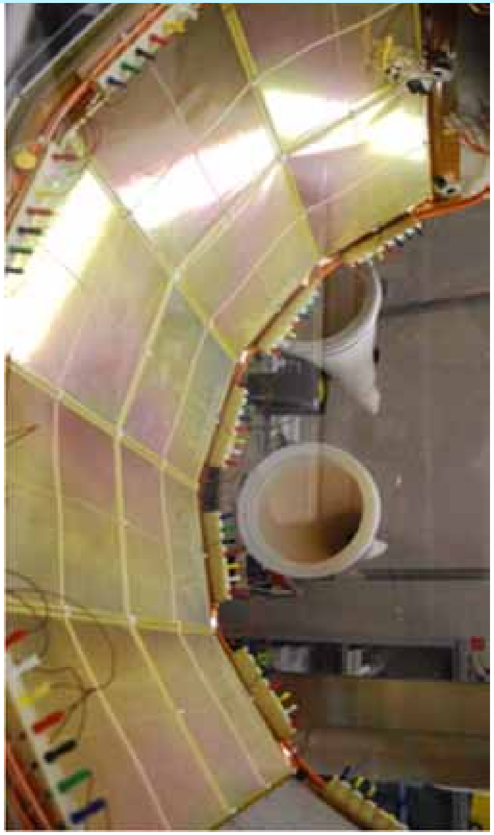


A. Breskin and R. Chechik, NIM A 595 (2008) 116

HBD- Cherenkov detector with GEMs +CsI

- ✓ 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

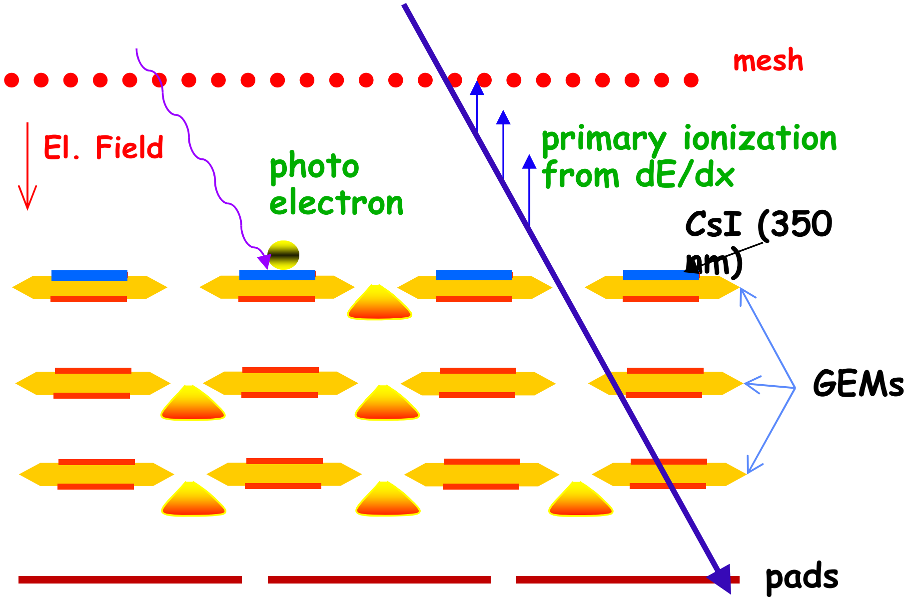


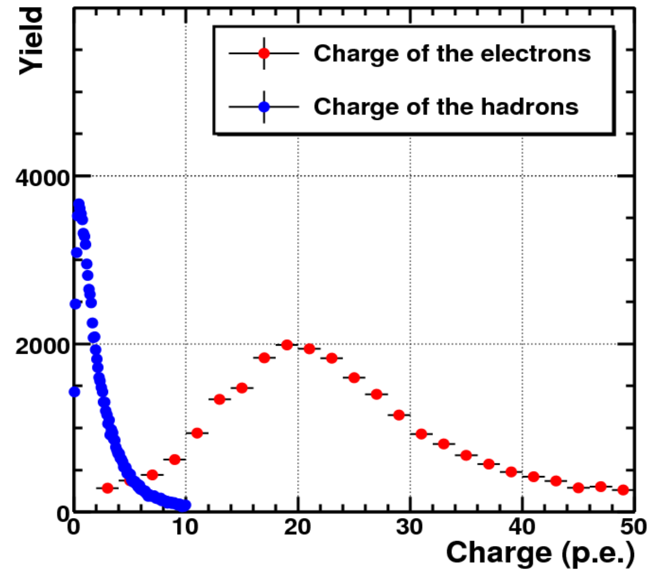


W. Anderson et al., NIM A 646 (2011) 35

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

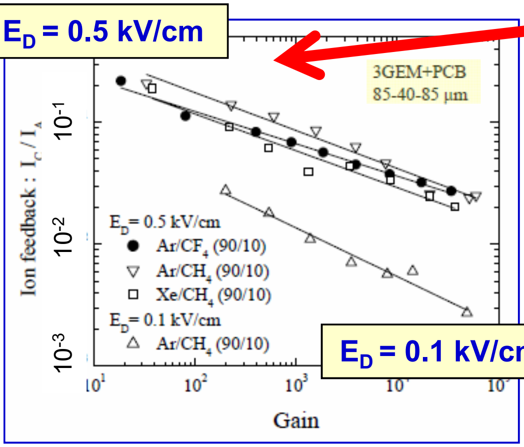
rich literature about IFB in GEM-based detectors

here examples with semi-transparent PC

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

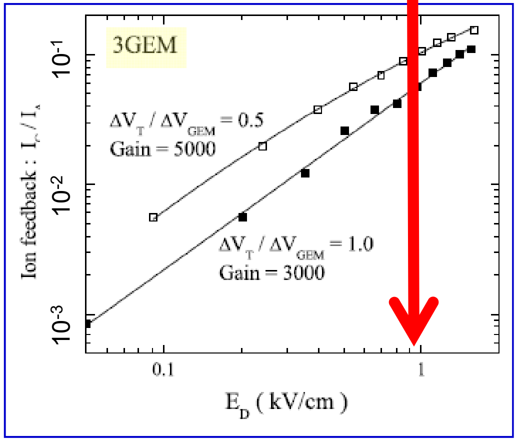
$E \sim$ 1 kV/cm needed for good photoelectron extraction

E_D = 0.5 kV/cm

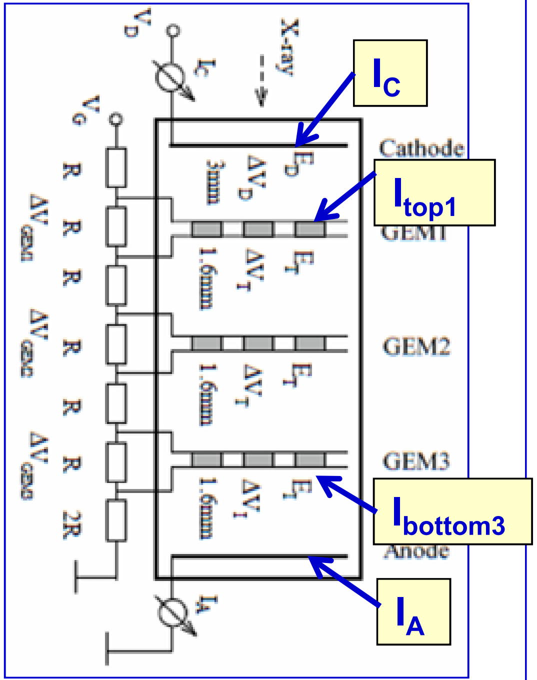


E_D = 0.1 kV/cm

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

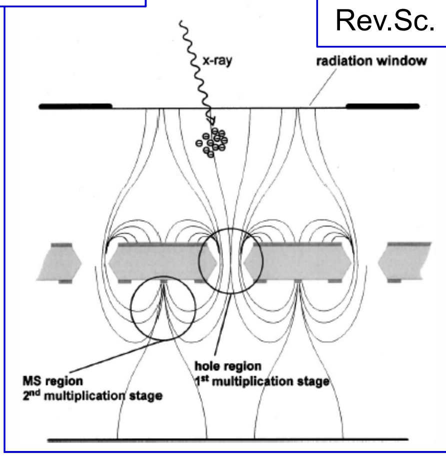
IBF: a few % level in effective GEM-based photon detectors

OVERCOMING IBF

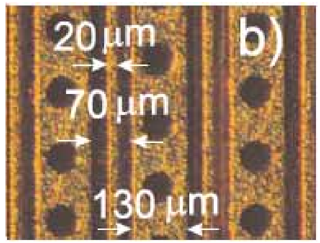
More complex geometries needed with extra electrodes to trap the ions:

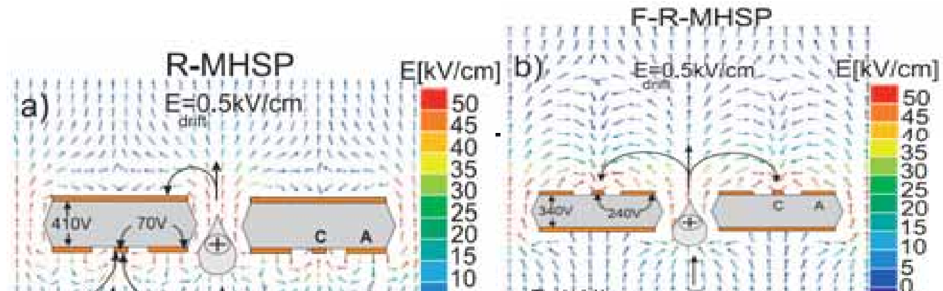
Micro-Hole & Strip Plate (MHSP), COBRA

MHSP



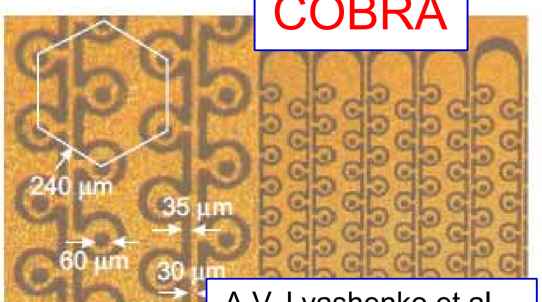
J.F.C.A. Veloso et al., Rev.Sc. Instr. 71 (2000) 2371



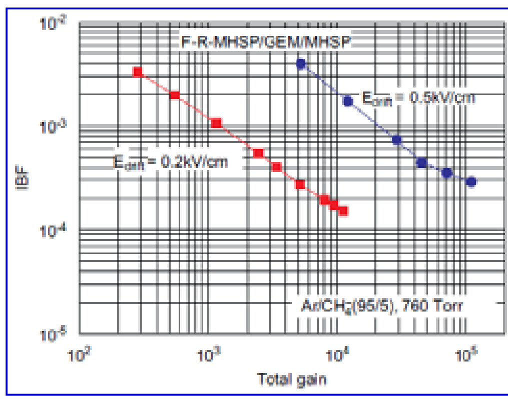


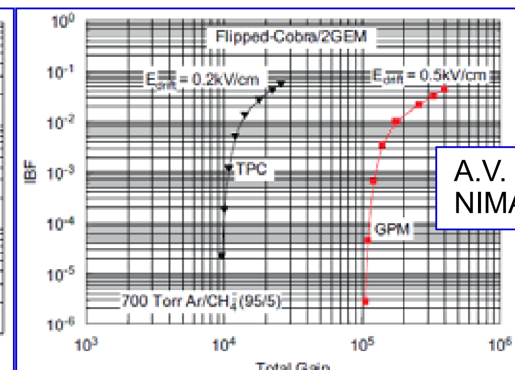
A.V. Lyashenko et al., JINST 2 (2007) P08004

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

THGEMs

GAS ELECTRON MULTIPLIER FORMED BY A RIGID DIELECTIC FOIL BETWEEN ELECTRODES, PROVIDED WITH A PATTERN OF HOLES.

In a proper gas and with electric bias it can provide large electron multiplication

Material:
- FR4, permaglass, …
- PTFE, PET, ARLON, …
- glass, PEG3 (etchable glass), …
- ceramic

Holes:
- mechanical drilling (1 € per 1000 holes)
- water jet
- laser
- chemical etching
- preformed (capillary plates)

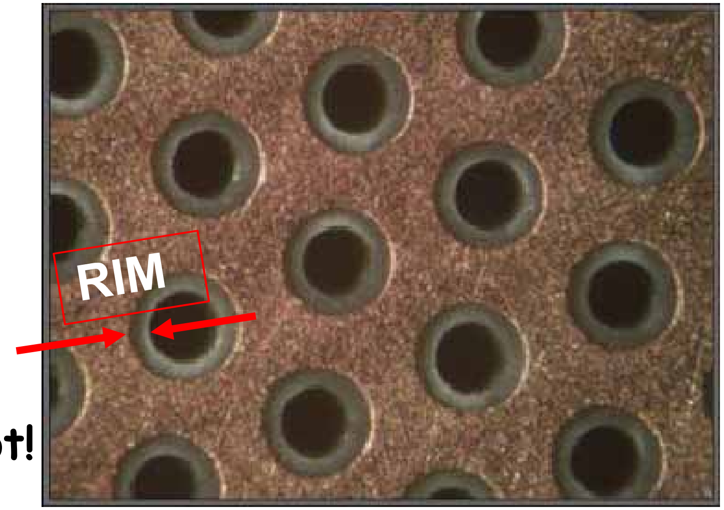
THGEM-based PDs, why ?

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



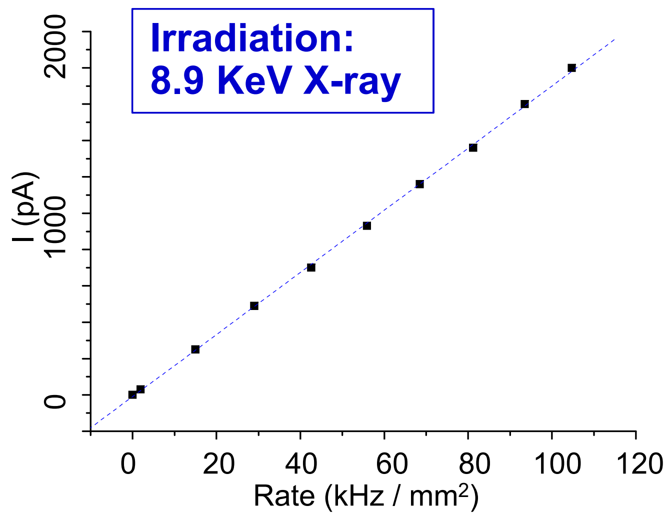
Comparing to GEMs

- 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

THGEM rate capability and IBF

High rate device

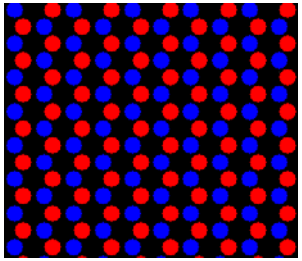


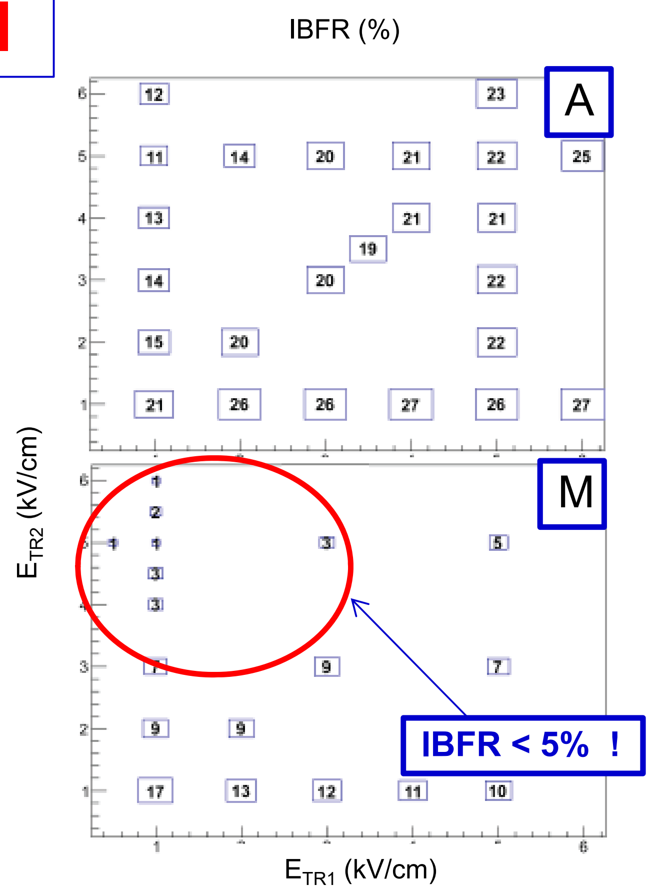
single THGEM, no RIM

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

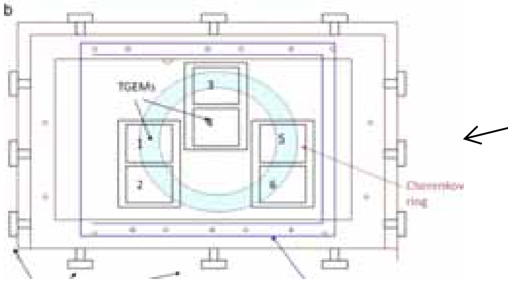




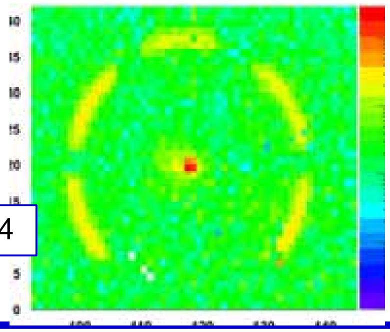
M. Alexeev et al., JINST 7 (2012) C002014

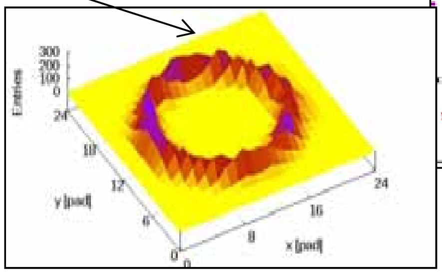
THGEM R&D for RICHes

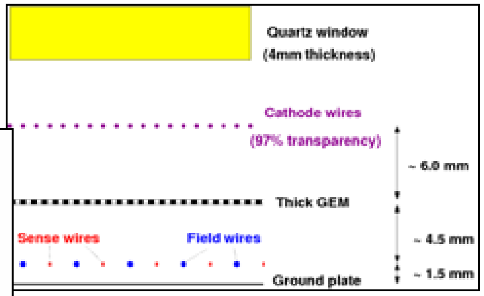
ALICE VHMPID
THGEM & HYBRID



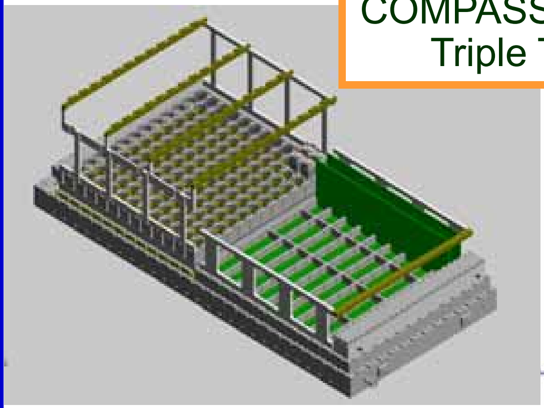
V.Peskov et al., NIMA 695 (2012) 154

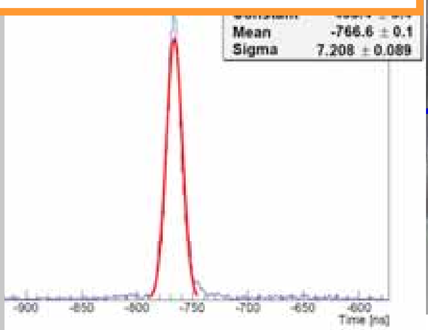


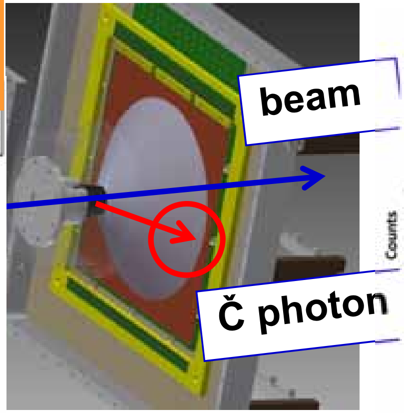


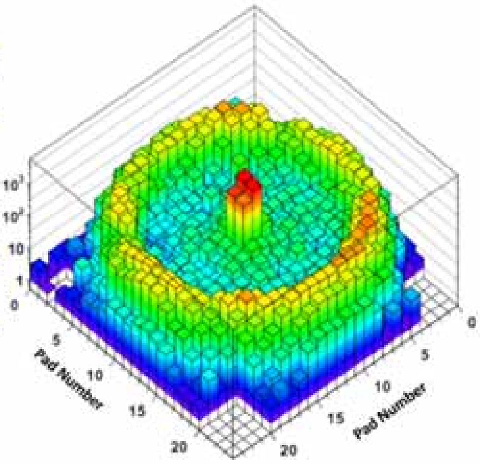


COMPASS, RICH-1 upgrade by
Triple THGEM detectors



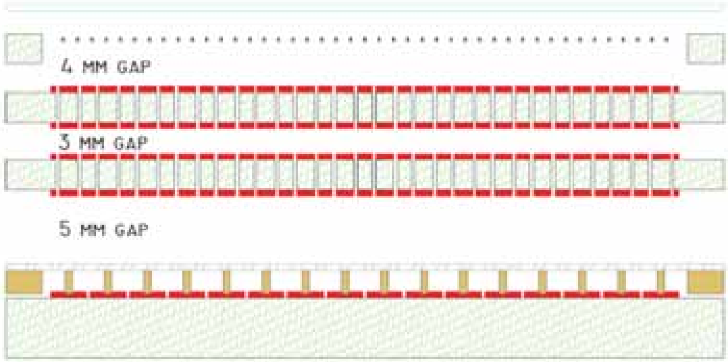


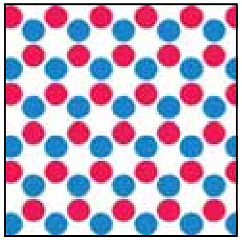




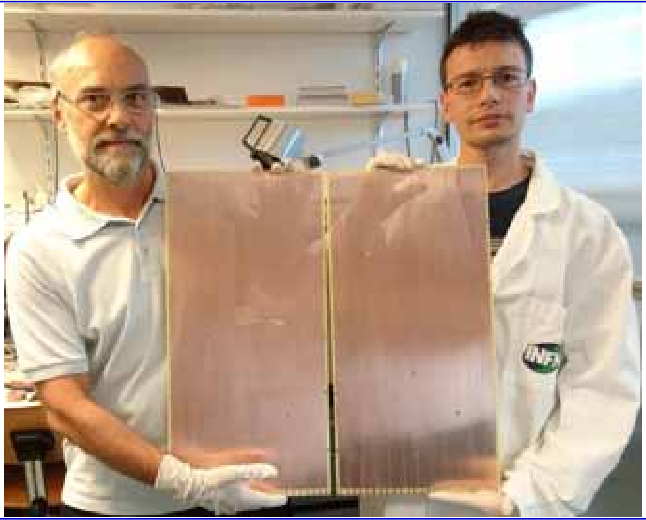
HYBRID MPGD PDs (THGEM + MM)

- 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





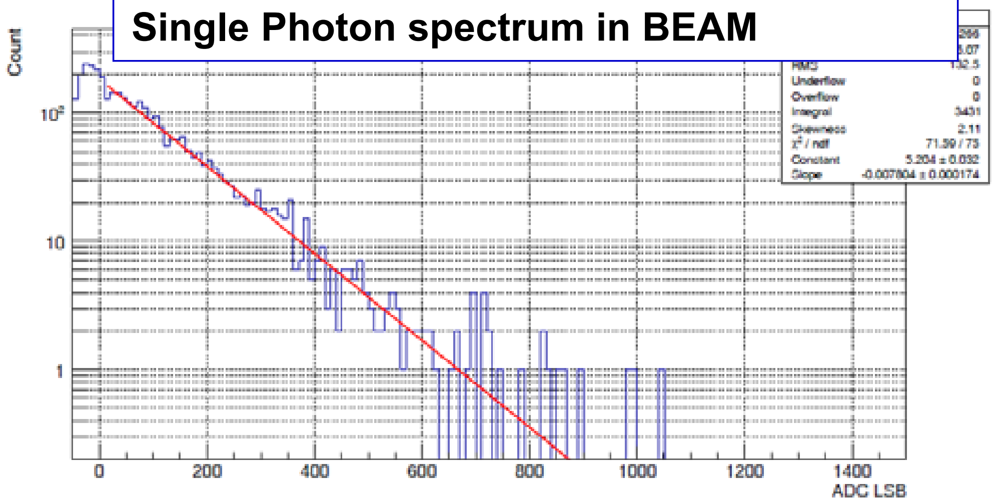
THGEM staggered !



The same architecture is independently studied as GPM for DM searches

Gain ~ 130K

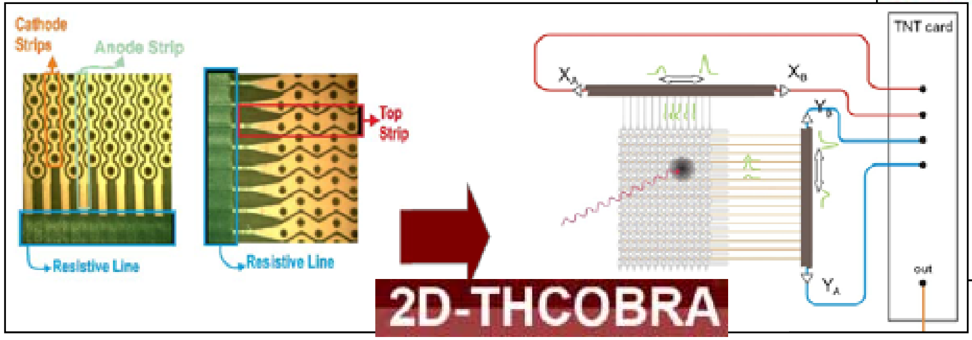
Single Photon spectrum in BEAM



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



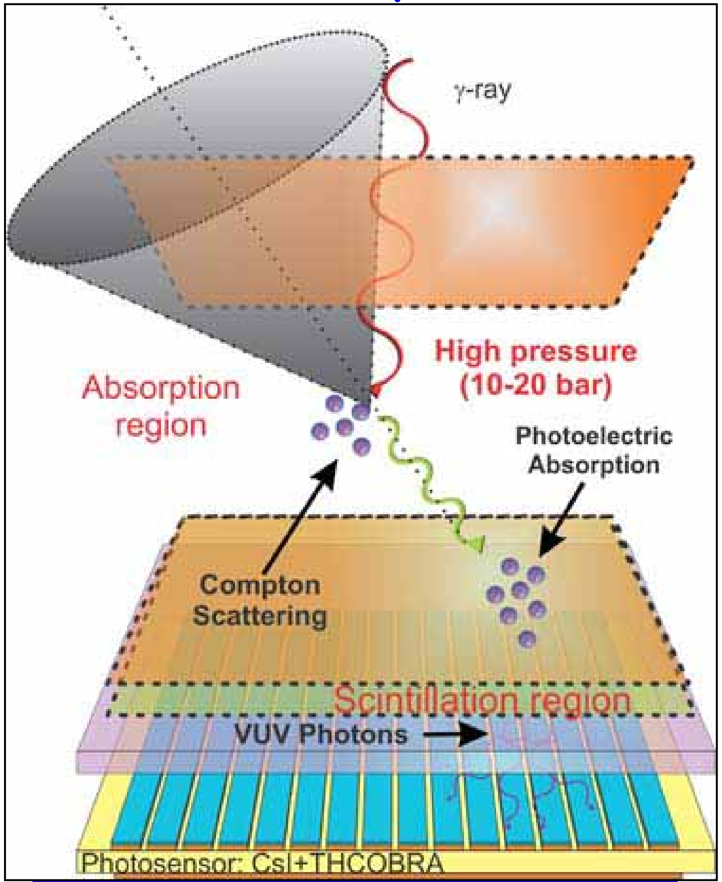
- Gas Photomultiplier (GPM) : 2D-THCOBRA
  - Good Performance
    - Gain of 10^6
    - IBF values of about: 20%
  - 2D THCOBRA adequate to obtain image
  - Position Resolution: FWHM= 300 μm, σ= 128μm
  - Count rate of 100kHz

T. Lopes 2013 JINST 8 P09002

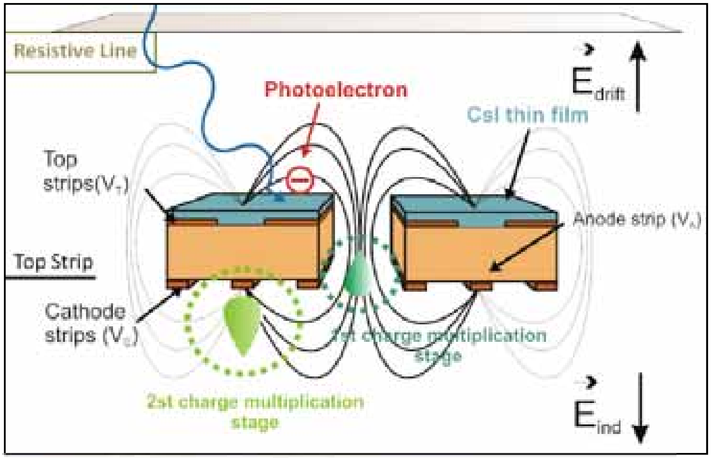
Gaseous Compton camera

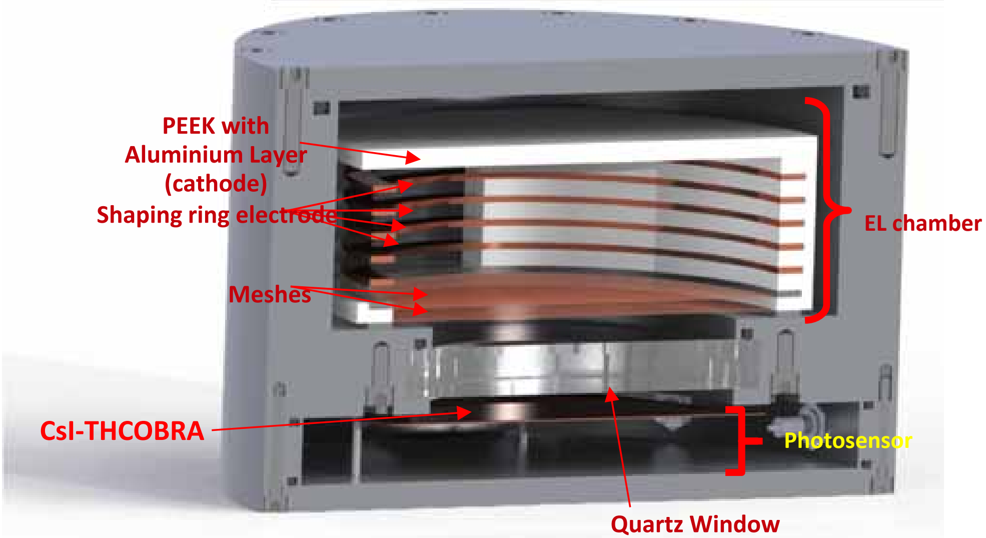
Electroluminescence light is detected by THCOBRA with 2D R-O

Drift time provides the third coordinate

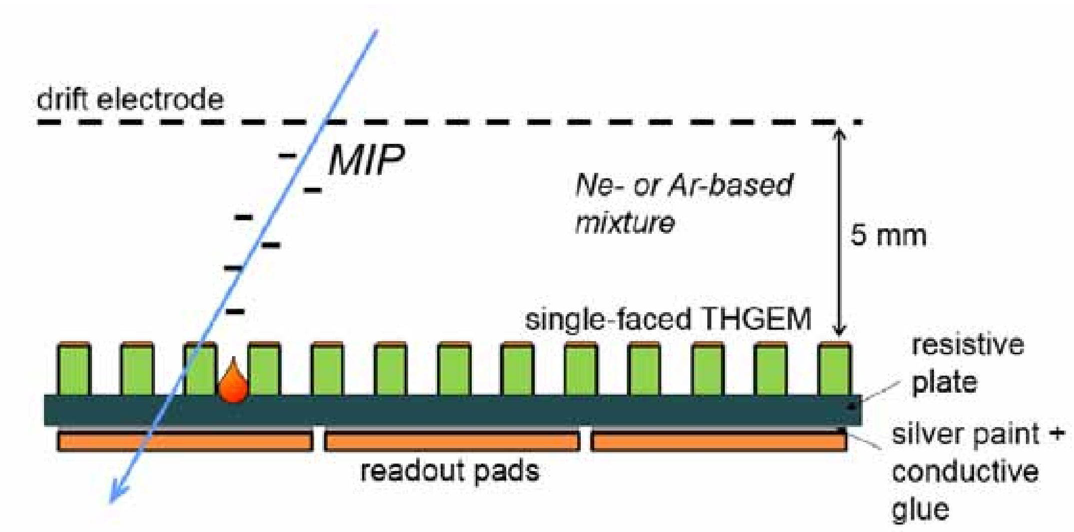


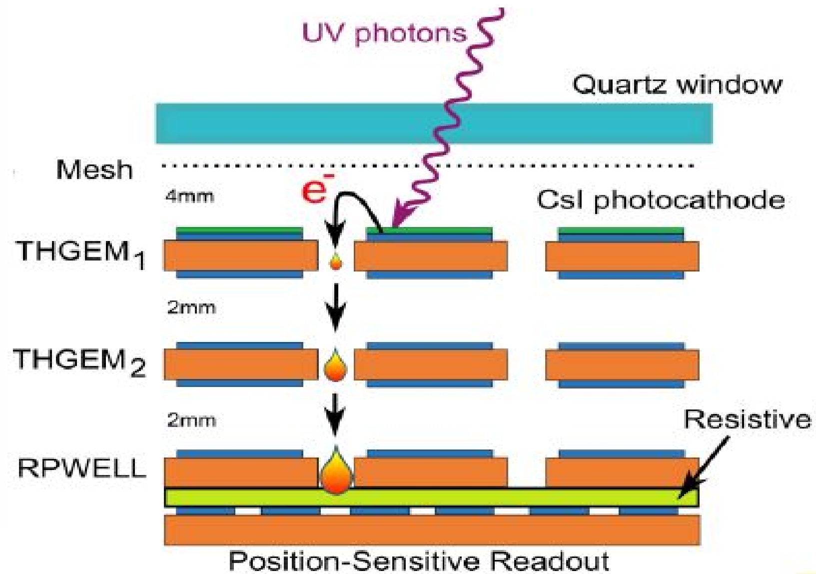
C. D. R. Azevedo et al., NIM A 732 (2013) 551





RPWELL





10^9 Ω cm resistive plate → discharge free operations. 99% eff. up to ~ 10^5 Hz/cm^2

proposed for digital hadron calorimetry

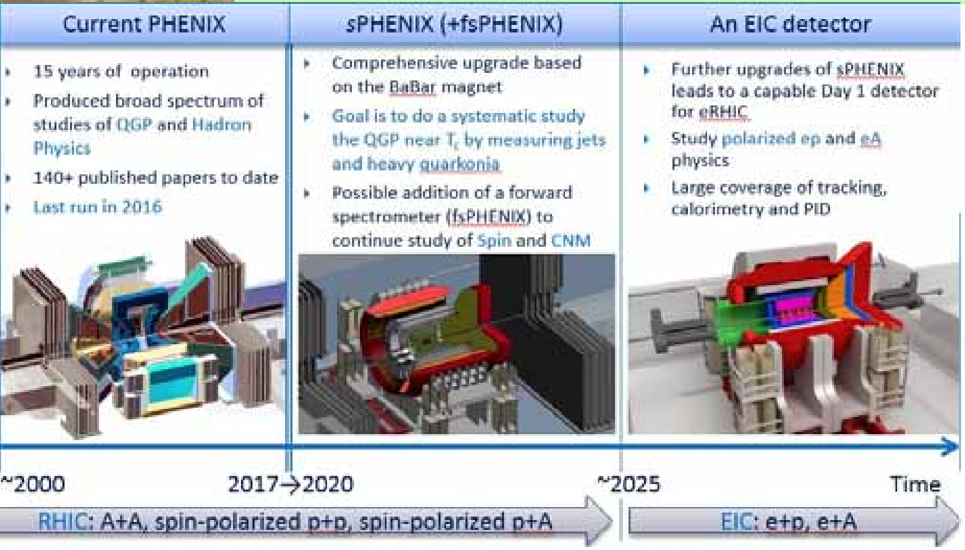
L. Moleri et al.,NIMA 845 (2017) 262

proposed for UV photon detection

S. Bressler et al. JINST July 2013 arXiv:1305.4657

L. Arazi et al. 2012 JINST 7 C05011 arXiv:1112.1915

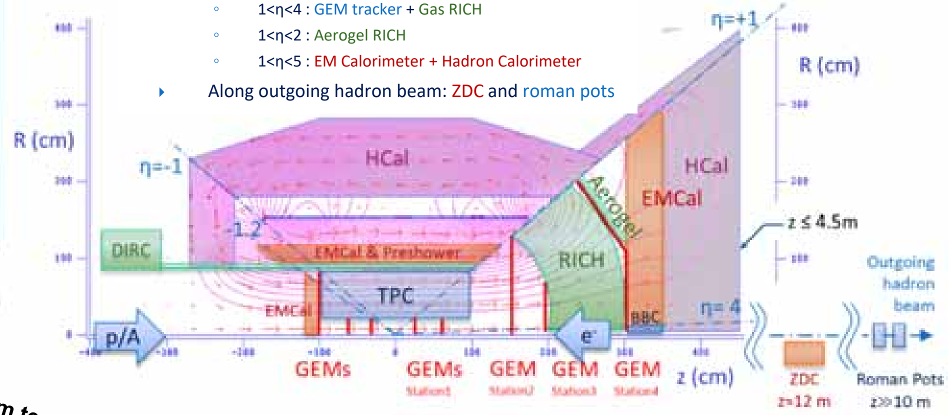
MPGD-based PDs for a detector at EIC

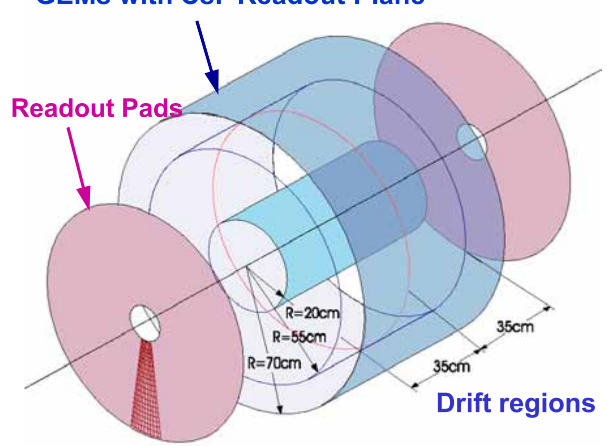


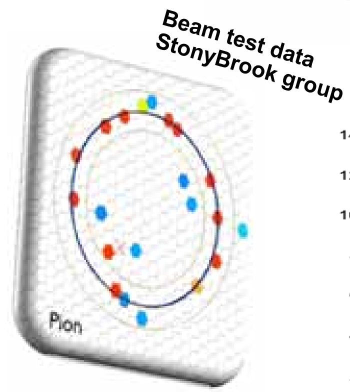
sPHENIX → eRHIC Detector

LOI: arXiv:1402.1209

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

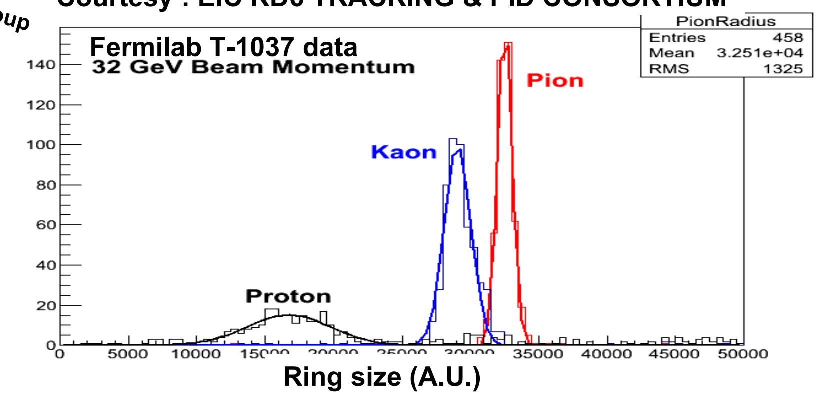




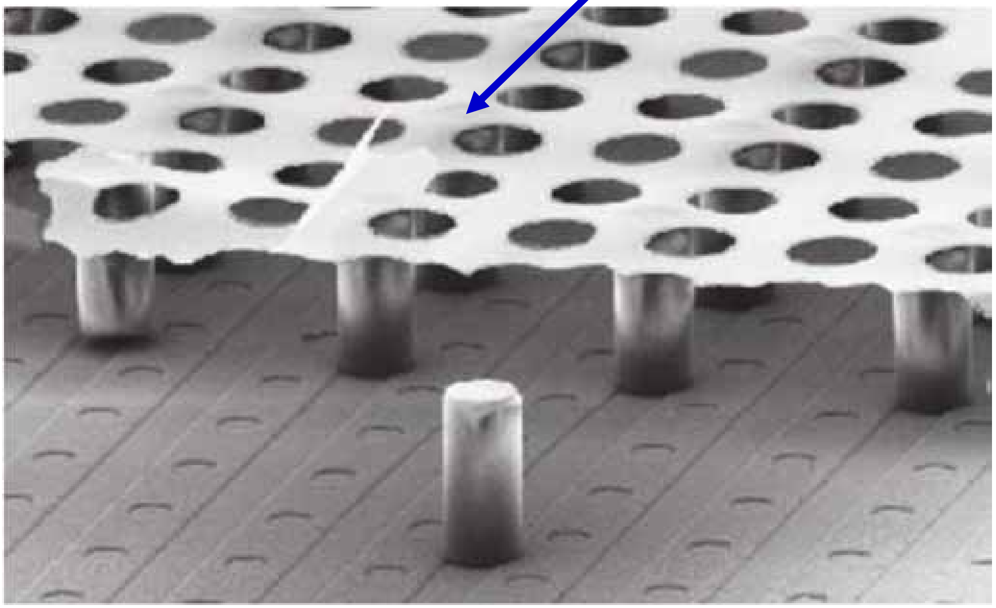


M.Blatnik et al. arXiv:1501.03530

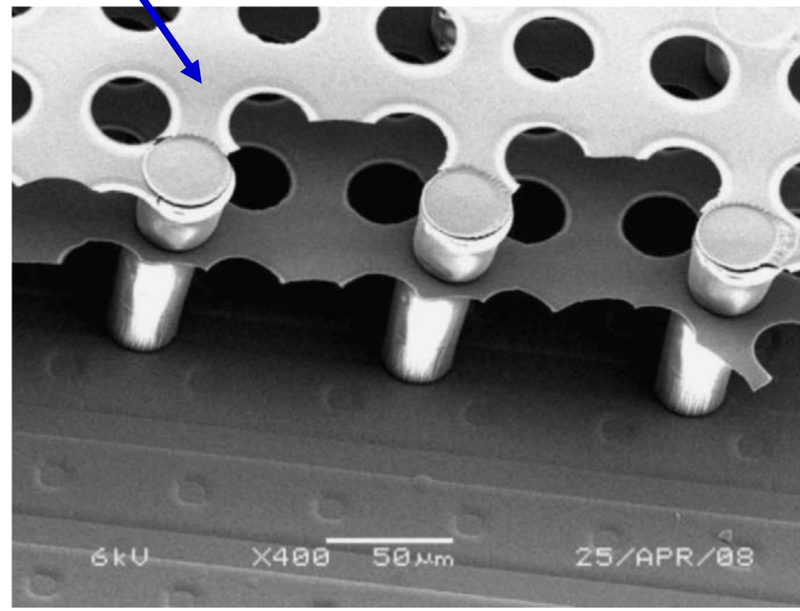
Courtesy : EIC RD6 TRACKING & PID CONSORTIUM



InGrid and TwinGrid



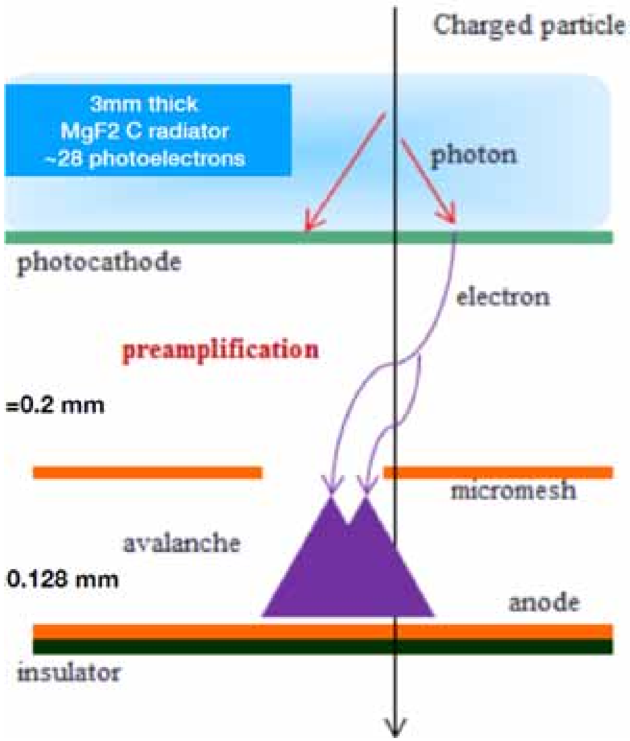
M.Chefdeville et al., Nucl. Instrum. Meth. A 556 (2006) 490.



Y.Bilevych et al., Nucl. Instrum. Meth. A 610 (2009) 644.

Excellent space resolution for single UV photons provided by InGrid with CsI coating of a micro-grid directly integrated by wafer post-processing production onto a CMOS pixel detector with the complete readout system.
The array of microgrid round holes corresponds to the array of CMOS pixel centers

"picosecond" timing with MPGDs?



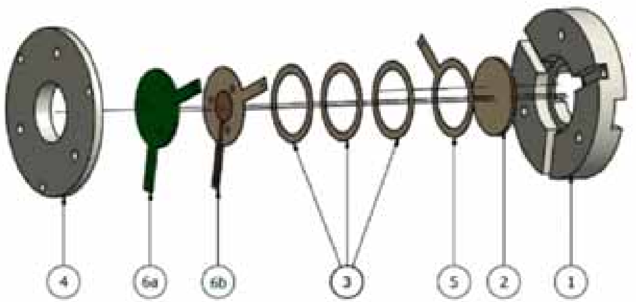
T.Papaevangelou et al, Fast Timing for High-Rate Environments with Micromegas, arXiv:1601.00123 (Jan. 2016).

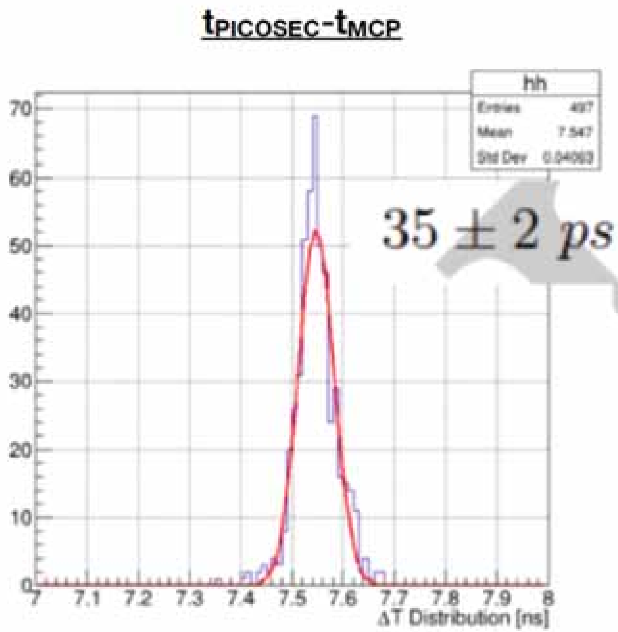
Talk of Sebastian White

Many configuration tested

Successfully achieved ~35 ps resolution in test beam.

Puzzling shift in spite of CF.





A NEW PHOTOCONVERTER: Rich-graphite Nano-Diamond film

CsI bandgap: 6.2 eV; electron affinity: 0.1 eV; hygroscopic; ages by ion bombardment (~mC/cm^2)

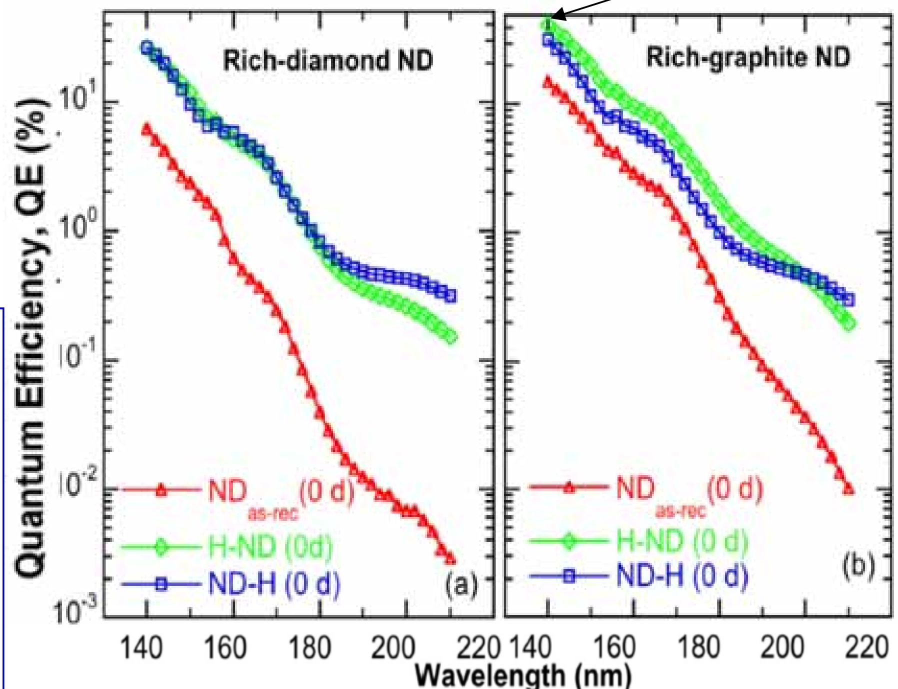
Diamond bandgap: 5.5 eV; chemically inert and robust; if hydrogenated: electron affinity -1.27 eV

Hydrogenated chemical vapor deposited diamond films (4-6 µm) known to have QE ~15% @ 140 nm.

Heterogranular-structured diamond-gold nanohybrids proposed as stable field emission cathode material

Nano-Diamond grains (size: ~250 nm), with variable sp^2 (graphite phase) and sp^3 (diamond phase) hybridized carbon contents treated in H2 microwave plasma show large QE: ~50% @ 140 nm

47 % (!)



L.Velardi, A.Valentini, G.Cicala, Diamond & Related Materials 76 (2017) 1

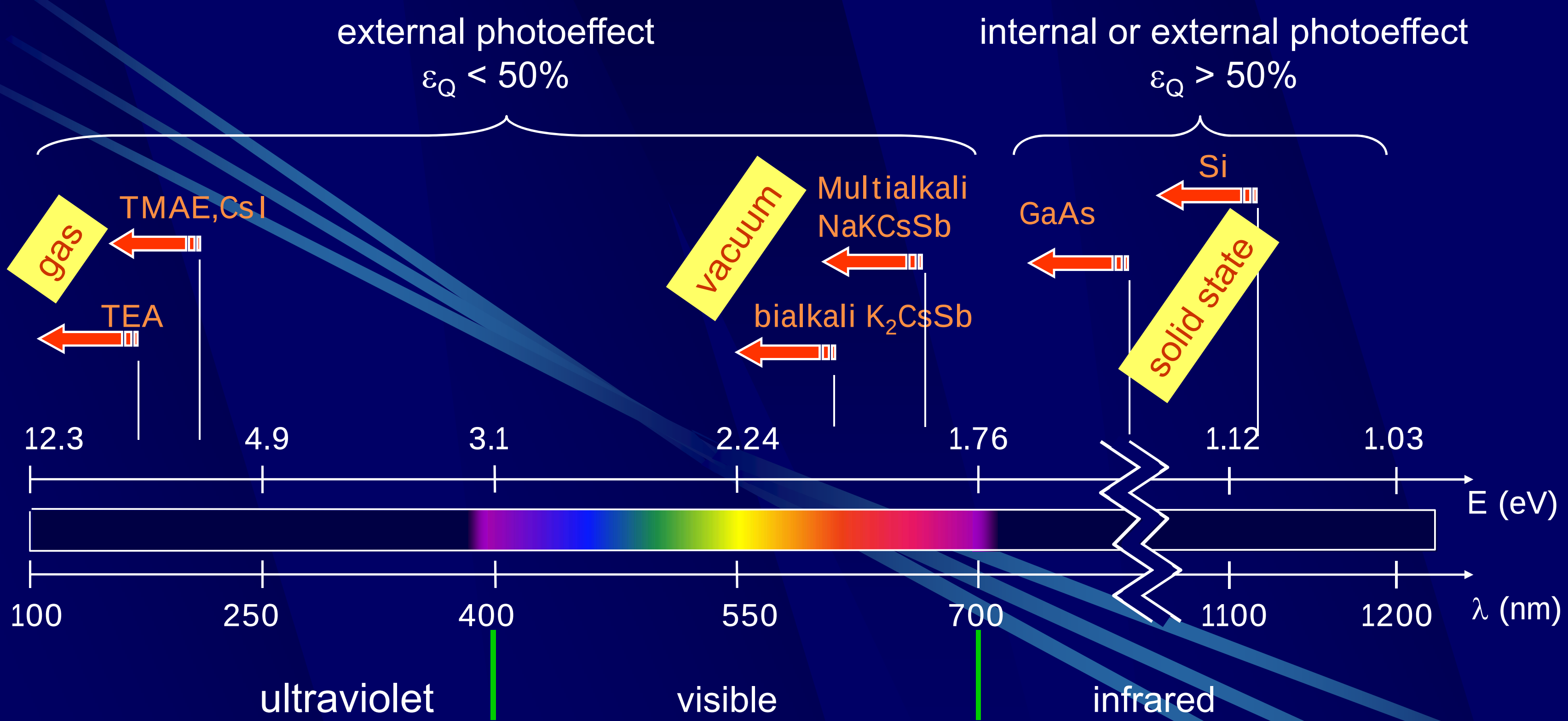
NEW !!!

Photocatodes: diamond film obtained with Spray Technique

Spray technique: T ~ 120° (instead of ~800° as in standard techniques)

Different photocathodes and their thresholds

$\varepsilon_Q = Q.E. = N_e / N_\gamma$



- Photon detection involves often materials like K, Na, Rb, Cs (alkali metals). They have the smallest electronegativity → highest tendency to release electrons.
- Most photocathodes are VERY reactive; Exceptions: Si and CsI.

PHOTOCATHODES FOR VISIBLE LIGHT

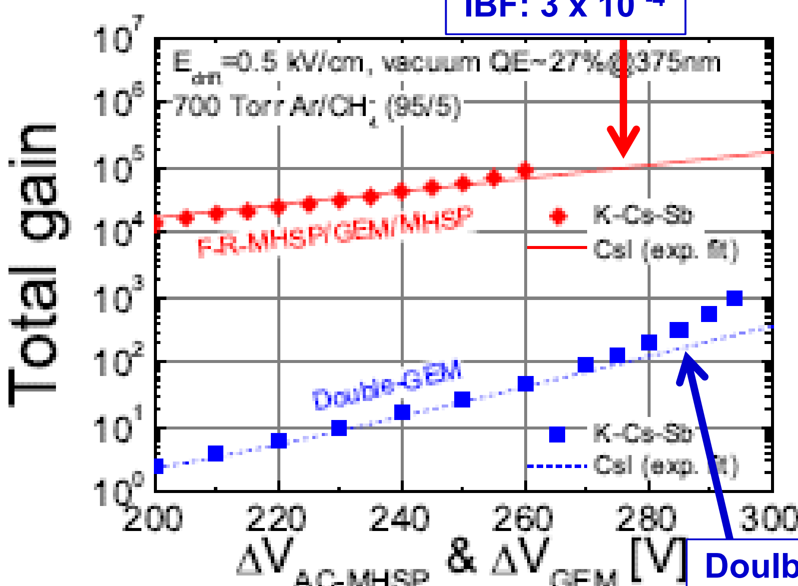
- Chemical reactivity (gas purity better than ppm level needed → UHV materials and sealed detectors)
- PC stability under ion bombardment - work function lower than CsI one
- AGEING CsI: -16% QE at 25μC/mm²
  Bilkaly: -20% QE at 0.4μC/mm²

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

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

K-Cs-Sb vs CsI

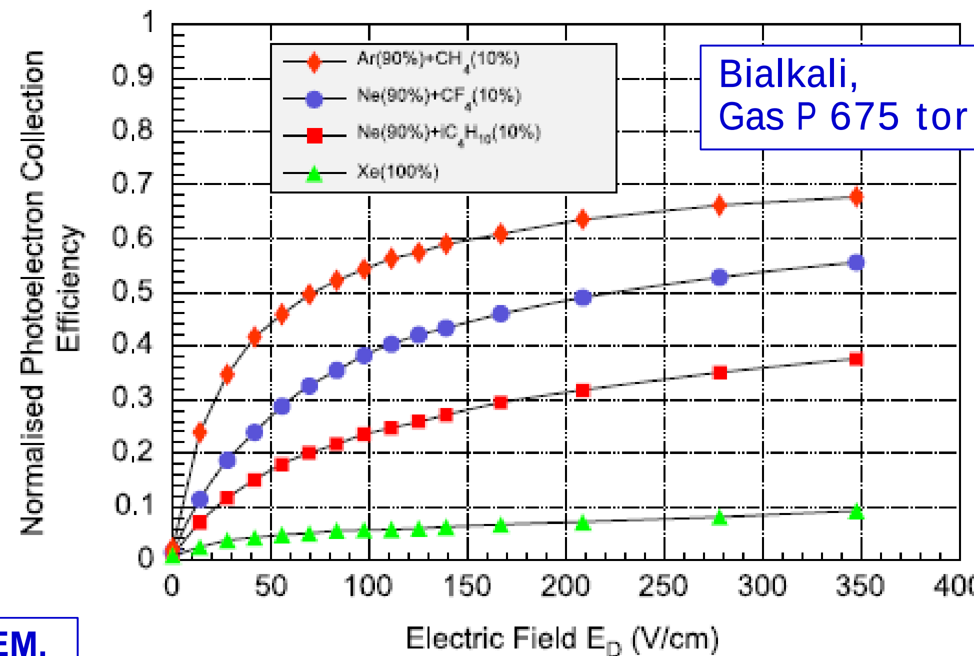
F-R-MHSP, IBF: 3×10^{-4}



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

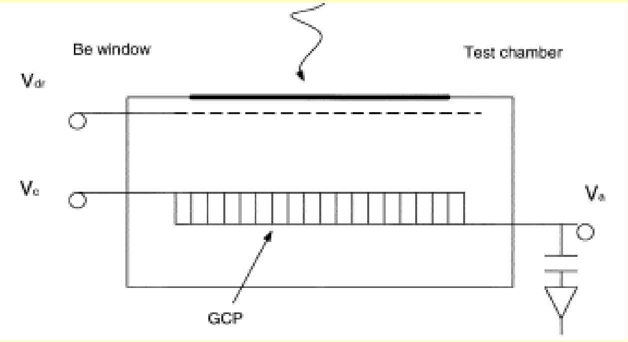
A.V.Lyashenko et al., 2009 JINST 4 P07005

Bialkali, Gas P 675 torr



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

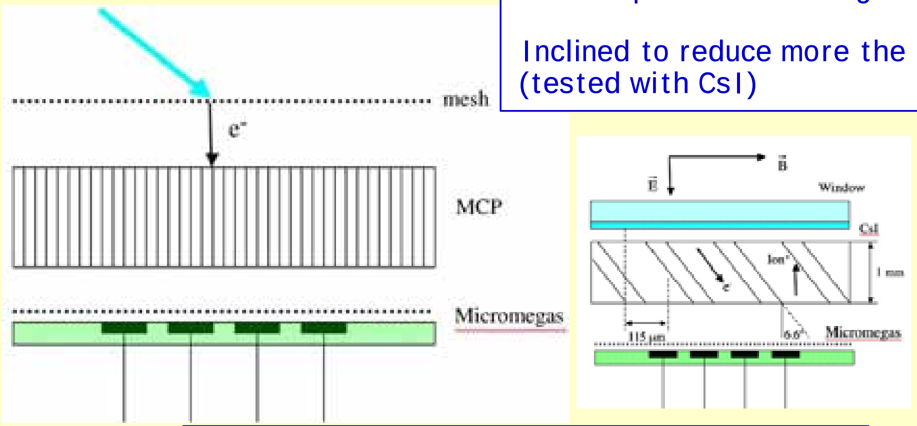
The Capillary Plate (CP) approach



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

MCP coupled to Micromegas

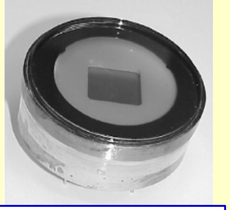
Inclined to reduce more the IBF (tested with CsI)



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

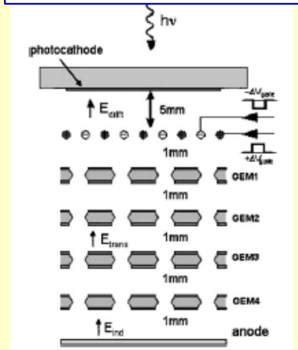
the GEM approach

Multiple GEM sealed



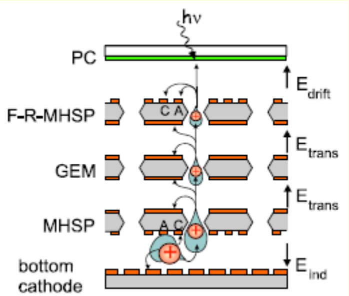
R.Chechik et al., NIMA 502 (2003) 195

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

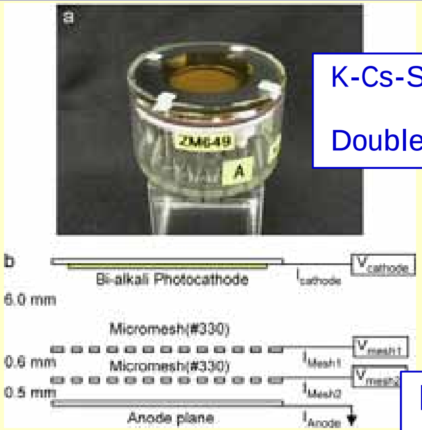
Poor compatibility of bialkali and GEM material ?

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

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

GASEOUS DETECTORS FOR VISIBLE LIGHT

the MicroMegas approach



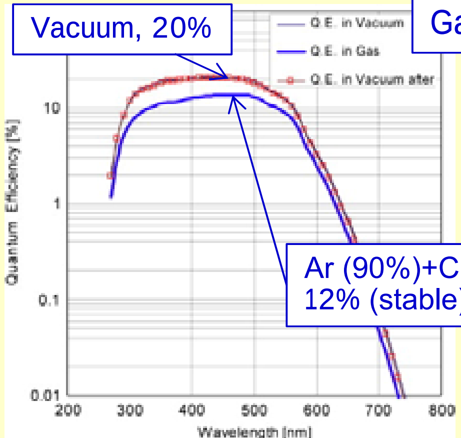
K-Cs-Sb

Double MM, Ni mesh

IBF : <2.5×10^{-3}

Gain < 10^4

Vacuum, 20%

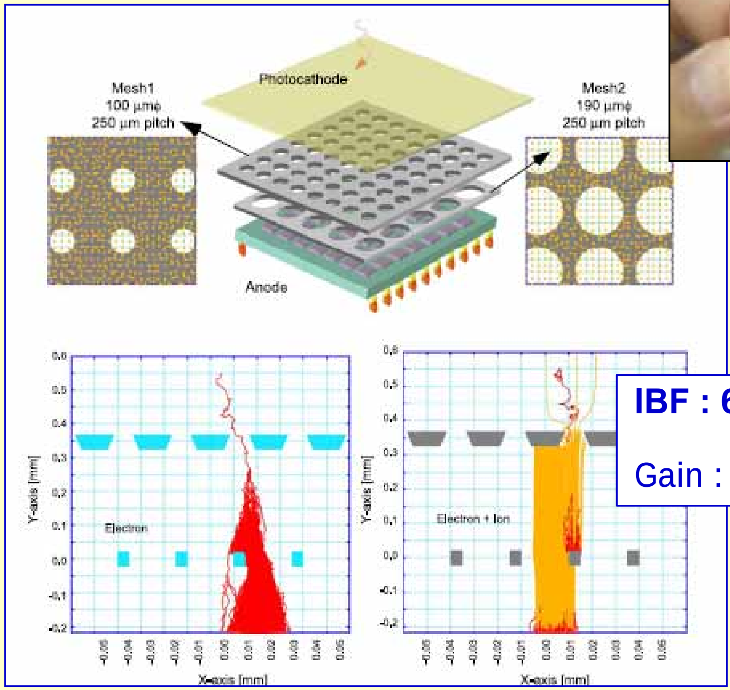


Ar (90%)+CH_4 (10%)
12% (stable) after 1.5 y

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

2 staggered MM layers to enhance ion trapping

In collaboration with HAMAMATSU



IBF : 6 ×10^{-4}

Gain : 10^4

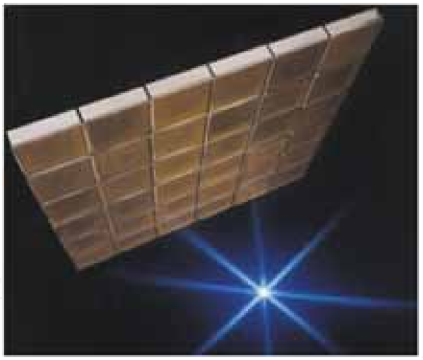
F. Tokanai et al., NIMA 766 (2014) 176

GASEOUS DETECTORS FOR VISIBLE LIGHT

Gaseous PMT

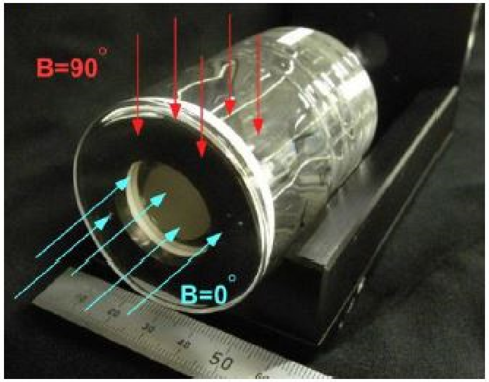
Yamagata U. TMU, HAMAMATSU

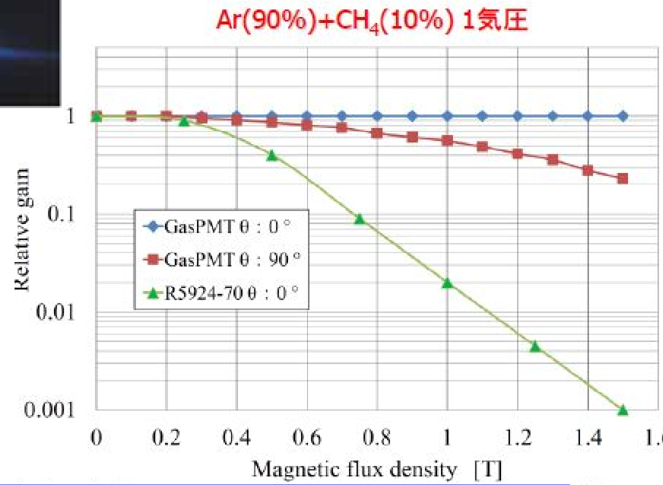
Sensor type	Sensitivity	Position Resolution	Timing Resolution	Uniformity	Price	Magnetic Field	Effective Area
Vacuum PMT	◎	△	◎	△	○	△	○
CCD / CMOS	△	◎	×	◎	△	◎	×
Gaseous PMT	○	○	○	○	◎	◎	◎

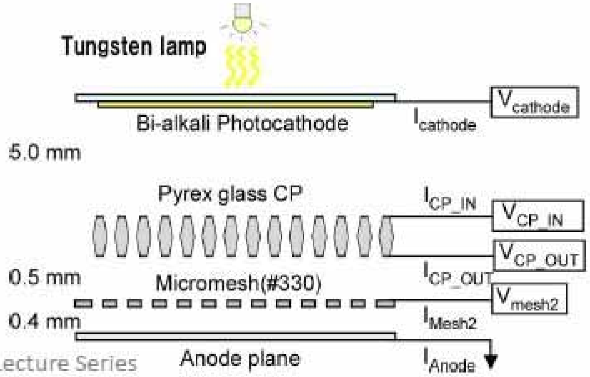


- The advantage of the **gaseous PMT**:
  - ✓It can achieve a **very large effective area** with moderate **position** and **timing** resolutions.
  - ✓It can be easily operated under a **very high magnetic field**.

Operation in magnetic field environmen



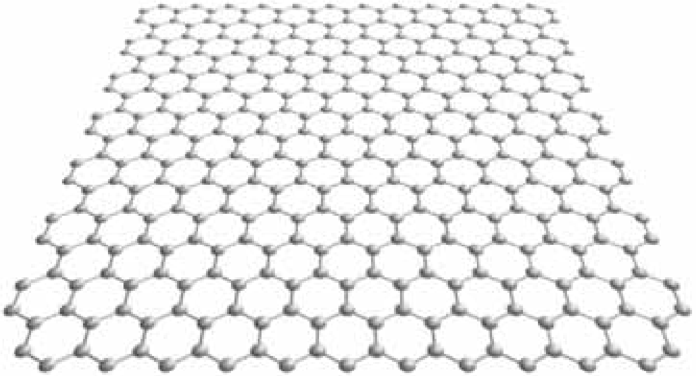




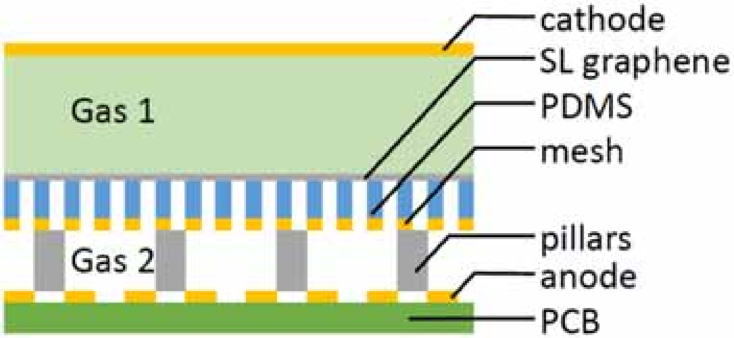
A. Ochi, MPGD Lecture Series

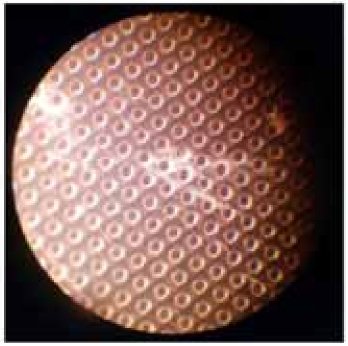
H. Sugiyama et al., NIMA (2016) in press

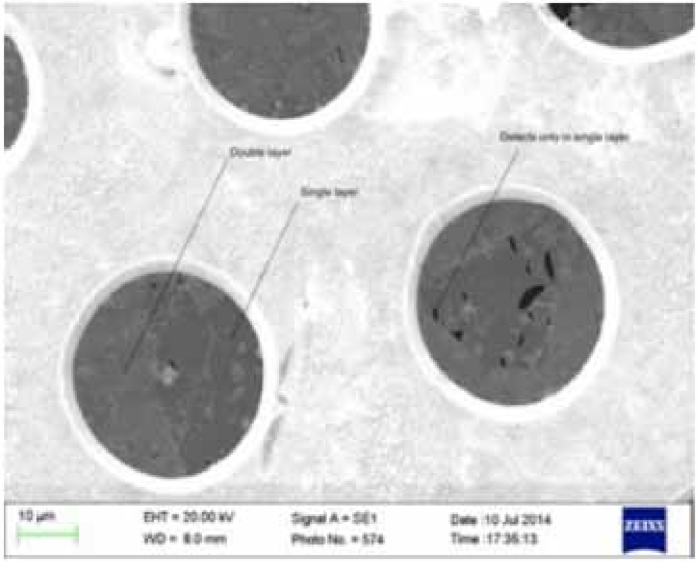
GRAPHENE



- Single layer of C atoms in hexagonal lattice
- Thinnest possible conductive mesh with 0.6 Å pores
- Very good ion blocking
- Charge transfer properties through graphene layers have been measured







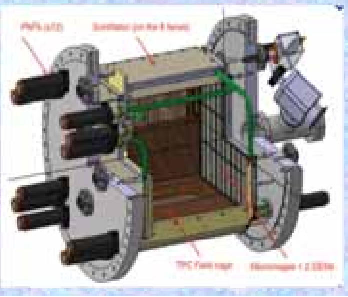
P. Thuiner[1,2], R. Hall-Wilton[3], R. B. Jackman[4], H. Müller[1], T. T. Nguyen[4], R. de Oliveira[1], E. Oliveri[1], D. Pfeiffer[1,3], F. Resnati[1], L. Ropelewski[1], J. A. Smith[4], M. van Stenis[1], R. Veenhof[5]

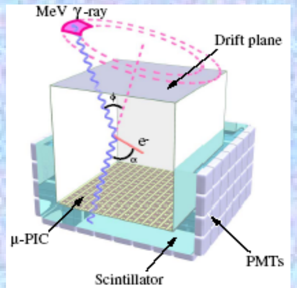
[1]CERN, [2]Technische Universität Wien, [3]ESS, [4]University College London, [5]Uludağ University

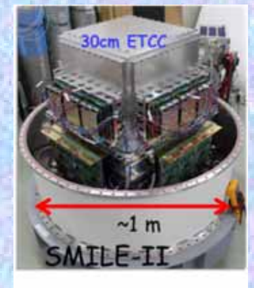
Promising new idea

MPGD Technologies for X-Ray Detection and γ-Ray Polarimetry

Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation characteristics / Performance	Special Requirements/ Remarks
KSTAR @ Korea Start: 2013	Xray Plasma Monitor for Tokamak	GEM GEMPIX	Total area: 100 cm^2 Total area: 10-20 cm^2	**Spat. res.:** ~ 8x8 mm^2 2 ms frames; 500 frames/sec Spat. res.: ~50x50 µm^2 1 ms frames;5 frames/sec	
PRAXyS Future Satellite Mission (US-Japan): Start 2020 - for 2years	Astrophysics (X-ray polarimeter for relativistic astrophysical X-rays	TPC w/ GEM	Total area: 400 cm^3 Single unit detect. (8 x 50cm^3) ~400cm^3	**Max.rate:** ~ 1 lcps **Spatial res.:** ~ 100 um **Time res.:** ~ few ns **Rad. Hard.:** 1000 krad	Reliability for space mission under severe thermal and vibration conditions
HARPO Balloon start >2017?	Astroparticle physics Gamma-ray polarimetry (Tracking/Triggering)	Micromegas + GEM	Total area: 30x30cm2 (1 cubic TPC module) Future: 4x4x4 = 64 HARPO size mod.	**Max.rate:** ~ 20 kHz **Spatial res.:** < 500 um **Time res.:** ~ 30 ns samp.	AGET development for balloon & self triggered
SMILE-II: Run: 2013-now	Astro Physics (Gamma-ray imaging)	GEM+µPIC (TPC+ Scintillators)	Total area: 30 x 30 x 30 cm^3	Point Spread Function for gamma-ray: 1˚	
ETCC camera Run: 2012-2014	Environmental gamma-ray monitoring (Gamma-ray imaging)	GEM+µPIC (TPC+ Scintillators)	Total area: 10x10x10 cm^3	Point Spread Function for gamma-ray: 1˚	





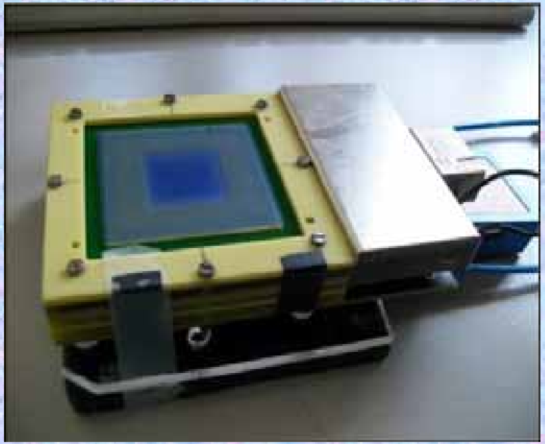


GEM (X-Ray) Detector for Tokamak Plasma Diagnostics

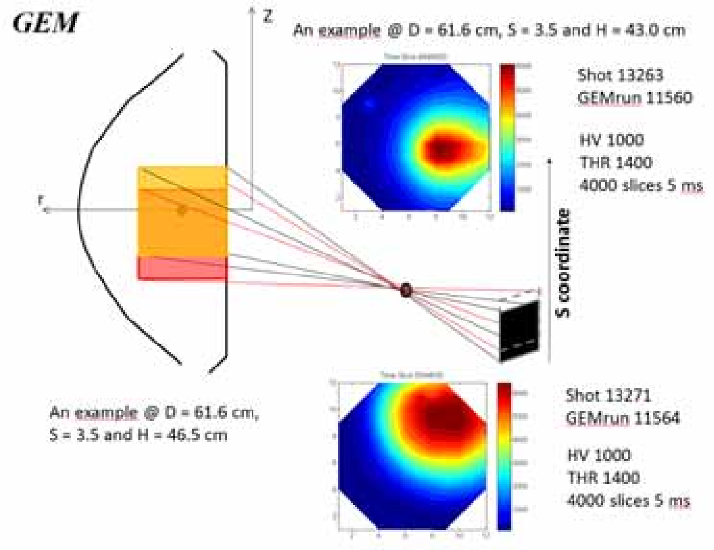
M. Titov, MPGD 2017

10x10 cm^2 GEM installed since 2013

GEMPIX (GEM + Timepix)



Plasma images (GEM) measured in 2015:
Movie of 200 images per sec



GEMPIX for Fusion:

F. Murtas

2015 measurement campaign:

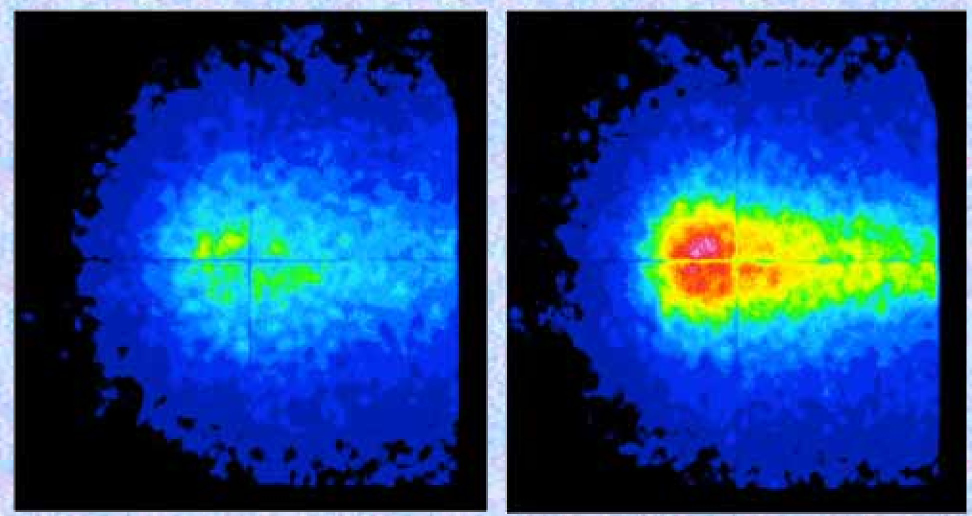


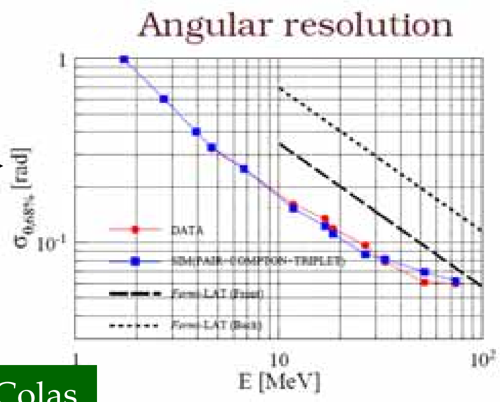
Image of KSTAR Plasma with spectroscopy measurements

MPGDs Technologies for MeV-GeV Polarimeter and γ-Ray Telescope

HARPO: TPC as a γ-ray Telescope and Polarimeter:

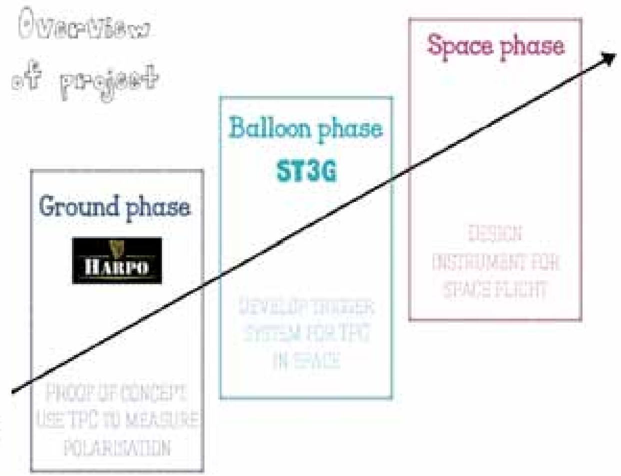
High-Pressure HARPO GEM+MM TPC (2014):

- Sensitivity to polarization in the 1-100 MeV range (A~ 10-15%)
- Angular resolution improved wrt FERMI-LAT



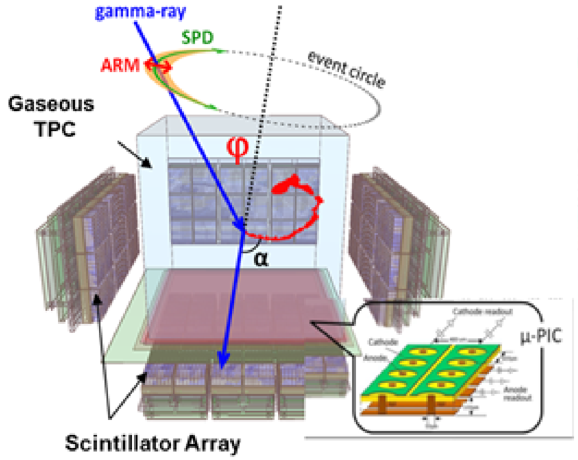
P. Colas

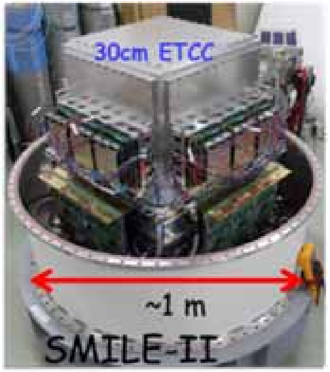
FUTURE:



Electron Tracking Compton Camera: μPIC+TPC:

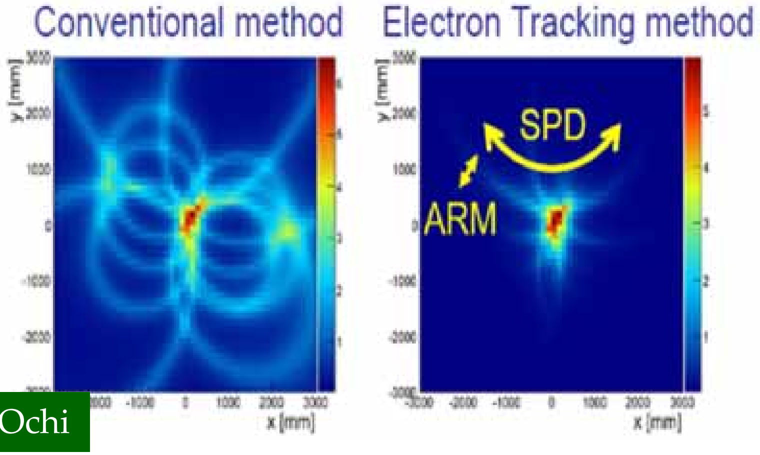
→ **tracking of recoil electron**





SMILE-II: A. Ochi

Both γ-ray imaging and and spectroscopy are available → color image



Scintillating Glass-GEM imager

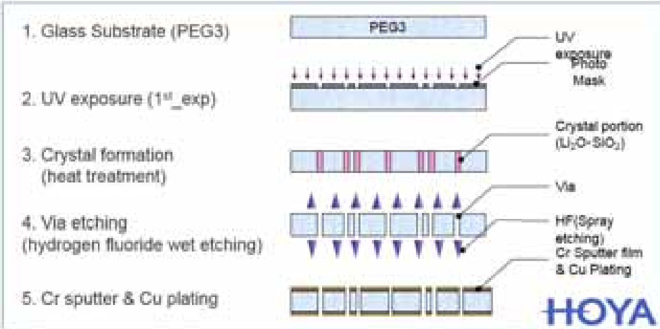
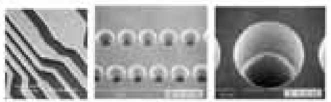
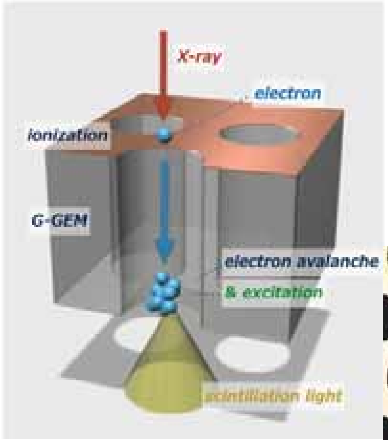
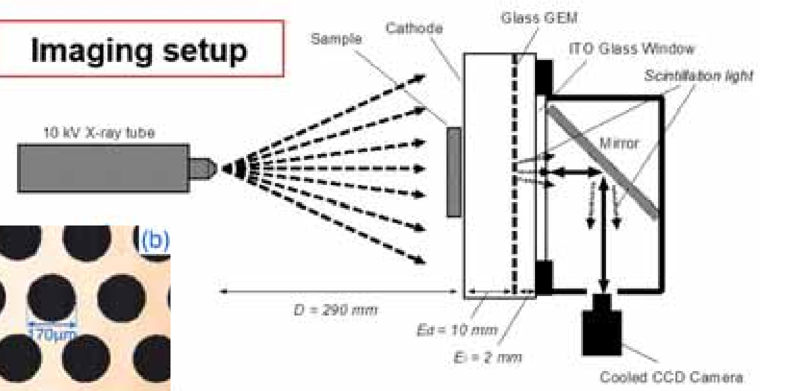


Photo Etchable Glass 3 : PEG3

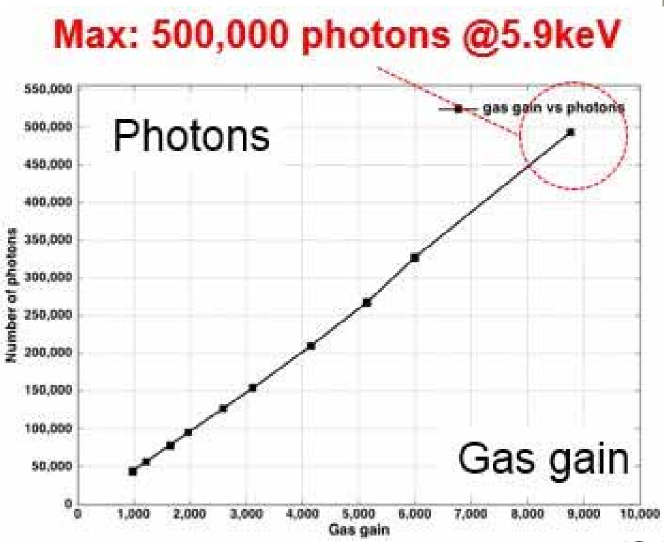
- Promising technique for precise patterning
- Able to drill high aspect hole
- 680μm deep hole (ex. CERN GEM: 50μm)

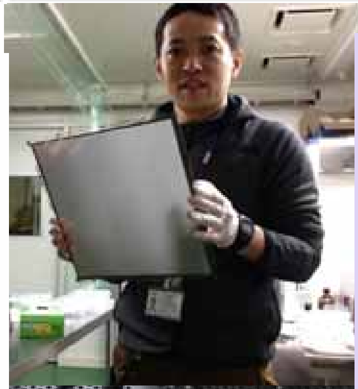


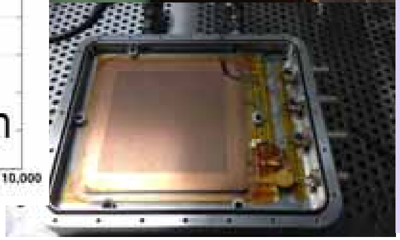


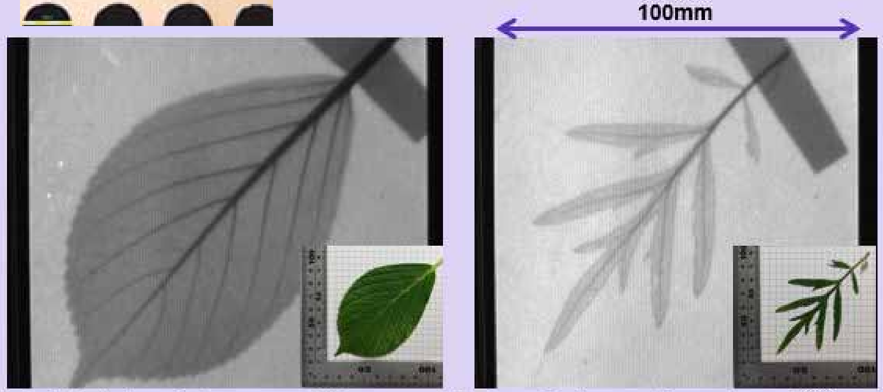


T. Fujiwara, et al., JINST 8 C12020, 2013









Obtained image of leaves (2 sec integration time)[10]

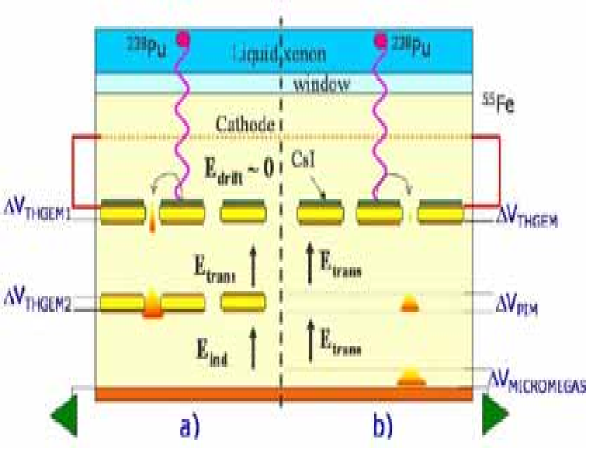
Excellent spatial resolution ≈500μm
Quick imaging of low Z material with low energy X-rays (≈7 keV)

CRYOGENIC MPGD-PDs

Read-out elements of cryogenic noble liquid detectors

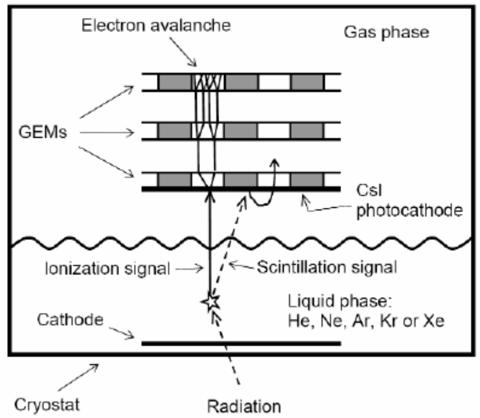
- Rear event detectors (ν, DM)
- Detecting the scintillation light produced in the noble liquids
- Options of scintillator light and ionization charge detection by a same detector !

with WINDOW



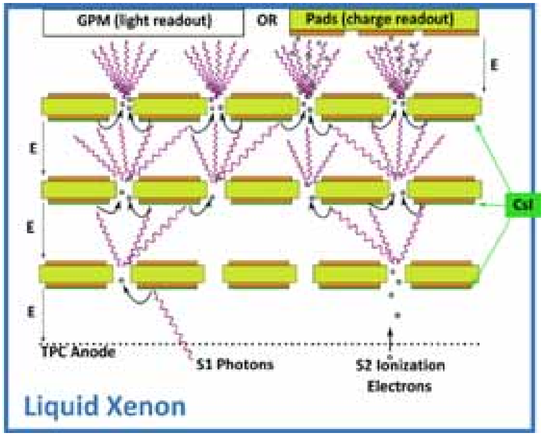
S.Duval et al., JINST 6 (2011) P04007

WINDOWLESS (2-PHASES)



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

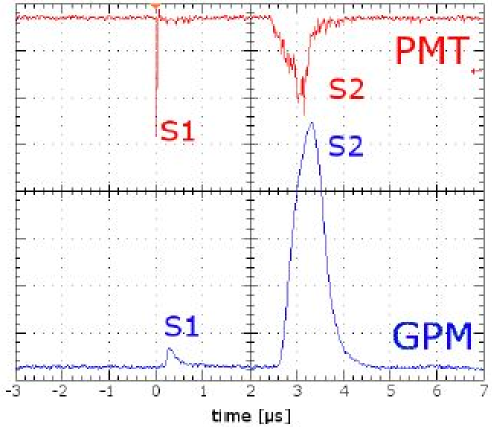
OPERATED IN THE CRYOGENIC LIQUID

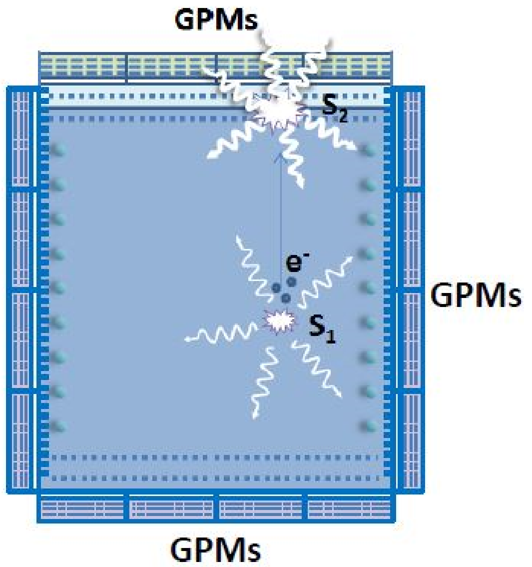


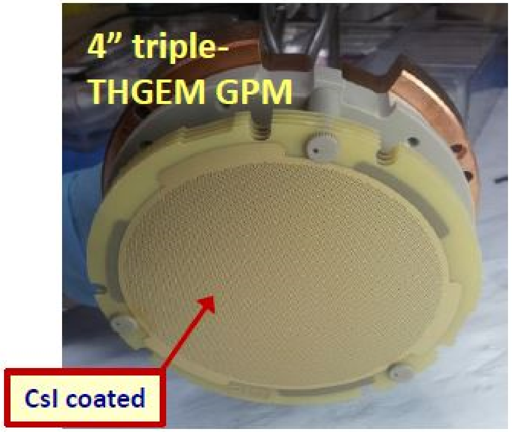
L.Arazi et al., JINST 8 (2013) C12004

Triple THGEM Gaseous Photo-Multiplier for DM

- WIS R&D on **GPMs** for future multi-ton LXe TPCs for dark matter searches (within DARWIN)
- Aim for **4π coverage** – not practical with PMTs (cost, bulkiness) or SiPMs (dark count rate)
- Successful demonstration of 4" cryogenic **triple-THGEM GPM** with reflective CsI coupled to dual phase LXe TPC: (arXiv:1509.02354)
  - Stable gain ~ 10^5
  - Large dynamic range: 1 – $O(10^3)$ photoelectrons
  - 1 ns timing (~ 200 PEs)
  - Expected PDE ~15% after optimization







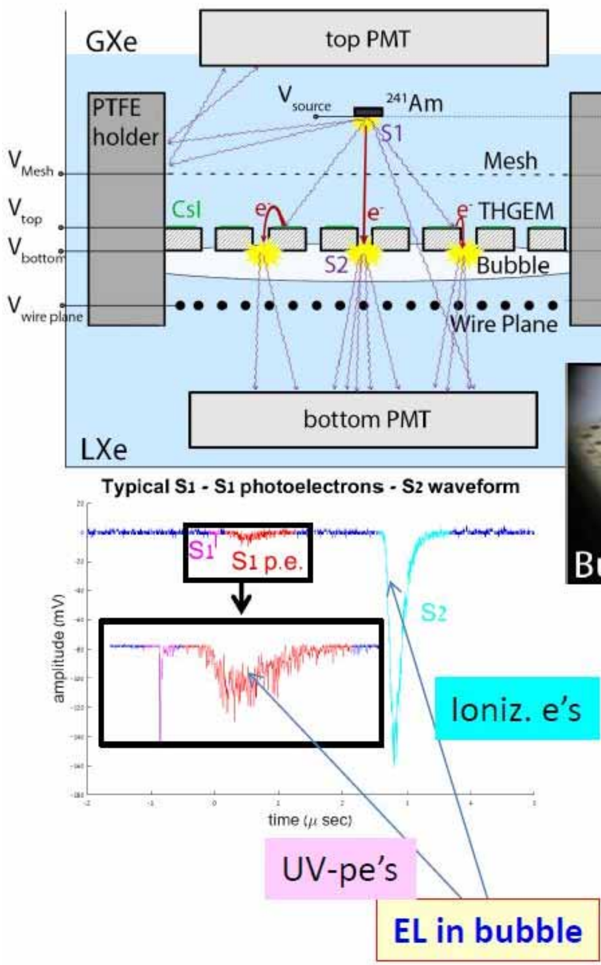
- Also: on-going R&D on **n/γ imaging** with pixilated readout (arXiv:1501.00150)

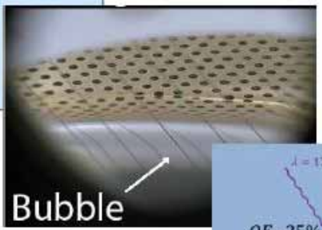
Bubble-assisted electroluminescence in LXe

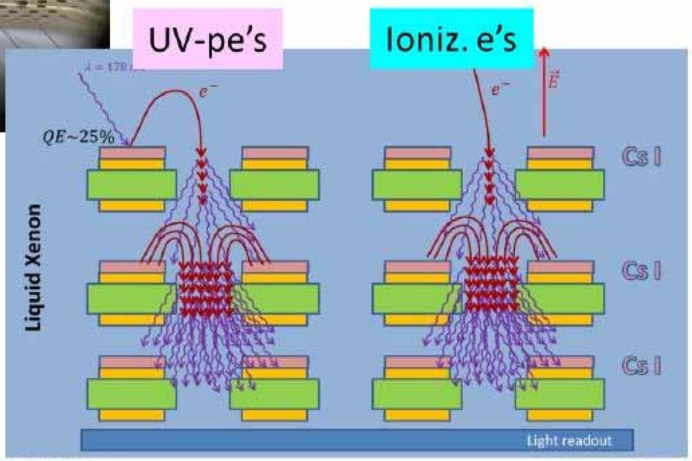
A "local dual-phase" noble-liquid detector

TOWARDS LARGE-SCALE NOBLE-LIQ DETs

Energy resolution 5MeV alphas: σ/E=7.5%
Time resolution: σ=10ns
Bubble (under THGEM, GEM) stable for days
CsI on THGEM: high pe extraction







A Breskin MPGD 2015 Trieste 33

Breskin, *J. Phys. Conf. Ser.* 460(2013) 012020

PTFE THGEMs for CDEX

Low level radioactivity THGEMs

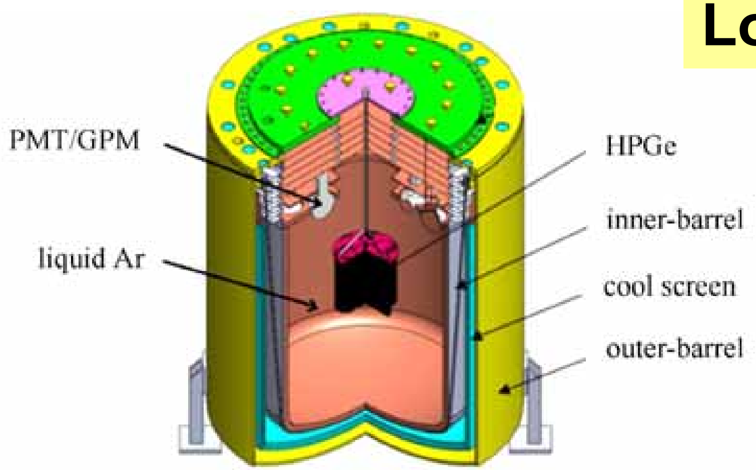


Fig. 1. Scheme design of the cryostat in CDEX.

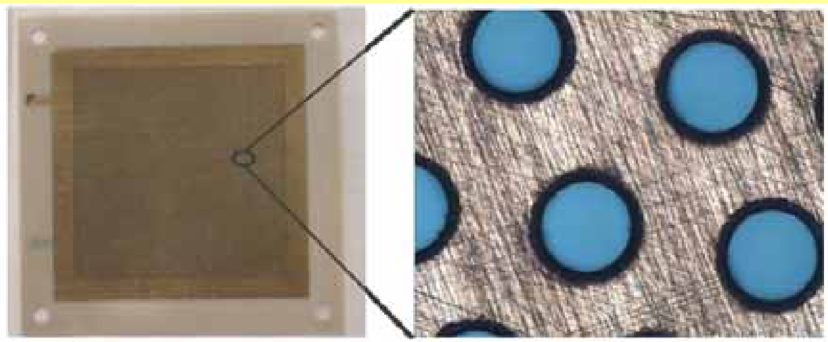


Fig. 2. A photograph of the PTFE-THGEM; the enlarged part (right) shows the holes and the rims surrounding them.

t = 0.38 mm,
d = 0.3 mm,
p = 0.7 mm,
r = 30 μm

Wen-Qing XIE et al, Chinese Physics C, Vol. 37, N. 11 (2013) 116001

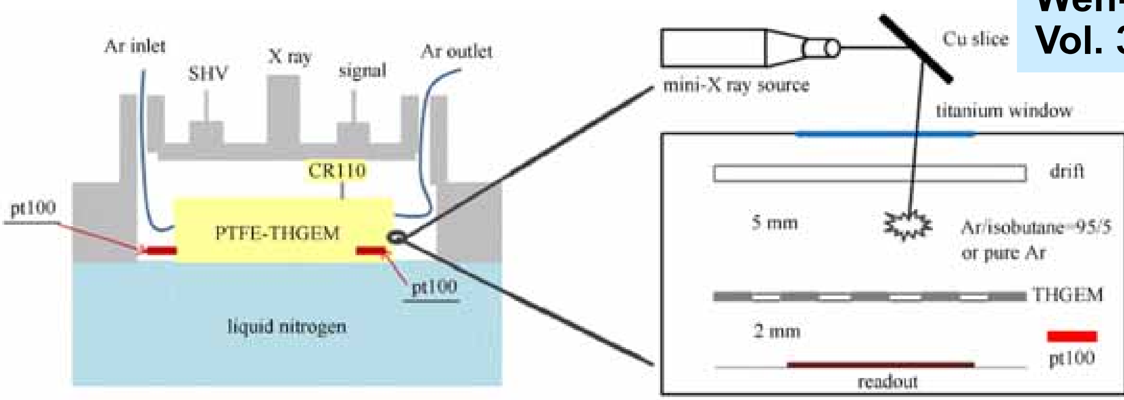
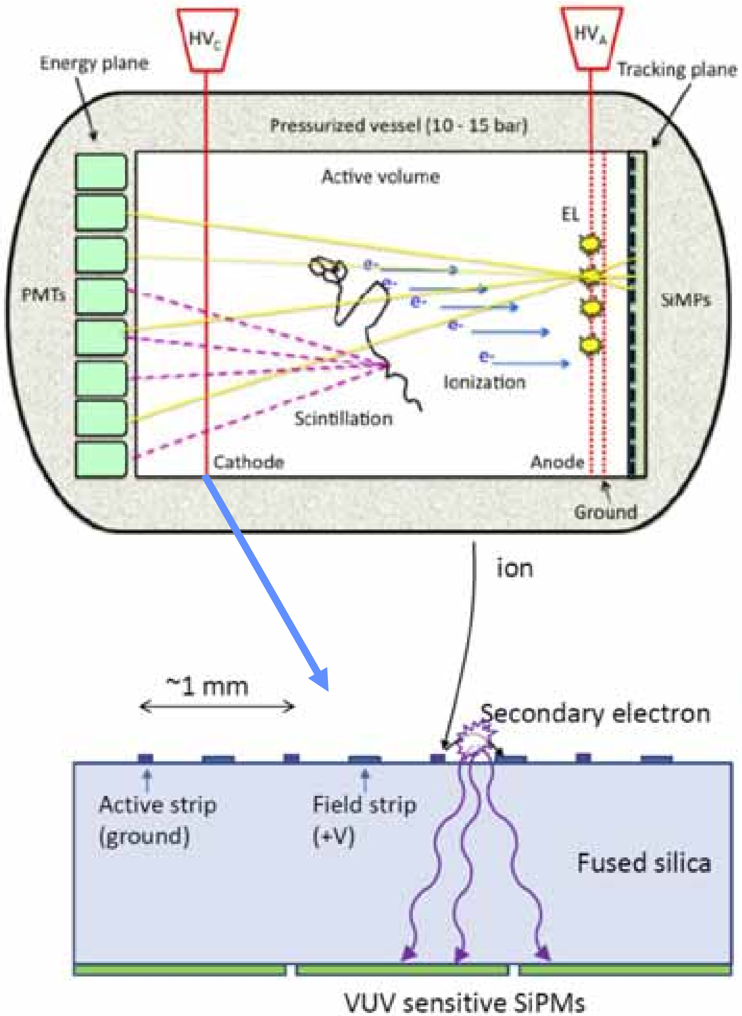


Fig. 3. Schematic diagram of the experimental setup. On the left is the test of the PTFE-THGEM at cryogenic temperature; and on the right is the internal structure of the PTFE-THGEM used.

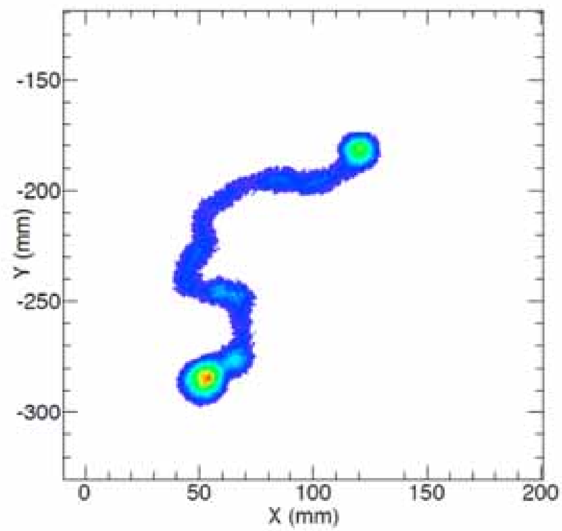
PMT disadvantages:
high cost, limited area, unmatched spectral response, radioactivity
→ PTFE THGEMs
Almost no radioactivity, demonstrated to operate nicely at 117 K

Exotic proposal for NEXT ββ0ν

LIOR ARAZI, WIZEMAN INSTITUTE OF SCIENCE



MC of ββ0ν event – 2 blobs at the ends



10 bar Xe, 300 V/cm

10^5 electron ion pairs/ev.

diffusion over L = 2m:

$\sigma_{electrons}$ = 18 mm,

σ_{ions} = 1.8 mm.

All Xe^+ atoms convert to Xe_2^+

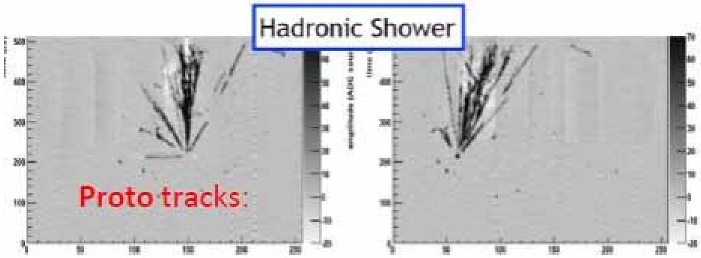
They reach the cathode in < 1 sec

Xe_2^+ on active cathode strips emit e^- by "Auger Neutralization" if the surface has electron affinity < 0

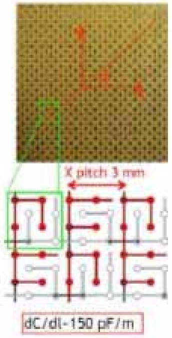
Secondary electrons go to field strips producing small avalanches with O(103) photons per detected ion.

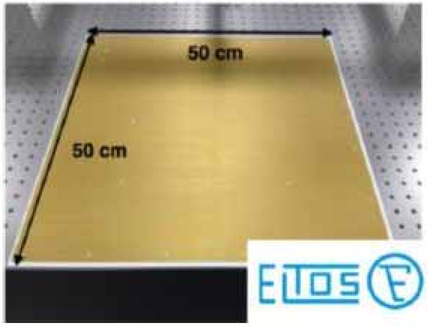
Dual-phase LAr LEM TPC

Goal: Neutrino oscillation experiments: WA105 (on ground) and future (underground) DUNE.



high ionization density in LAr→ need low gain





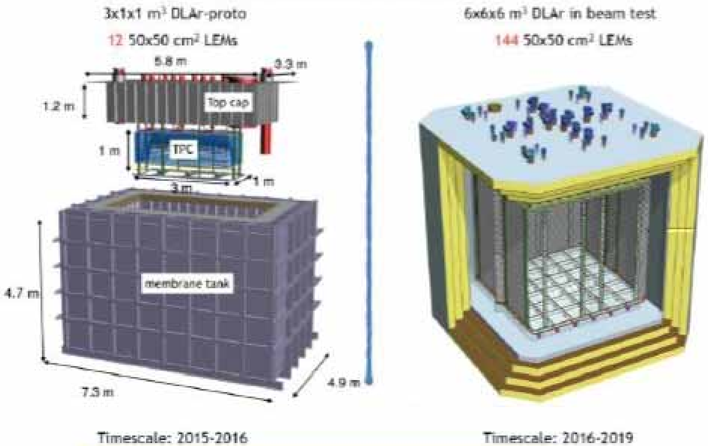
ptimised values

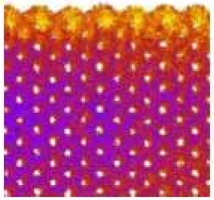
- 40 μm rim
- 1 mm FR4 thickness
- 500 μm diameter hole
- 800 μm hole pitch and hexagonal layout

C.Cantini et al., JINST 10 P03017 (2015)

DC: 5nA/LEM(50x50)
Stable gain ~20 (fine)

"demonstrators"





~3500V; spark on edges
(use COMPASS RICH solution?)
Charging up of rims: gain stabilizes. OK

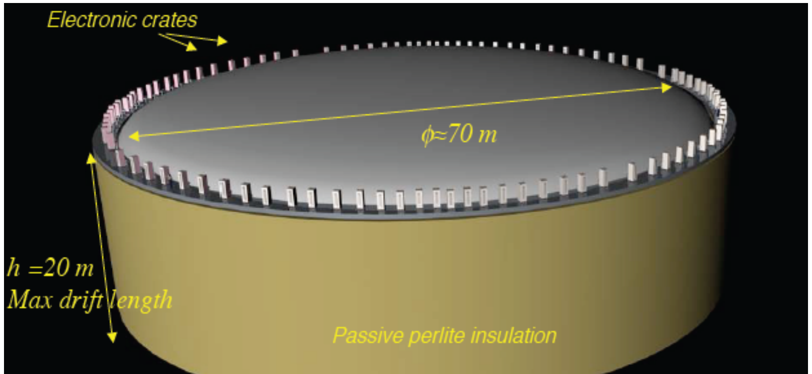
12 & 144 50x50cm² LEMs

DUNE: ~3000 LEMs (50x50)

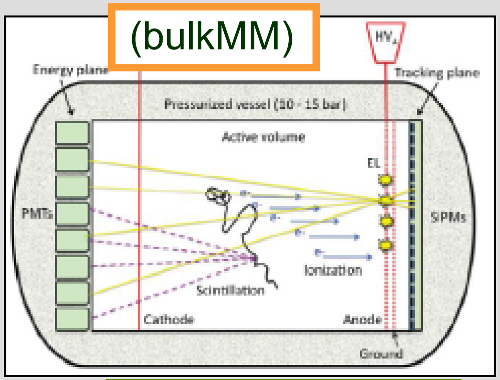
Ongoing R&D on RESISTIVE WELL concepts

LARGE SIZE PROJECTS

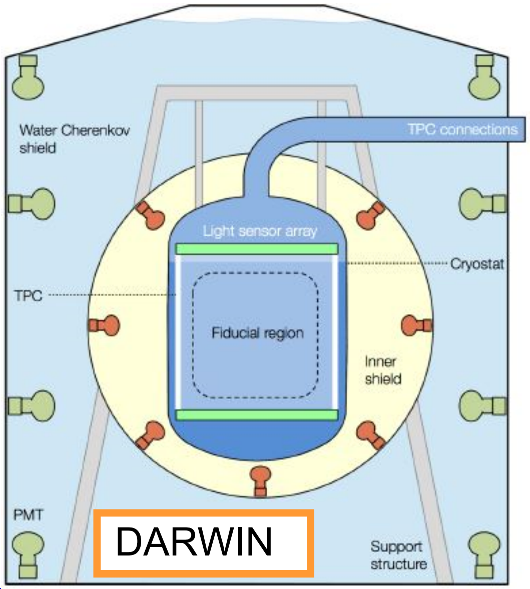
XENON (dark matter)



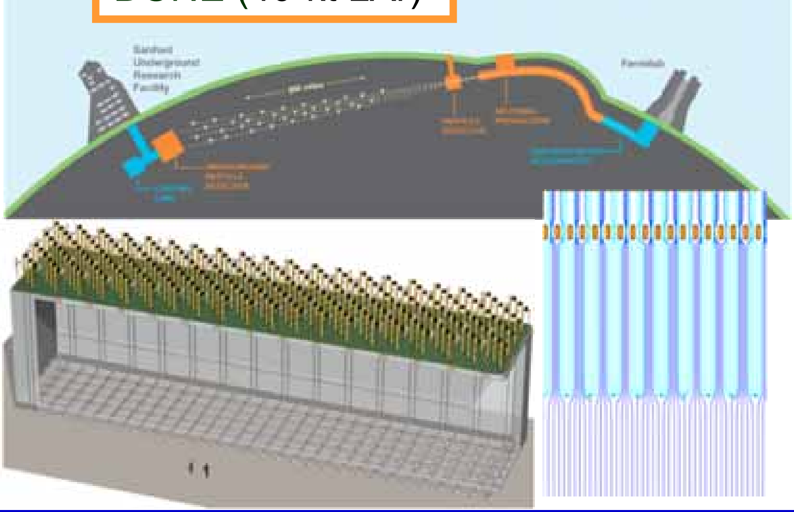
LBNO – GLACIER (THGEM)



NEXT-100 (neutrino-less double beta decay)



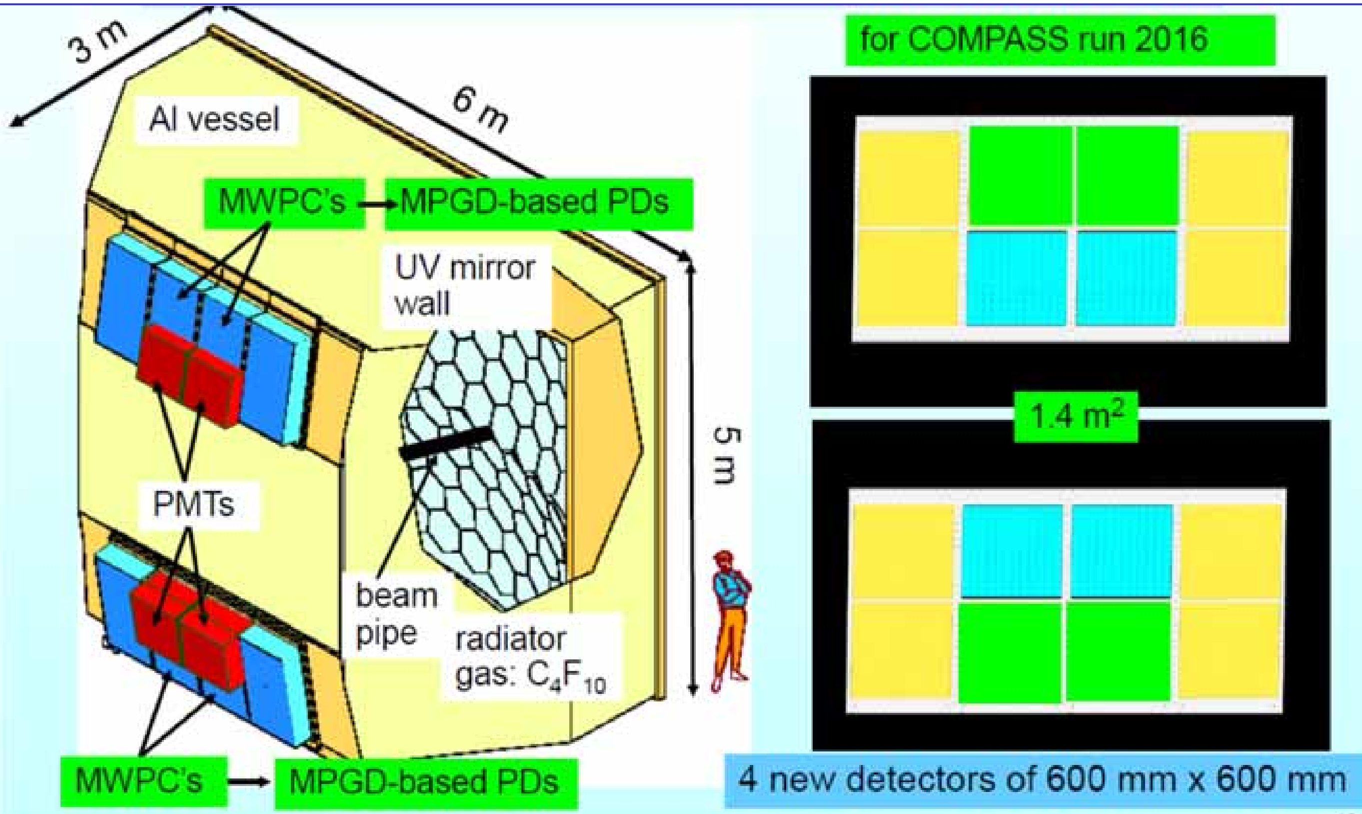
DARWIN

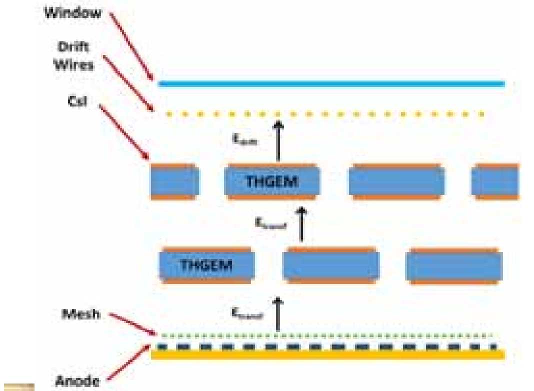


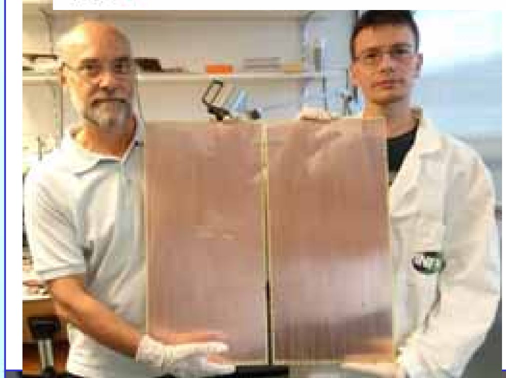
DUNE (40-kt LAr)

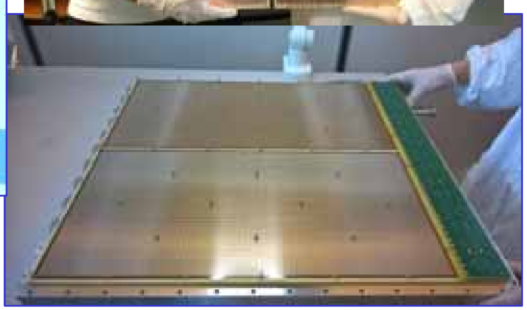
FIRST STEP TO LARGE SIZE

COMPASS RICH UPGRADE









talk by Shuddha Shankar Dasgupta

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