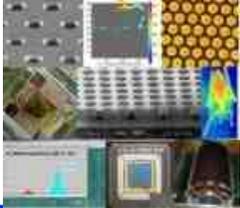


# MicroPattern Gas Detectors (MPGD)

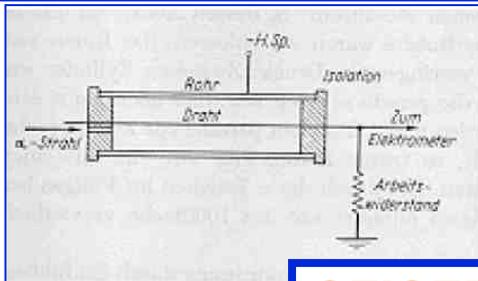
**S. Dalla Torre**



# INTRODUCTION

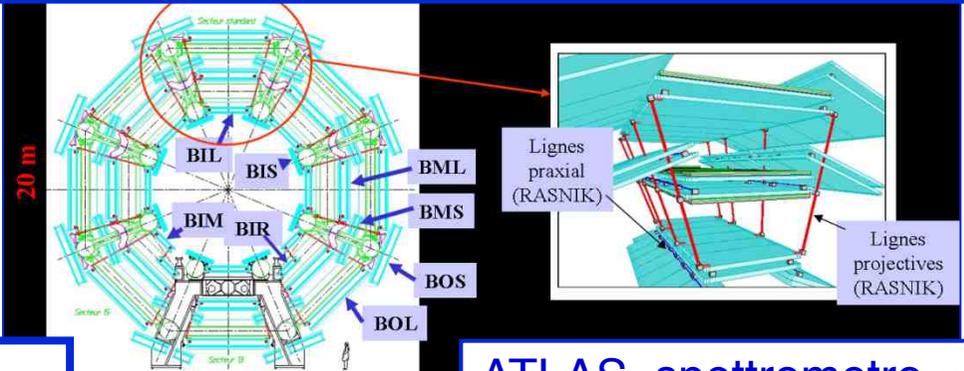
# GAS DETECTORS & FUNDAMENTAL RESEARCH

**STILL NOWADAYS THE ONLY TO INSTRUMENT LARGE VOLUMES AT MODERATE COSTS AND LIMITED MATERIAL BUDGET; THEY OPERATE IN B FIELD**



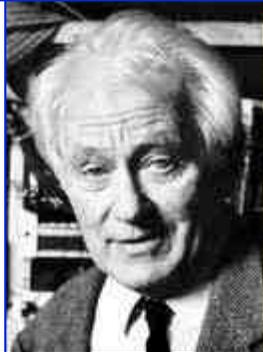
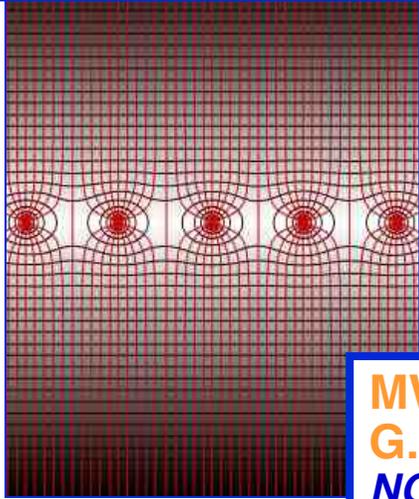
**GEIGER counter  
Rutherford, Geiger 1908**

**the only approach to achieve good space resolution before introducing the Si trackers**

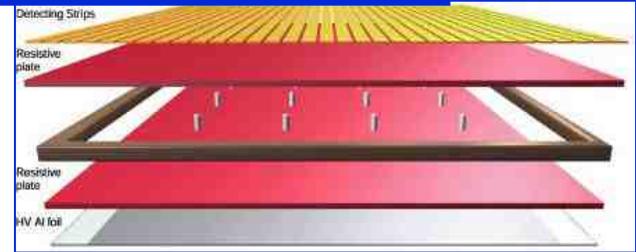


**ATLAS, spettrometro  $\mu$**

**Time resolution record in extended counters  
RPC:  $\sigma_t \leq 1$  ns  
trigger in ALICE, ATLAS, CMS**



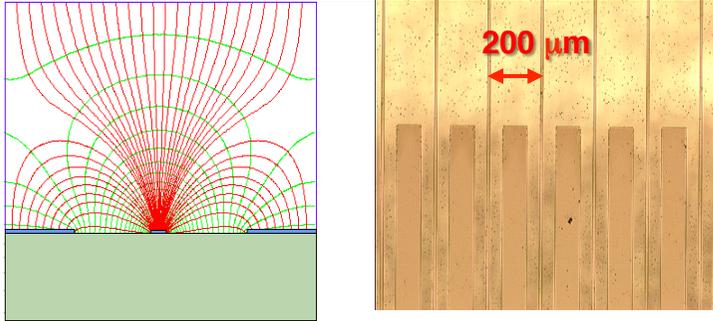
**MWPC,  
G. Charpak, 1968  
NOBEL prize in 1992**



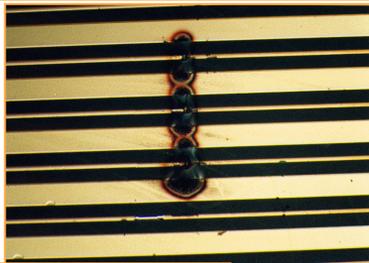
# MPGDs: THE EARLY DAYS

## MSGC - MicroStrip Gas Chamber

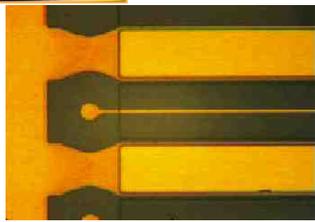
A. Oed, NIMA 263(1988) 351



- High E-values at the edge between insulator and strips → damages
- Charge accumulation at the insulator → gain evolution vs time



Later (~ 1999-2000):  
Passivation of the  
cathode edges  
→ MSGD  
operational!



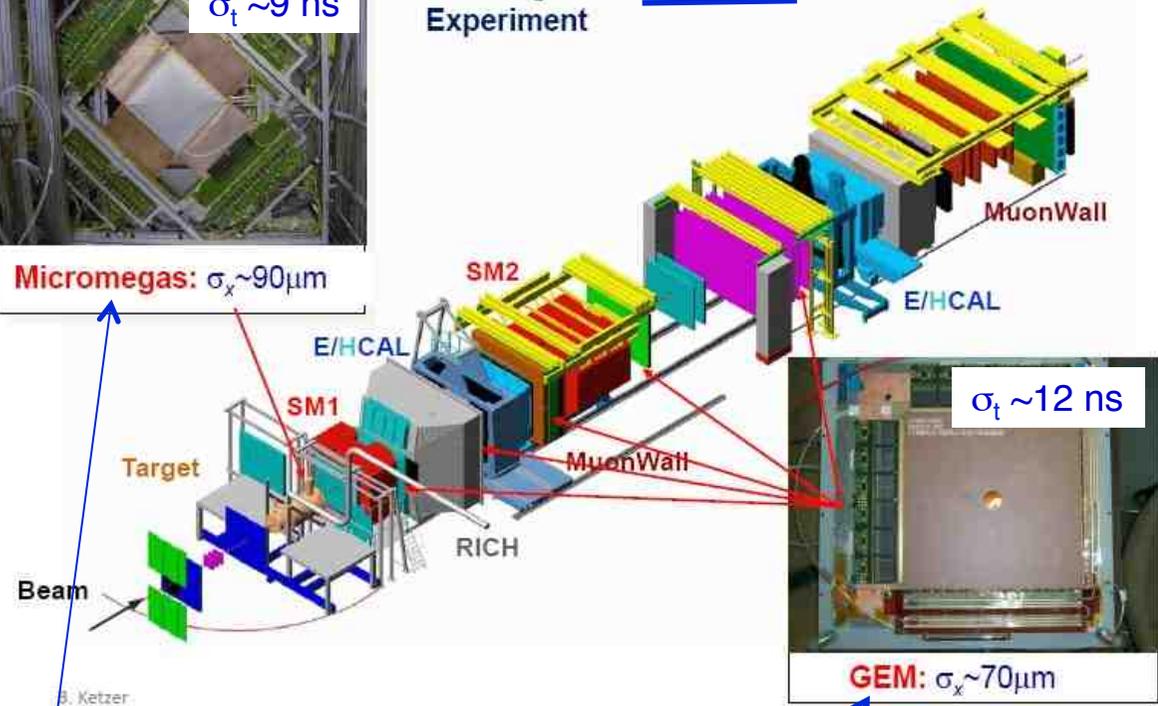
slide by W. Riegler, CERN Academic Training, April 2008

## First Large Scale Use of GEMs and MICROMEAGAs



Micromegas:  $\sigma_x \sim 90 \mu\text{m}$

Tracking in the COMPASS  
Experiment



GEM:  $\sigma_x \sim 70 \mu\text{m}$

**MICROMEAGAS (MM) :**  
Y. Giomataris et al,  
NIMA A376 (1996) 29

**GEM:**  
F.Sauli, NIMA A386 (1997) 531

# MPGDs: THE EARLY DAYS

by W. Riegler, CERN Academic Training, April 2008

of GEMs and MICROMEAS

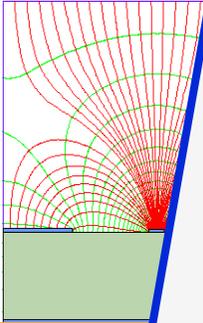
## ALREADY SOME LESSONS:

1. MPGDs, why?
  - High rates (granularity & occupancy, signal formation time)
  - Fine space resolution

→ Moving towards high luminosity / high precision experiments, i.e. towards the future

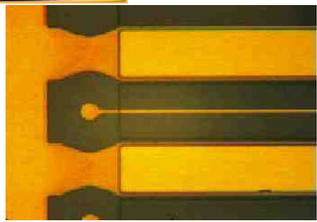
2. MPGDs, how?
  - Mastering the industrial processes of photolithography makes MPGDs possible
  - Technological maturity and accurate engineering are FUNDAMENTAL ingredients for successful MPGDs

MSGC - M



- High E insulat
- Charge insula

Later (~ 1999-2000):  
 Passivation of the cathode edges  
 → MSGD  
 operational!

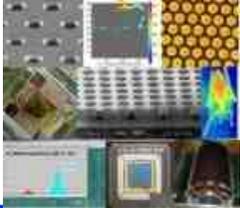


MICROMEAS (mm)  
 Y. Giomataris et al,  
 NIMA A376 (1996) 29

F.Sauli, NIMA (1997) 531

2 ns

0µm

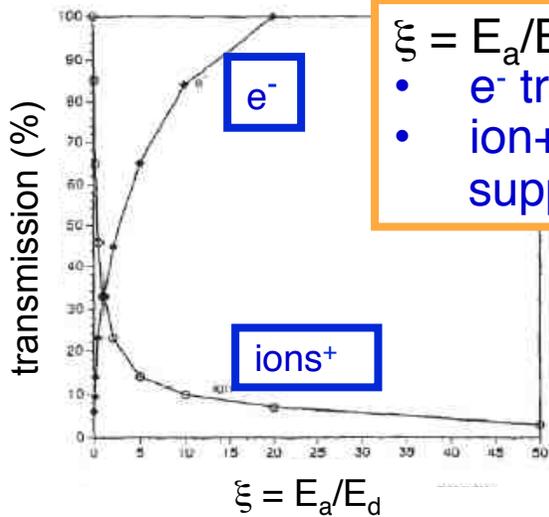
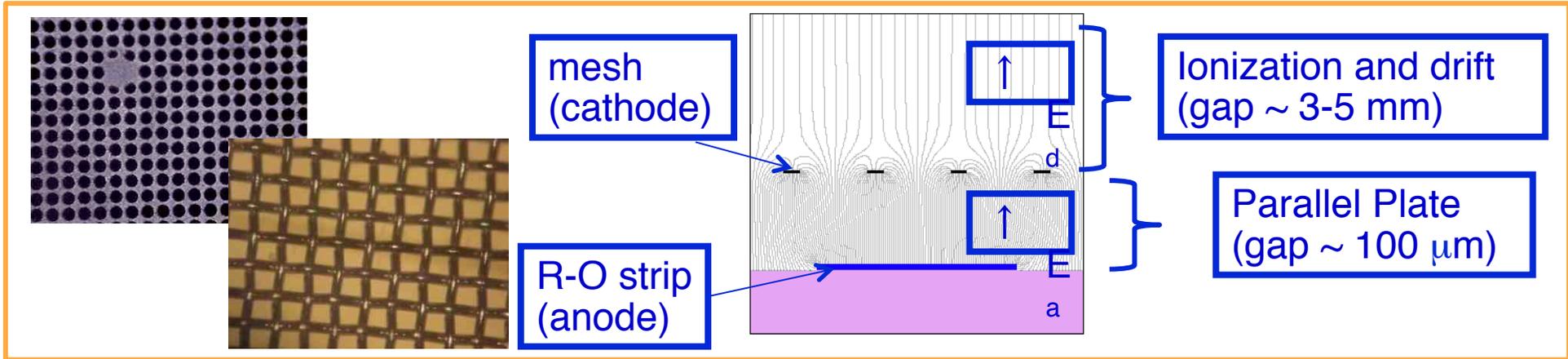
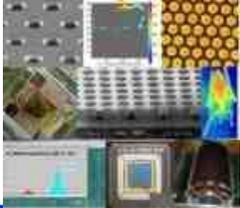


# THE MAIN MPGD ARCHITECTURES:

MICROME GAS, GEM, THGEM

AND THEIR CONSOLIDATION  
( by new ideas & technological progress)

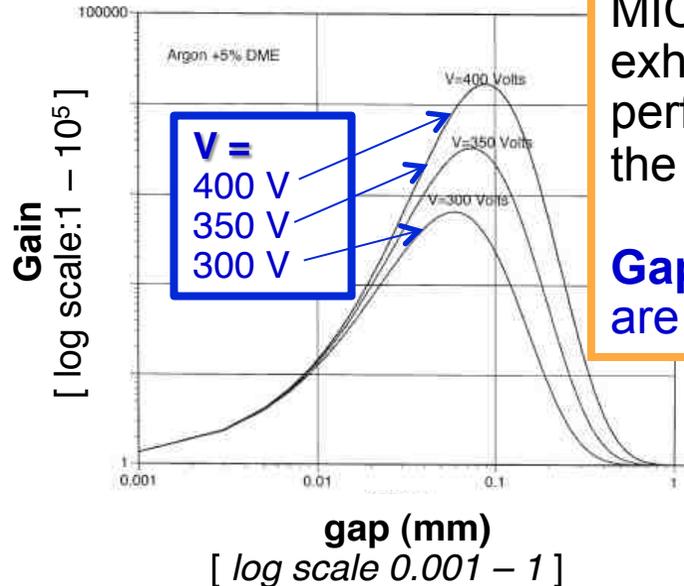
# MICROME GAS, THE PRINCIPLE



$\xi = E_a/E_d > \sim 20 \rightarrow$

- e<sup>-</sup> transparency
- ion+ feedback suppression

Y. Giomataris et al, NIMA A376 (1996) 29



MICROME GAS exhibit optimal performance in the peak region:

**Gap, gas and V are correlated**

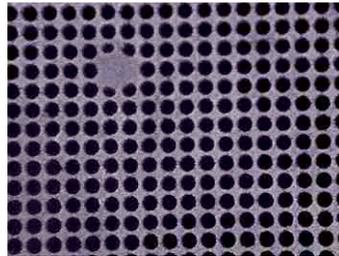
Y. Giomataris, NIMA A419 (1998) 239

# MICROMEAS, construction

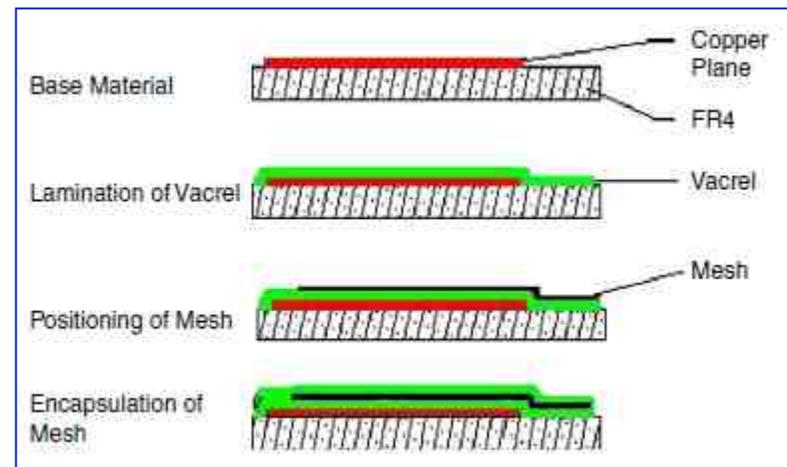
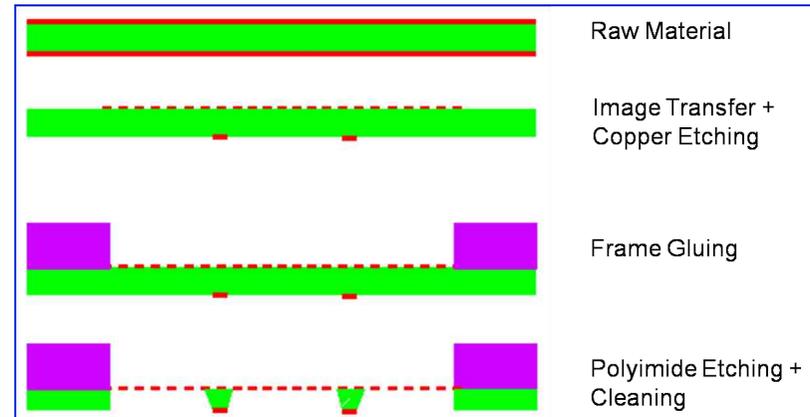
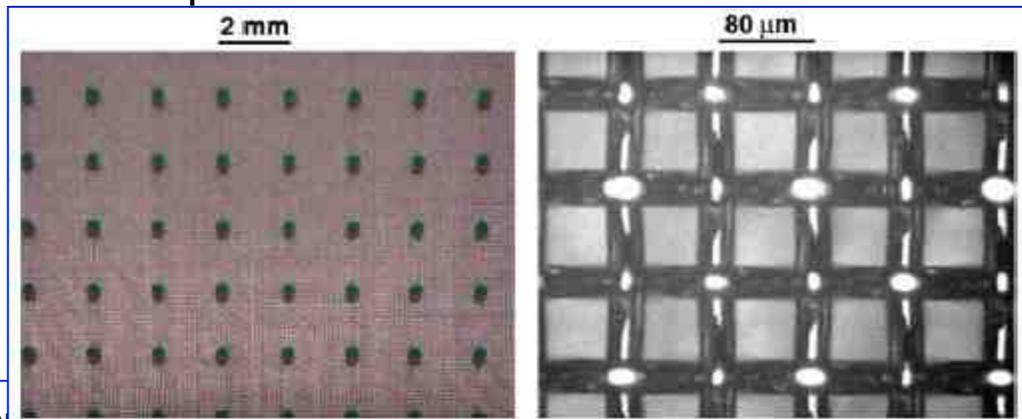
construction challenge: preserve the thin gap homogeneity by insulating spacers

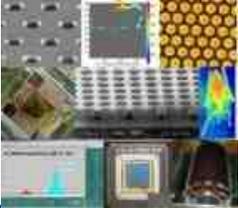
1) Nichel mesh by **elettroformation** + **quartz fibers**, diameter:  $75\ \mu\text{m}$

2) Form a **metalized polyimide micromesh** by chemical etching; small **pillars** supporting the mesh are formed by the same process



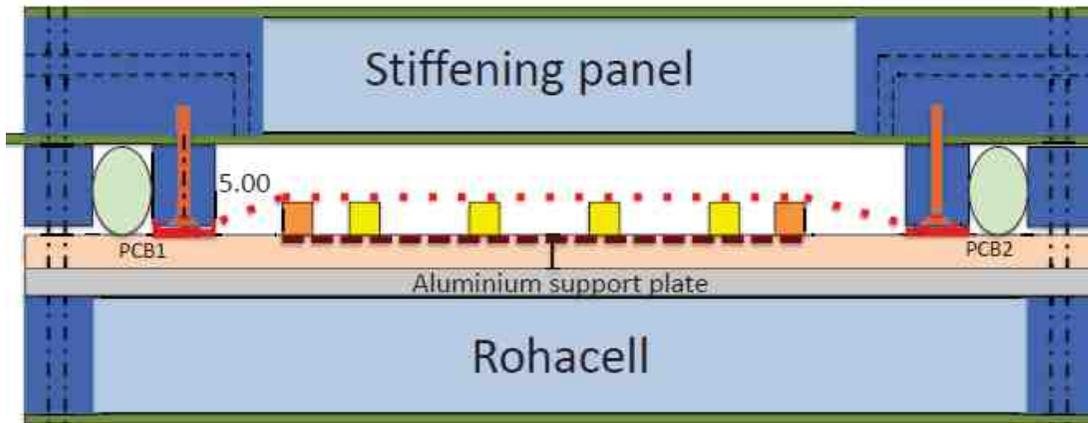
3) **Bulk micromegas**: pre-stretched steel mesh laminated together with a photoresistiv layer and the PCB; photoresistive then removed apart where pillars are formed





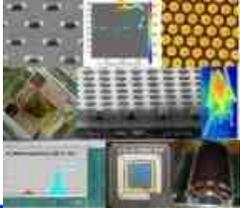
# MICROMEAS, construction

- 4) Grow pillars at the anode surface, keep the mesh in place by mechanical tension (ATLAS-MAMMA)



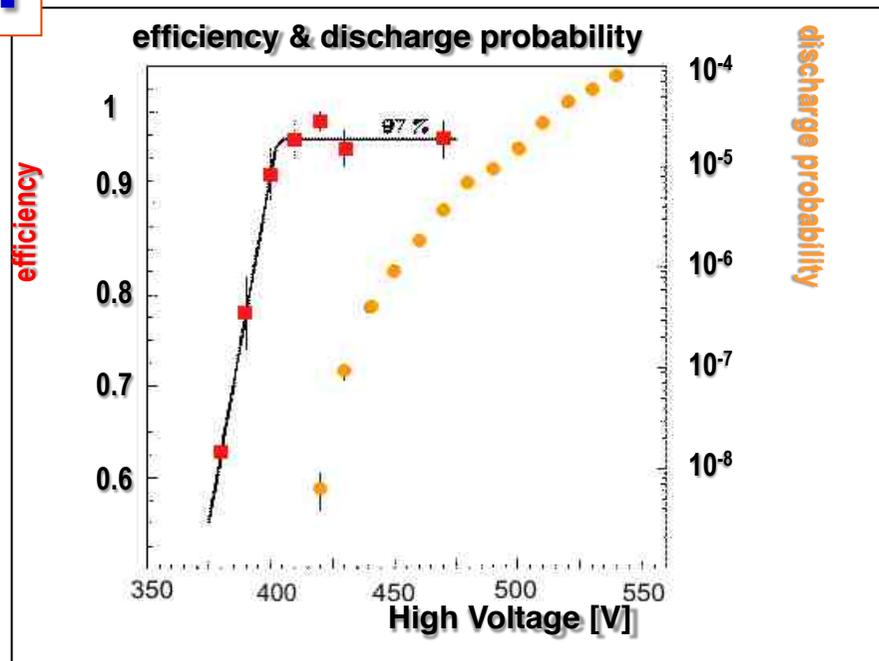
1 x 1 m<sup>2</sup> micromegas

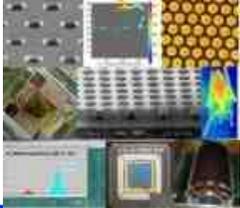
J.Wotschack, RD51 coll. meeting, 1/10/2012



# DISCHARGE RATE in MM

**MM**

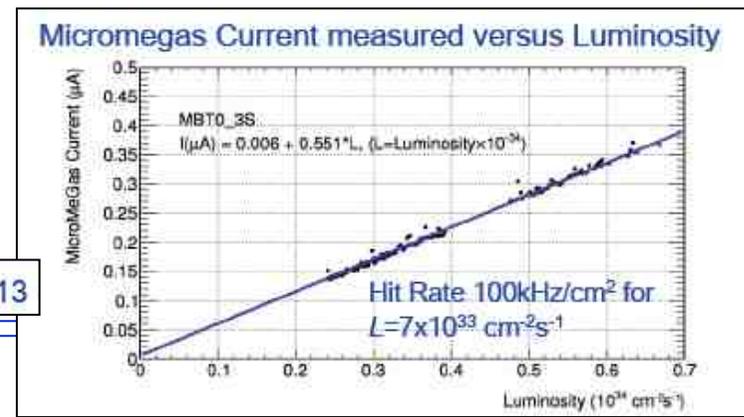


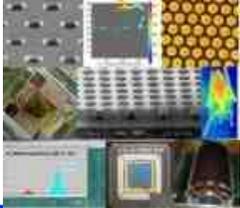


# MICROME GAS figures

- **Space resolution**
  - **COMPASS small area trackers,  $\sim 90\mu\text{m}$**  (P. Abbon et al., NIMA 577 (2007) 455.)
- **Time resolution**
  - **COMPASS small area trackers,  $\sim 9\text{ ns}$**  (P. Abbon et al., NIMA 577 (2007) 455.)
- **Gain**
  - **At COMPASS:  $G \sim 6400$**  (D Thers et al., NIMA 469 (2001) 133)
  - **T2K TPC:  $G \sim 1500$**  (N. Abgrall et al., NIMA 637 (2011) 25)
- **Material budget**
  - **COMPASS small area trackers:  $0.3\%$  X0** (P. Abbon et al., NIMA 577 (2007) 455.)
- **Rate capability**

George Iakovidis - MPGD 2013

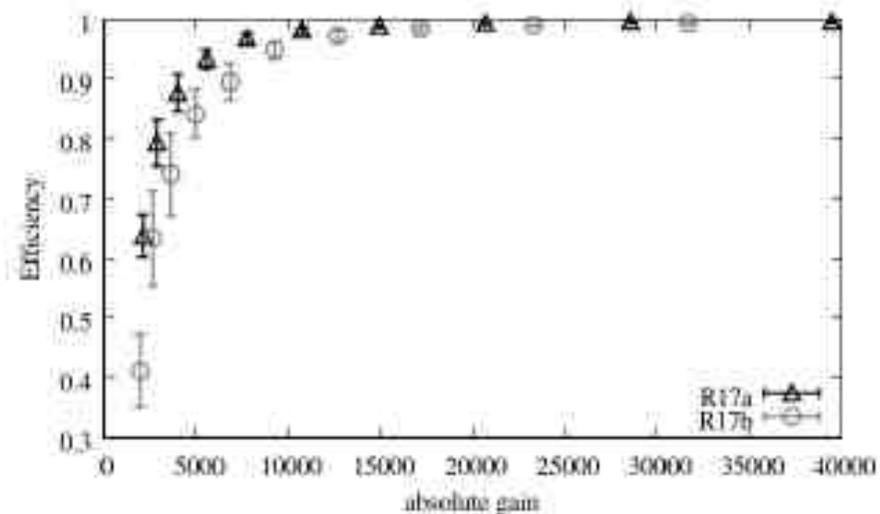




# MICROME GAS AGEING

## ■ MM, MAMMA studies

Irradiation with	Charge Deposit (mC/cm <sup>2</sup> )
X-Ray	225
Neutron	0.5
Gamma	14.84
Alpha	2.4



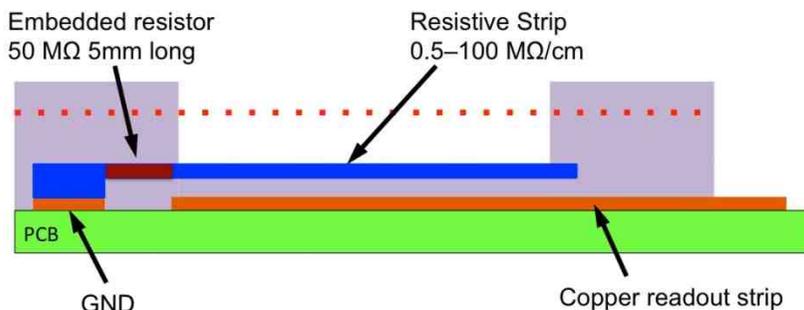
VCI2013 Conference Proceedings arXiv:1304.2053v1, J.Galan et al.

# MICROMEAS: recent developments

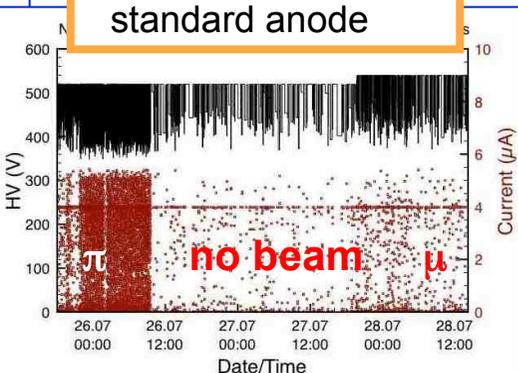
living with / overcoming the high discharge rate

## Resistive Anodes

Developed within the ATLAS-MAMMA project

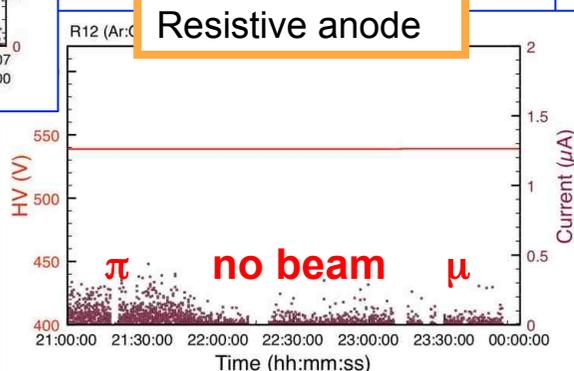


standard anode



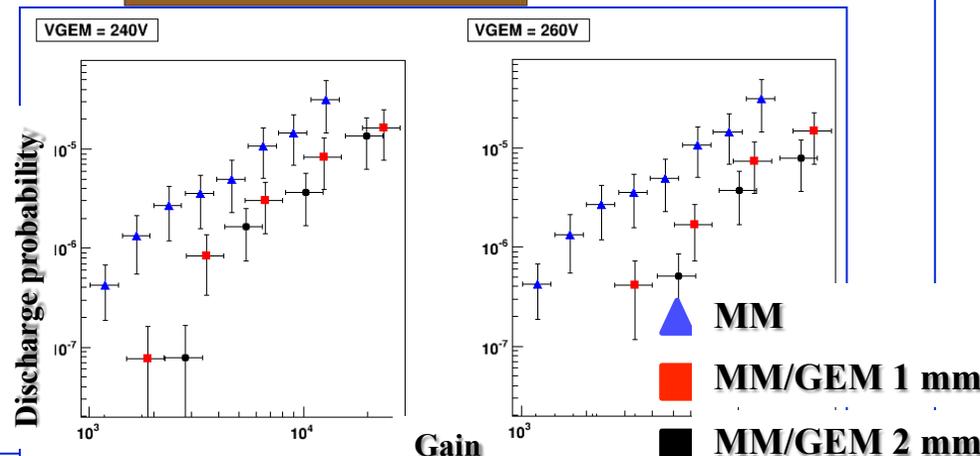
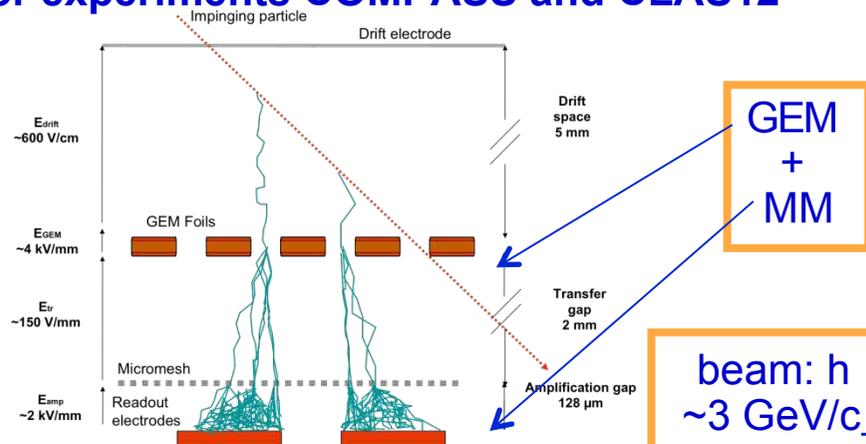
beam:  $\pi, \mu$   
120 GeV/c<sub>-</sub>

Resistive anode



## Hybrid Structures

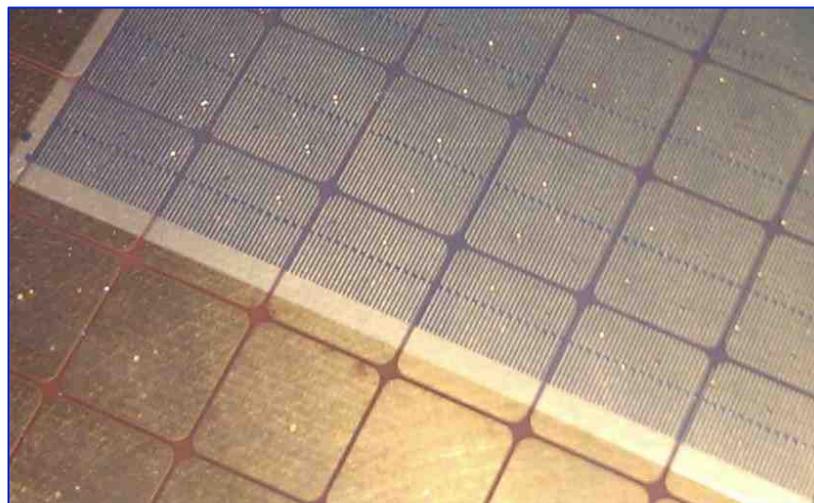
For experiments COMPASS and CLAS12



M. Vandenbroucke,  
MPGD 2011

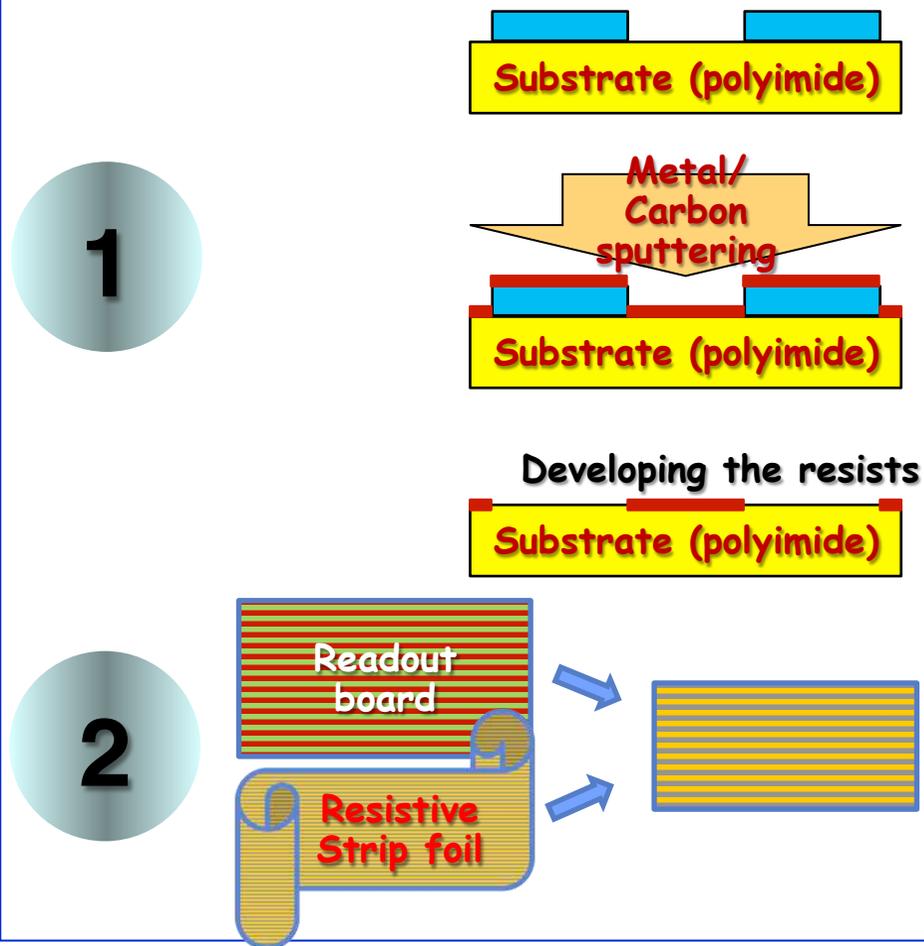
# MM, resistive anode implementation

## ■ Photolithography



## ■ Screen printing

## ■ New: by sputtering

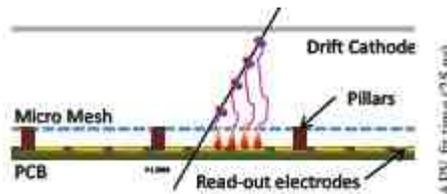


# MICROMEAS: recent developments

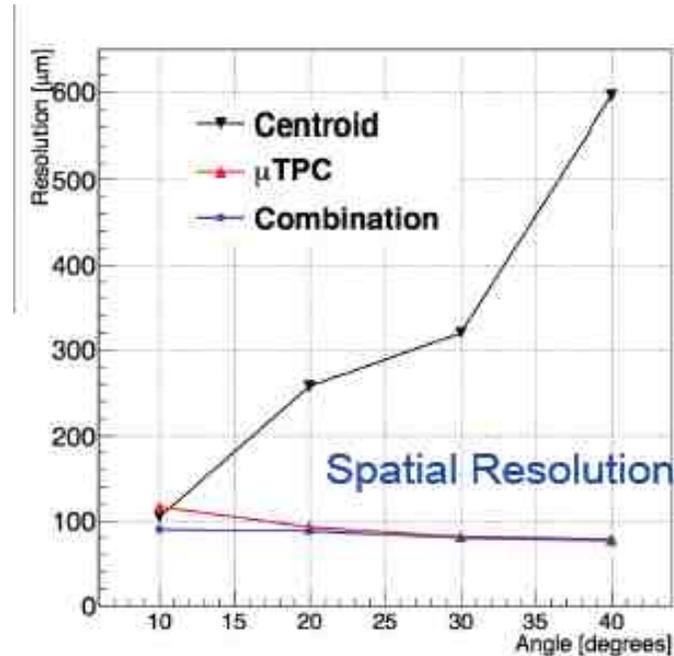
for a more powerful tracking

## MM operated in microTPC mode

- Development in the context of ATLAS MAMMA



Single Segment  
Reconstruction in a  
Micromegas

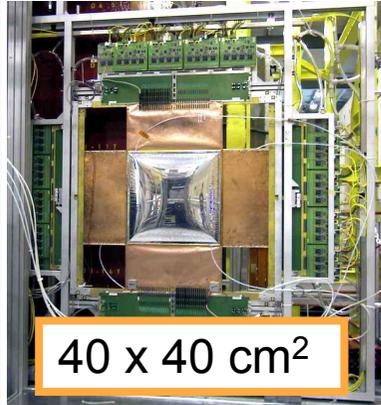


George Iakovidis - MPGD 2013

# MICROMEAS & experiments

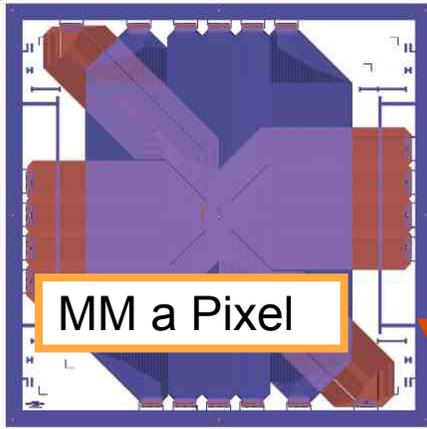
Non exhaustive example list

COMPASS



40 x 40 cm<sup>2</sup>

MM a Pixel



ATLAS – MAMMA project  
Goal: 1 x 2.5m<sup>2</sup>

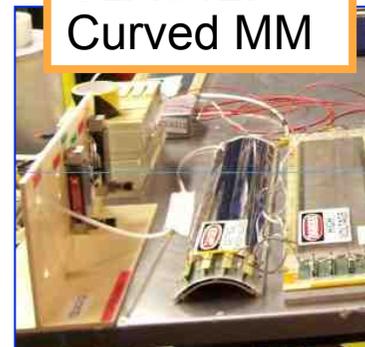
For the **New Small Wheel**,  
**ATLAS** muon system,  
**1200 m<sup>2</sup>**, tracking & trigger

FUTURE

ILC TPC



CLAS12:  
Curved MM

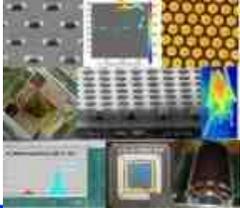


T2K : TPC  
read-out



CAST





# THE MAIN MPGD ARCHITECTURES:

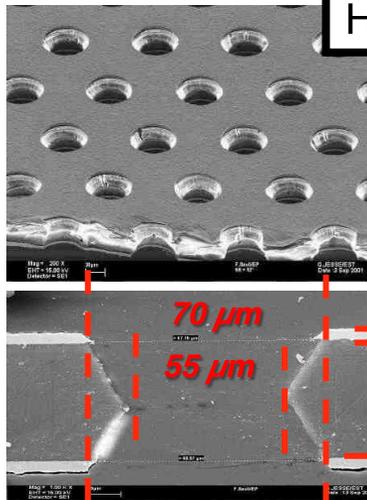
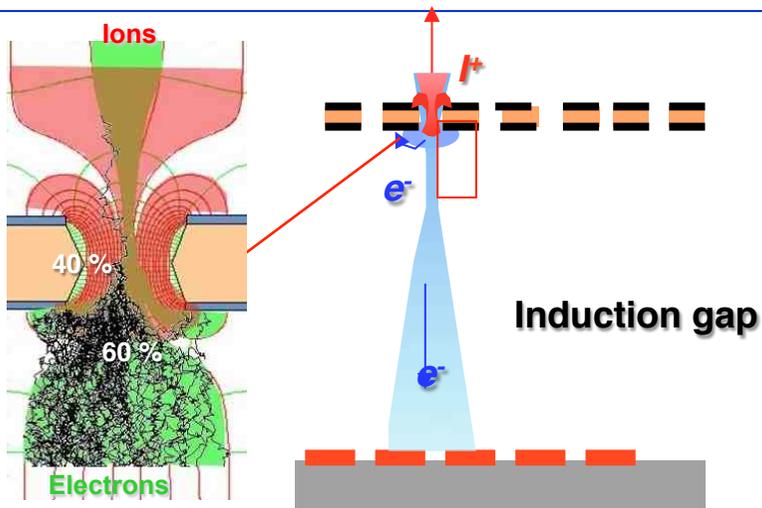
MICROME GAS, **GEM**, THGEM

AND THEIR CONSOLIDATION

( by new ideas & technological progress)

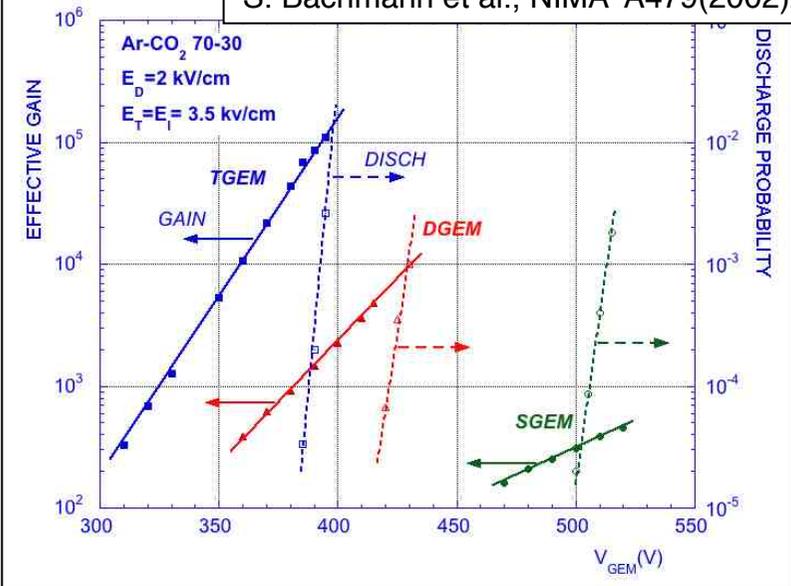
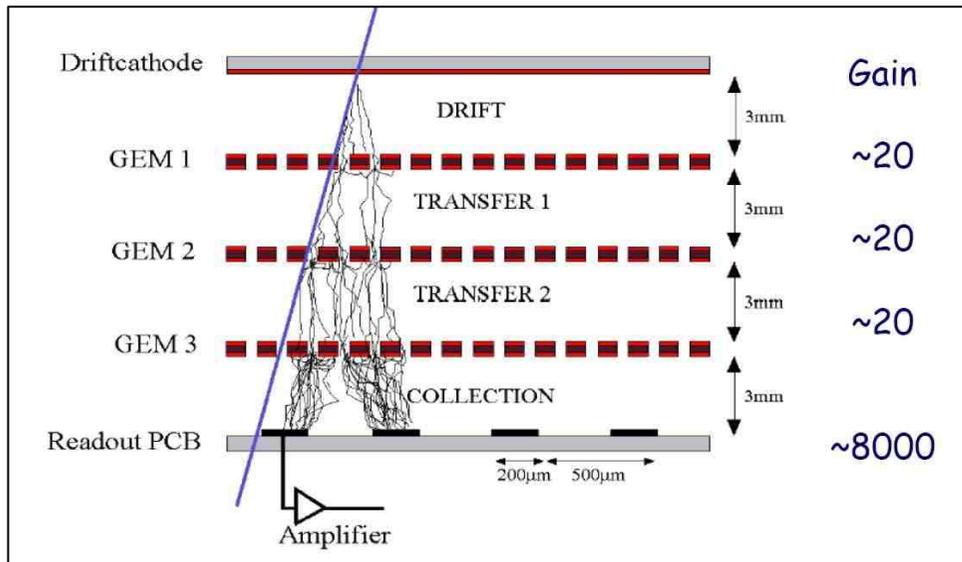
# GEM, il principio e la realizzazione

Metalized polyimide foil,  
Holes by chemical etching

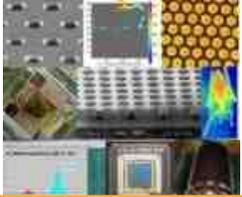


- Raw Material Vacuum deposited copper on polyimide
- Applying Resist Image Transfer
- Patterning Resist UV Exposure & Development
- Copper Etching
- Resist Stripping
- Polyimide Etching and Cleaning

S. Bachmann et al., NIMA A479(2002)294

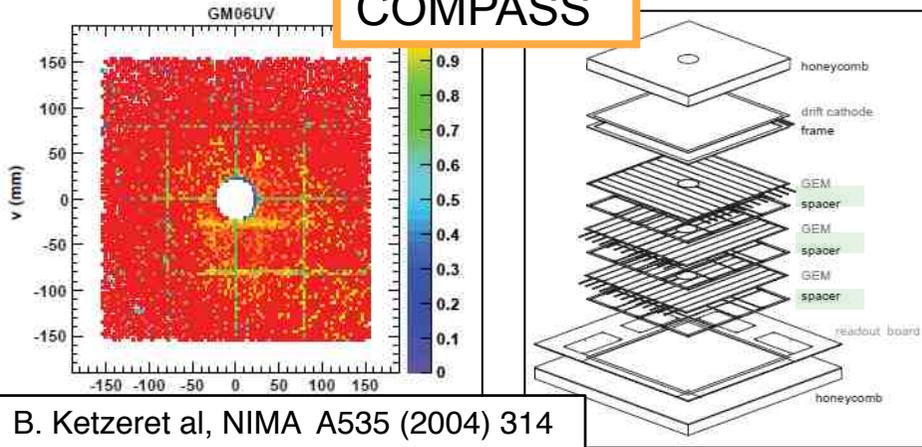


# GEMs, spacers & stretching



## GEM detectors w/ spacers

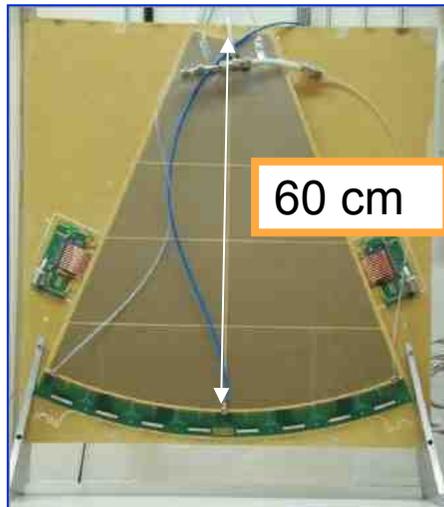
### COMPASS



B. Ketzeret al, NIMA A535 (2004) 314



### TOTEM



## Emphasis on GEM foils stretching

### no spacers



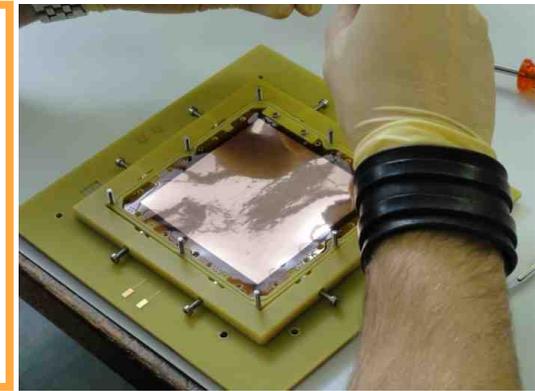
### LHCb

### KLOE2: Triple cylindrical GEM assembly completed 14/3/2013



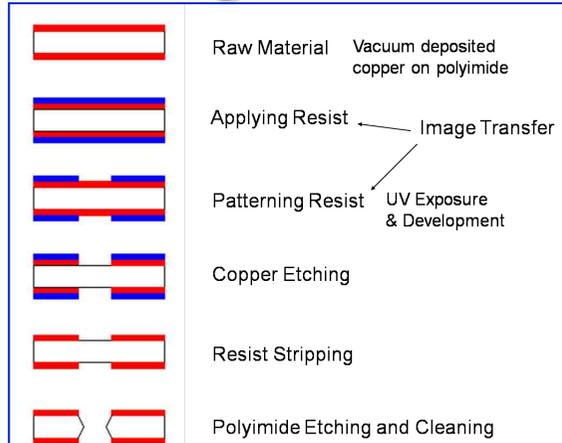
### no spacers

CMS upgrade:  
mechanical stretching  
for mass production  
Nowadays also  
large prototypes

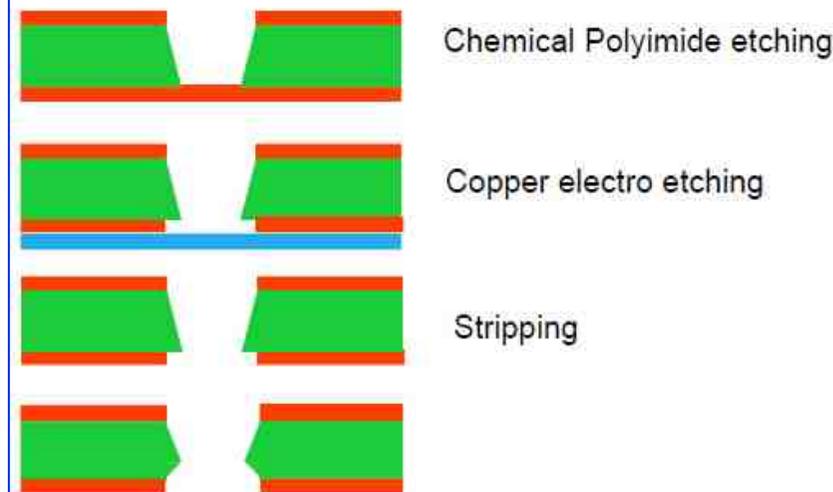
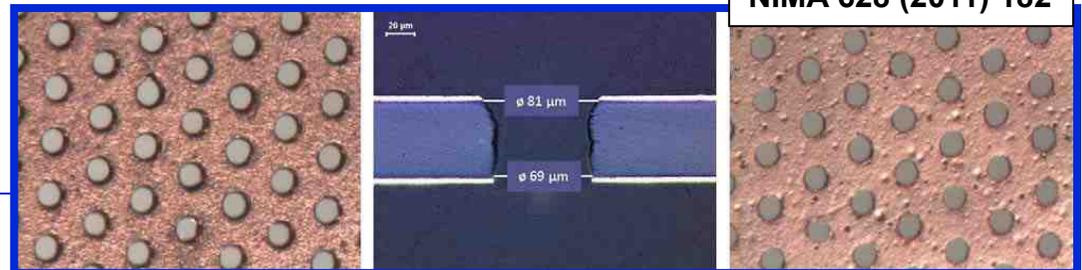


# GEMs, large foils

## Single mask: the way towards large size



- standard (double mask)
- single mask



The path:

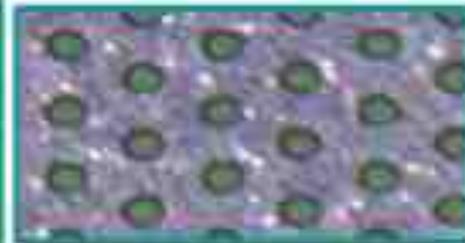
- TOTEM upgrade
- KLOE2
- CMS
- ( CBM )

# GEM FOIL QC

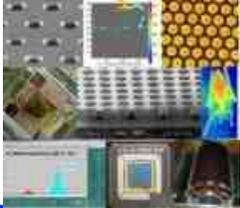
- By optical inspection @ Helsinki
  - TOTEM
  - superFRS



Based on 9 Mpix camera with integrated telecentric optics for this setup one pixel corresponds to  $17 \times 17$  microns



F.Garcia et al.,  
MPGD2013



# GEMs figures

## ■ Space resolution

- **COMPASS small area trackers,  $\sim 70 \mu\text{m}$**  (P. Abbon et al., NIMA 577 (2007) 455.)

## ■ Time resolution

- **COMPASS small area trackers,  $\sim 12 \text{ ns}$**  (P. Abbon et al., NIMA 577 (2007) 455.)
- **LHCb,  $4.5 \text{ ns}$  - dedicated effort** (M. Alfonsi NIMA 535 (2004) 319)

## ■ Gain

- **At COMPASS:  $G \sim 8000$**  (B. Ketzer, private comm.)
- **At LHCb:  $G \sim 4000$**  (M. Alfonsi NIMA 581 (2007) 283)
- **At TOTEM:  $G \sim 8000$**  (G. Catanesi, private comm.)
- **Phenix HBD:  $G \sim 4000$**  (W. Anderson et al., NIMA 646 (2011) 35)

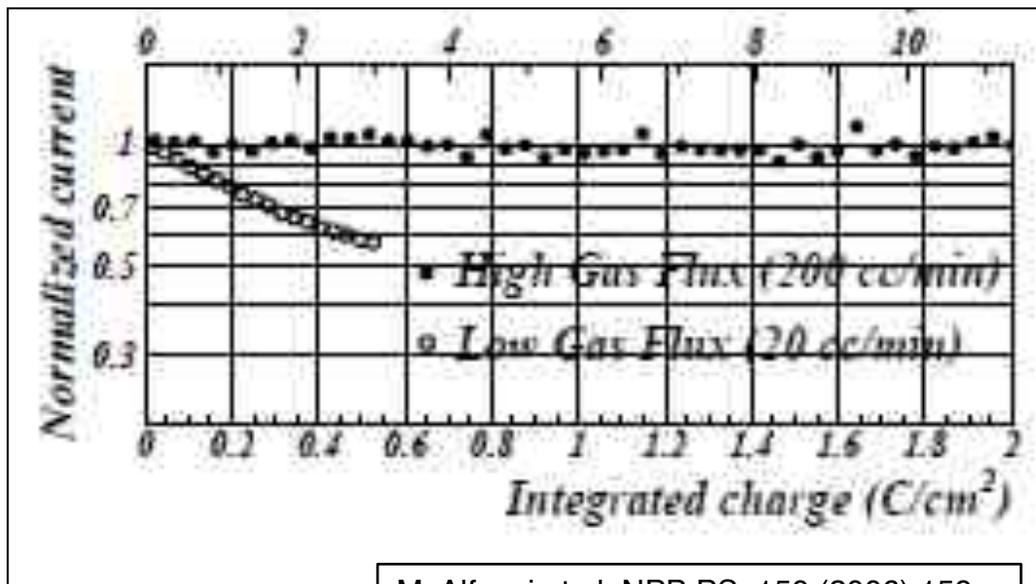
## ■ Material budget

- **COMPASS small area trackers:  $0.4 \% X_0$**  (P. Abbon et al., NIMA 577 (2007) 455.)
- **COMPASS pixelated GEMs:  $0.2 \% X_0$**  (A. Austregesilo et al., NP B PS 197 (2009) 113)

# GEM AGEING

## ■ GEM studies for LHCb

- Relevance of the gas flow at large rates



M. Alfonsi et al, NPB PS 150 (2006) 159

## ■ COMPASS Pixelised GEMs

- Observed:
  - Ageing
  - Incomplete glue curing
- No real indication of intrinsic ageing

# GEM and experiments

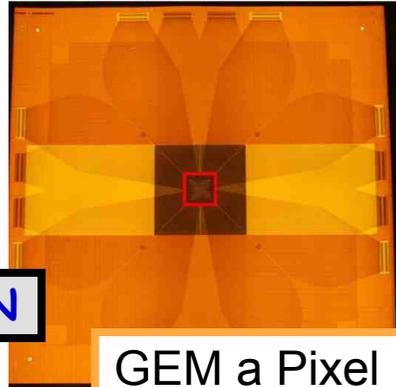
Non exhaustive example list

33 x 33 cm<sup>2</sup>

COMPASS



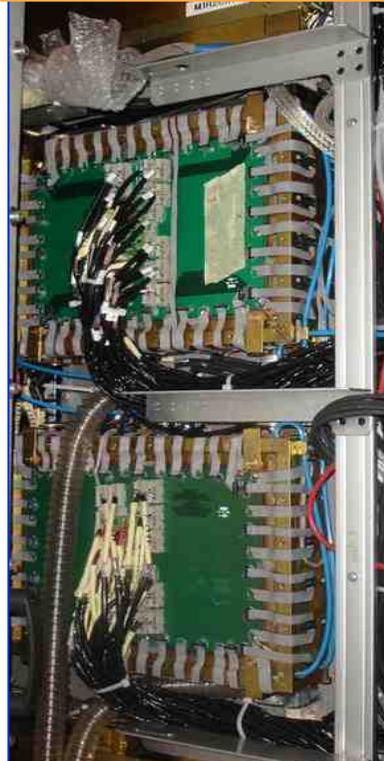
**IN OPERATION**



GEM a Pixel

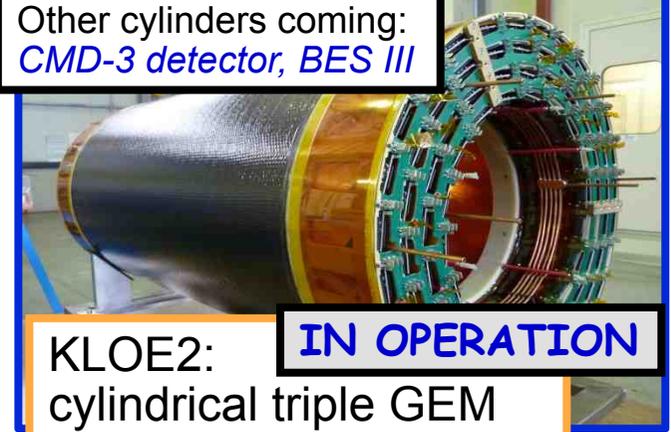
LHCb

Time resolution:  
4.5 ns rms



**IN OPERATION**

Other cylinders coming:  
*CMD-3 detector, BES III*

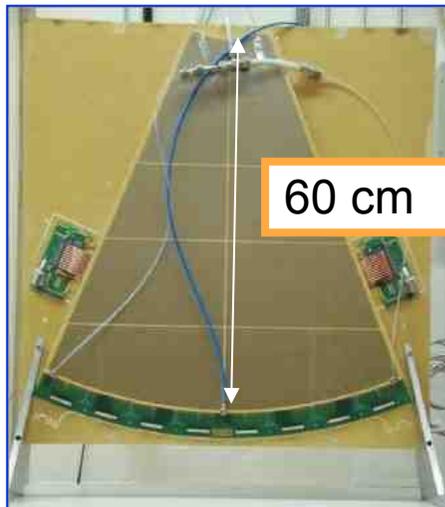


KLOE2: **IN OPERATION**  
cylindrical triple GEM

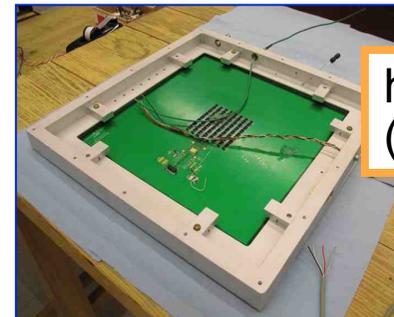


**IN OPERATION**

TOTEM



60 cm



h calorimetry  
(ATLAS, ILC)

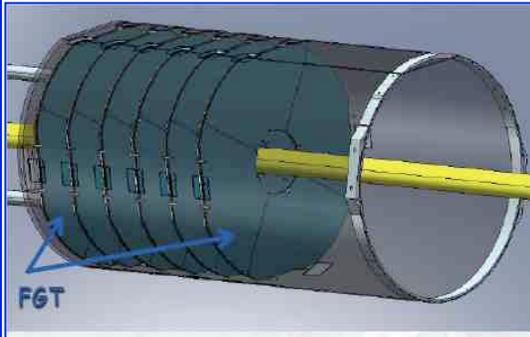


JLab Hall A  
40 x 50 cm<sup>2</sup>

# GEM and experiments, cont.

Non exhaustive example list

## STAR - Forward GEM Tracker

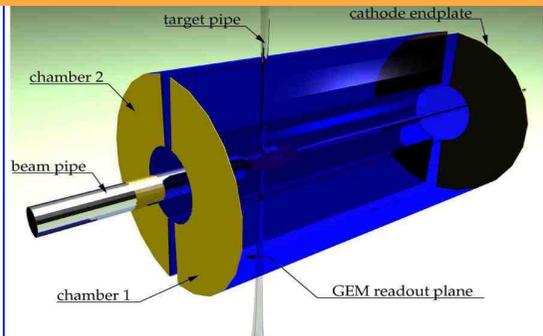


**CMS forward muon spectrometer : tracking & trigger, ~1000 m<sup>2</sup> di GEM**  
**First portion of the project approved**

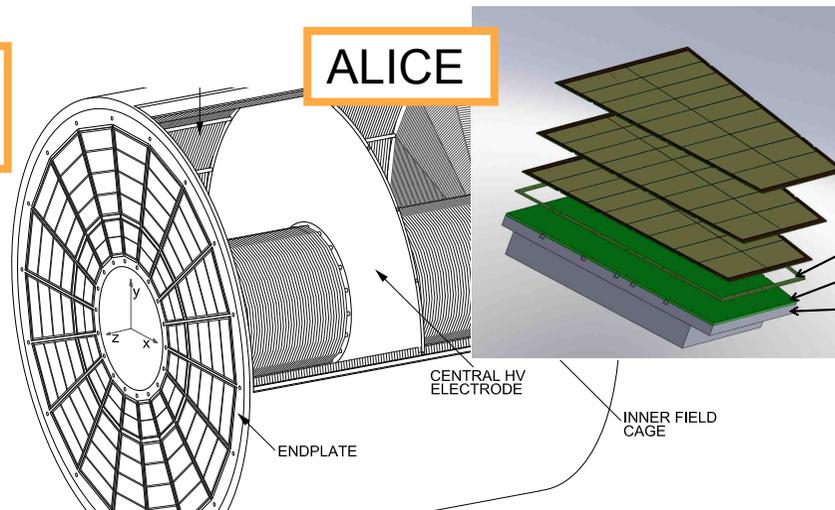


## R-O TPC

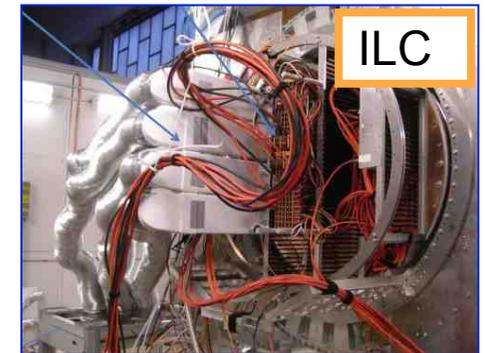
PANDA → prototype used at FoPi

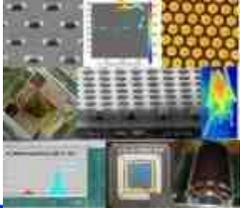


## ALICE



## ILC





# THE MAIN MPGD ARCHITECTURES:

MICROME GAS, GEM, THGEM

AND THEIR CONSOLIDATION  
( by new ideas & technological progress)

# THGEM, HOW and WHY

## PCB technology, thus:

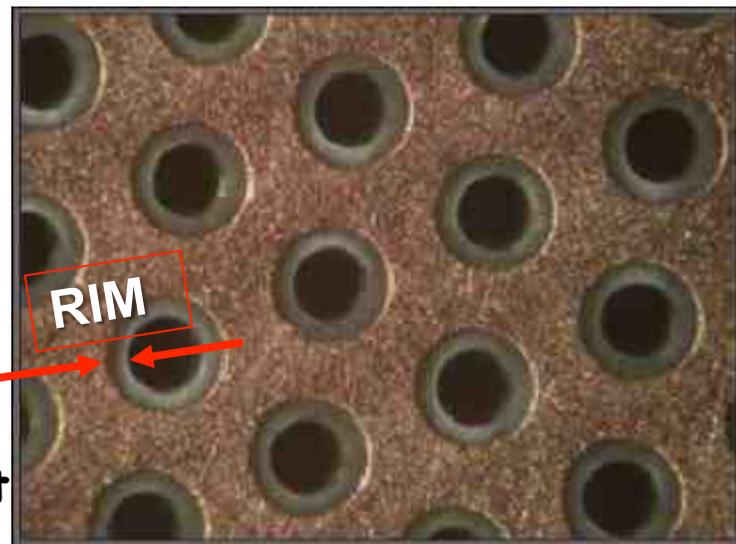
- robust
- mechanically self supporting
- industrial production of large size boards
- large gains have been immediately reported (**rim** !)

## Comparing to GEMs

- Geometrical dimensions  $\times \sim 10$ 
  - But  $e^-$  motion/multiplic. properties do not
  - Larger holes:
    - dipole fields and external fields are strongly coupled
    - $e^-$  diffusion plays a minor role

## About PCB geometrical dimensions:

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



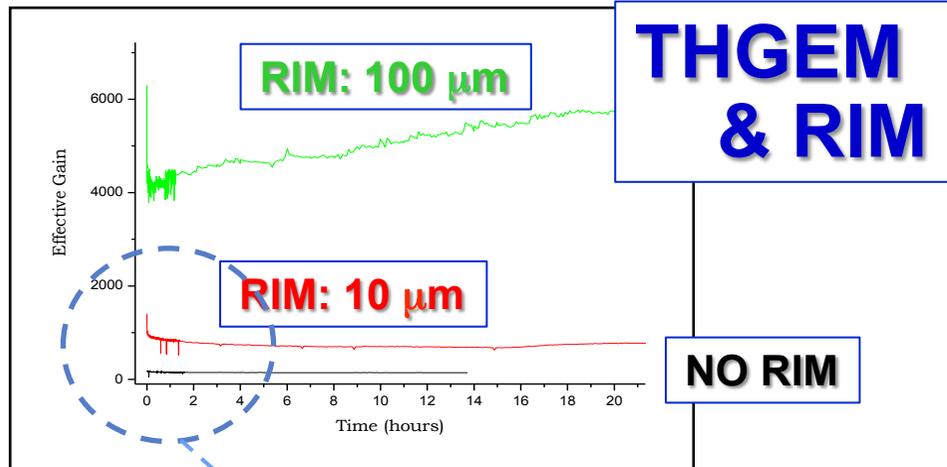
## introduced in // by different groups:

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

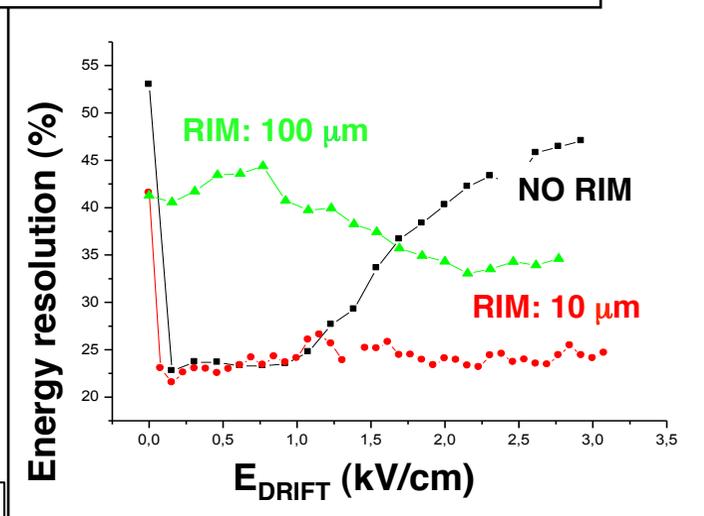
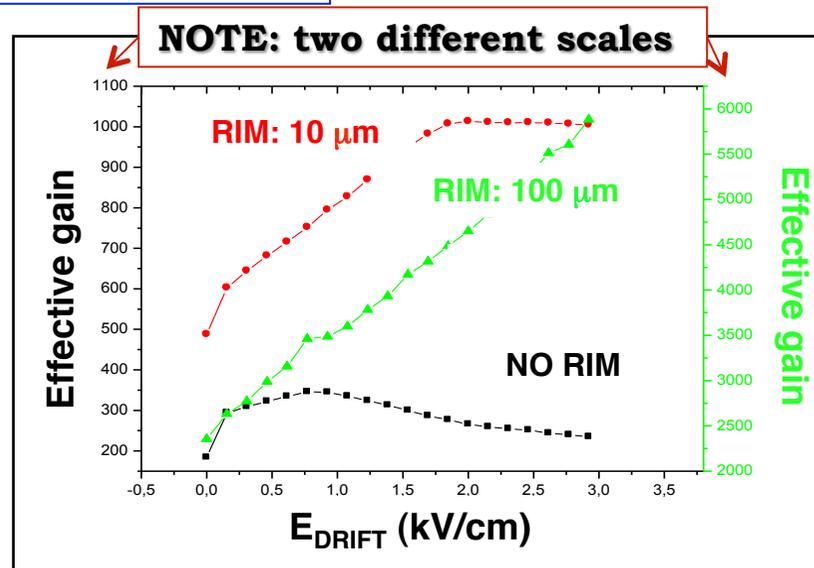
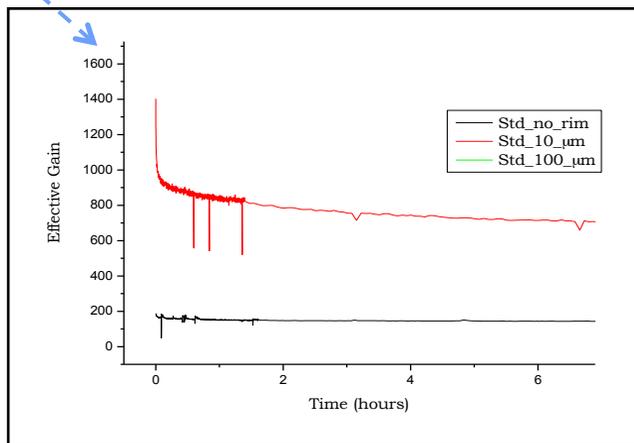
# ABOUT THE RIM

## X-ray measurements

### THGEM & RIM



zoom

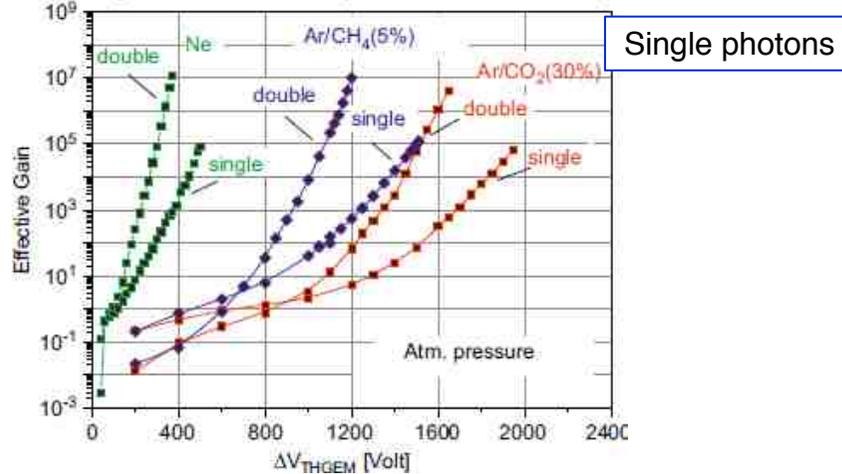


S. Dalla Torre et al.,  
IEEE – NSS 2008 , Dresden 19-25/10/2008

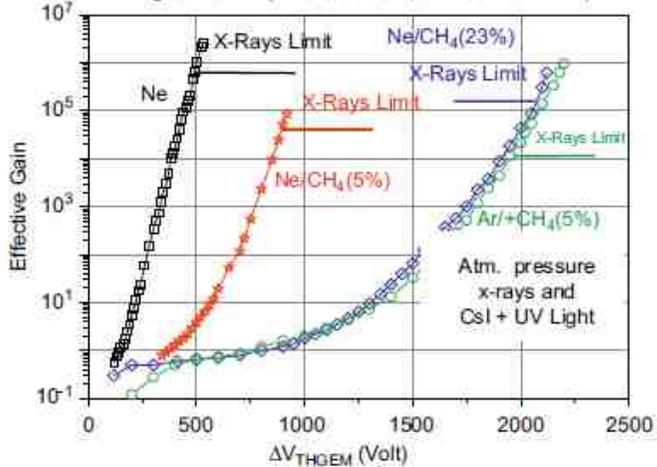
# THGEM RIM & GAIN

## employing large rim (100 $\mu\text{m}$ )

a single and double THGEM ( $t=0.4, d=0.5, a=1, h=0.1\text{mm}$ )

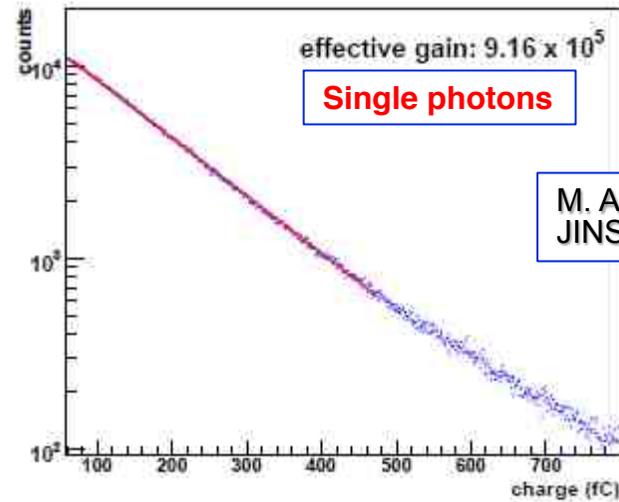
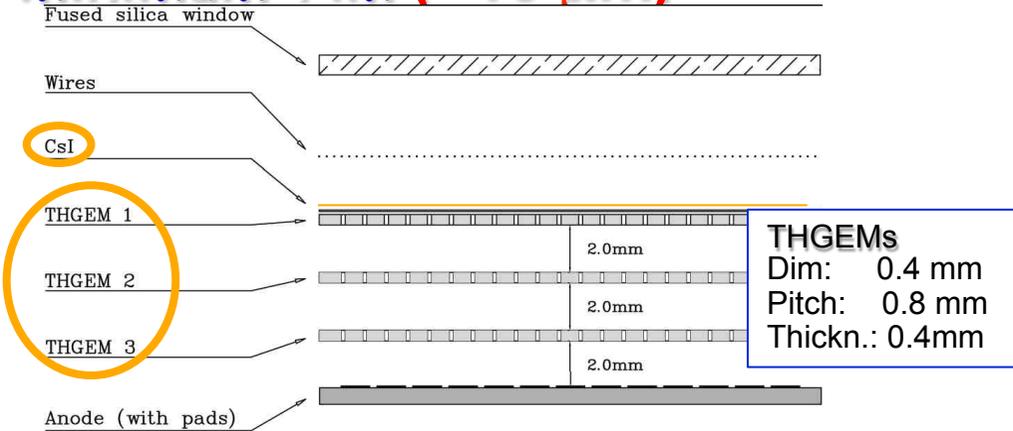


D single THGEM ( $t = 0.8, d = 0.6, a = 1, h = 0.1\text{ mm}$ )



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

## minimum rim (<10 $\mu\text{m}$ )

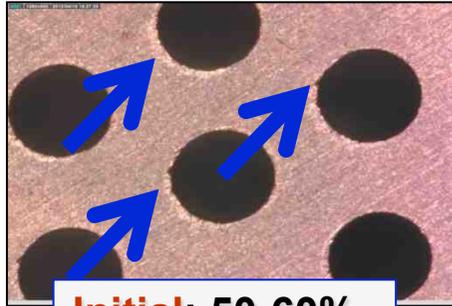


M. Alexeev et al.,  
JINST 5 (2010) P08009

Gain limited to  $\sim 10^5$  in test beam

# THGEM CONSOLIDATION

polishing (Pumice Powder)  
ultrasonic bath (~1 h) @ 50-60 °C  
in Sonica

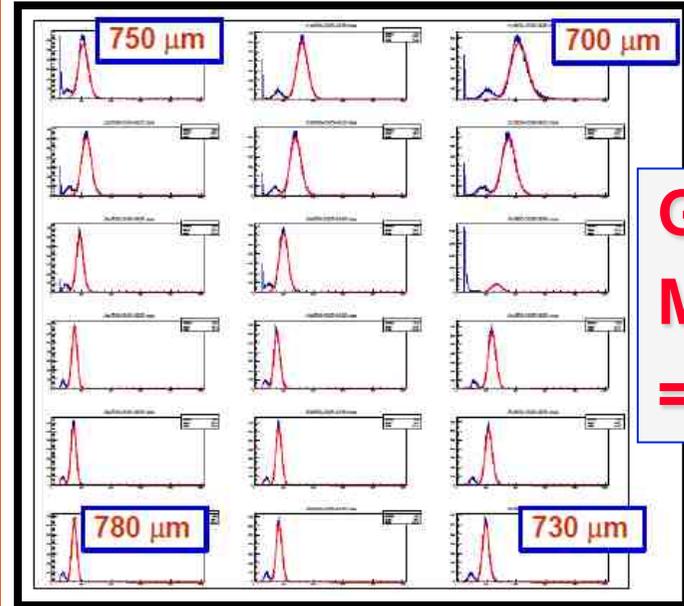


**Initial: 50-60%  
Paschen curve**



**Final: > 90%  
Paschen curve**

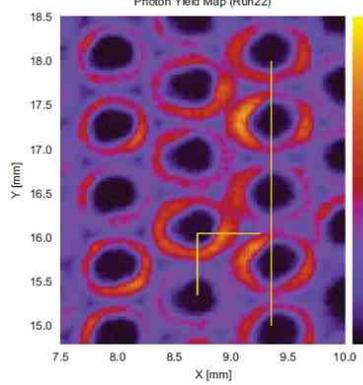
## Engineering aspects



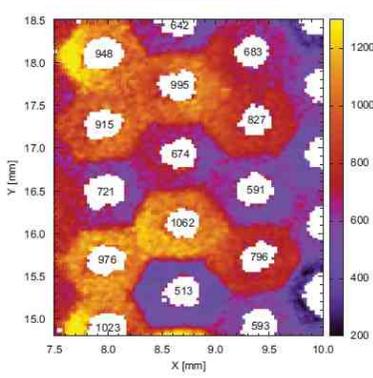
**GAIN  
Max/Min  
= 2.9**



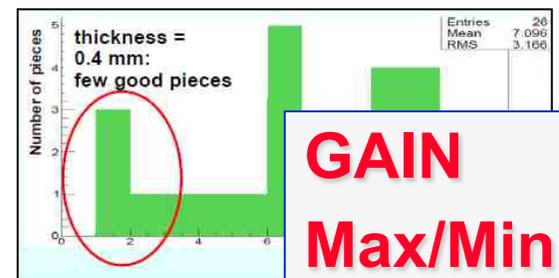
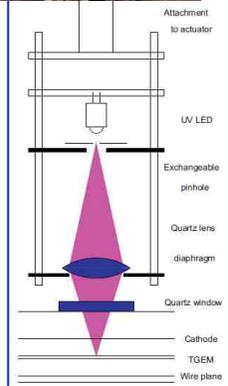
**Efficiency map**



**Gain map**



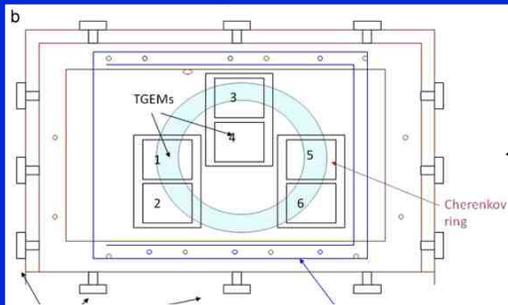
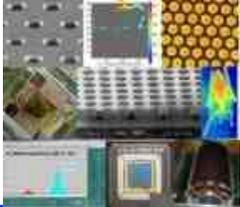
G.Hamar and D. Varga, NIMA 694(2012)16



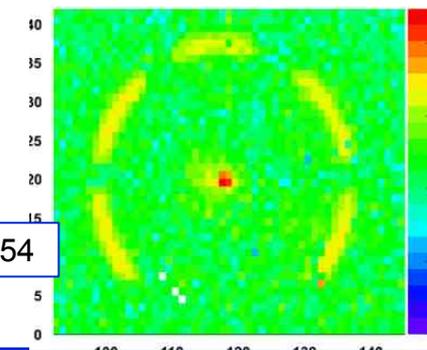
**GAIN  
Max/Min  
= 1.6**

Selecting uniform fiberglass plates

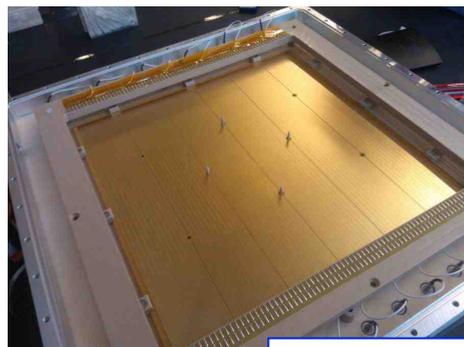
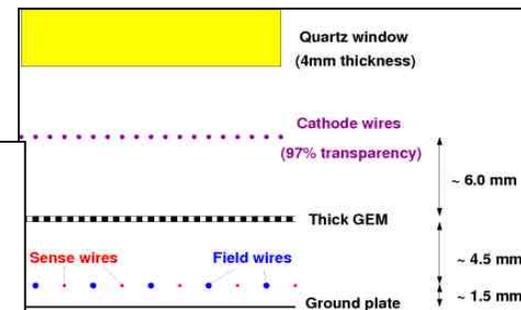
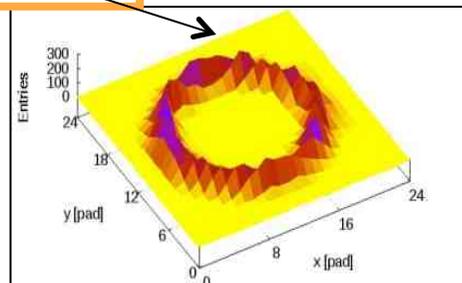
# THGEMs for PHOTON DETECTION in RICHes



**ALICE VHPID  
THGEM &  
HYBRID**

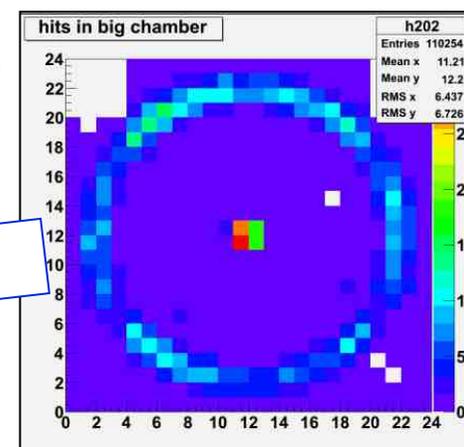
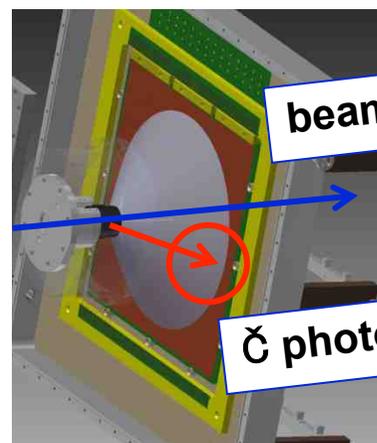


V.Peskov et al., NIMA 695 (2012) 154



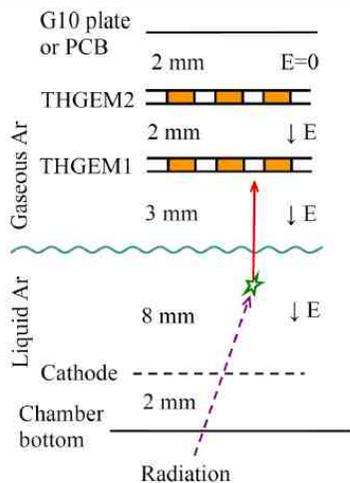
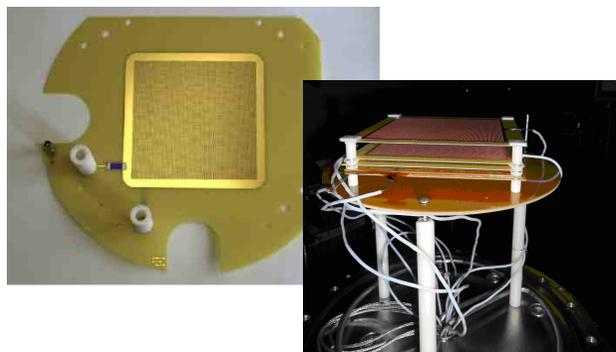
**COMPASS, RICH-1  
upgrade by  
Triple THGEM  
detectors**

300 x 300 mm<sup>2</sup> active surface



# THGEM, MORE APPLICATIONS

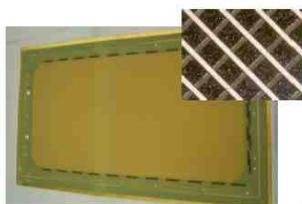
## THGEM-based cryogenic detectors (operated in gas with or w/o window; even in the liquid itself!)



### 2D projective anode and LEM for 250L

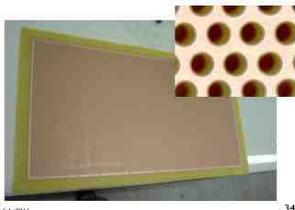
Manufacturer: CERN TS/DEM group

- 40 x 76 cm<sup>2</sup> active area (biggest ever constructed).
- 256 + 256 channels.
- 3 mm wide strips ( $\pm 45^\circ$  with respect to the length).
- 55 cm long strips (longest).



- 40 x 76 cm<sup>2</sup>,  $\sim 0.5 \times 10^6$  holes.
- 8 segments to decrease the LEM capacitance.
- PCB: 1 mm thick.
- hole  $\varnothing$  0.5 mm, 0.8 mm pitch.

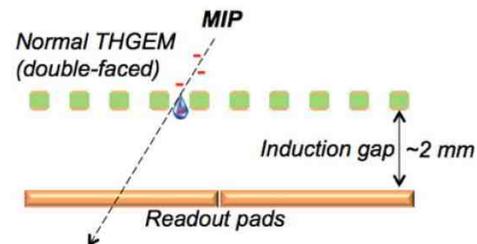
Manufacturer: ELTOS (Italy)



## THGEM, standard or well-type, as active elements in hadron sampling calorimetry

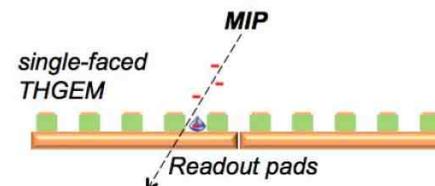
### Standard THGEM

- Cu coated in both sides
- Operated with induction gap

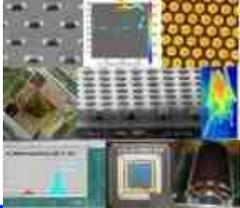


### WELL THGEM

- Cu coated in one sides
- No induction gap - electrode attached to the anode



S. Bressler et al,  
CALICE collaboration meeting,  
March 2013



# NOVEL ARCHITECTURES

# NOVEL ARCHITECTURES BY IMAGES

## (1) GEM-derived

Towards gas PMTs by

- Extremely reduced ( $\sim 10^{-4}$ ) IBF to PC
- Non outgassing materials

**MHSP**

**COBRA**

The MHSP diagram shows an x-ray entering from the Cathode Plane, passing through an MS region and a Hole region, and being detected by an Anode Strip. It labels the MHSP Top, Cathode Strip, and Cathode Plane, along with voltages  $-V_{c,T}$  and  $V_{a,C}$ , and electric fields  $E_{Drift}$  and  $E_{ind}$ . Dimensions shown are 70  $\mu m$ , 20  $\mu m$ , and 200  $\mu m$ . The COBRA micrograph shows a hexagonal grid with dimensions 240  $\mu m$ , 35  $\mu m$ , 60  $\mu m$ , and 30  $\mu m$ .

**Glass GEM**

A micrograph showing a dense, regular array of small circular holes in a glass substrate.

**Limit the discharge damages**

**Re-GEM: electrodes by resistive kapton**

A photograph of a detector assembly with a central panel and surrounding electronics.

**A different technology**

- PCB industry
- Robust
- Self-supporting plates

**THGEM**

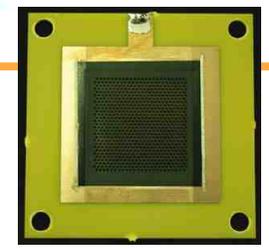
A micrograph showing a grid of circular holes in a dark, textured material.

**RTGEM**

A schematic diagram showing a cross-section of a detector with layers: Resistive coating, Metallic strips, Cs layer, and G-10 plate. It also shows Holes and an Avalanche region.

**Thick COBRA**

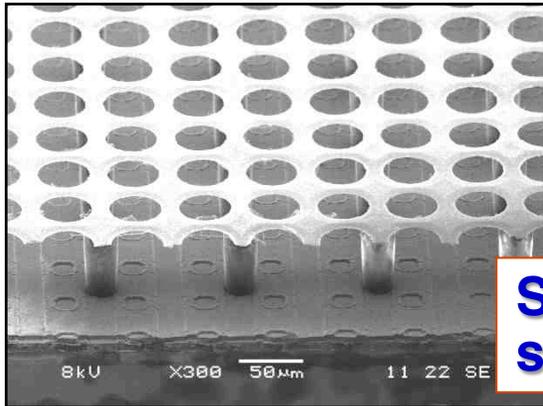
A schematic diagram showing two cross-sections: a) Top Strips with Resistive Line, and b) Anode Strips with Resistive Line and Cathode strips.



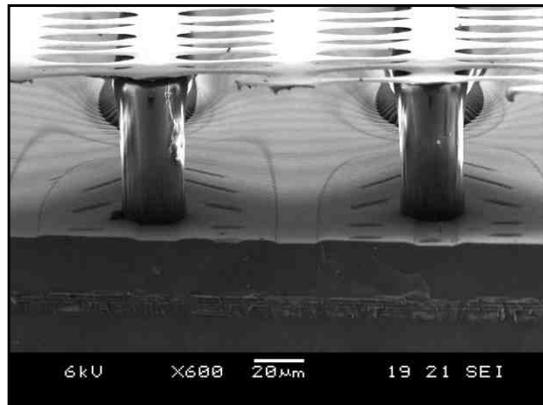
# NOVEL ARCHITECTURES BY IMAGES

## (2) MM-derived

Timepix chip + SiProt + Ingrid



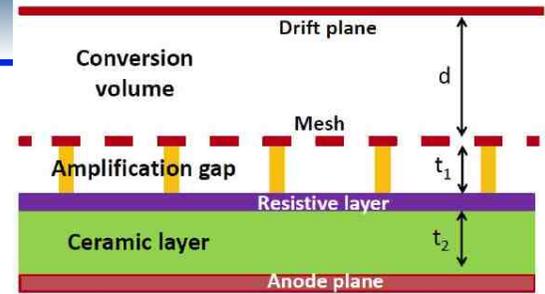
Single electron sensitivity



GRIDPIX



Large size!  
Large size!

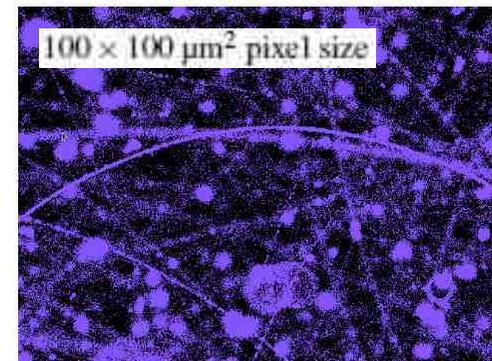
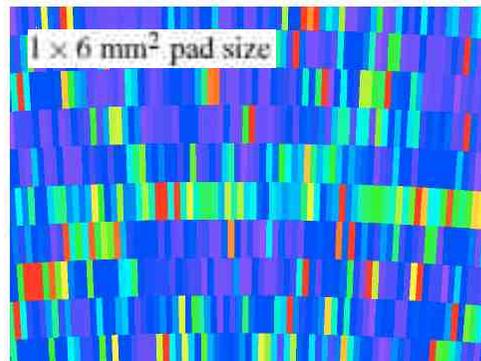


**Piggy Back:** read-out separated from the active volume



**Microbulk:**  
Low material budget,  
radioactive pure

Simulations for CLIC, M. Killenberg, LCD-Note-2013-005



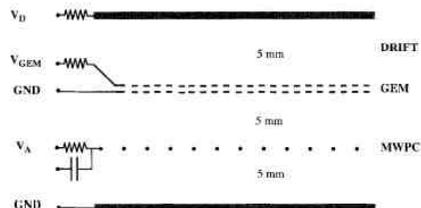
# NOVEL ARCHITECTURES BY IMAGES

## (3) hybrids

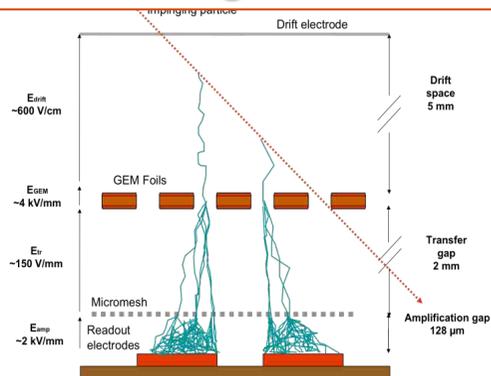
Towards gas PMTs:  
IBF control

Since the beginning  
(Sauli et al.):

- GEM + MWPC,**  
**GEM + MSGD**  
(NIMA 396 (1997) 50)



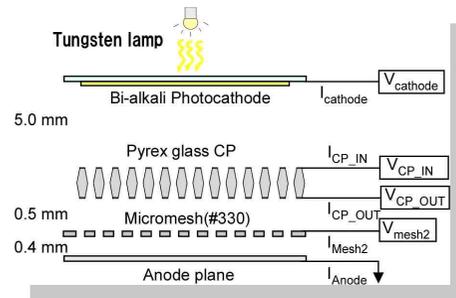
**GEM pre-amplification:**  
control the discharge  
rate in tracking



MM w GEM pre-amplification



GAS PMT



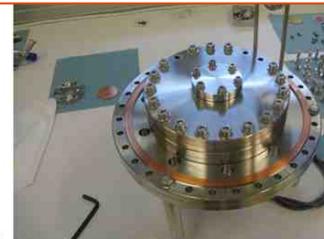
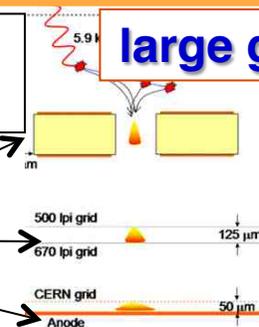
S. Duval et al.,  
NIMA 695  
(2012) 163

large gain / low IBF

THGEM

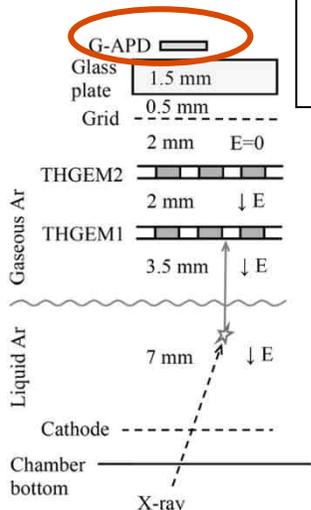
PIM

MM

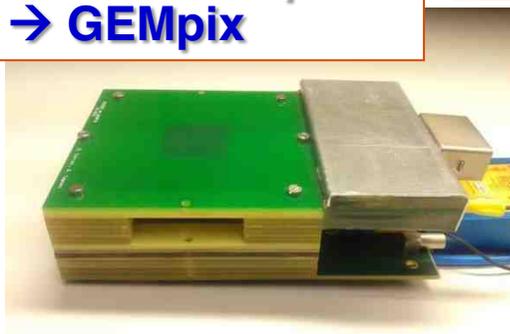


A. Bondaret al.,  
NIMA 628  
(2011) 364

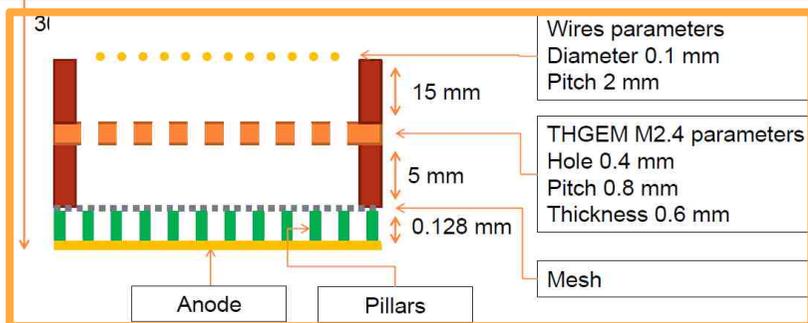
**THGEM + G-APD**  
Detect  
scintillation  
light



**GEM + medipix**  
→ **GEMPix**



**THGEM + MM**  
for single photodetection: IBF control



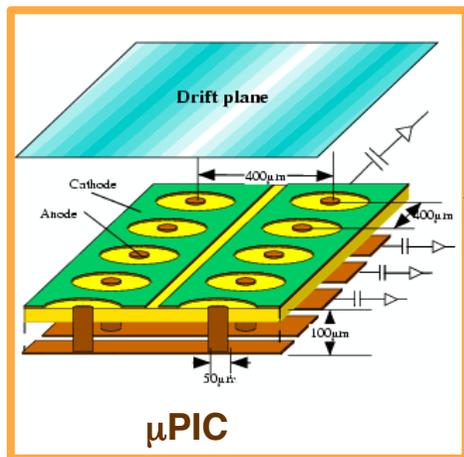
# NOVEL ARCHITECTURES BY IMAGES

## (4) novel geometries

General purpose tracking: fundamental research & applications

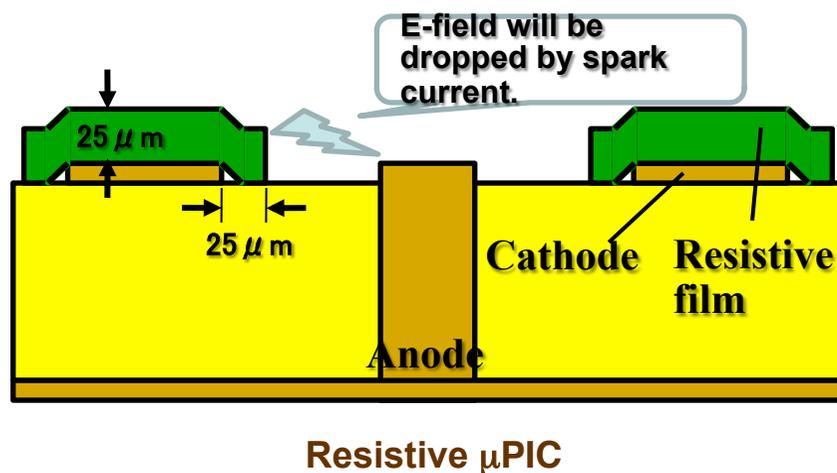
Motivation:

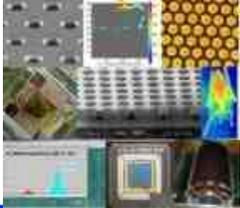
- use PCB technology for mass production,
- no floating structure



A.Ochi and T.Tanimori,  
NIMA 471 (2001) 264

Spark-tolerant structure





NOT ONLY  
TRACKING:

PHOTON  
DETECTION

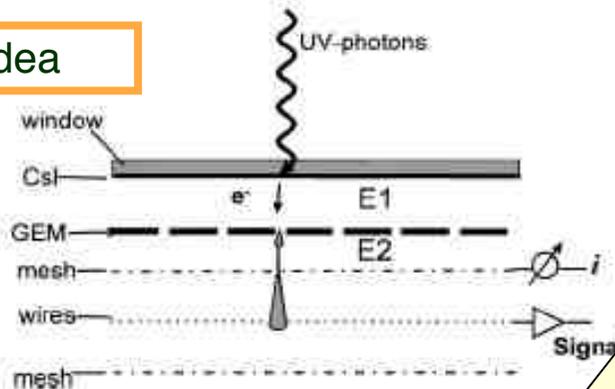
# WHY PHOTON DETECTION BY MPGDs?

## MPGD PDs

- Reduced photon and Ion BackFlow (IBF)
  - Reduced ageing
  - High gain  $\rightarrow$  high photoelectron detection efficiency
- Intrinsically fast gaseous detectors
  - Short integration time
  - High rate environments

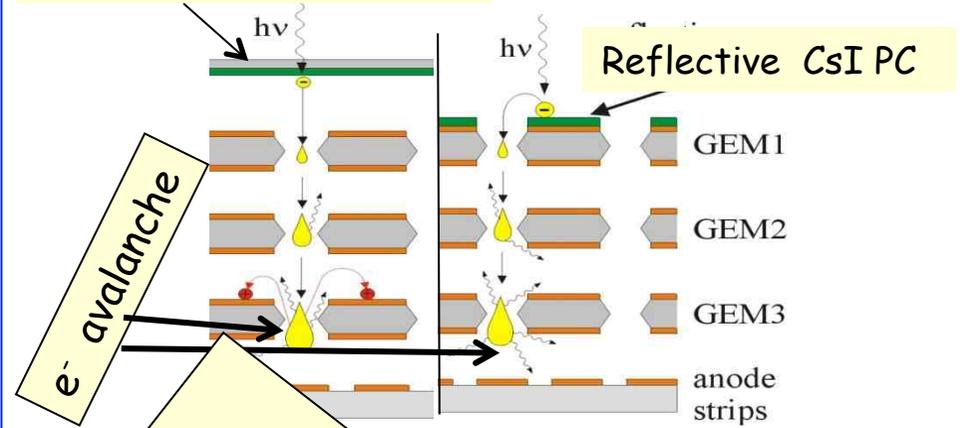
... first ideas

### An "old" idea

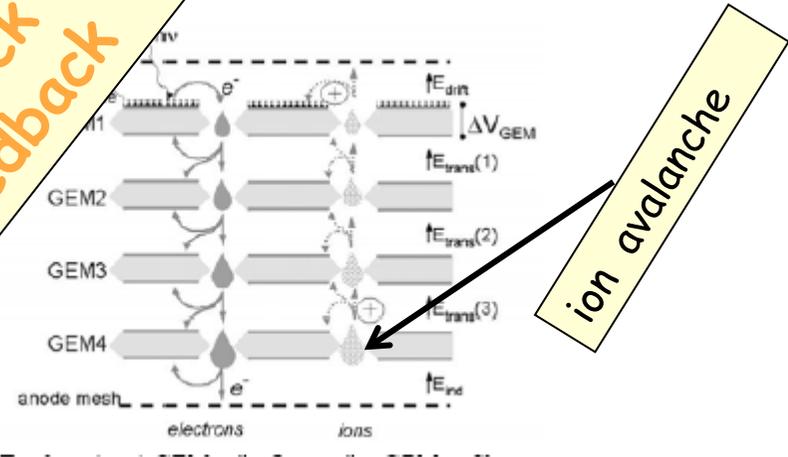


R. Chechwik et al., NIM A 419 (1998) 423

### Semi-transparent CsI PC



NO photon feedback  
Reduced ion feedback

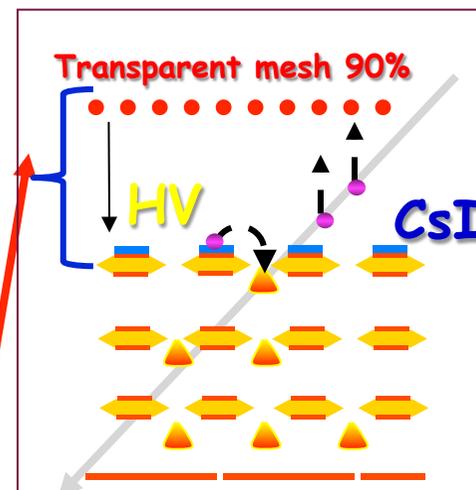
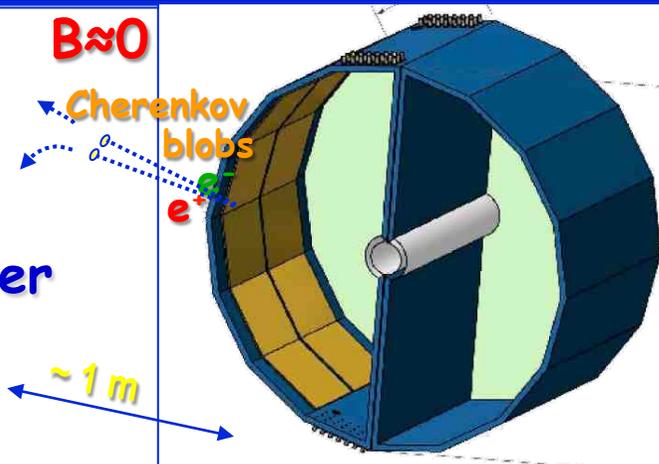


A. Breskin and R. Chechwik, NIM A 595 (2008) 116

# ION & PHOTON BLOCKING GEOMETRIES

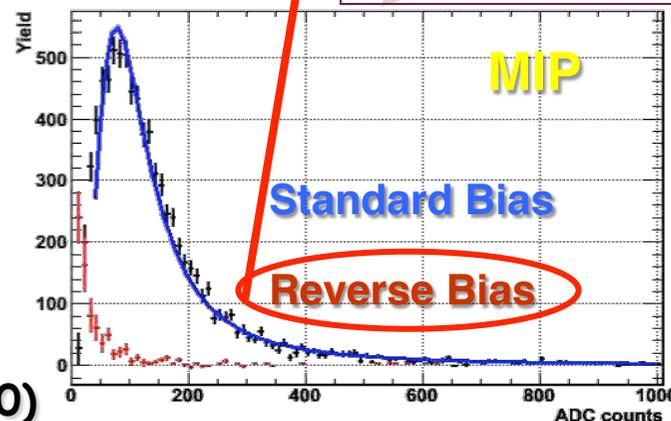
... and applications:

**PHENIX HBD,**  
a threshold Cherenkov counter  
(window-less)



Central message for any similar application

- Reversed bias cuts the MIP signal !



Aspects non exportable to imaging devices:

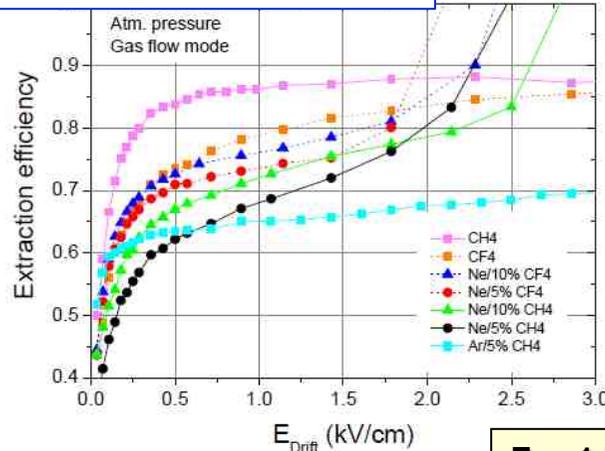
- detection of  $\gg 1$  photon per pad: low gain (5000)
- non negligible noise level (~20% single photon signal)
- detect photons with  $\lambda$  down to ~110 nm: chromaticity !

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

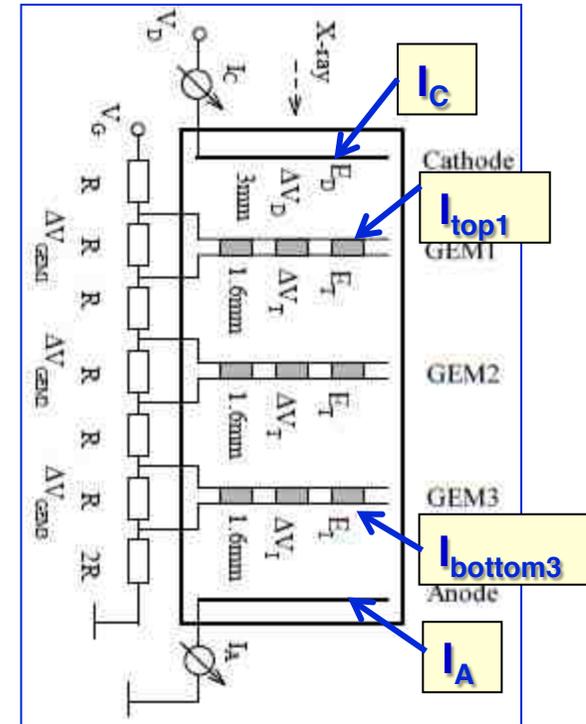
# THE DILEMMA

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

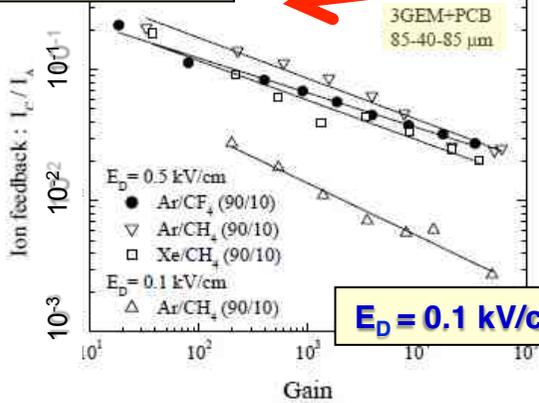
- $E > 0.5 - 1$  kV/cm needed for effective photoelectron extraction in gas atmosphere
- $\text{CH}_4$  (and  $\text{CH}_4$ -Ar mixtures rich in  $\text{CH}_4$ ) the best gas



Here illustrated for semitransparent PC  
The same for reflective PCs :  
small and reversed  $E_D$  is needed

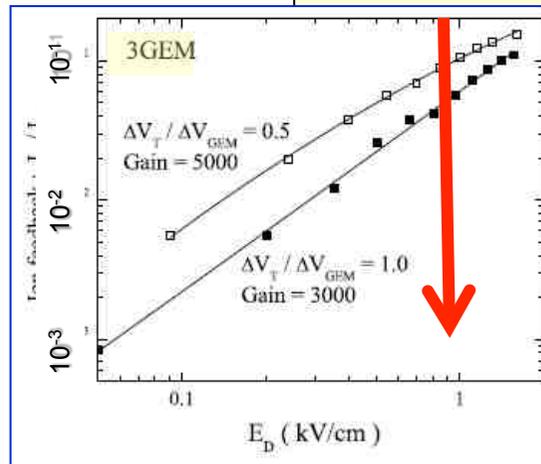


$E_D = 0.5$  kV/cm



$E_D = 0.1$  kV/cm

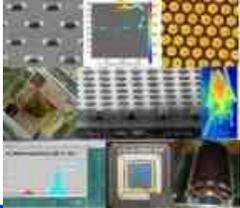
$E \sim 1$  kV/cm needed for good photoelectron extraction



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

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

IBF: at a few % level in effective GEM-based photon detectors:  
Ok for CsI; not for visible light PCs

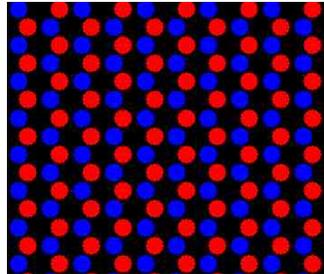
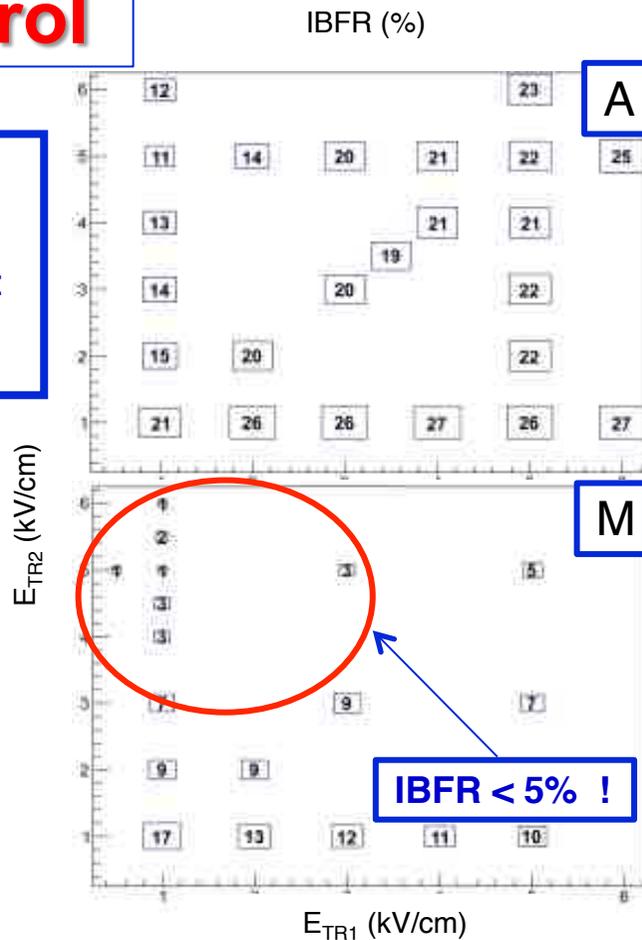


# THGEM & THE DILEMMA

## IBF control

Tripple THGEM:  
Ion Back Flow  
reduction by  
staggering plates:

Total  $\Delta V \sim 8$  kV

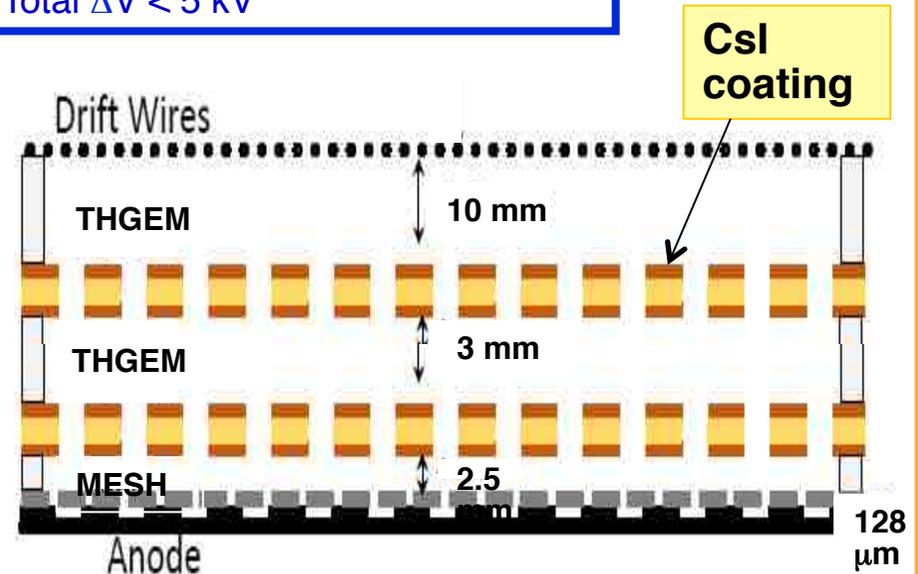


M. Alexeev et al., JINST 8  
(2013) P01021

## The Hybrid approach

2 THGEMs (*staggered!*) + 1 MM:

Total  $\Delta V < 5$  kV

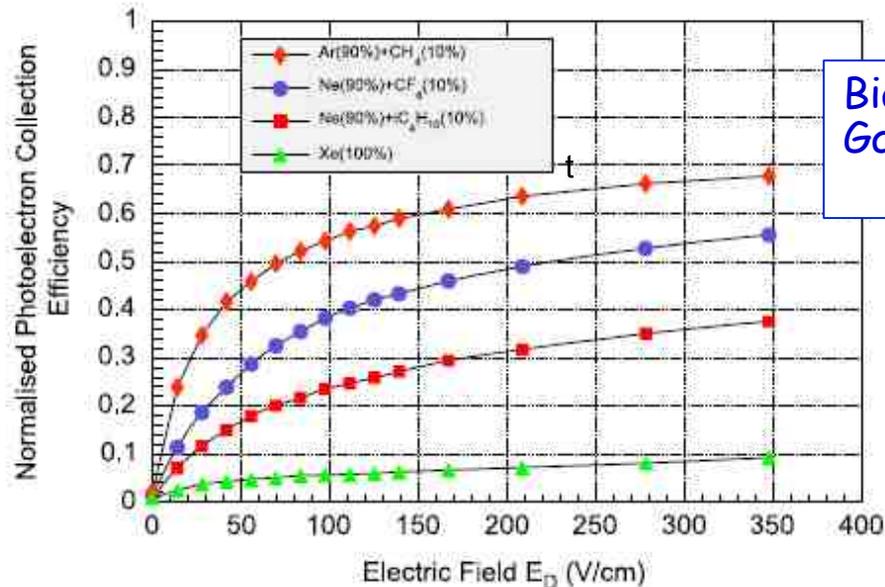


**IBFR < 5% !**

# GASEOUS PMTs

## ■ 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  $25\mu\text{C}/\text{mm}^2$  F.Tokanai et al., NIMA 628 (2011) 190  
Bilkaly: -20% QE at  $0.4\mu\text{C}/\text{mm}^2$  T.Moriya et al., NIMA 732 (2013) 263

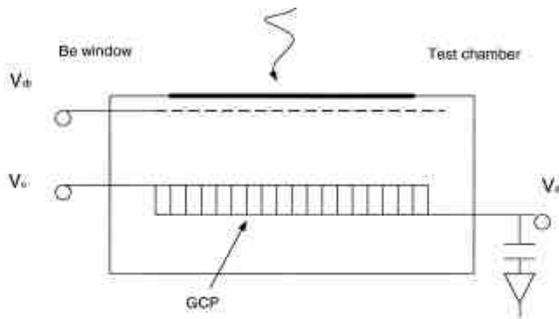


Bialkali,  
Gas P 675  
torr

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

# GASEOUS PMTs, THE APPROACHES

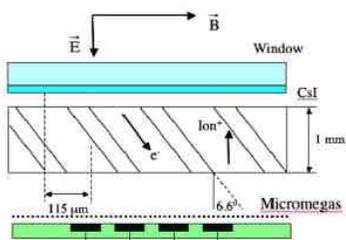
## By capillary plates



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

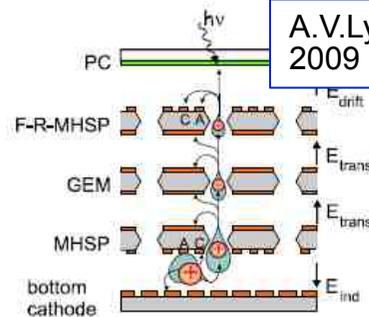
## By GEMs



Multiple GEM sealed

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

**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 ?**

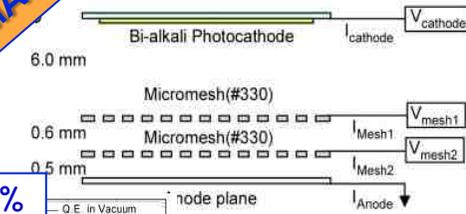
from poor QE of the bialkali PC

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

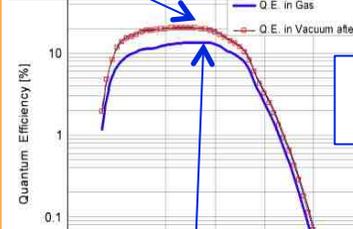
## By MMs

IBF :  $< 2.5 \times 10^{-3}$   
Gain  $< 10^4$

In collaboration with HAMAMATSU

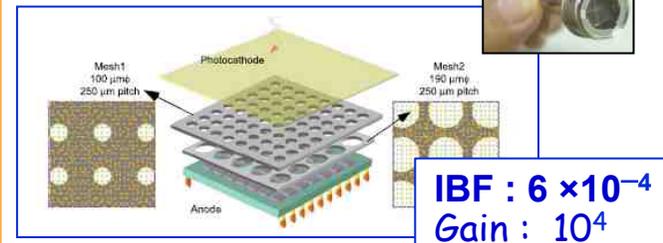


Vacuum, 20%



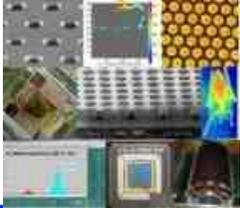
F. Tokanai et al., NIMA 610 (2009) 164

Ar (90%)+CH<sub>4</sub> (10%)  
12% (stable) after 1.5 y



IBF :  $6 \times 10^{-4}$   
Gain :  $10^4$

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



NOT ONLY  
TRACKING:

TPC READ-OUT

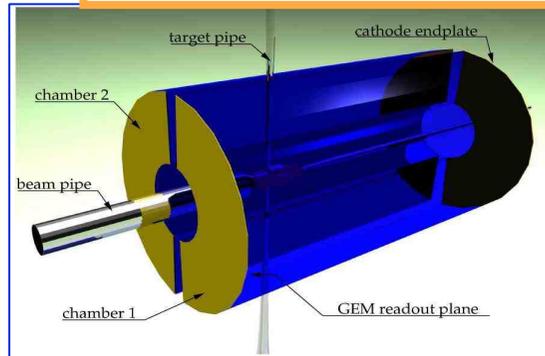
# MPGDs & TPC read-out

The path  
(gas TPC only)

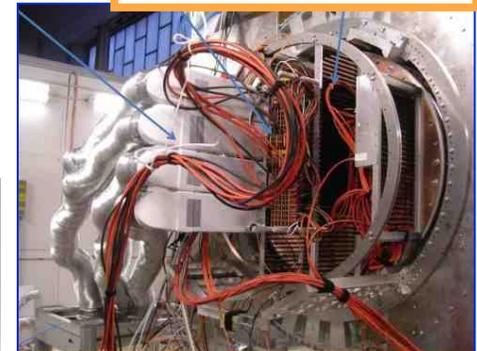
T2K : TPC  
MM read-out  
In operation  
@ very low rate



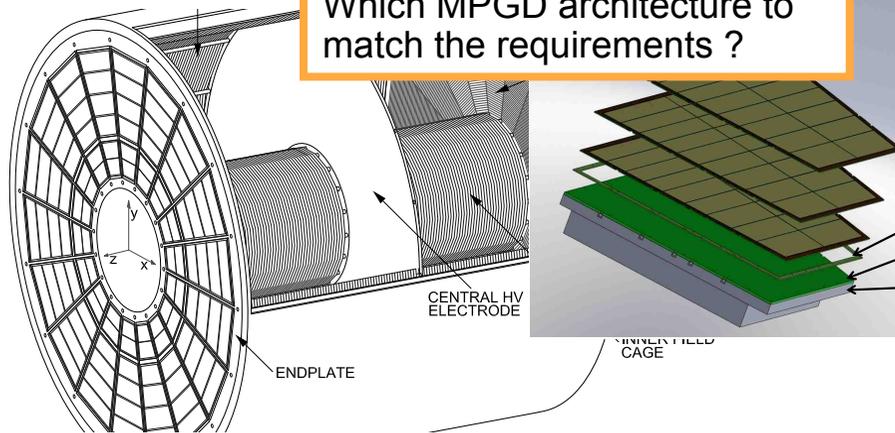
PANDA TPC with GEM R-O  
→ prototype used at FoPi



ILC TPC  
GEM vs MM  
approach



ALICE TPC  
Which MPGD architecture to  
match the requirements ?



# AGAIN IBF PRESCRIPTIONS

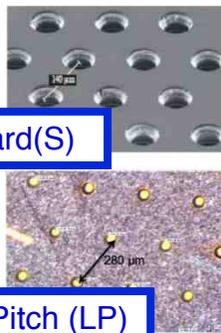
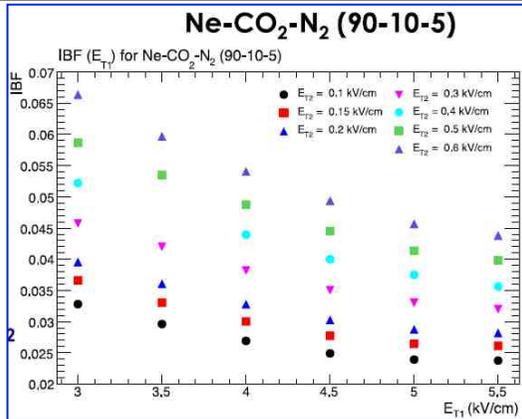
IBF modifies the electric field in front of the detector  
 → Distorted information (in particular at high rates)

- Requirements for ALICE TPC:
  - IBF < 1% at Gain = 2000 →  $\epsilon$  (=IBF × G) = 20
- MPGDs considered:

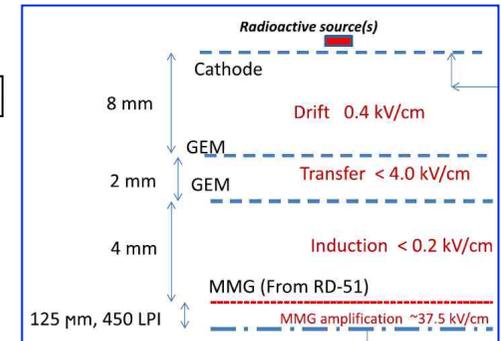
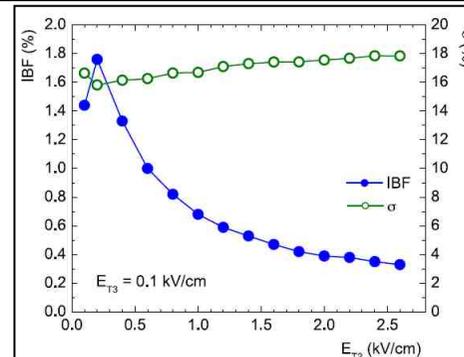
- use 4 layers alternating standard(S) and Large Pitch (LP) GEMs
- playing with all the parameters: gas, transfer fields,  $\Delta V_i$

Hybrid:  
 • 2 GEM + 1 MM

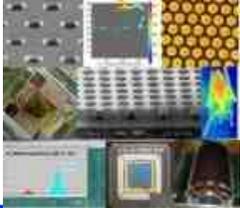
IBF ≈ 2.5 % with 3-GEM in Ne-CO<sub>2</sub>-N<sub>2</sub>



Baseline solution with S-LP-LP-S



IBF < 0.2 % using 3 component gas mixtures



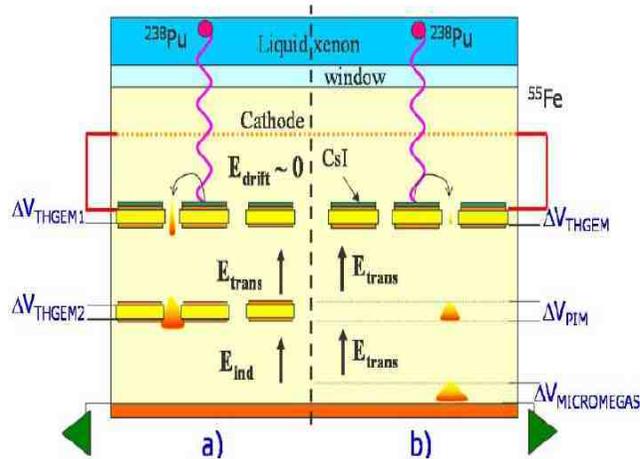
NOT ONLY  
TRACKING:

Cryogenic detectors  
and electroluminescence

# CRYOGENIC MPGD-PDs

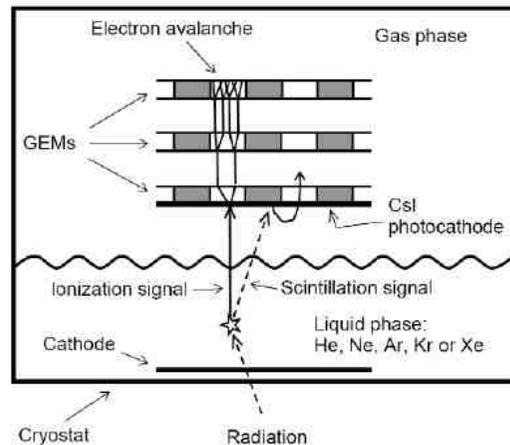
- **Read-out elements of cryogenic noble liquid detectors**
  - Rear event detectors ( $\nu$ , DM)
  - Detecting the scintillation light produced in the noble liquids
  - Options of scintillator light and ionization charge detection by a same detector !

## with WINDOW



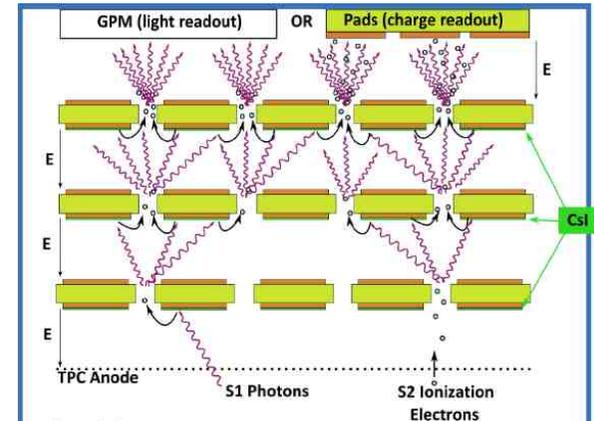
S. Duval et al., JINST 6 (2011) P04007

## WINDOWLESS (2-PHASES)



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

## OPERATED IN THE CRYOGENIC LIQUID

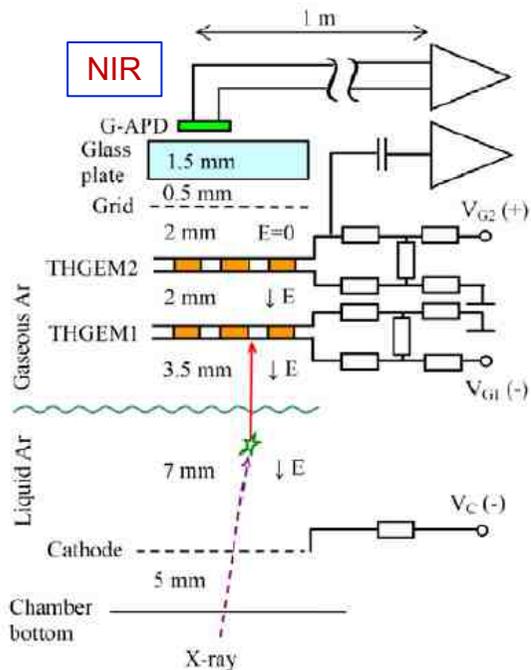


L. Arazi et al., JINST 8 (2013) C12004

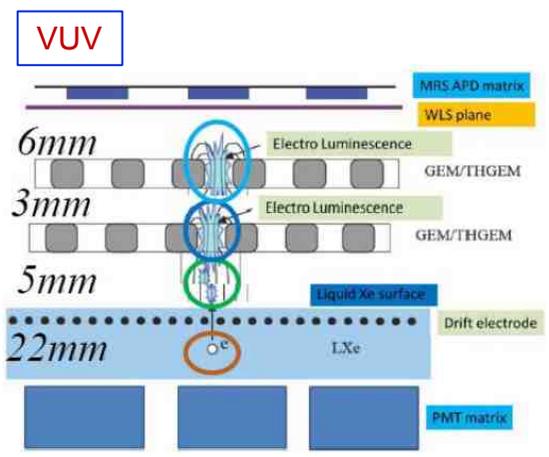
# ELECTROLUMINESCENCE

MPGDs are source (and detection) of electroluminescence

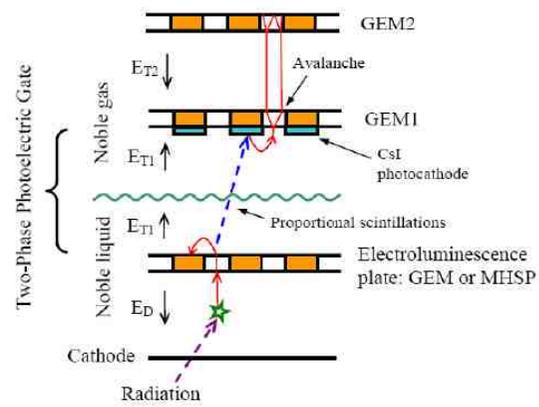
- Fast, no ion distortion



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



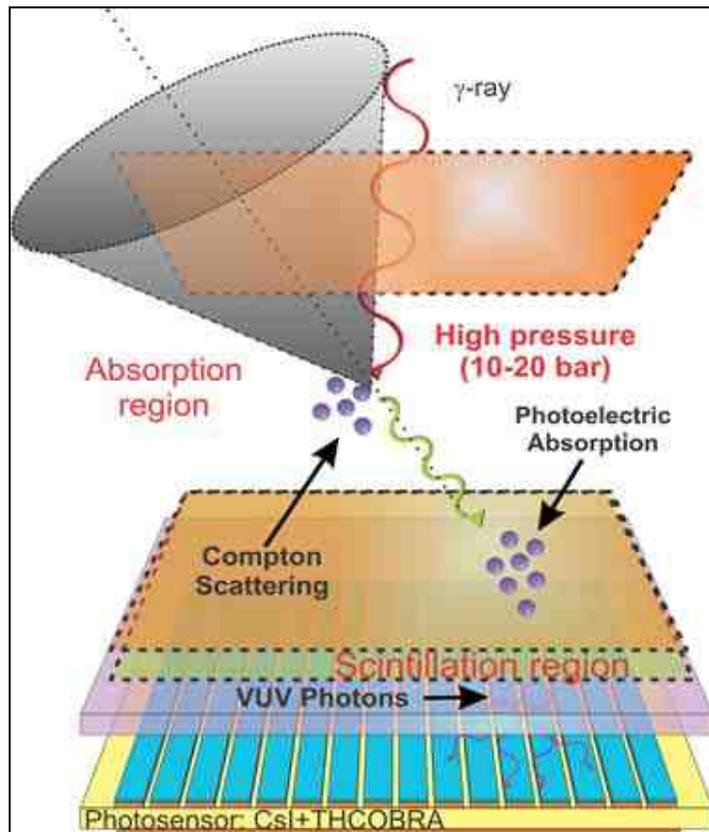
A. Akimov et al., NDIP2011



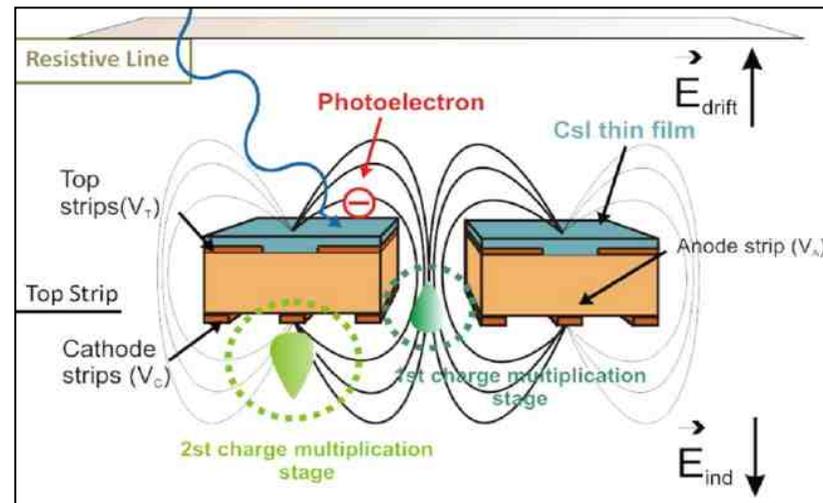
A. Buzulutskov et al.,  
JINST 1(2006) P08006

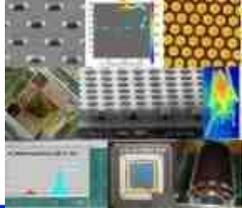
# ELETROLUMINESCENCE, more

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



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





# ENLARGING THE APPLICATION DOMAIN

(only a very limited number of examples)

# APPLICATION EXAMPLES

## MPGD-based X-ray detectors

- Sealed triple GEM for X-ray detection
- GEM-TPC X-ray Polarimeter (GEMS, XACT)
- diagnostic of Magnetic fusion plasmas

## MPGD-based neutron detectors

- GEMs coupled to n-converters for
  - ITER
  - n-beam diagnostic

F. Garcia,  
MPGD2013

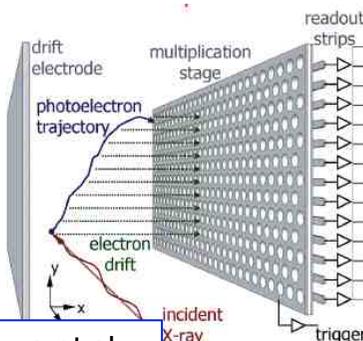


GEM-based Super FRS @  
FAIR (GEM)

P.Convert et al., Physica  
B 276-278 (2000) 93.



D20 diffractometer @ILL, MSGD



T. Tamagawa et al.,  
MPGD2013

GEMS-GEM TPC, NASA mission

F.Murtas,  
MPGD2013

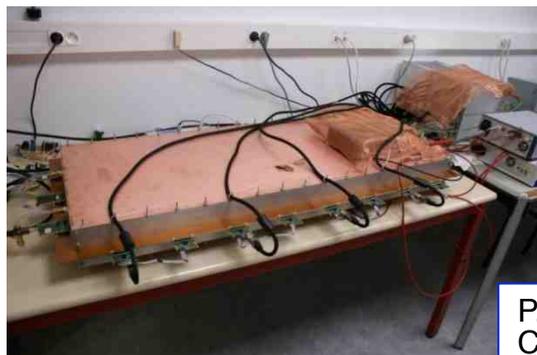


Neutron GEM (@ ISIS)

# APPLICATION EXAMPLES

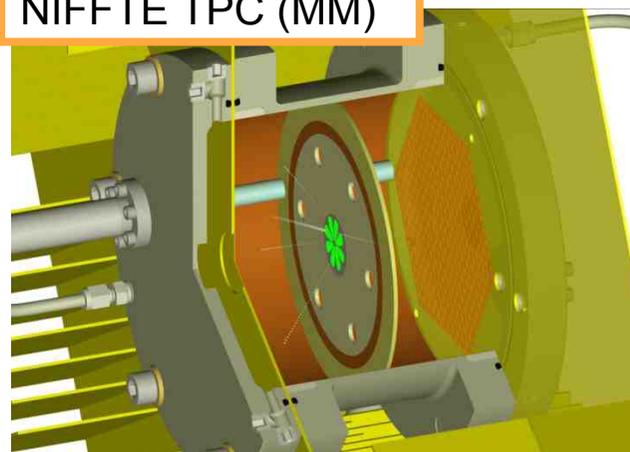
- **Nuclei studies**
  - Tracking of low energy nuclei by secondary electron detection (Spiral2, GANIL)
  - PID of exotic nuclei fragments (NIFFTE)
- **Muon radiography with MPGDs**
  - Homeland security (THGEM)
  - Geological studies (MM TPC)

2 layer MM TPC for geological studies



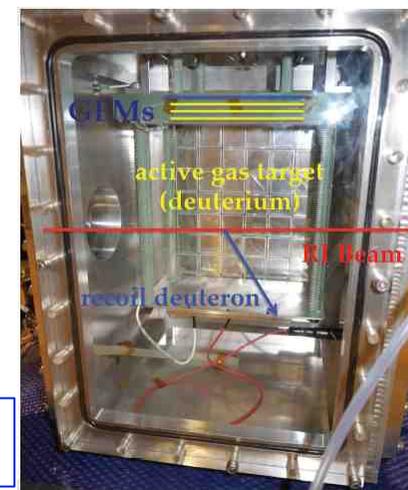
P.Salim @ RD51  
Col.. Meeting, Feb. 2013

NIFFTE TPC (MM)

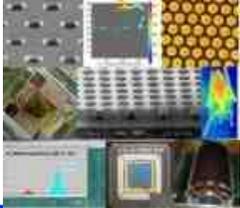


J. Ruz et al., JINST 8 (2013) C12018

NSC active Target:  
deuteron inelastic scattering off exotic nuclei (THGEM)



C.S.Lee,  
@ MPGD2013



# RD51

# RD51: A MPGD-DEDICATED COLLABORATION

## 2009-2013 – first term, 2014-2018 second term ongoing

“The proposed R&D collaboration, RD51, aims at facilitating the development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research.” (RD51 proposal, 28/7/ 2008)

## fundamental boost in MPGD filed progress since 2009

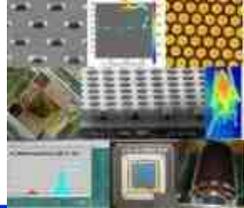
### RD51 contributions to MPGD progress:

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

L. Ropelewski, M. Titov, 114<sup>th</sup> LHCC Meeting, CERN, 12-13 June 2013

- Offering fundamental tools to the community
  - SIMULATION tools, including **GARFIELD** maintenance and continuous upgrade
  - **SRS** - Scalable Redout System Common Hardw. & softw. interfacing different FE, cheap (~ 2 CHF/ch w/o FE)
  - **Common TEST infrastructures**
    - RD51-GDD lab @ CERN
    - Common test beam @ CERN SPS
  - **@ CERN a reference workshop → New lab @ CERN (bld 107)**





# CONCLUSIONS

# CONCLUSIONS

- **Extremely wide on going activity**
  - R&D
  - Application in experiment
  - Technological transfer
- **Relevant potentialities demonstrated**
  - Performance
  - Large systems
  - Application beyond science

**Simplified construction  
&  
Industrialization**  
(see R. de Olivera's talk)