Thick GEM: a fast growing MPGD technology

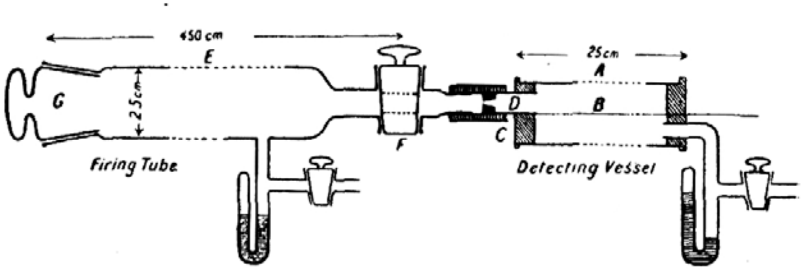
Fulvio Tessarotto (INFN – Trieste)

THGEMs

- Gaseous detectors and MPGDs
  - GEMs
    - THGEMs
      - THGEM characterization
      - Different materials, architectures and applications
    - THGEM-based Photon Detectors
  - Large cryogenic application projects
- First step toward large area coverage: COMPASS RICH-1 hybrid PDs

Glorious tradition: 100 years of gaseous detector developments

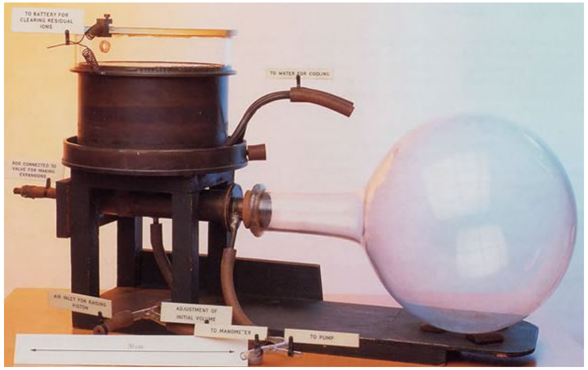
1908: FIRST WIRE COUNTER
USED BY RUTHERFORD IN THE STUDY OF NATURAL RADIOACTIVITY

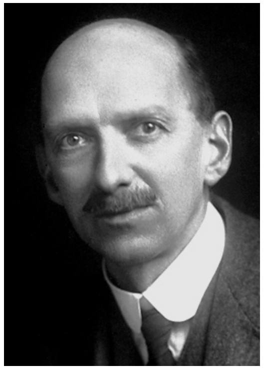


E. Rutherford and H. Geiger ,
Proc. Royal Soc. A81 (1908) 141

Nobel Prize in Chemistry in 1908

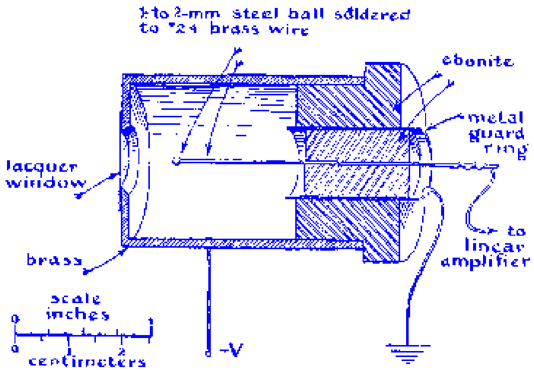
1911: CLOUD CHAMBER



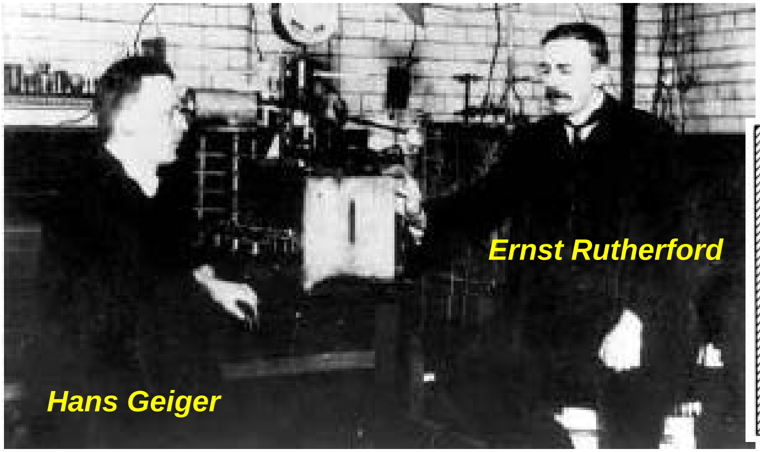


Charles T.R. Wilson
Nobel Prize in 1927

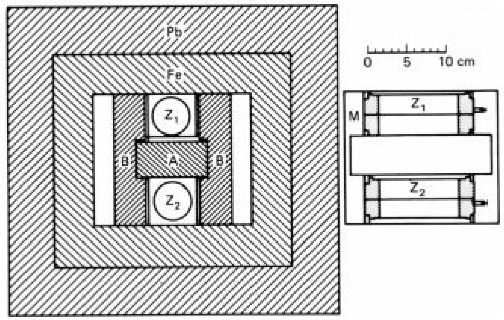
1928: GEIGER COUNTER
SINGLE ELECTRON SENSITIVITY

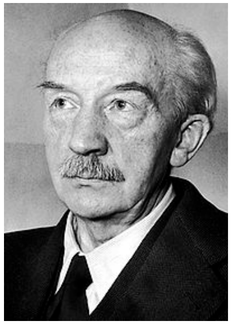


H. Geiger and W. Müller,
Phys. Zeits. 29 (1928) 839



COINCIDENCE METHOD

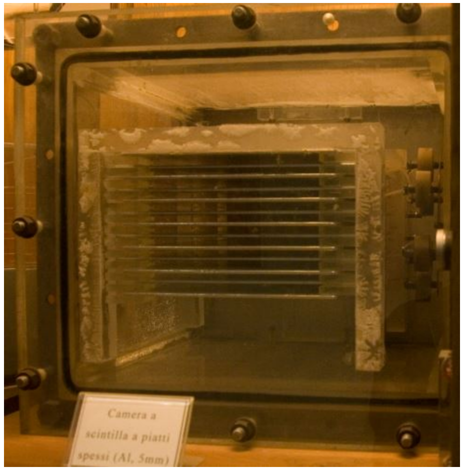




Walther Bothe
Nobel Prize in 1954

From Spark Chambers to MWPCs

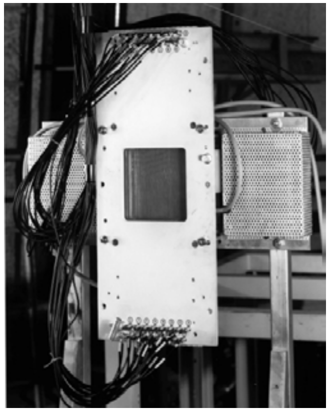
SPARK CHAMBER

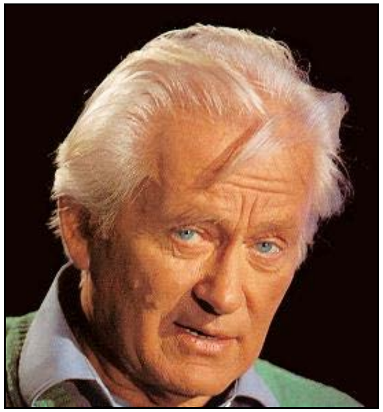


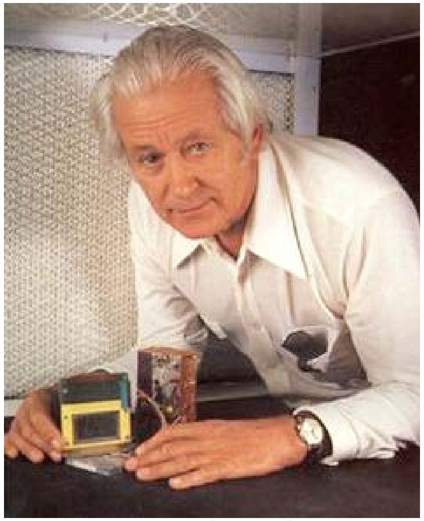
1952: BUBBLE CHAMBER

Donald A. Glaser
Nobel Prize in 1992

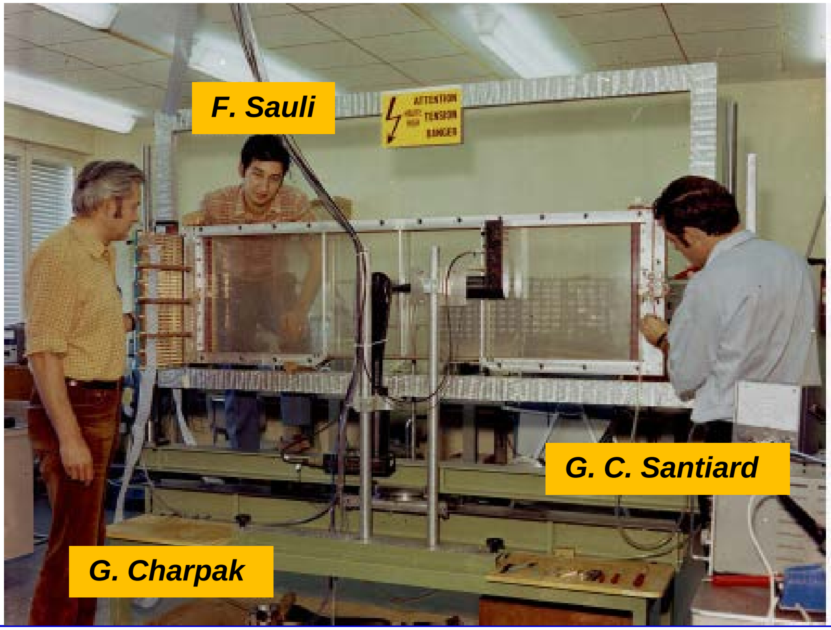
1968: MULTIWIRE PROPORTIONAL CHAMBER



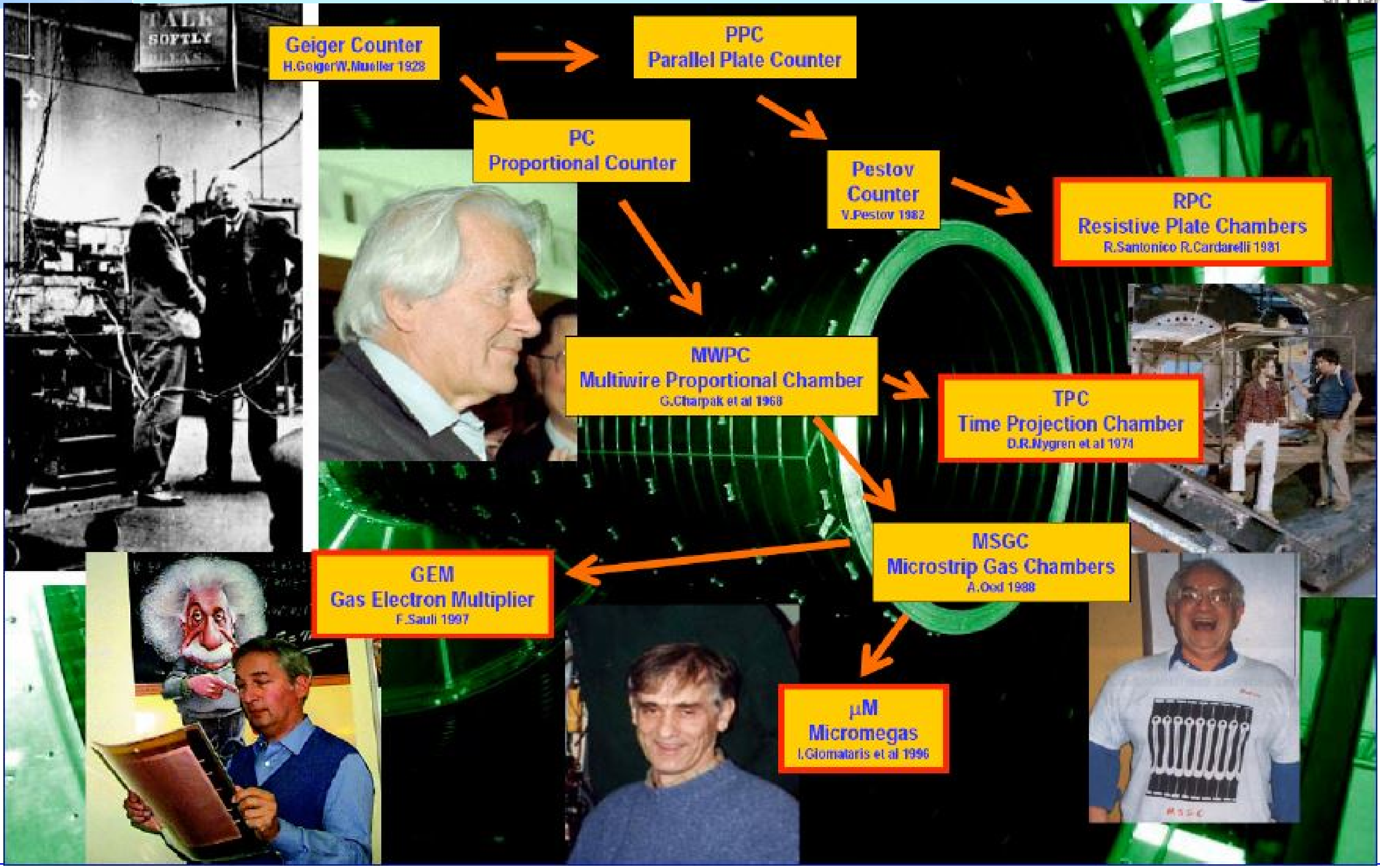




George Charpak
Nobel Prize in 1992



To Micro Pattern Gas Chambers



Geiger Counter
H.GeigerW.Mueller 1928

PPC
Parallel Plate Counter

PC
Proportional Counter

Pestov Counter
V.Pestov 1982

RPC
Resistive Plate Chambers
R.Santonico R.Cardarelli 1981

MWPC
Multiwire Proportional Chamber
G.Charpak et al 1968

TPC
Time Projection Chamber
D.R.Nygren et al 1974

MSGC
Microstrip Gas Chambers
A.Oed 1988

GEM
Gas Electron Multiplier
F.Sauli 1997

μM
Micromegas
I.Giomataris et al 1996

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 development of advanced gas-avalanche detector technologies and associated electronic-readout systems, for applications in basic and applied research."

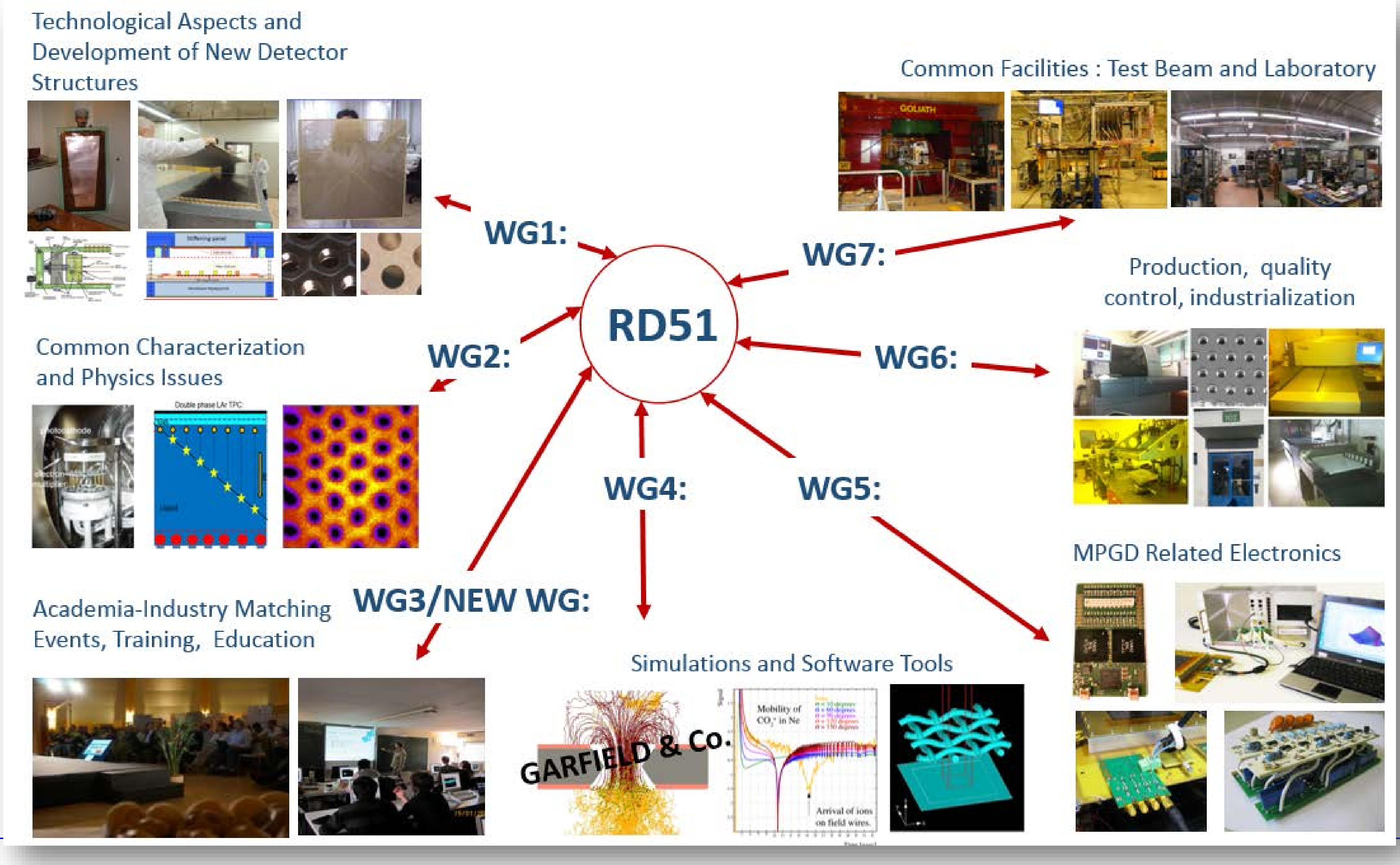
RD51 serves as an access point to MPGD "know-how" for the world-wide community

Unique in providing:

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

~ 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

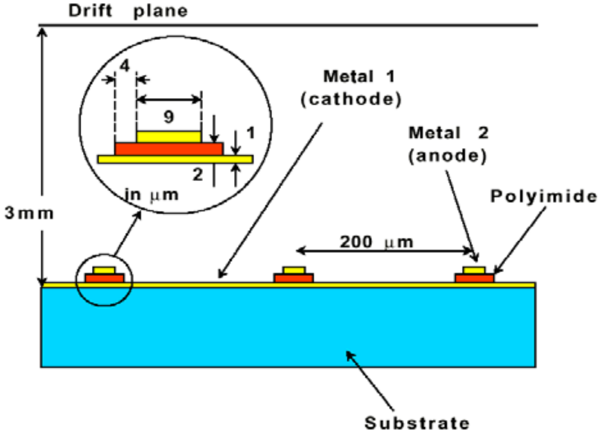
WG5: MPGD Related Electronics

WG6: Production, quality control, industrialization

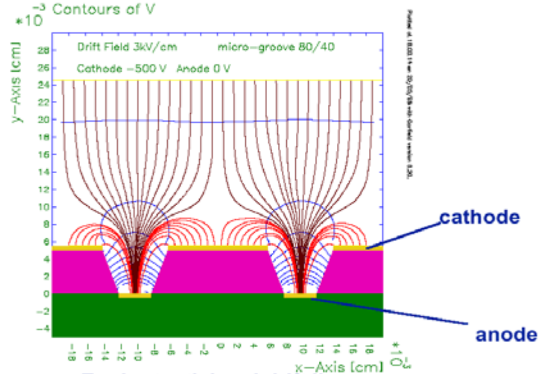
WG7: Common Facilities : Test Beam and Laboratory

Many different MPGDs have been developed

MICRO-GAP CHAMBER

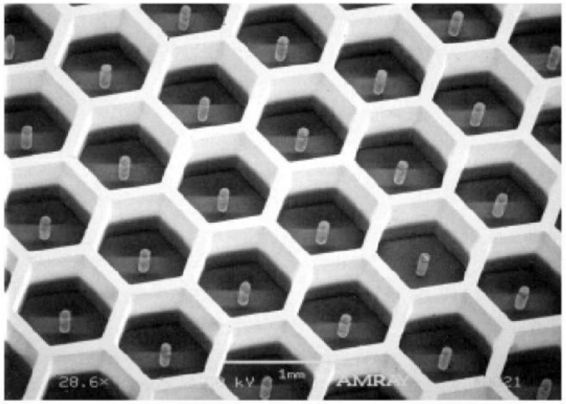


MICRO-GROOVE CHAMBER

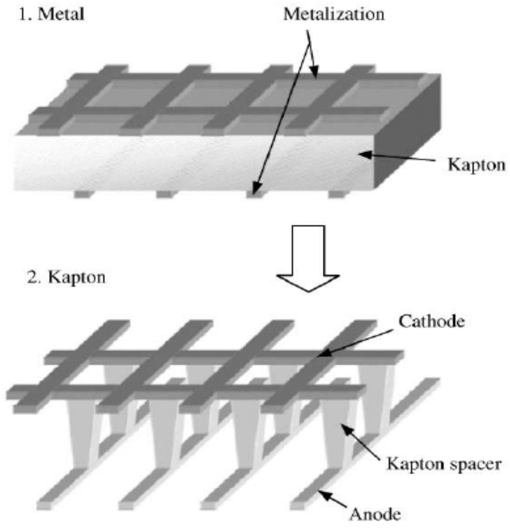


Equipotential and drift lines
(with zero diffusion)

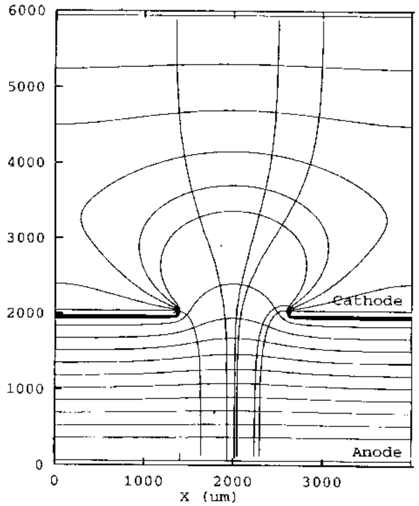
MICRO-PIN ARRAY



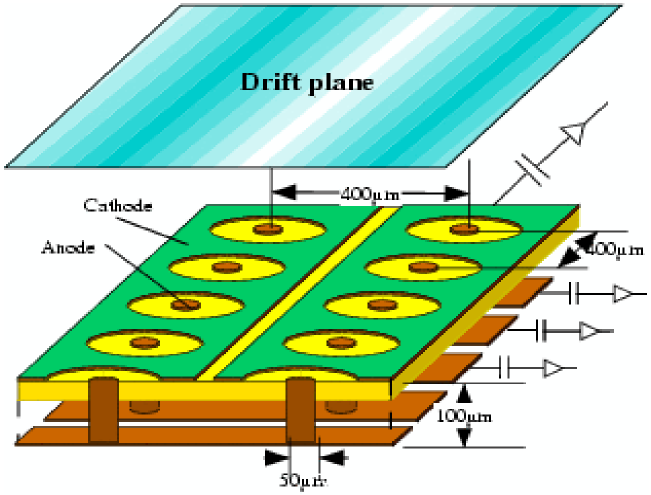
MICRO-WIRE CHAMBER



COMPTEUR A TROUS



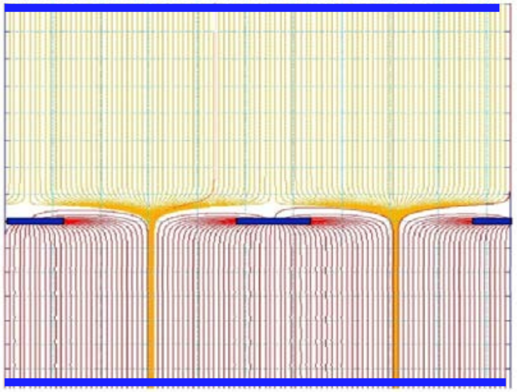
MICRO-PIXEL CHAMBER

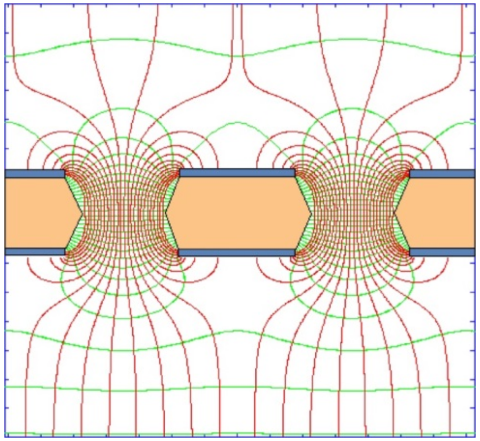


2 very solid, fully established technologies:

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





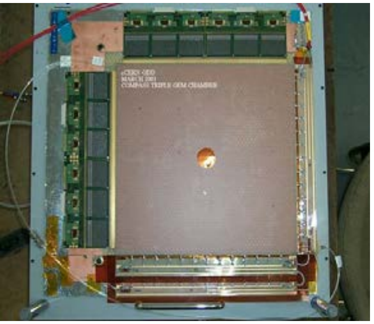
GAS ELECTRON MULTIPLIER (GEM)
Thin, metal-coated polymer foil with high density of holes, each hole acting as a proportional counter.

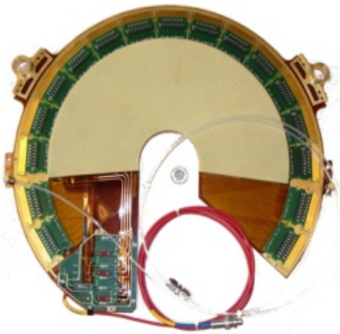
F. Sauli, Nucl. Instrum. Methods A386(1997)531

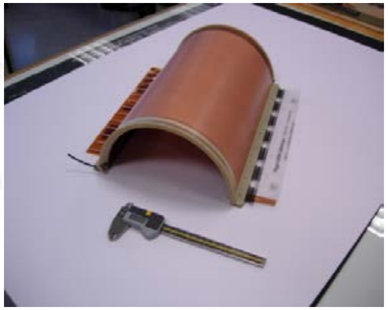
HIGHER LUMINOSITIES, HIGHER PRECISION EXPERIMENTS

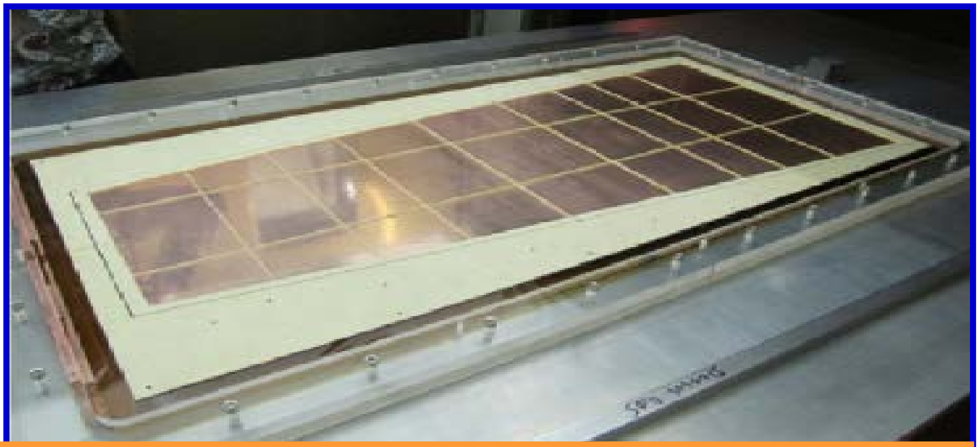
1. **MPGDs allow for**
   - **High rates (granularity & occupancy, signal formation time)**
   - **Fine space resolution**
2. **Technological maturity and accurate engineering FUNDAMENTAL for successful MPGDs**

GEMs

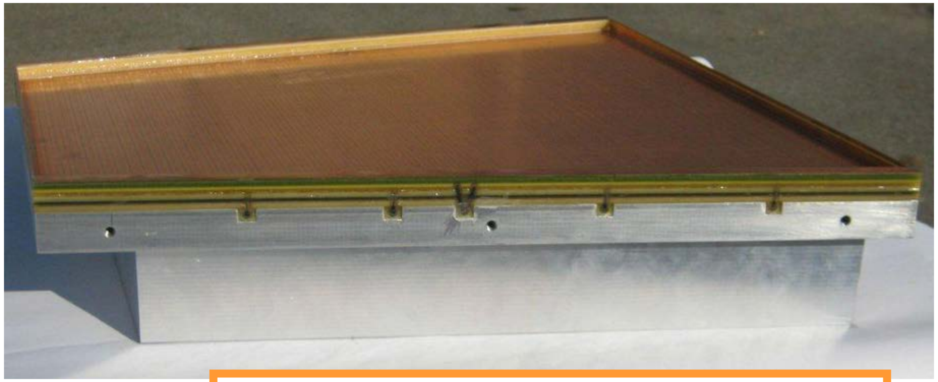








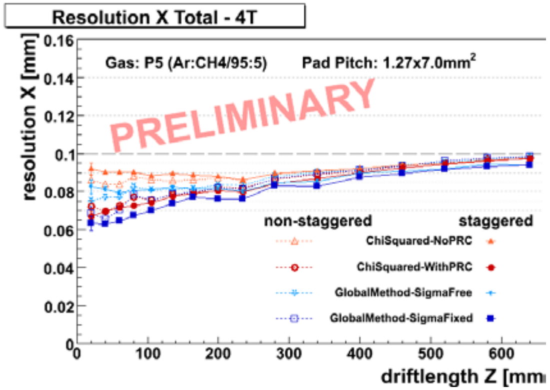
CMS UPGRADE:
1000 m² of GEM foils



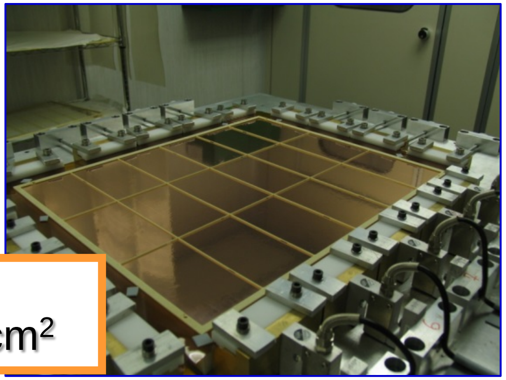
ALICE UPGRADE:
130 m² of GEM foils

other projects with GEMs

GEM ILC TPC,
T. Matsuda

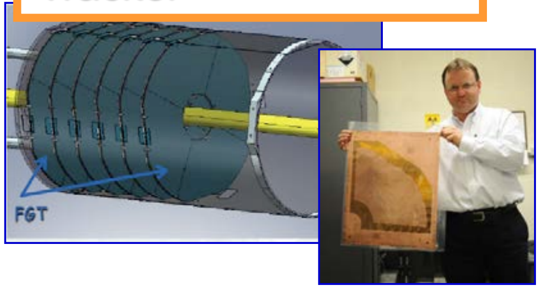


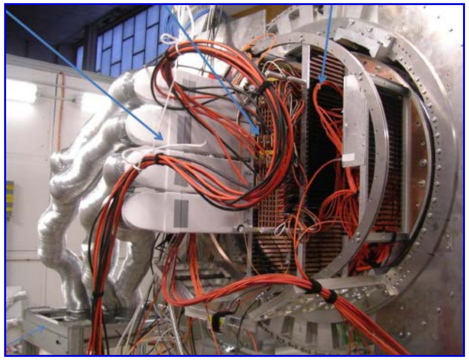
CMD3 @ BES



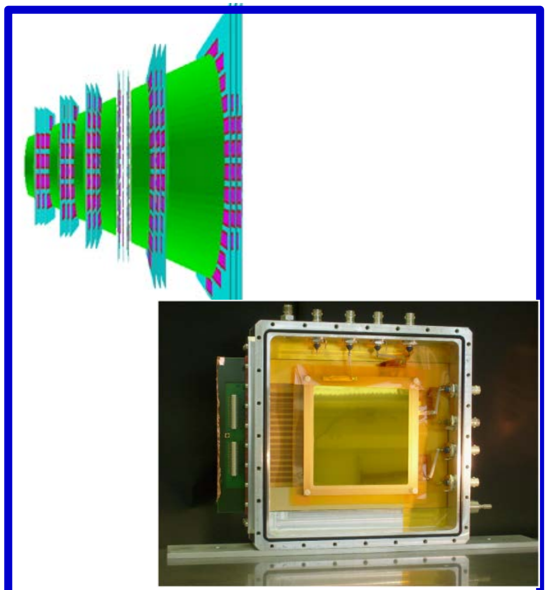
JLab Hall A
GEM 40 x 50 cm^2

STAR - Forward GEM
Tracker



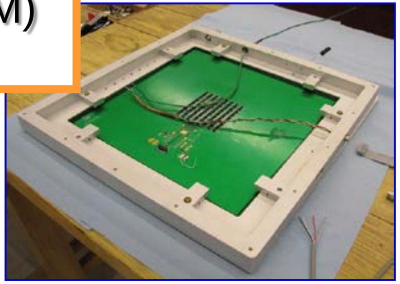


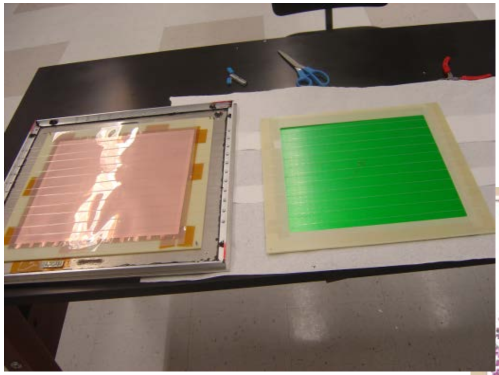
ILC TPC



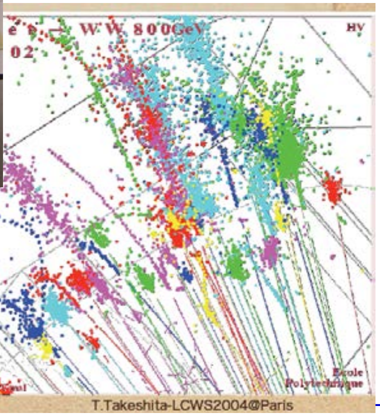
CBM: GEMs
for tracking

H calorimetry(GEM)
(ATLAS, ILC)





GEM ILC HCAL,
A. White



T.Takeshita-LCWS2004@Paris

THGEM

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)

Classical THGEMs

Standard PCB foil:

robust

mechanically self supporting

large size

industrially produced

Comparing to GEMs:

Geometrical dimensions X ~10

But e^- motion/multiplic. properties do not!

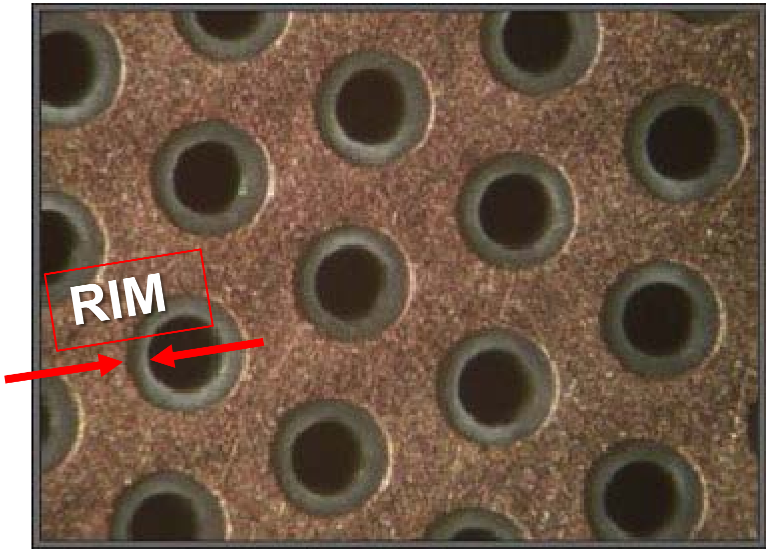
Larger holes:

dipole fields and external fields
are strongly coupled

e^- dispersion plays a minor role

About PCB geometrical dimensions:

Hole diameter : 0.2 – 1 mm
Pitch : 0.4 – 4 mm
Thickness : 0.2 – 2 mm



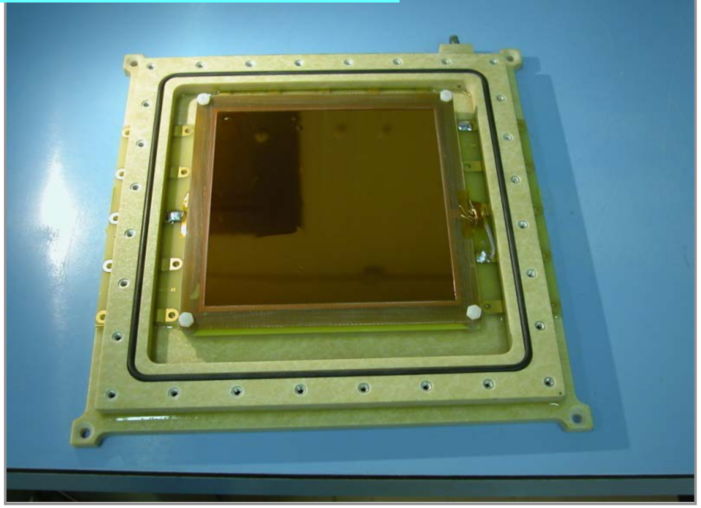
introduced in // by different groups:
L. Periale et al., NIM A478 (2002) 377.
P. Jeanneret, PhD thesis, Neuchatel U., 2001.
P.S. Barbeau et al, IEEE NS50 (2003) 1285
R. Chechik et al, .NIMA 535 (2004) 303

THGEM characterization

At Weizmann Institute, CERN, **Trieste**, Aveiro, Beijing, Nagoya, …

Full characterization as gas multiplier and photon converter substrates

Measurements, simulations, response dependence on parameters.

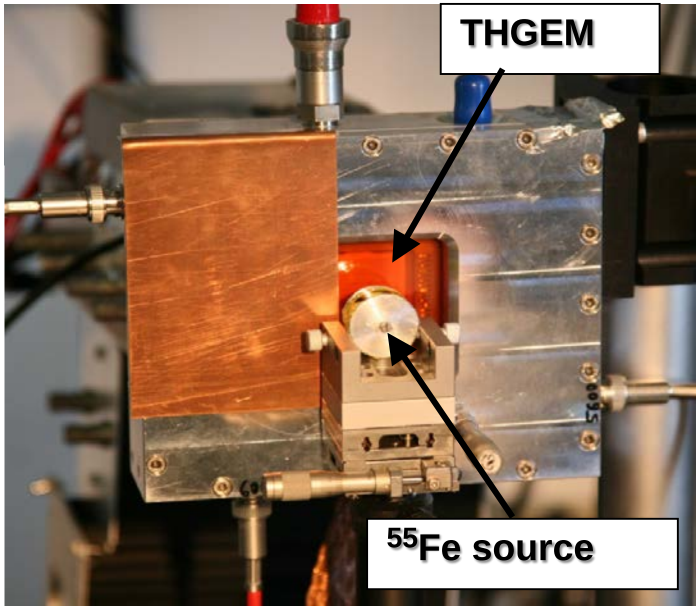


More than 50 different THGEM types have been characterized by us using X-ray:

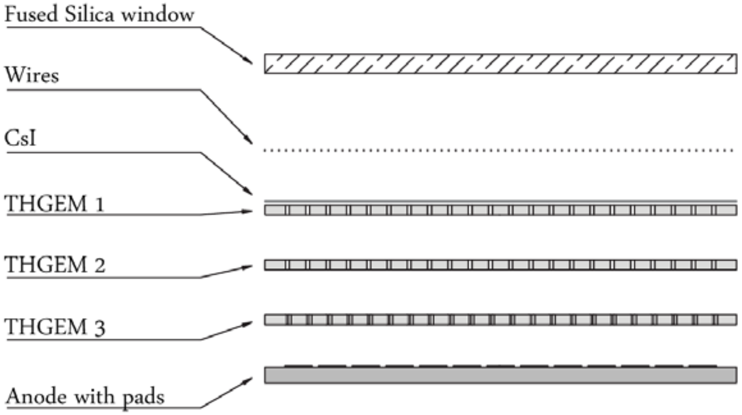
- optimized drift field (specific for each type)
- large rim → large gain but good gain stability guaranteed for small rim or no rim
- production procedure details are very important
- good rate capability

Using UV light source prototypes of small THGEM-based PD's have been built and tested:

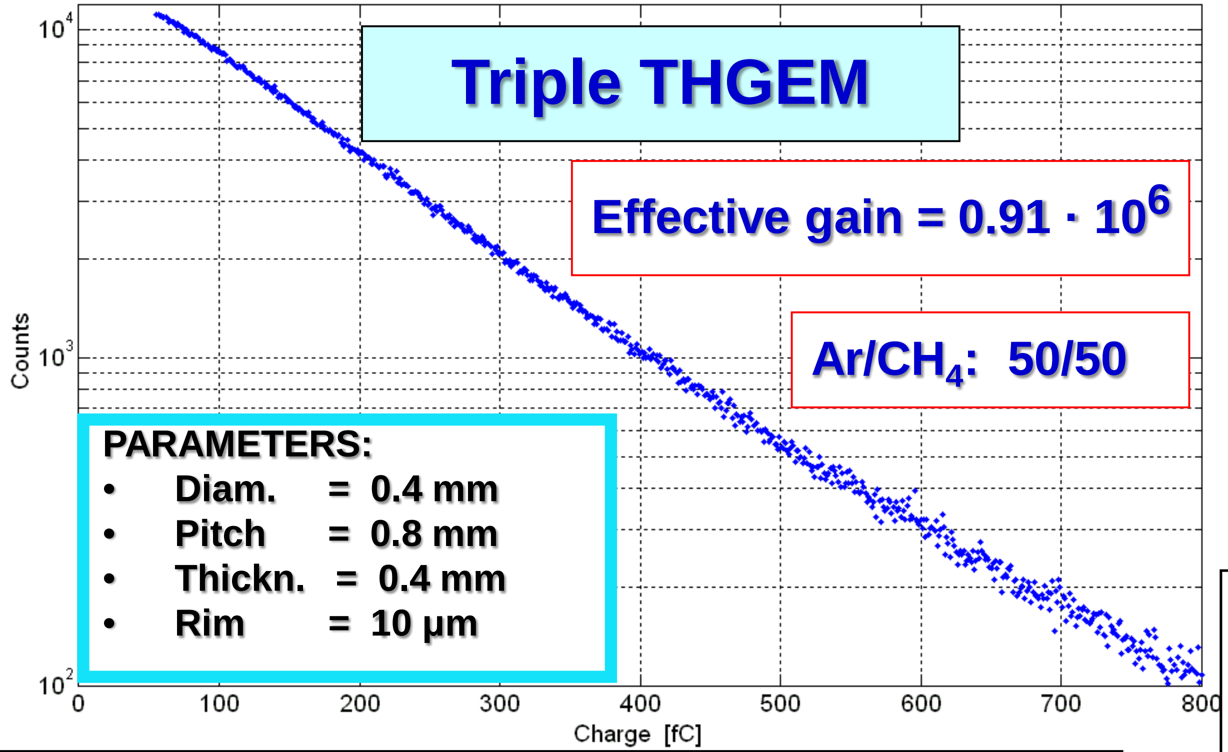
- photoelectron extraction and collection efficiency,
- timing properties of the signal (using 600 ps long light pulses)
- photoelectron detection efficiency with digital r/o



Many prototypes of small THGEM-based detectors have been built and tested



Gain ~ 1 M, time resolution ~ 8 ns



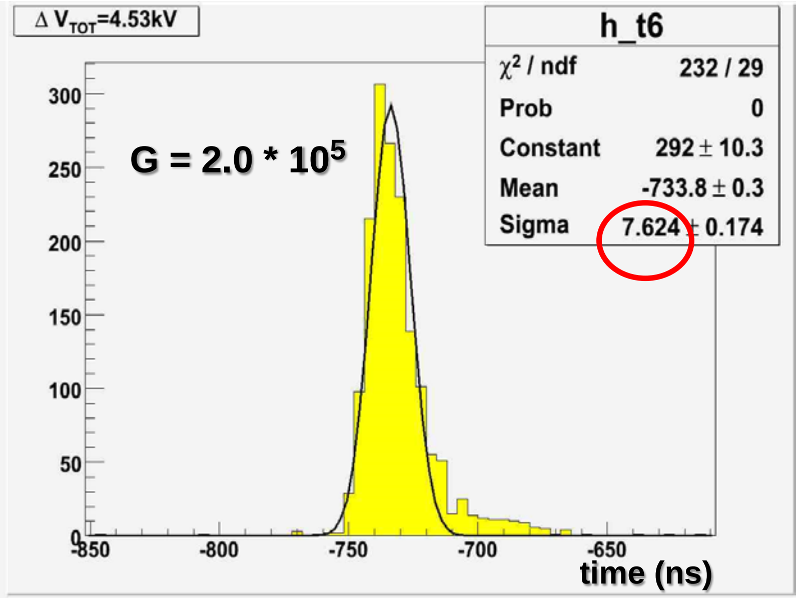
Triple THGEM

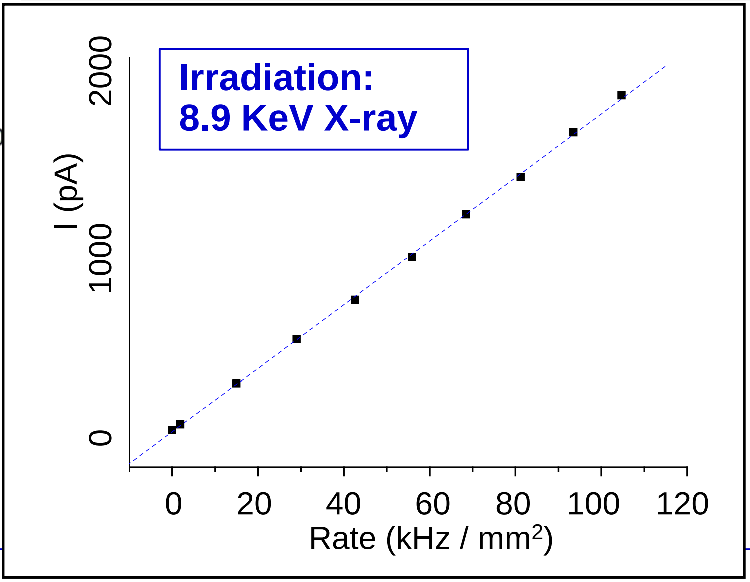
Effective gain = 0.91 · 10^6

Ar/CH$_4$: 50/50

PARAMETERS:

- **Diam. = 0.4 mm**
- **Pitch = 0.8 mm**
- **Thickn. = 0.4 mm**
- **Rim = 10 μm**





Small size PD's (active area = 30x30 mm^2):

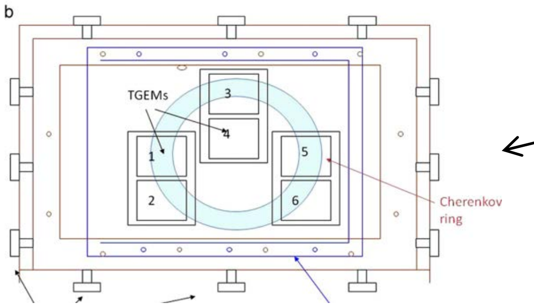
typical max. stable gain: with UV light in lab: 1 M
(during test beam: 0.2 M)

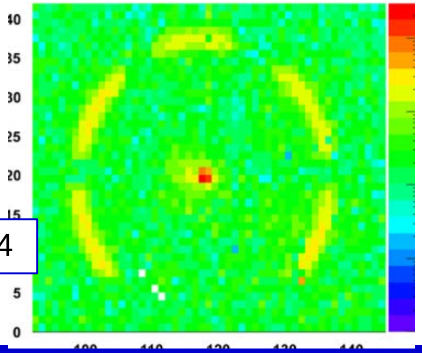
efficient detection of single photons

signal formation time ≈ 100 ns, time resolution ≈ 8 ns

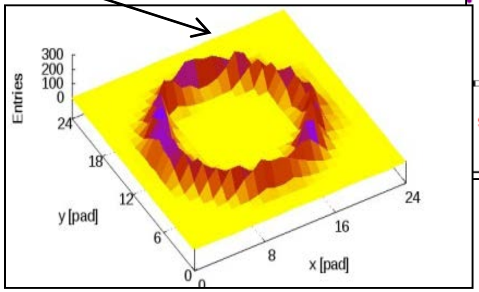
THGEM R&D for RICHes

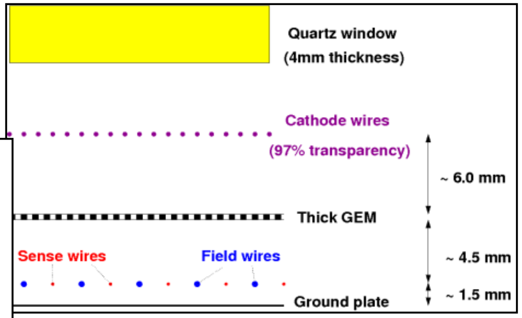
ALICE VHMPID
THGEM & HYBRID



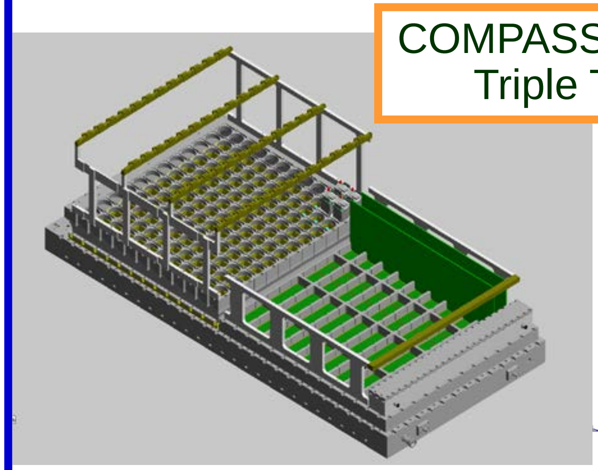


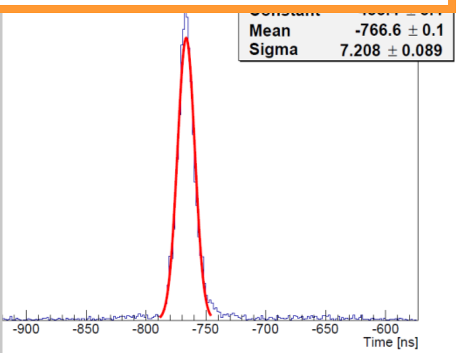
V.Peskov et al., NIMA 695 (2012) 154

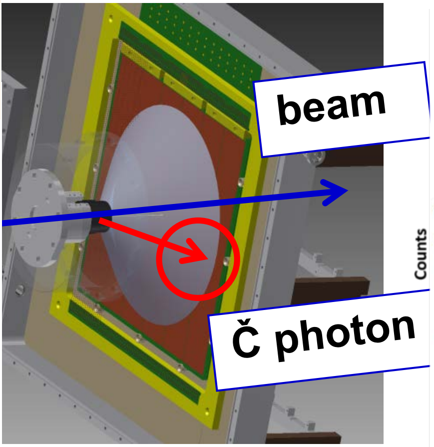




COMPASS, RICH-1 upgrade by
Triple THGEM detectors

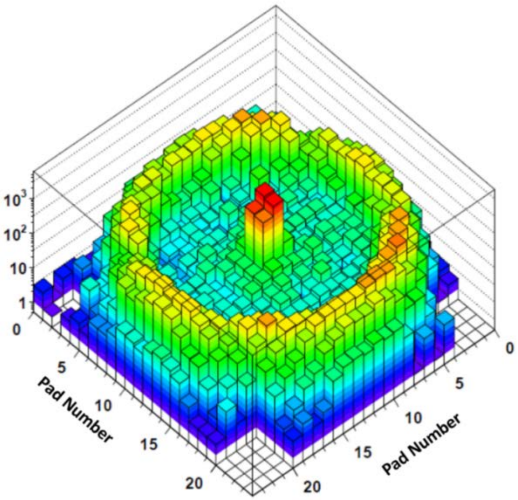




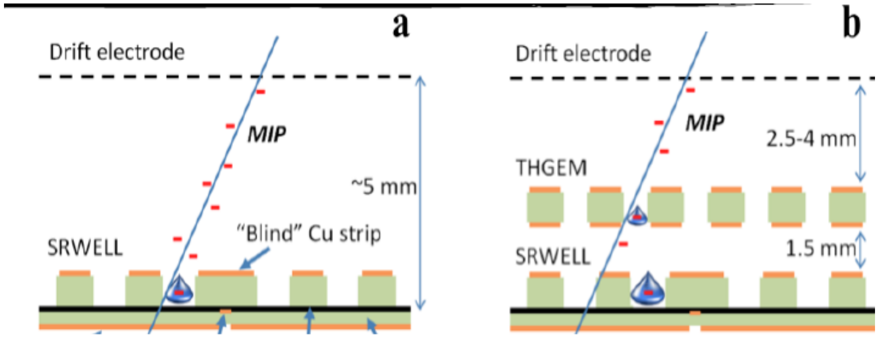


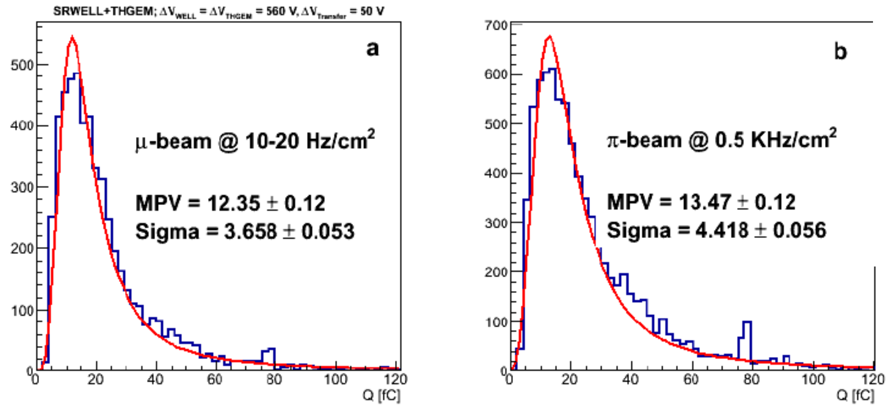
beam

Č photon



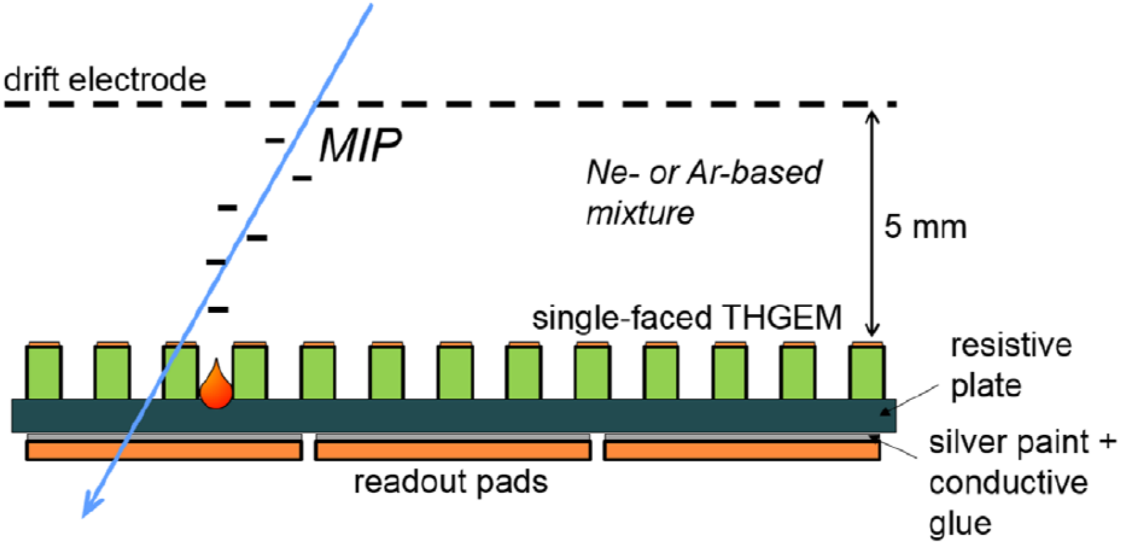
THGEM resistive WELL





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

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

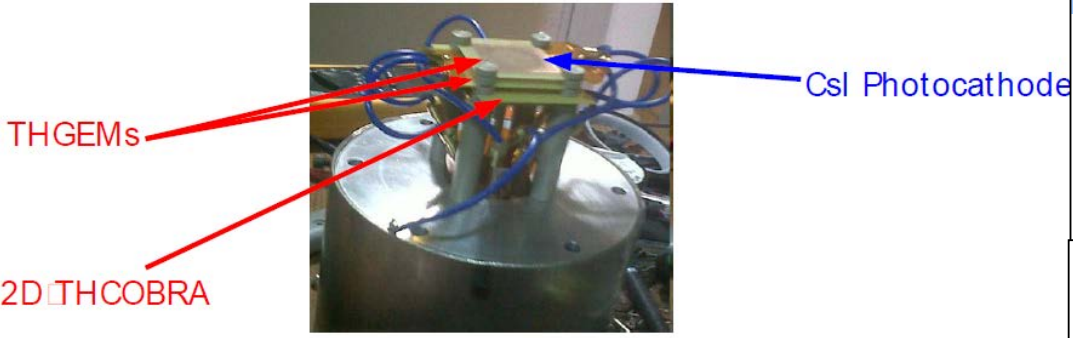


10^9 Ω cm resistive plate → discharge free operations. 99% eff. up to ~ 10^5 Hz/cm^2

proposed for digital hadron calorimetry

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

HYBRID THGEM + THCOBRA



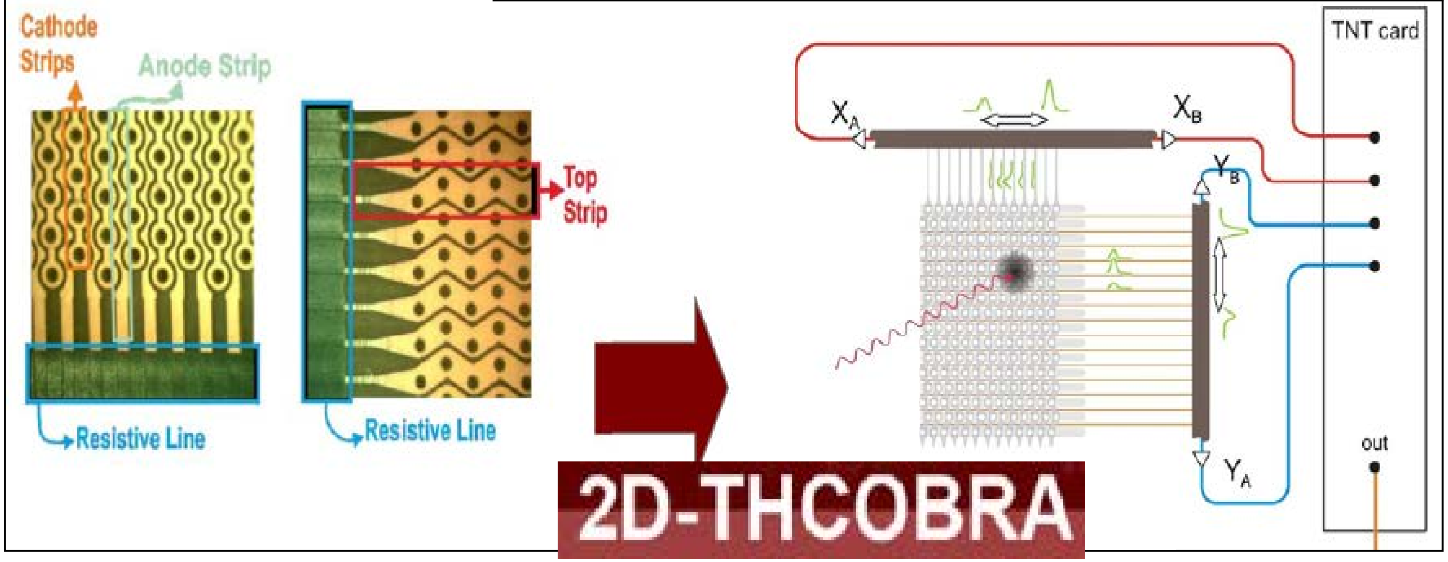
Parameters			
Structure	Hole Diameter (µm)	Pitch (µm)	RIM (µm)
THGEM 1	400	800	5
THGEM 2	700	1300	100
2D THCOBRA	400	1000	80

T. Lopes 2013 JINST 8 P09002

2 THGEMs

a THCOBRA with 2 d R-O structure

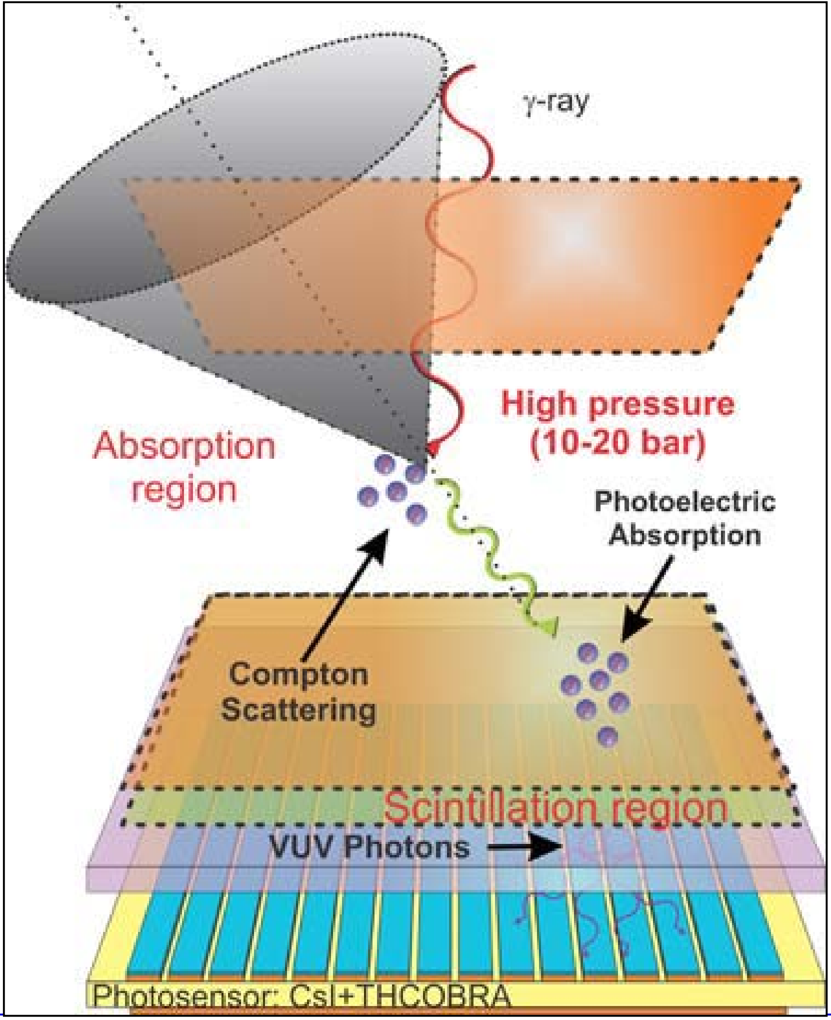
- Gas Photomultiplier (GPM) : 2D-THCOBRA
  - Good Performance
    - Gain of 10^6
    - IBF values of about: 20%
  - 2D THCOBRA adequate to obtain image
  - Position Resolution: FWHM= 300 µm, σ= 128µm
  - Count rate of 100kHz

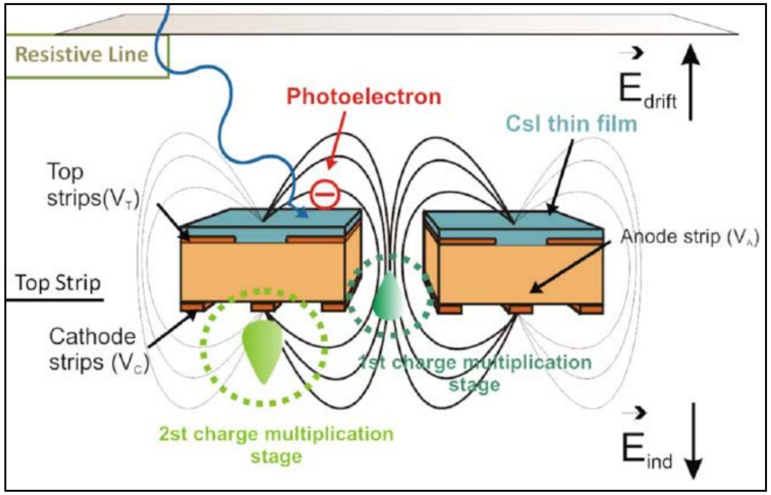


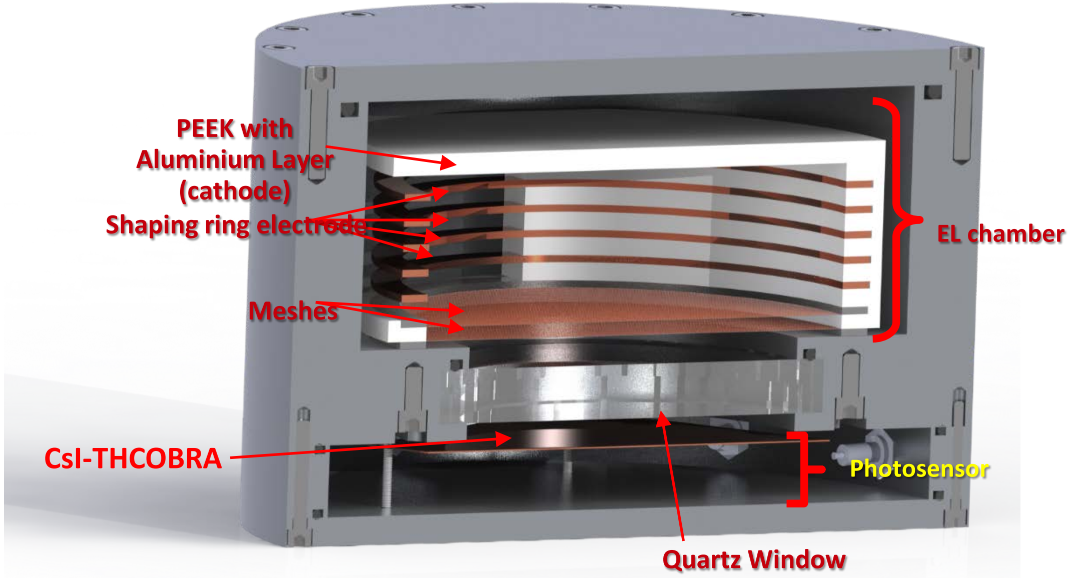
Gaseous Compton camera for medical imaging

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

Drift time provides the third coordinate







GASEOUS DETECTORS FOR VISIBLE LIGHT

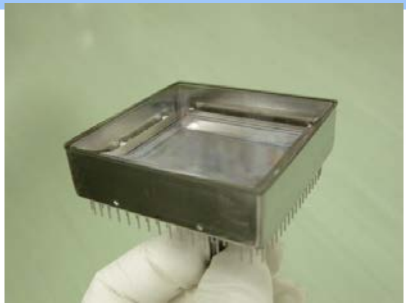
Gaseous PMT

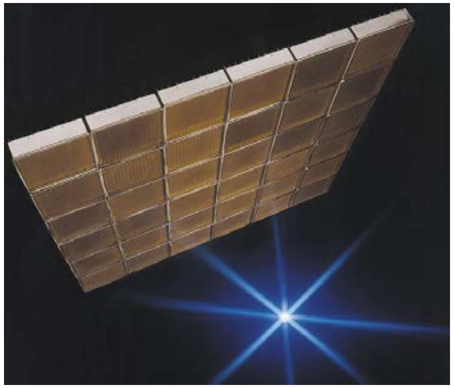
Yamagata U. TMU, HAMAMATSU

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

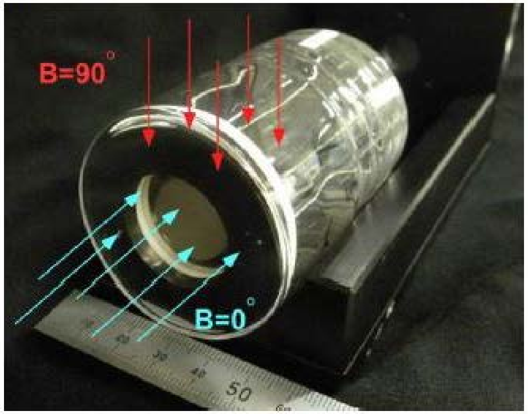

F. Sauli
Michigan University, Ann Arbor - May 23, 2002

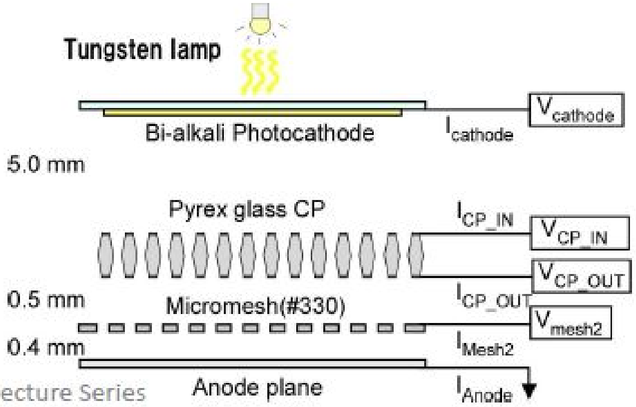
- The advantage of the **gaseous PMT**:
  - ✓It can achieve a **very large effective area** with moderate **position** and **timing** resolutions.
  - ✓It can be easily operated under a **very high magnetic field**.





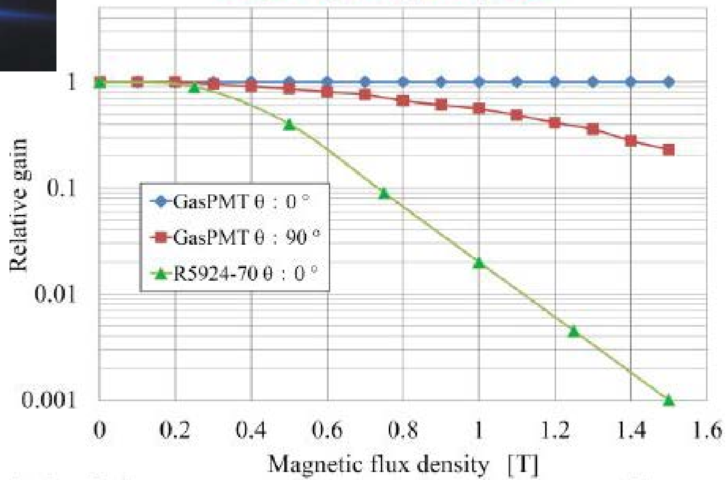
Operation in magnetic field environmen





A. Ochi, MPGD Lecture Series

Ar(90%)+CH_4(10%) 1気圧



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

Scintillating Glass-GEM imager

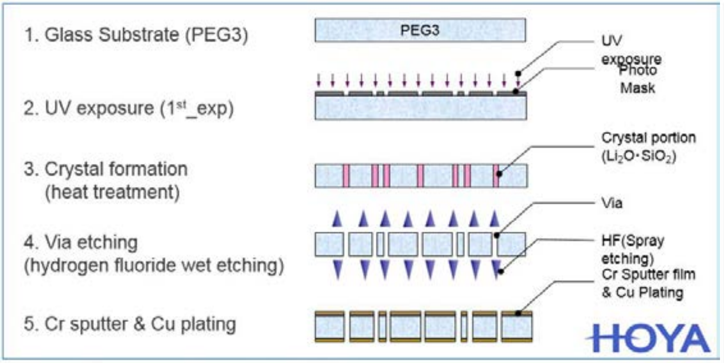
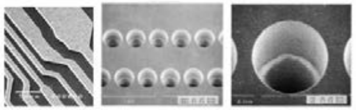
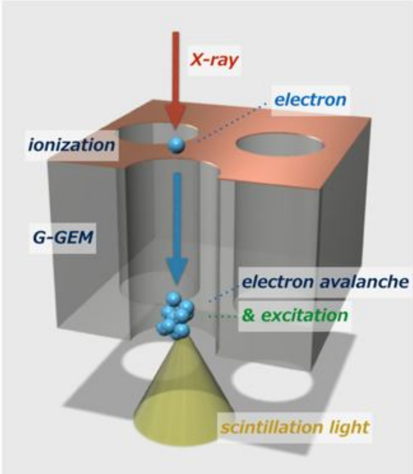
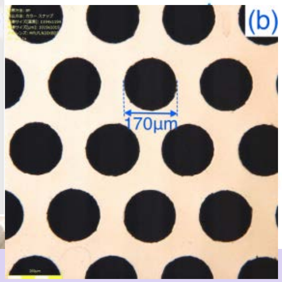


PHOTO ETCHABLE GLASS 3 : PEG3

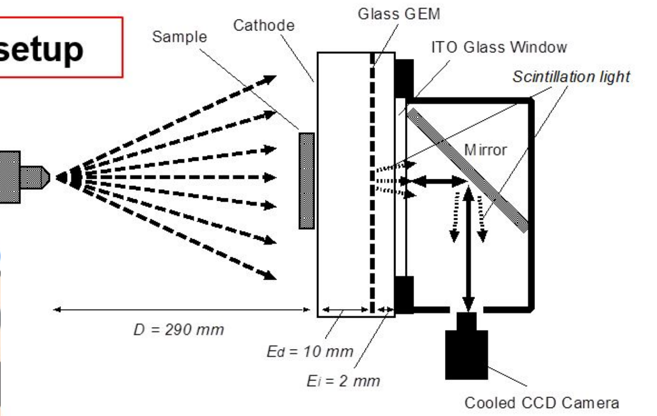
- Promising technique for precise patterning
- Able to drill high aspect hole
- 680µm deep hole (ex. CERN GEM: 50µm)





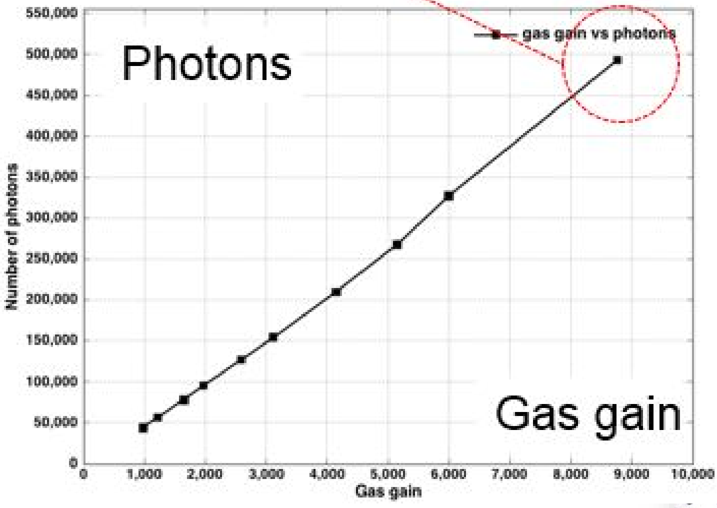


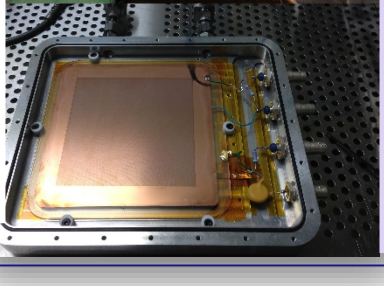
Imaging setup

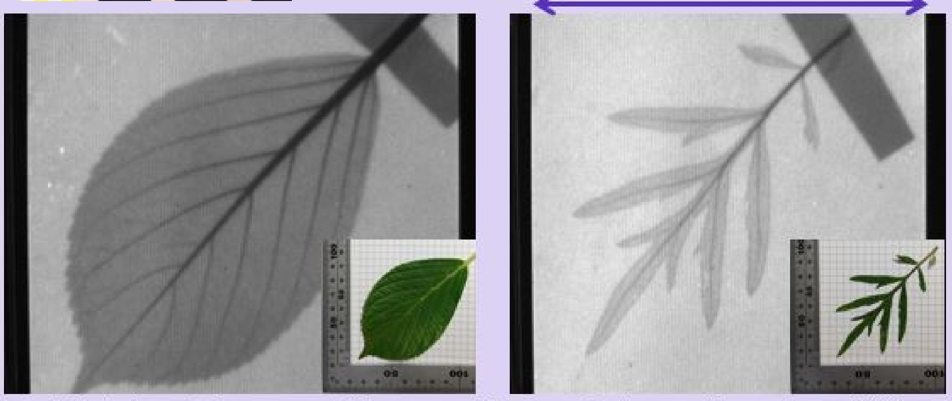


T. Fujiwara, et al., JINST 8 C12020, 2013

Max: 500,000 photons @5.9keV







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

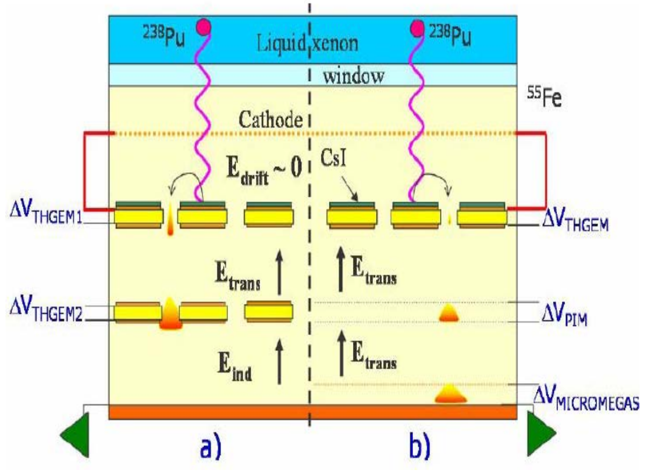
Read-out elements of cryogenic noble liquid detectors

Rear event detectors (ν, DM)

Detecting the scintillation light produced in the noble liquids

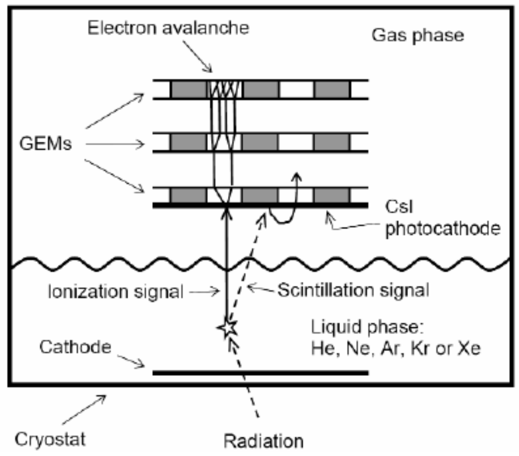
Options of scintillator light and ionization charge detection by a same detector !

with WINDOW



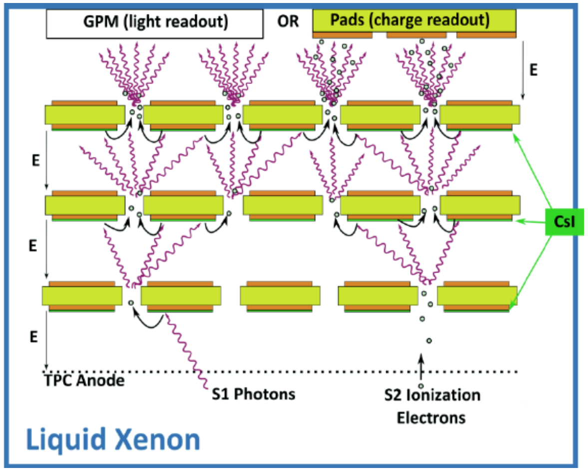
S.Duval et al., JINST 6 (2011) P04007

WINDOWLESS (2-PHASES)



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

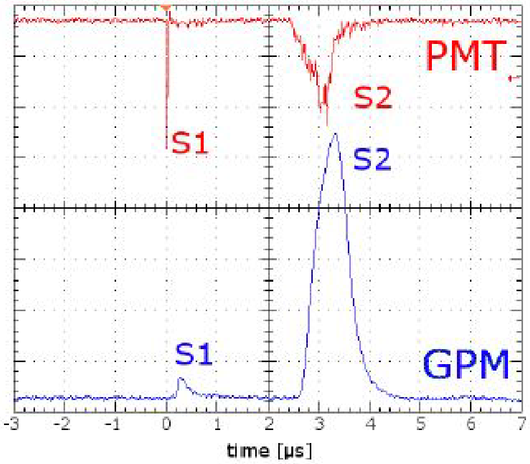
OPERATED IN THE CRYOGENIC LIQUID



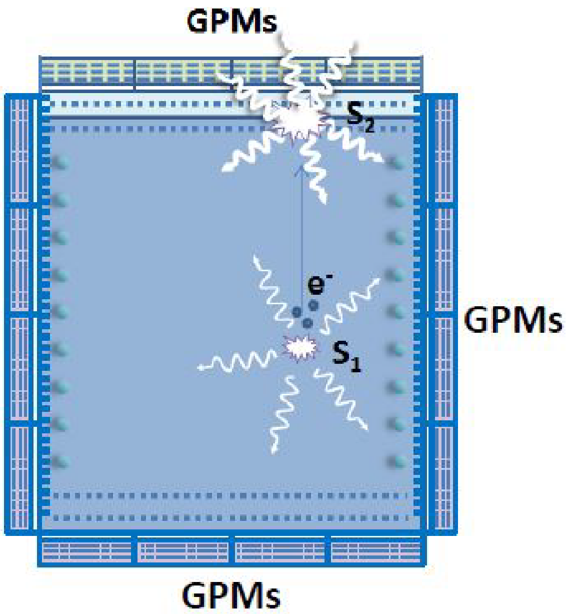
L.Arazi et al., JINST 8 (2013) C12004

Triple THGEM Gaseous Photo-Multiplier for DM

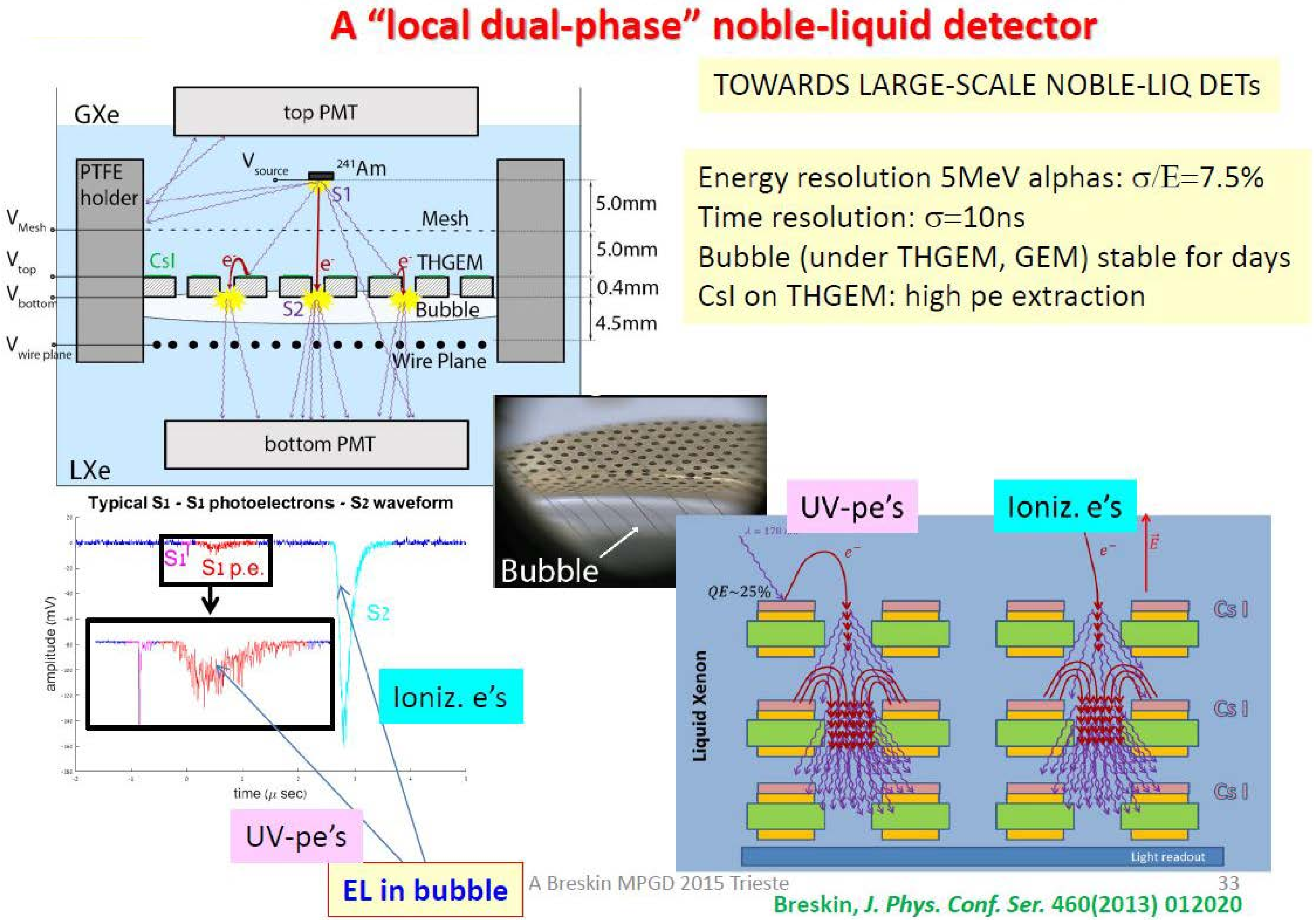
- WIS R&D on **GPMs** for future multi-ton LXe TPCs for dark matter searches (within DARWIN)
- Aim for **4π coverage** – not practical with PMTs (cost, bulkiness) or SiPMs (dark count rate)
- Successful demonstration of 4” cryogenic **triple-THGEM GPM** with reflective CsI coupled to dual phase LXe TPC: (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: $\sigma/E=7.5\%$
Time resolution: $\sigma=10ns$
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

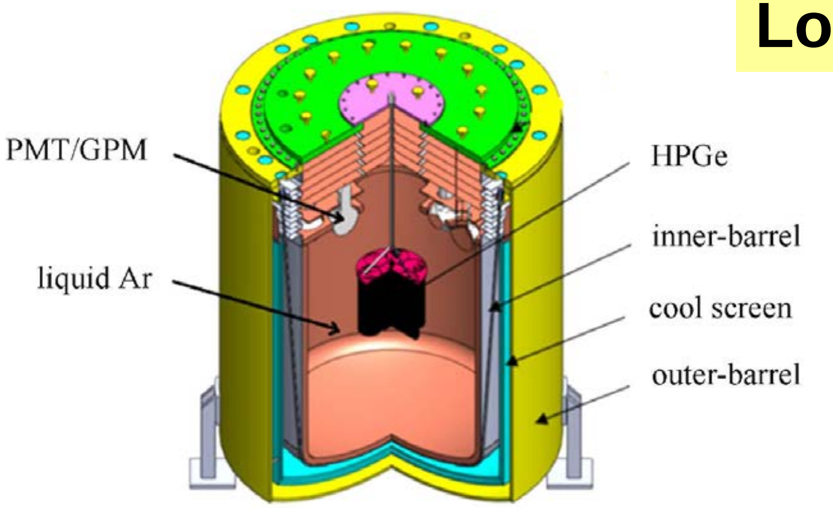


Fig. 1. Scheme design of the cryostat in CDEX.

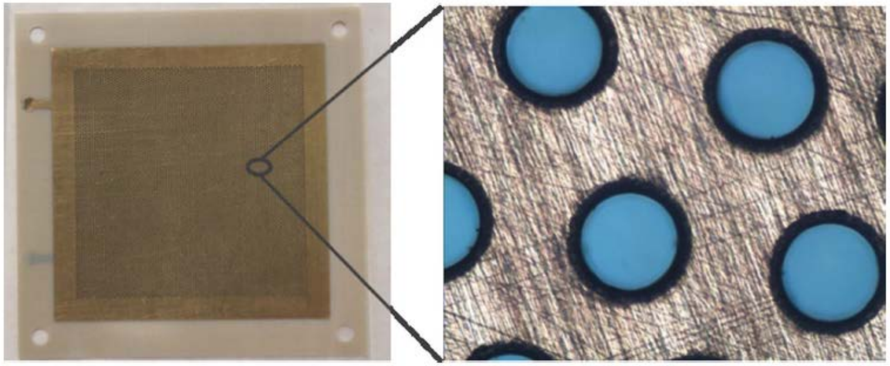


Fig. 2. A photograph of the PTFE-THGEM; the enlarged part (right) shows the holes and the rims surrounding them.

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

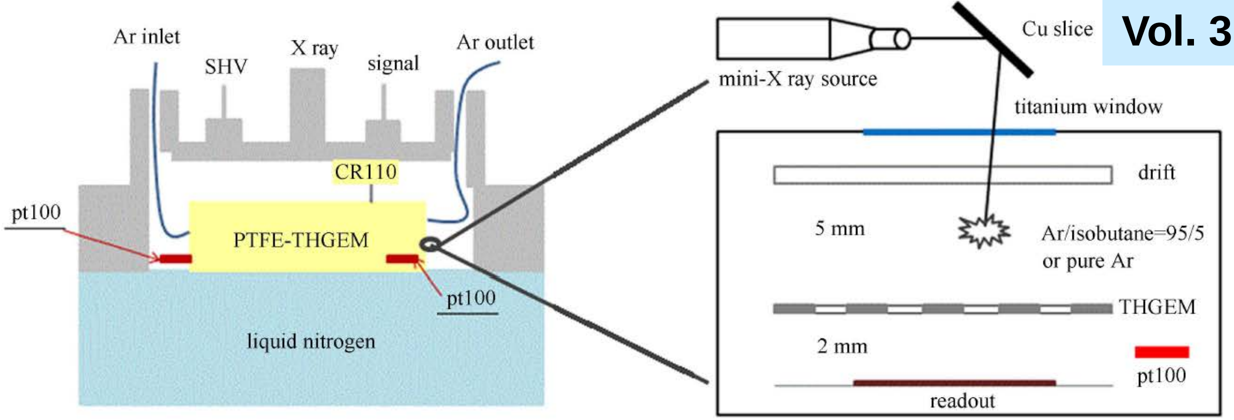
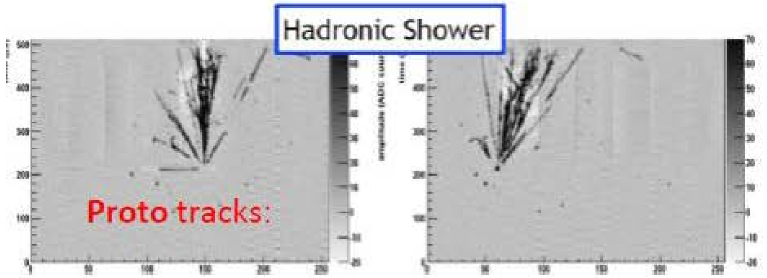


Fig. 3. Schematic diagram of the experimental setup. On the left is the test of the PTFE-THGEM at cryoge temperature; and on the right is the internal structure of the PTFE-THGEM used.

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

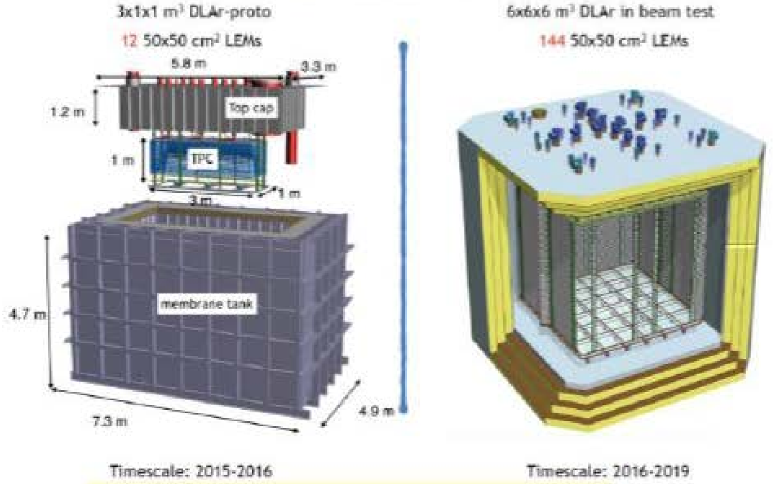
Dual-phase LAr LEM TPC

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



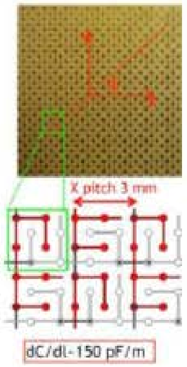
high ionization density in LAr➔ need low gain

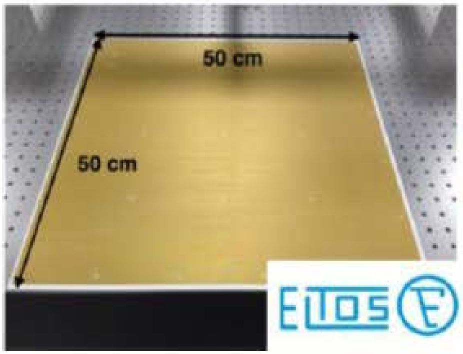
“demonstrators”



12 & 144 50x50cm² LEMs

DUNE: ~3000 LEMs (50x50)



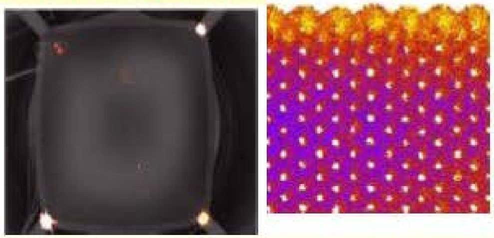


ptimised values

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

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

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



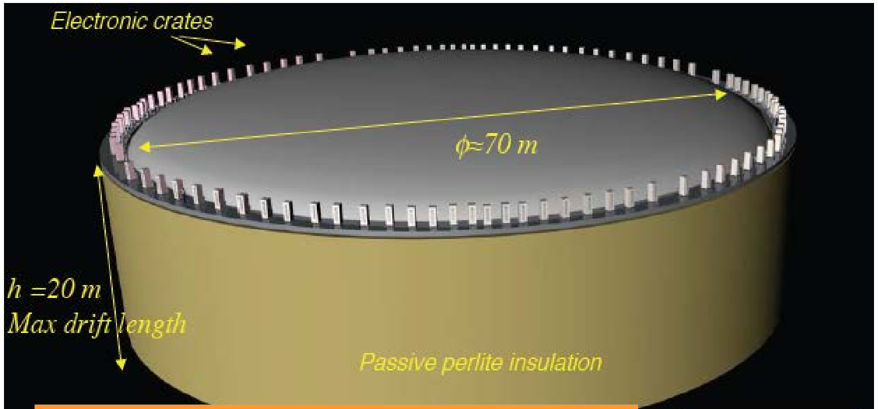
~3500V; spark on edges
(use COMPASS RICH solution?)
Charging up of rims: gain stabilizes. OK

Ongoing R&D on RESISTIVE WELL concepts

LARGE SIZE PROJECTS

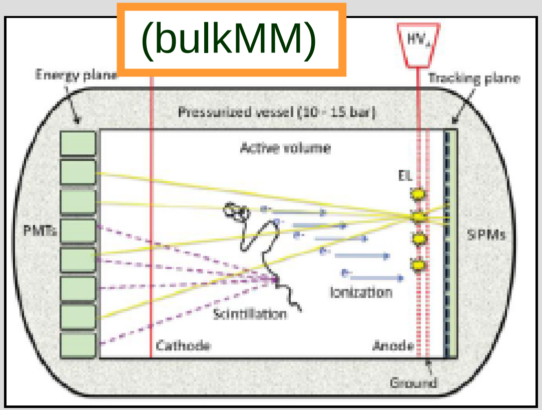
(THGEM)

XENON (dark matter)



LBNO – GLACIER (THGEM)

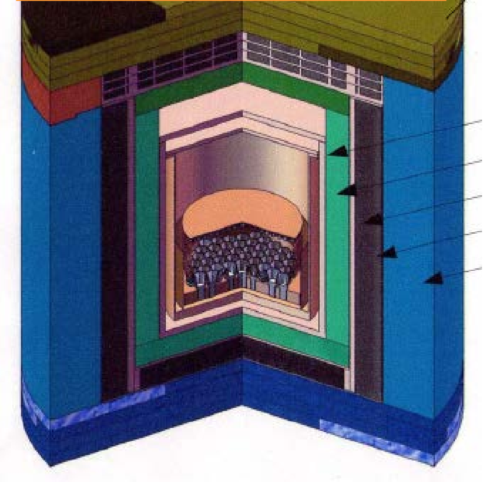
hep-ph/0402110
Venice, 2003

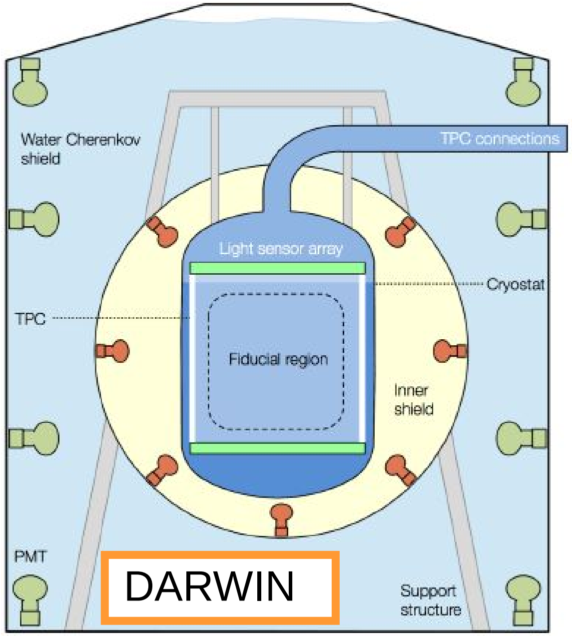


(bulkMM)

NEXT-100 (neutrino-less double beta decay)

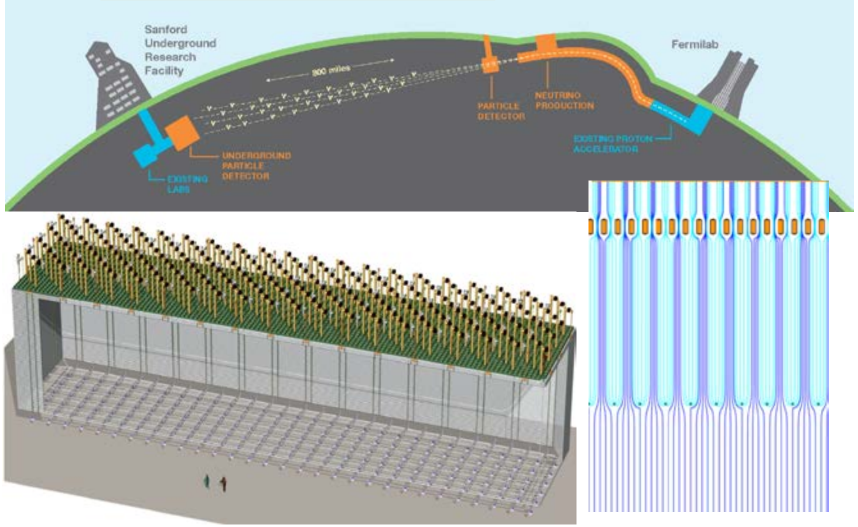
Panda-X, THGEM + MM (dark matter)





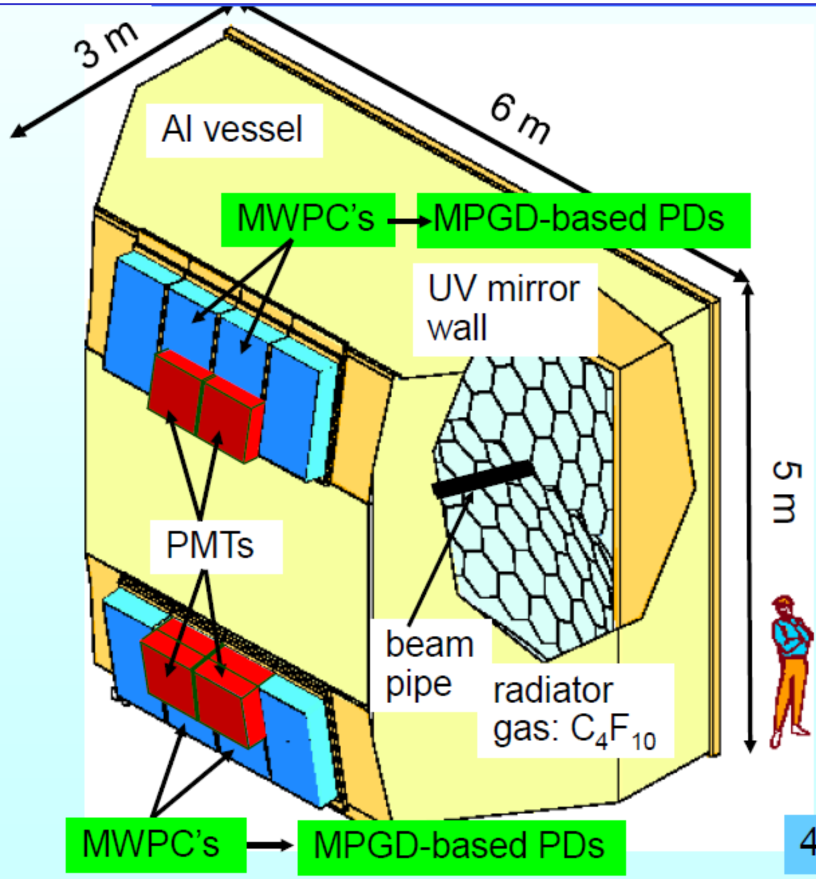
DARWIN

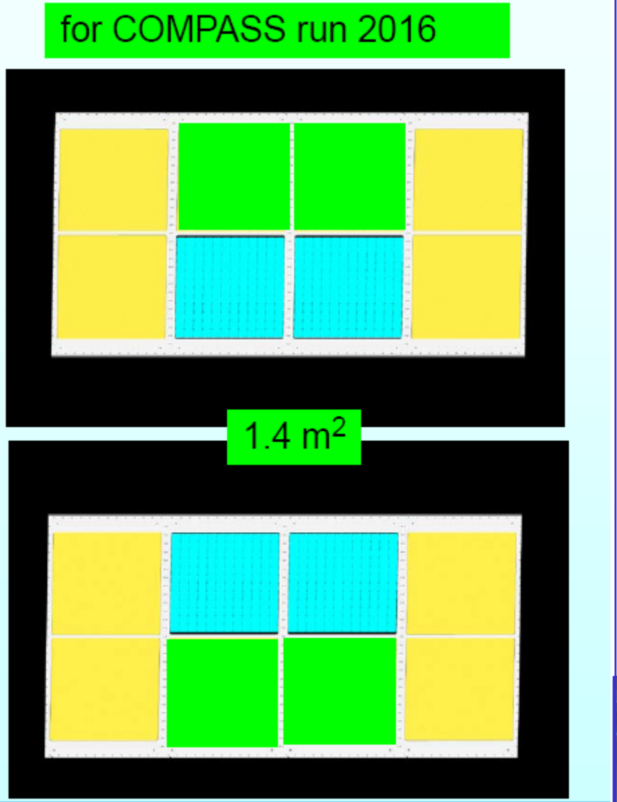
DUNE (40-kt LAr)



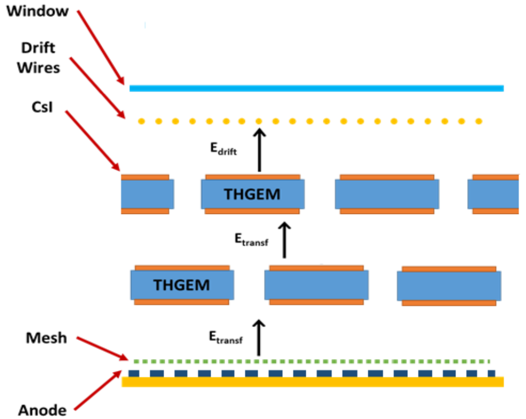
FIRST STEP TO LARGE SIZE

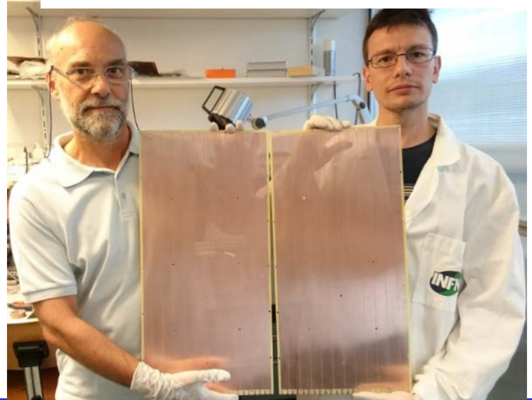
COMPASS RICH UPGRADE

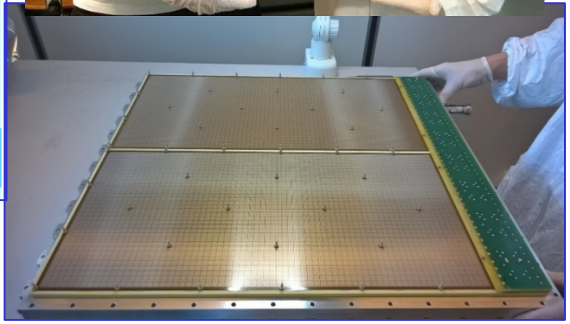




4 new detectors of 600 mm x 600 mm

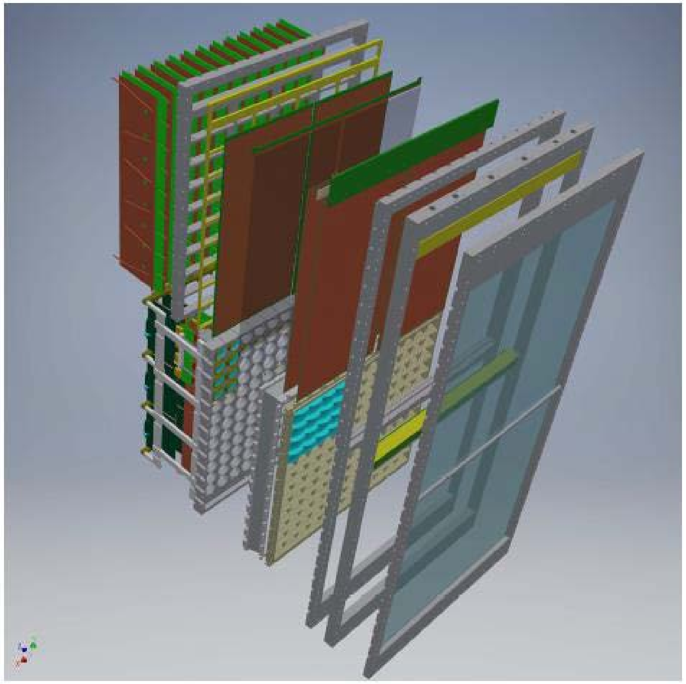


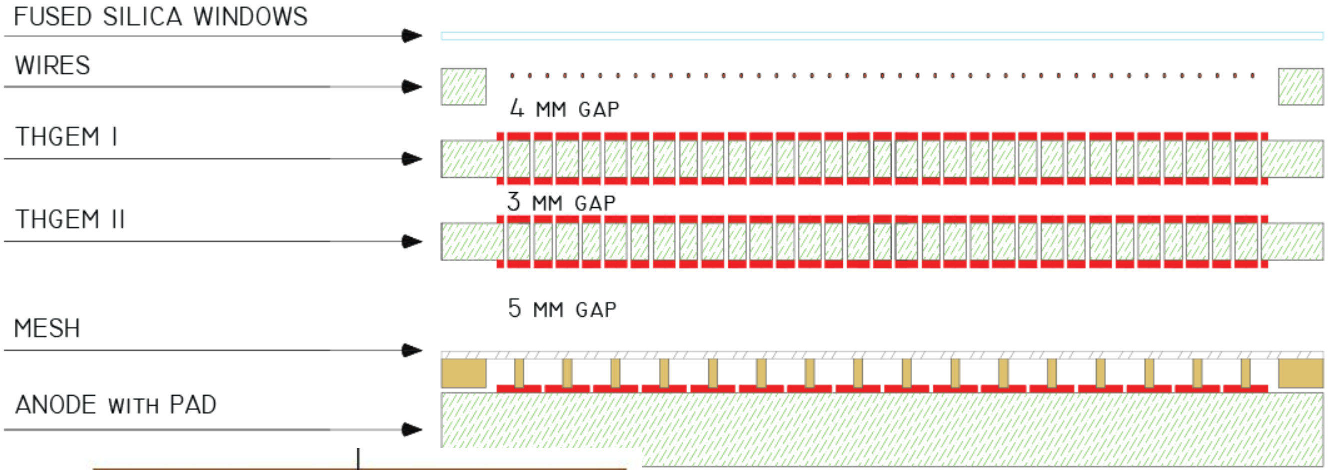




poster by Chandradoy Chattarjee

Replaced by Hybrid THGEM + Micromegas PDs





FUSED SILICA WINDOWS

WIRES

4 MM GAP

THGEM I

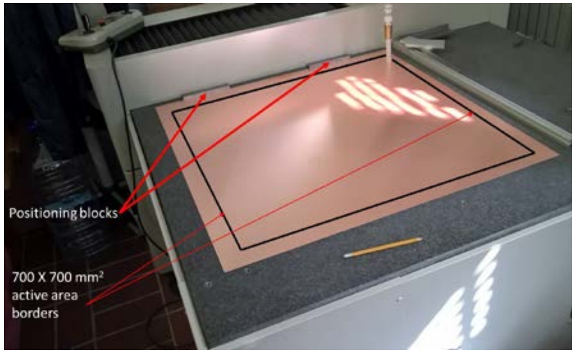
3 MM GAP

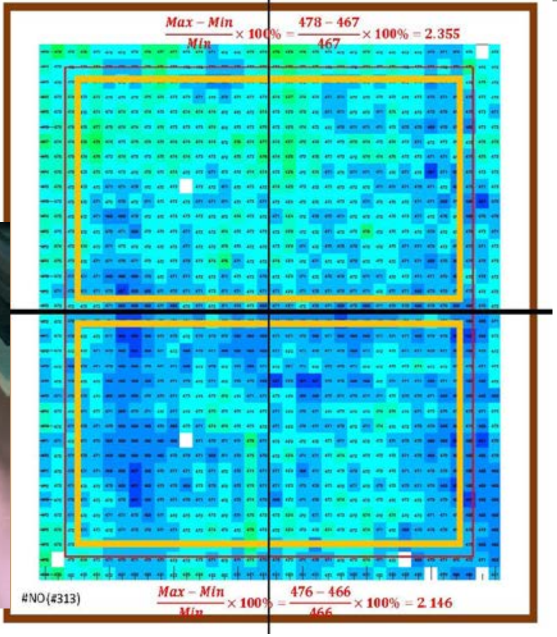
THGEM II

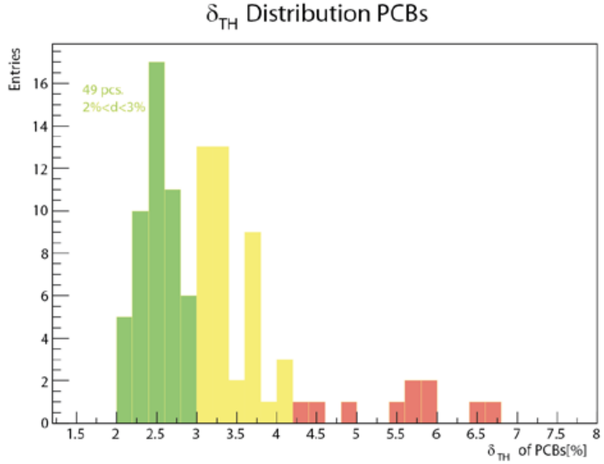
5 MM GAP

MESH

ANODE WITH PAD







PCB material selection:
50 THGEMs 300 mm x 600 mm
sent for producton to ELTOS SpA

THGEM production at ELTOS and surface treatment in Trieste

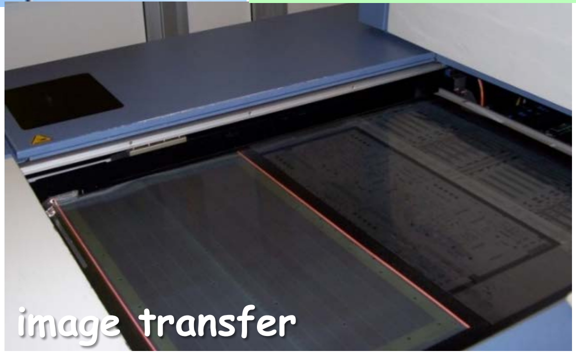
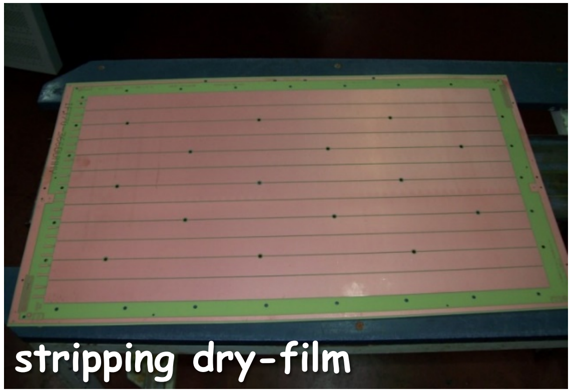
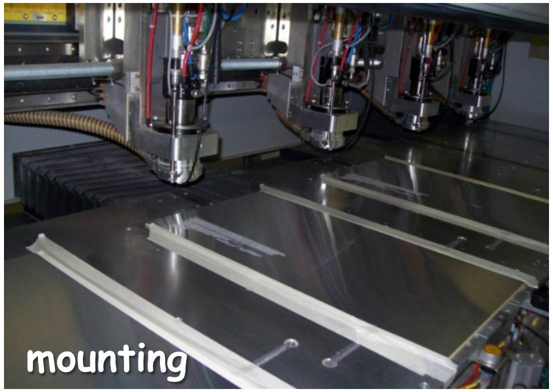
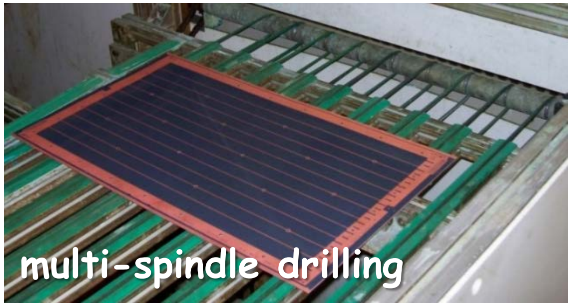


image transfer


development


stripping dry-film

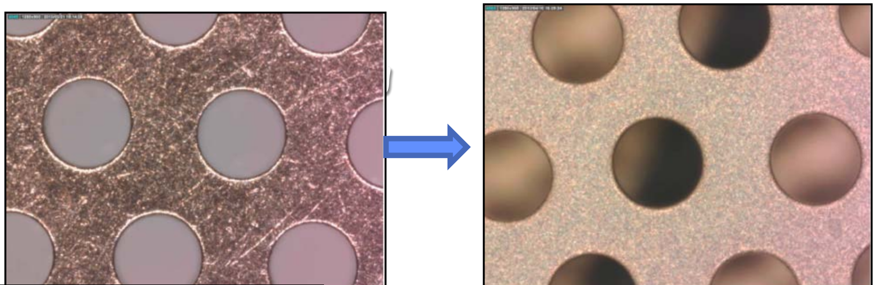

mounting

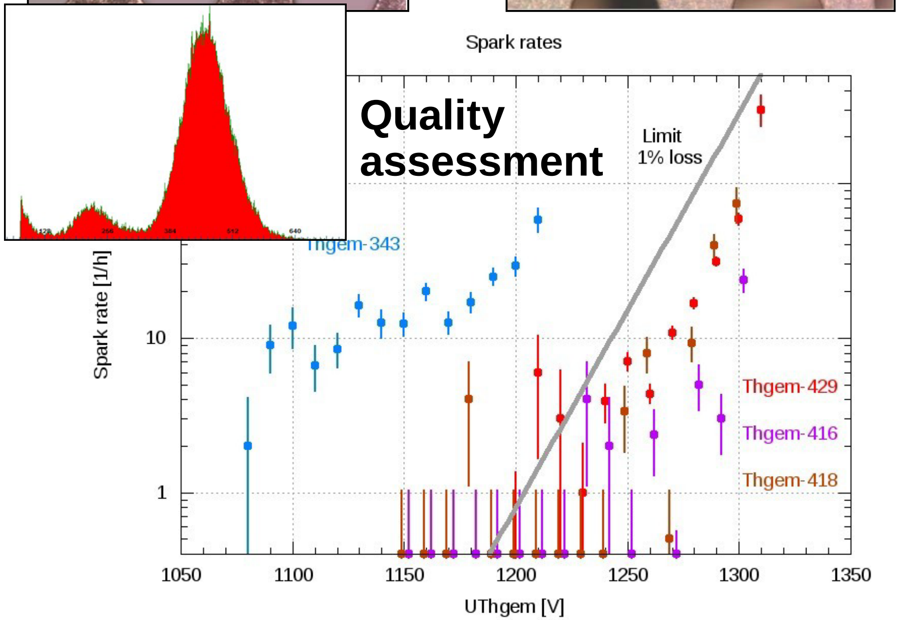

multi-spindle drilling


drilling

A post production specific surface treating and cleaning procedure developed in Trieste is applied:

- Surface Polishing.
- High pressure water cleaning.
- Ultrasonic Bath with Sonica PCB solution (PH11), distilled water rinsing and oven @ 160 ºC



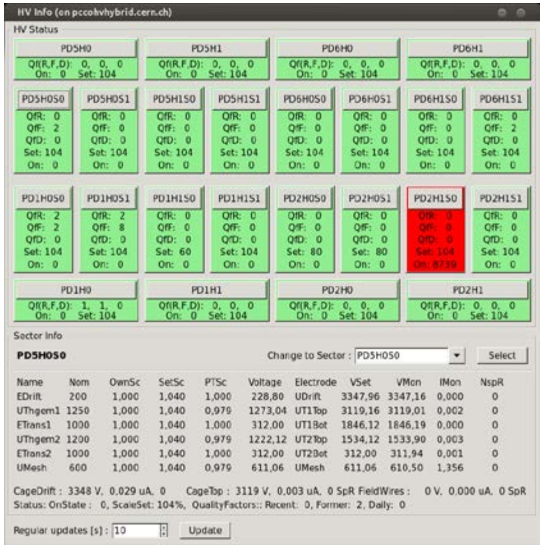


Quality assessment

Assembling, CsI coating and mounting the detectors on COMPASS RICH-1

Commissioning and 2016 COMPASS run

HV monitor and control system



HV Info (on pccohvhybrid.cern.ch)

HV Status

PD5H0	PD5H1	PD6H0	PD6H1
Qf(R,F,D): 0, 0, 0 On: 0 Set: 104	Qf(R,F,D): 0, 0, 0 On: 0 Set: 104	Qf(R,F,D): 0, 0, 0 On: 0 Set: 104	Qf(R,F,D): 0, 0, 0 On: 0 Set: 104

PD5H0S0	PD5H0S1	PD5H1S0	PD5H1S1	PD6H0S0	PD6H0S1	PD6H1S0	PD6H1S1
QfR: 0 QfF: 2 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 2 QfD: 0 Set: 104 On: 0

PD1H0S0	PD1H0S1	PD1H1S0	PD1H1S1	PD2H0S0	PD2H0S1	PD2H1S0	PD2H1S1
QfR: 2 QfF: 2 QfD: 0 Set: 104 On: 0	QfR: 2 QfF: 8 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 60 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 80 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 80 On: 0	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 8739	QfR: 0 QfF: 0 QfD: 0 Set: 104 On: 0

PD1H0	PD1H1	PD2H0	PD2H1
Qf(R,F,D): 1, 1, 0 On: 0 Set: 104	Qf(R,F,D): 0, 0, 0 On: 0 Set: 104	Qf(R,F,D): 0, 0, 0 On: 0 Set: 104	Qf(R,F,D): 0, 0, 0 On: 0 Set: 104

Sector Info

PD5H0S0

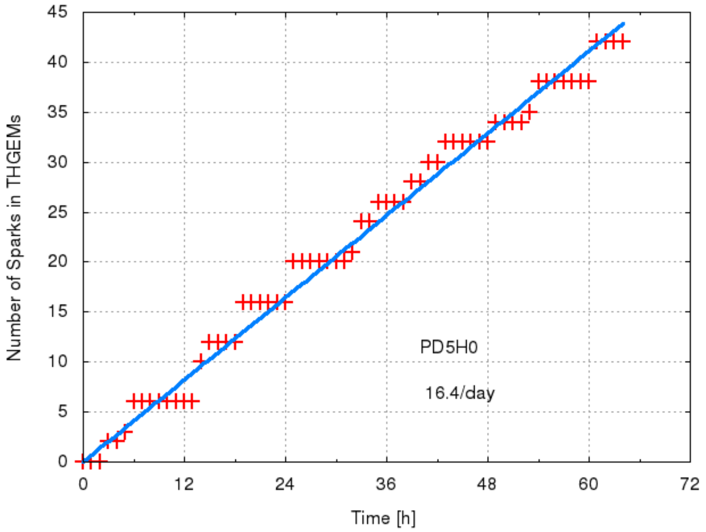
Change to Sector : PD5H0S0 ▾ Select

Name	Nom	OwnSc	SetSc	PTSc	Voltage	Electrode	VSet	VMon	IMon	NspR
EDrift	200	1,000	1,040	1,000	228,80	UDrift	3347,96	3347,16	0,000	0
UThgem1	1250	1,000	1,040	0,979	1273,04	UT1Top	3119,16	3119,01	0,002	0
ETrans1	1000	1,000	1,040	1,000	312,00	UT1Bot	1846,12	1846,19	0,000	0
UThgem2	1200	1,000	1,040	0,979	1222,12	UT2Top	1534,12	1533,90	0,003	0
ETrans2	1000	1,000	1,040	1,000	312,00	UT2Bot	312,00	311,94	0,001	0
UMesh	600	1,000	1,040	0,979	611,06	UMesh	611,06	610,50	1,356	0

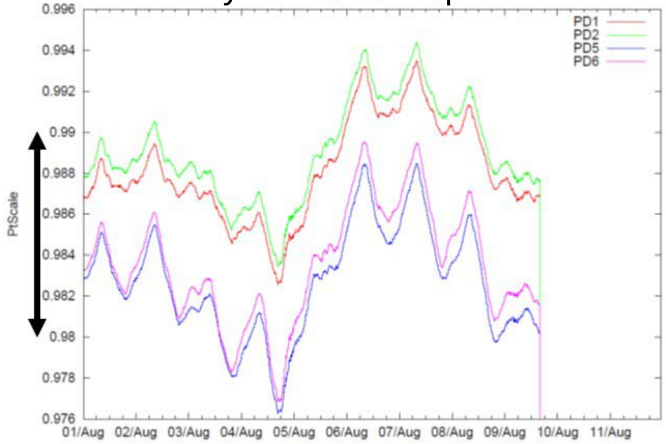
CageDrift : 3348 V, 0,029 uA, 0 CageTop : 3119 V, 0,003 uA, 0 SpR FieldWires : 0 V, 0,000 uA, 0 SpR
Status: OnState : 0, ScaleSet: 104%, QualityFactors:: Recent: 0, Former: 2, Daily: 0

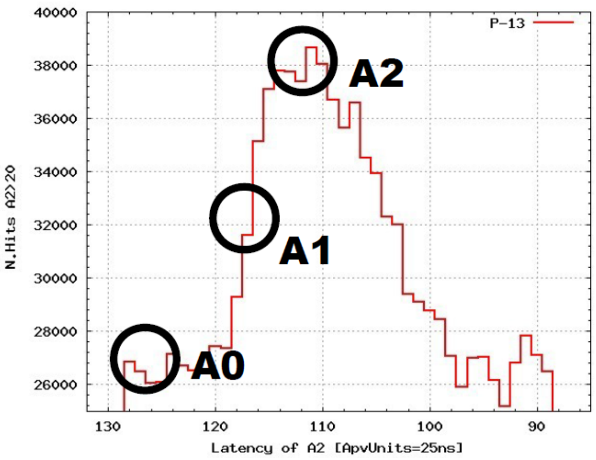
Regular updates [s] : 10 Update

~ 20 discharges/day during running

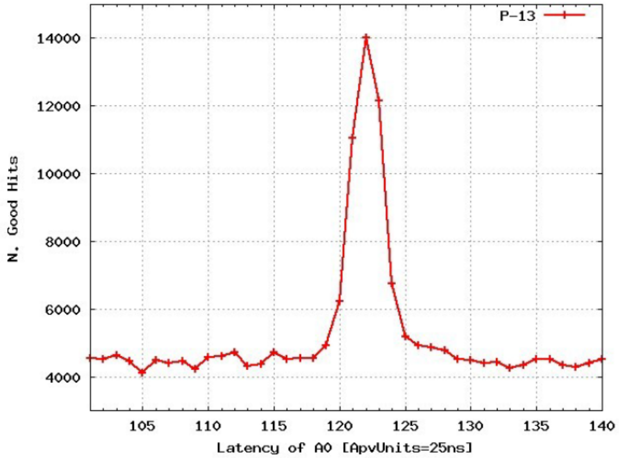


1% p,T variation → ~ 40 % gain variation without HV compensation, → 10% stability with HV compensation





APV25 samples the signal waveform



Cherenkov signals are clearly seen

- **1.4 m^2 of hybrid PDs operated**
- **Stable data taking conditions**
- **Effective suppression of signals from charged particles**
- **Ion Back-Flow < 3%**
- **More Cherenkov photons seen with respect to MWPCs + CsI**

CONCLUSIONS

THE DEVELOPMENT OF MPGDS IS SUCCESSFUL AND EXPANDING

Consolidated technologies are spreading over small and large projects

Advanced R&D is making continuous progress on new solutions

THGEMS ARE PROPOSED FOR VERY LARGE AREA DETECTORS OF γ, X, n

After long R&D phase it is now an almost consolidated technology

1.4 m^2 of detectors of single UV photons in operation at COMPASS RICH-1

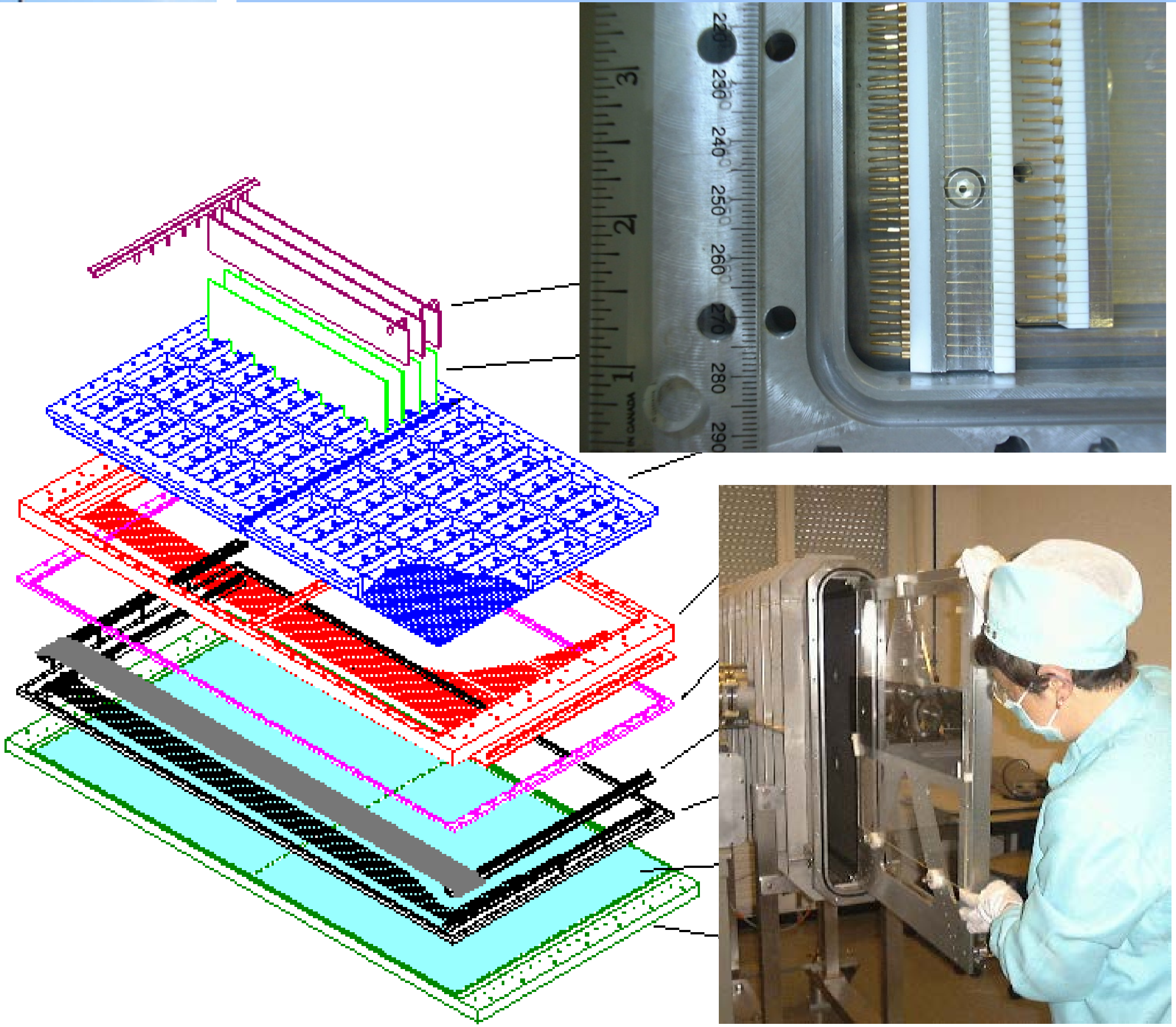
BRIGHT FUTURE FOR:

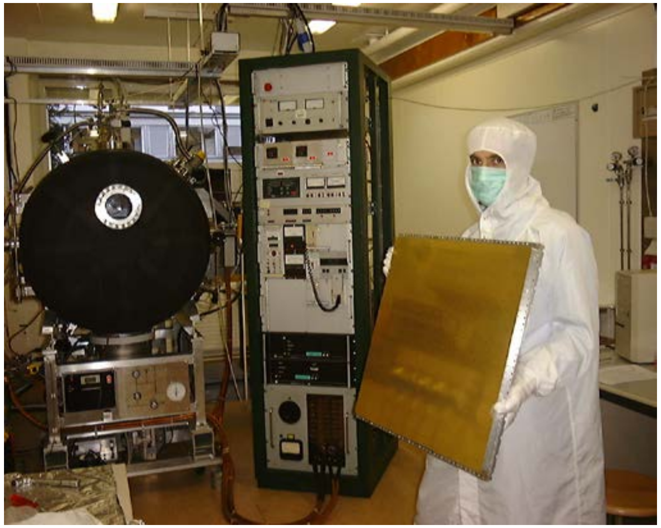
Inventions: new ideas, new techniques

Technology consolidation, new applications

Large scale projects

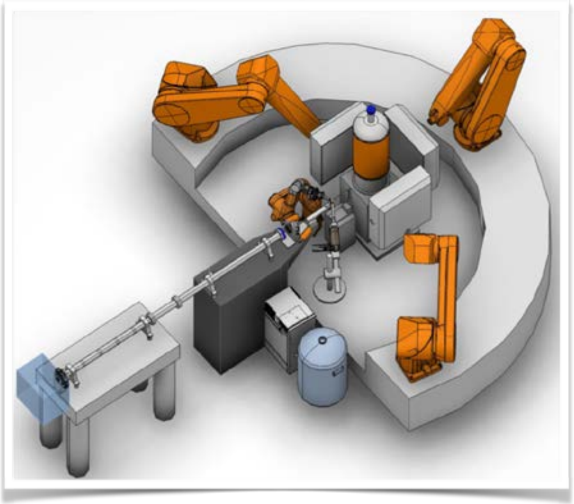
COMPASS MWPC's with CsI

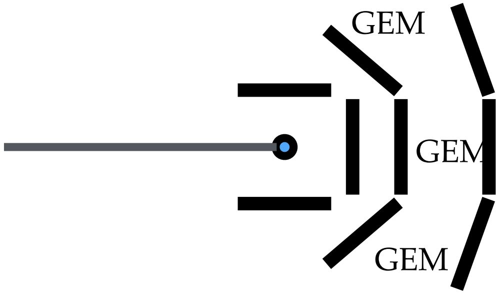




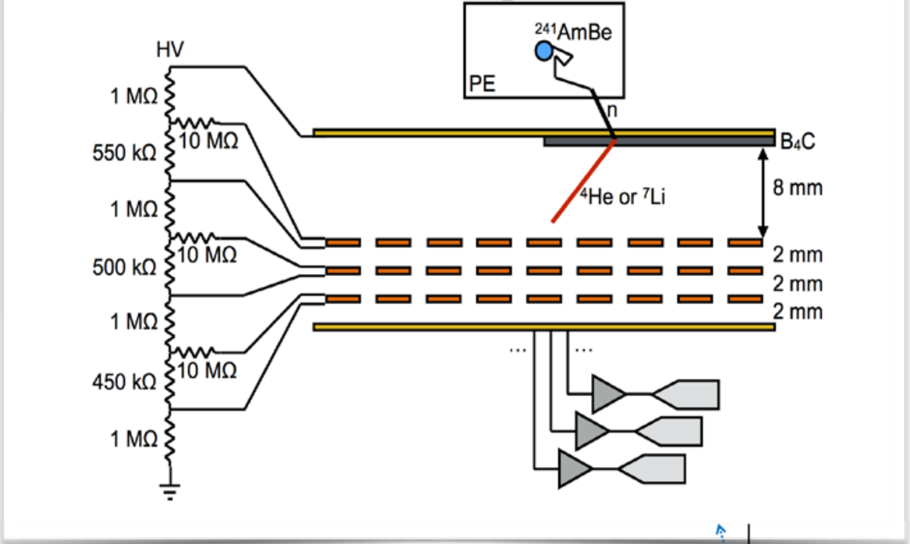
neutron detectors

NMX Spectrometer @ ESS



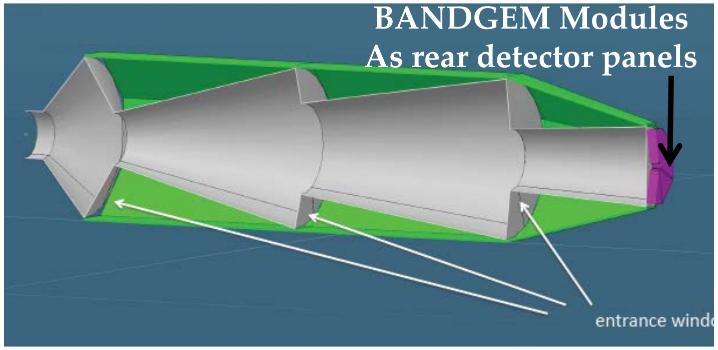


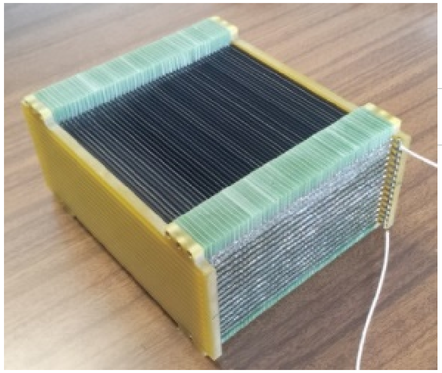
B(Gd)-GEM & uTPC concept

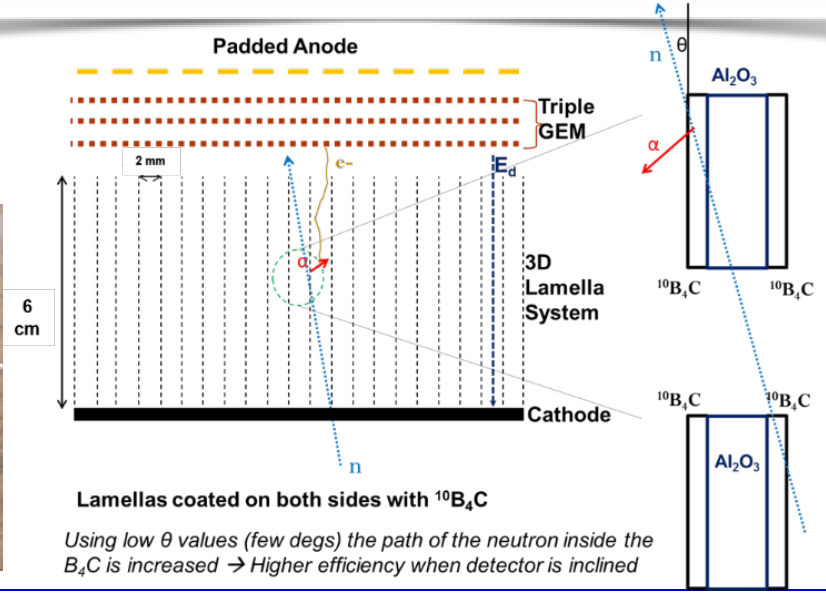


Triple GEM + 3D borated cathode
Thermal neutrons

LOKI-SANS Instrument @ ESS







Lamellas coated on both sides with $^{10}B_4C$

Using low θ values (few degs) the path of the neutron inside the B_4C is increased → Higher efficiency when detector is inclined