Micro Pattern Gas Detector technologies

Eraldo Oliveri, CERN, EP-DT-DD, Gas Detector Development (GDD) team

7th EIROforum School on Instrumentation, 7-11 June 2021

Micro Pattern Gas Detector technologies

The lecture will introduce basic principles, concepts and design choices of gaseous detectors with a particular focus on Micro Pattern Gas Detector technologies. We will review properties and performances that make these technologies of interest in different research fields and applications. Examples of detectors in operation, new developments and pioneering researches will be presented and discussed during the lecture.

7th EIROforum School on Instrumentation: https://workshops.ill.fr/event/279/

Outline

- **Basic principles of gas based radiation detectors, concepts and design choices**

- **Overview of Micro Pattern Gas Detector (MPGD) technologies**

- **Instrumentation & MPGD**

  - **from a new technology to mature INSTRUMENTS**

  - **MPGD based INSTRUMENTS: examples of Need and WAY OUT**

Outline

- **Basic principles of gas based radiation detectors, concepts and design choices (very short, with some useful link)**

- **Overview of Micro Pattern Gas Detector (MPGD) technologies (what we need to be on the same page, nothing more)**

- **Instrumentation & MPGD**

Main part of the lecture to have a more pronounced instrumentation perspective

using GEM (Gas Electron Multipliers) as example

- **from a new technology to mature INSTRUMENTS**

- **MPGD based INSTRUMENTS: examples of Need and WAY OUT**

to better highlight the potential on MPGD technologies in the development of instrumentation

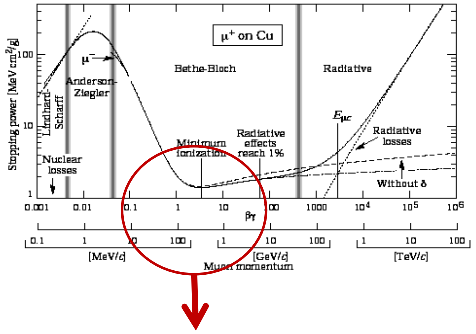
Some topics linked to Petra's contribution (CERN/HEP) some other to applications in other fields…

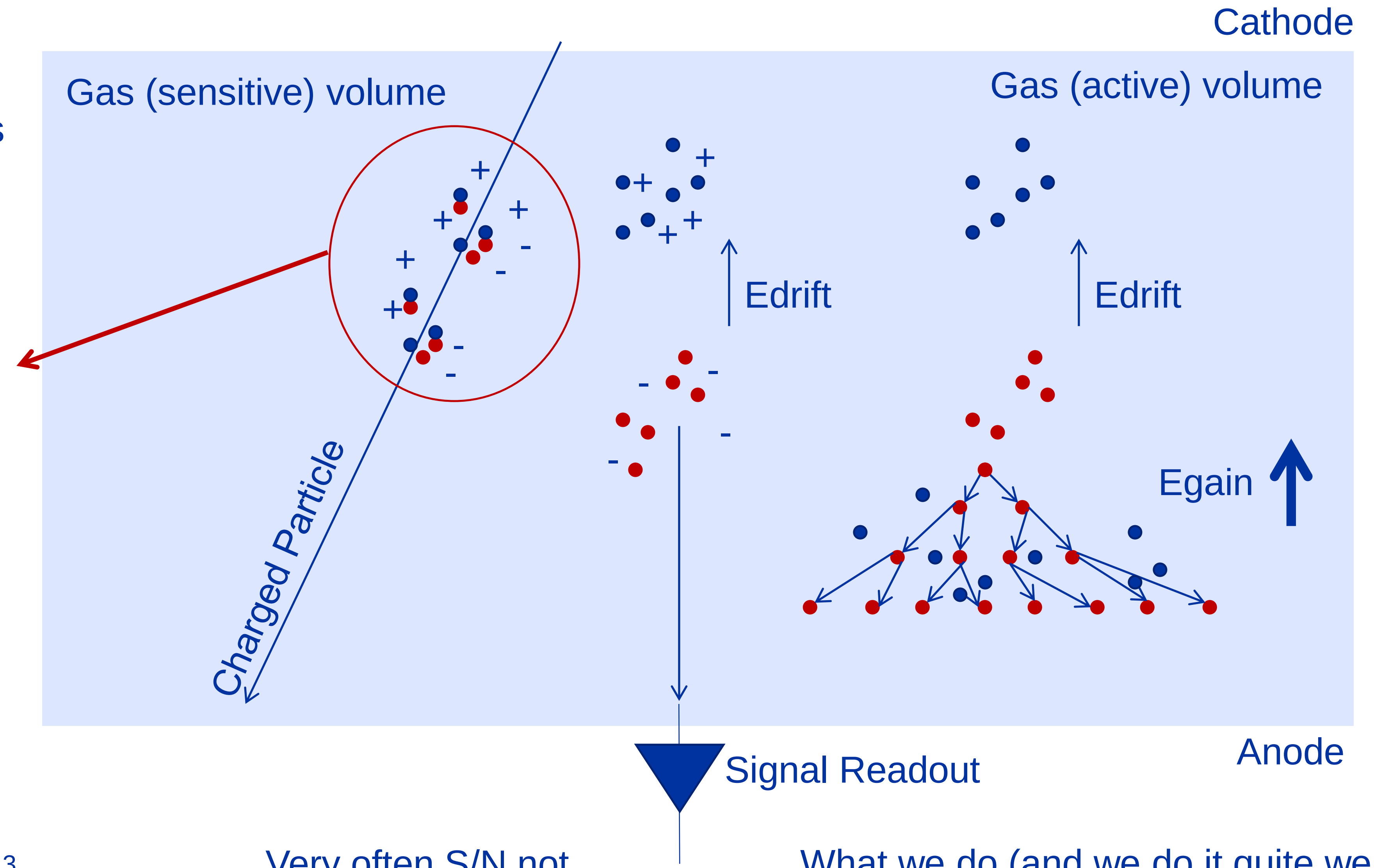
Basic principles of gas based radiation detectors, concepts and design choices.

This section should provide you references to basic principle of radiation detection with gas based instrumentation.

Normally (we will elaborate more on this later) we use the gas as the sensitive medium…

If we consider MIP (Minimum Ionizing Particles, as worst example of primary ionization)…





MIP≈ 2 Mev cm^2 /g…
gas density… ~10^{-3} g/cm^3

You will get something like 100 e$^-$/cm

Very often S/N not enough to discriminate the signal

What we do (and we do it quite well) is to amplify the signal (e-) in the gas (via ionization processes)

Basics of Gas Detectors

Rob Veenhof's lectures highly recommended..

Here just one example

Lectures II: Analytical and numerical description of physical processes in gaseous detectors, R. Veenhof

09:00 **Electron transport, mean gain**
Speaker: Rob Veenhof (Uludag University (TR))
mpgdtheory3.pdf

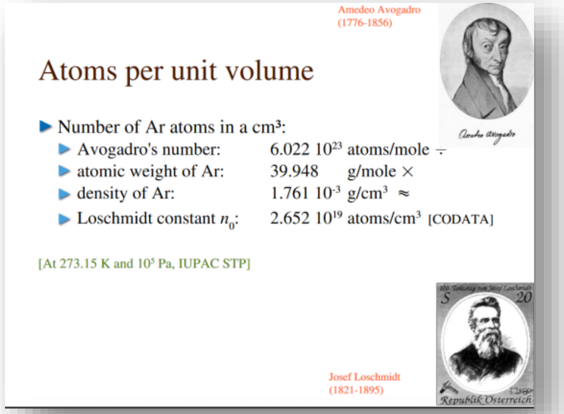
10:00 **Coffee Break**

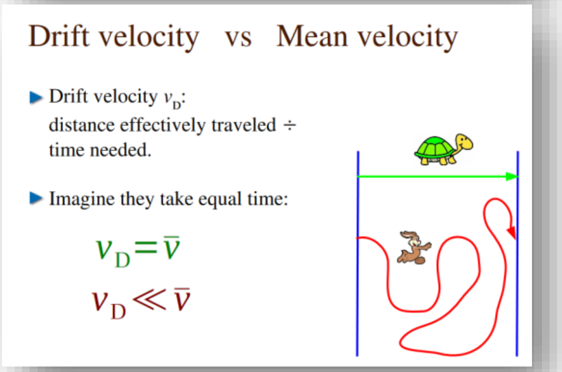
10:15 **Avalanche fluctuations**
mpgdtheory4.pdf

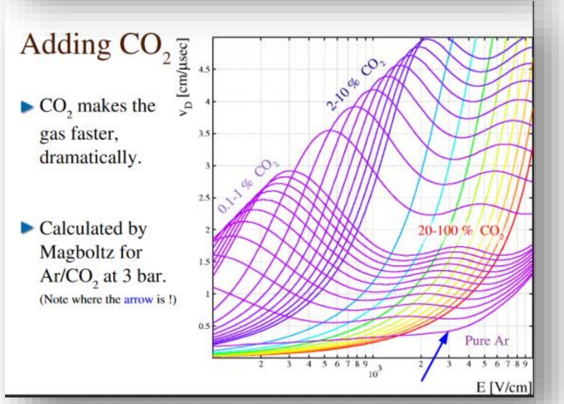
11:00 **Coffee break**

11:15 **Ion transport**
Speaker: Rob Veenhof (Uludag University (TR))
mpgdtheory5.pdf

https://indico.cern.ch/event/676702/timetable/





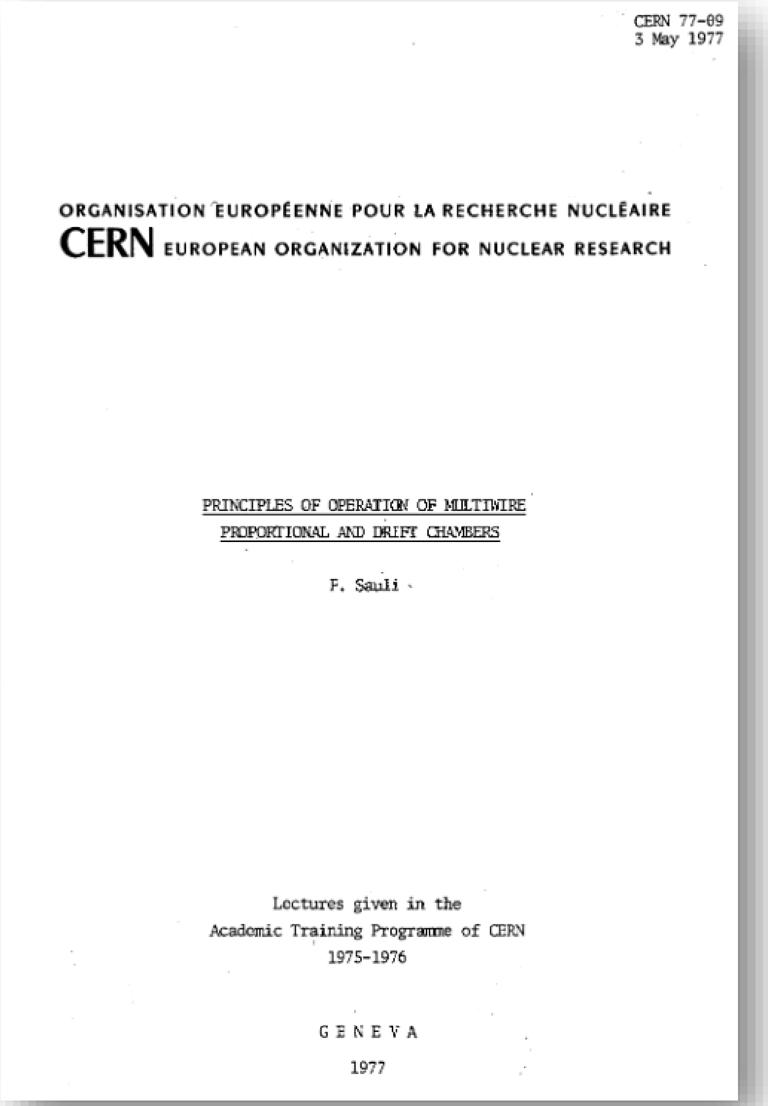


Key aspects on (gas) detector physics presented, explained and discussed, historical and literature references, data,…

Basics of Gas Detectors

Sauli’s Yellow Report CERN-77-09 highly recommended…

Report	
Report number	CERN-77-09
Title	**Principles of operation of multiwire proportional and drift chambers**
Author(s)	Sauli, Fabio
Imprint	92 p.
Series	(CERN Academic Training Lecture ; 81) (CERN Yellow Reports: Monographs)
Note	CERN, Geneva, 1975 - 1976
Presented at	Experimental techniques in high energy physics, pp.79-188
Presented at	Academic Training Lectures, CERN, Geneva, Switzerland, 1 Sep 1975 - 30 Jun 1976
DOI	10.5170/CERN-1977-009
Subject category	Detectors and Experimental Techniques
Other source	KEK ; Inspire
Copyright/License	© 1977-2021 CERN (License: CC-BY-3.0)


CERN 77-09
3 May 1977

ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

PRINCIPLES OF OPERATION OF MULTIWIRE
PROPORTIONAL AND DRIFT CHAMBERS

F. Sauli

Lectures given in the
Academic Training Programme of CERN
1975-1976

GENEVA
1977

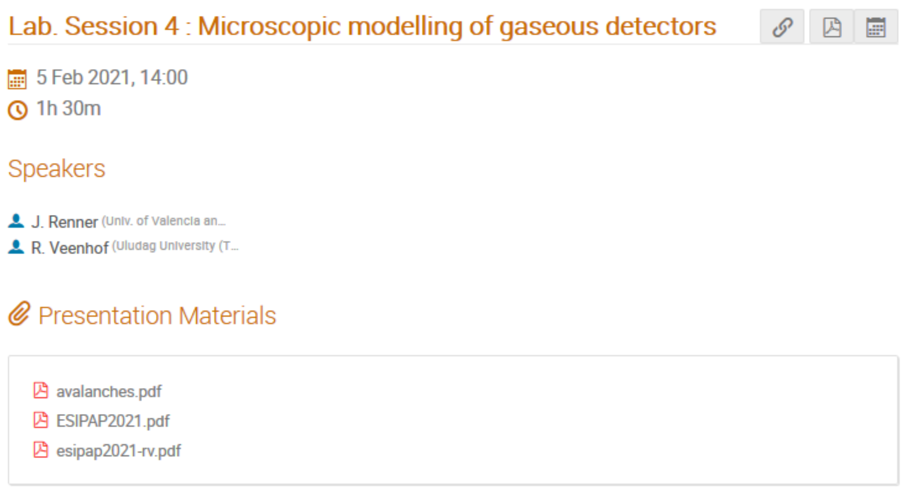
https://cds.cern.ch/record/117989?ln=fr

With the available information (I’m sure that) you will be able to develop your own instrument despite your technology (assuming obviously that it gas based) was not existing at the time of the report.

Basics of Gas Detectors

https://colab.research.google.com/github/jerenner/garfieldfem/blob/master/garfield_FEM_ESIPAP.ipynb

Potential fun (if still active), you can play with google notebook developed by Josh Renner where you can model (*) gas detectors (josh.renner@cern.ch)



Lab. Session 4 : Microscopic modelling of gaseous detectors

5 Feb 2021, 14:00
1h 30m

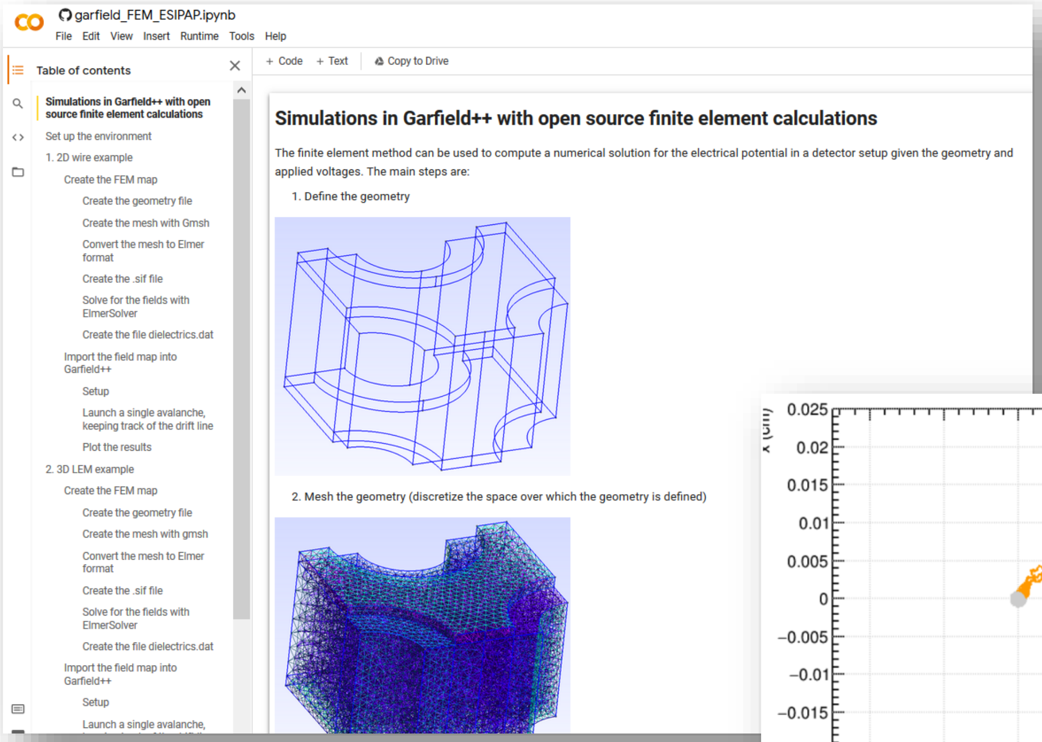
Speakers

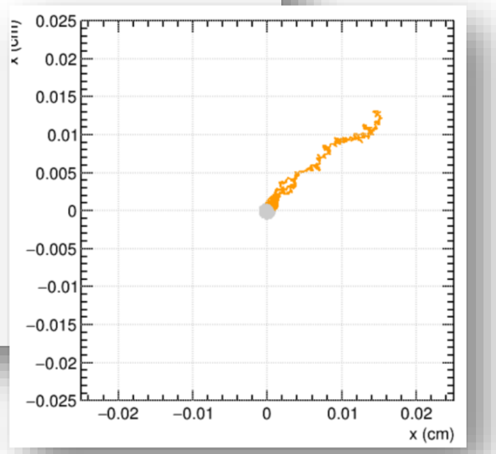
J. Renner (Univ. of Valencia an...
R. Veenhof (Uludag University (T...

Presentation Materials

avalanches.pdf
ESIPAP2021.pdf
esipap2021-rv.pdf

https://indico.cern.ch/event/973041/contributions/4097209/





“”small” avalanche around a wire

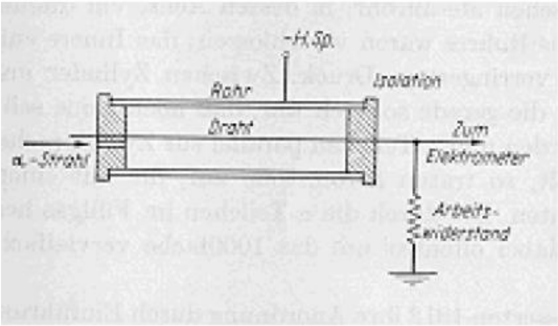
ESIPAP 2021 - COURSE 1 - Physics of particle and astroparticle detectors

(*) Several tools (Garfield/Garfield++ as first) that are a fundamental tool for our detector understanding and as well for instruments development.

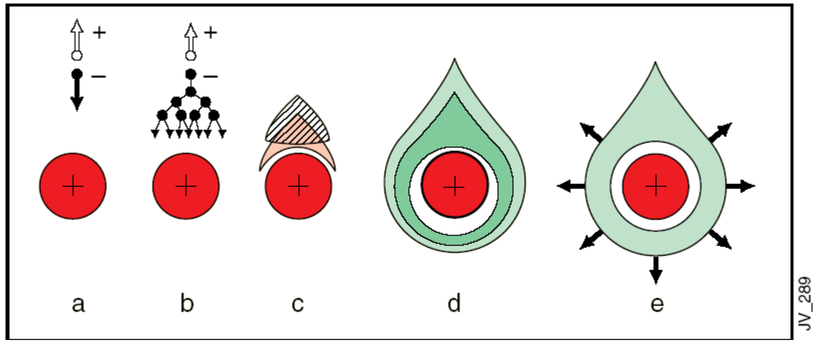
Micro Pattern Gas Detector technologies

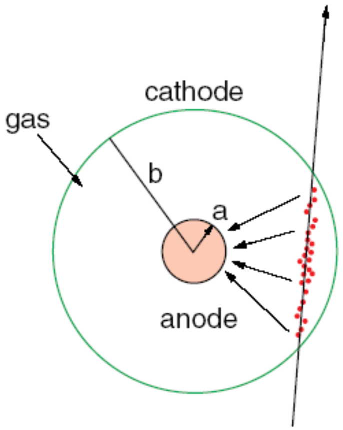
This section will focus on Micro Patter Gas Detector (MPGD) technologies, highlighting properties and performances that make these technologies of interest in different research fields and applications

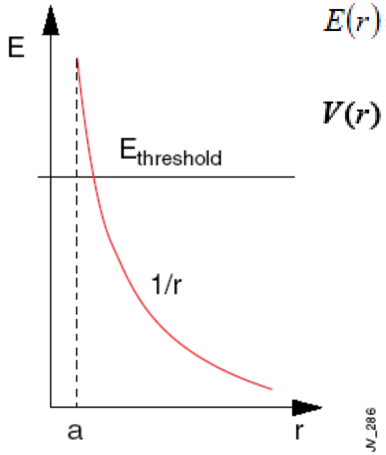
Single Wire Proportional Counter (SWPC) [Rutherford, E. and Geiger, H. (1908)]



Signal proportional to the original ionization (large collection volume – small amplification volume)

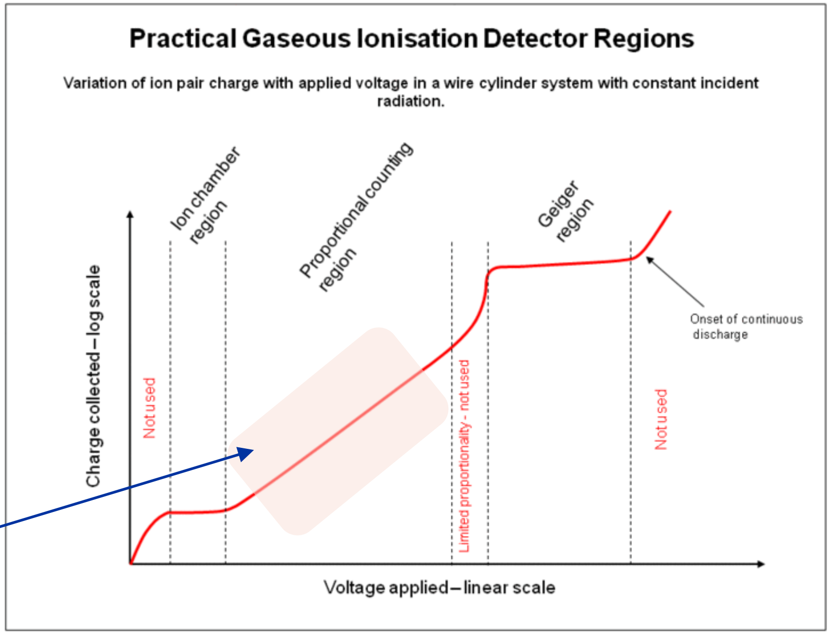






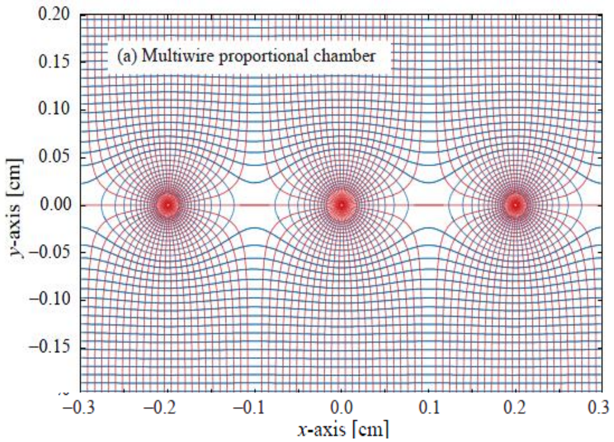
$$E(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \frac{1}{r}$$

$$V(r) = \frac{CV_0}{2\pi\varepsilon_0} \cdot \ln\frac{r}{a}$$



Today we will focus on detectors working in proportional counting region

Multi Wire Proportional Counter(MWPC) [Charpak, G. et al. (1968)]



De gauche à droite, Georges Charpak, Fabio Sauli et Jean-Claude Satiard en train de travailler sur une chamber multifils en 1970. (Image : CERN)

Fast position-sensitive detectors (1968)

Continuously active,

Efficient at particle fluxes up to several MHz/cm2

Sub-mm position accuracy

Noble Prize in 1992

First time (If I'm not wrong, I can be biased) signals (electronics) are recorded (statistics) in HEP experiments opening the today scenario (well presented by Petra yesterday)…

In the 80's…

See next slide

Limited multi-track separation: mechanical instabilities due to electrostatic repulsion - critical length of about 25cm for 10μm wires and 1mm spacing]

Fast gain drop at high fluxes: field-distorting space charge accumulation due to the long time taken by the ions produced in the avalanches to clear the region of multiplication.

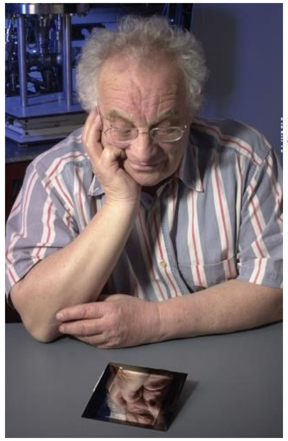
Aging: permanent damage of the structures after long-term exposure to radiation due to the formation of solid deposits on electrodes.

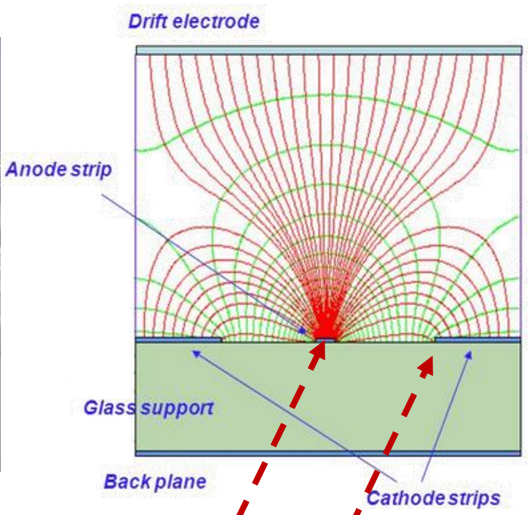
Micro Strip Gas Chamber (MSGC) [A.Oed (1988)]

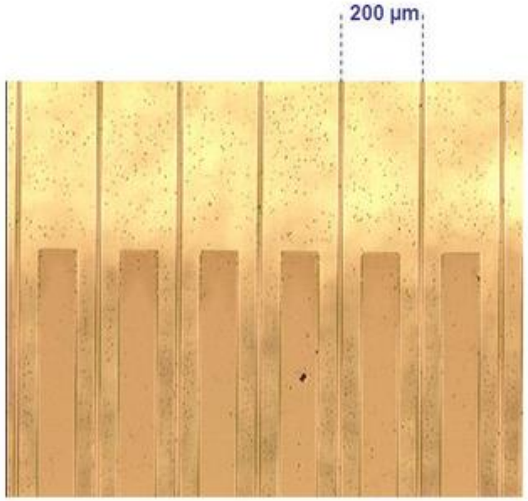
90's

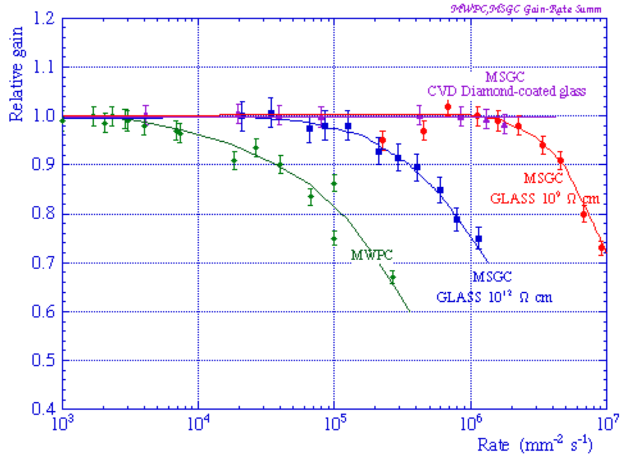
Novel **photolithographic techniques**

Photolithography: down in size from millimeters to tens of microns.. reducing the gas volume "used" by single events (improving resolution, multitrack separation, occupancy,..) and offering a faster evacuation of ions (reduced space charge).

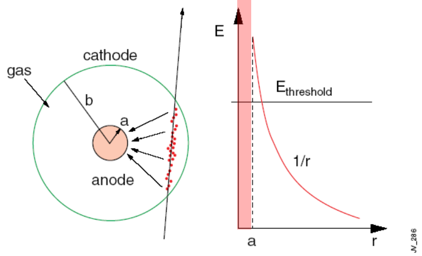




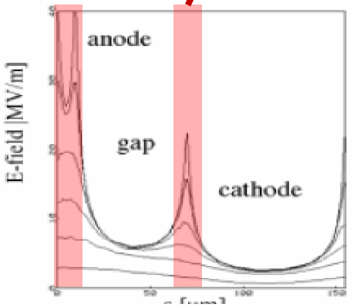




Impressive results t that time…



Fields in SWPC



Fields in MSGC

Two comments
(potentially useful or to keep in mind)

- **High Fields at both electrodes** (again compare with wire field)
- **Dielectric** between electrodes and facing the active volume (just compare with wires/all metals).

(On Fields… interesting developments in RPC community.. RCC Resistive Cylindrical Chamber See pag. 14 of https://indico.cern.ch/event/999799/contributions/4204006/attachments/2235619/3790575/Aielli_ECFA_2021.pdf)

MSGC: Instabilities and discharges

Several strategies followed as coating and passivation

Some of the MWPC limitations have been overcome, but other limitation appearing…

Observed instabilities:

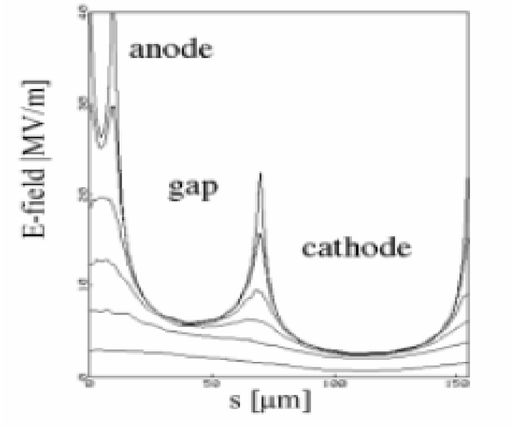
- **tendency to discharge (field configuration)**

- **time-dependent gain shifts** (charge movement in the substrate, polarization and charge accumulation) (dielectric (*))

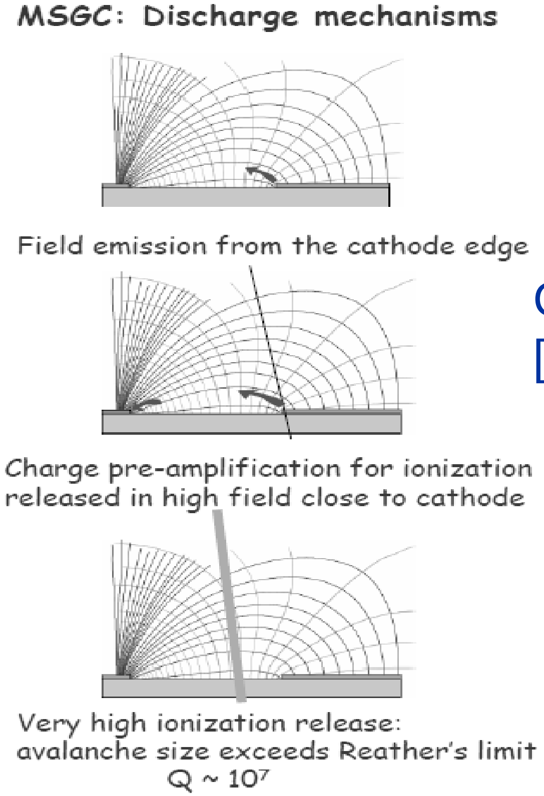
- **aging:** permanent deterioration during sustained irradiation

(*) medium- and long-term stability determined by physical parameters used to **manufacture** and operate the detectors as : **substrate** material, metal of the strips, type and purity of the gas mixture

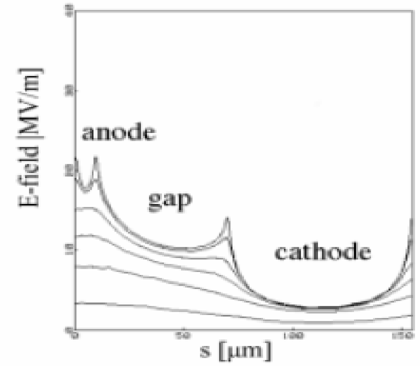
Discharges



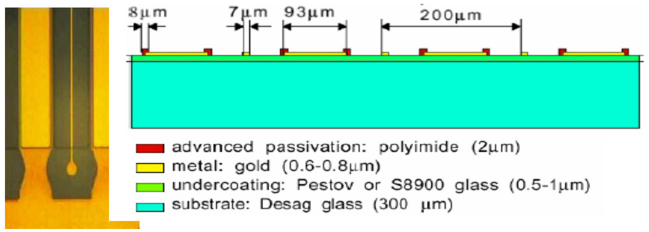
Micro-cathode → a pre-amplification stage for discharges



CVD Diamond Coated MSGC



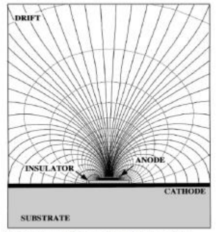
Cathode Edge Passivation [Bellazzini et al]



+ many alternatives “micro”structures.. See next slide

Micro Patterns

Micro Gap Chambers



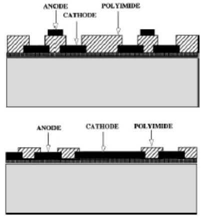


Figure 25 Two variants of small-gap chambers, using thick polyimide ridges to prevent the onset of discharges.

Angelini F, et al. Nucl. Instrum. Methods A335:69 (1993)

Micro Gap Wire Chamber

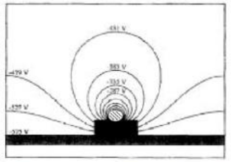


Figure 2.27 Scheme of a MGWC with equipotential and field lines. The circle filled with lines is the section of an anode wire [CHRISTOPHEL1997].

E. Christophel et al, Nucl. Instr. and Meth, vol 398 (1997) 195

MicroDot

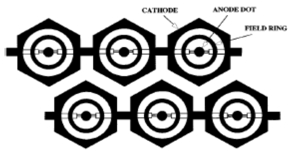


Figure 26 Schematics of the microdot chamber. A pattern of metallic anode dots surrounded by field and cathode electrodes is implemented on an insulating substrate, using microelectronics technology. Anodes are interconnected for readout.

Biagi SF, Jones TJ. Nucl. Instrum. Methods A361:72 (1995)

CAT

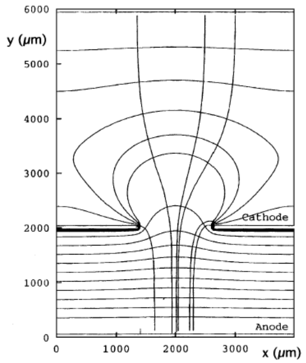


Figure 31 Schematics and fields in the compteur à trous.

A. Sarvestani et al., Nucl. Instr. And Meth. A410 (1998) 238

MICROMEGAS

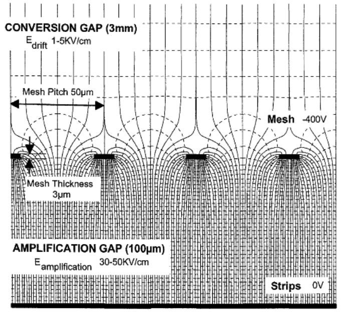


Fig. 1. Micromegas electric field map.

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

GEM

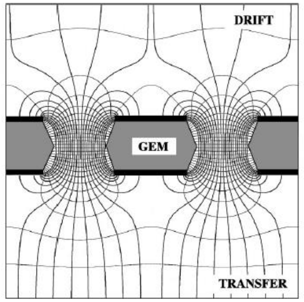
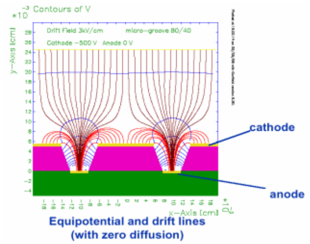


Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

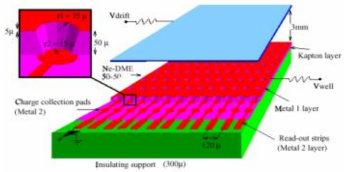
F. Sauli, Nucl. Instr. and Meth. A386(1997)531

MicroGroove



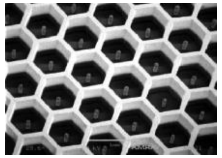
R. Bellazzini et al Nucl. Instr. and Meth. A424(1999)444

MicroWELL



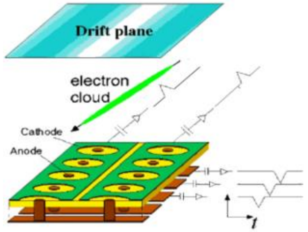
R. Bellazziniet al Nucl. Instr. and Meth. A423(1999)125

MicroPin



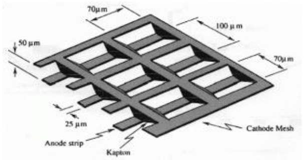
P. Rehak et al., IEEE Nucl. Sci. Symposium seattle 1999

μPIC



Ochi et al NIMA471(2001)264

Micro Wire Chamber

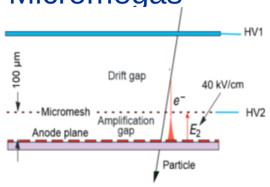


B. Adeva et al., Nucl. Instr. And Meth. A435 (1999) 402

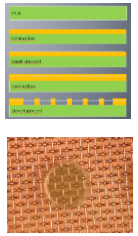
+ surely several missing ones…

Micro Pattern Gas Detector Family.. today

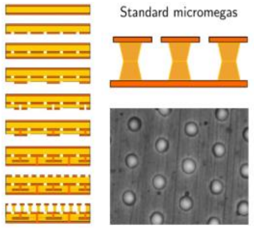
Micromegas



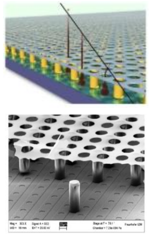
Bulk



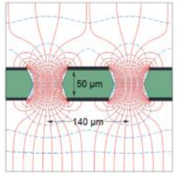
Micro bulk



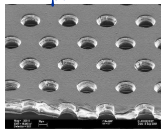
InGrid



GEM

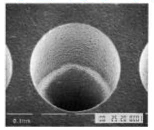


50µm GEM

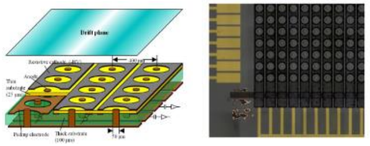


THGEM

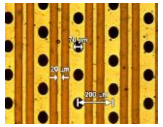
GLASS GEM

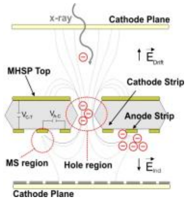


µPIC

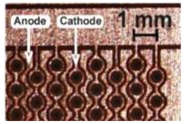


MHSP

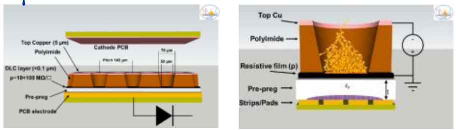


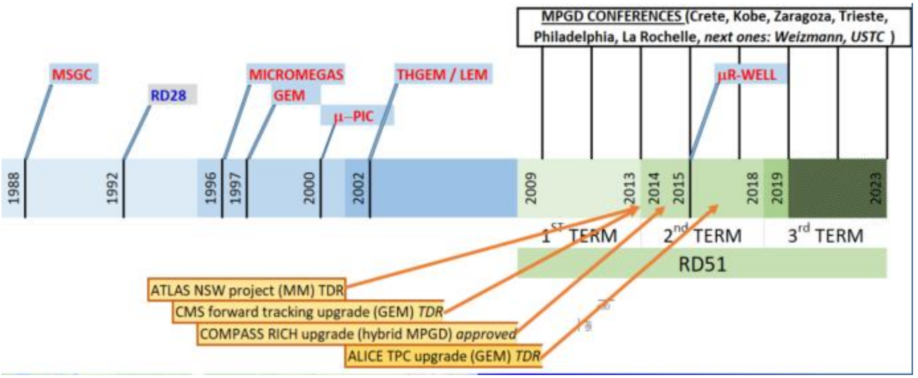


THCOBRA



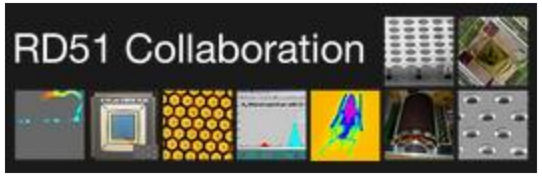
µRWELL





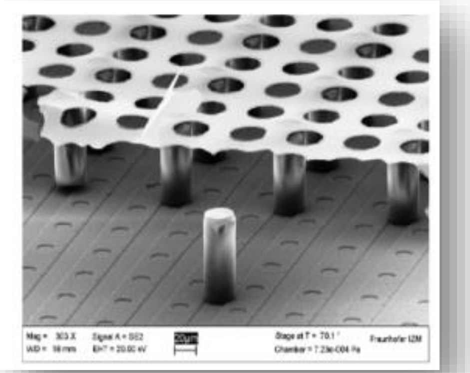
High Rate Capability	Up to MHz/mm^2 (MIP)
High Gain	Up to 10^5 -10^6
High Space Resolution	<100µm
Good Time Resolution	In general few ns , sub-ns in specific configuration
Good Energy Resolution	10-20% FWHM @ soft X-Ray (6KeV)
Excellent Radiation Hardness	
Good aging Properties	
Ion Backflow Reduction	% level sort of easy, below % in particular configuration
Photon Feedback Reduction	
Large size	m^2
Low material budget	
Low cost	
…	

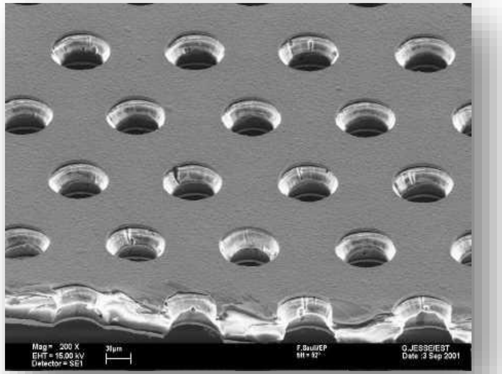
Technology share-point RD51 (**Development of Micro-Pattern Gas Detectors Technologies**)

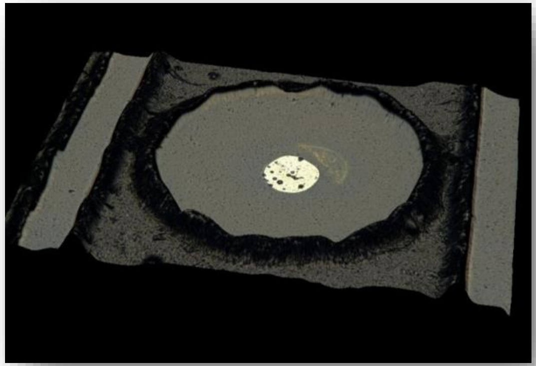


https://rd51-public.web.cern.ch/

Avalanches







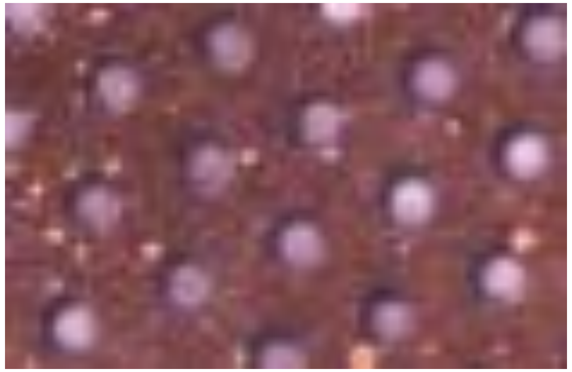
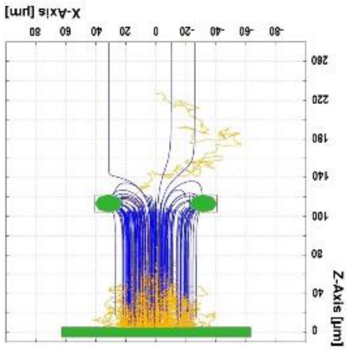
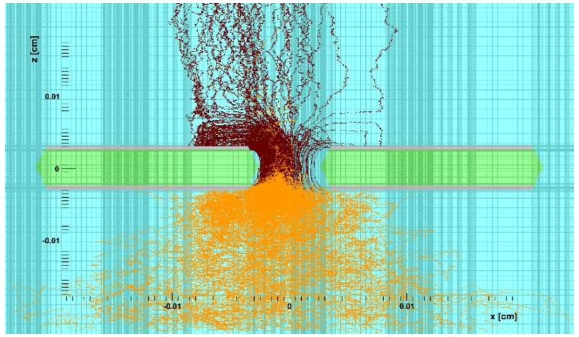


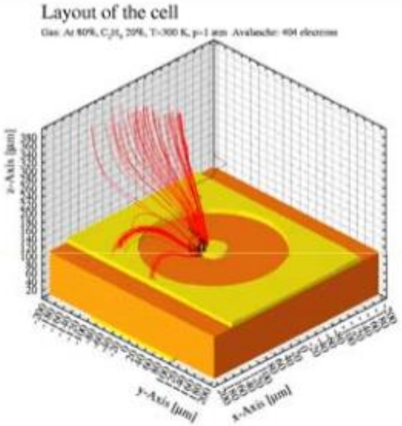
Figure 1: Electron avalanche and ion drift lines.



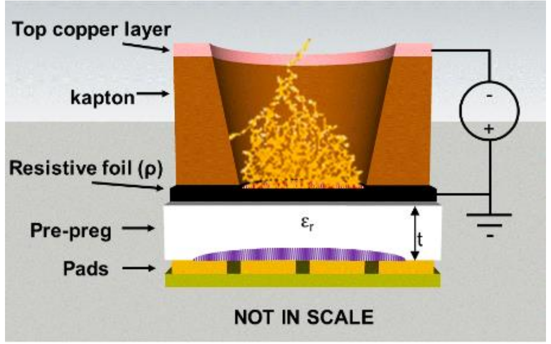
https://cds.cern.ch/record/2152254/files/arXiv:1605.02896.pdf



http://www-flc.desy.de/tpc/projects/GEM_simulation/



Development and tests of m-PIC Resistive Cathode, A. Ochi



https://cds.cern.ch/record/2238861/files/10.1088_1748-0221_10_02_P02008.pdf

Dissemination of MPGDs

Starting with the LHC

A remark:
Tables are from 2017…

- Some of the latest developments (as mRWELL detectors / LHCb muon system upgrade – small resistive pad micromegas for ATLAS muon tagger) **to be added** as potential candidates for future upgrades..
- Some of the listed options **to be removed** (CMS GEM/mm calorimetry..)

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
ATLAS Muon System Upgrade: Start: 2019 (for 15 y.)	High Energy Physics (Tracking/Triggering)	Micromegas	Total area: 1200 m^2 Single unit detect: (2.2x1.4m^2) ~ 2-3 m^2	**Max. rate**:15 kHz/cm^2 **Spatial res.:** <100μm **Time res.:** ~ 10 ns **Rad. Hard.:** ~ 0.5C/cm^2	- Redundant tracking and triggering; Challenging constr. in mechanical precision:
ATLAS Muon Tagger Upgrade: Start: > 2023	High Energy Physics (Tracking/triggering)	μ-PIC	Total area: ~ 2m^2	**Max.rate**:100kHz/cm^2 **Spatial res.:** < 100μm	
CMS Muon System Upgrade: Start: > 2020	High Energy Physics (Tracking/Triggering)	GEM	Total area: ~ 143 m^2 Single unit detect: 0.3-0.4m^2	**Max. rate**:10 kHz/cm^2 **Spatial res.:** ~100μm **Time res.:** ~ 5-7 ns **Rad. Hard.:** ~ 0.5 C/cm^2	- Redundant tracking and triggering
CMS Calorimetry (BE) Upgrade Start > 2023	High energy Physics (Calorimetry)	Micromegas, GEM	Total area: ~ 100 m^2 Single unit detect: 0.5m^2	**Max. rate**: 100 MHz/cm^2 **Spatial res.:** ~ mm	Not main option; could be used with HGCAL (BE part)
ALICE Time Projection Chamber: Start: > 2020	Heavy-Ion Physics (Tracking + dE/dx)	GEM w/ TPC	Total area: ~ 32 m^2 Single unit detect: up to 0.3m^2	**Max.rate**:100 kHz/cm^2 **Spatial res.:** ~300μm **Time res.:** ~ 100 ns **dE/dx:** 12 % (Fe55) **Rad. Hard.:** 50 mC/cm^2	- 50 kHz Pb-Pb rate; - Continues TPC readout - Low IBF and good energy resolution
TOTEM: Run: 2009-now	High Energy/ Forward Physics (5.3≤|eta|≤6.5)	GEM (semicircular shape)	Total area: ~ 4 m^2 Single unit detect: up to 0.03m^2	**Max.rate**:20 kHz/cm^2 **Spatial res.:** ~120μm **Time res.:** ~ 12 ns **Rad. Hard.:** ~ mC/cm^2	Operation in pp, pA and AA collisions.
LHCb Muon System Run: 2010 - now	High Energy / B-flavor physics (muon triggering)	GEM	Total area: ~ 0.6 m^2 Single unit detect: 20-24 cm^2	**Max.rate**:500 kHz/cm^2 **Spatial res.:** ~ cm **Time res.:** ~ 3 ns **Rad. Hard.:** ~ C/cm^2	- Redundant triggering
FCC Collider Start: > 2035	High Energy Physics (Tracking/Triggering/ Calorimetry/Muon)	GEM,THGEM Micromegas, μ-PIC, InGrid	Total area: 10.000 m^2 (for MPGDs around 1.000 m^2)	**Max.rate**:100 kHz/cm^2 **Spatial res.:** <100μm **Time res.:** ~ 1 ns	Maintenance free for decades

Maksym Titov, Conference Summary, 5th International Conference on Micro-Pattern Gas Detectors (MPGD2017), Temple University, Philadelphia,

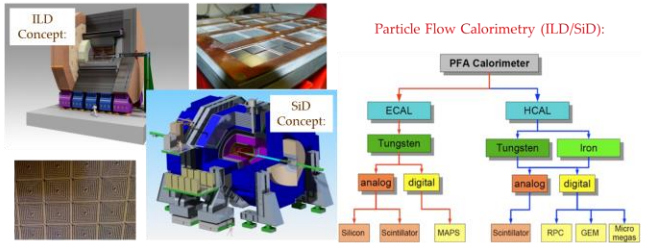
Dissemination of MPGDs

LHC

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
ATLAS Muon System Upgrade: Start: 2019 (for 15 y.)	High Energy Physics (Tracking/Triggering)	Micromegas	Total area: 1200 m² Single unit detect: (2.2x1.4m²) ~ 2-3 m²	**Max. rate:** 15 kHz/cm² **Spatial res.:** <100μm **Time res.:** ~ 10 ns **Rad. Hard.:** ~ 0.5C/cm²	- Redundant tracking and triggering; Challenging constr. in mechanical precision:
ATLAS Muon Tagger Upgrade: Start: > 2023	High Energy Physics (Tracking/triggering)	μ-PIC	Total area: ~ 2m²	**Max.rate:** 100kHz/cm² **Spatial res.:** < 100μm	
CMS Muon System Upgrade: Start: > 2020	High Energy Physics (Tracking/Triggering)	GEM	Total area: ~ 143 m² Single unit detect: 0.3-0.4m²	**Max. rate:** 10 kHz/cm² **Spatial res.:** ~100μm **Time res.:** ~ 5-7 ns **Rad. Hard.:** ~ 0.5 C/cm²	- Redundant tracking and triggering
CMS Calorimetry (BE) Upgrade Start > 2023	High energy Physics (Calorimetry)	Micromegas, GEM	Total area: ~ 100 m² Single unit detect: 0.5m²	**Max. rate:** 100 MHz/cm² **Spatial res.:** ~ mm	Not main option; could be used with HGCAL (BE part)
ALICE Time Projection Chamber: Start: > 2020	Heavy-Ion Physics (Tracking + dE/dx)	GEM w/ TPC	Total area: ~ 32 m² Single unit detect: up to 0.3m²	**Max.rate:** 100 kHz/cm² **Spatial res.:** ~300μm **Time res.:** ~ 100 ns **dE/dx:** 12 % (Fe55) **Rad. Hard.:** 50 mC/cm²	- 50 kHz Pb-Pb rate; - Continues TPC readout - Low IBF and good energy resolution
TOTEM: Run: 2009-now	High Energy/ Forward Physics (5.3≤|eta|≤6.5)	GEM (semicircular shape)	Total area: ~ 4 m² Single unit detect: up to 0.03m²	**Max.rate:** 20 kHz/cm² **Spatial res.:** ~120μm **Time res.:** ~ 12 ns **Rad. Hard.:** ~ mC/cm²	Operation in pp, pA and AA collisions.
LHCb Muon System Run: 2010 - now	High Energy / B-flavor physics (muon triggering)	GEM	Total area: ~ 0.6 m² Single unit detect: 20-24 cm²	**Max.rate:** 500 kHz/cm² **Spatial res.:** ~ cm **Time res.:** ~ 3 ns **Rad. Hard.:** ~ C/cm²	- Redundant triggering
FCC Collider Start: > 2035	High Energy Physics (Tracking/Triggering/ Calorimetry/Muon)	GEM,THGEM Micromegas, μ-PIC, InGrid	Total area: 10.000 m² (for MPGDs around 1.000 m²)	**Max.rate:** 100 kHz/cm² **Spatial res.:** <100μm **Time res.:** ~ 1 ns	Maintenance free for decades

MPGD Technologies for the International Linear Collider

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
ILC Time Projection Chamber for ILD: Start: > 2030	High Energy Physics (tracking)	Micromegas GEM (pads) InGrid (pixels)	Total area: ~ 20 m² Single unit detect: ~ 400 cm² (pads) ~ 130 cm² (pixels)	**Max. rate:** < 1 kHz **Spatial res.:** <150μm **Time res.:** ~ 15 ns **dE/dx:** 5 % (Fe55) **Rad. Hard.:** no	Si + TPC Momentum resolution : dp/p < 9*10-5 1/GeV Power-pulsing
ILC Hadronic (DHCAL) Calorimetry for ILD/SiD Start > 2030	High Energy Physics (calorimetry)	GEM, THGEM RPWELL, Micromegas	Total area: ~ 4000 m² Single unit detect: 0.5 - 1 m²	**Max.rate:** 1 kHz/cm² **Spatial res.:** ~ 1cm **Time res.:** ~ 300 ns **Rad. Hard.:** no	Jet Energy resolution: 3-4 % Power-pulsing, self-triggering readout



MPGD Tracking Concepts for Hadron / Nuclear Physics

Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics/ Performance	Special Requirements/ Remarks
COMPASS @ CERN Run: 2002 - now	Hadron Physics (Tracking)	GEM Micromegas w/ GEM preampl.	Total area: 2.6 m² Single unit detect: 0.31x0.31 m² Total area: ~ 2 m² Single unit detect: 0.4x0.4 m²	**Max.rate:** 10^7 Hz (~100kHz/mm²) **Spatial res.:** ~70-100μm (strip), ~120μm (pixel) **Time res.:** ~ 8 ns **Rad. Hard.:** 2500 mC/cm²	Required beam tracking (pixelized central / beam area)
KEDR @ BINP Run: 2010-now	Particle Physics (Tracking)	GEM	Toral area: ~0.1 m²	**Max. rate:** 1 MHz/mm² **Spatial res.:** ~70μm	
SBS in Hall A @ JLAB Start: > 2017	Nuclear Physics (Tracking) nucleon form factors / struct.	GEM	Total area 14 m² Single unit detect. 0.6x0.5m²	**Max. rate:** 400 kHz/cm² **Spatial res.:** ~70μm **Time res.:** ~ 15 ns **Rad. Hard.:** 0.1-1 kGy/y.	
pRad in Hall B @ JLAB Start: 2017	Nuclear Physics (Tracking) precision meas. of proton radius	GEM	Total area: 1.5m² Single unit detect. 1.2x0.6 m2	**Max. rate:** 5 kHz/cm² **Spatial res.:** ~70μm **Time res.:** ~ 15 ns **Rad. Hard.:** 10 kGy/y.	
SoLID in Hall A@ JLAB Start: ~ > 2020	Nuclear Physics (Tracking)	GEM	Total area: 40m² Single unit detect. 1.2x0.6 m2	**Max. rate:** 600 kHz/cm² **Spatial res.:** ~100μm **Time res.:** ~ 15 ns **Rad. Hard.:** 0.8-1 kGy/y.	
E42 and E45 @JPARC Start: ~2020	Hadron Physics (Tracking)	TPC w/ GEM, gating grid	Total area: 0.26m² 0.52m(diameter) x0.5m(drift length)	**Max. rate:** 10⁶ kHz/cm² **Spatial res.:** 0.2-0.4 mm	Gating grid operation ~ 1kHz
ACTAR TPC Start: ~2020 for 10 y.	Nuclear physics Nuclear structure Reaction processes	TPC w/ Micromegas (amp. gap -220 μm)	2 detectors: 25*25 cm2 and 12.5*50cm2	Counting rate < 10^4 nuclei but higher if some beam masks are used.	Work with various gas (He mixture, iC4H10, D2…)

Cylindrical MPGDs as Inner Trackers for Particle / Nuclear Physics

Experiment/ Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics/ Performance	Special Requirements/ Remarks
KLOE-2 @ DAFNE Run: 2014-2017	Particle Physics/ K-flavor physics (Tracking)	Cylindrical GEM	Total area: 3.5m² 4 cylindrical layers L(length) = 700mm R (radius) = 130, 155, 180, 205 mm	**Spatial res**:(r phi) = 250um **Spat. res.(z)** = 350um	- Mat. budget 2% X0 - Operation in 0.5 T
BESIII Upgrade @ Beijing Run: 2018-2022	Partcile Physics/ e+e- collider (Tracking)	Cylindrical GEM	3 cylindrical layers R ~ 20 cm	**Max. rate**: 10 kHz/cm² **Spatial res**:(xy) = 130um **Spat. res.(z)** ~ 1 mm	- Material ≤ 1.5% of X_0 for all layers - Operation in 1T
CLAS12 @ JLAB Start: > 2017	Nuclear Physics/ Nucleon structure (tracking)	Planar (forward) & Cylindrical (barrel) Micromegas	Total area: Forward ~ 0.6 m² Barrel ~ 3.7 m² 2 cylindrical layers R ~ 20 cm	**Max. rate**: ~ 30 MHz **Spatial res.**: < 200μm **Time res.**: ~ 20 ns	- Low material budget : 0.4 % X0 - Remote electronics
ASACUSA @ CERN Run: 2014 - now	Nuclear Physics (Tracking and vertexing of pions resulting from the p-antip annihilation	Cylindrical Micromegas 2D	2 cylindrical layers L = 60 cm R = 85, 95 mm	**Max. trigger rate**: kHz **Spatial res.**: ~200μm **Time res.**: ~ 10 ns **Rad. Hard.**: 1 C/cm²	- Large magnetic field that varies from -3 to 4T in the active area
MINOS Run: 2014-2016	Nuclear structure	TPC w/ cylindrical Micromegas	1 cylindrical layer L=30 cm, R = 10cm	**Spatial res.**: <5 mm FWHM Trigger rate up to ≈1 KHz	- Low material budget
CMD-3 Upgrade @ BINP Start: > ~2019 ?	Particle physics (z-chamber, tracking)	Cylindrical GEM	Total arear: ~ 3m² 2 cylindrical layers	**Spatial res.**: ~100μm	

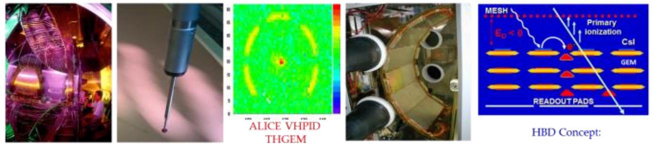
Good examples of geometries/shapes

MPGD Tracking for Heavy Ion / Nuclear Physics

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements/ Remarks
STAR Forward GEM Tracker @ RHIC Run: 2012-present	Heavy Ion Physics (tracking)	GEM	Total area: ~ 3 m² Single unit detect: ~ 0.4 x 0.4 m²	**Spatial res.**: 60-100 μm	Low material budget:: < 1% X0 per tracking layer
Nuclotron BM@N @ NICA/JINR Start: > 2017	Heavy Ions Physics (tracking)	GEM	Total area: ~ 12 m² Single unit detect: ~ 0.9 m²	**Max. rate**: ~ 300 MHz **Spatial res.**: ~ 200μm	Magnetic field 0.5T orthogonal to electric field
SuperFRS @ FAIR Run: 2018-2022	Heavy Ion Physics (tracking/diagnostics at the In-Fly Super Fragment Separator)	TPC w/ GEMs	Total area:~ few m² Single unit detect: Type I : 50 x 9 cm² Type II: 50 x 16 cm²	**Max. rate**:~ 10^7 Hz/spill **Spatial res.**: < 1 mm	High dynamic range Particle detection from p to Uranium
PANDA @FAIR Start > 2020	Nuclear physics p - anti-p (tracking)	Micromegas/ GEMs	Total area: ~ 50 m² Single unit detect: ~ 1.5 m²	**Max. rate**: < 140kHz/cm² **Spatial res.**: ~ 150μm	Continuous-wave operation: 10¹¹ interaction/s
CBM @ FAIR: Start: > 2020	Nuclear Physics (Muon System)	GEM	Total area: 9m² Single unit detect: 0.8x0.5m²-0.4m²	**Spatial res.**: < 1 mm **Max. rate**: 0.4 MHz/cm² **Time res.**: ~ 15ns **Rad hard.**: 10¹³ n.eq./cm²/year	Self-triggered electronics
Electron-Ion Collider (EIC) Start: > 2025	Hadron Physics (tracking, RICH)	TPC w/GEM readout Large area GEM planar tracking detectors	Total area: ~ 3 m² Total area: ~ 25 m²	**Spatial res.**: ~ 100 um (rϕ) Luminosity (e-p): 10³³ **Spatial res.**: ~ 50- 100 um **Max. rate**: ~ MHz/cm²	Low material budget Low material budget

MPGD Technologies for Photon Detection

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
COMPASS RICH UPGRADE Start > 2016	Hadron Physics (RICH - detection of single VUV photons)	Hybrid (THGEM + CsI and MM)	Total area: ~ 1.4 m² Single unit detect: ~ 0.6 x 0.6 m²	**Max.rate**:100 Hz/cm² **Spatial res.**: <~ 2.5 mm **Time res.**: ~ 10 ns	Production of large area THGEM of sufficient quality
PHENIX HBD Run: 2009-2010	Nuclear Physics (RICH – e/h separation)	GEM+CsI detectors	Total area: ~ 1.2 m² Single unit detect: ~ 0.3 x 0.3 m²	**Max. rate**: low **Spatial res.**: ~ 5 mm (rϕ) **Single el. eff.**: ~ 90 %	Single el. eff. depends from hadron rejection factor
SPHENIX Run: 2021-2023	Heavy Ions Physics (tracking)	TPC w/GEM readout	Total area: ~ 3 m²	**Multiplicity**: dNch/dy ~ 600 **Spatial res.**: ~ 100 um (rϕ)	Runs with Heavy Ions and comparison to pp operation
Electron-Ion Collider (EIC) Start: > 2025	Hadron Physics (tracking, RICH)	TPC w/GEM readout + Cherenkov RICH with GEM readout	Total area: ~ 3 m² Total area: ~ 10 m²	**Spatial res.**: ~ 100 um (rϕ) Luminosity (e-p): 10³³ **Spatial res.**: ~ few mm	Low material budget High single electron efficiency



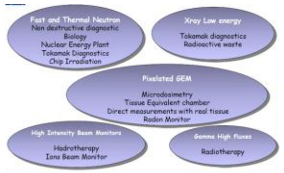
Maksym Titov, Conference Summary, 5th International Conference on Micro-Pattern Gas Detectors (MPGD2017), Temple University, Philadelphia,

Dissemination of MPGDs

Maksym Titov, Conference Summary, 5th International Conference on Micro-Pattern Gas Detectors (MPGD2017), Temple University, Philadelphia.

https://indico.cern.ch/event/581417/contributions/2558346/attachments/1465881/2266161/2017_05_Philadelphia_MPGD2017-ConferenceSummary_25052017_MS.pdf

MPGD-based Neutron Detectors



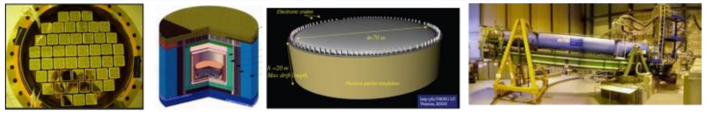
MPGD coupled to n-converters:

- ITER / Spallation Sources
- Neutron-beam diagnostics

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size)	Operation Characteristics / Performance	Special Requirements / Remarks
ESS NMX: Neutron Macromolecular Crystallography Start: > 2020(for 10 y.)	Neutron scattering Macromolecular Crystallography	GEM w/ Gd converter	Total area: ~ 1 m^2 Single unit detect: 60x60 cm^2	**Max.rate**: 100 kHz/mm^2 **Spatial res.**: ~500μm **Time res.**: ~ 10 us n.-eff: ~ 20% efficient - γ rejection of 100	Localise the secondary particle from neutron conversion in Gd with < 500um precision
ESS LOKI- SANS: Small Angle Neutron Scattering (Low Q) Start: > 2020(for 10 y.)	Neutron scattering: Small Angle	GEM w/ borated cathode	Total area: ~ 1 m^2 Single unit detect: 33x40 cm^2 trapezoid	**Max.rate**: 40 kHz/mm^2 **Spatial res.**: ~4 mm **Time res.**: ~ 100 us n. –eff. >60% (at λ= 4 Å) - γ rejection of 10^-7	Measure TOF of neutron interaction in a 3D borated cathode
SPIDER: ITER NBI PROTOTYPE Start: ~ 2017(for 10 y.)	CNESM diagnostic: Characterization of neutral deuterium beam for ITER plasma heating using neutron emission	GEMs w/ Al-converter (Directionality - angular) capability)	Single unit detect: 20x35 cm^2	**Max.rate**: 100 kHz/mm^2 **Spatial res.**: ~ 10 mm **Time res.**: ~ 10 ms n.-eff: >10^-5 γ rejection of 10^-7	Measurement of the n-emission intensity and composition to correct deuterium beam parameters
n_TOF beam monitoring/ beam profiler Run: 2008-now	Neutron Beam Monitors	MicroMegas μbulk and GEM w/ converters	Total area: ~ 100cm^2	**Max.rate**:10 kHz **Spatial res.**: .: ~300μm **Time res.**: ~ 5 ns **Rad. Hard.**: no	

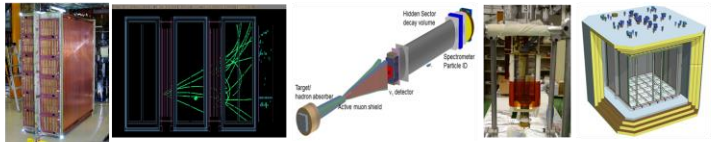
MPGD Technologies for Dark Matter Detection

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
DARWIN (multi-ton dual-phase LXe TPC) Start: >2020s	Dark Matter Detection	THGEM-based GPMT	Total area: ~30m^2 Single unit detect. ~20 x20 cm^2	**Max.rate**: 100 Hz/cm^2 **Spatial res.**: ~ 1cm **Time res.**: ~ few ns **Rad. Hard.**: no	Operation at ~180K, radiopure materials, dark count rate ~1 Hz/cm^2
PANDAX III @ China Start: > 2017	Astroparticle physics Neutrinoless double beta decay	TPC w/ Micromegas μbulk	Total area: 1.5 m^2	**Energy Res.**: ~ 1-3% @ 2 MeV **Spatial res.**: ~ 1 mm	High radiopurity High-pressure (10b Xe)
NEWAGE@ Kamioka Run: 2004-now	Dark Matter Detection	TPC w/ GEM+μPIC	Single unit det. ~ 30x30x41(cm^3)	Angular resolution: 40˚ @ 50keV	
CAST @ CERN: Run: 2002-now	AstroParticle Physics: Axions, Dark Energy/ Matter, Chameleons detection	Micromegas μbulk and InGrid (coupled to X-ray focusing device)	Total area: 3 MM μbulks of 7x 7cm^2 Total area: 1 InGrid of 2cm^2	**Spatial res.**: ~100μm **Energy Res**: 14% (FWHM) @ 6keV **Low bkg. levels (2-7 keV)**: μMM: 10-6 cts s-1keV-1cm-2 InGrid: 10-5 cts s-1keV-1cm-2	High radiopurity, good separation of tracklike bkg. from X-rays
IAXO Start: > 2023 ?	AstroParticle Physics: Axions, Dark Energy/ Matter, Chameleons detection	Micromegas μbulk, CCD, InGrid (+ X-ray focusing device)	Total area: 8 μbulks of 7 x 7cm2	Energy Res: 12% (FWHM) @ 6keV **Low bkg. Levels (1-7 keV)**: μbulk: 10-7cts s-1keV-1cm-2	High radiopurity, good separation of tracklike bkg. from X-rays



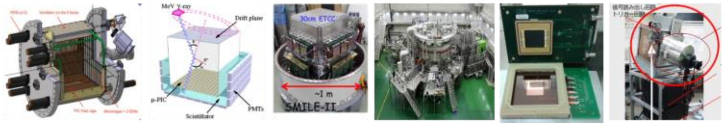
MPGD Technologies for Neutrino Physics

Experiment / Timescale	Application Domain	MPGD Technology	Total detector size / Single module size	Operation Characteristics / Performance	Special Requirements / Remarks
T2K @ Japan Start: 2009 - now	Neutrino physics (Tracking)	TPC w/ Micromegas	Total area: ~ 9 m^2 Single unit detect: 0.36x0.34m^2~0.1m^2	**Spatial res.**: 0.6 mm **dE/dx**: 7.8% (MIP) **Rad. Hard.**: no Moment. res.:9% at 1 GeV	The first large TPC using MPGD
SHiP @ CERN Start: 2025-2035	Tau Neutrino Physics (Tracking)	Micromegas, GEM, mRWELL	Total area: ~ 26 m^2 Single unit detect: 2 x 1 m^2 – 2m^2	**Max. rate**: < low **Spatial res.**: < 150 μm **Rad. Hard.**: no	Provide time stamp of the neutrino interaction in brick"
LBNO-DEMO (WA105 @ CERN): Start: > 2016	Neutrino physics (Tracking+ Calorimetry)	LAr TPC w/ THGEM double phase readout	Total area: 3 m^2 (WA105-3x1x1) 36 m^2 (WA105-6x6x6) Single unit detect. (0.5x0.5 m2) ~0.25 m^2	WA105 3x1x1 and 6x6x6: **Max. rate**: 150 Hz/m^2 **Spatial res.**: 1 mm **Time res.**: ~ 10 ns **Rad. Hard.**: no	Detector is above ground (max. rate is determined by muon flux for calibration)
DUNE Dual Phase Far Detector Start: > 2023?		LAr TPC w/ THGEM double phase readout	Total area: 720 m^2 Single unit detect. (0.5x0.5 m2) ~ 0.25 m^2	**Max. rate**: $4*10^{-7}$ Hz/m^2 **Spatial res.**: 1 mm **Rad. Hard.**: no	Detector is underground (rate is neutrino flux)



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

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



Wide spectrum of applications and instruments.

Different requirements and operation conditions depending on the specific application.

In the second part of this lecture we will try to highlight one of the reason why these technologies can be adapted to a wide sets of requirements (not all at the same time of course..)

MPGD for LHC (LS2 Upgrades) / Important milestone in the context of instrumenting large area systems

https://indico.cern.ch/event/1038992/contributions/4363702/attachments/2256312/3829107/LHCC_146th_ALICE_Status_Mesut_Arslandok_comp.pdf

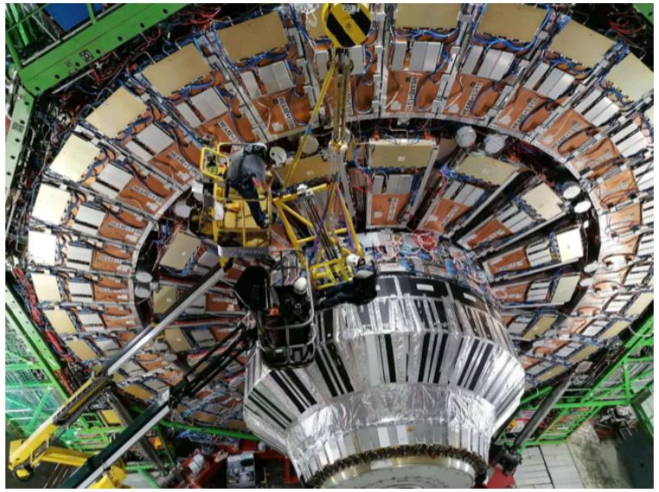
ALICE

TPC
GEM

ATLAS EXPERIMENT

Muon System (NSW) micromegas

https://indico.cern.ch/event/1038992/contributions/4363710/attachments/2256387/3828801/LHCC_ATLAS_OpenSession_June2nd.pdf



GE1/1 chambers being installed in CMS thereby completing the installation of the first station by Michele Bianco, Antonio Conde Garcia and Stephane Brachet of the EP-CMX Group.

https://ep-news.web.cern.ch/cms-gems-are-changing-gear

CMS

Muon System (GE1/1) GEM

THIS PART WILL BE STRONGLY FOCUSED ON DEVELOPMENTS AND INSTRUMENTS IN HEP and AT CERN

Instrumentation/MPGD[1]

From a new technology to mature INSTRUMENTS

Using Gas Electron Multipliers (GEM) as one example

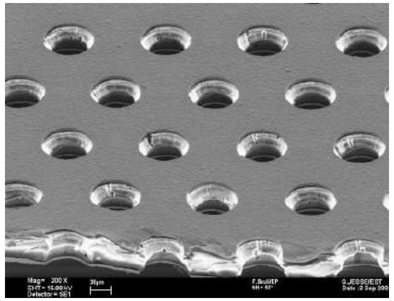
We will go through the path between the introduction of GEM and one of the latest applications (instrumenting large area detector systems @ the LHC).

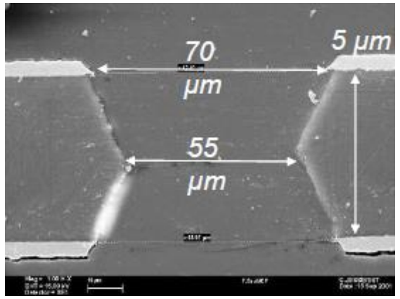
Gas Electron Multiplier (GEM)

In the next slides we will try to bridge 1996 (first GEM) and 2020 (GEM @ ALICE TPC/CMS MOUNS)

GEM: A new concept for electron amplification in gas detectors, F. Sauli, Nucl. Instr. and Meth. A386(1997)531

A thin, metal-clad polymer foil chemically perforated by a high density of holes, typically 100/mm2





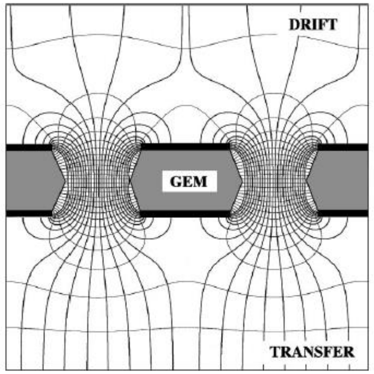
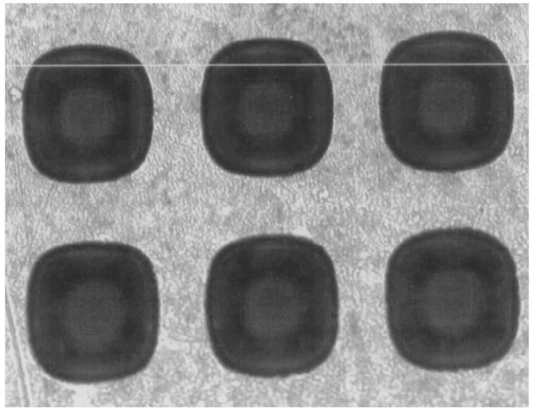
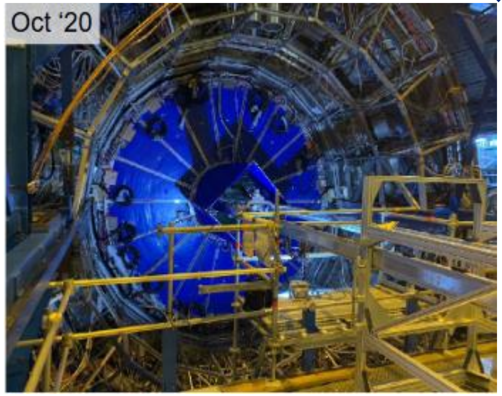


Figure 34 Electric field and equipotentials lines in the gas electron multiplier.

Amplification and Transfer

GDD, CERN, 1996(7)





ALICE TPC, CERN, 2020

CMS, GEM MUONS, 2020

Just a reminder about the context..
From few slides above (1)

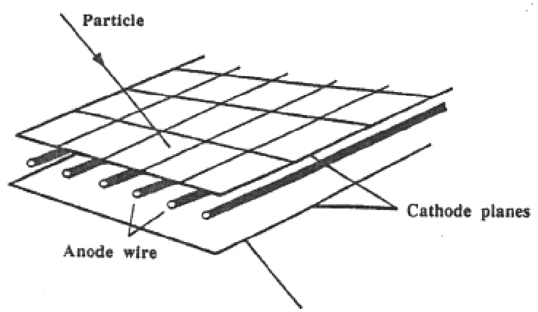
80's

Multi Wire Proportional Chamber (**MWPC**)

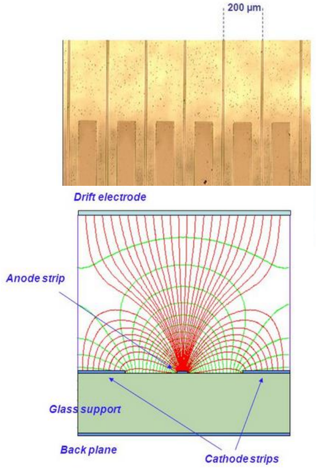
Limited multi-track separation: mechanical instabilities due to electrostatic repulsion - critical length of about 25cm for 10μm wires and 1mm spacing]

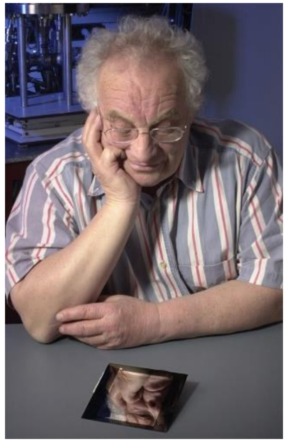
Fast gain drop at high fluxes: field-distorting space charge accumulation due to the long time taken by the ions produced in the avalanches to clear the region of multiplication.

Aging: permanent damage of the structures after long-term exposure to radiation due to the formation of solid deposits on electrodes.



De gauche à droite, Georges Charpak, Fabio Sauli et Jean-Claude Santiard en train de travailler sur une chamber multifils en 1970. (Image : CERN)





90's

Novel **photolithographic techniques** + A. Oed: Micro Strip Gas Chamber (**MSGC**, A.Oed, 1988)

Thanks to photolithography, it will be possible to go down in size from millimeters to tens of microns reducing the gas volume "used" by single events (improved occupancy) and faster evacuation of ions (reduced space charge).

Just a reminder about the context..
From few slides above (2)

MSGC (Oed A. Nucl. Instrum. Methods A263:351 (1988))

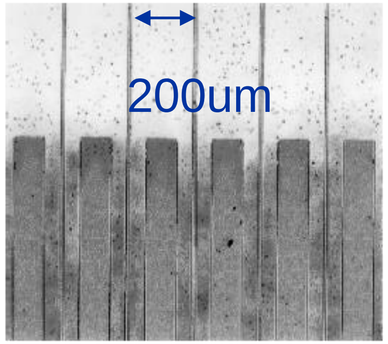


Figure 1 Close view of one of the first microstrip plates developed by Oed at the Institut Laue-Langevin. On an insulating substrate, thin metallic anode strips alternate with wider cathodes; the pitch is 200 μm.

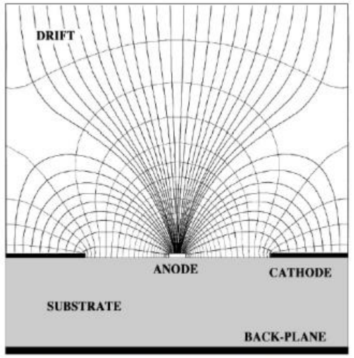
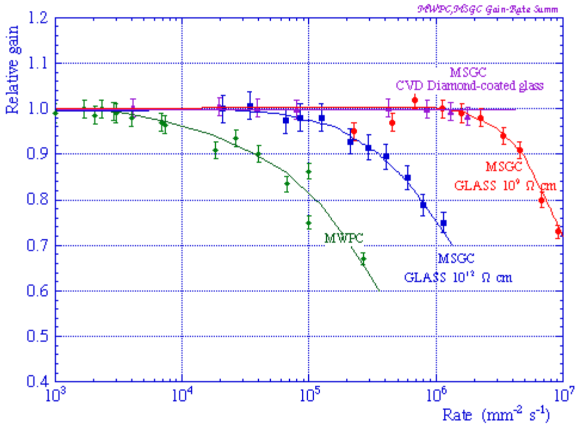


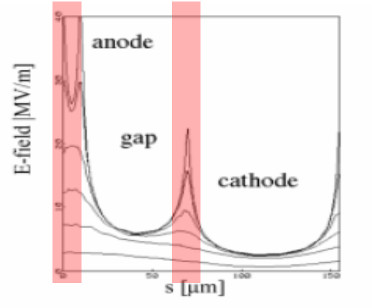
Figure 2 Equipotentials and field lines in the microstrip chamber, computed close to the substrate. The back-plane potential has been selected to prevent field lines entering the dielectric.



Excellent localization, high rate capability (reduced space charge build-up), good granularity

.. but some drawback

Strong field at anode as well at cathode.



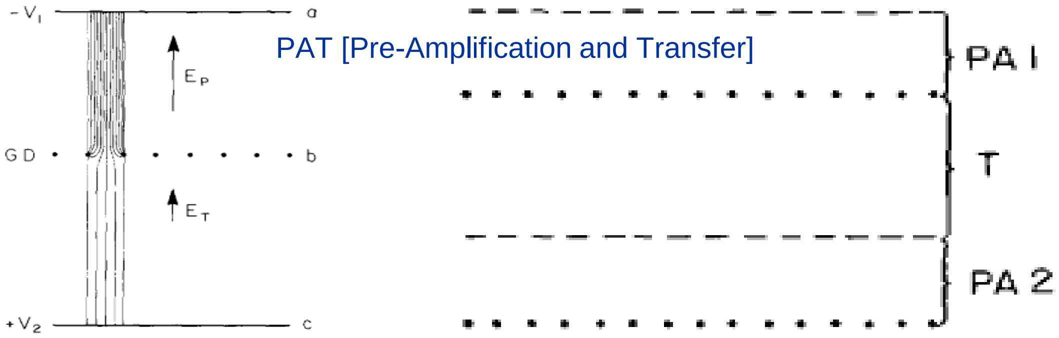
Prone to discharges.. Low mass and bad power dissipation… fragile

MSGC/Discharges…

Several strategies to solve the problem .. Among the others, one approach was to support the MSGC with a pre-amplification stage (coming from previous works from the 70's where amplification and transfer devices have been studied and proved their effectiveness of obtaining larger gain in safe condition

Multistep Avalanche Chamber (Charpak G, Sauli F. Phys. Lett. B78:523 (1978))

Made with a succession of metal meshes, the detector multiplied ionization electrons injected from a drift region into a high field. A fraction of the avalanche was then transferred through a lower field region into a second element of multiplication, a parallel plate or a wire chamber. **Despite the loss of charge in the transfer from high to moderate fields, effective pre-amplification factors of several hundred were possible**. Followed by a standard MWPC, the device permitted the high gains necessary to detect single photoelectrons.



"The multistep chamber **was mechanically complex to implement and had only limited success**, but demonstrated the **great potential of subdividing the gain among several cascaded elements separated by low-field gaps**" (F.Sauli)

mechanically complex.. new technological advancement in manufacturing techniques offered the way to have a good device that can do this.. Gas Electron Multipliers

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 386 (1997) 531–534

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Letter to the Editor

GEM: A new concept for electron amplification in gas detectors

F. Sauli

CERN, CH-1211 Genève, Switzerland

Received 6 November 1996

Abstract

We introduce the gas electrons multiplier (GEM), a composite grid consisting of two metal layers separated by a thin insulator, etched with a regular matrix of open channels. A GEM grid with the electrodes kept at a suitable difference of potential, inserted in a gas detector on the path of drifting electror channels. Coupled to other devices, multiwire or microstrip chambe critical conditions. The separation of sensitive and detection volumes offers other advantages: a built-in delay, a strong suppression of photon feedback. Applications are foreseen in high rate tracking and Cherenkov Ring Imaging detectors. Multiple GEM grids assembled in the same gas volume allow to obtain large effective amplification factors in a succession of steps.

Nov. 96

Pre-amplification and Transfer

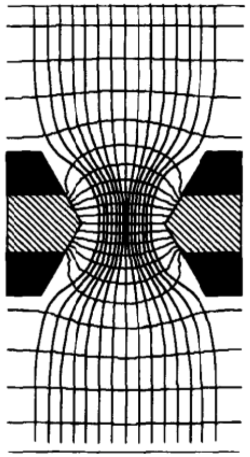


Fig. 2. Computed electric field in the multiplying channel. Only the central field lines have been plotted.

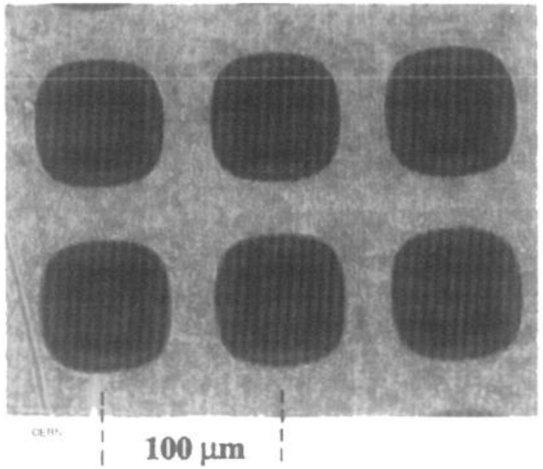
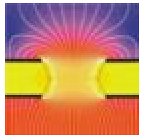


Fig. 1. Microphotography of the three-layer (metal–insulator–metal) GEM grid. The open channels diameter at the surface is 70 µm, with 100 µm distance.

Two metal layers separated by a thin insulator (Kapton/apical), etched with a regular matrix of open channels

J-C Labbe’ with R. de Oliveira and A. Gandi (*CERN* Surface Treatment Service, fabrication technology)



Gas Detector Development (GDD) lab at CERN

EUROPEAN LABORATORY FOR PARTICLE PHYSICS

CERN-PPE/96-177
4 November 1996

THE GAS ELECTRON MULTIPLIER (GEM)

R.Bouclier, M.Capeáns, W.Dominik, M.Hoch, J-C.Labbé, G.Million,
L.Ropelewski, F.Sauli and A.Sharma[a]

CERN, CH-1211 Genève, Switzerland
[a] VUB-ULB Brussels, Belgium

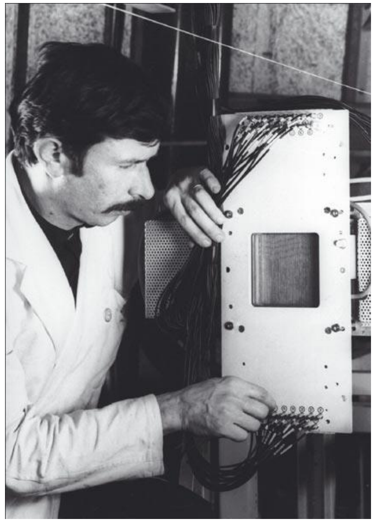
ABSTRACT

We describe operating principles and results obtained with a new detector component: the Gas Electrons Multiplier (GEM). Consisting of a thin composite sheet with two metal layers separated by a thin insulator, and pierced by a regular matrix of open channels, the GEM electrode, inserted on the path of electrons in a gas detector, allows to transfer the charge with an amplification factor approaching ten. Uniform response and high rate capability are demonstrated. Coupled to another device, multiwire or micro-strip chamber, the GEM electrode permit to obtain higher gains or less critical operation; separation of the sensitive (conversion) volume and the detection volume has other advantages, as a built-in delay (useful for triggering purposes) and the possibility of applying high fields on the photo-cathode of ring imaging detectors to improve efficiency.

Multiple GEM grids in the same gas volume allow to obtain large amplification factors in a succession of steps, leading to the realization of an effective gas-filled photomultiplier.

Presented by F. Sauli at the
IEEE1996 Nuclear Science Symposium and Medical Imaging Conference
Anaheim, November 3-9, 1996

F, Sauli: the inventor



R. Bouclier (in this picture with the MWPC #1): most likely the first one switching on a GEM…

L. Ropelewski, the first one seeing signals from GEM only

PMT (Photolithography & Microconnectics Technologies DEM-PMT)Workshop at CERN

The first large size GEMs produced in the PMT workshop for HERA-B.
(left to right: Angelo Gandi, Rui De Oliveira and Jean-Claude Labbé)

J-C Labbe' with R. de Oliveira and A. Gandi (*CERN* Surface Treatment Service, fabrication technology)

In paper #1.. Proof of concept (GEM+MSGC) + future perspective (vision)

[future] Can be a detector by itself?

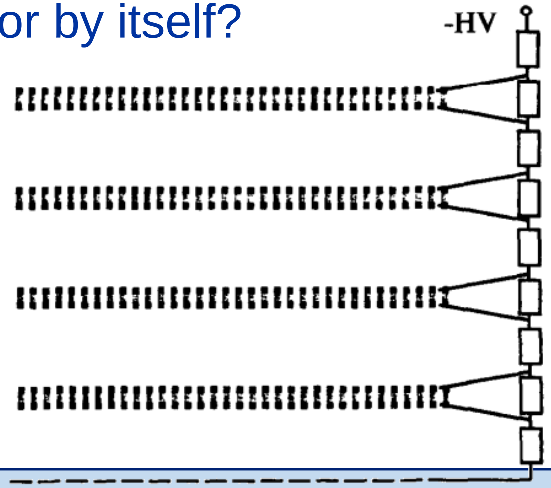


Fig. 6. A multi-grid GEM multiplier; electrons are amplified in a succession of steps. The readout can be implemented with a conventional multiwire or microstrip chamber, or directly on pad rows.

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 386 (1997) 531–534

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Letter to the Editor

GEM: A new concept for electron amplification in gas detectors

F. Sauli

CERN, CH-1211 Genève, Switzerland

Received 6 November 1996

Abstract

We introduce the gas electrons multiplier (GEM), a composite grid consisting of two metal layers separated by a thin insulator, etched with a regular matrix of open channels. A GEM grid with the electrodes kept at a suitable difference of potential, inserted in a gas detector on the path of drifting electrons, allows to pre-amplify the charge drifting through the channels. Coupled to other devices, multiwire or microstrip chambers, it permits to obtain higher gains, or to operate in less critical conditions. The separation of sensitive and detection volumes offers other advantages: a built-in delay, a strong suppression of photon feedback. Applications are foreseen in high rate tracking and Cherenkov Ring Imaging detectors. Multiple GEM grids assembled in the same gas volume allow to obtain large effective amplification factors in a succession of steps.

Nov. 96

The future already in paper#1

F. Sauli / Nucl. Instr. and Meth. in Phys. Res. A 386 (1997) 531–534 533

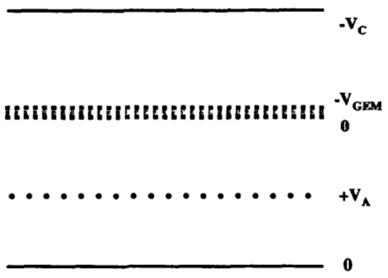


Fig. 3. Schematics of the test chamber used for the measurements. The GEM grid is installed replacing one cathode of a standard MWPC, and a drift volume is added.

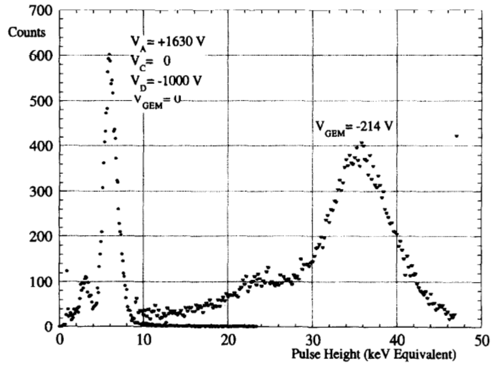


Fig. 4. [55]Fe pulse height recorded for X-rays directly converted in the MWPC (lower spectrum), and in the drift space with pre-amplification.

[future] Manufacturing Techniques

The success of the described applications will depend on the elaboration of a suitable, reliable technique for producing the GEM grids at a low cost.

Used as pre-amplification together with MWPC, MSGC

“A new generation of simple, reliable and cheap fast position-sensitive detectors seems at hand”

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 396 (1997) 50–66

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

New observations with the gas electron multiplier (GEM)

R. Bouclier[a], W. Dominik[a], M. Hoch[a], J.-C. Labbé[a], G. Million[a], L. Ropelewski[a], F. Sauli[a,*], A. Sharma[b], G. Manzin[c]

[a] Division PPE, CERN, CH-1211 Geneva 23, Switzerland
[b] GRPHE, Université de Haute Alsace, Mulhouse, France
[c] Laboratori Nazionali INFN, Legnaro, Italy

Received 28 February 1997

Feb. 97

https://doi.org/10.1016/S0168-9002(97)00648-7

operating voltages, completely eliminating discharge problems. Charge gains are large enough to allow detection of signals in the ionization mode on the last element, permitting the use of a simple printed circuit as read-out electrode; two-dimensional read out can then be easily implemented. The absence of charge multiplication in the last stage avoids charge build-up on the substrate and prevents ageing phenomena. A new generation of simple, reliable and cheap fast position-sensitive detectors seems at hand.

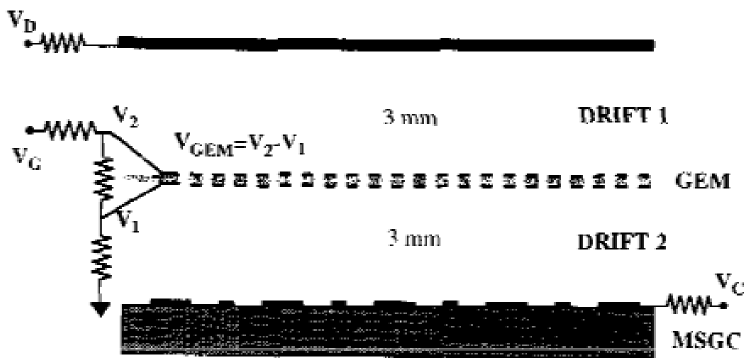


Fig. 12. Schematics of the MSGC + GEM assembly.

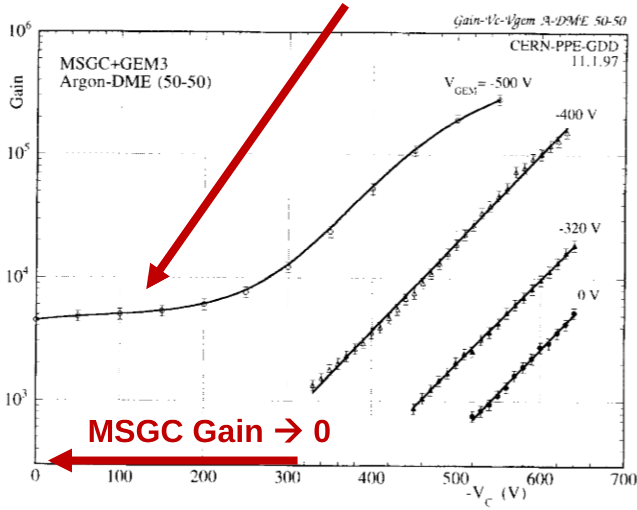


Fig. 13. Combined absolute gain of the MSGC – GEM detector, as a function of cathode voltage in the MSGC and potential across the GEM mesh. Gas filling: argon DME (50–50).

In the years right after the introduction of GEMs…

Searching in NIMA for Sauli/Ropelewski (CERN/GDD) in 1997-1999

Charge amplification and transfer processes in the gas electron multiplier
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 438, Issues 2–3, 11 December 1999, Pages 376-408
S. Bachmann, A. Bressan, L. Ropelewski, F. Sauli, … D. Mörmann

Recent progress in GEM manufacturing and operation
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 433, Issues 1–2, 21 August 1999, Pages 464-470
S. Bachmann, A. Bressan, L. Ropelewski, F. Sauli, D. Mörmann

Beam tests of the gas electron multiplier
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 425, Issues 1–2, 1 April 1999, Pages 262-276
A Bressan, J. C Labbé, P Pagano, L Ropelewski, F Sauli

High rate behavior and discharge limits in micro-pattern detectors
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 424, Issues 2–3, 21 March 1999, Pages 321-342
A Bressan, M Hoch, P Pagano, L Ropelewski, … A Sharma

Two-dimensional readout of GEM detectors
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 425, Issues 1–2, 1 April 1999, Pages 254-261
A Bressan, R De Oliveira, A Gandi, J. -C Labbé, … H. J Simonis

Further developments and beam tests of the gas electron multiplier (GEM)
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 419, Issues 2–3, 21 December 1998, Pages 410-417
J. Benlloch, A. Bressan, M. Capeáns, M. Gruwé, … F. Sauli

GEM operation in pure noble gases and the avalanche confinement
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 433, Issues 1–2, 21 August 1999, Pages 471-475
A. Buzulutskov, L. Shekhtman, A. Bressan, A. Di Mauro, … S. Biagi

Progress with the gas electron multiplier
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 409, Issues 1–3, 21 May 1998, Pages 79-83
C. Büttner, M. Capeáns, W. Dominik, M. Hoch, … A. Sharma

High gain operation of GEM in pure argon
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 423, Issue 1, 21 February 1999, Pages 119-124
A Bressan, A Buzulutskov, L Ropelewski, F Sauli, L Shekhtman

New observations with the gas electron multiplier (GEM)
Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 396, Issues 1–2, 1 September 1997, Pages 50-66
R Bouclier, W Dominik, M Hoch, J. -C Labbé, … G Manzin

NH ELSEVIER — Nuclear Instruments and Methods in Physics Research A 479 (2002) 294–308 — NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A — www.elsevier.com/locate/nima

Discharge studies and prevention in the gas electron multiplier (GEM)

S. Bachmann[a], A. Bressan[a], M. Capeáns[c], M. Deutel[a], S. Kappler[b], B. Ketzer[a], A. Polouektov[d], L. Ropelewski[a], F. Sauli[a,*], E. Schulte[e], L. Shekhtman[d], A. Sokolov[d]

[a] CERN, EP Division, 1211, Geneva, 23, Switzerland
[b] Institut für Experimentelle Kernphysik, Karlsruhe University, Germany
[c] Physikalisches Institut, Heidelberg University, Germany
[d] Budker Institute for Nuclear Physics, Novosibirsk, Russia
[e] Institute of Physics, Helsinki University, Finland

Received 18 December 2000; received in revised form 29 January 2001; accepted 5 March 2001

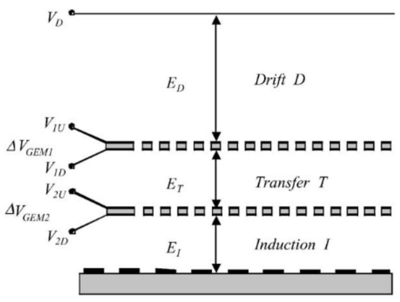


Fig. 1. Schematics of a double-GEM detector.

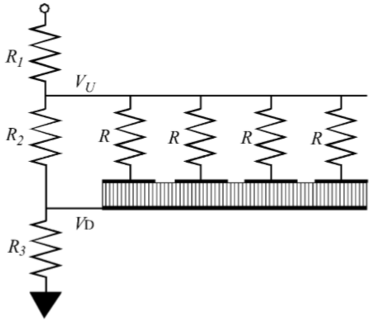


Fig. 2. Resistor partition network used to power a sectored GEM.

Long list of systematic measurement to optimize performances and stability

Stability vs number of gem foils, dependence on the asymmetry of the GEMs gain, discharge propagation probability, foil sectorization, powering,….

Most of the rules that we still follow today comes from those days …

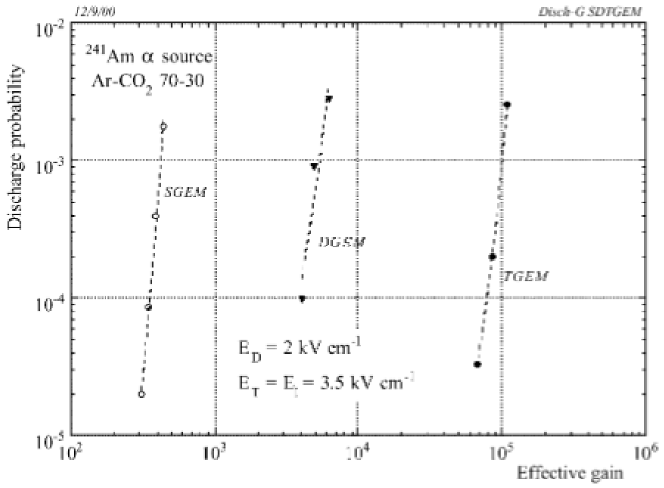


Fig. 8. Discharge probability as a function of total effective gain for single, double and triple GEM detectors.

One of the first applications: HERA-B MSGC

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
ELSEVIER Nuclear Instruments and Methods in Physics Research A 490 (2002) 223–242
www.elsevier.com/locate/nima

Studies of aging and HV break down problems during development and operation of MSGC and GEM detectors for the inner tracking system of HERA-B ☆

Y. Bagaturia[a], O. Baruth[b,1], H.B. Dreis[c,2], F. Eisele[c], I. Gorbunov[b], S. Gradl[c], W. Gradl[c], S. Hausmann[c,3], M. Hildebrandt[c,4], T. Hott[c,5], S. Keller[b,6], C. Krauss[c], B. Lomonosov[a,7], M. Negodaev[a,7], C. Richter[c,8], P. Robmann[d], B. Schmidt[c,9], U. Straumann[c,4], P. Truöl[d], S. Visbeck[c,10], T. Walter[d], C. Werner[c], U. Werthenbach[b], G. Zech[b,*], T. Zeuner[b], M. Ziegler[c,4]

[a] DESY, Hamburg, Germany
[b] Universität Siegen, Germany
[c] Universität Heidelberg, Germany
[d] Universität Zürich, Switzerland

Received 18 February 2002; received in revised form 9 April 2002; accepted 19 April 2002

https://doi.org/10.1016/S0168-9002(02)01002-1

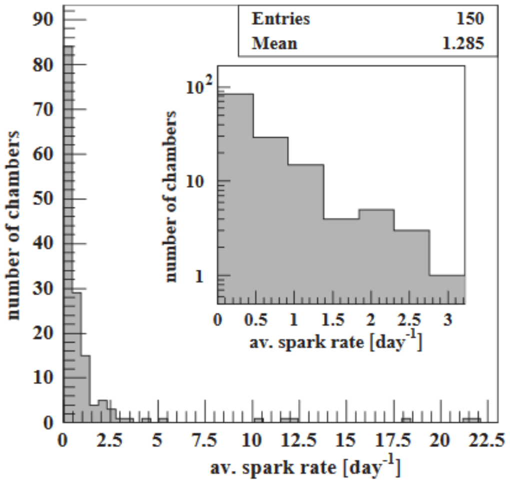
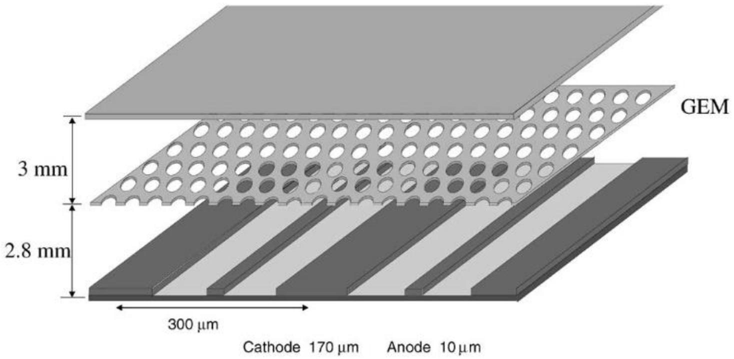
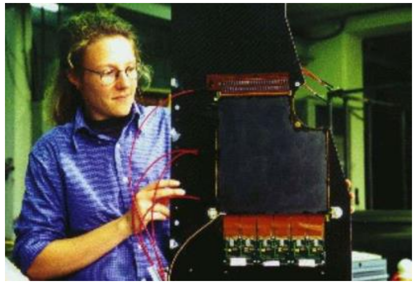


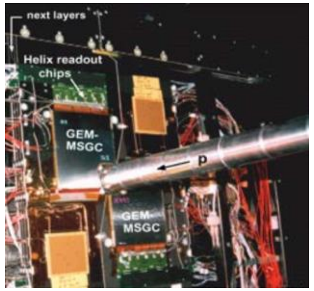
Fig. 17. Number of chambers as a function of their average spark rate. Most chamber show rates below 2 sparks/day at an average target rate of 5 MHz.



The MSGC with the dimensions necessary at HERA-B and the beam conditions of HERA cannot be operated reliably without the addition of a GEM. At the gas amplification required to

The first large size GEMs produced in the PMT workshop for HERA-B.
(left to right: Angelo Gandi, Rui De Oliveira and Jean-Claude Labbé)

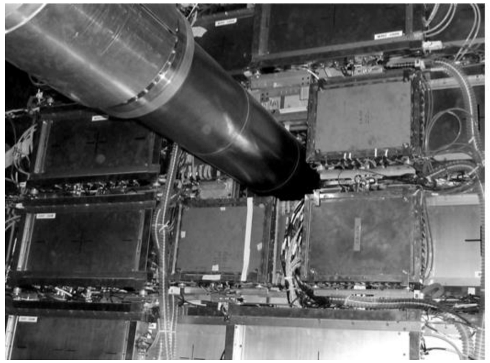




Technology is convincing and experiments at CERN get involved in the R&D…

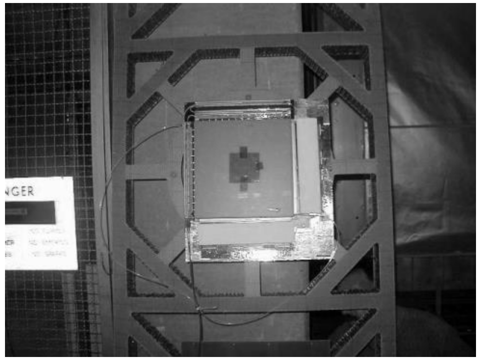
(collider/LHC)

- **LHCb Inner tracker (abandoned but picked up by muon)**
  - Proposed as pre-amplification for MSGC (GEM+MSGC) …
  - Soon moving to (triple) GEM without MSGC …
  - Tracker final selection … silicon
  - GEM technology picked up by **(M1) muon station**
  - **Still in operation**



- **COMPASS Muon Station**
  - Successful
  - Inspiring several other experiment (e.g. TOTEM, I grew up reading COMPASS paper…) and defining most of the common rules for GEM based detectors
  - **Still in operation**

(targer/SPS)



LHCb tracker

1

LHCb 98-068 TRAC
30 December 1998

X-ray Tests of Double and Triple-GEM Detectors for the LHCb Inner Tracker

B.Bochin, A.Kashchuk[*], V.Poliakov, A.A.Vorobyov

Abstract

Gas gain and operation stability of the detectors based on the Double and Triple-GEM (*Gas Electron Multiplier*) structures were studied with the X-rays. The tested detectors had the sensitive area of 100 cm^2. To stimulate discharges in the detectors, a gaseous α-source was introduced into the gas mixture. The measurements show that the Double-GEM chamber filled with the Ar(70%)+CO_2(30%) gas mixture was operating without discharges up to the effective gas gain of 1×10^4, while the Triple-GEM chamber could operate up to the gain of 4×10^4.

1.Introduction

The Gas Electron Multiplier (GEM) [1] might be a promising option for the LHCb Inner Tracker. The LHCb Technical Proposal [2] describes the GEM/MSGC combination as a baseline option for the LHCb Inner Tracker. In this combination, GEM is used as a preamplifier to MSGC. It seems also natural to consider a detector based on GEM only, without MSGC. In this case a Single, Double or Triple-GEM structure is just followed by a simple printed circuit board (PCB) with strips as the readout electrode. Such detector was a subject of intense investigations during last two years, with quite encouraging results [3-13]. High spatial resolution and reasonable time resolution, nonflamable gas mixture, possibility to operate with very high particle fluxes are the attractive features of the detector. On the other hand, there is some concern over GEM behaviour in the presence of heavily ionizing particles. Also, GEM ageing properties should be better understood. Our goal is systematic study of various options of the GEM-based detectors with the purpose to understand whether this detector could be used in the severe background conditions of the LHCb Inner Tracker and satisfy all the requirements. Here we report the results of the X-ray tests of the Double and Triple-GEM detectors filled with Ar/CO_2 gas mixture with an admixture of the α-active ^{220}Rn.

http://cdsweb.cern.ch/record/684669/files/lhcb-98-068.pdf

~2000

Removing the MSGC and working only with GEM.

Understanding GEM behavior in presence of highly ionizing particles

Understanding aging properties

Development of a Triple GEM Detector for the LHCb Experiment

Dissertation

zur

Erlangung der naturwissenschaftlichen Doktorwürde
(Dr. sc. nat.)

vorgelegt der

Mathematisch-naturwissenschaftlichen Fakultät

der

Universität Zürich

von

Marcus Ziegler

aus

Deutschland

Begutachtet von

Prof. Dr. Ulrich Straumann
Prof. Dr. Fabio Sauli

Zürich 2002

https://cds.cern.ch/record/705790/files/thesis-2004-006.pdf

The Ziegler's thesis represent a nice collection of numerous tests done in the initial phase of triple GEM detectors.
Several key measurements have been done and reported.
Not everything understood but "almost everything" explored/measured.

HERE TO UNDERLINE THE IMPORTANCE AND VALUE OF YOUR WORK

- Inner tracker went to silicon..
- But all the work done was important for the community…
- GEM picked up by LHCb for muons system (in few slides …)

COMPASS & GDD

Addressing issues as High Intensity beams/ Aging (raised also by LHCb tracker…)

~2000/2005

Available online at www.sciencedirect.com
SCIENCE DIRECT
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 515 (2003) 249–254
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Aging measurements with the Gas Electron Multiplier (GEM)

M.C. Altunbas[a], K. Dehmelt[b], S. Kappler[c,d,*], B. Ketzer[c], L. Ropelewski[c], F. Sauli[c], F. Simon[e]

[a] State University of New York, Buffalo, NY, USA
[b] Institut für Kernphysik, Mainz University, Germany
[c] EP division, CERN, CH-1211 Geneva 23, Switzerland
[d] Institut für Experimentelle Kernphysik, Karlsruhe University, Germany
[e] Department E18, Munich Technical University, Germany

https://doi.org/10.1016/j.nima.2003.09.006

Abstract

Continuing previous aging measurements with detectors based on the Gas Electron Multiplier (GEM), we investigated a 31×31 cm^2 triple-GEM detector, as used in the small area tracking of the COMPASS experiment at CERN. With a detector identical to those installed in the experiment, long-term high-rate exposures to 8.9 keV X-ray radiation were performed to study its aging properties. In standard operation conditions, with Ar/CO_2 (70:30) gas filling and operated at an effective gain of 8.5×10^3, no change in gain and energy resolution is observed after collecting a total charge of 7 mC/mm^2, corresponding to seven years of normal operation.

This observation confirms previous results demonstrating the relative insensitivity of GEM detectors to aging, even when manufactured with common materials.

Here to be careful… Insensitivity… maybe more appropriate "less sensitive".. Recent studies with methane (CH4/hydorcarbon) have shown that even GEM will suffer of aging (at higher accumulated charge than wires but they will do it as well)

N-H
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 470 (2001) 548–561
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A
www.elsevier.com/locate/nima

Performance of GEM detectors in high intensity particle beams

S. Bachmann[a], A. Bressan[a], B. Ketzer[a], M. Deutel[a], L. Ropelewski[a], F. Sauli[a,*], A. Bondar[b], A. Buzulutskov[b], L. Shekhtman[b], A. Sokolov[b], A. Tatarinov[b], A. Vasil'ev[b], S. Kappler[c], E. Schulte[d]

[a] CERN, EP Division, 1211 Geneva 23, Switzerland
[b] Budker institute of Nuclear Physics, Novosibirsk, Russia
[c] University of Karlsruhe, Germany
[d] University of Helsinki, Finland

Received 24 October 2000; received in revised form 8 December 2000; accepted 14 December 2000

https://doi.org/10.1016/S0168-9002(01)00802-6

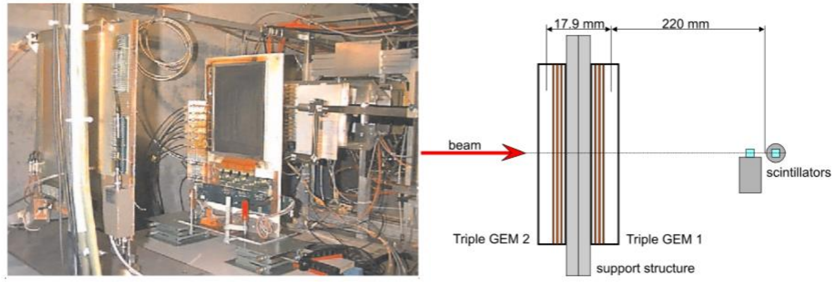


Figure 9.2: left: Setup at PSI in the πM1 area in December 1999. Four other groups tested their detectors simultaneously (CERN GDD group double GEM [42], University Lausanne and CEA/Saclay Micromegas [43], University Santiago de Compostela Microwire [44]). right: Schematic drawing of the Triple GEM detector arrangement (second prototype) and the scintillators.

3. Experimental tests

The COMPASS prototype has been tested for several weeks during August and September 1999 at CERN in the M2 beam line foreseen for the COMPASS experiment. In December 1999 the Double GEM, Triple GEM and the COMPASS prototype were tested in the πM1 beam at the Paul-Scherrer-Institut (PSI) in Villigen. This last exposure has been performed in the framework of systematic tests of micropattern gas detectors in view of their use for the LHCb inner tracking system.

In this section results from both test experiments are presented.

The very standard (in our field) Triple GEM configuration comes from these days/studies…

In RUN1 @ LHC: two detectors based on GEM

R&D, contruction, commissioning and installation [2000/2010]

(As previously anticipated) **LHCb Muon System**: tracking and triggering @ high rate in 25ns

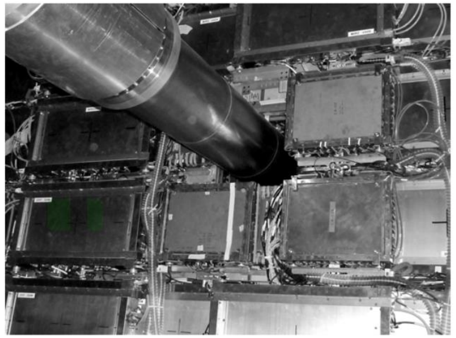


Fig. 4. View of M1 detectors around the LHC beam pipe. Detectors near the beam pipe are Triple-GEM chambers. There are six Triple-GEM chambers (of which only 3 are clearly visible in the picture) on each side of the M1 support wall.

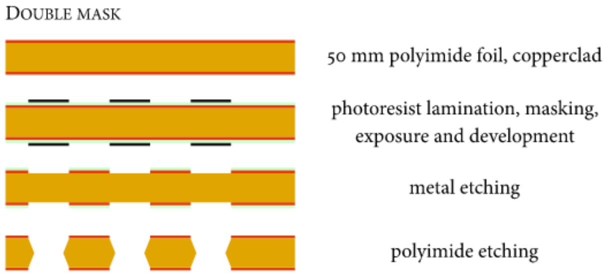
TOTEM Forward Inelastic Telescope: tracking and triggering in harsh environment

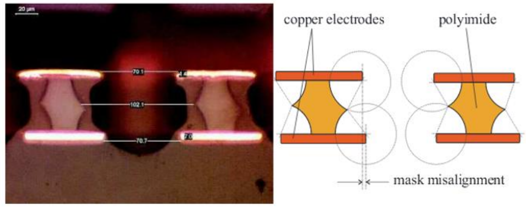
The success of COMPASS pushed the TOTEM collaboration to select GEMs as technological solution for the forward (high rate, high dose) inelastic telescope

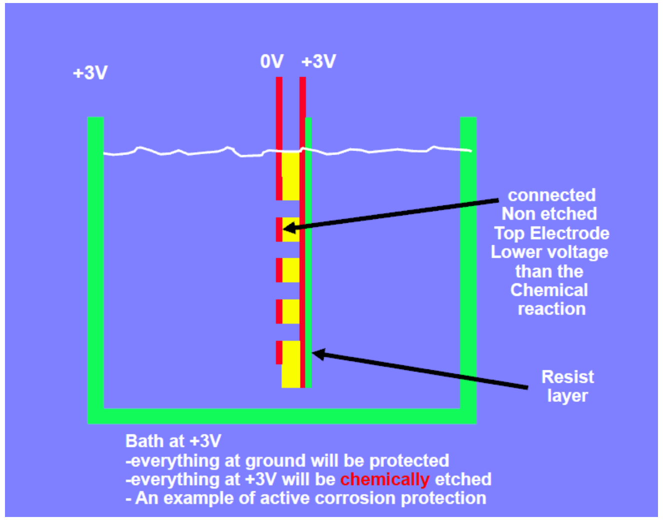
Removed now after the accomplishment of the program.

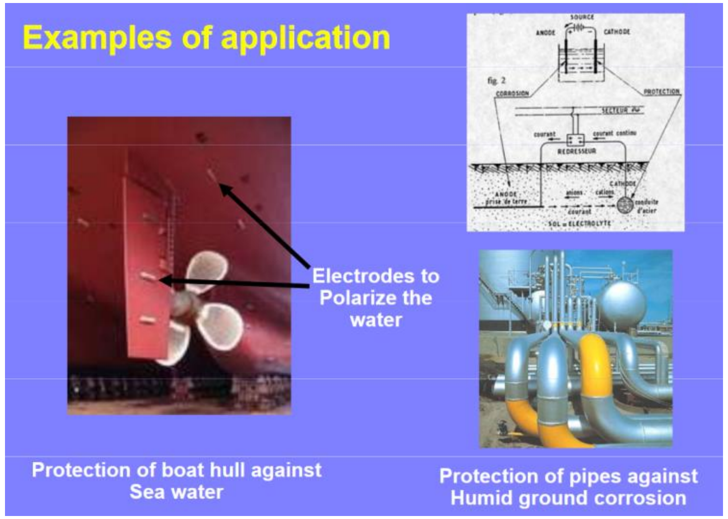
Next steps… Potential to go for large systems (typical for gas detector) but large area is required

Main limitation towards large Area: double mask production process / mask alignment



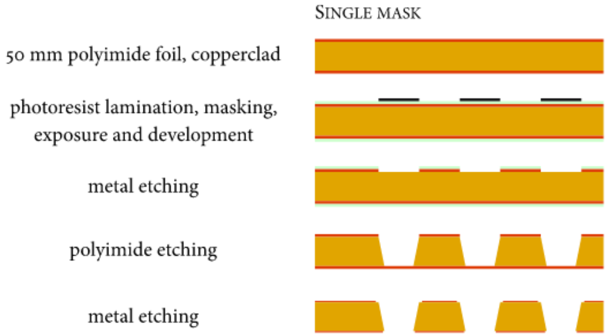


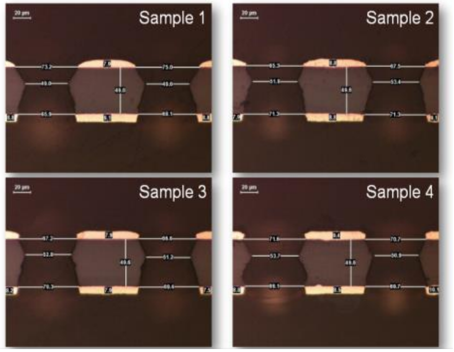




R. de Oliveira, https://indico.cern.ch/event/56216/session/1/contribution/5/material/slides/1.pdf

MPT workshop/GDD: Progress on large area GEMs
Serge Duarte Pinto et al., Jinst, November 26, 2009
{http://arxiv.org/pdf/0909.5039v2.pdf]





Solution: Single Mask Etching (implementing active corrosion protection)

In synergy/following these developments…
New applications at the LHC

(~2010) CMS GEM: similar as LHCb muon but large area and large volume..

(~2014) ALICE GEM TPC: stability and uniformity, low IBF and good energy resolution, high reliability (no redundancy)

IMPORTANT TO KEEP IN MIND THAT READY TO GO SOLUTION DOESN'T EXISTS VERY OFTEN…

- **Despite several years of R&D, characterization, testing, existing instruments… collaborations had to go through new and deep studies, troubleshooting, consolidation of the technology,…**

- **A lot has been learned/confirmed …**
  - Large effort to validate what has been observed in small prototype (performances, stabilities,…)
  - Several new "features" (problems) rising…
  - Assembly procedure to be well under control/shared between assembly institutes…
  - QA/QC to be well defined by detector experts…
  - No shortcuts to be taken or not well understood behaviors to be left unsolved…
  - Testing and testing facilities are fundamental…
  - Devil is in details and apparently "innocuous" changes.

Detector experts / knowledge transfer and critical mass in large experiment fundamental

GEM@LHC

~2000/2010

LHCb Muon System: tracking and triggering @ high rate in 25ns

In LHC since Run1.

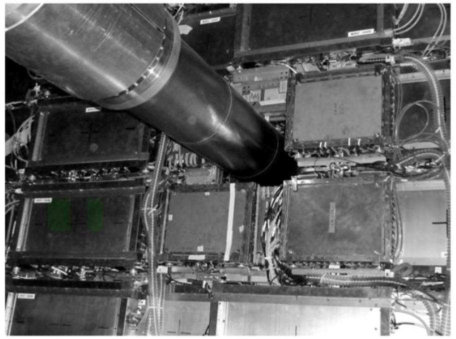
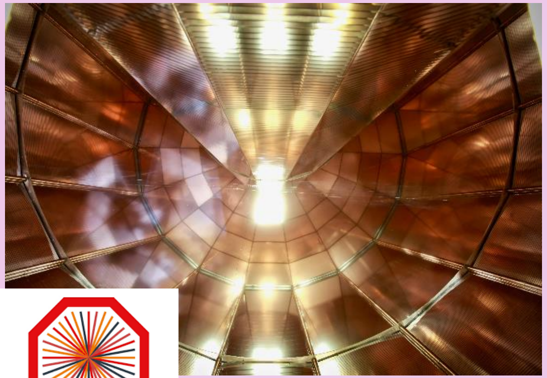


Fig. 4. View of M1 detectors around the LHC beam pipe. Detectors near the beam pipe are Triple-GEM chambers. There are six Triple-GEM chambers (of which only 3 are clearly visible in the picture) on each side of the M1 support wall.

TOTEM Forward Inelastic Telescope: tracking and triggering in harsh environment

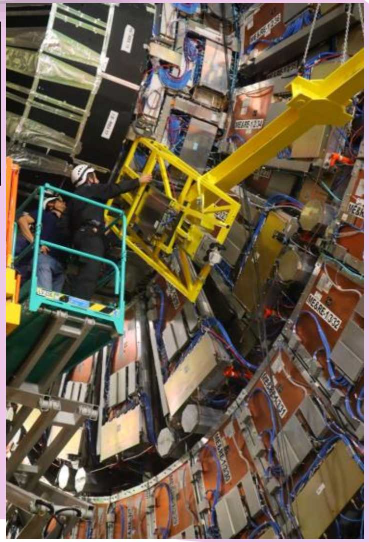
In LHC since Run1, program completed, now removed

~2010/2020



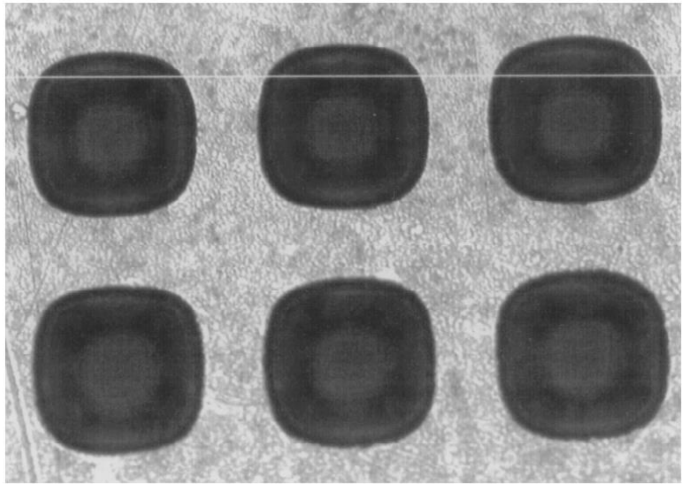
ALICE GEM TPC: low IBF and good energy resolution, high reliability (no redundancy)

CMS GEM: large area, assembly procedure compatible with large number of detector modules



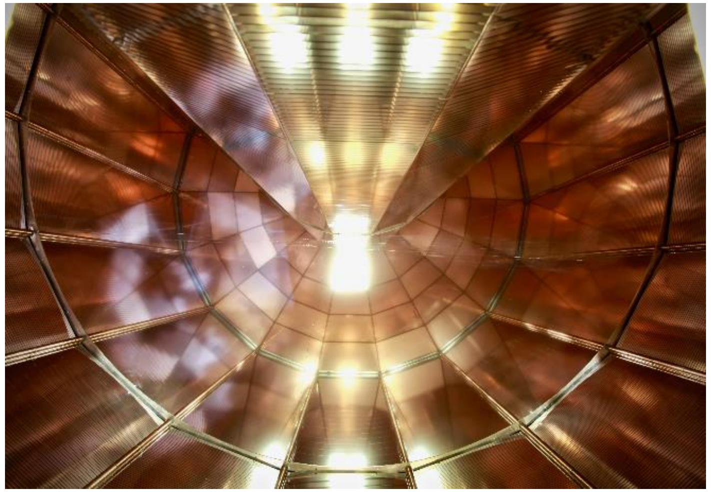
A wrap up message:

- New technologies require time to become a mature instrument …
- Every development/application will always add new aspects (problems) to be studied (solved)…
- Definitively worth to go through all of this because of the new potential/scenario you can open…
- You need a vision…
- Do not underestimate your (student/future researchers) contribution to these processes..



GDD, CERN, 1996(7)

Almost 25 years
from small prototypes to
large area systems



ALICE TPC, CERN, 2019

VISION

“A new generation of simple, reliable and cheap fast position-sensitive detectors seems at hand”

F. Sauli et al., 28 February 1997, https://doi.org/10.1016/S0168-9002(97)00648-7

Instrumentation/MPGD[2]

MPGD based INSTRUMENTS: examples of Need and WAY OUT

How MPDG’s versatility can help to address different requirements

This section will show examples where you will be hopefully able to appreciate the flexibility you can have implementing MPGD technologies into instruments (key factor to properly address different requirements)

Needs/Way Out

A simplified view of an instrument gas (MPGD) based

radiation →

GAS

Conversion	**Amplification**	**Signal**
Radiation to primary electrons in gas	Multiplying primary electrons via ionization processes in the gas (avalanches)	Detect secondary charge or photons produced in the avalanches
Conversion efficiency, released energy, topology of primary ionization, attachment in the gas, drift and diffusion, space charge (ions from amplification..),....	Amplification, attachment, drift and diffusion, charge losses, ions, discharges, space charge, charging up,..	Signal coupling (charge or light readout), readout plane granularity and number of readout channels/pixels, protection, FE electronics,..

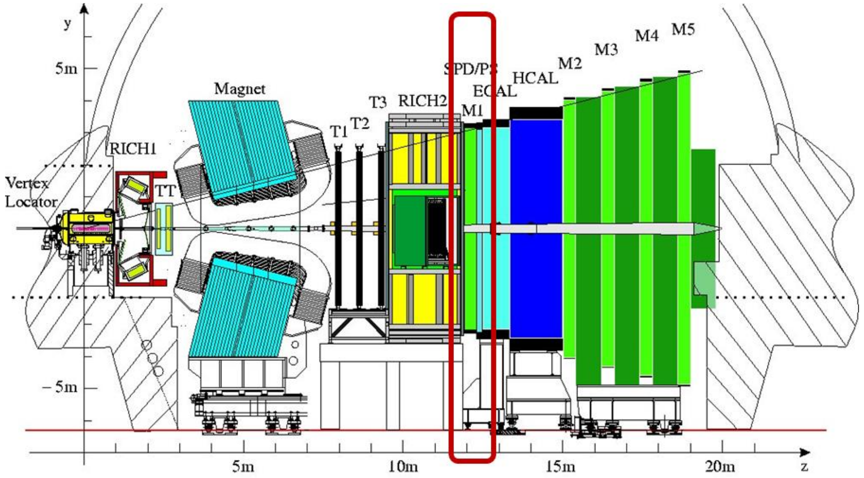
Once a need is defined, each part can be very often optimized to match the requirements independently from the others.

Optimization can be a **direct optimization** of the aimed performances (e.g. faster signals for timing detectors) or an **indirect optimization** that allows the use of potential solutions (e.g. amplifying stages with reduced ion back flow to allow the use of CsI photocathodes in UV detection),…

AIM of the next slides is to show that **the solution is often the developer** that is capable of identifying in the technologies (MPGD tech. help thanks to the various and versatile options) the right solution to the problem.

Need/Way Out [1]

Triggering minimum ionizing particles (muons), with high efficiency in few tens of nsec, in an environment of MHz/cm2, with low material budget...



http://cds.cern.ch/record/5701

Requirements (Environment) :
High Rate Capability: up to 1MHz/cm2
Radiation hardness: 1.6C/cm2 in 10 years @6k Gain
Low material budget

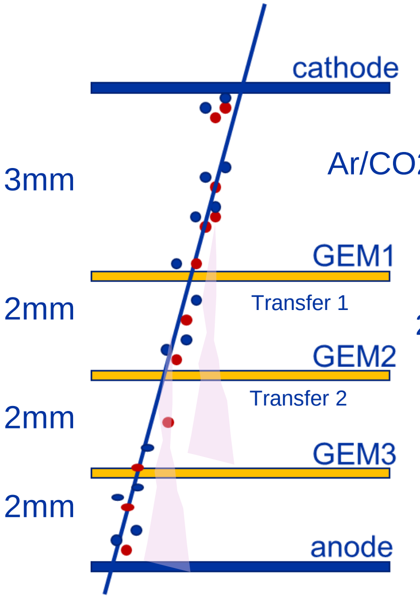
Requirements (Trigger):
Station Efficiency: >96% in 20ns time Window for two detectors in “OR”

RPC would be faster than GEM but rate capabilities would have been not satisfied

REAL CASE: LHCb first tracking station M1 of the muon system in front of the calorimeter system.

Need/Way Out [1]

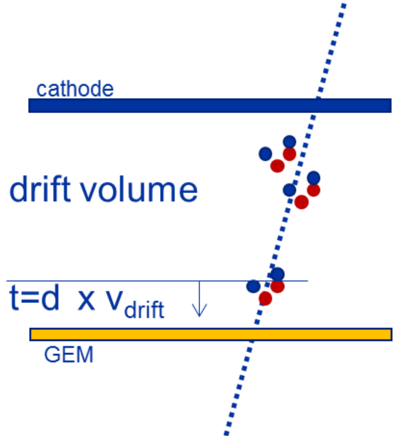
Starting from standard COMPASS 3/2/2/2 gaps, Ar/CO2 70/30

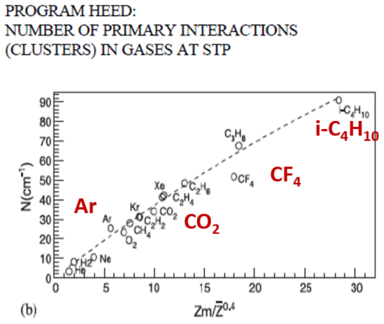


- Time resolution (gas & signal induction)~10-15ns
- Earlier trigger from conversion in Transfer 1

Gas choice: Improving intrinsic time resolution (threshold crossing time) with larger number of primary clusters and faster drift velocity.

$$\sigma_1(t_d) = \frac{1}{\overline{n} \cdot v_d}$$





n

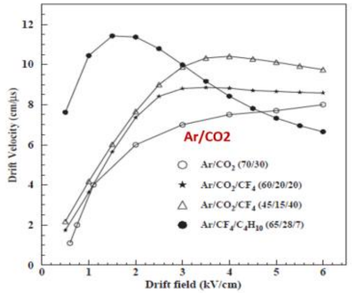


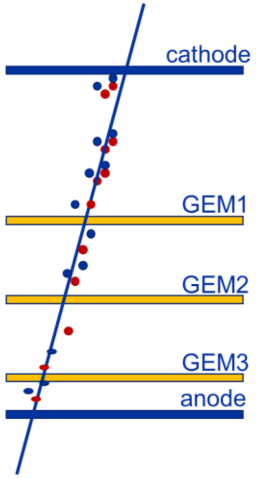
Fig. 2. Electron drift velocity for the tested gas mixtures.

v_d

Gas Mixture	Drift velocity (drift field)	< Clusters/mm >	Intrinsic time resolution
Ar/CO_2 (70/30)	7 cm/μs (@3 kV/cm)	3.3	4.7 ns (@3 kV/cm)
$Ar/CO_2/CF_4$ (60/20/20)	9 cm/μs (@3 kV/cm)	5	2.3 ns (@3 kV/cm)
$Ar/CO_2/CF_4$ (45/15/40)	10.5cm/μs (@3.5 kV/cm)	5.5	1.7 ns (@3.5 kV/cm)
Ar/CF_4/iso-C_4H_{10} (65/28/7)	11.5 cm/μs (@2kV/cm)	5.7	1.5 ns (@2 kV/cm)

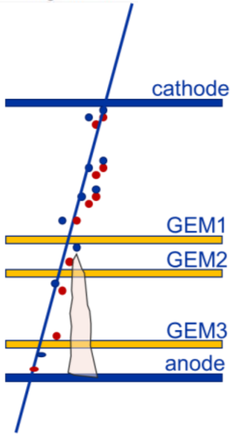
Table 3.1: Summary table of the gas mixture properties: optimized drift velocity and average cluster yield. The relative *intrinsic* time resolution is also reported.

Induction Gap:
Thinner induction gap and proper FE electronics to have a steeper rising edge of the signal/ prompt response



Reduced Induction gap: larger induced currents ($I=-qv_d/Gap_{Ind}$)

First Transfer Gap (after GEM1): thinner to reduce the probability/amplitude of precursors signals (primary charge released between first GEM and readout)



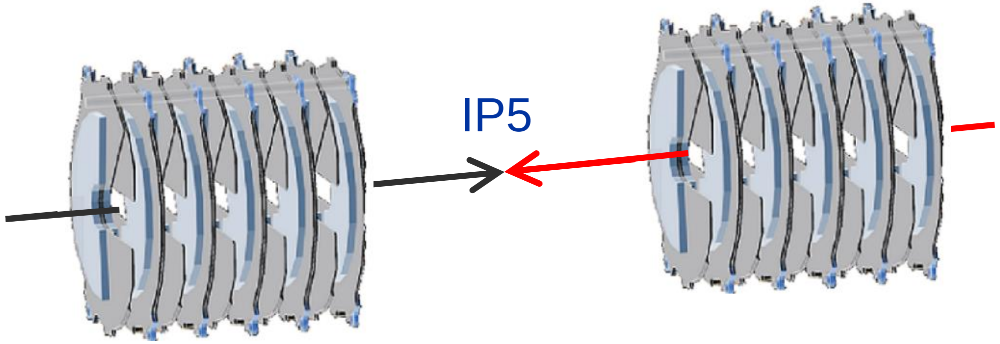
Reduced Transfer 1 gap: Reduce probability of triggering on Double GEM Signals (earlier in time)

M. P. Lener, Triple-GEM detectors for the innermost region of the muon apparatus at the LHCb experiment, Doctoral Thesis, https://cds.cern.ch/record/940631/files/thesis-2006-013.pdf

Need/Way Out [2]

TOTEM T2 forwards tracking and triggering telescope: tracking with high eta (radial) coarse phi resolution and triggering rods for trigger

Unique tracking/triggering instruments with different requirements on tracking/triggering: tracking vertex events with high radial resolution and fast triggering with coarse r-phi rods

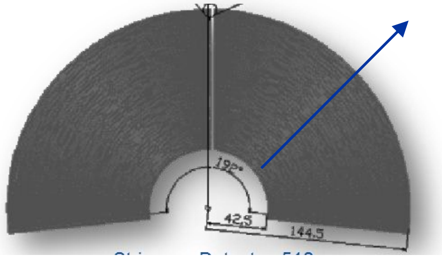


REAL CASE: TOTEM forwards telescope..

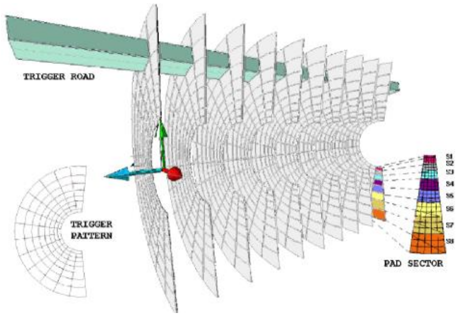
Can I build a single detector capable of doing this?

High granularity tracker (high radial resolution) (measurement of forward inelastic event rate and dN/deta distribution)

high radial resolution



Coarse triggering road



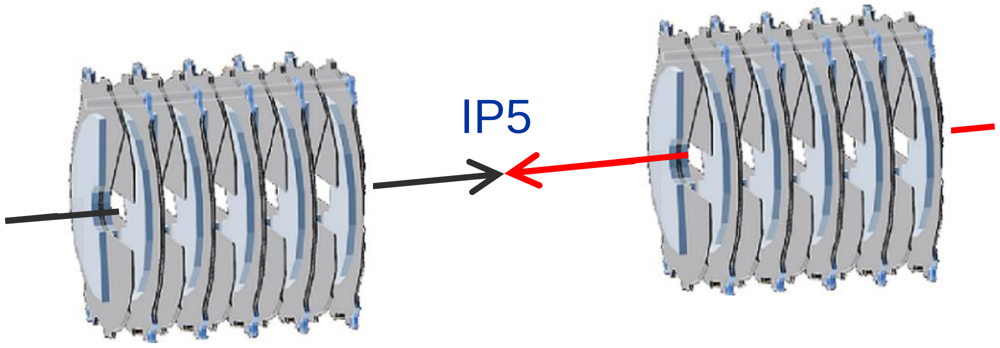
Triggering rod telescope (coarse r-phi channels) (background subtraction)

Need/Way Out [2]

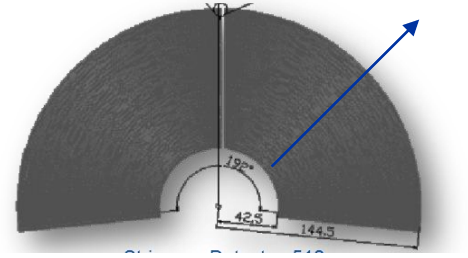
Readout plane of a GEM based detector is fully decoupled by the amplification stage and it doesn't play any role in the gain , i.e it can be independently optimized/modified..

Paying attention on signal coupling, I'm free to chose the best pattern for my application…

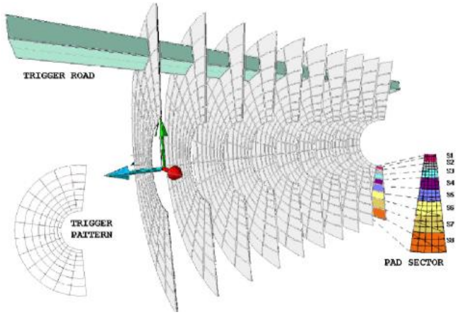
TOTEM T2 forwards tracking and triggering telescope: tracking with high eta (radial) coarse phi resolution and triggering rods for trigger



high radial resolution

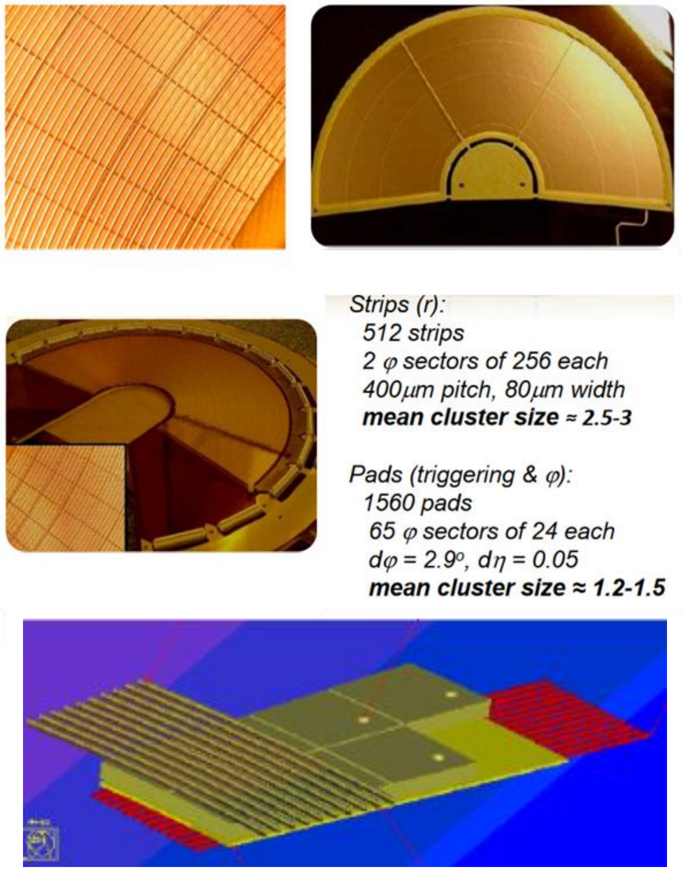


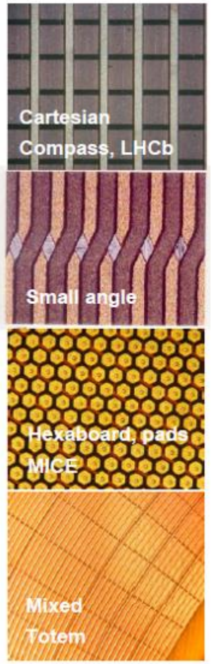
Coarse triggering road



Way out:
Multilayer readout plane with that copes with requirements defined by the physics/measurement ..

Fine pitch strips on top for radial impact point measurement and pads (different sizes) for triggering road and coarse phi.





M. Berretti, http://indico.cern.ch/event/252473/session/0/contribution/5/material/slides/0.pdf

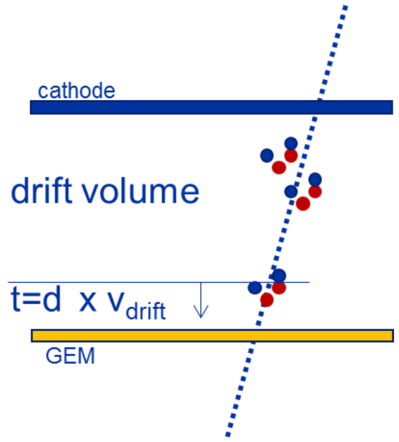
Need/Way Out [3]

In the first example we were talking about optimization in the scale of nsec time resolutions.

Can we develop MPGD-based (*) instrument with better time performances? Three order of magnitude better? going from nsec to psec?

(*) to be potentially used in high rate environment, to potentially cover a wide range of readout granularity & patterns, potentially proportional,..

$$\sigma_1(t_d) = \frac{1}{\overline{n} \cdot v_d}$$



Gas Mixture	Drift velocity (drift field)	< Clusters/mm >	Intrinsic time resolution
Ar/CO_2 (70/30)	7 cm/μs (@3 kV/cm)	3.3	4.7 ns (@3 kV/cm)
$Ar/CO_2/CF_4$ (60/20/20)	9 cm/μs (@3 kV/cm)	5	2.3 ns (@3 kV/cm)
$Ar/CO_2/CF_4$ (45/15/40)	10.5cm/μs (@3.5 kV/cm)	5.5	1.7 ns (@3.5 kV/cm)
Ar/CF_4/iso-C_4H_{10} (65/28/7)	11.5 cm/μs (@2kV/cm)	5.7	1.5 ns (@2 kV/cm)

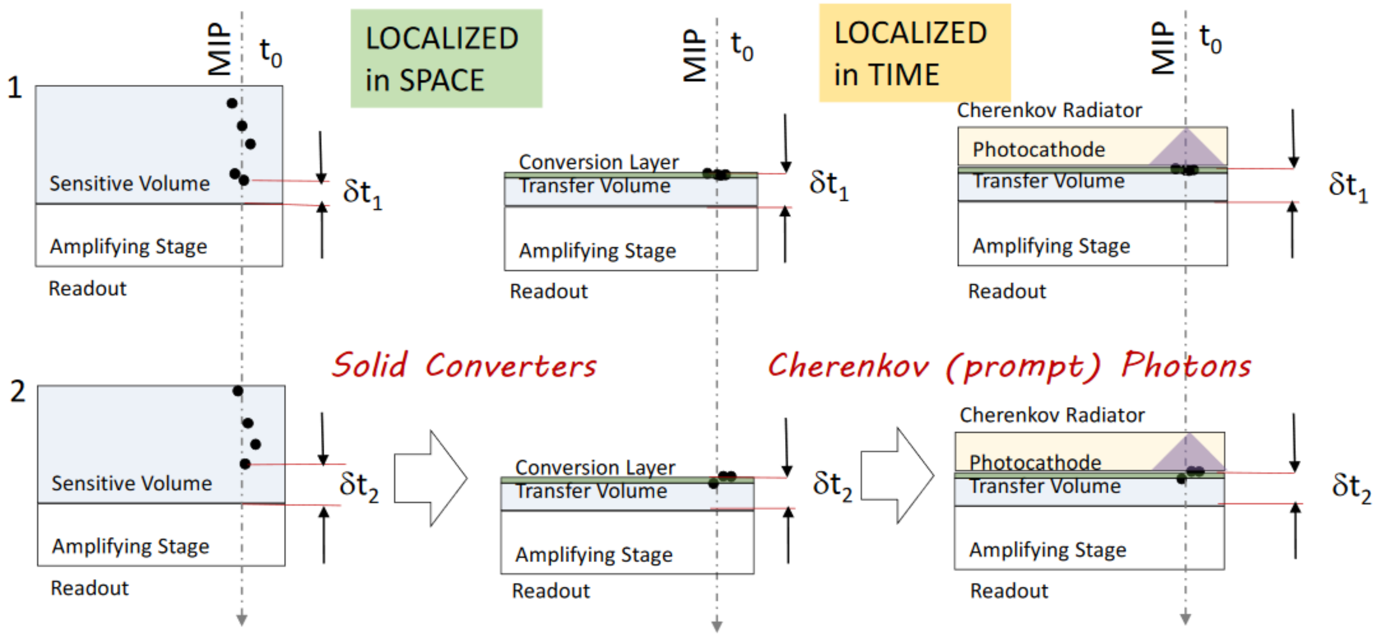
Table 3.1: Summary table of the gas mixture properties: optimized drift velocity and average cluster yield. The relative *intrinsic* time resolution is also reported.

Need/Way Out [3]

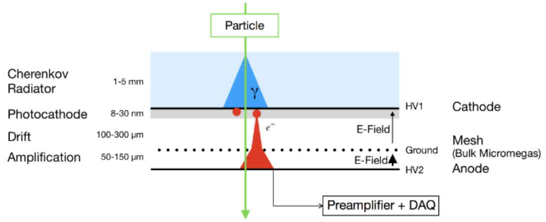
PICOSEC micromegas

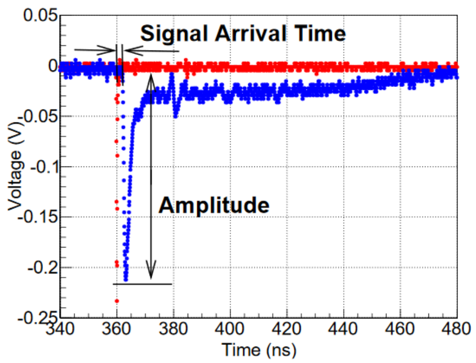
Defeat the intrinsic (few ns) time resolution of direct gas pimary ionization in Proportional Counters

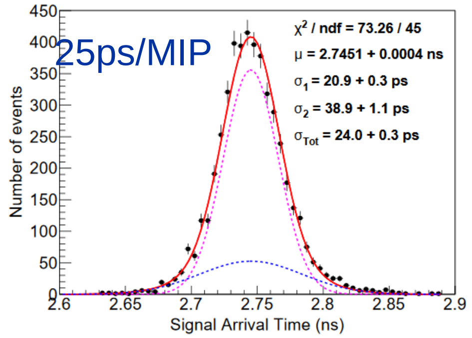
If picoseconds are aimed.. Different strategy, i.e. different source of primary charge: Cherenkov radiator (prompt) and photocathode (localized)



https://agenda.infn.it/event/15138/contributions/28611/attachments/20406/23149/EOliveri_FrascatiDetectorSchool2018.pdf







https://arxiv.org/pdf/1712.05256.pdf

breakthrough is conversion + others tricks in gas/amplification/signal

Need/Way Out [4]

Cherenkov detector to be operated in the radiator gas (to avoid windows, i.e. absorption) and insensitive to charged particles.

Real Case: Hadron Blind Detector for the PHENIX experiment

https://arxiv.org/pdf/1103.4277.pdf

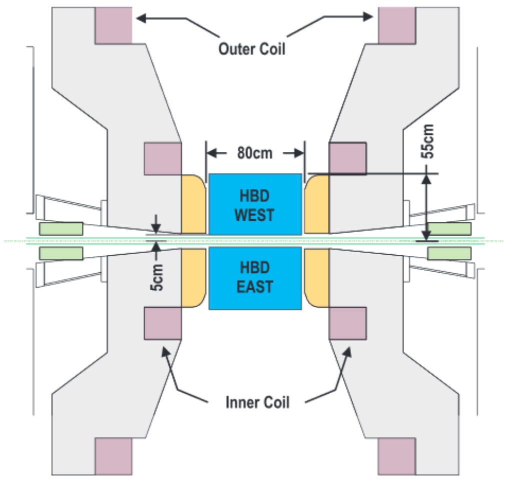
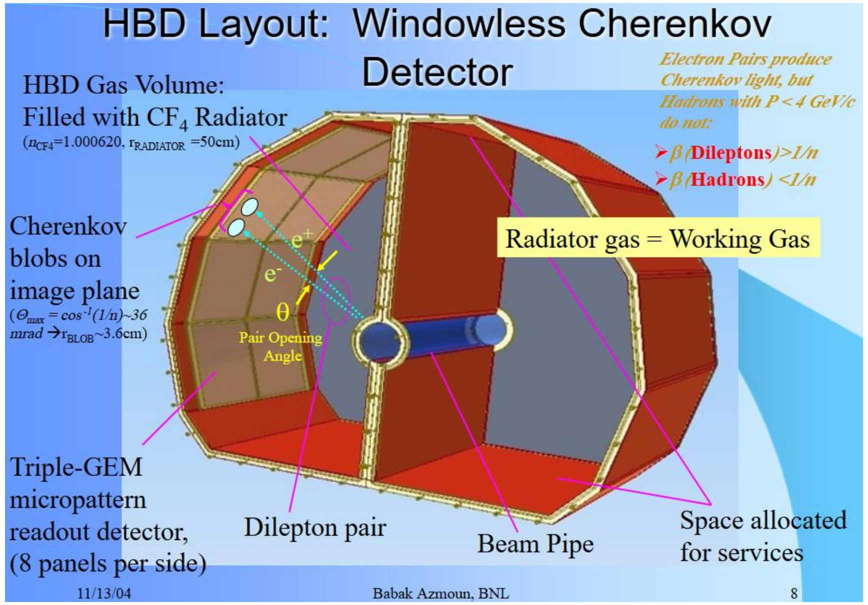


Fig. 1. Top layout of the inner part of the PHENIX central arm detector showing the location of the HBD and the inner and outer coils.



Need/Way Out [4]

windowless Cherenkov detector with photon feedback (avalanches) suppression and insensitive to charged particle

Hadron Blind Detector for the PHENIX experiment

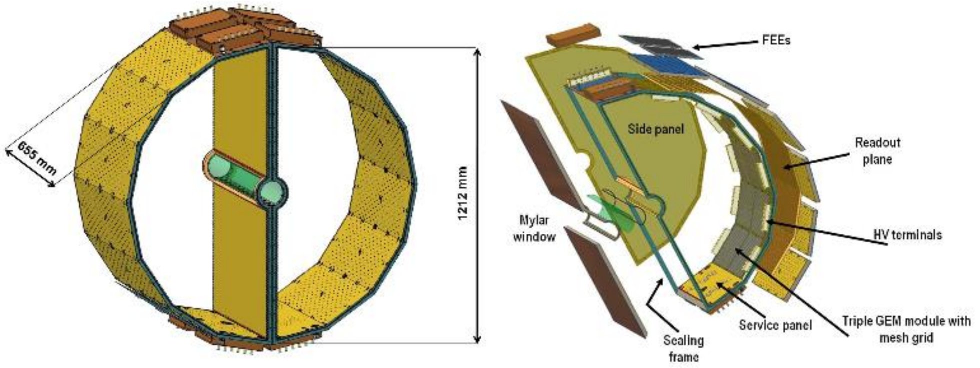


Fig. 3. Left panel: 3D view of the two arm HBD. Right panel: exploded view of one HBD arm.

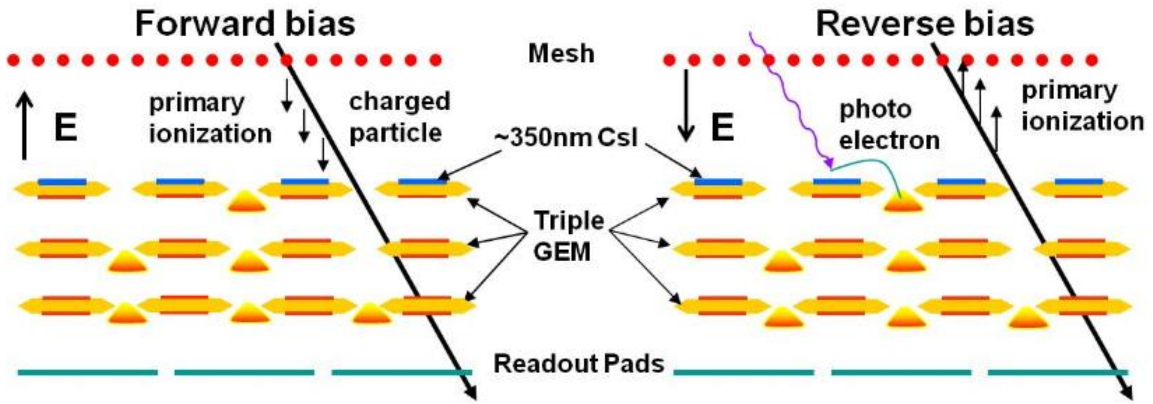


Fig. 2. Triple GEM stack operated in the standard forward bias mode (left) and in the hadron-blind reverse bias mode (right).

https://arxiv.org/pdf/1103.4277.pdf

- GEM as support of reflective photocathode
- GEM as suppression of photon (avalanches / feedback)
- Triple to have stable operation in CF4 (gas/radiator)
- Insensitive to charged particle (inverted field)

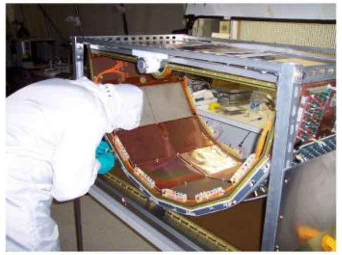


Fig. 9. Installation of standard copper GEMs into the HBD vessel prior to placing the vessel in the glovebox.

Conversion:

- CsI photocathode on top of a GEM (facing gas/Cherenkov photons without the need of support/windows between photons and photocathode (+ good shielding from photons produced in avalanches / feedback)
- Inverted drift field to be blind to charged particles

Amplification:

- Triple GEM allows to stably operate the amplification stage in pure CF4 (gas used as radiator), reduced Ion Back Flow (CsI) reduced photon feedback…

Need/Way Out [5]

Cherenkov detector (similar to previous example) but with more strict requirements on CsI aging under ion bombardment. Better Ion Back Flow suppression required.

REAL CASE: COMPASS RICH
Uniform and efficient UV photocathode, low Ion Back Flow (damaging of the PC), low photon feedback (instabilities/spurious signals), Large Gain and stable (from single photoelectron to many) ,…

Hybrids

You can combine different MPGD technologies to optimize the detector (here THGEM to hold/grow the CsI and reduce photon-feedback.. Multistage to increase gain/stability/feedbacks… and micromegas as last stage /intrinsically good for Ion Back Flow…)

J. Agarwala, M. Alexeev, C.D.R. Azevedo et al.

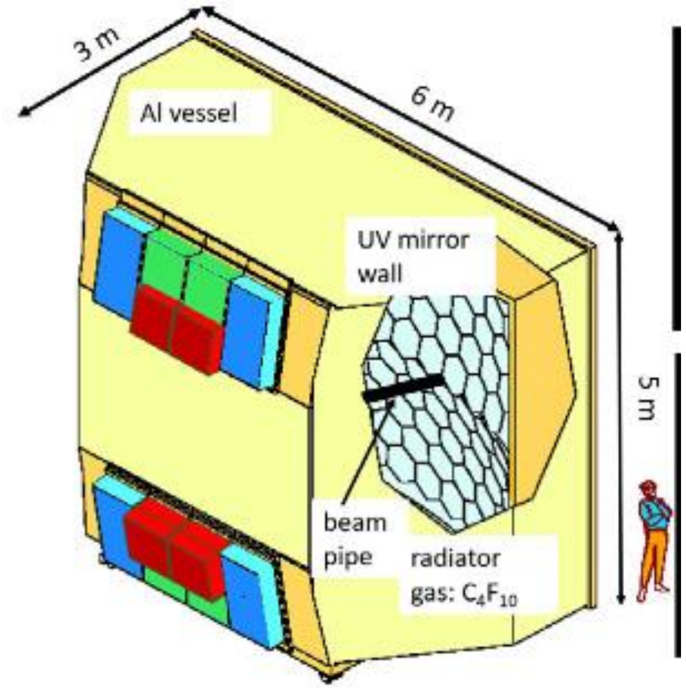


Fig. 1. Artistic view of the COMPASS RICH-1 (left) (not in scale) (right).

Need/Way Out [5] / MPGD hybrids

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

The hybrid MPGD-based photon detectors of COMPASS RICH-1

J. Agarwala [a,j], M. Alexeev [b], C.D.R. Azevedo [c], F. Bradamante [d], A. Bressan [d], M. Büchele [e], C. Chatterjee [d], M. Chiosso [b], A. Cicuttin [a,j], P. Ciliberti [d], M.L. Crespo [a,j], S. Dalla Torre [a], S. Dasgupta [a], O. Denisov [f], M. Finger [g], M. Finger Jr. [g], H. Fischer [e], M. Gregori [a], G. Hamar [a], F. Herrmann [e], S. Levorato [a], A. Martin [d], G. Menon [a], D. Panzieri [h], G. Sbrizzai [d], S. Schopferer [e], M. Slunecka [g], M. Sulc [i], F. Tessarotto [a,*], J.F.C.A. Veloso [c], Y. Zhao [a]

[a] INFN, Sezione di Trieste, Trieste, Italy
[b] INFN, Sezione di Torino and University of Torino, Torino, Italy
[c] I3N - Physics Department, University of Aveiro, Aveiro, Portugal
[d] INFN, Sezione di Trieste and University of Trieste, Trieste, Italy
[e] Universität Freiburg, Physikalisches Institut, Freiburg, Germany
[f] INFN, Sezione di Torino, Torino, Italy
[g] Charles University, Prague, Czech Republic and JINR, Dubna, Russia
[h] INFN, Sezione di Torino and University of East Piemonte, Alessandria, Italy
[i] Technical University of Liberec, Liberec, Czech Republic
[j] Abdus Salam ICTP, 34151 Trieste, Italy

https://doi.org/10.1016/j.nima.2019.01.058Get

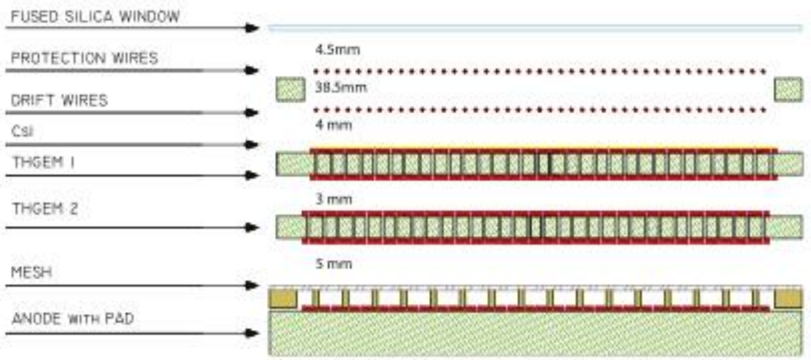


Fig. 2. Sketch of the hybrid single photon detector: two THGEM layers are coupled to a MM. Drift and protection wire planes are shown. Image is not to scale.

J. Agarwala, M. Alexeev, C.D.R. Azevedo et al.

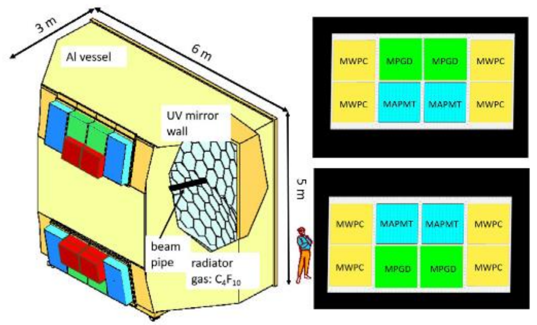


Fig. 1. Artistic view of the COMPASS RICH-1 (left) and scheme of the PD arrangement (not in scale) (right).

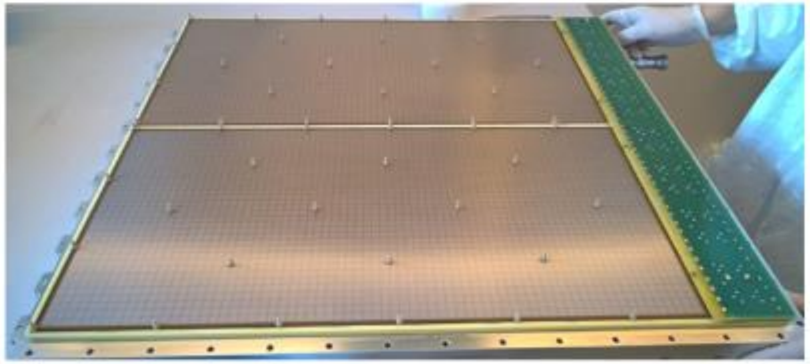


Fig. 3. Two Micromegas mounted side by side in a PD. The pillars that preserve the distance between the micromesh and the THGEM above it are also visible.

Multiple amplification stages
(larger GAIN[single photoelectron detection] and better stability [dynamic range] and reduced feedbacks (lower Ion Back Flow /IBF [protection of the photocathode from ion bombardment] and photon feedback (spurious signals/stability)

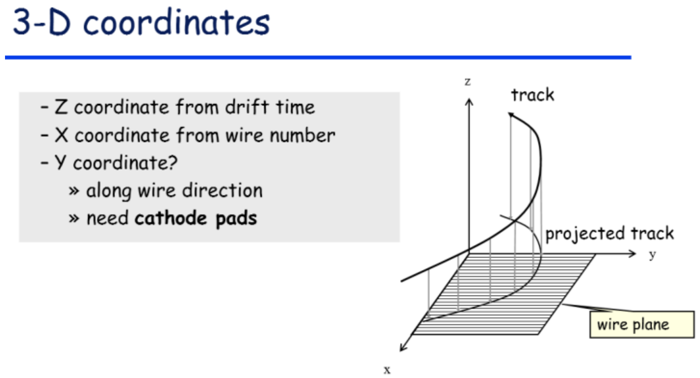
Reflective CsI on THGEM
(uniformity [not affected by thickness] reduced photon feedback[UV produced during the avalanches] and possibility to be blind to charged particle[inverted field])

Last amplification with Micromegas
(intrinsically lower IBF [protection of the photocathode from ion bombardment])

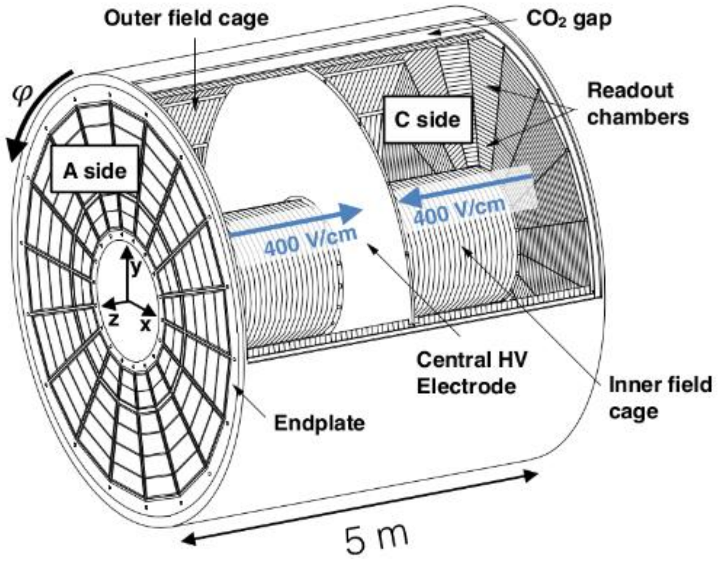
Need/Way Out [6]

REAL CASE: ALICE Time Projection Chamber (TPC): Space charge distortion (Ion Back Flow)

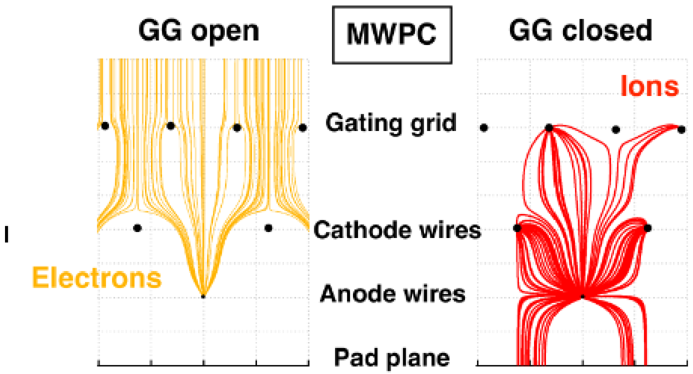
Still fighting Ions but this time field distortion in Time Projection Chambers (ions back-flowing in the sensitive volume of the TPC)..
+ good energy resolution..
+ good stability..
+ …



Time Projection Chamber, Ron Settles, MPI-Munich
Pere Mato, CERN, https://www.mpp.mpg.de/



https://indico.cern.ch/event/889369/contributions/4011360/attachments/2118260/3565900/2020-10-08_SCDCalibration.pdf



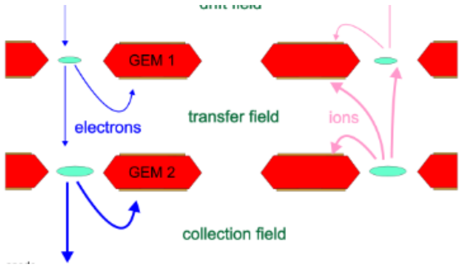
Till now Multi Wire Proportional Counter (MWPC) used as amplification stage and Gating Grid to prevent ions drifting back in the TPC volume.

This solution would not work with the rate expected in >=RUN3

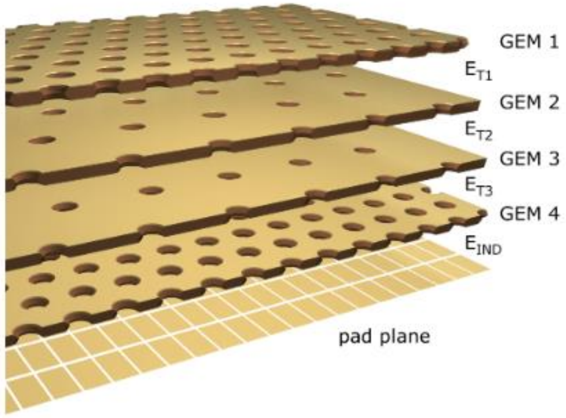
Need/Way Out [6]

ALICE Time Projection Chamber (TPC)

A multi stage detector can offer the possibility to trap ions in the electrodes of the stage preventing them to reach the TPC sensitive volume.



https://cds.cern.ch/record/1258672/files/CERN-THESIS-2010-054.pdf

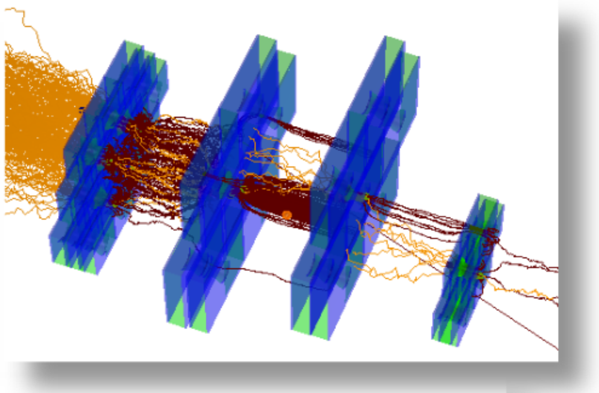


https://indico.cern.ch/event/889369/contributions/4011360/attachments/2118260/3565900/2020-10-08_SCDCalibration.pdf

Proposed/accepted solution: 4 GEM with different pitches and with optimized transfer/amplification fields to facilitate the trapping of the ions, preserve good energy resolution and offer a stable operation of the amplification stage.

IBF optimized configuration (7)

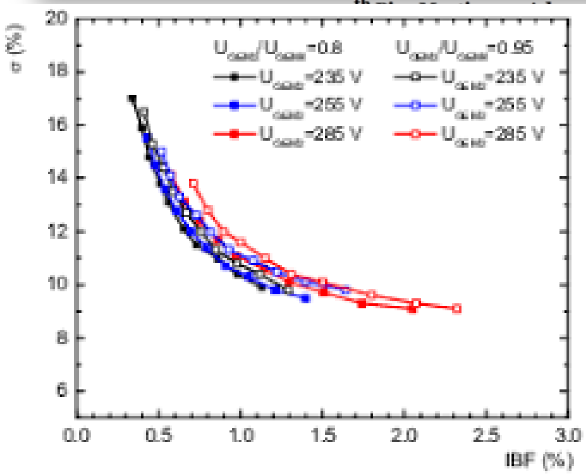
- Electron transport properties for IBF optimized voltage settings
- ε_{coll} = collection efficiency
- ε_{extr} = extraction efficiency
- M = gas multiplication factor
- $G = \varepsilon_{coll} \times M \times \varepsilon_{extr}$ = effective gain
- $n_{e\text{-}ion}$ = number of produced e-ions pairs
- $n_{ion,back}$ = number of ions drifting back into the drift volume



	ε_{coll}	$n_{e,in}$	M	n_{e-ion}	ε_{extr}	$n_{e,out}$	G	$n_{ion,back}$	fraction of total IBF (sim.)	fraction of total IBF (meas.)
GEM1 (S)	1	1	14	13	0.65	9.1	9.1	3.6 (28%)	40%	31%
GEM2 (LP)	0.2	1.8	8	12.7	0.55	8	0.88	3.3 (26%)	37%	34%
GEM3 (LP)	0.25	2	53	104	0.12	12.7	1.6	1.3 (1.3%)	14%	11%
GEM4 (S)	1	12.7	240	3053	0.6	1830	144	0.84 (0.03%)	9%	24%
Total				3183		1830	1830	9 (0.28%)		

d Detectors
Italy)

20

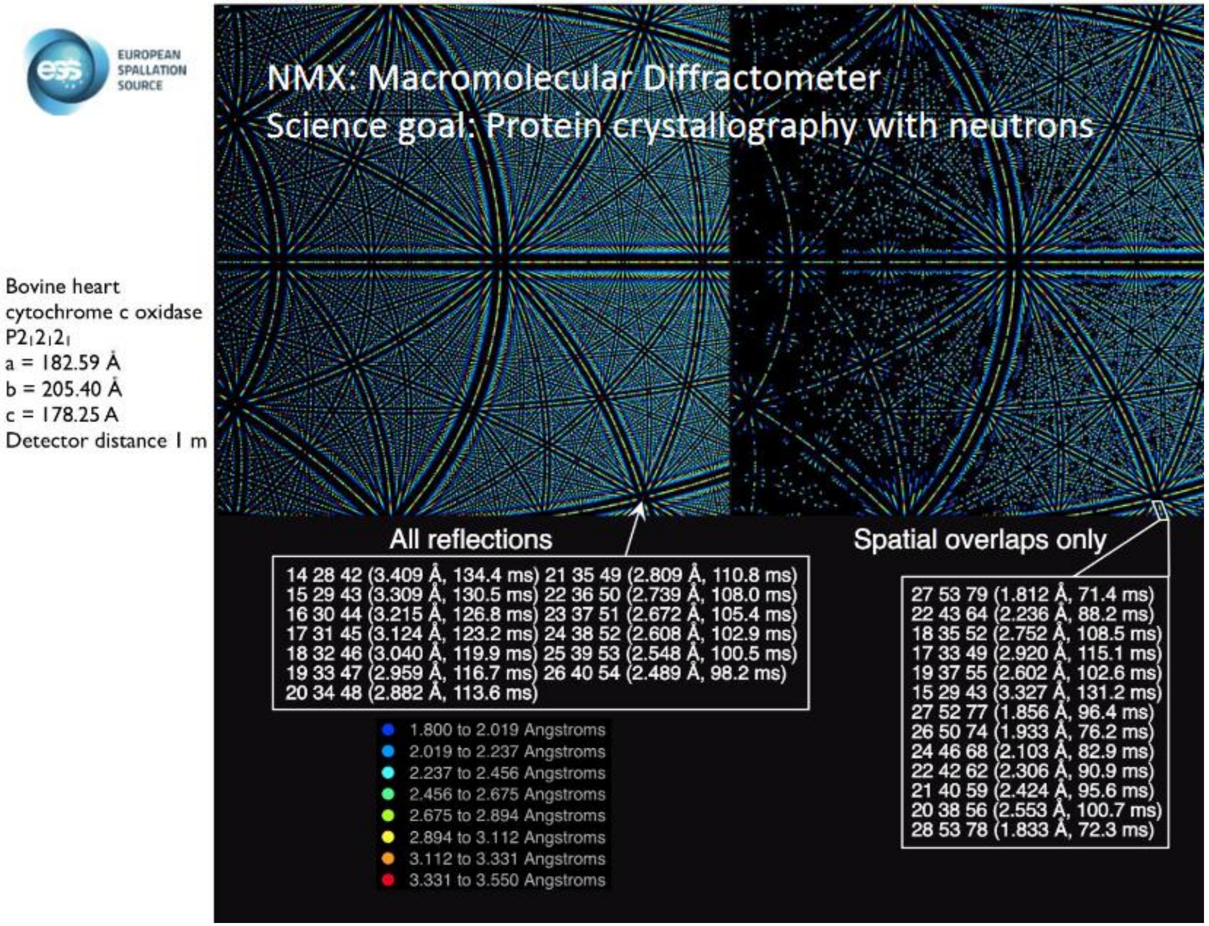


https://web-docs.gsi.de/~lippmann/files/presentations/pisa2015.pdf

Need/Way Out [7]

Detect high rate thermal neutrons efficiently, with position resolution of few hundreds μm.

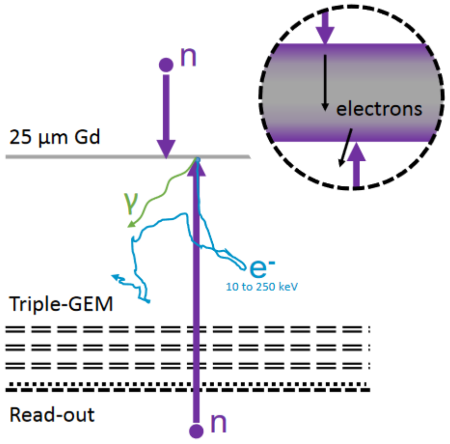
REAL CASE: ESS macromolecular diffractometer NMX instrument

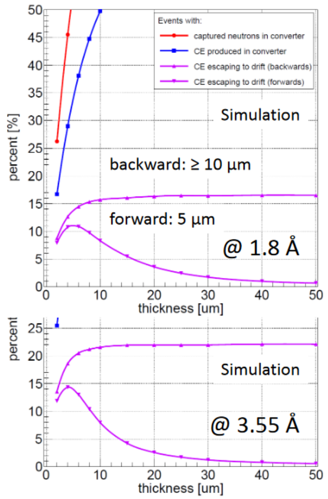


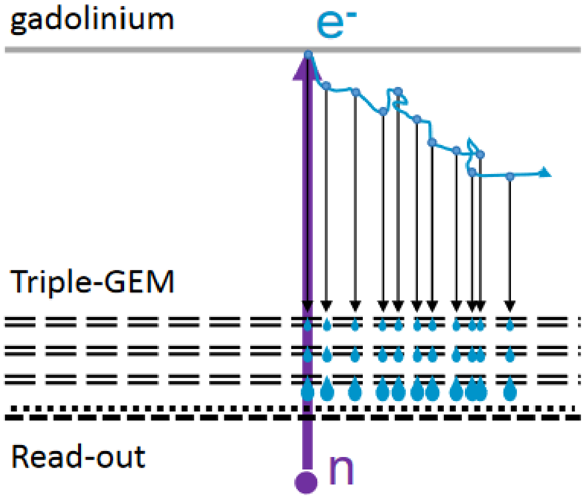
Need/Way Out [7]

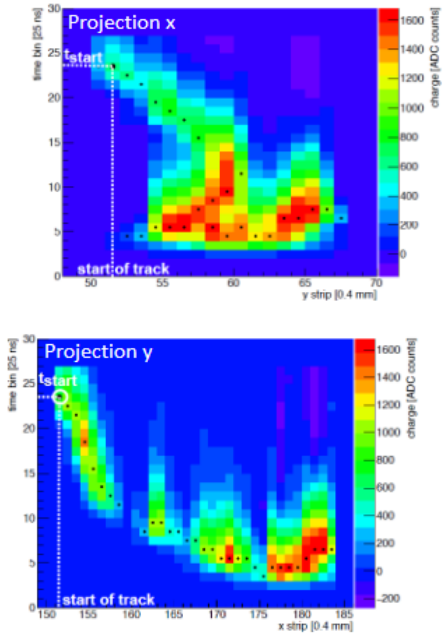
Neutron Detection for macromolecular diffractometer: high efficiency, good space resolution (ca 200μm), high rate

Space resolution
Gadolinium will emits tens to hundreds keV e^-
μTPC to get the impact point (later time)









Conversion.. Converter.. Efficiency.. **Gadolinium**

Shooting from readout: easier for **efficiency** (**reflective**/thickness)…
Detector **material** to be properly selected to **minimize scattering**

Proper design of readout plane (XY strips,400μm pitch, 25cm long) and proper **FE electronics (BNL VMM3a ASIC, self-triggering, high throughput, charge/time information)**…

https://indico.cern.ch/event/673355/attachments/1601054/2538407/20180215DTtrainingSeminarLupbergerThuiner.pdf

Need/Way Out [8]

REAL CASE: X-Ray diffraction / pinhole camera

X-Ray detection with reduced parallax errors.

Gas (cross sections for x-rays) force to have large drift volume and therefore large parallax errors in position reconstruction.

Diffraction

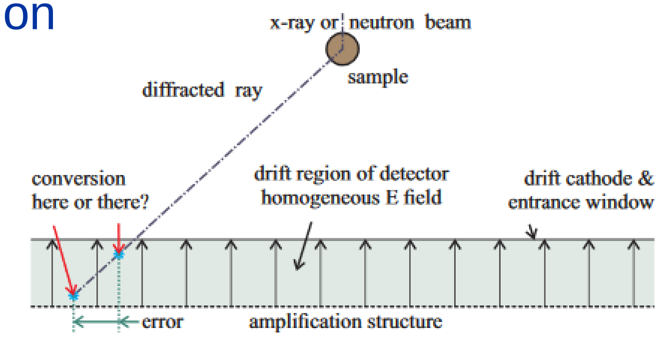
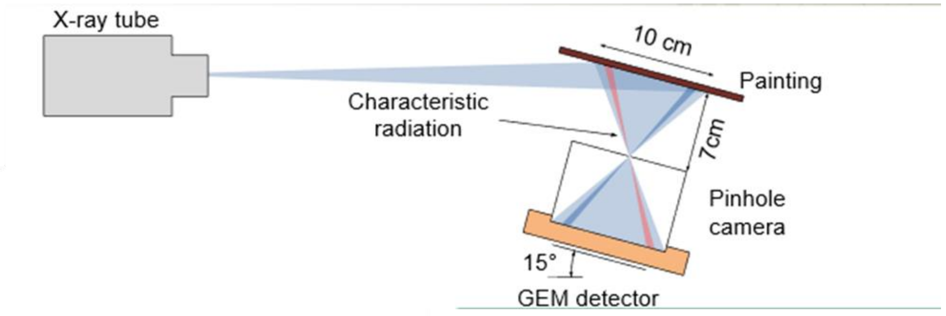


Figure 2. The cause of a parallax error in a gas detector with a homogeneous drift field.

https://arxiv.org/pdf/1011.5528.pdf

Pinhole

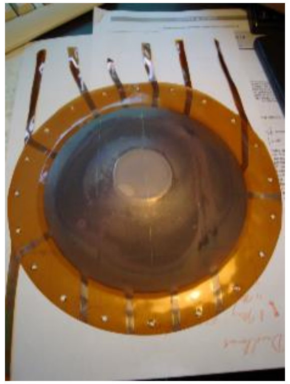


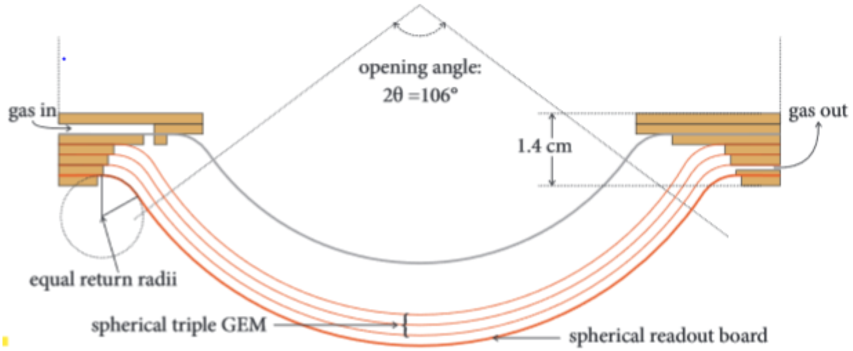
http://koza.if.uj.edu.pl/jagiellonian-symposium-2015/file/talks/s7_zielinska.pdf

Need/Way Out [8]

Create (mechanically/radial-spherical shape or electrostatically/multiple-electrodes) **proper (aligned with the photons trajectories) field lines** in the sensing volume

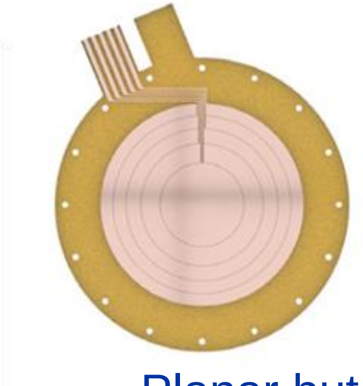
Parallax errors in X-Ray detection

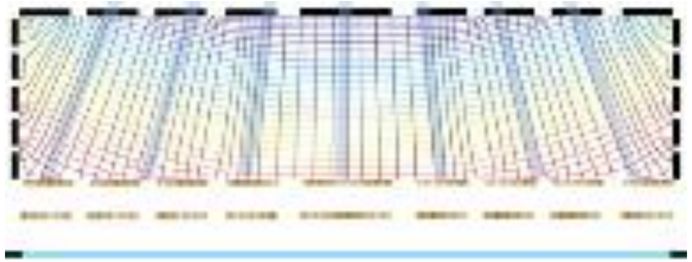




https://arxiv.org/pdf/1011.5528.pdf

Several electrodes biased at different voltages to shape the drift field properly





Planar but with sectors to create a radial field

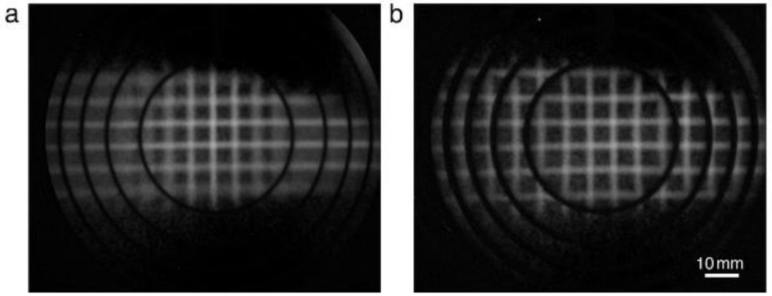


Fig. 9. X-ray fluorescence images of a Cu grid. (a) In the case of parallel drift field lines, the grid lines appear strongly washed out in the outward regions of the active detector area. (b) The radially focused drift field lines of the planispherical GEM allow distinction of grid lines even in the off-center regions of the detector and increase signal-to-noise ratio.

https://www.sciencedirect.com/science/article/pii/S0168900217309555?via%3Dihub

Way out: Deforming (left) or segmenting (right) the electrodes of the conversion volume to have radial field

Need/Way Out [9]

Readout: Space resolution / readout channels

Preserving the intrinsic (micro pattern) good space resolution of MPGD based detectors with reduced number of channels on large area detectors.

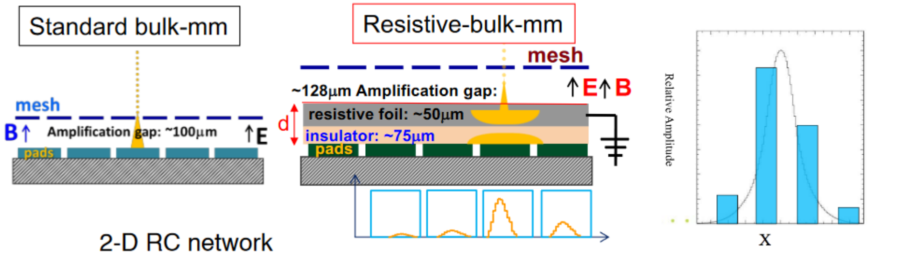
Need/Way Out [9]

Way out: Optimizing signal sharing (cluster size > 1 and centroid methods/encoding)

Readout: Space resolution / readout channels

SHARING/RESISTIVE

Again resistive layers but this time for charge sharing (in fact the first use of resistive layers in MPGDs)



2-D RC network

$$\rho(\mathbf{r},\mathbf{t}) = \frac{\mathrm{RC}}{2\mathrm{t}}\exp\left[-\frac{\mathrm{r}^2\mathrm{RC}}{4\mathrm{t}}\right]$$

R- surface resistivity
C- capacitance/unit area

Gaussian spreading as a function of time with :

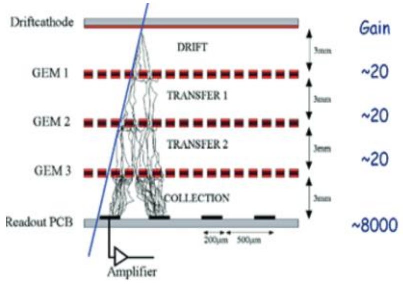
$$\sigma_r = \sqrt{\frac{2t}{RC}} \quad \begin{cases} t \approx \textit{shaping time (few 100 ns)} \\ RC_{[ns/mm^2]} = \dfrac{180\ R_{[M\Omega/\blacksquare]}}{d_{[\mu m]}/175} \end{cases}$$

https://indico.cern.ch/event/716539/contributions/3245960/attachments/1798809/2933398/Delbart_VCI2019_T2K_HA-TPC.pdf

(A. Sarvestani et al., Nucl. Instr. And Meth. A410 (1998) 238
one of the first example, mCAT & resistive layers for charge sharing)

SHARING/GEOMETRICAL

(using diffusion)



(using diffusion & layout)

Design Studies for a TPC Readout Plane Using Zigzag Patterns with Multistage GEM Detectors

B. Azmoun, P. Garg, T.K. Hemmick, M. Hohlmann, A. Kiselev, M.L. Purschke, C. Woody, A. Zhang

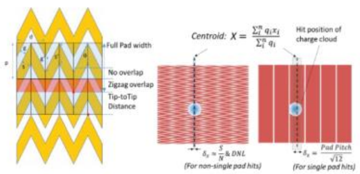


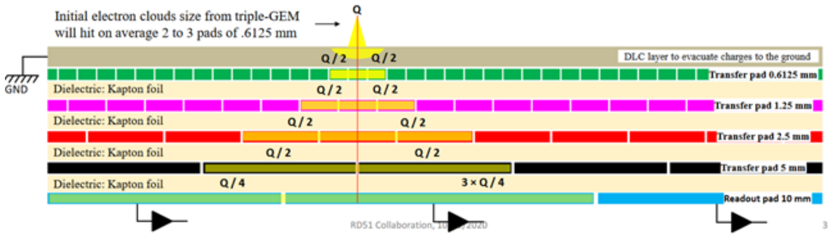
Fig. 1 The sketch on the left shows the 4 basic parameters of the zigzag pattern, including the pitch, zigzag period, gap width, and trace width, denoted by p, d, g, and s respectively. (θ, s', and g' are resultant parameters representing the characteristic angle, the trace width, and gap width at the zigzag apex.) The sketches on the right demonstrate charge sharing and centroid calculations for a zigzag and rectangular pad readout. 6 channels are shown for each pattern with a pitch of 2mm. (The drawings on the right are to scale.)

https://www.osti.gov/pages/servlets/purl/1466982

SHARING/CAPACITIVE

Preliminary Results of Spatial Resolution Performances of Capacitive Sharing Large Pad Readout in Test Beam

Kondo Gnanvo, University of Virginia, Charlottesville, US

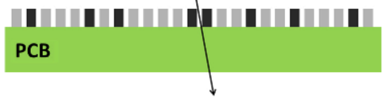


https://indico.cern.ch/event/889369/contributions/4042739/attachments/2119963/3567713/20201009_KG_RD51_Coll_Meeting.pdf

(in addition) ENCODING

Genetic multiplexing and first results with a 50 × 50 cm^2 Micromegas

S. Procureur [a,*], R. Dupré [a,b], S. Aune [c]



https://doi.org/10.1016/j.nima.2013.08.071

Fig. 4. Principle of the genetic multiplexing. A particle (array) leaves a signal on two neighbouring strips which are connected to two given channels. These channels are connected to other, non-neighbouring strips in the detector. The recorded signals on these two channels therefore localize without ambiguities the particle in the only place where strips are consecutive.

Need/Way Out [10]

Readout: Pixels

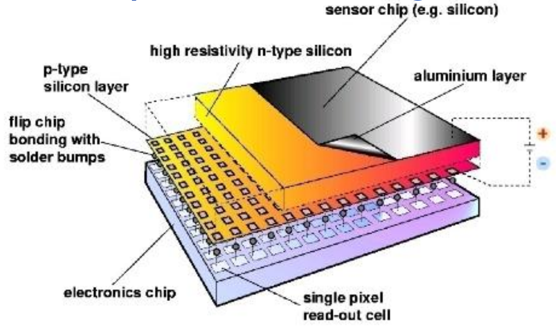
Implementing highly pixelated readout (10^5-10^6 pixels)

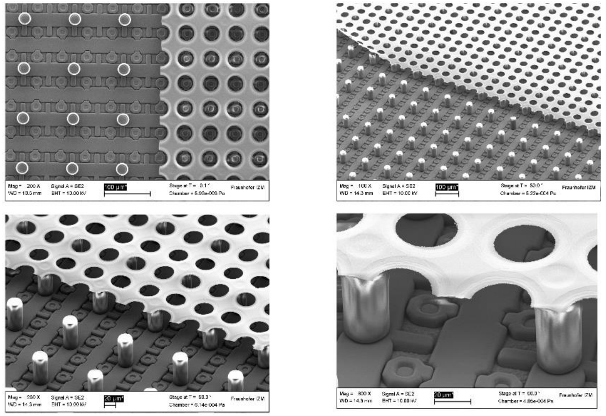
Need/Way Out [10]

Way out: Direct coupling with pixel chips (charge readout/sensor removed – just readout) or going for optical readout (if emission in visible – proper gas or wls – interesting commercial cameras available)

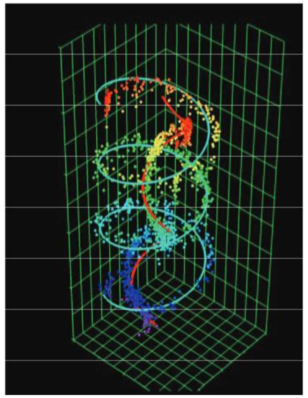
Highly pixelated readout (10^5-10^6 pixels)

Timepix&micromegas





https://indico.cern.ch/event/581417/contributions/2522462/attachments/1465797/2265982/GridPix_TP3.pdf



Available online at www.sciencedirect.com

ScienceDirect

Physics Procedia 17 (2011) 224–231

Physics Procedia

ELSEVIER

Physics of Fundamental Symmetries and Interactions – PSI2010

Gaseous and gasless pixel detectors

Harry van der Graaf

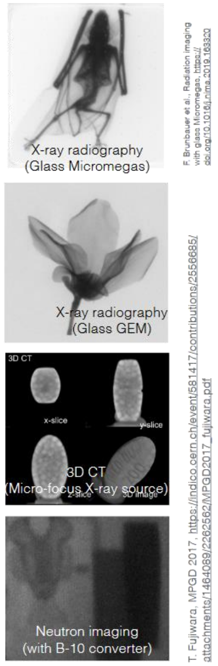
Nikhef, Science Park 105, 1098 XG Amsterdam, The Netherlands

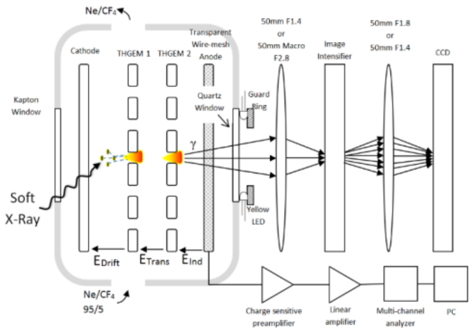
Fig. 2. Two ß's from a ^{90}Sr source, recorded with a Timepix based GridPix detector. Drift length: 30 mm. Gas: He/i-butane 80/20, with a magnetic field of 0.2 T oriented parallel to the (vertical) drift field. The bottom plane represents the Timepix chip (256 x 256 pixels; square pixel pitch 55 µm).

Optical readout

Image immediately available without need for reconstruction.

Two acquisition approaches:
- **Integrated imaging** collects all light within exposure time **without deadtime** with long exposure time
- **Event-by-event** recording with short exposure time for track reconstruction

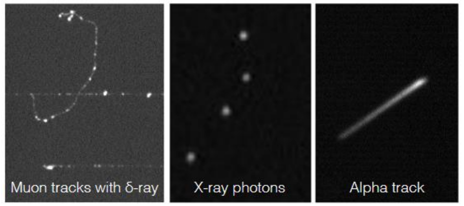




https://iopscience.iop.org/article/10.1088/1748-

https://indico.cern.ch/event/999799/contributions/4204161/attachments/2235612/3789884/OpticalHybridReadout.pdf

Optical scintillation light readout



Need/Way Out [11]

Resistive

REAL CASE: ATLAS NSW micromegas

Instruments based on stable single amplification stage(*)

(*) Different motivation behind this choice, sometimes linked to measurements requirements (less diffusion, ..) sometime to detector production and assembly, sometimes to….

Cylindrical trackers (triple GEM, mm, μRWELL)

Figure 1. The Inner Tracker detector before its installation in the KLOE-2 interaction region is shown in the left panel. All the four layers before assembling them to build the Inner Tracker are shown in the right panel.

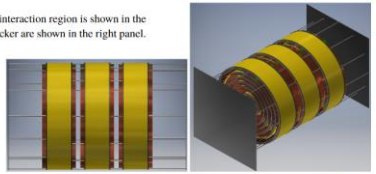


Figure 14: Left: Side view of tracker barrel design composed of three cylindrical μRWELL modules interconnected with thin rods that attach to the drift spacers. Right: Projected view of tracker barrel and endplates that the tracker cylinders would be stretched against. The outer diameter of the tracker barrel is approximately 1.6 m and the total length of the three segments is about 1.8 m.

Single amplification stages (micromegas). In the original version suffering of stability (highly ionizing events) compared to multi-stages (introduced in most of the cases to improve stability).

N·H
ELSEVIER
Nuclear Instruments and Methods in Physics Research A 376 (1996) 29–35
NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments

Y. Giomataris[a,*], Ph. Rebourgeard[a], J.P. Robert[a], G. Charpak[b]

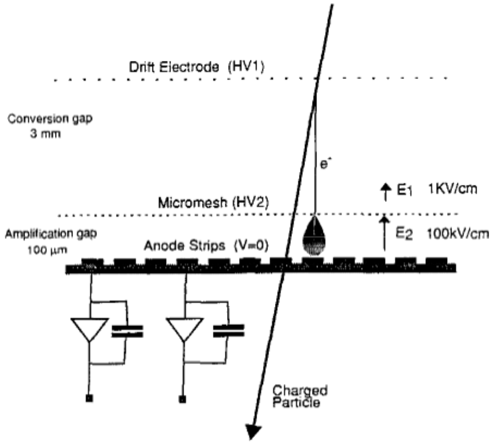
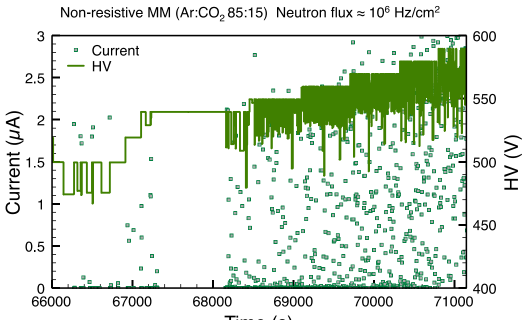


Fig. 1. A schematic view of MICROMEGAS: the 3 mm conversion gap and the amplification gap separated by the micromesh and the anode strip electrode.

Instabilities (sparks) increasing the amplification field



Nuclear Instruments and Methods in Physics Research A 640 (2011) 110–118

Need/Way Out [11]

Single stage & improved stability: Replace readout/conductive anode with resistive anode and readout the signal via capacitive coupling (MAMMA collaboration for ATLAS NSW)

Nuclear Instruments and Methods in Physics Research A 640 (2011) 110–118

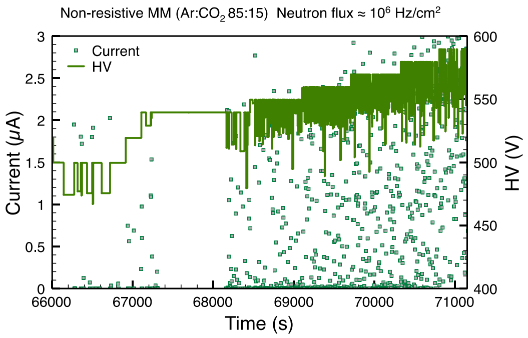
Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

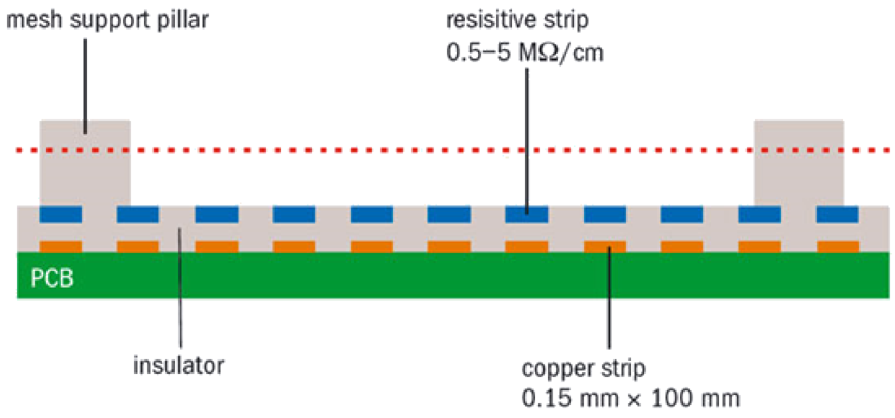
journal homepage: www.elsevier.com/locate/nima

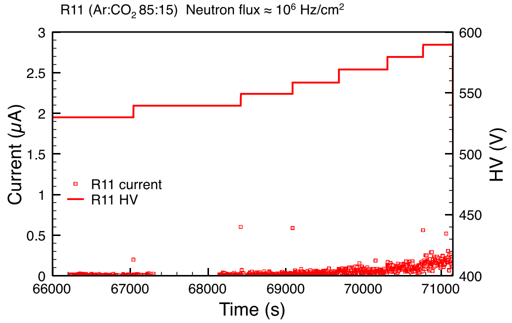
A spark-resistant bulk-micromegas chamber for high-rate applications

T. Alexopoulos [a], J. Burnens [b], R. de Oliveira [b], G. Glonti [b], O. Pizzirusso [b], V. Polychronakos [c], G. Sekhniaidze [d], G. Tsipolitis [a], J. Wotschack [b,*]



Instabilities (sparks) increasing the amplification field





Instabilities (sparks) quenched by the resistive anode

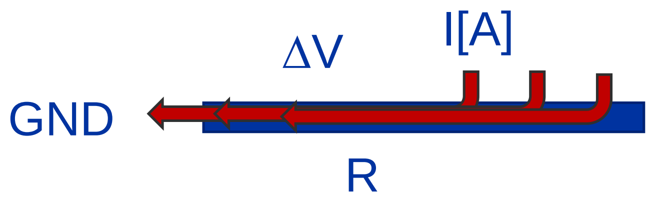
Nuclear Instruments and Methods in Physics Research A 640 (2011) 110–118

Need/Way Out [12]

Single stage, Resistive.. Ok..

What if I have to operate in high rate?

Single amplification stage (simpler assembly, less diffusion)… stable (discharges) with resistive anodes… but for high rate charge evacuation can be an issue



In plane… detector size dependent…

Charge Evacuation

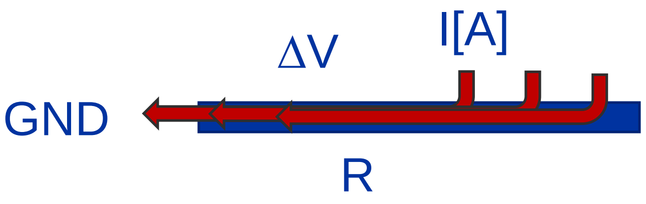
If resistive electrodes are implemented, obvious drawback is the rate capability.

Total charge collected has to flow to GND and drop on resistive layer can affects field and detector performances

Need/Way Out [12]

Single amplification stage (simpler assembly, less diffusion)… but stable (discharges) .. resistive anode… but for high rate… (charge evacuation)

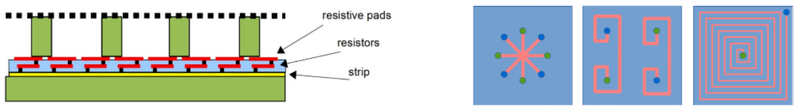
R&D for CALICE DHCAL
resistive pad micromegas



R&D for resistive micromegas
high rate muon tracker

Resistive patterns

- We tried different resistive pattern with different Q evacuation schemes
- And adopted the embedded resistor (de Oliveira et al. in 2010)
  - Pioneered by COMPASS Saclay group (2009 JINST 12 P12004)
  - Now, interest for ATLAS (M. Iodice et al., 2017 JINST 12 C03077)
  - In between, us.
- Allows segmentation of readout anode plane into pads (no Q spread)
- Control of the resistance through R-pattern
  → minimal charge-up & spark suppression

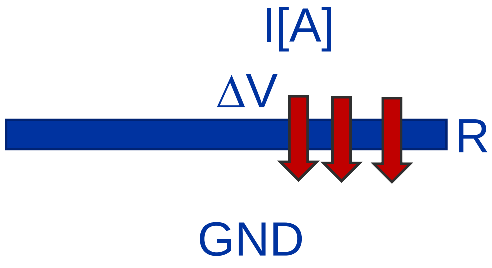


4

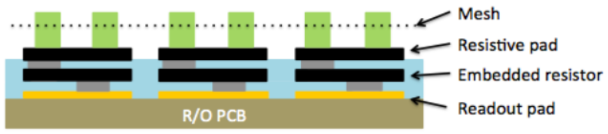
https://indico.cern.ch/event/702148/contributions/2910267/attachments/1606383/2548954/11_CHEFDEVILLE-chefdeville.pdf

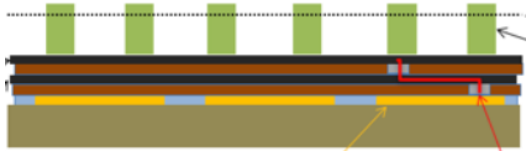
In plane… detector size dependent…

Way out:
Vertical evacuation of the charge



Vertical… detector size independent…





https://indico.cern.ch/event/757322/contributions/3402985/attachments/1839477/3015191/SmallPadMicromegas_MPGD19_v5.pdf

Need/Way Out [13]

Next two examples with a particular focus on **production/assembly** (large systems)

Starting with production and continuing in the line of the previous example….

Single stage…

With better stability implementing resistive layers at the amplification stage…

I can even develop some smart layout to prevent performances drop at high rate…

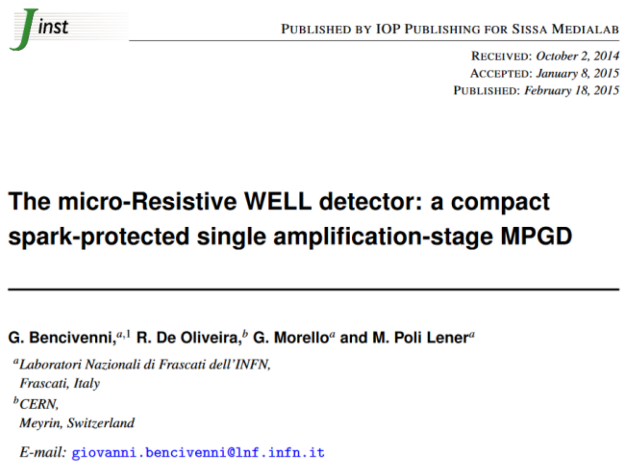
Can I transfer all of this to industry to simplify future productions? Ready detector from industry?

Natural choice is in the field of PCB maker..

Production that potentially fully handled by industry ("~standard" PCB technologies)

Need/Way Out [13]

Single stage… but stable (discharges) .. resistive anode… for high rate… (charge evacuation).. with a simplified production that could be potentially fully handled by industry (“~standard” PCB technologies)



JINST

PUBLISHED BY IOP PUBLISHING FOR SISSA MEDIALAB

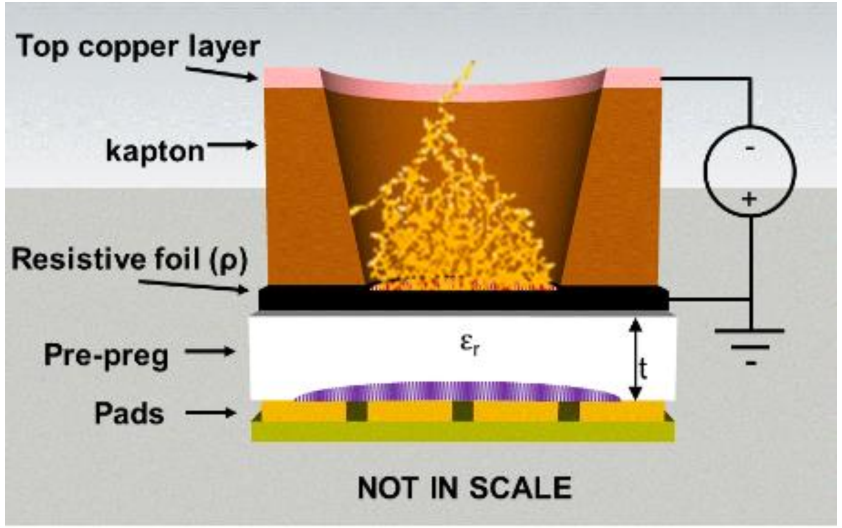
RECEIVED: *October 2, 2014*
ACCEPTED: *January 8, 2015*
PUBLISHED: *February 18, 2015*

The micro-Resistive WELL detector: a compact spark-protected single amplification-stage MPGD

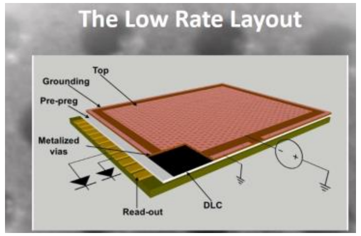
G. Bencivenni,[a,1] R. De Oliveira,[b] G. Morello[a] and M. Poli Lener[a]

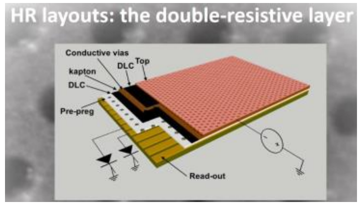
[a] *Laboratori Nazionali di Frascati dell’INFN, Frascati, Italy*
[b] *CERN, Meyrin, Switzerland*

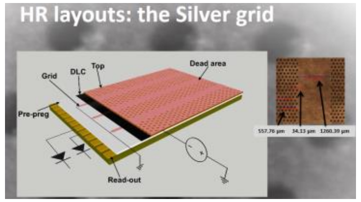
E-mail: giovanni.bencivenni@lnf.infn.it



And different layout schema to accommodate protection and rate capability Need







Involved workshop/companies: CERN MPT, ELTOS, TECHTRA,..)

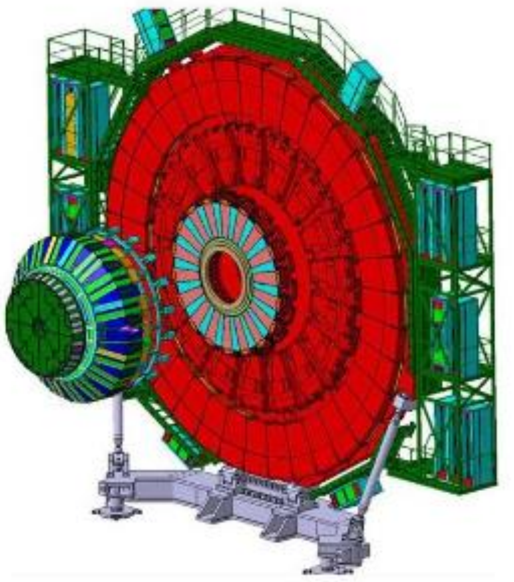
GEM on the anode (WELL)
+
resistive layers (previous example on mm)
+
Evacuation path

Ancestors…

- WELL detector, R. Bellazzini et al. NIM A423(1999)125
- Development and performance of Microbulk Micromegas detectors, S Andriamonje et al 2010 JINST5 P02001

https://indico.cern.ch/event/716539/contributions/3246634/attachments/1798069/2932152/micro-RWELL-VCI-2019-Vienna-feb-2019-Bencivenni-2.pdf

Need/Way Out [14]



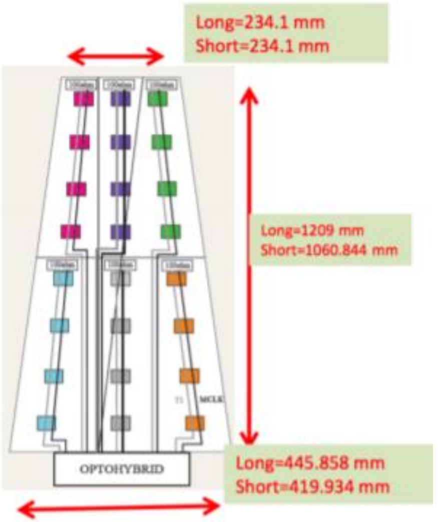
https://indico.inp.nsk.su/event/20/contributions/946/attachments/534/619/Talk_INSTR20-Draft3.pdf

72 Super-Chambers (144 single triple GEM detectors)

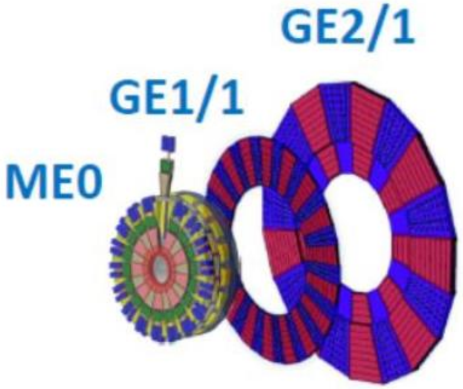
Now focusing on assembly…

Simplify detector assembly procedure to be "easily" transferred to institutes/companies

REAL CASE: CMS/GEM muon system



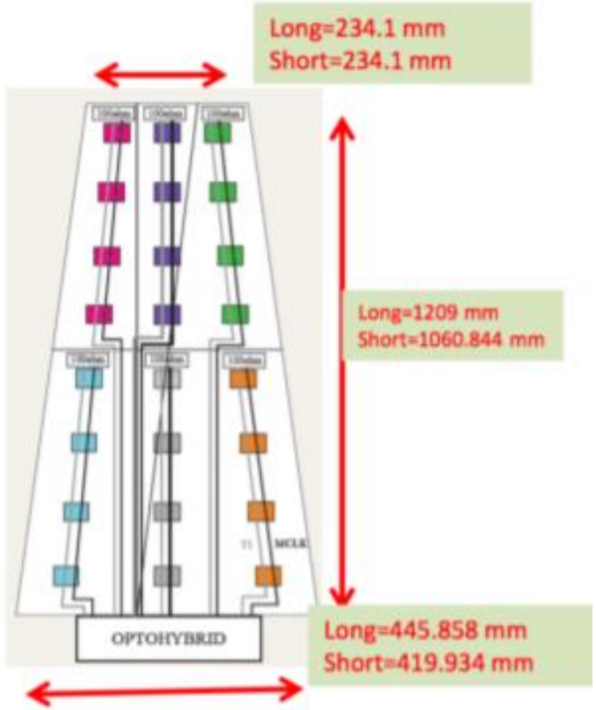
Year End Technical Stops and Long Shutdown 3
2022-2026

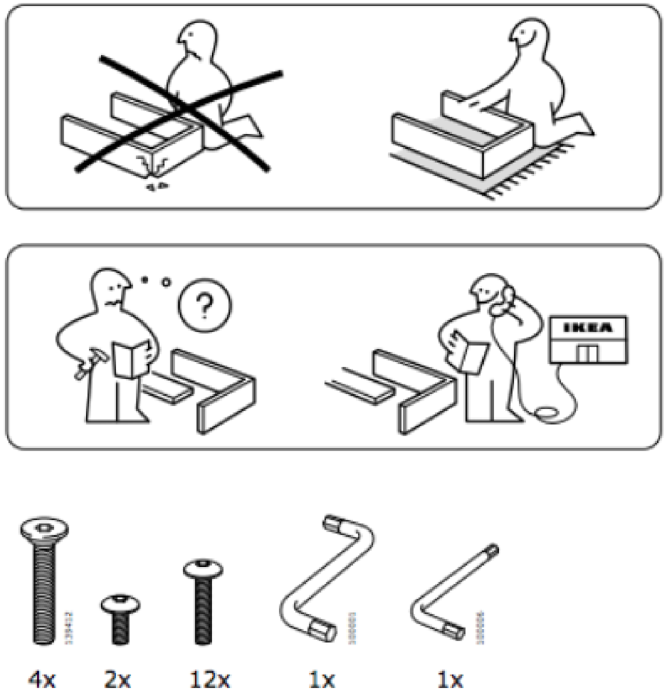


Installation of ME0 and GE2/1 GEMs stations by the end of LS3

Need/Way Out [14]

Simple & clear assembly procedure (for large system and several teams involved)





Nuclear Inst. and Methods in Physics Research, A 918 (2019) 67–75

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Layout and assembly technique of the GEM chambers for the upgrade of the CMS first muon endcap station

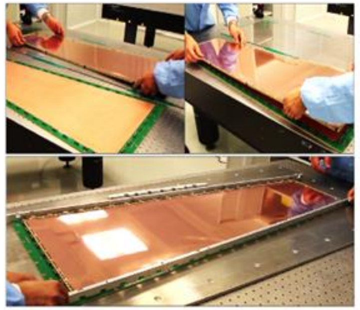


Fig. 20. (top) Placing the GEM stack onto the drift board. (bottom) The GEM stack on the drift board and fixation of the drift board with the assembly jig.

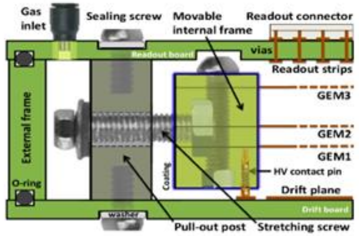


Fig. 21. Concept and mechanism employed to stretch the GEM foils in GE1/1 chambers [3].

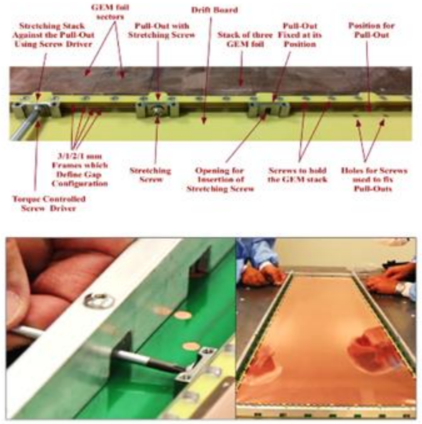


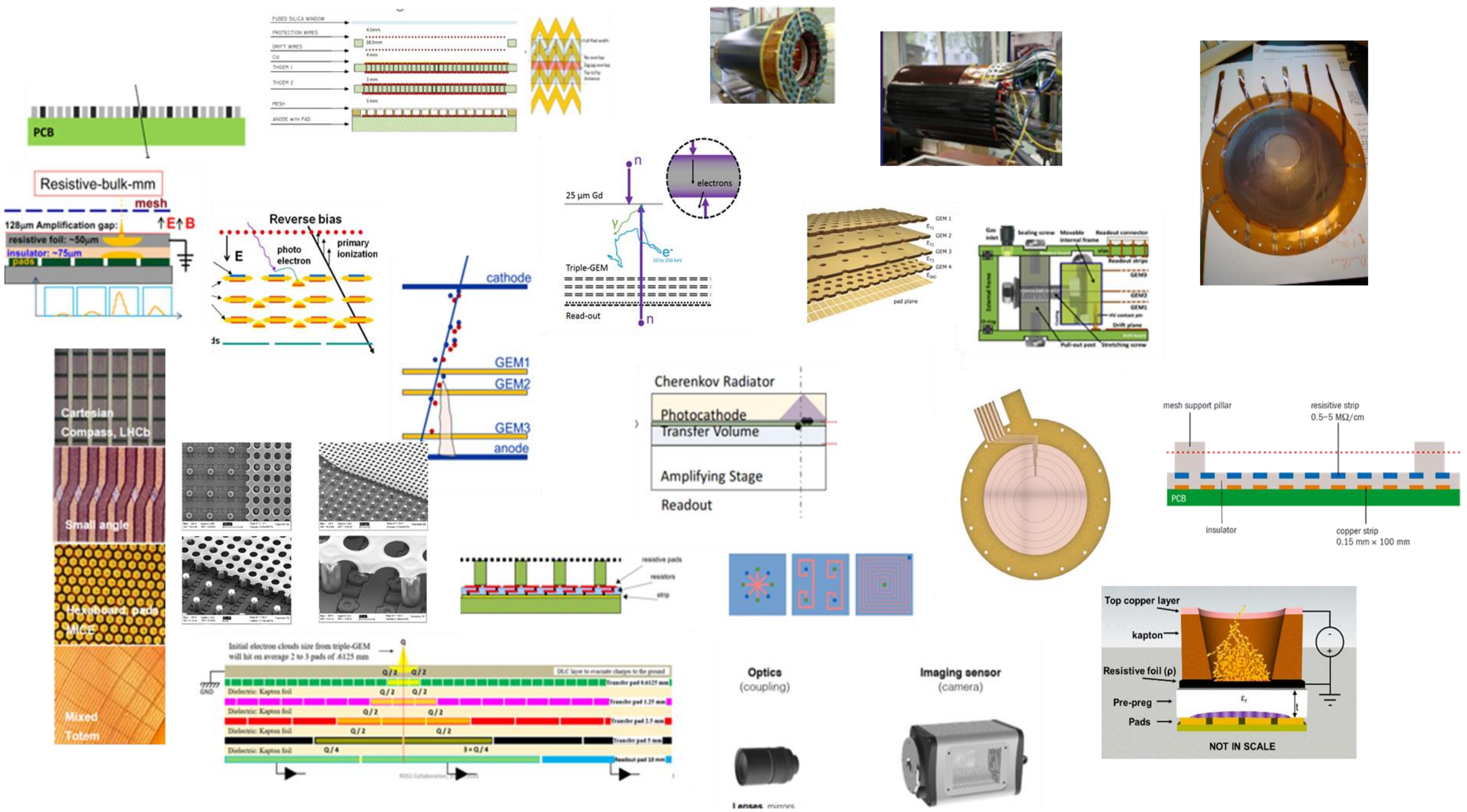
Fig. 22. (top) The implementation of the concept depicted in Fig. 21 by using various components to stretch the GEM stack against the pull-outs. Stretching screws are allowed to pass through the stainless steel pull-outs and are received by nuts embedded into the inner frame for tensioning the GEM foils in the stack. (bottom) The actual stretching is performed using a screw driver with an assembly jig mounted onto the drift board.

Handling of the components has to be done carefully, cleanness is fundamental in particular at certain steps, …

A part for specific cases (photocathodes,..) assembly doesn’t required specialized people (trained yes) or infrastructures (properly equipped yes)…

Needs/Way Out

Conversion	Amplification	Signal
Radiation to primary electrons in gas	Multiplying primary electrons via ionization processes in the gas (avalanches)	Detect secondary charge or photons produced in the avalanches
Conversion efficiency, released energy, topology of primary ionization, attachment in the gas, drift and diffusion, space charge (ions from amplification..),....	Amplification, attachment, drift and diffusion, charge losses, ions, discharges, space charge, charging up,..	Signal coupling (charge or light readout), readout plane granularity and number of readout channels/pixels, protection, FE electronics,..



AIM of the previous slides is to show that **the solution is often the developer** that is capable of identifying in the technologies (MPGD tech. help thanks to the various and versatile options / **quite large degree of freedom**) the right solution to the problem.

Conclusion/Instrumentation/MPGD

MPGD based INSTRUMENTS

- Micro Pattern Gas Detectors are based on several technologies with a wide set of properties and performances..
- These technologies can be integrated together to improve the matching of requirements, exploiting/mixing the best from different developments..
- Functional parts (conversion/gain/signal) can be often optimized 'independently from' or 'as a support of' the other parts…
- There is a large community working with MPGD (synergies and access to the technology) and already a large number of MPGD-based instruments in a wide range of applications (literature, data, experience, inspiration) most/many of them covered here at the EIROForum school…

Path from new technology to a mature INSTRUMENT

- New technologies require time to become a mature instrument …
- Every development/application will always add new aspects (problems) to be studied (solved)…
- Definitively worth to go through all of this because of the new potential/scenario you can open…
- You need a vision…
- **Do not underestimate your contribution to these processes..**

home.cern