Micromegas: Large size, High rate Trackers for COMPASS at CERN
from 1996 to 2023

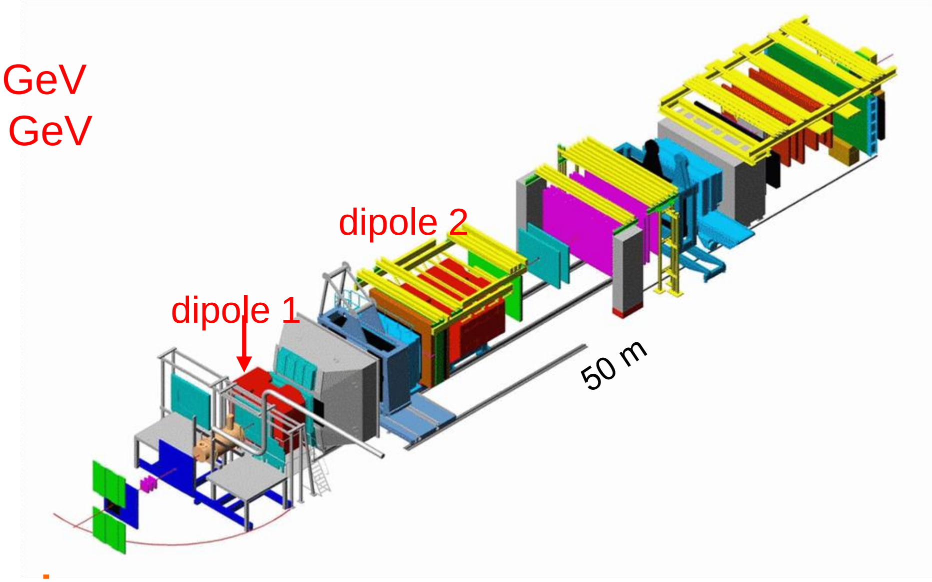
Fabienne KUNNE
CEA /Irfu /DPhN

Yannis Fest, Saclay, Oct. 5, 2023

The COMPASS experiment at CERN SPS

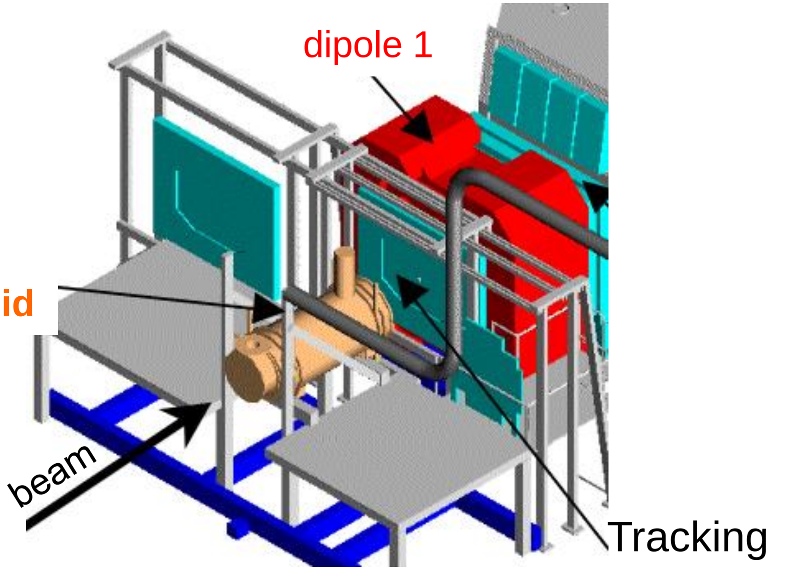
Physics:

- Nucleon spin structure μ 160-200 GeV
- Hadron spectroscopy & exotics π, p 100-300 GeV



Two stages spectrometer
1,2m long, thick polarized proton target
in a **superconducting target solenoid** 2.5T

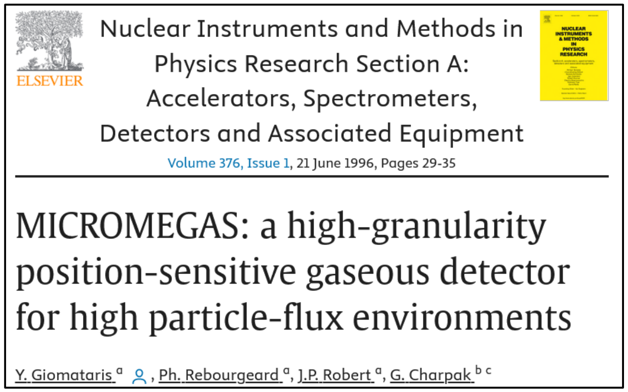
Collaboration started in 1996.
Looked for a solution for **tracking in hottest region:**
between target solenoid and dipole
(which sweeps low energy particles)



Requirements :

- Particle rates up to **5.10 ^{5} /s/cm^2**
  30 MHz integrated flux, beam area excluded
- Work in **fringe fields** of dipole and solenoid 1T
- Resolutions better than **100 μm, 10 -15 ns**
- **Low material** budget
- Size 40x40 cm2

Micromegas


Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment

Volume 376, Issue 1, 21 June 1996, Pages 29-35

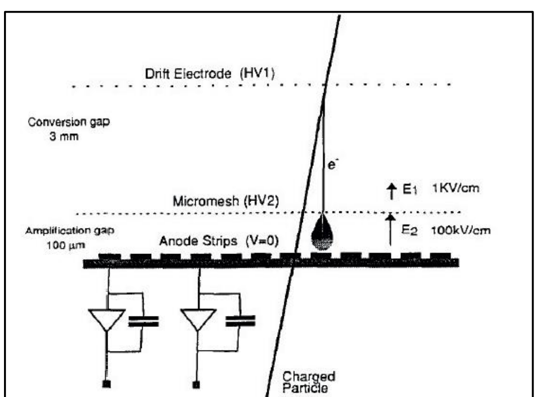
MICROMEGAS: a high-granularity position-sensitive gaseous detector for high particle-flux environments

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

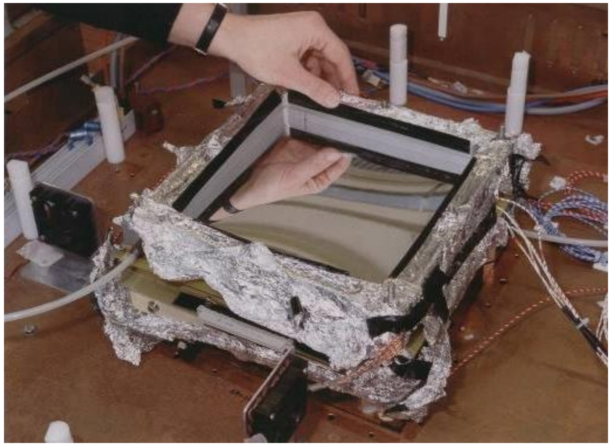
Micromegas:

- **High rate**
- **High resolution**
- **Low mass**

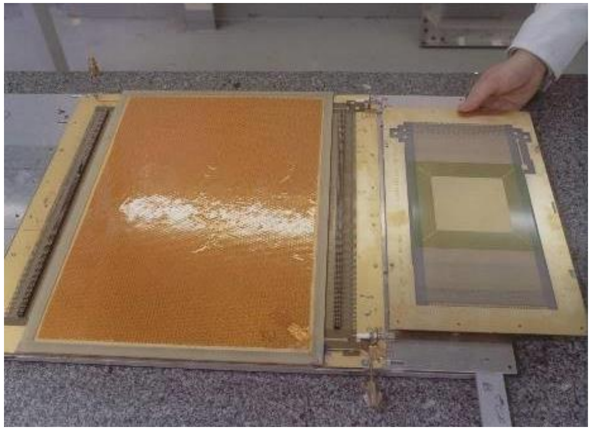
Ph. Rebourgeard,
Project leader for COMPASS
Micromegas & Drift Chambers



From the idea to a real detector: R&D 1997-2000

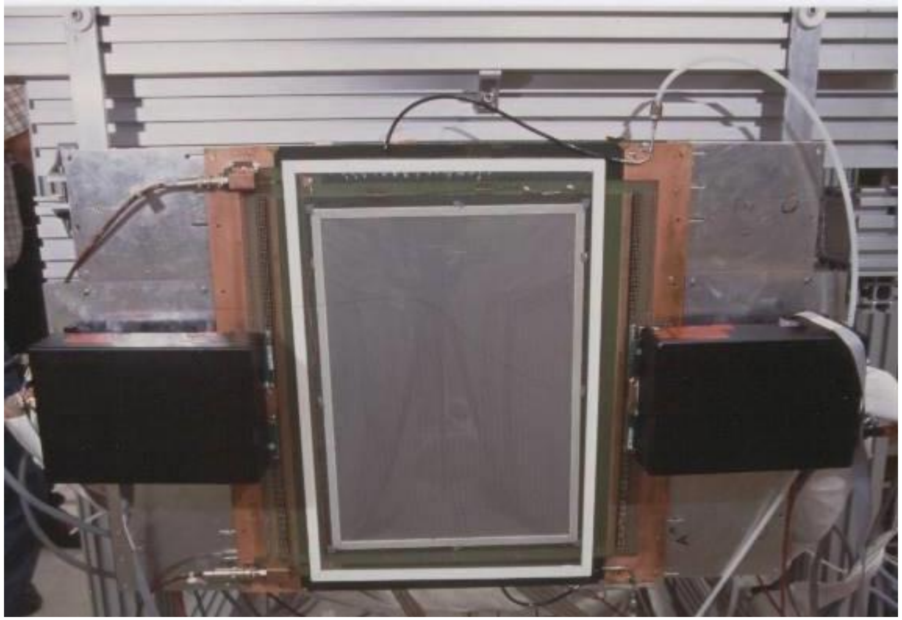


small prototype 14x14 cm^2 in lab



thin epoxy board, with sandwiched honeycom

alu. mylar shielding



Electroformed **Ni grids,** 4 μm thick for both mesh and drift electrodes

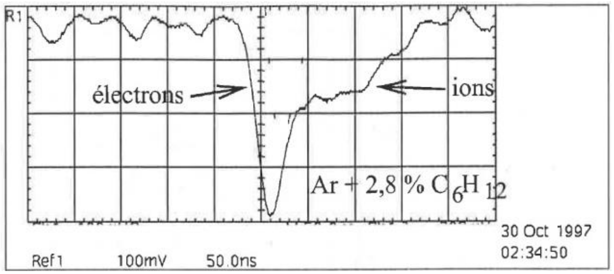
In test beam at CERN
64 strips read by Lecroy MQS104
4 channels, 15ns peaking time

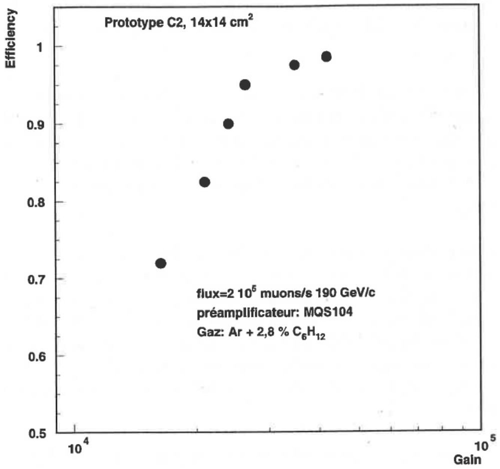
Setup used for extensive basic studies:
- gas mixture
- FE electronic characteristics
- performance

R&D : Prototype tests at CERN 1999

Philippe Rebourgeard, Hugo Pereira, Fabienne Kunne, Alain Magnon, Emile Pasquetto

Performance prototypes with MQS104





Gain G_0 à l'efficacité maximale	42000
$G_0 \times n_e$	1.9×10^6
taille des clusters	3.1 pistes
coefficient de correction du walk	α=0.7
TOT moyen	160 ns
résolution temporelle : σ_t	25 ns
résolution spatiale : σ_r	92 μm

D.Thers, PhD thesis, 2000

Micromegas is a viable solution

However: MQS104 too fast (balistic deficit) and too noisy;
Large occupancy: will not read the beam region
Using $Ar+C_6H_{12}$ → discharges at the high operating gain, with prohibiting dead time

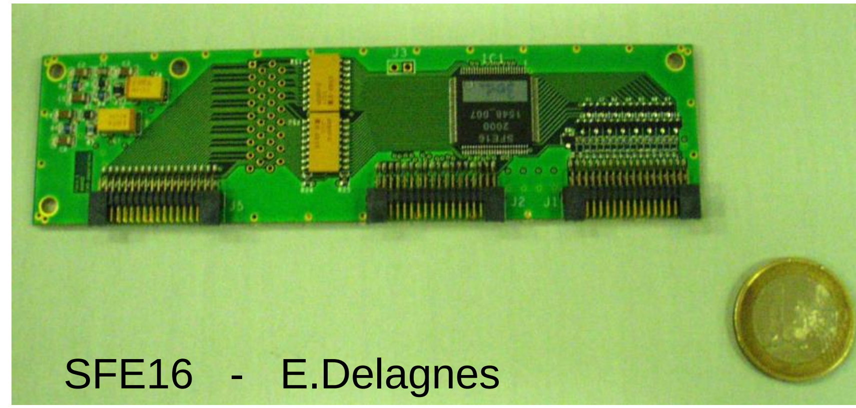
New FE electronics needed with :

- longer integration time
- low noise to operate at low gain against discharges
- Multichannel (to equip 12000 channels)

Gas mixture studies needed for optimal signal width → lighter quencher

New front-end electronics SFE16

Digital readout SFE16 custom circuit



SFE16 - E.Delagnes

- Preamplifier shaper, 16 channels
- **Adjustable peaking time** up to 85 ns
- Record leading and trailing times

→ **Time over threshold**

- **Low noise** < 900 e^- for 68 pF detector capacitance

Associated to F1 multi hit TDC chips

F1 cards (Gérard Tarte) in COMPASS general DAQ

Eric Delagnes

Philippe Abbon

Discharges in COMPASS environment

In COMPASS, 40 MHz muon beam on 1 radiation length target
→ ~ 30 MHz in detector (excluding beam area, including beam halo + target halo + hadrons…)

→ High discharge rate with impact on occupation, hence on efficiency and impact on detector

Actions to reduce number of discharges and their impact:

- **Gas mixture study**
- **Capacitive decoupling of strips**
  → reduces dead time per discharge to 3 ms
  with negligible effect on efficiency
- **Operate at lower gain** (SFE16 FEE)
- **Increase number of primary electrons** by increasing amplification gap
  →going from 2.5 to 3.2 mm reduces rate by factor 5

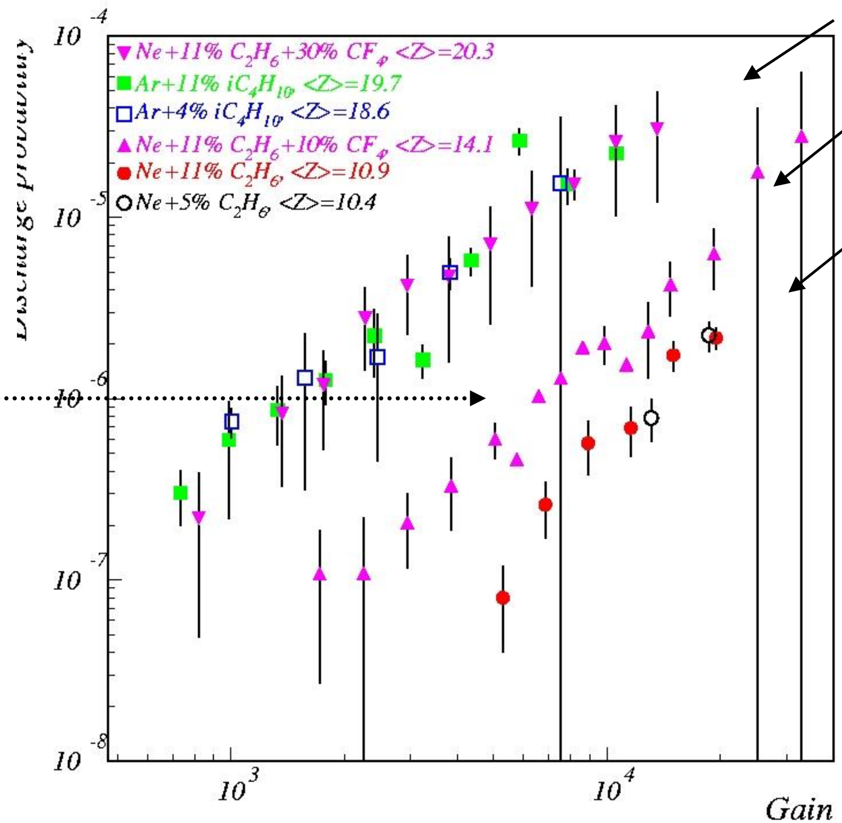
- **Perfect behavior with muon beam**
- **Anticipate further increase of gap for future hadron beam**

Discharge probability in hadron beam

Studies showed that light gases, not only quencher but also noble gases, favor reduction of discharge.

conversion gap : 2.5 μm
amplification gap : 100 μm

Ne-C_2H_6-CF_4
gain ~ 10^4



<Z> ~20

<Z> ~14

<Z> ~10

D.Thers, PhD thesis, 2000
NIM A469 (2001)133

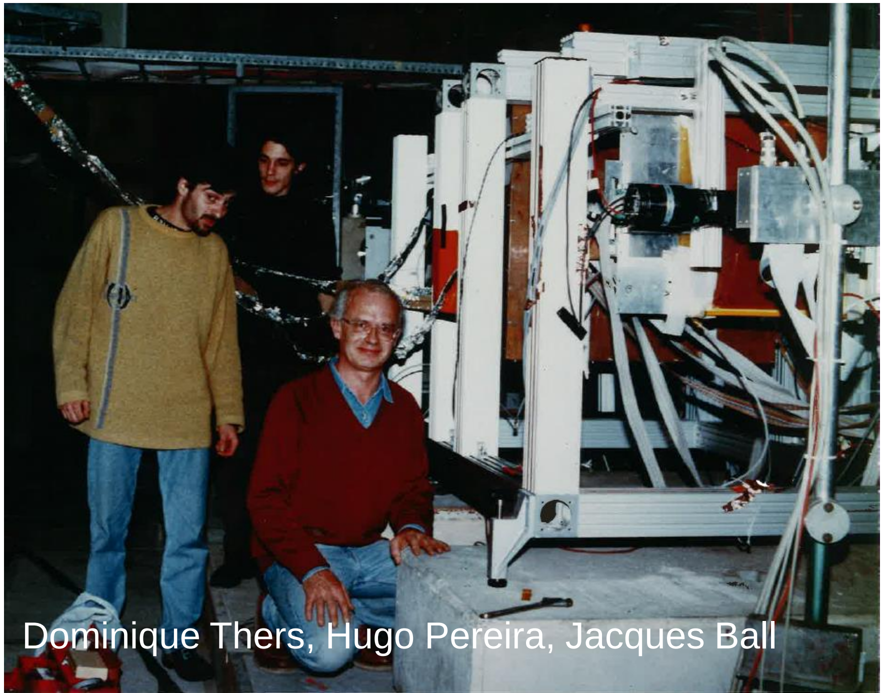
Discharge rate rises with <Z> of gas mixture

Gas mixture choice

Gas	Ar - iC_4H_{10} 89-11 %	Ne - C_2H_6 89-11 %	Ne-C_2H_6-CF_4 79-11-10 %
Gain	3700	14000	6400
Cluster size	2.4	2.9	2.1
Jitter (σ, ns)	12.3	17.	8.8
ToT(ns)	195	182	171
Resolution (μm)	62	80	50
Discharge probability	4. 10^{-6}	1.5 10^{-6}	9. 10^{-7}

Values at the operating point

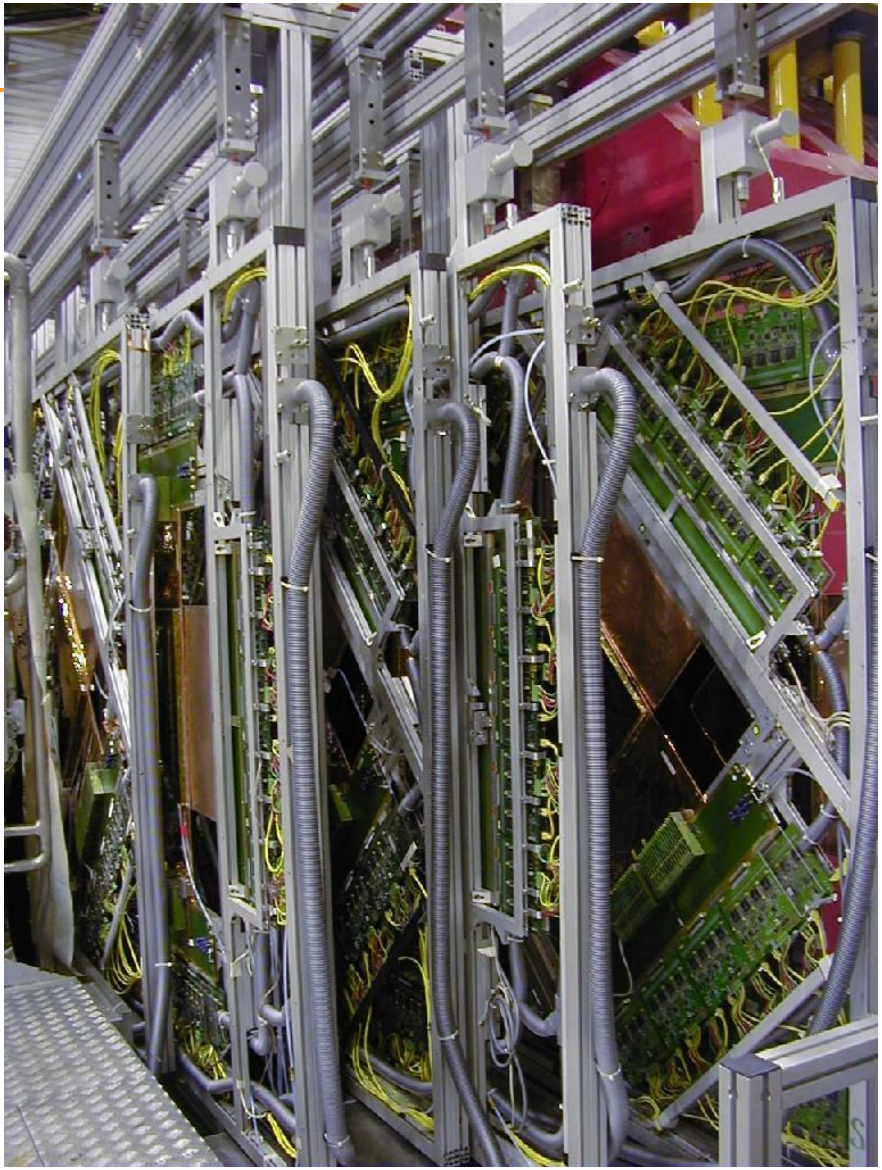
MM 317 μm pitch, gap 2.5mm, in π beam



Dominique Thers, Hugo Pereira, Jacques Ball

Micromegas /COMPASS

3 stations of 4 planes XYUV
total 30 MHz; 450 kHz/strip
pitch 360μm / 420 μm
0.2% X0 rad. length/plane



12 Micromegas planes 40x40 cm2

3 stations X Y U V (+/- 45°)

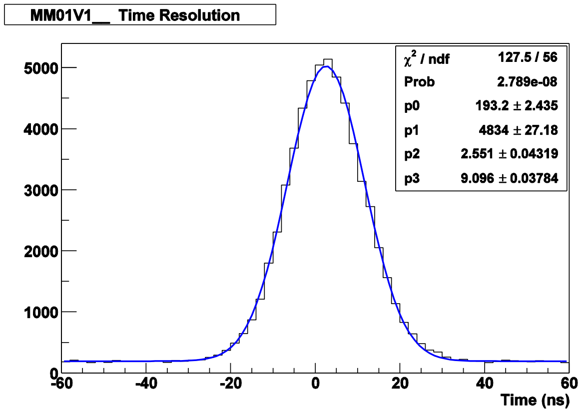
Saclay IRFU
CERN lab, R.de Oliveira

Performance Micromegas + SFE16. Time distributions

Leading & trailing edges of signal

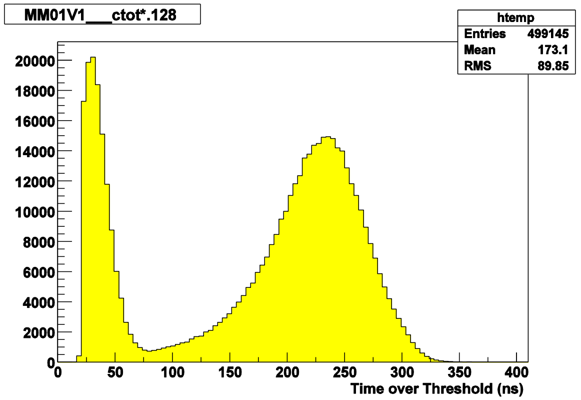
time walk suppressed

Time resolution σ = 9ns



Signal amplitude calculated from ToT (220 ns):

Improves background rejection and spatial resolution

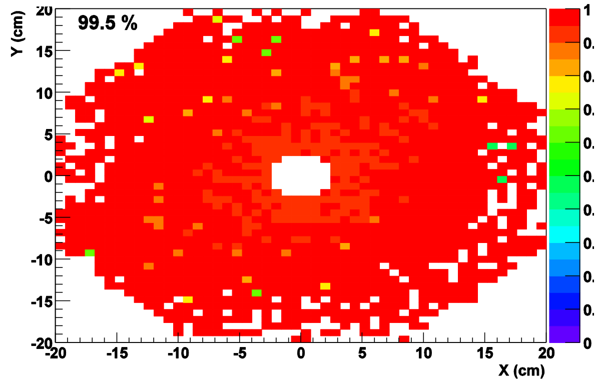


Performance in COMPASS environment, μ beam

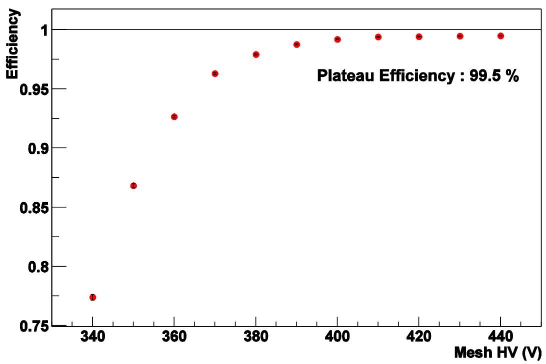
- efficiency 99.5 / 96 %
- resolution 70 / 90 μm

for low / high beam intensity

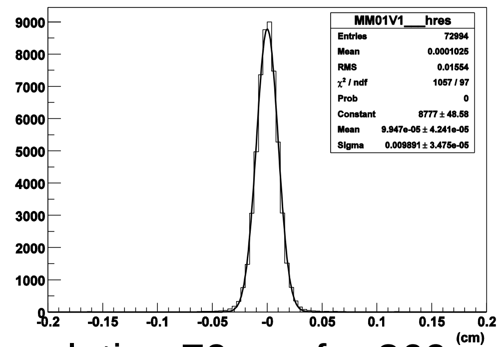
2D efficiency



Efficiency plateau



Spatial residuals



Resolution **70 μm** for 360 μm pitch

Accumulated charge during 6 years 2002-2007:

10^{13} p/cm^2 in hottest region

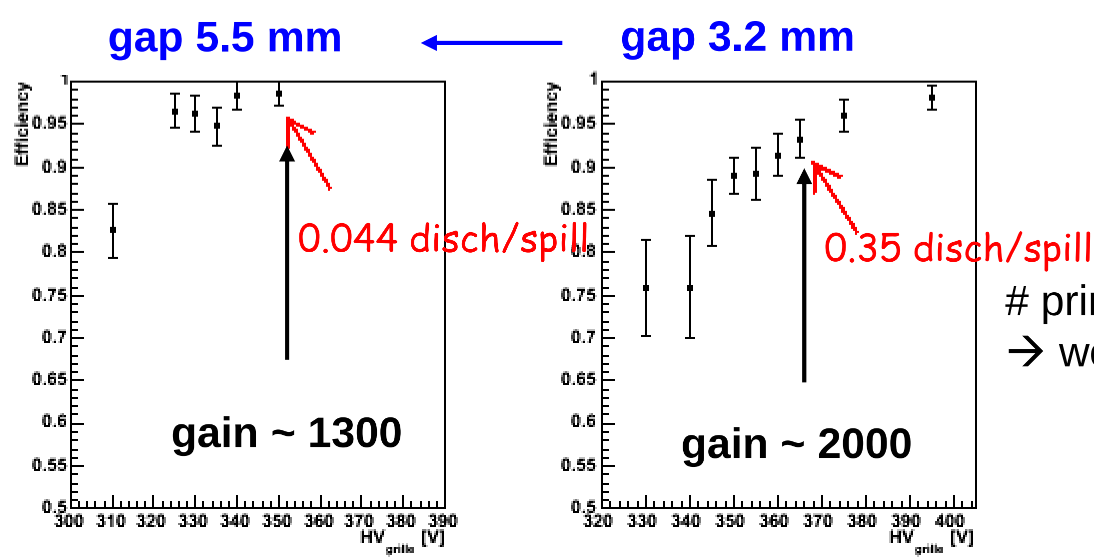
or **2 mC/mm²**

Excellent and stable performance over years since 2002

COMPASS hadron beam – 200 GeV π (2008)

In 2004, tests with pion beam show an high increase of discharge rate.
Decide on future modifications for the hadron beam program in 2008.

- **Increase Micromegas amplification gap** 3.2 mm→ 5.5 mm:
  Higher ionization #e-: 18→ 27 , efficient at lower gain
- **Change gas mixture : Ne-C_2H_6 (no CF_4)**



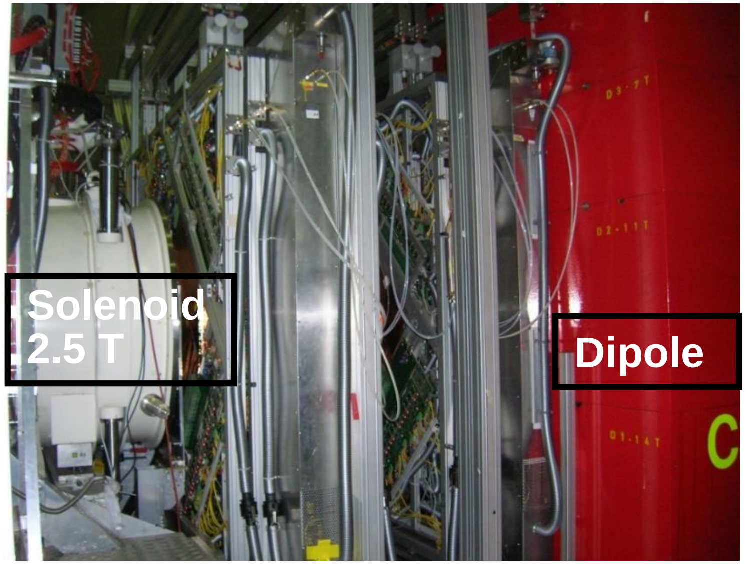
primary interactions too low
→ would need higher gain

With 5.5 mm gap, discharge rate as low as in muon beam

→ Micromegas detectors performing well in hadron beam

Operating in magnetic fringe fields

In 2006, old target solenoid is replaced by a **new large aperture solenoid** (OD Magnet)



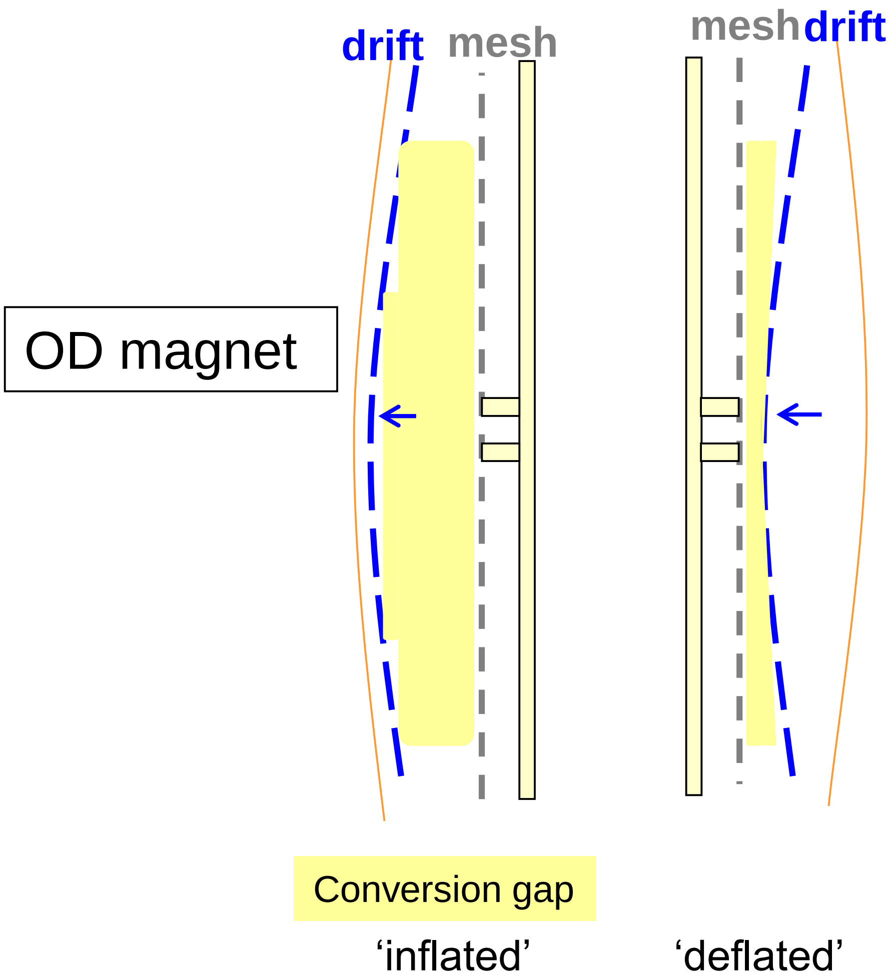
OD magnet (white) and dipole surrounding Micromegas stations

The new **high fringe field** crosses Micromegas detectors,
attracting or repelling the nickel drift grids depending on detector orientation.

Detectors start dying by shorts between mesh and drif nickel grids.

Operating in magnetic fringe fields

Micromegas doublet



Consequences:

- Lower efficiency, varying with position
- Variable time jitter
- Variable field

Correlated hardware problems :

- **shorts between mesh and drift**
- additional trips
- occasionally lost amplification (mesh movement)
- grids suffer high constrains

- Replaced mesh and drift nickel grids by copper ones

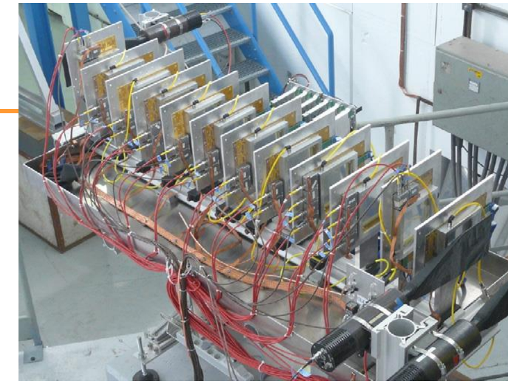
tried various geometries …

- Then we could use alternately muon or hadron beams with success till 2014

μ 160 GeV 2.10^{8} /5s spill

π, K 100 -300 GeV $5.\ 10^{7}$ /5s spill

Micromegas evolutions



In 2009, launch R&D with two goals:
- Make the detector active in central part
- Further reduce impact of discharges to enable higher intensity hadron beams

Joined COMPASS and CLAS R&D on resistive bulks and discharge study

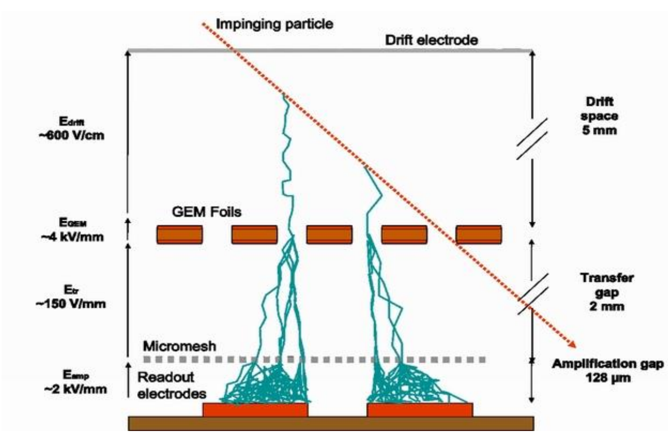
G. Charles et al. NIM 648 (2011)174

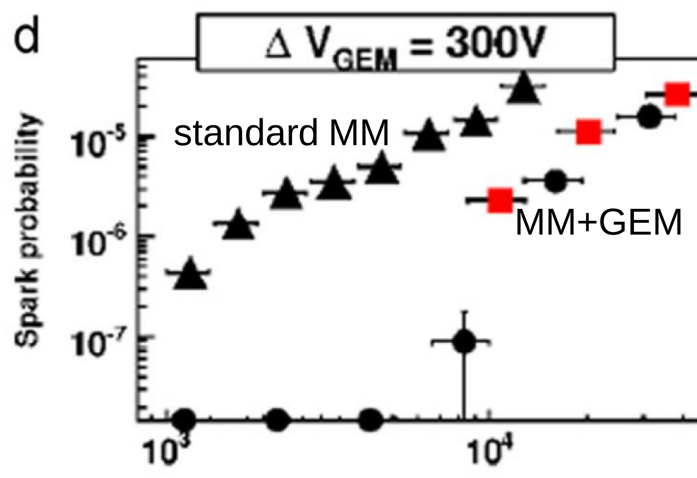
Nuclear Instruments and Methods in Physics Research A
journal homepage: www.elsevier.com/locate/nima

Discharge studies in Micromegas detectors in low energy hadron beams

G. Charles[a], M. Anfreville[b], S. Aune[b], J. Ball[a], Y. Bedfer[a], M. Boyer[b], P. Konczykowski[a], F. Kunne[a], C. Lahonde-Hamdoun[b], L. Cai[a], I. Mandjavidze[b], C. Marchand[a], O. Meunier[b], B. Moreno[a], H. Moutarde[a], D. Neyret[a], A. Obertelli[a], S. Procureur[a,*], F. Sabatié[a], M. Vandenbroucke[a]

Hybrid: Micromegas + GEM foil

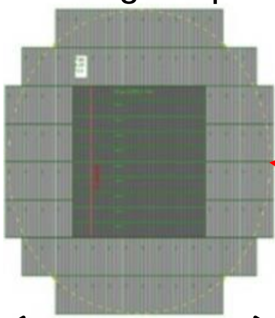




10 times less dicharges with hybrid

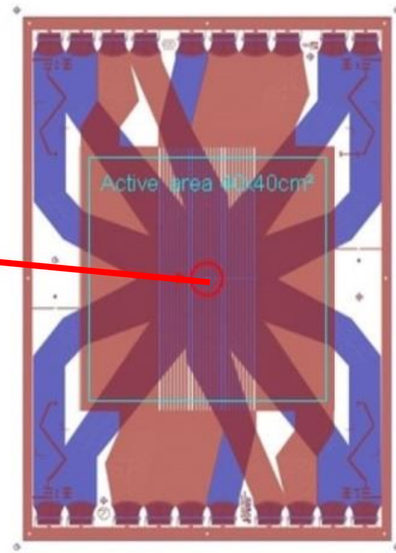
Hybrids with active central area

Central area1280
rectangular pixels

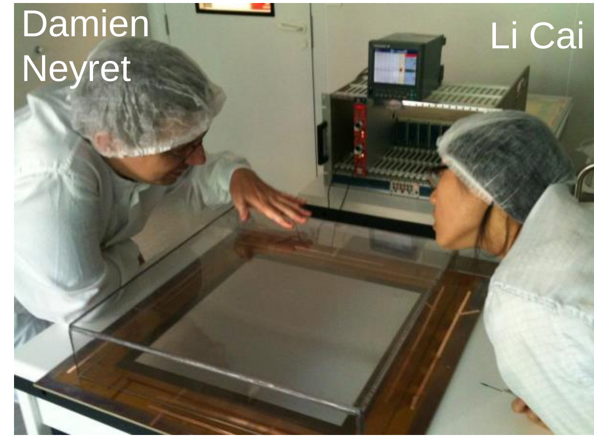


5 cm

Full board.

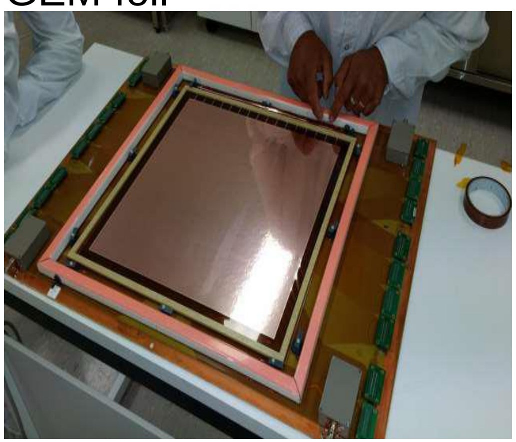


40 cm



Resistive bulk

GEM foil



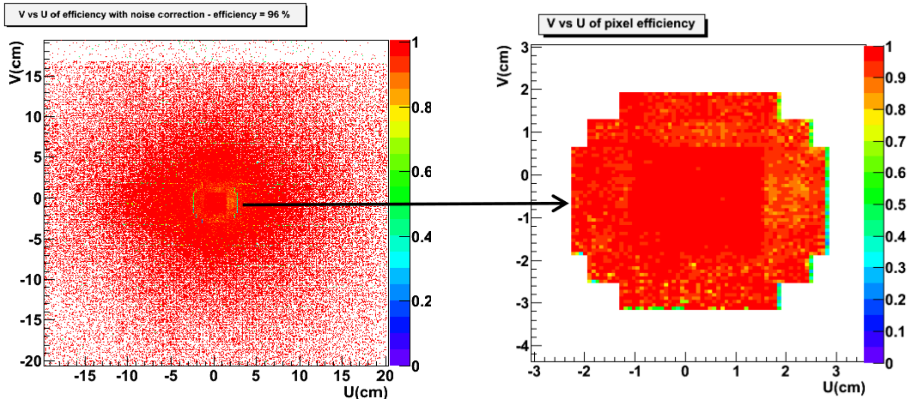
Hybrid MM+GEM, pixellized
In COMPASS, read by APVs

In 2015, the new detectors are ready
- **Hybrid Micromegas-GEM**
- **Central region pixellized**
- **Bulk**

Hybrid Micromegas+GEM foil - Performance

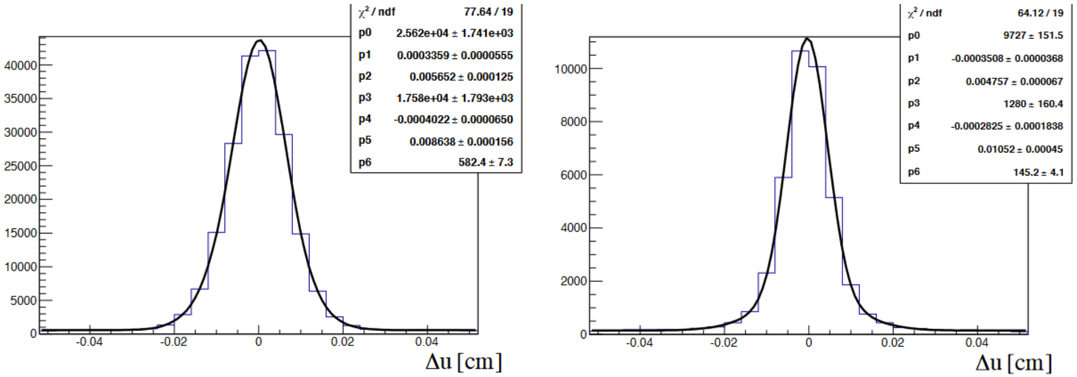
D. Neyret et al. JINST 7 (2012) C03006

Strip area | **Pixel area**



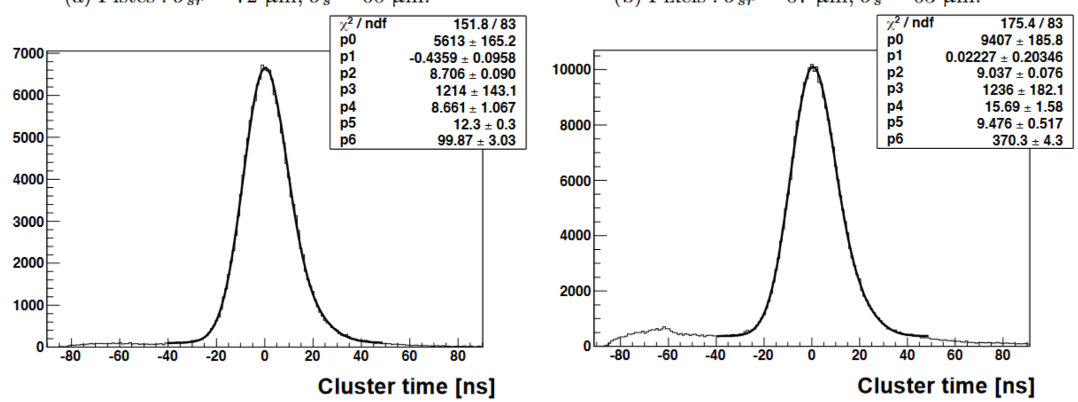
2D efficiency

F. Thibaud, PhD thesis, 2014



(a) Pistes : $\sigma_{sr} = 72$ μm, $\sigma_s = 60$ μm. (b) Pixels : $\sigma_{sr} = 67$ μm, $\sigma_s = 63$ μm.

Spatial resolution 60-67 μm



(a) Pistes : $\sigma_t = 8.7$ ns (b) Pixels : $\sigma_t = 9.1$ ns

Time resolution 8-9 ns

Conclusion – Micromegas for COMPASS

High precision, high rate and low mass detectors

- 12 planes 40x40 cm^2 in 30 MHz total flux , 12000 channels
- operated reliably with muons and hadrons, no aging
- resolutions : 60/90 μm , ~ 9 ns

Fruitful production of physics results with highly cited papers.

Many many people contributed to this adventure. Thanks to all of them.

Sincere thanks to Yannis for the ideas, the fruitful discussions and the final accomplishment of a beautiful detector