STATUS OF THE ART OF THE NEW GENERATION OF MPGD DETECTORS

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PREMISE

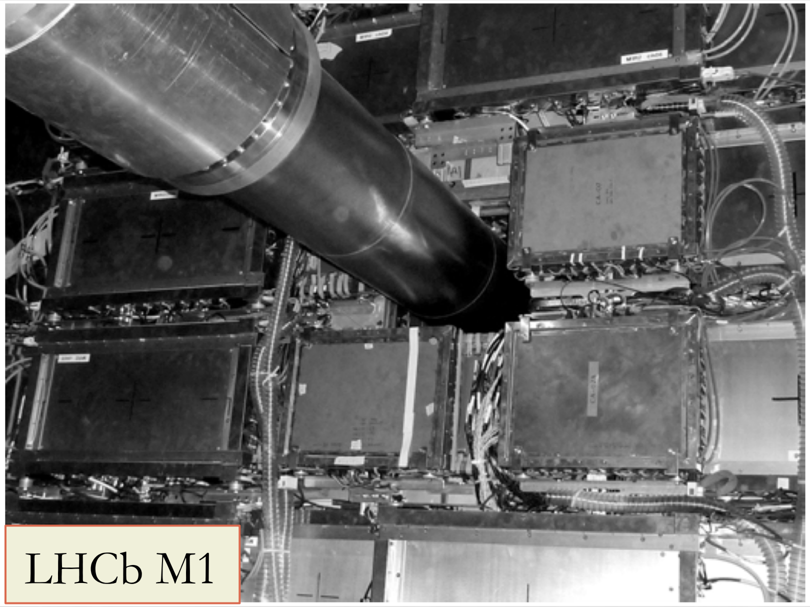
- **A wide variety of Micro Pattern Gas Detectors (MPGD)** is today on the market, many developments are in progress, thanks to the improvements of the **photolithographic technologies**.
- **RD-51** is the "forum" for this kind of developements
- **COMPASS** has been and is a pioneer under several aspects.
- In this talk ➔ prospects for the **LHC experiments upgrades**
  - Quest for large dimensions ($\approx$ m^2) detectors
  - Time resolutions at the "ns" level
  - Space resolutions at the "100 μm" level
  - Rate capability up to 10 kHz/cm^2 → MHz/cm^2.

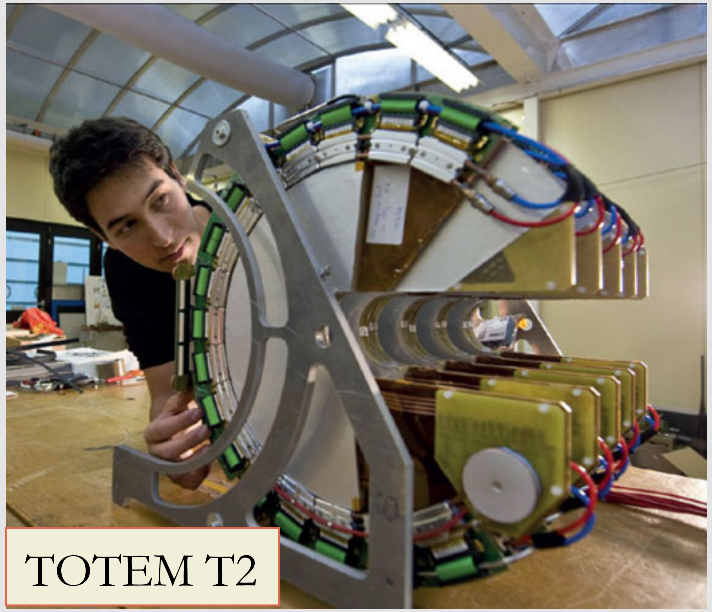
OUTLINE

- Introduction
  - The MPGD and the LHC experiments
  - The upgrades of the LHC experiments
- GEM
  - The CMS muon spectrometer upgrade
  - The new detector for the ALICE large TPC
  - Possible new developments in LHCb
- MicroMegas
  - The New Small Wheel upgrade of the ATLAS muon spectrometer
  - The Large Eta Tagger upgrade
- Recent developments
  - Fast Time MicroPattern (FTM) concept
  - μRWell concept
- Summary

INTRODUCTION - I

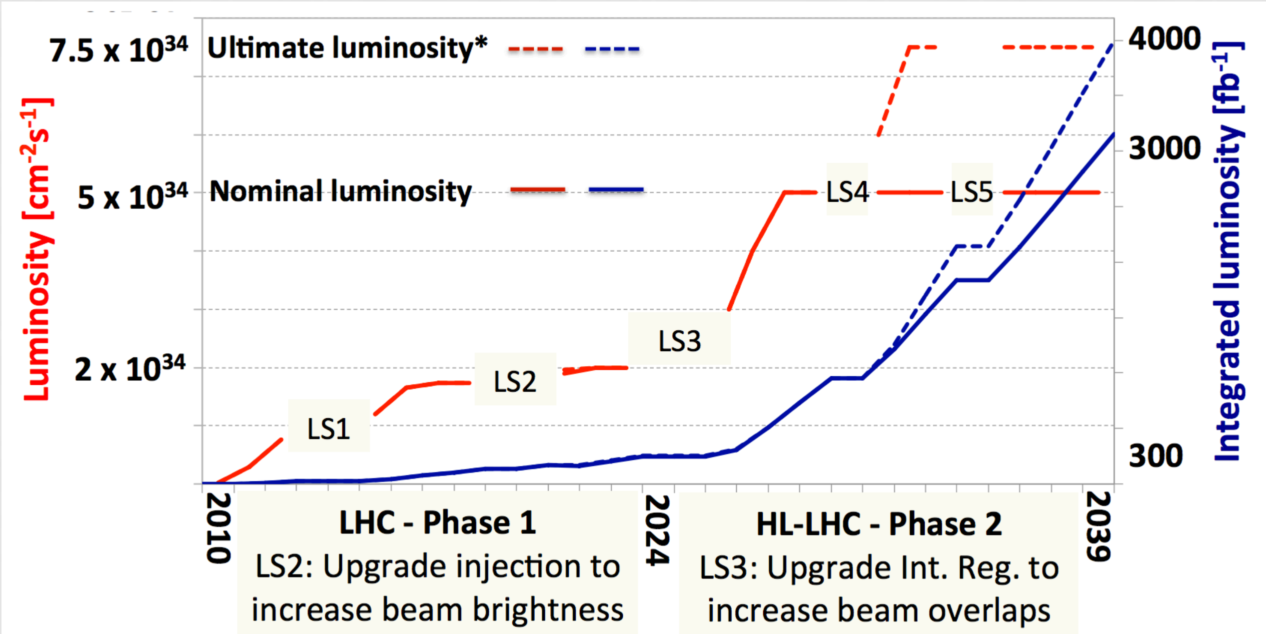
- First MPGD in the '90s: precision det. for high-rate applications
- At that time not mature enough to provide large area detectors for LHC experiments, with 2 "small" exceptions:
  - **LHCb M1** (20x20 cm^2 triple-GEMs for large-η muon trigger)
  - **TOTEM T2** (half-circles triple-GEMs 14 cm radius)





INTRODUCTION - II

- **LHC upgrades**: luminosity beyond baseline value ➔ higher rates are expected in the forward muon detectors.
  - From p-p collisions: O(100 kHz/cm^2) expected in the hottest regions
  - Heavy-ions collisions: bunch X-ing frequency up to 50 kHz (1 evt/20 μs)
- **MPGD** now considered BUT → extension to large dimensions



INTRODUCTION - III

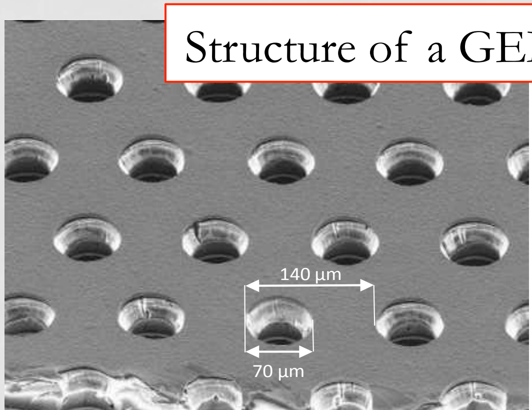
- Upgrade projects involving MPGDs
- **ALICE** TPC Read-Out chambers
  - Quadruple- GEMs: 72 chambers 0.2 ÷ 0.6 m^2 each (phase-I)
- **ATLAS** forward muon spectrometer
  - NEW SMALL WHELL: MicroMegas: 128 Q-plets 2÷3 m^2 area each (phase-I)
  - LARGE ETA TAGGER: Pad MicroMegas Concept OR µPIC OR µRWELL
- **CMS** forward muon spectrometer
  - GE1/1: 72 Triple-GEMs chambers 0.35 ÷ 0.4 m^2 each (phase-I)
  - ME0 + GE2/1: options considered (phase-II)
    - Triple-GEM with X-Y read-out
    - Fast Time MicroPattern new concept MPGD
    - µRWELL new concept MPGD
- **LHCb** forward muon spectrometer
  - Still under discussion, probably small MPGDs (30x30 cm^2) for triggering in a huge rate environment OR µRWELL

GAS ELECTRON MULTIPLIERS: GEM

MULTIPLE-GEM: PRINCIPLE OF OPERATION - I

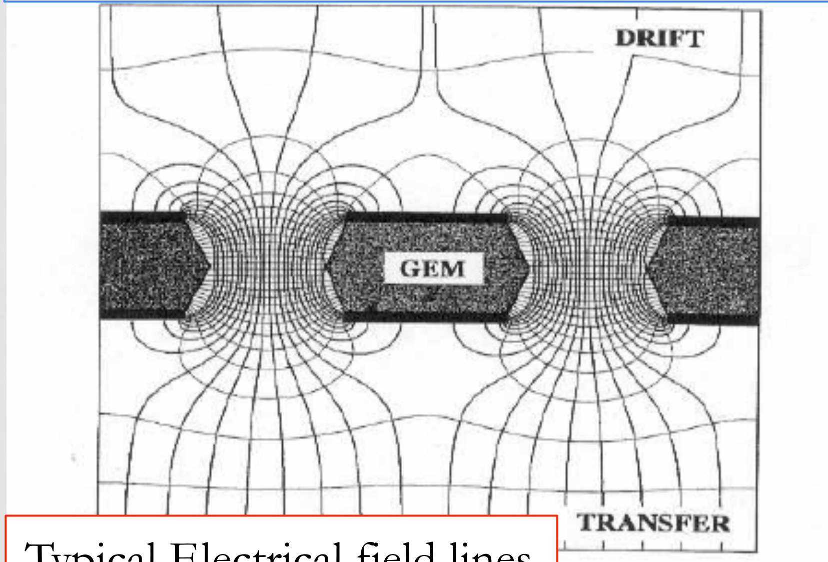
GEM foil: high-quality polymer foil coated on both sides with thin metal layers; → shaped holes with a large electrical field inside

- → Amplification avalanche in the hole region
- → Mostly "transparent" for electrons
- → Very small percentage of ions backflow
  - ➔ reduced space charge effect
  - ➔ reduced field distortion

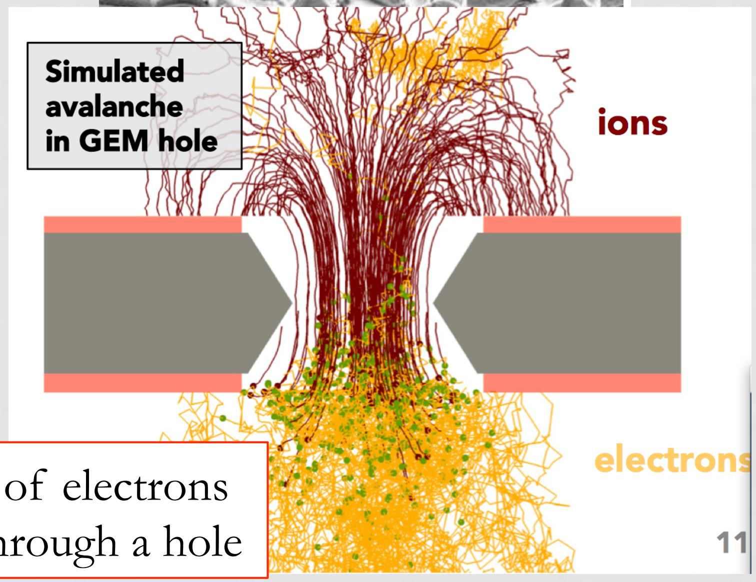


Structure of a GEM foil

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



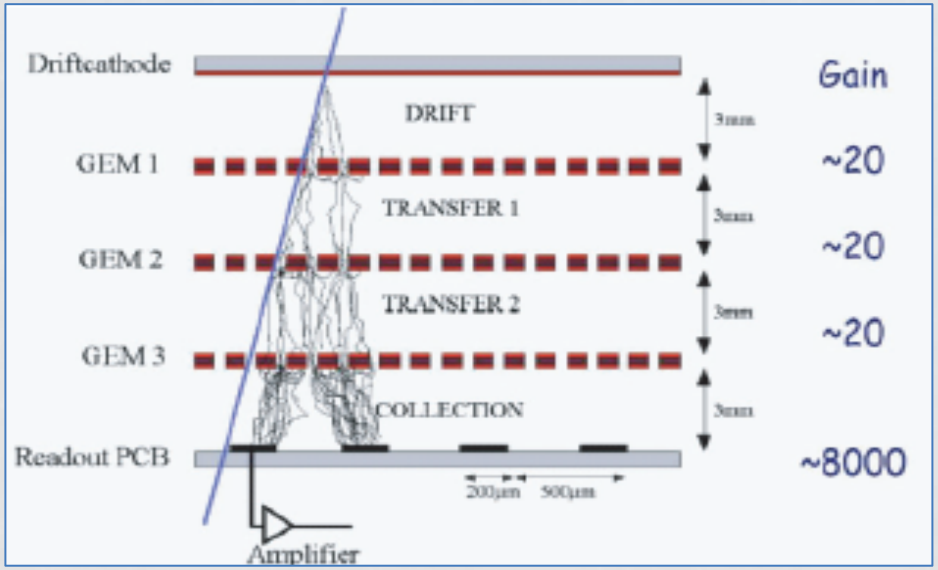
Typical Electrical field lines



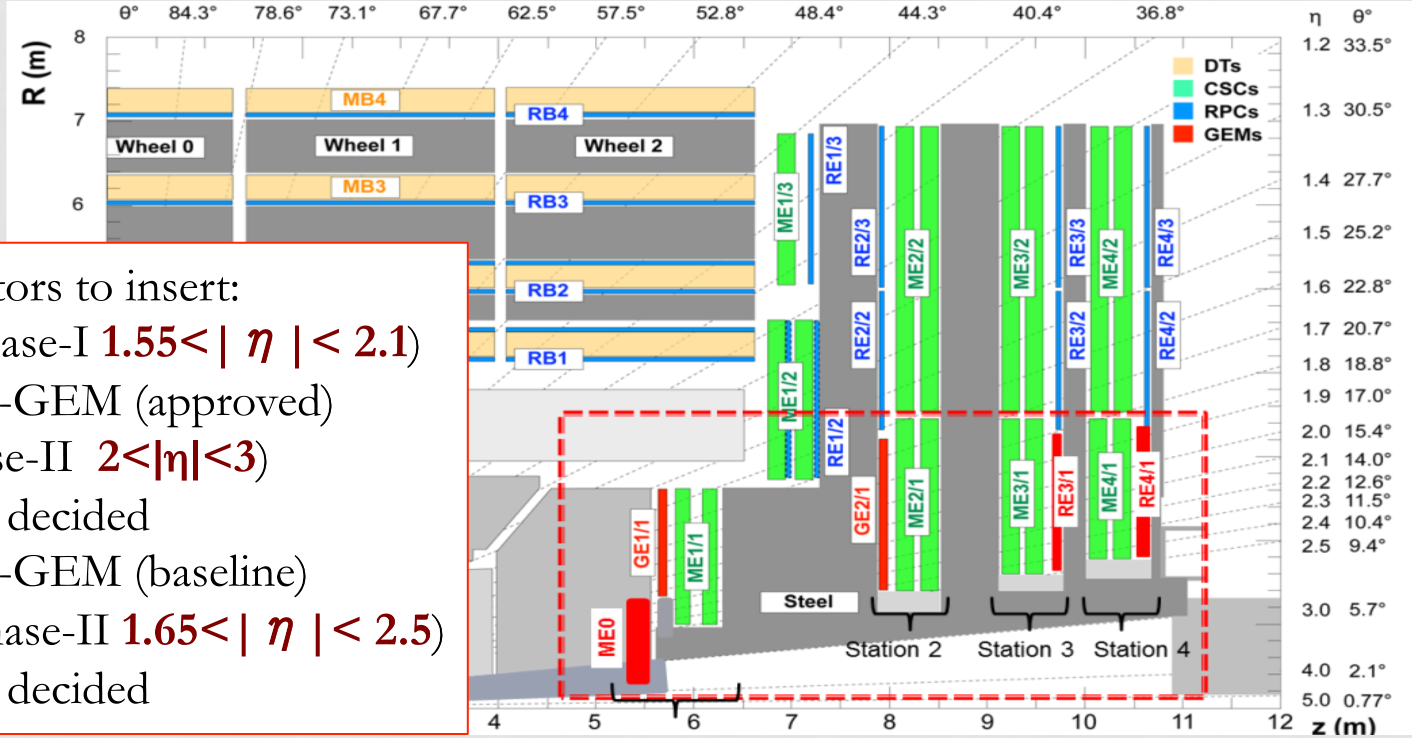
Behaviour of electrons and ions through a hole

MULTIPLE-GEM: PRINCIPLE OF OPERATION - II

- The technique has been extended to ≈ m^2 foils thanks to the *single-mask technology* → **large area** applications are possible
- Then go to **Multiple-GEM** allowing:
  - High gain obtained with electrodes at "low voltages" → less prone to discharges (*Raether limit hard to be reached*)
  - Freedom in the choice of the electrical fields → optimization of the IBF (*Ion Back Flow*) → reduction of field distortions



CMS: FORWARD MUON UPGRADE



New detectors to insert:

GE1/1 (phase-I **1.55<| η |< 2.1**)

Triple-GEM (approved)

ME0 (phase-II **2<|η|<3**)

To be decided

Triple-GEM (baseline)

GE2/1 (phase-II **1.65<| η |< 2.5**)

To be decided

Requirements:

See CMS-TDR-013 CERN-LHCC-2015-012

→ Maximum geometric acceptance within the given CMS envelope

→ **Rate capability** up to 100's kHz/cm^2; no gain loss due to aging after 3000 fb^{-1}

→ Single-chamber **efficiency** > 98 % for mips; **gain uniformity** of < 10%

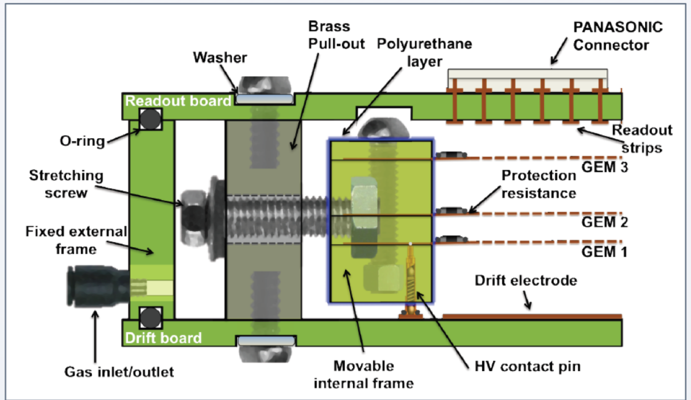
→ High **angular** (<300 μrad) and good **time resolution** (<10 ns)

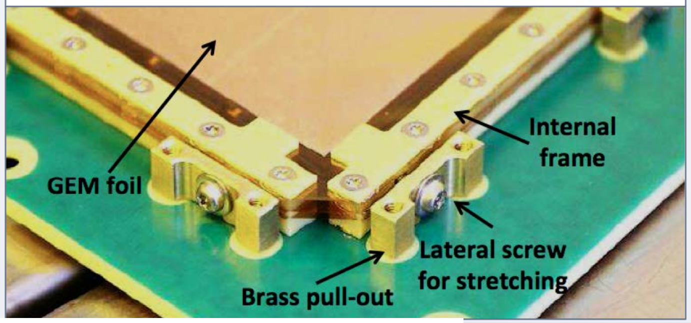
CMS GE1/1: LARGE SIZE TRIPLE-GEM

Major features of the GE1/1, design are:

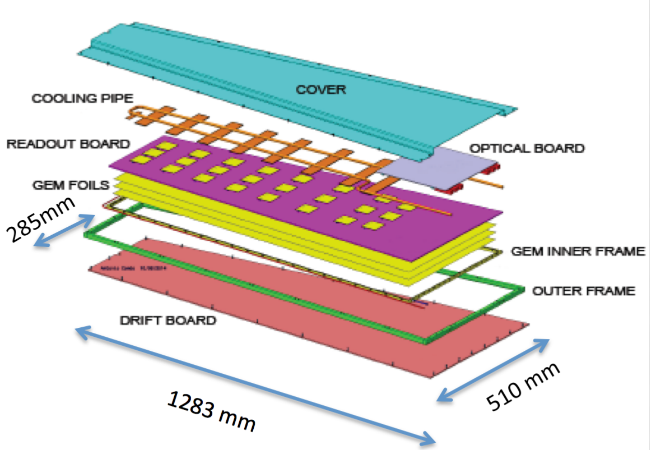
- Single-mask tehnology exploited
- The three GEM foils: gap config (3/1/2/1)
- Readout board with strips (3072 per chamber) with fixed ϕ pitch (463 μrad)
- Internal frame with lateral stretching screws
- External frame

72 trapezoidal triple-GEM Superchambers
0.22 ÷ 0.45 m^2 size 1.28 m maximum length
Read-out through VFAT3

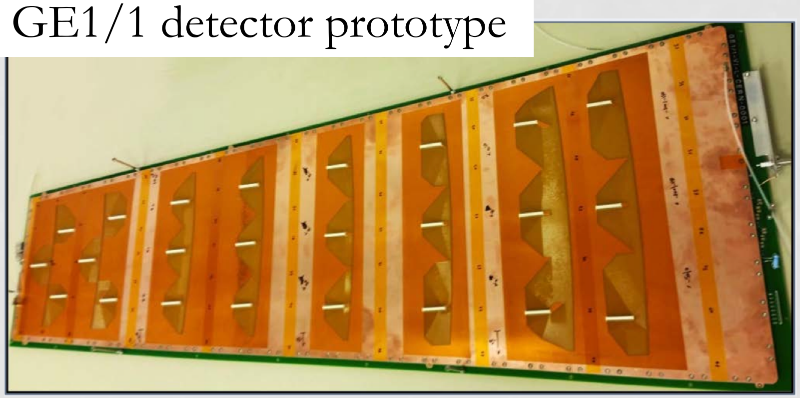




Exploded view of a long GE1/1 triple-GEM:



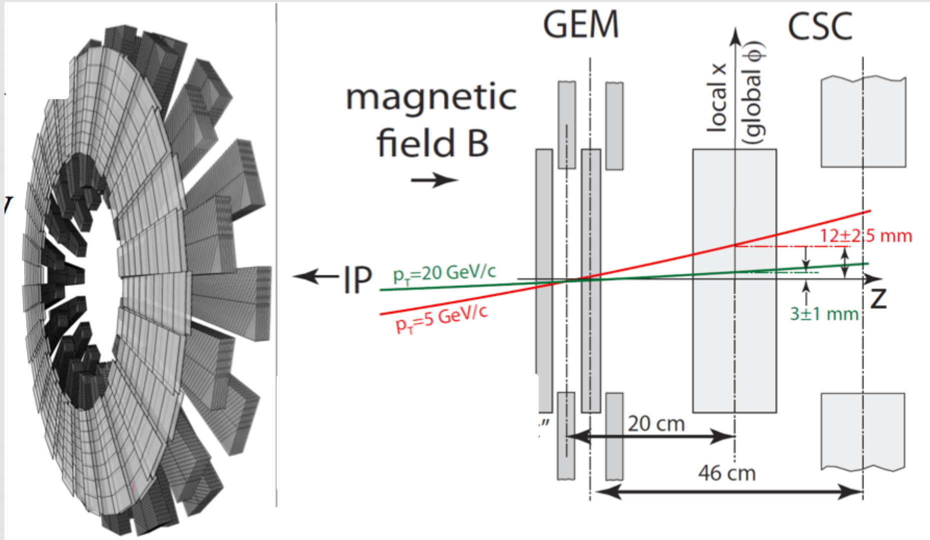
Assembled GE1/1 detector prototype

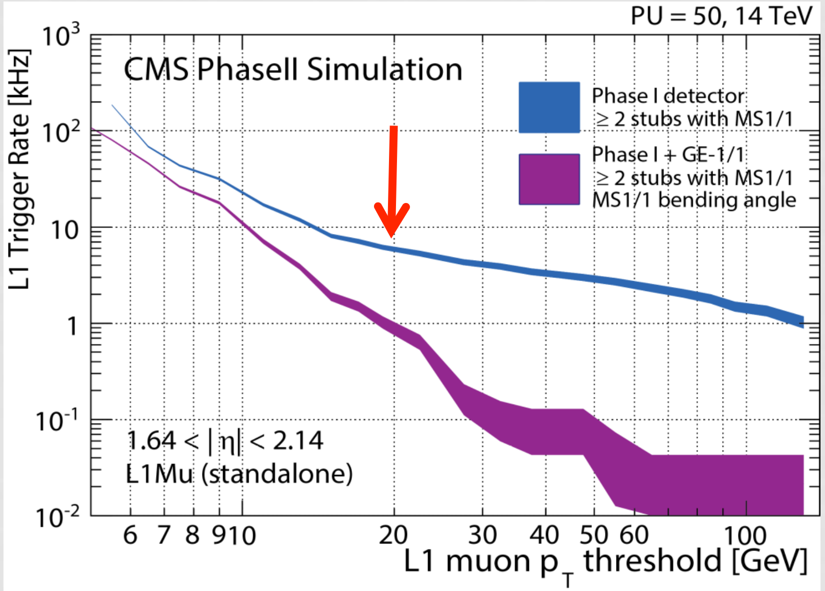


CMS GE1/1: IMPACT ON TRIGGER

In CMS, the ϕ coordinate is the precision one
➔ Radial strips with a fixed pitch in ϕ
➔ Tracks perpendicular ➔ charge centroid
Muon trigger: Δϕ measured @ L1 trigger level
CSC+GEM improves the lever arm
➔ reduce fake muon rate

L1 single muon trigger rate reduction according to present simulation:
p_T >20 GeV single muon trigger
Can be still used without prescale.

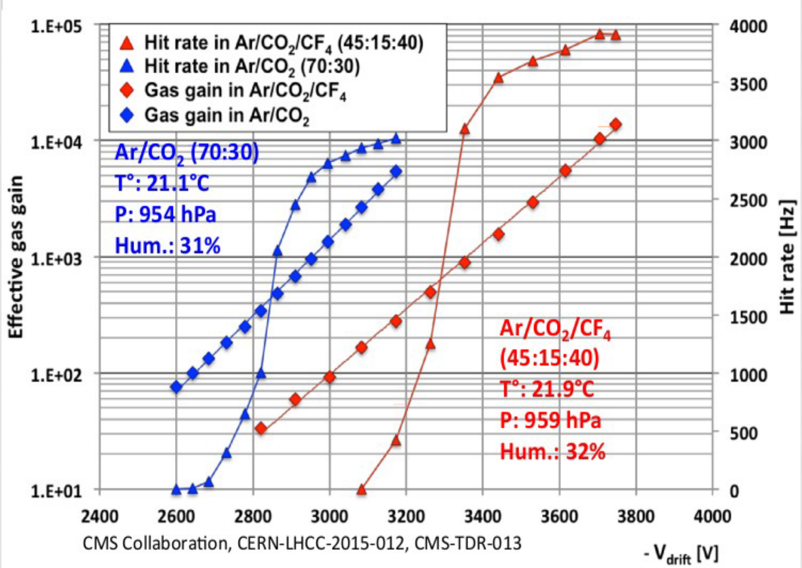


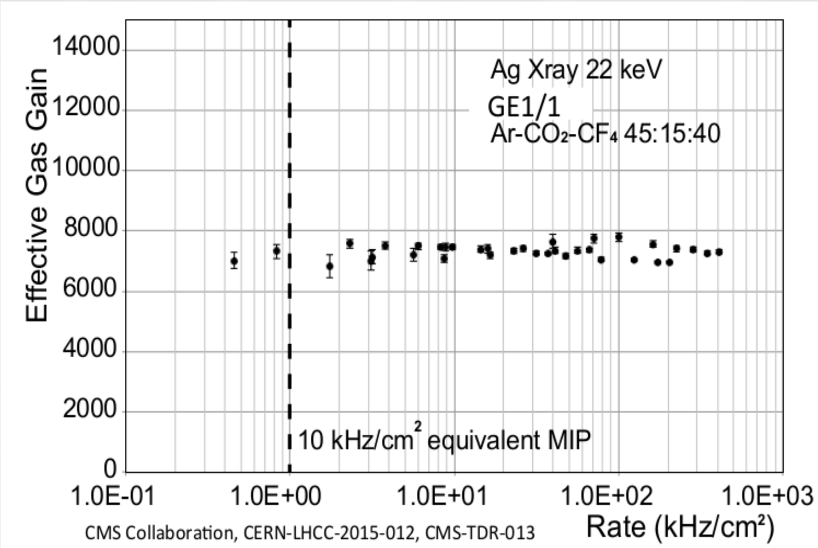


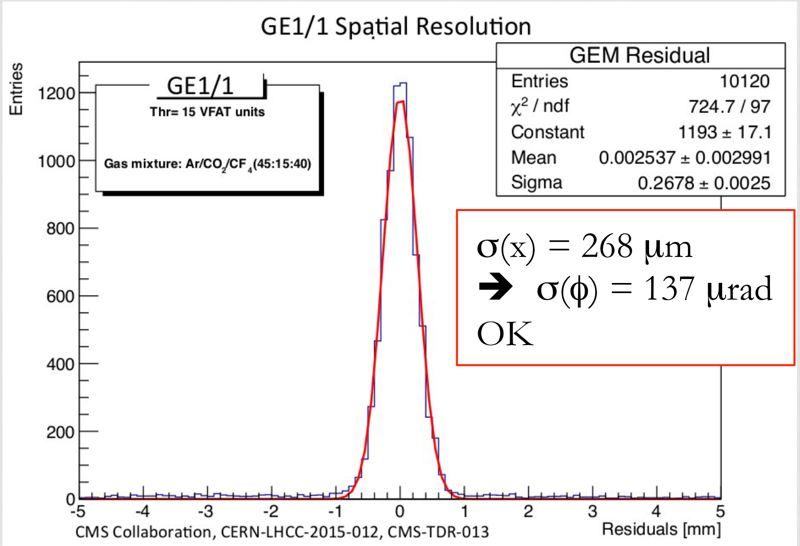
CMS: PERFORMANCE OF LARGE PROTOTYPES

- → Test-beam results on prototypes with two different gas mixtures
- → At gains ≈ 10^4 efficiency plateau and high rate operations
- → Time resolution ≈ 7 ns

➔ Triple-GEM technology perfectly meets the requirements imposed by the HL-LHC







$\sigma(x) = 268\ \mu m$
➔ $\sigma(\phi) = 137\ \mu rad$
OK

CMS: TRIPLE-GEM FOR ME0

ME0 extends muon coverage down to $\eta = 3$
to take advantage of the pixel extension

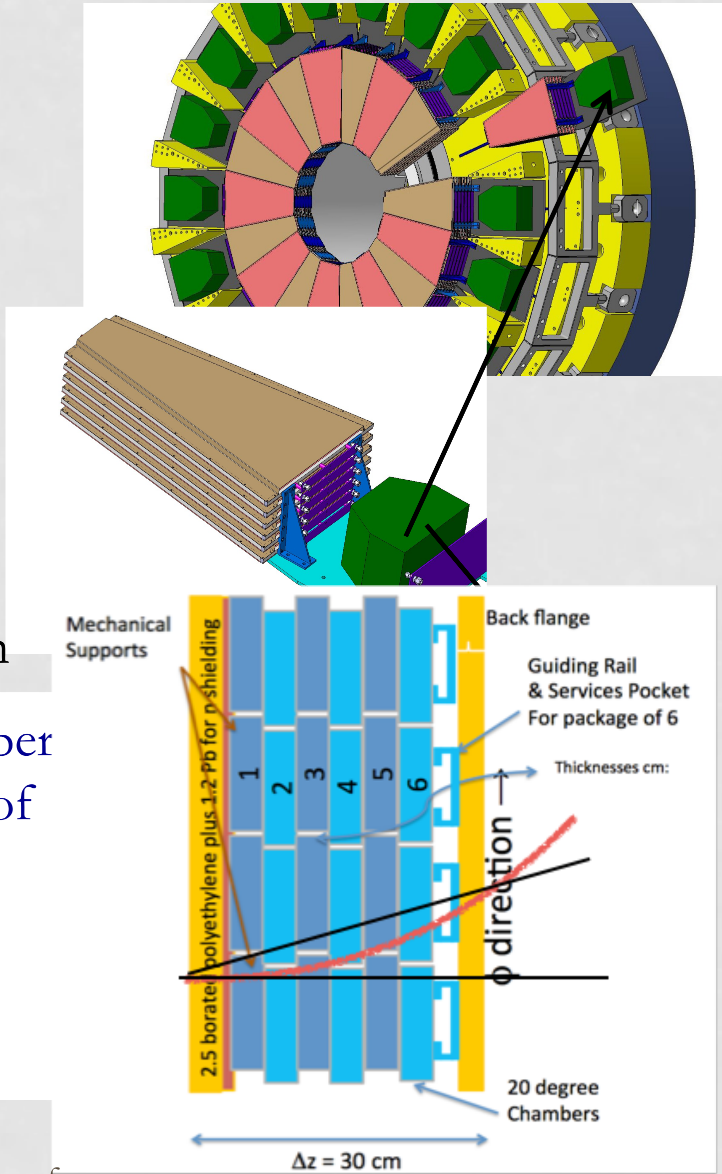
Main requirements:

-- High granularity and spatial segmentation

-- Multi-layered structure to reduce fakes

-- Precision Timing

- P_T assignment through $\Delta\phi$ measurement
- Discriminate muon (segment) against neutrons (uncorr hits).
- Reduce in-time PileUp , help vertex association

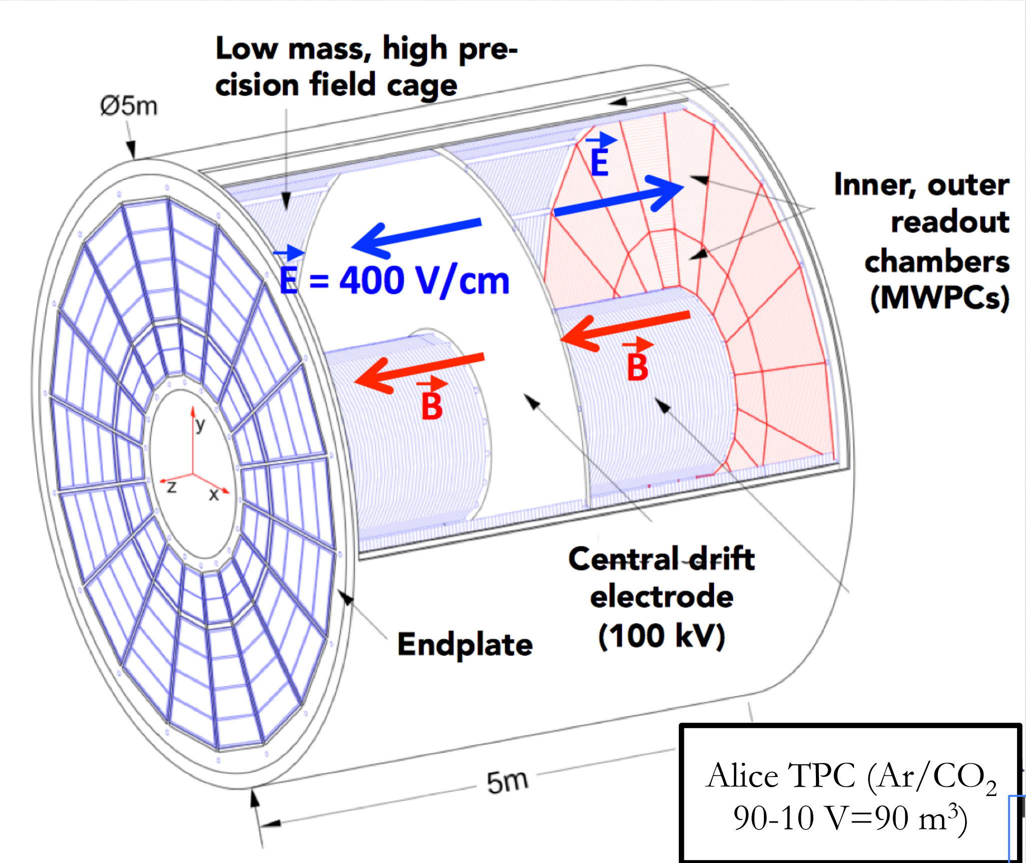


ME0 *baseline* layout consists of 216 triple-GEM chamber arranged in 36 20^0 super-module wedge each consist of **6 layers of triple GEMs (3 back-to-back),** covering $2<|\eta|<3$

Alternative technology → μRWell

ALICE TPC READOUT

- Heavy Ion collisions during Run3: 500 Hz → 50 kHz collisions (1 crossing / 20 μs)
- Important impact on the large ALICE TPC operation



Alice TPC (Ar/CO_2 90-10 V=90 m^3)

Ion flow removal through the "**gating grid**" method is NOT possible anymore (→280 μs intrisic deadtime)

➔ Continuous mode operation.

New Readout detector with:

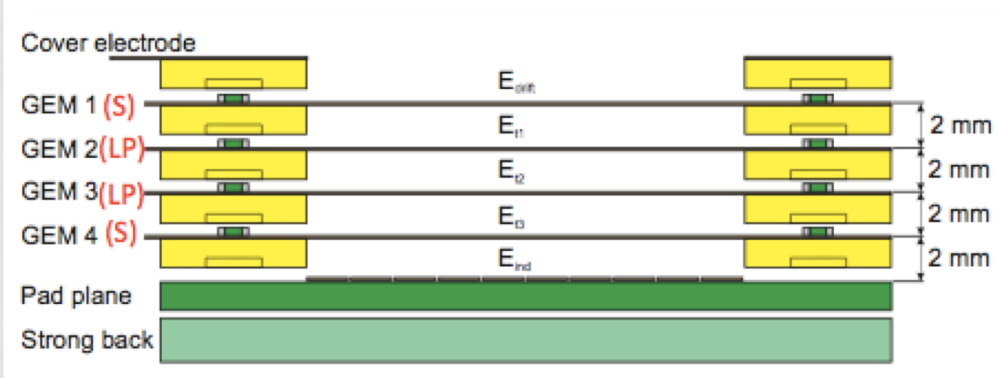
- high gain
- good dE/dx resolution
- low IBF (Ion Back Flow)

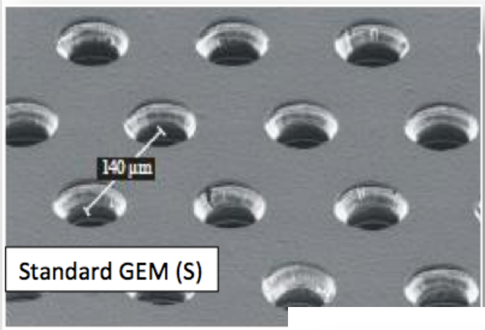
➔ Large Area Quadruple-GEM

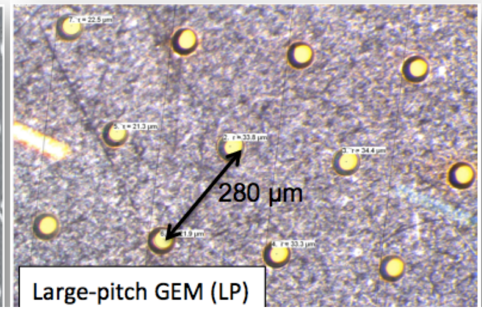
ALICE-TDR-016 CERN-LHCC-2013-020

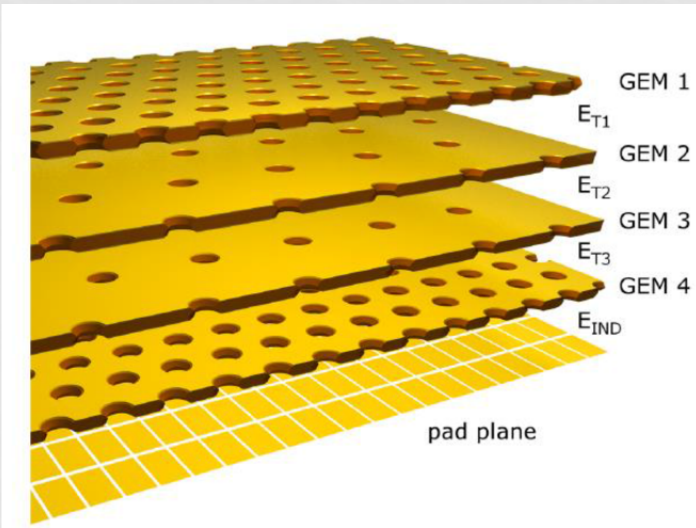
ALICE QUADRUPLE-GEM - I

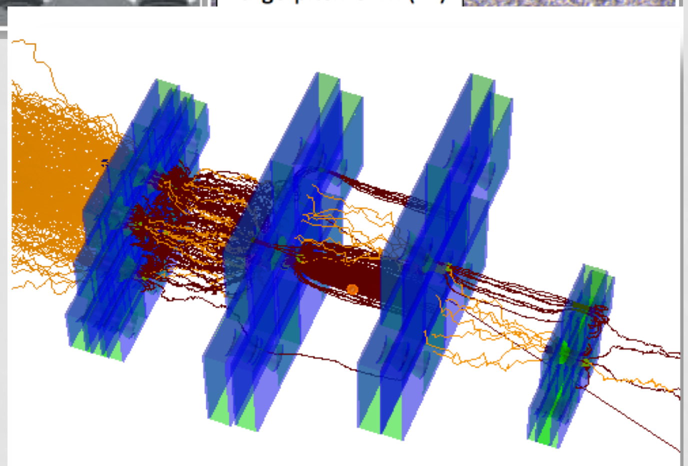
- **Quadruple-GEM** optimized to reduce IBF < 1% with high gain:
  - Ne-based gas mixture:
    → Ne-CO_2-N_2 (90-10-5)
  - Standard and Large-Pitch GEMs
  - Most of the gain in the last stage
  - Few mm pads → drift time and charge measurement







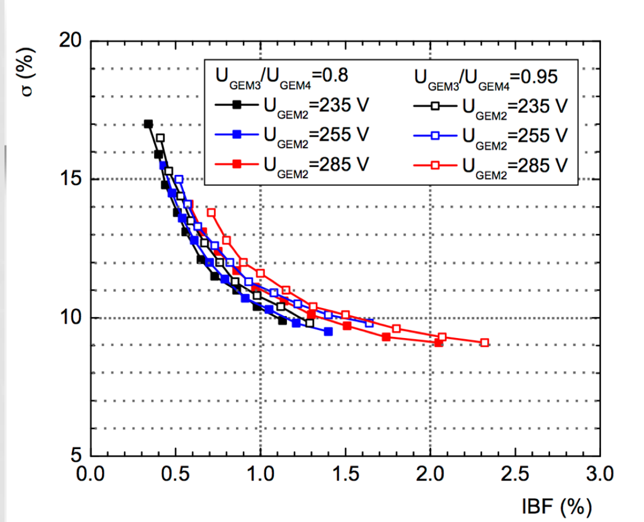


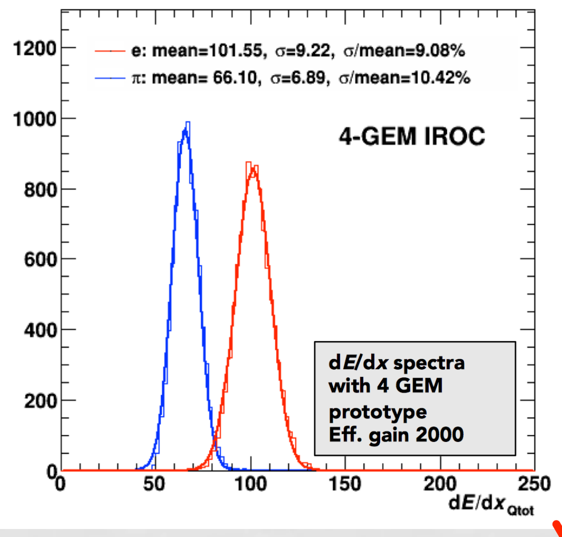


ALICE QUADRUPLE-GEM - II

- 72 Large area chambers: 0.6 m^2, 0.2 m^2
  - Single-mask technology exploited
- Results on first prototypes:
  - Gain ≈ 2000
  - $\sigma_x \approx \sigma_y \approx 1$ mm , $\sigma_z \approx 3$ mm
  - σ(dE/dx) ≈ 12% ^{55}Fe
  - IBF < 1%

164 cm





LHCB PROSPECTS

- Still under discussion in the collaboration
- Main points:
  - Probably remove M1 chambers
  - Additional small chambers (30x30 cm^2) for triggering in the huge rate regions (up to 0.5 MHz/cm^2) M2
  - Time resolutions below 5 ns required

  → GEM with CF_4 based gas mixtures

  → μRWell also is a possible choice to exploit the optimal time resolution for triggering purposes.

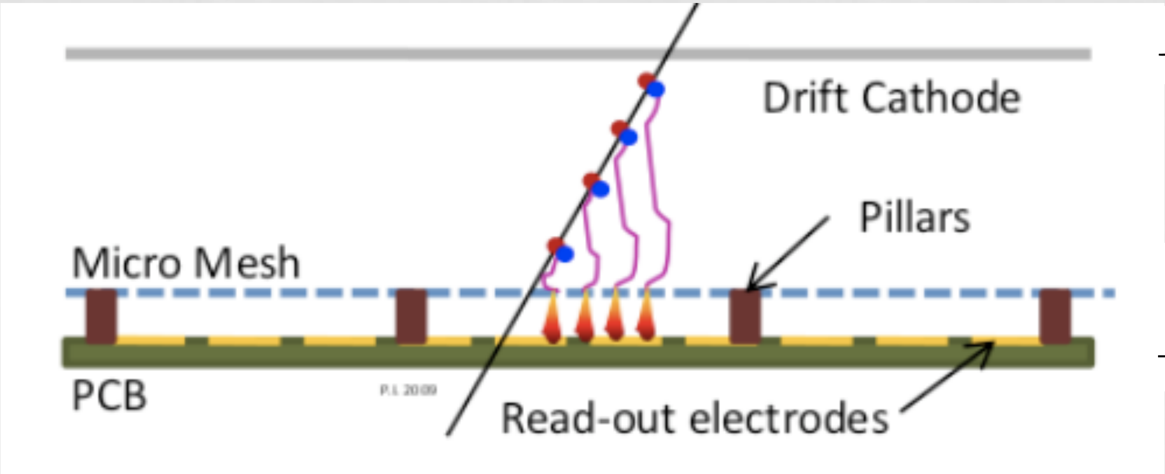
  BUT the very high rate is in conflict with high resistivity.

MICROMEGAS

MICROMEGAS: PRINCIPLE OF OPERATION - I

First proposed by Y.Giomataris, NIMA 376 1 (1996) 25

(1)
(2)
(3)
(4)
(5)



-300 V
0 V
+550 V

Detector components (the quoted numbers refer to the ATLAS project):

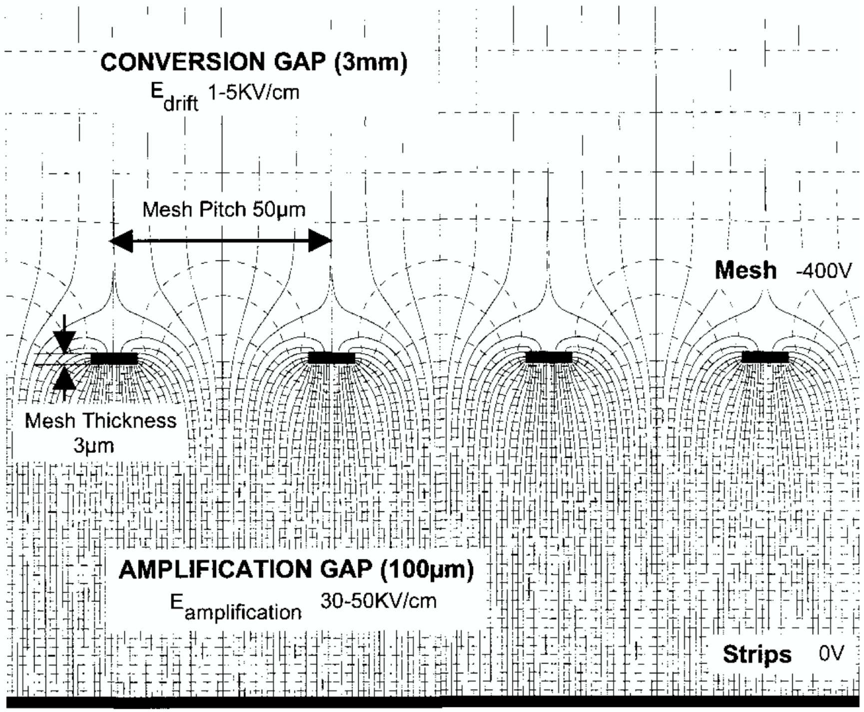
(1) Planar metallic cathode
(2) Gas gap (5 mm) with low electric field (0.6 kV/cm): conversion and electron drift
(3) Thin metallic mesh standing on "pillars" (128 μm high)
(4) 128 μm gap with high electric field (40÷50 kV/cm): avalanche
(5) Segmented anode with read-out strips (≈ 400 μm pitch) on Printed Circuit Board (PCB).

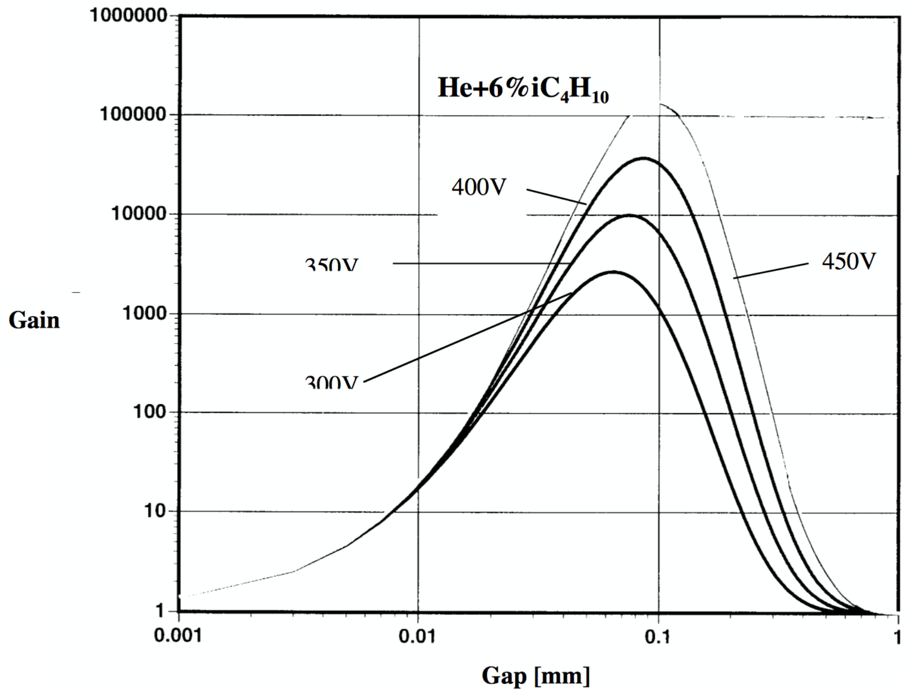
Maximum drift time = gap size / v(drift) = 5 mm / 50 μm/ns = 100 ns

MICROMEGAS: PRINCIPLE OF OPERATION - II

Electric field lines in the mesh region

Gain vs. gap size curves





Huge electric field ratio:

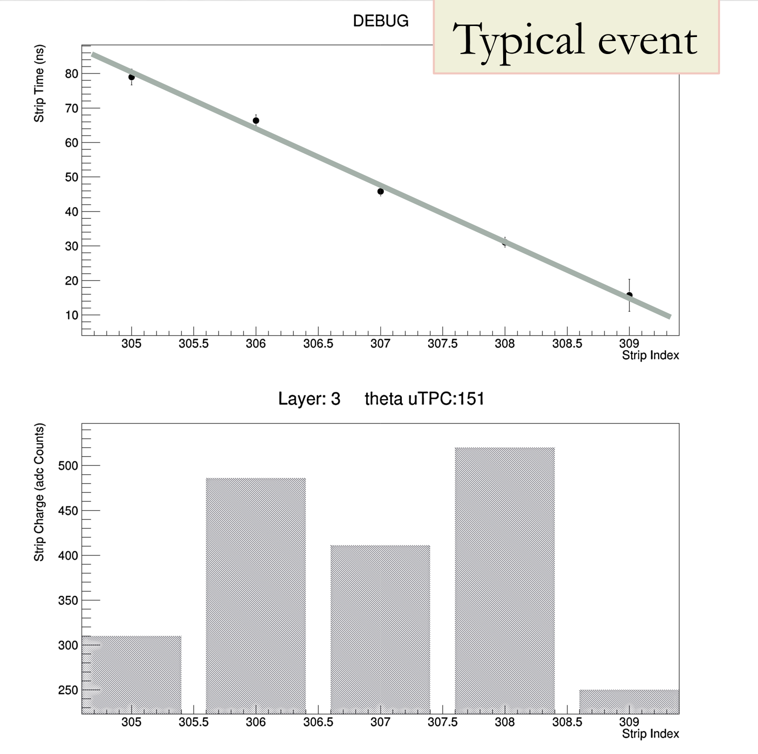
- ➔ The mesh is "transparent" for drift electrons
- ➔ Avalanche ions almost fully collected by the mesh (within ≈100 ns); negligible IBF

Gain "Plateau" ($10^4 \div 10^5$) around d = 100 µm

MICROMEGAS: PROTOTYPES PERFORMANCE - THE MTPC

10x10 cm^2 prototypes built and tested at CERN (MAMMA collaboration)

Typical event



For each strip, are measured:

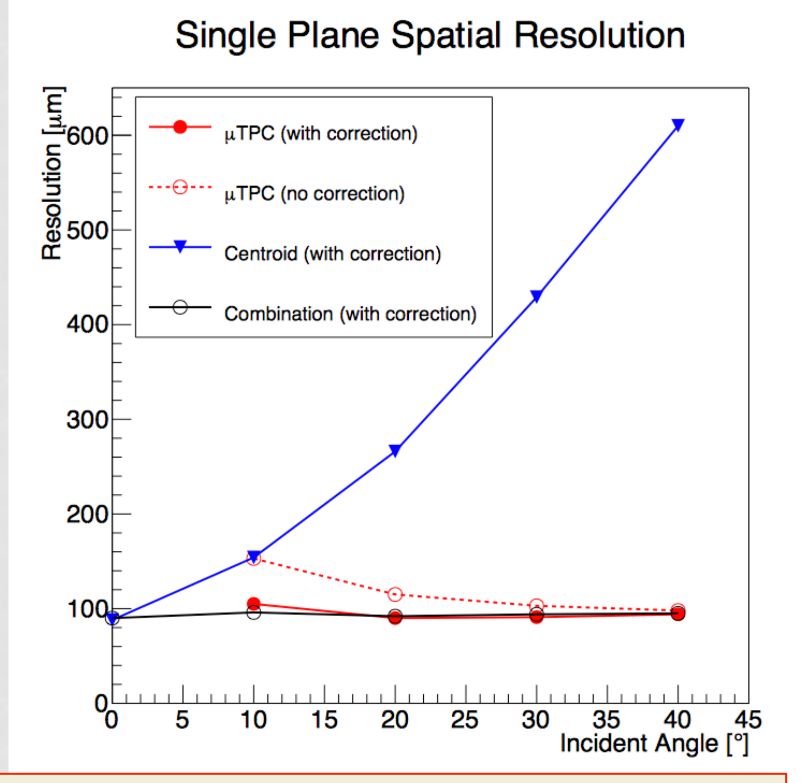
charge

time

➔ Charge centroid

➔ μTPC (position and angle)

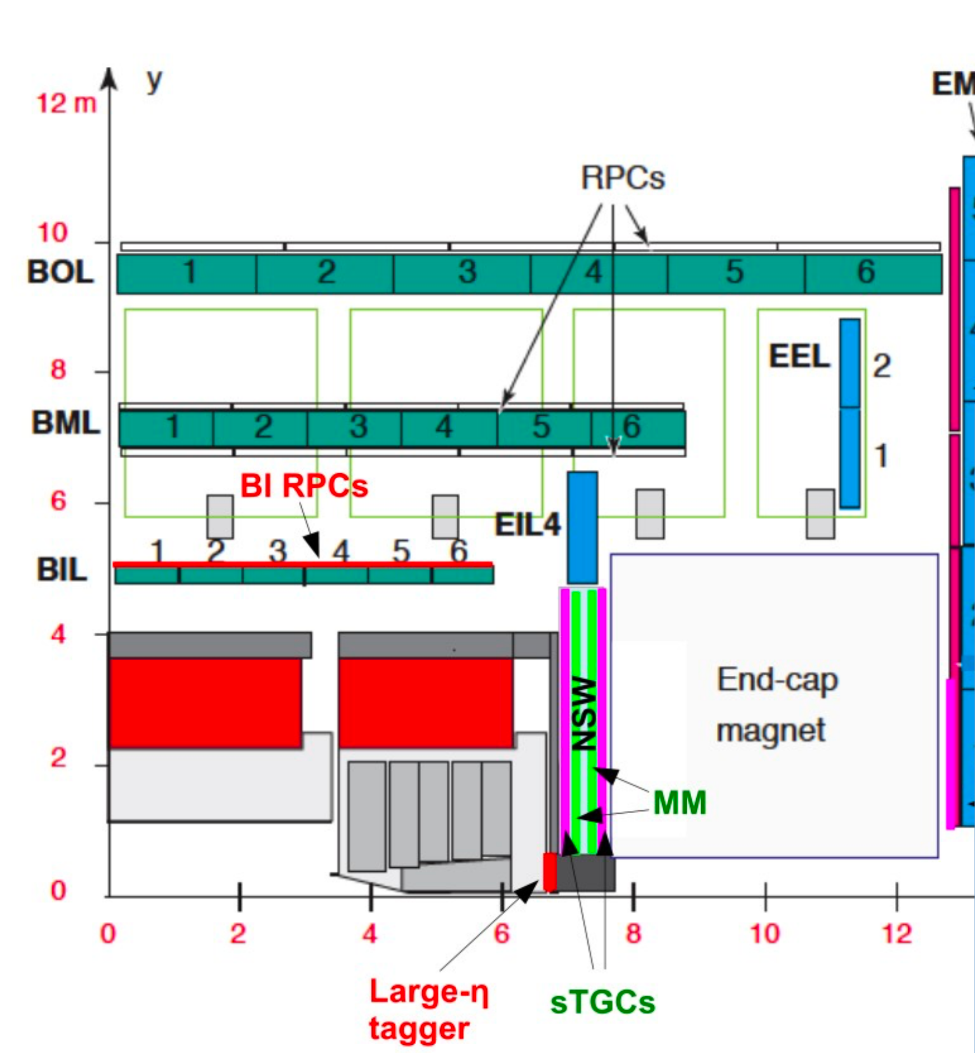
Space resolution measured on Test-Beam



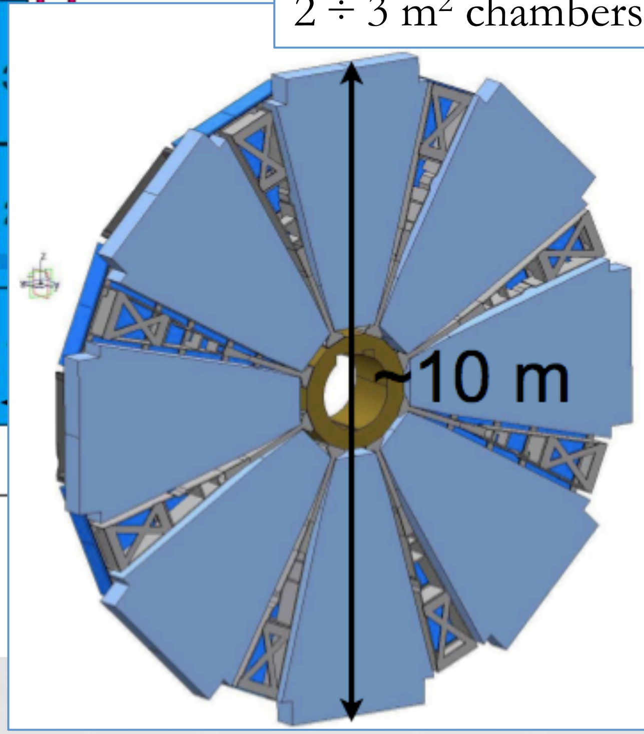
Important point: good measurement also for tracks at an angle (≈100 μm for $8<\theta<32°$)
→ good for ATLAS Muons !

ATLAS: MUON FORWARD UPGRADE

ATLAS_TDR-020 LHCC-2013-006



The New Small Wheel:
$2 \div 3$ m^2 chambers

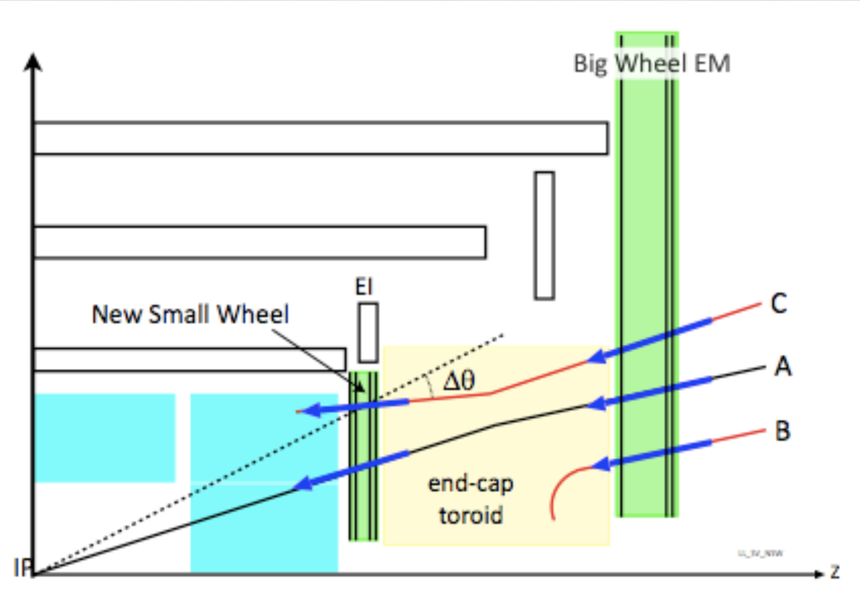


ATLAS NSW - MOTIVATIONS

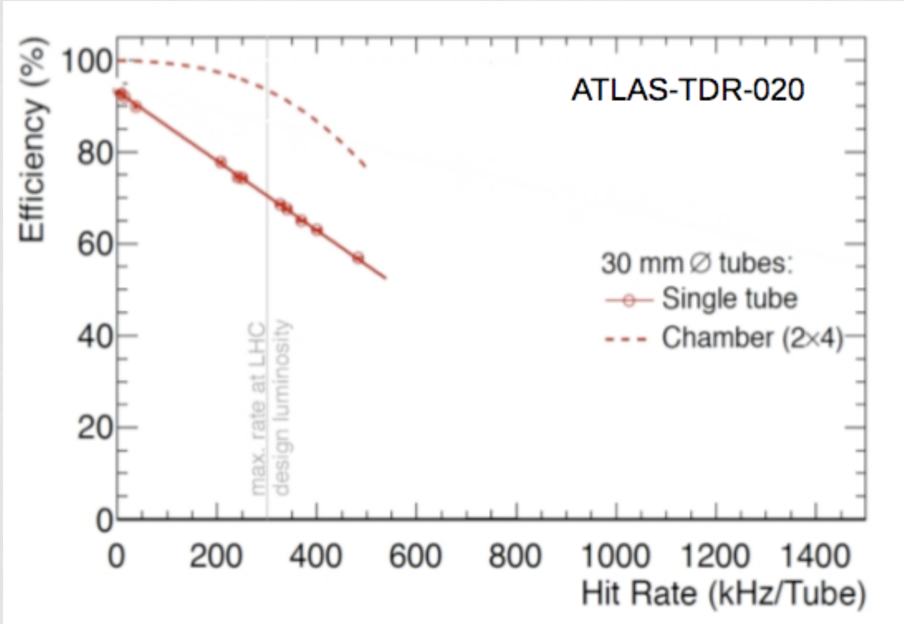
Let's consider the ATLAS forward muon case

Endcap muon trigger dominated by *fake muons*
→ $R(p_T>20\ GeV)=60\ kHz$ (@ 3×10^{34},14 TeV)
A factor >3 reduction → "pointing trigger"
allows to elimate 90% of the fakes
→ $R(p_T>20\ GeV)=21\ kHz$ (@ 3×10^{34},14 TeV)
Compatible with allowed bandwidth

MDT precision chambers:
Beyond project luminosity → *efficiency loss*
→"Tube size" ≈ 3 cm × 1 m × 750 ns;
→ @ 7×10^{34}, 14 TeV → ≈ 4 kHz/cm^2
>1 MHz/Tubo ≈ 1 /750 ns
> 50% drop in chamber efficiency



→Accept **topologies A** reject **B / C**



MICROMEGAS FOR ATLAS NSW - I

High expected rate: discharge probability to be reduced by maintaining a high gain ≈ 10^4

→ **Resistive strip anode**

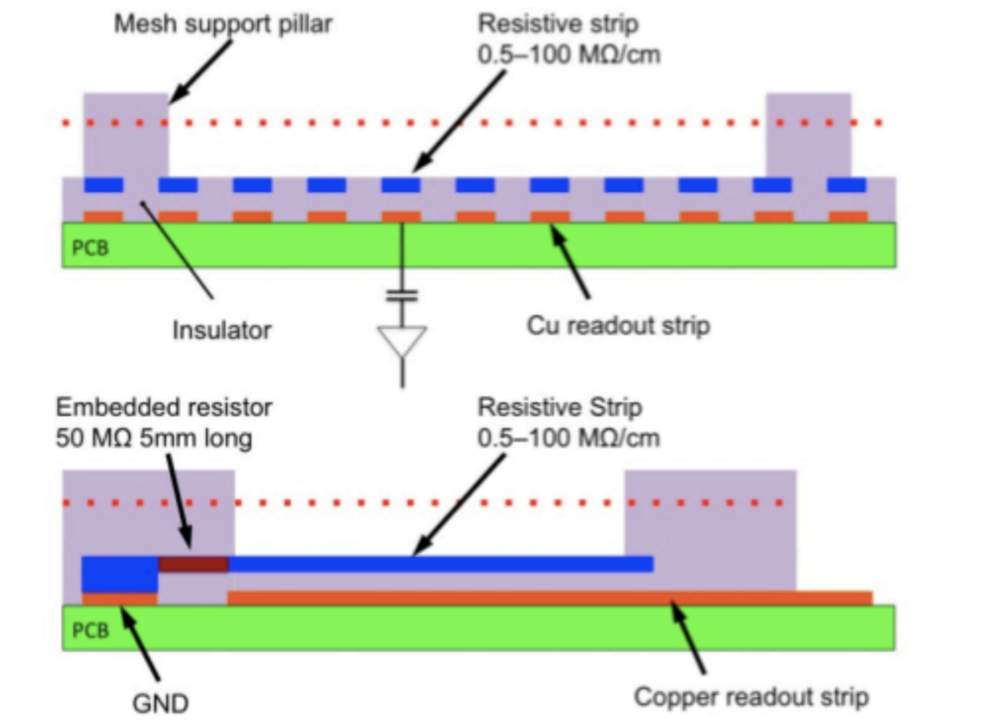
(≈20 MΩ/cm; ≈1MΩ/□)

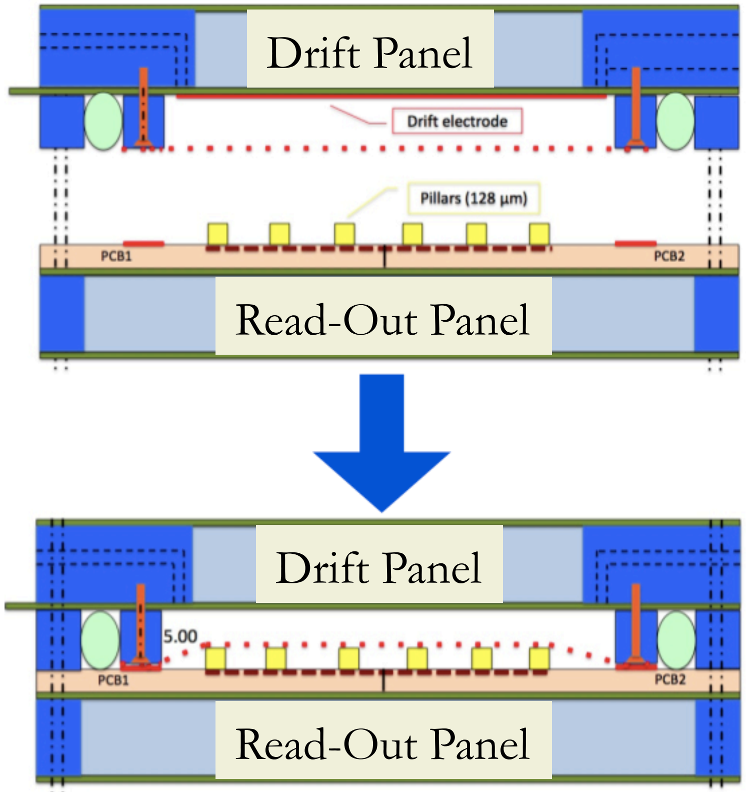
Large dimension chambers have to be built (2 ÷ 3m^2) with challenging mechanical precisions (30 ÷ 80 μm)

→ **new construction technique**

→ **Floating mesh**

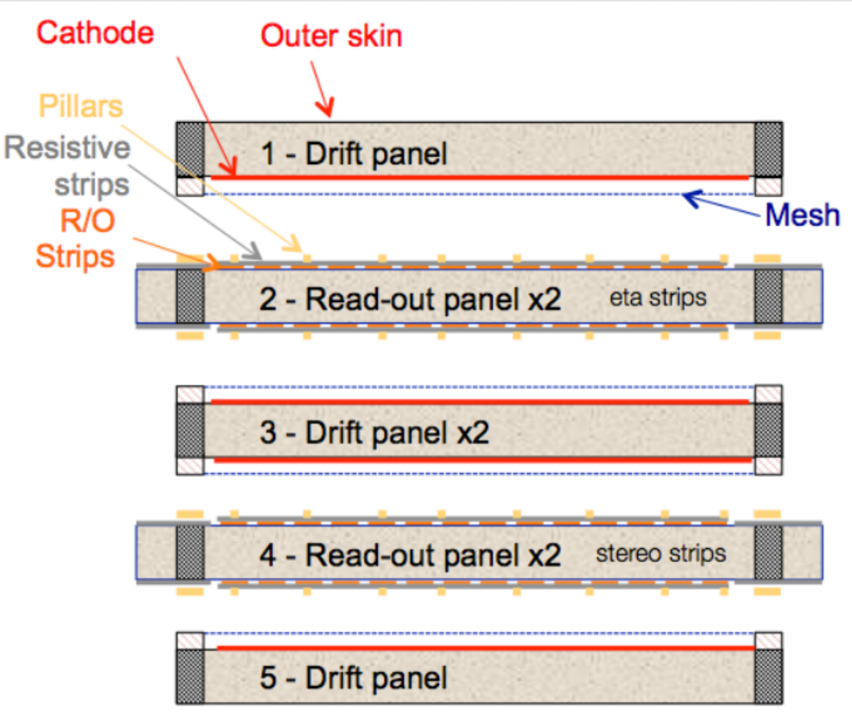
T.Alexopoulos et al. NIMA 640 (2011) 110-118



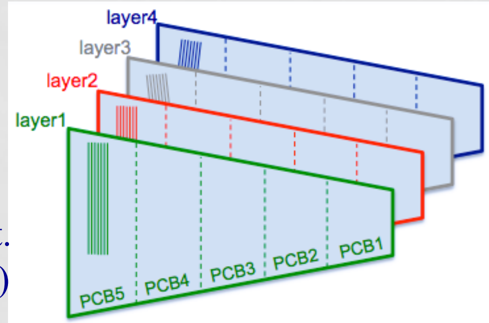


MICROMEGAS FOR ATLAS NSW - II

The ATLAS MicroMegas chambers are organized in Q-plets:
5 panels 1 cm thick 2 m^2 surface (planarity RMS<40μm)
    2 RO panels (with RO PCB)
    3 Drift panels + tensioned mesh
Stereo configuration to get the second coordinate at O(mm)
Operate in a moderate magnetic field (<0.3 T)

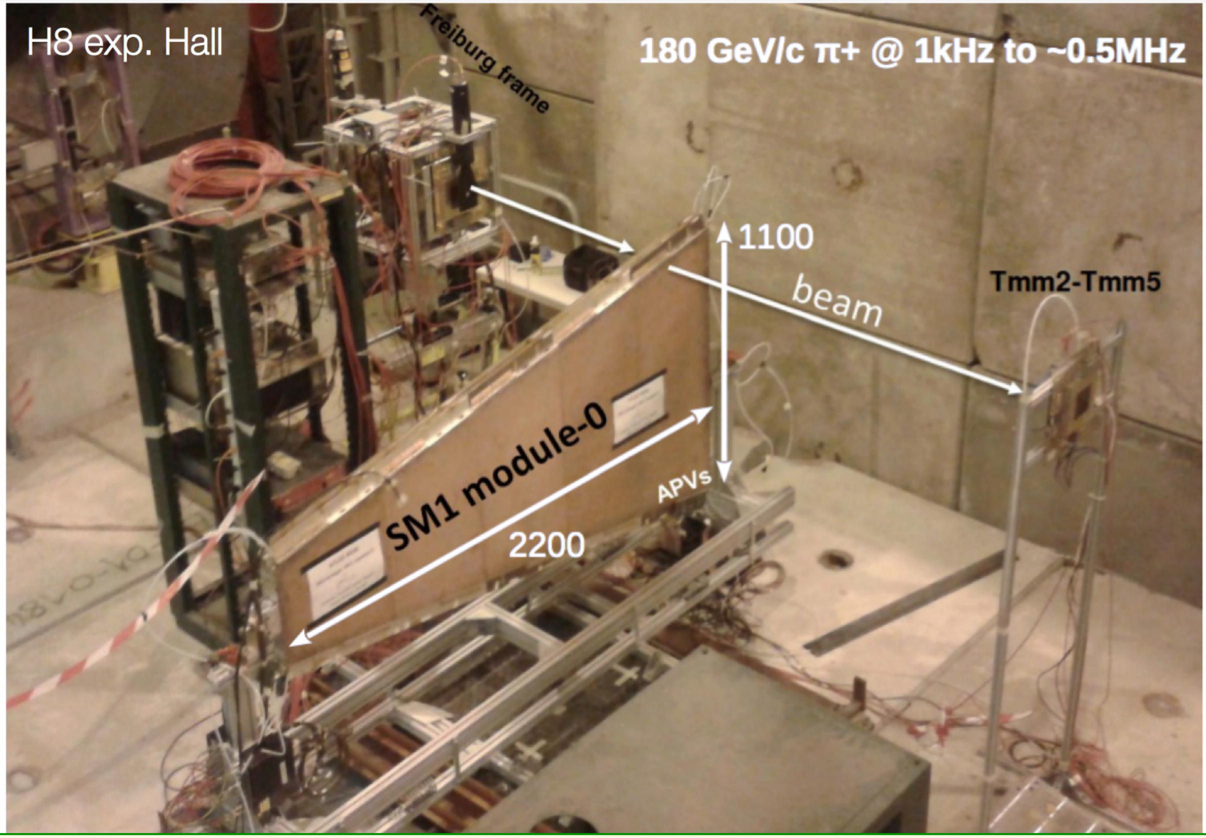


SM1 quadruplet:
- 425 μm strip pitch
- L1 & L2 vertical strips (eta),
- L3 & L4 ±1.5° w.r.t. vertical axis (stereo)



Module0s (full size) Q-plets built in 2016
SM1 (INFN) tested on beam → Next slide

SM1 MODULE0 – THE TEST-BEAM



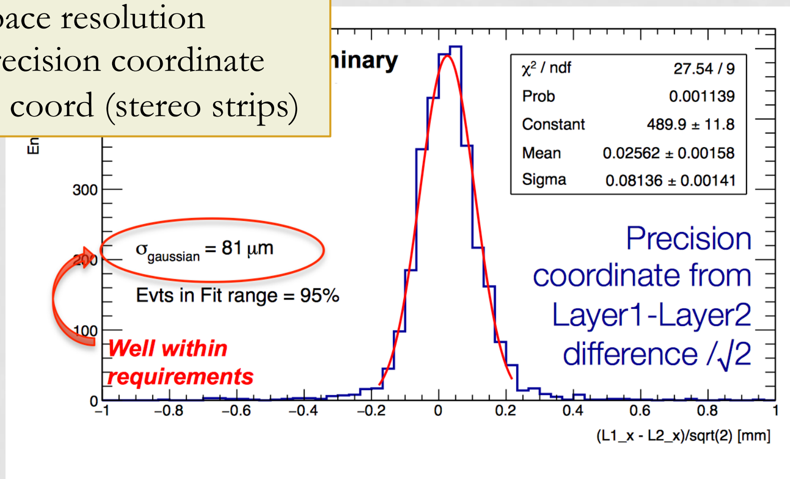
Measurements done on a 180 GeV beam in "standard" conditions
- -- Gas Mixture Ar/CO_2 (93%-7%) @ 20 l/hr
- -- HV(ampl) = 580 V, HV(drift) = 300 V
- -- FE electronics APV25

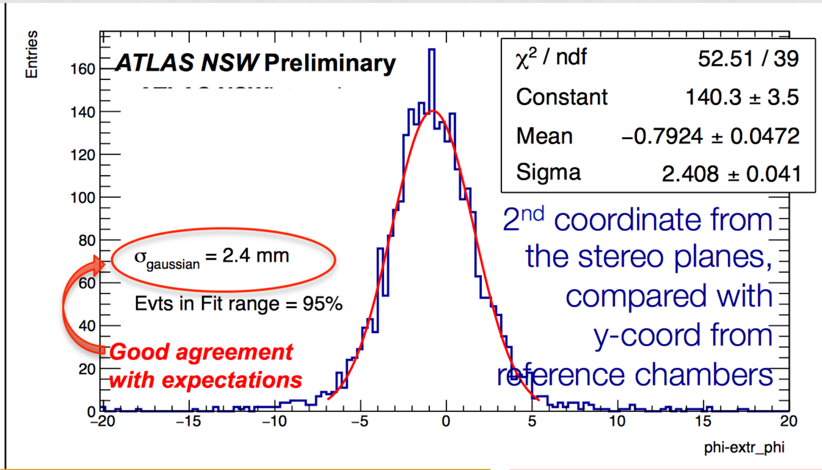
Aim: validation of the first 2 m^2 Q-plet

FIRST LARGE PROTOTYPE PERFORMANCE

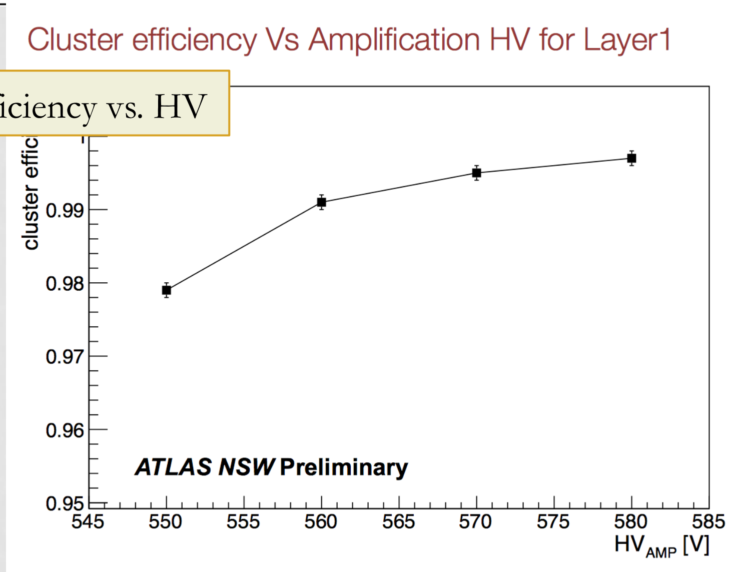
Preliminary results obtained for perpendicular tracks (charge centroid method)

Space resolution
Precision coordinate
2° coord (stereo strips)



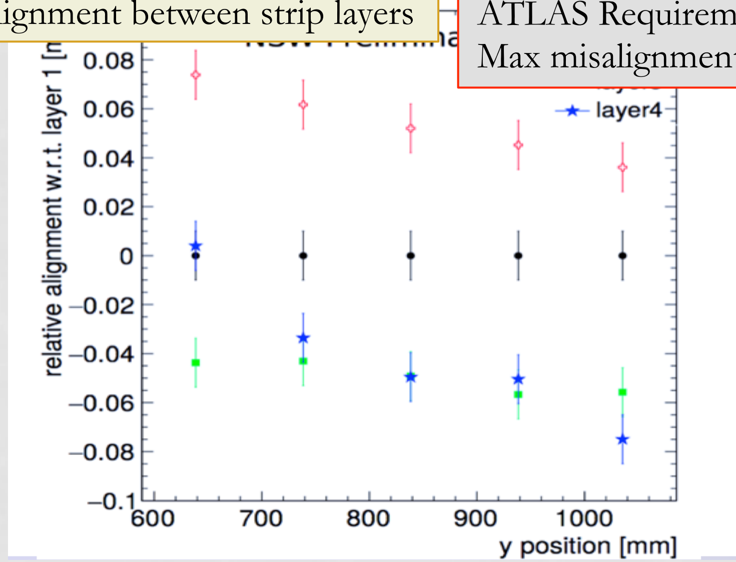


Efficiency vs. HV



Alignment between strip layers

ATLAS Requirement
Max misalignment < 60 μm



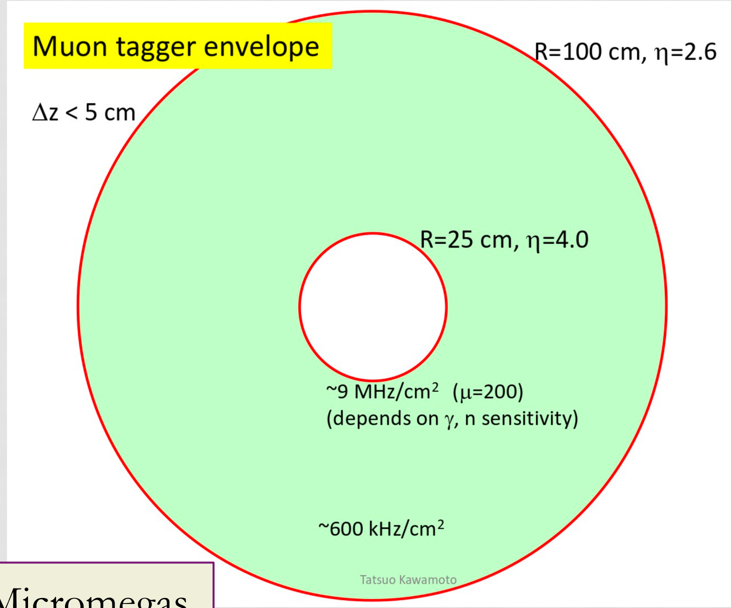
LARGE ETA TAGGER

Very large – η ➔ **2.7 < |η| < 4**

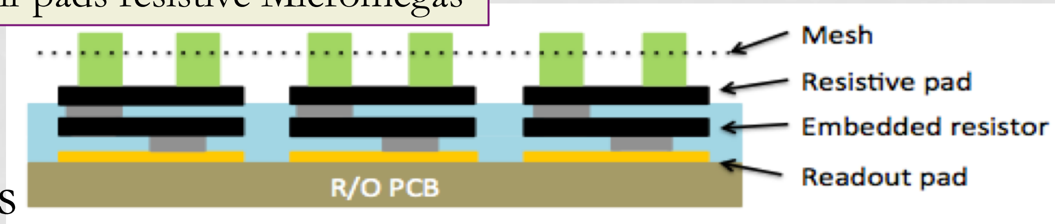
- Hit rates up to **9 MHz/cm²**
- @ highest L of HL-LHC (μ = 200)
- Resolution of few 100 μm

Crucial points:

- Hit granularity down to **1 mm** level
- Multi-layer
- 2D reconstruction

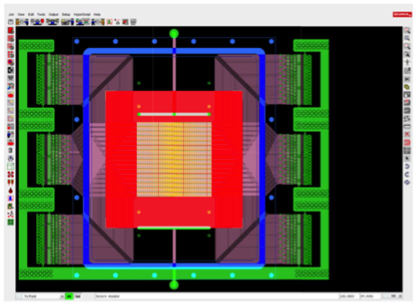


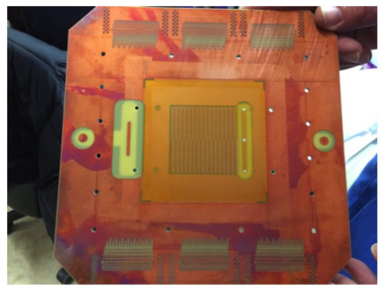
Small-pads resistive Micromegas



Three options are considered:

1. Small-pads resistive Micromegas
2. Micro Pixel Chamber (μ-PIC)
3. Micro-Resistive Well (μRWell)





Pads with rectangular shape 0.82.8 mm²
R&D in progress, first test-beam recently

RECENT DEVELOPMENTS

NEW DIRECTIONS

- MPGD principle of operation to obtain "triggering" and "tracking" detectors with, at the same time:
  - Stability of operation at high rates
  - Good space resolution O(100 μm)
  - **Improved time resolution O(ns)**
  - **Simplified construction/assembly procedures**
- Recent ideas:
  - **Micro-Resistive Well** (simplicity of construction)
  - **Fast Time Micropattern** (exploiting the possibility to reach O(1 ns) time accuracy)

MICRO-RESISTIVE-WELL

G. Bencivenni et al., 2015_JINST_10_P02008

"**Micromegas with a GEM foil for amplification**"..

➔ Simple assembly procedure (no gluing, stretching)

➔ High-rate bahaviour depends on the resistive stage (100 kHz/cm^2 up to 10 MHz/cm^2)

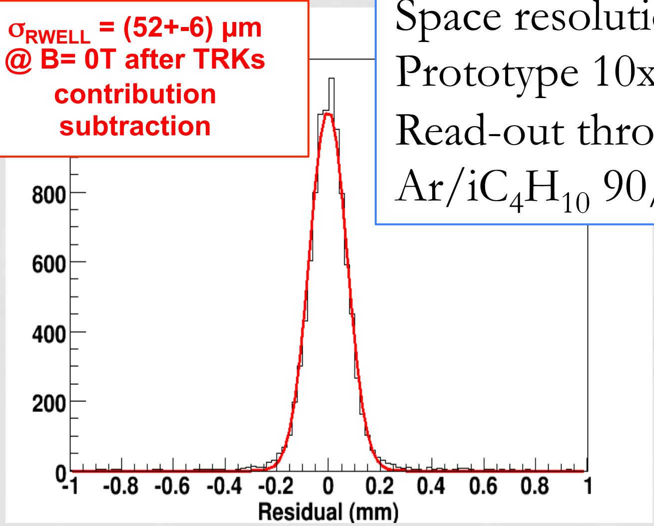
➔ Time resolution 6 ns

➔ Space resolution < 100 μm

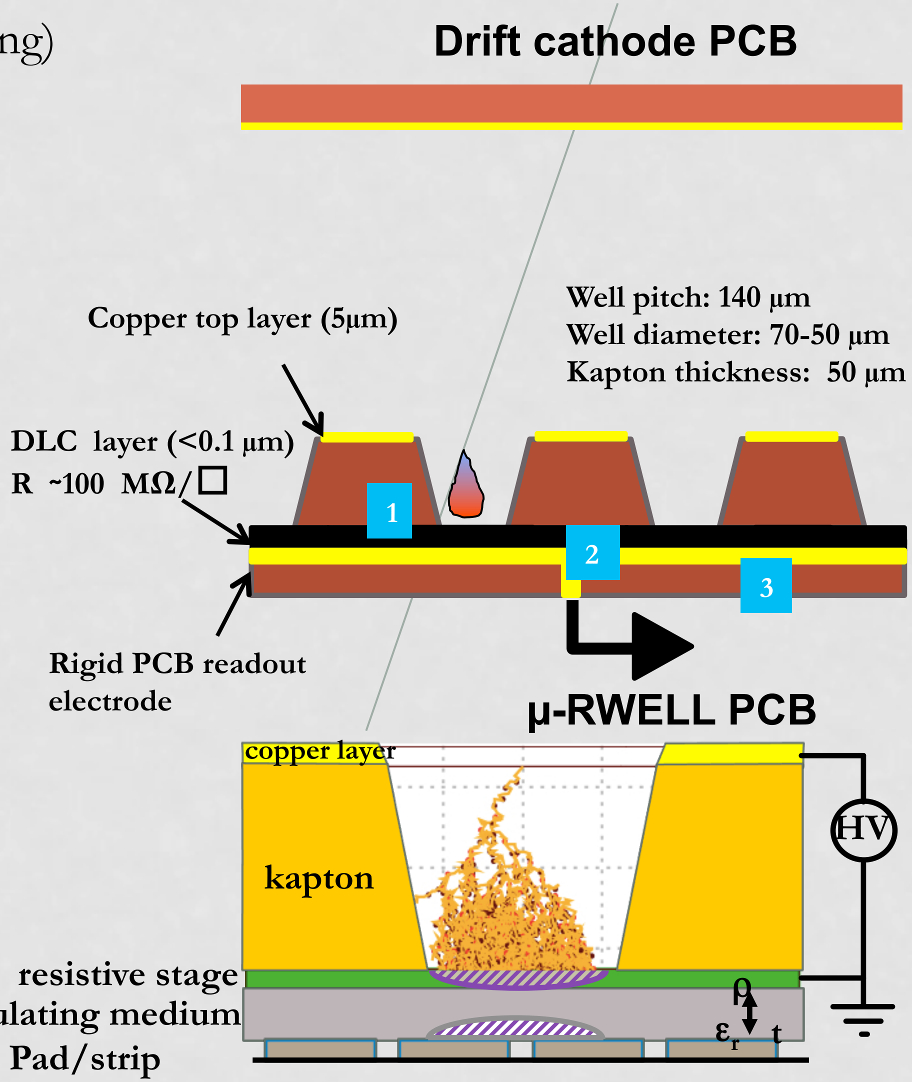
First large size prototype (GE1/1 size) under test, results soon

→ CMS GE2/1 and/or LHCb M2 chambers and/or ATLAS Large Eta Tagger

σ_{RWELL} = (52+-6) μm @ B= 0T after TRKs contribution subtraction



Space resolution:
Prototype 10x10 cm^2
Read-out through APV25
Ar/iC_4H_{10} 90/10



FAST TIME MICROPATTERN

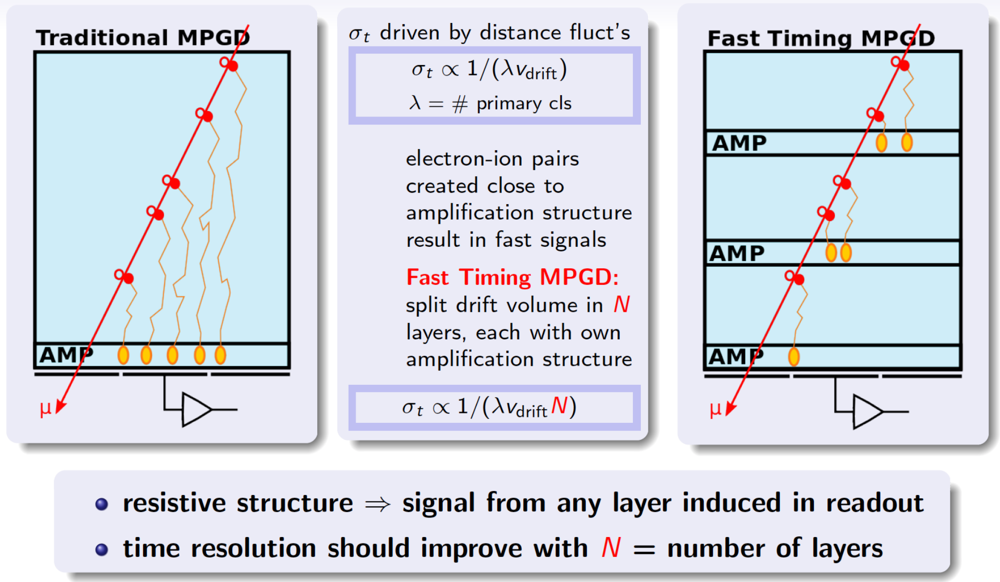
The time resolution in a MPGD depends on the fluctuation of the arrival time of the first electron

$$\sigma_t = 1/(\lambda v_d)$$

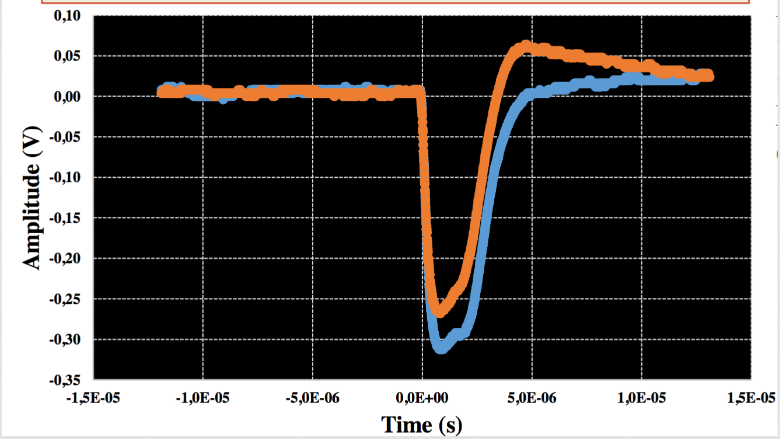
This can be reduced by a factor N_D , N_D being the number of independent drift-amplification stages.

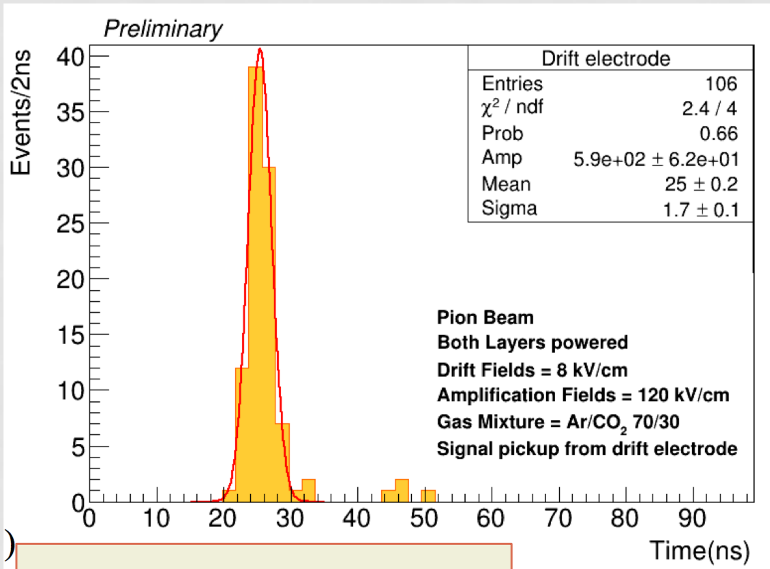
Resistive layers ➔ structure transparent to signals that can be extracted at every amplification stage

M. Maggi, A. Sharma, R. De Oliveira
arXiv:1503.05330v1



Signals obtained on both electrodes





$\sigma_t \approx 2$ ns with 2 stages

SUMMARY AND CONCLUSIONS

- Starting from **LHC Run3 (>2020)** large area MPGD will be used by the LHC experiments to support the expected large particle rates.
- **GEM technology** will be widely used (Alice, CMS, LHCb)
- **MicroMegas technology** will be used by ATLAS reaching the largest dimensions (up to 3 m^2 chambers)
- This is a challange under several points of view
- In the meantime **new MPGD concepts** are developed