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 developments
• COMPASS has been and is a pioneer under several aspects.
• In this talk ➔ prospects for the LHC experiments upgrades
  • Quest for large dimensions (≈ m²) detectors
  • Time resolutions at the “ns” level
  • Space resolutions at the “100 µm” level
  • Rate capability up to 10 kHz/cm² ➔ MHz/cm².
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

03/04/17

Status of the art of the new generation of MPGD detectors
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 cm² triple-GEMs for large-η muon trigger)
  • **TOTEM T2** (half-circles triple-GEMs 14 cm radius)
• **LHC upgrades**: luminosity beyond baseline value ➔ higher rates are expected in the forward muon detectors.
  - From p-p collisions: $O(100 \text{ kHz/cm}^2)$ 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 m² each (phase-I)
  • **ATLAS** forward muon spectrometer
    • NEW SMALL WHELL: MicroMegas: 128 Q-plets 2÷3 m² area each (phase-I)
    • LARGE ETA TAGGER: Pad MicroMegas Concept OR µPIC OR µR WELL
  • **CMS** forward muon spectrometer
    • GE1/1: 72 Triple-GEMs chambers 0.35 ÷ 0.4 m² each (phase-I)
    • ME0 + GE2/1: options considered (phase-II)
      • Triple-GEM with X-Y read-out
      • Fast Time MicroPattern new concept MPGD
      • µR WELL new concept MPGD
  • **LHCb** forward muon spectrometer
    • Still under discussion, probably small MPGDs (30x30 cm²) for triggering in a huge rate environment OR µR WELL
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

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

**Typical Electrical field lines**

**Structure of a GEM foil**

**Simulated avalanche in GEM hole**

**Behaviour of electrons and ions through a hole**
MULTIPLE-GEM: PRINCIPLE OF OPERATION - II

- The technique has been extended to $\approx m^2$ foils thanks to the single-mask technology $\Rightarrow$ large area applications are possible

- Then go to Multiple-GEM allowing:
  - High gain obtained with electrodes at “low voltages” $\Rightarrow$ less prone to discharges (Raether limit hard to be reached)
  - Freedom in the choice of the electrical fields $\Rightarrow$ optimization of the IBF (Ion Back Flow) $\Rightarrow$ reduction of field distortions
New detectors to insert:

**GE1/1** (phase-I $1.55 < |\eta| < 2.1$)
- Triple-GEM (approved)

**ME0** (phase-II $2 < |\eta| < 3$)
- To be decided
- Triple-GEM (baseline)

**GE2/1** (phase-II $1.65 < |\eta| < 2.5$)
- To be decided

**Requirements:**
- Maximum geometric acceptance within the given CMS envelope
- **Rate capability** up to 100’s kHz/cm²; 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)

See CMS-TDR-013 CERN-LHCC-2015-012
Major features of the GE1/1, design are:

- Single-mask technology exploited
- The three GEM foils: gap config (3/1/2/1)
- Readout board with strips (3072 per chamber) with fixed $\phi$ pitch (463 $\mu$rad)
- 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

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In CMS, the $\phi$ coordinate is the precision one

- Radial strips with a fixed pitch in $\phi$
- Tracks perpendicular $\Rightarrow$ charge centroid

Muon trigger: $\Delta \phi$ measured @ L1 trigger level

- CSC+GEM improves the lever arm
  - reduce fake muon rate

L1 single muon trigger rate reduction according to present simulation:

$\mathbf{p_T} > 20$ 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

\[ \sigma(x) = 268 \, \mu\text{m} \]
\[ \sigma(\phi) = 137 \, \mu\text{rad} \]

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 $\rightarrow$ $\mu$RWell
ALICE TPC READOUT

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

Ion flow removal through the “gating grid” method is NOT possible anymore (→ 280 µs intrinsic 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: $\rightarrow$ Ne-CO$_2$-N$_2$ (90-10-5)
  - Standard and Large-Pitch GEMs
  - Most of the gain in the last stage
  - Few mm pads $\rightarrow$ drift time and charge measurement

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ALICE QUADRUPLE-GEM - II

- 72 Large area chambers: $0.6 \, \text{m}^2$, $0.2 \, \text{m}^2$
  - Single-mask technology exploited

- Results on first prototypes:
  - Gain $\approx 2000$
  - $\sigma_x \approx \sigma_y \approx 1 \, \text{mm}$, $\sigma_z \approx 3 \, \text{mm}$
  - $\sigma(\text{d}E/\text{d}x) \approx 12\% \, ^{55}\text{Fe}$
  - IBF $< 1\%$

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LHCB PROSPECTS

• Still under discussion in the collaboration
• Main points:
  • Probably remove M1 chambers
  • Additional small chambers (30x30 cm²) for triggering in the huge rate regions (up to 0.5 MHz/cm²) M2
  • Time resolutions below 5 ns required
  → GEM with CF₄ 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

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
Huge electric field ratio:

- The mesh is “transparent” for drift electrons
- Avalanche ions almost fully collected by the mesh (within $\approx 100$ ns); negligible IBF

Gain “Plateau” ($10^4 \div 10^5$) around $d = 100 \mu m$
For each strip, are measured:
- charge time
- Charge centroid
- \( \mu \text{TPC} \) (position and angle)

Important point: good measurement also for tracks at an angle \((\approx 100 \text{ \mu m} \text{ for } 8^\circ < \theta < 32^\circ)\) ➔ good for ATLAS Muons!

MICROMEGAS: PROTOTYPES PERFORMANCE - THE MTPC

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

Typical event

Space resolution measured on Test-Beam

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

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ATLAS NSW - MOTIVATIONS

Let’s consider the ATLAS forward muon case

Endcap muon trigger dominated by *fake muons*

\[ R(p_T > 20 \text{ GeV}) = 60 \text{ kHz} \quad (@ 3 \times 10^{34}, 14 \text{ TeV}) \]

A factor >3 reduction \( \rightarrow \) “pointing trigger”

allows to eliminate 90% of the fakes

\[ R(p_T > 20 \text{ GeV}) = 21 \text{ kHz} \quad (@ 3 \times 10^{34}, 14 \text{ TeV}) \]

Compatible with allowed bandwidth

MDT precision chambers:
Beyond project luminosity \( \rightarrow \) *efficiency loss*

\( \rightarrow \)“Tube size” \( \approx 3 \text{ cm} \times 1 \text{ m} \times 750 \text{ ns} \);

\( \rightarrow \) @ \( 7 \times 10^{34}, 14 \text{ TeV} \) \( \rightarrow \approx 4 \text{ kHz/cm}^2 \)

> 1 MHz/Tubo \( \approx 1 \text{ /750 ns} \)

> 50% drop in chamber efficiency

\[ \Rightarrow \text{Accept topologies A reject B / C} \]

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**MICROMEGAS FOR ATLAS NSW - I**

*High expected rate:* discharge probability to be reduced by maintaining a high gain $\approx 10^4$

$\rightarrow$ **Resistive strip anode**

$(\approx 20 \text{M}\Omega/\text{cm}; \approx 1\text{M}\Omega/\square)$

Large dimension chambers have to be built ($2 \div 3 \text{m}^2$) with challenging mechanical precisions ($30 \div 80 \ \mu\text{m}$)

$\rightarrow$ **new construction technique**

$\rightarrow$ **Floating mesh**

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

03/04/17

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The ATLAS MicroMegas chambers are organized in Q-plets:
5 panels 1 cm thick  2 m² 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
Measurements done on a 180 GeV beam in “standard” conditions
-- Gas Mixture Ar/CO₂ (93%-7%) @ 20 l/hr
-- HV(ampl) = 580 V, HV(drift) = 300 V
-- FE electronics APV25
Aim: validation of the first 2 m² Q-plet
FIRST LARGE PROTOTYPE PERFORMANCE

Preliminary results obtained for perpendicular tracks (charge centroid method)

- **Space resolution**
- **Precision coordinate 2° coord (stereo strips)**

Cluster efficiency Vs Amplification HV for Layer 1

Efficiency vs. HV

Alignment between strip layers

ATLAS Requirement
Max misalignment < 60 µm

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Very large – $\eta \Rightarrow 2.7 < |\eta| < 4$

Hit rates up to $9 \text{ MHz/cm}^2$

@ highest L of HL-LHC ($\mu = 200$)

Resolution of few 100 $\mu$m

Crucial points:

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

Three options are considered:

1. Small-pads resistive Micromegas
2. Micro Pixel Chamber ($\mu$-PIC)
3. Micro-Resistive Well ($\mu$RWell)

Pads with rectangular shape 0.82.8 mm$^2$

R&D in progress, first test-beam recently
RECENT DEVELOPMENTS

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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 $O(100 \, \mu m)$
  • 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

“Micromegas with a GEM foil for amplification”:

- Simple assembly procedure (no gluing, stretching)
- High-rate behaviour depends on the resistive stage (100 kHz/cm² up to 10 MHz/cm²)
- 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

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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 \( \Rightarrow \) structure transparent to signals that can be extracted at every amplification stage.

\[ \sigma_t \approx 2 \text{ ns with 2 stages} \]
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 m² chambers)

• This is a challenge under several points of view

• In the meantime **new MPGD concepts** are developed