Micro Pattern Gaseous Detector Technologies and Applications: The Work of the RD51 Collaboration

Filippo Resnati (CERN and ESS) on behalf of the RD51 Collaboration

ICHEP - Chicago - 5th August 2016
Micro-Pattern Gaseous Detectors

From late ’80, conceived to overcome the limitations of MWPCs with respect to position resolution, capability to cope with high particle fluxes, and long-term stability.

All MPGDs have in common:
- production techniques typical of PCB manufacturing
- dielectric materials as support for the electrodes
- proximity of anode and cathode electrodes
MPGD strengths

- High particle flux capable (MHz/mm$^2$)
- Large dimensions (several m$^2$)
- Not expensive (< 5 kCHF/m$^2$)
- Good position resolution (<50 um)
- Excellent time resolution (<5 ns and even $O(100 \text{ ps})$)
- Radiation hard (10s year in forward muon chambers at LHC)
- Low material budget (<0.01 $X_0$)
- Compatible with magnetic field
RD51 collaboration

Established in 2008 to foster the coherent and synergistic developments of MPGDs, to prove the scalability of the concepts, the industrialisation of the production, and to facilitate the circulation of information, ideas and solutions.

Goal:
Advance the techniques of MPGDs, related electronics, and software, enhancing the effectiveness of the developments, still maintaining the identity and the specificity of each project.
Institute collaborations on MPGD developments based on publications

1999  | 2000  | 2001  | 2002

2003  | 2004  | 2005  | 2006

Most MPGDs already conceived

2007  | 2008  | 2009  | 2010

RD51 collaboration

2011  | 2012  | 2013  | 2014

Collaboration Spotting http://collspotting.web.cern.ch
A world-wide collaboration

86 institutes and more than 500 members
Unbiased benchmark of the effectiveness of the RD51 collaboration

A total of 28 contributions from 2015 Frontier Detector for Frontier Physics involved (in one way or another) RD51 collaboration

Thanks to Eraldo Oliveri for the slide
Achievements

MPGD developments for LHC upgrades (ALICE TPC, ATLAS NSW, and CMS GE1/1) - and not only - originally emerged from RD51 activities to make large $O(m^2)$ and reliable (stable and spark protected) MPGDs.

Several other examples of successful developments profit from (or are part of) these activities:
- BESSIII tracker (cylindrical GEM)
- CLAS12 tracker (planar and cylindrical MM)
- COMPASS RICH (THGEM+MM)
- ...
Large GEMs

Historically, GEMs were produced with *double-mask* technique.

Precision mask alignment implies constraints on detector size $O(30\times30\text{cm}^2)$.

Development of the *single-mask* method.

Size of the raw material is now the limit $O(>1\text{m} \times 60\text{cm})$.

Significant reduction of GEM price per square metre.
Large GEMs at LHC

ALICE TPC (4 GEMs)
130 m²

CMS GE1/1 (GEM)
1000 m²

Examples from MPGD 2015

A. Mathis, MPGD2015, https://agenda.infn.it/getFile.py/access?contribId=9&sessionId=2&resId=0&materialId=slides&confId=8839

B. Dorney, MPGD2015, https://agenda.infn.it/getFile.py/access?contribId=66&sessionId=2&resId=0&materialId=slides&confId=8839
Resistive MM

Discharges may occur in any MPGD

Reduction of the discharge probability and discharge effects is mandatory

Development of resistive electrodes that locally quench the discharges

Apply these techniques to the MM anode

Enable a natural way for the two views readout
Resistive MM at LHC

ATLAS NSW (MM)
1200 m²

Micromegas mesh is laid on pillars and fixed by electrostatic force
Floating mesh eases the production and the assembly phases

In production

Industrialisation:
Production of detector components will by done at PCB companies
Tenders were asked to ELTOS and ELVIA

Examples from MPGD 2015
Hybrid detectors

COMPASS RICH
2 THGEMs and bulk MM
4.5 m²

Very large and stable gain is required for single Cherenkov photon detection

2x THGEMs and a non-resistive bulk MM and CsI photocathode

Big effort put on reducing the discharge probability and gain uniformity

Industrialisation:
ELTOS and ELVIA actually produced the THGEM PCBs

Examples from MPGD 2015

F. Tessarotto, MPGD2015, https://agenda.infn.it/getFile.py/access?contribId=104&sessionId=2&resId=0&materialId=slides&confId=8839
Different shapes

BESSIII (Cylindrical GEM)

The Cylindrical GEM Inner Tracker

- 3 layers CGEM
- Beam-pipe

Detector requirements
- Rate capability: \( \sim 10^4 \) Hz/cm²
- Spatial resolution: \( \sigma_x = 130 \mu m \)
- Momentum resolution: opt/pt = 0.3% at 1 GeV
- Efficiency = \( \sim 98\% \)
- Material budget < 1.5% of \( X_0 \) for all layers
- Coverage: 93% 4π
- Operation duration ~ 5 years

Detector peculiarities and innovations
- Rohacell will be used in the cathode and anode structure with a substantial reduction of the thickness of the detector.

CGEM Assembly Technique
- A dedicated assembling machine has been designed and realized to perform the insertion of the electrodes.
- Axial alignment has a precision of 0.1mm/1.5m.
- The structure can rotate by 180° around its central horizontal axis.

CLAS12 (Cylindrical MM)

The CLAS12 Experiment
- Upgrade of the CLAS Experiment at Jefferson lab
- Study of the nucleon structure with high 11 GeV electron beam at high luminosity (10^35 cm⁻²·sec⁻¹)

Micromegas Vertex Tracker:
- Improve the track reconstruction in the vicinity of the target
- Reduced volume bet. the magnet and the silicon vertex tracker (SVT)
- Large curved Micromegas
- SI field
- Remote electronics
- Resistive technology
- Small dead space
- High particle rate (30 MHz)

CLAS12 Barrel Detectors
- "C" Barrel
- 1152 "C" strips
- 221 mm radius
- Pitch from 0.67 to 0.33 mm
- PCB thickness 100 µm, Drift thickness 250 µm
- 0.35% of \( X_0 \)
- Drift Field 5 kV/cm: 1.5kV on 3 mm gap
- Slow Gas: Ar + 10% iC

- "Z" Barrel
- 768 "Z" strips
- 225 mm radius
- 0.529 mm pitch
- PCB thickness 200 µm, Drift thickness 250 µm
- 0.41% of \( X_0 \)
- Drift Field 8 kV/cm: 2.4kV on 3 mm gap
- Resistive strips technology

Spherical GEMs are also possible
arXiv:1011.5528

ICHEP - Chicago - 5th August 2016
Future perspectives

Extend the scope of MPGDs:
- other applications in HEP (e.g. calorimetry)
- other applications in non-HEP (e.g. rare event search)
- applications beyond fundamental physics

Extending the performance of MPGDs:
- increase detection efficiency for gammas and neutrons
- improve the time resolution
Academia Industry Matching

Understand the requirements, possible new applications, and new communities

On neutron detection (1st)

14-15 October 2013
arXiv:1410.0107

On neutron detection (2nd)

16-17 October 2015
arXiv:1601.01534

On photon detection

10-11 June 2015

At the Globe de l’Innovation in front of CERN

arXiv:1410.0107

ICHEP - Chicago - 5th August 2016
Precise timing

Driving reason: development of large area and high-flux-capable detectors for pile-up mitigation in HL-LHC experiments

Presently, intrinsic time resolution to MIPs of MPGDs is of few nanoseconds

Improvement of almost two orders of magnitude needed
Timing with MPGDs

\[ \sigma_t = \sigma_l / v_e \sim 300 \, \text{um} / 50 \, \text{mm/\mu s} = 6 \, \text{ns} \]

Main limitation:

~10 clusters uniformly distributed over 3 mm

Statistics of the number of clusters helps, but contributions also from diffusion, electron velocity, signal to noise…
Timing with next MPGDs

Limiting factor becomes the gas diffusion

Cherenkov radiator

MgF$_2$ and CsI: $O(100)$ p.e./cm

Photocathode

Amplification

Readout

100um

200um
Detector operated in sealed mode

Tests with a femtosecond laser at LIDyL laboratory in CEA/Saclay
First test beam

Same detector operated in Ne/C$_2$H$_6$/CF$_4$

**Basically 100% efficient detector**

<table>
<thead>
<tr>
<th>htemp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>RMS</td>
</tr>
<tr>
<td>$\chi^2$/ndf</td>
</tr>
<tr>
<td>p0</td>
</tr>
<tr>
<td>p1</td>
</tr>
<tr>
<td>p2</td>
</tr>
</tbody>
</table>

**Without unfolding the t$_0$ measurement from the MCP-PMT**

Time resolution for MIPs

Sigma < 100 ps

**More than 5.5 p.e./mip**

**Preliminary**

Time resolution will naturally improve because:
Photocathode improvement will lead to > 2x p.e.
Improvement of the gas quality will lead to larger gain

Tests of different gases and photocathodes planned in the next test beam (starting from next Wednesday)

**Preliminary**

ICHEP - Chicago - 5th August 2016
Summary

RD51: consolidated international collaboration of 86 institutes

Major progresses in the MPGD technologies, some of which picked up by large experiments

Always developing new structures and new ideas to meet the new requirements

Development of new production techniques, industrialisation of the established ones and quality control

Dissemination via schools, workshops, and specialised events to reach new potential users and understand new requirements