The micro-RWELL detector

M. Poli Lener (a)

G. Bencivenni (a), R. de Oliveira (b), G. Felici (a), M. Gatta (a), G. Morello (a), A. Ochi (c), E. Tskahadadze (a,d)

(a) LNF-INFN, Italy, (b) CERN, Meyrin, Switzerland, (c) Kobe University, Kobe, Japan, (d) JINR, Dubna, Russia

5th International Conference on Micro-Pattern Gas Detectors
Outline

- The architecture & principle of operation

- The Low Rate scheme and its performance
  - Technology Transfer of the Low Rate version

- The High Rate scheme and its performance

- Conclusion
Why a new MPGD

The R&D on μ-RWELL is mainly motivated by the wish of improving the

stability under heavy irradiation

& simplify as much as possible

construction/assembly procedures

Consequently reducing the costs of the device
The detector architecture

The µ-RWELL is composed of only two elements: the µ-RWELL_PCB and the cathode.

The µ-RWELL_PCB, the core of the detector, is realized by coupling:

1. a “WELL patterned kapton foil” as “amplification stage”

2. a “resistive layer” for discharge suppression & current evacuation:
   i. “Single resistive layer” (SL) <100 kHz/cm²: single resistive layer → surface resistivity ~100 MΩ/□ (CMS-phase2 upgrade; SHIP)
   ii. “Double resistive layer” (DL) > 1 MHz/cm²: more sophisticated resistive scheme must be implemented (MPDG_NEXT - LNF) suitable for LHCb-Muon upgrade

3. a standard readout PCB

(*) DLC = Diamond Like Carbon
High mechanical & chemical resistant material

G. Bencivenni et al., 2015_JINST_10_P02008
Principle of operation

Applying a suitable voltage between top copper layer and DLC the “WELL” acts as multiplication channel for the ionization.

The charge induced on the resistive foil is dispersed with a time constant, \( \tau = \rho C \), determined by

- the \textit{surface resistivity}, \( \rho \)
- the \textit{capacitance per unit area}, which depends on the distance between the resistive foil and the readout plane, \( t \)
- the \textit{dielectric constant} of the insulating medium, \( \varepsilon_r \) [M.S. Dixit et al., NIMA 566 (2006) 281]

- The main effect of the introduction of the resistive stage is the suppression of the transition from streamer to spark
- As a drawback, the \textit{capability to stand high particle fluxes} is reduced, \textit{but an appropriate grounding of the resistive layer with a suitable pitch} solves this problem (see High Rate scheme)
Main detector features

The µ-RWELL is a single-amplification stage, intrinsically spark protected MPGD characterized by:

- **simple assembly procedure:**
  - only two components → µ-RWELL_PCB + cathode
  - no critical & time consuming assembly steps:
    - no gluing
    - no stretching (no stiff & large frames needed)
    - easy handling
  - suitable for large area with PCB splicing technique w/small dead zone

- **cost effective:**
  - 1 PCB r/o, 1 µ-RWELL foil, 1 DLC, 1 cathode and very low man-power

- **easy to operate:**
  - very simple HV supply → only 2 independent HV channels or a trivial passive divider (while 3GEM detector → 7 HV floating/channels)
Single resistive layer scheme
The Low Rate scheme (CMS/SHiP)

1. Copper layer 5 µm
   Kapton layer 50 µm
   DLC layer: 0.1-0.2 µm (10-200 MΩ/□)

2. DLC-coated kapton base material
   Insulating medium (50 µm)
   PCB (1-1.6 mm)

3. DLC-coated base material after copper and kapton chemical etching (WELL amplification stage)
The µ-RWELL performance: X-rays test

The prototypes, with different surface resistivities, have been tested with X-rays for first measurements in current mode (gain and rate capability under local irradiation).

Ar/iC$_4$H$_{10}$ = 90/10

Local irradiation

Gain

Detectors safely reach a gain $\geq 10000$

Under global irradiation we expect a lower rate capability for single layer scheme

$\Phi_{0.97} = 850$ kHz/cm$^2$; $\Phi_{0.97} = 77$ kHz/cm$^2$;

$\Phi_{0.97} = 3.4$ MHz/cm$^2$;
Beam tests results

H4 Beam Area (RD51)
Muon beam momentum: 150 GeV/c
Goliath: B up to 1.4 T

μ-RWELL prototype
5x5 cm² active area
12-80-880 Ω /□
400 μm pitch strips
APV25 (CC analysis)
Ar/iC₄H₁₀ = 90/10

BES III-GEM chambers

σ_RWELL = (52+6) μm
@ B= 0T after TRKs contribution subtraction

M. Poli Lener et al., NIM A 824 (2016) 565
The $\mu$-RWELL performance: Beam Tests

Analysis performed with the CC method, 400 $\mu$m strips pitch

$\text{Ar/iC}_4\text{H}_{10} = 90/10$

$\text{Ar/ISO=90/10}$

At low resistivity the spread of the charge (cluster size) on the readout strips increases, thus requiring a higher gain to reach the full detector efficiency. The space resolution exhibit a minimum width around 100 $\text{M}\Omega/\square$.

At low resistivity the charge spread increases $\rightarrow$ worse spatial resolution

At higher resistivity $\rightarrow \sim 1$ fired strip

22/05/17

M Poli Lener, LNF-INFN - MPDG 2017, Philadelphia
In the framework of the CMS-phase2 muon upgrade we have developed large size $\mu$-RWELLs, in strict collaboration with Italian industrial partners (ELTOS & MDT). The work is performed in two years with following schedule:

1. Construction & test of the first $1.2\times0.5\text{m}^2$ (GE1/1) $\mu$-RWELL 2016 - DONE
2. Mechanical study and mock-up of $1.8\times1.2\text{ m}^2$ (GE2/1) $\mu$-RWELL 2016-2017 ONGOING
3. Construction of the first $1.8\times1.2\text{m}^2$ (GE2/1) $\mu$-RWELL (only M4 active) 01-09/2017 near future
Double resistive layers scheme
Towards the High Rate scheme

single resistive layer, edge grounding, 2D evac. current

d

d (50cm)

d’

top layer

double resistive layer, 3D grounding

conductive vias

bottom layer

Ω ~ ρ_s x d/2πr

Ω’ ~ ρ_s’ x 3d’/2πr

Ω / Ω’ ~ (ρ_s / ρ_s’) x d/3d’

If ρ_s = ρ_s’ → Ω / Ω’ ~ ρ_s/ρ_s’ * d/3d’ = 50/3 = 16.7

(*) point-like irradiation, r << d
Ω is the resistance seen by the current generated by a radiation incident in the center of the detector cell

(*) Morello’s model: appendix A-B (G. Bencivenni et al., 2015_JINST_10_P02008)
The High Rate scheme (LHCb)

1. Copper layer 5 µm
   Kapton layer 50 µm
   DLC layer: 0.1 – 0.2 µm
   (10-200 MΩ/□)

2. 2nd resistive kapton layer with ~ 1/cm² “through vias” density

3. DLC-coated kapton base material
   2nd resistive kapton layer
   Insulating layer
   Pad/strips readout on standard PCB
   “through vias” for grounding

4. DLC-coated base material after copper and kapton chemical etching (WELL amplification stage)
Local irradiation is practically equivalent to global irradiation
Beam Test (CMS/LHCb collaboration)

H8 Beam Area (18th Oct. – 9th Nov 2016)
Muon/Pion beam: 150 GeV/c

GOAL: time resolution measurement (never done before)

3 µ-RWELL prototypes
13-26-70 MΩ /☐
VFAT (digital FEE)
Ar/CO₂/CF₄ = 45/15/40

Double resistive layer scheme
400 µm pitch strips

Single resistive layer scheme
800 µm pitch strips

Trigger=S1+S2+S3
Different chambers with different dimensions and resistive schemes exhibit a very similar behavior although realized in different sites (large detector realized @ ELTOS). The saturation at 5.7 ns is dominated by the fee (measurement done with VFAT2).

Past measurements done with GEM by LHCb group gave $\sigma_t = 4.5$ ns with VTX chip [1]. We wish to perform the same measurement with $\mu$-RWELL in order to have a direct comparison with GEM.

Ageing test: GIF++ (LNF, INFN-BO)

To validate the DLC-based detector in the GE2/1 region @CMS, it is necessary (mandatory) to study the behaviour of the chamber under global irradiation.

The detector, working at a gain 4000 (efficiency plateau) in Ar/CO2/CF4 45/15/40, will integrate about 2.5 mC/cm²

We plan to integrate 25 mC/cm² in about 60 days (10 years with s.f. 10)

The setup has been completed with two more μ-RWELL:

- Double resistive layers scheme (high rate)
- Single layer scheme (reference chamber)
Currents quite constant during the operating time gates & no dark current observed when source is off.
Conclusion

The µ-RWELL is a compact, single-amplification stage, simple to assemble & suitable for large area, MPGD:

✓ gas gain > 10^4
✓ intrinsically spark protected
✓ rate capability > 1 MHz/cm^2 (HR version)
✓ space resolution < 60µm
✓ time resolution ~ 5.7 ns
✓ cost effective detector

R&D/engineering in progress:

- **Low rate** (<100kHz/cm^2):
  - small and large area prototypes built and extensively tested
  - a well defined roadmap towards Technological Transfer to industry

- **High rate** (>1 MHz/cm^2):
  - first prototypes show very promising performance
  - the engineering is going to be started
Spare slides
The $\mu$-RWELL performance

Discharge study: $\mu$-RWELL vs GEM

- discharges for $\mu$-RWELL of the order of few tens of nA (<100 nA @ max gain)
- for GEM discharges the order of 1 $\mu$A are observed at high gas gain
The μ-RWELL vs GEM

The μ-RWELL is expected to exhibit a gas gain larger than a single-GEM.

- **Single-GEM:**
  - only 50% of the electron charge produced into the hole contributes to the signal, the rest of the electron charge is collected by the bottom side of the GEM foil
  - the signal is mainly due to the electron motion, the ion component is largely shielded by the GEM foil itself

- **μ-RWELL:**
  - 100% electron charge produced into the amplification channel is promptly collected on the resistive layer
  - the ionic component, apart ballistic effects, contributes to the formation of the signal
  - further increase of the gain achieved thanks to the resistive electrode which, quenching the discharges, allows to reach higher amplification field inside the channel
μ-RWELL: Energy Resolution

The prototype of μ-RWELL (100 MΩ/□) has been tested with X-rays tube (6keV) (Ar/CO₂=70/30) & the signal has been readout with an ORTEC amplifier.
The detector rate capability (with $E_d=3.5$ kV/cm) has been measured in current mode with a pion beam and irradiating an area of $\sim 3 \times 3$ cm$^2$ (FWHM).

Performance vs Rate

Rate capability vs. radiation flux ($\text{Ar:CO}_2:\text{CF}_4$)

- **Preliminary**

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>Data Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double resistive</td>
<td>$\mu$-RWELL Right, $G=4000$</td>
</tr>
<tr>
<td></td>
<td>$\mu$-RWELL Left, $G=6000$</td>
</tr>
<tr>
<td></td>
<td>$\mu$-RWELL 2, $G=9000$</td>
</tr>
<tr>
<td></td>
<td>$\mu$-RWELL 1, $G=10000$</td>
</tr>
<tr>
<td></td>
<td>$\mu$-RWELL 2, $G=12000$</td>
</tr>
</tbody>
</table>

- **Single resistive layer**

Chart showing normalized gain vs. radiation flux (in kHz/cm$^2$) for different data points.
μ-RWELL: Ion Feed-Back measurement

The prototype of μ-RWELL (100 MΩ/□) has been tested in current mode with X-rays tube (6keV) (Ar/ISO=90/10)

Gain ~ 10³

μ-RWELL: $B \neq 0$ with Ar/ISO=90/10

CC analysis

June 2015 – $\theta=0^\circ$, $B = 0$ T

Dec 2014 – $\theta=0^\circ$, $B = 0.5$ T

June 2015 – $\theta=0^\circ$, $B = 1$ T

June 2015 – $\theta=0^\circ$

For $\theta=0^\circ$ and $0 < B < 1$ T, $\sigma < 180 \mu$m and $\varepsilon > 98\%$
μ-RWELL: $B \neq 0$ with $Ar/ISO=90/10$

CC analysis

June 2015 - $\theta=0^\circ$

For $\theta=0^\circ$ and $0 < B < 1 \text{ T}$, $\sigma < 180 \mu\text{m}$ and $\varepsilon > 98\%$
X-ray measurements

Two prototypes with the **double resistive layer scheme** ($\rho=40 \, \text{M}\Omega/\square$) have been completed last Summer; the detectors have been tested with 5.9 keV X-rays (local irradiation).

Measurement performed in current mode. Gain measured up to 10000. Similar behavior for the two chambers.
The efficiency has been evaluated asking for TDC coincidence selected in a proper range. Then the ratio of the triplets on the doublets gives the value.

The TDC distribution is then fitted with a simple gaussian and the sigma is then deconvoluted by the contribution of the VFAT.

\[ \sigma_t^2 = \sigma_{TDC}^2 - \left( \frac{25}{\sqrt{12}} \right)^2 \]
Detector Gain (large area)

The prototype has been characterized by measuring the gas gain, rate capability in current mode with an 5.9 keV X-rays (local irradiation, ~1cm² spot).

A shift of ~ 25 V has been measured between the two sectors probably due to the different geometry of the amplification stage (to be confirmed with microscope check – left/right asymmetry)
Ageing test: GIF++

**GE1/1 CMS chamber** operation stability up to gain = 20 000 $\leftrightarrow$ $\Delta V = 550$ V

$I(g=4000) \sim 5$ nA/cm$^2$ corresponding to an equivalent mip rate of $\sim 60$-$90$ kHz/cm$^2$ evaluated on sectors #3

**High Rate chamber** operation stability up to gain = 10 000 $\leftrightarrow$ $\Delta V = 600$ V

$I(g=4000) \sim 10$ nA/cm$^2$ corresponding to an equivalent mip rate of $\sim 250$ kHz/cm$^2$
Detector scheme vs particle flux

Qualitatively: low resistivity $\rightarrow$ pad r/out $\&$ higher rate

high resistivity $\rightarrow$ strip/pixel r/out $\&$ lower rate
GE2/1 μ-RWELL preparation

Once validated the mechanics, the plan is to build a full scale GE2/1 μ-RWELL with M4 operating sectors.

1) M4 left and right are mirrored.
2) Size: 606.5 x 498.5 x 1 mm
3) Strip layout inspired to the GE2/1 GEM option
4) Final drawing ongoing (Gatta-LNF)
5) DLCed foils almost ready (Ochi-Kobe)
6) Preliminary tests at ELTOS done
GE2/1 μ-RWELL: mechanical studies

A very large μ-RWELL with the dimensions close to the GE2/1 chamber is going to be realized at LNF, in collaboration with INFN-BA and INFN-BO with M4 operating detectors. The dimensions of the chamber suggest preliminary studies on the mechanical aspect of the project.

The active volume is limited by two honeycombed panels, which composition has been validated by ANSYS simulations. The largest deformation (0.78 mm) at 8 mbar has been obtained with 3 mm thick honeycomb glued between two 1 mm thick fiberglass skins with the presence of 10 pillars.

After these results:
- the thickness of the honeycomb increased up to 4 mm
- the number of pillars in the active volume increased to 12
- Expected maximum deformation: < 0.2 mm per panel (5 mbar) → < 10% on conversion drift gap

Courtesy of M. Melchiorri (INFN-FE)