Small-pad resistive Micromegas
Comparison of patterned embedded resistors and DLC based spark protection systems

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for the “Small-pad micromegas” R&D Collaboration
(INFN Italy and CERN)

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Small Pads Resistive micromegas

**GOAL:** Development of Resistive Micromegas detectors, aimed at operation under very high rates $\sim 10 \text{ MHz/cm}^2$

- **R&D BASIC STEPS:**
  - Optimisation of the spark protection resistive scheme
  - Implementation of Small pad readout (allows for low occupancy under high irradiation)

- From existing R&D (see acknowledgement) we aim at reducing the pad size from $\sim 1\text{cm}^2$ to $< 3\text{mm}^2$.

- Possible application: ATLAS very forward extension of muon tracking (Large eta Muon Tagger – option for future upgrade), Muon Detectors at Future Accelerators

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**Layout of the small size prototypes:**

- Matrix of 48x16 pads
- Each pad: **0.8mm x 2.8mm** (pitch of 1 and 3 mm in the two coordinates);
- Active surface of **4.8x4.8 cm$^2$** with a total of 768 channels
Two different implementations of the Resistive layer

Two series of small pad resistive micromegas prototypes built so far with pad dimension 3 mm². The two series differ for the implementation of the resistive protection system against discharges:

**Side view of SERIES 1 prototype:**
PAD-Patterned resistive layer (screen printing)

- Pad size: 0.8x1.8 mm²
- Pitch: 1x3 mm²

**Side view of SERIES 2 prototype:**
Double DLC (Diamond Like Carbon) uniform resistive layer a’ la uRWell (see G. Bencivenni et al. 2015_JINST_10_P02008)

- Copper readout Pads
- One connection to ground through vias from top and internal DLC layers
- Grounding vias every 6 mm
- Grounding vias every 12 mm

**2 Prototypes tested with different DLC Foils:**
- High ~50-70 MOhm/sq (DLC50)
- Low 20 MOhm/sq (DLC20)
Characterization of the detectors

Measurements with sources and X-rays

Two radiation sources have been used:

- $^{55}$Fe sources with 2 two different activities
  - "Low activity" (measured rate ~1 kHz)
  - "High activity" (measured rate ~100 kHz)
- 8 keV X-rays peak from a Cu target with different intensities varying the gun excitation current

Gain measured with different methods

- Reading the detector current from readout pads OR from the mesh with a picoammeter and counting signal rates from the mesh
- Signals amplitude (mesh) from a Multi Channel Analyser

At High Rates (with X-Rays):

- Rates measured at low currents of the X-Ray gun
- Extrapolating Rate Vs X-Ray-current when rates not measurable reliably anymore

Gas mixture: Ar:CO$_2$ 93:7
### Comparison of different configurations

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In the following:

- All detectors tested with Ar/CO2 93/7, and Vdrift = 300 V; The drift gap is 5 mm
- Detectors Comparison at **High rates** done with SAME GAIN conditions
  - PAD-P HV = 527 V
  - DLC20 HV = 510 V
  - DLC50 HV = 504 V
  
  \[G \sim 8000\] (at 100kHz)
Reduction vs time of the detector current with High intensity $^{55}$Fe source [CHARGING-UP]

Gain reduction ~30% up to 12 MHz/cm$^2$ [CHARGING-UP + Ohmic Voltage Drop]

Gain drop increases as rate goes up. Still able to reach gain of $4 \times 10^3$ at a rate of 150 MHz/cm$^2$ of 8 keV photons

Modest Energy resolution

TEST-BEAM spatial resolution along the “precision coordinate” (1mm pad-pitch) ~190 $\mu$m
PAD-P vs DLC – Charging-up effect

Current measurement Vs Time with X-Rays on/off and increasing rate (X-Ray current) at each step

- PAD-P response compatible with dielectric charging-up of exposed Kapton surroundings the resistive pads
- DLC detectors (both DLC20 and DLC50) do NOT show any charging-up effects (expected from the uniformity of the resistive – no exposed dielectric, with the exception of the pillars)
PAD-P vs DLC – Energy Resolution

PAD-P
HV = 530 V

DLC50
HV = 520 V

FWHM
Peak = 29%

DLC prototypes have much better energy resolution
• more uniform electric field
• no pad border effects
Exploring the High rates
PAD-P, DLC20-6mm, DLC50-6mm

X-rays Exposure area 0.79 cm² (shielding with 1cm diameter hole)

DLC20-6mm shows a significantly better behaviour than DLC50-6mm (LOWER RESISTIVITY)

PAD-P below DLC for rates < 10 MHz/cm² (charging-up+Ohmic drop)

PAD-P and DLC20-6mm have a comparable behaviour in the explored region (up to ~90 MHz/cm²)

- Similar voltage drop

As expected DLC20 better than DLC50 (due to lower resistivity)
High Rates – PAD-P vs DLC50-6-12mm

X-rays Exposure area 0.79 cm² (shielding with 1 cm diameter hole)

No significant differences among PAD-P and DLC50 below 10 MHz/cm²

PAD-P: still a good behaviour up to ~100 MHz/cm²

DLC-50:
- Onset of voltage drop due to high current/high resistance.
- Clear difference between the regions with 6mm and 12 mm grounding vias pitch
Dependence on the exposed area

PAD-P X-rays exposure area 0.79 cm$^2$ and 12 cm$^2$

PAD-P: Response to illumination on 0.79 cm$^2$ and on 12 cm$^2$ does not show any significant difference up to the measured limit of ~8 MHz/cm$^2$

(total current was ~18 uA, close to the limit of the power supply)
Dependence on the exposed area

DLC50-6mm X-rays Exposure Area: 0.07, 0.79, 3.61 cm²

DLC50-6mm: December 2018 DATA (HV = 520 V)

- Clear indication of dependence on irradiated area above few MHz/cm²
Dependence on the exposed area

DLC50-6mm X-rays Exposure Area: 0.07, 0.79, 3.61, 12 cm²

- Clear indication of dependence on irradiated area above few MHz/cm²
- No significant difference between 0.79 cm² and 12 cm² up to the measured limit of ~700 kHz/cm²
- Measured range limited by onset of discharges

Unfortunately, due to discharges, no data for DLC20
Test Beam

SPS H4 CERN 2016, 2017 and October 2018
Spatial Resolution and cluster-size

Position resolution:
difference between the cluster position and the extrapolated position from external tracking chambers.

![Graph showing position resolution vs HV amp for DLC20, DLC50, and PAD-P]

Precision coordinate (pad pitch 1 mm)
Significant improvement of spatial resolution on the DLC prototypes (pad charge weighted centroid)
- More uniform charge distribution among pads in the clusters

Unbiased Residuals of DLC20 at 510 V

\[ \sigma_{\text{resol}} = \sqrt{\sigma_{\text{resid}}^2 - \sigma_{\text{track}}^2} \]

\( (\sigma_{\text{track}} \approx 50 \, \mu m) \)

Cluster-size for all prototypes vs HV

- Larger Cluster size for DLC due to uniform layer.
  Larger clusters for lower resistivity (DLC20 Vs DLC50)
# Comparison of patterned embedded resistors and DLC based spark protection systems

## Summary

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<td><strong>Energy Resolution</strong></td>
<td>40-50 %</td>
<td>better than 30%</td>
</tr>
<tr>
<td><strong>Spatial Resolution</strong></td>
<td>~190 µm</td>
<td>~70 – 90 µm. Improves with lower resistivity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(at the price of larger cluster size → higher occupancy)</td>
</tr>
<tr>
<td><strong>RATE CAPABILITY</strong></td>
<td>Charging-up: dominates the reduction of gain (~20%) above tens kHz/cm²</td>
<td>No evidence of charging-up on DLC</td>
</tr>
<tr>
<td>&lt;1 MHz/cm²</td>
<td>• Good. Gain Drop of 20-30% due to charging-up + Ohmic Voltage drop</td>
<td>• Good. Best for low resistivity and finer pitch grounding vias</td>
</tr>
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<td>• No Dependence on size of the exposed area</td>
<td>• No dependence on the size of exposed area (in all configuration tested)</td>
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<td>1-10 MHz/cm²</td>
<td>• OK and approximately linear with rates</td>
<td>• DLC20-6mm VERY GOOD linearity</td>
</tr>
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<td></td>
<td>• No Dependence on size of the exposed area</td>
<td>• Dependence with exposed area strongly depends on resistivity and grounding vias pitch – DLC50 shows a clear dependence – DLC20-6mm was not tested on large area</td>
</tr>
<tr>
<td>~100 MHz/cm²</td>
<td>• Excellent ! Gain drop still within 30% at 100 MHz/cm² Don’t expect dependence with size (not tested due to the very high current)</td>
<td>• Significant drop for the high resistivity (DLC50)</td>
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<td>• Excellent for DLC20 in the fine pitch vias region (6mm) ...but NEED to test DLC20-6mm dependence with exposed area</td>
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<td><strong>ROBUSTNESS</strong></td>
<td>• Very Good! No discharges observed in all tests done</td>
<td>• Local defects caused discharges preventing us fully comprehensive tests → to be optimised (see next slide)</td>
</tr>
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Next steps

So far very satisfactory results to identify and optimise a small-pad micromegas detector to adapt to different (high rates) end uses.

For very high rates (10-100 MHz/cm²) the patterned embedded resistor detector has been proven to give excellent results, with no dependence on the exposed area.

Very promising results for DLC20-6mm → Not fully tested due to discharges

Defects were localised on the silver vias, not perfectly covered by the pillars.

→ Next R&D step must focus on robustness:

  New prototype in “configuration DLC20-6mm” made with PCB standard SBU (Sequential Build technique),
  taking advantage of the now available copper-clad DLC foils
  • Improves precision of vias
  • Reduces size
  • Improves overlap with pillars

→ In parallel we are making (slow) good progress with the detector with integrated electronics:

  Prototype with integrated electronics on the back-end of the anode PCB to solve the problem of the signal routing when scaling to larger surface.
Prototype with integrated electronics on the back-end of the anode PCB built to solve the problem of the signal routing when scaling to larger surface.

- APV FE Layout implemented

First tests look promising:

- Nice Pedestals structure and signal response from APV using Fe55 source and random trigger for DAQ → BUT ONLY on some channels

- We know the reason (issue in the elx Layout → fixing it in the next proto !)
THANK YOU!

MANY THANKS TO:

CERN RD51 Collaboration for the continuous support and the CERN GDD Lab for MPGD tests.

R. De Oliveira, B. Mehl, O. Pizzirusso and A. Teixeira (CERN EP-DT)

R&D based on previous developments of Pad micromegas for COMPASS and for sampling calorimetry:

• C. Adloff et al., “Construction and test of a 1x1 m² Micromegas chamber for sampling hadron calorimetry at future lepton colliders” NIMA 729 (2013) 90–101.


DLC double resistive layer configuration re-arranged from micro-Resistive Well R&D:


• M. Poli-Lener “The μ-RWELL detector for the the phase 2 upgrade of the LHCb Muon System Upgrade” ICHEP 2018 (PoS forthcoming publication)
BACKUP
Figure 1. *Left: schematic view of the detector. Right: picture of detector anode.*
Dependence on the irradiated area

DLC20-12mm: December 2018 DATA (HV = 520 V)
Test Beam SPS H4 at CERN – SETUP

SPS H4 CERN 2016, 2017
Beam: muons/pions 150 GeV/c (low/high rates)
- Prototypes Tested:
  - PAD-P, DLC50

(see M.Alviggi, et al. JINST 13 (2018) no.11, P11019)

SPS H4 CERN OCTOBER 2018
Beam:
- 1st period: muons/pions 150 GeV/c
- 2nd period: pions 80 GeV/c
- Prototypes Tested:
  - DLC20, DLC50

OCTOBER 2018 SETUP: Chambers under test: DLC50 (50-70 MOhm/sq), DLC20 (20MOhm/sq), ExMe
- Tracking system: 2 Tmm strips micromegas (x-y readout) for external tracking
- Operating gas on DLC20, DLC50: Ar:CO2 93:7
- Gas studies on ExMe: Ar:CO2 93:7 and 85:15 – Ar:CO2:iso 88:10:2
- Scintillators for triggering
- DAQ: SRS + APV25 with custom DAQ

(Poster Maxence Vandenbroucke)
Cluster Efficiency of DLC50 @ 500 V
Vs extrapolated track impact position

- Inefficiencies are clearly seen in correspondence of pillars.
- These inefficiencies decrease with HV

“Cluster” and “software” efficiencies for DLC20 Vs HV

- “cluster”: any cluster found in the detector
- “software”: within 5\(\sigma\) (<1mm) from the track
- “loose” within 1.5 mm

Differences at the level of 1% still under investigation.
Possible causes:
different gains, different charge spread and cluster-size, ...