Pixelated Resistive Micromegas for Tracking Systems in High Rate environment

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Resistive Micromegas:

Now a mature technology for HEP experiments also taking advantage of the intense phase of R&D for the ATLAS Experiment were resistive strips MM will be employed in the New Small Wheel upgrade of the Muon Spectrometer (see talks by Ivan Gnesi and P. Tzanis)

- Resistive anode strips → suppress the intensity of discharge
- Large area: total surface of ~1200 m2 of gas volumes
- Operation at moderate hit rate up to ~15 kHz/cm² during the phase of High-Luminosity-LHC
GOAL:
Development of Resistive Micromegas detectors, aimed at operation under very high rates 10’s MHz/cm²

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 ~1cm² to < 3mm².
• Possible application: ATLAS very forward extension of muon tracking (Large eta Muon Tagger – option for future upgrade), Muon Detectors and TPC at Future Accelerators, …
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Keywords:
- Rate capability (10’s MHz/cm²)
- Low occupancy → high granularity (pad readout $\mathcal{O}(\text{mm}^2)$)
- Spatial resolution (depending on applications) ~100 µm
- Robustness
Layout of the small size prototypes

- Matrix of 48x16 pads – 768 channels
- Each pad: 0.8mm x 2.8mm - pitch of 1 x 3 mm²
- Active surface of 48x48 mm²
Two different implementations of the Resistive layer

Two series of small pad resistive micromegas prototypes built so far with **pad dimension 3 mm**. Different implementation of the resistive protection system against discharges:

**PAD-Patterned resistive layer**

- Embedded resistors by Screen-Printing
- Resistive pads by paste filling of photoimaging created vessels
- Each pad is totally separated from the others, for the anode, as well as for the resistive part

**Double DLC (Diamond Like Carbon)**

- Uniform resistive layer
- (pillars are superimposed on the vias)

- Same concept of uRWell (see G. Bencivenni et al. 2015_JINST_10_P02008)
- Double DLC layer with connection vias to ground every “few” mm
PROTOTYPES

PAD-P: Embedded resistor
• mean value of the embedded resistors ≈ 3-7 MΩ

DLC20, DLC50: ‘standard’ DLC, sputtered on kapton
• surface resistivity 20 MΩ/□ (DLC20)
• surface resistivity 50-70 MΩ/□ (DLC50)
• two regions, with conductive vias every 6 and 12 mm

SBU1, SBU2: Sequential Build Up of DLC foils copper cladded on both sides
• easier photolithographic construction process
• improving of the alignment of vias and centering of the pillars with the silver vias (every 6 mm)
• for both prototypes: 1st layer (nearest to the pads) resistivity 35 MΩ/□, 2nd layer 5 MΩ/□ (lower than requested)
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 measurement methods:

- Reading the detector current from the mesh (or from the readout pads) 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

Chosen as the safest gas to operate under high irradiation for long time
Current measurement Vs Time during cycles of X-Rays irradiation

- PAD-P response compatible with dielectric charging-up of exposed Kapton surroundings the resistive pads
- DLC detectors do show any sizable 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 = 48%

DLC prototypes have better energy resolution
• more uniform electric field
• no pad border effects
Gain Vs rates up to 30 MHz/cm²

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

**PAD-P:**
- Significant gain drop at “low” rates dominated by charging-up effects
- Relative drop ~20% at 20 MHz/cm² at 530 V
- Negligible ohmic voltage drop for the individual pads for rates > few MHz/cm²

**DLC20:**
- Significant ohmic voltage drop for rates > few MHz/cm² (relative drop ~20% at 20 MHz/cm² at 510 V)
- Gain DLC20 > PAD-P. Same gain if HV PAD-P = HV_DLC + (20-30) V
High irradiation with X-rays – Rate Capability

COMPARISON done at a gain of ~6500

X-rays Exposure area 0.79 cm$^2$ (shielding with 1 cm diameter hole)

The rate region < 10 MHz/cm$^2$

DLC20 and SBU show a significantly better behaviour than DLC50 (expected from the low resistivity)

PAD-P below DLC for rates < 10 MHz/cm$^2$

(charging-up + Ohmic drop)
DLC20 and SBU show a significantly better behaviour than DLC50 (expected from the low resistivity)

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

PAD-P, DLC20, SBU have a comparable behaviour in the explored region (up to ~100 MHz/cm²)
As expected DLC20 better than DLC50 (due to lower resistivity)
Dependence on the grounding vias pitch

**DLC-50:**
- Onset of ohmic voltage drop due to high current/high resistance.
- Clear difference between the regions with 6mm and 12 mm grounding via pitch.

**COMPARISON** done at a gain of ~6500

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

Mesh Curr per unit area (uA cm⁻²)

- DLC50-6mm exposure area 0.79 cm²
- DLC50-12mm exposure area 0.79 cm²
- PAD-P exposure area 0.79 cm²

Ext rate per unit area (Hz cm⁻²)

0 20 40 60 80 100 120 140 ×10⁶

0 2 4 6 8 10 12 14 16 18 20

DLC50-6mm

DLC50-12mm

PAD-P

X-rays Exposure area 0.79 cm² (shielding with 1cm diameter hole)
**Dependence on the exposed area**

**PAD-P:**
- Thanks to independent pads there is no dependence on the exposed area

**DLC:**
- Dependence of gain on the irradiated area above ~5 MHz/cm²
- The gain drop do not scale for areas > 3.7 cm² - i.e. when the exposed area is >> cell dimension of grounding vias (0.36 cm²)
Test Beams at CERN and at PSI

### Typical Test Setup:
- Two small scintillators for triggering
- Two double coordinate (xy) bulk strips micromegas ($10 \times 10 \text{ cm}^2$) for tracking
- Small-pads MM in between
- gas mixture: $\text{Ar/CO}_2=93/7$ pre-mixed
- DAQ: SRS+APV25
Spatial Resolution and cluster-size (TB CERN)

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

Position resolution:
Cluster residual wrt extrapolated position from external tracking chambers.

![Graph showing position resolution](image)

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

![Graph showing precision coordinate](image)

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

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

Cluster-size vs HV
- Larger Cluster size for DLC due to uniform layer. Larger clusters for lower resistivity (DLC20 Vs DLC50)

![Graph showing cluster-size vs HV](image)
Test-beam at PSI (analysis ongoing)

• Main purpose was to test the stability under a high intensity particle flow
• Unfortunately our setup could only be placed far downstream → Max flow was few MHz on the full area (about 25 cm²) of our detectors

→ Preliminary studies on gain and stability;
  Analysis on tracking in progress

Gain estimated from the detector current (mesh)
• The measurements with pions confirmed the previous results with 55Fe/X-rays on the difference of gains PAD-P Vs all DLC’s

(93:7)%Ar:CO₂

129.6 kHz/cm²
126 kHz/cm²
108.4 kHz/cm²
104.7 kHz/cm²

Gain estimated from the detector current (mesh)
• A part of the test beam was dedicated to DLC and PAD-P spark studies

• Spark rates and probabilities evaluated as a function of HV settings and at constant rates of about 100 kHz/cm²

• PAD-P prototype confirm its very high stability

• DLC20 is the most robust among the DLC series, despite to the constructive improvement of SBUs

• Possibly due to the low resistivity of the TOP DLC layer (5 MΩ/□ instead of the required 20 MΩ/□)
PAD PATTERNED and DLC based resistive scheme have been compared in similar conditions:

Gas mixture (possibly not the best) chosen to be on the safe side for ageing: Ar/CO2 93/7

Comparison in similar conditions: \( \text{GAIN} \sim 6500 \sim 7000 \) (most of the measurements with X-rays \( \rightarrow \) ionisation \( > > \) MIP)

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### PAD PATTERNED PROTOTYPE

- Quite significant charging-up that nevertheless saturate at \( \mathcal{O}(1\text{MHz/cm}^2) \)
- \(~20\%\) gain drop at 20 MHz/cm\(^2\)
- No dependence on the irradiated area
- Very stable up to gains \( >> 10^4 \)
- Degraded performance on energy and spatial resolution compared to DLC
- A new prototype has been built and is currently being tested for further checks of the results

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### DLC PROTOTYPES

Best performance with the “low resistivity” DLC (~20 M\(\Omega/\square\)) and with fine network of grounding vias (~6 mm)

- Gain reduction with rates dominated by ohmic voltage drop
- Gain reduction is \(~20\%\) at 20 MHz/cm\(^2\) when irradiated on a 1 cm spot (as for PADP); it increases to \(~30\%\) for larger areas.
- Excellent energy and spatial resolution
- Robustness not yet at the level of PAD-P \( \rightarrow \) the DLC-SBU technique promising but not yet conclusive
THANK YOU!

Micromegas

μRWell
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 phase 2 upgrade of the LHCb Muon System Upgrade” ICHEP 2018 (PoS forthcoming publication)
BACKUP
Next Step: the prototype with Integrated Electronics

- 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!
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

FWHM $< E >$ ~40%

TEST-BEAM spatial resolution along the “precision coordinate” (1mm pad-pitch) ~190 µm
SCAN in Ampl. voltage @ Low rates < 0.3 MHz/cm²

Gain measurement in RD51 LAB: with $^{55}$Fe and Xray(Cu target) sources and 0.79 cm² exposed area, (93:7)%Ar:CO₂

- To set the working amplification voltages for which the detectors have the same gain at low rates

The ohmic voltage drops on the resistive layers are negligible in this range while the charging-up effects are already visible in PAD-P prototype at high gain

PAD-P require an amplification voltage + (20-30) V respect to DLC20
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
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:
• 1\textsuperscript{st} period: muons/pions 150 GeV/c
• 2\textsuperscript{nd} period: pions 80 GeV/c
• Prototypes Tested:
  DLC20, DLC50

OCTOBER 2018 SETUP: Chambers under test: DLC50 (50-70 MOhm/sq), DLC20 (20MOhm/sq), ExMe
  o Tracking system: 2 Tmm strips micromegas (x-y readout) for external tracking
  o Scintillators for triggering
  o DAQ: SRS + APV25 with custom DAQ
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 5σ (<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, ...