Small-pad Resistive Micromegas for high rate applications

Speaker: Alessia Renardi
“High $\eta$ muon tagger” for the ATLAS experiment at CERN;

“Small-pad Resistive Micromegas” prototype;

Gain measurements as function of the amplification field, using $^{55}$Fe sources;

Alternative gain measurements as function of the X-ray rate, using the SRS system;

Estimates of detector efficiency and spatial resolution from test beam data analysis, using pions.

All measurements have been carried out in the GDD laboratory of the R&D 51 collaboration at CERN.
High $\eta$ muon tagger for ATLAS

ATLAS Phase II Upgrade (HL-LHC 2024)

Pseudorapidity $\eta = -\ln(\tan \theta/2)$

$\eta = 4 \quad \rightarrow \quad \theta = 0.5^\circ$

$\sim 25\text{cm}$ from the beam line

REQUESTED FEATURES:
- high granularity (few mm$^2$);
- performance at high rate (> 10 MHz/cm$^2$);
- spatial resolution about 100$\mu$m
Resistive strip Micromegas

Micro Mesh Gaseous Structure

OPERATION

TRANSPARENCY: part of electrons which gets through the mesh plane ($\propto E_{\text{ampl}}/E_{\text{drift}}$)

GAIN: ratio between the number of avalanche's electrons and the number of primary ionization electrons

ELECTRIC FIELD LINES

CONVERSION GAP (3mm)

AMPLIFICATION GAP (100µm)

93%Ar+7%CO₂
NEW PROTOTYPE:
Small-pad pattern with an embedded resistor between the resistive and the readout pads. It could be part of Phase II upgrade.

SECTION VIEW
The layout is composed by:
I black layer: resistive pads;
II black layer: embedded resistors;
Brown layer: kapton foils;
Grey area: conductive silver paste;
Yellow layer: readout pads.
Path of the collected electron

TOP VIEW
Readout channel mapping. Matrix of 48x16=768 pads (1x3)mm² each one, (5x5)cm² active area.
Gain measurement: $^{55}\text{Fe}$ sources

$^{55}\text{Fe}$ sources:
- low intensity (3.28 MBq in 2011)
- high intensity (1.1 GBq in 2012)

$G = \frac{I[A]}{e \cdot n_p \cdot R[Hz]}$;

Difference of ~20% between the sources

CHARGING UP EFFECT:
Part of the avalanche’s electrons is deposited on the dielectric plane between the resistive pads (200µm) and they can’t evacuate towards the ground. A localized charge effect is created and the electric field looks less intense.
Gain measurements: X rays

OPERATION

The linear trend is respected only for the first points. The saturation is due to the dead time of the electronic instruments used in the setup. The other ones are extrapolated by a linear fit:

\[ \text{Rate} = p_0 + p_1 \cdot I_{X\text{ray}} \]

The tube provides for X-ray at 8keV

The chamber has been placed orthogonal to the X ray beam
Gain measurements: X rays

A collimator (3mm) and a layer with 10mm opening have been used in order to change the rate/cm² and to vary the hit area.
SRS has been used to know the signal (charge, time, position) of each hit pad.

The SRS trigger is provided by a discriminated signal from the mesh plane. Collected signals are correlated with the trigger.
Beam profile

Pads hit by the X-ray beam, using layer with 10mm opening, 3D and 2D views
Cluster algorithm

REQUESTS

SPATIAL ONE: starting from the most energetic hit pad, eight closest pads to it are controlled;

TEMPORAL ONE: the time of the pad is distant or less of 50ns from the cluster mean time, or less of 25ns from the next pad.

Example of clusters built in the same event

\[ T_{\text{max}} - T_{\text{min}} \] distribution for each cluster

- **RED**: spatial and temporal requests
- **BLUE**: spatial request

100ns: drift time in 5mm
High rate calculation with X rays

Alternative method to calculate the rate

\[ R = \frac{A}{25ns \cdot nbins \cdot T} \]

A: entries in the selected area;
25ns: temporal size of each bin;
Nbins: bin number included in the range;
T: trigger number in all the run (number of events)

Distribution of the cluster mean time, weighted to the charge

The range has been chosen into the histogram tail to analyse only uncorrelated signals with the trigger.

Alternative method to calculate the rate

correlated events with the trigger

The range has been chosen into the histogram tail to analyse only uncorrelated signals with the trigger.
High rate calculation with X rays

HV = 490V - 690V – layer with 10mm opening

SYSTEMATIC ERROR AT THE $R_{SRS}$

Introduced by the choice of the temporal request in the cluster algorithm

Gain versus Rate/cm²

\[ G = \frac{I[A]}{e \cdot n_p \cdot R[Hz]} \]
Test beam: resolution and efficiency

Pions at 500GeV provided by the SPS@CERN

SETUP USED FOR THE MEASUREMENTS:
- two scintillators which provide the trigger signal;
- two strip Micromegas (TMM) used as external trackers;
- Paddy was placed in the middle.

LINEAR EXTRAPOLATION PROCESS IN 3D SPACE
Spatial resolution results

\[ \sigma_X = \left( \sigma_{X_{\text{residual}}}^2 - \sigma_{X_{\text{extrapolated}}}^2 \right)^{1/2} \]

Residual between the extrapolated point and the cluster in Paddy

Resolution in X view ~ 170μm (precision coordinate)
Spatial resolution results

\[
\sigma_Y = (\sigma_{Y_{\text{residual}}}^2 - \sigma_{Y_{\text{extrapolated}}}^2)^{1/2}
\]

Fermi-Dirac distribution

\[\sigma = D/\sqrt{12}\]

Resolution in Y view ~ 730μm
Detector efficiency

EFFICIENCY in 3σ from the extrapolated point

![Graph showing efficiency vs. rate (kHz)]
Saturation cut

Charge distribution of the single hit pad

Cut at 1650 ADC counts because of the ADC saturation peak

Entries 440781
Mean 579.3
Std Dev 617
Detector efficiency results

EFFICIENCY in $3\sigma$ from the extrapolated point

Studying a different criteria to analyze the saturated pad, without deleting the event
Conclusions

- Gain versus HV using $^{55}$Fe sources; stable values, about $10^3 \div 10^4$, are obtained.
- Gain versus rate/cm$^2$ using X ray beam and varying the hit area. Values about $10^3$ at $\sim 150$ MHz/cm$^2$ are obtained;
- Good agreement between the $R_{SRS}$ and $R_{fit}$, calculated by different ways, has been verified;
- The spatial resolution in x view is $\sim 170 \mu$m, in agreement with the precision coordinate requested in the “High $\eta$ muon tagger” project;
- The spatial resolution in y view is $\sim 730 \mu$m, because of the bigger size of the pad;
- The detector is efficient at 97% with a $\pi$ rate of 400kHz/cm$^2$. 
BACKUP
Paddy transparency
Charging up effect

From the MCA files:
~20% shift of the low source peak towards the right

From the picoammeter files:
Current reduction in about 20s

CHARGE UP:
Part of the avalanche’s electrons is deposited on the dielectric plane between the resistive pads (200µm) and they can’t evacuate towards the ground. A localized charge effect is created and the electric field looks less intense.
Charging up effect

Scan in the x way using X ray

Scan in the y way using X ray

~1mm  The width matches the pad size  ~3mm
Cluster algorithm

Number of clusters built for each event

Number of pad for each cluster

$T_{\text{max}} - T_{\text{min}}$ distribution for each cluster

**RED**: spatial and temporal requests
**BLUE**: spatial request
Detector efficiency

Residual in X view in Paddy

Closest cluster

Most energetic cluster

Entries 3658
$\chi^2 / \text{ndf}$ 157.9 / 47
Constant $279.6 \pm 6.1$
Mean $0.01139 \pm 0.00337$
Sigma $0.1953 \pm 0.0026$

Entries 3658
$\chi^2 / \text{ndf}$ 150.2 / 47
Constant $278.2 \pm 6.1$
Mean $0.01209 \pm 0.00335$
Sigma $0.1929 \pm 0.0026$

X_{EXTRAP} - X_{CLOSEST} [mm]

X_{EXTRAP} - X_{ENERGY} [mm]
Detector efficiency

Residual in Y view in Paddy

Closest cluster

Most energetic cluster

Fermi-Dirac function on the rising and falling side:

\[ f = (f_u \cdot f_d) + p_3 = \left( \frac{p_0}{1 + e^{-(x-p_1)/p_2}} \cdot \frac{1}{1 + e^{(x-p_4)/p_5}} \right) + p_3 \]

\[ \sigma = (p_4 - p_1)/\sqrt{12} \]

- \( p_0 \) normalization parameter
- \( p_1 \) and \( p_4 \) inflection point
- \( p_2 \) and \( p_5 \) from 10% to 90% for each side
- \( p_3 \) baseline
DLC prototype

\[ \chi^2 / \text{ndf} = 1.65 \times 10^5 / 5498 \]

- Constant: 154.2 ± 0.2465
- Mean: 3288 ± 0.8124
- Sigma: 439.5 ± 0.6834

\[ \chi^2 / \text{ndf} = 2.079 \times 10^5 / 5698 \]

- Constant: 155.4 ± 0.2852
- Mean: 3036 ± 0.8474
- Sigma: 403.2 ± 0.9343

MESH (bulk technique)

Pillars

DLC1
Top layer

DLC2
Internal layer

Copper readout Pads

One connection to ground through vias from top and internal DLC layers EVERY ~ 6x6 mm²