Performance of a 1 m$^2$ Micromegas Detector Using Argon and Neon based Drift Gases

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Working Principle of Micromegas

- MICROMEsh GAS detectors (Micromegas)
- electron drift region
- amplification region
- charge collection on resistive strips
- charge detection on readout strips by capacitive coupling

Centroid method: 
\[ x_{\text{cen}} = \frac{\sum_{\text{strips}} x_{\text{strip}} \cdot q_{\text{strip}}}{\sum_{\text{strips}} q_{\text{strip}}} \]

\[ \mu \text{TPC method: angle reconstruction} \]
\[ \Rightarrow \Theta = \arctan \left( \frac{1}{\text{slope}_\text{fit}} \times \frac{\text{pitch}}{v_{\text{drift}}} \right) \]
Micromegas under test
MDT reference Chamber
MDT reference Chamber
Trigger scintillators

- two Monitored Drift Tube (MDT) reference chambers
  ⇒ two reference tracks
- two trigger scintillator hodoscopes
  ⇒ second coordinate
  ⇒ segmentation of test Micromegas in 10 cm wide segments
- active area $9 \text{ m}^2$, $\Theta \in [-30^\circ, 30^\circ]$

⇒ investigation of the whole active area of the Micromegas
1 m² Micromegas Chamber

- **active area**: $0.92 \times 1.02$ m²
- **2048 electronic channels**
- **pitch**: 0.45 mm
- **amplification gap**: 128 µm
- **drift gap**: 5 mm
- **gas @ atmospheric pressure**
  - Ar:CO₂ 93:7 vol%
  - Ne:CF₄ 80:20 vol%
- **gas flux**: $\Phi = 8$ ln/h
- **16 APV25 front-end** boards à 57.6 mm (y - coordinate)
- **10 scintillators** à 100 mm (x - coordinate)

\[ \Rightarrow \text{subdivision of detector in } 16 \text{ APV } \times 10 \text{ scintillators} = 160 \text{ partitions} \]

The detector (L1) was provided by the MAMMA collaboration (CERN)
residual $\Delta y = y_{\text{measured}} - y_{\text{predicted}}$
fit distribution with Gaussian function $\Rightarrow \sigma_{\text{res}}$
variation of $E_{\text{drift}}$

**Ar:CO$_2$ 93:7 vol%**
- better spatial resolution for low $E_{\text{drift}}$
- due to smaller diffusion

**Ne:CF$_4$ 80:20 vol%**
- equal spatial resolution for all $E_{\text{drift}}$
- similar to Ar:CO$_2$ 93:7 vol%
  @ $E_{\text{drift}} = 200$ V/cm

**multiple scattering**
2 GeV: $\Delta y(z_{\text{MDT2}} = 0.5 \text{ m}) = 0.67 \text{ mm}$
$\Rightarrow \sigma_{\text{res}} > 0.45 \text{ mm}$

**120 GeV pions:** $\sigma_{\text{res}} \sim 90 \text{ \mu m}$ (CERN SPS H6)
Electron Transparency of the Mesh

simulation of transparency using Garfield++, ELMER and Gmsh:

- electron transparency $\neq$ optical transparency due to ratio between drift and amplification field
- transparency $> 95\%$ at low $E_{\text{drift}}$ for meshes with optical transparency $\approx 50\%$

MPV of pulse height distribution:

**Ar:CO$_2$ 93:7 vol%**
- low $E_{\text{drift}}$: slow electron drift $\Rightarrow$ integration time of readout not long enough
- high $E_{\text{drift}}$: low transparency

**Ne:CF$_4$ 80:20 vol%**
- similar as for Ar:CO$_2$ 93:7 vol%
- but higher transparency for high $E_{\text{drift}}$
3σ efficiency ($\Delta y < 3\sigma_{\text{res}}$):

- **Ar:CO$_2$ 93:7 vol%**
  - low $E_{\text{drift}}$: low efficiency due to integration time effect

- **Ne:CF$_4$ 80:20 vol%**
  - electron drift much faster for all $E_{\text{drift}}$
  - no integration time effect

**Ar:CO$_2$ 93:7 @ $E_{\text{drift}} = 400V/cm$**

**Ne:CF$_4$ 80:20 @ $E_{\text{drift}} = 400V/cm$**
Inhomogeneity of Drift Velocity

inclined muon tracks:

- drift gap deformation due to small overpressure (10 mbar)
- maximum deviation 0.8 mm from plane

⇒ 1.6 mm at drift cathode (stiff base plate support)
⇒ determination of drift velocity for each partition

measurement in CRF

Ph. Lösel (LMU)
μTPC Method - Angle Reconstruction

reconstruction of track angle
- drift velocity simulated with Magboltz
- strip pitch = 0.45 mm
- linear fit on (strip, \( t_{\text{drift}} \)) data points
  \[ \theta = \arctan \left( \frac{1}{\text{slope}_{\text{fit}}} \times \frac{\text{pitch}}{v_{\text{drift}}} \right) \]

capacitive coupling between strips

\[ \begin{align*} Q_{\text{strips}} & \begin{array} { c c c } s_1 & s_2 & s_3 \\ \end{array} \end{align*} \]

\[ \Rightarrow \text{needs correction for each strip and timebin} \]
Capacitive Coupling between Strips - LTspice Simulation

- simplified Micromegas, 3 resistive strips, network
- current pulse applied on middle resistive strip

\[ R_{xt} = 29\% \]

consequence:
reconstructed angle > real angle
**Angle Reconstruction with Charge Correction**

**Ar:CO₂ 93:7 vol%**
- calculation of $v_{\text{drift}}$ for each partition
- $E_{\text{drift}} \leq 300 \text{ V/cm}$: inhomogeneity of $v_{\text{drift}}$ too large within partitions
- $E_{\text{drift}} > 300 \text{ V/cm}$: good result

**Ne:CF₄ 80:20 vol%**
- good results for all $E_{\text{drift}}$
- better reconstruction of small angles for higher $E_{\text{drift}}$
Summary

- investigation of Micromegas in the Cosmic Ray Facility with different drift gas mixtures
  - Ar:CO₂ 93:7 vol%
  - Ne:CF₄ 80:20 vol%
- variation of \( E_{\text{drift}} \)
- equal spatial resolution with Ne:CF₄ 80:20 vol% for all \( E_{\text{drift}} \)
- homogeneous efficiency > 90% for \( E_{\text{drift}} \geq 200 \text{ V/cm} \)
- larger pulse height variation for Ar:CO₂ 93:7 vol% due to integration time effect and lower transparency
- simulation of capacitive coupling between strips of 29%
- good angle reconstruction with charge correction for Ne:CF₄ 80:20 vol% @ all \( E_{\text{drift}} \)
- improved algorithm for angular reconstruction and charge correction
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THANK YOU
Backup
Readout with APV25

- 128 preamplifier channels → Analogue pipeline buffer → Selected columns output

- 128 charge sensitive amplifier channels
- pipeline buffer of 192 cells depth for each input channel
- filled consecutively with every clock cycle
- blocks of one or more pipeline columns can be read out for each trigger
signal-rise fitted with \( q(t) = \frac{q_0}{1 + \exp\left(\frac{t_0 - t}{\Delta t}\right)} \Rightarrow t_0 \)

extrapolate starting point:

- straight line through: \(0.1 \times \text{Max}, 0.5 \times \text{Max} \) and \(0.9 \times \text{Max} \) of inv. Fermi function (\(\text{Max} \hat{=} \text{maximum of pulse height}\))
- extrapolate to \( t_s = t(q = \text{pedestal}) \)

\( \Rightarrow \) starting point: \( t_s = t_0 - \frac{\ln(81)}{1.6} \Delta t \)
correction in y (perpendicular tracks):
residual via centroid method:
\[ \text{res} = y_{\text{measured}} - y_{\text{predicted}} \]
\[ \Delta y = \text{res} \]

correction in z (inclined tracks):
\[ \Delta z = \frac{\text{res}}{\tan \alpha} \]
\[ \text{res} = m_y \cdot \Delta z \]
with \( m_y = \tan \alpha \)

fill a histogram
fit with a straight line
\[ \Rightarrow \Delta z = \text{slope} \]
\[ \Delta y = \text{intercept} \]

for each of the 160 segments
Charge Correction
due to capacitive coupling between strips

\[
\text{charge}(i) = \text{charge}(i) - 0.29 \cdot \text{charge}(i + 1) - 0.29 \cdot \text{charge}(i - 1)
\]

- cluster charge distribution for one timebin
- correct neighboring strips by coupling-effect-charge for each timebin
- neglect outer most strips if their charge is smaller than 29% charge of neighboring strip