Simulation of temperature dependence of avalanche properties of Resistive Plate Chambers.

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Contents:

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Geometry under Study

Trigger RPC

R. Cardarelli, R. Santonico,

- **Readout Strips (X)**
  - Insulator
  - Graphite Coating
  - High Resistivity Electrode
  - Gas Gap
  - High Resistivity Electrode

- **Readout Strips (Y)**

- **2mm gas gap**
- **2mm Bakelite, \( \rho \sim 10^{10} \, \Omega \text{cm} \)**
- **\( \text{C}_2\text{F}_4\text{H}_2/\text{Isobutane/SF}_6 \) 97/3/0.3**
- **\( \text{C}_2\text{F}_4\text{H}_2/\text{Isobutane/Ar} \) 75/10/15**
- **HV: 10kV ,8 kV**
RPC’s different modes of operation

1. Streamer (discharge)
   RPCs originally conceived to work on streamer mode (up to ~100 Hz/cm²).

2. Avalanche
   In experiments with high background and high hit rate up to ~1000 Hz/cm².
   RPCs will
RPC’s geometric configurations

- Single gap BABAR RPC
- Double gap BELLE & L3 RPC’s
- Multigap HARP RPC
Detector Physics of RPCs

1- Distance between Primary Clusters:

\[ \lambda = \frac{A}{\rho N_A} \frac{1}{\sigma_p(\beta)} \]

2- Cluster Size Distribution:

“These two can be obtained using the simulation program HEED”

3- Electron Multiplication

- Townsend \( \alpha \) and the attachment \( \eta \) coefficient

“These parameters + drift velocity can be calculated using the simulation program MAGBOLTZ”

- average number of electrons

\[ \frac{d\bar{n}}{dz} = (\alpha - \eta)\bar{n} \quad \Rightarrow \quad \bar{n}(z) = \exp((\alpha - \eta)z) \]
Detector Physics of RPCs

• avalanche multiplication is a stochastic process

The probability $P(n, x)$ for an avalanche started with a single electron to contain $n$ electrons after distance $x$ is defined by:

$$P(n, x + dx) = P(n - 1, x) \, (n - 1) \alpha \, dx \, (1 - (n - 1)\eta \, dx)$$

$$+ P(n, x) \, (1 - n\alpha \, dx) \, (1 - n\eta \, dx)$$

$$+ P(n, x) \, n\alpha \, dx \, n\eta \, dx$$

$$+ P(n + 1, x) \, (1 - (n + 1)\alpha \, dx) \, (n + 1)\eta \, dx.$$

Avalanche probability function

$$P(n, x) = \begin{cases} 
    k \frac{n(x) - 1}{n(x) - k}, & n = 0 \\
    \tilde{n}(x) \left( \frac{1-k}{\tilde{n}(x) - k} \right)^2 \left( \frac{\tilde{n}(x) - 1}{n(x) - k} \right)^{n-1}, & n > 0
\end{cases}$$

where

$$\tilde{n}(x) = e^{(\alpha - \eta)x}, \quad k = \frac{\eta}{\alpha}.$$  

variance $\sigma^2(x)$ of the distribution is given by:

$$\sigma^2(x) = \left( \frac{1 + k}{1 - k} \right) \tilde{n}(x)(\tilde{n}(x) - 1).$$
Detector Physics of RPCs

- The induced current $i(t)$ of $N(t)$ unit charges moving with velocity $v_D(t)$ at time $t$ is calculated using the weighting field formalism:

$$i(t) = \frac{E_w \cdot v}{V_w} e_0 N(t)$$

$$\frac{E_w}{V_w} = \frac{\varepsilon_r}{2b + d\varepsilon_r}$$

- The induced charge is calculated by integrating induced current through the gap.
Monte Carlo Avalanche Simulation

- Divide gas gap into several steps
- Create primary clusters

\[ P(x) = \frac{1}{\lambda} e^{-x/\lambda} \]

Mean free path \( \lambda \); cluster size distribution [HEED]

- Let electrons multiply and drift toward the anode.
- Avalanche development, calculated by means of Reigler formula. (NIM,500(2003) 144-162)
- Using central limit theorem for high \( N(t) \).

\[
\mu = n_i \bar{n}(\Delta x), \quad \sigma_\mu = \sqrt{n_i \sigma(\Delta x)}
\]

- Finally a comparison between \( N(t) \) and \( N_{\text{sat}} \ (5 \times 10^7) \) simulates space charge effect.

- Calculate Induced signals (current, charge spectrum and efficiency).
Simulation of RPC temperature dependence of avalanche properties

Townsend and attachment coefficients for four RPC gases (Ar, \( iC_4H_{10} \), \( C_2H_2F_4 \) and \( SF_6 \)) are calculated by Garfield at three ambient temperatures; 0°C, 20°C, and 40°C.

\[ \Delta \alpha(40/0) \text{ is } 10\%, 100\%, 79\%, \text{ and } 42\% \text{ for Ar, } iC_4H_{10}, \text{ C2H2F4, and } SF_6 \text{ in } 50 \text{ kV/cm electric field.} \]
Simulation of RPC temperature dependence (cont.)

- variations of Townsend and attachment coefficients for two different gas mixtures 
  $C_2H_2F_4/i-C_4H_{10}/SF_6 :: 96.7\%, 3\%, 0.3\%$ avalanche and $C_2H_2F_4/Ar/i-C_4H_{10} :: 75\%, 15\%, 10\%$ streamer gas.
Results of induced charge spectrum simulation:

- These results are related to a $g = 2\text{mm}$ gas gap RPC operated at 10 kV high voltage for the avalanche mode and at 8 kV for the streamer mode.
Calculating average number of avalanche electrons

• from simple formula \( n = n_0 e^{\alpha_{eff} g} \) (without any saturation effect)

• comparing it with \( n_{av} \) obtained by simulation:

<table>
<thead>
<tr>
<th>T (°K)</th>
<th>( \alpha_{eff} )</th>
<th>( n_{av} ) (calculation)</th>
<th>( n_{av} ) (simulation)</th>
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</thead>
<tbody>
<tr>
<td>Avalanche:</td>
<td></td>
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<tr>
<td>273</td>
<td>64.93</td>
<td>4.4 \times 10^5</td>
<td>4.04 \times 10^5</td>
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<tr>
<td>293</td>
<td>103.57</td>
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<td>7.5 \times 10^5</td>
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<td>313</td>
<td>141.12</td>
<td>1.8 \times 10^{12}</td>
<td>5.23 \times 10^8</td>
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<tr>
<td>Streamer:</td>
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<td></td>
</tr>
<tr>
<td>273</td>
<td>163.01</td>
<td>1.44 \times 10^{14}</td>
<td>2.85 \times 10^8</td>
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<td>293</td>
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<td>9.9 \times 10^{19}</td>
<td>4.65 \times 10^8</td>
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<tr>
<td>313</td>
<td>269.15</td>
<td>1.8 \times 10^{23}</td>
<td>6.43 \times 10^8</td>
</tr>
</tbody>
</table>
Results of efficiency simulation:

- Increase of temperature also increases the efficiency of RPCs as follows:
Experimental Results:

Fig. 8. (a) Efficiency vs. voltage at 19°C and 32.5°C. (b) Efficiency vs. corrected operating voltage.

Conclusions

- Theoretical simulation of RPCs.

- Induced signal strongly depends on the type of gas mixture.

- Temperature variation of avalanche characteristics of different gases simulated to study temperature dependence of RPC operation.

- Townsend coefficient with temperature depends on the gas type with iso-butane as the most temperature dependent gas and argon as the least one.

- Induced signal especially in avalanche mode operation of RPCs considerably increases with ambient temperature.

- Shift of efficiency plateau to lower voltages can be reproduced by our simulation.

- Dependency of resistivity on temperature has negligible effect on RPC operation.