RECENT EXPERIMENTAL RESULTS AND DEVELOPMENTS ON THE RESISTIVE PLATE CHAMBERS FOR THE CMS EXPERIMENT

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for

the CMS-RPC collaboration
2 complementary and independent systems for a very redundant and robust muon detector:

- RPC → fast dedicated trigger detectors
- DT + CSC → wire chambers for precise muon $p_T$ measurement (also used in the trigger)
The chosen design:

The trigger is based on a pattern comparator algorithm.

Physics requirements for the RPC system:

- muon identification
- bunch crossing assignment (25 ns spaced b. x.)
- cut on the muon $p_t$
Expected rates and dose

Rate: 10 years accumulated charge: 10 years integrated dose:
up to 1 kHz 0.04 C/cm² gap (barrel) < 1 Gy (barrel)
< 10 Gy (endcap)

Recent experimental results on the RPC for the CMS experiment

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Required performance

Complete simulation study of the CMS trigger system

Efficiency and time resolution

$\varepsilon_{\text{RPC}} > 95\%$

$\sigma_{\text{RPC}} < 3\,\text{ns}$

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Required performance: cluster size and noise

The output rate of LV1 trigger on single muon events should stay below 10 kHz. Achieving this goal requires:

Cluster size < 2 strips  
Noise < 10 Hz/cm²

Recent experimental results on the RPC for the CMS experiment
A useful tool: Simulation of the RPC detector

Signal induction by Ramo theorem

Number of clusters per event
Primary cluster position
Number of $e^-$ per cluster (from experimental data)
Avalanche fluctuations
Spatial charge effects

Induced charge (efficiency and charge spectra)

Induced current (timing properties)

Convolution with Front End response

$q_{\text{ind}} \rightarrow n = n_0 e^{\eta x}$

$\lambda = \text{cluster density (cm}^2\text{)}$
$\eta = \text{first Townsend coefficient (cm}^4\text{)}$

indications on:
- gas type
- # gaps
- gap width

Recent experimental results on the RPC for the CMS experiment

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The shape of the charge spectrum is ruled by the $\lambda/\eta$ (primary ionization density/first effective Townsend coefficient).

A gas providing a higher cluster density ensures:

- Higher efficiency at the same gas gain
- Lower $\eta$ operation and, consequently, lower streamer probability

Freon based gas mixtures

Recent experimental results on the RPC for the CMS experiment
Simulation: number of gaps and gap width

The ratio induced charge/drifting charge is maximum in the double gap design → lower streamer probability

For a better time resolution:
- narrow gap
- high number of gaps
- high operating voltage

Recent experimental results on the RPC
for the CMS experiment

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The CMS design

- 2 mm double gap
- bakelite resistivity: 2-5 x 10^{10} \, \Omega \text{cm}
- bakelite thickness: 2 mm
- gas mixture: 97\% C_2H_2F_4
  + 2.5\% \text{iso-C}_4H_{10} + 0.5\% \text{SF}_6
- operating voltage: \sim 9 \, \text{kV}

Recent experimental results on the RPC for the CMS experiment
CMS environmental conditions:

- severe timing (25 ns b.x.)
- high rate (up to 1 kHz) mainly due to neutral particle fluxes
- long term operation (>10 years) under irradiation (up to 10 Gy)
- large chambers (up to 3 m²) covering an overall surface of 4000 m² with projective geometry

1. Very good overall performance on chambers of large dimensions mass produced in factories
2. High rate capability (avalanche mode operation and use of low resistivity bakelite)
3. Limited performance degradation with high irradiation dose
4. Necessity to study the detector sensitivity to neutral particles
5. Special detector geometry design for the endcaps
Experimental test on response uniformity

Large chambers studied over most of their surface with a low rate muon beam at the CERN H2 experimental area

10 cm²

2 mm double gap
surface: ~2 m²
use of beam chambers

Results
• Efficiency
• Time properties
• Local and global performance

Recent experimental results on the RPC for the CMS experiment
Test on response uniformity: efficiency

The efficiency is only limited by the geometrical extension if the spacers (~1 cm²)

Recent experimental results on the RPC for the CMS experiment

Useful operating plateau: ~300 V
Test on response uniformity: timing

Corrected for the signal propagation

2 mm
HV=8.7 kV
\( \sigma=2.07 \text{ ns} \)

Time walk=1.3 ns/100V
Experimental test under high irradiation rate

GIF facility at CERN

CMS prototype; 2 mm double gap (2.4 x 1.24 m²)
- bakelite resistivity: 7 x 10¹⁰ Ω cm
- strip width: 2.5 cm
- gas mixture: 95% C₂H₂F₄, 4% iso-C₄H₁₀, 1% SF₆
Source: γ from 20 Ci ¹³⁷Cs (peak at 662 keV)
Results from single gap operation
TDC 2277 LeCroy common stop (64 μs buffer)
The rate is measured by means of the method of the exponential fit to the distribution of the time differences between consecutive clusters, ABS1 ~ 600 Hz/cm²

• ABS5 ~ 200 Hz/cm²

Cluster: number of adjacent strips fired in a 100 ns gate and with a maximum delay from the near one of 20 ns

Recent experimental results on the RPC for the CMS experiment
Efficiency and cluster size

98.5% HV=10.4 kV
95% HV=10.1 kV
93% HV=10.5 kV

- Cluster size < 2.3 strip
- Cluster with more than 7 strips < 5%

Recent experimental results on the RPC for the CMS experiment
Recent experimental results on the RPC for the CMS experiment

HV = 10.5 kV
Rate 540 Hz/cm²

ABS 1

σ < 1.6 ns

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Endcap chamber prototype (Korea)

Experimental area: GIF at CERN

CMS endcap prototype: 2 mm double gap (H=3.4 m; b=0.7 m; B = 1.35 m)

Bakelite resistivity: $2 \times 10^{10} \Omega \text{cm}$; strip width: 0.65 - 1.5 cm

Gas mixture: 95% C$_2$H$_4$F$_4$, 3.5% iso-C$_4$H$_{10}$, 1.5% SF$_6$

Source: $\gamma$ from a 20 Ci $^{137}$Cs (peak at 662 keV)

Investigated area: 10 x 10 cm$^2$

Efficiency and strip multiplicity

Time distribution

Recent experimental results on the RPC for the CMS experiment

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Aging and $\gamma$ sensitivity (low irradiation)

**Bari telescope**

- 2 mm double gap (1.3 x 1.2 m$^2$)
- Bakelite resistivity: $2 \times 10^{11} \, \Omega \, \text{cm}$
- Gas mixture: 95% $C_2H_2F_4$, 5% iso-$C_4H_{10}$
- Source: $\gamma$ from 15 mCi $^{60}$Co (two peaks at 1.17 and 1.33 MeV)
- 14 months irradiation time
- Cosmic muons

A simulation based on MCNP-4b has allowed to estimate:

- Total dose = 1.6 Gy
- Total charge = 0.05 C/cm$^2$ gap
The high voltage is corrected for temperature and pressure:

\[ HV = HV_0 \left( \frac{P}{P_0} \right) \left( \frac{T}{T_0} \right) \]

Recent experimental results on the RPC for the CMS experiment
The sensitivity is obtained as:

\[
S = \frac{(R_{on} - R_{off})}{N_{\gamma}} = 1.84 \pm 0.1 \times 10^{-2}
\]

- \(R_{on}\): rate with source on
- \(R_{off}\): rate with source off
- \(N_{\gamma}\): number of photons reaching the chamber per second (from simulation)

Recent experimental results on the RPC for the CMS experiment

The value expected from the simulation for \(^{60}\)Co is:

\[
\frac{N_e}{N_{\gamma}} = 1.7 \times 10^{-2}
\]
GIF facility at CERN

- 2 mm double gap (1.2 x 0.7 m²)
- bakelite resistivity: 4 x 10¹¹ Ω cm
- gas mixture: 95.5%
  C₂H₂F₄  3% iso-C₄H₁₀  1.5% SF₆
- Source: γ from a 20 Ci ¹³⁷Cs (one peak at 662 keV)
- screening filters
- 7x10⁶ s total irradiation time
- muon beam

the simulation (MCNP-4b) allows to estimate:
- Total dose=20 Gy
- Total charge= 0.2 C/cm² gap
Efficiency and $\gamma$ sensitivity

Efficiency
(HV corrected for T and P)

No relevant changes in the efficiency plateau except at maximum irradiation ABS1 ~ 600 Hz/cm$^2$

Sensitivity measured at ABS100:

$$S = \frac{(R_{on} - R_{off})}{N_{\gamma}} = 0.8 \times 10^{-2}$$

The value expected from the simulation for $\gamma$ from $^{137}$Cs is:
$$N_e / N_\gamma = 0.7 \times 10^{-2}$$
Results from a simulation study based on GEANT interfaced to MICAP (below 20 MeV) and to FLUKA (above 20 MeV)

The sensitivity is obtained as the ratio $N_{\text{charged}}/N_e$

Future experimental tests at the nTOF facility at CERN!

Recent experimental results on the RPC for the CMS experiment
An extensive R&D program on the RPCs for the CMS experiment has been carried on in recent years. This program has led to the following conclusions:

- Large RPCs have proved to show sufficient response uniformity and good overall performance for use in CMS
- The RPC performance is not spoiled at high incident rates (up to 600 Hz/cm²)
- No relevant aging effects have been observed for periods comparable to LHC experiments lifetime
- New measurements on detector sensitivity to neutral particles have been done or are going to be done in the near future