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Performance of a prototype of the CMS central detector

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Abstract

A prototype of the barrel Tracking Detector of the Compact Muon Solenoid (CMS) experiment proposed for LHC was built and tested in a beam and in a magnetic field of up to 3 T. It contained six microstrip gas chambers, 25 cm long, and three double-sided silicon microstrip detectors, 12.5 cm long. We report some preliminary results on the performance of the chambers.

1. Experimental set-up

The test was performed in the H2 beam of the CERN SPS North Area, using 300 GeV/c μ^-. The trigger was generated by a coincidence of three scintillating counters, the smallest measuring 2×2 cm^2. The experimental set-up consisted of three double-sided silicon microstrip detectors and six microstrip gas chambers (MSGCs) mounted on an optical bench, 1 m long, and installed inside the 3 T superconducting EHS magnet. The magnetic field (B) direction was perpendicular to the beam; the field and beam directions defined a horizontal plane. The read-out strips were parallel to the B direction. This choice allowed the simulation of the conditions of the barrel tracking system of CMS [1]. The detectors were mounted in frames whose support allowed for rotation around an axis parallel to the strips, to compensate for the Lorentz angle of the drifting carriers. The readout electronics consisted of Preshape32 chips, preamplifiers and shapers [3] with a peaking time of 45 ns; all the channels were read in parallel due to lack of multiplexing. Coaxial delay cables carried the signal from the detectors to the analog-to-digital converters (LeCroy 2280). To contain the weight of

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the cables, the number of strips read out per chamber was limited to 128.

1.1. Detectors

A compilation of references on the operational principles and detailed studies on the MSGCs can be found in Refs. [1,2]. The chambers installed in the test set-up were of different types. Five chambers were manufactured by Baumer on a 300 μm-thick Desag 263 glass, with a bulk resistivity of 10^{15} Ω cm. The aluminium strips were 25 cm long; the anode to anode pitch was 200 μm, while the anode and cathode width were 9 μm and 74 μm respectively. The readout pitch was 200 μm. The drift volume was defined by a fiberglass spacer 3 mm high for four chambers and 2 mm high for the fifth one. The substrate of the sixth MSGC [4], 500 μm thick, was made of a glass (S8900[2]), with a bulk resistivity of 10^{12} Ω cm. The gold strips were 10 cm long; the anode and cathode, 100 μm apart, were 12 μm and 80 μm wide respectively. The glass spacer maintained a drift gap of 4 mm. The chambers were filled with different types of gas mixture: the results reported here have been measured using exclusively DME gas.

The three silicon detectors are described in Ref. [1] and were built using techniques relevant to high radiation environments [6,7]. The strip length was 6.25 cm on the p-side. The readout pitch was 50 mm with a p+ strip width of 14 μm. The n-side strip have not been used in the analysis reported here. The telescope consisted of the three silicon chambers followed by the 4 mm-gap MSGC, the four 3 mm-gap and the 2 mm-gap MSGC.

2. Data analysis

About 4 000 000 events were recorded and analyzed. The pedestal information was recorded in runs at a typical interval of a few hours. The pedestal of each strip is defined as the mean value of a Gaussian fit to the distribution. The noise is defined as the standard deviation of the fitted curve. The pedestal value is contributed for about $\frac{2}{3}$ of its value by the analog-to-digital converter: typical values are about 300 ADC counts for the MSGCs and 250 counts for the p-side strips. The average noise per strip, as defined above, is 29.2±4.1 for MSGCs and 18.5±5.2 for the p-side strips.

The events were reconstructed by a cluster finder followed by pattern recognition and fitting procedures. The MSGCs clustering algorithm requires that each strip in the cluster have a signal to noise ratio larger than 1.4 and that the cluster amplitude be 3 times larger than the average noise of a single strip. The cluster finder for the silicon detectors requires an initiator, defined by a tight threshold, and opens then a search on neighboring strips, with milder requirements; the cluster definition is corrected for common mode. The study of the algorithms will be found in Ref. [10]. The fitting procedure used in the absence of a magnetic field consists of a least-squares fit to a straight line. In presence of a magnetic field we used a circle fitting algorithm [8].

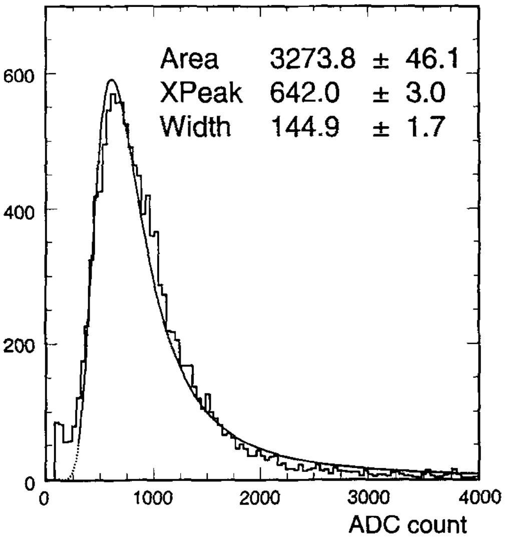

Fig. 1. Cluster amplitude distribution.

The chambers were "internally" aligned using iterative fitting procedures to center the residual distributions. The results reported in this paper focus on the study of the MSGCs; more extensive results will be found in Ref. [10].

2.1. Signal-to-noise ratio

The amplitude of the signal deposited in a gas detector is well described by a Landau function. The signal-to-noise will be characterized by the ratio of the most probable value of the Landau function to the average noise per strip, estimated on the strips participating in the cluster. The typical distribution of the cluster amplitude for a 3-mm gap MSGC is shown in Fig. 1. The solid line represents a Landau fit to the distribution. The average noise of the strips participating in the cluster is 29.3±1.0 ADC counts. The results are summarized in Table 1, where V_c and E represent the cathode voltage and the drift field, respectively.

Table 1
Signal to noise ratio in different conditions

Gap (mm)	V_c, E (V, kV/cm)	S/N
2	630/10.7	12.5±0.3
3	650/10.0	21.9±0.8
4	680/7.5	19.2±0.7

2.2. Spatial resolution

The resolution has been measured by studying the width of the residual distribution (R) in the chambers; for each detector the distribution is built storing the distance between the fitted track and the hit in the given chamber, when it has not been used to fit the track. In such condition, the standard deviation of R is well described by

$$\sigma(i) = \sqrt{\sigma_{\text{track}}^2(i) + \sigma_{\text{hit}}^2(i)},$$

where $\sigma_{\text{track}}(i)$ is the error on the track position at the ith chamber and σ_{hit} is the resolution to be measured. The pull distribution R/σ yields a standard deviation of 0.9978 and a mean of −0.03 for the estimated resolution. The results are summarized in Table 2.

A cross check has been done studying the pull

$$\frac{0.5[Y(i+1) + Y(i-1)] - Y(i)}{\sqrt{3/2}\sigma_{\text{hit}}},$$

where Y is the hit position in three chambers of the same type, set at equal distance from each other. This pull is independent from tracking errors and yields the same result.

The behavior of the resolution as a function of the magnetic field is shown in Fig. 2 when the chamber is filled with DME gas, $V_c = 650$ V and $E = 10.0$ kV/cm. The solid line is a parabolic fit to the data $(a_0 + a_1(x - a_3)^2)$. The tilt angle is $\theta = 8°$ and the minimum is reached for a value of the field B_{min} that causes a Lorentz angle $\alpha_L = \theta$. We measure $B_{\text{min}} = 2.5 \pm 0.2$ T, where the error is statistical. At the voltage condition specified above we measure a gradient $\alpha_L/B = 3.48 \pm 0.25° \text{T}^{-1}$.

It is of relevance to compare the performance of the detector at the compensation point to that observed at normal beam incidence when $B = 0$ T. The cluster amplitude distributions are alike and the resolutions are respectively 30 ± 1.1 μm and 32.7 ± 5.1 μm, where the second error is estimated from the fit parameters. The measurement shows the ability to recover the detector resolution degraded by the magnetic field effects.

2.3. Momentum measurement

The reconstructed momentum has been measured using the expression, $P[\text{GeV}] = 0.3B\ [\text{T}]/\rho\ [\text{m}]$, where ρ is the reconstructed track curvature.

Table 2
MSGC's resolution in different conditions

Gap (mm)	V_c, E (V, kV/cm)	Resolution (μm)
2	630/10.7	47±1.4
3	650/10	30±1.1
4	680/7.5	45±1.4

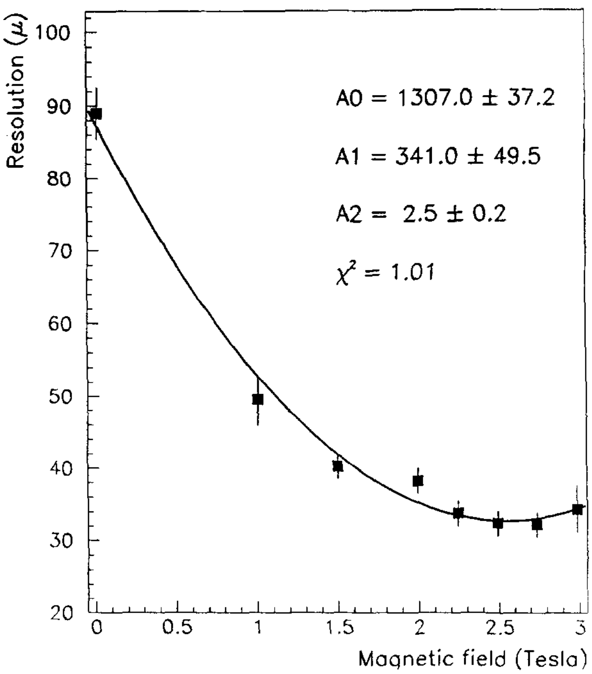

Fig. 2. Position resolution as a function of the magnetic field.

The MSGCs were filled with DME gas and operated at $V_c = 680, 650, 630$ V and $E = 7.5, 10.0, 10.7$ kV/cm for the 4, 3, 2-mm-gap detectors, respectively. The magnetic field was set at 3 T. The momentum distribution is well behaved and has a mean value of 300 ± 40 GeV/c. The momentum resolution $\delta P/P$ is shown in Fig. 3; parametrizing the momentum resolution as $\delta P/P = KP$, P in GeV/c, we measure $K = 4 \times 10^{-4}\ \text{GeV}^{-1}\ c$.

All the tracks with nine points fit have been used for this measurement.

It is of interest to extrapolate this result to the CMS detector configuration. A naive parametrization of the momentum resolution for a detector immersed in a magnetic field is given by [9]

$$\delta P/P = \frac{P\sigma_{\text{hit}}}{0.3qBL^2}\sqrt{\frac{\text{const.}}{M+6}},$$

where L is the projected track length, M is the number of tracking detectors, the constant term is a number depending on the spatial distribution of the M detectors and σ_{hit} is their position resolution. In the present study we will set $\sigma_{\text{hit}} = 50$ μm, i.e. the average resolution of all the detectors during this data taking. The CMS conditions consists of a field $B = 4$ T, a tracking lever arm of 1.2 m and at least 12 point per track. The average resolution of the detectors, without taking into account alignment errors, would be 25 μm:

$$\frac{(\delta P/P)_{\text{CMS}}}{(\delta P/P)_{\text{Test Beam}}} = \frac{K_{\text{CMS}}}{K_{\text{Test Beam}}} = 0.23.$$

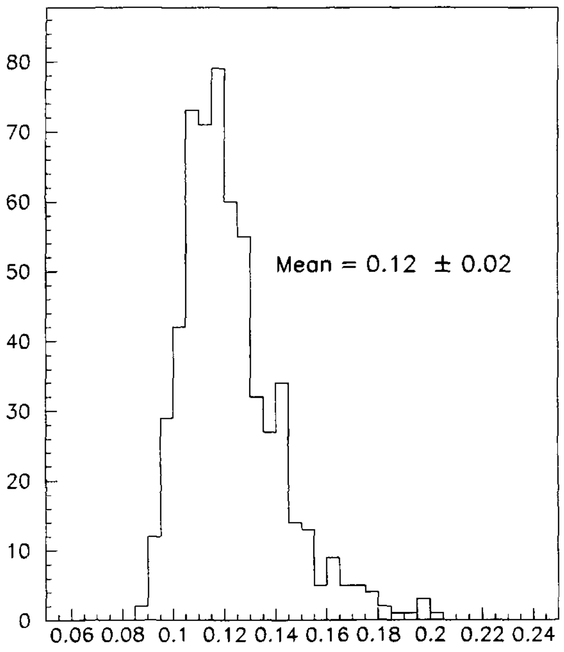

Fig. 3. Momentum resolution.

The ratio yields a naive estimate of $K_{CMS} = 0.92 \times 10^{-4}\,GeV^{-1}c$ to be compared with the CMS goal of $K_{CMS} = 1.0 \times 10^{-4}\,GeV^{-1}c$.

3. Conclusions

Preliminary results illustrating some basic performance of microstrip gas detectors immersed in a magnetic field have been reported. Different chamber prototypes have been studied. In the condition of data taking, the best signal-to-noise ratio has been observed in the case of a 3-mm-gap MSGC, filled with DME, 25 cm long; the ratio has been observed to be the same in presence of magnetic field, when the chamber is tilted as to compensate for the Lorentz angle. The spacial resolution for the 3 mm-gap chamber has been measured to be 30.0±1.1 μm, at normal beam incidence. The behaviour of the resolution as a function of the magnetic field has been studied; in compensation conditions the resolution is measured to be 32.7±5.1 μm. The dependence of the compensation angle on the magnetic field has been estimated as $\alpha_L/B = 3.48 \pm 0.25$. The momentum resolution has been measured to be $\delta P/P = 4 \times 10^4 P$. The extrapolation of this result to the CMS [1] detector geometry, in ideal conditions, yields $\delta P/P_{CMS} = 0.92 \times 10^4 P$. The experience done indicates that 25 cm long MSGCs can be safely operated at conveniently high electric fields and are suitable to the LHC environment for their signal-to-noise ratio, spatial and momentum resolution.

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