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CSC Performance at High Background Rates.

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Abstract

The different factors affecting on the CSC performance at high rate were considered. Their influence on the chamber position resolution and track inefficiency were estimated and measured in the beam test. The full size CSC prototype was tested at the X5 high radiation facility at CERN. The beam test demonstrated position resolution of 70 μm and inefficiency of 24.5 percent in the single layer at the maximum expected background rate. The performance of the CSC muon station as a whole was also estimated on the basis of the measured single layer characteristics. This study shows that for uncorrelated background in the worst case ($\eta = 2.7$) the muon station position resolution and track inefficiency are 50 μm and 2 percent respectively.

1 Introduction

In the inner station of the ATLAS muon spectrometer, Cathode Strip Chambers (CSC) will be employed for the precision measurement of muon tracks in the forward region ($\eta = 2 - 2.7$). The high performance of CSC has been demonstrated in many studies [1-5], although most of these measurements were performed at low or moderate rates. However, it is expected that the

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background environment of LHC experiments will be very hard especially in a forward region. That is why the study of CSC performance at high background rates is very important. This paper is devoted to the consideration of different factors which may affect the CSC behavior at high radiation background. For pattern recognition and muon momentum resolution, the most important parameters are the single layer position resolution and the track efficiency. Both of these were measured with CSC prototypes at different background rates at the X5 high radiation test facility at CERN. This facility delivers both a high momentum muon beam and high intensity gamma radiation. It provides the opportunity to check CSC characteristics at conditions close to the real at the LHC. The study of the performance of an eight layer muon station as a whole for uncorrelated background is also considered in this paper.

2 Experimental Set-up

During July 1998, the CSC prototype was tested at the X5 high radiation facility at CERN. Fig.1 shows the layout of the beam test set-up. The Silicon micro-strip telescope (Si) was installed at a short distance from the CSC prototype to determine track position in the CSC with high precision. Thus the Si telescope may be used as a reference to verify CSC position resolution and track efficiency. For most of the runs, muon beam momentum was more then 100 Gev/c. Beam divergence at this momentum was 1.7 mrad. This makes it possible to estimate CSC resolution by comparison of track positions in two layers with precision good enough for quick on-line monitoring. The beam illuminated area of the chambers was determined by the 5x5 cm^2 trigger counters (Sc1, Sc2). A high intensity radioactive gamma source ^{137}Cs was installed in the beam area. The variable lead absorbers were used to change the radiation intensity. The CSC prototype was placed at the distance of 1.5 m. from the gamma source. At this distance the open source provides maximum radiation background equal to the one expected in the ATLAS at the CSC position, when the conventional safety factor of five is taken into account.

It is important that the CSC high rate performance be studied with the full size prototype irradiated because all the sensitive area of the chamber may influence, at least on the low level, the signal of each cathode strip. In this test the CSC prototype contained three layers and its size was close to that of the ATLAS CSC chamber (fig.1). The chamber parameters are: anode-cathode spacing - 2.5 mm, anode wire diameter - 30 μm, the wire pitch - 2.5 mm, 20 anode wires joined to one anode group, cathode strip readout pitch - 5 mm (this distance contains three equal strips, one of them readout and other two intermediate strips). In this test the gas composition was $0.6Ar + 0.3CO_2 + 0.1CF_4$. For most runs the gas gain was 10^5.

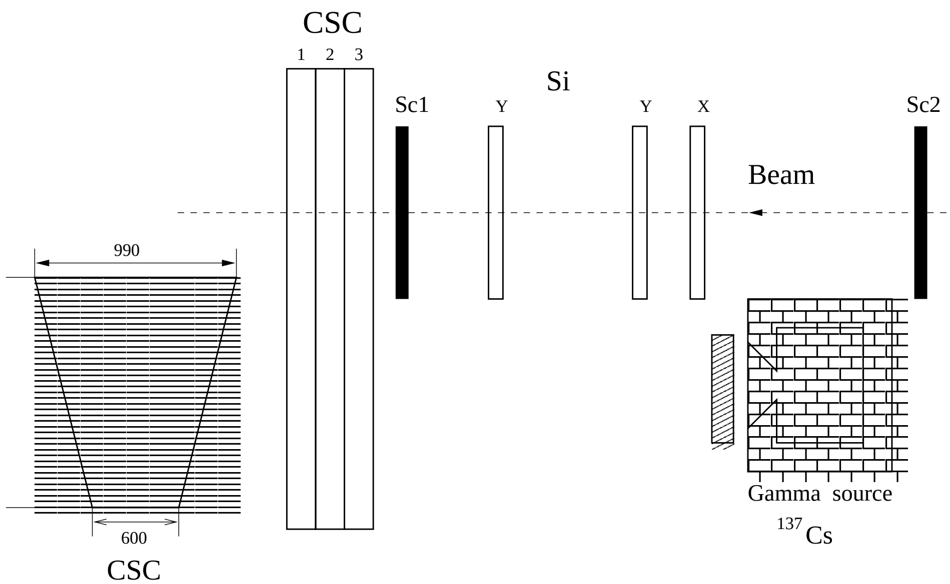


Figure 1: Beam test set-up layout.

The read-out electronic channel consists of preamplifier, shaping amplifier and peak-sensing 11-bit ADC. The low noise charge sensitive preamplifier and shaping amplifier were developed by BNL. The signal had bipolar form. Its peaking time was 75 nsec and the equivalent noise charge was 3500 e. To unify the electronics gain, a computer controlled calibration was carried on regularly (usually daily). For this purpose the amplitudes of the precision pulser were provided to one of the anode group. Due to the anode-cathode capacitances, a signal was induced on each cathode strip. This calibration procedure enabled uniformity of the neighboring channels with precision better than 0.5 percent. The pedestal runs were carried on more often (twice per day, usually).

3 Factors Affecting the High Rate CSC Performance

The detailed study of the CSC performance at low rates has been done in our previous works [4, 5]. This paper investigates mainly the factors that define CSC behavior at high rates. The most important of them are considered below in some detail.

- Overlapping of signals

One of the most obvious reasons of CSC performance degradation at high rates is the overlapping of the cathode strip signals. Because the position in CSC is obtained by interpolating the induced charge from several cathode strips, even minor disturbances of the signal on at least one of them may disturb the measured position significantly. To reduce this effect the shaping time of the amplifier should be as short as possible. Unfortunately, the short shaping time increases the amplifier noise and therefore affects the chamber position resolution. To compensate this effect, the gas gain may be increased but it is necessary to keep in mind the CSC aging resources. Thus the trade-off should be done carefully in order to choose the optimum parameters of CSC and its readout electronics.

- Baseline restoration

The amplifier baseline shift at high rates also may cause deterioration of the chamber performance. To keep the baseline more stable, the amplifier shaping should be bipolar. Although this somewhat increases the amplifier noise, the baseline restores much faster than in case of unipolar shaping.

- Anode-cathode crosstalk

The anode-cathode crosstalk is another factor which may affect CSC performance. In the CSC, anodes and cathodes lay perpendicular to each other and, due to the finite capacitance between them, some fraction of anode signal is sensed at the cathode strips. The value of the crosstalk charge on the cathode strip, q_{cross}, depends on the value of anode signal, $u_a = q_a/C_f$, and anode cathode capacitance, C_{ac}:

$$q_{cross} = u_a C_{ac} = q_a \frac{C_{ac}}{C_f}, \tag{3.1}$$

where C_f is the filter capacitance that connects the anode group to the ground.

Thus the anode-cathode crosstalk is defined by the ratio:

$$\frac{q_{cross}}{q_a} = \frac{C_{ac}}{C_f}. \tag{3.2}$$

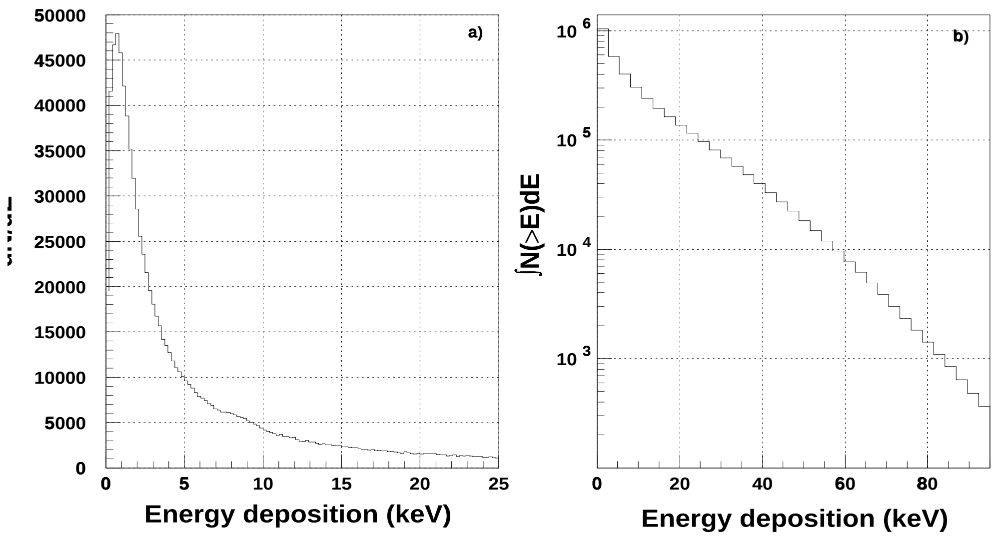


Figure 2: Differential (a) and integral (b) spectra of energy deposition in CSC from ^{137}Cs gamma source

In the CSC prototype, 20 anode wires are joined to one group and grounded through the C_f=5000 pf capacitance. The value of the capacitance between the anode group and cathode strips is C_{ac} = 0.43 pf. This result in the anode-cathode crosstalk of about 10^{-4}. The background at the LHC will be composed mainly by gamma and neutron interactions in the gas and materials of CSC and may deposit large energy in the chamber. In this case the cross-talk signal may be big enough to dislocate the track position in the chamber. Fig. 2 shows the differential and integral energy deposition spectra in the CSC radiated by gamma source ^{137}Cs (12 mm Al filter was applied to absorb beta electrons and the 32 keV K-line). It was found that the average energy deposition of the gamma ray in the single layer is equal to 8.5 keV (the same value for the MDT is equal to 45 keV). It should be noted that at a normal incidence muon deposits in one CSC layer, on average, only about 2 keV.

In spite of long tails of energy distribution most of the crosstalk signals on the cathode are rather small due to the strong suppression of crosstalk. Their frequency, however, is very high because any hit anywhere in the chamber may create at least a tiny signal on a cathode strip. The total rate of background hits in a single layer of CSC is expected to be of about 10^7 Hz. At such a rate, the crosstalk signals look like additional electronic noise. For this reason the crosstalk is responsible mainly for small disturbances of measured position or in other words it broadens the central part of the distribution of position resolution.

4 Data Analysis and Results

4.1 Position Determination

In principle a number of algorithms may be used to determinate the track position. All of them utilize the different combinations of charge on the strips around a maximum of cluster. Two of them were used in our analysis.

1. Weighted center-of-gravity algorithm:

$$x = x_{max} + d \cdot k \frac{q_{right} - q_{left}}{Q_3}, \tag{4.1}$$

where $Q_3 = q_{max} + q_{right} + q_{left}$ is the total charge in three strips, k is a coefficient of proportionality, d is the strip pitch, and x_{max} is the position of a strip with maximum charge.

This algorithm is very convenient due to the simple connection of the charge on the strips and the track position. However it does not work well at high rates due to its strong sensitivity to correlated fluctuations of the strip charges. Fluctuation of this kind originates particularly from anode-cathode crosstalk.

2. Ratio algorithm:

If $q_{right} > q_{left}$ then

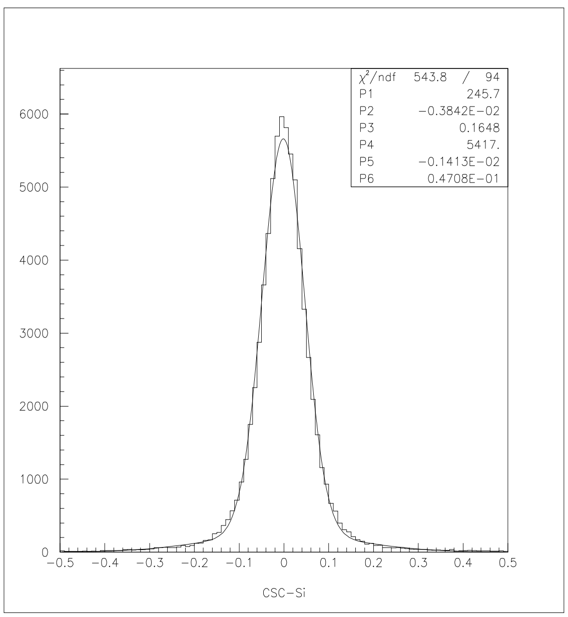
$$x = x_{max} + f\left(\frac{q_{max} - q_{left}}{q_{max} - q_{right}}\right), \tag{4.2}$$

if $q_{right} < q_{left}$ then left and right change places.

This algorithm is very stable at high rates. The function f can be obtained from measured data using the center-of-gravity algorithm as a reference. Most of the results presented below were obtained with the ratio algorithm.

4.2 CSC Position Resolution and Efficiency in the Single Layer

Good pattern recognition and accurate measurement of muon momentum are defined mainly by the position resolution and efficiency in layers of muon detectors. This is especially true for high rapidity where a multiple scattering contribution to the momentum resolution is small.



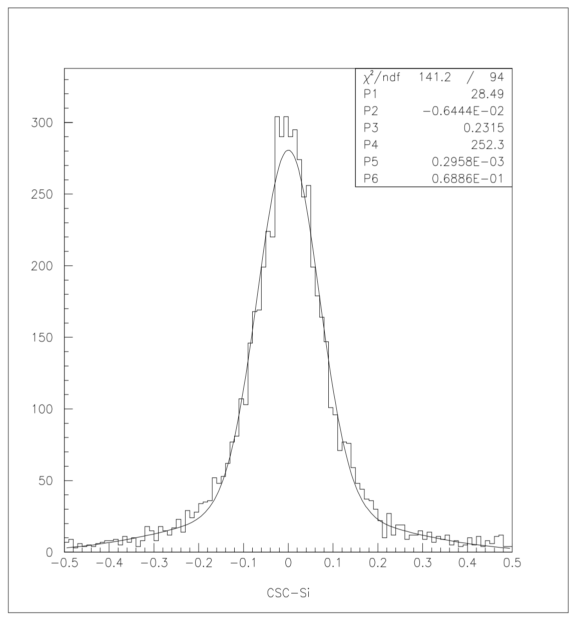


Figure 3: CSC-Si residual at background rates: a) 0.1 kHz/cm^2 b) 2.3 kHz/cm^2. The curvature is the two Gaussian fit. Abscissa axis scale is mm.

First, let's define the single layer position resolution. Fig.3 shows the CSC residual distribution in a single layer at two different radiation rates: $0.1 kHz/cm^2$ (muon beam only) and $2.3 kHz/cm^2$ (open gamma source). In both cases, the shape of the distribution has a central part and long tails. At high rates the main reason for tails is signal overlapping. At low rates the tails arise from δ-electrons and from events with low energy deposition on the track when the signals are so small that electronic noise may deteriorate measured position significantly.

Due to the long tails, it is difficult to cover the entire range of the histogram by a single Gaussian fit. Therefore the single layer position resolution is defined as σ of the Gaussian that fits the central part of the residual distribution in the range of $\pm 2\sigma$. Practically it can be done by sequential approximations (usually two-three iterations are enough to establish the value of σ). The same results can be obtained if the distribution is fitted by the sum of two Gaussians in a broad range ($\pm 0.5mm$, for example). In this case, the central part is described by one Gaussian and the tails by another (Fig.3).

The single layer efficiency is determined mainly by the tails of distribution. We defined it as the fraction of events inside the fixed range of $\pm 0.3mm$.

4.3 Choice of Gas Gain

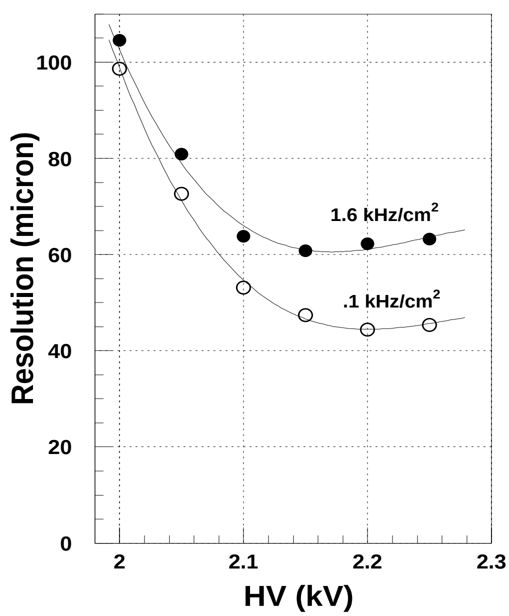


Figure 4: CSC position resolution versus an applied anode HV.

As was already mentioned, a high gas gain may reduce noise contribution to position resolution. Unfortunately, the price of this is an increased total accumulated charge and thus worsened aging performance of CSC. Moreover, at high gas gains, anode-cathode crosstalk may contribute significantly. For this reason resolution improves with gain more slowly than could be expected.

In the Fig. 4 the CSC position resolution is shown versus the applied anode HV at two rates. As one can see from this figure in both cases the resolution goes down more slowly beginning from some value of HV. Finally, anode HV was set at 2.15 kV. At this value of HV gas gain for the given gas mixture is $1.2 \cdot 10^5$ and consequently, in the worst case ($\eta = 2.7$) the total accumulated charge on the anodes will be less then 0.25 C/cm for the lifetime of measurements at LHC ($10^8 sec$).

4.4 Background Rates

The calculation performed by A. Ferrari for MDT (configuration TR43) was taken as a base to evaluate the expected background rate. To apply those calculations for CSC, sensitivities to neutrons and photons were taken into account. The measurements of CSC response to neutrons and photons were performed by the PNPI group [6] with strip chambers of similar geometry and made from the same materials.

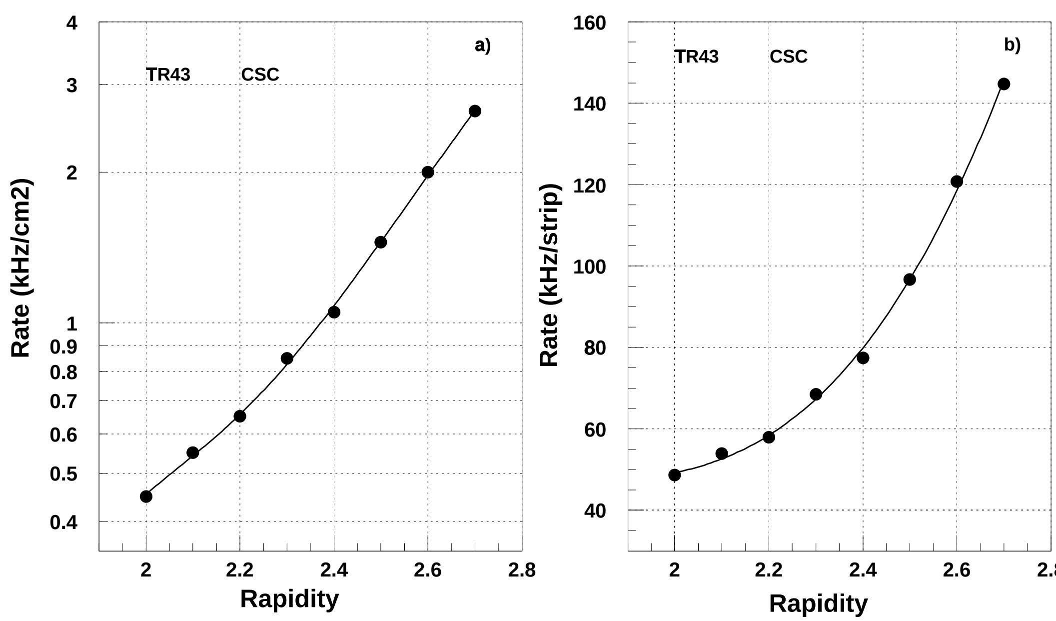


Figure 5: Background rate (a) per cm^2 and b) per strip in depending on rapidity

Results of the calculations are shown in Fig. 5 where the background rates a) per cm^2 and b) per strip are presented depending on rapidity. In both cases the rate was multiplied by a safety factor of five.

4.5 Results of Measurements

Dependence of the position resolution in the single layer on background rate is presented in Fig. 6a. At the minimum rate (muon beam only), the contribution to the resolution are shared roughly equally by electronic noise, calibration uncertainties and track pointing from Si telescope. At higher rates, signals overlapping and anode-cathode cross-talk give dominant contributions to resolution.

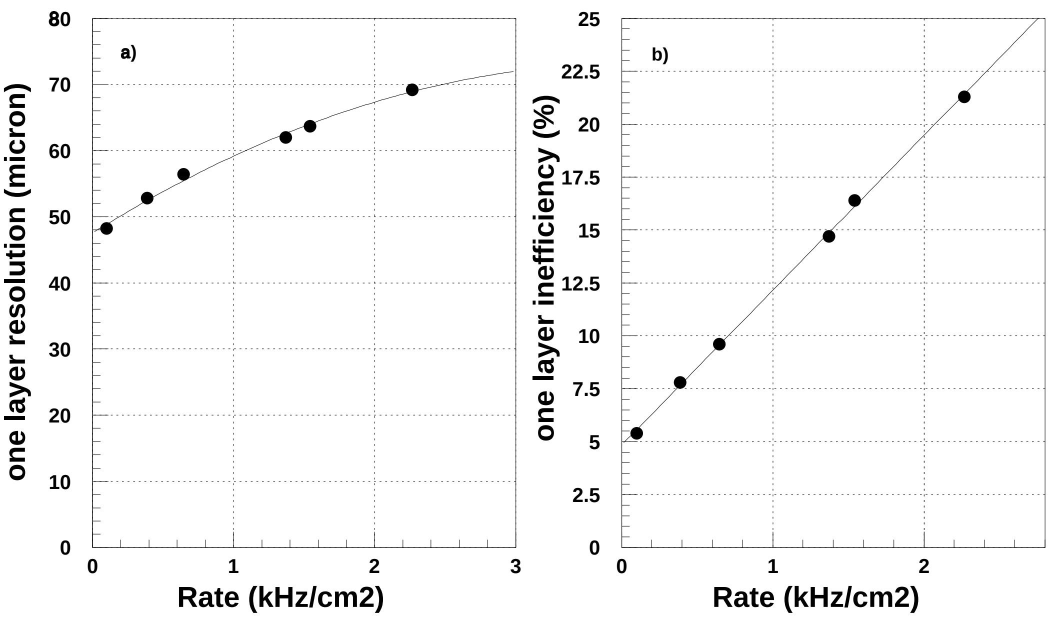


Figure 6: Dependence of a) the position resolution and b) inefficiency on background rate in the single layer.

The CSC single layer inefficiency is shown in Fig. 6b. Again, causes of chamber inefficiency are different at low and high rates. At a low rate the main contributions come from events with amplitudes higher than the ADC range (2.5 percent) and δ-electrons on the track. At high rates, signal overlapping is the main contribution to inefficiency.

The maximum background rate in CSC is reached at rapidity 2.7 and its predicted value is 2.7 kHz/cm^2. So, in the worst case ($\eta = 2.7$) the position resolution and inefficiency in the single layer of CSC are equal to 70 μm and 24.5 percent correspondingly.

4.6 Performance of CSC Muon Station.

The results obtained for the CSC single layer can be applied to estimate how uncorrelated background affects the performance of the muon station as a whole. Neutrons and photons produce mainly short range electrons in CSC and for this reason background in each layer is uncorrelated for these components. To estimate the muon station performance, the simulations were done by using measured residual distributions in the CSC single layer as a basis. The CSC muon station contains eight layers. The hit position in each layer was simulated from the single layer residual distribution and then the track parameters was determined by straight-line fitting. The deviation from a true track position was determined in the middle of the station. The slope of the fitted track also was determined as a track parameter for each event.

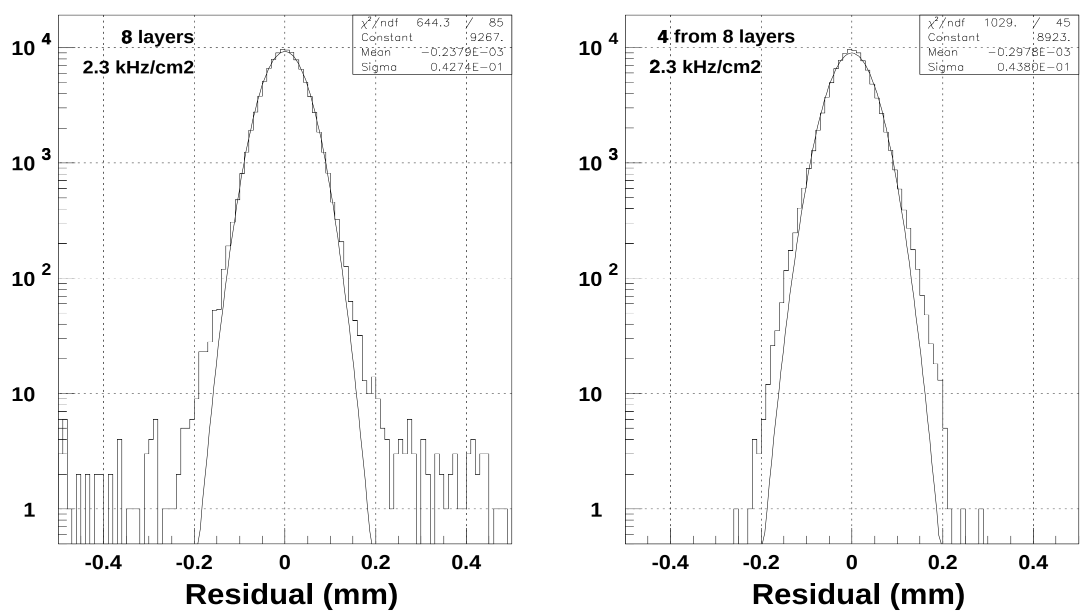


Figure 7: Track residual a) without selection and b) with selection of 4 layers from 8. The curvature is the Gaussian fit.

In Fig. 7a the residual of simulated tracks without any selections is shown. This distribution was obtained at a background rate of 2.3 kHz/cm^2. As one can see there are long tails in residual distribution with the result that the muon station efficiency is poor. To improve the efficiency the following method was applied. The layer with the maximum hit deviation from the fitted track was removed. After that, track parameters were determined again by using seven layers. Then again, the layer with the maximum deviation was removed and so on. This procedure was continued until four layers remained and the last track parameters were defined as final. As shown in Fig. 7b, tails in residual distribution practically disappeared after the above procedure was applied. It should be noted that the width of the central part of the residual distribution essentially does not change in spite of the four layers that were removed from the straight-line fit (σ are equal to 42.7 and 43.8 μm without and with selection). Thus, layer selection improves the muon station efficiency and at the same time, for practical purposes, does not deteriorate the position resolution.

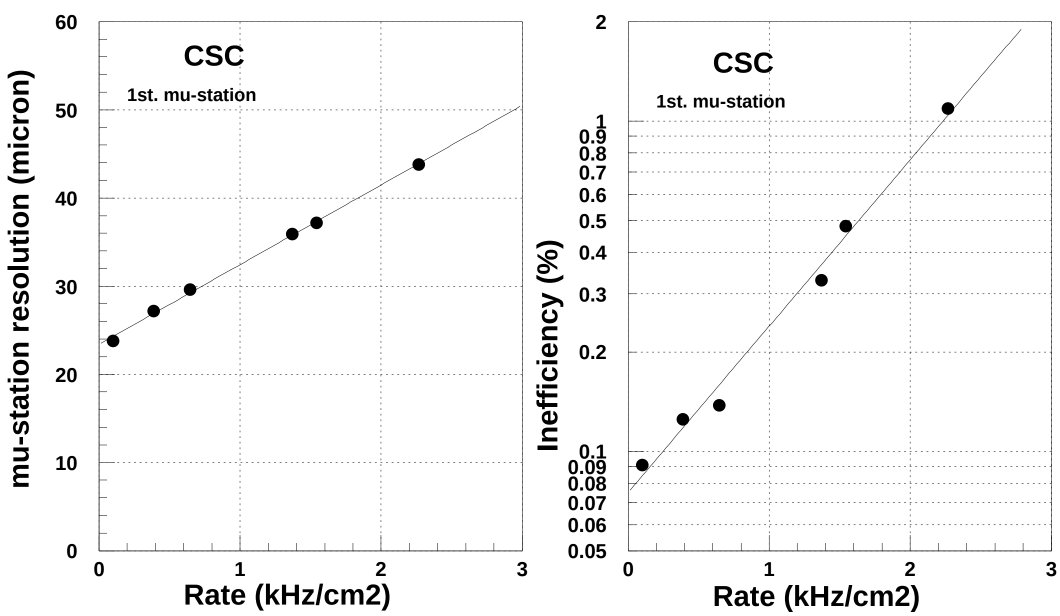


Figure 8: Dependence of CSC muon station (a) position resolution and (b) inefficiency on background rate

As opposed to the residual distribution in the single layer, after the selection the muon station did not contain long residual tails. For this reason it can be fitted by a single Gaussian in a whole range of histograms. Thus the station resolution can be defined as σ of this Gaussian. The station inefficiency is defined as a fraction of events outside the range of $\pm 4\sigma$. For this range the contribution of Gaussian itself to inefficiency is negligible (while, for example, for the range of $\pm 3\sigma$ the 0.26 percent inefficiency is due to the Gaussian itself).

Fig. 8 shows the dependence of the CSC muon station performance on uncorrelated background rate. In Fig. 9, both the single layer and the station performances are shown dependent on rapidity. As one can see in this figure, in the worst case ($\eta = 2.7$) the muon station resolution and inefficiency are better then 50 μm and 2 percent respectively. Fig. 10 presents dependence of the muon station angular resolution (a) on background rate and (b) on rapidity. Again, in the worst case the angular resolution is $\sigma_{angl} = 0.3$mrad.

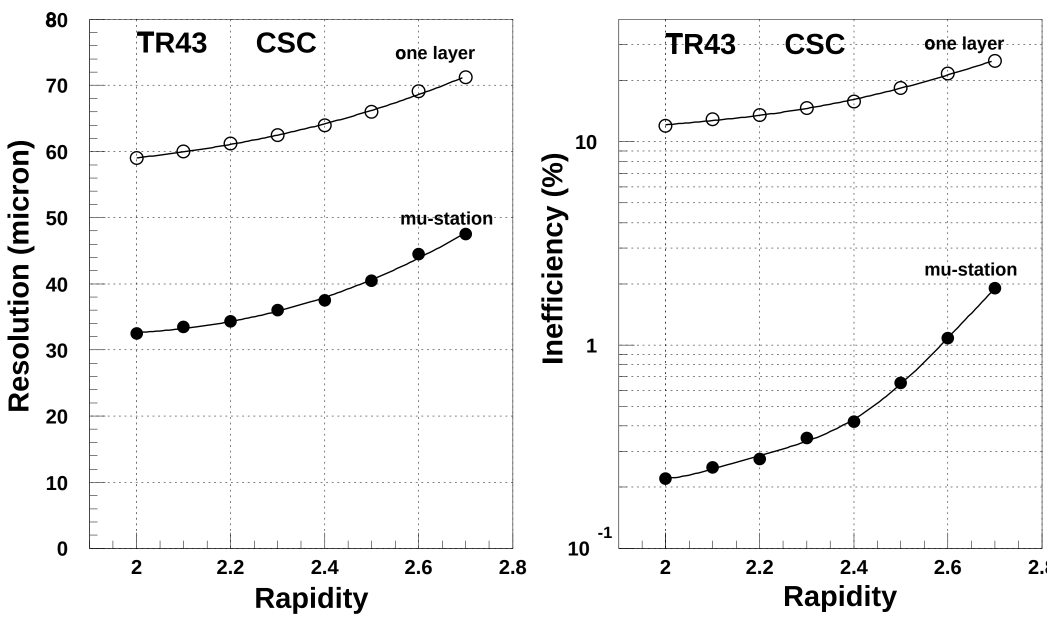


Figure 9: Dependence of (a) the position resolution and (b) inefficiency on rapidity for the single layer and for the whole muon station

5 Conclusion

The analysis of the beam test data has demonstrated the ability of the CSC to operate successfully at the maximum background rate expected during measurements at the LHC. For a normal track incidence in the worst case (η=2.7), the position resolution in the single layer is 70 μm and ineffi-

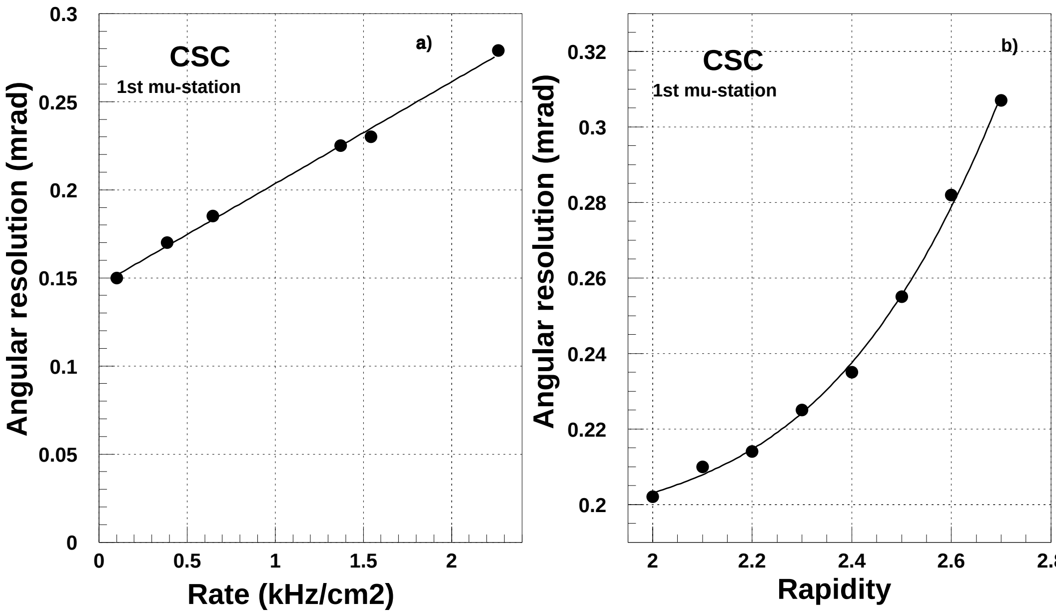


Figure 10: Dependence of the CSC muon station angular resolution (a) on background rate and (b) on rapidity

ciency is 24.5 percent. The major factors limiting the position resolution and inefficiency are the signal overlapping and anode-cathode cross-talk.

The short shaping time of the amplifier helps to improve CSC behavior at a high background rate. Electronics noise deterioration at short shaping time can be compensated by an increase of the gas gain. The value of gas gain was 10^5 for most runs. The total accumulating charge on the anode wires at this gas gain is 0.25 C/cm at $\eta = 2.7$. This value is not large enough to create any significant aging effects in CSC (for example, in comparison with 0.9 C/cm in the worst case of MDT at $eta = 2$). Nevertheless, the CF_4 component is added to the CSC gas mixture to suppress anode aging effects.

An important question is the performance of the CSC muon station as a whole. It is clear that this performance depends on the composition of background. Neutron and photon interactions create in CSC mainly short range electrons. For this reason, the background in separate CSC layers is mainly uncorrelated. In this case the performance of the muon station can be predicted rather accurately by means of simulation on the basis of measured residual distributions in the single layer. These calculations have been done and the following results at the maximum expected background was obtained: station position and angle resolution is about 50 μm and 0.3 mrad respectively, the station track inefficiency is less then 2 percent.

The performance of the CSC muon station at high rates of charged particles is a more complicated question. (Charged particles comprise about half of total background at rapidity $\eta = 2.7$). On one hand the particles deposit less energy in the CSC on the average than neutral components do. But, on the other hand, particles create signals in all layers simultaneously. In this connection the pattern recognition of the CSC station strongly depends on the angular divergence of background charged particles. The worst case is when background particles are parallel to muons, because, when the distance between them is small, they interfere in all CSC layers. This case can be checked in the beam test and we plan to do it next year.

6 References

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