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THE RATE CAPABILITY OF THE CSC CATHODE READOUT ELECTRONICS

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Operation of cathode readout electronics of the cathode strip chamber (CSC) for the first forward muon station (ME1/1) of the Compact Muon Solenoid Detector in high rate radiation background environment has been studied. The investigation has been performed with two cathode readout electronics, i.e., 16-channel preamplifier-shaper based on two ASICs: GASPLEX (CERN) and KATOD-1 (Minsk). The first one has been tested with 4-layer 0.5×0.5 m CSC in Dubna. One layer has been irradiated by X-ray tube ($E\gamma = 8$ keV) while the others were used for cosmic muon track reconstruction. Electronics based on Minsk ASIC has been tested with the P3 prototype of the ME1/1 CSC in pion beam at CERN H2 experimental area. For the electronics a background contribution to registered events, as a function of background rate is presented. Experimental results confirm that the prototype of the ME1/1 CSC, instrumented with KATOD-1 readout electronics, meets CMS requirements on the rate capability.

Изучено влияние фоновых загрузок на работу катодной электроники считывания для камер с сегментированным катодом для первой мюонной станции компактного мюонного соленоида. Исследования проведены для двух типов электроники — 16-канальных предусилителей-формирователей на основе микросхем GASPLEX (ЦЕРН) и КАТОД-1 (Минск). Первый тип электроники исследован в Дубне на 4-слойной катодной камере размером $0{,}5 \times 0{,}5$ м. Один из слоев облучался рентгеновской трубкой ($E\gamma = 8$ кэВ), а остальные использовались для реконструкции трека космических мюонов. Электроника на основе минской микросхемы исследована с прототипом P3 катодной камеры станции ME1/1 в пионом пучке на канале H2 в ЦЕРН. Для обоих типов электроники представлен вклад фона в регистрируемые события в зависимости от интенсивности фона. Экспериментальные результаты подтверждают, что прототип камеры с катодной электроникой на основе микросхемы КАТОД-1 удовлетворяет требованиям эксперимента по загрузочной способности.

INTRODUCTION

Physics goal and target performance of the innermost first forward muon station, ME1/1, of the Compact Muon Solenoid Detector [1, 2] are to provide a precise matching between inner tracker and end-cap muon system. The ME1/1 station must have better spatial resolution with respect to the other end-cap stations of 75 μm per 6-layer chamber and timing resolution of few nanoseconds for bunch-crossing identification. The cathode strip chambers (CSCs) in the ME1/1 muon station will operate at the highest background rates in the CMS muon system of the order of 100 kHz/strip [3–5]. The required performance of the ME1/1 station can be only achieved with front-end electronics perfectly matched with the chamber design parameters. That is why a rate capability of CSC cathode strip readout electronics is crucial for future operation in realistic experimental environment.

An increasing of background rates leads to a distortion of the shape of the readout electronics signal and, as a result, to the degradation of CSC spatial resolution. This effect depends on recovery time of the cathode strip readout electronics. An influence of recovery time of the cathode readout electronics on a probability to detect a background event has been estimated with the following equation:

$$R = 1 - e^{-tH}, \quad (1)$$

where: R is a probability of a background event with rate of H to take place in t — the time interval. Taking $t_0 = t$ as a mean «effective» recovery time of the cathode readout electronics, the value of t as a function of the background rate for different values of the background event probability was calculated as shown in Fig. 1.

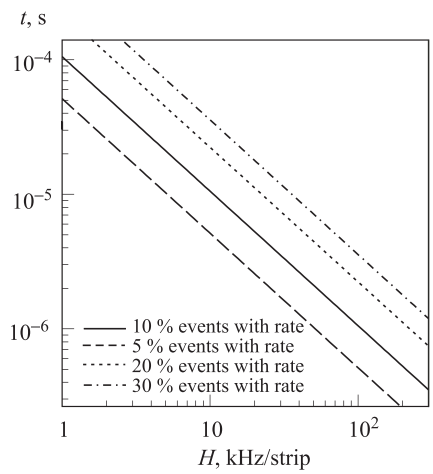


Fig. 1. Calculated recovery time of cathode readout electronics t as a function of the counting rates H for different values of background event probability R

One can see that operation with probability to detect background events at the 10 % level at 100 kHz/strip background rate require an electronics «effective» recovery time of 1 μs.

The recovery time t_0 can be extracted from CSC experimental data. A distribution of residuals — a deviation of the coordinate measured in the testing layer in respect to the reconstructed track in CSC, is described by fit of a sum of several gaussians [6]. The first gaussian, $G1$, corresponds to muon, the second one, $G2$, describes the events far from the centre of the distribution due to correlated radiation admixture of knock-on electrons [7], and the third one, $G3$, describes a contribution of the uncorrelated background. So, a value of background event probability is equal to $R = G3/(G1 + G2 + G3)$. Note, that for the ME1/1 CSC case, a typical ratio of $G1$ and $G2$ sigma is $\sigma_2 \approx 10\sigma_1$ and typical probability to measure muon position with accuracy of σ_1 is of ~ 0.9 [6]. In addition, measured values of spatial resolution σ_1 and efficiency of CSC layer in the presence of background can describe a rate capability on a quantitative level.

This paper presents a study of the influence of background rate on the precision of muon track reconstruction in CSC for two different readout electronics: the first one based on the GASPLEX chip [8] and the second one — on Minsk ASIC KATOD-1 [9].

1. GASPLEX CATHODE READOUT ELECTRONICS

The GASPLEX is a low-noise analogue signal processor [8] designed at CERN for readout of gaseous chambers. Main parameters of this chip are summarized in Table 1.

Rate capability of the cathode readout electronics based on GASPLEX has been tested with X-ray CSC prototype [2, p. 214] at Dubna cosmic-ray facility in 1996.

Table 1. **The GASPLEX specification**

Parameters	Value
Equivalent input noise, r.m.s.	580 e + 15 e/pF
Peaking time, ns	450
Overall system gain, mV/fC	10
Dynamic range, fC	0–200
Power per channel, mW	10

1.1. Experimental Layout. The layout of the experiment is shown in Fig. 2. The scintillation counters S_1 and S_2 separate the cosmic muons passed through the 40 cm iron absorber. The X-ray tube (XT) is a source of 8 keV gamma background. It irradiates the upper (testing) CSC layer through a thin mylar window with a background rate up to 500 kHz/strip. The influence of the X rays on the other layers is negligible. Thin absorbers have been used to vary the background rate. The value of the counting rate H (kHz/strip) has been measured directly from the strips using GASPLEX analogue signal output and discriminator. This measurement has been made separately from the data taking. Parameters of 0.5×0.5 m CSC are shown in Table 2. Each 4 layers have been instrumented with 16-channel readout electronics based on GASPLEX chip.

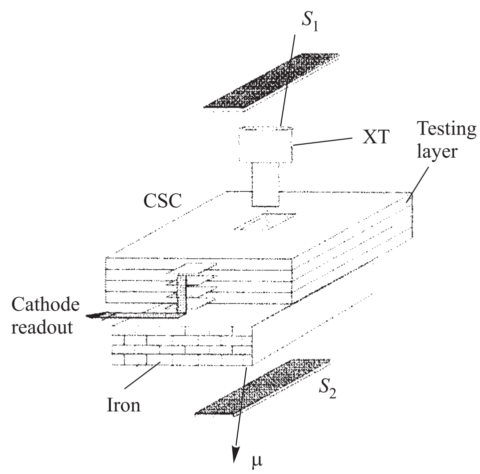


Fig. 2. Layout of the experiment

Table 2. **Parameters of** 0.5×0.5 **m CSC**

Number of layers	4
Anode-cathode gap, mm	2.5
Anode wire diameter, μm	30
Anode wire step, mm	2.5
Cathode strip length, m	0.44
Cathode strip readout pitch, mm	5.0
Anode-cathode geometry	Orthogonal
Sensitive area, mm	320×440
Nominal high voltage, kV	2.7
Gas mixture	Ar/CF4/CO2 (30:20:50)

1.2. Data Analysis and Results. The muon track has been reconstructed with 3-lower CSC layers with 50 mm level of arm. Residuals of the track coordinates measured in the testing layer with respect to the reconstructed ones for the background rates 0, 16, 38 and

90 kHz/strip are shown in Fig. 3,*a,b,c,d*. The fitting solid curves in Fig. 3,*a* are described in Introduction.

The probability of a background signal to overlap with a signal of a cosmic muon grows up with the background rate increase. In this case the CSC spatial resolution degrades. Fig. 4 shows the $R = G3/(G1 + G2 + G3)$ vs. the counting rate H (kHz/strip). The errors of R are statistical. The H errors represent the variation of the counting rate measured by different strips. The fitting curve is given by formula (1), where the mean «effective» recovery time for GASPLEX analogue signal is equal to $t_0 = 3.7$ μs.

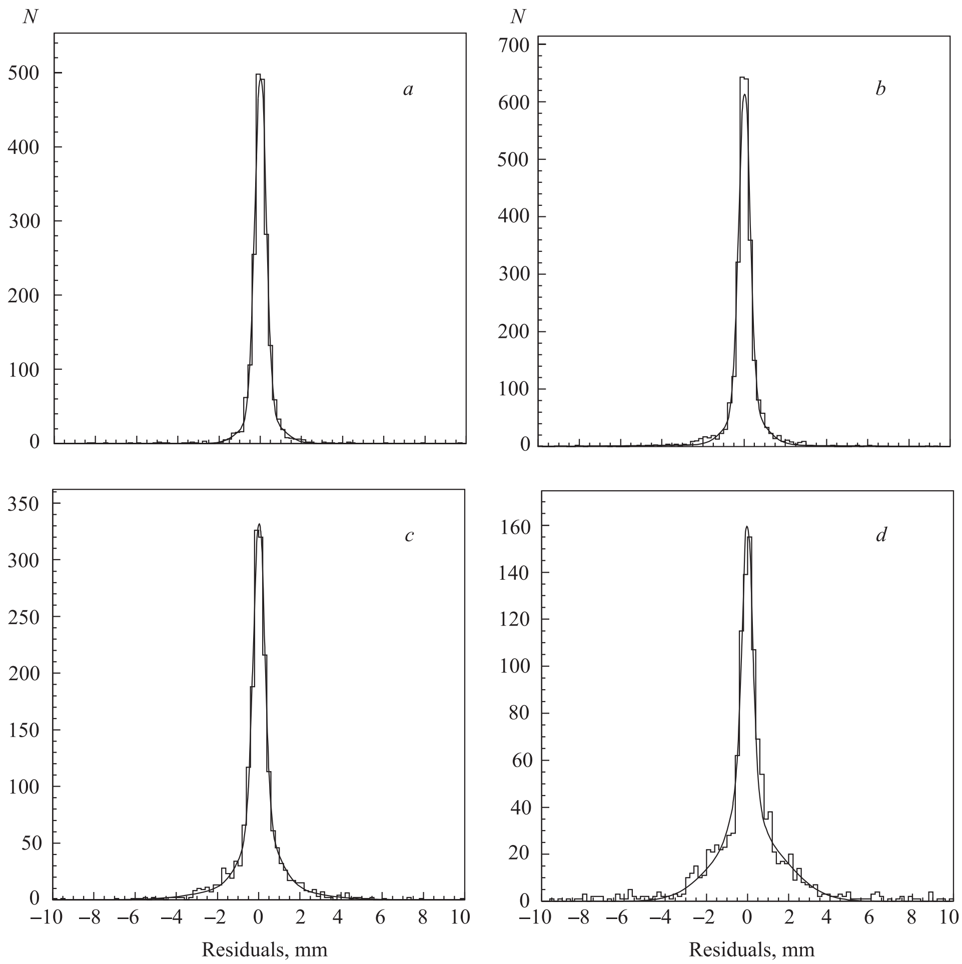
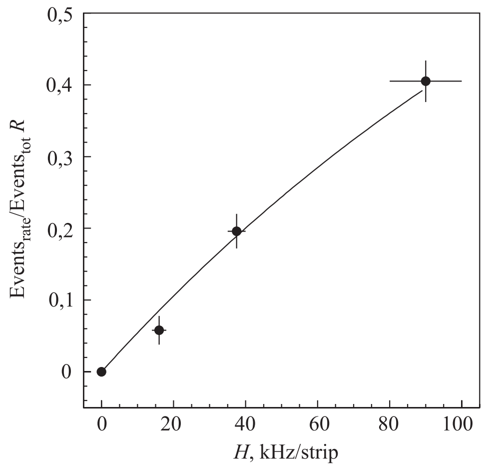
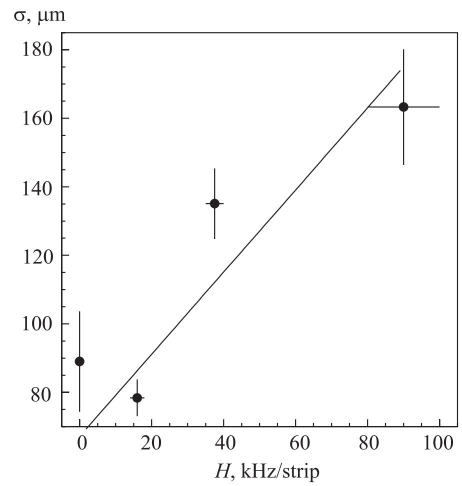


Fig. 3. Residuals in a testing layer without background (*a*) and at a background rate of 16, 38 and 90 kHz/strip (*b, c*, and *d*)

From Fig. 4 one can see that GASPLEX operate at 10 % level of background events probability only at background rate of 20 kHz/strip. Spatial resolution σ_1 of irradiated layer as a function of uncorrelated rate is shown in Fig. 5.





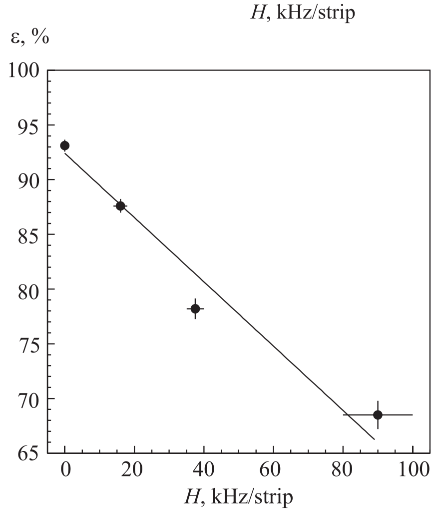


Fig. 4. The ratio R as a function of the counting rates H

Fig. 5. Spatial resolution σ of irradiated layer vs. uncorrelated gamma background

Fig. 6. Efficiency ϵ of irradiated layer vs. uncorrelated gamma background

Efficiency of the irradiated layer (ε), i.e., a probability to measure track position with an accuracy less than $3\sigma_{1,}$ as a function of gamma background is shown in Fig. 6.

Figures 5 and 6 show that the spatial resolution deterioration reached $\sigma_1 \approx 180$ μm and efficiency of $\varepsilon \approx 0.65$ at the background rate of 100 kHz/strip.

The results of 0.5×0.5 m CSC test in gamma background have shown that GASPLEX cathode readout electronics is not fast enough to operate at the background rates of about 100 kHz/strip as it has been expected. Nevertheless, these results gave the first insights into the problem associated with high rate environment. This was important for optimization of a new generation of cathode front-end ASICs designed in Minsk.

2. KATOD-1 READOUT ELECTRONICS

The KATOD-1 preamplifier–shaper [9] was designed to match specific requirements of ME1/1 cathode strip chambers. Main parameters of this chip are summarized in Table 3.

Table 3. **The main parameters of Minsk preamplifier-shaper ASIC KATOD-1**

Parameter	Value
Number of channels	16
Equivalent input noise, r.m.s.	240 e + 1e /pF
Peaking time, ns	≈ 100
Overall system gain, mV/fC	5
Tail cancellation	Tuning
Power per channel, mW	25

Minsk preamplifier–shaper ASIC has a peaking time about 100 ns, as shown in Fig. 7, what is significantly shorter than that for GASPLEX (450 ns).

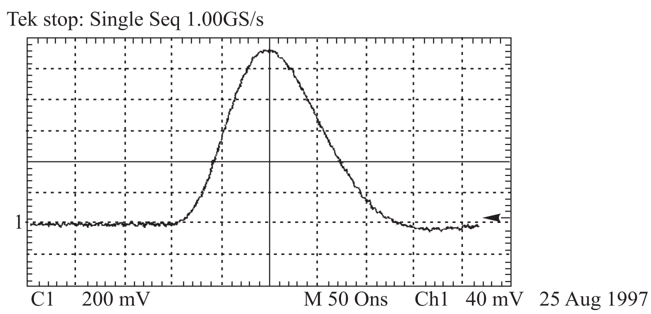


Fig. 7. Minsk preamplifier–shaper ASIC KATOD-1 response for 225 GeV muons. Scales: 200 mV/div vs. 50 ns/div

The prototype of strip readout electronics based on KATOD-1 has been tested with P3 — a full-scale prototype of ME1/1 CSC [10] in 1997. The test has been made in strong magnetic field up to 3 T with high intensity pion beam at CERN H2 experimental area.

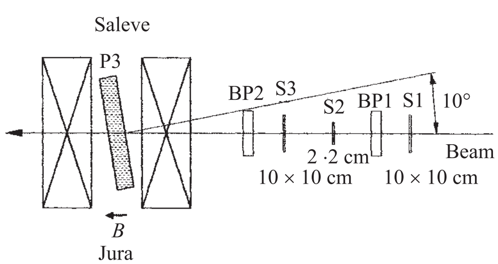


Fig. 8. Experimental layout (top view): S1–S3 — trigger counters; BP1, BP2 — beam profilemeters

2.1. Experimental Layout. Figure 8 shows a sketch of H2 experimental area. P3 is placed into the H2 magnet and turned with 10° with respect to the beam line in order to provide a ratio of radial, B_R, and axial, B_Z, components of magnetic field of $B_R/B_Z \approx 0.1$.

P3 prototype represents a full-scale 10° sector of the CMS end-cap muon station ME1/1. It consists of 6 trapezoidal layers having a radial strip structure. The strips cover the angle of $\pm 5.42°$. To compensate the effect of the avalanche shift in the magnetic field of 3 T the anode wires are positioned at the incline angle of 22° with respect to the perpendicular to the chamber axis. P3 has been instrumented with cathode readout electronics based on Minsk preamplifier–shaper KATOD-1. The main parameters of the prototype are given in Table 4.

Table 4. **The main parameters of P3 prototype**

CSC	Layers / CSC	6
	Inner radius, m	0.995
	Outer radius, m	2.700
	Height, m	1.705
	Inner width, m	0.340
	Outer width, m	0.663
	Area, m^2	0.85
	Sensitive area, m^2	0.55
	Strip channels	768
	Anode channels	384
Layer	Anode-Cathode distance, mm	2.8
	Wire Spacing, mm	2.5
Cathode strips:	Channels	64 + 64
	R/O pitch width: top, mm	7.8
	bottom, mm	3.15
	Strip shape	radial
Anode wires:	Diameter, μm	30
	Wires	625
	Channels	64
	Wires/group	7–12
Incline angle, degree	22	

2.2. Data Taking and Results. In this experiment a deterioration of CSC spatial resolution versus pion intensity has been studied. The trigger counters S1–S3 have monitored the beam intensity. Trigger option S1, S2, S3 separated about 75 % of the beam. The trigger count and beam profile have been taken for calculation of the strip counting rate H. To study the background contribution to the registered events one P3 layer has been taken as testing while the five others — for pion track reconstruction. The R ratio of the events with background to the total number of the registered events has been calculated as described in Introduction. The results are shown in Fig. 9.

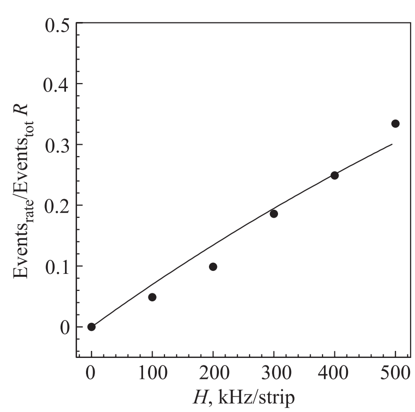


Fig. 9. The ratio R as a function of the counting rates H

The fitting curve is a calculation by formula (1). The «effective» recovery time for Minsk ASIC analogue signal is estimated as $t_0 = 484$ ns. One can see that KATOD-1 can operate at 10 % level of background event probability at 100 kHz/strip background rate. Spatial resolution σ_1 of tested layer as a function of pion background rate is shown in Fig. 10.

Efficiency of the irradiated layer (ε), i.e., a probability to measure track position with accuracy less than $3\sigma_{1,}$ as a function of gamma background is shown in Fig. 11.

Figures 10 and 11 show that spatial resolution of single CSC layer instrumented with KATOD-1 is about $\sigma_1 \approx 73$ μm at efficiency of $\varepsilon \approx 0.9$ at background rate of 100 kHz/strip.

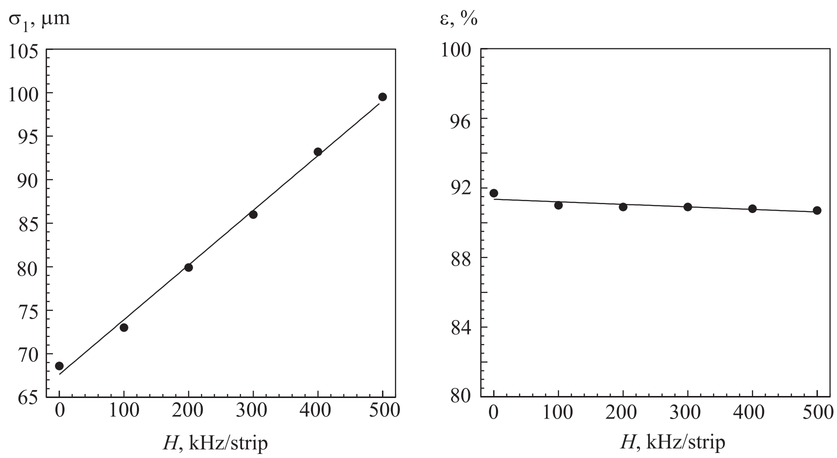


Fig. 10. Spatial resolution of tested layer vs. pion background

Fig. 11. Efficiency of tested layer vs. pion background

CONCLUSION

The test of cathode readout electronics based on GASPLEX chip with 0.5×0.5 m CSC in gamma background showed that this electronics is not fast enough to operate at rates of about 100 kHz/strip. Nevertheless, these results were important for optimization of a new generation of cathode front-end ASICs designed in Minsk. The test of cathode readout electronics based on Minsk ASIC KATOD-1 with the P3 ME1/1 CSC prototype in magnetic field showed that its operation capability at background exceeds 100 kHz/strip. At this rate the 10 % of events measured by single CSC layer relate to the background.

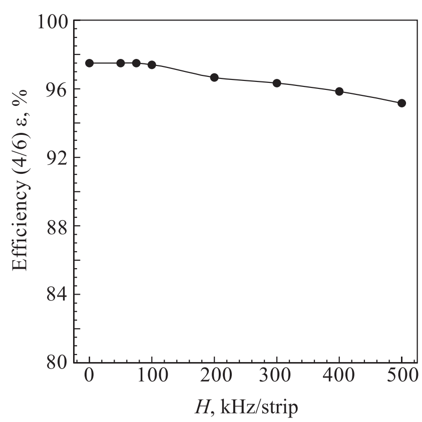


Fig. 12. Track reconstruction efficiency as a function of the counting rates H

The KATOD-1 electronics provided a possibility to analyse the efficiency of the track reconstruction by ME1/1 station prototype versus H counting rate as shown in Fig. 12. The track is regarded as efficient if strip clusters are found at least in 4 out of 6 CSC layers (criterion 4/6) with measured coordinates within the $\pm 3\sigma_1$ μm corridor. Figure 12 shows that efficiency of track reconstruction is about 97.5 % at 100 kHz/strip.

Experimental results confirm that prototype of the ME1/1 CSC, instrumented with KATOD-1 readout electronics, meets CMS requirements on the rate capability.

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