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A Micro-Strip Gas Counter Test with the RD20 front-end

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Abstract

A Micro-Strip Gas Counter equipped with the VLSI preamplifier of the RD20 chip has been tested with minimum ionizing particles. The measured pulse shape and the signal to noise ratio are presented. The time resolution of the detector is compared for Ar/DME and DME/CO₂ gas mixtures. Three methods for the bunch crossing identification at LHC are discussed.

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1. Introduction

The RD20 chip is a front-end for silicon detectors performing at LHC. It includes a preamplifier and shaper (AMP) [1], an Analog Delay and Buffer (ADB) [2] and an Analog Pulse Shape Processor (APSP) [3]. The capacitance of a MSGC detector is typically 0.5 to 1pF/cm of strip and the signal of minimum ionizing particles is about $40000e^-$. These features are similar to those of silicon detectors and it has been suggested that the same chip could be suitable for both detectors used in an LHC experiment. The first test of a MSGC equipped with the RD20 preamplifier is reported. The detector was produced by the french factory DME on a polished vitro-ceramic glass (Neoceram) of 10^{15}Ohm/square surface resistivity. The 10cm long aluminium anodes and cathodes have respectively a width of $10\mu\text{m}$ and $80\mu\text{m}$ with a pitch of $200\mu\text{m}$.

2. Shaping with the RD20 front-end

2.1. Generator calibration

The AMP is a charge preamplifier followed by a CR-RC shaping amplifier. In the present test, the time constant was adjusted to 30ns with the bias currents and voltages applied to the chip. Figure 1a shows the AMP response to a Dirac charge input of $40000e^-$. The measured output amplitude is 180mV including the gain 10 of a video-amplifier following the AMP. The peak to peak noise is about 10mV. The effect of the detector capacitance, equivalent 12 pF for the 10cm strip of the MSGC plus the connection to the preamplifier, is shown on figure 1b. For the $40000e^-$ Dirac input, the time constant is increased to 42ns and the output amplitude is reduced to 130mV. At the same time, the peak to peak noise is increased to 20mV.

2.2. Signal shape with ^{55}Fe and ^{90}Sr sources

With a ^{55}Fe source, we have measured the signal delivered by 5.9 keV X-rays crossing the MSGC, the time constant of the signal is 45ns, close to the response of the preamplifier to a Dirac input. The charge collection for a single cluster interaction in the gas is thus very fast and the signal delivered by a minimum ionizing particle is expected to be a sum of δ -currents corresponding to different cluster ionizations along the gas gap, as predicted by the simulation [4]. We used the 2 MeV electrons of a ^{90}Sr source to reproduce the energy loss of minimum ionizing particules in the detector. The gas mixture was Ar/DME 80/20% with a 3mm gap. Typical pulses registered at the output of the AMP are shown in figure 2. When compared to the X-ray source, they have the expected fluctuations in amplitude and shape, with a long timing contribution for high amplitudes, when the number of primary electrons produced along the gas gap is large. In this measurement the digital oscilloscope was triggered by a coincidence of two scintillators and the effect of the MSGC time resolution can be observed. Both the broadening of the pulses and the timing fluctuations are of the order of the drift time of primary electrons in the gas gap of the detector.

3. Charge measurement

3.1. Signal charge

The signal charge was measured in ADC modules triggered with a 250ns gate, provided by the signal itself in the case of the ^{55}Fe source or by the coincidence of two scintillators in the case of the ^{90}Sr β -source.

With a gas mixture of 80% Argon and 20% DME, the 5.9keV X-ray charge distribution exhibits the two peaks typical of the photon absorption in Argon (fig.3). The energy resolution achieved, when summing the charge shared on adjacent strips, was 14% at RMS. In the case of the electron source, the charge distribution has the Landau shape specific of the MIP energy loss in a small gas gap. Figure 4 shows the total charge measured on adjacent strips together with the highest charge collected on a single strip. The ratio of the charges at the maximum probability of the two distributions indicates that 70% of the signal is collected on a single strip. For the given gas mixture, a gas gap of 3mm and the 200 μm pitch between the strips, we measured that the charge is mainly shared on two strips.

The numbers of collected electrons for the total charge of maximum probability in the ADC spectra, are displayed in figure 5 as a function of the cathode voltage applied to the detector. Various experimental conditions are summarized. It is shown that the signal measured with the fast shaping RD20 front-end is 30% less than the one measured with a charge preamplifier of 2 μs shaping time which integrate the charge coming from the slow motion of ions. On the other hand, the MIP signal measured with the RD20 preamplifier was found linear up to a gas gap of 6mm, showing that the shaping time constant is large enough to measure the charge produced by all the primary electrons. With a 3mm gap, a drift voltage of -1800V and a cathode voltage of -510V, the signal collected on a single strip was 28000e $^{-}$ at the maximum probability of the Landau distribution, corresponding to a mean value of about 50000e $^{-}$.

3.2. Signal to noise ratio

The equivalent electron noise at the input of the RD20 preamplifier was estimated from the RMS of the ADC pedestal. It was found to be 1850e $^{-}$, leading to a signal to noise ratio of 15, considering that the signal is the charge of maximum probability on a single strip. For the operation of MSGC's at LHC, the relevant related parameters are the detector efficiency and the electronic noise occupancy for a given threshold on the measured charge. A fit to the ADC charge distribution leads to an efficiency of 99% and an electronic noise occupancy of 0.4% of the number of strips for a threshold at 3σ of the noise. A direct beam test measurement, with final detectors and electronics, will confirm if the present signal to noise ratio, achieved at the preamplifier level, is large enough for the application at LHC.

4. Time resolution

At LHC, interactions occur at each bunch crossing, every 25ns. To allow a good track reconstruction efficiency in the central detector of the experiments, a minimum pile-up of hits coming from interactions in different bunch crossings is needed. With MSGC

detectors, it will be determined by the fluctuations in the arrival time of the signal and the bunch crossing identification algorithm. The MSGC specific time resolution depends on the number of primary electrons produced in the gas gap and on their drift time towards the anode strips. The choice of the gas mixture and of the gas gap are thus the main parameters to reduce the timing fluctuations.

We studied the MSGC time resolution, with TDC modules, for Ar/DME 80/20% and DME/CO₂ 60/40% gas mixtures with a 3mm gap. The TDC start time, determining the MIP crossing, was provided by the coincidence of the signals delivered by two scintillators. The stop signal was the MSGC signal itself with a threshold at 3σ of the noise to avoid the background. The time resolution of one scintillator as compared to the other was measured to be 4ns and was neglected with regard to the MSGC timing fluctuations.

The overall time resolutions measured with Ar/DME 80/20% at a drift field of 5kV/cm and DME/CO₂ 60/40% at 8.5kV/cm were respectively 14ns and 11ns (fig.6). Assuming that the time difference between the beginning and the maximum of the TDC distribution reflects the path of primary electrons in half of the gas gap, the estimated electron drift velocities in the two gas mixtures are respectively 50 μ m/ns and 72 μ m/ns, close to the expected values [5]. If we do not measure the signal timing from the strip which has collected the highest charge in the MSGC, the resolutions are worsened to 17ns (Ar/DME) and 15ns (DME/CO₂). Another evidence of this effect is seen in the time distributions, measured for different sets of the charge collected in the MSGC (fig.6). The mean time and the resolution decrease when the charge increases, as expected if the timing is provided by the signal of the first primary electrons reaching the anode strip. Integrating all the charges, the present detector efficiency of one strip would have been 85-99% (Ar/DME) and 92-99% (DME/CO₂) respectively within the 50ns and 75ns gates corresponding to two and three bunch crossing intervals at LHC.

5. Signal processing

The purpose of the signal processing at LHC is a reduction of the data to the amplitude of the signal measured on each strip and its attribution to a fixed bunch crossing. The proposed method is based on a sampling of the preamplifier output pulse in an analog delay and buffer and then, at the trigger time, on the analysis of few selected points with a simple algorithm that can possibly be implemented on a chip.

With a MSGC associated to the RD20 front-end, we have registered sampled pulses with a digital oscilloscope. The gas mixture was Ar/DME 80/20% with a 3mm gap. We discuss three algorithms for the signal processing, a deconvolution or a fit of the preamplifier output pulse and an identification of the pulse maximum. In the following results, the efficiency refers to the ability of the algorithm to identify the hits produced in the trigger bunch crossing, the amplitude resolution is the ratio $\sigma(g)/g$ where g is the gain in amplitude of the algorithm and the false hits identification refers to the rate of hits identified at the trigger time but produced by interactions in the preceding or following bunch crossings, at the 25ns clock of LHC.

5.1. Deconvolution of the measured pulse

In the present RD20 design, the signal processing includes a deconvolution of the

Np	τ (ns)	Δt (ns)	Amplitude resolution (%)	Efficiency (%)	Rate of false hits (%)			Total bunch crossings
					bunch -1/+1	bunch -2/+2	bunch ≥ 3	
3	40	20	45	73	39/44	3/2	2	1.6
		30	38	85	56/62	7/13	10	2.4
		40	30	90	74/69	22/25	6	2.9
		50	27	92	83/76	41/32	15	3.3
		60	27	94	75/90	38/62	38	4.0
	50	40	32	87	69/61	11/11	1	2.4
		60	24	93	86/76	41/31	7	3.3
4	40	20	32	86	65/62	11/13	3	2.4
		30	25	92	85/75	43/31	14	3.4
	50	25	29	87	70/60	13/11	1	2.4
		40	21	94	86/85	44/49	13	3.7
5	40	20	24	92	79/74	28/32	9	3.1
	50	25	21	92	80/80	31/42	3	3.3

Table 1 : Efficiencies, amplitude resolutions and rates of false hits obtained with the deconvolution, of 3,4 or 5 points.

preamplifier output pulse, using the inverse transfer matrix of the chip [3]. The bunch crossing is identified by the trigger time and only the deconvoluted pulse amplitude at that time is preserved. The $(t/\tau)e^{-t/\tau}$ form of the RC-CR shaping allows to express this amplitude with the simple formula :

$$S_k = W_1 V_k + W_2 V_{k-1} + W_3 V_{k-2} \quad (1)$$

Where the amplitudes V are 3 sampled values of the output pulse and where the weights W have the following values :

$$W_1 = (\tau/\Delta t)e^{(\Delta t/\tau)-1}, \quad W_2 = -2(\tau/\Delta t)e^{-1}, \quad W_3 = (\tau/\Delta t)e^{-1-(\Delta t/\tau)}$$

Δt is the time interval between the sampled points and τ is the shaping time constant.

We have studied the deconvolution for different values of the time constant, using 3,4 or 5 points of the output pulse, sampled at various time intervals. In the case of 4 (5) points the deconvoluted amplitude was the sum :

$$V_d = S_k + S_{k+1} \quad (S_k + S_{k+1} + S_{k+2})$$

Where the amplitudes S are estimated according to formula (1). A signal V_d above 3σ of the deconvoluted noise was required to select a hit, so that the electronic noise occupancy of the counter after this selection is 0.4%. The efficiency and the resolution of the algorithm are summarized in table 1 together with the rate of false hits.

The inefficiency of this algorithm is mainly due to the pulses which are deconvoluted above the threshold but at a time different of the trigger time, as a consequence of the MSGC time resolution. With 4 or 5 points in the deconvolution the efficiency increases, but a similar effect can be obtained with 3 points when increasing the sampling step. In this case, the amplitude resolution is also improved. The false hits identification has two origins, the first one is the time resolution of the MSGC which allows a time overlap of the

signals produced in different interactions, the second one is the deconvolution of a same pulse above the threshold at different times. This effect is due to the time development of the MSGC signal which is not a single δ -current and so has not always a $(t/\tau)e^{-t/\tau}$ form at the output of the preamplifier (see section 2). Another consequence of this difference is the weak dependance of the deconvolution on the chosen time constant.

A 87% efficiency with an amplitude resolution of 30% was achieved with a 2.4 bunch crossing pile-up. To reach a 93% efficiency and a 25% resolution this number increases to 3.3. As it can be seen in table 1, the false hits come approximately in the same proportion from bunch crossings before and after the trigger time, showing that the algorithm is not very sensitive to the long tail of the pulses.

5.2. Fit to the measured pulse

In this method, both the signal timing as compared to the trigger time and its amplitude are determined. The chosen function adjusted to the sampled points of the pulse has the RC-CR shape :

$$f(t + t_0) = \lambda((t + t_0)/\tau)e^{-(t+t_0)/\tau}$$

Where, λ and t_0 are the free parameters representing respectively the normalisation and the time shift of the fitted pulse. With this function, the χ^2 minimization has the exact solutions described in appendix 1. The efficiency and the rate of false hits are determined by a window around the estimated value of t_0 and by a selection of the amplitudes above 3σ of the noise.

At a fixed efficiency of 94%, the amplitude resolution was 25% and the bunch crossing pile-up was 3.4 (table 2). As in the case of the deconvolution, the RC-CR shape does not always reproduce the pulse, especially its long tail. For this reason, the results are almost independant of the time constant and the best results were obtained with only 3 points selected at the beginning of the pulse with a 40ns step.

τ (ns)	Δt (ns)	Amplitude resolution (%)	Efficiency (%)	Rate of false hits (%)			Total bunch crossings
				bunch -1/+1	bunch -2/+2	bunch ≥ 3	
40	40	21	73	35/34	3/14	16	1.7
		24	85	43/57	4/27	22	2.4
		27	90	47/72	4/43	29	2.8
		27	94	56/85	6/58	39	3.4
		28	96	77/88	22/63	74	4.2
50	40	26	94	54/85	5/59	37	3.3
60	40	25	94	52/87	5/63	36	3.4

Table 2 : Efficiencies, amplitude resolutions and rates of false hits obtained with the fit algorithm.

5.3. Identification of the pulse maximum

This algorithm is based on the identification of the maximum of the pulse at the trigger time. We performed the analysis using 3 sampled points, requiring that the second

one is above the 3σ noise threshold and above the two other points. As in the case of the deconvolution, the final data is the amplitude given here by the sum of the three selected points, the bunch crossing being identified by the trigger time. The results are summarized in table 3 for different steps between the analysed points.

With a 50ns time interval, a 86% efficiency and a 15% resolution were achieved with a 2 bunch crossing pile-up. To reach a 97% efficiency with a pile-up of 3.4 bunch crossings, we choose the two first points 80ns apart and the third point 120ns after the second one.

$\Delta t_{12}/\Delta t_{23}$ (ns)	Amplitude resolution (%)	Efficiency (%)	Rate of false hits (%)			Total bunch crossings
			bunch -1/+1	bunch -2/+2	bunch ≥ 3	
40/40	15	77	21/44	1/5	2	1.5
50/50	15	86	35/55	3/7	2	1.9
60/60	15	92	51/63	6/10	2	2.2
70/70	15	94	66/69	15/15	3	2.6
60/120	18	95	66/81	11/26	3	2.8
70/120	18	96	68/87	16/38	3	3.1
80/120	19	97	81/88	28/38	4	3.4

Table 3 : Efficiencies, amplitude resolutions and rates of false hits obtained when identifying the pulse maximum.

The best efficiencies obtained with the three algorithms are compared as a function of the bunch crossing pile-up in figure 7. The method identifying the peak maximum is less sensitive than the other algorithms to the shape fluctuations of the MSGC signals which shows that the parametrisation assumed in the fit is not flexible enough. It gives the closest efficiencies to the values of 85% and 99% measured within a time window of 2 or 3 bunch crossing intervals in the time distribution presented in section 4. In the TDC measurement, the signal timing is measured when the pulse exceed the threshold and not at a fixed trigger time as in the preceding methods. It somehow fixes the limit of efficiency that can be achieved in a given time window.

IV Conclusion

A MSGC detector of 3 mm gap filled with an Ar/DME 80/20% gas mixture was tested with the RD20 preamplifier. The measured signal to noise ratio of 15 should allow a full detection efficiency with an electronic noise occupancy of 0.4% of the detector strips.

Using the pulses registered with a digital oscilloscope, three methods for the signal processing and the bunch crossing identification at LHC were studied. The deconvolution or the fit of 3 points of the pulse, selected at the trigger time, give similar results. The efficiency is 85% and the amplitude resolution is 30% with a pile-up of 2.4 bunch crossings. A 94% efficiency and a 25% resolution can be achieved with a bunch crossing pile-up of 3.4. The RC-CR shaping with a 40ns time constant seems suitable for this type of signal processing, although the question of the pile-up on a same MSGC strip was not

studied. Both methods are sensitive to the shape fluctuations of the MSGC signals and an increase of the number of analysed points does not clearly improve the results, an adequate choice of the time interval between the sampled points seems more effective. An algorithm requiring the maximum amplitude of the pulse at the trigger time gives the best results. A 86% (97%) efficiency and a 15% (19%) amplitude resolution were reached with a bunch crossing pile-up of 2 (3.4). In this case, the results could be even better with a pulse of shorter shaping time.

With a 60/40% DME/CO₂ gas mixture, we found that 92% of the pulses are detected in a time window of 50ns as compared to 85% with Ar/DME 80/20%. The higher cluster density should also reduce the fluctuations in the pulse shape. Such fast and highly ionizing gas mixtures combined to a gas gap smaller than 3mm should improve the bunch crossing identification at LHC.

References

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Appendix 1.

In the fit algorithm, the function :

$$f(t + t_0) = \frac{\lambda(t + t_0)}{\tau} e^{-\frac{t + t_0}{\tau}}$$

is adjusted to n sampled points of the preamplifier output pulse with two parameters, λ and t_0 , representing respectively the normalisation and the time shift of the fitted pulse. The χ^2 of the fit has the following form :

$$\chi^2 = \sum_{k=1}^n (V_k - \lambda f(t_k + t_0))^2$$

where, V_k are the fitted points and $t_k = (k - 1)\Delta t$, Δt being the time interval between the points. The system where the χ^2 derivatives in λ and t_0 cancel has the following exact solutions :

$$\lambda = \frac{W_1 + \frac{t_0}{\tau} W_2}{W_3 + 2\frac{t_0}{\tau} W_4 + \left(\frac{t_0}{\tau}\right)^2 W_5} e^{\frac{t_0}{\tau}}$$

$$t_0 = \frac{W_2 W_3 - W_1 W_4}{W_1 W_5 - W_2 W_4} \tau$$

Where :

$$W_1 = \sum_{k=1}^n V_k \frac{(k-1)\Delta t}{\tau} e^{-\frac{(k-1)\Delta t}{\tau}}$$

$$W_2 = \sum_{k=1}^n V_k e^{-\frac{(k-1)\Delta t}{\tau}}$$

$$W_3 = \sum_{k=1}^n \left(\frac{(k-1)\Delta t}{\tau} e^{-\frac{(k-1)\Delta t}{\tau}} \right)^2$$

$$W_4 = \sum_{k=1}^n \frac{(k-1)\Delta t}{\tau} e^{-\frac{2(k-1)\Delta t}{\tau}}$$

$$W_5 = \sum_{k=1}^n e^{-\frac{2(k-1)\Delta t}{\tau}}$$

Figure captions

Fig. 1 : Output pulse of the RD20 preamplifier plus video-amplifier for a Dirac input charge of $40000e^-$ and electronic noise. a) without input capacitance, b) with the 12pF capacitance of the MSGC strips and connections.

Fig. 2 : Typical pulses measured with a ^{90}Sr β -source for an Ar/DME 80/20% gas mixture and a 3mm gas gap.

Fig. 3 : Charge distribution measured with the ^{55}Fe X-ray source.

Fig. 4 : Distribution of the highest charge collected on one strip and of the total charge measured on adjacent strips with a ^{90}Sr β -source.

Fig. 5 : Numbers of electrons collected at the preamplifier input for the total charge of maximum probability as a function of the cathode voltage. The L3 preamplifier is a charge amplifier of $2\mu\text{s}$ shaping time constant.

Fig. 6 : TDC distributions of a single strip signal above 3σ of the noise (full line) and when it is the highest collected on a strip (dashed line). a) Ar/DME 80/20%, $E_{\text{drift}} = 5\text{kV/cm}$. b) DME/ CO_2 60/40%, $E_{\text{drift}} = 8.5\text{kV/cm}$. The gas gap was 3mm.

Fig. 7 : best efficiencies versus bunch crossing pile-up obtained with the three algorithms described in the text.

a

b

Figure 1

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Figure 7