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Timing Optimization of Thin Gap Chambers for the use in the ATLAS Muon Endcap Trigger

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The first level muon trigger in the endcap region of the ATLAS experiment requires the use of detectors with well defined high segmentation and good time resolution, to cope with high backgrounds at large rapidity. Thin Gap Chambers operating in a high gain mode have been proposed for this task due to its anode readout capability, that permits a well defined segmentation down to the two wire separation, combined with its good timing properties. An optimization of such a device for timing application has been performed using large (1.22×0.74 m^2) detectors under different operating conditions. A time resolution better than 3.7 ns has been achieved for a single layer, showing no deterioration under background rates at as high as 170 kHz/cm^2.

1. Introduction

Thin multiwire chambers (thin gap chamber, TGC) were first developed by S.Majewski et al. [1] and then optimized for the use in the sampling counters of calorimeters. [2-4] The operation in a high gain mode using strongly quenching gases such as CO_2+n-pentane provides large saturated signals. The saturation effect is essential to obtain a good energy resolution in calorimetric environment and makes the chamber amplification factor relatively insensitive to mechanical variations, this being advantage in construction of large chambers. The thin structure is also profitable to limit the longitudinal size of the detector. The pole tip hadron calorimeter and endcap presamplers of the OPAL experiment were constructed using 384 TGCs which have been operated successfully for several years.

Another characteristic of the TGC, which is less important for the calorimetric applications, is a narrow timing spread of the signals. For CO_2-based gases, the drift velocity of electrons does not reach saturation at high electric field, the field strength being high in the TGC operated in a high gain mode, therefore the drift time is short and the TGC provides good timing information. Because of this feature, we proposed to use TGCs in the first level muon trigger system of ATLAS experiment at LHC. [5] In LHC experiments it is required to identify the bunch crossing which occurs every 25ns.

In the endcap region of the ATLAS experiment, the background rate is estimated to be around 1 kHz/cm^2. The TGC has been tested under high background environment. It operated at high efficiency up to 10 kHz/cm^2. [2] The fine segmentation of about 1cm width is needed to set a sharp threshold for the transverse momentum. The TGC can be segmented down to two wire separation. Cathode strips of any desired geometry give second coordinate which are useful to reduce accidental trigger under high background condition.

2. Experimental setup

An experiment to study timing properties of the TGC was carried out under different operating conditions using a 3 GeV/c pion beam at KEK. Large test chambers of 122×74 cm^2 in size were supported vertically on a movable stage which allowed two dimensional positioning. A schematic view of the chamber is shown in Fig. 1. The details of the chamber structure is described in Ref.[3]. The anode plane consists of gold-plated tungsten wires (50 micron in diameter) with 2 mm pitch. Two graphite coated cathode planes are placed at a distance of 1.6 mm from the anodes. In order to reduce wire sag, support bars of 7 mm in width sandwich the wires located approximately 20 cm apart. Behind the graphite cathode planes are strips of 10 mm in width to pick up induced signals. The direction of strips are orthogonal to that of anode wires.

The gas mixtures used in this study were CO_2+n-pentane (55:45), a standard mixture for the TGC, and CF_4 + isobutane (80:20). The CO_2 passed through liquid n-pentane kept at 17 °C.

Contiguous five anode wires were grouped together and were capacitively coupled to preamplifiers. The gain of the amplifiers was about 300 and their bandwidth was 1 GHz. Cathode signals were read out individually. A total of 10 anode wire groups and 10 cathode strips were read out. The output signals of the preamplifiers were discriminated and digitized by using the TDCs with 0.7 ns/bit resolution. The start signal of the TDC was generated by taking a three fold coincidence of the trigger scintillation counters. The overall time resolution of the trigger system was less than 1 ns. The timing was not corrected for the pulse amplitude variation since time-walk correction will not be practical at the first level trigger. The trigger threshold was set at a value as low as possible above noise level.

The beam spot size at the TGC was 4 cm in diameter and an accurate position of each particle trajectory was obtained using drift chambers. The chamber position was adjusted according to the requirement of each measurement.

3. Timing properties

3-1 CO_2+n-pentane

In other study [4], the TGC with CO_2+n-pentane (55:45) was operated at around 4 kV. In this study, however, we set the high voltage at lower value taking into account the high rate background. The timing distribution of anode signals at 3.4 kV is shown in Fig. 2-a. When there were more than one TDC stop signals, the signal arrival time was defined by the earliest TDC stop. More than 99% of the total events fell into 25 ns time interval for both anode and cathode.

The non-Gaussian tail toward late arrivals in the distribution was reproduced by simulation. This tail came mainly from the particles hitting in the middle of two neighbouring wires where the electric field is weak and the electron drift velocity is slow. The time-walk effect was not a dominant contribution to this tail because the rise time of the pulse was less than 5 ns. The time resolution was defined as an r.m.s. of the data within 25 ns interval. At 3.4 kV a time resolution of 4.5 ns was reached for a single layer. No apparent high voltage dependence of the resolution was observed.

Signal propagation along wires and strips add some more time spread. Scanning the detector vertically and horizontally, the propagation speed was measured and found to be 4.0 ns/m and 6.6 ns/m respectively for wires and strips. In principle we can eliminate this effect if we combine second coordinate information to give the first level trigger at the expense of complexity of the trigger logic. Since a better time resolution is desirable, the possibility to improve the resolution by using a different gas mixture was investigated.

3-2 CF_4+isobutane

Since the slow drift velocity in the middle region gives rise to the late arrival tail of the time distribution, an operation with a fast gas is expected to improve the time resolution. We used the mixture of CF_4+isobutane (80:20) in this study. CF_4-based gases have been well studied by several groups and are known to have high drift velocity even in the low electric field. [6-10] A good time resolution has been reported in an application to a small MWPC using this mixture. [11] Ageing effect has not been observed up to 10 C/cm (accumulated charge per unit wire length). [12] In order to determine the optimum operating condition, the pulse height (total charge) was measured for a wide range of high voltages using a small size chamber (10×10 cm^2). The TGC was operated stably in a high gain mode in the range between 2.8 kV and 3.5 kV. (Fig.3) At higher voltages, broadening of pulse shape was observed probably due to tsecond avalanches. The timing distribution of anode signal at 3.1 KV (Fig. 2-b) was measured using the same setup as for the CO_2+n-pentane data. The slow end tail disappeared as expected and 99.7% of total events fell within 20 ns interval. Time resolution of 3.7 ns (r.m.s.) was achieved at 3.1kV for a single layer. It was noticed that there were two peaks in the distribution. This phenomenon was also reproduced by a simulation. Since the measurements of the drift velocity for the gas mixture being studied have been done only for the low electric field[8], the data were extrapolated to higher field (>5 kV/cm) following the similar curve as measured for the pure CF_4. [13-14]

4. Efficiency

For the trigger application, it is important to have a device with high efficiency. We have studied possible cause of three types of inefficiencies.

The first is the intrinsic inefficiency of the detector. It was measured by requiring a good hit to be within a proper timing window with respect to the beam trigger. The good hit was rquired to be located in the beam spot area which was determined by the drift chambers. The efficiency was measured to be higher than 99% for CO_2+n-pentane at 3.4 kV and 97.5% for CF_4+isobutane at 3.1 kV. Following the beam test results, simulation studies have been performed to understand an origin of the lower efficiency obtained with the latter gas mixture and to find a way to improve the efficiency. We included an effect of electron attachment in the simulation using the data of effective ionization coefficient described in Ref.[15]. An average number of electrons reaching the amplification region was estimated to be approximately 4, consistent with the above number.

Therefore the lower efficiency with the latter gas mixture can be explained by the electro-negative nature of CF_4. The simulations also indicated that small variations in the two wire distance could improve the efficiency. Preliminary results, obtained with small test chambers, confirmed that such an improvement is achievable, with only a moderate deterioration in the time resolution.

The second inefficiency comes from the width of time window set for the triggers. In making a coincidence of signals from several layers, the gate width must be kept short enough to identify the bunch crossing. Hits outside the gate timing are not detected by the trigger logic even if the chamber responded properly. Inefficiency arising from this effect was measured by changing the gate width as shown in Fig. 4. The time window starts at the leading edge of the signal timing distribution. For the window narrower than 22 ns, CF_4+isobutane showed higher efficiency because of the narrow time spread. With wider gate CO_2+n-pentane performed better owing to its high intrinsic efficiency.

The last inefficiency is due to the wire support structure which shadows the anode wires. In order to measure this effect, we put the TGCs on a movable stage and exposed the support structure area to the beam. The efficiency in the range where the supports are located is shown in Fig. 5. Although the width of the support structure is 7 mm, we found slightly wider inefficient region of about 9 mm around the supports. This area amounts to about 3% of the whole chamber area. Outside this region a constant efficiency was observed. For the real trigger system of the ATLAS experiment, this effect can be eliminated by staggering the positions of the support structure so that there is no overlap between layers.

5. Operation with High Background

The LHC experiment area will be full of low energy photons, low energy neutrons and muons. The number of those particles so far estimated is of order of 1 kHz/cm^2. Even under such high rate background the trigger system must function well. This condition was realized by placing a radioactive source (^{90}Sr:1mCi) close to the TGC surface. By adjusting the distance from the TGC we controlled the particle rate. The efficiency was measured during the beam test. In Fig. 6, the efficiency for CF_4+isobutane (80:20) at 3.1 kV is plotted as a function of the particle rate. The TGC was found to keep the efficiency as high as 94% up to 170 kHz/cm^2.

6. Summary

We have tested the TGCs for the trigger chamber. The intrinsic efficiency of higher than 99% and the time resolution of 4.5ns was observed for CO_2+n-pentane (55:45) . The better time resolution of 3.7 ns was achieved for CF_4+isobutane(80:20). However, the efficiency was found to be 97.5%. No significant deterioration was observed in the efficiency under high background rate up to 170 kHz/cm^2.

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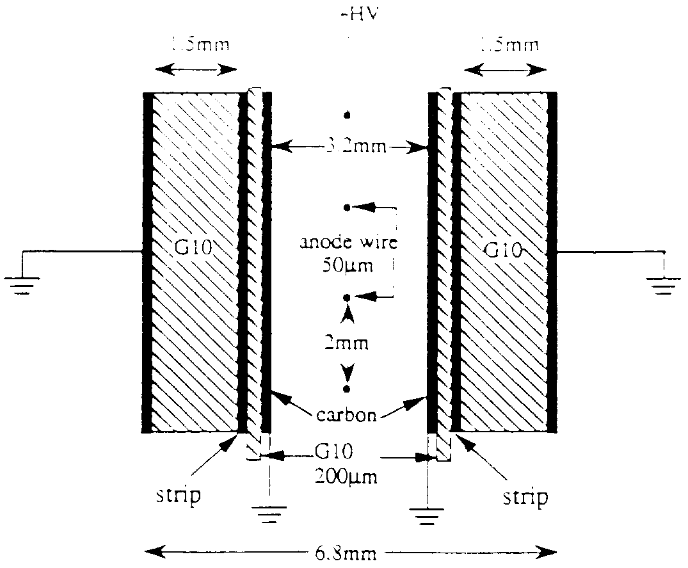

Fig. 1 Schematic drawing of the TGC.

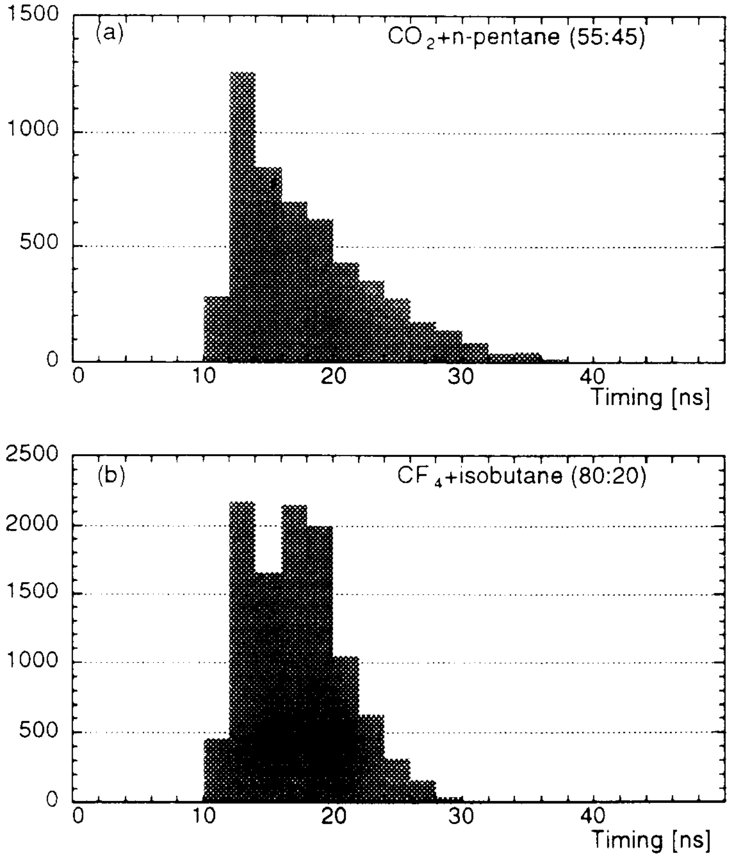

Fig.2 Timing distributions (a) with CO$_2$+n-pentane at 3.4 kV and (b) with CF$_4$+isobutane at 3.1 kV

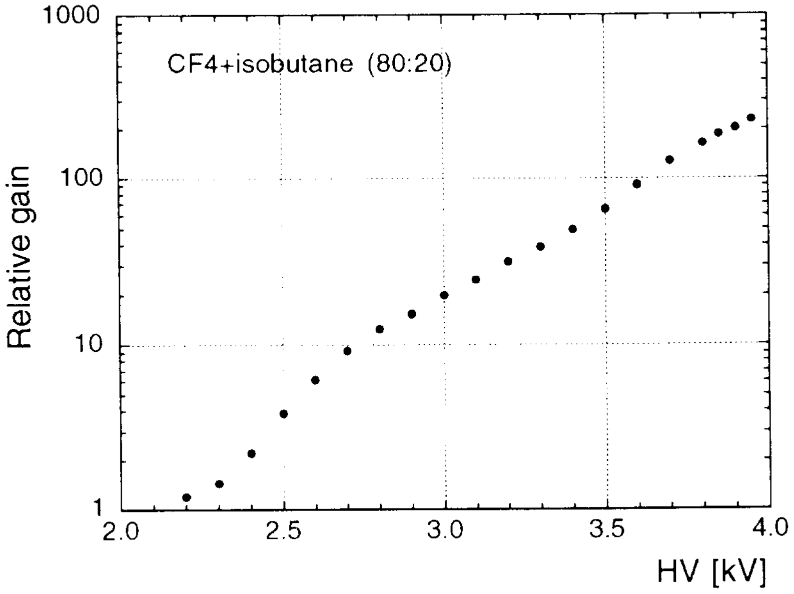

Fig. 3 Relative gain

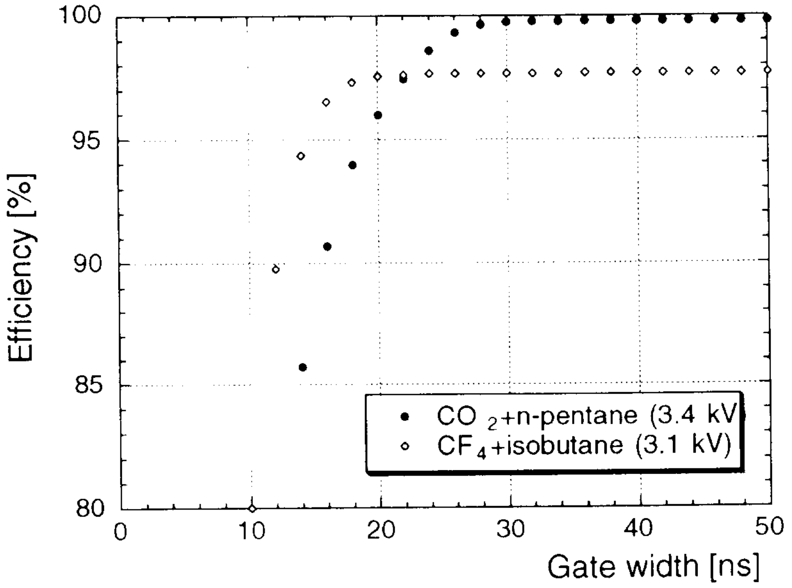

Fig.4 Efficiency as a function of gate width

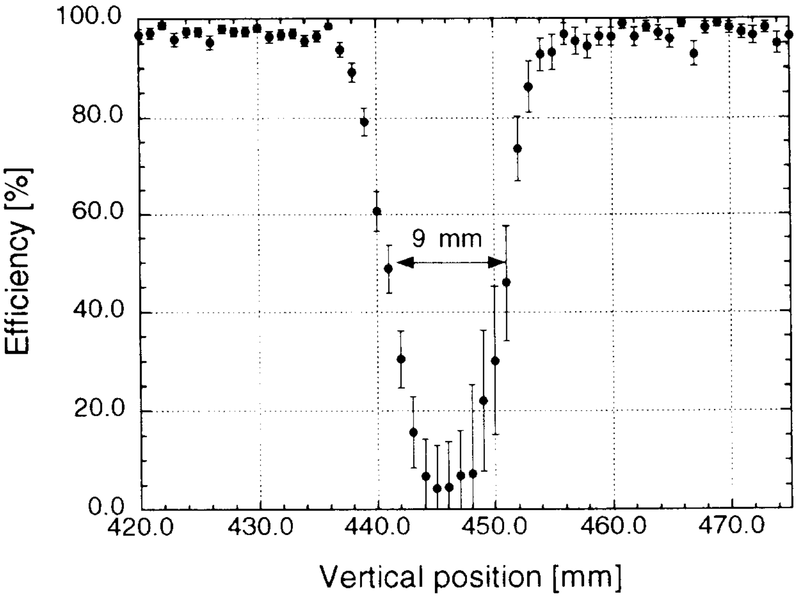

Fig.5 Effect of a wire support

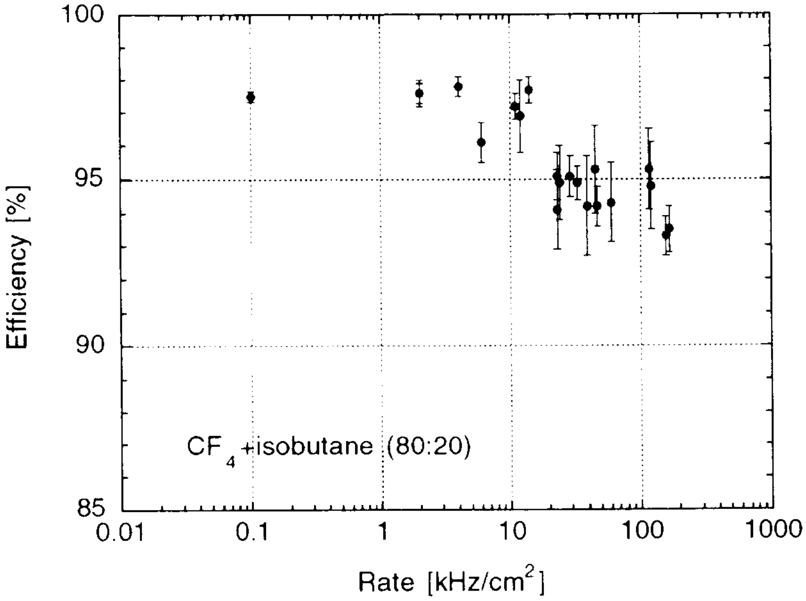

Fig.6 Rate dependence