Angular resolution of the gaseous micro-pixel detector Gossip

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Gossip is a gaseous micro-pixel detector with a very thin drift gap intended for a high rate environment like at the pixel layers of ATLAS at the sLHC. The detector outputs not only the crossing point of a traversing MIP, but also the angle of the track, thus greatly simplifying track reconstruction. In this paper we describe a testbeam experiment to examine the angular resolution of the reconstructed track segments in Gossip. We used here the low diffusion gas mixture DME/CO_2 50/50. An angular resolution of 20 mrad for perpendicular tracks could be obtained from a 1.5 mm thin drift volume. However, for the prototype detector used at the testbeam experiment, the resolution of slanting tracks was worsened by poor time resolution of the pixel chip used.

1. INTRODUCTION

Gossip is designed as a gaseous detector for tracking at the pixel layers of ATLAS at the future sLHC. For the b-layer at a radius of 37 mm, particle rates of up to 0.9 GHz/cm^2 are expected including a safety factor of 2 1]. To cope with this dense track environment, the pitch of the pixel chip is chosen as small as modern electronics permits. In addition the height of the drift volume is squeezed to a value where ionization efficiency is just 99%. Important is the surface that is available for gas amplification. This should be as large as possible to avoid dead time problems and reduce possible ageing. The collection of ions from the avalanche process should be fast.

In practice these constraints lead to a pixel pitch of about 55 x 55 µm using 130 nm CMOS technology. For the drift volume we end up with a height of 1.0 – 1.2 mm, depending on the gas chosen. For the gas amplification area, the perforated parallel plate concept is more suited than the well known thin wire concept since it has the widest area for the avalanches and a very rapid collection of the ions.

The concept of gas amplification by a perforated parallel plate (Micromegas) has been developed by Giomataris et al 2]. Subsequently Van der Graaf et al. have continued the development of this technology by integrating the perforated foil with the pixel chip using wafer postprocessing (InGrid process) 3]. For high rate applications at ATLAS at the sLHC, the concept of Gossip has been proposed where the height of the drift volume has been minimized 4].

The Gossip detector is described in detail in 5]. Its functioning is illustrated in Fig. 1.

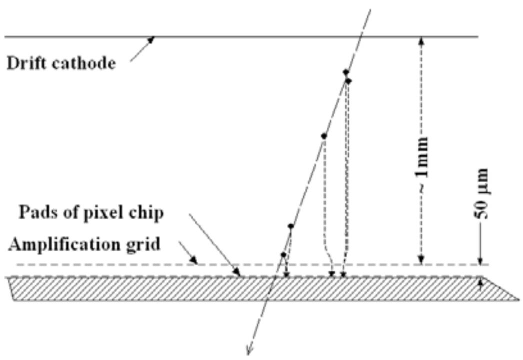

Figure 1. Principle of Gossip

Traversing particles are detected by the ~1.0 mm thick gas layer terminated by a cathode foil and the pixel chip. The perforated metal amplification grid is attached 50 µm above the chip surface. The 35

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µm wide holes of the grid match the pads of pixel chip. The potential of the grid is of the order of -500 V, the pads of the pixel chip are at ground potential.

In the typical MIP event drawn in Fig. 1 the particle liberates 5 primary electron-ion pairs. Because of the applied drift field, these electrons travel towards the amplification grid and are subsequently collected by one of the holes. The high electrical field between the grid and pads causes an avalanche process with a gas gain of the order of 5000.

The electronic circuitry of each pad does not only register the occurrence of a hit but also its arrival time after a common trigger. This enables a three-dimensional reconstruction of each primary electron since the drift velocity is well known. Fitting a track through the reconstructed electrons yields the final result of the Gossip detection process: a short track segment.

Note the pile-up effect for the illustrated event: 5 primary electrons are focussed onto 3 pads.

2. EXPERIMENTAL SET-UP

For the testbeam experiment we used Gossip detectors based on the TimePix-1 chip 6]. This chip features a pixel pitch of 55 x 55 µm where each pixel is equipped with a counter to register the arrival time relative to the common trigger. For the testbeam experiment a clock frequency of 80 MHz was used. This rather low clock frequency measures the drift time in units of 12.5 ns, corresponding to a drift length of 125 µm in Z, much larger than the pixel pitch.

As a detector gas we used a mixture of di-methyl-ether (DME) and CO_2 50/50. The mobility of this mixture is very low, resulting in a drift velocity of only 10 µm/ns at the applied drift field of 2.0 kV/cm (Fig. 2). The figure also shows the big advantage of the DME/CO_2 mixture: the diffusion is less than 70 µm/√cm at the working point. The cluster density of the mixture is rather high: 45 cm^{-1}, the total ionization is 75 cm^{-1} 7].

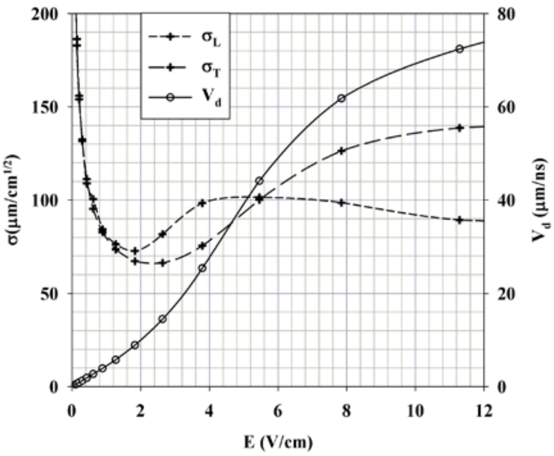

Figure 2. Calculated longitudinal and transversal diffusion (σ_L and σ_T) and drift velocity (V_d) as a function of the drift field (E) for DME/CO_2 50/50 8].

The testbeam experiment was done at the CERN PS using 6 GeV/c pions. Four Gossip detectors were mounted along the beam at 10 cm distance to each other. They had a drift gap of 1.5, 1.5, 1.0 and 19.3 mm respectively. We started taking data with the chip-surface perpendicular to the beam, and then tilted the detectors around a vertical axis. The measurements on the angular resolution that are described in this paper were all done with all detectors rotated around the vertical axis by 12 ± 2°.

We use as a coordinate system the Z axis in the drift direction, the X axis near vertical, and the Y axis horizontally along the chip surface.

Accordingly we had in the X-Z plane an almost perpendicular angle of incidence while the angle of incidence in the Y-Z plane was about 12° to the normal.

3. MEASUREMENTS

The detectors had not yet been operated before with DME/CO_2, a mixture requiring considerably higher amplification voltages than the more commonly used gas mixtures. Three of the four detectors suffered from discharge problems, probably not in the gas volume itself – DME is an excellent quencher – but at the edges of the pixel chip where wire bonds are located close to the borders of the grid. Only one detector where the wire bonds were passivated by GlobTop9], could achieve good single electron efficiency. The results presented in this report were all made with this detector. It had a drift gap of 1.5 mm.

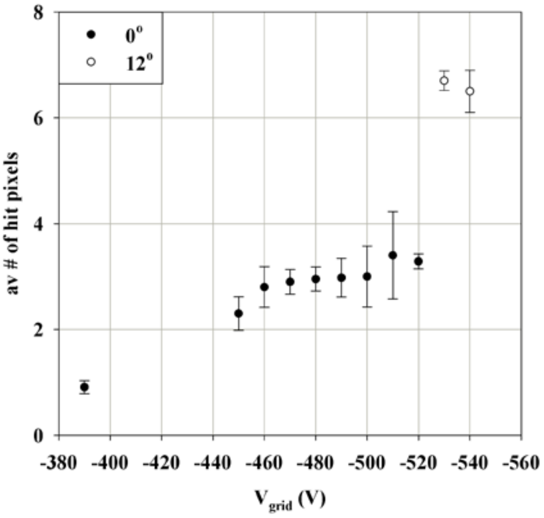

Figure 3. Measured average number of hit pixels as a function of the grid voltage (V_{grid}) for two different angles of incidence.

The operation of Gossip is based on the detection of single electrons. One may get an impression of the single electron efficiency by observing the average number of hits per track as a function of the gas amplification or rather the negative grid voltage. A plateau in the curve indicates good single electron efficiency. Fig. 3 shows that for the testbeam experiment there is indeed such plateau for grid voltages between -450 and -520 V using tracks at an angle of incidence of about 0°. Since the gas gain in this range is more than quadrupled, it is clear that the single electron efficiency should be high at Vgrid = -520 V.

But for slanting tracks (12°) the average number of hits per track is doubled, caused by the lower pile-up effect at this angle. However, also at 12° pile-up is still significant: while the measured average number of hits per track is about 6.5, the expected average number of primary electrons is about 11. The low diffusion of the DME/CO_2 mixture and the short drift distance result in a higher pile-up than for commonly used drift chamber gases.

The Gossip used for the angular measurements had a drift gap of 1.5 mm. It was operated at a grid voltage of -530 V. We defined the beam tracks by fitting a straight line through the crossing point with the Gossip under test and that of another Gossip having a drift gap of 19.3 mm. Although this Gossip, that was placed 30 cm downstream, had rather poor single electron efficiency (about 40%), it had excellent track detection efficiency because of its large drift gap.

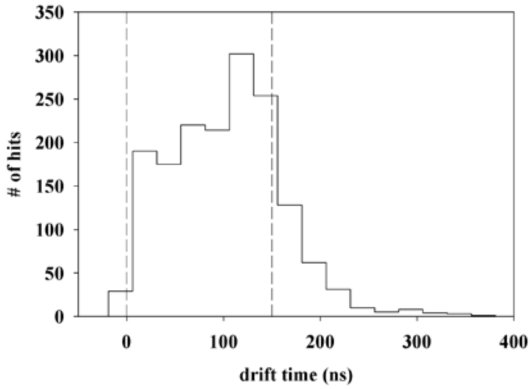

Figure 4. Measured drift time histogram using 25 ns binning.

Unfortunately the resolution in Z was considerably worse than anticipated, a phenomenon that can be understood from time-slewing of the pixel chip which is visible in the drift time spectrum in Fig. 4. Ideally, the drift time histogram should have a rectangular shape between 0 and 150 ns, based on the drift velocity of 10 μm/ns and the 1.5 mm drift gap. This area is indicated by the dashed reference lines. But the spectrum has a tail of longer drift times exceeding 100 ns from the expected area due to the finite rise time of the TimePix-1 chip (80 - 120 ns) 6] and the amount of additional charge needed to let the discriminator fire. Note that the TimePix-1 chip is derived from the MediPix-2 CMOS chip 10] that is designed for X-ray applications where signal timing does not play an important role.

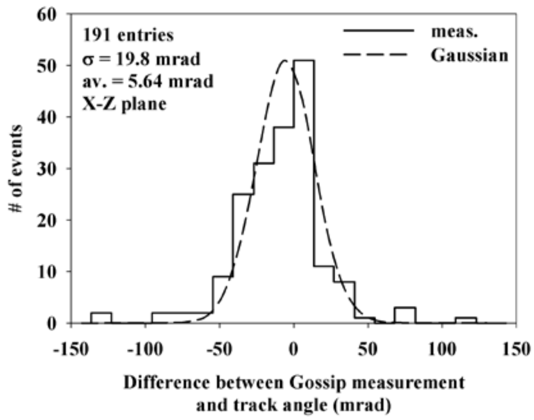

Figure 5. Measured angular resolution in the X-Z plane.

Figure 5 shows the angular resolution in the X-Z plane. Events of only one hit pixel (2.5%) were excluded from the analysis. The angle of incidence is about zero, so inaccuracy of the Z-measurement does not affect the result. But we also profit from the increased number of hits by the angle of 12° in the Y-Z plane. The angular distribution is more or less Gaussian with $\sigma \approx 20$ mrad around a centre value of 5.6 mrad of the Gaussian fit. Note the pronounced peak at 0 mrad, an artefact from events having exclusively pixel hits at the same X-coordinate.

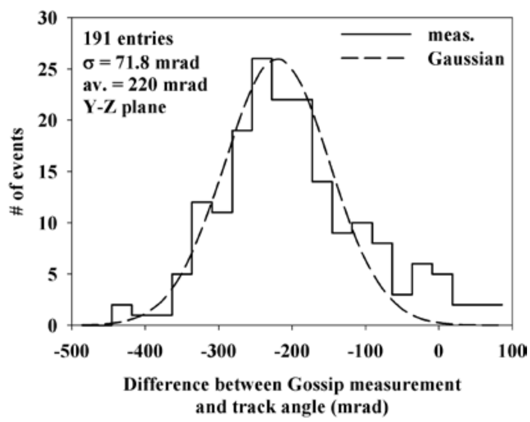

Figure 6. Measured angular resolution in the Y-Z plane.

In the Y-Z plane (Fig. 6) the measured distribution is much broader with $\sigma > 70$ mrad. Here the poor accuracy of the Z coordinate deteriorates the accuracy of the angular measurements. Note that the distribution is not completely symmetrical. The tail at angles around 0 mrad is caused by single electron hits with high Z values from a big slewing delay, diminishing the angle fit.

The angular resolution for a Gossip detector has been simulated 11] for the same gas mixture but smaller gas-gap (1 mm) and higher drift field, giving more diffusion. Here a resolution of about 40 mrad was found for incident angles between 0 and 45° using a pixel chip with a good Z accuracy. The simulations will be redone with the current detector and operating point to check how well the 20 mrad resolution can be understood.

4. CONCLUSIONS

For almost perpendicular angles of incidence, the Gossip detector filled with the low-diffusion DME/CO_2 mixture gives a very good angular resolution, taking into account that this originates from track lengths of only 1.5 mm. The additional angular information of Gossip is a great help for track reconstruction.

The angular resolution at 12° is worse due to the bad timing properties of the TimePix-1 chip. The TimePix-2 chip, which is presently in development, should correct this and give 20 mrad resolution over a wide range of incident angles. The frontend circuit of this chip has a clock frequency of 650 MHz while the rise time of the shaping circuit is reduced to about 10 ns.

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