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Simulation for ATLAS nSW Thin Gap Chambers

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The LHC will be upgraded in several phases with the goal of obtaining an instantaneous luminosity of $5-7\times10^{34}cm^{-2}s^{-s}$ at the center of mass energy of $14TeV$ and integrated luminosity of $3000 fb^{-1}$. In order to profit from the high luminosity and high energy runs of the LHC, the ATLAS collaboration plans to upgrade the present endcap small wheel muon spectrometer to improve the muon triggering as well as precision tracking. The proposed New Small Wheel (nSW) will be composed of two four-layer Micromegas detectors (MM) detector sandwiched between two four-layer small-strip Thin Gap Chambers (sTGC) quadruplets, where MM for precision tracking and sTGC for Level-1 triggering. In this paper, we focus on the Garfield [1] simulation of the sTGC detector to understand its timing performance and charge production. We also studied the sTGC timing under different magnetic fields and high voltages. These studies provide important guide lines for the sTGC detector and electronics development.

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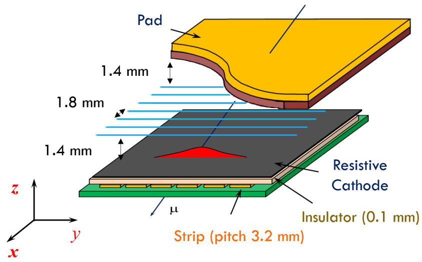

Figure 1: The structure of the proposed sTGC detector.

1. Introduction

A schematic view of the sTGC structure is shown in Fig. 1. The basic sTGC structure consists of a group of $50\mu m$ gold-plated tungsten wires (anode) with a $1.8mm$ pitch, sandwiched between two cathode planes at a distance of $1.4mm$ from the wire plane. The cathode planes are made of a graphite-epoxy mixture with typical surface resistivity of $100k\Omega/\square$ sprayed on a $100\mu m$ thick G-10 plane. Strips and pads are located on the opposite side of the sTGC detector, on a $1.6mm$ thick PCB with shielding ground on the other side. The strip pitch is $3.2mm$ ($2.7mm$ strip width + $0.5mm$ gap), and the pad size is about $8.7cm \times 8.7cm$. The operational gas is a mixture of CO_2 and n-pentane (C_5H_{12}) with a ratio of 55:45 at one atmospheric pressure.

2. Electric field simulation

The electric field inside the chamber is simulated using both the Maxwell [2] program based on a finite element method (FEM), and the neBEM package [3] using the nearly exact boundary element method. A field strength of a few kV/cm up to a few hundred kV/cm is seen for most regions. The electric field is more than $1kV/cm$ in 97% of the gas volume, with the weakest field only in a small region in the middle of the two neighboring wires. The electron avalanches are usually developed within a few tens of microns close to the wire where strong electric fields are present.

3. Ionization, electron transportation and charge production

Ionizations occur when a charged particle passing through the gas gap and transfers energy to gas molecules. In most of cases the knocked-out electrons have very short ranges and form a "cluster" near the interaction point. The number of clusters produced follows a Poisson distribution.

Ionized electrons will drift along the electric field towards the electrodes, and also diffuse laterally and longitudinally with respective to the electric field direction. The simulated electron drift velocities in a mixtures of CO_2:n-pentane (55:45) at 1 atm pressure are found in a good agreement with the measured data, with a electric field up to $10kV/cm$ [4]. The typical drift velocity is a few $cm/\mu s$ in most of space in sTGC chamber, and the transverse diffusion is less than $40\mu m$ over $1.4mm$ drift length. With a typical field strength of a few kV/cm in the most of the chamber, the contributions from the attachment process are negligible. In the present of a magnetic field

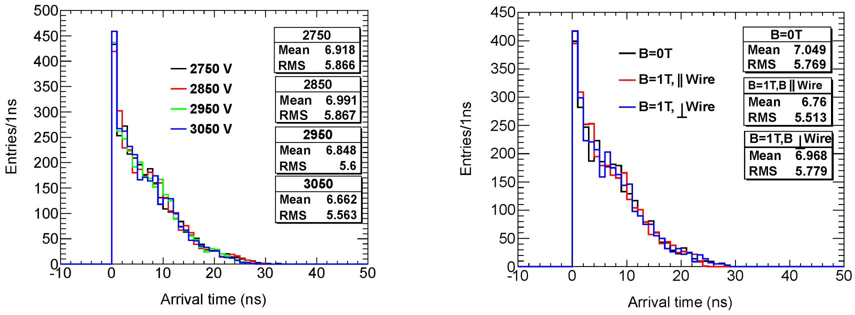

Figure 2: Earliest cluster arrival time distributions for different high voltages (left) and under B field (right).

orthogonal to the electric field direction up to 1T, the Lorentz angles are below 7°, and the its modification on the drift velocity is found to be negligible.

The electron avalanche process could happen within the space $20\mu m$ around the wire, the avalanche fluctuation of a single electron could be described by Polya distribution [5] – $P(n|\bar{n}) = \frac{1}{\bar{n}}\frac{\theta^{\theta}}{\Gamma(\theta)}\left(\frac{n}{\bar{n}}\right)^{\theta-1}e^{-n\theta/\bar{n}}$. When the $HV = 2.7kV$, the fitted parameter of Polya function are $\bar{n} = 1.307\times10^{4}$ and $\theta = 1.713$.

4. Timing performance

The timing performance of sTGC is crucial for Level-1 triggering to enable the detector to identify single bunch crossing at a collision rate of $40MHz$. The jitter of the detector response time mainly arises from the variation of the drift time of electrons generated in different places along the charged particle track. Due to the strong electric field near the wire and the relatively low electronics threshold (fC), the first few clusters near the wire usually create a signal exceeding the discrimination threshold. Therefore the physical limit of the time jitter will be mainly determined by the earliest cluster arrival time. The simulated earliest cluster arrival time distributions have been determined by tracking individual clusters and are shown in Fig. 2. The timing distribution with and without a magneic field are found to be very close.

5. Conclusion

Extensive simulations, including the electric field inside the chamber, electron transportation properties and charge production are performed in order to understand the operational principles of the sTGC detectors for the ATLAS nSW muon detector upgrade. Due to the strong electric field and small gas gap, most of the ionized electrons generated in the chamber will reach the wire within a few tens of nanoseconds. These features result in small time jitter together with fast collection of electron induced charges. Owing to the small Lorentz angle in the CO_2:n-pentane (55:45) gas mixture, the timing performance of sTGC are not expected to be affected by the presence of the magnetic field in the nSW. Results indicate that more than 95% of the total events can be identified within 25 ns in a single detector layer and thus fulfills the requirements for Level-1 triggering.

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