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 $5 - 7 \times 10^{34} \text{cm}^{-2}\text{s}^{-1}$ at the center of mass energy of 14 TeV 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 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.
1. Introduction

A schematic view of the sTGC structure is shown in Fig. 1. The basic sTGC structure consists of a group of 50µm 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 100kΩ/□ sprayed on a 100µm thick G-10 plane. Strips and pads are located on the opposite side of the sTGC detector, on a 1.4mm 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 × 8.7cm. The operational gas is a mixture of CO₂ and n-pentane (C₅H₁₂) 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 CO₂: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/µs in most of space in sTGC chamber, and the transverse diffusion is less than 40µm 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...
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 20µm around the wire, the avalanche fluctuation of a single electron could be described by Polya distribution \[ P(n|\bar{n}) = \frac{\theta^n}{\bar{n}^n \theta^n} \left( e^{-\frac{n}{\bar{n}}} - 1 \right) \]. When the HV = 2.7kV, the fitted parameter of Polya function are \( \bar{n} = 1.307 \times 10^4 \) 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 magnetic 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 CO₂: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.
References


