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Study and optimization of the spatial resolution for detectors with binary readout

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ABSTRACT

Using simulations and analytical approaches, we have studied single hit resolutions obtained with a binary readout, which is often proposed for high granularity detectors to reduce the generated data volume. Our simulations considering several parameters (e.g. strip pitch) show that the detector geometry and an electronics parameter of the binary readout chips could be optimized for binary readout to offer an equivalent spatial resolution to the one with an analog readout. To understand the behavior as a function of simulation parameters, we developed analytical models that reproduce simulation results with a few parameters. The models can be used to optimize detector designs and operation conditions with regard to the spatial resolution.

1. Introduction

In large experiments, comprising hundreds or thousand of detection elements, it is sometimes more advantageous to use a binary readout electronics than an analog one. Indeed it is not always feasible to integrate an analog-to-digital converter in each channel of the front-end ASIC; the constraints are typically associated with the total area of the integrated circuit and with the power consumption. With a binary readout the cost of an increased number of readout channels would then be balanced by a simpler readout circuitry. In addition the data volume is much smaller with a binary readout.

For many applications one can use the binary readout architecture. In this architecture each channel of the front-end electronics is equipped with an amplitude discriminator which generates 1-bit information in response to each signal above a given threshold. The information delivered by a strip detector is suppressed to the minimum already in the front-end circuit. Binary information can be easily stored in the integrated circuit separately for each channel, which allows one to cope with high rate of particles.

Another important concern for tracking detectors is the spatial resolution; however, it is not trivial if signal charges are shared with more than one readout strip. In this paper, we estimate by Monte Carlo simulations and analytically the spatial resolution with a binary readout for three types of detectors: silicon sensor, Micromegas, and GEM-based detectors.

This paper is organized as follows. Section 2 introduces a detector model and the technologies we refer to in this paper. Section 3 describes how our simulations work and presents a simulation result, followed by discussions with our analytical models in Section 4. A conclusion is given in Section 5.

2. Detector model

Let us begin by describing a simple detector model with some parameters with which different types of detector technologies are distinguished from each other. The detector model consists of the drift region and the induction region, which are separated by an amplification step (Fig. 1). The drift region is the sensitive part of the detector and the induction region is the volume where the signal is induced to the electronics. The drift region and the induction region have a parametrized size. The other end of the induction region is equipped with the electrode strips with the pitch p. The strips are to be connected to the readout electronics.

Those detectors are used to reconstruct the position of a 'charged particle track'. The position of a track is defined as the midpoint of the track segment in the drift region and is referred to x_{track} in this study. Note that x_{track} can be always defined from the center of the nearest strip to the track position and thus $-p/2 \le x_{track} \le +p/2$.

The parameters used to compute the spatial resolution in this

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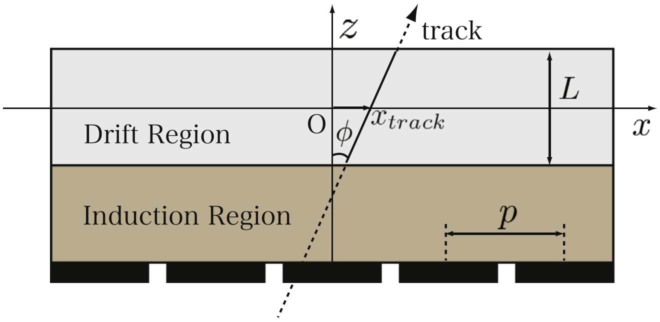

Fig. 1. A cross section of the detector model. In this report, only $\phi=0$ condition is considered.

study are the number of primary electrons and the gap of drift region L, the gap of the induction region, the track incident angle ϕ from the vertical axis (z) to the strip plane, the transverse diffusion coefficient C_d:$=\sigma_d/\sqrt{z}$ with σ_d being the diffusion width of an electron cloud which has drifted over a length z, namely C_d^{dr} for the drift region and C_d^{in} for the induction region, and an electronics threshold.

2.1. Micromegas

The Micromegas (MICRO MEsh GAseous Structure) concept was introduced in 1996 by Giomataris et al. [1]. The detector is filled with gas mixtures and charged particles create seed electrons, which will contribute to inducing signals, along their trajectories by ionizing the gas molecules. The created electrons in an electric field drift toward the anode plane, above which a cathode grid is placed (Fig. 2). This grid is maintained at 100 μm of the anode plane. A voltage of typically −400 V is applied to the grid and the anode plane is grounded via the readout electronics to create an electric field of about 40 kV/cm. This space, between the grid and the anode plane, define the volume of amplification which coincides with the induction region, in this case.

2.2. GEM

The GEM (Gas Electron Multiplier) concept was proposed in 1997 by Sauli [3]. The detector has the same sensitive volume as the Micromegas but has a different amplifying structure. The GEM consists of a 50 μm Kapton foil, copper cladded on both sides, chemically pierced with a high density of micro-holes (typically 50–100 holes per cm^2). The holes have a bi-conical shape and have a diameter of about 50 μm. Fig. 3 shows a SEM image of a GEM surface with its dimensions (Left) and the electric field lines in GEM holes (Right). The detector is typically built with multiple GEM layers (generally two or three) to achieve stable amplification or to reduce ion back-flow rate, which ions degrade detector performance.

2.3. Semiconductor detectors

The most important difference compared to Micromegas and GEM-based detectors is that a silicon detector uses a semiconductor material for its sensitive volumes instead of gas mixtures. Since the semiconductor has a factor 10 smaller ionization potential than gas, modern low-noise electronics can read out signals without amplification contrary to the gas-based detectors.

There is neither amplification nor induction region. The induction region coincides with the sensitive region also called the drift region (see our detector model above). Fig. 4 shows a schematic drawing of a semiconductor detector.

3. Simulation

A simulation of the detector has been developed following the model described before. We fix a simple geometry (the gap sizes, the pitch, and diffusion coefficients, etc.), then we create a track. Electrons are created along the track in the drift region. Those electrons drift and diffuse until the amplification region. Each electron arriving at the amplification region is multiplied by the gain g. After amplification, all electrons drift and diffuse until the strip plane.

We will now describe in details the implementation of all those steps in the simulation.

3.1. Charged particle track

We will first discuss the case of incident tracks perpendicular to the strip plane ($\phi=0°$), then we will discuss the angular case.

The straight track is defined by a number of electron clusters uniformly distributed in the drift region and with $x = x_{track}$.

It is well known that the detector medium affects the total number of ionized electrons, for instance, ~100/1 cm for MIP in Ar gas, ~10,000/100 μm for MIP in a silicon sensor. To take this fact into account in the simulation, the parameters for the gas-based and the semiconductor detectors are not the same.

For the gas-based detectors the number of clusters is taken randomly on a Poisson distribution with a mean value equal to 12, which is obtained from *Magboltz* [5] for a 3 mm argon based gas

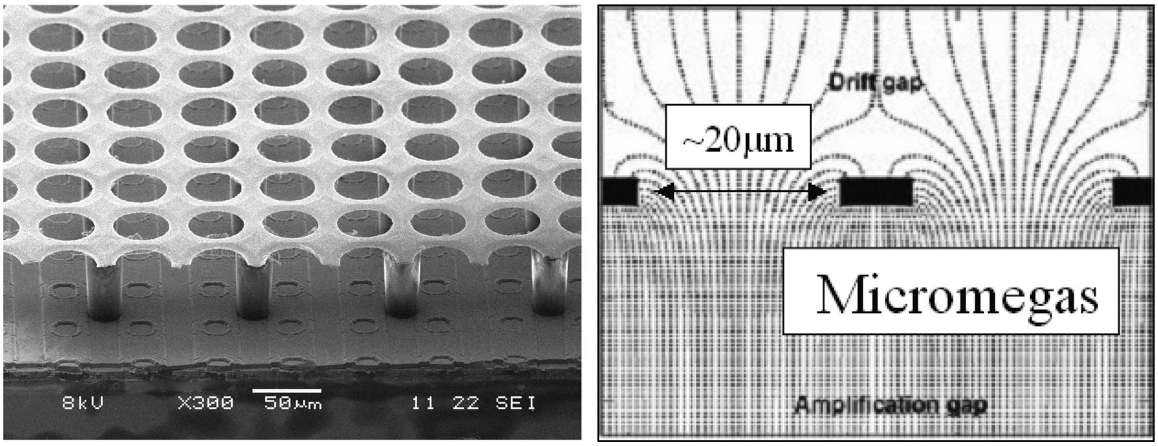

Fig. 2. SEM image of a Micromegas structure (Left) [2].The electric field lines around the Micromegas grid (Right).