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A gating grid driver for time projection chambers

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ABSTRACT

A simple but novel driver system has been developed to operate the wire gating grid of a Time Projection Chamber (TPC). This system connects the wires of the gating grid to its driver via low impedance transmission lines. When the gating grid is open, all wires have the same voltage allowing drift electrons, produced by the ionization of the detector gas molecules, to pass through to the anode wires. When the grid is closed, the wires have alternating higher and lower voltages causing the drift electrons to terminate at the more positive wires. Rapid opening of the gating grid with low pickup noise is achieved by quickly shorting the positive and negative wires to attain the average bias potential with N-type and P-type MOSFET switches. The circuit analysis and simulation software SPICE shows that the driver restores the gating grid voltage to 90% of the opening voltage in less than 0.20 μs, for small values of the termination resistors. When tested in the experimental environment of a time projection chamber larger termination resistors were chosen so that the driver opens the gating grid in 0.35 μs. In each case, opening time is basically characterized by the RC constant given by the resistance of the switches and terminating resistors and the capacitance of the gating grid and its transmission line. By adding a second pair of N-type and P-type MOSFET switches, the gating grid is closed by restoring 99% of the original charges to the wires within 3 μs.

1. Introduction

Since its invention [1], Time Projection Chambers (TPCs) have been used successfully in many experiments to measure charged particles emitted in nuclear collisions, using devices such as the EOS TPC [2,3], the CERES/NA45 Radial Drift TPC [4], the NA49 large acceptance hadron detector [5], the STAR detector at Relativistic Heavy Ion Collider (RHIC) [6] and the ALICE detector at the Large Hadron Collider (LHC) [7,8]. In this article, we will use the SAMURAI Pion-Reconstruction Ion-Tracker Time Projection Chamber (SπRIT-TPC) [9], designed for use with the SAMURAI spectrometer at the Radioactive Isotope Beam Factory (RIBF) at RIKEN, Japan [10] to illustrate the properties of the new gating grid driver.

The operation principle of a TPC and its wire planes are illustrated in Figs. 1 and 2.Fig. 1 shows a TPC field cage, which is filled with counter gas. Electrodes on the walls of the field cage provide a uniform electric gradient potential within the cage. The TPC is normally placed inside a uniform magnetic field, which is anti-parallel to the electric field. The magnetic field allows the determination of the momenta of charged particles and has the ancillary benefit of improving the resolutions of particle tracks by limiting the diffusion of drift electrons in directions perpendicular to the magnetic field.

When a violent heavy-ion reaction occurs, fast charged particles are produced in the target, which is located just outside of the upstream window of the field cage. These charged particles enter the field cage through the window and ionize the detector gas, liberating electrons that will be referred to as drift electrons. These drift electrons move along the anti-parallel electric and magnetic fields towards a set of three wire planes located at the top of the field cage. The wire planes are not visible in Fig. 1, but their functions are illustrated schematically in Fig. 2, in which the wires are drawn larger than scale to make them more visible. The 3 layers of wire planes are mounted just below a pad

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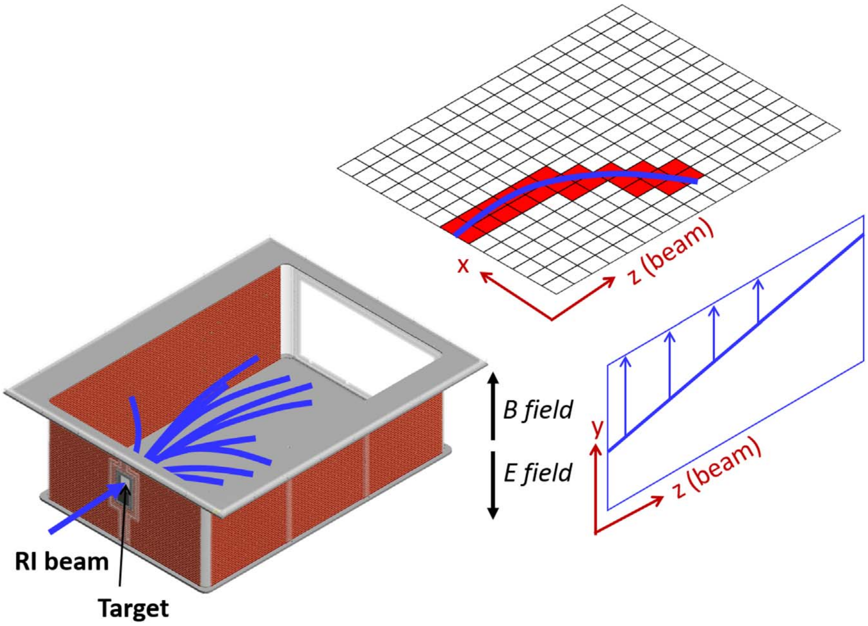

Fig. 1. Schematic representation of tracks of charged particles in the field cage of a TPC. The field cage provides a uniform electric field, E. Momenta of the particles can be obtained by placing the TPC inside a uniform magnetic field, B that is anti-parallel to E. By requiring uniform and anti-parallel fields E and B fields, one minimizes E×B forces on the drift electrons and improves the reconstruction of the tracks.

plane tiled with pads. This pad plane forms the upper boundary of the field cage volume, and the bottom boundary of the field cage is the cathode. By measuring the arrival time and the induced charge of the avalanche electrons produced around the anode wires, the TPC provides an accurate 3-D reconstruction of these tracks in the gas, from which the particle momenta and the energy loss of each charged particle detected in the counter gas can be deduced.

In many TPC applications, there are charged particles that enter the field cage that are not of scientific interest. In the SπRIT TPC experiments [9,11], these include beam particles that do not interact with the target or large projectile residues from very peripheral collisions. It is important to prevent the gas multiplication of the drift electrons from such undesired particles. Amplification of undesired events will accelerate the aging process of the anode wires by creating negatively charged polymers from the hydrocarbon components or impurities in the detector gas. If the deposition of such polymers on the anode wires is not controlled, the effective anode wire diameters can increase with time due to the deposit, reducing the gas gain and deteriorating the performance of the TPC [12].

To suppress the detection of unwanted particles, it is essential that the wire plane closest to the drift region, called the gating grid, remains “closed” to drift electrons resulting from the unreacted beam and other uninteresting events. In this closed state, as illustrated in the left panel of Fig. 2a, the gating grid captures the drift electrons produced in the field cage volume. When the external trigger detection system indicates the occurrence of an interesting event, the gating grid is opened as illustrated in Fig. 2b (right panel). Then, the drift electrons pass through the gating grid, and then through the ground wire plane, to reach the anode wires located between the ground plane and the pad plane. These drift electrons will then trigger an avalanche in the high electric field region of the anode wires, which multiplies the electrons by a typical gas gain of about 2000 depending on the anode voltage.

This avalanche also produces positive ions, whose motions away from the anode wires generates image currents on the pad plane as illustrated in Fig. 2b. These currents are amplified by the TPC electronics located above the pad plane and are recorded. After their

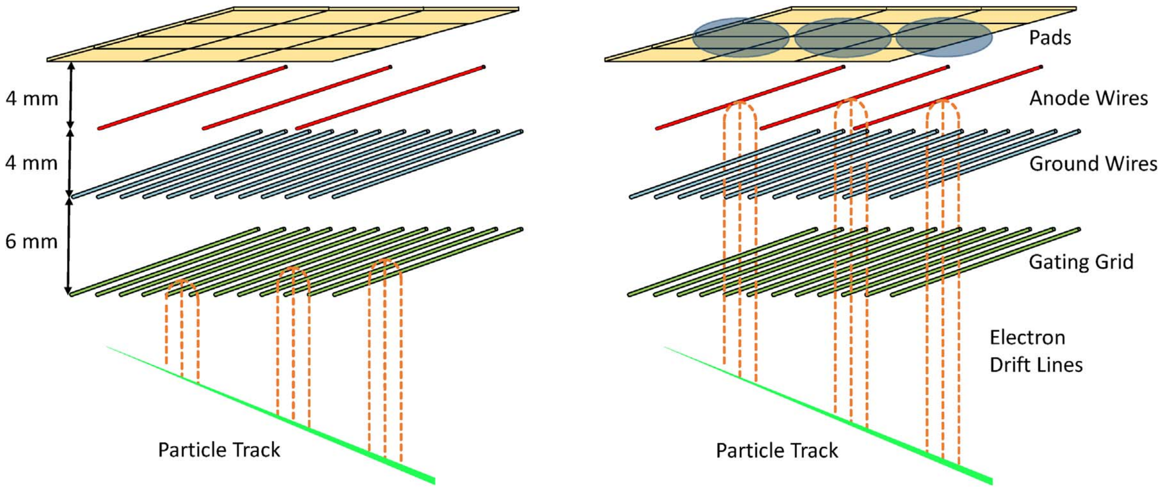

Fig. 2. A cartoon illustrating the closed (left panel) and open (right panel) state of the gating grid. For ease of viewing, the wire diameters and heights shown are not to scale. The wires run parallel to the x-axis. The z-axis defined by the beam in the direction of the particle track is orthogonal to the wires. The drift time of the electrons to the anode plane provides the vertical (y) location of the ionization track and the induced charge of the electrons at the pad plane provides the horizontal locations of the ionization track.