Spatial resolution of triple-GEM detectors

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Abstract

electron Multiplier (GEM) detectors are widely used in numerous collider experiments and, in particular, at the Budker Institute of Nuclear Physics (BINP). Thus, limits of spatial resolution, achieved by these detectors, are of significant interest. In order to determine the best possible spatial resolution, the simulation of charged particle registration process was accomplished. The simulation of applied detector configurations includes transport of electrons through the detector and tracking of avalanche evolution inside the working volume, as well as obtaining signal distributions along the readout strips. The simulation shows that spatial resolution is definitely less than 50 microns for applied detector configurations. The simulation of electron transport through single GEM and through GEM-cascade showed that an electron cluster is compressed by GEM holes and an effective transverse diffusion is reduced. The experimental part of the work is devoted to the operability tests of the designed detector for the Extracted Beam Facility (EBF-detector) at VEPP-4M collider with orthogonal strips readout with a pitch of 250 μm and the measurements of its characteristics including the dependence of gain on EGM-voltage, the detection efficiency and the spatial resolution.

Introduction

Charge particle tracking detectors based on Gas Electron Multiplier (GEM) [1] are used in several projects [2] at the Budker Institute of Nuclear Physics. Firstly, they operate at the Tagging System of the KEDR experiment at the electron-positron collider VEPP-4M since 2010 [3]. Secondly, GEM-based detectors are included in the Photon Tagging System of the KATRIN facility at VEPP-3 storage ring [4]. The readout in these detectors is provided by straight and inclined strips with a pitch of 500 μm. A new detector for Extracted Beam Facility at VEPP-4M collider [5], having orthogonal strips with a pitch of 250 μm, was assembled and its characteristics were measured.

The present work is aimed to study the limits of spatial resolution of the triple-GEM detector. For this purpose the simulation of different detector configurations in order to find the parameters providing the best spatial resolution was developed. The results of simulations are compared with the measurements performed with the detector.

Simulation with GEANT4 and HEED

The simulation study of spatial resolution of the triple-GEM detector is performed in two stages. At first, primary 1 GeV electrons with momentum perpendicular to the detector plane and randomly distributed initial transverse coordinates in the detector plane are transported through the complete model of the detector (described in GEANT4). After recording of all energy depositions in the drift gas (filled with CO2 gas), the second stage is started that includes introduction of electrons, gas gain fluctuation, distribution of signal between readout strips, accounting of electrons noise and calculation of the measured track position with Center of Gravity (CG) method.

The coordinate of the track, passing through the simulated detector is known exactly. This simulation of individual strips was aimed at optimization purposes and is intended for search of the best possible value of spatial resolution with parameters, providing this value.

The diffusion coefficient, set in the simulation, is of significant interest because standard values, which could be found in the literature, are not fitted for the discussed simulation because the influence of GEM operation should be taken into account. Thus additional study was provided in order to find the coefficient of effective transverse diffusion (see the next section).

In the first phase of the simulation the obtained value of effective transverse diffusion 300 μm/√G [7] is set to the simulation of detector response, the following results are obtained (Fig. 1). The simulation was provided for two types of readout structure. First, DEUTERON type of readout structure was simulated as a sequence of strips with a pitch of 500 μm and 250 μm width. Exactly three signal strips were accounted in the COG calculation. Second, EBF type of readout structure was simulated as a sequence of strips with a pitch of 250 μm and width 250 μm. Number of signal strips was 8 and determined by the threshold of 3 standard deviation of noise distribution (3σnoise) [6] on strips.

The results of simulation in Fig. 2 show that the expected spatial resolution in the case of DEUTERON detectors is 0.99 μm. The result is expected due to the limited signal of 3σnoise on strips in the COG calculation, in case of EBF detectors the expected spatial resolution is 1.87 μm which is worse than for DEUTERON detectors. The result show that algorithm gain calculation without fixed number of strips works better (resolution is better) for wide range of strip pitch.

Detector description

The readout strip structure of the detector, used for the measurements, is produced on 50 μm thick kapton foil, and all copper layers on GEM and readout foil (Fig. 4) are reduced as much as possible to decrease the amount of material. Earlier experiments on the measurement of the amount of material demonstrated that expected value of material budget (X/X0) of studied detectors is in the range 0.25% - 0.30%.

The readout structure consists of two layers. The strips width of the top layer is 50 μm. Strips of the bottom layer are orthogonal to the top ones with a width of 170 μm and the same pitch 250 μm. The distance between top and bottom layers is 50 μm. The configuration of the readout structure make charge being distributed equivalently between layers.

In order to provide the detailed simulation for effective transverse diffusion distribution, thousands events of 1 GeV electron penetration through the drift gap of the detector were generated in GEANT4 program. In Fig. 2, the spatial distributions of electrons are depicted. Then these electrons were transported (Fig. 3) through 5 cascades of GEMS with Garfield++ program in the presence of electric fields, calculated beforehand in the ANSYS program.

Experimental results

Electron beam with 3 GeV energy was used in the measurements. The same voltage was applied for all three GEMS in cascade. The dependence of the detector gain on signal distribution is shown in Fig. 6. The detector works in the proportional regime achieving gain of 5·106. Detection efficiency exceeds 99.5% for gain higher than 1·104.

Conclusions

1. The coefficient of effective transverse diffusion, obtained in the detailed simulation of electron transport in the detector is 300 μm/√G [7].
2. The effect of electron transport through detector and multiple scattering in the material of detector was limited up to 15 μm.
3. The simulation of detector response shows essential influence of COG calculation on the spatial resolution. At the same time, physical minimum of spatial resolution of 10 – 15 μm level is determined by delta-electron space distribution.
4. Detector for extracted beam facility with 250 μm strip pitch (EBF-detector) demonstrates stable operation with gas gain up to 5·106 and the detection efficiency exceeding 99% for standard operational parameter regime.
5. Spatial resolution of EBF-detector is measured as 3.1 ± 1.7 (stat.) ± 0.4 (syst.) μm.

The angular dependence of spatial resolution is in the agreement with the expectations.

References:

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