Nuclear Instruments and Methods in Physics Research A ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Study of spatial resolution of coordinate detectors based on Gas Electron Multipliers

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ARTICLE INFO

Article history:
Received 14 March 2016
Accepted 13 June 2016

Keywords:
Micro-Pattern Gaseous Detectors
Gas Electron Multiplier

ABSTRACT

Spatial resolution of GEM-based tracking detectors is determined in the simulation and measured in the experiments. The simulation includes GEANT4 implemented transport of high energy electrons with careful accounting of atomic relaxation processes including emission of fluorescent photons and Auger electrons and custom post-processing with accounting of diffusion, gas amplification fluctuations, distribution of signals on readout electrodes, electronics noise and particular algorithm of final coordinate calculation (center of gravity). The simulation demonstrates that the minimum of spatial resolution of about 10 μm can be achieved with a gas mixture of Ar – CO_2 (75–25 %) at a strips pitch from 250 μm to 300 μm. At a larger pitch the resolution quickly degrades reaching 80–100 μm at a pitch of 460–500 μm.

Spatial resolution of low-material triple-GEM detectors for the DEUTERON facility at the VEPP-3 storage ring is measured at the extracted beam facility of the VEPP-4 M collider. One-coordinate resolution of the DEUTERON detector is measured with electron beam of 500 MeV, 1 GeV and 3.5 GeV energies. The determined value of spatial resolution varies in the range from approximately 35 μm to 50 μm for orthogonal tracks in the experiments.

1. Introduction

Charge particle tracking detectors based on GEMs (Gas Electron Multipliers) [1] are used in several projects [2] at the Budker Institute of Nuclear Physics in Novosibirsk, Russia. Parameters of two types of GEM-based detectors are studied in this article. Detectors of the first type operate at the Tagging System of KEDR experiment (KEDR TS) at the electron-positron collider VEPP-4 M [3,4]. Detectors of the second type belong to the photon tagging system (PTS) of the DEUTERON facility at VEPP-3 storage ring [5,6].

KEDR TS detector is used to study two-photon processes, occurring in the case of interaction between electrons and positrons. Obtaining the information about kinematics of two-photon reaction is provided by measuring parameters of scattered electron and positron. Experiments at the DEUTERON facility, focused on the study of photo-nuclear processes, are associated with the introduction of an almost-real photon tagging system (PTS). The PTS will give the possibility to perform new measurements of the polarized observables in photo-nuclear reactions with higher photon energies – up to 1.5 GeV.

The difference between these two detector types arises mostly from the amount of material, which they possess. The total number of radiation lengths in the detector for KEDR TS is ~0.7 % of radiation length (X_0) and for the DEUTERON PTS this value is equal to $(0.24 \pm 0.05)\%\ X_0$. This particular study was inspired by the question of what is the physical limit of spatial resolution of the detectors consisting of triple-GEM cascades. In this article we describe the simulation study of the spatial resolution as a function of different detector parameters and a set of measurements with the low-material detectors.

2. Simulation

The simulation study of spatial resolution of the triple-GEM detectors was performed in two stages. At the first stage, the primary 1 GeV electrons with momentum perpendicular to the detector plane and randomly distributed initial transverse coordinates in the detector plane were transported through the complete model of the detector, which included honeycomb covered with drift electrode, drift (3 mm), two transport (each 1.5 mm width) and induction (2 mm width) gas gaps, GEMs and readout structure on glass fiber plate (thick version of the detector or regular layout).

Thin simulated version of the detector included only 3 mm gas gap. After recording of all energy deposition parameters in the

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http://dx.doi.org/10.1016/j.nima.2016.06.066
0168-9002/

drift gap, the second stage was started which included the introduction of electrons diffusion, gas gain fluctuation, distribution of signal between readout strips, accounting of electronics noise and calculation of the measured track position with center of gravity (COG) method.

The magnitude of the transverse electron diffusion of 170 $\frac{\mu m}{\sqrt{cm}}$ in the gas was taken in accordance with [7] for applied electric fields within the detector. Noise signals of readout electronics were introduced in the simulation by adding a random value to the final magnitude of the induced charge on each of the signal strips. This random value had Gaussian distribution centered at zero and a standard deviation, which could be varied. The noise (its standard deviation) for each simulation was calculated on the basis of knowledge of the average energy deposition in the drift gap and on the defined signal to noise ratio. The values of the signal to noise ratio in the simulation were changed, covering the experimental range.

Fluctuation of gas amplification coefficient were artificially introduced by multiplying the amount of energy deposition from each event by random variable having a Gaussian distribution with a mean equal to one and a standard deviation, which was a parameter. This parameter was taken equal to 12% of the average value of the energy deposition. This value was selected according to the experimental data from [8] for the study of photon absorption processes in the detector based on a triple-GEM cascade, which obtained the energy resolution of 30% (FWHM).

Firstly, it was determined that the effect of low material on spatial resolution is marginal and is only pronounced at strip pitches smaller than 300 μm [9]. However, all further simulation results were obtained for the regular detector layout.

The simulation of thick (regular) version of the detector was carried out in two ways. In the first case the coordinate of a track, passing through the studied detector was known exactly. In the second simulation the whole experimental set-up with two tracking and one studied detectors was arranged. Thus, the coordinates of a track were known with some errors.

In the first case the detector of KEDR TS was studied by simulation techniques. For this type of detectors a signal, induced on straight strips, is known to be equal to one third part of a total energy deposition in one event [4]. Therefore, the readout structure in the simulation constituted an array of adjacent elongated rectangles having the same geometrical dimensions. Each third rectangle served as a signal strip and the other area was not sensitive to signal. Each second rectangle served as a signal strip for the DEUTERON PTS GEM-based detector, whose readout structure was applied for the simulation of the whole set-up. These arrangements in the simulation provided correct amount of charge accounted by the readout structure.

The results of the first and the second types of the simulation are presented in Figs. 1 and 2 respectively. The results of the simulations presented in Fig.1 show that the best resolution of 10–15 μm can be achieved for strip pitch of 250 μm. For larger pitch the resolution degrades and the results of the simulation are worse than the experimental data. The simulation of individual detector aimed at optimization purposes and was intended for search of the best possible value of spatial resolution with parameters, providing this value.

Nevertheless, in the real measurements an electron track position is not known exactly because of limited spatial resolution of tracking detectors implemented. Furthermore, the multiple scattering effect in the studied detector has to be taken into account while track reconstruction. Consequently, the whole set-up has to be described in the simulation in order to compare the simulation results with experimental data.

Simulated spatial resolution of regular GEM-based detector, obtained for the case of the whole set-up, does not reach

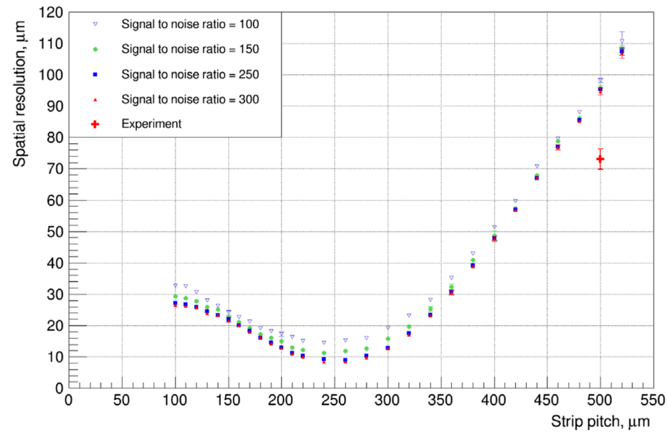

Fig. 1. Simulated spatial resolution as a function of strip pitch for the readout structure of KEDR TS detectors. Points of different colors correspond to different signal to noise ratio. A distinct detector is simulated. Experimental point is taken from [4]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

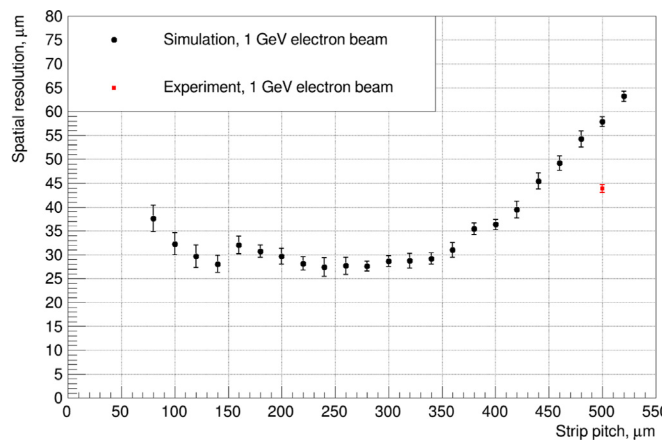

Fig. 2. Spatial resolution as a function of strip pitch for the readout structure of the DEUTERON PTS detectors [6], obtained in the simulation of the whole experimental set-up, and the result of the measurements. Both after correction for multiple scattering and limited resolution of the tracking detectors.

minimum of 10 μm as it used to be for the simulation of a single detector. Instead, minimal one-coordinate resolution achieves value of about 30 μm for the strip pith of 350 μm and below.

The correction on multiple scattering and limited coordinate resolution of the tracking detectors was provided while obtaining the mentioned values. The correction on multiple scattering effect was done by quadratic subtraction of a multiple scattering contribution to the track coordinate error. This subtracted value was calculated according to the knowledge on the amount of material in the studied detector and the distances between applied detectors.

The correction on limited coordinate resolution of the tracking detectors was done by dividing the value of spatial resolution (with multiple scattering effect being accounted for) by $\sqrt{3/2}$, which arises from statistical reasons (three detectors) and the assumption of equality of all the coordinate detectors spatial resolution. Consequently, it is the value which can be measured in the experiment for the mentioned configurations.

3. Experimental results

Amount of material and spatial resolution for triple-GEM detectors for the DEUTERON photon tagging system (Fig. 3) (PTS)