Limits of a spatial resolution of the cascaded GEM based detectors

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Abstract

Charge particle tracking detectors based on triple-GEM cascades are used in several projects at the Budker Institute of Nuclear Physics. This study was inspired by the question of what is the physical limit of spatial resolution of this kind of detectors. Spatial resolution of GEM based tracking detectors is simulated and measured. The simulation includes GEANT4 based 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 effect of electron cloud broadening due to a GEM operation is considered using ANSYS and Garfield++ simulation programs. Arguments on significant influence of this effect on spatial resolution are given. Detection efficiency and spatial resolution of two low-material triple-GEM detectors for the DEUTRON facility (Detectors №3 and №4) at VEPP-3 storage ring is measured at the extracted beam facility of VEPP-4M collider. One-coordinate resolution of the DEUTRON detector is measured with 2 GeV electron beam. The determined value of spatial resolution for the Detector №3 is equal to 46.6±0.1 μm for orthogonal tracks and for the Detector №4 spatial resolution is extracted as 38.5±0.2 μm.

GEM based tracking detectors are intended to be used at the DEUTERON facility [1] at the Budker Institute of Nuclear Physics. At the moment there are four such detectors, each of which has low material budget. The sensitive area is 160mm×40mm and the number of coordinate channels is 640. The readout is provided by straight and inclined strips with a pitch of 500 μm. Currently these detectors are tested and their parameters including spatial resolution are measured as well as simulated.

The simulation study of spatial resolution of the triple-GEM detectors for the DEUTERON facility (DEUTERON detectors) is performed in two stages. At first, the 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 gap (filled with Ar-CO_2(25%) gas), the second stage is started that includes introduction of electrons diffusion, gas gain fluctuation, distribution of signal between readout strips, accounting of electronic noise and calculation of the measured track position with center of gravity method.

The simulation is carried out in two cases. In the first one the coordinate of the track, passing through the studied detector is known exactly. This simulation of individual detector aims at optimization purposes and is intended for search of the best possible value of spatial resolution with parameters, providing this value. In the second case the whole experimental set-up with two tracking and one studied detectors is simulated (see the set-up in Fig. 5). The simulation of whole experimental set-up is carried out for its direct comparison with the experimental results. The results of the first and the second types of simulation are presented in Fig. 1 and Fig. 2 respectively in the form of the dependences of spatial resolution on a strip pitch for different values of signal-to-noise ratio.

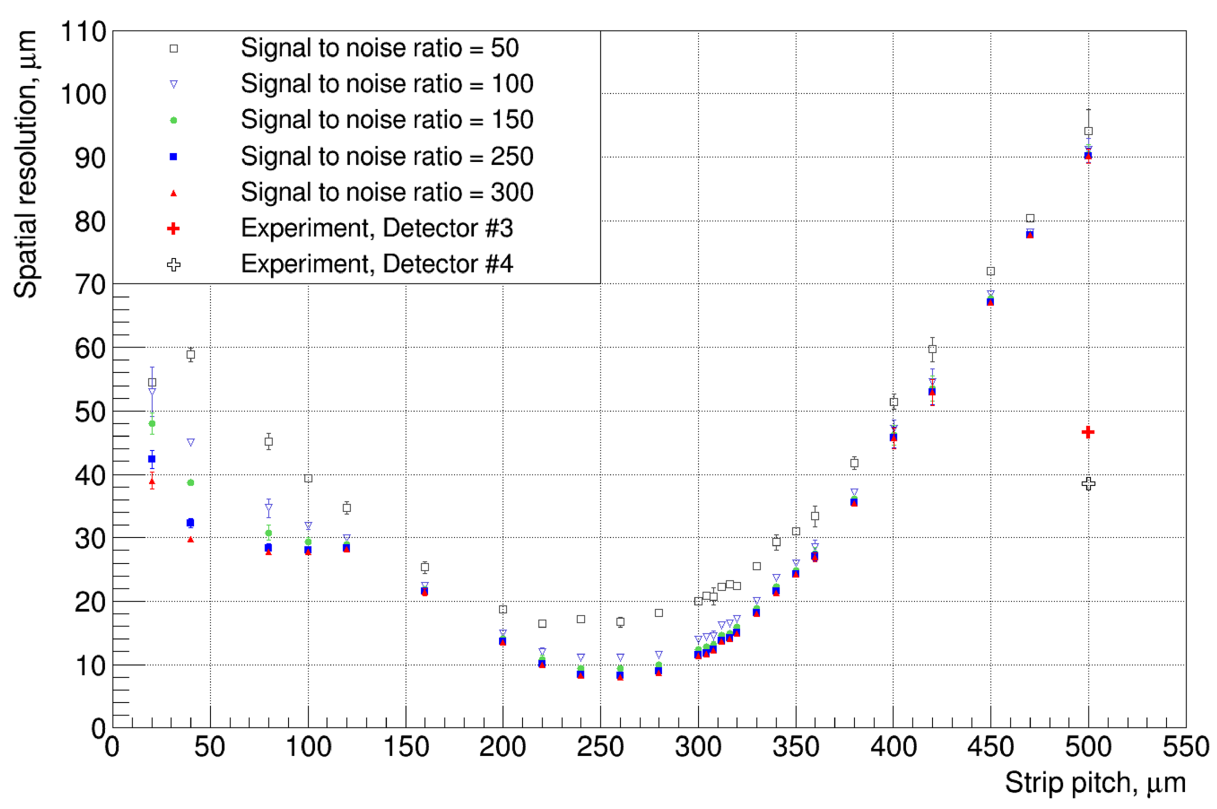

Fig. 1. Spatial resolution as a function of strip pitch for the readout structure of DEUTERON detectors. A distinct detector is simulated.

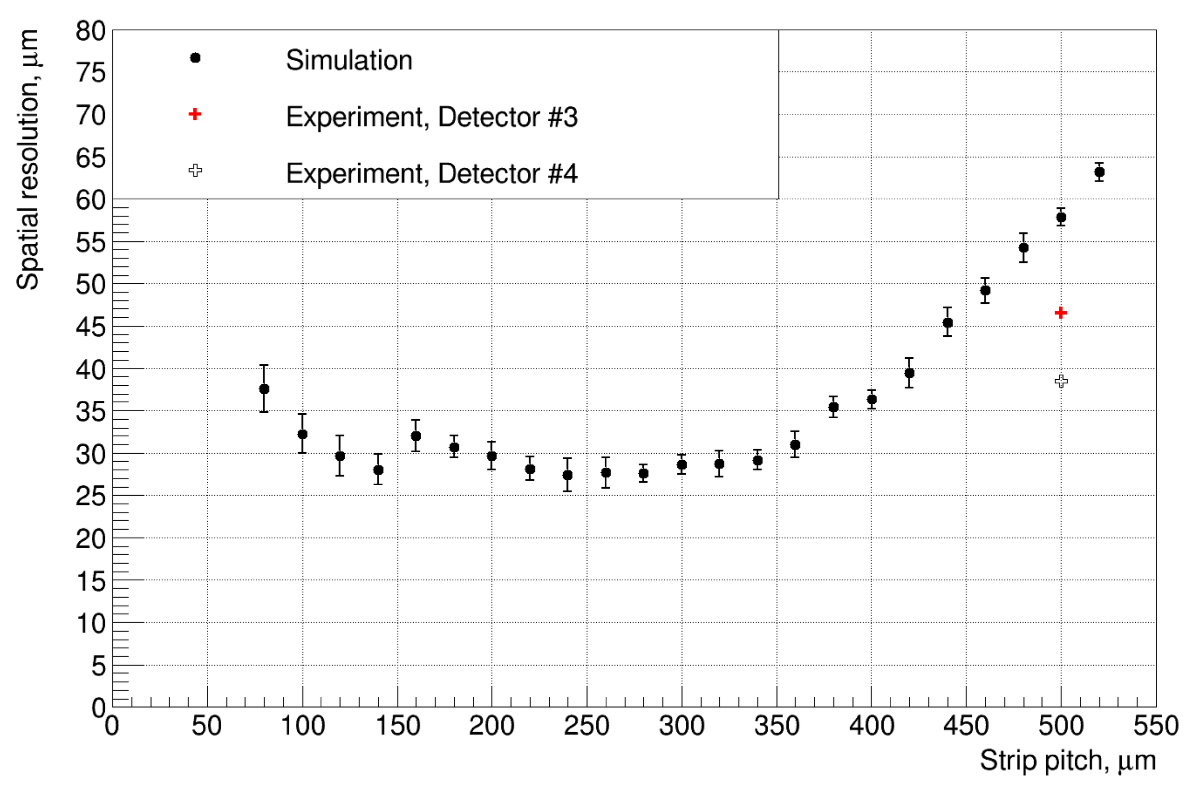

Fig. 2. Spatial resolution as a function of strip pitch for the readout structure of the DEUTRON detectors, obtained in the simulation of the whole experimental set-up, and the result of the measurements. Both after correction for multiple scattering and limited resolution of the tracking detectors.

The results of the simulations presented in Fig. 1 for different strip pitch of the readout structure show that the best resolution of 10-15 μm can be achieved for a strip pitch of 250 μm. For larger pitch the resolution degrades and the results of the simulation are worse than the experimental results.

Unlike the case of individual detector simulation, the simulation of whole experimental set-up (Fig. 2) demonstrates that a minimum value which can be measured with this set-up is about 30 μm. In order to measure better resolution (if it appears to be such) more precise tracking detectors are needed.

The deviation of the simulation from the experimental results leads to the search of the reasons, which were not described in the simulation, but could influence on the determined spatial resolution. Particularly, broadening of the electron cloud due to the GEM operation was not taken into account before. The simulation with ANSYS and Garfield++ programs was carried out for the determination of this broadening. The development of an avalanche in the holes of one-cascaded GEM was simulated (Fig. 3) and the final distribution width on the anode (z = -1 mm) of the electron cloud was extracted. The width of the electron distribution was calculated for different primary electron position along the x-axis and the same y, z coordinates as well as the constant initial kinetic energy 0.1 eV. Standard deviation values of the Gaussian function, describing the resulting x-coordinate distributions as a function of initial x-coordinates were determined. The comparison of these standard deviations with those, obtained with the diffusion coefficient being used before (170 $\mu m/\sqrt{cm}$) shows that the effective addition to the coefficient of the diffusion due to GEM operation is significant and varies in the range from 75 to 140 $\mu m/\sqrt{cm}$ (though the process of avalanche development is not a diffusion in a common understanding).

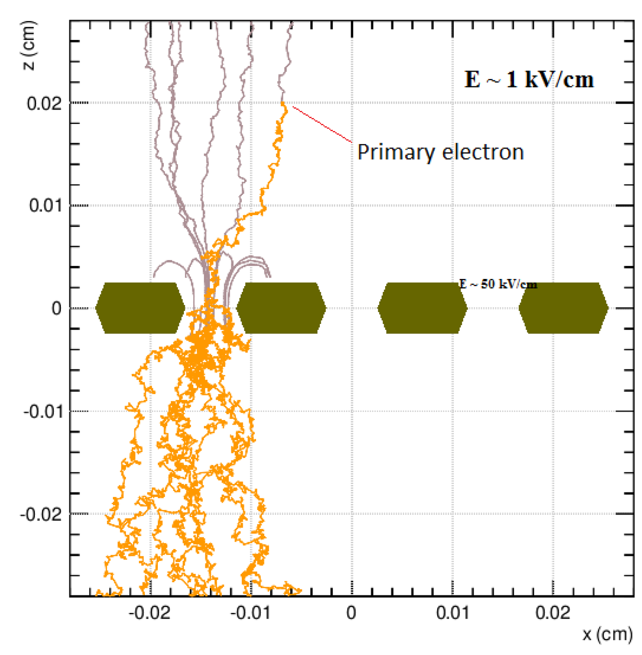

Fig. 3. The development of electron avalanche in the GEM hole and the diffusion of electrons in Ar-CO_2(25%) (1 atmosphere pressure and 20 ºC temperature) under electric field ~ 1 kV/cm in the gas gaps.

On the other side, the broadening of electron distribution width can lead to the improvement of the spatial resolution as can be concluded by regarding Fig. 1, which demonstrates that decreasing of strip pitch in the range 250-500 μm leads to the improvement of the spatial resolution. Consequently, the broadening of the electron cloud on the readout structure is equal to the decreasing of strip pith and lead to the improvement of spatial resolution. The simulation of triple-GEM cascade is developing and will show the effects of GEM operation more accurately in the case of the readout structure of the DEUTERON detectors.

The readout strip structure of the detectors, used for the measurements, is produced on 50 μm thick kapton foil and all copper layers on GEMs and readout flex (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 this value for one of the detectors for the DEUTERON facility is (2.4±0.5)×10^{-3} X_0. Such value corresponds to copper thickness on GEMs and readout flex of ~ 3μm.

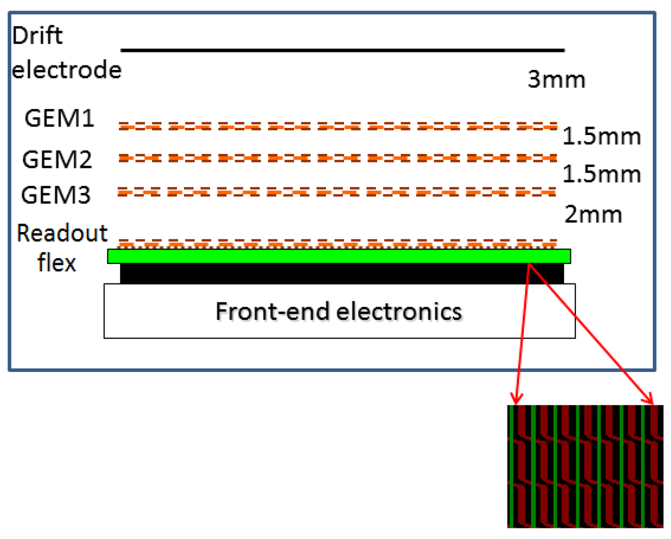

Fig. 4. DEUTRON detector structure and schematic view of the readout flex design.

Detection efficiency and spatial resolution of the Detector №3 and Detector №4 were measured with the set-up at the facility of extracted electron beam at VEPP-4M storage ring [2] shown in Fig. 5. The 2 GeV electron beam was used in the experiment on spatial resolution measurements.

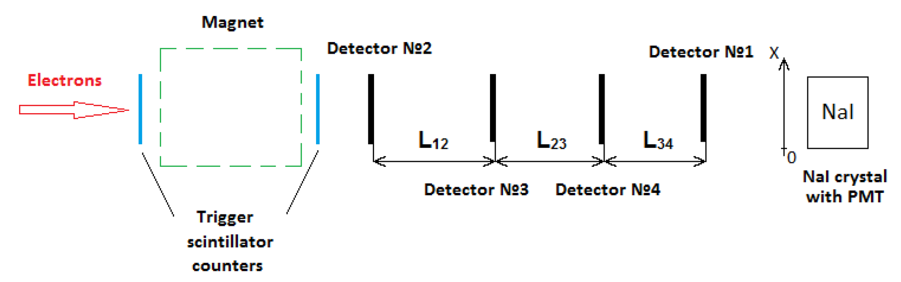

Fig. 5. Schematic view of the experimental set-up. Distances between detectors are L_{12} = 81.2 mm, L_{23} = 78.0 mm, L_{34} = 73.2 mm. Two detectors nearest to the studied ones are used as the tracking detectors.

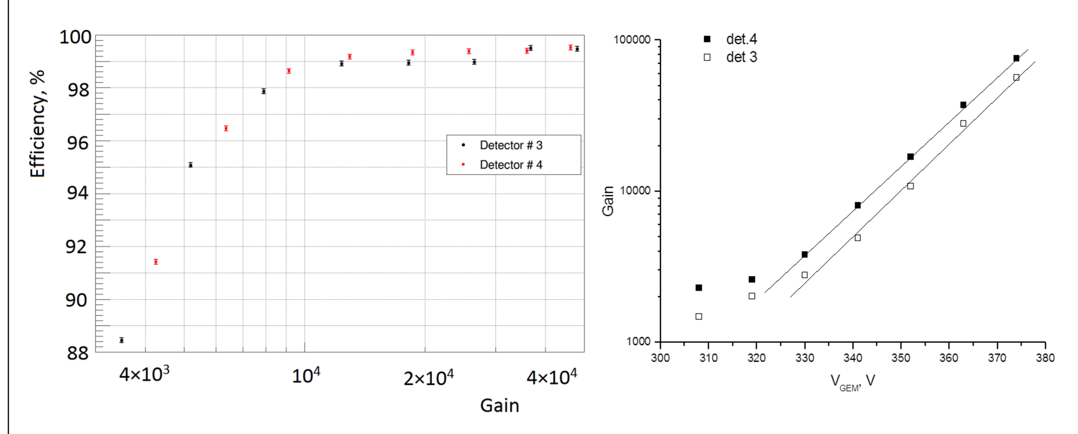

Fig. 6. Detection efficiency of the studied detectors and the dependence of triple-GEM gain on a voltage on one GEM.

The curve in the Fig. 7 is calculated using the formula of quadratic sum of the resolution for orthogonal tracks and track projection to the detector plane $\sigma = \sqrt{\sigma_0^2 + (L \times \tan(\alpha))^2/12}$, where σ_0 is chosen near minimum value of spatial resolution, L is the thickness of the drift gap (3 mm).

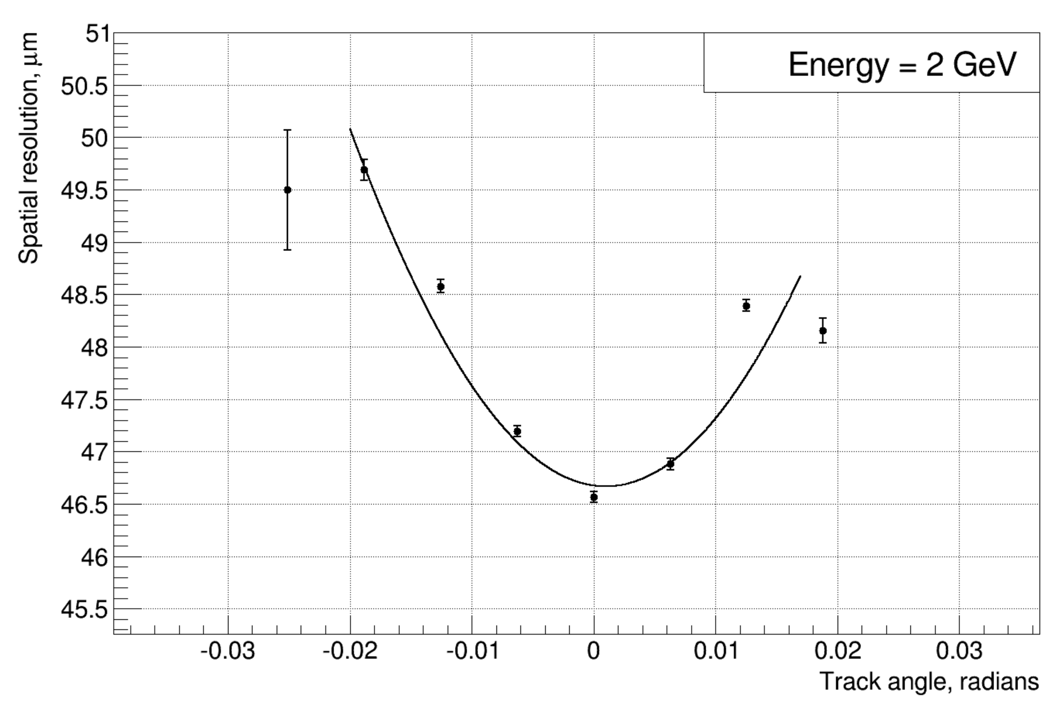

Fig. 7. Spatial resolution as a function of track angle, determined in the experiments with 2 GeV electrons after correction for multiple scattering and limited resolution of the tracking detectors.

Simulation studies show that ultimate resolution of 10 – 15 μm can be achieved for orthogonal tracks of high energy electrons in triple-GEM detectors with strip readout structure at a pitch of 250 μm. The significant influence of electron cloud broadening on spatial resolution for a large (> 400 μm) readout strip pitch due to a GEM operation is demonstrated.

The detection efficiency exceeds 99% at the gain of 2×10^4 and higher for both studied detectors. The determined value of spatial resolution of one of the detectors is equal to 46.6±0.1 μm for orthogonal tracks and for another one spatial resolution is extracted as 38.5±0.2 μm, where statistical uncertainties are listed.

References:

1. The development of high resolution coordinate detectors for the DEUTERON facility, V. N. Kudryavtsev, et al., 2014 JINST 9 C09024.
2. Extracted electron and gamma beams in BINP, G. N. Abramov, et al., 2014 JINST 9 C08022.