# Study of spatial resolution of low-material GEM tracking 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 simulation demonstrates that the minimum of spatial resolution of about 10 µm can be achieved with gas mixture of Ar – $CO_2$ (75% – 25%) at a strips pitch from 250 µm to 300 µm. At a larger pitch the resolution is quickly degrading reaching 80 – 100 µm at a pitch of 460 – 500 µm. Spatial resolution of low-material triple-GEM detectors for the DEUTRON facility 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 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.


The simulation study of spatial resolution of the triple-GEM detectors was 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, which includes honeycomb covered with drift electrode, drift (3mm), transport and induction gas gaps, GEMs and readout structure on glass fiber plate (thick version of the detector). Thin simulated version of the detector includes only 3 mm gas gap. After recording of all energy depositions in the drift gap, 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 (COG) method.

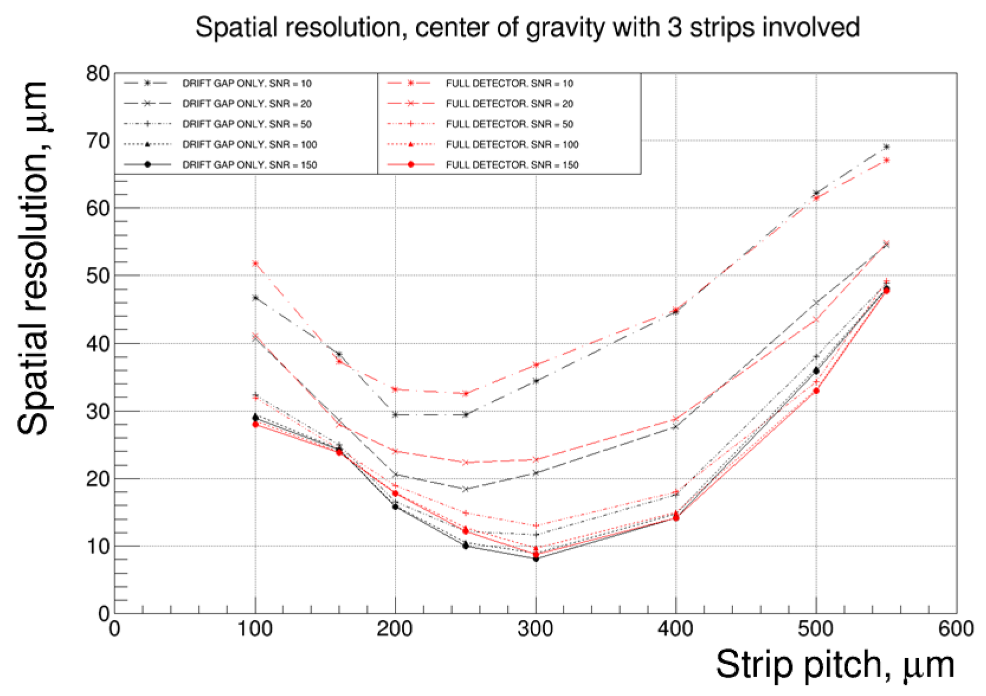


**Fig. 1**. Comparison of spatial resolution of "low-material" detector (only 3 mm drift gap, black points and curves) and regular detector with all the materials (red points and curves).

Fig. 1 demonstrates that effect of low material on spatial resolution is marginal and is only pronounced at strip pitches smaller than 300 µm. However, all further simulation results are obtained for regular detector layout. The simulation was carried out in two cases. In the first one the coordinate of the 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 provided (see the set-up in Fig. 5). The results of the first and the second types of simulation are presented in Fig. 2 and Fig. 3 respectively.

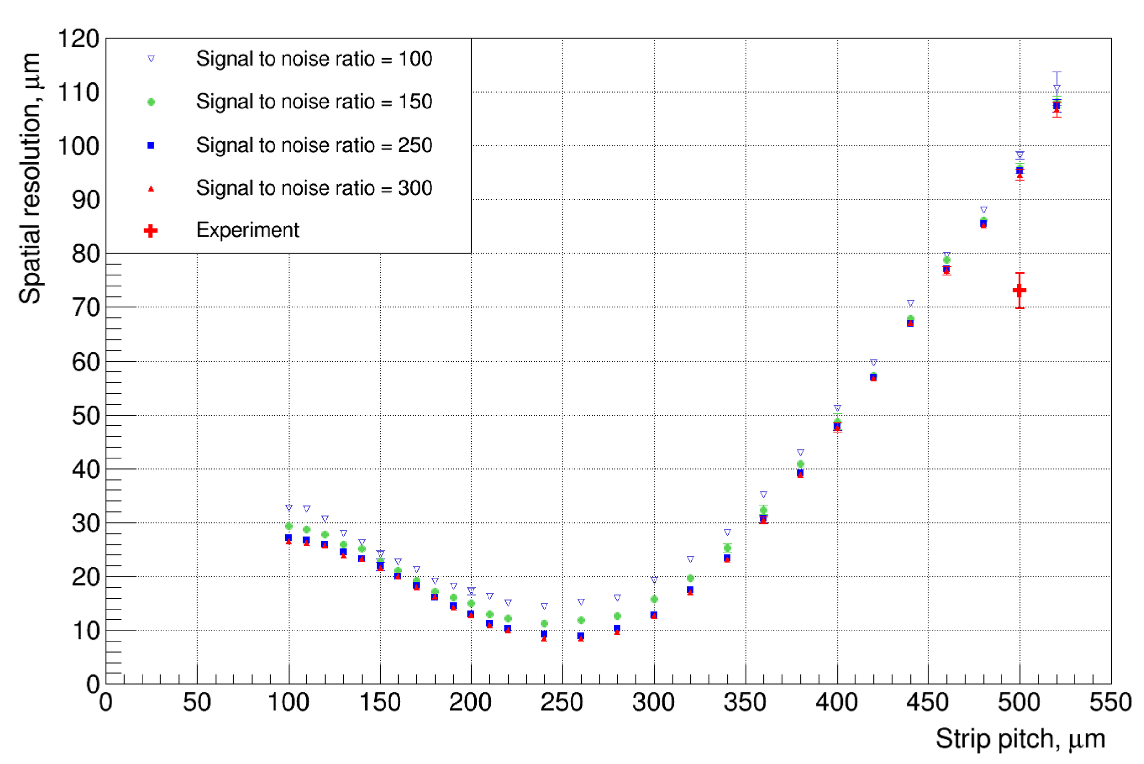


**Fig. 2**. Spatial resolution as a function of strip pitch for the readout structure of KEDR TS detectors [1]. A distinct detector is simulated. Experimental point is taken from [1].

The results of the simulations presented in Fig.2 and 3 for different geometries of readout strip structures 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 simulation are worse than the experimental results (Fig.2 and also see below).

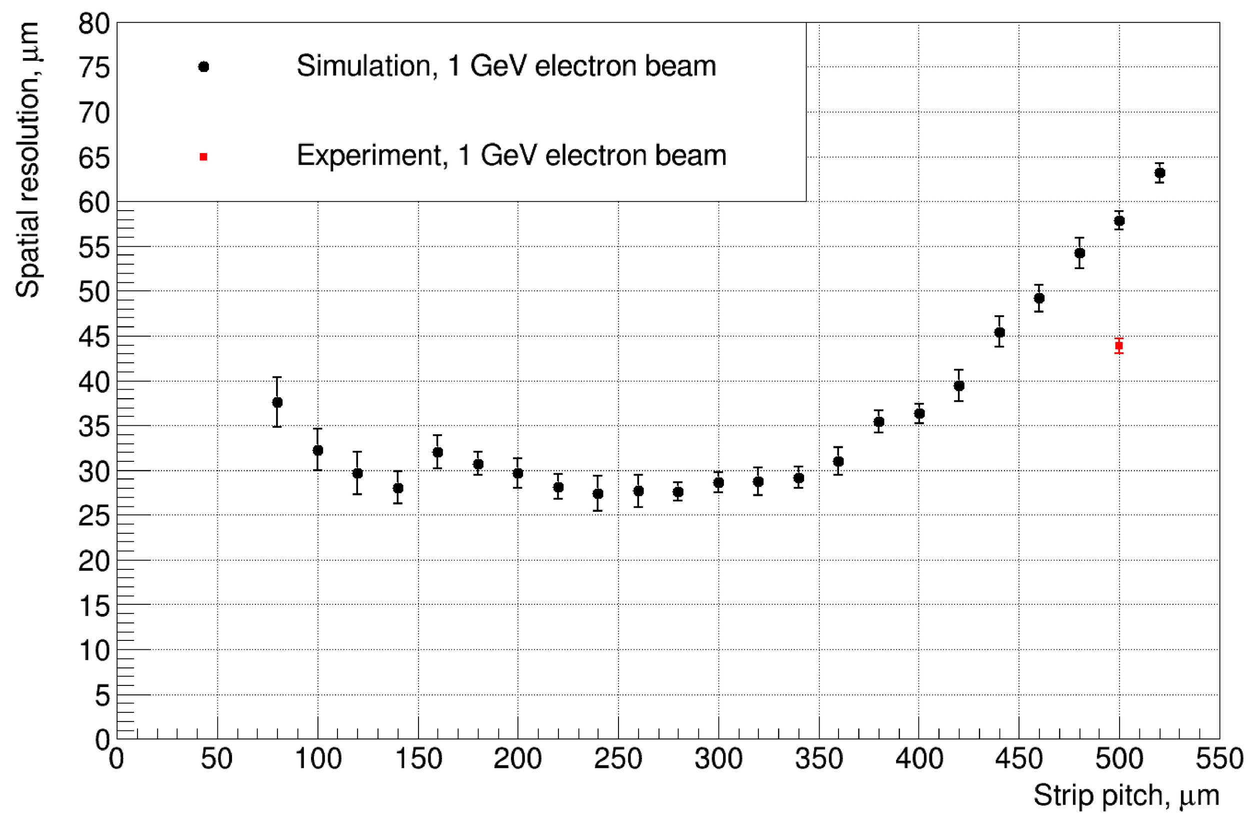


**Fig. 3**. Spatial resolution as a function of strip pitch for the readout structure of the DEUTRON PTS detectors [2], obtained in the simulation of the whole experimental set-up, and the result of the measurements. Both after correction for multiple scattering and limited resolution of the tracking detectors (see below).

The 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. The simulation of whole experimental set-up is carried out for its direct comparison with the experimental results.

Amount of material and spatial resolution in triple-GEM detectors for the DEUTRON photon tagging system (PTS) [2] were measured at the facility of extracted electron beam at VEPP-4M storage ring [3].

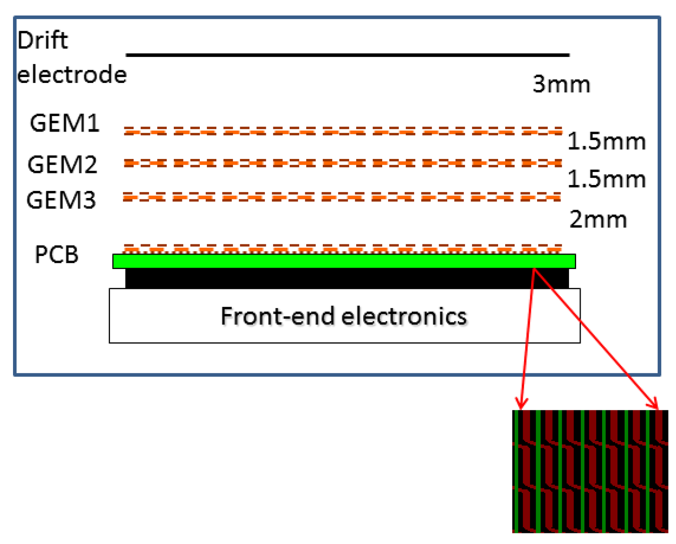


**Fig. 4**. DEUTRON PTS detector structure and schematic view of the PCB design.

The readout strip structure of the detectors is produced on 50 µm thick kapton foil and all copper layers on GEMs and readout PCB (printed circuit board) are reduced as much as possible to decrease the amount of material. The amount of material was measured, using 100 MeV electrons and experimental set-up shown in Fig. 5.

Angular distribution of tracks after multiple scattering in the 2nd detector corresponds to the amount of material of ~ $2.4\times10^{-3}$ $X_0$. This value corresponds to copper thickness on GEMs and PCB of ~ 3µm.

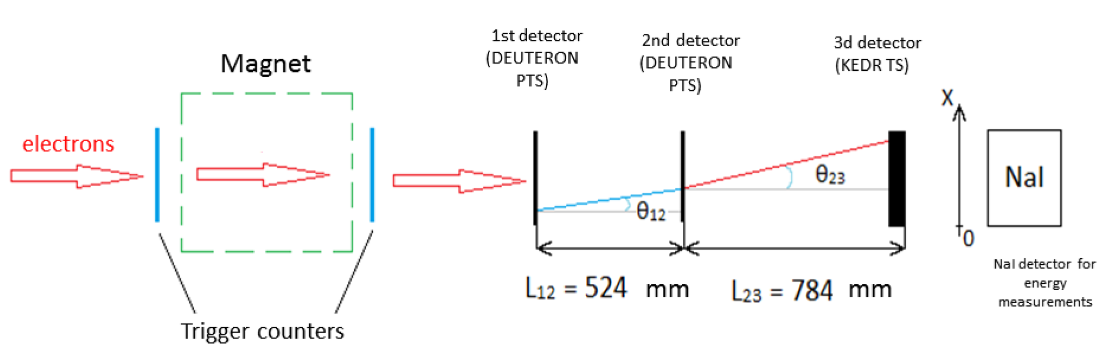


**Fig. 5**. Schematic view of the set-up for measurement of the amount of material in the detector.

Spatial resolution of the 2nd detector was measured with the same set-up (Fig.5), but the distances between the detectors were reduced to ~ 75 mm and beam energy was increased to 500 MeV. The similar experiments were carried out with 1 GeV and 3.5 GeV electrons (Fig. 6). The error bars in the figure represent the statistical errors.

The curves in the Fig. 6 are 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 $\sigma_0$ is chosen near minimum value of spatial resolution, $L$ corresponds to the distance between tracking detectors and α is a track angle.

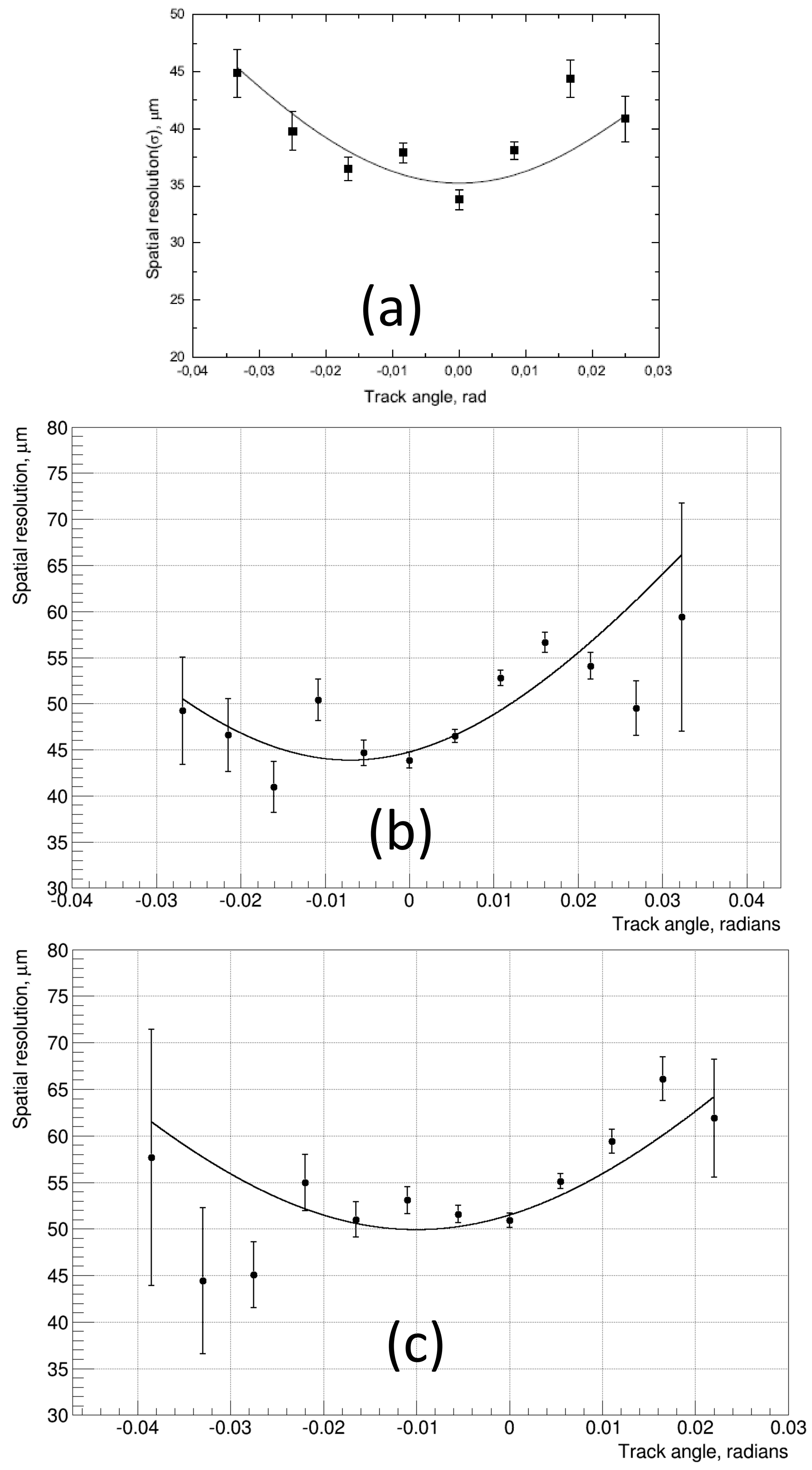


**Fig. 6**. Spatial resolution as a function of track angle, determined in the experiments with 500 MeV (a), 1 GeV (b) and 3.5 GeV (c) electrons after correction for multiple scattering and limited resolution of the tracking detectors.

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. At larger strip pitch simulation shows systematically worse resolution than the measurements that will require additional studies.

It is determined that the measured spatial resolution varies within 35 – 50 µm in different experiments for orthogonal tracks. Such differences probably appears due to a systematic error in accounting for multiple scattering effect and due to yet undetermined uncertainties.

**References:**


1. Operation of the triple-GEM detectors in the tagging system of the KEDR experiment on the VEPP-4M collider, V M Aulchenko, et.al., 2011 JINST 6 P07001
2. The development of high resolution coordinate detectors for the DEUTERON facility, V N Kudryavtsev, et.al., 2014 JINST 9 C09024
3. Extracted electron and gamma beams in BINP, G N Abramov, et.al., 2014 JINST 9 C08022