Studies of the possibility to use Gas Pixel Detector as a fast trigger tracking device

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Abstract. Gas Pixel Detector (GPD) technology offers new possibilities, which make them very attractive for application in existing and future accelerator experiments and beyond. GPDs combine advantages of silicon and gaseous detectors. They can be produced radiation hard and with low power consumption using relatively cheap technology. Low capacitance of the individual pixel channel allows us to obtain a large signal to noise ratio. Using a time projection method for GPD readout one obtains 3D track image with precise coordinate (31 μm) and angular information (0.40°). This feature would allow us to achieve performance of one GPD layer equal to a few layers of silicon detectors. Implementation of a fast readout and data processing at the front-end level allows one to reconstruct a track segment in less than 1 μs, and to use this information for the first level trigger generation. The relevant algorithms of data acquisition and analysis are described and the results of simulations are presented in this paper.

1. Introduction

Gas pixel detectors (GPD) have been proposed and developed to combine the advantages of a gas chamber and a small pixel readout techniques which is required for future accelerator experiments [1-5]. One GPD consists of cathode and anode planes with 10 - 16 mm drift gap between them filled with gas. The schematic view of GPD structure is shown on figure 1.

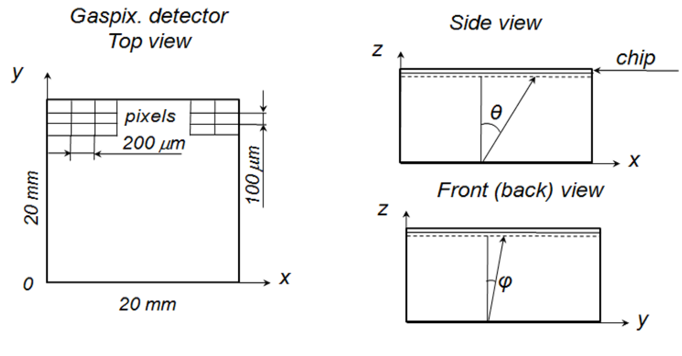

Figure 1. The schematic view of GPD structure.

Anode plane is a large electronic chip with pixel sensors and integrated electronics. There is a mesh in front of the sensors. About 50 μm space between the sensors and mesh is used for gas amplification.

The goal of presented work is to develop readout concept and analysis algorithms allowing to determine a particle trajectory in less than 1 μs and to use this information for a fast trigger generation.

Relatively large 100×200 μm^2 pixels have been selected for simulations to decrease the number of channels. Non square pixel size is aimed to achieve better angular resolution in the plane perpendicular beam axis and to improve an accuracy of p_T measurements in magnetic field. A 20×20 mm^2 chip size and 10 mm gap have been assumed. The other parameters were: number of pixels on X axis – 100, number of pixels on Y axis – 200, voltage between cathode and anode – 4000 V, gas amplification ≥ 1000, electron drift time from cathode to mesh – 200 ns, transverse electron diffusion during 200 ns – 300 μm, readout cycle – 25 ns.

Binary readout has been selected to speed up data acquisition and analysis. Gas and electronic amplifications ensure effective registration of every electron crossing the mesh.

2. Basic approaches to the time-projection method

Electrons generated by an ionizing particle in a gas drift along Z axis transversely to the chip surface (XY plane) independently of the particle trajectory. Electron drift velocity is constant (it does not depend on Z coordinate), because the electric field is uniform between the cathode and mesh. Figure 2 shows XZ projection of the particle track. The Z axis in this figure has two

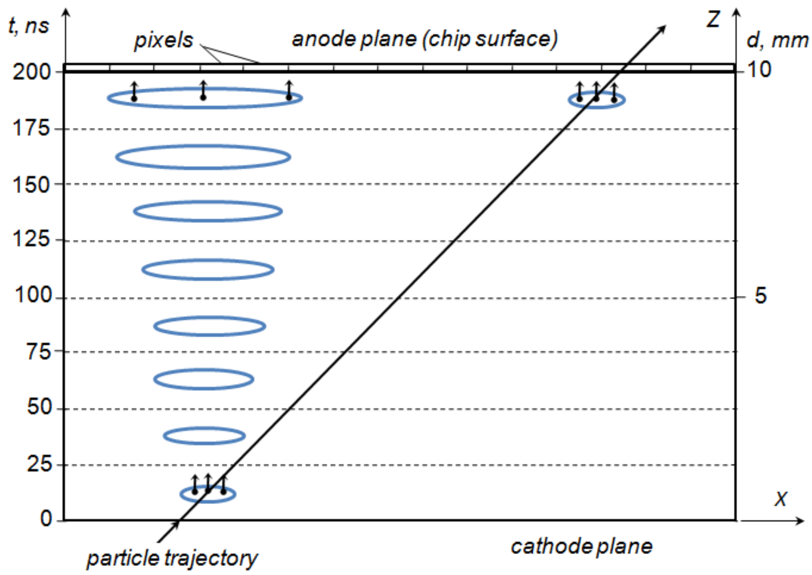

Figure 2. Electrons collecting on the GPD chip plane.

scales: one is the distance from an electron generation point to the chip surface, 0 - 10 mm, and the second one is the corresponding drift time 0 - 200 ns. The track angle to Z axis in this projection we call θ.

Let's assume that the particle crosses the detector at the time $t_0 = 0$. We can neglect the time difference between the particle entering and leaving detector, because it is in the range 0.03 – 0.05 ns, which is very small compared to readout time intervals of 25 ns. It is clear, that the electrons generated close to cathode, will drift to anode in the maximum time, and arrive there at t = 200 ns. But for electrons generated very close to the grid, the drift time will be practically zero. Thus during the 200 ns period all the electrons generated by the particle will be gathered and registered on the chip.

Taking into account that every readout cycle is equal 25 ns, all the available information related to the particle trajectory will be received in 8 cycles. The time scale in figure 2 is divided into 8 parts of 25 ns each, which corresponds to 1/8 of 10 mm or 1.25 mm in distance from cathode to anode. In such a way, the location of fired pixels in each of 8 time intervals reflects the particle coordinates in space (in XY plane) on each of 8 distances from chip surface. In the time interval t = 0 - 25 ns, the average drift time 25 / 2 = 12.5 ns corresponds to the particle-to-chip distance 1.25 / 2 = 0.625 mm. In other words, the average values of X and Y coordinates of the pixels fired during this interval (0 - 25 ns) represent the position of the particle in the detector at the third coordinate Z = 0.625 mm. Subsequently, the location of pixels fired in each of 8 readout cycles give us 8 measurements of 3D particle position within the detector volume, and makes it possible to reconstruct the particle trajectory.

3. Front-end electronics and readout algorithm

The process of transverse diffusion spreads the electrons around the particle trajectory during their up to 200 ns drift through the gas volume. Therefore up to 50 pixels can be fired during 25 ns readout cycle. It allows that this improves the accuracy of the measurements with relatively large pixels, but creates a real problem to transmit and analyze the coordinate of every fired pixel online. Therefore another method of data acquisition and analysis has been used. Every pixel has an integrated fast preamplifier, discriminator and flip-flop (FF) with two fixed current outputs connected to common X and Y lines going along the particular X_i and Y_i rows correspondingly (see figure 3). If a pixel is fired during a cycle, FF turns ON and current flows along the line. If a few (up to 15) pixels have been fired in the same row in the same readout circle, the sum of their currents appears in the corresponding line as shown in figure 4. Because all the pixels generate equal currents the sum is linearly proportional to the number or fired pixels. The end of each line is connected to a 4-bit flash ADC integrated in the X and Y processing blocks PBX and PBY positioned on the two edges of the chip. At the end of each cycle a special command is

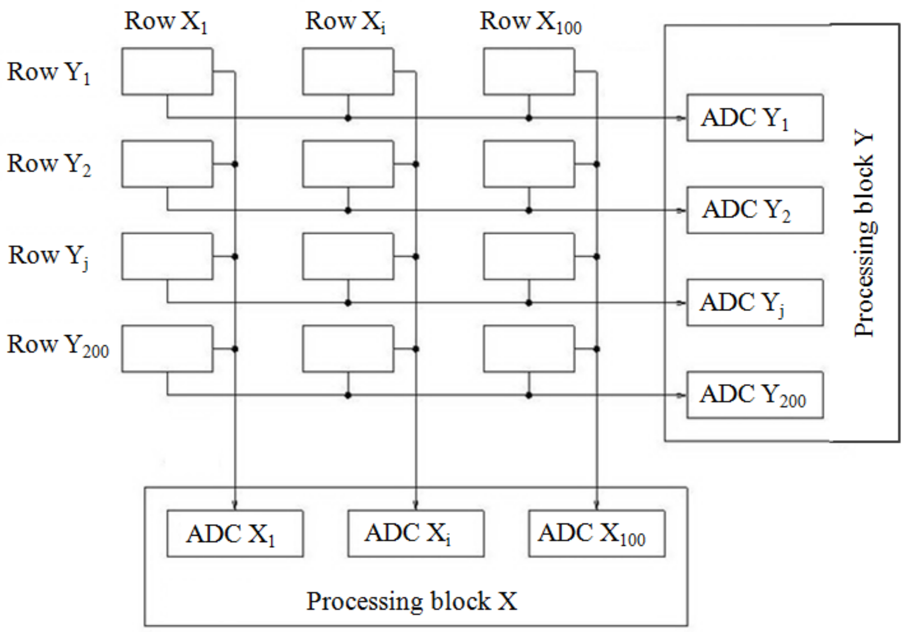

Figure 3. The block diagram of the readout algorithm.

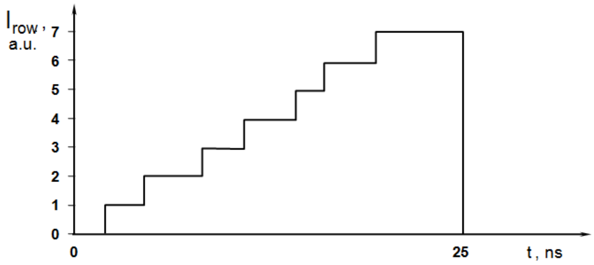

Figure 4. An example of the current in the row line if 7 pixels are fired during one 25 ns cycle.

generated and all the ADCs convert the current into the number of fired pixels in this row. The same command returns all the FFs into starting position preparing the channel to next readout cycle. This method allows us transmit the information from the row to the ADC using only one wire.

4. Reconstruction algorithm

If particle crossed the detector perpendicularly to the chip surface, both angles θ and ϕ are zero and the mean position of fired pixels cluster in XY coordinates is the same for all 8 cycles. Only the number of fired pixels increases from 1-st to 8-th cycle because of transverse diffusion. If one or both angles are not zero the cluster moves along axis X or Y or both of them reflecting particle trajectory within the detector. Figure 5 illustrates a typical cluster structure in XY plane and its projections on both axes for the 3-rd of 8 cycles. To calculate particle position in row number units we use center of mass approach. In each projection the row number R_X^i or R_Y^j is multiplied by the number of fired pixels in this row, n_X^i or n_Y^j, and the sum of the products is divided by the total number of fired pixels in the cluster N_P: $X=\Sigma R_X^i n_X^i/N_P$, $Y=\Sigma R_Y^j n_Y^j/N_P$.

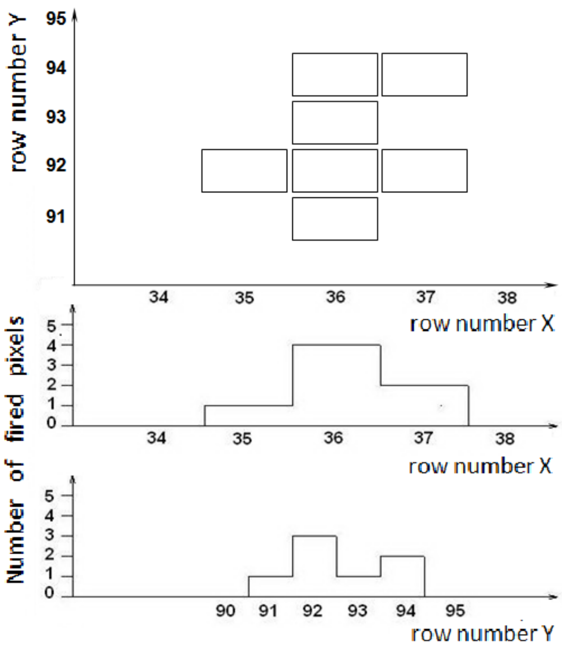

Figure 5. The example of the cluster structure in XY plane and its projections on X and Y axes.

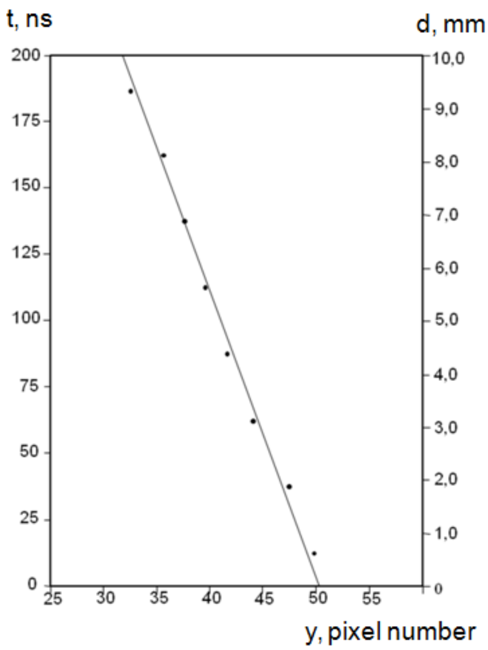

Figure 6. The example of the partice trajectory reconstruction.

This procedure is performed for each of 8 cycles. And the cycle number indicates the corresponding Z coordinate. Thus we can create two plots representing the XZ and YZ projections of the particle trajectory with 8 sets of found coordinates shown as dots in each plot. An example of one simulated event is presented in figure 6, where a straight line is drawn through 8 points using the least-squares method. From there we can determine the particle trajectory, i.e. XY coordinates where the particle crossed the cathode and anode planes as well as both angles: θ in the XZ plane and ϕ in YZ plane.

5. Expected resolution

To estimate the expected resolution dedicated MC simulation has been done. Figure 7 shows the example of simulated distributions for the 20 GeV pions crossing the detector with $\theta = 20°$ and $\phi = 3°$. It is clearly seen that the average values of the reconstructed angles ($\theta = 20.06°$ and $\phi = 3.00°$) is very close to the initial ones, and the r.m.s is about $0.4°$. For the reconstructed entry points r.m.s. is 0.26 of pixel size for X and 0.31 for Y coordinates which corresponds to 52 and 31 μm respectively.

Further simulations will be performed with improved algorithm and better resolution is expected.

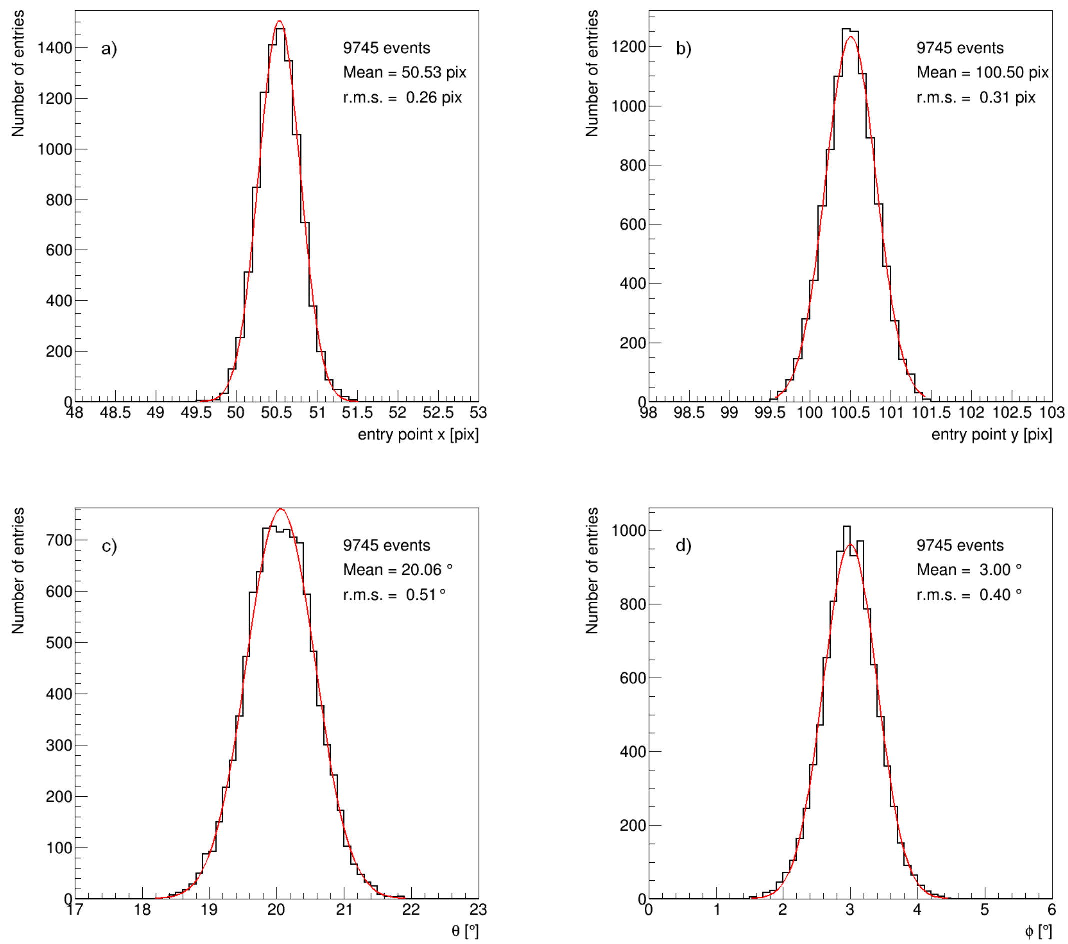

Figure 7. The distributions of the reconstructed track entry points coordinates: **a**) X; **b**) Y; and angles: **c**) θ; **d**) ϕ for 20 GeV pions crossing the GPD with $\theta = 20°$ and $\phi = 3.00°$.

6. Conclusion

The results of the simulations show that particle trajectory can be reconstructed with angular resolution 0.40° and space resolution 31 μm using only one layer of GPD. The proposed algorithms allow using online data analysis for a fast trigger generation.

Acknowledgments

This work was partially supported by Russian Foundation for Basic Research (grant No. 14-22-0353) and by MEPhI Academic Excellence Project (contract No. 02.a03.21.0005, 27.08.2013).

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