Hybrid tracking detector based on semiconductor and gas technologies

G. Bashindzhagyan[1], N. Korotkova[1], A. Romaniouk[2], N. Sinev[3], V. Tikhomirov[2;4]

[1] M.V.Lomonosov Moscow State University, Russia

[2] National Research Nuclear University MEPhI, Russia

[3] University of Oregon, Eugene, USA

[4] P. N. Lebedev Physical Institute of the Russian Academy of Sciences, Russia

# Gas Pixel Detector (GPD) – the basis of new detector

Gas Pixel Detector is a small flat drift chamber with 10 mm thick gas volume and with a large electronic chip with pixel sensors about 100x200 µm² as anode plane. A mesh is placed in about 50 µm in front of the sensors. Strong electric field between the mesh and anode sensors (~100kV/cm) allows to obtain gas amplification of the order of 10^3 to register every electron crossing the mesh.
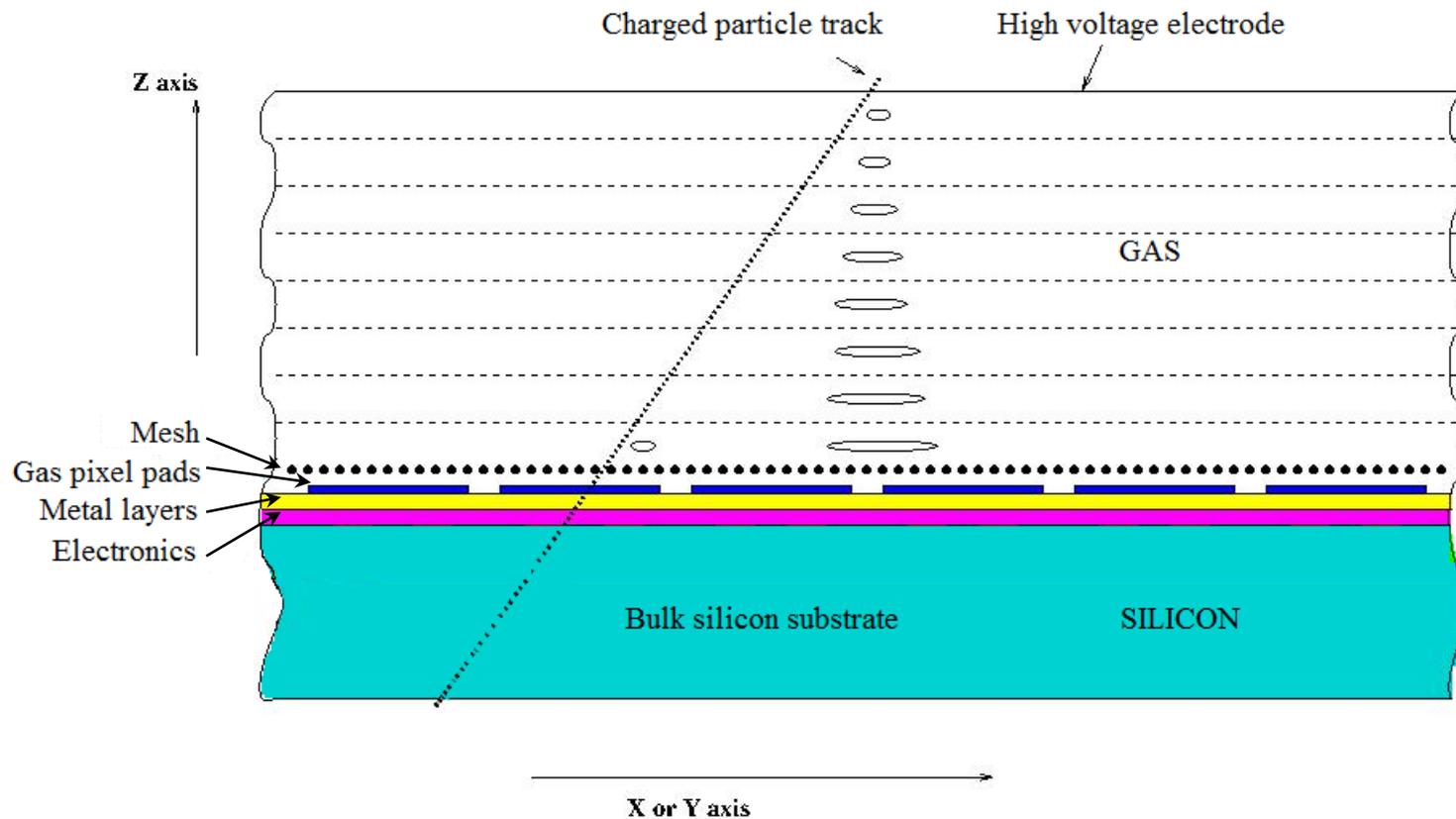
Main properties and advantages of GPD

- Very low material and relatively cheap structure combined with good particle track reconstruction.

- Time-projection method application and specially developed algorithms allow 3D particle track segment reconstruction with position accuracy of ~30 μm and angle measurement precision better than 0.5°.

- Because particle track reconstruction is realized on hardware level within chip electronics, it can be done very fast in about 1 μs if 25 ns readout cycle is used. This performance allows GPD to be used for a first level trigger generation in accelerator experiments.

Time-projection readout
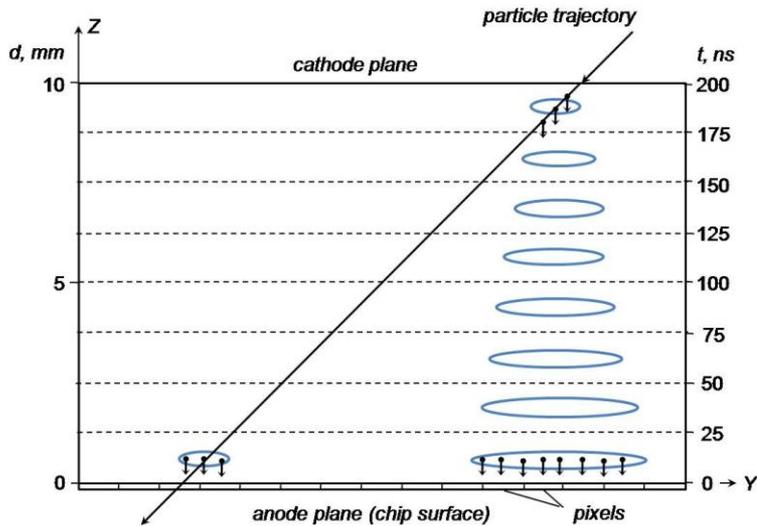
Electrons generated by an ionizing particle in a gas drift transversely towards the chip surface, where they are registered by the pixels of the chip every readout cycle.

The process of transverse diffusion spreads electrons during their drift, and up to 50 pixels can be fired during one readout cycle (25 ns). This improves the accuracy of the measurements with relatively large pixels, but creates a problem to transmit and analyze the data online.

With 25 ns readout cycle, 10 mm thick gas volume and maximum drift time of electrons about 200 ns, we can obtain 8 points with X and Y coordinates along the particle track and Z coordinate, which corresponds the number of the cycle when the coordinates were measured.
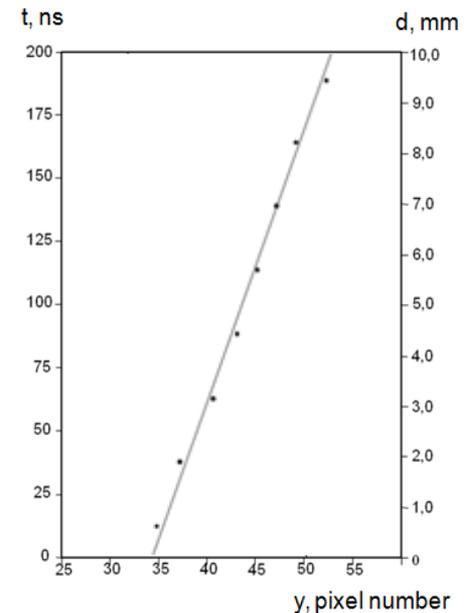
Online track reconstruction algorithm
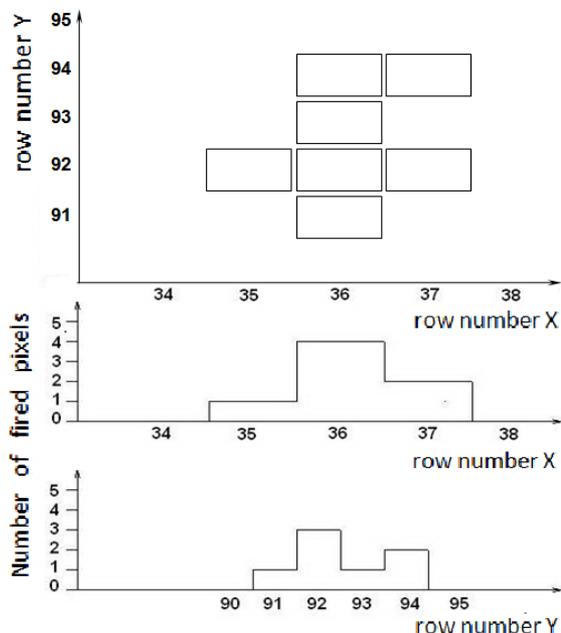
This picture presents a typical cluster structure in XY plane and its projections on both axes for the 3-rd of 8 cycles. To calculate particle position we use center of mass approach. In each projection the number of the row (n_X^i), is multiplied by the number of fired pixels in this row (R_x^i), and the sum of the products is divided by the total number of fired pixels in the cluster N_P :

$$X = \sum R_X^i n_X^i / N_P , \quad Y = \sum R_Y^j n_Y^j / N_P .$$

In experiments operating at high trigger rate the basic data processing must be performed already on chip level.

Every pixel has an integrated fast preamplifier, discriminator and flip-flop with two fixed current outputs connected to common X and Y lines going along the particular X_i and Y_j rows correspondingly. If a pixel is fired during a cycle, FF turns ON and current flows along the line.
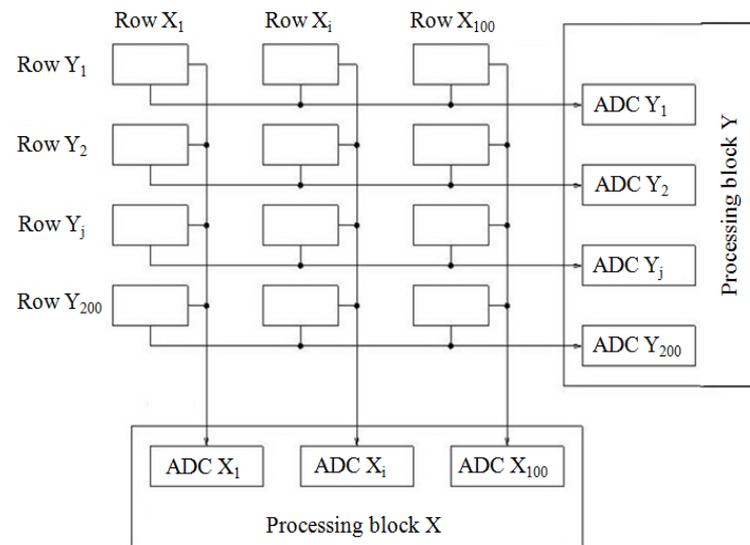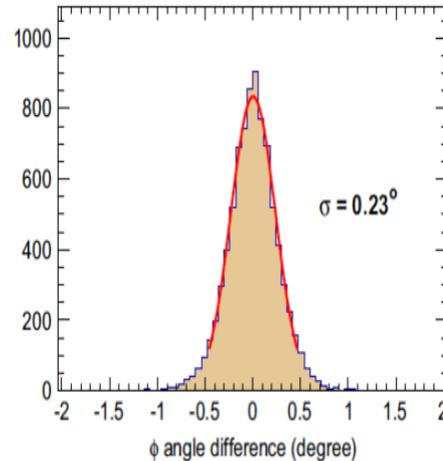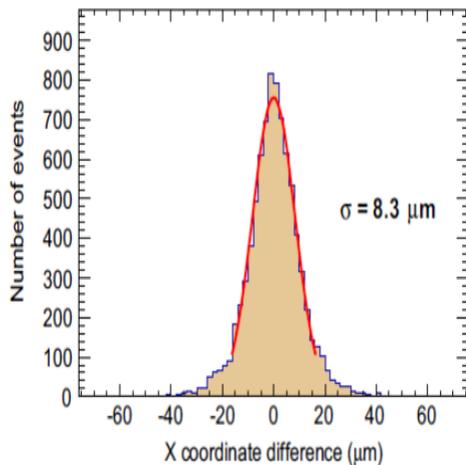
Expected and measured resolution
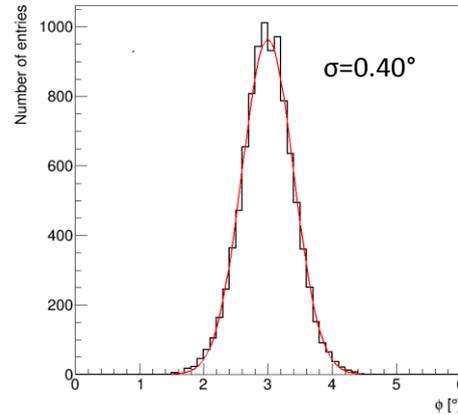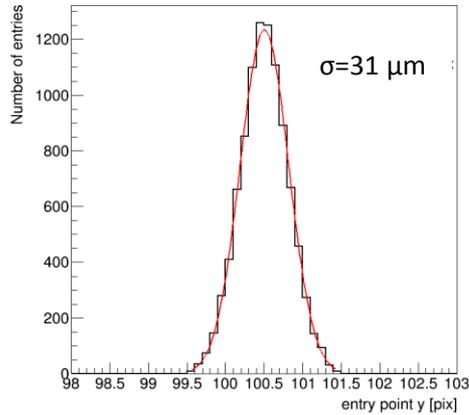
To estimate expected resolution MC simulations for different detector geometries and gas mixtures have been done.

These are the examples of simulated distributions for the 20 GeV pions crossing the detector with 100x200 μm^2 pixels and Xe gas mixture at angle θ =20°and φ = 3°.

Performance of GPD detector with DME/CO2 mixture and 55x55 μm^2 pixels is shown on the plots [3]: position determination accuracy across the track projection (right plot) and angle measurement accuracy of the track projection on the chip plane (left plot). Solid lines represent Gaussian fits applied to the central parts of distributions.

# Silicon pixels Implementation into GPD electronic chip

GPD assumes permanent data collection and processing with cycles corresponding collider beam crossing cycle. The disadvantage of the GPD is the absence of exact time knowledge when the particle crossed the detector. It becomes more essential if a few particles arrived during 200 ns drift time needed to collect the data.

The simple way to obtain time coordinate is to add a layer of silicon pad or strip detector to existed GPD structure. But it means additional layer of silicon, a lot of interconnections and essential increase of production cost. Therefore we propose to use a charged particle detection in epitaxial layer created during regular chip production technology.

Adding silicon sensors below chip electronics within epitaxial layer we can collect electrons generated by the charged particle in the epitaxial layer (~ 7-10 µm) in very short time about 1 ns and obtain exact information about the particle arrival very soon. Despite the charge generated in epitaxial layer is about 700 e, the signal at the amplifier input is sufficient for its registration because of very low capacitance of the silicon pixel (~ 1 pF).

Silicon-Gas Pixel Detector

SiGPD is a further development of the GPD concept with the determination of the exact time when particle crossed the detector, which can be realized by implementation of silicon pixel layer inside electronic chip without other changes in the existing GPD design and therefore without increasing the production cost of the device.
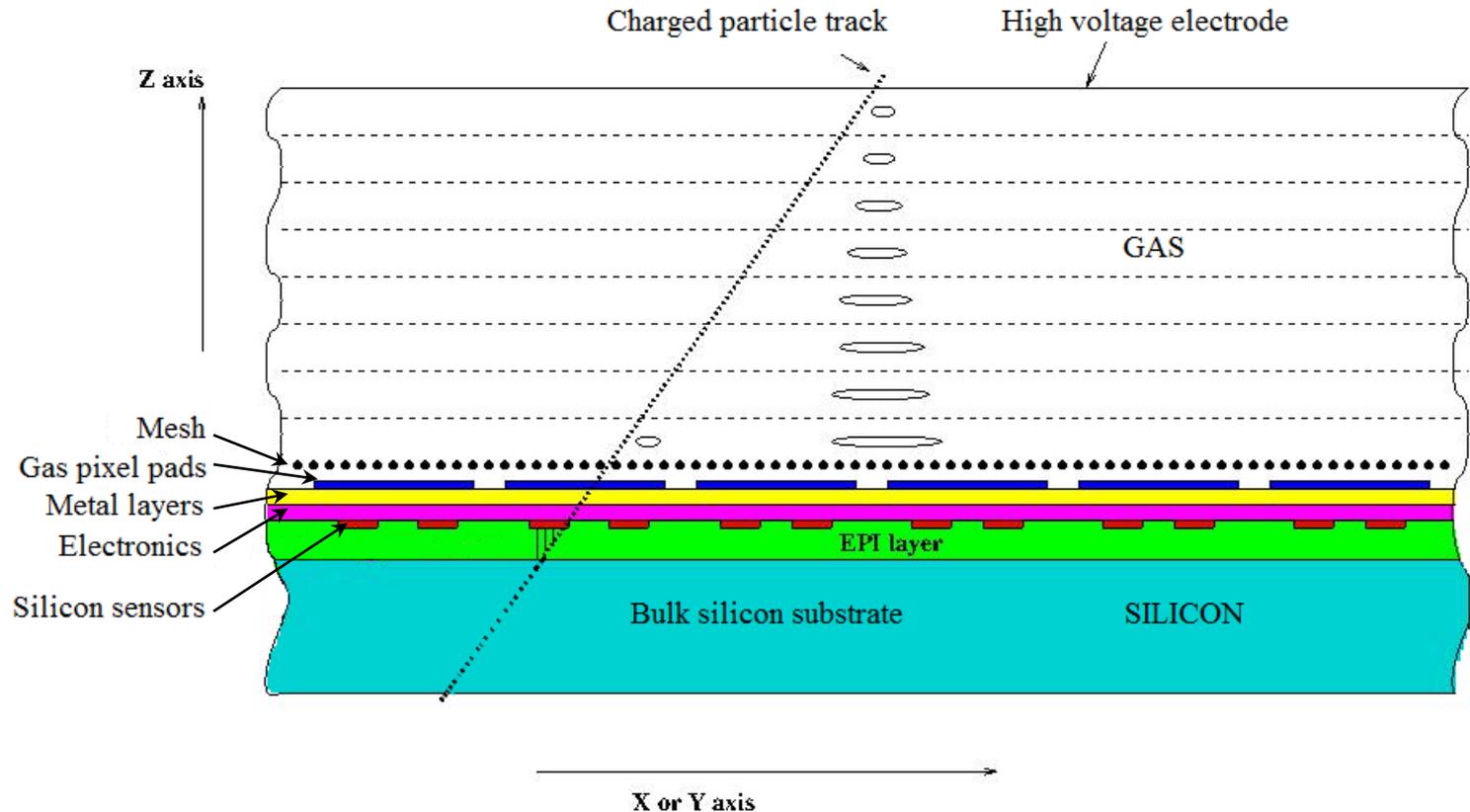
Properties and advantages of SiGPD

- With implemented silicon pixel layer we exactly know the time when particle crossed the detector and can use SiGPD as a completely self-triggered device.

- SiGPD can be used to generate fast trigger in accelerator experiments.

  SiGPD has an internal generator which starts readout process when particle crossed detector volume. If SiGPD works in accelerator environment its clocks must be synchronized with beam crossings.

  Suggested electronics can generate output signal for use in the level 1 trigger system. The latency of the output data is about 40 clock periods. With 40 MHz frequency used in LHC, it is 1 µs. If smaller latency is required one can increase frequency to 80 MHz and decrease latency to about 0.5 µs. If 0.25 µm technology is used for electronics production, 80 MHz looks like reasonable clock speed.

Properties and advantages of SiGPD (Cont.)

- Silicon pixels in SiGPD does not require high-resistivity silicon and can be implemented into GPD electronic chip within the standard chip production technology without increasing the production cost.

- All the silicon and gas pixel electronics , which measures and analyses signals from X and Y lines, is fully integrated in electronic chip structure and produced within the same chip production process. This means that SiGPD does not require any external electronics for its operation.

- SiGPD have higher radiation hardness compare to regular silicon detector, because of its very thin epitaxial detecting layer.

SiGPD readout

- As it was described earlier for GPD signals from gas pixels in each row X_i (or Y_j) are added together and transmitted to X (or Y) coordinate processing block, situated at the edges of the electronic chip. We may compare this readout system with two microstrip detectors with perpendicularly going strips. It seriously simplified and speeds up readout procedure. If particle density is high and a few particles can appear at the same clock we can avoid ambiguity adding one more interconnecting system of wires.

- Readout from Si sensors operates similar way as for the gas pixels, and even easier because it does not require a number of fired pixels in each row. In other words, we apply "binary" readout for silicon and "analogue" for gas pixels.

- With binary silicon pixel readout we can determine XY coordinate of the particle arrival with 7 µm accuracy. If power consumption/dissipation is a critical point, the silicon pixel size can be increased to 50×50 µm. This case XY accuracy is still 15 µm but power dissipation is four times less.

SiGPD chip layout

Chip electronics consists of blocks under each gas pixel pad, peripheral X & Y coordinate processing blocks and some communication logic to transfer data to host computer.
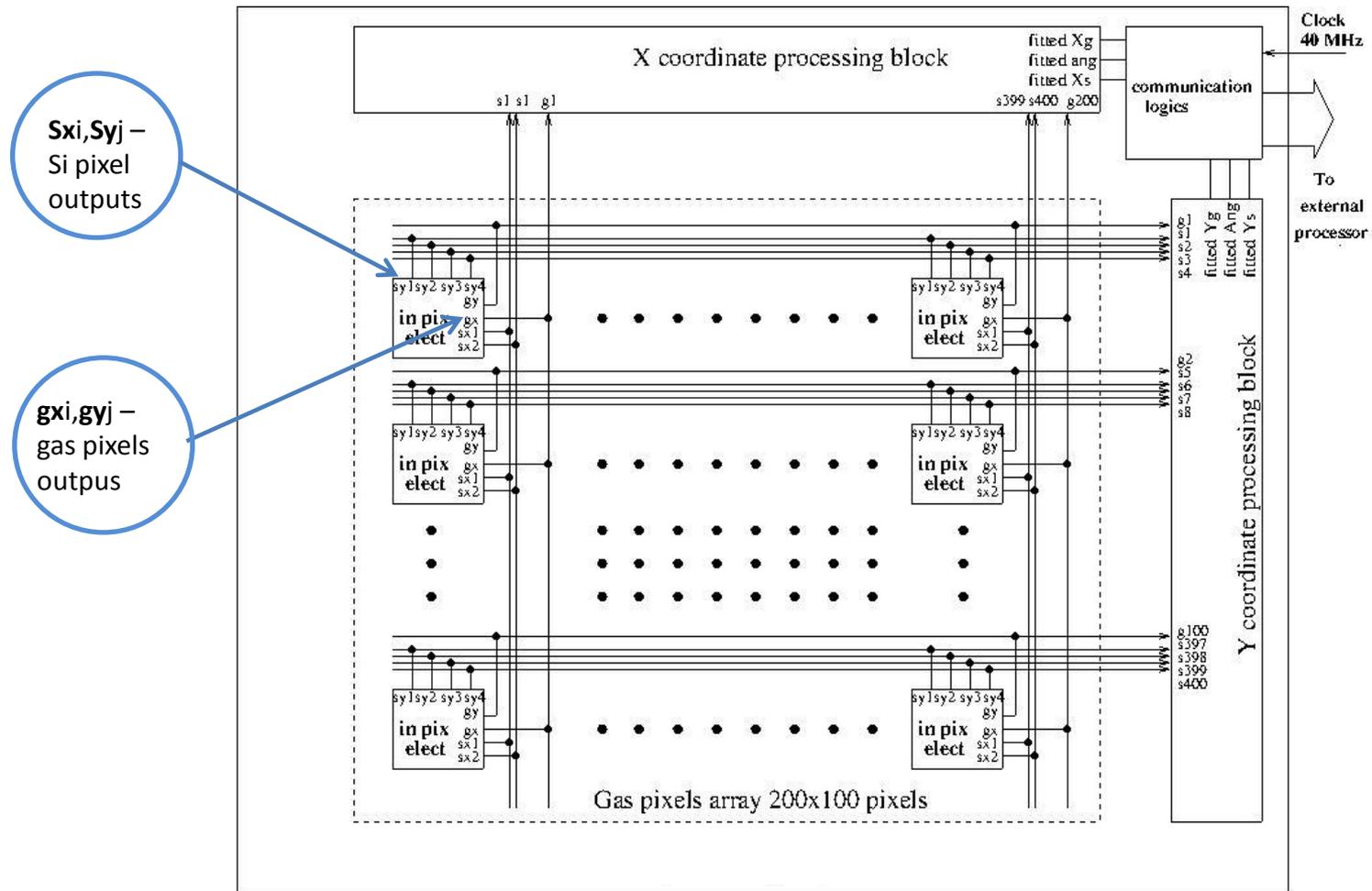
Conclusion

- A concept of new Silicon Gas Pixel Detector is developed. This new detector is based on proposed earlier Gas Pixel Detector. But with implemented into existing electronic chip silicon pixels new detector has significantly extended functionality and becomes more convenient and universal device.

- Fast on-line data processing and ability to present the full information about charged particle trajectory in ~ 0.5 μs can be very useful for a fast trigger generation.

- Very low material budget (~10 mm gas + ~100 μm Si) and relatively cheap structure combined with a good coordinate (~ 5-10 μm) and an angular (~ 0.4°) accuracies of particle track segment reconstruction.

- SiGPD works as a completely self-triggered device and can be used in many areas, where particle trajectory reconstruction is required.

Acknowledgments

References

[1] N.Sinev, G.Bashindzhagyan, N.Korotkova, A.Romaniouk, V.Tikhomirov. Silicon-Gas Pixel Detector. Journal of Physics: Conference Series, Volume 798 (2017), Particle physics

[2] N.Sinev, G.Bashindzhagyan, N.Korotkova, A.Romaniouk, V.Tikhomirov. Studies of the possibility to use Gas Pixel Detector as a fast trigger tracking device. Journal of Physics: Conference Series, Volume 675 (2016), Particle physics

[3] A. Boldyrev, et al. Tracking performance of Gas Pixel detectors in test beam studies. Nucl. Instr. and Meth. A807 (2016) 47–55.