The high-resolution particle tracking triple-GEM detector for the Test Beam facility at VEPP-4M collider.

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Abstract: *The goal of the Test Beam facility at the VEPP-4M e^+e^- collider is to test prototypes of new detectors for particle physics. Measurements taken at this installation require high-resolution low-mass tracking detectors to precisely determine particle trajectories.*

The Test Beam facility

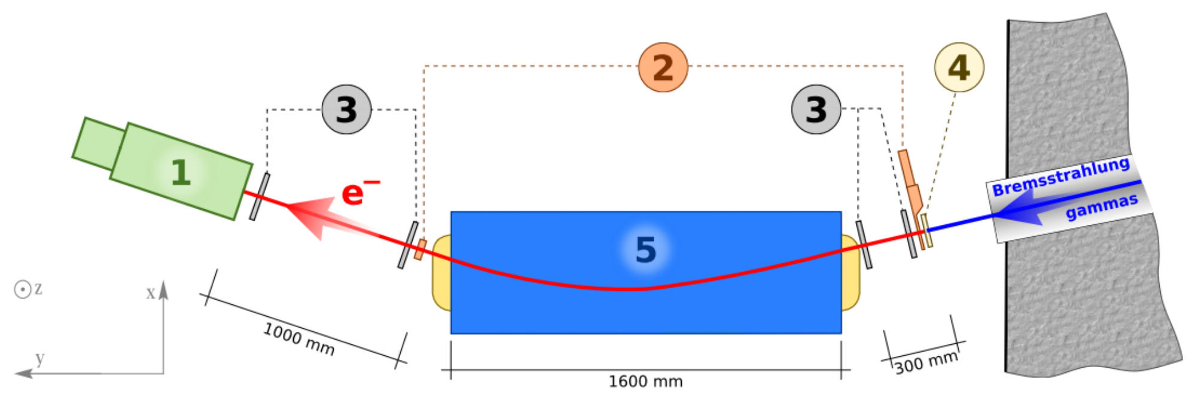

Figure. 1: *The Test Beam facility schematic view. Experimental setup: 1 – BGO/NaI calorimeter, 2 – trigger scintillation counters, 3 – GEM detectors, 4 – iron target, 5 – bending magnet.*

The Test Beam facility was built in the Budker Institute of Nuclear Physics at the VEPP-4M e^+e^- collider for generation of test beams of electrons and photons in a wide range of energies [1]. This installation is designed to test prototypes of detectors for particle physics and it has been used successfully for such studies since 2011. As seen in the overview of the facility presented in Fig. 1, four triple-GEM detectors will be installed for the upgrade.

The basic principle of the facility operation is the following: when a special probe is being moved close to the beam, generated Bremsstrahlung gammas pass through a special channel to the experimental hall and hit the iron target(4). The electrons produced pass through the first pair of coordinate detectors(3), bending magnet(5) and the second pair of the detectors(3), arriving finally at the calorimeter(1).

The intensity of the generated electron beam is no less than 50 Hz, while the electron energy ranges from 0.1 GeV to 3.5 GeV, the energy resolution of the calorimeter is about 2-3% for electrons with energy larger than 0.5 GeV. The gamma energy range is from 0.05 GeV to 4.0 GeV with an accuracy of 0.5% of energy and the designed intensity of the gamma beam is about 1000 Hz. [2]

The GEM Detector

The detector design was finalized according to the results of simulation studies of the limits of spatial resolution of the GEM detectors and experience gained during the development of the detectors for the DEUTERON PTS system [3, 4].

The prototype detector with high spatial resolution and low material content was developed and, during 2016, the first detector was manufactured (GEMs, flexible readout structures and electronics PCBs made at the CERN Workshop, assembly finalized at the BINP) [5].

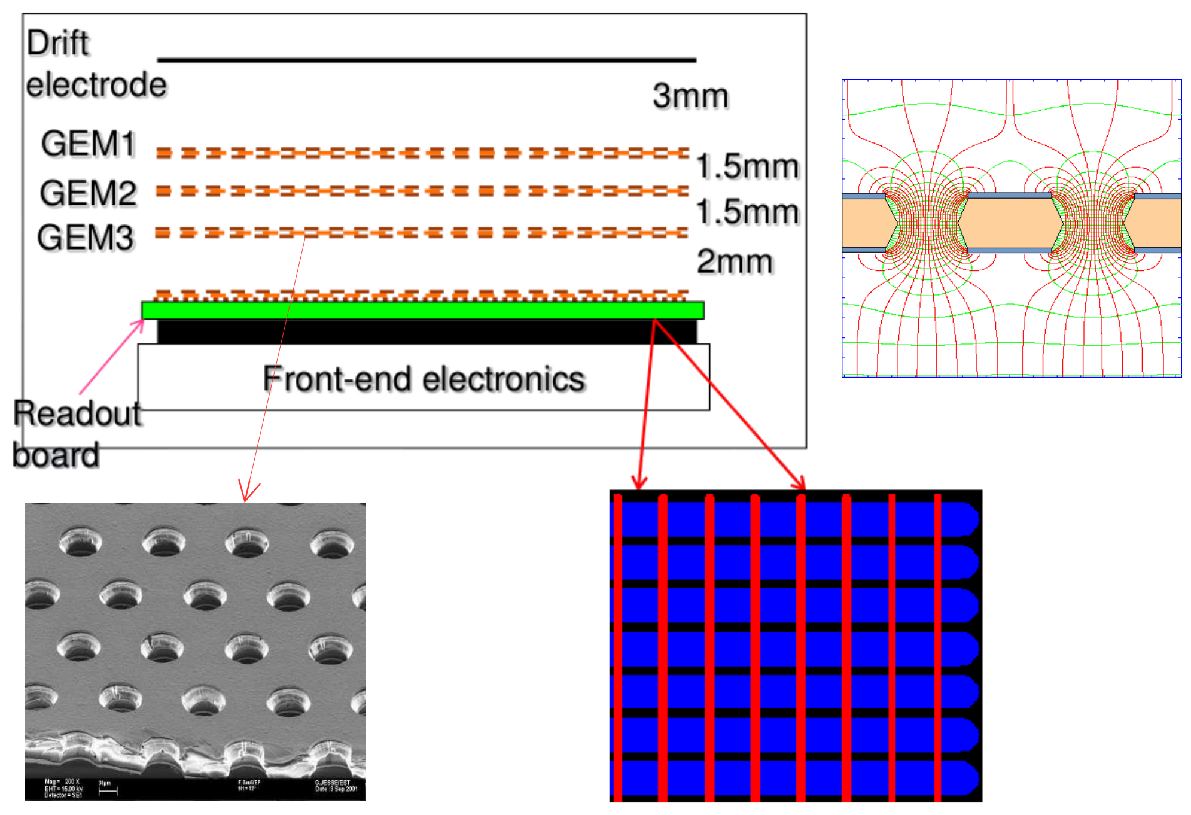

Figure 2: *Main components of the GEM detector with the schematic view of the cross section, side view of GEM and readout structure draft (red colored are X-strips on top of the blue colored Y-strips)*

The detector consists of a triple-GEM, orthogonal X-Y readout structure and detector electronics. Electronics is based on the APC128 ASIC (analog pipeline chip, 128 channels) [6], six of these chips are used covering 768 channels in total. These channels are connected to the readout structure, which has two layers: 512 vertical strips (red colored) and 256 horizontal strips (blue colored), both directions have a 0.25 mm pitch. Thus, the detector sensitive area is 128x64 mm^2.

In order to minimize multiple scattering the detector elements have a reduced thickness of copper down to 1-2 µm at each GEM side. Such an approach was investigated and it was found that thinning of copper layers does not affect the detector performance.

A triple-GEM detector with thinner copper layers can have the total amount of material seen by particles of ~0.15% of radiation length. The expected spatial resolution of this kind of detector is around 30 µm.

APC128 front-end chip

Figure 5 shows schematically one of 128 channels of the Analog Pipeline Chip. Each channel has a charge sensitive, low noise, low power preamplifier followed by a 32-cell storage pipeline. The storage pipeline consists of switched capacitors. When disconnecting the capacitors they store a charge proportional to the output voltage of the preamplifier. The storage capacitors of the pipeline are controlled by the pipeline shift register. This pipeline shift register can be operated with a frequency of 10 MHz.

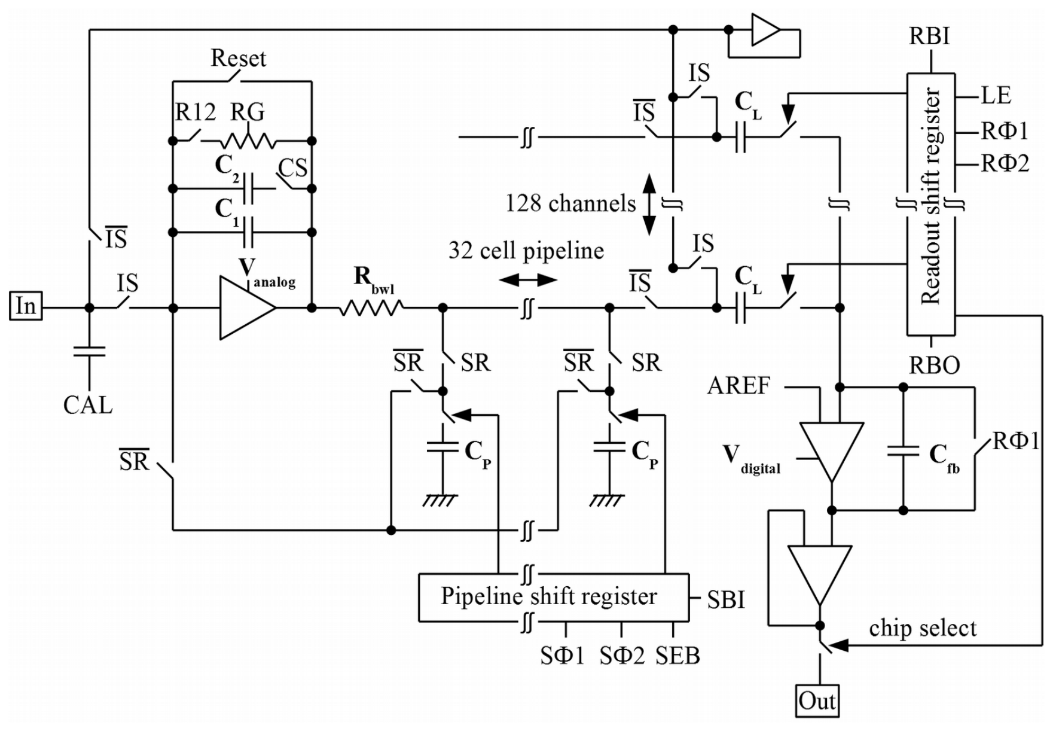

Figure 5: *Schematic view of the single channel of APC128*

Due to limited amount of APC128 chips and expecting better parameters from alternatives, future designs will be based on DMXG64 ASIC which was developed at the BINP.

Detector electronics

In Fig. 3 a photograph of the new detector is shown. The detector electronics consists of a motherboard PCB and two DAQ boards. Each DAQ board includes four blocks of APC128 ASIC and a dedicated 14-bit ADC covering 512 channels in total. Input channels of the DAQ board are wired through the special protection circuits against high voltage discharges (see Fig. 4).

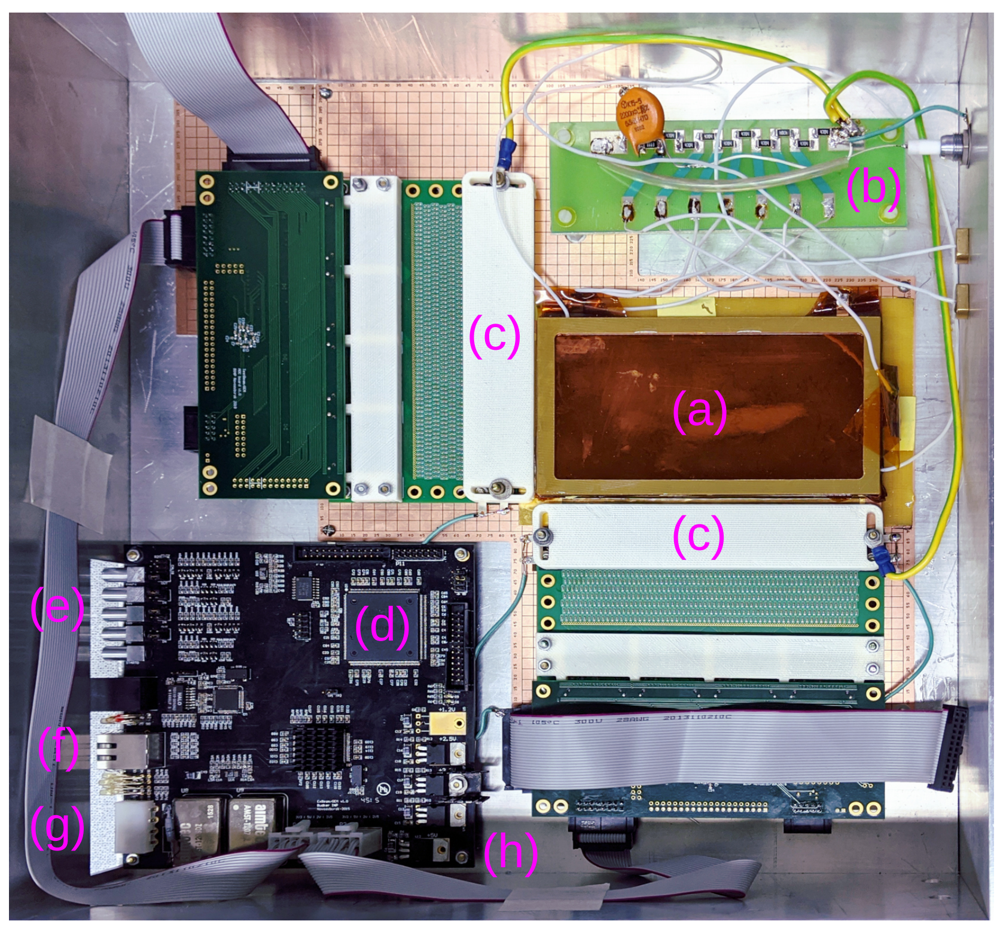

Figure 3: *Detector elements: (a) sensitive area, (b) high voltage, (c) DAQ boards, (d) FPGA, (e) trigger inputs, (f) 1GBit ethernet, (g) power +12V/1A, (h) analog power for DAQ boards.*

It the 2016 prototype detector each DAQ board was a single PCB, but in the revised design the DAQ board was split into Front-End board and ADC board. All the analog components (APC128 ASICs, protection circuits) are placed on the FE board while digital or bulky components (ADC, FPGA, IDC connectors) are placed on the ADC board. This provides opportunity for possible future upgrades of ADC.

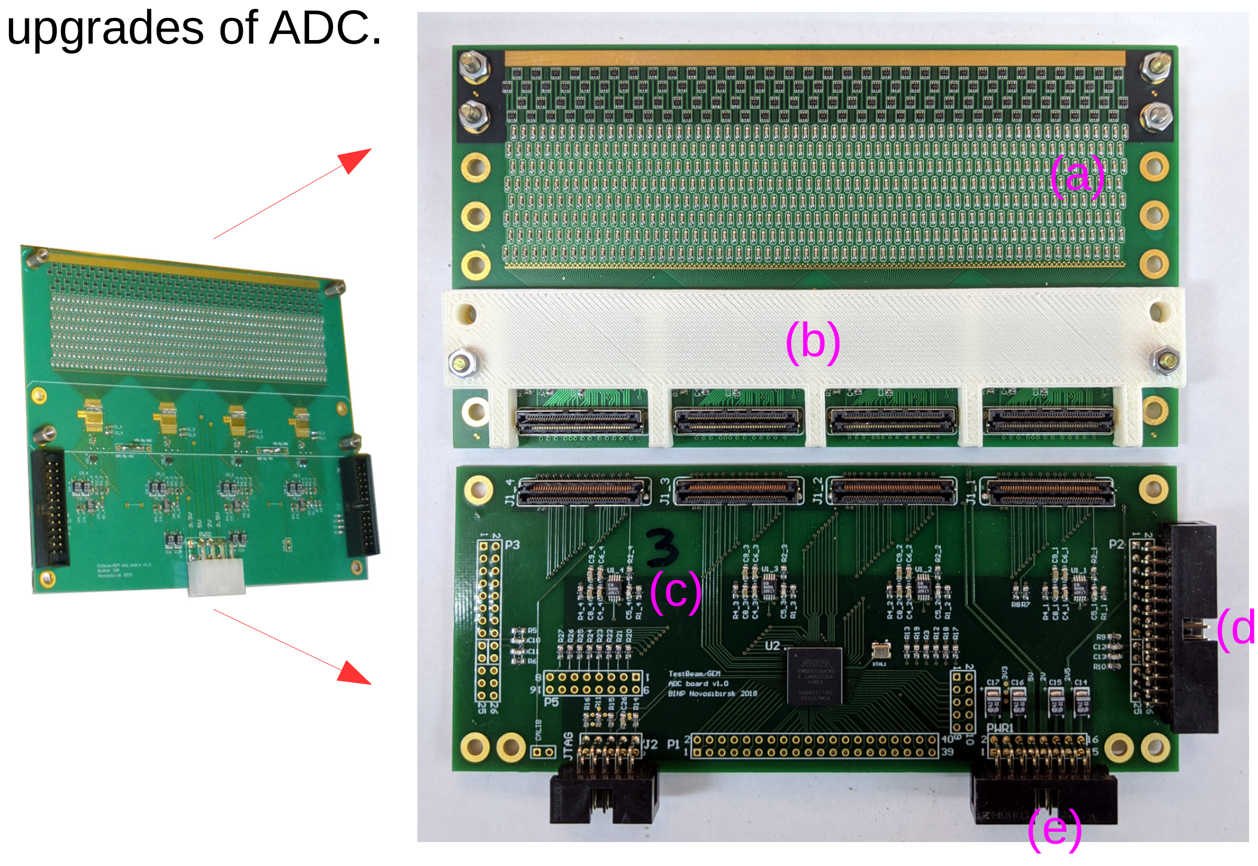

Figure 4: *DAQ board split into Front-End board and ADC board. DAQ board elements: (a) ESD protection circuits, (b) APC128 ASICs, (c) 14bit ADC, (d) motherboard interface connector, (e) power connector (+3.3/+5.0/+2.0/+2.5V/GND)*

Both DAQ boards are connected to the motherboard through flat ribbon cables, and custom power cables. The readout of all ADCs is performed in parallel and synchronously with the front-end chips readout sequence.

The Altera Cyclone III FPGA controls the data-taking process and is connected to the PC by the 1GBit ethernet interface. The interaction between electronics and PC is performed over UDP datagrams with commands and digitized data.

Because of the slow ADC currently used in the detector the minimum dead time is 500 µs, but for needs of the facility it is quite satisfactory.

2016 Prototype detector study

In 2016 the prototype detector was manufactured and proved to be operational. During 2017-2018 it was studied in the laboratory and at the Test Beam facility.

Using Sr^{90} radioactive source and cosmic radiation in the laboratory the gas amplification and detection efficiency of the charged particle tracks was measured. A maximum gain of 70000 was reached at 370 volts per GEM. The detector was operating with a gas mixture of Ar-CO_2 (75-25). The maximum efficiency of 97.5% was achieved at a gain of ~30000.

Under test beams the spatial resolution of the old detector was measured to be 31.5±7.5 µm.

Study of the final detector

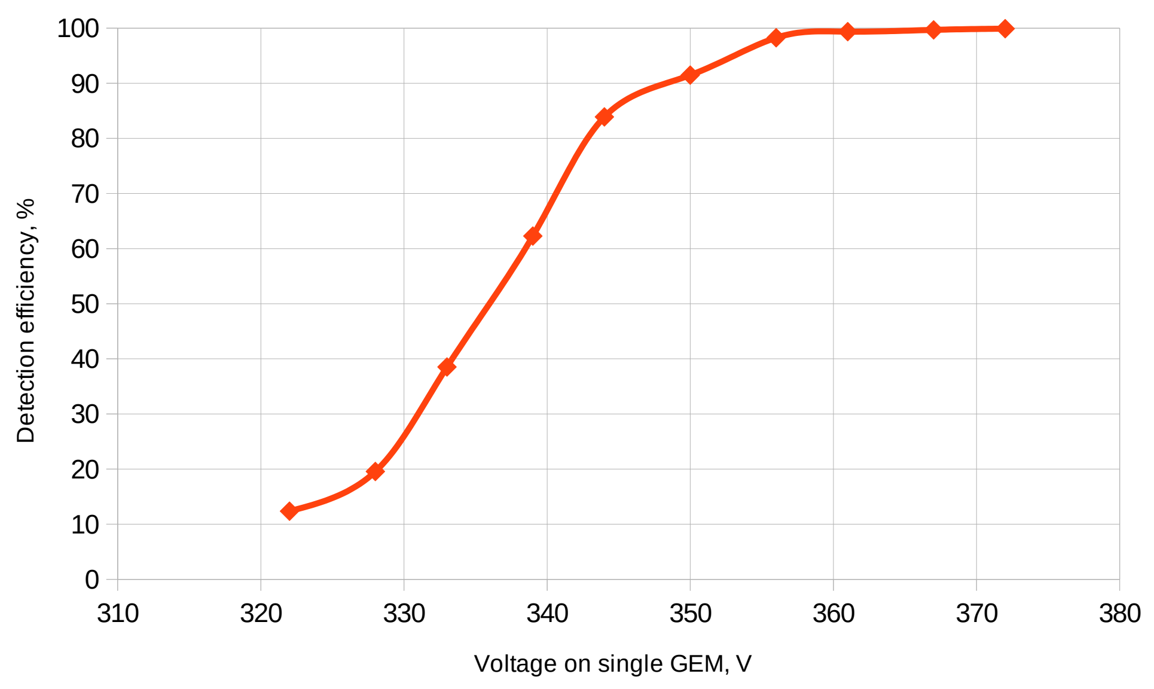

Figure 6: *Detection efficiency (%) as a function of single GEM voltage applied.*

In 2019 the manufacture of the first detector with the revised design was completed. In February of 2020 it was finally installed at the Test Beam facility.

Data taken during February runs show that detector works quite well despite having several dead channels (fig. 7) and detection efficiency reaches over 99% at the 361 volts per GEM and 99.9% at the 372 volts per GEM (fig. 6). Which is great improvement when compared with the result of the prototype detector study.

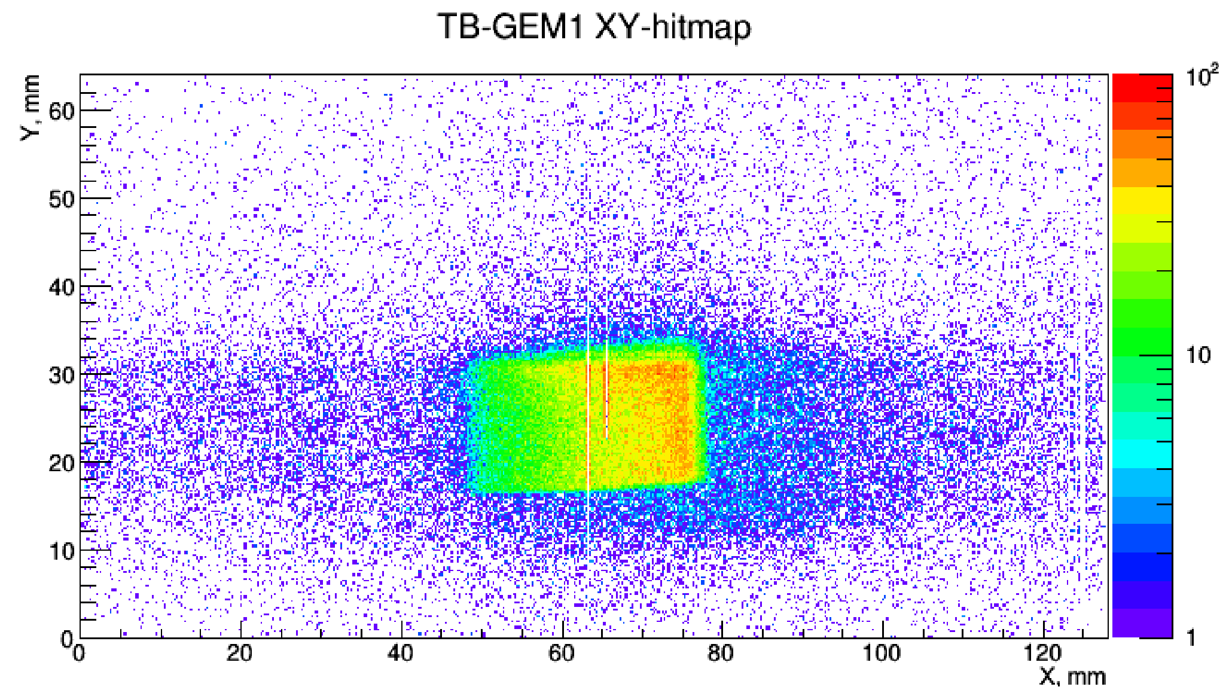

Figure 7: *Beam profile reveals its form in the new detector (data taken from 16/02/2020 runs).*

Conclusion

Detector with the revised design was manufactured and proved to be operational with the detection efficiency exceeding 99%.

The data for the spatial resolution study have been collected for the further analysis. As for the amount of material (X/X_0) of the triple-GEM detector, it is a subject of the future study.

References

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INSTR 2020, Instrumentation for Colliding Beam Physics, 24 - 28 February, 2020, BINP, Novosibirsk, Russia