PROCEEDINGS OF SCIENCE

The new CGEM Inner Tracker and the new TIGER ASIC for the BES III Experiment

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A new detector exploiting the technology of Gas Electron Multipliers is under construction to replace the innermost drift chamber of BESIII experiment, since its efficiency is compromised owing the high luminosity of Beijing Electron Positron Collider. The new inner tracker with a cylindrical shape will deploy several new features. The analogue readout and two complementary algorithms to reconstruct the position will allow achieving a spatial resolution of 130 µm in a 1 T magnetic field. For this purpose, TIGER, a new custom 64-channel ASIC, providing time and charge measurements, has been developed. Here, a summary of the most recent results on detector and electronics prototypes is given.

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1.Introduction

The BESIII experiment [1] has been operating since 2009 at the BEPCII double-ring e^+e^- collider in Beijing, collecting a very large data sample in the center-of-mass energy region between 2 and 4.6 GeV, which allows an investigation of different topics such as charmonium, charm physics, hadron physics [2], and τ-physics. In the last years, owing the high luminosity of 1.0×10^{33} $cm^{-2}s^{-1}$ achieved at BEPCII, the efficiency of the innermost drift chamber began to deteriorate [3]. The plan for the future is to continue data taking at least until the 2022. For this reason, a new inner tracker with a cylindrical shape, exploiting the technology of Gas Electron Multipliers (GEM), has been proposed to replace the current one. Specific requirements have been fixed for the new inner tracker; in particular, the $r\phi$ spatial resolution should be within 130 μm, operating in a high magnetic field of 1 T.

2.The Cylindrical GEM detector

The cylindrical GEM inner tracker (CGEM-IT) for BESIII experiment consists of three concentric layers of triple GEMs, a detailed description can be found in Ref. 4 and 5.

The first cylindrical GEM detector with four layers has been constructed for the KLOE-2 experiment [6] and operated in a magnetic field of 0.5 T, achieving a spatial resolution of 350 μm. The CGEM-IT project implements three new important features: the use of Rohacell 31 foam for the mechanical structure, which reduces the material budget of the three layers to a radiation length ~1% of X_0; a jagged strip layout of the anode which reduces the capacitance couplings between strips by ~ 30%; and the analogue readout of the strips, which allows loosening of the pitch size to 650 μm, using a limited number of channels (~10 000 instead of 25 000).

In particular, the analogue readout enables the use of charge-centroid (CC) and μTPC algorithms to reconstruct the position, as described in details in Ref. 5 and 7. Two different kinds of prototypes have been developed and tested since 2014: planar triple GEM prototypes of small size and, more recently, a cylindrical prototype of real size, which was intended to serve as one of the CGEM-IT layers. All the prototypes were studied with pions and muons at the H4 beam line of SPS at CERN, using a dipole magnet with a B field up to 1.5 T. Study of the spatial resolution was performed in various conditions: using two different gas mixtures, several working voltages, magnetic field on and off, and different incident angles of the particles.

In Figure 1 are shown the spatial resolutions of planar prototypes obtained with the CC and μTPC algorithms, as a function of incident angle (B field off) (left) and of the B field (with orthogonal tracks) (right). It turns out that each algorithm succeeds where the other fails in providing good spatial resolution. Nevertheless, using the planar prototypes, it has been proven [8] that a combination of the two algorithms allows keeping the spatial resolution stable at ~130 μm in the full range of incident angles with magnetic field on. This spatial resolution is the best achieved worldwide with triple GEM detectors operating in a high magnetic field of 1 T.

CGEM-IT must be built and fully tested to install in the BESIII spectrometer in the summer of 2018.

3.TIGER, a new ASIC for GEM readout electronics

To implement the analogue readout, a custom front-end ASIC with 64-channels has been designed. The Torino Integrated GEM Electronics for Readout (TIGER) ASIC [9], fabricated with UMC 110-nm CMOS technology, provides charge and time measurements with a fully digital output. It has been designed in accordance with the detector requirements, to operate with a sensor capacitance of up to 100 pF, a linear dynamic range between 1 and 50 fC, an event rate of 60 kHz/channel, a time resolution better than 10 ns, and a power consumption of ~ 10 mW/channel. Moreover, the digital back-end of the chip is protected for single-event upset (SEU).

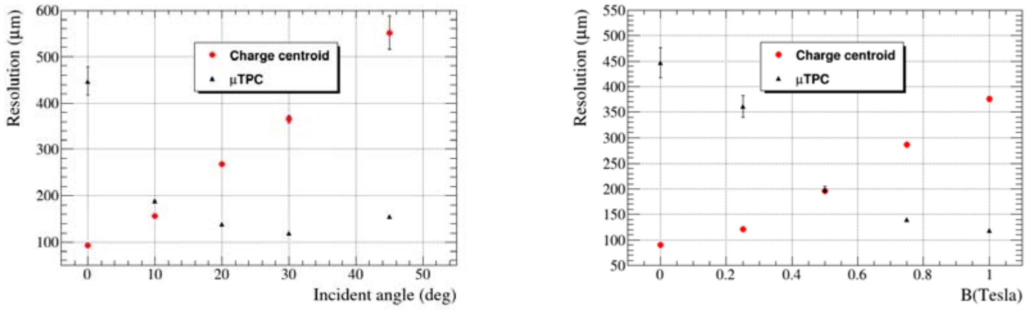

Figure 1. Spatial resolutions with CC and µTPC algorithms (*Left*) vs. incident angle from Ref. 5 and (*Right*) vs. magnetic field from Ref. 4.

A detailed description of TIGER can be found in Ref. 9. Each channel consists of a charge-sensitive amplifier followed by two shapers coupled to low-offset discriminators. The peaking time of one shaper is optimized for the time measurement; the peaking time of the other shaper is longer to enable a better integration and optimization of the signal-to-noise ratio for the charge measurement. The very front-end stage is followed by a mixed-mode back-end, with low-power TDCs and Wilkinson ADCs with derandomizing buffers to digitize the time-of-arrival and the charge of the input signal. The back-end design is an updated development of the TOFPET2 chip [10] for medical applications.

The first tapeout in silicon of the TIGER prototype was performed in May 2016, and electrical characterization began in October 2016. Test of the back-end electronics shows good performance. The Sample&Hold circuit, used for charge measurement, was tested by means of a known input charge and it showed a very good linearity (less than 0.2%) for the dynamic range of interest. The quantization error of the TDCs used for the time measurement was less than 50 ps r.m.s., therefore time resolution of the system will be limited only by the sensor and front-end amplifier response.

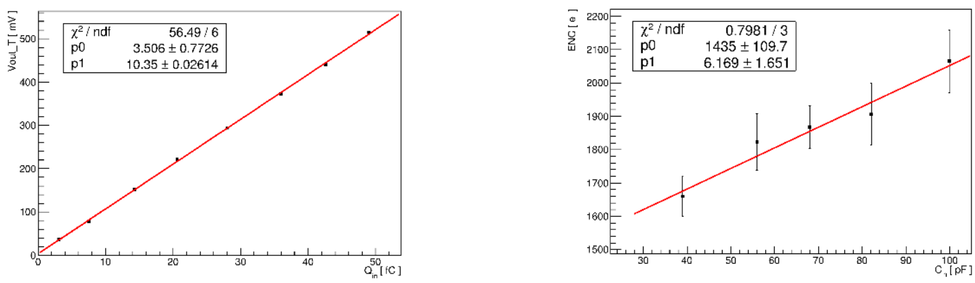

Figure 2. (*Left*) Gain measurement in one channel from Ref. 9. (*Right*) ENC of slow shaper output vs capacitance.

The assessment of the analogue front-end was performed for the two branches. The jitter of the time branch was measured as a function of different input capacitances and it was below 4 ns for an input charge of 3 fC with a capacitance of 100 pF. A direct measurement of the amplifier gain in one of the channels was performed, as shown in Figure 2(*left*). An average value of 10.4 mV/fC was found, in good agreement with the value of 11 mV/fC expected from the chip's post-layout simulation. Figure 2(*right*) shows the equivalent noise charge (ENC) of the slow shaper output of the energy branch, as a function of input capacitance. A value of about 2100 electrons r.m.s. at 100 pF was found, about 50% greater than that expected from simulations. The root cause of such extra noise was identified in the bias conditions of the holder circuit and an improved design has been done for the final engineering run.

Conclusions

A cylindrical GEM detector for the BESIII experiment with new features is under construction to replace the inner part of the drift chamber, compromised by aging. The analogue readout of each strip, by means of a custom ASIC in 110-nm CMOS technology, will allow to achieve the required spatial resolution of 130 µm. Two different readout algorithms were tested with planar triple-GEM prototypes and they look promising. The characterization of the first ASIC prototype shows the overall performance is adequate for the GEM detector and the final engineering run is ongoing with minor revisions.

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