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The sTGC Prototyping and Performance Test for the STAR Forward Upgrade

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Abstract: The STAR experiment at RHIC is implementing a new Forward Tracking System (FTS) which consists of a Forward Silicon Tracker (FST) and a Forward sTGC Tracker (FTT). The small-strip Thin Gap Chambers (sTGC) at STAR are designed to provide precision position measurements of about 100μm for charged particles at high luminosity, covering the forward rapidity region (2.5 $<\eta<4$). The extended rapidity coverage in particle tracking enables lots of physics opportunities in pp, pA and AA programs beyond 2021 at STAR. Two size sTGC prototypes have been designed and produced at Shandong University. The final designation will be finished by Feb.2020. In this paper, the sTGC prototype research and development details and some performance test results, such as detection efficiency, will be presented. Current status and future plan of the FTT upgrade will also be discussed.

Keywords: STAR forward upgrade, Forward Tracking System, Forward sTGC Tracker, Detection efficiency, High voltage burning, X-ray scan

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Contents

1 Introduction

The precisely imaging of gluons and sea quarks inside the proton and nuclei will address some of the deepest question regarding the emergence of nuclear properties from Quantum Chromodynamics (QCD) [1], such as how are the gluons and sea quarks, and their intrinsic spins, distributed in space and momentum inside the nucleon? How do quarks of different flavor dress themselves in nuclear matter to emerge as colorless hadrons? What does this dressing process tell us about the mechanisms by which quarks are normally confined inside nucleons [1]? To fully answer those scientific questions, experimental measurements need to extend to very high and low regions of Bjorken x [2].

The STAR experiment at the Relativistic Heavy Ion Collider (RHIC) has proposed a cold QCD physics program to address those fundamental questions and this QCD physics program requires detection capability at forward rapidity [3]. STAR has proposed detector upgrades at forward rapidities (2.5 $<\eta<$4) including a Forward Calorimeter System (FCS) and a Forward Tracking System (FTS) upgrade. The FTS is consists of a Forward Silicon Tracker (FST) and a Forward sTGC Tracker (FTT). The FST design is based on 3 layers silicon disks. The FTT design is based on 4 small-strip Thin Gap Chamber (sTGC) stations as shown in FIG. 1 (a). The sTGC stations would be placed 30 cm apart from each other, starting at 273 cm from the STAR-TPC center. Each station have two sTGC chambers to provide a precise x-y hit information. The forward sTGC tracker is required to measure charged particles's transverse momentum with 30% accuracy for $0.2 < p_T <$ 2 GeV/c and a tracking efficiency of ∼ 95%, and a position resolution between 100 µm ∼ 200 µm [1].

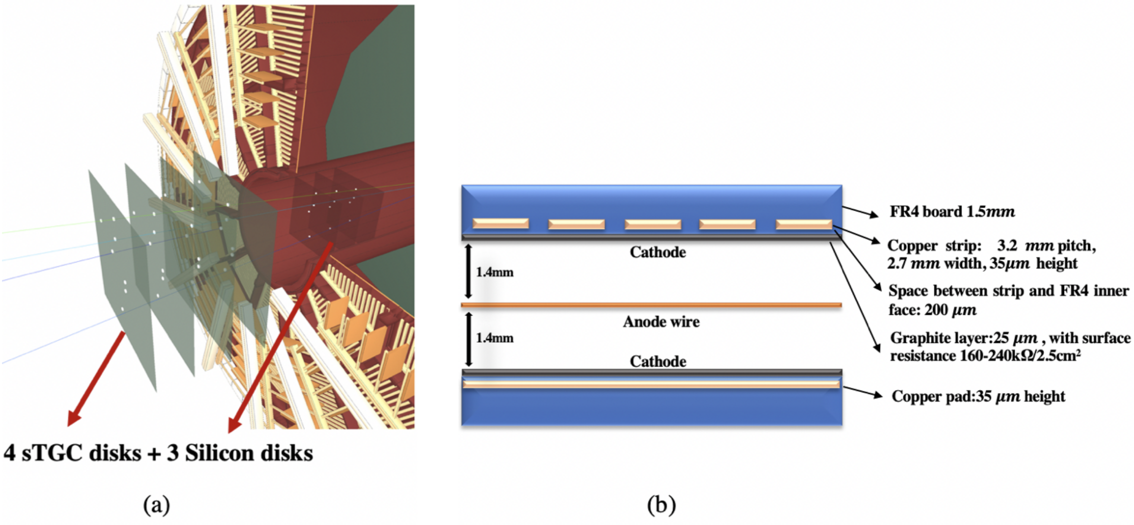

Figure 1. (a) The STAR FTS layout side view. (b) Schematic layout of a sTGC chamber.

2 sTGC prototype design and construction

FIG. 1 (b) shows the layout of a sTGC chamber. It consists of a gold-plated tungsten anode wire plane and two cathode planes. The anode plane has 340 wires pitched by 1.8 mm, each wire is 50 μm in diameter, and wires are sandwiched by two cathode planes. The cathode planes are made of 1.5 mm thick FR4 board and copper strips (pad). On one side of the cathode plane, copper strips are run perpendicular to the wires for precise coordinate measurements, and on the other side cathode plane are copper pads [4]. The copper strips, with a 3.2 mm pitch, act as readout electrodes and are optimized for good position resolution (100 μm). Both cathode planes are sprayed by high resistance graphite-epoxy mixture.

Three different shape of sTGC prototype stations have been designed and built at Shandong University. The first pre-prototype with a size of 30 cm × 30 cm has been installed at STAR in 2019 during the BES-II runs. The full size prototype with a size of 60 cm × 60 cm has been tested and will sent to BNL in May 2020. The latest prototype with a symmetric pentagon prototype will be constructed in early 2020. The pentagon design is motivated by special physical constrains of STAR. FIG. 2 shows the full size prototype, and all testing results presented in this proceeding are based on this prototype. The sTGC station consists of two chambers which are perpendicular to each other in the strip direction for two-dimensional read-out of a hit. The production of a sTGC is generally divided into six steps: carbon coating, wire winding, chamber combination, leakage current scan with X-ray, two chamber combination, performance test [8].

3 Leakage current monitoring and X-ray scan

After the chambers are combined, the high voltage burning was done to test and improve the sTGC station working stability. Before that, the sTGC station should have been flushed with 55% CO_2

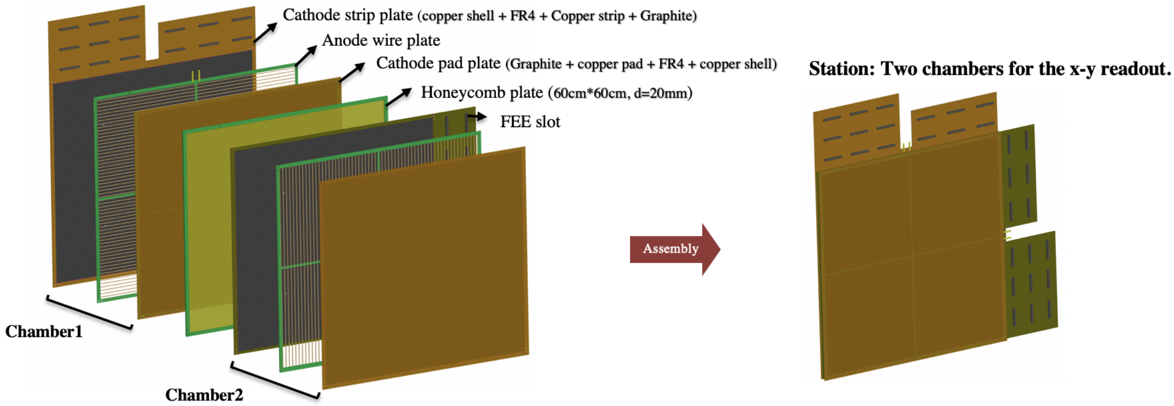

Figure 2. Station geometry of full size prototype.

and 45% n-pentane for at least 8 hours. And then the leakage current of the sTGC station was monitored at 3200 V. FIG. 3 shows the leakage current monitored over 11 hours over which no sparks are observed. The current fluctuation is about ±15 nA, as shown in the FIG. 3, that may be caused by changes in the laboratory humidity.

X-ray scanning ensures high quality and reliability of sTGC chambers [5, 6]. An Ag target X-ray tube and a XY 2D stepper system were used to scan the whole sTGC chamber plane. The X-ray beam could cover an area with a radius of about 2 mm on the chamber surface. With the stepper system moving slowly and continuously the current value of the detector can be smoothly recorded. FIG. 4 left shows the X-ray scan current of the sTGC chamber with 2900 V high voltage and 55% CO_2 and 45% n-pentane mixed working gas. The right of the FIG. 4: (a) is the current outside the active area, corresponding to the blue-purple part in the left of the FIG. 4; (b) is the inner support part of the sTGC, corresponding to the green region; (c) is the active area, corresponding to the red and yellow areas; (d) is the spark area as shown in FIG. 3. The distribution of the current for the sensitive area reflects the flatness of the sTGC chamber. The red areas have large current, representing a narrow gap in the detector. The more uniform the color, the better the flatness of the chamber. FWHM should be less than 20% to meet production requirements. The X-ray scan test results meet this requirements.

4 sTGC performance test system

The test system is shown in FIG. 5. The sTGC anode wires are operated at 2700 V, and all chambers are flowed with 55% CO_2 and 45% n-pentane gas. Two scintillator detectors are placed on top and bottom of the three sTGC chambers, the coincidence signal from the two scintillator serves as a trigger. The sTGC strip signals are read out by the STAR TPX electronics, which consists of the Front End Electronics (FEE) and the Readout board (RDO) [9]. The FEEs do the signal pre-amplification, shaping and digitization [10]. The RDO board transmits the digital data to a compute station via a optic fiber [10]. The signal read-out gate width is set to 9.4 µs and divided into

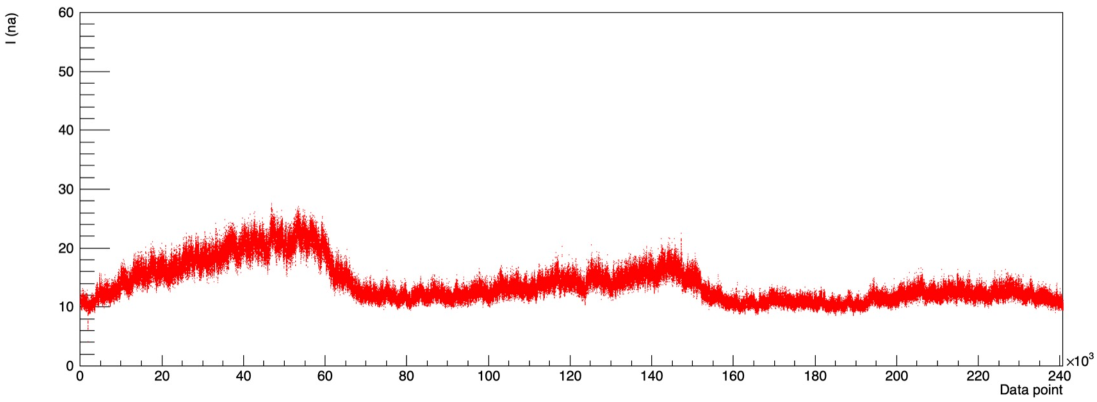

Figure 3. The full size prototype's leakage current monitoring at a high voltage of 3200 V.

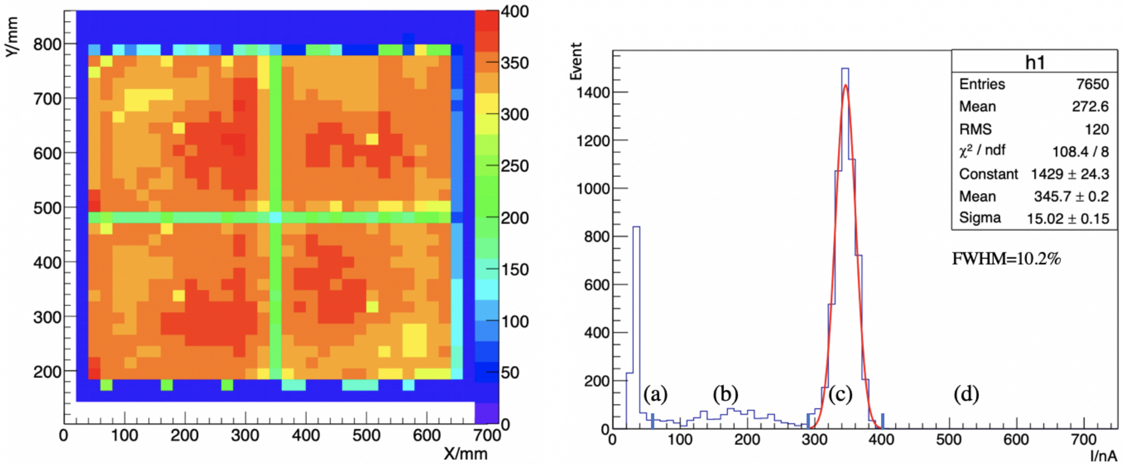

Figure 4. The X-ray scan result of the full size prototype chamber. Left: 2D scan result with X-ray scanner. Right: The current distribution during the X-ray scan.

94 time-bins [11]. To eliminate noise, a set of cuts are used for the signal selection: the signal width should be greater than 300 ns, number of fired strips should be larger than 3, and signal amplitude in each time-bin (100 ns) should be greater than 16 ADC values. FIG. 6 shows the cosmic ray analog signal without pre-amplification, shaping and digitization.

5 Detection efficiency

The detection efficiency of the full size prototype is estimated by the ratio of events with three chambers fired and events with two chambers fired as shown in FIG. 7 (a). To avoid random matching, events with two or more cosmic ray hits in any of these three layers of sTGC chamber have been excluded. A correlation in the hit position is also required to further suppress background. Assuming x-axis along the strip direction and the y-axis is perpendicular to the strip direction, then

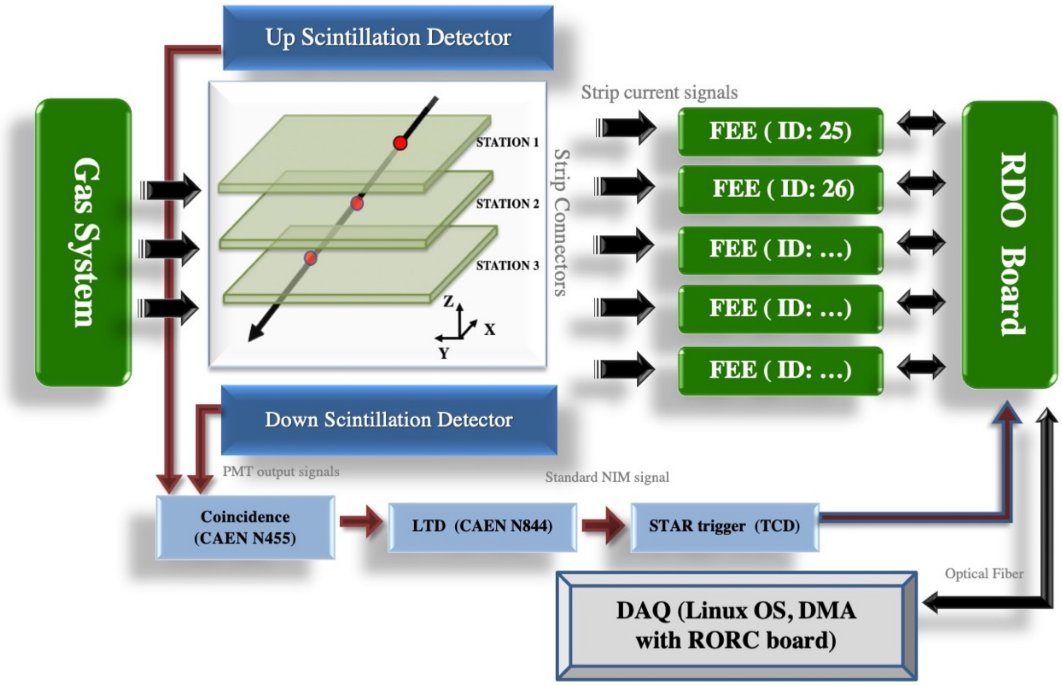

Figure 5. sTGC performance test system

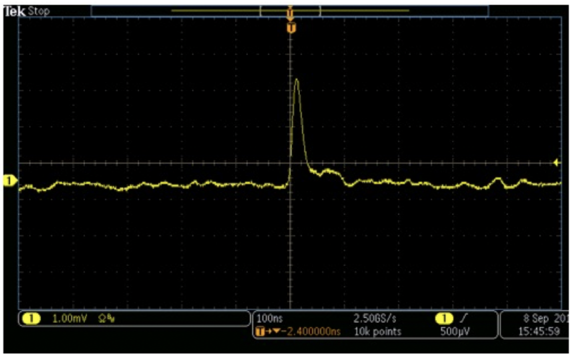

Figure 6. Cosmic ray analog signal on a strip. The signal width and amplitude are about 150 ns and 3 mV respectively.

the hit position in y is also required (taking the middle layer as an example):

$$y_{mid} - \frac{y_{up} + y_{down}}{2} < 10mm$$

With the event selection criteria mentioned above, a total of 7058 events with both hits on top and bottom sTGC chamber and 6869 events with hits among all three sTGC chambers are measured. The detection efficiency for the mid-layer sTGC chamber is 97.3% at 2700 V in the cosmic ray test. FIG. 7 (b) shows the detection efficiency of the pre-prototype at 2800 V during the STAR 2019 data-taking. The efficiency achieved is greater than 98%.

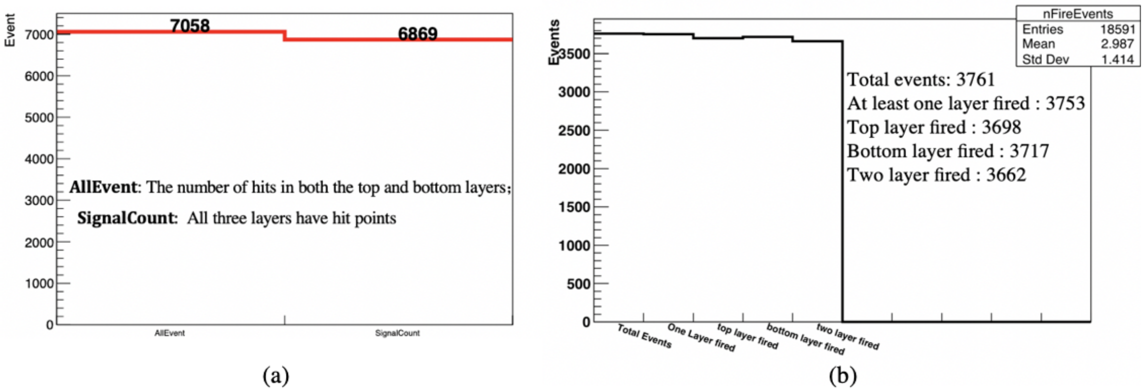

Figure 7. The signal coincidences of different sTGC chambers. (a) Full size prototype at 2700 V in cosmic ray test (Efficiency >97%). (b) Pre-prototype at 2800 V during the STAR 2019 data-taking (Efficiency >98%).

6 Summary

The FTS upgrade consisting of FTT and FST is on going. The forward upgrade provides an opportunity to investigate novel cold QCD physics. The sTGC is an essential part of STAR forward upgrade plan. Three different sTGC prototypes have been designed and built at Shandong University. The pre-prototype test result shows that the efficiency is >98% during the STAR 2019 data-taking. The full size prototype test result shows that the efficiency is greater than 97% at 2700 V during the cosmic ray test. The symmetric pentagon prototype has been designed and will be built by early 2020. The high voltage burning and X-ray scan ensures quality and reliability of sTGC chamber. Current prototype tests show that the prototype performances meet the STAR forward rapidity upgrade requirements. Next the position resolution will be test.

7 Acknowledgement

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