

Prototype sector production for the STAR inner TPC upgrade

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Abstract. The STAR experiment at the Relativistic Heavy Ion Collider (RHIC) is upgrading the Inner TPC sectors (iTPC). By increasing the number of inner pad rows from 13 to 40 and renewing the inner sector wires, this major detector upgrade will improve the rapidity coverage from $|\eta| < 1$ to $|\eta| < 1.5$, provide better momentum resolution, and better energy loss (dE/dx) resolution. The iTPC upgrade is crucial to STAR Beam Energy Scan Phase II (BES-II) program, which will provide in-depth understanding on QCD phase diagram and in-medium modification. In this paper we report on progress on the iTPC sector construction. The iTPC module fabrication techniques and testing results from the first full size prototype are presented.

1. Introduction

The STAR experiment [1] is dedicated to study the fundamental properties of the deconfined QCD medium (Quark-Gluon Plasma, QGP) via ultra-relativistic heavy-ion collisions at the RHIC [2]. To improve many results by an order of magnitude for the measurements done with STAR at lower collisions energies, where a critical point may be observed, the BES-II program is scheduled from year 2019 to year 2020 with collision energies from 7.7 GeV to 19.6 GeV. This important program calls for detector upgrades including iTPC, eTOF (endcap Time of Flight) and EPD (Event Plane Detector). The TPC [3] is the main detector in STAR for tracking and PID in the central region, which provides precise charged-particle tracking, momentum measurement, and particle identification in high multiplicity heavy-ion collisions [4, 5]. The major goals of the iTPC upgrade are as follows: wider rapidity coverage, better momentum resolution, and better dE/dx resolution [6]. The current inner TPC pad row geometry does not have continuous coverage at all radii. Distances between nearby pad rows are greater than 50mm while the pad rows are 11.5mm tall. Therefore, 80% of the inner pad plane area has no readout. In the iTPC upgrade, we will get continuous coverage on η , doubling the number of pads in the inner sector pad plane and increasing the pad size. This will increase the percentage of sampled track path length from 20% to 95%, which means we will design “continuous” pad rows on pad plane. The electronics will be upgraded accordingly due to the doubled number of readout pads. In addition, the multi-wire proportional chambers (MWPCs) in inner sectors will be renewed to reset the time for wire aging on anode wires due to the increasing integrated and instantaneous luminosity delivered by RHIC. In general, the goal for the projects is to replace all 24 existing inner sectors in the STAR TPC with new, fully instrumented, sectors.

2. Physics impact of the iTPC upgrade

The enhanced measurement capabilities of STAR after the iTPC upgrade are crucial for BES-II and provide a major benefit for many analyses, especially fluctuations (Kurtosis) and dielectron. The search for a possible critical point [7, 8] in the QCD phase diagram is one of the most interesting and important topics in heavy ion physics. The critical point, if it exists and if it can be identified, would provide a landmark in the phase diagram of nuclear matter and guide further experimental and theoretical studies of QCD under a wide range of conditions. RHIC has completed Phase-I of the beam energy scan program (BES-I) with center-of-mass beam energies per nucleon in Au+Au collisions of 39, 27, 19.6, 14.5, 11.5 and 7.7 GeV. The proposed BES-II will focus on an in-depth study of energies below 20 GeV with typically 20 times the statistics as in the same energy region exploited in BES-I. The iTPC upgrade extends the rapidity coverage by 50%. Wider rapidity coverage is important for this correlation study. For dielectron measurements [9], the iTPC upgrade will reduce hadron contamination from a dominant source of uncertainty to an expected statistical uncertainty of only 10%. With good statistics and better uncertainty control, in-medium modification behavior can be well studied in BES-II via dielectron measurements. Models comparison with different in-medium ρ broadening scenarios may give more clear physics messages.

3. The first prototype production

The first prototype of iTPC sector was fabricated in Shandong University. Design parameters compared with the old design can be found in Tab. 1. In the following we described the three steps of the MWPC production.

Table 1. Parameters for the original and new STAR TPC pad planes.

Item	Inner	Outer	iTPC	Comments
Pad Pitch (center to center)	3.35×12	6.70×20	5.00×16	mm
Isolation gap between pads	0.5	0.5	0.5	mm
Pad Size	2.85×11.5	6.20×19.5	4.5×15.5	mm^2
Number of pads	1750	3940	3440	
Anode to pad plane spacing	2	4	2	mm
Anode voltage	1170V	1390V	$\sim 1120V$	20:1 S/N
Anode Gas Gain	3770	1230	~ 2000	nominal
Anode Wire diameter	$20\mu\text{m}$	$20\mu\text{m}$	$20\mu\text{m}$	Au plated W
Anode Witch Pitch	4	4	4	mm

3.1. Wire winding

A wire winding machine is used to wind the wires on an Aluminum frame. Wire tension is kept via a sensor and wire pitch is controlled by stepper motor when winding. Before mounting the wires on TPC sector, they are checked when they are on wire frames. A laser system is designed to check the wire tension and pitch. Figure 1 shows a layout of this laser system. Synchronized with gas jet, the laser is used to scan each wire. Fundamental oscillator frequency can be derived from the voltage fluctuation transformed of laser absorption via a photodiode. Then wire tension can be calculated with known wire parameters. Wire pitch can be obtained simultaneously. Figure 2 shows the distribution of measured anode wire tensions. The desired mean value is 0.5N. All wire tensions are qualified (within $0.5 \pm 0.05N$). In the wire winding step,

the precision of wire pitch is about $50\mu\text{m}$, which will be further improved to less than $10\mu\text{m}$ by an wire comb in wire mounting step.

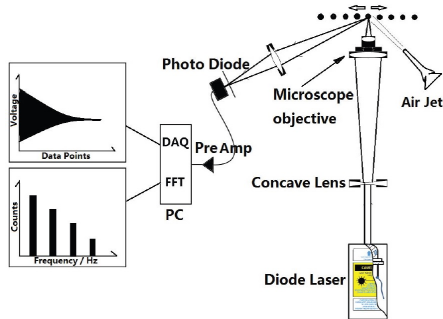


Figure 1. Layout of the laser system for wire tension measurement. Layouts of photodiode transition and Fast Fourier Transform are shown on left.

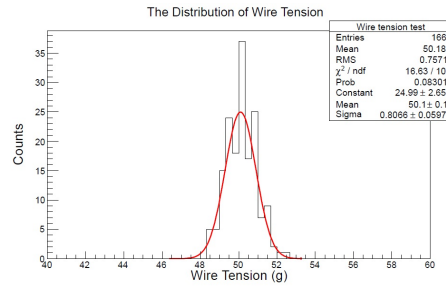


Figure 2. Wire tension distribution of anode wires. The desired mean value is set to 0.5N .

3.2. Wire mounting

The Aluminium supporting strong backer made by University of Texas, Austin with the glued pad plane is seen in Fig. 3. The pad plane and side wire mounts are reproduced with original drawings in China. The tolerance of height from pad plane to the bottom of strong back is required as $10\mu\text{m}$. Same tolerance standard is required for three wire planes. The qualified wire frames should be further mounted on the wire mount PCB which are installed on strong backer. Fig. 4 shows a photo in this wire mounting process. The wire tension and pitch are firstly guaranteed by wire winding machine. And then, wire pitch and height are modified by wire combs. These wire combs consist two parts. One structure like comb is to fix wire pitch while the other structure with straight edge is to fix wire height. After using wire comb, the height and pitch tolerance of wires are controlled to within $10\mu\text{m}$. After gluing and soldering, the installed wires need double check on wire tension and pitch. This double check shows good consistency with the test results before wire mounting.

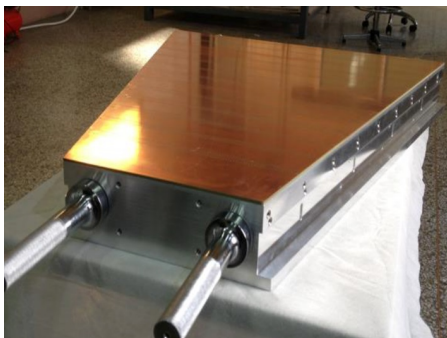


Figure 3. Pad plane glued on strong backer. The Aluminum strong backer shown in bottom is to provide mechanical support for all three wire frames.

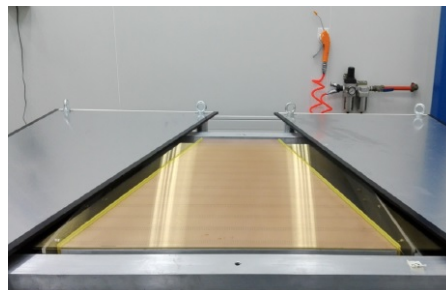


Figure 4. Wire frame laying on a sector in wire mounting process. Two protection covers are used to prevent unnecessary touching on wire comb.

3.3. Sector testing based on cosmic-ray

A testing system using a cosmic-ray trigger has been built in Shandong University. The trigger system contains two layers of scintillator readouts by PMTs. When a cosmic-ray muon passes across, the coincidence of two PMT signals provides the trigger signal. The first prototype of iTPC sector is located in Plexiglass chamber with an Aluminum supporting base. The size of this test chamber is $92 \times 76 \times 76.5$ cm. With one layer of cathode and one layer of ground, combined with a simplified field cage, the electric field uniformity is guaranteed. The operation gas P10 (90% Ar + 10% CH₄) is flowed into the testing chamber with good air tightness. With a DAQ similar to what STAR uses now, cosmic-ray signal can be collected. Figure 5 shows the ADC versus time bin (represent the ionized electron drift time, ~ 100 ns/bin) distribution of 30k events recorded. The cutoff at about time bin 170 is due to the drift length of the testing chamber. Since we observe a decrease of the signal with drift length there is likely an effect of absorption due to gas purity. This is under investigation. Some cosmic-ray tracks can be “seen” by pushing back the readout signals into 3 dimension (pad position X vs row position Y vs relative drift time Z). Figure 6 shows an example of the reconstructed cosmic-ray “track” left in the testing chamber. Cluster finder algorithm will be applied in our local track reconstruction soon.

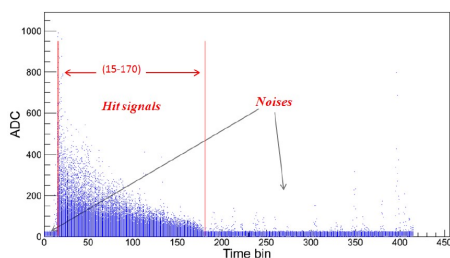


Figure 5. ADC versus time bin distribution of 30k recorded events in cosmic-ray test.

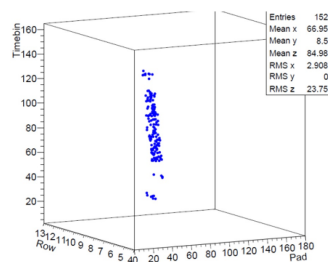


Figure 6. Observed ionization signal positions left in drift area for a cosmic-ray track.

4. Summary and Outlook

The STAR inner TPC upgrade is underway. This upgrade will improve many STAR physics results in statistics, acceptance coverage and systematic uncertainties. A complete construction plan is ready, aiming the BES-II program in year 2019 and 2020. First inner sector prototype has been produced with qualified wire tension, pitch and height. Testing system based on cosmic-ray has been built and operated while the data is taken smoothly. Additional testing for this first prototype is ongoing.

References

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