STAR Forward Detector Upgrade Status and Performance

Zhen Wang[1,*] , for the STAR collaboration

[1]Institute of Frontier and Interdisciplinary Science & Key Laboratory of Particle Physics and Particle Irradiation (Ministry of Education), Shandong University, Qingdao, Shandong, 266237, China

Abstract. An upgrade to the STAR detector system at forward rapidities has been completed before the RHIC RUN 2022. It consists of the Forward Tracking System (FTS) and the Forward Calorimeter System (FCS). The Forward Tracking System is composed of a Silicon Tracker and a small-strip Thin Gap Chamber Tracker. The Forward Calorimeter System contains an Electromagnetic Calorimeter and a Hadronic Calorimeter. These systems cover the pseudorapidity region of $2.5 < \eta < 4$, providing detection capabilities for neutral pions, photons, electrons, jets, and charged hadrons. This enables the STAR experiment to study cold QCD physics at very high and low regions of Bjorken x and to explore the longitudinal structure of the initial state in relativistic heavy-ion collisions by measuring the decorrelations at large η. This proceeding will introduce the STAR forward upgrade, its current status, and its performance during the STAR Run22.

1 Introduction

The major goal for the STAR forward upgrade is to explore the cold QCD physics in the very high and low Bjorken x regions. The forward upgrade allows STAR to extend its x coverage to the region where x is less than $2*10^{-3}$ and greater than 0.3. This detector upgrade will also provide the capabilities to explore the topics in the hot QCD, like the longitudinal structure of the initial state and the temperature dependent transport properties of the matter created in the relativistic heavy ion collisions [1]. The STAR forward upgrade includes two subsystems, the Forward Tracking System (FTS) and the Forward Calorimeter System (FCS). The Forward Tracking System is composed of a Silicon Tracker and a small-strip Thin Gap Chamber(sTGC) Tracker. The Forward Calorimeter System contains an Electromagnetic Calorimeter and a Hadronic Calorimeter. Both the FTS and FCS are located in STAR to face the blue beam, and cover the $2.5<\eta<4$ region. The installation of the STAR forward upgrade was completed in 2021 and has been integral to the trigger and data-taking system since 2022. Figure 1 shows a sketch of the STAR detector with the forward upgrade.

2 Forward Tracking System

The Forward Tracking System contains two subsystems, the Forward Silicon Tracker (FST) and the Forward sTGC Tracker (FTT). The whole FTS can provide 7 points to reconstruct the forward track with a η coverage of 2.5 to 4.

*e-mail: wang.zhen@sdu.edu.cn

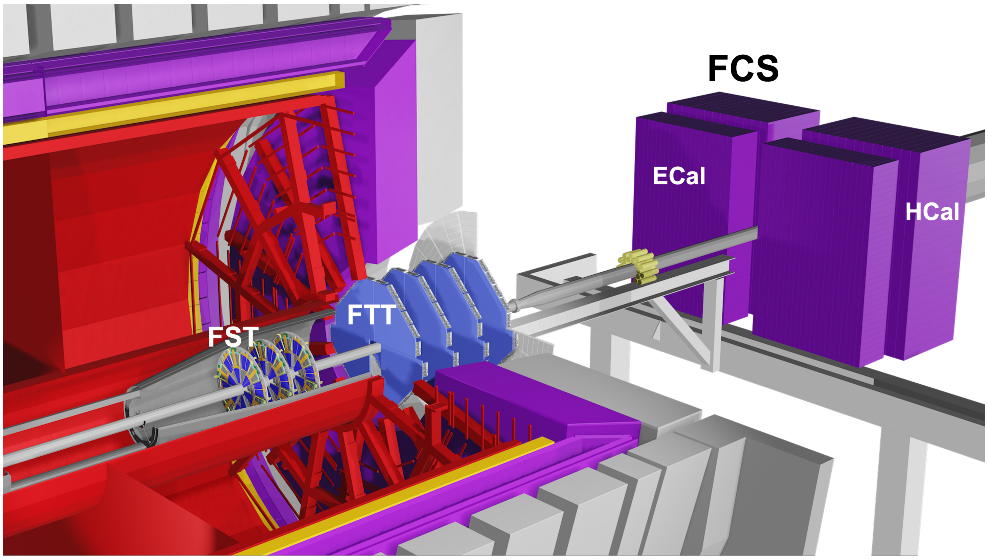

Figure 1. The sketch of the STAR detector with the forward upgrade. This sketch was created using Blender and is based on the actual geometry of the STAR detector. The components of the STAR forward upgrade are labeled in the figure. From left to right: the labeled components are Forward Silicon Tracker (FST), Forward sTGC Tracker (FTT), Electromagnetic Calorimeter (ECal) and Hadronic Calorimeter (HCal).

The Forward Silicon Tracker (FST) consists of 3 identical disks. These three disks are placed inside the STAR Time Projection Chamber (TPC) [2] where z locations are between 152 cm to 179 cm from the interaction point. Each FST disk contains 12 identical modules, and each module has fine granularity in the ϕ direction and coarse granularity in the R direction. FST reuses the electronics, DAQ and cooling system developed for the previous STAR Intermediate Silicon Tracker (IST) [3] to reduce cost. AVP25-S1 chips are used as the FST's readout electronics. The high voltage was set to 140V for the inner sensors and 160V for the outer sensors during the data taking.

The Forward small-strip Thin Gap Chamber Tracker (FTT) contains four identical planes, each comprising 4 pentagon shape gaseous detector modules [4]. These four planes are placed at z locations from 300 cm to 360 cm from the interaction point inside the magnet pole tip opening. Each module has two small-strip Thin Gap Chambers, including one X, one Y, and two diagonal readout layers to reconstruct the hit position. The FTT is operated with a gas mixture of 45% n-pentane and 55% CO_2. The readout electronics of the FTT utilize VMM electronics that follow the ATLAS design [5, 6]. The high voltage of sTGC was set to 2900V during the data taking.

The software framework for forward track reconstruction was initially established. Further optimization and testing are being conducted based on real and simulation data. The FST can provide up to three points, while the FTT can provide up to four points for track reconstruction. The track reconstruction algorithm based on Cellular Automata (CA) is used to do the track finding in the same detector. The points reconstructed on the FTT or FST will first be fit with points reconstructed on the same detector to obtain possible track segments. These segments will then serve as seeds for the overall track fitting, where they will be fit with points on another detector to determine the final possible track. The collision vertex reconstructed from TPC is used to constrain the tracks. If the TPC vertex is unavailable or vertex fitting fails for the forward track, the beamline can also be used to constrain the forward tracks.

The matching between the forward track and calorimeter hits can be used to test the forward tracking performance. Figure 2 shows the ΔX and ΔY distribution between the random combination of forward track projection hits and HCal hits. In the distributions of ΔX and ΔY, a clear peak can be observed around zero, indicating a good match between forward tracking and the calorimeter. However, since Hcal is divided into two independent modules in the X direction, there are two additional peaks in the ΔX distribution at ± 60 cm.

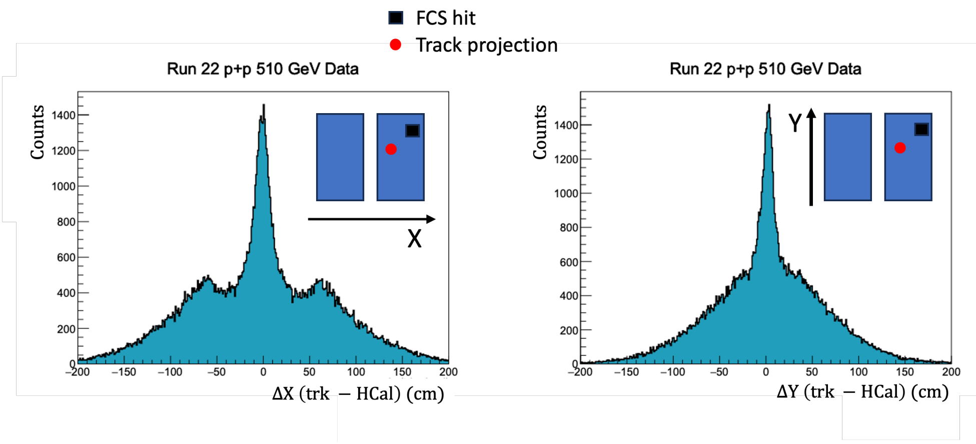

Figure 2. The ΔX (left panel) and ΔY (right panel) distributions between the random combination of forward track projection hits and HCal hits from Run22 p+p collisions data.

3 Forward Calorimeter System

The Forward Calorimeter System consists of an Electromagnetic Calorimeter (ECal) and a Hadronic Calorimeter (HCal). The FCS is located about 7 m away from the interaction point. The ECal consists of the refurbished PHENIX lead-scintillator calorimeter [7] and has 1496 channels. The HCal is an iron-scintillator sandwich sampling calorimeter with 520 channels. The FCS uses the SiPM-based readout electronics on the front face. These readout electronics were developed in collaboration with EIC R&D group.

The LED system integrated into the FCS monitors the radiation damage of the SiPMs, using the leakage current measured in LED runs to assess and qualify the damage. The radiation damage of most of the SiPM sensors was within the expectations. The attenuator and SiPM bias voltage on the front-end electronic board were regularly adjusted to mitigate the gain loss resulting from radiation damage.

The ECal was calibrated by reconstructing the invariant mass of π^0. A channel-by-channel gain correction factor was obtained through iterating the mass reconstruction. The right panel of Figure 3 shows the mass distribution after the calibration. After two rounds of iterations, all the ECal channels show a good performance of π^0 reconstruction. The left and middle panels of Figure 3 show the difference between the reconstructed π^0 mass and π^0 mass in PDG. The z-axis in these panels represents the fitting status of each channel, where the color red indicates a deviation of less than 10%. The HCal calibration will be done by MIP reconstruction. The calibration progress of HCal is currently ongoing.

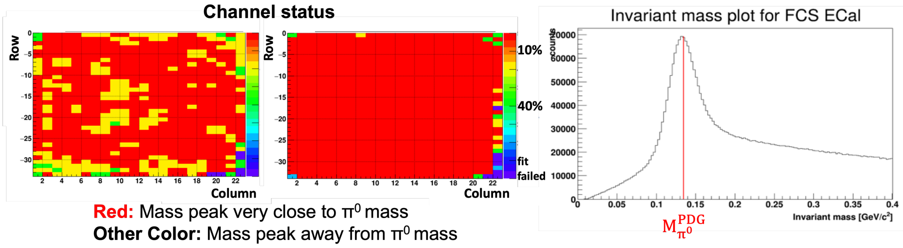

Figure 3. Left and middle panel are the channel status before and after the iteration. Red color means the reconstructed mass peak is close to the π^0 mass. Other colors mean that the reconstructed mass peak is away from the π^0 mass or fit failed. The right panel is the reconstructed mass distribution of one ECal channel.

4 Summary

All the forward upgrade detectors of STAR have been fully installed, commissioned, and integrated into the data-taking. With enormous efforts, the performance of the forward upgrade was as expected since the data-taking was very smooth during Run22 and Run23.

The algorithm of the forward tracking system has been established. Now the software group is testing and optimizing the tracking performance using data from pp collisions obtained in Run22. The calibration work of ECal has been done and the calibration of HCal is ongoing.

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