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The STAR Detector Upgrades for the BES-II and at Forward Rapidity

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Abstract: The Beam Energy Scan Phase II program (BES-II) at the Relativistic Heavy Ion Collider (RHIC) is examining the center-of-mass collision energy region from 7.7 GeV to 19.6 GeV which was determined from the results of BES-I. Key measurements such as the net proton kurtosis, the directed flow and the dilepton production are possible during BES-II with an order of magnitude better statistics due to the Low Energy RHIC electron Cooling (LEReC) upgrade and several STAR detector upgrades. Beyond BES-II, the STAR Collaboration is currently designing, constructing, and installing a suite of new detectors in the forward rapidity region ($2.5 < \eta < 4$), enabling a program of novel measurements in pp, pA and AA collisions. To fully explore this physics, the forward upgrade needs superior detection capability for neutral pions, photons, electrons, jets and leading hadrons by adding charged particle tracking and electromagnetic and hadronic calorimetry to STAR's capabilities at forward rapidity. In this proceedings, we will present the details on the STAR detector upgrades for the BES-II and at forward rapidity. The Cold QCD physics opportunities will also be discussed.

Keywords: STAR detector upgrade, BES-II, Cold QCD, Forward rapidity upgrade, sTGC, HCal, ECal

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Contents

1 STAR Detector Upgrades for RHIC Beam Energy Scan Phase II

The Relativistic Heavy Ion Collider (RHIC) at BNL is uniquely suited to study the phase diagram of strongly interacting nuclear matter, search for the critical point and find evidence of a first-order phase transition through its Beam Energy Scan (BES) program. The BES-I program has localized the most interesting regions (7.7 GeV - 19.6 GeV) and has identified the observables which are likely to be the most discriminating for understanding the QCD phase structure. However, several of the key measurements such as the net proton kurtosis, the directed flow and the dilepton production were found to require higher statistics in order to provide a quantitative physics conclusion [1]. Therefore, the second phase of the beam energy scan (BES-II) started in 2019 with the upgraded Low Energy RHIC electron Cooling (LEReC) and various sub-systems of the STAR detector. The STAR detector upgrades for BES-II consist of inner TPC (iTPC), Event Plane Detector (EPD), and the endcap TOF (eTOF) [2], as shown in FIG. 1.

The STAR iTPC upgrade is to replace all the inner-sector wire-chambers, which are aging with continuous pad rows [3]. The upgrade will provide better momentum resolution, a lower p_T threshold changing from 125 MeV/c to 60 MeV/c, better dE/dx resolution, improved acceptance at high rapidity from 1.0 to 1.5 and higher track reconstruction efficiency [1]. The EPD is to improve event-plane reconstruction for heavy-ion flow measurements, the collision centrality and serves as trigger detector. The new EPD covers the pseudo-rapidity range between 2.1 and 5.1 and replaces the Beam Beam Counter(BBC) [1, 4]. The eTOF upgrade extends particle identification (PID) capability and covers the pseudorapidity region of $2.5<\eta<4$. The STAR fixed-target program with the eTOF upgrade will enable the energy scan to extend below 7.7 GeV [5]. These three sub-detectors are fully operational in STAR BES-II program.

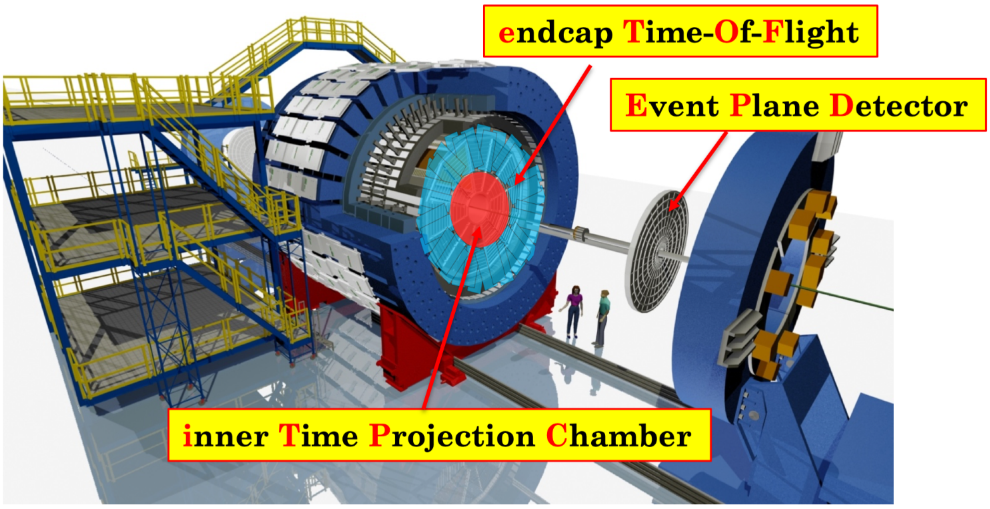


Figure 1. The layout of the STAR detector upgrades for the RHIC BES-II program.

2 Cold QCD Program

The detector upgrades for BES-II program substantially enhance STAR's already excellent capabilities. These upgrades will enable STAR to continue its unique, ground-breaking mid-rapidity science program in the period following BES-II. These upgrades are envisioned to address three broad areas of interest within the cold QCD community in the years following the BES-II. This programs will shed light on the dynamics of low and high x partons in cold nuclear matter (CNM) and how the fragmentation and hadronization of these partons is modified through interactions within the CNM and experiments to study the 2+1d spatial and momentum structure of protons and nuclei. These measurements will provide critical new insights into the QCD structure of nucleons and nuclei in the near term, as well as the high precision data that will be essential to enable rigorous universality tests when combined with future results from the Electron Ion Collider.

Transverse polarized protons colliding with unpolarized protons and the longitudinal polarized proton-proton collisions at $\sqrt{s}$=510 GeV are scheduled in 2022 at RHIC and STAR will be the only operational detector at RHIC during this period. The scientific goals are studies of the the parton transverse momentum distributions (TMDs) at low and high x as well as the gluon distribution at small x. With a delivered luminosity in the order of 1. fb^{-1}, it will give unprecedented precision for serval polarized observables such as the transverse spin asymmetries (A_{UT}) for observables sensitive to the Collins mechanism [6].

The transverse polarized proton-nuclear collisions at $\sqrt{s}$=200 GeV are scheduled in parallel with sPHENIX running, which including polarized proton with unpolarized proton, polarized proton-Au, and polarized proton light nuclei collisions. These collisions system are ideal to test gluon hadronization effects in cold nuclear matter at high collision energies and Q^2 accessed at RHIC, which will provide a clearer picture of modified hadronization. The high statistics polarized p+Au data and an A-scan can precisely determine the mass dependence of nuclear hadronization effects [6].

3 STAR Detector Upgrades at Forward Rapidity

The STAR detector upgrades at forward rapidity is currently in full swing ongoing to enable a cold and hot QCD program to address fundamental questions interesting topics. The upgrades are consist of a Forward Calorimeter System (FCS) and a Forward Tracking System (FTS) [7].

3.1 Forward Tracking System

The FTS includes 3 silicon disks and 4 small-strip Thin Gap Chamber (sTGC) disks, providing 7 tracking points in η coverage from 2.5 to 4.

The silicon tracker with fine granularity in ϕ and coarse granularity in r is using the single-sided double metal AC-coupled architecture. Each silicon disk has 12 modules. The silicon sensors have good charge separation, momentum resolution and precise position resolution to meet the physics requirement for the FTS [9]. It will be placed at z=139.9cm from the STAR IP, covering η from 2.5 to 4. The sensor signal is read out at its edge. The frontend readout chips to be used is APV25-S1 in FTS [9]. Each APV25-S1 has 128 channels, which have simultanously the function of pre-amplifier and shaper. 288 APV chips will be used in 3 silicon disks.

The sTGC is a gaseous detector based on the technology developed by the ATLAS collaboration [8]. The position resolution is designed at the level of ~100μm. The STAR sTGC project is planned to built 4 layers of sTGC, 4 modules per layer. Each sTGC module consists of two chambers, which are perpendicular to each other for a x-y coordinate position measurements. A first 30cm×30cm size pre-prototype was built at Shandong University and installed at STAR in June 2019. As shown in FIG. 2, simply taking the ratio of the signal counts with the coincidences between different chambers, the efficiency achieved in the test beam was >98%. A 60cm×60cm full size prototype has been built in late 2019 and the signal coincidences shown in FIG. 2 is consistent with that of the pre-prototype. Mass production is planned to start in 2020 and all 20 modules of sTGC (16 + 4 spares) will be finished in early 2021.

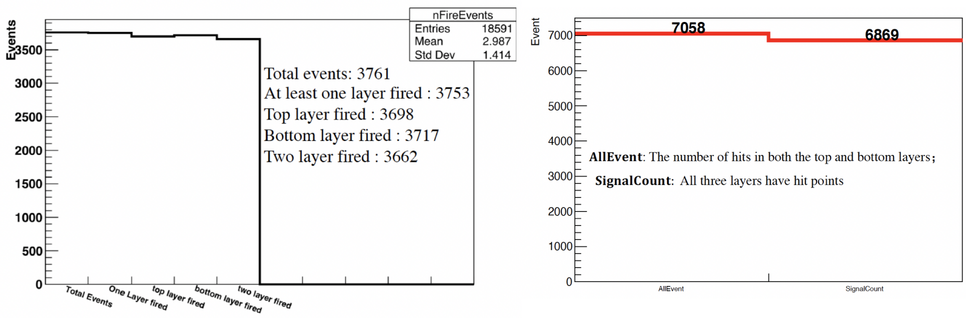


Figure 2. The signal coincidences of different sTGC chambers for efficiency check. Left: Pre-prototype in STAR 2019 data-taking. Right: Full size prototype in cosmic ray test.

3.2 Forward Calorimeter System

The FCS consisted of an Electromagnetic Calorimeter (ECal) and a Hadronic Calorimeter (HCal). The ECal reuses the lead-scintillator calorimeter from the PHENIX Collaboration with a new SiPM based readout and penetrating wavelength-shifting fibers for light collection. The HCal is the first hadronic calorimeter in STAR, which is an ion-scintillator sandwich sampling calorimeter with the same SiPM readout as the ECal. Intensive test beams for the Forward Calorimeters at FNAL has been done in 2019. FIG. 3 shows the performances of the ECal and HCal prototypes are close to the requirements.

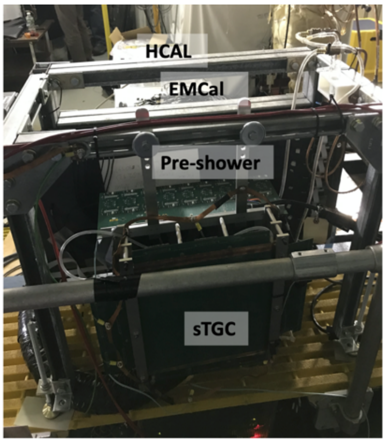
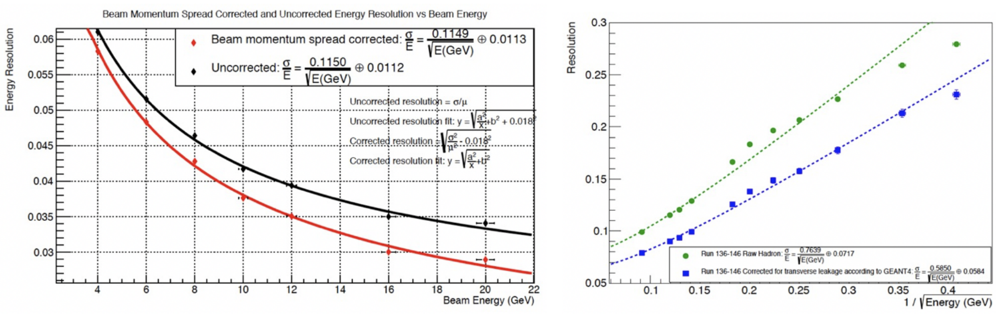


Figure 3. The first prototype including the HCal, the ECal, pre-shower, and the sTGC was installed for the 2019 data-taking in STAR.



(a) (b)

Figure 4. (a) ECal prototype energy resolution. (b) HCal prototype energy resolution.

4 Summary

The STAR detector upgrades, including the iTPC, the EPD, and the eTOF upgrades, have been finished and all three sub-detectors are fully operational for the RHIC BES-II program. A forward rapidity upgrade, which consists of tracking detectors (silicon and sTGC) and calorimeters (ECal and HCal) at STAR is ongoing to further investigate the nature of QCD, especially the cold QCD physics at both very high and very low partonic momentum fraction. Current prototype test shows that the prototype performances meet the STAR forward rapidity upgrade requirements.

5 Acknowledgement

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