Status and performance of the detector upgrades for STAR in the BES-II and beyond

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Abstract. The STAR collaboration has installed three detector upgrades for the beam energy scan phase II program at RHIC to aid the exploration of the QCD phase diagram. After BES-II the forward upgrade of STAR will enable novel measurements in pp, pA and AA collisions motivated by cold QCD and heavy-ion physics. Results from the commissioning of the new detectors and their performance during the first year of running in BES-II will be discussed together with the general progress of BES-II and the status of the forward upgrade.

Keywords: STAR, BES-II, iTPC, EPD, eTOF, forward upgrade

1 Introduction

One of the driving forces for the construction of the Relativistic Heavy Ion Collider (RHIC) was the aim to study the QCD phase-diagram over a wide range of temperatures and baryon densities. The beam energy scan phase I program (BES-I) conducted between 2010 and 2014 revealed interesting hints in several observables that are considered to be sensitive to the turn-off of QGP signatures and a first-order transition in the QCD phase diagram at collision energies below $\sqrt{s_{NN}} = 20\,\mathrm{GeV}$ [1]. These observables warrant a closer investigation with a beam energy scan phase II program (BES-II) that covers seven center-of-mass energies ranging from 7.7 GeV to 19.6 GeV in the years 2019 to 2021 as shown in Figure 1. Multi-differential studies will profit from datasets that are typically a factor 20 larger compared to the statistics collected during BES-I. In addition the STAR detector was upgraded with three new subsystems to enhance its experimental reach. Supplementing the collider program the STAR collaboration developed a fixed-target program (FXT) to measure heavy-ion collisions down to $\sqrt{s_{NN}} = 3\,\mathrm{GeV}$. Collisions at 7.7 GeV can be measured in both setups and serve as an important cross check.

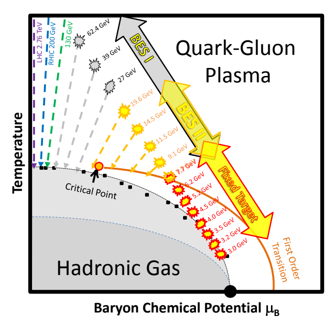

Fig. 1. Sketch of the QCD phase diagram with the BES-I and II programs highlighted.

The RHIC program in the years 2021+ will be devoted to address fundamental questions in both cold QCD and heavy-ion physics opening a portal towards the Electron-Ion Collider (EIC). RHIC has the unique capability to accelerate polarized protons and provide data in a kinematic regime in which nuclear modifications of the sea quark and gluon distributions are expected to be sizable and currently poorly constrained. The nuclear parton distribution functions (nPDF) for gluons and sea-quarks can be accessed with processes that experience no QCD final-state effects: the direct photon and Drell-Yan production. The forward upgrade at STAR will enable key measurements in pp, pA and AA collisions to improve for example our understanding of the spin of the proton and the longitudinal structure of the initial state in heavy-ion collisions. It consists of the Forward Tracking System (FTS) and the Forward Calorimeter System (FCS), both covering an acceptance of $2.5 < \eta < 4$ on the west side of STAR [2, 3].

2 BES-II

To allow for higher luminosity at the lowest BES-II collider mode energies the first RF linac-based electron cooler LEReC (Low Energy RHIC Electron Cooling) is under development. In 2019 electron cooling for two beams with a life time extension and a reduced transverse size was demonstrated. Further commissioning is ongoing to provide stable operation in 2020/21. Data at the first two collider energies ($\sqrt{s_{NN}} = 19.6$ and $14.6\,\mathrm{GeV}$) were collected from February to July 2019 with a surplus of events compared to the original expectation. In addition one fixed-target dataset at $\sqrt{s_{NN}} = 3.2\,\mathrm{GeV}$ was completed and small subsets of data were taken at several other fixed-target energies [4].

The Event Plane Detector [5] (EPD) was already fully installed for the data taking in 2018. With its higher granularity and larger acceptance compared to the Beam-Beam Counters (BBC), it improves significantly the event plane resolution and supplies means to define the centrality independent from the tracks measured in the TPC. In 2019 the EPD was also included into the minimum-bias trigger. An asymmetry cut on the activity in the east and west side EPD detectors was developed to veto beampipe collisions at the lowest collider energies.

The upgrade of the inner Time Projection Chamber [6] (iTPC) increased the segmentation of the inner pad plane of the TPC and therefore the maximum number of TPC hits a track can have from 45 to 72. This leads to an extended rapidity coverage (from $|\eta| < 1$ to $|\eta| < 1.5$) and low p_T acceptance (from $p_T > 125\,\mathrm{MeV/c}$ to $p_T < 60$ MeV/c). The increased number of hits also improves the particle identification (PID) via the ionization energy loss dE/dx by 15-30% as shown in the left panel of Figure 2.

The endcap Time Of Flight detector [7] (eTOF) installed on the east pole tip of STAR complements the particle identification capabilities at forward rapidities in collider mode allowing to study the rapidity dependence of several key observables from BES-I. It is also essential to provide PID in the fixed-target program at mid-rapidity. With online calibrations a time resolution better than 85 ps has been achieved in accordance with the design goals. The middle panel

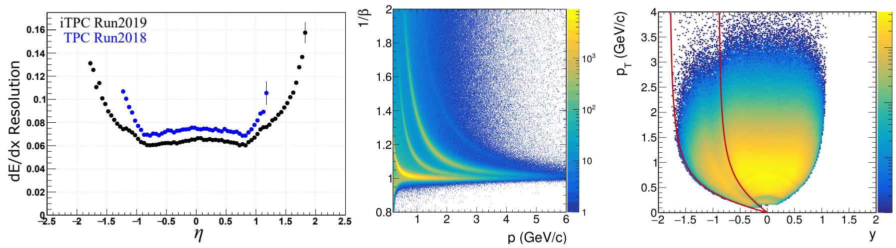

Fig. 2. Left: Comparison of dE/dx resolution in the TPC before and after the iTPC upgrade. Middle: $1/\beta$ measured with eTOF versus momentum (GeV/c). Right: Raw phase-space distribution of protons identified via m^2 cut in bTOF and eTOF in Au+Au collisions at $\sqrt{s_{NN}} = 14.6\,\text{GeV}$.

of Figure 2 shows an eTOF PID plot with particle bands separated over a large momentum range. The right panel of Figure 2 shows for Au+Au collisions at 14.6 GeV the raw phase-space distribution of protons identified via a squared mass m^2 cut in the barrel TOF (bTOF) and the eTOF. The acceptance in which the eTOF contributes is framed by the red lines $-1.8 < \eta < -0.9$ which is larger than the nominal eTOF acceptance of $-1.6 < \eta < -1.1$ due to a wide selection of event vertexes along the beam direction.

3 Forward upgrade

The forward tracking system (FTS) provides precision tracking with a position resolution better than $100\,\mu$m, charge discrimination, photon suppression and p_T measurements at forward rapidity. It consists of 3 layers of silicon mini-strip discs located 140 to 190 cm along the beam line from the center of the TPC and four layers of double-sided small-strip Thin Gap Chambers (sTGC) 270 to 360 cm away from the nominal interaction point inside the magnet pole tip opening (see Figure 3 left panel). The detector design for the silicon tracker builds on the STAR experience with the Intermediate Silicon Tracker installed between 2014 and 2016. A first prototype of a silicon module was assembled and tested in the lab. A $30 \times 30\,\text{cm}^2$ sTGC prototype (see Figure 3 right panel) was tested with cosmic rays, integrated into the STAR DAQ and successfully commissioned with beam during the last weeks of RHIC operation in 2019. A full-size prototype ($60 \times 60\,\text{cm}^2$) will be installed at STAR for the upcoming run in 2020. A new tracking algorithm for the forward region in a non-uniform magnetic field is under development.

The forward calorimeter system (FCS) consists of a preshower scintillator hodoscope (fPRE) as well as electromagnetic and hadronic calorimeters (Ecal, Hcal) shown in the middle panel of Figure 3. The Ecal reuses a lead-scintillator sandwich calorimeter from PHENIX. The Hcal will be the first hadronic calorimeter at STAR and utilize $10 \times 10\,\text{cm}^2$ towers out of iron-scintillator sandwich. The readout for all three sub-detectors will be based on SiPMs. Large-scale

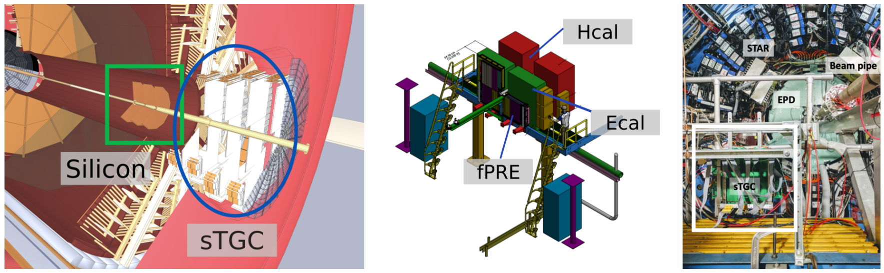

Fig. 3. Left: Schematic view of the FTS. Middle: Schematic view of the FCS. Right: sTGC prototype installed at STAR in 2019.

prototypes were tested at Fermilab in April 2019 demonstrating that the requirements on the energy resolution can be met. At the end of the 2019 beam operation at RHIC, prototypes of all FCS components were installed at STAR for commissioning with 200 GeV Au+Au collisions.

4 Summary

STAR has extended its experimental reach for the BES-II program with three detector upgrades (EPD, iTPC, eTOF) that will not only provide high quality data during the BES-II but also enable unique opportunities for mid-rapidity physics at top RHIC energy. Datasets at the two highest collider energies (19.6 and 14.6 GeV) and several fixed-target energies have been collected in 2019. The forward upgrade at STAR is targeted at addressing fundamental questions in QCD paving the way towards the EIC. Prototypes of the new tracking and calorimeter systems have been tested at STAR and will be ready for the post-BES-II era in autumn 2021 and beyond.

References

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