Available online at www.sciencedirect.com

ScienceDirect

Nuclear Physics A 982 (2019) 951–954

NUCLEAR PHYSICS A

www.elsevier.com/locate/nuclphysa

XXVIIth International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter 2018)

The STAR BES-II and Forward Rapidity Physics and Upgrades

Qian Yang (for the STAR Collaboration)

School of Physics and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Jinan 250100, China

Brookhaven National Laboratory, Upton, New York 11973, USA

Abstract

The second phase of the Beam Energy Scan at RHIC, BES-II, is scheduled to start in 2019 and will explore the high baryon density region of the QCD phase diagram with precision measurements. The detector upgrades will enhance some of the key measurements by extending STAR's kinematic reach, like the kurtosis of net-protons distribution which could pinpoint the position of a critical point. The upgrades currently under way comprise: the replacement of the inner TPC sectors, the Event Plane Detector (EPD) and the end-cap TOF. Building on these upgrades STAR is planning to further enhance its detector capabilities by installing a Forward Calorimeter System (FCS) integrating an electromagnetic and hadronic calorimeter and a Forward Tracking System (FTS) combining 3 Silicon mini-strip disks and 4 Small-Strip Thin Gap Chamber (sTGC) wheels. The forward upgrades are motivated by studying the initial state of nucleons and nuclei and the exploration of cold QCD physics in the very high and low x regions. This contribution will highlight these upgrades and some of the physics opportunities that they allow.

Keywords: QCD phase diagram, BES-II, Forward rapidity physics and Detector upgrades

1. The BES-II program and Related Detector Upgrades

1.1. The BES-II Physics Opportunities

In 2019, STAR will initiate the BES-II program [1]. The BES-II program involves dedicated low beam energy run and high precision measurements of observables that are expected to be sensitive to the phase structure of QCD matter. In addition to four BES-I center-of-mass energies ($\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5 and 19.6 GeV), STAR is planning to run a fifth energy at $\sqrt{s_{NN}}$ = 9.1 GeV to bridge the large gap in baryon chemical potential between 7.7 GeV and 11.5 GeV. The collaboration will also extend the center-of-mass energy range ($\sqrt{s_{NN}}$ = 3 - 7.7 GeV) by means of a fixed-target (FXT) program.

Searching for the critical point is an important goal of the RHIC BES program. Hints of a disappearance of QGP signatures at sufficiently low center-of-mass-energies were indeed seen in many measurements [2] during BES-I. However, some uncertainties remain in the interpretation of these observations. STAR has studied the kurtosis times the variance ($\kappa \times \sigma^2$) of net protons to search for the critical point. In the absence

https://doi.org/10.1016/j.nuclphysa.2018.10.029
0375-9474/

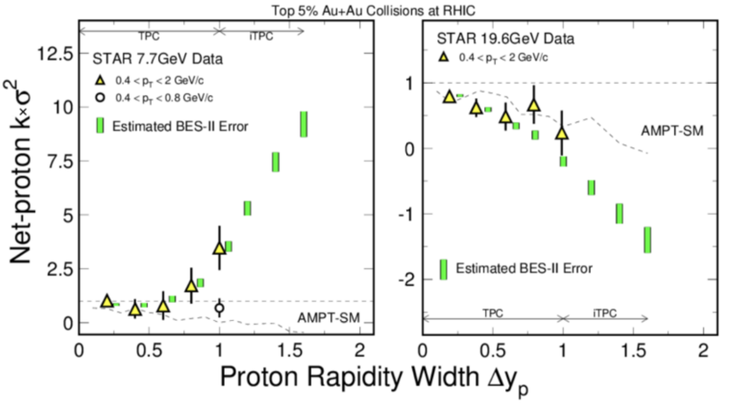

Fig. 1. The observed net-proton kurtosis times the variance as a function of the rapidity window from BES-I (yellow triangles) for Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7 GeV and 19.6 GeV. The green boxes represent the estimated statistical uncertainty for the BES-II program.

of a critical point, models [3] suggest that the values of $\kappa \times \sigma^2$ will be close to unity and have a monotonic dependence on the collision energy. In the BES-I, a non-trivial energy dependence has been observed as shown in Figure 1. With the BES-II program, we can study the net-proton cumulants over a wide rapidity range and with significantly larger statistics, which will provide a convincing assessment of the sensitivity of the net-proton kurtosis measurement to the QCD criticality. There are many other physics opportunities like searching for the first-order phase boundary by measuring the baryon directed flow, global polarization, the measurement of the transient magnetic field, the disappearance of the Chiral Magnetic Effect in low-energy Au+Au collisions as well as searching for chiral symmetry restoration. Details can be found in [1].

1.2. The Detector Upgrades for BES-II

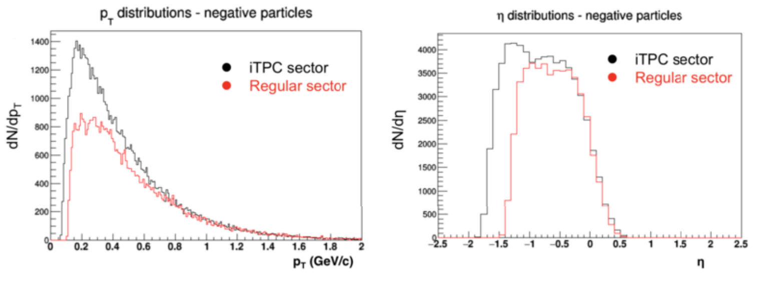

Fig. 2. Comparisons between reconstructed tracks for negatively charged particles in the iTPC and a regular sector. Left: raw p_T distribution, and Right: raw $dN/d\eta$ distribution.

STAR has three planned upgrades for the BES-II program: the inner Time Projection Chamber (iTPC) [4], the Event Plane Detector (EPD) [5] and the end-cap Time of Flight (eTOF) [6]. The iTPC upgrade will increase the segmentation of the inner pad planes from 13 to 40. It will extend the η coverage of the TPC from $|\eta| < 1$ to $|\eta| < 1.5$, and bring the lower transverse momentum cutoff down to 60 MeV/c. Furthermore, one achieves better momentum resolution for larger momenta and a 25% improvement in dE/dx resolution for full-length tracks. Currently, 16 out of 24 iTPC sectors have been produced. They performed excellently in bench tests. A gas gain uniformity of less than 1.5% (RMS) and energy resolution better than 20% (FWHM) were achieved. The detector performed reasonably under X-ray irradiation [7]. A fully tested iTPC sector was successfully installed on October 5, 2017 and has been included into the $\sqrt{s_{NN}}$ = 200 GeV isobar physics run in 2018. Figure 2 shows the improvement with the iTPC: a lower p_T cutoff of 60 MeV/c and an extended η coverage of about 0.4 units in the forward direction. The replacement of the inner sectors with the new iTPC sectors started in August 2018 and will be completed in December.

The EPD is a dedicated event-plane and centrality detector placed in the pseudo-rapidity range $2.1 < |\eta| < 5.1$, with 16 radial segments, 24 azimuthal segments and a total of 744 channels. The baseline detector design consists of optically isolated scintillator tiles, wavelength-shifting fibers and silicon photomultipliers (SiPMs) as the read-out. The EPD was installed before the 2018 physics run. Figure 3 shows a preliminary comparison of the second-order event-plane resolution for the Beam-Beam Counter (BBC) and EPD using the 2018 isobar data. An improvement of the event-plane resolution is clearly seen for all centralities.

The eTOF upgrade originates from a collaboration of CBM and STAR. CBM will install 10% of the CBM TOF modules at the east side of STAR with an η coverage of $-1.6 < \eta < -1.1$. The eTOF consists of 36 CBM TOF modules arranged in 12 sectors. Each module consists of 3 Multi-gap Resistive Plate Chambers (MRPCs) segmented in 32 strips. One eTOF sector was installed during the 2018 isobar run. A preliminary timing resolution of 83 ps was derived from the overlapping region of two MRPCs inside one TOF module. The full installation is anticipated for November 2018.

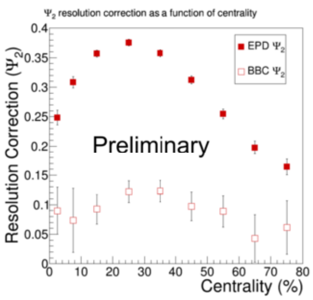

Fig. 3. An estimate of the second order event plane resolution at top energy Zr+Zr/Ru+Ru after azimuthal angle re-weighting to flatten the event plane for the EPD (solid square) and the BBC (open square).

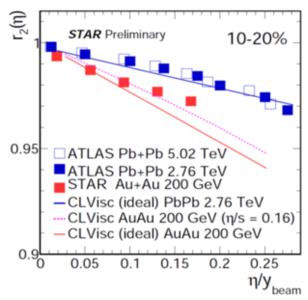

Fig. 4. Longitudinal de-correlation of elliptic anisotropy (r_2) in Au+Au at $\sqrt{s_{NN}}$ = 200 GeV using the existing FMS detector ($2.5 < \eta < 4$).

2. Physics at Forward Rapidity and Related Detector Upgrades

2.1. The Physics at Forward Rapidity

After the BES-II program, STAR has proposed a detector expansion at forward rapidities, which require further detector upgrades. The forward upgrades allow STAR to extend precision studies of the initial state of cold nuclear matter at very high and low x regions[8]. These upgrades also allow to study the initial stages of Au+Au collisions that eventually lead to the formation of the QGP. The kinematics of RHIC Au+Au collisions provides STAR the unique opportunity to make precise measurements of multiple flow harmonics and their correlations near beam rapidity. In comparison to the LHC, at RHIC both stronger breaking of the boost-invariance and stronger variation of the initial temperature are expected, therefore stronger sensitivity to the temperature dependent transport for a given rapidity window can be observed. Figure 4 shows the preliminary measurements of longitudinal de-correlation of elliptic flow (r_2) in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, using the Forward Meson Spectrometer (FMS) in the pseudo-rapidity range $2.5 < \eta < 4$. This demonstrates the capability of STAR to study the breaking of boost invariance in Au+Au collisions. With the new detector upgrades in the forward direction STAR will improve the systematics and help to remove non-flow background contributions for such measurements. The forward upgrades will also help to map out the temperature dependence of transport parameters such as η/s(T), particularly near the region of perfect fluidity and explore the rapidity dependence of vorticity via the newly discovered

Global Hyperon Polarization (GHP). These measurements will be an important step towards an improved understanding of the emergence of the near-perfect fluidity of QGP.

2.2. The Forward Rapidity Detector Upgrades

The forward rapidity detector upgrades [8] consist of a Forward Tracking System (FTS) and a Forward Calorimeter System (FCS). Both systems have a pseudo-rapidity coverage of $2.5 < \eta < 4$. The FTS is a combination of three layers of Silicon mini-strip detectors with four small-Strip Thin-Gap Chamber (sTGC) wheels. The silicon design will be finely granular in the ϕ direction and have a coarser granularity in the radial direction. Each silicon disk has 12 wedges covering the full 2π range in azimuth and 2.5 to 4 in pseudo-rapidity. Each wedge is segmented in 128×8 mini-stripes in the $\phi - \eta$ plane. All the sensors are read out from the outer radius, to reduce the material budget in the detector acceptance. Both silicon disks and the sTGCs have a low material budget, which helps to reduce the multiple scattering and photon conversion background. The first sTGC prototype will have a size of 60 cm × 60 cm and be made up of two layers, each with a strip length of 30 cm. This prototype will be produced in fall 2018 and installed in 2019. The FTS is designed to discriminate the charge of particles in $p + p$ and $p + A$ collisions, which is important for measurements of transverse single spin asymmetries and studies of the Drell-Yan process. Meanwhile, measurements of charged particle transverse momenta of $0.2 < p_T < 2$ GeV/c with 20-30% momentum resolution can be achieved in heavy ion collisions. The intensive R&D of the silicon sensors is ongoing based on the experience from the STAR Intermediate Silicon Tracker (IST). The FCS consists of a refurbished PHENIX sampling electromagnetic calorimeter and a hadronic calorimeter of sandwiched iron and scintillator plates, which is based on the extensive STAR Forward Upgrade and EIC Calorimeter Consortium R&D. Both calorimeters will share the same readout electronics and SiPMs as photosensors. The designed FCS system will have very good (10%∼20% $\sqrt{E}$) electromagnetic and (∼60% $\sqrt{E}$) hadronic energy resolutions.

3. Summary

The STAR BES-II program is scheduled to start in 2019 and will exploit precision measurements of the QCD phase diagram at high baryon densities. The BES-II related detector upgrades (iTPC, EPD, eTOF) will be completed by the end of 2018. A prototype of the iTPC upgrade was installed during the isobar run and good performance was seen. The EPD has been fully installed, and the preliminary second-order event-plane resolution is 0.37 for isobar collisions in 20-30% centrality events. The eTOF upgrade shows a timing resolution of 83 *ps* during the isobar run. After the BES-II, STAR has proposed a forward rapidity program to study the initial state from nucleon to nuclei, which requires the FTS and FCS upgrades. An sTGC prototype is planned to be installed in 2019, intensive R&D for the silicon sensors are ongoing and a large scale prototype calorimeter beam test is scheduled for spring 2019. The STAR forward upgrades are planned to be installed for RHIC run-2021.

References

[1] STAR Collaboration, STAR Note 598, https://drupal.star.bnl.gov/STAR/starnotes/public/sn0598.
[2] STAR Collaboration, STAR Note 493, https://drupal.star.bnl.gov/STAR/starnotes/public/sn0493.
[3] P. Garg, D. K. Mishra, P. K. Netrakanti, B. Mohanty, A. K. Mohanty, B. K. Singh, and N. Xu, Conserved number fluctuations in a hadron resonance gas model, Phys. Lett., B 726 (2013) 691–696.
[4] STAR Collaboration, STAR Note 619, https://drupal.star.bnl.gov/STAR/starnotes/public/sn0619.
[5] STAR Collaboration, STAR Note 666, https://drupal.star.bnl.gov/STAR/starnotes/public/sn0666.
[6] STAR Collaboration and CBM eTOF Group, arXiv:1609.05102.
[7] Fuwang Shen, Shuai Wang, Fangang Kong, Shiwei Bai, Changyu Li, Flemming Videbak, Zhangbu Xu, Chi Yang, MWPC prototyping and performance test for the STAR inner TPC upgrade, Nucl. Instrum. Meth. A 896 (2018) 90–95.
[8] STAR Collaboration, STAR Note 648, https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648.