Nuclear modification factor of inclusive charged particles in Au+Au collisions at $\sqrt{s_{NN}} = 27$ GeV with the STAR experiment.

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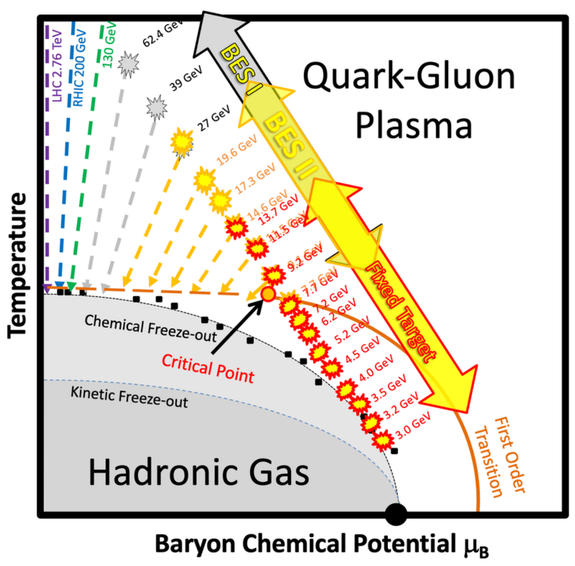
Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

Abstract

The Quantum ChromoDynamics (QCD) phase diagram, often represented using coordinates of temperature (T) and baryonic chemical potential (μ_B), includes a transition from a hadronic gas phase to a quark-gluon plasma (QGP) phase. The Beam Energy Scan (BES) program at Relativistic Heavy Ion Collider (RHIC) varies the gold-gold collision energy aiming to explore the phase diagram and pinpoint the critical point. BES's initial phase (2010-2014) revealed intriguing results, including the suppression of high transverse momentum particle production ($p_T > 2$ GeV/c) at collision energies from $\sqrt{s_{NN}}$ = 62.4 to 200 GeV that is quantified by the nuclear modification factor (R_{CP}). In 2018, STAR at RHIC collected a large-statistics dataset at $\sqrt{s_{NN}}$ = 27 GeV, ten times larger than BES-I. This poster introduces new BES-II measurements of inclusive charged particles at 27 GeV, extending BES-I findings across a wider transverse momentum range with better precision. The relevant physics implications including the potential jet quenching effects at low energy collisions will also be discussed.

Introduction



- **QCD Phase Diagram**
  - Cross-over transition expected at low baryon chemical potential (μ_B)
  - First-order transition expected at high μ_B
  - Critical point is the end point of the first-order phase transition
- **Beam Energy Scan (BES)**
  - Explore the QCD matter by colliding gold ions at different energies - and search for the potential QCD critical point
  - Seeking to map onset of deconfinement, and the predicted QCD critical point

p_T Spectra

The transverse momentum particle spectra for $Au+Au$ collisions at energy of $\sqrt{s_{NN}} = 27$ GeV for inclusive charged particles in different centrality classes are shown in figure 3.

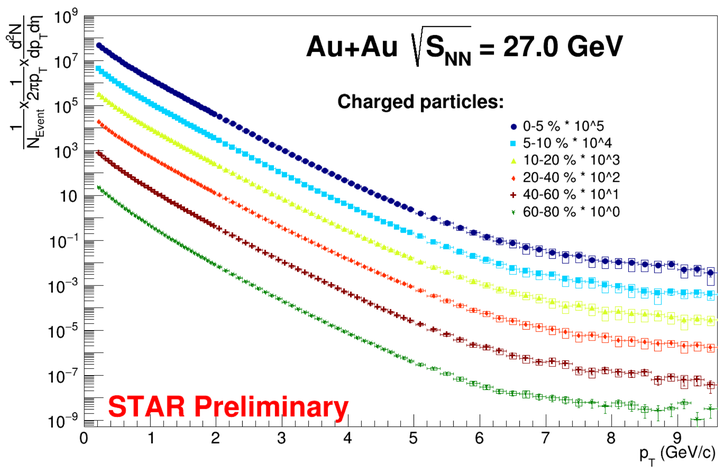


Figure 3: Transverse momentum distribution of inclusive charged particles for collision energy of 27 GeV.Each spectrum corresponds to a certain centrality class and is multiplied by coefficient from $1 - 10^5$ for visibility. The vertical error bars correspond to statistical uncertainties and the colored boxes to the systematic uncertainties.

From figure 3, it can be noticed that in the BES-II program, the spectra have a greater coverage in terms of transverse momentum p_T for all centrality classes, which enables a more comprehensive investigation of the nuclear modification factor.

Motivation

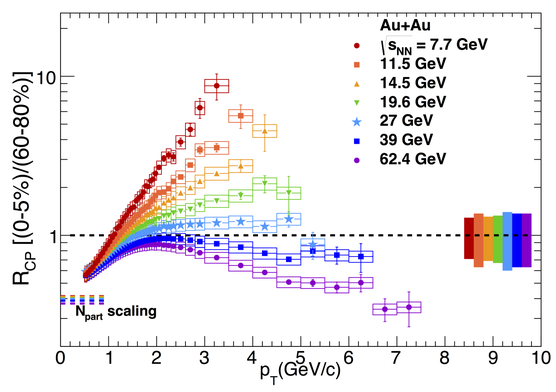


Figure 1: Dependence of the nuclear modification factor on the transverse momentum of produced particles (BES-I)[1]

The suppression effect of charged particle production with high transverse momenta ($p_T > 2$ GeV/c) is one of the most interesting results observed at the Solenoidal Tracker At RHIC (STAR) experiment during the BES-I program. This effect has been interpreted as the increase in energy loss of partons in the quark-gluon plasma produced at high energy heavy ion-collisions. It is commonly referred to as jet quenching in dense partonic matter and was predicted as a sign of the formation of the QGP phase, where simple model of hadron scattering cannot describe the observations. This effect can be quantified using the nuclear modification factor R_{CP}:

$$R_{CP} = \frac{\langle N_{coll} \rangle_{Peripheral}}{\langle N_{coll} \rangle_{Central}} \frac{\left(\frac{d^2N}{dp_T d\eta}\right)_{Central}}{\left(\frac{d^2N}{dp_T d\eta}\right)_{Peripheral}} \quad (1)$$

Figure 2 contrasts the statistics of BES-I and BES-II programs. Notably, BES-II exhibits significantly higher statistics, surpassing BES-I. At 27 GeV Au+Au collision energies, BES-II records approximately ten times more data than BES-I.

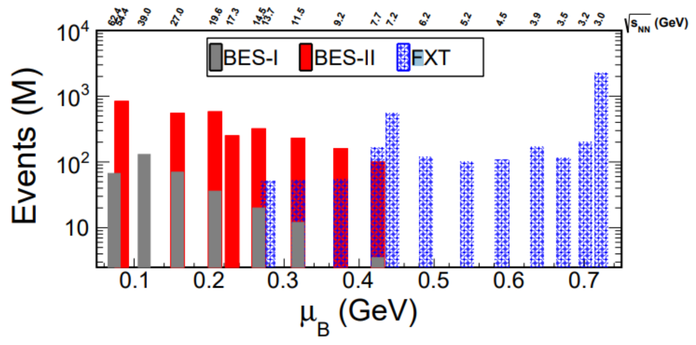


Figure 2: Comparison of statistics between *BES-I* (2010-2017) and *BES-II* (2019-2021)

Nuclear modification factor (R_{CP})

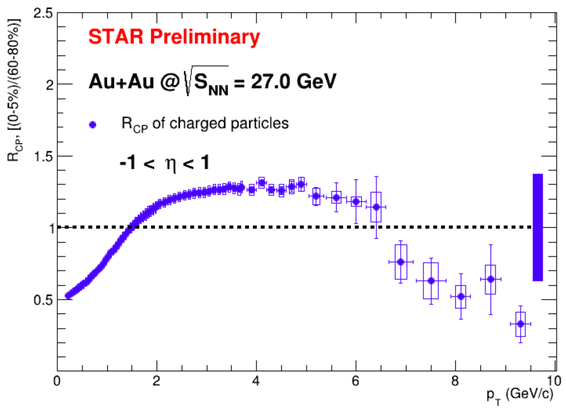


Figure 4: R_{CP} for inclusive charged particles at $\sqrt{s_{NN}} = 27$ GeV collision energy. The error band at unity on the right side of the plot corresponds to the p_T independent uncertainty on N_{bin} scaling. The vertical error bars correspond to statistical uncertainties and the colored boxes to the point-to-point systematic uncertainties.

Figure 4 demonstrates the R_{CP} for $Au+Au$ collisions at a collision energy of 27 GeV, for the pseudorapidity range of $-1 < \eta < 1$.

The growth of R_{CP} is seen at low values of p_T (up to $p_T \approx 2$ GeV/c), which is affected by effects such as Cronin enhancement [2], radial flow, and the relative dominance of coalescence over fragmentation during hadronization. However, as p_T increases, R_{CP} reaches a plateau and then demonstrates suppression of hadrons produced in central collisions with respect to peripheral collisions.

Conclusion

New data from the BES-II allow to extend investigation of the particle production modification in medium to the region of high transverse momenta p_T. First measurement of the nuclear modification factor R_{CP} at the collision energy of 27 GeV has shown a behavior similar to what was previously obtained at higher energies with a plateau and a decries at transverse momenta $p_T > 2$ GeV/c. An energy dependent study of the R_{CP} on data from BES-II should allow to better map the position of the phase transition from hadronic to partonic degrees of freedom in nuclear matter.

Acknowledgments: Supported by Russian Science Foundation under grant N 22-72-10028.

References

[1] L. Adamczyk et al. Beam Energy Dependence of Jet-Quenching Effects in Au+Au Collisions at $\sqrt{s_{\rm NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, and 62.4 GeV. *Phys. Rev. Lett.*, 121(3):032301, 2018.

[2] J. W. Cronin et al. Production of hadrons with large transverse momentum at 200, 300, and 400 GeV. *Phys. Rev. D*, 11:3105–3123, 1975.