The STAR Mid-Rapidity Physics Program after the BES-II

Qian Yang (Shandong University)

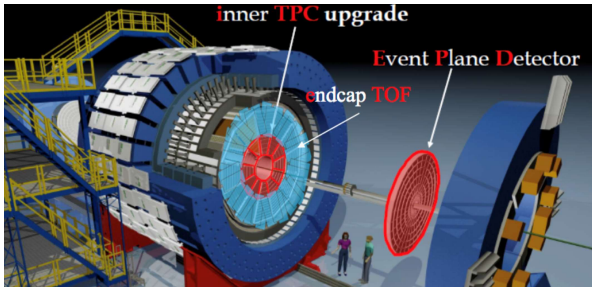
for the STAR Collaboration

Abstract

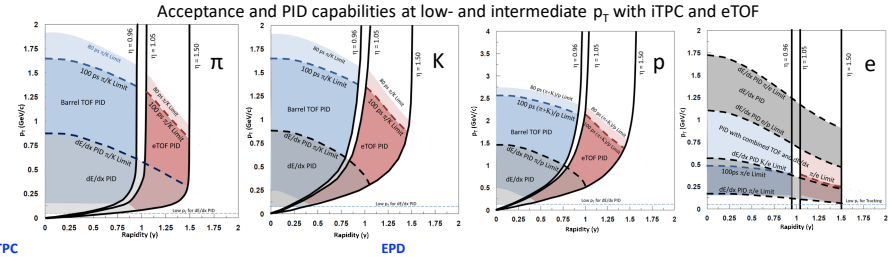
Upgrades that are currently underway to maximize the physics output from Beam Energy Scan (BES) phase II will substantially enhance STAR's already excellent capabilities. These upgrades will enable STAR to continue its unique, ground-breaking mid-rapidity science program in the period following BES-II. The key physics opportunities envisioned address three broad areas of interest within the cold QCD community in the years following the BES-II. These 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. In A+A collisions measurements with unprecedented precision using deep penetrating probes such as leptons and photons will enable us to probe the whole evolution of the collision. In addition, significantly improved hypertriton lifetime measurements may have important implications on astrophysics. We highlight mid-rapidity physics program post BES-II.

STAR Upgrades

A view of the STAR detector with the BES-II upgrades highlighted



Acceptance and PID capabilities at low- and intermediate p_T with iTPC and eTOF



iTPC
- Increase of acceptance from $|\eta|<1.0$ to $|\eta|<1.5$
- Improved the *dE/dx* resolution by up to 25%.
- Tracks reconstructed down to $p_T \sim 60$ MeV/c.

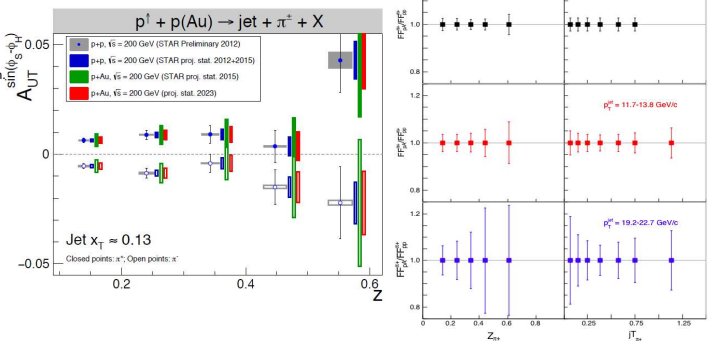
EPD
- Dedicated event plane, centrality and trigger detector with $2.1<|\eta|<5.1$
- Approximately 10 times the granularity of the BBC.

eTOF
- Time-of-flight measurement for particle identification in the range $-1.6 < \eta < -1.1$

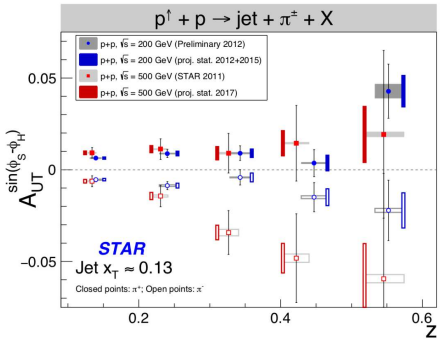
	Year	√s (GeV) and delivered Luminosity	Scientific Goals	Observable
Scheduled	Running in parallel with sPHENIX	$p^{\uparrow}p$ @ 200 with 300 pb^{-1}	Evolution of ETQS fct. properties and nature of the diffractive exchange in p+p collisions.	A_N for γ A_N for diffractive events
		$p^{\uparrow}Au$ @ 200 with 1.8 pb^{-1}	Nuclear dependence of TMDs and nFF.	$A_{UT}^{\sin(\phi_S-\phi_h)}$ modulations of $h^{\pm}$ in jets, nuclear FF
		$p^{\uparrow}Al$ @ 200 with 12.6 pb^{-1}	A-dependence of TMDs and nFF.	$A_{UT}^{\sin(\phi_S-\phi_h)}$ modulations of $h^{\pm}$ in jets, nuclear FF
		Au+Au @ 200	QGP properties and Hyperon-Nucleon interaction	Di-electron mass spectrum and Hypertriton lifetime
Potential	2021	$p^{\uparrow}p$ @ 510 with 1.1 fb^{-1}	TMDs at low and high x. Quantitative comparisons of the validity and the limits of factorization and universality in lepton-proton and proton-proton collisions.	A_{UT} for Collins observables.

Physics Opportunities with (un)Polarized proton-Nucleus Collisions

- ✓ Ideal tool to study gluon fragmentation.
- ✓ Test gluon hadronization effects in cold nuclear matter at high √s and Q^2 accessed at RHIC and EIC.
  - Clearer picture of modified hadronization.
- ✓ RHIC has the unique opportunity to extend the Collins effect measurements to nuclei
  - exploring the spin-dependence of the hadronization process in cold nuclear matter.
- ✓ A high statistics polarized p+Au dataset and a scan in A is essential to precisely determine the mass dependence of nuclear hadronization effect.
- ✓ With a better particle identification, as anticipated with the iTPC upgrade, the statistical uncertainties will be further reduced.



Physics Opportunities with (un)Polarized proton-proton Collisions



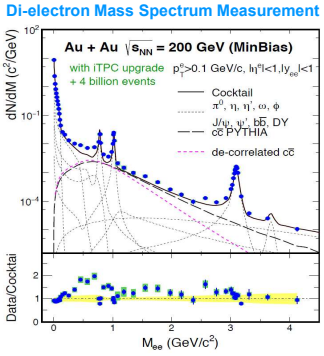
Unprecedented precision for several transverse polarized observables.

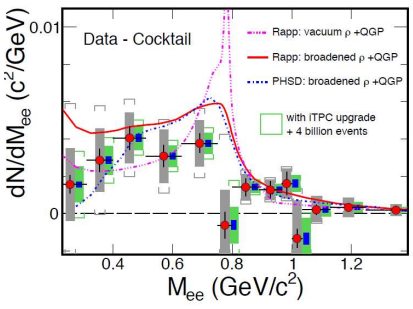
The errors can be shrunk by a factor of 2 with additional 10 weeks at √s = 500 GeV run → 1.1 fb^{-1} recorded.

- Transverse spin asymmetry (A_{UT})
  - ➢ transversity, Collins and Interference Fragmentation Function
- "Collins-like" effect for linearly polarized gluons.
- Sivers function over a wide $\gamma^{W/Z}$ range.
- Twist-3 ETQS function for gluons → A_N for inclusive jets
  - ➢ Provides a dataset if combined with EIC stringent tests of universality and factorization.

Physics Opportunities with Nucleus-Nucleus Collisions

■ Di-electron Mass Spectrum Measurement in 2020+





- ✓ Low invariant mass range ($M < 1.1$ GeV/c^2)
  - ✓ Vector meson in-medium mass and width modifications → chiral symmetry restoration
- ✓ Intermediate mass range ($1.1 < M < 3.0$ GeV/c^2)
  - ✓ Thermal radiation of Quark-Gluon Plasma
- ✓ Photons in the low transverse momentum range ($1 < p_T < 4$ GeV/c)
  - ✓ Thermal from QGP and hadronic gas.
- ✓ BES-II program will map out the modified ρ spectral function as a function of total baryon density.
- ✓ iTPC upgrade will enable a much more precise measurement of di-electron mass spectra in $\sqrt{s_{NN}} = 200$ GeV
  - ✓ Distinguish models with different ρ-meson broadening mechanism
  - ✓ Obtain the QGP thermal radiation from intermediate mass region.

■ Hypertriton Lifetime Measurement in 2020+

- The combined statistical and systematic uncertainties for the current lifetime measurement are 30%.
- The future measurement from four billion minimum-bias Au+Au collisions at $\sqrt{s_{NN}} = 200$ would have 9% combined statistical and systematic uncertainties.
- Physics implication on interaction strength between Hyperon-Nucleon (Y-N) will thus be obtained.

References:
[1]"Highlights of the STAR midrapidity Physics Program after 2020", https://drupal.star.bnl.gov/STAR/starnotes/public/sn0669
[2]"The STAR Forward Calorimeter System and Forward Tracking System beyond BES-II" Proposal https://drupal.star.bnl.gov/STAR/starnotes/public/sn0648