HIGH P_T PHYSICS WITH THE STAR EXPERIMENT AT RHIC*

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The STAR experiment at RHIC is a TPC-based, general purpose detector designed to obtain charged particle spectra, with an emphasis on hadrons over a large phase space. An electromagnetic calorimeter provides measurement of e's, γ's, π^0's and jets. Data-taking with $Au+Au$ collisions at $\sqrt{s} = 200$ GeV/c^2 begins in Fall 1999. The STAR experiment's investigation of techniques and signals using hard probes to study the high energy-density matter at RHIC and to search for quark-gluon plasma formation will be described.

1 Introduction

The Relativistic Heavy Ion Collider (RHIC) at BNL will provide collisions of ions from p to Au at $\sqrt{s}$ up to 500 GeV/c^2 (p beams) and 200 GeV/c^2 (Au beams) beginning in Fall 1999. The STAR experiment[1] is designed to study the high energy-density nuclear matter produced in these collisions and to search for the phase transition to a quark-gluon plasma (QGP). The QGP is a deconfined state of quarks and gluons, predicted by quantum chromodynamics (QCD) to exist at high energy-densities. One facet of the STAR experimental program is to use high transverse momentum (p_T) production to probe the dense matter produced at RHIC. In this paper, the motivation for studying high-p_T production in heavy ion collisions, predicted signatures of QGP using hard probes and the planned STAR measurements are described.

Measurements of high-p_T production from high energy collisions allow small distances, and therefore the earliest times after the collision, to be probed. The high-p_T partons retain information about the collision during hadronization. High-p_T production from hadron-hadron collisions has been shown to be well-described by perturbative QCD (pQCD)[2].

At RHIC, it has been estimated that up to 50% of the transverse energy produced is due to partonic processes[3]. Therefore, pQCD predictions become viable for the first time in relativistic heavy ion collisions. Incorporating standard nuclear effects such as nuclear modification of the parton distribution functions[4] and the Cronin effect[5] into the pQCD calculations lead to accurate

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predictions[6] of high-p_T production from $p + A$ collisions. These calculations can be extended to the $A + A$ collisions at RHIC. In addition, changes in high-p_T production due to the passage of partons through the dense environment and a QGP have been predicted[7] and incorporated into calculations[3,8]. Studying hard probes with the STAR detector will allow measurements of how partons are affected in the dense environment and comparisons to pQCD to be made.

2 The STAR Experiment at RHIC

During the first year, RHIC will run mainly $Au+Au$ collisions and is expected to reach 10% of the design luminosity by the end of the year. The full design luminosity, $\mathcal{L} = 2 \cdot 10^{26}$ cm^{-2}s^{-1}, is expected to be attained by the end of year 2. RHIC will also provide different beam energies and species and will include pA, pp and polarized pp collisions.

At the heart of the STAR detector[9] is the time projection chamber (TPC) enclosed in a 0.5 Tesla solenoidal magnet. The TPC covers a range of $|\eta| < 2$ over the full azimuth and provides charged particle tracking and individual track particle identification (PID) for $p \approx 0.15 - 1.2$ GeV/c and momentum resolution $\sigma_p/p \leq 1\%$ for $p < 5$ GeV/c. Inside the TPC, is a silicon vertex detector (SVT) which provides tracking and PID near the vertex point. The forward TPC's (FTPC) will extend the tracking coverage to $2.4 < |\eta| < 4.0$. A RICH detector[10] will be installed at STAR for the first three years. This detector will provide limited angular coverage of $0 < \eta < 0.3$, $\Delta\phi \approx 20°$ and extends PID to $p \approx 3 - 5$ GeV/c.

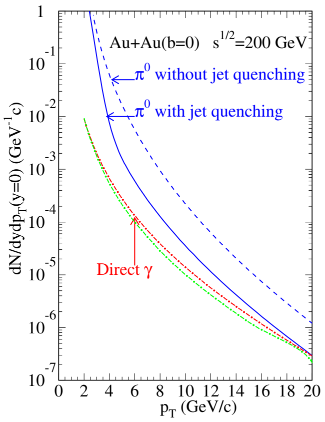
Surrounding the TPC is a finely-segmented (0.05×0.05 in $\Delta\eta \times \Delta\phi$) Pb-scintillator sampling electromagnetic calorimeter (EMC). A shower-maximum detector is located at $5X_\circ$. The barrel calorimeter covers a range of $|\eta| < 1$ with $\Delta\phi = 2\pi$. In year 1, 10% of the EMC will be installed, with 30% added each additional year. An endcap calorimeter, currently under review, will cover the range $1.05 < \eta < 2$ with $\Delta\phi = 2\pi$.

The charged particle multiplicity based hardware trigger (L0) covers the range $|\eta| < 2$. A software trigger (L3), used for enhancing the desired event samples, is expected to be ready for year 2 running.

3 High-p_T Probes of High Energy-Density Matter

STAR will search for changes in production and correlations of quantities at high-p_T using heavy ion collisions. Measurements will be done as a function of the amount of dense matter traversed by varying the centrality of collisions and using different beam species and energies. Data from $p+p$ and $p+A$ running will be used as a baseline for the high-p_T measurements. Some of the proposed signatures of QGP formation that STAR plans to measure are described below.

A predicted signal of QGP formation using hard probes is "jet quenching"[11], which is the softening of the p_T spectrum due to partons losing energy, in a dE/dx fashion, when propagating through dense matter. The p_T spectrum of π^0's is predicted[12] to soften if there are jet quenching effects in addition to standard nuclear effects, as shown by the pQCD prediction in Fig.1a. STAR can measure this spectrum by identifying $\pi^0 \to \gamma\gamma$ events using the EMC. An event sample of $\approx 2500(25)$ events at $p_T = 5(10)$ GeV/c is expected in year 1. A simulation of the reconstructed $\pi^0 \to \gamma\gamma$ mass peak with year 1 statistics is shown in Fig.1b. STAR will also measure charged particle high-p_T spectra in the first year.



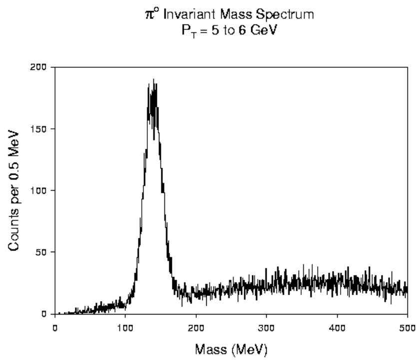


Figure 1. (a) pQCD prediction[12] of inclusive p_T spectrum of π^0's with and without dE/dx energy loss in $Au+Au$ collisions compared to direct γ's. (b) Simulation of reconstructed $\pi^0 \to \gamma\gamma$ mass spectrum with year 1 statistics in range $p_T = 5$ to 6 GeV/c.

The ratio of charged hadron to anti-hadron production as a function of p_T has been predicted[12] to change for $Au+Au$ relative to $p+p$ collisions as shown in Fig.2a. This ratio changes as a function of the energy loss factor due to jet quenching included in the calculation. The particle dependence of these ratios are due to differences in gluon and quark jet quenching in the dense medium. Using the RICH detector, it will be possible to measure the $\bar{p}/p$ ratio out to ≈ 5 GeV/c in year 1.

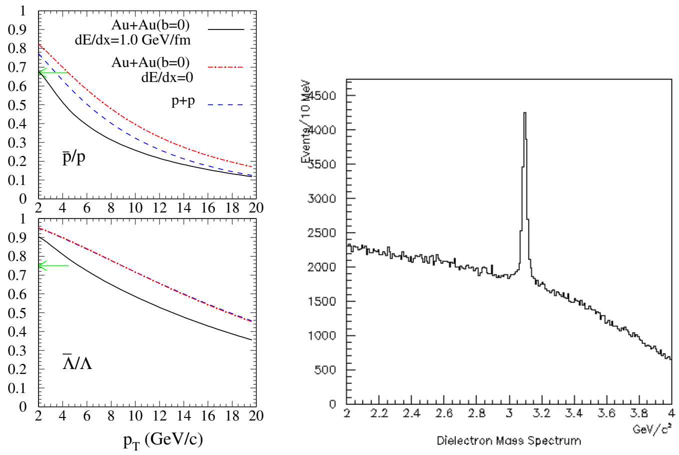


Figure 2. (a) The predicted[12] ratio of $\bar{p}$ to p and $\bar{\Lambda}$ to Λ spectra as functions of p_T in pp and central $Au + Au$ collisions with and without energy loss. (b) The reconstructed $J/\psi \to e^+e^-$ mass from a full detector simulation, assuming one year of full luminosity.

J/ψ production in a QGP is predicted[13] to be suppressed due to Debye screening of color charges in the plasma. STAR can measure $J/\psi \to e^+e^-$ events with the inclusion of the L3 trigger and using the TPC and EMC detectors. The reconstructed J/ψ mass from a simulation is shown in Fig.2b. With the full STAR detector and statistics expected from one year of running with full design luminosity and a requirement on the electrons of $p_T > 1.5$ GeV/c, STAR can expect to collect $\approx 4 \times 10^4$ J/ψ's per year.

Other high-p_T probes STAR can use are direct γ's and jets. Due to the large underlying event energies at RHIC, identification and energy measurements of jets may be difficult. Other ways to measure jets may be to use leading particle distributions or γ+jet events where the γ is tagged and used to identify and assign an energy to the jet. Studies of jets in the heavy ion collisions may also include angular correlations and di-jet production.

4 Summary

STAR's capabilities for using hard probes will include measurements of charged, neutral and leading hadron spectra, particle ratios, angular correlations, direct γ's, J/ψ and jet production. Simulations described here show the expected results for charged hadron ratios and π^0 and J/ψ spectra in the first few years of running. Using data from various energies, beam species and centralities, STAR will be able to provide detailed measurements of high-p_T production in the dense environment. The RHIC collider will offer unique and new regimes of dense matter and an excellent environment for new physics in the near future.

Acknowledgments

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