Future of Jets, Heavy Flavor, and EM Probes at RHIC and RHIC II

John W. Harris

1 Physics Department, Yale University, P.O. Box 208124, 272 Whitney Avenue, New Haven CT, U.S.A. 06520-8124

Abstract. Exciting results from the Relativistic Heavy Ion Collider (RHIC) have been presented at this Workshop. However, fundamental questions remain to be addressed in the future regarding whether the system is deconfined, chiral symmetry is restored, a color glass condensate exists in the initial state, and how the system evolves through eventual hadronization. Jets, heavy flavors and electromagnetic probes are sensitive to the initial high density stage of RHIC collisions, and should provide new insight. Significant additional capabilities will be added with a luminosity upgrade of RHIC (to RHIC II), upgrades of present detectors and a possible, new comprehensive detector at RHIC II.

Keywords: RHIC, relativistic heavy ions, quark-gluon plasma, quarkonium suppression, jets, large transverse momentum, jet quenching, heavy flavor

PACS: 25.75Nq

1. Introduction

The hard scattering and propagation of quarks and gluons, production of heavy flavors, and electromagnetic probes are sensitive to the initial high density stage of ultra-relativistic heavy ion collisions, and are expected to provide important information on the formation and properties of a Quark-Gluon Plasma (QGP).

The hard scattering of partons (fast quarks and gluons) from the incident nuclei occurs in the initial stage of ultra-relativistic heavy ion collisions, within the first 1 fm/c while the nuclei overlap. The scattered partons propagate outward and can be used to probe subsequent stages of the collision. These partons interact with the medium and subsequently fragment into clusters of particles, some at large momenta, called jets. Jets are used to determine the effects of the medium on their parent partons and establish its properties. Properties of jets can be measured via leading particles, particle correlations, photon-jet correlations, heavy quark (charm or beauty) tagged-jets, and topological jet energy. These provide information on
parton energy loss, properties of the medium through which the partons propagate, gluon shadowing, possible existence of a color glass condensate, and hadronization mechanisms.

The production of heavy flavor (charm and beauty) is most likely to occur in the initial stage of the collision, since heavy quarks require more energy to create than light quarks. Heavy flavors in the present context include open charm, open beauty, and quarkonia (charmonium and bottomonium states). Suppression of the yields of different quarkonium states is predicted and depends upon the color screening potential in a deconfined medium and the binding strength of each individual quarkonium state. Heavy quarks that do not result in quarkonia production lead to hadrons with open charm and open beauty. Measured yields of open heavy flavors can be used to test models for consistency of heavy flavor production and quarkonium suppression.

Electromagnetic probes in the form of photons and leptons probe all phases of the collision as they do not interact strongly with the medium. These can be divided into two categories: direct photons which tell us about thermal radiation and shadowing, and virtual photons (electron-positron pairs) that by way of their coupling to vector mesons may tell us about chiral symmetry restoration and possible bound states in a strongly-coupled QGP.

Many exciting results consistent with formation of the QGP have been presented at this Workshop. Some theorists state emphatically that evidence for the discovery of the QGP is conclusive [1, 2]. Experimentalists are cautious, stating that the evidence is not presently conclusive [3, 4, 5, 6]. Jets, heavy flavors and electromagnetic probes are expected to play a key role in settling this debate, as they reflect the initial high density stage, when formation of a QGP is most likely.

2. RHIC Experimental Capabilities

2.1. RHIC Detector Capabilities

The two large experiments at RHIC, PHENIX and STAR, continue to improve triggering and data acquisition capabilities in order to acquire data efficiently for jets, heavy flavors and EM probes. PHENIX and STAR will add detector capabilities and expand apertures with upgrades. Additional detector capabilities [7, 8] include micro-vertexing for identifying displaced vertices from heavy flavor decays in STAR (μVTX) and PHENIX (MVTX), adding better low-mass "hadron-blind" di-lepton capabilities in PHENIX (HBD), and extending particle identification to larger transverse momenta in STAR (ToF) and PHENIX (Aerogel).

2.2. RHIC Luminosities

In order to undertake extensive studies of heavy flavor production and jets at large transverse momenta (p_T), which have low cross section (and are often called rare probes), an upgrade in the RHIC luminosity will be necessary. The RHIC design
luminosity for Au+Au is \( L_0 = 2 \times 10^{26} \text{ cm}^{-2}\text{s}^{-1} \). RHIC now routinely reaches twice this value. Thus, the anticipated \( \int L dt \) per RHIC year (20 weeks operation) is approximately 2 - 3 nb\(^{-1}\). The p + p data are used as a reference to understand the fundamental production mechanisms, while d + Au data provide a comparison for the hot medium produced in Au + Au at RHIC. The p + p reference data and the d + Au comparison/control data require statistics similar to that of Au+Au and extended RHIC operation.

Many crucial measurements with hard and electromagnetic probes require \( \int L dt > 20 \text{ nb}^{-1} \), which is longer than a five year program at RHIC. For a vital program with rare probes to continue at RHIC, a luminosity increase to \( 40 \times L_0 \) or \( \int L dt \sim 100 \text{ nb}^{-1} \) is planned \cite{9}. This will be called the RHIC II Project, with a construction start possible in 2009 for operation in 2012.

3. Jets

High transverse momentum (\( p_T \)) particles and jets can be used to probe the QGP, study its properties and gain a better understanding of high density QCD and hadronization \cite{10}. Measuring the modifications of fragmentation functions (FF) of partons traversing the QGP in A+A collisions relative to p+p and p+A collisions should identify the properties of the QGP compared to those of a nuclear or hadronic medium. The RHIC energy regime appears to be ideal for these studies. Recent measurements in the forward direction at RHIC indicate possible gluon shadowing in the initial state at low x. Therefore, measurements over a specific part of phase space (e.g. forward- or mid-rapidities) selects the x region of the dominant process of interest. The higher energy regime of the Large Hadron Collider (LHC) will provide increased particle yields at high \( p_T \) and at low x.

The contributions of the various (u, d, s, c, b) quarks to the mass of stable particles can be extracted by measuring the fragmentation function of each particle in \( p+p \) interactions. Bourrely and Soffer \cite{11} use a statistical model for the fragmentation functions of the octet baryons (p, \( \lambda \), \( \Sigma \), and \( \Xi \)) in \( e^+e^- \) interactions at \( Q = 91.2 \text{ GeV} \). They find that the contributions of the light (u,d,), strange (s), and heavy (c,b) quarks to the production of these particles varies as a function of \( x_{Bj} \), with the fragmentation of heavy quarks dominating the fragmentation protons for parton momentum fractions \( x \leq 0.3 \) (see \cite{10} for more details). In order to measure these fragmentation functions at RHIC, leading particles in jets with large transverse momentum must be identified. Such measurements in A+A collisions will establish how fragmentation functions are modified by propagation of the various types of quarks in the dense medium and will reflect the various quark contributions to the particle masses as they fragment in the medium. It would be extremely exciting if fragmentation functions of some of the particles were to reflect properties of a chirally restored medium. In addition to accounting for the constituent quark masses, the chiral quark condensate is responsible for inducing transitions between left-handed and right-handed quarks, \( \overline{q}q = \overline{q}_Lq_R + \overline{q}_Rq_L \). Therefore, helicities of
leading particles in jets (determined from the polarization of leading Λ particles) may provide information on parity violation and chiral symmetry restoration \[12\].

Full utilization of hard parton scattering to probe high density QCD matter requires measurements of photons (to establish the parton energy), jets (another potential measurement of parton energy), high p\(T\) identified particles (for fragmentation functions of particles and flavor-tagging), as well as intrajet, jet-jet and photon-jet correlations. In addition, measurements are essential over a multi-parameter space that can be divided into initial state parameters (c.m. energy, system mass, collision impact parameter, \(x_1\) and \(x_2\) of the colliding beam partons, and \(Q^2\) of the collision) and those of the final state (\(p_T^{\text{parton}}\), \(y^{\text{parton}}\), \(\phi^{\text{parton}}\), \(p_T^{\text{jet/particle}}\), \(\chi^{\text{jet/particle}}\), \(\phi^{\text{jet/particle}}\), flavor\(jet/particle\), \(\phi^{\text{flowplane}}\)). Such a comprehensive study requires large data sets and high luminosity to extend measurements to large p\(T\). Furthermore, it would be of interest to investigate the difference in quark versus gluon propagation by implementing kinematic cuts (\(x_1\), \(x_2\)) in jet-jet correlations, and to utilize the expected differences predicted by QCD for the yields of gluon and quark jets as a function of transverse momentum and \(\sqrt{s}\).

3.1. Photon-tagged Jets

The primary advantage of photons is that they do not re-interact with the medium through which they propagate. Thus, they can be used to determine the parton energy in the original hard-scattering that produces the photon and away-side jet. The away-side jet will suffer energy loss in the medium and thus the difference of the photon and measured away-side jet energy can be used to determine the energy lost by the parton on the away-side of the photon. Correlation of the flavor of the leading hadron in the jet on the away-side of a photon provides additional information with which to test energy loss mechanisms. Another advantage of photon-jet correlations is that there are only two production diagrams that produce photons in leading order: quark-antiquark annihilation and quark-gluon Compton scattering. However, there is one major issue to be dealt with when utilizing prompt photons to determine the momentum of the hard-scattered parton. One must distinguish direct (prompt) photons from fragmentation photons. This is accomplished by using isolation cuts in elementary interactions. However, it is complicated by the large particle multiplicities in A + A collisions, and must be resolved through understanding the contribution of fragmentation photons and their momentum dependence.

STAR will undertake initial studies of photon-jet correlations up to 10 GeV/c photon momentum by utilizing a few nb\(^{-1}\) integral luminosity in Au+Au at RHIC. Approximately 1 percent of the jets have a leading hadron above background in an Au+Au collision at RHIC. A few year Au+Au run with 4 - 5 nb\(^{-1}\) integral luminosity yields \(\sim 8K\) charged hadrons in a spectrum on the away-side from a 10 GeV/c photon, and \(\sim 1K\) charged hadrons in a spectrum on the away-side from a 15 GeV/c photon in STAR. More detailed measurements, especially with identified particles on the away-side for fragmentation function modification of partons requires RHIC II luminosities and additional particle identification at large p\(T\).
PHENIX proposes to undertake statistical photon-jet correlation analyses with approximately 1000 photon-jet events. The maximum photon $p_T$ depends on the PHENIX detector complement. In the 2004 Au+Au run the maximum photon $p_T$ ($p_T^{\text{max}}(\gamma)$) is expected to be $\sim 6$ GeV/c; with a new time projection chamber (covering $-1 \leq \eta \leq 1$) at RHIC luminosity $p_T^{\text{max}}(\gamma) \sim 12$ GeV/c; with an additional nose cone calorimeter for expanded photon detection at RHIC II luminosity $p_T^{\text{max}}(\gamma) \sim 23$ GeV/c at mid-rapidity [13].

**Fig. 1.** Photon-jet results from PYTHIA 6.2 for $\sqrt{s} = 200$ GeV p+p interactions. Distributions as a function of pseudo-rapidity $\eta$ are shown from top to bottom for partons of all $p_T$, photons of all $p_T$, and photons with momenta $4 < p_T < 6$ GeV/c, $9 < p_T < 11$ GeV/c, and $14 < p_T < 16$ GeV/c, respectively.

Recent results from STAR [14] indicate that jets in Au+Au collisions broaden significantly in pseudo-rapidity on the near-side as well as on the away-side. This can be attributed both to the variation of parton momentum fractions for partons of the incoming beam nuclei (parton momentum fractions $x_1, x_2$) and to jet quenching in matter. The broadening in p+p interactions can be seen in calculations utilizing PYTHIA 6.2 for $\sqrt{s} = 200$ GeV at RHIC, shown in Fig. [1] The partons and photons from hard scattering processes extend widely over the pseudo-rapidity range $-3 \leq \eta \leq 3$. The same simulations show that the difference in pseudo-rapidity between a direct photon and associated away-side jet, shown in Fig. [2] has a width $\sigma(\eta_{\gamma} - \eta_{\text{jet}}) = 0.9, 1.0, 1.2,$ and $1.5$ units of pseudo-rapidity for parton or direct photon momenta ranging from $14 < p_T < 16$ GeV/c, $9 < p_T < 11$ GeV/c, $4 < p_T < 6$ GeV/c, and all $p_T$, respectively. Experiments seeking to undertake photon-jet measurements should have large acceptance for photons, high $p_T$ particles and jet energy in order to cover a range of parton momentum fractions ($x_1, x_2$).

### 3.2. Flavor-tagged Jets

Jets with a D- or B-meson as leading particles serve to study the response of the medium to heavy compared to light quarks. A high $p_T$ electron in coincidence with a leading hadron, both from a vertex displaced from the primary reaction vertex,
Fig. 2. Photon-jet results from PYTHIA 6.2 for $\sqrt{s} = 200$ GeV p+p interactions. Distributions for the difference in pseudo-rapidity between a direct photon and its associated away-side jet for parton or direct photon momenta ranging (top to bottom) from $14 < p_T < 16$ GeV/c, $9 < p_T < 11$ GeV/c, $4 < p_T < 6$ GeV/c, and all $p_T$, respectively. The standard deviation $\sigma$ of each distribution is also given.

will provide a trigger for heavy flavor decays. Significant measurements at large $p_T \sim 10$ - 15 GeV of D- and B-mesons as leading particles of jets require RHIC II luminosities and upgraded detectors in STAR ($\mu$-vertex, ToF) and PHENIX (VTX).

4. Heavy Flavors

4.1. Quarkonia

The production of quarkonium states in p+p, p+A, and A+A collisions provides a tool to study deconfinement in strongly interacting matter [15]. Studies of the dependence of the heavy-quark potential on the in-medium temperature in lattice QCD calculations with dynamical quarks [16] indicate a sequence of melting of the quarkonium states based upon their binding strengths: $T(\psi') < T(\Upsilon_{3S}) < T(J/\psi) \sim T(\Upsilon_{2S}) < T(\Upsilon_{1S})$ where $T(\Upsilon_{3S}) < T_c$ and $T(\Upsilon_{1S}) > T_c$, with $T_c$ the deconfinement phase transition temperature. Therefore, a measurement of the yields of the various bottomonium states will shed light on the production (via $\Upsilon_{1S}$) and suppression mechanisms ($\Upsilon_{2S}$ and $\Upsilon_{3S}$) of quarkonia avoiding many difficulties inherent in charmonium measurements. These measurements are challenging, requiring excellent momentum resolution to resolve the bottomonium states and very high rate (luminosity) and trigger capabilities because of the low production cross-sections.

The larger production cross-sections for charmonium states compared to bottomonium states have led to studies of charmonium and the subsequent observation of charmonium suppression in collisions of heavy ions at the SPS. PHENIX anticipates its first results with large statistics on charmonium suppression in Au+Au at RHIC from the large statistics 2004 data run. Bottomonium spectroscopy on the other hand requires higher luminosities. Since bottomonium is massive ($\sim 10$...
GeV/c^2) its decay leptons have sufficiently large momenta above background processes facilitating high-level triggering.

The PHENIX mass resolution for $\Upsilon \rightarrow e^+e^-$ with the VTX detector upgrade is $\Delta m = 60$ MeV. Without the VTX it is 170 MeV, making resolution of the $\Upsilon_{1S}$ (9.460 GeV), $\Upsilon_{2S}$ (10.020 GeV), and $\Upsilon_{3S}$ (10.360 GeV) challenging. The PHENIX mass resolution in the muon arms is worse than 170 MeV making it difficult to resolve the individual $\Upsilon$ states in the muon decay channel. Statistics for the $\Upsilon$ states, combined in Table 1, are low. In STAR, the mass resolution for $\Upsilon \rightarrow e^+e^-$ is $\Delta m = 340$ MeV using the time projection chamber tracking alone. A $\mu$-vertex detector upgrade would improve this resolution to $\Delta m = 170$ MeV. Only with a planned data acquisition system upgrade, will STAR be able to detect a significant number of $\Upsilon$'s (1750 combined in all three states with 1.5 nb$^{-1}$ Au+Au). In general, a meaningful bottomonium program at RHIC will require RHIC II luminosities ($\sim 100$ nb$^{-1}$) and large acceptances to obtain reasonable statistics.

The quarkonium statistics anticipated for Au + Au in PHENIX [8, 13] are presented in Table 1.

| Channel | RHIC (1.5 nb$^{-1}$) | RHIC II (30 nb$^{-1}$) |
|---------|---------------------|----------------------|
| $J/\psi \rightarrow e^+e^-$ | 2,800 | 56,000 |
| $\psi' \rightarrow e^+e^-$ | 100 | 2,000 |
| $\Upsilon \rightarrow e^+e^-$ | 8† | 155† |
| (all states) | | |
| $J/\psi (\psi') \rightarrow \mu^+\mu^-$ | 38,000 (1400) | 760,000 (28,000) |
| $\Upsilon \rightarrow \mu^+\mu^-$ | 35‡ | 700‡ |
| (all states) | | |

† requires MVTX upgrade
‡ requires $\mu$-trigger system upgrade.

4.2. Open Heavy Flavor

Heavy flavor (charm and bottom) yields are sensitive to the initial gluon density and are important components of understanding $J/\psi$ and $\Upsilon$ production. Measuring the energy loss of a heavy quark in the medium will indicate whether heavy quarks suffer less energy loss than light quarks in the medium as expected from the ”dead-cone effect” [17]. Also, the stronger quenching of gluons than quarks results in stronger quenching (and a stronger energy dependence of quenching) for light than heavy mesons, due to the contribution of gluons to light meson production [18].

Initial measurements of charm cross sections and charm flow have been made by identifying single electrons above background in STAR [19] and PHENIX [20]. These results indicate that low $p_T$ open charm exhibits elliptic flow and are
preliminary at the time of this Conference. Significant measurements of charm flow and charm jet energy loss up to moderate $p_T \sim 5 - 6$ GeV can be made with $\sim 3$ nb$^{-1}$ and upgraded detectors in STAR ($\mu$-vertex, ToF) and PHENIX (VTX). Recent calculations of the color charge and mass dependence of the energy loss indicate that the $p_T$ range for identifying significant differences in jet quenching of heavy versus light mesons at RHIC is $7 < p_T < 12$ GeV/c \[21\]. Such measurements require the increased machine and detector capabilities of RHIC II.

5. Electromagnetic Probes

5.1. Direct Photons

Photons in A+A collisions may provide information on thermal photon radiation. In p+A interactions, photons establish the degree of shadowing. Photons in p+p reactions are needed for reference data, to understand the underlying processes in p+A and A+A results. Preliminary results on photons in Au+Au and p+p at RHIC have been reported by PHENIX at this Workshop \[22\]. Photons measured in p+p are consistent with next-to-leading order (NLO) pQCD calculations. Those measured in Au+Au exhibit no thermal photons within present statistics. Furthermore, the Au+Au direct photons are consistent with binary scaling of p+p. A definite statement about direct photons in Au+Au at RHIC is anticipated from PHENIX from the recent RHIC 2004 high statistics Au + Au run \[22\].

5.2. Virtual Photons via $e^+e^-$ pairs

Thermal photons (measured via $e^+e^-$ pairs) are expected to be radiated from the QGP. However, at RHIC energies, the thermal di-lepton spectrum in the intermediate mass range (1 - 3 GeV) may be dominated by charm. In addition to information on thermal radiation, virtual photons (measured via $e^+e^-$ pairs) investigate possible modifications of vector mesons in the medium. The behavior of vector mesons in medium may shed light on the existence of chiral symmetry breaking and/or bound states in a strongly-coupled QGP.

In order to effectively pursue low mass electron pair measurements, PHENIX has proposed to install a hadron-blind TPC (HBD) and STAR has proposed a barrel Time-of-Flight detector (ToF) for electron identification at $p_T > 0.2$ GeV/c. A calculation of the light vector meson yield as a function of invariant mass of $e^+e^-$ pairs is displayed in Fig. \[23\]. Peaks for the $\omega$ and $\phi$ mesons are observed, but are swamped by $e^+e^-$ pairs from thermal and non-equilibrium photons and open charm. Careful investigation of medium modification of low mass vector mesons requires measuring and understanding all contributions to the di-lepton spectrum including detailed charm studies that require RHIC II luminosities.
6. A Comprehensive New RHIC II Detector

A comprehensive new detector has been proposed \cite{24} for RHIC II to undertake measurements of jets, heavy flavors, and electromagnetic probes, and to take full advantage of the high RHIC II luminosities. New RHIC II physics opportunities can be studied by utilizing a high field (\(\sim 1.5\) T) magnet, extensive charged hadron tracking and identification at high \(p_T\), electron and muon tracking and identification, and extensive coverage of electromagnetic and hadronic calorimetry. The capabilities of a comprehensive new detector include: 1) excellent charged particle momentum resolution to \(p_T = 40\) GeV/c in the central rapidity region, 2) complete hadronic and electromagnetic calorimetry over a large phase space (\(-3 \leq \eta \leq 3, \Delta \phi = 2\pi\)), 3) particle identification out to large \(p_T\) (\(\sim 20 - 30\) GeV/c) including hadron (\(\pi, K, p\)) and lepton (\(e, h, \pi, h\)) separation in the central and forward regions, and 4) high rate detectors, data acquisition, and trigger capabilities. A possible layout for a new RHIC II detector using the SLD magnet is shown in Fig. 4.

In order to identify all charged hadrons in a high \(p_T\) jet at RHIC II, hadron identification is necessary up to momenta of approximately 20 GeV/c. Lepton particle identification will be achieved through the \(e/h\) capabilities in the calorimeters and the muon chambers. Hadron and lepton particle identification will be achieved through a combination of \(dE/dx\) in the tracking detectors (\(p_T \leq 1\) GeV/c), a time-of-flight device (\(p_T \leq 3\) GeV/c), and a combination of two different Aerogel Cherenkov-threshold counters and a RICH detector with gas radiator (up to \(p_T \sim 20\) GeV/c). For more details on the comprehensive new detector see \cite{24}.
6.1. Jets in a Comprehensive New Detector

Jet rates over the large acceptance of a new detector (-3 \leq \eta \leq 3, \Delta \phi = 2\pi plus extended forward coverage to \eta \sim 4.5) at upgraded RHIC II luminosities will be significant. The anticipated jet yield for 40 GeV jets in such a new detector at RHIC II with 30 nb\(^{-1}\) of Au+Au at top energy is \sim 180,000. 19,000 \gamma-jet events are expected with p_T(\gamma) = 20 GeV/c, and 1,000 \gamma-jet events for p_T(\gamma) = 30 GeV/c with full away-side particle identification over -3 \leq \eta \leq 3 for determination of the modification of fragmentation functions of particles.

Extension of high resolution particle tracking, particle identification (PID), and calorimetry to forward rapidities will be important in elucidating the various particle production and hadronization mechanisms, which may be sensitive to the quark and gluon components of the hadronic wave functions. At very low x_B, gluons may be coherent over nuclear distances forming a color glass condensate [25, 26]. This would have effects on many hard physics observables that depend directly on the gluon structure, e.g. minijet rates and heavy flavor production, but can be clarified by comparisons of p+A physics with p+p. Thus, it is important to study high p_T processes away from midrapidity. To take full advantage of physics in the forward region, momentum measurements and PID must be undertaken up to p_T \sim 2-3 GeV/c, which is a real experimental challenge with longitudinal momenta of 20-30 GeV/c at large rapidities.
6.2. Quarkonia in a Comprehensive New Detector

For determination of the quarkonium melting sequence an energy resolution of better than $10\%/\sqrt{E}$ is required to resolve the quarkonium states with calorimeter information alone. Thus, quarkonium physics at RHIC II in this new detector will fully utilize an electromagnetic calorimeter in combination with high resolution tracking and large acceptance muon chambers. The mass resolution for $\Upsilon \rightarrow \mu^+\mu^-$ in the new comprehensive detector is $\Delta m = 60$ MeV. Furthermore, large acceptance in the Feynman $x_F$ variable is important for understanding quarkonium production and melting mechanisms. This leads to the need for large acceptance in $\eta$ for lepton pairs. The electron and muon coverage of the new detector extends over $-3 \leq \eta \leq 3$ and $\Delta \phi = 2\pi$. A similar acceptance in the new detector for charmonium feed-down photons from $\chi_c$ decays ($\chi_c \rightarrow J/\psi + \gamma$) allows determination of the $\chi_c$ feed-down contribution to $J/\psi$ production and subsequent suppression.

Anticipated quarkonium statistics in Au + Au for the comprehensive new detector are presented in Table 2, which can be compared directly to Table 1.

**Table 2. Quarkonium Program in Au + Au for a Comprehensive New Detector at RHIC II for $p_{\text{lepton}} > 2$ GeV/$c$ for $J/\psi$, and $p_{\text{lepton}} > 4$ GeV/$c$ for $\Upsilon$.**

| Channel          | RHIC II (30 nb$^{-1}$) |
|------------------|------------------------|
| $J/\psi \rightarrow$ di-leptons | 36,000,000             |
| $\psi' \rightarrow$ di-leptons     | 1,000,000              |
| $\chi_c' \rightarrow J/\psi + \gamma$ | 680,000               |
| $\Upsilon \rightarrow$ di-leptons   | 64,000                 |
| $\Upsilon' \rightarrow$ di-leptons  | 12,000                 |
| $\Upsilon'' \rightarrow$ di-leptons | 12,000                 |

7. Conclusions

There is new data still to be accumulated at RHIC utilizing jets, heavy flavors and electromagnetic probes. From this data new physics will be uncovered, since jets, heavy flavors and electromagnetic probes are sensitive to the initial high density stage of RHIC collisions. Questions still remain to be addressed as to whether 1) the system becomes deconfined, 2) chiral symmetry is restored, 3) in addition to a strongly-coupled QGP there is a weakly-interacting one, 4) a color glass condensate exists in the initial state, and 5) whether we can gain new understanding of the hadronization process. Precise timescales for new detector implementation to improve capabilities for rare probes at RHIC is uncertain due to ambiguities in the availability of funding. Significant capabilities will be added with new detectors at RHIC and a possible comprehensive new detector at RHIC II.
8. Acknowledgements

The author wishes to thank R. Bellwied, T. Ullrich, N. Smirnov, P. Steinberg, H. Caines, M. Lamont, C. Markert, J. Sandweiss, M. Lisa and D. Magestro for fruitful RHIC II physics discussions and contributions to this work. M. Gyulassy, B. Mueller and D. Kharzeev have contributed through enlightening discussions.

References

1. M. Gyulassy and L. McLerran, Nucl.Phys. A750 (2005) 30.
2. X.N. Wang, Nucl.Phys. A750 (2005) 98.
3. J. Adams et al., STAR White Paper, nucl-ex/0501000.
4. K. Adcox et al., PHENIX White Paper, nucl-ex/0410003v2.
5. B.B. Back et al., PHOBOS White paper, nucl-ex/0410022.
6. I. Arsene et al., BRAHMS White Paper, nucl-ex/0410020v.
7. STAR Decadel Plan, STAR Collaboration (2003),
   http://www.star.bnl.gov/STAR/smd/whitepaper-18.pdf
8. PHENIX Decadel Plan, PHENIX Collaboration (2003),
   http://www.phenix.bnl.gov/phenix/WWW/docs/decadal/2003/PHENIXDecadalPlan.pdf.
9. K.A. Drees, Proceedings of this Workshop.
10. R. Bellwied, Proceedings of this Workshop.
11. C. Bourrely and J. Soffer, Phys. Rev. D68 (2003) 014003.
12. D. Kharzeev and J. Sandweiss (private communication).
13. A. Drees et al (PHENIX), http://nsac2004.bnl.gov/pres/drees.pdf
14. D. Magestro et al (STAR), to be published in Eur.Phys.J.C.
15. T. Matsui and H. Satz, Phys. Lett. B 178 (1986) 416.
16. S. Digal, P. Petreczky and H. Satz, Phys. Rev. D64 (2001) 094015,
   [hep-ph/0106017] and Phys. Lett. B514 (2001) 57, [hep-ph/0105234].
17. Y.L. Dokshitzer and D.E. Kharzeev, Phys. Lett. B519 (2001) 199.
18. M. Djordjevic, M. Gyulassy, and S. Wicks, hep-ph/0410372.
19. F. Lane et al. (STAR), nucl-ex/0411007.
20. S.S. Adler et al. (PHENIX), nucl-ex/0409028.
21. N. Armesto et al., hep-ph/0501225.
22. T. Sakaguchi et al. (PHENIX) in Proceedings of this Workshop.
23. R. Rapp, nucl-th/0204003.
24. J.W. Harris et al., nucl-ex/0407021.
25. L. McLerran, Acta Phys.Polon. B34 (2003) 3029.
26. D. Kharzeev and E. Levin, Phys. Lett. B523 (2001) 79.