

R2D - The case for a comprehensive new RHIC-II detector

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A new detector concept (R2D) is needed to harvest the unique physics opportunities at RHIC-II during the LHC era. This concept is based on a high granularity hermetic array of detectors featuring high momentum particle identification and superior resolution for photon and onium measurements. Most components of R2D can also be applied to future electron-ion interactions. Thus, R2D allows us to perform precision QCD-type measurements at RHIC-II and eRHIC.

1. INTRODUCTION

Over the past two years our working group evaluated the physics opportunities of a luminosity upgrade at RHIC. Based on the many exciting discoveries of the first four RHIC years [1], we came to the conclusion that a full characterization of the properties of the strongly interacting QGP formed at RHIC will require a new experiment, which combines lessons learned from high energy particle and nuclear physics experiments over the past three decades. In particular the hermeticity and resolution of existing particle physics collider experiments is necessary and needs to be combined with high momentum particle identification and tracking in order to measure the properties of the novel collective partonic medium and its transition to hadronic matter, which is likely the mechanism that occurred in the early phase of the expansion of the universe. Thus, issues such as

- hadronic mass generation from a dense, collective partonic medium
- chiral symmetry restoration in a collective partonic medium
- deconfinement and initial thermodynamic conditions in a collective partonic medium
- conditions of matter at very high gluon densities (low x physics)

need to be explored in depth. Also, the extension of the RHIC spin program will continue to address the question of the spin generation in the proton through polarized pp measurements and, eventually, eA collisions. The proposed detector design can also be applied to a future high precision electron-ion era at RHIC (eRHIC) for low x and spin physics, and thus form the basis of an unprecedented QCD characterization program at BNL.

*For the full list of R2D authors and acknowledgements, see appendix 'Collaborations' of this volume

2. UNIQUE PHYSICS MEASUREMENTS AT RHIC-II

I point out five distinct physics topics that may be better addressed by a dedicated RHIC-II program than at the LHC. Certain lattice QCD based calculations show that for LHC collisions one should expect a weakly-interacting QGP in the early phase while a strongly-interacting, nearly-perfect liquid appears to be observed at RHIC [2]. This strong coupling of the degrees of freedom above the critical temperature might be unique to the RHIC initial conditions. It is likely that the initial LHC conditions will relax to the phase properties measured at RHIC, but observables that develop during the earliest stage of the collision, such as elliptic flow (v_2) and direct photons, may distinguish between a strongly interacting sQGP at RHIC and a more weakly interacting wQGP at LHC. Therefore, *RHIC-II is a unique place to study the sQGP.*

De-excitation of the LHC initial phase may lead to different degrees of freedom just above T_c than observed at RHIC. These degrees of freedom determine the production of baryonic matter from a collective partonic phase rather than the vacuum. The process is therefore more likely to resemble the mechanism of baryonic matter formation in the universe. Baryon/meson differences at higher transverse momentum in elliptic flow v_2 and for nuclear suppression factors R_{AA} [3,4] at RHIC suggest constituent quarks as the relevant degrees of freedom just above T_c [5,6]. Alternative models propose other constituents ranging from gluonic bound states to quasi-particles to resonant quasi-hadronic states above T_c [7–9]. These models differ in their generation of the hadronic masses, and it is important to perform identified particle yield, correlation and fluctuation measurements at high p_T to determine the baryonic production mechanism. Therefore, *RHIC-II is a unique place to study hadron formation out of a dense partonic medium.*

At the energy density of the collective partonic system at RHIC-II, the current masses of the heavier quarks, starting with the strange quark, may not be negligible. Therefore, the basic fragmentation process may be more quark flavor dependent than at higher energies [10,11]. Furthermore, the jet energy regime at RHIC is close to the kinematic limit and the jet energy loss in the medium may still be parton flavor dependent [12]. The LHC regime will extend the RHIC measurements out to higher p_T where the energy loss is expected to be universal and non-Abelian [13]. Therefore, *RHIC-II is a unique place to study energy loss and fragmentation in the strong coupling limit.*

At midrapidity at the LHC the x values are small requiring a very high gluon density (possibly the Color Glass Condensate) [14]. It may be cleaner experimentally to perform characterization measurements at an incident energy where one can control the level of saturation as a function of pseudo-rapidity. This appears to be the case based on preliminary measurements in the forward and central directions at RHIC-II energies [15]. Therefore *RHIC-II is a unique place to study the equation of state at low x .*

Finally, the combination of lower luminosity, less running time and higher collision energy at LHC leads to comparable integrated onium yields per year at RHIC-II and LHC. Enhanced detector capabilities in a new RHIC-II experiment, in particular for reconstructing the χ_c and resolving the Y -states over a large acceptance, allow determination of the yields and relative screening strength of all onium states. Therefore, *RHIC-II is a unique place to determine precisely the thermodynamic evolution of the system from initial to deconfinement conditions.*

3. REQUIREMENTS FOR A NEW DETECTOR

The requirements for a new detector emerge from the restricted capabilities of the existing detectors for certain key measurements mentioned above. In particular, RHIC-II detection capabilities should extend to near hermetic coverage and the highest accessible pseudo-rapidity. This is demonstrated through detailed simulations in our Letter of Intent [16], in particular the pseudo-rapidity distributions of the γ in the $\chi_c \rightarrow J/\Psi + \gamma$ decay and the away side leading particle distributions in high momentum γ -jet events. In both cases a mid-rapidity detector is not sufficient to measure the distributions. For a χ_c produced at central rapidity, the decay γ distinctly populates the forward region, and the leading away-side hadron in γ -jet events is spread over six units of pseudo-rapidity with respect to the jet axis. In addition the γ itself has a distribution that far exceeds the acceptance of the existing RHIC detectors. A new detector also needs to feature high precision vertexing and tracking at high momentum, which can be achieved through a solid-state tracker in a large magnetic field. It needs to have high granularity electromagnetic calorimetry for photon measurements (direct, decay, fragmentation and thermal photons), which drive the necessity for a crystal type calorimeter, and hadronic calorimetry to distinguish the different neutral particle energy contributions. Finally the detector needs a high momentum particle identification component to extend the critical flavor dependent measurements out to high momentum.

4. SCHEMATIC LAYOUT AND PERFORMANCE SIMULATIONS OF A NEW DETECTOR

In order to meet the physics requirements as well as the financial constraints to the RHIC-II project, we propose two alternate schematic layouts based on existing high energy physics experiment components. One layout is based on the large, high field SLD magnet (L-R2D), another is a more compact version based on the smaller superconducting CDF magnet (S-R2D). In both cases we envision that the magnet, calorimeters (hadronic and electromagnetic), muon chambers, and certain DAQ and trigger hardware components will be provided by a series of high energy experiments that are scheduled to complete operation before the end of the decade (i.e. SLD, CDF, CLEO, HERA-B, and D0). Components that need to be built specifically for R2D are the vertexing, tracking, and particle identification detectors as well as DAQ and trigger electronics. Details of the proposed components can be found in our original Letter of Intent and conference contributions [16–18]. Fig.1 shows the main detector layout for L-R2D, a S-R2D layout can be found in [18]. For a comparison of the two options it is important to note that particle identification out to 25 GeV/c will require a RICH detector, which sets the minimum size of the magnet.

Based on the present status of all R2D simulations [16] certain benchmark capabilities were established:

- identified particle spectra, from the pion to the D-meson, reach out to 25 GeV/c (around 10 Million pions and 5,000 D-mesons per RHIC-II year (i.e. 30 nb⁻¹).
- the away-side spectrum of γ -jets can be reliably measured out to a p_T^γ of 20 GeV/c (around 20,000 away-side leading charged particles above 5 GeV/c per RHIC-II year).
- all Υ states and the χ_c can be reconstructed (mass resolution $\sigma=50$ MeV/c²).

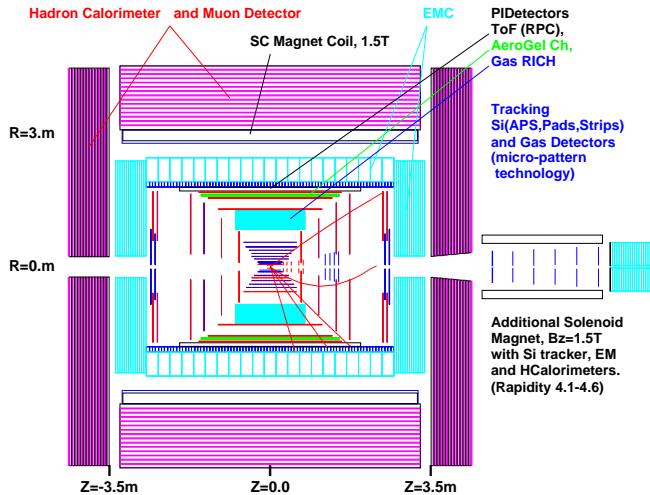


Figure 1. Large version of a new RHIC-II detector (L-R2D) based on the SLD magnet.

5. FUTURE PROSPECTS FOR R2D AT RHIC-II AND BEYOND

This detector must be viewed as the most comprehensive relativistic heavy ion device to date. It is essential to complete the characterization of the transition features, now that the QGP has been found and can be studied. The program described here is necessary to fully understand the unique physics of the hadronization of partonic matter in the universe. In light of the future interest in eA collisions at RHIC one should also note that significant parts of R2D, are very similar to early layouts of the central component of an eRHIC detector [19]. These parts could be used and complemented with dedicated forward components for eRHIC.

REFERENCES

1. RHIC whitepapers: Nucl.Phys.A757 (2005)
2. O. Kaczmarek et al., hep-lat/0406036 and hep-lat/0312015
3. J.Adams et al. (STAR collaboration), Phys. Rev. Lett. 92 (2004) 052302
4. S.S. Adler et al. (PHENIX collaboration), Phys. Rev. C 71 (2005) 051902(R)
5. R.J. Fries et al., Phys. Rev. C68 (2003) 044902
6. R. Hwa and C.B. Yang, Phys. Rev. C70 (2004) 024904
7. E.V. Shuryak and I. Zahed, Phys. Rev. D70 (2004) 054507
8. A. Peshier and W. Cassing, hep-ph/0502138
9. H. van Hees, V. Greco, and R. Rapp, nucl-th/0508055
10. S. Albino et al., hep-ph/0502188
11. C. Bourrely and J. Soffer, Phys.Rev. D68 (2003) 014003
12. I. Vitev, J.Phys. G31 (2005) S557
13. Q. Wang and X-N. Wang, nucl-th/0410049
14. L. McLerran, hep-ph/0311028 and references therein
15. I. Arsene et al. (BRAHMS collab.), Phys. Rev. Lett. 93 (2004) 242303
16. P. Steinberg et al., R2D Expression of Interest, nucl-ex/0503002
17. J. Harris et al., nucl-ex/0504023
18. R. Bellwied et al., nucl-ex/0505022
19. A. Deshpande et al., hep-ph/0506148