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B-Physics at RHIC- An opportunity

M. S. Atiya, S. White
Brookhaven National Laboratory, Upton, New York 11973
and
M. Marx
State University at Stony Brook, Stony Brook, New York, 11790

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B physics provides a unique window for investigation and confirmation of our picture of CP violation, as well as an opportunity to explore physics beyond the Standard Model. Because of this richness of physics, programs for the study of the B sector are in progress or under development at most of the major facilities for high energy physics in the world. In this note we suggest that a B program at the RHIC facility at BNL could provide timely and complementary information to our understanding of physics within and beyond the Standard Model.

The discussion of B physics opportunities at RHIC is not new, dating back to at least 1988. It has been dormant until recently because of the anticipated greater opportunity for B physics exploration at the now defunct SSC, and at FNAL as shown by the recent successes of CDF in B spectroscopy and identification of decay modes such as $B_d^0 \to J/\psi\ K_s$ which may eventually provide access to CP violation. The renewed interest in the opportunity at RHIC has been sparked by the conjunction of recent developments - the

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cancellation of the SSC; the successes at CDF; the likelihood that neither of the current FNAL collider experiments will reconfigure to exploit B studies as their highest priority, and that a new dedicated B experiment is not likely to displace them; the availability of a large sample of B's which will be produced in the currently approved RHIC HEP program; and finally, the current discussion of the US HEP program for the near and far term in light of the SSC cancellation.

The RHIC project at BNL is being constructed, and will be operated by the Nuclear Physics program of the DOE, starting operations in 1999. In addition to a complement of 4 experiments to study heavy ion physics, the BNL scientific program committee has approved a program of spin physics to measure high energy parity violation and structure functions using 250-on-250 Gev polarized protons, and also an experiment to measure pp total cross sections and elastic scattering. The constraint on this HEP program is that it should be limited to the approximately 12 weeks not scheduled for the nuclear program, and the incremental costs must be borne by HEP. These costs are currently estimated at less than \$ 1M/week. Using an estimate of 2×10^6 seconds of actual running (1 month), and the expected luminosity that can be achieved for 250-on-250 Gev protons on protons($4\times10^{32} sec^{-1} cm^{-2}$), results in a total B production of 10^{10}. The running conditions at RHIC also provide the attractive features of a short luminous region ($\sigma_z = 9$ cm) and a bunch spacing of 110 nsec, with about 1 interaction per crossing at the highest expected luminosity. Finally, there is an available intersection region, which has the foundations for a major detector facility and 20m of free space between the splitting dipoles. The main parameters for RHIC operation are shown in Table 1.

Table 2 shows comparisons of B production at various current and planned facilities, utilizing advertised design luminosities. Planning advice from FNAL now suggests using 50% of the luminosity shown in the table, and experience suggests it might take several years to reach the full luminosity of the B-factory. This table illustrates one of the major features of hadroproduction - approximately half of the B-flavored hadrons produced are not available in 4S running at a B-factory. Of the 10^{10} B's produced in a 1-month run at RHIC, 15% are B_s, 0.1% are B_c, and 10% are B-baryons. The other advantage for hadron colliders is the nearly 3 orders of magnitude more B_u and B_d produced per run. Initially it will be more difficult to exploit these mesons fully, due to higher backgrounds and trigger requirements , but once

Parameter	Value
$\sqrt{S}$	500 GeV
L_{peak}	4×10^{32}
β^*	1 m
ϵ	$15\pi \times 10^{-6}$ m
Number of bunches	114
Bunch separation	110 nsec
Luminous region (Initital)	$\sigma_z = 9$ cm $\sigma_t = 110\mu$m
Free space between splitting dipoles	± 10 m

Table 1: *RHIC machine parameters* .

one learns how to extract them, one can expect that the ultimate precision measurements of CKM matrix elements will be made at hadron colliders.

The general features of B-production at RHIC are best illustrated by Figures 1 and 2 , which show the number of B-mesons as a function of pseudo-rapidity η and the boost variable $\beta\gamma$. It is noteworthy that 60% of these mesons are in the central regions ($\eta < 1.5$), and that even in this region the typical $\beta\gamma$ is several times higher than that at the B-factory operating at the 5S ($\beta\gamma < .9$), considerably simplifying the measurement of the time evolution of B_s–$\bar{B}_s$ mixing out to x_s of greater than 20.

The availability of such large samples of B-flavored hadrons makes possible important studies of the spectroscopy of B_s, the much rarer B_c, and B-baryons. The B_c in particular, will be the first quark-antiquark system with two heavy quarks providing a unique testing ground for potential models and HQET. In addition, with 2×10^9 B_u and B_d mesons available per run, many important rare decay modes can be studied. For the B_s system, decays like $B_s^0 \to K^* l^+ l^-$ and $B_s^0 \to \phi l^+ l^-$ test the limits of the Standard Model and provide important new windows to extensions of the SM. This is also true of the FCNC decay $B_s \to K^* \mu^+ \mu^-$, and even more interesting lepton-number violating decays like $B_s \to K^* \mu^+ e^-$, which are completely independent of current searches in K and μ-decay, since the B decays sample

	RHIC	Tevatron Post MI	ABF SLAC	LEP (Z^0 pole)
L ($cm^{-2}sec^{-1}$)	4×10^{32}	5×10^{31}	10^{34}	2×10^{31}
σ (μb)	12.5	50	10^{-3}	7×10^{-3}
Sec/year	2×10^6	10^7	10^7	10^7
Total B's	10^{10}	2.5×10^{10}	10^8	10^5
$B_{u,d}$	5×10^9	1.25×10^{10}	10^8	4×10^6
B_s	1.5×10^9	4×10^9	0	8×10^5
B_c	10^7	2.5×10^7	0	4×10^3
Λ_b	10^9	2.5×10^9	0	4×10^5

Table 2: *Comparison of B production for hadronic and e^+e^- machines.*

effects due to the third generation which have never been explored. While these rare decays are challenging, most provide straight-forward triggers.

Taking into account the programs and time scales of currently approved projects at SLAC and KEK, the high probability of efforts at HERA and LHC, and the unlikelihood of a dedicated effort at FNAL, we believe there is a significant window of opportunity for a new dedicated effort at RHIC to study B physics. It is apparent that in order to make a timely and important contribution, this effort should focus, in priority order, on measurements of rare B decays, $B_s - \bar{B}_s$ mixing, B spectroscopy, and measurement of CKM angles. The last will most likely provide , at the initial stage, a confirmations of more precise measurements elsewhere, but with significantly different systematics. B spectroscopy will be significantly advanced by efforts at an upgraded CDF and HERA-B, but there is room for contributions from a dedicated effort at RHIC. However, B_s mixing and measurement of x_s, and in the large area of rare B-decays, a dedicated experiment at RHIC is likely to provide the most sensitive measurements for the next 10 years - at least until LHC turns on.

To take advantage of this opportunity, a dedicated experiment at RHIC must be designed that is optimized for the physics priorities. There can still be debate over whether a central or forward detector provides the best choice, and this choice must also be constrained by the availability of scarce

resources. There can be little debate over other features of such an experiment - it must have excellent particle identification to separate π and K up to several GeV, and it must have excellent vertex resolution with the possibility of triggering on detached vertices to enhance signal-to-background. A dedicated experiment can also provide opportunities for improvement over the current round of B-detectors, especially with regard to reconstruction of multi-particle final states. Here, small improvements in acceptance and efficiency can result in large increases in data samples. A detector with excellent measurement of photons will also improve efficiency of reconstruction. Development of an efficient yet discriminating trigger is the key to the success of a hadron collider B effort, and this must be augmented with a high bandwidth data acquisition system

While the initial advantage in studying CP violation in B decays is likely to be with the e^+e^- B-factories, the ultimate measurements will most probably be done at hadronic colliders like RHIC and LHC.Given the experience in studying rare K-decays and hadronic production of charm, one must accept the fact thay any such experiment will require several generations of upgrades to achieve the ultimate precision and sensitivity limited only by the production statistics. A program which focuses on the high priority items of B_s mixing and rare decays, and eventually extracts precision measurements of CP violation parameters is completely consistent.

A dedicated experiment to utilize the large number of B's which will be produced at RHIC can provide important and timely contributions to our understanding of the B sector, the Standard Model, and physics beyond the Standard Model. It is complementary and not redundant to efforts elsewhere, and we urge that such a program be considered as part of our overall national effort in high energy physics for the next decade.

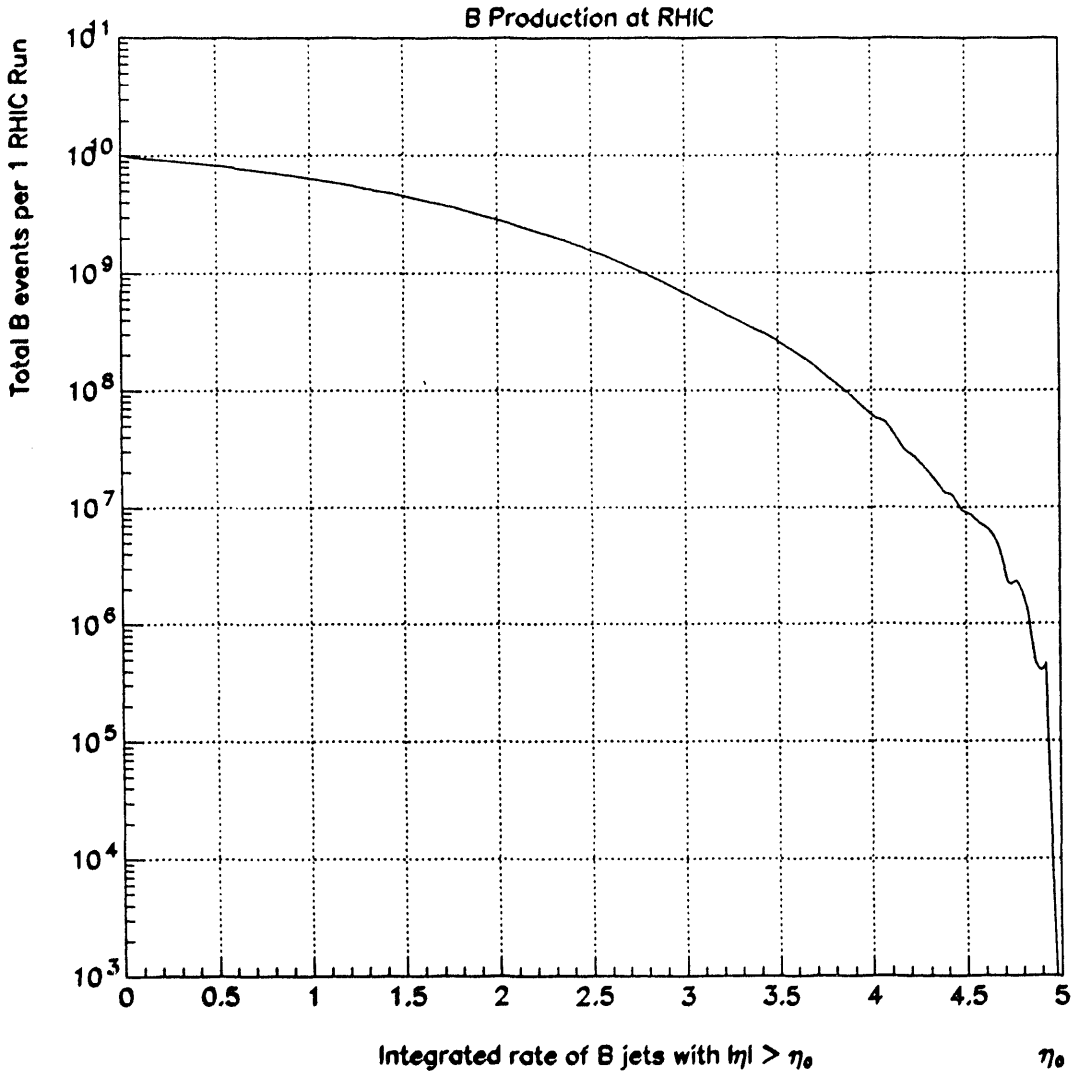

Figure 1: *Integrated rate of B production vs* η

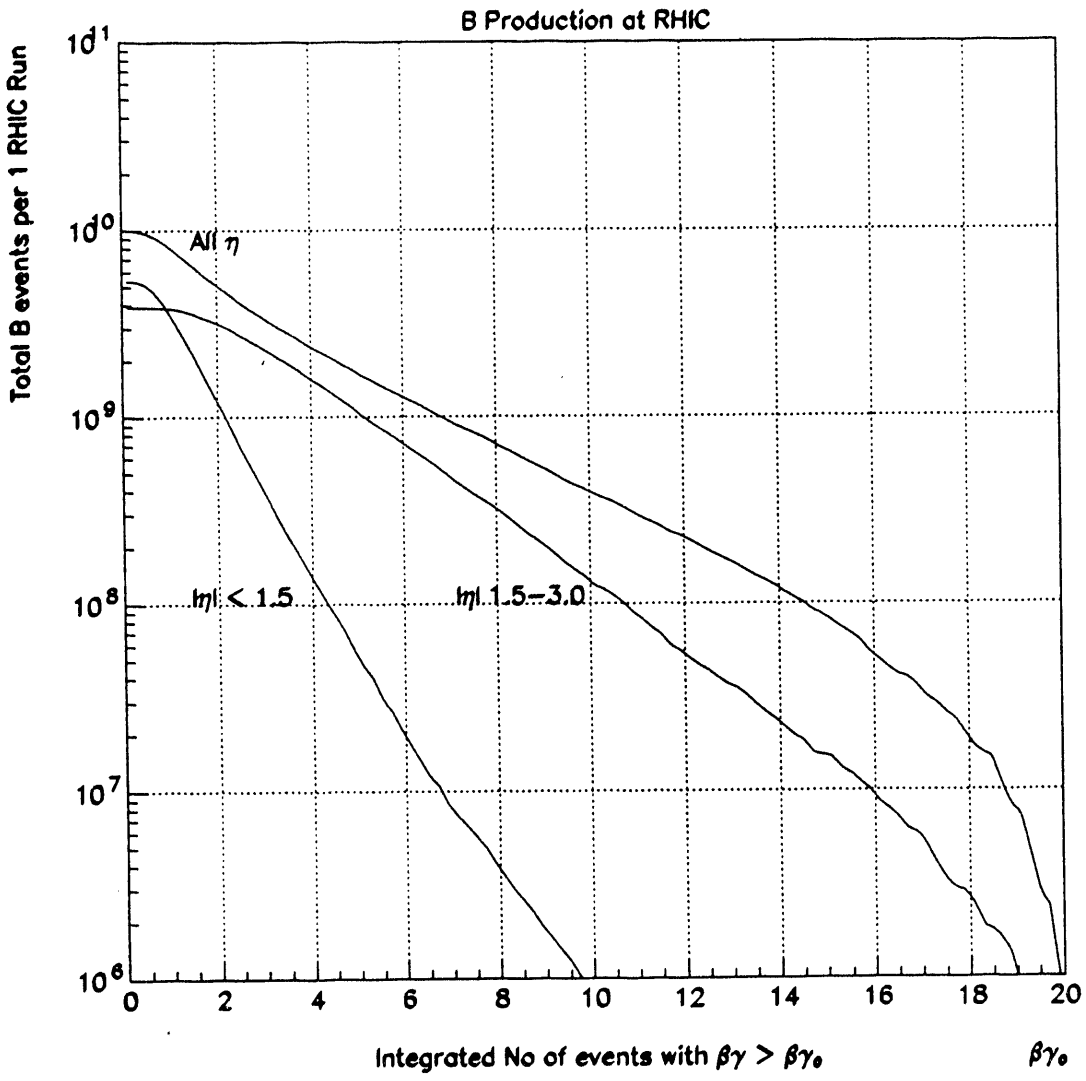

Figure 2: *Integrated rate of B production vs* $\beta\gamma$

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