Research Plan for Spin Physics at RHIC

Abstract

In this report we present the research plan for the RHIC spin program. The report covers 1) the science of the RHIC spin program in a world-wide context; 2) the collider performance requirements for the RHIC spin program; 3) the detector upgrades required, including timelines; 4) time evolution of the spin program.

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1 Executive Summary

An action item from the June 30-July 1, 2004 DOE Office of Nuclear Physics Science and Technology Review of the Brookhaven National Laboratory (BNL) Relativistic Heavy Ion Collider (RHIC) written Report, dated September 13, 2004, was that *"BNL should prepare a document that articulates its research plan for the RHIC spin physics program. A copy should be submitted to DOE by January 31, 2005."* This document is submitted to the DOE Office of Nuclear Physics on behalf of the Laboratory, in response to that action item.

We provide here a plan that addresses: 1) the science of the RHIC spin program in a worldwide context; 2) the collider performance requirements for the RHIC spin program; 3) the detector upgrades required, including timelines; 4) time evolution of the spin program. The RHIC Spin Plan Group was charged to formulate the plan by Thomas Kirk, BNL Associate Director for High Energy and Nuclear Physics.

The importance of the study of nucleon spin to nuclear physics and the anticipated contribution of RHIC is discussed in the first section of this report. Spin plays a central role in our theory of the strong interactions, *Quantum Chromodynamics* or QCD, and to understand spin phenomena in QCD will help to understand QCD itself. Nucleons, protons and neutrons, are built from quarks and the QCD force-carrier, gluons. *Unpolarized* deep inelastic scattering (DIS) experiments, scattering high energy electrons and muons from nucleons, first discovered quarks in the 1960s, and then over the next 30 years, DIS experiments exquisitely verified the QCD prediction for the energy dependence of the scattering. This was a triumph of QCD. *Polarized* deep inelastic scattering experiments then showed that the quarks in the nucleons carry only about 25% of the nucleon spin, a major surprise. The remaining 75% must be carried by the gluons and by orbital angular momentum. Experiments with polarization at RHIC will probe the proton spin in new profound ways. A particular strength of the RHIC spin program is to measure the gluon contribution to the proton spin. A second emphasis will be a clean, elegant measurement of the quark and anti-quark polarizations, sorted by quark flavor, through parity-violating production of W bosons. RHIC will also probe the structure of transversely polarized protons, which may be related to the orbital angular momentum of the quarks and gluons in the proton. To contribute to the understanding of nucleon structure and the nature of confinement of the quarks and gluons inside the nucleons is the primary goal of the spin physics program at RHIC.

The key points of this report are emphasized in the following three figures.

Science. In Figure 1, we show the sensitivity that we expect for measurements of gluon polarization in the proton. RHIC will measure this with a number of probes, which will test our understanding of the underlying physics, and produce a robust result for this key measurement. The expected sensitivity of the ongoing DIS experiment at CERN, Compass, is also shown. Measuring the gluon polarization is a worldwide quest, and RHIC will provide the most sensitive and definitive results.

The figure shows expected results for both high cross section processes (left panel, pions and

Figure 1: $\Delta G/G(x)$ vs. $\log x$ with a model showing the x range for various RHIC processes with expected uncertainties; 200 and 500 GeV data are shown with experimental uncertainties in RHIC and COMPASS for $Q^2 > 1$ GeV^2.

jets), and for the more precise but lower cross section process of direct photon production. The pion and jet probes will give important results earlier in the program with lower luminosity and polarization, with one result from the 2003 run already published, and it is anticipated that results from the 2005 run will greatly constrain the gluon polarization (see left panel of figure). The direct photon channel (right panel) most directly measures the gluon polarization. This ”golden channel” requires high luminosity and high polarization. We have a robust theoretical understanding of these reactions with confirmed predictions of cross sections from next-to-leading order QCD.

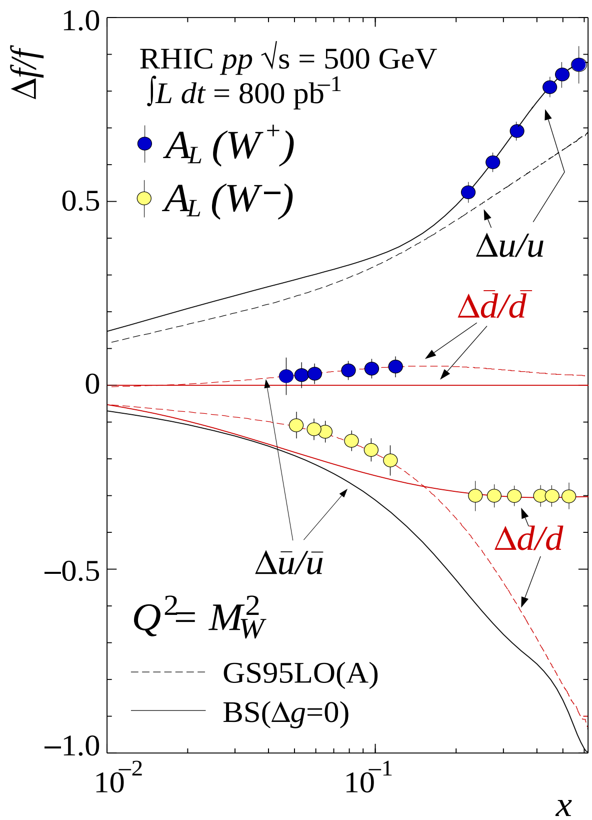

Figure 2: $\Delta q/q(x)$ vs. $\log x$ with a model for u, d, $\bar{u}$ and $\bar{d}$; with RHIC and DIS expected uncertainties.

In Figure 2, we show the expected sensitivity to anti-quark polarization, sorted by flavor. This is a direct measurement by observing the parity violating production of W bosons, with RHIC running at $\sqrt{s}$=500 GeV. RHIC will provide definitive measurements, where only model-dependent results presently exist from DIS. This will be an exciting result, addressing how it is that the combination of quark and anti-quarks in the proton carry little of the proton spin.

Experiment Upgrades for W Program To accomplish the W measurements, both STAR and PHENIX must upgrade their detectors. STAR requires additional precision forward tracking to unambiguously determine the charge sign of the ~40 GeV electrons for $W \rightarrow e^{\pm} + \nu$. This will be proposed in 2006, for completion for the 2010 run, at an estimated cost of \$5M. PHENIX requires additional triggering for selection of the $W \rightarrow \mu^{\pm} + \nu$ decays out of the expected 10 million collisions per second for the 500 GeV running. This is being proposed this year, for completion for the 2008 run, at an estimated cost of \$2.8M.

Accelerator Requirements and Time Evolution To accomplish these important physics goals, we need high polarization, high luminosity, and significant running at both $\sqrt{s}$=200 GeV (the present spin program energy) and at $\sqrt{s}$=500 GeV (RHIC at the full heavy ion rigidity). The present level of polarization is 45% and we expect to reach the target of 70% in 2006 for 200 GeV running. We plan to develop the polarization for 500 GeV running over the next several years, and expect to reach the target of 70% in time for the 500 GeV program in 2009. The minimum and maximum expected luminosities per year are shown in Figure 3, with three bands. The first band begins in 2005, and displays the integrated luminosity with time for 10 weeks of physics running per year, for 200 GeV. The 200 GeV run continues to mid-2009, when we show the changeover to 500 GeV. This change is dictated by reaching the target luminosity goal shown on the figure for 200 GeV. The target is the basis of the sensitivities shown in Fig. 1.

Beginning mid-2009, we switch to 500 GeV. Both W physics and gluon polarization physics will be pursued. This is shown reaching the target in 2012, with 10 physics weeks per year. This, then, gives the sensitivities shown in Figures 1 and 2.

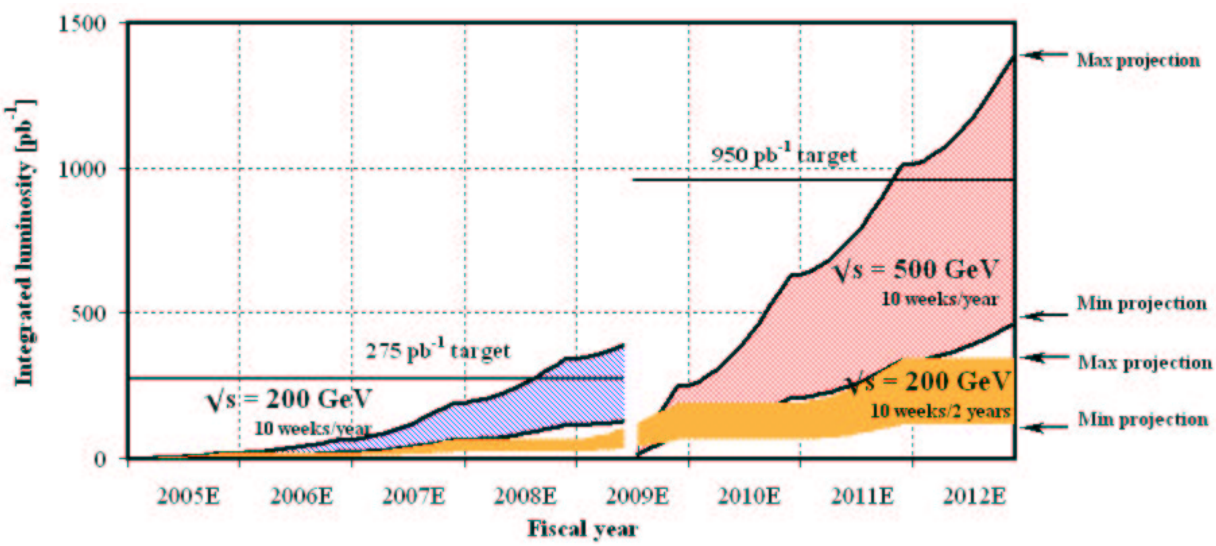

Figure 3: Minimum and Maximum projected integrated luminosity through FY2012. Delivered luminosity numbers are given for one of two interaction points. For the scenario with 10 weeks of physics operation per year, the assumed energy is $\sqrt{s}$=200 GeV until FY2009, and 500 GeV thereafter. For the scenario with 10 weeks every other year, the assumed CM energy is 200 GeV throughout the entire period.

Figure 3 also shows a band for running spin for 5 physics weeks per year, taken as 10 weeks every two years to reduce end effects. The band shows only 200 GeV running because, even by 2012, we will not have accumulated the target luminosity for gluon polarization measurements. To complete the program as we have shown it requires running to at least 2019.

The charge to the spin planning group for creating this plan is included as an appendix. We considered just two running scenarios, 5 and 10 spin physics weeks per year. These indicate *"the physics goals that can be met over a period of years without involving the Group in difficult funding and cost scenarios that are not central to the calculation of physics accomplishments over time."*

The 10 week per year scenario shown in Fig. 3 includes the assumption that the detector upgrades for STAR and PHENIX for the W program are accomplished by 2010, and is therefore "technically driven". This is the preferred scenario from BNL.

The 5 week per year scenario, shown also in Fig. 3, requires at least 6 years of running at each energy to accomplish the definitive measurements of gluon polarization and anti-quark polarization shown in Figures 1 and 2. Under this scenario, RHIC would run roughly 25% of the year and both the heavy ion and spin programs would be stretched a factor of greater that two in calendar time.

The 5 week per year plan would be a most difficult and unfortunate scenario, with RHIC poised to answer these major questions on nucleon structure. With this scenario, not only will the answers be very slow in coming, but the community of world-class accelerator physicists, experimenters, and theorists that drive the program, reaching already state of the art polarization and luminosity, and with remarkable physics output, will not be challenged to their capacities and these teams will be difficult to maintain.

By achieving the measurement sensitivities shown in Figures 1 and 2, RHIC will contribute major new understanding to the structure of the protons and neutrons that make up the known matter in the universe, and to our understanding of the theory of the strong interaction, Quantum Chromodynamics. This work will qualitatively change our understanding of the nuclear force, contributing to a field developed through major breakthroughs in theory, including the discovery of asymptotic freedom in QCD that received the 2004 Nobel Prize in Physics, and in experiment, with the discoveries of quarks, precision confirmation of predicted scaling violations, and the spin surprise that the quarks carry very little of the nucleon spin.

The body of the report provides the details for the program described above. The report also includes other exciting science areas, such as planned studies (and some already published measurements) on transverse spin, which may access orbital angular momentum. A number of heavy ion driven (or with spin) upgrades, based on a detector R&D program supported since FY 2003 as part of the RHIC operations budget, also offer exciting spin physics opportunities, and these are described in the Experiments section of the report.