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RHIC SPIN - THE FIRST POLARIZED PROTON COLLIDER*

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Abstract

The very successful program of QCD and electroweak tests at the high energy hadron colliders have shown that the perturbative QCD has progressed towards becoming a "precision" theory. At the same time, it has been shown that with the help of Siberian Snakes it is feasible to accelerate polarized protons to high enough energies where the proven methods of collider physics can be used to probe the spin content of the proton but also where fundamental tests of the spin effects in the standard model are possible. With Siberian Snakes the Relativistic Heavy Ion Collider (RHIC) will be the first collider to allow for 250 GeV on 250 GeV polarized proton collisions.

Polarized proton beams in the Relativistic Heavy Ion Collider (RHIC) will open up the completely unique physics opportunities of studying spin effects in hard processes at high luminosity, $250\,GeV$ on $250\,GeV$ proton-proton collisions. It will allow us to study the spin structure of the proton, in particular the degree of polarization of the gluons and antiquarks, and also to verify the many well documented expectations of spin effects in perturbative QCD and parity violation in W and Z production.

A number of experimentalists, particle and nuclear theorists and accelerator physicists have formed the RHIC Spin Collaboration (RSC) and its proposal[2] for a comprehensive program of spin physics has been approved in 1993. In fact, since its initial proposal the interest has been steadily growing and generated a number of new ideas such as the existence and possible observation of a new transversity structure function $h_1(x)$[1] and in general the significance of transverse spin effects in hard processes.

In the following I will briefly discuss the state of polarized proton acceleration in the AGS using the newly installed Partial Snake, describe the plans for the installation of Siberian Snakes, spin rotators, and polarimeters in RHIC and then present the physics opportunities using the two RHIC collider detectors STAR and PHENIX.

Figure 1 shows the AGS/RHIC accelerator complex with all the necessary additions to produce polarized proton collisions in RHIC. To achieve high luminosity, high energy polarized proton collisions in RHIC, twenty pulses of polarized H^- ions from the present AGS polarized proton source will be accumulated in the AGS Booster and, with an overall acceleration efficiency of about 25%, a single bunch in RHIC will contain about 2×10^{11} polarized protons with a normalized emittance of about $\epsilon_N = 20\pi\ mm\ mrad$ and about 70% polarization. At 250 GeV and 57 bunches in each RHIC ring the luminosity is then $2\times10^{32}\ s^{-1}cm^{-2}$.

During acceleration, the polarization may be lost when the spin precession frequency passes through a depolarizing resonance. These resonances occur when the number of

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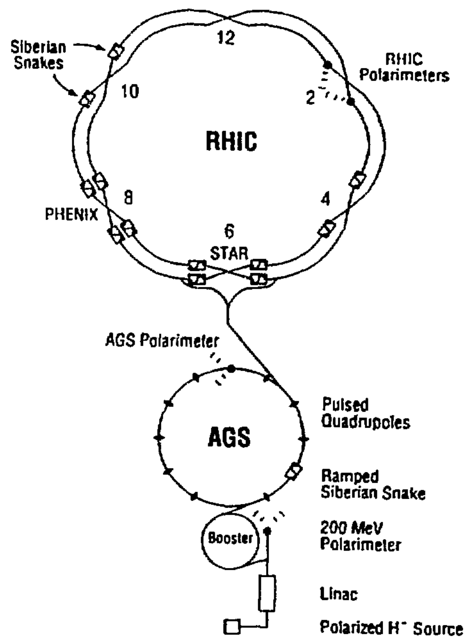

Figure 1: The Brookhaven accelerator complex, which includes 200 MeV LINAC the AGS booster, the AGS and RHIC.

spin precession rotations per revolution $G\gamma$ ($G = 1.793$ is the anomalous magnetic moment of the proton, $\gamma = \frac{E}{m}$) is equal to an integer (imperfection resonances) or equal to $kP \pm \nu_y$ (intrinsic resonances). Here $P = 12$ is the superperiodicity of the AGS, $\nu_y = 8.8$ is the vertical betatron tune and k is an integer. The depolarization is caused by the small horizontal magnetic fields present in all ring accelerators which, at the resonance condition, act coherently to move the spin away from the stable vertical direction. Traditionally, the depolarizing resonances in the AGS were corrected by the tedious harmonic correction method for the imperfection resonances and the tune jump method for the intrinsic resonances[3].

The experiment E-880 at the AGS has recently demonstrated the feasibility of polarized proton acceleration using a 5% partial Siberian Snake[4]. A 5% Snake is sufficient to avoid depolarization due to the imperfection resonances without using the harmonic correction method. Figure 2 shows that depolarization is limited to the intrinsic resonances which can be overcome in the future with the proven tune jump method. At 25 GeV, the polarized protons are transferred to RHIC. At this energy the transfer line between the AGS and RHIC is spin transparent.

Since each bunch is accelerated independently, we have the option of preparing the polarization direction of each bunch independently. Filling both RHIC rings with 57 bunches each and acceleration to full energy will only take about 10 minutes which is short compared to the expected lifetime of the stored polarized proton beams in RHIC of many hours.

By inserting two full Siberian Snakes on opposite sides of each of the two RHIC rings, depolarization from imperfection and intrinsic depolarizing resonances can be avoided up to the top energy of 250 GeV. In addition to the Siberian Snakes, spin

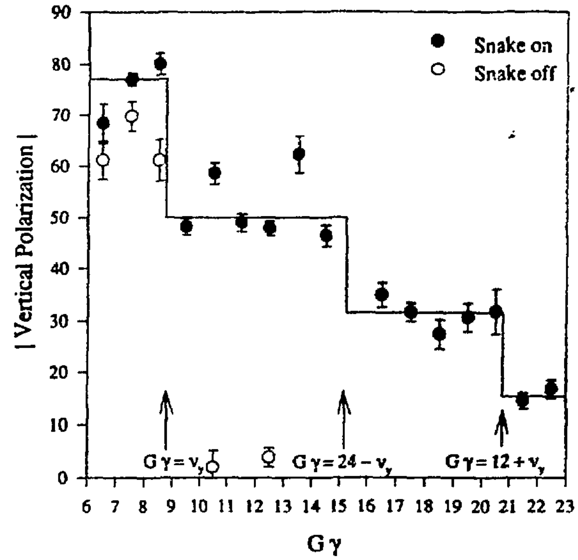

Figure 2: Vertical polarization as a function of $G\gamma$. Note that partial depolarization is due to intrinsic spin resonances at $G\gamma = \nu_y, 24 - \nu_y$ and $12 + \nu_y$.

rotators are required at the intersection points used by PHENIX and STAR to allow for measurements of spin effects with longitudinally polarized protons. The Siberian Snakes and spin rotators rotate the spin by 180° and 90° ,respectively, without generating a net orbit distortion. In both cases the spin rotation is accomplished with a sequence of constant field, superconducting helical dipole magnets.

The proton beam polarization in RHIC will be measured with π^- production from a Carbon fiber internal target. The analyzing power was measured[5] to be 18% at $X = 0.5$ and $p_T = 0.8\ GeV/c$.

Proton-proton collisions at high energies involve hard scattering of gluons and quarks. In this kinematic region factorization should hold and any asymmetry A measured for a high p_T reaction is a sum of corresponding asymmetries $\hat{a}$ at the parton level weighted by the actual degree of polarization of the initial partons given by the spin structure function:

$$A = \sum_{subprocesses} \frac{\Delta a}{a} \times \frac{\Delta b}{b} \times \hat{a}(a + b \rightarrow c + d)$$

The subprocess asymmetries are predicted by the standard model and are often large. For example, $\hat{a}_{LL}$ in QCD is 50% or larger for most subprocesses and the parity violating $\hat{a}_L$ is unity in weak processes. By measuring different reactions and different types of asymmetries we can determine subprocess asymmetries, the spin structure functions of all partons, and also perform self consistency checks. This very ambitious program is greatly simplified by the fact that the spin structure functions of valence quarks are known from deep inelastic scattering measurements and that we can select reactions that are dominated by just one subprocess. The RHIC energy is ideal in the sense that

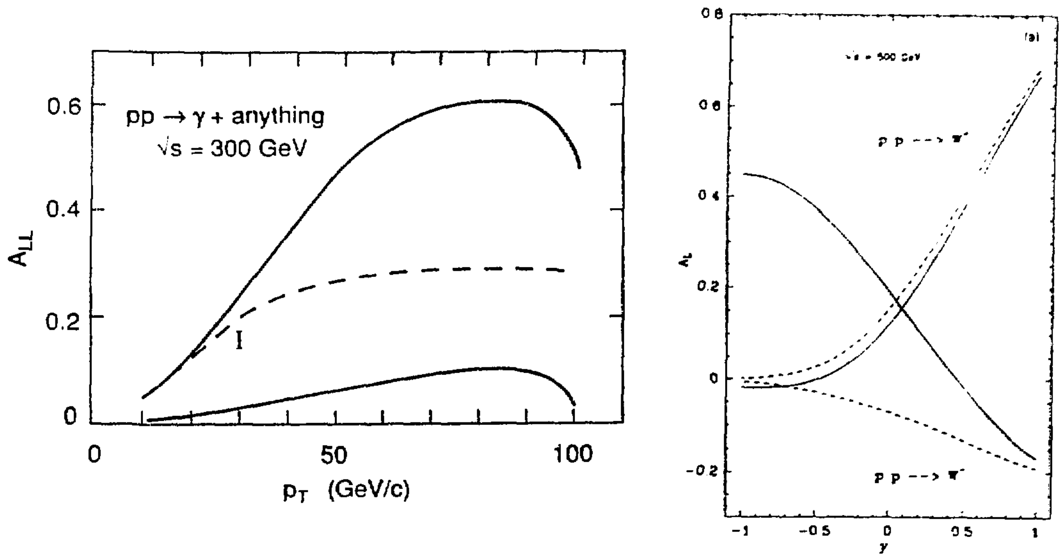

Figure 3: The left graph shows A_{LL} for direct photon production vs. p_T for standard ΔG (lower solid) and large ΔG (dashed: 90°, upper solid: 45°). The right graph shows A_L vs. rapidity for $W^{\pm}$ production for non-zero (solid) and zero (dashed) seaqurak polarization

it is high enough for perturbative QCD to be applicable and low enough so that the average x value is about 0.1 or larger which guarantees significant levels of polarization for the valence quarks.

The first example of such a reaction is direct photon production, where the Compton subprocess $qg \to q\gamma$ dominates the annihilation subprocess $q\bar{q} \to \gamma g$ at low or medium p_T. The measured asymmetry A_{LL} is therefore directly proportional to the gluon spin structure function $\frac{\Delta G}{G}$. A prediction[6] is shown in figure 3 for two values of $\frac{\Delta G}{G}$. Both PHENIX and STAR can achieve an accuracy of $\delta A_{LL} = 0.5\%$ for a 100 day run.

Unlike direct photon production, single jet production has main contributions of three subprocesses: elastic gluon-gluon, quark-gluon, and quark-quark scattering. However, their relative importance changes with p_T with gluon-gluon dominating at low p_T. Since jet production has a much higher rate a very high precession of $\delta A_{LL} = 0.005\%$ can be achieved.

The parity violating production of W and Z at the parton level is dominated by annihilation $q\bar{q} \to W^{\pm}, Z$ and can, therefore, be used to probe the spin structure functions of the sea quarks. As figure 3 shows the attainable precision is again very high compared to the very large parity violating asymmetry expected[7].

Measuring the transverse double spin asymmetry A_{TT} for Z production or Drell-Yan processes open up the very unique possibility to probe the transversity structure functions $h_1(x)$ of the quarks. h_1 measures the correlation between left and right handed quarks in a transversely polarized proton. Transversity is an equally fundamental observable as helicity but can not be observed in deep inelastic lepton scattering.

A separate experiment will study systematically proton-proton elastic scattering in the $\sqrt{s}$ range of 60-500 GeV, covering the four-momentum transfer $|t|$ up to $2\,(GeV/c)^2$.

There are two setups: at small $|t|$ in the Coulomb-Nuclear-Interference region, which requires large β^*, one can measure the total cross section, the ratio of real to imaginary part of scattering amplitude, and the slope parameter simultaneously with errors of a few percent; and at large $|t|$, where data can be taken with the standard lattice, one can reach $|t|$ values beyond the expected first dip in the structure region of the elastic cross section. The same setup can be used to study elastic scattering using polarized protons at RHIC. The following can be measured: the difference in the total cross sections as a function of initial transverse spin states, the analyzing power, and the transverse spin correlation parameter.

In addition to measuring spin structure functions, polarized proton collisions also allow for the first time the direct measurement of parton level spin effects, which are precisely predicted by the standard model or forbidden as in the case of parity violation in a QCD process. We can look forward to an exciting new field of high energy physics when the first polarized protons collide by the end of this century.

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