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# RHIC Spin Physics*

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The physics potential of colliding beams of protons, polarized either longitudinally or transversely, at RHIC is remarkable. A luminosity of $L = 2 \times 10^{32}$ $cm^{-2}$ with 70% polarized beams will be available with up to 250 GeV energy in each beam. The proposal to collide polarized protons in RHIC was submitted in August 1992 and approved in October 1993. We have funding for R&D on Siberian Snakes, so that RHIC will be able to accelerate polarized protons early in its program. The expected date of the first heavy ion collisions is 1999.

The spin physics program includes measurement of gluon and sea quark polarization in the longitudinally polarized proton, measurement and then application of parity violation in W and Z production, measurement of hard scattering parton-parton asymmetries, and quark polarization or transversity in transversely polarized protons. Single spin asymmetries allow sensitive searches for parity violation (longitudinal polarization), and correlations between quark spin and gluons (transverse). Probes include direct photons (to $p_T$ = 20 GeV/c), jets (to $p_T$ > 50 GeV/c), Drell-Yan pairs to $M_{\ell\ell}$ = 9 GeV, $W^{\pm}$, Z. This program is described in our Particle World paper.[1] Here we will emphasize the new information included in our Update, given to the Brookhaven PAC this September.

## New Physics

1. The transversity parameter measures the correlations between left and right handed quarks or antiquarks in a transversely polarized proton. By choosing a process where gluons do not contribute to lowest order to the unpolarized cross section, the sensitivity (or asymmetry) is maximized, since gluons do not contribute to a transverse asymmetry, but can contribute to the unpolarized cross section. Therefore, Drell-Yan pairs are an excellent probe. We have recently added the Z as a probe of transversity[2] with the advantage of its relatively large cross section. The asymmetry then measures

$$A_{TT}/\hat{a}_{TT} = \frac{\Sigma\ e_q^2\ h_1^q\ h_1^{\bar{q}}}{\Sigma\ e_q^2\ f^q\ f^q}$$

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where $h_1$ is the transversity, and f the unpolarized structure function. $\hat{a}_{TT}$ is the subprocess analyzing power and is expected to be of order one. If the transversity $h_1$ equals the longitudinal spin structure function $g_1$ (which would be the case for the nonrelativistic quark model), then

$$h_1^q(x) = \Delta q(x)$$

and

$$h_1^{\bar{q}}(x) = \Delta \bar{q}(X)$$

where $\Delta q(x)$ is the longitudinal quark asymmetry. Bourrely and Soffer then assume $\Delta \bar{u}(x) = \bar{u}(x) - \bar{d}(x)$ and obtain the hadronic asymmetry shown in Figure 1. STAR/Spin estimate that they will collect about 4000 Zs in 1000 hours at RHIC, giving an error in $A_{TT}$ of $\pm$ 0.03.

2. Doncheski *et al.*[3] have pointed out that parity-conserving W production gives additional information on antiquark polarization in the proton. The longitudinal asymmetries are sensitive to the following quark asymmetries:

$$\textit{Parity Conserving:}\quad A_{LL}(W^+) \sim \frac{\Delta u \, \Delta \bar{d}}{u \, \bar{d}} \qquad A_{LL}(W-) \sim \frac{\Delta d \, \Delta \bar{u}}{d \, \bar{u}} \;;$$

$$\textit{Parity Violating:}\quad A_L(W^+) \sim \frac{\Delta u \, \bar{d} - \Delta \bar{d} \, u}{u \, \bar{d} + \bar{d} \, u} \qquad A_L(W^-) \sim \frac{\Delta d \, \bar{u} - \Delta \bar{u} \, d}{d \, \bar{u} + \bar{u} \, d} \;.$$

At rapidity y=0, $u\bar{d} = \bar{d}u$ and $d\bar{u} = \bar{u}d$, so $A_L(W^+)_{y=0} = 1/2\left(\frac{\Delta d}{d} - \frac{\Delta \bar{u}}{\bar{u}}\right)$. Since we expect (from Deep Inelastic Scattering) $\Delta u >> \Delta \bar{d}$, $A_{LL}(W^+)$ is sensitive to $\Delta \bar{d}$. At RHIC, Ws are produced at large x, so we expect $d >> \bar{u}$. Therefore, $A_L(W^-)$ is sensitive to $\Delta \bar{u}$ (see Fig. 2). STAR/Spin should collect 70000 $W^+$, and 15000 $W^-$ in 1000 hours. PHENIX/Spin will collect 12000 $W^+$ and 4000 $W^-$.

3. RHIC will also be an excellent place to measure the asymmetry of the sea (is $\bar{d} > \bar{u}$?), with unpolarized protons.[4] A significant effect was seen in muon scattering data from NMC.[5] RHIC offers pp production of $W^{\pm}$ with high luminosity, and $W^{+}$ measures $\bar{d}$ and $W^{-}$ measure $\bar{u}$. The sea asymmetry in the NMC data would imply a 40% effect on the ratio $W^{+}/W^{-}$ at zero rapidity for one model of sea asymmetry where the asymmetry persists to larger x.

4. Important work has been done to connect measured asymmetry to parton polarizations. As much as half of the cross section for QCD processes is higher order (K factors). The issue is whether these corrections change the lowest order prediction for spin. Two groups have now studied both direct photons[6] and Drell-Yan.[7] For both processes, the studies have found that the relationship between hadron asymmetry and parton polarization, based on lowest order diagrams, is preserved when the next order diagrams are included. This is very important work.

5. PHENIX/Spin, joined by RIKEN, Japan, is developing a proposal to increase muon coverage. The baseline detector includes one forward muon arm. By adding a second arm around the other forward direction, they then have large acceptance around $y=0$ for dimuon mass above $J/\Psi$. This gives them sensitivity to antiquark polarization around $x \approx 0.1$. This is important because if x is too small, the parton polarization must be small due to the diverging number of partons at low x.

They also propose to use low energy for these studies because the counting rate for Drell-Yan pairs at fixed $(x_1,x_2)$ is proportional to $1/\sqrt{s}$. This comes about from the cross section scaling as $1/s$ and the luminosity as $\sqrt{s}$.

RIKEN proposes to build the second forward arm and additional $90^{o}$ muon coverage. This will allow PHENIX/Spin to determine the antiquark polarization in the longitudinally polarized proton and to measure $h_1(x)$ with transversely polarized protons.

6. Bourrely and Soffer[2] also point out that polarized proton-unpolarized deuteron collisions are very interesting, particularly if the struck neutron target can be tagged from the presence of the spectator proton in the beam. Their proposed program includes pn $W^{\pm}$ and Z production, compared to pp.

## Accelerator Conceptual Design and Review.

It is not easy to accelerate polarized protons to high energy. Many spin resonances must be crossed where the spin precession period matches whether the betatron tune or the periodicity of the accelerator lattice. In 1978 Derbenev and Kondratenko[8] proposed a series of magnets which rotate the spin $180^{o}$ and leave the orbit undisturbed. E. Courant dubbed the magnets Siberian Snakes. The snakes remove spin resonances from the acceleration process. There have been some beautiful tests of snakes done at Indiana.[9] RHIC requires 4 Siberian Snakes, and also polarimeters, and spin flippers. Experiments needing longitudinal polarization also need spin rotators (these are much the same as snakes). The RHIC management arranged a review of all this proposed hardware, which took place in June 1993. The members of the Review Committee were A. Chao (SSCL), S. Peggs (RHIC), R. Pollock (IUCF), L. Teng (ANL, Chair), and W. Weng (AGS). A Conceptual Design Report was the basis of the review, and the committee concluded that

> *"... the feasibility of producing, storing, and colliding 250 GeV polarized proton beams in RHIC is established with reasonable confidence."*
>
> *"The proposal has the flavor of the application of an ingenious technological invention (Siberian snakes) to make possible exciting physics research (polarization physics), reminiscent of the application of stochastic cooling to obtain $\bar{p}\,p$ beams for W and Z in the CERN SPS. We are indeed very enthusiastic about this total program."*

The Conceptual Design Report includes an inclusive $\pi^-$ polarimeter that uses the $A_N$ results from the ZGS and Fermilab. A 5% polarization measurement can be made in a few seconds using $\pi^-$ production at $x = .5$, $p_T = .8$ GeV/c from a carbon fiber target.

One important concern is to find the best design for the snakes and spin rotators. We are quite encouraged by the new design based on helical snakes, by Y. Shatunov.[10] RHIC has begun an R&D program to build a helical dipole at 4T field.

**Plans.**

The proposal is approved. It is necessary to find funding, and to develop a complete design report for the acceleration requirements. Our goals are to complete the Design Report for a review next June, to begin immediately R&D on snakes to be able to begin construction in 1995, with installation in time for the initial RHIC run in 1999.

The international contributions and interest in spin have already been crucial for our present progress. We have a large and exciting job ahead, and we welcome additional international (and national) collaboration.

## References


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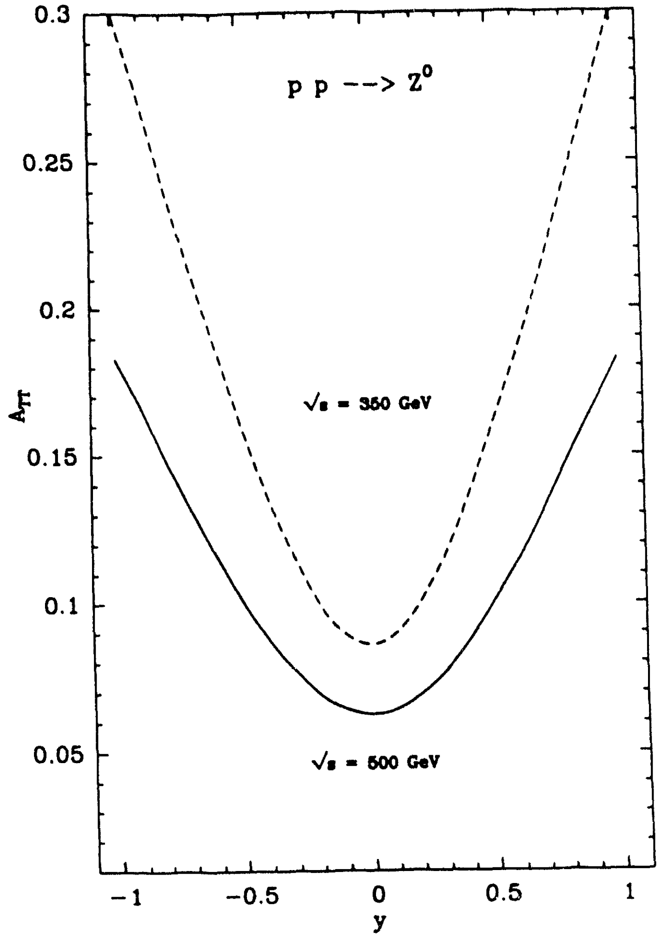


Fig. 1. Transverse asymmetry $A_{TT}$ for Z production at RHIC. A non-zero signal requires sea-quark polarization. The polarization assumed here is:

$$\Delta\bar{u}(x) = \bar{u}(x) - \bar{d}\ (x) \text{ and}$$
$$\Delta\bar{d}\ (x) = 0, \text{ from ref. 2.}$$

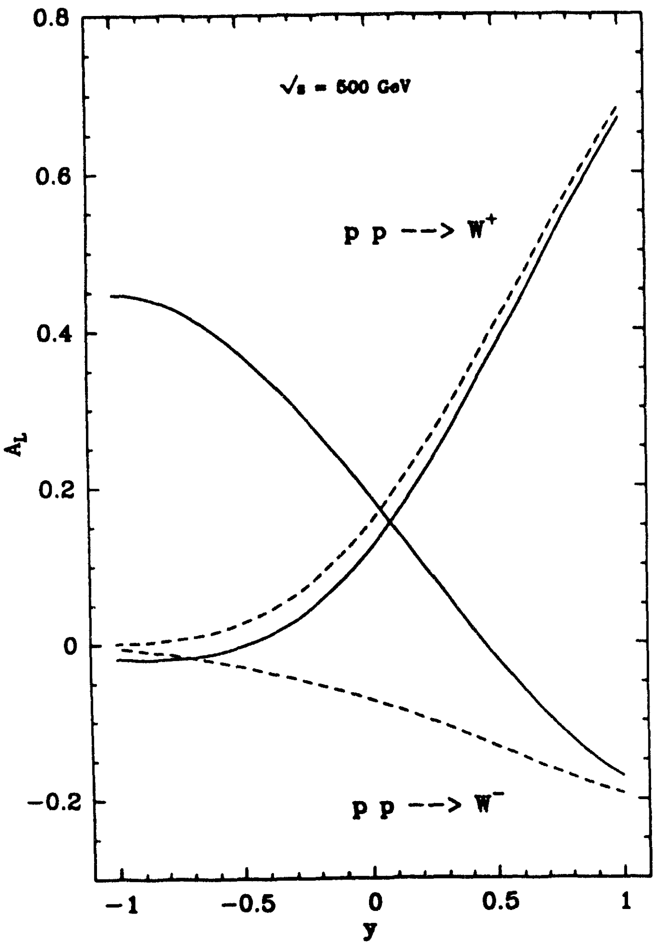


Fig. 2. Parity-violating asymmetry $A_L$ for W production at RHIC. The solid lines are for sea quark polarization as in Fig. 1, and the dashed lines are for zero sea polarization.[2]

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