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POSSIBILITIES OF POLARIZED PROTONS IN $Sp\bar{p}S$* AND OTHER HIGH ENERGY HADRON COLLIDERS

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The announced subject of this panel discussion is "Polarized Protons in the $Sp\bar{p}S$", but I would like to extend the terms of reference to include hadron colliders above 200 GeV in general. There are more than half a dozen machines in existence, being built, or being contemplated in this category, and polarized beams might be of interest in all of them:

NAME			Energy (GeV)	Injector Energies
$Sp\bar{p}S$	(CERN)	$p\bar{p}$	270-350	0.8, 14-30
Tevatron	(FNAL)	$p\bar{p}$	800-1000	10, 150
RHIC	(BNL)	p-ion	250-350	20-30
HERA	(DESY)	e-p	850	40
UNK	(Serpukhov)	p-$\bar{p}$	3000	70
LHC	(CERN)	p-p	5000-8000	0.8, 14-30, 350
SSC	(USA)	p-p	20000	70, 1000

To get collisions with polarized protons in these machines, one requires the following:

1. A source of polarized protons with respectable intensity.
2. Acceleration in the preinjector(s) without depolarization.
3. Traversal of polarization resonances in booster synchrotrons (up to 15-70 GeV).
4. Elimination of resonances in the large rings (above 100 GeV).

1. To obtain interesting luminosities, the injector ring should have around 10^{12} polarized protons. This implies and improvement in the performance capability of polarized sources of a factor around 100 compared to present-day achievements. I am told that this appears to be a very reasonable hope.

2. It is known that linear accelerators in the multi-100 MeV range do not depolarize appreciably.

3. Traversal of resonances has been demonstrated at Argonne, Saclay, and Brookhaven up to energies of 15-20 GeV. Extending these techniques should be straightforward up to 30 GeV or thereabouts.

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4. Above 30 GeV the "Siberian Snake" techniques should be feasible.

A 1983 study by Bovet, Moehl, and Ruth indicates that polarized proton operation should be feasible for the $Sp\bar{p}S$

To see what the problems may be for that and other colliders, let us briefly recall the facts of depolarizing resonances and "Siberian snakes" as outlined by R. Ruth at this Symposium.

Depolarizing resonances occur when the spin precession frequency equals a frequency contained in the spectrum of the field seen by the beam. These frequencies (in units of the revolution frequency) are:

k (any integer) due to orbit imperfections;

$kP \pm \nu$ (where f is the vertical betatron tune) for "intrinsic resonances"; here P is the periodicity of the lattice.

The spin precession frequency, in a ring where the ideal orbit lies in a plane, is normally

$$\gamma G = E/0.56 \text{ GeV}$$

where $G \equiv (g-2)/2 = 1.793$ is the anomalous moment factor of the proton. Therefore imperfection resonances arise every 560 MeV; intrinsic resonances in a machine with 4 superperiods such as the $Sp\bar{p}S$ arise twice every 4×0.56 GeV, or on the average every 1.12 GeV. Therefore there are hundreds of resonances in a machine of the energy range of the $Sp\bar{p}S$, and thousands in TeV machines.

The traditional cure, used at the ZGS, Saturne and the AGS, is: Fight them all! This is possible for energies of tens of GeV, where there are "only" around 10 to 100 resonances, some of them quite weak. But for higher energies this is quite hopeless, both because there are very many resonances and because the resonances tend to be stronger as the energy goes up (due to a factor E in the precession equations).

The cure is the famous "Siberian Snake". This is a device which makes the spin precession frequency essentially constant, independent of energy. This is accomplished by spin rotators, which precess the spin by 180° about either the longitudinal ("Type I snake") or the transverse horizontal (Type II snake) axis.

The rotators or "snakes" each consist of a set of 6 to 10 individual dipole or helix magnets which deflect the beam horizontally or vertically, and at the same time rotate the spin about the vertical or horizontal axis. The magnets of each snake are arranged so that they rotate the spin by 180° while at the same time giving no net deflection or displacement to the beam. Numerous detailed configurations for snakes of type I or type II have been devised. They all deflect the orbit along a twisted path (hence the name "snake"); with field of 2 to 4 Tesla the maximum excursion is around 5 to 15 cm (depending on the detailed configuration) for 20 GeV protons, and is inversely proportional to energy. A snake needs a total of 15 to 25 Tesla-meters of magnets; therefore the free space needed in the lattice to accommodate a snake is around 20 m if iron magnets are used, and 10 m in the case of superconducting magnets. The magnets need enough aperture to accommodate the snaking orbit at injection energy; if the injection energy is very high, small-aperture magnets will do (as in the case of the SSC).

With one snake of Type I or II present, the spin precession frequency is just 1/2, i.e. the spin precesses around the equilibrium spin direction by just 180° per revolution. Thus the spin precession frequency is just as far as possible from resonance with imperfections (integral value), and is also removed from resonance with betatron oscillations provided the betatron tune is not half integral. With given snake magnets the spin rotation is independent of energy while the orbit excursion is inversely proportional to energy.

The excursion is small enough to fit into a reasonable magnet aperture ($\lesssim$ 15 cm, say) for energies above 20 to 30 GeV. On the other hand, the "resonance fighting" mode works up to about this range. In the case of injector rings in the 40-100 GeV range it may be desirable, if possible, to switch from the "resonance fighting" mode to the Siberian snake mode in the same ring - this will have to be explored in future calculations.

At 180° from the snake the equilibrium spin direction is independent of energy, and is parallel to the snake's rotation axis. Elsewhere in the arcs the spin rotates rapidly in the horizontal plane, and its orientation at any point varies with energy.

If one snake is good, two must be better. If we have one snake of type I and one of type II, 180° apart, the precession frequency is still 1/2, but the equilibrium spin is now up in one 180° arc and down in the other, independent of energy. This is evidently a more stable state of affairs.

However, the behavior of the ideal machine will be affected by the presence of errors. At high energy there will be many complete precessions in each arc, counterbalanced by an equal number in the opposite direction in the other arc. If, instead of a single pair of snakes, we have more, the arcs will be shorter and the number of precessions per arc will be fewer. If, somewhat arbitrarily, we wish to have not more than about 200 to 500 precessions per arc, the arcs should have no more than 2000 to 5000 T-m of bending magnets, i.e. there should be a "snake" every kilometer or two along the ring circumference. Thus Sp$\bar{p}$S can probably manage with one pair of snakes; HERA or the Tevatron may be better off with 4 or 6 snakes, while the SSC (about 100 km circumference) may want 20 to 50 snakes.

Much of the physics interest in polarized beams pertains to helicity, i.e. longitudinal polarization. In the multi-snake lattices described here the polarization is always vertical (transverse) except in the middle of the snakes. Therefore further spin rotators may be desirable to turn the spin into the longitudinal direction at some of the beam crossing points. This can be accomplished by splitting some of the snakes into two 90° rotators, or else by incorporating dedicated 90° rotators in addition to the snakes.

In conclusion, it seems likely that operation with polarized protons, including both transverse and longitudinal polarization, should be possible at all the high energy hadron colliders now in existence or being contemplated.