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Polarized protons in HERA

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ABSTRACT

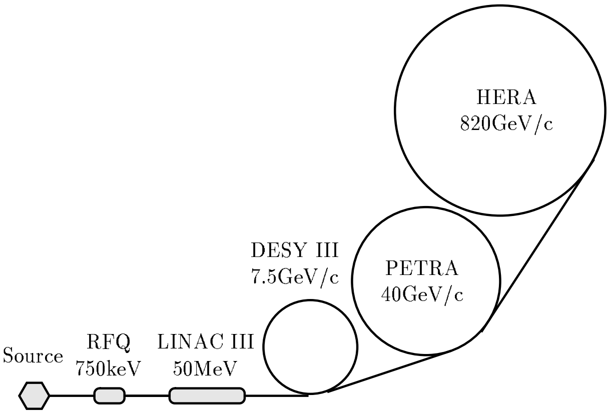
Polarized protons have never been accelerated to more than about 25GeV/c. The production of polarized proton beams in RHIC (250GeV/c), HERA (820GeV/c), and the TEVATRON (900GeV/c) are therefore challenging projects. A collaboration of many different laboratories has been evaluating the possibilities of accelerating and storing polarized proton beams in HERA. Problems involved with accelerating polarized protons from an H^- source to medium energies will be illustrated by the preaccelerators DESY III (7.5 GeV/c) and PETRA (40 GeV/c). Solutions to these problems will be suggested. After polarized beams are accelerated to high energy, the polarization has to be stable for several hours in order to be useful for the experiments H1 and ZEUS and for any future experiment. At HERA energies the spin of a particle rotates by 90° if the particles trajectory is curved by only 1 mrad. This illustrates that the equilibrium polarization direction can vary substantially across the beam in the interaction region of the high energy experiments when no countermeasure is taken. It will be shown how the polarization can be optimized by minimizing the opening angle of the equilibrium spin distribution with a suitable choice of Siberian snakes.

Introduction

While the synchrotron power radiated from electrons in a circular accelerator is accompanied with a self polarizing mechanism at high energy, the lack of sufficient synchrotron radiation in present proton accelerators makes it necessary to accelerate polarized protons from a polarized source to high energy with no appreciable loss of polarization. Much experience in creating and accelerating polarized proton beams up to about 25GeV/c has already been obtained at the AGS [1]. Drawing on that experience and the invention of Siberian snakes [2], RHIC has developed a polarized proton program for energies up to 250GeV/c [3]. The methods sought for RHIC have also been used to analyze the polarized proton capability of the TEVATRON [4]. This work gave essential input to initial studies for HERA [5,6]. The SPIN Collaboration which published the TEVATRON report has started to become involved also in the polarized proton project at DESY. This group of physicists and other collaborators are currently writing up a report to the DESY directorate listing the changes necessary to accelerate polarized protons to 820GeV/c [7]. Many of these changes are similar to the changes which where necessary in the AGS, in RHIC, and in the TEVATRON. Therefore, subjects which are specific to the HERA project will be emphasized here.

Polarization in the preaccelerator chain of HERA

At this time one can produce polarized protons in either a polarized atomic beam source (ABS) [8] or in an optically pumped ion source (OPIS) [9]. Up to 80% polarization for beam currents of up to 0.6mA and 1.6mA respectively has been achieved with these sources. In these experiments the OPIS was used in a DC mode and up to 20mA are expected in a pulsed operation with normalized 2σ emittances of 2π mm mrad. We are awaiting results in the near future. Since currently about 20mA pass the low energy beam transport (LEBT) system at DESY with a comparable emittance, such a polarized ion source, combined with an upgrade of the LEBT and the RFQ, could lead to a polarized beam Luminosity comparable to HERA's current unpolarized beam Luminosity. However, since 1.6mA polarized source currents have not been exceeded so far, [7] contains thoughts on stacking schemes for increasing the proton current. For polarization optimization, several polarimeters will have to be installed in the beamline. To measure the polarization at the source, a Lyman–α polarimeter can be used. The transfer of polarized particles through LINAC III has to be optimized with yet another polarimeter which could be of the type used for the ZGS LINAC. Each of the following accelerator rings will need their own polarimeter. The polarimeter for DESY III could be similar to the AGS internal polarimeter. Since polarization at DESY III momentum of up to 7.5GeV/c has been achieved at several labs, the technology of all the polarimeters mentioned so far is well understood. It is different with the polarimeters required for PETRA and HERA. Theoretical concepts for two kinds of appropriate high energy polarimeters have been developed, the Coulomb Nuclear Interference (CNI) polarimeter, and the inclusive pion polarimeter. Since the technology involved has not been tested, it seams advisable to plan an installation of both types of polarimeter in order to cross calibrate measurements. A p–p elastic experiment, proposed by the Spin Collaboration, could itself be used to measure the polarization in HERA.



The preaccelerator chain for HERA.

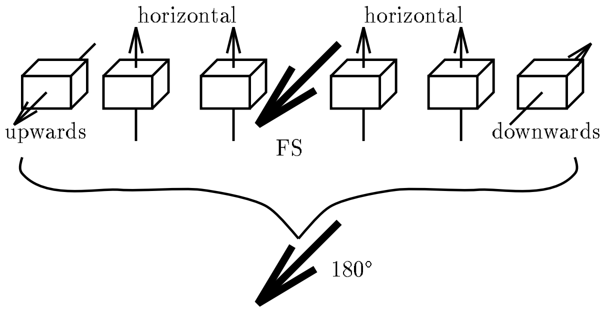
Theoretically it has been expected, and experimentally verified at several accelerators that polarization can be lost when the rate of spin precession in the guiding magnetic filed, expressed by the spin tune ν_s, crosses an integer value or multiples of the orbit tunes. Without precaution, the spin tune can cross such resonances when the energy is ramped since the spin tune is a function of energy. In a flat ring, ν_s is in deed proportional to the particle's momentum. At DESY III the only relevant integer resonance is at $\nu_s = 8$. There the depolarizing resonance strength is 0.013 for 3mm rms closed orbit deviations and it is planed to preserve polarization with a partial Siberian snake. At the 4 relevant orbit tunes the depolarizing resonance strength are bellow 0.0102 for a normalized 2σ emittance of 20π mm mrad. It is planed to cross these resonances either with tune jumping quadrupoles or by flipping the polarization while kicking the beam on an off closed orbit trajectory.

Full Siberian snakes are devices which hardly influence the particles trajectory outside the snake but rotate the spins by 180° around the snake axis. An appropriate choice of these snake axes of the snakes installed in a ring makes the spin tune independent of energy. Ones ν_s is adjusted to a certain non resonant value, it will stay at that value during the complete energy ramp. Unfortunately the orbit excursions in such a snake are rather extensive at low energies and full snakes can not be applied in DESY III. For PETRA an interesting idea has been considered for [7]. If there is a longitudinal snake in a flat ring, then 180° away from it, the periodic spin direction on the closed orbit, $\vec{n}_0$, is longitudinal and ν_s is 1/2. One can insert a partial snake at this point which has an adjustable rotation angel and a rotation axis which is perpendicular to the beam direction for all rotation angles. Such a partial snake can be constructed from a combination of horizontal and vertical bends. Then ν_s stays 1/2 for all snake strength. Therefore, one can ramp this snake with the beam energy, avoiding big excursions as well as avoiding resonance crossing. In this setting one would inject the beam longitudinally and extract it vertically.

Nevertheless even in this scheme one snake with rather big orbit excursions at 7.5GeV/c is required. Unfortunately, when only two snakes are used in PETRA, one of them has to be a full snake with big orbit excursions at low energy. The depolarizing resonance strength of below 0.063 (for 25π mm mrad and 2mm rms) indicate that two snakes are sufficient to stabilize polarization in PETRA.

Polarization in HERA

The HERA proton ring has some specific features which complicate the polarized proton project. The HERA lattice is not flat; downstream and upstream of the East, North, and South interaction regions, the proton beam is first bent vertically by 5.74 mrad then four times horizontally by 15.1 mrad and then −5.74 mrad vertically. In a flat unperturbed lattice, $\vec{n}_0$ is vertical for all energies and therefore the spin tune can be set to 1/2 by a Siberian snake with an energy independent rotation axis. In a non flat ring such as HERA, the direction of $\vec{n}_0$ varies strongly with energy and Siberian snakes can not be used without further modifications. A solution to that problem is suggested in [7]. One can insert a radial snake in between the four horizontal bends mentioned in the figure to the right. The total region from the first vertical bend to behind the inverse vertical bend then



Flattening snakes for the compensation of the vertical bends in HERA.

simply rotates the spins by 180° around the radial axis for all energies. What spin dynamics on the closed orbit is concerned, the HERA lattice is then flat; $\vec{n}_0$ is vertical in the arcs for all energies. For this reason we refer to the snakes in between the vertical bends as "flattening snakes" (FS).

Spin stability at high energy

The analysis of depolarizing resonance strength for HERA has shown [10,7] that resonances are very strong and that it will be hard to compensate them with four Siberian snakes. The imperfection resonances at integer values of the spin tune have strength of up to 3.75 and the intrinsic resonances have strength of up to 1.65 (for 25π mm mrad and 2mm rms). To shed more light on this situation which initially seams to be very unfortunate, the spin dynamics has been analyzed in more detail. Depolarizing resonance strength describe how much the spin motion varies over phase space. A more direct way of observing this variation is to look at the distribution of spin directions in phase space which is established at equilibrium. A significant divergence of the polarization direction would not only diminish the average polarization available to the particle physics experiment, but it would also make the polarization involved in each collision analyzed in a detector strongly dependent on the phase space position of the interacting particle. Thus, the average polarization of the beam can be seriously limited by the spread of the equilibrium polarization direction. Two papers in these proceedings [11] discuss the theory and the application of our method of "stroboscopic averaging" obtained with the program SPRINT. This analysis validated the result that the spin stability at HERA is very marginal with four Siberian snakes. However, the traditional depolarizing resonance analysis [12], which by now has been applied successfully in small rings for nearly two decades, does not lead to an evaluation of different snake schemes. Simulations have shown that some choices of snake axes are more effective than others in controlling the phase space dependent spin distribution. We have applied a filtering algorithm [6] to determine the most effective snake scheme. For this purpose we employed a computer program which systematically checked all snake arrangements with rotation axis either vertical or in the horizontal plane with $n \cdot 22.5°$ to the beam direction. Out of 10000 possible combination 3600 lead to a spin tune of 1/2, 150 lead to a vertical polarization direction in the arcs, and out of these we selected the one with minimal variation of the equilibrium spin direction in phase space. For the best snake arrangement found so far the average opening angle of the spin distribution for a normalized 1σ emittance of 4π mm mrad is 11° and would be acceptable. The opening angle of the equilibrium spin distribution alone, not mentioning misalignments, the energy ramp, and other effects, do not seem to be a game stopper for polarized protons in HERA.

Further problems to be studied

Much ground has been made already and several ideas solve specific problems of polarized proton acceleration at HERA, nevertheless there is a multitude of problems which still have to be studied. The most pressing questions, which will have to be

addressed are the following [13]:
1. Understand the effects of misalignments. Find cures.
2. Include linear and nonlinear synchrotron oscillations.
3. Determine the maximum allowed emittances.
4. Study the efficacy of the chosen snake scheme for controlling the spin 'equilibrium' during the adiabatic acceleration.
5. Evaluate the advantages of increasing the symmetry of the ring and the optic.
6. Determine the influence of the beam-beam effect.
7. Understand the influence of noise in power supplies.
8. Calculate with optical nonlinearities and optical coupling.
9. Evaluate the effect of intra-beam scattering, if any.
10. Investigate the relevance and feasibility of spin matching and in particular the 'strong spin matching' proposed by K. Steffen.

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