POLARIZED ANTIPROTONS WITH THE SPIN SPLITTER

H. Kreiser (Univ. Hamburg), Y. Onel (Iowa State Univ.), A. Penzo (CERN), and R. Rossmanith (CEBAF)
representing the Spin Splitter Collaboration[1]
CEBAF, 12000 Jefferson Avenue, Newport News, VA 23606

Abstract

In this paper we will be discussing a method for polarizing protons, antiprotons, and ions using the Stern-Gerlach effect. A test of this effect is described foreseen for the low energy antiproton storage ring LEAR at CERN. In this test particles with different spin directions are separated by a combination of a solenoid together with several skew quadrupoles: this device is called a spin splitter.

Introduction

Until now only electrons and positrons could be polarized during storage in storage rings. Electrons and positrons are polarized via the emission of photons according to the Sokolov-Ternov effect.[2] Polarized protons can only be stored when the beam is produced by a polarized source[3] and accelerated to the final energy. In general the beam has to cross many depolarizing resonances.[4] In order to keep polarization relatively high, precautions for reducing the strength of the depolarizing resonances have to be developed.[5]

In this paper a selfpolarization mechanism for proton and ion storage rings is described. This is especially required for stored polarized antiprotons, for which only very weak sources exist.[6] These sources utilize the fact that Lambdas decay into polarized antiprotons via the weak interaction. Several years ago at a workshop in Bodega Bay, California, methods for storing polarized antiproton beams were discussed.[7] At that meeting the idea of producing polarized antiprotons in a storage ring using the Stern-Gerlach effect was introduced.[8]

The Stern-Gerlach Effect In A Storage Ring

The cell of a storage ring is very similar to the magnet assembly used in the Stern-Gerlach-Rabi effect (Fig. 1). In this effect a gradient field is used to kick particles with different spin orientations into different directions. Afterwards an homogenous field rotates the spin by 180 degrees and an additional inhomogenous field adds an additional kick. In the storage ring the elements with the inhomogenous fields are quadrupoles and the spin rotating fields are bending magnets.

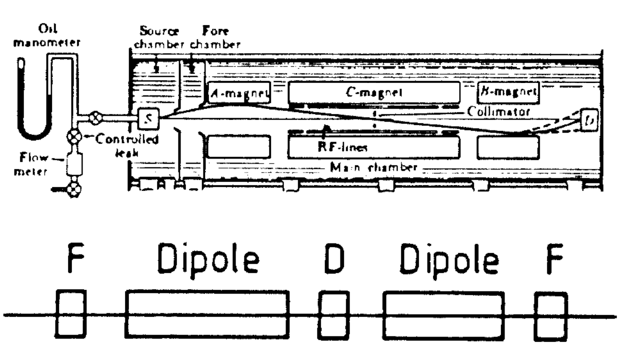

Figure 1 Comparison of a magnet assembly in a Stern-Gerlach-Rabi experiment (upper drawing) with a cell in the storage ring. The magnets A and B in the Stern-Gerlach-Rabi experiment have gradient fields, C is a dipole magnet. In the storage ring lattices F and D are quadrupoles.

Nevertheless, despite these similarities the two assemblies differ in the following two points:

- whereas the Stern-Gerlach-Rabi experiment is performed with two gradient magnets, the storage ring consists of many cells, and therefore of many quadrupoles, and
- whereas the Stern-Gerlach-Rabi experiment is performed with neutral particles, the particles in the storage ring are charged.

The first statement has the consequence that the kicks can only add when a resonance condition is fulfilled.

$$G\gamma = n \pm Q$$

where G is anomalous magnetic moment (1.793 for protons), γ is the Lorentz factor, n is any integer, and Q is the Q-value of the machine.

The above mentioned equation describes not only a condition for adding many kicks over many revolutions but also decribes a condition for a depolarizing resonance. In order to avoid depolarization on the depolarizing resonance the Stern-Gerlach kicks can only be added over a particular range of the machine. An example of this idea will be discussed later.

The second point is a more fundamental one. Since the particles in a storage ring are charged and the beam has a transverse extension each particle is deflected in a different way by the gradient (quadrupole) field. This individually different deflection adds to the Stern-Gerlach kick and smears the deflection out. Fortunately, the Stern-Gerlach kicks can add and the kicks according to the field cancel over many revolutions. A more general quantum mechanical treatment of this statement can be found in Reference 9. For this experiment J. Bell discussed this assumption in more detail.[10] Recently the validity of this argument was proved in a very elegant experiment[11] with free electrons.

The idea is to inject an unpolarized beam into a storage ring. After a certain time particles with different spin directions perform betatron oscillations. The phase of the betatron oscillation is mainly influenced by the spin via the Stern-Gerlach effect. One spin direction is dumped and the remaining beam is polarized.

The Spin Splitter

Two years ago investigations were started to apply this idea for producing polarized antiprotons in LEAR. LEAR is a low energy antiproton storage ring. The principle layout is shown in Fig. 2. In order to separate the two spin directions in one of the straight sections a device called a spin splitter can be installed.[12]

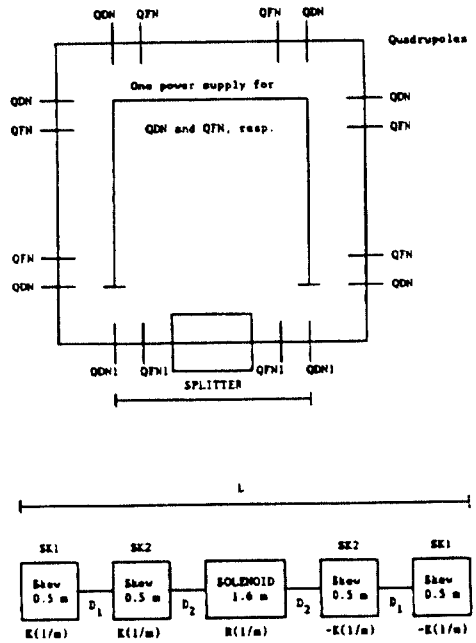

Figure 2 The position of the spin splitter in LEAR (top), and the arrangements of the magnets in the spin splitter (bottom)

The spin splitter consists of two skew quadrupoles on each side of a solenoid. The whole device is optically transparent. The particles are kicked in the skew quadrupoles in a direction which depends on the spin orientation of the particle. The spin is rotated in the solenoid by 180 degrees so that both the quadrupoles in front of and after the solenoid can contribute to the Stern-Gerlach effect.

The strength of the kick $\delta x'$ is

$$\delta x' = \frac{b\mu}{p\beta}$$

where b is the gradient in the quadrupole, μ is $1,41.10^{-23}$ erg/Gauss for protons, p is the momentum of the particle and β is v/c. The separation speed of the spins is, therefore, $\approx$ 2.5 mm/hour at a beam energy of 200 MeV/c with the spin splitter.

The optics of LEAR with the integrated spin splitter is shown in Fig. 3.

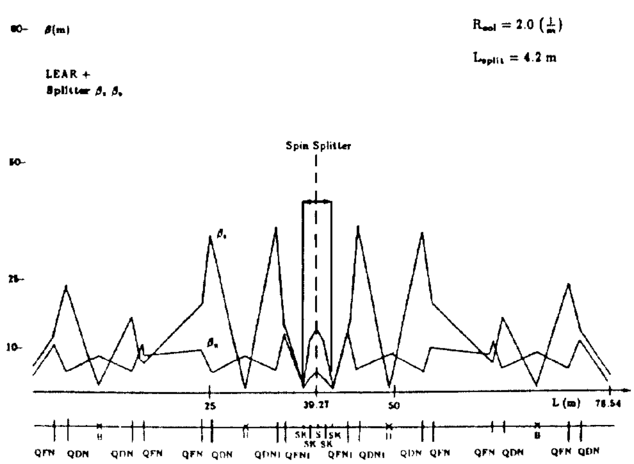

Figure 3 The LEAR optics with the integrated spin splitter

Spin Dynamics In A Machine With A Spin Splitter

The spin dynamics of the particles in a machine with a spin splitter is complicated. The spin splitter acts similarly to a Siberian snake.[13] The closed solution for the spin ($\vec{n}$-axis) lies in the horizontal plane. As shown above the kicks have to coincide with the betatron frequency. Since a storage ring does not operate at an integer Q-value particles with spins aiming in the direction of the $\vec{n}$-axis cannot be excited by the Stern-Gerlach effect. For this effect the spins have to oscillate around the n-axis.

In a ring with a snake the oscillations around the n-axis are no longer free (when only horizontal spin motions are considered): after two revolutions the spin comes back to its original position.[14]

As a result the resonance condition mentioned at the beginning has to be modified to

$$m \pm 1/2 = n \pm Q$$

independent of the spin tune $G\gamma$ in the machine. Nevertheless, the strength of the excitation is related to the magnitude $G\gamma$:

$$\delta x' \approx \frac{|1 - cos(G\gamma)|}{2}$$

According to this condition the Q-value of the machine must be one-half. Since a storage will not work with a spin tune of one-half, the following trick can be used. When the spin is somewhere vertically deflected in the storage ring, the snake only compensates this deflection after two revolutions when the perturbation is opposite the snake.[15] Thus, a small vertical spin deflection somewhere in the ring (e.g., a closed orbit bump) can rotate the spin slightly around the momentum axis and change the resonance condition:

$$m \pm 1/2 - \Delta = n \pm Q$$

During the last months the influence of the Q-spread on the degree of the polarization was studied. If particles have a Q-value deviating from the Q-value in the resonance condition, the degree of separation remains small. In order to investigate this effect the nonlinear spin tracking program SITROS,[16] originally developed for electrons, was modified for proton beams. The modified program was baptized PROTEUS. With PROTEUS a set of particles and their spins were tracked over many revolutions. PROTEUS takes into account second order optical effects and higher order spin effects. The second order magnetic field components produce the well known Q-spread. According to this program each particle has a different Q-value from revolution to revolution. The distribution of the Q-value is shown in Fig. 4. It can be clearly seen that the actual Q-value oscillates around the Q-value of the linear machine.

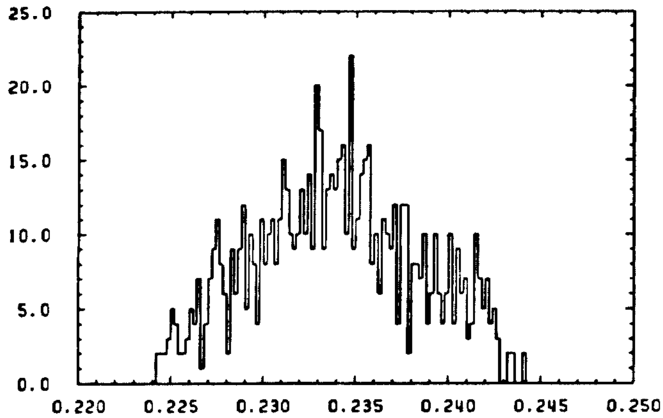

Figure 4 The distribution of the Q-value of a single particle. The particle is tracked over many revolutions. The horizontal axis shows the Q-value.

Oscillations of this type do not affect the build up of the polarization. The reason is the following: the Stern-Gerlach kicks are not distributed over the whole machine but are concentrated at one point. Therefore, the resonance has a certain bandwidth. If the Q-value variation is also within this bandwidth and the build-up time of the separation is long compared with these oscillations, the resonance condition is fulfilled. In that case the Q-spread does not influence the separation.

When taking higher order fields into account, e.g., octupoles, this statement will not be valid under certain circumstances. The remaining effects, however, are so small that it is possible to compensate them experimentally by varying the amplitude of a beam bump in an octupole.

In summary it may be said that the production of polarized protons or antiprotons by the Stern-Gerlach effect seems to be possible. With the spin splitter in LEAR the separation time of different spin directions is in the order of half an hour. The Q-spread does not seem to influence the separation time. One problem which still needs investigations is the diagnostics of the beam with separated spins.

Acknowledgement

The author wishes to thank the many people who made the investigations possible or contributed to this work: J. Bell from CERN, T. Walcher from Mainz, E. Steffens from Heidelberg, U. Strohbusch from Hamburg, T. Limberg from CERN, and C. Leeman from CEBAF. We also thank A. Skrinski and J. Shatunotov from Novosibirsk, A. Chao from Berkeley, A. Krisch from Michigan, E. Courant and L. Ratner from BNL for many discussions.

This work was supported by the U.S. Department of Energy under Contract DE-AC05-84ER40150.

References

[1] The Spin Splitter Group: D. Cline, M. Conte, M. Gazzaly, R. Giacomich, M. Giorgi, J. Hall, J. Kewisch, H. Kreiser, K. Kuroda, T. Niinikoski, Y. Onel, G. Pauletta, A. Penzo, A. Pisent, M. Pusterla, P. Riley, R. Rossmanith, N.M. Stewart and X. J. Wang.

[2] A. A. Sokolov and I. M. Ternov, Sov. Phys. Dokl., 8, 1203 (1964).

[3] Workshop on Polarized Sources and Targets, Helvetica Physica Acta, vol. 59, No. 4.

[4] E. D. Courant, S. Y. Lee and S. Tepikian (see Ref. 7).

[5] A. D. Krisch, Proc. VII Internat. Symp. on High Energy Spin Physics, Protvino 1986.

[6] A. Yokosawa (see Ref. 7).

[7] A. D. Krisch, A. Ling and O. Chamberlain (ed.), AIP conference Proc. No. 145 Particles and Fields Series 34.

[8] T. O. Niinikoski and R. Rossmanith (see Ref. 7).

[9] N. Ramsey, IEEE Trans. IM 36, 155 (1987).

[10] J. Bell, CERN TH-group, private communication.

[11] R. van Dyke, P.Schwinberg and H. Dehmelt, Phys. Rev. D, 34(1986)722.

[12] A. Penzo, Proc. Physics at LEAR with low energy antiprotons, Nucl. Sc. Res. Conf. Series, Vol. 14, Harwood Academic Publishers.

[13] Y. Derbenev and A. Kondratenko, Part. Acc. 8,115.

[14] Y. Onel et al. (see Ref. 5).

[15] A. D. Krisch, S. R. Mane and T. Roser, Michigan preprint UM HE 87-04.

[16] J. Kewisch, DESY report 83-032(1985).