FACILITIES FOR POLARIZATION IN EUROPE

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ABSTRACT

A short survey is given of European facilities for the acceleration and storage of polarized particles.

INTRODUCTION

In the last decade the acceleration of polarized protons, deuterons and electrons has become almost routine and many existing accelerator facilities for medium and high energy physics can provide polarized particles. Furthermore most proposals for future facilities mention the wish to run with polarized beams.

Techniques for the self polarization of particles in storage rings are not so far advanced.

Here, we will give a short summary of things that are happening in these fields in Europe. This survey is intentionally short: It would be impossible to do full justice to all the various projects in just a few pages. Instead, this should be viewed as a pointer to much fuller accounts given at this Symposium by the respective experts.

We begin with a 'laundry list' of accelerator projects and then discuss specific aspects of storage rings.

POLARIZED PROTON AND DEUTERON ACCELERATION

In Europe, the provision of medium and high energy polarized protons and deuterons is the business of the cyclotrons at the Paul Scherrer Institute (PSI) at Villigen in Switzerland[1] and the synchrotron at C.E.N. Saclay in France[2]. Both of these laboratories have brought the techniques to a high level.

At PSI there is a 72 MeV cyclotron which can feed a 590 MeV cyclotron. More than fifty percent of the running time is devoted to accelerating protons or deuterons. A proton polarization of up 85% can be achieved and by polarization transfer from protons to neutrons on a carbon target, narrow band neutron beams at 500 MeV and 40% polarization are available. Fluxes of 5.10^5neutron/sec/sq.cm. are obtained and it is planned to increase this by a factor of ten in the near future. The duty cycle is 100%.

The SATURNE II complex can accelerate protons with up to 80% polarization to 3 GeV and polarized deuterons to 2.3 GeV with 60% vector polarization. The intensities have reached 2.10^{11} particles per cycle. Helium 3 ions can also be accelerated. Neutrons with 60% polarization in a narrow band beam are obtained by deuteron stripping on beryllium.

In the proposed European Hadron Facility[3], which is being designed with the aim of providing intense (100 microamp) proton beams and a wide range of intense secondary beams of muons,pions, kaons,antiprotons and neutrinos, it is also intended that polarized protons be accelerated. The energy would range from 9 GeV to 30 GeV and the acceleration chain would be complex, consisting of a linac, a booster ring, an accumulator, a main ring and a stretcher. To maintain polarization in these circumstances will require considerable care. It is proposed to use Q-jumping (see below) to cross the intrinsic resonances in the booster and to install siberian snakes[4] in the main ring.

At the other extreme, namely that of no acceleration at all, plans are afoot to install a polarized gas jet target in the SPS at CERN[5].

POLARIZED ELECTRON ACCELERATION

Polarized electrons are accelerated to medium and high energies at the Gutenberg University, Mainz, Fed. Rep. Germany[6] and at the University of Bonn, Fed. Rep. Germany[7].

The facilities at Mainz consist of a 350MeV linac and racetrack microtrons. When the third and last microtron comes into operation in 1989, electrons of up to 840 MeV will be available. Polarized electrons are obtained from a GaAsP source and it is expected that 40% polarization will be achieved at the top energy. The duty factor is 100%.

NIKHEF-K in Amsterdam, the Netherlands[8] operates a 500 MeV linac. It is planned to have a 900 MeV stretcher ring operating in 1992 and then to add a polarized jet cell and polarized source.

The facilities in Bonn consist of a 2.5 GeV synchrotron and a recently commissioned accelerator-stretcher ring,ELSA. The latter can accelerate the 2.5 GeV electrons up to 3.5 GeV or can act as a stretcher, giving 100% duty factor, at 2 GeV.

This is the first stretcher of such an energy. It came into operation in the spring of 1988. Polarized electrons are provided using a GaAs source and after rotating the electron polarization into the longitudinal direction, it will be possible to produce circularly polarized photons via bremsstrahlung. Tagged,linearly polarized photons will be produced by coherent bremsstrahlung in crystals.

ASPECTS OF POLARIZED PARTICLE PRODUCTION AND ACCELERATION

These successes in obtaining polarized beams of protons, deuterons and electrons demonstrate that the technology of polarized sources is well under control and that steady improvements are being made.

Acceleration up to a few GeV without loss of polarization in a synchrotron is a non-trivial undertaking. As the energy is increased, the spin tune, ν passes through values which satisfy the resonance condition

$$\nu = k + m_x Q_x + m_z Q_z + m_s Q_s \ , \tag{1}$$

where k, m_x, m_z, m_s are integers, and the $Q_{x,z,s}$ are orbital tunes. Strong depolarization or spin flip can then occur[9,10,11]. However, by careful correction of the closed orbit and by techniques such as Q-jumping[9,10], polarization can be preserved.These methods need careful preparation but are now otherwise routine.

The polarization from GaAs electron sources may not even be limited to 50%[12]. Work is in hand to exceed this limit by using sophisticated techniques in solid state physics[12].

So the situation is healthy for existing machines. The attainment of polarization in storage rings is, however, not so straightforward. We discuss this next.

SELF POLARIZATION OF ANTIPROTONS

The behaviour of spins in both electron and proton accelerators can be understood sufficiently well with the aid of a deterministic picture of classical spin motion. The same would be true for the storage of protons and antiprotons which have already been polarized. Indeed the reports by Krisch[13] on recent experiments at 180 MeV with a siberian snake at the Indiana cyclotron seem to confirm this. Methods for reaching high energy are under intense discussion[14,15].

However there is also strong interest in obtaining polarized antiprotons. In Europe, thoughts are centred on LEAR[16] . Since it is to date impossible to construct high intensity polarized antiproton sources, one must rely on self polarization. Two methods are under active discussion, namely by the FILTEX (Filter Experiment) group[17] and the Spin Splitter group[18] .

The idea of the FILTEX technique is to install a polarized proton storage cell in LEAR and to take advantage of the fact that the cross-section for scattering antiprotons out of the ring depends on whether the proton and antiproton spins are parallel or antiparallel. If there were a small difference, one antiproton spin state would be preferentially depleted and a nett antiproton polarization could be obtained. The cross-section difference is not known with any precision so that it is difficult to make a reliable estimate of the rate of polarization build up. With a reasonable choice of parameters it seems that characteristic times of about ten hours would be possible, given the improvements in target density which come with the use of a storage cell[17] instead of a simple jet. Antiproton polarizations of 10% might be reached.

Now we come to a characteristic difference between acceleration of polarized particles, a largely deterministic process, and self polarization: In the latter the polarization build up takes a long time and the particles may be stored for a long period. Then one must take account of the long term effects of stochastic forces on the beam and of such things as tune fluctuations..

In FILTEX,the stochastic component is the scattering on the target which could blow up the beam. For this reason it would be necessary to leave the electron cooling system running. The experiments at Indiana which are at similar energies suggest that the cooling process would not depolarize the beam, at least in the short term. The question of resonant depolarization of the target by the fields of the bunches has been discussed at this Symposium[19] . The answers to such questions should emerge from measurements with the Test Storage Ring currently under construction at Heidelberg.

The principle of the Spin Splitter is to use the (very small) Stern-Gerlach force, that an antiproton experiences in a quadrupole field, to bring about a spacial separation of the two spin states. It is proposed to install a strong solenoid which rotates spins from up to down. The spin tune is then half integer and the spin direction would repeat on every second turn. In order to correct the twist that such a solenoid would put on the orbital motion, very strong 45 degree quadrupoles would be installed on each side on the solenoid. Vertical spins would receive vertical Stern-Gerlach kicks in these quadrupoles and because of the difference in polarities and the spin rotation in the solenoid, the kick would be in the same direction in both sets of quadrupoles.

Imagine now that the ring were to run with half-integer vertical orbit tune, Q_z. Then the vertical orbit motion would repeat every two turns also and the Stern-Gerlach kicks would always be in just the right direction to cause a resonant build up of amplitude[20]. Eventually, one would obtain a coherent vertical betatron standing wave locked to the lattice and the 'up' spin states would oscillate in antiphase with the 'down' states. If one were to observe the standing waves stroboscopically at some point on the ring just when they had reached maximum amplitude one would find that the antiprotons in the 'up' wave always had one spin state and that those in the 'down' wave had the other. Thus one would have achieved separation. Estimates suggest that the amplitudes would grow at the order of a few millimeters per hour. For this scenario to work as described the orbital tunes would have to be stable over 10^9 to 10^{10} turns.

In practice it is not possible to run a storage ring on half integer tune: The orbital motion would be unstable. Furthermore, the orbital tunes oscillate owing to instabilities in power supplies. These and other questions are being addressed with the help of a tracking program[21] .

The balance of stochastic and systematic effects appears for the Spin Splitter too and it is presumably important that the Stern-Gerlach force be large compared with other forces resulting from noise in the electromagnetic fields of the beam.

SELF POLARIZATION OF ELECTRONS

The example, par excellence, of the interaction of stochastic and systematic influences occurs in the case of electron self polarization[22,23].

That electrons in storage rings could become self polarized was first noticed by Loskutov, Korovina, Sokolov and Ternov[24] who pointed out that the emission of synchrotron radiation in a simple storage ring can cause electron spins to flip from up to down and vice versa and that there is a difference in the rates. Only a very small fraction of the synchrotron radiation power causes spin flip but nevertheless this asymmetry in the rates should lead to a build up of polarization along the vertical direction.

However, there is more to the story: The sudden changes in particle energy, brought about by the discrete, stochastic radiation of photons, amount to an excitation of the beam which would then expand to occupy more phase space. But there are also damping mechanisms operating and the distribution of the beam in the six dimensional canonical phase space actually reaches equilibrium. In a naive classical picture one would expect this stochastic motion to cause the spins to 'see' stochastic magnetic fields in the quadrupoles and that the spins would then diffuse or depolarize[23] . A complete quantum statistical treatment which takes account of the various effects in a unified way was originally given by Derbenev and Kondratenko[25] . The methods and concepts used are more subtle than those of the original treatments[24,26] and result in the following expression for the equilibrium polarization

$$P_{eq} = \frac{8}{5\sqrt{3}} \frac{\langle \frac{1}{|\rho|^3} \hat{b} \cdot \left[\hat{n} - \gamma \frac{\partial \hat{n}}{\partial \gamma} \right] \rangle}{\langle \frac{1}{|\rho|^3} \{ 1 - \frac{2}{9} (\hat{n} \cdot \hat{v})^2 + \frac{11}{18} \left| \gamma \frac{\partial \hat{n}}{\partial \gamma} \right|^2 \} \rangle} \tag{2}$$

where $\hat{n}$ is a classical unit spin vector defined at each point in the six dimensional beam phase space and $\gamma\ \partial\hat{n}/\partial\gamma$ is a partial derivative with respect to energy. $\gamma\ \partial\hat{n}/\partial\gamma$ encapsulates the quantum mechanics of the effect of the orbit motion on the spin. These and other terms are explained in Ref. (27). In a perfectly aligned flat machine, $\hat{n}$ is vertical and parallel to the guide field and $\gamma\ \partial\hat{n}/\partial\gamma$ is zero. The polarization is then 92.4%. In reality, storage rings are not perfectly aligned and

$\gamma\ \partial\hat{n}/\partial\gamma$ can be large, when the resonance condition of Eq. (1) for the spin tune ν is satisfied.

Another quantum mechanical derivation and an elucidation of the Derbenev-Kondratenko formula has been given by Mane[28] , who derives it from a point of view somewhat different from that of Derbenev and Kondratenko. Mane has also written a program, SMILE, for calculating $\hat{n}$, $\gamma\ \partial\hat{n}/\partial\gamma$ and hence the polarization. The calculations are analytical and the program runs on standard machine optical data files. It can be set to calculate the polarization to arbitrarily high order in the resonance structure and by definition automatically includes all resonance interference effects. This is a major advance. Previously, it was only possible to make rough estimates of restricted catagories of high order effects[29] or to calculate the lowest order resonances using the program SLIM[23] See the talk by Mane at this Symposium for further details and an example of a comparison of theory and data for the SPEAR machine[28].

The direction of the polarization at each point in the ring and the phase space is given by $\hat{n}$. Away from resonances, $\hat{n}$ is closely parallel to $\hat{n}_0$,which is the $\hat{n}$ direction on the closed orbit. From Eq. (2) one sees that to obtain high polarization, $\hat{n}_0$ must be fairly parallel to the guide field in most of the ring. $\gamma\ \partial\hat{n}/\partial\gamma$ must also be small at those places in the ring where $1/\rho^3$ is large. The latter can often be achieved in linear approximation by optimizing the optics. We call this procedure 'lowest order spin matching'[30] .

Two large projects involving electron storage are under construction in Europe, namely HERA and LEP[22,31]. HERA is an electron-proton colliding beam facility at DESY in Hamburg. The electron ring is complete and has been running since August 1988. The design energy for the electrons is 35 GeV. For the protons it is 820 GeV. LEP is the electron-positron storage ring under construction at CERN in Geneva.

The users of both machines wish to have longitudinal electron polarization at the interaction points. Since the polarization vector must be vertical in the arcs, it is then necessary to rotate the polarization from vertical to longitudinal just before the interaction points and back to vertical afterwards. This must be achieved with aid of spin rotators consisting of special strings of interleaved vertical and horizontal bending magnets. At HERA the 'Mini-Rotator' layout of Buon and Steffen[32] has been adopted and rotator magnets have already been delivered and are under test[33] . The advantage of this set-up is that the spin rotation can be accomplished in only 56 metres so that no quadrupoles need be included in the rotator. At LEP the Richter-Schwitters scheme is being studied[31,34]. This has no horizontal bends and is near to 200 metres long. It must therefore include quadrupoles[35,36].

Whereas at HERA, the polarization build up time at 35 GeV is 11 minutes, at LEP at 46 GeV per beam where Z_0 physics will be studied, the build up time is 90 minutes.At LEP it will be necessary to install dedicated asymmetric wigglers to enhance the polarization rate and this is under study[31,37].

Preliminary calculations with SMILE for HERA are presented in an accompanying article[27] .

We report, lastly, the suggestion[38] to install a polarized gas jet target at HERA to enable further study of hadron structure functions and help resolve the nature of hadron internal spin distributions[39].

ACKNOWLEDGEMENTS

The author would like to thank K. Althoff, J. Arvieux, F. Bradamante, J. Buon, H. deVries, L.Dick, J. Giroux, J-P. Koutchouk, H.Kreiser, A.Krisch, H. Mais, S. R. Mane, E. Reichert, G. Ripken, R. Rossmanith, P. Schmelzbach, C. Sinclair, K. Steffen, E. Steffens, and K. Terwilliger, for helpful discussions or for providing information about their projects.

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