POLARISED $e^+e^-$ IN LEP WITH THE SIBERIAN SNAKE

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1. Introduction

In Ref. 1 it was shown that polarised electrons were excluded in a 100 GeV LEP because of integer depolarising resonances excited by harmonics of vertical closed-orbit distortions. In the note LEP-70/10 2) the conclusion was confirmed for a 70 GeV LEP of normal geometry, with the reservation that an unconventional scheme recently proposed by Derbenev, Kondratenko et al. 3) might make it possible to circumvent the depolarisation effects at high energies. During the "Workshop on Polarised Protons" at Ann Arbor in October 1977 4) the D-K proposal aroused much interest and was believed to be sound in principle; it was nicknamed the "Siberian Snake".

The physics possibilities of LEP would be substantially enhanced if polarised electrons and positrons could be stored. It is therefore important to know at an early stage whether the D-K scheme stands a reasonable chance of being effective in LEP and, if so, what precautions must be taken in the basic LEP design to enable such a scheme to be implemented, either during the initial construction or as a later modification. The present note is a first attempt to answer these questions using the criteria of Ref. 3; more detailed studies will be necessary, however, to arrive at firm conclusions.

2. "Conventional" storage rings

In a storage ring (or accelerator) with a planar orbit the spin vector of a particle precesses around a constant eigenvector \( \hat{n} \), which is in the direction of the magnetic guide field \( \hat{B} \) (Fig. 1), with a precession wave number \( \nu \), relative to the velocity, given by

\[
\nu = \gamma a
\]

where \( a = (g - 2)/2 \) is the anomalous part of the gyromagnetic ratio \( g \).
and $\gamma$ is the Lorentz factor. Motion away from the ideal orbit subjects particles to perturbing fields which couple the spin motion to betatron and synchrotron oscillations, and to distortions of the closed orbit, giving rise to depolarising resonances of the general form

$$\nu = k_0 + k_x \Omega_x + k_z \Omega_z + k_s \Omega_s$$ (1)

where $\Omega_x$, $\Omega_z$, $\Omega_s$ are the betatron and synchrotron wave numbers, and the $k_i$ are positive or negative integers.

In high-energy electron machines the integer resonances $\gamma \alpha = k_0$ are the most important. They occur at intervals of $\sim 440$ MeV throughout the energy spectrum and are driven mainly by the corresponding harmonics of vertical closed-orbit distortions. Since 440 MeV corresponds to about $5\sigma_E$ of the LEP-70 energy spread, a substantial fraction of the beam inevitably straddles some integer spin resonances. It does not appear feasible in normal machines of design energy above $\sim 30$ GeV to reduce closed-orbit harmonics sufficiently to prevent depolarisation of the beam in a time short compared with the natural polarisation time.

It must be emphasised that a 70 GeV machine operating at below 30 GeV would not develop polarised beams, since the polarisation time, which scales as $\gamma^{-5}$, would greatly exceed the beam lifetime. Injecting a beam already polarised would not help much, because acceleration through the first few resonances would quickly depolarise it.

One sees that the essence of the problem is the energy-dependence of precession frequency $\nu$ combined with the large absolute energy spread in electron storage rings of high energy.

3. Principle of the "Siberian Snake"

The radical proposal of Derbenev and Kondratenko is to introduce into a section of the storage ring a special magnet arrangement which has the effect of making the precession frequency essentially independent of energy. To demonstrate how this is achieved we consider the racetrack ring of Fig. 2. The straight section BC contains a magnet configuration which rotates spin vectors around the $y$ (velocity) axis by an angle $\pi$;
for the purpose of illustration we can suppose this to be a solenoid
magnet. The other straight section A is field-free.

We follow separately the evolution of the three orthogonal components
of an arbitrary spin vector for a particle moving on an ideal closed
orbit. In Fig. 2(a) the z-component starts at A in position 1 and re-
 mains along the z-axis parallel to the bending field up to B. Between
B and C the field of the solenoid rotates the vector by \( \pi \) around y such
that it goes through the second bending arc anti-parallel to the z-axis.
Back at A in position 2 it has simply been rotated by \( \pi \) around the
y-axis relative to its starting position 1. In Fig. 2(b) the x-component
precesses in the x,y plane through an angle 2k \( \pi + \theta \) around the z-axis
between A and B. Between B and C, rotation by \( \pi \) around the y-axis is
equivalent to a rotation by \( \pi - 2\theta \) around the z-axis. Finally, between
C and A a further precession by 2k \( \pi + \theta \) about the z-axis brings the
total rotation to \((4k+1)\pi\) between positions 1 and 2. The y-component
of the spin vector, Fig. 2(c), rotates 2k \( \pi + \theta \) between A and B; the
rotation of \( \pi \) around the y-axis from B to C corresponds to a z-rotation
of \(-2\theta\) and a further 2k \( \pi + \theta \) along CA brings the total to 4k \( \pi \), making
positions 1 and 2 identical.

From the above we see that the y-component at A corresponds to a
periodic solution; this is an eigenvector \( \mathbf{\hat{n}} \) of the matrix around one
revolution at A. Any spin solution in this system is a linear combina-
tion of the three components discussed above, and any component trans-
verse to \( \mathbf{\hat{n}} \) rotates around \( \mathbf{\hat{n}} \) by \( \pi \) in each revolution of the machine,
independently of the basic precession angle 2k \( \pi + \theta \) in each main arc.
Although 2k \( \pi + \theta \) is a function of energy, the effective precession wave
number \( \nu \) is exactly one-half and is independent of energy. This is in
strong contrast to a conventional ring arrangement, where the eigenvector
\( \mathbf{\hat{n}} \) is everywhere parallel to the z-axis and where \( \nu = \gamma a \) is
energy dependent.

Since spin motion couples only to dipole-like fields there are no
half-integer resonances and \( \nu = \frac{1}{2} \) is as far from adjacent integers as
it can be. Thus, with some reservations to be discussed later, a
polarised beam can be accelerated over a wide energy range without
crossing any integer spin resonances. Furthermore, the energy spread of the beam no longer gives rise to a corresponding spread in $\nu$ and the major source of depolarisation in normal high-energy electron machines is absent with this configuration.

The Siberian Snake scheme suffers from one basic drawback; the normal radiative polarisation mechanism of Sokolov and Ternov is absent since the periodic solution $n$ is perpendicular to the direction $z$ of the magnetic field in the main arcs, where most of the synchrotron radiation occurs. The radiative effect on the other components averages to zero over one revolution, as one can readily deduce from Fig. 2. In the absence of self-polarisation, the beams must be injected already polarised, requiring the use of a storage-ring injector to hold the beams long enough for radiative polarisation to develop. On the other hand, this allows either direction of polarisation to be chosen at will since, in Fig. 2(c), both helicity states at A (i.e. $\pm n$) are equally stable.

It has been shown by Derbenev and Kondratenko $^5$ that, in the absence of the normal Sokolov-Ternov mechanism, another radiative polarisation effect may exist, depending on the properties of the focusing system. At present it is not clear whether this process could be made to work in LEP; however, it would certainly put additional constraints on the choice of betatron parameters. Furthermore, the polarisation time from this mechanism would, even at best, be a substantial fraction of the beam lifetime, leading to a reduction of the average polarisation available. Thus this scheme does not appear at present to be appropriate to LEP.

4. Transverse-field magnets

In section 3 we supposed the spin rotation around the direction of motion to be produced by a solenoid magnet. At high energies this becomes impracticable because the precession rate in a longitudinal field is smaller by a factor $\gamma(g - 2)/g = 1.16 \times 10^{-3} \gamma$ than in a transverse field. Thus, at 70 GeV, a solenoid of 733 Tm would be required to rotate an electron spin through $\pi$. A rotation of $\pi$ in a transverse field requires 4.61 Tm, independent of energy.
The spin rotation around the direction of motion, as produced by a solenoid, can be simulated by a succession of transverse-field magnets. These necessarily produce bending of the orbit in both horizontal and vertical planes and consequently modify the local geometry of the machine. Also, since transverse fields of a given magnitude produce precession angles which are independent of energy it follows that one cannot have both fixed geometry and fixed precession conditions over a range of energies. This is not such a serious constraint as it might appear, and the implications are discussed in later sections.

Two transverse-field configurations have been proposed by Derbenev and Kondratenko 3) and are shown schematically in Fig. 3, together with their geometrical projections in the vertical and horizontal planes. Both schemes restore the orbit direction to its original one but neither restores the horizontal orbit displacement. Consequently two additional bends, whose precession effects cancel, are required to compensate the horizontal displacement in both cases. The arrows show the directions of the fields in the successive magnets and the arguments in brackets are the corresponding precession angles.

The arrangement of Fig. 3(a) is equivalent to a rotation of $\pi$ around the velocity direction and thus simulates the situation of Fig. 2 in the region BC. However, that of Fig. 3(b) corresponds to a rotation of $\pi$ around the transverse horizontal x-axis and is not the same as we have so far discussed. In fact it is readily seen from Fig. 2(b) that the corresponding periodic solution (principal eigenvector) lies along the x-axis at $\lambda$. Since this results in a zero helicity state at $\lambda$, such an arrangement appears to be of little or no practical interest for LEP.

Other suitable configurations of transverse-field magnets can be invented. Two that I have recently found are shown in Fig. 4(a) and (b); they are both equivalent, at nominal energy, to a rotation of $\pi$ around the y-axis and hence do the same job as the D and K version of Fig. 3(a), but with only two-thirds of the bending power, i.e. a total of 9.22 Tm both for (a) and for (b) of Fig. 4. Since version 4(a) may be more convenient geometrically, and has been examined in some detail, it is adopted here as a model for discussion of the implications on the LEP design, although 4(b) may later turn out to have some advantages.
5. Variation of characteristics with energy

So far we have discussed the properties of systems at their nominal precession angles which, for a given orbit geometry, correspond to some reference energy \( E_0 \). With fixed geometry the magnetic fields have to be varied with energy and the nominal spin properties of the system change. We continue for the moment to concentrate on the behaviour of the eigenvector in the "privileged" interaction region (A in Fig. 2) diametrically opposite the "snake" insertion.

5.1 Effective precession frequency \( v(\gamma) \)

It should be clear from section 3 that in the schemes under discussion one must distinguish between the precession wave number (or frequency) of the eigenvector in the main bending arcs and the effective wave number of an arbitrary solution precessing around this eigenvector. The former corresponds to the true precession frequency of an arbitrary solution in a classical storage ring; the precession phase per revolution is given by

\[
\chi = 2\pi \gamma \left( \frac{g - 2}{2} \right) = 2\pi \gamma a
\]  

The introduction of a Siberian Snake is a topological trick which makes the effective precession wave number \( v \) exactly half-integer and essentially independent of energy at nominal conditions. However, imposing the constraint of fixed geometry results in the nominal precession conditions no longer being satisfied away from the reference energy \( E_0 \). The rotation angle \( \phi \) around the \( y \)-axis in the snake, at energy \( E \), is then given by

\[
\phi = \frac{\pi E}{E_0}
\]

To calculate the behaviour under general conditions it is convenient to use 2-component spinor algebra. From the trace of the matrix around one revolution it can be shown that the effective precession frequency \( 2\pi v \) for the configuration of Fig. 4 (a) is given by

\[
\cos(\pi v) = \cos \frac{\phi}{2} \left\{ \cos \frac{\chi}{2} - \sin \frac{\phi}{2} \sin \frac{\chi}{2} \right\}
\]

where \( \chi, \phi \) are as defined in (2), (3). Since at 70 GeV \( \gamma a = 159 \), one
sees that $\chi \gg \phi$. In fact, $\cos(\pi \nu)$ oscillates as a function of energy with a period of $\sim 890$ MeV; the amplitude of this oscillation is a measure of how close the precession frequency approaches the integer resonances corresponding to $\cos(\pi \nu) = \pm 1$.

The magnitude of the extrema of Eq. (4) is plotted as a function of $E/E_0$ in Fig. 5. One sees that at energy excursions of $\pm 55\%$ from the nominal, $\cos(\pi \nu)$ is less than one-tenth integer away from the resonances. This clearly limits the energy range over which the scheme is usable with fixed geometry. How closely one might approach the integer resonances will be discussed later.

5.2 Projection of the polarisation vector

Another important property is the variation with energy of the projected polarisation in the privileged interaction region. Solving for the eigenvectors gives the projection along the beam direction

$$|P_y| = \sqrt{\frac{\sin^2 \frac{\phi}{2}}{1 - \cos^2 \frac{\phi}{2}\left(\cos \frac{\chi}{2} - \sin \frac{\phi}{2} \sin \frac{\chi}{2}\right)^2}}$$ (5)

which also oscillates with $\chi/2$. It can be shown that here $P_x$ is always zero, consequently the polarisation eigenvector $\hat{\Pi}$ lies in the vertical plane through the orbit and oscillates between limits given by

$$\begin{align*}
(P_x)_{\text{extr}} &= \pm \cos \frac{\phi}{2} \sqrt{1 + \sin^2 \frac{\phi}{2}} \\
|P_y|_{\text{min}} &=\sin^2 \frac{\phi}{2}
\end{align*}$$ (6)

Twice every oscillation, i.e. at intervals of 440 MeV, $P_z$ goes through zero and $|P_y|_{\text{max}} = 1$. The $|P_y|_{\text{min}}$ is shown as a function of $E/E_0$ in Fig. 5.

One should note that, quite generally, both $+\hat{\Pi}$ and $-\hat{\Pi}$ are equivalent solutions and can be obtained by the appropriate choice of signs. This follows simply from the fact that the eigenvalues form a
complex-conjugate pair. It should also be recalled that, in discussing projections of vectors, we are referring to normalised vectors of unit magnitude and that the useful polarisation will be reduced by the degree of polarisation of the beam which cannot exceed 92.4%.

5.3 Spin resonances

Even using the Siberian Snake, depolarising resonances of the form given in Eq. (1) are present in principle. However, since $v$ is now given by Eq. (4), rather than by $v = \gamma a$ in a conventional machine, one can satisfy the condition

$$0 < v < 1$$

over a wide energy range. This drastically reduces the number of integer ($k_H$) combinations in Eq. (1) which can give rise to resonance conditions. Since high-order spin resonances are normally very weak we need only consider the lowest order.

Taking first the spin resonances arising from betatron motion we can write the tune in either plane as

$$Q = Q_0 \pm \Delta Q$$

where $Q_0$ is an integer and $\Delta Q$ is the fractional part. Betatron spin resonances then occur for

$$v = \Delta Q \quad \text{or} \quad 1 - v = \Delta Q.$$  

If, for example, $\Delta Q = 0.2$ the resonance condition corresponds to $|\cos(\pi \nu)| = 0.809$. From Fig. 5 one sees that this situation might restrict the energy range available to $\nu \pm 44\%$ around $E_0$. There is thus a strong incentive to operate with small values of $\Delta Q$ at the extremes of the energy range.

Synchrotron oscillations also give rise to spin resonances which occur for

$$v = Q_s \quad \text{or} \quad 1 - v = Q_s.$$  

Again it is desirable that $Q_s$ be small in order not to restrict unduly the available energy range.
In principle the integer resonances are broadened by closed-orbit deviations in the main arcs. This effect is small, however, and can be neglected for the present discussion.

It appears from the above considerations that, in order to avoid all significant depolarising resonances, the energy range might be limited to around $\pm 50\%$ about the reference energy $E_0$. Thus polarised beams in LEP up to at least 70 GeV with fixed geometry might require a choice of energy for the storage-ring injector in the range of 20 to 25 GeV. However, some degree of variable geometry would extend the operating range and will be discussed briefly further on. Also, it is not excluded that a snake configuration might be found with more favourable characteristics in this context.

6. Other interaction regions

So far we have considered the behaviour of the polarisation vector $\vec{P}$ only in the "privileged" interaction region diametrically opposite the snake. In a machine with $S$ interaction regions, equally spaced in normal-arc bending angle, the longitudinal component of polarisation is given by

$$\pm P_y = \frac{\sin^2 \frac{\phi}{2} \cos \left( \frac{(2n - 1) \chi}{2} \right)}{\sqrt{1 - \cos^2 \frac{\phi}{2} \left( \cos \frac{\chi}{2} - \sin \frac{\phi}{2} \sin \frac{\chi}{2} \right)^2}}$$  \hspace{1cm} (7)

where $n$ is the ordinal number of the interaction region counting from the snake. For $n = S/2$ this reduces to Eq. (5).

The behaviour of (7) with $\chi(\gamma)$ for $n \neq S/2$ is more complicated. Close to the nominal energy $E_0$, where $\sin^2 \frac{\phi}{2} = 1$, the polarisation vector $\vec{P}$ rotates in the median plane of the main arcs. At any interaction region $n$ there is a line spectrum of energies for which $P_y = 1$ (or $-1$), given by $\left( \frac{2n}{S} - 1 \right) \gamma a = \text{integer}$. The energy spacing of these lines decreases the further $n$ is from $S/2$.

Away from nominal energy $|P_y| < 1$ in general, since the $P_z$ and $P_x$ components can never vanish at the same energy for $S = 8$ as in LEP. The value of $P_y$ may be calculated as a function of energy from Eq. (7), using the energy dependence of $\chi$ and $\phi$ given in Eqs. (2) and (3). To
obtain an overall assessment of the "utility factor" of these insertions for polarised-beam experiments is beyond the scope of this note and will require more detailed study in the light of the physics requirements.

7. **Layout and geometry of a LEP snake**

To obtain a preliminary idea of a possible layout in LEP we take the nominal energy $E_0$, for ideal polarisation kinematics, to be 50 GeV. At this energy the precession requirements in the snake correspond to a total bending field of 9.2 Tm; of this one half is horizontal bending which, in principle at least, be subtracted from the bending in the adjacent arcs. In addition, two compensating vertical bends are required outside the snake to restore the orbit to the median plane of the machine. There is no a priori constraint on these bends so we take them to be similar to the vertical bends in the snake, requiring 4.6 Tm at 50 GeV.

For fixed geometry, these bending strengths increase by a factor of 1.4 at 70 GeV making a total of 19.3 Tm, including orbit restoration.

The introduction of a snake makes a substantial change in the local geometry of the machine and the effect of the resulting unit super-periodicity on closed-orbit errors in the machine will have to be investigated. The geometry is also likely to have some influence on the tunnel cross-section and civil engineering in this region.

In principle the snake could be located anywhere in one of the long straight sections of LEP; one might therefore be tempted to fit it into the extremity of a straight section, close to a dispersion suppressor, in order to retain the availability of the adjacent interaction region for physics. Such a solution would, however, present very serious problems. To accommodate a total of nearly 20 Tm of bending in the limited space available near the RF cavities would require strong bending fields; the resulting hard synchrotron radiation would give rise to severe background difficulties in the nearby detectors in addition to the technological problems of shielding the cavities themselves. Such an arrangement would also seriously prejudice the possibility of variable geometry.
It is therefore proposed to dedicate one interaction region entirely to the snake. The reduced constraints on space and layout then facilitate the optimisation of the geometry and the shielding of machine components from synchrotron radiation. Stronger bending fields than those of the lattice can be used to reduce the length of the snake giving more freedom for matching of betatron and dispersion functions.

A region dedicated to the snake would clearly not require a large experimental hall and the associated facilities. Instead one would have a somewhat enlarged tunnel and a reduced pit and lift installation sufficient only for klystrons and other machine components. Such an arrangement, christened the Snakepit by B. Zotter, would result in some useful savings in civil engineering work which would help to pay for the extra machine costs arising from polarised beams.

If it were decided to provide for a Siberian Snake in the LEP design but not to install it initially, the Snakepit could still be used with normal orbit geometry for a limited range of physics experiments not requiring large detectors. The changeover to snake geometry could be an operation on the scale of installing a small to medium-sized experiment.

A dilemma arises in the choice of the insertion type to be replaced by the Snakepit. To avoid sacrificing one of the four high-luminosity interaction regions the snake should be installed in a ± 10 m type insertion. This would result in the polarisation-privileged insertion being of the same type and therefore having the lower luminosity. The resolution of this dilemma will depend mainly on physics arguments since the extra 10 m space available for the snake, although useful, is not likely to be of crucial importance.

No low-β optics would be required in this region and the betatron parameters would preferably be as near as possible to those of the adjacent lattice. Dispersion suppression is still necessary in the RF cavities, and both vertical and horizontal dispersions introduced by the bending in the snake will require matching out. Removal of a low-β section introduces a unit superperiodicity into the betatron motion and the consequences of this will require investigation. The unit superperiodicity will also appear in chromatic effects and a re-arrangement
of sextupole families will most likely be required. Separation of $e^+$ and $e^-$ beams at the collision point will be necessary at all energies and the different beam optics in this region may impose a different design of the electrostatic plates from that of the other intersections.

7.1 Fixed geometry

A primitive example of a fixed-geometry snake is shown schematically in Fig. 6. Here we have taken $E_0 = 50$ GeV at which energy at bending strength of 2.3 Tm, corresponding to $\pi/2$ precession angle, gives a bending angle of 13.8 mrad. At 70 GeV the required bending strength is 3.22 Tm for the same angle. In this example the horizontal bending in the snake (27.6 mrad) is not subtracted from the lattice but is taken up by a pair of horizontal compensator magnets. Assuming the effective length of a 13.8 mrad module to be 13 m, the field is 0.248 T at 70 GeV, about 2.5 times the field in the normal lattice magnets of LEP. At this field level the critical energy of the synchrotron radiation is 0.81 MeV.

The overall geometry, including the restoration of the vertical orbit position, is necessarily asymmetric. Here the whole insertion of ~140 m total length has been centred on the nominal crossing point and the horizontal bending centre is therefore displaced from this crossing point. Assuming the vertical bends for orbit restoration to be similar to those in the snake itself we have a total of 104 m bending field of 0.248 T, giving a synchrotron-radiation energy loss of 39.4 MeV per turn at 70 GeV and a radiation power of 0.83 MW for two beams each of 10.5 mA. This already constitutes a non-trivial problem of synchrotron radiation, both in terms of RF power requirements and in the linear power density which must be carried away by cooling.

About 25% of the bending could be saved by eliminating the compensator magnets and subtracting the horizontal bending of the snake from the adjacent arcs of the lattice. This results in a horizontal orbit displacement with respect to the unperturbed position of about 3.6 m and would require the tunnel either to be widened or to follow a slightly different geometry, depending on whether or not one wishes to keep open the possibility of normal LEP geometry. Removing the compensators would also enable the bending fields to be weakened somewhat within the same total
length, bringing a further reduction in synchrotron radiation loss. Also the vertical compensators could be weakened and lengthened, even in the example of Fig. 6.

With fixed geometry there is considerable freedom in dividing up the units of bending to accommodate focusing quadrupoles. This is just as well, since it will be necessary to find focusing configurations which permit matching both the horizontal and vertical dispersion arising from the bending elements of the snake.

7.2 Variable geometry

The possibility of varying the geometry of the snake as a function of energy has been mentioned earlier as a means of extending the energy range over which polarised beams could be accelerated and maintained in LEP. The e-p insertion in CHEEP 6) includes variable geometry for similar reasons. The design of a variable-geometry snake for LEP is, however, substantially more difficult, partly because of synchrotron-radiation problems in the high energy range and partly because spin kinematics must be satisfactorily controlled all the way up from injection energy.

The main problems arise as follows. In the higher-energy range the bending fields must be kept fairly weak to reduce synchrotronradiation losses; this tends to make the snake rather long. At the lower energies, the fields may be increased but the long bending modules then lead to large aperture requirements in order to accommodate the orbit excursions. Quadrupoles can only be located at nodal points through which orbits of all momenta pass, but must nevertheless be capable of compensating the variable horizontal and vertical dispersions.

Although variable geometry is not excluded, it will require a serious and detailed study to find an acceptable solution.

8. Conclusions and questions

From this preliminary study it appears that the provision of a Siberian Snake in LEP-70 offers, in principle, the possibility of e+e- colliding beams in both helicity states over a wide energy range. For
technological and economic reasons this will probably require the
sacrifice of one LEP insertion for installation of the snake, thus
making it unavailable as an experimental region.

Provision could be made in the LEP design to permit the incorpora-
tion of a snake either as an option to be added some time after initial
operation or, if funds permit, as part of the initial installation.
Such provision involves some important commitments. A storage ring
injector, rather than a synchrotron, is necessary to pre-polarise the
e⁺/e⁻ beams before injection into LEP. The currently assumed injection
energy of 15 GeV is probably too low to maintain polarised beams up to
70 GeV and the storage ring injector should have at least the capability
of energy extension up to about 25 GeV.

A logical consequence of sacrificing one interaction region would
be to replace the corresponding large experimental hall by a much more
modest section of enlarged tunnel with a smaller access pit. The saving
in civil-engineering costs would go some way towards paying for the
polarisation facility; if the latter were nevertheless delayed, the
Snakepit could still be usable for a limited range of experiments re-
quiring only small detectors.

More detailed studies will be necessary, both to ensure that the
strong perturbation to the machine geometry and beam optics can be
tolerated, and also to arrive at the optimum configuration for the spin
kinematics. Technological problems with synchrotron radiation may be
severe and will have to be balanced against the need to operate with
relatively high bending fields in the snake due to space restrictions.

The storage ring injector will require special attention in order
to retain possibilities for increasing the energy, should this prove
necessary, and to yield a high degree of polarisation within a short
polarisation time. The beam transfer channel between the injector and
LEP must be provided with special magnetic bending configurations to
rotate the e⁺ and e⁻ spins into the correct orientation for injection
into LEP in either helicity state.

Polarimeters will be required to measure the degree of polarisation
both in the storage ring injector and in LEP. Polarisation measurement
in LEP may present special problems in the higher-energy range, further
complicated by the curious spin kinematics.
It should be evident from these considerations that the addition of polarised-beam facilities to LEP will require a considerable extra effort in the study programme. A major fraction of this work will be needed simply to establish the practical feasibility before one can make firm, long-term commitments. It is therefore important to establish at a sufficiently early stage the utility of polarised $e^+/e^-$ beams to the physics programme envisaged for LEP, taking account of the theoretical, practical and economic constraints. The present note is a first step in providing some information necessary for making such an assessment.

Finally, a caveat. Polarised $e^+/e^-$ beams have so far been obtained to my knowledge, in only three storage rings (ACO, VEPP2M, SPEAR) and one synchrotron (Bonn, quite recently), all below 2.5 GeV. Extrapolations to higher-energy $e^+/e^-$ are based entirely on theory. Although there is no reason to doubt the soundness of the theory, uncertainties can arise in its application when the properties of a future machine can only be simulated to a limited approximation. There is therefore an element of risk involved in polarised beams for LEP, a risk which should not be overlooked when making important commitments in the LEP design.

References
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5) Ya.S. Derbenev and A.M. Kondratenko; Preprint IYaF 76-84, Novosibirsk (1976) and Proc. V All-Union Conf. on Charged Particle Accelerators, Dubna (1976).
6) CHEEP Study Groups; Report CERN 78-02 (1978).
Fig. 1 Spin Precession in Normal Storage Ring
Fig. 2 Principle of the Siberian Snake
**Fig. 4(a)**

- $B_1$ (VERTICAL)
- $B_2$ (HORIZONTAL)

**Fig. 4(b)**

- $B_4$ (VERTICAL)
- $B_2$ (HORIZONTAL)