RESONANCE METHOD TO PRODUCE A POLARISATION ASYMMETRY IN ELECTRON-POSITRON STORAGE RINGS

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ABSTRACT

Pulsed solenoids of a few tens of ampere turns, operated in synchronism with the $\gamma\left(\frac{g-2}{2}\right)$'th harmonic of the orbit period, can be used to prevent a stored electron beam from becoming polarised through the emission of synchrotron radiation. With such low fields it is easy to arrange that only some of the stored bunches are affected. This makes it possible to produce collisions between counter-rotating electrons and positrons stored in a single ring in which the electron and positron polarisations are not equal and opposite.

I INTRODUCTION

Despite the small value of the magnetic moment of the electron (0.58×10^{-4} electron volts/Tesla), the emission of synchrotron quanta which align the moment with the guide field in a storage ring is sufficiently favoured that the beam becomes almost completely polarised with a build up time constant(1 of

$$N_p = \frac{0.8}{\sqrt{3}\,\pi}\left(\frac{m_e c^2}{\hbar c}\right)^2 \frac{1}{\alpha}\,\frac{\rho^2}{\gamma^5} \quad \text{revolutions.}$$

ρ is the bending radius in metres, $\gamma = \frac{E}{m_e c^2}$ is the Lorentz factor of the electron, $\alpha = \frac{1}{137}$ and $\frac{m_e c^2}{\hbar c} = 2.59 \times 10^{12}$ metres^{-1}. For EPIC, at 14 GeV, $N_p = 2.6 \times 10^8$ revolutions(2.

This presumes that depolarising resonances are avoided, typically that(3 $\gamma\left(\frac{g-2}{2}\right) \neq$ Integer ± Integer multiples of the horizontal and vertical betatron tunes of the machine. $g = 2(1 + 1.16 \times 10^{-3})$ is the Landé g-factor of the electron.

The polarisation vector is normal to the orbit plane. Since spin and magnetic moment are aligned for positrons, opposed for electrons, the spin polarisation vectors of electrons and positrons stored in the same ring are opposed, ie, $\vec{P}_+ + \vec{P}_- = 0$. No combination of magnetic fields through which both positrons and electrons pass can alter this situation. We describe below a method using pulsed fields which affect only one beam to produce a non zero value of $\vec{P}_+ + \vec{P}_-$, normal to the orbit(4.

This will greatly enhance experiments to search for possible parity violating effects in $e^+ e^-$ annihilation(5 such as might be produced by the presence of a weak neutral current, for example. In some of these experiments, and also in experiments to measure the spin structure functions of spin $\frac{1}{2}$ particles in conventional one photon annihilation[6], it is necessary to have a component of $\vec{P}_+ + \vec{P}_-$ parallel to the direction of motion of the interacting beams. Methods to rotate polarisation into the longitudinal direction have been discussed elsewhere[7]. They can be combined with the scheme described in this note.

2 RESONANT INHIBITION OF POLARISATION

We consider a bunch of particles with a polarisation of magnitude P aligned at an angle θ to the normal to the plane of the orbit, which we take to be horizontal.

The vertical component of P is increased by

$$\delta_1 \; (P\cos\theta) = \frac{P_{max} - P\cos\theta}{N_P}$$

on each orbit, due to the emission of synchrotron radiation. P_{max} is the maximum polarisation which can arise from this mechanism, and is ~ 0.92.[1] Any horizontal component will precess in the orbit plane relative to the beam direction at a rate of $\gamma\left(\frac{g-2}{2}\right)$ revolutions per orbit. Because of the spread in mean energy of the particles in the bunch and fluctations in the mean energy of any one particle, depolarisation will occur[8] with a time constant

$$N_{DP} \simeq \frac{1}{N_D\left(\gamma \frac{g-2}{2} \quad \alpha 2 \quad \left(\frac{\Delta\hat{\gamma}}{\gamma}\right)^2\right)^2} \qquad \text{revolutions}$$

where N_D is the damping time constant (= beam energy ÷ energy loss per turn), α_2 is a machine constant typically ~ 3, and $\frac{\Delta\hat{\gamma}}{\gamma}$ is the RMS value of the amplitude of synchrotron oscillations. At EPIC, $N_{DP} \simeq 3.3 \times 10^5$ orbit revolutions. This leads to changes in the orbit plane polarisation of

$$\delta_1\,(P\sin\theta) = -\frac{P\sin\theta}{N_{DP}} \quad \text{on each revolution.}$$

For times substantially less than N_{DP}, the orbit plane polarisation survives and we can arrange to pulse a solenoid in synchronism with the $\gamma\left(\frac{g-2}{2}\right)$ precession frequency, its field alternating in sign so that the vertical component of polarisation is always decreased. If the angle through which a vertical component is rotated on a single traversal is η, the solenoid produces the changes

$$\delta\,(P\cos\theta) = \frac{2}{\pi}\,P\sin\theta\sin\eta - 2\,P\cos\theta\,\sin^2\frac{\eta}{2}$$

$$\delta\,(P\sin\theta) = P\cos\theta\,\sin\eta - 2\left(\frac{2}{\pi}\right)P\sin\theta\sin^2\frac{\eta}{2}$$

on each traversal. ($\frac{2}{\pi}$ is the mean value of $|\text{cosine}|$).

Stable polarisation is achieved when

$$\delta_1\,(P\cos\theta) + \delta\,(P\cos\theta) = 0 = \delta\,(P\sin\theta) + \delta_1\,(P\sin\theta)$$

and if we set

$$\eta = \frac{k}{\sqrt{N_p D_{DP}}} \quad \text{for convenience}$$

we find

$$\tan\theta = k\sqrt{\frac{N_{DP}}{N_p}} \quad \text{and} \quad P\cos\theta = \frac{P_{max}}{1+\frac{2k^2}{\pi}}$$

3 REALISATION AT EPIC

The large values of N_p and N_{DP} mentioned above mean that P can be kept small with quite modest solenoidal fields.

For $k = 4$, we have $P\cos\theta \sim .083$ and $\tan\theta \sim 0.14$. η is 4.3×10^{-7} radians, and requires only 16 ampere turns per orbit to produce it, at 14 GeV.

We should note, however, that in 3.3×10^5 revolutions there are $\sim 10^7$ spin precession periods and it may be unrealistic to presume that the machine energy remains stable to ~ 1 in 10^7 over periods as long as 2.4 seconds, which is necessary if we are to remain in synchronism. However, a stability of one part in 10^5 over 24 milliseconds, which reduces the effective depolarising time constant by a factor of 100, would only increase η by a factor of 10.

The solenoid fields could be provided by a number of single turn coils placed at suitable points in the straight sections between the 1.5° bending magnets. With an orbit period of 7.3×10^{-6} seconds and two bunches of electrons, two of positrons stored, there is a spacing of 1.8×10^{-6} seconds between the passage of a bunch of electrons and a bunch of positrons at a point midway between two interaction regions, giving ample time to arrange that only selected bunches are affected by the pulsed solenoids.

For example, one could arrange to depolarise one bunch of e^- and one of e^+ so that collisions would alternate between polarised e^+ with unpolarised e^- and unpolarised e^+ with polarised e^-.

We note that polarisation phenomena should provide extremely sensitive methods of calibrating the absolute energy of the machine.

REFERENCES AND FOOTNOTES

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2 Data from G Rees, private communication.
The orbit period is 7.3×10^{-6} secs, so $\tau_p \sim 1900$ secs

This may be an uncomfortably large fraction of the lifetime of a pair of stored interacting beams. However, electrostatic separators designed to keep electrons and positrons apart in the interaction region during acceleration can be operated during the build up of polarisation so that the lifetime during polarisation is the single beam lifetime.

3 R F Schwitters - SLAC Pub. 1348 - 1973.

4 A similar scheme has been suggested by M Harold (private communication).

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