Polarisation in the eRHIC electron(positron) ring [a]

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We report on the status of, and plans for, calculations of the spin polarisation in the electron (positron) ring of the eRHIC complex.

Introduction

This article gives an update on calculations of electron and positron ($e^{\pm}$) polarisation for the 5–10 GeV ring in the ring–ring version of eRHIC. This is the proposed high luminosity $e^{\pm}$–proton(ion) facility in which longitudinally polarised $e^{\pm}$ would collide with high energy longitudinally polarised protons or with ions in the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory (BNL). The basic concepts of the project are described in the Zero$^{\rm th}$–Order Design Report [1]. See Fig. 1.

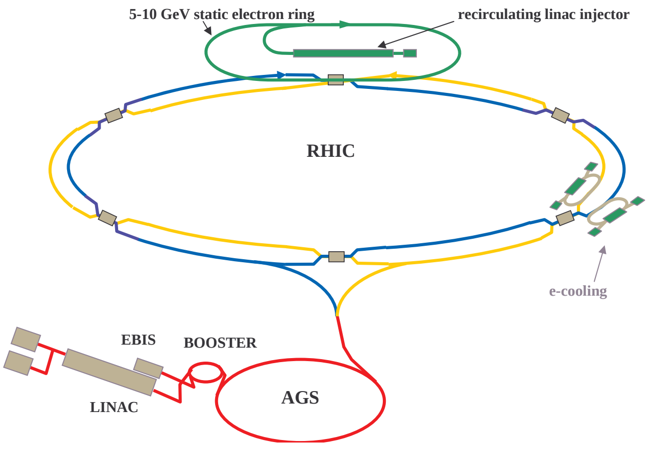

Figure 1: The layout of eRHIC in the ring–ring version [1].

[a] Extended version of a talk presented at the 16th International Spin Physics Symposium SPIN-2004, Trieste, Italy, October 2004

Polarisation in the $e^{\pm}$ ring and calculations

$e^{\pm}$ circulating in the (vertical) guide field of a storage ring emit synchrotron radiation (SR) and can become polarised by the Sokolov–Ternov (S–T) effect. In the case of an ideal simple flat ring the polarisation reaches a value of $\frac{8}{5\sqrt{3}} = 92.4\%$ and points along the guide field in the arcs [2]. The polarisation rate is proportional to the fifth power of the energy. For example, for the $e^{\pm}$ ring of eRHIC the S–T polarisation time is about 11 hours at 5 GeV and 20 minutes at 10 GeV.

However, real rings delivering beam to experiments often have strong solenoids and so–called spin rotators and the particles experience beam–beam forces. Moreover, a ring is inevitably slightly misaligned. Then the SR can also lead to depolarisation due to the stochasticity of photon emission. If this has a time scale comparable to, or shorter than the S–T time scale, the attainable polarisation can be much lower than 92.4%. The depolarising rate can be especially high compared to the S–T rate at the so-called spin orbit resonances [2,3] and tends to increase strongly with energy. However, depolarisation can often be substantially overcome by arranging for "spin transparency" (see below) and by careful adjustment of the closed orbit. Detailed accounts of the theory and phenomenology of these effects can be found in [2,3,1].

Although the $e^{\pm}$ could in principle become polarised by the S–T effect, this would take too long in the energy range 5–8.5 GeV. Thus for electrons a prepolarised beam would be injected at full energy, even up to 10 GeV. For details of the source and the linear accelerator see [1]. Since no simple sources of polarised positrons exist, measurements with positrons will be restricted to 9–10 GeV where the S–T time scale is short enough.

The polarisation vector must be close to the vertical in the arcs in order for the S-T process to function and to prevent depolarisation. On the other hand the high energy physics programme needs longitudinal polarisation at the interaction point. This is obtained with the aid of the spin rotators [4] sketched in Fig. 2 whereby vertical polarisation in the arcs is brought into the horizontal plane by a pair of solenoids, rotated to longitudinal for the interaction point by dipoles, and then returned to the vertical by dipoles and solenoids of reversed polarity. However, such a system can also lead to strong depolarisation. Fortunately, it can be made "spin transparent" [2] by a special choice of the strengths of the quadrupoles between the solenoids in each pair [4,1]. Then, in the absence of misalignments, almost all depolarising effects should be eliminated. This is confirmed by analytical calculations with the code SLICK [1]. However, with misalignments, strong depolarisation can still occur. This is unlikely to be too important at 5 GeV, but it would certainly need attention at the high end of the energy range where a small depolarisation time would lead to an unacceptably low equilibrium polarisation. Note that even with an injected electron polarisation of 80% the polarisation would settle down (or up) to the equilibrium polarisation determined by the state of the ring and on a time scale shorter than the smaller of the polarisation and the depolarisation time scales. A positron beam would be injected with 0% polarisation. Thus a careful study of the attainable equilibrium polarisation is needed, at least above 8 GeV. SLICK uses a linearisation of the spin motion. The calculations can then only exhibit first order spin–orbit resonances.

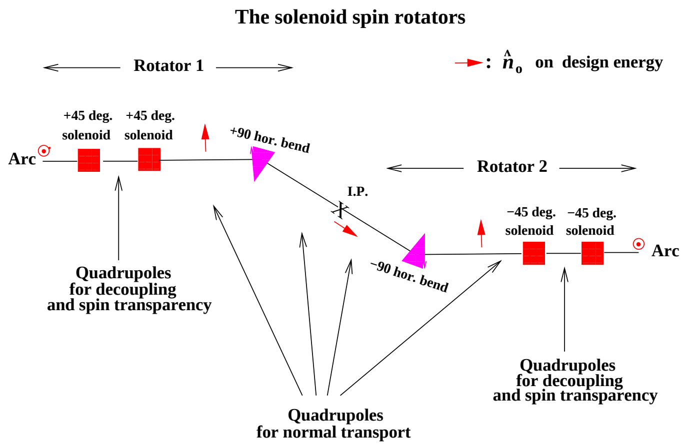

Figure 2: Schematic of the spin rotators [4] in the $e^{\pm}$ ring.

Typical results from SLICK for the equilibrium polarisation in the range 9.25–10.58 GeV with realistic misalignments and subsequent optimisation of the closed orbit are shown in [1] where one sees that polarisations of up to 80% are reached. The corresponding S-T and depolarising times for 9.25–9.69 GeV are shown in Fig. 3. The first order spin–orbit resonances are clearly visible. The best way to estimate the

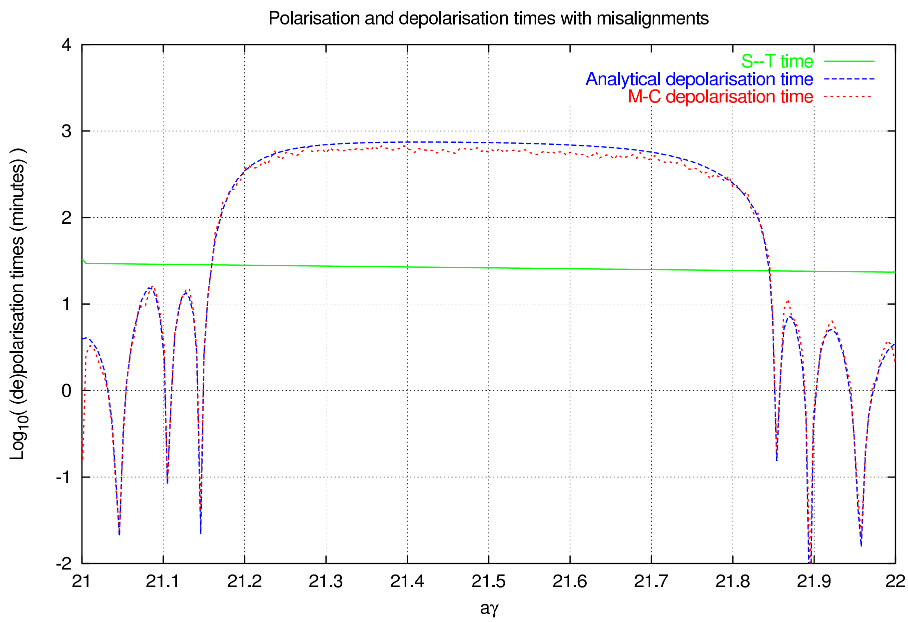

Figure 3: The S–T time and first order estimates of the depolarising time vs. design orbit spin tune.

effects of higher order resonances, including the effects of nonlinear orbit motion and beam–beam forces, is to simulate the effects of stochastic photon emission in a Monte–Carlo (M–C) spin–orbit tracking code which operates on a large ensemble of particles and includes the full 3–D spin motion. Analytical methods [2] lack the required power and generality. The M-C is being implemented in the code SLICKTRACK, an extended version of SLICK. A sample result, for calibration of the concept, of running the Monte–Carlo with linearised spin motion under the same conditions as in the basic (i.e. analytical) SLICK, is shown in Fig. 3. It is clear that the M–C model is good even at energies where the "measurement" of the depolarisation time can be imprecise because it is large. The M–C approach was pioneered in the early 1980's in the code SITROS [2] but with SLICKTRACK, advantage has been taken of the subsequent huge increase in available computer power and of experience, to create a new, much simpler software architecture. This in turn facilitates detailed investigation of the depolarisation process and of the effect of lack of spin transparency of sections of the ring under the heading: "diagnostics", so that the potential for unreliable results is minimised. It is intended that SLICKTRACK should provide a powerful general tool for studying polarisation in all the $e^{\pm}$ accelerators and rings of the eRHIC complex.

References

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Subsequent work

Following submission of the original paper, M–C calculations with SLICKTRACK for full 3–D spin motion became available. Fig. 4 shows the resulting equilibrium polarisation for the same conditions as in Fig. 3. One can now see the expected higher order resonances. They are essentially the so–called synchrotron sidebands of the first order resonances and it is clear that with the inclusion of full 3–D spin motion, high polarisations are still attainable. The next step, which is well underway, is the inclusion of beam–beam forces.

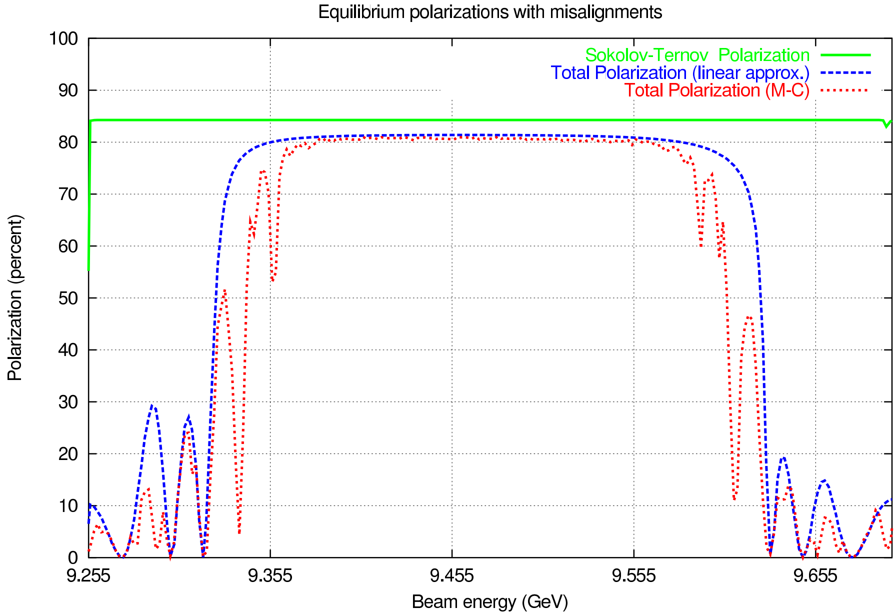

Figure 4: A comparison of the equilibrium polarisation calculated using full 3–D spin motion, with the polarisation calculated analytically with linearised spin motion in SLICK.