

ELECTRON POLARIMETRY FOR ERLs*

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Abstract

Polarimetry at the planned ERL based linac-ring colliders can rely on similar techniques as have been developed for storage rings such as HERA. However, due to the low energy, operation of polarimetry at the prototype devices such as MESA is shown to be considerably more difficult. The usage of atomic traps which serve as a target of complete electron polarization is discussed for MESA.

INTRODUCTION

In collisions of spin-polarized particles, online analysis of the beam polarization is highly desirable. Usually, a high quality result will also call for a high absolute accuracy $\Delta P/P$ of the polarization measurement. Electron Polarimeters have been operated successfully in ring/ring ep-colliders for instance at HERA [1] and also at LINACs such as SLACs SLC [2]. If we consider the situation in an ERL based linac/ring collider such as eRHIC [3] or LHeC [4] we find that the high beam power at an ERL also requires minimally invasive techniques. In comparison with storage rings several advantages come into play. First, stronger interaction is possible between the beam and the analyzer, since any beam particle makes only a single passage through the interaction region at the experiment and/or the polarimeter. A further advantage lies in the fact that the beam can be analyzed invasively after deceleration in the ERL, i.e. before the beam dump, if the polarimeter can be made compatible with the still high beam power. Due to the rapid deceleration in an ERL the polarization loss between target will usually only lead to negligible depolarization, since depolarizing resonances are crossed very rapidly. Therefore, the information obtained from a dump-polarimeter may still be useful for the interpretation of the experimental data. In the following we will briefly address the issue of the high energy polarimeter for the planned ERL-ring colliders which may be realized in the next decade. In contrast to high energies, new techniques seem necessary for low energy projects like MESA which are going to be realized on a shorter timescale.

POLARIMETRY AT GEV LEPTON ENERGIES

In Laser-Compton polarimeters (LCP) circularly polarized optical photons with an energy $E_{\gamma,0}$ (typical a few eV) are backscattered off the extreme relativistic ($E_{beam} \gg m_{lepton}$) lepton beam. The backscattered photons whose

energy E_{γ} is in the many MeV region are concentrated in a small angular region ($\approx 2/\gamma = 2m_{lepton}/E_{beam}$, typically smaller 1 mrad) around the backscattering direction. A beam polarization dependent signal (asymmetry) $A = P_{lepton} P_{\gamma,0} * S_{long,trans}$ can be generated by switching the circular photon-polarization $P_{\gamma,0}$. The character of the analyzing power $S_{long,trans}$ depends on the transverse or longitudinal state of the electron beam polarization. For the transverse case a left/right asymmetry exists, causing a small shift of the center of intensity distribution, the detection of which causes some requirements towards the position resolution of the photon detector. In the longitudinal case an intensity asymmetry occurs, even if the scattered photon-spectrum is integrated over all angles. In this case energy resolution is necessary, since the quantity $S_{long}(E_{\gamma})$ varies strongly with the energy of the scattered photon. In the following only the longitudinal case is considered. The largest asymmetry is carried by the photons with the highest energy, i.e. the backscattered photons. The Laser Compton has distinct advantages since the product $S_{eff} = D * P_{\gamma,0} * S(E_{\gamma})$, the so-called effective analyzing power, can be determined very accurately. First, $P_{\gamma,0}$, the circular polarization of the photons, which can be considered as a target polarization, is comparatively easy to determine with an accuracy in the per mille range. Second the analyzing power $S_0(E_{\gamma})$ can be calculated very accurately for this QED process. The factor D contains all experimental dilutions, like backgrounds or uncertain calibration of the detectors energy-scale. It has been shown that these can be controlled at the sub percent level too.

For electron beam energies of a few GeV or lower the energy of the backscattered photon is still much lower than the incoming beam energy. In this case the approximations in the following paragraph are valid. An exact calculation of the analyzing powers for arbitrary energies can be found in [5].

For 180 degree backscattering the energy of the photon is maximum and it is determined by the relativistic factor γ of the lepton beam: $E_{\gamma,max} \approx 4E_{\gamma,0}\gamma^2$. For a 1 GeV beam and incoming laser Photons of 2.5 eV (typical for frequency doubled high repetition rate laser systems) we obtain $E_{\gamma,max} = 40 MeV$. On the other hand, the asymmetry is $E_{\gamma,max}/E_{beam}$ which is 0.04 for this example. The averaging over the photon spectrum leads to further reduction of this value in a real experiment.

Small asymmetries ($A < 0.01$) are difficult to measure accurately, not only because the measurement time for a given statistical accuracy increases $\propto 1/A^2$, but also because the contribution of systematic effects - e.g. background from residual gas scattering - becomes increasingly

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difficult to control. From this reasoning we conclude that some value of beam energy must be surpassed to make a LCP effective as a fast and accurate device. This limit is of the order of one GeV. In order to get an idea of the obtainable measurement speed we can compare with the Mainz LCP where 1% statistical accuracy was obtained within 12 hours at $E_{beam}=1.5$ GeV [6]. With 2.5 GHz c.w. beam at MAMI this experiment is similar to ERL conditions, but with a much lower beam current of $20 \mu A$. Since the currents at ERLs are several magnitudes larger, it seems reasonable to assume that LCPs can be used effectively at ERLs whose energy considerably exceeds 1 GeV. This is of course the case for the EIC and LHeC projects.

POLARIMETRY AT THE 100 MEV SCALE: THE HYDRO-MØLLER AT MESA

So far, MESA is foreseen to operate with spin-polarized beam only in external beam (EB-) mode. This is motivated by the fact that production of polarized beam at the 10 mA level is a demanding task which would add considerably to the already high complexity of the MESA-project. However, the usage of a polarized internal target in ERL-mode is already being discussed which would then operate with a polarized beam. Figure 1 shows the outline of MESA together with the location of polarimeters as if they would have been rearranged for ERL-operation. There are three EB-mode polarimeters [7]. Two of those are "Mott"-polarimeters, which are invasive. They only could be useful in ERL-operation if they are used as dump polarimeters.

MESA is foreseen to operate at a maximum energy of 200 MeV, where using the LCP is unattractive. Therefore another principle is foreseen to be used. This scheme - the so-called Hydro-Møller - was proposed by Chudakov and Luppov [8]. It uses the fact that hydrogen atoms can be trapped axially by a strong solenoid field. Radial trapping can be achieved by cooling the walls of the trap to 0.3 K and by covering these walls with a suprafluid ^4He -film. Though the feasibility of such a trap was demonstrated already a long time ago, we estimate several years of development time necessary, since the device is technologically demanding. The Hydro-Møller potentially carries similar advantages as the LCP, in particular the hydrogen atoms in the trap are polarized to a level of $P_{target} = 1 - \epsilon$, with $\epsilon \approx 10^{-5}$ in a magnetic field of $B=8$ T. Therefore, as in the LCP, the uncertainty in the knowledge of the target polarization is not a major issue. For 90 degree scattering in the CM-system the analyzing power is $7/9$, so that with complete target polarization of the Hydro-Møller the observed asymmetry will become very large. Though the target density will be relatively small (of the order 10^{16} cm^{-2}) a sufficiently high measurement speed can be obtained, even if operated at the 0.15 mA current level foreseen for the P2 external beam experiment at MESA [9]. In addition, the low target density allows for on-line operation. Besides the technical issues, another challenge is of course to make the ERL lattice compatible with beam passage through the 8 T

field. The length of the trap is about 0.5 m, but additional space must be foreseen for the detection system. It should be noted that the *nuclei* in the trap can also be polarized the device may therefore also serve as a polarized nuclear target.

POLARIMETRY AT RECOVERED ENERGIES

At the recovered energy one can think to install a polarization monitoring device which resides permanently in the beam. In the region of several MeV - corresponding to the recovered beam energy - Mott and Compton-transmission polarimeters have been tested at MAMI at power levels of several hundred Watts [10]. It is an open question if Mott polarimeters can handle the much higher beam power in ERL-mode, though one could think of rotating targets in order to reduce the thermal stress induced by the multi-kW beam. Compton transmission polarimeters, on the other hand, seem reasonably simple and robust to be used for this purpose [10].

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Scenario: Polarimetry in ERL-mode

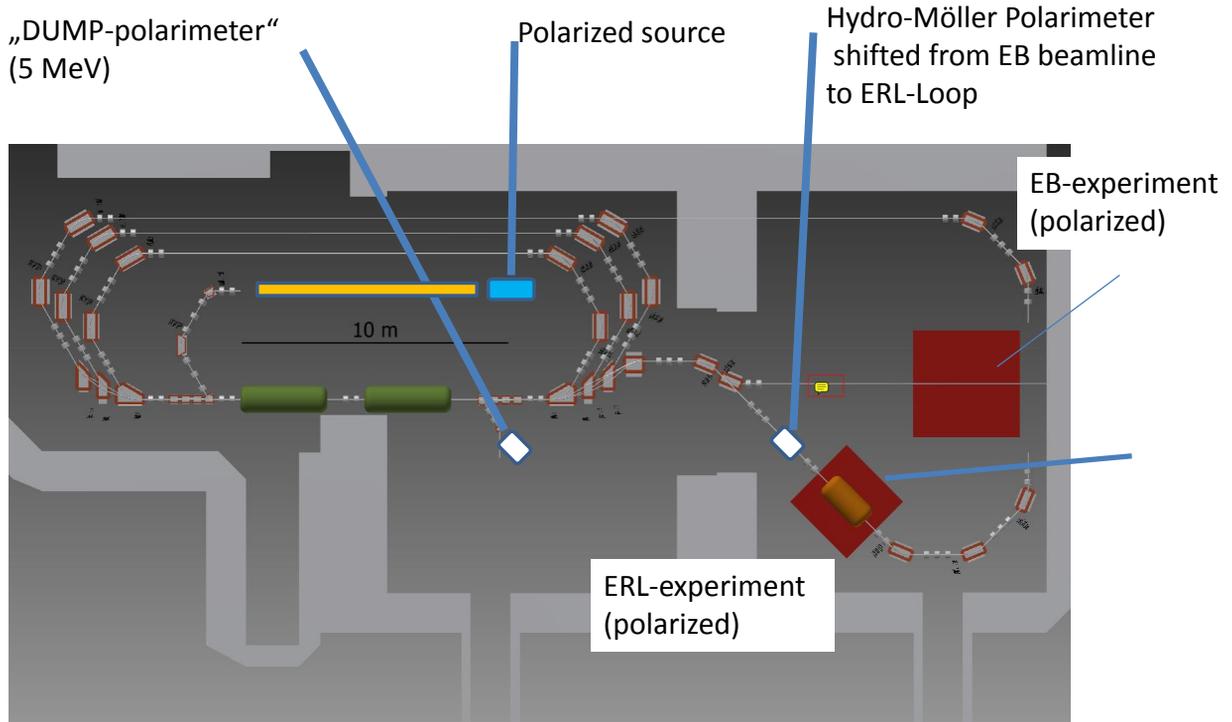


Figure 1: Outline of the MESA lattice with a scenario "as if" the polarimeters foreseen for EB-mode would be used in ERL-mode.