MEASUREMENT OF BEAM POLARIZATION IN VEPP-3 STORAGE RING USING INTERNAL POLARIZED TARGET-BASED MØLLER POLARIMETER

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Abstract

A method for beam polarization measurement in a storage ring based on measuring the asymmetry in scattering of polarized beam electrons on the internal polarized gas jet target has been for the first time developed and applied. Using this method we have studied the radiative polarization in VEPP-3 storage ring, which serves as a source of polarized beams for VEPP-4M electron-positron collider in the planned experiment on high-precision measurement of tau-lepton mass.

INTRODUCTION

During the preparation of the experiment [1] on a high-precision measurement of tau-lepton mass at the VEPP-4M electron-positron collider with the use of the resonant depolarization technique (RD) [2] the necessity has arisen to study a radiative polarization in the booster storage ring VEPP-3. The latter is a source of polarized beams for VEPP-4M in the beam energy range $E \sim 1.5 \div 1.9$ GeV. The beam energy in the mentioned experiment is in the vicinity of the tau-lepton production threshold ($E = 1777$ MeV) where the closeness of the machine integer spin resonance (1763 MeV) significantly enhances the depolarizing effect of magnetic field imperfections in storage rings. Therefore, the search of the energy range acceptable from the point of view of obtaining the polarized beams in VEPP-3 and injecting them into the VEPP-4M is important. With this aim we have developed a method for measurement of the beam polarization in VEPP-3 by a non-destructive way based on measuring the asymmetry in Møller scattering of polarized beam electrons on an internal polarized gas jet target (IPT) [4]. In contrast to the polarimeter based on intra-beam-scattering effect (IBS) [5], also used at VEPP-4M and VEPP-3, Møller polarimeter provides an absolute measurement of the polarization degree and does not require to destroy the beam polarization. An idea to apply Møller polarimeter based on IPT (in the form of hydrogen atomic beam) was discussed in [2]. In 2000 we carried out at VEPP-3 a first similar experiment using the internal polarized deuterium target [3]. In 2003 the advanced Møller polarimeter was installed at VEPP-3 and the polarization of circulating beams was measured with its help [4].

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MEASURABLE EFFECT

In the case of transverse polarization of both the relativistic beam electron and the target electron the differential cross section in the center-of-mass system is expressed most simply [6]:

$$\frac{d\sigma}{d\Omega} \approx \frac{r_e^2}{2\gamma}\left[\frac{(3+\cos^2\chi)^2}{\sin^4\chi} + |\vec{\xi}||\vec{\xi_t}|\cos(2\varphi+\varphi_1)\right]. \quad (1)$$

Here, the first term in the square brackets represents the spin independent part of Møller-scattering; $\gamma >> 1$ is Lorentz factor of the electron beam in the laboratory system; χ is a scattering angle in c.m.; $\varphi_1 = \widehat{\vec{\xi}\vec{\xi_t}}$ is an angle between the polarization vectors of the beam ($\vec{\xi}$) and of the target ($\vec{\xi_t}$); φ is an angle between the scattering plane and the plane which is normal to $\vec{\xi}$. The spin dependent contribution (the second term in (1)) is maximal if the following conditions are fulfilled simultaneously: a) $2\varphi+\varphi_1 = 0$ or π; b) $\chi \approx \pi/2$. In particular, the first condition may be realized when Møller scattering in the vertical or horizontal plane is under study while both polarization vectors are vertical. It is suitable to describe the spin effect by an asymmetry

$$\mathcal{A} \equiv \frac{d\sigma_{\uparrow\uparrow} - d\sigma_{\uparrow\downarrow}}{d\sigma_{\uparrow\uparrow} + d\sigma_{\uparrow\downarrow}} = \frac{\sin^4\chi}{(3+\cos^2\chi)^2}\vec{\xi}\vec{\xi_t}$$

determined from two different experiments: with the parallel ($\uparrow\uparrow$) and anti-parallel ($\uparrow\downarrow$) vectors of the beam and target polarizations. The condition of $\approx 90^\circ$-scattering in c.m. system means that in the laboratory system both the scattered and recoil electrons have the same energy $\approx \gamma/2$ and scatter symmetrically at the angles $\approx \pm\sqrt{2/\gamma}$ to the beam direction. The detector of scattering electrons must be allocated in accordance with such an optimal kinematic scheme. Hence a geometrical factor $\mathcal{A}_g$ in the expression $\mathcal{A} = \mathcal{A}_g|\vec{\xi}||\vec{\xi_t}|$ is close to a theoretical maximum $max\mathcal{A}_g = 1/9$. In practice, one can find the beam polarization $\xi = |\vec{\xi}|$ by the known target polarization degree $\xi_t = |\vec{\xi_t}|$ measuring the asymmetry

$$\mathcal{A} \equiv \frac{N_{\uparrow\uparrow} - N_{\uparrow\downarrow}}{N_{\uparrow\uparrow} + N_{\uparrow\downarrow}} = \mathcal{A}_g\xi\xi_t. \quad (2)$$

Here $N_{\uparrow\uparrow}$ and $N_{\uparrow\downarrow}$ are the numbers of scattering events registered in two states of the relative polarization orientation provided by switching a sign of target polarization; the factor $\mathcal{A}$ is less than $1/9$ because of a non-zero angular acceptance of the detector.

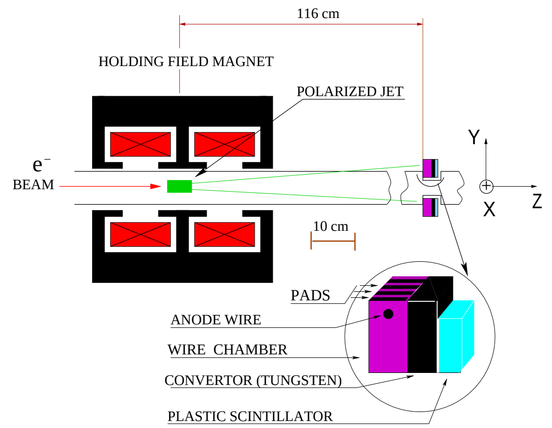

Figure 1: Lay-out of Møller Polarimeter with Internal Target.

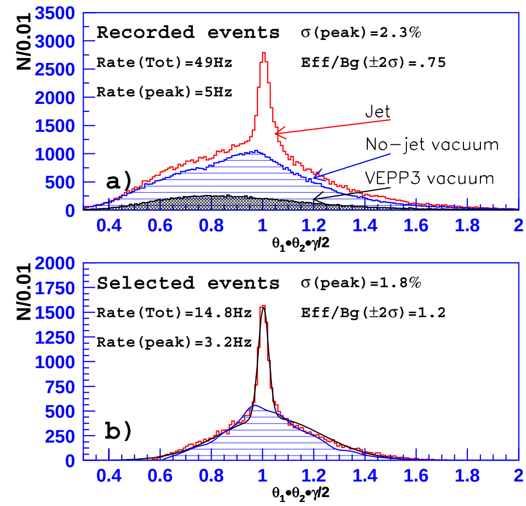

Figure 2: The distributions over parameter R for typical 1 hour run. a) no selection; b) background suppressed.

EXPERIMENTAL SETUP

The internal target with the thickness of $\sim 5 \cdot 10^{11}$ electron/cm^2 is formed by the jet of polarized deuterium atoms from the Atomic Beam Source (ABS) of Deuteron Facility [3]. Gas jet crosses the electron beam at a right angle near the axis of VEPP-3 vacuum chamber (see Fig.1). High degree of electron polarization ($\xi_t \approx 100\%$) of the jet as well as a high-quality focusing of the latter is achieved by the use of a set of sextupole magnets in ABS. With the purpose to reduce the flow of atoms into the storage ring and to get better background condition a rectangular slit diaphragm with a size of 4x15 mm was introduced between ABS and the vacuum chamber of the storage ring. The ion pump was used to pump the reflected atoms from the vicinity of the diaphragm. In the vacuum chamber of the storage ring three ion pumps were used. However a relatively high background pressure was observed in the experiment (see below). It could be explained by high density of the gas near the rectangular diaphragm due to pumping speed of ion pumps were smaller than nominal. The direction of target polarization was flipping periodically (every 20 sec) parallel or anti-parallel to the electron beam polarization. It is done by the holding field magnet, which creates a magnetic field with magnitude 300 G near the beam-jet interaction region (see Fig.1).

The polarimeter detector system (see Fig.1) is placed at 116 cm distance from the target jet. It consists of two nearly identical arms, installed symmetrically with respect to XZ-plane, to detect both electrons in coincidence taking into account their coordinate correlation in XY-plane. The coordinate resolution of the detecting system is estimated to be about 0.2 mm. The geometrical factor determined by a solid angle of the detection system $A_g \approx 0.089 \div 0.088$ in the energy range $E = 1900 \div 1800$ MeV. Design parameters of the polarimeter provide a counting rate of about 6 Hz at the beam current of ~ 100 mA. It takes about 8 minutes for data acquisition to measure the asymmetry with a 20% statistical error in case of 80% beam polarization.

DATA ANALYSIS

In the experiment the average event rate was 50-70 Hz that is about 10 times larger than the expected one. The residual gas in vacuum chamber is found to be the main source of background. In presence of the target the gas density increases in a wide region around the target because of non-Gaussian tails of the gaseous jet and of a lack of pumping capacity. The events of e^-e^- scattering are selected using the polar and azimuthal angular correlations pertinent to elastic scattering. Then the distribution of selected events over the parameter $R = \theta_1 \cdot \theta_2\gamma/2$ ($\theta_{1,2}$ are the polar angles of two detected electrons) is analyzed. A typical example is shown in Fig.2. The peak corresponds to the beam-jet scattering and the wide wings are due to background events. The background contribution of 'natural' residual gas is estimated from the run with no jet. Another wide background could be explained by insufficient pumping speed for atoms reflected by the diaphragm. This background shape is tested in a special experiment with a controllable leak of the deuterium gas used instead of a jet. The effect/background ratio under the peak ($\pm 2\sigma$) is about 0.75. To observe the effect of beam polarization the events are separated into two groups according to a sign of target polarization. Two distributions over R for different target polarizations are used to determine the polarization from (2).

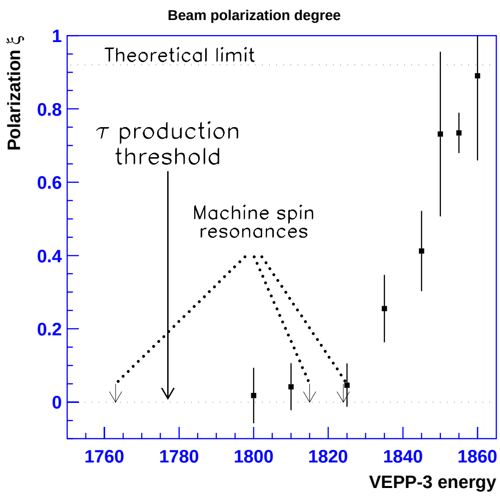

Figure 3: Measured Beam Polarization degree vs. VEPP-3 Beam Energy

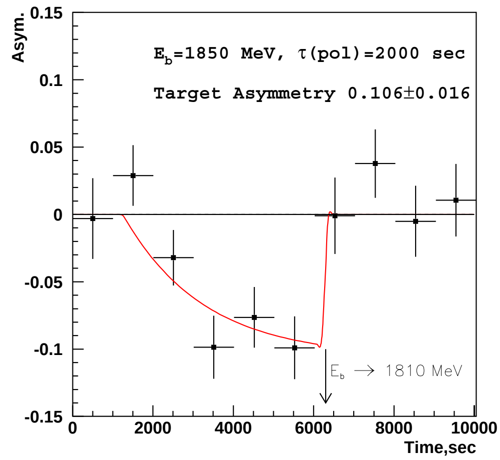

Figure 4: Measurement of the asymmetry in the processes of build-up of the polarization and crossing spin resonances.

RESULTS OF MEASUREMENT

The measured equilibrium degree of radiative self-polarization is plotted in Fig.3 versus the beam energy. The characteristic time of polarization buildup is about 2000 seconds in the energy region under study (from 1855 to 1800 MeV); the beam current was up to 100 mA. The important result was an observation of the significant depolarizing influence of the machine spin resonances associated with the frequencies of spin precession (ν) and of betatron oscillations ($\nu_{x,y}$). The corresponding resonant energies are (see Fig.3) $E \approx 1815$ ($\nu_x - \nu = 1$), $E \approx 1825$ MeV ($\nu_y - \nu = 1$) and $E = 1763$ MeV ($\nu = 4$, the integer spin resonance). The polarization appeared to be small in a wide range below 1840 MeV because of a combined effect of spin resonances. Fig.4 shows the measured process of the polarization buildup in VEPP-3 which was then interrupted by lowering the energy from 1850 MeV down to 1810 MeV with a rate about 2 MeV/sec. Because of insufficiently fast crossing the spin resonance range the beam appeared unpolarized in a final state (a 'fast crossing' condition without depolarization requires the rate ~ 10 MeV/sec).

DISCUSSION

Despite of the excessive background caused by shortcomings of the vacuum pump system used, the application of a new method has allowed to carry out an absolute measurement of a degree of polarization in a wide range of VEPP-3 energy with sufficient efficiency. It follows from these measurements that an injection of polarized particles from VEPP-3 at above or close to $E = 1850$ MeV and subsequent lowering of the beam energy in VEPP-4M down to the tau-threshold is reasonable for the experiment on tau-lepton mass measurement [7].

The developed method is most effective in a case of the storage rings with a plenty of bunches and therefore with a large average current of polarized electrons/positrons. One can measure the beam polarization in Main Damping Ring (MDR) from NLC Project [8] at its designed energy 1.98 GeV using IPT-based Møller polarimeter with parameters close to ours. The average beam current in MDR makes up 0.8 A. Therefore the figure of merit at MDR is a factor 8 larger than that for VEPP-3. Thus it would take $1 \div 2$ minutes to measure the polarization averaged over MDR operation cycles with a statistical accuracy $\sim 20\%$.

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