PROCEEDINGS OF SCIENCE

Measurement of Beam Polarization at an e^+e^- B-Factory with New Tau Polarimetry Technique

Caleb Miller
on behalf of the BaBar collaboration
University of Victoria,
3800 Finnerty Rd, Victoria, Canada
E-mail: calebmiller@uvic.ca

Belle II is considering upgrading SuperKEKB with a polarized electron beam. The introduction of beam polarization to the experiment would significantly expand the physics program of Belle II in the electroweak, dark, and lepton flavour universality sectors. For all of these future measurements a robust method of determining the average beam polarization is required to maximize the level of precision. The BaBar experiment has developed a new beam polarimetry technique, Tau Polarimetry, capable of measuring the average beam polarization to better than half a percent accounting for both statistical and systematic uncertainties. Tau Polarimetry strongly motivates the addition of beam polarization to SuperKEKB and could also be used at other e^+e^- colliders with polarized beams.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

PoS(ICHEP2022)872

1. Introduction

Polarized beams and a precise measurement of the average beam polarization in e^+e^- collisions enables a number of precision tests of electroweak theory under the standard model. We present a novel technique for measuring the average beam polarization in e^+e^- collisions and a preliminary result of its application from the BABAR data focused on a detailed evaluation of the systematic uncertainty and statistical sensitivity of the technique. This novel technique, Tau Polarimetry, exploits two features present in the $e^+e^- \to \tau^+\tau^-$ process in order to extract the beam polarization. The first feature is the strong relationship between the beam polarization and the polarization of the τ produced, which at a center-of-mass energy of 10.58 GeV can be expressed as:

$$P_\tau = P_e \frac{cos\theta}{1+cos^2\theta} - \frac{8G_F s}{4\sqrt{2}\pi\alpha} g_V^\tau \left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2 g_A^e \frac{cos\theta}{1+cos^2\theta} \right)$$

The second feature allowing the beam polarization to be measured is the coupling of the τ polarization to the kinematics of the final state particles produced in the τ decay. As an example, in the $\tau^\pm \to \pi^\pm \nu_\tau$ decay the single chiral state available to the neutrino forces the pion to be emitted forward or backward relative to the τ momentum vector. This results in a strong momentum correlation between the pion and the polarization of the τ. Combining these two features with a sufficiently large τ dataset allows the average beam polarization to be measured. This technique is intended to be applied to future polarized e^+e^- collisions such as Belle II with a polarized electron beam. The Belle II experiment has proposed upgrading SuperKEKB to have a polarized electron beam[1] which would allow for a number of world-leading precision measurements in the electroweak sector. It is expected that for these proposed measurements the dominant systematic uncertainty will be the precision with which the average beam polarization is known, which motivates this analysis.

2. Event Selection

In developing the analysis it was found that the $\tau^\pm \to (\rho \to \pi^\pm\pi^0)\nu_\tau$ decay, tagged with a $\tau^\pm \to e^\pm \nu_\tau \overline{\nu}_e$ decay of the second τ provided a high efficiency and high purity selection for measuring the beam polarization. The $\Upsilon(4S)$ data collected at the BABAR detector[2, 3] are used as a proof of concept for the development of the Tau Polarimetry technique. Of the available 424 fb^{-1}, 32.28 fb^{-1} were used to initially study and develop the analysis and are excluded from the final measurement. In order to select the $\tau^\pm \to (\rho \to \pi^\pm\pi^0)\nu_\tau$ decays (rho decays), the events are required to contain two charged particles which are in opposite hemispheres as defined by the thrust axis in the center-of-mass frame. One of the charged particles must be tagged as an electron by the BABAR particle identification algorithms, and have no neutral particles identified in its hemisphere. The signal τ, the rho decay, is required to have a neutral pion in its hemisphere either identified by the BABAR particle identification algorithms or from a pair of neutral particles which have an invariant mass consistent with a neutral pion. Finally a requirement that the event exceeds 1.2 GeV of transverse momentum removes the majority of any remaining Bhabha events and two-photon events. With this event selection a τ sample purity of 99.7% is achieved, with an overall selection efficiency of 2.4% (27.1% accounting for branching fractions).

3. Polarization Measurement

In order to extract the beam polarization from the data sample a Barlow and Beeston template fit is implemented[4]. For the rho decay mode, the fit requires three variables to extract the average beam polarization. First, $\cos\theta$ is required due to the sign flip dependent on the sign of $\cos\theta$ as seen in Equation 1. Next, due to the spin 1 nature of ρ, two variables are required to disentangle the polarization information. The first, $\cos\theta^*$, is the angle between the τ and ρ momentum vectors in the τ rest frame; and second, $\cos\psi$, which is the angle between the ρ and the pion momentum vectors in ρ rest frame. These 3 angular variables are binned into 3D histograms for the fitting algorithm. The electric charge of the τ is also important for the fit as the polarization coupling flips sign with electric charge. This effect is accounted for by performing the fit independently for the two charge states, and then combining the two fits to arrive at the final result. In order to be sensitive to the beam polarization, τ MC was produced with KKMC[5] for both a left and right handed beam polarization. The fit then uses both of these polarized MC samples along with existing *BABAR* non-τ MC as templates in the fit. The average beam polarization is then defined as the difference between the fitted contribution for the left and right polarized templates. For the *BABAR* data an average beam polarization of $-0.0011 \pm 0.0036_{\mathrm{stat}}$ was found.

4. Polarization Sensitivity

Since PEP-II is expected to have no inherent beam polarization, *BABAR* has carried out MC studies of the Tau Polarimetry performance at arbitrary beam polarization states. This is performed by splitting the generated polarized τ MC into two samples. One to mix a specified beam polarization state, and the other to perform the polarization fit. Figure 1 shows the response of the fit to various input polarizations, and demonstrates that Tau Polarimetry performs well at any beam polarization state.

5. Systematic Uncertainties

The systematic uncertainties were evaluated by quantifying the shift in the level of agreement between data and MC beam polarization from the fit in response to a systematic shift in a variable. Systematic uncertainties were then evaluated independently for each of the *BABAR* datasets which represent different running periods. Each systematic source is then combined across datasets in a way that accounts for correlations in the uncertainties. Finally all the systematic uncertainties are summed in quadrature to arrive at a final systematic uncertainty. The dominant systematic uncertainty in this analysis arose from uncertainties associated with the *BABAR* neutral pion identification algorithms, which contribute an uncertainty of 0.0015. The sub-leading uncertainties arise from the modelling of neutral split-offs from charged particles (0.0011), modelling of $\cos\psi$ (0.0010), modelling of $\cos\theta$ (0.0009), minimum neutral particle energy to be included in the event (0.0009), and neutral pion mass reconstruction (0.0009). When the systematic uncertainties are summed in quadrature a total systematic uncertainty of 0.0030 is found.

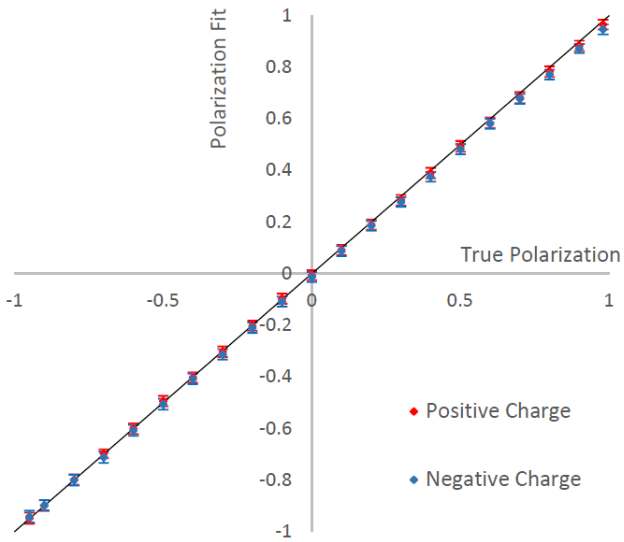

Figure 1: Beam polarization measured in MC samples as a function of input beam polarization.

6. Conclusions

The first use of the novel Tau Polarimetry technique as implemented by the *BABAR* collaboration has found the average beam polarization of PEP-II to be $-0.0011 \pm 0.0036_{\text{stat}} \pm 0.0030_{\text{sys}}$. This level of precision exceeds the performance required for the physics projections in the Belle II polarization upgrade proposal[1], and we expect Belle II to outperform the precision *BABAR* is able to achieve in this measurement. It is also expected that Tau Polarimetry could be implemented at future e^+e^- colliders which implement beam polarization, although a detailed study at the specific beam energy will be required.

References

[1] S. Banerjee, J. M. Roney *et al.*, arXiv:2205.12847 (2022)

[2] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Meth. A, **479**, (2002)

[3] B. Aubert *et al.* (*BABAR* Collaboration), Nucl. Instrum. Meth. A, **729**, (2013)

[4] R. J. Barlow and C. Beeston, Comput. Phys. Commun., **77**, 219 (1993)

[5] S. Jadach, B.F.L. Ward, and Z. Wąs, Comput. Phys. Commun. **130**, 260 (2000)