BEAM ENERGY CALIBRATION IN EXPERIMENT ON PRECISE TAU LEPTON MASS MEASUREMENT AT VEPP-4M WITH KEDR DETECTOR

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Abstract

Experiment on mass measurement of tau lepton requires an absolute energy calibration. The resonant depolarization technique is used for most accurate (1 keV) but once at a time energy calibration. The measured energy is used for calibration of the germanium detector for Compton backscattering energy monitoring. The developed Compton backscattering facility allows continuous energy monitoring with accuracy of 50 keV for 10 minutes data acquisition. Tau lepton threshold is in vicinity of integer spin resonance, which minimizes polarization life time in presence of vertical orbit distortions. Therefore spin matching of the VEPP-4M is required. The achieved life time is sufficient for absolute energy calibration.

INTRODUCTION

In the ongoing experiment on mass measurement of tau lepton we use resonant depolarization technique (RD) [1, 2] for energy calibration. The beam energy is varied from 1775 Mev to 1779 MeV around the tau lepton threshold. Polarized beams are obtained in booster ring VEPP-3 at the energy of 1850 MeV, because required time for polarization build up is much smaller than in VEPP-4M. This energy is chosen by results of the beam polarization study in VEPP-3 [4]. For energy calibration two bunches (polarized and unpolarized) are injected in VEPP4-M, which then decelerated to the energy of the experiment. Than there is a pause for 30 minutes to allow magnetic field relaxation in magnets of the VEPP-4M. Next, beams are suffering a frequency scan of the external TEM wave. The moment of the depolarization is registered by the jump in the counting rate of intra-beam scattered electrons from the polarized bunch normalized on counting rate from the unpolarized bunch with the help of polarimeter device. The amplitude of the TEM wave is chosen to partially depolarize the beam in order to perform a backward frequency scan. In such a way, we measure spin precession frequency twice with the opposite direction of the frequency scans. This is done in order to measure and to control errors of the energy calibration associated with the width of the spin frequency distribution and depolarization of the beam on parasitic side bands. Briefly described procedure of energy calibration is followed by injection of the electron and positron beams for statistics acquisition run at the obtained energy. After acquiring necessary amount of events magnetization cycles are performed and energy calibration-statistics acquisition run is repeated.

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In order to perform energy calibration by RD one has to study systematical errors of the method. This have been done and published in [3]. For the mass measurement experiment of tau lepton the systematical error of energy calibration should be less than 50 keV ($3 \cdot 10^{-5}$).

The thorough description of the polarimeter, depolarization process, energy calibration is given in [5, 6, 7]. The developed procedure of the energy calibration have been successfully used in recent experiments on mass measurements of J/Ψ, Ψ' mesons [8] and achieved relative accuracy of the energy calibration was 10^{-6}.

DIFFICULTIES OF ENERGY CALIBRATION AT TAU THRESHOLD

Relaxation Times of Magnetic Field and Beam Energy

Studies of the beam polarization build up in VEPP-3 showed that beam polarization does not exists below energy of 1820 Mev. Therefore injection of the polarized beam is performed at the high energy and followed by the beam deceleration. Such a strong change of the accelerator energy causes beam energy drift due to relaxation of the magnetic fields in the elements of the VEPP-4M. Studies showed that magnetic field (measured by NMR sensor) relaxation time is about 30 minutes (see Fig. 1). In order to study energy relaxation after beam declaration the whole energy region from injection to experiment have been likely shifted to higher energies. Studies of such a translated energy calibrations showed that energy relaxation time is about the same as relaxation time of magnetic field. In order to achieve designed accuracy of energy calibration (about 100 keV) the 30 minutes pause have been chosen after deceleration of the beams.

Intrinsic Spin Resonance

The energy of the tau threshold (1777 MeV) is in vicinity of the integer spin resonance $\nu = 4$ ($E \approx 1763$ MeV,

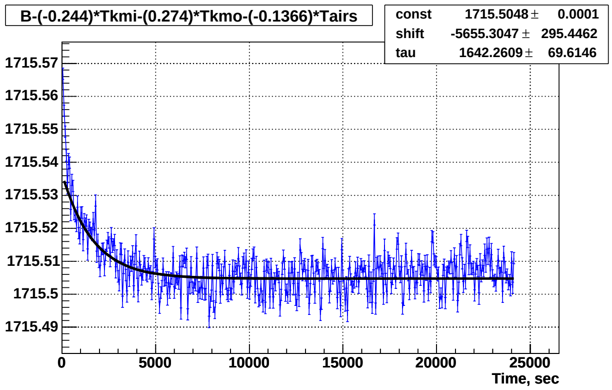

Figure 1: Magnetic field (B, Gauss) relaxation after demagnetization cycle. Temperature dependence of the magnetic field is subtracted.

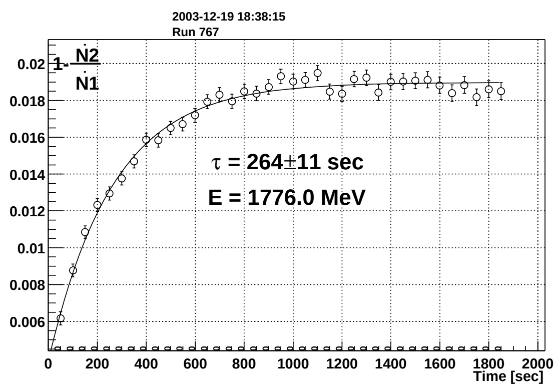

Figure 2: Relaxation of the beam polarization due to radiative depolarization processes ($\tau_r = 2\tau$).

$\nu = E[\text{MeV}]/440.65$ is spin tune in units of a revolution frequency). Because of a small distance to resonance ($\epsilon_k = \nu - k \approx 0.03$) the depolarizing effect of quantum fluctuations related to field imperfections is significantly strengthened. The sources of the field imperfections could be radial fields from the vertically displaced or tilted focusing magnets of VEPP-4M and longitudinal magnetic field. Theoretical studies and numerical simulations showed that alignment of magnetic elements is sufficient to provide polarization life time (τ_r, PLT) in VEPP-4M more than 50 minutes with probability of 100%. However, experimental measurements of PLT gave value about 10 minutes (see Fig. 2). Further experimental studies showed that switching off all electrostatic separation in the VEPP-4M increases PLT to more than 30 minutes. The corresponded energy shift is less than 10 keV, which is sufficient for tau lepton experiment.

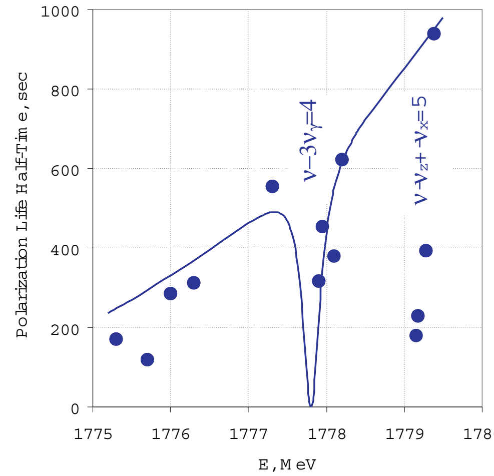

Figure 3: Measured and calculated half PLT versus beam energy near the tau lepton threshold. Solid line is calculation, dots are experimental results.

Working Point in Betatron and Synchrotron Frequencies

Experimental studies of the polarization life time at different energies revealed a structure of the spin resonances (see Fig. 3). Approximately, PLT depends on detuning from the integer resonance in the fourth power as it should be in a case of integer spin resonance. Besides, there are two narrow valleys in the studied energy region. One of them is determined by modulation spin resonance depending on a synchrotron oscillation tune ν_γ: $\nu = 4 + 3\nu_\gamma$. It presents a 'fine structure' of the main resonance $\nu = 4$. Another one is connected with the 3d-order resonance $\nu - \nu_y + \nu_x = 5$. In order to get rid of modulation resonance the RF voltage was lowered providing 10% change of ν_γ which shifted resonance position approximetly by 500 keV. The expected increase of the PLT has been observed.

Longitudinal Detector Field

Longitudinal detector field is compensated by two additional solenoids on both ends of the detector. The closeness of the experiment energy to the integer spin resonance impose strict requirements on accuracy of the detector field compensation. Dependence of PLT on the current of additional solenoids has been experimentally studied. Results are presented on Fig. 4.

COMPTON BACKSCATTERING TECHNIQUE

The head-on interaction of the intense monochromatic laser light with the electron beam gives a flux of backscattered photons. In case of the low energy photon and ultrarelativistic electron ($\varepsilon \gg m \gg \omega$), the highest possible

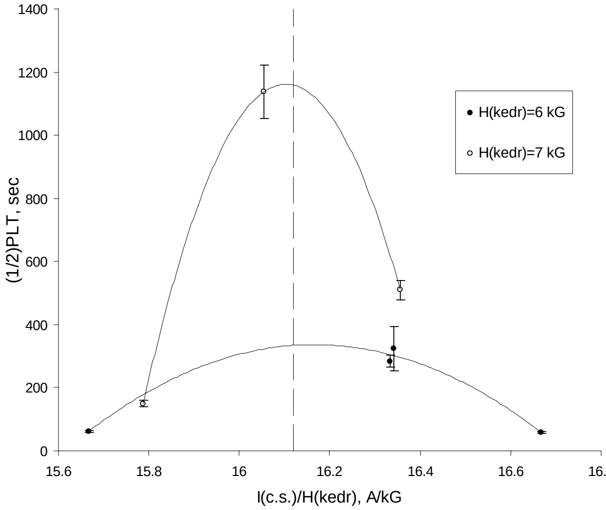

Figure 4: Half of the PLT versus compensation solenoid current to detector field.

energy of backscattered photon is given by:

$$\omega_{max} = \frac{\varepsilon^2}{\varepsilon + m^2/4\omega_0}, \quad (1)$$

where ε is an energy of electron, ω_0 is an energy of laser photon, m is an electron rest mass. Knowing the electron mass m and the laser photon energy ω_0 one can get the average energy of the particles in the electron beam from the measured value of ω_{max}. The width of the energy spectrum edge allows to measure the beam energy spread. This technique was originally implemented at the BESSY-I and BESSY-II storage rings [9, 10].

To satisfy the needs of the experiment the infrared CO_2 laser with wave length of 10.591 μ and output continuous power of $25 \div 50$ Wt was chosen. The photon spectrometer is based on the High Purity Germanium (HPGe) calorimeter (Canberra model GC2518 detector, 120 ml active volume). The maximum energy of scattered photons is about 6 MeV at the energy range of the τ lepton threshold. Detector calibration is done by RD technique and radionuclide gamma lines. The spectrometer energy resolution is 1.5 keV.

The CBS technique allowed energy calibration with accuracy of $5 \cdot 10^{-5}$ and beam energy spread measurement with accuracy of 20%.

As it was mentioned before energy calibration by RD is performed in the beginning of the statistics acquisition run, then energy is controlled by CBS monitor. An extensive study [11] of energy dependence on accelerator parameters (nmr measurement of the guide field, magnets temperatures etc.) allowed us to reconstruct energy during statistics acquisition run (see Fig. 5).

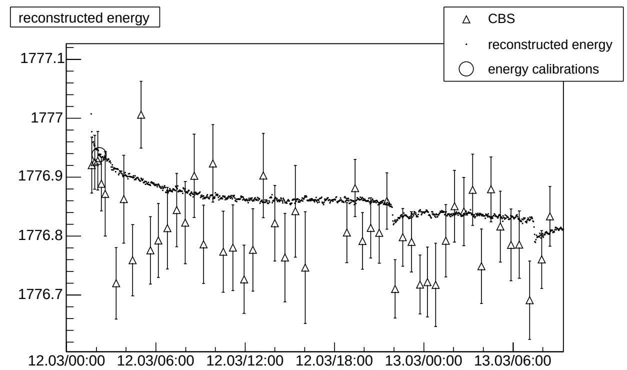

Figure 5: Example of the energy drift during one of the statistics acquisition run.

CONCLUSION

Comprehensive experimental and theoretical studies allowed us to increase polarization life time and to perform energy calibration by resonant depolarization technique in spite of closeness to integer spin resonance. Accuracy of energy calibration is about 30 keV. Energy monitoring is done by the CBS monitor with accuracy of 80 keV.

REFERENCES

[1] A.D. Bukin et al. Varshava, 1975, 138.

[2] Ya.S. Derbenev et al., Particle Accelerators 10 (1980) 177.

[3] V.E. Blinov et al., NIM A 494 (2002) 68-74.

[4] A. Grigoriev et al., Proceedings of EPAC, 5-9 July 2004, Luzern, Switzerland, pp. 2727-2729.

[5] V.E. Blinov et al., NIM A 494 (2002) 81-85.

[6] A. Bogomyagkov et al., Proceedings of PAC, 16-20 May 2005, Knoxville, Tennessee, pp. 1138-1140.

[7] V.E. Blinov et al., Proceedings of EPAC, 2002, Paris, France, pp. 1954-1956

[8] V.M. Aulchenko et al., Phys. Lett. B 573 (2003) 63-79.

[9] R. Klein et al., NIM A 384 (1997) 293-298.

[10] R. Klein et al., NIM A 486 (2002) 545-551.

[11] A.V. Bogomyagkov et al., Proceedings of EPAC 2002, pp.386-388.