Touschek polarimeter for beam energy measurement of VEPP-4M collider

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Outline

Introduction

High precission measurement of masses of J/ψ, ψ',ψ'', D mesons and τ-lepton is very important:

- Metrology and spectroscopy
- Theory test (QCD and Lepton universality)
- Calibration of energy scale of accelerators.

It requires absolute calibration of collider's energy.

- Resonance depolarization method: BINP Novosibirsk Russia, 1975: $K^{\pm}$, K^0, ω, ϕ, J/ψ, ψ', Υ, Υ', Υ''

$$\frac{\Delta m}{m} = 10^{-4} \div 4 \times 10^{-6}$$

- Applied at VEPP-2(M), VEPP-4(M), DORIS-II, CESR, LEP, BESSY-II, SLS, ALS.

Resonance depolarization method (RDM)

- Spin precession frequency depends on beam energy:

$$\Omega_{spin} = \Omega_0(1 + \gamma\frac{\mu'}{\mu_0})$$

  Ω_0 — revolution frequency, μ_0,μ' — normal and anomal part of electron magnetic moment, $\gamma = E/m_e$
- Sokolov-Ternov radiation polarization, 1964:

$$\frac{1}{\tau_{pol}} \simeq \frac{5\sqrt{3}}{8}\frac{\lambda_e r_e c}{R^3}\gamma^5$$

- Polarization is destructed by external electromagnetic field with frequency Ω_{dep}:

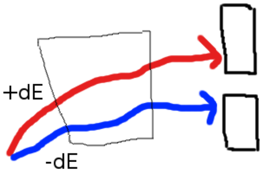
$$\Omega_{spin} = n\Omega_0 + \Omega_{dep}, \;\; n \in \mathbf{Z}$$

- Ω_s is measured at the moment of depolarization during Ω_{dep} frequency scan.
- Polarization destruction can be detected on jump in the rate of intra-beam scattering.

Intra-beam scattering (Touschek effect)

- Cross section of intra-beam scattering depends on polarization of scattered particles:

$$\frac{d\sigma}{d\Omega} = \frac{4r_0^2}{v^4}\left(\frac{4}{\sin^4\theta} - \frac{3}{\sin^2\theta} - \frac{\vec{\zeta_1}\vec{\zeta_2}}{\sin^2\theta}\right)$$

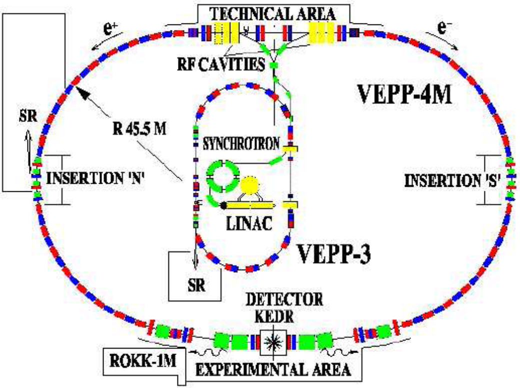


- Scattered particles hit scitillator counters

- Counting rate:

$$\dot{N} = \frac{\sqrt{\pi} r_0^2 c N^2}{\gamma^5 V (\sigma_p/p)^3}\left(I_1 + \zeta^2 I_2\right)$$

VEPP-4 accelerating-storage complex

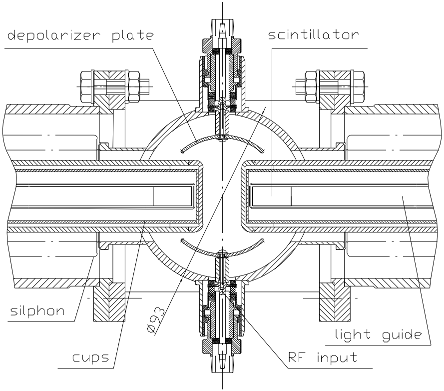


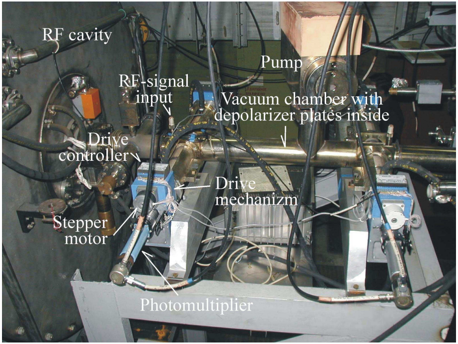
- Linear accelerator LINAC (50 MeV).
- booster synchrotron (350 MeV).
- VEPP-3 storage ring (2 GeV).

VEPP-4M collider

- Beam energy $1 \div 6$ GeV
- Bunch number 2×2
- Luminocity, $E = 1.5$ GeV: 2×10^{30}

Touschek polarimeter





- 4 pairs of scintillator counters are located in different places of VEPP-4M. Due to correlation between counters we use only 2 of them.
- Counting rate is $50 \div 100$ kHz$/mA^2$ per counter.
- Total counting rate is $0.5 - 1.5$ MHz.

Energy calibration procedure

- Prepare polarized beam in VEPP-3 storage ring (2000 sec). Inject it into VEPP-4M.
- Prepare unpolarized beam.
- Equalize currents in polarized and unpolarized beam.
- Monitor relative difference of counting rate of polarized and unpolarized beams.

$$\Delta = \frac{\dot{N}_{pol} - \dot{N}_{unpol}}{\dot{N}_{unpol}}$$

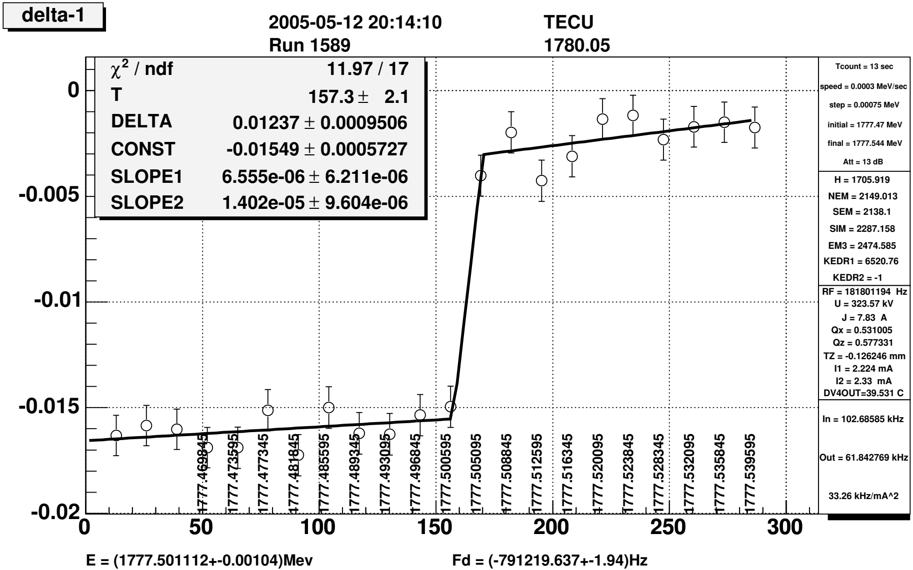
- Turn on the depolarizer and change Ω_{dep} in a region where resonance depolarization expected.
- Find and fit jump in counting rate.

Accuracy of single energy calibration

$$\sigma_E = 1 \text{ keV} \sim 5 \times 10^{-7}$$

- Two energy calibrations using same bunches (partial depolarization).

Example of energy calibration at τ



Energy interpolation between calibrations

$$E = \alpha_H H(1 + \alpha_T \Delta T) + \sum_i \alpha_i \Delta P_i$$

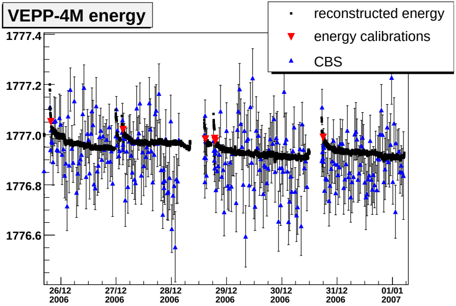
- H - guiding magnetic field in calibrating magnet measured by NMR method
- $\Delta T = T_{CM} - T_{RING}$, T_{RING} - average temperature of accelerators magnets.

P_i are:

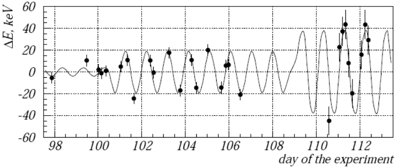
- Temperature of VEPP-4M tunnel.
- Temperature of cooling distilled water
- Average radial orbit
- Air,tech water temperatures,. . .

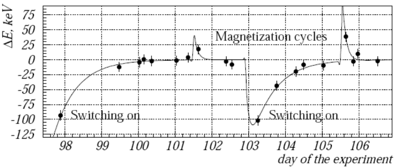
Examples of energy interpolation

VEPP-4M energy in tau mass experiment.



Difference between interpolated energy and the measured energy with all aperiodic dependeces accounted (J/ψ mass experiment)





Application of RDM in experiments with KEDR detector

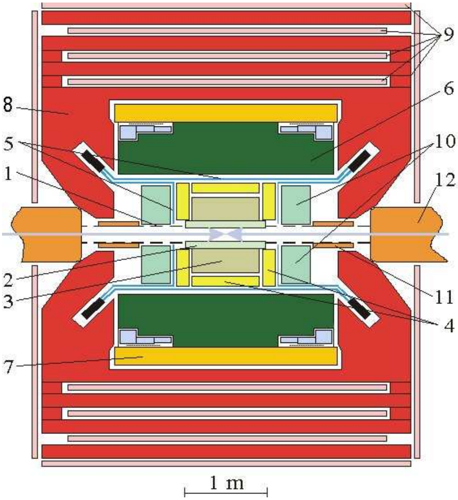
Charmonium masses

- 2002: Scan of J/ψ ($40\ nb^{-1}$)
- 2002: Scan of ψ' ($76 nb^{-1}$)
- 2005: J/ψ ($230 nb^{-1}$)
- 2004-2006: 3 scan of ψ' ($230 nb^{-1}$)
- 2004: $\psi(3770)$

Tau mass

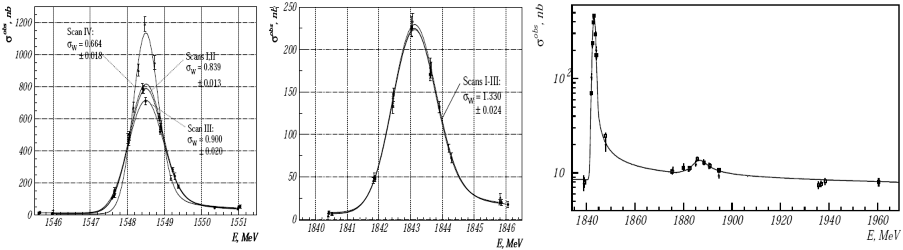
- 2005-2007: $5.2 pb^{-1}$

KEDR detector



1. Vacuum chamber
2. Vertex detector
3. Drift chamber
4. Aerogel Cherenkov counters
5. TOF scintillation counters
6. LKr barrel calorimeter
7. Superconducting coil (6 kGs)
8. Magnet yoke
9. Muon tubes
10. CsI end cap calorimeter
11. Compensating solenoid
12. Quadrupole

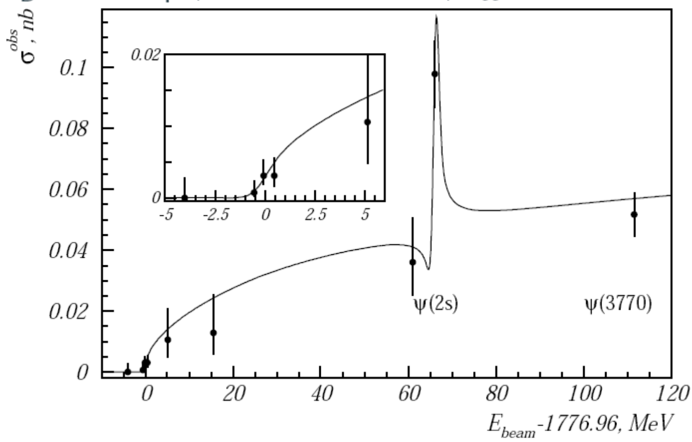
J/ψ , ψ',ψ'' mesons mass measurement.



- $M_{J/\psi} = 3096.917 \pm 0.01 \pm 0.007$ MeV (2002)
- $M_{\psi(2S)} = 3686.117 \pm 0.012 \pm 0.015$ MeV (preliminary)
- $M_{\psi(3770)} = 3773.5 \pm 0.9 \pm 0.6$ MeV (preliminary)

Tau mass measurement

$\sigma_B = 0^{+0.58}$ pb, $\varepsilon = 2.25 \pm 0.28$ %, $\Gamma_{ee}^{\psi'} \cdot B^{\psi' \to \tau\tau} = 8.0 \pm 2.2$ eV



$$M_\tau^{KEDR} = 1776.81^{+0.25}_{-0.23} \pm 0.15 \text{ MeV}$$

$$M_\tau^{KEDR} - M_\tau^{PDG'06} = -0.18^{+0.25}_{-0.23} \pm 0.15 \; ({}^{+0.29}_{-0.26} \; PDG) \text{ MeV}$$

Summary

- Accuracy of single energy calibration is around 1 keV 5×10^{-7}
- More than 2k calibrations done.
- Touschek polarimeter is succesfuly applied for high precision charmonium and tau masses measurement with KEDR detector.
- Accuracy of VEPP-4M energy interpolation is 7 keV for charmonium mass measurement and 30 keV for tau mass measurement.