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Final Result on the Mass of the Tau Lepton from the BES Collaboration*

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ABSTRACT

A data-driven energy scan in the immediate vicinity of τ pair production threshold has been performed using the Beijing Spectrometer (BES) at the Beijing Electron-Positron Collider (BEPC). Approximately 5 pb^{-1} of data, distributed over twelve scan points, have been collected. An initial τ lepton mass value, obtained using only the $e\mu$ final state, has been published. In this paper, the final BES result on the mass measurement, based on the combined data samples of ee, $e\mu$, $e\pi$, eK, $\mu\mu$, $\mu\pi$, μK, $\pi\pi$ and πK events, is presented. A maximum likelihood fit yields the value $m_\tau = 1776.96 \,^{+0.18}_{-0.19}\,^{+0.20}_{-0.16}$ MeV.

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The measurement of the mass of the tau lepton by BES is based on a data-driven energy scan within 25 MeV of the threshold for $e^+e^- \rightarrow \tau^+\tau^-$ production. During the scan, $\tau^+\tau^-$ events were identified by means of the $e\mu$ topology in which one tau decays via $\tau \rightarrow e\nu\bar{\nu}$ and the other via $\tau \rightarrow \mu\nu\bar{\nu}$, and the mass value obtained from a likelihood fit to the 14 observed $e\mu$ events was $m_\tau = 1776.9\,^{+\mathbf{0.4}}_{-\mathbf{0.5}} \pm 0.2$ MeV.[2] This paper presents a new result based on a much larger event sample which combines events from the ee, $e\mu$, $e\pi$, eK, $\mu\mu$, $\mu\pi$, μK, $\pi\pi$ and πK channels, where the $\pi(K)$ result from the decay $\tau \rightarrow \pi(K)\nu_\tau$.

The experimental details are described in Ref. 1. The total data sample consists of 10^7 event triggers corresponding to 5 pb^{-1} of integrated luminosity. The initial selection of $\tau^+\tau^-$ candidates is effected by means of simple topological and particle identification criteria.

It is required that exactly two charged tracks be well reconstructed, without regard to net charge. For each track, the point of closest approach to the beam line should have radius ≤ 1.5 cm and $|z| \leq 15$ cm where z is measured along the beam line from the nominal beam crossing point; in addition $|z_1 - z_2|$ must be less than 5 cm. Furthermore, each track is required to satisfy $|cos\theta| \leq 0.75$, where θ is the polar angle, to ensure it is contained within the cylindrical barrel region of the detector. These criteria reduce the data sample by a factor of ~ 20.

Next it is required that the transverse momentum of each track be above the 100 MeV/c minimum needed to traverse the barrel time-of-flight counter and reach the outer radius of the barrel shower counter in the 0.4 Tesla axial magnetic field. In addition, the magnitude of the momentum must be less than the maximum expected in any tau decay at the given center-of-mass energy within a tolerance of 3 standard deviations in momentum resolution. These constraints on momentum together reduce the data sample by over an order of magnitude leaving $\sim 40,000$ events. Most of this reduction is due to the removal of Bhabha and μ pair events.

A further requirement is that there be no isolated photon present with measured energy greater than 60 MeV and making an angle of greater than $12°$ with the original direction of each of the charged tracks. This reduces the data sample to ~ 33000 events.

The particle identification procedure is applied to the remaining events. For each mass hypothesis (e, μ, π, K, or p) for each track, the measured momentum is used to predict the expected values of dE/dx, time-of-flight and shower counter energy. The corresponding measured quantities and resolutions are then used to create an overall χ^2 value, which is converted to a confidence level using the number of contributing devices as the number of degrees of freedom. Events are rejected for which a positively charged track has $CL(p) \geq 5\%$ (this removes 3441 events due mainly to beam-gas interactions). Next, the μ hypothesis is assigned to a track if $CL(\mu) \geq 5$ %, $|\vec{P}| \geq 0.5\ GeV/c$ and there are corroborating muon counter hits. Failing the muon requirement, a track is assigned the one of the e, π, and K hypotheses with the highest confidence level, provided it is at least 5%. For the π or K assignments it is further required that $|\vec{P}|$ be consistent with 2-body tau decay at the three sigma level; for the calculation of the relevant momentum limits, m_τ is taken 1.0 MeV *below* the previous measurement[2] to make the $\tau \to \pi$, K selection efficiencies independent of center-of-mass energy and to avoid biasing the new mass measurement.

After the particle identification procedures there remain 12571 ee, 1340 $\mu\mu$ and 127 events in the other channels. The ee sample results predominantly from two-photon $e^+e^- \to e^+(e^-e^+)e^-$ events for which the leading e^+ and e^- in the final state are undetected. The $\mu\mu$ sample similarly results from $e^+e^- \to e^+(\mu^+\mu^-)e^-$ events with additional contributions from cosmic rays. These background events are characterized by small observed net transverse momentum and, for the QED events, large missing energy. The $\tau^+\tau^-$ final states are separated from these sources of background by requiring that the ratio of total transverse momentum to the maximum possible missing energy be greater than 0.4 for ee, 0.1 for $e\mu$, and 0.2 for all other channels. The final event sample consists of 64 events distributed as 4 ee, 18 $e\mu$, 19 $e\pi$, 2 eK, 3 $\mu\mu$, 5 $\mu\pi$, 3 μK, 4 $\pi\pi$ and 6 πK.

A maximum likelihood fit is performed to find the values of the mass, m_τ, of the τ lepton, the overall absolute efficiency, ϵ, for identifying $\tau^+\tau^-$ events, and the effective background cross section, σ_B, which is assumed constant over the limited range of center-of-mass energy involved. By fitting the parameter, ϵ, uncertainties in the luminosity scale and trigger and detector efficiencies are implicitly taken into account. The likelihood function is the product over the twelve scan points of the Poisson probability for the observed number of events at each point, where the expected number of events, μ, is given by

$$\mu = (\epsilon \times \sigma(W, m_\tau) + \sigma_B) \times L(W)\ ;$$

here L is the integrated luminosity, and the cross section, $\sigma(W, m_\tau)$, for $\tau^+\tau^-$ production is corrected for Coulomb interaction, initial and final state radiation, vacuum polarization, and the spread ($\sigma \cong 1.4 MeV$) in center-of-mass energy, W.

The parameter values resulting from the fit are $m_\tau = 1776.96$, $\epsilon = 4.14\,\%$, and $\sigma_B = 0$. The statistical uncertainty of m_τ is found by setting $\epsilon = 4.14\,\%$, $\sigma_B = 0$, and integrating the likelihood function to find the 68.3% confidence level interval, with result $m_\tau = 1776.96^{+0.18}_{-0.19}$ MeV. The cross section curve which results from this mass value is plotted over the data in Figs. 1(a), and 1(b); the corresponding likelihood function is shown in Fig. 1(c).

The uncertainty in the efficiency, $\Delta\epsilon =^{+0.54}_{-0.50}$, contributes systematic errors $\Delta m_\tau =^{+0.08}_{-0.09}$ MeV to the mass of the τ, and that in the background cross section, $\Delta\sigma_B = +0.61$ pb (which corresponds to a 1σ background level of 3.1 events), contributes systematic error $\Delta m_\tau = +0.12$ MeV; possible bias in the scanning procedure contributes $\Delta m_\tau = \pm 0.10$ MeV, as estimated from Monte Carlo simulations; and uncertainties in the center-of-mass energy scale and energy spread yield $\Delta m_\tau = \pm 0.09$ MeV and $\Delta m_\tau = \pm 0.02$ MeV respectively.

Combining the systematic errors in quadrature, the final BES result on the mass of the τ lepton is

$$m_\tau = 1776.96\ ^{+0.18}_{-0.19}\ ^{+0.20}_{-0.16}\ \text{MeV}$$

where the first errors are statistical, and the second systematic.

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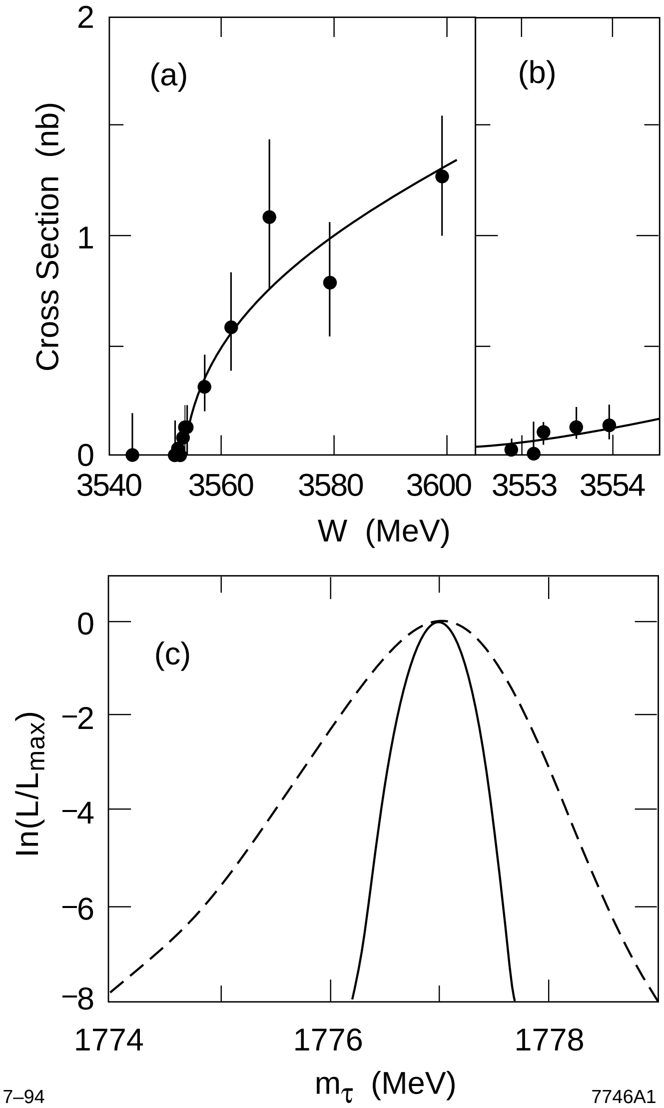

Figure 1: (a) The center-of-mass energy dependence of the $\tau^+\tau^-$ cross section resulting from the likelihood fit (curve), compared to the data (Poisson errors). It should be emphasized that the curve does not result from a direct fit to these data points. (b) An expanded version of (a), in the immediate vicinity of $\tau^+\tau^-$ threshold. (c) The solid curve shows the dependence of the logarithm of the likelihood function on m_τ, with the efficiency and background parameters fixed at their most likely values; the dashed curve shows the likelihood function from Ref. 2.