$\tau\nu$ Decay Signature for Detecting $F^{\pm}$ and $B^{\pm}$ Mesons in e^+e^- Collisions

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The decay modes $F(c\bar{s}), B(b\bar{u}, b\bar{c}) \to \tau\nu$ are proposed as triggers for $e^+e^- \to F\bar{F}, B\bar{B}$ production. Decay branching fractions of order $B(F) \simeq 15\%$ and $B(B) \simeq (1$ to $2)\%$ are estimated. The sequential $\tau \to e\nu\bar{\nu}, \mu\nu\bar{\nu}$ decays provide clear signatures, with the hadronic decay of the associated F, B carrying exactly half the energy. These triggers can be extended to study F^* and B^* resonance production and also to exploit the $\tau \to \pi\nu, \rho\nu, A_1\nu$ decays.

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The detection of F ($\bar{c}s$) mesons in e^+e^- experiments has proved to be difficult. The detection of B ($b\bar{q}$) mesons will likely be difficult also because of small decay branching fractions into quasi two-body modes,[1] and the difficulty of identifying charm-particle decay products. The purpose of this Letter is to draw attention to the promise of $\tau\nu$ decay as a clear signal of $F\bar{F}$ or $B\bar{B}$ production, especially near threshold. Our proposal is based on branching fractions $B(F^{\pm} \to \tau\nu) \simeq 0.15$ and $B(B^{\pm} \to \tau\nu) \simeq 0.02$, for which estimates we give arguments later. The key element is sequential leptonic $\tau \to e\nu\bar{\nu}, \mu\nu\bar{\nu}$ decays with combined branching fraction 0.36, that convert the original F or B meson into one charged lepton and three neutrinos. In the class of events with one $\tau\nu$ decay and one hadronic decay of the produced $F\bar{F}$ or $B\bar{B}$, exactly half of the available energy is hadronic, while the other half is leptonic and mostly invisible. The signature is thus very clear: one charged lepton plus $E(\text{hadrons}) = \frac{1}{2}\sqrt{s}$. Also, for production near threshold, the net hadronic momentum will be small. The invariant mass of the hadrons should be exactly m_F or m_B.

The background from $e^+e^- \to \tau\bar{\tau}$ should be easily distinguished both by $E(\text{hadrons}) < \frac{1}{2}\sqrt{s}$ and $m(\text{hadrons}) < m_\tau$. We believe that triggers of the kind proposed here have not been exploited in the past, because of cuts $E(\text{hadrons}) \gg \frac{1}{2}\sqrt{s}$ imposed to eliminate beam-gas backgrounds. However, the events under discussion will not look like beam-gas events because of their net hadronic momentum, which is not constrained to be in the beam direction and is small near threshold. Our trigger requires large solid-angle acceptance to reduce background from events where some particles miss the detectors. It also requires that neutral hadrons be detected. The background from $e^+e^- \to e^+e^-X$ events where one electron escapes detection gives predominantly hadronic states X of low invariant mass, unlike the trigger of interest.

The $\tau\nu$ trigger can also be exploited, with minor modifications, to study resonance production such as $e^+e^- \to B\bar{B}^*$ with $B^* \to B\pi$ or $B\gamma$. The sequential modes $\tau \to \pi\nu, \rho\nu, A_1\nu$ can also be employed in a missing-energy trigger; in these cases an identified charged π, ρ, or A_1 can play the same role as the charged lepton did in the purely leptonic mode.

For the tagged events obtained as indicated, further checks may be made through the distinctive distributions of the charged particle originating from the τ decay. For this purpose we present the relevant calculated distributions below.

For a pure leptonic decay $H \to \tau\nu$ for pseudoscalar $H(Q\bar{q}) = F(c\bar{s}), B_u(b\bar{u}), B_c(b\bar{c})$, the decay rate is

$$\Gamma(H \to \tau\nu) = |U_{Qq}|^2 G_F^2 f_H^2 m_H m_\tau^2 (1 - m_\tau^2/m_H^2)^2/8\pi, \quad (1)$$

where U_{Qq} is the Kobayashi-Maskawa mixing matrix[2] and f_H is the meson decay constant. Information about the mixing angles has been deduced from analyses of K^0-$\bar{K}^0$ mixing[3,4] and from Cabibbo-suppressed D^0 decays.[5] The favored values of U_{Qq} are[3,5,6]

$$|U_{cs}| = 0.97,\quad |U_{bu}| = 0.07\text{–}0.12,\quad |U_{bc}| = 0.13\text{–}0.16. \quad (2)$$

For our estimates we use the central values of these ranges. For the F-decay constant, we assume $f_F = f_D$ and take $f_D \simeq 0.43$ GeV as determined[7] from $D^{*+,0}$ and $D^{+,0}$ electromagnetic mass split-

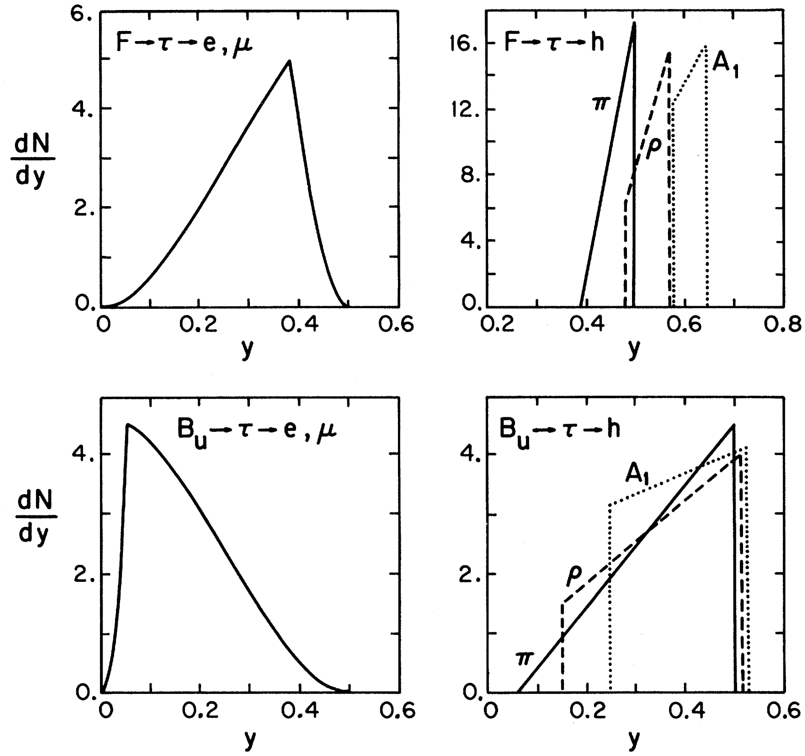

FIG. 1. Invariant distributions dN/dy in $y = p_h \cdot p_H / m_H^2$, where p_h is the momentum of the charged particle emitted in the τ decay stage of $H \to \tau\nu$. The curves illustrate the cases $H = F(c\bar{s})$ and $H = B_u(b\bar{u})$, with $\tau \to e\nu\bar{\nu}$, $\pi\nu$, $\rho\nu$, and $A_1\nu$. In the H rest frame $y = E_h/m_H$, where E_h is the charged-particle energy.

tings. For the B_u decay constant we take $f_B = 0.5$ GeV, from theoretical calculations,[8] and assume the same value for B_c. With the above inputs, and masses $m_F = 2.03$ GeV, $m_{B_u} = 5.3$ GeV, $m_{B_c} = 6.7$ GeV, we obtain

$$\Gamma(F \to \tau\nu) = 4.7 \times 10^{11}\ \mathrm{s}^{-1},$$
$$\Gamma(B_u \to \tau\nu) = 2.4 \times 10^{11}\ \mathrm{s}^{-1}, \qquad (3)$$
$$\Gamma(B_c \to \tau\nu) = 7.7 \times 10^{11}\ \mathrm{s}^{-1}.$$

For the total widths, we rely on theoretical F-meson[9] and B-meson[6] lifetime calculations which give

$$\tau(F^+) \sim (2-4) \times 10^{-13}\ \mathrm{s},$$
$$\tau(B_u) \sim (5-10) \times 10^{-14}\ \mathrm{s}, \qquad (4)$$
$$\tau(B_c) \sim (1-3) \times 10^{-14}\ \mathrm{s}.$$

In the B case these calculations have not included annihilation-diagram contributions which may reduce these lifetimes somewhat. From Eqs. (3) and (4), we obtain branching fractions

$$B(F \to \tau\nu) \sim (10-20)\%,$$
$$B(B_u \to \tau\nu) \sim (1-2)\%, \qquad (5)$$
$$B(B_c \to \tau\nu) \sim (1-2)\%,$$

that are within the range of feasibility. In particular, the B_u branching fraction compares favorably with inclusive ψ-decay estimates[10] of a few percent, the detection of which involves a factor $B(\psi \to \mu\mu, ee) = 0.07$. Moreover, the study of $\tau\nu$ decay modes, combined with experimental measurements of lifetimes, will provide a measurement of the decay constants f_F and f_B, which are of considerable theoretical significance.

As a cross-check on the identification of $\tau\nu$ modes from the missing-energy trigger and the invariant-mass constraint, the invariant distribution in $y = p_h \cdot p_H / m_H^2$ can be measured, where p_h is the momentum of the charged particle with mass m_h emitted in τ decay. For H produced at rest, $y = E_h/m_H$ and dN/dy is the energy distribution. In an arbitrary frame dN/dy is related to the conventional invariant rate by

$$dN/dy = [4\pi m_H (y^2 m_H{}^2 - m_h{}^2)^{1/2}] E_h dN/d^3p_h. \tag{6}$$

In terms of $R = (m_\tau/m_H)^2$ and $r = (m_h/m_\tau)^2$, with $m_e = m_\mu = 0$, the various dN/dy distributions (normalized to unity) are

$$dN(e,\mu)/dy = \begin{cases} \frac{16}{3}[(1+2R)/R^2]y^2(3-4y), & 0 \le y \le \frac{1}{2}R, \\ \frac{4}{3}[(3-2R)/(1-R)^2](1-2y)^2(1+4y), & \frac{1}{2}R \le y \le \frac{1}{2}; \end{cases}$$

$$dN(\pi)/dy = 4[2y-(r+R)]/[(1-R)^2(1-r)^2], \quad \tfrac{1}{2}(R+r) \le y \le \tfrac{1}{2}(1+rR);$$

$$dN(\rho, A_1)/dy = 4[2(1-2r)y + (2r^2R + r - R)]/[(1-R)^2(1-r)^2(1+2r)], \quad \tfrac{1}{2}(R+r) \le y \le \tfrac{1}{2}(1+rR).$$

The dN/dy distributions for F and B decays to $\tau\nu$ are shown in Fig. 1.

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[1]A. Ali, J. G. Körner, G. Kramer, and J. Willrodt, Z. Phys. C 1, 269 (1979).

[2]M. Kobayashi and K. Maskawa, Prog. Theor. Phys. 49, 652 (1973).

[3]V. Barger, W. F. Long, and S. Pakvasa, Phys. Rev. Lett. 42, 1585 (1979).

[4]R. E. Shrock, S. Treiman, and L.-L. Wang, Phys. Rev. Lett. 42, 1589 (1979).

[5]V. Barger and S. Pakvasa, Phys. Rev. Lett. 43, 812 (1979).

[6]V. Barger, W. F. Long, and S. Pakvasa, J. Phys. G 5, L147 (1979).

[7]M. Suzuki, private communication.

[8]R. N. Cahn and S. D. Ellis, Phys. Rev. D 16, 1484 (1977); V. A. Novikov *et al.*, Phys. Rev. Lett. 38, 626 (1977); S. S. Gershtein and M. Yu. Khlopov, JETP Lett. 23, 338 (1976) [Pis'ma Zh. Eksp. Teor. Fiz. 23, 374 (1976)].

[9]M. Bander, D. Silverman, and A. Soni, Phys. Rev. Lett. 44, 7 (1980); V. Barger, J. P. Leveille, and P. M. Stevenson, University of Wisconsin, Madison, Report No. COO-881-124 (unpublished).

[10]H. Fritzsch, Phys. Lett. 86B, 164 (1979); M. Wise, Phys. Lett. 89B, 229 (1980); T. A. DeGrand and D. Toussaint, Phys. Lett. 89B, 256 (1980); J. H. Kühn, S. Nussinov, and R. Rückl, Max-Planck-Institut, Munich, Report No. MPI-PAE/PTh 50/79, 1979 (to be published).

Differential and Total Proton Cross Sections, Particle Production, and the Parton Model

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Using parton-model concepts together with data on resonance production in proton-proton interaction, we present a model for p-p elastic scattering and total cross sections. The energy dependence is the result of gluon-gluon annihilation. The comparison with experiment shows remarkable agreement.

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Inspection of the experimental data for hadron-proton reaction products indicates an expected division into central production and beam or target fragmentation.[1] For example, in K-p reactions one finds a substantial component of the vector meson $K^*(890)$ in both the central and fragmentation regions whereas for p-p interaction there is no significant beam fragmentation component for $K^*(890)$ production.