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Limits on the Production of Pointlike, Charged, Spin-0 Particles in e^+e^- Annihilations at 29 GeV

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A search for charged, pointlike, spin-0 particles with large couplings to the τ lepton has been done at the PEP e^+e^- storage ring (Stanford Linear Accelerator Center). No evidence for such particles is seen, and limits are placed on the branching fraction to $\tau\nu_\tau$ as a function of mass.

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In currently accepted gauge theories of weak interactions,[1] fermions and gauge bosons acquire masses from spontaneous symmetry breaking. This is acheived through fundamental Higgs fields or dynamically through composite scalar fields (technicolor theories[2]). The minimal Weinberg-Salam model has one physical, neutral Higgs boson, whose couplings to fermions are proportional to the fermion masses. Other models, based on larger gauge groups or with extra Higgs doublets, have additional, charged Higgs bosons, whose couplings, however, are not as rigidly fixed as in the minimal model. Dynamical symmetry-breaking models introduce a new strong interaction at a scale of ~1 TeV, which results in a rich spectrum of pseudo-Goldstone bosons[3] (hyperpions), some of which are expected to have masses of a few gigaelectronvolts. No Higgs boson or hyperpion, charged or neutral, has yet been observed.

A search for charged Higgs particles or hyperpions (referred to as a Higgs and represented by $H^\pm$ hereafter) has been done with data collected by the Mark II detector[4] at the PEP storage ring (Stanford Linear Accelerator Center). The data correspond to an integrated luminosity of 14.4 pb^{-1} accumulated at a center-of-mass energy ($\sqrt{s}$) of 29 GeV. Higgs pairs are assumed to be produced via the reaction

$$e^+e^- \to H^+H^-$$

with a cross section of

$$d\sigma/d\Omega = \alpha^2\beta^3 \sin^2\theta/8s, \tag{1}$$

where α is the fine-structure constant, β is the velocity of the Higgs, and θ is the polar angle. The Higgs is assumed to decay rapidly to the heaviest fermions possible, either heavy quarks or the heavy lepton τ and its neutrino. Two cases have been considered: (1) One Higgs decays to hadrons and the other to $\tau\nu_\tau$, and (2) both Higgses decay to $\tau\nu_\tau$.

Events where one Higgs decays to hadrons and the other to $\tau\nu_\tau$ are expected to have a low-multiplicity "jet" from the τ opposite to a multiprong jet. The charged particles in each event are divided into two groups by the plane perpendicular to the thrust axis[5] and the following criteria applied: (1) Total energy (charged particles + photons) $>s^{1/2}/4$; (2) one group of particles has exactly one charged track, fewer than three photons, and an invariant mass <2 GeV/c^2; (3) the other group of particles has at least three charged particles, any number of photons, and invariant mass >2 GeV/c^2; and (4) the highest-momentum particle in at least one of the groups has momentum >2 GeV/c, enters the liquid-argon fiducial volume, and deposits energy $<30\%$ of its momentum. Criterion (1) rejects two-photon-exchange events, criterion (2) selects one-prong τ decays, criterion (3) rejects τ-pair events, and criterion (4) rejects radiative Bhabha events with a γ conversion in the material surrounding the interaction region.

These selection criteria leave 22 observed events compared to 6000 produced hadronic events. A transverse-momentum imbalance between the two groups of decay products is expected in Higgs-pair events as a result of undetected neutrinos. To search for a Higgs signal in these events, an axis in the plane perpendicular to the beam is chosen so that the momenta transverse to this axis for the two groups of particles are equal and minimum. This common transverse momentum is defined to be P_T and is given by

$$P_T = |(\vec{p}_1 \times \vec{p}_2)\cdot\hat{z}|/|(\vec{p}_1 - \vec{p}_2)\times\hat{z}| ,$$

where $\vec{p}_{1,2}$ are the total momenta of the two groups and $\hat{z}$ is the unit vector in the beam direction. The P_T distribution for events meeting the above criteria is shown in Fig. 1. All of the events fall at low P_T, typical of the 300-MeV/c transverse momentum seen in normal hadronic jet events. The solid curve in Fig. 1 is the prediction of a Monte Carlo simulation of hadronic production normalized by a factor of 0.5 to agree with the observed number of events. This simulation is only used to set a P_T cut (discussed below). The results of this analysis are relatively insensitive to this P_T cut, and hence small uncertainties in the hadron Monte Carlo program are not a bias to this measurement. The P_T distribution expected from a Higgs is also calculated from a Monte Carlo simulation program, which produces a pair of Higgses according to the differential cross section given in Eq. (1). One Higgs decays to a $c\bar{s}$ quark pair, each member of which hadronizes via Feynman-Field fragmentation.[6] The other Higgs decays to $\tau\nu_\tau$, and the τ decays according to the measured decay modes. The only property of the hadronic decay of the Higgs Monte Carlo program crucial to this analysis is the charged multiplicity distribution. The average charged multiplicity of a Higgs decay in the Monte Carlo program agrees with e^+e^- data at an equivalent energy. The rest of the analysis is based on the kinematics of producing particle pairs and not on the details of quark fragmentation into hadrons.

The dashed curve in Fig. 1 shows the expected P_T distribution for a Higgs with mass 7 GeV/c^2 and branching ratios $B(H\to\text{hadrons}) = 1 - B(H \to \tau\nu_\tau) = 0.5$. The discrimination between Higgs production and the background is at large P_T. A cut of $P_T = 0.6$ GeV/c is chosen solely from the Monte Carlo curves to maximize the statistical significance of a potential Higgs signal. If one assumes that the Higgs decays only to hadrons and to $\tau\nu_\tau$, the absence of events above $P_T = 0.6$ GeV/c leads to limits (90% C.L.) on branching fractions as a function of mass as shown by curve *I* of Fig. 2. The lower bound on the mass is due to the expected P_T spectrum from a Higgs narrowing to low P_T values as the mass is reduced. The upper bound is due to reduction of the number of expected Higgs from the β^3 threshold term in the production cross section.

The shape of the excluded region in Fig. 2 is relatively insensitive to the P_T cut. Increasing

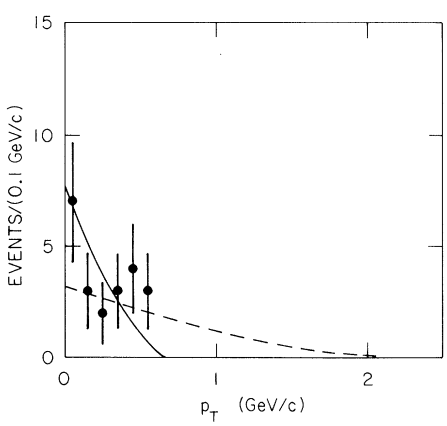

FIG. 1. P_T distribution for events with one prong opposite a multiprong jet. The solid curve is the prediction of the hadron Monte Carlo program normalized to the data. The dashed curve is the expectation for a Higgs with mass 7 GeV/c^2 and $B(H\to\text{hadrons}) = 1 - B(H\to\tau\nu_\tau) = 0.5$.

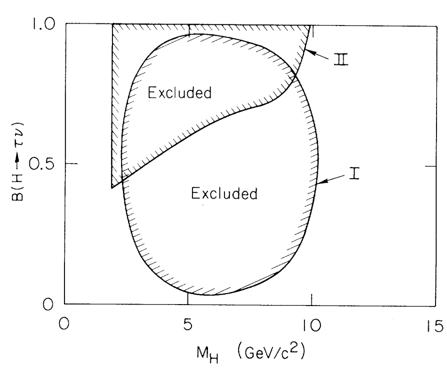

FIG. 2. Excluded regions (90% C.L.) for events where one Higgs decays to hadrons and the other to $\tau\nu_\tau$ (curve *I*) and for events where both Higgses decay to $\tau\nu_\tau$ (curve *II*). The branching ratio to hadrons plus the branching ratio to $\tau\nu_\tau$ is constrained to sum to 1.

the cut to 0.7 GeV/c moves the lower mass bound of the excluded region from ~3 to ~4 GeV/c^2 and changes the rest of the contour very little. Decreasing the P_T cut to 0.5 GeV/c has a larger effect because of the three events between 0.5 and 0.6 GeV/c, but there is still a substantial excluded region extending from M_H = ~3.5 to ~8 GeV/c^2 and from B_τ = ~10% to ~90%. The shape of the excluded region in Fig. 2 is insensitive to whether the Higgs decays to $c\bar{s}$, $c\bar{b}$, or $u\bar{d}$ in the Monte Carlo program.

To search for events where both Higgses decay to $\tau\nu_\tau$, τ-pair events are selected. The criteria below are optimized to find events from $e^+e^- \rightarrow \tau^+\tau^-$ (see Blocker *et al.*[7]). The particles (charged and neutral) in each event are again divided into two groups by the plane perpendicular to the thrust axis, and the following cuts applied (reactions in parentheses are the primary background rejected by the cut): (1) There are one to three charged particles in each group; (2) total energy (charged particles + photons) $> s^{1/2}/4$ (two-photon-exchange events); (3) each group has invariant mass < 2 GeV/c^2; (4) all the charged particles in at least one group have momentum less than 8 GeV/c (μ-pair events); (5) the event contains no muon (identified by the muon system) with momentum > 3 GeV/c (radiative μ-pair events); (6) the highest-momentum particle in at least one of the groups has momentum > 2 GeV/c, enters the liquid-argon fiducial volume, and deposits energy $< 30\%$ of its momentum (Bhabha events); (7) both groups cannot contain exactly one charged particle that is a muon with momentum > 2 GeV/c ($e^+e^- \rightarrow e^+e^-\mu^+\mu^-$); (8) the time of flight of the highest-momentum particle in each group is within 3 ns of the expected time (cosmic rays); (9) the two groups have different charge; and (10) the acollinearity angle between the total momentum of each group is less than 50°. Criteria (1), (3), and (9) select the general τ-pair topology, and criterion (10) reduces radiative corrections.

The same variable P_T defined above is used to look for a Higgs contribution to τ-pair production. The observed P_T distribution (Fig. 3) is well fitted by a τ-pair Monte Carlo simulation and no evidence for Higgs-pair production is seen. To place limits on Higgs production, the data in Fig. 3 are fitted by a sum of the τ-pair Monte Carlo prediction and the Higgs Monte Carlo prediction for various masses of the Higgs. The branching ratio of the Higgs to $\tau\nu_\tau$ is the only free parameter in this fit, which gives the limits (90% C.L.) shown by curve *II* of Fig. 2.

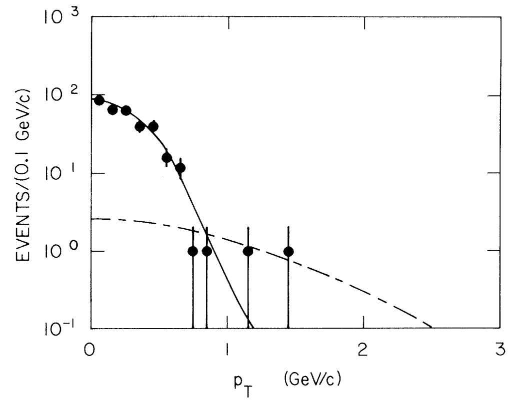

FIG. 3. P_T distribution for τ-pair events. The solid curve is the expectation for normal τ-pair production. The dashed curved is the expectation for a Higgs with mass 7 GeV/c^2 and $B(H \rightarrow \tau\nu_\tau) = 1$.

The left boundary of curve *II* is given by the τ mass. The existence of a charged Higgs with mass less than m_τ and couplings proportional to mass is excluded by the measured properties of the τ, such as the equality of the muonic and electronic decay rates.[8]

Supersymmetry theories[9] predict a scalar partner for the τ ($\tilde{\tau}$), which decays to $\tau\tilde{\gamma}$ where $\tilde{\gamma}$ is the supersymmetry partner of the photon. In most models, the $\tilde{\gamma}$ has low mass, is long lived, is weakly interacting, and escapes detection. Thus, the decay $\tilde{\tau} \rightarrow \tau\tilde{\gamma}$ has identical signature to the decay $H \rightarrow \tau\nu_\tau$. Setting β_τ equal to 1 in Fig. 2 rules out a scalar τ with mass from m_τ to 9.9 GeV/c^2.

Several PETRA experiments have done similar searches for fundamental scalars. Bartel *et al.* and Adeva *et al.* place limits[10,11] on both cases studied in this Letter, that is, where one Higgs decays to $\tau\nu_\tau$ and the other Higgs decays to hadrons or to $\tau\nu_\tau$. Behrend *et al.* have studied[12] the case where both Higgses decay to $\tau\nu_\tau$. The CLEO group at the Cornell Electron Storage Ring has studied[13] charged Higgs production in B-meson decays.

It is difficult to exclude a large hadronic branching ratio of a Higgs, since if both Higgses decay to $q\bar{q}$, the events look very similiar to normal hadronic events. At larger Higgs masses the events are richer in three- and four-jet topologies, but gluon radiation by quarks in hadronic events and decay of heavy quarks (bottom) are large backgrounds.

In conclusion, charged, pointlike, spin-0 particles coupling primarily to heavy fermions and having a mass less than ~10 GeV/c^2 and a branching fraction to $\tau\nu_\tau$ greater than ~10% are excluded.

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