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# Limits on the Production of Point-like, Charged, Spin 0 Particles in $e^+e^-$ Annihilations at 29 GeV*

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## ABSTRACT

A search for charged, point-like, spin 0 particles with large couplings to the $\tau$ lepton has been done at the PEP $e^+e^-$ storage ring. 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 mass. 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] (technipions) some of which are expected to have masses of a few GeV. No Higgs boson or technipion, charged or neutral, has yet been observed.

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

$$e^+e^- \rightarrow H^+H^-$$

with a cross section of

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2\beta^3\sin^2\theta}{8s} \qquad (1)$$

where $\alpha$ is the fine structure constant, $\beta$ is the velocity of the Higgs, $\theta$ is the polar angle, and s is the square of the center-of-mass energy. The Higgs is assumed to decay to the heaviest fermions possible, either heavy quarks or the heavy lepton $\tau$. Two cases have been considered: (1) one Higgs decays to hadrons and the other to $\tau\nu_\tau$ and (2) both Higgs decay to $\tau\nu_\tau$.

To look for events where one Higgs decays to hadrons and the other to $\tau\nu_\tau$, events with one charged particle (from the $\tau$) opposite a multiprong jet are selected. 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) $> \sqrt{s}/4$,

(2) one group of particles has exactly one charged track, less than 3 photons, and an invariant mass $< 2$ GeV/c$^2$,

(3) the other group of particles has at least 3 charged particles, any number of photons, and invariant mass greater than 2 GeV/c$^2$, and

(4) the highest momentum particle in at least one of the groups has momentum above 2 GeV/c, enters the fiducial volume of the liquid argon shower counters, and deposits energy less than 30% of its momentum.

Criterion (1) rejects two photon exchange events, and criterion (4) rejects radiative Bhabha events with a gamma conversion in the material surrounding the interaction region.

These selection criteria leave 22 observed events. To search for a Higgs signal in these events, an axis in the plane perpendicular to the beam is chosen so that the momentum transverse to this axis is equal for the two groups of particles. This has two solutions; the one with minimum transverse momentum is chosen. This common transverse momentum is defined to be $P_T$ and is given by

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

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 Figure 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 Figure 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 Higgs according to the differential cross section given in equation (1). One Higgs decays to a $c\bar{s}$ quark pair, which hadronize via Feynman-Field fragmentation.[6] The other Higgs decays to $\tau\nu_\tau$, and the $\tau$ 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 Figure 1 shows the expected $P_T$ distribution for a Higgs with mass 7 GeV/c$^2$ and branching ratios $B(H\to hadrons) = 1 - B(H\to\tau\nu_\tau) = 0.5$. 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 for a mass of 7 GeV/$c^2$ and B(H→hadrons) = 1 - B($H \to \tau\nu_\tau$) = 0.5. Assuming 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 Figure 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 $\beta^3$ threshold term in the production cross section.

The shape of the excluded region in Figure 2 is relatively insensitive to the $P_T$ cut. Increasing the cut to 0.7 GeV/c moves the lower mass bound of the excluded region from ~3 GeV/$c^2$ 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 due to the 3 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 $B_\tau$ = ~10 to ~90%. The shape of the excluded region in Figure 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 Higgs decay to $\tau\nu_\tau$, events containing $\tau$-pairs are selected. The criteria below are optimized to find events from $e^+e^- \to \tau^+\tau^-$, as described in more detail in Reference 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 parenthesis are the primary background rejected by the cut):

(1) 1 to 3 charged particles in each group,

(2) total energy (charged particles + photons) > $\sqrt{s}/4$ (2 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 ($\mu$-pair events),

(5) the event contains no muon (identified by the muon system) with momentum > 3 GeV/c (radiative $\mu$-pair events),

(6) the highest momentum particle in at least one of the groups has momentum above 2 GeV/c, enters the fiducial volume of the liquid argon shower counters, and deposits energy less than 30% of its momentum (Bhabha events),

(7) both groups cannot contain exactly one charged particle that is a muon with momentum above 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°.

The same variable $P_T$ defined above is used to look for a Higgs contribution to $\tau$-pair production. The observed $P_T$ distribution (Figure 3) is well fit by a $\tau$-pair Monte Carlo simulation and no evidence for Higgs-pair production is seen. To place limits on Higgs production, the data in Figure 3 are fit to a sum of the $\tau$-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 Figure 2. The left boundary of curve II is given by the $\tau$ mass. The existence of a charged Higgs with mass less than $m_\tau$ and couplings proportional to mass is excluded by the measured properties of the $\tau$, such as, the equality of the muonic and electronic decay rates.[8] A low mass, charged Higgs with large couplings to charm is excluded by measurements of charmed particle lifetimes.[9]

Supersymmetry theories[10] predict a scalar partner for the $\tau$ ($\tilde{\tau}$), which decays to $\tau\tilde{\gamma}$ where $\tilde{\gamma}$ is a photino (the supersymmetry partner of the photon). In most models, the photino has low mass, is long-lived, is weakly interactin, and escapes detection. Thus, the decay $\tilde{\tau} \rightarrow \tau\tilde{\gamma}$ has identical signature to the decay $H \rightarrow \tau\nu_\tau$. Setting $B_\tau$ to 1 in Figure 2 rules out a scalar $\tau$ with mass from $m_\tau$ to 9.9 GeV/$c^2$.

Several PETRA experiments have done similiar searches for fundamental scalars. The JADE and Mark J collaborations place limits[11,12] 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 $\tau\nu_\tau$. The CELLO collaboration has studied[13] the case where both Higgs decay to $\tau\nu_\tau$.

It is difficult to exclude a large hadronic branching ratio of a Higgs, since if both Higgs decay to $q\bar{q}$, the events look very similiar to normal hadronic events. At larger Higgs masses the events are richer in 3 and 4 jet topologies, but gluon radiation by quarks in hadronic events and decay of heavy quarks (bottom) are large backgrounds. More statistics will be necessary to make a statement about Higgs production in this region.

In conclusion, charged, point-like, 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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## FIGURE CAPTIONS

1. $P_T$ distribution for events with 1 prong opposite a multi-prong 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→hadrons) = 1 - B($H \to \tau\nu_\tau$) = 0.5.
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 Higgs decays to $\tau\nu_\tau$ (curve II). The branching ratio to hadrons plus the branching ratio to $\tau\nu_\tau$ is contrained to sum to 1.
3. $P_T$ distribution for $\tau$-pair events. The solid curve is the expectation for normal $\tau$-pair production. The dashed curved is the expectation for a Higgs with mass 7 GeV/$c^2$ and B($H \to \tau\nu_\tau$) = 1.

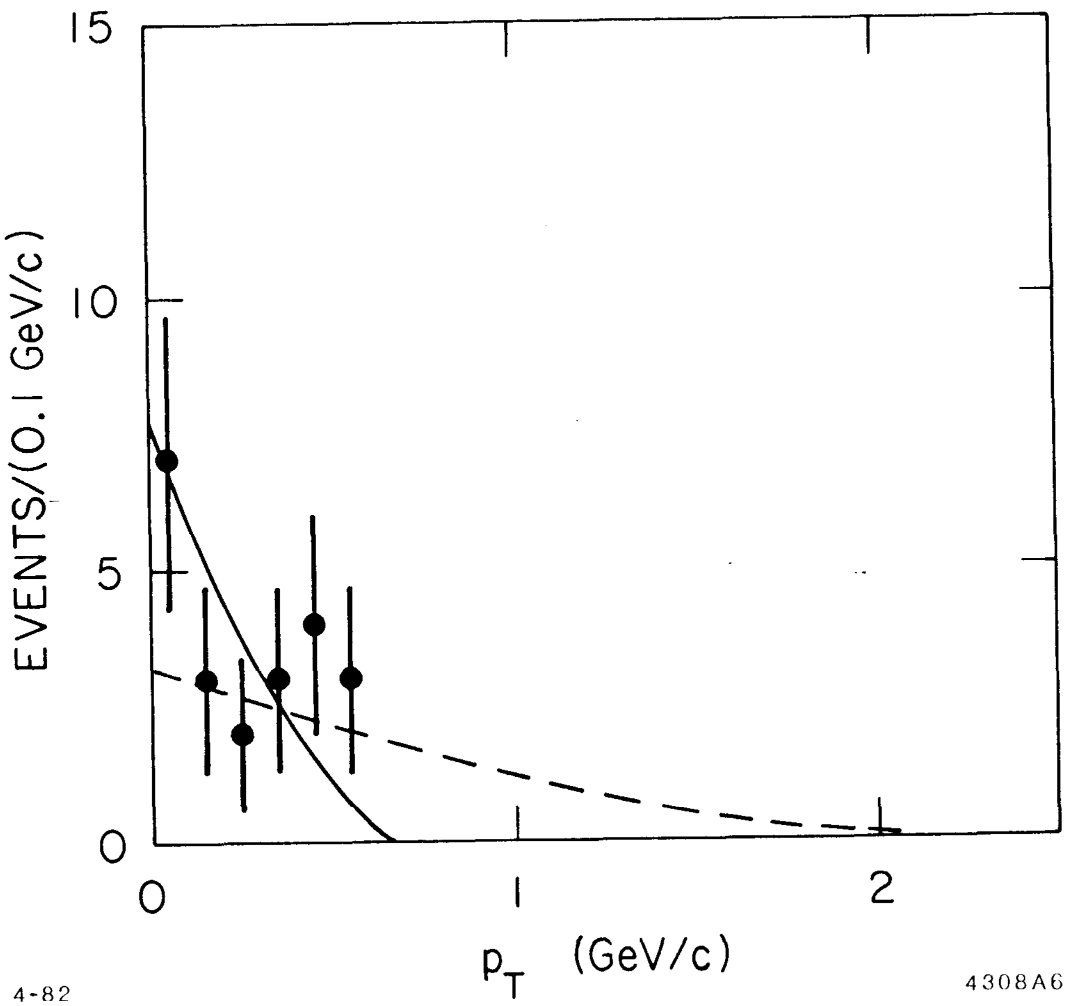


Figure 1

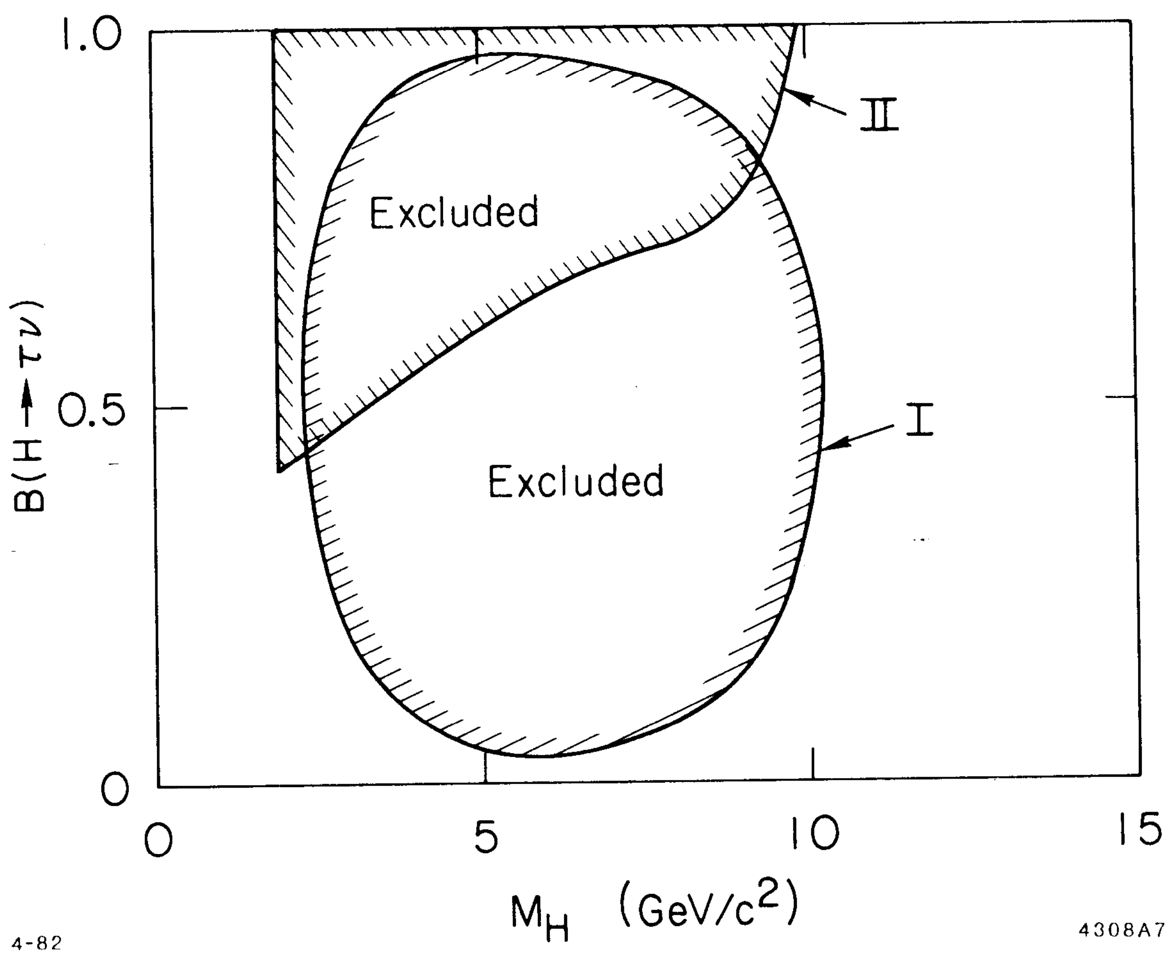
1.0
0.5
0
0
5
10
15
B(H → τν)
M_H (GeV/c²)
Excluded
Excluded
II
I
4-82
4308A7

Figure 2

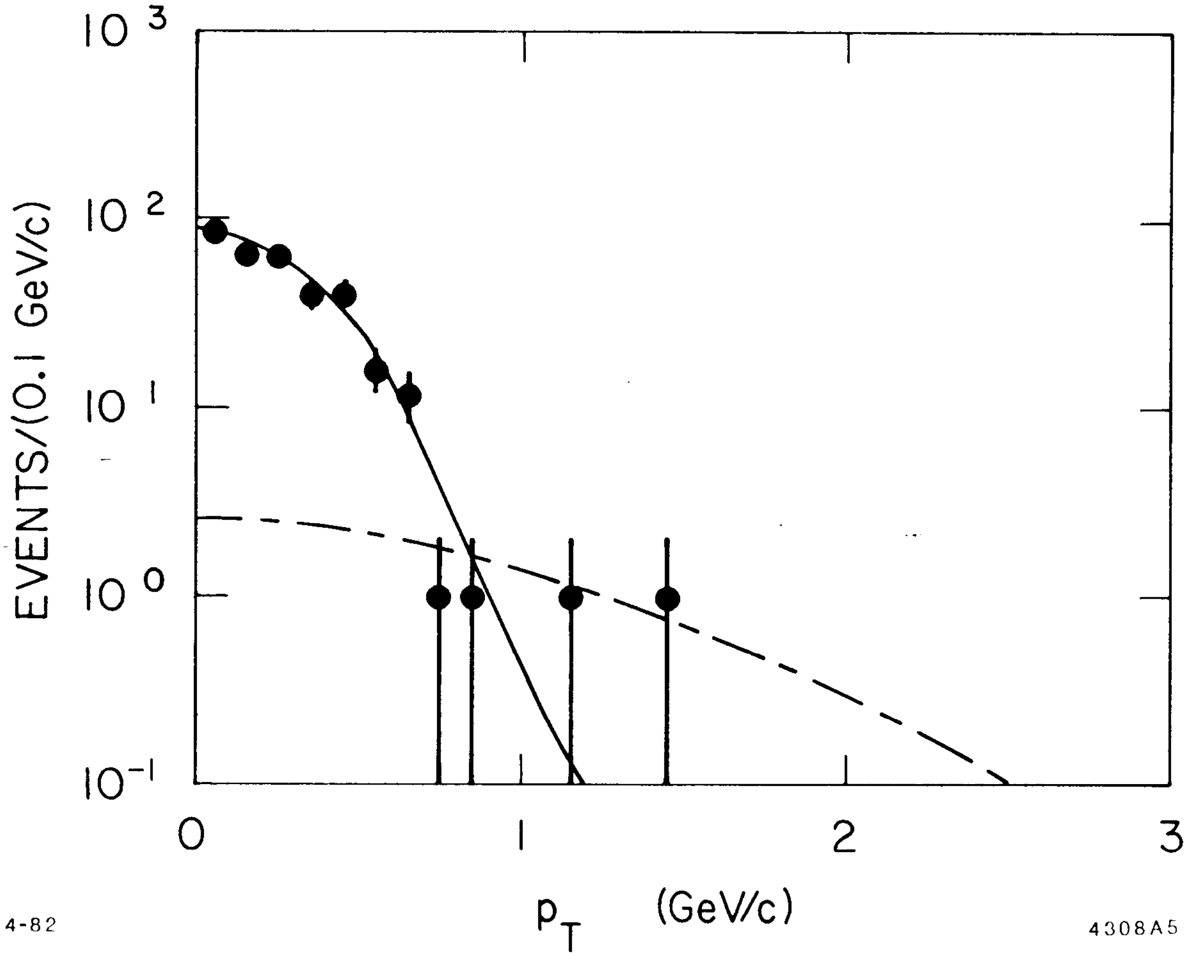


Figure 3