ly seen. For events with $0.600 < M_{\pi^0} < 0.950$ GeV/$c^2$, the residual contamination is found to be negligible for $\rho^0\pi^\pm$ and on the order of 4% for $\rho^\pm\pi^\mp$. The ratio between the production of neutral and charged modes, $\sigma_{\rho^0\pi^0}/(\sigma_{\rho^+\pi^-} + \sigma_{\rho^-\pi^+})$, should be equal to 0.5 for $I=0$, or equal to 2 for $I=2$. The experimental ratio is $0.59 \pm 0.17$ which clearly favors the assignment $I=0$.

In conclusion the branching ratios for multipion final states strongly indicate odd $G$ parity for the direct hadronic decays of the $\psi(3095)$. The analysis of the $\rho\pi$ decay channel leads to the result $I=0$. We conclude, therefore, that the $\psi(3095)$ has quantum numbers $I^G=0^\ast$.

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**Mass of the Higgs Boson**

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The stability of the vacuum sets a lower bound of order $\sqrt{G_F^{-1/2}}$ on the Higgs-boson mass. For the simplest SU(2) $\otimes$ U(1) model, this lower bound is $1.738\sqrt{G_F^{-1/2}}$, or 3.72 GeV.

If the gauge symmetry of the weak and electromagnetic interactions is spontaneously broken by the vacuum expectation values of a set of weakly coupled elementary scalar fields, then there should exist a corresponding set of massive scalar particles, one for each elementary scalar field, other than those corresponding to Goldstone bosons. These have come to be known as the “Higgs bosons.” This note will present a theoretical lower bound on the Higgs-boson mass.

It is usually said that gauge theories do not put any constraints on the Higgs-boson masses, and that experimental searches must consequently explore all mass ranges, even down to zero mass. This statement is based on lowest-order perturbation theory. If the typical scalar mass in the Lagrangian is of order $M$ and the typical $\phi^4$ coupling is $f$, then the scalar-field vacuum expectation values $\langle \phi \rangle$ will be of order $M/\sqrt{f}$, while the Higgs-boson masses will be of order $M$. We more or less know $\langle \phi \rangle$, which is of order $G_F^{-1/2} \cong 300$ GeV. But even for fixed $\langle \phi \rangle$, we can apparently make the Higgs-boson mass $M_H \cong \langle \phi \rangle \sqrt{f}$ as small as we like, by taking both $f$ and $M$ to be sufficiently small.

However, if we make $f$ too small, the effective
potential becomes dominated by gauge vector-boson loops and this argument breaks down. These one-loop diagrams are of order $e^4 \phi^4$, where $e$ is a typical gauge coupling constant. Hence there is an effective lower bound on $f$ of order $e^4$, and we expect a lower bound on the Higgs-boson mass of order $e^2 \langle \phi \rangle$, or several GeV.

$$V(\phi) = -\frac{1}{2} M^2 \phi^2 + e^6 \phi^4 + (64\pi^2)^{-1} \text{Tr}(3\mu^2 \ln \mu^2 + M^4 \ln M^2 - 4m^4 \ln m^2),$$

(1)

where $\mu$, $M$, and $m$ are, respectively, the zeroth-order vector, scalar, and spinor mass matrices for a scalar-field vacuum expectation value $\phi$. We can safely drop the $M$ term, because if $M$ is as large as the vector-boson masses it is very much larger than the lower bound we are trying to derive. We will also drop the $m^4$ term, because all the fermions we know are much lighter than the intermediate vector bosons. (This is the only term that would be affected by strong interactions.) The potential may then be put in the form

$$V(\phi) = -\frac{1}{2} M^2 \phi^2 + B \phi^4 \ln(\phi^2/M^2),$$

(2)

where $M$ is a mass parameter chosen to absorb all $\phi^2$ terms in $V(\phi)$, and $B$ is a positive dimensionless constant of order $e^4$.

$$B = \frac{3}{64\pi^2} \text{Tr} \mu^2 = \frac{3}{64\pi^2} \langle \phi \rangle^2 \sum_\mu \mu^2,$$

(3)

with the sum running over all intermediate vector bosons. This potential has a local minimum at a point $\langle \phi \rangle$ given by

$$\langle \phi \rangle^2 [\ln(\langle \phi \rangle/M^2)] + \frac{1}{2} = M^2/4B$$

(4)

and the Higgs mass is

$$M_\text{H}^2 = V''(\langle \phi \rangle) = 8B \langle \phi \rangle^2 [\ln(\langle \phi \rangle/M^2)] + 1.$$

(5)

It may now appear that for given values of the "known" quantities $\langle \phi \rangle$ and $B$, we can give $M_\text{H}^2$ any value we like by a suitable choice of $f$, or $M_f$. However, not all these solutions are physically acceptable. The potential at the point (4) has the value

$$V(\langle \phi \rangle) = -B \langle \phi \rangle^2 [\ln(\langle \phi \rangle/M^2)] + 1$$

(6)

and this must be less than $V(0) = 0$ if the local minimum is to be an absolute minimum. With the logarithm thus constrained to be greater than $-1$, Eq. (5) yields the lower bound

$$M_\text{H}^2 \geq 4B \langle \phi \rangle^2 \langle \phi \rangle^2 \sum_\mu \mu^2.$$

(7)

For instance, in the SU(2) \times U(1) model with a

To make this precise, let us consider any gauge theory with only a single scalar Higgs boson$^3$ as in Ref. 1. The effective potential is then a function $V(\phi)$ only of the modulus $\phi^2 = \sum_i \Phi^2_i \Phi_i$ of the scalar multiplet $\Phi_i$. We assume that $V(\phi)$ can be calculated perturbatively, but to take into account the possibility that the $\phi^4$ coupling is very weak, we include one-loop as well as zero-loop terms. It then takes the form$^4$

$$\langle \phi \rangle = 2^{1/4} G^{-1/2},$$

(8)

where $\phi$ is the weak mixing angle. Even with $\theta$ unknown, $M_\text{H}$ has the lower bound $1.738\alpha/\sqrt{G_F}$, or 3.72 GeV. For $\theta = 35^\circ$ as suggested by experiment, the lower limit on $m_\text{H}$ is 4.9 GeV. As noted by Ellis, Gaillard, and Nanopoulos$^5$ a Higgs boson this heavy would decay chiefly into heavy leptons and charmed hadrons, with a very small branching ratio to $\mu^\pm$ pairs.

Similar arguments apply to theories with several Higgs bosons, but the results are less useful. In general, one can show that

$$M_\text{H}^2 \geq (3/16\pi^2) \sum_\nu \mu_\nu^2.$$
son would tend to be emitted from the exchanged intermediate vector boson line. Aside from numerical phase-space factors, the probability of producing the Higgs boson would be of order $G_F^2$.

I am grateful for valuable conversations with S. Coleman and E. Gildener.

*Note added.—After this paper was submitted for publication, I received a Lebedev Physics Institute report by A. D. Linde (to be published) in which similar conclusions are presented. Linde calculated the lower bound only for Abelian gauge theories, but his estimate for the more realistic $SU(2) \otimes U(1)$ theory agrees with the results given here.

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2For instance, the possibility of a massless or very light Higgs boson was seriously considered by R. Jackiw and S. Weinberg, Phys. Rev. D 5, 2396 (1972). A comprehensive review of methods which might be used to detect Higgs bosons of various masses is given by J. Ellis, M. K. Gaillard, and D. V. Nanopoulos, CERN Report No. Ref. TH. 2093-CERN (to be published).

3These are the theories described in Sect. VII of S. Weinberg, Phys. Rev. D 2, 168 (1973) in which the scalar fields form a representation of the gauge group which is transitive in a sphere.


5For $M^2 < 0$, this has two real roots; the local minimum is at the larger root. For $M^2 > 0$ there is one real root.

6S. Coleman (unpublished) has given an argument that any vacuum which corresponds to a local but nonabsolute minimum will be unstable.

7E. Gildener and S. Weinberg, to be published.

8D. Cline, private communication.

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Search for Charmed Mesons and Baryons

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Data from a 15-GeV/c $\pi^+d$ experiment have been used to search for both short- and long-lived narrow resonances. No statistically significant high-mass narrow resonance has been observed up to a mass of 5 GeV. There is a single long-lived $V$ that remains unexplained. Cross-section limits (95% confidence level) of 0.7 pb for the long-lived possibility and 2 to 4 $\mu$b for the short-lived possibilities have been obtained.

Since the discovery of the $J(\psi)$ and $\psi'$ narrow resonances, there has been a lot of speculation whether these resonances are the manifestation of a new quantum number called charm. If charm exists then it should be possible to form meson and baryon resonances which contain the charm quantum number. The least massive of the charmed mesons and baryons should decay weakly, implying long lifetimes and narrow widths. There are many predicted decay modes for these resonances but to date only a few experimental searches have been reported. There has been one experiment looking for long-lived charmed mesons with a sensitivity several orders of magnitude lower than ours. There are a few other experiments which search for short-lived high-mass narrow resonances with negative results. Only one experiment has reported one possible event which could be a charmed baryon. In our experiment, in addition to searching for long-lived charmed particles, we also searched for narrow high-mass resonances among such final states as $K^+\pi^-$, $K^0\pi^+$, $K^+\pi^+\pi^-$, $K^+\rho$, $K\pi\eta$, etc.

The data of this experiment come from an exposure of a 15-GeV/c rf-separated $\pi^+$ beam to