TABLE I. $S = A_{eff}/A$ at the various energies. Thin- $(0.02X_0)$ and thick-target $(0.08X_0)$ data have been combined. Only statistical errors are listed.

Energy ν (GeV)	Carbon	Aluminum	Copper	Tantalum
2.00	0.896 ± 0.024	0.919 ± 0.026	0.865 ± 0.024	0.872 ± 0.030
2.87	0.960 ± 0.027	0.888 ± 0.028	0.937 ± 0.033	0.900 ± 0.034
3.91	0.928 ± 0.028	0.909 ± 0.026	0.882 ± 0.030	0.870 ± 0.033
4.90	0.914 ± 0.034	0.915 ± 0.037	0.933 ± 0.043	0.900 ± 0.043
8.45	0.961 ± 0.040	0.925 ± 0.044	0.815 ± 0.042	0.859 ± 0.045

photoproduction results. One can take the view that there is little shadowing at any value of Q^2, as evidenced by the electroproduction results; or that there is a remarkably rapid dependence on Q^2 between 0 and 0.1 $(\text{GeV}/c)^2$. Both alternatives contradict VMD.

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Determination of the *G* Parity and Isospin of $\psi(3095)$ by Study of Multipion Decays*

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We present here a measurement of six branching ratios of $\psi(3095)$ corresponding to the decays $\psi(3095) \to \rho\pi$, $2(\pi^+\pi^-)$, $2(\pi^+\pi^-)1\pi^0$, $3(\pi^+\pi^-)$, $3(\pi^+\pi^-)1\pi^0$, and $4(\pi^+\pi^-)1\pi^0$. From this study, the isospin and G-parity quantum numbers are found to be $I^G = 0^-$.

We report here the analysis of multipion decays of the $\psi(3095)$[1,2] found among 50 000 events collected by the Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory magnetic detector at SPEAR.[3] By using only the information from the detected charged tracks, it is possible to observe either totally charged modes $[e^+e^- \to n(\pi^+\pi^-),\ n = 1,2,3,\dots]$ or modes involving one

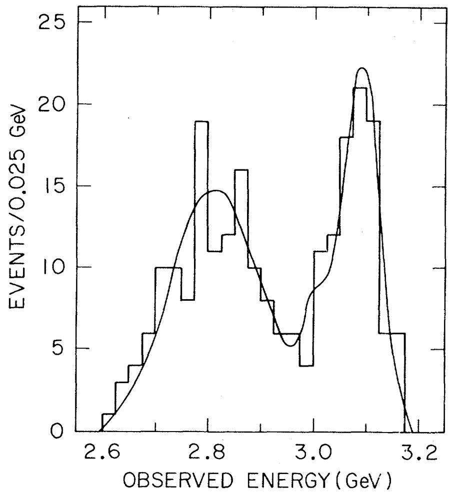

FIG. 1. Total energy of the charged tracks observed in four-prong events with a momentum imbalance of less than 0.100 GeV/c and a total charge equal to 0, assuming all particles are pions. The curve is a Monte Carlo fit to the data.

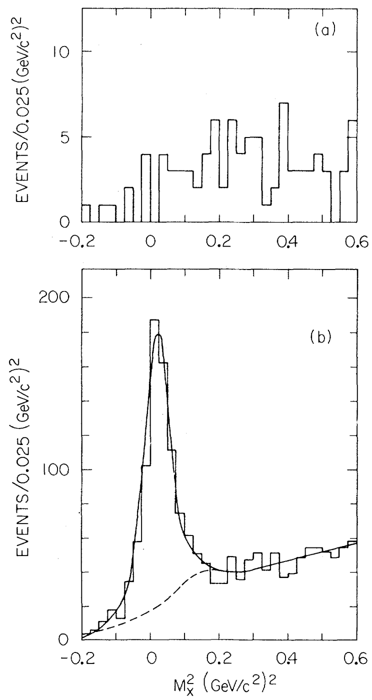

FIG. 2. Distribution of the four-prong events with a momentum imbalance greater than 200 MeV/c and a total charge zero at (a) c.m. energy of 3.0 GeV, (b) $\psi(3095)$; the curve shows the Monte Carlo fit to the data.

missing neutral $[e^+e^- \to n(\pi^+\pi^-) + \pi^0]$. The comparison between the multipion production on resonance and off resonance enables us to determine the G parity of $\psi(3095)$. Furthermore, the measurement of the channel $\psi(3095) \to \rho\pi$, where the $\rho\pi$ system is observed in the three charge states, unambiguously determines the isospin.

A series of cuts is applied to select a clean sample of events. First, the sum of the charges of all reconstructed tracks is required to be 0. A 2-standard-deviation cut on the reconstructed longitudinal vertex position reduces beam-gas background to less than 0.1% A cut on the minimum angle between any pair of particles ($<10°$) removes events having a photon converted in the vacuum pipe or in the first scintillation counter. This cut also removes events with a δ ray associated with a track. Events having one or more particles striking any of the internal support posts of the detector have been discarded.

The same cuts previously defined are put into the Monte Carlo program which calculates the detection efficiencies. A Lorentz-invariant phase-space distribution reproduces fairly well both the angular and the momentum distribution of the observed multipion events.

The $n(\pi^+\pi^-)$ events are selected by requiring the missing momentum to be less than 0.100 GeV/c. The distribution of the total energy observed, assuming pion masses, is then fitted by a Monte Carlo distribution which includes the contributions coming from all known sources of events. In the case of $2(\pi^+\pi^-)$ shown in Fig. 1, the fit takes into account three possible contaminating channels: $\pi\pi KK$, $K_s^0K\pi$, and $2(\pi^+\pi^-)1\pi^0$.

For the $n(\pi^+\pi^-)1\pi^0$ events a missing momentum greater than 0.200 GeV/c is required. The missing-mass-squared distribution is fitted taking into account the known contaminating channels. Figure 2(b) shows the fit obtained for $2(\pi^+\pi^-)1\pi^0$. The background events observed under the peak come mainly from higher charged multiplicity states $[3(\pi^+\pi^-), 3(\pi^+\pi^-)+\pi^0]$ and from $K_s^0K^\mp\pi^\pm\pi^0$ or $2(\pi^+\pi^-)2\pi^0$.

Only runs within $\pm$ 1 MeV of the peak energy are used. They represent about 75% of the data and amount to an integrated luminosity of $\int\mathcal{L}\,dt = 35.6 \pm 3.5\ \mathrm{nb}^{-1}$. Table I gives the branching ratios obtained for all the channels investigated so far. An overall correction of 7% takes into account the events lost by scattering in the material preceding the first chamber or not found by the tracking program. A 10% systematic error has been added in quadrature to the statistical errors.

Assuming that the $\psi(3095)$ couples to the lepton

TABLE I. Branching ratios for some multipion decay channels of the $\psi(3095)$.

Mode	Branching ratio (%)	No. of events observed
$\rho\pi$	1.3 ± 0.3	153 ± 13
$2\pi^+2\pi^-$	0.4 ± 0.1	76 ± 9
$2\pi^+2\pi^-\pi^0$	4.0 ± 1.0	675 ± 40
$3\pi^+3\pi^-$	0.4 ± 0.2	32 ± 7
$3\pi^+3\pi^-\pi^0$	2.9 ± 0.7	181 ± 26
$4\pi^+4\pi^-\pi^0$	0.9 ± 0.3	13 ± 4

pairs via an intermediate photon, we expect[4] about 17% of the hadronic events produced at $\psi(3095)$ to come from the second-order electromagnetic decay $\psi(3095) \to \gamma \to$ hadrons. Those states which are coupled to the ψ only via a virtual photon should exhibit the same properties on and off resonance. Off resonance, the quantity $R_{\rm off} = \sigma_{\rm off}{}^F/\sigma_{\rm off}{}^{\mu\mu}$ measures the ratio of the cross section for producing a given hadronic final state F to the μ-pair cross section (both produced via a virtual photon). On resonance, the μ pairs are still produced via a virtual photon, but the observed hadrons can either come from a direct decay ($\psi \to F$) or be produced via a virtual photon ($\psi \to \gamma \to F$). In the latter case, $R_{\rm on} = \sigma_{\rm on}{}^F/\sigma_{\rm on}{}^{\mu\mu}$ and $R_{\rm off}$ will be equal.

The off-resonance data were taken at 3.0 GeV ($\int \mathcal{L}\, dt = 195 \pm 15$ nb^{-1}). In this sample, the $2(\pi^+\pi^-)$ and $3(\pi^+\pi^-)$ are well identified, but because of the very low statistics, background events and signal cannot be well separated for $\rho\pi$, 5π, or 7π [see Fig. 2(a)]. Therefore, no subtraction has been made and only an upper limit for $R_{\rm off}$ is obtained for these channels.

It is convenient to study the quantity

$$\alpha = \frac{R_{\rm on}}{R_{\rm off}} = \frac{N_{\rm on}{}^F}{N_{\rm off}{}^F}\, \frac{N_{\rm off}{}^{\mu\mu}}{N_{\rm on}{}^{\mu\mu}}\, \frac{\epsilon_{\rm off}{}^F}{\epsilon_{\rm on}{}^F}\, \frac{\epsilon_{\rm on}{}^{\mu\mu}}{\epsilon_{\rm off}{}^{\mu\mu}}\ ;$$

α will be equal to 1 if only a second-order electromagnetic decay occurs and greater than 1 if there are also direct decays. The detection efficiencies $\epsilon_{\rm off}$ and $\epsilon_{\rm on}$, calculated by the Monte Carlo simulation, differ only by about 10%. Since the hadronic events and the μ pairs are selected off and on resonance in the same way, most of the systematic errors cancel out in the computation of α. Figure 3 shows α versus the pion multiplicity. Both channels with even numbers of pions are consistent with a second-order electromagnetic decay, whereas all three channels with

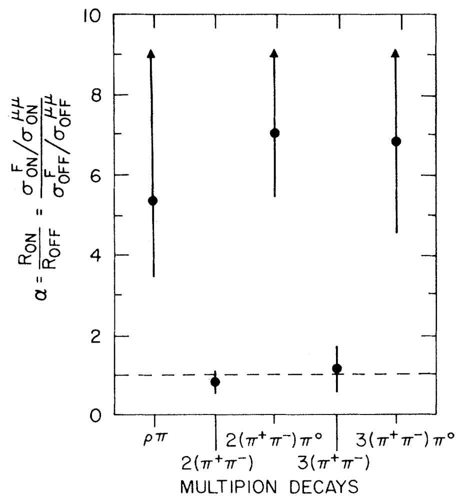

FIG. 3. Comparison of the ratio of multipion to μ-pair production on resonance and off resonance, for various multipion channels.

odd numbers of pions are considerably enhanced. The observation that α is consistent with unity for the $2(\pi^+\pi^-)$ and $3(\pi^+\pi^-)$ states is evidence that $\psi(3095)$ couples to leptons via an intermediate photon. The G-parity selection rule appears to work strikingly well and is consistent with the assignment $G = -1$. Thus, the isospin, I, which is related to G by $G = C(-1)^I$, must be even.

This result could be affected if $\psi(3095)$ decayed radiatively to $n(\pi^+\pi^-)\gamma$. Although a small contribution of such decays is not ruled out, the missing-mass-squared distributions agree very well with the distributions expected for a missing π^0 [see Fig. 2(b), for example]. Furthermore, we observe exclusive channels such as $\rho\pi$ (> 70% of $\pi^+\pi^-\pi^0$), $\omega\pi\pi$ [20% of $2(\pi^+\pi^-)1\pi^0$], $\rho\pi\pi\pi$ [30% of $2(\pi^+\pi^-)1\pi^0$]. They represent a significantly large fraction of the decays and lead us to conclude that most of the direct decays of $\psi(3095)$ into multipions include a π^0.

Direct determination of the isospin may be obtained by studying the decay $\psi(3095) \to \rho\pi$. To study this mode it is necessary to introduce an additional requirement on event selection, viz. that the two prongs be noncoplanar with the beam by at least 15° in order to eliminate radiatively degraded elastic events (e.g., $e^+e^- \to e^+e^-\gamma$). Furthermore, the proper angular distributions for the cascade decay of $\psi(3095)$ into three pions, via $\rho\pi$, were used in the Monte Carlo.[5] The detection efficiency for $\rho^0\pi^0$ is 0.135, and for $\rho^\pm\pi^\mp$, 0.084. The selected events are shown in the Dalitz plot in Fig. 4. The three ρ bands are clear-

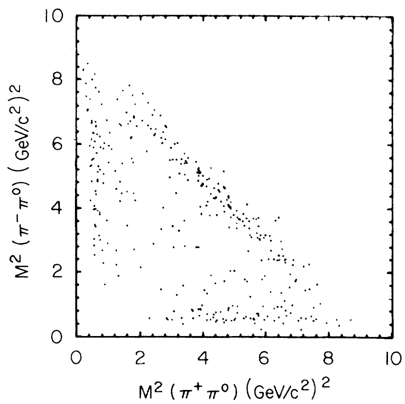

FIG. 4. Dalitz plot for the $\pi^+\pi^-\pi^0$ decay of $\psi(3095)$.

ly seen. For events with $0.600 < M_{\pi\pi} < 0.950$ GeV/c^2, the residual contamination is found to be negligible for $\rho^0\pi^0$ 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 ± 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 $I^G = 0^-$.

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Mass of the Higgs Boson*

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The stability of the vacuum sets a lower bound of order $\alpha G_F^{-1/2}$ on the Higgs-boson mass. For the simplest SU(2)⊗U(1) model, this lower bound is $1.738\alpha G_F^{-1/2}$, 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,[1] 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.[2] This statement is based on lowest-order perturbation theory. If the typical scalar mass in the Lagrangian is of order M and the typical φ^4 coupling is f, then the scalar-field vacuum expectation values $\langle\varphi\rangle$ will be of order $M/\sqrt{f}$, while the Higgs-boson masses will be of order M. We more or less know $\langle\varphi\rangle$, which is of order $G_F^{-1/2}\approx 300$ GeV.[1] But even for fixed $\langle\varphi\rangle$, we can apparently make the Higgs-boson mass $M_H \approx \langle\varphi\rangle\sqrt{f}$ as small as we like, by taking both f and M to be sufficiently small.

However, if we make f too small, the effective