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OBSERVATION OF A RESONANCE AT 4.4 GeV AND ADDITIONAL STRUCTURE NEAR 4.1 GeV IN e^+e^- ANNIHILATION*

J. Siegrist, G. S. Abrams, A. M. Boyarski, M. Breidenbach, F. Bulos, W. Chinowsky, G. J. Feldman, C. E. Friedberg, D. Fryberger, G. Goldhaber, G. Hanson, D. L. Hartill,† J. Jaros, B. Jean-Marie,†† J. A. Kadyk, R. R. Larsen, D. Lüke,††† V. Lüth, H. L. Lynch, R. Madaras, C. C. Morehouse, K. Nguyen,‡‡‡ J. M. Paterson, M. L. Perl, I. Peruzzi,‡ F. M. Pierre,‡ M. Piccolo,‡ T. P. Pun, P. Rapidis, B. Richter, B. Sadoulet, R. F. Schwitters, W. Tanenbaum, G. H. Trilling, F. Vannucci,‡‡ J. S. Whitaker, F. C. Winkelmann,‡‡ J. E. Wiss

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

and

Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

ABSTRACT

We observe a resonance-like structure in the total cross section for hadron production by e^+e^- colliding beams at a mass of 4414 ± 7 MeV having a total width $\Gamma = 33 \pm 10$ MeV. From the area under this resonance, we deduce the partial width to electron pairs to be $\Gamma_{ee} = 440 \pm 140$ eV. Further structure of comparable width is present near 4.1 GeV.

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† Permanent address Cornell University, Ithaca, New York

†† Permanent address Laboratoire de l'Accelerateur Lineaire, Orsay, France

††† Fellow of Deutsche Forschungsgemeinschaft

‡ Permanent address Laboratori Nazionali di Frascati, Frascati, Italy

‡ Permanent address Centre d'Etudes Nucleaires de Saclay, France

‡‡ Permanent address Institut de Physique Nucleaire, Orsay, France

‡‡ Present address Carleton University, Ottawa, Canada

‡‡‡ Permanent address LPNHE, Universite de Paris VI, Palaiseau, France

In a previous Letter[1] we reported structure in the total cross section σ_T for hadron production by e^+e^- annihilation near the center-of-mass energy E_{cm} = 4.15 GeV. The width of that structure appeared to have a typical hadronic value of several hundred MeV, yet the area under it was comparable to the areas under the very narrow resonances ψ(3095)[2] and ψ(3684).[3] We report here results from additional measurements of σ_T in the c.m. energy range 3.9 GeV to 4.6 GeV. These data show strong evidence for a new state at 4414 $\pm$ 7 MeV having a total decay width of approximately 30 MeV and a partial width to lepton pairs only about 10% of the ψ(3095). The new data also suggest that the broad 4.15 GeV peak noted in our previous Letter has substructure on a scale of 50 MeV or less.

This experiment was performed with the SLAC/LBL magnetic detector at the SLAC e^+e^- storage ring SPEAR. Operation of the detector, event selection criteria and other aspects of the experiment relating to the measurement of σ_T are identical to those discussed in Ref. 1. Briefly, we select as hadrons those events where three or more charged tracks form a vertex within the luminous region of the beams, or where two prongs with momenta $p > 0.3$ GeV/c are present and, if oppositely charged, the two prongs are acoplanar with respect to the incident beam direction by at least 20°. We normalize to Bhabha scattering ($e^+e^- \rightarrow e^+e^-$) events observed in the detector. Bhabha scattering events are selected by collinearity ($\theta_c < 10^o$), momentum ($p > \frac{1}{4}E_{cm}$) and shower counter pulse height criteria as discussed in Refs. (1) and (4). Cosmic rays are rejected by time-of-flight criteria.

Our basic measurement is the ratio of the number of hadron events to the number of Bhabha scattering events. To obtain the more useful quantity R, the ratio of σ_T to the total cross section for muon pair production, we correct the number of hadronic events by the average detection efficiency ϵ of the apparatus and assume the validity of QED to relate the number of Bhabha events to the total number of muon pairs produced. In Ref. (1), ϵ was determined by an unfold procedure where the produced hadron multiplicity distribution was derived from the observed multiplicity distribution and known properties of the detector. Here, where we are only interested in possible structure in R over a limited range of E_{cm}, a smooth function was fitted to the energy dependence of ϵ found in Ref. (1) and this was then used to determine R. As shown in Fig. 1, both the observed mean charged particle multiplicity and momentum have a smooth energy dependence justifying the use of the smoothed ϵ which varies between 0.53 at E_{cm} = 3.90 GeV to 0.57 at E_{cm} = 4.60 GeV.

The data were corrected for contamination from beam-gas interactions ($< 5\%$) by normalizing to events with vertices outside the luminous region of the beams. Radiative tails of the narrow ψ resonances have been subtracted.

We estimate the systematic uncertainty in the absolute normalization of R to be $\pm 15\%$ arising mainly from uncertainties in ϵ. Point-to-point changes in R coming from instrumental effects are estimated to be less than 5%. Data spanning the entire energy range considered here and taken during different periods of time separated by several months are in excellent agreement where they overlap in energy as shown in Fig. 2. The ratio between the integrated luminosities derived from Bhabha scattering events observed in the detector and events detected by small angle ($\theta \approx 20$ mrad) counter telescopes was constant within statistical errors at all energies. Both the Bhabha scattering and multihadron event samples were stable to the imposition of more stringent spark chamber tracking criteria, thus verifying the stability of our tracking efficiency at all energies.

The data are presented in Fig. 2. Different symbols (open and closed circles) indicate data taken during different running periods separated by several months. The indicated errors are statistical only. Our previous measurement at $E_{cm} = 3.8$ GeV is also plotted. There is clear evidence for a peak in R near 4.4 GeV. Between 3.9 GeV and 4.3 GeV, R has a broader peak with evidence for substructure on a scale of energy comparable to the peak at 4.4 GeV. Indeed, a separate peak at 3.95 GeV and a dip near 4.08 GeV are indicated by the data of Fig. 2. However, with the present data, we cannot say whether this substructure represents several independent resonances or an interference effect between two resonances.

We have fitted the cross section in the region 4.290 GeV to 4.540 GeV with a Breit-Wigner resonance term plus a term linear in E_{cm} to represent the non-resonant cross section. The fit assumed that the resonant and non-resonant contributions do not interfere and included the effects of radiative corrections [5] to the resonance line shape. Resonance parameters derived from the fit are summarized in the table along with our previous[2,3] values for the $\psi(3095)$ and $\psi(3684)$. The data used in the fit and the resulting fit for the $\psi(4414)$ are given in Fig. 3. The χ^2 is 17.9 for 20 degress of freedom. Assuming this structure to be a vector particle and that we observed the total production cross section, its decay width to e^+e^- pairs is $\Gamma_{ee} = 440 \pm 140$ eV, where we have included the uncertainty in absolute detection efficiency in our estimate of the error.

Given their proximity in mass, it is natural to compare these new structures with the narrow ψ resonances. The magnitudes and widths of the 4 GeV structures are considerably different than those of the ψ particles; the $\psi(4414)$ has a full width over 100 times that of the $\psi(3684)$, yet its coupling to e^+e^- pairs, Γ_{ee}, is only 1/5 of the $\psi(3684)$. The area under the broad 4.1 GeV peak is comparable to the $\psi(3684)$, but it may represent the sum of several states. If the $\psi(4414)$ is related to the narrow resonances, its much greater width may indicate that the selection rules responsible for the narrowness of the $\psi(3095)$ and $\psi(3684)$ may no longer be operative at 4 GeV. Several theoretical models[6] of the new particles have shown that structure in the 4 GeV region can arise from either new vector states or new production thresholds, or both.

References

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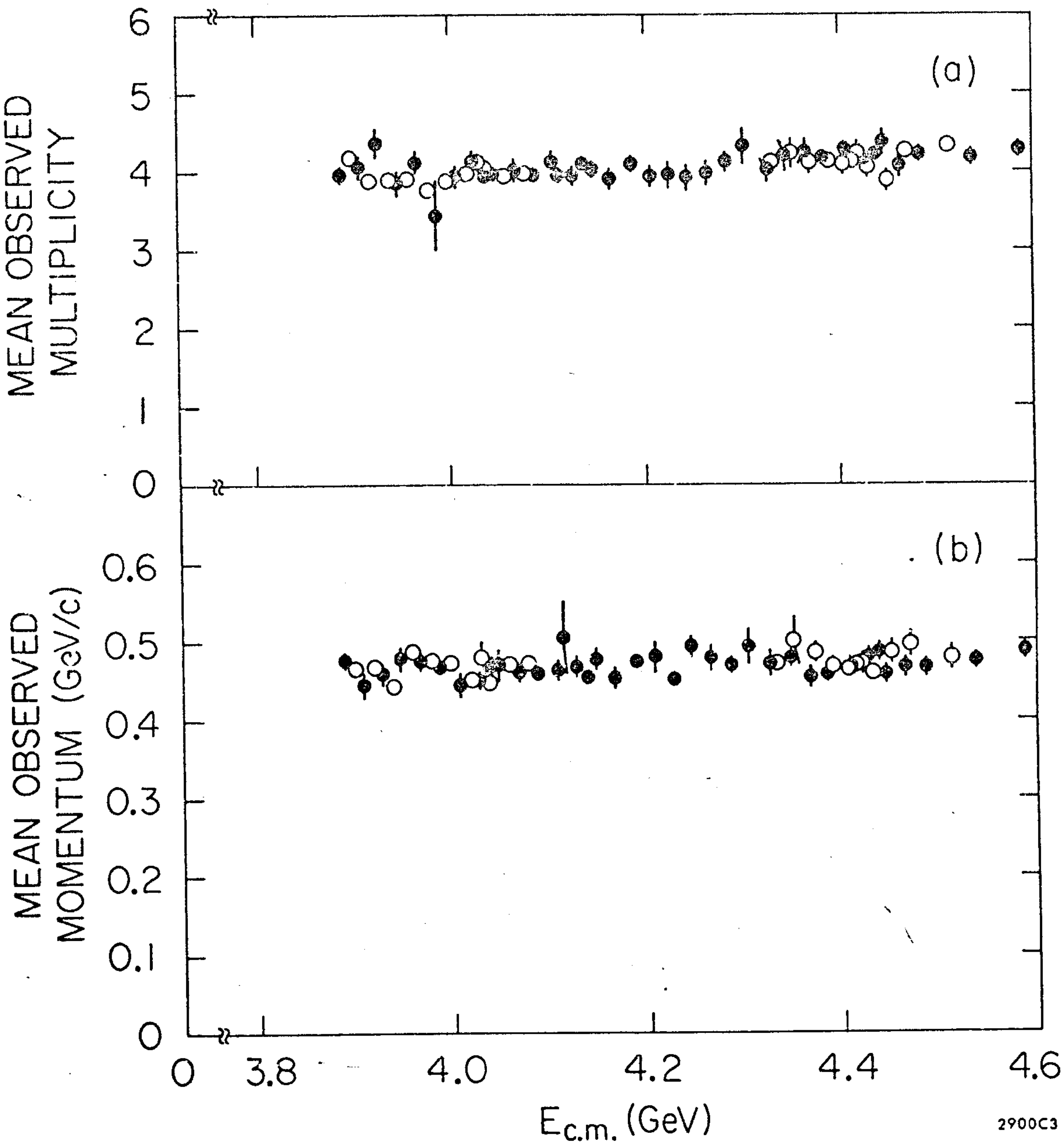
Figure Captions

1. a) Observed mean charged particle multiplicity versus E_{cm}.
   b) Observed mean charged particle momentum versus E_{cm}.
2. Ratio R of hadronic cross section to muon pair cross section versus E_{cm} in the 4 GeV region. The open, closed circles refer to data separated by several months in time. The crossed point as taken from Ref. 1.
3. Detailed plot of R versus E_{cm} for data points used in the fit of the 4414 MeV resonance.

TABLE

Resonance parameters for the $\psi(3095)$, $\psi(3684)$, and $\psi(4414)$. Γ is the full width, Γ_{ee} the partial width to electron pairs, and B_{ee} the branching ratio to electron pairs.

State	$\psi(3095)$ (Ref.2)	$\psi(3684)$ (Ref.3)	$\psi(4414)$
Mass (MeV)	3095 ± 4	3684 ± 5	4414 ± 7
Γ (MeV)	0.069 ± 0.015	0.228 ± 0.056	33 ± 10
Γ_{ee} (keV)	4.8 ± 0.6	2.1 ± 0.3	0.44 ± 0.14
B_{ee}	0.069 ± 0.009	0.0093 ± 0.0016	$(1.3 \pm 0.3)\times10^{-5}$



MEAN OBSERVED MULTIPLICITY
(a)
MEAN OBSERVED MOMENTUM (GeV/c)
(b)
0
1
2
3
4
5
6
0.1
0.2
0.3
0.4
0.5
0.6
0
3.8
4.0
4.2
4.4
4.6
Ec.m. (GeV)
2900C3

Fig. 1

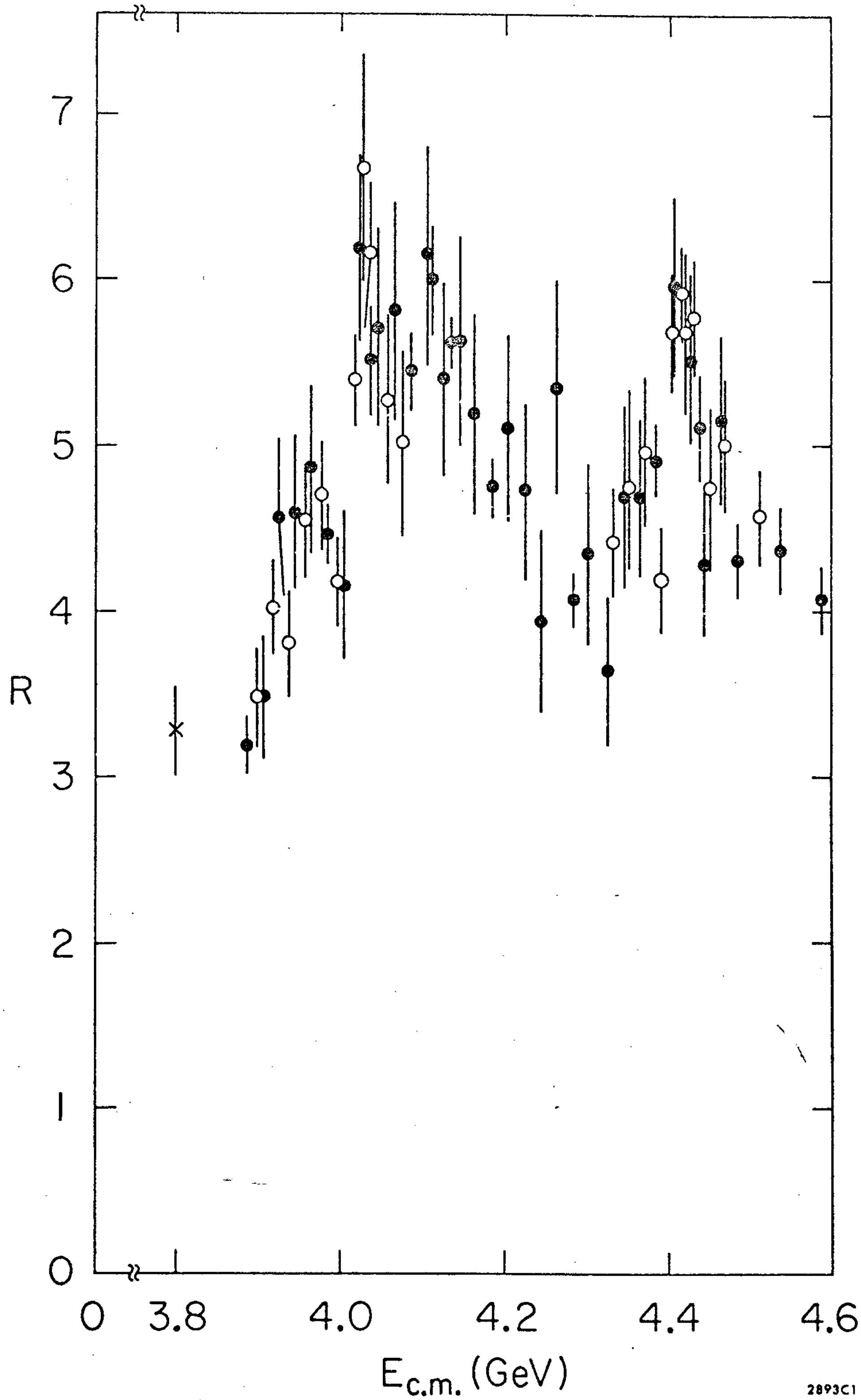


Fig. 2

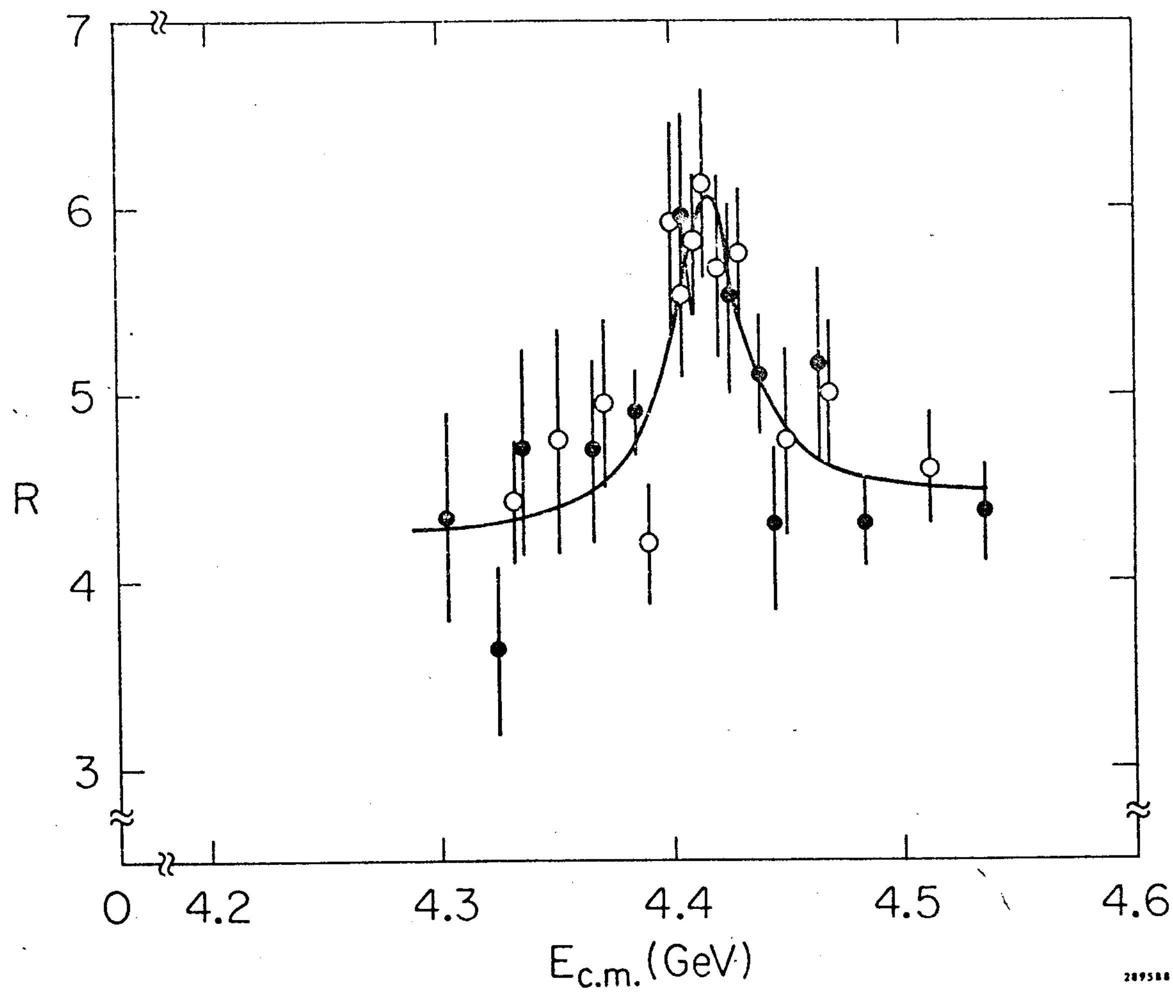


Fig. 3