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THE SEARCH FOR NEW EFFECTS IN e^+e^- INTERACTIONS*

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1. INTRODUCTION AND SUMMARY

Over the past decade, e^+e^- colliding beam machines have been a rich source of interesting and frequently exciting new physics. This has been particularly true for the energy range of the J/ψ and Υ; however, results from the PEP/PETRA machines have also been valuable, *e.g.*, the measurement of the B lifetime.

Much effort has been expended in the search for new effects. These include searches for charged and neutral fundamental scalars, new families of quarks, new leptons, lepton–quark substructure, and supersymmetric particles, plus many other topics. In this report I will discuss a few of these experiments in some detail, some in a broader review, and unfortunately some not at all. For those that I have missed I apologize, as these experiments are necessary and rather difficult to carry out, while the fate of unrequited searches is frequently ignominy.

2. THE MEASUREMENT OF R_{hadron}

All particles with an electric or weak charge couple in pairs to the e^+e^- initial state. Figure 1 shows the diagram for this process along with R for the pair production of spin 1/2 and spin 0 particles from one photon exchange (the data presented here has an energy low enough that the Z° exchange mechanism is negligible). As is also shown in the figure, spin 0 pairs contribute a smaller fraction to R_{hadron} than spin 1/2 pairs, and a much smaller fraction "near" threshold. Thus the comparison of measurements of R_{hadron} to what is theoretically expected from QCD may yield information on new physics; however, measurement with errors on the few percent level or less are needed as the contribution of a new spin 0 particle to R_{hadron} is less than 7%.

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In this section I will discuss recent measurements of R_{hadron} which have systematic overall scale errors on the absolute value of R_{hadron} of $\pm 7\%$ or less. The most accurate measurements from the JADE[1] and MAC[2] collaboration are reported at the 2–3% level. The range in $\sqrt{s}$ of all the measurements is 5 to over 40 GeV, and thus the full combination of QCD and electroweak contributions to R_{hadron} must be considered.

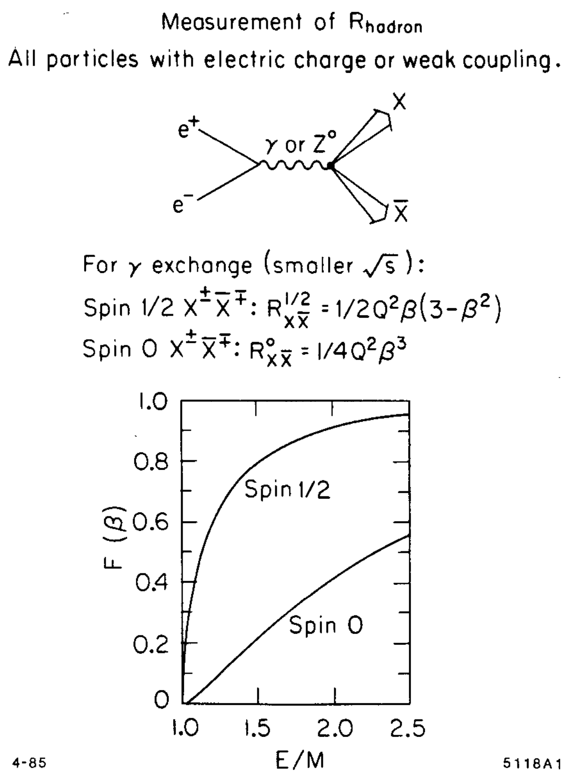

Fig. 1. R for Pair Production of point-like particles, X, with spin 1/2 or spin-0, and charge Q. Only the one photon exchange diagram is calculated. F(β) vs E/M is shown at the bottom of the figure. F(β) is chosen such that F(1) = 1, note: $\beta = P/E$.

In the quark-parton model the ratio, $R_{hadron} = \sigma_{hadron}/\sigma_{\mu\mu}$ of the total hadronic cross section to the lowest order muon pair cross section is given by summing over the available quark flavors, n_f,

$$R_0(s) = 3\left(\sum_{q=1}^{n_f} Q_q^2 - v_e Re(g(s))\sum_{q=1}^{n_f} Q_q v_q + \frac{1}{4}(v_e^2+a_e^2)\,|g(s)|^2\sum_{q=1}^{n_f}(v_q^2+a_q^2)\right) \tag{1}$$

where, Q_q are the quark charges, v_i and a_i are the neutral current vector and axial vector coupling constants of the electro-weak theory[3], and,

$$\begin{aligned} g(s) &= \frac{1}{8\sin^2\theta_W\cos^2\theta_W}\left(\frac{s}{s-M_Z^2+iM_Z\Gamma_Z}\right) \\ &= \frac{G}{\sqrt{2}}\frac{1}{4\pi\alpha}\frac{sM_Z^2}{s-M_Z^2+iM_Z\Gamma_Z}\ . \end{aligned} \tag{2}$$

It has been shown[4] that a rapidly converging perturbative expansion for R_{hadron} may be obtained from QCD,

$$R_{hadron}(s) = R_o(s)\left(1+\frac{\alpha_s}{\pi}+C\left(\frac{\alpha_s}{\pi}\right)^2\right)\ . \tag{3}$$

Calculated in the modified minimal subtraction ($\overline{MS}$) scheme one has, $C = 1.986 - 0.115n_f$. Additional corrections are needed for finite quark mass effects near $q\bar{q}$ thresholds.[4,5] The coupling constant α_s is predicted in QCD to run as a function of $\sqrt{s}$; the rate of the logarithmic decrease of α_s with increasing $\sqrt{s}$ is governed by $\Lambda_{\overline{MS}}$, the QCD scale parameter. Thus by determining α_s at one energy, the $\sqrt{s}$ dependence of R_{hadron} predicted in QCD can be checked, and at higher $\sqrt{s}$ the weak contribution to R_{hadron} can be measured in principle. The possibility of confronting theory with experiment depends on being able to measure R_{hadron} to within a few percent. The difficulty of such measurements is partially illustrated in Fig. 2 where a number of e^+e^- reactions are shown. Many of these reactions pose serious backgrounds to the process to be measured (in the cubby in the upper right of the figure). In addition, cosmic rays, beam gas interactions, and other machine generated backgrounds can destroy the accuracy of an R_{hadron} measurement if not treated properly. Finally, the measurement of the integrated luminosity, typically using Bhabha scattering, is an important element in the accuracy of the measurement.

In order to best measure R_{hadron} certain detector features must be present, and an example of the generic R_{hadron} detector is shown in Fig. 3. Illustrated in the figure are the requirements of large solid angle ($>$ 90% of 4π), good hadron and electromagnetic calorimetry (over the entire solid angle), charge particle tracking (over most of the solid angle), and at least two independent measurements of the luminosity needed by a proper R_{hadron} detector (large and small angle measurements, the later with an independent apparatus).

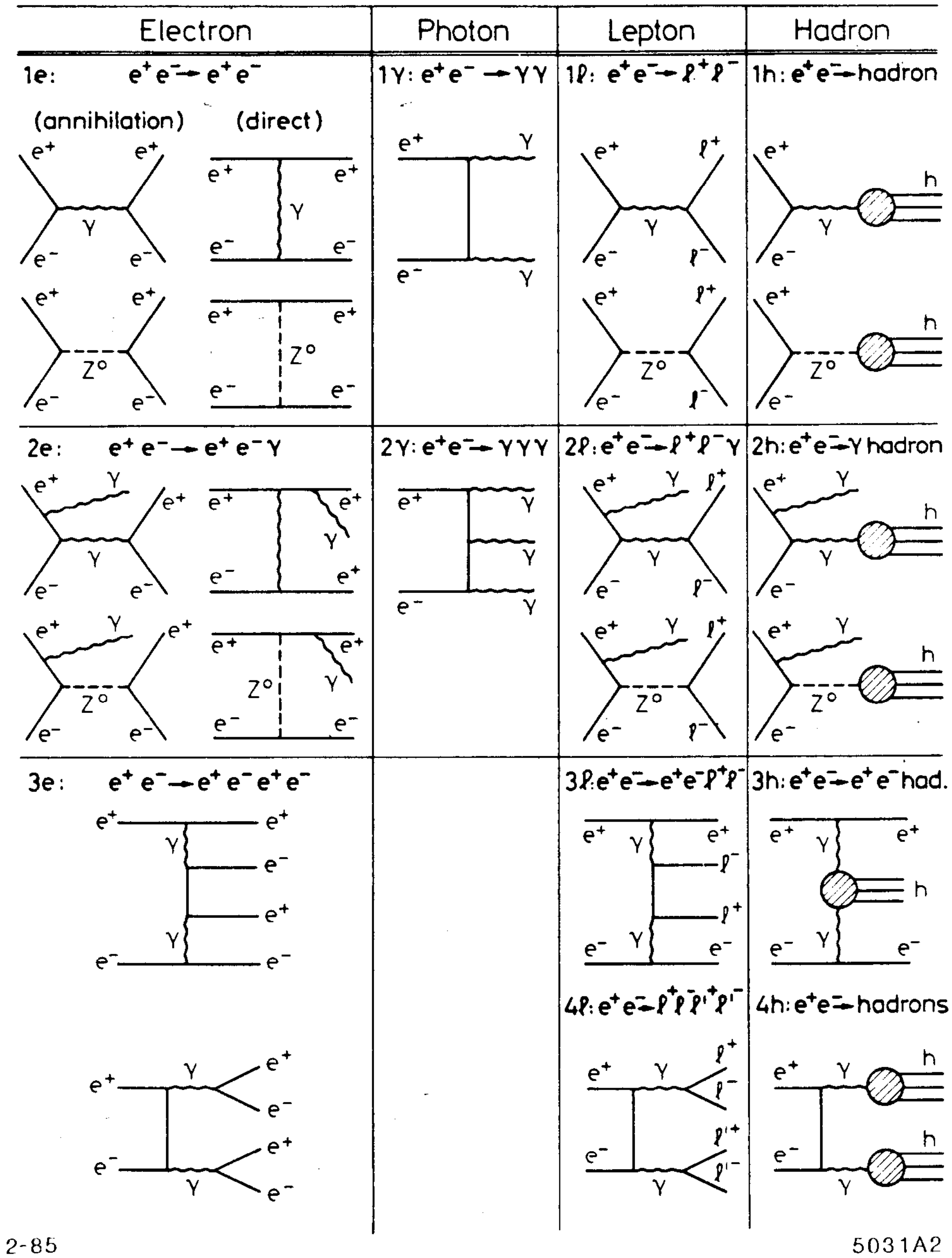

Fig. 2. The various types of interactions seen from an e^+e^- initial state. Many of these reactions are serious backrounds to R_{hadron} (the upper right cubby).

Figure 4 illustrates the importance of large solid angle. In this example from the MAC collaboration,[2] distributions in two (of a number of) variables used to extract the hadronic events are shown as obtained from data and Monte Carlo. The agreement is excellent, giving confidence that the hadronic event extraction

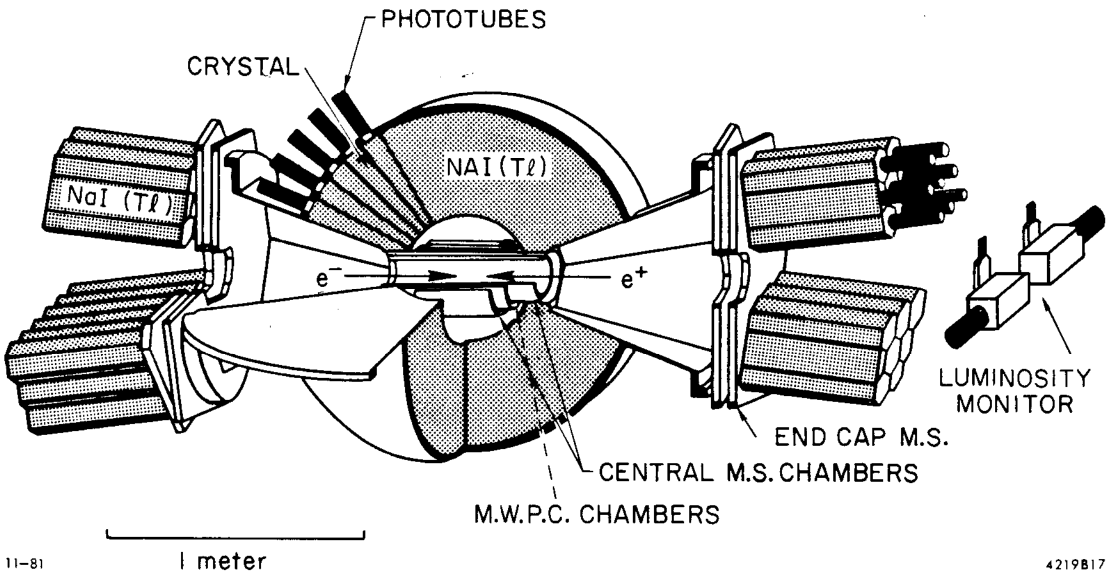

Fig. 3. The generic R_{hadron} detector as illustrated by the Crystal Ball detector.

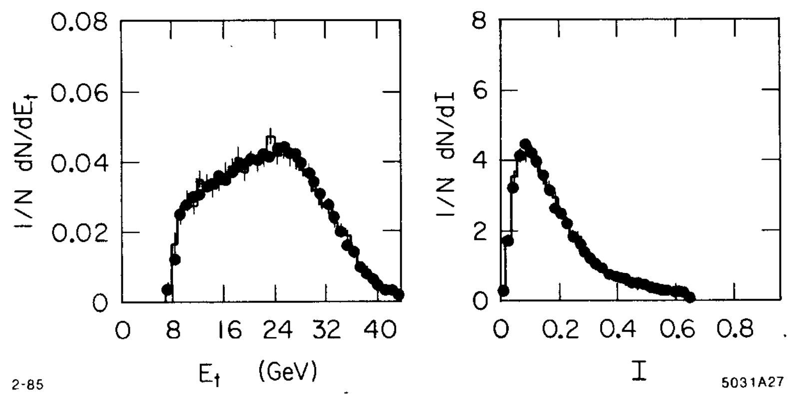

Fig. 4. Comparison, in the MAC detector, of data (solid circles) and Monte Carlo (histogram) for distributions of transverse energy, E_t, and energy asymmetry, I.

efficiency is well understood. A large acceptance of the detector allows for a large hadronic efficiency, and the ability to observe most of the event. Under such conditions, it is unlikely that the experimenters will be mislead by errant Monte Carlo's, and even liberal error estimates on Monte Carlo parameters yield only a small contribution to the overall systematic error. Figure 5 illustrates the advantage of good calorimetry. This example from the Crystal Ball collaboration[6] demonstrates the ease of separating certain types of background. Using simple calorametric variables obtained from only the energies and angles from each of the approximately 700 NaI(Tl) elements of the detector, an almost totally complete separation of cosmic ray events (real data) and hadronic events (Monte Carlo) is achieved. The need for independent measurements of the luminosity is shown in Fig. 6 also using results from the Crystal Ball. In observing the differences in the two measurements, one can with confidence estimate the systematic errors (overall and point to point) coming from the luminosity; in the case of the Crystal Ball the systematic errors are ±2.7% overall, with an additional contribution from point to point.[6]

Figure 7 shows selected R_{hadron} values from experiments which have systematic errors less than 7%. The statistical errors are added in quadrature with

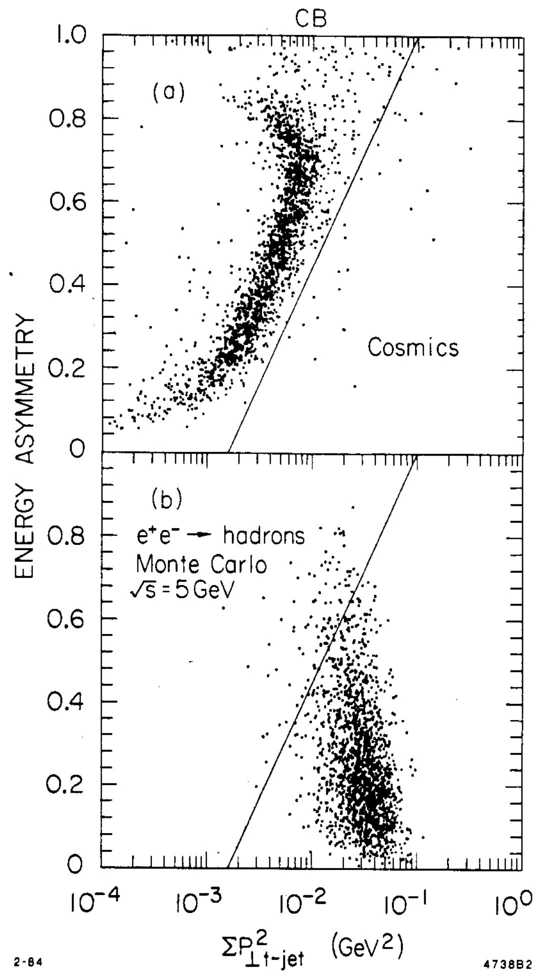

Fig. 5. Comparison, in the Crystal Ball detector, of energy assymetry for, (a) cosmic rays, (b) Monte Carlo hadrons at $\sqrt{s} = 5$ GeV.

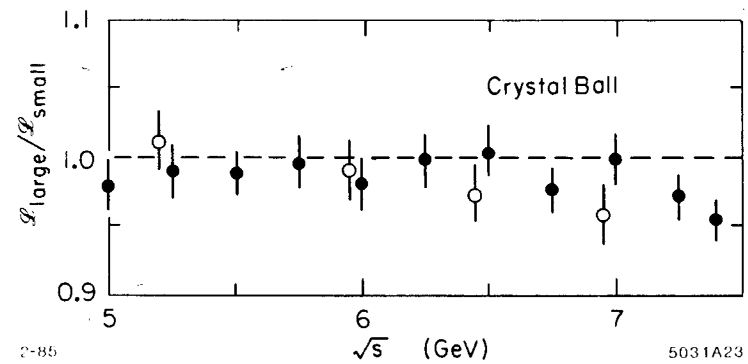

Fig. 6. The ratio of large angle luminosity measurments to small angle in the Crystal detector. The open circles are 1980 data, the closed circles 1981 data.

the quoted point to point systematic errors to yield the error bars shown in the figure. The rest of the (overall) systematic error of each experiment is given in the figure. Note that MAC reports a $\pm 2.3\%$ systematic error on their R_{hadron} value measured at $\sqrt{s} = 29$ GeV ; this is the smallest error yet to be reported. Figure 8 repeats Fig. 7 with the prediction of the simple parton model overlaid (electroweak effects are not included). The impression one obtains from Fig. 8 is one of an increase in R_{hadron} at $b\bar{b}$ threshold, and a general excess over the simple parton model over the entire range of $\sqrt{s}$ shown. These qualitative impressions are in agreement with the expectations of QCD; however, as we shall see, quantitative comparisons are not particularly supportive of QCD.

Figure 9 shows results to higher values of $\sqrt{s}$ for the Mark-J[7] and TASSO[8] collaborations. Only beyond $\sqrt{s}$ of 40 GeV may one hope to see an effect from the purely weak contribution to R_{hadron}; however, the errors are still too large for a useful determination of the Weinberg angle. Also, the overall systematic uncertainty on R_{hadron} of about $\pm 5\%$, for these experiments, precludes the precise determination of α_s needed to obtain the QCD baseline from which the electroweak contribution can deduced at the high energies.

Of primary interest is how the value of R_{hadron} vs $\sqrt{s}$ quantitatively compares with the predictions of QCD. In order to attempt such a comparison, a reliable determination of α_s at low energy is needed. Recently, the use of $\Upsilon(1S)$ decays have been considered to be reliable for such purposes. In particular the calculation of Mackenzie and Lepage[9] which determines α_s from a simple ratio of well measured $\Upsilon(1S)$ decays is particularly appealing,

$$\alpha_s^3(0.48M_\Upsilon) = \frac{\Gamma_{had}(\Upsilon)}{\Gamma_{\mu\mu}(\Upsilon)}\,\alpha_{QED}^2\,\frac{81\pi Q_b^2}{10(\pi^2-9)}\,. \tag{4}$$

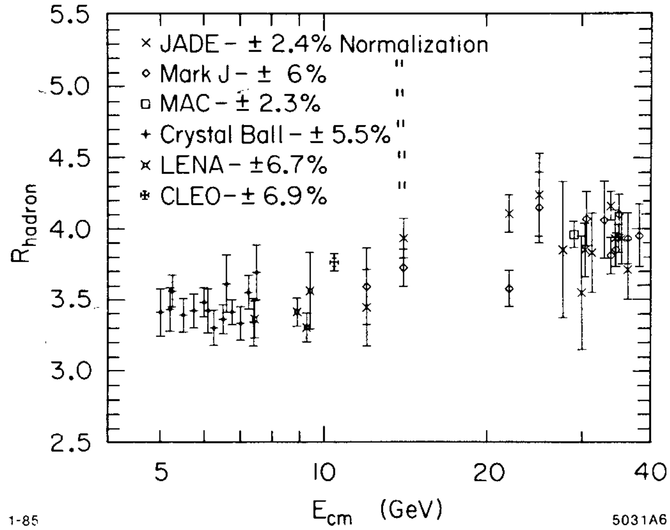

Fig. 7. R_{hadron} for selected measurements with the overall systematic error ±7%. The references to the various measurements are given in the text, except for LENA.[35]

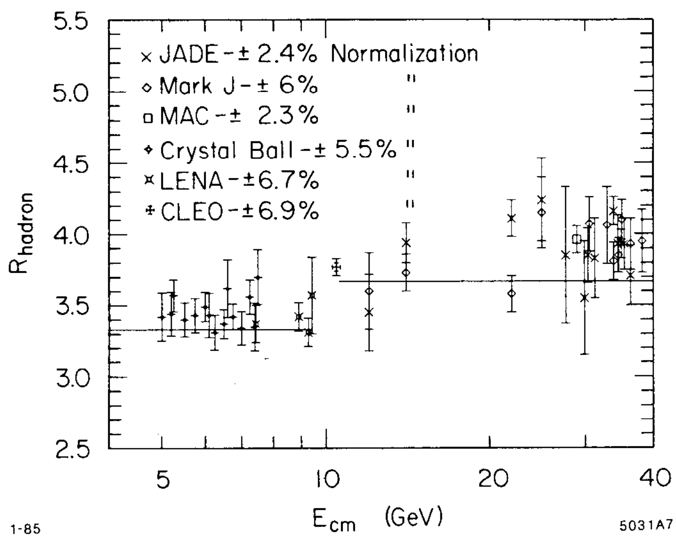

Fig. 8. Same as for Fig. 7, except lines at R_{hadron} = 0.333 and 0.667, from simple parton model shown for reference.

α_s is defined to second order in the $\overline{MS}$ renormalization scheme by,

$$\alpha_s(\sqrt{s}) \equiv \frac{12\pi}{(33-2n_f)\ln(s/\Lambda^2_{\overline{MS}})}\left[1-\frac{462\ln\ln(s/\Lambda^2_{\overline{MS}})}{625\ln(s/\Lambda^2_{\overline{MS}})}\right]. \qquad (5)$$

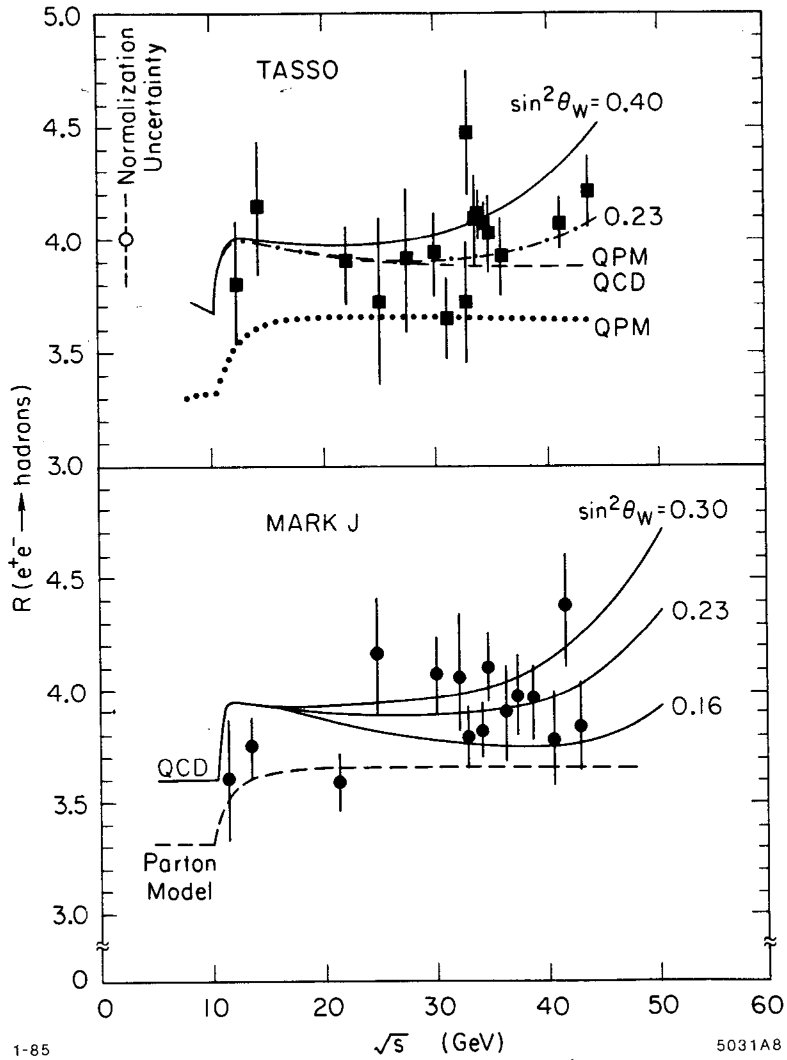

Fig. 9. R_{hadron} from Tasso and MARK J compared to full electroweak theory and ranges of $\sin(\theta_W)$.

Application of Eq. (4) to the $\Upsilon(1S)$ data[10] yields the first value shown in Table 1 and $\Lambda_{\overline{MS}} = 118^{+16}_{-15}$ MeV. The other entries in Table 1 are obtained from R_{hadron} measurements, the UA-1 measurements of the ratio of the number of two jet to three jet events presented at this conference,[11] and a recent Mark J measurement using energy-energy correlations as a function of energy[12] (as indicated in the table). That QCD is not well confirmed by the R_{hadron} data in its prediction of a decreasing α_s with increasing $\sqrt{s}$ is evident by examination of the table. The MAC experiment alone shows almost a 2 standard deviation disagreement with the extrapolation of α_s from the $\Upsilon(1S)$ determination, while the UA-1 results and those from Mark J, which measure α_s in other ways, are in good agreement with the determination using the $\Upsilon(1S)$. However, it is clear that more data is needed, and with even smaller errors, to reliably check the QCD predictions using R_{hadron}.

Table 1. α_s from various sources.

$(\sqrt{s})_{\text{effective}}$(GeV)	α_s^{Theory}	$\alpha_s^{\text{Experiment}}$	Comments
4.54	—	0.165 ± 0.005	Υ decay, (10)
6	0.155	0.12 ± 0.11	R, CB, (6)
29	0.125	0.23 ± 0.06	R, No electroweak included, MAC, (2)
32	0.123	~ 0.20	R, $\sin^2\theta_W = 0.23$, JADE, (1)
32	0.123	~ 0.18	R, $\sin^2\theta_W = 0.23$, TASSO, (8)
44	0.117	0.12 ± 0.02	Energy-Energy correlations, Mark J, (12)
89	0.116	$0.133 \pm 0.024 \pm 0.02$	$N_f = 6$, UA-1, (11)

3. THE SEARCH FOR EXOTIC EFFECTS IN e^+e^- AT THE HIGHEST AVAILABLE ENERGIES

In the main, PEP/PETRA have made the contributions to these types of searches which include: new particle searches, the search for monojets (motivated by the UA-1 monojets,[13]) and the search for lepton and quark compositeness. An enormous effort has gone into these experiments, and the results have all been negative. In particular, the search for the top quark has essentially dominated the PETRA program since the machine turned on, with the result that we now are sure that the top quark mass is greater than 23.3 GeV.

A recent review of limits in new particle searches[14] gives the following best limits so far obtained for sequential leptons (L) and point-like, unit charge, spin-zero particles (H):

$$e^+e^- \to L^+L^-,\ \tau_L < 10\ \text{ns},$$
$$M_L > 22.5\ \text{GeV}\ \ (95\%\ \text{C. L., Mark J})\ . \tag{6}$$

$$e^+e^- \to H^+H^-, \ H \to (\tau\nu) \text{ or hadron,}$$
$$\text{excludes } 5 < M_H < 13 \text{ GeV } (95\% \text{ C. L., JADE \& TASSO}) . \tag{7}$$

$$e^+e^- \to H^+H^-, \ Br(H \to \tau\nu) > 0.25,$$
$$M_H > 17 \text{ GeV } (95\% \text{ C. L., Mark J}) . \tag{8}$$

Technipions have been the main motivation for the spin-zero particle searches, as the mass of charged technipions has been predicted[15] to be in the range 5 to 14 GeV; decays of technipions into the heaviest kinematically allowed quarks and leptons are theoretically favored. The result of Eqs. (7) and (8) above is to remove technicolor as an attractive phenomenological possibility.

Supersymmetry[16] has been more successful at maintaining its options in the mass range currently available to accelerators. Many negative searches have been made, but the theory has had the flexibilty to deal with these results. A qualitative improvement has been made in the limits reported by the MAC experiment recently, as their results do not depend on the particle's lifetime. I report here recent limits obtained by the MAC collaboration[17] on the production of photinos ($\tilde{\gamma}$) and sneutrinos ($\tilde{\nu}$) in e^+e^+ production at $E_{c.m.} = 29$ GeV. Figure 10 shows the diagrams tested for. The photino diagram has been calculated,[18] and

$$\sigma(e^+e^- \to \gamma\tilde{\gamma}\tilde{\gamma}) \sim \alpha^3 s/(M_{\tilde{e}})^4 . \tag{9}$$

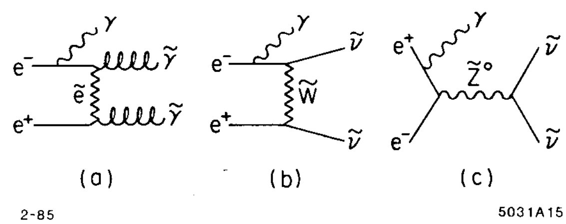

Fig. 10. Diagrams used to calculate a) $e^+e^- \to \gamma\tilde{\gamma}\tilde{\gamma}$; b) and c) $e^+e^- \to \gamma\tilde{\nu}\tilde{\nu}$.

Candidate events are selected by the size of their "perpendicular energy", $E_\perp$. All that is seen in the detector is a single photon candidate with,

$$E_\perp \geq (\sqrt{s} - E_\gamma) \ \sin(\theta_{veto}) , \tag{10}$$

where E_γ is the measured energy of the photon, and θ_{veto} is the minimum angle covered by the detector. Figure 11 shows the result of the search. Part (a) shows the observed $E_\perp$ spectrum for the first data sample taken of (36 pb^{-1})

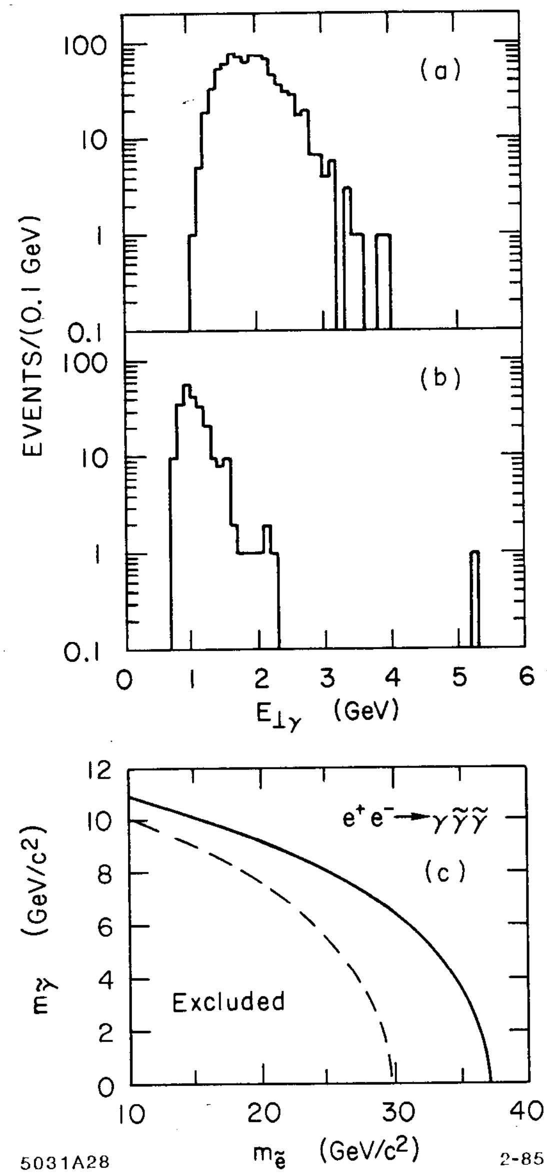

Fig. 11. Results from the MAC collaboration on $\tilde{\gamma}$ production. a) The observed $E_\perp$ spectrum for the first data sample of 36 pb^{-1} with $\theta_{veto} = 10°$ and search region $E_\perp > 4.5$ GeV, b) the spectrum for the second data sample of 80 pb^{-1} with $\theta_{veto} = 5°$ and search region $E_\perp > 3.0$ GeV, c) the lower limit for $M_{\tilde{e}}$ as a function of $M_{\tilde{\gamma}}$; the solid curve is for $M_{\tilde{e}L} = M_{\tilde{e}R}$; the dashed curve for $M_{\tilde{e}L} \gg M_{\tilde{e}R}$; the limits are at 90% C.L.

with $\theta_{veto} = 10°$ and search region $E_\perp > 4.5$ GeV/c^2. Part (b) shows the observed $E_\perp$ spectrum for the second data sample taken of (80 pb^{-1}), with $\theta_{veto} = 5°$ and search region $E_\perp > 3.0$ GeV/c^2. One event is observed in the latter data sample. This result leads to the upper limit for photino production versus $\tilde{e}$ mass shown in part (c) of the figure. The experimental observations can also be turned into a limit on the sneutrino mass,[18] for $20 < M_{\tilde{W}} < 29$ GeV, $M_{\tilde{\nu}} > 10$ GeV/c^2. See Ref. 14 for a review of other recent limits.

Motivated by the monojets reported by UA-1,[13] the HRS collaboration has initiated a search at PEP,[19] with $\sqrt{s} = 29$GeV and integrated luminosity of 176 pb^{-1}, for

$$e^+e^- \rightarrow x_1 x_2 \ , \tag{11}$$

where x_1 is a light unobservable particle, and x_2 decays promply into a jet. The mechanism for the production of x_1 and x_2 is assumed to be the decay from the tail of the Z° as shown in Fig. 12.

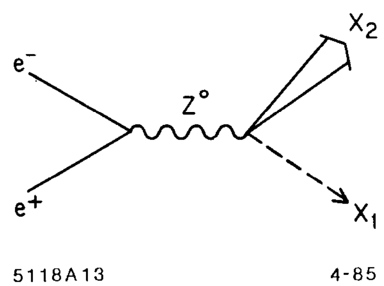

Fig. 12. The diagram tested for in the HRS Experiment at PEP.

The HRS collaboration has seen one candidate, which is consistent with a backround estimate of 3.3 ± 1.5 events. The backround comes from initial state radiation where the radiated photon gets lost in a crack in the detector. The result excludes Z° mediated production of scalar particles in the mass range 2–10 GeV as the source of most of the observed UA-1 monojet events.

The physics associated with the possibility of composite quarks and leptons has been well presented at this conference.[20] Figure 13, taken from Ref. 20, summerizes the present limits on compositeness in terms of the phenomenological lagrangian,[21] $\mathcal{L}_{HD}$, shown at the top of the figure. This lagrangian has analogy to the one invented by Fermi to decribe the low energy phenomenology of the weak interactions. The f's are lepton or quark fields, $\Lambda_\pm$ is just the new scale of compositness, and η gives the strength of the interaction. In Fermi's case, these two constants were combined into one, as gauge bosons were not in vouge in those days. As pointed out in Ref. 21, a more general form of this contact interaction is

$$\mathcal{L}_{HD} = \pm \frac{4\pi\eta}{2\Lambda_\pm} \sum C_A \left[\mathrm{f}_1 \, \Gamma^A \, \mathrm{f}_2 \right] \times \left[\, \mathrm{f}_3 \, \Gamma'_A \, \mathrm{f}_4 \right] \tag{12}$$

where Γ^A or Γ'_A can be V−A (L) or V+A (R) and C_A are constants.

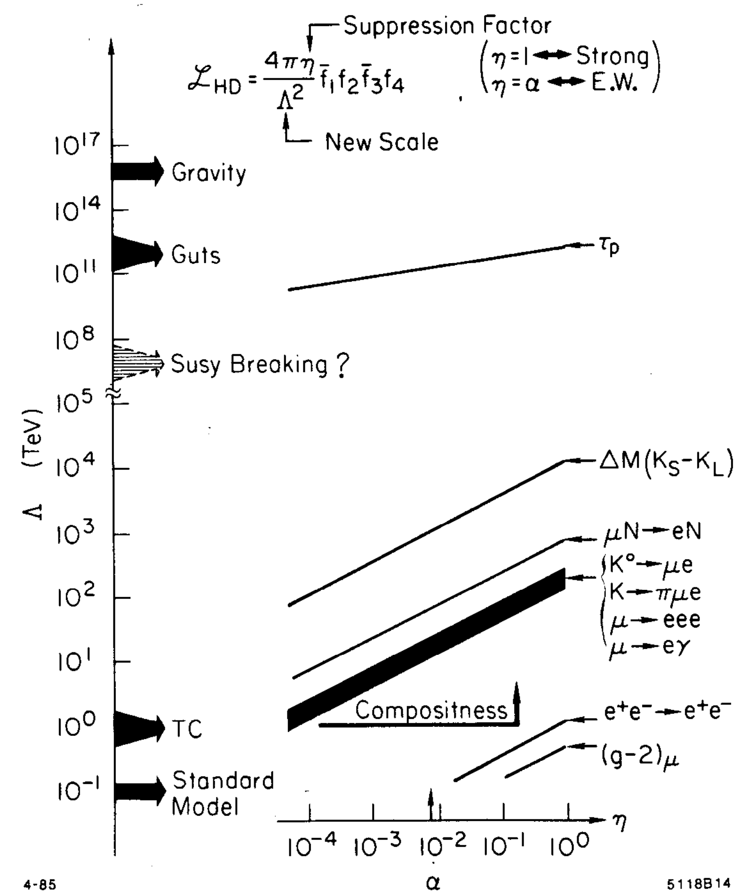

Fig. 13. A summary of tests for compositions of quarks and leptons. The phenomenalogical interaction used is shown at the top of the figure.

Results from Bhabha scattering and mu pair production have been reviewed from PETRA.[22] Figure 14 shows the scale limits obtained from TASSO for Bhabha scattering at $\sqrt{s} = 34.5$ GeV, and for various combinations of left and right handed currents. Figure 15 shows similar results for μ pair production. The 95% C.L. limits on $\Lambda_\pm$, assuming $\eta = 1$, are given in Table 2.

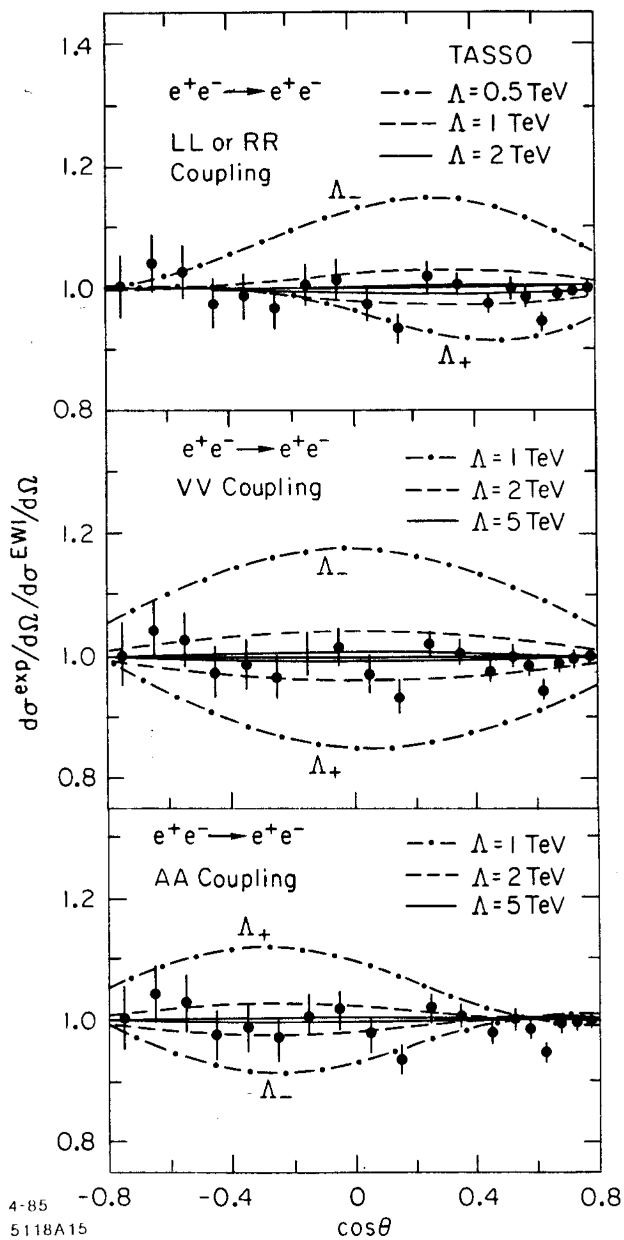

Fig. 14. Results from TASSO on Bhabha Scattering used to test for the compositness scale of electrons. Results are shown asumming: a) LL or RR coupling; b) VV coupling; c) AA coupling. For a summary of these results and those from Fig. 15, see Table 2.

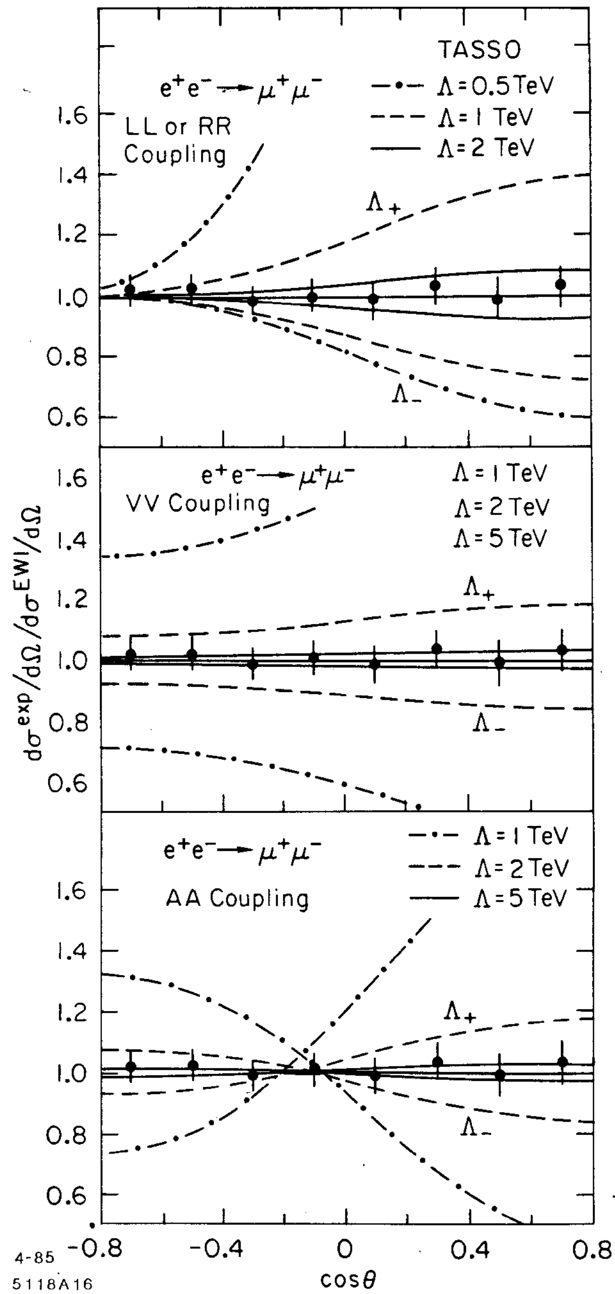

Fig. 15. The same as Fig. 14, except $e^+e^- \to \mu^+\mu^-$ is tested.

Table 2. 95% confidence level lower limit from $e^+e^- \to e^+e^-$, $e^+e^- \to \mu^+\mu^-$, at $\sqrt{s} = 34.5$ GeV on lepton substructure; for this table $\mu = 1$. The $\Lambda_\pm$ values are for a $\pm$ sign in the amplitude for the contract term. L = V–A, R = V+A. The results are from Ref. 21.

Reaction	Coupling	95% C.L.L.L. Λ_+ (TeV)	95% C.L.L.L. Λ_- (TeV)
$e^+e^- \to e^+e^-$	LL or RR	0.7	1.9
	VV	1.9	2.9
	AA	2.0	2.3
$e^+e^- \to \mu^+\mu^-$	LL or RR	2.1	2.6
	VV	3.4	4.4
	AA	3.0	3.4

4. THE SEARCH FOR NARROW STATES IN THE RADIATIVE DECAYS OF THE J/ψ AND Υ

First I will dicuss results from the Mark III detector at SPEAR on a narrow state at a mass of 2.2 GeV in J/ψ radiative decays. This is really a brief status report on this state, called the ξ, since it was first reported in conferences in the summer of 1983.[23] For a complete and recent status report see Ref. 24.

Figure 16 shows the signal as seen in 1982 data and the sum of 1982 and 1983 data. In the 1982 sample of about 1.8 million J/ψ decays the signal is fitted as a 5 standard deviation (s.d.) effect; however, the sum of the 1982 and 1983 data, 2.6 million J/ψ decays, shows a lower significance of 4.6 s.d. The best estimate of mass and width are[23]

$$\begin{aligned} m_\xi &= 2.218 \pm 0.003 \pm 0.01 \text{ GeV} \\ \Gamma &\geq 0.040 \text{ GeV} \quad (95\% \text{ confidence}) . \end{aligned} \tag{13}$$

The state is best seen in γK^+K^-, and the product branching ratio is

$$[J/\psi \to \gamma\xi(2.2)] \times \left[\xi \to K^+K^-\right] = (5.7 \pm 1.9 \pm 1.4) \times 10^{-5} . \tag{14}$$

The J^P of the state is not measured with the present data, but the most likely hypotheses are J = 0, 2, or 4.[24] Figure 17 shows the 1982 and 1983

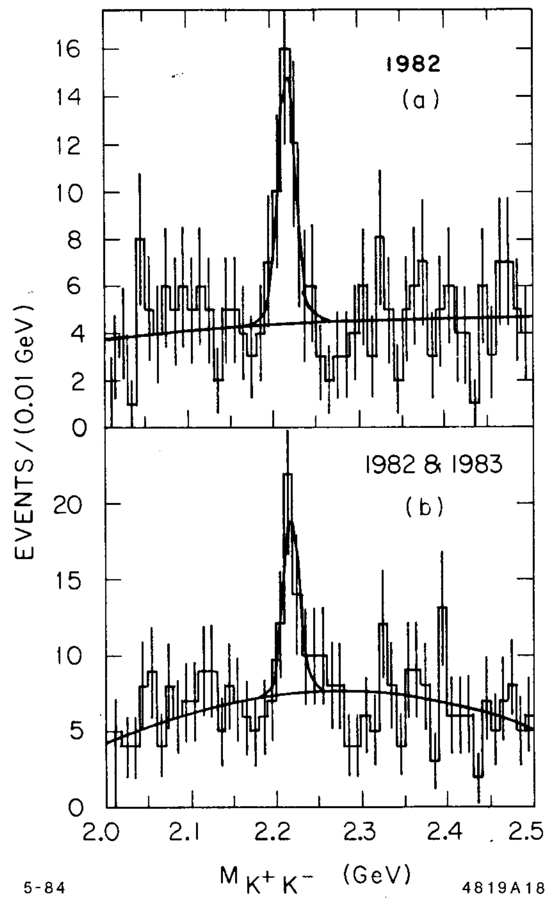

Fig. 16. Mark III results for $J/\psi \to \gamma\xi$, $\xi \to K^+K^-$. a) 1983 data alone, b) 1983+1982 data combined.

separately. In parts (a) and (b) of the figure the masses are allowed to be different in the two data samples, and they show structures at different masses. If the mass is fixed to that seen in the 1983 data sample (see 17d), the fit of Fig. 17c results. In order to further explore the ξ signal, the Mark III collaboration has gathered about 2.5 million additional J/ψ events in the first part of 1985. It should be noted that DM2 at DCI has only reported upper limits on the ξ which are in conflict with the Mark III results. Figure 18 shows the mass spectrum for the K^+K^- in the decay to γK^+K^- from 4.4 million J/ψ decays in the DM2 detector at DCI.[25] Using the quoted Mark III branching ratio to γK^+K^-, the DM2 efficiency of 9% and their mass resolution of 15 MeV, DM2 expects about 23 ξ events over a 30 event background in a 40 MeV mass interval about the ξ. They see no indication of a signal.

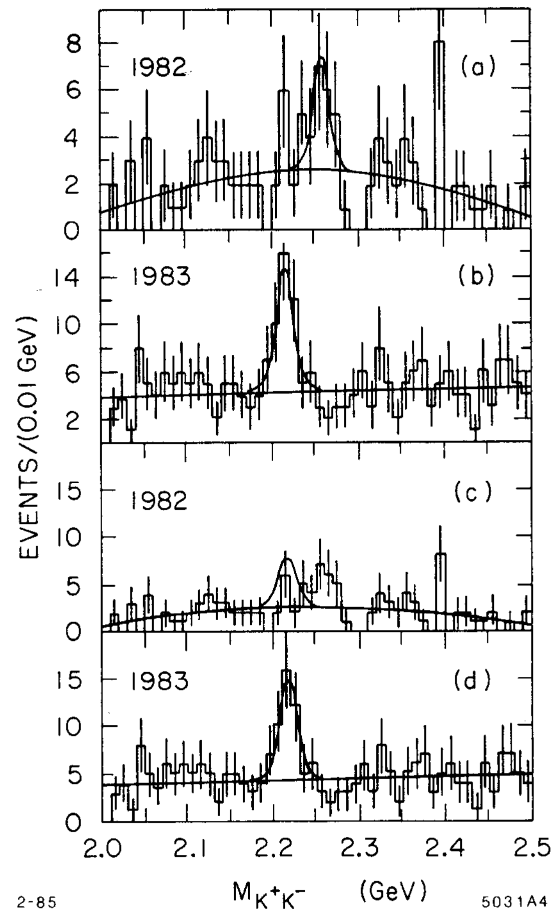

Fig. 17. Mark III $\xi(2.2)$ results continued. a) 1982, b) 1983 results fit allowing the mass of the resonance to vary in the fit. c) 1982 d) 1983 results fit keeping the resonance mass fixed at the 1983 value.

The possible existence of a narrow resonance in this mass range in J/ψ radiative decays has stimulated speculation that the ξ might be a non-S-M Higgs boson,[26] but at present more prosaic explanations[27] seem more likely.

Considerably more excitement was caused in the summer of 1984 by the announcement from the Crystal Ball collaboration of evidence for a narrow state in Υ radiative decays.[28] The large mass of this state, called ς, at 8.3 GeV, suggested to a number of theorists the possibility that the state was a non-S-M Higgs candidate.[29] Evidence for the state was observed by the Crystal Ball in two independent final state configurations, one of higher multiplicity and hadronic character, and one of lower multiplicity resembling $\tau\bar{\tau}$.

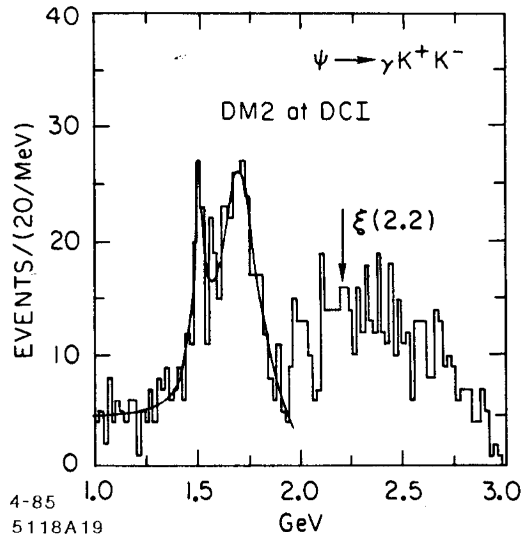

Fig. 18. Results from 4 million J/ψ decays in the DM2 detector at DCI on J/$\psi \to \gamma K^+K^-$. No indication of the $\xi(2.2)$ is seen.

Given the numerous reports on the $\varsigma(8.3)$ over the past six months, I will only briefly review the results presented at the summer conferences[28] as an orientation to presenting recent results from a run of about 200K Υ events taken by the Crystal Ball at DESY last Fall, and results from the CUSB detector also from a Fall run at CESR. These latest results are preliminary.

The first results from the Crystal Ball came from a sample of about 100K Υ(1S) decays (10.4 pb^{-1}). The signal in the high multiplicity final state was 4.2 s.d. The low multiplicity final configuration showed a 3.3 s.d. effect at a mass 10 MeV away from that found in the high multiplicity case, and well within the statistical error on the mass measurement. Taken as independent, the two final state configurations yield a signal of over 5 s.d. The best estimate of the mass and width of the state is[28]

$$\begin{aligned} M_\varsigma &= 8.322 \pm 0.008 \pm 0.024 \text{ GeV} , \\ \Gamma &< 80 \text{ MeV (90\% confidence)} . \end{aligned} \tag{15}$$

The branching ratio, $\Upsilon \to \gamma\varsigma$, is somewhat model dependent since the manner in which the ς decays can effect the efficiency for finding photons in the final state. This is reflected in the product branching ratio into hadrons for the ς,

$$B[\Upsilon(1S) \to \gamma\varsigma] \times B[\varsigma \to hadrons] = (0.47 \pm 0.11 \pm 0.26)\% , \tag{16}$$

where the first error is statistical, and the second error is systematic with the bulk of this systematic error coming from uncertainties in the photon detection efficiency. Including the low multiplicity final state complicates matters even more, thus the Crystal Ball collaboration prefers to give the result as,

$$B\left[\Upsilon(1S) \rightarrow \gamma\varsigma\right] \sim 0.5\%. \tag{17}$$

Given the excitement the announcement of the ς caused, it was natural that a large effort was mounted to check the initial report from the Crystal Ball. This was done both at DESY and Cornell in the Fall of 1984. The Crystal Ball obtained about 200K more Υ decays in the detector (22 pb^{-1}). The CUSB detector has obtained about 340K more Υ decays in their detector (about 22 pb^{-1} at CESR due to the narrower beam energy spread), making about 450k events in total when adding in older data. The results I report here for both detectors, essentially, have been reported elsewhere.[30,31]

In the interim between the 1983 (100K Υ) and 1984 (200K Υ), the Crystal Ball detector underwent a major upgrade. A new tracking chamber system was installed which increased the number of proportional tube chamber layers from six to eight. Also, a new gas was used (Ar-CO_2-Methane) which stopped the chamber degradation with beam exposure which was previously plaguing the detector. This change necessitated a major restructuring of the online data acquisition hardware and software, and offline analysis software. These changes had been in progress for some time, but the Fall of 1984 run was the first real physics data taken with the new system; of course there were problems in the initial part of the run. The problems were later corrected in offline software.

A preliminary analysis of all the new data for the high multiplicity configuration will be presented here. The low multiplicity channel is more problematic since the backgrounds in the analysis are sensitive to the tracking chamber quality (not the case for the high multiplicity analysis). Thus, the dramatic improvement of the new chamber system over the old one has necessitated a total re-thinking of the charged particle cuts in the low multiplicity analysis.

Figure 19a,b shows a comparison of the high multiplicity channel analysis from the 1983 run, 100K Υ, and the 1984 run, 200K Υ. The new data obviously do not confirm the ς. Fitting the new spectrum we find -29 ± 29 counts at the expected mass of the ς. There is over a 4 s.d. difference at the ς mass between the 1983 data and this preliminary analysis of the 1984 data.

Extensive checks have been made on the data's quality in both the 1983 and 1984 data sets. In particular, confidence was sought in the energy calibration, energy resolution, and scaled multiplicities. In order to make the checks, all $\Upsilon(1S)$ data were divided into 1 pb^{-1} subsets. Every known "signal" in these

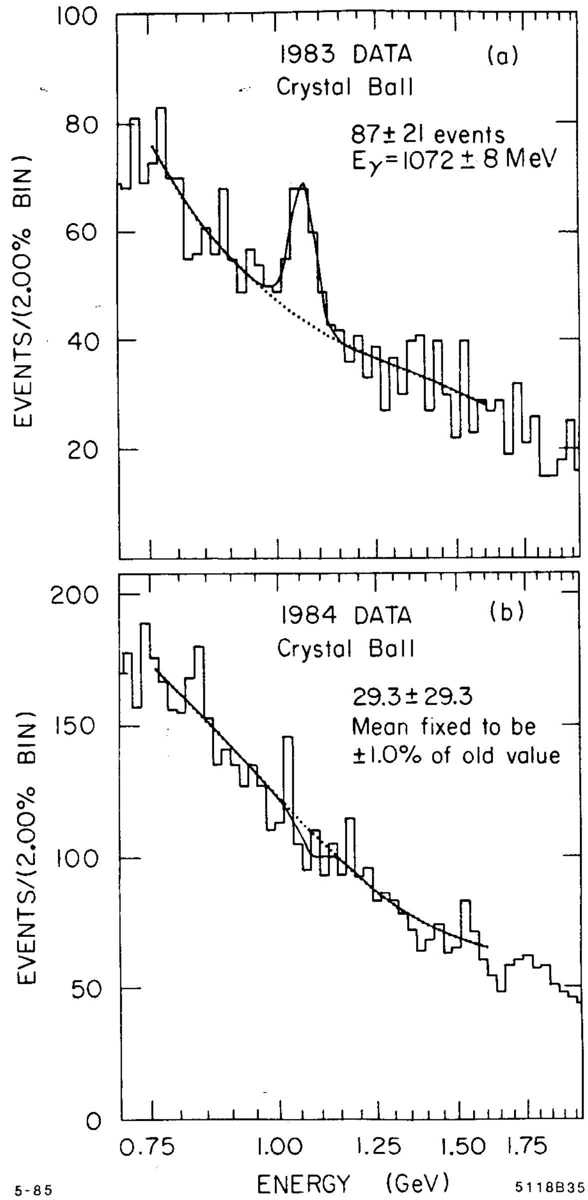

Fig. 19. Results on $\Upsilon(1S) \rightarrow \gamma X$ from the Crystal Ball experiment at DORIS II. a) The inclusive photon spectrum obtained for the high multiplicity analysis using the 1983 $\Upsilon(1S)$ data (100K $\Upsilon(1S)$ decays, $\sim$ 10 pb $^{-1}$). b) The inclusive photon spectrum obtained for the high multiplicity analysis using the 1984 $\Upsilon(1S)$ data (200K $\Upsilon(1S)$, $\sim$ 20 pb $^{-1}$). There is over a 4 s.d. difference between these two spectra at a mass $\sim$ 8.3 GeV.

data were checked for a consistent mean, amplitude and width over each 1 pb^{-1} interval. The "signals" involved were the π^0 and η peaks in the 2 photon invariant mass plots, the charged particle minimum ionizing peak which is at about 203 MeV in the Crystal Ball, and the Bhabha peak. For the π^0's, one photon was required to have an energy greater than 400 MeV so photons closer to the ς region of about 1070 MeV would be tested. By fitting each of these peaks, constraints were set on any shifts in the energy scale or energy resolution. From the π^0, η and minimum ionizing peaks it was found that photon energies in the few hundred MeV range should not have shifted more than $\pm 1.0\%$ from those in the 1983 sample and their width should be within 5.0% of the width seen in 1983. Additionally, Bhabha studies show that photons around 4.6 GeV have a mean within 0.5% and width within 5.0% of that seen in the 1983 data. Photons in the 1 GeV range were studied by fitting 3 photon QED events where one photon was required to be between 500–2000 MeV. No energy shifts were found when fitted and measured energies were compared. These tests indicate that the ς should have been seen with mean within $\pm 1.0\%$ and width within $\pm 5.0\%$ of that seen in the 1983 data.

There is, however, one difference between the 1983 and 1984 data sets, the value of R_{hadron}. Figure 20 shows the value of R_{hadron} vs run number for the two data sets. The average value of R_{hadron} in the 1983 data is 11.1 while the average value in the 1984 data is 12.2. If this shift is real, it implies, together with the 8 MeV $E_{c.m.}$ energy resolution (σ) at DORIS, a shift in the e^+e^- center-of-mass energy of about ± 4 MeV. We also estimate the systematic errors in the measurement of R_{hadron} to imply a ± 4 MeV error in the corresponding center-of-mass energy. Thus a conservative estimate for the shift in center-of-mass energies between the 1983 and 1984 data sets is 0–8 MeV.

One model which can explain the ς's disappearance in the 1984 data is that of Tye and Rosenfeld[32] (T&R). As schematically indicated in Fig. 21a, this model assumes that the 1983 energy was displaced from the $\Upsilon(1S)$ resonance for all or part of the run, and the ς peak is the radiative decay of some state (X) near the $\Upsilon(1S)$. The above limit on the shift in center-of-mass energy of 8 MeV allows us to put constraints on such a model. Radiative corrections and DORIS's intrinsic energy resolution allows some probability of creating this hypothetical state and seeing its radiative decay and thus a ς signal in the 1984 data. Such a possibility was studied using all data accumulated on and near the resonance. There are two questions to ask: (1) how does all data, excluding the 1983 data which spawned the T&R model in the first place, limit the model; (2) how much consistency does the model allow between the 1983 and 1984 data.

Figure 21b shows $Br(X \to \gamma\varsigma) \times \Delta R_X$ at 90% C.L. vs the mass of a hypothetical state X (note the log scale for the ordinate). The three curves with

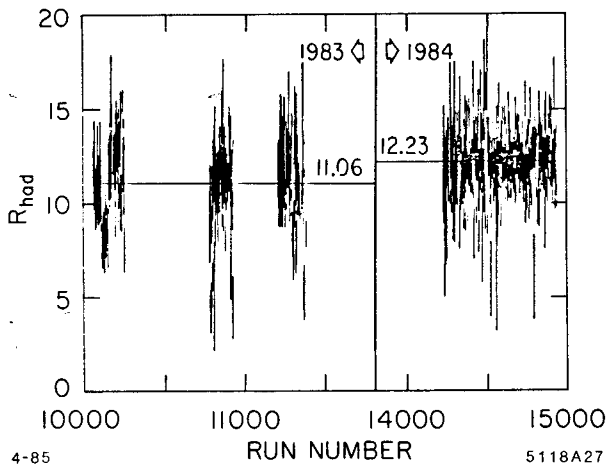

Fig. 20. R_{hadron} vs Run Number from the Crystal Ball. The Nominal energy is that of the $\Upsilon(1S)$. The 1983 R_{hadron} shows a systematic downward shift as compared to the 1984 result. Though compatable within "boxcar" systematic errors, these results suggest that the 1983 energy could have been off resonance by as much as 8 MeV.

minima at about $M_X = 9.40$, 9.43, and 9.48 GeV are obtained from the radiatively corrected DORIS energy resolution function convoluted with data off the resonance, whereas the curve at 9.46 GeV comes from convoluting the 1984 data taken on the $\Upsilon(1S)$. The hatched regions attached to the curves are to indicate the scale error on the normalization of $E_{c.m.}$. In addition the figure shows the measurement of the ς from the 1983 data, with $E_{c.m.}$ uncertainty, and the T&R prediction for the state X, with mass and strength uncertainty. Clearly, the data do not severely constrain the T&R model.

Can the T&R model explain the discrepancy between the 1983 and 1984 data shown in Fig. 19a,b? In order to explore this possibility, Fig. 22a,b magnifies the region around 9.460 GeV. The three solid curves are the same as those in Fig. 21b. In addition, the two dashed curves correspond to the branching fraction reported for the ς (the cross), but shifted in energy by ± 8 MeV. In Fig. 22a,b consistency between the 1983 and 1984 data is allowed if a T&R state exists and its mass is in the range where the dashed curves are below the solid curves. Of course, the allowed mass range depends on the relative beam energy shift for the 1983 vs 1984 data and the confidence level tested. Figure 22a shows the allowed mass range for such a state at the 90% C.L. and for a 8 MeV shift in the relative center-of-mass energy. This figure implies that

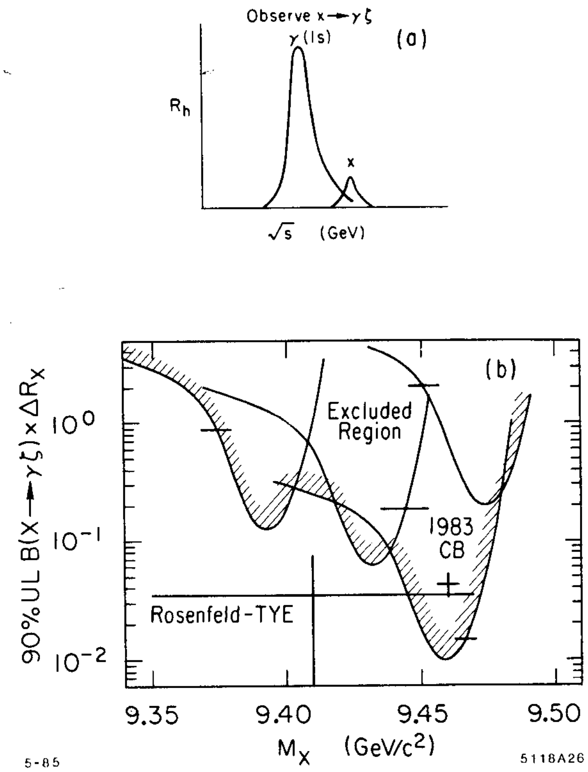

Fig. 21. a) A diagramatic representation of the T&R model. The state X, shown in the picture at slightly higher $E_{c.m.}$ than the Υ(1S), decays to the $\gamma\varsigma(8.3)$ final state. b) The 90% C.U.L. for $B(X \rightarrow \gamma\varsigma) \times \Delta R_X$ vs M_X obtained from Crystal Ball data on and off resonance. For completeness, the 1983 CB result, which spawned the R&T model in the first place, is also shown. The data do not seriously limit the model predictions which are also shown in the figure.

the 1984 result rules out the 1983 result to the 90% C.L. level unless some state exists between about 16–26 MeV above the Υ(1S) (Fig. 22b gives the 98% C.L. result). Given the results of Fig. 22, this model seems an unlikely possibility for explaining the disagreement between the 1983 and 1984 data sets.

Along with acquiring additional data, we continued looking for problems in the 1983 analysis. One check we performed involved measuring the branching ratio for the process $\Upsilon \rightarrow \gamma\varsigma$ as our analysis cuts were applied. This was done by calculating the effective branching ratio after each cut, taken in their nominal order. Figure 23a shows the expected behavior for such a comparison

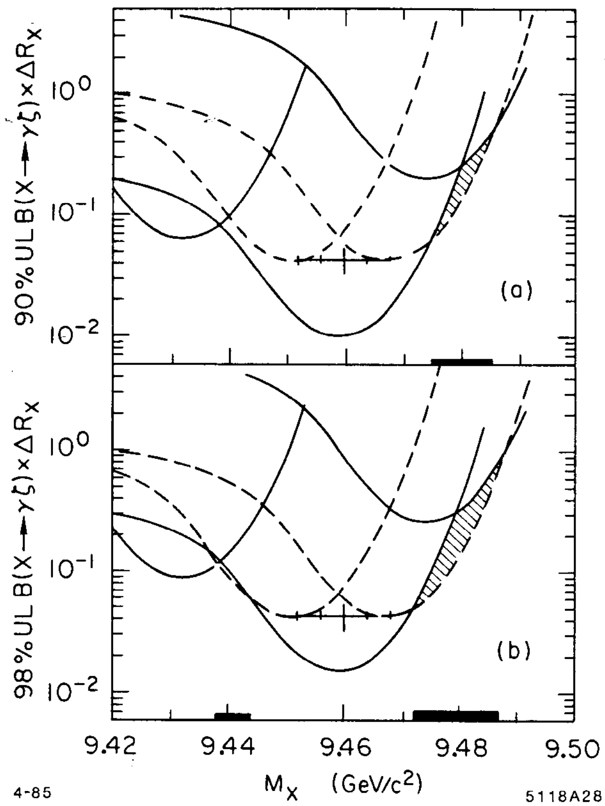

Fig. 22. Is the 1983 CB result consistent with the 1984 result under the T&R model? a) The solid lines are the 90% U.L. on $B(X \to \gamma\varsigma) \times R_X$ shown in Fig. 21. The dashed lines are the values implied for $B(X \to \gamma\varsigma) \times R_X$ vs M_X, from the CB 1983 measurement, taking into account the DORIS beam energy spread and radiative corrections. The two dashed lines are shown shifted from the nominal $\Upsilon(1S)$ energy by ± 8 MeV. For M_X in the range where the dashed lines lie below the solid lines the existence of a T&R like state would allow consistancy of the 1983 and 1984 CB results. b) The same as for a), but considering the 98% C.U.L.

as simulated by adding 500 $\gamma c\bar{c}$ Monte Carlo events ($E_\gamma = 1070$ MeV) to 100K 3 gluon (3% are γ gluon gluon) + 25K $q\bar{q}$ Monte Carlo events. The solid line indicates the number of counts (projected from the number after all cuts) using the $\gamma c\bar{c}$ Monte Carlo to estimate the detection efficiency after each cut. The points with errors are obtained by fitting the inclusive photon distribution for a

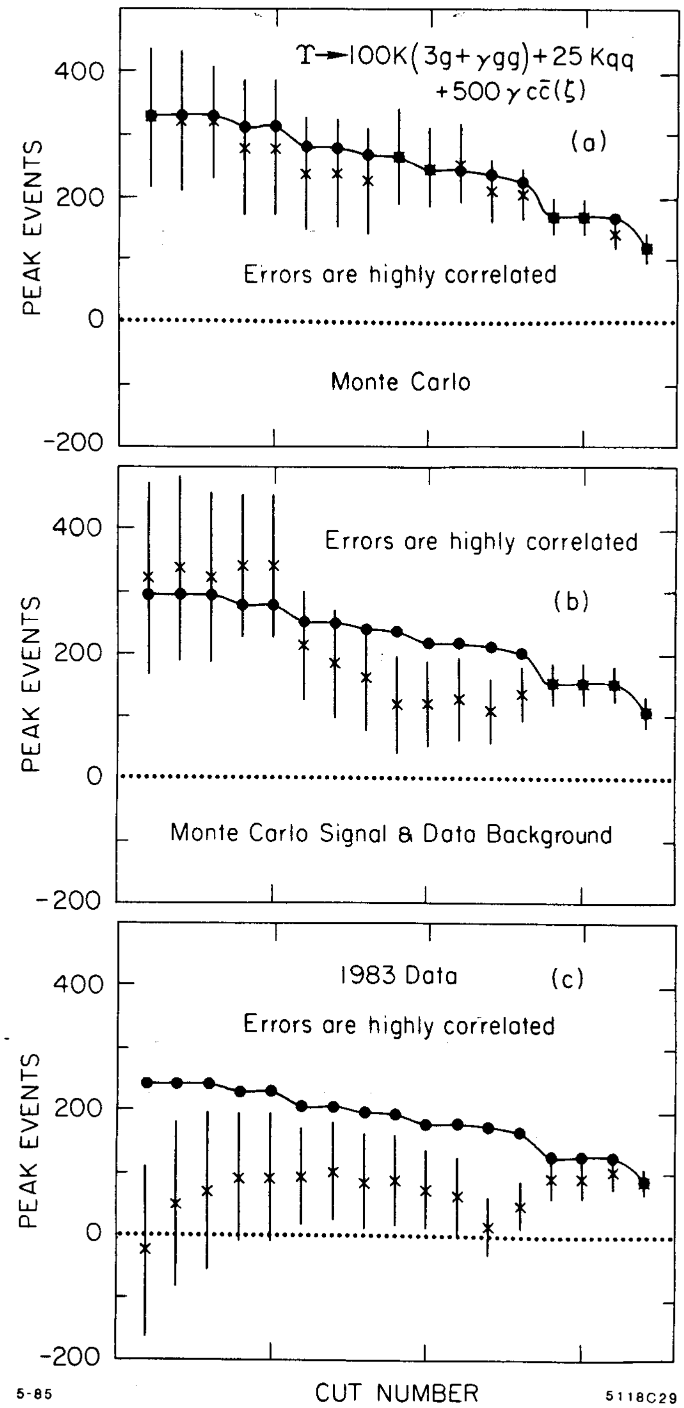

Fig. 23. Number of extracted peak events vs cut number in the Crystal Ball high multiplicity analysis. Three cases are considered: (a) All events Monte Carlo; 100K (3 gluons + γ 2 gluon) + $25Kq\bar{q}$ with a signal of 500 $\gamma c\bar{c}$ events at the ς mass. (b) Signal Monte Carlo and Background real events. 100K $\Upsilon(1S)$ events (1984 data) plus a signal of 500 $\gamma c\bar{c}$ events at the ς mass. (c) The 1983 data. See the text for the interpretation of these results.

peak after each cut. The curve and the points are in good agreement. Note that the errors on the points are highly correlated. In Fig. 23b, the same 500 $\gamma c\bar{c}$ M.C. events are added to 100K real events from the 1984 data sample taken at the $\Upsilon(1S)$ energy. Though there is some scatter of the points about the expected curve, agreement is still acceptable.

In Fig. 23c, the 1983 $\Upsilon(1S)$ sample is compared to the curve obtained again from the $\gamma c\bar{c}$ Monte Carlo. The ratio of the data points to the curve (proportional to the branching ratio) after all cuts is found to be significantly higher than that obtained after partial cuts, indicating the number of peak events does not behave in the qualitative manner predicted by the Monte Carlo calculations. While this sort of analysis is not quantitative, it suggests the peak is not a true signal.

Figure 24 shows the upper limit derived from the 1984 data alone as shown in Fig. 19b. From this plot one can read off the following upper limit:

$$BR(\Upsilon \rightarrow \gamma\varsigma) < 0.08\% \text{ (1984 Data : 90\% C.L. Upper Limit)} . \qquad (18)$$

Assuming the 1983 and 1984 data sets can be combined for the study of Υ decay, we find a 1.9 σ excess at the ς mass leading to the upper limit:

$$BR(\Upsilon \rightarrow \gamma\varsigma) < 0.19\% \text{ (All Data : 90\% C.L. Upper Limit)} . \qquad (19)$$

The CUSB collaboration has also reported new results. Their result at the Leipzig Conference[33] was an upper limit of 0.2% (90% C.L.) for the product branching ratio, $B(\Upsilon \rightarrow \gamma\varsigma) \times B(\varsigma \rightarrow hadrons)$. This result was based on a sample of 112K Υ decays. However, this upper limit was calculated using a photon efficiency based on a model of the QCD process, $\Upsilon \rightarrow \gamma gg$, for ς radiative decays. If this model is used to obtain the branching ratio in the Crystal Ball (the 0.5% value in the Crystal Ball is obtained using a $c\bar{c}$ model for the hadronic decay of the ς[28]) the value obtained is about 0.25%. The new preliminary results from the CUSB collaboration, using their new data (340K decays), combine data from the new sector of the detector made from BGO scintillator ($\Delta\Omega_{BGO} \sim 0.25$) with the old part made from NaI(Tl). They find an upper limit for the product branching ratio of 0.09% (90% confidence).[31] The same model for Υ decays, $\Upsilon \rightarrow \gamma gg$, was used to calculate the photon efficiency.

In summary, the absence of the ς in the Crystal Ball 1984 high multiplicity analysis and the CUSB spectra, together with the Crystal Ball studies of their 1983 analysis and the Tye-Rosenfeld model, indicate the ς's existence is very unlikely.

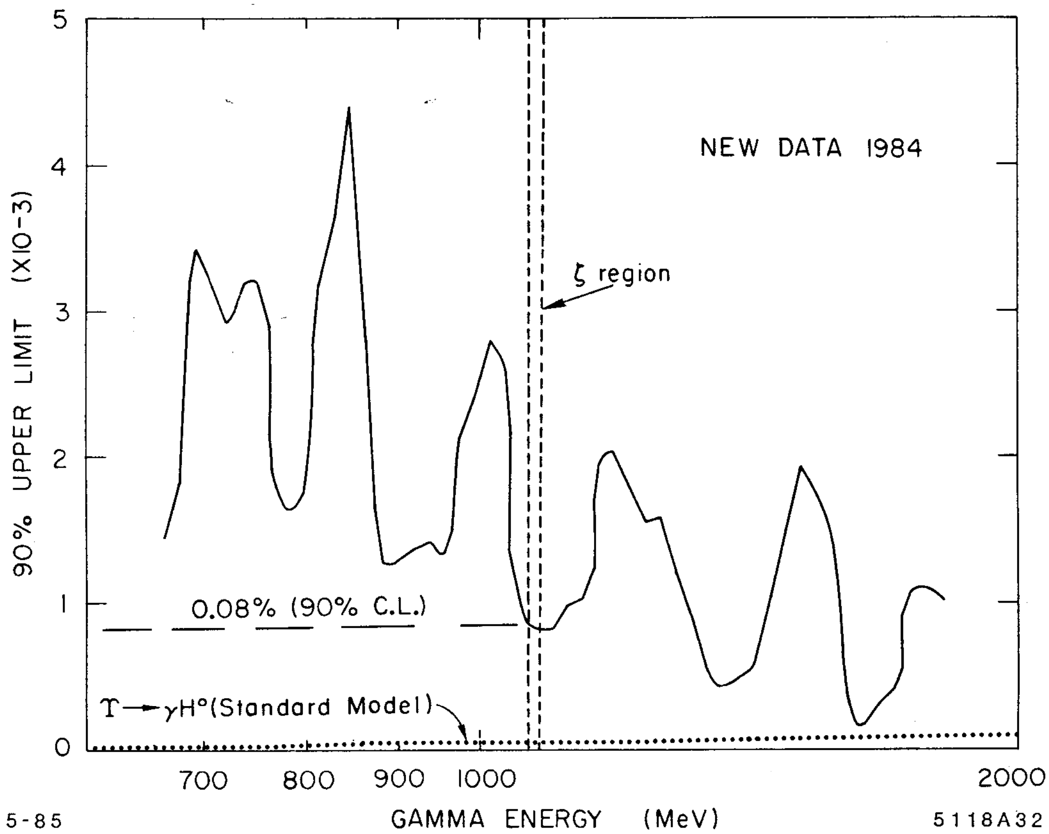

Fig. 24. The 90% C.L. upper limit for $B(\Upsilon(1S) \to \gamma X) \times B(X \to c\bar{c})$ from the 1984 CB data alone. In this upper limit it is assumed that X decays hadronically as modeled by $X \to c\bar{c}$. The vertical dashed lines show the position of the ς signal in the 1983 data. The dotted line gives the Standard Model estimate[34] for $\Upsilon(1S) \to \gamma H^\circ$.

5. CONCLUSIONS

This report represents the efforts of many people over many years. It is all work that should have been done; however, it now appears that no surprises have emerged:

- There may be an excess in R_{hadron}, though the theoretical and experimental errors make this interpretation only one of many (more prosaic) possibilities.
- No new particles have been seen at PEP/PETRA. Lepton compositness limits $\lesssim$ few Tev seem impressive.
- The existence of the $\xi(2.2)$ seems unlikely given the recent results of the MARK III and DM2 detectors.

- The existence of the $\varsigma(8.3)$ is very unlikely given the results of the Crystal Ball and CUSB detectors.

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