SEARCHES FOR NEW PARTICLES AT TRISTAN

Akiya Miyamoto
National Laboratory for High Energy Physics

ABSTRACT

Recent TRISTAN results on searches for new particles, such as charged higgs, leptoquark, colored lepton and abnormal dE/dx particle are presented. As an indirect search, fits by a Z' model to R_{had}, R_{ll} and A_{ll} data below Z^0 are updated including the latest TRISTAN data and parameters of Z' to reproduce slightly high R_{had} and low R_{ll} are studied.

1. Introduction

Since the begining of TRISTAN, May 1987, each TRISTAN experiment has accumulated about 35 pb^{-1} in the energy range $\sqrt{s} = 50$ GeV to 64 GeV. All TRISTAN groups had been searching extensively for new particle productions as energy frontier experiments till LEP and SLC started operation last summer. The new particle searches done so far at TRISTAN are summarized in fig.1. Target particles are shown by vertical axis and searched modes are described in the figure. Fourth generation b' quark decaying through FCNC ($b' \to b\gamma, bg$) was searched in four-jet and isolated γ modes for the first time. No positive evidences of these particles were found and mass limits close to the beam energy were obtained. Now these limits are superseded by SLC and LEP results. Recent new particle searches at TRISTAN which are not included in fig.1 are described in the next section.

Other topics related to the new particle searches include the study of the effect of Z' considered to explain the slightly high R_{had} and low R_{ll} below Z^0[2,3]. We discuss this in section 3 including the latest TRISTAN data. Finally, a summary with a brief comment on new particle searches at future TRISTAN ends this paper.

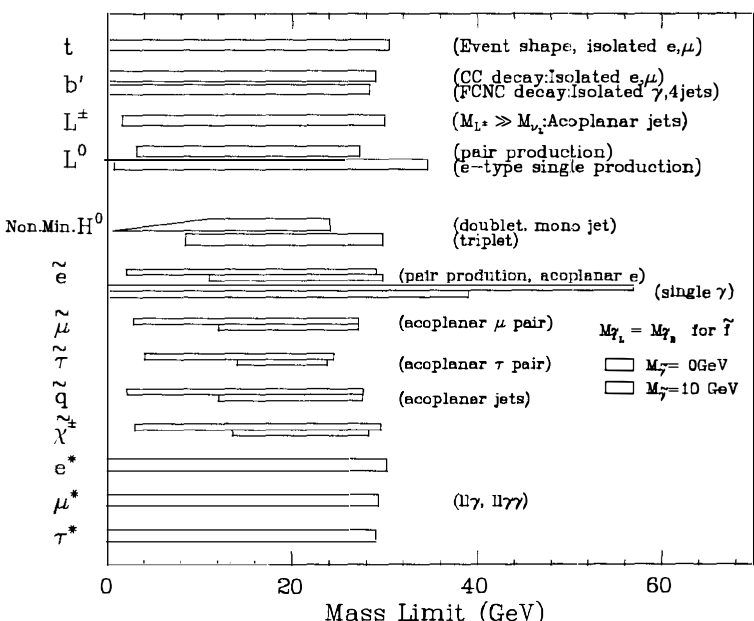


Fig.1 Summary of mass limits of new particles[1]

2. Recent results on searches for new particles

2.1. Charged Higgs

SUSY models require at least two higgs doublets. Therefore a charged higgs($H^{\pm}$) is naively expected, which has been searched by TOPAZ[4] and VENUS[5]. In the minimal SUSY model[7], charged higgs' can be pair produced by e^+e^- annihilation through γ or Z exchange and its cross section is uniquely determined as: $d\sigma/d\Omega = \frac{3}{32\pi}\sigma_0\beta^3\sin^2\theta$, where β and θ are the velocity and the production angle of H, respectively,

$$\sigma_0 = \frac{4\pi}{3s}\alpha^2\left[1 - 2C_V C_V^H \frac{s(s-m_Z^2)}{(s-m_Z^2)^2 + m_Z^2\Gamma_Z^2} + (C_V^2 + C_A^2)C_V^{H\,2}\frac{s^2}{(s-m_Z^2)^2 + m_Z^2\Gamma_Z^2}\right],$$

and C_V, C_A, and C_V^H are couplings of electron and $H^{\pm}$; $C_V = (1 - 4\sin^2\theta_W)/f, C_A = -1/f$, and $C_V^H = (-2 + 4\sin^2\theta_W)/f$ with $f \equiv 4\sin\theta_W\cos\theta_W$.

On the other hand, the decay amplitude of $H^{\pm}$ depends on the ratio of the two vacuum expectation values which are unknown. Therefore two decay modes, namely $H^- \to \tau\bar{\nu}_\tau$ and $s\bar{c}$, were considered in the search. The $H^- \to b\bar{c}$ decay mode was not considered, since it had a better efficiency and would give more stringent limits. The event signatures to be searched for are (1) two jets + two jets with each jet pair having the same invariant mass, or (2) two jets + a τ with a large missing p_t , or (3) an acoplanar τ pair, corresponding to the combinations of the decay modes. TOPAZ searched for these three signatures based on 23.3 pb^{-1} data taken in the energy range $\sqrt{s} = 52.0$ to 61.4 GeV and obtained mass limits as shown in fig.2. A combined limit, $m_H > 22$ GeV, was obtained if the hadronic branching fraction was 0.6. VENUS searched for signatures (2) and (3) and obtained preliminary limits slightly higher than those of TOPAZ .

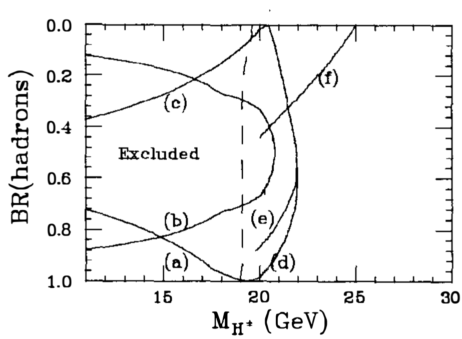
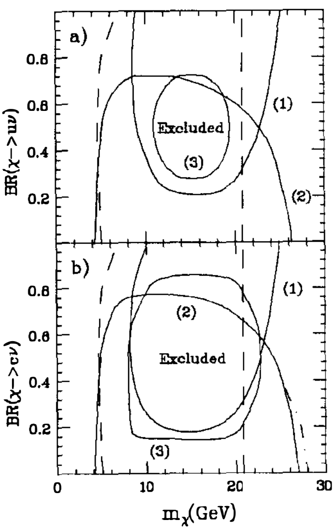


Fig.2. The 95 % C.L. limits of the mass of $H^{\pm}$ as a function of the hadronic decay branching ratio. (a), (b), (c), and (d) are the TOPAZ results obtained from 2 jets + 2 jets mode, 2 jets + τ mode, $\tau+\tau$ mode , and combining the three modes, respectively. (e) and (f) are the VENUS preliminary results from $\tau + \tau$ and $\tau +$ 2 jets modes. Dashed line is a CELLO result[6].

2.2. Lepto quark and colored lepton

Lepto-quark and colored lepton are expected in various composite and technicolor models. Searches for these particles were carried out by AMY[8] and VENUS[5]. Lepto-quark(χ) is a spin zero color triplet with a fractional charge and is assumed to be produced through photon exchange in e^+e^- annihilation and to decay into an up type quark and a neutrino or a down type quark and a charged lepton[9]. Therefore AMY and VENUS searched the signatures: (1) two acoplanar jets with a missing transverse energy, (2) two jets with an isolated lepton, and (3) two jets with two isolated leptons. No excess in these signatures was observed and imporoved mass limits of lepto-quarks were obtained(fig.3).



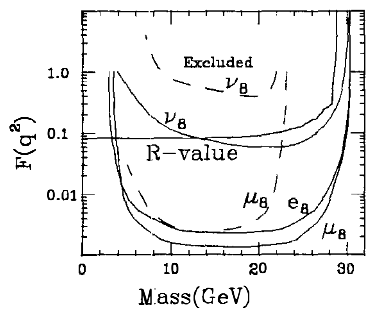


Fig.4. The 95% C.L. limits of l_8 as a function of the form factor. Solid lines are the AMY results and dashed lines are the JADE results[10].

Fig.3. The 95% C.L. limits of the mass of (a) first generation lepto-quark and (b) second generation lepto-quark as a function of the decay branching ratio to up type quark and neutrino. Solid lines are the AMY results, dot-dashed line is the VENUS and dashed lines are the JADE results[10].

The signatures used in the above are also applicative to the search for colored lepton. Colored lepton(l_8) is a color octet partner of the ordinary lepton expected in the composite models. l_8 can be pair-produced by s-channel photon exchange. Using a form factor, $F(q^2)$, its cross section is expressed as $\sigma_{l_8} = 8F(q^2)\sigma_{\mu\mu}f(\beta)$, where $f(\beta)$ is a threshold factor:$f(\beta) =$

$\beta(3-\beta^2)/2$ for $l_8^\pm$ and $f(\beta) = \beta(3+\beta^3)/4$ for ν_8. Since l_8 decays into a lepton and a gluon ($l_8 \rightarrow lg$), l_8's signatures are: (1) two acoplanar jets (ν_8) or (2) two jets and two isolated leptons ($l_8^\pm$). In the case of the color octet electron(e_8), t-channel e_8 exchange diagram also contributes. In this case, the cross section is $\sigma = \frac{32\pi\alpha_s^2}{5}\frac{s^3}{(\Lambda m_{e_8})^2}$ and e_8 could show up as an increase of the hadronic R ratio. In the AMY's search, no excess of these signatures was obsereved and new limits as shown in fig.4 were obtained.

2.3. Abnormal dE/dx particles

TOPAZ has a time projection chamber as its central tracking system[11], which allows particle identification through the energy loss measurements with a 4.6% resolution. Using this feature, TOPAZ has searched inclusive productions of abnormal dE/dx particles, namely heavy stable particles or fractionally charged particles. Candidate events were selected requiring at least 3 good tracks. To reject overlapped e^+e^- tracks due to γ conversions at the beam pipe, $\gamma\gamma$ and Bhabha events were rejected requiring that the number of neutral clusters with an energy greater than half the beam energy should be less than 2. A dE/dx distribution for good tracks in the selected events is shown in fig.5. Bands for $e, \mu/\pi, K, p$ and d are clearly seen. Search regions were defined as p/Q> 2 GeV and a dE/dx more than 4 σ away from the bands of the known stable particles. In the search regions, 3 tracks were observed, which were found to be overlapped tracks. Thus no events with abnormal dE/dx particles were observed. The 90% C.L. mass limits on the abnormal dE/dx particles were obtained assuming the following cross section formula; $\sigma(e^+e^- \rightarrow q\bar{q}X) = F_{q\bar{q}X}\frac{4\pi\alpha^2}{3s}Q^2\frac{\beta}{2}(3-\beta^2)$. The results are shown in fig.6 .

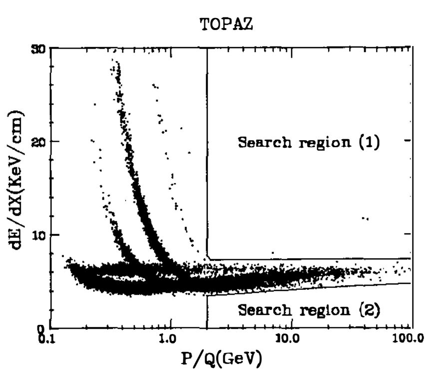


Fig.5. A scatter plot of apparent momentum(p/Q) and dE/dx of good tracks.

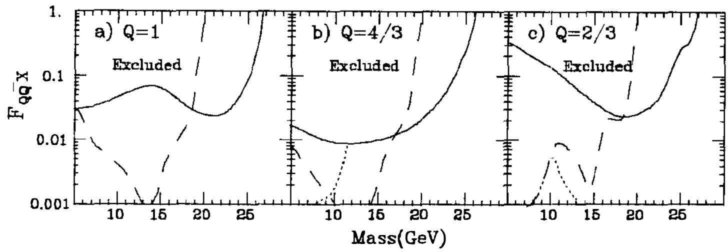


Fig.6. The 90 % C.L. limits of the form factor, $F_{q\bar{q}X}$ for the productions of abnormal dE/dx particles of charge (a) 1, (b) 4/3, and (c) 2/3. Previous results by TPC[12]and JADE[13]groups are shown by dashed and dotted lines, respectively.

3. Constraint on Z' to explain slightly low R_{ll} and R_{had}

As discussed by the previous speaker[14], below Z^0 the R_{ll} seems slightly low and the R_{had} slightly high(fig.7). Though the deviation from the standard model is 1-to-2-σ level, It is interesting to study the effect of Z' including the latest TRISTAN data, since Z' can cause such trends.

In models with an extra U(1), the neutral current Lagrangian is expressed as a sum of photon, Z_0, and Z' currents:

$$-\mathcal{L} = eJ^{\mu}_{EM}A_{\mu} + g_1 J^{\mu}_1 Z^0_{1\mu} + g_2 J^{\mu}_2 Z^0_{2\mu}.$$

Current eigen states, Z^0_1 and Z^0_2, mix with an angle θ_E to form mass eigen states, Z_1 and Z_2, where Z_1 is the Z^0 with a mass 91.1 GeV and Z_2 is Z':

$$\begin{pmatrix} Z_1 \\ Z_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_E & \sin\theta_E \\ -\sin\theta_E & \cos\theta_E \end{pmatrix} \begin{pmatrix} Z^0_1 \\ Z^0_2 \end{pmatrix}.$$

The masses of Z's are related to the mixing angle as, $\tan^2\theta_E = (M^2_{Z^0_1} - M^2_{Z_1})/(M^2_{Z_2} - M^2_{Z^0_1})$, where $M_{Z^0_1} = M_W/\cos_{\theta_W}$.

The lowest order cross section of fermion pair production by e^+e^- annihilation including γ, Z^0, and Z' propagators is

$$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2}{8s}\Big\{(1+\cos\theta)^2\big[|A^{ef}_{LL}|^2 + |A^{ef}_{RR}|^2\big] + (1-\cos\theta)^2\big[|A^{ef}_{LR}|^2 + |A^{ef}_{RL}|^2\big]\Big\},$$

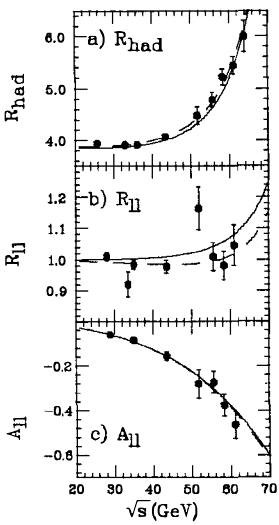
where A^{ef}_{ij}'s are helicity amplitudes $A^{ef}_{ij} = Q_e Q_f + g^e_{1i}g^f_{1j}s/s_{z1} + g^e_{2i}g^f_{2j}s/s_{z2}$, $(i,j = L$ or $R)$, $g^f_{\alpha i}$'s(α = 1 or 2) are $f\bar{f}Z_\alpha$ couplings, and s_{z_α}'s are propagator factors $s_{Z_\alpha} = s - M^2_{Z_\alpha} +$

$iM_{Z_\alpha}\Gamma_{Z_\alpha}$. If θ_E is non zero, the $f\bar{f}Z_\alpha$ couplings mix as

$$\begin{cases} g_{1i}^{f} = g_{1i}^{0f}\cos\theta_E + g_{2i}^{0f}\sin\theta_E \\ g_{2i}^{f} = -g_{1i}^{0f}\sin\theta_E + g_{2i}^{0f}\cos\theta_E \end{cases}.$$

Therefore the $f\bar{f}Z^0$ couplings would be different from the standard model expectation, which could be observable by precise measurements at LEP-I.

Even if $\theta_E = 0$, Z' in a suitable mass range can cause some deviation of the R ratio from the standard model. Fig.8 shows R_{ll} and R_{had} including the Z' effect normalized by the standard model values. While the effect is negligible at LEP-I, it is significant at TRISTAN and is to increase R_{had} and decrease R_{ll}.



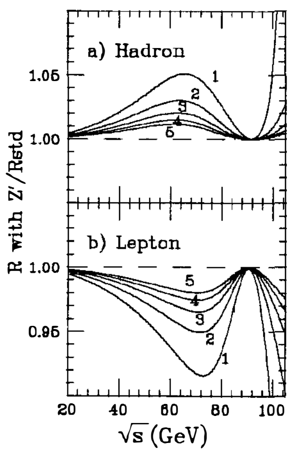


Fig.8. (a) R_{had} and (b) R_{ll} with Z' normalized by the standard model R. Solid lines, 1 to 5, assume the Z_η model of a mass of 110 GeV to 190 GeV in 20 GeV step and $\theta_E = 0$.

Fig.7. (a) R_{had}, (b) R_{ll} , and (c) A_{ll} data used for the fit. For the display purpose only, data are combined into several energy bins taking properly into account the common errors in a experiment. In (b) and (c), $\mu\mu$ and $\tau\tau$ data are combined. Solid line is the standard model values, while dashed lines are a fit by the Z_η model ($M_{Z_\eta} = 120$ GeV and $\theta_E = 0.08$).

To see the allowed region of Z' parameters to explain the observed $1 \sim 2\sigma$ deviation of the R_{ll} and R_{had} data, a Z' fit was made using the data on $R_{\mu\mu}, R_{\tau\tau}, R_{had}, A_{\mu\mu}$, and $A_{\tau\tau}$ from PEP/PETRA/TRISTAN[15,16] including preliminary TRISTAN data reported by Dr.

T. Sumiyoshi[5]. In the χ^2 calculation, common errors among measurements of a observable by a single experiment were properly taken into account. The data used in the fit are shown in fig.7. In the fit, M_{Z^0} and $\sin^2\theta_W$ were fixed to 91.170 GeV and 0.23, respectively, while $M_W = 80.0 \pm 0.6$ GeV[19] was included as an adjustable parameter.

As for the couplings, a super string inspired E_6 model[3] was assumed. In this model, E_6 breaks down as follows, resulting in 2 extra-U(1)'s (2 extra Z's).

$$E_6 \rightarrow SO(10) \times U(1)_\psi \rightarrow SU(5) \times U(1)_\chi \times U(1)_\psi \rightarrow SU(3) \times SU(2) \times U(1) \times U(1)_\chi \times U(1)_\psi$$

These extra Z bosons are parametrized as $Z_\beta = Z_\psi \cos\beta + Z_\chi \sin\beta$. Z_β includes Z_χ and Z_ψ as special case. When $\beta = \tan^{-1}\sqrt{3/5}$, Z_β is called Z_η. This analysis is an extension of previous analyses[3,17,18] with the inclusion of new TRISTAN data and with the latest M_{Z^0} and M_W values.

Fig.9 shows χ^2_{min} of the fits at several values of β. χ^2 for the standard model was 248.5 with NDF=322. The reductions of χ^2_{min} of about 8 were observed in the β range : $\frac{1}{6}\pi \lesssim \beta \lesssim \frac{4}{6}\pi$. The fit results in the case of the Z_η model are shown in fig.7. An improvement of the fit is clearly seen. However, this result alone cannot assert the esistence of a low mass Z', since even for the standard model, χ^2/NDF is much less than 1. This may imply too conservative systematic error estimates or unknown correlations among experiments, inevitable for the analysis combining experimental data. High stastics data by a single experiment is highly awaited. The allowed region of $M_{Z'}$ at the 90% C.L., $\Delta\chi^2 = 2.71$ above χ^2_{min}, is shown in fig.10 together with the previous results[3,18]. If the Z_η is a source of the slightly high R_{had} and the slightly low R_{ll}, M_{Z_η} between 100 GeV and 170 GeV is favarable (90% C.L.).

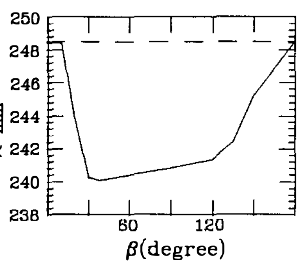


Fig.9. Minimum chi-square values(χ^2_{min}) obtained by the fit. χ^2_{min}s were obtained at several values of β and solid line is drown to connect these points for eye guide. Dashed line is the χ^2 value of the standard model.

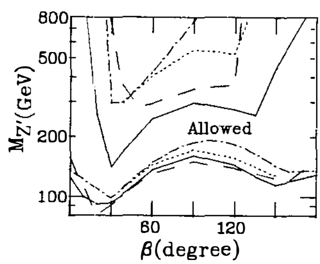


Fig.10. Allowed region of the mass of Z' at 90 % CL. Dashed lines are the results by Hagiwara, et.al[3]. Dotted and dot-dashed lines are the fit by M. Sakuta[18] including recent VENUS data and neutrino experiment data, respectively.

4. Summary and future prospects

Since the begining of TRISTAN, all the experimental groups searched for new particles extensively. Recently, charged higgs, lepto-quark, colored lepton, and abnormal dE/dx particle were searched for. No positive evidence was found for the production of new particles and improved limits were set. Those are now objectives for LEP.

As an indirect search, e^+e^- data were fitted by the E_6 inspired Z' model. For Z_β with $\frac{1}{6}\pi \lesssim \beta \lesssim \frac{4}{6}\pi$, χ^2 improves by about 8 compared to the standard model. High statistics data in the TRISTAN region are highly awaited to avoid the difficult treatment of error correlations among different experiments fateful to such analysis as presented here.

Finally, new particle searches at TRISTAN in future is briefly described. TRISTAN is going to install super-conducting quadrapole magnets this summer to accumulate more than 300 pb^{-1} in a few years. With this high luminosity, two kinds of new particle searches are possible. First is a search for photino by a measurement of single photon processes. ($e^+e^- \rightarrow \gamma\ \tilde{\gamma}\tilde{\gamma}$). At TRISTAN, the background from $e^+e^- \rightarrow \gamma\nu\bar{\nu}$ is relatively small. With the 300pb^{-1} data, we will be sensitive to $m_{\tilde{e}}$ up to 80 GeV if $m_{\tilde{\gamma}} = 0$. The other topics is the study of the Z' effect. At present, the error of the R ratio is dominated by statistics. However, with the 300 pb^{-1} data, the systematic error will be dominant and be a few % level is expected, which is crucial for the study of the Z' effect (fig.12).

Author wishes to thank M. Sakuta and R. Najima for discussions on the Z' fit.

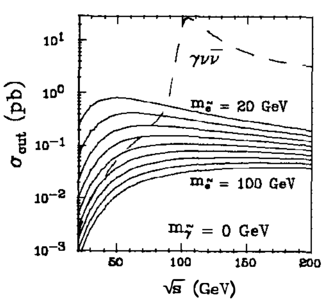


Fig.11. Total cross section of single γ production. Solid lines are $e^+e^- \rightarrow \gamma\ \tilde{\gamma}\tilde{\gamma}$ with $m_{\tilde{\gamma}} = 0$ GeV and $m_{\tilde{e}} = 20$ to 100 GeV in 10 GeV step. Dashed line is $e^+e^- \rightarrow \gamma\nu\bar{\nu}$

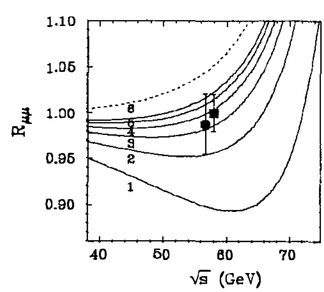


Fig.12. Solid lines are $R_{\mu\mu}$ including Z' with $\beta = 60^o$ and mass from 100 to 200 GeV. Dotted line is that for the standard model. Error at present combined statistics(circle) and that of the single experiment expected for 300pb^{-1} are also shown.

REFERENCES

1. See references in: K. Fujii, KEK Preprint 89-182, Jan. 1990; E. H. Low, to be appear in the 1989 International Europhysics Conference on Particle Physics, Madrid, Sept.6-13, 1989. For excited leptons: K. Abe, *et al.* Phys. Lett. B213(1988)400; I. Adachi, *et al.* Phys. Lett. B228(1989)553; S. K. Kim, *et al.* Phys. Lett. B223(1989)476.
2. A. A. Pankov and C. Verzegnassi, Phys. Lett. B233(1989)259.
3. K. Hagiwara, *et al.* Phys. Rev. D41(1990)815.
4. I. Adachi, *et al.* to be published in Phys. Lett. B.
5. T. Sumiyoshi, private communication.
6. W. Bartel, *et al.* Z. Phys. C33(1986)23.
7. H. P. Nilles, Phys. Rep. 110(1984)1.
8. G.N. Kim, *et al.* KEK Preprint 89-177, Dec 1989.
9. B. Schrempp, *et al.* Phys. Lett. B153(85)101.
10. W. Bartel, *et al.* Z. Phys. C36(1987)15.
11. A. Shirahashi, *et al.* UT-HE-87/4, Oct. 1987.
12. H. Aihara, *et al.* Phys. Rev. Lett.52(1984)168, ibid. 52(1984)2332.
13. S. Komamiya, Proceedings of the 1985 International Symposium on Lepton and Photon Interactions at High Energies, Kyoto, P.612.
14. T. Sumiyoshi, these proceedings.
15. I. Adachi, *et al.* Phys. Lett. B234(1990)525; K. Abe, *et al.* KEK Preprint 89-135, Oct. 1989; T. Kumita, *et al.* KEK Preprint 89-188, Feb. 1990; H. -J. Begrend, *et al.* Phys. Lett. B183(1987)400
16. I. Adachi, *et al.* Phys. Lett. B208(1988)319; K. Abe, *et al.* KEK-Preprint-89-192, Feb 1990; A. Bacala, *et al.* Phys. Lett. B218(1989)112; H. -J. Begrend, *et al.* Phys. Lett. B222(1989)163, ibid. B191(1987)209, Z. Phys. C14(1982)283; W. Braunschweig, *et al.* Z. Phys. C43(1989)549; ibid. C40(1988)163; M. Althoff, *et al.* Z. Phys. C26(1985)521; ibid. C22(1984)13; W. Bartel, *et al.* Z. Phys. C30(1986)371; B. Adeva, *et al.* Phys. Rev. D38(1988)2665; S. Abachi, *et al.* Phys. Rev. D40(1989)902; M. Derrick, *et al.* Phys. Rev. D31(1985)2352; E. Fernandez, *et al.* Phys. Rev. Lett. 54(1985)1620; W. W. Ash, *et al.* Phys. Rev. Lett. 55(1985)1831; M. E. Levi, *et al.* Phys. Rev. Lett. 51(1983)1941.
17. U. Amaldi, Phys. Rev. *et al.* D36(1987)1385, G. Costa,*et al.* Nucl. Phys. B297(1988)244.
18. M. Sakuta, private comunication;Y. Nagashima, OULNS 89-14.
19. L. Nordulman, talk presented at the 1989 International Europhysics Conference on Particle Physics, Madrid, Sept.6-13, 1989.