Electroweak Physics at TRISTAN

Masanori Yamauchi

KEK, National Laboratory for High Energy Physics
1-1 Oho, Tsukuba, Ibaraki 305, Japan

Abstract

The recent results from the three experimental groups at TRISTAN on the electroweak physics are reviewed. On the leptonic sector, the total cross sections and the forward-backward charge asymmetry of $\mu^+\mu^-$ and $\tau^+\tau^-$ productions are updated, and we obtain a_μ/a_τ=1.14±0.09 from those measurements. The $R_{\mu\mu}$ is smaller than the standard model prediction by 2σ. The polarization of τ in $\tau^+\tau^-$ production is measured, which gives a constraint on the vector coupling v_τ. The total cross section for multihadron production R is updated. The R is in good agreement with the standard model prediction, which leads to an upper limit to the mass of top quark at 350 GeV/c^2 (90%CL). The forward-backward charge asymmetry for $q\bar{q}$ production is measured for charm quark by $D^{*\pm}$ reconstruction and for bottom quark by large p_T leptons. The result of the $b\bar{b}$ charge asymmetry, combined with the results of the other experiments, leads to a lower limit to the $B_s^0\overline{B_s^0}$ mixing parameter r_s at 0.18 (90% CL).

Introduction

In this report, the recent results from the three experimental groups at TRISTAN on the electroweak physics are reviewed. At the energy region of TRISTAN, between 50 and 64 GeV in the center of mass energy, the interference between γ and Z^0 propagators is very important. The fermion pair production at this $\gamma - Z^0$ interference region is now predicted precisely by the standard model using the parameters measured at SLC and LEP on Z^0 pole [1]. Therefore an attempt is made to compare the results from TRISTAN with the prediction of the standard model.

Lepton pair production

The $\mu^+\mu^-$ and $\tau^+\tau^-$ productions are the simplest reactions to test the standard model. The three experimental groups at TRISTAN measured these quantities between $\sqrt{s}$=50 and 64 GeV. The differential cross sections have been translated to the tree level Born cross section using the radiative correction calculated by Fujimoto and Shimizu [2]. The total cross sections and the charge asymmetry are obtained by fitting those differential cross sections to the following expression.

$$\frac{d\sigma}{d\cos\theta} = \frac{3}{8}\sigma_0 R_{\ell\bar{\ell}}(1+\cos^2\theta + \frac{8}{3}A_{\ell\bar{\ell}}\cos\theta)$$

The measurements by the three groups are combined in Fig.1 and Fig.2. The smooth curves in the figures are the standard model predictions with the following parameters; $\sin^2\theta_W$=0.230, m_Z=91.1 GeV and Γ_Z=2.50 GeV, and the data points at the lower energies are the results by the experiments at PEP and PETRA [3]. These parameters will be used to calculate the standard model predictions in the rest of this report.

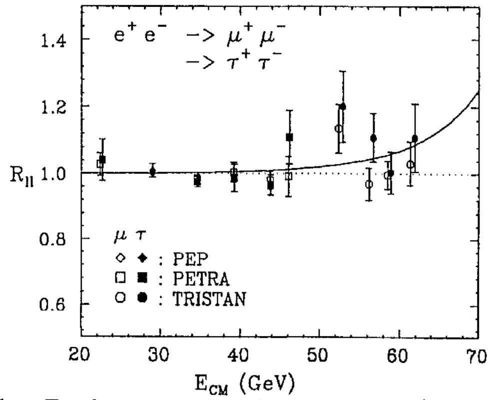

Fig. 1. Total cross sections for $\mu^+\mu^-$ and $\tau^+\tau^-$ productions normalized by the lowest order QED cross section for $\mu^+\mu^-$ production.

The $R_{\tau\bar{\tau}}$ is larger than unity at the TRISTAN energies as predicted by the standard model, but $R_{\mu\bar{\mu}}$ is apparently smaller than the prediction. This tendency exists also at the PETRA energy, and is about two standard deviation effect at TRISTAN. The charge asymmetry is consistent with the prediction of the standard model.

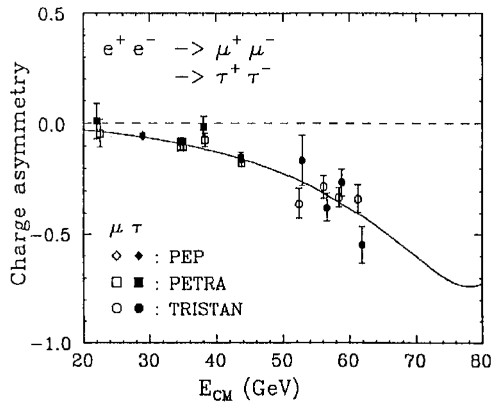

Fig. 2. Forward-backward charge asymmetry for $\mu^+\mu^-$ and $\tau^+\tau^-$ productions.

To look at these results from a different aspect, the data on R and the asymmetry are fitted with the standard model expression leaving the coupling constants of μ and τ as free parameters, while those of electron are assumed as the standard model values. The values of a_f's determined by this fit are listed in Table 1. The a_μ is consistent with the standard model but a_τ is slightly smaller. This possibility has been reported by PETRA before, especially JADE has pointed out that the ratio of a_μ to a_τ averaged over all the available data from PETRA is 1.26±0.15, which is 1.7σ larger one [4]. This ratio becomes 1.14±0.09 by adding the data from TRISTAN. It should be noted though that the experiments at LEP measured the partial decay widths of Z^0, and $\mu - \tau$ universality has been confirmed with ≈5% error at Z^0 pole [1].

Table 1. The values of the axial vector couplings determined by fitting all the data from PEP, PETRA and TRISTAN.

		$\chi^2/DOF =$
a_μ	−1.034±0.044	1.29
a_τ	−0.908±0.064	1.30
$a_\mu = a_\tau$	−0.992±0.036	1.27

Polarization of τ

The standard model predicts the polarization of the final state fermion, which can be observed in $\tau^+\tau^-$ production. It should be emphasized that in the experiments at $\sqrt{s} \approx m_Z$, the interference between the vector and axial vector couplings of Z^0 produces the polarization, whereas the polarization is produced by the interference between γ and Z^0 at the TRISTAN energy region.

For the polarized τ's the angular distribution of the decay products in the τ rest frame is asymmetric, which leads to a characteristic distortion of the laboratory momentum of the decay particles. For two body decays as $\tau^- \to \rho^-\nu_\tau$ and $\tau^- \to \pi^-\nu_\tau$, the laboratory momentum of ρ or π distributes as follows, where x is a normalized momentum and α depends on the spin of the decay hadron, 1.0 for π and 0.46 for ρ.

$$\frac{df}{dx} \propto 1 + 2\alpha \mathrm{P}\,(x - \frac{1}{2})$$

$$x \equiv \frac{p - p_{min}}{p_{max} - p_{min}} \approx \frac{2p}{\sqrt{s}}, \quad \alpha = \begin{cases} 1.0 & (\pi^\pm) \\ 0.46 & (\rho^\pm) \end{cases}$$

Therefore by fitting the momentum distribution of π or ρ with this expression with a free parameter P, the polarization is calculated. For leptonic decays $\tau^- \to \ell^-\bar{\nu}_\ell\nu_\tau$, the polarization is obtained by a similar procedure using the following expression.

$$\frac{df}{dx} \propto a(x) + \mathrm{P}\,b(x)$$

$$a(x) = \frac{1}{3}(5 - 9x^2 + 4x^3), \quad b(x) = \frac{1}{3}(1 - 9x^2 + 8x^3)$$

From the measurements of x distributions of $\rho^\pm$, $\pi^\pm$, $e^\pm$ and $\mu^\pm$, the average polarization of τ and its asymmetry are obtained as;

$$\begin{aligned} <\mathrm{P}_\tau> &= -0.170 \pm 0.205 \text{ (AMY)} \\ & +0.58 \pm 0.30 \text{ (TOPAZ)} \\ A^{FB}(\mathrm{P}_\tau) &= +0.260 \pm 0.194 \text{ (AMY)} \end{aligned}$$

To calculate the vector coupling of τ, these data are combined with the previous measurements by CELLO ($A^{FB}(\mathrm{P}_\tau) = +0.01 \pm 0.22$) [5] and MAC ($A^{FB}(\mathrm{P}_\tau) = +0.06 \pm 0.07$) [6], and we obtain $v_\tau = -0.93 \pm 0.60$.

Hadronic cross section

The total hadronic cross section in e^+e^- annihilation is expressed traditionally as a ratio R. This is an important quantity which directly reflects the effect of strong and weak interactions. To calculate R from the number of the observed hadronic events we use the radiative correction factor calculated by Fujimoto and Shimizu which includes all the electroweak diagrams up to $O(\alpha^3)$ [2]. The results from the three groups are combined and shown in Fig.3 with the standard model prediction. The points at $\sqrt{s}$=58, 63.6 and 64 GeV are the new measurements in 1989−1990.

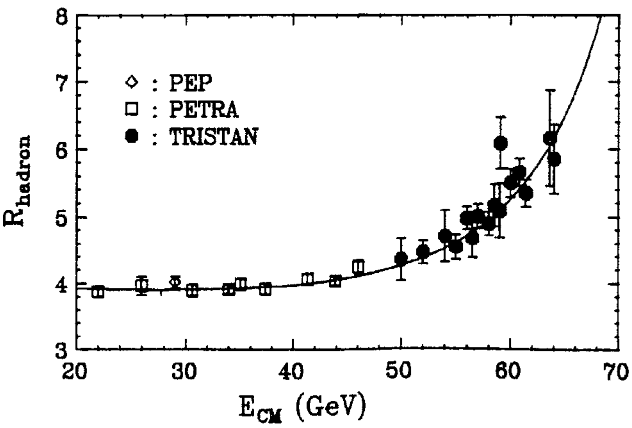

Fig. 3. The R ratio measured at PEP, PETRA and TRISTAN [7].

The values of R depend on the top quark mass m_t through the radiative correction factor, and the theoretical curve also depends on it because $\sin^2\theta_W$ includes m_t dependent radiative correction. Hence the data in Fig.3 are fitted with the standard model prediction of R leaving m_t and $\Lambda_{\overline{MS}}$ as free parameters. From this analysis, we set the upper limit to the top quark mass at 350 GeV/c^2 (90% CL).

Charge asymmetry of heavy quarks

The forward-backward charge asymmetry for $q\bar{q}$ productions also becomes very large at the TRISTAN energy region. To measure this asymmetry, the flavor and charge of the quark have to be identified. VENUS uses $D^{*\pm}$'s to identify charm events and to distinguish c and $\bar{c}$ jets. The D^0 candidates are selected in the decay modes; $K^{\mp}\pi^{\pm}$, $K^{\mp}\pi^{\pm}\pi^0$ and $K^{\mp}\pi^{\mp}\pi^{\pm}\pi^{\pm}$, and the mass differences between the possible $D^{*\pm}$'s and the D^0 candidates is plotted in Fig.4. Taking the com-

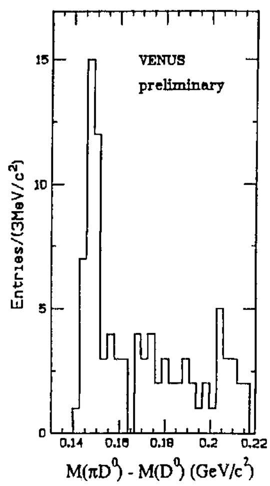

Fig. 4. Mass differences between D^0 candidates and $\pi^{\pm} - D^0$ system (VENUS).

binations with the mass difference below 150 MeV, 35 $D^{*\pm}$ candidates are selected including 9 estimated background events. From the angular distribution of $D^{*\pm}$'s we obtain that the charge asymmetry of charm quark is $-0.42^{+0.21}_{-0.19}$ at an average center of mass energy 58.5 GeV (Fig.5).

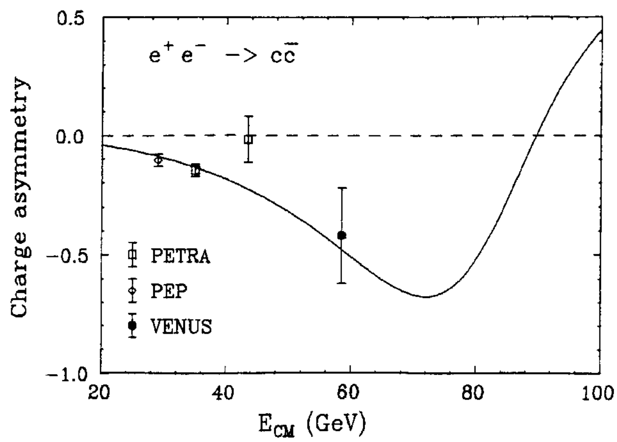

Fig. 5. The $c\bar{c}$ charge asymmetry measured by VENUS at $\sqrt{s} = 58.5$ GeV. The data by the other groups were taken from [9].

The forward-backward charge asymmetry of $b\bar{b}$ productions are measured using prompt leptons. AMY and TOPAZ use $\mu^{\pm}$'s, and VENUS uses both $e^{\pm}$'s and $\mu^{\pm}$'s to identify $b\bar{b}$ events. Out of the μ inclusive events selected by the μ detectors, $b\bar{b}$ events are enriched by requiring the large transverse momentum to the μ's. The major background is μ's from charm decays, which is estimated by LUND Monte Carlo program [8], and subtracted from the angular distribution. VENUS identifies inclusive $e^{\pm}$ by the matching of the shower energy and the track momentum and $b\bar{b}$ events are enriched by making a cut in the electron p_t at 1 GeV. The $b\bar{b}$ charge asymmetry measured by those analyses are summarized in Fig.6 with the theoretical curve and the previous measurements [10]. These data will be used to estimate $B^0\overline{B^0}$ mixing later.

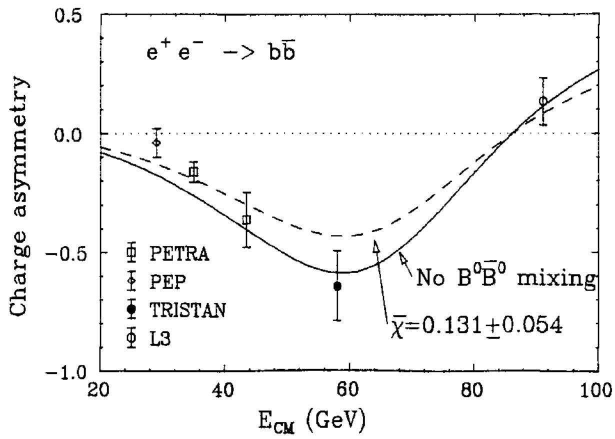

Fig. 6. Forward-backward charge asymmetry for $b\bar{b}$ events

The measurements of $q\bar{q}$ charge asymmetry of an individual quark flavor is only feasible for heavy quarks, and then only with a small efficiency. Alternatively we combine all five quark flavors and study the asymmetry by distinguishing between negatively and positively charged jets. We define the jet charge asymmetry by the following expression, where the positive jet is a jet in the direction of the positively charged initial quark, *i.e.*, u, $\bar{d}$, $\bar{s}$, c and $\bar{b}$.

$$A_{jet} = -\frac{\sigma_F(\text{positive jet}) - \sigma_B(\text{positive jet})}{\sigma_F(\text{positive jet}) + \sigma_B(\text{positive jet})}$$

The expected asymmetry is only +10% at the TRISTAN energy.

In the analysis by TOPAZ, the charge of jet is defined by the following two methods, where the summation runs over all charged particles in a jet.

$$\text{method 1}: \quad Q_{jet} = \sum_{jet} q_i \eta_i^{\alpha},$$

$$\left(\eta_i = \frac{1}{2} \ln \frac{E_i + p_i}{E_i - p_i}, \quad \alpha = 0.8 \right)$$

$$\text{method 2}: \quad Q_{jet} = \sum_{jet} q_i z_i^{\alpha},$$
$$(\quad z_i = p_i/E_{beam}, \quad \alpha = 0.4)$$

A jet with the larger Q_{jet} is identified as a positive jet. A probability of correct charge assignment for each of the quark flavor is studied by LUND Monte Carlo program [8], and we estimate that the initial quark charge is identified with 70% probability if α=0.8 and 0.4 are chosen for the method-1 and -2, respectively. The jet charge asymmetry is calculated from the angular distribution of the positively charged jets as +0.091±0.014±0.016 at an anaverage center of mass energy 57.9 GeV.

$B^0\overline{B^0}$ mixing

The $B^0\overline{B^0}$ mixing parameter can be estimated from the observed charge asymmetry of $b\bar{b}$ event combined with the results of the other experiments. The mixing parameter r_d has been measured by ARGUS and CLEO as follows.

$$\begin{aligned} r_d &\equiv \frac{\Gamma(B_d^0 \to \overline{B_d^0} \to \ell^- \bar{\nu} X)}{\Gamma(B_d^0 \to \ell^+ \nu X)} \\ &= 0.21 \pm 0.06 \ \text{(ARGUS, 1989) [11]} \\ &= 0.14 \pm 0.05 \ \text{(CLEO, 1989) [12]} \end{aligned}$$

On the other hand, UA1, MAC and Mark-II have reported the measurements of same sign dilepton production in $\bar{p}p$ or e^+e^- interactions, and they obtained the average probability that b quark decays as $\bar{b}$.

$$\begin{aligned} \bar{\chi} &= 0.121 \pm 0.047 \ \text{(UA1) [13]} \\ & \quad 0.21^{+0.29}_{-0.15} \ \text{(MAC) [14]} \\ & \quad 0.17^{+0.15}_{-0.08} \ \text{(Mark II) [15]} \end{aligned}$$

This probability $\bar{\chi}$, is expressed in terms of f_s and f_d, the fractions of B_d^0 and B_s^0 in the final states, and r's as follows.

$$\bar{\chi} \equiv f_d \frac{r_d}{1 + r_d} + f_s \frac{r_s}{1 + r_s}$$

In the measurement of the charge asymmetry of $b\bar{b}$, the observed asymmetry will be smaller than the true asymmetry of the $b\bar{b}$ production. This ratio is expressed using $\bar{\chi}$ of the same definition as;

$$A_{b\bar{b}}^{obs.} = (1 - 2\bar{\chi}) A_{b\bar{b}}^{true}$$

In Fig.6, the data points are fitted to this expression with a free $\bar{\chi}$ assuming the standard model. From this fit we obtain that $\bar{\chi}$ measured from the charge asymmetry is 0.131 ± 0.054. This value is again combined with the measurements on the same sign dilepton productions, and we finally obtain $\bar{\chi}$=0.139±0.032. Introducing an assumption, f_d=0.375 and f_s=0.150, the measurement of $\bar{\chi}$ is expressed on the plane of r_d and r_s (Fig.7). Combining these two results together, the allowed region of r_d and r_s is determined as in Fig.8. The most probable value for r_d and r_s is indicated by *, and the contours are one sigma and 90% confidence level allowed regions. From this plot, we conclude that the full mixing is favored for $B_s^0\overline{B_s^0}$ mixing, and the lower limit to r_s is 0.18 at 90% confidence level. Zero mixing (r_s=0) is excluded at 95% confidence level.

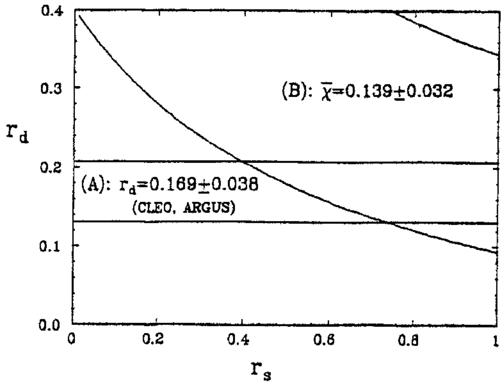

Fig. 7. Allowed values for r_d and r_s. The region (A) is determined from the measurements of r_d by ARGUS and CLEO, and (B) is determined from $\bar{\chi}$.

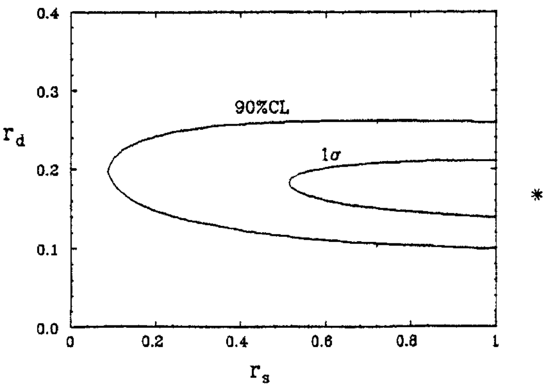

Fig. 8. The 1σ and 90% CL allowed regions for r_d and r_s determined by combining all the available data.

Fig.9 shows how the limit to r_s depends on the assumption on the values of f_d and f_s. The horizontal axis is a ratio f_s/f_d under an assumption $2f_d + f_s$=0.9, leaving 10% probability for bottomed baryon production. The previous assumption corresponds to f_s/f_d=0.4 in this plot. The most probable value of r_s depends on the assumption of f_s/f_d but r_s=0 is excluded at 90% CL independent of the assumption unless $f_s/f_d < 0.3$, where r_s can not be smaller than one.

Conclusion

Three experimental groups at TRISTAN improved the measurements on the lepton pair productions at

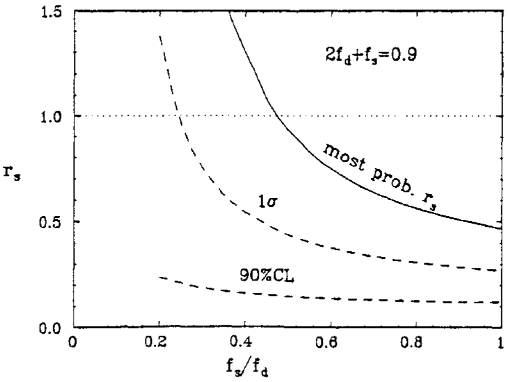

Fig. 9. The most probable value of r_s and its lower limit depend on the ratio f_s/f_d. However an assumption "r_s=0" is excluded at more than 90% CL over the wide range of the ratio.

the γ-Z^0 interference region. Adding the new results on the cross section and the forward-backward charge asymmetry of $\mu^+\mu^-$ and $\tau^+\tau^-$ productions, the ratio of the axial vector couplings, a_μ/a_τ has become closer to one, but $R_{\mu\mu}$ is smaller than the standard model prediction by 2σ.

The polarization of τ in $\tau^+\tau^-$ production is measured by AMY and TOPAZ, which provides a direct measurement of the vector coupling v_τ. Combining the data with the previous results by CELLO and MAC, we obtain $v_\tau = -0.93\pm0.60$.

The total cross section for multihadron production R is updated. The R is in good agreement with the standard model predictions, which leads to the upper limit to the mass of top quark at 350 GeV/c^2.

The forward-backward charge asymmetry for $q\bar{q}$ production is measured for charm quark by $D^{*\pm}$ reconstruction and for bottom quark by prompt leptons. Using the result of the $b\bar{b}$ charge asymmetry and the other experiments an allowed region in the $r_d - r_s$ is determined. From this analysis a 90% CL lower limit to r_s is set at 0.18.

References

1. ALEPH Collab., D.Decamp et al., Phys. Lett. 235B, 399 (1990); OPAL Collab., M.Z.Akrawy et al., Phys. Lett. 240B, 497 (1990); DELPHI Collab., P.Abreu et al., Phys. Lett. 241B, 435 (1990); L3 Collab., B.Adeva et al., Phys. Lett. 247B, 473 (1990)
2. J.Fujimoto and Y.Shimizu, Mod. Phys. Lett. A3, 581 (1988)
3. CELLO Collab., H.J.Behrend et al., Phys. Lett. 191B, 209 (1987); JADE Collab., W.Bartel et al., Z. Phys. C30, 371 (1986); MARK-J Collab., B.Aveda et al., Phys. Rev., D30, 371 (1986); PLUTO Collab., Ch.Berger et al., Z. Phys. C27, 341 (1985) and C28, 1 (1985); TASSO Collab., M.Althoff et al., Z. Phys. C22, 13 (1984); MAC Collab., W.W.Ash et al., Phys. Rev. Lett. 55, 1831 (1985); MARK-II Collab., M.E.Levi et al., Phys. Rev. Lett. 51, 1941 (1983); HRS Collab., M.Derrick et al., Phys. Rev., D31, 2352 (1985)
4. JADE Collab., W.Bartel et al., Z. Phys. C46, 547 (1990)
5. CELLO Collab., H.J.Behrend et al., Phys. Lett. 127B, 270 (1983)
6. MAC Collab., W.T.Fort et al., Phys. Rev. D36,, 1971 (1983)
7. CELLO Collab., H.J.Behrend et al., Phys. Lett. 183B, 400 (1987) and 144B, 297 (1984); TASSO Collab., M.Althoff et al., Phys. Lett. 138B, 441 (1984) and 154B, 236 (1985); JADE Collab., W.Bartel et al., Phys. Lett. 129B, 145 (1983) and 160B, 337 (1985); MARK-J Collab., B.Adeva et al., Phys. Rev. Lett. 53, 134 (1984)
8. T.Sjöstrand and M.Bengtsson, Comp. Phys. Comm., 43, 367 (1987)
9. HRS Collab., P.Baringer et al., Phys. Lett. 206B, 551 (1988); TPC Collab., H.Aihara et al., Phys. Rev. D34, 1945 (1986); TASSO Collab., W.Braunschweig et al., Z. Phys. C44, 365 (1989); CELLO Collab., H.J.Behrend et al., DESY 89-125, Sep. 1989; JADE Collab., E.Elsen et al., Z. Phys.C46, 349 (1990); MARK-J COllab., B.Adeva et al., Phys. Rep. 109, 133 (1984)
10. HRS Collab., C.R.Ng et al., ANL-HEP-PR-88-11, Nov. 1988; MAC Collab., H.R.Band et al., Phys. Lett. 218B, 369 (1989); TPC Collab., H.Aihara et al., Z. Phys. C27, 39 (1985) and Phys. Rev. D31, 2719 (1985); CELLO Collab., H.J.Behrend et al., DESY 89-125, Sep. 1989; JADE Collab., E.Elsen et al., Z. Phys.C46, 349 (1990); MARK-J Collab., B.Adeva et al., Phys. Rep., 109, 133 (1984); TASSO Collab., M.Althoff et al., Z. Phys. C22, 219 (1984) and Phys. Lett. 146B, 443 (1984)
11. M.V.Danilov, Proc. of the 1989 International Symposium on Lepton and Photon Interaction at High Energies, Stanford (1989)
12. D.L.Kreinick, Proc. of the 1989 International Symposium on Lepton and Photon Interaction at High Energies, Stanford (1989)
13. UA1 Collab., C.Albajar et al., Phys. Lett. 186B, 247 (1987)
14. MAC Collab., H.R.Band et al., Phys. Lett. 200B, 221 (1988)
15. Mark-II Collab., A.J.Weir et al., Phys. Lett. 240, 289 (1990)

DISCUSSION

Q. **C. Buchanan** *(UCLA)*: If f_s/f_d were ~ 0.2, would the B-mixing analysis still be o.k. or would it become inconsistent?

A. **M. Yamauchi**: I believe that the mixing analysis excludes values of f_s/f_d below 0.3.