Recent results from VENUS

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Abstract

Recent results from VENUS detector at $\sqrt{s}$ up to 61.4GeV are presented. Measured observables are consistent with the standard model. No indications were found for new particles. No single photon was observed and the upper limit of the number of light neutrino types was set to be 11 at 90%CL. The QCD cut-off parameter was determined as $\Lambda_{\overline{MS}}$ = 254MeV using NLL approximation.

1 Introduction

The data used for the present study have been collected with the VENUS detector at the TRISTAN e^+e^- collider. The accumulated integrated luminosity is about $33pb^{-1}$. In the present analysis, multihadron events are selected as follows[1];

1) total calorimeter energy > 5GeV
2) number of charged tracks $\geq$ 5
3) visible energy ($E_{vis} = E_{cal} + \Sigma|p_{track}|$) > E_{beam}
4) longitudinal momentum balance ($p_{bal} = |\Sigma p_z|/E_{vis}$) < 0.4.

In this paper we calculate the standard model prediction using M_Z = 91.1GeV/c^2 and $sin^2\theta_w = 0.231$.

2 Total cross sections and FB charge asymmetry

We can use total cross sections and forward-backward(FB) charge asymmetries to test the results of the standard theory. The normalized total cross sections and charge asymmetries of $e^+e^- \rightarrow$ hadrons { R, A_{jet} }, $e^+e^- \rightarrow \mu^+\mu^-$ { $R_{\mu\mu}$, $A_{\mu\mu}$ } and $e^+e^- \rightarrow \tau^+\tau^-$ { $R_{\tau\tau}$, $A_{\tau\tau}$ } are mentioned here.

2-1 R-ratio

The total cross section of multihadronic event is usually represented by R-ratio

$$R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma_0,$$

where σ_0 is the lowest order QED μ-pair cross section. The data sample of integrated luminosity 29.2pb^{-1} at the energy range 54.0 - 61.4GeV was used to study R-ratio [1]. The data for R is shown in Fig.1. The measured R-ratios are consistent with the standard model using the five known quraks and M_Z = 91.1GeV/c^2. The mass of top quark was excluded below 30.2GeV/c^2.

2-2 Ajet

We studied the average quark charge asymmetry A_{jet}

$$A_{jet} = f_d A_d - f_u A_u + f_s A_s - f_c A_c + f_b A_b$$

where f_i is the fraction of the relative production rate of quarks[2]. A_{jet} was studied with an integrated luminosity of $32.2 pb^{-1}$ at C.M. energies between 52.0 and 61.4 GeV. Two jet events were selected from the multihadron event sample by requiring the thrust > 0.85 and some other conditions. The jet charge is identified by calculating

$$Q_j = \Sigma Q_i (p_i/E_{beam})^{0.4}$$

for each jet j based on the information on each track i. LUND5.3[3] Monte Carlo calculation shows that the charge identification probabilities of original quarks are over 70%. The measured differential cross section is shown in Fig.2. The obtained asymmetry is 11.4±2.2% at 57.6GeV. The theoretical expectation is A_{jet} = 8.7% without $B^0\bar{B}^0$ mixing and 9.4 - 10.9% with $B^0\bar{B}^0$ mixing. By assuming the universality of the quark axial vector couplings, we obtained the product of the electron and quark axial vector coupling constants $\langle a_e a_q \rangle = -1.03 \pm 0.10$.

2-3 R_{ll} and A_{ll}

The FB charge asymmetry in lepton pair production provides a valuable test of the standard model since the interference between electromagnetic and weak interactions causes a large FB asymmetry in TRISTAN energy region. The data sample corresponding to the integrated luminosity of $25.3 pb^{-1}$ is accumulated at $50.0 \le \sqrt{s} \le 60.8$GeV. Values for $R_{\mu\mu}$, $A_{\mu\mu}$, $R_{\tau\tau}$ and $A_{\tau\tau}$ are presented in Fig.3, 4 and 5. The cross sections and the asymmetries are agree well with predictions of the standard model. The axial-vector coupling constants for muons and taus are determined from the measured asymmetries and are $g_a^e g_a^\mu$ = 0.202±0.040 and $g_a^e g_a^\tau$ = 0.274±0.046 respectively. The ratio of axial-vector couplings g_a^τ / g_a^μ = 1.36±0.35 is consistent with the μ-τ universality.

2-4 Compositness scale parameters

We have observed no deviation in the differential cross sections in quark, μ and τ pair productions. Thus the lower limits of the compositeness scales for various couplings were obtained[4] and are given in Table 1.

3 Search for b' qurak

As stated before, the measured R-ratios are consistent with the standard model using the 5 known quraks. But it requires more analysis regarding event topology to exclude the production of b'.

To search for b' production we should study two kind of decay modes:

1) charged current (CC) decay mode

$b' \to c + W^-$

$W^- \to l^- + \bar{\nu}, q + \bar{q}$

2) flavor changing neutral current (FCNC) decay mode

$b' \to \quad b + \gamma, \quad b + Z^0, \quad b + g, \quad b + H^0,$

The event signature of CC decay is either isolated lepton events or multi-jet events. That of FCNC decay is either isolated photon events or multi-jet events. The effect of Z^0 decay is negligible in TRISTAN energy region. Thus event samples to be searched by experiment are

1) energetic isolated lepton events
2) energetic isolated photon events
3) multi-jet events.

3-1 Isolated lepton events

Isolated energetic lepton events are selected from multihadron event by the condition of

1) thrust < 0.9
2) lepton id

   electron: $0.8 \leq E/p \leq 1.3$

   muon: track matching between CDC & muon chamber
3) lepton momentum p > 4GeV/c
4) energy flow within 30° around the lepton < 1.0GeV.

There were 2 electron events and 3 muon events in accumulated luminosity of about $25pb^{-1}$ between C.M. energy of 56.0 and 61.4GeV (Fig.6). The expected numbers of events from known processes are 2.5±0.4 and 1.2±0.3 respectively.

3-2 Isolated photon events

Isolated energetic photon events are selected by

1) $E_\gamma/E_{beam} > 0.1$
2) $|\cos\theta_\gamma| < 0.7$
3) no other particle within 30° around the photon

from multihadron sample[5]. E_γ/E_{beam} spectrum of isolated photon events is shown in Fig.7(a). The spectrum agrees well with the 5 flavor Monte Carlo simulation. The Monte Carlo simulation for $b' \to b\gamma$ predicts the photon spectrum as shown in Fig.7(b). We obtained 8 events between $0.3 < E_\gamma/E_{beam} < 0.7$. The expectation from the initial state radiation is 11.8±0.5.

3-3 Multi-jet events

If b' quark can decay through FCNC mode, the topology of FCNC multi-jet event tends to be planar near the b' production threshold. In that case, the sensitivity of global parameters is decreased. Here we use the following two variables to detect new quark flavors[1]. The event sample for these analyses is the same one as R-ratio.

3-3-1 Transverse energy product X_t

For events with $|\cos\theta_{thrust}| < 0.7$, final state particles are divided into hemispheres (F&B). Transverse energies perpendicular to the direction defined by a vectorial sum of the momenta in each hemisphere are summed, and X_t is defined by

$$X_t = (\Sigma E_t)_F \cdot (\Sigma E_t)_B / (E_{vis}^2) \cdot$$

The X_t distribution is plotted in Fig.8(a). There are 13 events within the region of X_t>0.085 and 9±2 events are expected in the same region from the 5 flavors production.

3-3-2 Acollinearity of the most energetic two jets $\cos\theta_{j1j2}$

This approach uses explicit clustering by the LUND algorithm[6]. Observed multi-jet fractions are plotted in Fig.9. Our data agrees well with 5 flavors prediction. The events with the number of jets ≥ 4 and the directions of all jets being within $|\cos\theta_{ji}| < 0.85$ have been accepted. The distribution of the acollinearity of the most energetic two jets, $\cos\theta_{j1j2}$, is shown in Fig.8(b). We take events within $-0.3<\cos\theta_{j1j2}<0.6$ as candidates for new quark production. There are 8 events within the region, while 91 events are expected from the production of the 5 known flavors.

3-4 b' mass limit

From the previous discussions, we can set the excluded regions for the b' mass as in Fig.10. In summary, our data excludes b' mass region between 19.4 and 28.2GeV/c^2 with 95%CL, regardless of the decay modes.

4 Search for single photon

The VENUS detector with hermetic calorimeter is excellent to search for single photon events[7]. The cross-section measurement of these events can estimate the number of light neutrinos N_ν[8].

The analysis is based on a data sample of 28.2pb^{-1} at $\sqrt{s}$=54.0 - 61.4GeV. Single photon candidates were selected with the requirement

1) only one energetic cluster with E_γ>4.0GeV
2) this cluster is in $40° < \theta_\gamma < 140°$
3) no other cluster with E_γ>0.2GeV in LG, LA and LM.
4) no other track in CDC
5) cluster profile is good.

Finally, the QED background were rejected by a cut

$$X_t = E_\gamma / E_{beam} > 2\sin\theta_{veto}/(1+\sin\theta_{veto}).$$

Fig.11 shows the Xt distribution. We used final cut of X_t>0.18 and no events remained. From this result the single photon cross section is

$\sigma<0.13(0.17)$pb at 90(95)%CL. The number of light neutrino types N_ν is limited to $N_\nu<11(15)$ at 90(95)%CL. If we combine the present data with the data from ASP[9], MAC[10], CELLO[11] and MARK-J[12], we can obtain an upper limit of N_ν to be $N_\nu<3.9(4.8)$ at 90(95)%CL The present results, together with those from other e^+e^- experiments, are summarized in Table 2.

5 Determination of QCD cut-off parameter

We determined the QCD cut-off parameter $\Lambda_{\overline{MS}}$ by using 3-jet fraction R_3 obtained by jet clustering algorithm (JADE method[13]). The QCD cascade shower was generated based on Next-to-Leading Logarithmic (NLL) approximation[14]. The analysis is based on a data sample of 29.2pb^{-1} at $\sqrt{s}$=54.0 - 61.4GeV. Fig.12 shows the relative rates of multi-jet productions together with the NLL-QCD cascade with $\Lambda_{\overline{MS}}$=254MeV. Obtained cut-off parameter is $\Lambda_{\overline{MS}}=254+59-52\pm56$MeV. For $<\sqrt{s}>$=58.5GeV, coupling constant α_s is calculated to be $0.129\pm0.005+0.004-0.005$

6 Summary

1. The total cross sections and charge asymmetries R, A_{jet}, $R_{\mu\mu}$, $A_{\mu\mu}$, $R_{\tau\tau}$ and $A_{\tau\tau}$ agree well with the standard model predictions.
2. The lower limits of the compositness scales for leptons and for quark have been updated.
3. The mass limit for t quark has been obtained to be $m_t >$ 30.2GeV/c^2 at 95%CL.
4. The mass limit for b' quark has been set to be $m_{b'} <$ 19.4GeV/c^2 or 28.2GeV/c^2 $< m_{b'}$ at 95%CL.
5. No anomalous single-photon production has been observed. The limit for the number of light neutrino types has been obtained as $N_\nu < 11$ at 90%CL.
6. Using an NLL approximation, the QCD cut-off parameter $\Lambda_{\overline{MS}}$ has been determined as $\Lambda_{\overline{MS}} = 254+59-52\pm56$MeV.

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Figure Captions

Fig.1 R-ratio measured at VENUS. The solid line indicates the prediction from the production of the 5 known flavors, the dashed, from the additional "open" top quark, and the dot-dash, from the additional "open" b' quark.

Fig.2 Differential cross section of $e^+e^- \to q\bar{q}$. The solid line is a χ^2 fit to the present data and the dashed line is the prediction of the standard theory.

Fig.3 The ratio of the measured total cross section to the QED lowest total cross section for the process of $e^+e^- \to \mu^+\mu^-$ (a) and of $e^+e^- \to \tau^+\tau^-$ (b).

Fig.4 The differential cross section of $e^+e^- \to \mu^+\mu^-$ (a) and of $e^+e^- \to \tau^+\tau^-$ (b) at $<\sqrt{s}> = 56.6$Gev.

Fig. 5 The forward-backward charge asymmetry $A_{\mu\mu}$ (a) and $A_{\tau\tau}$ (b).

Fig.6 Scatter plot of isolated lepton events. (a) muon channel, (b) electron channel, (c) Monte Carlo sample based on 5 flavor and (d) Monte Carlo sample of b' production.

Fig.7 (a) Energy spectrum of isolated photons. Closed circles show the real data, and crossed points, the estimated π^0 background from isolated charged pions. The histogram with a solid line is the Monte Carlo simulation with 5 flavors. The contribution of π^0 background is shown with a dashed line. (b) Monte Carlo simulation of the photon spectrum from b' decay with masses of 29 (solid line), 26 (dashed line) and 20 (dotted line) GeV/c^2.

Fig.8 (a) The transverse energy product X_t distribution and (b) the acollinearity of the most energetic two jets $cos\theta_{j1j2}$ distribution. The solid lines represent the productions from 5 flavors, and the dashed lines from 100% branching into FCNC decay of b' with a mass of 28GeV/c^2 at the 61.4GeV C.M. energy.

Fig.9 (a) Number of jets of accepted events, and of the productions of 5 flavors (solid line), clustered by the LUND algorithm. (b) Number of jets in $t \to b + W$, (c) in $b' \to c + W$, (d) in $b' \to b + \gamma$ or $b + g$ and (e) in $b' \to b + H^0$.

Fig.10 (a) The excluded mass region with 95%CL for b' as a function of the branching ratio into FCNC decay (Br(CC)+Br(FCNC)=1.0). A branching ratio of 10% for the photonic decay mode in FCNC decay is assumed. (b) The excluded mass region with 95%CL for b' as a function of the Higgs mass (Br(Higgs)=1.0).

Fig.11 Xt distribution of single photons with the cut of $\theta_{veto}=15.0°$ (a) and $\theta_{veto}=5.0°$ (b). The solid line is the prediction from the QED processes ($e^+e^- \to e^+e^-\gamma$ and $e^+e^- \to \gamma\gamma\gamma$).

Fig.12 The relative production rate of N-jet. Solid lines represent the results of the NLL-QCD cascade at $\Lambda_{\overline{MS}}$ = 254MeV.

Table 1 Lower Limits on Compositeness Scale (TeV, 95%CL)

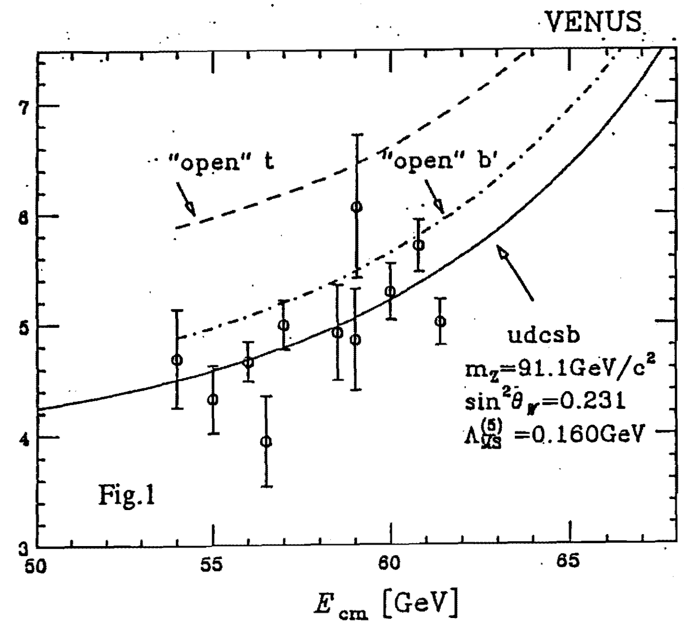
	Λ^+_{LL}	Λ^-_{LL}	Λ^+_{RR}	Λ^-_{RR}	Λ^+_{VV}	Λ^-_{VV}	Λ^+_{AA}	Λ^-_{AA}
$e^+e^- \to \mu^+\mu^-$	1.3	1.4	1.3	1.4	2.2	2.7	2.1	2.0
$e^+e^- \to \tau^+\tau^-$	0.9	1.8	1.5	2.5	3.9	2.4	3.4	5.5
$e^+e^- \to$ jets(*)	0.9	1.7	1.7	1.9	3.0	2.6	3.7	4.2
$e^+e^- \to$ jets(**)	1.5	1.6	1.5	1.6	2.4	3.1	2.5	2.2

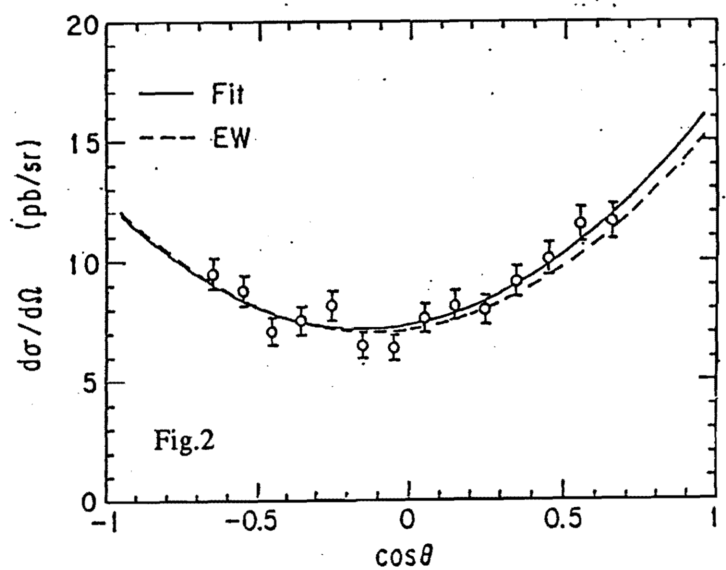
*) without an effect of $B^0\bar{B}^0$ mixing

**) with an effect of $B^0\bar{B}^0$ mixing

Table 2 Neutrino countings in the e^+e^- experimets

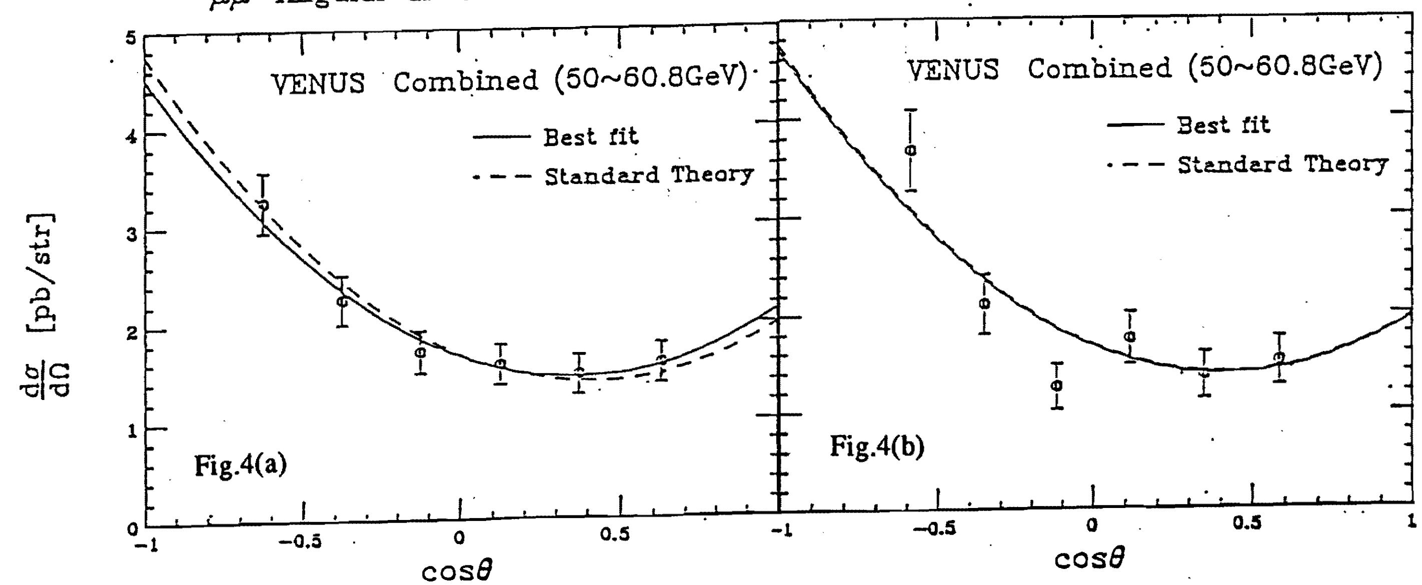
	ASP	CELLO	MAC	MARK-J	VENUS	Combined
Expected	2.6	1.87	1.15	0.39	0.82	6.83
observed	1.6	1.26	1	0	0	3.86
N_ν(90%CL)	<7.9	<8.7	<17	<26	<11	<3.9
N_ν(95%CL)	<10.4	<11.3			<15	<4.8
ΔN_ν(90%CL)	<7.4	<8.2			<12	<3.0
ΔN_ν(95%CL)	<9.3	<10.9			<16	<3.8





μμ Angular distribution

ττ Angular distribution



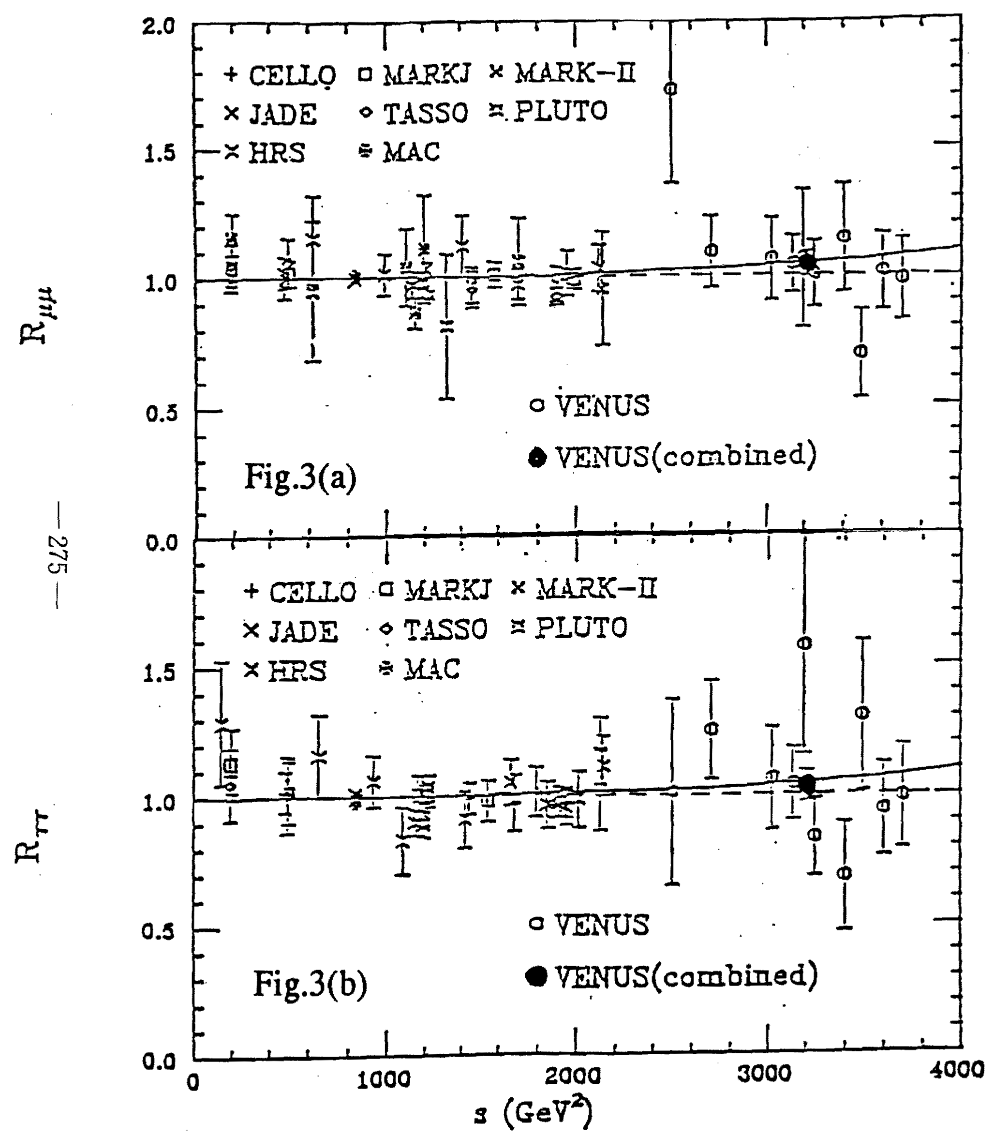


Fig.3(a)
+ CELLO
□ MARKJ
× MARK-II
× JADE
◇ TASSO
PLUTO
× HRS
MAC
○ VENUS
● VENUS(combined)
$R_{\mu\mu}$
Fig.3(b)
+ CELLO
□ MARKJ
× MARK-II
× JADE
◇ TASSO
PLUTO
× HRS
MAC
○ VENUS
● VENUS(combined)
$R_{\tau\tau}$
2.0
1.5
1.0
0.5
0.0
0
1000
2000
3000
4000
s (GeV^2)

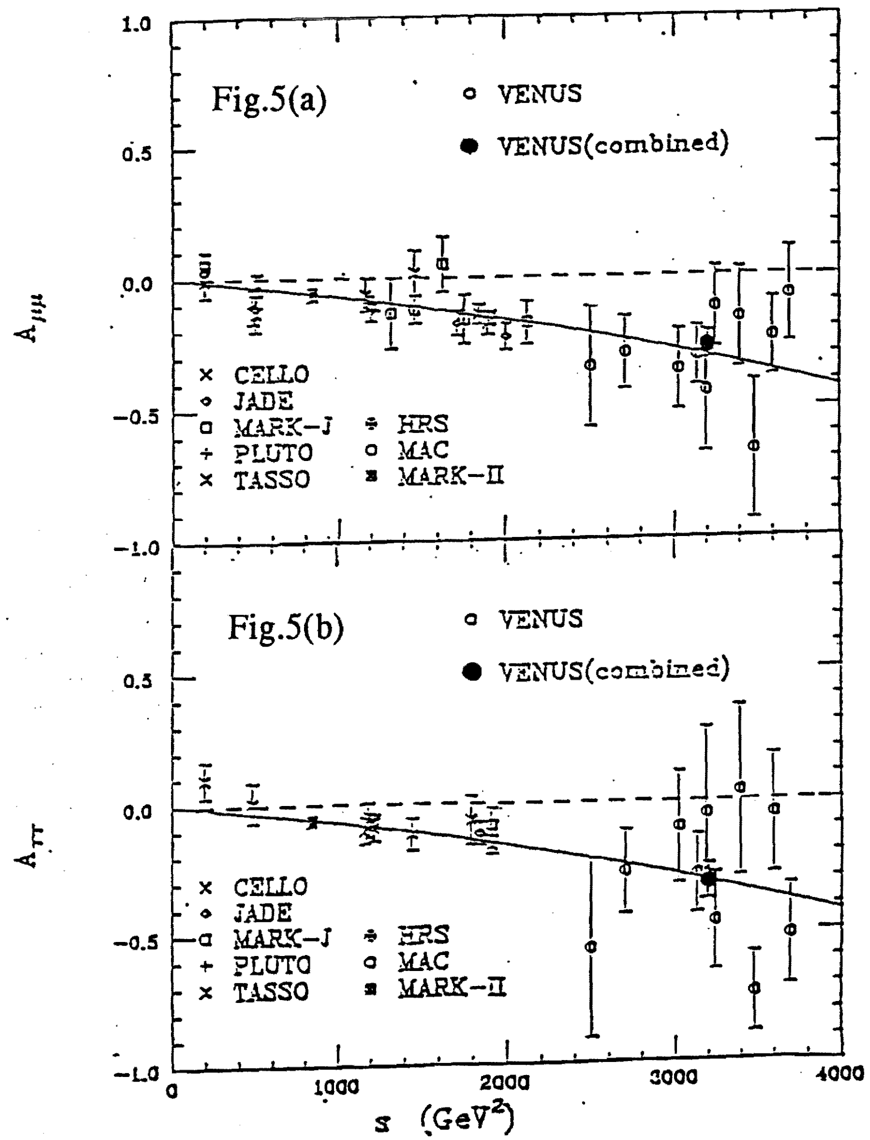


Fig.5(a)
○ VENUS
● VENUS(combined)
$A_{\mu\mu}$
× CELLO
◇ JADE
□ MARK-J
+ PLUTO
× TASSO
HRS
○ MAC
MARK-II
Fig.5(b)
○ VENUS
● VENUS(combined)
$A_{\tau\tau}$
× CELLO
◇ JADE
□ MARK-J
+ PLUTO
× TASSO
HRS
○ MAC
MARK-II
1.0
0.5
0.0
−0.5
−1.0
0
1000
2000
3000
4000
s (GeV^2)

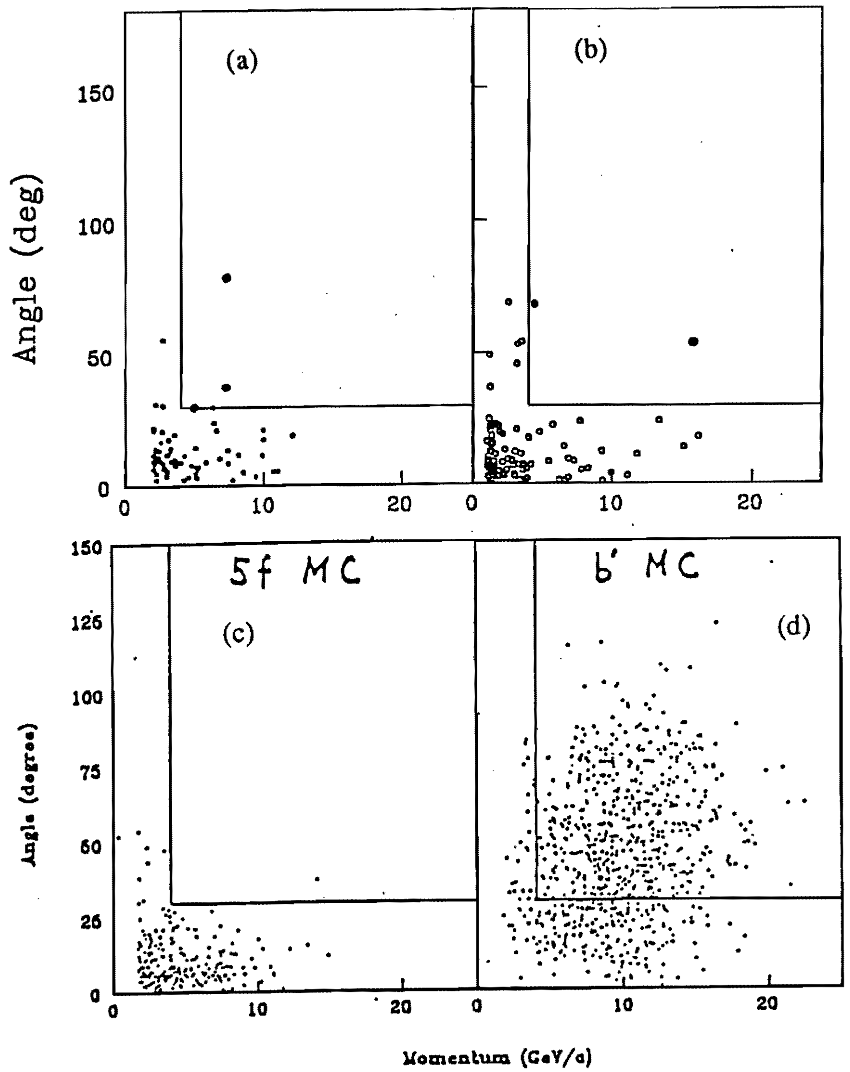


Fig.6

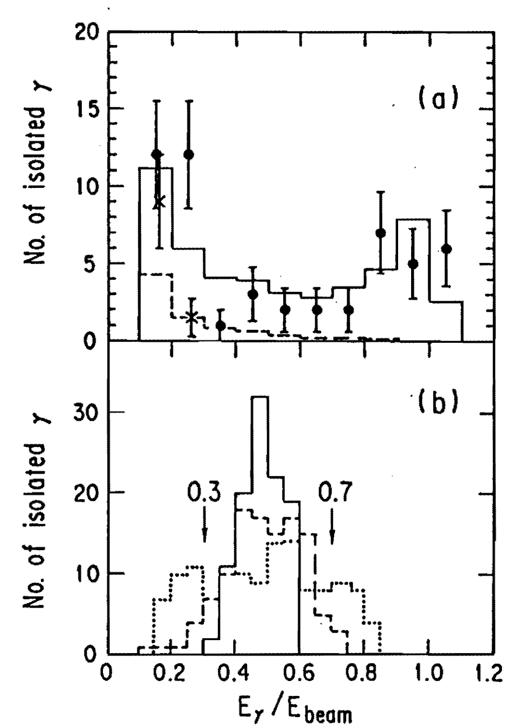


Fig.7

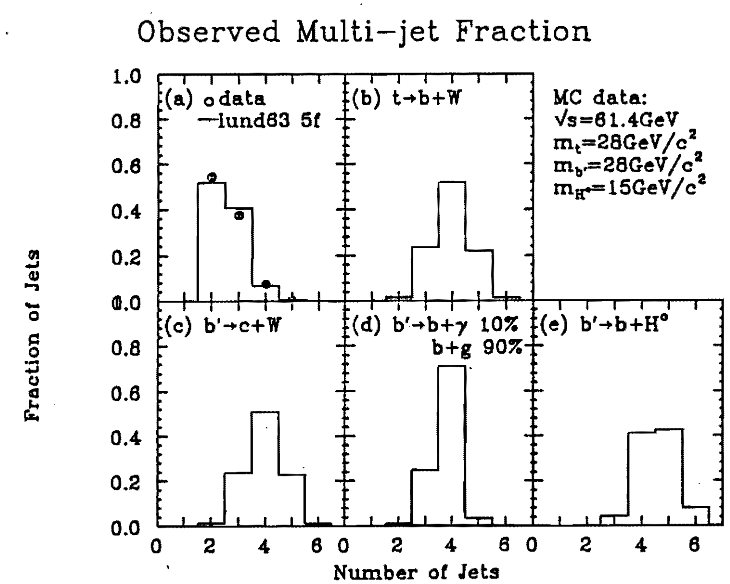


Fig.9

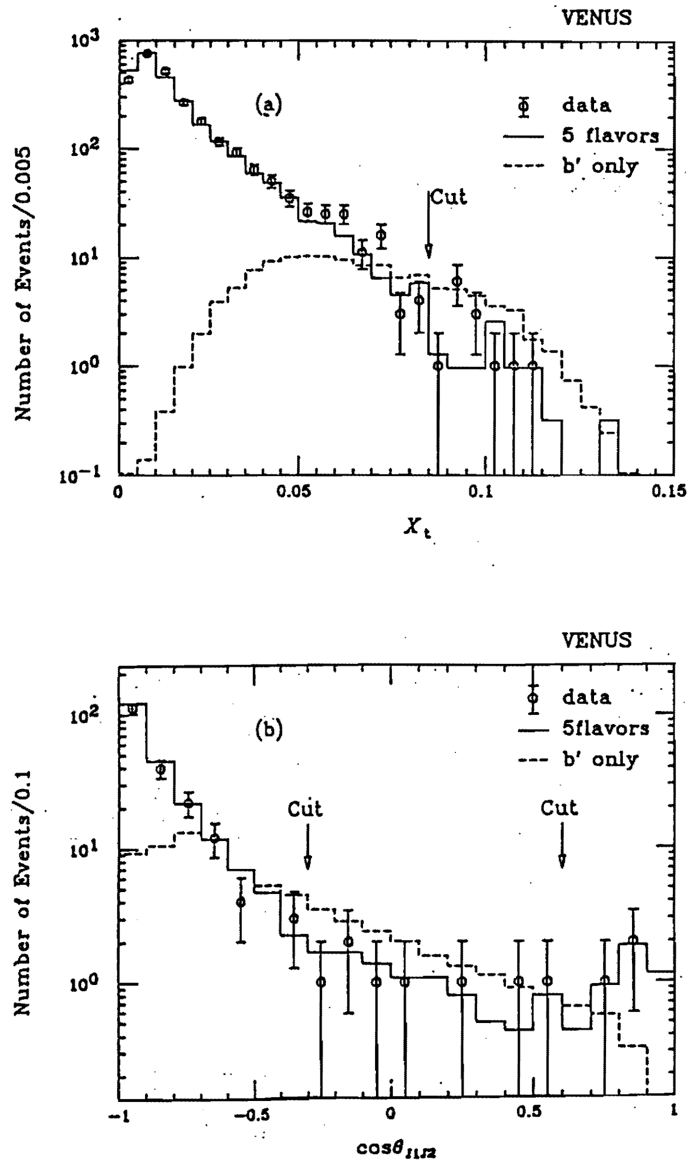
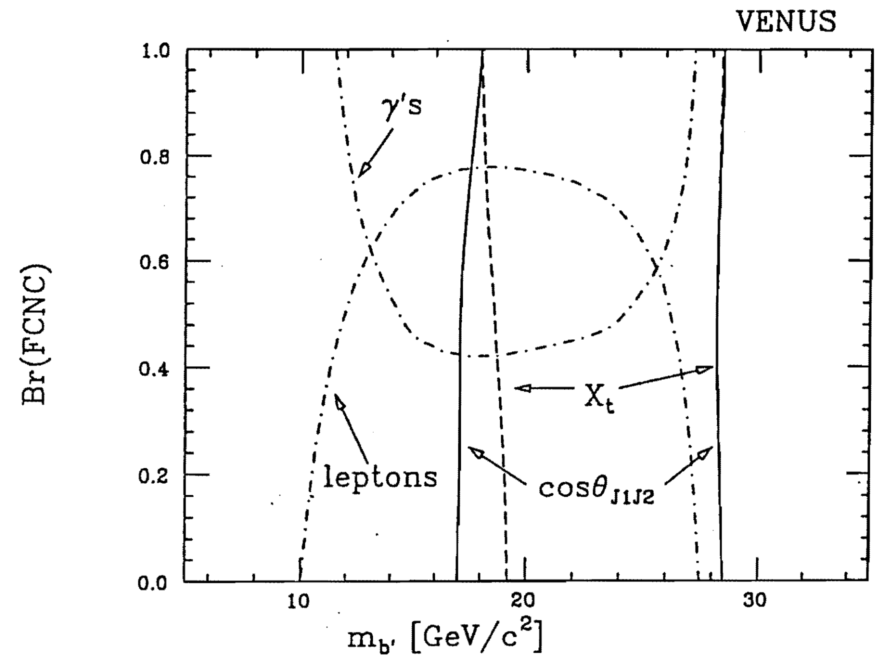

VENUS
(a)
data
5 flavors
b' only
Cut
Number of Events/0.005
X_t
VENUS
(b)
data
5flavors
b' only
Cut
Cut
Number of Events/0.1
$\cos\theta_{J1J2}$

Fig.8


VENUS
γ's
leptons
X_t
$\cos\theta_{J1J2}$
Br(FCNC)
$m_{b'}$ [GeV/c^2]

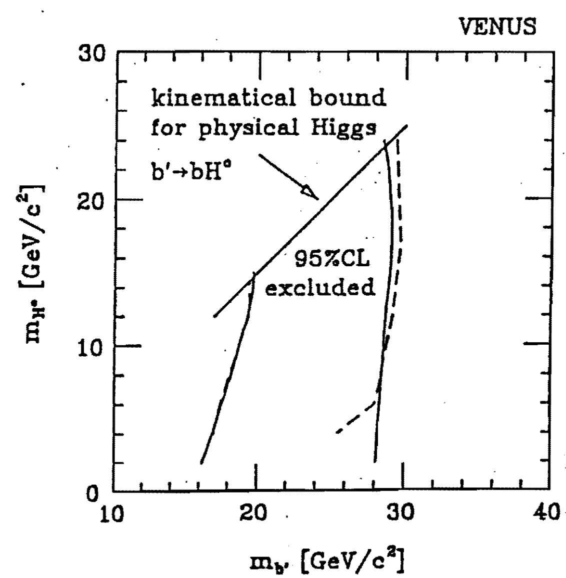

VENUS
kinematical bound
for physical Higgs
b'→bH°
95%CL
excluded
m_{H^0} [GeV/c^2]
$m_{b'}$ [GeV/c^2]

Fig.10

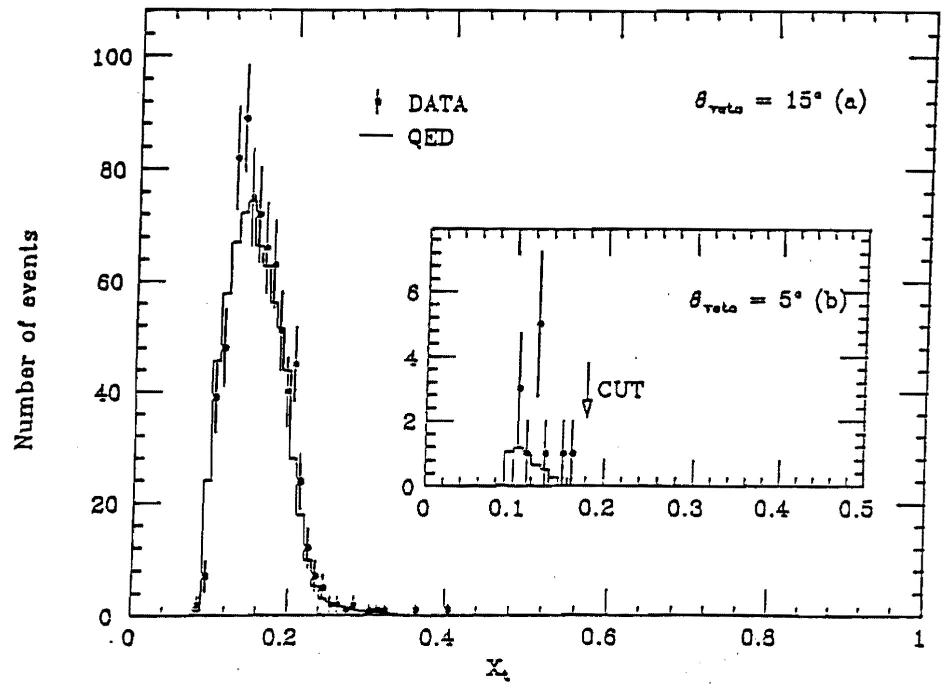

DATA
QED
θ_{veto} = 15° (a)
θ_{veto} = 5° (b)
CUT
Number of events
X_t
100
80
60
40
20
0
0
0.2
0.4
0.6
0.8
1
6
4
2
0
0
0.1
0.2
0.3
0.4
0.5

Fig.11

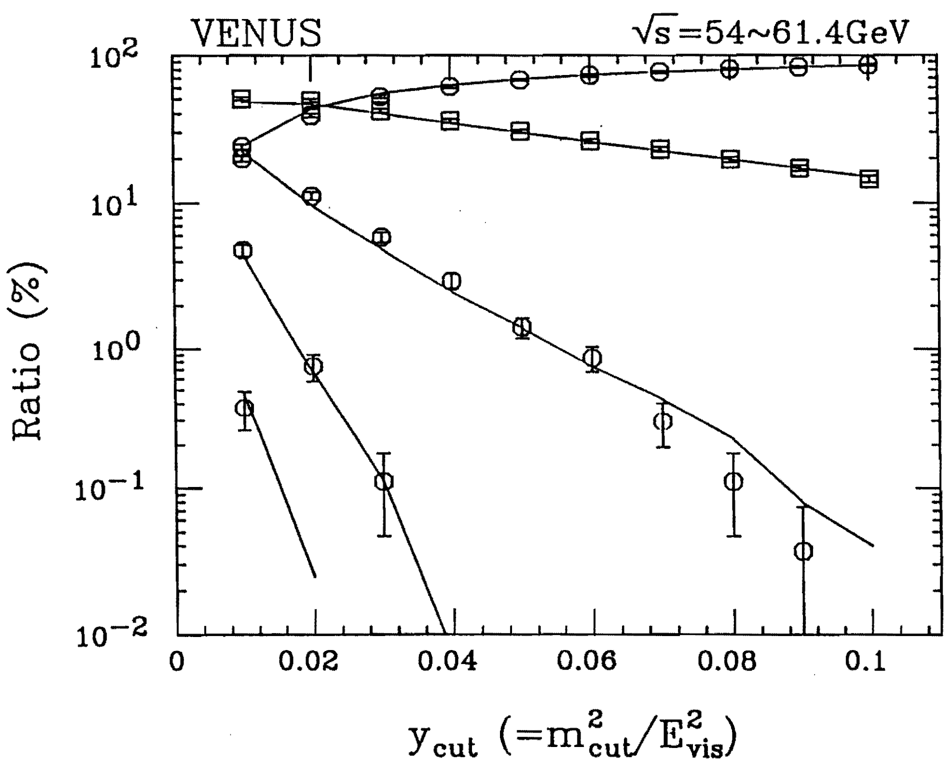

VENUS
$\sqrt{s}$=54~61.4GeV
Ratio (%)
10^2
10^1
10^0
10^{-1}
10^{-2}
0
0.02
0.04
0.06
0.08
0.1
y_{cut} $(=m^2_{cut}/E^2_{vis})$

Fig.12