# RECENT RESULTS FROM AMY AT TRISTAN

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## 1. INTRODUCTION

Since the TRISTAN $e^+e^-$ collider started its operation in late 1986, the AMY experiment has accumulated 19.3 $pb^{-1}$ of the data at $\sqrt{s} = 50 \sim 57$ GeV in 1987 and 1988. In this year (1989), the data have been taken at $\sqrt{s} = 57.25 \sim 60.8$ in Jan/Mar run period and recently at the highest energy 61.4 GeV in May/Jul run period. Total accumulated luminosity is now 33.7 $pb^{-1}$.

On the other hand, the SLC started its operation and Mark II experiment reported its first physics results on $Z^0$. They measured $Z^0$ mass and width with much improved accuracy from $p\bar{p}$ collider experiments: $M_{Z^0} = 91.11 \pm 0.23$ GeV/$c^2$ and $\Gamma_{Z^0} = 2.5 \pm 0.5$ GeV/$c^2$.[1] They also reported the lower mass limits for heavy flavors: $m_t < 44$, $m_{b'} < 45$, $m_{L^0} < 43$ GeV/$c^2$.[2] Further more, the LEP also started physics production run recently after the successful start up operations.

Therefore, the TRISTAN is not the highest energy $e^+e^-$ collider machine any more. Accordingly, as mentioned by Prof. Iwata (a head of KEK physics division), the "PHASE-I" of the TRISTAN has been over and the TRISTAN should make transition into "PHASE-II". In the "PHASE-I", the energy of machine has been kept raised as the energy frontier machine of the $e^+e^-$ collider. On the other hand, in the "PHASE-II", the high luminosity (300 $pb^{-1}$ or more) should be pursued in order to survive as physics frontier machine competing with the

SLC/LEP. The physics subject should also be chosen with above view point.

In this report, first I like to shed a light on the "PHASE-I" physics topics which are going to be fade. Then, topics and results which could be continued toward "PHASE-II" are reported.

## 2. TRISTAN "PHASE-I" TOPICS

### 2.1 New Heavy Quark Search

A new heavy quark search has been one of the hot topics of the "PHASE-I". Fig. 1a shows the total hadronic cross section ($R_{HAD}$) of the AMY[3] together with the lower energy results. $R_{HAD}$ is given by

$$R_{HAD} = \frac{\sigma(e^+e^- \to \text{hadrons})}{\sigma_{\mu\mu}(\text{QED})} = \frac{N_{obs} - N_{BG}}{\epsilon(1+\delta)L\sigma_{\mu\mu}}$$

and a contribution to the error from each item is listed in Table 1. Fig. 1b is the expanded plots for only TRISTAN energy region. The points with open circle are average value for $\sqrt{s}$ from 50 to 55 GeV and from 56 to 61.4 GeV, respectively. The solid line is the 5 flavor standard model expectation with $M_Z$ = 91 GeV/$c^2$, $\sin\theta_W$ = 0.23, and $\Lambda_{\overline{MS}}$ = 0.15 GeV. A dashed (dotdashed) line shows the expectation with top (b′) quark with mass of 25 GeV/$c^2$. The data clearly disagree with open top. The data up to 55 GeV shows good agreement with standard model but the data above 56 GeV shows about 8% higher value ($\sim$ 1.6 $\sigma$) than the standard model and consistent with b′. However, thrust distribution at the highest energy (61.4 GeV) does not show any deviation from 5 flavor expectation (Fig. 2).

Fig. 3 shows comparison of number of low Thrust and high Aplanarity events in hadronic events for data and Monte Carlo as a function of energy. It dose not show any significant deviations expected from b′ quark. More stringent mass limits for heavy quark are obtained by the dedicated analyses described below.

### A. Isolated Lepton Events (Charged Current Decay)

One of the distinct signature of the heavy quark is an isolated lepton event where the lepton comes from the leptonic decay of charged current decay of heavy quark. We applied the following cuts to select the isolated lepton events in hadronic event sample:[4] (1) Thrust $< 0.9$; (2) The sum of the energy within the cone of half angle $20°$ around the lepton is less than 3 GeV; (3) For electron case, momentum of the electron is less than 16 GeV/c and the invariant mass of hadronic system is larger than $\sqrt{s}/2$. The number of events found in the data is listed in Table. 2, compared with the expected number of 5 flavor hadronic events by Monte Carlo. The data are consistent with Monte Carlo expectation and the 95% C.L. lower mass limits are 29.0 and 30.4 GeV/$c^2$ for top and b′, respectively.

## B. b′ Search including FCNC Decay

The charged current decay of b′ involves transition of quarks between 2 generation apart and the amplitude is expected to be quite small. Therefore, flavor changing neutral current (FCNC) decay mode via one W loop might have considerable contributions.[5] In the FCNC decay mode, b′ can decay into either b + gluon or b + $\gamma$. The branching ratios B(b′ $\rightarrow cW^*$), B(b′ $\rightarrow$ b$g$), and B(b′ $\rightarrow$ b$\gamma$) are unknown and hence we treat them as free parameters.

Besides Thrust, we used a event shape variable called lesser biwidth (LBW) which is specially useful for FCNC decay mode.[6] LBW is defined as follows: First divide the event into hemispheres with a plane perpendicular to the thrust axis. For each hemisphere, use the sum of the vector momenta for the particles in that hemisphere to define an axis, and sum the magnitudes of the perpendicular components of momenta for all particle in the hemisphere. The smaller of two sums, divided by the visible energy is LBW.

Since we do not see any excess from the back ground, we have set the lower mass limit for b′ with the following two steps; 1) get limit with tight cut which eliminates background to the negligible level. The limits are obtained without background subtraction. 2) use loose cut to increase efficiency for b′. In this case, background is subtracted from observed events. The background is estimated using lower energy data where b′ is already excluded. We used Monte Carlo to estimate energy dependence of the amount of background.

The results are shown in Fig. 4, together with the cuts used in each region.

### 2.2 New Particle Search

AMY has searched various kind of new particles using their distinct event topologies.[7,8] The particles and topologies searched for by AMY are listed in Table. 3. As seen in the table, the topologies searched for are widely covered. We have not found any evidence of their existence. However, we have extended mass limits from previous PEP/PETRA experiments. Comparison of AMY results and previous experiments are shown in Fig. 5.

## 3. TRISTAN "PHASE-II" TOPICS

### 3.1 Electro-Weak Interference

The effect of electro-weak interference appears as the forward - backward asymmetry of the fermion pair production. The asymmetry is nearly maximum around TRISTAN energy region for all type of fermions. At $Z^0$ pole, the asymmetry is small and the TRISTAN has much advantage over the LEP.

We have measured the asymmetry for lepton-pair ($\mu$ and $\tau$),[9] b-quarks,[10] and jets (average for quarks).[11] Here, b-quark asymmetry result is described briefly.

The measurement of b-quark asymmetry is quite interesting since it can distinguish whether b-quark belongs weak iso-doubles (top quark should exist) or iso-singlet (no top quark). If b-quark belongs to iso-doublet, the asymmetry is -0.56 as predicted by the standard model, while the asymmetry is zero in case of iso-singlet. The measurements at lower energies, which are consistent with doublet case, do not gives definite answer due to small value of expected asymmetry.

We have measured b - quark asymmetry using inclusive muon events in hadronic event sample. The data of $\sqrt{s} = 52 \sim 57$ GeV (18.6 $pb^{-1}$) are analyzed and 123 muon events are used. The fraction of b-quark events are enhanced by requiring $p_t > 0.7$ Gev/c for muons, where $p_t$ is the transverse component of the muon momentum with respect to the Thrust axis. The cosine distribution of the b-quarks are obtained by subtracting the contributions of c-quark (~ 30%) and hadron fake events (~ 20%) from the data (Fig. 6a). These contributions are estimated by Monte Carlo simulation. We obtained $A_{b\bar{b}}$ = -0.72 ± 0.28 (stat.) ± 0.13 (sys.) (Fig. 6b). Our result strongly indicates $A_{b\bar{b}}$ is non-zero. The measurement is not so precise due to small statistics and uncertainty of background estimation. More precise measurement is interesting since it might give the estimate of $B_s - \bar{B}_s$ mixing before the B factory result comes out.

### 3.2 Precise Measurements of Cross Sections for Standard Processes

Even if we do not see any direct evidence for new particles because of their high masses, we can see their effect if they appear in the cross section of standard processes. Since, these effects will appear as small deviations from the standard model prediction, we need to measure cross section quite precisely. The $e^+e^-$ collision is suitable for this purpose because of the low background and clean event signatures comparing to other machines. The measurement at $Z^0$ pole is not so sensitive to these small additional terms because the cross section at $Z^0$ pole is so huge. Therefore, TRISTAN still has a chance to find something new competing with the LEP.

The following effect can be considered, for example;

*a*) Extra Z (Z′): if $M_{Z'}$ is around 100 to 200 GeV/$c^2$, we should see slight higher value of $R_{HAD}$ and slight lower value of $R_{\mu\mu}$, $R_{\tau\tau}$, $A_{\mu\mu}$, and $A_{\tau\tau}$ compared with the standard model.

*b*) Contact interactions (Compositeness scale): This can be seen in the deviation of angular distribution of $e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$, $\gamma\gamma$, and $< q\bar{q} >$ productions.

In the AMY measurement, the total hadronic cross section ($R_{HAD}$) shows about 8% higher (~ 1.6 $\sigma$) than the standard model, as mentioned before. Fig. 7 shows the total cross section for $\gamma$ - pair production where the points with open circle are average value for $\sqrt{s}$ from 50 to 55 and from 56 to 61.4 GeV, respectively.[12] It also shows about 10% higher cross section for the higher energy region ($\sim$ 2.2 $\sigma$ with statistical error only), while that for lower energy region is consistent with the expectation. In both cases, still errors are too big to say definitely.

### 3.3 Two Photon Processes

TRISTAN has also advantage over the LEP for the two photon processes. Since photon does not couple with $Z^0$, the cross section for the two photon process is not so large and the huge cross section via s-channel $Z^0$ exchange gives large background at $Z^0$ pole. AMY has been working both for hadronic[13] and leptonic[14] two photon processes. The statistics is not good enough at present but we can give interesting results when we accumulate more luminosity.

### 3.4 QCD and Jets

AMY has been working quite actively on QCD and Jet physics so far.[15] The LEP has advantage over TRISTAN on QCD and Jet physics because of the large hadronic cross section and the higher energy. However, still there are a lot of things to be investigated, especially more quantitative measurements are needed. In order to understand QCD and jets quantitatively, the energy dependence are quite important and the results from TRISTAN will give the valuable information at energy between PEP/PETRA and LEP.

## 4. AMY 1.5 UPGRADE

Toward the TRISTAN "PHASE-II" high luminosity run, AMY is now proceeding the upgrade of the detectors (AMY 1.5). As shown in Fig. 8, the endcap part will be replaced completely with new one and the vertex chamber will be added inside the Inner Tracking Chamber. The Endcap Shower Counter (ESC) extends the coverage for photons with good position information. This will increase the acceptance for hadronic events. Together with the Small Angle Counter (SAC), the detector covers $\theta > 3°$ for photons without any hole. This enables us to do single photon physics for which TRISTAN also has an advantage over the LEP. The installation of ESC and SAC is completed in the summer shutdown in 1989. The Forward Tracking Chamber (FTC) extends the coverage of charged particles from the CDC. The Vertex Chamber (VTX) enables the measurement of the secondary vertex points and gives efficient identification for b-quarks. The FTC and VTX are planned to be installed in the summer of 1990.

## 4. SUMMARY

As described above, TRISTAN is finishing its jobs as a highest energy $e^+e^-$ collider machine ("PHASE-I"). Various measurements at new energy points have been added. A new heavy quark and variety of new particles have been searched. Unfortunately, no evidence of their existence are found and mass limits are extended from previous PEP/PETRA results. These search are now continued by the higher energy machines such as the SLC and LEP. The Mark-II at SLC already extended mass limits up to 45 GeV/$c^2$for heavy quarks and neutral heavy leptons. Other new particles will be also searched for soon.

However, there are still many physics which TRISTAN can contribute as a physics frontier machine ("PHASE-II"). The most important thing in "PHASE-II" is accumulate large amount of luminosity and running with high luminosity is essential. Some of the present measured values shows deviation from standard model expectation, though the significances are not large enough to be definite. The measurement with much more luminosity will provide answer these questions. AMY detector is also being upgraded according to the requirement for the high luminosity phase.

## REFERENCES


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8) S.K. Kim *et al.*, Phys. Lett. **223B**, 476 (1989).

9) A. Bacala *et al.*, Phys. Lett. **218B**, 112 (1989).

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11) D. Stuart *et al.*, KEK Preprint 89-127 (1989).

12) H.J. Kim *et al.*, KEK Preprint 89-52 (1989).

13) T. Sasaki *et al.*, KEK Preprint 89-56 (1989).

14) Y. Kurihara *et al.*, KEK Preprint 89-64 (1989).

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Table 1. Systematic Errors in Total Hadronic Cross Section

| Item | Error |
|---|---|
| (1) Event Selection: $N_{obs}$ = number of observed events<br>i) $N_{track} \geq 5$ ($\lvert\cos\theta\rvert < 0.85$)<br>ii) $E_{vis} > \sqrt{s}/2$, $E_{SHC} > 5$GeV<br>iii) $\lvert\Sigma p_z/E_{vis}\rvert < 0.4$ | 1.7% |
| (2) Background: $N_{BG}$ = number of background events<br>$e^+e^- \to \tau^+\tau^-$ (1.0%)<br>$e^+e^- \to e^+e^-$ + hadrons (0.5%)<br>beam gas (0.3%)<br>cosmic ray (0.5%)<br>beam wall (0.8%) | 0.47% |
| (3) $\epsilon$ : selection efficiency<br>LUND 6.3 + AMY simulator | 1.3% |
| (4) $(1+\delta)$ : radiative corrections<br>use FS full electro-weak [$O(\alpha^3)$] calculation<br>$M_Z$ : ±2 GeV → ±0.6%<br>$M_t$ : 40 ~ 200 GeV → −1.4%<br>$M_{H^0}$ : 10 ~ 1000 GeV → +0.6% | 1.3% |
| (5) L : Luminosity (measured by PTC) | 2.5% |
| Total overall normarization error | 3.5% |

Table 2. Isolated Lepton Events

| | $\sqrt{s}$ | 50 ~ 52 | 55 ~ 57 | > 57 | Total |
|---|---|---|---|---|---|
| $\mu$ | Data | 0 | 1 | 0 | 1 |
| | 5F MC | 0.47 | 0.98 | 0.33 | 1.78 ± 0.43 |
| e | Data | 0 | 3 | 3 | 6 |
| | 5F MC | 0.47 | 1.23 | 1.21 | 2.92 ± 0.54 |
| | $2\gamma$ MC | 0.08 | 0.24 | 0.12 | 0.44 ± 0.10 |

Table 3. New Particles Searched by AMY

| | | | Signatuers | Mass Limits (GeV) |
|---|---|---|---|---|
| Heavy Lepton | $L^{\pm}$ | $m_{L^{\pm}} >> m_{\nu_L}$ | Acoplanar jets | 29.5 ($m_\nu$=0) |
| | | | Isolated lepton + missing $p_t$ | 27.7 ($m_\nu$=0) |
| | | $m_{L^{\pm}} \sim m_{\nu_L}$ | Acoplanar 2-prong | 18.6 ($\delta$=3GeV) |
| | $L^0$ | C.C. | Isolated 2-leptons | 28.1($\mu$),26.5(e) |
| | | FCNC | Mono-jet | 20.1 |
| Higgs | $(h_1^0, h_2^0)$ | | Mono-jet | 28.0 ($m_{h_1^0} \sim 0$) |
| | $H^{\pm}$ | | 4-jets | |
| | | | $\tau$ + jets | |
| | | | Acoplanar $\tau^+\tau^-$ | 23.5 ($B_{\tau^+\tau^-}$=1) |
| SUSY | $\tilde{e}$ | | Acoplaner $e^+e^-$ | 28.9 |
| | $\tilde{\mu}$ | | Acoplanar $\mu^+\mu^-$ | 27.1 |
| | $\tilde{\tau}$ | | Acoplanar $\tau^+\tau^-$ | 25.6 |
| | $\tilde{q}$ | | Acoplanar jets | 26.9(Q=2/3),25.0(-1/3) |
| | $\tilde{\chi}^{\pm}$ | | Acoplanar $\ell^+\ell^-$ | 29.7 ($B_\ell$=1) |
| | | | Acoplanar jets | 29.8 ($B_\ell$=0) |
| | $(\tilde{h}_1^0, \tilde{h}_2^0)$ | | Mono-jet | 41.0 ($m_{\tilde{h}_1^0} \sim 0$) |
| Composite Model | $L_q$ | (Leptoquark) | Acoplaner jets | 22.6 (1st Gen) |
| | | Q=2/3 | Isolated lepton + missing $p_t$ | 23.2 (2nd Gen) |
| | | | Isolated 2-leptons | |
| | $e_8$ | | Isolated di-electron | 30.3 (F=1) |
| | $\mu_8$ | | Isolated di-muon | 30.3 (F=1) |
| | $\nu_8$ | | Acoplanar jets | 29.8 (F=1) |
| | $e^*$ | | $e^+e^-\gamma, e^+e^-\gamma\gamma, \gamma\gamma$ | 56. |
| | $\mu^*$ | | $\mu^+\mu^-\gamma, \mu^+\mu^-\gamma\gamma$ | 52. |
| Heavy Stable Particle | J=1/2 | $L^{\pm}$, $\tilde{\chi}^{\pm}$ | Excess of $\mu$-pair | 30.1 |
| | J=0 | $\tilde{\mu}, \tilde{\tau}$ | non-e non-$\mu$ | 27.1 |
| | | $H^{\pm\pm}$ | back-to-back pair | 26.3 |

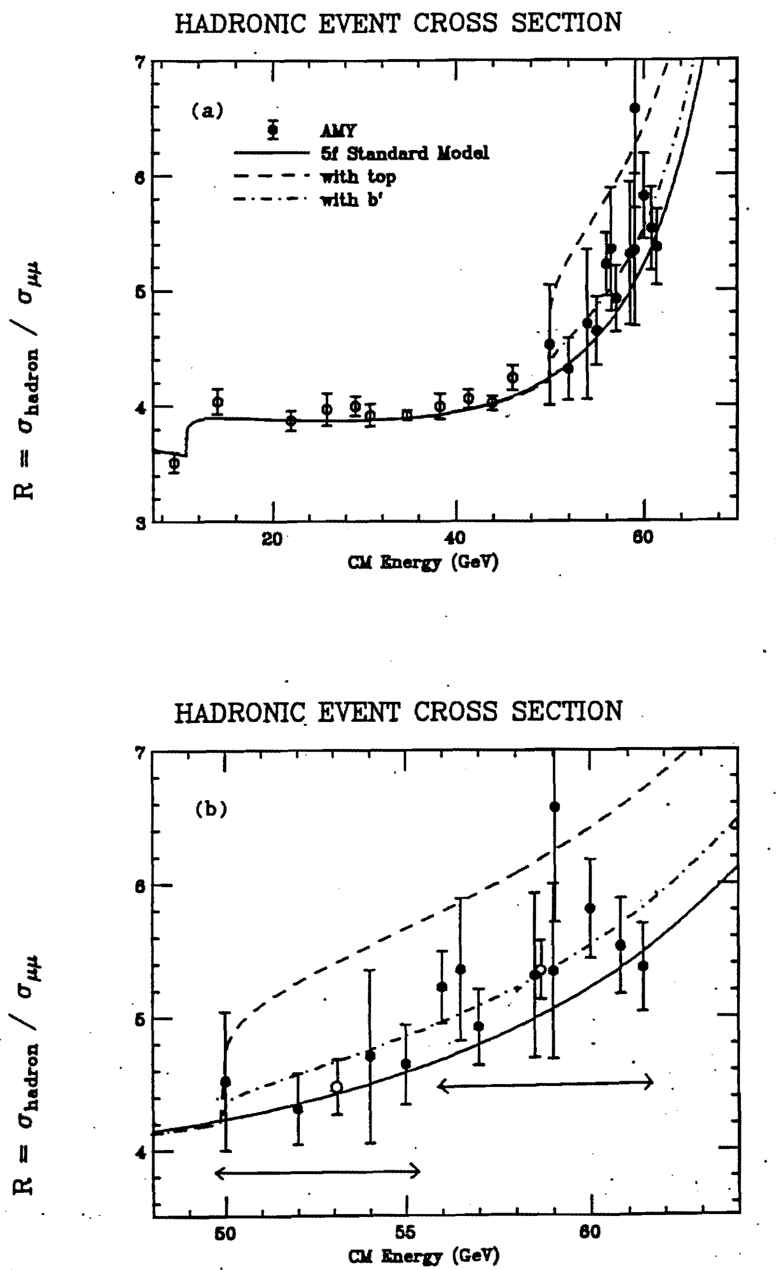
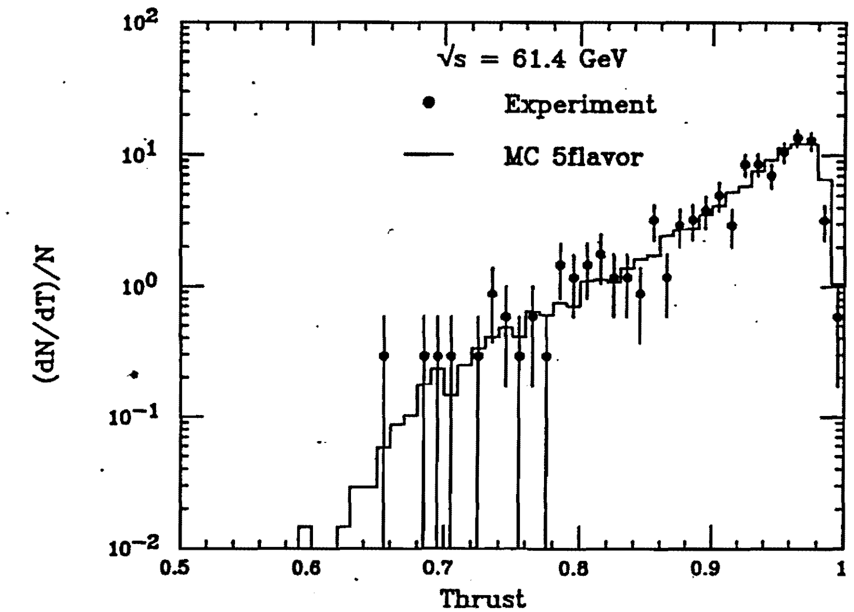



Fig. 1




The normalized thrust distribution for 61.4 GeV. The solid histogram indicates the LUND 6.3 Monte Carlo predictions for five quark flavors.

Fig. 2

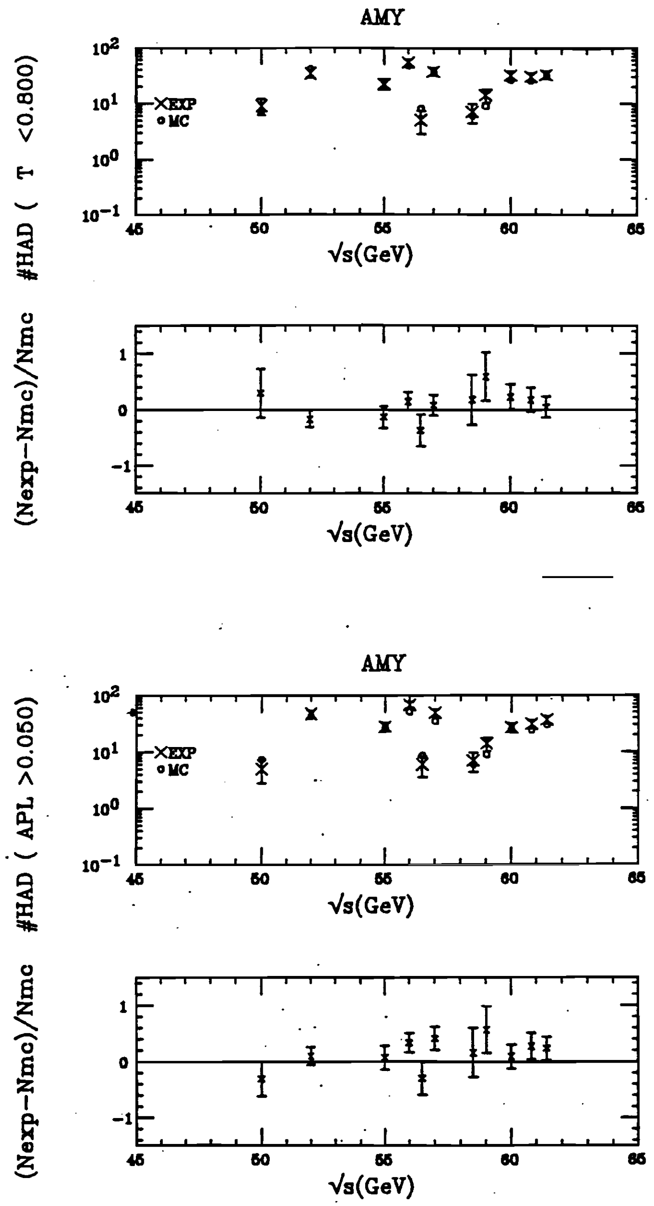

AMY
#HAD ( T <0.800)
×EXP
∘MC
√s(GeV)
(Nexp−Nmc)/Nmc
√s(GeV)
AMY
#HAD ( APL >0.050)
×EXP
∘MC
√s(GeV)
(Nexp−Nmc)/Nmc
√s(GeV)

Fig. 3

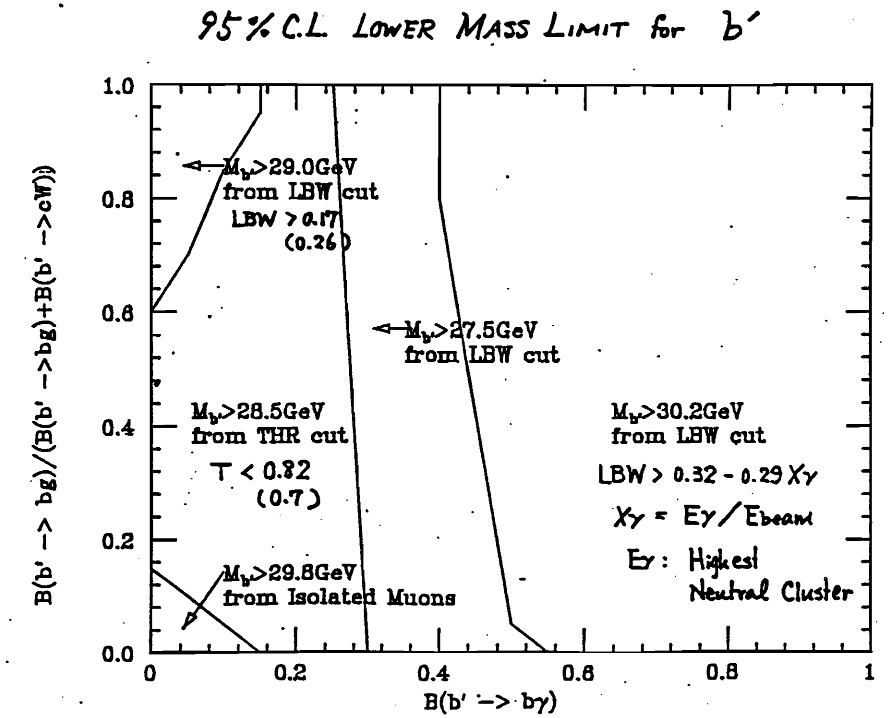

95% C.L. Lower Mass Limit for b'
B(b' −> bg)/(B(b' −>bg)+B(b' −>cW))
B(b' −> bγ)
Mb'>29.0GeV
from LBW cut
LBW > 0.17
(0.26)
Mb'>27.5GeV
from LBW cut
Mb'>28.5GeV
from THR cut
T < 0.82
(0.7)
Mb'>30.2GeV
from LBW cut
LBW > 0.32 - 0.29 Xγ
Xγ = Eγ / Ebeam
Eγ : Highest
Neutral Cluster
Mb'>29.8GeV
from Isolated Muons

Fig. 4

New Particle Search Excluded Mass Region

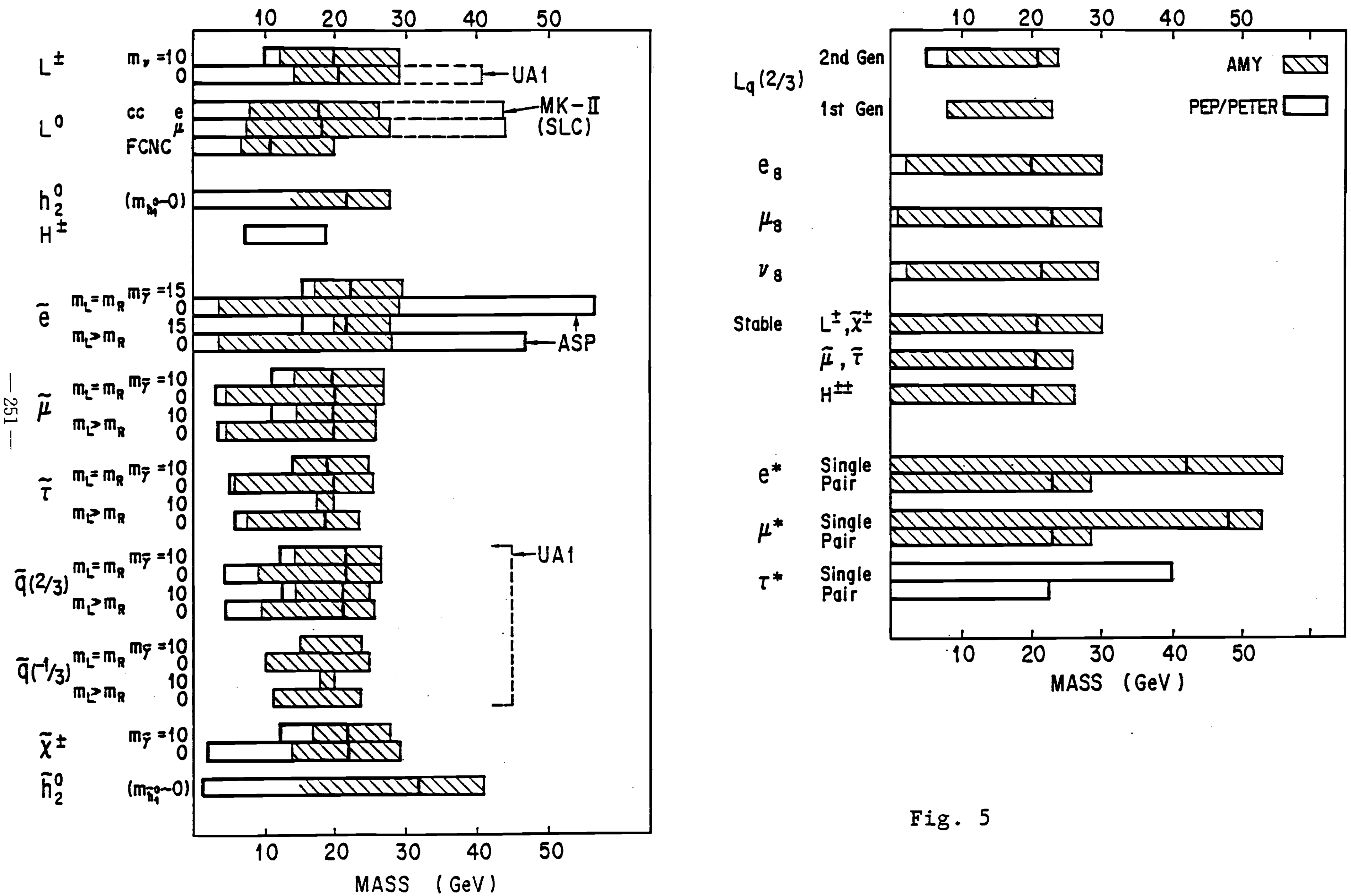



Fig. 5

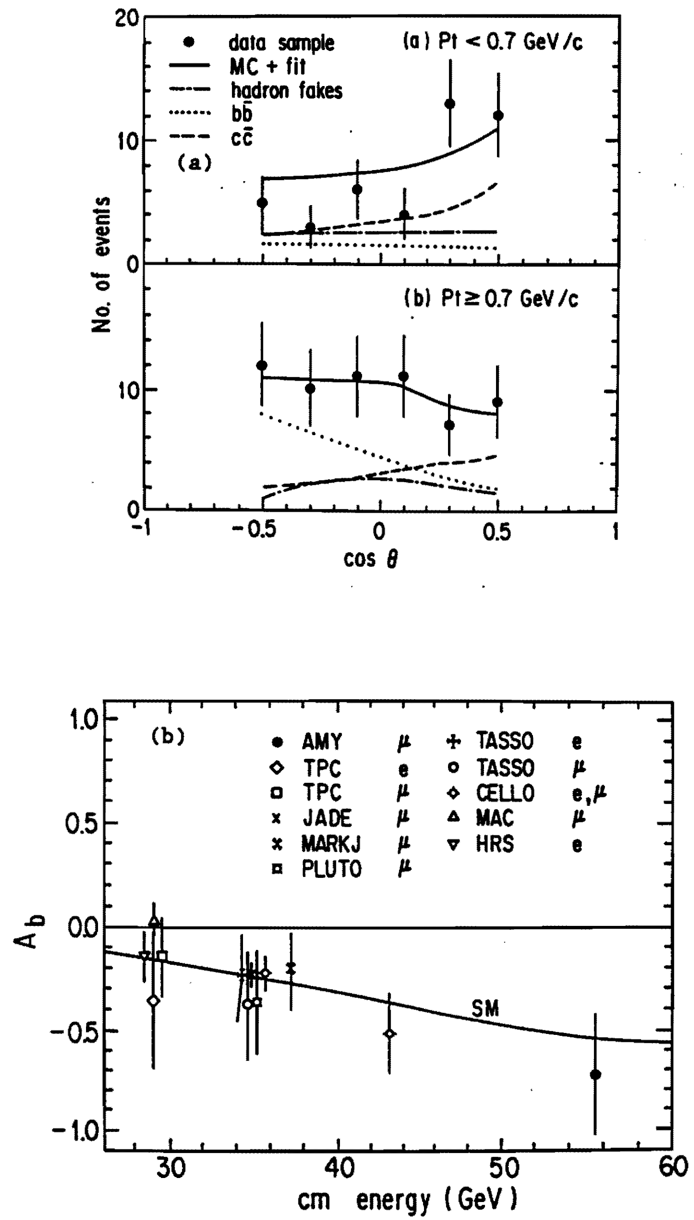

data sample
MC + fit
hadron fakes
$b\bar{b}$
$c\bar{c}$
(a)
(a) Pt < 0.7 GeV/c
(b) Pt ≥ 0.7 GeV/c
No. of events
cos θ
(b)
AMY μ
TPC e
TPC μ
JADE μ
MARKJ μ
PLUTO μ
TASSO e
TASSO μ
CELLO e,μ
MAC μ
HRS e
SM
$A_b$
cm energy (GeV)

Fig. 6

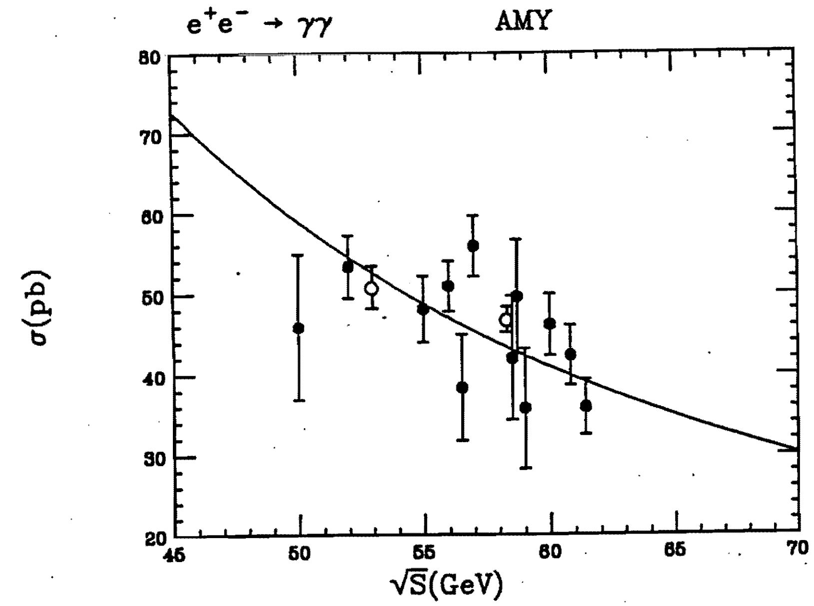
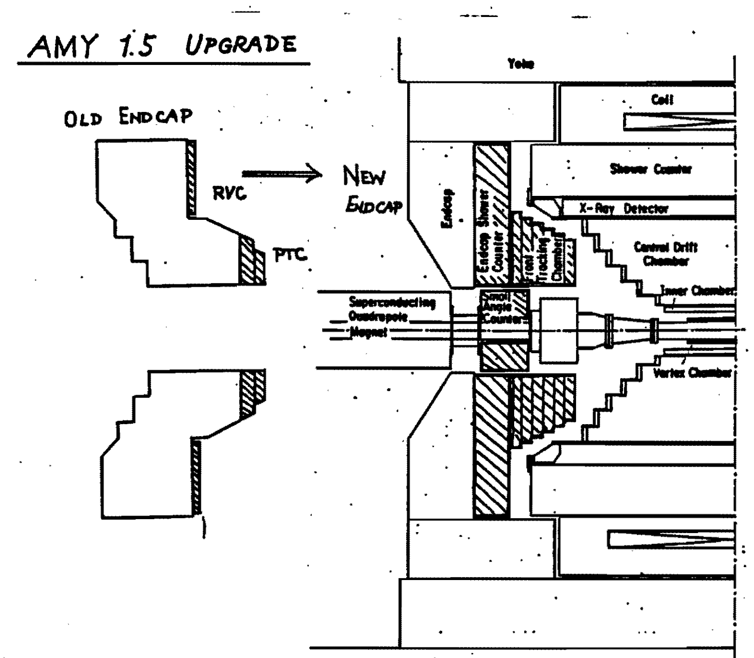

$e^+e^- \to \gamma\gamma$
AMY
σ(pb)
√S(GeV)

Fig. 7


AMY 1.5 UPGRADE
OLD ENDCAP
RVC
PTC
NEW ENDCAP
Yoke
Coil
Shower Counter
X-Ray Detector
Central Drift Chamber
Inner Chamber
Vertex Chamber
Endcap
Endcap Shower Counter
Superconducting Quadrupole Magnet
Small Angle Counter