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Search for Heavy Quarks in e^+e^-*

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1. Introduction

The Open Top Group[1] of the Mark II Collaboration at the SLAC SLC has been studying how to find new heavy quarks, particularly the top quark, in decays of the Z^0. Recent evidence suggests that the top quark mass (M_t) may be larger than half the mass of the Z^0 (M_Z). The UA1 Collaboration[2] has set the limit $M_t > 44$ GeV/c^2 using a conservative calculation for $\sigma(p\bar{p} \rightarrow t\bar{t})$ and > 56 GeV/c^2 using a "reasonable" calculation for this cross section. Similarly, they have set limits on the b' quark mass of 25 and 41 GeV/c^2. The ARGUS Collaboration[3] has reported the observation at the $\Upsilon(4s)$ of B_d^0–$\overline{B}_d^0$ mixing at the 20% level, which indicates $M_t \gtrsim$ 50–120 GeV/c^2, unless there are more than three generations. The three experiments at TRISTAN[4] — AMY, TOPAZ, and VENUS — have reported $M_t > 26$ GeV/c^2, although that is not a problem for the SLC since we are sensitive to a top quark of mass as large as 46 GeV/c^2.

The Mark II Open Top Group is still optimistic that top may be found at the SLC. In any case, the search methods we have developed are quite general and could be applied to searches for other heavy particles in SLC data. The work of the Group has been divided into three main topics: (1) establishing a signal, (2) measuring the mass and (3) determining the identity.

We will first discuss the Monte Carlo models, cross sections and analysis procedures, followed by the specific work on these topics. More details are given in Reference 5.

2. Models, Cross Sections and Analysis Procedures

2.1. Monte Carlo Models

The Monte Carlo models used for multihadronic background from $e^+e^- \rightarrow Z^0 \rightarrow u\bar{u}$, $d\bar{d}$, $s\bar{s}$, $c\bar{c}$, and $b\bar{b}$ were the Lund model[6] with order α_s^2 QCD matrix elements and symmetric string fragmentation of the partons, the Lund model with leading log parton shower evolution and symmetric string fragmentation, and the Webber model[7], which also uses leading log parton shower evolution but uses a combination of string and cluster fragmentation. The two models with leading log shower evolution have been found to fit multihadronic data from e^+e^- annihilation at PEP/PETRA energies significantly better than models using order α_s^2 QCD matrix elements.

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The models used for heavy quark production from $Z^0 \to Q\bar{Q}$ were the Lund model with order α_s^2 QCD matrix elements with either symmetric string fragmentation or Peterson fragmentation and the Webber model. In the Lund model with symmetric fragmentation pairs of heavy quark mesons are usually produced with no other particles because the mesons are very hard. In the Lund model with Peterson fragmentation the heavy quark mesons are somewhat softer and one can see some evidence of gluon radiation and production of other particles. In the Webber model decays occur on the quark level ($Q \to qW$) as opposed to the Lund model in which heavy quark *mesons* decay. In the Webber model mesons and baryons are formed only at the ends of the decay chains, and the quarks can radiate gluons, even at intermediate stages of the decays. The branching ratios used for top decay in the Lund and Webber models are shown in Table 1.

2.2 Production Cross Section

The effect of the first-order radiative QCD corrections (Schwinger terms)[8] on the $t\bar{t}$ width is large, as shown in Fig. 1. We have assumed $M_Z = 93$ GeV/c^2 and $\sin^2\theta_W = 0.22$. The width is increased by 15% at $M_t = 25$ GeV/c^2, by 39% at $M_t = 40$ GeV/c^2, and by a factor of two at $M_t = 45$ GeV/c^2. These corrections should be accurate to $\sim$ 10%, unless M_t is very close (< 50 MeV/c^2) to $M_Z/2$. In the absence of other new particles produced in Z^0 decay, the QCD-corrected $t\bar{t}$ width leads to the cross sections listed in Table 2. We have used these cross sections to calculate rates for this Report; they include a factor of 0.80 for QED radiative corrections. The cross section for multihadronic events from u, d, s, c, and b quarks, including the factor of 0.80 for QED radiative corrections, is taken to be 30.68 nb on the Z^0.

2.3. Analysis Procedures

Events from heavy quark production or *udscb* background were generated according to the Monte Carlo models described in Section 2.1. Interactions of the resulting particles in the Mark II detector, shown in Fig. 2, were then simulated, producing "raw data" which was then analyzed using the standard programs. Cuts were applied just as for real data. The total visible energy, which is the sum of the detected charged particle momenta and photon energies, was required to be greater than the beam energy. The event was required to have at least five charged tracks (0.03% of $t\bar{t}$ events are lost by this cut). We also made a loose cut on the polar angle of the thrust axis: $|\cos\theta_T| < 0.95$.

Electrons were identified in the lead/liquid argon barrel calorimeters or in the lead/proportional tube endcap calorimeters. To be identified as an electron, a particle must have momentum (p) > 1 GeV/c and $|\cos\theta| < 0.85$ (the latter cut is necessary for good momentum resolution in the central drift chamber). Muons were identified in the iron/proportional tube external muon identification system. A muon candidate must have $p > 2$ GeV/c and $|\cos\theta| < 0.50$.

3. Establishing a Heavy Quark Signal

We considered the following methods for establishing a heavy quark signal: (1) shape parameters, (2) leptons with high transverse momentum (p_T), (3) isolated leptons, (4) multilepton events, (5) cluster counting and (6) total hadronic cross section.

In this report we will discuss the use of shape parameters, high-p_T leptons, and isolated high-p_T leptons to establish a heavy quark signal. Preliminary work has indicated that cluster counting does not work well because the number of events in the background with large numbers of jets is quite high relative to the signal from $t\bar{t}$ events and is also model dependent.

3.1. Shape Parameters

The use of shape parameters to establish a heavy quark signal is an obvious method; the idea, of course, is that heavy quark events will be "fat" and easily distinguishable from the ordinary multihadronic background. We will summarize here the results, shown in Table 3, of using the parameter aplanarity to try to establish a top signal. One can see from the Table that the number of high aplanarity events is model dependent both for the multihadronic background and for $t\bar{t}$ production, particularly for relatively low top masses of 25–30 GeV/c^2. For the *udscb* background there is a factor of two difference between the Lund leading log and the Webber models, both of which fit e^+e^- data in the PEP/PETRA energy range. For $t\bar{t}$ production at lower top masses the Lund model with symmetric fragmentation produces fewer events with high aplanarity than either the Lund model with Peterson fragmentation or the Webber model, which agree rather well.

Our conclusion is that a large number of high-aplanarity events may be a sign of new physics, but one cannot trust the Monte Carlo calculations quantitatively for either the multihadronic background or the signal from heavy quark production. We have also investigated other shape parameters with similar results and have therefore concluded that shape parameters are not a reliable method for establishing a heavy quark signal.

3.2. High-p_T Leptons

Semileptonic decays of heavy quark mesons provide a source of high-p_T leptons which can be used to establish a signal. We calculate p_T relative to the thrust axis. The numbers of e's and μ's with $p_T > 3$ GeV/c for $t\bar{t}$ production and for *udscb* background are shown in the third column of Table 4. The numbers of high-p_T leptons are model independent, both for the background and for $t\bar{t}$ events. However, the background from *udscb* multihadronic events is rather large.

We tried reducing the background by applying a loose shape parameter cut of aplanarity > 0.02, as shown in the fourth column of Table 4. Using only the Lund order α_s^2 model for background, we found that we could reduce the background by a large factor without reducing the signal very much. However, with the more realistic background models with leading log parton shower evolution we found that the aplanarity cut was much less effective. Also, the effect of the aplanarity cut was model dependent for $t\bar{t}$ production.

3.3. Isolated High-p_T Leptons

Another approach to reducing the background to high-p_T leptons from *udscb* multihadronic events is to require that the high-p_T leptons be isolated. The philosophy is to look for leptons which are not in jets in order to reduce the background from *udscb* multihadronic events in which gluons have been radiated. The thrust axis in such events is not along the $q\bar{q}$ axis, which causes leptons from known heavier quark decays (especially b's) to appear to have higher p_T, as shown in Fig. 3. For top meson decays one would select the lepton from the direct top semileptonic decay but would reject leptons which come from the semileptonic decay of the b from the top decay. Thus the signal would be reduced as compared with simply counting high-p_T leptons.

To select isolated leptons, we required that a high-p_T lepton have no nearby clusters. First we selected a lepton with $p_T > 3$ GeV/c as described in Section 3.2. In order to determine whether the lepton is isolated, we used the VECSUB routine LCLUS$ to find clusters using all the other detected particles, charged and neutral. Then we calculated the quantity ρ defined[9] as

$$\rho = \min\left(\sqrt{E_\ell\,(1 - \cos\theta_{\ell j})}\right) \quad , \tag{1}$$

where E_ℓ is the energy of the lepton and $\theta_{\ell j}$ is the angle between the lepton and the j^{th} cluster. Figure 4 shows the distribution of ρ for leptons with $p_T > 3$ GeV/c for 10,000 *udscb* events from the Lund leading log Monte Carlo and for the corresponding number of 512 $t\bar{t}$ events for $M_t = 40$ GeV/c^2. We made the cut $\rho > 1.8$ GeV$^{1/2}$ (it could be made as low as 1.4 GeV$^{1/2}$).

The numbers of isolated e's and μ's with $p_T > 3$ GeV/c for $t\bar{t}$ production and for $udscb$ multihadronic background are shown in the fifth column of Table 4. The background rejection is excellent. The top signal is reduced by about a factor of two as compared with counting the number of leptons with $p_T > 3$ GeV/c. There is, however, some model dependence in the isolation cut. For top masses between 25 and 35 GeV/c^2 the isolation criterion removes more leptons with $p_T > 3$ GeV/c in the Webber model than in either version of the Lund model probably because of more gluon emission in the Webber model.

We have looked at backgrounds to isolated high-p_T leptons from heavy quark production due to misidentified hadrons. Using the Monte Carlo simulations we multiplied the number of isolated hadrons with $p_T > 3$ GeV/c within the fiducial regions of the calorimeters or the muon identification system by the relevant misidentification probabilities in the Mark II detector. The backgrounds from misidentified hadrons are given in Table 5 for $t\bar{t}$ production. There is no problem at all with background from isolated misidentified hadrons simply because there are very few isolated hadrons to misidentify.

4. Measuring the Heavy Quark Mass

We have studied the following methods for measuring heavy quark masses: (1) number of high-p_T or isolated high-p_T leptons, (2) shape of the p_T distribution for isolated leptons, (3) hadronic jet mass in events with a single semileptonic decay, (4) reconstructed jet masses in events with double semileptonic decays and (5) reconstructed jet masses in events with double hadronic decays.

The mass of the heavy quark might be measured simply by counting the number of high-p_T or isolated high-p_T leptons and comparing with the predicted number as a function of mass for the accumulated luminosity. However, there are problems with normalization due to knowing the identity of the heavy quark, QCD corrections to the production cross section, assuming the semileptonic branching ratios, and estimating the detection efficiencies. In practice, this method would be used with one of the other methods as a cross check. We will discuss the second and third methods here. The other methods are discussed in Reference 5.

4.1. Measuring a Heavy Quark Mass from the Shape of the p_T Distribution for Isolated Leptons

The shape of the lepton p_T distribution varies with the mass of the heavy quark meson due to the kinematics of the semileptonic decay. Figure 5 shows the p_T distributions for isolated leptons for various top masses. Of course, the p_T distribution shifts to higher p_T as the top mass increases.

We have used a likelihood method to study the differences in shapes for various top masses. One could also look at the average p_T, but the likelihood method should give the maximal information.

In order to study the method, we generated 10,000 $t\bar{t}$ events at various masses between 30 and 42.5 GeV/c^2 to obtain accurate predictions of the p_T distributions and generated fake data by looking at the number of isolated leptons in each p_T bin for the first 512 $t\bar{t}$ events (corresponding to 10,000 *udscb* events) in one of the 40 GeV/c^2 runs. We assumed a Poisson distribution, so the ln likelihood is given by

$$\ln \text{likelihood} = \sum n \ln \bar{n} \quad , \tag{2}$$

where n is the measured number in each bin and $\bar{n}$ is the predicted number in each bin. The normalization is fixed by

$$\sum n = \sum \bar{n} \tag{3}$$

since we are studying the shape only. We use only those p_T bins for all of the mass hypotheses for which we have a reliable prediction for each mass hypothesis. For example, if we include the hypothesis $M_t = 25$ GeV/c^2 and there are no isolated leptons with $p_T > 13$ GeV/c for that mass hypothesis, then for testing all hypotheses we would include only those bins $3 < p_T < 13$ GeV/c in the ln likelihood calculation.

The fake data for $M_t = 40$ GeV/c^2 compared with the predictions for $30 < M_t < 42.5$ GeV/c^2 are shown in Fig. 5 and the ln likelihood for each mass hypothesis is shown in Fig. 6. Note that even with only 512 events (83 isolated leptons with $3 < p_T < 15$ GeV/c), we can see a distinct difference in ln likelihood between the different mass hypotheses (0.5 unit of ln likelihood corresponds to one standard deviation difference in M_t). One would need to run more Monte Carlo data to map out the shape of the ln likelihood near the maximum. It looks as if one could measure M_t to $\pm \sim 1.5$ GeV/c^2 for $M_t \sim 40$ GeV/c^2 with a data sample of this size.

4.2. Measuring a Heavy Quark Mass from the Hadronic Jet Mass in Events with a Single Semileptonic Decay

The philosophy of this method is to select events in which one heavy quark decays hadronically and the other semileptonically. We selected events with an isolated lepton and four clusters and then formed the quantity

$$M_{Hadron} = \frac{E_{Beam}}{\gamma_{Measured}} \quad . \tag{4}$$

$\gamma_{Measured}$ is the γ of the resultant four-vector of the three clusters assumed to come from the hadronic decay of the heavy quark. This definition reduces the smearing due to varying amounts of missing energy. Additional cuts are made to ensure that the event topology is consistent with the hypothesis. Figure 7 shows the distribution of M_{Hadron} for $b'\bar{b}'$ with $M_{b'} = 40$ GeV/c^2.

5. Determining the Identity

If we find a signal for some type of new particle which seems to fit the criteria for heavy quark production, we have to establish its identity. The methods which we have considered are the following: (1) impact parameter analysis of the decay $Q \rightarrow q\bar{\ell}\nu X$, (2) measure the semileptonic inclusive branching ratios to establish that it is a heavy quark, (3) measure the $q\bar{q}$ forward-backward asymmetry using lepton tags, (4) explicitly rule out other possibilities such as heavy lepton or supersymmetry and (5) measure the momentum distribution of the lepton from the semileptonic decay.

We have not yet worked on measuring the semileptonic branching ratios; there are the obvious normalization difficulties discussed in Section 4. The other methods are described in the following Sections.

5.1. Impact Parameter Analysis of the Decay $Q \rightarrow q\bar{\ell}\nu X$

We can establish the identity of a new particle which decays into $q\bar{\ell}\nu X$ by examining the impact parameters of isolated high-p_T leptons and associated clusters. In Fig. 8 we show the impact parameter of the lepton *vs.* the impact parameter of the jet for various hypotheses for a 25 GeV/c^2 heavy quark. If the heavy quark is top, we would expect it to decay with a short lifetime into a B with a long lifetime. Therefore the impact parameter of the lepton would be small while the impact parameter of the jet would be large. If the new particle is a short-lived particle which decays into cW^-, both impact parameters would be small. If, on the other hand, the new particle is long-lived, both impact parameters would be large.

5.2. Measuring the $q\bar{q}$ Forward-Backward Asymmetry

The polar angle distribution for any fermion pair from Z^0 decay is given by

$$\frac{d\sigma}{d\cos\theta} = \frac{\pi\alpha^2}{2s}(1 + \cos^2\theta) + \frac{G_F^2 M_Z^4}{256\pi\Gamma_Z^2}\left[(v_e^2 + a_e^2)(v_f^2 + a_f^2)(1 + \cos^2\theta) + 8a_e v_e a_f v_f \cos\theta\right] , \qquad (5)$$

where α is the fine structure constant, s is the center-of-mass energy squared, G_F is the Fermi coupling constant, Γ_Z is the width of the Z^0, and $a_{e,f}$ and $v_{e,f}$ are the axial vector and vector weak coupling constants for the electron and fermion.

Integrating over cos θ for the forward and backward regions, we obtain the forward-backward asymmetry:

$$A_{FB} = \frac{3a_e v_e a_f v_f}{(a_e^2 + v_e^2)(a_f^2 + v_f^2)} \quad . \tag{6}$$

The forward-backward asymmetry can be used to distinguish between charge-1/3 and charge-2/3 quarks. The forward-backward asymmetry is 0.12 for the t quark and 0.17 for the b quark at the Z^0 peak (assuming $\sin^2\theta_W = 0.22$). These would be rather difficult to distinguish experimentally, except that the charge asymmetries of the leptons from the semileptonic decays have different signs. This happens because a top quark decays into a positively-charged lepton, whereas a bottom quark decays into a negatively-charged lepton. The $q\bar{q}$ forward-backward asymmetry may be reduced by the effects of the large quark mass or by other details of heavy quark meson production; nevertheless, it is an important physical measurement to make to establish the identity of the heavy quark.

We have used Monte Carlo simulations to study how to measure the $t\bar{t}$ forward-backward asymmetry for top masses as large as 40 GeV/c^2. One can measure a forward-backward asymmetry for the sphericity axis pointed in a hemisphere determined by the sign of the charge of the lepton from the top semileptonic decay, or one can measure a forward-backward charge asymmetry for the leptons directly. One must be careful to use cuts to ensure that the leptons come only from the top semileptonic decay since the major background is leptons from b-quark decays, which have the opposite asymmetry. We determined high-p and high-p_T cuts which give leptons which come from the top semileptonic decay 94% of the time for $M_t = 40$ GeV/c^2 (see Reference 5). In order to reduce the background from $udscb$ multihadronic events we also require that the leptons be isolated, as described in Section 3.3, which reduces the signal by 16%. Figures 9(a) and (b) show the cos θ distributions for the positively- and negatively-charged isolated high-p, p_T leptons from $t\bar{t}$ production at $M_t = 40$ GeV/c^2. (The reason for the depletion of leptons for $|\cos\theta| > 0.50$ is the lack of muon detection in that region.) The forward-backward asymmetry is a function of cos θ and is largest for large $|\cos\theta|$. Thus one can increase the sensitivity of the forward-backward asymmetry measurement simply by using only isolated high-p, p_T leptons with large $|\cos\theta|$. For example, for 10^5 $udscb$ multihadronic events one would have 230 isolated high-p, p_T

leptons with $|\cos\theta| \geq 0.44$ from 5120 $t\bar{t}$ events with $M_t = 40$ GeV/c^2 and would have a measured $A_{FB} = 0.112 \pm 0.066$, which would be compared with an expected negative asymmetry for a charge-1/3 quark. The background from *udscb* multihadronic events would be $\sim 9 \pm 9$ isolated high-p, p_T leptons. The forward-backward asymmetry measurement can be improved by using longitudinally polarized electrons which increase the forward-backward asymmetries for fermion pairs by factors of 3–5.

5.3. Measuring the Lepton Momentum Distribution

Another method for distinguishing between a charge-1/3 and charge-2/3 quark is a measurement of the momentum distribution of the leptons from semileptonic decays. This measurement is complicated by the effects of heavy quark polarization and spin correlation. Heavy quarks from Z^0 decay are produced with a high degree of longitudinal polarization, even if the beams are not polarized. However, depolarization[8] takes place in the process of fragmentation and decay. Figure 10 shows the energy spectra from t and b' quarks with and without polarization[10,11]. The average energy for a b' quark is significantly higher than for a t quark with no polarization, and the effect is increased with polarization.

6. Conclusions

Isolated leptons with $p_T > 3$ GeV/c appear to be the most background-free method for establishing a heavy quark signal. We should be able to establish a signal using this method with ~ 7000 Z^0's for heavy quark masses $\lesssim 43$ GeV/c^2. We can measure the quark mass to $\pm$ 1–2 GeV/c^2 with 10,000 Z^0's, depending on the value of the mass. We can average several methods if they are consistent with each other. With 10^5 Z^0's we can measure the mass to < 1 GeV/c^2.

With 10^5 Z^0's we should definitely be able to establish the identity of a new heavy-quark-like object, assuming we find something, using the following methods:

- Establish the decay $Q \rightarrow q\ell\nu X$ with an impact parameter analysis
- Measure the $q\bar{q}$ forward-backward asymmetry
- Measure the average momentum for isolated leptons.

But will there be any new heavy quarks with mass less than $M_Z/2$? Maybe there are four generations!

References

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Table 1. Top branching ratios.

Lund					
	$t\bar{q} \rightarrow$	$bu\bar{d}$	+	Spectator	33%
		$bc\bar{s}$	+	"	26%
		$ub\bar{d}$	+	"	4%
		$cb\bar{s}$	+	"	3%
		$be^+\nu_e$	+	"	12%
		$b\mu^+\nu_\mu$	+	"	12%
		$b\tau^+\nu_\tau$	+	"	10%
Webber					
	$t \rightarrow$	$bu\bar{d}$			1/3
		$bc\bar{s}$			1/3
		$be^+\nu_e$			1/9
		$b\mu^+\nu_\mu$			1/9
		$b\tau^+\nu_\tau$			1/9

Table 2. $t\bar{t}$ production cross sections for various top masses including first-order QCD corrections and a factor of 0.80 for QED radiative corrections.

M_t (GeV/c^2)	$t\bar{t}$ Production Cross Section (nb)
25	3.94
30	3.24
35	2.44
40	1.57
42.5	1.14
45	0.74
46	0.60

Table 3. Number of events with aplanarity > 0.12 for different multihadronic background models and for $t\bar{t}$ production for the different models and at various top masses normalized to the same number of Z^0's. QCD corrections were used for the $t\bar{t}$ cross sections. Error bars reflect the statistical errors of the Monte Carlo samples. 10,000 *udscb* events can be obtained in 38 days of running at a luminosity of 10^{29} cm^{-2} s^{-1}.

M_t (GeV/c^2)		Number of Events Produced	Number of Events with Aplanarity > 0.12
Background			
	Lund Order α_s^2	10,000 *udscb*	12 ± 3.5
	Lund Leading Log	(1.4 × 10^4 Z^0's)	37 ± 5.6
	Webber		76 ± 9.1
25	Lund Symmetric	1283	27 ± 6
	Lund Peterson		112 ± 12
	Webber		94 ± 7.8
30	Lund Symmetric	1058	71 ± 8.7
	Lund Peterson		138 ± 3.8
	Webber		126 ± 8.2
35	Lund Symmetric	795	129 ± 10
	Lund Peterson		147 ± 3.4
	Webber		132 ± 7.2
40	Lund Symmetric	512	108 ± 2.6
	Lund Peterson		116 ± 2.4
	Webber		112 ± 5.3
42.5	Lund Symmetric	372	79 ± 5.4
	Lund Peterson		84 ± 1.8
45	Lund Symmetric	240	40 ± 3.1
46	Lund Symmetric	195	29 ± 2.4

Table 4. Number of e's and μ's with $p_T > 3$ GeV/c relative to the thrust direction for various top masses and background models with no additional cuts, with aplanarity cut, and with isolation cut.

M_t (GeV/c^2)		Number of Events Produced	No Cuts $p_T > 3$ GeV/c	Aplanarity > 0.02 $p_T > 3$ GeV/c	Isolated ($\rho > 1.8$ GeV$^{1/2}$) $p_T > 3$ GeV/c
Background					
	Lund Order α_s^2	10,000 *udscb*	81 ± 9	16 ± 4	–
	Lund Leading Log	(1.4 × 10^4 Z^0's)	79 ± 8.2	42 ± 6.0	2.6 ± 1.5
	Webber		87 ± 9.8	46 ± 6.8	3.3 ± 1.9
	Lund Symmetric		325 ± 20	189 ± 16	177 ± 15
25	Lund Peterson	1283	344 ± 21	258 ± 18	145 ± 14
	Webber		307 ± 14	238 ± 5.8	121 ± 8.8
	Lund Symmetric		298 ± 18	222 ± 15	149 ± 13
30	Lund Peterson	1058	299 ± 5.6	239 ± 5.0	150 ± 4.0
	Webber		291 ± 12	231 ± 13	125 ± 8.1
	Lund Symmetric		230 ± 14	184 ± 12	109 ± 9.3
35	Lund Peterson	795	240 ± 4.4	203 ± 4.0	122 ± 3.1
	Webber		250 ± 10	206 ± 10	97 ± 6.2
	Lund Symmetric		150 ± 3.1	124 ± 2.8	76 ± 2.2
40	Lund Peterson	512	158 ± 2.8	137 ± 2.7	76 ± 2.0
	Webber		170 ± 6.5	141 ± 2.8	74 ± 4.3
42.5	Lund Symmetric	372	111 ± 6.4	93 ± 5.9	61 ± 4.7
	Lund Peterson		122 ± 2.1	107 ± 2.0	62 ± 1.5
45	Lund Symmetric	240	78 ± 4.4	65 ± 4.0	38 ± 3.1
46	Lund Symmetric	195	57 ± 3.3	44 ± 2.9	30 ± 2.4

Table 5. Hadron misidentification backgrounds for isolated leptons with $p_T > 3$ GeV/c. The numbers of isolated particles with $p_T > 3$ GeV/c are given for leptons from $t\bar{t}$, leptons from *udscb*, misidentified hadrons from $t\bar{t}$, and misidentified hadrons from *udscb* for 10,000 *udscb* events and the corresponding number of 512 $t\bar{t}$ events for $M_t = 40$ GeV/c^2. C is the probability that a hadron will be misidentified as an e or a μ.

	Isolated Leptons From $t\bar{t}$	Isolated Leptons From *udscb*	Isolated Hadrons From $t\bar{t} \times$ C	Isolated Hadrons From *udscb* $\times$ C
Electrons (C = 0.005)	49.0	2.6	0.1	0.2
Muons (C = 0.01)	22.4	0.0	0.1	0.2

Figure Captions

Fig. 1. Number of produced $t\bar{t}$ events for one year at a luminosity of 10^{30} cm^{-2} s^{-1} as a function of M_t without and with first-order QCD corrections. A factor of 0.80 for QED radiative corrections is included.

Fig. 2. Mark II Detector at the SLC.

Fig. 3. Multihadronic event with gluon radiation showing how the p_T of a lepton in a jet can be increased because the thrust axis is not along the jet direction.

Fig. 4. Isolation criterion for leptons with $p_T > 3$ GeV/c. Distribution of ρ (defined in text) for leptons with $p_T > 3$ GeV/c for 10,000 *udscb* events from the Lund leading log model and for 512 $t\bar{t}$ events with $M_t = 40$ GeV/c^2 from the Lund model with Peterson fragmentation.

Fig. 5. p_T distribution for isolated leptons from 512 $t\bar{t}$ events at $M_t = 40$ GeV/c^2 compared with predictions for $30 < M_t < 42.5$ GeV/c^2. There are 83 isolated leptons with $3 < p_T <$ 15 GeV/c.

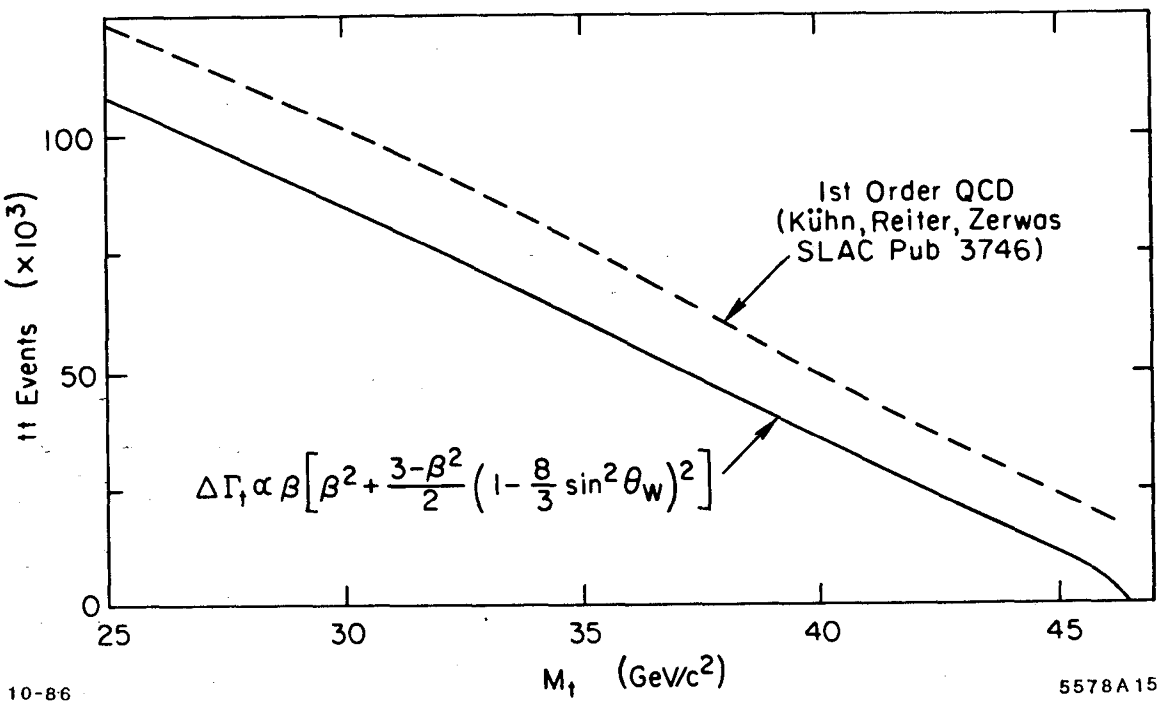
Fig. 6. The ln likelihood that each of four mass hypotheses fits the shape of the p_T distribution for the 512 $t\bar{t}$ events at $M_t = 40$ GeV/c^2 shown in Fig. 5. The dashed line is drawn 0.5 unit of ln likelihood lower than the largest ln likelihood of the four hypotheses.

Fig. 7. Distribution of M_{Hadron} for $b'\bar{b}'$ with $M_{b'} = 40$ GeV/c^2.

Fig. 8. Impact parameter of the lepton *vs.* impact parameter of the jet for various hypotheses for a 25 GeV/c^2 heavy quark.

Fig. 9. Cos θ distribution for (a) positively-charged isolated high-p, p_T e's and μ's and (b) negatively-charged isolated high-p, p_T e's and μ's for 50,438 $t\bar{t}$ events at $M_t = 40$ GeV/c^2.

Fig. 10. Energy distributions for electrons from semileptonic decays of (a) t quark and (b) b' quark with and without polarization. The mass of the heavy quark is 42.5 GeV/c^2, but there is little mass dependence.



100
50
0
25
30
35
40
45
$t\bar{t}$ Events (×10³)
M_t (GeV/c²)
1st Order QCD
(Kühn, Reiter, Zerwas
SLAC Pub 3746)
$\Delta\Gamma_t \propto \beta\left[\beta^2 + \frac{3-\beta^2}{2}\left(1 - \frac{8}{3}\sin^2\theta_W\right)^2\right]$
10-86
5578A15

Fig. 1

MARK II AT SLC

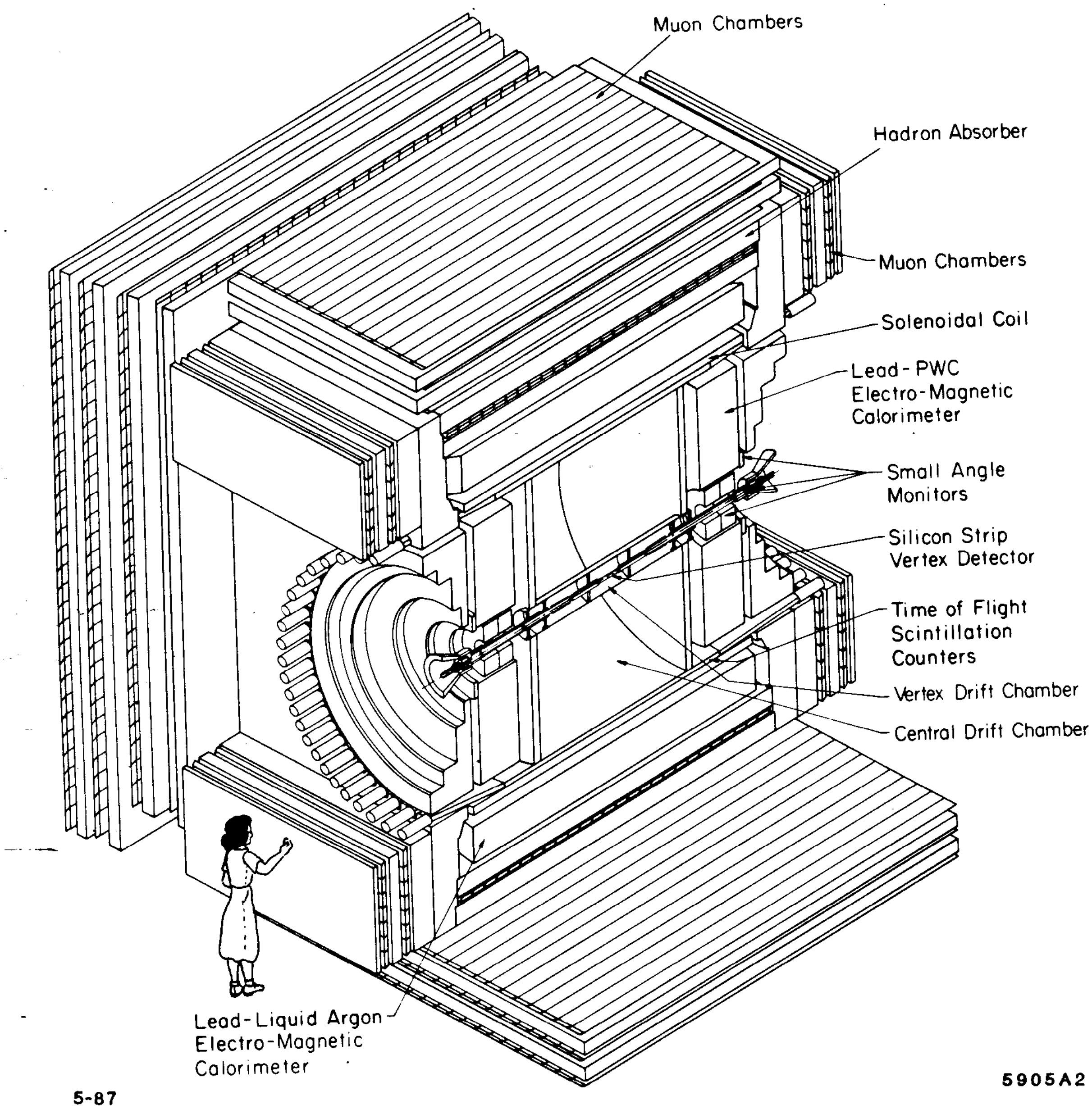


Fig. 2

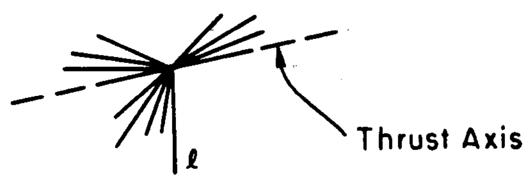
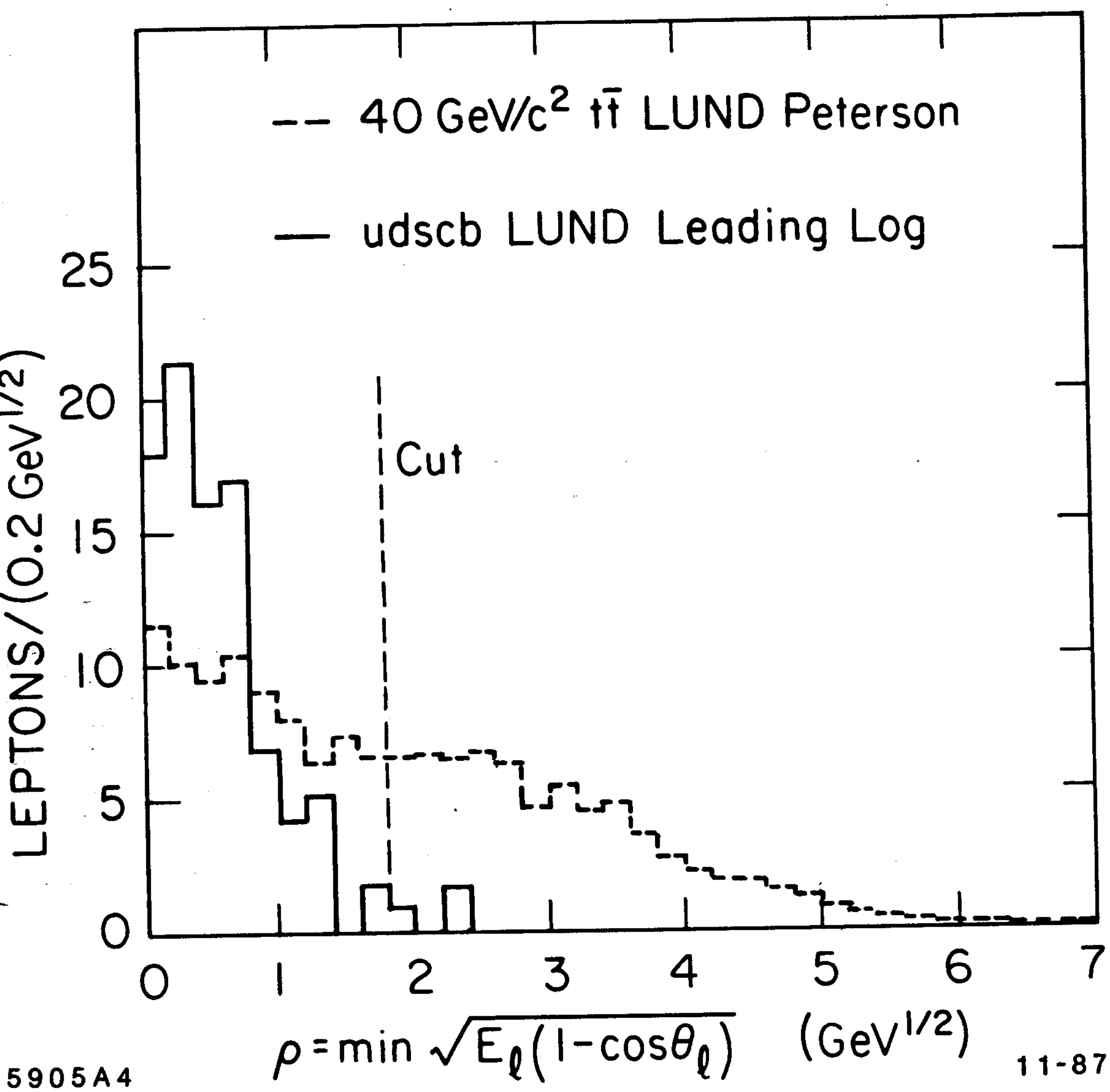


Fig. 3



-- 40 GeV/c² tt̄ LUND Peterson
— udscb LUND Leading Log
Cut
LEPTONS/(0.2 GeV^1/2)
0
5
10
15
20
25
0
1
2
3
4
5
6
7
ρ = min √(E_ℓ(1−cosθ_ℓ)) (GeV^1/2)
5905A4
11-87

Fig. 4

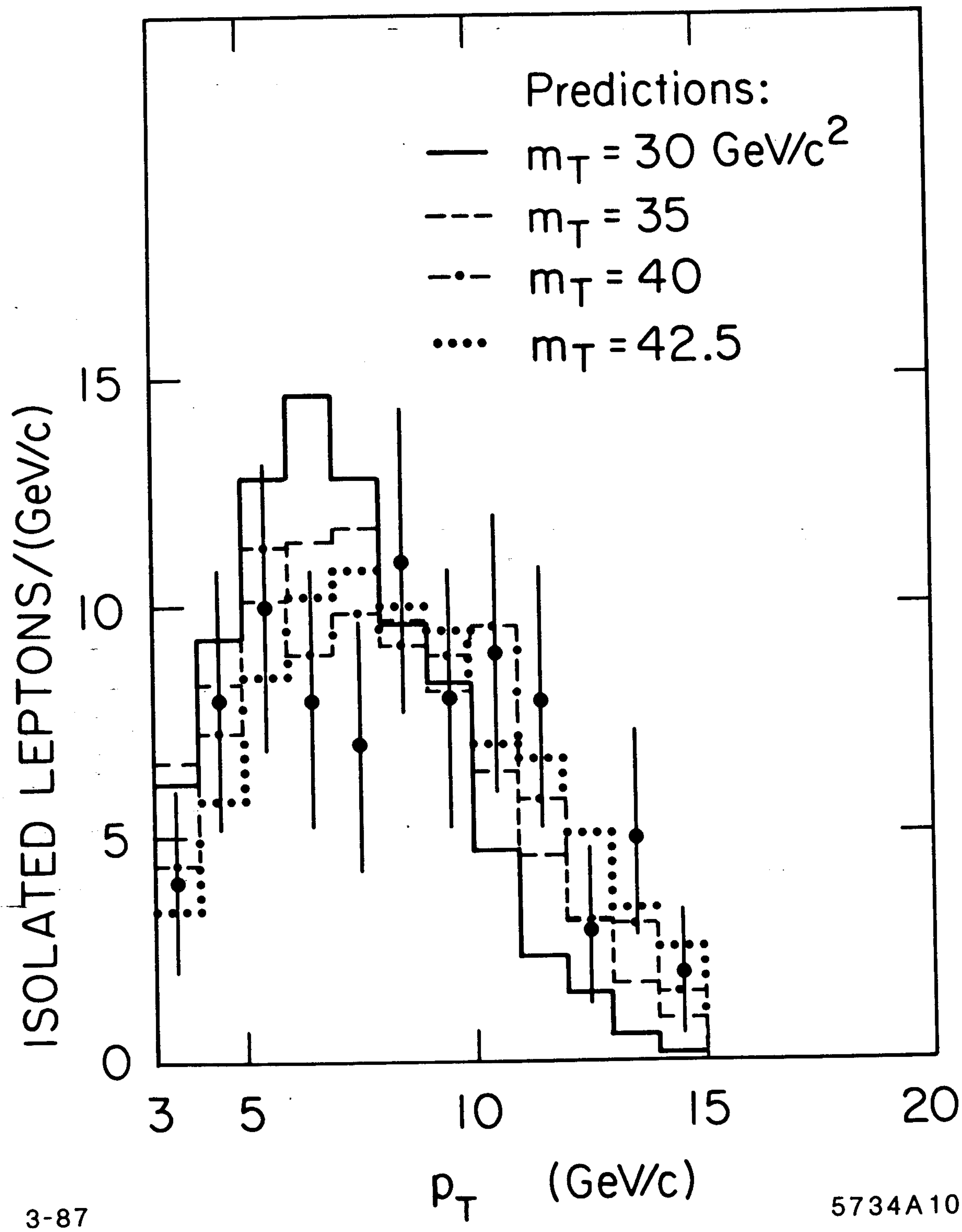
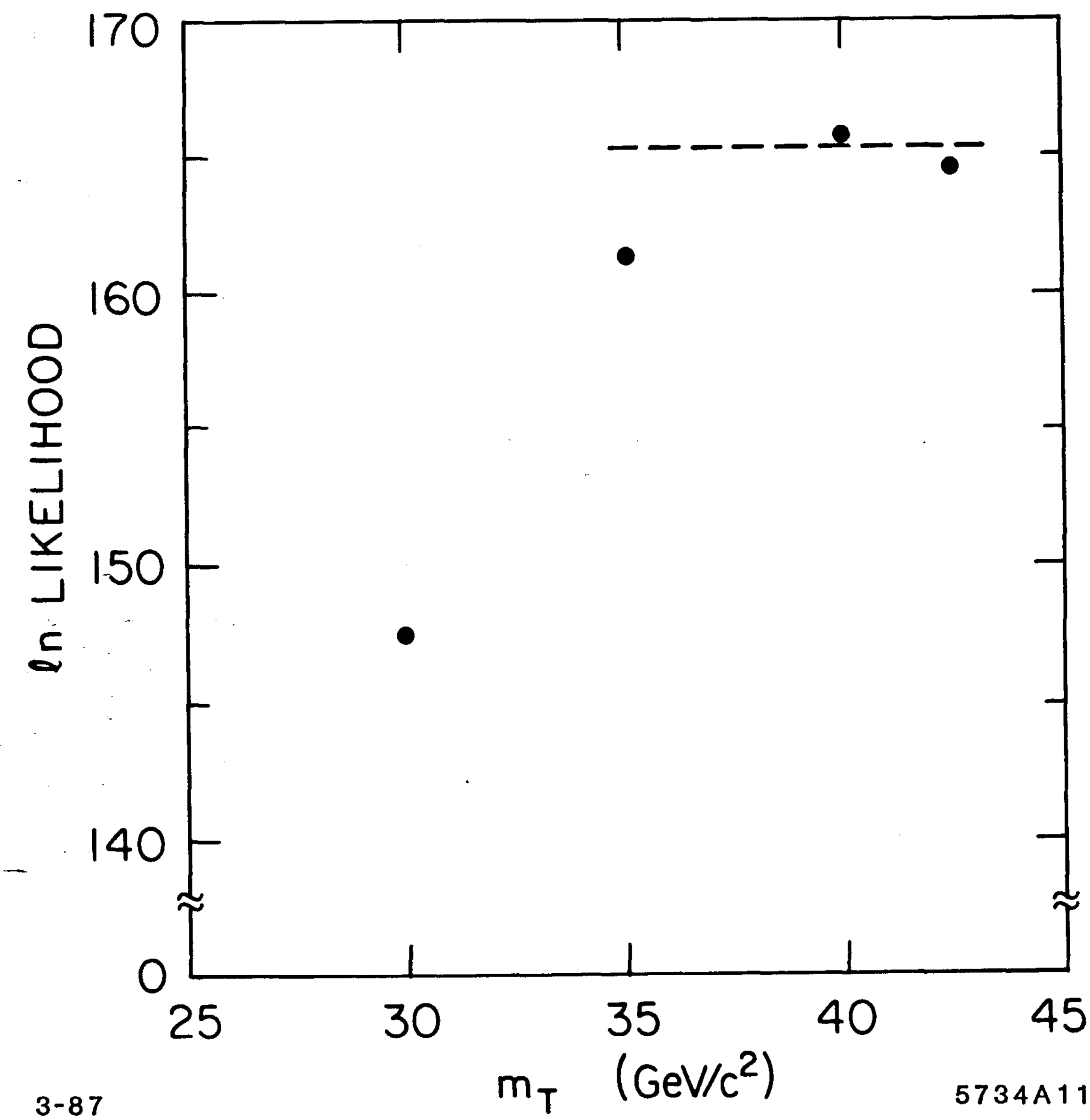
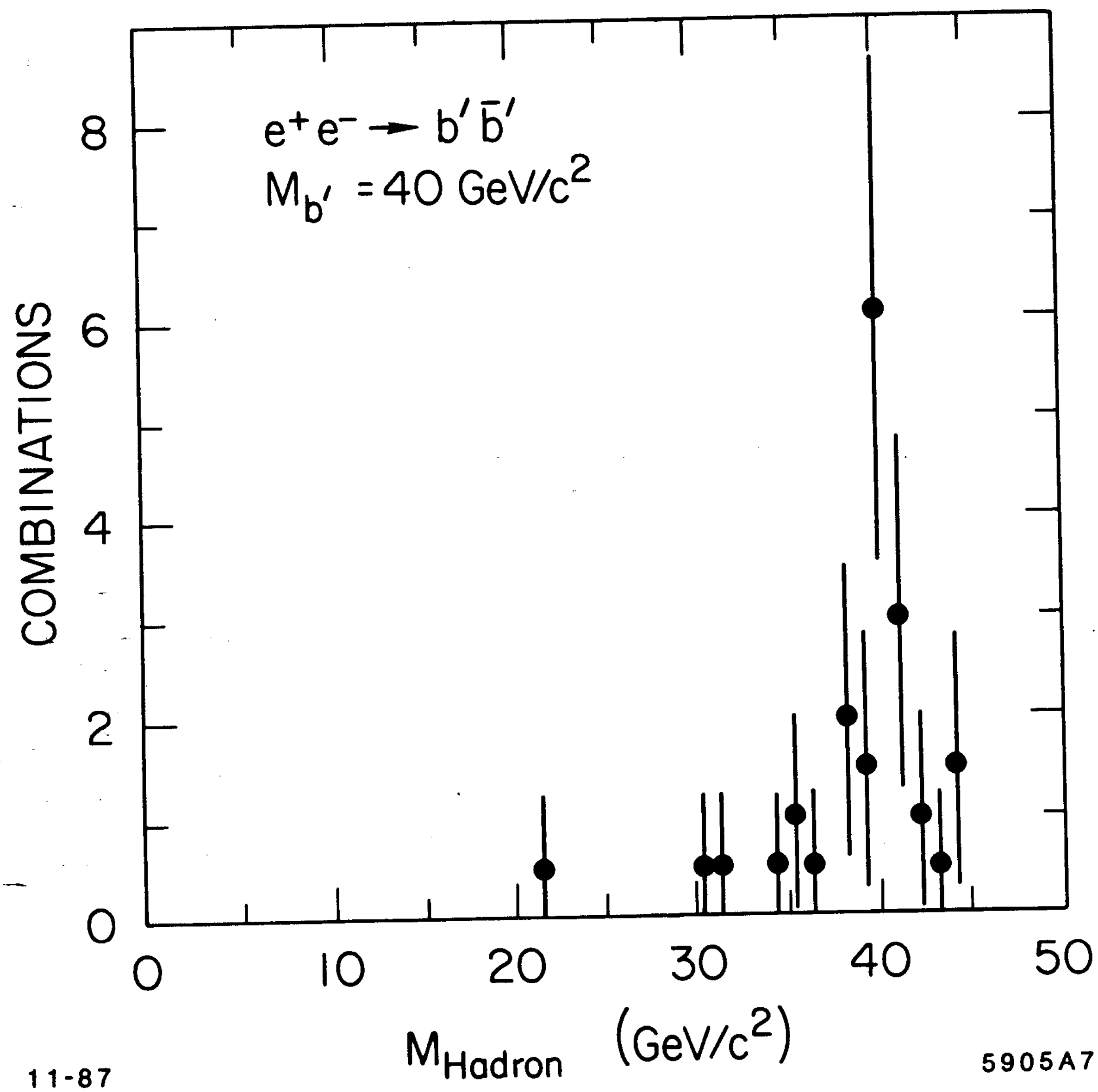

Predictions:
mT = 30 GeV/c2
mT = 35
mT = 40
mT = 42.5
ISOLATED LEPTONS/(GeV/c)
15
10
5
0
3
5
10
15
20
pT (GeV/c)
3-87
5734A10

Fig. 5



170
160
150
140
0
25
30
35
40
45
ln LIKELIHOOD
m_T (GeV/c^2)
3-87
5734A11

Fig. 6



e⁺e⁻ → b′b̄′
M_b′ = 40 GeV/c²
COMBINATIONS
0
2
4
6
8
0
10
20
30
40
50
M_Hadron (GeV/c²)
11-87
5905A7

Fig. 7

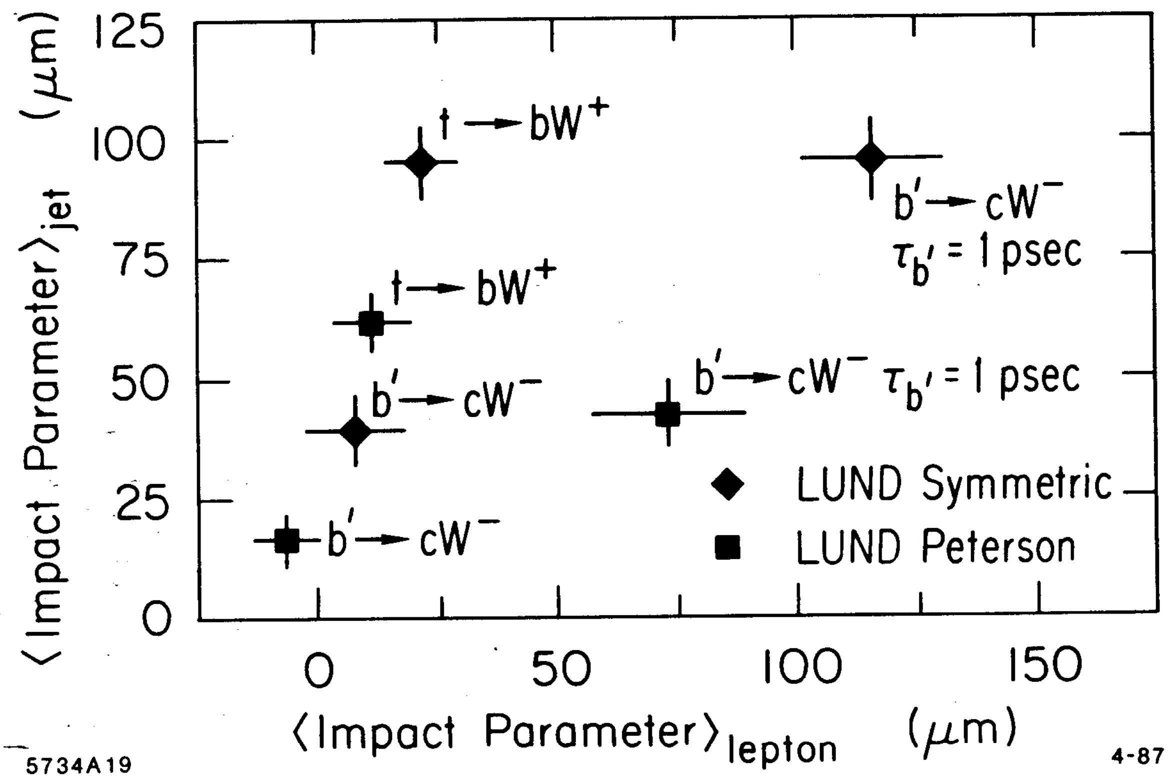

125
100
75
50
25
0
⟨Impact Parameter⟩jet (μm)
t → bW+
b′ → cW−
τb′ = 1 psec
t → bW+
b′ → cW− τb′ = 1 psec
b′ → cW−
LUND Symmetric
b′ → cW−
LUND Peterson
0
50
100
150
⟨Impact Parameter⟩lepton (μm)
5734A19
4-87

Fig. 8

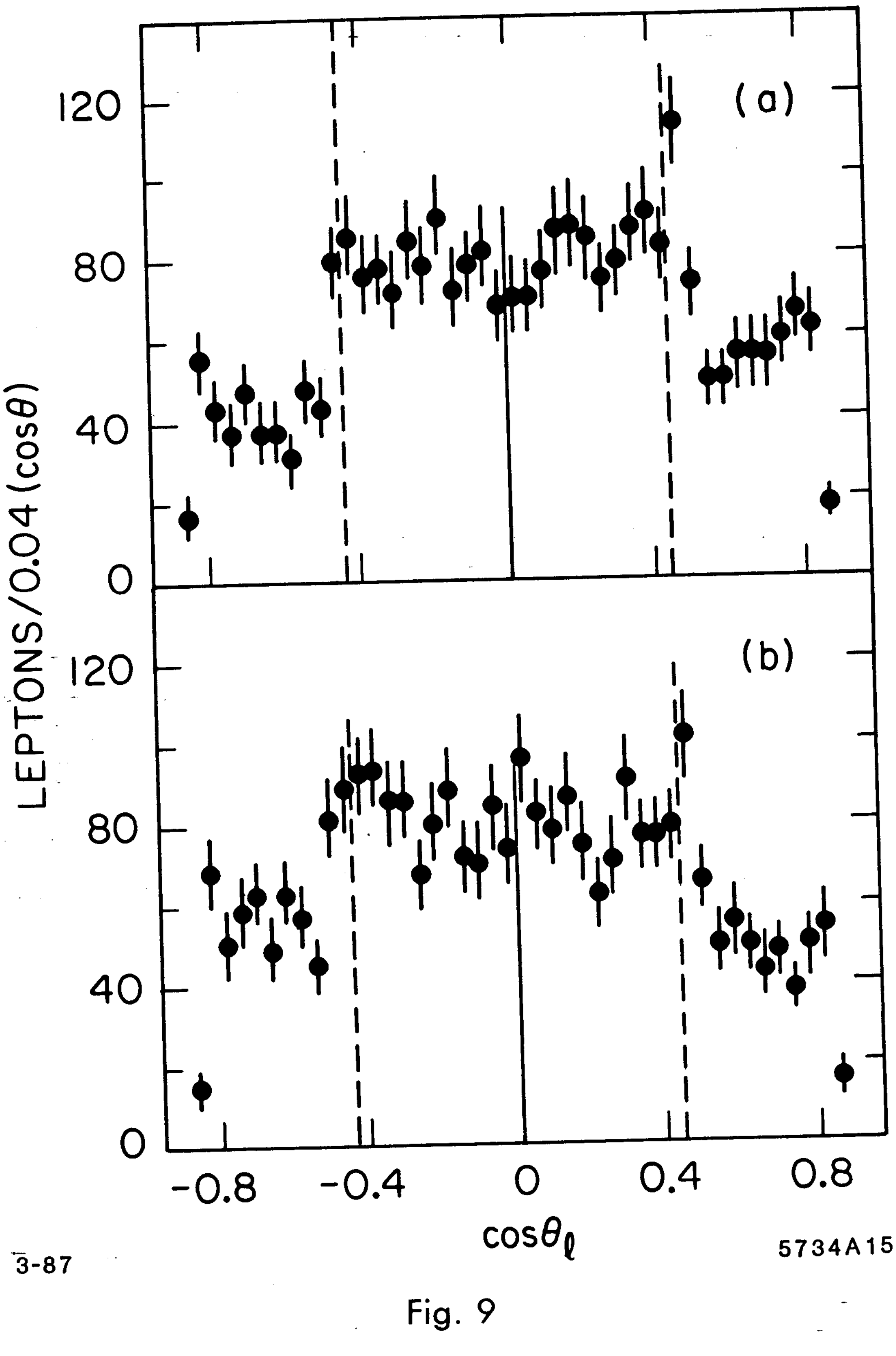
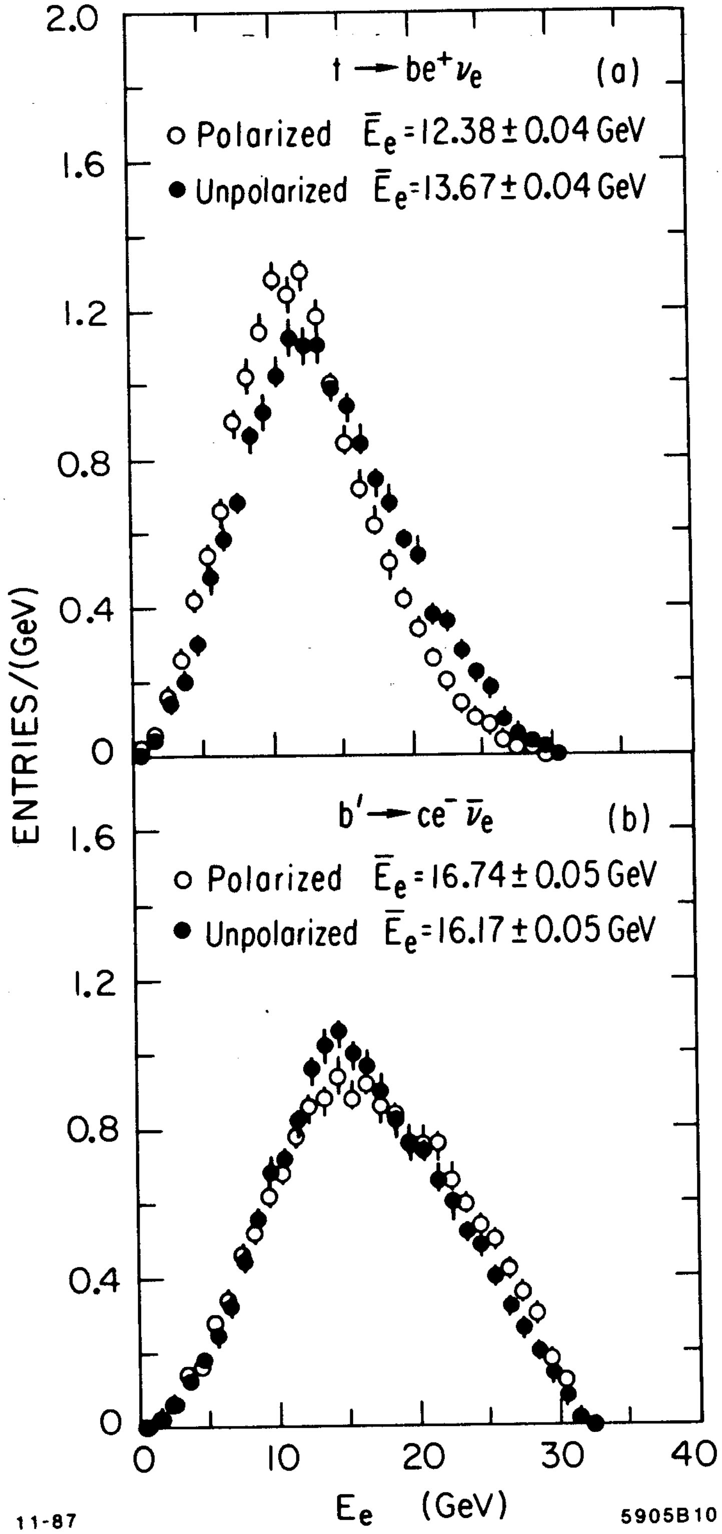


Fig. 9



2.0
1.6
1.2
0.8
0.4
0
$t \rightarrow be^+\nu_e$
(a)
○ Polarized $\bar{E}_e = 12.38 \pm 0.04$ GeV
● Unpolarized $\bar{E}_e = 13.67 \pm 0.04$ GeV
ENTRIES/(GeV)
1.6
1.2
0.8
0.4
0
$b' \rightarrow ce^- \bar{\nu}_e$
(b)
○ Polarized $\bar{E}_e = 16.74 \pm 0.05$ GeV
● Unpolarized $\bar{E}_e = 16.17 \pm 0.05$ GeV
0
10
20
30
40
E_e (GeV)
11-87
5905B10

Fig. 10