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RECENT RESULTS FROM

THE MAC AND MARK II DETECTORS AT PEP*

Jonathan Dorfan
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

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ABSTRACT

Data from PEP are presented for the MAC and MARK II detectors. All data are at a center-of-mass energy of 29 GeV and corresponds to a data set varying from 15-30 pb⁻¹. $R = \sigma_{\text{hadronic}}/\sigma_{\mu\mu}$ is presented by both groups, and inclusive momentum distributions $[S(d\sigma/dx)]$ for SPEAR and PEP energies are presented by the MARK II. The $S(d\sigma/dx)$ distributions exhibit sizeable scaling violations. Both groups have measured energy-energy correlations. The measurements yield $\alpha_s = 0.20 \pm 0.01 \pm 0.02$ (MAC) and $\alpha_s = 0.19 \pm 0.01 \pm 0.03$ (MARK II) where α_s is the strong coupling constant to first order. It is stressed however that this measurement of α_s is very sensitive to nonperturbative (fragmentation) effects. The MARK II group has observed a clean $D^{*\pm}$ signal from which they obtain $\sigma(D^{*\pm}) = 0.25 \pm 0.10$ as the cross section for producing a charged D^* at 29 GeV. The charm fragmentation function is measured and it appears to be fairly hard with an average fractional energy for the $D^{*\pm}$ of ~ 0.6 . The MAC group has measured the τ lifetime and finds a value $t_\tau = (4.9 \pm 2.0) \times 10^{-13}$ secs. The MARK II group has measured the τ branching fractions into one (B_1) and three ($B_3 = 1 - B_1$) charged prongs. They find $B_1 = (86 \pm 3 \pm 1)\%$. They also find $B_3 < 0.5\%$ at the 90% confidence level. Also presented from the MARK II group are limits on the production of charged scalar particles (Higgs or technipions; $H^\pm$) which couple to τ 's. For $2 < H^\pm \text{ mass} < 10 \text{ GeV}/c^2$, the branching fraction for $H^\pm$ to $d\bar{e} \nu_\tau$ is found to be less than 5% at the 90% confidence level.

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INTRODUCTION

The results presented below come from data taken at PEP by the MARK II and MAC detectors. The MARK II detector is well-known and a description of the detector can be found in Ref. 1. During the 1981 summer shutdown, the MARK II group removed their inner drift chamber and replaced it with a vertex detector. The vertex detector (fully described in Ref. 2) is a high-precision drift chamber which has four layers of axial wires clustered close to the beam axis at an average radius of 11 cm and three layers clustered at an average radius of 31 cm. The chamber construction and operating considerations have been chosen so as to achieve excellent spatial resolution. The chamber routinely achieves a spatial resolution (per layer) of $< 100 \mu$ and has been successfully incorporated into the detector trigger, software, et cetera. Because of a short in the Mark II coil, all data taken since January 1982 have half the normal magnetic field of 4.5 Kg. Fortunately the vertex chamber's impressive resolution all but salvages the lost momentum resolution due to the reduced field. Most of the MARK II data presented herein correspond to 14.5 pb^{-1} collected prior to the installation of the vertex detector or the short in the magnet. Some results, as noted in the text, are based on additional data with the vertex chamber and the reduced field. The Monte Carlo simulations for this new data incorporate the changes in the detector configuration.

The MAC detector, shown in Fig. 1, has excellent solid angle coverage for all process ($\pm 95\%$ of 4π). It provides good identification for photons, muons and electrons. In addition, with the strong

emphasis on both hadronic and electromagnetic calorimetry, good energy containment for hadronic events is achieved. A more complete description of the detector can be found in Ref. 3. Figure 2 attests to the excellent solid angle coverage of the MAC detector. The angular distribution of the thrust axis for multihadron events, not corrected for detector losses, is shown in comparison with the produced $1 + \cos^2\theta$ distribution. Full efficiency is achieved for $\cos\theta \leq 0.9$.

All the FEP data presented below were taken at $E_{c.m.} = 29$ GeV. Topics covered are the total hadronic cross section, inclusive momentum distributions, energy-energy correlations and thereby a measure of α_s , the observation of D^+ 's and a measurement of the charm fragmentation function, τ charged particle branching fractions, measurement of the τ lifetime and a search for charged, spin 0 scalars.

R, INCLUSIVE MOMENTUM DISTRIBUTIONS AND SCALING VIOLATIONS

The total hadronic cross section is an important quantity to measure since it potentially heralds the production of new particles. In addition it has been stressed many times⁴ that for QCD the evaluation of $R = \sigma_{hadron}/\sigma_{\mu\mu}$ is a 'gold-plated' calculation which can be trusted to all orders. The QCD correction to R (as calculated in the parton model) is $R = R_{parton} [1 + (\alpha_s/\pi)]$ or $R \sim R_{parton} \times 1.05$. If the systematics in the measurement of R can be held to $\leq 2\%$, a meaningful measurement of α_s could be obtained. So far this level of precision has not been achieved.

We present first the measurement of the MARK II group.⁵ The MARK II ran for about one and one-half years at SPEAR and included

in this writeup are a comparison between their data taken at SPEAR and at PEP. Because the detector was essentially unchanged on arrival at PEP, these measurements permit a comparison of $\bar{x}$ and inclusive momentum distributions using the same apparatus, software, et cetera, and spanning a large range of q^2 . In this way the relative systematics between the SPEAR and PEP energy range have effectively been reduced. Data from three center-of-mass energies ($E_{c.m.}$) 5.2 GeV (4160 nb⁻¹, SPEAR) 6.5 GeV (1630 nb⁻¹, SPEAR) and 29 GeV (13.5 pb⁻¹, PEP) are included in the analysis. The tracking efficiency for data taken at SPEAR is >99% and 95% at PEP where the higher track density is sometimes problematical. The hardware trigger required at least two particles to be within the central 65% of the detector solid angle. In addition a total energy trigger was developed at PEP which required at least 1 GeV of deposited energy in each of two liquid argon modules. Using the redundancy provided by this trigger for Bhabha events, the trigger efficiency was checked and found to be in excess of 99%.

For the SPEAR data, hadronic events were selected to have at least three charged particles with transverse momentum > 100 MeV/c and $|\cos\theta| < 0.79$. Good location with respect to the known position of the beam interaction point was required for the individual tracks. To eliminate background events not coming from the e^+e^- collisions, the vertex defined by the charged particles in the event was required to be consistent with the beam interaction point to within 10 cm along the beam direction and 4 cm radially. To remove contamination from radiative QED processes, events containing a track with momentum >900 MeV/c, identified as an electron by the liquid argon shower counters,

were removed. Events coming from the production and subsequent decay of τ 's were accounted for using a Monte Carlo simulation program. After the subtractions (summarized in Table I) there remained 44180 events at 5.2 GeV and 11900 events at 6.5 GeV.

For the PEP data at $E_{c.m.} = 29$ GeV hadronic events were selected to have at least five charged tracks as defined above. In addition, to suppress background from two-photon processes and beam gas interactions, cuts were made on the visible energy in the detector. These cuts isolate a very clean sample of hadronic events (see Table I). After the subtractions there remained 4750 events.

Detection efficiencies were obtained from Monte Carlo simulations based on the quark fragmentation model of Feynman and Field⁶ with extensions by Ali et al.,⁷ for gluon emission at high energies. With appropriate parameters these models provide a good description of the observed detector distributions. The charged particle detection efficiency as a function of x is shown in Fig. 3. Here x represents the fractional energy carried by the charged particle, where all particles are assumed to be pions. By varying the selection cuts and the model parameters and by comparing the results of the efficiency determination with those of two other models, the MARK II group has estimated a 4% systematic uncertainty in the efficiency determination at $E_{c.m.} = 29$ GeV and 4% (at low x) rising to 7% (at high x) systematic uncertainty for the two lower energies.

Corrections for initial state radiation, which results in an effective lowering of $E_{c.m.}$, were made using the method of Berends and Kleiss⁸ and are summarized in Table I. The experiment was normalized

using Bhabha events observed in the central detector. The uncertainty in this normalization is estimated to be $\pm 3\%$, mainly due to uncertainties in the α^3 radiative corrections.

The total systematic error in the inclusive cross sections is estimated to be $\pm 6\%$ at low x , rising to 10% at high x . The rise is due to the model dependence and the τ subtraction at SPEAR energies and due to uncertain tracking efficiency and momentum resolution effects at 29 GeV. For the measurement of R the nonradiatively corrected efficiencies are 0.80, 0.84 and 0.74 at 5.2 GeV, 6.5 GeV and 29 GeV, respectively. At all three energies the total systematic error in R is $\pm 6\%$.

The results for R are presented in Table II. We see that R (29 GeV) is consistent with the prediction of $R = 3.85$ from QCD and with the data from PETRA.⁹ The SPEAR data is also consistent with the low energy expectation of $R = 3.6$. The measurement at 29 GeV has sufficient precision to rule out the presence of the charged two-thirds t -quark ($R = 5.2$).

Consider now the measurement of the inclusive spectra $S(d\sigma/dx)$ as shown in Fig. 4. The relative systematics between the data at 5.2 GeV and 6.5 GeV are 2%; between the SPEAR data and the PEP data 5%. At small x (≤ 0.2) we see substantial differences in the three spectra but these are probably explained as finite mass effects. If scaling were sound we would expect $S(d\sigma/dx)$ to be independent of $E_{c.m.}$ for $x \geq 0.2$. Clearly this is not borne out by the data and sizeable scaling violations are observed — observations way outside the range of the systematic errors. One expects some scaling violations because of the emission,

at high energies, of gluons which will soften the momentum spectra. This agrees with the trend of the data, but it remains to be shown that the QCD perturbative effects can account for the magnitude of the violations. In Fig. 5 the same data are displayed and compared with the data of TASSO¹⁰ which cover the energy range $11 \text{ GeV} \leq E_{\text{c.m.}} \leq 36 \text{ GeV}$. The data have been normalized to the measured total cross section which compensates for differences in normalization and the effects of b quark production above 10 GeV. The agreement between the two experiments is gratifying.

We turn now to the measurement of R from the MAC detector group. Because of its large solid angle coverage and excellent energy containment, this detector is very well suited to the measurement of the total hadronic cross section. The data presented below correspond to an integrated luminosity of 25 pb^{-1} all at $E_{\text{c.m.}} = 29 \text{ GeV}$. MAC uses two different analysis procedures to obtain R. Both are discussed below. In order to reduce the background from the two photon process, two variables are formed:

$$\vec{\beta} = \frac{\sum_i E_i \vec{n}_i}{\sum_i E_i}$$

and

$$E_1 = \sum_i E_i \sin\theta_1$$

where i is the calorimeter energy parcel index, E_i the energy in the parcel which is at polar angle θ_i and direction $\vec{n}_i$. Multihadron (2γ) events are expected to have large (small) E_1 and small (large) $|\vec{\beta}|$.

The first analysis method uses the full acceptance of the detector, removes two-photon events with appropriate cuts and makes an efficiency correction based on a Monte Carlo simulation. The specific cuts used to isolate the 11,000 hadronic events are: at least three charged particles of scalar momentum sum ≥ 2 GeV/c, a visible energy of ≥ 12 GeV (see Fig. 6), $E_1 > 7.5$ GeV and $|\vec{\beta}| < 0.65$. Two photon contamination is reduced by rejecting events failing two or more of: visible energy > 15 GeV, $E_1 > 9.1$, or $|\vec{\beta}| < 0.55$. Figure 6 shows the response of the detector with the prediction of the Monte Carlo simulation program superposed on the data. Using this Monte Carlo, the detection efficiency, including the effects of initial state radiation, is obtained and found to be 82.6% of the radiatively corrected cross section ($1.32 \sigma_{\mu\mu}$).

Events from multibody decays on the τ are removed by scanning (three or four tracks) or subtracted statistically (> 4 tracks) using published branching ratios. The purity of the event sample is estimated to be $\sim 98\%$. The luminosity is obtained both from Bhabhas scattered into the central calorimeters ($\pm 3\%$) and the small angle luminosity monitor ($\pm 4\%$). As these two methods are found to be consistent within their errors, an average is used. Using this analysis procedure the MAC group measures

$$R = 3.93 \pm 0.04 \pm 0.17$$

where the first error is statistical and the second systematic. The systematic error has roughly equal contributions of 2.5% from the normalization, the efficiency determination and the radiative corrections. The last contribution is a theoretical problem and remains, for all experiments, the limiting systematic error in the measurement of R .

The second method used is what might be described as a 'bootstrap' since the corrections to the data for losses are obtained from the data itself. In order to obtain a stable 'bootstrap', a sharply defined fiducial volume, one which excludes the endcap regions of the detector, is used. The selection criteria, which isolate 6700 events, for this analysis are: at least five charged prongs, the (momentum) thrust axis must lie in the polar angle range of $55^\circ \rightarrow 125^\circ$ and at least 16 GeV of visible energy. Using a judicious choice of cuts, a test sample of strongly enhanced annihilation events (at least nine charged particles in the fiducial volume) is obtained from the data which permits a measure of the loss of true events with less than 16 GeV visible energy. Making these corrections, using a Monte Carlo simulation program to estimate the detection efficiency and background contamination, and obtaining the luminosity from Bhabhas scattered into the same fiducial volume as the hadronic sample yields

$$R = 3.87 \pm 0.05 \pm 0.17$$

in excellent agreement with the result obtained using the other method.

The conclusions one draws from these measurements are identical with those drawn earlier in this section based on the MARK II measurement. A charged $2/3$ -quark (t) is ruled out and the results are in good agreement with the predictions of QCD and all other measurements at PEP and PETRA.⁹

ENERGY-ENERGY CORRELATIONS

It is desirable to perform tests of QCD which are not strongly dependent on Monte Carlo simulations which, in themselves, embody QCD. Tests performed in which the detected data are compared with the Monte Carlo predictions can depend very strongly on the models used in the Monte Carlo programs. It is preferable to perform tests on quantities that can be calculated in the framework of QCD and can be measured directly in an experiment which requires only small corrections for detector biases. In this way the data stand on their own and should the theoretical predictions change (higher orders are included), valid comparisons are still possible with the data. Among such quantities the energy-energy correlation is particularly interesting because it does not require the selection of specific event topologies, such as three-jet events, nor does it depend on the definition of a jet axis. Both the MARK II¹¹ and MAC groups have made a high statistics study of the energy-energy correlation in the PEP hadronic events. This method looks at energy flow by considering the correlations in energy between particle pairs. We can define an energy-weighted cross section for observing the energy E in the phase space element $d\Omega$ and E' in $d\Omega'$ as

$$\frac{1}{\sigma_0} \frac{d}{d\Omega d\Omega'} = \frac{1}{N} \sum_N \sum_{\text{pairs}} \frac{E}{\sqrt{s}} \frac{E'}{\sqrt{s}} \quad (1)$$

The first sum ranges over the total number of events (N), the second over all pairs of particles in the phase space elements $d\Omega$ and $d\Omega'$. The total hadronic cross section is denoted σ_0 and $\sqrt{s} = E_{\text{c.m.}}$.

For the sake of further discussion we define χ to be the angle between the direction vector of the two particles entering the calculation of the cross section.

The cross section defined for hadrons in (1) has been calculated¹² for partons in the framework of first order perturbative QCD. The form of the cross section for partons is

$$\frac{1}{\sigma_0} \frac{d\sigma}{d\Omega d\Omega'} = \frac{3\alpha_s}{16\pi} \left[A(\chi, \alpha_s) (2 + \cos^2 \theta + \cos^2 \theta') + B(\chi, \alpha_s) (\cos \chi + \cos \theta \cos \theta') \right] \quad (2)$$

The functions A and B depend on only one angle, χ , and have been calculated to first order in α_s . They both vary linearly with α_s . The function A describes the correlation between a quark and an antiquark; B describes the correlation between a quark (antiquark) and a gluon. In each case the partons are characterized by the polar angles θ and θ' and the angle between them is χ . The explicit forms of A and B add little insight to this discussion and can be found in Ref. 12.

In order to make a meaningful comparison between the experimental cross section for hadrons, (3), and the theoretical prediction for partons, (4), we must account for the nonperturbative effects of fragmentation. This has the effect of augmenting the term A above. It has been calculated¹³ that this function has the form

$$A_{qf}(\chi) = \frac{C \langle p_{\perp} \rangle}{\sqrt{s} \sin^3 \chi} = \frac{A_0^q}{\sqrt{s} \sin^3 \chi} \quad (3)$$

Here $\langle p_{\perp} \rangle \sim .3$ GeV characterizes the average transverse momentum in the hadronization and C is a constant (~ 4) which is a measure of

the 'density' of hadrons in the fragmentation process. It is important to notice that A_{qf} is symmetric about $\chi = \pi/2$. This is expected since it arises from the symmetric two-jet final state. The first order perturbative cross section (4) has a singularity at $\chi = \pi$ which corresponds to a quark and antiquark becoming collinear with a soft gluon. There is a weaker singularity at $\chi = 0$ when a quark (antiquark) becomes collinear with a hard gluon. In the intermediate angular range ($30^\circ < \chi < 150^\circ$), where one is not dealing with correlations in the center of the jets, there is a pronounced asymmetry about $\chi = \pi/2$. This serves to distinguish the perturbative and nonperturbative contributions to the energy correlation.

The cross section (1) can be presented in an integral form where we sum over all external particle directions keeping the angle χ fixed. This yields the following cross section

$$\frac{1}{\sigma_0} \frac{dE}{d\cos\chi} = \frac{1}{\Delta\chi \cos\chi N} \sum_N \sum_{\text{pairs}} \frac{EE'}{s} \quad (4)$$

Simple selection cuts based on charged particle multiplicity and observed energy suffice to define the multihadron data sets for the two experiments. The MAC experiment uses only calorimetric energy in the evaluation of (4) and hence have excellent solid angle coverage. The MARK II group use charged particles tracked in the drift chamber and photons found in the liquid argon barrel calorimeters. Accordingly they apply a fiducial volume requirement of $|\cos\theta| < 0.7$ for any particle which enters the summation in (4). Figure 7 (MAC) and Fig. 8 (MARK II) show the measurement of $(1/\sigma_0)(dE/d\cos\chi)$. The normalization

for the two experiments do not agree because MAC had corrected for the effects of uninstrumented solid angle, while the MARK II group has integrated $(1/\alpha_0)(dI/d\cos\chi)$ only over the specified fiducial volume, thereby keeping its corrections small. In both cases the theoretical predictions using (3) and (4) do a poor job of fitting the observed spectra. This was first noted by the MARK II group¹¹ who pointed out that the theory was missing an important contribution to $(1/\alpha_0)(dI/d\cos\chi)$ — namely the effects of gluon fragmentation. Physically such a term will spread the correlations at $\chi = 0$ to larger χ . In addition such a term will be inherently asymmetric about $\chi = 90^\circ$ because for three jet events there is no jet at 180° . So the MARK II suggested the following ansatz for gluon fragmentation [cf. (3)]

$$\begin{aligned} A_{gf}(\chi) &= \alpha_s \frac{A_0^g}{\sqrt{s} \sin^3 \chi} \quad , \quad \text{for } \chi < 90^\circ \\ &= \alpha_s \frac{A_0^g}{\sqrt{s}} (1 + \cos\chi) \quad , \quad \text{for } \chi > 90^\circ \end{aligned} \quad (5)$$

The rationale for this ansatz is simple: for $\chi < 90^\circ$ one expects a form similar to that for quarks while for $\chi > 90^\circ$ all one needs is a smooth analytic continuation to $A_{gf}(\chi) = 0$ at $\chi = 180^\circ$. The MAC group have adopted this ansatz with the trivial (i.e., it doesn't matter) change of $(1 + \cos\chi) \rightarrow \sin\chi$ for $\chi > 90^\circ$.

Addition of (5) gives an excellent fit to both the MAC and the MARK II data (see Figs. 7 and 8). Omission of (5) changes the χ^2 for the overall fit by a factor of ~ 9 for MAC and a factor of ~ 2 for the MARK II. The results of the fits are:

$$\text{MAC} \left\{ \begin{array}{l} \alpha_s = 0.20 \pm 0.01 \pm 0.02 \\ A_0^q = (1.2 \pm 0.08 \pm 0.15) \text{ GeV} \\ A_0^g = (2.5 \pm 0.2 \pm 0.4) \text{ GeV} \end{array} \right.$$

and

$$\text{MARK II} \left\{ \begin{array}{l} \alpha_s = 0.19 \pm 0.02 \pm 0.03 \\ A_0^q = (0.7 \pm 0.2) \text{ GeV} \\ A_0^g = (2.5 \pm 0.5) \text{ GeV} \end{array} \right.$$

The agreement between the two fits is striking. The systematic errors in α_s come from the uncertain effects introduced by fragmentation.

Both groups wish to stress that this measurement of α_s is strongly dependent on fragmentation effects. The asymmetry introduced by gluon fragmentation limit, in a very real way, the sensitivity of this measurement to α_s . This is contrary to the original expectations based on (3) and (4) which implied that any asymmetry seen in $(1/\sigma_0)(d\mathcal{L}/d\cos\chi)$ would be mostly due to gluon bremsstrahlung. We should also point out that the α_s obtained above is good only to first order in perturbation theory.

THE PRODUCTION OF D^{*} 'S; THE CHARM FRAGMENTATION FUNCTION

Heavy quark fragmentation functions are of great practical and theoretical interest. Direct measurements of the charm fragmentation functions, performed using D 's at SPEAR,¹⁴ have been limited to large

values of Z , where Z is the fractional energy of the detected D ($Z = E_D/E_{\text{beam}}$). With $Z \geq 0.6$ only a small portion of the fragmentation function, $S(d\sigma/dZ)$, was accessible. But with the observation by the MARK II group¹⁵ of D^* 's at FEP, all $Z \geq 0.14$ are kinematically accessible and a much clearer picture of the charm fragmentation function emerges. In fact the implication of the fits to the low energy data was that charm fragmentation functions could be parametrized like light quark fragmentation functions, namely $S(d\sigma/dZ) \sim (1 - Z)^n$. The D^* data from FEP imply that this is not the case—indeed the $\langle Z \rangle$ appears to be 0.6.

For this analysis¹⁵ the MARK II group have used 30 pb^{-1} which comprises most of their data logged to date. Multihadron events are selected in the usual fashion by requiring at least five charged particles and a reasonable large ($\geq 25\%$) observed energy fraction. Events are sought which are consistent with the production chain

The observed particles are therefore the $K^\mp$, $\pi^\pm$ and $\pi^\pm$. Because of the high momentum of the decay secondaries, the time-of-flight (TOF) system is not adequate to do positive particle identification. However consistency with the TOF measurements was required—particles with inconsistent mass assignments (within $\sim 2\sigma$, $\sigma \approx 360 \text{ psecs}$) were not included in the appropriate mass combinations. The invariant mass of all $K^\mp \pi^\pm$ combinations is shown in Fig. 9, split into two bands [9(a,b)] of

$Z = 2(E_D/E_{c.m.})$. Although there is no signal seen in the region of the D^0 ($m_{D^0} = 1.863 \text{ GeV}/c^2$), mass combinations in the region of the D^0 were selected as D^0 candidates, and the two tracks were kinematically fit to the D^0 mass. (Mass combinations with poor χ^2 were rejected) The D^0 mass window was chosen as $1.80 \leq M_{K\pi} \leq 1.93 \text{ GeV}/c^2$ for the data with full magnetic field and no vertex chamber; $1.76 \leq M_{K\pi} < 1.96 \text{ GeV}/c^2$ for the data with half field and the vertex chamber. The D^0 candidates were then combined with an additional pion whose charge was opposite to that of the kaon. The $D^{*+} - D^0$ mass difference is plotted in Fig. 10 for two bands of $Z = 2(E_D^*/E_{c.m.})$. The restrictive kinematics of the D^{*+} decay give it a signal to noise background advantage over the D decay of two orders of magnitude and a clear D^* peak is seen for $Z > 0.4$. For $0.2 \leq Z \leq 0.4$ there is no obvious signal. The observed width of the D^{*+} ($1-2 \text{ MeV}/c^2$) is consistent with that expected from experimental resolution alone. The $D^{*+} - D^0$ mass difference was determined to be $145.5 \pm 0.5 \text{ MeV}/c^2$ and is in good agreement with the world average of $145.5 \pm 0.3 \text{ MeV}/c^2$.

In order to obtain $S(ds/dZ)$, D^{*+} events were selected as those having a mass difference of $144-147 \text{ MeV}/c^2$ and a background subtraction and efficiency correction were applied to the data. As a consistency check on the analysis the $K\pi$ mass spectrum is shown in Fig. 9(c) for events having a mass difference in the range $144-147 \text{ MeV}/c^2$. One sees a clear D^0 signal.

The background contribution to the D^{*+} signal is estimated by extrapolation of the data in the mass difference plot outside the signal region and also by studying the sidebands of the $K\pi$ mass plot. A total

of 30 events are found with $Z > 0.4$ with an estimated background of four events. For $Z < 0.2$ the events are consistent with being entirely due to background. The detection efficiency for observing the $D^{*\pm}$ was obtained using a Monte Carlo simulation program and is constant at 25% for $Z > 0.2$. The background subtracted signal, corrected for detection inefficiency, corresponds to a cross section for the production of $D^{*\pm}$ of

$$\sigma(D^{*\pm}) = 0.25 \pm 0.10 \text{ nb}^{-1}.$$

For this cross section we have used¹⁶ $B(D^0 \rightarrow K^+ \pi^-) = (3.0 \pm 0.6)\%$ and $B(D^{*\pm} \rightarrow D^0 \pi^\pm) = (44 \pm 10)\%$. We note that while the error is large for $\sigma(D^{*\pm})$ (dominated by the errors in the branching fractions), this cross section ($\sigma_{\text{uu}} = 0.1 \text{ nb}$) more than saturates the total charm expectation. (The MARK II group expects that the contamination from b's is less than 20%.) The corrected fragmentation function is shown in Fig. 11. The average Z is 0.59 ± 0.06 for $Z > 0.2$. The data favor a charm fragmentation function which is peaked at intermediate values of Z and which seems inconsistent with a fragmentation function falling with $Z[10(1-Z)^n]$. In fact the recently suggested form¹⁷ of

$$\frac{d\sigma}{dz} \sim \frac{1}{z \left[1 - z - \frac{\epsilon}{1-z} \right]^2}$$

accounts very well for the data if $\epsilon \approx 0.3$.

MEASUREMENT OF THE LIFETIME OF THE HEAVY LEPTON

A measurement of the τ lifetime is a direct determination of the strength of the coupling of the τ to the charged weak current. In the

standard model (μ - τ universality) one predicts

$$\tau_{\tau} = \left(\frac{M_{\mu}}{M_{\tau}} \right)^5 \tau_{\mu} B_{\tau} = (2.8 \pm 0.2) \times 10^{-13} \text{ secs}$$

for $B_{\tau} = 17.6 \pm 1.6$. Heavy leptons produced at $E_{\text{c.m.}} = 29 \text{ GeV}$ will therefore have an average flight path of 700 μ . The MAC group has measured the τ lifetime using the distribution of vertices coming from τ three-prong decays.

The data reported here correspond to an integrated luminosity of 16.9 pb^{-1} , of which 15 pb^{-1} were taken at $E_{\text{c.m.}} = 29 \text{ GeV}$ and the remainder were taken at $E_{\text{c.m.}} = 28 \text{ GeV}$. A comprehensive report on this measurement can be found in Reference 19. Events selected to have at least four charged particles and sphericity²⁰ less than 0.1 were divided into two jets by the plane perpendicular to the sphericity axis. One jet was required to have three charged particles. In all cases tracks consistent with coming from photon conversions in the beam pipe were removed. Each triplet of tracks was required to have a net charge of ± 1 . The three prong decay candidates were required to have well measured tracks defined by at least seven drift chamber hits per track and a χ^2 for the vertex fit of less than 15 for three degrees of freedom. The sample thereby selected has background arising from:

- (1) Bhabha electron pairs with an additional pair of tracks from a conversion of a radiated photon, (2) beam gas interactions, (3) multihadron four- and six-prong events, (4) production via the two-photon process of $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$ and $e^+e^- \rightarrow e^+e^- + \text{hadrons}$.

Requiring that (a) the total calorimetric energy be less than 24 GeV (electromagnetic equivalent) removes radiative Shabha events; (b) the charged particle sphericity be less than 0.03 retains most of the τ -pairs but removes a large fraction of the beam gas and two photon background; (c) the total momentum of the triplet be greater than 4 GeV/c discriminates further against two-photon τ -pair production and (4) the larger of the two-jet invariant masses, as determined from energy-flow in the calorimeters, be less than 4.5 GeV/c removes contamination from hadronic events.

There are 135 events which pass the above criteria. The events contain 139 three-prong decays. Using Monte Carlo simulations, the background is estimated to be seven events from multihadrons and one event from $e^+e^- \rightarrow e^+e^-\tau^+\tau^-$. For the selected events, distributions like total energy, total charged particle energy, individual track momenta, three-prong mass, etc., have been compared with the expectations for τ -pair production, and in all cases the agreement is good. As an example, Fig. 12 shows a comparison between the data and the Monte Carlo simulation program for the total charged particle momentum.

A χ^2 minimization is done to find the best common vertex position for the three decay prongs. Using the measured beam interaction point, the τ decay length is obtained. The vertex finding is done in the plane perpendicular to the beam direction and this transverse length is then projected onto the triplet momentum vector. This momentum vector reproduces, within a few degrees, the parent τ direction. The coordinates of the beam interaction point are found on a run-by-run basis using Shabha scattering events recorded simultaneously with the

τ -pair data. Figure 13 shows the distribution of the flight path error. Events with errors larger than 8mm are excluded.

The decay path distribution is shown in Fig. 14. In Figure 14(a) each event enters with unit weight, while in Fig. 14(b) the events are weighted inversely as the square of the decay path error. In both Figs. 14(a) and 14(b) there is a clear indication of a finite, positive flight path and, although the resolution for the decay length, l , is larger than l , the value of l can be deduced from the mean in the distributions 14(a) and 14(b). The data can be treated as the result of the convolution of an exponential decay length distribution with the experimental resolution function. If x_b is a possible bias in the mean value obtained from the experimental resolution function then

$$l = \langle x \rangle - x_b$$

$$\sigma_l = \frac{\sigma_x^2 - l^2}{N}$$

where $\langle x \rangle$ and σ_x are the mean and standard deviation of the observed distribution, σ_l is the error in the decay path and N is the number of events.

A Monte Carlo simulation for τ 's with zero lifetime is used to determine the experimental resolution function. It does exhibit a nonzero bias as given in Table II, for both the weighted and unweighted events. This bias is attributed to the χ^2 vertex fitting procedure which computes a weighted average of the intersection points of three pairs of tracks. The weight assigned to each intersection decreases with the distance from the measured track points, which results in a bias of the triplet vertex towards these points.

Referring to Table II we see that the τ corrected (for bias) flight path obtained from the two methods agree well and that indeed a net positive result is obtained.

As a further check on the analysis procedure, a set of τ -like events are constructed from multihadron events observed in the detector. Random triplets were chosen whose kinematics mimicked, as closely as possible, that of the τ 's. The decay path distributions for these events are shown in Fig. 15 and the mean values are entered in Table II under the heading of 'control sample'. Also shown in the Table are the estimate of the bias which is obtained from the Monte Carlo simulation in which decays of hadrons are suppressed. By subtraction then, one obtains the effective path length for the pseudo- τ sample which can be compared with the expectation for μ - τ decays which is obtained (last entry in the Table) by setting the drift chamber resolution to zero in the Monte Carlo. From the control sample one sees that agreement at the 200-300 μ level is obtained and based on this a 300 μ systematic error is assigned to the measurement of L . This error is incorporated in the error quoted below.

Using the weighted mean from Table II one finds

$$\tau_{\tau} = (4.9 \pm 2.0) \times 10^{-13} \text{ secs}$$

which is consistent with the expectation for μ - τ universality. This result can be compared with the results of the MARK II group²¹

$\tau_{\tau} = (4.6 \pm 1.9) \times 10^{-13}$ secs and the TASSO group¹⁴ $\tau_{\tau} = (-0.25 \pm 3.5) \times 10^{-13}$ secs.

MEASUREMENT OF THE τ DECAY CHARGED PARTICLE MULTIPLICITY

The τ is unique amongst the charged lepton family because it is sufficiently heavy to decay into hadrons. Since these decays are mediated by the $W^\pm$, they permit a study of low energy weak interaction theories. The striking feature of the τ hadronic decays is the low observed charged multiplicity. In addition to the theoretical interest, knowledge of the τ hadronic decay branching fractions is of practical interest for the design and interpretation of experiments.

The MARK II group has made a study of these branching ratios using their FEP data. Because of the low multiplicities involved in the

decays, simple topological cuts isolate a clear sample of τ decays. This should be contrasted with the studies done at low energies (SPEAR, DORIS) where there was substantial overlap between the hadronic events and the multibody τ hadronic decays. The data comprises 26.7 pb^{-1} all at $E_{\text{c.m.}} = 29 \text{ GeV}$. 14.5 pb^{-1} are with full magnetic field and no vertex chamber and the rest were taken with half field and the vertex chamber installed. With the addition of the vertex chamber, the amount of material preceding the main drift chamber dropped from 10% rl to 3% rl . To reduce the systematic errors due to the uncertainties in the individual τ branching fractions, events are selected on the basis of topological cuts as summarized below. All events are divided into two groups by a plane perpendicular to the thrust axis.²³

Candidate τ events are selected according to:

- (1) there is at least one charged particle in each group,
- (2) each group has an invariant mass (including photons) $< 2 \text{ GeV}/c^2$.

- (3) total energy (charged particles + photons) $\geq E_{c.m.}/4$,
- (4) all the charged particles in at least one group have momentum $< 8 \text{ GeV}/c$ (μ -pair).
- (5) the highest momentum particle in at least one of the groups has momentum above $2 \text{ GeV}/c$, enters the liquid argon fiducial volume, and deposits an energy less than 30% of its momentum (Bhabha),
- (6) both groups cannot contain exactly one charged particle that is a muon with momentum above $2 \text{ GeV}/c$ ($e^+e^- \mu^+\mu^-$),
- (7) for the highest momentum particle in each group, the TOF is within 3 ns of the expected time (cosmic rays),
- (8) the difference in total charge between the two groups is not zero, and,
- (9) the acollinearity angle between the total momenta of the two groups is $< 50^\circ$.

These selection criteria leave 944 τ -pair candidate events, which correspond to 973 events when corrected for trigger efficiency (99%) and time-of-flight (TOF) efficiency (98%). Criteria (1), (2), (8) and (9) select the general τ -pair topology, and criteria (3) - (7) reduce the background contamination. The final states listed in parenthesis above are the primary background rejected by that criteria.

The observed τ decay multiplicities and calculated backgrounds are shown in Table III. The data is divided into two groups according to the amount of radiator which precedes the main drift chamber. The background contributions have been obtained from Monte Carlo simulations and the fraction of background relative to the signal is 0.4% from $e^+e^- \rightarrow e^+e^-$, 1.9% from $e^+e^- \rightarrow \mu^+\mu^-$, 5.9% from $e^+e^- \rightarrow \text{hadrons}$,

4.1% from $e^+e^- \rightarrow e^+e^- \nu^+ \mu^-$ and 1.0% from $e^+e^- \rightarrow e^+e^- \tau^+ \tau^-$. There are ten τ candidates with five charged prongs. From photon conversions in 1- and 3-prong decays, ten events are expected in the 5-prong category. Verification of this comes from the fact that in eight of the ten 5-prong decays, there are two oppositely charged prongs which have an invariant mass $< 50 \text{ MeV}/c^2$ when the particles are assigned electron masses. Based on the two remaining candidates the MARK II group is able to set a limit $B_5 = B(\tau \rightarrow 5 \text{ charged prongs}) < 0.5\%$ (95% confidence level). The TASSO²⁴ group placed an upper limit on B_5 of 6%. The MAC detector group have reported²⁵ a 95% confidence upper limit of $B_5 < 0.7\%$. The CELLO group at PETRA²⁶ have a signal in the 5-prong category and quote a result of $B_5 = (1.0 \pm 0.4)\%$.

The produced τ decay multiplicity is determined from the observed 1-, 2- and 3-prong distribution by the unfold method.²⁷ In this method the observed multiplicity distribution is related to the produced distribution via a matrix which is obtained from the Monte Carlo simulation program. It is also assumed that the produced events contain only 1- and 3-prong decays. The result of the unfold method is

$$B_1 = 1 - B_3 = (86.0 \pm 1.5 \pm 1.0)\%$$

where the first error is statistical and the second is systematic. The result agrees well with the PEP and PETRA results of MAC,²⁵

$$B_1 = (84.7 \pm 3.5 \pm 1.0)\%, \text{ TASSO}^{24} \quad B_1 = (76 \pm 6)\%, \text{ and CELLO}^{26}$$

$B_1 = (84 \pm 2)\%$. A world average²⁸ of data from SPEAR and DORIS imply $B_1 = (68 \pm 10)\%$. As was pointed out earlier the possible discrepancy between this low energy result and that of the PEP and PETRA experiments

is most probably due to the difficulty with isolating the 3-prong decays at low energies.

SEARCH FOR CHARGED, SPIN 0 SCALAR PARTICLES

In our currently accepted gauge theories of the weak interactions, gauge bosons and fermions acquire mass via the mechanism of spontaneous symmetry breaking.²⁹ This can be achieved by dynamical means, such as in technicolor theories,³⁰ or through the inclusion of fundamental Higgs fields. In the minimal Weinberg-Salam model a single doublet of complex Higgs fields is introduced. Three of the fields contribute mass to the $W^\pm$ and Z^0 and the fourth field manifests itself as a physical neutral, spin 0, scalar (H^0). In this model the coupling of H^0 to fermions is specified and proportional to the fermion mass. However the mass of the H^0 is not calculated by the model. Extra Higgs doublets can be added to the minimal model which result in charged Higgs bosons whose couplings to fermions are not as rigidly specified. In the technicolor models a new strong interaction scale of ~ 1 TeV is introduced which results in a rich spectrum of pseudo-Goldstone bosons, otherwise known as technipions. Some of these charged scalar technipions are expected to have masses in the few GeV range. The MARK II group³¹ has undertaken a search for these charged, spin 0, scalars and limits for their production and subsequent decay to either ν_τ or $c\bar{s}$ quarks are presented below.

The MARK II data correspond to 14.4 pb^{-1} all at $E_{\text{c.m.}} = 29 \text{ GeV}$. The charged scalars, henceforth referred to as Higgs particles ($H^\pm$), are assumed to be produced according to

$$e^+e^- \rightarrow H^+H^-$$

with a production cross section

$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2 \beta^3 \sin^2 \theta}{8E_{c.m.}^2}$$

where α is the fine structure constant, β the Higgs velocity and θ its polar angle. The Higgs is assumed to decay to the heaviest fermions possible—either to quarks ($c\bar{s}$) or to the heavy lepton τ . Two cases are considered: (a) both Higgs decay to $\tau\nu_\tau$ and (b) one Higgs decays to $\tau\nu_\tau$ and the other decays to hadrons ($c\bar{s}$ quarks).

The event selection for case (a) is identical to that of the previous section with the extra requirement that the two jets defined by the thrust axis have one, two or three particles only. This corresponds then to those events which were used in the unfold to determine the true τ decay multiplicity distribution. To search for a Higgs signal in these events, an axis in the plane perpendicular to the beam is chosen so that the momentum transverse to this axis is equal for the two groups of particles. Formally $p_\perp$ is defined by

$$p_\perp = \left| \frac{\vec{p}_1 \wedge \vec{p}_2 \cdot \vec{z}}{\vec{p}_1 - \vec{p}_2 \wedge \vec{z}} \right|$$

where $\vec{p}_{1,2}$ are the total momenta of the two groups of particles and $\vec{z}$ is the unit vector in the beam direction. The $p_\perp$ distribution for the selected events is shown in Fig. 16 along with the absolutely normalized prediction of the τ -pair Monte Carlo. The τ -pair production provides an excellent accounting of the data and there is no evidence

for an additional source in these events. To set limits on Higgs production the data in Fig. 16 are fit to the sum of τ -pair production and the prediction of the Higgs Monte Carlo for various Higgs masses. The only free parameter in the fit is $B(H \rightarrow \tau\nu_\tau)$ and Fig. 17 (curve II) shows the 90% confidence limit contour of $B(H \rightarrow \tau\nu_\tau)$ as a function of the Higgs mass.

To look for events where one Higgs decays to hadrons and the other to $\tau\nu_\tau$, events with one charged particle (from the τ) opposite a multi-prong jet are selected. The charged particles in each event are divided into two groups by the plane perpendicular to the thrust axis and the following criteria applied:

- (1) total energy $> E_{c.m.}/4$ (charged particles + photons),
- (2) one group of particles has exactly one charged track, less than three photons, and an invariant mass $< 2 \text{ GeV}/c^2$,
- (3) the other group of particles has at least three charged particles, any number of photons, and invariant mass $> 2 \text{ GeV}/c^2$, and
- (4) the highest momentum particle in at least one of the groups has momentum above $2 \text{ GeV}/c$, enters the fiducial volume of the liquid argon shower counters, and deposits energy $< 30\%$ of its momentum.

Criterion (1) rejects two photon exchange events, and criterion (4) rejects radiative Bhabha events with a gamma conversion in the material surrounding the interaction region.

These selection criteria leave 22 observed events. The $P_\perp$ distribution for these events is shown in Fig. 18. The solid curve in Fig. 18 is the prediction of a Monte Carlo simulation program for

hadronic production. We observe in Fig. 18 that the typical $P_{\perp}$'s are ~ 300 MeV/c, characteristic of normal hadronic events. The only role the hadron Monte Carlo plays is to set the cut in $P_{\perp}$ beyond which a search will be made for Higgs production. The analysis is relatively insensitive to the choice of $P_{\perp}$ cut; the cut will be placed at 0.6 GeV/c. The $P_{\perp}$ distribution for the Higgs is calculated from a simulation program which produces Higgs particles according to the differential cross section presented at the beginning of this section. One Higgs decays into a $c\bar{s}$ quark pair which hadronize according to the Feynman-Field prescription.⁶ The other Higgs particle decays to ν_{τ} and the τ decays according to the measured branching fractions. Because of the event selection cuts described above, the only critical aspect of the hadronic decay of the Higgs is its charged multiplicity distribution. The average charged multiplicity of the Higgs decay has been chosen to agree with e^+e^- data at an equivalent energy. The dashed curve in Fig. 18 shows the expectation for a Higgs particle of mass $7 \text{ GeV}/c^2$ and a branching ratio $B(H \rightarrow \text{hadrons}) = 1 - B(H \rightarrow \nu_{\tau}) = 0.5$. Limits on Higgs production are obtained for various Higgs masses using the absence of events above $P_{\perp}$ of 0.6 GeV/c. The curve in Fig. 17 labeled I represents the 90% confidence level limits for $B(H \rightarrow \nu_{\tau}) = 1 - B(H \rightarrow \text{hadrons})$ as a function of the assumed Higgs mass.

Combining the data from methods (a) and (b) as summarized in Fig. 17, the MARK II group is able to set limits at the 90% confidence level which exclude charged Higgs particles in the mass range $2 - 10 \text{ GeV}/c^2$ with decay branching fraction to ν_{τ} , $B(H \rightarrow \nu_{\tau})$, above 5%. The experiments³² at

PETRA have presented similar limits on the production of scalars. JADE and MARK J collaborations place limits using both methods presented here. CELLO uses only method (a). These limits apply to slightly higher masses, $M_H \leq 14 \text{ GeV}/c^2$. Notice that, using these methods, it is hard to exclude a large Higgs hadronic branching ratio because if both Higgs decay to $q\bar{q}$, the events look very similar to normal hadronic events.

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 Stanford, CA 94305. D. E. Groom, H. Y. Lee, E. C. Loh, Department
 of Physics, University of Utah, Salt Lake City, UT 84112;
 M. C. Delfino, B. K. Heltsley, J. R. Johnson, T. Maruyama,
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TABLE 1

Corrections applied to the data are summarized as a function of $E_{c.m.}$.

	$E_{c.m.} = 5.2 \text{ GeV}$	6.5 GeV	29.0 GeV
Beam Gas	6.5 ± 0.6	15.8 ± 1.6	--
$\tau^+\tau^-$	8.6 ± 1.3	6.8 ± 1.2	2.5 ± 0.5
2γ Process	3.7 ± 0.8	3.7 ± 0.8	1.5 ± 0.8
Radiative Effects	10 ± 2	10 ± 2	15 ± 2

TABLE 11

R as a function of $E_{c.m.}$

$E_{c.m.}$ GeV	R
5.2	$3.90 \pm 0.02 \pm 0.25$
6.5	$3.95 \pm 0.05 \pm 0.25$
29.0	$3.90 \pm 0.05 \pm 0.25$

TABLE III

Summary of decay path and bias values, in mm. See text for definition of the weights referred to in the column headings.

	Unweighted	Weighted
<u>τ Sample</u>		
τ Raw $\langle x \rangle (\sigma_x)$	1.57 (5.48)	1.75 (4.43)
Monte Carlo $\langle x \rangle = x_b$	0.50 ± 0.01	0.55 ± 0.01
τ Corrected λ	1.07 ± 0.49	1.20 ± 0.39
<u>Control Sample</u>		
Raw $\langle x \rangle (\sigma_x)$	0.31 (4.86)	0.68 (4.03)
x_b	0.30 ± 0.10	0.30 ± 0.08
λ_{eff}	0.01 ± 0.21	0.38 ± 0.17
λ_{eff} (calculated)	0.18 ± 0.08	--

TABLE IV

Observed τ decay multiplicities, calculated backgrounds
and the resulting produced inclusive branching fractions.

Number of Prongs	10% X_0 Data		3% X_0 Data		Branching Fraction (%)
	Number Observed	Background	Number Observed	Background	
1	764	91	738	77	86 ± 2
2	62	14	49	12	--
3	152	19	137	16	14 ± 2
4	7	8	9	6	--
5	6	4	4	4	< 0.5
6	1	1	0	0	--
≥ 7	0	0	0	0	--

FIGURE CAPTIONS

- Fig. 1. MAC detector layout. The components labeled in the figure are: central drift chamber (DC), shower chamber (SC), trigger/timing scintillators (TC), central and endcap hadron calorimeters (HC,EC), and the inner and outer muon drift chambers (MI,MO). Also indicated are the solenoid and toroid coils.
- Fig. 2. Angular distribution of the thrust axis for multihadron events, determined from calorimeter energy.
- Fig. 3. The charged particle detection efficiency as a function of $x = p/E_{\text{beam}}$ at $\sqrt{s} = 5.2, 6.5$ and 29.0 GeV.
- Fig. 4. The cross section $s d\sigma/dx$ versus x for charged particles measured at $\sqrt{s} = 5.2, 6.5$ and 29.0 GeV. Only statistical errors are plotted.
- Fig. 5. $(1/\sigma)(d\sigma/dx)$ versus center-of-mass energy. Both statistical and systematic errors are included. Also plotted are data from Ref. 10 at $\sqrt{s} = 14, 22, 34$ and 35 GeV.
- Fig. 6. Total visible calorimetric energy in MAC.

Fig. 7. $(1/\sigma_0)(dI/d\cos\chi)$ as a function of $\cos\chi$. The solid line is a best fit to the data. Also shown are the relative contributions to the fit from perturbative QCD, quark fragmentation and gluon fragmentation.

Fig. 8. $(1/\sigma_0)(dI/d\cos\chi)$ as a function of $\cos\chi$. The size of the dots corresponds to the statistical errors. The solid line is the QCD prediction of Ref. 5 including the nonperturbative contributions. The broken line is the nonperturbative part alone.

Fig. 9. The $K^{\pm}\pi$ invariant mass is shown for $z = E_D/E_{c.m.} < 0.4$ (a) and $z > 0.4$ (b). No clear D^0 signal is seen. In (c) the $K^{\pm}\pi$ invariant mass is shown for events having a $D^0\pi^+ - D^0$ mass difference in the range $144 - 147 \text{ MeV}/c^2$.

Fig. 10. The $D^0\pi^{\pm} - D^0$ mass difference is shown for the bands of z . For $z > 0.4$ a clear $D^{*\pm}$ signal is seen.

Fig. 11. The $s(d\sigma/dz)$ spectrum of produced D^{*+} 's. The errors shown are statistical only.

Fig. 12. The total charged track momentum is shown for events selected as candidates for the τ lifetime measurement (MAC). Prediction of a τ -pair Monte Carlo simulation program is shown as a solid line.

Fig. 13. Distribution of the decay path length error from vertex fits to three-prong τ decays.

Fig. 14. Decay length distribution for τ decays: (a) unweighted; (b) weighted by the reciprocal squared error.

Fig. 15. Decay length distribution for control events: (a) unweighted; (b) weighted by the reciprocal squared error.

Fig. 16. P_T distribution for τ -pair events. The solid curve is the expectation for normal τ -pair production. The dashed curve is the expectation for a Higgs with mass $7 \text{ GeV}/c^2$ and $B(H \rightarrow \tau\nu_\tau) = 1$.

Fig. 17. Excluded regions (90% C.L.) for events where one Higgs decays to hadrons and the other to $\tau\nu_\tau$ (curve I) and for events where both Higgs decay to $\tau\nu_\tau$ (curve II). The branching ratio to hadrons plus the branching ratio to $\tau\nu_\tau$ is constrained to sum to 1.

Fig. 18. P_T distribution for events with one prong opposite a multi-prong jet. The solid curve is the prediction of the hadron Monte Carlo normalized to the data. The dashed curve is the expectation for a Higgs with mass $7 \text{ GeV}/c^2$ and $B(H \rightarrow \text{hadrons}) = 1 - B(H \rightarrow \tau\nu_\tau) = 0.5$.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

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Fig. 9

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Fig. 10

Fig. 11

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Fig. 16

Fig. 17

Fig. 18