The $\mu\tau$ and eτ decays of top quark pairs produced in p$\bar{\text{p}}$ collisions at $\sqrt{s}$=1.8 TeV

SLT(e) τ SLT(μ) μ
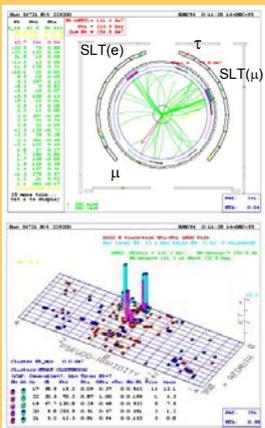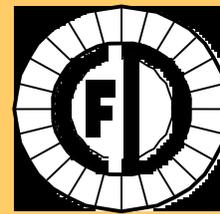
Event display of a
$\mu\tau$ candidate event

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M.G. and M.H. studied this decay channel as part of their Ph.D. work at the INFN Padova and University of Roma II, and at the University of Chicago, respectively.

Introduction

Here we present a search for top quark decays in the "tau dilepton" channel, where one W decays into $e\nu_e$ or $\mu\nu_\mu$ and the other into the third-generation leptons, τ and ν_τ. This channel is of particular interest because the existence of a charged Higgs boson H$^\pm$ with $m_{H\pm} < m_{top}$ could give rise to anomalous τ lepton production through the decay chain $t \to H^+b \to \tau^+\nu_\tau b$, which could be directly observable in this channel.

Interesting
- SM predicts this decay channel
- increase acceptance of dilepton channel
- involves exclusively third generation quarks/leptons
- excess would signal new physics

Rare
- small cross section ($\sigma_{t\bar{t}}$~5-6 pb)
- only ~5% of all top quark pair decay modes

Challenging
- tau identification at a hadron collider is difficult
- lower p_T than e or μ, due to ν_τ
- quark and gluon jets can fake taus
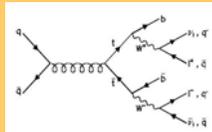
channel	signature	BR
"standard dilepton"	ee,μμ,eμ+2b jets	4/81
"lepton+jets"	eμ+jets+2b jets	24/81
"all hadronic"	jets+2b jets	36/81
tau dileptons	eτ,μτ+2b jets	4/81
tau+jets	τ+jets+2b jets	12/81

Tau dilepton channel

The data sample used in this analysis comprises high-p_T inclusive lepton events that contain an electron with E_T>20 GeV or a muon with p_T>20 GeV in the central region ($|\eta|$<1.0). The identification of hadronically decaying taus is difficult due to the misidentification of the much more numerous quark and gluon jets as taus: we use two complementary techniques, one "track-based" and the other "calorimeter-based." Top events and background have different topologies. Dilepton events from top decays are expected to contain 2 jets from b decays. We therefore select events with ≥2 jets with E_T>10 GeV and $|\eta|$<2.0. The transverse missing energy ($\not{E}_T$) is corrected for muons and jets. As top events are expected to have a large amount of $\not{E}_T$ due to undetected neutrinos, a cut is applied on the $\not{E}_T$ significance (S_{MET}). We require S_{MET}>3 GeV$^{1/2}$. Because of the large top quark mass, top events exhibit large total transverse energy, H_T. We require H_T>180 GeV. Finally, leptons must have opposite charge.

Tau identification

Search for taus in their hadronic decays:
$\tau \to$ 1 charged hadron BR~50%
$\tau \to$ 3 charged hadrons BR~14%
(BR – branching ratio)
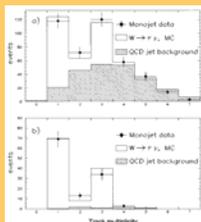
- hadronic taus are identified using tracking and calorimeter information
- isolated track is a powerful discriminant against quark/gluon jets
- taus often produce neutral pions (use EM calorimeter to identify $\pi^0 \to \gamma\gamma$)

tau efficiency: ε_τ^{ID} =(59±4(stat)±3(syst))%
tau fake rate: ~0.2% per QCD jet
(similar values are found for the calorimeter-based tau selection)

Tau efficiency is checked using a data sample enriched in W→τν$_\tau$ .Typically, this decay mode has one jet from the tau and $\not{E}_T$ due to the neutrinos. A monojet sample is selected by requiring one central jet with 15<E_T<40 GeV, no other jet with E_T>7 GeV in $|\eta|$<4.0, and 20<$\not{E}_T$<40 GeV. The Figure (top) shows the track multiplicity in this sample and in a background sample of QCD jets. The latter is normalized to the monojet sample using the bins with ≥4 tracks, where there is a very small contribution from W→τν$_\tau$ events. Data show a clear excess in the one-prong and three-prong bins, as a sample with significant tau fraction. The W→τν$_\tau$ content is estimated to be 45±5(stat)% by subtracting the QCD background.

Acceptance

The product of all BR's, geometric and kinematic acceptance, trigger efficiencies, lepton identification, and cuts on the event topology yields a total acceptance A_{tot}=(0.085±0.010(stat)±0.012(syst))% for the track-based selection and A_{tot}=(0.134±0.013(stat)±0.019(syst))% for the calorimeter-based selection. The systematic uncertainty on A_{tot} is dominated by uncertainties on identification efficiencies for the tau (6%) and the primary lepton (7%), the top mass (6%), and the hadronic energy scale of the calorimeter (5%). Of the total one-prong events selected, 19% (38%) are expected to be found only by the track-(calorimeter-) based technique, and 43% by both. Based on the top cross section as measured by CDF from other decay modes, we expect 0.7±0.2(stat)±0.1(syst) and 1.1±0.3(stat)±0.2(syst) events from top production in the two selections, respectively.

Background

Table I lists the contributions from the various background sources. The dominant background is due to Z→γ→τ$^+$τ$^-$+jet events. If one tau decays leptonically and the other hadronically, this process can mimic the top signature. From Monte Carlo simulations we expect a background of 0.89±0.28 (1.48±0.38) events due to this process for the track(calorimeter)-based tau selection and smaller backgrounds from WW and WZ production. The "fake tau" background is due to W+ ≥3 jet events with one jet misidentified as a tau. We calculate the fake rates as a function of E_T by applying the tau selection criteria to jets in QCD jet samples. Applying the fake rates bin-by-bin to the E_T spectrum of all jets that could be misidentified as taus in a W+≥3 jets sample gives the number of fake events. We expect 0.25±0.02 fake one-prong taus with the track-based tau selection and 0.78±0.04 fake one- and three-prong taus with the calorimeter-based selection. The total expected backgrounds are 1.28±0.29 and 2.50±0.43 events, respectively.

The Figure shows S_{MET} versus $\not{E}_T$ for data events with a primary lepton and a tau candidate that passes the calorimeter-based selection cuts. After all cuts four candidate events are identified, 2 eτ and 2 $\mu\tau$ events. There is in addition one same-sign $\mu^+\tau^+$ event, consistent with the 0.78 expected background events from fake taus. The track-based tau selection finds the same four events.
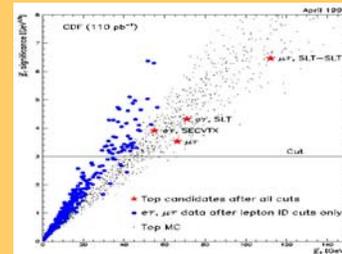
b-tagging

We use the presence of a soft lepton from semileptonic b decays (SLT) or of a secondary vertex (SVX) in the silicon vertex detector to identify jets from b quarks. Three of the four candidate events have b-tagged jets. One event has an SLT-SLT double tag. For the calorimeter-based selection we expect 0.16 (0.18) background events with ≥1SVX (SLT) tag, for a total background including correlations of 0.28±0.02 events. The probability to observe ≥ 3 background events is 0.3% after b-tagging. For top signal plus background we expect 0.64±0.12(stat) (0.37±0.06(stat)) events with an SVX (SLT) tag and observe one (two) event(s). Using the track-based selection, we expect 0.08±0.01 tagged events from background and 0.46±0.14 tagged events from top plus background.

Conclusions

In conclusion, we have developed a method to use tau leptons in the analysis of top decays. We observe 4 candidate events where we expect ~1 event from top decays and ~2 background events. In three of the events we identify jets from b quark decays, which supports the $t\bar{t}$ hypothesis. Using the numbers of estimated background and observed events in the Table (N_{jet}≥2) and the acceptances (A_{tot}), we calculate a production cross section. We find $\sigma_{t\bar{t}}=10.2^{+16.3}_{-10.2}$ (stat) ± 1.6 (syst) pb for the calorimeter-based selection and $29.1^{+26.3}_{-18.4}$ (stat) ± 4.7 (syst) pb for the track-based selection, consistent with the latest measured values given the large statistical uncertainty.

Search for the Charged Higgs Boson - Phys.Rev.D 62, (2000) 012004.

(43 citations in SPIRES)
Top quark production offers the unique opportunity to search for a charged Higgs boson (H$^\pm$), as the contribution from t→H$^+$b→τ$^+$νb can be large in extensions of the Standard Model. We use results from the search for top quark pair production in the eτ+$\not{E}_T$+jets and $\mu\tau$+$\not{E}_T$+jets signatures to set an upper limit on the branching ratio of B(t→H$^+$ b). The upper limit is in the range 0.5 to 0.6 at 95% C.L. for H$^+$ masses in the range 60 to 160 GeV/c^2, assuming the branching ratio for H$^+$→ τ ν is 100%.