DØ collaboration

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Direct measurement of the mass difference between top and antitop quarks

CPT theorem requires that the mass of a particle and that of its antiparticle be identical. This has never been tested directly on quarks because they are never observed in isolation. Top quarks are unique because they decay before they hadronize, providing a way to measure the mass difference less ambiguously.

We search for any difference between the mass of the top and the antitop quark produced in $p\bar{p}$ collisions at $\sqrt{s}$=1.96 TeV using data corresponding to 1fb^{-1} of integrated luminosity collected with the D0 detector during Run II of the Fermilab Tevatron Collider. This analysis is based on 220 $t\bar{t}$ candidate events in the lepton+jets channel selected by requiring one isolated lepton with high p_T, a large amount of missing transverse momentum, and exactly four high p_T jets with at least one jet identified as a b jet.

The analysis is conducted separately for the e+jets and +jets channels using the positively (negatively) charged leptons to tag the top (antitop) quark in each event. We do this analysis with the matrix element method developed at D0. For more details, please see arXiv:0906.1172 [hep-ex].

Extracting the mass difference

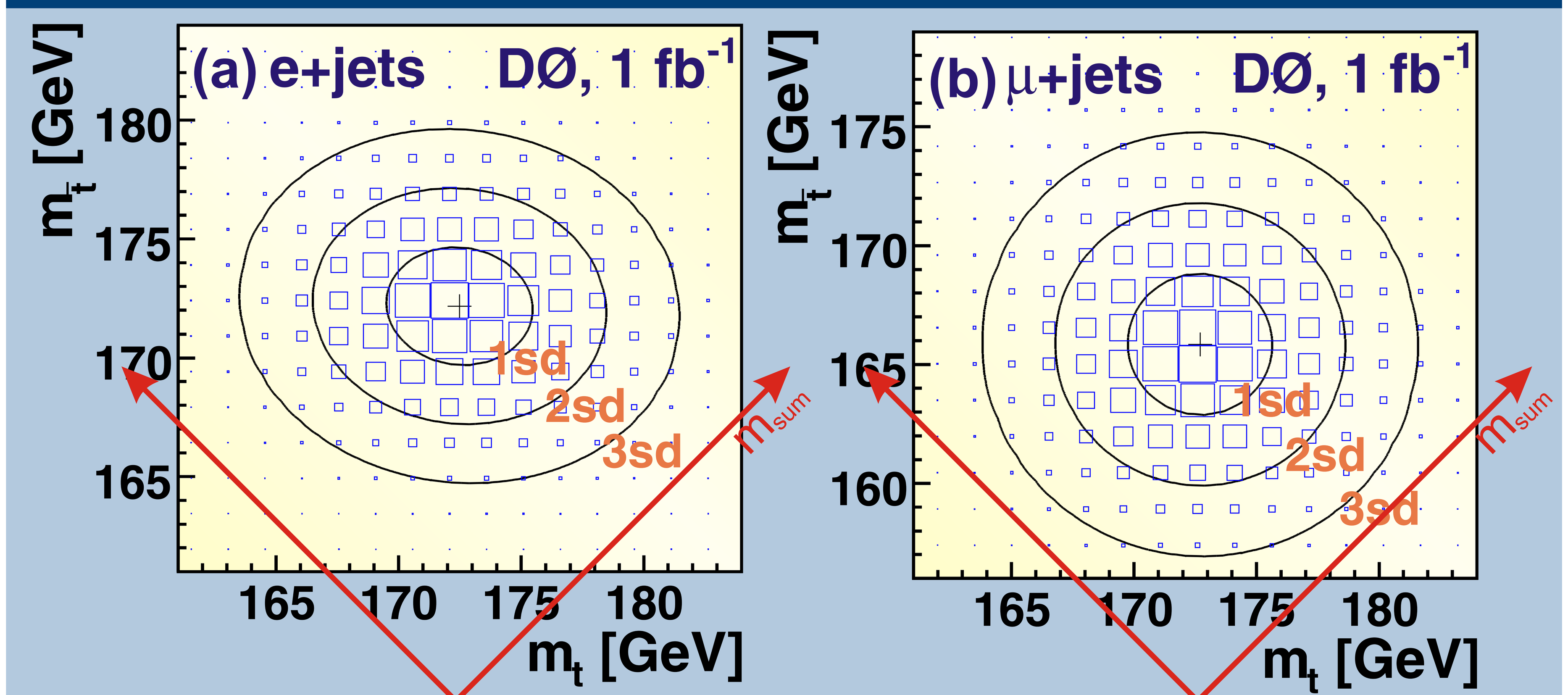

Figure 1: Fitted contours of equal probability for the 2D likelihoods as a function of m_t and $m_{\bar{t}}$ for (a) e+jets and (b) +jets data. The boxes, representing the bins in the 2D histograms of the likelihoods, display areas proportional to the bin contents, set equal to the value of the likelihood evaluated at the center of the bin.

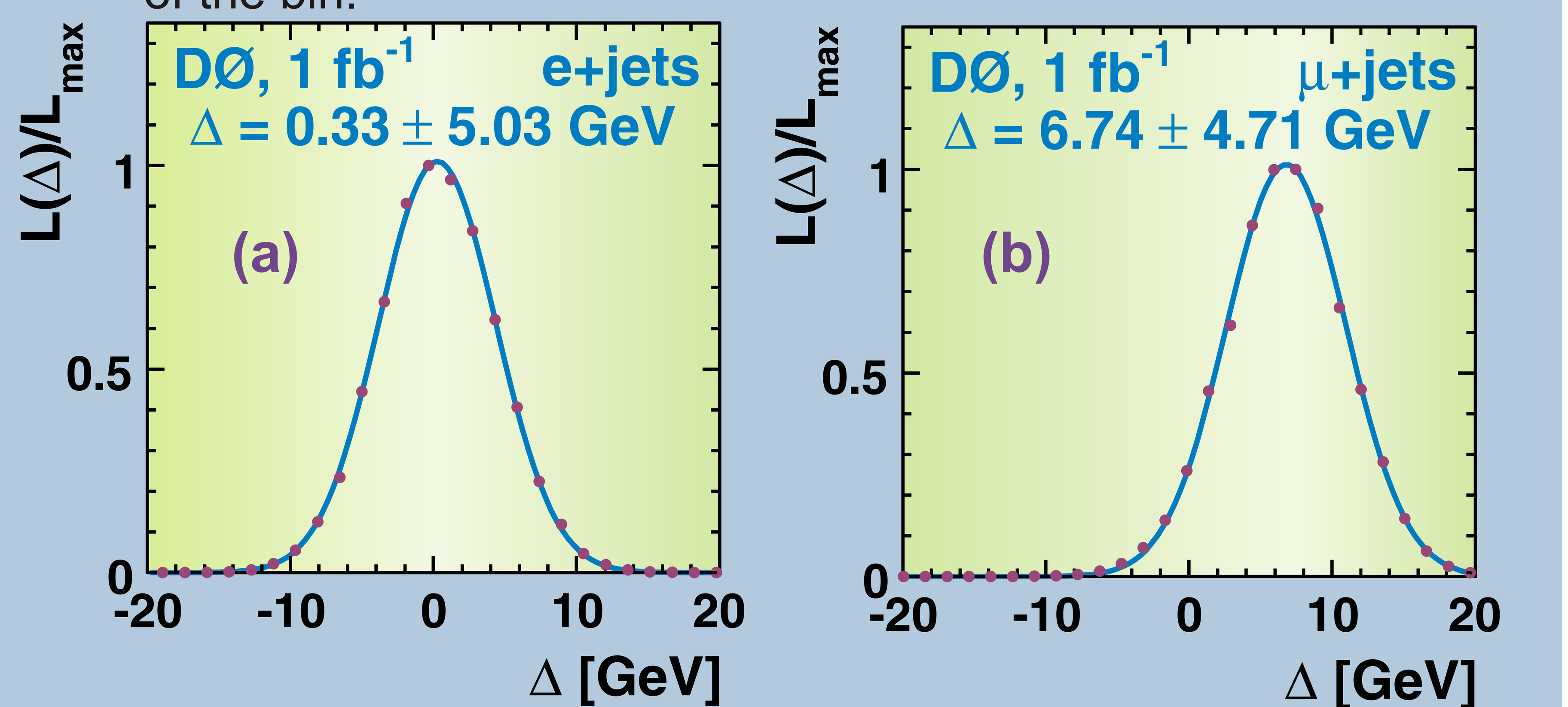

Figure 2: Projections of the 2D likelihoods onto the $=m_t-m_{\bar{t}}$ axis (drawn in red in Fig. 1) for (a) e+jets and (b) +jets data. Values of extracted from the projections are shown in each plot. Combining the extracted from each channel gives = 3.8±3.4(stat.)

Matrix element technique

The matrix element (ME) method used in this analysis relies on the extraction of the properties of the top quark trhough a likelihood technique based on probability densities (PD) for each event, calculated from the ME for the two major processes ($t\bar{t}$ and W+jets) that contribute to the selected lepton+jets sample. The PD for each event is given in terms of the fraction of signal (f) and of background ($1-f$) in the data and the masses of the top quark (m_t) and the antitop quark ($m_{\bar{t}}$):

$$P_{\rm evt} = A(x)[f P_{\rm sig}(x;\, m_t,m_{\bar{t}})+(1-f)P_{\rm bkg}(x)]$$

where x denotes the measured jet and lepton energies and angles, $A(x)$ is a function only of x and accounts for the detector acceptance and efficiencies, and $P_{\rm sig}$ and $P_{\rm bkg}$ represent the PD for $t\bar{t}$ and W+jets production, respectively.

$P_{\rm sig}$ and $P_{\rm bkg}$ are calculated by integrating over all possible parton states leading to the measured set x through a convolution of the partonic differential cross section d $(y;m_t,m_{\bar{t}})$ with the PDs for the initial state partons and the transfer functions $W(y,x)$ that account for jet fragmentation effects and detector resolution.

The parameters m_t and $m_{\bar{t}}$ are then determined from a likelihood constructed from the product of the $P_{\rm evt}$ for all events.

Result

Table I: Summary of systematic uncertainties on .

Source	Uncertainty (GeV)
Physics Modeling	
Signal	±0.85
PDF uncertainty	±0.26
Background modeling	±0.03
Heavy flavor scale factor	±0.07
b-fragmentation	±0.12
Detector Modeling	
b/light response ratio	±0.04
Jet identification	±0.16
Jet resolution	±0.39
Trigger	±0.09
Overall jet energy scale	±0.08
Residual jet energy scale	±0.07
Muon resolution	±0.09
Wrong charge leptons	±0.07
Asymmetry in $b\bar{b}$ response	±0.42
Method	
MC Calibration	±0.25
b-tagging efficiency	±0.25
Multijet contamination	±0.40
Signal fraction	±0.10
Total in quadrature	±1.22

We have measured the t and $\bar{t}$ mass difference in 1 fb^{-1} of data in lepton+jets $t\bar{t}$ event and find the mass difference to be:

$$m_t \quad m_{\bar{t}} \quad 3.8 \quad 3.7\,\mathrm{GeV}$$

corresponding to a relative mass difference of (2.2 2.2)%. This is the first direct measurement of a mass difference between a quark and its antiquark partner.