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31305: Tevatron Searches for Compositeness

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31305: Tevatron Searches for Compositeness

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Abstract. Tevatron experiments have recently set or improved limits on quark and lepton compositeness. Included here are results from $\sqrt{s} = 1.8$ TeV $p\overline{p}$ collider experiments DØ and CDF and from fixed target neutrino experiment CCFR, who report limits on quark-quark, quark-lepton, and quark-neutrino compositeness, respectively.

1 Introduction

Compositeness theories hypothesize that any or all Standard Model (SM) fundamental particles may have substructure. Recent interest in compositeness is due to the CDF observation of an excess in the inclusive jet E_T spectrum at high E_T and the excess of events with high x and Q^2 in deep inelastic scattering at HERA.

In general, composite models define an energy scale Λ_C (a *compositeness scale*) at which preons (quark or lepton subparticles) are bound within the quark or lepton states. In the SM, $\Lambda_C = \infty$, and consequently quarks and leptons are pointlike. But if Λ_C is finite, then substructure would be observed at energy scales above Λ_C. At lower energies, other effects may be observed as described in the searches herein.

Three Tevatron experiments have recently set or improved limits on quark and lepton compositeness. These searches assumed that the center-of-mass energy of the parton-parton system is much smaller than the compositeness scale ($\sqrt{\hat{s}} << \Lambda_C$). Under these conditions, quarks and leptons appear nearly pointlike and effective new interactions due to compositeness can be described by additional four fermion contact interactions. They also assumed that the gauge bosons are elementary, and that in the quark-lepton compositeness searches, the compositeness scale of quarks and leptons is the same. The datasets and event topologies in each search are distinct and therefore are described in separate sections below.

2 DØ Compositeness - Dijet Angular Distribution

One manifestation of quark compositeness would be an increase in the cross section for the production of jets in $p\overline{p}$ collisions. This increase is expected to be most apparent at high transverse energy (E_T), which is the source of the acute interest in the excess of events observed by CDF in the high end of the E_T spectrum (see E.Buckley-Geer talk 413 in these proceedings). Interest turned to controversy when DØ reported no such excess (see R.McCarthy talk 412 in these proceedings). A more sensitive measure of compositeness

in jet production is found by studying the dijet angular distribution. This measurement is not subject to the large uncertainties of the jet cross section prediction due to the choice of parton distribution functions (pdf).

DØ exploits it's high resolution, hermetic calorimetry [2] to search for compositeness in QCD dijet events using their inclusive jet data sample collected during the 1994-1995 run. The angle θ^* is defined as the parton-parton center of mass scattering angle. By transforming to the variable $\chi = (1+\cos\theta^*)/(1-\cos\theta^*)$, the expected next-to-leading order (NLO) QCD distribution $1/NdN/d\chi$ is relatively flat while a contact term features a steep rise at low χ, enhancing the signal to background in this region. The data are separated into four bins in dijet invariant mass, the highest of which is expected to be most sensitive to a compositeness signal.

The data points of Figure 1 show the dijet invariant mass distribution in the variable χ for the highest mass bin ($M_{jj} > 635$GeV). Statistical errors are indicated on the data points while systematic uncertainties are shown as a band below. The NLO predictions (generated using JETRAD [3]) are indicated by the solid curve. Dashed and dotted curves indicate the change in the prediction due to the addition of contact interaction terms. For this and the other mass bins, the NLO prediction is in good agreement with the data and is found to be insensitive to the pdf choice. The result changes somewhat with the choice of renormalization/factorization scale. Using a Bayesian technique and an assumption that the prior probability distribution is flat in $1/\Lambda_C^2$, limits on compositeness at the 95% CL were found. Assuming all quarks to be composite, the resulting lower limits on the quark compositeness scale range from 2.1 to 2.4 TeV. Results vary with the choice of renormalization scale and the sign of the interference term in the contact interaction Lagrangian, as detailed in Reference [1].

3 CDF Compositeness - Drell-Yan Spectrum

If the HERA excess of events (see D.Acosta/U.Bassler talks 31301/31302 in these proceedings) at high Q^2 is indeed due to quark and lepton compositeness, it would also appear in the dilepton invariant mass spectra in $p\overline{p}$ collisions. CDF exploits its fine tracking resolution [4] to study dielectron and dimuon production and search for quark-lepton compositeness.

The model predicts that four-fermion contact interaction partonic cross sections are proportional to the mass squared. Therefore, substructure would be observable in the l^+l^- pair mass spectra at high masses, atop of the steeply falling spectrum of pairs produced via the Drell-Yan process. This search channel is ideal because the Drell-Yan topology is very distinctive, containing two well separated, oppositely charged leptons in the final state which tend to be isolated from jets or other activity.

Figure 2 shows the dielectron and dimuon invariant mass spectra obtained from an analysis including 110 pb^{-1} of $p\overline{p}$ collisions observed in the CDF detector. The measured e^+e^- and $\mu^+\mu^-$ invariant mass spectra are normalized to the SM cross section over $50 < M_{l^+l^-} < 150$ GeV. The SM prediction

(solid curve) is obtained from a next-to-leading-logarithmic (NLL) QCD calculation using MRS A′ pdf's, the results of which are clearly consistent with the data. Additional dotted and dashed curves indicate the change in the theoretical prediction due to a 2 TeV scale contact interaction.

The compositeness model assumed a general Lagrangian with interacting fermions having either chiral, vector, scalar, or axial current interactions. Dielectron, dimuon and combined datasets were used to obtain quark-electron, quark-muon, and quark-lepton (assuming lepton universality) limits on compositeness scales, a complete list of which is available in Reference [5]. To briefly summarize, lower limits on chiral qe and qμ compositeness scales range from 2.5 to 4.2 TeV.

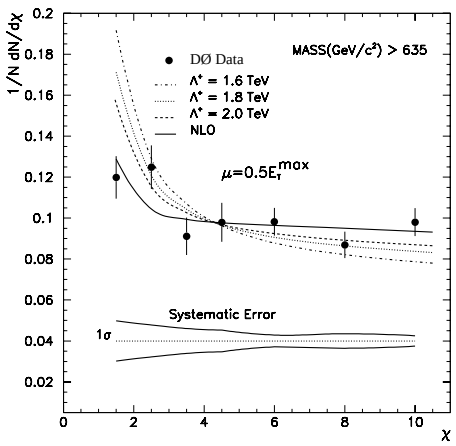

Fig. 1. Datapoints indicate the measured DØ dijet angular distribution in χ compared to the NLO QCD prediction (solid) and the change in the theory with additional contact terms.

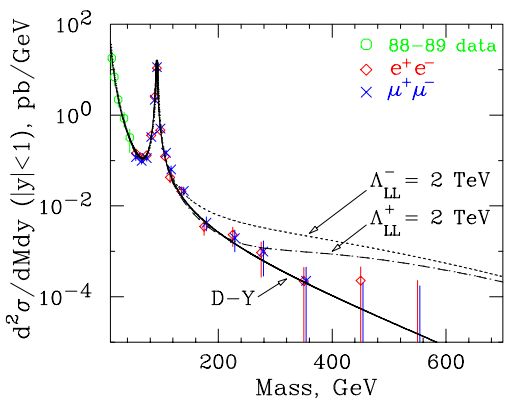

Fig. 2. CDF e^+e^- (diamonds) and $\mu^+\mu^-$ (crosses) invariant mass distribution compared to a SM NLL calculation (solid) and SM + compositeness prediction (dashed/dotted curves).

4 CCFR - Ratio of Charged to Neutral Current Events

The CCFR experiment is a Tevatron fixed target neutrino experiment which utilizes a beam containing ν and $\bar{\nu}$ from decay secondaries produced by 800 GeV protons on a BeO target. Neutrino (or $\bar{\nu}$) induced events are observed in a 690 ton neutrino target calorimeter. In the SM, the interaction of a ν with nuclear matter proceeds via heavy charged and neutral vector boson exchange commonly referred to as charged (CC) and neutral current (NC) interactions. The ratio (R) of CC to NC cross sections is predicted by the SM. A measure of this ratio yields a precision measurement of a SM constant,

$\sin^2\theta_W$. For the extraction of $\sin^2\theta_W$, SM couplings $u_{L,R}$ and $d_{L,R}$ (the left and right-handed couplings of up and down quarks to the Z^0) are fixed to their SM expectations while allowing $\sin^2\theta_W$ to vary. Results are consistent with SM expectations (see J.Yu talk 701 in these proceedings).

A measure of the ratio R can also be used to constrain the couplings $u_{L,R}$ and $d_{L,R}$. The measurement is used to constrain linear combinations of deviations from standard model expectations in the variables $g^2_{L,R}$ and $\delta^2_{L,R}$, the sum and difference of the squares of the q-Z^0 couplings. To set limits on compositeness, a general contact interaction Lagrangian is assumed which allows chiral, vector or axial vector couplings between ν and/or $\bar{\nu}$ and up and down quarks. Resulting lower limits on $\nu - q$, $\bar{\nu} - q$, and combined-q contact interactions are shown in the table below. Further details are available in Reference [6].

CCFR constraints on $\nu - q$ couplings						
Interaction	ν		$\bar{\nu}$		ν and $\bar{\nu}$	
	Λ^+	Λ^-	Λ^+	Λ^-	Λ^+	Λ^-
LL	4.6 TeV	5.1 TeV	1.3 TeV	2.2 TeV	5.0 TeV	5.4 TeV
LR	4.1 TeV	4.3 TeV	3.8 TeV	4.0 TeV	5.8 TeV	5.8 TeV
LV	6.5 TeV	6.5 TeV	4.3 TeV	4.5 TeV	7.9 TeV	7.8 TeV
LA	2.1 TeV	3.2 TeV	3.1 TeV	3.7 TeV	3.0 TeV	1.8 TeV

5 Conclusions

Three Tevatron experiments have improved compositeness limits:

- CCFR uses the ratio of charged to neutral current cross sections in $\nu - N$ interactions to set limits on $\nu - q$ compositeness of order 1.3 to 7.9 TeV.
- CDF sets improved limits on q-l compositeness in the range from 2.5 to 4.2 TeV by studying the high mass dilepton production spectrum in $p\bar{p}$ collisions.
- DØ, another collider detector, sets improved limits on q-q compositeness ranging from 2.1 to 2.4 TeV by looking for deviations from NLO predictions in the dijet angular distribution.

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