DØnote 4922-CONF

Search for Quark-Lepton Compositeness in the Dimuon Channel with 400 pb^{-1} DØ Run II Data

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We report preliminary results of a search for a compositeness signature of quarks and leptons in the dimuon channel using data collected by the DØ detector at the Fermilab Tevatron at $\sqrt{s}$=1.96 TeV. We set model-dependent lower limits at the 95% confidence level on the compositeness scale of 4.2 to 9.8 TeV for constructive and destructive interference between the Drell-Yan (DY) amplitude and the contact interaction for various quark and lepton chiralities.

Preliminary Results for Winter 2005 Conferences

I. INTRODUCTION

The Standard Model (SM) of quarks and leptons does not predict their mass spectra or the number of their families. This suggests that there might exist a more fundamental basis. In one such scenario, fundamental constituents called preons interact via a new strong gauge interaction of metacolor. Below a certain characteristic energy scale, Λ, the interaction becomes strong and binds the preons together to form leptons, quarks and heavy bosons. This can be modeled with an effective four-fermion contact interaction and represented by a Lagrangian:

$$\begin{aligned} L_{ql} = \tfrac{g_0^2}{\Lambda^2}\{&\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{\mu}_L\gamma_\mu\mu_L) + \eta_{LR}(\bar{q}_L\gamma^\mu q_L)(\bar{\mu}_R\gamma_\mu\mu_R) \\ &+ \eta_{RL}(\bar{u}_R\gamma_\mu u_R)(\bar{\mu}_L\gamma^\mu\mu_L) + \eta_{RL}(\bar{d}_R\gamma_\mu d_R)(\bar{\mu}_L\gamma^\mu\mu_L) \\ &+ \eta_{RR}(\bar{u}_R\gamma^\mu u_R)(\bar{\mu}_R\gamma_\mu\mu_R) + \eta_{RR}(\bar{d}_R\gamma^\mu d_R)(\bar{\mu}_R\gamma_\mu\mu_R)\} \end{aligned} \tag{1}$$

where $q_L = (u,d)_L$ is left-handed quark doublet; u_R and d_R are right-handed quark singlets; and μ_L and μ_R are the left- and right-handed muons respectively. η is a sign factor, -1 for constructive and +1 for destructive interference. Only dominant contributions from the first generation of light-quarks have been considered due to severe experimental constraint on intergeneration transitions like $K \to \mu e$ (Flavour Changing Neutral Currents, FCNC).

The signature for this compositeness would be a significant deviation from the Standard Model prediction for high energy cross sections. The null results of such experimental searches are used to set lower limits on the characteristic scale Λ.

DØ and CDF have pioneered searches for quark-lepton compositeness in (final state) dilepton channels. In Run I, DØ reported a limit on quark-lepton compositeness of 3.3 TeV to 6.1 TeV in the dielectron channel, depending on the chirality model [1]. In Run II a preliminary limit of 3.6 TeV to 9.1 TeV was reported for the same channel [2]. We extend to a two-dimensional analysis in the dimuon channel in search for quark-lepton compositeness.

II. MODELS OF COMPOSITENESS

The experimental signature of contact interaction would be the deviation from the SM cross section for dilepton production through the Drell-Yan (DY) process. This is highly model-dependent and can be classified according to the corresponding LL, RR, RL and LR terms of equation 1 and their combinations. The total dilepton cross section, modified by the contact interaction, is given by:

$$\frac{d^2\sigma^\Lambda}{dmd\cos\theta^*} = \frac{d^2\sigma}{dmd\cos\theta^*}(DY) + \beta_C I + \beta_C^2 C \tag{2}$$

where $\beta_C = 1/\Lambda^2$, m is the dilepton invariant mass, I is the interference of DY and the contact term, and C is the pure contact term contribution to the cross section (see Fig. 1). The invariant mass of the dilepton pair and the cosine of the scattering angle in the center-of-mass frame completely determine the leading order (LO) $2 \to 2$ scattering process. This choice of variables yields optimum sensitivity to the contribution from contact interaction and yields a factor of enhancement of 20% for parity-flipping chirality channels.

III. SEARCH FOR QUARK-LEPTON COMPOSITENESS IN DIMUON CHANNEL

A. Monte Carlo Studies

Dimuon events are generated using the parton-level leading order (LO) Monte Carlo generator of Reference [3] and another LO MC generator used at DØ. The former MC includes the Standard Model (SM) DY contributions, Kaluza-Klein gravitation exchange diagrams and their interference in dimuon production. The latter MC also includes SM DY contributions, but the contact interaction in different helicity channels, and their interference. They are merged into a bigger generator, keeping all but irrelevant parts. The muon simulation is parametrized in terms of muon energy and momentum resolutions. This parametrization takes into account detector acceptance, detection efficiencies, initial state radiation and the effect of different parton distributions. The leading order parton distribution functions CTEQ5L are used for the nominal prediction [3]. The parameters of the detector model are tuned using the Z boson data. Since the generator is only LO, the effects of next-to-leading order (NLO) are modeled by adding a transverse momentum to the dimuon system based on the transverse momentum spectrum observed in the data. The transverse part of the NLO processes is taken into account by applying a random p_T-kick to the system, based on the p_T spectrum of dielectron events observed in the data. The scattering angle θ^* is defined in the dimuon helicity frame, i.e. relative to the direction of the boost of the dimuon system. The number of events are corrected for higher orders using a K-factor of 1.3. The same factor is used for the compositeness signal.

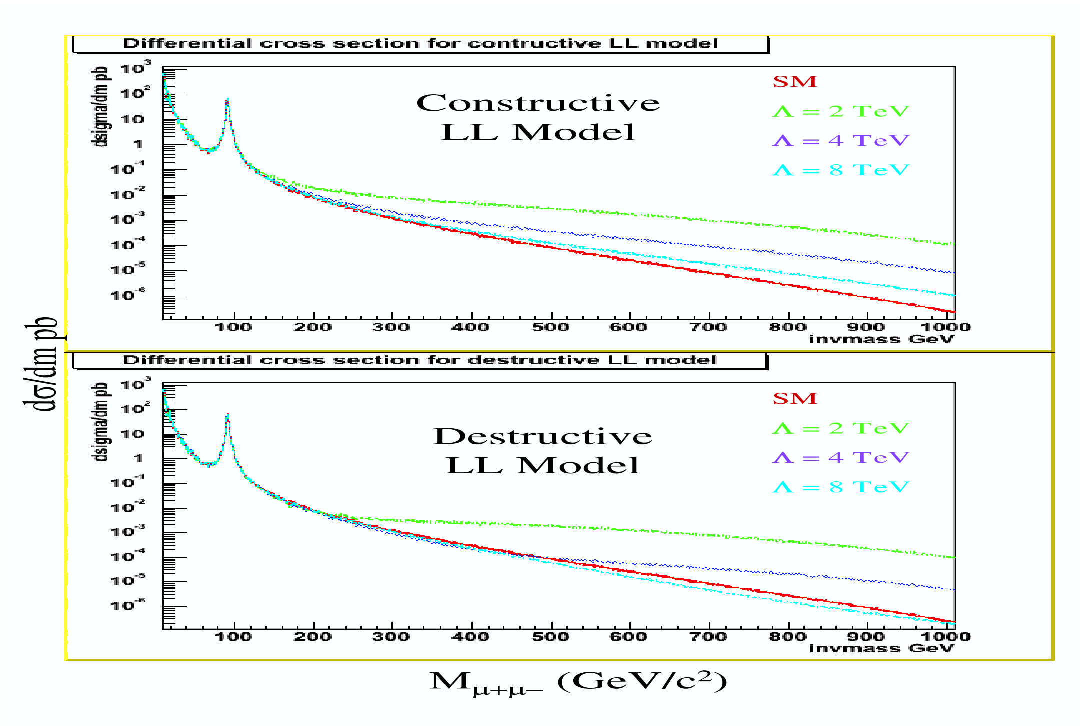

FIG. 1: Theoretical cross section versus dilepton invariant mass for the SM DY process and for three different values of Λ in the LL channel for constructive (left) and destructive (right) interference.

B. Data Analysis

This analysis is based on all data collected with the DØ detector in the Tevatron Run II (through August 2004) and is reconstructed with the most recent version of the DØ reconstruction program. The integrated luminosity for dimuon and single muon triggers required in this analysis is 406 ± 26 pb^{-1} for this sample.

Events selected are required to have at least two muons. They are required to have high $p_T$and high invariant mass and to pass track quality, cosmic ray and isolation cuts. A p_T re-scaling procedure as in [5] is applied to the data sample. This procedure sets the transverse momenta of either muon to a weighted average of the original measured momenta and their errors. After the p_T scaling, four momenta of the muons are recalculated and the invariant mass cut is reapplied to get a final data set of 28017 events, as shown in Table I.

Cut	Number of events passing
Initial sample	169221
Track quality cuts	94167
$M_{\mu\mu} > 50$ GeV cut	63297
Cosmic cut	39828
Isolation cuts	28635
$M_{\mu\mu} > 50$ GeV reapplied	28017

TABLE I: Data selection

C. Background

The contribution of the SM Drell-Yan process is included in the output of the fast Monte Carlo as the background. The normalization of this background is determined by fitting the mass region of the Z-peak in the dimuon mass spectrum to this background.

The other contributions to the background are dimuon events which are decay products of $\tau^+\tau^-$ or $b\bar{b}$ production. The cosmic ray rejection cuts and muon isolation cuts are optimized to reduce such contribution to a negligible level.

D. Data and MC Comparison

The event selection cuts and p_T fix procedure in subsection III.B are also applied to the fast MC background and signal sample.

Figure 2 shows the comparisons of the dimuon invariant mass for data and for Drell-Yan MC and of $|\cos\theta^*|$.

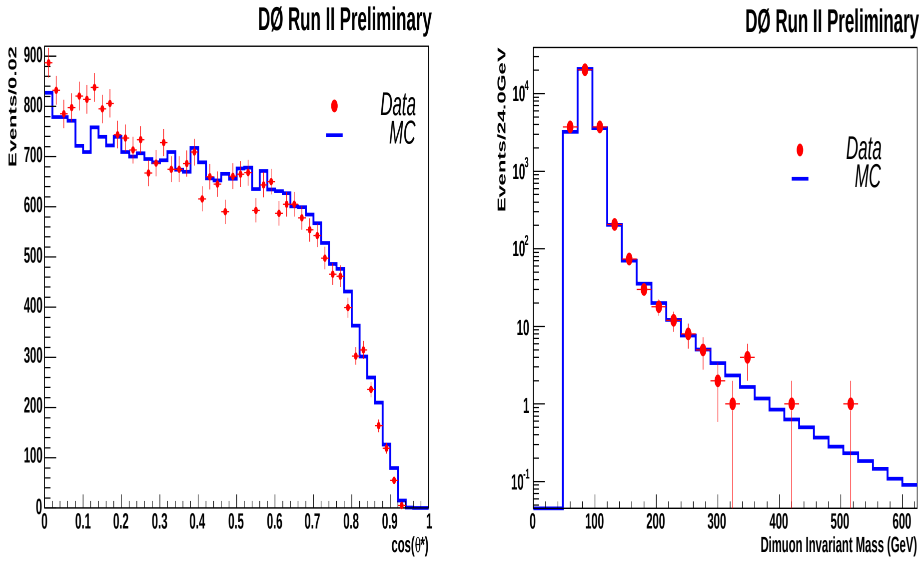

FIG. 2: Comparison between data (points) and backgrounds (histogram) for $|\cos\theta^*|$ and $M_{\mu\mu}$ distribution

Figure 3 shows the $M_{\mu\mu}$ vs. $|\cos\theta^*|$ distributions for data and MC.

Table II helps to quantify the agreement between data and backgrounds, in mass space, by comparing the prediction for the background above a certain mass cut-off with that of data. It also gives the Poisson probability for the background to fluctuate to or beyond the observed number of events.

Minimum $M_{\mu\mu}$	Expected background	Data	Poisson probability
120 GeV	366.2	361	0.61
150 GeV	140.7	119	0.97
180 GeV	72.5	59	0.95
210 GeV	41.4	37	0.77
240 GeV	25.2	22	0.77
270 GeV	16.2	13	0.82
300 GeV	10.8	7	0.91
330 GeV	7.4	7	0.61
360 GeV	5.2	2	0.97
390 GeV	3.8	2	0.89
420 GeV	2.9	1	0.94
450 GeV	2.2	1	0.89
480 GeV	1.7	1	0.82
510 GeV	1.4	1	0.75
540 GeV	1.1	0	1.0

TABLE II: Data and expected background comparison for events above certain dimuon mass cut-off.

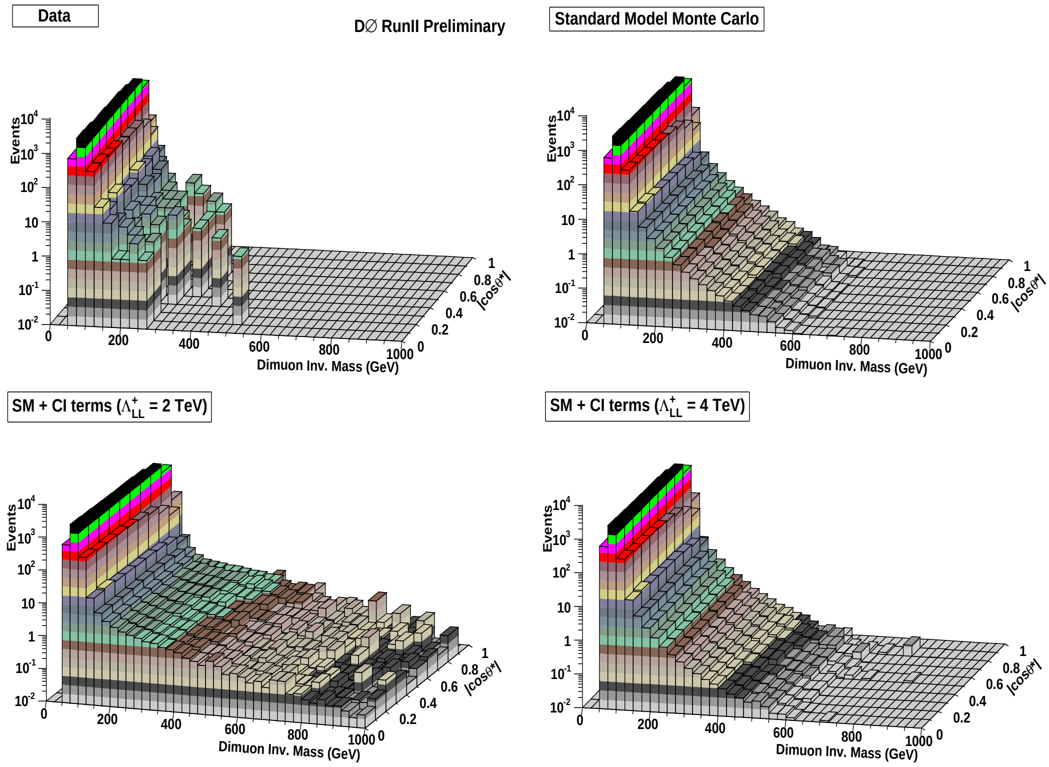

FIG. 3: The distribution in M$\mu\mu$ vs. $|\cos\theta^*|$ space for data and MC for the constructive LL contact interaction channel. MC is scaled by the effective luminosity.

In the $|\cos\theta^*|$ distributions for data and MC, there is still a discrepancy in the low $|\cos\theta^*|$ region. The excess in data is mostly from Z boson events. Since it appears outside the region sensitive to compositeness (as seen in Fig. 1 and Fig. 3), the discrepancy does not affect the result of this analysis. A systematic uncertainty of 5% is included in the uncertainties of the choice of the fast MC p_T smearing and p_T-kick and accounted for in the limit setting procedure of this analysis.

E. Limit Calculation of Scale of Compositeness Λ

Having seen the agreement between the dimuon data with SM Drell-Yan, we proceed with setting limits on compositeness scale Λ.

A Bayesian fitting method is used to obtain the most likely value of parameter β_C. The fit uses three two-dimensional MC templates for the SM DY cross section, the direct contact interaction and the interference between them. Systematic uncertainties of 13% on the acceptance and the p_T dependence of efficiency, the energy dependence of the K factor, the choice of parton distribution functions, the choice of p_T smearing and the background estimate are used as input in the limit setting procedure. The normalization uses the effective luminosity, defined as the factor that scales the NLO Z-peak cross section to the data.

The fitting program uses the data, background and signal MC two-dimensional distributions to calculate the best value for β_C and its errors. It also sets the 95% CL upper limit on β_C, denoted β_C^{95} which can be used to set a lower limit on the compositeness scale Λ. The above procedure is repeated for each chirality channel. The best fit values for β_C are shown in Table III.

The results from setting limits independently are shown in Table IV for each chirality channel of the contact interaction Lagrangian LL, RR, LR, RL, and their combinations LL+RR, LR+RL, LL-LR, RL-RR, VV and AA.

To show that the results are stable w.r.t. the granularity of the two-dimensional grid (20×10 in M×$|\cos\theta^*|$), the number of bins used for $|\cos\theta^*|$ is reduced from 10 to 1. The 95% confidence limit using only the one-dimensional mass distribution can be calculated. The one-dimensional 95% CL limits on β_C are obtained for constructive chirality channels LL and RR:

Model	β_C^+(TeV^{-2})	errors	β_C^-(TeV^{-2})	errors
LL	0.018	+0.021-0.017	0.000	+0.006-0.000
RR	0.020	+0.022-0.019	0.000	+0.007-0.000
LR	0.000	+0.015-0.000	0.007	+0.002-0.000
RL	0.000	+0.014-0.000	0.007	+0.018-0.000
LL+RR	0.013	+0.013-0.000	0.000	+0.003-0.000
LR+RL	0.000	+0.009-0.000	0.006	+0.012-0.000
LL-LR	0.018	+0.015-0.015	0.000	+0.005-0.000
RL-RR	0.000	+0.006-0.000	0.016	+0.014-0.015
VV	0.005	+0.008-0.000	0.000	+0.004-0.000
AA	0.017	+0.010-0.011	0.000	+0.003-0.000

TABLE III: Best fit value for β_C for different constructive (β_C^+) and destructive (β_C^-) contact interaction models in the dimuon channel.

Model	Λ^+(TeV)	Λ^-(TeV)
LL	4.19	6.98
RR	4.15	6.74
LR	5.32	5.10
RL	5.31	5.17
LL+RR	5.05	9.05
LR+RL	6.45	6.12
LL-LR	4.87	7.74
RL-RR	5.07	7.41
VV	6.88	9.81
AA	5.48	9.76

TABLE IV: 95% CL lower limit on compositeness scale Λ for different constructive and destructive contact interaction models in the dimuon channel.

$$\beta_{LL}^{1D95\%} = 6.06 \times 10^{-2}$$
$$\beta_{RR}^{1D95\%} = 6.06 \times 10^{-2}.$$

These are about 6% and 4% worse than the limits obtained using two-dimensional distributions (5.71×10^{-2} and 5.80×10^{-2} respectively).

For parity flipping constructive channels RL and LR and their combinations such as LRRL, RLRR, and VV, the gains of including $|\cos\theta^*|$ to get the two-dimensional analysis range from 10% to 22%:

$$\beta_{LR}^{1D95\%} = 4.03 \times 10^{-2}, \text{ 14\% worse than its two-dimensional } \beta_{LR}^{2D95\%} = 3.53 \times 10^{-2}$$
$$\beta_{RL}^{1D95\%} = 4.21 \times 10^{-2}, \text{ 19\% worse than its two-dimensional } \beta_{RL}^{2D95\%} = 3.55 \times 10^{-2}$$
$$\beta_{LRRL}^{1D95\%} = 2.94 \times 10^{-2}, \text{ 22\% worse than its two-dimensional } \beta_{LRRL}^{2D95\%} = 2.40 \times 10^{-2}$$
$$\beta_{RLRR}^{1D95\%} = 2.01 \times 10^{-2}, \text{ 10\% worse than its two-dimensional } \beta_{RLRR}^{2D95\%} = 1.82 \times 10^{-2}$$
$$\beta_{VV}^{1D95\%} = 2.52 \times 10^{-2}, \text{ 19\% worse than its two-dimensional } \beta_{VV}^{2D95\%} = 2.11 \times 10^{-2}.$$

For a sensitivity study, 200 trial experiments are run, using randomly filled two-dimensional histograms in $M_{\mu\mu}$ according to the SM background and the effective luminosity. The two-dimensional SM histogram are fluctuated using Poisson statistics and then refilled. Then the limit setting procedure is applied to find the 95% CL limit. This is done for each chirality channel for constructive and destructive contact interactions. The distributions of 95% CL limits on β_C for the 200 trials for chirality channels LL are shown in Figure 4 which shows that the results (Table III) are within the expected sensitivity.

IV. CONCLUSIONS

We performed a search for quark-lepton compositeness in the dimuon channel using 400 pb^{-1} of Run II DØ data. No evidence for a compositeness has been observed. The lower 95% CL limits on the compositeness scale Λ for different chirality models ranging from 4.2 to 9.8 TeV were obtained. The results are the world's most stringent limits in the dimuon channel for the compositeness scale.

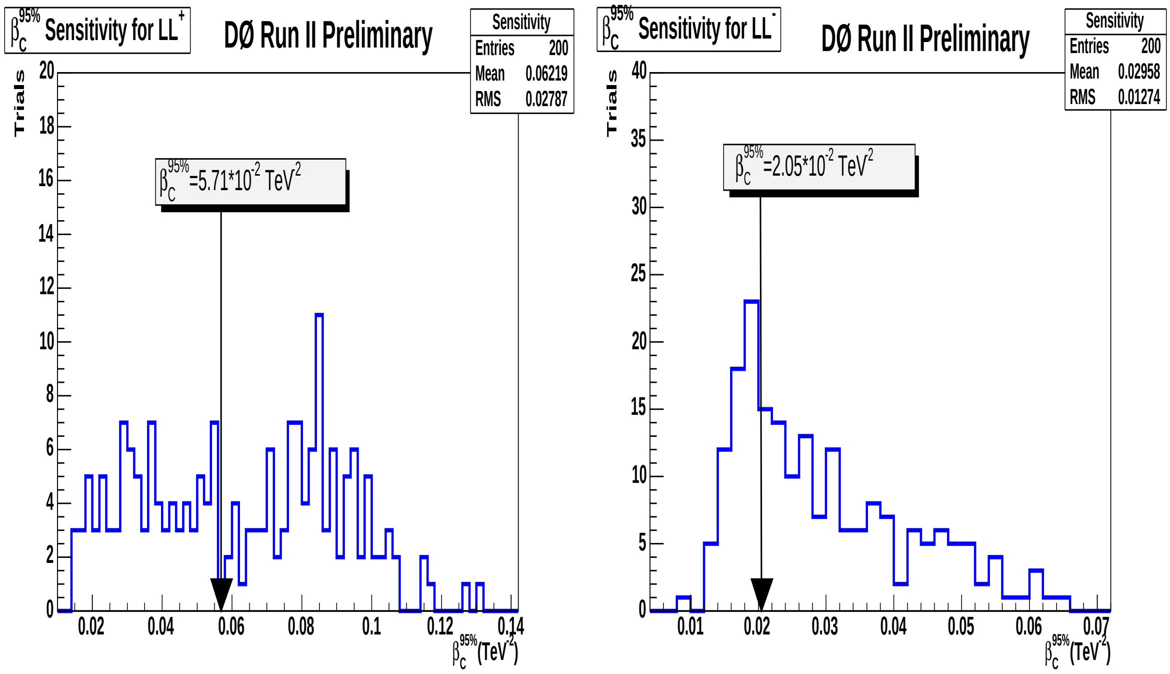

FIG. 4: The distribution of best fit values on β_C for 200 MC trials for LL (constructive and destructive)

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