Search for Quark-Lepton Compositeness at Tevatron and LHC

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We make a Monte Carlo study on compositeness of first generation quarks and leptons using the Drell-Yan distribution in the high dielectron mass region at the Tevatron and LHC energies. The current experimental lower limits on the compositeness scale, Λ, vary from 2.5 to 6.1 TeV. In the present analysis, we assume that there will be no deviation of the dielectron mass spectrum from Standard Model prediction at center of mass energy 2 TeV (Tevatron) and 14 TeV (LHC). We then find that in the LL, RR, RL and LR chirality channels of the quark-electron currents, it is possible to extend the lower limits on Λ (at 95% CL) to a range of 6 to 10 TeV for 2 fb^{-1} and 9 to 19 TeV for 30 fb^{-1} of integrated luminosity at Tevatron. At LHC, the corresponding limits extend to a range of 16 to 25 TeV for 10 fb^{-1} and 20 to 36 TeV for 100 fb^{-1} of integrated luminosity.

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The proliferation of quarks and leptons has inspired the speculation that they could be composite structures, i.e. bound states of more fundamental constituents often called preons [1]. Below a characteristic energy scale called the compositeness scale, Λ, the preon-binding interaction becomes strong and binds the constituents to form composite states like the quarks and leptons. With such a composite structure, there would be significant deviation from the Standard Model (SM) prediction of high energy cross sections. No such deviation has been observed so far. These null results have been used to put lower limits on quark-lepton compositeness scale Λ. which varies from 2.5 to 6.1 TeV [2] in the various chirality channels of the quark-lepton currents.

In this paper, we consider the effects of composite structure of first generation quarks and leptons on the Drell-Yan (DY) process $q\bar{q} \rightarrow e^+e^-$ [3]. If the compositeness scale, Λ, is much greater than $\sqrt{\hat{s}}$, the center of mass energy of the colliding partons, the quarks and electrons would appear to be point-like. The substructure coupling can then be approximated by a four-fermion contact interaction giving rise to the following effective lagrangian[1] [1]:

$$\mathcal{L}_{ql} = \frac{g_0^2}{\Lambda^2}\Big\{\eta_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{e}_L\gamma_\mu e_L) + \eta_{LR}(\bar{q}_L\gamma^\mu q_L)(\bar{e}_R\gamma_\mu e_R) \quad (0.1)$$
$$+ \ \eta_{RL}(\bar{u}_R\gamma_\mu u_R)(\bar{e}_L\gamma^\mu e_L) + \eta_{RL}(\bar{d}_R\gamma_\mu d_R)(\bar{e}_L\gamma^\mu e_L)$$
$$+ \ \eta_{RR}(\bar{u}_R\gamma^\mu u_R)(\bar{e}_R\gamma_\mu e_R) + \eta_{RR}(\bar{d}_R\gamma^\mu d_R)(\bar{e}_R\gamma_\mu e_R)\Big\}$$

where

$$q_L = \begin{bmatrix} u \\ d \end{bmatrix}_L$$

is the left-handed quark doublet. u_R and d_R are the right-handed quark singlets. e_L and e_R are the left- and right-handed electrons respectively. The compositeness scale (Λ) is chosen so that $\frac{g_0^2}{4\pi} = 1$ and the largest $\mid \eta_{ij} \mid = 1$, where g_0 is the coupling constant for the contact interaction and η_{ij} is the interference term between the contact interaction and the SM lagrangian for the ij^{th} channel, with i and j representing the helicities of the quark and the lepton currents. Including the above contact interaction (at $\Lambda >> \sqrt{\hat{s}}$), the DY cross section gets transformed as [4]:

$$\frac{d\sigma^\Lambda}{dm} = \frac{d\sigma}{dm}(DY) + \beta I + \beta^2 C, \quad (0.2)$$

where $\beta = 1/\Lambda^2$ and m is the dielectron invariant mass. In this expression, I is due to the interference of DY and the contact term, and C is the pure contact term contribution to the cross-section. The deviation in the dielectron production from SM expectations would be dominant in the high mass region above the Z pole. We have made separate studies for quark- electron compositeness for an integrated luminosity of 2 fb^{-1} (Run II) and 30 fb^{-1} (TEV33) with respect to the DØ detector at Tevatron and an integrated luminosity of 10 fb^{-1} and 100 fb^{-1} with respect to the CMS detector at LHC. However the results should be valid for the CDF detector at Tevatron and the ATLAS detector at LHC as well. We have simulated dielectron production through DY process alone in $p\bar{p}$ (pp) collisions at center of mass energy, $\sqrt{s}$, equal to 2 TeV (14 TeV) using PYTHIA [5]. However since PYTHIA does not incorporate all the compositeness models, we have used a separate parton level Monte Carlo program to estimate dielectron production rates in the presence of compositeness. Assuming that the Tevatron and LHC data on dielectron production are consistent with DY predictions under SM, we extract limits on compositeness scale using Bayesian technique of statistical inference [6,7]. We have considered four different models corresponding to the LL, RR, RL and LR chirality channels of equation 0.1 for quark-electron compositeness. The choice of η_{ij} for the different models of compositeness is listed in Table I.

TABLE I. Choice of η_{ij} for different contact interaction models. The superscript on the model denotes the nature of interference between the contact interaction and the SM lagrangian. Constructive interference ($\eta_{ij} = -1$) is denoted by a + and destructive interference ($\eta_{ij} = +1$) is denoted by a $-$.

Model	η_{LL}	η_{RR}	η_{LR}	η_{RL}
$LL^\pm$	∓1	0	0	0
$RR^\pm$	0	∓1	0	0
$LR^\pm$	0	0	∓1	0
$RL^\pm$	0	0	0	∓1

Exploring the lower limits on Λ at Tevatron

We simulate $p\bar{p}$ collisions using PYTHIA at 2 TeV and generate DY dielectron events between 95 GeV and 1.5 TeV of the dielectron invariant mass. The total number of dielectron events generated by PYTHIA, N_{gen}, gives the expected number of background subtracted dielectron events, N_{DY}, to be collected at Tevatron as :

$$N_{DY} = \epsilon \times N_{gen} \quad (0.3)$$

where ϵ is the detection efficiency of the dielectron. The detection efficiency, ϵ, of the dielectron involves contribution from the following terms:

(a) Energy smearing,

[1] Here we have assumed that the contact interaction is color singlet and weak-isoscalar.

(b) Electron identification efficiency, ϵ_1, and

(c) Acceptance, ϵ_2.

The energy resolution of the electromagnetic calorimeter of the upgraded DØ detector is parameterized as :

$$(\frac{\sigma}{E})^2 = C^2 + (\frac{a}{\sqrt{E}})^2 \quad (E\ in\ GeV) \tag{0.4}$$

where the constant term, C, and the stochastic term, a are taken to 2 % and 16 % respectively . We take the electron identification efficiency, ϵ_1, for a single electron to be 85%. The identification efficiency for a dielectron is then ϵ_1^2. The acceptance, ϵ_2, of dielectron events in $p\bar{p}$ collisions is defined as the fraction of events in which the e^+e^- pair passes the fiducial and the kinematic cuts after taking into account the energy smearing. The fiducial and the kinematic cuts used are:

- $\mid \eta \mid \leq 2.5$, where η is the pseudorapidity ($= -ln[tan(\frac{\theta}{2})]$). This ensures that the dielectron event selected is in the active detector region.
- A kinematic cut of $p_T \geq 25\ GeV$, where p_T is the transverse momentum of the electron and the positron. This cut ensures an efficient trigger.[2]

The dielectron detection efficiency, ϵ, is then :

$$\epsilon = {\epsilon_1}^2 \times \epsilon_2 \tag{0.5}$$

We then generate the *expected* number of dielectron events, N^{Λ}_{exp}, in various mass bins including the effect of the composite structure of quarks and electrons for various values of Λ using the parton level Monte Carlo. We calculate the cross section (σ^{Λ}) for the production of dielectrons including terms from the contact interaction lagrangian of equation 0.1 with the SM lagrangian. The LO cross section calculation is corrected for higher order QCD effects using a K-factor of 1.22[3]. We checked the parton level MC calculation by comparing its prediction with that from PYTHIA for the Drell-Yan process. Both calculations agree to within a few percent as shown in Fig. 1.

In order to obtain the lower limit on Λ, we then use the Bayesian technique to compare the Drell Yan dielectron mass distribution (ie., N_{DY}) in the high mass region with the expected dielectron mass distribution for various values of Λ (ie., N^{Λ}_{exp}). Limits are obtained independently for each separate channel of the contact interaction lagrangian: LL, RR, RL and LR with $\eta_{ij} = \pm 1$.

[2]This cut is based on the DØ Run I analysis of DY data at 1.8 TeV [8].

[3]This K-factor is the ratio of the NNLO DY cross section to the LO DY cross section at 1.8 TeV [9,10]. We consider the same value for the K-factor for DY + compositeness at 2 TeV.

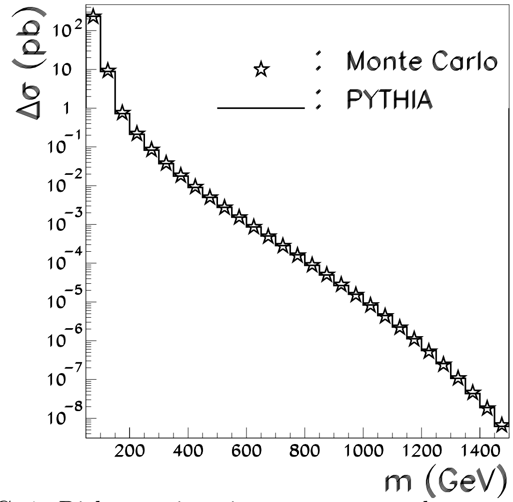

FIG. 1. Dielectron invariant mass spectra between 80 GeV and 1.5 TeV for DY process at $\sqrt{s} = 2\ TeV$, as predicted by PYTHIA and as calculated using our parton level Monte Carlo.

Fig. 2 shows the cross section versus the dielectron invariant mass, in the high mass region between 50 GeV and 1.8 TeV in the LL channel for different values of Λ for $\eta_{ij} = -1$ (constructive interference) and Fig. 3 shows the corresponding plot for $\eta_{ij} = +1$ (destructive interference).

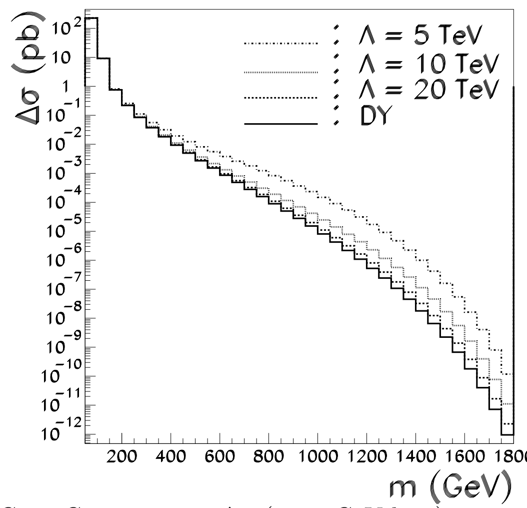

FIG. 2. Cross section, $\Delta\sigma$ (in 50 GeV bins), versus dielectron invariant mass, m, between 50 GeV and 1.8 TeV for DY process and three different values of Λ in the LL channel for $\eta_{ij} = -1$.

Since the effect of compositeness is most pronounced in the high dielectron mass region we consider 10 different mass bins of variable width between 120 GeV and 1.5 TeV. The expected number of events at the compositeness scale, Λ, in the k^{th} mass bin is given as :

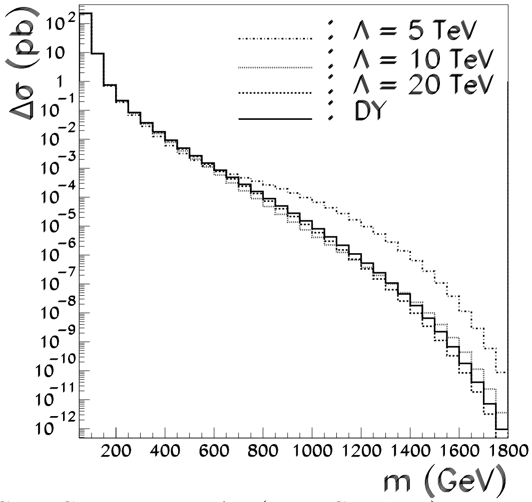

FIG. 3. Cross section, $\Delta\sigma$ (in 50 GeV bins), versus dielectron invariant mass, m, between 50 GeV and 1.8 TeV for DY process and three different values of Λ in the LL channel for $\eta_{ij} = +1$.

$$N^{\Lambda,k}_{exp} = \epsilon^k \; (\sigma^{\Lambda,k} \times L), \tag{0.6}$$

where $\sigma^{\Lambda,k}$ is the cross section (including compositeness) for the k^{th} mass bin and L is the integrated luminosity. The posterior probability for the compositeness scale to be Λ given the expected DY dielectron data distribution, d_O, is:

$$P(\Lambda \mid d_O) = \frac{1}{\mathcal{Z}} \prod_{k\,=\,1}^{n} P^k(N^k_{DY} \mid N^{\Lambda,k}_{exp}) \; P(\epsilon^k,\; L,\; \Lambda) \tag{0.7}$$

where $\mathcal{Z}$ is the normalization constant. $P^k(N^k_{DY} \mid N^{\Lambda,k}_{exp})$ is the *likelihood* function which follows a Poisson distribution for small $N^{\Lambda,k}_{exp}$:

$$P^k(N^k_{DY} \mid N^{\Lambda,k}_{exp}) = \frac{e^{-N^{\Lambda,k}_{exp}} \; (N^{\Lambda,k}_{exp})^{N^k_{DY}}}{N^k_{DY}!}, \quad (N^{\Lambda,k}_{exp} \;<\; 10) \tag{0.8}$$

and a Gaussian distribution for large $N^{\Lambda,k}_{exp}$, with mean $N^{\Lambda,k}_{exp}$ and standard deviation, σ_1, ($\sigma_1 \;=\; \sqrt{N^{\Lambda,k}_{exp}}$) [11] :

$$P(N^k_{DY} \mid N^{\Lambda,k}_{exp}) = \frac{1}{\sqrt{2\pi}\sigma_1} \; e^{-\frac{(N^k_{DY} - N^{\Lambda,k}_{exp})^2}{2\sigma_1^2}}, \quad (N^{\Lambda,k}_{exp} \;\geq\; 10). \tag{0.9}$$

$P(\epsilon^k,\; L,\; \Lambda)$ is the joint *prior* probability for the dielectron detection efficiency, ϵ^k, the integrated luminosity, L, and the compositeness scale, Λ. Taking ϵ^k, L and Λ to be independent,

$$P(\epsilon^k, L, \Lambda) = P(\epsilon^k) \; P(L) \; P(\Lambda). \tag{0.10}$$

The *prior* probabilities of detection efficiency, ϵ^k, and integrated luminosity, L, are assumed to be Gaussian with their estimated value in each bin as the *mean* and corresponding error as the *width* of the Gaussian. The prior distribution $P(\Lambda)$ is chosen to be uniform in $1/\Lambda^2$. This represents a prior essentially flat in cross section. The resulting posterior density $P(\Lambda \mid d_O)$ peaks at $1/\Lambda^2 \;=\; 0$ and falls off monotonically with increasing $1/\Lambda^2$. The 95% CL lower limit on Λ is defined by:

$$\int_{\Lambda_{lim}}^{\infty} d\Lambda' \; P(\Lambda' \mid d_O) = 0.95. \tag{0.11}$$

The values of efficiency, ϵ^k, and the expected number of DY events, N^k_{DY}[4], in individual mass bins are listed in Table II for an integrated luminosity of 2 fb^{-1} and 30 fb^{-1}. The expected 95% CL lower limits on Λ for the LL, RR, RL and LR helicity channels of the quark- electron currents for both constructive and destructive interference are listed in Table III and Table IV for integrated luminosities of 2 fb^{-1} and 30 fb^{-1} respectively.

TABLE II. Detection efficiency and expected number of DY events in different mass bins

mass bin (GeV)	ϵ^k	N^k_{DY} $L \;=\; 2\; fb^{-1}$	N^k_{DY} $L \;=\; 30\; fb^{-1}$
120-160	0.590	2335.8	34508.1
160-200	0.629	606.9	8990.1
200-240	0.655	236.3	3589.4
240-290	0.663	117.8	1942.8
290-340	0.675	66.5	877.1
340-400	0.668	34.0	461.7
400-500	0.689	23.8	276.0
500-600	0.712	6.5	98.3
600-1000	0.677	1.5	42.6
1000-1500	0.723	0	2.2

TABLE III. Expected 95% CL lower limits, Λ_{lim}, on the compositeness scale for different helicity channels of the quark-electron currents for $L \;=\; 2\; fb^{-1}$ at 2 TeV with $\delta\epsilon^k \;=\; 15$ % and $\delta L \;=\; 5$ %

Channel	Λ_{lim} (TeV) $(\eta_{ij} \;=\; -\;1)$	Λ_{lim} (TeV) $(\eta_{ij} \;=\; +\;1)$
LL	10.1	8.0
RR	9.3	6.0
RL	7.8	5.7
LR	7.3	6.0

Exploring the lower limits on Λ at LHC

We have made a similar analysis of the DY process including the effect of quark-electron compositeness at

[4] N^k_{DY} is generated with a K-factor of 1.22 in PYTHIA.

TABLE IV. Expected 95% CL lower limits, Λ_{lim}, on the compositeness scale for different helicity channels of the quark-electron currents for $L = 30\ fb^{-1}$ at 2 TeV with $\delta\epsilon^k = 15$ % and $\delta L = 5$ %

Channel	Λ_{lim} (TeV) $(\eta_{ij} = -1)$	Λ_{lim} (TeV) $(\eta_{ij} = +1)$
LL	18.9	17.8
RR	17.0	15.1
RL	13.5	9.1
LR	12.1	9.2

14 TeV. As before we have assumed that DY dielectron data that would be collected by the CMS detector at LHC would agree with SM prediction. We then use the Bayesian technique to obtain the lower limits on Λ at 14 TeV. We have made separate studies for 10 fb^{-1} of data and 100 fb^{-1} of data. A K-factor of 1.13 [9,10] has been used as the NNLO correction factor. Fig. 4 shows the cross section versus the dielectron invariant mass, in the high mass region between 50 GeV and 2 TeV in the LL channel for different values of Λ for $\eta_{ij} = -1$ (constructive interference) and Fig. 5 shows the corresponding plot for $\eta_{ij} = +1$ (destructive interference).

We generated DY events in the dielectron mass range of 150 GeV to 2 TeV. We then compared the expected number of DY events, N_{DY}, at $\sqrt{s} = 14$ TeV with the expected number of dielectron events, N^{Λ}_{exp}, at various values of Λ in the mass range of 500 GeV to 2 TeV where the deviation from SM predictions due to the composite structure of quarks and electrons is most pronounced at LHC. The electron identification efficiency, ϵ_1, is taken to be 95% [12]. The constant and stochastic terms in the energy resolution of the electromagnetic calorimeter of the CMS detector are taken to be [12]:

$$\begin{aligned} C &= 0.55\%, \quad and \\ a &= 2.7\%, \quad |\eta| \leq 1.5 \\ &\quad 5.7\%, \quad 1.5 < |\eta| \leq 2.5 \end{aligned} \tag{0.12}$$

The fiducial and kinematic cuts selected are the same as for DØ. The values of ϵ^k and N^k_{DY}[5], in individual mass bins are listed in Table V for integrated luminosities of 10 fb^{-1} and 100 fb^{-1}. The expected 95% CL lower limits on Λ for the LL, RR, RL and LR helicity channels of quark-electron currents for both constructive and destructive interference are listed in Table VI and Table VII for integrated luminosities of 10 fb^{-1} and 100 fb^{-1} respectively.

The discovery limits for Λ (defined as a deviation of 5σ from SM prediction) for the various models have been listed for integrated luminosities of 10 fb^{-1}, 50 fb^{-1}, 100 fb^{-1}, 200 fb^{-1} and 500 fb^{-1} in Table VIII for $\eta_{ij} = -1$ and in Table IX for $\eta_{ij} = +1$.

Plots of the discovery limit versus the integrated luminosity for the various chirality channels are shown in Fig. 6 for $\eta_{ij} = -1$ and in Fig. 7 for $\eta_{ij} = +1$.

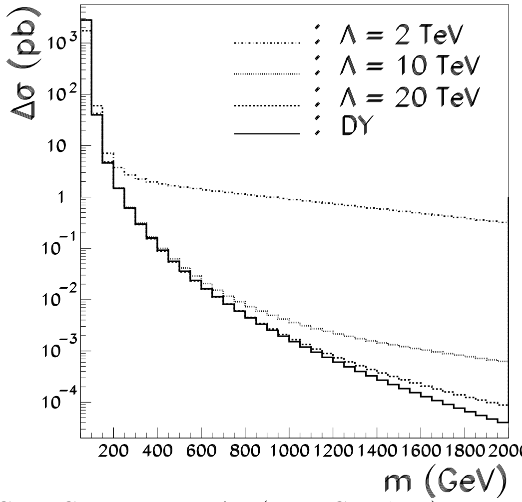

FIG. 4. Cross section, $\Delta\sigma$ (in 50 GeV bins), versus dielectron invariant mass, m, between 50 GeV and 2 TeV for DY process and three different values of Λ in the LL channel for $\eta_{ij} = -1$.

To conclude, we have performed a Monte Carlo study of the dielectron invariant mass spectrum (DY + compositeness) for $p\bar{p}$ collisions at 2 TeV and pp collisions at 14 TeV. We have considered the LL, RR, RL and LR chirality channels of the quark-electron currents. Assuming that Standard Model will describe the high mass DY dielectron data at 2 TeV and 14 TeV we have found that it is possible to extend the lower limits on the compositeness scale, Λ, from the existing limits.

- For $p\bar{p}$ collisions at Tevatron we have made separate studies for integrated luminosities of 2 fb^{-1} and 30 fb^{-1} with respect to the DØ detector. The expected 95 % CL lower limits on Λ range between 6 to 10 TeV and 9 to 19 TeV for 2 fb^{-1} and 30 fb^{-1} of dielectron data, respectively. These limits are in agreement with similar limits on Λ quoted between 6 to 10 TeV for 2 fb^{-1} and 14 to 20 TeV for 30 fb^{-1} of data with respect to the CDF detector at Tevatron [13].

- For pp collisions at LHC we have considered 10 fb^{-1} and 100 fb^{-1} of dielectron data with respect to the CMS detector. The expected 95 % CL lower limits on Λ range between 16 to 25 TeV for 10 fb^{-1} and between 20 to 36 TeV for 100 fb^{-1} of

[5] N^k_{DY} is generated with a K-factor of 1.13 in PYTHIA.

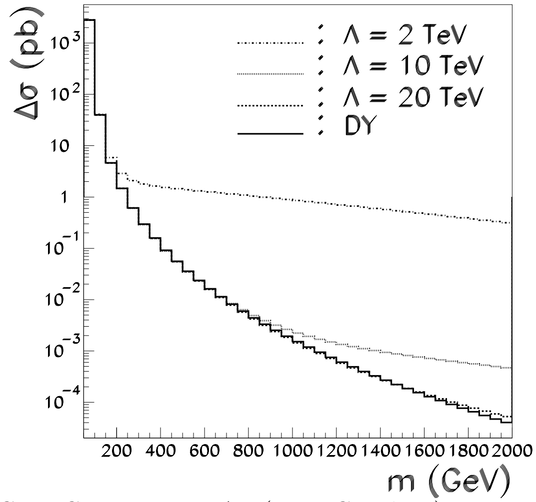

FIG. 5. Cross section, $\Delta\sigma$ (in 50 GeV bins), versus dielectron invariant mass, m, between 50 GeV and 2 TeV for DY process and three different values of Λ in the LL channel for $\eta_{ij} = +1$.

dielectron data.

- We have also explored the discovery potential for quark-electron compositeness (defined as a deviation of 5σ from SM prediction) at LHC as a function of integrated luminosity.

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TABLE V. Detection efficiency and expected number of DY events in different mass bins

mass bin (GeV)	ϵ^k	N^k_{DY} $L = 10\ fb^{-1}$	N^k_{DY} $L = 100\ fb^{-1}$
500-510	0.660	56.86	586.63
510-520	0.617	44.22	506.30
520-530	0.668	48.74	493.67
530-540	0.654	44.22	425.98
540-550	0.647	37.91	418.76
550-560	0.662	46.03	378.15
560-570	0.666	37.91	361.90
570-580	0.668	34.30	329.41
580-600	0.673	45.13	552.33
600-625	0.684	57.76	621.82
625-650	0.678	50.54	509.91
650-675	0.681	45.13	419.66
675-700	0.692	28.88	386.27
700-750	0.717	52.35	589.33
750-800	0.728	36.10	452.15
800-900	0.731	53.25	613.70
900-1000	0.756	31.59	336.63
1000-1200	0.752	36.10	315.88
1200-1400	0.782	16.25	151.62
1400-2000	0.791	16.25	135.38

TABLE VI. Expected 95% CL lower limits, Λ_{lim}, on the compositeness scale for different helicity channels of the quark-electron currents for $L = 10\ fb^{-1}$ at 14 TeV with $\delta\epsilon^k = 15\ \%$ and $\delta L = 5\ \%$

Channel	Λ_{lim} (TeV) $(\eta_{ij} = -1)$	Λ_{lim} (TeV) $(\eta_{ij} = +1)$
LL	24.0	16.4
RR	24.0	16.5
RL	21.4	17.6
LR	21.7	17.4

[1] E. Eichten, K. Lane and M.Peskin, Phys. Rev. Lett. **50**, 811 (1983);
E. Eichten, I. Hinchliffe, K. Lane and C. Quigg, *Review of Modern Physics*, **56**, October 1984.

[2] OPAL Collaboration, K. Ackerstaff *et al.*, Phys. Lett. B **391**, 221 (1997); CDF Collaboration, F. Abe *et al.*, Phys. Rev. Lett. **79**, 2198 (1997); DØ Collaboration, B. Abbott *et al.*, Phys. Rev. Lett. **82**, 4769 (1999).

[3] S.D.Drell and T.M.Yan, Phys. Rev. Lett. **25**, 316 (1970).

[4] T. Lee, Phys. Rev. D **55**, 2591 (1997).

[5] T. Sjøstrand, Comput. Phys. Commun. **82**, 74 (1994).

[6] G. Larry Bretthorst, Washington University, *An Introduction to Model Selection Using Probability Theory as Logic.*

[7] I.Bertram, G.Landsberg, J.Linneman, R.Partridge, M.Paterno, H.B.Prosper, *A Recipe for the Construction of Confidence Limits*, DØ Note 2775A, December 18, 1995.

[8] Ambreesh Gupta, *Search for New Physics in $\bar{p}p$ Collisions at 1.8 TeV*, Ph.D thesis, Tata Institute of Fundamental Research, India, 1999.

[9] R.Hamberg, W.L. van Neerven and T.Matsuura, Nucl. Phys. B **359**, 343 (1991).

[10] W.L. van Neerven, *Drell-Yan Production at Large Hadron Colliders*, INLO - PUB - 3/94.

[11] Giulio D ' Agostini, *Probability and Measurement uncertainty in Physics* - a Bayesian Primer (Notes based on lectures given to graduate students in Rome, May, 1995, and summer students at DESY, September, 1995;

[12] *The Electromagnetic Calorimeter Project*, Technical Design Report, CERN/LHCC 97-33,15 December 1997.

[13] P.de Barbaro (CDF), *et al.*, Sensitivity to Compositeness Scale for 2 fb^{-1} and 30 fb^{-1} using Drell-Yan *ee* and $\mu\mu$ events at the Tevatron, Proceedings of Snowmass 96 Conference.

TABLE VII. Expected 95% CL lower limits, Λ_{lim}, on the compositeness scale for different helicity channels of the quark-electron currents for $L = 100\ fb^{-1}$ at 14 TeV with $\delta\epsilon^k = 15\ \%$ and $\delta L = 5\ \%$

Channel	$\Lambda_{lim}\ (TeV)$ $(\eta_{ij} = -1)$	$\Lambda_{lim}\ (TeV)$ $(\eta_{ij} = +1)$
LL	33.8	20.1
RR	33.7	20.2
RL	29.2	22.1
LR	29.7	21.8

TABLE VIII. $\Lambda_{5\sigma}$ for five different integrated luminosities for $\eta_{ij} = -1$ at $\sqrt{s} = 14$ TeV with $\delta\epsilon^k = 15\ \%$ and $\delta L = 5\ \%$

	$\Lambda_{5\sigma}\ (TeV)$				
Channel	$10\ fb^{-1}$	$50\ fb^{-1}$	$100\ fb^{-1}$	$200\ fb^{-1}$	$500\ fb^{-1}$
LL	16.0	20.6	23.4	26.2	31.0
RR	16.0	20.5	23.3	26.2	30.8
RL	15.1	18.6	20.9	23.2	26.8
LR	15.1	19.1	21.1	23.5	27.1

TABLE IX. $\Lambda_{5\sigma}$ for five different integrated luminosities for $\eta_{ij} = +1$ at $\sqrt{s} = 14$ TeV with $\delta\epsilon^k = 15\ \%$ and $\delta L = 5\ \%$

	$\Lambda_{5\sigma}\ (TeV)$				
Channel	$10\ fb^{-1}$	$50\ fb^{-1}$	$100\ fb^{-1}$	$200\ fb^{-1}$	$500\ fb^{-1}$
LL	12.4	14.9	15.9	17.1	18.3
RR	12.4	14.9	16.0	17.1	18.4
RL	13.1	15.8	17.3	18.5	20.2
LR	13.0	15.7	17.2	18.3	20.0

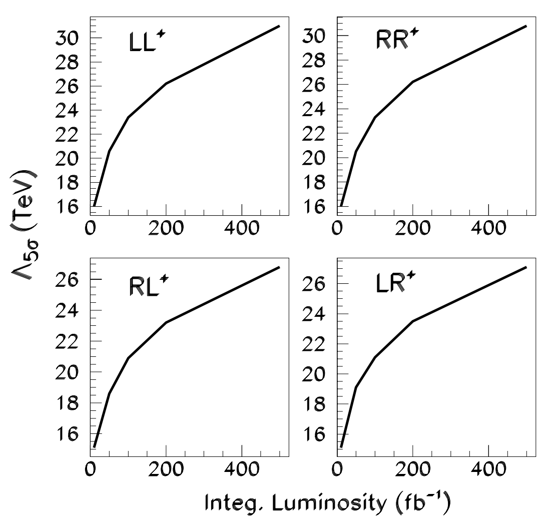

FIG. 6. 5σ discovery limit versus the integrated luminosity for $\eta_{ij} = -1$ (constructive interference).

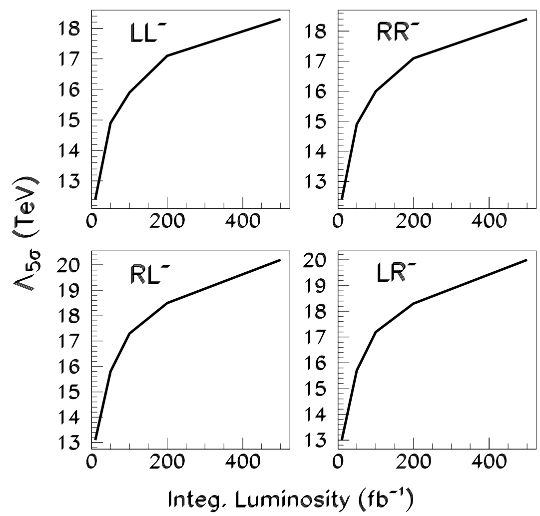

FIG. 7. 5σ discovery limit versus the integrated luminosity for $\eta_{ij} = +1$ (destructive interference).