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B. Abbott et al.
The D0 Collaboration

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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Search for Quark-Lepton Compositeness using the Drell-Yan process at DØ

The DØ Collaboration *
Fermi National Accelerator Laboratory, Batavia, Illinois 60510
(July 13, 1998)

Abstract

We present preliminary results on the search for quark-lepton compositeness using the Drell-Yan process in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. If quarks and leptons were composite with common substructure, the dielectron mass spectrum would show an excess in the high mass region relative to the Standard model. We observe no such excess. We set a 95% confidence level lower limit on the compositness scale using a contact interaction model.

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B. Abbott,[40] M. Abolins,[37] V. Abramov,[15] B.S. Acharya,[8] I. Adam,[39] D.L. Adams,[48] M. Adams,[24] S. Ahn,[23] H. Aihara,[17] G.A. Alves,[2] N. Amos,[36] E.W. Anderson,[30] R. Astur,[42] M.M. Baarmand,[42] V.V. Babintsev,[15] L. Babukhadia,[16] A. Baden,[33] V. Balamurali,[28] B. Baldin,[23] S. Banerjee,[8] J. Bantly,[45] E. Barberis,[17] P. Baringer,[31] J.F. Bartlett,[23] A. Belyaev,[14] S.B. Beri,[6] I. Bertram,[26] V.A. Bezzubov,[15] P.C. Bhat,[23] V. Bhatnagar,[6] M. Bhattacharjee,[42] N. Biswas,[28] G. Blazey,[25] S. Blessing,[21] P. Bloom,[18] A. Boehnlein,[23] N.I. Bojko,[15] F. Borcherding,[23] C. Boswell,[20] A. Brandt,[23] R. Breedon,[18] R. Brock,[37] A. Bross,[23] D. Buchholz,[26] V.S. Burtovoi,[15] J.M. Butler,[34] W. Carvalho,[2] D. Casey,[37] Z. Casilum,[42] H. Castilla-Valdez,[11] D. Chakraborty,[42] S.-M. Chang,[35] S.V. Chekulaev,[15] L.-P. Chen,[17] W. Chen,[42] S. Choi,[10] S. Chopra,[36] B.C. Choudhary,[20] J.H. Christenson,[23] M. Chung,[24] D. Claes,[38] A.R. Clark,[17] W.G. Cobau,[33] J. Cochran,[20] L. Coney,[28] W.E. Cooper,[23] C. Cretsinger,[41] D. Cullen-Vidal,[45] M.A.C. Cummings,[25] D. Cutts,[45] O.I. Dahl,[17] K. Davis,[16] K. De,[46] K. Del Signore,[36] M. Demarteau,[23] D. Denisov,[23] S.P. Denisov,[15] H.T. Diehl,[23] M. Diesburg,[23] G. Di Loreto,[37] P. Draper,[46] Y. Ducros,[5] L.V. Dudko,[14] S.R. Dugad,[8] A. Dyshkant,[15] D. Edmunds,[37] J. Ellison,[20] V.D. Elvira,[42] R. Engelmann,[42] S. Eno,[33] G. Eppley,[48] P. Ermolov,[14] O.V. Eroshin,[15] V.N. Evdokimov,[15] T. Fahland,[19] M.K. Fatyga,[41] S. Feher,[23] D. Fein,[16] T. Ferbel,[41] G. Finocchiaro,[42] H.E. Fisk,[23] Y. Fisyak,[43] E. Flattum,[23] G.E. Forden,[16] M. Fortner,[25] K.C. Frame,[37] S. Fuess,[23] E. Gallas,[46] A.N. Galyaev,[15] P. Gartung,[20] V. Gavrilov,[13] T.L. Geld,[37] R.J. Genik II,[37] K. Genser,[23] C.E. Gerber,[23] Y. Gershtein,[13] B. Gibbard,[43] B. Gobbi,[26] B. Gómez,[4] G. Gómez,[33] P.I. Goncharov,[15] J.L. González Solís,[11] H. Gordon,[43] L.T. Goss,[47] K. Gounder,[20] A. Goussiou,[42] N. Graf,[43] P.D. Grannis,[42] D.R. Green,[23] H. Greenlee,[23] S. Grinstein,[1] P. Grudberg,[17] S. Grünendahl,[23] G. Guglielmo,[44] J.A. Guida,[16] J.M. Guida,[45] A. Gupta,[8] S.N. Gurzhiev,[15] G. Gutierrez,[23] P. Gutierrez,[44] N.J. Hadley,[33] H. Haggerty,[23] S. Hagopian,[21] V. Hagopian,[21] K.S. Hahn,[41] R.E. Hall,[19] P. Hanlet,[35] S. Hansen,[23] J.M. Hauptman,[30] D. Hedin,[25] A.P. Heinson,[20] U. Heintz,[23] R. Hernández-Montoya,[11] T. Heuring,[21] R. Hirosky,[24] J.D. Hobbs,[42] B. Hoeneisen,[4,*] J.S. Hoftun,[45] F. Hsieh,[36] Ting Hu,[42] Tong Hu,[27] T. Huehn,[20] A.S. Ito,[23] E. James,[16] J. Jaques,[28] S.A. Jerger,[37] R. Jesik,[27] J.Z.-Y. Jiang,[42] T. Joffe-Minor,[26] K. Johns,[16] M. Johnson,[23] A. Jonckheere,[23] M. Jones,[22] H. Jöstlein,[23] S.Y. Jun,[26] C.K. Jung,[42] S. Kahn,[43] G. Kalbfleisch,[44] D. Karmanov,[14] D. Karmgard,[21] R. Kehoe,[28] M.L. Kelly,[28] S.K. Kim,[10] B. Klima,[23] C. Klopfenstein,[18] W. Ko,[18] J.M. Kohli,[6] D. Koltick,[29] A.V. Kostritskiy,[15] J. Kotcher,[43] A.V. Kotwal,[39] A.V. Kozelov,[15] E.A. Kozlovsky,[15] J. Krane,[38] M.R. Krishnaswamy,[8] S. Krzywdzinski,[23] S. Kuleshov,[13] S. Kunori,[33] F. Landry,[37] G. Landsberg,[23] B. Lauer,[30] A. Leflat,[14] J. Li,[46] Q.Z. Li-Demarteau,[23] J.G.R. Lima,[3] D. Lincoln,[23] S.L. Linn,[21] J. Linnemann,[37] R. Lipton,[23] F. Lobkowicz,[41] S.C. Loken,[17] A. Lucotte,[42] L. Lueking,[23] A.L. Lyon,[33] A.K.A. Maciel,[2] R.J. Madaras,[17] R. Madden,[21] L. Magaña-Mendoza,[11] V. Manankov,[14] S. Mani,[18] H.S. Mao,[23,†] R. Markeloff,[25] T. Marshall,[27] M.I. Martin,[23] K.M. Mauritz,[30] B. May,[26] A.A. Mayorov,[15] R. McCarthy,[42] J. McDonald,[21] T. McKibben,[24] J. McKinley,[37] T. McMahon,[44] H.L. Melanson,[23] M. Merkin,[14] K.W. Merritt,[23] H. Miettinen,[48] A. Mincer,[40] C.S. Mishra,[23] N. Mokhov,[23] N.K. Mondal,[8] H.E. Montgomery,[23] P. Mooney,[4] H. da Motta,[2] C. Murphy,[24] F. Nang,[16] M. Narain,[23] V.S. Narasimham,[8] A. Narayanan,[16] H.A. Neal,[36] J.P. Negret,[4] P. Nemethy,[40] D. Norman,[47] L. Oesch,[36] V. Oguri,[3] E. Oliveira,[2] E. Oltman,[17] N. Oshima,[23] D. Owen,[37] P. Padley,[48] A. Para,[23] Y.M. Park,[9] R. Partridge,[45] N. Parua,[8] M. Paterno,[41] B. Pawlik,[12]

J. Perkins,[46] M. Peters,[22] R. Piegaia,[1] H. Piekarz,[21] Y. Pischalnikov,[29] B.G. Pope,[37] H.B. Prosper,[21] S. Protopopescu,[43] J. Qian,[36] P.Z. Quintas,[23] R. Raja,[23] S. Rajagopalan,[43] O. Ramirez,[24] S. Reucroft,[35] M. Rijssenbeek,[42] T. Rockwell,[37] M. Roco,[23] P. Rubinov,[26] R. Ruchti,[28] J. Rutherfoord,[16] A. Sánchez-Hernández,[11] A. Santoro,[2] L. Sawyer,[32] R.D. Schamberger,[42] H. Schellman,[26] J. Sculli,[40] E. Shabalina,[14] C. Shaffer,[21] H.C. Shankar,[8] R.K. Shivpuri,[7] M. Shupe,[16] H. Singh,[20] J.B. Singh,[6] V. Sirotenko,[25] W. Smart,[23] E. Smith,[44] R.P. Smith,[23] R. Snihur,[26] G.R. Snow,[38] J. Snow,[44] S. Snyder,[43] J. Solomon,[24] M. Sosebee,[46] N. Sotnikova,[14] M. Souza,[2] A.L. Spadafora,[17] G. Steinbrück,[44] R.W. Stephens,[46] M.L. Stevenson,[17] D. Stewart,[36] F. Stichelbaut,[42] D. Stoker,[19] V. Stolin,[13] D.A. Stoyanova,[15] M. Strauss,[44] K. Streets,[40] M. Strovink,[17] A. Sznajder,[2] P. Tamburello,[33] J. Tarazi,[19] M. Tartaglia,[23] T.L.T. Thomas,[26] J. Thompson,[33] T.G. Trippe,[17] P.M. Tuts,[39] V. Vaniev,[15] N. Varelas,[24] E.W. Varnes,[17] D. Vititoe,[16] A.A. Volkov,[15] A.P. Vorobiev,[15] H.D. Wahl,[21] G. Wang,[21] J. Warchol,[28] G. Watts,[45] M. Wayne,[28] H. Weerts,[37] A. White,[46] J.T. White,[47] J.A. Wightman,[30] S. Willis,[25] S.J. Wimpenny,[20] J.V.D. Wirjawan,[47] J. Womersley,[23] E. Won,[41] D.R. Wood,[35] Z. Wu,[23,†] H. Xu,[45] R. Yamada,[23] P. Yamin,[43] T. Yasuda,[35] P. Yepes,[48] K. Yip,[23] C. Yoshikawa,[22] S. Youssef,[21] J. Yu,[23] Y. Yu,[10] B. Zhang,[23,†] Y. Zhou,[23,†] Z. Zhou,[30] Z.H. Zhu,[41] D. Zieminska,[27] A. Zieminski,[27] E.G. Zverev,[14] and A. Zylberstejn[5]

(DØ Collaboration)

[1]Universidad de Buenos Aires, Buenos Aires, Argentina
[2]LAFEX, Centro Brasileiro de Pesquisas Físicas, Rio de Janeiro, Brazil
[3]Universidade do Estado do Rio de Janeiro, Rio de Janeiro, Brazil
[4]Universidad de los Andes, Bogotá, Colombia
[5]DAPNIA/Service de Physique des Particules, CEA, Saclay, France
[6]Panjab University, Chandigarh, India
[7]Delhi University, Delhi, India
[8]Tata Institute of Fundamental Research, Mumbai, India
[9]Kyungsung University, Pusan, Korea
[10]Seoul National University, Seoul, Korea
[11]CINVESTAV, Mexico City, Mexico
[12]Institute of Nuclear Physics, Kraków, Poland
[13]Institute for Theoretical and Experimental Physics, Moscow, Russia
[14]Moscow State University, Moscow, Russia
[15]Institute for High Energy Physics, Protvino, Russia
[16]University of Arizona, Tucson, Arizona 85721
[17]Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720
[18]University of California, Davis, California 95616
[19]University of California, Irvine, California 92697
[20]University of California, Riverside, California 92521
[21]Florida State University, Tallahassee, Florida 32306
[22]University of Hawaii, Honolulu, Hawaii 96822
[23]Fermi National Accelerator Laboratory, Batavia, Illinois 60510

[24]University of Illinois at Chicago, Chicago, Illinois 60607
[25]Northern Illinois University, DeKalb, Illinois 60115
[26]Northwestern University, Evanston, Illinois 60208
[27]Indiana University, Bloomington, Indiana 47405
[28]University of Notre Dame, Notre Dame, Indiana 46556
[29]Purdue University, West Lafayette, Indiana 47907
[30]Iowa State University, Ames, Iowa 50011
[31]University of Kansas, Lawrence, Kansas 66045
[32]Louisiana Tech University, Ruston, Louisiana 71272
[33]University of Maryland, College Park, Maryland 20742
[34]Boston University, Boston, Massachusetts 02215
[35]Northeastern University, Boston, Massachusetts 02115
[36]University of Michigan, Ann Arbor, Michigan 48109
[37]Michigan State University, East Lansing, Michigan 48824
[38]University of Nebraska, Lincoln, Nebraska 68588
[39]Columbia University, New York, New York 10027
[40]New York University, New York, New York 10003
[41]University of Rochester, Rochester, New York 14627
[42]State University of New York, Stony Brook, New York 11794
[43]Brookhaven National Laboratory, Upton, New York 11973
[44]University of Oklahoma, Norman, Oklahoma 73019
[45]Brown University, Providence, Rhode Island 02912
[46]University of Texas, Arlington, Texas 76019
[47]Texas A&M University, College Station, Texas 77843
[48]Rice University, Houston, Texas 77005

I. INTRODUCTION

Measurement of the Drell-Yan differential cross section in the high dielectron invariant mass region provides a test for quark and lepton compositeness. If quarks and leptons were composite with common substructure, they will interact, thus modifying the cross section predicted by the Standard Model. Interaction between these constituents well below the energy scale of compositeness Λ can be described by an effective four fermion contact interaction.

A general contact interaction lagrangian [3], [4] is written as

$$\begin{aligned} L = \frac{g_0}{\Lambda^2}\{&\eta^0_{LL}(\bar{q}_L\gamma^\mu q_L)(\bar{l}_L\gamma_\mu l_L) + \eta^1_{LL}(\bar{q}_L\gamma^\mu\frac{\tau_a}{2}q_L)(\bar{l}_L\gamma_\mu\frac{\tau_a}{2}l_L) \\ &+ \eta^u_{LR}(\bar{l}_L\gamma^\mu l_L)(\bar{u}_R\gamma_\mu u_R) + \eta^d_{LR}(\bar{l}_L\gamma^\mu l_L)(\bar{d}_R\gamma_\mu d_R) \\ &+ \eta^e_{RL}(\bar{q}_L\gamma^\mu q_L)(\bar{e}_L\gamma_\mu e_L) \\ &+ \eta^u_{RR}(\bar{u}_R\gamma^\mu u_R)(\bar{e}_R\gamma_\mu e_R) + \eta^d_{RR}(\bar{d}_R\gamma^\mu d_R)(\bar{e}_R\gamma_\mu e_R) \\ &+ \eta_{SC}(\bar{q}^i_L d_R u_L)\bar{e}_R e_L l^i_L) + h.c\} \end{aligned} \tag{1}$$

where l_L=$(\nu, e)_L$ and q_l=$(u, d)_L$, $L(R)$ denotes the left(right) helicity projection, SC denotes scalar channel, and τ_a are Pauli matrices. The compositeness scale Λ is chosen so that the coupling $g_0^2/4\pi$=1 and largest $|\eta_{ij}|$=1. We set limit on compositeness scale Λ for LL, RR, RL and LR terms of equation 1. The choice of coupling coefficients η_{ij} for these models are shown in the following table:

Model	η_{LL}	η_{RR}	η_{LR}	η_{RL}
$LL^\pm$	$\pm$ 1	0	0	0
$RR^\pm$	0	$\pm$ 1	0	0
$LR^\pm$	0	0	$\pm$ 1	0
$RL^\pm$	0	0	0	$\pm$ 1
$VV^\pm$	$\pm$ 1	$\pm$ 1	$\pm$ 1	$\pm$ 1
$AA^\pm$	$\pm$ 1	$\pm$ 1	$\mp$ 1	$\mp$ 1

The VV and AA denote vector and axial vector coupling.

II. DATA SELECTION

We use the Run 1 data taken in 1992-1993 and 1994-1995 collider run corresponding to an integrated luminosity of 120.9 pb^{-1}. The dielectron trigger requires two EM clusters of 7 GeV at level 1, one of which has an energy of 12 GeV with EM fraction of 85% at level 1.5. This is a hardware trigger. In level 2 two EM clusters of 20 GeV with loose quality and isolation cuts are selected.

Electron identification is defined with two categories: "tight" and "loose".

A tight electron satisfies the following criteria: the calorimeter cluster has high electromagnetic fraction($>$ 95%); the cluster shape (transversely and longitudinally) is consistent with that expected for an electron; the cluster is isolated from other calorimeter activity,

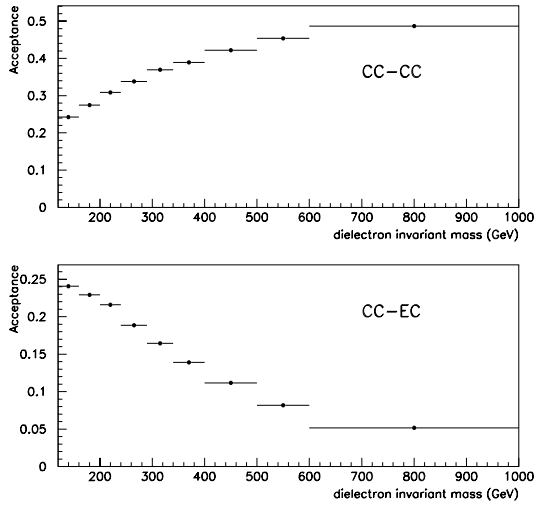

FIG. 1. Acceptance calculated for Drell-Yan events.

and there is a good quality track matched with the cluster. This last criteria is not imposed for a loose electron.

In addition, electrons are restricted to the pseudorapidity region $\mid \eta \mid < 1.1$ for Central Calorimeter(CC), and $1.5 < \mid \eta \mid < 2.5$ for the End Calorimeter. Electrons in CC near the calorimeter module edges are removed by requring $\mid \phi_e - \phi_{edge} \mid > 0.05$.

Dielectron event selection requires either both electrons central(CC-CC), or one electron central and other electron forward(CC-EC). Every event requires at least one tight electron, second electron could be tight or loose. Forward electrons are always requird to be tight. Both electrons are required to have $E_T > 25$ GeV

III. ACCEPTANCE

The acceptance of dielectron events in $p\bar{p}$ collisions is defined as the fraction of events in which both electrons pass the fiducial and kinematic cuts. We calculate the acceptance using dielectron events from Drell-Yan process, generated using PYTHIA. The detector simulation is performed using parametric Monte Carlo. Figure 1 shows the dependence of acceptance with respect to dielectron invariant. MRSA′ parton distribution functions (pdf) is used.

IV. ELECTRON IDENTIFICATION EFFICIENCY

The offline selection efficiencies for electrons are determined using the $Z \rightarrow ee$ data sample. One tight electron tags the event so that other electron can be used to calculate efficiencies. The events are chosen in mass window around Z mass.

SELECTION CUTS	CC	EC
Loose electron id	92.9±0.7%	–
Tight electron id	74.1±0.6%	52.6±1.0%

Triggers are fully efficient in the high dielectron invariant mass region. The combined dielectron identification efficiency is 81.4±1.4% for CC-CC electrons, and 47.9±1.0% for CC-EC electrons.

The mass dependence of dielectron identification efficiency is studied using GEANT based detector simulation. It shows the efficiency to be independent of dielectron mass.

V. BACKGROUNDS

The major background source is QCD jets being misidentified as electrons. Taking an unbiased jet sample which is free of electrons we estimate the probability of a jet to be misidentified as an electron. The probability depends on jet E_T and electron category. Probability of a jet with 100 GeV E_T to be misidentified as a tight electron is about 0.0008 and a loose electron is about 0.0018. The significance of this background is due to the large QCD cross section. Contributions from multijet and γ-jet events are estimated independently.

The choice of electron selection categories permits a photon to be identified as an electron. The following sources are also considered for background estimation

- $W\gamma \rightarrow ee$
- $Z\gamma \rightarrow ee$
- $t\bar{t} \rightarrow ee$
- $WW \rightarrow ee$
- $\gamma^*/Z \rightarrow \tau\tau \rightarrow ee$

We generate these process using PYTHIA and then simulate for detector effects using parametric Monte Carlo. We find these backgrounds to be small in the high dielectron invariant mass region.

VI. CROSS SECTION CALCULATION AND K FACTOR

We calculate the cross section for Drell-Yan+contact term process using the matrix elements provided in [3], [4]. These cross sections being leading order, are corrected for higher order processes using a K-factor. The K-factor is defined to be ratio of NNLO Drell-Yan cross section from [6] to LO Drell-Yan cross section calculation.

VII. LIMIT CALCULATION AND RESULTS

Figure 2 shows the event distribution of dielectron data. Figure 2 also shows normalized event distributions expected from Drell-Yan and Drell-Yan+contact interaction processes. Background is added to theoretical expectation. The effects of kinematic and fiducial cuts and detector smearing are simulated using a parametric Monte Carlo. The theoretical expectations are normalized to the data using luminosity of data, dielectron identification efficiency and K-factor. We observe no deviation from the Standard Model.

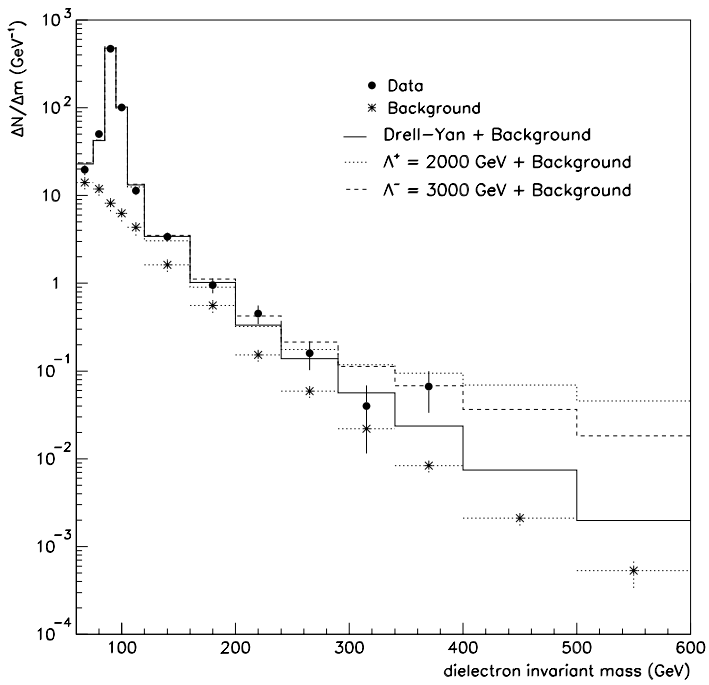

FIG. 2. Event distribution of dielectron data. The corresponding distributions for theoretical expectations are also shown, where the effects of kinematic and fiducial cuts and detector smearing are folded into the theory, and the theory is normalized to the data luminosity, dielectron identification efficiency and K factor. Background is added to theoretoical expectation. Errors shown are statistical.

In a model of composite quarks and leptons, the expected number of events N_Λ^k in the kth invariant mass bin for a compositeness scale Λ can be written in the form

$$N_\Lambda^k = b^k + \mathcal{L}\epsilon_\Lambda^k \sigma_\Lambda^k \tag{2}$$

where b^k is the expected background, $\mathcal{L}$ is the luminosity of data, ϵ_Λ^k is the signal efficiency and σ_Λ^k is the cross section predicted by the compositeness model.

The probability of the observed distribution of dielectron events, with N_0^k events in k^{th} bin, given the expected distribution due to compositeness with scale Λ can be written as

$$P(d|b_\Lambda \mathcal{L}\epsilon_\Lambda \sigma_\Lambda) = \prod_{k=1}^{n} \frac{e^{-N_\Lambda^k} {N_\Lambda^k}^{N_0^k}}{N_0^k!} \tag{3}$$

Using the Bayes technique the above probability is inverted to obtain Posterior probability denstity P($\Lambda|d$). Variation of P($\Lambda|d$) with respect to Λ is shown for positive and negative interference in figure 3. Confidence limit is calculated from the plot of cumulative probability density also shown in figure 3. The Λ value at which the cumulative probability density equals 0.95 is the 95% CL limit on Λ.

For different contact interaction models, 95% CL lower limit on energy scale of compositeness Λ is shown in the following table:

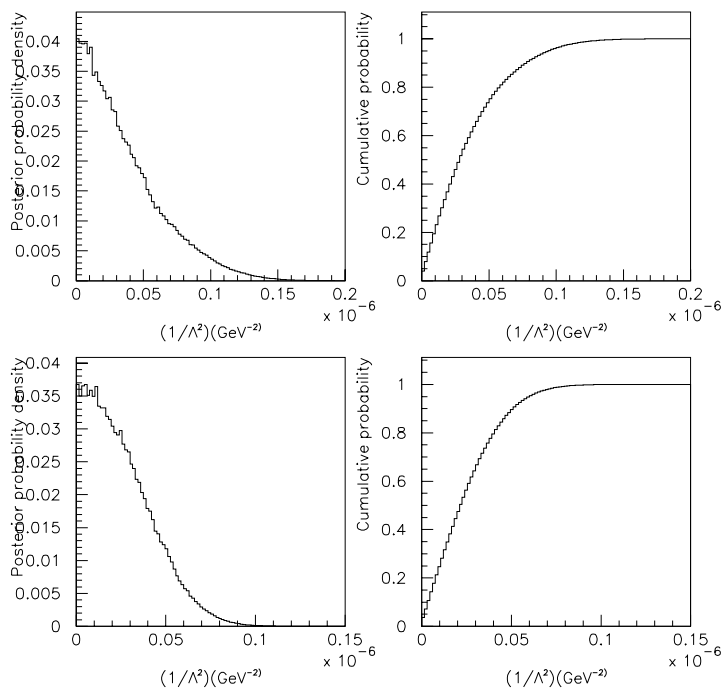

FIG. 3. Confidence level of compositeness scale Λ calculated using cumulative probability for positive and negative interference terms for the LL model.

Model	Λ^+ (GeV)	Λ^- (GeV)
LL	3300	4200
RR	3300	4000
LR	3400	3600
RL	3300	3700
VV	4900	6100
AA	4700	5500

VIII. CONCLUSIONS

Using the Run 1 data, we have studied the dielectron invariant mass spectrum at high mass. We find that the observed number of events are consistent with the Standard Model prediction and the expected backgrounds. We set limits on the cross section for quark-electron contact interactions due to compositeness. The 95% lower limit varies from $\Lambda^+ = 3300$ GeV in RR model to $\Lambda^- = 6100$ GeV in VV model.

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* Visitor from Universidad San Francisco de Quito, Quito, Ecuador.
† Visitor from IHEP, Beijing, China.

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