

Search for stopped gluinos from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV

V.M. Abazov,³⁵ B. Abbott,⁷⁵ M. Abolins,⁶⁵ B.S. Acharya,²⁸ M. Adams,⁵¹ T. Adams,⁴⁹ E. Aguilo,⁵ S.H. Ahn,³⁰
M. Ahsan,⁵⁹ G.D. Alexeev,³⁵ G. Alkhazov,³⁹ A. Alton,^{64,*} G. Alverson,⁶³ G.A. Alves,² M. Anastasoie,³⁴
L.S. Ancu,³⁴ T. Andeen,⁵³ S. Anderson,⁴⁵ B. Andrieu,¹⁶ M.S. Anzelc,⁵³ Y. Arnoud,¹³ M. Arov,⁵² A. Askew,⁴⁹
B. Åsman,⁴⁰ A.C.S. Assis Jesus,³ O. Atramentov,⁴⁹ C. Autermann,²⁰ C. Avila,⁷ C. Ay,²³ F. Badaud,¹² A. Baden,⁶¹
L. Bagby,⁵² B. Baldin,⁵⁰ D.V. Bandurin,⁵⁹ P. Banerjee,²⁸ S. Banerjee,²⁸ E. Barberis,⁶³ A.-F. Barfuss,¹⁴
P. Bargassa,⁸⁰ P. Baringer,⁵⁸ J. Barreto,² J.F. Bartlett,⁵⁰ U. Bassler,¹⁶ D. Bauer,⁴³ S. Beale,⁵ A. Bean,⁵⁸
M. Begalli,³ M. Begel,⁷¹ C. Belanger-Champagne,⁴⁰ L. Bellantoni,⁵⁰ A. Bellavance,⁵⁰ J.A. Benitez,⁶⁵ S.B. Beri,²⁶
G. Bernardi,¹⁶ R. Bernhard,²² L. Berntzon,¹⁴ I. Bertram,⁴² M. Besançon,¹⁷ R. Beuselinck,⁴³ V.A. Bezzubov,³⁸
P.C. Bhat,⁵⁰ V. Bhatnagar,²⁶ M. Binder,²⁴ C. Biscarat,¹⁹ G. Blazey,⁵² F. Blekman,⁴³ S. Blessing,⁴⁹ D. Bloch,¹⁸
K. Bloom,⁶⁷ A. Boehnlein,⁵⁰ D. Boline,⁶² T.A. Bolton,⁵⁹ G. Borissov,⁴² K. Bos,³³ T. Bose,⁷⁷ A. Brandt,⁷⁸
R. Brock,⁶⁵ G. Brooijmans,⁷⁰ A. Bross,⁵⁰ D. Brown,⁷⁸ N.J. Buchanan,⁴⁹ D. Buchholz,⁵³ M. Buehler,⁸¹
V. Buescher,²¹ S. Burdin,⁵⁰ S. Burke,⁴⁵ T.H. Burnett,⁸² E. Busato,¹⁶ C.P. Buszello,⁴³ J.M. Butler,⁶² P. Calfayan,²⁴
S. Calvet,¹⁴ J. Cammin,⁷¹ S. Caron,³³ W. Carvalho,³ B.C.K. Casey,⁷⁷ N.M. Cason,⁵⁵ H. Castilla-Valdez,³²
S. Chakrabarti,¹⁷ D. Chakraborty,⁵² K. Chan,⁵ K.M. Chan,⁷¹ A. Chandra,⁴⁸ F. Charles,¹⁸ E. Cheu,⁴⁵
F. Chevallier,¹³ D.K. Cho,⁶² S. Choi,³¹ B. Choudhary,²⁷ L. Christofek,⁷⁷ T. Christoudias,⁴³ S. Cihangir,⁵⁰
D. Claes,⁶⁷ B. Clément,¹⁸ C. Clément,⁴⁰ Y. Coadou,⁵ M. Cooke,⁸⁰ W.E. Cooper,⁵⁰ M. Corcoran,⁸⁰ F. Couderc,¹⁷
M.-C. Cousinou,¹⁴ S. Crépe-Renaudin,¹³ D. Cutts,⁷⁷ M. Ćwiok,²⁹ H. da Motta,² A. Das,⁶² G. Davies,⁴³
K. De,⁷⁸ P. de Jong,³³ S.J. de Jong,³⁴ E. De La Cruz-Burelo,⁶⁴ C. De Oliveira Martins,³ J.D. Degenhardt,⁶⁴
F. Déliot,¹⁷ M. Demarteau,⁵⁰ R. Demina,⁷¹ D. Denisov,⁵⁰ S.P. Denisov,³⁸ S. Desai,⁵⁰ H.T. Diehl,⁵⁰ M. Diesburg,⁵⁰
A. Dominguez,⁶⁷ H. Dong,⁷² L.V. Dudko,³⁷ L. Dufлот,¹⁵ S.R. Dugad,²⁸ D. Duggan,⁴⁹ A. Duperrin,¹⁴ J. Dyer,⁶⁵
A. Dyshkant,⁵² M. Eads,⁶⁷ D. Edmunds,⁶⁵ J. Ellison,⁴⁸ V.D. Elvira,⁵⁰ Y. Enari,⁷⁷ S. Eno,⁶¹ P. Ermolov,³⁷
H. Evans,⁵⁴ A. Evdokimov,³⁶ V.N. Evdokimov,³⁸ A.V. Ferapontov,⁵⁹ T. Ferbel,⁷¹ F. Fiedler,²⁴ F. Filthaut,³⁴
W. Fisher,⁵⁰ H.E. Fisk,⁵⁰ M. Ford,⁴⁴ M. Fortner,⁵² H. Fox,²² S. Fu,⁵⁰ S. Fuess,⁵⁰ T. Gadfort,⁸² C.F. Galea,³⁴
E. Gallas,⁵⁰ E. Galyaev,⁵⁵ C. Garcia,⁷¹ A. Garcia-Bellido,⁸² V. Gavrilov,³⁶ P. Gay,¹² W. Geist,¹⁸ D. Gelé,¹⁸
C.E. Gerber,⁵¹ Y. Gershtein,⁴⁹ D. Gillberg,⁵ G. Ginther,⁷¹ N. Gollub,⁴⁰ B. Gómez,⁷ A. Goussiou,⁵⁵ P.D. Grannis,⁷²
H. Greenlee,⁵⁰ Z.D. Greenwood,⁶⁰ E.M. Gregores,⁴ G. Grenier,¹⁹ Ph. Gris,¹² J.-F. Grivaz,¹⁵ A. Grohsjean,²⁴
S. Grünendahl,⁵⁰ M.W. Grünewald,²⁹ F. Guo,⁷² J. Guo,⁷² G. Gutierrez,⁵⁰ P. Gutierrez,⁷⁵ A. Haas,⁷⁰ N.J. Hadley,⁶¹
P. Haefner,²⁴ S. Hagopian,⁴⁹ J. Haley,⁶⁸ I. Hall,⁷⁵ R.E. Hall,⁴⁷ L. Han,⁶ K. Hanagaki,⁵⁰ P. Hansson,⁴⁰ K. Harder,⁴⁴
A. Harel,⁷¹ R. Harrington,⁶³ J.M. Hauptman,⁵⁷ R. Hauser,⁶⁵ J. Hays,⁴³ T. Hebbeker,²⁰ D. Hedin,⁵²
J.G. Hegeman,³³ J.M. Heinmiller,⁵¹ A.P. Heinson,⁴⁸ U. Heintz,⁶² C. Hensel,⁵⁸ K. Herner,⁷² G. Hesketh,⁶³
M.D. Hildreth,⁵⁵ R. Hirsosky,⁸¹ J.D. Hobbs,⁷² B. Hoeneisen,¹¹ H. Hoeth,²⁵ M. Hohlfield,¹⁵ S.J. Hong,³⁰ R. Hooper,⁷⁷
P. Houben,³³ Y. Hu,⁷² Z. Hubacek,⁹ V. Hynek,⁸ I. Iashvili,⁶⁹ R. Illingworth,⁵⁰ A.S. Ito,⁵⁰ S. Jabeen,⁶² M. Jaffré,¹⁵
S. Jain,⁷⁵ K. Jakobs,²² C. Jarvis,⁶¹ R. Jesik,⁴³ K. Johns,⁴⁵ C. Johnson,⁷⁰ M. Johnson,⁵⁰ A. Jonckheere,⁵⁰
P. Jonsson,⁴³ A. Juste,⁵⁰ D. Käfer,²⁰ S. Kahn,⁷³ E. Kajfasz,¹⁴ A.M. Kalinin,³⁵ J.M. Kalk,⁶⁰ J.R. Kalk,⁶⁵
S. Kappler,²⁰ D. Karmanov,³⁷ J. Kasper,⁶² P. Kasper,⁵⁰ I. Katsanos,⁷⁰ D. Kau,⁴⁹ R. Kaur,²⁶ V. Kaushik,⁷⁸
R. Kehoe,⁷⁹ S. Kermiche,¹⁴ N. Khalatyan,³⁸ A. Khanov,⁷⁶ A. Kharchilava,⁶⁹ Y.M. Kharzheev,³⁵ D. Khatidze,⁷⁰
H. Kim,³¹ T.J. Kim,³⁰ M.H. Kirby,³⁴ B. Klima,⁵⁰ J.M. Kohli,²⁶ J.-P. Konrath,²² M. Kopal,⁷⁵ V.M. Korablev,³⁸
J. Kotcher,⁷³ B. Kothari,⁷⁰ A. Koubarovsky,³⁷ A.V. Kozelov,³⁸ D. Krop,⁵⁴ A. Kryemadhi,⁸¹ T. Kuhl,²³ A. Kumar,⁶⁹
S. Kunori,⁶¹ A. Kupco,¹⁰ T. Kurča,¹⁹ J. Kvita,⁸ D. Lam,⁵⁵ S. Lammers,⁷⁰ G. Landsberg,⁷⁷ J. Lazoflores,⁴⁹
P. Lebrun,¹⁹ W.M. Lee,⁵⁰ A. Leflat,³⁷ F. Lehner,⁴¹ V. Lesne,¹² J. Leveque,⁴⁵ P. Lewis,⁴³ J. Li,⁷⁸ L. Li,⁴⁸ Q.Z. Li,⁵⁰
S.M. Lietti,⁴ J.G.R. Lima,⁵² D. Lincoln,⁵⁰ J. Linnemann,⁶⁵ V.V. Lipaev,³⁸ R. Lipton,⁵⁰ Z. Liu,⁵ L. Lobo,⁴³
A. Lobodenko,³⁹ M. Lokajicek,¹⁰ A. Lounis,¹⁸ P. Love,⁴² H.J. Lubatti,⁸² M. Lynker,⁵⁵ A.L. Lyon,⁵⁰ A.K.A. Maciel,²
R.J. Madaras,⁴⁶ P. Mättig,²⁵ C. Magass,²⁰ A. Magerkurth,⁶⁴ N. Makovec,¹⁵ P.K. Mal,⁵⁵ H.B. Malbouisson,³
S. Malik,⁶⁷ V.L. Malyshev,³⁵ H.S. Mao,⁵⁰ Y. Maravin,⁵⁹ B. Martin,¹³ R. McCarthy,⁷² A. Melnitchouk,⁶⁶
A. Mendes,¹⁴ L. Mendoza,⁷ P.G. Mercadante,⁴ M. Merkin,³⁷ K.W. Merritt,⁵⁰ A. Meyer,²⁰ J. Meyer,²¹
M. Michaut,¹⁷ H. Miettinen,⁸⁰ T. Millet,¹⁹ J. Mitrevski,⁷⁰ J. Molina,³ R.K. Mommsen,⁴⁴ N.K. Mondal,²⁸ J. Monk,⁴⁴

R.W. Moore,⁵ T. Moulik,⁵⁸ G.S. Muanza,¹⁹ M. Mulders,⁵⁰ M. Mulhearn,⁷⁰ O. Mundal,²¹ L. Mundim,³ E. Nagy,¹⁴ M. Naimuddin,⁵⁰ M. Narain,⁷⁷ N.A. Naumann,³⁴ H.A. Neal,⁶⁴ J.P. Negret,⁷ P. Neustroev,³⁹ H. Nilsen,²² C. Noeding,²² A. Nomerotski,⁵⁰ S.F. Novaes,⁴ T. Nunnemann,²⁴ V. O'Dell,⁵⁰ D.C. O'Neil,⁵ G. Obrant,³⁹ C. Ochando,¹⁵ V. Oguri,³ N. Oliveira,³ D. Onoprienko,⁵⁹ N. Oshima,⁵⁰ J. Osta,⁵⁵ R. Otec,⁹ G.J. Otero y Garzón,⁵¹ M. Owen,⁴⁴ P. Padley,⁸⁰ M. Pangilinan,⁷⁷ N. Parashar,⁵⁶ S.-J. Park,⁷¹ S.K. Park,³⁰ J. Parsons,⁷⁰ R. Partridge,⁷⁷ N. Parua,⁵⁴ A. Patwa,⁷³ G. Pawloski,⁸⁰ P.M. Perea,⁴⁸ K. Peters,⁴⁴ Y. Peters,²⁵ P. Pétroff,¹⁵ M. Petteni,⁴³ R. Piegaia,¹ J. Piper,⁶⁵ M.-A. Pleier,²¹ P.L.M. Podesta-Lerma,^{32,§} V.M. Podstavkov,⁵⁰ Y. Pogorelov,⁵⁵ M.-E. Pol,² A. Pompoš,⁷⁵ B.G. Pope,⁶⁵ A.V. Popov,³⁸ C. Potter,⁵ W.L. Prado da Silva,³ H.B. Prosper,⁴⁹ S. Protopopescu,⁷³ J. Qian,⁶⁴ A. Quadt,²¹ B. Quinn,⁶⁶ M.S. Rangel,² K.J. Rani,²⁸ K. Ranjan,²⁷ P.N. Ratoff,⁴² P. Renkel,⁷⁹ S. Reucroft,⁶³ P. Rich,⁴⁴ M. Rijssenbeek,⁷² I. Ripp-Baudot,¹⁸ F. Rizatdinova,⁷⁶ S. Robinson,⁴³ R.F. Rodrigues,³ C. Royon,¹⁷ P. Rubinov,⁵⁰ R. Ruchti,⁵⁵ G. Sajot,¹³ A. Sánchez-Hernández,³² M.P. Sanders,¹⁶ A. Santoro,³ G. Savage,⁵⁰ L. Sawyer,⁶⁰ T. Scanlon,⁴³ D. Schaile,²⁴ R.D. Schamberger,⁷² Y. Scheglov,³⁹ H. Schellman,⁵³ P. Schieferdecker,²⁴ C. Schmitt,²⁵ C. Schwanenberger,⁴⁴ A. Schwartzman,⁶⁸ R. Schwienhorst,⁶⁵ J. Sekaric,⁴⁹ S. Sengupta,⁴⁹ H. Severini,⁷⁵ E. Shabalina,⁵¹ M. Shamim,⁵⁹ V. Shary,¹⁷ A.A. Shchukin,³⁸ R.K. Shivpuri,²⁷ D. Shpakov,⁵⁰ V. Siccardi,¹⁸ R.A. Sidwell,⁵⁹ V. Simak,⁹ V. Sirotenko,⁵⁰ P. Skubic,⁷⁵ P. Slattery,⁷¹ D. Smirnov,⁵⁵ R.P. Smith,⁵⁰ G.R. Snow,⁶⁷ J. Snow,⁷⁴ S. Snyder,⁷³ S. Söldner-Rembold,⁴⁴ L. Sonnenschein,¹⁶ A. Sopczak,⁴² M. Sosebee,⁷⁸ K. Soustruznik,⁸ M. Souza,² B. Spurlock,⁷⁸ J. Stark,¹³ J. Steele,⁶⁰ V. Stolin,³⁶ A. Stone,⁵¹ D.A. Stoyanova,³⁸ J. Strandberg,⁶⁴ S. Strandberg,⁴⁰ M.A. Strang,⁶⁹ M. Strauss,⁷⁵ R. Ströhmer,²⁴ D. Strom,⁵³ M. Strovink,⁴⁶ L. Stutte,⁵⁰ S. Sumowidagdo,⁴⁹ P. Svoisky,⁵⁵ A. Sznajder,³ M. Talby,¹⁴ P. Tamburello,⁴⁵ A. Tanasijczuk,¹ W. Taylor,⁵ P. Telford,⁴⁴ J. Temple,⁴⁵ B. Tiller,²⁴ F. Tissandier,¹² M. Titov,¹⁷ V.V. Tokmenin,³⁵ M. Tomoto,⁵⁰ T. Toole,⁶¹ I. Torchiani,²² T. Trefzger,²³ S. Trincz-Duvoid,¹⁶ D. Tsybychev,⁷² B. Tuchming,¹⁷ C. Tully,⁶⁸ P.M. Tuts,⁷⁰ R. Unalan,⁶⁵ L. Uvarov,³⁹ S. Uvarov,³⁹ S. Uzunyan,⁵² B. Vachon,⁵ P.J. van den Berg,³³ B. van Eijk,³⁵ R. Van Kooten,⁵⁴ W.M. van Leeuwen,³³ N. Varelas,⁵¹ E.W. Varnes,⁴⁵ A. Vartapetian,⁷⁸ I.A. Vasilyev,³⁸ M. Vaupel,²⁵ P. Verdier,¹⁹ L.S. Vertogradov,³⁵ M. Verzocchi,⁵⁰ F. Villeneuve-Seguiet,⁴³ P. Vint,⁴³ J.-R. Vlimant,¹⁶ E. Von Toerne,⁵⁹ M. Voutilainen,^{67,‡} M. Vreeswijk,³³ H.D. Wahl,⁴⁹ L. Wang,⁶¹ M.H.L.S Wang,⁵⁰ J. Warchol,⁵⁵ G. Watts,⁸² M. Wayne,⁵⁵ G. Weber,²³ M. Weber,⁵⁰ H. Weerts,⁶⁵ A. Wenger,^{22,#} N. Wermes,²¹ M. Wetstein,⁶¹ A. White,⁷⁸ D. Wicke,²⁵ G.W. Wilson,⁵⁸ S.J. Wimpenny,⁴⁸ M. Wobisch,⁵⁰ D.R. Wood,⁶³ T.R. Wyatt,⁴⁴ Y. Xie,⁷⁷ S. Yacoob,⁵³ R. Yamada,⁵⁰ M. Yan,⁶¹ T. Yasuda,⁵⁰ Y.A. Yatsunenko,³⁵ K. Yip,⁷³ H.D. Yoo,⁷⁷ S.W. Youn,⁵³ C. Yu,¹³ J. Yu,⁷⁸ A. Yurkewicz,⁷² A. Zatserklyaniy,⁵² C. Zeitnitz,²⁵ D. Zhang,⁵⁰ T. Zhao,⁸² B. Zhou,⁶⁴ J. Zhu,⁷² M. Zielinski,⁷¹ D. Zieminska,⁵⁴ A. Zieminski,⁵⁴ V. Zutshi,⁵² and E.G. Zverev³⁷

(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 *Instituto de Física Teórica, Universidade Estadual Paulista, São Paulo, Brazil*

⁵ *University of Alberta, Edmonton, Alberta, Canada, Simon Fraser University, Burnaby, British Columbia, Canada, York University, Toronto, Ontario, Canada, and McGill University, Montreal, Quebec, Canada*

⁶ *University of Science and Technology of China, Hefei, People's Republic of China*

⁷ *Universidad de los Andes, Bogotá, Colombia*

⁸ *Center for Particle Physics, Charles University, Prague, Czech Republic*

⁹ *Czech Technical University, Prague, Czech Republic*

¹⁰ *Center for Particle Physics, Institute of Physics, Academy of Sciences of the Czech Republic, Prague, Czech Republic*

¹¹ *Universidad San Francisco de Quito, Quito, Ecuador*

¹² *Laboratoire de Physique Corpusculaire, IN2P3-CNRS, Université Blaise Pascal, Clermont-Ferrand, France*

¹³ *Laboratoire de Physique Subatomique et de Cosmologie, IN2P3-CNRS, Université de Grenoble 1, Grenoble, France*

¹⁴ *CPPM, IN2P3-CNRS, Université de la Méditerranée, Marseille, France*

¹⁵ *Laboratoire de l'Accélérateur Linéaire, IN2P3-CNRS et Université Paris-Sud, Orsay, France*

¹⁶ *LPNHE, IN2P3-CNRS, Universités Paris VI and VII, Paris, France*

¹⁷ *DAPNIA/Service de Physique des Particules, CEA, Saclay, France*

¹⁸ *IPHC, IN2P3-CNRS, Université Louis Pasteur, Strasbourg, France, and Université de Haute Alsace, Mulhouse, France*

¹⁹ *IPNL, Université Lyon 1, CNRS/IN2P3, Villeurbanne, France and Université de Lyon, Lyon, France*

²⁰ *III. Physikalisches Institut A, RWTH Aachen, Aachen, Germany*

²¹ *Physikalisches Institut, Universität Bonn, Bonn, Germany*

²² *Physikalisches Institut, Universität Freiburg, Freiburg, Germany*

²³ *Institut für Physik, Universität Mainz, Mainz, Germany*

²⁴ *Ludwig-Maximilians-Universität München, München, Germany*

²⁵ *Fachbereich Physik, University of Wuppertal, Wuppertal, Germany*

- ²⁶ Panjab University, Chandigarh, India
²⁷ Delhi University, Delhi, India
²⁸ Tata Institute of Fundamental Research, Mumbai, India
²⁹ University College Dublin, Dublin, Ireland
³⁰ Korea Detector Laboratory, Korea University, Seoul, Korea
³¹ SungKyunKwan University, Suwon, Korea
³² CINVESTAV, Mexico City, Mexico
³³ FOM-Institute NIKHEF and University of Amsterdam/NIKHEF, Amsterdam, The Netherlands
³⁴ Radboud University Nijmegen/NIKHEF, Nijmegen, The Netherlands
³⁵ Joint Institute for Nuclear Research, Dubna, Russia
³⁶ Institute for Theoretical and Experimental Physics, Moscow, Russia
³⁷ Moscow State University, Moscow, Russia
³⁸ Institute for High Energy Physics, Protvino, Russia
³⁹ Petersburg Nuclear Physics Institute, St. Petersburg, Russia
⁴⁰ Lund University, Lund, Sweden, Royal Institute of Technology and Stockholm University, Stockholm, Sweden, and Uppsala University, Uppsala, Sweden
⁴¹ Physik Institut der Universität Zürich, Zürich, Switzerland
⁴² Lancaster University, Lancaster, United Kingdom
⁴³ Imperial College, London, United Kingdom
⁴⁴ University of Manchester, Manchester, United Kingdom
⁴⁵ University of Arizona, Tucson, Arizona 85721, USA
⁴⁶ Lawrence Berkeley National Laboratory and University of California, Berkeley, California 94720, USA
⁴⁷ California State University, Fresno, California 93740, USA
⁴⁸ University of California, Riverside, California 92521, USA
⁴⁹ Florida State University, Tallahassee, Florida 32306, USA
⁵⁰ Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA
⁵¹ University of Illinois at Chicago, Chicago, Illinois 60607, USA
⁵² Northern Illinois University, DeKalb, Illinois 60115, USA
⁵³ Northwestern University, Evanston, Illinois 60208, USA
⁵⁴ Indiana University, Bloomington, Indiana 47405, USA
⁵⁵ University of Notre Dame, Notre Dame, Indiana 46556, USA
⁵⁶ Purdue University Calumet, Hammond, Indiana 46323, USA
⁵⁷ Iowa State University, Ames, Iowa 50011, USA
⁵⁸ University of Kansas, Lawrence, Kansas 66045, USA
⁵⁹ Kansas State University, Manhattan, Kansas 66506, USA
⁶⁰ Louisiana Tech University, Ruston, Louisiana 71272, USA
⁶¹ University of Maryland, College Park, Maryland 20742, USA
⁶² Boston University, Boston, Massachusetts 02215, USA
⁶³ Northeastern University, Boston, Massachusetts 02115, USA
⁶⁴ University of Michigan, Ann Arbor, Michigan 48109, USA
⁶⁵ Michigan State University, East Lansing, Michigan 48824, USA
⁶⁶ University of Mississippi, University, Mississippi 38677, USA
⁶⁷ University of Nebraska, Lincoln, Nebraska 68588, USA
⁶⁸ Princeton University, Princeton, New Jersey 08544, USA
⁶⁹ State University of New York, Buffalo, New York 14260, USA
⁷⁰ Columbia University, New York, New York 10027, USA
⁷¹ University of Rochester, Rochester, New York 14627, USA
⁷² State University of New York, Stony Brook, New York 11794, USA
⁷³ Brookhaven National Laboratory, Upton, New York 11973, USA
⁷⁴ Langston University, Langston, Oklahoma 73050, USA
⁷⁵ University of Oklahoma, Norman, Oklahoma 73019, USA
⁷⁶ Oklahoma State University, Stillwater, Oklahoma 74078, USA
⁷⁷ Brown University, Providence, Rhode Island 02912, USA
⁷⁸ University of Texas, Arlington, Texas 76019, USA
⁷⁹ Southern Methodist University, Dallas, Texas 75275, USA
⁸⁰ Rice University, Houston, Texas 77005, USA
⁸¹ University of Virginia, Charlottesville, Virginia 22901, USA
⁸² University of Washington, Seattle, Washington 98195, USA

(Dated: April 11, 2007)

A long-lived, colored, heavy particle is predicted in several models of beyond the standard model physics, one example being the gluino (\tilde{g}) in split supersymmetry. Gluinos carry color charge and are thus expected to hadronize, if long lived, into colorless bound states called R-hadrons. Some

fraction of the R-hadrons can become charged and lose enough momentum through ionization to come to rest in dense particle detectors. Approximately 410 pb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96 \text{ TeV}$ collected with the D0 detector during Run II of the Fermilab Tevatron collider is analyzed in search of such “stopped gluinos” decaying into a gluon and a neutralino (χ_1^0), reconstructed as a jet and missing energy. No excess is observed above the expected backgrounds, and limits are placed on the (gluino cross section) \times (probability to stop) \times $[\text{BR}(\tilde{g} \rightarrow g\chi_1^0)]$ as a function of the gluino and χ_1^0 masses, for gluino lifetimes from $30 \mu\text{s} - 100 \text{ hours}$.

PACS numbers: 14.80.Ly, 13.85.Rm, 12.60.Jv, 11.30.Pb, 13.85.-t, 14.80.-j

Split supersymmetry is a relatively new variant of supersymmetry (SUSY), in which the SUSY scalars are heavy (possibly GUT-scale) compared to the SUSY fermions [1]. Due to the scalars’ high masses, gluino decays are suppressed, and the gluino can be long-lived. The gluinos hadronize into “R-hadrons” [2], colorless bound states of a gluino and other quarks or gluons. In $p\bar{p}$ collisions, gluinos could be pair produced through strong interactions. As studied in Ref. [3], some 20–30% (depending on $M_{\tilde{g}}$) of R-hadrons at the Tevatron can become “stopped gluinos” by becoming charged through nuclear interactions, losing all of their momentum through ionization, and coming to rest in surrounding dense material.

About 410 pb^{-1} of data taken with the D0 detector [4] from November 2002 to August 2004 were analyzed in search of stopped gluinos. The D0 detector has a magnetic central tracking system surrounded by a uranium/liquid-argon calorimeter, contained within a muon spectrometer. The tracking system consists of a silicon microstrip tracker (SMT) and a central fiber tracker (CFT), both located within a 2 T solenoidal magnet. The SMT and CFT have designs optimized for tracking and vertexing at pseudorapidities $|\eta| < 2.5$, where $\eta = -\ln[\tan(\theta/2)]$, and θ is the polar angle with respect to the proton beam direction (z). The calorimeter has a central section (CC) covering up to $|\eta| \approx 1.1$, and two end calorimeters (EC) extending coverage to $|\eta| \approx 4.2$, all housed in separate cryostats [5]. The calorimeter is divided into an electromagnetic part followed by fine and coarse hadronic sections. Calorimeter cells are arranged in pseudo-projective towers of size 0.1×0.1 in $\eta \times \phi$, where ϕ is the azimuthal angle. The muon system consists of a layer of tracking detectors and scintillation trigger counters in front of 1.8 T iron toroidal magnets (the A layer), followed by two similar layers behind the toroids (the B and C layers), which provide muon tracking for $|\eta| < 2$. The luminosity is measured using scintillator arrays located in front of the EC cryostats, covering $2.7 < |\eta| < 4.4$. The trigger system comprises three levels (L1, L2, and L3), each performing an increasingly detailed event reconstruction in order to select the events of interest.

We search for stopped gluinos decaying into a gluon and a neutralino. The gluino lifetime is assumed to be long enough such that the decay event is closest in time

to an accelerator bunch crossing later than the one that produced the gluino. For the L1 trigger to be live again during the decay even if the production event was triggered on, this lifetime must be at least $30 \mu\text{s}$, due to trigger electronics deadtime. The efficiency for recording the gluino decay is modeled as a function of the gluino lifetime, up to a lifetime of 100 hours. When the decay occurs during a bunch crossing with very little other high- p_T activity, the signal signature is a largely empty event with a single high-energy deposit in the calorimeter, reconstructed as a jet and large missing transverse energy (\cancel{E}_T).

Since no $p\bar{p}$ interaction is expected to be correlated with the stopped gluino decay, the trigger for each event requires that neither of the luminosity scintillator arrays fired. At least two calorimeter towers of size $\eta \times \phi = 0.2 \times 0.2$ with $E_T > 3 \text{ GeV}$ are also required at L1. A reconstructed jet with $E_T > 15 \text{ GeV}$ is required at L3. Jets are reconstructed with the Run II Improved Legacy Cone Algorithm [6] with a cone of radius 0.5 in $\eta \times \phi$ space. Loose cuts are used to select a data sample to study. We require exactly one jet in the event with $E > 90 \text{ GeV}$, and no other jets with $E_T > 8 \text{ GeV}$. The 90 GeV threshold is high enough such that the calorimeter part of the trigger is nearly 100% efficient.

To simulate stopped gluino decays, the PYTHIA [7] event generator is used to produce Z +gluon events, with the Z boson forced to decay to neutrinos. The location of the interaction point is placed inside the calorimeter, and events are further weighted such that the final decay position distribution is that expected for stopped gluinos. The radial location of the gluino when it decays depends on the way gluinos lose energy via ionization and stop in the calorimeters. This calculation was performed [3] for a distribution of material similar to that of the D0 calorimeters and a gluino velocity distribution as expected from production at the Tevatron. The η distribution is determined by the fact that gluinos would tend to be produced near threshold at the Tevatron, and that only slow gluinos would stop. The gluinos are thus expected to be distributed proportionally to $\sin \theta$. More than 75% of gluinos that stop have $|\eta| < 1$. Initial-state radiation is turned off in PYTHIA as are multiple parton interactions. The spectator particles coming from the rest of the $p\bar{p}$ interaction, such as the underlying event, are removed at the generator stage by removing

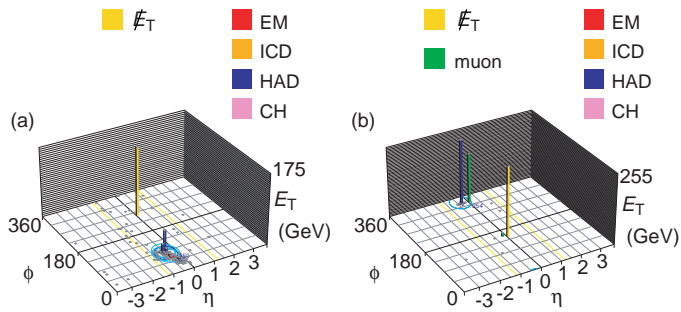


FIG. 1: a) A simulated stopped gluino decay event, for $M_{\tilde{g}}=400$ GeV. b) A typical cosmic muon shower, from hard Bremsstrahlung. The height of each bar corresponds to the total E_T in that $\eta \times \phi$ calorimeter tower. The \cancel{E}_T is shown as a yellow bar and reconstructed muons are shown in green (color online).

all far-forward particles with $|p_z/E| > 0.95$. Because the gluinos are at rest and randomly oriented in space when they decay, the gluon is emitted in a random direction. Thus a random 3D rotation is applied to the simulated particles.

The energy of the gluon, which hadronizes and fragments into a jet, depends on the gluino and neutralino masses: $E = (M_{\tilde{g}}^2 - M_{\chi_1^0}^2)/2M_{\tilde{g}}$. Simulated jets are corrected for relative differences between the data and simulation jet energy scales. The calorimeter electronics sample the shaped ionization signal only once per bunch crossing, at the assumed peak of the signal for jets originating from a $p\bar{p}$ interaction, but the gluino decay can occur at any time with respect to a bunch crossing. So jet energies in the simulation are also corrected (downwards) according to a model of this “out-of-time” calorimeter response. The average degradation of energy is 30%, although more than half of the jets are not significantly degraded.

We generate four samples of stopped gluinos, containing about 1000 events each, using a GEANT-based [8] detector simulation and reconstructed using the same algorithms as data. They correspond to gluino masses of 200, 300, 400, and 500 GeV, with a neutralino mass of 90 GeV. These samples correspond to generated gluon energies of 80, 137, 190, and 242 GeV, respectively. An event display of a simulated stopped gluino decay is shown in Fig. 1(a).

The primary source of background is cosmic muons, which are able to fake a gluino signal if they initiate a high-energy shower within the calorimeter. Hard Bremsstrahlung emission is responsible for the majority of the showers. These showers tend to be very short, since they are electromagnetic in nature and thus have small lengths compared to hadronic showers. Most of the energy is deposited in a few calorimeter towers, forming a narrow cluster, see Fig. 1(b). However, sometimes a wide, hadronic-like, shower can be created either due to

real deep-inelastic scattering, fluctuations of the shower, or detector effects.

Cosmic muons can usually be identified by the presence of a high-energy muon, either entering or exiting the detector, using the muon detectors. In particular, a coincidence of muon hits in the outer two layers of the muon system, behind the thick iron toroid magnet, is very strong evidence of a muon. The inner-layer muon hits are often also caused by the signal, due to particles escaping the calorimeters, so are difficult to use for background rejection. Sometimes the muon is not detected, due to detector inefficiencies, being out-of-time with the bunch crossing, or the limited acceptance. Muons can also be detected, in principle, through their ionizing interactions in the calorimeter, where they are a minimum-ionizing particle (MIP). However, these MIP trails are difficult to identify in this geometry where the direction of the muon path is unknown, and also there is a large shower nearby which overlaps with the energy deposited by the MIP.

Another source of background events is beam-halo muons, or “beam-muons.” These are real muons, synchronized with the $p\bar{p}$ bunch crossings, and traveling nearly parallel to the beam. Often, a muon scintillator hit or two can be associated with the muon, and the muon is measured to be within $\Delta t < 10$ ns of a bunch crossing. Another feature of the beam-muons is that they are nearly all in the plane of the accelerator beam, due to the geometry of the accelerator bending magnets. Beam-muon showers are also typically very narrow in ϕ .

Since the trigger requires no firing of the luminosity scintillator arrays, nearly all of the $p\bar{p}$ beam produced backgrounds are eliminated. An exception is diffractive events with forward rapidity gaps in both the positive and negative η regions. Typical $p\bar{p}$ events have a primary vertex (PV) reconstructed from tracks which originate near to each other along the beamline, where the $p\bar{p}$ interaction occurred. After requiring no PV to be reconstructed and large \cancel{E}_T (implicit from the requirement of a single high-energy jet), the $p\bar{p}$ events are eliminated. Dijet events in the same data sample are studied to understand the \cancel{E}_T spectrum and PV reconstruction efficiency for beam-related backgrounds. Other sources of physics background considered are cosmic neutrons and neutrinos, both of which are found to be negligible.

Finally, since the signal process is rare, we also consider occasional fake signals caused by detector readout errors or excessive noise. We require the jet to be in $|\eta| < 0.9$, since the forward regions of the calorimeter are observed to have more frequent (yet still rare) problems. Also, the gluino signal tends to be concentrated in the central detector region. Remaining problems are isolated to a specific set of runs, detector region, or both, and such events are removed.

Given the background characteristics, the following criteria are used to select events containing “wide-showers”:

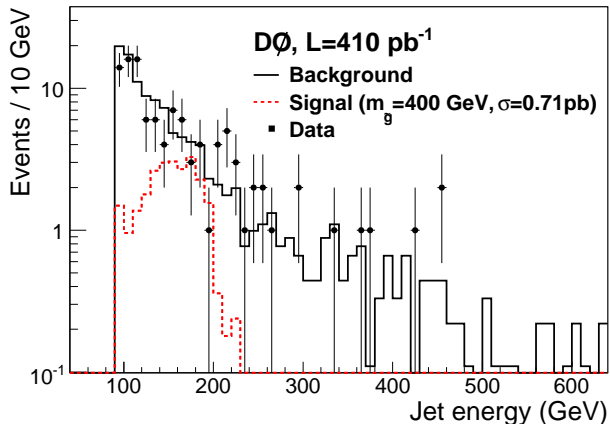


FIG. 2: A comparison of the wide-shower no-muon data (points) to the expected background (solid histogram). Also shown is the simulated signal for $M_{\tilde{g}}=400$ GeV and $M_{\chi_1^0}=90$ GeV at the excluded production cross section limit of 0.71 pb (dashed histogram).

jet η -width and ϕ -width >0.08 and jet $n_{90} \geq 10$, where n_{90} is the smallest number of calorimeter towers in the jet that make up 90% of the jet transverse energy. The reverse criteria define a “narrow-shower.” Criteria are also defined which select events containing “no-muon” or a “cosmic-muon.” An event contains no-muon if there are no B-C layer muon segments in the event, and no A layer segments with $\Delta\phi > 1.5$ radians from the jet direction. Cosmic-muon events have at least one B-C layer muon segment with $|\Delta t| > 10$ ns from the bunch crossing time. A candidate stopped gluino decay event contains both a wide-shower and no-muon.

To estimate the number of such wide-shower no-muon events expected from backgrounds, we use the assumption that the probability not to reconstruct the cosmic muon in the muon system is independent of whether the muon’s shower in the calorimeter is narrow or wide. We first measure the probability to not reconstruct the muon (P_{nomu}) in the narrow-shower muon data sample, and determine $P_{\text{nomu}}=0.11 \pm 0.01$, independent of jet energy. This probability is then applied to the wide-shower cosmic-muon data sample to predict the jet energy spectrum of wide-shower no-muon background events, as shown in Fig. 2 along with the observed wide-shower no-muon events in data. The data agree with the estimated background, and there is no significant excess of data in any jet energy range.

We search for a signal in jet energy ranges with sizes chosen from the jet energy resolutions of the simulated signal samples. The ranges are from $M - \sigma/2$ to $M + 2\sigma$, where M is the mean jet energy of the sample and σ is the sample’s jet energy RMS after all selections and corrections. Approximately 80% of the simulated signal events are within this window cut, depending weakly on

TABLE I: The data, background, signal efficiency (for stopped gluinos where $\tilde{g} \rightarrow g\chi_1^0$), and expected and observed cross section upper limits (at the 95% C.L.) for each jet energy range, for a small gluino lifetime, less than 3 hours.

Energy (GeV)	Data	Bgnd.	Eff.	Exp. (pb)	Obs. (pb)
92.5–104.6	30	37	0.017	2.61	1.81
112.4–156.6	39	40	0.049	0.94	0.89
141.3–213.0	34	31	0.068	0.56	0.71
168.7–270.6	32	26	0.072	0.48	0.75

the signal mass. An asymmetric window is chosen since the background is steeply falling with increasing jet energy.

To first order, the detection efficiency for the decays of the stopped gluino signal events can be estimated from the simulation, but some effects are not modeled. There is a loss of efficiency at the trigger level from the requirement of neither luminosity scintillator array firing. If a minimum bias collision happens to occur during the bunch crossing when the gluino decays, a luminosity scintillator array may fire. The fraction of the time this occurs has been measured using cosmic-muon events triggered on a jet-only trigger with high threshold. The efficiency of the luminosity scintillator array trigger requirement, averaged over the data set, is 75%. The probability to have minimum bias interactions during a given crossing is Poisson distributed, with a mean proportional to the instantaneous luminosity. A detailed model of the trigger efficiency is made as a function of the gluino lifetime, for lifetimes up to 100 hours, using the typical Tevatron store luminosity profile as an input. Stores typically last about 24 hours with a 50% chance of another store following, 6 hours later. Another source of inefficiency is that the trigger is not live all the time, but only during the “live super-bunches,” which make up 68% of the total run time.

The uncertainties from all sources which affect the signal acceptance are added in quadrature, totaling (20–25)%. They include the modeling of the out-of-time jet response (12%), the data/simulation jet energy scale (9%), the η and radial distributions of stopped gluinos [(7–9)%], other geometrical or kinematic acceptances (5%), and trigger efficiency [(5–15)%].

Given an observed number of candidate events, an expected number of background events, and a signal efficiency in a certain jet energy range, we can exclude at the 95% C.L. a calculated rate of signal events giving jets of that energy, taking systematic uncertainties into account. This is a fairly model-independent result, limiting the rate of any out-of-time mono-jet signal of a given energy. Table I shows the observed and expected cross section limits, for a small gluino lifetime, less than 3 hours.

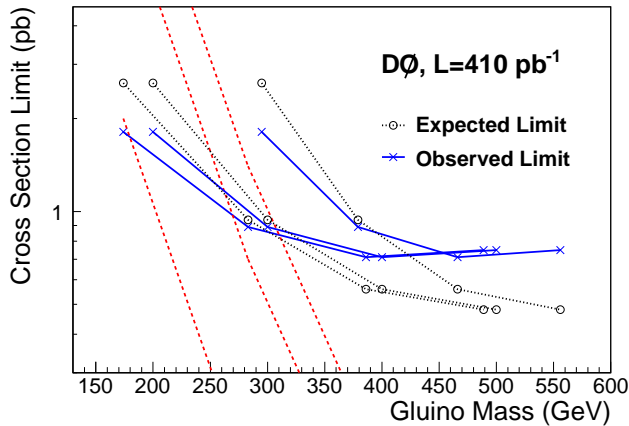


FIG. 3: The 95% C.L. expected (dotted line, circles) and observed (solid line, crosses) upper limits on the cross section of stopped gluinos, assuming a 100% BR of $\tilde{g} \rightarrow g\chi_1^0$ and a small gluino lifetime (< 3 hours), for three choices of the simulated χ_1^0 mass: 50, 90 and 200 GeV, from left to right. Also shown is the theoretical cross section (dashed line), from Ref. [3], for conversion cross sections of 0.3, 3, and 30 mb (left to right).

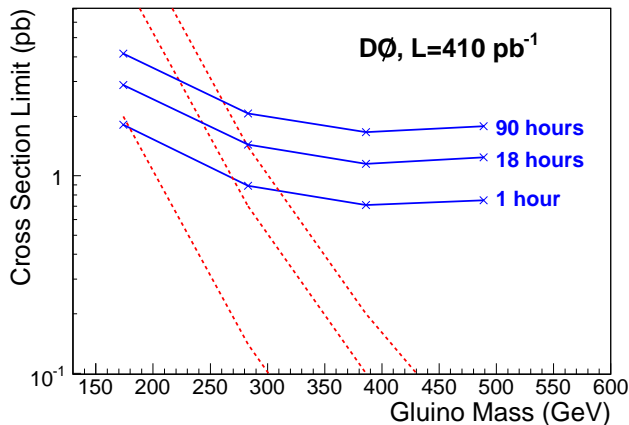


FIG. 4: The 95% C.L. upper limits observed on the cross section of stopped gluinos (solid line, crosses), assuming a 100% BR of $\tilde{g} \rightarrow g\chi_1^0$, for various assumptions of the gluino lifetime: 1, 18, and 90 hours, for a χ_1^0 mass of 50 GeV. Also shown is the theoretical cross section (dashed line), from Ref. [3], for conversion cross sections of 0.3, 3, and 30 mb (left to right).

From the relation between the gluino and χ_1^0 masses and the observed jet energy, results can be translated from the generated set of signal samples to any other set of $(M_{\tilde{g}}, M_{\chi_1^0})$ which would give the same jet energy. We can therefore place upper limits on the stopped gluino cross section vs. the gluino mass, for an assumed χ_1^0 mass, assuming a 100% branching fraction for $\tilde{g} \rightarrow g\chi_1^0$. These can be compared with the predicted cross sections for stopped gluinos (which include its production rate and its probability to stop) taken from Ref. [3]. Three curves are drawn to represent the large theory uncertainty, resulting

from the variation of the neutral to charged R-hadron conversion cross section used. Fig. 3 shows these upper limits for χ_1^0 masses of 50, 90, and 200 GeV, for a small gluino lifetime, less than 3 hours. If the gluino lifetime is greater than 3 hours, the average efficiency of the trigger degrades because signal events are not recorded between accelerator stores. The resulting effect on the stopped gluino cross section limits for a χ_1^0 mass of 50 GeV is shown in Fig. 4.

This is the first search for exotic, out-of-time energy deposits at a high-energy collider. The results from 410 pb^{-1} of Tevatron data are able to exclude a cross section of about 1 pb for gluinos stopping in the D0 calorimeter and decaying to a gluon plus neutralino. For a χ_1^0 mass of 50 GeV, we are able to exclude $M_{\tilde{g}} < 270$ GeV, assuming a 100% branching fraction for $\tilde{g} \rightarrow g\chi_1^0$, a gluino lifetime less than 3 hours, and a neutral to charged R-hadron conversion cross section of 3 mb.

Thanks to Jay Wacker for very helpful inputs and discussions. We thank the staffs at Fermilab and collaborating institutions, and acknowledge support from the DOE and NSF (USA); CEA and CNRS/IN2P3 (France); FASI, Rosatom and RFBR (Russia); CAPES, CNPq, FAPERJ, FAPESP and FUNDUNESP (Brazil); DAE and DST (India); Colciencias (Colombia); CONACyT (Mexico); KRF and KOSEF (Korea); CONICET and UBACyT (Argentina); FOM (The Netherlands); PPARC (United Kingdom); MSMT (Czech Republic); CRC Program, CFI, NSERC and WestGrid Project (Canada); BMBF and DFG (Germany); SFI (Ireland); The Swedish Research Council (Sweden); Research Corporation; Alexander von Humboldt Foundation; and the Marie Curie Program.

-
- [*] Visitor from Augustana College, Sioux Falls, SD, USA.
 - [§] Visitor from ICN-UNAM, Mexico City, Mexico.
 - [‡] Visitor from Helsinki Institute of Physics, Helsinki, Finland.
 - [#] Visitor from Universität Zürich, Zürich, Switzerland.
- [1] N. Arkani-Hamed, S. Dimopoulos, G. F. Giudice, and A. Romanino, Nucl. Phys. B **709**, 3 (2005).
 - [2] G. R. Farrar and P. Fayet, Phys. Lett. B **76**, 575 (1978).
 - [3] A. Arvanitaki, S. Dimopoulos, A. Pierce, S. Rajendran and J. Wacker, arXiv:hep-ph/0506242.
 - [4] V. M. Abazov *et al.* [D0 Collaboration], Nucl. Instrum. Methods A **565**, 463 (2006).
 - [5] DØ Collaboration, S. Abachi *et al.*, Nucl. Instrum. Methods A **338**, 185 (1994).
 - [6] G. C. Blazey *et al.*, in *Proceedings of the Workshop: QCD and Weak Boson Physics in Run II*, edited by U. Baur, R. K. Ellis, and D. Zeppenfeld, Fermilab-Pub-00/297 (2000), Sec. 3.5.
 - [7] T. Sjöstrand *et al.*, Comp. Phys. Comm. **135**, 238 (2001).
 - [8] R. Brun and F. Carminati, CERN Program Library Long Writeup W5013, 1993 (unpublished).