

Physics

Physics Research Publications

Purdue University

Year 2009

Search for Long-Lived Massive Charged
Particles in 1.96 TeV p(p)over-bar
Collisions

T. Aaltonen, J. Adelman, T. Akimoto, B. A. Gonzalez, S. Amerio, D. Amidei, A. Anastassov, A. Annovi, J. Antos, G. Apollinari, A. Apresyan, T. Arisawa, A. Artikov, W. Ashmanskas, A. Attal, A. Aurisano, F. Azfar, W. Badgett, A. Barbaro-Galtieri, V. E. Barnes, B. A. Barnett, P. Barria, V. Bartsch, G. Bauer, P. H. Beauchemin, F. Bedeschi, D. Beecher, S. Behari, G. Bellettini, J. Bellinger, D. Benjamin, A. Beretvas, J. Beringer, A. Bhatti, M. Binkley, D. Bisello, I. Bizjak, R. E. Blair, C. Blocker, B. Blumenfeld, A. Bocci, A. Bodek, V. Boisvert, G. Bolla, D. Bortoletto, J. Boudreau, A. Boveia, B. Brau, A. Bridgeman, L. Brigliadori, C. Bromberg, E. Brubaker, J. Budagov, H. S. Budd, S. Budd, S. Burke, K. Burkett, G. Busetto, P. Bussey, A. Buzatu, K. L. Byrum, S. Cabrera, C. Calancha, M. Campanelli, M. Campbell, F. Canelli, A. Canepa, B. Carls, D. Carlsmith, R. Carosi, S. Carrillo, S. Carron, B. Casal, M. Casarsa, A. Castro, P. Catastini, D. Cauz, V. Cavaliere, M. Cavalli-Sforza, A. Cerri, L. Cerrito, S. H. Chang, Y. C. Chen, M. Chertok, G. Chiarelli, G. Chlachidze, F. Chlebana, K. Cho, D. Chokheli, J. P. Chou, G. Choudalakis, S. H. Chuang, K. Chung, W. H. Chung, Y. S. Chung, T. Chwalek, C. I. Ciobanu, M. A. Ciocci, A. Clark, D. Clark, G. Compostella, M. E. Convery, J. Conway, M. Cordelli, G. Cortiana, C. A. Cox, D. J. Cox, F. Crescioli, C. Cuenca Almenar, J. Cuevas, R. Culbertson, J. C. Cully, D. Dagenhart, M. Datta, T. Davies, P. de Barbaro, S. De Cecco, A. Deisher, G. De Lorenzo, M. Dell'Orso, C. Deluca, L. Demortier, J. Deng, M. Deninno, P. F. Derwent, P. Di Canto, G. P. di Giovanni, C. Dionisi, B. Di Ruzza, J. R. Dittmann, M. D'Onofrio, S. Donati, P. Dong, J. Donini, T. Dorigo, S. Dube, J. Efron, A. Elagin, R. Erbacher, D. Errede, S. Errede, R. Eusebi, H. C. Fang, S. Farrington, W. T. Fedorko, R. G. Feild, M. Feindt, J. P. Fernandez, C. Ferrazza, R. Field, G. Flanagan, R. Forrest, M. J. Frank, M. Franklin, J. C. Freeman, I. Furic, M. Gallinaro, J. Galyardt, F. Garberson, J. E. Garcia, A. F. Garfinkel, P. Garosi, K. Genser, H. Gerberich, D. Gerdes, A. Gessler, S. Giagu, V. Giakoumopoulou, P. Giannetti, K. Gibson, J. L. Gimmell, C. M. Ginsburg, N. Giokaris, M. Giordani, P. Giromini, M. Giunta, G. Giurgiu, V. Glagolev, D.

Glenzinski, M. Gold, N. Goldschmidt, A. Golossanov, G. Gomez, G. Gomez-Ceballos, M. Goncharov, O. Gonzalez, I. Gorelov, A. T. Goshaw, K. Goulianos, A. Gresele, S. Grinstein, C. Grosso-Pilcher, R. C. Group, U. Grundler, J. G. da Costa, Z. Gunay-Unalan, C. Haber, K. Hahn, S. R. Hahn, E. Halkiadakis, B. Y. Han, J. Y. Han, F. Happacher, K. Hara, D. Hare, M. Hare, S. Harper, R. F. Harr, R. M. Harris, M. Hartz, K. Hatakeyama, C. Hays, M. Heck, A. Heijboer, J. Heinrich, C. Henderson, M. Herndon, J. Heuser, S. Hewamanage, D. Hidas, C. S. Hill, D. Hirschbuehl, A. Hocker, S. Hou, M. Houlden, S. C. Hsu, B. T. Huffman, R. E. Hughes, U. Husemann, M. Hussein, J. Huston, J. Incandela, G. Introzzi, M. Iori, A. Ivanov, E. James, D. Jang, B. Jayatilaka, E. J. Jeon, M. K. Jha, S. Jindariani, W. Johnson, M. Jones, K. K. Joo, S. Y. Jun, J. E. Jung, T. R. Junk, T. Kamon, D. Kar, P. E. Karchin, Y. Kato, R. Kephart, J. Keung, V. Khotilovich, B. Kilminster, D. H. Kim, H. S. Kim, H. W. Kim, J. E. Kim, M. J. Kim, S. B. Kim, S. H. Kim, Y. K. Kim, N. Kimura, L. Kirsch, S. Klimentenko, B. Knuteson, B. R. Ko, K. Kondo, D. J. Kong, J. Konigsberg, A. Korytov, A. V. Kotwal, M. Kreps, J. Kroll, D. Krop, N. Krumnack, M. Kruse, V. Krutelyov, T. Kubo, T. Kuhr, N. P. Kulkarni, M. Kurata, S. Kwang, A. T. Laasanen, S. Lami, S. Lammel, M. Lancaster, R. L. Lander, K. Lannon, A. Lath, G. Latino, I. Lazzizzera, T. LeCompte, E. Lee, H. S. Lee, S. W. Lee, S. Leone, J. D. Lewis, C. S. Lin, J. Linacre, M. Lindgren, E. Lipeles, A. Lister, D. O. Litvintsev, C. Liu, T. Liu, N. S. Lockyer, A. Loginov, M. Loreti, L. Lovas, D. Lucchesi, C. Luci, J. Lueck, P. Lujan, P. Lukens, G. Lungu, L. Lyons, J. Lys, R. Lysak, D. MacQueen, R. Madrak, K. Maeshima, K. Makhoul, T. Maki, P. Maksimovic, S. Malde, S. Malik, G. Manca, A. Manousakis-Katsikakis, F. Margaroli, C. Marino, C. P. Marino, A. Martin, V. Martin, M. Martinez, R. Martinez-Bellarin, T. Maruyama, P. Mastrandrea, T. Masubuchi, M. Mathis, M. E. Mattson, P. Mazzanti, K. S. McFarland, P. McIntyre, R. McNulty, A. Mehta, P. Mehtala, A. Menzione, P. Merkel, C. Mesropian, T. Miao, N. Miladinovic, R. Miller, C. Mills, M. Milnik, A. Mitra, G. Mitselmakher, H. Miyake, N. Moggi, C. S. Moon, R. Moore, M. J. Morello, J. Morlock, P. Movilla Fernandez, J. Mulmenstadt, A. Mukherjee, T. Muller, R. Mumford, P. Murat, M. Mussini, J. Nachtman, Y. Nagai, A. Nagano, J. Naganoma, K. Nakamura, I. Nakano, A. Napier, V. Necula, J. Nett, C. Neu, M. S. Neubauer, S. Neubauer, J. Nielsen, L. Nodulman, M. Norman, O. Norriella, E. Nurse, L. Oakes, S. H. Oh, Y. D. Oh, I. Oksuzian, T. Okusawa, R. Orava, K. Osterberg, S. Pagan Griso, E. Palencia, V. Papadimitriou, A. Papaikonomou, A. A. Paramonov, B. Parks, S. Pashapour, J. Patrick, G. Pauletta, M. Paulini, C. Paus, T. Peiffer, D. E. Pellett, A. Penzo, T. J. Phillips, G. Piacentino, E. Pianori, L. Pinera, K. Pitts, C. Plager, L. Pondrom, O. Poukhov, N. Pounder, F. Prakoshyn, A. Pronko, J. Proudfoot, F. Ptohos, E. Pueschel, G. Punzi, J. Pursley, J. Rademacker, A. Rahaman, V. Ramakrishnan, N. Ranjan, I. Redondo, P. Renton, M. Renz, M. Rescigno, S. Richter, F. Rimondi, L. Ristori, A. Robson, T. Rodrigo, T. Rodriguez, E. Rogers, S. Rolli, R. Roser, M. Rossi, R. Rossin, P. Roy, A. Ruiz, J. Russ, V. Rusu, B. Rutherford, H. Saarikko, A. Safonov, W. K. Sakumoto, O. Salto, L. Santi, S. Sarkar, L. Sartori, K. Sato, A. Savoy-Navarro, P. Schlabach, A. Schmidt, E. E. Schmidt, M. A. Schmidt, M. P. Schmidt, M. Schmitt, T.

Schwarz, L. Scodellaro, A. Scribano, F. Scuri, A. Sedov, S. Seidel, Y. Seiya, A. Semenov, L. Sexton-Kennedy, F. Sforza, A. Sfyrla, S. Z. Shalhout, T. Shears, P. F. Shepard, M. Shimojima, S. Shiraishi, M. Shochet, Y. Shon, I. Shreyber, P. Sinervo, A. Sisakyan, A. J. Slaughter, J. Slaunwhite, K. Sliwa, J. R. Smith, F. D. Snider, R. Snihur, A. Soha, S. Somalwar, V. Sorin, J. Spalding, T. Spreitzer, P. Squillacioti, M. Stanitzki, R. St Denis, B. Stelzer, O. Stelzer-Chilton, D. Stentz, J. Strologas, G. L. Strycker, D. Stuart, J. S. Suh, A. Sukhanov, I. Suslov, T. Suzuki, A. Taffard, R. Takashima, Y. Takeuchi, R. Tanaka, M. Tecchio, P. K. Teng, K. Terashi, J. Thom, A. S. Thompson, G. A. Thompson, E. Thomson, P. Tipton, P. Ttito-Guzman, S. Tkaczyk, D. Toback, S. Tokar, K. Tollefson, T. Tomura, D. Tonelli, S. Torre, D. Torretta, P. Totaro, S. Tourneur, M. Trovato, S. Y. Tsai, Y. Tu, N. Turini, F. Ukegawa, S. Vallecorsa, N. van Remortel, A. Varganov, E. Vataga, F. Vazquez, G. Velez, C. Vellidis, M. Vidal, R. Vidal, I. Vila, R. Vilar, T. Vine, M. Vogel, I. Volobouev, G. Volpi, P. Wagner, R. G. Wagner, R. L. Wagner, W. Wagner, J. Wagner-Kuhr, T. Wakisaka, R. Wallny, S. M. Wang, A. Warburton, D. Waters, M. Weinberger, J. Weinelt, W. C. Wester, B. Whitehouse, D. Whiteson, A. B. Wicklund, E. Wicklund, S. Wilbur, G. Williams, H. H. Williams, P. Wilson, B. L. Winer, P. Wittich, S. Wolbers, C. Wolfe, T. Wright, X. Wu, F. Wurthwein, S. Xie, A. Yagil, K. Yamamoto, J. Yamaoka, U. K. Yang, Y. C. Yang, W. M. Yao, G. P. Yeh, J. Yoh, K. Yorita, T. Yoshida, G. B. Yu, I. Yu, S. S. Yu, J. C. Yun, L. Zanello, A. Zanetti, X. Zhang, Y. Zheng, and S. Zucchelli

This paper is posted at Purdue e-Pubs.

http://docs.lib.purdue.edu/physics_articles/962

Search for Long-Lived Massive Charged Particles in 1.96 TeV $p\bar{p}$ Collisions

T. Aaltonen,²⁴ J. Adelman,¹⁴ T. Akimoto,⁵⁶ B. Álvarez González,^{12,t} S. Amerio,^{44b,44a} D. Amidei,³⁵ A. Anastassov,³⁹ A. Annovi,²⁰ J. Antos,¹⁵ G. Apollinari,¹⁸ A. Apresyan,⁴⁹ T. Arisawa,⁵⁸ A. Artikov,¹⁶ W. Ashmanskas,¹⁸ A. Attal,⁴ A. Aurisano,⁵⁴ F. Azfar,⁴³ W. Badgett,¹⁸ A. Barbaro-Galtieri,²⁹ V. E. Barnes,⁴⁹ B. A. Barnett,²⁶ P. Barria,^{47c,47a} V. Bartsch,³¹ G. Bauer,³³ P.-H. Beauchemin,³⁴ F. Bedeschi,^{47a} D. Beecher,³¹ S. Behari,²⁶ G. Bellettini,^{47b,47a} J. Bellinger,⁶⁰ D. Benjamin,¹⁷ A. Beretvas,¹⁸ J. Beringer,²⁹ A. Bhatti,⁵¹ M. Binkley,¹⁸ D. Bisello,^{44b,44a} I. Bizjak,^{31,y} R. E. Blair,² C. Blocker,⁷ B. Blumenfeld,²⁶ A. Bocci,¹⁷ A. Bodek,⁵⁰ V. Boisvert,⁵⁰ G. Bolla,⁴⁹ D. Bortoletto,⁴⁹ J. Boudreau,⁴⁸ A. Boveia,¹¹ B. Brau,^{11,b} A. Bridgeman,²⁵ L. Brigliadori,^{44a} C. Bromberg,³⁶ E. Brubaker,¹⁴ J. Budagov,¹⁶ H. S. Budd,⁵⁰ S. Budd,²⁵ S. Burke,¹⁸ K. Burkett,¹⁸ G. Busetto,^{44b,44a} P. Bussey,²² A. Buzatu,³⁴ K. L. Byrum,² S. Cabrera,^{17,v} C. Calancha,³² M. Campanelli,³⁶ M. Campbell,³⁵ F. Canelli,^{14,18} A. Canepa,⁴⁶ B. Carls,²⁵ D. Carlsmith,⁶⁰ R. Carosi,^{47a} S. Carrillo,^{19,o} S. Carron,³⁴ B. Casal,¹² M. Casarsa,¹⁸ A. Castro,^{6b,6a} P. Catastini,^{47c,47a} D. Cauz,^{55b,55a} V. Cavaliere,^{47c,47a} M. Cavalli-Sforza,⁴ A. Cerri,²⁹ L. Cerrito,^{31,p} S. H. Chang,²⁸ Y. C. Chen,¹ M. Chertok,⁸ G. Chiarelli,^{47a} G. Chlachidze,¹⁸ F. Chlebana,¹⁸ K. Cho,²⁸ D. Chokheli,¹⁶ J. P. Chou,²³ G. Choudalakis,³³ S. H. Chuang,⁵³ K. Chung,¹³ W. H. Chung,⁶⁰ Y. S. Chung,⁵⁰ T. Chwalek,²⁷ C. I. Ciobanu,⁴⁵ M. A. Ciocci,^{47c,47a} A. Clark,²¹ D. Clark,⁷ G. Compostella,^{44a} M. E. Convery,¹⁸ J. Conway,⁸ M. Cordelli,²⁰ G. Cortiana,^{44b,44a} C. A. Cox,⁸ D. J. Cox,⁸ F. Crescioli,^{47b,47a} C. Cuenca Almenar,^{8,v} J. Cuevas,^{12,t} R. Culbertson,¹⁸ J. C. Cully,³⁵ D. Dagenhart,¹⁸ M. Datta,¹⁸ T. Davies,²² P. de Barbaro,⁵⁰ S. De Cecco,^{52a} A. Deisher,²⁹ G. De Lorenzo,⁴ M. Dell'Orso,^{47b,47a} C. Deluca,⁴ L. Demortier,⁵¹ J. Deng,¹⁷ M. Deninno,^{6a} P. F. Derwent,¹⁸ P. Di Canto,^{47b,47a} G. P. di Giovanni,⁴⁵ C. Dionisi,^{52b,52a} B. Di Ruzza,^{55b,55a} J. R. Dittmann,⁵ M. D'Onofrio,⁴ S. Donati,^{47b,47a} P. Dong,⁹ J. Donini,^{44a} T. Dorigo,^{44a} S. Dube,⁵³ J. Efron,⁴⁰ A. Elagin,⁵⁴ R. Erbacher,⁸ D. Errede,²⁵ S. Errede,²⁵ R. Eusebi,¹⁸ H. C. Fang,²⁹ S. Farrington,⁴³ W. T. Fedorko,¹⁴ R. G. Feild,⁶¹ M. Feindt,²⁷ J. P. Fernandez,³² C. Ferrazza,^{47c,47a} R. Field,¹⁹ G. Flanagan,⁴⁹ R. Forrest,⁸ M. J. Frank,⁵ M. Franklin,²³ J. C. Freeman,¹⁸ I. Furic,¹⁹ M. Gallinaro,^{52a} J. Galyardt,¹³ F. Garbersson,¹¹ J. E. Garcia,²¹ A. F. Garfinkel,⁴⁹ P. Garosi,^{47c,47a} K. Genser,¹⁸ H. Gerberich,²⁵ D. Gerdes,³⁵ A. Gessler,²⁷ S. Giagu,^{52b,52a} V. Giakoumopoulou,³ P. Giannetti,^{47a} K. Gibson,⁴⁸ J. L. Gimmell,⁵⁰ C. M. Ginsburg,¹⁸ N. Giokaris,³ M. Giordani,^{55b,55a} P. Giromini,²⁰ M. Giunta,^{47a} G. Giurgiu,²⁶ V. Glagolev,¹⁶ D. Glenzinski,¹⁸ M. Gold,³⁸ N. Goldschmidt,¹⁹ A. Golossanov,¹⁸ G. Gomez,¹² G. Gomez-Ceballos,³³ M. Goncharov,³³ O. González,³² I. Gorelov,³⁸ A. T. Goshaw,¹⁷ K. Goulianos,⁵¹ A. Gresele,^{44b,44a} S. Grinstein,²³ C. Grosso-Pilcher,¹⁴ R. C. Group,¹⁸ U. Grundler,²⁵ J. Guimaraes da Costa,²³ Z. Gunay-Unalan,³⁶ C. Haber,²⁹ K. Hahn,³³ S. R. Hahn,¹⁸ E. Halkiadakis,⁵³ B.-Y. Han,⁵⁰ J. Y. Han,⁵⁰ F. Happacher,²⁰ K. Hara,⁵⁶ D. Hare,⁵³ M. Hare,⁵⁷ S. Harper,⁴³ R. F. Harr,⁵⁹ R. M. Harris,¹⁸ M. Hartz,⁴⁸ K. Hatakeyama,⁵¹ C. Hays,⁴³ M. Heck,²⁷ A. Heijboer,⁴⁶ J. Heinrich,⁴⁶ C. Henderson,³³ M. Herndon,⁶⁰ J. Heuser,²⁷ S. Hewamanage,⁵ D. Hidas,¹⁷ C. S. Hill,^{11,d} D. Hirschbuehl,²⁷ A. Hocker,¹⁸ S. Hou,¹ M. Houlden,³⁰ S.-C. Hsu,²⁹ B. T. Huffman,⁴³ R. E. Hughes,⁴⁰ U. Husemann,⁶¹ M. Hussein,³⁶ J. Huston,³⁶ J. Incandela,¹¹ G. Introzzi,^{47a} M. Iori,^{52b,52a} A. Ivanov,⁸ E. James,¹⁸ D. Jang,¹³ B. Jayatilaka,¹⁷ E. J. Jeon,²⁸ M. K. Jha,^{6a} S. Jindariani,¹⁸ W. Johnson,⁸ M. Jones,⁴⁹ K. K. Joo,²⁸ S. Y. Jun,¹³ J. E. Jung,²⁸ T. R. Junk,¹⁸ T. Kamon,⁵⁴ D. Kar,¹⁹ P. E. Karchin,⁵⁹ Y. Kato,^{42,m} R. Kephart,¹⁸ J. Keung,⁴⁶ V. Khotilovich,⁵⁴ B. Kilminster,¹⁸ D. H. Kim,²⁸ H. S. Kim,²⁸ H. W. Kim,²⁸ J. E. Kim,²⁸ M. J. Kim,²⁰ S. B. Kim,²⁸ S. H. Kim,⁵⁶ Y. K. Kim,¹⁴ N. Kimura,⁵⁶ L. Kirsch,⁷ S. Klimenko,¹⁹ B. Knuteson,³³ B. R. Ko,¹⁷ K. Kondo,⁵⁸ D. J. Kong,²⁸ J. Konigsberg,¹⁹ A. Korytov,¹⁹ A. V. Kotwal,¹⁷ M. Kreps,²⁷ J. Kroll,⁴⁶ D. Krop,¹⁴ N. Krumnack,⁵ M. Kruse,¹⁷ V. Krutelyov,¹¹ T. Kubo,⁵⁶ T. Kuhr,²⁷ N. P. Kulkarni,⁵⁹ M. Kurata,⁵⁶ S. Kwang,¹⁴ A. T. Laasanen,⁴⁹ S. Lami,^{47a} S. Lammel,¹⁸ M. Lancaster,³¹ R. L. Lander,⁸ K. Lannon,^{40,s} A. Lath,⁵³ G. Latino,^{47c,47a} I. Lazzizzera,^{44b,44a} T. LeCompte,² E. Lee,⁵⁴ H. S. Lee,¹⁴ S. W. Lee,^{54,u} S. Leone,^{47a} J. D. Lewis,¹⁸ C.-S. Lin,²⁹ J. Linacre,⁴³ M. Lindgren,¹⁸ E. Lipeles,⁴⁶ A. Lister,⁸ D. O. Litvintsev,¹⁸ C. Liu,⁴⁸ T. Liu,¹⁸ N. S. Lockyer,⁴⁶ A. Loginov,⁶¹ M. Loretì,^{44b,44a} L. Lovas,¹⁵ D. Lucchesi,^{44b,44a} C. Luci,^{52b,52a} J. Lueck,²⁷ P. Lujan,²⁹ P. Lukens,¹⁸ G. Lungu,⁵¹ L. Lyons,⁴³ J. Lys,²⁹ R. Lysak,¹⁵ D. MacQueen,³⁴ R. Madrak,¹⁸ K. Maeshima,¹⁸ K. Makhoul,³³ T. Maki,²⁴ P. Maksimovic,²⁶ S. Malde,⁴³ S. Malik,³¹ G. Manca,^{30,f} A. Manousakis-Katsikakis,³ F. Margaroli,⁴⁹ C. Marino,²⁷ C. P. Marino,²⁵ A. Martin,⁶¹ V. Martin,^{22,1} M. Martínez,⁴ R. Martínez-Ballarín,³² T. Maruyama,⁵⁶ P. Mastrandrea,^{52a} T. Masubuchi,⁵⁶ M. Mathis,²⁶ M. E. Mattson,⁵⁹ P. Mazzanti,^{6a} K. S. McFarland,⁵⁰ P. McIntyre,⁵⁴ R. McNulty,^{30,k} A. Mehta,³⁰ P. Mehtala,²⁴ A. Menzione,^{47a} P. Merkel,⁴⁹ C. Mesropian,⁵¹ T. Miao,¹⁸ N. Miladinovic,⁷ R. Miller,³⁶ C. Mills,²³ M. Milnik,²⁷ A. Mitra,¹ G. Mitselmakher,¹⁹ H. Miyake,⁵⁶ N. Moggi,^{6a} C. S. Moon,²⁸ R. Moore,¹⁸ M. J. Morello,^{47a} J. Morlock,²⁷ P. Movilla Fernandez,¹⁸ J. Mülmenstädt,²⁹ A. Mukherjee,¹⁸ Th. Muller,²⁷ R. Mumford,²⁶ P. Murat,¹⁸ M. Mussini,^{6b,6a} J. Nachtman,¹⁸ Y. Nagai,⁵⁶ A. Nagano,⁵⁶ J. Naganoma,⁵⁶ K. Nakamura,⁵⁶ I. Nakano,⁴¹ A. Napier,⁵⁷ V. Necula,¹⁷ J. Nett,⁶⁰

C. Neu,^{46,w} M. S. Neubauer,²⁵ S. Neubauer,²⁷ J. Nielsen,^{29,h} L. Nodulman,² M. Norman,¹⁰ O. Norriella,²⁵ E. Nurse,³¹ L. Oakes,⁴³ S. H. Oh,¹⁷ Y. D. Oh,²⁸ I. Oksuzian,¹⁹ T. Okusawa,⁴² R. Orava,²⁴ K. Osterberg,²⁴ S. Pagan Griso,^{44b,44a} E. Palencia,¹⁸ V. Papadimitriou,¹⁸ A. Papaikononou,²⁷ A. A. Paramonov,¹⁴ B. Parks,⁴⁰ S. Pashapour,³⁴ J. Patrick,¹⁸ G. Pauletta,^{55b,55a} M. Paulini,¹³ C. Paus,³³ T. Peiffer,²⁷ D. E. Pellett,⁸ A. Penzo,^{55a} T. J. Phillips,¹⁷ G. Piacentino,^{47a} E. Pianori,⁴⁶ L. Pinera,¹⁹ K. Pitts,²⁵ C. Plager,⁹ L. Pondrom,⁶⁰ O. Poukhov,^{16,a} N. Pounder,⁴³ F. Prakoshyn,¹⁶ A. Pronko,¹⁸ J. Proudfoot,² F. Ptohos,^{18,j} E. Pueschel,¹³ G. Punzi,^{47b,47a} J. Pursley,⁶⁰ J. Rademacker,^{43,d} A. Rahaman,⁴⁸ V. Ramakrishnan,⁶⁰ N. Ranjan,⁴⁹ I. Redondo,³² P. Renton,⁴³ M. Renz,²⁷ M. Rescigno,^{52a} S. Richter,²⁷ F. Rimondi,^{6b,6a} L. Ristori,^{47a} A. Robson,²² T. Rodrigo,¹² T. Rodriguez,⁴⁶ E. Rogers,²⁵ S. Rolli,⁵⁷ R. Roser,¹⁸ M. Rossi,^{55a} R. Rossin,¹¹ P. Roy,³⁴ A. Ruiz,¹² J. Russ,¹³ V. Rusu,¹⁸ B. Rutherford,¹⁸ H. Saarikko,²⁴ A. Safonov,⁵⁴ W. K. Sakumoto,⁵⁰ O. Saltó,⁴ L. Santi,^{55b,55a} S. Sarkar,^{52b,52a} L. Sartori,^{47a} K. Sato,¹⁸ A. Savoy-Navarro,⁴⁵ P. Schlabach,¹⁸ A. Schmidt,²⁷ E. E. Schmidt,¹⁸ M. A. Schmidt,¹⁴ M. P. Schmidt,^{61,a} M. Schmitt,³⁹ T. Schwarz,⁸ L. Scodellaro,¹² A. Scribano,^{47c,47a} F. Scuri,^{47a} A. Sedov,⁴⁹ S. Seidel,³⁸ Y. Seiya,⁴² A. Semenov,¹⁶ L. Sexton-Kennedy,¹⁸ F. Sforza,^{47b,47a} A. Sfyrila,²⁵ S. Z. Shalhout,⁵⁹ T. Shears,³⁰ P. F. Shepard,⁴⁸ M. Shimojima,^{56,r} S. Shiraishi,¹⁴ M. Shochet,¹⁴ Y. Shon,⁶⁰ I. Shreyber,³⁷ P. Sinervo,³⁴ A. Sisakyan,¹⁶ A. J. Slaughter,¹⁸ J. Slaunwhite,⁴⁰ K. Sliwa,⁵⁷ J. R. Smith,⁸ F. D. Snider,¹⁸ R. Snihur,³⁴ A. Soha,⁸ S. Somalwar,⁵³ V. Sorin,³⁶ J. Spalding,¹⁸ T. Spreitzer,³⁴ P. Squillacioti,^{47c,47a} M. Stanitzki,⁶¹ R. St. Denis,²² B. Stelzer,³⁴ O. Stelzer-Chilton,³⁴ D. Stentz,³⁹ J. Strologas,³⁸ G. L. Strycker,³⁵ D. Stuart,¹¹ J. S. Suh,²⁸ A. Sukhanov,¹⁹ I. Suslov,¹⁶ T. Suzuki,⁵⁶ A. Taffard,^{25,g} R. Takashima,⁴¹ Y. Takeuchi,⁵⁶ R. Tanaka,⁴¹ M. Tecchio,³⁵ P. K. Teng,¹ K. Terashi,⁵¹ J. Thom,^{18,i} A. S. Thompson,²² G. A. Thompson,²⁵ E. Thomson,⁴⁶ P. Tipton,⁶¹ P. Ttito-Guzmán,³² S. Tkaczyk,¹⁸ D. Toback,⁵⁴ S. Tokar,¹⁵ K. Tollefson,³⁶ T. Tomura,⁵⁶ D. Tonelli,¹⁸ S. Torre,²⁰ D. Torretta,¹⁸ P. Totaro,^{55b,55a} S. Tourneur,⁴⁵ M. Trovato,^{47d,47a} S.-Y. Tsai,¹ Y. Tu,⁴⁶ N. Turini,^{47c,47a} F. Ukegawa,⁵⁶ S. Vallecorsa,²¹ N. van Remortel,^{24,c} A. Varganov,³⁵ E. Vataga,^{47d,47a} F. Vázquez,^{19,o} G. Velev,¹⁸ C. Vellidis,³ M. Vidal,³² R. Vidal,¹⁸ I. Vila,¹² R. Vilar,¹² T. Vine,³¹ M. Vogel,³⁸ I. Volobouev,^{29,u} G. Volpi,^{47b,47a} P. Wagner,⁴⁶ R. G. Wagner,² R. L. Wagner,¹⁸ W. Wagner,^{27,x} J. Wagner-Kuhr,²⁷ T. Wakisaka,⁴² R. Wallny,⁹ S. M. Wang,¹ A. Warburton,³⁴ D. Waters,³¹ M. Weinberger,⁵⁴ J. Weinelt,²⁷ W. C. Wester III,¹⁸ B. Whitehouse,⁵⁷ D. Whiteson,^{46,g} A. B. Wicklund,² E. Wicklund,¹⁸ S. Wilbur,¹⁴ G. Williams,³⁴ H. H. Williams,⁴⁶ P. Wilson,¹⁸ B. L. Winer,⁴⁰ P. Wittich,^{18,i} S. Wolbers,¹⁸ C. Wolfe,¹⁴ T. Wright,³⁵ X. Wu,²¹ F. Würthwein,¹⁰ S. Xie,³³ A. Yagil,¹⁰ K. Yamamoto,⁴² J. Yamaoka,¹⁷ U. K. Yang,^{14,q} Y. C. Yang,²⁸ W. M. Yao,²⁹ G. P. Yeh,¹⁸ J. Yoh,¹⁸ K. Yorita,⁵⁸ T. Yoshida,^{42,n} G. B. Yu,⁵⁰ I. Yu,²⁸ S. S. Yu,¹⁸ J. C. Yun,¹⁸ L. Zanello,^{52b,52a} A. Zanetti,^{55a} X. Zhang,²⁵ Y. Zheng,^{9,e} and S. Zucchelli^{6b,6a}

(CDF Collaboration)

¹*Institute of Physics, Academia Sinica, Taipei, Taiwan 11529, Republic of China*²*Argonne National Laboratory, Argonne, Illinois 60439, USA*³*University of Athens, 157 71 Athens, Greece*⁴*Institut de Física d'Altes Energies, Universitat Autònoma de Barcelona, E-08193, Bellaterra (Barcelona), Spain*⁵*Baylor University, Waco, Texas 76798, USA*^{6a}*Istituto Nazionale di Fisica Nucleare Bologna, I-40127 Bologna, Italy*^{6b}*University of Bologna, I-40127 Bologna, Italy*⁷*Brandeis University, Waltham, Massachusetts 02254, USA*⁸*University of California, Davis, Davis, California 95616, USA*⁹*University of California, Los Angeles, Los Angeles, California 90024, USA*¹⁰*University of California, San Diego, La Jolla, California 92093, USA*¹¹*University of California, Santa Barbara, Santa Barbara, California 93106, USA*¹²*Instituto de Física de Cantabria, CSIC–University of Cantabria, 39005 Santander, Spain*¹³*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*¹⁴*Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, USA*¹⁵*Comenius University, 842 48 Bratislava, Slovakia; Institute of Experimental Physics, 040 01 Kosice, Slovakia*¹⁶*Joint Institute for Nuclear Research, RU-141980 Dubna, Russia*¹⁷*Duke University, Durham, North Carolina 27708, USA*¹⁸*Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA*¹⁹*University of Florida, Gainesville, Florida 32611, USA*²⁰*Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy*²¹*University of Geneva, CH-1211 Geneva 4, Switzerland*²²*Glasgow University, Glasgow G12 8QQ, United Kingdom*²³*Harvard University, Cambridge, Massachusetts 02138, USA*

- ²⁴*Division of High Energy Physics, Department of Physics, University of Helsinki and Helsinki Institute of Physics, FIN-00014, Helsinki, Finland*
- ²⁵*University of Illinois, Urbana, Illinois 61801, USA*
- ²⁶*The Johns Hopkins University, Baltimore, Maryland 21218, USA*
- ²⁷*Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76128 Karlsruhe, Germany*
- ²⁸*Center for High Energy Physics: Kyungpook National University, Daegu 702-701, Korea; Seoul National University, Seoul 151-742, Korea; Sungkyunkwan University, Suwon 440-746, Korea; Korea Institute of Science and Technology Information, Daejeon, 305-806, Korea; Chonnam National University, Gwangju, 500-757, Korea*
- ²⁹*Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA*
- ³⁰*University of Liverpool, Liverpool L69 7ZE, United Kingdom*
- ³¹*University College London, London WC1E 6BT, United Kingdom*
- ³²*Centro de Investigaciones Energeticas Medioambientales y Tecnologicas, E-28040 Madrid, Spain*
- ³³*Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
- ³⁴*Institute of Particle Physics: McGill University, Montréal, Québec, Canada H3A 2T8; Simon Fraser University, Burnaby, British Columbia, Canada V5A 1S6; University of Toronto, Toronto, Ontario, Canada M5S 1A7; and TRIUMF, Vancouver, British Columbia, Canada V6T 2A3*
- ³⁵*University of Michigan, Ann Arbor, Michigan 48109, USA*
- ³⁶*Michigan State University, East Lansing, Michigan 48824, USA*
- ³⁷*Institution for Theoretical and Experimental Physics, ITEP, Moscow 117259, Russia*
- ³⁸*University of New Mexico, Albuquerque, New Mexico 87131, USA*
- ³⁹*Northwestern University, Evanston, Illinois 60208, USA*
- ⁴⁰*The Ohio State University, Columbus, Ohio 43210, USA*
- ⁴¹*Okayama University, Okayama 700-8530, Japan*
- ⁴²*Osaka City University, Osaka 588, Japan*
- ⁴³*University of Oxford, Oxford OX1 3RH, United Kingdom*
- ^{44a}*Istituto Nazionale di Fisica Nucleare, Sezione di Padova-Trento, I-35131 Padova, Italy*
- ^{44b}*University of Padova, I-35131 Padova, Italy*
- ⁴⁵*LPNHE, Universite Pierre et Marie Curie/IN2P3-CNRS, UMR7585, Paris, F-75252 France*
- ⁴⁶*University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA*
- ^{47a}*Istituto Nazionale di Fisica Nucleare Pisa, I-56127 Pisa, Italy*
- ^{47b}*University of Pisa, I-56127 Pisa, Italy*
- ^{47c}*University of Siena, I-56127 Pisa, Italy*
- ^{47d}*Scuola Normale Superiore, I-56127 Pisa, Italy*
- ⁴⁸*University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA*
- ⁴⁹*Purdue University, West Lafayette, Indiana 47907, USA*
- ⁵⁰*University of Rochester, Rochester, New York 14627, USA*
- ⁵¹*The Rockefeller University, New York, New York 10021, USA*
- ^{52a}*Istituto Nazionale di Fisica Nucleare, Sezione di Roma 1, I-00185 Roma, Italy*
- ^{52b}*Sapienza Università di Roma, I-00185 Roma, Italy*
- ⁵³*Rutgers University, Piscataway, New Jersey 08855, USA*
- ⁵⁴*Texas A&M University, College Station, Texas 77843, USA*
- ^{55a}*Istituto Nazionale di Fisica Nucleare Trieste/Udine, I-34100 Trieste, Italy*
- ^{55b}*University of Trieste/Udine, I-33100 Udine, Italy*
- ⁵⁶*University of Tsukuba, Tsukuba, Ibaraki 305, Japan*
- ⁵⁷*Tufts University, Medford, Massachusetts 02155, USA*
- ⁵⁸*Waseda University, Tokyo 169, Japan*
- ⁵⁹*Wayne State University, Detroit, Michigan 48201, USA*
- ⁶⁰*University of Wisconsin, Madison, Wisconsin 53706, USA*
- ⁶¹*Yale University, New Haven, Connecticut 06520, USA*
- (Received 7 February 2009; published 10 July 2009)

We performed a signature-based search for long-lived charged massive particles produced in 1.0 fb^{-1} of $p\bar{p}$ collisions at $\sqrt{s} = 1.96 \text{ TeV}$, collected with the CDF II detector using a high transverse-momentum (p_T) muon trigger. The search used time of flight to isolate slowly moving, high- p_T particles. One event passed our selection cuts with an expected background of 1.9 ± 0.2 events. We set an upper bound on the production cross section and, interpreting this result within the context of a stable scalar top-quark model, set a lower limit on the particle mass of $249 \text{ GeV}/c^2$ at 95% C.L.

Most searches for massive particles arising from physics beyond the standard model (SM) rely upon the assumption that the particles decay immediately. Long-lived or stable non-SM states could exist, however, due to a new symmetry [1], a weak coupling [2], a kinematic constraint [3], or a potential barrier [4]. If the lifetime is long compared to the transit time through the detector, then the particle may escape the detector, thereby evading the limits imposed by direct searches for decay products. However, a charged, massive long-lived particle (CHAMP) will be directly observable within the detector through the distinctive signature of a slowly moving, high transverse-momentum (p_T) particle. The low velocity results in a long time of flight (TOF) and an anomalously large ionization-energy loss rate (dE/dx). Since the particle loses energy primarily through low-momentum-transfer interactions, even if strongly interacting [5,6], it will be highly penetrating and will likely be reconstructed as a muon.

Previous CHAMP search results have been presented within the context of a variety of models [7–10]. CDF in Run I, for instance, used dE/dx and set 95% C.L. lower mass limits on stable fourth-generation down-type ($190 \text{ GeV}/c^2$) and up-type ($220 \text{ GeV}/c^2$) quarks [7]. The ALEPH experiment also used dE/dx to exclude a stable scalar top squark (\tilde{t}), the supersymmetric partner of the top quark, with a mass below $95 \text{ GeV}/c^2$ at 95% C.L. [8]. A combined result from the LEP2 experiments excluded a stable supersymmetric partner for SM leptons with a mass below $99.5 \text{ GeV}/c^2$ at 95% C.L. [9].

In this Letter, we present a blind signature-based search for isolated CHAMPs promptly produced in $p\bar{p}$ collisions at $\sqrt{s} = 1.96 \text{ TeV}$ with the CDF II detector [11] at the Fermilab Tevatron. Using an integrated luminosity of 1.0 fb^{-1} of $\bar{p}p$ collisions collected with a high p_T muon trigger, the analysis isolated CHAMP candidates by calculating their mass from their measured velocity and momentum. We interpret the results within two scenarios. The first case, production of a single CHAMP within a reference volume of the CDF II detector, is largely model independent. The second scenario assumes a benchmark model for stable top-squark-pair production within the reference volume. Since the leading-order contributions to \tilde{t} production depend only upon the \tilde{t} mass [12], the result will generally apply to all stable \tilde{t} production models.

Details of the CDF II detector can be found in Ref. [11]. CDF measures the trajectories and momenta of charged particles using an inner silicon-strip detector [13] and an open-cell drift chamber (COT) [14]. A TOF detector [15] surrounding the outer tracker allows precise arrival time measurements for tracks projected into the detector with a pseudorapidity [16] in the range $|\eta| \lesssim 1$. Calorimeters located outside the tracking volume measure energy deposition of particles, and prevent all but the most penetrating

from reaching the muon detectors [17] positioned beyond the calorimeters.

Our data sample was collected with a trigger that identifies muon candidates with $|\eta| < 0.7$ and $p_T > 18 \text{ GeV}/c$. An event entered the analysis if the highest- p_T muon candidate reconstructed offline had $p_T > 20 \text{ GeV}/c$, originated from the most energetic $\bar{p}p$ collision, passed quality criteria that reduce backgrounds from punchthrough and particles that decay in-flight, and satisfied a calorimeter energy isolation criterion in which the ratio $\Sigma E_T(0.4)/p_T(\text{muon}) < 0.1$, where $\Sigma E_T(0.4)$ is the sum of transverse energy within a cone of $\Delta R = 0.4$ around the candidate's direction, excluding the energy deposited by the candidate itself.

We assign the selected events to signal or control subsamples depending upon whether the track of the highest- p_T muon candidate is a signal-region ($p_T > 40 \text{ GeV}/c$) or control-region ($20 < p_T < 40 \text{ GeV}/c$) track. The second-highest- p_T muon candidate (or the highest- p_T nonmuon track in events with only one muon candidate) is also a signal- or control-region track if it is in the same p_T region and originates from the same vertex as the first muon candidate. Tracks with $p_T < 20 \text{ GeV}/c$ are used to measure the $p\bar{p}$ interaction time (t_0) and are referred to as “ t_0 tracks.” The event t_0 , which is needed to determine the velocity of signal- and control-region tracks, is estimated using a maximum likelihood fit to all t_0 tracks from an interaction vertex, simultaneously taking into account all possible mass hypotheses. The t_0 resolution of single tracks is about 120 ps, so a single t_0 track is adequate to obtain the interaction time.

To separate a CHAMP signal from background, we use the velocity and momentum to calculate the mass of the candidate particle. In events with two signal-region or control-region tracks, both are considered. The track velocity for all candidate and control-region tracks is measured by dividing the path length of the track by its TOF. The measured average velocity, $\beta = v/c$, and single-track resolution of control-region tracks is 1.000 ± 0.029 , but with significant non-Gaussian tails. For signal-region tracks, we require $\beta < 0.9$ to suppress SM particles.

The non-Gaussian tails in the time resolution functions introduce a large background to the CHAMP candidate sample. The residuals to the track fit in the COT can be used to estimate the t_0 and track β with resolutions that are about a factor of 3 worse than those made with the TOF detector, but that are reliably parametrized by single Gaussian distributions. Requiring that the event t_0 and candidate track β measurements from the TOF detector and COT agree reduces this background.

Cosmic-ray muons are uncorrelated in time with $p\bar{p}$ interactions and present a potentially serious background. In a sample of 1.5×10^5 cosmic rays, only four pass the CHAMP selection. After applying a cosmic-ray filter [18],

we expect negligible residual cosmic-ray background. The filter removes less than 1% of signal events.

We estimate the efficiency for identifying a CHAMP candidate within our two scenarios. In general, CHAMPs are expected to have very large p_T and be highly isolated. Final-state radiation is strongly suppressed, even if the CHAMP is strongly interacting [5]. These characteristics make $W \rightarrow l\nu$ and $Z \rightarrow l^+l^-$ events, where l is either an electron or muon, reasonable models for both the isolated CHAMP track and the underlying event.

We use the muons in $Z \rightarrow \mu^+\mu^-$ events selected from the original trigger sample to measure the trigger and track reconstruction efficiency for a single muon to be $(94.0 \pm 0.3)\%$. To study the β dependence of the tracking efficiency, we isolate slow deuterons and pions using dE/dx in the tracking detector and measure the ratio of deuterons to pions, which we assume is constant as a function of β . We find that the efficiency is constant for $\beta > 0.4$ and drops for slower particles, a result confirmed in a CHAMP Monte Carlo simulation (MC) [19]. We therefore assume a flat efficiency of $(94.0 \pm 0.3)\%$ for $\beta > 0.4$ and zero for $\beta < 0.4$ for CHAMPs.

Using vertices and electron tracks in $W \rightarrow e\nu$ events, we determine the efficiency for finding the primary event vertex, calculating an event t_0 , and reconstructing an isolated CHAMP track from the vertex to be $(71.4 \pm 0.2)\%$. The event t_0 and track-vertex association dominate the losses in this efficiency (87% and 86%, respectively).

The efficiency for measuring the arrival time in the TOF detector for CHAMP tracks that are within the muon detector acceptance is determined directly from the muon data; for tracks that are not within the muon detector's acceptance, we use electron tracks in $W \rightarrow e\nu$ events. Including the efficiency for the TOF result to be consistent with COT timing information, we obtain a TOF measurement efficiency of $(62.8 \pm 2.6)\%$ for tracks within the muon detectors and $(56.3 \pm 2.7)\%$ for other tracks. The criteria used to identify well-measured arrival times account for most of the efficiency loss.

The dominant systematic uncertainties in the efficiencies are a 5% value to cover the effect of errors in the modeling of initial- and final-state radiation and track multiplicities in CHAMP events on the vertex and t_0 efficiencies, and a 3% uncertainty in the arrival time efficiency to cover differences observed for electrons, muons, and changes in the TOF detector gain during the run.

Strongly interacting CHAMPs are subject to QCD effects [5,6] that can reduce the overall detection efficiency relative to that of weakly interacting CHAMPs. Quarklike CHAMPs, for instance, can hadronize into either charged or neutral color-singlet states. Charge-exchange interactions in the material of the detector can change an initially charged particle into a neutral particle, and vice versa, before it reaches the muon detectors. At least one CHAMP must leave a track segment in both the COT and the muon chambers to satisfy our trigger.

In order to estimate the efficiency loss due to these hadronic effects, we consider the case of an up-quark-like CHAMP, Q , that hadronizes into a $Q\bar{q}$ or $\bar{Q}q$ R -hadron state [20]. The fraction hadronizing into a charged R hadron is assumed to be $(52.9 \pm 2.9)\%$, based upon the rate for charged b -meson production measured at CERN LEP [21]. The center-of-mass energy for collisions between a massive Q moving at low velocity and a light quark is small. As a result, hadronic interactions of the R hadron with the detector material involve primarily the light quark, while the Q remains a spectator [5,6]. Since the R hadron contains a single light valence quark, we assume the interaction length for the R hadron to be 3 times that for a proton. Under these assumptions, we estimate that the probability that an initially charged R hadron undergoes rehadronization before reaching the outermost of the two layers of muon detectors is 93%. At each interaction, the Q rehadronizes according to the same prescription as for the initial hadronization. To estimate the systematic uncertainty, we take the difference between the result above and the efficiency assuming that 100% of R hadrons rehadronize.

Combining all efficiencies, the net efficiency for detecting a single, weakly interacting CHAMP within the muon trigger acceptance is $(38 \pm 2)\%$; for a strongly interacting up-quark-like CHAMP, the efficiency is $(8.8 \pm 1.6)\%$.

As a reference model we use PYTHIA [19] to calculate the geometric and kinematic acceptance for top-squark pair production. The trigger and detection efficiencies are calculated by combining the single-track and vertex-finding efficiencies as estimated for the case of a single up-quark-like CHAMP with the relative rate at which one or two top-squark R hadrons are within the fiducial volume of the detector as predicted by the MC calculations. The acceptances for various \tilde{t} masses are listed in Table I.

Figure 1 shows the observed and predicted mass distribution for tracks in the signal region. The uncertainty in the

TABLE I. Results of the search for stable top squarks in 1.0 fb^{-1} of $p\bar{p}$ collisions, as a function of the \tilde{t} mass.

\tilde{t} mass (GeV/ c^2)	100	120	140	160	180	200	220	240	260
Expected background	4.7 ± 0.3	1.9 ± 0.2	0.8 ± 0.1	0.37 ± 0.05	0.18 ± 0.03	0.09 ± 0.02	0.05 ± 0.01	0.03 ± 0.01	0.016 ± 0.005
Observed events	4	1	1	0	0	0	0	0	0
Total acceptance (%)	3.6 ± 0.5	4.2 ± 0.5	4.5 ± 0.6	5.1 ± 0.7	5.5 ± 0.8	5.8 ± 0.8	5.9 ± 0.9	5.9 ± 0.8	6.2 ± 0.9
Expected limit (fb)	190	120	90	71	61	56	55	53	51
95% C.L. limit (fb)	160	90	100	60	56	53	52	52	50

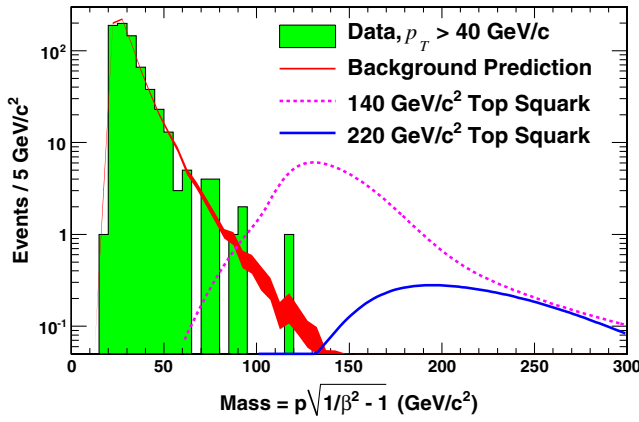


FIG. 1 (color online). Observed (histogram) and predicted (band) mass distributions for candidate tracks in the muon sample. The curves on the right show the MC distributions expected for a 140 and a 220 GeV/c^2 long-lived top squark.

β measurement is independent of the momentum for tracks with $\beta \approx 1$. We therefore obtain an absolute prediction for the background mass distribution for a given set of tracks by convolving the momentum distribution for those tracks with the distribution of $\sqrt{1/\beta^2 - 1}$, normalized to unit area, for control-region tracks. We find agreement between the observed and predicted mass distributions within the control- and signal-region electron tracks and within the control region of the muon sample. The background prediction for the signal region is shown by the band in Fig. 1.

We find one candidate track with a mass above 100 GeV/c^2 and none above 120 GeV/c^2 , consistent with the predicted background of 1.9 ± 0.2 events above 100 GeV/c^2 . From this result, we set a model-independent upper limit on the production cross section for a single, isolated, weakly interacting CHAMP within the muon trigger acceptance (approximately $|\eta| < 0.7$) with $p_T > 40 \text{ GeV}/c$, $0.4 < \beta < 0.9$, and a measured mass $m > 100 \text{ GeV}/c^2$ to be $\sigma < 10 \text{ fb}$ at 95% C.L. Similarly, the cross-section limit for an up-quark-like CHAMP under the same assumptions is $\sigma < 48 \text{ fb}$ at 95% C.L.

To count the number of events consistent with a stable \tilde{t} of a given mass m_s , we must take into account our mass resolution. For tracks with $\beta > 0.4$ and momenta in the signal region, the mass resolution is determined by the momentum resolution [22], which is well modeled by the MC simulation. We can therefore accurately predict the \tilde{t} mass line shape. We search for a \tilde{t} signal by integrating all events within a one-sided window from $0.8m_s$ upward. Table I shows the resulting number of events as a function of the \tilde{t} mass. From the estimated efficiencies and the number of observed events, we calculate the 95% C.L. upper limit on the cross section shown in Fig. 2. The band represents the theoretical next-to-leading-order \tilde{t} pair production cross section, as calculated using the PROSPINO2 program [23]. From the intersection of the

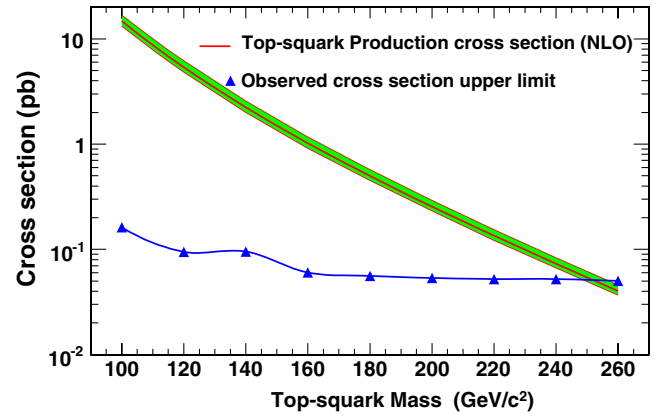


FIG. 2 (color online). The observed 95% C.L. limits on the cross section for production of a stable top-squark pair (triangles), compared to the theoretical next-to-leading-order cross section [12] (curve). The band represents theoretical and parton distribution function uncertainties. The intersection of the band with the limit curve yields a lower mass limit for a stable top squark of 249 GeV/c^2 .

edge of the band and the limit curve, we infer a 249 GeV/c^2 95% C.L. lower limit on the mass of a stable \tilde{t} . This is the most stringent limit to date.

In conclusion, we have used the CDF II TOF and COT systems to measure the masses of highly penetrating, high- p_T tracks. The observed mass distribution is consistent with the expected background, which is dominated by SM particles with mismeasured velocity or momentum. From this result, we set upper limits for the production cross section times acceptance of single weakly (up-quark-like strongly) interacting CHAMPs to be less than 10 (48) fb at 95% C.L. The 95% C.L. lower limit on the mass of a stable top squark is 249 GeV/c^2 .

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. In particular we thank Steve Mrenna for help with the CHAMP simulation. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science, and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A. P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Science and Technology Facilities Council and the Royal Society, UK; the Institut National de Physique Nucleaire et Physique des Particules/CNRS; the Russian Foundation for Basic Research; the Ministerio de Ciencia e Innovación, and Programa Consolider-Ingenio 2010, Spain; the Slovak R&D Agency; and the Academy of Finland.

- ^aDeceased.
- ^bVisitor from University of Massachusetts Amherst, Amherst, MA 01003, USA.
- ^cVisitor from Universiteit Antwerpen, B-2610 Antwerp, Belgium.
- ^dVisitor from University of Bristol, Bristol BS8 1TL, United Kingdom.
- ^eVisitor from Chinese Academy of Sciences, Beijing 100864, China.
- ^fVisitor from Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, 09042 Monserrato (Cagliari), Italy.
- ^gVisitor from University of California Irvine, Irvine, CA 92697, USA.
- ^hVisitor from University of California Santa Cruz, Santa Cruz, CA 95064, USA.
- ⁱVisitor from Cornell University, Ithaca, NY 14853, USA.
- ^jVisitor from University of Cyprus, Nicosia CY-1678, Cyprus.
- ^kVisitor from University College Dublin, Dublin 4, Ireland.
- ^lVisitor from University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom.
- ^mVisitor from University of Fukui, Fukui City, Fukui Prefecture, Japan 910-0017.
- ⁿVisitor from Kinki University, Higashi-Osaka City, Japan 577-8502.
- ^oVisitor from Universidad Iberoamericana, Mexico D.F., Mexico.
- ^pVisitor from Queen Mary, University of London, London, E1 4NS, England.
- ^qVisitor from University of Manchester, Manchester M13 9PL, England.
- ^rVisitor from Nagasaki Institute of Applied Science, Nagasaki, Japan.
- ^sVisitor from University of Notre Dame, Notre Dame, IN 46556, USA.
- ^tVisitor from University de Oviedo, E-33007 Oviedo, Spain.
- ^uVisitor from Texas Tech University, Lubbock, TX 79609, USA.
- ^vVisitor from IFIC (CSIC–Universitat de Valencia), 46071 Valencia, Spain.
- ^wVisitor from University of Virginia, Charlottesville, VA 22904, USA.
- ^xVisitor from Bergische Universität Wuppertal, 42097 Wuppertal, Germany.
- ^yOn leave from J. Stefan Institute, Ljubljana, Slovenia.
- [1] See R. Barbieri, L. J. Hall, and Y. Nomura, *Phys. Rev. D* **63**, 105007 (2001); T. Appelquist, H. C. Cheng, and B. A. Dobrescu, *Phys. Rev. D* **64**, 035002 (2001).
- [2] See for instance P. H. Frampton and P. Q. Hung, *Phys. Rev. D* **58**, 057704 (1998); M. Dine, A. E. Nelson, and Y. Shirman, *Phys. Rev. D* **51**, 1362 (1995); M. Dine, A. E. Nelson, Y. Nir, and Y. Shirman, *Phys. Rev. D* **53**, 2658 (1996); N. Arkani-Hamed and S. Dimopoulos, *J. High Energy Phys.* **06** (2005) 073.
- [3] J. L. Feng, T. Moroi, L. Randall, M. Strassler, and S. Su, *Phys. Rev. Lett.* **83**, 1731 (1999); J. L. Feng and T. Moroi, *Phys. Rev. D* **61**, 095004 (2000).
- [4] M. Strassler and K. Zurek, *Phys. Lett. B* **651**, 374 (2007).
- [5] M. Drees and X. Tata, *Phys. Lett. B* **252**, 695 (1990).
- [6] M. Fairbairn *et al.*, *Phys. Rep.* **438**, 1 (2007).
- [7] F. Acosta *et al.*, *Phys. Rev. Lett.* **90**, 131801 (2003).
- [8] A. Heister *et al.* (ALEPH Collaboration), *Phys. Lett. B* **537**, 5 (2002).
- [9] LEP SUSY Working Group, ALEPH, DELPHI, L3, and OPAL collaborations, note LEPSUSYWG/02-05.1 (<http://lepsusy.web.cern.ch/lepsusy/Welcome.html>).
- [10] P. F. Smith *et al.*, *Nucl. Phys.* **B206**, 333 (1982); M. Byrne, C. F. Kolda, and P. Regan, *Phys. Rev. D* **66**, 075007 (2002).
- [11] D. Acosta *et al.* (CDF Collaboration), *Phys. Rev. D* **71**, 032001 (2005).
- [12] W. Beenakker *et al.*, *Nucl. Phys.* **B515**, 3 (1998); E. L. Berger, M. Klasen, and T. Tait, *Phys. Rev. D* **59**, 074024 (1999).
- [13] A. Sill *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **447**, 1 (2000); A. Affolder *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **453**, 84 (2000).
- [14] T. Affolder *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **526**, 249 (2004).
- [15] D. Acosta *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **518**, 605 (2004).
- [16] We use a coordinate system where ϕ is the azimuthal angle around the beam axis and θ is the polar angle measured with respect to the proton direction. The pseudorapidity, η , is defined by $\eta \equiv -\log \tan(\theta/2)$ and $\Delta R \equiv \sqrt{\Delta\eta^2 + \Delta\phi^2}$.
- [17] G. Ascoli *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **268**, 33 (1988).
- [18] A. V. Kotwal, H. K. Gerberich, and C. Hays, *Nucl. Instrum. Methods Phys. Res., Sect. A* **506**, 110 (2003).
- [19] T. Sjöstrand, S. Mrenna, and P. Skands, *J. High Energy Phys.* **05** (2006) 026; see also <http://home.thep.lu.se/~torbjorn/Pythia.html>.
- [20] “*R* hadron” refers to hadrons containing an *R*-parity-conserving supersymmetric particle. From G. R. Farrar and P. Fayet, *Phys. Lett. B* **76**, 575 (1978).
- [21] E. Barberio *et al.* [Heavy Flavor Averaging Group (HFAG)], arXiv:0704.3575.
- [22] A. Abulencia *et al.* (CDF Collaboration), *J. Phys. G* **34**, 2457 (2007).
- [23] See <http://www.ph.ed.ac.uk/~tplehn/prospino> for details on PROSPINO2. The calculation for top-squark pair production is based upon Ref. [12].