

3-11-2005

First Measurements of Inclusive W and Z Cross Sections from Run II of the Fermilab Tevatron Collider

Darin Acosta

University of Florida, acosta@phys.ufl.edu

Kenneth A. Bloom

University of Nebraska - Lincoln, kbloom2@unl.edu

Collider Detector at Fermilab Collaboration

Follow this and additional works at: <http://digitalcommons.unl.edu/physicsbloom>



Part of the [Physics Commons](#)

Acosta, Darin; Bloom, Kenneth A.; and Fermilab Collaboration, Collider Detector at, "First Measurements of Inclusive W and Z Cross Sections from Run II of the Fermilab Tevatron Collider" (2005). *Kenneth Bloom Publications*. 31.

<http://digitalcommons.unl.edu/physicsbloom/31>

This Article is brought to you for free and open access by the Research Papers in Physics and Astronomy at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in Kenneth Bloom Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

First Measurements of Inclusive W and Z Cross Sections from Run II of the Fermilab Tevatron Collider

D. Acosta,¹⁶ T. Affolder,⁹ T. Akimoto,⁵⁴ M. G. Albrow,¹⁵ D. Ambrose,⁴³ S. Amerio,⁴² D. Amidei,³³ A. Anastassov,⁵⁰ K. Anikeev,³¹ A. Annovi,⁴⁴ J. Antos,¹ M. Aoki,⁵⁴ G. Apollinari,¹⁵ T. Arisawa,⁵⁶ J-F. Arguin,³² A. Artikov,¹³ W. Ashmanskas,² A. Attal,⁷ F. Azfar,⁴¹ P. Azzi-Bacchetta,⁴² N. Bacchetta,⁴² H. Bachacou,²⁸ W. Badgett,¹⁵ A. Barbaro-Galtieri,²⁸ G. J. Barker,²⁵ V. E. Barnes,⁴⁶ B. A. Barnett,²⁴ S. Baroiant,⁶ M. Barone,¹⁷ G. Bauer,³¹ F. Bedeschi,⁴⁴ S. Behari,²⁴ S. Belforte,⁵³ G. Bellettini,⁴⁴ J. Bellinger,⁵⁸ D. Benjamin,¹⁴ A. Beretvas,¹⁵ A. Bhatti,⁴⁸ M. Binkley,¹⁵ D. Bisello,⁴² M. Bishai,¹⁵ R. E. Blair,² C. Blocker,⁵ K. Bloom,³³ B. Blumenfeld,²⁴ A. Bocci,⁴⁸ A. Bodek,⁴⁷ G. Bolla,⁴⁶ A. Bolshov,³¹ P. S. L. Booth,²⁹ D. Bortoletto,⁴⁶ J. Boudreau,⁴⁵ S. Bourov,¹⁵ C. Bromberg,³⁴ E. Brubaker,²⁸ J. Budagov,¹³ H. S. Budd,⁴⁷ K. Burkett,¹⁵ G. Busetto,⁴² P. Bussey,¹⁹ K. L. Byrum,² S. Cabrera,¹⁴ P. Calafiura,²⁸ M. Campanelli,¹⁸ M. Campbell,³³ A. Canepa,⁴⁶ M. Casarsa,⁵³ D. Carlsmith,⁵⁸ S. Carron,¹⁴ R. Carosi,⁴⁴ M. Cavalli-Sforza,³ A. Castro,⁴ P. Catastini,⁴⁴ D. Cauz,⁵³ A. Cerri,²⁸ C. Cerri,⁴⁴ L. Cerrito,²³ J. Chapman,³³ C. Chen,⁴³ Y. C. Chen,¹ M. Chertok,⁶ G. Chiarelli,⁴⁴ G. Chlachidze,¹³ F. Chlebana,¹⁵ I. Cho,²⁷ K. Cho,²⁷ D. Chokheli,¹³ M. L. Chu,¹ S. Chuang,⁵⁸ J. Y. Chung,³⁸ W-H. Chung,⁵⁸ Y. S. Chung,⁴⁷ C. I. Ciobanu,²³ M. A. Ciocci,⁴⁴ A. G. Clark,¹⁸ D. Clark,⁵ M. Coca,⁴⁷ A. Connolly,²⁸ M. Convery,⁴⁸ J. Conway,⁵⁰ B. Cooper,³⁰ M. Cordelli,¹⁷ G. Cortiana,⁴² J. Cranshaw,⁵² J. Cuevas,¹⁰ R. Culbertson,¹⁵ C. Currat,²⁸ D. Cyr,⁵⁸ D. Dagenhart,⁵ S. Da Ronco,⁴² S. D'Auria,¹⁹ P. de Barbaro,⁴⁷ S. De Cecco,⁴⁹ G. De Lentdecker,⁴⁷ S. Dell'Agnello,¹⁷ M. Dell'Orso,⁴⁴ S. Demers,⁴⁷ L. Demortier,⁴⁸ M. Deninno,⁴ D. De Pedis,⁴⁹ P. F. Derwent,¹⁵ C. Dionisi,⁴⁹ J. R. Dittmann,¹⁵ P. Doksus,²³ A. Dominguez,²⁸ S. Donati,⁴⁴ M. Donega,¹⁸ J. Donini,⁴² M. D'Onofrio,¹⁸ T. Dorigo,⁴² V. Drollinger,³⁶ K. Ebina,⁵⁶ N. Eddy,²³ R. Ely,²⁸ R. Erbacher,¹⁵ M. Erdmann,²⁵ D. Errede,²³ S. Errede,²³ R. Eusebi,⁴⁷ H-C. Fang,²⁸ S. Farrington,²⁹ I. Fedorko,⁴⁴ R. G. Feild,⁵⁹ M. Feindt,²⁵ J. P. Fernandez,⁴⁶ C. Ferretti,³³ R. D. Field,¹⁶ I. Fiori,⁴⁴ G. Flanagan,³⁴ B. Flaughner,¹⁵ L. R. Flores-Castillo,⁴⁵ A. Foland,²⁰ S. Forrester,⁶ G. W. Foster,¹⁵ M. Franklin,²⁰ J. Freeman,²⁸ H. Frisch,¹² Y. Fujii,²⁶ I. Furic,³¹ A. Gajjar,²⁹ A. Gallas,³⁷ J. Galyardt,¹¹ M. Gallinaro,⁴⁸ M. Garcia-Sciveres,²⁸ A. F. Garfinkel,⁴⁶ C. Gay,⁵⁹ H. Gerberich,¹⁴ D. W. Gerdes,³³ E. Gerchtein,¹¹ S. Giagu,⁴⁹ P. Giannetti,⁴⁴ A. Gibson,²⁸ K. Gibson,¹¹ C. Ginsburg,⁵⁸ K. Giolo,⁴⁶ M. Giordani,⁵³ G. Giurgiu,¹¹ V. Glagolev,¹³ D. Glenzinski,¹⁵ M. Gold,³⁶ N. Goldschmidt,³³ D. Goldstein,⁷ J. Goldstein,⁴¹ G. Gomez,¹⁰ G. Gomez-Ceballos,³¹ M. Goncharov,⁵¹ O. González,⁴⁶ I. Gorelov,³⁶ A. T. Goshaw,¹⁴ Y. Gotra,⁴⁵ K. Goulianos,⁴⁸ A. Gresele,⁴ C. Grosso-Pilcher,¹² M. Guenther,⁴⁶ J. Guimaraes da Costa,²⁰ C. Haber,²⁸ K. Hahn,⁴³ S. R. Hahn,¹⁵ E. Halkiadakis,⁴⁷ R. Handler,⁵⁸ F. Happacher,¹⁷ K. Hara,⁵⁴ M. Hare,⁵⁵ R. F. Harr,⁵⁷ R. M. Harris,¹⁵ F. Hartmann,²⁵ K. Hatakeyama,⁴⁸ J. Hauser,⁷ C. Hays,¹⁴ H. Hayward,²⁹ E. Heider,⁵⁵ B. Heinemann,²⁹ J. Heinrich,⁴³ M. Hennecke,²⁵ M. Herndon,²⁴ C. Hill,⁹ D. Hirschbuehl,²⁵ A. Hocker,⁴⁷ K. D. Hoffman,¹² A. Holloway,²⁰ S. Hou,¹ M. A. Houlden,²⁹ B. T. Huffman,⁴¹ Y. Huang,¹⁴ R. E. Hughes,³⁸ J. Huston,³⁴ K. Ikado,⁵⁶ J. Incandela,⁹ G. Introzzi,⁴⁴ M. Iori,⁴⁹ Y. Ishizawa,⁵⁴ C. Issever,⁹ A. Ivanov,⁴⁷ Y. Iwata,²² B. Iyutin,³¹ E. James,¹⁵ D. Jang,⁵⁰ J. Jarrell,³⁶ D. Jeans,⁴⁹ H. Jensen,¹⁵ E. J. Jeon,²⁷ M. Jones,⁴⁶ K. K. Joo,²⁷ S. Jun,¹¹ T. Junk,²³ T. Kamon,⁵¹ J. Kang,³³ M. Karagoz Unel,³⁷ P. E. Karchin,⁵⁷ S. Kartal,¹⁵ Y. Kato,⁴⁰ Y. Kemp,²⁵ R. Kephart,¹⁵ U. Kerzel,²⁵ V. Khotilovich,⁵¹ B. Kilminster,³⁸ D. H. Kim,²⁷ H. S. Kim,²³ J. E. Kim,²⁷ M. J. Kim,¹¹ M. S. Kim,²⁷ S. B. Kim,²⁷ S. H. Kim,⁵⁴ T. H. Kim,³¹ Y. K. Kim,¹² B. T. King,²⁹ M. Kirby,¹⁴ L. Kirsch,⁵ S. Klimenko,¹⁶ B. Knuteson,³¹ B. R. Ko,¹⁴ H. Kobayashi,⁵⁴ P. Koehn,³⁸ D. J. Kong,²⁷ K. Kondo,⁵⁶ J. Konigsberg,¹⁶ K. Kordas,³² A. Korn,³¹ A. Korytov,¹⁶ K. Kotelnikov,³⁵ A. V. Kotwal,¹⁴ A. Kovalev,⁴³ J. Kraus,²³ I. Kravchenko,³¹ A. Kreymer,¹⁵ J. Kroll,⁴³ M. Kruse,¹⁴ V. Krutelyov,⁵¹ S. E. Kuhlmann,² N. Kuznetsova,¹⁵ A. T. Laasanen,⁴⁶ S. Lai,³² S. Lami,⁴⁸ S. Lammel,¹⁵ J. Lancaster,¹⁴ M. Lancaster,³⁰ R. Lander,⁶ K. Lannon,³⁸ A. Lath,⁵⁰ G. Latino,³⁶ R. Lauhakangas,²¹ I. Lazzizzera,⁴² Y. Le,²⁴ C. Lecci,²⁵ T. LeCompte,² J. Lee,²⁷ J. Lee,⁴⁷ S. W. Lee,⁵¹ N. Leonardo,³¹ S. Leone,⁴⁴ J. D. Lewis,¹⁵ K. Li,⁵⁹ C. Lin,⁵⁹ C. S. Lin,¹⁵ M. Lindgren,¹⁵ T. M. Liss,²³ D. O. Litvintsev,¹⁵ T. Liu,¹⁵ Y. Liu,¹⁸ N. S. Lockyer,⁴³ A. Loginov,³⁵ M. Loretì,⁴² P. Loverre,⁴⁹ R-S. Lu,¹ D. Lucchesi,⁴² P. Lujan,²⁸ P. Lukens,¹⁵ L. Lyons,⁴¹ J. Lys,²⁸ R. Lysak,¹ D. MacQueen,³² R. Madrak,²⁰ K. Maeshima,¹⁵ P. Maksimovic,²⁴ L. Malferrari,⁴ G. Manca,²⁹ R. Marginean,³⁸ M. Martin,²⁴ A. Martin,⁵⁹ V. Martin,³⁷ M. Martínez,³ T. Maruyama,⁵⁴ H. Matsunaga,⁵⁴ M. Mattson,⁵⁷ P. Mazzanti,⁴ K. S. McFarland,⁴⁷ D. McGivern,³⁰ P. M. McIntyre,⁵¹ P. McNamara,⁵⁰ R. McNulty,²⁹ S. Menzemer,³¹ A. Menzione,⁴⁴ P. Merkel,¹⁵ C. Mesropian,⁴⁸ A. Messina,⁴⁹ T. Miao,¹⁵ N. Miladinovic,⁵ L. Miller,²⁰ R. Miller,³⁴ J. S. Miller,³³ R. Miquel,²⁸ S. Miscetti,¹⁷ G. Mitselmakher,¹⁶ A. Miyamoto,²⁶ Y. Miyazaki,⁴⁰ N. Moggi,⁴ B. Mohr,⁷ R. Moore,¹⁵ M. Morello,⁴⁴ T. Moulik,⁴⁶ P. A. Movilla Fernandez,²⁸ A. Mukherjee,¹⁵ M. Mulhearn,³¹ T. Muller,²⁵ R. Mumford,²⁴ A. Munar,⁴³ P. Murat,¹⁵ J. Nachtman,¹⁵ S. Nahn,⁵⁹ I. Nakamura,⁴³

I. Nakano,³⁹ A. Napier,⁵⁵ R. Napora,²⁴ D. Naumov,³⁶ V. Necula,¹⁶ F. Niell,³³ J. Nielsen,²⁸ C. Nelson,¹⁵ T. Nelson,¹⁵ C. Neu,⁴³ M. S. Neubauer,⁸ C. Newman-Holmes,¹⁵ A-S. Nicollerat,¹⁸ T. Nigmanov,⁴⁵ L. Nodulman,² O. Norniella,³ K. Oesterberg,²¹ T. Ogawa,⁵⁶ S. H. Oh,¹⁴ Y. D. Oh,²⁷ T. Ohsugi,²² T. Okusawa,⁴⁰ R. Oldeman,⁴⁹ R. Orava,²¹ W. Orejudos,²⁸ C. Pagliarone,⁴⁴ F. Palmonari,⁴⁴ R. Paoletti,⁴⁴ V. Papadimitriou,¹⁵ S. Pashapour,³² J. Patrick,¹⁵ G. Pauletta,⁵³ M. Paulini,¹¹ T. Pauly,⁴¹ C. Paus,³¹ D. Pellett,⁶ A. Penzo,⁵³ T. J. Phillips,¹⁴ G. Piacentino,⁴⁴ J. Piedra,¹⁰ K. T. Pitts,²³ C. Plager,⁷ A. Pomposh,⁴⁶ L. Pondrom,⁵⁸ G. Pope,⁴⁵ O. Poukhov,¹³ F. Prakoshyn,¹³ T. Pratt,²⁹ A. Pronko,¹⁶ J. Proudfoot,² F. Ptohos,¹⁷ G. Punzi,⁴⁴ J. Rademacker,⁴¹ A. Rakitine,³¹ S. Rappoccio,²⁰ F. Ratnikov,⁵⁰ H. Ray,³³ A. Reichold,⁴¹ B. Reisert,¹⁵ V. Rekovic,³⁶ P. Renton,⁴¹ M. Rescigno,⁴⁹ F. Rimondi,⁴ K. Rinnert,²⁵ L. Ristori,⁴⁴ W. J. Robertson,¹⁴ A. Robson,⁴¹ T. Rodrigo,¹⁰ S. Rolli,⁵⁵ L. Rosenson,³¹ R. Roser,¹⁵ R. Rossin,⁴² C. Rott,⁴⁶ J. Russ,¹¹ A. Ruiz,¹⁰ D. Ryan,⁵⁵ H. Saarikko,²¹ A. Safonov,⁶ R. St. Denis,¹⁹ W. K. Sakumoto,⁴⁷ G. Salamanna,⁴⁹ D. Saltzberg,⁷ C. Sanchez,³ A. Sansoni,¹⁷ L. Santi,⁵³ S. Sarkar,⁴⁹ K. Sato,⁵⁴ P. Savard,³² A. Savoy-Navarro,¹⁵ P. Schemitz,²⁵ P. Schlabach,¹⁵ E. E. Schmidt,¹⁵ M. P. Schmidt,⁵⁹ M. Schmitt,³⁷ L. Scodellaro,⁴² A. Scribano,⁴⁴ F. Scuri,⁴⁴ A. Sedov,⁴⁶ S. Seidel,³⁶ Y. Seiya,⁴⁰ F. Semeria,⁴ L. Sexton-Kennedy,¹⁵ I. Sfiligoi,¹⁷ M. D. Shapiro,²⁸ T. Shears,²⁹ P. F. Shepard,⁴⁵ M. Shimojima,⁵⁴ M. Shochet,¹² Y. Shon,⁵⁸ I. Shreyber,³⁵ A. Sidoti,⁴⁴ J. Siegrist,²⁸ M. Siket,¹ A. Sill,⁵² P. Sinervo,³² A. Sisakyan,¹³ A. Skiba,²⁵ A. J. Slaughter,¹⁵ K. Sliwa,⁵⁵ D. Smirnov,³⁶ J. R. Smith,⁶ F. D. Snider,¹⁵ R. Snihur,³² S. V. Somalwar,⁵⁰ J. Spalding,¹⁵ M. Spezziga,⁵² L. Spiegel,¹⁵ F. Spinella,⁴⁴ M. Spiropulu,⁹ P. Squillacioti,⁴⁴ H. Stadie,²⁵ A. Stefanini,⁴⁴ B. Stelzer,³² O. Stelzer-Chilton,³² J. Strologas,³⁶ D. Stuart,⁹ A. Sukhanov,¹⁶ K. Sumorok,³¹ H. Sun,⁵⁵ T. Suzuki,⁵⁴ A. Taffard,²³ R. Tafirout,³² S. F. Takach,⁵⁷ H. Takano,⁵⁴ R. Takashima,²² Y. Takeuchi,⁵⁴ K. Takikawa,⁵⁴ M. Tanaka,² R. Tanaka,³⁹ N. Tanimoto,³⁹ S. Tapprogge,²¹ M. Tecchio,³³ P. K. Teng,¹ K. Terashi,⁴⁸ R. J. Tesarek,¹⁵ S. Tether,³¹ J. Thom,¹⁵ A. S. Thompson,¹⁹ E. Thomson,⁴³ P. Tipton,⁴⁷ V. Tiwari,¹¹ S. Tkaczyk,¹⁵ D. Toback,⁵¹ K. Tollefson,³⁴ T. Tomura,⁵⁴ D. Tonelli,⁴⁴ M. Tönnemann,³⁴ S. Torre,⁴⁴ D. Torretta,¹⁵ W. Trischuk,³² J. Tseng,⁴¹ R. Tsuchiya,⁵⁶ S. Tsuno,³⁹ D. Tsybychev,¹⁶ N. Turini,⁴⁴ M. Turner,²⁹ F. Ukegawa,⁵⁴ T. Unverhau,¹⁹ S. Uozumi,⁵⁴ D. Usynin,⁴³ L. Vacavant,²⁸ A. Vaiciulis,⁴⁷ A. Varganov,³³ E. Vataga,⁴⁴ S. Vejcik III,¹⁵ G. Velev,¹⁵ G. Veramendi,²³ T. Vickey,²³ R. Vidal,¹⁵ I. Vila,¹⁰ R. Vilar,¹⁰ I. Volobouev,²⁸ M. von der Mey,⁷ R. G. Wagner,² R. L. Wagner,¹⁵ W. Wagner,²⁵ R. Wallny,⁷ T. Walter,²⁵ T. Yamashita,³⁹ K. Yamamoto,⁴⁰ Z. Wan,⁵⁰ M. J. Wang,¹ S. M. Wang,¹⁶ A. Warburton,³² B. Ward,¹⁹ S. Waschke,¹⁹ D. Waters,³⁰ T. Watts,⁵⁰ M. Weber,²⁸ W. C. Wester III,¹⁵ B. Whitehouse,⁵⁵ A. B. Wicklund,² E. Wicklund,¹⁵ H. H. Williams,⁴³ P. Wilson,¹⁵ B. L. Winer,³⁸ P. Wittich,⁴³ S. Wolbers,¹⁵ M. Wolter,⁵⁵ M. Worcester,⁷ S. Worm,⁵⁰ T. Wright,³³ X. Wu,¹⁸ F. Würthwein,⁸ A. Wyatt,³⁰ A. Yagil,¹⁵ U. K. Yang,¹² W. Yao,²⁸ G. P. Yeh,¹⁵ K. Yi,²⁴ J. Yoh,¹⁵ P. Yoon,⁴⁷ K. Yorita,⁵⁶ T. Yoshida,⁴⁰ I. Yu,²⁷ S. Yu,⁴³ Z. Yu,⁵⁹ J. C. Yun,¹⁵ L. Zanello,⁴⁹ A. Zanetti,⁵³ I. Zaw,²⁰ F. Zetti,⁴⁴ J. Zhou,⁵⁰ A. Zsenei,¹⁸ and S. Zucchelli⁴

(CDF Collaboration)

¹*Institute of Physics, Academia Sinica, Taipei 11529, Taiwan, Republic of China*²*Argonne National Laboratory, Argonne, Illinois 60439, USA*³*Institut de Fisica d'Altes Energies, Universitat Autònoma de Barcelona, E-08193, Bellaterra (Barcelona), Spain*⁴*Istituto Nazionale di Fisica Nucleare, University of Bologna, I-40127 Bologna, Italy*⁵*Brandeis University, Waltham, Massachusetts 02254, USA*⁶*University of California at Davis, Davis, California 95616, USA*⁷*University of California at Los Angeles, Los Angeles, California 90024, USA*⁸*University of California at San Diego, La Jolla, California 92093, USA*⁹*University of California at Santa Barbara, Santa Barbara, California 93106, USA*¹⁰*Instituto de Fisica de Cantabria, CSIC-University of Cantabria, 39005 Santander, Spain*¹¹*Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA*¹²*Enrico Fermi Institute, University of Chicago, Chicago, Illinois 60637, USA*¹³*Joint Institute for Nuclear Research, RU-141980 Dubna, Russia*¹⁴*Duke University, Durham, North Carolina 27708, USA*¹⁵*Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA*¹⁶*University of Florida, Gainesville, Florida 32611, USA*¹⁷*Laboratori Nazionali di Frascati, Istituto Nazionale di Fisica Nucleare, I-00044 Frascati, Italy*¹⁸*University of Geneva, CH-1211 Geneva 4, Switzerland*¹⁹*Glasgow University, Glasgow G12 8QQ, United Kingdom*²⁰*Harvard University, Cambridge, Massachusetts 02138, USA*²¹*The Helsinki Group: Helsinki Institute of Physics and Division of High Energy Physics, Department of Physical Sciences, University of Helsinki, FIN-00044, Helsinki, Finland*²²*Hiroshima University, Higashi-Hiroshima 724, Japan*

- ²³University of Illinois, Urbana, Illinois 61801, USA
²⁴The Johns Hopkins University, Baltimore, Maryland 21218, USA
²⁵Institut für Experimentelle Kernphysik, Universität Karlsruhe, 76128 Karlsruhe, Germany
²⁶High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305, Japan
²⁷Center for High Energy Physics: Kyungpook National University, Taegu 702-701, Korea,
 Seoul National University, Seoul 151-742, Korea,
 and SungKyunKwan University, Suwon 440-746, Korea
²⁸Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, California 94720, USA
²⁹University of Liverpool, Liverpool L69 7ZE, United Kingdom
³⁰University College London, London WC1E 6BT, United Kingdom
³¹Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA
³²Institute of Particle Physics, McGill University, Montréal H3A 2T8, Canada and University of Toronto, Toronto M5S 1A7, Canada
³³University of Michigan, Ann Arbor, Michigan 48109, USA
³⁴Michigan State University, East Lansing, Michigan 48824, USA
³⁵Institution for Theoretical and Experimental Physics, ITEP, Moscow 117259, Russia
³⁶University of New Mexico, Albuquerque, New Mexico 87131, USA
³⁷Northwestern University, Evanston, Illinois 60208, USA
³⁸The Ohio State University, Columbus, Ohio 43210, USA
³⁹Okayama University, Okayama 700-8530, Japan
⁴⁰Osaka City University, Osaka 588, Japan
⁴¹University of Oxford, Oxford OX1 3RH, United Kingdom
⁴²University of Padova, Istituto Nazionale di Fisica Nucleare, Sezione di Padova-Trento, I-35131 Padova, Italy
⁴³University of Pennsylvania, Philadelphia, Pennsylvania 19104, USA
⁴⁴Istituto Nazionale di Fisica Nucleare, University and Scuola Normale Superiore of Pisa, I-56100 Pisa, Italy
⁴⁵University of Pittsburgh, Pittsburgh, Pennsylvania 15260, USA
⁴⁶Purdue University, West Lafayette, Indiana 47907, USA
⁴⁷University of Rochester, Rochester, New York 14627, USA
⁴⁸The Rockefeller University, New York, New York 10021, USA
⁴⁹Istituto Nazionale di Fisica Nucleare, Sezione di Roma 1, University di Roma “La Sapienza,” I-00185 Roma, Italy
⁵⁰Rutgers University, Piscataway, New Jersey 08855, USA
⁵¹Texas A&M University, College Station, Texas 77843, USA
⁵²Texas Tech University, Lubbock, Texas 79409, USA
⁵³Istituto Nazionale di Fisica Nucleare, University of Trieste/ Udine, Italy
⁵⁴University of Tsukuba, Tsukuba, Ibaraki 305, Japan
⁵⁵Tufts University, Medford, Massachusetts 02155, USA
⁵⁶Waseda University, Tokyo 169, Japan
⁵⁷Wayne State University, Detroit, Michigan 48201, USA
⁵⁸University of Wisconsin, Madison, Wisconsin 53706, USA
⁵⁹Yale University, New Haven, Connecticut 06520, USA
 (Received 28 June 2004; published 9 March 2005)

We report the first measurements of inclusive W and Z cross sections times leptonic branching ratios for $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV, based on their decays to electrons and muons. The data correspond to an integrated luminosity of 72 pb^{-1} recorded with the CDF detector at the Fermilab Tevatron. We test e - μ universality in W decays, and we measure the ratio of leptonic W and Z rates from which the leptonic branching fraction $B(W \rightarrow \ell\nu)$ can be extracted as well as an indirect value for the total width of the W and the Cabibbo-Kobayashi-Maskawa matrix element, $|V_{cs}|$.

DOI: 10.1103/PhysRevLett.94.091803

PACS numbers: 13.38.Be, 12.38.Qk, 13.85.Qk, 14.70.Fm

We report the first measurements of the inclusive production of W and Z bosons in $p\bar{p}$ collisions at the upgraded Run II Fermilab Tevatron operated at $\sqrt{s} = 1.96$ TeV. Measurements during Run I at $\sqrt{s} = 1.8$ TeV have been reported by the CDF and D0 collaborations [1]. The data were collected with the Collider Detector at Fermilab (CDF) detector and comprise $72.0 \pm 4.3 \text{ pb}^{-1}$. W and Z bosons are identified by their decays to electrons and muons, from which we obtain the total rates $\sigma(p\bar{p} \rightarrow W) \times B(W \rightarrow \ell\nu)$ and $\sigma(p\bar{p} \rightarrow Z) \times B(Z \rightarrow \ell^+\ell^-)$ [2]. We test e - μ universality in W decays using the ratio of inclusive W production for

the two lepton species. We derive the leptonic branching ratio $B(W \rightarrow \ell\nu)$ and an indirect value for the total W width, Γ_W^{tot} , from the ratio of leptonic rates,

$$R \equiv \frac{\sigma(p\bar{p} \rightarrow W) \times B(W \rightarrow \ell\nu)}{\sigma(p\bar{p} \rightarrow Z) \times B(Z \rightarrow \ell^+\ell^-)}. \quad (1)$$

Measurements of Γ_W^{tot} test the standard model (SM), which predicts Γ_W^{tot} in terms of electroweak parameters and the Cabibbo-Kobayashi-Maskawa (CKM) matrix elements [3].

The CDF detector has been substantially upgraded since the end of the previous data-taking period [4]. The

central outer tracker (COT) is a precision drift chamber which provides up to 96 space points for a track falling within its fiducial range $|\eta| < 1$ [5]. The COT sense wires are arranged in eight “superlayers,” four of which provide axial coordinates and four of which provide stereo measurements. Precise track coordinates closer to the beam are provided by the silicon vertex detector. The fiducial coverage of the central electromagnetic (em) and hadronic (had) calorimeters has been extended to $|\eta| \sim 2.8$, and the muon chambers provide coverage out to $|\eta| \sim 1$.

The selection of candidate W and Z decays begins with the requirement of a high- p_T lepton. Electrons are identified on the basis of their electromagnetic showers. We require an energy cluster in a well instrumented region of the calorimeter with $E_T > 25$ GeV, matched to a single track with $p_T > 10$ GeV that extrapolates to the position of the cluster at a depth corresponding to shower maximum. The ratio E_T/p_T must be less than 2, and the energy in the hadronic calorimeter must be relatively small: $E_{\text{had}}/E_{\text{em}} < 0.055 + 0.00045 \times E_{\text{em}}$. The shape of the shower must be consistent with that observed from test-beam data. Beyond the central tracker coverage, $|\eta| > 1$, only calorimetry is used to identify electrons.

Muons are identified on the basis of a track segment (“stub”) reconstructed in the muon chambers with positions well-matched to the extrapolation of a single track. We require $p_T > 20$ GeV, and energy depositions in the calorimeters consistent with those expected from a minimum-ionizing particle.

Requirements on the reconstructed track are common to both the electron and muon selections. At least three axial and three stereo COT superlayers must have seven hits or more. Not all the lepton tracks have hits from the silicon vertex detector, so for the sake of uniformity in the p_T measurement, we drop these hits and constrain the track fit to the transverse beam profile. For muons, we apply a cut on the χ^2 for the track fit to eliminate kaons and pions which have decayed in flight. The coordinate of the lepton along the beam line must fall within 60 cm of the center of the detector to ensure a good energy measurement in the calorimeter. This requirement eliminates $\sim 5\%$ of the data, according to studies with minimum-bias events.

After the selection of high- p_T leptons, we establish the W and Z samples. For $W \rightarrow \ell\nu$ candidates, we require $\cancel{E}_T > 25$ GeV (20 GeV) in the electron (muon) channel as evidence for the neutrino. In the muon channel, events with any second charged particle ($p_T > 10$ GeV) are rejected as potential background from $Z \rightarrow \mu^+\mu^-$. For Z candidates, a second electron is required in the electron channel, and a second charged particle in the muon channel. These must pass the same E_T and p_T cuts as the first lepton. The identification requirements are looser for the second lepton in order to maintain good efficiency for these events. For example, for loose electrons in the central region, an associated track is required, but the

requirements on E_T/p_T , of the match of the track to the center of the cluster, and on the lateral shower shape are dropped.

For $W \rightarrow e\nu$ candidates we accept electrons reconstructed in the central calorimeter, which corresponds to $|\eta| \lesssim 1$. For $Z \rightarrow e^+e^-$ candidates, one electron must come from the central calorimeter, while the second can come from the forward region, which extends out to $|\eta| = 2.8$.

A significant background comes from leptons from the decays of heavy-flavor hadrons, which can be reduced by requiring that the lepton be isolated. We require that the calorimetric energy not associated with the lepton in a cone of $\Delta R = 0.4$ around the lepton must be no more than 10% of the energy of the lepton [6].

Cosmic-ray muons contaminate the muon samples. We use the timing capabilities of the COT to reject events with two muon tracks, one of which travels from outside of the COT toward the beam pipe. We also require that the muon tracks pass close to the beam line, within distances less than 0.02 cm (0.2 cm) for tracks with (without) silicon hits.

The kinematic and geometric acceptance is estimated using the PYTHIA 6.203 event generator [7] and a full simulation of the CDF detector based on the GEANT simulation package [8]. The key quantity is the boson rapidity, y , so we extract the acceptance $A(y)$ from the simulation and convolve it with a next to next to leading order calculation of $d\sigma/dy$ [9], which depends on the parton distribution functions (PDF's). We compute the central values of the acceptance using the Martin-Roberts-Stirling-Thorne (MRST) PDF's [10]. We estimate the uncertainties using the PDF eigenvector basis sets for CTEQ6M [11], and obtain 1.3% for $W \rightarrow e\nu$ and $\mu\nu$, and 0.7% for $Z \rightarrow e^+e^-$ and 2.1% for $Z \rightarrow \mu^+\mu^-$. These are roughly a factor of 2 larger than what we obtained using the MRST error PDF's.

The amount of material an electron passes through is known to 10–30%, depending on η ; this contributes $\lesssim 1\%$ to the acceptance uncertainty for the electron channels. The energies of hadronic jets recoiling against the W bosons enter the calculation of \cancel{E}_T . We test the accuracy of the simulation using a χ^2 test with scale factors and offsets for the components of these energies which are parallel and perpendicular to the lepton momentum vector. Taking a variation corresponding to $\Delta\chi^2 = 9$, we infer systematic uncertainties of about 0.3%. The energy and momentum scales for the leptons are treated in a similar manner, resulting in an uncertainty of 0.2%–0.3%. Finally, we vary the parameters of the PYTHIA model which influence the boson p_T distribution, as allowed by χ^2 tests with the Run I measurement [1], and find the uncertainty on the acceptance is negligible.

Lepton reconstruction, identification, isolation, and trigger efficiencies are measured directly with the data. We use $Z \rightarrow \ell^+\ell^-$ decays in which the standard cuts are applied to one lepton and the second candidate lepton is

TABLE I. Background estimates.

category	channel			
	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$	$Z \rightarrow e^+e^-$	$Z \rightarrow \mu^+\mu^-$
multijet	587 ± 299	220 ± 111	41 ± 18	0_{-0}^{+1}
$Z \rightarrow \ell^+\ell^-$	317 ± 14	1739 ± 75
$Z \rightarrow \tau^+\tau^-$	negligible	negligible	3.7 ± 0.4	1.5 ± 0.3
$W \rightarrow \tau\nu$	752 ± 17	998 ± 31	negligible	negligible
$W \rightarrow \ell\nu$	16.8 ± 2.8	negligible
cosmic rays	negligible	33 ± 23	negligible	12 ± 12

tested to see whether it passes the given criteria. The statistical uncertainties are below 1% and studies with the simulation show negligible bias with respect to W decays. The cuts to eliminate cosmic rays remove a very small fraction of signal events in the muon channel, as measured by applying the cuts to $W \rightarrow e\nu$ and $Z \rightarrow e^+e^-$ events. The track-reconstruction efficiency is measured using a trigger demanding an energetic calorimeter cluster which provides a sample of $W \rightarrow e\nu$ events independent of the tracking. The efficiency for rejecting $Z \rightarrow \mu^+\mu^-$ events in the $W \rightarrow \mu\nu$ channels is estimated using the simulation.

Backgrounds fall into three categories: multijet events with no W or Z bosons, weak-boson backgrounds ($Z \rightarrow \ell^+\ell^-$ and $W \rightarrow \tau\nu$ appearing in $W \rightarrow \ell\nu$, and $Z \rightarrow \tau^+\tau^-$ and $W \rightarrow \ell\nu$ appearing in $Z \rightarrow \ell^+\ell^-$), and noncollision backgrounds, primarily cosmic rays. Estimates of these backgrounds are summarized in Table I.

The multijet background is estimated with the data. Such events are characterized by a significant energy in the cone around the lepton and a small \cancel{E}_T , with tails in both quantities. We assume that these tails are not correlated, and estimate the number of background events by comparing to control regions with either low \cancel{E}_T or high energy in the isolation cone, after taking into account the W events which fall in the control regions. We vary the cuts on \cancel{E}_T and isolation which define the control regions, and then estimate changes in a manner reproduced by the simulation. We assign a systematic uncertainty of 50% for this background estimate.

The weak-boson backgrounds are obtained using the simulation to compute the acceptance relative to that of the signal. To normalize the contribution of $Z \rightarrow \ell^+\ell^-$ backgrounds to $W \rightarrow \ell\nu$ channels, we use the theoretical value for the ratio of cross sections, with an uncertainty corresponding to previous measurements of W and Z cross sections [1]. Backgrounds from diboson and $t\bar{t}$ production are negligible.

For estimating the cosmic-ray contamination in the $W \rightarrow \mu\nu$ sample, we use the azimuthal distribution of muon chamber hits opposite the high- p_T muon. For the $Z \rightarrow \mu^+\mu^-$ sample, we use the distribution of the cosine of the angle between the two muon tracks. In both cases, the contribution from cosmic rays is very small.

The uncertainty on the luminosity measurement is 6.0%, of which 4.4% comes from the acceptance and operation of the luminosity monitor and 4.0% comes from the calculation of the total $p\bar{p}$ cross section [12].

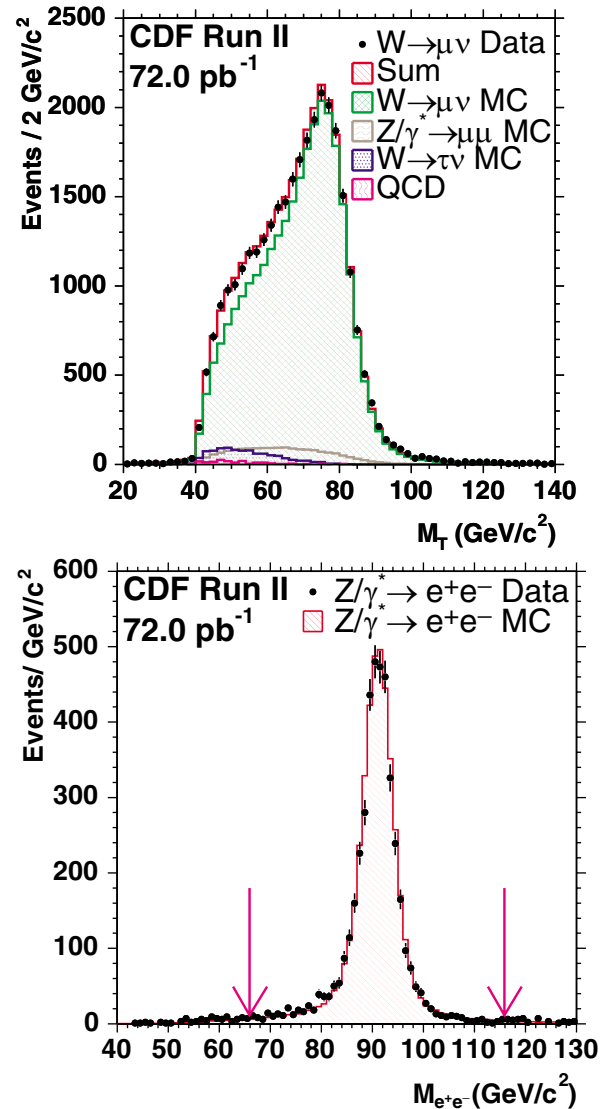


FIG. 1 (color online). Distributions of M_T for $W \rightarrow \mu\nu$ (top) and $M_{e^+e^-}$ for $Z/\gamma^* \rightarrow e^+e^-$ (bottom). The arrows in the $M_{e^+e^-}$ distribution define the mass window.

TABLE II. Number of selected events, and estimated acceptance, efficiency, and expected number of background events. Cross sections are reported in picobarn, with a statistical and systematic uncertainty. A common uncertainty due to the luminosity measurement is 166 pb (15 pb) for the W (Z) channels.

category	channel			
	$W \rightarrow e\nu$	$W \rightarrow \mu\nu$	$Z/\gamma^* \rightarrow e^+e^-$	$Z/\gamma^* \rightarrow \mu^+\mu^-$
N candidates	37 584	31 722	4242	1785
acceptance	0.2397 ± 0.0039	0.1970 ± 0.0027	0.3182 ± 0.0041	0.1392 ± 0.0030
efficiency	0.749 ± 0.009	0.732 ± 0.013	0.713 ± 0.012	0.713 ± 0.015
background	1656 ± 300	2990 ± 140	62 ± 18	13 ± 13
cross section (pb)	$2780 \pm 14 \pm 60$	$2768 \pm 16 \pm 64$	$255.8 \pm 3.9 \pm 5.5$	$248.0 \pm 5.9 \pm 7.6$

We compute the transverse mass of each candidate W decay: $M_T \equiv \sqrt{E_T \cancel{E}_T - (E_x \cancel{E}_{T,x} + E_y \cancel{E}_{T,y})}$, where E_x and E_y are measured with the calorimeter for electrons, and with the COT for muons. In the $Z \rightarrow \ell^+ \ell^-$ channels, we compute the invariant mass of the lepton pair, and count the candidates in the mass window $66 \text{ GeV} < M_{\ell^+ \ell^-} < 116 \text{ GeV}$. The cross sections $\sigma(p\bar{p} \rightarrow Z/\gamma^* \rightarrow \ell^+ \ell^-)$ reported here include the contributions from virtual photon exchange. Distributions for $W \rightarrow \mu\nu$ and $Z \rightarrow e^+e^-$ are shown in Fig. 1, which demonstrate that the simulations match the data well.

The measurement of the cross section requires the number of events selected for the given luminosity, and the estimates of the acceptance, efficiencies, and backgrounds. A summary of these quantities and the inferred cross sections is given in Table II.

We test e - μ universality in W decays by taking ratios of the W cross sections. Many uncertainties cancel in this ratio, and we find for the ratio of W - ℓ - ν couplings: $g_\mu/g_e = 0.998 \pm 0.004_{(\text{stat})} \pm 0.011_{(\text{syst})}$.

Since there is no sign of nonuniversality, we combine our measurements taking correlated uncertainties into account and obtain

$$\begin{aligned} \sigma \times B(p\bar{p} \rightarrow W \rightarrow \ell\nu) &= 2775 \pm 10_{(\text{stat})} \pm 53_{(\text{syst})} \\ &\quad \pm 167_{(\text{lum})} \text{ pb} \\ \sigma \times B(p\bar{p} \rightarrow Z/\gamma^* \rightarrow \ell^+ \ell^-) &= 254.9 \pm 3.3_{(\text{stat})} \pm 4.6_{(\text{syst})} \\ &\quad \pm 15.2_{(\text{lum})} \text{ pb}. \end{aligned}$$

Agreement with SM predictions [13,14] is good.

We compute the ratio, R [Eq. (1)], taking all correlations among channels into account, and obtain $R = 10.92 \pm 0.15_{(\text{stat})} \pm 0.14_{(\text{syst})}$, after correcting for virtual photon exchange (we multiply the measured Z/γ^* cross section by a factor 1.004 ± 0.001). Using the measured value $B(Z \rightarrow \ell^+ \ell^-) = 0.033\,658 \pm 0.000\,023$ [15] and a theoretical calculation of the ratio of production cross sections [14], we extract the leptonic branching ratio $B(W \rightarrow \ell\nu) = 0.1089 \pm 0.0022$.

Using the theoretical value for the leptonic partial width, $\Gamma(W \rightarrow \ell\nu) = 226.4 \pm 0.3 \text{ MeV}$ [15], we extract the total width of the W boson: $\Gamma_W^{\text{tot}} = 2079 \pm 41 \text{ MeV}$

which can be compared to the SM value, $2092.1 \pm 2.5 \text{ MeV}$ and the current world average, $2118 \pm 42 \text{ MeV}$ [15]. Alternatively, rather than using the measured value for $B(Z \rightarrow \ell^+ \ell^-)$, we can use the SM value for $\Gamma(Z \rightarrow \ell^+ \ell^-)$ and extract the ratio of total widths: $\Gamma_W^{\text{tot}}/\Gamma_Z^{\text{tot}} = 0.833 \pm 0.017$.

Finally, in the SM, the total width Γ_W^{tot} depends on electroweak parameters and certain CKM matrix elements, which we can constrain using Γ_W^{tot} [3]. Using world average values [15] for all CKM matrix elements except $|V_{cs}|$, we derive $|V_{cs}| = 0.967 \pm 0.030$.

We appreciate the help we received from William Stirling and Lance Dixon. We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. 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 Research Corporation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnología, Spain; in part by the European Community's Human Potential Programme under contract no. HPRN-CT-20002, Probe for New Physics; and by the Research Fund of Istanbul University Project No. 1755/21122001.

- [1] CDF Collaboration, T. Affolder *et al.*, Phys. Rev. Lett. **84**, 845 (2000); CDF Collaboration, F. Abe *et al.*, Phys. Rev. D **59**, 052002 (1999); , Phys. Rev. Lett. **76**, 3070 (1996); D0 Collaboration, B. Abbott *et al.*, Phys. Rev. D **60**, 052003 (1999).
- [2] The symbol “ ℓ ” refers to electrons or muons.
- [3] P. B. Renton, Rep. Prog. Phys. **65**, 1271 (2002).

- [4] R. Blair *et al.*, Fermilab Report No. FERMILAB-Pub-96/390-E.
- [5] Let θ be the polar angle with respect to the proton beam axis, and ϕ the azimuthal angle. The *pseudorapidity* is $\eta \equiv -\ln[\tan(\theta/2)]$. The *transverse momentum*, p_T , is the component of the momentum projected onto the plane perpendicular to the beam axis. The *transverse energy*, E_T , of a shower or calorimeter tower is $E \sin\theta$. The *missing energy*, \cancel{E}_T , is the vector which points opposite the vector sum of all calorimeter energy: $\cancel{E}_{Tx} = -\sum_i E_{T,i} \cos\phi_i$, where the sum extends over all towers, $E_{T,i}$ is the transverse energy of the i^{th} tower. A similar expression holds for the y -component.
- [6] $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$; ϕ is measured in radians.
- [7] Torbjörn Sjöstrand, Leif Lonnblad, and Stephen Mrenna, *Comput. Phys. Commun.* **135**, 238 (2001).
- [8] R. Brun, R. Hagelberg, M. Hansroul, and J.C. Lassalle, CERN Report No. CERN-DD-78-2-REV.
- [9] C. Anastasiou, L. Dixon, K. Melnikov, and F. Petriello, *Phys. Rev. D* **69**, 094008 (2004); *Phys. Rev. Lett.* **91**, 182002 (2003).
- [10] A.D. Martin, R.G. Roberts, W.J. Stirling, and R.S. Thorne, *Eur. Phys. J.* **C28**, 455 (2003).
- [11] J. Pumplin *et al.*, *J. High Energy Phys.* 07 (2002) 012.
- [12] S. Klimenko, J. Konigsberg, and T.M. Liss, Fermilab Report No. FERMILAB-FN-0741.
- [13] P.J. Sutton, A.D. Martin, R.G. Roberts, and W.J. Stirling, *Phys. Rev. D* **45**, 2349 (1992); P.J. Rijken and W.L. van Neerven, *Phys. Rev. D* **51**, 44 (1995); R. Hamberg, W.L. van Neerven, and W.B. Kilgore, *Nucl. Phys. B* **359**, 343 (1991); R.V. Harlander and W.B. Kilgore, *Phys. Rev. Lett.* **88**, 201801 (2002).
- [14] We compute the theoretical cross sections on the basis of NLO calculations by A.D. Martin *et al.*, *Eur. Phys. J.* **C35**, 325 (2004), and on the programs of W.L. van Neerven [13], and obtain $\sigma \times B(p\bar{p} \rightarrow W \rightarrow \ell\nu) = 2687 \pm 54$ pb, $\sigma \times B(p\bar{p} \rightarrow Z \rightarrow \ell^+\ell^-) = 251.3 \pm 5.0$ pb and $R = 10.69 \pm 0.08$ ($B(W \rightarrow \ell\nu) = 0.1068$ and $B(Z \rightarrow \ell^+\ell^-) = 0.033658$ are used).
- [15] K. Hagiwara *et al.*, *Phys. Rev. D* **66**, 010001 (2002).