

December 17, 2008

**Closeout Report**  
**Department of Energy Grant**  
**DE-FG02 95ER40931**  
**Advanced Map Methods for the**  
**Description of Particle Beam Dynamics**

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**Abstract**

The above grant was active at Michigan State University from 1994 until 2007. We summarize and document the various activities and key output under the grant, including degrees awarded to graduate students at MSU and through the VUBeam program sponsored by the grant, the books, publications and reports produced, the meetings organized, and the presentations given.

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## **I. Degrees Awarded**

1. Johannes Grote, Ph.D. (Defense May 2008)
2. Alexey Poklonskiy, Ph.D. (Defense May 2008)
3. Stephen Weathersby, Ph.D. 2007
4. Pavel Snopok, Ph.D. 2007
5. Xiaosong Geng, M.Sc. 2007 (VUBeam)
6. Salma Al-Rasheed, M.Sc. 2007 (VUBeam)
7. Mahuya Sengupta, M.Sc. 2006 (VUBeam)
8. Shashikant Manikonda, Ph.D. 2006
9. Andrew Steere, M.Sc. 2005 (VUBeam)
10. Carlos Maidana, M.Sc. 2004 (VUBeam)
11. Reiko Taki, Rijken, Japan, M.Sc. 2003 (VUBeam)
12. Mohamad Nasr, King Saud University, Saudi Arabia, M.Sc. 2003 (VUBeam)
13. Ralf Toenjes, M.Sc. 2002
14. Jason Ong, M.Sc. 2002 (VUBeam)
15. Mandi Meidlinger, M.Sc. 2002 (VUBeam)
16. David Meidlinger, M.Sc. 2002 (VUBeam)
17. Bela Erdelyi, Ph.D. 2001
18. Jens Hoefkens, Ph.D. 2001
19. Khodr Shamseddine, Ph.D. 1999
20. Jens von Bergmann, M.Sc. 1999
21. Michael Lindemann, M.Sc. 1998 (VUBeam)
22. Kyoko Makino, Ph.D. 1998
23. Meng Zhao, M.Sc. 1996
24. Weishi Wan, Ph.D. 1995
25. Georg Hoffstätter, Ph.D. 1994

## II. Meetings Organized

1. Chair, 2004 Muon Collider Simulation Workshop, Miami, FL, 2004
2. Co-chair, 2004 Computational Accelerator Conference, St. Petersburg, Russia, July 2004
3. Host and Chair, 2002 Computational Accelerator Physics Conference, East Lansing, October 2002
4. Co-chair, Workshops on Taylor Model Methods 2002, 2003, 2004, 2006
5. Host, 1998 Annual USA Symposium of German National Merit Foundation (Studienstiftung des Deutschen Volkes), East Lansing, October 1998
6. Organizer, Symposium on Computational Differentiation and Verified Methods, SIAM Annual Meeting, Toronto 1998
7. Session Chair, APS Spring Meeting 1998
8. Organizer, Symposium on Interval and Computational Differentiation Techniques, SIAM Annual Meeting, Stanford, July 1997
9. Chair, Second SIAM Conference on Computational Differentiation, Santa Fe, New Mexico, February 1996
10. Co-Organizer, Symposium on Computational Differentiation, SIAM Annual Meeting, Kansas City, May 1996
11. Organizer, COSY User's Meeting, Santa Fe, New Mexico, February 1996
12. Organizer, Symposium on Nonlinear Effects in Accelerators, SIAM Conference on Nonlinear Dynamics, Snowbird, Utah, May 1995
13. Session Chair, Fourth Conference on Charged Particle Optics, Tsukuba, October 1994

### III. Presentations

#### A. Invited Talks by PI Berz

1. 07/18/07 “Efficient Taylor Model based Verified ODE and Flow Integration using Differential-Algebraic Methods”, 6th International Congress on Industrial and Applied Mathematics, Zurich, Switzerland.
2. 05/28/07 “Rigorous Computation of Topological Entropy in the Plane”, SIAM Conference on Dynamical Systems, Snowbird, Utah
3. 12/06/06 “Domain Decomposition for Rigorous Integration of Flows”, Fourth International Workshop on Taylor Methods, Boca Raton, FL
4. 10/02/06 “A High-Order Differential Algebraic Vlasov Solver”, ICAP 06, 9th International Computational Accelerator Physics Conference, Chamonix Mont-Blanc
5. 08/14/06 “Verified Dependency Free Computation” Summer School on Hierarchy and Symmetry in Mathematical Models, Dortmund
6. 08/12/06 “Verified Solution of Elliptic and Vlasov-type PDEs”, International Conference on Applied Mathematics, Plovdiv, Bulgaria
7. 07/12/06 “Existence and Uniqueness of Solutions of ODEs in Nonarchimedean Fields”, Ninth International Conference on Non-Archimedean Analysis, Concepcion, Chile
8. 06/19/06 - 06/30/06, “Computational Accelerator Physics”, Course at US Particle Accelerator School, Boston (with K. Makino)
9. 06/08/06 “Verified Integration of Large Parameter Spaces”, Dynamics, Topology, and Computation, Bedlewo, Poland
10. 02/16/06 “The DOE AARD Theory Program”, Presentation to HEPAP Review Panel, Chicago
11. 02/06/06 “Large Emittance Simulations of Muon Dynamics with COSY”, Muon Collider Conference, Chicago
12. 09/21/05 “Domain Reduction for Validated Global Optimization with Taylor Models”, G005, International Workshop on Global Optimization, Almería, Spain. M. Berz.
13. 09/16/05 “An Accurate High-order Verified Method to Solve the 3D Laplace Equation”, International Conference on Systems Theory and Scientific Computation, Malta, invited talk. M. Berz.
14. 09/15/05 “High-order Verified Representation of Poincaré Maps”, Int. Conf. Systems Theory and Scientific Computation, Malta
15. 08/25/05 “Taylor Model Integration of ODEs, Poincare Sections, and Long-Term Behavior”, Second Scandinavian Workshop on Interval Methods and their Applications, Lyngby, Denmark
16. 08/01/05 “Self-Validated Integration of ODEs – Avoiding the Wrapping Effect”, Conference on Differential and Difference Equations and Applications, Melbourne, FL.

17. 07/11/05 “Performance of Taylor Model Methods for Validated Integration of ODEs”, 17th IMACS World Congress, Scientific Computation, Applied Mathematics and Simulation, Paris, France
18. 07/07/05 “Validated Integration of ODEs and PDEs with Taylor Model-based Tools”, Conference on Foundations of Computational Mathematics Conference, Santander, Spain, highlighted talk
19. 05/27/05 “An Accurate High-order Validated Method to Solve Boundary Value Problems for the Laplace and Poisson Equations based on Taylor Models”, SciCADE05, 2005 International Conference on Scientific Computation and Differential Equations, Nagoya, Japan
20. 12/19/04 “Taylor Model Range Bounding Schemes (QFB, Quadratic Fast Bounder and Validated Global Optimization)”, Third International Workshop on Taylor Methods, Miami.
21. 12/16/04 “Introduction to Taylor Model Methods”, Third International Workshop on Taylor Methods, Miami, tutorial. M. Berz.
22. 12/15/04 “Principles of COSY Simulations of Collider Rings”, 2004 Workshop on Muon Collider Simulation, Miami
23. 10/05/04 “Shrink Wrapping and Preconditioning for Validated Integration”, 11th GAMM - IMACS International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics, SCAN 2004, Fukuoka, Japan. M. Berz.
24. 09/16/04 “High-Order Dependency Free Range Bounding for Validated Global Optimization”, NSF Workshop on Reliable Engineering Computing, Savannah, Georgia
25. 07/19/04 “Higher Order Methods”, Fourth Conference on Automatic Differentiation, Chicago, invited tutorial
26. 07/09/04 “Different Forms of Differentiability on  $\{L\}$ - $\{C\}$ - $\{H\}$ - $\{R\}$  Fields and their Consequences”, Eighth International Conference on p-adic Analysis, Clermont-Ferrand, France, invited talk
27. 06/29/04 “Recent Advances in Modern Map Methods”, Eighth Computational Accelerator Physics Conference, St. Petersburg, Russia, plenary lecture.
28. 04/23/04 “Validated High-Order Methods and Applications to Integration”, Fifth International Conference on Applied Mathematics, Fort Lauderdale, invited talk
29. 01/27/04 “COSY High-Order Field Computation”, Muon Collaboration Meeting, Riverside, California, invited talk
30. 08/27/03 “ Muon Emittance Exchange Workshop, Chicago, invited talk
31. 08/21/03 “Validation of Transfer Maps Using Taylor Models”, Physics and Control 2003, St. Petersburg, Russia, plenary talk
32. 08/15/03 “Taylor Model Methods and Applications to Nonlinear Dynamics”, Scandinavian Workshop on Interval Methods and Their Applications, Copenhagen, plenary talk
33. 08/19/03 “Global Optimization with Taylor Model Methods”, 18th International Symposium on Mathematical Programming, Copenhagen

34. 08/12/03 “New Applications of Taylor Model Methods”, Numerical Analysis and Computer Science 2002, Plovdiv, Bulgaria
35. 05/22/03 “Proving Long-Term Stability with Validated ODE Integrators”, Dynamical Systems and Applications 2002, Atlanta
36. 06/08/02 “Map Methods in Cooling Simulations”, NUFACT 2002, New York
37. 01/20/02 “Higher Order Convergence”, Symposium on Validated Methods, Dagstuhl, Germany
38. 12/16/02 “Introduction to Taylor Model Methods”, 2002 Taylor Model Workshop, Miami
39. 11/21/02 “COSY simulations of Ring Coolers”, Ring Cooler and Emittance Exchange Workshop, Fermilab
40. 10/23/02 “New Approaches for the Validation of Transfer Maps using Remainder-Enhanced Differential Algebra”, Sixth Charged Particle Optics Conference, Greenbelt, Maryland
41. 08/12/02 “Self-Validated Integration from the Perspective of Computational Dynamics”, 2002 Conference on Foundations of Computational Mathematics, Minneapolis, MN
42. 08/07/02 “Nonlinear Dynamics in Large Particle Accelerators”, International Conference on Scientific Computation, Atlanta, GA
43. 06/21/02 “A Cauchy Theory on the Levi-Civita Field”, Seventh International Conference on Non-Archimedean Analysis, Nijmegen, Netherlands
44. 06/11/02 “Recent Advances in Self-Validated Methods”, World Automation Congress, Orlando, FL
45. 05/30/02 “Recent Advances in the Treatment of the Wrapping Effect”, Workshop on Validated Methods for Optimization, Fields Institute, Toronto
46. 05/29/02 “Self-Validated Implementation of Numerics in the Taylor Model Framework”, Workshop on Validated Methods for Optimization, Fields Institute, Toronto
47. 05/28/02 “What Taylor Models Are Not”, Workshop on Validated Methods for Optimization, Fields Institute, Toronto
48. 05/23/02 “Taylor Model Based Verified Integration for the Volterra Equations and the Lorenz System”, SIAM Workshop on Validated Computing, Toronto
49. 05/23/02 “Validated Integration of Asteroid Orbits”, SIAM Workshop on Validated Computing, Toronto
50. 05/22/02 “Taylor Models and Their Heuristics for Global Optimization”, SIAM Conference on Optimization, Toronto
51. 05/11/02 “Recent Muon Simulation Results with COSY”, Neutrino Factory and Muon Collider Collaboration Meeting, Shelter Island, NY
52. 03/09/02 “Nonlinear Effects and 6D Dynamics in Muon Accelerator Scenarios”, Muon Collaboration Meeting, Los Angeles, CA

53. 11/21/01 “Verified Integration under Avoidance of the Wrapping Effect”, Symposium on Numerical Integration and its Complexity, Oberwolfach, Germany
54. 10/09/01 “Simulation of Quadrupole Cooling Channel”, 2001 Emittance Exchange Workshop, Berkeley, California
55. 09/11/01 “Taylor Model-based Verified Integrators”, Workshop on Verified Solution of Differential Equations, Fields Institute, Toronto
56. 08/09/01 “High-Order Verified Methods and Applications to Symplectic Integration”, Workshop on the Dynamics of Numerics, Fields Institute, Toronto
57. 08/02/01 “Verified ODE and DAE integration controlling the wrapping effect”, Sci-CaDE 2001, Vancouver
58. 07/16/01 “Recent Advances in Differential Algebraic Methods”, Workshop on Nonlinear Beam Dynamics, Snowmass, CO
59. 07/14/01 “Map Methods for the Analysis of Cooling Dynamics”, Workshop on Cooling Dynamics, Snowmass, CO
60. 07/13/01 “Normal Form Methods and Optimization for Nonlinear Properties of Cooling Channels”, Workshop on Cooling Dynamics, Snowmass, CO
61. 07/03/01 “Verified Solutions of Differential Equations without Wrapping”, 2001 International Conference on Applied Mathematics, Pohang, Korea
62. 09/20/00 “Higher Order Verified Methods”, SCAN2000 - Interval 2000, Karlsruhe, Germany
63. 08/12/00 “Preservation of Hamiltonian Structure in 3D Curvilinear Dynamics”, 2000 Colloquium on Numerical Analysis and Computer Science, Plovdiv, Bulgaria
64. 07/21/00 “Verified Integration of ODEs”, WCNA 2000, Catania, Italy
65. 07/10/00 “Verified Integration and Taylor Model Methods in Nonlinear Dynamics”, WSES 2000, Vouliagmeni, Greece
66. 07/03/00 “Verified Methods for Control Theory”, CAO 2000, Sankt Petersburg, Russia
67. 07/01/00 “Spin Dynamics”, 2000 Conference on Beam Dynamics and Optimization, St. Petersburg, Russia
68. 06/21/00 “Towards a Universal Data Type for Scientific Computing”, Automatic Differentiation 2000, Nice, selected talk
69. 06/14/00 “Verified Integration of Near-Earth Asteroids”, WAC 2000, Maui, HI
70. 06/11/00 “Verified Computational Methods”, Symposium and Tutorial on Modern Methods in Numerics, Maui, HI
71. 05/24/00 “Nonlinear Effects in Neutrino Factories”, Neutrino Factory Conference, Monterey, CA
72. 05/01/00 “Effects of Fringe Fields on Muon Ring Dynamics, APS Spring Meeting, Long Beach, CA
73. 12/16/99 “Nonlinear Effects in Muon Storage Rings, 1999 Muon Collider and Neutrino Factory Conference, San Francisco, CA

74. 11/21/99 “Verified Integration of ODEs, Symbolic-Algebraic Methods and Verification, Dagstuhl, Germany
75. 10/01/99 “Fringe Field and Kinematic Effects in Muon Rings, 1999 Muon Collider Collaboration Meeting, Montauk, NY
76. 08/15/99 “Experiences with On-Line Education in Beam Physics”, International Internet Education Workshop, Romania,
77. 08/13/99 “New Methods for Verified Integration of ODEs”, Eighth International Colloquium for Numerical Analysis, Plovdiv, Bulgaria
78. 05/14/99 “The Taylor Model Method for Verified Integration of ODEs”, Symposium on Verified Integration, Atlanta, GA
79. 05/13/99 “Verified Integration in Celestial Mechanics”, SIAM Annual Meeting, Atlanta, GA
80. 03/23/99 “The Beam Physics Virtual University Initiative”, APS Centennial Meeting, Atlanta, GA
81. 10/29/98 “Verified Integration of Orbits and Flows”, Second MICS Workshop on Predictability of Complex Systems, Albuquerque, NM,
82. 07/14/98 “Verified Computational Differentiation through Numerical Integrators”, SIAM Annual Meeting, Toronto, Canada
83. 07/07/98 “Verified Integration under avoidance of the Wrapping Effect”, 1998 International Conference on Differential Equations, St. Louis, MO
84. 06/30/98 “Nonlinear Beam Dynamics - New Trends”, 1998 Conference on Beam Dynamics and Optimization, St. Petersburg, Russia
85. 05/19/98 “Verified Differentiation through ODE solvers”, 1998 Computational Differentiation Theory Institute, Argonne, IL
86. 04/21/98 “Recent Advances in Differential Algebraic Methods”, APS Spring Meeting, Columbus, OH
87. 12/10/97 “Experiences with International Distance Education”, National Research Council / National Academy of Science Panel on Distance Education, Washington, D.C.
88. 10/16/97 “Estimating the Effects of Remainders in Map Methods”, 1997 International Conference on Beam Dynamics and Optimization, Dubna (not presented due to visa problems)
89. 07/28/97 “Rigorous Long-Term Stability Estimates in Particle Accelerators”, SPIE Symposium on Charged Particle Optics, San Diego, CA
90. 07/17/97 “Taylor Model Methods for the Integration of ODEs”, SIAM Annual Meeting, Stanford, CA
91. 05/18/97 “Applications of COSY INFINITY for the Muon Collider”, Muon Collaboration Annual Meeting, Orcas Island, WA
92. 05/07/97 “Dependency Elimination and Higher-order Bounding with RDA Methods”, 1997 Workshop on Interval Methods, El Paso, TX

93. 12/09/96 through 12/13/96 "Differential Algebraic Techniques and Applications", Series of four invited lectures, DESY/KFA Symposium on Mathematical Aspects of Accelerator Physics, Bad Honnef, Germany
94. 12/03/96 "From Taylor Series to Taylor Models and Remainder Differential Algebras," Symposium on Nonlinear Effects in Accelerator Physics, Santa Barbara, CA
95. 11/23/96 "Infinitely Small Numbers and Almost Infinitely Large Accelerators", Studienstiftung Annual USA Meeting, Dallas, TX
96. 09/25/96 "Differential Algebras with Remainder and Rigorous Proofs of Long-Term Stability," Fourth Conference on Computational Accelerator Physics, Williamsburg, VA
97. 09/16/96 "Computational Differentiation with Remainder Bounds," International Conference on Modelling and Computing in Physics, Dubna
98. 07/26/96 "Taylor Models, Small Numbers, and Large Accelerators: Proving Long Term Stability of Weakly Nonlinear Systems," SIAM Symposium on Verification Theory, Techniques and Software, Kansas City, KS
99. 07/24/96 "Infinitely Small Numbers and Their Use in Beam Physics," SIAM Annual Meeting, Kansas City, KS
100. 07/16/96 "Rigorous Bounds on Survival Times for Motion around Elliptical Fixed Points ," Second World Congress on Nonlinear Analysis, Athens, Greece
101. 07/04/96 "Rigorous Bounds for Stability Times in Storage Rings," Beam Dynamics and Optimization 1996, St. Petersburg, Russia
102. 05/29/96 "Stability of Weakly Nonlinear Dynamical Systems," Nonlinear Dynamics 96, Springfield, MO
103. 02/13/96 "The Applications of COSY INFINITY to Nonlinear Dynamics," Second SIAM Conference on Computational Differentiation, Santa Fe, NM
104. 02/12/96 "Calculus and Numerics on Levi-Civita Fields," Second SIAM Conference on Computational Differentiation, Santa Fe, NM
105. 07/08/95 "Stability of Weakly Nonlinear Systems," ISSAC Montreal,
106. 07/05/95 "COSY INFINITY and its Use in Beam Physics," ICIAM 95, Hamburg
107. 05/22/95 "Differential Algebraic Methods in Beam Physics," SIAM Conference on Nonlinear Dynamics, Snowbird, UT
108. 02/25/95 "Proving Stability of Complex Dynamical Systems," Conference on Interval Methods, El Paso, TX
109. 10/05/94 "Modern Map Methods," Fourth Charged Particle Optics Conference, Tsukuba, Japan
110. 09/21/94 "Differential Algebraic Formulation of Spin Dynamics," 1994 Conference on Spin Physics, Bloomington, IN
111. 09/13/94 "The Use of Interval Methods for the Estimation of Stability in Particle Accelerators," Workshop on Verified Computation, Karlsruhe, Germany
112. 09/06/94 "Modern Map Methods in Accelerator Physics," Conference on Nonlinear Problems in Accelerators, Arcidosso, Italy

## B. Contributed Talks, Seminars, Colloquia by PI Berz

1. 09/28/07 “Rigorous Integration of Flows of ODEs”, Department of Aerospace Dynamics, University of Milan, Italy
2. 09/26/07 “Rigorous Determination of Bounds on Topological Entropy in the Plane”, University of Amsterdam, Netherlands
3. 07/23/07 “Domain Decomposition for the Solution of Flows”, Seminar, University of Karlsruhe, Germany
4. 09/21/05 “Domain Reduction for Validated Global Optimization with Taylor Models”, G05, International Workshop on Global Optimization, Almería, Spain
5. 08/01/05 “Self-Verified Integration of ODEs – Avoiding the Wrapping Effect”, Conference on Differential and Difference Equations and Applications, Melbourne, FL
6. 05/31/05 “Stability Estimates by Validated Global Optimization”, KEK, Japan, Seminar
7. 12/16/04 “Introduction to Taylor Model Methods”, Third International Workshop on Taylor Methods, Miami, tutorial
8. 10/05/04 “Shrink Wrapping and Preconditioning for Validated Integration”, 11th GAMM - IMACS International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics, SCAN 2004, Fukuoka, Japan
9. 10/05/04 “High-Order Constraint Satisfaction via Taylor Models”, 11th GAMM - IMACS International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics, SCAN 2004, Fukuoka, Japan
10. 07/05/04 “Asymptotic Behavior of Preconditioned Long-Term Validated Integration”, University of Karlsruhe, Seminar
11. 06/25/04 “Validated ODE Integration - Methods and Tools”, University of Frankfurt, Seminar
12. 06/23/04 “Advances in Validated ODE Integration”, PARA 2004, Copenhagen
13. 05/12/04 “Asymptotic Stability of High-Order Validated Integration”, Fields Institute, University of Toronto, Seminar
14. 12/14/03 “Asymptotic Behavior of Validated Integration Algorithms”, 2003 Taylor Model Workshop, Miami
15. 09/15/03 “Preconditioning Methods for Validated Integration, University of Toronto, Seminar
16. 12/18/02 “Validated ODE Integration”, 2002 Taylor Model Workshop, Miami
17. 12/17/02 “Comparison of Bounding with Taylor Models and Other Modern Tools”, 2002 Taylor Model Workshop, Miami
18. 07/30/02 “Ring Cooler Simulations in COSY based on Transfer Maps”, Seminar, Fermilab
19. 06/19/02 “Measure Theories on Non-Archimedean Levi-Civita Fields”, Contributed Talk, Conference on Non-Archimedean Analysis, Nijmegen,

20. 06/12/02 “Reconstructive Correction of Large Particle Spectrographs”, Seminar, Catania
21. 06/11/02 “Fringe Field Effects in Quadrupole Cooling Channels”, Seminar, Fermilab
22. 05/29/02 “Taylor Models - Order of Convergence and the Linear Dominated Bounder”, Fields Institute Thematic Program on Numerical and Computational Challenges in Science and Engineering, Validated Methods for Optimization, Toronto
23. 05/23/02 “Methods of Proving Chaos in Dynamical Systems via Transfer Maps”, SIAM Workshop on Validated Computing, Toronto
24. 05/21/02 “Tight Range Enclosures with Taylor Model Methods”, SIAM Conference on Optimization, Toronto
25. 03/19/02 “Quadrupole Channel Cooling Simulations”, Seminar, Fermilab
26. 01/25/02 “Chaos at Large Accelerators”, MSU Campus Theory Seminar
27. 10/12/01 “VUBeam - The Online Master’s and Ph.D. program in Beam Physics”, Seminar, College of Natural Science, MSU
28. 08/08/01 “Verified ODE solvers”, Contributed Talk, Workshop on Dynamics of Numerics, Fields Institute, Toronto
29. 04/12/01 “The MSU VUBeam Initiative and Related Activities”, Seminar, Fermilab
30. 02/13/01 “Dependency Reducing Extensions of Interval Methods”, Seminar, Sun Microsystems, Palo Alto, CA
31. 10/16/00 “Verified Computational Methods”, Colloquium, Kansas State University, Manhattan, KS
32. 09/13/00 “Nonlinear Effects in Muon Storage Rings”, Contributed Talk, International Computational Accelerator Physics Conference, Darmstadt, Germany
33. 08/10/00 “Verified Integration of ODEs”, Contributed Talk, BIT2000, Lund, Sweden
34. 07/06/00 “Analysis and Computational Methods for the Levi-Civita Field”, Contributed Talk, 2000 Conference on Non-Archimedean Analysis, Ioannina, Greece
35. 08/05/99 “Dependency-Free Verified Methods”, Seminar, University of Aachen, Germany
36. 07/15/98 “High-Order Verified Methods and Control of Dependency and Wrapping Effect”, Contributed Talk, SIAM Annual Meeting, Toronto
37. 04/14/98 “The Influence of Fringe Fields on Particle Dynamics in the LHC”, Contributed Talk, Fifth Conference on Charged Particle Optics, Delft, Netherlands
38. 04/14/98 “High-Order Maps and Bounds for Taylor Remainders”, Contributed Talk, Fifth Conference on Charged Particle Optics, Delft, Netherlands
39. 04/07/98 “New Verified Methods for High-Performance Applications”, Seminar, Mathematics and Computer Science Division, Argonne National Laboratory
40. 04/06/98 “Nonlinear Effects in Accelerators: Fringe Fields, Resonances, and Momentum Compaction and other delights”, Seminar, Fermilab

41. 11/15/97 “Nonlinear Dynamics Simulation of the Muon Collider”, Seminar, Fermilab
42. 07/18/97 “Verified Integrators for Maps”, Seminar, Stanford Linear Accelerator Center
43. 05/14/97 “New Features in COSY INFINITY”, 1997 Particle Accelerator Conference, selected talk
44. 04/17/97 “Experiences with Distance Education in Beam Physics”, Seminar, College of Natural Science, MSU
45. 03/25/97 “Nonlinear Map Methods”, Seminar, Fermilab
46. 07/30/96 “Remainder Differential Algebras and Their Use in Global Optimization,” Seminar, Mathematics and Computer Science Division, ANL, Argonne, IL
47. 05/10/96 “Reconstructive Correction of Aberrations in Spectrographs,” Seminar, CEBAF, Newport News, VA
48. 02/16/96 “Remainder Differential Algebras,” Contributed Talk, COSY User’s Meeting, Santa Fe, NM
49. 09/21/95 “Paradoxes of Theoretical Physics and Modern Logic,” Seminar, Olang Summer School, Studienstiftung des Deutschen Volkes
50. 07/06/95 “Problems Associated with a Covariant General Relativistic Treatment of Spin Dynamics,” Seminar, DESY Hamburg
51. 10/13/94 “Differential Algebras and Superconvergent Newton Methods,” Seminar, Institute of Statistical Mathematics, Tokyo University
52. 10/13/94 “Differential Algebraic Methods in Beam Physics,” Seminar, Institute of Statistical Mathematics, Tokyo University
53. 03/11/94 “From Differential Algebras to Remainder Differential Algebras,” Seminar, Institute for Nuclear Research, Moscow State University
54. 03/08/94 “Rigorous Proofs for Long-Term Stability of Dynamical Systems,” Contributed Talk, Conference on Interval Arithmetic 1994, St. Petersburg
55. 03/02/94 “Rigorous Proofs for Long-Term Stability of Dynamical Systems,” Seminar, Mathematics and Computer Science Division, Argonne

### C. Invited Talks by PI Makino

1. 06/05/06. “Demonstration of the code COSY INFINITY”, DyToComp 2006, International Conference on Dynamics, Topology and Computations, Bedlewo, Poland.
2. 06/04/06. “Taylor Model-based Verified Integration of ODEs”, DyToComp 2006, International Conference on Dynamics, Topology and Computations, Bedlewo, Poland.
3. 09/16/05. “Range Bounding with Taylor Models for Global Optimization”, 5th WSEAS International Conference on Systems Theory and Scientific Computation, Malta.
4. 08/25/05. “Advances in Global Optimization with Taylor Models”, Second Scandinavian Workshop on Interval Methods and their Applications, Lyngby, Denmark.

5. 07/11/05. “Taylor Model Methods for High Performance Validated Computations”, 17th IMACS World Congress, Scientific Computation, Applied Mathematics and Simulation, Paris, France.
6. 07/08/05. “Validated Global Optimization and Stability Estimates”, FoCM 2005, Foundations of Computational Mathematics Conference, Santander, Spain.
7. 05/27/05. “Taylor Model-based Validated Integration of ODEs”, SciCADE05, 2005 International Conference on Scientific Computation and Differential Equations, Nagoya, Japan.
8. 09/15/04. “Recent Advances in the Validated Integration of ODEs”, NSF Workshop on Reliable Engineering Computing, Savannah, GA.
9. 04/22/04. “Range Bounding with Taylor Models – Some Case Studies”, WSEAS MATH 2004, Differential Equations: Theory and Applications Symposium, Fort Lauderdale, FL.
10. 01/28/04. “Straight Quadrupole Cooling Channel Simulations”, Muon Collaboration Meeting, Riverside, CA.
11. 09/10/03. “Simulation of Muon Ionization Cooling Systems using Transfer Map Method”, Illinois Institute of Technology, Chicago, IL.
12. 08/28/03. “Quadrupole Cooling Channel Simulation – Particles from Buncher, Phase Rotator through the Quad-Channel in COSY”, Ring Coolers and Emittance Exchange Workshop, Fermilab, IL.
13. 08/26/03. “Simulation of Muon Ionization Cooling Systems using Transfer Map Method”, University of Illinois at Urbana-Champaign, Urbana, IL.
14. 08/21/03. “Nonlinear Transfer Map Treatment of Beams through Systems with Absorbing Material”, International Conference Physics and Control, Saint Petersburg, Russia.
15. 08/15/03. “High Order Range Bounding Using Taylor Models”, 1st Scandinavian Workshop on Interval Methods and Their Applications, Technical University of Denmark, Copenhagen, Denmark.
16. 06/06/03. “Balbekov (Tetra) Ring Simulation Results in COSY”, NuFact03, 5th International Workshop on Neutrino Factories & Superbeams, Columbia University, New York.
17. 01/24/03. “Quad Cooling Channel Simulation”, MuCool Meeting, Fermilab, IL.
18. 05/31/02. “Taylor Models - Hand Calculation for a Linear ODE System”, Fields Institute, Thematic Programs, Numerical and Computational Challenges in Science and Engineering, Validated Methods for Optimization, Toronto, Canada.
19. 05/28/02. “Taylor Models - Roundoff”, Fields Institute, Thematic Programs, Numerical and Computational Challenges in Science and Engineering, Validated Methods for Optimization, Toronto, Canada.
20. 05/23/02. “Taylor Model Based Verified Integration for the Volterra Equations and the Lorenz System”, SIAM Workshop on Validated Computing, Toronto, Canada.
21. 05/13/02. “Nonlinear Effects in Quadrupole Cooling Channels”, Neutrino Factory and Muon Collider Collaboration Meeting, Shelter Island, NY.

22. 03/08/02. "COSY Simulation Code", Ring Cooler Workshop, UCLA, Los Angeles, CA.
23. 03/07/02. "Linear/Nonlinear Cooling Theory", Ring Cooler Workshop, UCLA, Los Angeles, CA.
24. 09/13/01. "Verified Integration with Taylor Models - Nonlinear Examples", Fields Institute, Thematic Programs, Numerical and Computational Challenges in Science and Engineering, Validated Methods for ODEs and DAEs, Toronto, Canada.
25. 06/20/01. "Magnet Fringe Fields, Nonlinear Effects, and Compensation in Large Acceptance Rings", 2001 Particle Accelerator Conference, Chicago, IL.
26. 05/15/01. "High-order Transfer Maps and Verification of Stability in Particle Accelerators", Understanding Complex Systems Symposium, University of Illinois at Urbana-Champaign, May 15, 2001.
27. 05/03/01. "Tracking Study on Nonlinear Effects in the 20-GeV Feasibility II Muon Storage Ring", Nu-mu Collaboration Meeting, Fermilab, May 2-3, 2001.
28. 10/10/01. "Cooling Channel Simulation by COSY Infinity", Emittance Exchange Workshop, Lawrence Berkeley National Laboratory, Berkeley, CA.
29. 10/09/01. "Quad Cooling Channel Simulation", Emittance Exchange Workshop, Lawrence Berkeley National Laboratory, Berkeley, CA.
30. 09/19/00. "Advances in Verified Integration of ODEs", SCAN 2000, International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics, Karlsruhe, Germany.
31. 08/15/00. "Perturbative Equations of Motion and Differential Operators in Nonplanar Curvilinear Coordinates", 9th International Colloquium on Numerical Analysis and Computer Science with Applications, Plovdiv, Bulgaria.
32. 07/12/00. "Verified Global Optimization with Taylor Model Methods", WSES CSCC-MCP-MCME 2000, Athens, Greece.
33. 07/07/00. "Nonlinear Spin Dynamics", Beam Dynamics Optimization, BDO2000, St. Petersburg, Russia.
34. 07/07/00. "Nonlinear Effects on the Dynamics in Muon Storage Rings", Beam Dynamics Optimization, BDO2000, St. Petersburg, Russia.
35. 07/06/00. "Differential Algebraic Methods for Feedforward Control Theory", 11th IFAC International Workshop, Control Applications of Optimization, CAO2000, St. Petersburg, Russia.
36. 07/05/00. "Verified Control of Near-Earth Asteroid Orbits", CAO2000, St. Petersburg, Russia.
37. 06/14/00. "Verified Integration of Near-Earth Asteroids", World Automation Congress, WAC2000, Maui, Hawaii.
38. 12/14/99. "Effects of Kinematic Correction", Neutrino Factory and Muon Collider Collaboration Meeting, Berkeley, CA.
39. 05/13/99. "Control of the Dependency Problem", SIAM Annual Meeting, Atlanta, Georgia.

40. 06/30/98. “Rigorous Long-term Stability Estimates”, BDO-98, Fifth International Workshop, Beam Dynamics and Optimization, St. Petersburg, Russia.
41. 05/20/98. “Differential Algebraic Methods on Taylor Models”, Argonne Theory Institute on Differentiation of Computational Approximations to Functions, Argonne, IL.
42. 04/23/98. “Verified High Order Numerical Integrators Based on Taylor Models”, International Conference on Interval Methods and their Application in Global Optimization (INTERVAL’98), Nanjing, China.
43. 04/23/98. “New Methods for High-Dimensional Verified Quadrature”, International Conference on Interval Methods and their Application in Global Optimization (INTERVAL’98), Nanjing, China.
44. 07/18/97. “Verified Analysis of Stability in Particle Accelerators”, SIAM 45th Anniversary Meeting, Stanford, CA.
45. 05/15/97. “Rigorous Integration of Maps and Long-Term Stability”, 1997 Particle Accelerator Conference, Vancouver, BC, Canada.
46. 02/16/96. “Integration through Measured Fields”, COSY User’s Symposium, Santa Fe, New Mexico.

#### **D. Contributed Talks, Seminars, Colloquia by PI Makino**

1. July 18, 2007. “High-Order Box Rejection and Pruning for Global Optimization based on Taylor Model Methods”, 6th International Congress on Industrial and Applied Mathematics, Zurich, Switzerland, July 16-20, 2007.
2. 12/18/06. “Recent Advances in Taylor Model based Rigorous Global Optimization”, 4th International Workshop on Taylor Methods, Boca Raton, Florida.
3. 10/04/06. “COSY INFINITY”, ICAP 06, 9th International Computational Accelerator Physics Conference, Chamonix Mont-Blanc, France. Code Demonstration Panel.
4. 10/03/06. “Rigorous Global Optimization for Parameter Estimates and Long-Term Stability Bounds”, ICAP 06, 9th International Computational Accelerator Physics Conference, Chamonix Mont-Blanc, France.
5. 09/29/06. “Dependency Reduced High-Order Derivative based Box Rejection for Global Optimization”, SCAN’ 2006, 12th GAMM - IMACS International Symposium on Scientific Computing, Computer Arithmetic and Validated Numerics, Duisburg, Germany.
6. 06/12-16/06. USPAS course “Computational Accelerator Physics”, USPAS, Boston. Lectures.
7. 09/22/05. “Practical Performance of Verified Global Optimization Tools using Taylor Models”, G05, International Workshop on Global Optimization, Almeria, Spain.
8. 08.01/05. “Validated Flows, Normal Forms, and the Stability of the Tevatron”, Conference on Differential and Difference Equations and Applications, Melbourne, FL.
9. 05/31/05. “Validated Integration of ODEs”, KEK, Japan. Seminar.

10. 12/19/04. "Taylor Model Range Bounding Schemes (LDB, Linear Dominated Bounder and QDB, Quadratic Dominated Bounder)", Third International Workshop on Taylor Methods, Miami, FL.
11. 12/18/04. "Preconditioning Methods in the Taylor Model ODE Integrator", Third International Workshop on Taylor Methods, Miami, FL.
12. 10/08/04. "Range Bounding for Global Optimization with Taylor Models", SCAN 2004, 11th GAMM - IMACS International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics, Fukuoka, Japan.
13. 10/07/04. "Rigorous Stability Estimates for the Dynamics in the Tevatron via Nekhoroshev-type Estimates based on Normal Form Pseudo Invariants", SCAN 2004, 11th GAMM - IMACS International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics, Fukuoka, Japan.
14. 10/05/04. "Shrink Wrapping and Preconditioning for Validated Integration", SCAN 2004, 11th GAMM - IMACS International Symposium on Scientific Computing, Computer Arithmetic, and Validated Numerics, Fukuoka, Japan.
15. 07/09/04. "Computational Implementation and Application of the Arithmetic and Operations of the Levi-Civita Field", 8th International Conference on p-adic Functional Analysis, Clermont-Ferrand, France.
16. 06/30/04. "COSY INFINITY Version 9", Eighth Computational Accelerator Physics Conference, St. Petersburg, Russia.
17. 12/20/03. "High Order Range Bounding Using Taylor Models – LDB and QDB", Taylor Model Symposium, Miami, FL.
18. 08/01/03. "Quadrupole Cooling Channel Simulation – Particles from Buncher, Phase Rotator through the Quad-Channel in COSY", Ring Coolers/Emittance Exchange Meeting, Fermilab, IL.
19. 02/04/03. "Progress on Linear Quadrupole Cooling Channel", Ring Coolers / Emittance Exchange Meeting, Fermilab, IL.
20. 01/28/03. "Progress on Linear Quadrupole Cooling Channel", Ring Coolers / Emittance Exchange Meeting, Fermilab, IL.
21. 12/16/02. "Basics of Taylor Models", Taylor Model Symposium, Miami, FL.
22. 12/16/02. "Taylor Models and Other Polynomial Methods", Taylor Model Symposium, Miami, FL.
23. 12/17/02. "Comparison of Taylor Model Bounding with Other State of the Art Methods", Taylor Model Symposium, Miami, FL.
24. 12/18/02. "COSY's Taylor Model Operations", Taylor Model Symposium, Miami, FL.
25. 12/18/02. "Validated ODE Integration with Taylor Models", Taylor Model Symposium, Miami, FL.
26. 12/20/02. "Taylor Model ODE Solver - An Example", Taylor Model Symposium, Miami, FL.
27. 11/21/02. "COSY Simulations on Muon Beam Ring Cooler by V. Balbekov", Ring-Coolers and Emittance Exchange Workshop, Fermilab, IL.

28. 10/23/02. "COSY INFINITY", CPO-6, 2002 International Charged Particle Optics Conference, Greenbelt, Maryland.
29. 10/23/02. "High Order Map Treatment of Cavities and Absorbers with Superimposed Solenoidal Fields", CPO-6, 2002 International Charged Particle Optics Conference, Greenbelt, Maryland.
30. 10/17/02. "New Solenoid Elements in COSY INFINITY", 7th International Computational Accelerator Physics Conference, MSU, East Lansing, MI.
31. 07/30/02. "Balbekov Ring Simulation in COSY (Transfer Maps)", Ring Coolers/Emittance Exchange Meeting, Fermilab, IL.
32. 06/11/02. "Fringe Field Effects in Quadrupole Cooling Channels", Ring Coolers/Emittance Exchange Meeting, Fermilab, IL.
33. 05/29/02. "Taylor Models - Order of Convergence, the Linear Dominated Bounder", Fields Institute, Thematic Programs, Numerical and Computational Challenges in Science and Engineering, Validated Methods for Optimization, Toronto, Canada.
34. 05/21/02. "Tight Range Enclosures with Taylor Model Methods", SIAM Conference on Optimization, Toronto, Canada.
35. 03/19/02. "Quad Channel Cooling Simulation", Ring Coolers / Emittance Exchange Meeting, Fermilab, IL.
36. 09/14/01. "Dependency Free Range Bounding", Fields Institute, Thematic Programs, Numerical and Computational Challenges in Science and Engineering, Validated Methods for ODEs and DAEs, Toronto, Canada.
37. 09/11/01. "Validated ODE Integration of Taylor Models and Examples", Fields Institute, Thematic Programs, Numerical and Computational Challenges in Science and Engineering, Validated Methods for ODEs and DAEs, Toronto, Canada.
38. 08/08/01. "Optimal Control of the Wrapping Effect in Taylor Model based Verified Integration", Fields Institute, Thematic Programs, Numerical and Computational Challenges in Science and Engineering, Dynamics of Numerics, Toronto, Canada.
39. 07/16/01. "Recent Application of COSY to Nonlinear Beam Dynamics Problems", Snowmass 2001, the Future of Particle Physics, Snowmass, Colorado.
40. 07/14/01. "Cooling Channel Simulation based on Map Methods", Snowmass 2001, the Future of Particle Physics, Snowmass, Colorado.
41. 07/03/01. "Verified Solutions of ODEs over Large Domains without Wrapping", Com<sup>2</sup>MaC-2, Pohang, Korea.
42. 03/20/01. "Nonlinear Dynamics in Muon Accelerators", University of Illinois at Urbana-Champaign. Seminar.
43. 03/12/01. "Report on BNL Storage Ring Study", Muon Collaboration Meeting.
44. 08/28/00. "Fringe Field Computation and COSY Infinity", KEK, Tsukuba, Japan.
45. 08/10/00. "Verified High Order Range Enclosure of Multivariate Functions", 40th Anniversary of the Journal BIT - Numerical Mathematics, BIT2000, Lund, Sweden.
46. 07/21/00. "Higher Order Verified Inclusions of Multidimensional Systems by Taylor Models", 3rd World Congress of Nonlinear Analysts, WCNA2000, Catania, Italy.

47. 06/27/00. "Verification of Invertibility and Charting of Constraint Manifolds in Differential Algebraic Equations", 6th IMACS International IMACS Conference on Applications of Computer Algebra, IMACS ACA 2000, St. Petersburg, Russia.
48. 06/27/00. "Differential Algebraic Structures and Verification", IMACS ACA 2000, St. Petersburg, Russia.
49. 06/23/00. "New Applications of Taylor Model Methods", 3rd International Conference on Automatic Differentiation, AD2000, Nice, France.
50. 05/07/98. "Precise and Verified Calculation of High Order Transfer Maps for General Fields", KEK, Tsukuba, Japan.
51. 04/15/98. "COSY Infinity Version 8", Fifth International Conference on Charged Particle Optics, Delft University of Technology, The Netherlands.
52. 04/06/98. "Nonlinear Effects in Rings: Fringe Fields, Resonances, Momentum Compactions, and Other Delights", Fermilab, IL.
53. 02/10/98. "Precise and Verified Calculation of High Order Maps for General Fields", Fermilab, IL.
54. 01/98. "Taylor Models, and Verified Integration of ODEs and Flows", Lecture at USPAS course "Computational Methods in Beam Physics" by Martin Berz, University of Texas at Austin, Austin, Texas.
55. 01/98. "Equation of Motion in Curvilinear Coordinates", Lecture at USPAS course "Computational Methods in Beam Physics" by Martin Berz, University of Texas at Austin, Austin, Texas.
56. 01/98. "Introduction to COSY INFINITY", Lecture at USPAS course "Computational Methods in Beam Physics" by Martin Berz, University of Texas at Austin, Austin, Texas.
57. 07/28/97. "Arbitrary Order Aberrations for Elements Characterized by Measured Fields", SPIE Optical Science, Engineering, and Instrumentation 42nd Annual Meeting, San Diego, CA.
58. 05/08/97. "Efficient Verified Integration Schemes", 1997 Interval Workshop, ACM Symposium on Theory of Computing, El Paso, Texas.
59. 02/20/97. "Introduction to COSY INFINITY", Lecture in video telecast course PHY861 "Introduction to Beam Physics", Michigan State University.
60. 09/25/96. "COSY INFINITY Version 7", 1996 Computational Accelerator Physics Conference, Williamsburg, Virginia.
61. 02/12/96. "Remainder Differential Algebras and Their Applications", Second International Workshop on Computational Differentiation, Santa Fe, New Mexico.
62. 06/95. "Equation of Motion in Particle Optical Coordinates", Lecture at USPAS course "Introduction to Beam Optics" by Martin Berz, University of Washington, Seattle, Washington.

#### **IV. Courses at Summer Schools etc.**

1. Course on Computational Accelerator Physics, 3 Credits, 2006 US Particle Accelerator School, Boston/Massachusetts
2. Course on Computational Accelerator Physics, 3 Credits, 1998 US Particle Accelerator School, Austin/Texas
3. Course on Non-Archimedean Analysis, Studienstiftung Summer Academy, Olengheto/Italy 1995
4. Course on Particle Optics, 3 Credits, 1995 US Particle Accelerator School, Seattle/Washington

## V. Publications

During the performance period, a variety of publications were produced. These include a total of five books, nine PhD dissertations, 110 refereed publications, 32 non-refereed publications, and 21 technical reports have been produced.

### 1. Books

1. D. O. Ovsyannikov, M. Berz and K. Makino (Eds.), Computational Accelerator Physics, Elsevier 2006
2. M. Berz, K. Makino (Eds.), Computational Accelerator Physics, IOP Publishing, 2004
3. M. Berz, K. Makino and W. Wan, Introduction to Beam Physics, in progress
4. M. Berz, Modern Map Methods in Particle Beam Physics, Academic Press, 1999
5. M. Berz, C. Bischof, A. Griewank and G. Corliss (Eds.), Computational Differentiation: Techniques, Applications, and Tools, SIAM, Philadelphia, 1996

### 2. Ph.D. Dissertations

1. Stephen Weathersby<sup>1</sup>
2. Pavel Snopok<sup>2</sup>
3. Shashikant Manikonda<sup>3</sup>
4. Bela Erdelyi<sup>4</sup>
5. Jens Hoefkens<sup>5</sup>
6. Khodr Shamseddine<sup>6</sup>
7. Kyoko Makino<sup>7</sup>
8. Weishi Wan<sup>8</sup>
9. Georg Hoffstätter<sup>9</sup>

### 3. Publications

The publications are listed in the bibliography; items 1-9 are dissertations, 10-119 are refereed publications, 120-151 are non-refereed publications, and 152-172 are technical reports.

## VI. Research Bibliography

- <sup>1</sup>S. Weathersby. *Damping Higher Order Modes in the PEP-II B-Factory Storage Ring Collider*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 2007.
- <sup>2</sup>P. Snopok. *Optimization of Accelerator Parameters Using Normal Form Methods on High-Order Transfer Maps*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 2007.
- <sup>3</sup>S. Manikonda. *High Order Finite Element Methods to Compute Taylor Transfer Maps*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 2006.
- <sup>4</sup>B. Erdélyi. *Symplectic Approximation of Hamiltonian Flows and Accurate Simulation of Fringe Field Effects*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 2001.
- <sup>5</sup>J. Hoefkens. *Verified Methods for Differential Algebraic Equations*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 2001.
- <sup>6</sup>K. Shamseddine. *New Elements of Analysis on the Levi-Civita Field*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 1999. <http://bt.pa.msu.edu/cgi-bin/display.pl?name=shamseddinephd>.
- <sup>7</sup>K. Makino. *Rigorous Analysis of Nonlinear Motion in Particle Accelerators*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 1998. Also MSUCL-1093.
- <sup>8</sup>W. Wan. *Theory and Applications of Arbitrary-Order Achromats*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 1995. also MSUCL-976.
- <sup>9</sup>G. H. Hoffstätter. *Rigorous bounds on survival times in circular accelerators and efficient computation of fringe-field transfer maps*. PhD thesis, Michigan State University, East Lansing, Michigan, USA, 1994. also DESY 94-242.
- <sup>10</sup>J. Grote S. Newhouse, M. Berz and K. Makino. On the estimation of topological entropy on surfaces. *Contemporary Mathematics*, 469:243–270, 2008.
- <sup>11</sup>K. Shamseddine and M. Berz. Intermediate value theorem for analytic functions on a Levi-Civita field. *Bulletin of the Belgian Mathematical Society*, 14:1001–1015, 2007.
- <sup>12</sup>J. Grote, M. Berz, K. Makino, and S. Newhouse. Taylor model-based enclosure of invariant manifolds for planar diffeomorphisms and applications. *ICIAM*, 6, 2007.
- <sup>13</sup>P. Di Lizia, F. Bernelli Zazzera, and M. Berz. High order integration and sensitivity analysis of multibody systems using differential algebra. *AIDAA*, 19, 2007.
- <sup>14</sup>C. J. Johnstone, M. Berz, and K. Makino. Staging acceleration and cooling in a neutrino factory. *Nuclear Instruments and Methods*, 558,1:282–291, 2006.
- <sup>15</sup>K. Shamseddine and M. Berz. Generalized power series on a non-Archimedean field. *Indagationes Mathematicae*, 17,3:457–477, 2006.
- <sup>16</sup>K. Makino and M. Berz. Suppression of the wrapping effect by Taylor model-based verified integrators: The single step. *International Journal of Pure and Applied Mathematics*, 36,2:175–197, 2006.
- <sup>17</sup>Alexey Poklonskiy, Dmitri A. Ovsyannikov, Alexander D. Ovsyannikov, David Neuffer, and Martin Berz. Optimization of the buncher and phase rotator for a neutrino factory. *SPbSU Messenger (Vestnik)*, 10,1, 2006.

- <sup>18</sup>S. L. Manikonda and M. Berz. Multipole expansion solution of the Laplace equation using surface data. *Nuclear Instruments and Methods*, 558,1:175–183, 2006.
- <sup>19</sup>Kyoko Makino, Martin Berz, Youn-Kyung Kim, and Pavel Snopok. Long term stability of large accelerators. *ECMI Newsletter*, 39, 2006.
- <sup>20</sup>J. Grote, M. Berz, and K. Makino. High-order DA methods for the determination of Poincare sections. *Nuclear Instruments and Methods*, 558,1:106–111, 2006.
- <sup>21</sup>Pavel Snopok, Dmitri A. Ovsyannikov, Alexander D. Ovsyannikov, Martin Berz, and Carol Johnstone. Modeling and optimization of muon collider interaction regions. *SPbSU Messenger (Vestnik)*, 10,1, 2006.
- <sup>22</sup>K. Makino and M. Berz. Suppression of the wrapping effect by Taylor model- based verified integrators: Long-term stabilization by preconditioning. *International Journal of Differential Equations and Applications*, 10,4:353–384, 2005.
- <sup>23</sup>M. Berz and K. Makino. Suppression of the wrapping effect by Taylor model- based verified integrators: Long-term stabilization by shrink wrapping. *International Journal of Differential Equations and Applications*, 10,4:385–403, 2005.
- <sup>24</sup>M. Berz, K. Makino, and Y.-K. Kim. Long-term stability of the Tevatron by validated global optimization. *Nuclear Instruments and Methods*, 558:1–10, 2005.
- <sup>25</sup>K. Shamseddine and M. Berz. Analytical properties of power series on non-Archimedean fields. *Annales Mathématiques Blaise Pascal*, 12:309–329, 2005.
- <sup>26</sup>S. L. Manikonda, M. Berz, and K. Makino. High-order verified solution of the 3D Laplace equation. *Transactions on Computers*, 4-11:1604–1610, 2005.
- <sup>27</sup>P. Snopok, M. Berz, K. Makino, and C. Johnstone. Simulation and optimization of the Tevatron accelerator. *Lecture Notes on Computational Science and Engineering*, 50:199–209, 2005.
- <sup>28</sup>J. Grote, K. Makino, and M. Berz. High-order validated representation of Poincaré maps. *Transactions on Systems*, 4,11:1986–1992, 2005.
- <sup>29</sup>A. A. Poklonskiy, D. Neuffer, C. J. Johnstone, M. Berz, K. Makino, D. A. Ovsyannikov, and A. D. Ovsyannikov. Optimizing adiabatic bunchers and phase rotators. *Nuclear Instruments and Methods*, 558:135–141, 2005.
- <sup>30</sup>J. Grote, M. Berz, and K. Makino. High-order representation of Poincare maps. *Lecture Notes on Computational Science and Engineering*, 50:59–66, 2005.
- <sup>31</sup>C. Johnstone, M. Berz, and K. Makino. Optimal staging of acceleration and cooling in a neutrino factory. *Nuclear Physics*, 149 Suppl.:316–319, 2005.
- <sup>32</sup>K. Makino and M. Berz. Range bounding for global optimization with Taylor models. *Transactions on Computers*, 4,11:1611–1618, 2005.
- <sup>33</sup>P. V. Snopok, C. J. Johnstone, M. Berz, D. A. Ovsyannikov, and A. D. Ovsyannikov. Study and optimal correction of a systematic skew quadrupole field in the Tevatron. *Nuclear Instruments and Methods*, 558:142–146, 2005.
- <sup>34</sup>M. Berz and K. Makino. Performance of Taylor model methods for validated integration of ODEs. In *Lecture Notes in Computer Science*, volume 3732, pages 65–74, 2005.

- <sup>35</sup>S. L. Manikonda and M. Berz. An accurate high-order method to solve the Helmholtz boundary value problem for the 3D Laplace equation. *International Journal of Pure and Applied Mathematics*, 23,3:365–378, 2005.
- <sup>36</sup>K. Makino and M. Berz. COSY INFINITY version 9. *Nuclear Instruments and Methods*, 558:346–350, 2005.
- <sup>37</sup>M. Berz and K. Makino. New approaches for the validation of transfer maps using remainder-enhanced differential algebra. *Nuclear Instruments and Methods A*, 519:53–62, 2004.
- <sup>38</sup>N. Revol, K. Makino, and M. Berz. Taylor models and floating-point arithmetic: Proof that arithmetic operations are validated in COSY. *Journal of Logic and Algebraic Programming*, 64/1:135–154, 2004.
- <sup>39</sup>B. Erdélyi and M. Berz. Local theory and applications of extended generating functions. *International Journal of Pure and Applied Mathematics*, 11,3:241–282, 2004.
- <sup>40</sup>D. Errede, K. Makino, M. Berz, C. J. Johnstone, and A. van Ginneken. Stochastic processes in muon ionization cooling. *Nuclear Instruments and Methods A*, 519:466–471, 2004.
- <sup>41</sup>K. Makino, M. Berz, and Y.-K. Kim. Range bounding with Taylor models - some case studies. *Transactions on Mathematics*, 3,1:137–145, 2004.
- <sup>42</sup>C. J. Johnstone, M. Berz, D. Errede, and K. Makino. Muon beam ionization cooling in a linear quadrupole channel. *Nuclear Instruments and Methods A*, 519:472–482, 2004.
- <sup>43</sup>K. Makino and M. Berz. Tetra cooler ring simulation in COSY INFINITY. In *Neutrino Factories and Superbeams*, volume 721, page 418. AIP Conference Proceedings, 2004.
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- <sup>45</sup>M. Berz and K. Makino. Higher order multivariate automatic differentiation and validated computation of remainder bounds. *Transactions on Mathematics*, 3,1:37–44, 2004.
- <sup>46</sup>M. Berz, K. Makino, and C. J. Johnstone. Propagation of a large-emittance muon beam through a straight, quadrupole-based precooling channel. In *Neutrino Factories and Superbeams*, volume 721, page 413. AIP Conference Proceedings, 2004.
- <sup>47</sup>M. M. Alsharo’a et al. Recent progress in neutrino factory and muon collider research within the muon collaboration. *Physical Review ST-AB*, 6:081001, 2003.
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- <sup>49</sup>M. Berz and K. Makino. Constructive generation and verification of Lyapunov functions around fixed points of nonlinear dynamical systems. *International Journal of Computer Research*, 12,2:235–244, 2003.
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- <sup>58</sup>K. Makino and M. Berz. High order flows around fixed points and verification of stability of local dynamics with applications to particle accelerators. *Complexity*, 2002.
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- <sup>64</sup>M. L. Shashikant, M. Berz, and B. Erdélyi. COSY INFINITY’s EXPO symplectic tracking for LHC. *IOP CP*, 175:299–305, 2002.
- <sup>65</sup>M. Berz. Towards a universal data type for scientific computing. In G. Corliss, C. Faure, A. Griewank, L. Hascoët, and U. Naumann, editors, *Automatic Differentiation of Algorithms from Simulation to Optimization*, pages 373–381. Springer, 2002.
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