Curriculum vitæ
of
Massimo Giovannozzi

Education

September 1979 - July 1984:	High school (Diploma di maturità scientifica)
November 1984 - March 1989:	Master course in physics at Bologna University with a thesis on nonlinear dynamics applied to accelerator physics
November 1989 - November 1993:	Doctorate in mathematical physics at the University of Bologna with a thesis on non-linear beam dynamics performed at CERN

Career

January 1994 - May 1996:	Unpaid Scientific Associate at CERN
June 1994 - September 1996:	Fellow at CERN
December 1996 - March 1997:	Unpaid Scientific Associate at CERN
April 1997 - present:	Staff physicist in the CERN accelerator physics group
January 2001 - December 2002:	Scientific secretary of the "PS Performance Committee"
January 2003 - January 2004:	Scientific secretary of the "Accelerator Performance Committee"
January 2003 - present:	Member of the LHC "Magnet Evaluation Board"
April 2003 - January 2007:	Member of the LHC "Field Quality Working Group"
July 2003 - October 2006:	Chairman of the "Study Group on the New PS Multi-Turn Extraction"
January 2004 - June 2009:	Scientific secretary of the LHC "Magnet Evaluation Board"
July 2005 - December 2006:	Leader of the LHC Optics and Commissioning Section
October 2006 - present:	Leader of the PS Multi-Turn Extraction Project
January 2007 - December 2013:	Leader of the LHC Upgrade and Commissioning section
July 2007 - present:	Senior staff physicist in the CERN accelerator physics group
January 2008 - December 2008:	LHC System Commissioner
January 2011 - present:	Leader of Task 2.3 - Single particle simulations - of the HiLumi LHC Work Package 2 - Accelerator Physics and Performance
January 2012 - present:	Member of the American Physical Society, Division of Physics of Beams
January 2013 - January 2016:	Leader of the Task 2.2 - Optics and layout - of the HiLumi LHC Work Package 2 - Accelerator Physics and Performance
January 2014 - June 2020:	Leader of the Hadron Synchrotrons Single-particle effects section of the CERN Accelerators and Beam Physics Group
September 2014 - December 2017:	LHC Machine Co-ordinator
January 2017 - present:	Co-chair of HL-LHC Working Group on Aligment
March 2020 - present:	Visiting Professor at Bologna University teaching accelerator physics for the Master students
March 2020 - April 2022:	member of the CERN against COVID-19 task force
September 2020 - present	Fellow of the American Physical Society
January 2021 - present	Member at Large of the APS DPB Publication Committee
December 2022 - present	Co-Chair of the CERN Magnet Assessment Board

International tasks

January 2005:	Member of the International Advisory Committee of the Workshop "Coulomb05"
January 2009:	Member of the International Advisory Committee of the Workshop "Coulomb09"
June 2011:	Co-organiser of the "Optics Measurements, Corrections, and Modelling for High-Performance Storage Rings" Workshop
June 2013:	Co-organiser of the "LHC Optics Measurement and Corrections Review"
November 2014:	Member of the Chinese SNS Accelerator Technical Advisory Committee
February 2015:	Co-organiser of the "Advanced Optics Control" workshop
June 2015:	Member of the Review Panel of the "Future Circular Collider Tunnel Footprint and implantation"
January 2016:	Member of the International Advisory Committee of the EuCARD-2 XRING, and HIC for FAIR workshop "The Slow Extraction Workshop"
March 2022:	Member of the Editorial Board of the ICFA HB2023 Workshop

List of publications by Massimo Giovannozzi

Thesis

1. M. Giovannozzi (1989). "Analisi di stabilità per mappe hamiltoniane e loro applicazioni alla fisica degli acceleratori", tesi di Laurea Università di Bologna.

2. M. Giovannozzi (1993). "Aspetti di dinamica non lineare con applicazioni in dinamica dei fasci", tesi di Dottorato Università di Bologna, *CERN THESIS 99-068*.

Books and proceedings

1. M. Giovannozzi and G. Turchetti (Eds.) (2006). "Workshop on High Intensity Beam Dynamics - Coulomb'05", *Nucl. Instrum. & Methods A*, **561**.

2. M. Giovannozzi (Ed.) *et al.* (2006). "The CERN PS multi-turn extraction based on beam splitting in stable islands of transverse phase space: Design Report", CERN-2006-011.

3. G. Turchetti, V. Malka, and M. Giovannozzi (Eds.) (2010). "Workshop on Ions Acceleration with high Power Lasers: Physics and Applications - Coulomb'09", *Nucl. Instrum. & Methods A*, **620**.

4. S. Gilardoni (Ed.), D. Manglunki (Ed.) *et al.* (2011). "Fifty years of the CERN Proton Synchrotron : Volume 1", CERN-2011-004.

5. S. Gilardoni (Ed.), D. Manglunki (Ed.) *et al.* (2013). "Fifty years of the CERN Proton Synchrotron : Volume 2", CERN-2013-005.

6. M. Giovannozzi (2011). "The LHC machine: from beam commissioning to operation and future upgrades", in *Theoretical Physics to Face the Challenge of LHC*, Lecture Notes of the Les Houches Summer School: Volume 97, August 2011, Oxford University Press.

7. D. Angal-Kalinin *et al.*, in "High-Luminosity Large Hadron Collider (HL-LHC). Preliminary Design Report", ed. by G. Apollinari, I. Béjar Alonso, O. Brüning, M. Lamont, L. Rossi, CERN-2015-005 (CERN, Geneva, 2015), 21-60, DOI: http://dx.doi.org/10.5170/CERN-2015-005.21.

8. K. Brown, M. Giovannozzi, T. Roser, in "Challenges and Goals for Accelerators in the XXI Century", ed. by O. Brüning and S. Myers (World Scientific Publishing, Singapore, 2016).

9. M. Giovannozzi and C. Steinbach, in "Technology meets research", ed. by C. Fabjan, T. Taylor, D. Treille and H. Wenninger (World Scientific Publishing, Singapore, 2017).

10. M Giovannozzi *et al.*, in "High-Luminosity Large Hadron Collider (HL-LHC). Technical Design Report V.0.1", edited by Apollinari G, Bejar Alonso I., Bruning O., Fessia P., Lamont M, Rossi L., Tavian L., CERN Yellow Reports: Monographs, Vol.4/2017, CERN-2017-007-M (CERN, Geneva, 2017). https://doi.org/10.23731/CYRM-2017-004.

11. C. Barschel *et al.* (2020). "LHC fixed target experiments: Report from the LHC Fixed Target Working Group of the CERN Physics Beyond Colliders Forum", CERN-PBC-REPORT-2019-001 CERN-2020-004.

12. G. Arduini *et al.*, in "High-Luminosity Large Hadron Collider (HL-LHC): Technical design report", CERN Yellow Reports: Monographs, CERN-2020-010-M (CERN, Geneva, 2017). https://doi.org/10.23731/CYRM-2020-0010.17

13. R. Appleby, A. Bazzani, M. Giovannozzi, E. Levichev (Guest Editors) (2023) "Focus point on high-energy accelerators: advances, challenges, and applications", Eur. Phys. J. Plus **138** 12.

14. A. Apollonio, X. Buffat, R. Bruce, R. De Maria, M. Giovannozzi, G. Iadarola, A. Lechner, E. Métral, G. Sterbini, R. Tomás, M. Zerlauth (2023). "HL-LHC configuration and operational challenges", in The Future of the Large Hadron Collider, ed. by O. Brüning, M. Klein, L. Rossi, and P. Spagnolo, World Scientific.

15. G. Arduini, R. De Maria, M. Giovannozzi, G. Iadarola, E. Métral, Y. Papaphilippou and R. Tomás (2024). "Machine Physics and Performance", in The High Luminosity Large Hadron Collider, ed. by O. Brüning and L. Rossi, World Scientific.

16. E. H. Maclean, F. Carlier, J. W. Dilly, M. Giovannozzi, N. Karastathis, T. H. B. Persson and R. Tomás (2024). "Non-Linear Optics Measurements and Corrections", in The High Luminosity Large Hadron Collider, ed. by O. Brüning and L. Rossi, World Scientific.

17. M. Giovannozzi (2024). "The Future CERN Circular hadron collider", in: Proceedings of the Joint Universities Accelerator School (JUAS): Courses and exercises, E. Métral (ed.), CERN Yellow Reports: School Proceedings, CERN-2024-003, DOI: 10.23730/CYRSP-2024-003, p. 1971.

18. M. Giovannozzi (2024). "Non-linear beam manipulations in the transverse space", in: Proceedings of the Joint Universities Accelerator School (JUAS): Courses and exercises, E. Métral (ed.), CERN Yellow Reports: School Proceedings, CERN-2024-003, DOI: 10.23730/CYRSP-2024-003, p. 2017.

International Journals

1. M. Giovannozzi and S. Marmi (1990). "Existence of complex invariant circles in the quadratic area–preserving map", *Rendiconti di Matematica* **9** 457.

2. A. Bazzani, M. Giovannozzi, G. Servizi, E. Todesco and G. Turchetti (1993). "Resonant normal forms, interpolating hamiltonians and stability analysis of area preserving maps", *Physica D* **64** 66.

3. M. Giovannozzi (1993). "Analysis of the Stability Domain for the Hénon Map", *Phys. Lett. A* **182** 255.

4. A. Bazzani, M. Giovannozzi and E. Todesco (1995). "A program to compute Birkhoff normal forms of a symplectic map in $\mathbf{R}^4$", *Comp. Phys. Comm.* **86** 199.

5. D. Bortolotti, M. Giovannozzi, G. Servizi, E. Todesco and M. N. Vrahatis (1995). "GIOTTO: a Code for the Nonlinear Analysis of Area-Preserving Mappings", *Int. J. of Mod. Phys. C* **6** 651.

6. M. Giovannozzi, R. Grassi, W. Scandale and E. Todesco (1995). "A Sorting Approach to the magnetic random errors", *Phys. Rev. E* **52** 3093.

7. R. Bartolini, A. Bazzani, M. Giovannozzi, W. Scandale and E. Todesco (1995). "Tune evaluation in simulations and experiment", *Part. Accel.* **52** 147.

8. M. Giovannozzi and E. Todesco (1996). "Dynamic aperture estimates and phase space distortions in nonlinear betatronic motion", *Phys. Rev. E***53** 4067.

9. M. Giovannozzi (1996). "Stability domain of planar symplectic maps using invariant manifolds", *Phys. Rev. E***53** 6403.

10. M. Giovannozzi, W. Scandale, E. Todesco (1996). "Inverse Logarithmic Extrapolation of Survival Plots in Hadron Colliders", *Beam Dyn. Newsl.* **12** 6.

11. M. Giovannozzi, W. Scandale, E. Todesco (1996). "Prediction of long-term stability in large hadron colliders", *Part. Accel.* **56** 195.

12. W. Fischer, M. Giovannozzi and F. Schmidt (1997). "Dynamic aperture experiment at a synchrotron", *Phys. Rev. E***55** 3507.

13. M. Giovannozzi and E. McIntosh (1997). "Development of parallel codes for the study of nonlinear beam dynamics", *Int. Jou. Mod. Phys. C* **8** 155.

14. M. Giovannozzi, E. Todesco, A. Bazzani and R. Bartolini (1997). "PLATO: a program library for the analysis of nonlinear betatronic motion", *Nucl. Instrum. & Methods A* **388** 1.

15. E. Todesco, M. Gemmi and M. Giovannozzi (1997). "NERO: a code for the Nonlinear Evaluation of Resonances in One-turn mapping", *Comp. Phys. Comm.* **106** 169.

16. M. Giovannozzi (1997). "Stability domain and invariant manifolds of 2D area-preserving diffeomorphisms" *Cel. Mech.***68** 177.

17. M. Giovannozzi, W. Scandale and E. Todesco (1998). "Dynamic aperture extrapolation in presence of tune modulation", *Phys. Rev. E***57** 3432.

18. R. Bartolini, M. Giovannozzi, W. Scandale, E. Todesco (1998). "Sorting strategies for non-local compensation of non-linear errors in large hadron colliders", *Nuovo Cimento***113 B** 511.

19. R. Cappi, M. Chanel, R. Garoby, M. Giovannozzi, E. Métral, G. Métral (1999). "Beam dynamics Activities at the CERN PSB-PS", *Beam Dyn. Newsl.* **20** 39.

20. G. Arduini, M. Giovannozzi, K. Hanke, D. Manglunki, M. Martini, (2001). "New Methods to Derive the Optical and Beam Parameters in Transport Channels", *Nucl. Instrum. & Methods A* **459** 16.

21. R. Cappi, M. Giovannozzi (2001). "Studies of multi-turn extraction at CERN-PS via particle-trapping in islands of phase space", *Beam Dyn. Newsl.* **25** 13.

22. R. Cappi, M. Giovannozzi (2002). "Novel Method for Multi-Turn Extraction: Trapping Charged Particles in Islands of Phase Space", *Phys. Rev. Lett.* **88** 104801.

23. R. Cappi, M. Giovannozzi, E. Métral, G. Métral, G. Rumolo, F. Zimmermann (2002). "Electron cloud buildup and related instability in the CERN Proton Synchrotron", *Phys. Rev. ST Accel. Beams* **5** 094401.

24. M. Giovannozzi, E. Métral, G. Métral, G. Rumolo, F. Zimmermann (2003). "Electron cloud buildup and instability: Numerical simulations for the CERN Proton Synchrotron", *Phys. Rev. ST Accel. Beams* **6** 010101.

25. G. Franchetti, I. Hofmann, M. Giovannozzi, E. Métral, M. Martini (2003). "Space charge and octupole driven resonance trapping observed at the CERN Proton Synchrotron", *Phys. Rev. ST Accel. Beams* **6** 124201.

26. R. Cappi, M. Giovannozzi (2003). "Multi-turn Extraction and Injection by Means of Adiabatic Capture in Stable Islands of Phase Space", *Phys. Rev. ST Accel. Beams* **7** 024001.

27. M. Giovannozzi (2005). "Recent Advances on the Multi-Turn Extraction Using Stable Islands of Transverse Phase Space", *Beam Dyn. Newsl.* **36** 43.

28. S. Gilardoni, M. Giovannozzi, M. Martini, E. Métral, P. Scaramuzzi, R. Steerenberg, A.-S. Müller, (2006). "Experimental evidence of adiabatic splitting of charged particle beams using stable islands of transverse phase space", *Phys. Rev. ST Accel. Beams* **9** 104001.

29. M. Giovannozzi and J. Morel (2007). "Principle and analysis of multiturn injection using stable islands of transverse phase space", *Phys. Rev. ST Accel. Beams* **10** 034001.

30. R. Tomás, M. Giovannozzi, and R. de Maria (2009). "Nonlinear correction schemes for the phase 1 LHC insertion region upgrade and dynamic aperture studies", *Phys. Rev. ST Accel. Beams* **12** 011002.

31. A. Franchi, S. Gilardoni, M. Giovannozzi (2009). "Progresses in the studies of adiabatic splitting of charged particle beams by crossing nonlinear resonances", *Phys. Rev. ST Accel. Beams* **12** 014001.

32. M. Giovannozzi, D. Quatraro, G. Turchetti (2009). "Generating unstable resonances for extraction schemes based on transverse splitting", *Phys. Rev. ST Accel. Beams* **12** 024003.

33. M. Aiba, S. Fartoukh, A. Franchi, M. Giovannozzi, V. Kain, M. Lamont, R. Tomás, G. Vanbavinckhove, J. Wenninger, F. Zimmermann, R. Calaga, and A. Morita (2009). "First β-beating measurement and optics analysis for the CERN Large Hadron Collider", *Phys. Rev. ST Accel. Beams* **12** 081002.

34. R. Tomás, O. Brüning, M. Giovannozzi, P. Hagen, M. Lamont, F. Schmidt, G. Vanbavinckhove, M. Aiba, R. Calaga and R. Miyamoto (2010). "CERN Large Hadron Collider optics model, measurements, and corrections", *Phys. Rev. ST Accel. Beams* **13** 121004.

35. S. Fartoukh, M. Giovannozzi (2012). "Dynamic aperture computation for the as-built CERN Large Hadron Collider and impact of main dipoles sorting", *Nucl. Instrum. & Methods A* **671** 10.

36. M. Giovannozzi (2012). "A proposed scaling law for intensity evolution in hadron storage rings based on dynamic aperture variation with time", *Phys. Rev. ST Accel. Beams* **15** 024001.

37. T. Adam et al. (2012). "Measurement of the neutrino velocity with the OPERA detector in the CNGS beam", *J. High Energy Phys.* **1210** 093.

38. S. Gilardoni, M. Giovannozzi, and C. Hernalsteens (2013). "First observations of intensity-dependent effects for transversely split beams during multiturn extraction studies at the CERN Proton Synchrotron", *Phys. Rev. ST Accel. Beams* **16** 051001.

39. A. Bazzani, C. Frye, M. Giovannozzi, and C. Hernalsteens (2014). "Analysis of adiabatic trapping for quasi-integrable area-preserving maps", *Phys. Rev. E* **89**, 042915.

40. A. Bazzani, M. Giovannozzi, P. Londrillo, S. Sinigardi, G. Turchetti (2014). "Case studies in space charge and plasma acceleration of charged beams", *Comptes Rendus Mécanique* **342** 647.

41. A. Franchi and M. Giovannozzi (2015). "Novel technique for injecting and extracting beams in a circular hadron accelerator without using septum magnets", *Phys. Rev. ST Accel. Beams* **18**, 074001.

42. N. Aquilina, M. Giovannozzi, M. Lamont, N. Sammut, R. Steinhagen, E. Todesco, J. Wenninger (2015). "Tune variations in the Large Hadron Collider", Nucl. Instrum. Methods Phys. Res., A **778** 6.

43. E. H. Maclean, R. Tomás, M. Giovannozzi, and T. H. B. Persson (2015). "First measurement and correction of nonlinear errors in the experimental insertions of the CERN Large Hadron Collider", *Phys. Rev. ST Accel. Beams* **18** 121002 .

44. J. Borburgh, S. Damjanovic, S. Gilardoni, M. Giovannozzi, C. Hernalsteens, M. Hourican, A. Huschauer, K. Kahle, G. Le Godec, O. Michels and G. Sterbini (2016). "First implementation of transversely split proton beams in the CERN Proton Synchrotron for the fixed-target physics programme", *EPL* **113** 34001.

45. S. Abernethy, A. Akroh, H. Bartosik, A. Blas, T. Bohl, S. Cettour-Cave, K. Cornelis, H. Damerau, S. Gilardoni, M. Giovannozzi, C. Hernalsteens, A. Huschauer, V. Kain, D. Manglunki, G. Métral, B. Mikulec, B. Salvant, J.-L. Sanchez Alvarez, R. Steerenberg, G. Sterbini, and Y. Wu (2017). "Operational performance of the CERN injector complex with transversely split beams", *Phys. Rev. Accel. Beams* **20**, 014001.

46. R. Bruce, C. Bracco, R. De Maria, M. Giovannozzi, A. Mereghetti, D. Mirarchi, S. Redaelli, E. Quaranta, B. Salvachua (2017). "Reaching record-low β^* at the CERN Large Hadron Collider using a novel scheme of collimator settings and optics", *Nucl. Instrum. & Methods A* **848** 19.

47. A. Huschauer, A. Blas, J. Borburgh, S. Damjanovic, S. Gilardoni, M. Giovannozzi, M. Hourican, K. Kahle, G. Le Godec, O. Michels, G. Sterbini, and C. Hernalsteens (2017). "Transverse beam splitting made operational: Key features of the multiturn extraction at the CERN Proton Synchrotron", *Phys. Rev. Accel. Beams* **20**, 061001.

48. S. Machida, C. Prior, S. Gilardoni, M. Giovannozzi, A. Huschauer, and S. Hirlander (2017). "Numerical investigation of space charge effects on the positions of beamlets for transversely split beams", *Phys. Rev. Accel. Beams* **20**, 121001.

49. J. Barranco, Y. Cai, D. Cameron, M. Crouch, R. De Maria, L. Field, M. Giovannozzi, P. Hermes, N. Høimyr, D. Kaltchev, N. Karastathis, C. Luzzi, E. Maclean, E. McIntosh, A. Mereghetti, J. Molson, Y. Nosochkov, T. Pieloni, I. D. Reid, L. Rivkin, B. Segal, K. Sjobak, P. Skands, C. Tambasco, F. Van der Veken, and I. Zacharov (2017). "LHC@Home: a BOINC-based volunteer computing infrastructure for physics studies at CERN", *Open Eng.* **7**, 378.

50. Y. Cai, Y. Nosochkov, M. Giovannozzi, T. Risselada, E. Todesco, D. Zhou, F. Zimmermann (2017). "HE-LHC Optics Development", *ICFA Beam Dyn. Newsl.* **72** 141.

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52. M. Giovannozzi, F. Van der Veken (2018). "Description of the luminosity evolution for the CERN LHC including dynamic aperture effects. Part II: application to Run 1 data", *Nucl. Instrum. & Methods A* **908**, 1.

53. A. Abada *et al.* (2019). "Future Circular Collider: Conceptual Design Report Vol. 1 Physics Opportunities", *Eur. Phys. J. C* **79**, 474.

54. A. Abada *et al.*. "FCC-ee: The Lepton Collider ? Future Circular Collider Conceptual Design Report Volume 2", *Eur. Phys. J. Special Topics* **228**, 261.

55. M. Benedikt *et al.* (2018). "Future Circular Collider: Conceptual Design Report Vol. 3 The Hadron Collider (FCC-hh)", *Eur. Phys. J. Special Topics* **228**, 755.

56. F. Zimmermann *et al.* (2018). "Future Circular Collider: Conceptual Design Report Vol. 4 The High-Energy LHC (HE-LHC)", *Eur. Phys. J. Special Topics* **228**, 755.

57. E.H. Maclean, M. Giovannozzi, and R.B. Appleby (2019). "Innovative method to measure the extent of the stable phase-space region of proton synchrotrons", *Phys. Rev. Accel. Beams* **22**, 034002.

58. M. Giovannozzi, F. Van der Veken (2019). "Erratum to "Description of the luminosity evolution for the CERN LHC including dynamic aperture effects. Part I: The model", [Nucl. Instrum. Methods A 905 (2018) 171–179]", *Nucl. Instrum. & Methods A* **927**, 471.

59. A. Alexopoulos *et al.* (The BGV Collaboration) (2019). "Noninvasive LHC transverse beam size measurement using inelastic beam-gas interactions", *Phys. Rev. Accel. Beams* **22**, 042801.

60. E.H. Maclean *et al.* (2019). " New approach to LHC optics commissioning for the nonlinear era", *Phys. Rev. Accel. Beams* **22**, 061004.

61. A. Huschauer *et al.* (2019). "Advancing the CERN proton synchrotron multiturn extraction towards the high-intensity proton beams frontier", *Phys. Rev. Accel. Beams* **22**, 104002.

62. A. Bazzani, M. Giovannozzi, E.H. Maclean, C.E. Montanari, F.F. Van der Veken, and W. Van Goethem (2019). "Advances on the modeling of the time evolution of dynamic aperture of hadron circular accelerators", *Phys. Rev. Accel. Beams* **22**, 104003.

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64. A. Bazzani, M. Giovannozzi, E.H. Maclean (2020). "Analysis of the non-linear beam dynamics at top energy for the CERN Large Hadron Collider by means of a diffusion model", *Eur. Phys. J. Plus* **135**, 77.

65. X. Cui, S. Gilardoni, M. Giovannozzi and G. Iadarola (2020). "Numerical simulations of electron cloud build-up in circular accelerators in the presence of multimode distribution beams", *EPL* **129** 24003.

66. A. Gorzawski, R.B. Appleby, M. Giovannozzi, A. Mereghetti, D. Mirarchi, S. Redaelli, B. Salvachua, G. Stancari, G. Valentino, and J.F. Wagner (2020). "Probing LHC halo dynamics using collimator loss rates at 6.5 TeV", *Phys. Rev. Accel. Beams* **23**, 044802.

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74. N. Fuster-Martínez, R.W. Aßmann, R. Bruce, M. Giovannozzi, P. Hermes, A. Mereghetti, D. Mirarchi, S. Redaelli and J. Wenninger (2022). "Beam-based aperture measurements with movable collimator jaws as performance booster of the CERN Large Hadron Collider", *Eur. Phys. J. Plus* **137**, 305.

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Main scientific activities

Master thesis

The goal was to study the region of bounded motion of the 2D Hénon map and to determine its boundary using analytical techniques. The possibility of computing the border of the region where stable motions occur opens up the possibility of finding methods to extend such a region. In terms of applications, given that the 2D Hénon map is a good model of nonlinear betatronic motion, this study could help finding means of increasing the dynamic aperture of circular accelerators.

The solution was found using the concept of invariant manifolds. These are invariant sets related to hyperbolic fixed points of the dynamical system. It was possible to show that the boundary of the dynamic aperture is given by the inner envelope of the invariant manifolds emanating from hyperbolic fixed points, whose period is given by the order of the resonance that dominates the overall dynamics.

PhD thesis

Three topics were addressed, namely: the generalisation of the results obtained in the Master thesis dealing with the dynamic aperture of the 2D Hénon map and its relation with invariant manifolds; the analysis of correction schemes of the magnetic field errors in the LHC main dipoles using Normal Forms; the analysis of the experiments performed at the SPS to study the effect of power converter ripple on beam dynamics.

The focus of the studies performed has been slowly moving from the domain of classical dynamical systems to applications of nonlinear dynamics to circular particle accelerators.

CERN Fellowship

As an acting liaison physicist, support in the optics design and setting up of the transfer lines from the CERN Low Energy Antiproton Ring and the experimental South Hall was provided. Moreover, the complete design and beam commissioning of the new experimental area of the CERN Antiproton Decelerator ring had been started and successfully carried out.

In parallel, studies on nonlinear beam dynamics were pursued, in particular in the domain of refined techniques to compute the transverse tunes in a circular machine as well as in the evaluation of the dynamic aperture for both simple models, such as the 4D Hénon map, as well as realistic models of the LHC lattice. These studies aimed to critically review the algorithms used to numerically compute the dynamic aperture.

The main outcome of these activities was the observation that the dynamic aperture features a rather simple scaling law as a function of time that can be understood in terms of the two keystone theorems of dynamical systems theory, namely the Kolmogorov-Arnold-Moser and the Nekhoroshev theorems.

CERN Staff

At the beginning of the contract, as a staff member, the activity was transferred to the PS machine and also included the role of PS machine supervisor. In this framework, a key activity was the study and improvement of the optical properties of the transfer line that joins the PS and the SPS to mitigate possible injection mismatch effects in the SPS.

These studies evolved towards finding a replacement of the so-called Continuous Transfer (CT) extraction at the PS, in view of reducing or even suppressing the beam losses and ring activation. This led to the proposal of using transverse beam splitting by crossing a stable resonance as a means to perform multi-turn extraction from the PS.

I co-ordinated a study group in charge of numerical studies and the experimental activities aimed at testing the theoretical proposal and assessing its feasibility. After the positive result of the activities of the study group, a formal project was launched with the mandate of continuing the study and proposing an implementation scheme. This was successfully achieved in 2008, with the completion of the installation and of the hardware commissioning of the novel multi-turn extraction (MTE).

The beam commissioning started soon after, and, following the conclusions of the MTE workshop in 2011, a second stage of the project was launched, with the mandate of finding mitigation measures to the issues observed during the short operational period during the 2010 proton run.

The efforts continued with the proposal, design, installation and commissioning of a so-called dummy septum in the PS, which was achieved after Long Shutdown 1. Finally, the full operational state of MTE was reached at the end of 2015. Since then, several studies have been performed to assess the suitability of MTE for high-intensity beams in view of future fixed-target experiments, such as SHIP. The successful outcome of the experimental campaigns culminated in the decision to remove the hardware for CT installed in the PS ring, and by the next PS start-up in 2020 after the Long Shutdown 2, MTE will be the unique means of extraction of proton beams for SPS fixed target experiments.

In parallel, since 2005, when I was appointed leader of the LHC Optics and Commissioning section of the Accelerator Beam Physics Group, I have resumed the activity at LHC after the partial stop during the fellowship contract.

I joined the LHC Magnet Evaluation Board (MEB) and was in charge of assigning the most appropriate slot in the LHC tunnel of all insertion magnets (dipoles and quadrupoles). The selection of the appropriate slot is based on a detailed analysis of the mechanical, geometric, and magnetic properties of each magnet. In a second stage, I was also appointed the scientific secretary of the MEB, a role I held until the end of the formal activities of the board.

Note that, due to the planned replacement of some main dipoles and quadrupoles during the Long Shutdown 1, I provided support for the selection of the replacement magnets, thus broadening my initial responsibility beyond insertion magnets. Moreover, the recent extension of the MEB mandate to cover the selection and slot allocation of the new magnets for the LHC luminosity upgrade implies that I will also be involved in the MEB activities in the coming years.

The activity on non-linear beam dynamics applied to the study of the single-particle effects in the LHC was pursued. Detailed analysis of the dynamic aperture and its dependence on the field quality of the various magnet classes was performed throughout the whole period of magnet acceptance at the MEB. A great amount of data from the magnetic field measurements have been used to provide accurate estimates of the dynamic aperture of the LHC using the best description of the machine.

On the theoretical side, the analysis of nonlinear beam dynamics in the LHC culminated with the proposal of a scaling law of the beam intensity as a function of time based on the results about the scaling law of the dynamic aperture vs. time. This proposal has been successfully tested experimentally and is the basis for a new method for measuring the dynamic aperture under study in the LHC. The ultimate goal is to make a direct comparison between measurements and numerical simulations.

The role of section leader continued through the years, with changes to the mandate of the section, whose focus shifted from LHC and the preparation of its commissioning to LHC and its upgrade, and currently covers all single-particle effects for all CERN hadron synchrotrons.

Note that in 2010 I proposed increasing the extraction energy of the PSB in view of mitigating the space-charge effects at injection in the PS ring. This allows for an improvement in the overall performance of the LHC injector chain, and this proposal is now part of the LIU project.

More recently, a leading role in LHC operations was added, starting in 2008, when, as an appointed commissioner in charge, I took part in the specification of the beam commissioning process, as well as some of the beam measurements. Finally, in 2014 I was appointed LHC machine coordinator until the end of 2017.

Recent activities are based on a two-prong research programme: the study of novel techniques of beam manipulation by means of nonlinear effects, which are combined with experimental activities on the PS synchrotron; the study of diffusive models suitable to describe the nonlinear beam dynamics in the LHC as an alternative path to the research carried out in the vast domain of dynamic aperture. An example of the first activity is the recent set of tests carried out with a barrier bucket to further reduce extraction losses for the PS Multi-Turn Extraction and the studies on alternative means to perform beam splitting using AC dipoles. An example of the latter is the analysis of measurements carried out at top energy in the LHC by means of a new diffusion model and the analysis of the relationship between the scaling laws of the dynamic aperture, the form of the diffusion coefficient for Hamiltonian systems representing circular accelerators, and the stability-time estimate of the Nekhoroshev theorem.

Since March 2020, I am a visiting professor at the University of Bologna, teaching a course of Accelerator Physics for Master students in Physics.

Supervision of students and postdocs

CERN Summer students

- Nine students have been supervised on topics covering multi-turn extraction (theory and numerical simulations); LHC dynamic aperture studies (determination of novel models for dynamic aperture vs. time); refined methods for tune computation.

CERN Trainees

- Four students have been supervised covering different multi-turn extraction aspects: theory, analysis of experimental results, space-charge effects, multiturn injection.
- One student has been supervised on new models to describe the time evolution of the dynamic aperture.

Bachelor students

- F. O. Pancaldi, "A code to perform harmonic analysis of a time series". Supervisor: M. Giovannozzi. Co-supervisor: F. Giacomini, University of Bologna, Academic year 2022-2023.

Master students

- R. Grassi, "Strategie di ordinamento dei magneti di LHC in presenza di errori multipolari". Supervisor: Prof. G. Turchetti. Co-supervisors: M. Giovannozzi and E. Todesco, University of Bologna, Academic year 1995-1996.
- P. Scaramuzzi, "Studio di una nuova tecnica per estrarre fasci di particelle cariche da un acceleratore circolare usando risonanze stabili dello spazio delle fasi trasversale", Supervisor: Prof. G. Bellomo. Co-supervisor: M. Giovannozzi, University of Milan, Academic year 2003-2004.
- D. Quatraro, "Utilizzo delle forme normali per l'estrazione multi giri da PS ad SPS". Supervisor: Prof. G. Turchetti. Co-supervisor: M. Giovannozzi, University of Bologna, Academic year 2006-2007.
- C. Hernalsteens, "Analytical and numerical studies of transverse beam splitting used for the CERNPS Multi-Turn Extraction", Supervisor: Prof. A. Dubus. Co-supervisors: M. Giovannozzi and D. Manglunki, Université libre de Bruxelles, Academic year 2010-2011.
- F. Capoani, "Adiabatic theory for slowly varying Hamiltonian systems with applications to beam dynamics". Supervisor: Prof. A. Bazzani. Co-supervisor: M. Giovannozzi, University of Bologna, Academic year 2017-2018.
- C. E. Montanari, "Diffusive approach for non-linear beam dynamics in a circular accelerator". Supervisor: Prof. A. Bazzani. Co-supervisor: M. Giovannozzi, University of Bologna, Academic year 2018-2019.
- G. Faletti, "Optimisation of LHC Integrated Luminosity". Supervisor: Prof. A. Bazzani. Co-supervisor: M. Giovannozzi, University of Bologna, Academic year 2020-2021.
- G. Campri, "Diffusion Model of the Hollow Electron Lens for HL-LHC". Supervisor: Prof. A. Bazzani. Co-supervisor: M. Giovannozzi, University of Bologna, Academic year 2021-2022.
- T. Amezza, "Dynamic Aperture Model for LHC Integrated Luminosity Optimisation". Supervisor: M. Giovannozzi. Co-supervisor: A. Sbrizzi, University of Bologna, Academic year 2022-2023.
- F. O. Pancaldi, "A parallel code for studying adiabatic beam splitting with space-charge effects". Supervisor: M. Giovannozzi. Co-supervisors: S. Balducci, P. Londrillo, University of Bologna, Academic year 2024-2025.
- E. Mazzola, "Optimisation of integrated luminosity of a circular collider in presence of levelled luminosity". Supervisor: M. Giovannozzi. Co-supervisors: M. Aquilina, F. Capoani, University of Bologna, Academic year 2024-2025.
- E. Nori, "Adiabatic manipulation of longitudinal beam distributions in the presence of energy damping and random perturbations". Supervisor: A. Bazzani. Co-supervisors: F. Capoani, M. Giovannozzi, University of Bologna, Academic year 2024-2025.

PhD students

- C. Hernalsteens, "Transverse splitting of charged particle beams as new manipulation tool in circular particle accelerators", University supervisor: Prof. L. Rivkin. CERN supervisor: M. Giovannozzi, École Polytechnique Fédérale de Lausanne, to be completed in the academic year 2015-2016.
- S. Hirlander, "Exact Solutions of Indirect Transverse Field Effects in Elongated Structures with Applications to CERN LHC and PS", CERN-THESIS-2020-009. University supervisor: Prof. M. Benedikt. CERN supervisor: M. Giovannozzi, Vienna University of Technology.

- F. Capoani, “Shaping transverse beam distributions by means of adiabatic crossing of resonances”, University supervisor: Prof. A. Bazzani. CERN supervisor: M. Giovannozzi, Bologna University.
- G. Russo, “Precise tune determination and split beam emittance reconstruction at the CERN PS synchrotron”, University supervisor: Prof. G. Franchetti. CERN supervisor: M. Giovannozzi, Frankfurt University.
- C. E. Montanari, “Diffusive models and chaos indicators for non-linear betatron motion in circular hadron accelerators”, University supervisor: Prof. A. Bazzani. CERN supervisor: M. Giovannozzi, Bologna University.
- D. E. Veres, “Non-linear Manipulations of Charged Particle Beams with Bent Crystals and Transverse Exciters”, University supervisor: Prof. G. Franchetti, Frankfurt University. CERN supervisor: M. Giovannozzi.

CERN Fellows

- Four postdocs have been supervised on topics covering different aspects of multi-turn extraction: theory, experimental part, and implementation in future machines, such as PS2.
- Four postdocs have been co-supervised on topics related to studies for the luminosity upgrade of the LHC.
- Two postdoc have been supervised on topics covering FCC-hh design and FCC-ee non-linear beam dynamics.

Seminars and oral contributions to international conferences and workshops

- October 1992 - Upton (NY-USA), *Workshop on Stability of Particle Motion in Storage Rings*: "Invariant manifolds and stability."

- October 1992 - Upton (NY-USA), *Workshop on Stability of Particle Motion in Storage Rings*: "LHC correction scheme."

- January 1994 - CERN, Group seminar: "Simulations for the SPS experiment on diffusion".

- March 1994 - CERN, Group seminar: "Normal Forms and accelerator physics".

- October 1995 - Montreux (Switzerland), conference *LHC95: Single Particle Effects in Large Hadron Colliders*: "Numerical methods to estimate the dynamic aperture".

- December 1995 - Madrid (Spain), Universidad Complutense, Group seminar: "Early indicators of long-term stability".

- May 1996 - Lausanne (Switzerland), École Polytechnique Fédéral, Département de Matématique, Department seminar: "Normal Forms for Hamiltonian maps: theory and applications to accelerator physics".

- May 1996 - GSI, Group seminar: "Applications of nonlinear dynamics tools to accelerator physics".

- September 1996 - Madrid (Spain), Conference *Supercomputation in Nonlinear and Disordered Systems: Algorithms, Applications and Architectures*: "Evaluation of the dynamic aperture of the CERN-LHC using fast indicators of long-term stability".

- November 1997 - Geneva (Switzerland), Workshop 4^{th} *ICFA Beam Dynamics Mini-Workshop on Transverse Emittance Preservation and Measurements*: "Nonlinear Fields at extraction".

- November 1997 - Geneva (Switzerland), Workshop 4^{th} *ICFA Beam Dynamics Mini-Workshop on Transverse Emittance Preservation and Measurements*: "Multi-grid measurements in a transfer line".

- February 2001 - London (England), *Workshop on Instrumentation for Muon Cooling Studies*: "A layout for a muon test facility at the CERN-PS: the primary proton beam".

- February 2001 - London (England), *Workshop on Instrumentation for Muon Cooling Studies*: "The standard approach to measure beam emission in a transfer line".

- October 2002 - Brookhaven National Laboratory (NY - USA), 10^{th} *ICFA Mini-Workshop on Slow Extraction*: "Multiturn Extraction Using Adiabatic Capture in Islands of Transverse Phase Space: Theoretical Predictions and Preliminary Measurements Results".

- October 2002 - Greenbelt (MD - USA), *2002 Charged Particle Optics Conference*: "Multiturn Extraction: Performance Analysis of Old and New Approaches".

- May 2003 - PAC2003 Conference, contributed talk: "Adiabatic Beam Trapping in Stable Islands of Transverse Phase Space: Measurement Results at CERN Proton Synchrotron".

- May 2003 - HALO'03 Workshop, invited talk: "Dynamic Aperture for Single-Particle Motion: Overview of Theoretical Background, Numerical Predictions and Experimental Results".

- April 2004 - ISS, Forschungszentrum Karlsruhe, *ANKA Seminar*: "A novel approach to multi-turn extraction: adiabatic capture in stable islands of transverse phase space".

- July 2004 - EPAC 2004, contributed talk: "Multiturn Extraction Based on Trapping in Stable Islands at CERN PS: Recent Measurement Advances".

- September 2004 - AB Seminar: "Recent results of the studies for a novel multi-turn extraction at the CERN PS".

- October 2004 - 33^{rd} ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams, invited talk: "Multiturn Extraction Based on Trapping in Stable Islands".

- October 2004 - HHH 2004, First CARE-HHH-APD Workshop on Beam Dynamics in Future Hadron Colliders and Rapidly Cycling High-Intensity Synchrotrons, invited talk: "Multiturn extraction and injection using stable resonances".

- December 2004 - Bologna University INFN Section Seminar: "A novel approach to multiturn extraction from a circular particle accelerator: beam trapping in stable islands of transverse phase space".

- May 2005 - Conference PAC05, invited talk: "Final Results from the Novel Multi-turn Extraction Studies at CERN Proton Synchrotron".

- September 2005 - Workshop COULOMB'05, invited talk: "Resonant multi-turn extraction: principle and experiments".

- May 2006 - Workshop HB2006, invited talk: "Design and Tests of a Low-Loss Multi-Turn Ejection for the CERN PS".

- June 2007 PAC07 Conference, contributed talk: "Magnet acceptance and allocation at the LHC Magnet Evaluation Board".

- June 2007 - Fermilab, Accelerator physics and technology seminar: "Resonant multi-turn extraction project: principle and experiments at the CERN Proton Synchrotron".

- November 2007 - IR07 Workshop, invited talk: "Optics issues for phase-1 and phase-2 upgrades".

- January 2008 - Symposium for the 65^{th} anniversary of Giorgio Turchetti, invited talk: "The use of resonances for multi-turn beam extraction from circular accelerators".

- February 2008 - Seminaire de la Société Française de Physique: "Le Large Hadron Collider (LHC) : le futur collisionneur de particules du CERN".

- May 2008 - Invited talk at "La 16éme rencontre de prospectives du LAL": "LHC: La machine".

- May 2010 - IPAC10 Conference, contributed talk: "Results from the 2009 Beam Commissioning of the CERN Multi-turn Extraction".

- May 2012 - Invited talk at "Eleventh Conference on the Intersections of Particle and Nuclear Physics": "The CERN LHC machine: current status and future upgrade plans".

- October 2012 - Seminar of the accelerator division at Frascati National Laboratories: "Dynamic aperture studies for LHC and its upgrade".

- May 2013 - Physics colloquium of the University of Graz and the Graz University of Technology: "Controlling non-linear effects in circular particle accelerators and the dynamic aperture saga: the case of the CERN LHC".

- May 2013 - Special seminar of the Graz University of Technology: "Using non-linear effects to manipulate beams in circular accelerators: beam splitting by particles' trapping into resonance islands".

- July 2013 - Seminar of the John Adams Institute - Oxford: "Manipulation of transverse beam distribution in circular accelerators: beam splitting by particles? trapping into resonance islands".

- November 2013 - Fermilab, Accelerator physics and technology seminar: "The LHC dynamic aperture saga: overview, ideas and recent developments".

- November 2013 - Invited talk at "2013 US LHC Users Organisation Annual Meeting": "Status and Outlook of the LHC".

- December 2013 - Invited talk at "Beam Dynamics meets Magnets" Workshop: "Sorting of the LHC magnets and lessons learnt".

- February 2014 - Bologna University, Physics Dept.: "Non-linear Beam Dynamics in Particle Accelerators: Friend or Foe?".

- September 2015 - CMS week, Ischia, Italy: "LHC status and perspectives".

- September 2015 - LHCb week, Bologna - Italy: "LHC status and prospects for Run II".

- January 2016 - ASTeC/ISIS seminar: "Recent progress with Multi-Turn Extraction at CERN PS and possible future applications of stabile islands in circular machines'.

- February 2016 - Bologna University, Physics Dept. Bologna University: "LHC status and prospects for Run II and beyond".

- June 2016 - The Slow Extraction Workshop, invited talk: "Resonant extraction: review of principles and experimental results".

- October 2016 - 14th Topical Seminar on Innovative Particle and Radiation Detectors (IPRD16), invited talk: "High Luminosity LHC".

- February 2017 - EuCARD-2 XBEAM Strategy Workshop, invited talk: "Using Resonance Islands for Optimum Performance and Advanced Commissioning Techniques".

- September 2017 - International ICFA mini-Workshop on Nonlinear dynamics and collective effects in particle beam physics (NOCE 2017), invited talk: "Could synchrotron light sources benefit from experience with beams split at CERN?".

- December 2018 - LNF Accelerator Division Seminar: "Could synchrotron light sources benefit from the CERN experience with beams split in horizontal phase space?".

- November 2019 - Seminars and Journal Clubs, Center for Cosmology, Particle Physics and Phenomenology, Louvaine-la-Neuve: "Current situation and prospects for accelerator upgrades at CERN".

- November 2019 - Invited talk at the TRIBs Control room Workshop at BESSY II, Berlin: "Transverse beam splitting - CERN applications and other ideas".

- February 2020 - Invited talk at the Kickoff workshop for a dedicated muon EDM search using the frozen spin technique at PSI: "Novel techniques for injecting or extracting beams from a circular ring".

- May 2021 - John Adams Institute Seminar, Oxford: "The CERN future circular hadron collider".

Courses

- January 1999 - PS/OP Shutdown Lectures: “AD Experimental Area”.

- February 1999 - PS/OP Shutdown Lectures: “The new T8 beam line in the East Area”.

- February 1999 - PS/OP Shutdown Lectures: “Beam sharing in the East Area”.

- October 2005 - CERN Accelerator School - Intermediate Course, Lecture: “Sources of emittance growth”.

- July 2007 - First French-Ukrainian Summer School of Particle Physics - Lecture: “The LHC machine”.

- March 2008 - AB OP Shutdown Courses: “PS MTE principle and measurements until 2007”.

- November 2008 - Seminar in the framework of the course “Introduction to accelerator physics” - LAL Orsay: “The CERN LHC machine”.

- June 2009 - Seminar in the framework of the event “Nuit des Sciences” - Collège St. Louis - Corsier (GE): “La physique des Particules et le LHC”.

- October 2009 - CERN Accelerator School - Intermediate Course, Lecture: “Sources of emittance growth”.

- July 2010 - Trans-European School of High Energy Physics - Lecture: “The LHC machine”.

- November 2010 - Seminar in the framework of the Nuclei Particles Astrophysics Cosmology Master Degree Course “Introduction to accelerator physics” - LAL Orsay: “The CERN LHC machine”.

- August 2011 - Ecole de physique des Houches - La physique théorique face au défi du LHC, Lecture: “The LHC machine: commissioning and operation”.

- August 2011 - Ecole de physique des Houches - La physique théorique face au défi du LHC, Lecture: “The LHC machine: prospects”.

- September 2011 - CERN Accelerator School - Intermediate Course, Lecture: “Sources of emittance growth”.

- October 2011 - Seminar in the framework of the Nuclei Particles Astrophysics Cosmology Master Degree Course “Introduction to accelerator physics” - LAL Orsay: “The CERN LHC machine”.

- July 2012 - Seminar in the framework of the “Rencontres de l’infiniment grand à l’infiniment petit 2012: Promotion Ettore Majorana”: “The CERN LHC machine: a Higgs factory”.