

Procedura di selezione per la chiamata a **professore di II fascia** da ricoprire ai sensi dell'art. 18, commi 1 e 4, della Legge n. 240/2010 per il **settore concorsuale 02/A2**, (**settore scientifico-disciplinare FIS/02**) presso il **Dipartimento di Fisica**, (avviso bando pubblicato sulla G.U. n. 68 del 01/09/2020)

Codice concorso 4415

Curriculum Vitae

First name:	Giuseppe
Last name:	Bozzi
Date of birth:	22/02/1977

Qualifications

- **02/2020 - 12/2024:** Qualified for a position of **Professor in Theoretical Physics** (Professeur des Universités - Section 29 - Constituants Élémentaires) in French Universities
- **07/2018 - 07/2027:** Qualified for a position of **Associate Professor in Theoretical Physics** (Professore Associato - 02/A2 - Fisica Teorica delle Interazioni Fondamentali) in Italian Universities
- **25/06/2004 PhD** in Physics (University of Florence)
- **24/10/2000 Master Degree** in Physics (University of Pisa)

Scientific Path

- **07/2016 - present:** **Researcher (RTDa)** - University of Pavia (IT)
- **09/2014 - 06/2016:** **Contract Professor** - University of Milano (IT)
- **08/2013 - 07/2016:** **Contract Professor** - E-Campus University (IT)
- **03/2013 - 03/2016:** **Teaching Fellow** - Politecnico Milano (Italy)
- **01/2009 - 12/2012:** **Post-doctoral research associate** - University of Milano (IT)
- **10/2006 - 12/2008:** **Post-doctoral research associate** - ITP, Karlsruhe (DE)
- **09/2004 - 09/2006:** **Post-doctoral research associate** - University of Grenoble (FR)
- **04/2001 - 04/2004:** **Ph.D. student in Physics** - University of Florence (IT).
Thesis discussed on June 25th, 2004.
PhD Thesis: "Higgs boson production at hadron colliders and its transverse-momentum distribution"
Supervisor: Dr. Stefano Catani
- **10/1995 - 10/2000:** **Undergraduate student in Physics** - University of Pisa (IT).
Laurea in Physics obtained on October 24th, 2000 *with highest grade and cum laude*
Master Thesis: "Fermioni chirali su reticolo" (*in italian*)
Advisor: Prof. Adriano Di Giacomo

Research

- **Research Interests**

- Perturbative QCD: radiative corrections and all-order (resummed) predictions for electroweak observables (Higgs, Drell-Yan and multi-boson final states) at hadron colliders; phenomenology of SM and BSM processes at hadron colliders.
- Non-perturbative QCD: impact of proton internal structure on precision electroweak observables at hadron colliders; fit of transverse momentum dependent (TMD) PDFs from Drell-Yan and Semi-Inclusive DIS data; TMD factorisation.
- Aim: promote the synergy and exploit the complementarity between LHC and EIC, both bringing my high-energy expertise in the hadronic community and promoting the physics case for TMD studies at CERN, in order to provide a better description of the nucleon structure and an increasingly precise understanding of the strong interactions.

- **Research Products** (INSPIRE data)

- 47 research products (papers and proceedings)
- Bibliometrics (w/o proceedings): 2500+ citations, h-index = 22, avg. cit./paper = 86.2

- **Ongoing collaborations**

- Member of the LHC Electroweak Working Group (high precision electroweak measurements, benchmarking of different formalisms for low transverse-momentum processes)
- Member of the Electron Ion Collider User Group (identification of measurements for existing or new physics topics at the EIC, and their impact on detector design)
- Active collaboration with U. Pavia, U. Cagliari, U. Alcalà, Penn State U., JLab, CEA Saclay (global TMD fit, TMD factorisation at subleading twist, interplay between LHC and EIC)
- Active collaboration with U. Tübingen, U. Sapienza (Drell-Yan at low invariant mass)
- Active collaboration with U. Milano, PSI, ATLAS W Mass Team (reduction of theoretical systematics for W mass measurements)

Teaching

- **2019-2020 : University of Pavia (34 h)**

- Problem sessions for "Analytical Mechanics" (24 h) and "Quantum Electrodynamics" (10 h)

- **2018-2019 : University of Pavia (44 h)**

- Problem sessions for "Analytical Mechanics" (24 h) and "Quantum Electrodynamics" (10 h)
- Introduction to resummation methods for the "Strong Interactions" PhD course (10 h)

- **2017-2018 : University of Pavia (34 h)**

- Problem sessions for "Analytical Mechanics" (24 h) and "Quantum Electrodynamics" (10 h)

- **2016-2017 : University of Pavia (24 h)**

- Problem sessions for "Analytical Mechanics" (24 h)

- **2015-2016 : University of Milano (48h)**

- Full course (Lectures and Problem sessions) of "Quantitative methods for social sciences" (48h)

- **2015-2016 : Politecnico Milano (60 h)**

- Problem sessions for "Analytical Mechanics" (40 h) and "Geometry and Linear Algebra" (20 h)

- **2015-2016 : E-Campus University (online)**
 - Full course (Lectures and Problem sessions) of "Analytical Mechanics"
- **2014-2015 : University of Milano (68h)**
 - Full course (Lectures and Problem sessions) of "Quantitative methods for social sciences" (48h)
 - Problem session for "Mathematics" (20h)
- **2014-2015 : Politecnico Milano (156 h)**
 - Problem sessions for "Analytical Mechanics" (112 h), "Mathematics and Mechanics of Solids" (14 h) and "Geometry and Linear Algebra" (30 h)
- **2014-2015 : E-Campus University (online)**
 - Full course (Lectures and Problem sessions) of "Analytical Mechanics"
- **2013-2014 : Politecnico Milano (84h)**
 - Problem sessions for "Analytical Mechanics" (74 h) and "Geometry and Linear Algebra" (10 h)
- **2013-2014 : University of Milano (40h)**
 - Problem sessions for "Elements of Nuclear Physics" (20 h) and "Quantum Mechanics" (20 h)
- **2013-2014 : E-Campus University**
 - Full course (Lectures and Problem sessions) of "Analytical Mechanics"
- **2012-2013 : Politecnico Milano (30h)**
 - Problem sessions for "Analytical Mechanics" (20 h) and "Geometry and Linear Algebra" (10 h)
- **2012-2013 : University of Milano (50h)**
 - Problem sessions for "Elements of Nuclear Physics" (20 hours) "Quantum Mechanics" (30 h)
- **2011-2012 : University of Milano (50h)**
 - Problem sessions for "Theoretical Physics" (20 h) and "Quantum Mechanics" (30 h)
- **2010-2011 : University of Milano (80h)**
 - Problem sessions for "Quantum Mechanics" (30 h), "Theoretical Physics" (20 h) and "Elements of Nuclear Physics" (30 h)
- **2009-2010 : University of Milano (20h)**
 - Problem sessions for "Quantum Mechanics" (20 h)
- **2006-2007 : University of Karlsruhe (24h)**
 - Problem sessions for "Theoretical Particle Physics I" (24 h)
- **2005-2006 : University of Grenoble (108h)**
 - Problem sessions and laboratory for "General Physics" (66 h) and "Fundamental Physics" (42 h)

Students

- **04/2019 - 12/2019 : supervisor of a Bachelor student** (Federica Moroni) - U. of Pavia
Thesis: "Il vettore di Laplace-Runge-Lenz e la simmetria nel problema di Keplero e nell'atomo di idrogeno" (*in italian*)
- **04/2011 - 09/2012 : co-supervisor of a Bachelor student** (Davide Napoletano) - U. of Milano
Thesis: "Studio dei contributi non perturbativi alla produzione di bosoni vettori ai collisori adronici" (*in italian*)

- **11/2008 - 02/2009: external referee** for a **PhD thesis** (Luca Panizzi) - U. of Trieste
Thesis: "One-loop electroweak analysis for third family scalar quarks production at the LHC"
- **09/2004 - 09/2006: co-supervisor** of a **PhD student** (Benjamin Fuks) - U. of Grenoble
Thesis: "QCD resummation and non-minimal flavour-violation for supersymmetric particle production at hadron colliders"

Organisation and coordination duties

- **Member** of the Local Organising Committee - Transversity 2020 - Pavia
- **Member** of the Local Organising Committee - REF 2019 - Pavia
- **Member** of the INFN Scientific Committee of the "Asimov Prize" for science books
- **Member** of the Selection Committee for the admission to "Collegio Universitario S.Caterina", Pavia
- **Co-organiser** of the "Strong Interactions" course for the PhD in Physics at the University of Pavia
- **Referee** for Nuclear Physics B, Journal of High Energy Physics, European Physics Journal C
- Postdoctoral researchers' (elected) **representative** - University of Milano, 2009-2012
- Preparation and submission of proposals for national research grants (FIRB/MIUR)
- **Organiser** of the Theoretical Physics Seminar Series in Milano, 2009-2012
- **Organiser** of the ITP Weekly Research Seminar in Karlsruhe, 2006-2008

Outreach

- Editorial consultant for "Raffaello Cortina Editore" ("Scienza e Idee" series)
- Scientific and technical (LaTeX) consultant for "Codice edizioni" and "Treccani"
- Scientific and literary translations (ENG-ITA)
 - R. Panek "The Trouble with Gravity" - Houghton Mifflin Harcourt
("Il mistero sotto i nostri piedi" - Raffaello Cortina Editore - 2020)
 - L.Susskind, G. Hrabovsky "The Theoretical Minimum" - Basic Books
("Il minimo teorico" - Raffaello Cortina Editore - 2019)
 - S. Hossenfelder "Lost in Math" - Basic Books
("Sedotti dalla matematica" - Raffaello Cortina Editore - 2019)
 - N. Polson, J. Scott "AIQ" - St. Martin's Press
("Numeri intelligenti" - UTET - 2019)
 - L. Susskind, A. Friedman "The Theoretical Minimum - Special relativity and classical field theory"
("Relatività ristretta e teoria classica dei campi" - Raffaello Cortina Editore - 2018)
 - D. Stipp "A most elegant equation" - Basic Books
("L'equazione di Dio - Eulero e la bellezza della matematica" - Codice Edizioni - 2018)
 - N. deGrasse Tyson "Astrophysics for people in a hurry" - W.W.Norton and Company
("Astrofisica per chi va di fretta" - Raffaello Cortina Editore - 2018)
 - L. Susskind, A. Friedman "The Theoretical Minimum - Quantum Mechanics" - Basic Books
("Meccanica quantistica" - Raffaello Cortina Editore - 2015)
 - J.J. Sakurai, J. Napolitano "Modern Quantum Mechanics" - Addison Wesley
("Meccanica quantistica moderna" - Zanichelli - 2013)

- Interactive installation on the concept of Void in physics, art and philosophy, selected for the International Festival **"The Story of Space"**, Goa, India, November 2017 (financial support by Italian Ministry of Foreign Affairs)
- *Coordinator* of the Physics section for the ViaLattea scientific divulgation website
- *Contributor* to the QueryOnline magazine of the Italian Skeptics Association (CICAP)
- Public speech
 - 02/04/2020 Physics Department, Pavia - Speakable and unspeakable in data fitting
 - 17/12/2019 Physics Department, Pavia - Common misunderstandings in science divulgation
 - 26/09/2019 European Researchers Night, Pavia - Debunking of climate change denial
 - 11/03/2019 Collegio Unversitario S.Caterina da Siena, Pavia - Void in Physics and Art
 - 28/09/2018 European Researchers Night, Pavia - Statistics of gambling
 - 07/04/2017 Liceo Scientifico N. Moreschi, Milano - Void and Elementary Particles
 - 27/03/2014 Liceo Scientifico S.Ambrogio, Milano - Elementary Particles
 - 24/05/2013 Liceo Scientifico Vittorio Veneto, Milano - Elementary Particles
 - 09/11/2012 Circolo ARCI La Scighera, Milano - The Higgs Boson

Other skills

- **Foreign languages**
 - *Italian*: native
 - *English*: fluent
 - *French*: fluent
- **Computing**
 - *Operating systems*: Linux, Mac OS (user and administrator)
 - *Coding*: Fortran, LaTeX, Mathematica, Shell-scripting, Python
 - *Working experience in*: Monte Carlo simulation, cluster management (PBS/gLite), repositories (SVN, git), Wordpress
- **Volunteering**
 - Italian Red Cross - Volunteer: first aid in emergencies, ambulance, support for refugees, international cooperation, first-aid teaching for schools and private companies: (2009-present)
- **Music**
 - Polyphonic Choir "V. Galilei" (Pisa) - Bass/Baritone: baroque and renaissance music (1995-2001)
 - Polyphonic Choir "Città Studi" (Milan) - Bass/Baritone: baroque and romantic music (2011-2015)
 - Polyphonic Ensemble "Aenigma" (Milan) - Bass/Baritone: early baroque and renaissance music (2014-present)

List of Publications

1. **G. Bozzi, S. Catani, D. de Florian, M. Grazzini**
"The q_T spectrum of the Higgs boson at the LHC in QCD perturbation theory"
Phys. Lett. B564, 65 (2003) (hep-ph/0302104)
2. **G. Bozzi**
" Q_T resummation in Higgs boson production at the LHC"
in "Proceedings of the XV IFAE - Italian Meeting on High Energy Physics"
hep-ph/0311194
3. **K. A. Assamagan et al.**
"The Higgs working group: summary report 2003"
in "Proceedings of the 3rd Les Houches Workshop: Physics at TeV Colliders"
hep-ph/0406152
4. **G. Bozzi, B. Fuks, M. Klasen**
"Slepton production at polarized hadron colliders"
Phys. Lett. B609, 339 (2005) (hep-ph/0411318)
5. **G. Bozzi, B. Fuks, M. Klasen**
"Non-diagonal and mixed squark pair production at hadron colliders"
Phys. Rev. D72, 035016 (2005) (hep-ph/0507073)
6. **G. Bozzi, S. Catani, D. de Florian, M. Grazzini**
"Transverse-momentum resummation and the spectrum of the Higgs boson at the LHC"
Nucl. Phys. B737, 73 (2006) (hep-ph/0508068)
7. **G. Bozzi, B. Fuks, M. Klasen**
"Transverse-momentum resummation for slepton-pair production at the LHC"
Phys. Rev. D74, 015001 (2006) (hep-ph/0603074)
8. **G. Bozzi**
"QCD corrections to Higgs physics at the LHC"
in "Proceedings of the XVIII IFAE - Italian Meeting on High Energy Physics"
hep-ph/0609171
9. **G. Bozzi, B. Jäger, C. Oleari and D. Zeppenfeld**
"Next-to-leading order QCD corrections to W^+Z and W^-Z production via vector-boson fusion"
Phys. Rev. D75, 073004 (2007) (hep-ph/0701105)
10. **G. Bozzi, B. Fuks, M. Klasen**
"Threshold resummation for slepton-pair production at Hadron Colliders"
Nucl. Phys. B777, 157 (2007) (hep-ph/0701202)
11. **G. Bozzi, B. Fuks, B. Herrmann, M. Klasen**
"Squark and gaugino hadroproduction and decays in Non-Minimal Flavour Violating Supersymmetry"
Nucl. Phys. B787, 1 (2007) (arXiv:0704.1826)
12. **G. Bozzi, S. Catani, D. de Florian, M. Grazzini**
"Higgs boson production at the LHC: transverse-momentum and rapidity dependence"
Nucl. Phys. B791, 1 (2008) (arXiv:0705.3887)
13. **G. Bozzi, B. Fuks, M. Klasen**
"Joint resummation for slepton-pair production at Hadron Colliders"
Nucl. Phys. B794, 46 (2008) (arXiv:0709.3057)
14. **G. Bozzi, B. Jäger, C. Oleari and D. Zeppenfeld**
"Vector boson pair production via vector-boson fusion at NLO QCD"
J. Phys. Conf. Ser. 110:042006 (2008) (arXiv:0710.1572)

15. **G. Bozzi, B. Jäger, C. Oleari and D. Zeppenfeld**,
"Vector Boson Pair Production via Vector Boson Fusion at NLO QCD"
DOI 10.1007/978 – 88 – 470 – 0747 – 510
16. **G. Bozzi**
"Threshold effects in slepton pair production at the LHC"
J. Phys. Conf. Ser. 110:072004 (2008) (arXiv:0710.1573)
17. **G. Bozzi**
"Soft-gluon resummation for Higgs differential distributions at the LHC"
in "Proceedings of SUSY 07 - Karlsruhe, Germany"
(arXiv:0710.2422)
18. **del Aguila et al.**
"Collider aspects of flavor at high Q"
Eur. Phys. J. C 57, 183 (2008) (arXiv:0801.1800)
19. **S. Bolognesi, G. Bozzi and A. Di Simone**
"Higgs at LHC"
Nuovo Cim. 123B, 499 (2008) (arXiv:0804.4401)
20. **G. Bozzi**
"Selected Items in Jet Algorithms"
Nuovo Cim. 123B, 744 (2008) (arXiv:0808.0792)
21. **K. Arnold et al.**
"VBFNLO:A parton level Monte Carlo for processes with electroweak bosons"
Comput. Phys. Commun. 180, 1661 (2009) (arXiv:0811.4559)
22. **G. Bozzi, S. Catani, G. Ferrera, D. de Florian, M. Grazzini**
"Transverse-momentum resummation: a perturbative study of Z production at the Tevatron"
Nucl. Phys. B815, 174 (2009) (arXiv:0812.2862)
23. **G. Bozzi**
"Higgs boson production at the LHC: Transverse-momentum resummation and rapidity dependence"
PoS RADCOR 2007, 039 (2007)
24. **G. Bozzi**
"Soft-gluon resummation for Higgs differential distributions at the Large Hadron Collider"
Nuovo Cim. 123B, 772 (2008)
25. **G. Bozzi, F. Campanario, V. Hankele, D. Zeppenfeld**
"NLO QCD corrections for $W^+W^-\gamma$ and $ZZ\gamma$ production with leptonic decays"
Phys. Rev. D81, 094030 (2010) (arXiv:0911.0438)
26. **B. Jäger, G. Bozzi, C. Englert, C.Oleari, M. Worek, D. Zeppenfeld**
"Weak boson scattering at the Large Hadron Collider"
PoS RADCOR 2009, 057 (2009) (arXiv:1001.2649)
27. **D. Zeppenfeld, G. Bozzi, F. Campanario, C. Englert, V. Hankele, S. Platzer, B. Jäger, C.Oleari, M. Spannowsky, M. Worek**
"NLO QCD corrections to processes with multiple electroweak bosons"
PoS RADCOR 2009, 017 (2009) (arXiv:1002.0292)
28. **G. Bozzi, S. Catani, G. Ferrera, D. de Florian, M. Grazzini**
"Production of Drell-Yan lepton pairs in hadron collisions: transverse-momentum resummation at next-to-next-to-leading logarithmic accuracy."
Phys. Lett. B696, 207 (2011) (arXiv:1007.2351)
29. **G. Bozzi, F. Campanario, M. Rauch, H. Rzehak, D. Zeppenfeld**
"NLO QCD corrections for $WZ\gamma$ production with leptonic decays"
Phys. Lett. B696, 380 (2011) (arXiv:1011.2206)

30. **G. Bozzi, F. Campanario, M. Rauch, D. Zeppenfeld**
 "NLO QCD corrections for $W\gamma\gamma$ production with leptonic decays"
Phys. Rev. D **83**, 114035 (2011)(arXiv:1103.4613)
31. **G. Bozzi, J. Rojo, A. Vicini**
 "The impact of PDF uncertainties on the measurement of the W boson mass at the Tevatron and the LHC"
Phys. Rev. D **83**, 113008 (2011) (arXiv:1104.2056)
32. **G. Bozzi, F. Campanario, M. Rauch, D. Zeppenfeld**
 " $Z\gamma\gamma$ production with leptonic decays and triple photon production at NLO QCD"
Phys. Rev. D **84**, 074028 (2011) (arXiv:1107.3149)
33. **K. Arnold et al.**
 "VBFNLO:A parton level Monte Carlo for processes with electroweak bosons – Manual for version 2.5.0"
 (arXiv:1107.4038)
34. **G. Bozzi, F. Campanario, C. Englert, M. Rauch, M. Spannowsky, D. Zeppenfeld**
 "Precision Multiboson Phenomenology"
 (arXiv:1205.2506)
35. **K. Arnold et al.**
 "Release Note - VBFNLO 2.6.0"
 (arXiv:1207.4975)
36. **G. Bozzi, L. Citelli and A. Vicini**
 "Parton density function uncertainties on the W boson mass measurement from the lepton transverse momentum distribution"
Phys. Rev. D **91**, no. 11, 113005 (2015)
37. **G. Bozzi, L. Citelli, M. Vesterinen and A. Vicini**
 "Prospects for improving the LHC W boson mass measurement with forward muons"
Eur. Phys. J. C **75**, no. 12, 601 (2015)
38. **H. W. Lin et al.**
 "Parton distributions and lattice QCD calculations: a community white paper"
Prog. Part. Nucl. Phys. **100** (2018) 107
39. **A. Bacchetta, G. Bozzi, M. Radici, M. Ritzmann and A. Signori**
 "Effect of flavor-dependent partonic transverse momentum on the determination of the W boson mass in hadronic collisions"
Phys. Lett. B **788**, 542 (2019) (arXiv:1807.02101 [hep-ph])
40. **G. Bozzi and A. Signori**
 "Non-perturbative uncertainties on the transverse momentum distribution of electroweak bosons and on the determination of the W boson mass at the LHC"
Advances in High Energy Physics, vol. 2019 (arXiv:1901.01162 [hep-ph])
41. **A. Bacchetta, G. Bozzi, M. Lambertsen, F. Piacenza, J. Steiglechner, W. Vogelsang**
 "Difficulties in the description of Drell-Yan processes at moderate invariant mass and high transverse momentum"
Phys. Rev. D **100**, 014018 (2019) (arXiv:1901.06916 [hep-ph])
42. **C. Aidala et al.**
 "The LHCSpin Project"
 in **Probing Nucleons and Nuclei in High Energy Collisions**, 204 (arXiv:1901.08002 [hep-ex])

43. **A. Bacchetta, G. Bozzi, M. G. Echevarria, C. Pisano, A. Prokudin, M. Radici,**
 “Azimuthal asymmetries in unpolarized SIDIS and Drell-Yan processes: a case study towards TMD factorization at subleading twist,”
Phys. Lett. B797, 134850 (2019) (arXiv:1906.07037 [hep-ph])
44. **F. Piacenza, A. Bacchetta, G. Bozzi, M. Lambertsen, J. Steiglechner, W. Vogelsang**
 “Difficulties in the description of Drell-Yan processes at moderate invariant mass and high transverse momentum”
PoS SPIN2018 (2019) 056
45. **M. Radici, A. Bacchetta, G. Bozzi, M. Ritzmann and A. Signori**
 “Effect of flavor-dependent partonic transverse momentum on the determination of the W boson mass in hadronic collisions”
PoS DIS2019 (2019) 133
46. **S. Camarda *et al.***
 “DYTurbo: Fast predictions for Drell-Yan processes”
Eur Phys. J. C 80, 251 (2020) (arXiv:1910.07049 [hep-ph])
47. **A. Bacchetta, V. Bertone, C. Bissolotti, G. Bozzi, F. Delcarro, F. Piacenza and M. Radici**
 “Transverse-momentum-dependent parton distributions up to N³LL from Drell-Yan data,”
JHEP 07 (2020), 117 (arXiv:1912.07550 [hep-ph])

Detailed research activity

Lattice QCD

The work done for my master thesis at Pisa University, under the supervision of Adriano Di Giacomo and Luigi Del Debbio, was devoted on the possibility of formulating QCD on the lattice trying to preserve the chiral properties of the continuum theory.

Lattice QCD has the great advantage of being able to treat both the perturbative and non-perturbative regime of hadron phenomenology. Within this formulation the theory is defined on a four-dimensional euclidean space-time lattice of finite dimension and lattice spacing a . The introduction of the lattice regularises the theory by cutting off momentums greater than $1/a$, and at the same time it permits the numerical calculations of physical observables by means of Monte Carlo methods.

Actually at finite lattice spacing it is much difficult to obtain some properties of the continuum theory, because this regularisation breaks several symmetries: among the others, chiral symmetry. As an example, a “no-go” theorem exists that prevents from constructing a Dirac operator anti-commuting with γ_5 and that, in the limit of small momenta, gives the standard continuum propagator.

A possible solution to overcome this problem is to construct Dirac operators that satisfy a precise relation (Ginsparg-Wilson condition) and, inside this class, we have chosen to consider the one that in literature is known as “Neuberger operator”. The numerical simulation of this operator is very difficult mainly because it has an infinite interaction range and because of the huge dimension of the matrices involved.

The original part of my work was the investigation of the possible implementing procedures of the Neuberger operator and their comparison in order to choose the most convenient one and suitable to be inserted in a full QCD MonteCarlo algorithm.

Higgs/DY Physics and Soft-Gluon Resummation

During my Ph.D. course at Florence University, I worked with Stefano Catani, Massimiliano Grazzini (CERN) and Daniel de Florian (Buenos Aires University) on soft gluon resummation in perturbative QCD, with particular emphasis on the transverse momentum spectrum of the Higgs boson produced in hadron collisions. The main SM Higgs production mechanism at high energy colliders is the gluon-gluon fusion which is ex-

pected to receive large radiative corrections. As the QCD predictions for the total cross section are under good control now, we chose to investigate another important observable: the transverse-momentum (q_T) distribution of the Higgs boson. An accurate theoretical prediction of this observable at the LHC is very important to enhance the statistical significance of the signal over the background and to improve strategies for the extraction of the signal.

We can separate the q_T spectrum in three regions. In the large q_T region ($q_T > m_H$), the perturbative series is controlled by a small expansion parameter and thus gives reliable predictions. In the small q_T region ($q_T \ll m_H$) it is well known that the multiple soft emissions from initial state greatly enhance the coefficients of the perturbative series, thus spoiling the convergence of the series itself: so we need to use the resummation formalism to correctly take into account these effects. Finally in the intermediate q_T region it is necessary to match the fixed order result with the resummed one to prevent possible double counting.

We have implemented the matching of the resummation result at NNLL order with the fixed order result at NLO, thus achieving a matching at order α_S^4 .

The results in the case of Higgs production at the LHC were presented in [1] and show, besides the great importance of resummation effects for this observable, the stability of the main features of the distribution with respect to scale variations or inclusion of higher order terms in the resummed expansion and the modest influence of non-perturbative effects [3].

In a second paper [6] we performed a more phenomenological study for SM Higgs production at LHC and we gave the details of our resummation formalism, which is actually quite general and applies to the production of generic high-mass systems (lepton pairs, vector bosons, Higgs particles,...) in hadronic collisions.

We also pointed out the main differences of our approach with respect to other implementations of the resummation procedure: universality (i.e. process independence) of the form factor which embodies all the logarithmic contributions; implementation of resummation formula at the level of the partonic cross section (to avoid the extrapolation of parton distributions at non-perturbative energies); and slight modification of the resummation formula (imposing a constraint of perturbative unitarity) in order to avoid unjustified resummed contributions at intermediate and large q_T .

In [12] we further extended the resummation formalism to include rapidity dependence using the impact parameter and double Mellin moments to implement and factorise the multiparton kinematics constraint of transverse- and longitudinal-momentum conservation.

In [22] we applied the method described above to the Drell-Yan case and compared our predictions at NLL+LO with the available Tevatron data, finding a good agreement within the theoretical uncertainties.

In [28] we have extended the results presented in [22] to the NNLL+NLO accuracy. The NNLL corrections are not large and make the q_T spectrum slightly harder, while the size of the scale uncertainties is considerably reduced in going from NLL+LO to NNLL+NLO accuracy. We have compared the resummed calculation with the results of measurements of the normalised q_T spectrum at the Tevatron Run II. The perturbative uncertainty of the NNLL+NLO results turns out to be comparable with the experimental errors. The NNLL+NLO results (without the inclusion of any non-perturbative effects) are consistent with the experimental data in a wide region of transverse momenta.

In [46] we introduced a new numerical program, DYTurbo, for the calculation of the QCD transverse-momentum resummation of Drell-Yan cross sections up to next-to-next-to-leading logarithmic accuracy, combined with the fixed-order results at next-to-next-to-leading order (α_S^2), including the full kinematical dependence of the decaying lepton pair with the corresponding spin correlations and the finite-width effects. The DYTurbo program is an improved reimplementation of the previous DYqT, DYRes and DYNLO programs, which provides fast and numerically precise predictions through the factorisation of the cross section into production and decay variables, and the usage of quadrature rules based on interpolating functions for the integration over kinematic variables. DYTurbo is already widely used in experimental collaborations working on DY processes (ATLAS, in particular).

SUSY and Flavour Phenomenology

I joined the Theory Group at LPSC in Grenoble as a post-doc research associate in september 2004 and I started to work with Michael Klasen and a PhD student, Benjamin Fuks, on the phenomenology of slepton and squark pair production at hadron colliders.

In [4] we presented a new calculation of cross sections and asymmetries for slepton pair production through neutral and charged electroweak currents in polarised hadron collisions. Our analytical results are valid for general slepton masses and include the mixing of the left- and right-handed interaction eigenstates relevant for third generation sleptons.

Numerically, we have studied in detail the dependence of the longitudinal single-spin asymmetry on the tau slepton mixing angle for pair production of the lighter tau slepton mass eigenstate. Its physical mass and the mixing angle at the electroweak scale have been calculated with the help of renormalisation group equations after imposing restricted sets of SUSY breaking parameters at the unification scale.

The determination of these parameters in measurements of the longitudinal single-spin asymmetry at the only existing polarised pp collider RHIC was found to be difficult due to its limited center-of-mass energy and luminosity, even in a gauge mediated SUSY breaking model with a very light tau slepton.

In contrast, a polarisation upgrade for the proton beam of the Tevatron would give direct access to the trilinear coupling A_0 in a typical minimal supergravity model, independently of the tau slepton mass and the unpolarised cross section.

At the LHC, where larger masses are easily accessible and where we have studied an alternative minimal supergravity model with enhanced tau slepton masses and mixings, the sensitivity of the longitudinal single-spin asymmetry to the mixing angle and the trilinear coupling A_0 is found to be reduced and hampered by a large uncertainty from the not well-known polarised parton densities at small values of their longitudinal momentum fractions in the proton.

For all colliders, an asymmetry measurement would allow for a straightforward discrimination of the SUSY signal from the associated SM background of tau lepton pair production due to the opposite sign of SUSY and SM asymmetries.

In [5] we analyse the squark pair production at hadron colliders, namely stop and sbottom pairs. We extend the previous LO calculations for the stop sector including the polarisation effects, while in the non-diagonal case (stop1-stop2 or sbottom1-sbottom2 pair production) we compute the QCD contribution (sbottom loops) and the EW contribution (which turns out to be by far the dominant one). We also considered, for the first time, mixed squark pair production (stop1-sbottom2 or stop2-bottom1) via W-boson exchange. We provided squared helicity amplitudes for all considered channels in analytic form, as they expose the left- and right-handed contributions in the EW channels, allow for future applications to polarised hadron collisions, and may be easily implemented in general purpose Monte Carlo programs. Numerically, we have focused on top and bottom squark production, including mixing in both cases, at the Tevatron and the LHC. We found that associated light sbottom and stop production may allow for confirmation or exclusion of light sbottom scenarios at the Tevatron. In more traditional scenarios (SPS 1a or SPS 5), non-diagonal and mixed squark production can probably only be studied at the LHC, where these channels may allow for additional constraints on SUSY masses, mixing angles, or the SUSY CKM matrix.

In [7] we performed the first precision calculation of the q_T -spectrum in slepton- (or slepton-sneutrino associated-) pair production at the LHC. We implemented soft-gluon resummation up to NLL and subsequently matched the result to the LO α_S result. We gave numerical results for $\tilde{\tau}_1\tilde{\tau}_1^*$ et $\tilde{\tau}_1\tilde{\nu}_\tau^* + \tilde{\tau}_1^*\tilde{\nu}_\tau$, also including some recent proposals for the parametrisation of non-perturbative effects. The results show the relevance of the resummed contributions both in the small- and intermediate- q_T region and small dependence on scale variations and non-perturbative effects.

In [10] we presented a first and extensive study of threshold resummation effects for supersymmetric (SUSY) particle production at hadron colliders, still focusing on Drell-Yan like slepton-pair and slepton-sneutrino associated production. After confirming the known next-to-leading order (NLO) QCD corrections and generalizing the NLO SUSY-QCD corrections to the case of mixing squarks in the virtual loop contributions,

we employed the usual Mellin N -space resummation formalism with the minimal prescription for the inverse Mellin-transform and improved it by resumming $1/N$ -suppressed and a class of N -independent universal contributions. Numerically, our results increase the theoretical cross sections by 5 to 15% with respect to the NLO predictions and stabilize them by reducing the scale dependence from up to 20% at NLO to less than 10% with threshold resummation.

In [13] we presented a precision calculation of the transverse-momentum and invariant-mass distributions for supersymmetric particle pair production at hadron colliders, focusing on Drell-Yan like slepton pair and slepton-sneutrino associated production at the CERN Large Hadron Collider. We implemented the joint resummation formalism at the next-to-leading logarithmic accuracy with a process-independent Sudakov form factor, thus ensuring a universal description of soft-gluon emission, and consistently match the obtained result with the pure perturbative result at the first order in the strong coupling constant, i.e. at $\mathcal{O}(\alpha_s)$. We also implemented three different recent parameterisations of non-perturbative effects. Numerically, we give predictions for selectron pair production and compare the resummed cross section with the perturbative result. The dependence on unphysical scales is found to be reduced, and non-perturbative contributions remain small.

In [11] we presented an extensive analysis of squark and gaugino hadroproduction and decays in non-minimal flavour violating supersymmetry. We employed the so-called super-CKM basis to define the possible misalignment of quark and squark rotations, and we used generalised (possibly complex) charges to define the mutual couplings of (s)quarks and gauge bosons/gauginos. The cross sections for all squark-(anti-)squark/gaugino pair and squark-gaugino associated production processes as well as their decay widths have then been given in compact analytic form. For four different constrained supersymmetry breaking models with non-minimal flavour violation in the second/third generation squark sector only, we established the parameter space regions allowed/favoured by low-energy, electroweak precision, and cosmological constraints and display the chirality and flavour decomposition of all up- and down-type squark mass eigenstates. Finally, we computed numerically the dependence of a representative sample of production cross sections at the LHC on the off-diagonal mass matrix elements in the experimentally allowed/favoured ranges.

Vector-boson production

I joined the ITP as a post-doc research associate in October 2006 and I started to work with Dieter Zeppenfeld and his research group on the phenomenology of vector-boson production at hadron colliders.

In [9] we have described the calculation of the NLO QCD corrections to $W^\pm Zjj$ production at the LHC, and its implementation in a fully flexible parton-level Monte Carlo program that allows for the computation of kinematic distributions within realistic experimental cuts. We found that the scale uncertainties of the NLO predictions for total cross sections are at the 2% level, which indicates that the perturbative calculation is under excellent control. Care has to be taken, however, if NLO distributions are to be approximated by LO results, as shapes can change considerably when going from LO to NLO. In this regard, a “proper” choice of factorisation scale can help. We found that, with a factorisation scale chosen as the momentum transfer, Q , of the t -channel electroweak boson, the LO calculation can better reproduce the shape of NLO distributions than when taking a fixed scale, $\mu_F = m_V$.

Together with the phenomenology group at the ITP, we developed [21,33] a fully flexible parton level Monte Carlo program (VBFNLO) for the simulation of vector boson fusion, double and triple vector boson production in hadronic collisions at next-to-leading order in the strong coupling constant. VBFNLO includes Higgs and vector boson decays with full spin correlations and all off-shell effects. In addition, VBFNLO implements CP-even and CP-odd Higgs boson via gluon fusion, associated with two jets, at the leading-order one-loop level. A variety of effects arising from beyond the Standard Model physics are implemented for selected processes. This includes anomalous couplings of Higgs and vector bosons and a Warped Higgsless extra dimension model. The program offers the possibility to generate Les Houches Accord event files for all processes available at leading order.

In [25,29,30,32] we performed the computation of the NLO QCD corrections to the cross sections for WWA, ZZA, WZA, WAA, ZAA, AAA production in hadronic collisions. We considered the case of real photons in the final state, but included full leptonic decays of the W and Z bosons. Numerical results for the LHC and the Tevatron have been obtained through a fully flexible parton level Monte Carlo based on the structure of the VBFNLO program, allowing an easy implementation of arbitrary cuts and distributions. We showed the dependence on scale variations of the integrated cross sections and provided evidence that NLO QCD corrections strongly modify the LO predictions for observables at the LHC both in magnitude and in shape.

Precision physics for EW observables

Together with Alessandro Vicini and the phenomenology group of the Physics Department in Milano, from early 2009 I started working in the framework of the W Mass Workshop. The workshop collects experimentalists of both the Tevatron and the LHC and phenomenologists interested in precision measurements of the W boson mass, with the common effort of reliably estimating the various possible sources of (theoretical and experimental) uncertainties.

In [31] we studied at a quantitative level the impact of the uncertainties on the value of the W boson mass measured at hadron colliders due to: *i*) the proton parton distribution functions (PDFs), *ii*) the value of the strong coupling constant α_s and *iii*) the value of the charm mass used in the PDF determination. The value of the W boson mass was extracted, by means of a template fit technique, from the lepton-pair transverse mass distribution measured in the charged current Drell-Yan process. We studied the determination of M_W at the Tevatron and at the LHC with 7 and 14 TeV of center-of-mass energy in a realistic experimental setup. The analysis has been done at the Born level using the event generator HORACE and at NLO-QCD using the event generators DYNLO and ResBos. We considered the three global PDF sets, CTEQ6.6, MSTW2008 and NNPDF2.1. We estimated that the total PDF uncertainty on M_W is below 10 MeV both at the Tevatron and at the LHC for all energies and final states. We concluded that PDF uncertainties do not challenge a measurement of the W boson mass at the level of 10 MeV accuracy.

In [36] we applied the same analysis of [31] to the case of the lepton transverse-momentum distribution, obtaining an uncertainty on M_W that ranges between 18 and 24 MeV, depending on the final state and collider energy.

In [37] we discussed the potential of a M_W measurement by the LHCb experiment based on the lepton transverse momentum spectrum in W decays. The unique forward acceptance of LHCb means that the PDF uncertainties would be anti-correlated with those of p_T based measurements by ATLAS and CMS. We computed an average of ATLAS, CMS and LHCb measurements of m_W from the p_T distribution, and we found that this average is a factor of 1.3 more precise than an average of ATLAS and CMS alone.

Hadronic structure

In July 2016 I joined the group of Alessandro Bacchetta in Pavia and we started collaborating on the 3DSPIN project, an ERC-funded project focused on the study of the internal structure of the proton. We are currently working on the extraction of TMD PDFs from relevant observables at hadron colliders, implementing the most advanced perturbative and non-perturbative theoretical predictions, on Drell-Yan lepton pair production at low- Q^2 , and on the impact of flavour-dependent intrinsic k_T on precision EW measurements.

In [39], within the framework of transverse-momentum-dependent factorisation, we investigated for the first time the impact of a flavour-dependent intrinsic transverse momentum of quarks on the production of W^\pm bosons in proton-proton collisions at $\sqrt{s} = 7$ TeV. We estimated the shift in the extracted value of the W boson mass M_W induced by different choices of flavour-dependent parameters for the intrinsic quark transverse momentum by means of a template fit to the transverse-mass and the lepton transverse-momentum distributions of the W -decay products. We obtained shifts in M_W comparable to those induced by PDF variations, thus calling for more detailed investigations of flavour-dependent non-perturbative effects linked to the proton structure at hadron colliders.

In [40] we presented an overview of recent results concerning the impact of a possible flavour dependence of the intrinsic quark transverse momentum on electroweak observables. In particular, we focused on the q_T spectrum of electroweak gauge bosons produced in proton-proton collisions at the LHC and on the direct determination of the W boson mass. We showed that these effects are comparable in size to other non-perturbative effects commonly included in phenomenological analyses, and should thus be included in precise theoretical predictions for present and future hadron colliders.

In [41] We studied the Drell–Yan cross section differential with respect to the transverse momentum of the produced lepton pair, in the case of moderate invariant mass Q of the leptonic system (between 4.5 GeV and 13.5 GeV) and similar values of the transverse momentum q_T . We found that the collinear framework predicts cross sections that in most cases are significantly below available data at high q_T . We discussed additional perturbative and possible non-perturbative effects that increase the predicted cross section, but not by a sufficient amount.

In [43] we considered the azimuthal distribution of the final observed hadron in semi-inclusive deep-inelastic scattering and the lepton pair in the Drell-Yan process. In particular, we focused on the $\cos\phi$ modulation of the unpolarised cross section and on its dependence upon transverse momentum. At low transverse momentum, for these observables we proposed a factorised expression based on tree-level approach and conjectured that the same formula is valid in transverse-momentum dependent (TMD) factorisation when written in terms of subtracted TMD parton distributions. Our formula correctly matches with the collinear factorisation results at high transverse momentum, solves a long-standing problem and is a necessary step towards the extension of the TMD factorisation theorems up to the subleading twist.

In [47] we presented an extraction of unpolarised Transverse-Momentum-Dependent Parton Distribution Functions based on Drell-Yan production data from different experiments, including those at the LHC, and spanning a wide kinematic range. We dealt with experimental uncertainties by properly taking into account correlations and we included resummation of logarithms of the transverse momentum of the vector boson up to N3LL order together with non-perturbative contributions, obtaining a remarkable agreement with data.

List of Conferences and Talks

- **LPC Workshop on Physics Connections between the LHC and EIC**
Fermilab (USA), November 13th-15th, 2019 (*invited talk*)
- **National meeting EIC-NET**
Bari (IT), November, 7th-8th, 2019 (*invited talk in plenary session*)
- **LHC Electroweak Working Group meeting**
CERN (CH), October, 14th-15th, 2019 (*invited talk*)
- **LFC 19: Strong dynamics for physics within and beyond SM at LHC and future colliders**
Trento (IT), September, 9th-13th, 2019 (*invited talk*)
- **SarWors 2019 - Sardinian Workshop on Spin Studies**
Cagliari (IT), July, 8th-10th, 2019 (*invited talk*)
- **LHC Electroweak Working Group meeting**
CERN (CH), July 1st-3rd, 2019 (*invited talk*)
- **LHC Electroweak Working Group meeting**
Durham (UK), April 2nd-5th, 2019 (*invited talk*)
- **Rencontres de Moriond - QCD**
La Thuile (IT), March 23rd-30th, 2019 (*invited talk*)
- **LHC Electroweak Working Group meeting**
CERN (CH), December 12th, 2018 (*invited talk*)
- **Probing Nucleons and Nuclei in High Energy Collisions**
Seattle (USA), October 13th-27th, 2018 (*invited talk*)
- **SPIN 2018**
Ferrara (IT), September 10th-14th, 2018 (*invited talk in parallel session*)
- **LHC Electroweak Working Group meeting**
CERN (CH), June 20th-22nd, 2018 (*invited talk*)
- **30th Rencontres de Blois**
Blois (FR), May 3rd-8th, 2018 (*invited talk*)
- **QCD Evolution**
Santa Fe (USA), May 20th-24th, 2018 (*invited talk*)
- **The Flavor Structure of Nucleon Sea**
Seattle (USA), October 2nd-7th, 2017 (*invited talk*)
- **Spatial and Momentum Tomography of Hadrons and Nuclei**
Seattle (USA), September 22nd-29th, 2017 (*invited talk*)
- **2nd Italian Workshop on Hadron Physics and Non-Perturbative QCD**
Pollenzo (IT), May 22nd-24th, 2017
- **XIV International Workshop on Hadron Structure and Spectroscopy**
Cortona (IT), April 2nd-5th, 2017
- **Parton Distributions and Lattice Calculations in the LHC era**
Oxford (UK), March 22nd-24th, 2017
- **PDF4LHC Working Group**
CERN (CH), April 17th, 2013 (*invited talk*)
- **IPPP**
Durham (UK), December 7th, 2012 (*invited talk*)

- **IFAE 2012**
Ferrara (IT), April 11th-13th, 2012 (*talk given in plenary session*)
- **Hadron Collider Physics Symposium**
Paris (FR), November 14th-18th, 2011
- **LHCb Physics Week**
Bad Honnef (DE), April 26th-29th, 2011 (*invited talk given in parallel session*)
- **LHC WG on EW precision measurements**
CERN, April 4th-5th, 2011 (*2 invited talks*)
- **W Mass Workshop - 2nd Meeting**
Fermilab (USA), October 4th-5th, 2010 (*invited talk*)
- **HP2 High Precision for Hard Processes**
Firenze (IT), September 14th-17th 2010 (*invited talk*)
- **Transverse Momentum Distributions 2010**
Trento (IT), June 21st-25th 2010 (*invited talk*)
- **INFN Pavia**
Pavia (IT), March 26th, 2010 (*invited talk*)
- **IPN Lyon**
Lyon (FR), February 25th, 2010 (*invited talk*)
- **RADCOR 2009**
Ascona (CH), October 25th-30th, 2009
- **LC 2009 - e^+e^- Physics at the TeV scale**
Perugia (IT), September 21st-24th, 2009 (*invited talk*)
- **IFAE 2009**
Bari (IT), April 15th-17th, 2009 (*talk given in parallel session*)
- **INFN Milano**
Milano, December 22nd, 2008 (*invited talk*)
- **THEP Mainz**
Mainz, May 27th, 2008 (*invited talk*)
- **HERA and the LHC**
CERN, May 26th-28th, 2008 (*invited talk given in parallel session*)
- **IFAE 2008**
Bologna (IT), March 26th-28th, 2008 (*two talks given in parallel session*)
- **V Workshop on physics at the LHC**
Perugia (IT), February 1st-2nd, 2008 (*invited talk in plenary session*)
- **RADCOR 2007**
Firenze (IT), October 1st-5th, 2007 (*talk given in parallel sessions*)
- **SUSY 2007**
Karlsruhe (D), July 25th - August 1st, 2007 (*talk given in parallel session*)
- **EPS-HEP 2007**
Manchester (UK), July 19th-25th, 2007 (*2 talks given in parallel sessions*)
- **Congresso di Fisica Teorica**
Cortona (IT), May 28th - June 1st, 2007 (*talk given in parallel session*)
- **IFAE 2007**
Napoli (IT), April 11th-13th, 2007 (*talk given in parallel session*)

- **SFB/TR9 Meeting**
Aachen(D), February 21st-23rd, 2007 (*talk given in plenary session*)
- **LHC-D Workshop**
Wuppertal(D), January 22nd-23rd, 2007
- **ICHEP 06**
Moscow, July 27th - August 2nd, 2006 (*contribution to poster session*)
- **Congresso di Fisica Teorica**
Cortona (IT), May 29th - June 1st, 2006 (*talk given in parallel session*)
- **IFAE 2006**
Pavia (IT), March 27th-29th, 2006 (*invited review talk on Higgs phenomenology*)
- **ATLAS France (coll. meeting)**
Autrans (FR), March 27th-29th, 2006 (*invited review talk on Higgs phenomenology*)
- **Rencontre de Physique des Particules 2006**
Paris (FR), March 1st-3rd, 2006 (*talk given in MSSM session*)
- **Flavour in the era of the LHC**
CERN, February 6th, 2006
- **SUSY 05**
Durham (UK), July 18th-23th, 2005 (*talk given in parallel session*)
- **Congresso di Fisica Teorica**
Cortona (IT), May 25th-28th, 2005 (*contribution to poster session*)
- **SUSY-GDR Meeting**
Grenoble (FR), April 6th-8th, 2005
- **HERA and the LHC**
CERN, January 17th, 2005
- **SUSY-EuroGDR Meeting**
Frascati (IT), November 25th-27th, 2004 (*talk given in parallel session*)
- **LPSC Grenoble (FR)**
September 23th, 2004 (*"newcomer's talk"*)
- **INFN Firenze (IT)**
June 9th, 2004 (*invited talk*)
- **Congresso di Fisica Teorica**
Cortona (IT), May 26th-29th, 2004
- **INFN Bari (IT)**
December 3rd, 2003 (*invited talk*)
- **INFN Ferrara (IT)**
June 16th, 2003 (*invited talk*)
- **Congresso di Fisica Teorica**
Cortona (IT), May 28th-31st, 2003 (*talk given in parallel session*)
- **Short term visitor at CERN, Theory Division**
May 2003
- **IFAE 2003**
Lecce (IT), April 23rd-26th, 2003 (*talk given in QCD parallel session*)
- **CMS-Italia meeting**
Firenze (IT), February 14th, 2003 (*invited talk*)