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Luca Panizzi
CURRICULUM VITAE

INFORMAZIONI PERSONALI (NON INSERIRE INDIRIZZO PRIVATO E TELEFONO FISSO O CELLULARE)

COGNOME	**PANIZZI**
NOME	**LUCA**
DATA DI NASCITA	31/07/1980

INSERIRE IL PROPRIO CURRICULUM
(non eccedente le 30 pagine)

CURRICULUM VITAE

Luca Panizzi

Personal Data

Birthdate and place:	July 31, 1980 - Mantova, Italy
Citizenship:	Italian
Tel:	+39 3925969283 (mobile)
e-mail:	panizzi@ge.infn.it; lcpnzz@gmail.com

Education and qualifications

29 September 2005

Degree in Physics (Laurea), University of Florence, Italy
Thesis Title: *Neutrini a Massa Variabile in Cosmologia e Principio di Equivalenza* (in English: *Mass Varying Neutrinos in Cosmology and the Equivalence Principle*)
Advisors: Prof. Antonio Masiero (University of Padova) and Prof. Roberto Casalbuoni (University of Florence)

13 March 2009

Ph.D. in Physics, University of Trieste, Italy
Thesis Title: *One-Loop Electroweak Analysis for Third Family Scalar Quarks Production at LHC*
Advisor: Prof. Claudio Verzegnassi (University of Trieste)

January 2014

Qualification aux fonctions de maître de conférences (eligibility to access faculty positions of associate professor in France)

Positions

2009 - 2012	Postdoctoral position (Chercheur CNRS), Institut de Physique Nucléaire de Lyon and CNRS
2012 - 2016	Postdoctoral Research Associate, University of Southampton, UK
2016 - 2017	Postdoctoral position, University of Genova, Italy

Visiting positions and affiliations

March 2009 - June 2009	Visitor, School of Physics and Astronomy, University of Southampton, UK
July 2009 - November 2009	Visitor, Department of Theoretical Physics, University of Trieste, Italy
November 2010	One-month collaboration visit to KEK, Tsukuba, Japan
February 2011 - March 2011	One-month collaboration visit to Tsinghua University, Beijing, China
October 2012 - Semptember 2016	Visiting Scientist, Rutherford Appleton Laboratory (RAL), UK
July 2015	Two-weeks collaboration visit to FAPESP, Sao Paulo, Brazil
June 2015 - present	Analysis-based affiliation to the CMS collaboration
October 2016 - present	Visiting Scientist, University of Southampton, UK
April 2017 - present	Affiliation to ORSA (Interdepartmental center for Observations and Research in Astronomical Sciences) at the University of Genova, Italy
July 2017 - August 2017	Two-months visiting position, CERN
December 2017 - present	Visiting Scientist, University of Genova, Italy
February 2018 - March 2018	Two-months visiting position, Laboratoire Physique des Hautes Energies et Astrophysique, Marrakech, Morocco

Grants and awards

March 2009 - June 2009	Royal Society International Travel Grants 2008
July 2009 - November 2009	Grant of the Consorzio per la Fisica, University of Trieste
March 2018	Seal of Excellence by the European Commission for the project *"Characterisation of signals of new physics at the Large Hadron Collider and beyond"*

Teaching, Supervision and Tutorial Experience

Teaching

2012-2013	Demonstrator for the laboratory computing module "PHYS2022, Physics from evidence I", University of Southampton
2014	Demonstrator and examiner for the laboratory module "PHYS6008, Physics from Evidence II", University of Southampton
2014	Demonstrator for the module "MATH1007, Mathematical Methods for Physical Sciences", University of Southampton
2017	Demonstrator and examiner for the module of General Physics (FIS/01) at the Engineering Department, University of Genova

Supervision

2013	Supervisor of a student of Master M1 of ENS-Lyon for a three-months internship at the University of Southampton
2014	Participation to the "Postgraduate Certificate in Academic Practice Session 5: Supervising Research Students" at the University of Southampton
2014-present	Co-supervision of two PhD students in the Southampton High Energy Physics group
2015	Supervision of two students of Master M1 of ENS-Lyon for three-months internships at the University of Southampton
2016	Co-supervision of an undergraduate student of the University of Southampton for his research placement in the Southampton High Energy Physics group

Tutorial at PhD schools

2014	Tutor for the BUSSTEPP 2014 UK PhD School at the University of Southampton
2015	Tutor for the BUSSTEPP 2015 UK PhD School at the King's College, London
2016	Tutor for the BUSSTEPP 2016 UK PhD School at the University of Manchester

Referee Activity

from 2012	Physical Review D (PRD) and Journal of High Energy Physics (JHEP)
from 2013	Physics Letters B (PLB)
from 2015	Physical Review Letters (PRL)
from 2018	European Physical Journal C (EJPC)

Organisation and administration activity

2010-2012	Member of the équipe séminaires in the IPN Lyon
2013-2014	Organisation of the Thursday (internal) seminars of the Southampton High Energy Physics group
2014	Member of the LOC of the Fourth NExT PhD Workshop at the University of Southampton
2014	Member of the LOC of the BUSSTEPP 2014 UK PhD School at the University of Southampton
2014-2016	Organisation of the Friday (external) seminars of the Southampton High Energy Physics group

Computer Competences

Operative Systems	Linux
Software	Good knowledge of C++, Fortran, Perl, Python, ROOT, Mathematica and of specific particle physics software as Madgraph, CalcHep and Feynrules. I have developed a public software, with name XQCAT (eXtra Quark Combined Analysis Tool).

Languages

Italian (native), **English** (fluent), **French** (very good/fluent)

Outreach Activity

2008 - present	activity of science popularization through public conferences organised by the amateur astronomers association in Mantova, Italy, about particle physics and cosmology subjects
2013	Outreach activity at the Winchester Science Centre and Planetarium, UK
2017	Participation to the "Piano Nazionale Lauree Scientifiche" (outreach activity for high school students at the University of Genova, Italy); Lecture at the "Università della Terza Età" (aimed at providing education to older people, around retirement age).

Conferences, schools and seminars

Conferences

Conferences where I gave (or will be giving) a talk are marked with *

1. *13th International Symposium on Particles, Strings and Cosmology: PASCOS-07*, Imperial College, London, 2-7 July 2007
2. *V workshop italiano sulla fisica p-p ad LHC*, Perugia, 30 January - 2 February 2008
3. **Rencontres de Physique des Particules 2010*, IPN Lyon, 25-27 January 2010
4. *GDR Terascale*, Saclay, 29-31 March 2010
5. *Planck 2010*, CERN, 31 May - 4 June 2010
6. *TOOLS 2010 - Tools for SUSY and the New Physics, Sharpening our Tools*, Winchester, 29 June - 2 July 2010
7. **Rencontres de Physique des Particules 2011*, LPC Clermont-Ferrand, 13-14 January 2011
8. *Implications of LHC results for TeV-scale physics*, CERN, 29 August - 2 September 2011
9. **Frontiers in Neutrino Physics*, APC, Paris, October 4-6, 2011
10. **GDR Terascale*, CPPM Marseille, 11-13 October 2011
11. **Focus Workshop on Heavy Quarks at LHC*, National Taiwan University, 19-20 January 2012
12. *TOP 2012 - 5th International Workshop on Top Quark Physics*, Winchester, 16-21 September 2012
13. *Neutrinos at the forefront of elementary particle physics and astrophysics*, Lyon, 22-24 October 2012
14. **NExT Meeting*, Royal Holloway University of London, 14 November 2012
15. **Rencontres de Physique des Particules 2013*, LPSC Grenoble, 16-18 January 2013
16. **LC13: Exploring QCD from the infrared regime to heavy flavour scales at B-factories, the LHC and a Linear Collider*, ECT Trento, 16-20 September 2013
17. **New Perspectives in Dark matter*, IPN Lyon, 22-25 October 2013
18. **19th International Symposium on Particles, Strings and Cosmology: PASCOS 2013*, Taipei, 20-26 November 2013
19. *Annual Theory Meeting 2013*, Durham University, 16-18 December 2013
20. **Rencontres de Physique des Particules 2014*, IPHC Strasbourg, 20-22 January 2014
21. **Excited QCD 2014*, Sarajevo, 2-8 February 2014
22. **Astroparticle Physics 2014*, Amsterdam, 23-28 June 2014
23. **26th Recontres de Blois - Particle Physics and Cosmology*, Blois, 18-23 May 2014
24. **Workshop on vector-like quarks 2014*, DESY, Hamburg, 15-16 September 2014
25. **Calculations for Modern and Future Colliders*, Joint Institute for Nuclear Research, Dubna, 23-30 July 2015
26. **NExT Meeting*, Rutherford Appleton Laboratory, Didcot, 4 November 2015
27. **IFAE 2016*, University of Genova, 30 March - 1 April 2016
28. **Special CMS B2G Event at the LPC*, Fermilab, Chicago, 7-8 April 2016
29. **(Re)interpreting the results of new physics searches at the LHC*, CERN, 15-17 June 2016
30. **LIO international conference on Composite Models, Electroweak Physics and the LHC*, Lyon, France, 5-8 September 2016
31. *(Re)interpreting the results of new physics searches at the LHC*, CERN, 12-14 December 2016
32. **6th International Conference on New Frontiers in Physics (ICNFP2017), OAC, Creta, 17-29 August 2017*
33. **DAνCo: DArk matter, neutrinos and their Connections, CP3-Origins, Denmark, 17-29 August 2017*

PhD Schools

1. *Summer School on Particle Physics*, ICTP, Trieste, 11-22 June 2007
2. *The 2008 Hadron Collider Physics Summer School*, Fermilab, Chicago, 12-22 August 2008
3. *The 4th UniverseNet School - Frontiers of Particle Cosmology*, Lecce, 13-19 September 2010

Seminars

2009 University of Southampton, University of Freiburg, Institut de Physique Nucleaire de Lyon
2010 KEK (Tsukuba), IPMU (Tokio), University of Nagoya
2011 Tsinghua University, Peking University, IHEP Beijing, King's College London, University College London, LAPTH Annecy, LPC Clermont-Ferrand, LUPM Montpellier, Ecole Polytechnique, LPT Orsay, Universite Catholique de Louvain, University of Southampton
2012 IPhT Saclay, Centre for Mathematical Science (Cambridge), Southern Methodist University (Dallas)
2013 University of Sussex, Rutherford Appleton Laboratory, University of Bern
2014 LUPM Montpellier
2015 Max Planck Institute (Munich), University of Sao Carlos, ICTP Sao Paulo, University of Sussex
2016 University of Edinburgh, University of Genoa
2017 CERN

I have also given multiple vidyo presentations within CMS related to the analyses I was working on.

Publications, preprints and proceedings

Publications

1. M. Beccaria, G. Macorini, L. Panizzi, F. M. Renard and C. Verzegnassi, "Supersymmetry spectroscopy in stop-chargino production at LHC", Phys. Rev. **D74** (2006) 093009, [arXiv: hep-ph/0610075].
2. F. del Aguila et al., "Collider aspects of flavour physics at high Q," Eur. Phys. J. **C57** (2008) 183-308, arXiv:0801.1800 [hep-ph].
3. M. Beccaria, G. Macorini, L. Panizzi, F. M. Renard and C. Verzegnassi, "Stop-antistop and sbottom-antisbottom production at LHC: a one-loop search for model parameters dependence," Int. J. Mod. Phys. **A23** (2008) 4779-4810, arXiv:0804.1252 [hep-ph].
4. M. Beccaria, G. Macorini, E. Mirabella, L. Panizzi, F. M. Renard and C. Verzegnassi, "One-loop electroweak effects on stop-chargino production at LHC," Int. J. Mod. Phys. **A24** (2009) 5539, arXiv:0812.4375 [hep-ph].
5. M. Beccaria, G. Macorini, L. Panizzi, F. M. Renard and C. Verzegnassi, "Associated production of charged Higgs and top at LHC: the role of the complete electroweak supersymmetric contribution," Phys. Rev. **D80** (2009) 053011, arXiv:0908.1332 [hep-ph].
6. M. Beccaria, G.O. Dovier, G. Macorini, E.Mirabella, L. Panizzi, F. M. Renard and C. Verzegnassi, "Semi-inclusive bottom-Higgs production at LHC: The complete one-loop electroweak effect in the MSSM," Phys. Rev. **D82** (2010) 093018, arXiv:1005.0759 [hep-ph].
7. G. Macorini, S. Moretti, L. Panizzi, "Strong and Electro-Weak Supersymmetric Corrections to Single Top Processes at the Large Hadron Collider," Phys. Rev. **D82** (2010) 054016, arXiv:1006.1501 [hep-ph].
8. G. Cacciapaglia, R. Chierici, A. Deandrea, L. Panizzi, S. Perries, S. Tosi, "Four tops on the real projective plane at LHC," JHEP **1110** (2011) 042, arXiv:1107.4616 [hep-ph].
9. G. Cacciapaglia, A. Deandrea, N. Gaur, D. Harada, Y. Okada and L. Panizzi, "Heavy Vector-like Top Partners at the LHC and flavour constraints," JHEP **1203** (2012) 070, arXiv:1108.6329 [hep-ph].
10. G. Cacciapaglia, A. Deandrea, L. Panizzi, "Superluminal neutrinos in long baseline experiments and SN1987a," JHEP **1111** (2011) 137, arXiv:1109.4980 [hep-ph].
11. Y. Okada and L. Panizzi, "LHC signatures of vector-like quarks," Adv. High Energy Phys. **2013** (2013) 364936, arXiv:1207.5607 [hep-ph].
12. G. Cacciapaglia, A. Deandrea, S. Perries, V. Sordini and L. Panizzi, "Heavy Vector-like quark with charge 5/3 at the LHC," JHEP **1303** (2013) 004, arXiv:1211.4034 [hep-ph].
13. G. Cacciapaglia, A. Deandrea, J. Ellis, J. Marrouche and L. Panizzi, "LHC Missing-Transverse-Energy Constraints on Models with Universal Extra Dimensions," Phys. Rev. D **87** (2013) 075006, arXiv:1302.4750 [hep-ph].
14. M. Buchkremer, G. Cacciapaglia, A. Deandrea and L. Panizzi, "Model Independent Framework for Searches of Top Partners," Nucl. Phys. B **876** (2013) 376, arXiv:1305.4172 [hep-ph].
15. D. Barducci, S. Belyaev, J. Blamey, S. Moretti, L. Panizzi and H. Prager, "Towards a model-independent approach to the analysis of interference effects in pair production of new heavy quarks," JHEP **1407** (2014) 142, arXiv:1311.3977 [hep-ph].

16. N. Chen, Y. Zhang, Q. Wang, G. Cacciapaglia, A. Deandrea and L. Panizzi, "Higgsphobic and fermiophobic Z' as a single dark matter candidate," JHEP **1405** (2014) 088, arXiv:1403.2918 [hep-ph].
17. D. Barducci, S. Belyaev, M. Buchkremer, G. Cacciapaglia, A. Deandrea, S. De Curtis, J. Marrouche, S. Moretti and L. Panizzi, "Framework for Model Independent Analyses of Multiple Extra Quark Scenarios," JHEP **1412** (2014) 080, arXiv:1405.0737 [hep-ph].
18. S. F. King, A. Merle and L. Panizzi, "Effective theory of a doubly charged singlet scalar: complementarity of neutrino physics and the LHC," JHEP **1411** (2014) 124, arXiv:1406.4137 [hep-ph].
19. D. Barducci, A. Belyaev, M. Buchkremer, J. Marrouche, S. Moretti and L. Panizzi, "XQCAT: eXtra Quark Combined Analysis Tool,", Comput. Phys. Commun. **197** (2015) 263, arXiv:1409.3116 [hep-ph].
20. G. Cacciapaglia, A. Deandrea, N. Gaur, D. Harada, Y. Okada and L. Panizzi, "Interplay of vector-like top partner multiplets in a realistic mixing set-up," JHEP **1509** (2015) 012, arXiv:1502.00370 [hep-ph].
21. T. Geib, S. F. King, A. Merle, J. M. No and L. Panizzi, "Probing the Origin of Neutrino Masses and Mixings via Doubly Charged Scalars: Complementarity of the Intensity and the Energy Frontiers," Phys. Rev. D **93** (2016) no.7, 073007, arXiv:1512.04391 [hep-ph].
22. S. Moretti, D. O'Brien, L. Panizzi and H. Prager, "Production of extra quarks at the Large Hadron Collider beyond the Narrow Width Approximation," arXiv:1603.09237 [hep-ph], Phys. Rev. D **96** (2017) no.7, 075035.
23. S. Jain, F. Margaroli, S. Moretti and L. Panizzi, "The 750 GeV threshold to a new particle world," arXiv:1605.08741 [hep-ph], Phys. Rev. D **95**, no. 1, 014037 (2017).
24. S. Kraml, U. Laa, L. Panizzi and H. Prager, "Scalar versus fermionic top partner interpretations of $t\bar{t}+E_T^{\rm miss}$ searches at the LHC," JHEP **1611** (2016) 107, arXiv:1607.02050 [hep-ph].
25. A. Belyaev, L. Panizzi, A. Pukhov and M. Thomas "Dark Matter characterization at the LHC in the Effective Field Theory approach," JHEP **1704** (2017) 110, arXiv:1610.07545 [hep-ph].
26. S. Moretti, D. O'Brien, L. Panizzi and H. Prager, "Production of extra quarks decaying to Dark Matter beyond the Narrow Width Approximation at the LHC," Phys. Rev. D **96** (2017) no.3, 035033, arXiv:1705.07675 [hep-ph].
27. D. Barducci and L. Panizzi, "Vector-like quarks coupling discrimination at the LHC and future hadron colliders," JHEP **1712** (2017) 057, arXiv:1710.02325 [hep-ph].
28. D. Barducci, A. Deandrea, S. Moretti, L. Panizzi and H. Prager, "Characterising Dark Matter Interacting with Extra Charged Leptons," arXiv:1801.02707 [hep-ph], accepted for publication in PRD.

Publications and preprints with experimental collaborations

1. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for single production of a vector-like T quark decaying to a Z boson and a top quark in proton-proton collisions at sqrt(s) = 13 TeV," arXiv:1708.01062 [hep-ex].
2. A. M. Sirunyan *et al.* [CMS Collaboration], "Search for single production of vector-like quarks decaying to a b quark and a Higgs boson," arXiv:1802.01486 [hep-ex].

Proceedings

I only list proceedings for conferences in which I have personally given a talk.

1. L. Panizzi, "Vector-like quarks: t' and partners," Nuovo Cim. C **037** (2014) 02, 69.
2. L. Panizzi, "Model-independent Analysis of Scenarios with Vector-like Quarks," Acta Phys. Polon. Supp. **7** (2014) 3, 631.

Summary of research activity

Luca Panizzi

Throughout my research career I have being working on the phenomenological aspects at colliders of different new physics scenarios and I have developed a wide range of skills and competences in both theoretical and experimental aspects. My approach is *model-independent* and *bottom-up*, and it is nowadays widely adopted by the phenomenological community: it consists in identifing and analysing relevant signatures in minimal extensions of the SM (*e.g.* effective field theories or simplified models) and reinterpret them to reconstruct more complex scenarios which approximate the complete signatures predicted by theoretically motivated models of new physics.

In the first years of my activity I have worked on the calculation of NLO corrections in the electroweak sector to different processes of production of SM and supersymmetric states at the LHC, such as in Refs. [1,2].

The main focus of my work so far, however, has consisted in the analysis of signatures generated by the production and decay of new heavy quarks, mostly with vector-like properties. My studies resulted in the production of relevant publications [3–9] and in the generation of public models for numerical simulations [5,6], which are systematically used and referenced by both ATLAS and CMS experimental collaborations and in phenomenological papers. As a result of my studies I also developed a public tool to recast LHC public data in these scenarios [7,8].

My established reputation in the field allowed me to be directly involved in the development and publication of experimental searches. I actively collaborate with CMS, first through the Rutherford Appleton Laboratory (RAL) in UK and currently through the CMS group in the University of Genova. Through this collaboration I can directly contribute to the editing of experimental publications, have access to the relevant subset of non-public data and influence the way results are presented to the scientific community, while keeping my independence as theoretical physicist for the rest of my research projects. This has resulted in my authorship of one CMS publication [9] and, in the forthcoming future, I will be included as author of at least another one which is already in its final stage of develoment [10].

My research interests have also gradually spanned into different aspects of new physics, and my focus has shifted to the in-depth characterisation of possible signals and excesses to allow their interpretation in terms of theoretical scenarios and narrow down the possibilities, which is the research path I am willing to follow in the next years.

Since recently, I have started the analysis of signatures with missing transverse energy, which can be interpreted as originating from dark matter (DM) candidates, with the purpose of characterising the properties of DM and especially its spin. The strategy I adopted is to identify and analyse combinations of observables with the aim of associating specific features of the final states to the spin of DM and therefore discriminate between different scenarios. The importance of this analysis is due to the fact that if signals compatible with the presence of a DM candidate are observed at the LHC, a precise and detailed characterisation of their properties would allow to embed the DM state in a subset of theoretical scenarios and exclude other scenarios. I have already produced different important results, where signatures originated by fermionic DM were compared with analogous signatures with bosonic DM [6,11,12] in different contexts. The characterisation of DM properties at colliders has been given mild attention in literature, but my approach is gaining growing popularity. I am working with the CMS groups of São Paulo (Brasil) for applying shape-analysis techniques with the aim of discriminating signals in the context of a two-Higgs doublet model.

Parallelly to my main research activity, I have worked on different projects, related to extra-dimensions [13] and neutrino physics [14] and I have recently taken part to a project for the measurement of the Hubble constant at the University of Genoa, in which I proposed novel observational techniques and analysis strategies for extracting data from non-resolved astrophysical objects, which are being currently used in observational campaigns of gravitationally lensed quasars with an optical telescope [15].

References

[1] M. Beccaria, G. Macorini, L. Panizzi, F. M. Renard, and C. Verzegnassi *Int. J. Mod. Phys.* **A23** (2008) 4779–4810, [arXiv:0804.1252]. [2] M. Beccaria, G. Macorini, L. Panizzi, F. M. Renard, and C. Verzegnassi *Phys. Rev.* **D80** (2009) 053011, [arXiv:0908.1332]. [3] G. Cacciapaglia et al. *JHEP* **03** (2012) 070, [arXiv:1108.6329]. [4] Y. Okada and L. Panizzi *Adv.High Energy Phys.* **2013** (2013) 364936, [arXiv:1207.5607]. [5] M. Buchkremer et al. *Nucl.Phys.* **B876** (2013) 376–417, [arXiv:1305.4172]. [6] S. Kraml et al. *JHEP* **11** (2016) 107, [arXiv:1607.0205]. [7] D. Barducci et al. *JHEP* **12** (2014) 080, [arXiv:1405.0737]. [8] D. Barducci et al. *Comput. Phys. Commun.* **197** (2015) 263–275, [arXiv:1409.3116]. [9] **CMS** Collaboration, A. M. Sirunyan et al. arXiv:1708.0106. [10] **CMS** Collaboration, CMS-PAS-B2G-17-009. [11] G. Cacciapaglia et al. *Phys. Rev.* **D87** (2013), no. 7 075006, [arXiv:1302.4750]. [12] A. Belyaev et al. arXiv:1610.0754. [13] G. Cacciapaglia, R. Chierici, A. Deandrea, L. Panizzi, S. Perries, and S. Tosi *JHEP* **10** (2011) 042, [arXiv:1107.4616]. [14] S. F. King, A. Merle, and L. Panizzi *JHEP* **11** (2014) 124, [arXiv:1406.4137]. [15] http://www.orsa.unige.net/index.php/en/research/time-delay-for-gravitationally-lensed-quasar/.

Research Statement - Luca Panizzi

Characterisation of signals of new physics at the Large Hadron Collider and beyond

My research proposal sits in the broad context of the **phenomenology of new physics at colliders**. After the discovery of the Higgs boson at the Large Hadron Collider (LHC), the focus has now shifted in trying to solve the outstanding issues of the Standard Model (SM), which will eventually – and hopefully – lead to the discovery of signatures of new physics (NP) in the forthcoming years.

My project consists in the development and application of novel and model-independent analysis strategies for the characterisation of new physics states of different kinds from their signatures at colliders. The ultimate goal is to pin down the theoretical scenario(s) at the origin of observations of new phenomena in experimental data at the LHC or future colliders.

Physical case studies

In the following I describe with some detail *two* case studies which will allow me to present the kind of problems addressed by my research proposal. They have been chosen considering the research topics I have been working in the last years and for which I have a now a wide expertise and a strong record of publications, giving me a deep knowledge of open problems, technical aspects and observational potentialities. I stress, however, that *the techniques I will develop have a much broader reach*, and will be applied to address a larger number of open problems related to manifestations of physics beyond the SM.

• ***Characterisation of the spin of Dark Matter candidates.*** One of the current "hot topics" among experimental searches and phenomenological analyses at the LHC is the exploration of signatures with missing transverse energy (E_T^{miss}), which *can* be originated by dark matter (DM) particles. In case of observation of a signal with E_T^{miss}, it is crucial to *determine the properties of the DM candidate*, its *spin* being one of the most interesting from both theoretical and experimental points of view. A determination of the spin of DM candidates at the LHC (or at least the identification of their spin-statistics properties) would indeed rule out or put into tension with data entire classes of models – with a *very high theoretical impact* – and would allow experiments (both at collider and in complementary sectors, as direct and indirect detection) and phenomenological analyses to focus only on a much smaller subset of predictions. This goal, however, strongly depends on the assumptions about how the DM interacts with the SM sector. Hence, this analysis requires an identification of how different channels are sensitive to the DM spin when different hypotheses about the DM properties are taken into account. A systematic analysis of different signatures with E_T^{miss} with the aim of characterising the properties of DM, its spin in particular, is thus hugely needed and will become a crucial interpretation element in case of future observations. This part of the project will take at least two years, to analyse all possible channels at the LHC and future colliders, and will produce a series of papers about the most relevant channels and a final review paper.

• ***Characterisation of the properties of extra-fermions.*** New heavy extra fermions (XFs), either quarks (XQs) or leptons (XLs) are predicted by a large number of theoretical models. Signatures from XQs, and especially those with vector-like properties (VLQs) – are among the mostly explored scenarios of exotic NP at the LHC. A remarkable feature of VLQs is the correspondence between their representation under $SU(2)$ and the dominant chirality of their couplings to SM states [1]. In case of observation of a signal compatible with a VLQ, the determination of its coupling properties would be therefore essential for embedding the new state into a theoretical scenario. However, a quantitative determination of the discrimination potential in case of VLQ discovery is *missing*. I will explore it for different hypotheses about VLQ couplings (a first analysis has been recently undertaken [2]) exploiting, for the first time, correlations between kinematic properties of final state objects. Signal regions (SRs) for experimental searches optimised for chirality discrimination will be designed, exploiting multivariate analysis techniques. This part of the project will last at least three years, due to the wide range of final states to explore and to the potential connections between new fermions and DM, with the production of a series of papers (including experimental ones resulting from my ongoing collaboration with CMS) dedicated to the characterisation of VLQs and other XFs in specific channels.

Further physical cases which will be considered are the characterisation of the **spin of leptoquarks**, which are often invoked to explain current anomalies and for which I will exploit similar techniques as for the DM

spin, or **signatures of states with large width** (comparable to their mass), which have never received experimental attention. The approach I will adopt in the development of the analysis techniques and search strategies will allow me to promptly address all the above examples, and further ones which may gain high priority, possibly driven by LHC observations.

The aspects related to **future colliders** will be treated considering both high-energy upgrades of the LHC and linear colliders. A promising analysis at linear collider would be, for example, the **characterisation of leptophilic DM scenarios** and specifically DM interacting with electrons, in which DM interactions are mediated by new fermionic or bosonic lepton partners, such as XLs or sleptons.

Analysis strategies, their implementation and experimental applications

My approach is *model-independent* and *bottom-up*, and it is nowadays widely adopted by the phenomenological community: it consists in identifying and analysing relevant signatures in minimal extensions of the SM (*e.g.* effective field theories or simplified models) and reinterpret them to reconstruct more complex scenarios which approximate the complete signatures predicted by theoretically motivated models of NP.

I present here the main technical aspects of my project, though different and further improvements will be developed in due course, depending on the specific issues related to different phenomenological studies.

1) Channel selection criteria. The starting point of the analysis consists in identifying and studying relevant channels or *combinations of channels* which are more sensitive to differences in NP properties. An important aspect of this project is that an individual channel may not provide enough information for a complete discrimination between NP scenarios, but the analysis of different channels, with different discovery reaches, could be a viable strategy. Combining the results from different channels can therefore provide essential and novel insight about the properties of NP states, not just their discovery potential.
2) Shape analysis. For each specific channel, an analysis of the *shapes of key kinematics distributions* will then be performed to determine the likelihood ratios of different hypotheses. Such analysis is common in experimental searches, but it is optimised for the *discovery* of NP. I will go beyond this approach and consider distributions of kinematics observables which are mainly sensitive to the key physical properties under investigation, designing selection and kinematics cuts to optimise the significance of the signal in regions of parameter space where *characterisation* can be achieved. A first example of the application of shape analysis techniques for the characterisation of DM spin can be found in [3].
3) Correlations between observables. Multi-dimensional correlations between different observables in collider events will be heavily investigated. When correlations are considered in phenomenological analyses, the goal is usually to optimise the analysis for *discovery*. Cut-and-count and shape analysis techniques will be applied to multi-dimensional distributions of key observables in *characterisation regions*, and advanced statistical methods for the extraction of information from data will be exploited.

To improve the effectiveness of the analysis, optimise its performance, and increase the perspectives for experimental implementations, state-of-the-art *machine-learning techniques* will be exploited. The study of the analysis strategies will therefore be associated to the **development of a software** for their automation, which will be publicly released to allow advanced phenomenological analyses by the community. My experience in the development of public software for physics analysis will guarantee the high-impact, effectiveness and reliability of the final product. Indeed, I have already ideated, designed and developed a public software, named XQCAT [4–6], for the recasting of LHC data in scenarios with XQs: I have pioneered the development of *recasting tools*, which are nowadays commonly used among phenomenologists, and I will have the opportunity to pioneer the development of *characterisation tools* which will play a pivotal role in the high-luminosity and high-energy eras of collider physics.

An essential aspect of the development of new analysis strategies is related to my **direct collaboration with the experimental community**: I have always liaised with experimentalists of both ATLAS and CMS to propose new observations and improve current searches. This aspect has allowed me to be directly involved in various experimental searches of CMS, through an analysis-based affiliation to the collaboration. I can now influence the development of selected searches and their interpretation stage and contribute in the editing of the final scientific publications [7]. I am planning to collaborate with experimentalists in order to apply my analysis strategies for NP characterisation in forthcoming experimental searches. My project will lead to the **definition of SRs optimised for the characterisation of NP**, which will depend on the scenario under study and will be different, in general, from SRs optimised for discovery. Furthermore, a

phenomenological guidance on the potentialities of a multivariate analysis to characterise an excess will be a new and extremely useful element for the experimental community. The development and optimisation of **algorithms for the analysis of experimental data to characterise an observation** will be a relevant milestone for experimental analyses and will represent one of the major successes of my project.

As a final comment about my skills in **developing new analysis strategies**, I have recently taken part to a project for the measurement of the Hubble constant at the University of Genoa (thus completely different from my main research lines), where I proposed novel observational techniques and novel analysis strategies for extracting data from non-resolved astrophysical objects, which are being currently used in observational campaigns of gravitationally lensed quasars with an optical telescope [8]. *My flexibility in the approach of physical problems allows me to quickly address new research areas and immediately give essential contributions to their advancement.*

Aptness, timeliness and promptness of the project

The LHC Run II is ongoing, new data are currently and rapidly piling up and are being analysed: the development of techniques to *identify* and *characterise* signals of NP from experimental data is **paramount and timely** and I believe I can play a major role in such quest. Indeed, during my career I have provided important contributions to research programmes for the analysis and interpretation of LHC data, introducing new ideas and developing research lines which are allowing me to play an active role in collaborations with experimentalists and participate to the development of their analyses. I have produced results mostly about manifestations of NP scenarios featuring new heavy quarks, dark matter candidates and their interactions (see CV), writing a numerical model [1, 9] which is currently a *benchmark tool* for CMS analyses and a software for the recasting of LHC data [4–6]. My project is a further step forward for the quest of discovery and interpretation of new physics.

Projections for characterisation of signatures which can be tested with better accuracy at future colliders (High-Energy LHC and linear ones, such as ILC or CLIC) will also be produced. Given the ongoing feasibility studies, **proposing searches for future experiments** is also essential and timely.

My research program will provide **new analysis strategies and tools** to test aspects of NP which have not been explored yet and which will lead to a far better understanding of future observations of new phenomena. I am hence in the *best* position and in the *perfect* moment to influence the strategies for experimental searches of NP in current and future colliders and to interpret their outcomes.

Finally, my research proposal is **flexible** with respect to dynamically and rapidly changing scenarios, driven by the new data produced at the LHC and other experiments, and can take huge advantages from this. The model-independent nature of my project and the absence of a theoretical bias in my research will allow me to **quickly respond to changes** determined by experimental results, and to be able to adapt and optimise the characterisation techniques to a potentially changed context. Furthermore, the diversification of the analysis I am proposing guarantees the possibility to put constraints with unprecedented detail. Therefore, the results I will obtain will also be essential for the **recasting of experimental data**.

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IN NOME DELLA LEGGE

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RETTORE DELL'VNIVERSITA'
DEGLI STVDI DI FIRENZE

VEDVTI GLI ATTESTATI DEGLI STVDI COMPIVTI DA

LVCA PANIZZI

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VEDVTO L'ESITO DELL'ESAME FINALE
SVPERATO IL 29 SETTEMBRE 2005

GLI CONFERIAMO LA LAVREA IN

FISICA

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DATO A FIRENZE IL 12 OTTOBRE 2005

IL RETTORE

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IL PRESIDE DI FACOLTA'

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CONFERISCE IL GIORNO 13 MARZO 2009

IL TITOLO DI

DOTTORE DI RICERCA

IN

FISICA

A

LUCA PANIZZI

NATO A MANTOVA IL 31 LUGLIO 1980

IL RETTORE

DATO A TRIESTE IL GIORNO 30 DEL MESE DI GIUGNO DELL'ANNO 2009

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nato a Mantova (MN) il 31/07/1980
ammesso a frequentare il dottorato di ricerca in FISICA
istituito per il XXI Ciclo (durata di 3 anni accademici)
con sede amministrativa presso UNIVERSITA' DEGLI STUDI DI TRIESTE
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La commissione giudicatrice era formata dai professori:
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RECAPITULATIF DES QUALIFICATIONS VALIDES
publiées au 13/12/2015*

Par M. LUCA PANIZZI

Né(e) le 31/07/1980 à MANTOVA

CORPS	SECTION**	N° QUALIFICATION	DATE	CAMPAGNE	DATE EFFECTIVE PEREMPTION
MCF	29	14229260159	31/01/2014	2014	31/12/2018

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The project proposal **794635, NPC-LHC**

Characterisation of signals of new physics at the Large Hadron Collider and beyond

Submitted under the Horizon 2020's **Marie Skłodowska-Curie actions**
call **H2020-MSCA-IF-2017** of **14 September 2017**
by
Luca PANIZZI
and
EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
ROUTE DE MEYRIN CERN
1211 GENEVA 23
Switzerland

following evaluation by an international panel of independent experts

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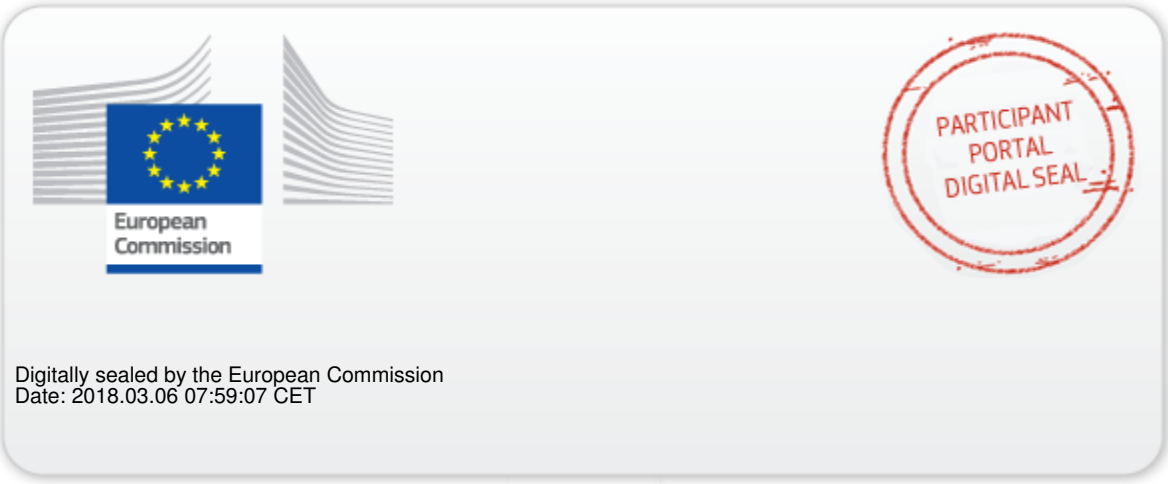

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