

Mirco Dorigo | Curriculum Vitæ

INFN Trieste – AREA science park – Padriciano, 99 – 34149 Trieste, Italy

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Professional positions

Since 12/2017: Permanent researcher of INFN

Experimental high-energy physics group of the Trieste section

02/2017 – 02/2019: Research Fellow at CERN

Experimental physics department (on leave of absence from INFN between 03/2018 and 02/2019)

05/2013 – 01/2017: Postdoctoral research associate at EPFL

Laboratory of high-energy physics

Education

2010 – 2013: *PhD in Physics*, University of Trieste, Italy

Thesis: Search for new physics in the $B_s^0 \rightarrow J/\psi \phi$ and $B_s^0 \rightarrow \phi \phi$ decays at CDF ([PDF link](#))

Supervisors: Dr. A. M. Zanetti (INFN Trieste), Dr. M. Rescigno (INFN Roma 1)

2007 – 2009: *MSc in Physics* (Laurea Specialistica in Fisica), University of Trieste, Italy

Thesis: Measurement of the polarization amplitudes of the $B_s \rightarrow \phi \phi$ decay at CDF ([PDF link](#))

Supervisors: Dr. A. M. Zanetti (INFN Trieste), Dr. M. Rescigno (INFN Roma 1)

Top marks with highest honours (110/110 e lode)

2004 – 2007: *BSc in Physics* (Laurea di Primo Livello in Fisica), University of Trieste, Italy

Top marks (110/110)

Leadership and service

- Convenor, “Exclusive decays” sub-group of the “Semileptonic B decays” working-group of the LHCb collaboration, between 01/2018 and 03/2020 ([website link](#))
- Convenor, Stream 2 (Semileptonic decays, rare decays, and tests of lepton flavour universality) at the *2018 Workshop on implications of LHCb measurements and future prospects*, CERN 17–19/10/2018 ([website link](#)).
- Convenor, Working Group 7 (Mixing and CP violation in the D system) at the *10th International Workshop on the CKM Unitarity Triangle*, Heidelberg, 17–21/09/2018 ([website link](#)).
- Convenor, “Intensity Frontier” session at the *XVI Italian Meeting on High Energy Physics (IFAE)* Trieste, 19-21/04/2017 ([website link](#)).
- Convenor, “flavour-tagging” group of the LHCb collaboration, between 01/2014 and 03/2016 ([website link](#)).
- Member of 5 physics analysis review committees (3 chairs) in LHCb and CDF.
Responsible for reviewing the analyses and certifying the results to seek approval for publication by the LHCb collaboration [[JHEP 1506, 131 \(2015\)](#); [PLB 762, 484 \(2016\)](#); [PLB 771, 21 \(2017\)](#); [EPJC 79, 706\(2019\)](#)] and the CDF collaboration [[PRL 120, 202006 \(2018\)](#)].

Seminars

- Invited to give departmental HEP seminars and colloquia at (2020) Munich Technical University, (2018) EPFL ([link](#)) and INFN-Trieste ([link](#)), (2012) Nikhef Institute, Physikalisches Institut Heidelberg, EPFL.

Selected talks

- *CP* violation in beauty decays at LHCb
plenary at *FLAVOR 2019: new Physics in flavor from LHC to Belle II*, MIAPP, Munich, 2019 ([website link](#))
- *B* properties, lifetimes, and B_c decays at LHCb
plenary at *17th International Conference on B-Physics at Hadron Machines*, La Biodola, Isola d'Elba, 2018 ([website link](#))
- Measurements of *CP* violation and mixing in charm and beauty at LHCb
plenary at *Les Rencontres de Physique de la Vallée d'Aoste*, La Thuile, 2016 ([website link](#))
- LHCb status report
plenary at *120th LHCC meeting*, CERN, 2014 ([website link](#))
- *B* flavour tagging in *pp* collisions
parallel at *37th International Conference on High Energy Physics*, Valencia, 2014 ([website link](#))
- Measurements of *CP* violation in the B_s^0 system
parallel at *Phenomenology 2014 Symposium*, Pittsburgh, 2014 ([website link](#))
- CDF results on *CP* violation in hadronic *B* decays
parallel at *36th International Conference on High Energy Physics*, Melbourne, 2012 ([website link](#))
- Recent heavy flavor results from the Tevatron
plenary at *47th Rencontres de Moriond, QCD and High Energy Interactions*, La Thuile, 2012 ([website link](#))
- Suppressed B_s^0 decays at CDF
plenary at *13th International Conference on B-Physics at Hadron Machines*, Amsterdam, 2011 ([website link](#))
- Charmless and penguin decays at CDF
parallel at *6th International Workshop on the CKM Unitarity Triangle*, Warwick, 2010 ([website link](#))
- Measurements of the masses, lifetimes and decay modes of hadrons at Tevatron
plenary at *45th Rencontres de Moriond, QCD and High Energy Interactions*, La Thuile, 2010 ([website link](#))

Teaching and supervision

- External referee of three MSc theses (Ek-In Surapat [PDF link](#), Praz Cyrille [PDF link](#), Wampler Philippe Andrew [PDF link](#)) on high energy physics at EPFL for the spring semester 2018.
- Introduction to *CP* violation and mesons mixing for MSc students in particle physics at Rome "La Sapienza" University, 4 hours in the spring semester 2016 ([website link-1](#) and [link-2](#))
- Teaching assistant at EPFL:
 - "General physics II" for first-year BSc students (lecturer Prof. T. Nakada, 5 CFU), spring semester 2015: 2 hours per week of exercises to complement ex-cathedra lectures, 14 weeks ([website link](#));
 - "Nuclear and particle physics I" for third-year BSc students (lecturer Prof. O. Schneider, 4 CFU), fall semester 2014: 2 hours per week of exercises to complement ex-cathedra lectures, 14 weeks ([website link](#));
 - internship in the laboratory of high-energy physics for first-year MSc students (8 CFU), spring semesters in 2016 and 2014: 1 full day per week, 14 weeks ([website link](#)). Supervised students: Marko Stamenkovic, Lino Ferreira Lopes, Aurélie Flandi.
- Co-supervisor of 4 MSc theses in particle physics: Lino Ferreira Lopes (EPFL, [PDF link](#)); Matthieu Marinangeli (EPFL, [PDF link](#)); Brice Maurin (EPFL, [PDF link](#)); Lucia Grillo (University of Trieste, [PDF link](#)).
- Tutoring of summer students at CERN (Veronika Sølund Kirsebom, Niels Bohr Institute of Copenhagen, [see this link](#)) and Fermilab (Gabriele Bertoli, University of Trieste, [website link](#))

Research

Executive summary: My interest is in experimental high-energy physics at hadron colliders. I am member of the CDF (since 2009) and LHCb (since 2013) collaborations.

I've done pioneering measurements of *CP* violation in the mixing of B_s^0 meson decays in CDF [[PRL 107, 261802 \(2011\)](#); [PRL 109, 171802 \(2012\)](#)], and continued with high-precision measurements in decays of B_s^0 , B^0 , and D^0 mesons in LHCb [[PRL 114, 041801 \(2015\)](#); [PRL 115, 031601 \(2015\)](#); [JINST 11, P05010 \(2016\)](#); [JHEP 06, 084 \(2018\)](#), [PRL122, 011802 \(2019\)](#)]. In LHCb, I've also expanded my research towards the complementary

field of rare decays [PLB 743, 46 (2015)]. More recently, I focused on semileptonic B decays and developed a novel method that allowed the measurement of the B_s^0 and D_s^+ lifetimes with high-precision [PRL 119, 101801 (2017)]. Using the same dataset of B_s^0 decays, I also devised a new method that allowed the first measurement of the CKM matrix element $|V_{cb}|$ at an hadron collider [arXiv:2001.03225]. In this analysis I also measured for the first time form factors and branching ratios of the $B_s^0 \rightarrow D_s^{(*)-} \mu^+ \nu_\mu$ decays. In the following, I briefly detail each research topic I have been working on.

CP violation in B_s^0 , B^0 , and D^0 flavor oscillations.....

Mixing of neutral mesons proceeds through loop transitions where possible unknown particles can contribute yielding indirect evidence for physics beyond the standard model. In particular, measurements of the CP -violating phase of the mixing amplitude can probe energy scales higher than those directly accessible with current and foreseen high-energy colliders. This makes such measurements chief goals of current flavour physics.

$B_s^0 \rightarrow \phi\phi$ analysis: The $B_s^0 \rightarrow \phi\phi$ is a decay of a pseudoscalar meson into two vector particles, whose dynamics involves three different decay amplitudes corresponding to the polarization states allowed by angular momentum conservation. Such polarisation states have different CP parities, and their interference allows to probe CP violations. In preparation towards CP violation studies, in 2009 for my master thesis, I did the first measurement of the $B_s^0 \rightarrow \phi\phi$ polarisation amplitudes with 300 signal candidates. As the only student and main responsible for the analysis in a team of 3 people, I selected and validated the data and wrote the fit to extract the results with a precision of around 4% [PRL 107, 261802 (2011)]. In the first year of my PhD, I devised an original method to measure time-integrated CP -violating asymmetries in this decay mode: in close collaboration with phenomenologists (J. Rosner, University of Chicago) I constructed new observables that make CP violation accessible in $B_s^0 \rightarrow \phi\phi$ decays even with small samples. I did a measurement of these observables, obtaining the first constraint on CP violation in $B_s^0 \rightarrow \phi\phi$ decays with a 6% precision [PRL 107, 261802 (2011)].

ϕ_s at CDF: Because of high rate and clean experimental signature, the $B_s^0 \rightarrow J/\psi\phi$ decays is the most effective probe of ϕ_s , the CP -violating mixing phase of the B_s^0 system. The main topic of my PhD thesis was the final CDF measurement of ϕ_s with about 11000 $B_s^0 \rightarrow J/\psi\phi$ decay candidates. I was the main contributor of the analysis in a team of 5 people with control on each step of the work, from the selection of the data and control samples, to the generation of simulated samples, to the determination of the results and their systematic uncertainties. We obtained improved confidence intervals for the B_s^0 mixing phase, which, at that date, were second in precision only to LHCb [PRL 109, 171802 (2012)]. From the same analysis, measurements of the decay width difference between the B_s^0 physical states, the B_s^0 average lifetime, and polarization amplitudes of the $B_s^0 \rightarrow J/\psi\phi$ decay among the most precise available at that date were also determined.

ϕ_s at LHCb: With the end of CDF operations I moved to LHCb. Here I specialised in the methods for the identification of the flavour of neutral B mesons at production, so-called “flavour tagging”. This is an essential ingredient of any measurement of decay-time-dependent CP violation, as the effective efficiency of the flavour tagging determines the statistical sensitivity to the CP asymmetries. Thus, improvements in flavour tagging strongly boost the reach. In a team of 15 people, I was responsible for the flavour-tagging methods in the most precise determination to date of ϕ_s with about 90000 $B_s^0 \rightarrow J/\psi\phi$ decay candidates from the LHC Run I data set [PRL 114, 041801 (2015)]; in particular, I performed the calibration of the tagging algorithms, and contributed to the development of a new algorithm for B_s^0 mesons [JINST 11, P05010 (2016)], which featured the use of multivariate classifiers (neural networks). The effective efficiency of the improved flavour-tagging algorithms enhanced by 20% the statistical reach of the $B_s^0 \rightarrow J/\psi\phi$ data sample with respect to pre-existing tools. In the update of this measurement [EPJC 79, 706(2019)], I’ve been appointed as chair of the review committee internal to the LHCb collaboration for scrutinising the analysis to seek publication.

2β measurement: In the B^0 system the quantity corresponding to ϕ_s is the angle 2β of the CKM unitarity triangle, which is known within about 1.5 degrees combining all existing measurements. Yet possible new physics contributions up to 15% are not excluded, from the comparison of direct and indirect determinations. I contributed to the measurement of 2β with $B^0 \rightarrow J/\psi K_S$ decays at LHCb [PRL 115, 031601 (2015)], done by a team of 8 people. This is the most precise determination of this quantity at an hadron collider with an uncertainty of 3.4 degrees, competitive with the B -factories measurements. Obtaining such a precision in the harsher environment represented by proton-proton collisions is a benchmark for measurements of CP violation in the B^0 and B_s^0 sector at high precision in LHC Run II and beyond. In this analysis, I performed a dedicated

calibration of the “opposite-side” tagging algorithms which offered a 60% reduction of the leading systematic uncertainty with respect to the approach adopted in an early measurement.

$2\beta + \gamma$ measurement: The measurement of the decay-time-dependent CP asymmetries in $B^0 \rightarrow D^- \pi^+$ decays allows to extract the combination of the angles of the CKM unitarity triangle $2\beta + \gamma$. By fixing β from precise and independent measurements, one can determine γ , the least known angle of the CKM unitarity triangle. I performed such a measurement in a team of 4 people, using a sample of 500 thousand signal candidates, the largest sample ever employed in a decay-time-dependent analysis for CP violation in B decays. In this analysis, a deep understanding of the flavour-tagging tools is crucial, because mis-calibrations of the algorithms can severely bias the measurement of CP asymmetries. The precision on the measured asymmetries, around 2% [JHEP 06, 084 (2018)], is about 40% better than the previous world’s best result (from the Belle experiment). From these asymmetries, confidence intervals on the quantities $|\sin(2\beta + \gamma)|$ and γ are derived in agreement with world’s average values.

y_{CP} measurement: Because of flavour oscillations, D^0 decays to CP -even final states, such as $D^0 \rightarrow K^- K^+$ and $D^0 \rightarrow \pi^- \pi^+$, have an effective lifetime which differs from that of D^0 decays to flavour-specific final states, such as $D^0 \rightarrow K^- \pi^+$. The ratio of the effective lifetimes of these decays allows to measure the charm-mixing parameter y_{CP} , and to test CP violation in D^0 - \bar{D}^0 mixing, which is expected to be highly suppressed in the standard model. Hence, high-precision measurements of y_{CP} offer sensitivity to a broad class of non-standard-model processes, complementary to those accessed in neutral B decays, that could contribute to the mixing amplitude by increasing the oscillation rate and/or introducing CP -violation effects. Together with a CERN colleague, I worked on a high-precision measurement of y_{CP} , using large samples of D^0 mesons produced in semileptonic B^+ and B^0 decays. The challenge of the analysis is to prove that biases on the D^0 decay-time distributions are understood and corrected for with an unprecedented precision for the y_{CP} measurement. We devised several tests in large control samples of data which guarantee to achieve the smallest uncertainty on y_{CP} to date, 0.16%, which is as precise as the current world average. This is the first time that a competitive measurement of y_{CP} is performed at a hadron collider. We found no evidence of CP violation [PRL122, 011802 (2019)].

Flavour-tagging group convenorship.....

Between January 2014 and March 2016, I convened the group responsible for flavour tagging in LHCb. The group comprised about 15 active members and about 90 mailing-list subscribers. During my convenorship, I worked on three main aspects: i) support in the finalisation of the flagship analyses with the full Run I data set; ii) development of new algorithms to increase the effective efficiency; iii) a way to cope with the reduced manpower of the group.

About point i), optimisations of the algorithms and improved calibrations allowed a $O(20\%)$ enhancement of the effective taggers efficiency, which benefited several analyses [PRL 114, 041801 (2015); PRL 115, 031601 (2015); PLB 742 (2015) 38; PLB 736 (2014) 186; PRD 90 (2014) 052011; JHEP 1411 (2014) 060; PRL 113 (2014) 211801].

On point ii), I led the group towards the developments of three novel algorithms: the improved algorithm for B_s^0 mesons, for which I was one of the proponents, that enhances by about 50% the effective efficiency of the previous tool [JINST 11, P05010 (2016)]; an algorithm that exploits the charges of the decay products of charm mesons from the decay of the b hadron produced in association with the signal B meson, which improves by a relative 10% the effective tagging efficiency [JINST 10, P10005 (2015)]; and the first algorithm to exploit the correlation between the flavour of B^0 mesons and the charge of protons produced in association with them [EPJC 77, 238 (2017)].

On point iii), I guided the development of a tool to allow the analysts to calibrate the algorithms on their own, freeing the flavour-tagging group from this time-consuming task, such that the manpower can focus in the development of new algorithms.

Search for rare decays of B^0 and B_s^0 mesons into $\pi^+ \pi^- \mu^+ \mu^-$

Along with a PhD student from EPFL, I did the first search for the rare decays of B^0 and B_s^0 mesons into the $\pi^+ \pi^- \mu^+ \mu^-$ final state, where the $\mu^+ \mu^-$ pair is not originating from the decay of a resonance and the $\pi^+ \pi^-$ invariant mass is within 0.5 and 1.3 GeV/c^2 . No experimental information existed on these decays, which are

expected to be very suppressed in the standard model. Theoretical predictions on their branching fractions suffer from large uncertainties on the hadronic parameters entering the calculation of the decay amplitudes, and span the range 10^{-9} – 10^{-7} . Such very rare decays are experimentally challenging to discover because of the large background from favoured decays, featuring rates much larger than those of the searched signals, which mimic the signal when final-state particles are misidentified. We searched for these rare decays using the full data set collected in Run I, managed to control the background from particles misidentification, and observed about 50 B_s^0 decay and 40 B^0 decays obtaining the first measurement of their branching fractions (about 10^{-7} for B_s^0 and 10^{-8} for B^0), with a relative precision of around 20% [PLB 743, 46 (2015)].

High-precision lifetime measurements.....

Measurements of B lifetimes are stringent tests of effective models used to calculate parameters associated with the strong interaction, which in turn limits predictions in many indirect searches of new physics. The large event samples of semileptonic decays offer the best potential for the ultimate precision in lifetime measurements. However, neutrinos and possibly neutral mesons in the final state, prevent from fully reconstructing the decay, thus introducing serious challenges. The aim of the analysis I've done with 3 coworkers is to provide a high-precision determination of the B_s^0 lifetime using a large yield of semileptonic $B_s^0 \rightarrow D_s^- (\rightarrow K^+ K^- \pi^-) \mu^+ X$ decays. The idea to control the systematic uncertainties is to infer the lifetime from a fit to the ratio between the $B_s^0 \rightarrow D_s^- (\rightarrow K^+ K^- \pi^-) \mu^+ X$ and $B^0 \rightarrow D^- (\rightarrow K^+ K^- \pi^-) \mu^+ X$ signal yields as a function of the decay time, where the precisely known value of the B^0 lifetime is used as an external input. The choice of a reference decay kinematically similar to the signal allows for a significant suppression of uncertainties associated with partial signal reconstruction and lifetime-biasing selection criteria. We also improved significantly the determination of the D_s^+ lifetime by the same method, using as input the D^- lifetime. The results [PRL 119, 101801 (2017)] improved by 15% the best measurement of the B_s^0 lifetime and by a factor of two the one of the D_s^+ lifetime, whose precision had not been improved in the past decade.

First measurement of $|V_{cb}|$ with $B_s^0 \rightarrow D_s^{(*)-} \mu^+ \nu_\mu$ decays.....

A longstanding puzzle concerns the value of the CKM matrix element $|V_{cb}|$, which describes the coupling between charm and beauty quarks in weak interactions. This parameter is measured with two methods, the so-called inclusive and exclusive approaches, which yield values in disagreement by approximately three standard deviations. The exclusive determination of $|V_{cb}|$ relies on the description of strong-interaction effects for the b and c quarks bound in mesons, the so-called form factors (FF), which are calculated using non-perturbative QCD techniques. Recently, the FF parametrisation used in the exclusive determination has been considered to be a possible origin of the inclusive–exclusive discrepancy, and comparisons between the results for $|V_{cb}|$ obtained using different parametrisations, such as that by Caprini, Lellouch and Neubert (CLN) and that by Boyd, Grinstein and Lebed (BGL), are considered a key check. Exclusive determinations have been carried out only at e^+e^- colliders and using B decays. Operating at the $\Upsilon(4S)$ resonance, the full decay kinematics can be determined, despite the undetected neutrino, and the total number of B mesons produced, needed to measure $|V_{cb}|$, is known precisely. The situation is more challenging in a hadron collider. In a team of 4 colleagues, I carried out a measurement of $|V_{cb}|$ using for the first time $B_s^0 \rightarrow D_s^{(*)-} \mu^+ \nu_\mu$ decays. A key advantage of semileptonic B_s^0 decays, compared to B decays, is that their FF can be more precisely computed. I devised a novel method that, contrary to analysis done at e^+e^- colliders, does not require the momentum of particles other than D_s^- and μ^+ to be estimated to assess the FF and measure $|V_{cb}|$. We employed both CLN and BGL parametrisations to measure $|V_{cb}|$ for the first time at an hadron-collider experiment. The results in the two parametrisations are compatible with each other and agree with previous measurements with exclusive decays, as well as the inclusive determination [arXiv:2001.03225]. This new technique can also be applied to B^0 decays, giving excellent prospects for new $|V_{cb}|$ measurements at LHCb.

Selected publications

As a member of the LHCb and CDF collaborations, I am co-author of about 500 papers (see <http://inspirehep.net/author/profile/M.Dorigo.1> for the complete list). Below I list the papers where I am either the main person responsible or one of a few primary authors.

- **Measurement of polarization and search for CP-violation in $B_s^0 \rightarrow \phi\phi$ decays**
T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **107**, 261802 (2011). [INSPIRE-link](#), 46 citations.
First paper from my PhD thesis, which includes also results from my Master thesis (polarisation measurement). I am the primary author of this work done by a team of 3 people.
- **Measurement of the bottom-strange meson mixing phase in the full CDF dataset**
T. Aaltonen *et al.* [CDF Collaboration], Phys. Rev. Lett. **109**, 171802 (2012). [INSPIRE-link](#), 93 citations.
Second paper from my PhD thesis. I am one of the two primary authors of this work done by a team of 5 people.
- **Precision measurement of CP violation in $B_s^0 \rightarrow J/\psi K^+ K^-$ decays**
R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **114**, 041801 (2015). [INSPIRE-link](#), 186 citations.
In a team of 15 people, I was responsible for the flavour-tagging methods of the measurement.
- **Measurement of CP violation in $B^0 \rightarrow J/\psi K_S^0$ decays**
R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **115**, 031601 (2015). [INSPIRE-link](#), 93 citations.
In a team of 8 people, I was responsible of the flavour-tagging calibrations which provided a significant reduction of the systematic uncertainty.
- **Study of the rare B_s^0 and B^0 decays into the $\pi^+\pi^-\mu^+\mu^-$ final state**
R. Aaij *et al.* [LHCb Collaboration], Phys. Lett. B **743**, 46 (2015). [INSPIRE-link](#), 22 citations.
I am one of the two primary authors in a team of 2 people.
- **A new algorithm for identifying the flavour of B_s^0 mesons at LHCb**
R. Aaij *et al.* [LHCb Collaboration], JINST **11**, P05010 (2016). [INSPIRE-link](#), 34 citations.
I am one of the three primary authors in a team of 8 people.
- **Measurement of B_s^0 and D_s^- meson lifetimes**
R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **119**, 101801 (2017). [INSPIRE-link](#), 14 citations.
I am one of the two primary authors in a team of 4 people.
- **Measurement of CP violation in $B^0 \rightarrow D^{\mp}\pi^{\pm}$ decays**
R. Aaij *et al.* [LHCb Collaboration], JHEP **06**, 084 (2018). [INSPIRE-link](#), 14 citations.
I am one of the two primary authors in a team of 4 people.
- **Measurement of the charm-mixing parameter y_{CP}**
R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **122**, 011802 (2019). [INSPIRE-link](#), 7 citations.
I am one of the two primary authors.
- **Measurement of $|V_{cb}|$ with $B_s^0 \rightarrow D_s^{(*)-}\mu^+\nu_\mu$ decays**
R. Aaij *et al.* [LHCb Collaboration], accepted by Phys. Rev. D, arXiv:2001.03225. [INSPIRE-link](#), 2 citations.
I am one of the two primary authors in a team of 4 people.

Le dichiarazioni rese nel presente curriculum sono da ritenersi rilasciate ai sensi degli artt. 46 e 47 del D.P.R. 445/2000

Trieste, March 15, 2020

