8 Particle Physics with LHCb

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The full LHCb collaboration consists of 74 institutes from Brazil, China, Colombia, France, Germany, Ireland, Italy, Poland, Romania, Russia, Spain, Switzerland, the Netherlands, Ukraine, the United Kingdom and the United States of America.

(LHCb Collaboration)

LHCb is a heavy flavour physics experiment at the Large Hadron Collider (LHC) [1] at CERN, optimised for precision tests of the Standard Model (SM) and for indirect searches for physics beyond the Standard Model (BSM) via precision measurements of *CP* violating phases and rare heavy-quark decays. The detector is designed as a forward dipole spectrometer and is fully instrumented in the pseudorapidity range $2 < \eta < 5$, including detectors for precise vertex and track reconstruction, electromagnetic and hadronic calorimeters and detectors for efficient particle identification. The forward acceptance and the ability to trigger on particles with relatively low transverse momentum allow to probe particle production in a unique kinematic range. Many physics analyses go beyond the initial heavy-flavour physics programme and have established LHCb in the wider particle physics community as a successful general-purpose detector in the forward region. These features will be further strengthened in the upgrade of the experiment, foreseen to be installed in the next long shutdown of the LHC in 2019/2020.

Our group is responsible for the operation and maintenance of silicon micro-strip detectors in the tracking system and we contribute to R&D for the upgrade of the tracking detector. Furthermore, our group makes significant contributions to measurements in a variety of rare *b*-hadron decays and to measurements sensitive to parton densities.

Members of our group hold various positions of responsibility inside the collaboration: Katharina Müller has been a member of the LHCb Speakers Bureau since 2016 and chairs this body since October 2017. Patrick Owen and Albert Puig Navarro are conveners of the semileptonic and rare decays physics analysis working groups, respectively, while Rafael Silva Coutinho has been appointed convener of the rare electroweak penguins sub-working group in January 2018. Barbara Storaci was project leader of the Silicon Tracker project until she left the field in January 2018. Carlos Abellan has been appointed deputy project leader of the Silicon Tracker project in January 2018. The work of our group members has also been rewarded with grants and prizes: Rafael Silva Coutinho was awarded an SNF ambizione grant; Elena Graverini won a UZH Forschungskredit to continue her research upon completion of her PhD thesis in our group in March 2018; Jonas Eschle won a UZH Semester prize for his Bachelor thesis that he completed in our group in summer 2017. Nicola Serra has been appointed successor of Ulrich Straumann upon the latter's retirement from his professorship at our institute in June 2018.

[1] LHCb Collab., JINST 3 S08005 (2008).

8.1 LHCb performance and plans

The LHCb experiment has collected high-quality data with an efficiency exceeding 90% since the startup of the LHC in 2010. During Run 1, which lasted from 2010 till 2012, the LHC collided protons with collision energies of 7 and 8 TeV and LHCb collected a data sample corresponding to an integrated luminosity of 3 fb^{-1}. Most analyses discussed in the following sections are based on this data sample. After a first long shutdown (LS1) in 2013/2014, the LHC resumed operation for Run 2 in 2015, now colliding protons at a collision energy of 13 TeV. For LHCb, the increase in collision energy means a twofold increase in the production cross section for *b* quarks. Combined with significant improvements in trigger and selection efficiencies for interesting events, this allows the experiment to collect interesting b decays at more than twice the rate compared to Run 1. LHCb has already collected data corresponding to an integrated luminosity of 3.7 fb^{-1} in Run 2 and we expect this number to grow to more than 5 fb^{-1} by the end of Run 2 at the end of 2018. Combined with the increased b production cross section and selection efficiency, this implies for most of the analyses discussed below a more than four-fold increase in the numbers of selected signal events compared to the published results.

The scientific output of the collaboration is prolific and well recognized in the community. More than 420 papers on physics analyses have been submitted to peer-reviewed scientific journals and have collected more than 20’000 citations. On average, about 300 oral presentations at international conferences have been assigned by the LHCb Speaker’s Bureau per year since 2013.

A comprehensive upgrade of the LHCb detector is planned to be installed during the second long shutdown (LS2) of the LHC in 2019/2020. The goal of this upgrade is two-fold: firstly, relevant detectors will be upgraded to finer granularity, to allow collecting data at a five times higher instantaneous luminosity; secondly, the first, hardware-based level of the current trigger system is going to be abolished to allow selecting interesting events with higher efficiency. Abolishing the hardware trigger requires to read out the full detector and operate a software trigger at the LHC bunch-crossing rate of 40 MHz.

The LHCb collaboration has submitted an expression of interest [2] for further upgrades of the detector in the subsequent long shutdowns of the LHC in 2024-2026 (LS3) and 2030 (LS4). Our group is getting involved in simulation studies and detector R&D for these upgrades.

[2] LHCb Collab., CERN-LHCC-2017-003.

8.1.1 TT detector performance

E. Graverini, A. Mauri, O. Steinkamp, B. Storaci

The Tracker Turicensis (TT) is a large surface silicon microstrip detector installed in front of the magnet of the LHCb spectrometer. The TT was developped and built by our group. It has continued to perform well also in 2017. At the end of the year, more than 99.5% of its 143’360 readout channels were fully operational. One out of the 1050 silicon sensors seems to have developed a bad bias-voltage contact inside the detector box. Simulation studies have shown that the effect on physics analyses is negligible. It has therefore been decided to not attempt a repair in order to avoid the risk associated with opening the detector. In view of the harsh radiation environment at the LHC, the monitoring of radiation damage in the silicon detectors remains an important task. Leakage currents in the detector are monitored continuously and regular charge-collection efficiency scans allow to determine the bias voltage at which the silicon sensors fully deplete. The analysis of these bias-voltage scans has been a topic of the PhD thesis of Elena Graverini. A paper describing the method and results is currently under collaboration-wide review. The results of our studies agree well with expectations from a detailed model calculation. Based on these results, we expect no degradation of the detector performance until its foreseen replacement during the LHCb upgrade in LS2.

8.2 LHCb upgrade

C. Abellan, Ch. Betancourt, Ia. Bezshyiko, O. Steinkamp

Despite its excellent performance, the current TT detector will have to be replaced as part of the LHCb upgrade in LS2, since its front-end readout electronics is not compatible with the upgraded readout scheme. The replacement for the TT, dubbed Upstream Tracker (UT), is being developed by a collaboration including our group as well as CERN and six institutions from Italy, Poland and the US [3]. One of the most critical items is the development of the front-end readout chip (SALT). Carlos Abellan has made major contributions towards tests on prototype chips and our group has taken the full responsibility for the development of test infrastructure for the quality assurance of the final chips. In particular, Iaroslava Bezshyiko is developing readout and analysis software for this project as part of her PhD thesis in our group. Exploiting his expertise in FPGA programming, Carlos Abellan has also taken the responsibility for the development of the UT specific firmware needed to process the detector data in the LHCb readout boards.

[3] LHCb Collab., CERN-LHCC-2014-001.

8.3 Physics results

The LHCb collaboration has published about 50 papers on physics analyses during the past year [4], covering a wide range of topics. A brief summary of a few selected highlights is given here, followed by slightly more detailed discussions of analyses with direct contributions from our group.

One of the LHCb results that echoed most in the particle physics community is the measurement of the ratio of branching fractions [5]

$$R(K^*) = \frac{\mathcal{B}(B^0 \to K^* \mu\mu)}{\mathcal{B}(B^0 \to K^* ee)}$$

in two regions of the squared dilepton invariant mass (q^2). In the SM, this quantity is expected to be very

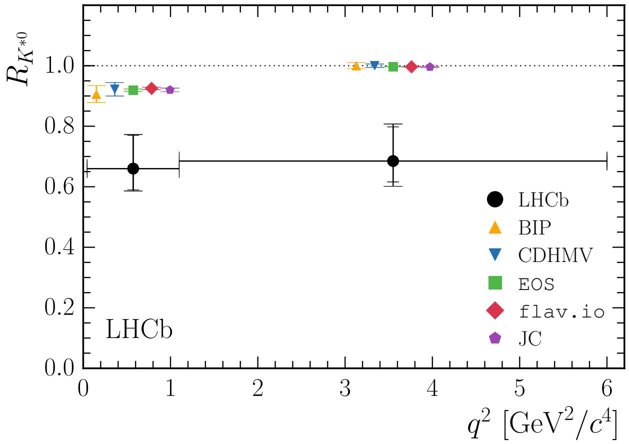

FIG. 8.1 – Comparison of the LHCb measurements of $R(K^*)$ with Standard-Model predictions: BIP [6] CDHMV [7], `EOS` [8], `flav.io` [9] and JC [10]. Data points for the predictions are displaced horizontally for clearer presentation.

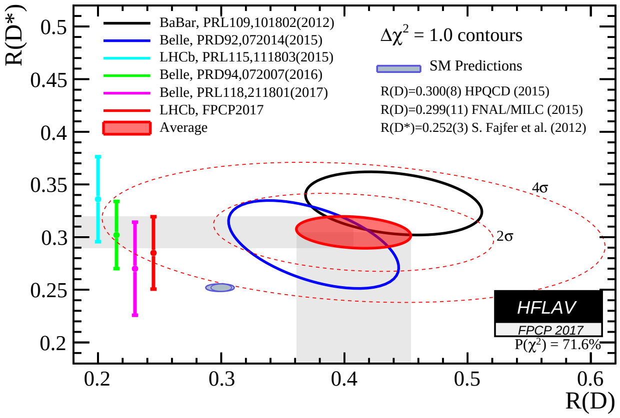

FIG. 8.2 – Measured values for $R(D^{(*)})$ and $R(D)$ by the BaBar, Belle and LHCb experiments. The Standard Model prediction is also shown.

close to unity, with only small deviations due to the mass difference between muons and electrons. The LHCb results are lower than predicted in the SM as is shown in Fig. 8.1. Intriguingly, the measured value (especially that in the region $1.1 < q^2 < 6.0$ GeV^2) is numerically coherent with a set of anomalous results by LHCb, consisting of the observables P_5' [11, 12] and the ratio of branching fractions $R(K^*) = \mathcal{B}(B^0 \to K^*\mu\mu)/\mathcal{B}(B^0 \to K^*ee)$ [5]. Our group is involved in a variety of measurements that are aimed at clarifying the origin of these anomalies, as discussed in Sec. 8.3.1.

The Lepton Flavour Universality (LFU) ratio $R(D^{(*)}) = \mathcal{B}(B \to D^{(*)}\tau\nu)/\mathcal{B}(B \to D^{(*)}\mu\nu)$ has been measured by LHCb [13] as well as by the experiments BaBar [14, 15] and Belle [16, 17]. The LHCb measurement used the decay $\tau \to \mu\nu_\tau\overline{\nu}_\mu$ to reconstruct the τ lepton. The results from all three experiments are higher than the value expected in the SM. Combined, the measurements deviate by about four standard deviations from SM predictions, as summarized in Fig. 8.2 (reproduced from Ref. [18]). Recently, LHCb has published a new measurement of $R(D^*)$ using the hadronic decay mode of the τ lepton, $\tau \to 3\pi\nu_\tau$. The result of this measurement is compatible with the SM as well as with previous measurements [19]. While its overall uncertainty is larger than those of the earlier measurements, it has different systematics. Future improvements of this measurement with larger statistics will provide an important consistency check.

In addition, LHCb has measured the LFU ratio $R(J/\psi) = \mathcal{B}(B_c \to J/\psi\tau\nu)/\mathcal{B}(B_c \to J/\psi\mu\nu)$ [20] for the first time. This measurement is still limited by statistics due to the small production rate of B_c mesons. However, it provides an important proof of principle, since in the future it will be important to measure LFU ratios in complementary channels. Our group is working towards a measurement in related decays with higher statistics, as described in Sec. 8.3.3.

LHCb has made many high-impact measurements that demonstrate it should be considered not only a dedicated B-physics experiment but rather a general purpose experiment covering the forward direction at the LHC. For instance, the collaboration reported the first observation of the doubly charmed baryon Ξ_{cc}^{++}, using the decay channel $\Lambda_c^+ K^- \pi^+ \pi^-$ [21]. Also, LHCb presented the first measurement of the effective lifetime of the decay $B_{(s)}^0 \to \mu^+\mu^-$ [22]. LHCb has also contributed to searches for Hidden Sector particles, for example setting limits on the existence of Dark Photons [23].

[4] http://lhcb.web.cern.ch/lhcb/

[5] LHCb Collab., Phys. Rev. Lett. **113** (2014), 151601.

[6] M. Bordone, G. Isidori and A. Pattori, Eur. Phys. J. C**76** (2016) 440.

[7] B. Capdevila, S. Descotes-Genon, L. Hofer and J. Matias, JHEP **04** (2017) 016.

[8] N. Serra, R. Silva Coutinho and D. van Dyk, Phys. Rev. D **95** (2017) 035029.

[9] D. Straub *et al.*, flav-io/flavio v0.19

[10] S. Jäger and J. Martin Camalich, Phys. Rev. D **93** (2016) 014028.

[11] LHCb Collab., Phys. Rev. Lett. **111** (2013) 191801.

[12] LHCb Collab., JHEP **02** (2016) 104.

[13] R. Aaij *et al.* [LHCb Collab.], Phys. Rev. Lett. 115 (2015) 111803, arXiv:1506.08614

[14] J. P. Lees *et al.* [BaBar Collab.], Phys. Rev. Lett. **109**, 101802 (2012).

[15] J. P. Lees *et al.* [BaBar Collab.], Phys.Rev.D **88**, 072012 (2013).

[16] M. Huschle *et al.* [Belle Collab.], Phys. Rev. D **92**, 072014 (2015).

[17] A. Abdesselam *et al.* [Belle Collab.], arXiv:1603.06711

[18] Heavy Flavour Averaging Group (HFLAV), https://hflav.web.cern.ch/

[19] R. Aaij *et al.* [LHCb Collaboration], arXiv:1708.08856.

[20] R. Aaij *et al.* [LHCb Collaboration], arXiv:1711.05623

[21] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **119** (2017) 112001.

[22] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **118** (2017) 191801.

[23] R. Aaij *et al.* [LHCb Collaboration], Phys. Rev. Lett. **120** (2018) 061801.

8.3.1 Study of $b \to s\ell^+\ell^-$ transitions

M. Atzeni, A. Mauri, E. Graverini, F. Lionetto, P. Owen, A. Puig Navarro, N. Serra, R. Silva Coutinho, Z. Wang

Recent studies of rare semileptonic decays of beauty mesons, mediated through virtual quantum loops, reported intriguing discrepancies with SM predictions, in particular in angular analyses of the $B \to K^{*0}\mu^+\mu^-$ decay [24] and ratios of branching fractions of $B^{(+,0)} \to K^{(+,*0)}\mu^+\mu^-$ and $B^{(+,0)} \to K^{(+,*0)}e^+e^-$ [25,26]. Whilst the individual significances of the present results are still inconclusive, these deviations seem to form a coherent pattern. Global fits to all these observables report deviations from SM predictions at the level of four standard deviations [27].

In order to achieve a further understanding on the nature of these anomalies, our group is involved in several key measurements testing LFU. The primary goal of our effort is to perform an angular analysis of the decay $B^0 \to K^{*0}e^+e^-$ and compare the results with those obtained in $B \to K^{*0}\mu^+\mu^-$.As a first step towards this goal, measurements of the difference of CP-averaged angular observables in the decay $B^0 \to K^{*0}e^+e^-$ have been performed in a simplified counting experiment using the data of $3\,\mathrm{fb}^{-1}$ collected in Run 1. The results are found to be comparable with those obtained in the decay $B^0 \to K^{*0}\mu^+\mu^-$ and compatible with SM predictions within their currently still significant statistical uncertainties. This analysis has been the main topic of the PhD thesis of Federica Lionetto. We also pursue for the first time a full simultaneous amplitude analysis of the muonic and electronic decay modes, which we find to have a compelling discovery potential, as discussed in Sec. 8.3.2. Finally, complementary measurements of ratios of branching fractions, *e.g.* $R_{K\pi} = \mathcal{B}(B^0 \to K\pi\mu^+\mu^-)/\mathcal{B}(B^0 \to K\pi e^+e^-)$ and $R_{K\pi\pi} = \mathcal{B}(B^+ \to K\pi\pi\mu^+\mu^-)/\mathcal{B}(B^+ \to K\pi\pi e^+e^-)$ are led by our group. For the electron modes these are also first observations of the respective decays.

[24] R. Aaij *et al.* [LHCb Collab.], JHEP **02** (2016) 104.

[25] R. Aaij *et al.* [LHCb Collab.], PRL **113** (2014), 151601.

[26] R. Aaij *et al.* [LHCb Collab.], JHEP **08** (2017) 055.

[27] B. Capdevila *et al*, **1801** (2018) 093.

8.3.2 Towards establishing New Physics in $B \to K^{*0}\ell^+\ell^-$ decays

A. Mauri, N. Serra, R. Silva Coutinho

Deviations from SM predictions in angular analyses of the decay mode $B \to K^*\mu^+\mu^-$, notably in the observable P_5', have been suggested as potential signatures of Physics Beyond the SM (BSM). However, non-perturbative QCD contributions, that are difficult to assess reliably from first principles, could either mimic or camouflage BSM effects. We investigate the prospects to disentangle these effects in an unbinned amplitude analysis of this decay mode, relying on state-of-the-art parametrisations of non-perturbative contributions [28]. A simultaneous analysis of theory predictions, measurements of semileptonic decays and measurements of the hadronic decays $B \to K^*J/\psi$ and $B \to K^*\psi(2S)$ is performed to control systematic uncertainties related to the model dependence on direct fits to the underlying Wilson Coefficients.

The deviations observed in angular observables, combined with measurements of R_K and R_{K^*}, hint towards a possible violation of LFU. We propose a novel approach to independently and complementary probe this hypothesis by performing a simultaneous amplitude analysis of the decay modes $B^0 \to K^{*0}\mu^+\mu^-$ and $B^0 \to K^{*0}e^+e^-$ [29]. This method enables the direct determination of observables that encode potential non-equal couplings of muons and electrons, and are found to be insensitive to non-perturbative QCD effects. If the current hints for deviations are indeed due to BSM effects, our approach could allow a discovery of these effects with the dataset collected in Run 2. Figure 8.3 illustrates the usefulness of the method by combining the information from angular analyses and branching ratio measurements.

[28] M. Chrzaszcz, A. Mauri, N. Serra, R. Silva Coutinho and D. van Dyk, arXiv:1805.06378.

[29] A. Mauri, N. Serra and R. Silva Coutinho, arXiv:1805.06401.

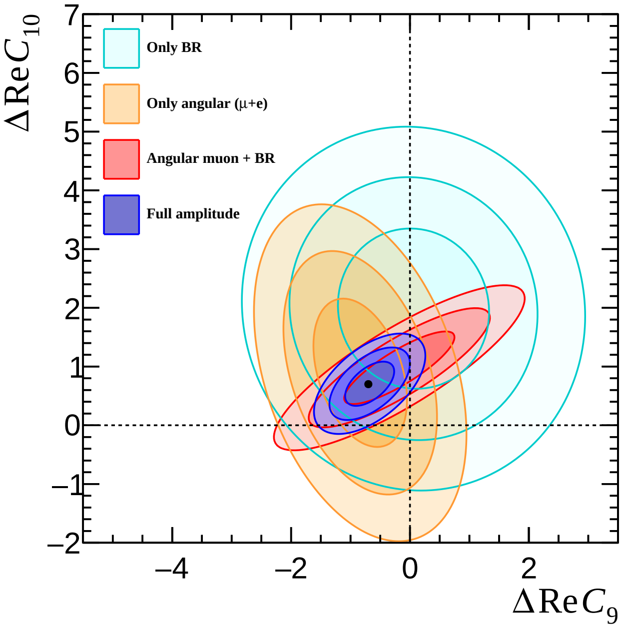

FIG. 8.3 – Projected sensitivity to BSM effects in the Wilson Coefficients $\mathcal{C}_9$ and $\mathcal{C}_{10}$ for the expected statistics after Run 2. The relative contributions (1, 2, 3σ contours) from each step of the analysis are shown in different colours, together with the result of the full amplitude method.

8.3.3 Semileptonic decays

Ia. Bezshyiko, A. Buonaura, E. Graverini, P. Owen, J. Pardiñas, N. Serra

The strongest evidence for a possible violation of LFU is currently seen in measurements of the branching fractions of semileptonic decays involving a τ lepton, in particular the measurement of the observables $R(D)$ [30, 31] and $R(D^*)$ [30–32]. The observed enhancement can be explained in many extensions to the SM, which preferentially couple to third generation leptons. Examples are models with an additional charged Higgs boson or a leptoquark.

Our group is involved in a measurement of $R(D^+) = \mathcal{B}(B \to D^+\tau\nu)/\mathcal{B}(B \to D^+\mu\nu)$, which has the potential to disentangle enhancements to the observables $R(D)$ and $R(D^*)$. An illustration of the sensitivity for $R(D^+)$ is shown in Fig. 8.4. We are also involved in preparations for a test of Lepton Universality in the ratio $R(\Lambda_c^*) = \mathcal{B}(\Lambda_b^0 \to \Lambda_c^*\tau\nu)/\mathcal{B}(\Lambda_b^0 \to \Lambda_c^*\mu\nu)$, which will be one of the main topics for the PhD thesis of Iaroslava Bezshyiko. The measurement of $R(\Lambda_c^*)$ provides complementary information to those of $R(D)$, $R(D^*)$ and $R(D^+)$, since it concerns the decay of a fermion, which behaves differently under the laws of angular momentum conservation. In preparation for this measurement, we have been involved in a phenomenological analysis of the decay, designed to control uncertainties related to QCD effects [34].

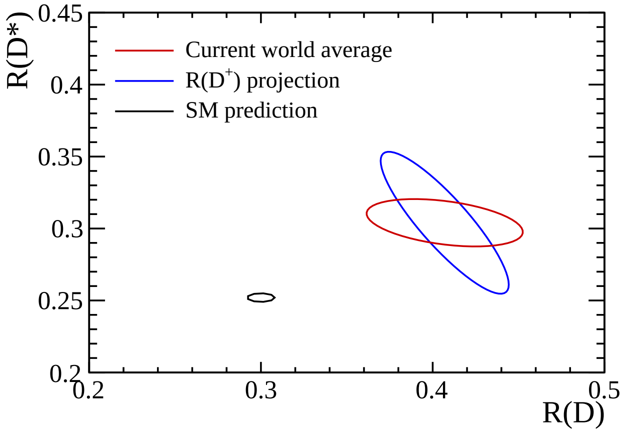

FIG. 8.4 – Projection for the observable $R(D^+)$ for Run 2 of LHCb, compared with the current world average [33] of the observable $R(D^{(*)})$. This measurement has the potential to break the correlation between $R(D)$ and $R(D^*)$.

[30] J. P. Lees *et al.* [BaBar Collab.],
Phys.Rev.D **88**, 072012 (2013).

[31] M. Huschle *et al.* [Belle Collab.],
Phys. Rev. D **92**, 072014 (2015).

[32] LHCb Collab., Phys. Rev. Lett. **115** (2015) 111803.

[33] HFAC Collaboration
http://www.slac/stanford.edu/xorg/hfag

[34] P. Böer *et al.*, arXiv:1801.08367

8.3.4 Charmless *b*-hadron decays

J. García Pardiñas, R. Silva Coutinho

Measurements of time-dependent *CP*-violating asymmetries in decays of B_s^0 mesons to two vector mesons, such as $\phi(1020)$ or $K^*(892)$, provide sensitive probes for as-yet undiscovered heavy particles that can enter in penguin quantum loops. Our group has been involved in the updated measurement of the *CP*-violating phase $\phi_s^{s\bar{s}s}$ and triple-product asymmetries in $B_s^0 \to \phi\phi$ decays using an integrated luminosity of 5.0 fb^{-1} [35]. The results are found to be consistent with the hypothesis of *CP* conservation. Moreover, an improved limit has been set on the branching fraction of the decay $B^0 \to \phi\phi$ [35].

The decay $B_s^0 \to K^{*0}(\to K^+\pi^-)\overline{K}^{*0}(\to K^-\pi^+)$ is another example of a transition dominated by gluonic penguins, in this occasion with a $b \to sd\bar{d}$ quark content. A key feature of this decay mode is the possibility to control the theoretical uncertainty on the associated phase $\phi_s^{d\bar{d}}$ via a U-spin analysis of the decay $B^0 \to K^{*0}\overline{K}^{*0}$.

The first measurement of $\phi_s^{d\bar{d}}$ has been recently performed using the Run 1 data set [36]. To increase the available statistics, not only the $K^{*0}(\overline{K}^{*0})$ resonance was inspected, but also several scalar, vector and tensor $K\pi$ components present in a two-dimensional $K\pi$ mass window from 750 to 1600 MeV/c^2. The *CP*-violating phase has found to be compatible with SM predictions within uncertainties. The longitudinal polarisation fraction of the $B_s^0 \to K^{*0}\overline{K}^{*0}$ decay has been found to be lower than predicted by the SM, confirming an earlier measurement [37].

Our group has also contributed to Dalitz-plot analyses of the decay mode $B^0 \to K_S^0\pi^+\pi^-$. The *CP* asymmetry between the conjugate $\bar{B}^0 \to K^*(892)^-\pi^+$ and $B^0 \to K^*(892)^+\pi^-$ decay rates is determined to be -0.308 ± 0.062, constituting the first observation of a non-vanishing *CP* asymmetry in this mode [38]. Furthermore, our group is leading the update of the search for *CP* violation in the decay $\Lambda_b^0 \to K_S^0 p\pi^-$. The asymmetry in this decay mode is expected to be large and its measurement has the potential to yield the first observation of *CP* violation in the b-hadron sector.

[35] LHCb Collab., LHCb-CONF-2018-001,
https://cds.cern.ch/record/2314360.

[36] LHCb Collab., J. High Energy Phys. **03** (2018) 140.

[37] LHCb Collab., Phys. Lett. B**709** (2012) 50.

[38] LHCb Collab., arXiv:1712.09320, to appear in PRL

8.3.5 Measurements sensitive to parton distributions

M. Chrząszcz, K. Müller, A. Weiden

Measurements of the production cross-section of electroweak bosons constitute an important test of the SM at LHC energies. Since predictions in perturbative quantum chromodynamics are known at the percent level, these measurements are sensitive to the momentum distribution of the partons in the proton. Inclusive measurements of electroweak boson production as well as measurements of electroweak boson production with jets have been performed by LHCb in the past years in various decay channels with significant contributions from our group [39–42]. Many of these measurements are now entering precision area aiming to reach systematic uncertainties below the %-level.

Andreas Weiden performs in his PhD thesis a measurement of low mass Drell-Yan production down to masses of 10 GeV^2. He developed new methods to control the backgrounds at low masses which are hardly distinguishable from signal. A different approach is taken in the Bachelor thesis of Thomas Neuer who uses machine learning techniques to distinguish signal from background. The two different approaches can in the end be used to study systematic effects.

[39] LHCb Collab., Phys. Lett B**776** (2017) 430.

[40] LHCb Collab., JHEP **09** (2016) 136.

[41] LHCb Collab., JHEP **05** (2016) 131.

[42] LHCb Collab., Phys. Lett. **B767** (2017) 110.

[43] LHCb Collab., JHEP **08** (2011) 034.

8.4 Outreach activities

K. Müller, A. Puig Navarro, O. Steinkamp

Besides our contributions to the LHCb detector and physics analyses, members of our group have also engaged in a variety of outreach activities. We participated with a stand at "Scientifica 2017", the Zurich Science days organised jointly by UZH and ETHZ. We carried out advanced training days in particle physics for high-school teachers and organised the International Masterclass in particle physics [44] for high-school students. O. Steinkamp and A. Puig Navarro contributed to the Outreach, education and diversity session at the 2017 edition of the EPS Conference on High Energy Physics [45, 46]. K. Müller has been appointed Swiss representative in the International Particle Physics Outreach Group (IPPOG).

[44] http://physicsmasterclasses.org/

[45] A. Puig Navarro *et al.* [LHCb Collab.],
PoS(EPS-HEP2017)565

[46] O. Steinkamp *et al.* [LHCb Collab.],
PoS(EPS-HEP2017)569

8.5 Summary and Outlook

The LHCb experiment has again performed very well throughout the 2017 LHC run, operating stably and collecting high-quality data with high efficency. The LHCb collaboration has continued to produce physics analyses of high quality, resulting in about 50 publications in peer-reviewed journals and more than 300 oral presentations at international conferences. Analyses of the data collected in Run 2 data are ongoing and significant improvements in the precision of many measurements are expected in the near future. The preparation of the LHCb upgrade for the long shutdown LS2 in 2019/2020 is underway and studies for further upgrades in LS3 and LS4 are starting.

Our group has continued to make important contributions to the operation of the experiment, to physics analyses and to the preparation for the upgrade.