LHCb/LNF 2018

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LHCb is a dedicated heavy flavour physics experiment at the Large Hadron Collider (LHC). The experiment is designed for precision measurements of CP violation and rare decays of beauty and charm hadrons. LHCb published more than 470 papers using mainly Run 1 (2010-2012) with an increasing contributions using also the full Run 1 + Run 2 dataset. During Long Shutdown 1 (LS1) in 2013-2014, the LHCb detector remained essentially unchanged, while major upgrades are foreseen for subsequent long shutdowns. During Run 2 (2015-2018), LHCb successfully afforded many operational challenges and collected $\sim$7 fb^{-1} that sum up to the $\sim$3 fb^{-1} collected in Run 1. LHCb collaboration has been approved for an upgrade of the experiment intended to collect $\sim$ 50 fb^{-1} starting in 2020, after the LS2 of the LHC. This very large sample should allow to determine several SM variables in the flavor sector to a precision comparable with the ultimate theoretical uncertainty.

LHCb Frascati group is deeply involved in all the ongoing activities from the operation of the detector (with important responsibilities on the hardware) to the data analysis, from the preparation of the upgrade to the R&D in view of possible future upgrades after LS3 and LS4 of the LHC.

1 Data analysis activity

Since tens of years, the $B_s^0 \to \mu^+\mu^-$ decay has been identified as a very interesting measurement that could show clear indications of NP and/or constrain the parameter space of models describing physics beyond the SM. After the publication in March 2017 LHCb of the new result for the search for the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ using data collected in pp collisions during the Run 1 + Run 2

(2015 and 2016 only), in late 2018 the LNF group restarted the data analysis to perform the measurement using the 10 fb^{-1} collected in the full Run 1 + Run 2. This measurement will improve the accuracy on $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ and $B_s^0 \to \mu^+\mu^-$ effective lifetime measurements, aiming also at the first observation of the $B^0 \to \mu^+\mu^-$ mode.

In the SM the couplings of the electroweak bosons to the leptons of different families are exactly the same. This property is called Lepton Flavour Universality (LFU) and it is experimentally well-established. However, tensions with respect to the SM predictions are observed in some b-hadron decay processes, of which the most recent updates come from the LHCb experiment. The observables involving b-hadron decays that show tensions with respect to the SM come from two different elementary processes: the tree-level b $\to$ c$\ell\nu$ and the FCNC b $\to$ s$\ell^+\ell^-$. LNF group is directly is both areas, namely through the study of the semileptonic decays of B_s^0 with a τ lepton in the final state, working in particular on the measurement of exclusive $R(D_s^\star)$ and inclusive $R(D_s)$ ratios, and through the study of the Λ_b^0 decays.

Among the B mesons, B_s are particularly interesting because allow to overcome one the most important background that affects the B semi-tauonic decays. This background, associated with the decays of orbitally and radially excited charm-meson states, is in fact much less relevant in B_s decays. Moreover, semileptonic B_s decays offer many interesting kinematic observables that can be exploited to constrain various plausible new physics scenarios. Frascati group is doing the measurement of the $R(D_s^\star)$ ratio and just completed the measurement of the $B \to D_s^\star\mu\nu$ form factors, ancillary to the relative RD ratio. Another important study led in Frascati is the evaluation of the long-distance electromagnetic contributions of the decay channels involved in the R(D^+) and (D^0) ratios. The impact on published and ongoing RD ratios has been studied and a paper is in preparation.

LFV from baryon decays is less explored than the analogous phenomenon from mesons. Being fermions, the baryons obey to different Lagrangian interaction terms and have a different (half-integer) spin, which generates decays with different angular structures. They therefore can provide complementary and independent information on new physics phenomena. Frascati group is involved in studying the FCNC processes b $\to$ s$\ell^+\ell^-$ using the Λ_b^0 decays. Two measurements are ongoing. The search for the $\Lambda_b^0 \to e^+e^-$ decay, whose BR is predicted to be $(4.6 \pm 1.6) \times 10^{-6}$ in the SM and that has not yet been observed so far; if observed it could led also to the measurement of the R(Λ_b) ratio increasing the LHCb sensitivity to LFU test processes. These can be explored also searching for the $\Lambda_b^0 \to e\mu$ decay. While being practically zero in the SM, its branching fraction would be significantly enhanced in alternative models in which the existence of new mediators contribute to the process. Results for both measurements are expected to be completed in 2019.

Finally, in April 2018 the measurement of the $D_s^\pm$ production asymmetry in pp collisions at $\sqrt{s} = 7$ and $\sqrt{s} = 8$ TeV by considering prompt $D_s^\pm \to K^+K^-\pi^\pm$ decays in the full Dalitz plane has been completed by a LNF member and published. Together with similar results, it constitutes a fundamental input for many CP related measurements ongoing at LHCb.

2 Operation and Upgrade activities

In addition to the work on the physics analyses, a considerable effort has been spent by the LNF team on the so-called operational aspects of the experiment. Frascati team played a central role in Data Taking, Detector Maintenance, Online, Computing and Particle Identification (PID). B. Sciascia, in her capacity of deputy Operation Coordinator, led almost all 2018 LHCb Operations. Still in 2018 M. Palutan led the LHCb Muon System Project.

A perfect design with large redundancy factors, and excellent construction quality allowed to run the detector at $\times 2$ with respect to the design luminosity for the whole Run 1 and Run 2, and to move forward for another decade of operation at $\times 10$ luminosity. Beyond securing the good running of the system during the last year of data taking (in 2018 about 25% of the "Muon expert on call" shifts were taken by Frascati people), a lot of effort has been put in the planning of the activities towards next Runs starting from Run 3 in 2021. To mitigate the high rates expected in the inner regions of the second station, M2, an additional shielding behind the HCAL has been designed and it will be built and installed during 2019. In the last years a good number of MWPC spares have been produced such as to guarantee efficient operation for the next 10 years. In Run 3 LHCb will profit of a full software trigger making the first muon station, M1, useless. M1 (MWPCs except of its inner region instrumented with GEM detectors) will be dismounted in March 2019 and Frascati team has been deeply involved in the preparatory work for the dismantling. Finally the apparatus of the new Muon system off-detector electronics (nODE) has been redesigned to be compliant with the 40 MHz readout of the detector, and the LNF electronic team (LNF-SEA) coordinated by P. Ciambrone, has the task of producing, testing and commissioning it. The first 4 nODE boards arrived in December 2018 and have been tested. In the first months of 2019 the 20 nODE of the preproduction will be assembled and tested, and finally the the 166 board full production will be launched requiring about 2 months for the full test. The new ODE board requires to review the architecture of the ECS completely: also this work is fully under the Frascati responsibility and is ongoing in close touch with the commissioning team at CERN. In parallel the same LNF-SEA team put in place the full acquisition chain (the so called "miniDAQ") needed for the final test of all the boards.

Another important contribution to the present performance of the Muon System has been the in deep review (lead by P. De Simone in her capacity of Muon Software group coordinator) of the software used to reconstruct the muon information and to make it available for the collaboration. This code, mostly produced at the beginning of the 2000's demonstrated to be highly performing, it is used also in the software trigger and needed a review mainly for increasingly stringent timing requests. A complete review has been done without modifying the final performance of the involved algorithms and paving the way for the changes needed for the upgrade. All the work will naturally feed in the RTA (Real Time Analysis) Project, a brand new LHCb project that will start beginning of 2019 to coordinate the full software trigger and online analysis of the experiment. The Muon software trigger lines for

the upgrade phase will have to guarantee an adequate signal to background ratio, while respecting, at the same time, the severe timing constrains required by the full software trigger adopted for the upgrade. To fulfill these ambitious challenges, many approaches are under study including the use of machine learning techniques, also thank to a PhD student in co-sharing with Yandex Data School and Sapienza University.

Finally, under the coordination of P. Di Nezza, the SMOG2 project (the upgrade of the internal fixed gas target) has been approved and will be installed during the LHC LS2. In a productive effort carried on by the proponents and several relevant LHC working groups, the R&D has been finalised and documented both in a Technical Proposal for the hardware part and in a publication about the physics opportunities. The system, consisting on a storage cell attached upstream of the VELO radio frequency (RF) boxes and an advanced Gas Feed System able to give precise determination of the luminosity, enters now in the construction phase. Fixed target collisions at LHCb will open new exciting fields of investigation allowing to study production of particles carrying a large momentum fraction of the target nucleon in the nucleon-nucleon center-of-mass frame, at an energy scale up to 115 GeV, paving the way to innovative and fundamental measurements, from QCD to astroparticle, in regions of the kinematic plane essentially unexplored .

3 Future LHCb upgrades

Further upgrades are proposed for the LHCb experiment in order to take full advantage of the flavour-physics opportunities at the HL-LHC, and other topics that can be studied with a forward spectrometer. These Upgrades, which will be installed starting from LS3 onwards, will build on the strengths of the current experiment and the Phase-I Upgrade, but will consist of re-designed sub-systems that can operate at a luminosity $2 \times 10^{34} cm^{-2} s^{-1}$ ten times that of the Phase-I Upgrade detector.

For what concerns the Muon System, an intense R&D is undergoing to develop and test new generation Micro-pattern-Gaseous-Detectors (MPGDs) which are suitable for rates as high as several MHz/cm^2. The micro-Rwell is a compact spark-protected single amplification stage MPGD. The detector amplification stage, realized with a micro-patterned polyimide structure with blind-hole matrix, is embedded, through a thin Diamond Like Carbon sputtered resistive layer, in the readout PCB. In 2018 the team, led by G. Bencivenni, worked to the design and the production of new high rate layout based on an improving of the Single Resistive layout with a thin conductive grid deposited on the resistive layer. Several prototypes $10{\times}10$ cm^2 have been realized with different current evacuation geometrical parameters, such as the pitch of the grid, and equipped with with $0.6{\times}0.8$ cm^2 pad readout as foreseen for the Upgrade of the LHCb Muon System. Systematic studies of the performance, in terms of efficiency, pad cluster size, rate capability, of several high rate resistive layouts of micro-Rwell detector have been performed at π-M1 Paul Scherrer Institute (Zurich).

4 Conclusions

The Frascati LHCb group is active in most of the areas of the experiment, ranging from data collection and analysis, to the development of solutions for beyond-Phase-I upgrades. The support of all the LNF services is fundamental to keep the high quality of results the group is obtaining. As usual, the scientific work has been complemented with some LHCb-specific outreach activity. In particular, the LHCb masterclass has been given to 42 high school students in March 2018, as part of the LNF MasterClass program, and to a couple of classes in February 2018, as part of the Alternanza Scuola Lavoro program.

5 List of Talks by LNF Authors in Year 2018

1. P. De Simone "Flavour results at LHCb", 56th International Winter Meeting on Nuclear Physics, 22 -26 January 2018, Bormio (ITALY)

2. P. Di Nezza "Internal gas target experiments at the LHC", Invited talk at SPIN2018 Ferrara (Italy), September 2018

3. P. Di Nezza "Spin physics at the LHC", Invited talk at the Probing Nucleons and Nuclei in High Energy Collisions - Seattle (US), October 2018

4. P. Di Nezza "Heavy ion and fixed target results at LHCb", MPI LHC, Perugia, Dic 2018

5. P. Di Nezza "SMOG2 or the SMOG upgrade", Tunnel Region Experiments, CERN, December 2018

6. S. Klaver "Hadron spectroscopy, exotic states and heavy flavour production at LHCb", Moriond QCD 2018.

7. S. Klaver "Overview of LHCbs semileptonic measurements", LHCb Implications Workshop, CERN 2018

8. G. Lanfranchi, inveted talk,"Flavour Overview", Workshop "BSM: where do we go from here?", Johns Hopkins Series Workshops, GGI,(Florence, Italy), October 2018.

9. M. Poli Lener "The micro-RWELL technology: status and perspectives", 56th International Winter Meeting on Nuclear Physics, 22 -26 January 2018, Bormio (ITALY)

10. M. Poli Lener "The micro-Resistive-WELL detector for the phase 2 upgrade of the LHCb muon detector", XXXIX International Conference on High Energy Physics, 4-11 July 2018, Seoul

11. M. Rotondo "Mini review on Vub and Vcb LHCb and B-Factories", XXIV Cracow Epiphany Conference, Cracow 2018

12. M. Rotondo "Lecture on semileptonic decays" given within The GDR-Intensity lectures program, at Institute Henri Poincar 2-3/07/2018

13. M. Rotondo "Semileptonic $\Lambda_b \to \Lambda_c(*)$ decays at LHCb" CKM18 Heidelberg

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2. G. Bencivenni et al."The μ-Rwell technology: status and perspectives", PoS(BORMIO2018)123

3. G. Bencivenni et al., "The micro-Resistive-WELL detector for the phase 2 upgrade of the LHCb muon detector", PoS(ICHEP2018)536

4. P. Boer, M. Bordone, E. Graverini, P. Owen, M. Rotondo and D. Van Dyk, "Testing lepton flavour universality in semileptonic $\Lambda_b \to \Lambda_c^*$ decays", JHEP 1806 (2018) 155, arXiv:1801.08367

5. S. Calì, M. Rotondo, and B. Sciascia "SL_Decay: a new C++ class that implements the semileptonic B decay differential width", LHCb-INT-2018-015

6. S. Calì et al. "Measurement of the shape of the $B_s^0 \to D_s^{\star+}\mu^-\nu_\mu$ differential distribution", LHCb-ANA-2018-045 (in preparation)

7. M. Calvi, D. Fazzini, and M. Rotondo, "Studies on the SSLambda tagger", LHCb-INT-2018-031

8. J. Cerasoli, "Study of the $\Lambda_b^0 \to \Lambda^0 e^+ e^-$ decay at the LHCb experiment", http://www.infn.it/thesis/thesis_dettaglio.php?tid=12793

9. J. Cerasoli, M. Santimaria, B. Sciascia et al. "Search for and test of lepton universality with the decay $\Lambda_b^0 \to \Lambda^0 e^+ e^-$", LHCb-ANA-2018-012 (in preparation)

10. P. Ciambrone, M. Palutan et al. "Pad chambers for the consolidation of muon detector", LHCb-INT-2018-009

11. P. Di Nezza et al. "Physics opportunities with the fixed-target program of the LHCb experiment using an unpolarized gas target", LHCb-PUB-2018-015

12. P. Di Nezza et al. "SMOG2 Technical Proposal", CERN-PBC-Notes-2018-007

13. P. Di Nezza et al. "The LHCSpin Project", CERN-ESPP-Note-2018-111

14. P. Di Nezza et al. "Design Considerations of a Polarized Gas Target for the LHC", https://pos.sissa.it/ (in print).

15. P. Di Nezza et al. "Internal gas target experiments at the LHC", https://pos.sissa.it/ (in print).

16. P. Di Nezza et al.- "Future physics opportunities for high-density QCD at the LHC with heavy-ion and proton beams", arXiv:arXiv:1812.06772

17. S. Klaver, M. Rotondo, and B. Sciascia, "Consideration about QED radiative corrections for R(D) ratios", LHCb-INT-2018-017

18. S. Klaver, M. Rotondo, and B. Sciascia, "Considerations about QED radiative corrections for R(D) ratios", LHCb-INT-2018-017.

19. G. Lanfranchi "Rare b-hadron decays as probe of new physics", published in Int.J.Mod.Phys. A33 (2018) no.14, 1830012

20. A. Lupato, G. Simi, and M. Rotondo, "Measurement of the ratio $\mathcal{B}(\Lambda_b^0 \to \Lambda_c^{*+}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\Lambda_b^0 \to \Lambda_c^{*+}\mu^-\bar{\nu}_\mu)$ using 2012 LHCb data", LHCb-ANA-2018-026

21. M. Rotondo et al (HFLAV Collaboration) "HFLAV input to the update of the European strategy for Particle Physics", arXiv:1812.0746

22. M. Santimaria, "Search for the $B_d^0 \to \mu^+\mu$ decay and measurement of the $B_s^0 \to \mu^+\mu$ branching fraction and effective lifetime", http://www.infn.it/thesis/thesis_dettaglio.php?tid=12639

23. M. Santimaria et al. "Search for the Lepton Flavour Violating decay $\Lambda_b^0 \to \Lambda^0 e^\pm \mu^\mp$", LHCb-ANA-2018-013 (in preparation)