LHCb/LNF 2016

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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 360 papers using mainly Run 1 (2010-2012) data. During Long Shutdown 1 (2013-2014) the LHCb detector remained essentially unchanged, while major upgrades are foreseen for subsequent long shutdowns. In the ongoing Run 2 (2015-2018) LHCb successfully afforded many operational challenges and already collected ~ 2 fb^{-1} (end of 2016) that sum up to the ~ 3 fb^{-1} collected in Run 1. LHCb Frascati group is deeply involved in all the ongoing activities from data analysis to the R&D for the upgrade.

1 Research activity

In March 2017 LHCb published 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 whole Run 1 + Run 2. An excess of $B_s^0 \to \mu^+\mu^-$ events is observed with a significance of 7.8 standard deviations, representing the first observation of this decay in a single experiment. The branching fraction is $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (30 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$, where the first uncertainty is statistical and the second systematic. The first measurement of the $B_s^0 \to \mu^+\mu^-$ effective lifetime, $\tau(B_s^0 \to \mu^+\mu^-) = (2.04 \pm 0.44 \pm 0.05)$ ps, is measured in the same data set. No significant excess of $B^0 \to \mu^+\mu^-$ events is found and a 95% confidence level upper limit $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.4 \times 10^{-10}$ is determined. All results are in agreement with the Standard Model expectations. The LNF team contributed substantially also to this new achievement, participating in all the aspects of the measurement.

Besides the activity on rare dimuon decays, the LNF people is involved in the study of the semileptonic decays of B_s^0 with a τ lepton in the final state. This is particular important since significant departures from the SM predictions have been recently measured in the ratio of B^0 semileptonic decays to τ and μ leptons, respectively. Lepton universality, enshrined within the standard model, requires equality of couplings between the gauge bosons and the three families of leptons. Hints of lepton nonuniversal effects in $B^+ \to K^+e^+e^-$ and $B^+ \to K^+\mu^+\mu^-$ decays have been seen, but no definitive observation of a deviation has yet been made. However, a large class of models that extend the SM contain additional interactions involving enhanced couplings to the third generation that would violate this principle. Semileptonic decays of b-hadrons to third generation leptons provide a sensitive probe for such effects. In particular, the presence of additional charged Higgs bosons, which are often required in these models, can have a significant effect on the rate of the semitauonic decay. Semitauonic B meson decays have been observed by the Babar, Belle, and LHCb collaborations The LHCb result is the first measurement of any decay of a b-hadron into a final state with τ leptons at a hadron collider, and the techniques demonstrated in this result open the possibility to study a broad range of similar b-hadron decay modes with multiple missing particles in hadron collisions in the future. In particular the LNF group is working on the measurement of exclusive $R(D_s^\star)$ and inclusive $R(D_s)$ ratios.

Finally S. Ogilvy is leading the measurement of of the $\Lambda_c^+ \to ph'h$ branching fractions. The hadronic decay $\Lambda_c^+ \to pK^-\pi^+$ is the reference mode for the measurements of branching fractions of the Λ_c^+ baryon to any other final state and its branching ratio has been measured by Belle for the first time in a model independent way. LHCb aims at completing the picture started by Belle, measuring the branching ratio for the full suite of $\Lambda_c^+ \to ph'h$ decays.

2 Operation activities

In addition to a direct involvement in 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 the Computing and in the Particle Identification (PID).

R. Vazquez Gomez is the coordinator of the last step of the LHCb Computing model, the process that organises the reconstructed events in sub-groups based on selections provided by the physics working groups. Only the events passing one or more of these selections are made available for further analysis.

For the PID the work in LHCb has been coordinated by B. Sciascia in the last three years. During LS1 the selection of PID calibration samples has been completely revisited bringing to new concepts. Upgrades to the LHCb computing infrastructure in the first long shutdown of the LHC have allowed for high quality decay information to be calculated by the software trigger making a separate offline event reconstruction unnecessary. A new dedicated stream of data was defined where the information evaluated in the trigger is stored together with the full raw event, which is then reconstructed and processed offline. A dedicated algorithm allows to match trigger and offline candidates and to produce datasets to be used as input for the package that allows analysts to access the calibration samples. The new stream created for the PID, due to the simultaneous presence of the online and offline versions of each event, allowed also to test the functionality of the package which manage the recover of the reconstruction information calculated in the trigger. Finally, Frascati group collaborated to the complete rewriting of the PIDCalib package, a tool widely used within the LHCb Collaboration, which provides access to the calibration samples of electrons, muons, pions, kaons and protons.

3 Preparation for the LHCb upgrade

Even though the physics harvest is now in full flow, and will continue certainly during the ongoing LHC Run 2, the LHCb collaboration has been already approved for an upgrade of the experiment, intended to collect ~ 50 fb^{-1} starting in 2020, after the long shutdown 2 of 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. Frascati group is deeply involved in several activities to prepare the muon detector for the upgrade. This activity has a point of strength also in the nomination, at the end of 2016 and for 2 years, of M. Palutan as Muon Project Leader with the mandate of coordinate both the Run 2 and the upgrade activities.

The LNF electronic team (LNF-SEA), coordinated by P. Ciambrone, has the task of constructing the new readout board for the muon detector (nODE), which will operate at 40 MHz rate. The LNF team worked to the construction of the first prototype equipped with the final version of the chip (nSYNC) that will be ready in the first months of 2017. The new ODE requires to completely review the related ECS (Experiment Control System) architecture; the needed work started at the end of 2016. In parallel the team started the development of the complete acquisition chain (the so called "miniDAQ") that should be in place mid of 2017

Moreover, the LNF team is in charge of the production of 30 MWPC of large dimensions (the ones used in the fifth station of the muon system) to use as spares for the muon detector in the next LHCb runs. Accepting this challenge was possible thanks to the support of LNF infrastructure, and to the local highly qualified expertise in this field. The construction consists of three distinct steps: the preparation of the panels equipped with PCB, fully completed, the chamber wiring and assembling, also completed, and the chamber test on a Cs-137 source has to be finalized in the next months. The latter phase is done in a new facility prepared at the laboratory for testing detectors with radioactive sources, and which we have equipped with the specific tools needed to operate such test. LNF team is in charge also of the production of few GEM chambers needed as spares for inner part of the first muon station for the ongoing Run 2. The assembly of these chambers in almost completed.

For the upgrade phase, one of the main challenges in operating the muon detector will be reaching the present high efficiency in identifying the muons, while maintaining the misidentification rate of hadrons at an acceptable level. If we cannot guarantee the above conditions, the increase in luminosity will not translate into an increase of sensitivity for many golden physics channels with muons in the final state. This is particular true since in the upgrade conditions the detector hardware efficiency will be limited by the intense flux of particles especially in the innermost regions close to the beam pipe, which also tends to affect the hadron misidentification. Detailed studies on the muon identification performance have been carried out in the last couple of years by the LNF team (with M. Palutan until the end of 2016 and now P. De Simone being the coordinators of LHCb muon identification working group), which consisted in integrating more information available from the detector in the muon identification algorithms. Preliminary versions of these algorithms will be used in the ongoing Run 2 data taking, allowing for testing the performance in the trigger environment.

A further upgrade, called Phase-II Upgrade, is 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. This Upgrade, which will be installed in Long Shutdown 4 of the LHC (2030), 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, test beam studies have been done of μ-Rwell detectors by LNF team in the framework of INFN R&D on new detector technologies. The preliminary results are very promising, showing a rate capability, as measured with X-rays, up to several MHz/cm^2 with very limited gain loss, and a time resolution around 5 ns. During 2016 prototypes have been designed and constructed suitable for operating in the very high-rate of the inner region of the second station of the muon system during the Phase-II era. In parallel, a customized frontend electronics, based on the VFAT3 front-end ASIC designed for the CMS GEM detectors, has been developed and used in test beams done with the new prototypes. It is feasible that new chambers could be installed already during LS3. Simulation studies have begun to understand the benefits in physics performance from the improved chambers, and the effect of having the shielding installed already for $2 \times 10^{33} cm^{-2} s^{-1}$ operation in Run 4.

4 List of Talks by LNF Authors in Year 2016

1. P. Campana, "Flavor Physics perspectives with the LHCb upgrade", Vulcano Workshop 2016, Sicily, Italy, 22 - 28 May 2016.

2. M. Rotondo "Mini-review on $|V_{ub}|$ & $|V_{cb}|$ at LHCb: status and prospects ", 9th International Workshop on the CKM Unitarity Triangle, Mumbai, India, 28 Nov - 2 Dec 2016

3. M. Rotondo "Exotic Spectroscopy at LHCb", Heavy Quark and Leptons 2016, Virginia, United States Of America, 22 - 27 May 2016

4. M. Rotondo "Experimental Tests of Lepton Flavor Universality (with B meson decays)", 11th Franco-Italian Meeting on B Physics, Paris, France, 11 - 13 Apr 2016

5. B. Sciascia “Prompt physics analysis from the trigger candidates at LHCb: strategy and new dedicated” 38th International Conference on High Energy Physics, Chicago, IL, USA, 03 - 10 Aug 2016

6. B. Sciascia “The early career, gender, and diversity actions within the LHCb Collaboration” 38th International Conference on High Energy Physics, Chicago, IL, USA, 03 - 10 Aug 2016

7. B. Sciascia “LHCb Run 2 trigger performance” The 16th International Conference on B-Physics at Frontier Machines, Marseille, France, 2 - 6 May 2016

8. B. Sciascia “Flavour physics in the precision era: the operational strategy at LHCb” Invited seminar at Bristol University, 27 April 2016

9. R. Vazquez Gomez “Overview of LHCb Results” 19th International Seminar on High Energy Physics, Pushkin, Russia, 29 May - 4 Jun 2016

References

1. The CMS and LHCb Collaborations, “Observation of the rare $B_s^0 \to \mu^+\mu^-$ decay from the combined analysis of CMS and LHCb data”, Nature 522 (2015) 68.

2. LHCb Collaboration, “Measurement of the $B_s^0 \to \mu^+\mu^-$ branching fraction and effective lifetime and search for $B^0 \to \mu^+\mu^-$ decays”, LHCb-PAPER-2017-001 [arXiv:1703.05747] (submitted to PRL)

3. R. Aaij et al., “Tesla: an application for real-time data analysis in High Energy Physics”, Comput. Phys. Commun. **208**, 35 (2016) [arXiv:1604.05596 [physics.ins-det]]

4. O. Lupton et al., “Calibration samples for particle identification at LHCb in Run 2”, LHCb-PUB-2016-005.

5. L. Anderlini et al., “The PIDCalib package”, LHCb-PUB-2016-021.

6. L. Anderlini et al., “Computing strategy for PID calibration samples for LHCb Run 2”, LHCb-PUB-2016-020.

7. F. Archilli et al.,“Search for the $\mathrm{B}^0 \to \mu^+\mu^-$ decay and measurement of the $\mathrm{B}_s \to \mu^+\mu^-$ branching fraction and effective lifetime”, LHCb-ANA-2016-038

8. S. Ogilvy et al, “$\Lambda_c^+ \to phh'$ branching ratios”, LHCb-ANA-2016-058

9. J. Albrecht et al., “Optimization of the Muon Identification software for LHCb Run 2”, LHCb-INT-2017-003

10. A. Cardini et al., “New muon identification algorithms”, LHCb-INT-2016-006 (in preparation).

11. L/ Anderlini et al., “Working group production for calibration samples”, LHCb-INT-2016-029 (in preparation).

12. LHCb Collaboration, “Measurement of the ratio of branching fractions $\mathcal{B}(\bar{B}^0 \to D^{\star +}\tau^-\bar{\nu}_\tau)/\mathcal{B}(\bar{B}^0 \to D^{\star +}\mu^-\bar{\nu}_\mu))$”, Phys. Rev. Lett. 115 (2015) 159901, Phys. Rev. Lett. 115 (2015) 111803

13. T. Blake, G. Lanfranchi, D. M. Straub, “Rare B decays as test of the standard Model”, Progress in Particle and Nuclear Physics, 92 (2017) 51 - 91.

14. LHCb Collaboration, “Expression of Interest for a Phase-II LHCb Upgrade: Opportunities in flavour physics, and beyond, in the HL-LHC era”, CERN-LHCC-2017-003