LHCb/LNF 2017

P. Albicocco (AdR), P. Anelli (Ass.), G. Bencivenni,
P. Campana , P. Ciambrone, P. De Simone, P. Di Nezza,
G. Felici, S. Klaver (Bors. PostDoc), G. Lanfranchi,
G. Morello (Art. 23), S. Ogilvy (Bors. PostDoc), M. Palutan,
E. Paoletti (Tec.), L. Pasquali (Tec.), M. Poli Lener (Art. 23),
M. Rotondo, M. Santimaria (Dott.), A. Saputi (Tec.),
A. Sarti (Ass.), F. Sborzacchi (Tec.), B. Sciascia (Resp.),
R. Vazquez Gomez (AdR), A. Zossi (Tec.)

In collaboration with "LNF-SEA"
A. Balla, M. Carletti, G. Corradi, M. Gatta

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 410 papers using mainly Run 1 (2010-2012) with some contributions also from the Run 2 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 ~ 3.7 fb^{-1} (end of 2017) 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 upgrades, having also important responsibilities on the hardware.

1 Data analysis activity

In March 2017 LHCb published the new result for the search for the rare decays $B^0_s \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ using data collected in pp collisions during the whole Run 1 + Run 2 (2015 and 2016 only). An excess of $B^0_s \to \mu^+\mu^-$ 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 $\mathcal{B}(B^0_s \to \mu^+\mu^-) = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$, where the first uncertainty is statistical and the second systematic. The first measurement of the $B^0_s \to \mu^+\mu^-$ effective lifetime, $\tau(B^0_s \to \mu^+\mu^-) = (2.04 \pm 0.44 \pm 0.05)$ 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^0_s with a τ lepton in the final state. In fact, measurements performed at B-Factories and LHCb show a hint of violation of Lepton Flavor Universality (LFU) from the comparison of the $B \to D^\star \tau \nu_\tau$ (semi-tauonic) and $B \to D^\star \mu \nu_\mu$ decay widths. Hints of LFU violation effects have been seen also studying $B \to K e^+ e^-$ and $B \to K \mu^+ \mu^-$ decays, but also in these case no definitive observation of a deviation from SM prediction has yet been made. If these hints would be confirmed by other measurements it will clearly be a sign of physics beyond the SM. It is then important to study semi-tauonic decays in other b-hadron species both to check the presence of large LFU violation in alternative environments, and to explore different kinematic variables aiming to pin down the kind of new physics that explains the observed anomalies in the LFU. Frascati group is deeply involved in the study of semileptonic decays of B_s mesons, working in particular on the measurement of exclusive $R(D_s^\star)$ and inclusive $R(D_s)$ ratios.

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.

During 2017, members of Frascati group worked also in two other measurements. The first is the measurement of the branching ratio of the full suite of $\Lambda_c^+ \to p h' h$ decays ($h'h = K^-\pi^+, K^-K^+, \pi^-\pi^+, \pi^-K^+$). The hadronic decay $\Lambda_c^+ \to p K^- \pi^+$ 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. The measurements published by LHCb last autumn, using 2011 data, complete the picture started by Belle result. The second measurement is 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. The result will be published by the 2018 winter conferences and, together with similar results, constitutes a fundamental input for many CP related measurements ongoing at LHCb.

Finally, thanks to the important contribution of a INFN-DOE summer student, we improved the performance of flavor tagging of the B_s meson by the detection of Λ baryons created in same-side $b\bar{b}$ fragmentation through correlations between the flavor of the Λ to that of the B_s.

2 Operation 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).

Until June 2017, R. Vazquez Gomez coordinated the *Stripping*, the last step of the LHCb Computing model, which is 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.

Until March 2017 the work on Particle Identification in LHCb has been coordinated by B. Sciascia. Since 2015, with the restart of the LHC for its second run of data taking, LHCb has been empowered with a dedicated computing model to select and analyse special data samples to measure the performance of the particle identification and tracking detectors and algorithms. The novel technique was developed within the framework of the innovative trigger model of the LHCb experiment, which relies on online event reconstruction for most of the datasets, reserving offline reconstruction to special physics cases. The selected calibration samples allow a more complete study of the systematic uncertainties due to imperfections in the simulation of the detector response and to develop reconstruction algorithms in preparation for the upcoming LHCb upgrade.

Starting from January 2017, M. Palutan is the Project Leader of the Muon System of the experiment. Beyond securing the good running of the system during the current data taking (about 40% of the “Muon expert on call” shifts are taken by Frascati people), some planning of the activities towards next Run 3 and Run 4 started. To guarantee the best performance until the end of Run 2, Frascati built and tested 6 Triple GEM chambers for the most irradiated part of the Muon detector. Three of the new chambers have been just installed in the detector to replace chambers damaged during 2017 data taking. Another important contribution to the present performance of the Muon System has been the 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, is used also in the software trigger and since it demonstrated to be highly performing, 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. Finally, Run 3 and 4 will be about eight years of data taking, after Long Shutdown 2 (LS2) upgrade, during which the same MWPCs will be used for the Muon detector, but operated at five times higher luminosity. For this, a major effort has been put to setup a test facility at CERN where spare chambers, from both past and recent productions, can be easily verified for what concerns high voltage, front-end electronics, and gas tightness. Specifically for Frascati, the 30 large dimensions MWPCs produced between 2016 and 2017 thanks to the support of LNF infrastructure and to the local highly qualified experts, have been transferred in the CERN test area, dressed with electronics, and tested. Two of them have been already successfully installed in LHCb in December. The luminosity foreseen for Run 3 will produce a too high flux of particles in the the first station of the Muon System, M1. The planning of the dismounting of M1 (MW PCs except of its inner region instrumented with GEM detectors) is ongoing under direct Frascati responsibility, including the use of the Muon station shield as neutron shield and its possible interactions with the SciFi, the Scintillating Fiber Tracker, one of the new detectors for the Phase-I upgrade.

3 Preparation for the LHCb upgrades

The physics harvest is now in full flow: at the end of 2017 the total integrated luminosity in Run 1 and Run 2 by LHCb is 7 FBI^{-1} and should reach 9 fb^{-1} by the end of 2018 data taking. In parallel LHCb collaboration has been approved for an upgrade of the experiment intended to collect ~ 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. Frascati group is deeply involved in several activities related to this upgrade and also in view of possible future upgrades after LS3 and LS4 of the LHC.

The LNF electronic team (LNF-SEA) coordinated by P. Ciambrone, has the task of producing, testing and commissioning the apparatus of the new Muon system off-detector electronics (nODE) which has been redesigned to be compliant with the 40 MHz readout of the detector. The first prototype equipped with the final version of the chip (nSYNC) has been fully tested and characterised in 2017, including the Trigger Fast Control (TFC) and Experiment Control System (ECS) interfaces, with a bit error rate $< 10^{-13}$ 99% CL. Test results have been presented and fully approved during the Production Readiness Review. Frascati is now ready for the production of 180 nODEs (156 on detector + spares): 20 boards will be pre-produced in spring 2018 and the full production will follow after a test phase. 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 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.

In parallel to the work on the FEE, a considerable effort is ongoing under the coordination of LNF team, to prepare the Muon software trigger lines for the upgrade phase. These lines 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 fulfil these ambitious challenges, many approaches are under study including the use of machine learning techniques.

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, an intense R&D is undergoing to develop and test new generation MPGDs detectors which are suitable for rates as high as several $\mathrm{MHz/cm}^2$. In particular, the Frascati team lead by G. Bencivenni is the driving force in the development of micro-Rwell detectors, a single-amplification stage resistive MPGD with integrated electronics. This technology inherits from the GEMs the amplification channels, obtained by etching a kapton clad with copper on one side, and from the MicroMegas the presence of a resistive layer quenching the discharges amplitude. Many layouts have been developed and studied in the last year also having in mind the possibility of an easier industrialization of the high-rate operated detectors.

Finally, P. Di Nezza coordinates the group which is responsible for the development of the new internal gas fix target (SMOG2) that can strongly impact on the fixed target physics program ongoing at LHCb. The system consists on a split storage cell attached upstream of the VELO radio frequency (RF) boxes and which would move together with the same RF boxes. Such a scheme should increase the useful target density up to two orders of magnitude for the same gas flow to the LHC. SMOG2 is foreseen to be implemented in LS2. A detailed engineering design and physics simulations have been performed for the approval of the project. This system is also meant as R&D for a potential polarised gas target to be installed during LS3 in the region immediately upstream of the VELO vacuum tank. The storage cell could contain polarised hydrogen or deuterium, and also other unpolarised gases. The physics programme with polarised gas would open new frontiers in the LHC physics.

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. Finally in the last year, the scientific work has been complemented with some LHCb-specific outreach activity. The LHCb masterclass has been given to both high school students (March 2017) and as training course for high school physics teachers (October 2017). A couple of small-size special MWPCs have produced to be exposed in the LNF visitor center and to be used for hands-on session with students and teachers.

5 List of Talks by LNF Authors in Year 2017

1. G. Bencivenni "The micro-Rwell detector", Instrumentation for Colliding Beam Physics (INSTR 17), Novosibirsk (Russia),
2. G. Bencivenni "Proposal for a high-rate micro-Rwell detector", 2nd LHCb workshop on Phase-II upgrade, Elba (Italy) 2017
3. P. Di Nezza "A proposal for an polarised gaseous target LHC", Physics Beyond Colliders, CERN Nov 2017
4. P. Di Nezza "Nuclear Physics at the Electron-Ion Colliders", Secondo incontro sulla fisica con ioni pesanti a LHC, Torino (Italy) 2017
5. P. Di Nezza "Nuclear Dynamics probed in Electron-Ion scattering at TeV energies" European Physical Society, Venice (Italy) 2017

6. P. Di Nezza "W and Z production at the LHC" Transversity, Frascati (Italy) 2017
7. G Morello "Advances on micro-Rwell gaseous detector", 55th International Winter Meeting on Nuclear Physics, Bormio (Italy)
8. M. Poli Lener "The micro-Rwell detector", 5th International Conference on Micro-Pattern Gas Detectors (MPGD2017), Temple University, Philadelphia, USA,
9. S. Ogilvy "Heavy flavour production and spectroscopy at LHCb", The 2nd Flavour Physics Conference, Quy Nhon, Vietnam
10. M. Rotondo "Review on present experimental results on $B \to D^{(*,**)}\ell\nu$", Second LHCb open semitauonic workshop, Orsay, France
11. M. Rotondo "Puzzles in SL decays" Second LHCb open semitauonic workshop, Orsay, France
12. M. Santimaria "Very rare B decays at LHCb", Lake Louise Winter Institute, Edmonton, Canada

References

1. G. Bencivenni et al."The μ-Rwell detector", 2017_JINST_12_C06027.
2. G. Morello et al., "Advances on micro-Rwell gaseous detector", PoS(BORMIO2017)002
3. M. Poli Lener et al., "The micro-Rwell detector", submitted to PoS.
4. M. Palutan and H. S. Kuindersma "Considerations on muon detector granularity at upgrade", LHCb-INT-2017-019,
5. M. Anelli et al. "Status of spare chambers for the LHCb MUON detector", LHCb-INT-2017-028
6. R. Lenci et al. "Quality of the spare triple-GEM detectors", LHCb-PUB-2017-021
7. L. Anderlini et al., "Working group production for calibration samples", LHCb-INT-2016-029
8. R. Aaij et al., "Optimization of the Muon Identification software for LHCb Run 2", LHCb-PUB-2017-007

9. 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

10. T. Blake, G. Lanfranchi and D. M. Straub, "Rare B Decays as Tests of the Standard Model," Prog. Part. Nucl. Phys. **92**, 50 (2017) doi:10.1016/j.ppnp.2016.10.001 [arXiv:1606.00916 [hep-ph]].

11. 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", Phys. Rev. Lett. 118 (2017) 19, LHCb-PAPER-2017-001 (arXiv:1703.05747)

12. LHCb Collaboration Measurements of the branching fractions of $\Lambda_c^+ \to p\pi^-\pi^+$, $\Lambda_c^+ \to pK^-K^+$, and $\Lambda_c^+ \to p\pi^-K^+$, LHCB-PAPER-2017-026 (arXiv:1711.01157), Submitted to JHEP.

13. M. Artuso et al "Measurement of the $D_s^\pm$ production asymmetry with $D_s^\pm \to K^+K^-\pi^\pm$ decays", LHCb-ANA-2016-035.