LHCb/LNF 2022

M. Anelli (Ass), P. Albicocco, G. Bencivenni, S. Cali (Dott.),
P. Campana, G. Capon (Ass.), P. Ciambrone, E. De Lucia,
P. De Simone, P. Di Nezza, G. Felici, M. Giovannetti (Dott),
G. Lanfranchi, G. Morello, M. Palutan, M. Poli Lener,
M. Rotondo, P. Santangelo, M. Santimaria (AdR),
F. Sborzacchi (Tec.), B. Sciascia (Resp.).

In collaboration with "LNF-SEA"
A. Balla (Tec.), M. Carletti (Tec.), D. Di Bari (Tec.), M. Gatta (Tec.)

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 650 papers (55 of which in 2022) using mainly the full Run 1 + Run 2 data set. During LHC Long Shutdown 1 (LS1) in 2013-2014, the LHCb detector remained essentially unchanged, while major upgrades were 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} whose harvest began in 2022. The installation and the commissioning during the LS2, have been heavily touched by the CoViD19 pandemic. The Collaboration was able to arrange a new effective plan but not all the sub-detectors were able to recover the delay. LHCb started the commissioning with beams of the Upgraded detector on April 2022 with only half of the vertex detector (VELO C-side) and without the first tracking detector (UT). The VELO A-side was then installed in September 2022, while the UT installation has been postponed to the End of the Year Technical Stop, started in December 2022. Year 2022 has been mostly a commissioning year of the brand new detectors and front end electronics installed during LS2 and only a small fraction of the 27-38 fb^{-1} expected in Run 3 have been collected with this incomplete LHCb. The very large sample that will be collected from Run 3 on, should allow to determine several SM variables in the flavour sector to a precision comparable with the ultimate theoretical uncertainty.

Being part of the *Muon System* and *SMOG2* projects the LHCb Frascati group is deeply involved in all the ongoing experimental activities. These range from the operation of the detector (with important responsibilities on the hardware) to the data analysis for flagship measurements, from the preparation of the upgrade and Run 3, 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 by 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. The analysis has been completed in 2021 and finally published in 2022 [3] and [4]. The $B_s^0 \to \mu^+\mu^-$ branching fraction and effective lifetime are measured, while no significant signal for $B^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-\gamma$ decays is found (the upper limits at 95% confidence level are determined). Additionally, the ratio between the $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-$ branching fractions is measured to be in agreement with the Standard Model predictions.

In the SM the couplings of the electroweak bosons to the leptons of different families are exactly the same. This property, called Lepton Flavour Universality (LFU), 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 $\mathrm{b} \to \mathrm{c}\ell\nu$ and the FCNC $\mathrm{b} \to \mathrm{s}\ell^+\ell^-$. LNF group is directly involved in 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 already published the measurement of the $B \to D_s^\star\mu\nu$ form factors, ancillary to the relative R_D ratio, and is now working to the measurement of the $R(D_s^\star)$ ratio for which the result is expected for the 2023 Spring conferences.

2 Operation and Upgrade activities

The LHCb detector has been be upgraded in 2019 - 2022, during the LS2. The goal of this upgrade is to allow the LHCb detector to take data at an instantaneous luminosity of $2 \times 10^{33} cm^{-2} s^{-1}$, a factor of five more than during LHC Run 2. A key requirement is to process the full 30 MHz bunch crossing rate of the LHC using a dedicated computing centre. This software-only approach requires two stages: a fast reconstruction and selection stage, referred to as HLT1 and running on GPUs, and a second step with full reconstruction and real-time analysis, known as HLT2 and running on CPUs [5]. Between the two trigger stages the real-time alignment and calibration of the detector are performed. The Real Time Analysis (RTA) project started beginning of 2019 to develop and maintain the full software trigger and the real-time processing of LHCb's data for Run 3 and beyond. The Frascati group participated to the RTA project contributing to the software for the decoding of the muon system data and for the identification of the muons in the HLT1 and the HLT2. The group is also deeply involved in the development of the new online monitoring system. The latter is an important component of the operation of the upgraded LHCb detector. A lot of experience was gained during Runs 1 and 2 but the foreseen large increase of the data rate imposes new constraints on the monitoring system. Finally, Frascati team strongly contributed to the shifts needed to run the experiment, assuming a large variety of roles (Shift Leader, Muon piquet, SMOG2 piquet, Run Chief, DQCS).

For what concerns the Muon System 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. A lot of effort has been put in the planning of the activities towards next Runs starting from Run 3 in 2022. 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 built. The installation started in 2019 and has been completed at the beginning of 2021. Also, in the last years a good number of MWPC spares have been produced at LNF such as to guarantee efficient operation for the next 10 years.

The off-detector electronics boards (Service Boards, nSB, Pulse Distribution Module, nPDM, and Off-Detector, nODE) of the Muon system have been completely redesigned to be compliant with the 40 MHz readout of the detector. The LNF electronic team (LNF-SEA), has produced, tested and commissioned the 185 nODE boards; the apparatus is fully instrumented with the needed 144 nODE and successfully took data in 2022. Since the new ODE board requires to review the architecture of the Electronic Control System (ECS) completely, a new version of the nSYNC libraries with all the basic functions implemented has been deployed beginning of 2021 allowing for the systematic connectivity tests (CT) of the stations, all equipped with the new nSB and nODE boards. The final nSYNC and nODE libraries are under completion and will be deployed before the beginning of 2023 data taking.

Studies are ongoing to use the counters available in the very front-end electronics board to build an online luminosity monitor. First results from the test with LHC are promising for a <2% accuracy in the luminosity measurement and a paper has been prepared to describe the adopted method [1].

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 constraints required by the full software trigger adopted for the upgrade. For this another important contribution to the present performance of the Muon System has been the in deep review 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 and needed a review mainly for the increasingly stringent timing requests. Under the coordination of the RTA project, a complete review has been done keeping the final performance of the involved algorithms and paving the way for the changes needed for the upgrade. Also a new identification operator, rooted in the GAN algorithm class (one of the most used in modern machine learning), has been developed with improved performance and deployed in the HLT sequence mainly thanks to a PhD thesis work conducted under the supervision of the Frascati team. The performance of the MuonID algorithms has been studied using the first data collected using the full suite of detectors, in November 2022.

Since many years Frascati team contributes also to both the Technical Coordination Team (TCT) and the Online project. For the TCT, in 2022 the team worked in particular to the completion of the installation of the M2 beam plug, and to the coordination for the mechanical installations of UT. For the Online, in 2022 the team focused its action on the virtualisation cluster hosting the LHCb ECS control system and on the final commissioning of the HLT2 output storage [6]; both systems have been successfully and reliably used during the whole 2022 data taking.

The SMOG2 project, the first internal fixed gas target at the LHC, was part of the major upgrade of the LHCb detector and started its operation in 2022 with the LHC Run 3. With the first beams, circulating in June 2022, an intensive commissioning campaign has been started. The temperature behaviour of the storage cell, monitored by 5 thermocouples, was understood in connection to the beam conditions. The Gas Feeding System was calibrated and operational procedures were developed in order to have the highest stability in the gas flow, reaching the level of 1%. By these procedures the local pressure bump into the storage cell is reached in very few minutes and, once the flow is stopped, the standard vacuum conditions are established again in not more than 3 minutes. It has been clearly evaluated that the gas injection does not reduce the LHC beam lifetimes and further no negative feedback has been seen. This brought LHC to authorise LHCb to inject gas when needed without explicit contacts with the LHC operators. All the currently available gas loaded into the reservoirs were tested: H_2, He, Ne, and Ar. In particular it has been seen that, with the Argon gas flow 5 times smaller than the one used with SMOG in Run 2, the density (luminosity) reached by SMOG2 was already 6 times higher. Hydrogen injection was a milestone reached after many simulations and laboratory tests performed in collaboration with the LHC vacuum group. The reconstruction code and HLT1 trigger have been successfully implemented and the system is ready for taking high-quality data. First collected data showed that the beam-beam and beam-gas primary vertices can be reconstructed with high efficiency, that the K_s invariant mass is reconstructed with the same resolution if produced in the beams collisions or in the gas ones. The data flow increase related to the presence of the gas, has been evaluated to be of about 1% only. Studies for measuring the beam-gas luminosity have been finalised showing the very low value of 1.4% systematic uncertainties. Fixed target collisions at LHCb open exciting new fields of investigation, allowing the production of particles carrying a large momentum fraction of the target nucleon to be studied in kinematic regions poorly explored up to now. In the nucleon-nucleon centre-of-mass frame, at an energy scale up to 115 GeV, interactions of the LHC beam with gasses such as H, D going through the noble gasses up to the heavier Kr, and Xe, pave the way for innovative and fundamental measurements. All these make LHCb the first experiment ever to be able to run with two completely different interaction points simultaneously, opening new frontiers in QCD and astroparticle.

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 onward, will build on the strengths of the Run 1 and Run 2 experience and on the Phase-I Upgrade during Run 3, and 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 the phase-2 upgrade foreseen for the LHC Run 5, the excellent performance of the current muon detector will need to be maintained at 40 times the pile-up level experienced during Run-2. The rate requirements have been estimated using the counters available through the actual very front-end electronics board. Single channel rates as a function of the μ have been acquired during the two Van der Meer scans performed during the 2022 data taking, and have been studied to derive an accurate estimate of the rates that will hit the MWPC at the U2 luminosity. Many paths have been followed in the last years by Frascati team, within the Muon Project, to prepare the Muon system for the future upgrades. To mitigate the challenging conditions of Upgrade 2, an improved shielding that decreases the rate, particularly in the inner region, has been studied. Since the HCAL is not used in the trigger from Run 3 onward, and plays a limited role in muon PID, the option exists to remove it and exploit the freed volume for new shielding to reduce the rate by about a factor two at the M2 station. The proposed shielding consists of an iron core covering the acceptance of regions R1 to R3, an iron/concrete/iron sandwich on the median plane of region R4, with an effective thickness similar to HCAL and a full concrete part on the top/bottom bands of region R4, where the input rate does not pose problems even with a slightly reduced effective thickness compared to HCAL. With the above design the simulated occupancy on the M2 station is reduced to 58%, 31% and 36% of those values found with the HCAL in place, in regions R1, R2, and R3 respectively. The iron to be used has been discarded from the OPERA experiment taking data at LNGS and now finished. The Frascati LHCb team organised the transport at CERN where a suitable shed has been found to store the plates pending future processing. The use of Opera plates instead of an brand new filter implies an estimated saving at current market prices of around 200 kEuro. Furthermore, in ecological terms, recycling the slabs implies the emission of 150 t of CO2 (due to various transports) compared to ∼950 t released during the new production.

Requirements for the innermost regions of the muon stations are challenging: the detectors should exhibit a rate capability up to 1 MHz/cm^2 and capable to stand an integrate charge up to $\sim$ 1 C/cm^2. For some years now, an intense optimisation program of the micro-RWELL technology has been launched by the Frascati Detector Design Group, together with a technology transfer to the industry operating in the PCB field. The micro-RWELL detector (μ-RWELL) is a single amplification stage resistive Micro Pattern Gaseous Detector (MPGD), based on a copper-clad polyimide foil patterned with a micro-well matrix coupled with the readout PCB through a DLC resistive film ($10 \div 100 M\Omega/\square$). In order to fulfil the requirements, a new layout of the detector with a very dense current evacuation grid of the DLC has been designed. The detector, co-produced by the CERN-EP-DT-MPT Workshop and the ELTOS Company, has been characterised achieving a rate capability exceeding 10 MHz/cm^2, while the long term stability tests are in progress.

For what concerns the outer regions of the muon stations, the strategy rely on the observation that, in the nine years of operation of Run 1 and Run 2, the collected charge on the most irradiated MWPC, in M1R2, reached values of up to ∼0.6 C/cm per wire without any drop in performance being observed. In the low-rate regions R3 and R4, which represent 94% of the instrumented area, this charge will only be accumulated after 350 fb^{-1} of integrated luminosity, and then only for M2R3, with the other sub-regions being comfortably below this value. Hence there exists the opportunity to profit from the re-use of the current MWPC detectors and also exploit the existing detector infrastructure, for Run 5 and beyond. This project is now challenged by the consequences of the Russia attack to Ukraina, with the Russian Federation likely excluded from any new project at CERN. Alternative solutions are under study. After the publication of the framework TDR of the phase-2 LHCb upgrade [15], the next goal is the preparation of the TDR of the single subdetectors. To coordinate the effort toward the Muon TDR, the Frascati team has organised in June 2022 at LNF a dedicated workshop to gather all the interested groups to start discussing the detailed project of the future Muon system.

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 group is deeply involved in the activities ongoing to ensure the finalisation of the Phase-I Upgrade commissioning and the successful start of Run 3 data taking in 2023. 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 organised for about 60 high school students meeting for a whole week in March 2022, as part of the IPPOG MasterClass program.

5 List of Contributions at conferences prepared by LNF Authors in Year 2022

1. G. Morello, "The micro-RWELL detector for the phase-2 upgrade of the LHCb muon system" talk at 15th Pisa Meeting on Advanced Detectors; proceedings here
2. G. Morello, "The micro-RWELL detector for the phase-2 upgrade of the LHCb Muon system" talk at ICHEP22; proceedings here
3. M. Santimaria, SQM2022 Conference (online):

   https://indico.cern.ch/event/1037821/contributions/4842075/ proceedings (pre-print) here https://arxiv.org/abs/2210.13997
4. M. Santimaria, KAON2022 Conference (online):

   https://conference-indico.kek.jp/event/169/contributions/3475/ proceedings (pre-print) here https://arxiv.org/abs/2210.14004
5. M. Santimaria, "Diffraction and Low-x workshop 2022:

   https://indico.cern.ch/event/1148802/contributions/4981854/
6. M. Santimaria, EIC phase 2 Workshop (Stony Brook):

   https://indico.bnl.gov%/event/14504/contributions/63159/
7. M. Santimaria, proceedings for Low-X 2021 (published on June 2022)

   https://kuscholarworks.ku.edu/handle/1808/32791
8. M. Santimaria, proceedings for DIS 2021 (published on July 2022)

   https://scipost.org/10.21468/SciPostPhysProc.8.050

9. M. Giovannetti, contribution to the 7^{th} International Conference on Micro Pattern Gaseous Detectors 2022, Rehovot, Israel: "The surface Resistive Plate Counter (sRPC): an MPGD technology based RPC" (proceedings to be submitted)

10. M. Giovannetti, poster presented at 5^{th} Pisa Meeting on Advanced Detectors, La Biodola, Italy: "uRANIA: a micro-Resistive WELL for neutron detection"; proceedings avaialble at https://doi.org/10.1016/j.nima.2022.167432

11. R. Farinelli et al., The μ-RWELL technology at the IDEA detector, , 41^{st} International Conference on High Energy Physics (ICHEP2022), Bologna, Italy, https://doi.org/10.22323/1.414.0333

12. G. Bencivenni et al., The surface Resistive Plate Counter: a novel RPC based on MPGD technologies, NIM (2022), 15^{th} Pisa Meeting on Advanced Detectors, La Biodola, Italy, https://doi.org/10.1016/j.nima.2022.167728

13. R. Farinelli et al., The μ-RWELL technology for the preshower and muon detectors of the IDEA detector, NIM (2022), 15^{th} Pisa Meeting on Advanced Detectors, La Biodola, Italy, https://doi.org/10.1016/j.nima.2022.167993

14. G. Morello et al., The micro-RWELL detector for the phase-2 upgrade of the LHCb Muon system, NIM (2022), 15^{th} Pisa Meeting on Advanced Detectors, La Biodola, Italy https://doi.org/10.1016/j.nima.2023.168075

15. G. Bencivenni et al., The Surface Resistive Plate Counter: A new RPC based on resistive MPGD technology, NIM A 1038 (2022), 16^{th} Vienna Conference on Instrumentation, Vienna, Austria, https://doi.org/10.1016/j.nima.2022.166948

16. F. Sborzacchi et al, "The LHCb HLT2 storage system: a 40 GB/s system made from commercial off-the-shelf components and open-source software" presented at "23rd Virtual IEEE Real Time Conference"

    https://indico.cern.ch/event/1109460/contributions/4893312/

17. M. Rotondo, "Significant LHCb results and plans for the future", presented at IPA Interplay between Particle and Astrophysics, Vienna 5-9 Sett. 2022

18. M. Palutan, Plenary talk al "30th International Symposium on Lepton Photon", "Future flavour experiments", 14/1/2022, Manchester.

19. M. Palutan, Plenary talk a "LHC performance workshop", "LHCb Upgrade II, 26/1/2022, Chamonix.

20. M. Palutan, Plenary talk a 10th Large Hadron Collider Physics Conference, "LHCb highlights and perspectives", 16/5/2022, Taipei.

21. P. Di Nezza, "The LHCspin project: status and perspectives" CPHI conference, Duke US, March 2022

22. P. Di Nezza, "Fixed targets at LHC" APCPT workshop, Seul Korea, July 2022

23. P. Di Nezza, "Spin and 3D structure" DIS conference, Santiago Spain,

24. P. Di Nezza, "LHC fixed target experiments" IWHSS conference, Cern, Aug 2022

25. P. Di Nezza, "Fixed target experiments at LHC" Opportunities with JLab Energy and Luminosity upgrade meeting, ETC* Trento, Oct 2022

26. P. Di Nezza, "The LHCspin project" PSTP22 workshop, Mainz Germany, Sep 2022

27. P. Di Nezza, "Fixed targets at LHC" Transversity workshop, Pavia Italy, May 2022

References

1. P. Albicocco, W. Baldini, S. Belin, V. Bocci, N. Bondar, D. Brundu, S. Cadeddu, A. Cardini, M. Carletti, G. Chiodi, *et al.* "A Method Based on Muon System to Monitor LHCb Luminosity," Symmetry **14**, no.5, 860 (2022) doi:10.3390/sym14050860

2. P. Albicocco, R. Assiro, F. Bossi, P. Branchini, B. Buonomo, V. Capirossi, E. Capitolo, C. Capoccia, A. P. Caricato, S. Ceravolo, *et al.* JINST **17**, no.08, P08032 (2022) doi:10.1088/1748-0221/17/08/P08032 [arXiv:2205.03430 [physics.ins-det]].

3. R. Aaij *et al.* [LHCb], "Analysis of Neutral B-Meson Decays into Two Muons," Phys. Rev. Lett. **128**, no.4, 041801 (2022) doi:10.1103/PhysRevLett.128.041801 [arXiv:2108.09284 [hep-ex]].

4. R. Aaij *et al.* [LHCb], "Measurement of the $B_s^0 \to \mu^+\mu^-$ decay properties and search for the $B^0 \to \mu^+\mu^-$ and $B_s^0 \to \mu^+\mu^-\gamma$ decays," Phys. Rev. D **105**, no.1, 012010 (2022) doi:10.1103/PhysRevD.105.012010 [arXiv:2108.09283 [hep-ex]].

5. R. Aaij *et al.* [LHCb], "A Comparison of CPU and GPU Implementations for the LHCb Experiment Run 3 Trigger," Comput. Softw. Big Sci. **6**, no.1, 1 (2022) doi:10.1007/s41781-021-00070-2 [arXiv:2105.04031 [physics.ins-det]].

6. P. Cifra, F. Sborzacchi, N. Neufeld and F. Hemmer, "The LHCb HLT2 Storage System: A 40 GB/s System Made of Commercial Off-the-Shelf Components and Open-Source Software," in IEEE Transactions on Nuclear Science, doi: 10.1109/TNS.2023.3240882, available at https://ieeexplore.ieee.org/document/10032178

7. J. P. Lees *et al.* [BaBar], Phys. Rev. Lett. **128**, no.13, 131802 (2022) doi:10.1103/PhysRevLett.128.131802 [arXiv:2111.01800 [hep-ex]].

8. J. P. Lees *et al.* [BaBar], Phys. Rev. Lett. **128**, no.9, 091804 (2022) doi:10.1103/PhysRevLett.128.091804 [arXiv:2109.03364 [hep-ex]].

9. HFLAV, "Averages of b-hadron, c-hadron and tau-lepton properties as of 2021", arXiv:2206.07501 accepted September 2022 to be published in Phys.Rev.D.

10. N. Amapane, M. Antonelli, F. Anulli, G. Ballerini, L. Bandiera, N. Bartosik, M. Bauce, A. Bertolin, C. Biino and O. R. Blanco-Garcia, *et al.* "Muon detection in electron-positron annihilation for muon collider studies," Nucl. Instrum. Meth. A **1024**, 166129 (2022) doi:10.1016/j.nima.2021.166129 [arXiv:2105.12624 [physics.ins-det]].

11. G. Bencivenni, R. De Oliveira, G. Felici, M. Gatta, M. Giovannetti, G. Morello and M. Poli Lener, "The micro-RWELL detector for the LHCb Muon system phase-2 upgrade," PoS **ICHEP2022**, 339 doi:10.22323/1.414.0339

12. G.Graziani *et al.*, "A Neural-Network-defined Gaussian Mixture Model for particle identification applied to the LHCb fixed-target programme", 2022 JINST 17 P02018

13. M.Santimaria *et al.*, "The LHCspin project" SciPost Phys. Proc. 8, 050 (2022)

14. L.L.Pappalardo *et al.* "Polarised target experiments at LHC", JPS Conf. Proc. 37, 011008 (2022)

15. LHCb Collaboration, "Framework TDR for the LHCb Upgrade II; Opportunities in flavour physics, and beyond, in the HL-LHC era", CERN-LHCC-2021-012, LHCB-TDR-023, https://cds.cern.ch/record/2776420",