PLANS AND PHYSICS OUTLOOK FOR NON-HIGH LUMINOSITY EXPERIMENTS UNTIL AND AFTER LS3

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Abstract

Based on the current physics scene, the future holds more than ever a joint enterprise of precision measurements and direct searches. With its very broad scientific program of heavy flavour precision measurements both in the beauty and the charm sector, as well as forward electroweak precision physics, LHCb has demonstrated to be a powerful forward general purpose detector complementary to ATLAS and CMS. After the expected lifetime of $10fb^{-1}$ for the current experiment, the precision of many measurements will still be limited by statistics. Experience from Run 1 shows that systematic uncertainties are not expected to limit the precision down to the theoretical uncertainties. LHCb will thus undergo one major upgrade in LS2 to the ultimate flexibility of a full software trigger, together with a sub-detector configuration which should allow improving the physics yield up to an instantaneous luminosity of $2x10^{33}$ $cm^{-2}s^{-1}$, with the goal of collecting an integrated luminosity of at least $50fb^{-1}$ by 2028. The flexibility of the upgrade also prepares LHCb for any changes in the physics scene beyond LS2.

The ion program is an integral part of the LHC physics program. For the purpose of physics normalization, detector re-commissioning and calibrations, the ALICE experiment requires data taking during the nominal proton-proton physics and at nucleon-nucleon energies equivalent to the heavy ion collisions. This will evolve with the major upgrade of ALICE which is currently planned for LS2.

In view of the LHC and the injector upgrades, this paper reviews the physics motivations, the upgrade and consolidation programs, and the operational requirements and schedule for LHCb and for the ALICE proton-proton data taking into the HL-LHC era. For completeness, it also covers the relevant aspects of the LHC forward physics program and other special runs.

INTRODUCTION

The current physics scene after the LHC Run 1 in both proton-proton physics and in heavy ion physics is intriguing to say the least. While the discovery of the existence of a scalar in nature compatible with a $126GeV/c^2$ Standard Model Higgs boson is vital for the Standard Model (SM), direct searches did not reveal any signs of new particles beyond the Standard Model. Moreover, the Standard Model prevails in all the LHC precision measurements. In particular, the absence of a non-SM signal in precision tests in the heavy flavour sector have narrowed down the space for New Physics with flavour related couplings up to a mass scale of many tens of TeV. Nevertheless, New Physics is required to explain the neutrino oscillations and masses, and account for the cosmological observations of baryon asymmetry, the Dark Matter, and Dark Energy. However, while unitarity arguments allowed establishing an upper bound on the mass of the Higgs boson, there is no such trivial indication for the energy scale of this New Physics. Taken together, this indicates that precision measurements are likely to be the best compass at the LHC to suggest the direction on physics beyond the Standard Model. Clearly the nature of the newly found boson should be studied through precise measurements of the couplings to the vector bosons and the fermions, as well as of the Higgs self-interactions in order to reconstruct the scalar potential and establish its role in the electroweak symmetry breaking and mass generation. The general purpose nature of flavour physics together with the fact that one of the most fundamental unexplained question about the baryon asymmetry is of flavour nature show that continued precision measurements on rare heavy flavour decays and CP violation are of equal importance in the search for New Physics. Of course, the direct searches for on-shell production of new particles will continue to play an important role.

The LHC is also able to produce ultra-relativistic heavy ion physics at energies exceeding previous machines by more than an order of magnitude. The higher energy is expected to make the strongly interacting medium hotter and denser, and should increase significantly the cross-sections for the production of the hard objects which are used indirectly to probe the final state medium to quantify its density, temperature, and its transport properties. Theory and previous experiments predict that the formation of Quark Gluon Plasma (QGP) should leave distinct signatures on charged particle production, jets, heavy flavour of which quarkonia are of particular interest, and on the production of photons and low mass di-leptons.

With only a percent of the integrated luminosity currently foreseen for the entire LHC Pb-Pb operation and three weeks of p-Pb collisions in 2013 at around half the nominal LHC energy, the LHC has already produced a number of unexpected and important results [1][2]. While measurements of the elliptic flow in Pb-Pb collisions still show that the medium behaves like a very strongly interacting, almost perfect fluid, and most observables are at least in qualitative agreement with the 'Heavy Ion Standard Model' which emerged with RHIC, the big surprises showed up in the p-Pb and even in the p-p data. One of the most striking discoveries is the long-range two-particle correlations appearing as ridges in the rapidity-azimuthal plane in high multiplicity p-p interactions and even stronger in p-Pb. These observations are compatible with a collective hydrodynamic flow of a strongly coupled medium hinting at the formation of QGP fire balls even in p-p interactions. Another completely unexpected recent feature is the large enhancement at high Q^2 and x in the inclusive charged particle forward-backward asymmetry in p-Pb. Further findings in p-Pb collisions indicate a stronger than expected suppression of ψ(2S) relatively to J/ψ that cannot be explained by effects associated with Cold Nuclear Matter or energy loss, and that hint at final state effects. In the opposite sense, a very important result from Pb-Pb data seems to confirm the coalescence mechanism whereby the J/ψ suppression associated with QGP is compensated at higher energies by a subsequent charm recombination during hadronization. Currently many of the results are statistically insufficient to be used effectively for constraining theoretical models.

Taken together, the LHC has demonstrated the need for better understanding of p-p and p-Pb data in order to disentangle the many effects present in p-p, p-Pb, and Pb-Pb and improve the interpretation of QGP signatures. The results also show that p-Pb collisions are more than just a control experiment and that we can expect a wealth of interesting results to come.

LHCb PLANS AND PHYSICS OUTLOOK

LHCb Physics Objectives

The main objective of LHCb is measuring indirect effects of New Physics in heavy flavour processes with CP violation and strong suppressions in the Standard Model, such as those involving Flavour Changing Neutral Currents (FCNC) mediated by box and penguin diagrams. The new particles are expected to appear and contribute through virtual quantum fluctuations and produce discernible effects on measurable quantities which are well predicted in the Standard Model and which characterize the processes in a distinct fashion, such as decay rates, angular distributions, forward-backward (a)symmetries, etc. The access to virtual effects allows indirectly probing energies higher than the centre-of-mass energy of the LHC. Apart from assuming that the New Physics couples to flavour, this strategy to search for New Physics is largely model independent. The contribution from New Physics generally enters into the measurable quantities as a correction of order $\delta C^{NP} \propto \epsilon^{NP}/\Lambda_{NP}^2$, where ϵ^{NP} is the coupling and Λ_{NP} corresponds to the scale of masses of the new particles. Clearly, in order to discern the New Physics, the error on the measurement must be significantly smaller than the correction for New Physics. For a given resolution, a smaller coupling entails less reach in the mass scale. In practice this means to continually reduce the statistical error and manage extremely well the error from systematic effects. As an example, Figure 1 shows the expected sensitivity for LHCb and Belle II on the zero-crossing of the forward-backward asymmetry in the $B_d \to K^*\mu^+\mu^-$ decay [3][4].

The LHC is to a large extent a charm and a beauty factory. LHCb and the upcoming upgrade aim at exploring fully the very rich repertoire of decays and topologies, and all the possible observables which are sensitive to New Physics. The theoretical understanding for many of these observables is very good within the framework of the SM, and the LHCb upgrade aims at reaching experimental sensitivities which are comparable to the theoretical uncertainties. In addition, LHCb has also demonstrated to be capable of making important measurements in electroweak physics, on Lepton Flavour Violation, and in QCD.

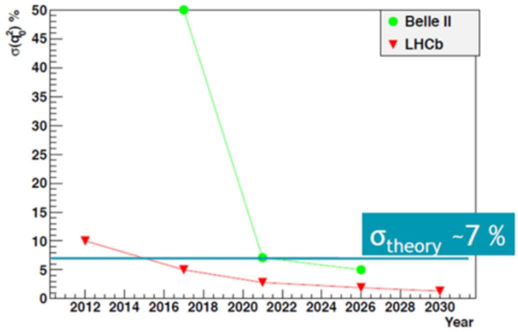

Figure 1: Expected evolution of the sensitivity for LHCb and Belle II on the zero-crossing of the forward-backward asymmetry in the $B_d \to K^*\mu^+\mu^-$ decay [4].

LHCb Run 1 Lesson and Run 2 Plans

With the impressive performance of LHC and the demonstration that LHCb can successfully perform forward precision measurements with event pileup, the operation and trigger strategy evolved significantly during the LHC Run 1 allowing LHCb to collect over $3fb^{-1}$ at centre-of-mass energies of 7TeV and 8TeV [5]. Experience with the detector operation and with the analysis of the data show that systematic effects may be managed very well, and that the precisions in many measurements are not expected to be limited by systematic uncertainties. This also includes regular polarity switches of the LHCb spectrometer dipole which allows averaging out systematics from detector asymmetries. The large statistics and well managed systematic effects together with the stable trigger and data taking conditions have led to a very large number of world-class measurements and dominance in heavy flavour physics [6], in addition to a reputation of an excellent forward general purpose detector at the LHC. Long Shutdown (LS) 1 will allow LHCb to fully explore the large statistics collected and prepare LHCb for Run 2.

In Run 2 with 25ns bunch spacing, the current LHCb baseline is to operate the detector at a levelled luminosity of $4x10^{32}cm^{-2}s^{-1}$, i.e. at an average number of interactions per bunch crossing of around unity. The aim is to collect at least an additional 5-6 fb^{-1} by LS2. Since it seems likely that a virtually new LHC machine, the increase of beam energy and the shift to 25ns operation may lead to a limited integrated luminosity in 2015, LHCb favours an extension of Run 2 by between six and twelve months. On the contrary, LHCb disfavours a delay of the start of LS2 beyond 2018. It should also be noted that the expected system lifetimes of the LHCb trackers is around $10fb^{-1}$. For the luminosity levelling, the $\beta*$ setting, or range in the case of levelling by $\beta*$, should be such that it allows LHCb to run at constant luminosity with a levelling lifetime which is of the order of the longest typical fill duration (10-15h).

LHCb Upgrade Strategy and Prospects

Even after an expected total integrated luminosity of 10 fb^{-1} in Run 2, many of the LHCb precision measurements will remain limited by statistics, and some exploratory physics modes will not even be accessible yet. A 5 to 10-fold, depending on the final state, increase in statistics will not only allow reaching the desired statistical power but would also allow opening the door to new physics modes both within the field of flavour physics but also in the other physics topics for which the LHCb acceptance is particularly interesting. With the encouraging experience of working in an environment with event pileup during Run 1, this large statistics can be achieved efficiently by firstly operating the experiment in Run 3, in Run 4 and beyond at a higher luminosity of up to $2x10^{33}cm^{-2}s^{-1}$. Secondly, it requires a major change to the LHCb trigger architecture to remove the current limitations and increase the trigger efficiency, in particular for hadronic modes. Upgrades of some of the LHCb detectors are necessary as a consequence of the required radiation longevity. In addition, the upgrade provides an opportunity to re-optimize the experiment with new technologies to cope more efficiently with the higher occupancies and further improve the physics capabilities. The LHCb upgrade [7] strategy therefore consists of reading out the entire detector at 40MHz, and performing solely the triggering based on the full event topology in software on a CPU farm. Several of the sub-detectors should be improved to provide the appropriate granularity to allow a fast full reconstruction, and to allow operating the detector at a luminosity of up to $2x10^{33}cm^{-2}s^{-1}$, ie. at an average number of interactions per crossing of close to five. Some sub-detector replacements are of course also needed as a result of the radiation effects up to 2018 and the higher integrated dose associated with the aim of collecting at least $50fb^{-1}$. In order to profit from the higher luminosity and the higher trigger efficiency, the physics output rate will need to be 20 kHz.

The consequence of the 40 MHz readout is that all the sub-detector Front-End and Back-End electronics must be redone. Secondly the detector and the readout upgrade must be done in one single Technical Shutdown. A single sub-detector operating in the old configuration will force LHCb to continue operating with the current limitations until it is upgraded.

In terms of sub-detector upgrades (Figure 2), the aim is to achieve the same performance as now but at significantly higher pileup and occupancy. The biggest detector replacement concerns the tracking system from the VErtex Locator (VELO) up to the main tracking stations. The aim is to optimize the upgraded tracking detectors to allow faster tracking and vertexing. For the Trigger Tracker (TT) the idea is to rebuild the detector with the same technology of silicon strips but with higher segmentation, improved sensor overlap, and better small-angle coverage.

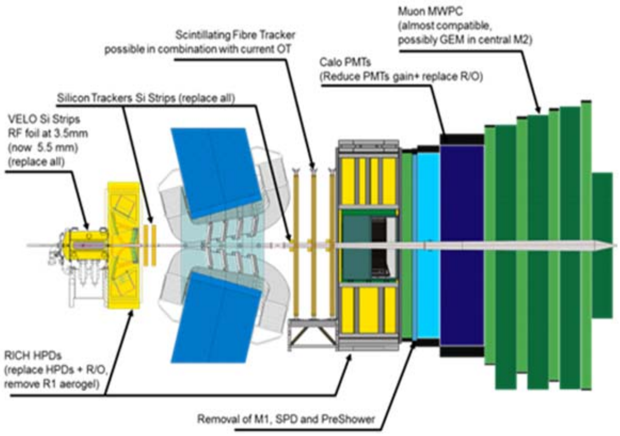

Figure 2: The LHCb sub-detector upgrades in LS2.

In the case of the main tracking stations, the Inner Tracker (IT) will be entirely replaced, either with a somewhat larger detector based on the same silicon strip technology, or with a large scintillating fibre tracker. In the case of the two RICHes, the hybrid photo-multipliers (HPD) will be replaced by multi-anode photo multipliers. This is also necessary since the FE electronics is integrated in the HPDs. In addition, the aerogel will be removed from RICH1 since the background due to the large number of tracks is too high in the upgrade to allow reconstructing the rings from the signal photons. The RICH1 optics will be re-optimized in order to allow operating at a luminosity of $2x10^{33}cm^{-2}s^{-1}$. In order to run at higher luminosity, the calorimeters will only reduce the gain on the photomultipliers and compensate with an increased electronics gain. The signal to noise has been demonstrated to be sufficient. As it stands currently, the muon detectors after the calorimeters will remain as they are.

The first muon detector layer (M1), and the scintillating pad detector (SPD) and preshowers used for e/γ separation with the calorimeter, will be entirely removed as they will not contribute at the expected very high occupancy.

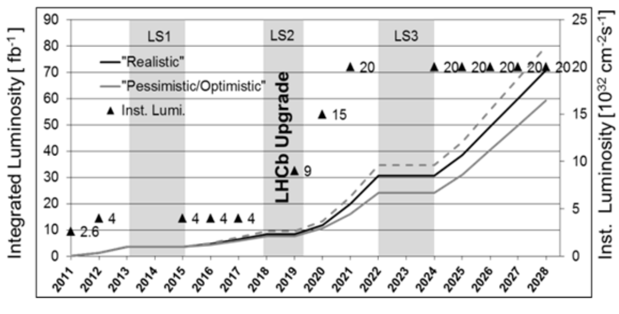

Figure 3: Example of the luminosity prospect up to 2028.

Currently LHCb is in the final phase of reviews and choice of technologies. The preparation of the Technical Design Reports and the prototype validation is starting now. Finally the full installation of the detector and the 40MHz readout is scheduled for the LS2, expected to take

Table 1: Expected statistical sensitivities after LHC Run 2 and after $50 fb^{-1}$ with the LHCb Upgrade as compared to current theoretical uncertainties for a list of key observables [8].

Type	Observable	LHCb 2018	Upgrade ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s\ (B_s^0 \to J/\psi\ \phi)$	0.025	0.008	~ 0.003
	$2\beta_s\ (B_s^0 \to J/\psi\ f_0(980))$	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	0.09	0.02	< 0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	5 %	1 %	0.2 %
Electroweak penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.025	0.008	0.02
	$s_0\, A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08	0.025	~ 0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	8 %	2.5 %	~ 10 %
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	~ 100 %	~ 35 %	~ 5 %
Unitarity triangle angles	$\gamma\ (B \to D^{(*)}K^{(*)})$	4°	0.9°	negligible
	$\gamma\ (B_s^0 \to D_s K)$	11°	2.0°	negligible
	$\beta\ (B^0 \to J/\psi\, K_S^0)$	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	0.65×10^{-3}	0.12×10^{-3}	–

place in 2018-19, with the requirement of an 18-month access to the cavern. As mentioned above, LHCb believes an extension of Run 2 by between six and twelve months may be justified in order to increase significantly the integrated luminosity in Run 2. It is also clear that the preparation for the upgrade installation in LS2 would benefit from an extension of Run 2. On the contrary, an LS1.5 is of limited use and would not reduce the installation time needed for the upgrade in LS2.

Taking together the best of knowledge from LHCb and LHC during Run 1, the strategy of the LHCb upgrade and the future schedule, Figure 3 shows an example of a luminosity projection up to 2028 with the LHCb upgrade in 2018. Table 1 also shows the expected statistical precision for representative key physics channels after $50 fb^{-1}$ [8]. Generally speaking, nearly all the key measurements should have reached precisions close to the theoretical uncertainties. However, it should be stressed that the strength of the LHCb upgrade is only partly about satisfying the final precision for flavour physics. More importantly, the ultimate flexibility in the upgraded trigger and detector re-optimization allow adapting the LHCb physics program and running conditions to any signature which may come out of a changing physics scene after 2020.

ALICE UPGRADE PLANS AND NEEDS FOR REFERENCE DATA

Motivation for Reference Data

With the large statistics of heavy ion collisions which will be available at the LHC, and the complete detector coverage to low p_T and large rapidity to study with high precision all the different types of hard probes, it is becoming equally important to collect large statistics of reference data in p-p, and in p-Pb collisions. The p-p data is needed to normalize to the effects of soft and perturbative QCD and fragmentation in the vacuum, and p-Pb data allow factorizing out initial state effects and cold nuclear matter effects. The aim is to achieve an error on the reference data which is negligible compared to the heavy ion data. While scaling of the hard probe observables with the centre-of-mass energy is possible to some extent, in most cases it introduces unacceptably large errors. For this reason the reference data should be recorded at the equivalent nucleon-nucleon centre-of-mass energy.

The reference data is equally important for ALICE, ATLAS and CMS for physics normalization. In addition, ALICE requires p-p data for operational reasons to perform detector commissioning and calibrations. However, these may be done at the nominal beam energy for high-luminosity p-p operation.

The design choice of the detector configuration for heavy ion physics means that ALICE has readout limitations which translate into a relatively strong limitation on the luminosity at which the detector can collect p-p data. Currently, this is related to the electron drift time of 100μs in the TPC.

ALICE Run 2 Plans

In Run 2, ALICE aims at collecting up to ten times more statistics than in Run 1 and profiting from the detector improvements which are currently being implemented in LS1. The larger statistics will allow improving significantly on the precision of the measurements in Run 1 and exploring new observables. Run 2 will also extend the current measurements at $\sqrt{s_{NN}}$= 2.76 TeV up to 5.1 TeV (6.5Z TeV/beam with lead ions) to study the energy dependence.

ALICE is not requesting a special p-p reference run at equivalent energy in Run 2. For the physics normalization it is considered sufficient to apply energy scaling with the help of the p-p data recorded at 7 and 8 TeV, and the future data at 13 TeV. For this reason, ALICE is planning low luminosity operation throughout the nominal p-p runs (~24 weeks/year). The current plan is to collect minimum bias reference data in 2015 at a levelled instantaneous luminosity of 1-10x10^{29}cm^{-2}s^{-1}. With beam parameters expected from the Bunch Compression and Merging Scheme [9][10] in Run 2, this luminosity implies a separation of close to 5σ at the injection β* of 10m. The exact value of the luminosity will depend on the quality of the vacuum conditions in the ALICE Long Straight Section which already caused some difficulties in Run 1. In case of poor vacuum conditions, the optimal luminosity becomes a trade-off between minimizing the contamination of beam-gas events in the minimum-bias sample and minimizing the fraction of events with pile-up from multiple crossings in the 100μs TPC readout time.

In 2016 and 2017 ALICE expects to collect rare triggers at a levelled p-p luminosity of 5-10x10^{30}cm^{-2}s^{-1}.

It should be noted that ATLAS and CMS have a strong preference for an annual p-p reference sample at equivalent nucleon-nucleon centre-of-mass energy to follow the integrated luminosity of the heavy ion physics. Since they have no limitation on the instantaneous luminosity, the equivalent sample can be collected in the order of a day (e.g. 30 pb^{-1} at <10^{33}cm^{-2}s^{-1}> with 30% machine availability) plus the setup time. ALICE will participate in these runs but will not be able to collect sufficient statistics.

Since p-Pb measurements have yielded a number of surprising results which impact significantly the understanding of QGP signatures, it seems a strong motivation for operating also the p-Pb run at the expected Pb-Pb energy of $\sqrt{s_{NN}}$= 5.1TeV (4.1Z TeV/beam with lead ions) instead of at the maximum p-Pb energy of $\sqrt{s_{NN}}$=8.2TeV (6.5Z TeV/beam). This would also avoid requiring yet another p-p reference sample at the equivalent energy for the p-Pb run.

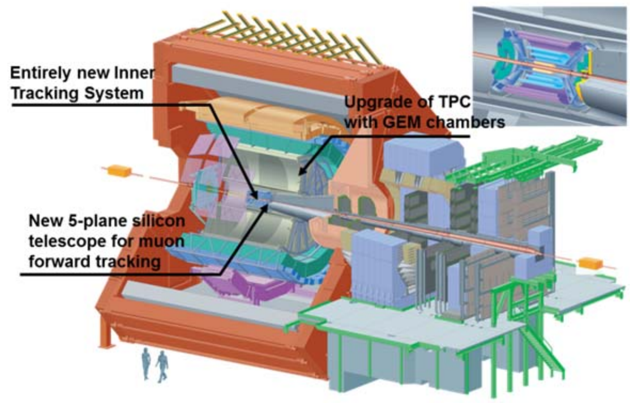

Figure 4: The major ALICE sub-detector upgrades in LS2

ALICE Upgrade Strategy and Run Plan

The ALICE upgrade [11] is aimed at taking full advantage of the rare physics processes which allow probing the characteristics of the hot and dense QCD matter, such as quenching of jets, medium transport of heavy flavour and quarkonium, and photons and low-mass di-leptons as probes of the thermal history of the system. In particular, these probes require coverage to low transverse momentum, and very large statistics in order to perform multi-dimensional analysis. These goals may be achieved with ten times the integrated luminosity of Pb-Pb collisions collected in Run 1 and Run 2 (10nb^{-1}) and by increasing the statistics of low-p_T events by a factor 100 (8x10^{10} events).

The ALICE strategy for Run 3 and Run 4 therefore consists of a major upgrade of the sub-detector readout electronics and the central readout system in order to be able to operate the detector at a levelled instantaneous luminosity of 6x10^{27}cm^{-2}s^{-1} and to be able to accept a rate of 50 kHz of Pb-Pb interactions with only a minimum bias trigger, and perform the online data reduction based on an event reconstruction at the 50 kHz. A new Inner Tracking System is being built with an improved vertexing based on an ultra-low mass silicon tracker around a significantly smaller beam pipe and more efficient tracking at low p_T with increased granularity. In order to run at higher luminosity, the ion feedback problem in the TPC readout chambers is solved by replacing the MWPC by GEM chambers and by implementing a continuous un-gated readout. In addition, a new Muon Forward Tracker based on a 5-plane silicon telescope with the same rapidity coverage as the Muon Spectrometer is added in front of the hadron absorber in order to perform accurate muon tracking back to the vertex region.

Table 2: ALICE run plan for Run 3 and Run 4.

Year	System	Luminosity
2019	Pb Pb (5.1* TeV) – 4 weeks	2.85 nb^{-1}
2020	Pb Pb (5.1 TeV) – 4 weeks	2.85 nb^{-1}, lower B field (0.2T)
2021	pp (5.1 TeV) – 8 weeks	ALICE: 6 pb^{-1} (4 x 10^{11} events)
2022	LS3	
2023	LS3	
2024	Pb Pb (5.1 TeV) – 4 weeks	2.85 nb^{-1}
2025	½ PbPb + ½ pPb	PbPb:1.42 nb^{-1}, pPb:50 nb^{-1}
2026	Pb Pb (5.1 TeV) – 4 weeks	2.85 nb^{-1}

The complete upgrade operation on the detector and the installation of the new readout is scheduled for the LS2, expected to take place in 2018-19, with the requirement of an 18-month access to the cavern. The intervention on the TPC itself requires 10 months on the surface. ALICE would not object to an extension of Run 2 by up to 12 months. On the contrary, in the current planning, an LS1.5 is of limited use and would not reduce the installation time needed for the upgrade in LS2.

The ALICE run plan for Run 3 and Run 4 is shown in Table 2. In terms of p-p reference data for ALICE at the corresponding nucleon-nucleon centre-of-mass energy, the $10nb^{-1}$ of low-p_T Pb-Pb data is equivalent to about 6 pb^{-1} of p-p data. ALICE expects to be able to operate the detector at a levelled luminosity of $5\text{-}10x10^{30}cm^{-2}s^{-1}$ which translates the data set into the equivalent of 1-2 months of gross running time. It is preferable to collect this data in one run period. In order to increase the acceptance towards low p_T for the low mass di-lepton studies, the Pb-Pb data taking plan includes a running period with a reduced solenoid field from 0.5T to 0.2T. This may also have to be complemented by a p-p run at reduced field to collect about 10^9 events, equivalent to a few hours of data taking. For the high p_T measurements and jets, the current ALICE baseline is to use the p-p data collected at 7, 8 and 13 (14) TeV and scale with the help of perturbative QCD.

As opposed to Run 1 and Run 2, ALICE will not participate in the nominal p-p run for the entire running year in Run 3 and Run 4. Instead, they need about 1-2 months of nominal p-p physics in the period before each heavy ion run in order to commission the detector and to perform detector calibrations.

In order to deduce the need for p-p reference data to match the ATLAS and CMS high p_T measurements in Pb-Pb collisions, the equivalent nucleon-nucleon luminosity should be scaled with the number of partons interacting. As a consequence, the $10nb^{-1}$ of Pb-Pb data is equivalent to 300 pb^{-1}. Again ATLAS and CMS prefers that the p-p reference data taking follows the integrated luminosity of Pb-Pb. This is particularly important for CMS in order to calibrate the jet energy scale at the equivalent nucleon-nucleon centre-of-mass energy. Again, at essentially no limit on the instantaneous luminosity, this data may be collected in a few days plus the setup time.

FORWARD PHYSICS PLANS

The definition of forward physics here include those measurements with very forward detectors located outside of the experimental caverns and that typically perform tagging of leading protons or detection of showers from diffractive or electromagnetic processes. These physics measurements may be split into two types: those that are performed parasitically or in parallel with high luminosity operation and with a nominal machine configuration, and those which require a special setup of the machine. For the former type, all of the experiments have their programs, and TOTEM and LHCb are making upgrades currently in LS1. LHCb will have the ideal conditions for studying Central Exclusive Production in Run 2 [12]. TOTEM is implementing the capability of resolving event pileup and multiple tracks in the proton detectors, and aims at accommodating timing detectors for reconstructing the longitudinal vertex position of the leading protons in central diffractive events [13]. This type of physics measurements in nominal conditions will continue in Run 2 and Run 3. While there are no plans currently, it is possible that this type of forward detectors will also still exist beyond Run 3. It should of course not be forgotten that while the future forward physics in parallel with the high luminosity operation will not require a special configuration of the LHC, the forward detector may still require special commissioning runs, such as for instance the Roman Pot alignment runs.

For the TOTEM physics program, and ATLAS/ALFA, which involve the high β^* operation (2.5km planned for Run 2) and that should be performed at each of the major LHC beam energies, the aim is to complete the data taking in Run 2. This assumes that the cables for the optics are installed for TOTEM. If this is not the case, the program may only be completed in Run 3. LHCf will complete their program in the very early stages of 2015.

There is clearly no plan for high β^* operation in the HL-LHC era.

ALICE & LHCB POLARITY SWITCHES

ALICE will only need infrequent polarity reversals in the future in order to keep control on the effects of space charge distortions in the TPC at high luminosity. As a rule of thumb, ALICE requires a polarity switch per running period with a new type of data set. Most likely ALICE will not request any polarity reversal during the nominal p-p runs at 13 TeV. As ALICE is not planning on running throughout the entire operational year with nominal p-p collisions in Run 3 and Run 4, the plan is to keep the solenoid off and the dipole permanently on to avoid machine re-commissioning before ALICE switches the detector on for the commissioning and calibration period, and the heavy ion run.

In order to maintain full control on systematics effects, LHCb is requiring annually as close as possible to equal statistics with both polarities, and polarity reversals at approximately bi-weekly frequency. For the tilted crossing angle, the relatively small number of analyses which have explored fully in detail the systematic effects in the 2011 data with a purely horizontal crossings and the 2012 data with the tilted crossing, have not yet observed a significant improvements with the tilted crossing scheme. For this reason it is not felt justified at this point to request this complicated scheme for Run 2. More information will come in the course of the next few months. Nevertheless, it is important to point out that it has been shown that there is clear benefit from reducing the asymmetry as much as possible by minimizing the difference between the overall crossing angle in the positive and negative polarity.

LUMINOSITY CALIBRATIONS

Luminosity calibrations are a special mode of operation involving a dedicated setup of the LHC machine which will continue to be mandatory into the HL-LHC era.

Obviously, a luminosity calibration is required at each major beam energy. It can also be expected that luminosity calibrations may be needed early in the run each year to recalibrate the luminosity monitors of the experiments. It is assumed that the goal on the accuracy of the calibrations will remain <2%.

As opposed to the luminosity calibrations in the past at ≤8TeV, the calibrations at higher energy will require β^* values larger than the current injection values to compensate for the smaller beam size. For the van der Meer scan method, ATLAS and CMS require a β^* of 15-20m. To exploit fully the beam gas imaging method in LHCb with the SMOG system [14], in addition to the vdM scan method, LHCb requires a β^* of 30-40m. This will allow fully measuring the single beam shapes and tails, and map out x-y correlations. This information is used by all experiments to achieve the ultimate accuracy on the luminosity calibrations. On the other hand, increasing the emittance as compensatory measure against the smaller beam size is strongly disfavoured as it introduced strong effects on the bunch shape in the past and was difficult to control.

As previously, the luminosity calibrations will continue requiring reduced bunch intensity (<$8\text{x}10^{10}$ ppb) to avoid the effects of dynamic beta and beam-beam deflections, a normalized emittance of around 3μm, and filling schemes with well separated isolated bunches. If present, it may be advantageous to maintain crab cavities off during the calibration for stability reasons and there may also be special requirements on the crossing angle.

As stated above, the LHCb SMOG system will remain in the LHCb upgrade, and will be kept operational beyond LS3.

CONCLUSIONS

The impressive performance of the LHC accelerator in the first three years of operation has enabled the LHCb experiment to pave the way for heavy flavour physics at an entirely new level of precision which will be pursued further in Run 2 into the territory where small deviations from the SM may be expected with another 5-6 fb^{-1}. Nevertheless, the ultimate precision and the access to many physics modes may only be achieved with a 5 to 10-fold increase in statistics.

The astonishing flexibility of the LHC also allowed already re-examining the understanding in heavy ion collisions with the sequel of a number of surprising measurements and discoveries. In particular data from p-Pb collisions and even p-p reference exhibit some collective phenomena which require more understanding to interpret the strongly interacting medium and QCD effects in Pb-Pb collisions. Run 2 should produce a 5-, 10-fold increase in statistics at higher energy with the potential to produce measurements with sufficient precision to start constraining models.

In order to exploit at maximum the LHC capacity and physics potential, both ALICE and LHCb are each going through a major upgrade in LS2, both of which will require an 18 month access to the experimental cavern.

Both upgrades should allow collecting an order of magnitude more luminosity during Run 3 and Run 4 and beyond with the promise of a large number of results of fundamental importance.

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