

Recent results from LHCb and future prospects

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Abstract

A review of the operation and of the performance of the LHCb experiment at the LHC collider is presented, together with highlights of recent physics results based on the data collected in the 2011 run, which correspond to an integrated luminosity of $\sim 1 \text{ fb}^{-1}$. These measurements have already relevant implications on the contributions of New Physics processes in the field of rare b decays, and in the search for CP violation in B^0 and B_s^0 mesons decays. The prospects and the main items of the planned upgrade of LHCb are also discussed.

Keywords: LHCb; flavour physics; CP violation

1. Introduction

The Standard Model (SM) of Particle Physics is known to be incomplete, as it contains too many free parameters, such as the fermion masses and the quark mixing angles. The goal of the experiments at the Large Hadron Collider (LHC) is to identify the hidden mechanism that will supersede the SM at an higher energy scale, expected in the TeV region and therefore accessible at the LHC. This would imply new symmetries, particles, dynamics, and flavour structure (the so called New Physics, NP) that can be discovered either directly or indirectly.

The direct approach (usually referred as the “energy frontier”) exploited by ATLAS and CMS, aims at the observation of new particles produced on shell in LHC pp collisions.

The indirect approach (usually referred as the “intensity frontier”) on the other hand, consists of measuring quantum effects in the decay of known particles, especially in flavour-changing neutral current (FCNC) transitions, strongly suppressed in SM, and looking for deviations from the predictions. At the LHC, this strategy is most suited to the LHCb experiment, which has been designed specifically for precise measurements of CP violation and rare decays of hadrons containing a b or c

quark.

The two approaches are complementary: NP possibly observed at the TeV scale needs to have a non-trivial flavour structure in order to provide the suppression mechanism for the already observed FCNC processes. Only indirect measurements can access the phases of the new couplings and therefore shed light on the NP flavour structure. Moreover, it is well known that precision physics can access mass scales higher than direct searches.

One of the strategies for indirect searches in hadronic decays consists of measuring in several different ways observables that can be related to the magnitudes and phases of the elements of the Cabibbo-Kobayashi-Maskawa (CKM) [1, 2] matrix describing the SM flavour structure in the quark sector. Any inconsistency between the interpretations of these measurements within the CKM picture will be a sign of NP. Another strategy is to identify and measure single FCNC processes, for which a clear SM prediction can be made, and where NP is likely to contribute with loop diagrams mediated by new particles.

Following these strategies, LHCb is measuring rates of very rare decays $B_s^0 \rightarrow \mu^+ \mu^-$ and $B^0 \rightarrow \mu^+ \mu^-$, CP-violating phases induced by mixing effects in $B_s^0 \rightarrow J/\psi \phi$, interference between $b \rightarrow u$ and $b \rightarrow c$ transi-

tions in tree-level $B \rightarrow DK$ decays, CP asymmetries in two-body B and D decays, and probing the helicity structure of weak interactions (photon polarization in $B_s^0 \rightarrow \phi\gamma$ and other radiative decays, asymmetries in $B^0 \rightarrow K^{*0}\mu^+\mu^-$ decays).

Those measurements represent the core physics program of LHCb. However, a wider program includes many more measurements, mostly in the production of heavy-flavour states and electroweak gauge bosons, in QCD and in searches for exotica.

In LHCb, and at the LHC in general, no hints of deviations from the SM has been observed so far, but there is still excellent discovery potential in the ongoing 2012 run, and beyond.

2. The LHCb experiment at the LHC

The LHCb detector [3] is a single-arm forward spectrometer covering the pseudo-rapidity range $2 < \eta < 5$, designed for studying particles containing b or c quarks, the production of which peaks in the forward region (Fig. 1).

The environment at LHCb is dominated by pp elastic (not observed in LHCb) and inelastic interactions with a huge cross-section (~ 70 mb). The $b\bar{b}$ production cross-section has been measured to be $\sim 280 \mu\text{b}$ (of which about $70 \mu\text{b}$ is in the LHCb acceptance) at 7 TeV [4]. At the LHC, the whole spectrum of b -hadrons is accessible with a composition of B^0 ($\sim 40\%$), B^+ ($\sim 40\%$), B_s^0 ($\sim 10\%$), and others b -hadrons (such as B_c^+ , Λ_b , etc... $\sim 10\%$).

The experiment is required to provide an excellent vertex resolution to suppress background and to resolve fast B_s^0 oscillations (on average, the flight path of b mesons is ~ 7 mm), a very good mass resolution and good particle identification (K/π and μ) to reduce the background in the interesting final states, an efficient trigger for hadronic and leptonic states with as low as possible contamination from minimum bias events, and good flavour tagging capabilities.

The detector includes a high-precision tracking system consisting of a silicon-strip vertex detector (VELO) surrounding the pp interaction region, a large-area silicon-strip detector (TT) located upstream of a dipole magnet with a bending power of about 4 Tm, and three stations (T) of silicon-strip detectors and straw drift tubes placed downstream. The combined tracking system has a momentum resolution $\Delta p/p$ that varies from 0.4% at 5 GeV/c to 0.6% at 100 GeV/c, an impact parameter resolution of $20 \mu\text{m}$ for tracks with high transverse momentum, and a decay time resolution of 50 fs.

Charged hadrons are identified using two ring-imaging (RICH) Cherenkov detectors. Photon, electron and hadron candidates are identified by a calorimeter system consisting of scintillating-pad and pre-shower detectors, an electromagnetic calorimeter, and a hadronic calorimeter. Muons are identified by a system composed of alternating layers of iron and multi-wire proportional chambers.

The LHCb trigger consists of a first level hardware stage (L0), based on information from the calorimeter and muon systems with the task of reducing the primary visible collision rate (~ 12 MHz) to 1 MHz, followed by a second level software stage (HLT) which applies a full event reconstruction, bringing the total output on tape to 5 kHz. The trigger efficiencies (L0xHLT) for off-line selected events, amount to 70-90% for B decays with dimuons in the final states, to 20-50% for B decays in hadrons, and to 10-20% for charm events.

In 2012 the L0 trigger rate has been brought to its maximum allowable, that is ~ 1 MHz, while a “deferred trigger”, allowing the processing of an extra 20% of events staged on HLT farm disks, during LHC inter-fill gaps, has been successfully deployed. The computing system is able to reprocess and to prepare the final stripped data resident on disks at an output rate of approximately 300 Hz.

The invariant mass resolutions of the main resonances decaying into muons and of B mesons [5] are the best achieved at the LHC: J/ψ (13 MeV/c²), $\Upsilon(1S)$ (47 MeV/c²), $B^0 \rightarrow K\pi$ (25 MeV/c²), $B_s^0 \rightarrow J/\psi\phi$ (7 MeV/c²).

Kaons and protons are identified with very good purity and efficiencies by the RICH systems, while the muon efficiency and mis-id are respectively $\sim 97\%$ and $\sim 1\%$ for $p > 20$ GeV/c, being the mis-id mainly dominated by kaon decays in flight.

The LHCb experiment collected 1.0 fb^{-1} of integrated luminosity during the 2011 run, at a centre of mass energy of $\sqrt{s} = 7$ TeV, while in 2012 it has so far collected 0.75 fb^{-1} at an energy of $\sqrt{s} = 8$ TeV (Fig. 2).

The LHCb luminosity is kept constant throughout the fill and at a value compatible with safe and efficient detector operation, using the “luminosity levelling” technique, achieved through the partial separation of colliding beams at the interaction point of LHCb.

In 2012, to reduce the detector sensitivity to the systematics introduced by the change of beam crossing angles in the horizontal plane during regular LHCb magnetic polarity swaps, the LHC beams have been brought in collisions in the vertical plane, therefore providing a nearly perfect symmetric configuration.

Data are currently recorded at an instantaneous lumi-

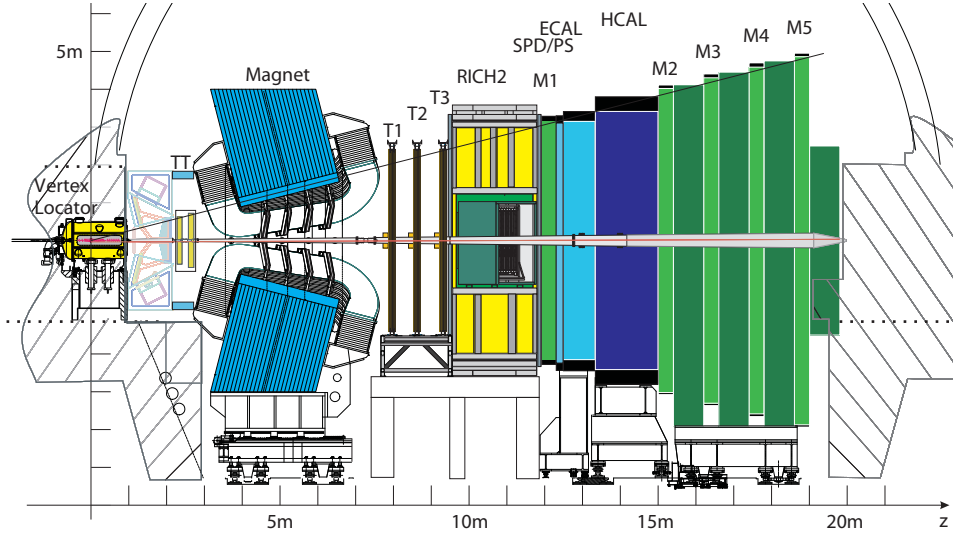


Figure 1: The LHCb detector.

osity of $\sim 4 \cdot 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ (a factor 2 above the design value) and with a pile-up rate of ~ 1.7 (four times the nominal one), at a bunch spacing of 50 ns. Based on the experience of 2011, and including the recently approved extension of the pp run, LHCb expects in 2012 to collect on tape a luminosity in excess of 2.2 fb^{-1} .

LHCb will also participate to the data taking with (pA, Ap) beams in the early period 2013, so to exploit the contributions that the experiment can provide to these measurements in an unique kinematic domain equipped with particle identification.

3. Highlights of LHCb Physics Results

Several LHCb physics results are covered in detail at this Workshop by other speakers. Let us briefly describe some of the most important measurements recently performed by the experiment.

3.1. The rare decay $B_s^0 \rightarrow \mu^+ \mu^-$

The flavour changing neutral current (FCNC) processes are highly suppressed in the SM and thus constitute a stringent test of the present description of particle physics.

Precise predictions of the branching fractions [6] of the FCNC decays, $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) = (3.23 \pm 0.27) \times 10^{-9}$ and $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) = (0.11 \pm 0.01) \times 10^{-9}$ make these modes powerful probes in the search for deviations from the SM, as contributions from new processes or new heavy particles can significantly modify these values,

in particular in SUSY models where $\tan \beta$ has a high value.

The strategy for the search for this decay in LHCb is based on an initial selection followed by the classification of events as signal or background based on two uncorrelated quantities: the invariant mass and the output of a multivariate operator which takes into account several kinematical variables.

The branching ratio is extracted using three normalization channels: $B^+ \rightarrow J/\psi K^+$, $B^0 \rightarrow K^+ \pi^-$ and $B_s^0 \rightarrow J/\psi \phi$. The compatibility of the observed distribution of events with that expected for a given branching fraction hypothesis is computed using the CL_s method [7]. The invariant mass distribution of selected $B_s^0 \rightarrow \mu^+ \mu^-$ candidates from 1.0 fb^{-1} integrated luminosity by the LHCb experiment is shown in Fig. 3.

LHCb has obtained the best published limits [8], $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 4.5 \times 10^{-9}$ and $\mathcal{B}(B^0 \rightarrow \mu^+ \mu^-) < 1.0 \times 10^{-9}$ at 95% confidence level (CL), with an expected value (if the signal is assumed to be SM-like) of $< 7.2 \times 10^{-9}$ at 95% CL for the $B_s^0 \rightarrow \mu^+ \mu^-$ channel. A recent combination of LHCb, CMS and ATLAS measurements, brings to a limit of $\mathcal{B}(B_s^0 \rightarrow \mu^+ \mu^-) < 4.2 \times 10^{-9}$ at 95% CL [9].

It is also worth noticing that in several NP models, in particular those with a Higgs singlet, the branching fraction may indeed be suppressed with respect to the SM value [10].

3.2. The rare decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$

In the SM, the electroweak penguin decays $b \rightarrow s(d)l^+l^-$, where $l = \mu, e, \tau$, are only induced at the one-loop level, leading to small branching fractions and thus rather high sensitivity to contributions from NP beyond the SM. The rare decay $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ is a $b \rightarrow s$ flavour changing neutral current decay which in the SM is mediated by electroweak box and penguin diagrams. It can be a highly sensitive probe for new right handed currents and new scalar and pseudoscalar couplings. These NP contributions can be probed by studying the angular distributions of the B^0 daughter particles.

The most prominent observable is the forward-backward asymmetry of the muon pair (A_{FB}). A_{FB} varies with the invariant mass-squared of the dimuon pair (q^2) and in the SM changes sign at a well defined point, where the leading hadronic uncertainties cancel. In many NP models the shape of A_{FB} as a function of q^2 can be dramatically altered.

The latest LHCb analysis [11] uses 1.0 fb^{-1} of data collected during 2011 to measure A_{FB} , and other relevant angular variables as a function of q^2 . The first measurement of the zero-crossing point of the forward-backward asymmetry of the dimuon system of $q^2(0) = (4.9_{-1.3}^{+1.1}) \text{ GeV}^2/c^4$ has been performed, to be compared with SM predictions [12, 13, 14] that are in the range $[4.0 - 4.3] \text{ GeV}^2/c^4$ (Fig. 4).

These results are in good agreement with SM predictions. The experimental uncertainties are presently statistically dominated, and so the precision overall will improve with a larger data set. More details on LHCb results on B rare decays can be found at another talk at this Workshop [15].

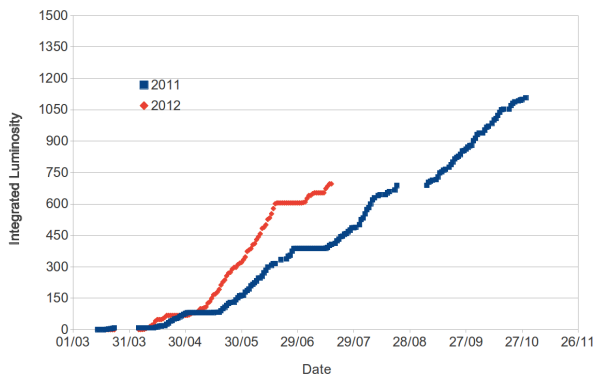


Figure 2: Plot of luminosity collected by LHCb in 2011 and 2012.

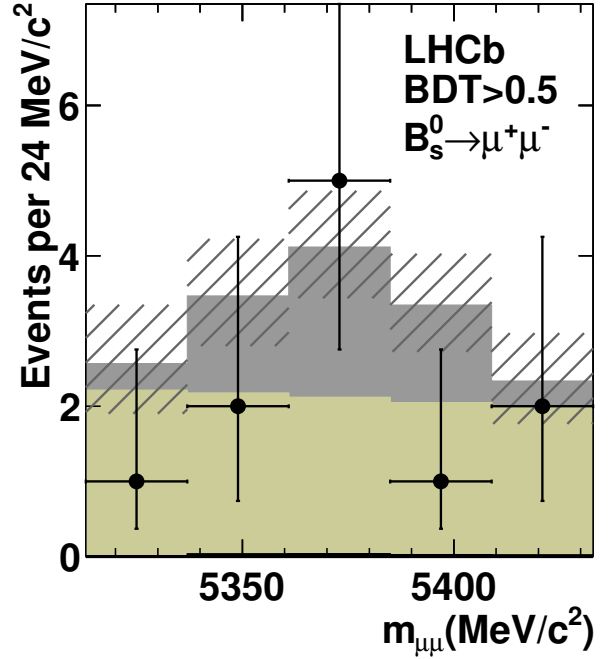


Figure 3: Mass distribution of $B_s^0 \rightarrow \mu^+ \mu^-$ selected candidates (black points) and expectations for the signal (gray), the combinatorial background (light gray) and peaking $B \rightarrow h^+ h^-$ background (black, barely visible on the bottom part of the plot). The hatched areas depict the uncertainty on the sum of the expected contributions.

3.3. CP violation in the B_s^0 system

Decays of neutral B_s^0 mesons provide a unique laboratory to study CP-violation originating from a non-trivial complex phase in the CKM matrix. The relative phase between the direct decay amplitude and the amplitude of decay via mixing gives rise to time-dependent CP-violation, a difference in the proper decay time distribution of B_s^0 and \bar{B}_s^0 meson decays.

The decay $B_s^0 \rightarrow J/\psi \phi$ is considered the golden mode for measuring this type of CP-violation. In the Standard Model the CP-violating phase (ϕ_s) in this decay is predicted to be very small, while NP contributions could significantly alter this value [16]. Measurements of B_s^0 mixing have been performed by the Tevatron experiments [17, 18], but these only provide weak constraints on the value of the CPV phase ϕ_s .

LHCb has performed measurements of ϕ_s both in $B_s^0 \rightarrow J/\psi \phi$ and $B_s^0 \rightarrow J/\psi \pi^+ \pi^-$ channels, with 1.0 fb^{-1} , obtaining [19, 20] a combined value of $\phi_s = (-0.002 \pm 0.083 \pm 0.027) \text{ rad}$, consistent with SM predictions within the present accuracy.

The $B_s^0 \rightarrow J/\psi \phi$ sample allowed also to perform the first direct observation for a non-zero value of $\Delta\Gamma_s =$

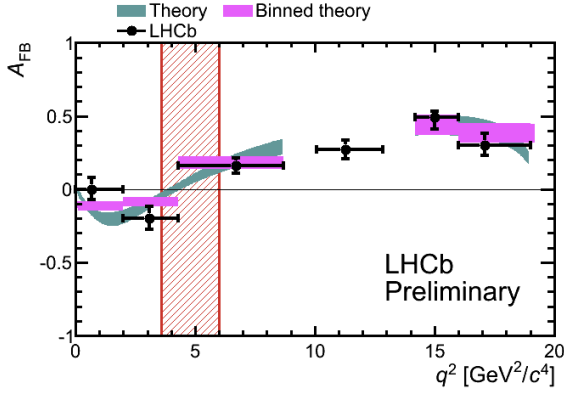


Figure 4: The forward backward asymmetry distribution as a function of q^2 in $B^0 \rightarrow K^{*0} \mu^+ \mu^-$ events.

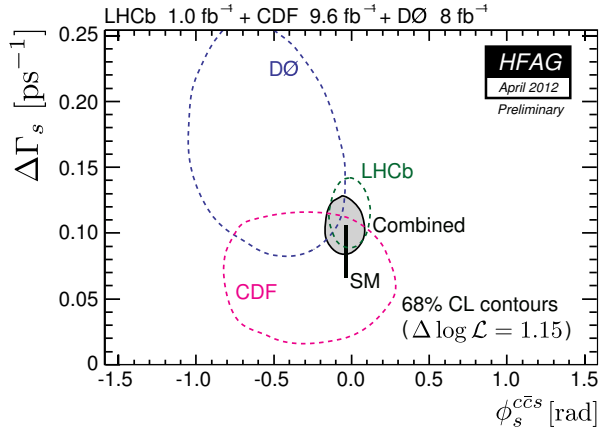


Figure 5: The ϕ_s vs. $\Delta\Gamma_s$ contour plot showing the LHCb, CDF and D0 results and the SM prediction.

$(0.116 \pm 0.018_{\text{stat}} \pm 0.006_{\text{syst}}) \text{ ps}^{-1}$, where $\Delta\Gamma_s$ is the mean decay width difference of the light and the heavy B_s^0 mass eigenstates (Fig. 5).

Moreover, the sign ambiguity under the sign reversal of ϕ_s and $\Delta\Gamma_s$ has been removed by LHCb by studying the variation of the difference of the strong phase between the $K^+ K^-$ S-wave and P-wave amplitudes in $B_s^0 \rightarrow J/\psi K^+ K^-$ decays as a function of the $K^+ K^-$ invariant mass around the $\phi(1020)$ resonance [21]. This determines the sign of the decay width difference $\Delta\Gamma_s$ to be positive, and eliminates an ambiguous solution in the ϕ_s analysis, leaving the solution quoted above, assigning unambiguously the correct CP states to the B_H , B_L mass eigenstates.

In the search for NP in the B_s^0 system, the D0 measurements [22, 23] of the muon and di-muon asymme-

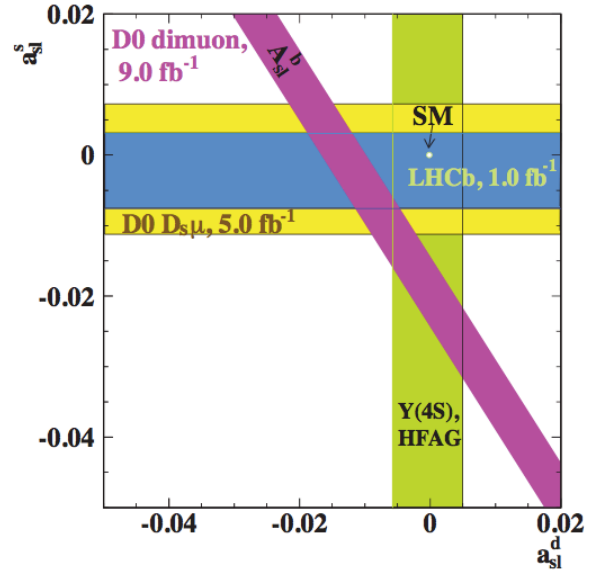


Figure 6: Measurements of semileptonic decay asymmetries at B -factories, D0 and LHCb. The bands correspond to the central values ± 1 standard deviation.

tries, still display a large deviation from the SM, pointing possibly to non-SM contributions to ϕ_s and $\Delta\Gamma_s$.

Recently LHCb has presented [24] a measurement on the CP violation asymmetry a_{sl}^s using samples of B_s^0 and B_s^0 semileptonic decays using an integrated luminosity of 1.0 fb^{-1} . The detected final states are $D_s^\pm \mu^\mp X$ with D_s reconstructed in the $\phi\pi$ mode. Data driven methods have been developed to measure all the efficiency ratios needed to determine the asymmetry, obtaining $a_{sl}^s = (-0.24 \pm 0.54 \pm 0.33)\%$, in good agreement with the SM expectation, although still compatible at 2σ level with the D0 result (Fig. 6).

More details on CP violation studies in LHCb can be found in other talks at this Workshop [25, 26].

3.4. CPV in charm SCS decays

The charm sector is a promising place to probe for the effects of physics beyond the Standard Model. While charm mixing has been firmly established at the B -factories and CDF, available data show no evidence for any kind of CP violation and several methods are being exploited by LHCb to search for it.

Since the startup of data taking in 2010, it was realized that LHCb had very good prospects as far as measurements in the charm sector were concerned. The very high charm production cross section, $\sigma_{c\bar{c}} \sim 6 \text{ mb}$ [27], and the recognition that LHCb had a sizeable trigger

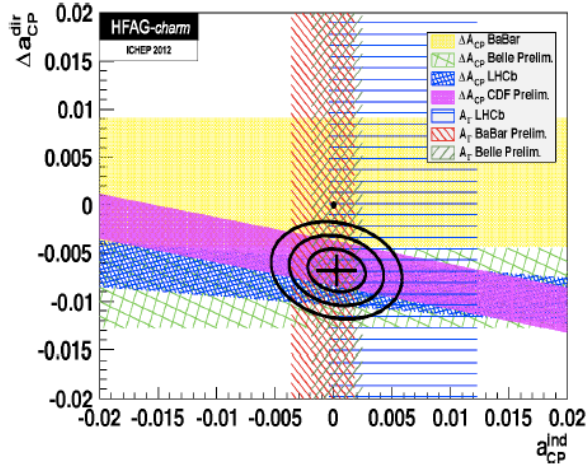


Figure 7: The HFAG fit of the latest experimental values of a_{CP}^{ind} and a_{CP}^{dir} from LHCb, B factories and CDF.

efficiency also on charm decaying into hadronic final states, with typical low p_T , made possible to include it in the core physics program of LHCb since then. In fact, between 2010 and 2011 and even more in 2012, the HLT was improved to increase the efficiency for charm detection.

Of particular relevance is the search for CP violation in Cabibbo suppressed charm decays (SCS), where interference between tree and penguin diagrams could generate direct CP violation. Until recently, asymmetry values of $O(1\%)$, were considered potential sign of NP [28, 29].

In LHCb the measurement is performed using D^* tagged D^0 decays with $\pi^+\pi^-$ or K^+K^- in the final state. Detector and production asymmetries biases are removed (at least at first order) building the variable $\Delta A_{CP} = A_{raw}(KK) - A_{raw}(\pi\pi)$ where the production and the D^* detection asymmetries cancel out. Also the indirect CP violation cancels out as this is invariant for any final state (in reality, due to different lifetime acceptances for KK and $\pi\pi$ final states, still a 10% effect due to a_{CP}^{ind} is present). The measurement [30] has been performed on a sample that is already 10 times larger than that available at B -factories.

The present result suggests a 3.4σ non-zero value of the asymmetries difference: $\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$. This value is in agreement with the HFAG average [31] and with recent similar measurements performed by the CDF Collaboration [32]: $\Delta A_{CP} = (-0.62 \pm 0.23)\%$ and Belle Collaboration [33]: $\Delta A_{CP} = (-0.87 \pm 0.41)\%$, as shown in Fig. 7.

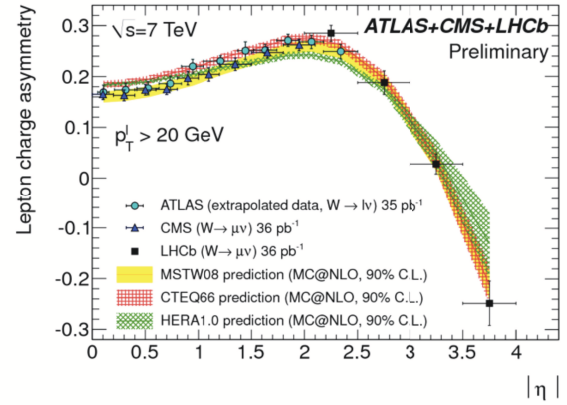


Figure 8: Lepton charge asymmetry from W^\pm decays as a function of pseudorapidity.

The result has generated a strong interest from theorists. However, several authors [34, 35] have suggested that a QCD enhancement of penguin matrix elements could be a possible Standard Model source of this effect. Further tests will be performed and the analysis of the full 2011-2012 dataset will allow to clarify better the situation or to improve the accuracy.

3.5. Non-flavour physics

The LHCb forward acceptance provides very interesting PDF studies, complementary to those of ATLAS and CMS one, as the experiment can profit from the accessibility of two very distinct and unique regions in the (x, Q^2) space (respectively at 10^{-2} and at 10^{-5} in the x variable). Measurements of the W and Z cross-sections and of low-mass Drell-Yan cross-sections, constitute an important test of the Standard Model in pp collisions, and the study of the charge asymmetry in W decays as a function of pseudo-rapidity provides useful information on PDFs. The forward region covered by LHCb shows a steeper dependence of this asymmetry on the η variable and therefore has a high predictive power as far as the comparison between models is concerned (Fig. 8). All results so far obtained [36] are consistent with next-to-next-to-leading order theoretical predictions.

Quarkonium spectroscopy and production in hadron collisions is a subject of large interest and is treated in detail in a talk at this Workshop [37].

Non-flavour physics are complemented by searches for Majorana neutrinos in 0.4 fb^{-1} of data collected in 2011 [38] in several B^+ decay channels, and by limits on detection of long lived particles, for which the LHCb vertex detector acceptance is very well suited.

As already mentioned, LHCb will participate in the (pA , Ap) data taking, which will take place at the end of the pp run. The expected instantaneous luminosity will be quite low ($\sim 10^{26} \text{ cm}^{-2} \text{ s}^{-1}$) but interesting for the kind of contribution which can be given at low η and with a good particle ID. The physics items concern soft QCD measurements (particle multiplicities, strangeness production and energy flow), J/ψ related measurements (cross section and polarization) and more advanced topics (DY and low- x phenomena, open charm, Υ and b mesons) where much bigger statistics would be however needed.

4. Implications of LHCb results on New Physics

Recent precision results from LHCb have started to produce implications on the allowable amount of phase space for the parameters of models of physics beyond the SM [39].

In this respect, the measurements that have produced the most relevant implications for NP constraints are the limit on $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$, the measurement of ϕ_s and ΔA_{CP} . Also the measurements with $B^0 \rightarrow K^{*0}\mu^+\mu^-$ decay have implications for NP models and we refer to [40] for a more detailed discussion.

The experimental evidence that the $B_s^0 \rightarrow \mu^+\mu^-$ decay is not largely enhanced by NP, shows that, at least in minimal supersymmetrical models the value of $\tan\beta$ is moderate. Therefore, in the case of SUSY models where $\tan\beta$ is large, the area of non-allowed values of two of the relevant SUSY parameters (m_0 and $m_{1/2}$), is well beyond the limits currently available from direct searches in ATLAS and CMS (Fig. 9).

In the SM it is also known that the ratio of $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-)$ and $\mathcal{B}(B^0 \rightarrow \mu^+\mu^-)$ is a powerful test for the validity of SM. The present limits on this ratio already rule out several models [42].

The measurement of ϕ_s with high precision has also implications for NP searches. On one hand, when the value of ϕ_s is correlated with the current limit on $B_s^0 \rightarrow \mu^+\mu^-$ decay it provides a strong reduction in the number of possible models fitting current data (Fig. 10).

Moreover, the determination of ϕ_s allows also to test the compatibility of various CKM fits in the B_s^0 mixing. The correlation with the several different muon asymmetries determinations (such as those of D0 and LHCb) is important, and future higher statistics measurements in this field will help in clarifying clarify the overall picture (Fig. 11).

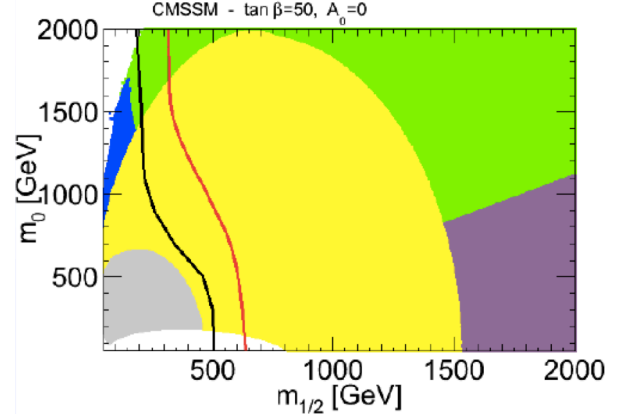


Figure 9: Exclusion regions for m_0 and $m_{1/2}$ parameters from fit to CMSSM assuming $\tan\beta=50$: in yellow the area provided by $B_s^0 \rightarrow \mu^+\mu^-$ limit, the red (black) line referring to limits from direct searches at LHC with 4 fb^{-1} (1 fb^{-1}). Reproduced from [41].

5. The LHCb Upgrade

The flavour sector offers a very rich complementarity to the High Energy Frontier (ATLAS and CMS) searches for NP. Recent LHCb results have shown the potentialities of flavour physics at LHC and the good performances of the detector: LHCb is unique for NP searches in the B_s^0 system, works well also for B^0 decays and a huge sample of charm is available, showing very good complementarity also in respect to upgraded B factories. The detector can be operated also at the future High Luminosity LHC (HL-LHC) via luminosity leveling.

The LHCb experiment, by the end of 2017, will collect $\sim 5 \text{ fb}^{-1}$ or more at the energy of $\sqrt{s} = 14 \text{ TeV}$. However, pinning down the theoretical error on several variables on which Standard Model is able to provide theoretically precise predictions, such as γ , the angular variables of the $B^0 \rightarrow K^{*0}\mu\mu$ decay, ϕ_s or the $\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) / \mathcal{B}(B^0 \rightarrow \mu^+\mu^-)$ ratio, will require more statistics. The above considerations make easily justifiable the plan for the upgrade of the LHCb detector.

The main limitation of the current LHCb experiment is due to the built-in maximum detector readout rate of 1 MHz. Even increasing the luminosity, the efficiency for channels with hadrons will decrease, caused by the need of increasing the E_T threshold, to stay within the bandwidth limit. Consequently, the LHCb upgrade plans to remove this limitation, allowing for a fully software 40 MHz readout trigger. To achieve this challenging goal, and to perform optimally up to a luminosity of $\sim 2 \cdot 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$ and at an average pile-up of ~ 4 , intense plan-

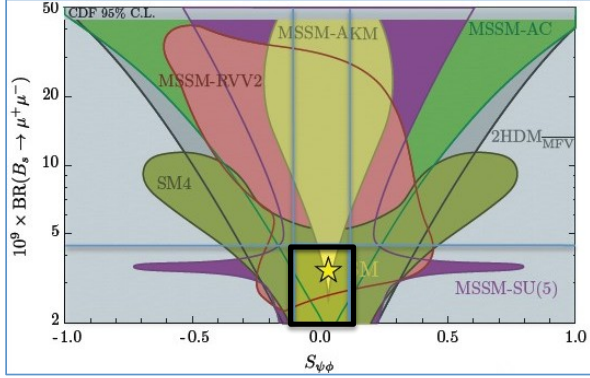


Figure 10: Correlation between the branching ratio of $B_s^0 \rightarrow \mu^+ \mu^-$ and the mixing-induced CP asymmetry $S_{\psi\phi}$ in the SM4, the two-Higgs doublet model with flavour blind phases and three SUSY flavour models. The SM point is marked by a star, while the experimental allowed region is inside the box (adapted from [43]).

ning is underway for a detector upgrade, which foresees a new vertex detector, a new tracking system, and 40 MHz readout on all subsystems. The plan is to have the experiment ready to restart data taking just after the long shutdown 2 (LS2) in 2019, and to collect 50 fb^{-1} afterwards.

With respect to data collected in 2011, we expect an increase ($\sim \times 10$) of the yields of channels with muons in the final state, and a much higher one in channels decaying in hadrons (at least $\times 20$) due to the capabilities of a software based trigger to lower the E_T thresholds.

The relevant changes in the detector foreseen for the upgrade concern the tracking systems: the vertexing (VELO) and the tracking (TT and T stations) systems.

For the vertex detector, two technologies are under scrutiny: one based on a pixel detector (developed starting from the Timepix chip), which foresees a readout granularity of $55 \times 55 \mu\text{m}^2$ and a second one that is an evolution of the present silicon strip detector.

The biggest challenges in this area are related to capability of dealing with huge rates in the inner sectors, and the possibility of withstand radiation levels of $n_{eq} \sim 8 \cdot 10^{15} \text{ cm}^{-2}$. Several R&D activities are in common between the two technologies: new cooling interface, new RF foil, and reduction of material budget. The decreasing of the distance to the IP is also under study.

The tracking stations before the magnet (TT) will be equipped with silicon detectors (as in the current layout); for the detectors after the magnet (T), one option is based on the use of a Scintillating Fiber Central Tracker, covered by $250 \mu\text{m}$ fibers readout by SiPM photo-sensors, the alternative option being to re-design

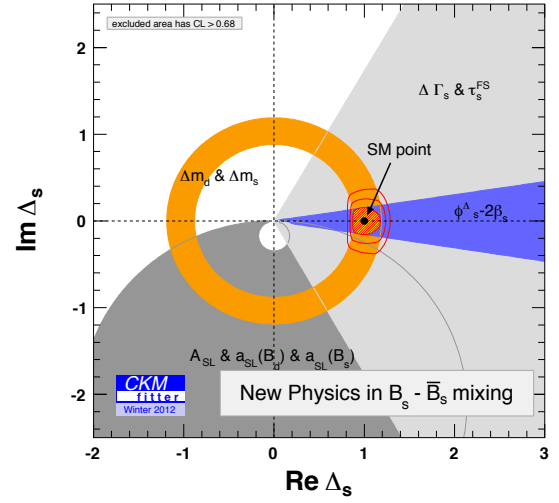


Figure 11: Contour plot for complex parameter Δ_s describing New Physics in B_s^0 mixing. Reproduced from [44].

the current layout made of silicon strips (inner part) and straw tubes (outer part), allowing for a larger area with silicon detectors, to cope for the increased tracks occupancy.

Preliminary fibre modules tested with beams show that the spatial resolution is the one needed for LHCb. Here the relevant key issues are the possibility of decreasing the material budget in the hypothesis of a larger IT Silicon tracker and the resistance to radiation of SiPM and fibres in the option of the Scintillating Fibre Central Tracker. It has been shown that lowering the temperature of SiPM (below -10°C) reduces the radiation effects.

RICH, calorimeter and muon systems will also be upgraded, in particular as far as photo-sensors and front-end electronics (RICH) and readout electronics (calorimeter and muons) are concerned. For the RICH, the current baseline makes use of Multi anode PMT.

In March 2011, LHCb has presented to the LHC Committee a *Letter of Intent for the Upgrade* [45], which was fully endorsed, inviting the Collaboration to proceed towards the Upgrade TDR. In June this year, a *Framework TDR for the LHCb Upgrade* [46] has been submitted to the LHC Committee for approval, describing the plans, the cost and the resources needed for the upgrade. The preparation of TDRs for the various sub-detectors is planned for the end of 2013.

6. Conclusions

Thanks to LHC performances, to luminosity leveling technique, and the excellent performances of the detector, LHCb has collected over 1.0 fb^{-1} in the 2011 run, $\sim 0.75 \text{ fb}^{-1}$ in 2012 - and is planning to more than triple the last year statistics, by the end of current run.

Analyses in the core physics channels are well advanced, with areas of world record measurements: $B_s^0 \rightarrow J/\psi\phi$, $B_s^0 \rightarrow \mu^+\mu^-$, $B^0 \rightarrow K^{*0}\mu^+\mu^-$, B_s^0 mixing and charm physics. A large amount of other channels are under study with very good perspectives for future new measurements in CPV in b and c decays, the CKM angle γ , radiative and rare decays, and in non-flavour physics.

The Standard Model shows its solidity, but there is still room available for New Physics and the implications coming from LHCb measurements show its complementarity with ATLAS and CMS in constraining Supersymmetry.

The 40 MHz LHCb upgrade will allow to fully exploit an higher luminosity from LHC and to enhance the efforts for New Physics searches in the next decade: the collaboration is preparing the upgrade of the experiment, intended to collect $O(50 \text{ fb}^{-1})$ starting in 2019, after the long shutdown no.2 of LHC.

This very large sample should allow to determine several Standard Model variables in the flavour sector to a precision comparable with the ultimate theoretical uncertainty.

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