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Precise B-Decay Measurements sensitive to Beyond Standard Model Physics at ATLAS

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Abstract. The LHC experiments will perform sensitive tests of physics phenomena beyond the Standard Model (BSM). Investigation of decays of beauty hadrons represents an alternative approach in addition to direct BSM searches. The ATLAS efforts concentrate on those B decays that can be selected already at the first and second trigger levels. The most favorable trigger signature will be for B hadrons decaying to $J/\psi \to \mu\mu$. Using this trigger ATLAS will be able to accommodate unprecedently high statistics in so called Golden LHC channel $B_s \to J/\psi\phi$ allowing a measurement of the CP violation effect, where BSM models predicted values are significantly higher than SM. In the rare decays sector, these are purely di-muon decays, and families of semi-muonic exclusive channels. Already with 1 fb^{-1} the ATLAS sensitivity in the di-muon channels will be comparable to today worlds statistics. The strategy is to carry on the di-muon channel program up to nominal LHC luminosity. In particular the $B_s \to \mu^+\mu^- X$ signal with 4.3 σ significance can be measured combining low luminosity samples with those of one year of LHC operation at a luminosity of 10^{34} cm^{-2}s^{-1}. This precision allows excluding or confirming the SM unambiguously.

1. ATLAS B-Physics and Trigger Strategy

The expected inclusive production cross section for $b\bar{b}$ pairs at LHC is estimated to be $\sigma_{b\bar{b}} \approx 500$ μb leading to more than 10^6 produced pairs per second at design luminosity. The experimental precision reached at ATLAS should at least allow the verification of the SM prediction. With an integrated luminosity of 30 fb^{-1}, corresponding to a data taking period of 3 years at the initial luminosity of $\mathcal{L} \approx 10^{33}$ cm^{-2}s^{-1}, this is feasible for most of the B-physics channels in question. In the case of the rare B-decays, clearly more luminosity is needed to achieve sensitive upper limits for the indirect BSM searches. Therefore, the most relevant part of the ATLAS-B-physics program will be taken in the initial phase at lower luminosities with an extension into the high luminosity phase.

1.1. General Strategy for B-Physics

ATLAS is a general-purpose experiment with main emphasis on searches for new phenomena based on high p_T particles. Since most of the B-physics appears in a lower p_T range, triggering within the LHC environment on those events is a challenge. Nevertheless, ATLAS has also good capabilities for a rich B-physics program, based on the precise and flexible vertexing and tracking, the good muon identification, the high-resolution calorimetry and on the dedicated and flexible trigger scheme. The B-physics program is well defined for all the stages of the LHC luminosity operation. Huge b-flavored-hadron production rates allow for precise measurements of their properties. Furthermore, theoretical descriptions of heavy flavored hadrons need input from LHC, where precision measurements are already achievable after one year of data taking.

The envisaged measurements in the B-physics sector at ATLAS [1, 2] are extending the discovery potential for physics beyond the SM. This is the measurement of CP violation parameters in the $B_s \to J/\psi\phi(\eta)$ decay, which are predicted to be small in the SM and of rare B decays, as $B_d \to K^*\gamma$, $B_d \to K^*\mu\mu$, $B_s \to \phi\mu\mu$, $B_s \to \gamma\mu\mu$ and $B \to \mu\mu$. Due to the stiff competitions from B-factories, the ATLAS B-physics program is focused on topics not accessible to them, as B_s decays and oscillations, b-baryons and doubly heavy flavored hadrons as $B_s \to J/\psi\phi(\eta)$, $B_s \to \phi\mu^+\mu^-$, $B_s \to \phi\gamma$, $B_c \to J/\psi\pi$, $\Lambda_b \to \Lambda^0\mu^+\mu^-$, $\Lambda_b \to \Lambda^0 J/\psi$ and the $B_s \to D_s\pi/a_1$ decay, which will be used for the Δm_s measurement (see Chap. 2.2).

1.2. Trigger Strategy

Since only a small fraction of the limited bandwidth of the ATLAS trigger system is devoted to the B-physics triggers, highly efficient and selective triggers are needed. In addition, c- and b-events are containing mostly low p_T particles, which is an additional challenge for the trigger. On the other hand, many b decays are containing J/ψ mesons, which are useful for calibration, optimization and understanding of the detector, the trigger system and the topology of B-physics events at ATLAS. Most of those triggers are based on single and di-muon events in the final state leading to a clean signature at early trigger levels and giving a flavor tag [3, 4, 5].

For the run phases at lower luminosities ($\mathcal{L} < 10^{33}$ cm^{-2}s^{-1}), the trigger strategy is mainly based on a single muon trigger at the first level, which could be combined with certain calorimeter trigger objects at higher trigger levels to select hadronic final states ($B_s \to D_s\phi$) or e/γ final states ($J/\psi \to e^+e^-$, $K^*\gamma$ or $\phi\gamma$). In order to not exceed the available bandwidth, in the phase of higher luminosities above $2 \cdot 10^{33}$ cm^{-2}s^{-1} the main working trigger will be based on di-muons on the first level, enabling a clean measurement of rare B-decays ($B \to \mu\mu$ or $B \to K^{*0}\mu\mu$), double semi-leptonic decays and the $B \to J/\psi(\mu\mu)$ decay channels.

2. CP Violation and BSM Sensitivities

2.1. CP Violation in $B_s \to J/\psi\phi$

The weak phase Φ_s of the of the decay of the CP eigen state $J/\psi\phi$ of the B_s decay is tiny within the SM ($\Phi_s = -0.036 \pm 0.003$), but the presence of new physics could lead to an enhanced and measurable CP violation within this decay channel [6]. The angular distribution of the decay is described by 7 parameters: two independent amplitudes ($A_{L,T}(t = 0)$) and two phases ($\delta_{1,2}$) as well as three weak decay parameters ($\Delta\Gamma_s$,Γ_s,Φ_s), which are extracted in a maximum likelihood fit. Despite the enormous LHC statistics and the well controlled background several parameters are highly correlated due to experimental resolutions. To avoid unreasonable fit results due to a high correlation of Δm_s and Φ_s, the value of Δm_s was fixed based on the analysis described in Sec. 2.2. In the future, this should be fitted simultaneously using the results from the $B_s \to D_s\pi/a_1$ measurements. With an integrated luminosity of 30 fb^{-1} (Fig. 1) a sensitivity of $\sigma(\Phi_s = 0.04$ could be achieved, based on about 270.000 signal events. The main background contamination (ca. 15 %) originates from $J/\psi K^{0*}$ and $b\bar{b} \to J/\psi X$ decays.

2.2. Δm_s Measurement

An other sensitive check on BSM is the measurement of of Δm_s in the $B_s^0/\overline{B_s^0}$ system [7]. Although the precision measurement will be done by LHCb, the aim of the ATLAS measurement of Δm_s using the decay channels $B_s \to D_s\pi$ and $B_s \to D_s a_1$ will be used to fix or simultaneously fit for the parameters Δm_s in the CP-fit for $B_s \to J/\psi\phi$. The probability, that an initial pure B_s^0 state produced at $t = 0$ is measured after a certain time t as B_s^0 is $p_+(t)$ (or as a $\overline{B_s^0}$ is ($p_-(t)$

resp.) is given as

$$p_{\pm}(t) = e^{-\Gamma t}\Big(\cosh(\frac{\Delta\Gamma_s t}{2}) \pm \cos(\Delta m_s t)\Big)\frac{\Gamma^2 - \Delta\Gamma_s^2}{2\Gamma} \tag{1}$$

where Δm_s can be derived from the measurement of the asymmetries:

$$\frac{p_+(t) - p_-(t)}{p_+(t) + p_-(t)} = \frac{\cos(\Delta m_s t)}{\cosh(\frac{\Delta\Gamma_s t}{2})} \tag{2}$$

Compared to the sensitivity of measurements of CDF, ATLAS would be able to make a significant measurement of $\Delta m_s \leq 20$ ps^{-1} in a 5 σ limit within one year based on a luminosity of 10 fb^{-1} giving an important constraint for the measurement of the weak phase mentioned in Sec. 2.1.

3. Rare B-Decays

Flavor changing neutral currents, a direct transition from $b \to d, s$, are forbidden at the tree level in the SM and occur at the lowest order through one loop diagrams. Since they are a sensitive test of the SM and its possible extension, delivers information on the long distance QCD effects and enable a determination of the CKM matrix elements $|V_{td}|$ and $|V_{ts}|$ they are taken into the B-physics program of ATLAS. Furthermore, some of the rare decay channels contribute to the background for others channels, which are very sensitive to BSM effects. Generally, precision measurements of rare B-decays are sensitive tools for searches for new physics at LHC.

3.1. Search for $B_s \to \mu^+\mu^-$

An upper limit of the branching ratio $BR(B_s^0 \to \mu^+\mu^-)$ can allready be extracted after one year of data taking at $\mathcal{L} = 10^{33}$ cm^{-1}s^{-1} corresponding to a integrated luminosity of 30 fb^{-1}. Therein, $n_{\text{signal}} = 7$ signal- and $n_{\text{bg}} = (20 \pm 12)$ background-events are expected [8].

$$BR(B_s^0 \to \mu^+\mu^-) \leq \frac{N(n_{\text{signal}}, n_{\text{bg}})}{2\,\sigma_{B_s}\,\mathcal{L}\,\alpha\,\epsilon_{\text{total}}} \tag{3}$$

After four years of data taking, the sensitivity of the the SM predictions could be reached (Fig. 2). The continuation of this measurement at nominal LHC luminosities has been proven leading to a clear statement with a 5 σ sensitivity after allready one additional year of data taking at design luminosity of 10^{34}cm^{-2}s^{-1}. The selection for this events is based on cuts on p_T, the invariant mass $M_{\mu\mu}$, the transverse decay length L_{xy} of the di-muon system and on isolation requirements.

3.2. Semi-muonic Exclusive Searches

A study has been performed [9] on the feasibility of measuring the production polarization of beauty hadrons by analyzing of the angular distributions of secondary particles for several decyas as $B_d \to K^{0*}\mu^+\mu^-$, $B_s \to \phi\mu^+\mu^-$, $B^+ \to K^+\mu^+\mu^-$, $B^+ \to K^{+*}\mu^+\mu^-$ and $\Lambda_b \to \Lambda_0\mu^+\mu^-$. In the decay $\Lambda_b^0 \to \Lambda^0 J/\psi(\mu^+\mu^-)$ the shape of the asymmetry A_{FB} provides a strong indirect test for BSM physics. The shape of the distribution is sensitive to trigger and off-line selection cuts especially in the low q^2 region, since the detector acceptance and muon trigger prefer higher p_T due to the p_T-cut causing an A_{FB} reduction by a factor of 0.6 at $q^2/M_{\Lambda_b}^2 < 0.1$. Furthermore, the small $\mu^+\mu^-$-opening angle constitutes a challenge to the trigger. With 30 fb^{-1} an amount of 800 events could be expected for the $\Lambda_b^0 \to \Lambda^0\mu^+\mu^-$

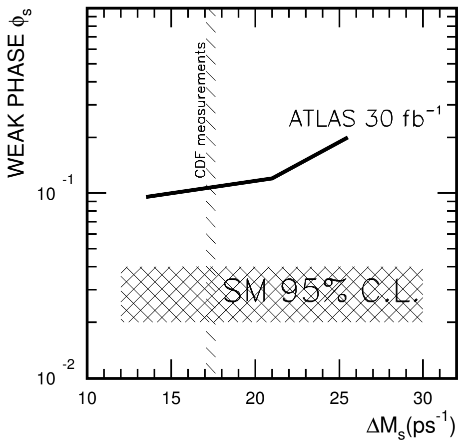

Figure 1. Correlation of the weak phase Φ_s precision and Δm_s in CP violation in the decay $B_s \to J/\psi\phi$ and the achievable sensitivity with an integrated luminosity of 30 fb^{-1}.

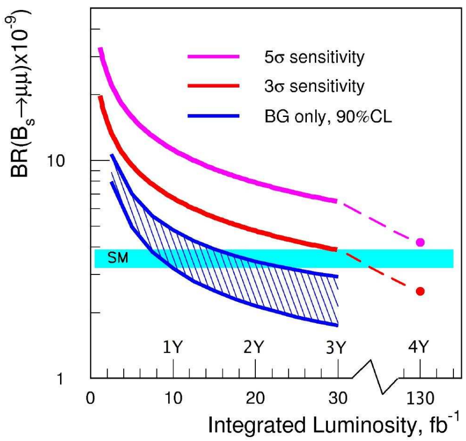

Figure 2. Sensitivity of ATLAS for the upper limit for the rare decay $B_s \to \mu^+\mu^-$ as a function of the integrated LHC luminosity. After 4 years of data taking, the sensitivity of the SM prediction could be reached.

4. Conclusion

The ATLAS experiment has a well defined B-physics program based on clearly defined trigger strategies for all luminosity phases of the LHC. These measurements will contribute to CP violation studies with B_s-mesons and its sensitivity to BSM as well in studies of rare B decays. The precision measurement of B-physics processes are an alternative method to explore the presence of new physics at LHC in addition to the direct SUSY searches.

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