ATLAS plans on heavy flavor physics

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With the starting up of the Large Hadron Collider, the ATLAS experiment is getting ready to perform many interesting measurements as part of its program on heavy flavor physics. Here we present a summary of feasibility tests we have performed and the plans we have prepared to analyze the data collected by the ATLAS detector at the LHC.

1. INTRODUCTION

One of the important parts of the physics program in the ATLAS experiment [1] at the Large Hadron Collider (LHC), is the measurement of heavy hadrons properties and the search for physics beyond the Standard Model by using rare decays in this heavy sector. The physics program on heavy hadrons at ATLAS includes measurements of heavy hadron masses, lifetimes, production rates, and possible discovery of no yet observed heavy hadrons. All these measurements can directly be compared to theoretical predictions. As part of the preparations for data taking, ATLAS is performing many different studies on simulated data to determine which topics could be possible to attack depending on the collected data and the desired sensitivity for each measurement. Here we present some results of these studies and the plans we have prepared to exploit the collected data by the ATLAS detector since the very first day of the data taking.

2. HEAVY FLAVOR PHYSICS PROGRAM

The heavy flavor physics program in ATLAS begins with the first data collected by the ATLAS detector. Figure 1 shows the different steps in the program according to the integrated luminosity of the collected data. From 10–100 pb^{-1}, most of the program will be related to calibration and alignment of the detector, trigger synchronization, and the measurement of quarkonium production at the energies of the LHC [2]. From 0.1–1 fb^{-1} it will be possible to perform the first measurements on B hadron properties, such as masses, lifetimes, production decay limits, and begin the study of some decays that will be background for rare decays in which physics beyond the Standard Model will be searched for. Once we reach 1–10 fb^{-1} of data, we could begin with the measurement of other B hadron properties such as Λ_b polarization and B_s oscillation. These measurements, including CP violation studies and semi-rare decays observation will be performed in more detail and with high precision with 10–30 fb^{-1} of data. With 100 fb^{-1} of integrated luminosity it will be possible to attack the rare decays program in ATLAS. In the next sections we present results on some of the analyzes we have performed on simulated data in order to prepare and test our analysis framework, and get it ready for the arriving of data from the LHC.

2.1. Lifetime measurements

One of the first measurements in ATLAS will be the lifetime of heavy hadrons. In addition to the inherent physics relevance of this property of B hadrons, some of these measurements, for example the B^+ lifetime, will be of great importance for ATLAS from the point of view of detector alignment and calibration, this specially due to the high precision on the world average on some of these quantities. Table 1 shows the expected statistics in some of the B hadron decays which will be studied in ATLAS. Decays with

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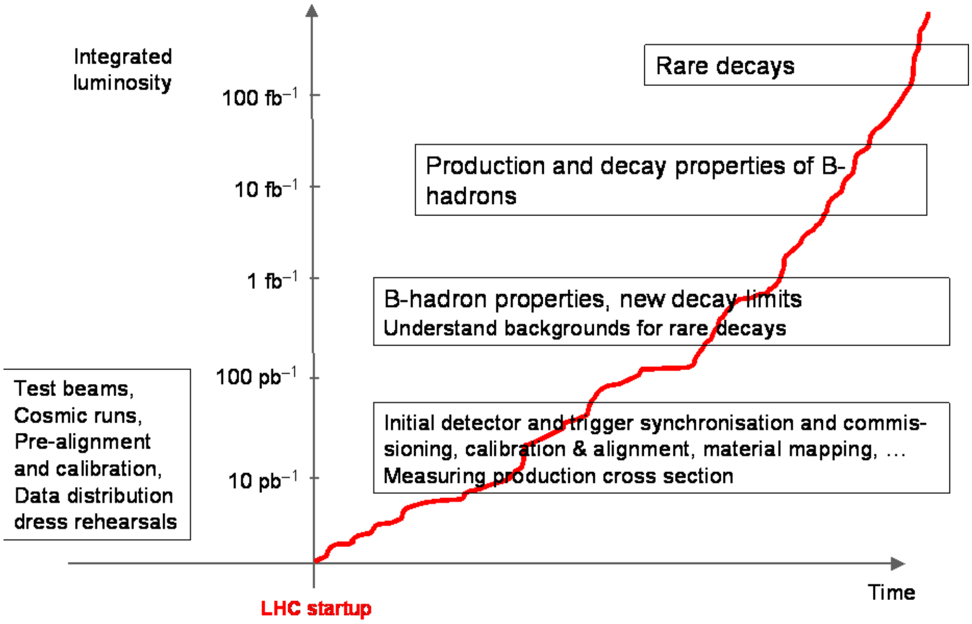

Figure 1. Time-line plans for the heavy flavor program in ATLAS.

a $J/\psi \to \mu^+\mu^-$ at the end of the decay chain will be of great importance due to the presence of dimuon triggers, including one totally dedicated to $J/\psi \to \mu^+\mu^-$ decays. With 200 pb^{-1} of data, the ATLAS collaboration will be in position of perform B hadrons lifetime measurements with a precision comparable to the current world average values.

2.2. Semi rare decays

Before collecting enough data to search for rare decays in heavy hadrons, semi rare decays will be a subject of study in ATLAS. Table 2 shows some of the decays channels that will be under study and the expected statistics with 30 fb^{-1} of data. Also shown in the table is the expected statistical uncertainty on the forward-backward asymmetry (A_{FB}) on these decays. A_{FB} will test Standard Model and beyond the Standard Model predictions on these semi rare decays, which with high statistics will be possible to separate. Our studies have shown that we don't expect significant detector acceptance effects in A_{FB} due to the triggers. Figure 2 illustrates this for A_{FB} in $B_s \to \phi\mu^+\mu^-$ decays.

Decay channel	Expected statistics	Uncertainty on A_{FB} (in 1–6 GeV)
$B_b \to K^{0*}\mu^+\mu^-$	2500	4.8%
$B_s \to \phi\mu^+\mu^-$	900	6.0%
$B^+ \to K^+\mu^+\mu^-$	4000	3.0%
$B^+ \to K^{+*}\mu^+\mu^-$	2300	5.2%
$\Lambda_b \to \Lambda\mu^+\mu^-$	800	6.0%

Table 2
Expected semi rare decays ($b \to (d,s)\mu^+\mu^-$) statistics and forward-backward asymmetry for 30fb^{-1}.

2.3. Polarization of the Λ_b

The Λ_b is the lightest baryon containing a b quark, and it created a great deal of interest due

Hadron	Decay	Approximated statistics with 10 pb^{-1}	Lifetime statistical uncertainty	
B^+	$B^+ \to J/\psi K^+$	1600	2.2%	
B^0	$B^0 \to J/\psi K^{0*}$	1000	3.1%	
		Approximated statistics with 200 pb^{-1}		World average today (stat + syst)
B^+	$B^+ \to J/\psi K^+$	32000	0.49%	0.67%
B^0	$B^0 \to J/\psi K^{0*}$	18000	0.69%	0.9%
B_s (single τ fit)	$B_s \to J/\psi\phi$	1800	4.2%	2.7%
Λ_b	$\Lambda_b \to J/\psi\Lambda$	520	5.8%	5.0%

Table 1
Expected precision on lifetime measurements with first data collected with the ATLAS experiment.

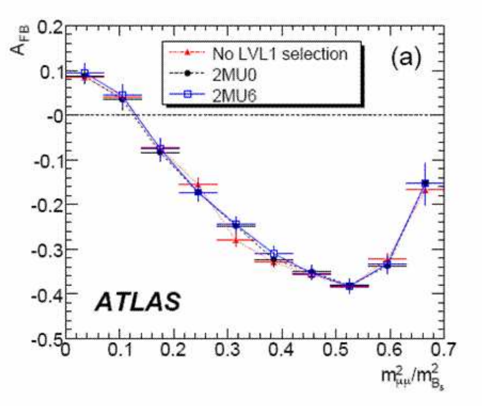

Figure 2. Comparison of forward-backward asymmetry in $B_s \to \phi\mu^+\mu^-$ decays as function of $m^2_{\mu^+\mu^-}/m_{B_s}$, for different triggers conditions: No level one trigger selection (No LVL1) vs two different dimuons triggers.

to the so-called Λ_b lifetime puzzle [3]. In addition, the Λ_b has been subject of various theoretical studies ranging from proposed tests of CP violation [4], T violation tests and new physics studies [5], and measurement of top quark spin correlation functions [6] and the extraction of the weak phase γ of the CKM matrix [7].

In ATLAS we investigated the feasibility of measuring the polarization of the Λ_b in the decays $\Lambda_b \to J/\psi\Lambda$, followed by $J/\psi \to \mu^+\mu^-$ and $\Lambda \to p\pi^-$. As by product of the Λ_b polarization measurements it will be possible to extract the four complex amplitudes describing this decay. If we take into account normalization and free rotation conditions in the complex plane, the number of unknown parameters in the $\Lambda_b \to J/\psi\Lambda$ decay are seven: three amplitudes, three relative phases, and the polarization.

The polarization of Λ_b can be determined from angular correlations of the $\Lambda_b \to J/\psi(\mu^+\mu^-)\Lambda(p\pi^-)$ final decay products. In ATLAS we have studied full simulated data samples including these angular correlations for different polarization values. Figure 3 shows one example of the extraction -from full simulated Monte Carlo data- of the three amplitudes ($|a_+|$, $|a_-|$, and $|b_+|$), the three relatives phases ($\alpha_+ - \beta_-$, $\alpha_- - \beta_-$, $\beta_+ - \beta_-$), and the polarization, that describes the Λ_b decay. Figure 4 shows the expected statistical uncertainty on the polarization measurement for different values of the polarization. For 30 fb^{-1} of data we expect after all detector acceptances and trigger efficiencies, around of 13000 Λ_b events, and we can measure with good precision almost any value of the polarization. Figure 5 shows the expected statistical uncertainty on the parity violating asymmetry parameter:

$$\alpha_b = \frac{|a_+|^2 - |a_-|^2 + |b_+|^2 - |b_-|^2}{|a_+|^2 + |a_-|^2 + |b_+|^2 + |b_-|^2} \qquad (1)$$

According to our studies, we can measure this parameter with good precision even for zero Λ_b polarization. Specific physics interest on the Λ_b parity violating parameter α, is its ability to serve as a test for various heavy quark factorization models and perturbative QCD.

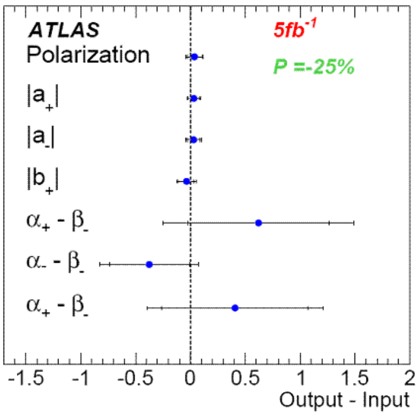

Figure 3. Comparison of extracted polarization and other decay parameters compared to the known values in the Monte Carlo data. Simulated data correspond to 5 fb^{-1}, and we use $\alpha = -0.457$ and polarization of -25%.

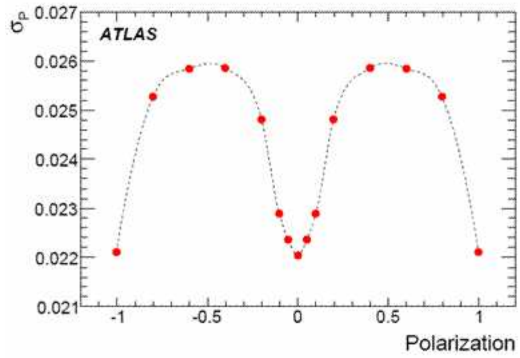

Figure 4. Expected statistical uncertainty on the Λ_b polarization measurement as function of the polarization. Simulated data correspond to 30 fb^{-1}, and we use $\alpha = -0.457$.

2.4. Study of $B_s \to \mu^+\mu^-$

B_s rare decays such as $B_s \to e^+e^-$, $B_s \to \mu^+\mu^-$, and $B_s \to \tau^+\tau^-$, are mediated by flavor-changing neutral currents that are forbidden in the Standard Model at tree level. However, in extensions of the Standard Model, the branching ratio of these decays could be enhanced by several orders of magnitude due to new loop diagrams that interfere constructively with those of the Standard Model. To exploit the excellent muon detector of ATLAS, we are working in preparations for the measurement of the branching ratio of $B_s \to \mu^+\mu^-$.

The key issue for $B_s \to \mu^+\mu^-$ observation at the LHC is a huge background suppression. The main background contribution is expected to be due to combinatorial background with two muons in the final state. However, we also expect background from decays such as $B_s \to \pi^+\pi^-$, $B_s \to K^+K^-$, $B_s \to \pi^+K^-$, $B_s \to K^-\mu^+\nu$, and similar decays from B^0 mesons. In order to reduce the contribution from all these background sources, as preliminary selection criteria, we have used for the B_s candidates a minimum decay distance in the transverse plane to the beam axis of 0.5 mm. In addition, the pointing angle between the B_s candidate flight direction (dimuon pair momentum) and the direction of the decay vertex as seen from the interaction vertex, is required to be greater than 0.017 radians. Finally, we apply an isolation criteria based on the transversal momentum of the muons. This isolation variable is required to be greater than 0.9. Figure 6 shows the invariant mass distribution of $B_s \to \mu^+\mu^-$ decays and background contributions, after all selection criteria. For 10 fb^{-1} we expect 5.7 $B_s \to \mu^+\mu^-$ candidates and 14^{+13}_{-10} background events from $b \to \mu^+\mu^- X$ decays. Figure 7 summarizes the ATLAS expectation for $BR(B_s \to \mu^+\mu^-)$ as function of the integrated luminosity of the collected data.

3. SUMMARY

The ATLAS collaboration has prepared a very reach program on heavy flavor physics, starting

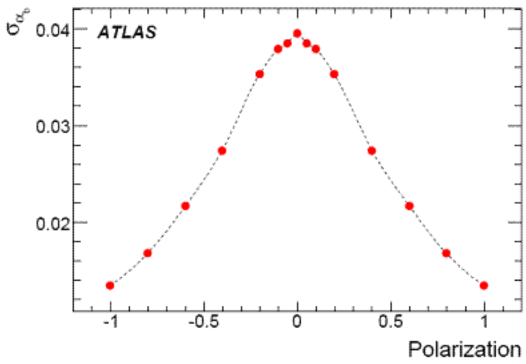

Figure 5. Expected statistical uncertainty on the parity violating parameter α_{Λ_b} as function of the polarization. Simulated data correspond to 30 fb^{-1}, and this study corresponds to simulated Monte Carlo samples with $\alpha = -0.457$.

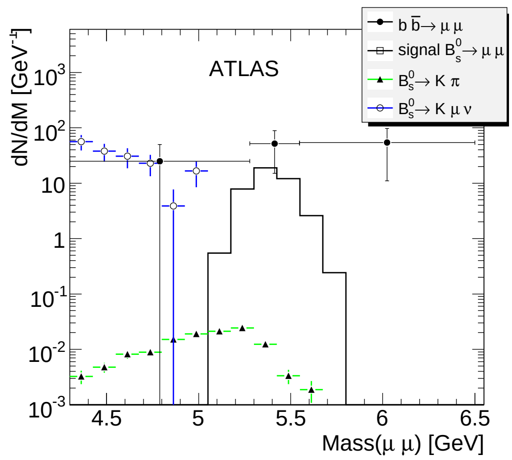

Figure 6. Dimuon invariant mass distribution after all selection cuts are applied.

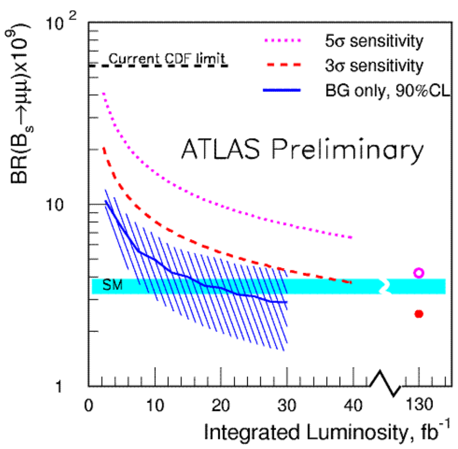

Figure 7. Expectation for the measurement at ATLAS of the branching ratio of $B_s \to \mu^+\mu^-$ as function of the integrated luminosity.

from the very first data. B hadron lifetimes measurements, as for example the B^+ lifetime, will help on testing alignment of the tracking detector. In addition to lifetime measurements, CP violation and mixing in the B_s system (no presented here), a well as spin-related measurements will be performed. The long term part of the program is the study of new physics signatures in rare decays of B hadrons, such as $B_s \to \mu^+\mu^-$ for example. The ATLAS heavy flavor physics program is ready for the LHC start up.

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