# $\Lambda_b$ polarization study in the ATLAS experiment

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From preliminary studies it has been estimated that approximately 75000 $\Lambda_b$ will be available in the first years of the ATLAS running with integrated luminosity of $30fb^{-1}$, and we will be able to measure the polarization with accuracy of about 2%. In this paper we present the technical feasibility of measuring the polarization of $\Lambda_b$ hyperons in ATLAS experiment.

## 1. INTRODUCTION

The polarization measurements of $\Lambda_b$ hadrons could throw light on the understanding of production mechanism of polarization in hyperons and clarify the problems of different polarization models. Significant $\Lambda$ polarization was measured in the early Fermilab neutral hyperon beam [1], and there is no theory that can give the compete picture and explain unusual shape of polarization curve. If the $\Lambda$ and $\Lambda_b$ polarizations are determined by the polarization of s and b quarks, respectively, since the u-d system is in singlet state. Thus, if the s and b production mechanisms are similar a negative $\Lambda_b$ polarization can be expected.

In addition to the substantial contribution to understanding of the production mechanism, the decay of $\Lambda_b$ hadron may include interesting information. The decay amplitudes of $\Lambda_b$ can be described and calculated using PQCD factorization theorems. Moreover, we will have the direct way for testing CP conservation by measuring asymmetry parameter $\alpha_b$ for both $\Lambda_b$ and $\overline{\Lambda_b}$. Numerous theoretical predictions of asymmetry parameter [2–8] demonstrate the increasing interest to this subject. The predicted values of $\alpha_b$ varies from -0.457 to 0.4.

We measure the $\Lambda_b$ polarization in ATLAS experiment trough the decay channel $\Lambda_b \rightarrow$ J/$\psi(\mu^+\mu^-)\Lambda(\pi$p). The preliminary study from [9] shows that around 75000 of such $\Lambda_b$ and $\overline{\Lambda_b}$ will be collected during integrated luminosity of $30fb^{-1}$. This work presents the details of various technical aspects of generation and reconstruction of $\Lambda_b$ in the ATLAS detector; fitting technique developed to extract unknown parameters; the estimation for the precision of measurement for $P_b$ and for the asymmetry parameter depending on the integrated luminosity. We plan to extract the polarization information using current $D\O$ data, so in this work we present the preliminary estimation for the precision of measurement for $\alpha_b$ and $\alpha_b P_b$ using very low statistics.

## 2. ANGULAR DISTRIBUTION

The $\Lambda_b$ decay can be described by 4 complex helicity amplitudes A($\lambda_\Lambda$, $\lambda_{J/\psi}$), where $\lambda_\Lambda$ is the helicity of $\Lambda$ and $\lambda_{J/\psi}$ is the helicity of $J/\psi$, normalized to unity: $a_+ = A(1/2,0)$, $a_- = A(-1/2,0)$, $b_+ = A(-1/2,1)$, $b_- = A(1/2,-1)$. The $\Lambda_b$ polarization can be measured through an analysis of the angular distributions associated with its decay into J/$\psi(\mu^+\mu^-)\Lambda(\pi$p).

$$w(\vec{\theta},\vec{A},P_b) = \frac{1}{(4\pi)^3}\sum_{i=0}^{i=19} f_{1i}(\vec{A})\; f_{2i}\; F_i(\vec{\theta}) \qquad (1)$$

where the $f_{1i}(\vec{A})$ are bilinear combinations of the helicity amplitudes $\vec{A} = (a_+, a_-, b_+, b_-)$, $f_{2i}$ stands for $P_b\alpha_\Lambda$, $P_b$, $\alpha_\Lambda$, or 1, where $P_b$ is a projection of the polarization vector on the production analyzer and $\alpha_\Lambda$ is the decay asymmetry parameter of $\Lambda$, and $F_i$ are orthogonal angular functions defined in Table 1 of [9]. The five angles $\vec{\theta} = (\theta, \theta_1, \theta_2, \varphi_1, \varphi_2)$ in this probability density function are $\theta$, the angle between the direction of the polarization vector and the direction of the $\Lambda$ in the rest frame of the $\Lambda_b$ particle; $\theta_1$ and $\phi_1$ are the polar and azimuthal angles that define the direction of proton in the $\Lambda$ rest frame with respect to the direction of the $\Lambda$ in the $\Lambda_b$ rest frame; and $\theta_2$ and $\phi_2$, define the direction of $\mu^+$ in the $J/\psi$ rest frame with respect to the direction of the $J/\psi$ in the $\Lambda_b$ rest frame. The detailed description of the angles can be found in [9]. The distribution in Equation 1 depends on 7 independent unknown parameters: $\alpha_\Lambda$, $P_b$, $|a_+|^2 + |a_-|^2$, $|a_+|^2 - |a_-|^2$, $\alpha_+ - \beta_-$, $\alpha_- - \beta_-$, $\beta_+ - \beta_-$, where $\alpha_+$, $\alpha_-$, $\beta_+$ and $\beta_-$ are phases of the helicity amplitudes.

## 3. SIMULATION

We generated samples of decay $\Lambda_b \rightarrow J/\psi(\mu^+\mu^-)\Lambda(\pi p)$ for different polarization values using certain set of helicity amplitudes, calculated from PQCD model described at [8]. The Generation of undecayed $\Lambda_b$ particle is done by Pythia. The helicity amplitudes of the $\Lambda_b$ decay and the $P_b$ are set by using EvtGen [10], due to its capability to manipulate the spinor algebra. The samples of polarized $\Lambda_b$ particles has been passed through the ATLAS detector simulation program GEANT4. The fiducial acceptance cuts and the $p_T$ cuts has been applied on the generated particle to emulate the level-1 trigger system and pre-reconstruction requirements. The reconstruction involved several stages: first all the events with the reconstructed $J/\psi$ were preselected, then we searched for $\Lambda(\pi p)$ in this subset and combined them with $J/\psi$. For the selection of $J/\psi$ candidates we required at least one Muon Spectrometer hit for each Inner Detector track using the low $p_T$ muon identification algorithm [11]. Those tracks we marked as muon candidates. Then we selected dimuons with $2.8 < M(\mu^+\mu^-) < 3.3$ GeV/$c^2$ and formed vertex for each dimuon candidate with $\chi^2 < 20$. The selection of long lived $\Lambda$ was performed by coupling two oppositely charged tracks form the vertex with $\chi^2 < 30$ and $1.1 < M(p\pi) < 1.125$ GeV/$c^2$. M was computed under the assumption that the track with the highest transverse momentum is a proton. For each dimuon and $\Lambda$ candidates we formed vertex with $\chi^2 < 30$ and $5.44 < M(\Lambda_b) < 5.84$ GeV/$c^2$.

The final reconstruction efficiency was found to be about 24%. Figures 1 show the invariant mass distribution of $J/\psi$, $\Lambda$ and $\Lambda_b$ candidates. The angular resolution of 5 angles has been measured for each $\Lambda_b$ candidate and found to be of the order of 10mrad.

## 4. STATISTICAL UNCERTAINTIES STUDY

For uncertainties estimation we used toy MC probabilistic approach to generate polarized $\Lambda_b$ particle including the angular resolution from fully reconstructed samples and detector acceptance simulation. Using toy MC we easily generated many samples of polarized $\Lambda_b$ particles with different values of polarization. We used the log-likelihood method to extract the unknown parameters. The log-likelihood is defined by

$$L = -2\sum_{j=1}^{N} \log(w_{obs}(\vec{\theta}', \vec{A}, P_b)) \qquad (2)$$

$$w(\vec{\theta}', \vec{A}, P_b) = \frac{\int w(\vec{\theta}', \vec{A}, P_b) T(\vec{\theta}, \vec{\theta}') d\vec{\theta}}{\int\int w(\vec{\theta}', \vec{A}, P_b) T(\vec{\theta}, \vec{\theta}') d\vec{\theta} d\vec{\theta}'} \qquad (3)$$

where $w(\vec{\theta}', \vec{A}, P_b)$ is defined in Equation 1, $\vec{\theta}'$ is measured angles, $\vec{\theta}$ is produce angles and $T(\vec{\theta}, \vec{\theta}')$ is defined as

$$T(\vec{\theta}, \vec{\theta}') = \epsilon(\vec{\theta}) R(\vec{\theta}, \vec{\theta}') \qquad (4)$$

where $\epsilon(\vec{\theta})$ is the efficiency function and $R(\vec{\theta}, \vec{\theta}')$ is the resolution function. We compared the output we obtained with the inputs for each sample. Following figures present the results of this study. Figure 2 presents the statistical uncertainty in $P_b$ and $\alpha_b$ as function of different polarization value

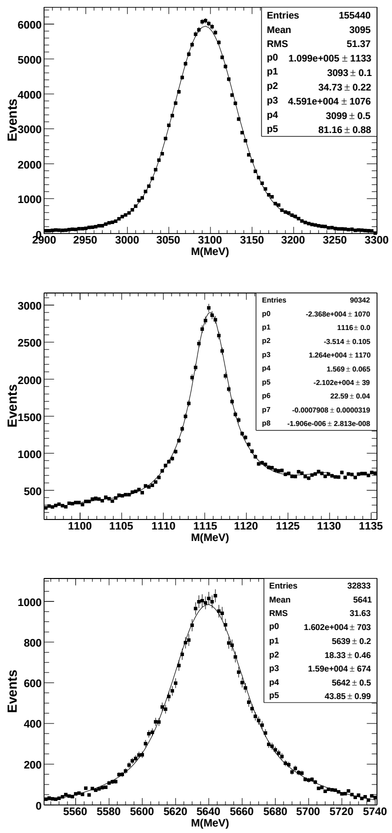


Figure 1. Mass distribution of J/$\psi$ (top), $\Lambda$ and $\Lambda_b$(bottom) candidates after selection cuts.

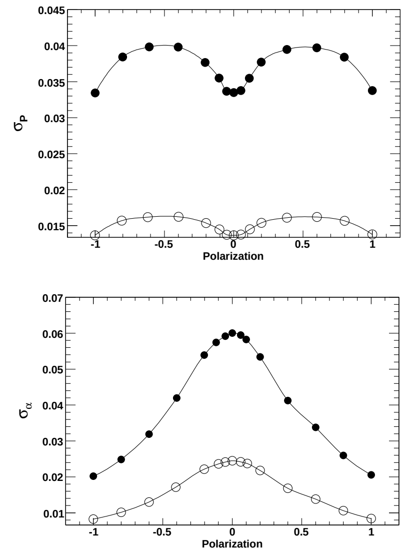


Figure 2. Statistical unsertainty in $P_b$(top) and $\alpha_b$(bottom) vs. $P_b$ for $5fb^{-1}$ (empty circle) and $30fb^{-1}$ (filled circle)

for integrated luminosity of $5fb^{-1}$ and $30fb^{-1}$. The study was done for $\alpha_b$ = - 0.457. We found out that even for very low polarization values the maximum error is less then 15%. Figure 3 shows the correlation between $\alpha_b$ and $P_b$ vs. $P_b$ for $30fb^{-1}$, the correlation values were extracted from Maximum Likelihood fit results.

We conducted special study to estimate statistical uncertainties for very low statistics. Such a low number of the $\Lambda_b$ is likely to be observed during the first year of the ATLAS operarion or in $D\O$ experiment. In this case we will not be able to extract all the unknown parameters. If we would integrate the Equation 1 over $\theta_1$, $\theta_2$, $\phi_1$ and $\phi_2$, we will get the following simple equation:

$$w(\vec{\theta}, \vec{A}, P_b) = \frac{1}{2}(1 + P_b \alpha_{\Lambda_b} cos(\theta)) \qquad (5)$$

which will allow easy extraction of $P_b\alpha_{\Lambda_b}$ from $cos(\theta)$ distribution. We did the toy MC study using 100 $\Lambda_b$ event, to estimate the error on $\alpha_b P_b$, see Figure 4. The Maximum Likelihood method has been used in the fit. Figure 5 presents the error on $\alpha_b P_b$ we expect to get vs. collected number of $\Lambda_b$ events. We did this estimation for $P_b$=0.5 and used two different fitting methods: Maximum Likelihood and Method of Moments.

The main question we ask is how many events will be necessary to separate $\alpha_b$ from P. Integration of Equation 1 over $\phi_1$ and $\phi_2$ give 4 unknown parameters: P, $|a_+|^2$, $|a_-|^2$, $|b_+|^2$, where $\alpha_b$=$|a_+|^2$-$|a_-|^2$+$|b_+|^2$-$|b_-|^2$ . The MC study has been done using the Method of moments to estimate the uncertainty in $\alpha_b$ for $\alpha_b$ = -0.457, see Figure 5. The results presented in this plot

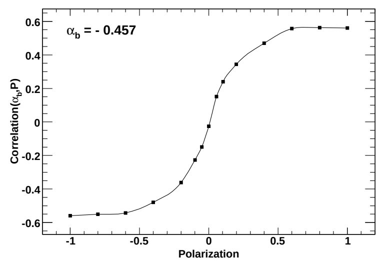


Figure 3. Correlation of $\alpha_b$ and $P_b$ vs. $P_b$

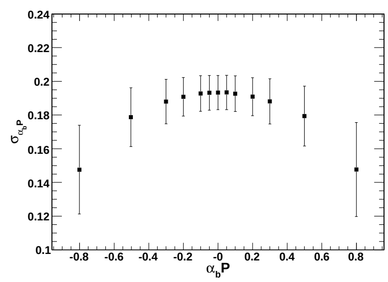


Figure 4. Statistical uncertainty in $\alpha_b P_b$ vs. $\alpha_b P_b$.

are consistent with our estimations for $5fb^{-1}$ and $30fb^{-1}$.

## 5. CONCLUSIONS

Expected uncertainties for polarization and asymmetry parameter measurements in ATLAS experiment look very promising even for the first year of the ATLAS operation.

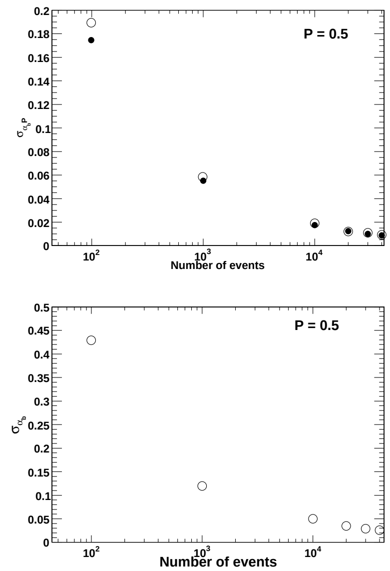


Figure 5. Statistical uncertainty in $\alpha_b P_b$(top) and $\alpha_b$(bottom) vs. Number of $\Lambda_b$ events for $P_b$=0.5 using Maximum Likelihood (filled circle) and Method of Moment (empty circle)

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