Additional Material for Paper LHCB-PAPER-2013-008

In this additional document we report the measurement of the frame-independent parameter $\lambda_{\rm inv}$, defined according to the formula below

$$\lambda_{\rm inv} = \frac{\lambda_\theta + 3\lambda_\phi}{1 - \lambda_\phi}. \tag{1}$$

The parameter is of physics interest as it should not depend on the reference frame used to perform the measurement and as such it is easily comparable to theory curves and to results of other experiments [1]. The measurement at LHCb is shown in Fig. 1 as a function of the J/ψ transverse momentum and rapidity for the helicity frame and Collins-Soper frame as the other λ parameters whose measurements are reported in the draft. In the ideal case, the results for the helicity frame and Collins-Soper frame should be identical in each bin of J/ψ $p_{\rm T}$ and y, however because the two frames behave differently with regards to the systematic effect, there are small difference between the two measurements.

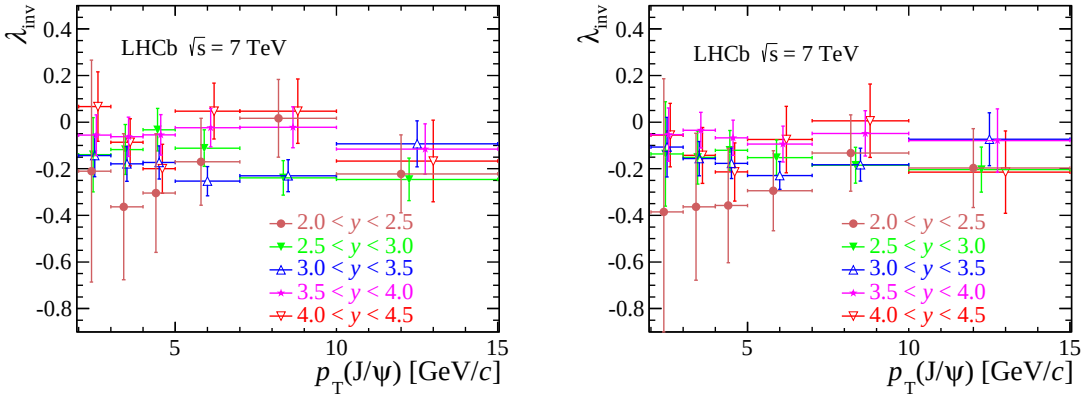

Figure 1: The measured polarization parameter $\lambda_{\rm inv}$ in (*left*) the helicity frame and (*right*) the Collins-Soper frame in bins of the J/ψ $p_{\rm T}$ and y. The uncertainty is the statistical and systematic properly added.

The uncertainties of $\lambda_{\rm inv}$ are propagated from λ_θ and λ_ϕ (shown in Table 2 of the draft), taking their correlation into account properly, and the correlation is found to be small in the helicity frame.

In Tables 1 and 2 the values of $\lambda_{\rm inv}$, its uncertainties and the correlation between λ_θ and λ_ϕ are reported for the helicity frame and Collins-Soper frame respectively.

Table 1: The measured polarization parameter $\lambda_{\rm inv}$ and the correlation coefficient between λ_θ and λ_ϕ in bins of $p_{\rm T}$and y for the helicity frame. The first uncertainty is statistical (from the fit and the background subtraction) while the second is the systematic uncertainty.

$p_{\rm T}$(GeV/c)	Quantity	$2.0 < y < 2.5$	$2.5 < y < 3.0$	$3.0 < y < 3.5$	$3.5 < y < 4.0$	$4.0 < y < 4.5$
2-3	$\lambda_{\rm inv}$	-0.21±0.13±0.46	-0.140±0.013±0.159	-0.144±0.008±0.090	-0.056±0.008±0.087	0.067±0.015±0.148
	corr.	0.56	-0.067	-0.218	-0.242	-0.180
3-4	$\lambda_{\rm inv}$	-0.36±0.10±0.30	-0.117±0.012±0.107	-0.179±0.009±0.074	-0.063±0.010±0.084	-0.086±0.017±0.100
	corr.	0.44	-0.096	-0.113	-0.193	-0.447
4-5	$\lambda_{\rm inv}$	-0.30±0.08±0.24	-0.032±0.013±0.090	-0.173±0.011±0.071	-0.055±0.013±0.086	-0.200±0.020±0.103
	corr.	0.38	0.031	0.040	-0.025	-0.375
5-7	$\lambda_{\rm inv}$	-0.17±0.05±0.18	-0.112±0.012±0.077	-0.253±0.011±0.062	-0.024±0.014±0.081	0.047±0.024±0.118
	corr.	0.33	0.107	0.103	0.074	-0.182
7-10	$\lambda_{\rm inv}$	0.03±0.06±0.16	-0.239±0.016±0.072	-0.230±0.016±0.067	-0.022±0.022±0.085	0.05±0.04±0.13
	corr.	0.28	0.105	0.089	0.08	-0.019
10-15	$\lambda_{\rm inv}$	-0.22±0.07±0.15	-0.246±0.029±0.087	-0.093±0.034±0.093	-0.12±0.04±0.10	-0.17±0.08±0.16
	corr.	0.18	0.068	0.051	0.05	0.03

Table 2: The measured polarization parameter $\lambda_{\rm inv}$ and the correlation coefficient between λ_θ and λ_ϕ in bins of $p_{\rm T}$and y for the Collins-Soper frame. The first uncertainty is statistical (from the fit and the background subtraction) while the second is the systematic uncertainty.

$p_{\rm T}$(GeV/c)	Quantity	$2.0 < y < 2.5$	$2.5 < y < 3.0$	$3.0 < y < 3.5$	$3.5 < y < 4.0$	$4.0 < y < 4.5$
2-3	$\lambda_{\rm inv}$	-0.39±0.13±0.56	-0.137±0.013±0.223	-0.107±0.008±0.127	-0.054±0.008±0.114	-0.056±0.015±0.135
	corr.	0.49	0.224	0.054	0.021	0.001
3-4	$\lambda_{\rm inv}$	-0.36±0.10±0.30	-0.152±0.012±0.113	-0.157±0.009±0.073	-0.035±0.010±0.076	-0.143±0.017±0.119
	corr.	0.37	-0.100	-0.318	-0.296	-0.144
4-5	$\lambda_{\rm inv}$	-0.36±0.08±0.23	-0.121±0.014±0.084	-0.177±0.011±0.064	-0.067±0.013±0.075	-0.214±0.019±0.123
	corr.	0.29	-0.333	-0.463	-0.417	-0.210
5-7	$\lambda_{\rm inv}$	-0.29±0.05±0.16	-0.152±0.012±0.075	-0.229±0.011±0.059	-0.094±0.013±0.076	-0.075±0.024±0.141
	corr.	0.20	-0.459	-0.498	-0.453	-0.271
7-10	$\lambda_{\rm inv}$	-0.13±0.06±0.15	-0.185±0.016±0.075	-0.183±0.016±0.068	-0.049±0.022±0.095	0.006±0.040±0.153
	corr.	0.01	-0.475	-0.457	-0.419	-0.322
10-15	$\lambda_{\rm inv}$	-0.20±0.07±0.15	-0.204±0.029±0.092	-0.073±0.034±0.108	-0.08±0.04±0.13	-0.22±0.08±0.16
	corr.	-0.18	-0.427	-0.363	-0.34	-0.30

References

[1] P. Faccioli, C. Lourenço, J. Seixas, and H. K. Wöhri, *Towards the experimental clarification of quarkonium polarization*, Eur. Phys. J. C **69** (2010) 657, arXiv:1006.2738.