Abstract

Electric and magnetic dipole moments (EDMs and MDMs) of elementary and composite particles are a powerful tool to probe physics beyond the Standard Model: permament EDMs are a potential signature of new sources of CP symmetry violation, while MDMs can be used to test the validity of the CPT theorem.

One approach to study EDMs and MDMs is to exploit the precession of the particle's spin they trigger when flying through a magnetic field; this is achieved by comparing initial and final polarization states of a sample of particles through a fit of the angular distribution of their decay products. This technique is ripe for study at LHCb, a single-arm spectrometer designed to study heavy-flavour physics using proton-proton collisions at the Large Hadron Collider.

In this thesis, I present my work in preparation of a measurement of the electromagnetic dipole moments of the Λ^0 baryon with the LHCb experiment. Long-lived Λ^0 baryons from the exclusive $\Lambda_b^0 \to J/\psi \, (\to \mu^+\mu^-) \, \Lambda^0 \, (\to p\pi^-)$ decay are selected with the requirement that the Λ^0 decay after the LHCb dipole magnet, allowing for the comparison of initial and final polarization states.

For the first part of my thesis, detailed in Chapter **??**, I report on my work in understanding and improving the vertex reconstruction process in LHCb, with the main goal of mitigating the low efficiency of $\Lambda^0 \to p\pi^-$ reconstruction in $\Lambda_b^0 \to J/\psi \, \Lambda^0$ events. I also analyze the z resolution of the reconstructed Λ^0 vertex to gauge possible sources of bias.

In the second part of my thesis, I focus on the development and finalization of the three major steps in the signal selection process: preliminary filters, rejection of $B^0 \to J/\psi \, K_S^0$ physical background (including a newly-introduced K_S^0 veto based on the Armenteros-Podolanski technique), and discrimination of signal through the training and testing of a supervised learning multivariate classifier. Results on this front are collected in Chapter **??**.

Finally, in Chapter **??** I capitalize on my earlier work to perform a first analysis of the angular distribution of $\Lambda^0 \to p\pi^-$ decay products, a key stepping stone in the prospective measurement of the Λ^0 electromagnetic dipole

moments.

Electric and magnetic dipole moments of particles are sensitive to physics within and beyond the Standard Model. In this thesis, I worked on various aspects of the $\Lambda_b^0 \to J/\psi\,(\to \mu^+\mu^-)\,\Lambda^0\,(\to p\pi^-)$ decay analysis in preparation of a first measurement of the Λ^0 electromagnetic dipole moments using the LHCb Run 2 dataset.

Less than half of candidate $\Lambda^0 \to p\pi^-$ events reach convergence in the vertex reconstruction process. I conducted topological studies on a sample of simulated events to show that this is a result of a conflict of information in xz (bending) and yz (non-bending) track propagation planes. Through further investigation of the measured kinematic variables and comparison with the Monte Carlo generated values, I exposed a systematic underestimation of p_z in pion tracks reconstructed from hits in the T1–T3 downstream tracking stations. Said bias is only observed in non-converging $\Lambda^0 \to p\pi^-$ events and is understood to play a role in the xz-yz discrepancy at the origin of the vertexing failure. Additional research is under way to locate and fix the source of p_z bias, starting with the track momentum fit process at T station level.

For the time being, I demonstrated that recovery of a significant percentage of failed events in possible by modifying the main vertex fitting algorithm to increase the weight of track propagation in a specific plane. A threefold refit approach, attributing more importance to yz, xz and xy planes sequentally, results in a +26.4% increase in signal statistics. Comparisons to Monte Carlo truth reveal that recovered events have suboptimal reconstruction, with a median bias on the z component of the $\Lambda^0 \to p\pi^-$ vertex $20\,\mathrm{cm}$ greater than standard reconstructed events. Studies confirm that this is due to poor track information available in these events; the impact of lower vertex resolution on the Λ^0 electromagnetic dipole moment measurement will have to be evaluated in future analyses.

Working on $\Lambda_b^0 \to J/\psi\,\Lambda^0$ signal selection, I finalized the three main steps of the process: loose preliminary selections for long-lived Λ^0 events, including requirement of Decay Tree Fitter convergence with J/ψ and Λ^0 mass constraints; rejection of $B^0 \to J/\psi\,K_S^0$ physical background with an invariant mass veto and a cut in the Armenteros-Podolanski α–p_{T} space; the final selection of signal with a histogram-based gradient boosting classification tree, trained with simulated signal and LHCb combinatorial background and optimized to maximize $\Lambda_b^0 \to J/\psi\,\Lambda^0$ signal significance. The $m(J/\psi\,\Lambda^0)$ invariant mass fit after all steps shows excellent agreement with data, estimating a signal (background) yield of 3590 ± 60 (2420 ± 50).

As first step of the future Λ^0 dipole moment measurement, I computed angular distribution (θ_p, ϕ_p) of proton momentum in the Λ^0 helicity frame, which probes the final polarization state of decaying Λ^0 required for the spin preces-

sion technique. Angular reconstruction is unbiased net of acceptance effects; resolutions of 0.2–0.3 (1.0–1.2) for $\cos\theta_p$ (ϕ_p) are reasonably low, amounting to less than one third of the allowed angular ranges.

Simulated $\Lambda_b^0 \to J/\psi\,\Lambda^0$ events passing the full selection process retain a median $14\,\mathrm{cm}$ bias in the z component of the reconstructed $\Lambda^0 \to p\pi^-$ vertex, which has a detrimental effect on $\cos\theta_p$ and ϕ_p resolutions. This can mostly be attributed to proton and pion tracks being bent by the magnetic field into a second downstream crossing point, acting as local χ^2 minimum during the vertexing process and being erroneously selected as the Λ^0 decay vertex. Removing this class of events (31.6% of the simulated sample) improves proton angular resolutions by a factor 2–3 across the full range of values. Changing the vertex fitting algorithm to account for multiple χ^2 minima would therefore significantly affect the dipole moment measurement and must be considered a high priority for the analysis.

None of the issues I have identified during my work on this analysis compromise the prospective first measurement of the Λ^0 electromagnetic dipole moments. On the contrary, the achieved signal yield and absence of bias in the observed angular distributions are a resounding confirmation that physics results with long-lived Λ^0 baryons are possible at LHCb with just Run 2 data. Given the upcoming statistics surge projected for Run 3 and the significant resolution boost an improved vertexing algorithm would provide, the outlook is promising for a competitive measurement of Λ^0 gyroelectric and gyromagnetic ratios.