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.

Electromagnetic dipole moments of long-lived particles can be measured from the precession of their spin-polarization vector in a strong magnetic field, which depends on the particle's gyroelectric and gyromagnetic factors. 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. Theoretical background for the EDM/MDM measurement approach and specifics on the LHCb detecting apparatus are reported in Chapters **??** and **??** respectively.

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 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 precession 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 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.