Measurement of the prompt $\chi_{c1}$ and $\chi_{c2}$ polarizations at CMS

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The process of how quarks are bound into hadrons by the strong interaction is not yet fully understood. Quarkonia, bound states of a heavy quark and its antiquark ($q\bar{q}$), are ideal probes to study hadron formation. In the currently prevalent theoretical framework of Non-Relativistic Quantum Chromodynamics (NRQCD) the production of quarkonia is factorized into two separate steps, the formation of an initial $q\bar{q}$ pair and its subsequent evolution into the bound quarkonium state. While the first part can be calculated within perturbative QCD, the second step depends on inputs from experiments, quarkonium cross section and polarization measurements.

With the advent of the Large Hadron Collider (LHC) physics program a multitude of quarkonium cross section and polarization measurements has recently become available. While the cross sections and polarizations of all $S$-wave states are by now well measured, especially at mid-rapidity and high transverse momenta, experimental results on $P$-wave states are scarce. In particular, no measurements of the polarization for any $P$-wave state exist.

Phenomenological studies using the published results of the LHC experiments have observed remarkably simple patterns in the production of the studied quarkonia. These are in striking contrast with the complexity of the mixture of processes that are considered in the NRQCD approach. Nevertheless, calculations made within the NRQCD framework are able to reproduce the measurements very well. This seeming disparity between the simplicity of the data and the complexity of the theory comes with a clear-cut prediction, the polarizations of the $\chi_{c1}$ and $\chi_{c2}$ mesons should be large and, more importantly, opposite.

This dissertation presents the first measurement of the polarizations of the prompt $\chi_{c1}$ and $\chi_{c2}$ mesons using data collected in 2012 by the CMS experiment at the LHC in proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 8$ TeV corresponding to a total integrated luminosity of 19.1 fb$^{-1}$. The $\chi_c$ mesons are reconstructed via their radiative $\chi_c \to J/\psi \gamma$ decay, where the photon is used to identify the $\chi_{c1}$ and $\chi_{c2}$ states. A measurement of the relative polarization in the helicity frame is performed via the analysis of $\chi_{c2}$ over $\chi_{c1}$ cross section ratios as a function of the polar and azimuthal angle of the dimuon decay of the associated $J/\psi$. The parameters $\Delta \lambda_\vartheta \equiv \lambda_\psi^{c2} - \lambda_\psi^{c1}$ and $\Delta \lambda_\varphi \equiv \lambda_\psi^{c2} - \lambda_\psi^{c1}$ are reported together with lower bounds for the parameter $\lambda_\psi^{c1}$ in three ranges of $J/\psi$ transverse momentum, 8–12, 12–18 and 18–30 GeV.

While no significant deviation from zero is found for the azimuthal anisotropy difference, $\Delta \lambda_\varphi$, the results for $\Delta \lambda_\vartheta$ suggest strong and opposite polar anisotropies for the prompt $\chi_{c1}$ and $\chi_{c2}$ mesons. A comparison of the measured cross section ratios with the expected analytic shapes reveals that the measurement disfavors the unpolarized scenario, where both states have the same polarization, but is in agreement with the NRQCD prediction.