ALPs in External Magnetic Fields

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The Standard Model (SM) of particle physics, despite its remarkable success, fails to account for approximately 27% of the universe's energy density in the form of dark matter. Astrophysical and cosmological observations, from galactic rotation curves to the cosmic microwave background, provide evidence for the existence of non-baryonic dark matter that interacts only weakly with ordinary matter.

Among the most promising candidates are Axion-Like Particles (ALPs), pseudo-scalar bosons that arise naturally in many extensions of the SM. Originally motivated by the strong CP problem through the Peccei-Quinn mechanism, ALPs represent a broader class of light dark sector particles characterized by their derivative couplings to SM fields. The phenomenologically most relevant interaction is the ALP-photon coupling, described by the effective Lagrangian term $\frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu} \in \mathcal{L}$, where a is the ALP field, $F_{\mu\nu}$ is the electromagnetic field tensor, and $g_{a\gamma\gamma}$ is the coupling strength. This interaction enables both the production of ALPs in high-energy environments and their detection through the Primakov effect.

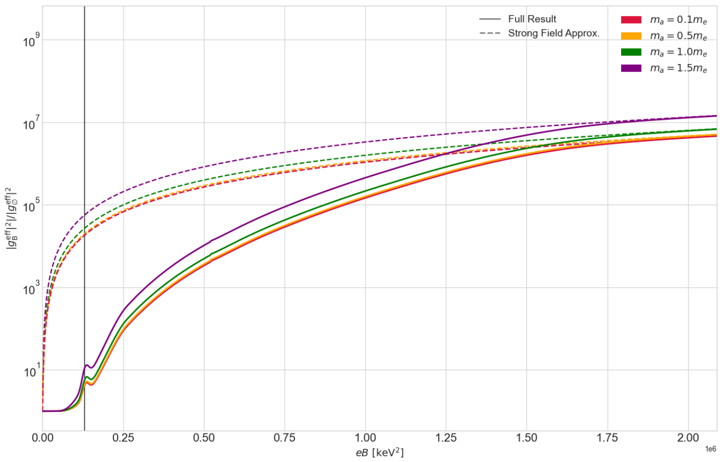

Figure 1: ALP to two photon relative decay rate as a function of magnetic field strength for different ALP masses, compared to the Leading Landau Level (LLL) approximation.

This project focuses on two complementary aspects of ALP physics: precision theoretical calculations and collider phenomenology. The first project involved computing the ALP-to-two-photon decay amplitude at one-loop level in the presence of external magnetic fields. This calculation uses the Schwinger proper-time method to handle the complexity introduced by the external field background. The Schwinger propagator formalism allows for exact summation over all Landau levels, providing a non-perturbative treatment of the magnetic field effects, while keeping the quantum effects perturbatrive. This allows us to understand the behaviour of ALPs in magnetized environments, relevant for both astrophysical contexts (neutron star magnetospheres) and laboratory experiments (strong magnetic field facilities). Results can be seen in Fig. 1.

In the future, we aim to expand our calculations to consider furture categories of BSM partices, and to explore the implications of our findings for ongoing and planned experimental searches for ALPs. By combining precision theoretical work with collider phenomenology, we hope to contribute to the effort to underdstand dark matter.