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MSc Research Project Reading Notes

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2 New Experimental Approaches in the Search for Axion-Like Particles (Irastorza and Redondo (2018))

Theoretical Motivation to Search for Axions

Consider Lagrangian of SM at energies below EW symmetry breaking. There are two possible terms that violate parity (P) and time reversal without changing quark flavour

$$\mathcal{L}_{CP} = -(\overline{\mathbf{q}_L} m_q e^{i\theta_\gamma} \mathbf{q}_R + h.c) - \frac{\alpha_S}{8\pi} G^a_{\mu\nu} \tilde{G}^{\mu\nu}_a \theta_{QCD} \tag{1}$$

where $\mathbf{q} = (u, d, ...)$ is a vector of quark flavours, α_S is the QCD equivalent of the fine structure constant, and $G_{\mu\nu}$ is the gluon field strength tensor, with $\tilde{G}^{\mu\nu^a} = \epsilon^{\nu\mu\alpha\beta} G^a_{\alpha\beta}/2$ is its dual, and, θ_{QCD} is the angle determining the gauge-invariant QCD vacuum. The measurement of the neutron EDM imposes the restriction that

$$|\theta| < 1.3 \times 10^{-10}$$

where $\theta = \theta_{QCD} + N_f \theta_Y$, where N_f represents the number of quark flavours and θ_Y is a common phase among these flavours. The essence of the strong CP problem is to determine why θ is so small if composed of two arbitrary phases.

Peccei and Quinn noted that having a $U(1)_A$ symmetry only violated by the colour anomaly term $G\tilde{G}$ would clear the strong CP problem. They suggested that such a symmetry could exist if it were spontaneously broken at a high-energy scale. This symmetry is known as the Peccei Quinn (PQ) symmetry. Weinberg and Wilczek both realised that such a spontaneously broken global symmetry implied a new pseudo Nambu Goldstone (pNG) boson, which was named the 'axion'. The nature of the axion makes it an ideal dark matter candidate

Axion Like Particles (ALPs)

Axion-like particles (ALPs) are particles with properties similar to those of axions. A key difference that exists between them is that both the mass m_A and the coupling strength to photons $g_{a\gamma}$ are proportional to the energy scale in the case of axions, whereas they are independent parameters for ALPs. ALPs cannot account for the strong CP problem, as they are much less constrained, while the axion is linked only to the strong force. ALPs can couple predominantly to gauge boson pairs such as $gg, \gamma\gamma, ZZ, \gamma Z, W^+W^-$, etc.

The $B \to K^{(*)}A, A \to \gamma\gamma$ Process

The coupling of the ALP to the weak gauge bosons $W^{\pm}$ gives rise to observable signatures, unlike different ALP models wherein the main effective coupling is with photons and/or gluons (see Shuve, Lin paper) and the ALP mass is below 5 GeV. In the sitution where the ALP only directly couples with quarks, the aforementioned decay channel is only dominant below the π mass threshold. Assuming that the ALP couples only to the field strength of the $SU(2)_W$ gauge bosons

$$\mathcal{L} = (\partial_\mu a)^2 - \frac{1}{2}M_a^2 a^2 - \frac{g_{aW}}{4} W^a_{\mu\nu}\tilde{W}^{a\mu\nu} \tag{2}$$

CONTINUE THIS SECTION

3 Meeting Notes (20/07/2022): Background Candidates for $B^0 \to K^{0*}\gamma$

3.1 LHCb Collaboration (2012): Measurement of the Ratio of Branching Fractions of $B^0 \to K^{*0}\gamma$

3.1.1 Signal and Background Description

- The signal yield of the $B^0 \to K^{*0}\gamma$ decays are determined from an extended unbinned maximum-likelihood fit performed simultaneously to the invariant mass distributions for the B^0 candidates.

- The reconstructed mass distribution of the combinatorial background has been determined from the low-mass sideband of the K^{*0} mass distribution as an exponential function with an attenuation constant for this decay channel.

- Additional contamination from several exclusive backround decays is studied using simulated samples. The irreducible $B_s^0 \to K^*\gamma$ decays, and the $\Lambda_b^0 \to \Lambda^*(pK^-)\gamma$ decays, and the charmless $B_s^0 \to h^+h'^-\pi^0$ decays produce peaked contributions under the invariant mass peak of $B^0 \to K^{*0}\gamma$

- Since the experimental branching fractions of the charmless B_s^0 and Λ_b^0 decays are unknown, the corresponding contamination rates are estimated either using the predicted branching fraction in the case of $B_s^0 \to K^{*0}\gamma$ decays, assuming SU(3) symmetry for $B_s^0 \to h^+h'^-\pi^0$, or by directly estimating the signal yield from an independent sample, as is the casefor $\Lambda_b^0 \to \Lambda^*\gamma$ decays

- The overall contribution from these decays is estimated to represent $(2.4\pm 0.4)\%$ of the $B_s^0 \to K^{*0}\gamma$ signal
- Each of these contributions is modelled with a Crystal Ball function, determined from a simulated sample, and their yields are fixed in the fit.
- Partial reconstruction of the charged $B \to h^+h'^-\gamma X$ or $B \to h^+h'^-\pi^0 X$ decays gives a broad contribution at lower candidate masses, with a high mass tail that extends into the signal region
- The partially reconstructed $B^+ \to K^{*0}\pi^+\gamma$ produces a peaking contribution in the low-mass sideband at around 5.0 GeV/c^2. This contamination has been estimated to be $(3.3 \pm 1.1)\%$
- The partially reconstructed neutral B meson decays also contribute at the same level and several other channels exhibit a similar final state topology
- These contributions are described by a Crystal Ball function and the yields are left to vary in the fit
- Additional contributions from the partial reconstruction of multi-body charmed decays and $B \to V\pi^0 X$ have been added to the simultaneous fit in the same way. The shape of these contributions follow an ARGUS function, peaking around 4.0 GeV/c^2

4 The LHCb Detector

4.1 Structure of the LHCb Detector

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