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On the search for the electric dipole moment of strange and charm baryons at LHC

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Summary. — Electric dipole moments (EDMs) are powerful probes for physics beyond the Standard Model. We propose to search for the EDMs of strange and charm baryons at LHC, measured from spin precession in intense electromagnetic fields. The experimental layout based on the LHCb detector and expected sensitivities are discussed.

1. – Introduction

The spin-electromagnetic field interaction is driven by dipole moments, magnetic $\boldsymbol{\mu} = g\mu_B \mathbf{s}/\hbar$ (MDM) and electric $\boldsymbol{\delta} = d\mu_B \mathbf{s}/\hbar$ (EDM). The EDM violates parity and time-reversal symmetries, thus CP assuming the CPT theorem. EDMs in the Standard Model are practically zero, with strong interaction CP violation (CPV) heavily constrained by the neutron EDM limit, therefore being background-free probes of new physics. Moreover, the degree of matter-antimatter asymmetry in the Universe calls for new sources of CPV.

We propose to search for the EDMs of strange and charm baryons at LHC, allowing the first measurement on charm baryons Λ_c^+, Ξ_c^+ and an improvement of the Λ baryon EDM limit by two orders of magnitude [1].

2. – Method

The EDM is extracted from baryon spin precession in an electromagnetic field, intense enough to induce a sizeable precession before baryon decay. Charm baryons are selected from p-nucleus collisions, having orthogonal polarization to the p-Λ_c^+ plane for parity symmetry in strong interactions. Spin precession is achieved in the interatomic electric field of a bent crystal: baryons channeled between atomic planes feel a non-zero field thanks to the centrifugal force. The polarization after the crystal is derived assuming

EDM effects to be first-order corrections to the MDM-driven precession,

$$\mathbf{s} = s_0 \left(\frac{d}{g-2} (\cos\Phi - 1), \cos\Phi, \sin\Phi \right), \qquad \Phi \approx \frac{g-2}{2} \gamma \theta_C,$$

measurable via the charm baryon decay angular distribution, *e.g.*, using $\Lambda_c^+ \to \Delta^{++} K^-$ decays. The EDM signature is a polarization component orthogonal to the main precession plane otherwise not present.

Strange (Λ) baryons are selected from weak decays of charm baryons produced in pp collisions, with parity-violation–induced longitudinal polarization ($\gtrsim 90\%$), and precess in the LHCb detector magnetic field. For Λ baryons aligned to the longitudinal axis z, $\mathbf{B} = B_y \hat{\mathbf{y}}$ and assuming small EDM effects,

$$\mathbf{s} = s_0 \left(-\sin\Phi, -\frac{d\beta}{g} \sin\Phi, \cos\Phi \right), \qquad \Phi \approx \frac{g D_y \mu_B}{\beta \hbar c}, \quad D_y \equiv \int_0^l B_y \mathrm{d}l'.$$

The baryon polarization after the magnet is extracted from the $\Lambda \to p\pi^-$ angular distribution. The EDM signature is, again, a polarization component orthogonal to the main precession plane otherwise not present.

3. – Sensitivity studies

The frequency of Λ_c^+ baryons produced with a proton beam impinging on a fixed-target, channeled in the bent crystal and reconstructed in the detector is

$$\frac{\mathrm{d}N_{\Lambda_c^+}^{\mathrm{reco}}}{\mathrm{d}t} = \frac{F}{A} \sigma(pp \to \Lambda_c^+ X) N_T \mathcal{B}(\Lambda_c^+ \to \Delta^{++} K^-) \varepsilon_{TOT},$$

in which F, A are the beam intensity and area, N_T is the number of target nucleons and ε_{TOT} is the total efficiency $\approx 10^{-5}$. The uncertainty is dominated by statistics,

$$\sigma_d \approx \frac{g-2}{\alpha s_0 (\cos\Phi - 1)} \left(N_{\Lambda_c^+}^{\mathrm{reco}} \right)^{-\frac{1}{2}}.$$

Considering one month of data taking and a polarization $s_0 \approx 50\%$, $\sigma_\delta(\Lambda_c^+/\Xi_c^+) \approx (1.3/2.0) \times 10^{-17}\, e \cdot \mathrm{cm}$.

The number of suitable Λ baryons is estimated as

$$\begin{aligned} N_\Lambda = {} & 2\mathcal{L}\sigma_{q\bar{q}} f(q \to H_c) \mathcal{B}(H_c \to \Lambda X') \\ & \times \mathcal{B}(\Lambda \to p\pi^-) \mathcal{B}(X' \to \text{charged}). \end{aligned}$$

The charm baryon H_c decays in Λ chosen according to the relative probability and possibility of complete reconstruction, of order $10^{11}/\mathrm{fb}^{-1}$. The reconstruction efficiency is $\approx 0.16\%$ for the LHCb detector upgraded for Run 3. The EDM sensitivity is studied using pseudoexperiments assuming $50\,\mathrm{fb}^{-1}$ of integrated luminosity, $\sigma_d \approx 1.3 \times 10^{-18}\, e \cdot \mathrm{cm}$.

REFERENCES

[1] Botella F. J., Garcia Martin L. M., Marangotto D., Martinez Vidal F., Merli A., Neri N., Oyanguren A. and Ruiz Vidal J., *Eur. Phys. J. C*, **77** (2017) 181, arXiv:1612.06769.