PROCEEDINGS OF SCIENCE

Experiment for direct measurements of short-lived particle dipole moments at LHC

A. Merli,[a] **F. Martinez Vidal,**[b] **N. Neri,**[a] **D. Marangotto,**[a] **E. Spadaro Norella,**[a] **G. Tonani,**[a,b] **I. Sanderswood,**[b] **J. Fu,**[c] **J. Ruiz Vidal**[b] **and Z. Wang**[c]

[a] *INFN and Università degli Studi di Milano, Via Celoria, 16, Milan, Italy*

[b] *Instituto de Física Corpuscular and Universitat de València, Catedratico Jose Beltrán, 2, València, Spain*

[c] *University of Chinese Academy of Science Zhongguancun East St., 80, Haidian Dist., Beijing, China*

E-mail: giorgia.tonani@mi.infn.it

An experiment to directly measure magnetic and electric dipole moments of charmed baryons at the LHC is presented. These measurements offer new opportunities for physics within and beyond the Standard Model, as they are sensitive to the baryon internal structure and CP violation. Electromagnetic dipole moments have never been measured before for charmed baryons due to their extremely short life-time. To overcome this difficulty a setup with bent crystals has been proposed. A proof of principle for this experiment to be performed at the LHC is detailed in this contribution.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

https://pos.sissa.it/

PoS(ICHEP2022)1189

1. Introduction

A worldwide effort is ongoing to measure electromagnetic dipole moments of many particles, but a result for charmed baryons has not been accomplished up to date. The reason is mainly to be attributed to their short lifetime, which imposes significant experimental challenges. In this letter we focus on the proposal for their first measurement. The magnetic dipole moment (MDM, $\vec{\mu}$) and the electric dipole moment (EDM, $\vec{\delta}$) are static properties and for spin 1/2 particles they are defined as

$$\vec{\mu} = g\mu_B \frac{\vec{s}}{2}, \tag{1}$$

$$\vec{\delta} = d\mu_B \frac{\vec{s}}{2}. \tag{2}$$

The spin-polarization vector $\vec{s}$ is equal to $2 < \vec{S} > /\hbar$, with $\vec{S}$ the spin operator. The particle magneton is $\mu_B = e\hbar/(2mc)$, and d and g are the gyroelectric and gyromagnetic factors respectively. The EDM is T-odd and P-odd, therefore the existence of a non-zero EDM would imply a new source of CP violation, considering valid the CPT theorem. This implication is relevant for the understanding of baryogenesis. Furthermore the Standard Model prediction for the charmed baryons EDM is approximately $< 4.4\times10^{-17} e$ cm, which is indirectly derived from the experimental limit on the EDM of the neutron [1]. At the current experimental sensitivity any measurement significantly above this value would imply a new source of Beyond the Standard Model physics. On the other hand, the MDM does not violate any symmetry, but can offer new information on the internal structure of the baryon, thus giving hints for the understanding of low-energy QCD models [2]. Moreover, if the MDM for the particle and antiparticle can be measured, their comparison can provide a test of the CPT theorem.

2. Experimental method

To measure the electromagnetic dipole moments we want to exploit the spin-polarization precession in an electromagnetic field [3]. To induce a detectable precession in the case of charmed baryons, with a lifetime of the order of 10^{-13} s, a magnetic field of hundreds of Tesla is required. Up to date the available magnets cannot provide such a field and a solution is given by bent crystals [4] [5], which have an electric field of the order of GV/cm between their atomic planes and can induce an effective magnetic field strong enough to induce a sizable precession. The production polarization $\vec{s} = (0, s_0, 0)$ is perpendicular to the production plane xz (Fig. 1) due to parity conservation in strong interactions. The polarization after the precession can be derived solving the T-BMT equation [6] [7],

$$\vec{s}' \simeq \left(s_0 \frac{d}{g-2}(\cos\Phi - 1), s_0\cos\Phi, s_0\sin\Phi\right), \tag{3}$$

where the x component is sensitive to the presence of the EDM and Φ is the precession angle, defined as the angle between the polarization vector after the precession and the y axis, with which we can access the MDM:

$$\Phi \simeq \frac{g-2}{2}\gamma\theta_C. \tag{4}$$

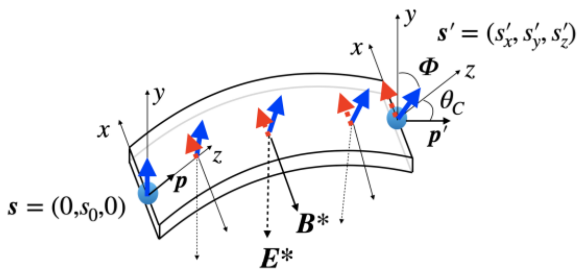

Figure 1: Spin-polarization precession in the yz and xz plane induced by the MDM and the EDM, respectively.

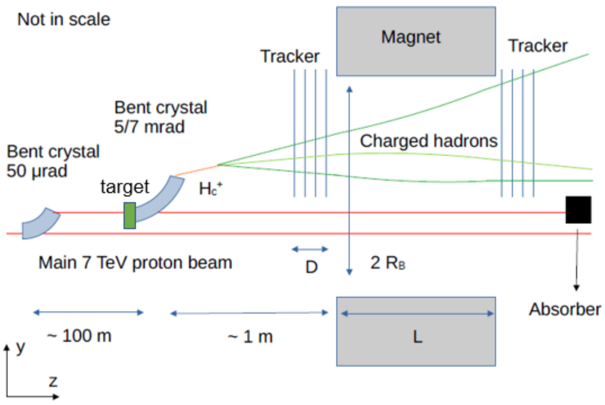

Figure 2: IR3 test set up.

Here γ represents the Lorentz boost, assumed to be $>> 1$ and θ_C is the crystal bending angle. The polarization $\vec{s}'$ can be measured exploiting the angular distribution of the final-state particles of the charmed baryon, such as $\Lambda_c^+ \to pK^-\pi^+$. In this work we propose a setup to perform a proof-of-principle test at the LHC, in particular at Interaction Region 3 (IR3), to be installed during the Run 3. With this test we want to demonstrate the feasibility of a dedicated experiment for heavy baryon electromagnetic dipole moments exploiting a double-crystal layout. In particular, we want to prove that the channeling of charm hadrons is possible with a significant yield and we aim at characterizing the background. Many studies for the implementation of the experiment have already been completed, such as a first test at the SPS with the double-crystal layout. The channeling in crystals has been proven by UA9 at 6.5 TeV at the LHC [9] and LHC machine layout simulations have been successfully performed [8]. For the test at IR3 we consider the Λ_c^+, D^+ and D_s^+ decays into three charged hadrons. To separate the Λ_c^+ signal from the other background decays we want to reach a sufficient resolution in invariant mass with the setup pictured in Fig. 2. The halo is extracted from the main proton beam with a first bent crystal with a bending radius of about 50 μrad. This step is a common procedure at the LHC [9]. The extracted proton beam interacts with a target, made of tungsten, producing charmed baryons to be channeled in the second bent crystal. The optimal target thickness is found to be about 2 cm, taking into account the number of particles at target exit and the detector occupancy. To correctly place in position the target and the second crystal a goniometer is needed, with an accuracy on the position of about 20 μm and a rotation angle of about 20 μrad. The second crystal was tested at 180 GeV/c momenta and performed a channeling efficiency greater than 10% [10]. The length and bending angle still need to be optimized, with the considered materials being silicon and germanium. Once the baryons exit the second crystal, they decay and produce the final state particles to be reconstructed with a spectrometer composed by a magnet enclosed between two tracking stations. At IR3 a corrector magnet is already present (MCBW), with a length of 1.7 m and a magnetic field of 1.1 T. It can be used to perform the test, since it shows an acceptance greater than 80%. For the tracking stations we are considering to employ silicon pixel sensors, the number of layers and their position need to be optimized through a full simulation. Finally an absorber is needed for the extracted beam halo.

3. Sensitivity studies

We simulated 7 TeV proton beam, with an intensity of 10^6 protons/s, and we obtained the baryons production spectrum from PYTHIA 8 after channeling through a 7 cm length, 5 mrad bent Ge crystal. The expected yields obtained for the IR3 test are of the order of thousands of $D^+ \to K^-\pi^+\pi^+$ decays recordable in few days of data taking, while we would need less than two months of data taking to collect the same order of magnitude of signal $\Lambda_c^+ \to pK^-\pi^+$ and $\Xi_c^+ \to pK^-\pi^+$ events. Increasing the intensity to 10^7 protons/s, one week would be enough to collect the same amount of data. Considering a long-term dedicated experiment, with 2 years of data taking at 10^{13} protons on target, we could reach a per cent precision on the MDM, while the expected sensitivity on the EDM is of the order of $10^{-16} e$ cm [3].

Acknowledgement

This work is the result of the collaboration of Bonn, CERN, Ferrara, IJCLAB, LHC collimation, Milano, PBC, UCAS and Valencia groups. We acknowledge support from the ERC Consolidator Grant SELDOM G.A. 771642.

References

[1] J. M. Pendlebury et al., Phys. Rev. **D92** (2015), 9 092003.

[2] A. Dainese et al., CERN PBC REPORT (2018) 008.

[3] F. J. Botella et al., Eur. Phys. J. **C77**, (2017) 181.

[4] V.G. Baryshevsky, Pis'ma Zh. Tekh. Fiz. **5** (1979) 182.

[5] A.S. Fomin et al., J. High Energ. 2017 (2017) 120.

[6] L. H. Thomas, Phil. Mag. **3** (1927) 1.

[7] V. Bargmann, L. Michel, and V. L. Telegdi, Phys. Rev. Lett. **2** (1959) 43.

[8] D. Mirarchi et al., Eur. Phys. J. **C80** (2020) 10:929.

[9] W. Scandale et al., Phys. Lett. **B758** (2016) 129:133.

[10] S. Aiola et al., Phys. Rev. **D103** (2021) 072003.