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Proof-of-principle test for a charm baryon experiment at the LHC(*)

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Summary. — In the research for physics within and beyond the Standard Model, electric and magnetic dipole moments have proven to be powerful probes. As of today, they haven't been measured for the case of charm baryons due to their really short lifetime. A new experiment has been proposed at the insertion region 3 of the LHC during Run 3, featuring an innovative technique that will exploit the use of bent crystals. A first proof-of-principle test at the LHC is foreseen by the end of 2025. The goals of the test and the experimental challenges will be presented in this paper together with the physics program that exploits the unique forward acceptance of the future experiment.

1. – Electromagnetic dipole moments

Electric and magnetic dipole moment (EDM/MDM) are defined, for spin 1/2 particles, as $\delta = \frac{1}{2}d\mu_B P$ and $\mu = \frac{1}{2}g\mu_B P$, where g and d are the gyroelectric and gyromagnetic factors and P is the spin polarization unit vector, $P = 2 < S > /\hbar$, with S the spin operator [1]. Measurements of MDM and EDM are relevant for studying physics within and beyond the SM. A non-zero measurements of the EDM of these particles would represent a new source of CP violation beyond the SM, while the measurement of the MDM would provide important information on the strong interactions and for QCD calculations. As of today, there are no measurements for the EDMs and MDMs of charm baryons due to their extremely short lifetime $\sim 10^{-13}$ s [2, 3]. To fill this gap, a new experiment has been proposed, exploiting the phenomenon of particle spin precession inside bent crystals [4]. The strong electric field, that is present inside the bent crystal, induces the precession of the particle spin vector [5, 6]. The value of the gyromagnetic factor of the particle can be extracted from the precession angle $\phi = \omega\big(1 + \gamma\frac{g-2}{2}\big)$ while the gyroelectric factor is proportional to the spin-polarization component perpendicular to the production plane, $s_x = s_0\frac{d}{g-2}(1 - cos\phi)$ [7, 8]. In addiction to the spin precession effect, bent crystal can be used to steer particles trajectories. This phenomenon is called planar channeling and occurs if the particles impinge upon the crystal surface with a

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small enough angle with respect to the crystal symmetry plane. In the past, bent crystal have already been used for their steering properties and for measuring the MDM of Σ^+ particles at Fermilab [9].

2. – Proposed experiment and expected sensitivity

As described in the previous section, EDMs and MDMs of charm baryons are difficult to measure due to the short lifetime of these particles. An innovative solution was proposed few years ago: a fixed target experiment designed to measure the Λ_c^+ EDM and MDM at the Large Hadron Collider (LHC). In this experiment, the 7 TeV protons of the LHC would interact with a tungsten target, producing the charm baryons with an initial polarization perpendicular to the production plane due to parity conservation in strong interactions. The produced baryons would then be channeled by a bent crystal to induce the spin precession and make the measurement possible. To deflect the main proton beam of the LHC, a first silicon bent crystal would be used, with a deflecting angle of 50 μrad. A second silicon crystal, with a bend of 7 $mrad$, will be placed right after the target to channel the produced charm baryons and to steer their trajectories inside the detector acceptance. A spectrometer composed of several tracking layers and a magnet would complete the experimental setup and allow the reconstruction of the baryons. There are two possible scenarios for this experiment that are being considered. A first option is to place the target right before the LHCb detector while the second possibility is to build a new dedicated experiment in the interaction region 3 (IR3) of the LHC [10]. While the LHCb detector covers a pseudorapity range between $2 < \eta < 5$, the new detector at IR3 has been designed as a forward spectrometer to give access to zero angle production of positively charged particles. The expected integrated luminosity for two years of data taking at IR3 is about 12 pb^{-1}, and has been calculated using a flux of 10^6 p/s on the W target multiplied by the nucleon density of the target. The new experiment at IR3 allow us to gain a factor 2 in precision with respect to the LHCb scenario, achieving a value on the EDM of $7 \cdot 10^{-17}$ e cm and about 2% precision on the MDM. Moreover, with the new dedicated setup there would be the possibility to enlarge the physics case in the very forward region. As of today, a proof-of-principle test is scheduled before the end of 2025 at LHC at IR3, to test the apparatus and the feasibility of the experiment. Then, if approved, the experiment would take place after the Long Shutdown 3 (LS3) of the LHC.

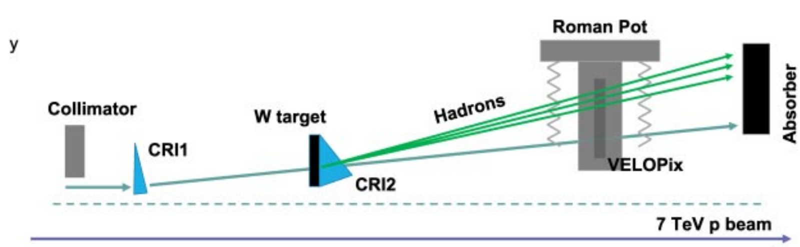


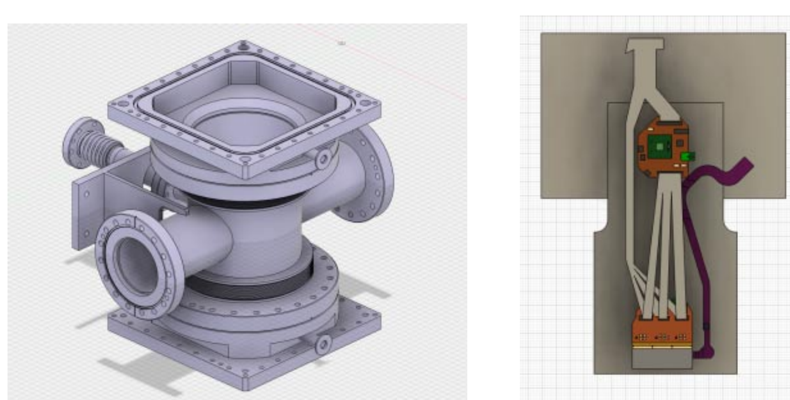
Fig. 1. – Experimental setup for the proof-of -principle test at IR3.

3. – Proof-of-principle test at the IR3 of LHC

The experimental apparatus for the proof-of.principle (PoP) would be a simplified version of the one for the experiment. The schematic is shown in fig. 1. The goals of the test are the measurement of the channeling efficiency of the second bent crystal at the TeV energies and the measuremet of background for pW collisions. During this first run there will be only one tracking layer put inside a Roman Pot, a cylindrical vessel that allows to place the tracking sensors as close as possible to the main circulating beam without breaking the primary vacuum of the LHC, as shown in fig. 2(a). In this way it will be possible to cover the very forward region, collecting hits from both the channeled and the unchanneled particles. Silicon pixel sensors will be used for the tracking system. The chosen sensors are the VeloPix Silicon pixel sensor, state of the art technology already used by the Vertex Locator detector of LHCb. The pixel dimension is $55 \times 55 \mu m^2$ with a pitch of 12 μm and a maximum readout rate of 600 MHz/cm^2 [11]. A schematic layout of the trackingmodule configuration inside the roman pot is shown in fig. 2(b). The R&D for the mechanical support and readout electronics is already in advanced state and the installation of the apparatus is foreseen for the end of 2024.

4. – Future experiment

Simulation studies are in progress to optimize the detector geometry, to maximize the acceptance of the detector for the signal $\Lambda_c^+ \rightarrow p^+ K^- \pi^+$ decays. Further studies are ongoing to evaluate the feasibility of other physics measurements that would become available in the forward region covered by the detector. This could be a unique opportunity to study not only Λ_c^+ forward production but also D mesons production and perform charm cross-section measurements. It could be also possible to study photoproduction processes in pW fixed target collisions. In particular, photoproduction of J/ψ meson in ultraperipheral collisions, whose cross-section has been estimated from [12], and Pentaquark photoproduction [13]. The preliminary cross-section for the pentaquarks has been estimated starting from upper limit of GlueX in 2019 [14] and scaled to their new statistic. To perform such measurements and increase the precision on the reconstruction



(a) (b)

Fig. 2. – (a) Schematic drawing of the inner part of the roman pot that will house the sensors. (b) Schematic drawing of the VeloPix sensors and front end hybrids inside the roman pot.

of $\Lambda_c^+ \to p^+ K^- \pi^+$ decays, additional components must be included in the experimental apparatus. The final apparatus would include a complete spectrometer, composed by four roman pots with two tracking layers each and a bending magnet. Two roman pots would be placed before the magnet and two after. Then also a Cherenkov detector would be needed, to discriminate between the daughters of the Λ_c^+. Finally, a Muon Chamber detector could be placed downstream, to identify muons.

5. – Conclusions

To summarize, an experimental method for the measurement of the EDMs and MDMs of charm baryons has been proposed in the form of a fixed target experiment at the LHC. Two different scenarios are being evaluated, and strong efforts are being put on the design of a dedicated experiment at the interaction region 3. This represents a unique opportunity to measure charm dipole moments and also open the possibility to perform measurements of cross-sections in the very forward direction. Processes of interest are meson production and photoproduction of pentaquarks. A proof-of-principle test is foreseen in 2025 at IR3. R&D is ongoing for the tracking stations. The installation works at the LHC will start at the end of 2024.

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