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

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Summary. — Magnetic and electric dipole moments of particles provide powerful probes for physics within and beyond the Standard Model. For the case of charm baryons these have not been experimentally accessible to date due to the difficulties imposed by their short lifetimes. An experimental test at the insertion region 3 of LHC is foreseen during Run3 to demonstrate the feasibility of a fixed-target experiment with bent crystals. The goal of the proof-of-principle test and the perspective for a future experiment are described in this article along with projected sensitivities for different experimental scenarios.

1. – Electromagnetic dipole moments

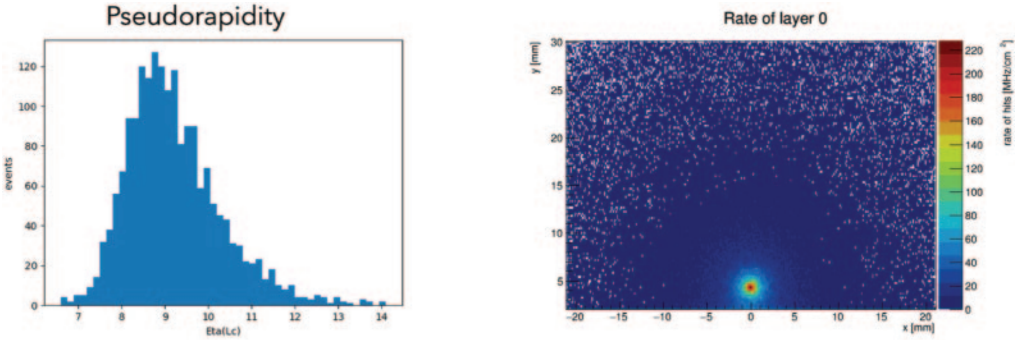
The electric dipole moment (EDM) measures the separation of positive and negative charge inside a particle while the magnetic dipole moment (MDM) determines the force that the particle experiences inside a magnetic field. Spin 1/2 particles have an intrinsic electric and magnetic dipole moments defined as $\delta = \frac{1}{2} d\mu_B P$ and $\mu = \frac{1}{2} g\mu_B P$, where d and g are the gyroelectric and gyromagnetic factors and P is the spin polarization unit vector $P = 2\langle S\rangle/\hbar$, with S being the spin operator [1]. EDMs and MDMs are known to be stringent tests of the Standard Model. Measurements of particle magnetic dipole moments would provide important information for the modeling of strong interaction and for QCD calculations. On the other hand, non-zero measurements of electric dipole moments would represent a source of physics beyond the SM. In fact, in the Hamiltonian of the system $H = -\mu \cdot B - \delta \cdot E$ the term proportional to the EDM violates T and P, and therefore CP through the CPT theorem. As for today there are no measurements of the electromagnetic dipole moments of charm baryons due to their short lifetime $\leq 2 \cdot 10^{-13}\,\mathrm{s}$ [2, 3]. To overcome this limitation, an innovative experimental method has been proposed that exploits the phenomenon of particle spin precession inside bent crystals [4]. Particles that impinge on the crystal surface with a small enough angle are not only channeled but the strong electric and magnetic fields present inside the bent crystal induce the precession of particle spin vector [5,6]. The value of the magnetic dipole moment of the particle can thus be extracted from the precession angle $\phi = \omega\big(1 + \gamma\frac{g-2}{2}\big)$ while the electric dipole moment 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].

2. – Fixed target at the LHC

Bent crystal have already been used for their steering properties and for measuring the MDM of Σ^+ particles at Fermilab [9]. The new proposal is to measure the Λ_c^+ EDM and MDM in a fixed-target experiment to be installed at the Large Hadron Collider (LHC). The charm baryon will be produced in the interactions of the 7 TeV proton beam of the LHC with a tungsten target, and will have an initial polarization perpendicular to the production plane due to parity symmetry conservation in strong interactions. Part of the halo of the main LHC proton beam will be deflected onto the target by a first silicon (Si) bent crystal with a deflection angle of 50 μrad and a second Si bent crystal, with a deflection angle of 7 mrad, will be placed right after the target to channel the produced baryons and induce the precession of their spin. Finally, a spectrometer composed of several tracking layers and a magnet will be placed downstream to reconstruct the baryons and perform the measurement. 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 that is well suited for this measurement thanks to his forward geometry. The second possibility is to build a new dedicated detector in the interaction region 3 (IR3) of the LHC [10]. The new dedicated detector foresees the use of Roman pots that are cylindrical vessels that allow to place the selected tracking sensors as close as possible to the main circulating beam without breaking the primary vacuum of the LHC. In this way it is possible to optimize the acceptance and the performances of the detector according to the proposed measurement, and also try to enlarge the physics case and exploit the very forward particle production region.

3. – Feasibility studies and measurements of interest

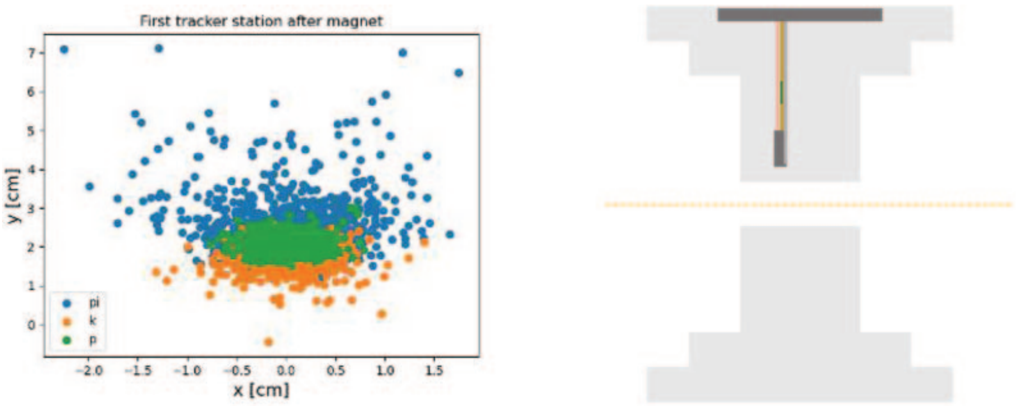
Different studies have been conducted to understand the feasibility of the measurement and which scenario might be better suited for the future experiment. The first considerations to be done are on the kinematics of the produced charm baryons. Starting from 7 TeV protons of LHC, charm baryons are produced in a very forward direction and with very high momentum, higher than 1 TeV. The pseudorapity range of the baryons is shown in fig. 1(b). While the LHCb detector covers a pseudorapity range of $2 < \eta < 5$, the new detector at IR3 has been designed as a forward spectrometer to give access to zero angle production of positively charged particles, covering larger η up to 10. This upper limit is given by the granularity of the tracking sensors. The expected integrated luminosity for two years of data taking at IR3 is of 12 pb^{-1}, and has been calculated using a flux of 10^6 p/s on the target multiplied by the nucleon cross-section and integrated over the data taking period. The first bent crystal would be aligned to the secondary halo of the main proton beam of LHC at 7 TeV and the halo extraction would allow to have a flux of protons on the 2 cm W target of 10^6 p/s. In these conditions, the new experiment at IR3 would gain a factor of 2 in precision with respect to the LHCb scenario, achieving a sensitiviy on the EDM of $7 \cdot 10^{-17}$ e × cm and the 2% precision on the MDM. Lots of effort are being done towards the construction of the independent experiment at the interaction region 3 due to his unique forward acceptance. Simulation studies are in progress to optimize the detector geometry, in particular taking into account the acceptance and



(a) (b)

Fig. 1. – (a) Charm baryons pseudorapidity distribution when produced by the collision of the 7 TeV proton beam with a W target. (b) Simulated occupancy rate/area in the first tracking station after the target.

the occupancy of the tracking sensors. The hit distribution of channeled $\Lambda_c^+ \to p^+K^-\pi^+$ decays in the first tracking station is shown in fig. 2(a). In general, this would be a unique opportunity to study not only Λ_c^+ forward production but also D mesons production to perform charm cross-section measurement in the forward region. Moreover, the opportunity to study photoproduction in a fixed target is being evaluated. Possible physics cases are the photoproduction of J/ψ meson in ultraperipheral collisions, whose cross-section has been estimated from [11], and pentaquark photoproduction [12]. The preliminary cross-section for the pentaquarks has been estimated starting from the upper limit of GlueX [13] and scaled to their new statistic. Expanding the physics case would probably require the addition of a sub detector dedicated to the particle identification, as a Cherenkov ring detector, and possibly muon chambers.



(a) (b)

Fig. 2. – (a) Hit distribution of the Λ_c daughters in the first tracking station. (b) Schematic drawing on the inner boxes of the Roman pot, one filled with the VeloPix sensors.

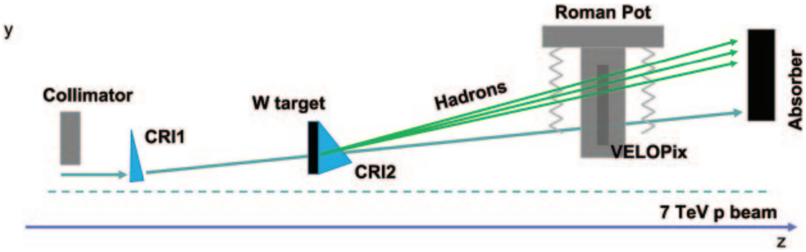


Fig. 3. – Experimental setup for the proof-of-principle test at IR3.

4. – Proof-of-principle test

If approved, the experiment for the measurement of the EDM and MDM of charm baryons will take place after the long shutdown 3 of LHC. For now, a first proof-of-principle test is scheduled for 2025 at the LHC in the interaction region 3. The experimental apparatus for the proof of principle would be a reduced version of the one of the experiment as shown in fig. 3. The first crystal is used to channel the secondary halo of the proton beam while the second one is used for the spin precession and to channel the baryons. For this first test, downstream to the second crystal there will be only one tracking station placed inside a Roman pot. This test will prove the feasibility of the double crystal set up at TeV energies and test the tracking system. The main goals of the test are the measurement of the crystal channelling efficiency and the test of the sensors and their read-out electronics. The R&D is already in advanced state and the installation of the apparatus is foreseen for the end of 2024. 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 $55 \times 55\ \mu\text{m}^2$ with a resolution of $12\ \mu$m and a maximum readout rate of $600\,\text{MHz/cm}^2$ [14]. The sensors will be placed few mm far from the main circulating beam and will measure the channeled particles with respect to the non-channeled to make the efficiency measurement. This test will then provide important information for the optimization of the EDM and MDM experimental setup.

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, but strong efforts are being put on the construction of a dedicated experiment at the interaction region 3. This could represent a unique opportunity for forward physics, enlarging the number of measurement of interest to meson production and photoproduction of pentaquarks. A first test is foreseen in 2025, always at IR3 with a reduced setup. R&D is ongoing for the tracking stations while the crystals have already been tested at the SPS. The installation works at the LHC will start at the end of 2024.

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REFERENCES

[1] Atwood D. *et al.*, *Phys. Lett. B*, **291** (1992) 293.
[2] Beacham J. *et al.*, *J. Phys. G: Nucl. Part. Phys.*, **47** (2020) 010501.
[3] Dainese A. *et al.*, CERN-PBC-REPORT 008 (2018).
[4] Aiola S. *et al.*, *Phys. Rev. D*, **103** (2021) 072003.
[5] Baryshevsky V. G., *Pisma Zh. Tekh. Fiz.*, **5** (1979) 182.
[6] Fomin A. S. *et al.*, *Eur. Phys. J. C*, **77** (2017) 828.
[7] Botella F. J. *et al.*, *Eur. Phys. J. C*, **77** (2017) 181.
[8] Bagli E. *et al.*, *Phys. Rev. D*, **103** (2021) 072003.
[9] Chen D. *et al.*, *Phys. Rev. Lett.*, **69** (1992) 3286.
[10] Mirarchi D. *et al.*, *Eur. Phys. J. C*, **80** (2020) 929.
[11] Gonçalves V. P. *et al.*, *Eur. Phys. J. C*, **78** (2018) 693.
[12] Adhikari S. *et al.*, *Phys. Rev. C*, **108** (2023) 025201.
[13] Gonçalves V. P. *et al.*, *Phys. Lett. B*, **805** (2020) 135447.
[14] LHCb Collaboration, CERN-LHCC 021 (2013).