PROCEEDINGS OF SCIENCE

Silicon pixel detector developments for direct measurement of charm baryon dipole moments at LHC

Federico Zangari[a,*] **on behalf of the TWOCRYST collaboration and ALADDIN proto-collaboration**

[a] *Università degli Studi di Milano and INFN,*
Via Celoria 16, 20133, Milan, Italy

E-mail: federico.zangari@mi.infn.it

TWOCRYST is a proof-of-principle test for the proposed ALADDIN experiment dedicated to the direct measurement the dipole moments of charm baryons at LHC. The TWOCRYST data taking is planned during the LHC Run 3. A silicon pixel detector for the measurement of signal charm baryons is under construction. It is based on the LHCb VELO pixel sensors and readout system and it will work in the secondary vacuum of a Roman Pot, positioned inside the LHC beam pipe. The design and integration of the pixel detector within the Roman Pot will be discussed, as well as the expected performance.

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*Speaker

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1. Introduction

The measurement of electric dipole moments (EDM) and magnetic dipole moments (MDM) is a powerful tool to test the Standard Model (SM) predictions and probe for new physics. For a spin 1/2 particle, the EDM and MDM are defined as $\delta = \frac{1}{2} d \mu_B P$ and $\mu = \frac{1}{2} g \mu_B P$ respectively. Here d and g are the gyroelectric and gyromagnetic factors, P is the spin polarization unit vector $P = 2 \langle S \rangle / \hbar$ of the spin operator S, μ_B is the the Bohr magneton [1]. The Hamiltonian of the system is given by $H = -\mu \cdot B - \delta \cdot E$. The term involving the EDM is not invariant under the action of both the T and P operators. Therefore, the existence of a particle EDM would imply, via the CPT theorem, a CP violation that is not predicted by the Standard Model [2, 3]. On the other hand, the measurement of MDMs can be used as a probe for the violation of CPT symmetry, which implies MDMs to be identical in magnitude but opposite in sign for a particle and its corresponding antiparticle. The measure of MDMs can also provide important inputs to models describing the strong interaction and QCD calculations [4].
Despite their importance, up to date there is no direct measurement of such quantities for charm and beauty baryons and the τ lepton. These measures are experimentally challenging due their short lifetime $\leq 4 \cdot 10^{-13}$ s [5]. An interaction with an intense electromagnetic field is needed to induce spin precession before the particle decays, which is not possible with standard magnets. In recent years, a novel experimental technique, based on bent crystals, has been proposed to overcome this challenge for the Λ_c^+ and Ξ_c^+ baryons[6–8]. When a particle impinges on the crystal within the acceptance angle, it gets trapped between the crystalline planes, and its trajectory is steered by the bending angle of the crystal [9, 10]. Furthermore, the intense electric and magnetic fields inside the crystal will also induce spin precession. The charm baryon MDM and EDM are related to the precession angle of the spin-polarization vector, originally produced perpendicular to the production plane. These two properties are therefore determined by measuring the angular distributions of the decay products of the baryons.

2. The ALADDIN and TWOCRYST experiments

The ALADDIN experiment (A Lhc Apparatus for Direct Dipole moments INvestigation) has been proposed to measure charm baryons dipole moments at the LHC [11, 12]. It features a fixed-target with double-crystal layout [13], where protons from the halo of the main 7 TeV beam are extracted by a first bent crystal, the target collimator crystal for splitting (TCCS). These protons are then intercepted by a tungsten target. The TCCS has a 50 μrad bending angle and it is placed 100 m downstream the target. The charm baryons produced in the collision are channeled in a second bent crystal, the target collimator crystal for precession (TCCP), placed right after the tungsten target. The TCCP crystal has a 7.0 mrad bending angle, and it is used to induce spin precession to the channeled charm baryons. The tracks of the decay products are reconstructed using a forward magnetic spectrometer. Two tracking stations, based on silicon pixel detectors, will be placed before a warm dipole magnet, with other two stations after it, covering the pseudorapidity region $5 < \eta < 7$. The particle identification (PID) is performed with a Ring Imaging Cherenkov (RICH) detector, optimized for momenta up to 1 TeV/c. The layout of the proposed experiment is represented in Fig. 1. The baseline solution for the location of the experiment is the Insertion

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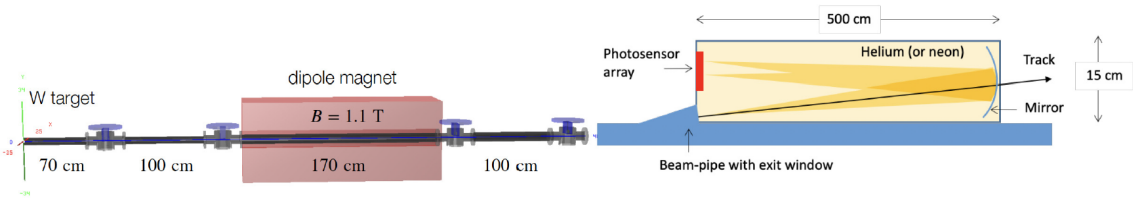

Figure 1: Proposed experimental layout for the ALADDIN experiment.

Region 3 (IR3) of LHC. A Letter of Intent (LoI) was submitted to the LHCC (LHC Committee) for the proposed ALADDIN experiment, which has given a positive recommendation to proceed with the preparation of a Technical Proposal.

A proof-of-principle test, called TWOCRYST, has been approved for installation in IR3 during 2025. The main goals of this test are the following: (i) demonstrate the operational feasibility of the double crystal and tracking detector setup at the LHC; (ii) confirm the estimated achievable proton rates on target; (iii) measure for the first time the channeling efficiency of long crystals at TeV energies; (iv) perform the necessary background studies to validate the simulations and the detector optimization. This test will provide crucial information for ALADDIN, like the channeling efficiency, which are so far only accessible through simulations. The setup used in TWOCRYST is a reduced version of what will be used for ALADDIN, see Fig. 2. The configuration with the TCCS and target plus TCCP is identical to ALADDIN. The two bent crystals were manufactured at INFN Ferrara according to the specifications required for installation at LHC. They were tested at CERN SPS H8 beam line in 2023. The results show a channeling efficiency of roughly 60% and 16% for the TCCS and the TCCP, respectively.

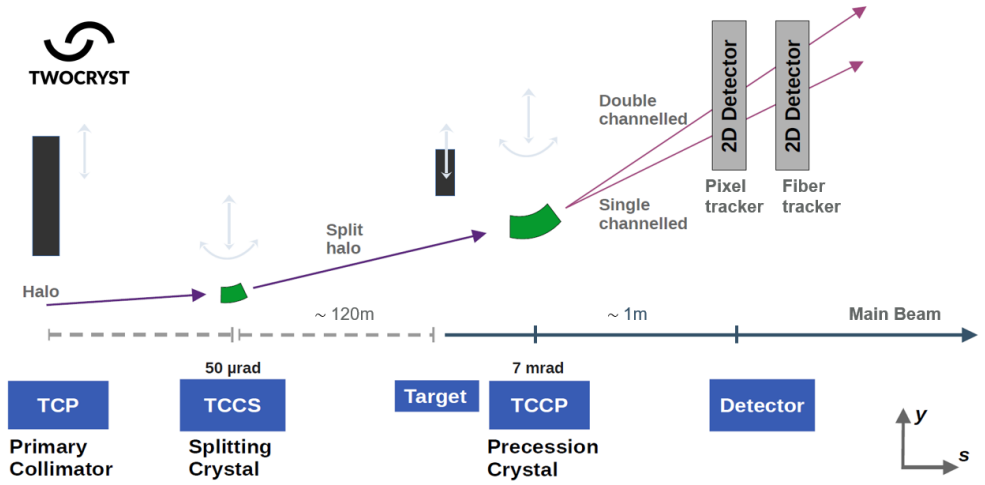

Figure 2: Experimental setup of the proof-of-principle test TWOCRYST.

For the proof-of-principle test, only two tracking stations with 2D detectors will be placed downstream of the crystals. These detectors are needed to measure the channeling efficiencies by measuring the spatial distributions of the deflected and unchanneled particles. A silicon pixel detector based on the LHCb Vertex Locator (VELO) is placed in the first tracking station. The

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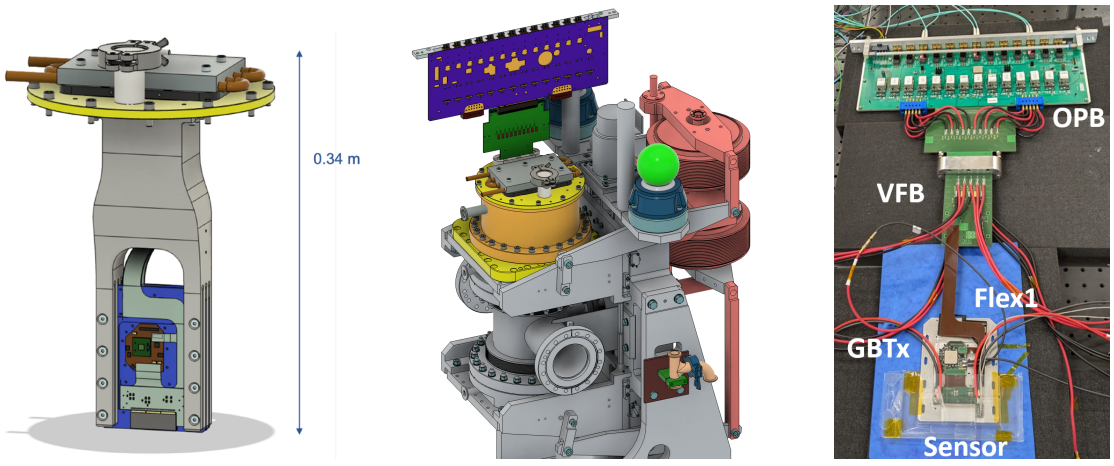
second station houses a module of the ATLAS-ALFA experiment [14] for detector redundancy. The installation of the devices has started at the beginning of the Year End Technical Stop (YETS) 24/25. The data taking period of TWOCRYST will take place during the Machine Development (MD) shifts of the LHC schedule of 2025.

3. The silicon pixel tracker

The detector requirements for TWOCRYST include a minimum of one detection layer for background and efficiency studies, with three layers planned to be installed. An active area of at least 1 cm^2 is needed to detect both channeled and unchanneled particles. The chosen sensors are the VeloPix Silicon pixel sensor, currently used by the Vertex Locator (VELO) detector of LHCb [15]. The hybrid tile is composed of a 200 μm thick silicon sensor bump-bonded with 3 VeloPix ASICs. The pixels pitch is 55×55 μm^2 with a spatial resolution of 12 μm.
Given a bending angle of 7 mrad of the TCCP and a distance below 1 m between the TCCP and the detector, the radial distance of the spot of the channeled particles from the main circulating beam will be less than 1 cm. Therefore, the detector must be placed inside the beam pipe. To achieve this, two Roman Pot stations were retrieved from the ATLAS-ALFA experiment and installed at IR3. To avoid bulging the thin window of the station, the detector is kept under secondary vacuum at about 2 mbar. The design of the VELO module had to be re-adapted to fit the geometry of the Roman Pot station.



(a) **(b)** **(c)**

Figure 3: **(a)** New design of the detector modules and mechanical support. **(b)** Detector package integrated in the Roman Pot station. **(c)** Detector module assembled and connected to the readout chain.

The new design for the detector modules and mechanical support is shown in Fig. 4. Up to three modules can be housed inside the Roman Pot volume. The modules are composed of a sensor tile, a GBTx hybrid and a data flex cable, mounted on an aluminum plate. The GBTx is a bidirectional 4.8 Gb/s link between the radiation-hard on-detector electronics and the off-detector systems. New data flex cables were designed to integrate in a single circuit data and control signals and power distribution. A Vacuum Feed-through Board (VFB) was produced, adapting the VELO

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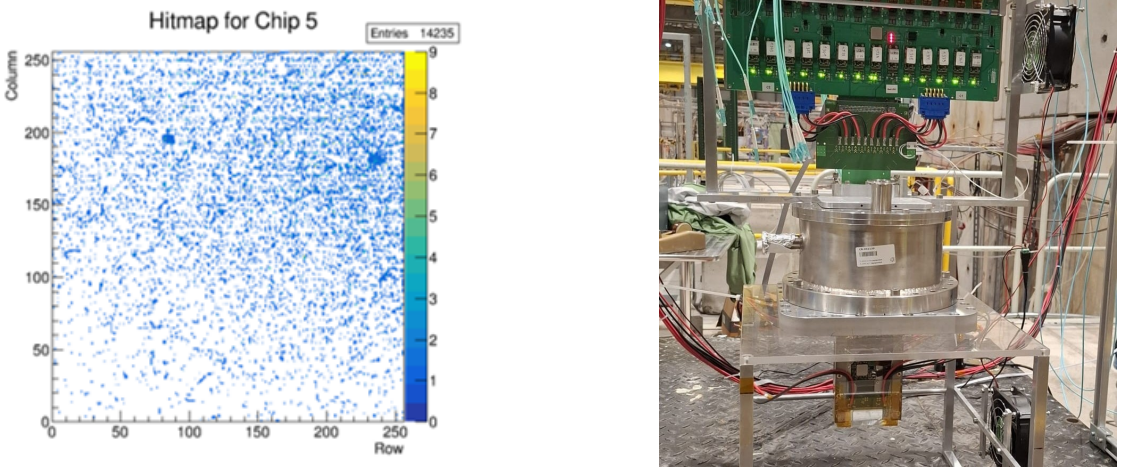
design, to allow the passage of data, control signals, low and high voltage from the atmospheric side to the vacuum side. The VFB interfaces with the Optical and Power Board (OPB), which converts high-speed data and control signals from electrical to optical form and with its DC/DC converters it also manages low voltage power distribution.
The cooling system is designed to keep the silicon sensors at a temperature below 20°C during operations. It is used to dissipate the heat generated by the electronics and by the circulating beam. The conservative estimate of the total power budget is about 37 W. The system is based on thermo-electric cooling with a Peltier cell placed inside vacuum, between the mechanical support and the sealing flange. The heat moved to the hot side of the Peltier is then removed with an heat-exchanger, placed outside the vacuum flange and flushed with water at 27° C and 20 bar, coming from a derivation in a nearby magnet. The temperature of the detector will be monitored using Pt100 probes [1]. These signals, together with alarm signals coming from the vacuum system and the water flow-meter are handled by a Programmable Logic Controller (PLC). Based on these information the PLC is programmed to perform an hardware interlock on the power supply for detector safety.
In October 2024, a test-beam campaign was held at SPS H8 beam line to test the detector package. In this occasion, one module and the full readout chain were assembled for the first time. It was then possible to configure the VeloPix ASICs, perform the equalisation of the pixel thresholds, test the data acquisition system and record the first data of particles hits.



(a) **(b)**

Figure 4: **(a)** Hitmap of particles hits recorded by the middle ASIC of the module. **(b)** Detector package installed at SPS H8.

4. Conclusion

In conclusion, the proposed ALADDIN experiment aims to measure EDMs and MDMs of charm baryons with a fixed-target setup at the LHC. A first test, called TWOCRYST, is planned

[1] RS: 362-9812.

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to operate during 2025 with a reduced setup. A new pixel detector has been developed, based on the LHCb Vertex Locator, to operate inside a Roman Pot station. The detector modules have been tested in the laboratory and during a test-beam campaign at SPS H8. Work is in progress to finalize the installation in the LHC tunnel, started at the beginning of January 2025.

Acknowledgments

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