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# TESTING THE DOUBLE-CRYSTAL SETUP FOR PHYSICS BEYOND COLLIDERS EXPERIMENTS IN THE UA9-SPS EXPERIMENT

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*Abstract*

The UA9 experiment is installed in the CERN SPS to study how coherent interaction in crystalline materials can be used to steer particles beams. Recently, new experiments requiring complex beam manipulations by means of crystals have been proposed in the framework of the Physics Beyond Colliders study group at CERN. In particular, it was proposed to use a first crystal to direct protons from the LHC beam halo on a target placed in the beam pipe and to use a second crystal to deflect the particles produced in the target (double-crystal setup), allowing to measure their polarization. The layout of the UA9 experiment in the CERN SPS has been modified to study the feasibility of the proposed scenario and its compatibility with the delicate environment of a superconducting collider. A first set of measurements was performed in 2017 proving that the protons deflected by the first crystal can be intercepted and successfully deflected by a second crystal. A further upgrade of the experiment in 2018 will allow measuring more precisely the combined efficiency of the two crystals and the beam-induced background.

## INTRODUCTION

The UA9 Experiment investigates the possibility to use bent silicon crystals to steer beams of charged particles. The main installation of the experiment is in the Long Straight Section 5 (LSS5) of the CERN SPS, and since 2009 provided measurements supporting the implementation of a crystal-assisted collimation system in the LHC [2–6]. A prototype system was installed in the LHC in 2014, providing its first encouraging results soon after [7]. Recently new investigations have started, such as the possibility to implement crystal-assisted slow extraction at the SPS [8].

The main process exploited in these studies is the so-called “planar channeling”: particles impinging on a crystals with a direction close to the one of the lattice planes are forced to move between the planes by the atomic potential, with high efficiency; if the crystal is bent, the trapped particles follow the bending and are deflected. The probability to interact with the atoms of the crystal is reduced for particles which are channeled.

In 2016 it was proposed to measure the magnetic moments of baryons with heavy flavoured quarks at the SPS and the LHC by using the strong effective magnetic field inside the channels of a bent crystal to induce the precession of the polarization vector associated to the baryons [9]. At LHC energies the produced baryons have large boost, allowing measurements for particles with shorter lifetimes.

Since no extracted beam exists at the LHC, a first crystal could be used to direct protons from the beam halo on a target placed in the beam pipe while a second crystal should deflect the baryons produced in the target (double-crystal setup). A detector system downstream the second crystal should identify the deflected particles from their decay products and measure their magnetic moment. The concept have been further investigated and discussed at the Physics Beyond Colliders study group, which has the mandate of preparing the CERN contribution to next European HEP strategy update [10, 11]. The UA9 Experiment in the SPS has been indicated as a possible test bench to verify the feasibility of the double-crystal scheme [12].

## LAYOUT OF THE EXPERIMENT IN SPS

The SPS installation of the UA9 Experiment includes goniometers to align different crystals with respect to the circulating beam, several beam intercepting devices, detectors and beam loss monitors (BLM) [13]. In order to perform measurements relevant for the double-crystal experiments, three successive stages of hardware upgrades and measurements have been conceived. This strategy allows to profit from a working test bench with minimal delay and modifications to the existing setup, while preparing optimized instrumentation for the more advanced measurements.

The first stage of the upgrade took place during the technical stop in July 2017 and allowed obtaining the setup illustrated in Fig. 1. The figure shows in red the horizontal circulating beam envelope at $4\sigma$ in the region of the experiment, for a tune of $Q_h = 20.13$ and a physical emittance at $1\sigma$ of $\epsilon_h = 5\times10^{-9}$ m rad. The beam intercepting devices are represented by vertical lines and each of them has a BLM installed about 1 m downstream. Crystal1 was displaced from its original position close to Crystal2 at about 90 degrees of phase advance upstream. Protons in the beam halo are channeled by Crystal1 and deflected according to the green beam envelope. They are further deflected if they are channeled by Crystal2 (double-channeling). Protons which are channeled only by Crystal1 (single-channeling) continue their trajectory inside the green dashed beam envelope. Both the channeled beams are stopped by a 60 cm long tungsten absorber.

A LHC prototype collimator (1 m graphite) and a Roman Pot containing a Timepix detector [14] can be used to probe the channeled beams. The characteristics of the crystals are summarized in Table 1: since they were installed in the past for collimation studies they are not yet optimized for this experiment, in particular the width of Crystal2 is only

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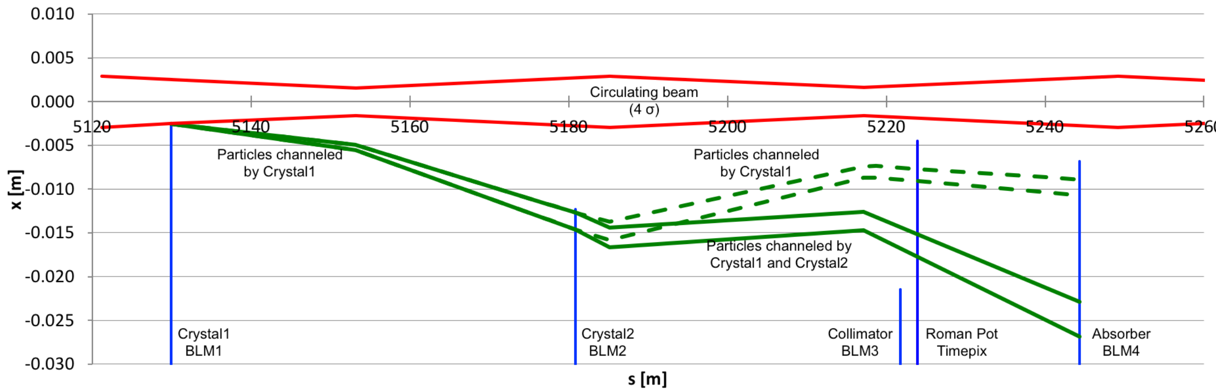


Figure 1: Horizontal beam envelope and position of the main devices in the UA9 Experiment installation.

Table 1: Characteristics of the Crystals

| | Crystal1 | Crystal2 |
|---|---|---|
| Deflection angle (μrad) | 165 | 176 |
| Lenght (mm) | 1.87 | 2 |
| Width (mm) | 0.5 | 0.5 |

0.5 mm, while the width of the single-channeled beam at its position is expected to be ~2 mm.

The second stage of the upgrade happened during the 2017-2018 Winter Technical Stop and included new optimized crystals, plus a new absorber and a Roman Pot with Timepix detectors installed just upstream Crystal2. This would allow a detailed characterization of the single-channeled beam impinging on Crystal2, which is primordial to compute the efficiency of the double-channeling process.

The third stage of the upgrade shall include a new crystal with a short tungsten target in front of it, to be installed in place of Crystal2. With this installation, the double-crystal setup proposed for baryon studies would be completely implemented, with the exception of the downstream detector system for particle identification.

## DATA TAKING AND RESULTS

The goal of the data taking runs in 2017 was to demonstrate the feasibility of the double-channeled process, to define the operational procedures for future measurements and to assess the possibility to measure the efficiency of the process with existing or upgraded detectors. About 24 hours were devoted to the study, divided in two runs which took place in September and October 2017; during the first run the Timepix detector was not operational. Single bunches of $\sim 10^{11}$ protons were injected in the SPS configured with $Q_h = 20.13$ and $Q_v = 20.18$, they were accelerated to 270 GeV/c and then kept in storage mode for few hours during the measurements. The physical emittance at $1\sigma$ at the beginning of each fill was measured to be $\epsilon_h \approx \epsilon_v \approx 5\times10^{-9}$m rad.

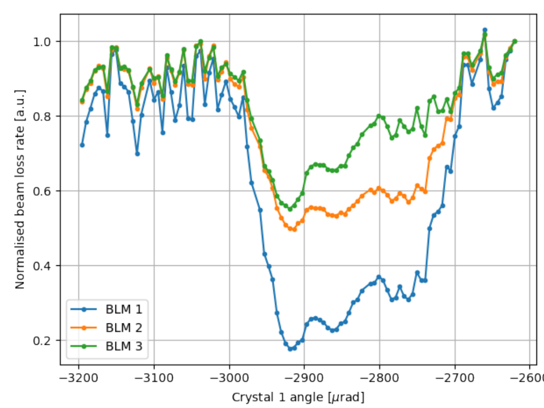


Figure 2: Beam loss rate as a function of the orientation of Crystal1 during its alignment.

### *Alignment of the Crystals*

The first operation to perform in order to obtain the double-channeled beam is the alignment of Crystal1. This was performed following the standard procedures in use in the experiment [13]: the crystal was approached to the circulating beam and then rotated by means of a goniometer while observing the signal measured by the downstream BLMs. The result of the measurement is reported in Fig. 2, which shows the beam loss rate normalized to the circulating beam intensity as a function of the orientation of the crystal. The minimum of the loss rate (~−2915 μrad) corresponds to the orientation where the maximum of the particles impinging on the crystal are channeled, minimizing the interactions responsible of the beam losses.

After fixing Crystal1 in channeling orientation, the second crystal should be aligned with the single-channeled beam. It was moved towards the beam, expecting an increase of the beam loss rate on the downstream BLM once the crystal has encountered the channeled beam. The increase could not be noticed during the operations and the crystal was finally placed at the computed position of the single-channeled beam. Its channeling orientation was studied as shown in Fig 3, where the beam loss rate normalized to the circulating beam intensity is shown as a function of the orientation

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of Crystal2. A first angular scan was performed without finding any indication of the channeling orientation ("Collimator OUT", red and green curve in Fig 3). A second scan was performed while placing the downstream collimator at a position where it could intercept the double-channeled particles, but not the single-channeled ones: in this case a clear peak (~1500 μrad) is visible in the loss rate on BLM3 ("Collimator IN", yellow and blue curve in Fig 3), due to the interaction of the double-channeled particles on the collimator.

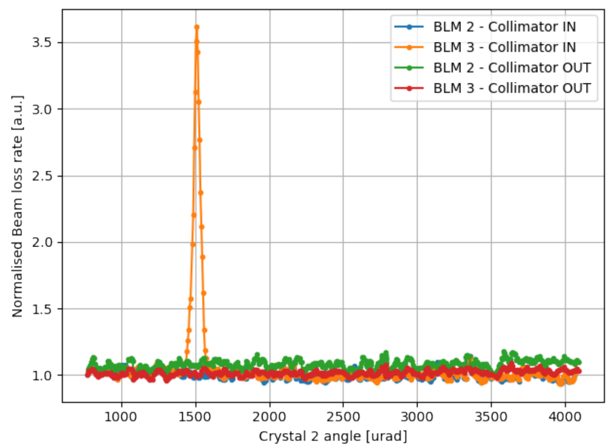


Figure 3: Beam loss rate as a function of the orientation of Crystal2 during two scans performed for its alignment.

### *First Studies and Outlook*

After positioning both crystals according to the results of the alignment procedure, the double-channeling setup was achieved for the first time. During the rest of the data taking, the procedure was repeated several times.

The first characterization of the system was obtained by observing the evolution of the beam loss rate when moving the collimator. A comparison of the results obtained for different configurations is shown in Fig. 4. The beam loss rate on BLM3, normalized to the beam intensity, is plotted as a function of the collimator position; the center of the circulating beam is expected to be at ~0 mm. While approaching the collimator to the circulating beam, an increase of the loss rate is expected, proportional to the number of intercepted protons.

When Crystal2 is retracted and Crystal1 is not in channeling orientation (orange line), a roughly exponential profile of the loss rate is seen, due to protons diffusing into the halo from the circulating beam. When Crystal1 is in channeling orientation (green line), the protons diffusing out of the circulating beam are channeled: the profile of the loss rate has a steep increase from ~−8 mm to ~−6 mm due to the crossing of the single-channeled beam, then it is relatively flat since very few protons are circulating between the channeled and the circulating beam. Finally, when both Crystal2 and Crystal1 are in channeling orientation (blue line), two increases of the beam losses can be seen: from ~−13 mm to ~−11 mm due to the double-channeled protons and from ~−8 mm to ~−6 mm due to the single-channeled ones. An accurate analysis of these data is ongoing to estimate the channeling efficiency of the crystals as well as the background due to particles escaping the channeling conditions using the methods described in [15].

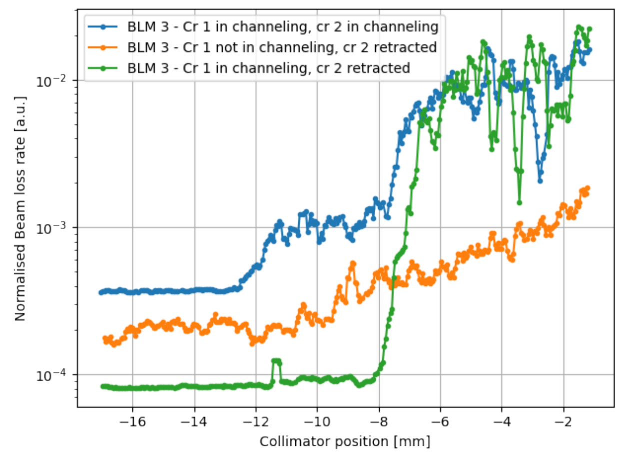


Figure 4: Beam loss rate as a function of the position of the collimator for different configurations of the crystals.

The use of the Timepix detector during the second data taking run allowed simplifying the alignment operations by providing a clear visual feedback of the setup. In Fig. 5 a screenshot of the data acquired by the detector is shown. In the upper part of the image the single-channeled beam can be seen, its spot appears separated in two parts by the shadow of Crystal2. In the middle of the image, another spot is visible, due to the double-channeled beam. Analysis of these data is ongoing, to assess the possibility to measure the efficiency of the various deflections and the possible background.

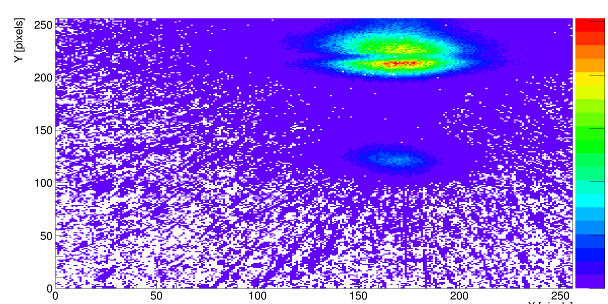


Figure 5: Image of the single-channeled (top) and double-channeled (middle) beams on the Timepix detector. The image should be rotated by 90°counter-clockwise in order to reproduce the real spatial position of the beams. The color scale represents the average number of counts per second per pixel.

## CONCLUSIONS

Following the proposal to measure the magnetic moments of baryons with heavy flavored quarks using a double-crystal

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scheme, the installation of the UA9 Experiment in the SPS has been upgraded and initial beam studies have been performed. A double-channeled beam of protons has been consistently obtained after defining adapted operational procedures. The setup has been investigated by means of collimator scans and using a Timepix detector, a complete analysis of the collected data is ongoing.

Further upgrades will allow to test a system with optimized crystals and, finally, with secondary particles produced in a target close to the second crystal.

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