CRYSTAL COLLIMATION EFFICIENCY MEASURED WITH THE MEDIPIX DETECTOR IN SPS UA9 EXPERIMENT

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Abstract

The UA9 experiment was performed in 6 MDs from May to November 2009 with the goal of studying the collimation properties of a crystal in the framework of a future exploitation in the LHC collimation system. An important parameter evaluated for the characterization of the crystal collimation is the efficiency of halo extraction when the crystal is in channeling mode. In this paper it is explained how this efficiency can be measured using a pixel detector, the Medipix, installed in the Roman Pot of UA9. The number of extracted particles counted by the Medipix is compared with the total number of circulating particles measured by the Beam Current Transformers (BCTs): from this comparison the efficiency of the system composed by the crystal, used in channeling mode, and a tungsten absorber is proved to be greater than 85%.

INTRODUCTION AND LAYOUT

A bent crystal, positioned before the collimator, could deflect the particles from the halo of an angle larger that what an amorphous scatterer can do and large enough to allow the increase of the collimator's aperture. The latter fact can mitigate the transverse resistive impedance from the collimators, which can dominate the total LHC impedance [1]. The aim of the UA9 experiment is to verify if the configuration Crystal–Collimator can be reliable in terms of cleaning efficiency.

The experiment was performed in the CERN-SPS in 2009. The layout is shown in Fig. 1; a full description can be found in [2], while the general description and motivations of the experiment are summarized in [3]. The CERN

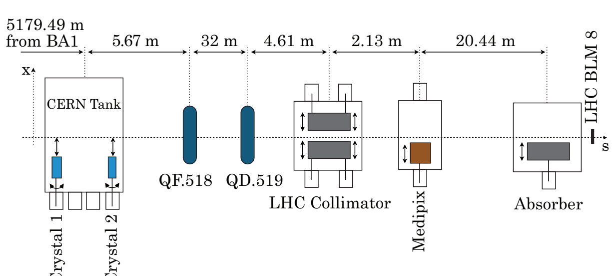

Figure 1: UA9 Layout.

tank contains two crystals mounted on two independent goniometers and rails; the crystals are capable to rotate and move in the beam halo. Downstream the crystals, there is an LHC Collimator with two mobile jaws, followed by a Roman Pot containing a Medipix device and eventually by a tungsten absorber. The Medipix is a silicon pixel detector capable to reconstruct a spot in the transverse plane due to its interaction with protons from the beam halo, and it is the instrument used in these measurements to evaluate the efficiency of the crystal–absorber collimation system. The protons deflected by the crystal are arrested by an absorber consisting of 60 cm of tungsten. Assuming that the number of protons counted by the Medipix corresponds to the number of protons caught by the absorber, the collimation efficiency can be evaluated comparing the beam losses measured with the Beam Current Transformers (BCTs) with the number of protons detected by the Medipix. With an ideal cleaning efficiency of 100%, all the losses would be localized in the crystal–medipix–absorber region, and the number of lost protons measured with the Medipix should be exactly the same as that measured with BCTs. In this paper it is shown that such efficiency is slightly lower than 100%, depending on several factors which we discuss farther in the following sections.

MEDIPIX

The Medipix device is exhaustively described in [4]. For the purpose of the UA9 experiment only the relevant parameters are described here. The active area of the device consists of 256×256 square pixels of 55 μm pitch. Each pixel stores the number of particles detected in a digital counter. The counters of the full pixel matrix are read out and saved once per second. The return to zero time of the pixel preamplifier is about 1 μs, which sets the upper limit for the resolution of two subsequent hits in the same pixel. Such time is smaller than the SPS period (23 μs). In a beam with only one bunch, as in UA9, it is consequently possible to see the beam halo at each turn. On the other hand, the time resolution of the Medipix is larger than the bunch length ($\sim$ 3 ns): in this way, if two particles from the same bunch cross the same pixel, they will be counted as one particle. This eventuality is rare in the beam used in UA9 ($\sim 10^{10}$ protons), because the area of a single pixel is small with respect the beam density. The typical output of the Medipix, integrated within a time window of 1 s, is shown in Fig. 2a. Here the crystal is in channeling mode and the plot represents the transverse $(x - y)$ distribution of

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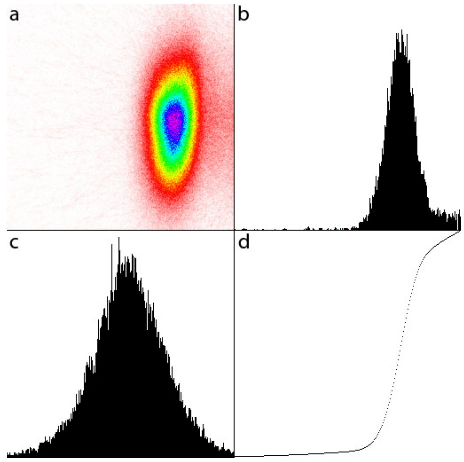

Figure 2: Medipix output (see text for details).

the protons extracted by the crystal. The vertical distribution of the channeled beam (Fig. 2c) is Gaussian, according to the initial conditions of the beam; the horizontal distribution (Fig. 2b) is Gaussian too but, with a tail on the right side due to volume capture and dechanneling of protons in the crystal itself and to the scattering of protons from the beam core with the window of the Roman Pot where the Medipix is installed.

SETUP

The Medipix is a counting device, a feature which can be exploited to evaluate the efficiency of the crystal–absorber system. The experimental procedure can be resumed as follows:

- transversal alignment of the devices is performed;
- the crystal is put in channeling mode;
- the Medipix is used to count the number of deflected particles, which is compared with the losses as estimated from the BCT beam lifetime distribution.

From the point of view of its position in the transverse plane, the request for the crystal is to act as a primary collimator: it should be positioned in the halo to intercept and channel particles, while the particles not channeled at their first crystal traversal might intercept the crystal again and be channeled in the next turns. The Medipix and the tungsten absorber will be placed farther from the crystal, in order to intercept only protons deflected by the crystal and not directly protons of the halo.

The LHC collimator was used as a reference in the alignment of the other devices. The collimator is instrumented with a Beam Loss Monitor (BLM), which can show when the collimator jaws are touching the beam halo: as the signal on this BLM increases, the position of the jaw is fixed and it is considered as the transverse reference position of the instrumentation with respect to the beam halo. The other instruments are aligned with the same procedure: when a device steps towards the beam halo more than the collimator, it will produce a signal on the BLM. After the full transversal alignment, the Medipix and the tungsten absorber are retracted by a fixed offset chosen to optimize the multi-turn effect of the crystal. The requirement is that the particle randomly scattered will not hit the Medipix or the absorber at the first turn of amorphous scattering [3]; Then the LHC collimator is fully opened and the measurement can start.

The crystal is rotated using the goniometer until the two peaks in Fig. 2b and 2c are maximized and the noise in the tails is minimized. This position corresponds to the channeling mode of the crystal, when the efficiency of the protons' extraction from the beam halo is maximum.

EFFICIENCY MEASUREMENTS

When the crystal is in the channeling orientation, the flux of particles seen from the Medipix is supposed to collide with the absorber and not anymore circulating into the machine. Under this hypothesis, the total beam intensity in the SPS is decreasing due to the halo extraction performed by the crystal. The total circulating current in the machine is measured with the BCTs. The number of protons deflected by the crystal and caught by the absorber are measured with the Medipix. Let I_0 be the number of protons circulating at time $t_0 = 0$, as measured with the BCTs; after a time interval Δt, the total number of protons circulating into the machine as evaluated with the Medipix will be

$$I_{\mathrm{m}}(t) = I_0 - \sum_{i=0}^{\Delta t} m(i) \qquad (1)$$

where $m(i)$ is the number of protons read by the Medipix at the second i.

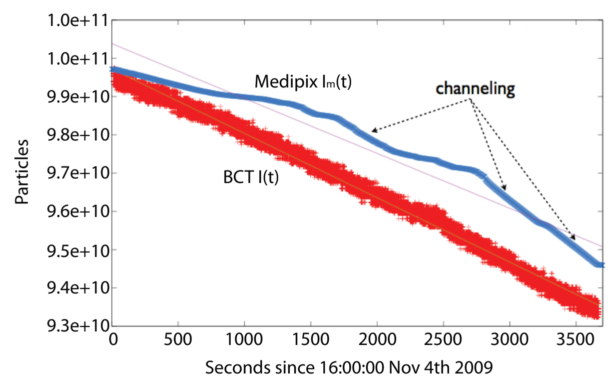

Figure 3: Beam lifetime with BCT and Medipix.

The slope of $I_m(t)$ is compared with that of $I(t)$: if these two slopes are equal, all the losses of the machine are represented by the particles which are detected by the Medipix. On the other hand, an horizontal slope for $I_m(t)$ means that the $I_m(t)$ is constant and no particles crosses the Medipix.

In Fig. 3 the slope of $I_m(t)$ changes frequently: during the selected time interval, from 16:00 to 17:00 (Local Time) November 4th, 2009, the crystal orientation has been changed several times from amorphous to channeling mode. The correlation between crystal orientations and losses in the machine is also described in [5].

When the crystal is in not in channelling orientation, the protons receive a kick from the crystal (acting as an amorphous scatterer) not sufficient to be deflected on the Medipix. Such particles will be lost in some other place into the machine, but are not counted by the Medipix, and the resulting slope of $I_m(t)$ will be far from $I(t)$. When the crystal is in channeling (the channeling regions marked in Fig. 3) the slope of $I_m(t)$ is parallel to the slope of $I(t)$. To emphatize a pure channeling measurement it is possible to consider a restricted time interval as it is shown in Fig. 4

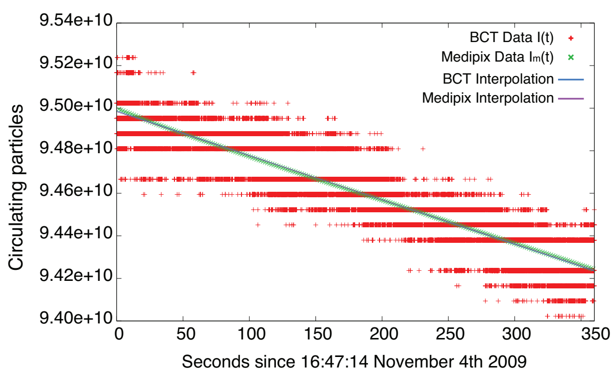

Figure 4: Beam lifetime with BCT and Medipix in an interval of pure channeling.

The extraction efficiency of the crystal-absorber system, in a time interval $[0, T]$, can be defined as:

$$\eta = \frac{1}{T} \int_0^T \frac{\dot{I}_m(t)}{\dot{I}(t)} dt \tag{2}$$

where $\dot{I}_m(t) = dI_m(t)/dt$ and $\dot{I}(t) = dI(t)/dt$. When the crystal is in channeling, as in the time interval of Fig. 4, $\eta \approx 0.97$; in the case of Fig. 3 the corresponding η is about 0.85.

SOURCES OF ERRORS

Some considerations are necessary to estimate the possible errors in the measurement of η, i.e. about

- the precision of the BCTs measurements;
- the stability of the crystal and beam positions;
- the calibration of the Medipix detector;

The BCT readout within a 1 s time window is unstable, an effect which can be seen in Fig. 4 for a small time interval. Considering for example only the first 50 s, it is difficult to evaluate the value of the current between 9.48e+10 and 9.50e+10, consequently the estimate of the beam intensity slope in such interval will have a great uncertainty. To reduce this problem the time interval in which the lifetime estimate fit is performed must be taken as wide as possible.

With a wider time interval, another issue is the stability of the crystal position and angle, and the stability of the beam itself. During the long term observations, when the crystal was fixed in the stable channeling position, the channeled beam sometimes blinked on the Medipix image unexpectedly. Moreover one of the two goniometers was not properly stable. A small change in the angle of the crystal or in the beam orbit can change the behavior of the crystal from channeling to amorphous, the result is a measurements of mixed layout and not pure channeling, with a false degradation of the efficiency.

Finally an important source of uncertain is the calibration of the Medipix: each pixel counts a certain number of "events", but this number should be related to the real number of protons that crosses the pixel. The signal generated by one proton can be shared between adjacent pixels and may be counted more than once, depending on the impact position and incidence angle. Therefore a calibration factor is necessary to relate the number of recorded events in the Medipix to the real number of particles. In one hour of measurements the number of read pixels is larger than 10^{10}, even a small error of calibration in the pixel conversion factor, can have a big impact on the final measurements. The calibration for UA9 was done according to [6], but a beam–based calibration must be considered in the future.

CONCLUSIONS

The system composed by crystal and absorber seems to have an efficiency of collimation close to 100% when the crystal is in the channeling orientation. The experience developed with the Medipix can drive a second stage of measurements in the direction to reduce the possible sources of errors and to increase the reliability of the efficiency measured. This kind of experiment can largely benefit of the BLMs of the machine: when the halo is not going trough the Medipix it should be lost in another place of the machine, and the sum of Medipix measurement with the BLMs should recover the current see from the BCTs.

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