IL NUOVO CIMENTO Vol. 34 C, N. 6 Novembre-Dicembre 2011
DOI 10.1393/ncc/i2011-11031-8

Colloquia: IFAE 2011

Crystal collimation of hadron beam, the UA9 experiment

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(ricevuto il 29 Luglio 2011; pubblicato online il 2 Novembre 2011)

Summary. — The UA9 experiment was installed in the CERN-SuperProtonSynchrotron (SPS) in March '09 with the aim of investigating crystal-assisted collimation in coasting mode. Beam collimation is a major challenge for colliders aiming to achieve high beam current. Crystal channeling represents a viable solution to improve the collimation efficiency and reduce the background in the accelerators. Results of 2010 tests on SPS are shown demonstrating how this technique is mature to be tested directly on the Large Hadron Collider.

PACS 29.27.-a – Beams in particle accelerators.
PACS 61.85.+p – Channeling phenomena (blocking, energy loss, etc.).

1. – Introduction

Circular accelerators need specific beam collimation systems to eliminate unwanted halo particles. Such systems protect from fast losses and clean the beam to eliminate slow losses. They are traditionally implemented using passive objects acting as scatterers and absorbers of undesired particles in various stages. In the last years bent crystals have been efficiently used to extract beam particles out of an accelerator [1-4] using the coherent interaction of the charged particles with the crystal (*crystal channeling*).

Charged particle entering crystals with a angle θ_{IN} with respect to the lattice plane smaller than a critical angle θ_C are trapped within the lattice planes oscillating in the periodic potential (with U_0 well depth) of the crystal [5]. If the crystal is bent, a centrifugal component adds to the periodic potential resulting in a deflection of the charged particle exiting the crystal. θ_C is $\sqrt{\frac{2U_0}{E}}$ where E is the energy of the particle and for silicon (110) crystal at 400 GeV θ_C is around 10 μrad.

A classic two-stage collimation system [6] in accelerators consists of a primary element acting as a small scattering target and a secondary element absorbing particles impinging on it. An amorphous primary target scatters particles in no preferred direction. On the other hand a bent crystals traps particles with the coherent scattering on aligned atomic planes and kicks them in only one direction. The halo protons can be redirected so that they hit the secondary absorber with a large impact parameter and, therefore, can be efficiently removed.

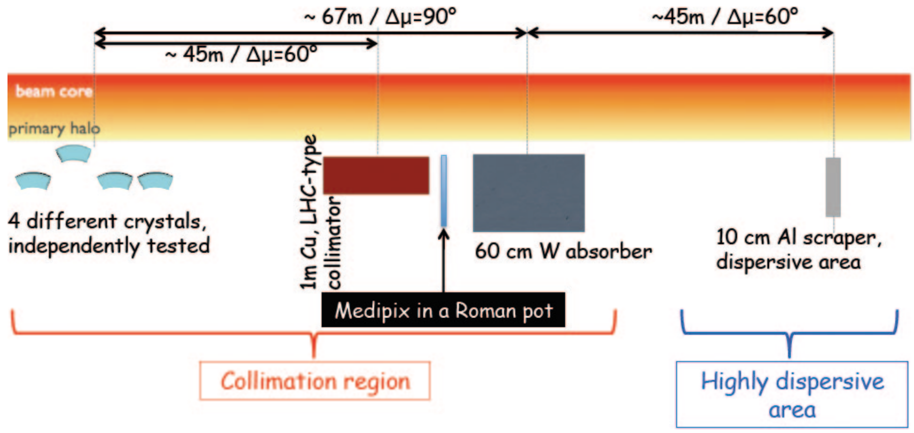

Fig. 1. – Sketch of the main component of UA9 layout in SPS. Crystals and tungsten absorber (TAL) define the collimation region where several devices (not explicitely indicated) are used to monitor the beam. A high-dispersion region is instrumented with a duralumin scatterer and some BLMs.

CERN approved in 2008 the UA9 experiment with the aim of testing directly the crystal-assisted collimation as an alternative for both protons and lead ion beam collimation in the LHC. UA9's final goal is to demonstrate that a crystal-based collimation has a higher cleaning efficiency than traditional scheme.

2. – UA9 at SPS

In fig. 1 a sketch of the UA9 experimental layout is shown. UA9 instrumentation is located in the Long Straight Section 5 of SPS. It has been used during dedicated data-taking period with either proton or lead ion beam in coasting mode at 120 GeV momentum per nucleon. A collimation region is defined at one end by the crystals (four different silicon crystal, two of them strip-like) which are moved into the beam to act as primary collimators. In the vicinity of them, several detectors of different type are used to record the losses due to inelastic interaction of the particles in the crystals (beam loss monitor, BLM). At the other end, at about 70 m downstream the crystal where the phase advance $\Delta\mu$ is about 90° the deflected beam is intercepted by a 60 cm long tungsten absorber (TAL). The collimation efficiency is measured by the amount of halo particle surviving the cleaning process. A second station (TAL2) is located 130 m downstream the crystal where the dispersion of the accelerator is large.

In fig. 2 a strip crystal mounted in a vacuum vessel is shown. It has dimensions $0.5 \times 70 \times 2\,\mathrm{mm}^3$ (width × height × thickness) and is bent at about 150 μrad using anticlastic deformation. It has been fully characterized with a low-divergence beam showing a 83% channeling efficiency. In the same fig. 2 a picture of the high-precision gonimeter used to move and rotate the crystals in vacuum is shown.

3. – Beam losses measurements

Before any measurement of beam loss and collimation efficiency all the movable device must be aligned with respect to the beam. At the end of such operation the crystal is the closest object to the beam with particles diffusing on its edge.

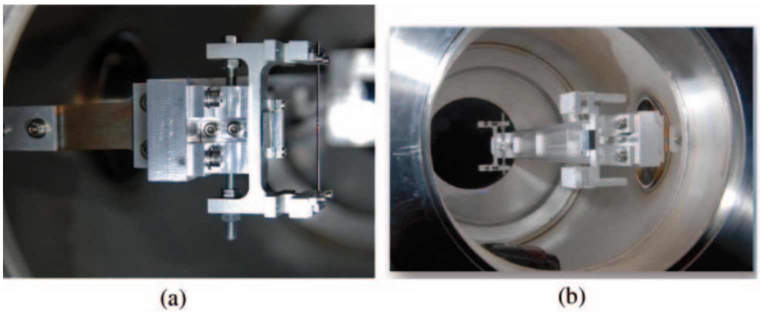

Fig. 2. – Silicon strip crystal installed in vacuum vessel (left) and two-arm goniometer used to position precisely the crystal (right).

The crystal is then rotated and at the same time the rates measured by the BLMs positioned few meters downstream are recorded. This rate is due to a fraction of the particles interacting inelastically with the crystal and producing showers of secondary particles. In fig. 3 an angular scan plot is shown where the rate is correlated with the angular crystal position. The higher rate corresponds to the crystal in amorphous condition where the particles directions are not aligned with the lattice planes. The dip in the distribution corresponds to the channeling condition. The rate reduction factor has been measured to be about 10 with some variation depending on the crystal under test. The channeling condition is confirmed by the image of the channeled beam (fig. 4) crossing a silicon pixel detector (Medipix [7]) before reaching the absorber.

4. – Cleaning efficiency

Outside the collimation region it is possible to evaluate the relative cleaning efficiency of this collimation system when the primary collimator is an amorphous material or an

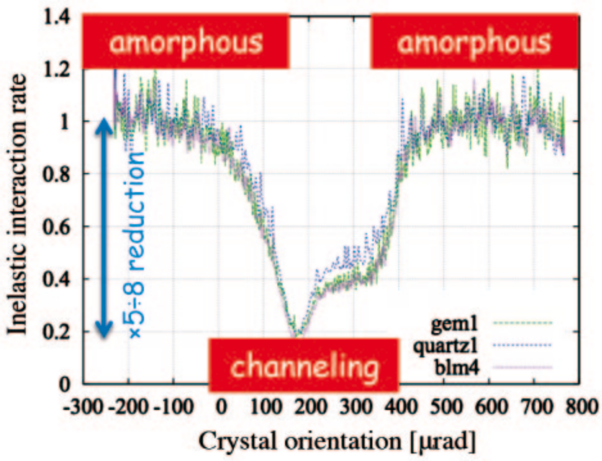

Fig. 3. – Angular scan plot: BLM rate (measured with ionization chambers, Gas Electron multiplier chambers and Cherenkov detector) as a function of the crystal angular position. The dip corresponds to the channeling condition.

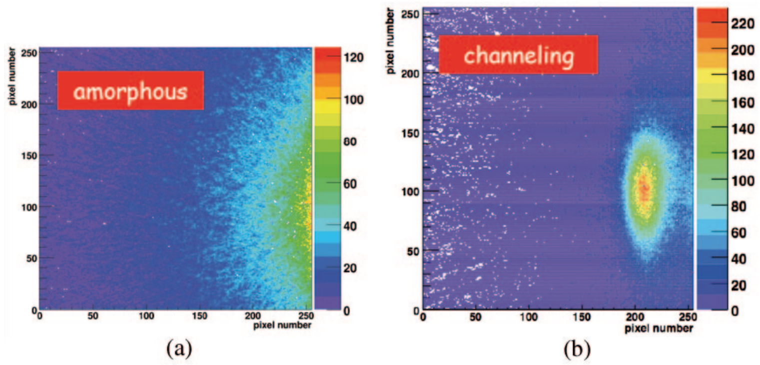

Fig. 4. – Medipix image of the beam, in amorphous condition (left) and in channeling condition (right).

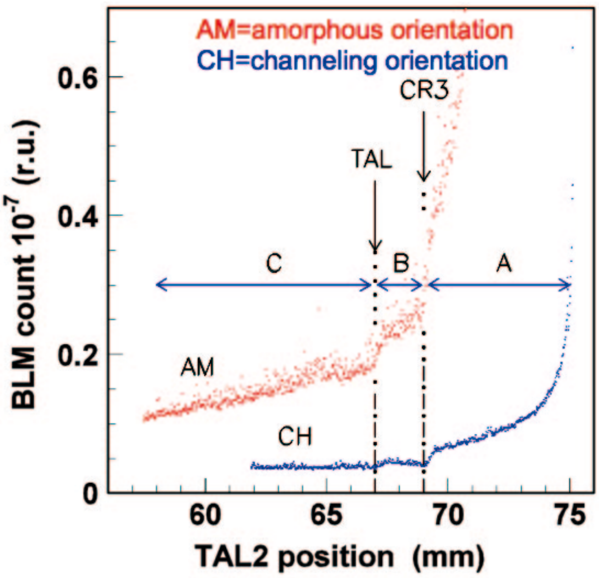

Fig. 5. – Dispersive area scan: BLM rate for the two conditions (amorphous and channeling). The positions of fast change of the derivative of the distribution correspond to the project shadow of the obstacles present in the collimation region, the crystal and the TAL absorber.

oriented crystal in channeling condition. At the azimuth of the TAL2 given the high dispersion a shift $\delta p = p\text{-}p_0$ [1] translates into a lateral displacement of the particle. It is therefore possible to observe also such off-momentum particles that might have been originated by diffractive processes in the crystal —another serious danger for the collider operations. Moving into the beam a duralumin target the residual halo is intercepted. Halo particles are scattered in the proximity of such target and recorded by near BLMs. In fig. 5 the BLMs rates for the two-crystal condition as a function of the lateral target

(1) p (p_0) is the momentum of a (closed orbit) particle.

position are shown. In channeling condition the residual halo is clearly less populated, indicating an improvement of a factor 3–5 of cleaning efficiency.

5. – Outlook

UA9 has carried out a program of test of crystal assisted collimation in SPS. Using high-quality crystal it has been shown that the use of crystal in channeling condition can lower the beam loss of factor almost ten and can improve the collimation cleaning efficiency by a factor 3 to 5. A crystal assisted collimation system for the Large Hadron Collider has been proposed [8] and a letter of intent sent to propose to extend such technique to the 7 TeV energy proton or lead ion beam.

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Work supported by the EuCARD programme GA 227579, within the "Collimators and Materials for high power beams" work package (Colmat-WP8). The author acknowledges the support from MIUR (grant FIRB RBFR085M0L 001/I11J10000090001).

REFERENCES

[1] Arduini G. *et al.*, *Phys. Rev. Lett.*, **79** (1997) 21, 4182.
[2] Afonin A. G. *et al.*, *Nucl. Instrum. Methods B*, **234** (2005) 1.
[3] Doble N., Gatignon L. and Grafström P., *Nucl. Instrum. Methods B*, **119** (1996) 181.
[4] Murphy C. T. *et al.*, *Nucl. Instrum. Methods B*, **119** (1996) 231; Carrigan R. A., Jr. *et al.*, *Nucl. Instrum. Methods B*, **90** (1994) 128132; *Phys. Rev. ST Accel. Beams*, **5** (2002) 043501; Carrigan R. A., Chen D., Jackson G. *et al.*, *Phys. Rev. ST Accel. Beams*, **1(2)** (1998) 022801; Fliller R. P. *et al.*, *Phys. Rev. ST Accel. Beams*, **9** (2006) 013501.
[5] Lindhard J., *Phys. Lett.*, **12** (1964) 126.
[6] Jeanneret J. B., *Phys. Rev. ST Accel. Beams*, **1** (1998) 081001.
[7] Campbell M., *Nucl. Instrum. Methods Phys. Res. A*, **633** (2010) S1.
[8] Assmann R. W., Redaelli S. and Scandale W., *Optics study for a possible crystal-based collimation system for the LHC, EPAC 06* (Edinburgh) 2006.