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Manipulation of hadron beams with bent crystals in circular accelerators

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Summary. — Over the past years the understanding and use of coherent interactions of charged particles with ordered crystal lattices has achieved excellent results. Improving collimation of hadron beams in circular accelerators, like the Large Hadron Collider (LHC) of the European Council for Nuclear Research (CERN), it is one of the possible applications. The aim of the UA9 experiment is to demonstrate the feasibility of a two-stage collimation system in the CERN-SPS : the first stage is a bent crystal oriented for an optimal channeling of the incoming halo particles; the second stage is a massive absorber. Two crystals were installed in the LHC last year and a test of crystal assisted collimation at the highest energy will be possible as early as 2015. Finally, the UA9 Collaboration is investigating extraction of particles from a circular accelerator, based on bent crystals.

1. – Introduction

High-energy particle interacting with a mono-crystalline material can be trapped by the electromagnetic potential generated by atomic planes in the crystal lattice [1]. The phenomena strongly depend on the orientation of momentum of the particle relative to crystalline planes. The UA9 collaboration studies how the tiny bent crystal could assist and improve the LHC collimation system, for ultra-high luminosity operation. The collaboration studies are performed in SPS with a fixed target experiment (extraction beamline H8 of the SPS) and measurements of performance of the crystal assisted collimation system in SPS. The fixed target experiment is used to study the interaction of high energy particle with crystals. Several detectors are used in SPS to measure the beam losses in the presence of a crystal as a primary collimator.

2. – LHC collimation system

Beam losses can cause superconductive magnet quench, and of course damage to accelerator components, hence a collimation system is required. The present LHC collimation system is based on Multiple Coulombian Scattering (MCS) which diffuse the

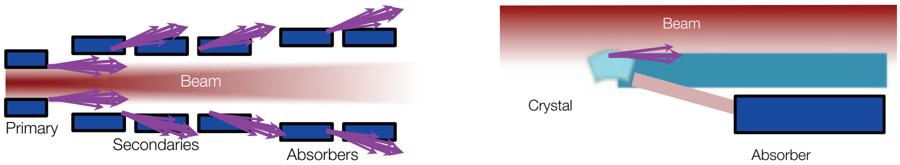

Fig. 1. – Left. Sketch of the actual LHC collimation system. Right. Sketch of the crystal-assisted collimation system.

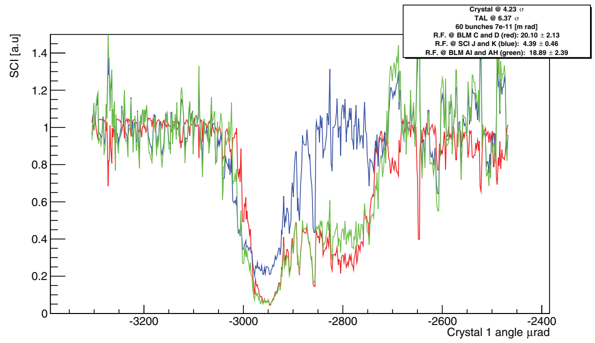

Fig. 2. – Beam losses as a function of crystal orientation in three different position. Red is at crystal position, blue is at first dispersion point, green is at maximum dispersion point. In channeling orientation the losses are reduced by a factor 20.

halo particle to larger orbits where they can be collected by absorbers (fig. 1). At LHC energy, we have a small MCS contribution(1) so several stages are required to move the halo particles to absorber positions. This setup can reach a cleaning inefficiency 10^{-5}(2).

3. – Crystal assisted collimation

The UA9 collaboration proposed to use a thin bent silicon crystal to steer halo particle trough the absorber. This layout is composed of only one thin crystal and one absorber per stage (fig. 1). With a crystal as primary collimators the beam halo is deflected of several tens of μrad, this gives the possibilities to use only one stage of absorber. Another distinctive features is to reduce the production of ionization losses and nuclear interaction production for passage into the crystal.

3·1. *UA9 SPS collimation.* – Silicon crystals a few mm long have been selected, during the fixed target tests, for an optimal channeling efficiency. The crystal orientation was easily optimized and the collimation process steadily achieved with the installed goniometer having an angular reproducibility of about $\pm 1\,\mu$rad. The loss profile in the area of the crystal-collimator setup was strongly reduced by about an order of magnitude [2], whilst the off-momentum particle population resulting from the interaction of the primary halo with the bent crystal was reduced by a similar amount, as shown in fig. 2. In recent runs

(1) With 7 TeV proton beam interacting with graphite $\langle\theta_{MCS}\rangle \sim 3.4\,\mu$rad.
(2) Ratio between losses on first cold section and losses on collimation section.

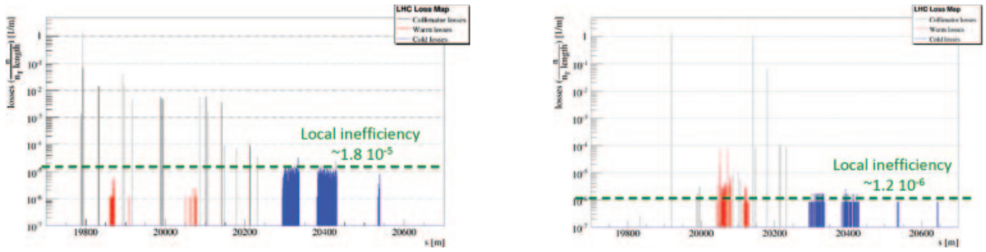

Fig. 3. – Beam losses as a function of accelerator linear position normalized to the primary collimator losses. Left : standard collimation case. Right : crystal-assisted simulation prediction.

at high intensity and high diffusion halo speed, a reduced loss regime was observed also far downstream of the crystal location. The accumulated observations strongly support extending the UA9 tests to the CERN-LHC collimation system.

3·2. *LHC prediction.* – The CRYSCOLL [4] routines have been developed to simulate the crystal contribution in the SixTrack simulation code. SixTrack is used by the CERN Collimation Team to study the efficiency of the collimation system in LHC. CRYSCOLL is used to evaluate the cleaning inefficiency in the presence of a bent silicon crystal as a primary collimator in LHC, and also in SPS where the routine is compared with experimental data. These studies point out that optimizing the crystal characteristic to the present collimation system a cleaning inefficiency of 10^{-6} (fig. 3) can be reached [3]. Such a result allowed the collaboration to install two high-precision piezo-goniometer prototype in LHC in 2014. Each goniometer is equipped with a crystal, and tests are foreseen for the second part of 2015.

4. – New application of crystal channeling

The studies and the results of UA9 can be developed to new kind of application. Use the bent crystal as a device to extract a beam is the main field of investigation. UA9 is actually collaborating with Accelerator Beam Transfer team to develop an optimized device to perform the extraction with a bent crystal from SPS. The Crysbeam [5] project is aiming to create an extraction device for LHC beam. The goal is to perform a fixed target experiment and also the project of a smart absorber is ongoing.

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