EXPERIMENTAL STUDY OF CRYSTAL CHANNELING AT CERN-SPS FOR BEAM-HALO CLEANING

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Abstract

An efficient and robust collimation system is mandatory for any superconducting hadron collider, in particular for the LHC, which will store a beam of unprecedented high intensity and energy. The usage of highly efficient and short primary bent-crystal collimators might be a possibility for reaching nominal and ultimate LHC intensity. Over the last years, groups in Italy (Ferrara) and Russia (St. Petersburg) have developed crystal production methods, that considerably improve the crystal quality. These developments led, in turn, to a surprising increase in the channeling efficiency and to the recent observation of the "volume reflection" mechanism.

The aim of the proposed experiment is the setup of a beam test facility, directing primary protons from the SPS onto a bent silicon crystal, and the quantitative study of single-pass efficiency for all involved processes. Final goal will be the extrapolation of important information on the feasibility of a crystal collimator for halo cleaning in the LHC.

The experiment will be performed in the H8 beamline at the CERN SPS where a beam with very small divergence can be provided thus representing a unique facility for tests and characterization of crystals to be used for particle channeling studies.

CRYSTAL CHANNELING AS AN OPTION FOR LHC COLLIMATION

For the new generation high intensity hadronic machines as, for instance, LHC, halo collimation is a necessary condition to make the accelerator operational at the highest possible luminosity and to prevent the damage of superconductor magnets caused by spurious halo particles [1].

Channeling of particles in crystals has been widely experimented in circular machines and has shown record efficiencies (up to 85%) for 70 GeV/c protons in extraction mode at IHEP [2]. Aside particle channeling, a new phenomenon of deflection in crystals, called "volume reflection", has been experimentally observed during last months [3]. This effect is closely related with channeling in the basic physics, but is not characterized by channeling of particles among crystalline planes. However such phenomenon needs a systematic study to deepen its comprehension and, ultimately, to understand whether such effect could be employed in the physics of accelerators, in particular for collimation in adronic machines.

Silicon crystals have been employed since more than a decade to extract high intensity beams of relativistic particles with more and more rising efficiencies by channeling effect. Particles, channeled among lattice planes of a mechanically bent crystal, do follow the curvature of the crystal, thus allowing their extraction out of the accelerator.

Such crystal may be an optimal candidate for collimation: in fact particles trapped within the potential well of atomic planes can be steered towards the desired direction, i.e. an aligned crystal substitutes disordered diffusion of single-atom scattering in an amorphous target with coherent diffusion along the atomic planes. Thus a small and highly efficient crystal could be employed as primary collimator, which would make it possible to retract the secondary collimator further from the beam and to make the LHC work at the highest luminosity, as a result of the consequent drop in the machine impedance.

EXPERIMENTAL LAYOUT

The experiment consists of a single-particle tracking system for the particles passing through the crystal that will make it possible to measure precisely the single pass efficiency of all processes concerned with channeling and "volume reflection".

The secondary line allows the production of a beam characterized by an extremely low divergence (about 2 μrad), which is an exquisitely precise probe for the study of channeling. For this purpose, it is necessary to equip the beamline with a suitable telescope for particle tracking and with a high-precision goniometric system necessary to the experiment.

The experimentally determined deflection efficiency, for channeling or volume reflection, is defined as the number of fully deflected particles originating from a specific area on the entrance face of the crystal, divided by the number of particles incident on this area. Therefore it is possible

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to determine the dependence of the efficiency on the proton impact position on the crystal surface and to study efficiency around crystal edge with great detail.

Goniometric system

The experiment will use a goniometric system whose angular resolution is about 1 μrad and having 3 degrees of freedom, of which two are translationals and one rotational (Figure 1). The study of channeling phenomena requires very precise angular alignment of the crystal with respect to the proton beam. Since the proton beam we are going to use has an angular divergence of about 2 μrad and that the critical angle for channeling of 400 GeV/c protons is about 10 μrad, the most demanding issue of the goniometric system will be the repeatability of the alignment process (that must be of 1 μrad).

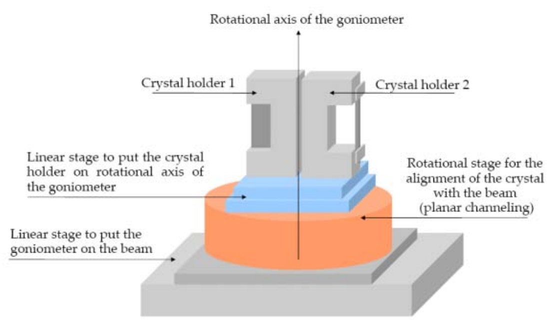

Figure 1: Goniometer system

The rotation stage, with 360° range around the vertical axis, enables alignment of the crystal along the vertical axis allowing the channeling of the beam in the planes of the crystal and the investigation of planar channeling conditions. Two linear stages (horizontal and vertical) will be used to place the crystal exactly inside the beam.

The goniometer will host two mechanical holders for crystals: with a 180° rotation and a linear movement it is possible to select either one crystal or the other one, placing them on the beam axis. This solution enables to study two different crystals without interfering with the data taking and keeping the same experimental conditions.

Two kinds of crystals have been fabricated for the experiment: the first one has been built following a strip configuration [4], while the second one exploits the quasi-mosaicity effect [5]. In order to fulfill the proposed objectives, crystals will be fabricated starting from high quality silicon, i.e. available as wafer with an extremely low angle between the crystal nominal direction and the crystal surface direction ("miscut angle"). Starting from these wafers, crystals specifically designed to optimize 400 GeV/c protons channeling will be realized. In particular, the deflection angle foreseen for best halo collimation in LHC will be considered, that is an angle of about 100 μrad. Corresponding to such an angle, simulations by specific codes have produced an optimal thickness of 3 mm for the crystal crossed by particles. The crystals have been characterized, in addition, in terms of surface morphological structure with both XRD at PNPI and through Rutherford Back-Scattering (RBS) spectroscopy in channeling mode at LNL [6].

Beamline layout

In order to be able to measure channeling efficiency of protons on mechanically bent silicon crystals and to resolve the beam component that experienced "volume reflection", it is necessary to arrange a tracking system with excellent spatial resolution and good time resolution.

The experiment will make use of a primary proton beam with 400 GeV/c momentum, 5 mm diameter in the horizontal plane and 4 mm in the vertical plane and with a very small (2 μrad) divergence. The primary beam intensity is very high (20×10^{11} ppp), but can be reduced down to $10^4 - 10^5$ ppp without affecting significantly the beam divergence. This intensity is relatively low and allows to track every single beam particle and therefore to completely reconstruct an event.

The experimental scheme is illustrated in Figure 2. The crystals will be mounted on mechanical holders, fixed on the goniometer, that will be moved by a remote control system. A laser system is necessary to define the relative position of the goniometer in measurement site, essential reference to define the absolute position through linear and angular positions. Crystal alignment with respect to the beam will be carried out through an angular scanning, producing a crystal rotation around a vertical axis. Therefore it will be possible to identify channeling conditions for the crystal, rotating it until a peak in the protons distribution near channeling angle is observed. From an experimental point of view it will be possible to separate the different beam components at a distance of about 40 m and 65 m downstream of the crystal.

For a crystal bending angle of 100 μrad, we expect that the channelled component of the beam, incident on the crystal, is detected at a distance of 4 mm (at 40 m from the crystal) with respect to the component of the beam which has just undergone multiple scattering. The divergence of the channeled component in the crystal is determined by critical angle and therefore is of the order of 10 μrad. Considering recent results and dedicated simulations, we expect that the component of the beam which undergoes volume reflection is deviated of an angle of about 10-20 μrad in the opposite direction of the channeled one. On the contrary there is no experimental information on the divergence of such component, but we expect it to be of the order of 10 μrad. The basic idea of the experiment is to track every single particle that crosses the crystal and to determine single pass efficiencies for the various processes.

Particle tracking

The tracking system will be made of two different silicon microstrip detectors having excellent spatial resolution.

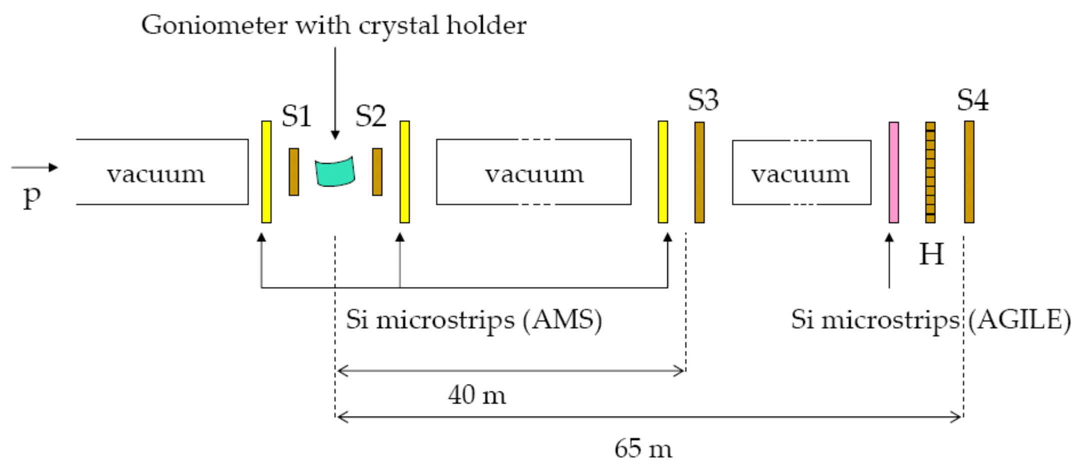

Figure 2: Experimental layout

Those detectors were designed for space applications and are best suited for this experiment in virtue of their resolution and thickness. In particular AMS-type [7, 8] double sided and AGILE-type [9] single sided silicon microstrip detectors will be used in different locations along the beam direction.

The first measurement stations will be placed upstream of the crystal and next to it, in order to define proton impact point on crystal surface. A second station will be placed, following protons trajectory, at about 40 m from crystal, while the last one will be installed at 65 m from the goniometer. These last stations will define, with great precision, the trajectory of the particle coming out from the crystal and will allow to distinguish the different beam components. In addition, the limited material budget of the detectors (300-400 μm along the beam direction for silicon strips, 1-2 mm for scintillators) allows to preserve the beam divergence.

A trigger system, based on scintillation counters (S1-S4), is necessary in order to remove background and not interesting events. Trigger signal will be made up, in the simplest configuration, of a coincidence between a downstream counter and one upstream of the crystal. In addition a hodoscope made up of scintillating strips (H) will be constructed, which will be employed to give quick information about crystal alignment and moreover to select events considering their particular topology. Crystal positioning system inside the beam will be made up of a couple of scintillators (S1, S2), having the same sizes of the crystal and fixed on a system integral with itself, with the possibility to be withdrawn during data taking.

CONCLUSIONS

Main features of the proposed experiment are the use of new generation crystals and the tracking of single particles in an external beamline at the SPS (CERN). Goals of the experiment are the determination of single-pass channeling and volume reflection efficiency. A two weeks data taking period with protons is scheduled for September 2006 in the H8 beamline at the SPS.

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