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Advanced Tracking System for Crystal Physics

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Riassunto

Crystals are solid materials composed of microscopic constituents (either atoms, molecules or ions) arranged in a highly ordered structure, the crystal lattice. Crystals play a crucial role in particle Physics and in fact they are widely used in the design of particle detectors and beam instrumentation. However, in such applications they are generally treated as unordered materials: this approximation is justified by the fact that a crystal reveals its ordered nature to an external observer only under certain conditions.

One of the limits of this approximation is the fact that it cannot explain several phenomena which can be observed when a charged particle impinges on a crystal with a small angle with respect to one of its symmetry axes/planes. In such cases, the incident particle may be "trapped" inside the potential well generated by the crystal axis/plane and then be forced to oscillate in such well. This effect is known as *channelling* and results in the particle following the direction of the crystal axis/plane itself. Moreover, if the crystal is bent along the beam direction, the net effect for the channelled particle is a deflection of its direction with respect to the incoming one. These phenomena have been studied for decades and they are now understood well enough to be exploited in the development of novel tools for particle Physics applications.

The idea for this thesis work was born in the framework of two possible applications of crystals which require an intense experimental activity on charged particle beams to understand their feasibility:

- The development of a novel technique for the efficient production of high intensity positron beams: this idea is based on the fact that the radiation emitted by a charged particle when trapped inside a crystal has a higher intensity with respect to the bremsstrahlung one, due to the particle multiple oscillations occurring in the axial potential well. It is thus possible to use a thin crystal to produce high energy secondary photons from a beam of high

energy electrons, and then use another crystalline target to make the photons convert into e^+e^- pairs, with an overall reduced amount of budget material. This idea is being pursued by the e+BOOST (Intense positron source Based On Oriented crySTals) project, financed by the Italian Ministry of Research.

- The development of a new generation of bent crystals: the insertion of a lattice interruption at the very beginning of the crystal should act as a focussing lens and thus should yield a channelling efficiency of nearly 100 %. This technical development has been proposed by the GALORE project of the National Institute of Nuclear Physics.

The identification of the different effects in oriented crystals, needs an intense test activity on extracted beams and requires to track the incoming charged particles (and in the case of GALORE, also the outgoing direction of the particle) with a high spatial resolution. The detection system developed by the INSULAB group of the Insubria University, based on microstrip silicon detectors, has been used in several crystal tests and is able to satisfy this requirement.

Moreover, for crystals directional effects to happen, a very precise alignment of the crystal with respect to the particle beam is required. Furthermore, only particles that impinge onto the crystal face within the angular acceptance of the effect under study can undergo the effect itself.

The study and characterization of the GALORE and e+BOOST crystals required a strict control over the beam dimension and the beam angular divergence. Acting on the beam optics, it is possible to modify the divergence and the beam profile. Unfortunately, when decreasing the beam divergence, the beam profile increases, and vice versa. In order to acquire a statistics large enough in a relatively short time, it turned out to be necessary to select only a portion of the beam.

This thesis work has started from the INSULAB tracking system and has improved it in order to make it able to select a portion of the beam itself: this possibility was achieved by allowing the microstrip tracking detectors to self generate a trigger signal when the charged particle crosses the detector itself in a given range of strips.

The frontend and readout electronics needed to be upgraded to reach this goal: for instance, the firmware of a custom designed board was programmed to allow the selection of the strips to trigger on, the trigger threshold and to implement different logical conditions with the trigger signals from different modules, such as the AND or the OR of these signals, in order to select just a part of the beam and to reduce the divergence.

The upgraded system was first tested in the INSULAB laboratory: after testing each channel with an external calibration signal to measure the analog response, the Application Specific Integrated Circuits (ASICs) were tested in terms of noise trigger rate to identify the noisy channels that must be disabled by the DAQ system. The silicon detectors have been characterized studying the pull (that is the ratio of the pulse height of the strip with the maximum signal in the event and its rms noise), the cluster Signal to Noise Ratio (SNR) and the eta distribution (which is a parameter defining the symmetry of the charge sharing). The pull and the cluster SNR allowed to measure the optimal value of the hold that is the time between the trigger and the sampling of the analog signal by the ASICs themselves. The hold scan is usually performed also when putting the detectors on the beam to optimize the SNR.

The upgraded system has been taken to the BeamTest Facility of the Frascati National Laboratories to verify the performance on beam. The system proved to be able to select a portion of the beam, by using single detectors or a logic condition, such as the AND of two silicon modules. As a consequence of this selection, a reduction in the angular divergence was observed and measured. This result was fundamental in view of the GALORE beamtest where the control over both the beam size and the beam divergence was mandatory to understand the performance of the crystal design.

The GALORE beamtest was performed at CERN in June 2023 on the H8 SPS extracted beamline with a positive 180 GeV/c pion beam. The whole beam, which has a dimension of around 1 cm and a divergence of around 80 µrad, has been used in the preliminary phase to center the crystal on the beam.

The GALORE crystal is a 4.1 mm long in the beam direction silicon crystal with a face perpendicular to the beam of 0.5 x 55 mm^2. The micro structure is 0.15x10 mm^2 measured in the middle of the crystal sample. If the whole beam were used, given the crystal size, only a few percent of the particles would have interacted with the crystal itself and thus almost all the events would have been rejected in the offline analysis. The possibility to select a very small region (thirteen 50 µm strips) allowed to acquire statistics 20 to 30 times faster while at the same time reducing the divergence from 86 µrad to 32.2 µrad.

The goal of this thesis was the development of the tracking system able to allow a measurement to be performed in a short time and not a detailed analysis of the crystal channeling performance, which anyway resulted to be at least 65 % in the micro trench region. The goal of a $\sim$ 100 % channeling efficiency is still far from being reached, and this is probably related to imperfections in the crystal lattice.

The same system was used also for the e+BOOST beamtest on the PS T9 beamline in August 2023. In this case the requirements were less stringent, but the possibility to trigger on a part of the beam in the vertical direction has allowed to test at the same time 3 different crystal radiators to be used in the design of a hybrid crystal based positron source collecting a large enough statistics. By using a bending magnet to swipe all charged particles, an electromagnetic calorimeter can be used to detect and measure the produced radiation in the non oriented and axial case.

The upgraded test system proved to work properly, for both the experiments, allowing the collection of a statistics large enough in a short time (which is essential when taking data on extracted beamlines where different users have to alternate). Furthermore, thanks to its versatility, the same test system can be applied to any kind of beamtest where a high resolution particle tracking is needed, with the possibility to select a small portion of the beam thus reducing also the divergence, which is a fundamental parameter when studying oriented crystals.