BEAM LOSS PREDICTIONS FOR THE UA9 CRYSTAL COLLIMATION EXPERIMENT

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Abstract

The UA9 experiment at the SPS aims at testing bent crystals for usage as collimators with high energy stored proton and heavy ion beams. The experiments will try to establish crystal-based cleaning efficiency with slowly diffusing beam halo. One method for evaluating efficiency relies on Roman Pots and is described elsewhere. An alternative method relies on observing the beam loss signals around the ring. Comparisons of losses escaping from standard collimators and bent crystals will allow determination of cleaning efficiency, equivalent to the definition used for the LHC collimation design. This alternative method is described and simulations with LHC collimation tracking tools for UA9 are discussed. The predicted beam losses along the SPS ring are presented for different orientations and amorphous layer thicknesses of the crystal. The effect of different diffusion speeds of the beam are discussed.

INTRODUCTION

The UA9 experiment is a crystal channeling experiment,taking place in the SPS in summer 2009, aiming at verifying the usability of a well characterized crystal for collimation purposes in a high energy circulating proton machine. A bent crystal will be inserted in the halo of the circulating beam, and its effect will be studied for different angular orientations. A tungsten absorber of 60 cm, located 64 m downstream the crystal, is foreseen to intercept the channeled beam. Two roman pots are set in between the crystal and the absorber to measure the position and intensity of the channeled beam. A detailed description of the experiment layout can be found in [1]
A set of dedicated beam loss monitors (BLM) and secondary emission monitors (SEM) have been installed in proximity of the crystal, of the roman pots and of the absorber. Together with the dedicated BLMs, the readings from the 216 BLMs already installed in the machine (one per quadrupole) will provide us with a detailed map of the losses along the whole ring.
While our team will provide support during the experimental runs, here focus is given to the outcome of our simulations, which intend to reproduce the BLM signal for different orientations of the crystal. The comparison between measured and simulated beam loss pattern will then allow to validate our tracking codes. The same operation has been done in SPS for LHC prototype collimator in 2004 and 2007 [2].

SETUP OF THE SIMULATIONS

For the simulations, a new routine has been implemented in our standard tracking tools, e.g. the tracking programs Colltrack (which does dot include dispersion or chromatic effects) and Sixtrack (which provide a full 6-dimension description)[3]. The result of beam losses presented here were obtained evaluating the particle tracks generated by Colltrack. The losses are evaluated with a 10 cm precision. The required input for the software are:

1. the machine optics;
2. a collimator database with a complete description of the material used, the thicknesses of the elements and their apertures. In particular here we consider the crystal, the RP and the absorber as collimator-like objects: details are given below;
3. the distribution of the impacting beam.

Machine Optics

The machine optics is generated by the program madx for the standard 120 GeV SPS optics. The crystal, the two RP and the absorber are installed as collimator.

Collimator Database

The crystal is a Si crystal, 111 orientation. The length is 1 mm and the curvature radius is 6.67, that means a channeling angle of 150 μrad. Its transverse directions are typical dimensions for a strip crystal, i.e. a width of 500 μm and a height of 50 mm. We made a scan of 27 different crystal orientations between -250 and +200 μrad. The crystal is set at 6 σ.

Table 1: Equivalent thickness in Cu for the different RP regions. The value for the detector region can vary depending on the number of Si detectors inserted in the RP.

RP region	transverse dimension	equivalent Cu thickness
Detector	$b > 650\mu$m	664-882μm
Dead	$150\mu\text{m} < b < 650\mu$m	370 μm
Border	$0 < b < 150\mu$m	1.16 cm

The Roman Pots are multi-layered objects both in longitudinal and in vertical direction. We used an equivalent thickness in Cu, rescaling with the nuclear interaction

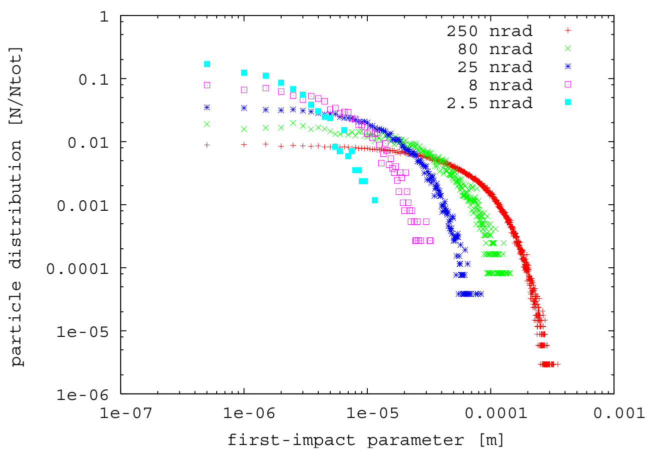

Figure 1: Distribution of the impact parameters of the first impact on the crystal face for diffusive kicks with different maximum amplitudes.

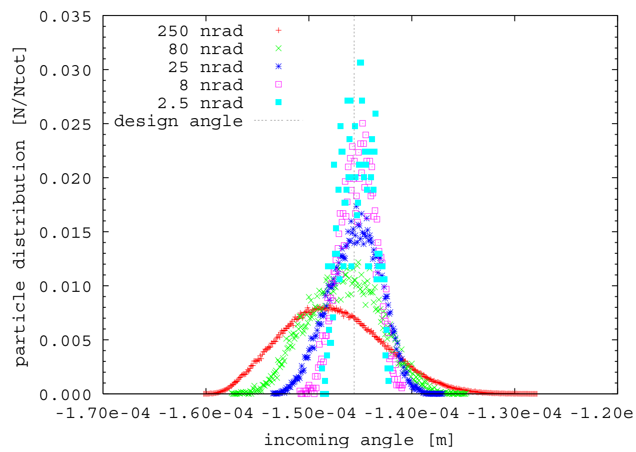

Figure 2: Distribution of angles of the particles impacting for the first time on the crystal for diffusive kicks with different maximum amplitudes.

length, to represent each RP transverse layer (edge, dead region, detector region). For each layer we got a different equivalent thickness, as summarized in table 1. Since our code does not foreseen multi-layer elements in the transverse direction, we choose to use a Cu thickness of 750μm, representative of the detector region. Both RP are set at 6 σ + 1 mm.

The absorber (TAL) is a Tungsten one-side collimator, whose lenght is 60 cm. The TAL has an aperture of 6 σ + 1 mm.

Impacting Beam Features

The incoming beam is a critical parameter for out collimator. Since a device will be used to artificially increase the transverse emittance growth rate, the average impact parameter on the crystal will depend on the tuning of the kicker. The device is an electrostatic kicker to which a white noise will be applied. The maximum applied voltage is 300 V, which corresponds to a maximum kick of 25 urad. To further speed up the simulations, we have written a dedicated code to study the variation of the particle first impact distribution on the crystal versus different maximum kicker currents. The code generates a matched gaussian tail distribution both in the transverse and in the longitudinal dimension. It take into account the off momentum effects, including both syncrotron and betatron oscillation, but it treats a perfectly linear machine, and there is no detuning with amplitude. Particles receive a random kick (flat random distribution) every turn and their transverse position at the crystal location is checked. Once the particle hit the crystal entrance face, the position and angle of the particle is registered, and the particle is no longer tracked. The results of the impact parameter and angle distributions for maximum kicks between 2.5 and 250 μrad are presented in picture 1 and 2. The impact parameter distributions are well fitted by exponential functions, and the average impact parameter for our case results 13 um: this result was used as an input for our simulations. We tracked 1 million particles for 1000 turns for each crystal orientation. The resulting angular spread is 8 urad, which is much lower than the the channeling acceptance of the Si crystal at 120 GeV, whose value is 30 urad.

SIMULATION RESULTS

The main purpose of ous tracking codes is to evaluate the both the global and the local efficiency of the collimator system. Definitions and results will be given further in this section.

The global efficiency is a function of the amplitude, and is defined as the number of particles which exit the collimation system with an amplitude greater than a specific amplitude, normalized with respect to the total number of particles absorbed by the collimation system. The varia-

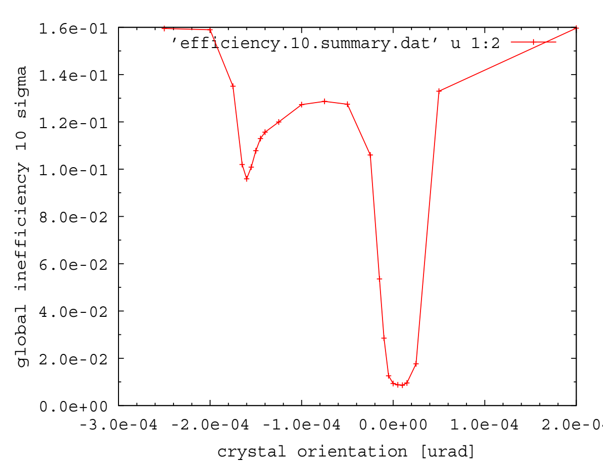

Figure 3: Global cleaning efficiency at 10 σ for different orientations of the crystal.

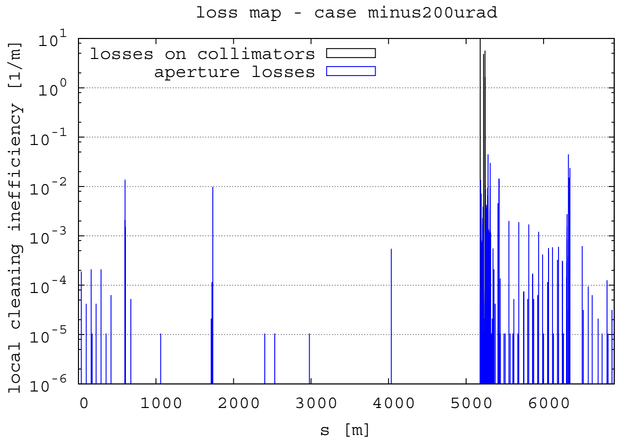

Figure 4: Local cleaning inefficiency along the ring for the crystal in amorphous orientation.

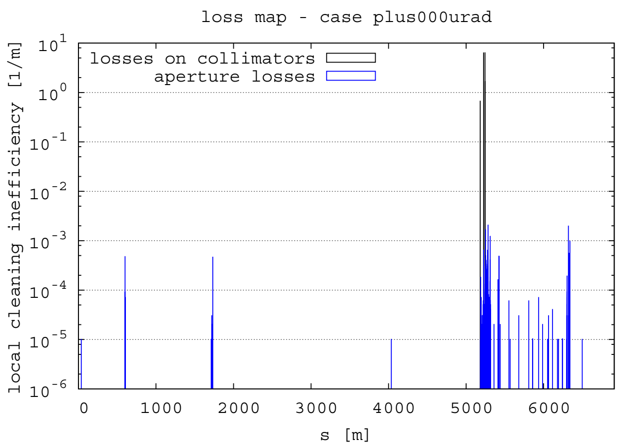

Figure 5: Local cleaning inefficiency along the ring for the crystal in channeling orientation.

tion of the global efficiency at 10 sigma versus the crystal orientation is given in picture 3.

The channeling peak is well defined and its FWHM is 50 μrad. Since the critical angle at 120 GeV is $\theta_c =\sim 30$ μrad, the expectation of channeling acceptance is 1.5 θ_c, i.e. 45 μrad. A slightly larger channeling peak is due to the angular spread of the incoming particle, already commented in the previous section. The improvement between the amorphous position of the crystal and the global efficiency in channeling regime is evaluated as a factor 20.

The local cleaning inefficiency η is defined as:

$$\eta = \frac{N_{abs}(dl)}{N_{Tot} \cdot dl} \quad (1)$$

e.g. the number of particles N_{abs} hitting the aperture in the longitudinal interval dl over the total number of particles absorbed by the collimation system N_{Tot}, normalized over the length. The plot of the local cleaning inefficiency along the ring is called loss map: examples for amorphous and channeling case are presented in pictures 4 and 5. The maximum local cleaning inefficiency goes from a value of $4.5 \cdot 10^{-2}$ for the amorphous orientation, to $2.1 \cdot 10^{-3}$ for the channeling orientation, confirming a gain factor of 20 in efficiency.

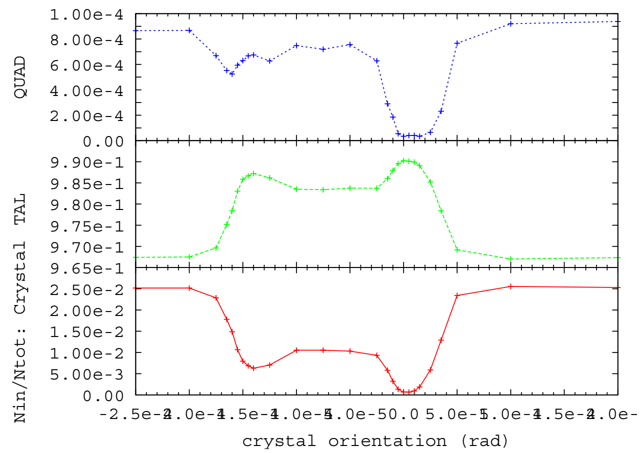

Figure 6: Inelastic interactions at some selected elements (crystal, TAL, QF52210) normalized over the total number of particles absorbed, versus the crystal orientation.

In order to be able to compare simulation results with future BLM measurements, the losses are integrated over the full lenght of the elements. In particular in picture 6 we present the losses behavior for the crystal, the absorber and one the quadrupole (QF52210). The quadrupole is located at ∼129 meters downstream the crystal, where a peak loss is expected. It should be remarked that the integrated losses on the quadrupole are reduced of a factor 25 by the use of the channeling effect.

CONCLUSIONS

A complete set of simulations has been performed with the tracking code colltrack for the simulation of the UA9 experiment. Beam loss maps have been generated for different orientations of the crystals, showing an improvement of a factor 20 on the loss peaks in case of crystal channeling. The integrated losses for different elements have also been calculated, showing an even higher improvement for certain elements. To finally validate our codes, the obtained results and loss distributions will be compared with the BLM measurements taken during the beam tests.

REFERENCES

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