

SIMULATION RESULTS FOR CRYSTAL COLLIMATION EXPERIMENT IN SPS UA9

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Abstract

The UA9 experiment will first take place in 2009 at the CERN-SPS and will evaluate the feasibility of silicon crystals as primary collimators for a storage ring. A crystal placed at 6σ from the beam core will deviate protons towards two Roman Pots and a tungsten absorber (TAL). In this paper the authors show simulations of the expected beam dynamics and of the capture efficiency into the secondary collimator. The result of these simulations will guide us in interpreting the experimental data expected in UA9.

SIMULATION SETUP

UA9 will be an experiment in SPS with the aim of testing if bent crystals, used as primary collimators in a two-stage collimation system, are more effective than amorphous collimators. This experiment will first take place late in 2009 [1]. The full description of the layout is presented in [2] and [3]; the main elements considered in the simulation of UA9 are:

- Lattice and Beam: the lattice of SPS and the beam used for the simulation.
- Geometrical layout: the physical positions of the crystal and instrumentation in the machine.
- Crystal: the parameters of the crystal used in the experiment.
- Halo exciting system (dumper): the device used to dump protons from the core of the beam to the halo in order to emphasize the behavior of the crystal.
- Roman Pot: the device used to see the track of protons.

Lattice and Beam

The lattice used for the SPS is the release 2008 implemented with MadX and available on the Internet site [4]. The simulation is performed at 120 GeV without the radio-frequency enabled and resumed in Table 1. The crystal will be placed at 5128 m from the beginning of the machine (BA1), just before the focusing quadrupole QF.518. The first Roman Pot will be 43.45 m after the crystal and 6.739 m after the defocusing quadrupole QD.519. The second Roman Pot is 15.602 m after the first one and 3.03 m before the absorber in tungsten (TAL).

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Table 1: SPS Beam Parameters

	Parameters
Momentum P [Gev/c]	120
Tune Q_x	26.13
Tune Q_y	26.18
Norm. emittance at 1σ [m rad]	1.5×10^{-6}
Transverse radius (RMS) [mm]	1
Beam intensity [Protons]	$10^{11} \div 10^{12}$
Beam lifetime [h]	80

Geometrical Layout

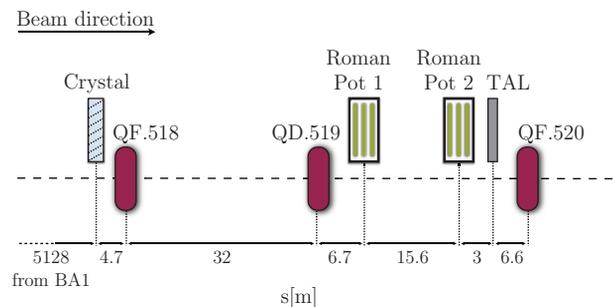


Figure 1: Crystal, Roman Pots and TAL in UA9 experiment.

Table 2: UA9 Layout

Device	S [m]	β_x [m]	$\Delta\mu_x$ [rad]	x [mm]
Crystal	5182.00	96.05	0.00	6.35
RP1	5225.45	31.00	1.13	4.11
RP2	5243.45	85.18	1.49	6.81
TAL	5245.12	92.25	1.51	7.09

From the point of view of the transversal position in the horizontal plane the request for the crystal is to act as a primary collimator: it should be positioned in the halo to intercept particles for channeling; the particles not channeled, amorphously scattered, will have the possibility to intercept the crystal again in the next turns. The Roman Pots and the TAL will be placed at a distance greater than the crystal in order to intercept only protons deflected by the crystal and not directly protons of the halo. The positions are summarized in Fig. 1 and Table 2.

Crystal

The silicon crystal used as primary collimator will be 0.5 mm thick, oriented along the (111) planes; the bend angle will be $\alpha = 150 \mu\text{rad}$ and with a length along the beam $L = 1 \text{ mm}$. This gives a bend radius $R = 6.67 \text{ m}$ and, consequently, a critical radius for 120 GeV protons of $R_c = 21.46 \text{ cm}$. In these conditions, the particles deflected in the second collimator of tungsten (TAL) should have large impact parameters, of about 6-8 mm. The crystal bend radius, which produces the maximum extraction efficiency for 120 GeV protons, is about 1-2 m, i.e. about 5-10 times R_c .

Dumper

To populate the halo at 6σ with a constant flux of particles the dumper proposed in [5] is used. This device consists in an electric dipole with a length $l = 2.4 \text{ m}$, a plate separation of $d = 0.124 \text{ m}$, that provides a random kick with the frequency $\nu_{rev} = 43375 \text{ Hz}$, the revolution frequency of SPS, and a random amplitude that is limited by the power supply between $\pm 3.5 \text{ kV}$. The kick that a particle receives when goes trough the dipole is:

$$k = \frac{l\Delta V}{\gamma E_0 d} \quad (1)$$

where ΔV is the voltage between the plates, γ is the relativistic factor (at 120 GeV $\gamma \approx 127$) and E_0 is the proton rest energy. The kick is applied on the horizontal plane. The emittance growth per second, with a voltage random flat-distributed, is [6]:

$$\langle \Delta \epsilon \rangle = \frac{1}{2} \beta \langle k^2 \rangle \nu_{rev} \quad (2)$$

where $\nu_{rev} = 43375 \text{ Hz}$ is the revolution frequency of the SPS. The maximum voltage for the dumper is fixed in 330 V in order to have a constant flux of particles in the crystal, according to [3].

Roman Pot

The Roman Pots considered in the simulation are schematized as three different area: the longitudinal window made of aluminum with an interaction length of $L_b = 3 \text{ cm(Al)}$; the clearance slot, made of steel with an interaction length of $L_s = 400 \mu\text{m(Fe)}$; the third area is the detector made of iron and silicon with an interaction length of $L_d = 400 \mu\text{m(Fe)} + 900 \mu\text{m(Si)}$ for the first Roman Pot and $L_d = 400 \mu\text{m(Fe)} + 1500 \mu\text{m(Si)}$ for the second Roman Pot that will be with 5 strips of silicon instead the three strips of the first Roman Pot. The vacuum in the box is 10^{-6} tor , that is negligible from the point of view of the scattering.

SIMULATION

The first simulated layout is the situation with the crystal aligned to the angle of particles, that is when the crossing

angle between the planes of the crystal and the maximum of the angle distribution in the region of the crystal is zero (θ_o). Under this condition the crystal is mainly working in channeling and the peak on the Roman Pot is evident. The result is shown in Fig. 2; the $x = 0$ of the plot is scaled of the 6σ in the point of Roman Pot 1 plus an additional offset of 1 mm as explained in the previous section. The dumping system is, at this stage considered as a constant flux of particles on the crystal. The plot of Fig. 2 is the output of the simulation after few turns, when the effect of the random scattering inside the Roman Pot is negligible.

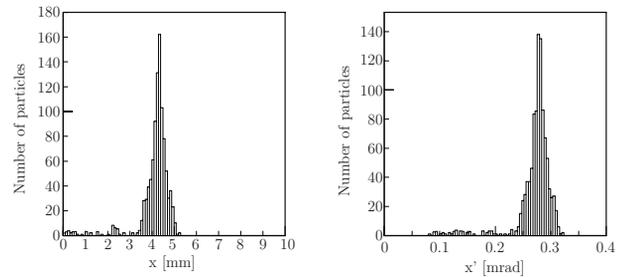


Figure 2: Impact parameters x and x' on the Roman Pot 1 when $\theta_o = 0 \mu\text{rad}$. Single turn simulation.

The effect of the random scattering in the Roman Pots is evident in multi turns as shown in Fig. 3

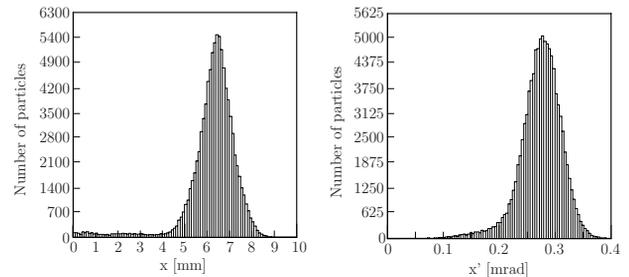


Figure 3: Impact parameters x and x' on the Tungsten Absorber (TAL) when $\theta_o = 0 \mu\text{rad}$. Multi turn simulation.

Here the multiple scattering creates a bigger spread in the impact parameter and in the angle, and the resulting distribution is due to the effect of the Roman Pot. These two preliminary plots are already interesting for the goal of this simulation, that is to see if the simulator, composed by MadX plus the CRYM routine plus the simulation of Roman Pot multiple scattering, can predict the behavior of particles in a real machine.

In order to stress the simulator and to verify the other properties of the crystal, the multi turn simulation was performed with the crystal rotated of different angles. The first rotation is $\theta_o = 20 \mu\text{rad}$ and the result is shown in Fig. 4.

Another interesting case is when $\theta_o = -200 \mu\text{rad}$: in this condition the distributions are broadened and the Volume Reflection maximum is smoothed down. This configuration is shown in Fig. 5. The last situation is when $\theta_o = 75 \mu\text{rad}$ that is when the crystal is working as an

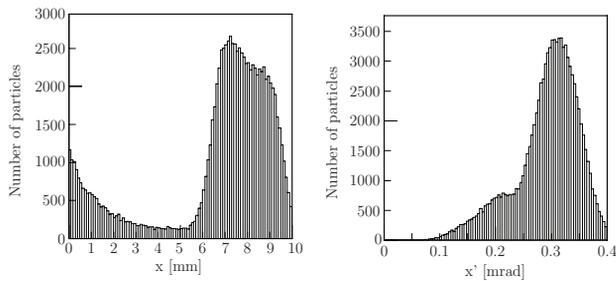


Figure 4: Impact parameters x and x' on the Tungsten Absorber (TAL) when $\theta_0 = 20 \mu\text{rad}$. Multi turn simulation.

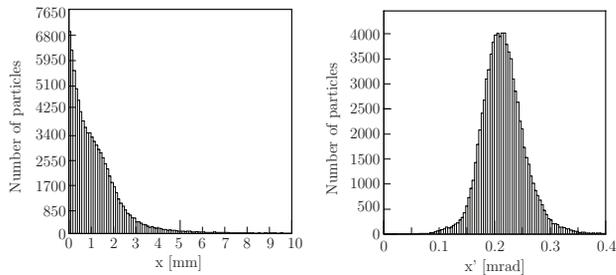


Figure 5: Impact parameters x and x' on the Tungsten Absorber (TAL) when $\theta_0 = -200 \mu\text{rad}$. Multi turn simulation.

amorphous layer and the protons hit the crystal mainly for diffusion and multiple scattering. This result is in Fig. 6. The simulation is in good agreement with a similar work presented in [7].

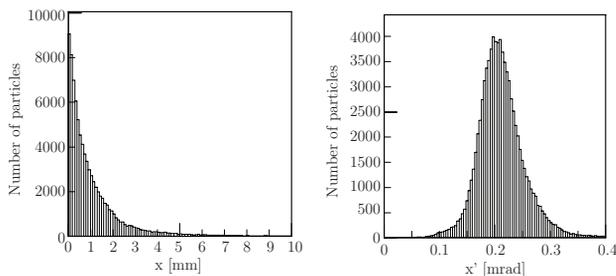


Figure 6: Impact parameters x and x' on the Tungsten Absorber (TAL) when $\theta_0 = 75 \mu\text{rad}$. Multi turn simulation.

The use in the simulation of a real dumping system has an impact on the signal detected by the Roman Pots: the angular spread of the protons that collide on the crystal is a function of the last kick received by particles. With a maximum voltage of 330 V for the dumper, coupled with the octupoles powered with a gradient of $K3L = 4.52 \text{ T/m}^3$, the result is shown in Fig. 7.

The effect of the dumper is to produce a noise on the left of the main peak due to the particles not channeled or dechanneled. The ratio between signal and noise can be controlled acting on the voltage of the dumper and the gradient of the octupoles. The parameters proposed here are a starting point for the real parameters that will be used in the control room during the experiment.

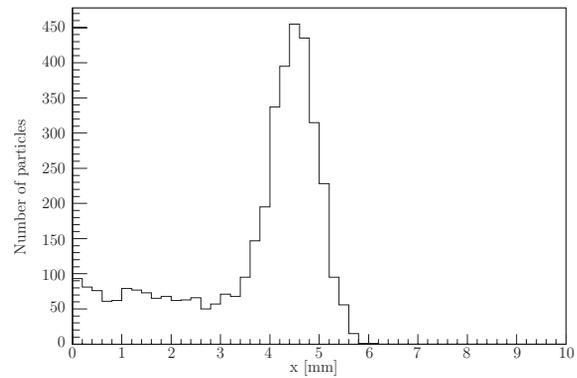


Figure 7: Impact parameter x at Roman Pot 1 when $\theta_0 = 0 \mu\text{rad}$ using the forced halo diffusion system (dumper+octupoles).

CONCLUSION

The UA9 experiment will start in the summer 2009 and, after an initial setup, the first signal on Roman Pots and on TAL should be as predicted in the simulation here presented. Moreover, during the develop of this simulation, several devices were modeled; for example the dumper for the halo excitation required a special set of simulations in order to understand how to power the device during the experiment to obtain a constant flux of particles on the crystal. This acquired experience will be useful during the preliminary operations of the experiment to better understand how to correctly setup the devices. The next step in the simulation program will be to develop a flexible structure capable, during the experiment, to simulate the behavior of the real machine including the parameters observed in the control room. In this way it will be possible to have a virtual platform to check the experiment during the runs.

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