THE UA9 EXPERIMENT AT THE CERN-SPS

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Abstract

The UA9 experiment intends to assess the possibility of using bent silicon crystals as primary collimators to direct coherently the beam halo onto the secondary absorber, thus reducing out-scattering, beam losses in critical regions and radiation load. The experiment will be performed in the CERN-SPS in storage mode with a 120 or 270 GeV/c proton beam. The otherwise stable beam will be perturbed to create a diffusive halo. The setup consists of four stations: the *crystal station* with two goniometers for crystals, *two tracking stations* at about 90 degrees phase advance with detectors for single particle tracking and the *collimation (TAL) station* with a 600 mm long tungsten absorber. The observables are the localization of the losses in the collimation area, the collimation efficiency and the shape of the deflected beam phase space. We discuss the experimental layout and the way we expect to collect data in 2009.

INTRODUCTION

In a two-stage collimation system a bent crystal used as primary deflector may deviate coherently the incoming halo at angles larger than what can be obtained with amorphous materials. Hence, the collimation efficiency that is the fraction of the halo collected by the secondary absorber is expected to increase. With last-generation crystals, the majority of the incoming particles are deflected [1] in the first crystal traversal. The escaping ones will cross the crystal again and have an additional probability of being coherently deviated and absorbed in the following turns (multi-turn extraction) [2]. The supposed advantages of crystal collimation are twofold: larger collimation efficiency due to larger deflecting angles and faster extraction mechanisms, reduced impedance due to the use of shorter primary. In addition, the particles trapped in the crystal planes will have far encounters with the nuclei of the lattice resulting in reduced probability of diffractive proton scattering events and of ion fragmentation and electromagnetic dissociation.

Pioneering tests at CERN [3] and FNAL [4] demonstrated the feasibility of high efficiency crystal channelling in hadron colliders. On-going experiments in the North Area of the SPS assessed important features of high-energy proton interactions with bent crystals, demonstrating high deflection efficiency in crystals much shorter that the dechanneling length due to multiple scattering [5], volume reflection [6] and its dependence on crystal curvature [7], multiple reflection in a sequence of crystals [8] and axial channelling [9]. Both strip [10, 11] and quasimosaic [12] crystals were successfully used.

Two crystal collimation experiments took place in hadron colliders, one at RHIC (with gold ions) and the other at the Tevatron (with 980 GeV protons). In both cases, the same O-shaped crystal from PNPI, 5 mm long with a bending angle of 440 μrad was used as primary deflector. At RHIC, the effect of the crystal was visibly detrimental for the background regime, most likely due to inappropriate optical conditions at the crystal location [13]. At the Tevatron instead, the same crystal provided a factor of two reduction of the experimental background in comparison to what the amorphous tungsten primary could perform.

UA9, approved in September 08 by the CERN Research Board, will study features of crystal channelling using single-particle detectors and compare the effect of different crystal technologies, strip or quasimosaic, using either channelling or volume reflection or even multi-reflection with a sequence of aligned crystals.

THE UA9 LAYOUT

The layout of UA9 is shown in Figure 1. The halo particles should be deflected by the crystal and kept by the secondary collimator in the horizontal plane where the SPS aperture is larger. All the components of UA9 are retractable for an easy routine operation at high intensity. The layout is as compact as possible to save on cost of cables and of other infrastructures.

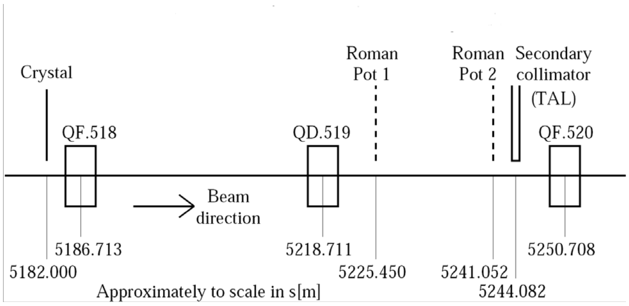

Figure 1: Layout of UA9

The core of the UA9 is installed in the two dipole-empty cells of the long straight section 5 of the SPS, just across the cavern formerly hosting UA1.

A large tank is in place, equipped with several devices. There are two goniometers each with a holder and a single-crystal, one strip and one quasi-mosaic, which will be used in alternative as crystalline collimators. The goniometer can be moved towards the beam and oriented to its direction with a resolution of a tenth of μrad, i.e. of the order of the critical angle for channeling at the nominal beam energy of 120 GeV. A movable thin target in tungsten is added for comparison, which will be used as an amorphous primary collimator. The tank also contains three feed-through for 100 twisted pair cables, for future use, should active piezoelectric motors be

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*http://greybook.cern.ch/programmes/experiments/UA9.html required to mutually orient multi-crystal assemblies. In the wall side of the tank an external laser system is used to align the crystals with an autocollimator and two penta-prisms at the installation time. Later alignment checks will be made with the same system, through quartz windows located just in front of the crystals. In the upstream and downstream faces of the tank, two gas electron multiplier (GEM) pads and a pair of scintillator counters are mounted in air. Their counting rate is normally proportional to the background rate, about equal in the two face positions. When the crystal is in place, the rate of the downstream detectors should be increased by the rate of nuclear reactions in the crystal itself. The GEM pads and the scintillator counters provide similar information, for redundancy. The pads have 20x30 channels and may also give rough indications of the lateral distribution of the background. The tank can house also a bar of quartz movable laterally in vacuum, which once aligned to the crystal will be used as a Cerenkov detector and count the number of particles incoming into the crystal itself. This detector is to be installed in May 09, just before the running in of UA9.

The collimator tank houses a movable block of tungsten 600 mm long, 30x30 mm^2 wide (TAL). Attached to it and aligned to its front face, there is a bar of quartz, movable in vacuum, used a Cerenkov detector, by which the number of particles reaching the collimator is counted.

The roman pot 1 is in place, equipped with one silicon-strip detector, mounted in the inner side of the ring. The other pot, in the outer side of the ring, will be equipped, by the end of May '09, with one pixel pad detector and for redundancy with a scintillation fibrometer.

Additional detectors are used in UA9. A set of scintillator counters, mounted in air in both sides of the vacuum pipe, are installed downstream of the first half-cell with bending dipoles. They will be used to detect off-momentum beam loss induced by the collimation process. In addition, a set of fast beam loss monitors (BLM) has been installed in area of UA9, to reveal the fast loss. Later in 2009, another vacuum tank with two goniometers in construction at IHEP and the roman pot 2 in construction at SLAC and the associated detectors (silicon-strips, pixels and scintillating counters) will be added.

BEAM AND CRYSTAL PARAMETERS

UA9 will be operated at two energies, 120 and 270 GeV. The former value is the nominal one of RD22 [2, 3], the crystal extraction experiment performed in the early nineties in the SPS, for which we have numerous reference data. The latter value of 270 GeV is the energy of other machine experiments planned in the SPS simultaneously to UA9, a choice that may significantly speed-up the duration of the accelerator setting. The beam parameters will be those of Table 1, where the transverse RMS beam radius is computed in the middle of a focusing (defocusing) quadrupole for the horizontal (vertical) plane, whilst the tunes are the ones for the high intensity operation mode of the SPS. The beam intensity will be of a few 10^{10} up to 10^{12} particles. The RF beam structure will be either unbunched or bunched in one or a few tens of bunches. The accelerator will operate in storage mode.

Table 1: beam parameters for UA9 operation.

	High energy	**Nominal energy**
p [GeV/c]	270	120
Q_x	26.13	26.13
Q_y	26.18	26.18
Q_s	0.0021	0.004
ε_{N} (1 σ) [µrad]	1.5	1.5
σ_x, σ_y [mm]	0.67	1
$\Delta p/p$ (1 σ)	2 to 3×10^{-4}	4×10^{-4}
ε_L [eVs]	0.4	0.4
V_{RF} [MV]	1.5	1.5

The beam lifetime is determined by the SPS vacuum and should be larger than 80 h. By applying an external noise to the damper, the beam lifetime should be reduced to a value ranging from a few tenths of minutes to a tenth of hour. A similar approach had been used successfully in RD22, with the hardware still currently operational in the SPS. The subsequent halo flux hitting the crystal should be sustainable by our detectors in the roman pots. In practice, we will produce one of the following conditions. A halo flux of a few 10^2 to a few 10^4 particles per turn evenly distributed along the revolution period (unbunched beam) or synchronous to the bunch structure (bunched beam), which can be investigated with the detectors in the roman pots, avoiding counting saturation. In alternative, larger fluxes up to a few 10^5 particles per turn, which may saturate the monitors in the roman pots and hence should be studied using only the beam loss monitors of the SPS.

The optimal primary collimator is a silicon crystal oriented along the (111) planes, with a bend angle α=150 µrad and a length along the beam L=1 mm. This gives a bend radius R=6.67 m (the critical radius for 120 GeV protons is R_c=21.46 cm). In these conditions, the particles deflected in the 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. 5-10 times R_c [7]. The crystal parameters, α and L, we selected are a sound compromise in between the optimal values for SPS and those eventually required for LHC. Both strip crystals with anticlastic curvature and bulk quasi-mosaic crystals may be built with parameters close to the above values.

In operational conditions, the crystal will be oriented in channelling mode and its edge will be at the distance of x_{bc}=6σ_{beam} from the closed orbit. Also the TAL and the two roman pots will be retracted from the beam centre, at a distance, which must be larger than that chosen for the crystal. This should guarantee in all circumstances that the crystal could intercept the halo particles before any other experimental device, thereby acting as the effective primary collimator. In addition, this should ensure that halo particles, which are not channeled in the first crystal passage and which are deflected by multiple scattering as if the crystal was an amorphous material, could hit the crystal again in the subsequent revolutions, thereby having additional chances of being eventually channeled. In other word, the multi-turn channeling mechanism should be fully active and can eventually produce the maximal collimation efficiency.

The simplest option is to position the edges of the two roman pots and of the TAL, in normalized coordinates, at the same distance $6\sigma_{beam}+x_{of}$ from the beam centre, shifted by the same offset x_{of} with respect to the crystal edge position. The size of x_{of} is chosen in such way that the multi-turn effect has a high probability of happening, see Table 2. Non-channeled 120 GeV particles, in traversing the 1 mm long silicon crystal, are randomly scattered in all directions. The RMS scattering angle is $\theta_{\mathrm{ms}}\approx 10$ µrad. By requiring that particles deflected by up to $4.25\cdot\theta_{\mathrm{ms}}$ in the horizontal plane stay clear from TAL and roman pots, the probability of loosing multiple scattered particles in the first turn becomes negligible, i.e. of about 10^{-5}.

Table 2: Beam size and offset along UA9.

	Crystal	QD 519	RP1	RP2	TAL	QF 520
$6\sigma_{beam}$ [mm]	6.35	2.97	3.61	5.98	6.23	6.60
x_{of} [mm]	0	0.41	0.5	0.83	0.86	0.91

EXPERIMENTAL PROCEDURES

The SPS is to be set in storage mode at 120 GeV, initially with a single circulating bunch of $5\cdot 10^{10}$ protons. The main parameter, such as the closed orbit, the tune, the chromaticity, the beam profile, the RMS beam size, the lifetime and the beam loss pattern along the ring, can be recorded. Once the diffusive halo is activated though a continuous power injection in the beam damper, several actions will be performed. The various movable devices of UA9 will be aligned to each other using the BLM in the UA9 area. As a side effect this procedure should provide information of the closed orbit stability. By inserting and retracting the TAL close to its nominal position at about $6\sigma_{beam}$ from the closed orbit, one can measure the diffusion speed and the counting rate of the protons that cross the UA9 detectors. This method should allow setting up the optimal loss rate and diffusion speed to avoid saturation of the UA9 counters and, at the same time, it will provide the expected value of the impact parameter and impact angle onto the crystal, when located in its nominal position.

With the UA9 equipments in their nominal transverse position, one can start orienting the crystal and searching for the optimal angle for channelling. This angle should correspond to a minimal counting rate in the counters located in the downstream tank face, once the background detected in the upstream face is subtracted. As a side effect, this procedure should be able to provide the optimal alignment of the crystal for volume reflection that is the crystal orientation in the middle of the angular range for reflection mode.

With the crystal in channelling orientation and the TAL in its nominal position, it should be possible to take a snapshot of the beam losses around the ring and in the UA9 area in order to compare them with those produced when the amorphous tungsten primary in the UA9 tank is replacing the crystal. This should provide the first set of relevant observables, by which the localization of the beam loss of a crystal collimation system could be evaluated. The evaluation can be made as well in volume reflection mode.

With the crystal in channelling orientation and the collimation in place, there are two methods to evaluate the collimation efficiency. The first method is indirect, based on the assumption that the crystal is the only object in the ring, which can absorb the halo and hence determine the beam lifetime. In a given interval of time, the number of particles touching the crystal can then be given through the lifetime record, whilst the quartz Cerenkov counter counts the flux lost in the TAL. A more direct measurement should be based on the use of the second Cerenkov close to the crystal, by which the particles touching the crystal can be given. To avoid systematic errors, the effect of multi-turn should be properly accounted for.

By inserting the roman pot in its nominal position the profile of the extracted beam on its path to the TAL can be recorded.

Before the end 2009, UA9 will be able to run and collect relevant data on crystal collimation, thanks to the heavy commitment of the full UA9 Collaboration and to the generous support of the funding agencies.

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