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# UA9 status report for 2010

## Analysis of the 2009 data

In 2009, the UA9 studies with bent crystals at the SPS circulating beam have demonstrated the following findings [1].

1. The crystal alignment for halo particle deflection in channeling states is fast and well reproducible. The alignment can be based on the readings of beam loss detectors downstream the crystal and eventually on the images of the deflected beam observed with the MEDIPIX detector in the Roman pot.
2. The collimation and channeling efficiencies can be measured using the LHC prototype collimator to scan the deflected beam [2]. A deflection efficiency of halo protons in channeling states of more 70% was registered in the runs last year. However, the observed values of the efficiency, of the angle and the width of the deflected beam were distributed over a non-negligible range. This fact was eventually explained by some residual misalignment of the crystal with respect to the beam halo envelope during the various measurements. The channeling efficiency should indeed be maximal when the crystal orientation is as close as possible to the perfect alignment. An inaccurate alignment procedure may eventually induce a reduction of the first-hit channeling and favor particle extraction through multi-turn crystal hits, thereby increasing the probability of nuclear inelastic interactions and multiple Coulomb scattering of the protons in the crystal traversal.
3. The nuclear loss rate in the aligned crystal registered by the beam loss monitors (BLM) downstream the crystal was reduced by up to a factor five with respect to the crystal amorphous orientation. This is in fact one of the main advantages of using the crystal as a primary collimator. However, simulations showed that the nuclear loss rate in the aligned crystal should have been even smaller than observed. We therefore supposed that some torsion of the crystal and the goniometer inaccuracy must have played an important role in this respect.
4. The beam losses induced by the crystal in its channeling orientation in far regions around the SPS ring have shown a reduction by only 30% with respect to the amorphous orientations. In fact this ratio is significantly smaller than predicted. We therefore supposed that the sensitivity of the BLM detectors around the ring is too low for our needs

and that a higher sensitivity detection method was required to observe the collimation leakages outside the collimation area.

## Improvement of the UA9 devices in 2010

The upgrade of UA9 devices in 2010 was inspired by the considerations of the previous Section. Our aim was to optimize the crystal channeling efficiency and have improved methods to investigate it. We therefore installed the following new equipment.

A. Two new crystals, one strip and one quasimosaic bent with considerably reduced torsion.

B. A new goniometer made in IHEP (Protvino, Russia) with a better angular accuracy. Its measured value is of about ±10 μrad, i.e. a factor of 3 better than in 2009.

C. A new station of targets limiting the accelerator aperture, located in the high-dispersive area downstream of the crystal-absorber region, for the optimal registration of the off-momentum particles eventually produced in the collimation process. The station is called TAL2 and comprises a beam scraper, a Cherenkov detector and a telescope of scintillator counters.

The modified scheme of UA9 is shown in Fig.1 and Fig.2.

The IHEP goniometer is shown in Fig1, whilst the equipment for the collimation leakage measurements in the high-dispersive area downstream the absorber is shown in Fig.2.

In the following sections we present results obtained in the 2.5 days of run already undertaken in 2010 using the upgraded UA9 devices.

## Measurement of the beam loss induced by the crystal

Let us consider the results obtained with the so-called crystal 3, a 2 mm long quasimosaic crystal installed in the IHEP goniometer. The beam size and the alignment positions of the UA9 elements were selected by closing the LHC collimator with the half gap of $X_{1/2}=4.73$ mm (about $9\sigma_x$). The aligned positions of crystal 3 (CR3) and of the absorber (TAL) were $\overline{X}_{CR3}=X_{1/2}(\beta_x^{CR3}/\beta_x^{COL})^{1/2}=8.20$ mm and $\overline{X}_{TAL}=X_{1/2}(\beta_x^{TAL}/\beta_x^{COL})^{1/2}=9.00$ mm, respectively. In collimation mode, the crystal CR3 was moved towards the beam by 0.68 mm and the TAL was moved away by 0.80 mm. Their operational positions became $X_{C3}=\overline{X}_{C3}-0.68=7.52$ mm and $X_{TAL}=\overline{X}_{TAL}+0.80=9.80$ mm. The offset between the crystal and TAL was about 1.55 mm.

The beam losses in CR3 were registered with the scintillation telescope ScB- ScL, shown just downstream of the IHEP tank in Fig.1. Fig.3 shows the dependence of the telescope count normalized to the beam intensity on the orientation angle of CR3 (curve 1, blue color). The telescope count is reduced by about a factor sixteen when the crystal plane direction at its entrance face is close to the beam halo particle direction (left minimum). The halo protons were deflected by the crystal in channeling states and absorbed by TAL in the same turn. The nuclear inelastic interactions occur for a small non-channeled fraction of the halo. The angular range with reduced counts to the right of the channeling minimum is due to volume reflection (VR) of protons from bent planes in the crystal. The angular range of VR is about equal to the crystal bend angle, that is 168 μrad.

The dependence of nuclear inelastic losses of protons on the crystal orientation obtained by simulation for the experimental conditions is shown by the curve 2 (in red color) of Fig.3. At the channeling peak, the measured and the predicted values of the inelastic loss differ by a factor of about 2. With respect to the experimental result last year, shown in Fig.3 of Ref.[1], the theoretical loss level in channeling mode is closer to the experimental data, whilst in VR mode the difference is more pronounced. To explain this we use the following arguments. The channeling efficiency is increased and the loss rate reduced by the usage of a better crystal, with smaller torsion, better oriented to the beam envelope by a better performing goniometer. On the other hand, we suppose that the loss rate reduction in VR is caused by the increase of the crystal and TAL distances from the beam orbit by a factor of 2 in the present runs with respect to the measurements last year. We are going to study the dependence of nuclear inelastic interaction probability in VR range of the crystal orientations on the distance of the crystal from the orbit.

## Efficiency measurement with LHC collimator scan

During the channeling efficiency measurements with the LHC collimator scan, the CR3 was positioned in the middle of the channeling minimum of the angular scan. Then the LHC collimator was steered to slowly approach the orbit from the garage position crossing the deflected beam. The secondary particles generated by protons in the inelastic interactions with the collimator jaw were registered by the BLM downstream.

Fig.4 shows the BLM count rate as a function of the collimator position. The count is proportional to the number of intersected protons. The BLM count increases fast from the left to the right when the collimator intersects the beam fraction deflected by the crystal. Then the count rate increases slowly up to the position where a sharp increase indicates the intersection of the multi-turn halo between the crystal and TAL.

In Fig.4, the dashed line shows the fit of the experimental data with an error function. The fit center is at $a_m$=-12.427 mm, with an RMS spread $\sigma_a$=0.6 mm. When taking into account the orbit shift value $x_{orb}$=-3.70 mm introduced by a local bump during the last run the deflected beam distance from the orbit is $x_m=a_m-x_{orb}$=-8.73 mm. The crystal position projection at the LHC collimator position is $x_{col}$(CR3)=-4.61 mm. Therefore, the distance of the deflected beam centroid from the crystal projection is of 4.10 mm. In these conditions, the plateau value in Fig.4 provides the estimate for the channeling efficiency of Pch≈80%.

The simulation results for the LHC collimator scan conditions show that the observed deflected beam shift is obtained for the crystal orientation angle close to $\theta_o$=10 μrad. The crystal without torsion used in the simulation gives the channeling efficiency about 92% and the RMS beam width about $\sigma_s$=0.33 mm. The increase of the deflected beam width and the decrease of the channeling efficiency registered in the experiment in comparison with the simulation prediction for the same crystal orientation were most likely caused by the crystal torsion and the anticlastic bending yet uncompensated by the crystal support.

## Leakage measurements with TAL2 scan

The collimation leakage of the beam halo particles was estimated by using the scraper of the TAL2 station. Fig.5 shows the dependence of the BLM count on the horizontal position of the scraper during two scans from the garage position to the crystal projection one. The measurements were collected in the same SPS fill during contiguous time periods. In one case the crystal was in the amorphous orientation; the corresponding data in Fig 5 are colored red, labeled AM. In the other case the crystal was in the channeling orientation; the corresponding data are colored blue, labeled CH. Two arrows indicate the projections of the TAL-absorber and the crystal CR3 positions at the TAL2-scraper location, respectively. The collimation leakage is determined by the particle number behind the TAL shadow. For the situations considered, the collimation leakage for the well-aligned crystal was reduced by about a factor five in comparison with the amorphous orientation. Simulations will be performed to confirm this result.

## Conclusions

The UA9 studies performed with bent crystals at the SPS circulating beam during the 2.5 days of run in 2010 allow the following conclusions.

1. The improvement of the crystal shape and of the goniometer accuracy allowed reducing the nuclear inelastic losses in the aligned crystal by a factor of more than 16 in comparison with the amorphous orientation.
2. The collimation leakage measured in the high-dispersion area downstream the collimator-absorber for the aligned crystal can be reduced by a factor about five in comparison with the amorphous crystal.
3. Further analysis and comparisons with simulations should confirm these conclusions

## References

[1] W.Scandale et al., Phys. Letters B 692 (2010) 78.

[2] V. Previtali, *Performance evaluation of a crystal-enhanced collimation system for the LHC,* EPFL PhD Thesis, Lausanne 2010.

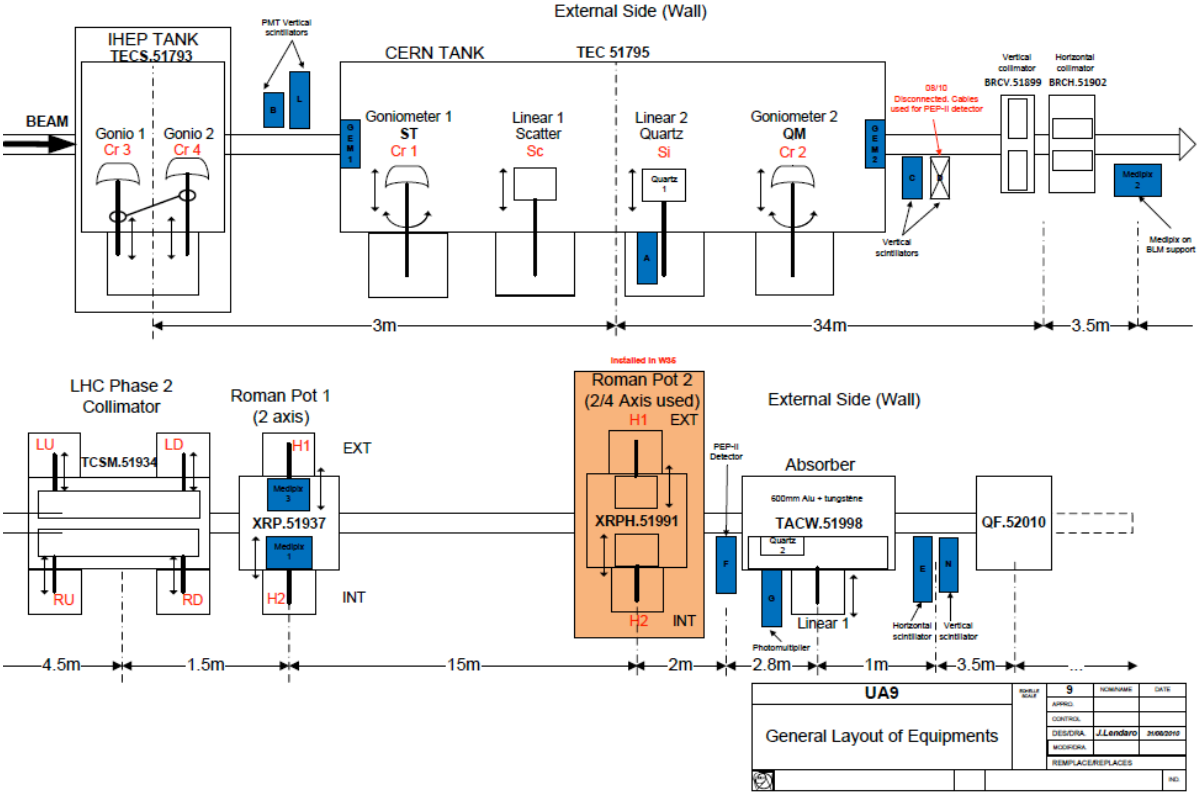

Fig.1. The modified layout of the UA9 experiment. The new crystal-goniometer setup is installed upstream of the CERN TANK. The second roman pot is installed upstream of the TAL absorber in the TACW.51998 tank.

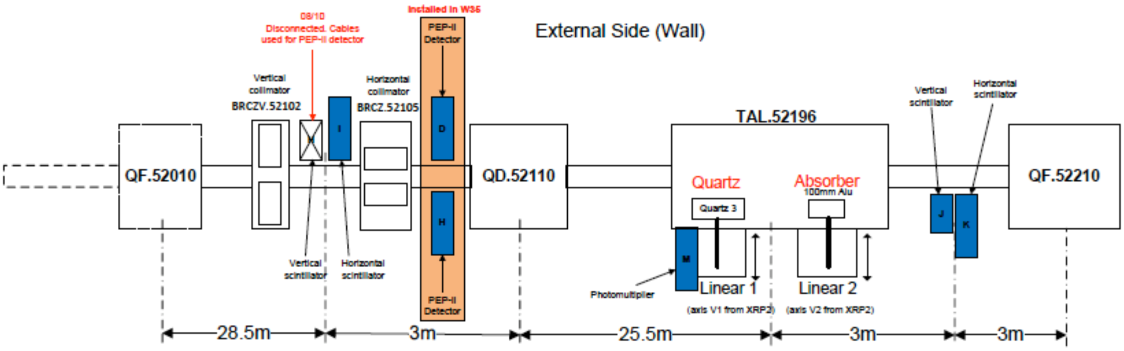

Fig.2. The modified layout of the UA9 experiment. The TAL2 station is installed upstream the quadruple QF 52210.

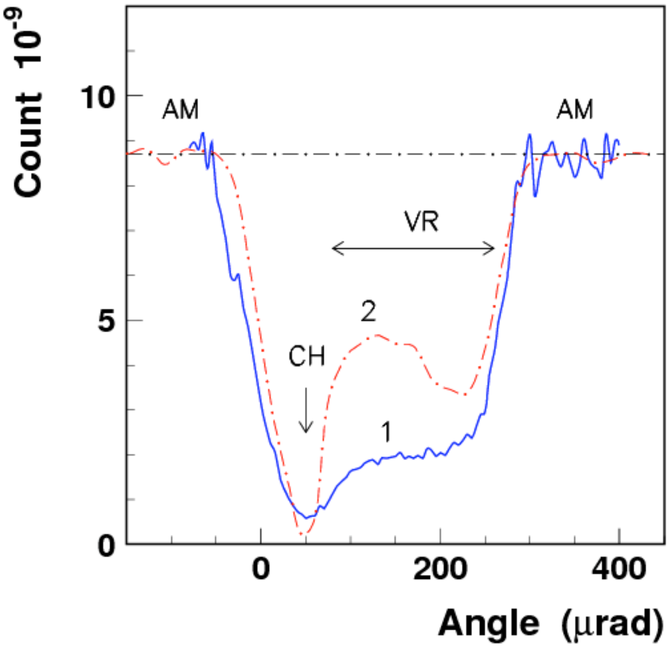

FIG. 3. (1) The dependence of the SB-SL telescope count (downstream of the IHEP tank in Fig.1) on the angular position of the crystal 3, (2) The dependence of the number of inelastic nuclear interactions of protons in the crystal on its orientation angle obtained by simulation. The dot-dashed line shows the level of the beam losses for the amorphous orientation of the crystal.

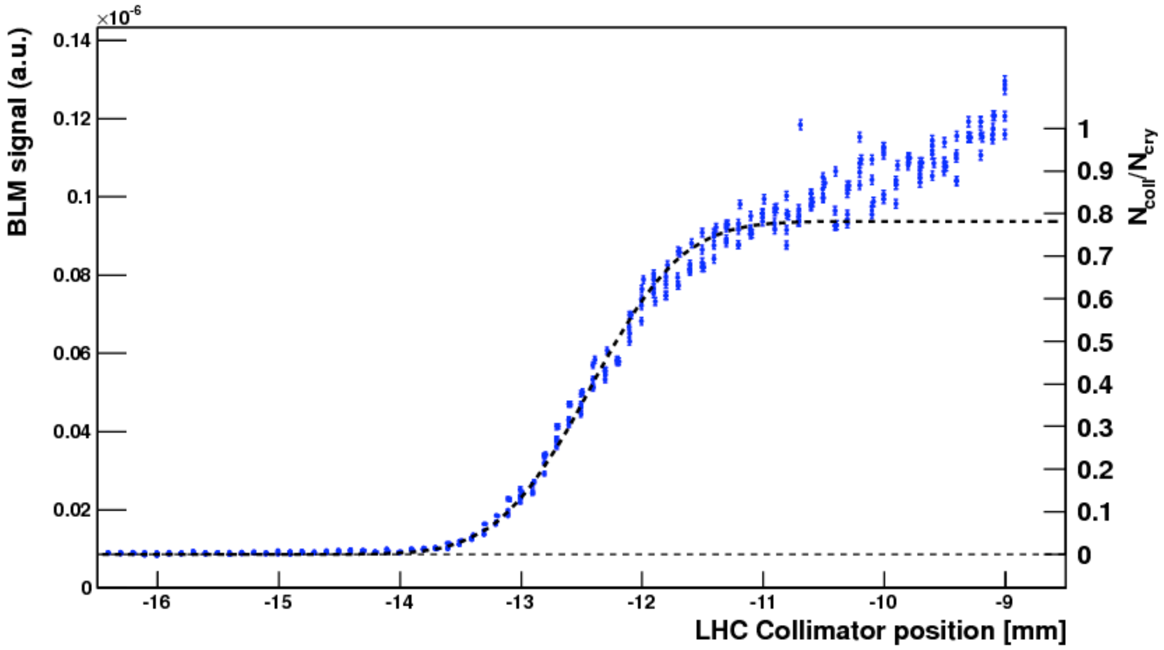

Fig.4. The dependence of the BLM signal on the horizontal position of the collimator during its scan from the beam periphery towards the orbit when it intercepts the beam deflected by the crystal 3. The error function fit is shown by the dashed line. $N_{coll}$ is proportional to the number of secondary halo protons hitting the collimator in its current position; $N_{cry}$ is proportional to the total number of the secondary halo particles.

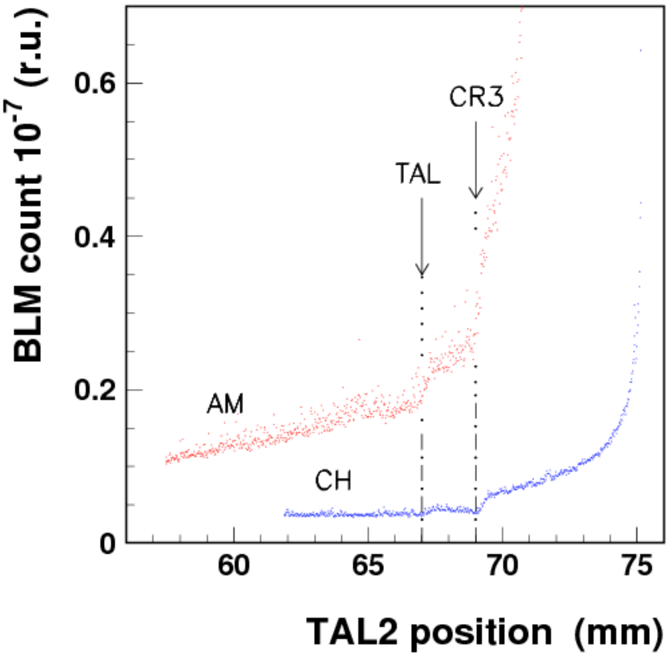

Fig.5. The dependence of the BLM count on the horizontal position of the scraper in a high-dispersive area behind the collimator-absorber during the scraper scan from the beam periphery towards the orbit for the crystal 3 in the amorphous (AM) and channeling (CH) orientations. The projections of the TAL and the crystal CR3 positions are shown by the arrows.