UA9 report for 2012

Introduction

This paper describes the recent UA9 progress adding new evidence to the feasibility of crystal-assisted collimation in hadron colliders. A new goniometer with shorter crystals was used to more efficiently deflect the SPS beam halo with a larger reduction of the off-momentum halo generated in the collimation system. Such a reduction was particularly remarkable for heavy-ions. A considerable reduction of losses was detected by the loss-maps along the whole accelerator circumference. A fraction of the running time was devoted to optimize the configuration of the collimator setup in view of maximizing the collimation efficiency and to investigate effects that could play an important role in LHC. In the North Area the activity devoted to the characterization of the crystals for the SPS and LHC was continued.

The UA9 results collected in 2012 were presented in four international conferences and workshops (ELBA-workshop on frontier detectors, IPAC12, HB2012, Channeling2012). In the two latter cases the presentation was invited. One paper (Physics Letters B 714 (2012) 231–236) was accepted in a Journal with referees and an invited review paper (Modern Physics Letters A Vol. 27, No. 6 (2012) 1230007 (25 pages)) was also published.

Three summer students and two trainees visited UA9 in 2012. Two master theses were completed and two PhD theses started.

Recall of the main UA9 findings in 2011

The results described below were gathered in 2011 and are extracted from Ref [1, 2].

1. Crystal-assisted collimation with Pb-ion beam was extremely successful and the measured collimation efficiency was large. However, the crystal resistance to irradiation with high-energy heavy ion beams should be thoroughly investigated to better estimate the possibility of using a crystal primary collimator for the LHC ion beams. In channeling mode, the loss reduction downstream of the crystal is smaller for Pb-ions, than for protons. Two concurrent effects cause this: during the crystal traversal in non-aligned orientations, ion beams have more nuclear interactions and larger ionization loss resulting in the increase of the oscillation amplitudes. As a result the ion extraction towards the absorber is faster and the potential improvement in channeling is smaller.

2. A strong correlation was found between the reduction of the ion beam losses in the crystal and of the off-momentum halo population in channeling condition. It was confirmed that both the effects were produced by non-channeled halo fraction. It was also confirmed that collimation leakage decreases with increasing channeling efficiency.

3. Preliminary data were collected showing the loss maps in some spot positions of the SPS circumference. The information was considered reliable in these locations and the recorded background rate was smaller when the crystal was in channeling orientation with respect to its amorphous orientation.

Improvement of the UA9 devices in 2012

In the 2012 winter shutdown and in the subsequent technical stops the UA9 setup was upgraded and extended. A new goniometer fabricated in IHEP was installed with two new crystals having a shorter length more adapted to the SPS storage energy of 270 GeV. The new goniometer was expected to be more precise than the old one. The goniometers recuperated from RD22 were definitively dismounted. The collimator upstream of the crystal stations was replaced with a new one with a more reliable positioning system. The collimator in the dispersive area was equipped with a supplementary arm in the outer side of the ring. After a test run, in one of the technical stops, a multistrip crystal to test halo deflection though multi-reflection process replaced one of the short crystals in the new goniometer.

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

In the following sections we present the main results obtained in 2012 using 120 GeV/c and 270 GeV/c proton beams and 270 GeV/c per charge Pb ions. They are extracted in part from Ref. [3].

Strong reduction of the off-momentum halo population

Halo particles leaking out of the crystal collimation system in the SPS are mostly off-momentum particles generated in the crystal and in the absorber. To detect off-momentum halo we used one of the inner target in the high-dispersion area immediately downstream of the collimation. The target was located in the shadow of the secondary collimator absorber (TAL). The target was either the scraper SC, made of a 10 cm long duralumin bar, or the movable Roman pot (RP) having a 3 cm long stainless steel edge 0.1 mm thick. Fig.2-4 shows the dependencies on the angular position of the crystal C4 (2 mm long) for beam losses observed in the crystal (a) and in the HD area target (b). The simulation results for the number of inelastic nuclear interactions in the crystal are also shown (curves 2).

The off-momentum halo population minima are observed at the same angular positions as the beam loss minima in all cases, for protons of 120 GeV/c (Fig.2) and 270 GeV/c (Fig.3) as well as for Pb ions of 270 GeV/c per charge (Fig. 4). A remarkable similarity of the beam loss dependencies recorded downstream of the crystal and in the HD target was observed for Pb ions. Indeed in this case, the loss reduction in the HD area is practically the same as in the crystal. For protons, instead, in both cases (Fig.2 and 3) the reduction in the HD area is smaller than in the crystal. This different behavior should be caused by the larger contribution of particles scattered back to the circulating beam from the TAL in the case of protons.

The far off-momentum halo population is the potential source of collimation leakage and inefficiency. In channeling stated both with Pb ions and with protons its population was reduced by a factor larger than 7. The simultaneous reduction observed for the beam losses in the crystal was of a factor about 9 with 270 GeV/c protons and of a factor about 7 with Pb-ions.

The agreement of the simulation results with the experimental data was considerably improved with taking into account the miscut angle between the crystal planes and its surface.

Loss map measurements

A high-intensity beam made of four trains of 72 bunches spaced 25 ns for a total of $2\cdot 10^{13}$ protons at 270 GeV/c was used to increase by a substantial amount the intensity of the halo leakage, hence to collect larger BLM signals in the loss map around the SPS ring. Fig. 5 shows the beam loss reduction R_{bl} that is the ratio of the BLM signals in amorphous and channeling orientations of the crystal, detected by the BLMs with the same gain of 16 in the whole SPS. The beam losses were strongly reduced in all the ring locations where the BLM sensitivity was sufficient for a reliable observation.

Optimization of the crystal collimator parameters

The crystals used up to 2012 in the UA9 experiment were 2 mm long with the bend angle of about 170 μrad and the bend radius R of about 11 m. In the typical UA9 operational conditions, with 270 GeV beams, a shorter crystal 1 mm long, with a bending radius of 5-6 m and a bending angle of about 200 μrad, is expected to be more efficient in channeling orientation, as it was shown by simulations and confirmed by the IHEP experience. Two crystals of about 1 mm length were installed in a new IHEP goniometer in the SPS. Fig.6 shows the dependence of the beam losses in 1 mm long QuasiMosaic (QM) crystal on its orientation. The observed loss reduction in the aligned crystal is about 18, which is more than twice larger than it was observed with 2 mm long crystals. This result confirmed the quality of our prediction model, by which we fixed to 3 mm the optimal length of the LHC crystal.

As already mentioned, during high-intensity runs we used a circulating beam made of 288 nominal proton bunches distributed in four batches of 72 bunches each, spaced by 25 nS, with a total circulating intensity of a few 10^{13} particles. The bunching time structure was the same as in the nominal LHC filling scheme. In these conditions, for certain position of the goniometer the e-cloud effect was activated, resulting in a large bump of the residual pressure and in a large loss rate close to the goniometer. To check the nature of the phenomenon we wounded a solenoid around one of the goniometer and we powered it to produce a 50 Gauss longitudinal field during the e-cloud activity period. This procedure induced the mitigation of the e-cloud strongly reducing the loss and the vacuum pressure. Thanks to this observation, a carbon coating of the LHC goniometer will be foreseen in order to fully prevent e-cloud formation in any circumstance.

An industrially produced goniometer was made available for the SPS. The accuracy, sensitivity and reproducibility of the linear and angular positioning measured at the industry premises and in the CERN laboratory were found to be compatible with the LHC specification. Unfortunately the goniometer could not be installed on time in the SPS and was not tested with beams. Our wish is to test it with beam if one day run will be allocated to UA9 in 2013.

Conclusions

The UA9 results with protons and Pb ions at 120 GeV/c and 270 GeV/c per charge collected in 2012 give a supplementary indication that crystal assisted collimation is well mastered and understood.

1. With a crystal 1 mm long, fully suited to the SPS beam energy, in channeling orientation the loss rate close to the crystal is reduced by a factor close to 20 and the far off-momentum halo population is reduced by factor 7.

2. The miscut angle between the crystal planes and its surface plays an important role. Taking it into account brings the UA9 experimental data in an excellent agreement with simulation results.

3. The beneficial effect of a crystal primary collimator is global. Although the electronics of the beam loss monitors is not fully adequate for the UA9 running conditions, consistent and reliable indications are available on the fact that the loss map around the SPS circumference shows strong reduction of losses in channeling orientation.

4. The first industrial goniometer compliant with the LHC specification is now available. Tests with beam should supplement as soon as possible the positive results obtained in the laboratory.

All these indications make us confident that we could be ready to extend to LHC the UA9 test with beams.

References

[1] UA9 status report for 2011.

[2] W. Scandale et al., Phys.Letters B 703 (2011) 547.

[3] W. Scandale et al., Phys.Letters B 714 (2012) 231.

Figure captions

FIG. 1. Layout of the UA9 experiment in the SPS environment. (a) Crystal-collimator area of UA9. (b) High dispersion area of UA9.

FIG. 2. Beam of 120 GeV/c protons. Curves (1) are the dependencies of beam losses observed in the crystal (a) and in the HD area target (b) on the angular position of the crystal C4. Curves (2) are the dependence of the number of inelastic nuclear interactions of protons in the crystal on its orientation angle obtained by simulation with taking into account the crystal miscut.

FIG. 3. Beam of 270 GeV/c protons. The same as in Fig.2.

FIG. 4. Beam of Pb ions with 270 GeV/c per charge. The same as in Fig.2.

FIG. 5.The beam loss map in the SPS shown as the loss ratio between the crystal in amorphous and channeling orientations.

FIG. 6. The reduction factor of beam losses observed in the QM crystal C2 from amorphous to channeling orientation.

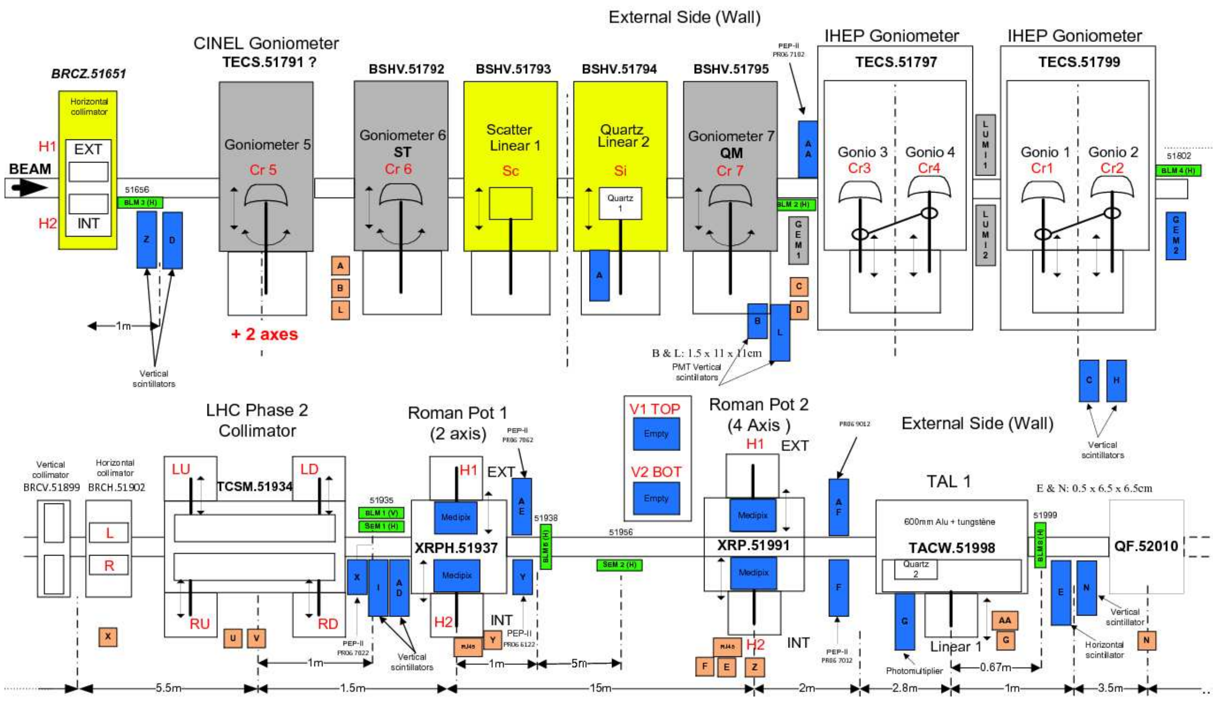


Figure 1a

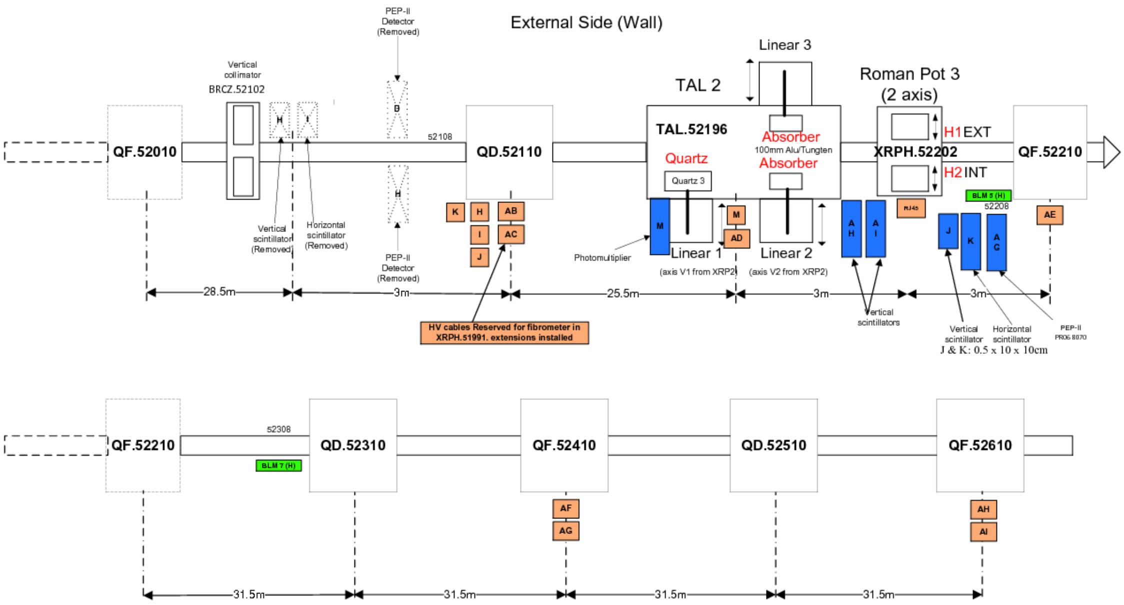
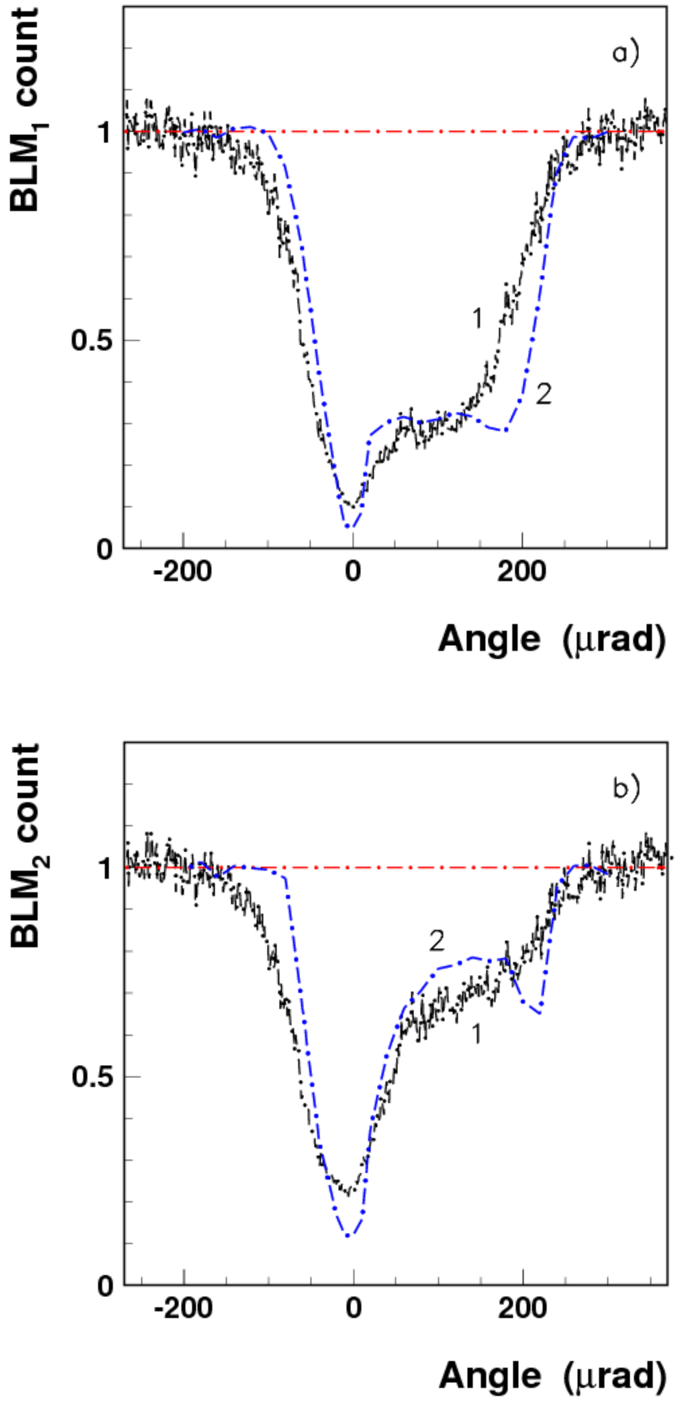
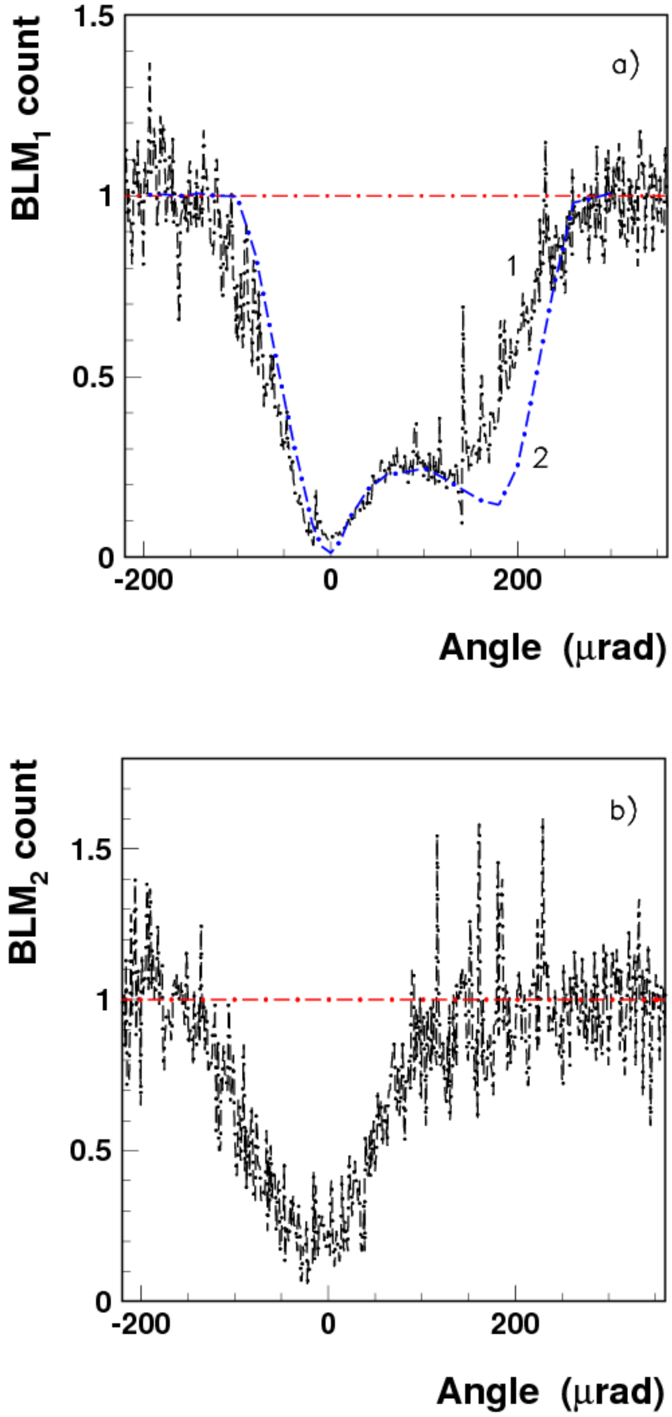


Figure 1b



a)
BLM1 count
1
0.5
0
-200
0
200
Angle (μrad)
1
2
b)
BLM2 count
1
0.5
0
-200
0
200
Angle (μrad)
2
1

Figure 2



BLM1 count
1.5
1
0.5
0
a)
1
2
-200
0
200
Angle (μrad)
BLM2 count
1.5
1
0.5
0
b)
-200
0
200
Angle (μrad)

Figure 3

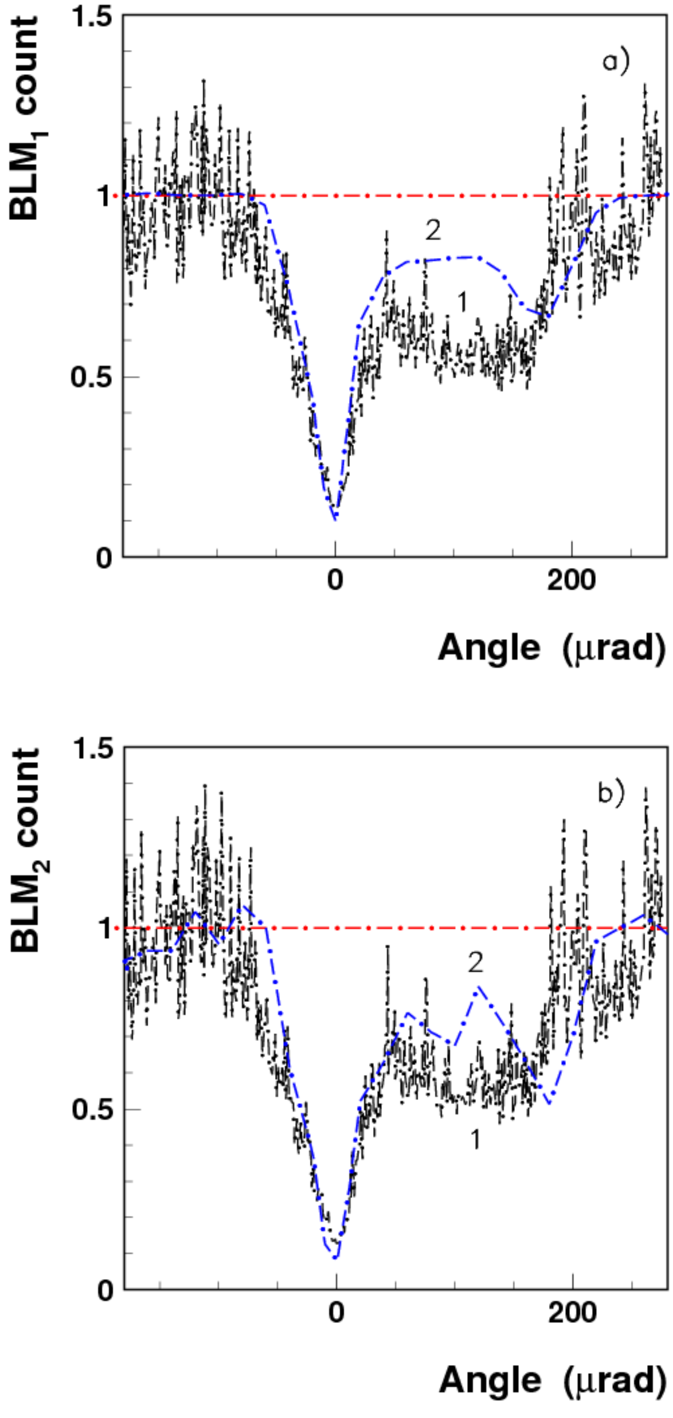

1.5
a)
BLM_1 count
1
2
1
0.5
0
0
200
Angle (μrad)
1.5
b)
BLM_2 count
1
2
0.5
1
0
0
200
Angle (μrad)

Figure 4

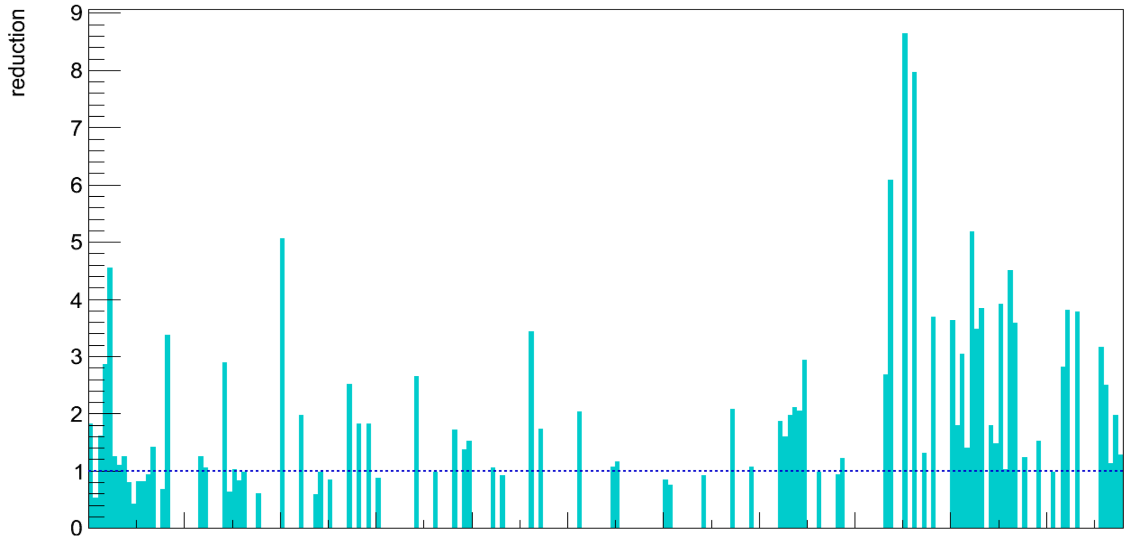
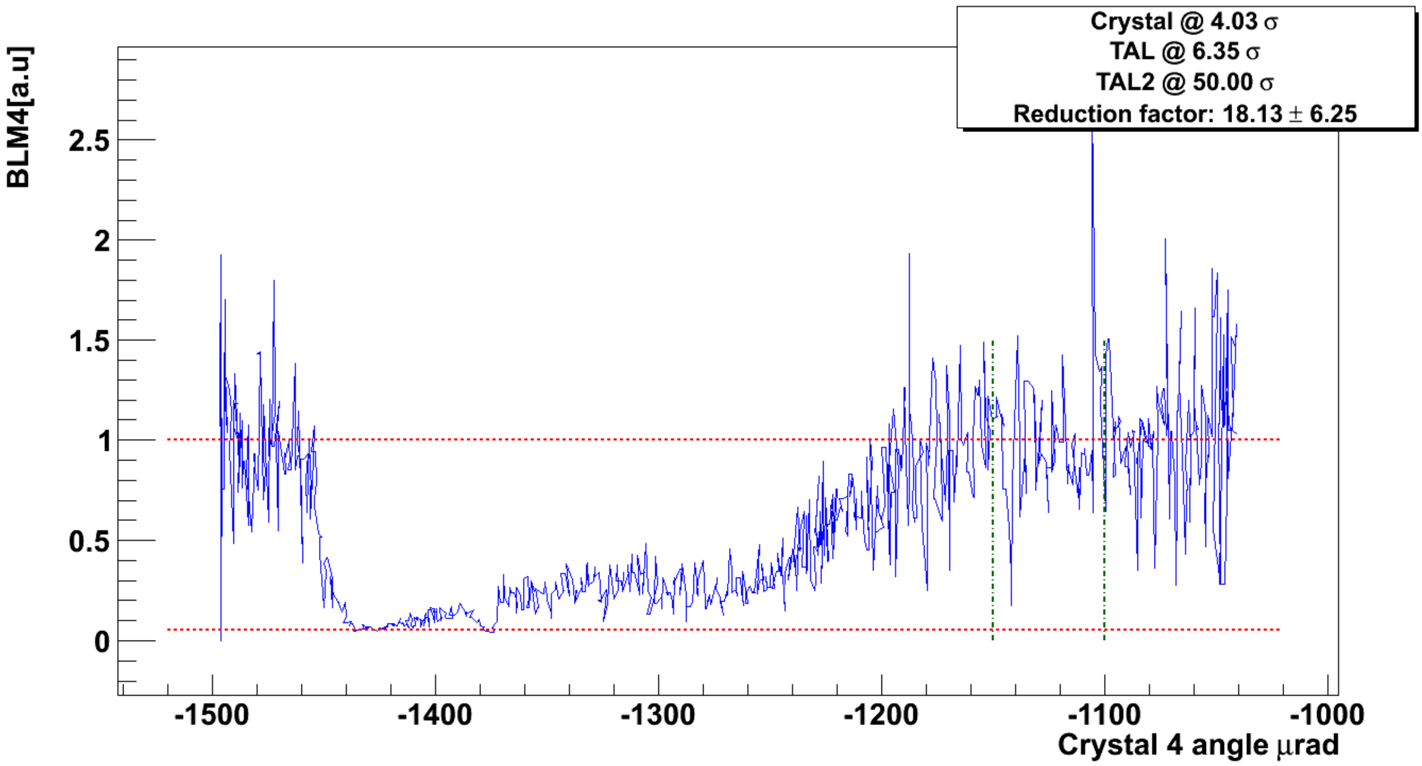


Figure 5



Crystal @ 4.03 σ
TAL @ 6.35 σ
TAL2 @ 50.00 σ
Reduction factor: 18.13 ± 6.25
BLM4[a.u]
2.5
2
1.5
1
0.5
0
-1500
-1400
-1300
-1200
-1100
-1000
Crystal 4 angle μrad

Figure 6