Comparisons between simulations and data for crystal-assisted collimation

Daniele Mirarchi,

Stefano Redaelli, Walter Scandale, Roberto Rossi

Introduction

Preliminary tests of Crystal-assisted Collimation are foreseen after the machine commissioning in 2015

- ✓ Crystals were installed in the IR7 at beginning of April

Extensive campaign of simulation needed to prepare them in the best way

- Location for gonimeters installation
- Crystal parameters
- Layout configuration

Simulations made using the Collimation version of SixTrack, in which a routine to simulate interactions with bent crystals is implemented

Crucial to benchmark the simulation tools for reliable predictions for the LHC

Benchmark strategy

Two main main “blocks” to be tested:

Crystal routine itself

Coupling with complete set of tools to generate loss maps for the LHC

Simulations to be compared w.r.t.

data taken on SPS extraction line (H8)
(and other simulation tools for energy scaling)

data taken on the SPS during crystal-assisted collimation tests

All the experimental data are taken in the framework of the UA9 Collaboration

Crystal routine

Crystal routine itself

Crystal routine: pure Monte Carlo emulator of interactions between protons and bent crystals

<u>Benchmark carried out w.r.t. experimental data at 400 GeV, and analytical crystal routine for scaling to higher energy (made by A. Taratin and demonstrated to be predictive)</u>

What has been done:

- ✓ Improved scattering routine for amorphous interaction (based on the one used in SixTrack to treat interaction with standard collimator jaws)
- ✓ Improved calculation of ionization energy loss in crystals
- ✓ Implementation of nuclear interactions for channeled protons
- ✓ Fine tuning of free parameters used to reproduce the Nuclear Dechanneling

Everything performed w.r.t. experimental data already published by the UA9 Coll.

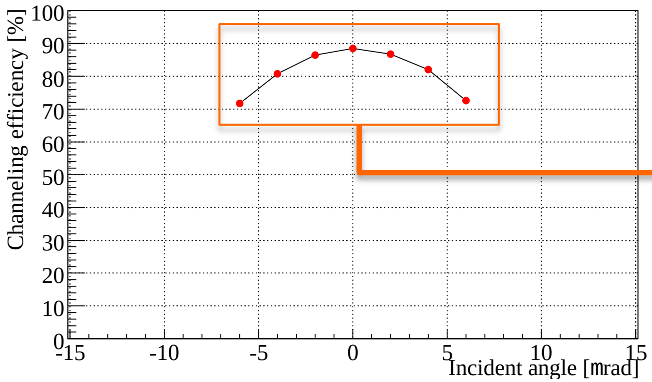
Plans for the next short term:

- Systematic comparisons w.r.t. new data analysis performed by R. Rossi has been started
- Introduction of improved parameterizations arising from this new analysis

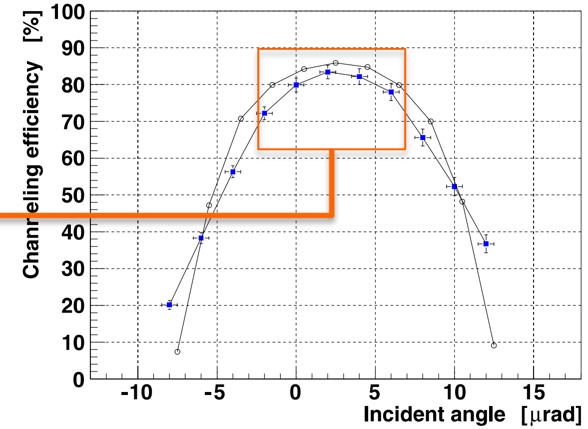
Benchmark done

SixTrack Simulations | **From the papers**

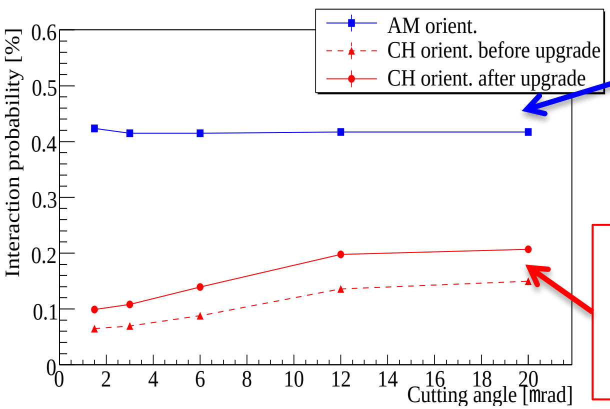
Single pass channeling efficiency:



Agreement within 2% w.r.t. Taratin's sim (dots).
And %5 w.r.t data (blue).



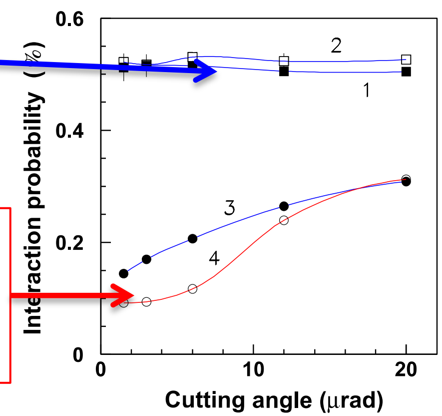
Nuclear interaction rate:



Difference due to inelastic cross section:

- In SixTrack taken from PDG
- Better agreement in Glauber's approx.

Much better agreement w.r.t. Tartin's code. Discrepancy w.r.t. exp. data (3) due to resolution of goniometer and telescope

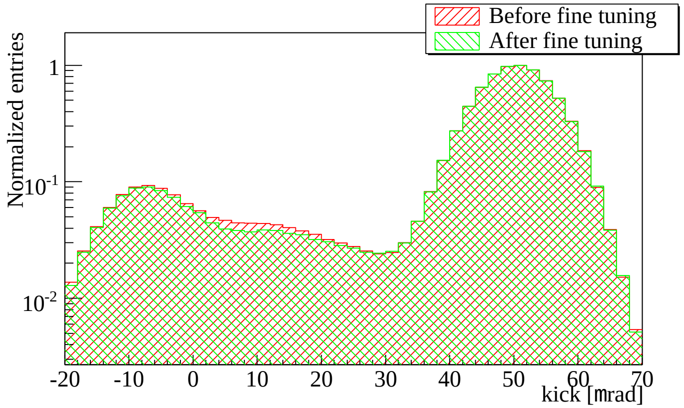


We are mainly interested to very low angles for collimation studies

Benchmark done

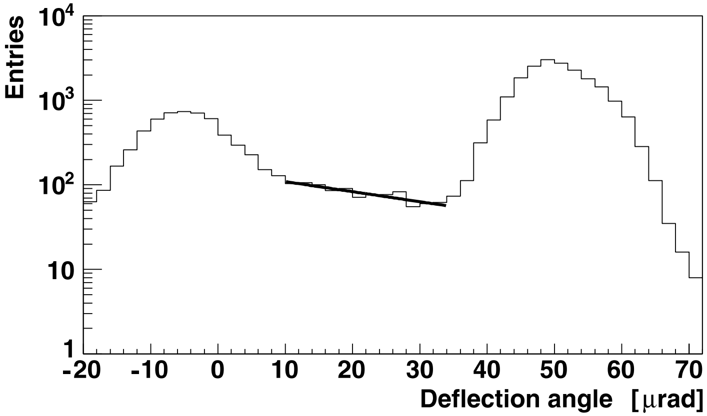
SixTrack Simulations

Nuclear Dechanneling length:



Simulated Ld =~ 0.9mm before fine tuning
~1.35mm after

From the papers



Measured L_d = ~ 1.5mm

Agreement w.r.t. data increased from ~60% to ~90%

Ongoing Benchmark

Comparisons w.r.t. data not yet published and still under analysis has been started

Preliminary benchmarking performed:

- ✓ Experimental conditions reproduced and simulated. Then results were compared for any crystal tested in H8

Key features compared:

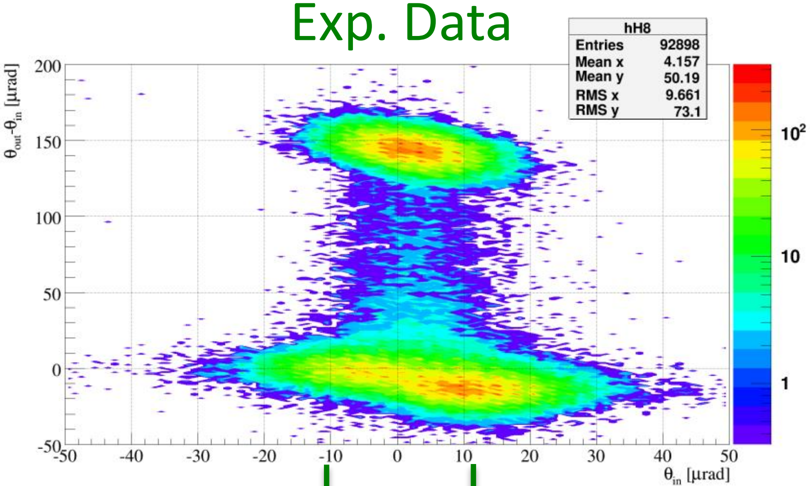
- ➢ Single pass channeling efficiency → Found an agreement within the 5%
- ➢ Angular distributions of kicks given by the crystal to the impinging protons

  → Examples are reported in the next two slides

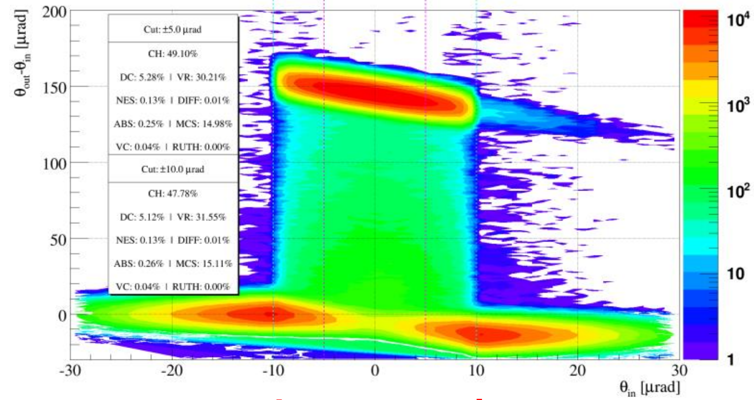
Ongoing Benchmark

Kicks distribution in hi-stat channeling run related to the crystal STF45 (look Roberto's slide)

Exp. Data



Simulation

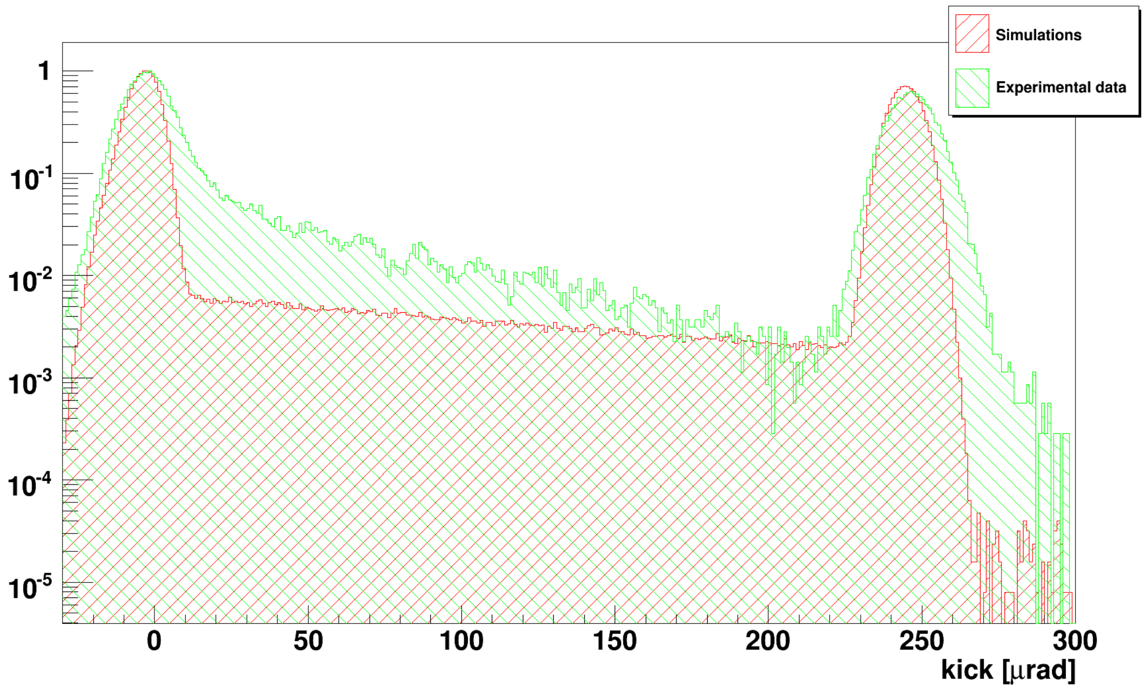


Kicks distr. superimposed in key angular range:

Ongoing Benchmark

As expected the models in the crystal routine are not enough accurate to describe crystals where the nuclear contribution is strong: bending radius close to the critical one.

Crystal STF49 taken as example:
(bending radius ~3m, critical bending at 400GeV ~2m)

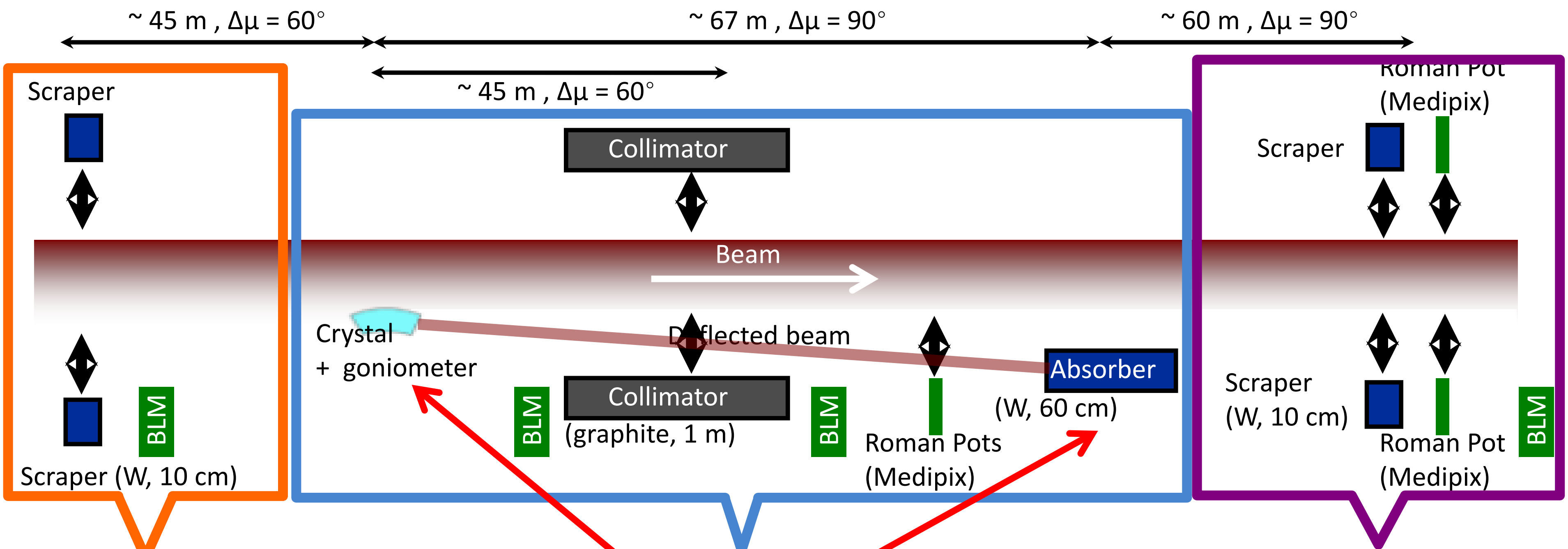


Multiturn simulations

UA9 schematic layout in SPS

UA9 is placed in the SPS LSS5 (old UA1 cavern), key regions are:

- Upstream scraper to study what comes back after a revolution
- Crystal-assisted collimation insertion
- High-dispersive area to study the production of off-momentum particles by the system



Non-dispersive area for measurements “far” from the collimation system

Crystal collimation system (in two stages)

With instrumentation for loss rate and efficiency measurement

High-dispersion area for measurements on off-momentum halo

Key Benchmark

Crucial to understand and reproduce the UA9 results in the SPS,
in view of predictions for the LHC

Main efforts focused on the comparison of:

- Loss rate at the crystal location
- Loss rate in the high-dispersive area
- Dependence of the loss rate in the high-dispersive area from clearance between crystal and absorber
- Beam loss pattern around the whole ring

Unfortunately due to a electricity cut happened yesterday the hard-drive used as storage was damaged. Was impossible to recover it on time for today: "proper plots" are not available today for what in the next. Please "stay with me" and don't get lost in the text!! Text is there only as reference, to say by word what should be drawn…

Loss rate studies

Key point: loss maps simulations give us the density of primary protons lost on the aperture

Direct comparison w.r.t. measured beam loss rate by BLMs valid only in first approx.

Since BLM signal is due to the convolution of hadronic showers generated by primary protons lost on the aperture:

- Present studies focused on integrated losses and not on single peaks on loss maps
- SPS ring divided in 5 Region of Interest (RoI)
- Compared the losses around the whole SPS for different crystal orientation

Crucial for the next:

Simulated nuclear interaction rate at the crystal for different crystal orientation (normalized to the protons intercepted by the system)

Crystal orientation	rate
Channeling	1.72e-3
Amorphous	1.23e-1

→ Reduction of ~70 when in channeling w.r.t. amorphous orientation

Region of Interest (RoI)

ID	s [m]	Commenti
1	5180 -> 5240	Region between crystal and Abs., pure betatronic losses
2	5240 -> 5264	Almost zero D_x, purely betatronic losses
3	5264 -> 5307	D_x starts to be not negligible. Mainly betatronic losses, dispersive losses arising.
4	5307 -> 5314	High Dx region. Purely dispersive losses.
5	5314 -> 5180	Rest of the machine. Mix of betatronic and dispersive losses.

Crucial RoI for comparison with measurements is the # 4, where an LHC-BLM type is present

Loss sharing

Studied how the losses on the aperture are shared between the RoI as function of the crystal orientation, looking at their "origin":

If crystal in Channeling orint.

ID	From Cr	From Abs.
1	65.81%	0.02%
2	8.9%	31.2%
3	1.6%	28.5%
4	0.3%	7.6%
5	23.3%	32.7%

If crystal in Amorphous orint.

ID	From Cr	From Abs.
1	64.25%	0.2%
2	9.0%	22.2%
3	1.5%	26.4%
4	0.3%	9.4%
5	25.0%	41.8%

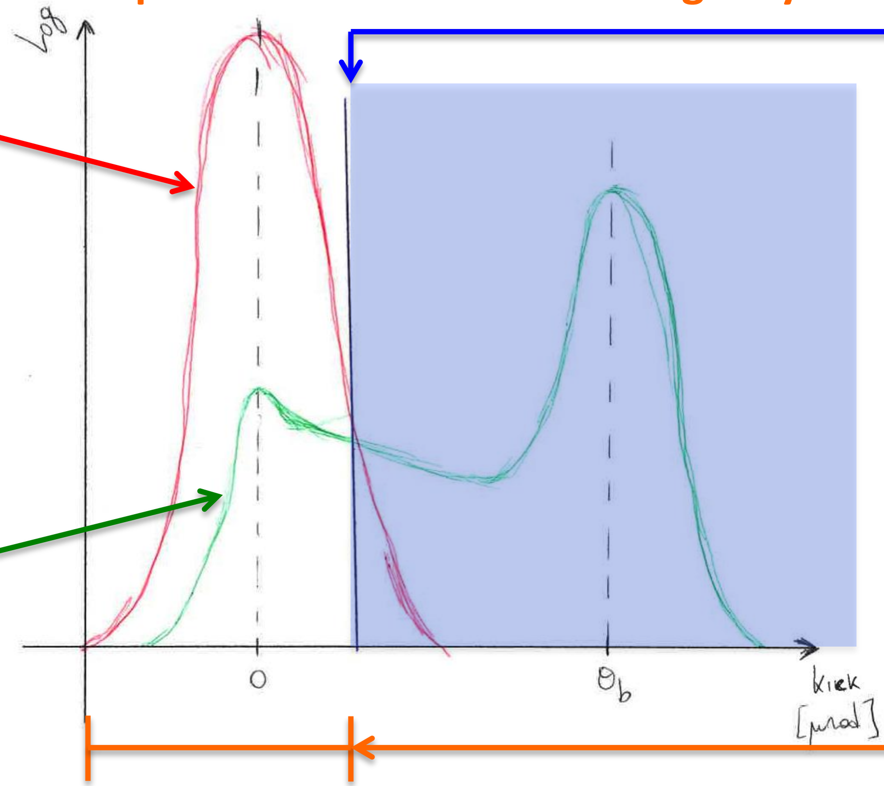
Percentage of total losses in that region coming directly from:

- The crystal without touching anything else.
- The Absorber, i.e. particles are kicked by the crystal and imping on the Abs. but are not absorbed.

Loss sharing interpretation

Let's focus on the protons lost after interacting only with the crystal

Kick distr. given by the crystal if in amorphous orient.



Angular cut performed by the Abs. Everything got higher kick is intercepted by the Abs.

Kick distr. given by the crystal if in channeling orient. Where θ_b is the crystal bending.

Differential eq. theory tells us that with same starting condition, particles will follow same trajectory.

Purely betatronic losses due to particles which interacted only with the crystal will be shared in the same way. (i.e. losses due to protons in this range)

Loss rate

Previous considerations are crucial to understand the measured loss rate reduction when crystal in channeling w.r.t. in amorphous orient.

Simulated loss rate in the RoI, normalized to the protons intercepted by the system:

If crystal in Channeling orint.

ID	From Cr	From TAL
1	1.54e-4	3.83e-7
2	2.09e-5	7.07e-4
3	3.73e-6	6.44e-4
4	7.66e-7	1.73e-4
5	5.44e-5	7.39e-4

If crystal in Amorphous orint.

ID	From Cr	From TAL
1	1.0e-2	2.55e-5
2	1.41e-3	2.86e-3
3	2.42e-4	3.39e-3
4	4.67e-5	1.21e-3
5	3.91e-3	5.38e-3

Loss rate reduction given by: loss rate in AM orient./loss rate in CH orient. (see next slide)

Key point on these tables: loss rate in any place of the ring dominated by losses due to protons which emerge from the Abs. (unless in RoI 1, i.e. between crystal and Abs.)

Loss rate reduction

ID	Loss rate reduction		
	From Cr	From TAL	Convolution
1	64.9	66.6	64.9
2	67.4	4.0	5.9
3	64.9	5.3	5.6
4	60.9	7.0	7.2
5	71.8	7.3	11.7

Direct comparison w.r.t. exp. BLM data

Reduction given by the convolution of the two contributes in well agreement with exp. Data (sorry again plots and data are not available today since are in the hard-drive too, however they can be found in literature)

Different integration range were probed mainly for the RoI 4: no particular dependence was found.

Final integration range taken around the BLM location in that area, where a significant distribution of particle loss in present.

Considerations

Seems that the loss rate measured in the SPS is dominated by losses due to protons able to emerge from the Abs.

Loss rate reduction all around the ring seems coherent with what measured.
In case of protons the measured reduction was always in the range 5-10 either at the crystal location and high dispersive area (RoI 4)

This gives us the feeling that the reduction seen in the SPS is mainly due to the efficiency with which the extracted halo is absorbed.

Only in the region between crystal and Abs. simulations says we are dominated by losses coming directly from the crystal. Here we should expect a reduction really proportional to the reduction of inelastic interaction at the crystal. This is not seen experimentally, maybe due to a strong contribution of the multiturn effect. Work is on-going and in promising direction.

As support

To test the effect of the extracted halo which is not absorbed, simulations with Abs. as black absorber were performed: loss rate reduction all around the SPS found to be about the same of the reduction of nuclear interaction at the crystal.
It means that if this was the experimental situation we should measure a loss rate reduction around the ring of a factor ~50 when in channeling w.r.t. in amorphous.
Moreover it means that if losses from crystal are dominant we should expect a flat reduction of losses around the ring (at least where the betatronic one are dominant), while the convolution with what coming from the Abs. gives a modulation of the loss reduction around the ring. Experimentally a flat reduction is not seen.

Simulations for the LHC predictions support it as well.
In the IR7 DS losses are purely dispersive and due to the complexity of the system (here the extracted halo sees at least 1m of CFC and 3m of W instead then only 1m of W as in the SPS) contribution of losses coming directly from the crystal or after interaction with any other collimator are comparable.
Here a factor about 50 is expected in the level of losses in the DS when crystal in different orientation.

Conclusions

- ✓ Crystal routine benchmarked and upgraded according with experimental data on SPS extraction line (H8) already published by the UA9 Collaboration.

- ✓ Further benchmarking and upgrades based on new sets of H8 data have been started.

- ✓ Simulations to reproduce the experimental tests of crystal-assisted collimation in the SPS arise a new possible way to interpret the experimental results, which seems in agreement with them.

- ➢ Work is still on-going to reproduce the dependence of off-momentum particles leakage from the system, as function of the clearance between crystal and absorber