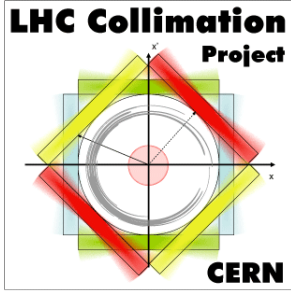

Crystal-based collimation studies and status of routines

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3rd Joint HiLumi LHC-LARP Annual Meeting,
WP5 Simulation Workshop
15 November 2013

Special thanks to: E. Bagli, P. Schoofs, A. Taratin and the UA9 Collaboration

http://indico.cern.ch/conferenceTimeTable.py?confId=274810#20131106.detailed
(INDICO link to the last UA9 Collaboration Meeting)

Outline

- ✓ Introduction
- ✓ Introduction on Crystals
- ✓ Crystal routines
- ✓ Crystal routine in SixTrack
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Introduction

Installation of crystals (H&V) in the LHC during LS1 and future feasibility tests of the system require detailed tracking simulations

Main tool used: SixTrack for prediction of expected less maps pattern
(on which has been based the choice of the positions for the installation in the LHC)

Main needs for such simulations:

- Very fast routines due to the high-statistics required
(e.g.: 10-20M particles tracked for 200/2000 turns, depending on crystal orientation)

- Of course, good description of nuclear events "dangerous" for the cleaning performance of collimation systems is crucial

(Basic limitation at the LHC: particles that lose energy at the primaries and lost in the dispersion suppressor)

Many crystal routines have been developed during last years

- ✓ Different physics approaches are used
- ✓ Very brief overview of their main features it is given (a seminar for each of them would be needed)
- ✓ A bit closer view to the one implemented in SixTrack is reported

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Introduction on Crystals

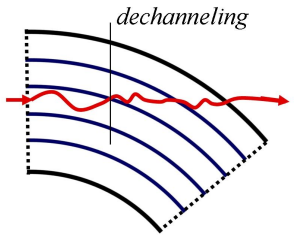
What is needed from a crystal routine:

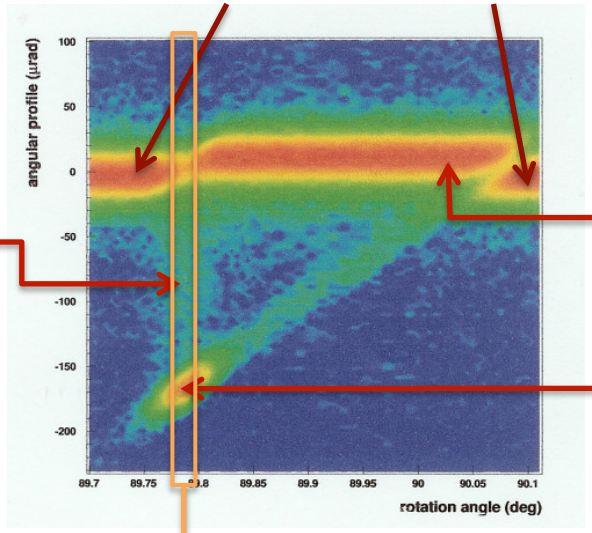
Good overall description of all physics process known in bent crystals (topology, probability, energy scaling)

From test beam on the H8 line at CERN North Area

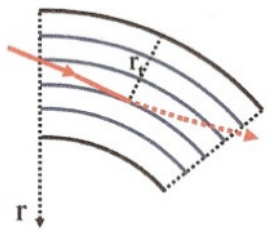
Crystal is seen as any amorphous material

Dechanneling



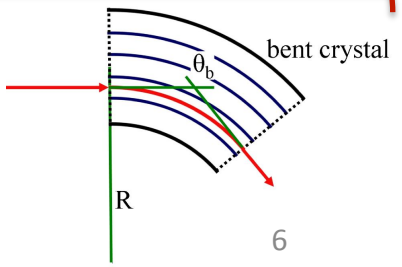


Volume Reflection



In "extraction mode" during collimation, crystal will be working here

Desired **deflection** if channeled for all the path



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Crystal routines

Many crystal routines have been developed during last years

Different physics approaches are used

✓ *Fully analytical code*

(solving differential eq. of motion inside crystalline structure)

Precise predictions but very slow

✓ *Pure Monte Carlo approach*

(emulation of all known physics process in bent crystal well described in literature and tuned on experimental data)

Approximated emulation but very fast (key factor: approximations limit)

✓ *Implementation of "crystal geometry" in more wide-range simulation tools, such as FLUKA and GEANT4*

(very roughly "a mix" of the previous two approaches)

If a flag is activated, coherent effects in bent crystals are simulated, depending mainly from its momentum and angle w.r.t. crystalline planes.

Could reach the precision of the fully analytical ones, but not the speed of a pure Monte Carlo

Of course, every routine/approach has to give similar results

Organization of a dedicated Workshop on crystal simulations is ongoing, and foreseen within the next 3/6 months

Crystal routines

Resume of the present crystal routine:

Fully analytical code:

- A. Taratin: extensively tested w.r.t. experimental data in the UA9 experiment.
  A good overview is given in: "Particle channeling in a bent crystal", PPN review, 29, 5, 1998
- A. Sytov and V. Tikhomirov: summer studentship in the Collimation Team last summer,
  work on an internal note is ongoing
- A. Babaev and S. Dabagov: Still work ongoing soon a final report

http://indico.cern.ch/getFile.py/access?contribId=30&sessionId=1&resId=1&materialId=slides&confId=274810

Pure Monte Carlo approach:

- Originally written by I. Yazinin, implemented in SixTrack by V. Previtali,
  main upgrades made by D. Mirarchi some of which are shown here

Implementation of "crystal geometry" in more wide-range simulation tools:

- In FLUKA made by P. Schoffs

http://indico.cern.ch/getFile.py/access?contribId=23&sessionId=1&resId=1&materialId=slides&confId=274810

- In GEANT4 made by E. Bagli

http://indico.cern.ch/getFile.py/access?contribId=24&sessionId=1&resId=0&materialId=slides&confId=274810

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Crystal routine in SixTrack

Checks made in the past were showing reasonable results on emulation of coherent effects

Main improvements implemented:

- ✓ "Brand new" scattering routine
- ✓ Energy scaling of energy loss by ionization and Dechanneling Length
- ✓ Implementation of nuclear interactions for particles channelend for the whole crystal length

Comparative studies w.r.t. FLUKA pointed out some inconsistency

Scattering routine completely rewritten accordingly with the "standard" scattering routine present in SixTrack
(scattering routine called for Monte Carlo simulation of interaction between protons and standard collimator jaws)

Main goals achieved:

- Correlation between kick and energy loss when Single Diffractive event is experienced
- Better "description" of cross sections and relative energy scaling
- Better description of Nuclear Elastic Scattering
- Implementation of Rutherford Scattering

Before: tabulated in a BLOCK DATA and strictly valid for 400GeV impinging protons
Now: implemented analytical calculation for each impinging protons

Further checks have been made on coherent effects too, and their energy scaling

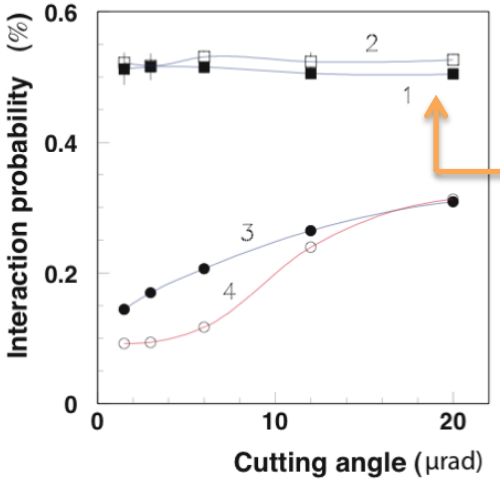
Nuclear interactions

Nuclear interactions for channeled particles were not taken into account at all in the routine

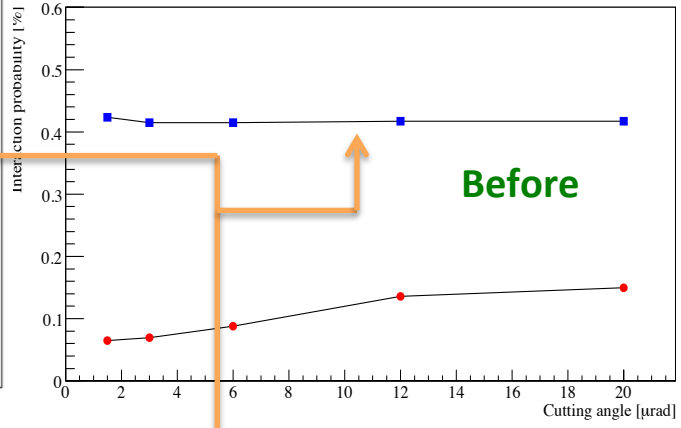
Checks made on such assumption comparing simulations w.r.t. experimental data reported in:
W. Scandale et al., "Probability of inelastic nuclear interactions of high-energy protons in a bent crystal", NIMB 268 (2010) 2655-2659

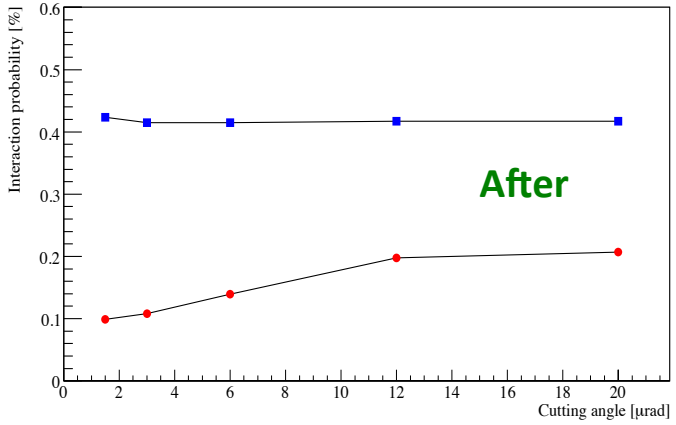
Implementation of nuclear interaction description needed for such particles!
(taking into account the average nuclear density seen along the trajectory)

From the paper:



"SixTrack" simulations





(1) Cr. in AM orient. – Data
(2) Cr. in VR orient. – Data
(3) Cr. in CH orient. – Data
(4) Cr. in CH orient. – Taratin's sim

Difference in AM orient. Due to nuclear inelastic cross section implemented for Si
- In the paper used 0.504 b (Glauber's approx.)
- In the code used 0.430 b (using pdg)

Not yet perfect agreement at "large" angles,
anyway for SixTrack goals much more important the agreement at "small" angles (at least w.r.t. Taratin's sim.)

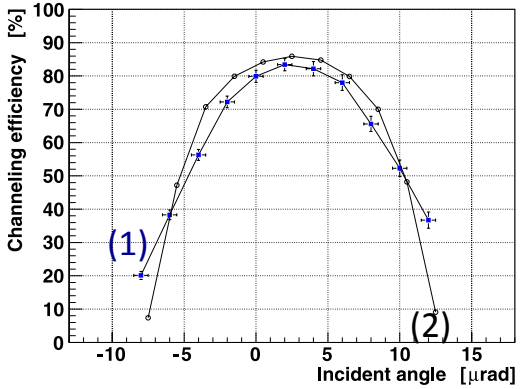
Coherent effects

Comparison made w.r.t.:

W. Scandale et al., "Observation of nuclear dechanneling for high-energy protons in crystals", Phys. Lett. B 680 (2009) 129-132

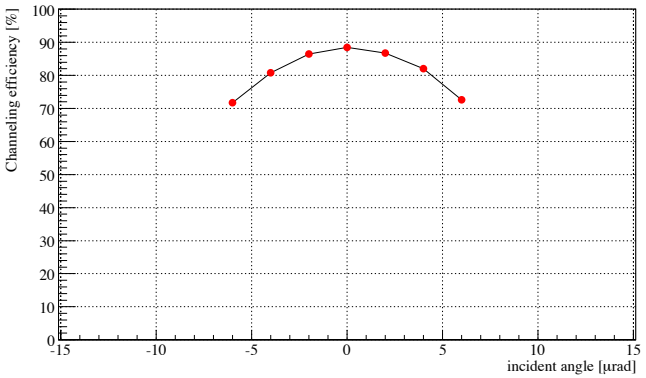
Single pass channeling efficiency:

From the paper



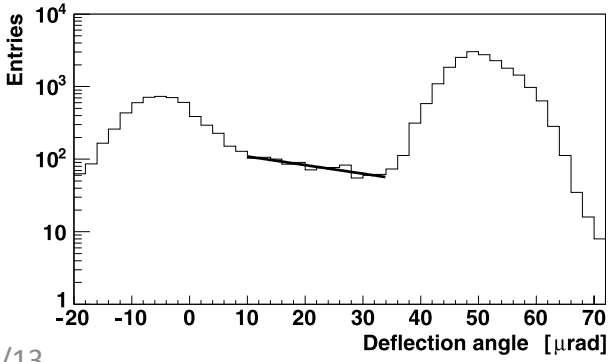
(1) Experimental data (2) Taratin's simulations

From "SixTrack" simulations

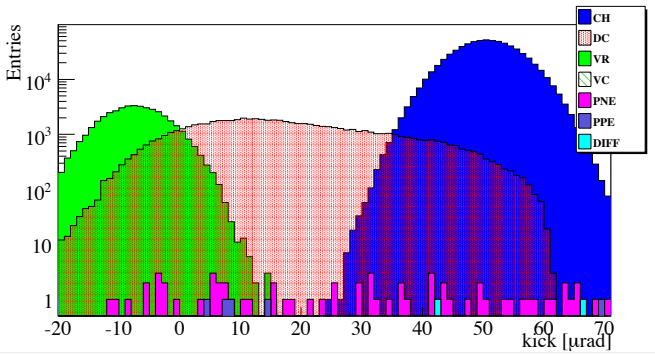


Good agreement w.r.t. Taratin's simulation found (within 2%)

Nuclear Dechanneling length:



Measured ~1.5mm



After fine tuning of the parameters involved ~1.35mm

Energy scaling of coherent effects

Comparisons made with respect to Taratin's code at 7 TeV

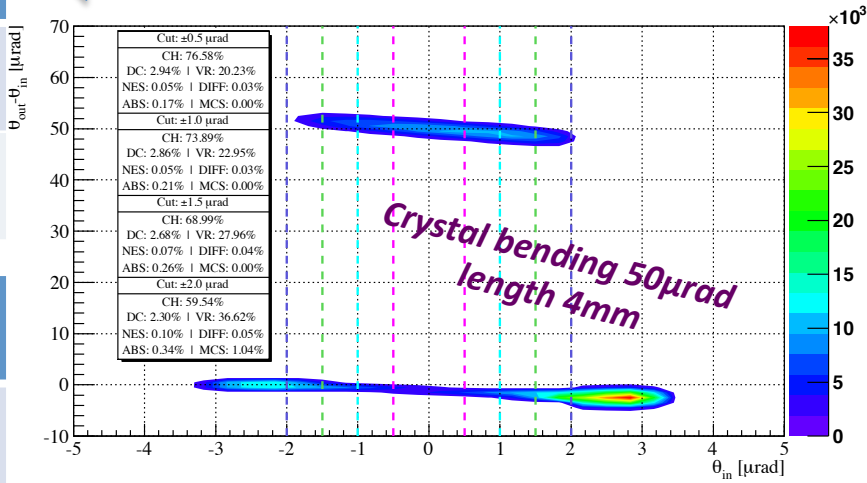
Simulations made without any stand-alone routine, but generating "a fake halo" in SixTrack

To avoid any problem during "updates migration" between codes

Example of analysis output for SixTrack simulations "H8-like"

θ[μrad]→ l[mm]↓	20	40	60	80
3	CH: 84.18% VR: 13.55%	CH: 72.98% VR: 24.49%	CH: 61.84% VR: 35.38%	
4	CH: 86.38% VR: 10.86%	CH: 77.97% VR: 19.01%	CH: 69.76% VR: 26.99%	CH: 61.10% VR: 35.37%

Using crystal emulator in SixTrack



θ[μrad]→ l[mm]↓	20	40	60	80
3	CH: 83.19% VR: 14.00%	CH: 74.15% VR: 22.40%	CH: 63.05% VR: 33.50%	
4	CH: 84.98% VR: 12.00%	CH: 78.82% VR: 18.00%	CH: 70.81% VR: 25.20%	CH: 62.54% VR: 33.30%

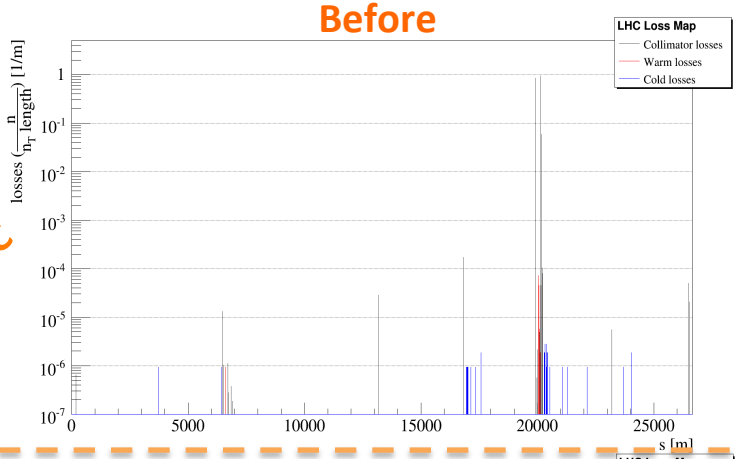
Using stand-alone fully analytical crystal simulator

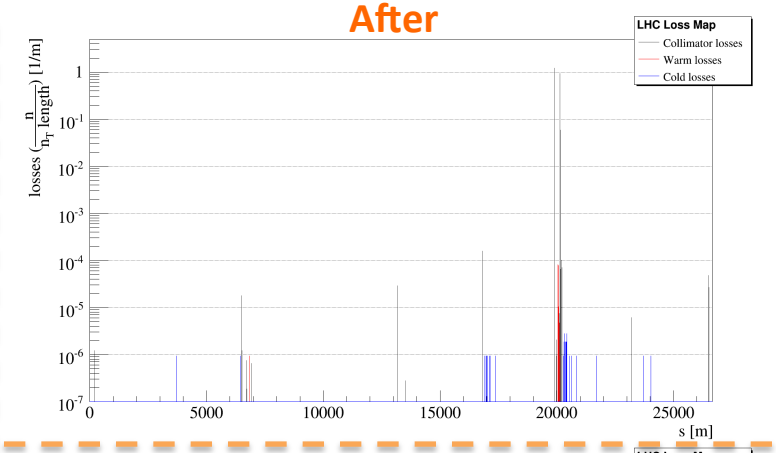
Effects on cleaning performance

Comparison of the cleaning performance expected for the first tests in LHC is shown, before and after the new implementations

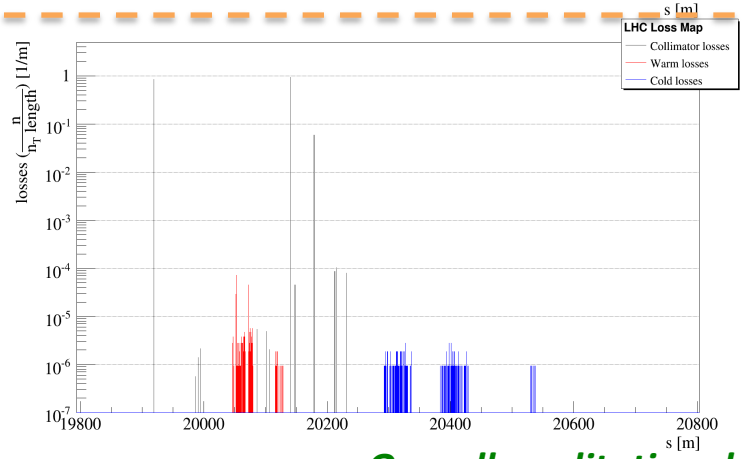
Before **After**

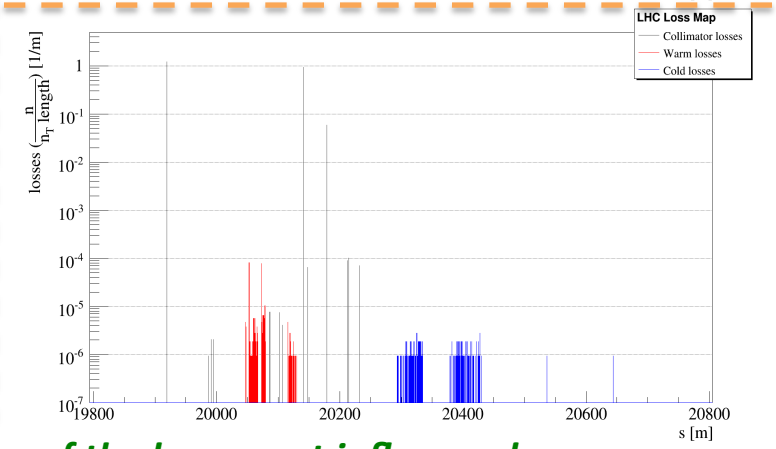
Whole LHC





IR7





Overall qualitative shape of the losses not influenced

Quantitative studies show an increment of the total number of particles lost in the DS (factor ~1.4) which is comparable with the improvements in the treatment of nuclear interactions for channeled protons

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Conclusion

An overview of all the existing crystal routines has been given
(at least on the key concepts behind the different physics approach used)

An overall description of the main study and improvements made on the crystal routine implemented in SixTrack was shown

Checks made in the past showed reasonable results on emulation of coherent effects

Present studies and free parameters fine tuning based on comparison with experimental data, regarding either coherent and incoherent effects in bent crystal,
show that we can rely on this crystal routine for loss maps prediction in the LHC.

Last but not least: presently this is the only routine suitable for such high-statistics study.

Organization of a dedicated Workshop on crystal simulations is ongoing,
and foreseen within the next 3/6 months.