Summary on Crystal Simulation Routines for Particle Accelerators: Comparison and Benchmarking with Experimental Data

Francesca Galluccio

INFN – Napoli

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Outlook

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- Conclusions

Motivation

Within the UA9 collaboration we use several computer codes to simulate the interactions between charged particle beams and crystals.

It is extremely important that the physics model inside these tools is the most realistic and complete one because:

- Some of these routines are to be integrated/interfaced to very general use simulation tools (FLUKA, GEANT4, SixTrack);
- They are used as predictive tools for the Collimation experiment in the LHC.

We have started a program to compare these routines among each other and to benchmark them against the UA9 data (both H8 and SPS), with the aim of finally validating them in order to make them available for the general use.

Available routines

- Multi-pass codes:

1) Taratin's code, CRYD, based on the integration of equations of motion in the crystal, interfaced with a relatively simple transfer matrix tracking code.
2) Mirarchi's CrysColl code, thorough revision of original Yazynin's code, based on event probability, interfaced to SixTrack by V.Previtali.

- Single-pass codes ready for multi-pass implementation:

3) Schoofs' code, in which the crystal is modeled in "FLUKA style", although not yet implemented in FLUKA itself.
   A version of SixTrack exists, already interfaced to FLUKA for the treatment of collimators.
4) Bagli's code, in which the coherent interactions have been implemented in GEANT4 on top of the treatment of crystal structures already available in GEANT4.
   An interface either to SixTrack or to ICOSIM++ is foreseen.

DYNACHARM++ (Bagli) is a Monte Carlo code based on the numerical solution of the equation of motion of particles in crystals whose electron densities and electric fields are computed from x-ray analysis. It is too slow to be implemented in a multi-turn code, but can be used for cross-checking.

Other codes exist. At the moment they are not specifically used within the UA9 Collaboration.

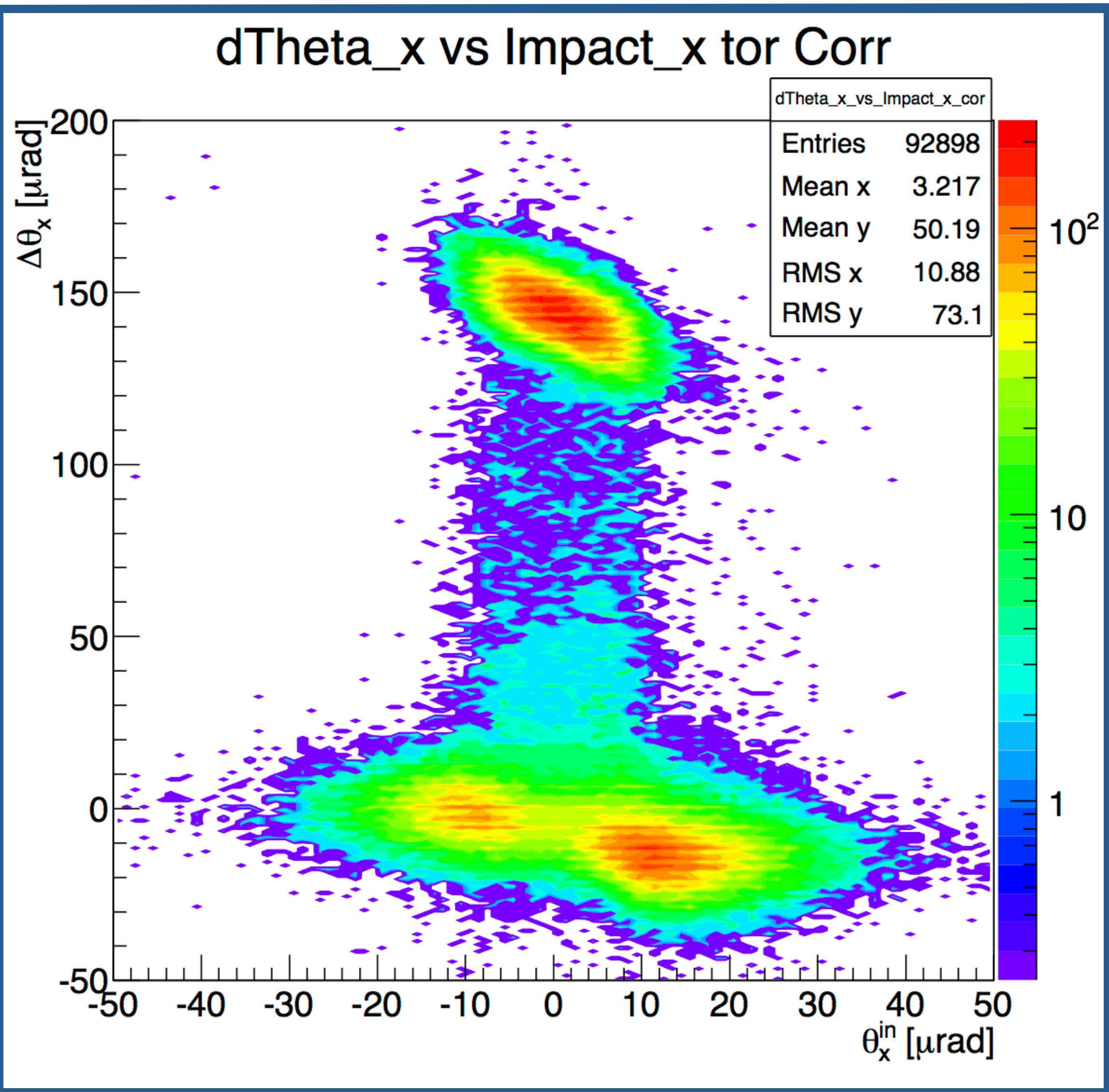
Strategy

- Start comparing single-pass mode
  - Use UA9 crystal measurement data at CERN SPS H8 extraction line as benchmark
    http://lhc-collimation-upgrade-spec.web.cern.ch/LHC-Collimation-Upgrade-Spec/H8_input.php
    - STF45 crystal selected as reference: measurements with high statistics and well controlled beam conditions:
      bending angle = 144 μrad, length = 2 mm, bending radius = 13.9 m
    - Required to reproduce results from data analysis.
      - Reproduce beam conditions of RUN 415
        σ_x = 1.00 mm , $\sigma_{x'}$=10.6 μrad, σ_y = 0.72 mm, $\sigma_{y'}$= 7.7 μrad
      - Calculate a certain number of key parameters
- Implement an appropriate multi-turn codes and extend comparison to multi-turn mode

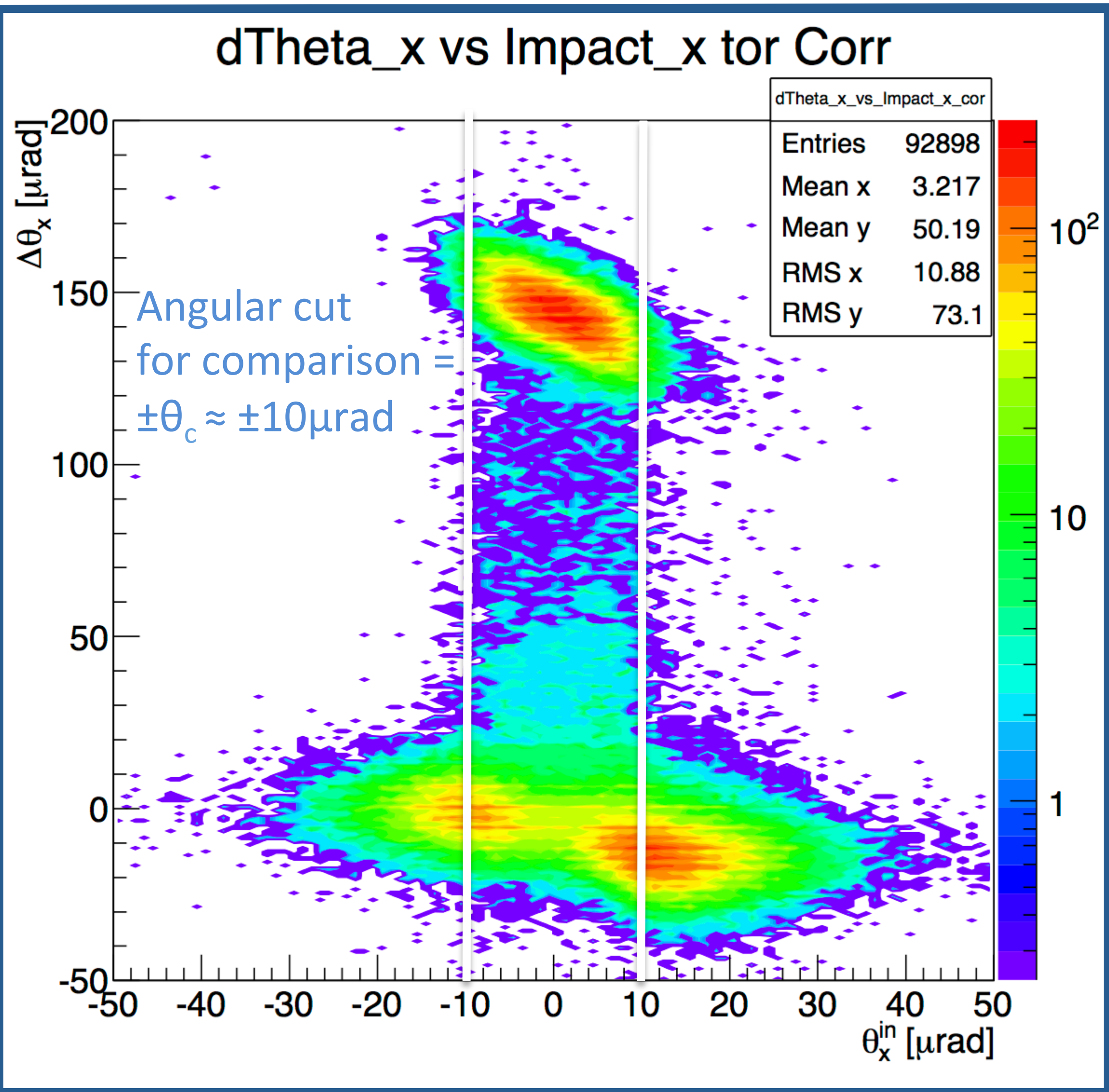
Key parameters

- Distribution of deflection angle vs. impact angle
- Distribution of deflection angle for impact angle selection of ± 5 and ± 10 µrad, with calculation of:
  - Channeling angle distribution sigma
  - Channeling efficiency
  - Dechanneling length
- Volume reflection angle and its sigma from distribution of deflection angle for an impact angle selection in the range $[+2\theta_c, +3\theta_c]$
- Amorphous angle and its sigma from distribution of deflection angle for impact angle selection in the range $[-3\theta_c, -2\theta_c]$
- Channeling angle and its sigma as a function of impact angle
- Transition region peak and its sigma as a function of the impact angle
- Channeling and dechanneling population (normalized to total number of particle) as a function of the impact angle

Experimental Results

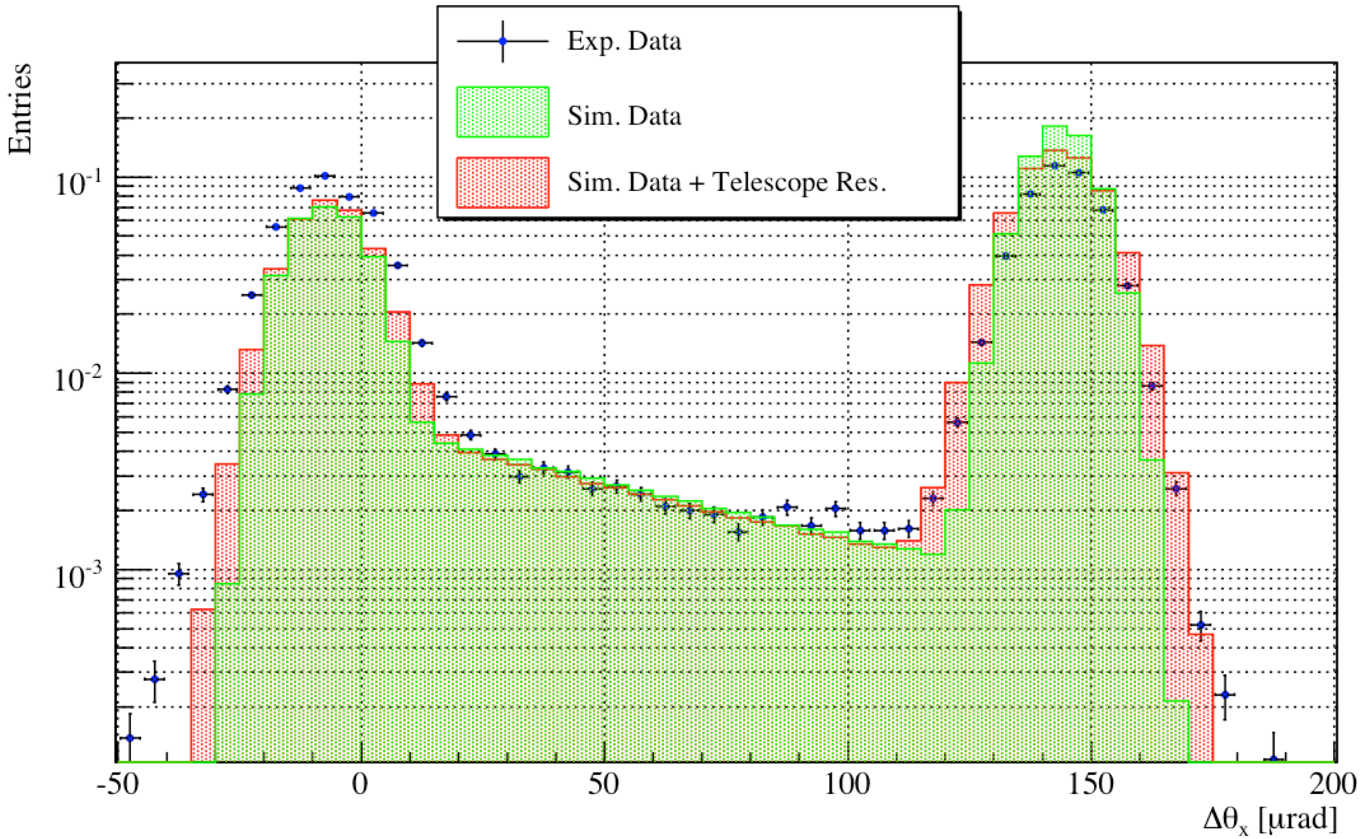


Experimental Results



Comparison of simulation results: CrysColl

Global comparison



Angular cut ±10μrad, similar results with ±5μrad but more prominent effects of resolution

<u>Very good overall agreement between experimental and simulated data!</u>

Imperial College London

Daniele Mirarchi, 2014 October 10th, Channeling 2014

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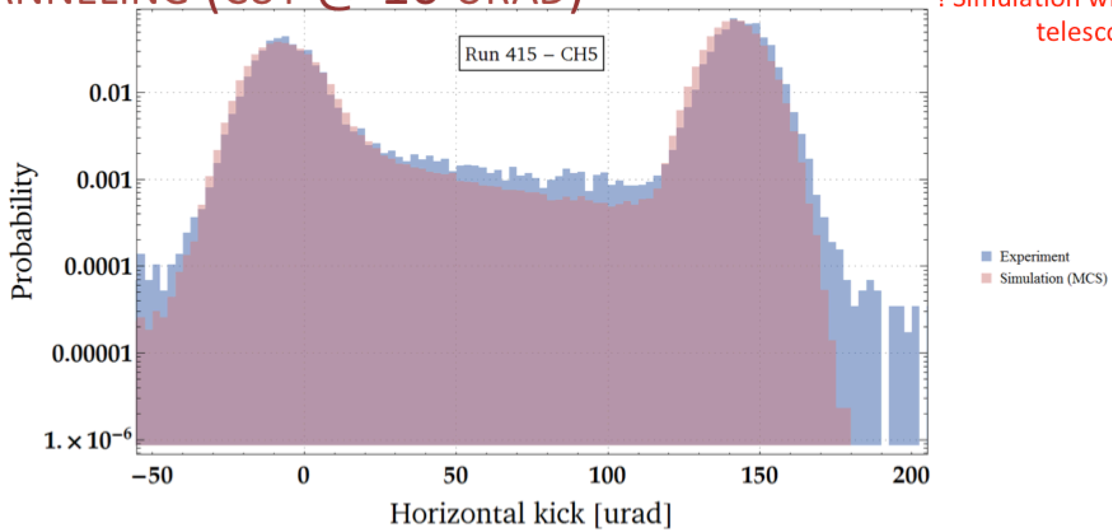
Comparison of simulation results: FLUKA

RESULTS – X. BENCHMARKING (H8)

- CHANNELING (CUT @ 10 URAD)

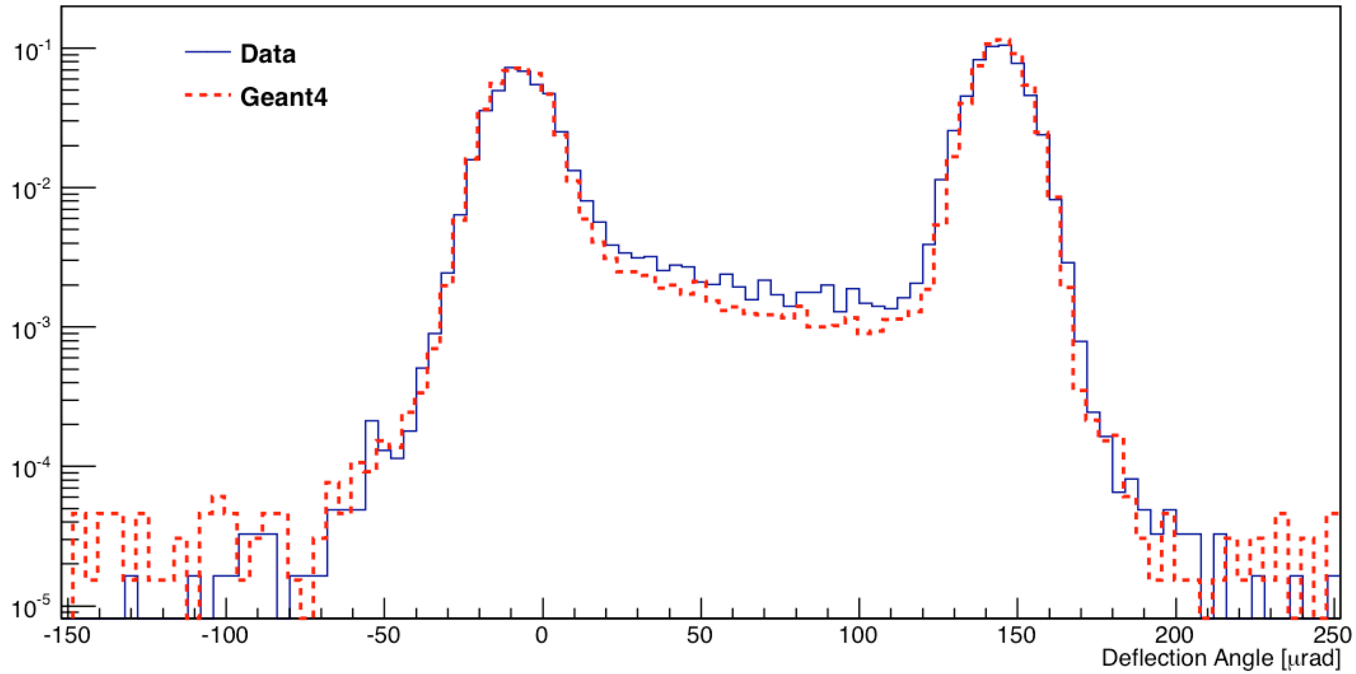
! Simulation with MCS from telescope !



415	VR/AM peak	CH peak	CH rate	DC rate	L_D
	[urad]	[urad]	[%]	[%]	[mm]
Simulation	-6.2 σ 10.2	141.6 σ 8.0	56.94 ± 0.15	3.37 ± 0.06	
Experiment	(-5.9 σ 9.5)	143.8 σ 8.2	54.0	(5.13 ± 0.18)	1.408

Schoofs - Channeling 2014 conference, Capri, 10.10.2014

Deflection Angle Distribution



Outgoing Particles/Incoming Particles = (98.8 +/- 0.9) %

Comparison of simulation results

Run 415 Crys.STF45	**CUT**	**Telescope Correction**	**VR/AM σ**	**CH peak σ**	**CH efficiency**	**DC rate**	**L_D**
	[urad]		[urad]	[urad]	[%]	[%]	[mm]
Experiment	**5**	**yes**	**9.3**	**7.2**	**68.9**	**4.76 ± 0.24**	**1.41**
CRYD	5	no			70.7		1.42
CrysColl	5	yes	8.1	7.7	69.8	5.18	1.06
FLUKA	5	no	8.6	4.9	68.86	3.71 ± 0.08	1.02
FLUKA	5	yes	10.3	7.1	68.9	3.32 ± 0.07	
GEANT4	5	yes	7.6	6.6	70	3.4 ± 0.5	1.28
Experiment	**10**	**yes**	**9.5**	**8.2**	**54.0**	**5.13 ± 0.18**	**1.23**
CRYD	10	no			58.4		1.3
CrysColl	10	yes	8.1	8.8	62.0	5.10	1.09
FLUKA	10	no	8.6	6.1	56.90	3.71 ± 0.06	0.845
FLUKA	10	yes	10.2	8.0	56.9	3.37 ± 0.06	
GEANT4	10	yes	8.6	7.5	54.4	4.0 ± 0.6	1.09

On-going studies and future plans

- Transition region thorough analysis
- Nuclear interaction event rate comparison

- Extension to 7 TeV, and benchmarking of codes vrt codes.

- Interface of the GEANT4 and FLUKA routines in multi-turn codes and benchmark all codes to the SPS ring UA9 data

- Implementation of an Ion-crystal routine

Conclusions

- Within the UA9 we have
  - 2 routines already implemented in multi-turn codes
  - 2 routines ready to be implemented
- They reproduce the measured data within 10%, and in particular channeling efficiency within 1% in a range of 1 critical angle.
- Few refinements in the models can still be done, but they would hardly affect the predictive power of the codes for collimation purposes @450 GeV

- The benchmark @ 7TeV will be more delicate as there are not experimental data at that energy, and should start very soon.

THANK YOU
FOR
YOUR ATTENTION