Simulation of orientational coherent effects via Geant4

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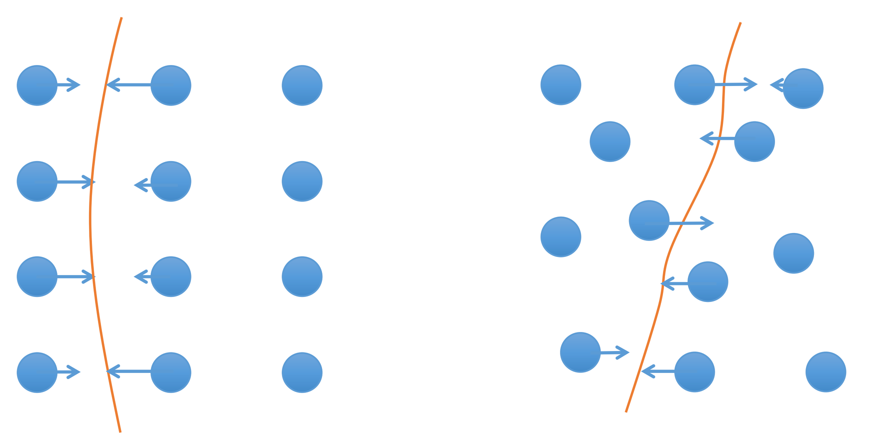
Beam manipulation of high- and very-high-energy particle beams is a hot topic in accelerator physics. Coherent effects of ultra-relativistic particles in bent crystals allow the steering of particle trajectories thanks to the strong electrical field generated between atomic planes. Recently, a collimation experiment with bent crystals was carried out at the CERN-LHC [1], paving the way to the usage of such technology in current and future accelerators. Geant4 [2] is a widely used object-oriented tool-kit for the Monte Carlo simulation of the interaction of particles with matter in high-energy physics. Moreover, its areas of application include also nuclear and accelerator physics, as well as studies in medical and space science. We present the Geant4 model for the simulation of orientational effects in straight and bent crystals for high energy charged particles [3]. The model allows the manipulation of particle trajectories by means of straight and bent crystals and the scaling of the cross sections of hadronic and electromagnetic processes for channeled particles. Based on such a model, the extension of the Geant4 toolkit has been developed. The code and the model have been validated by comparison with published experimental data regarding the deflection efficiency via channeling and the variation of the rate of inelastic nuclear interactions.

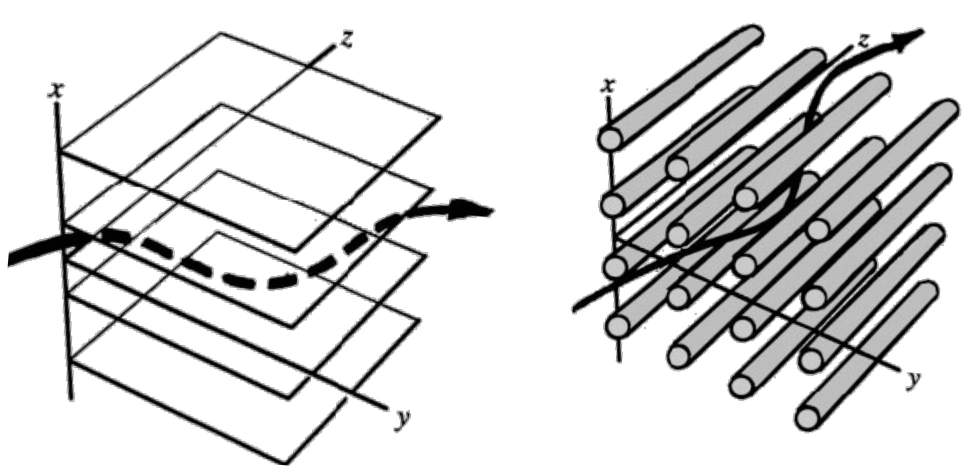
[1] CERN Bulletin 11 November 2015, Crystals channel high-energy beams in the LHC (2015).
[2] S. Agostinelli et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 506, 250 (2003).
[3] Bagli, E., Asai, M., Brandt, D., Dotti, A., Guidi, V., and Wright, D. H., Eur. Phys. J. C 74, 2996 (2014).

Coherent Interactions

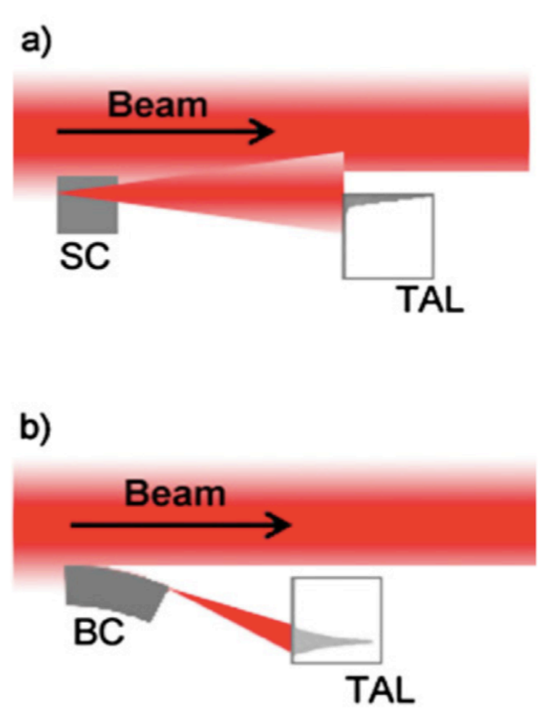


In such case the Coulomb potentials of single atoms can be replaced by an average continuous potential of the plane (string) and the particle dynamics can be described by the interaction with the atomic plane (string) as a whole.

When a charged particle interacts with a crystal and its trajectory is inclined with respect to major atomic planes or strings by a small angle, a series of correlated collisions of the particles with atoms in the same plane (string) occurs, i.e. coherent interactions of the particle with a crystal.



UA9 Experiment



In a hadron collider a multi-stage collimation system is used to absorb the beam halo particles preventing quenches of its superconducting magnets and reducing the collider experiment background. A crystal can be used as a primary collimator to deflect particles of the halo toward a secondary collimator. The main advantages of this scheme are the possibility to deflect the beam out and reduce the beam losses.

Channeling model for Geant4

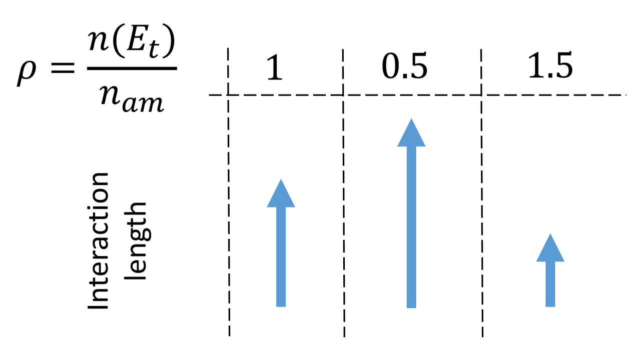
The model proposed in this poster has been implemented by a process describing the channeling and wrappers that modify the material density in existing processes.

Channeling process

When a particle crosses the boundary between two geometrical volumes, one with and one without a crystal lattice, the channeling process limits the step of the particle and checks if the particle is subject to orientational effects. A uniformly distributed random number is generated to deter- mine the impact position of the particle on the crystal channel. The particle momentum is projected on the channeling plane to evaluate the transverse momentum. Thus, such parameters are used to compute the particle trajectory in the crystal channel. As a result, the channeling process proposes to the Geant4 core an alignment of the particle momentum with the direction of the transverse momentum in the channel and furnish the average density of material to the wrappers of the other physics processes.

Wrappers

In order to modify the cross section of existing processes and to preserve code re-usability for future releases of Geant4, wrapper classes for the discrete and continuous processes were developed. For both these classes, the inter- action length of discrete processes is resized proportionally to the modified material density.



Average density

The average density of material seen by a particle traversing a crystal aligned with its planes is strongly affected by the transverse energy of the particle. Thus, the probability of interaction with nuclei and electrons has to be weighted as a function of the transverse energy. The modified cross section of each phenomenon is

$$\sigma(E_t) = \sigma_{am} \frac{n(E_t)}{n_{am}}$$

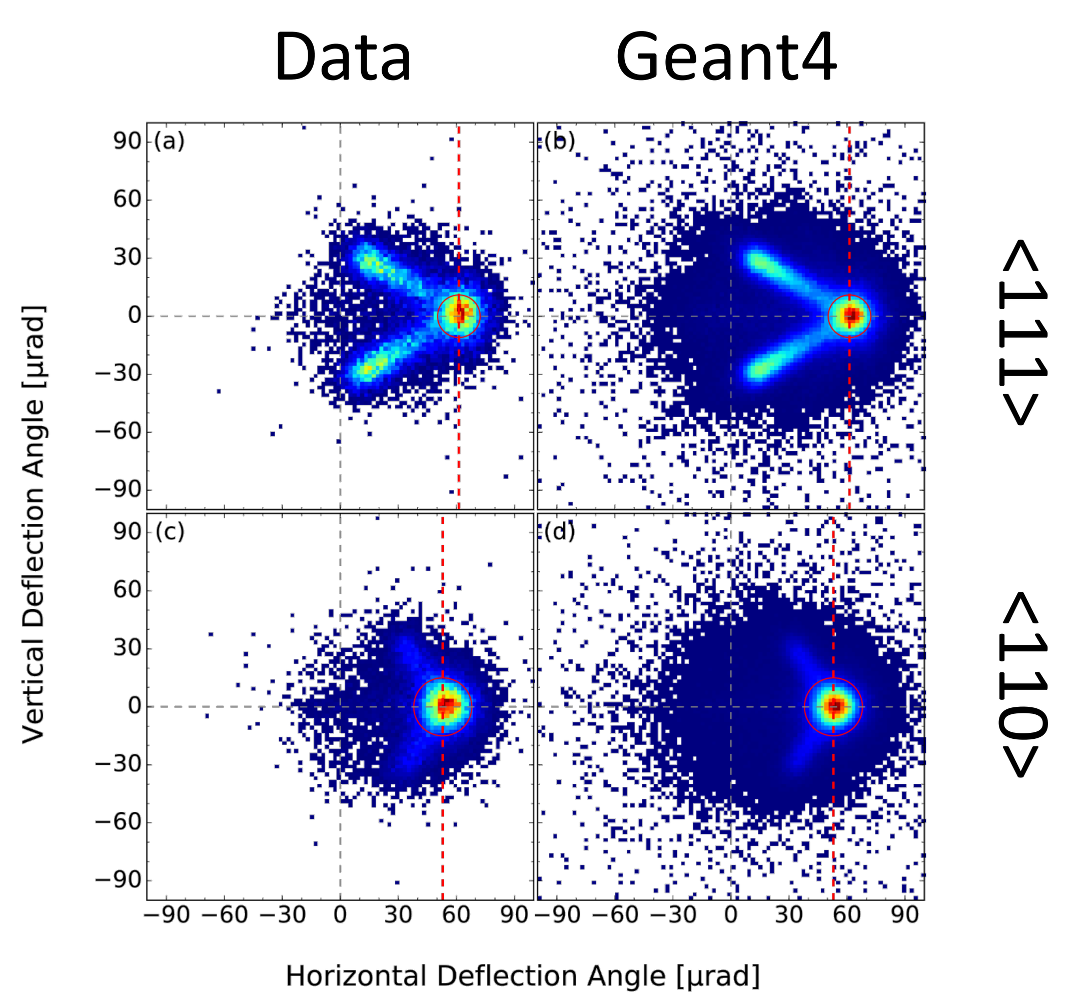
where σ_{am} is the cross section in amorphous material, n_{am} is the density of the amorphous material and n(Et) is the modified density.

Geant 4

Monte Carlo Toolkit

Geant4 (GEometry ANd Tracking) is a platform for the simulation of the passage of particles through matter, using Monte Carlo methods. Geant4 includes facilities for handling geometry, tracking, detector response, run management, visualization and user interface. For many physics simulations, this means less time needs to be spent on the low level details, and researchers can start immediately on the more important aspects of the simulation. Because of its general purpose nature, Geant4 is well suited for development of computational tools for analysing interactions of particle with matter in many areas. These include high-energy physics, space applications, medical applications, radiation effects in microelectronics, nuclear physics.

Experimental Data Comparison



The axial channeling with ⟨110⟩ and ⟨111⟩ silicon crystals causes 90 % of the particles to be one side deflected. The particles captured by the skew planes (~ 15 %) for the ⟨110⟩ axis acquire a deflection angle similar to α, while while the two most strongly acting (110) planes of the ⟨111⟩ axis cause a considerable fraction (~ 45 %) of the particles to be deflected at an angle lower than α but > 0. The simulated distribution of the deflection angles reproduce the experimental results.

W. Scandale, Phys.Lett. B 760 (2016) 826-831