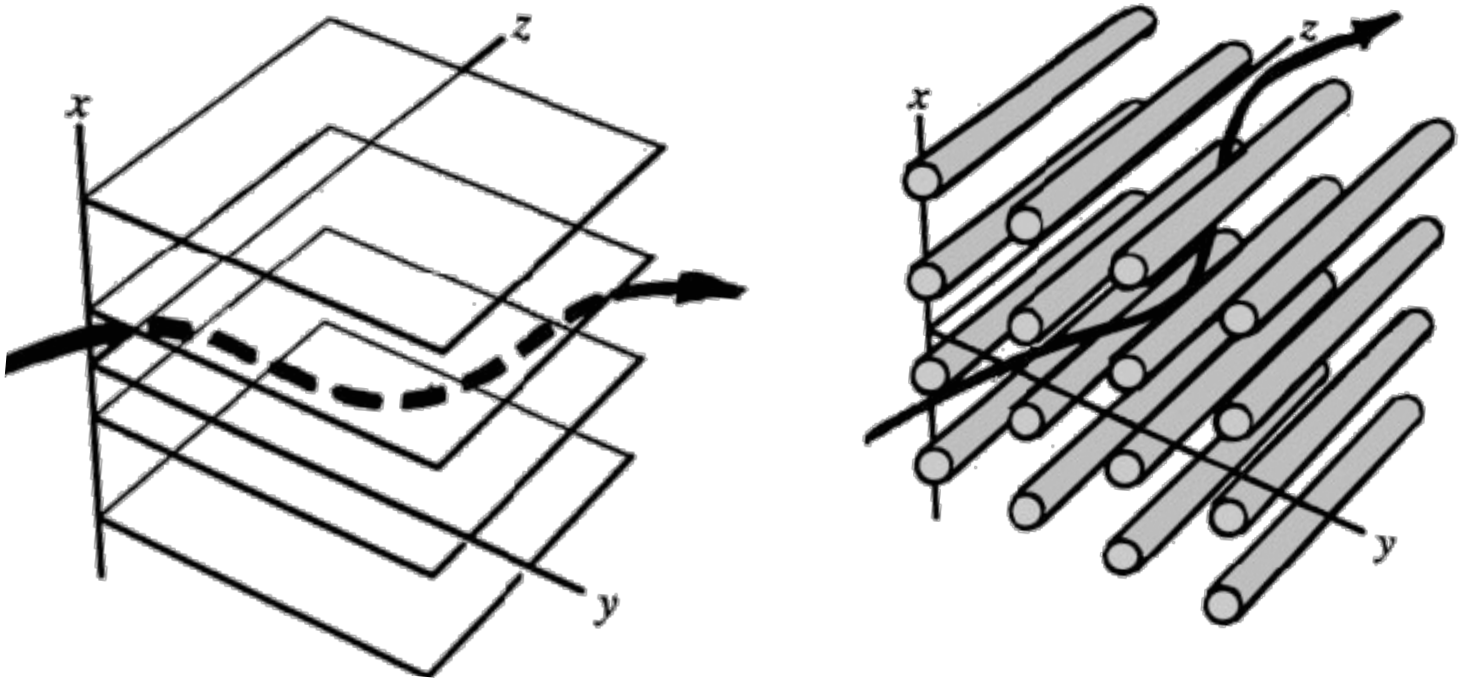
NEW MODEL FOR THE GEANT4 SIMULATION OF CHANNELING

E. Bagli

INFN Section of Ferrara & Ferrara University, Italy

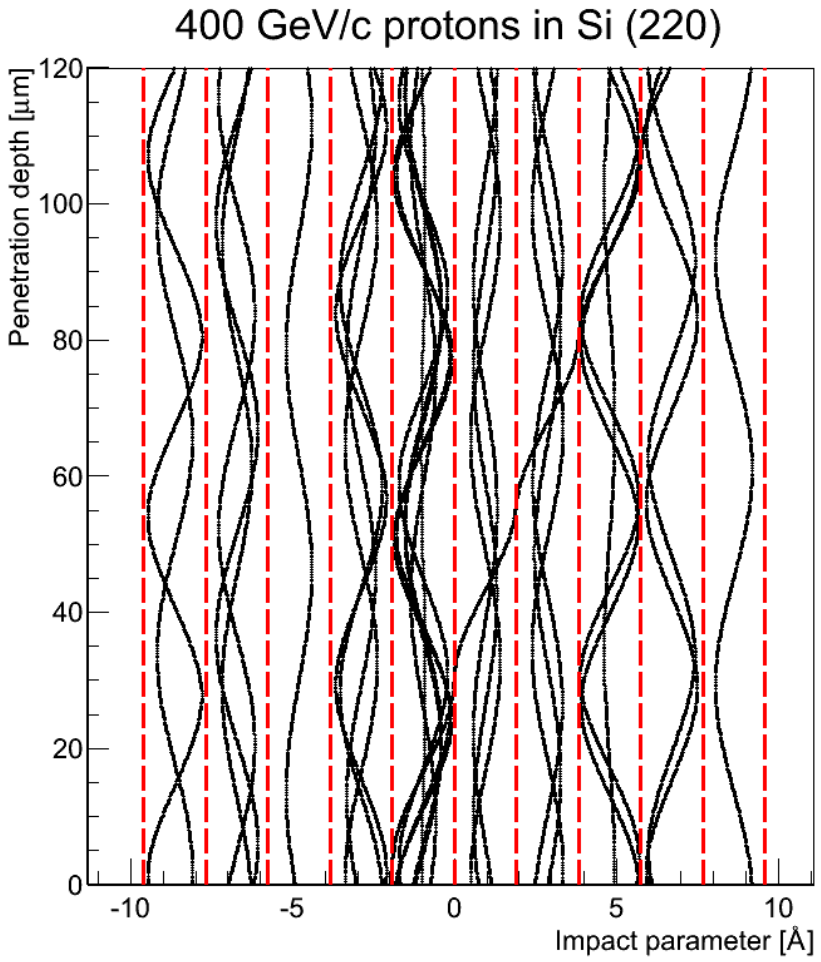
Particle interaction with aligned crystals



Condition for coherent effects: particle direction of motion nearly aligned with crystal planes or axes.

Crystal

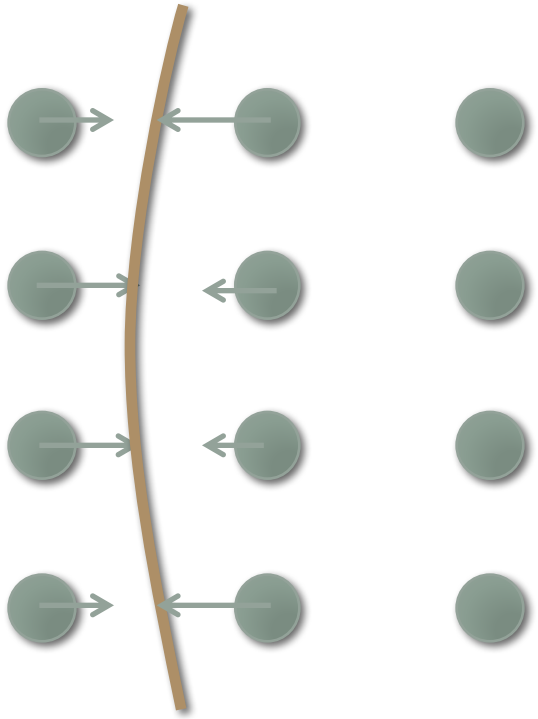
- Ordered pattern of atoms.
- Aligned atoms can be seen as planes or axes.
- Strong electromagnetic field between planes and between axes (~GeV/cm).
- Particle direction aligned with planes or axes



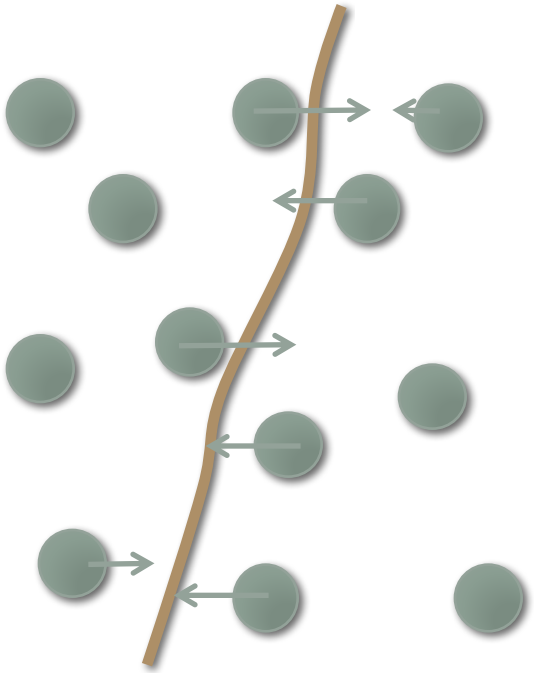
DYNECHARM++ - E. Bagli, V. Guidi, NIMB 309, 124 (2013)

Charged Particle Interaction

Crystal

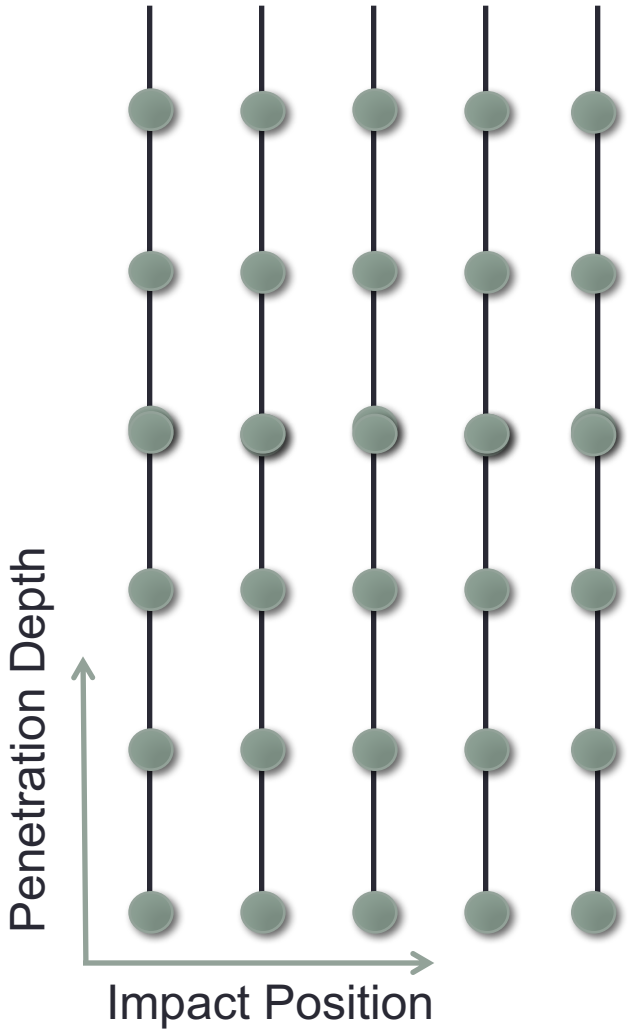


Amorphous

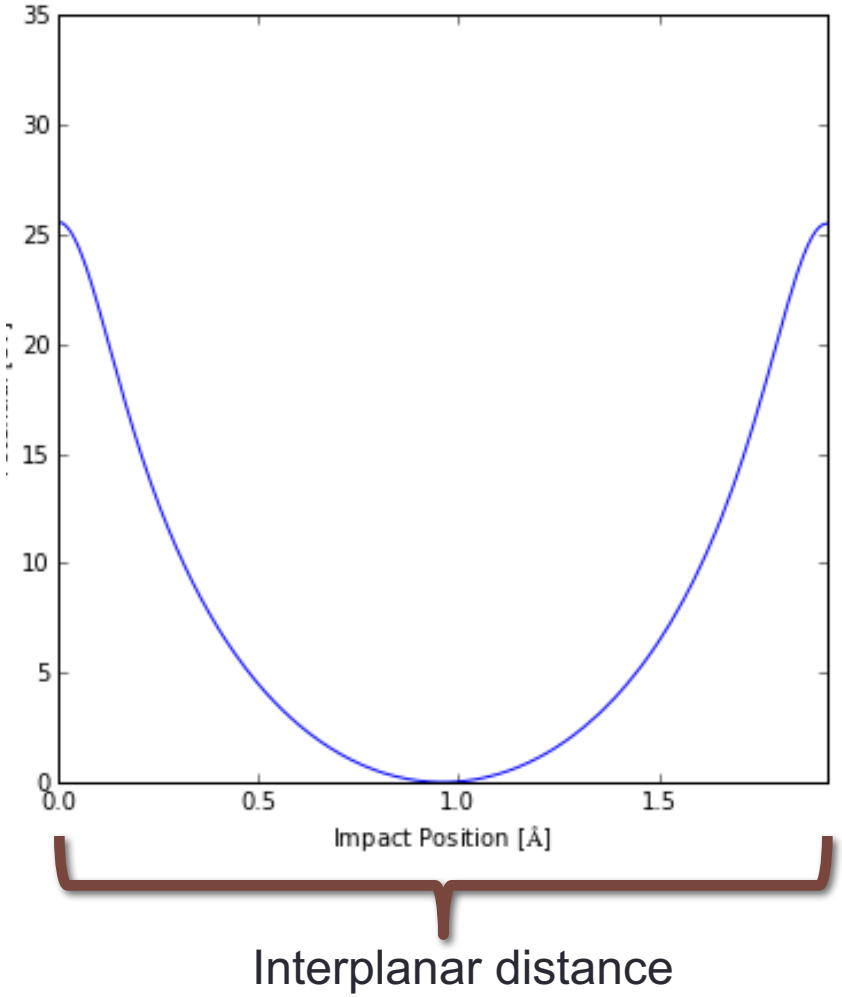


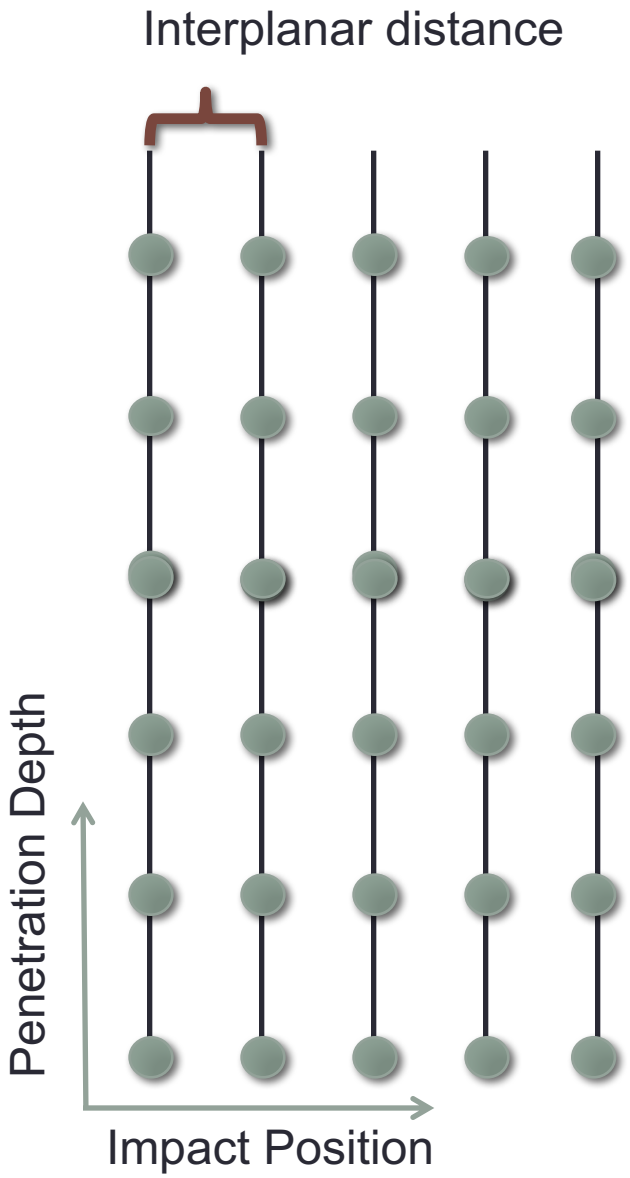
Interplanar potential

- The aligned atom can be seen as a single axis or plane by a particle moving aligned with them (continuum approximation by Lindhard).



Interplanar potential

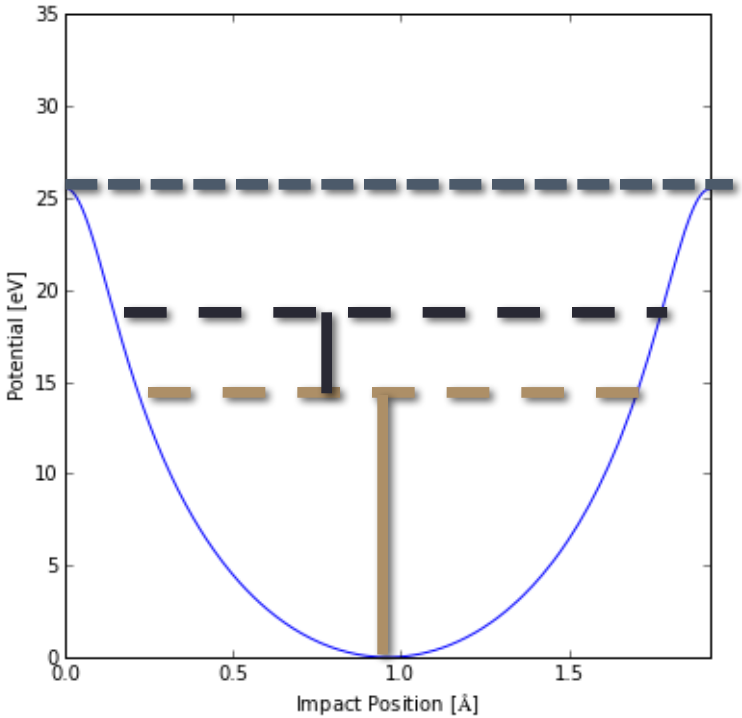




Condition for channeling

Straight crystal

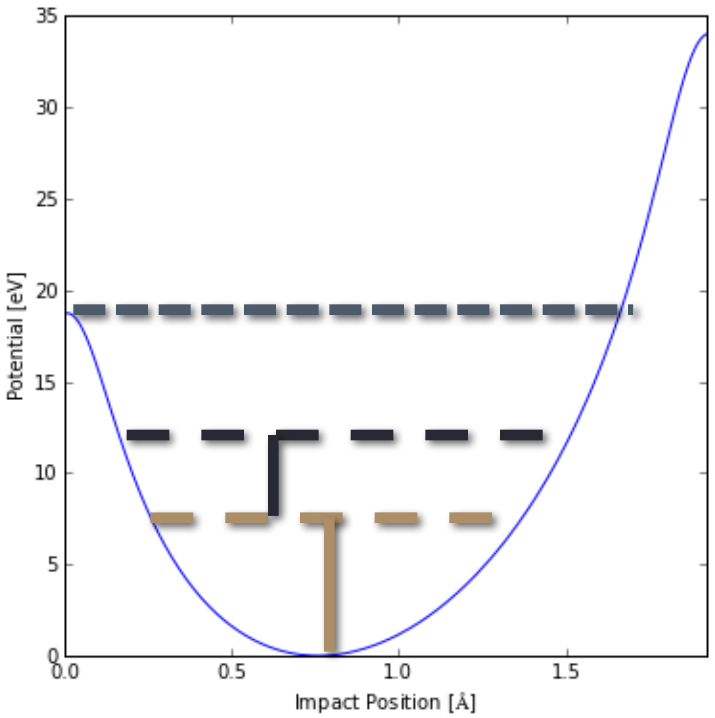
$$E_T < U_{\max}$$



$$E_T' = \frac{p\beta}{2}\theta^2 + U'(x)$$

Bent crystal

$$E_T' < U_{\max}'$$



$$E_T = \frac{p\beta}{2}\theta^2 + U(x)$$

Geant4 Approach – 2016

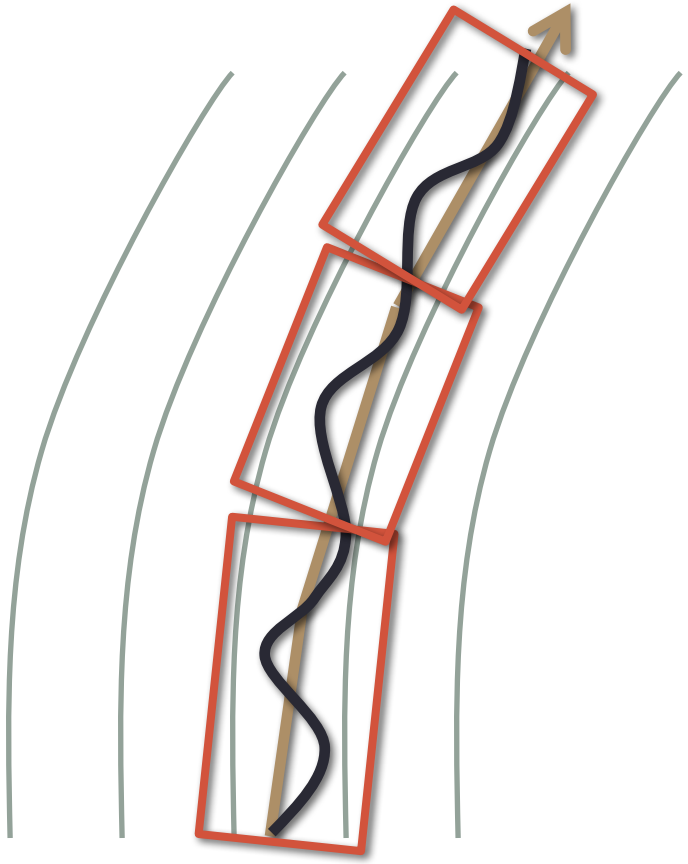
1. The particle initial transverse momentum is evaluated at the entrance of the crystal and a position in the crystal channel is chosen randomly. These are the only information stored.

2. At each step, which can be limited by the other Geant4 processes, the variation of position and momentum are computed via the integration of the particle trajectory in the continuum potential.

3. In a crystal, the modified value of nuclei and electron density is passed to the Geant4 processes via the biasing technique.

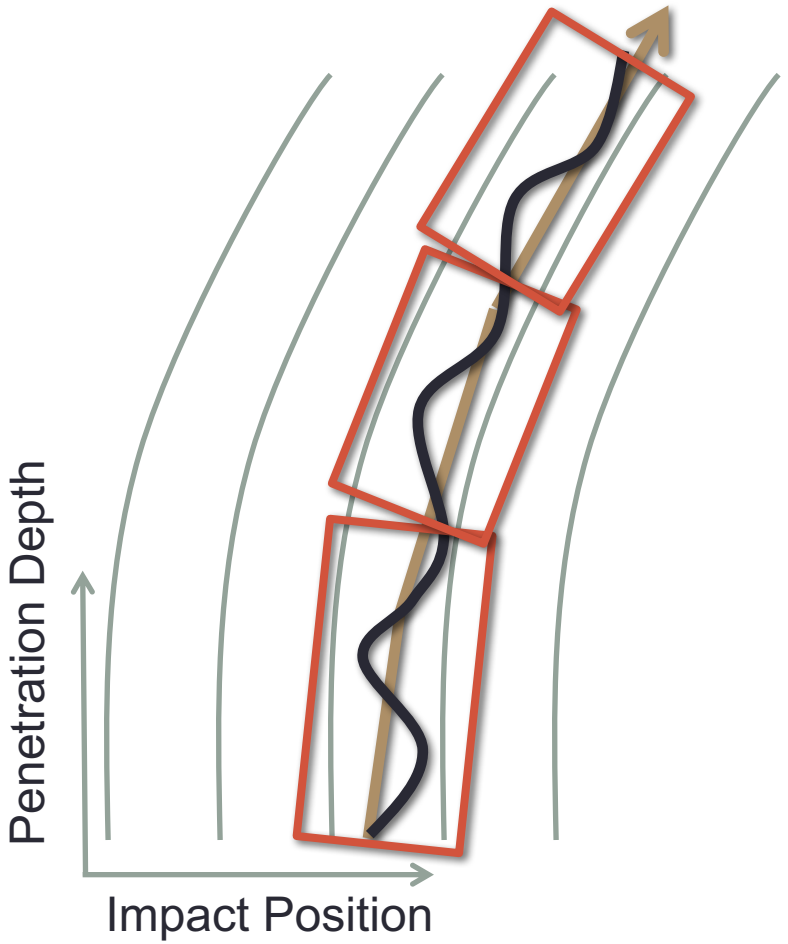
Geant4 Approach – 2016

- Maintain current implementation of:
  - Modification of Geant4 process cross-section.
  - Crystal classes.
- Between each step solve exact trajectory.
- Possibility to estimate:
  - Coherent radiation production.
  - Influence of defects.
  - Undulating structures.
  - Mirror effect.
  - …
- **Very slow.**



Modified density

- Before the simulation starts, the table of the average density of nuclei and electrons as a function of the particle position in the channel is loaded from an external file.
- At each step the path is integrated and a new value of electron and nuclei density ratio is stored and passed to the biased processes.



Geant4 processes

Discrete processes

- The mean free path of the discrete processes is recomputed at each step using the modified density because it is directly proportional to the density (ρ) of the material.

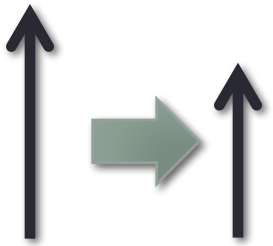
Continuous processes

- Material density (ρ) for the calculation of continuous energy loss (dE/dx) is modified at each step (dx=ρdz) to enable the reduction or the enhancement of the energy loss due to channeling.

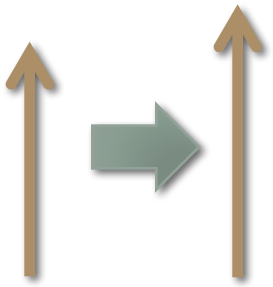
Modified density

Geant4 Mean Free Path Modification

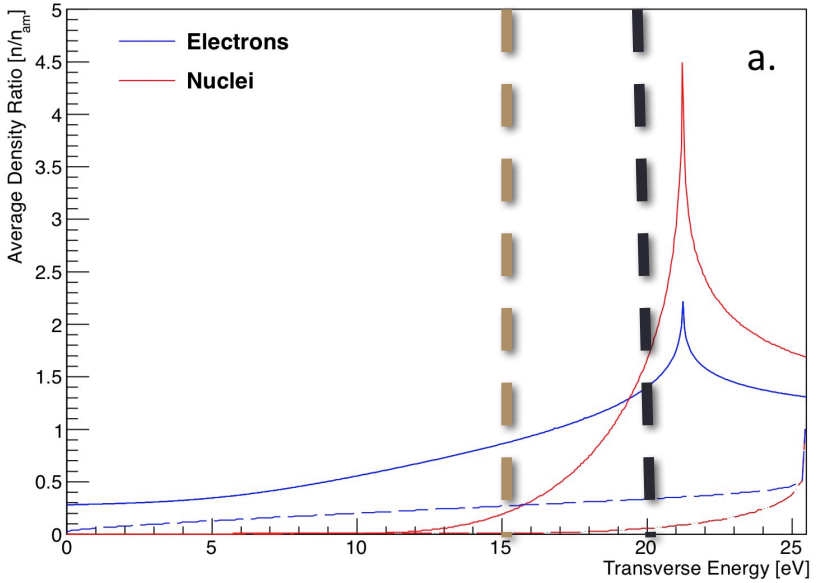
(@20 eV) Density Ratio = 1.5



(@15 eV) Density Ratio = 0.8



Density Ratio



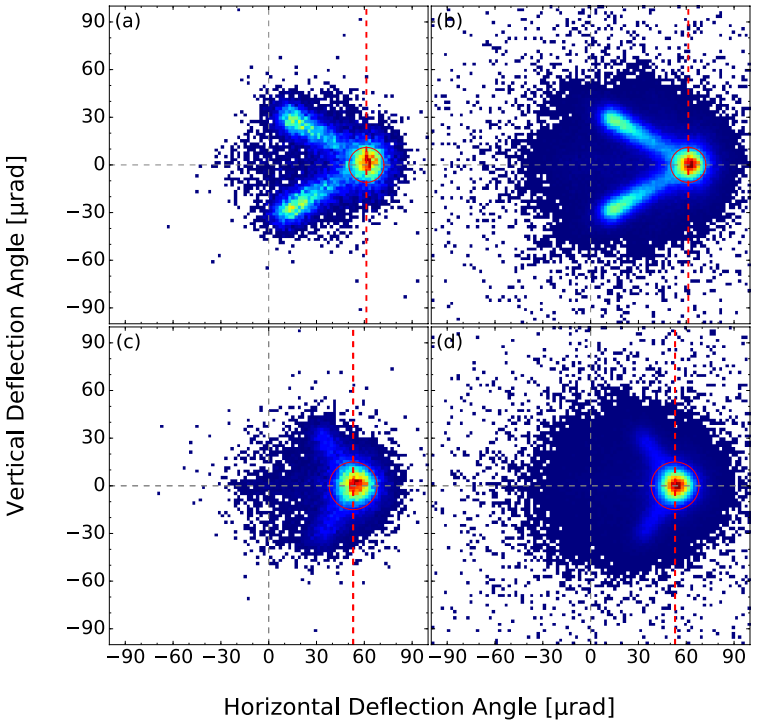
Depending on the trajectory of the particle, the density “seen” is different

Geant4 Approach 2016 – Pros/Cons

- Simulation of full particle trajectory.
- The current classes can be updated in order to maintain
  - Implementation of crystal structures, which is independent from the channeling process
  - Modification of Geant4 processes cross-section via the biasing technique.
- Main consequences:
  - Terrible slowing down of the computation.
  - Possible to take into account all the orientational phenomena at high-energies.
  - Computation of the coherent radiation spectrum emitted by particles under coherent effects.
  - Modification of particle trajectory due to the presence of lattice variation, e.g., undulating structure, defects, etc…

Geant4 Channeling Simulation

<111> and <110> axes



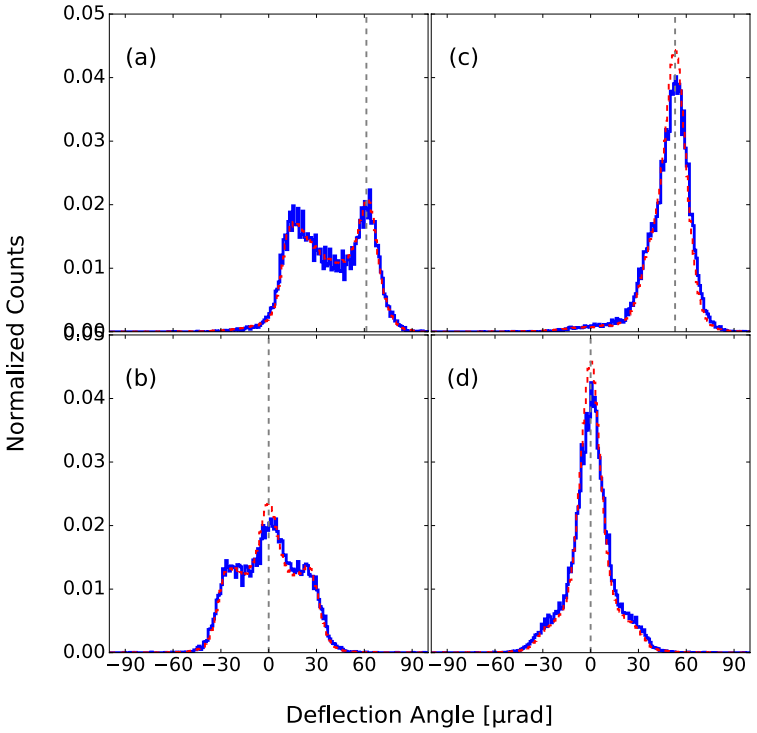
W. Scandale, Phys.Lett. B 760 (2016) 826-831

UA9 Experiment

- Experiment with 2 mm Si crystals with 400 GeV/c protons.
- Crystals oriented for axial channeling <111> (top) and <110> (bottom)
- Full beam line and channeling effect simulated.
- Agreement between experimental data (left) and Geant4 (right)

Geant4 Channeling Simulation

<111> and <110> axes



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

Projections

- Horizontal (top) and vertical (bottom) Projections show good agreement too.
- Channeling peak and dechanneling tails are well simulated for both vertical and horizontal projections.