Geant4 Channeling

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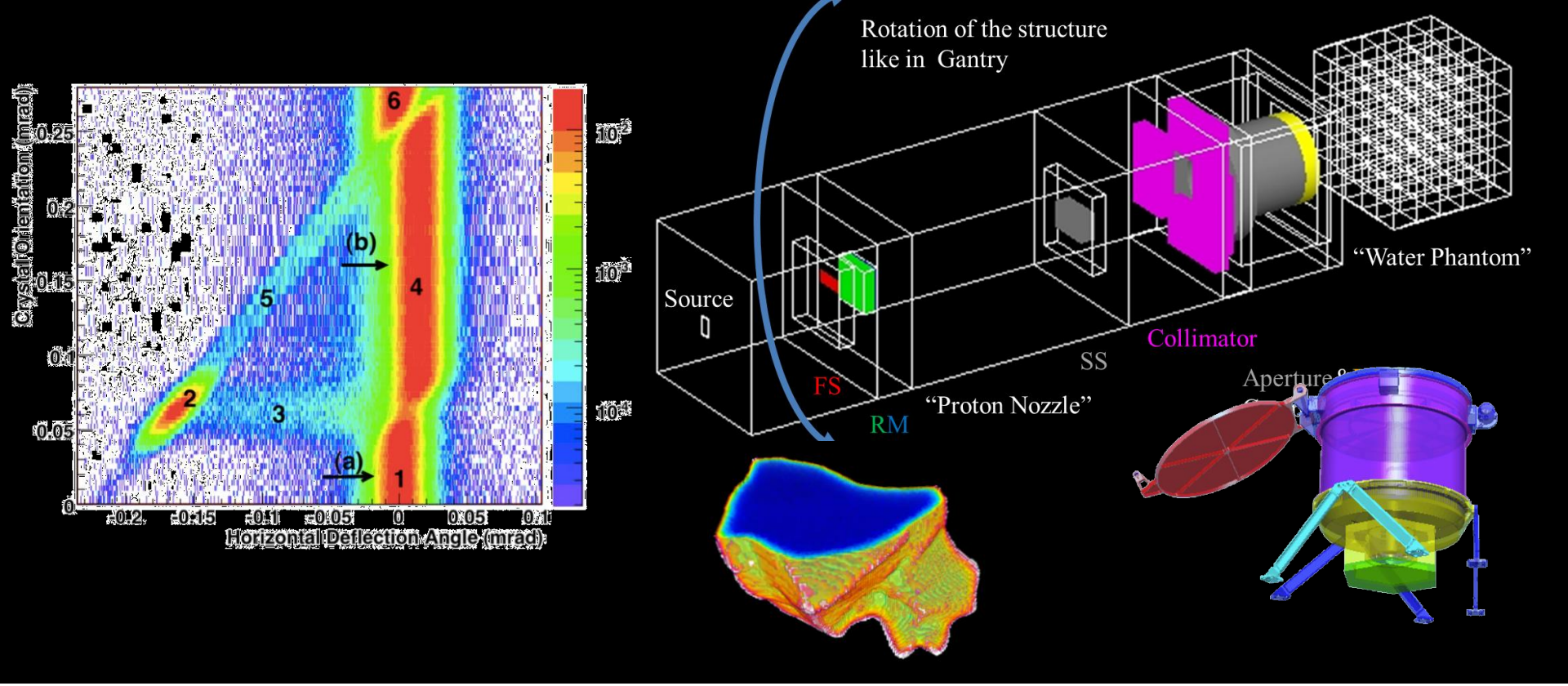


Channeling in Bent Crystals With Geant4

GEANT4 CHANNELING

Geant4

- Geant4 is a toolkit for the simulation of the passage of particles through matter. Its areas of application include high energy, nuclear and accelerator physics, as well as studies in medical and space science.
- Applications simulated by Geant4 range from particle transportation in the LHC detectors to calculations of dose distribution curves for a typical proton therapy beam line, and from radiation analysis for space instruments to early biological damage induced by ionizing radiation at the DNA scale

Introduction

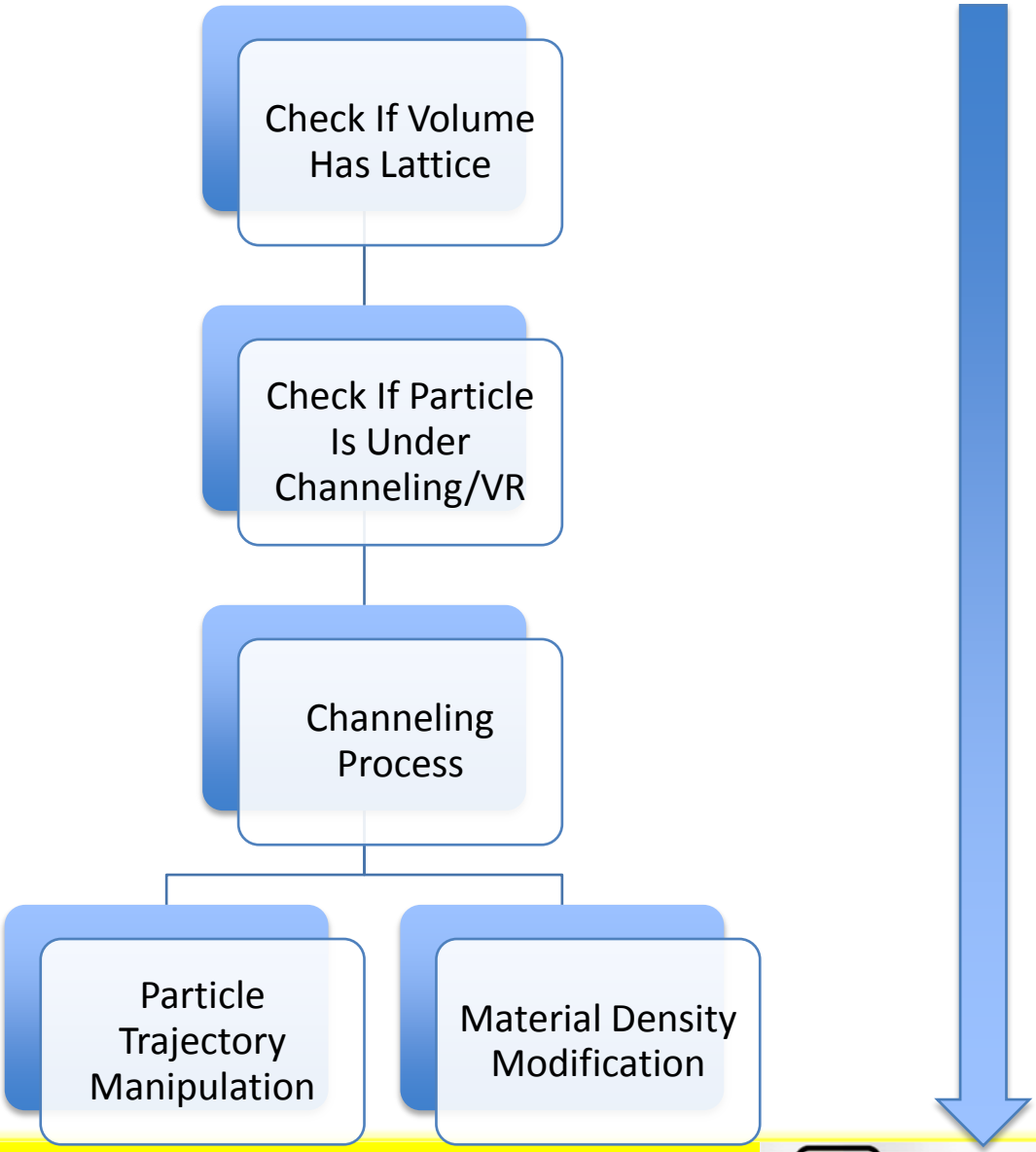
- Stand-alone software to simulate channeling do not allow to consider all the physics processes implemented into Geant4.
- Geometry package in Geant4 permits the simulation of complex experimental setup.
- Geant4 is continuously updated and physics models have been extensively validated (no need to reinvent the wheel).
- Model validation against experimental data generated by the interaction of a single-pass beam instead of multi-turn beam to reduce the complexity of the simulation.
- Data analysis by Roberto Rossi (INFN/CERN).

Geant4 processes modification

By modifying the trajectory of the particle and the density of the material "seen" by the particle the orientational effects in a crystal affect all the Geant4 physical process.

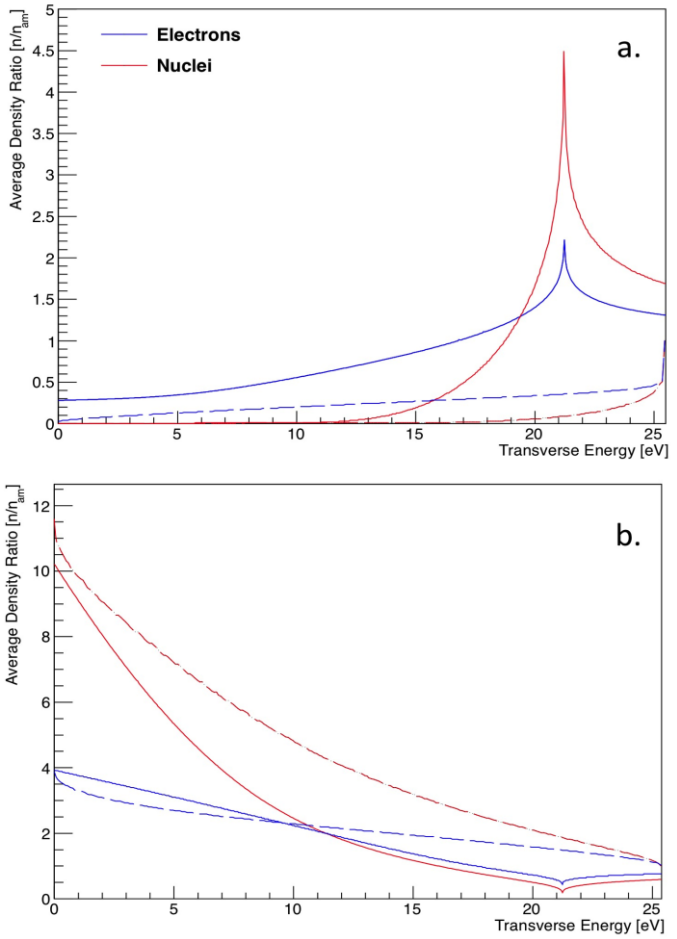
The trajectories of channeled particles are "forced" to be tangent to crystal curvature.

The density of materials seen by the channeled particles depends on transverse energy of the particles.



Modified density

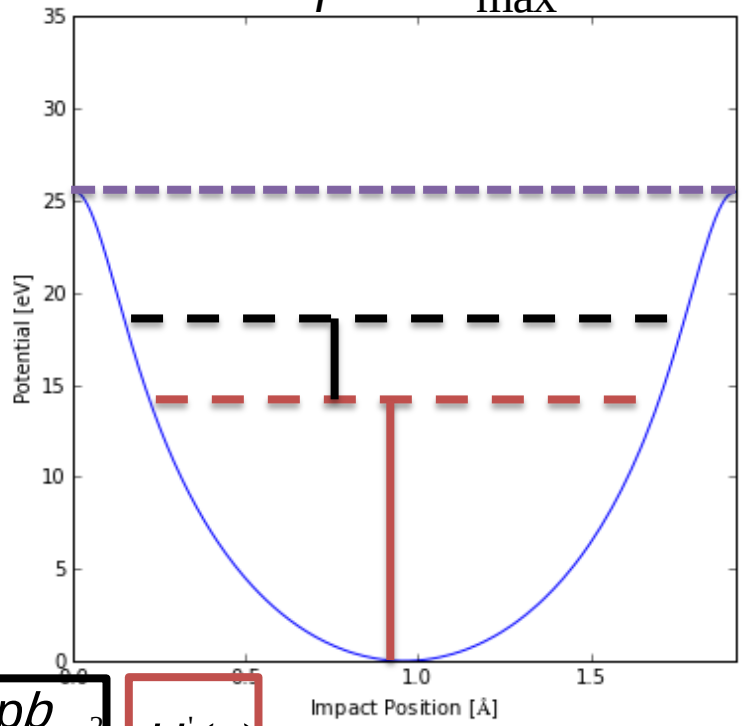
- Nuclei and electron density tables are computed for positive and negative particles as a function of the particle transverse energy.
- This approach can be used for crystal with dimension parallel to the beam much longer than the channeling oscillation period.
- Processes for shorter crystals, e.g., “mirror effect”, will be added in a future release.



Condition for channeling

Straight crystal

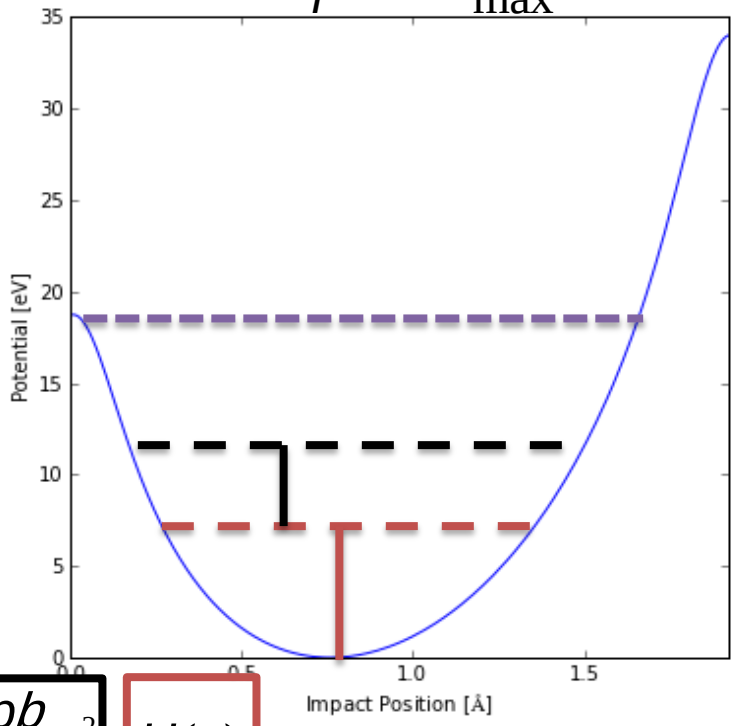
$$E_T < U_{max}$$



$$E_T' = \frac{pb}{2}q^2 + U'(x)$$

Bent crystal

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

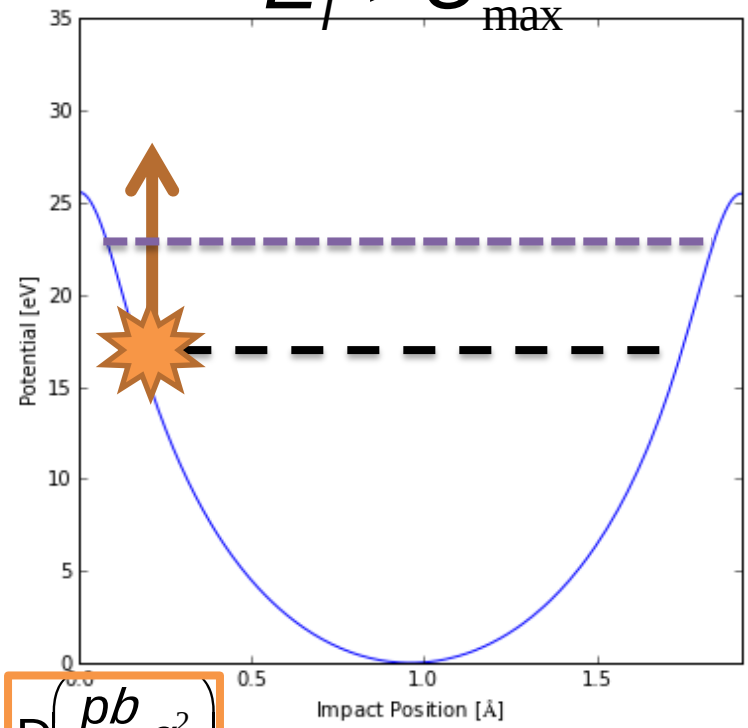


$$E_T = \frac{pb}{2}q^2 + U(x)$$

Dechanneling & Volume Reflection

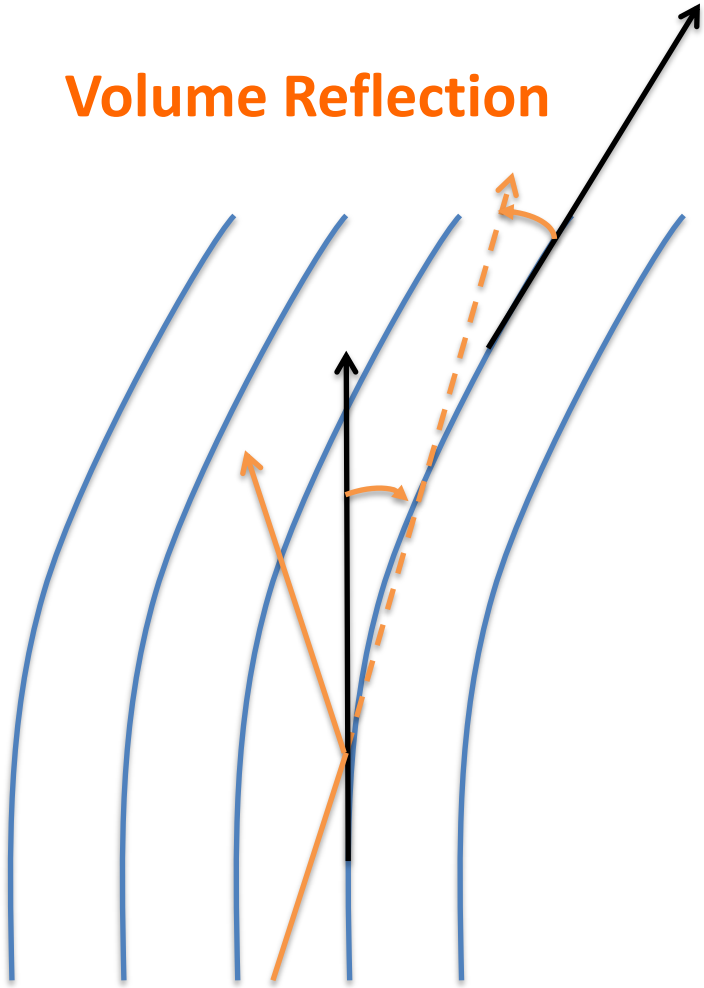
Dechanneling

$$E_T > U_{max}$$



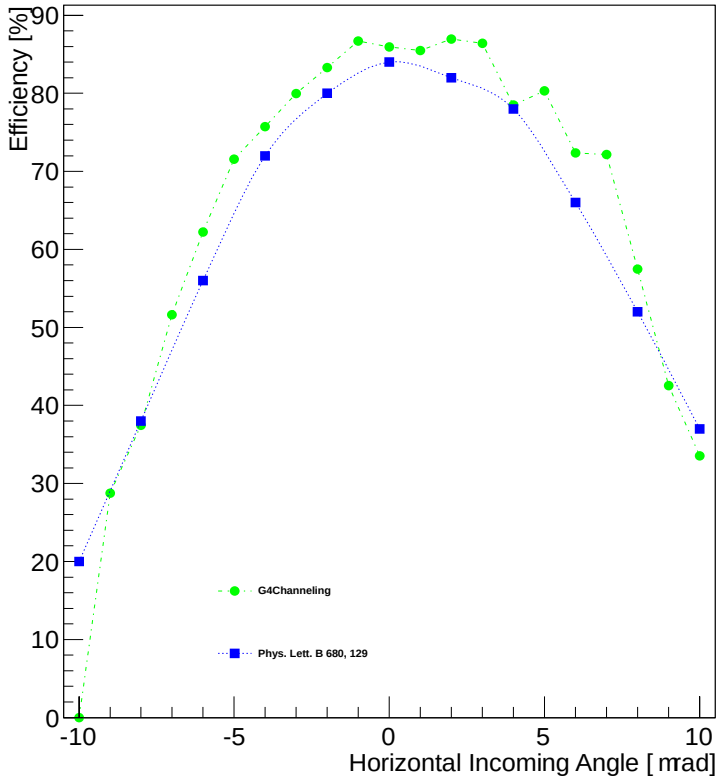
$$DE_T = D\left(\frac{pb}{2}q^2\right)$$

Volume Reflection

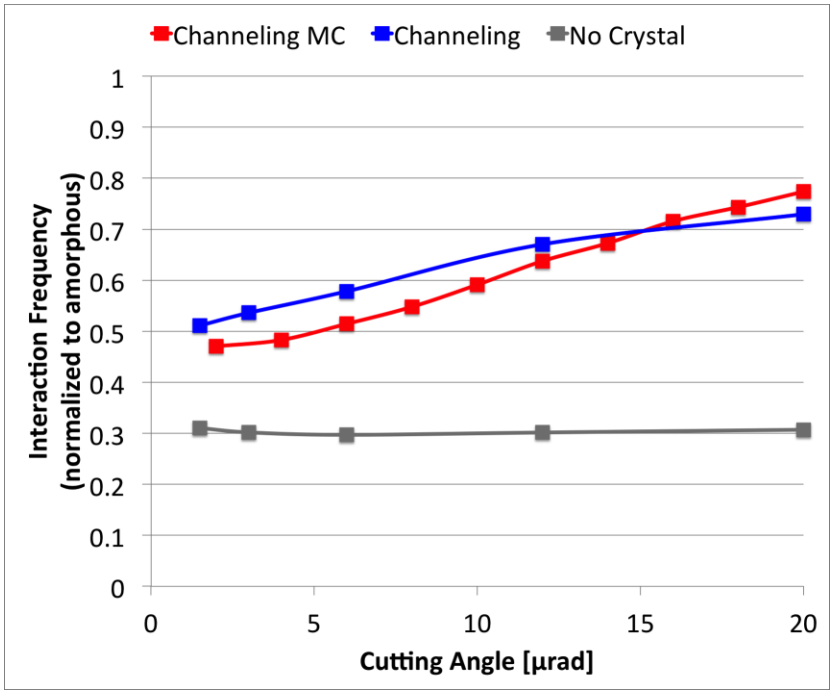


Nuclear interactions rate variation

Channeling Efficiency
W. Scandale et al., PLB 680 (2009) 129



Nuclear interaction
W. Scandale et al., NIMB 268 (2010) 2655



Channeling Example in Geant4

Beam Deflection

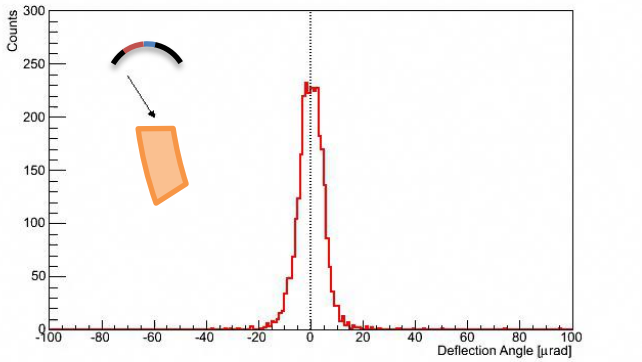
Channeling

Volume Reflection

Not Aligned

Bent Crystal

Beam



Experimental Setup

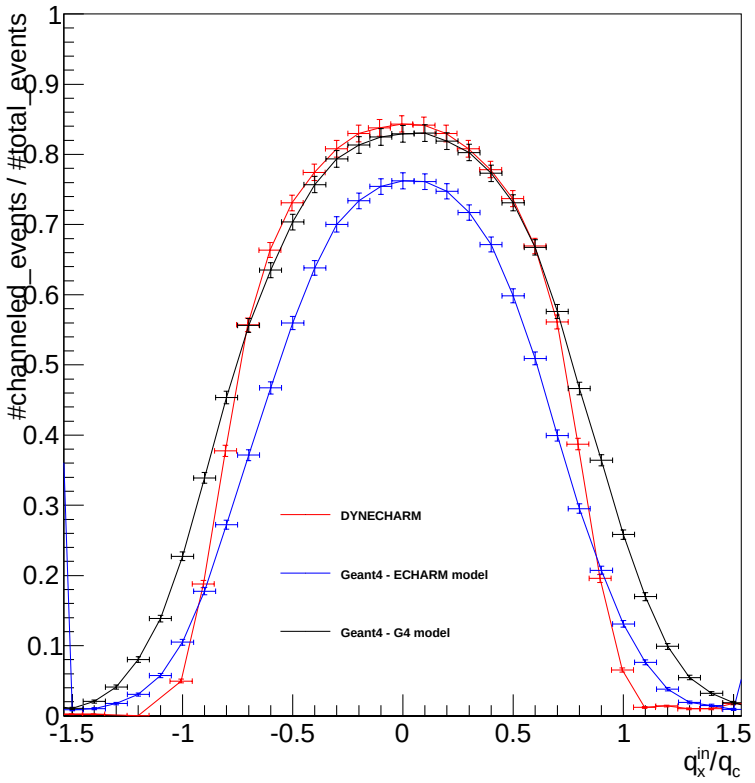
- The example simulates the channeling of 400 GeV/c protons in bent Si crystal.
- The example provides the physical model for planar channeling and volume reflection in bent crystals.
- Physical model published in:
  - E. Bagli, M. Asai, D. Brandt, A. Dotti, V. Guidi, D. H. Wright, "A model for the interaction of high-energy particles in straight and bent crystals implemented in Geant4", European Physics Journal C 74, 2996 (2014)

Geant4 Model Parameters

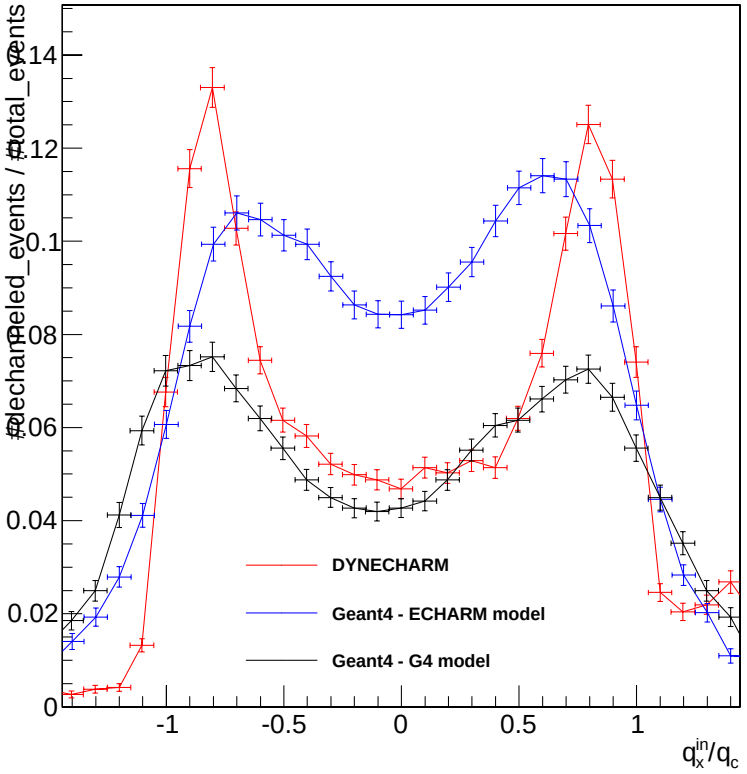
- Atomic Form Factor:
  - The model for the calculation of the from factor affects mainly the the intensity of the dechanneling and the distribution of the dechanneling population.
- Temperature:
  - The temperature modifies the thermal vibration amplitude (TVA) of the lattice atoms.

Potential & Density Calculation

Channeling Population

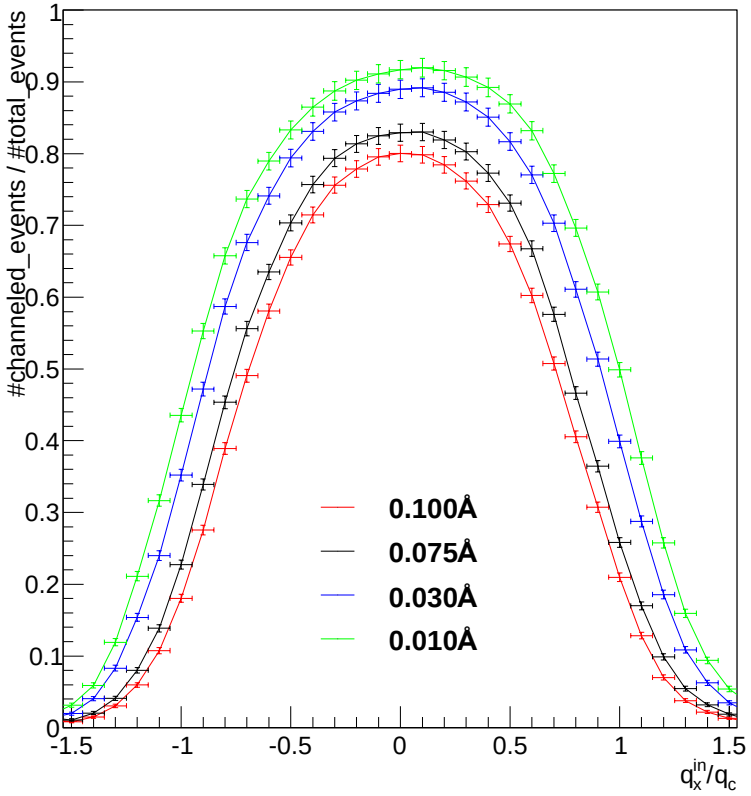


Dechanneling Population

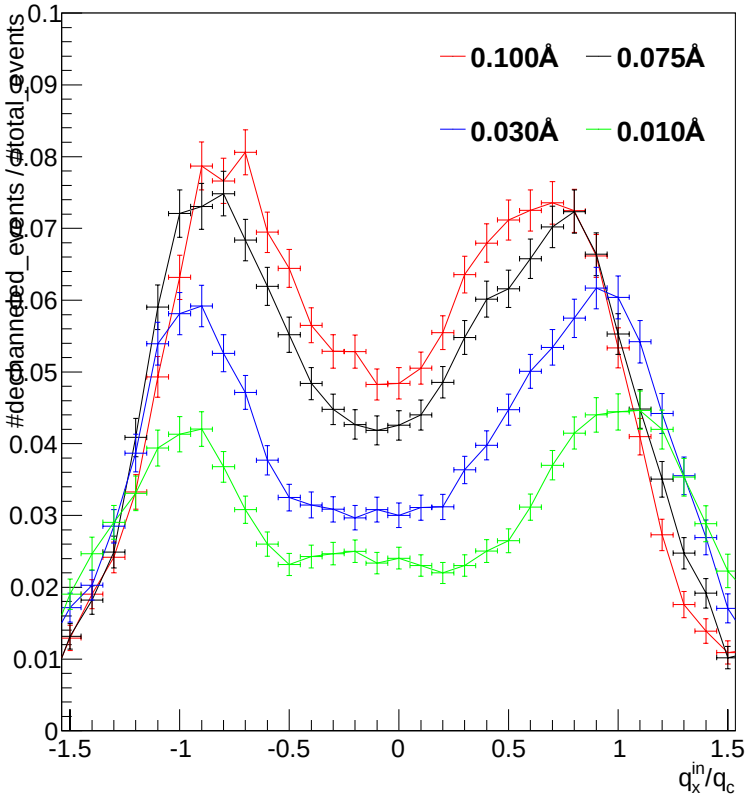


Temperature Dependence (G4)

Channeling Population

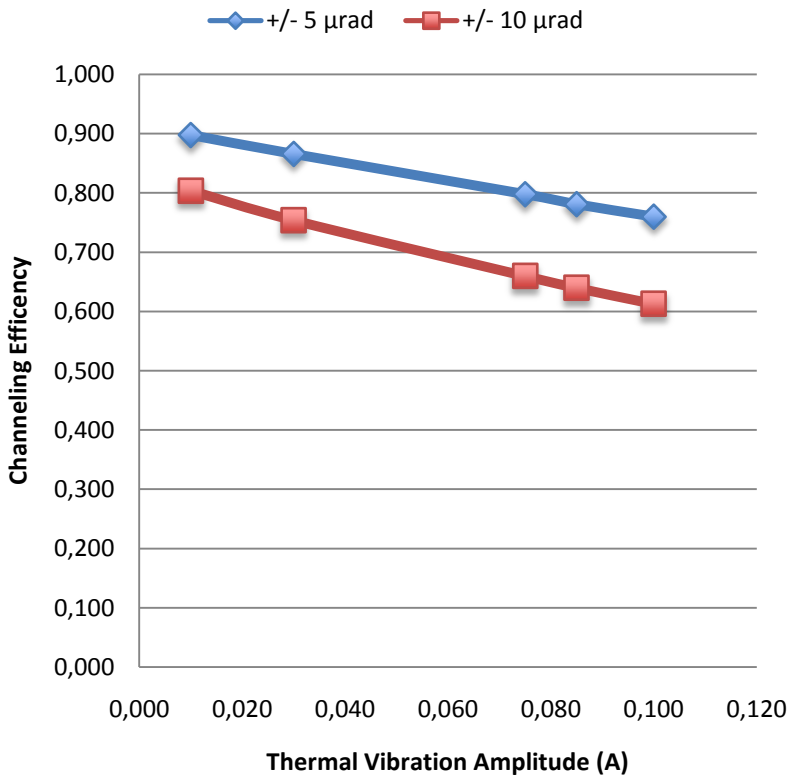


Dechanneling Population

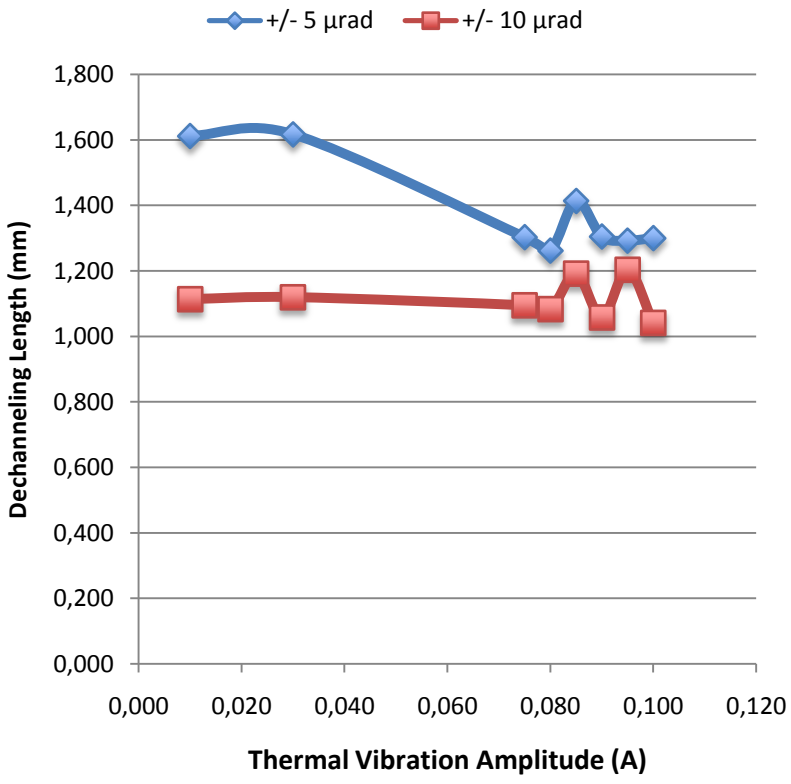


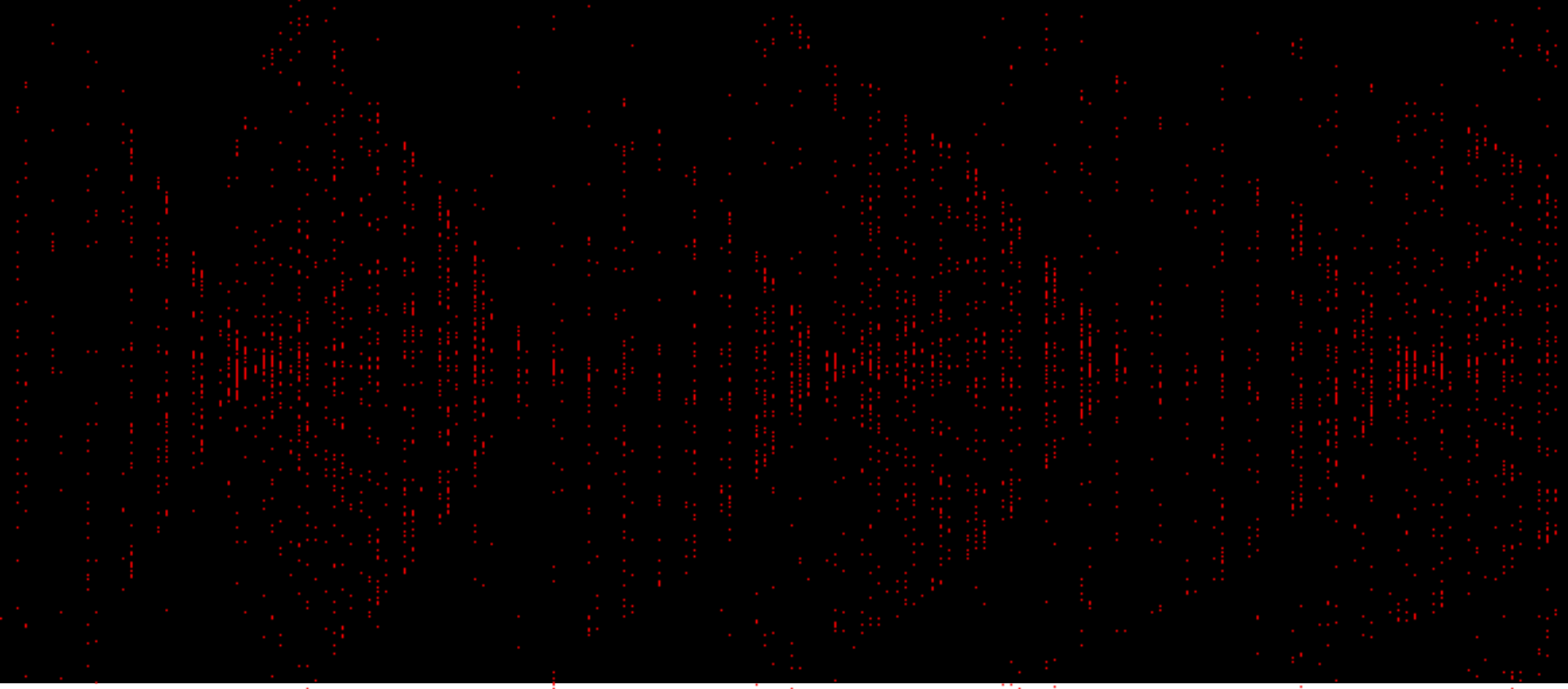
Temperature Dependence (G4)

Channeling Efficiency



Dechanneling Length



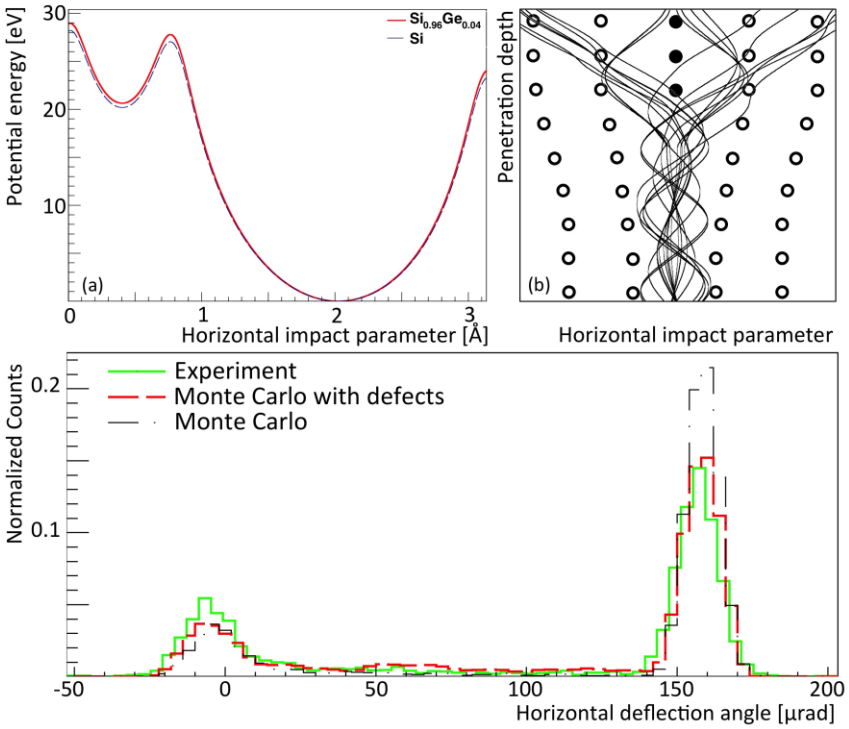


DYNECHARM++

DYNECHARM++

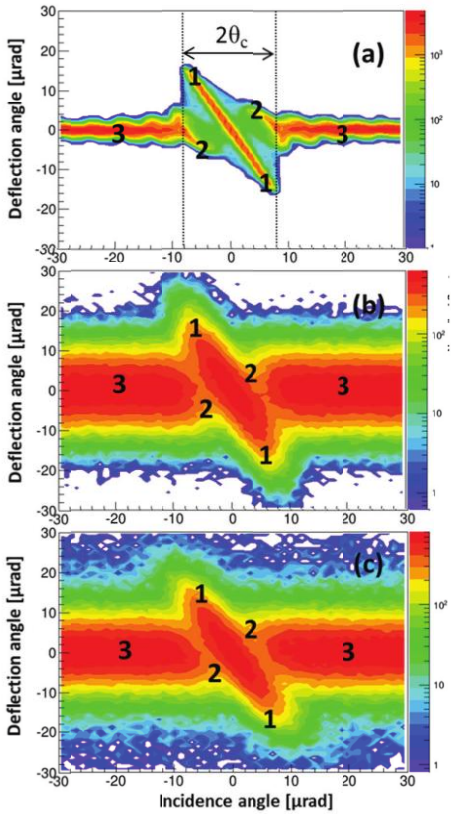
E. Bagli and V. Guidi, NIMB 309, 124 (2013)

Dislocations



E. Bagli et al., PRL 110, 175502 (2013)

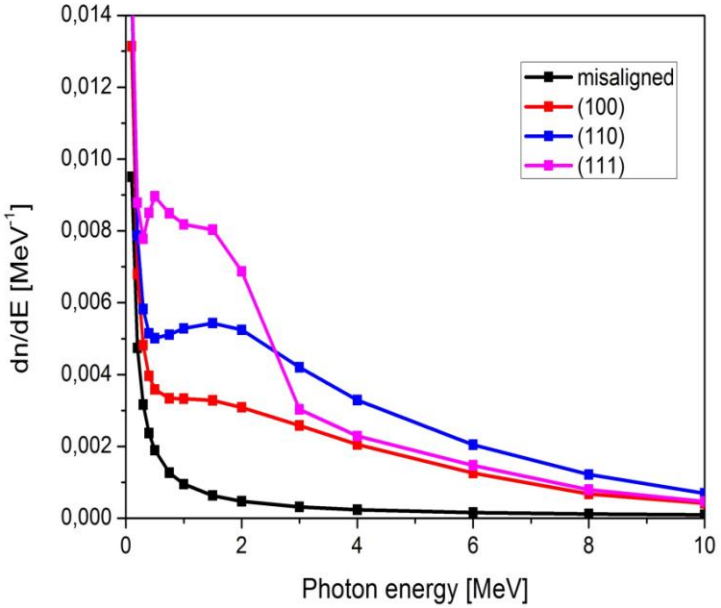
Mirror



W. Scandale et al., Phys. Lett. B 734, 1 (2014)

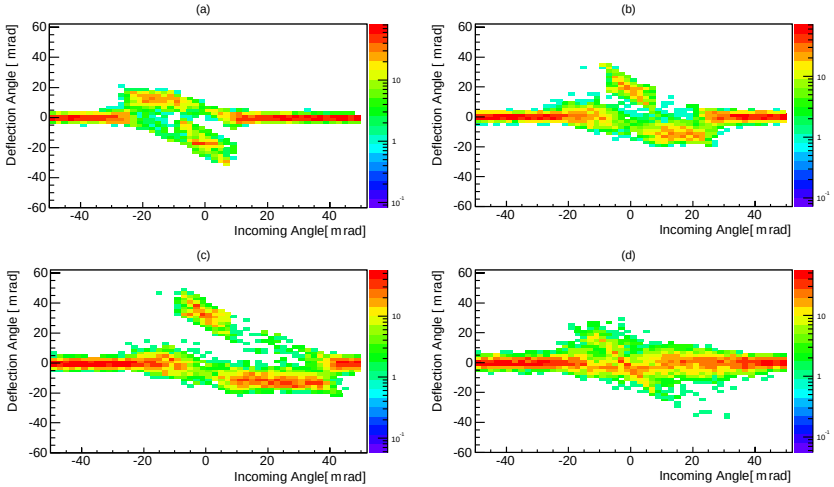
DYNECHARM++

Radiation

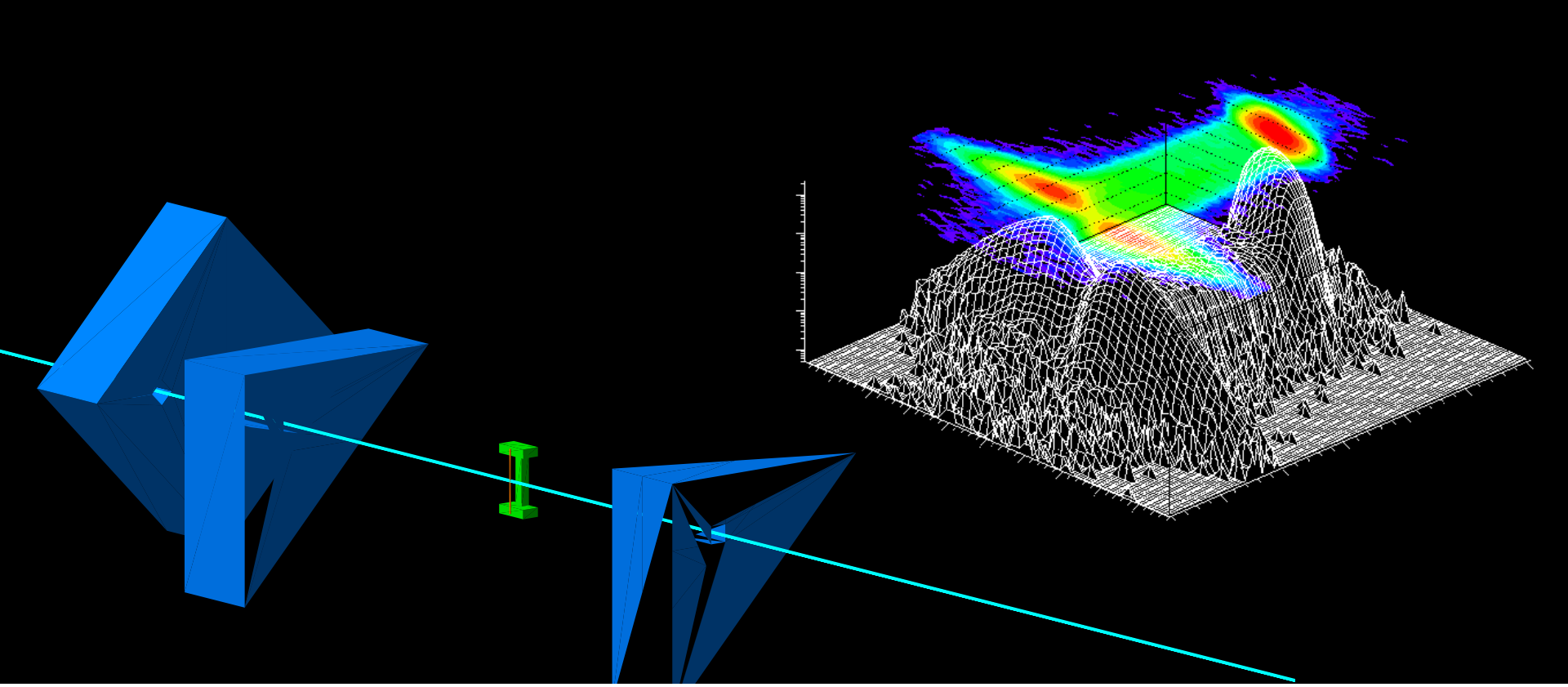


L. Bandiera, E. Bagli, V. Guidi, V.V. Tikhomirov, “RADCHARM++”, Channeling 2014

Undulator



E. Bagli et al., EPJC, under publication, (2014), http://arxiv.org/abs/1410.0251



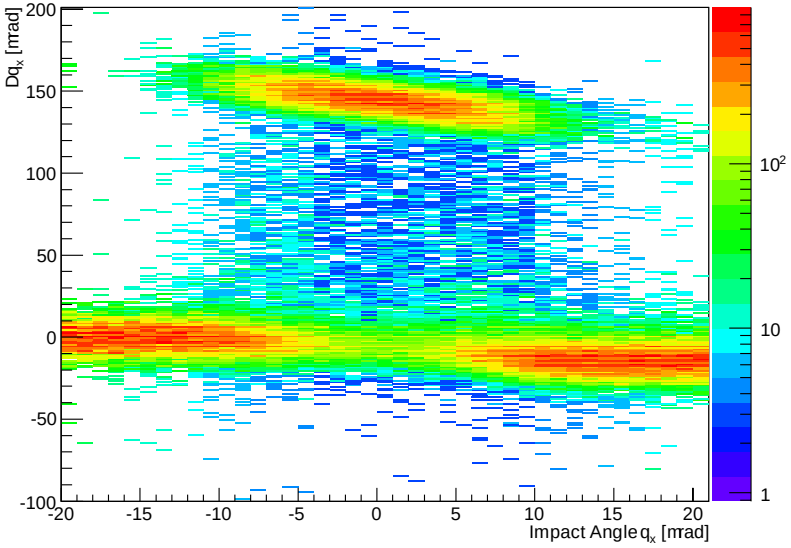
GEANT4 SIMULATION OF CHANNELING EXPERIMENT AT H8 LINE

Geant 4

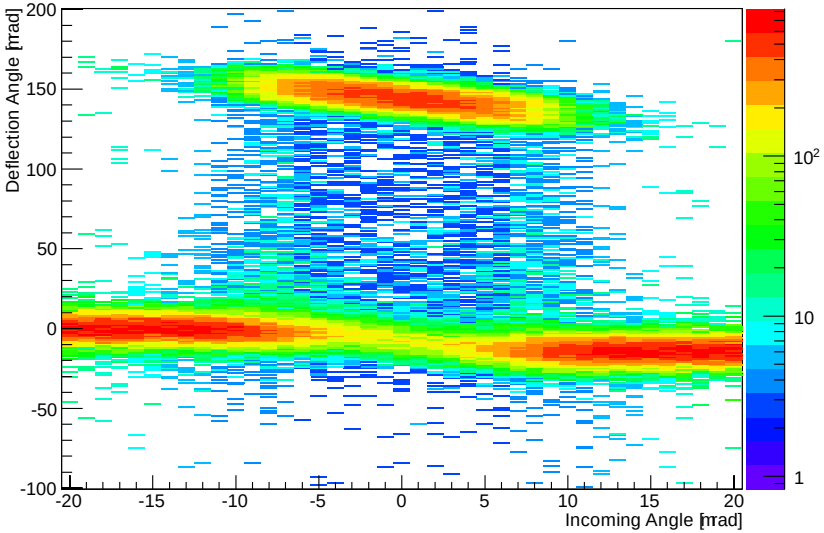
Sensor and Semiconductor Laboratory

Deflection Angle Distribution

Data

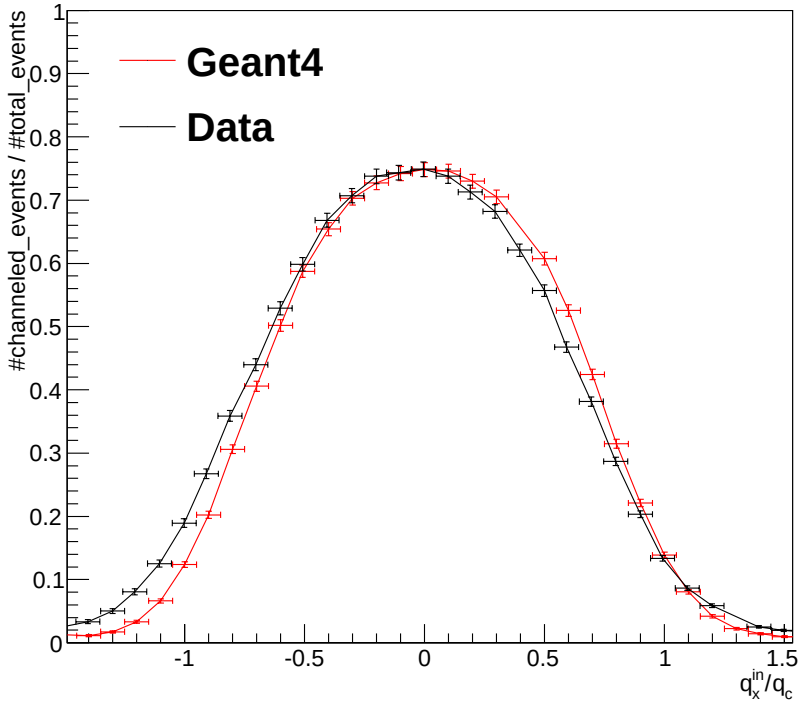


Geant4

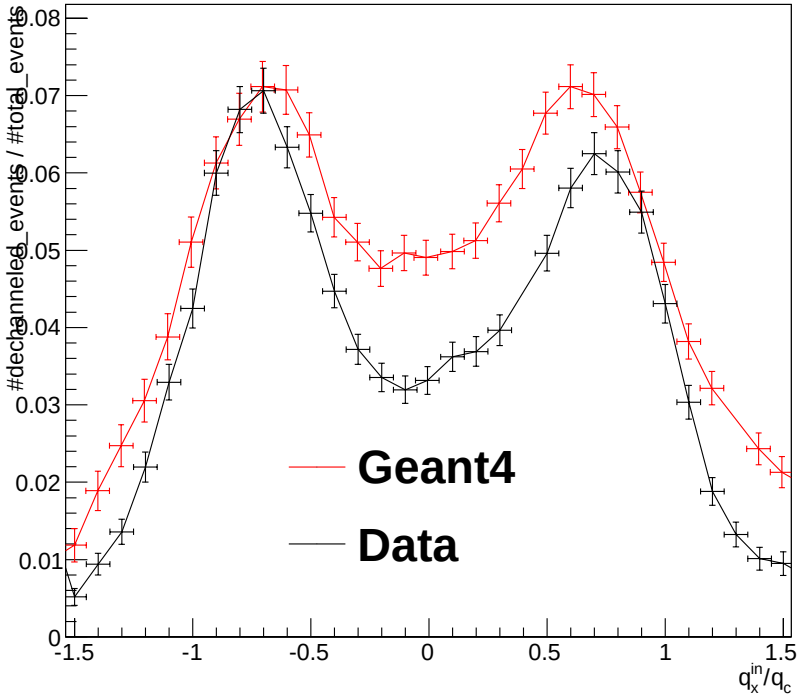


Comparison with experimental data

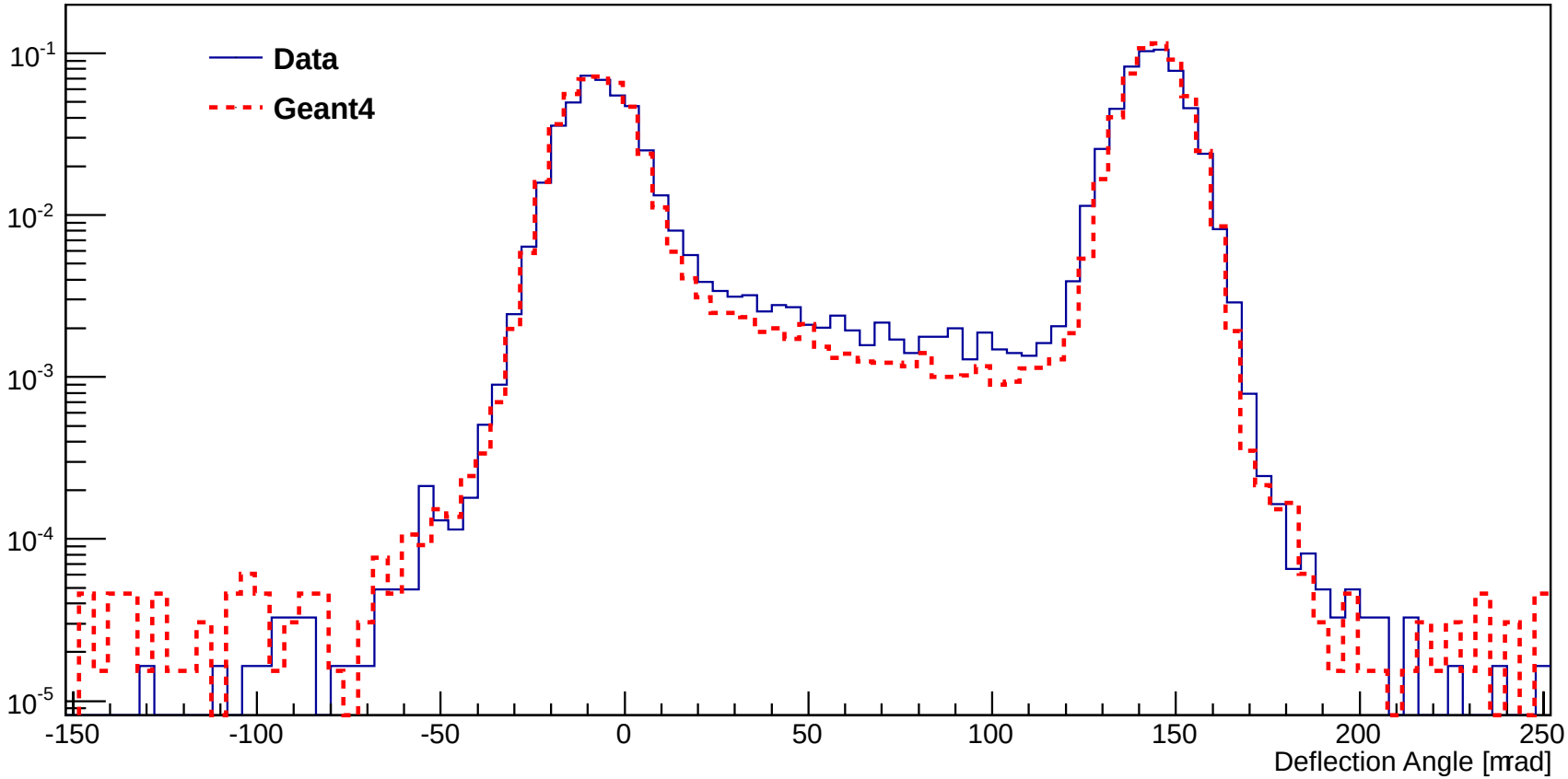
Channeling Population



Dechanneling Population



Deflection Angle Distribution



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

Conclusions

- Possibilities to study the secondary particles produced and to track them under channeling condition.
- Public (ExExCh example in the Geant4 10.01 Release).
- Fine tuning of the parameter of the model.
- Plug in of Geant4 in codes for the simulation of circular accelerators.
- Addition of other coherent/orientational effects, e.g., channeling radiation, mirror effect, etc…
- Channeling at MeV energies.

Thank you for the attention