Focusing of High Energy Electron Beam using Crystal Lenses for Applications in Radiotherapy – Feasibility Study

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Introduction

The aim of this thesis was to investigate the feasibility of focusing a very high-energy electron beam using crystal lenses for application in radiotherapy treatment. For this purpose, a Geant4 simulation model has been developed by extending the available *channeling* example. Features implemented into the code cover shaping the bent Si crystal for the purpose of providing focusing; five more detectors placed behind the crystal which can detect beam distribution, as a way to be able to check the trajectory of the beam more precisely; water phantom which serves as a detector to check the energy deposition of the focused beam inside a tissue-like material; new expanded macros to include more options for controlling the beam and the geometry of the simulation. **The simulation model is well prepared for the development and optimization of crystal lenses that could be potentially used to focus high-energy electron beams.**

Focusing

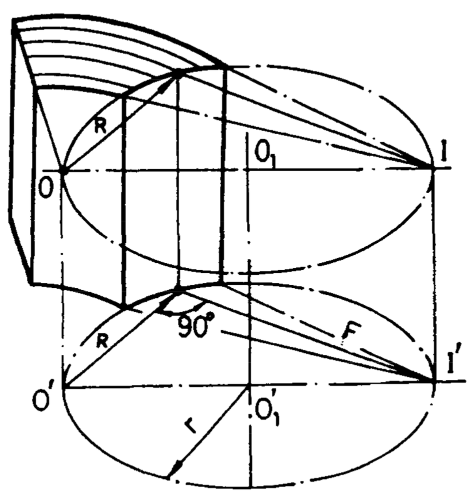
In order to focus the beam after it passes through the crystal, the output of the crystal must be properly profiled. Such a crystal is supposed to behave like a focusing lens. To profile the exit of the crystal, it is cut with a section of a cylinder. In this example a beam of accelerated particles enters the crystal from the left side and is channeled inside the crystal, and after exiting it, is focused at a distance F [1].

Crystal length (L):

$$L = R * \theta_b \tag{1}$$

The radius of the cutting cylinder (r):

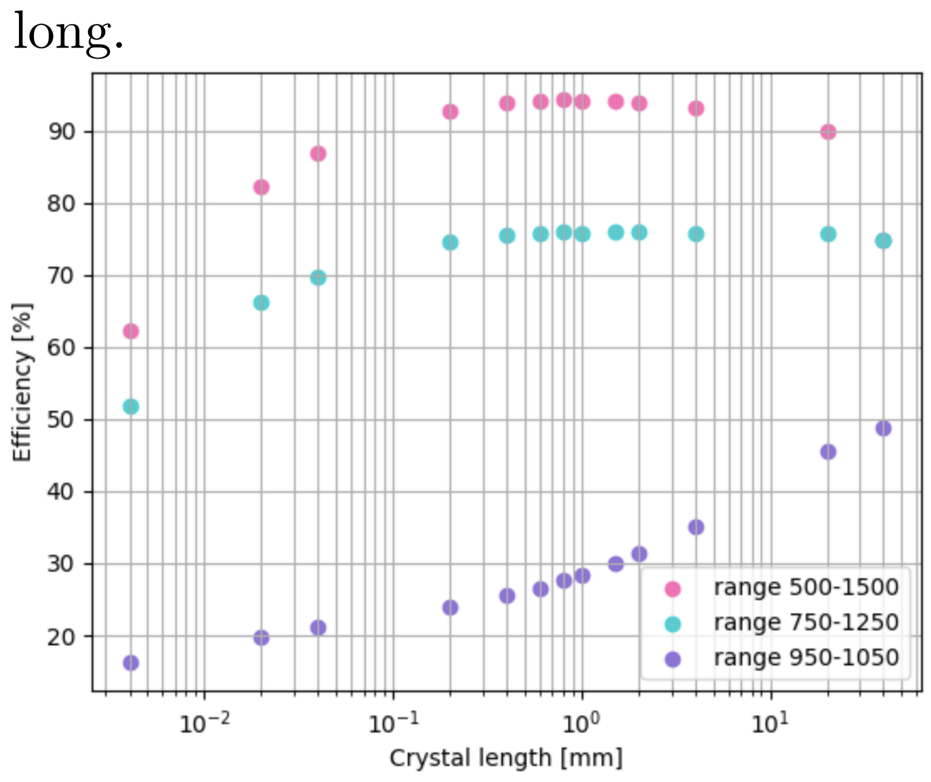
$$r = \frac{1}{2}\sqrt{F^2 + R^2} \tag{2}$$



Crystal length	Cylinder radius lengths
2 mm	1118.03mm
4 mm	2061.55mm
20 mm	10012.49mm

Efficiency of channeling

The efficiency of electron beam channeling as a function of crystal length. The most effective crystal length is considered to be a few millimeters long.



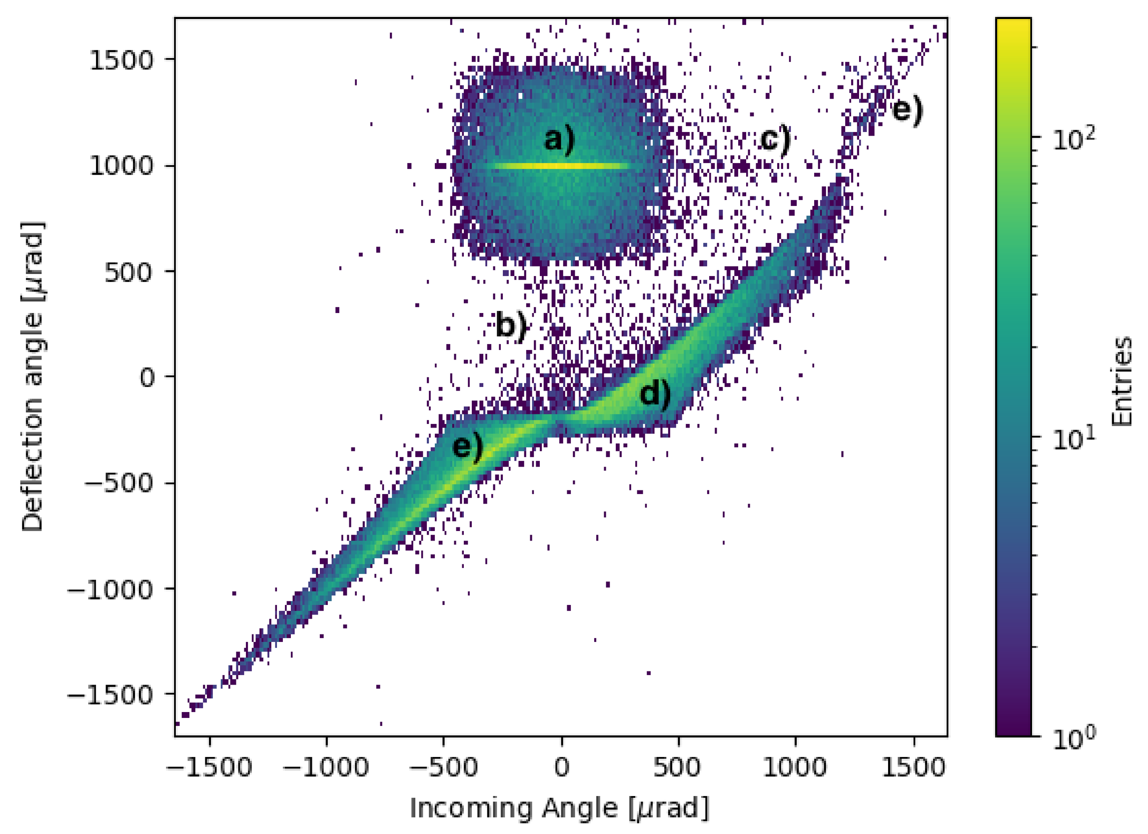
References

[1] Y. Chesnokov, “Review of ihep experiments for focusing and deflection 70 gev proton beam with bent crystals”, Nuclear Instruments and Methods in Physics Research B, 119, pp. 163–171, 1996.

[2] D. Mirarchi, “Crystal collimation for lhc”, Ph.D. thesis, High Energy Phys. Dept., Imperial College, London, England, 2015.

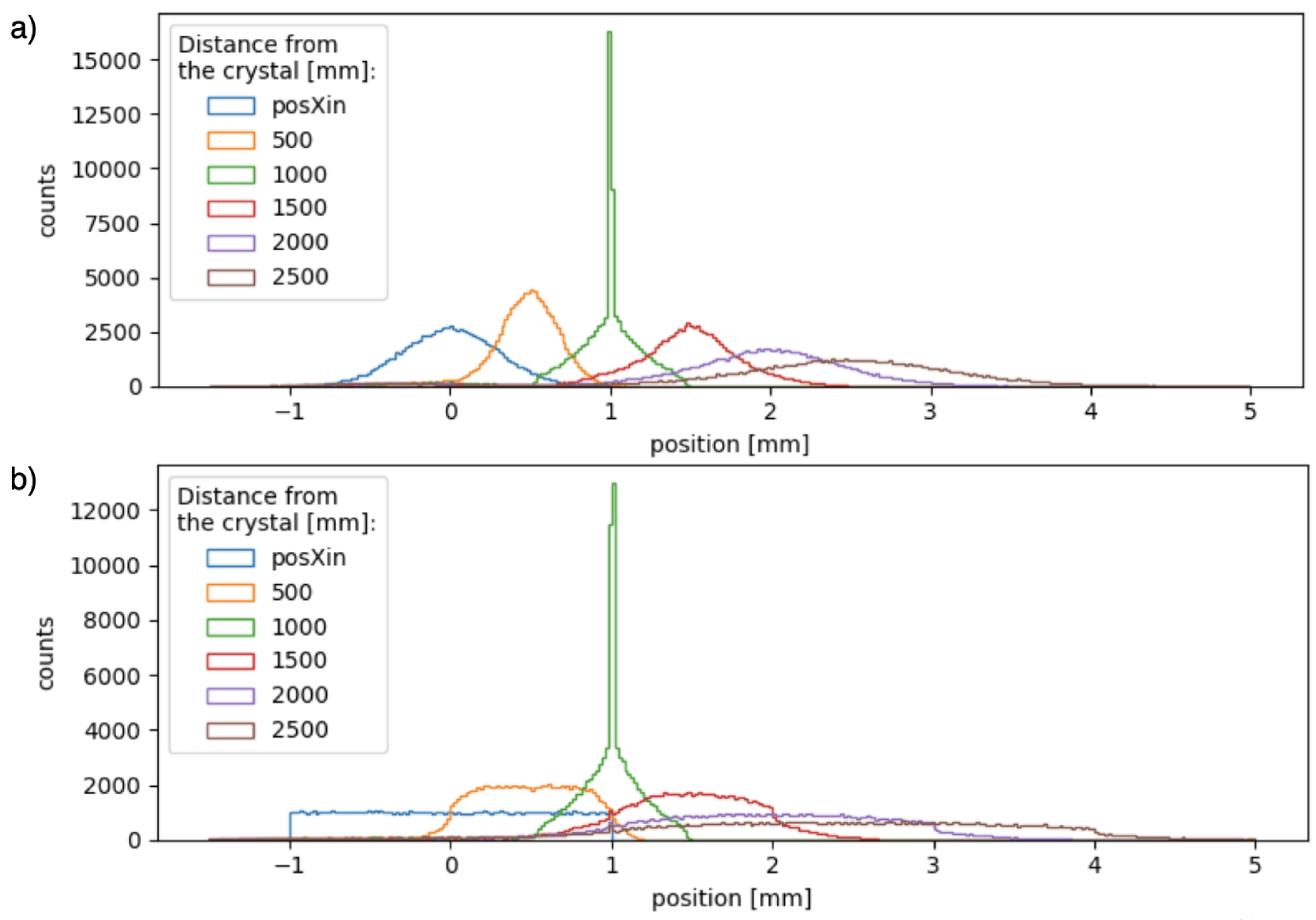
Channeling

Crystals have ordered patterns of atoms. Channeling is the phenomenon of guiding charged particles through a periodic internal structure of a crystal if particle direction is aligned with its planes or axes. The strong electromagnetic field creates a collective potential derived from crystal structure that captures charged particles as they enter the crystal [2]. Distribution of the deflection angle of particles with energy 200 MeV that passed through 4 mm long crystal, depending on the incoming angle; a) channeled particles, b) dechanneling, c) volume capture, d) volume reflection, e) amorphous scattering.



Results

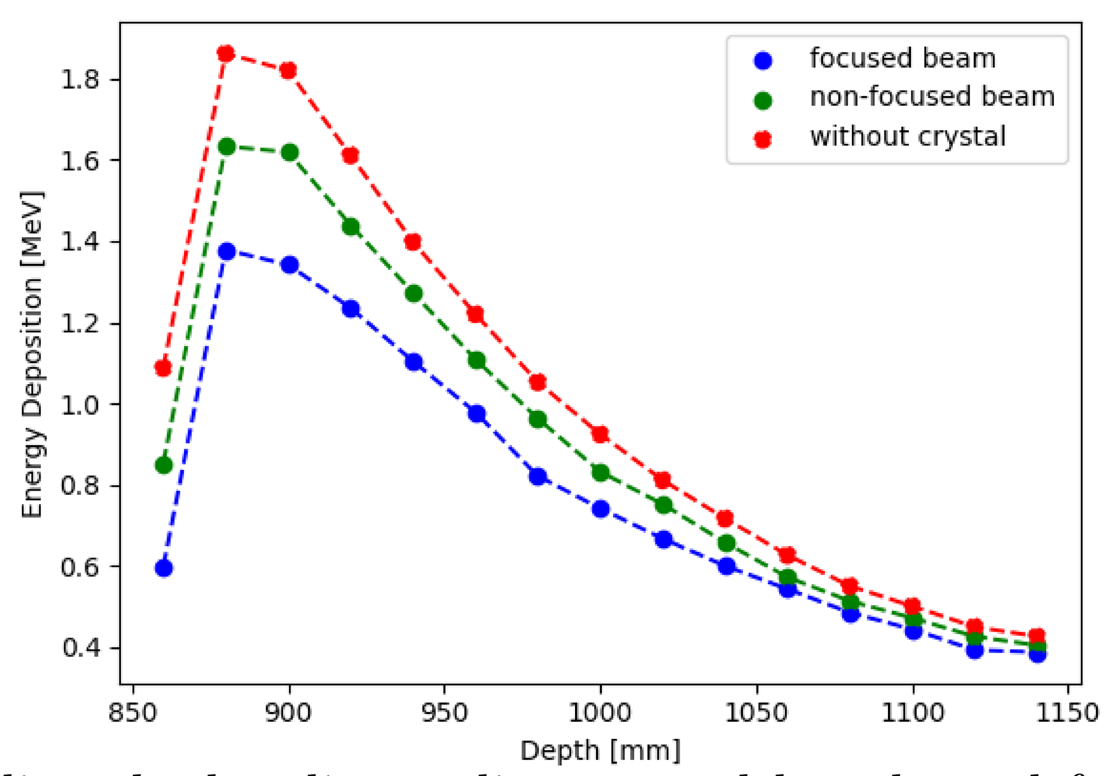
The figure on the right presents, the distribution of the beam position before entering the profiled crystal with a bending radius 4000mm, and after passing through the crystal at distances 0.5m, 1m, 1.5m, 2m, and 2.5m respectively, a) for a beam of Gaussian distribution, and b) for a beam of uniform distribution. Bin width is 20 μm.



Beam focusing by using bent crystals with profiled exits was demonstrated. Crystals with lengths in the order of a few millimeters proved to be the most optimal set of parameters for deflecting the beam by an angle of 1000 μrad. The results obtained from two types of beams, with a Gaussian distribution and with a uniform distribution are similar. The focusing is stronger in the case of uniform beam distribution because there are significantly more particles at positions further from the middle of the beam approaching the crystal.

Conclusions

The energy deposition curve inside a water phantom is unfortunately far from expected. The obtained result resembles an outcome that can be acquired by a non-focused or weakly focused VHEE beam. The conclusion is that the focusing strength of the proposed crystal is not strong enough. The main reasons might be the limitation of the beam width approaching the crystal lens, which is around 2 mm at the maximum, and the focal length of 1 m might not be the optimal choice, it should be shorter.



The search for optimal crystal parameters, including the bending radius, crystal length, and focal length, is still ongoing. By shortening the focal length and lengthening the crystal transverse dimension, the focusing strength can be improved. As an alternative, it is possible to create something resembling a Fresnel lens by assembling a collection of focusing crystals.