AN IDEA FOR STUDYING A MULTIPASS CRYSTAL EXTRACTION BY THE ENERGY LOSS DETECTOR

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Abstract

We consider a proton extraction from accelerator by a crystal equipped with an energy loss detector. The idea is proposed that the energy loss dE/dz deposited in the crystal by a channeled proton may indicate, whether this proton was extracted in the first pass, or in the subsequent passes; this is a key question in the crystal extraction.

1 INTRODUCTION

Because of the abnormally low energy losses shown by channeled protons, the technique of dE/dz detectors built-in in crystals has found wide application in the high-energy channeling experiments. The energy-loss spectrum in aligned crystal is split into the "channeled" and "random" fractions, thus providing a way to distinguish between these two sorts of particle motion (Fig.1).

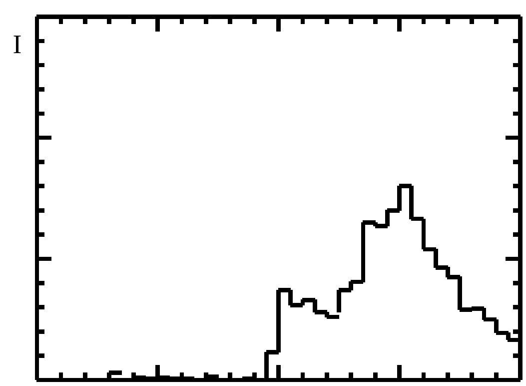

Figure 1: The energy-loss spectrum in aligned crystal of Si(110) simulated for 900-GeV protons with divergence (σ) of 11.5 μrad.

In the crystal extraction experiments, in a diffusion mode, the first passage of protons through the crystal is very close to the surface, at a depth of $<$1 μm. Then the escape of δ-electrons (knocked out by a channeled proton) from the crystal modifies the dE/dz *deposited* in the crystal, thus making it depend on a depth (impact parameter) b. Hence one may hope to resolve the first pass or multi-passes, observing dE/dz deposition of the extracted protons in a crystal.

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2 ENERGY LOSS DEPOSITION

The difference between the energy loss and its deposition in the detector is a well-known effect due to the mentioned leakage of the most energetic electrons from the detector. Here this effect is brought to its extreme, going from typical thickness of $\sim$1 mm to $<$1 μm for the first passage in crystal extraction.

The mean energy loss for channeled particle in the electronic scattering can be written as a function of the position x [1]:

$$-\frac{\mathrm{d}E}{\mathrm{d}z} = \frac{D}{2\beta^2}\Big(\ln\frac{2m_\mathrm{e}c^2\beta^2\gamma^2}{I} - \beta^2 - \delta + C(x)$$

$$+\rho_\mathrm{e}(x)\left(\ln\frac{T_\mathrm{max}}{I} - \frac{T_\mathrm{max}}{2m_\mathrm{e}c^2\gamma^2}\right)\Big)$$

where $D = 4\pi N_\mathrm{A} r_\mathrm{e}^2 m_\mathrm{e}c^2 Z_\mathrm{i}^2 \frac{Z}{A}\rho$, and the other notation being standard[2]. Here $T_\mathrm{max} \approx 2m_\mathrm{e}c^2\beta^2\gamma^2$ is the maximal energy transfer to a single electron. $C(x)$ is correction[1].

To calculate the dE/dz deposition in a 1-mm thick Si, one should use $T_\mathrm{max}\approx$1 MeV because the electrons with energy $>$1 MeV have ranges $>$1 mm, and leak out. The practical range l in Si of the electron of T (keV) energy is [2]

$$l[\mu\mathrm{m}] \approx 2.4T\left(1 - \frac{0.9841}{1+0.0030T}\right)$$

For instance, l=1μm corresponds to T=10 keV. With the average $\rho_\mathrm{e}\approx Z_\mathrm{v}/Z\approx$0.3 ($Z_\mathrm{v}$ $\approx$4 is the number of valence electrons), one finds the dE/dz deposition to be reduced by $\sim$15% if one restricts T $<$10 keV instead of 1 MeV. In fact, some energy carried by electrons with 10 keV$<$ T $<$1 MeV may be deposited, while the rest of it escapes. The escape is a random-walk process.

3 SIMULATION

In order to check the discussed idea, the simulation code CATCH [3] was applied. Fig. 2 shows a simulated spectrum for the parallel beam of 900 GeV protons incident on aligned Si(110) crystal. Here T_{max}=1 MeV, corresponding to the proton depth b of order of 1 mm from the crystal surface. As opposed, Fig.3 shows the same spectrum for the protons passing through the crystal at b $\simeq$1 μm near the surface.

The comparison of Figs. 2 and 3 shows that the reduction of the mean dE/dz signal for the protons extracted with a single pass may be of order 10%, w.r.t. the protons extracted with multi-passes. The width of dE/dz peak for

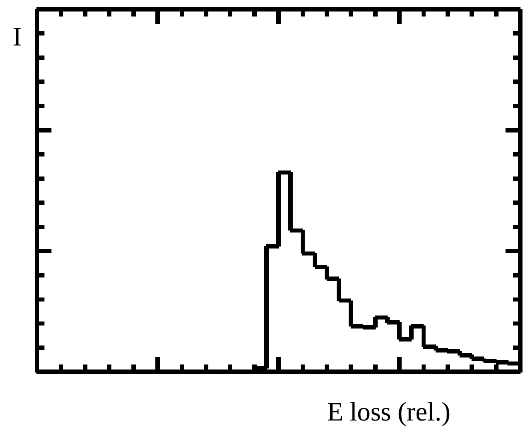

Figure 2: The energy-loss spectrum simulated for a parallel beam of protons in the bulk of Si(110) crystal.

the channeled protons is due to energetic electrons, hence it is greatly reduced for the “low-b” signal. Therefore, if the contribution of the first pass to the extraction efficiency is significant, it should be seen in the dE/dz spectrum. Ideally, this contribution may be sharply peaked, thus even splitting the dE/dz spectrum of extracted protons into the ”first-pass peak” and the ”secondary-pass peak”. If the first-pass signal were easily recognized, this would give a great deal of possibilities for research. By reducing the primary b below 1 μm, one may make the dE/dz signal even more pronounced, thus exploring the crystal at very small depths. Note that dE/dz in the secondary passes depends on the depth also, thus also providing information.

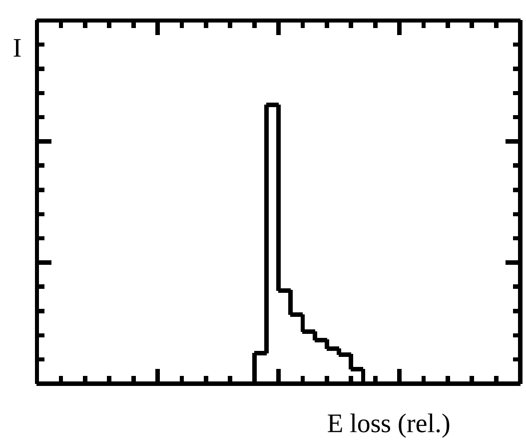

Figure 3: The energy-loss spectrum simulated for parallel protons channeled within 1 μm from the surface of Si(110) crystal.

4 REFERENCES

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[2] Particle Data Group, Phys. Lett. B **239** (1990)

[3] Biryukov V., Phys. Rev. E **51**, 3522 (1995); **52**, 2045 (1995); **52**, 6818 (1995).