WORKSHOP ON PARTICLE CHANNELING AT HIGH ENERGY

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Channeling of relativistic particles by single crystals represents an interesting conjunction between high-energy and solid-state physics. The interface between these two fields has long been recognized as important in detector systems, but in particle channeling it seems to be even more direct and symbiotic. Exploration of the status and prognosis of particle channeling at high energies was the subject of an informal Workshop at Fermilab on April 7-8, cosponsored by the State University of New York at Albany (SUNYA) and Fermilab. Descriptions of experiments carried out at CERN by an Aarhus (Denmark), Strasbourg, CERN collaboration and at Fermilab by a Dubna, Fermilab, Lehigh, SUNYA, UCLA collaboration comprised the status, while additional contributions from Dubna, SLAC, Livermore, Yerevan, and Moscow representatives added to the prognosis.

Anyone who has gotten this far without knowing what particle channeling is deserves an explanation, albeit brief. Charged particles moving through a crystal at a small angle to a row or plane of atoms experience deflections from each atom that is passed that are correlated and can add up to a gentle steering of the particle trajectory away from the row or plane (if the particle is positive) or toward the row or plane (if the particle is negative). In fact, when this occurs it is convenient and correct to consider the potential exerted by the atomic row or plane as distributed in the form of a rod (for a row) or sheet (for a plane) of charge and to calculate with classical electrostatics the particle motion in the resulting potential. Clearly, if the

transverse energy of the particle exceeds the potential, the particles are not so gently steered away and the whole picture breaks down.

This leads to the idea of a critical transverse energy or, for a given particle energy, a critical angle between the row or plane direction and the particle direction of motion. According to the electrostatic model, this critical angle depends on the inverse square root of the particle momentum-velocity product.

The new experiments demonstrate that the critical angle scales successfully from 10 keV up to the recent 250 GeV measurements at Fermilab (and presumably beyond). Such tests of scaling constitute perhaps the first reason for high-energy channeling studies. To channeling experts, not only the existence, but also the stability of channeled particle trajectories is of central importance. Here is the second--and perhaps from the channeling point of view--the main reason for doing such measurements at very high energies. Destruction of channeling trajectories (appropriately called de-channeling) comes about by multiple scattering of particles from electrons or from thermally displaced nuclei in the crystal. Multiple scattering scales in angle as the inverse of the particle momentum-velocity product; hence, as the energy increases, channeling should become more stable. Dechanneling lengths (at which half of a channeled beam is lost) should increase from tens of microns at a few MeV particle energy to tens of centimeters at 250 GeV/c. The Fermilab measurements verify this expectation.

From the channeling point of view, the increased stability of particle channeling at high energies may make it possible to see effects that would

otherwise be masked by dechanneling. For possible applications, this increased stability may also matter. One such new effect, which has been suggested by high-energy physics experiments, involves cooling of the channeled particle beam such that particles emerge from the crystal with smaller transverse energy than they had when they went in. Since "cooling" is a magic word in high-energy accelerator physics, this is interesting. Any such effect is largely discounted by channeling experts, thus providing the first controversy.

What say the experiments? Both 15-GeV/c measurements at CERN and 100-and 250-GeV/c measurements at Fermilab show the emergent distribution peaked at zero transverse energy for particles incident near a crystal axis and at angles near the critical channeling angle. Cooling? Channelers still say "not necessarily so." This could be the residue of multiple scattering (dechanneling), which can reduce as well as increase transverse energy. More analysis of present experiments or more experiments may be able to say.

If "cooling" is possible, and maybe even if it isn't, perhaps "bending" is. Since channeled particles are obviously steered through the crystal, what would happen if the channels are curved by carefully bending the crystal? Would the particles follow? Again, channeling experts think not, but the benefits could be so great that the next generation of channeling experiments will probably include tests of this possibility. The limiting radius suggested by critical channeling conditions is a phenomenal 2 cm for 100 GeV/c! Nothing is known on this yet, and it probably depends critically on the "cooling" question.

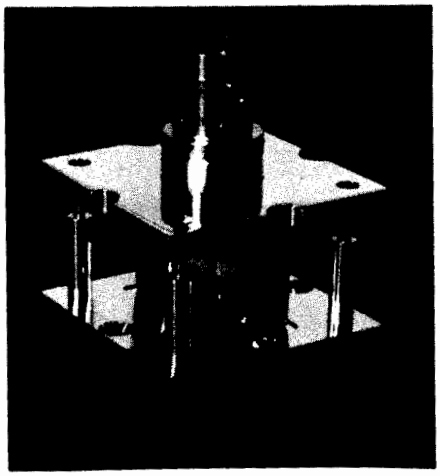
The question of energy loss is more clear but nonetheless interesting. Well-channeled positive particles lose energy in the crystal less rapidly than non-channeled particles because they are confined to the low-density regions. These differences are easy to measure if the crystal is itself a semiconductor detector. Applications for selection (or identification) of particles that are well channeled, and therefore have specific directions of motion are obvious. At energies as high as 250 GeV/c, density effects are expected to be important in the energy-loss process. These should affect non-channeled and channeled particles differently, so quantitative analysis of the ratio of the energy loss of channeled and non-channeled particles may provide a sensitive test of the theory.

One of the most interesting applications of particle channeling (actually of its complementary effect, involving particle emission from crystals called "particle blocking") is the measurement of short nuclear-decay times. Decays as short as one attosecond (10^{-18} sec) have been measured. For relativistic particles it should be possible, in principle, to go even shorter because of Lorentz contraction, perhaps as short as 10^{-20} seconds. A systematic survey of possibilities by the Aarhus group shows the η^{o} lifetime to be a promising candidate for measurement by this technique.

The newest and perhaps the most exciting possibility from high-energy channeling involves synchrotron radiation from channeled particles. Channeled particle trajectories oscillate with a short period. These curved trajectories should radiate from the turnaround point, just as particles in a

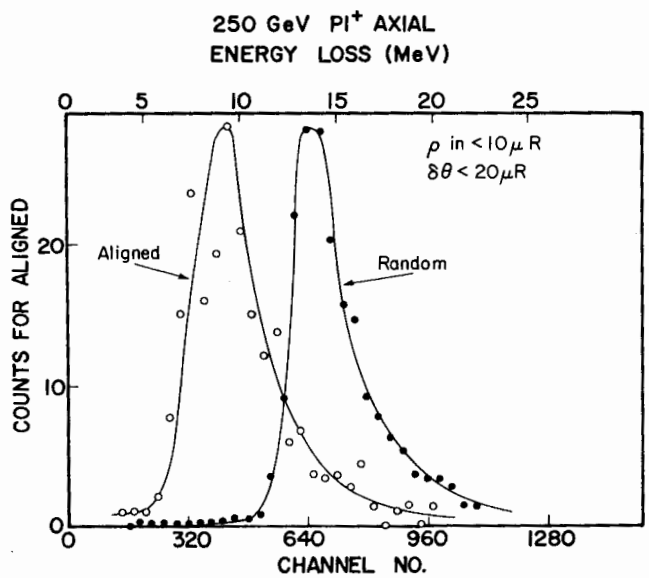
circular trajectory or in a wiggler magnet emit synchrotron radiation, except more so. The bending radius can be very small (of order 2 cm for 100 GeV/c) and for planar channeled particles the radiation should be tightly collimated along the particle direction, perhaps producing coherent interference between successive oscillations. It was generally concluded from the Workshop discussion that the radiation intensity and frequency should scale as $\gamma^{3/2}$. Many possibilities exist, most of them too speculative to discuss here. No measurements have yet been made of channeled-particle synchrotron radiation. Experiments are planned or underway at Livermore, SLAC, Saclay, Dubna, Serpukhov, and probably others. Saclay and Livermore will soon start measurements on positron and electron beams up to about 40 MeV. The SLAC, Dubna, and Serpukhov studies will go to higher energies.

Obviously it isn't yet possible to say with any conviction what high-energy channeling has to offer either for solid-state or for high-energy physics. The effect is, however, well established up to the highest available particle energies. Thus far, only two crystals have been identified as being perfect enough to use for such studies, dislocation-free germanium and silicon, because the extremely small critical angles (about 40 microradians at 250 GeV/c) require nearly perfect crystals. The experimental challenges to continue and extend these studies are formidable. The promise appears to make such efforts worthwhile.



Hyper-pure germanium crystal used for Fermilab channeling studies. The dark block on the lower plate is the crystal. Note the BNC connector for scale.

(Photograph by Fermilab Photo Unit)



Energy loss as measured in an oriented single crystal of germanium at 250 GeV. The positive particles lose much less energy in the crystal when they travel along a crystal axis.