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Proposal to Improve the Deflection of High Energy Particle Beams by Channeling in Bent Crystals of Si and Ge

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Summary

The E660 collaboration has made significant progress toward an understanding of the mechanisms responsible for deflection of high energy charged particles in bent Si crystals. One application of this technique, replacing a magnetic septum with a crystal septum, has already been demonstrated in the M-Bottom line at Fermilab.

We plan to carry out further beam bending measurements using Ge as well as Si crystals and evaluate an alternative method to produce more nearly circular curvature of a crystal by utilizing the strain field introduced in a crystal by the addition of a very thin ZnO coating. Detectors along the length of semiconductor crystals will also be tested under strain conditions. Four hundred hours of running time are requested. Ideally, we would like to continue in M-Bottom where all of the equipment is set up and ready to run.

The experiments proposed will improve the understanding of the bending mechanism as well as explore channeling phenomena at very high energies. Improved materials processing and detector performance should lead to the design and development of more efficient crystal septa.

Introduction

The deflection of a beam of charged particles moving within the planes of a bent crystal of silicon was first observed at Dubna[1] with 8.4 GeV protons and later at CERN[2] at 12 GeV. In more recent experiments at Fermilab[3-5] the intensity loss of channeled particles along the crystal bend was studied for particle momenta between 12 and 180 GeV/c.

In all of these experiments a three-point bending device was used to bend the Si crystal. At the relatively low energies used in the Dubna and CERN experiments the outgoing angular distribution of particles showed two strong peaks, one corresponding to forward particles dechanneled before reaching the bend region and the other to particles that remained channeled throughout the bend and therefore underwent a net deflection corresponding to the total bend. In the measurements made at Fermilab, similar angular distributions were found but at the higher energies (30 GeV and above) a third peak appeared intermediate in angular deflection, corresponding to particles lost at the middle pin of the bending jig where the curvature is greatest (radius of curvature is smallest). Also in these experiments, it was found that the number of particles lost before the middle pin was greater than after the middle pin. The general character of the spectrum could be accounted for from the theory for elastic bending of beams[6] coupled with channeling theory for bent crystals. To reduce the loss of particles in the bend region, a four- point bending apparatus was used [3-5] which, for the same angle of bending used with the three-point bending jig, resulted in a greater transmission of particles through the bend region because of the better approximation to a region of constant curvature.

While the beam bending measurements were being carried out, detailed channeling calculations were made [7,8] which provided some understanding of the loss of channeled particles caused by the crystal bend. Fair agreement has been found between measurements and the predictions for particle loss in the bend region as a function of bending radius and energy[3-5]. More information would be useful from the experimental standpoint, for material behaviour, and for theoretical interpretation of the results.

The Fermilab results came from E660 and test beam experiments following the completion of E660 in June, 1982. One practical application of this work was the demonstration in January 1984 that a bent crystal, mounted in a four-point bending jig, could replace a magnetic septum in the M-Bottom beamline at Fermilab[9]. Also, some basic channeling measurements were made using Si crystals that had several energy-loss detectors along the length of the crystal.

Progress in these experiments has called for the mobilization of a strong supporting program in advanced materials science and technology. We have drawn internationally upon a wide array of materials processing and characterization techniques, most recently from the two contributing laboratories with major materials R & D programs. The requirements of present and future experiments in high energy channeling and its applications continue to pose challenging problems to materials experts and will call for innovative solutions. We anticipate useful spin-off, e.g. to the development of silicon strip detectors. It is worth noting that yet another vital interface has been established between the conceptually remote disciplines of particle physics and materials science.

New Experiments

We propose to carry out more experiments both on the bending phenomenon and on studies of basic channeling phenomena.

We have recently shown that it is possible to bend Si and Ge wafers by other methods such as sputter-coating one side of the wafer with ZnO or by stresses induced by high dose implantation of low energy light ions. Since the residual strain field is uniform, the curvature which it produces is constant, that is circular, which should result in higher transmission of bent particles than those produced by mechanical benders. A test wafer of Si, 0.5 mm thick, 12 mm wide and 34 mm long, was bent permanently through an an angle of 50 mrad by a 12 μm thick coating of ZnO. No relaxation effects have been observed. We propose to make ZnO coated crystals with energy loss detectors on both ends to study the distribution of particles in channeled and random beams that travel through the bend region. This approach will call for evaluation of detector performance on strained sections of the crystal, under high energy particle channeling conditions.

Ge is also of interest for bending because, like Si, it can be produced nearly defect free and with low mosaic spread. Also, like Si, it is a semiconductor so it can have active detectors incorporated along its length. Because Ge has an atomic number much higher than Si, the critical angles for channeling are correspondingly larger. This is important for increasing the acceptance in applications. We propose to study beam bending in Ge wafers using both mechanical benders and ZnO coatings. Calculations[7)] indicate that a (110) plane in Ge should have an efficiency for bending approximately two times greater than that for Si. Studies of bending in Ge have not been made previously because energy-loss detectors on Ge will only operate satisfactorily below -150°C. However, our equipment contains the necessary apparatus for cooling crystals using a liquid nitrogen cold trap and operation of a cooled Ge detector has already been demonstrated.

We also propose to study basic channeling processes, in particular "feeding-in" and "feeding-out" (dechanneling) as high energy particles move through an unbent crystal. This can be done by fabricating several energy-loss detectors along the length of the detector. Of further interest are the same measurements but with the crystal bent in a three- or four-point bender. These measurements and their interpretation are very important in the design of more efficient crystal septa.

Equipment, Data Collection and Analysis

The equipment to be used is shown in Figure 1 and is that used for E660 and subsequent test beam experiments. The drift chambers, vacuum tube and helium bag are currently in position in the M-Bottom beam line; the vacuum chamber, goniometer and associated hardware have been returned to Chalk River for minor improvements which will be completed by December 1984. All equipment has worked satisfactorily.

The PDP 11/34 computer, tape deck, interfaces, disk drive, teletype terminal, tektronix terminal and Bison box and all necessary electronic modules are currently in place in the M-Bottom Portakamp. A list of PREP equipment is given in the Appendix. If necessary, we could share our computer with other groups using the same beam line, as was done in the spring of 1984.

In previous experiments we had to rely on Si crystals being provided by collaborators from Russia or France. We have now developed the necessary expertise to fabricate wafers of Si, as well as of other crystals, at Chalk River. Through low energy channeling techniques the crystal planes of Si and Ge crystals can be aligned to better than 0.1° with the geometrical surface of the crystal. Surface preparation of these crystals and ion implantation to make detectors along the crystal length are also done at Chalk River.

The necessary software for data collection and on-line analysis already exists. Off-line data analysis programs are running on the Cyber computers at Fermilab and at CRNL. As well, we now have running at Chalk River a copy of the Monte-Carlo simulation program[10)] used by the CERN-Aarhus channeling group.

Request

We request 400 hours of beam to make these measurements. This includes about 100 hours for aligning the crystals and 300 hours for the measurements.

During this upcoming period there will be new conditions in M-Bottom due to the background from M-Centre. We ran our apparatus during M-Centre tests last summer and appeared to have no significant problems with background. However, lack of access to the pit is a problem. To ameliorate this we will install remote controls for the horizontal position of the goniometer and the crystal anti-coincidence scintillator. This should eliminate the most annoying need for access. Parenthetically, our pit equipment operates very reliably. We may also add a modest scintillator hodoscope upstream of the first drift chamber to increase reconstruction efficiency and possibly help with background problems.

We would like this running to be broken into two or possibly three running periods and interleaved with other experiments.

We would prefer to stay in the present location in M-Bottom, if possible, since everything is set up there and we could be ready to run on very short notice. However, if it is necessary to move to another location, we could move to the downstream area of the M-Bottom pit. In such a case we would need laboratory assistance in moving the apparatus, in resurveying and in recabling about 100 channels (TDC, linear amplifiers, goniometer control, etc.).

References

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10) J.F. Bak et al., Nucl. Phys. B242 (1984) 1.

APPENDIX

PREP Equipment

Quantity	Item	Model	Supplier
1	Mini-Computer	PDP 11/34	DEC
1	Disk Drive	RK05	DEC
1	Magnetic Tape Drive	TU 01	DEC
1	Hard Copy Terminal	DECwriter II	DEC
1	Hard Copy Printer	Versatec	Xerox
1	Display Unit	613	Tektronix
1	PDP-11 Camac Interface	411	Jorway
1	Bison Interface Controller	III	Fermilab
1	Camac Crate Controller	70A (Type A-1)	Jorway
1	Camac Branch Termination Unit	50	Jorway
1	Camac Crate with Power Supply		
10	TDC units (8 channel)	2228A	Le Croy
1	Camac ADC	AD811	Ortec
1	Camac NIM Input Register	65	Jorway
3	Camac Scaler	85 A	Jorway
2	Camac Scaler	85	Jorway
1	Camac IGOR	3061	Kinetic Systems
7	NIM Crates		
2	Dual Channel Scalers	1880 A	Jorway
1	Preset Scaler	1883	Jorway

APPENDIX (cont'd)

Quantity	Item	Model	Supplier
2	Dual Channel Scalers	800	Jorway
4	Quad Discriminator Units	621	Le Croy
6	Four-Fold Logic Units	365	Le Croy
9	Dual Gate Generators	99202	Ortec
4	Dual Gate Generators	222	LeCroy
4	Fan-In/Fan-Out Units	429	Le Croy
1	Level Adaptor Unit	688	Le Croy
1	Constant Fraction Discriminator	473 A	Ortec
4	Linear Gate and Stretcher Unit	442	Ortec
1	Detector Bias Supply	428	Ortec
1	Spectroscopy Amplifier	452	Ortec
1	Gated Biassed Amplifier	444	Ortec
1	Multi-channel Analyzer	NS 600	Northern Scientific
6	Dual MWDC Power Supply	5900	HIC
2	Oscilloscopes	475	Tektronix
1	PM High Voltage Power Supply	415 B	Fluke
1	Precision Pulse Generator		BNC

SCHEMATIC LAYOUT: HIGH ENERGY CHANNELING EXPERIMENT

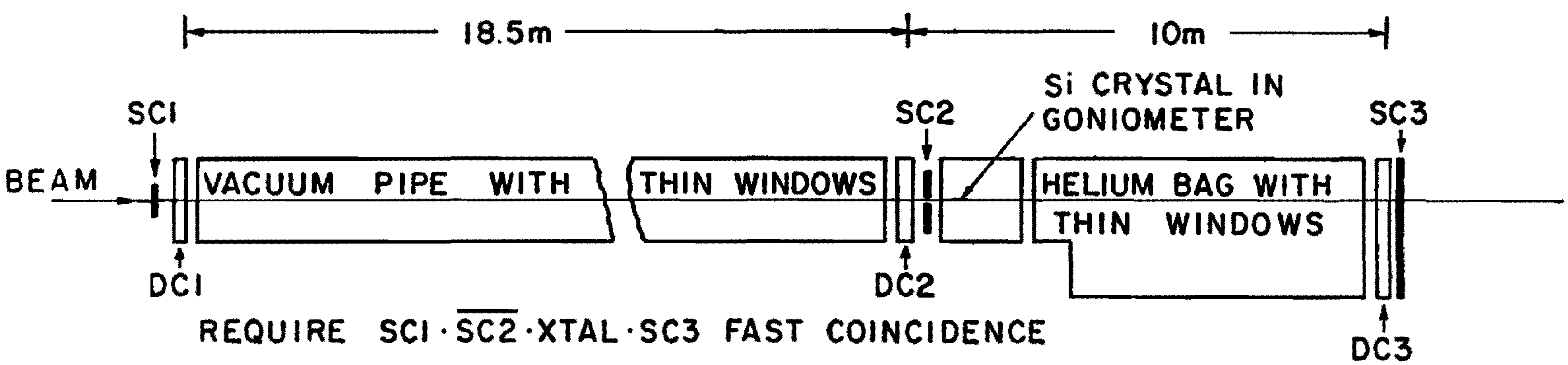

Figure 1