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PROPOSAL TO STUDY THE EFFECT OF BENT CRYSTALS ON CHANNELING NEAR THE CRITICAL RADIUS OF BENDING

R.Carrigan, S.Baker, T.Toohig, - Fermilab

W.Gibson (Spokesman*), C.R.Sun, I.-J.Kim, G.O.Williams
S.Salman, R.Wong, K.Wang -
State University of New York at Albany

Z.Guzik, T.S.Nigmanov, E.N.Tsyganov, and
A.S.Vodopianov
Joint Institute for Nuclear Research, Dubna, U.S.S.R.

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*W. Gibson's phone number is (518) 457-8333

The Spokesman responsibility will
periodically rotate between
Gibson, Sun, and Carrigan.

Summary

Our joint Soviet-Albany-Fermilab collaboration working at Dubna has recently demonstrated that it is possible to deflect charged particle beams using channeling in bent single crystals. Deflections correspond to those possible from megagauss magnetic fields. Such high equivalent fields could have significant applications to accelerators and experiments. At Dubna the radius of curvature in the crystal was twenty times the critical radius. It is important to study bending down to the critical radius, that is to the smallest possible radius of curvature. This is best done at high energy where the critical radius is larger and the net deflections are smaller.

We plan to carry out these tests of beam deflection with bent crystals using a simple apparatus consisting of three modules of electronic planes. Three hundred hours of running are requested. An ideal situation would be to use the existing E497 hyperon apparatus in P-center but other beams or setups might serve equally well.

We believe that it is important to carry out these tests quickly since if successful, they could lead to applications for accelerators and particle physics experiments.

Introduction

Channeling, the behavior of charged particle moving through the planes and rows of aligned single crystals, has been successfully observed by some of us at Fermilab[1]. (A short general perspectus on channeling is given in the proposal for E-507.) As an outgrowth of our collaboration to study channeling at Fermilab one of our colleagues, E.Tsyganov, suggested that particles moving in a crystal could be deflected by bending the crystal[2]. Tsyganov derived a critical radius

$$R_T = \frac{E}{e\,E_c}$$

where E is the total energy of the particle and E_c is the electric field intensity at the distance from an atomic plane of the crystal where the trajectory of the particle no longer remains stable due to its interaction with individual atoms. At 200 GeV for the (110) plane in silicon this radius is approximately 30 cm.

Subsequently our joint Soviet-Albany-Fermilab collaboration has observed particle deflection at 8 GeV using a bent silicon crystal at Dubna[3]. In that experiment particles were deflected up to 26 millirads using the (111) plane of a silicon crystal 1/2 mm thick and 1 cm long in the bent portion. This constitutes a bending radius of about 40 cm. The Tsyganov critical radius at that energy is 2 cm.

The effective bending power of the crystal can be expressed as an equivalent magnetic field. The Dubna experiment corresponds to an equivalent field of 800 kilogauss. At the critical radius the same crystal could give an equivalent field of about 15 megagauss. Some crystals are even better; tungsten at the critical radius could give equivalent fields of 160 megagauss.

These are extraordinary field strengths and suggest a number of applications. One possibility is the use of crystals as extraction elements in accelerators. Another possibility is to produce separated charm particle beams since a tungsten crystal can deflect a charm particle on the order of a hundred milliradians before it decays. These potential applications are reviewed in Fermilab 80/45[4].

Some of these applications require that the crystals be bent nearly to the critical radius. Therefore, it is now important that the limits of the technique be explored by measuring down to the critical radius. For crystal thicknesses that are easy to handle (1/2 mm and higher) this is most easily carried out at high energy since the critical radius is larger and the crystal easier to bend. High energy is also conveneint in that the relative deflections are smaller and more easily treated. (The beam was deflected beyond the edge of the downstream detector at Dubna so that the length of the experiment eventually had to be made smaller with concomitantly poorer resolution.)

The experiment at Dubna reached a radius twenty times the critical radius. That bending radius is equivalent to the critical radius at several hundred GeV.

These measurements may also produce valuable new insights into the channeling process since they will provide a rather different probe of the continuum model that is used for channeling theory. In particular, this type of experiment may be one of the more successful ways of studying the dechanneling process.

"Bending to the Critical Radius" Experiment

We propose to carry out the bending tests with an apparatus like that presently in P-Center for the charged hyperon experiment E-497. All of the equipment necessary for a bending experiment already exists in the hyperon set-up outside of apparatus specifically connected with crystal operation. In particular several sets of high precision, high pressure proportional plane modules and a set of large drift chamber planes with good resolution (200 microns) are in operation with all of the associated electronics and an operating on-line program.

A possible apparatus based on the E-497 configuration is shown in Figure 1. In brief the experimental set up would consist of two modules of high resolution planes each with a spatial resolution on the order of 65 microns. Each module will contain 2X, 2Y, and 2U planes and have an aperture on the order of one inch. These modules 5 to 10m apart, will establish the incident direction of a particle. They will be followed by the single crystal configured so that its bend can be changed from an infinite radius to the critical radius. A drift chamber module with 200 micron spatial resolution will be located about 30m downstream of the crystal. The position measurement from that detector coupled with the entering position on the crystal will establish the exit direction of a particle. The downstream drift module will be sufficiently large so that it will be able to detect beam deflections out to the critical radius for energies of several hundred GeV.

The experiment will be performed by aligning the crystal so that a crystal plane will lie within the angular emittance of the beam and perpendicular to the direction of bend. The plane will be detected by selecting events on a combination of small energy loss and small scattering angles. The angular width of the planar effect is on the order of twice the channeling planar critical angle. This angle changes inversely with the square root of the momentum. At 200 GeV the (110) planar critical angle is 11.5 microradians. Along the plane the transmission for low energy and small scattering angle cuts will be greatly enhanced. The crystal will then be bent. The outgoing particles in the channels will follow the bend and be deflected across the downstream detector system. Near the critical radius transmission will fall off. One of the principal objectives of the experiment will be to measure this degradation with increasing bending radius.

For the experiment we will acquire a set of oriented, thin silicon crystals fabricated so that the upstream portion of a particular crystal operates as an intrinsic semiconductor detector. This makes it possible to detect the low energy loss in the upstream portion of a crystal when particles pass along the planes or axis and permits dynamic alignment of a crystal in the particle beam. This is a technique that we have already used successfully at both Fermilab and Dubna with silicon and germanium crystals. In this measurement, we will probably use silicon detectors rather than germanium since silicon can be operated at room temperature.

We plan to obtain the crystals from a commercial vendor. This was done successfully for the 1977 Fermilab experiment. Ortec was able to deliver a specially-fabricated germanium crystal detector on a time scale of two months. Several sets of crystals with different thicknesses in the bend plane and different lengths will be obtained. We will have some backups since our Dubna experience indicates that crystals will be broken. We will also have available some tungsten crystals for tests since they may be the most promising for eventual applications.

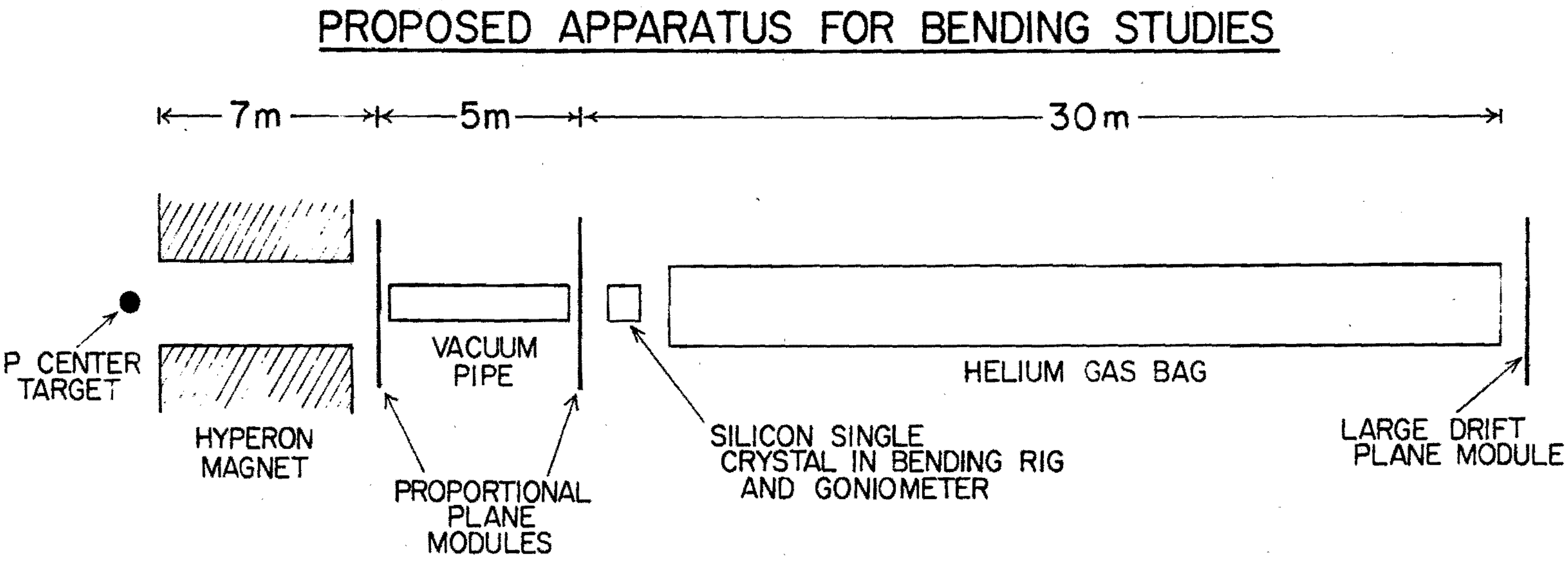

PROPOSED APPARATUS FOR BENDING STUDIES
7m
5m
30m
P CENTER TARGET
HYPERON MAGNET
VACUUM PIPE
PROPORTIONAL PLANE MODULES
SILICON SINGLE CRYSTAL IN BENDING RIG AND GONIOMETER
HELIUM GAS BAG
LARGE DRIFT PLANE MODULE

Figure 1

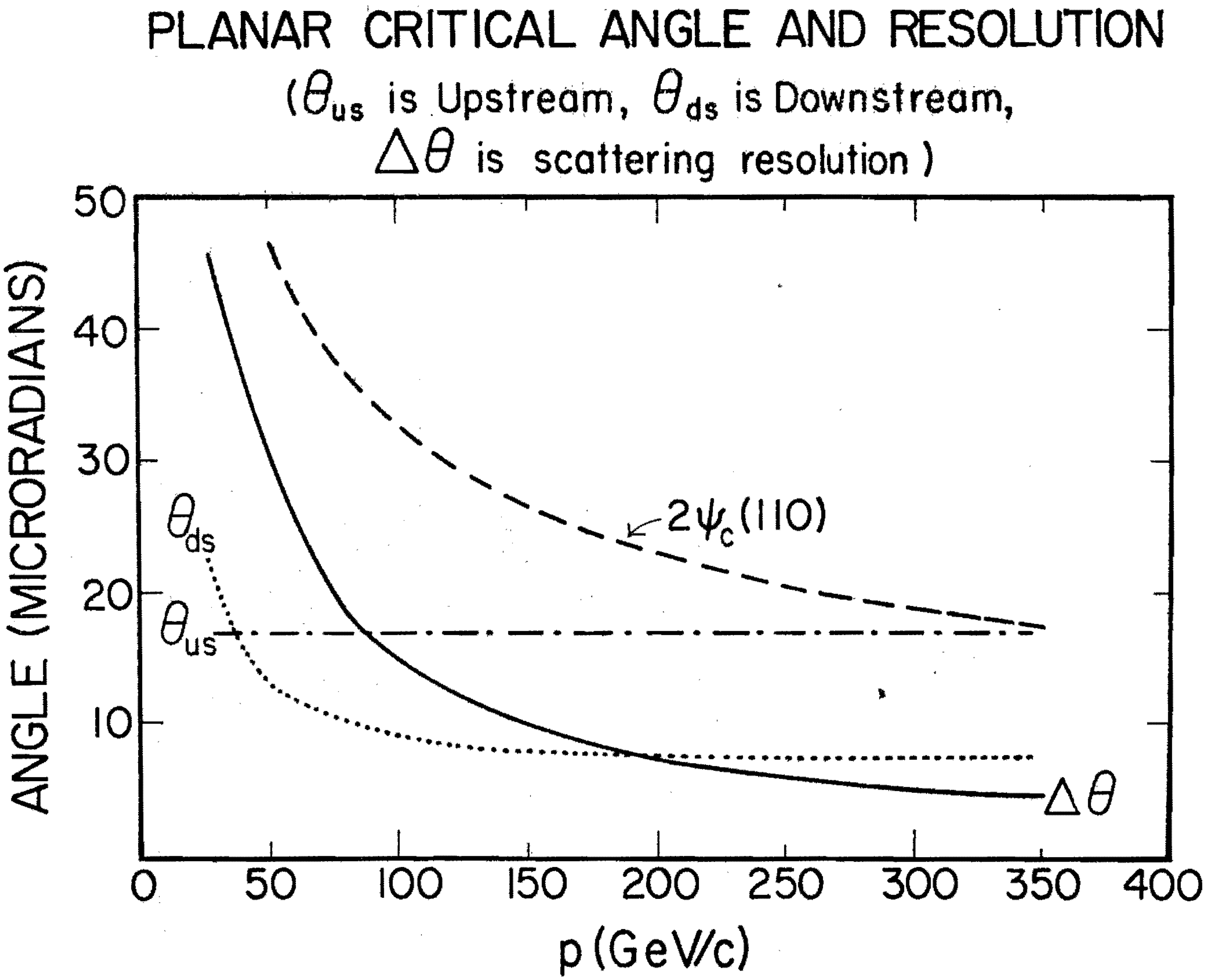
The goniometer we used at Fermilab is now in use at Serpukhov for channeling radiation studies. We have an auxiliary goniometer available at Albany that could be used. We may instead build a simple goniometer specifically intended for high energy applications where a small range of θ_x, θ_y coordinates is in some ways more practical and direct than the more flexible goniometers that have been developed principally for low energy experiments. We believe that the goniometer represents no substantial difficulty. Incorporated in the goniometer will be a bending jig along the lines used in the Dubna experiment. It should be noted that bending a modern single crystal is not a complicated operation. Breaks normally occur at approximately the stress where they could be expected. In any case, the bends required at several hundred GeV are no greater than those already achieved at Dubna. It may be desirable to enclose the entire crystal in a vacuum housing. This is no significant complication.

We intend to devote a serious effort to prealignment of the crystals. There is no reason that a crystal could not be oriented to within 20 microradians with straightforward techniques. As a check and backup procedure, the crystal will also be able to be aligned with the beam.

The beam available from the P-Center target should be satisfactory. Intensity will be no problem. In M1 the experiment operated with 300 counts per pulse in the crystal. This was enough to give satisfactory channeling runs in 2 hours. This is quite satisfactorily matched with the data taking capability of the E-497 apparatus. In P-Center, the beam intensity through the apparatus could be controlled by changing the production angle on the P-Center target.

For channeling experiments, it is often desirable to have an incident beam with a large angular divergence to fully illuminate all the features of the planes and axes. At 200 GeV, a divergence of several hundred microradians would be desirable. It is likely that this will occur naturally in the hyperon beam. If necessary, this could be increased by inserting several centimeters of lead in the hyperon beam. We know from our observations and theory that at these energies the particle mass has little effect on the channeling behavior. For that reason it is unnecessary that this test be performed in P-Center. Any positive beam operating at several hundred GeV with a flux on the order of 1000 particles/cm^2 would be satisfactory. For example, the apparatus could be set up behind another experiment in M1 or M6.

Good angular resolution is necessary to enhance the detection of the crystal planes. These have a width of approximately twice the critical angle. Three types of resolution are involved - the upstream direction resolution due to the reading error of the two upstream modules (it is assumed the intervening region is filled with a vacuum), the downstream direction resolution including the effect of a helium gas bag, and the scattering angle resolution due to the 10^{-2} radiation lengths of material in the second detector module. Figure 2 shows these resolutions as a function of energy (based on the hyperon apparatus) compared to two times the critical angle. Each is important from the standpoint of the experiment. However, for establishing a crystal plane, the most significant factors are the upstream and downstream resolutions. At 200 GeV clearly both are sufficient to resolve structure at the level of two times the critical angle, although it may be desirable to extend the lever arm of the upstream portion.



PLANAR CRITICAL ANGLE AND RESOLUTION (θ_{us} is Upstream, θ_{ds} is Downstream, $\Delta\theta$ is scattering resolution)

Figure 2

The apparatus should be able to operate satisfactorily anywhere above 100 GeV.

Requests

We request 300 hours of beam to perform these bending measurements. This includes 100 hours for dynamically aligning crystals, 100 hours for two different beam energies and two thicknesses of silicon crystals bent to the critical radius, and 100 hours of miscellaneous studies on tungsten crystals, axial channeling and negative particle bending.

We believe that these runs could be broken into 100 hour periods and interleaved with the running of other experiments. We would like to seriously consider the possibility of running some portion of these tests at the earliest opportunity since a promising answer might lead to interesting applications that could have immediate impacts on accelerator technology and particle physics experiments.

The experiment will not need much in the way of Laboratory support. The principal requirement from the Laboratory will be rigging support and a downstream helium gas bag. We will request some linear electronics and a pulse height analyzer to process the pulse height signal from the crystal. The Fermilab participants plan to ask the Physics Department for $10,000 to $20,000 spread over FY80 and FY81 for half of the cost of the crystals, magnetic tapes and miscellaneous expenses.

If the P-Center apparatus or something similar is not available, it will be necessary to construct three sets of drift chamber modules, two of which will have modest apertures. In addition, we will need an on-line computer. We believe our existing software can be converted to a new system. A full on-line philosophy was developed for the original Fermilab experiment. Essentially the same system will be used. Complete off-line software now exists.

The Albany experimenters are already funded by DOE to pursue some channeling studies.

Other Considerations

Our collaboration is currently running at Serpukhov, principally on channeling radiation. These measurements are slated to continue through calendar 80. We anticipate a net of three man months of time on that activity. Obviously the Soviet collaboration has certain non-technical difficulties. The U.S. portion of the experiment has no substantial responsibilities for analysis. We hope that our Soviet colleagues will be able to join us. However, the U.S. collaborators can operate this experiment with the present U.S. complement of people. The Albany portion of the experiment is planning to submit a proposal to BNL late this year to study the eta lifetime with a channeling experiment. The experiment would not run at BNL for some time.

We are seriously discussing the P-Center apparatus with the members of the E497 collaboration to see if the experiment is compatible with their interests. We have also be approached by others interested in channeling and may very well add additional collaborators.

If the bending process proceeds as we anticipate, one of the next steps would be to place a bent crystal in a large aperture spectrometer with a selective charm trigger to see if charm particle production could be enriched.

References

1. R.A.Carrigan, Jr., et al., Nuc. Phys. B163, 1 (1980).

2. E.N.Tsyganov, Fermilab TM-682, TM-684, Batavia, (1976).

3. A.F.Elishev, et al., Phys. Let. 88B, 387 (1979).

4. R.A.Carrigan, Jr., Fermilab 80/45 (1980).