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ON THE POSSIBILITY OF A PSI PARTICLE BEAM USING PRODUCTION CHANNELING

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ABSTRACT

The lifetime of the ψ (3105) is sufficiently long so that an energetic psi could interact with the nucleus of the next atomic neighbor. It is shown that under some conditions a significant effect could occur if the incident production particle is properly aligned with a psi production target consisting of a single crystal. Similar production channeling effects could occur for other particles at Fermilab energies.

The unusually long lifetime of the recently discovered ψ (3105)[1] suggests a tantalizing possibility. A preliminary estimate of the width of the ψ is 50 keV giving a mean life of 1.3×10^{-20} sec. A ψ with an energy of several hundred GeV will travel a mean distance of several angstroms or roughly an atomic diameter. Thus, it will be possible for a ψ produced on one nucleus to interact with the nucleus of the next atomic neighbor, giving in effect a beam-target geometry.

Coherent particle production distributions off of lead with incident particles of several hundred GeV energy give characteristic scattering angles on the order of 0.1 milliradians. For example,[2] the characteristic coherent laboratory scattering angle in pN collisions is

$$\theta_c = \frac{2\hbar c}{ER}, \tag{1}$$

where R is the nuclear radius and E is the incident energy. The half angle subtended by a heavy nucleus an atomic diameter away is on the order of 0.01 milliradians, or

$$\theta_n = \frac{R}{L}, \tag{2}$$

where L is the interatomic spacing.

A secondary particle distribution produced coherently by a primary particle in an atomic lattice will fan out over a solid angle of $(\pi/4)\theta_c^2$ while the nearest nucleus will subtend a solid angle of $(\pi/4)\theta_n^2$. If the primary particle direction is correctly aligned with the atomic lattice and the outgoing particle is channeled by the production process, the probability of striking the nucleus is

$$P = \left(\frac{\theta_n}{\theta_c}\right)^2 = \left(\frac{ER^2}{2L\hbar c}\right)^2. \tag{3}$$

(The psi decay probability has been ignored here.) The probability of collision is enhanced by high energies, large nuclear radii and small interatomic spacings. At several hundred GeV, this probability is 1% while at several thousand GeV it is 100%. This picture is critically dependent on the production process of the ψ. Many incoherent production processes would lower the probability of nearest neighbor interactions rapidly. However, other processes might result in even more highly collimated ψ production angles so that the production channeling could become important at lower energies. An example is the Primakoff effect in photoproduction.[3]

There appears to be no fundamental problem in aligning an incident particle beam with a single crystal target to better than 0.1 milliradians. Achieving alignments of 0.01 milliradians may be somewhat more difficult. At Fermilab the angular divergences in the Meson Laboratory neutral beams are now in the neighborhood of one-hundredth of a milliradian. Goniometers used for aligning single crystals for polarized gamma-ray production in electron machines are characteristically aligned to 0.1 milliradians.[4] Mosaic effects in diamonds apparently become a problem in achieving uniform alignment at about the level of 0.1 milliradians. Also, goniometer vibrations are significant at a level around 0.1 milliradians. These effects should both be amenable to selection and design. Multiple coulomb scattering of the incident beam does not present any grave technical limitation at Fermilab energies for experiments with charged particles.

Whether or not a measurable effect occurs depends critically on the psi-nucleus interaction probability. At the time of writing, the nature of the ψ remains unknown. If the ψ is a particle that interacts weakly with nuclei no significant effect will occur when it passes through the nearest neighbor atomic nucleus. On the other hand, if the ψ is an unusual two quark state containing charmed or colored quarks, it may have a nuclear interaction probability similar to a rho, making it possible for it to interact strongly with the nearest atomic neighbor. A measurable effect with a variation in crystal alignment would result if the psi was strongly absorbed or significantly rescattered.

If the psi-nucleus interaction is large and if the psi production distribution is narrow, it should be possible for a determined experimenter to see alignment effects at Fermilab. Early indications of ψ production cross sections at Fermilab suggest that samples of tens of thousands of psis could be gathered in several days running time. This implies that one per cent experiments might be possible. At several thousand GeV, an energy that is potentially accessible at Fermilab, the production channeling effects could be quite strong.

Other particles beside the $\psi(3105)$ should exhibit this effect. The requirements are a lifetime such that the particle can go at least one atomic diameter, a production distribution sufficiently narrow to effectively channel the particle to a nearby nucleus in the lattice, and a reasonable particle-nucleus interaction probability.

For accelerator energies the lifetime criterion rules out the low mass vector mesons. However, both the π^o and η^o satisfy the lifetime requirements at Fermilab energies.

The π^o and the η^o can be produced by photoproduction on complex targets. The Primakoff effect gives a sharp forward peaking in the photoproduction cross section with a characteristic laboratory angle of

$$\theta_p = \frac{1}{2}\left(\frac{m}{E}\right)^2 . \qquad (4)$$

Substantial effects will occur for production channeling when $\theta_n \simeq \theta_p$. This will occur at approximately 30 GeV for the π^o and at 120 GeV for the η^o. For both the π^o and the η^o the interaction cross section should be sufficiently large so that there is not a problem with the magnitude of the effect depending in an unknown way on the interaction cross section. Observation of an effect due to π^o or η^o production channeling might be used as an alignment tool for a single crystal prior to searching for the more problematical ψN interaction.

There seems to be no obvious reason that production channeling should not occur for any particle that satisfies the criteria. For example coherent proton scattering off a complex nucleus in a properly aligned single crystal target should exhibit a shallower forward slope because of the enhanced plural nuclear scattering.

If production channeling effects can be observed it should be possible to do a number of interesting interaction experiments with short-lived particles.

REFERENCES

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[2] G. Bellettini et al., Nucl. Phys. 79, 609 (1966).

[3] H. Primakoff, Phys. Rev. 81, 899 (1951). For a recent discussion see, for instance, G. Bellettini et al., Nuovo Cimento 66A, 243 (1970).

[4] See, for instance, U. Timm, Fortschritte der Physik 17, 765 (1969).