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VERTEX DETECTORS EMPLOYING MAGNETIC FIELDS ALONG THE BEAM AXIS

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ABSTRACT

Calculations show that a "solenoidal" geometry (magnetic field along the incoming beam direction) has a number of advantages over more conventional geometries for a vertex detector. The detectors themselves are no more difficult to build than those for a conventional geometry and the magnet, while large, is not prohibitive in cost and is probably competitive with those employing other geometries.

Introduction

One large class of problems at NAL will be the measurement of the properties of low-energy recoil particles or resonant states. Considered as a group, these typically carry a transverse momentum of less than 0.6 GeV/c and are produced at large angles to the forward direction. The Q of the resonances relative to their production kinetic energy is such that the azimuthal angle of many of the individual decay particles is only weakly correlated with the production plane. A magnet with field perpendicular to the incoming beam will have serious azimuthal angular biases due to differences in measuring accuracy as a function of angle. These will of necessity leave holes in the angular distribution needed to evaluate density-matrix elements. A magnetic field along the beam direction greatly alleviates this bias. It measures directly the transverse momenta of the particles, which is often a crucial parameter in identifying an event. It therefore seemed worthwhile to evaluate the feasibility of making measurements by an applied magnetic field along the beam direction.

In brief, the conclusion is that it is perfectly feasible to make sufficiently accurate measurements in such a geometry. The magnet would be large and expensive but perhaps not out of line with more conventional vertex magnets being considered. It would be possible to use in conjunction with a downstream spectrometer to measure the high-energy forward particles. It should be emphasized that the purpose of this note is not to advocate building this device over some other arrangement. Insufficient calculations have been made to justify such a position either on a physics or a financial basis. The purpose is merely to write down certain properties and delineate the limits of a solenoidal-field magnet as a vertex-measuring instrument.

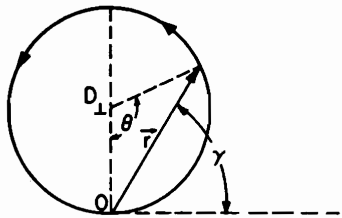
Trajectory Equations

Suppose we set up a polar coordinate system r, Z, γ whose origin is the particle origin. Then for a field in the Z direction the trajectory for a particle is

$$r = D \sin\alpha \sin\gamma$$

$$Z = \gamma D \cos\alpha,$$

where α is the original angle of the particle to the Z direction and D(m) = 2p(GeV/c)/ 0.03B (kG). We will also use $D_\perp = 2p_\perp/0.03B = D \sin\alpha$. Note that the angle of rotation $\theta = 2\gamma$. We can easily devise an equation



for the error in the measurement of D (and hence p) due to errors in R, Z, and γ

$$\frac{\delta D}{D} = \frac{1}{D^2}\left[\frac{r}{\sin^2\gamma}\,\delta r + \frac{Z}{\gamma^2}\,\delta Z - \left(\frac{r^2}{\sin^3\gamma} + \frac{Z^2}{\gamma^3}\right)\delta\gamma\right]$$

As would be expected the error in D is enormous for small values of γ and also for γ near nπ. Perhaps it is more enlightening to rewrite the above expression as

$$\frac{\delta D}{D} = \sin^2\alpha\,\frac{\delta r}{r} + \cos^2\alpha\,\frac{\delta Z}{Z} - \left(\frac{\sin^2\alpha}{\sin\gamma} + \frac{\cos^2\alpha}{\gamma}\right)\delta\gamma\,.$$

Let us assume we wish to measure D to about 1-2% which is sufficient for most recoil experiments and consistent with errors which can reasonably be expected to be present due to multiple scattering and energy loss of these low-energy particles. Then for any reasonable sized magnet, the terms in δr and δZ can certainly be easily made unimportant. The third term in δγ is the equivalent of the sagittal or bending-angle measurement. If a continuous detector, like a bubble chamber or streamer chamber, is used, one is basically making a sagittal measurement. For γ less than ~1 radian $\sin\gamma \simeq \gamma$ and the last term becomes $\delta\gamma/\gamma$ which is approximately $\delta\ell/\ell$ where ℓ is the sagitta. Thus, $\delta\ell/\ell \simeq 0.01$ is the desired accuracy. For a streamer chamber, a conservative estimate for $\delta\ell$ is ±0.5 mm and the lower limit on ℓ is therefore 5 cm. If we visualize a large but feasible magnet of 1 meter radius with a 20-kG field, momenta up to 1.5 GeV/c can be measured to about 1% accuracy.

For ordinary wire spark chambers of proportional planes, similar accuracies can be attained, and the analysis given above is still valid. It is, however, possible to optimize the system somewhat. One would like to minimize the numbers of data-recording elements that are required to be read out. The geometry is such that for a given spatial resolution the number of such elements needed is small near the axis and very large at the periphery of the solenoid. Thus, one might think of high-resolution detectors on the incoming beam and immediately outside the LH_2 target which define very well (to ~±50μ) two positions and therefore the azimuthal angle of the particle. The incoming angle and outgoing position are then used for the momentum measurement. The same accuracy as in the previous analysis (1% at 1.5 GeV/c) is obtained with relaxed requirements on the peripheral detectors of a factor of 4 to ±2 mm. Accuracies of ±2 mm on the r and Z measurements are sufficient to define α to 3 mrad. In light of the multiple scattering at these energies higher accuracy is not warranted except under special circumstances. With ~10^4 total detector elements measurements can be made to the desired momentum and accuracy.

Whether used with a streamer chamber or proportional chambers, the cost of a spectrometer of the solenoidal type will be largely in the magnet. A 2-meter diameter pair of superconducting Helmholz coils 2 m apart operating at 40 kG central field were estimated to cost about $1,000,000 complete with refrigerator. Perhaps another $250,000 would be needed for detectors. For this you buy a very large solid angle vertex detector with low transverse momentum bias.

A closer look at this geometry seems warranted before large investments are made in vertex devices with other field configurations.