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SOME NOTES ON THE USE OF DISC CERENKOV COUNTERS FOR BEAM SURVEYS AT NAL

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These (not very profound) notes are based upon existing literature on DISC counters [1-3] and conversations with G. Giacomelli, who participated in the recent CERN-IHEP beam survey at Serpukhov.

Design Parameters of the DISC

There are only 3 parameters in the design of the DISC:

1. The useful aperture of the DISC. This should be ~ the aperture of the beam quadrupoles, which we take here as 4 in. diameter

2. θ, the Cerenkov angle

3. $\delta\theta$, the angular aperture of the light acceptance diaphragm are related by the expression

$$\tan\theta \ \delta\theta = \frac{\Delta\beta}{\beta},$$

where $\Delta\beta/\beta$ is the velocity resolution achieved by the counter. We take as our severest case the separation of π's from K's at 200 GeV/c--this should be comfortably in excess of anything we would require in practice. If the Cerenkov light from K's falls in the center of the diaphragm, we require that the light from π's be one aperture width away. It can then be shown that

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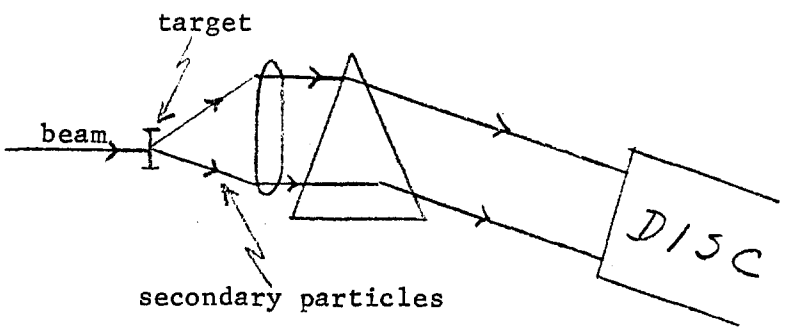
$$\tan\theta\ \delta\theta = \frac{\Delta\beta}{\beta} = \frac{1}{\gamma_K^2} - \frac{1}{\gamma_\pi^2} = 2.5 \times 10^{-6}$$

It is difficult to make $\delta\theta$ much less than 0.1 mrad (see later) and so we take $\delta\theta = 0.1$ mrad, and then $\tan\theta \approx \theta = 25$ mrad.

The choice of $\delta\theta$ can also be affected by properties of the beam in which the DISC is to be used, since all particles passing through the counter must be parallel to its axis to within $\pm\ \delta\theta/2$, otherwise the DISC performance (efficiency and resolution) will be impaired. This gives some severe limitations on the design of the beam in which the DISC is to be placed, although we will not discuss this in detail here. We point out two simple effects. In the arrangement shown in the figure, where we have a lens producing a parallel beam through the DISC,



particles emitted from the target not on the axis (due to the finite spot size of the incident beam) will not go through the DISC parallel to those emitted on the axis. Similarly, particles of momenta not equal to the central value will be deflected different amounts by the magnet. In both cases, if the deviation from the central direction is greater than

$\pm\ \delta\theta/2$, the particle will not be counted.

(We may note that at the momenta we are considering, the change in β due to a finite momentum spread is not relevant. Using the relation

$$\frac{\Delta p}{p} = \gamma^2 \frac{\delta\beta}{\beta}$$

we find that for a 200-GeV/c K, a 5% momentum bite produces a spread in β of $\approx 0.3 \times 10^{-6}$, which is considerably smaller than the resolution 2.5×10^{-6} required to separate K's from π's.)

An inefficiency of the DISC can of course be measured: in high momentum negative beams, which consist almost entirely of pions, a determination of TC/T, where T = counts in the defining telescope, and C = counts in DISC, gives the efficiency. At lower momenta, or in positive beams, we would need a threshold Cerenkov counter set to count π's for determining efficiency.

Length of DISC

An empirical relation for the length L is derived in Ref. 1:

$$L(\text{cm}) = \frac{0.4}{\theta^2} \quad .$$

This gives a length of 6-1/2 meters for $\theta = 25$ mrad. However, the above relation assumed the use of 56 UVP photomultipliers in the counter, and we can now use the newer bialkali photocathode tubes, such as 56 DUVP, which have a factor ~ 2 better photocathode efficiency. The length can thus be reduced to a conservative 4 meters or less.

Gas Pressure

We take the lower velocity limit as 20 GeV/c $\bar{p}$, in order to compare with results at AGS energies. For 25 mrad Cerenkov angle, this requires a CO_2 gas pressure of ~ 55 psi absolute. Since we often have to evacuate the counter, the lower pressure limit is 0 psi absolute. The counter body and windows have thus to be constructed strong enough to withstand this pressure range.

Dimensions of DISC

We have arrived at a possible design for a DISC of

aperture: 4-1/2 in.

θ: 25 mrad

$\delta\theta_{minimum}$: 0.1 mrad

useful length: 4 meters.

Using the design for the DISC shown in Ref. 2, we can show that the radius of curvature of the spherical mirror is ≈ 8 meters and its full aperture ≈ 32 cm; the photomultipliers are on a circle of radius ~ 10 cm. The smallest diaphragm aperture of $\delta\theta$ = 0.1 mrad corresponds to a diaphragm opening of ~ 1/2 mm, which may cause some mechanical problems. This can only be eased by increasing the length and diameter of the counter.

Electronic Logic

The CERN DISC used at Serpukhov had 9 photomultipliers; for the highest resolution (separating K's from π's at 55 GeV/c) the outputs

were put into 9-fold coincidence, giving the highest rejection but an efficiency of only ~30%. The next best resolution was obtained by 6-fold coincidence of 1+2, 3, 4+5, 6, 7+8, and 9 where the numbers designate the tubes around the diaphragm and + means passively adding tube outputs; the efficiency was ≈ 60%. Higher efficiency and poorer resolution was obtained with the triple coincidence 1+2+3, 4+5+6, and 7+8+9. The particular combination used at any time depended on the resolution required -- at higher momenta, of course, more resolution is needed.

The IHEP DISC had 12 photomultipliers; this may be better as there are more possible combinations of outputs.

Testing of a DISC

In Ref. 2, the CERN DISC was tested in a pion beam of 11 GeV/c and showed that separation between π's and μ's could be achieved. To test the resolution in this manner for a counter with $\Delta\beta/\beta = 2.5 \times 10^{-6}$, we would need a pion/muon beam of ~40 GeV/c. However, even with a beam of ~25 GeV/c, satisfactory tests of performance can still be made (for instance by a study of the shape and width of the pressure curves).

Performance of Existing DISCS

It is reassuring to note that at Serpukhov, the CERN DISC performed as calculated, with $\Delta\beta \leq 10^{-5}$ where the calculation gave 9×10^{-6} (it could have separated K's from π's at ~100 GeV/c). Prior

to the run, computer calculations were made to determine the axicon position, and these calculated values were used in the experiment. (The axicon need only be moved for large variations in β; at 55 GeV/c, no axicon change was needed between π^- and $\bar{p}$.)

The Serpukhov experiment showed that good beam optics were extremely important for getting the best performance from the DISC, as also is extreme care in DISC mechanical construction. The CERN counter performed better than that of IHEP because of this.

Miscellaneous

Carbon dioxide gas was used as the radiator at Serpukhov; helium or hydrogen may be better in some applications.

When the DISC is used for beam particle identification (for example, in a total cross-section measurement), it is advisable to anticoincidence π's when counting K's. It may be possible to put photomultipliers in the DISC at a larger Cerenkov angle than the main tubes and use them in anticoincidence, though there are a number of mechanical difficulties, and it has not been done on existing DISCS. At Serpukhov, threshold Cerenkov counters were used to anticoincidence π's and probably can be used also at NAL energies.

REFERENCES

[1] O. Danielsson et al., CERN Report ECFA 67/16 Vol. I, p. 357 (1967).

[2] P. Duteil et al., Rev. Sci Instr. 35, 1523 (1964).

[3] J. Allaby et al., CERN Report NP/Int 66-2 (1966).