THREE-COMPONENT SEPARATION OF ULTRA-HIGH ENERGY PARTICLES

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Abstract

Some theoretical problems of separation of ultra-high energy particles are considered. The separation of wanted kinds of particles in a three-cavity separator for beams with two kinds of unwanted particles is investigated as a function of intercavity distances for a wide range of particle momenta up to 200 GeV/c. When four cavities are used, it is possible to separate heavy particles in beams with antiprotons, kaons, and pions. A computer programme was written to calculate muon contamination in pure beams of ultra-high energy particles.

1. Introduction

Radio-frequency separators of two or three deflectors are used to separate beams of high-energy secondary particles. The drift space between the sections is proportional to the square of the momentum of the particles, e.g. the space of 2795 m is necessary with $\lambda = 3.2$ cm when separating particles with p = 140 GeV/c momentum by means of a two-cavity separator. The three-cavity system permits one to reduce the drift length to 1800 m with the same λ[1], i.e. an intermediate cavity decreases the length by about 1000 m. Therefore the influence of the number of cavities upon the maximal momentum of separated particles and/or upon the reduction of intercavity space must be thoroughly investigated.

2. Particle dynamics in a separator with "n" cavities

The following initial assumptions were made: the phase shift of particles with respect to the wave τ, power attenuation q, input displacement X_0, and deflection X_0', are neglected; the transfer matrix between the cavities is $M = \begin{pmatrix}-1 & 0\\ 0 & -1\end{pmatrix}$. The deflection angle of separated particles is given by Eq. (1), the unwanted particles of the two other kinds not being deflected irrespective of the initial phase:

$$x' = \bar{X}'_{max}\, B \cos(\phi_0 - \delta)\ , \tag{1}$$

where $\bar{X}'_{max} = eE_0L/pc\beta_\phi$, E_0 = maximal (by breakdown condition) equivalent deflecting field in one of the cavities, L = length of the waveguide, p, β_ϕ = particle momentum and velocity, ϕ_0 = input phase; B = amplitude function for the separator with "n" deflectors, which may be written in the following form:

$$B = \left[\sum_{h=1}^{n} D_h^2 + 2\sum_{j=1}\ \sum_{h=j+1} (-1)^{j+h} D_j D_h \cos\left(\psi'_{1j} + \psi'_{1h}\right)\right]^{\frac{1}{2}} \tag{2}$$

where n = total amount of sections, j, h are the serial numbers of the cavities, ψ'_{1j}, ψ'_{1h} are total dephasings of j, h cavities with respect to the first deflector [these dephasing expressions are given elsewhere[2-4]]; $\psi'_{11} = 0$, $D_{h,j} = E_{h,j}/E_0$, where $E_{h,j}$ are the amplitudes of equivalent deflecting fields in the h^{th} and j^{th} cavities, respectively.

The ratio of the fields in the two sections may be expressed through the field ratios in other sections, which are the free parameters, and through the dephasings of sections for unwanted particles. If antiprotons are chosen to be separated, then K and π mesons are unwanted, and D_2, D_3 may be expressed as follows:

$$D_2 = \frac{D_1 \sin\psi'^K_{13} + \sum_{h=4}^{n} (-1)^h D_h \sin\left(\psi'^K_{1h} - \psi'^K_{13}\right)}{\sin\left(\psi'^K_{13} - \psi'^K_{12}\right)} \tag{3}$$

$$D_3 = \frac{D_1 \sin\psi'^K_{12} + \sum_{h=4}^{n} (-1)^h D_h \sin\left(\psi'^K_{1h} - \psi'^K_{12}\right)}{\sin\left(\psi'^K_{13} - \psi'^K_{12}\right)} \tag{4}$$

When n = 3, these formulae are transformed into well-known expressions for amplitude function and field ratios for a three-deflector separator[3].

Figure 1 shows the amplitude functions when separating antiprotons in systems of three, four, five, and six deflectors, the fields in cavities for each momentum being chosen in a such way that the amplitude function is maximal. The drift space between the first and last sections ℓ_{1n} was taken equal to 1800 m (n = 3, 4, 5, 6); the sections are located equidistantly [i.e. $\ell_{h,h+1} = \ell_{1n}/(n-1)$, where $\ell_{h,h+1}$ is the distance between the adjacent sections (h = 1, 2 ... n - 1)]; the wavelength is $\lambda = 3.2$ cm.

The table gives the values of maximal momenta p_{max}, for which the separation is possible, as well as the increase in particle momentum compared with a three-cavity system, Δp_{max}, and the reduction of the drift length $\Delta\ell_{1n}$ of the multi-cavity system with respect to a three-cavity separator with the same maximal momentum p_{max}.

Table 1

Number of section	p_{max} GeV/c	Δp_{max} GeV/c	$\Delta\ell_{1n}$ m
3	205	-	-
4	234	29	420
5	234	29	420
6	240	35	490

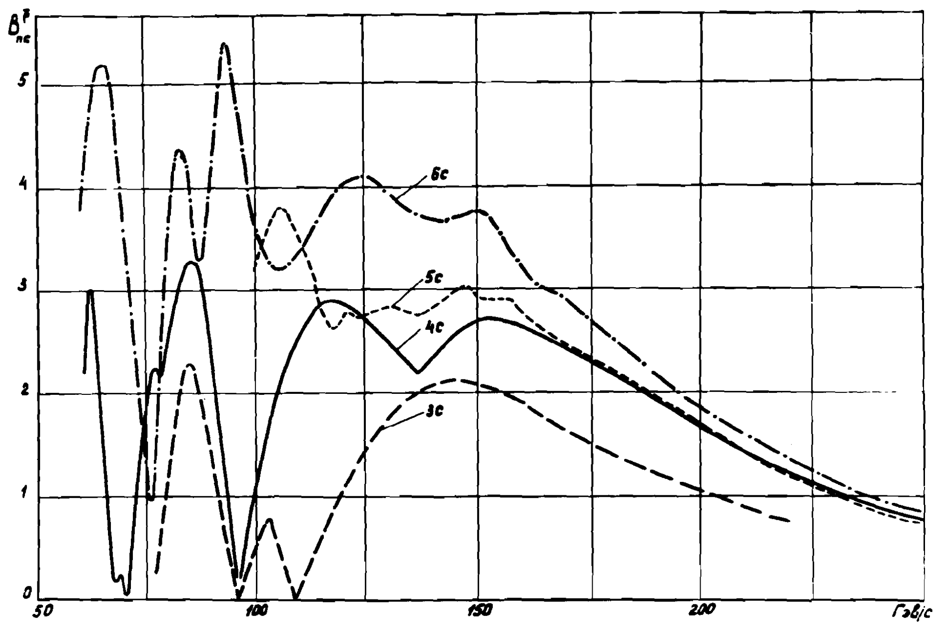

Fig. 1

It may be seen from Fig. 1 that separators with $n > 3$ have better characteristics because of higher values of B and have higher p_{max} compared with three sections. Moreover, the drift length of such separators may be substantially reduced (see Table 1).

In our opinion the most promising is the separator with four cavities which is not worse than a five-cavity system with respect to p_{max} and $\Delta\ell_{1n}$. The separator with $n = 6$ has somewhat better parameters than a four-cavity system but it is hardly worth while to introduce two additional sections to achieve a 6 GeV/c increase in p_{max} or to decrease the ℓ_{1n} by 70 m as compared with a four-cavity system.

3. On the possibility to use a four-cavity separator in search of new particles

There exist a number of theoretical works that point out the possibility of the existence of quarks, anti-nuclei, and other particles, including stable particles, which may have an integral as well as sub-integral charge.

We suggest a system which allows one to obtain an almost pure beam of new particles (denoted as X particles) by separating them from a beam of π, K, $\bar{p}$, and X particles. The principle of its operation is the following. The first three waveguides and the first beam stopper act as a common three-cavity separator. Here the unwanted particles are K and π mesons having zero deflection after the third cavity and being stopped at the beam stopper Π_1. The drift length ℓ_{13} and the phasing of the first three sections are chosen to maximize the deflection of X particles for a particular design momentum p_0. Therefore, after the first beam-stopper a two-component beam consisting of $\bar{p}$ and X particles remains. The elimination of antiprotons is achieved by means of the fourth cavity, the excitation of which is determined by the angle of antiprotons after the third cavity. The second beam stopper Π_2 removes the rest of the antiprotons from the beam. The drift space ℓ_{14} and the phasing of the fourth cavity with respect to the first cavity are determined by the conditions of maximum deflection angle of X particles with the rest energy W_{0X} and the elimination of $\bar{p}$ deflection after the fourth section for the design momentum p_0:

$$\ell_{14} = \frac{\lambda}{\pi}\left[(\delta^{\bar{p}} + \delta^{x}) - \pi(2m+1)\right]\frac{p_0 c}{W_{0x}^2 - W_{0\bar{p}}^2}\,, \qquad m = -1, -2, \ldots \tag{5}$$

$$\psi_{14} = -\delta^{\bar{p}} - \frac{2\pi\ell_{14}}{\lambda}\left[1 + \frac{1}{2}\left(\frac{W_{0\bar{p}}}{pc}\right)^2\right], \tag{6}$$

where $\delta^{\bar{p},X}$ are the initial phases for which the deflections of $\bar{p}$ and X after the third section are maximal and defined by:

$$\mathrm{tg}\,\delta^{\bar{p},x} = \frac{D_2 \sin\psi_{12}'^{\bar{p},x} - D_3 \sin\psi_{13}'^{\bar{p},x}}{D_1 - D_2\cos\psi_{12}'^{\bar{p},x} + D_3\cos\psi_{13}'^{\bar{p},x}}\,. \tag{7}$$

As an example, the parameters of the system with $W_{0X} = 4.85$ GeV/c, $p_0 = 28$ GeV/c, $\lambda = 10.5$ cm, were calculated. We have obtained $\ell_{12} = 17.5$ m, $\ell_{13} = 35$ m, $\ell_{14} = 61.33$ m.

Figure 2 shows the amplitude functions B for particles with rest energies $W_{0X} = 2, 3, 4,\ 4.85$ GeV. It may be seen from these curves that this system may have reasonable characteristics of separation in a

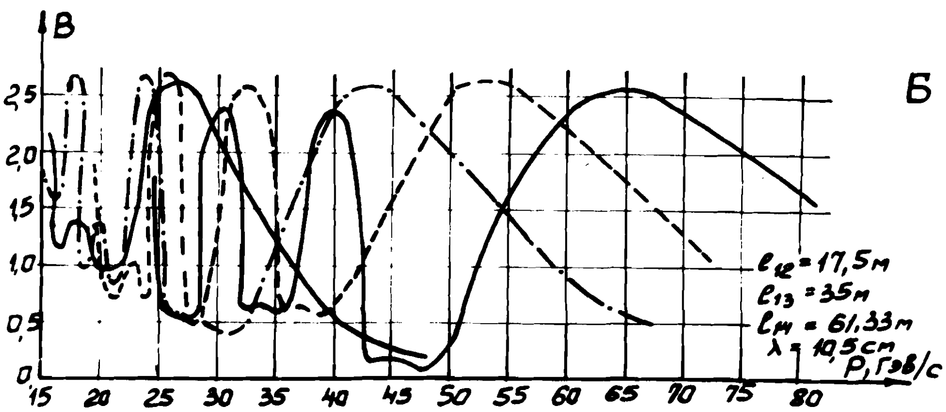

Fig. 2

broad range of momenta and a good regulation capability about the design momentum p_0 = 28 GeV/c. Besides, Fig. 2 shows that a separator with the above drift spaces is well adapted for separation of particles with W_{0X} = (45-90) GeV/c.

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References

1) B.N. Babkin and A.A. Glazkov, "Accelerators", M. Atomizdat 1970, issue 12, p. 148.

2) A.A. Glazkov and B.N. Babkin, "Techn. Phys." USSR. 40, N 3, p. 283.

3) P. Bernard, P. Lazeyras and H. Lengeler, "Particle separation with two- and three-cavity RF separators at CERN", CERN 68-29 (1968).

4) O.A. Valdner and A.A. Glazkov, 7th Int. Conf. on High-Energy Accelerators, Yerevan (1969), Vol. 1, p. 525.