SOME NEW POSSIBILITIES FOR RF-SEPARATION AT CERN

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Abstract

A number of improvements have been performed on the RF-separator, enabling more sophisticated applications and an extension of the separation towards lower and higher momenta. We have separated π^- at 4 GeV/c by using the method of phase slip in a single deflector. By combining the phase slip method with the normal two-cavity separation, rejection of deuterons during K^+-separation between 6 and 16 GeV/c has been achieved. Separation of the 16 GeV/c K^- from π^- has been successfully performed by using an inter-cavity distance of only 22m. This shows that separation with phase differences between wanted and unwanted particles as low as 30° is possible, and, for a given inter-cavity distance, allows separation to much higher momenta than performed up to now.

At CERN we have designed and constructed new deflectors[1] for the RF-separator which, compared to the old ones, have several advantages. They accept safely the 20 MW RF-power available from the klystron amplifiers and their high-frequency properties have been greatly improved by the use of new techniques for the tuning of the disk-loaded waveguides and the mode transformers (couplers). In combination with a very simple and reliable technique for joining short sections of disk-loaded waveguides this allows the construction of very long deflectors with highly uniform deflecting fields and phase velocity. We, therefore, were lead to re-consider the idea of a one-cavity separator which was advanced already in · 1959 by Blewett[2] and Montague[3]. For our momentum range it was quite natural to combine this "phase slip" method with the two and three-cavity separation, hitherto used for RF-separation (cf. also ref. 4). Both possibilities were successfully applied at CERN for several bubble chamber experiments.

1. One-Cavity Separation (Phase Slip Method)

(For details see the original papers and e.g. ref. 4 and 5)

If the particle velocity v is different from the phase velocity v_ϕ of the deflecting wave, a phase slip occurs between particle and wave which reduces the amplitude of deflection. For a constant deflecting field A(z) = A one obtains for the reduction factor F

$$F(\tau_\ell) = \frac{\sin \tau_\ell/2}{\tau_\ell/2} \qquad (1)$$

where $\tau_\ell = \tau_\ell(v, v_\phi)$ is the phase slip between wave and particle over the deflector length ℓ. In the case of an exponentially decaying field

$$A(z) = A^{-\alpha z} \qquad (2)$$

$\quad \alpha$: voltage attenuation coefficient (Np/m)

the expression for F becomes more complicated but (1) remains a good approximation[5] for not too high values of $\alpha\ell$. (For the calculation of τ_ℓ, cf.

reference 5). The function $F(\tau_\ell)$ has zeros for $\tau_\ell = 2N\pi$. Thus, if the difference in phase slip can be made $2N\pi$ for two kinds of particles, one can make the deflection of the wanted particles (velocity v_w) a maximum by equalizing $v_w = v_\phi$. The deflection of the unwanted particles will then be zero and this independently of its entry phase ϕ.

Generally, the difference in phase slip for two particles ("a" and "w") over the deflector length ℓ, τ_ℓ^{aw}, will be far less than 360°. One then can change the phase velocity v_ϕ until for the unwanted particles "a" one has $\tau_\ell(v_a, v_\phi) = 360^\circ$, thus obtaining for the final deflection D_a of unwanted particles.

$$D_a = 0 \qquad (3)$$

For the wanted particles the phase shift then will be

$$\tau_\ell(v_w, v_\phi) = 360^\circ - \tau_\ell^{aw}$$

and their deflection will be reduced by the factor

$$F(360^\circ - \tau_\ell^{aw}) = \frac{\sin(360^\circ - \tau_\ell^{aw})/2}{(360^\circ - \tau_\ell^{aw})/2} \qquad (4)$$

Using this method, one not only fulfills the crucial condition $D_a = 0$, but the difference in the final deflection between wanted and unwanted particles is higher because the function $F(\tau_\ell)$ varies rapidly near the points $\tau_\ell = \pm 360^\circ$. If the intensity of unwanted particles is comparable or even lower than the intensity of wanted particles, one can relax the condition $D_a = 0$ and obtain higher deflections of wanted particles.

The advantage of this type of separator lies in its simplicity. It is possible to use just one deflector of a two or three-cavity separator for this kind of separation. This possibility has been applied in the CERN RF separated beam for the separation of 4 GeV/c π^+ by using our normal 3,50 m deflectors (λ = 10,5 cm). A more detailed study[5] shows that under actual CPS-conditions one can separate in this beam with a single 6m-deflector.

π^+ between ~ 4 and 12 GeV/c

$\bar{p}$ between ~ 4 and 10 GeV/c

d between ~ 4 and 14 GeV/c

thereby extending the lower limit of the separation range[6] for these particles from ~ 7 GeV/c to ~ 4 GeV/c. For kaon-separation in bubble chamber exposures one generally has to reject protons and pions and the phase velocity "bias" cannot be applied. As a consequence the difference in phase slip $\tau_\ell^{p\pi}$ has to be of the order of 720° which, for the CERN RF separator, leads to separation momenta well below 4 GeV/c where the decay losses become overwhelming.

2. Combination of the Phase Slip Method with the Normal Two-Cavity Separation

It is clear that in a two-cavity separator one should always try to get for the wanted particles $v_w = v_\phi$. At lower energies this condition alone is already sufficient to reject the deuterons and the protons. But there exist momenta regions where only a judicious use of the phase slip method can make separation possible or at least can improve it. As a first example we consider the problem of deuteron-rejection in a bubble chamber beam. In a CERN bubble chamber experiment with 16 GeV/c -K^+, a contamination with deuterons of 7% was found. The separation was done in the U5-beam with a two-cavity separator using an intercavity distance $L_{12} = 50$ m. The deflector length is 3.5 m. In Fig. 1a the vector diagram for this separation is shown. The dephasing between protons and pions over L_{12} is different from 2 $N\pi$, and it is, therefore, not possible to cancel completely the deflection of these particles. As to the deuterons, their final deflection turned out to be even higher than the one for the kaons. Their deflection is reduced in the following way. The phase velocity in both deflectors is changed until the phase shift conditions of Fig. 1b are obtained. By applying the corresponding reductions in deflection to the vector diagram, one obtains the vector diagram of Fig. 1c. As one can see, D_2^d now is reduced nearly to $D_2^K/2$. This should bring the deuteron contamination will below some percent. One has to pay for this improvement by a reduction in acceptance of about 40% which, considering the K^+-intensities available, does not seem to be prohibitive. Obviously there is no need to make $D_2^d = 0$ (or $\tau_\ell^d = 360°$) because D_2^p and D_2^π are also different from zero, and this would reduce the acceptance unnecessarily. This method has been used for about 500,000 bubble chamber exposures showing an unmeasurable contamination with deuterons.

As a second example, we consider $K^\pm$-separation below 8 GeV/c. In a two-cavity separator there exist only a few isolated points where this separation is possible. One gives to the protons a phase slip of 360° in both cavities, so that they are no longer deflected and then remains with the problem of rejecting with the two-cavity separation only the pions. This can be done over large momentum ranges. In Fig. 2 the separation conditions are indicated for 6 GeV/c $K^\pm$ separation. Due to the 360° phase slip of the protons the kaon deflection also is reduced (F = 0.35), but there remains enough deflection to use the full acceptance given by the beam.

In the near future we intend to separate deuterons around 11 GeV/c. In two- or three-cavity separation there is no momentum where the deflection of protons, pions and kaons is simultaneously zero as it should be for deuteron separation. The best conditions which can be found in this momentum region are shown in the vector diagram of Fig. 3a. The final deflection of kaons is more than 50% of the final deflection of deuterons, which leads to very small acceptances. Things again can be improved by the phase-slip method as shown in Figs. 3b and 3c.

A "bias" of 130° is chosen which should given the high quality separation needed in this application because the ratio of unwanted to wanted particle intensity at the bubble chamber (without separator) is of the order of 4,000.

3. Upper Limit of Separation

Up to now we have always separated particles when the final deflection of wanted particles D^w was higher than the maximum deflection, A_{max} given to the particles in one of the deflectors [6]. This corresponds to a phase shift between wanted and unwanted particles over the inter-cavity distance

$$\tau_{12}^{aw} > 60°$$

In a bubble chamber exposure at CERN we have pushed this limit considerably towards higher momenta by separating successfully at 16 GeV/c K^- from π^- with an inter-cavity distance of only 22m ($\tau_{12}^{aw} = 33°$).

The expected particle ratios at the bubble chamber (without separator) were

$$\pi^- : K^- : \bar{p} = 225 : 1 : 0,1$$

Compared to the normal separation (using $L_{12} = 50$m) the intensity of K^- (for the same conditions of the primary proton beam!) is about three times smaller. The contamination with π^- is increased from ~ 1% to 2,5% and the contamination with muons from 10% to 50%. This result is of interest for the separation of particles in the 100 GeV/c range where it could lead to a substantial reduction of the inter-cavity distances needed.

We note that in this special example the $\bar{p}$ are not rejected. For counter physics this would be no problem and for bubble chambers the $\bar{p}$ intensity can be lowered sufficiently by a slight reduction of the primary proton momentum. For K^+ separation, however, the separation is more difficult because the protons and π^+ have to be rejected in any case. At the upper limit of separation the best way is the use of a three-cavity separator. Passing from the condition $D_3^w/A_{max} = 1$ to $D_3^w/A_{max} = 0,5$ increases the separation range only by 16%.

References

(1) Ph. Bernard, H. Lengeler, V. Vaghin, CERN 70-26 (1970).

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(3) B.W. Montague, CERN Rpt. PS/Int. AR/PSep/60-1 (1960).

(4) R.L. Kustom, C.T.M. Chang and J.W. Dawson, Nucl. Inst. and Methods 87 (1970) 19.

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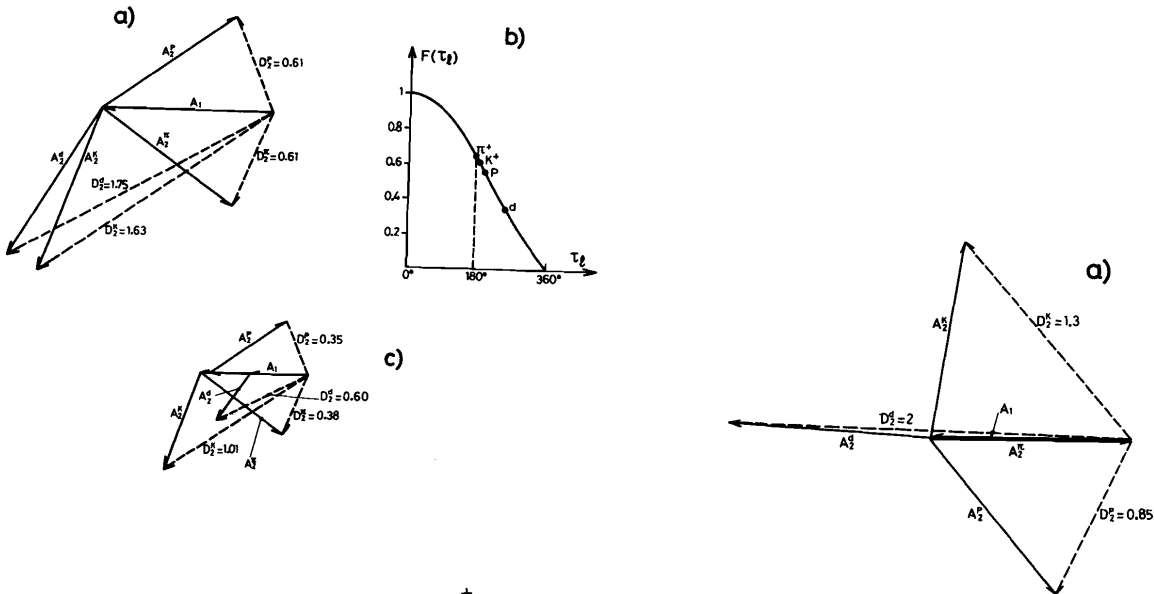(6) Ph. Bernard, P. Lazeyras, H. Lengeler, V. Vaghin, CERN 68-29 (1968).

Fig. 1 Deuteron rejection for 16 GeV/c K$^+$-separation
   a) Vector diagram of normal two-cavity
      separation (short deflectors). A_1, A_2 :
      deflection given to particles in deflector
      1 and 2 respectively, D_2 : final deflect-
      ion of particles.
   b) Phase shift conditions applied : the re-
      duction in deflection amplitude of the
      different particles in a deflector of
      3.5 m length is shown.
   c) Vector diagram resulting from the combin-
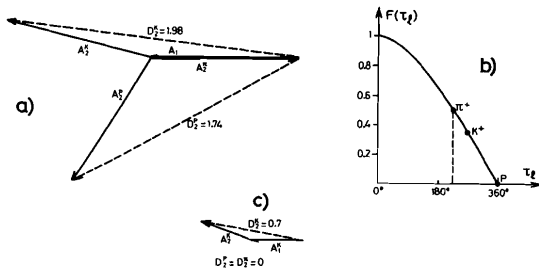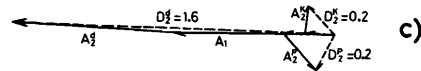   ation of a) and b).

Fig. 2 6 GeV/c, K$^+$ -separation
   a) Vector diagram for two-cavity separation.
   b) Phase shift conditions applied.
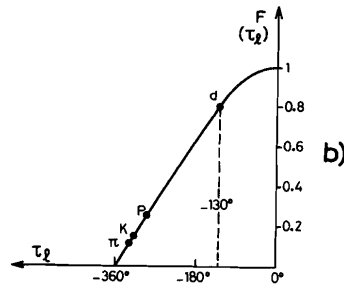   c) Vector diagram resulting from the
      combination of a) and b)

Fig. 3 Like fig. 1 and 2, 11,4 GeV/c-deuteron-
       separation.
       Note that a negative phase "bias" is given
       to the particles because the deuterium is
       the heaviest particle.