A HIGH MOMENTUM SEPARATED PARTICLE BEAM FOR USE WITH THE 1.50 m BRITISH NATIONAL HYDROGEN BUBBLE CHAMBER AT CERN

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1. INTRODUCTION

A separated particle beam called the «02» beam, incorporating both Electrostatic and Radiofrequency separators, is at present being built in the East experimental area of the CERN Proton Synchrotron (PS). Its main purpose is to provide the 1.50 m British National Hydrogen Bubble Chamber (NBC) with reasonably pure beams of kaons, pions, protons and antiprotons up to a momentum of around 15 GeV/c.

The Electrostatic separators are probably the more useful at the lower momenta and the Radiofrequency separators at the higher momenta, although the exact point at which one or other of the two techniques becomes superior is not certain. Probably the main reason for employing the two types of separator is that Electrostatic separation, despite its limitations is a known technique, but Radio-frequency separation, despite its potentialities is as yet untried.

Since the functions of most of the beam transport elements depend on the technique of separation used, it is convenient to regard the 02 beam as a superposition of two independent beams, the ES beam and RF beam.

2. TARGETING

As secondary particle production is strongly peaked in the forward direction at high energies [1, 2], it is desirable to have as low a production angle as possible. In the 02 beam this is achieved for negative secondary particles by placing the target inside Magnet Unit 60 of the PS [3]. Thus when the energy of of the circulating protons is 25 GeV, essentially zero degree production is obtainable up to a momentum of 8 GeV/c, the angle then increasing to 3.8° at 20 GeV/c. Four different target azimuths are available and the radial position is continuously variable up to a distance 3 cm on either side of the equilibrium orbit. For positive secondaries, where the standard target position in PS straight section 61 is used, the production angle is 5.1°.

With the ES beam standard short burst (about 1 ms) targeting techniques will be employed. Since the RF cavities are only under power for a few microseconds single traversal targeting must be used. The kicker magnet used in the fast ejection scheme [4] will deflect the protons onto the rather large target.

3. BEAM LAYOUT AND DESIGN

The layout of the 02 beam, length approximately 180 m, between the target and the bubble chamber is shown in Fig. 1. Standard CERN Quadrupole and Bending Magnets are used throughout the beam. The particles will everywhere be confined to within about 5 cm of the beam axis thus eliminating the need for special shimming of the magnets to remove the aberrations present at large distances from the axis.

All the collimators are in vacuum boxes. The blocks are faced with copper and are remotely and independently adjustable. This is partly to facilitate the tuning of the beam, and partly because the optimum settings of the collimator openings are different at different momenta, and for the ES and RF beams. The electrostatic separator tanks are standard CERN type [5] with a plate length of 9 m each. The RF separators are described in a paper presented to this Conference by Bell et al. [6].

a) The E. S. Beam. The design of the ES beam has been optimised for the production of kaons with a momentum about 5 GeV/c.

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In Fig. 2 we give ray traces; in particular the rays leaving the centre of the target at an angle in both the horizontal and vertical planes, and the central ray in the horizontal plane at an off momentum are traced through the system. The beam may conveniently be regarded as being made up of three parts. In the first part the phase space acceptance (product of target area and solid angle acceptance) and the momentum bite are defined. In the second part mass analysis is carried out. In the final section the phase space acceptance and momentum bite are approximately redefined and the beam shaped for entry into the bubble chamber.

After leaving the target the secondary particles pass through an iron pipe which shields them from the effects of the fringing field of the following PS Magnet Unit. The vertical and horizontal collimators C1 and C2 define the angular acceptance from the target in the two planes. The quadrupole lens triplet Q1, Q2, Q3 refocuses the beam at the centres of the collimators C3 and C4 in the horizontal and vertical planes respectively. The bending magnets M1, M2 produce dispersion in the horizontal image at C3 enabling the momentum bite of the beam to be defined at this point.

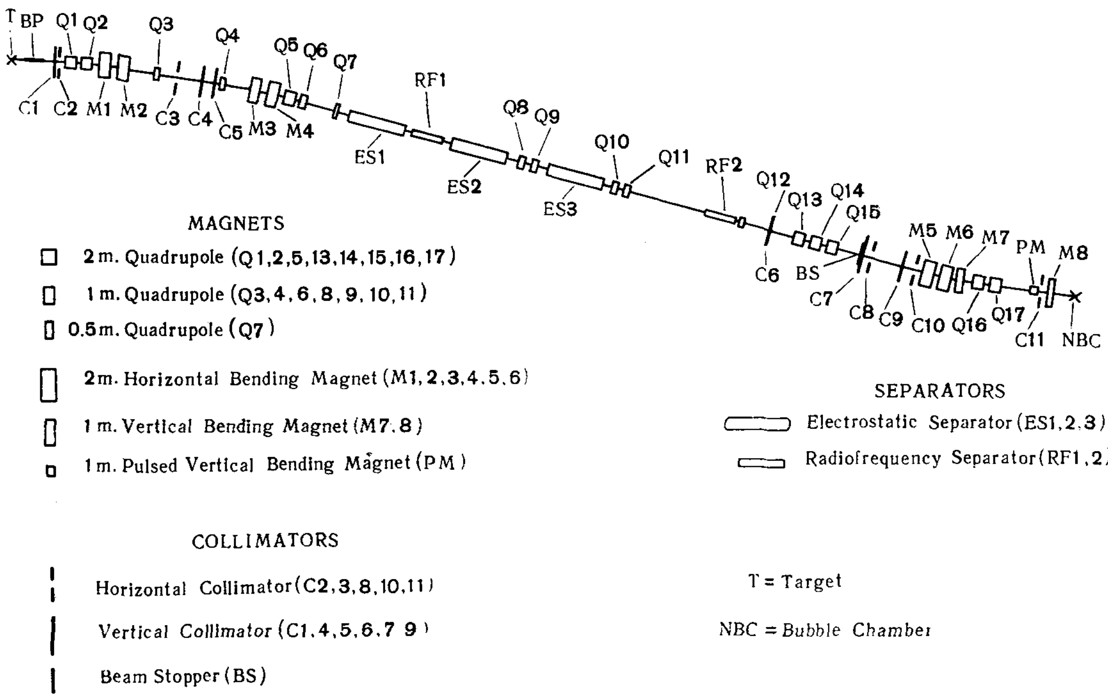

Fig. 1. Schematic layout of the 02 beam between the target and NBC.

The horizontal and vertical images are separated as elsewhere in the beam with a view to decreasing the background of both muons and scattered particles. After passing through the lens Q4 and the bending magnets M3 and M4 the beam is again dispersion free. This is achieved by arranging that each of the four bending magnets bend the beam by the same amount and that the bending centre of M1 and M2 and the bending centre of M3 and M4 form conjugate foci at unit magnification of the lens doublet Q3, Q4. This dispersion free property permits the transmission of a large momentum bite if desired.

The collimator C4 acts as a source for the single mass analysis stage of the beam. Given a fixed length of beam and a fixed length of separator a purer beam is obtainable in theory in a beam with two or more stages of mass separation than is possible in a single stage beam. However the greater purity is only obtained at the expense of having a much lower flux of wanted particles and a much inferior separation at the «mass slits». Calculations indicate that reasonable purity is obtainable in the ES beam as designed, thus enabling the ES beam to be used at higher momenta than would have been possible if it had been necessary to design it as a multi-stage separated beam.

The lens triplet Q4, Q6, Q7 produces a parallel beam in the vertical plane, and an intermediate horizontal focus, inside the electrostatic separators. The location of the horizon-

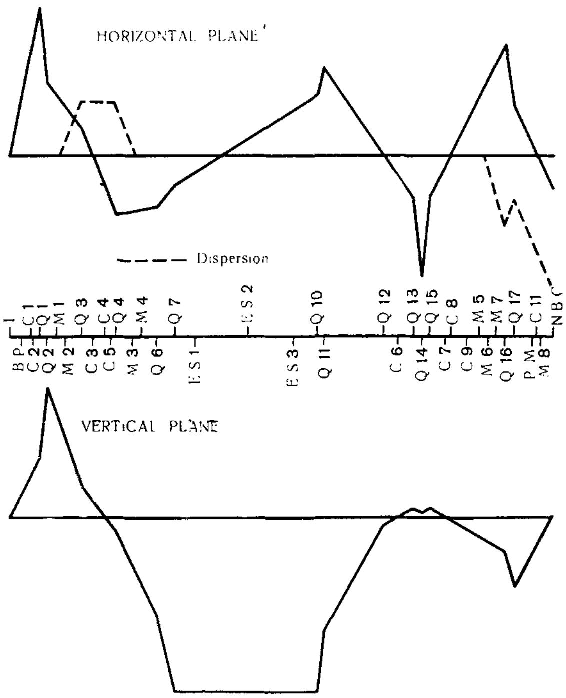

Fig. 2. Ray traces in the ES beam. Trajectories of particles of the correct momentum leaving the target at an angle are shown together with the central ray for an off momentum particle. The positions of the centres of beam transport elements used in the ES beam are indicated.

tal focus can be varied in order to change the magnification of the images at subsequent horizontal foci. The lens triplet Q10, Q11, Q12 produces a vertical focus at the collimator C6 where mass analysis takes place. By using a triplet a large output focal length from the separators is obtained. There is a horizontal focus at Q12 which acts as a field lens in this plane. The lens triplet Q13, Q14, Q15 refocuses the beam onto the collimators C7 and C8 in the vertical and horizontal planes respectively. The angular acceptance is roughly redefined using the collimator C9 in the vertical plane and the gap of the vertical bending magnet M7 in the horizontal plane. A dispersed horizontal image is obtained at the collimator C11 using the bending magnets M5 and M6 and the lens doublet Q16, Q17. The momentum bite is redefined at this point. The purpose of redefining the phase space acceptance and momentum bite is to reduce the background to a low level. However it is because the background cannot be removed completely that it is proposed to use the system of track labelling in the bubble chamber described here.

To obtain a vertical spread in the bubble chamber the lenses Q16 and Q17 can be used to produce a vertical focus which is swept across the bubble chamber by the pulsed magnet, as in the Track labelling scheme. Alternatively the lenses can be used to produce a divergent beam although in this case the distribution of tracks across the bubble chamber will be less uniform. The two vertical bending magnets M7 and M8 are used to steer the beam into the bubble chamber.

b) The RF Beam. The design of the RF beam has been optimised for the production of kaons of momentum about 10 GeV/c. Ray traces through the system are given in Fig. 3. Like the ES beam, the RF beam may also be regarded as being composed of three sections with functions similar to those in the ES beam. The optics of the first part of the beam is the same as for the ES beam. The principles of separation used in the second part of the beam are those given by Bell et al. [6].

Horizontal and vertical images of the target are produced in the first cavity RF 1 by the lens quadruplet Q4, Q5, Q6, Q7 and in the second cavity RF 2 by the lens quadruplet Q8, Q9, Q10, Q11. The «angle defining slit», the vertical collimator C5, is imaged almost to infinity in the two cavities. It is in fact the source for the separation stage corresponding to C4 in the ES beam. The lens system between the cavities is symmetrical and is such that in the vertical plane the transfer matrix between the cavities is $\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix}$. Mass separation takes place at the central «Beam Stopper» onto which the angle defining slit C5 is imaged. The four collimators C7 — C10 after the beam stopper are used to redefine phase space acceptance. The collimators C7 and C8 are used to define the angle in the vertical and horizontal plane respectively. Collimators C9 and C10 are at images of the target in the two planes. Using the bending magnets M5 and M6 and the quadrupole lenses Q16 and Q17 a final momentum analysis in the horizontal plane is carried out using the

Collimator C8 as source. The gap of the last vertical bending magnet M8 will act as the momentum defining slit. In the vertical plane a divergent beam is produced in the bubble chamber by the lenses Q16 and Q17.

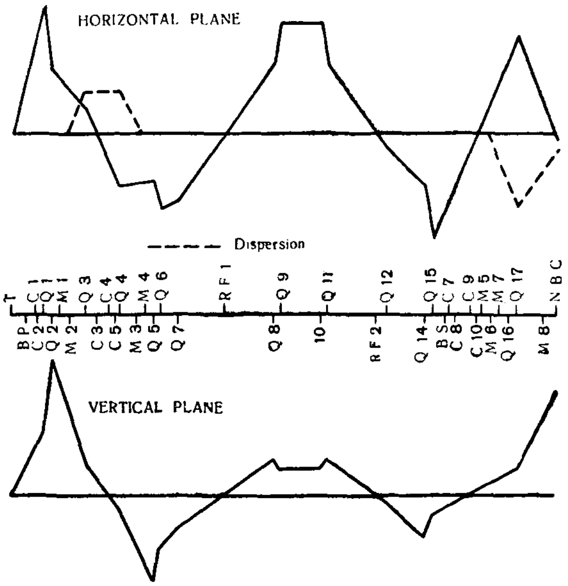

Fig. 3. Ray traces in the RF beam. Trajectories of particles of the correct momentum leaving the target at an angle are shown together with the central ray for an offf momentum particle. The positions of the centres of beam transport elements used in the RF beam are indicated.

4. TRACK LABELLING

Previous systems of track labelling for bubble chambers [7, 8, 9] have used a broad beam of particles and some sort of hodoscope arrangement to locate the marked particles spatially. These systems have all suffered from the drawback that it is not immediately obvious which tracks in the bubble chamber correspond to which marks, lengthy geometrical reconstruction usually being necessary. The proposed system, designed for use with the ES beam, is based on rather different principles [10].

The beam is brought to a sharp vertical focus just inside the bubble chamber. A pulsed bending magnet (PM) sweeps this focus vertically across the bubble chamber A pick up coil inside the magnet generates a voltage proportional to the rate of change of magnetic field, which is then integrated electronically and applied to the X-plates of a cathode ray tube (CRT). In this way the spot on the CRT screen traces a line in time with the sweep of the beam across the bubble chamber. The label to be attached to the track is obtained from counters placed in the beam and can be displayed as suitable deflections of the spot on the CRT screen in the Y direction.

The CRT trace is photographed by one of the bubble chamber cameras in such a way that the labels overlap with the corresponding tracks, no complicated geometrical reconstruction being necessary. A focusing type Cherenkov counter situated in the gap between the lens Q15 and the Beam stopper (BS) is used to identify the particles as either wanted or unwanted. Two scintillation counters, one behind the Cherenkov counter and the other in front of the bubble chamber, are used to indicate whether the particles passing through the Cherenkov counter reach the bubble chamber. The counters are placed as close as possible to foci in the beam to minimise the effects of Coulomb scattering. However, the collimator C7, and the subsequent momentum analysis in the horizontal plane, effectively removes any background generated by the Cherenkov counter and the first scintillation counter.

The theoretical vertical spot size in the bubble chamber is the same as the height of the target but aberrations in the last part of the beam and scattering in the bubble chamber beam entry windows will broaden the image to some extent. However at any given instant at least 90% of the particles will probably lie within a region 2 mm high. Since the useful region of bubble chamber is about 20 cm a high efficiency of labelling should be possible up to quite high particle numbers.

5. EXPECTED CHARACTERISTICS AND PERFORMANCE

With the large number of beam transport elements the 02 beam can be operated in a great variety of ways, to obtain many different types of particle over a wide range of momenta. As examples some of the expected properties of the ES beam when used to produce 5 GeV/c kaons, and of the RF beam when used to produce 10 GeV/c kaons, are listed in Tables 1 and 2. The range of usefulness of the ES and RF beams can of course

Table 1

Some Properties of the ES Beam

Beam operated in the mode suggested for 5 GeV/c kaons

1. Target

Height	0.5 mm
Width	2 mm
Length	80 mm
Material	Be
Efficiency	10%

2. Production Angle

K^+	5.1°
K^-	1.5°

3. Transmission

Solid Angle × Momentum Bite = 3×10^{-6} GeV/c·sterad

4. Separation

Electric Field	50 kv/cm
Plate Gap	10 cm
Plate Length	27 m
π—K separation	12 mm
Magnification relative to target	3.5

5. Circulating Proton Beam in PS

Intensity	5×10^{11}
Energy	25GeV

6. Flux of Secondaries at 5 GeV/c at NBC

K^+	70
K^-	70

85

Table 2

Some Properties of the RF Beam

Beam operated in the mode suggested for 10 GeV/c kaons

1. Target

Height	7 mm
Width	2 mm
Length	100 mm
Material	Cu or W
Efficiency	15%

2. Production Angle

K^+	6.0°
K^-	3.0°

3. Transmission

Solid Angle × Momentum Bite = 6×10^{-6} GeV/c·sterad

4. Separation

Loss at Beam Stopper	50%

5. Circulating Proton Beam in PS

Intensity	5×10^{11}
Fnergy	25 GeV

6. Flux of Secondaries at 10 Gev/c at NBC

K^+	80
K^-	150

only be determined with any certainty experimentally. However some indication of the limitations of the two beams can be obtained from general considerations.

At low momenta the acceptance of the ES separators is not a limitation. Beams of pions, protons and antiprotons should be possible down to below 1 GeV/c. It is however unlikely that kaons will be obtainable at below 4 GeV/c because the decay loss is much too great. At high momenta the separation of particles at the mass slit is inversely proportional to the cube of the momentum and the transmission (phase space acceptance x momentum bite) varies as something like the inverse sixth power of momentum. The flux of particles from the target also falls off as the momentum is increased, although for kaons this effect is counteracted to some extent by the smaller decay loss.

If the stability of the separators were perfect then it would be possible to obtain kaons up to 8 GeV/c, antiprotons up to 11 GeV/c and pions and protons up to 15 GeV/c at intensities of 10 or more per pulse. It seems almost certain that these upper limits will not be realised. Fortunately the RF beam can be used at low momenta although in its present design with a distance of 50 m between the cavities it is more suited to the higher momenta. At low momenta the phase slip between particles of different mass changes rather rapidly with momentum, the effect being to limit the momentum bite that can be transmitted. Further the higher phase space acceptance of the RF beam is somewhat counterbalanced by the need to use a larger target.

With two cavities there are certain preferred momenta at which transmission is a maximum. At other momenta although beams are still possible the efficiency will be reduced. These preferred momenta are: $12.31/\sqrt{n}$ GeV/c for pions; $14.32/\sqrt{n}$ GeV/c for kaons; $7.31/\sqrt{n}$ GeV/c for antiprotons, where n is any positive integer.

Of course, the 02 beam can be operated as an unseparated particle beam. In this case a sufficient flux of pions or protons is obtainable up to 20 GeV/c. It is not possible to go above this momentum as some of the bending magnets are then operating at maximum field. The purity of the various beams is difficult to estimate with any accuracy, since it is not possible to include all sources of contamination with any certainty. However as an example let us consider the purity of a 5 GeV/c negative kaon beam from the ES beam. In the K 1 [11] and M 1 beams at CERN the ratio of background particles in the bubble chamber to pions at the target when they were used to produce 1.5 GeV/c kaons and 3.0 GeV/c antiprotons respectively was in both cases about 1×10^{-3}. However in neither of these single stage beams was an attempt made to redefine phase space acceptance and momentum bite after the mass slit. Calculation shows that in the case of the ES beam this redefinition should give at least a factor 10 improvement, leading to a ratio of less than 10^{-4}. Since the ratio of negative kaons at the bubble chamber to pions at the target is $\sim 2.4 \times 10^{-4}$, one thus expects that more than half the particles entering the bubble chamber will be kaons.

Keil [12] has made a detailed computer study on muon contamination in the RF beam. He estimates that the ratio of negative muons to negative kaons in the bubble chamber will be about 2.0 at 5 GeV/c decreasing to about 0.2 at 15 GeV/c according to an inverse square momentum law. In both the ES and RF beams the contamination for other types of particle will be much lower than for negative kaons.

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