Courant: It would seem to me that quite generally, regardless of the details of the r.f. structure, Hamiltonian beam dynamics requires that a device which produces a phase-dependent transverse deflection must also produce an acceleration dependent an transverse position.

Loew: Yes.

Lapostolle: In addition to B. Montague's remark. I should like to notice that this description of LOLITA as a half LOLA results in a twice as large shunt impedance (same field for half flux of power) in reasonable agreement with experiments.

RADIO-FREQUENCY PARTICLE SEPARATION USING PRIMARY BEAM MODULATION

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1. INTRODUCTION

In January of this year the CERN radio-frequency separator (1) came into full operation in the 02 beam (2) (3); by April it had successfully completed three runs, during which a total of over 200'000 photos of 10 GeV/c K^- were taken in the 1m52 British Hydrogen Bubble Chamber.

The long shut-down of the PS this summer has been used to make a number of improvements to the r.f. separator. This autumn, operation will start again in a new beam, called U1, which will serve the CERN 2-metre Bubble Chamber. The U1 beam will use an external target in conjunction with a fast-ejected primary beam from the CPS.

One of the practical problems associated with high-energy separated beams from proton synchrotrons is the long flight path required to carry out momentum selection and mass separation sequentially. R.f. separators in particular make heavy demands in this direction, partly because of the high momenta for which they are most interesting and partly because of the need for an efficient final momentum selection after mass separation.

The necessity for re-defining momentum just before the bubble chamber arises mainly from the relatively large acceptance of r.f. separated beams compared with those of electrostatic separators, which makes for greater transmission of unwanted background. In particular there is a substantial contribution of muons resulting from pion decay; such muons are emitted at angles small enough to remain within the acceptance of the beam channel but not so small as to continue along the trajectories of their parent pions to hit the beam stopper. A narrow momentum acceptance near the end of the beam can do much to reduce this muon contamination.

When the 02 beam operated during the first half of 1965, practical limitations on flight path length and layout limited the resolution of the final momentum analyser, resulting typically in a muon flux of 30-40% of the total flux in the bubble chamber. Although, again due to lack of space and bending angle, the U1 beam will have even less momentum selection at the end, other factors in the beam design are expected to reduce the muon flux in the bubble chamber substantially below that of the 02.

Nevertheless, reduction in length between target and beam stopper would permit a further reduction in muon contamination, not only because of the extra length available for final momentum selection, but also because of the shorter flight path fo rpion decay. The r.f. separation scheme proposed in this paper should make possible a useful saving in length by arranging that one section of the beam fulfils two functions simultaneously. The method is dependent on ha-

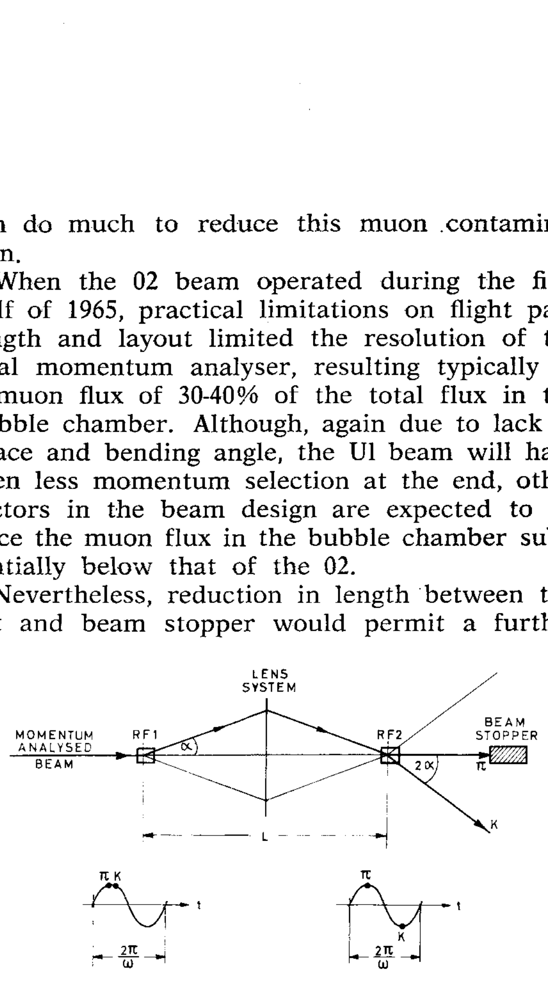

Fig. 1 - Principle of CERN r.f. separator.

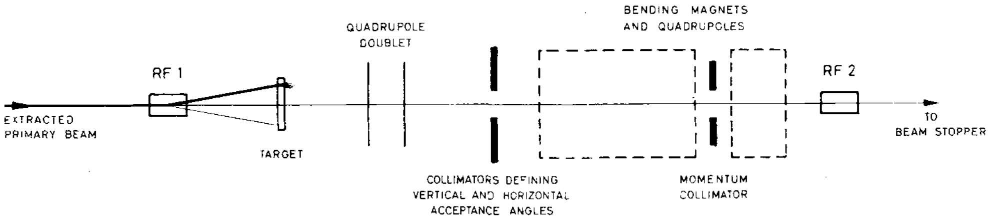

Fig. 2 - Schematic layout of primary beam modulation system.

ving available an ejected primary beam from the synchrotron; this beam is subjected to r.f. deflecting fields before it strikes the target.

2. THE PRESENT CERN R.F. SEPARATOR

To illustrate the essential features of primary beam modulation it is useful first to recall the principles on which the CERN and Brookhaven r.f. separators are based.

Mixed secondary particles from the target pass through a beam transport system which defines, in momentum and transverse phase space, the beam entering the first r.f. deflector (r.f. 1 - Fig. 1). The deflection forces in r.f. 1 sweep the beam through an angle ($\pm \alpha$) in the vertical plane at radio-frequency, and a lens system images r.f. 1 into the second deflector r.f. 2. Over the distance L between r.f. 1 and r.f. 2, the velocity difference between particles of different rest mass shows up as a difference in arrival time at r.f. 2. Conditions can be so arranged that the initial deflection of one type of particle is cancelled in r.f. 2, irrespective of its arrival time, whereas another particle type is distributed over a fan of-semi angle 2α. A central beam stopper, in conjunction with a quadrupole lens system intercepts one type of particle, allowing the other to pass on to the bubble chamber.

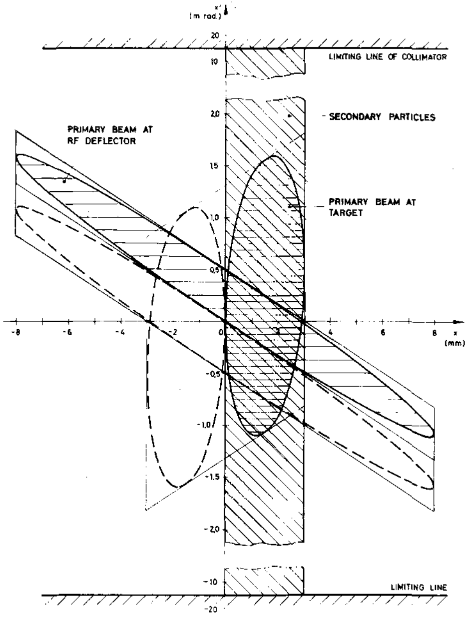

Fig. 3 - Phase plane contours at primary beam r.f. deflector and at target.

3. PRINCIPLES OF PRIMARY BEAM MODULATION

In contrast to this classical method of defining the beam optics before the mass separation stage, the present proposal is to apply r.f. deflection in the vertical plane to the extracted primary beam before it strikes the target, thus producing a source of secondary particles modulated in position at radio-frequency. The first part of the secondary beam channel serves not only for momentum selection and beam shaping but also as part of the velocity selection flight path, thus enabling the second r.f. deflector to be placed closer to the target than is normally the case.

A simplified layout is shown schematically in Fig. 2. R.f. 1 is the r.f. cavity deflecting the primary beam and causing the source position of the secondaries to be modulated at radio-frequency. A quadrupole doublet after the target combined with collimators in both horizontal and vertical planes are arranged to define the acceptance angles at the target independently of the position modulation of the secondary source. Further quadrupoles, bending magnets and a horizontal collimator make up the remainder of the momentum analyser.

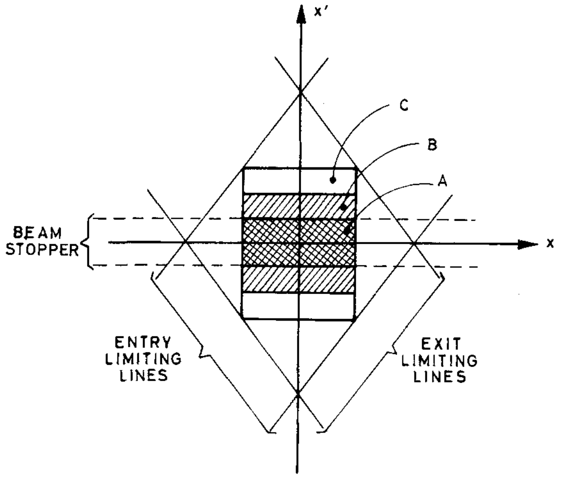

Fig. 4 - Phase plane diagram for conventional r.f. separator.

When the particles in the selected momentum band arrive at the deflector r.f. 2, the correlation between phase plane position and time is different for particles of different velocity. R.f. 2 therefore converts this difference into a spatial separation exactly as in the normal type of r.f. separator.

A similar separation scheme has been proposed by Maschke and reported by Hahn (4). Maschke's proposal uses the primary beam deflection to produce a chopped secondary beam rather than one modulated in position; it has the drawback that at least 50% of the primary beam must be dmuped or diverted to another, compatible experiment.

4. PRIMARY BEAM AND TARGET OPTICS

The ejected primary beam from the synchrotron is first shaped by a lens system so that, in the absence of r.f., a small focused beam spot is produced on the target. With a suitable r.f. power level in the first deflector, the primary beam is swept across the target with a peak displacement equal to, or slightly more than, the radius of the beam spot. Fig. 3 shows superimposed the vertical phase plane diagrams at the deflection centre of the r.f. cavity and at the target 6 metres beyond. The focused beam spot is conservatively assumed to be 3 mm diameter and the phase plane area of the beam corresponds approximately to the CPS parameters. It is seen that a deflection of ± 0.25 milliradian is just sufficient to deflect the beam by a total of one diameter at the target. For a primary beam of 28 GeV/c, the required 7 MeV/c transverse impulse could be obtained with about 7 MW of r.f. power in a one-metre length of large-aperture wave-guide rather similar to that used on the existing CERN r.f. separator. However, since the beam is less than 20 mm diameter here, a smaller aperture waveguide would be more economical in r.f. power. Rough estimates suggest that 3-4 MW in one metre of waveguide would be sufficient.

Fig. 3 also shows the band of secondary particles produced at a given moment of time. The horizontal limiting lines are the transformation back to the target of the collimator which defines the acceptance angle in the vertical plane. In the horizontal plane the optics are similar in this region, except that no r.f. modulation is present.

5. FIRST MOMENTUM ANALYSER

The beam channel between the target and the momentum collimator must, of course, fulfil the normal function of momentum selection. However, the fact that this section of the system forms part of the velocity selection flight path imposes an extra restriction on the beam optical design, namely that isochronism must be maintained in both vertical and horizontal planes. In the vertical plane the difference in path length of axial and extreme trajectories is of the same order as that occuring between the cavities of the existing CERN r.f. separator. The resulting anisochronism is fairly small but not completely negligible.

In the horizontal plane, however, the bending angles give rise to path length differences which

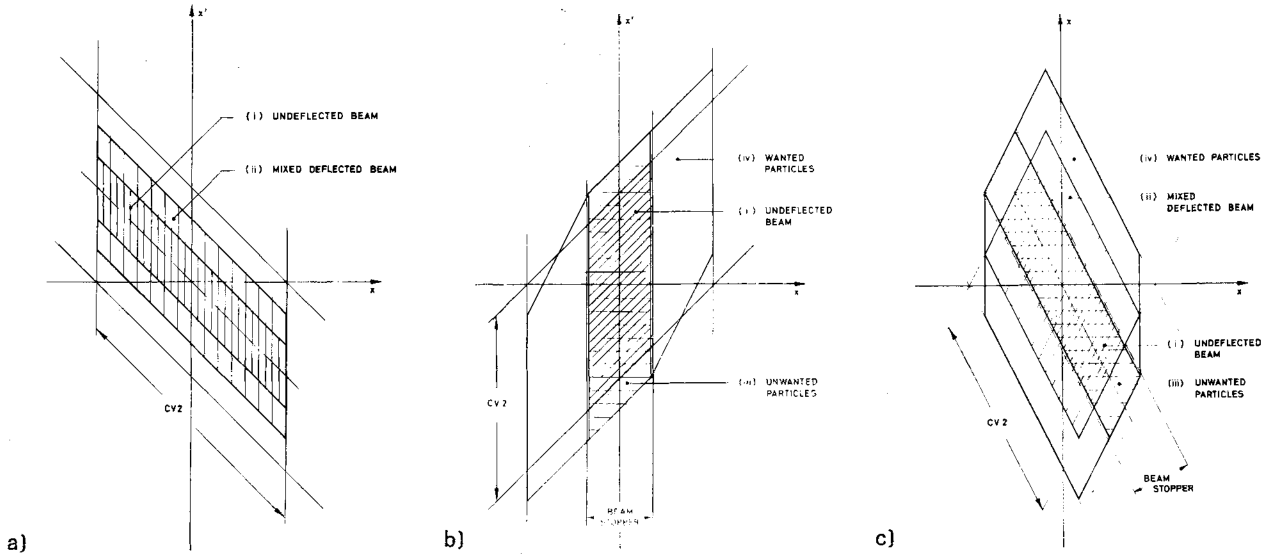

Fig. 5 - Phase plane diagrams for system with « skew » optics.

can be an order of magnitude greater than those in a straight beam. Conseguently, a specifically isochronous design may be necessary for this part of the beam channel.

6. SKEW OPTICS AT THE DEFLECTOR R.F. 2

With the normal r.f. separator it is customary to arrange for the target to be imaged, in both planes, in the centres of the two r.f. cavities in such a way that the phase plane contours are right rectangles, as in Fig. 4. This system, proposed by Schnell (5), was adopted for its relative simplicity and symmetry at a time when there were some misgivings about the difficulties of setting up the optics of r.f. separated beams. Experience now shows that, with proper instrumentation, setting up of the beam optics presents no major problems.

One sees from Fig. 4 that only half the available phase area in each plane is exploited; there is therefore a potential factor of 4 increase in particle flux available if the phase area could be better utilised. One way of achieving this is to make the boundaries in the phase plane parallel to the limiting lines of the r.f. cavity. This possibility had been considered earlier by Montague (6).

An improved version of such « skew optics » is illustrated in Fig. 5 for the vertical plane. The optics of the horizontal plane would be similarly arranged but would be no r.f. displacement. The essential feature of such a scheme is that the vertical angle defining collimator of the beam in imaged to the entry of r.f. 2 (preferably defined by another collimator CV 2) whereas the target is imaged to the exit of r.f. 2 where the central beam stopper is placed. Fig. 5 (a), (b) and (c) show the situations referred respectively to the entry, effective centre and exit of r.f. 2. Despite the fact that the equivalent point deflection is not parallel to either of the principal axes of the parallelogram, one type of particle is brought back completely to the strip of phase plane covered by the beam stopper.

The beam setting up for such a system of skew optics will probably be somewhat easier than with the classical system, since the beam " waists " occur outside the r.f. cavity where collimators can be situated. A further advantage is the reduction in length of beam channel resulting from the elimination of distinct beam-shaping quadrupole doublet sections. The functions of beam shaping for the mass separation stage are largely taken over by optical system of the momentum analyser.

Although this arrangement resulted from certain features of the primary beam modulation scheme, it could also be used to increase the acceptance and reduce the length of the conventional type of r.f. separator. In either case, however, there might be practical reasons preventing the full factor of 4 flux increase being achieved. This is because increased acceptance, by the laws of Nature, requires increased deflection fields for exploitation; the resulting increase in r.f. power requirements may be subject to practical or economic limitations. There remains, nevertheless, the factor of two in the horizontal plane which is independent of r.f. considerations, and the extra vertical phase plane area could be useful in relaxing restrictions on the achromatism in the beam transport system.

7. CONCLUSION

It is difficult to give a precise estimate of the saving in length of flight path resulting from the proposed improvements, as this will depend upon the detailed design of the beam. We can, however, make a comparison with the CERN 02 beam, (now replaced by the U 1), which was designed for a maximum momentum of 15 GeV/c. Here it appears that a saving of about 30 metres would have resulted from the primary beam modulation. Some 12 metres of this would be taken up by the external primary beam channel, but this is inevitable for any form of external targetting in the East Area of the CPS.

The skew optics would appear to save between 30 and 40 metres of flight path giving a total net gain of 48-58 metres in this example.

Acknowledgements

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A POLARIZED PROTON TARGET FOR NIMROD

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(Presented by A.J. Egginton)

1. INTRODUCTION

This paper describes briefly the main characteristics of a polarized proton target built at the Rutherford Laboratory for high energy physics experiments with Nimrod. The target has been used by the resident Counter Group at the Laboratory in a study of πp scattering to determine the parities of the $N^*_{1/2}$ (1688) and $N^*_{3/2}$ (1920) isobars (1).

The target is based on the same physical method as was used by Abragam, Borghini et al. (2) in the first polarized target incorporated in a nuclear physics experiment, and by Jefferies and the Chamberlain group in the Berkeley target (3): namely, the dynamic polarization by the solid effect of the protons in the hydrogen atoms (the 'free' protons) of the water of crystallization in single crystals of lanthanum magnesium nitrate $La_2 Mg_3 (NO_3)_{12} \cdot 24 H_2O$, 'LMN' containing a dilute paramagnetic impurity.

Although only about 3% of the nucleons in LMN are free protons, in this experiment it was possible to distinguish between scattering from free and bound protons by the kinematics of the scattering process (1).

2. THE TARGET

The target consists basically of four single crystals of LMN tied together to form a cube of side 2.5 cm. Each crystal was grown* (from a seed) to the required thickness of about 6 mm over a period of several months by gradually lowering the temperature of a solution of LMN in which the paramagnetic impurity was introduced by replacing $^1/_2$ of the La atoms by Nd^{144}. The crystals were then each cut to the dimensions 25 mm × 25 mm × about 6 mm, one long side being parallel to one of the natural hexagonal sides of the crystal so that when mounted together to form the final target cube, all the crystals had the same crystallographic orientation (to within about $^1/_2{}^0$).

This crystal block is mounted in a microwave cavity of copper (Fig. 1), similar to that used at

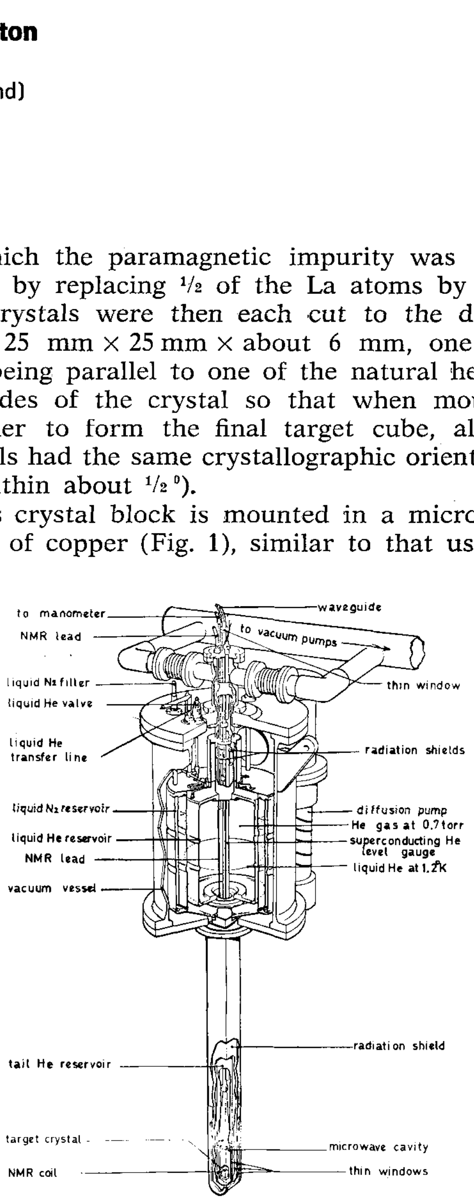

Fig. 1 - The cryostat.

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* By J. C. H. Waldron, AERE, Harwell.