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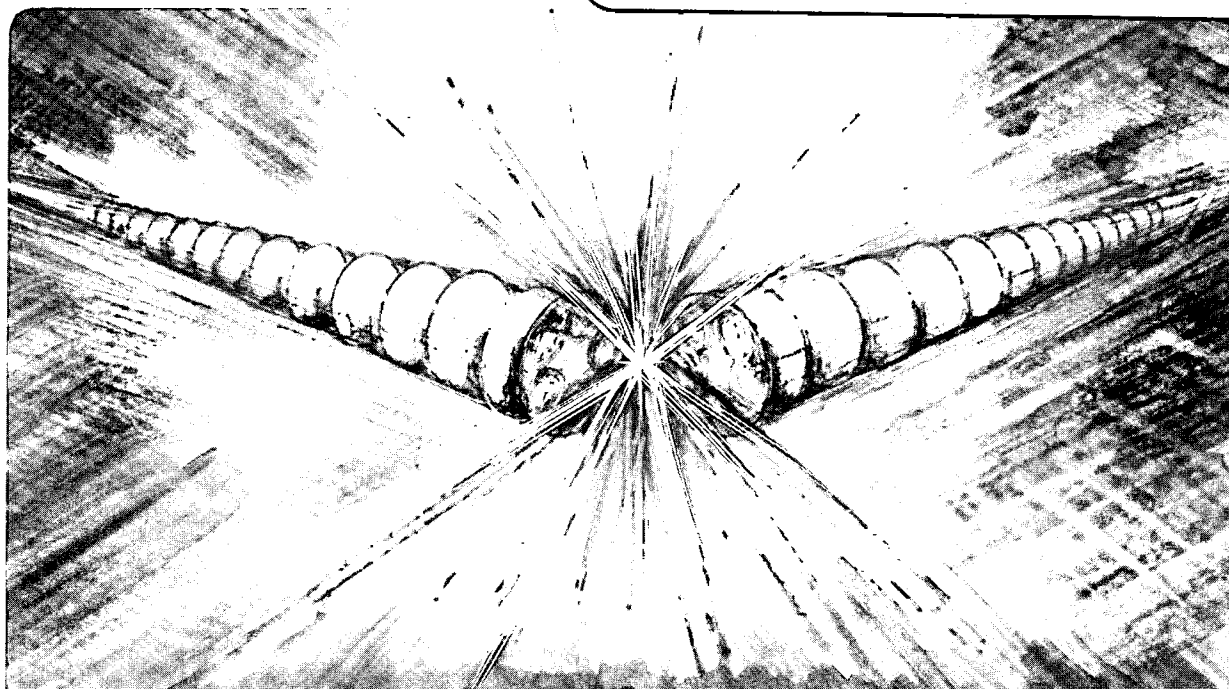
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RADIOACTIVE ION BEAMS AT THE BEVALAC: GREATLY ENHANCED FRAGMENT SEPARATION FOR HIGH ENERGY BEAMS*

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Abstract

Radioactive beams are routinely produced at the Bevalac by the fragmentation process. High energy beams (energies ~ 800 MeV/u) produce fragments with nearly the original beam momentum, forming a radioactive ion beam. A new beamline is being constructed which will provide resolution for ions approaching the mass 100 region, compared to the present mass 20 capability, by strongly increasing the dispersion and also increasing the beam size for easier tuning and more effective collimation. In addition, the angular acceptance has been more than doubled. Details of the design will be presented.

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1. Introduction

The first radioactive ion beams were produced and characterized at the Bevalac in the early 1970's, even before the Transfer Line connecting the SuperHILAC and the Bevatron was built in 1974 [1]. At present there are three active programs using radioactive beams. The biomedical program uses Ne-19 to confirm the stopping point for Ne-20 radiation therapy treatment planning with Positron Emission Tomography (PET) [2]. A second program at the Bevalac stops radioactive fragments, produced using a primary beam energy of approximately 200 MeV/u, to study beta-decay properties and magnetic moments [3]. The third program, which benefits from the improvements to be discussed here, studies basic properties of nuclei, such as neutron-proton distributions in neutron-rich isotopes [4]. The radioactive beams, produced by fragmentation of high energy (~ 800 MeV/u) primary beams, are then separated out from the fragmentation products and directed towards targets for the research. High energies are used to take advantage of kinematic focusing to maximize transmission of the secondary beam. A new facility has been designed to allow high mass beams (~ 80 AMU) to be effectively separated, increasing the separation capability by about a factor of four.

Fig. 1 shows a schematic of our present and planned beamlines for production of high energy radioactive beams. A thick low-Z target (eg: ~ 5 g/cm² Be) is placed at the non-dispersive focal point, F1. Fragments produced at F1 are then separated according to their charge-to-mass ratio by the bending magnet labeled XM4. The desired fragments pass through a collimator at the dispersive focal point, F2. These high energy beams can pass through several centimeters of lead, so thick collimators are necessary. Thick collimators introduce a substantial amount of slit scattering, however, so a thin lip is usually placed on the collimator. The part of the beam which passes through the lip will lose energy, so that after passing through another bending magnet, it can be separated out by a second collimator placed at the next focal point, F3. Final identification of the beam must be performed for each nucleus, using the pulse height in a radiation detector such as a scintillator, since more than one nucleus can have the same charge-to-mass ratio.

A fragment separator must take into account the following characteristics of the secondary beams. The secondary beam will have a larger momentum spread than that of the primary beam due to a combination of two major effects, shown schematically in Fig. 2 [5]. The first effect is the fragmentation itself. Depending on the mass of the primary and secondary beams, the Fermi motion of the nucleons will contribute a momentum spread of the order of $\sigma(P_{\parallel}) \approx 90 \text{ MeV}/c$, where σ is the standard deviation of a Gaussian fit to the momentum distribution. A second effect is produced by the difference in energy loss (dE/dX) of the primary and secondary beams in the target. Given an energy loss difference, $\Delta(dE/dX)$, between the secondary fragment and the primary beam, the fragments will leave the targets at different energies as a function of where they are produced in the target. The maximum spread in energies is shown in Fig. 2, where fragmentation occurs at the upstream and downstream surfaces of the target. The optimum target thickness would make both contributions to momentum spread approximately equal. Another important characteristic of the secondary beam is its divergence. The divergence of the secondary beam will be larger than that of the primary beam due to perpendicular Fermi motion [5], with an additional contribution from multiple Coulomb scattering [6] in the thick target.

An ideal fragment separator should therefore have, in addition to good resolution, as large a momentum acceptance as possible, and as large an angular acceptance as possible. We will describe the present beamline for separation of high energy radioactive beams, point out some deficiencies, and then present a description of the planned improvements.

2. Present Fragment Separator

The upper beamline in Fig. 1, beamline B42, is presently used for the production and separation of high energy radioactive beams at the Bevalac. The bend angle at XM4 is only 6.5° , which, together with the downstream quadrupole doublet, produces a dispersion of $\eta_x = 0.2 \text{ m}$ at F2. (A particle with 1% more momentum than the on-momentum particle will be off-axis by 1 cm at a point where $\eta_x = 1 \text{ m}$.) The dispersion allows separation of particles with different charge-to-mass ratios (q/A), since magnetic separation is proportional to q/A . However this resolution will decrease with increasing beam momentum spread. Since the momentum width of the secondary

beam, while large compared to the primary beam, can be small compared to the difference in q/A of the fragments, magnetic analysis primarily selects a given q/A by collimation at F2.

The beam is bent again before reaching the next focal point, F3. This allows the placement of additional collimation to clean up the beam, as described above. Table I lists the important parameters of the B42 fragment separator. Note that the beam horizontal size is very small at F2, which increases the divergence and makes collimation difficult.

3. New Fragment Separator

A schematic of the new fragment separator, beamline B46, is shown in the lower section of Fig. 1. The bend angle at XM4 has been increased to 9.6° , which, along with a change in the quadrupole location, results in a dispersion of $\eta_x = 2.0$ m at F2. Fig. 3 shows an optics diagram of the beamline, where the upper line represents the horizontal half-width, the lower line represents the vertical half-width, and the line beginning at XM4 represents the dispersion. The apertures of XM4, X1Q5B, and X1M6 limit the horizontal angular acceptance, while the apertures of XM4 and X1Q5A limit the vertical angular acceptance. The momentum acceptance is limited by B46Q1B to $\Delta P/P = 1.1\%$. Table I also lists the parameters of the B46 fragment separator.

4. Comparison

Table I lists the relevant parameters of the two beamlines. There are a number of important advantages to the new beamline. The dispersion of B46 increases by an order of magnitude compared to B42 at the principal separation point, F2. Although the resolution (defined as η_x / x) only improves by a factor of 1.4, it does so while the horizontal beam size increases from 1.1 mm to 8.2 mm. This increase in beam size, which also reduces the horizontal beam divergence at F2 by a factor of 2.9, is critical to fabrication of a collimator. It allows us to use collimators with larger horizontal apertures and longer lengths, reducing beam clipping and improving the effective resolution. Figures 4a and 4b show the dramatic difference in the beam horizontal size and divergence at F2.

In addition, the transmission of fragments is greatly improved by the new beamline. Assuming that the acceptance is filled, then transmission is proportional to the product of the angular acceptances (horizontal and vertical) and the momentum acceptance. However, for production of heavy ($A > 55$ AMU) secondary beams at these high energies ($E > 300$ MeV/u) the momentum width $\Delta P_{\parallel}/P_{\parallel} < 1\%$. Given these conditions, the B46 beamline yields a transmission improvement of 2.5.

5. Conclusion

A new beamline is planned to improve separation of high energy radioactive beam fragments produced at the Bevalac. The new line features increased transmission, increased resolution, and a practical improvement in beam size compared with the existing high energy fragment separator. It is expected that these improvements will result in increasing the useful mass range of the facility from about 20 AMU to almost 100 AMU.

References

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Table I

Beamline	Acceptances [a]			Dispersive Focal Point (F2) [b]		
	Angular		Momentum	Dispersion	Beam Size	Resolution
	Horizontal	Vertical	$\Delta P_{\parallel}/P_{\parallel}$	η_x	Horizontal	η_x/x
	x' (mrad)	y' (mrad)	(%)	(cm/%)	x (cm)	(% ⁻¹)
B42	± 3.6	± 5.0	± 6.0	0.20	0.11	1.80
B46	± 9.2	± 4.9	± 1.1	2.01	0.82	2.46

Notes:

[a] Angular acceptances are calculated assuming $\Delta P_{\parallel}/P_{\parallel} = 0$. Momentum acceptances are calculated assuming $x' = 0$.

[b] Beam size is horizontal FWHM, and assumes that $\Delta P_{\parallel}/P_{\parallel} = 0$.

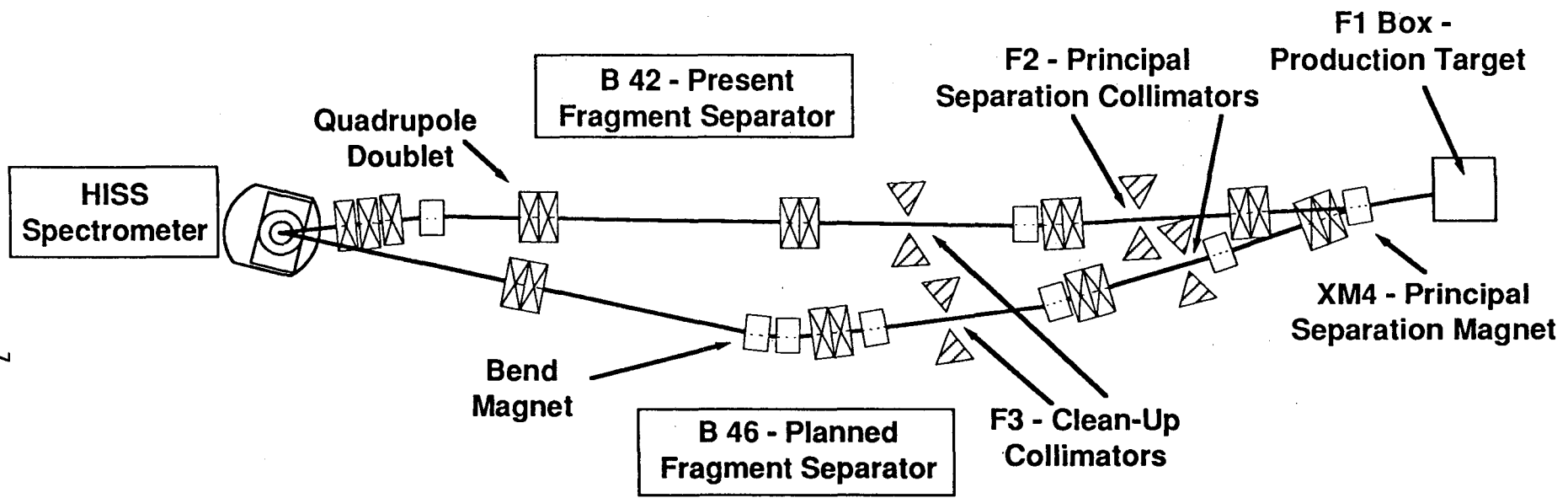


Figure 1

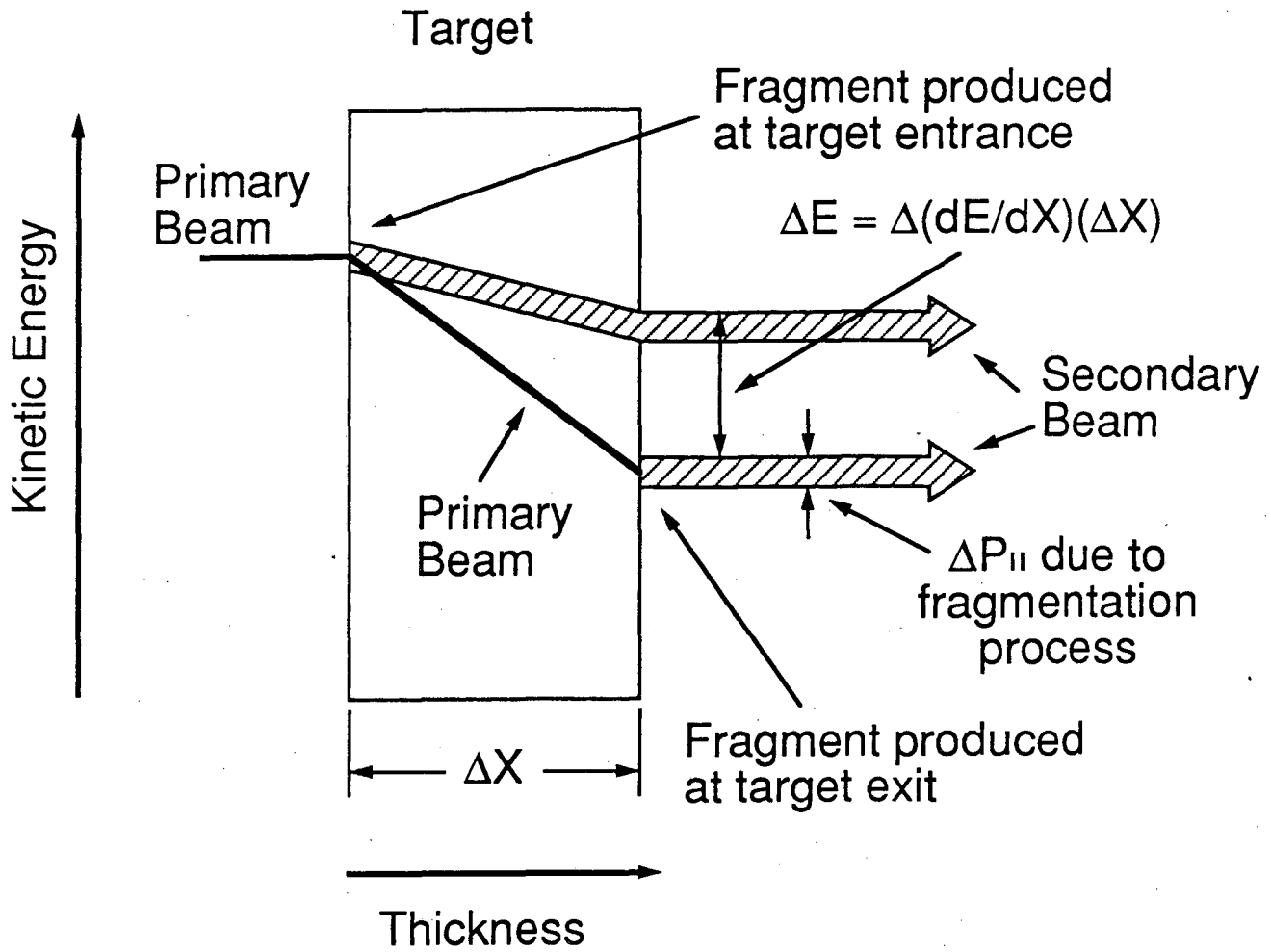


Figure 2

B46 Optics

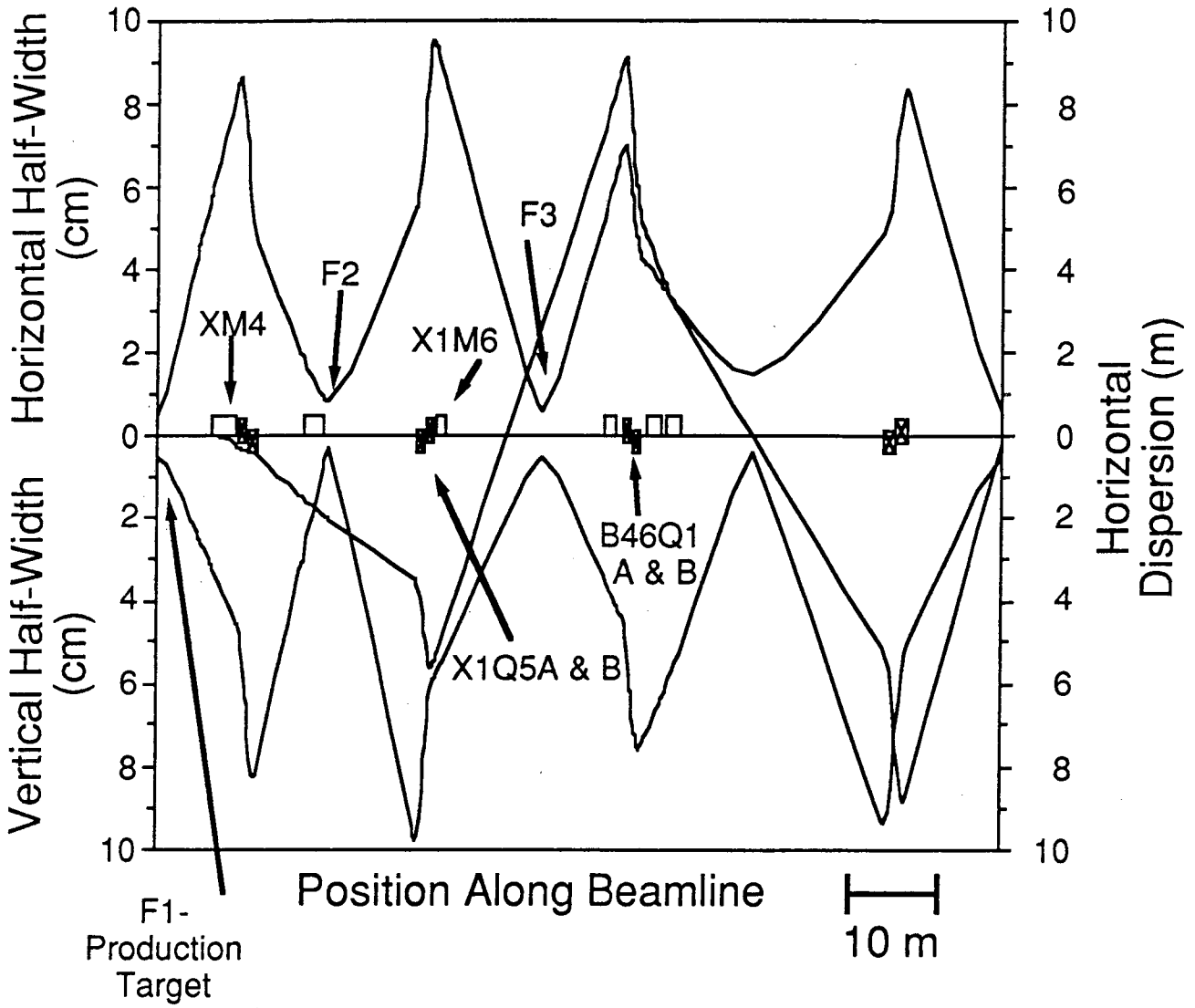


Figure 3

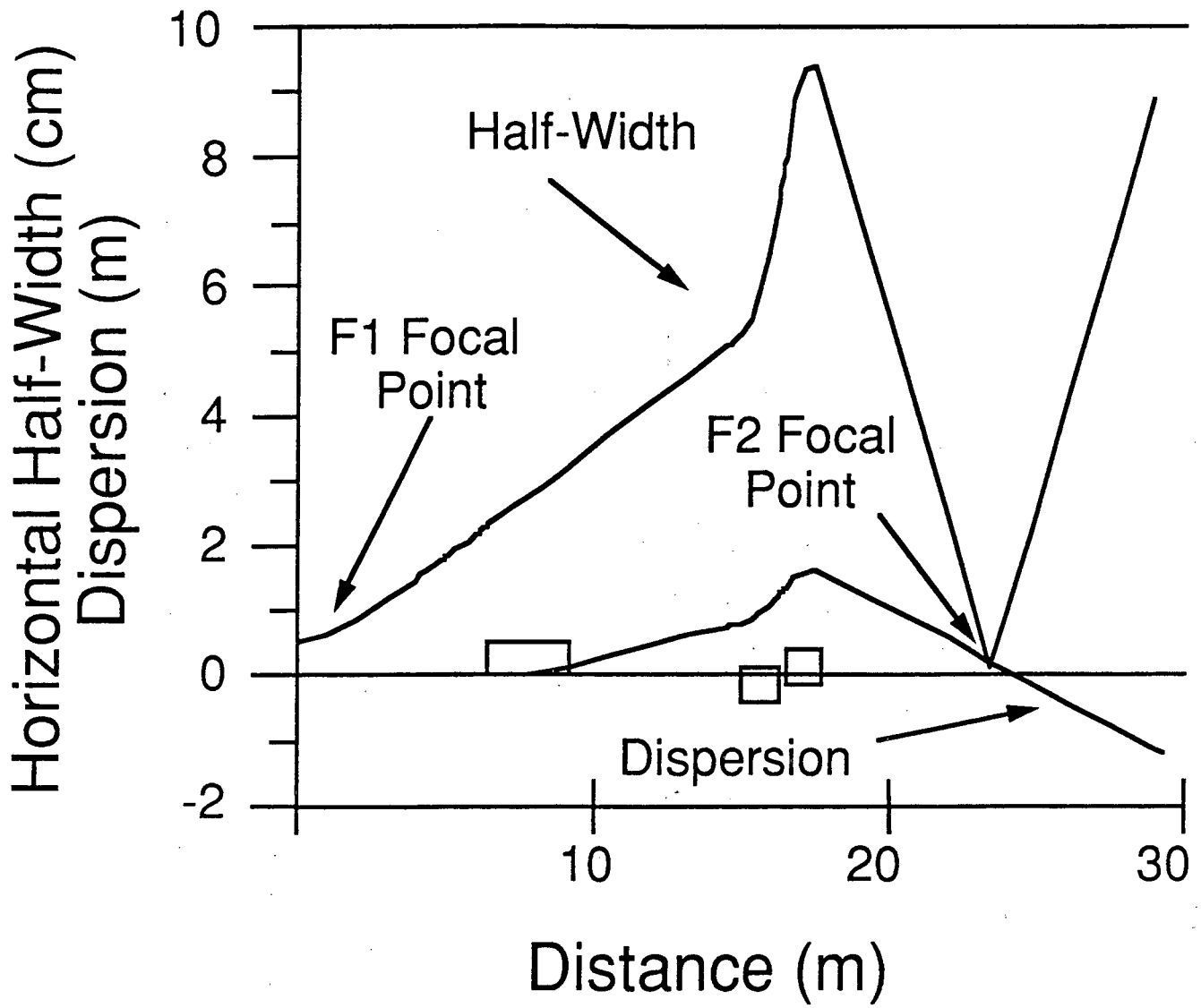


Figure 4a

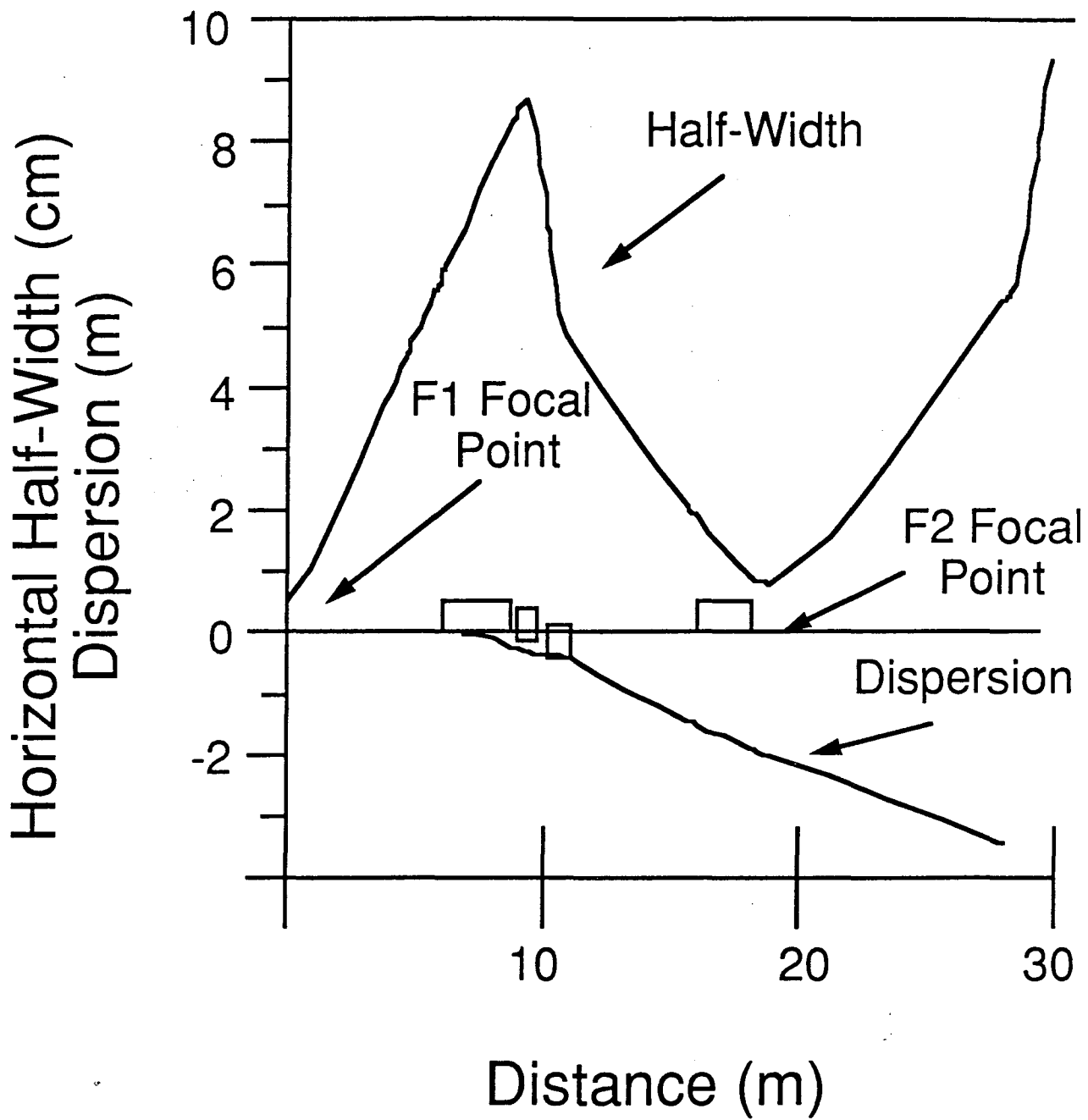


Figure 4b

Figure Captions

Fig. 1. Schematic of the Bevalac beamlines for production of high energy radioactive beams.

Fig. 2. Schematic description of momentum spread in a production target.

Fig. 3. Optics diagram of the B46 fragment separator.

Fig. 4a. Optics diagram of the existing B42 fragment separator, from the production target, F1, to the principal separation point, F2.

Fig. 4b. Optics diagram of the planned B46 fragment separator, from the production target, F1, to the principal separation point, F2.

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