Strong Solenoidal Final Focus Lens for HEDP

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Ion driven HEDP experiments require small focal radii for beam pulses that have very large momentum variations. This is because the plasma that neutralizes the beam's space charge also eliminates the longitudinal electric field, which could remove the velocity tilt prior to final focus. A typical assumed momentum variation is around $\pm$ 5-10%, applied to compress the pulse by a factor of 200 in duration. This range is well beyond the maximum $\pm$ 1% that is typical of high-energy accelerators. The complicated combinations of bends and sextupoles that are used to produce an achromatic focus for small momentum spread appear unattractive and probably mal-functional in the present context due to their large higher order aberrations. An alternative, which is proposed here, is to live with the (second order) chromatic aberration of a linear lens system, and design The final focus to make the effect no worse than that of the natural focal spot blowup due to finite emittance. This is done by using a single strong lens (a short solenoid) that acts on a relatively small initial pulse radius in parallel-to-point focal optics. The focal length of the lens is made as short as possible in order to minimize the spot radius due to emittance. A third important consideration is that the physical length of the lens be less that its focal length so that the HEDP experiment does not get placed inside the magnet bore.

The competing desires for the focal system would not be very difficult to accommodate if the "magnetic rigidity" of beam ions (momentum/charge) was less that about .5 T-m. However, for the typical HEDP example of 20MeV N_e^+, the rigidity is $[\square\square]$=2.88 T-m. Suppose the focal length is f=.5m and the length of the magnet's wire layer is ℓ=.25m. The high rigidity requires peak solenoid field of about

$$\square = \frac{2[\square\square]}{\sqrt{\ell f}} = \frac{2x2.88}{\sqrt{.25x.5}} = 16.3T$$

Fortunently solenoids with fields this high are now available commercially, built with NbSn wire cooled to 4.2K.

We can now compute the approximate focal radius for a concrete example:

Ion = 20Mev Ne^+ $\begin{bmatrix} q = 1 \\ m = 20amu \end{bmatrix}$

normalized edge emittance $\square_n = 10^{\square 6}(\square)\ \ m\square r$

momentum variation $\frac{\square P}{P} = \pm .05$

$$\square = \sqrt{\frac{2E}{Mc^2}} \quad = \quad .0463$$

emittance $\square = \frac{\square_n}{\square} = 2.16x10^{\square 5}(\square)\ \ m\square r$

initial radius $a_0 = .015m$

Peak Magnetic Field $\square = 16.3T$

Wire layer length $\ell = .25m$

Rigidity $[\square\square] = \square\frac{Mc}{qe} = 2.88T\,\square m$

Focal Length $f = \frac{4[\square\square]^2}{\square^2\ell} = .50m$

Convergence half angle $\square = \frac{a_0}{f} = .03radian$

Natural spot radius from emittance $r_e = \frac{\square}{\square} = .72mm$

Chromatic aberration radius from $\square P/P$ $\quad r_c = a_0\frac{\square P}{P} = .75mm$

effective spot radius $\quad r_s = \sqrt{r_e^2 + r_c^2} = \underline{\underline{1.04mm}}$

The above case (which does achieve an effective spot radius of about 1.0mm) also displays the tradeoff among variables. For example, a larger initial radius a_0 would increase $\square$ and therefore decrease r_e. But larger a_0 would also increase r_c. Shorter f would be helpful because we could then increase $\square$ at constant a_0 or decrease a_0 at constant $\square$. But shorter f requires even higher $\square$ than the already impressive 16.3T that was assumed. Another idea is to strip the neon ions to a higher charge state, say +7, at some point prior to final focus. This has penalties such as loss of ~50% of the beam pulse and probable emittance growth.