Influence of focal length and beam rigidity on final focusing at HHT

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For future experiments on investigation of high-energy-density (HED) matter at GSI where an intense heavy ion beam *and* a petawatt laser beam from PHELIX will be used simultaneously, a new vacuum target chamber is required. Due to dimensions of the laser guiding and focusing optics, the new chamber has to be considerably larger than the presently installed at the HHT. It may therefore be necessary to shift the position of the interaction point father from the ion beam final focusing system. In order to study the influence of the extended focal length on the focusability of the ion beam and consequently, on the achievable levels of energy deposition in the target, a series of ion optical simulations has been carried out.

In the simulations, the exact layout of the beamline from SIS-18 to the HHT target chamber as well as the actual initial beam parameters (α- and β-functions at the extraction) have been considered. Large transverse emittances of 40 mm·mrad (horizontal) and 10 mm·mrad (vertical) are assumed. Such values are typical for uncooled heavy ion beams at energies about 300 AMeV. The first-order ion optical simulations have been performed for uranium beams of three different magnetic rigidities:

a) $^{238}\mathbf{U}^{73+}$, 151 AMeV $\Longrightarrow$ 6 Tm;

b) $^{238}\mathbf{U}^{73+}$, 350 AMeV $\Longrightarrow$ 9.57 Tm;

c) $^{238}\mathbf{U}^{28+}$, 196 AMeV $\Longrightarrow$ 18 Tm;

using the code COSY INFINITY [1]. The case **a)** is supposed to be the design optimum for the present focusing system. The case **b)** corresponds to the recent beamtime experiment [2] and is preferable to case **a)** because of a higher ion energy and therefore longer ranges of ions in a target material. Due to a smaller charge, the highest intensity of uranium beams will be obtained by using $\mathbf{U}^{28+}$ ions of case **c)**. This 18 Tm beam is also very important for operation of the GSI future facility SIS-100.

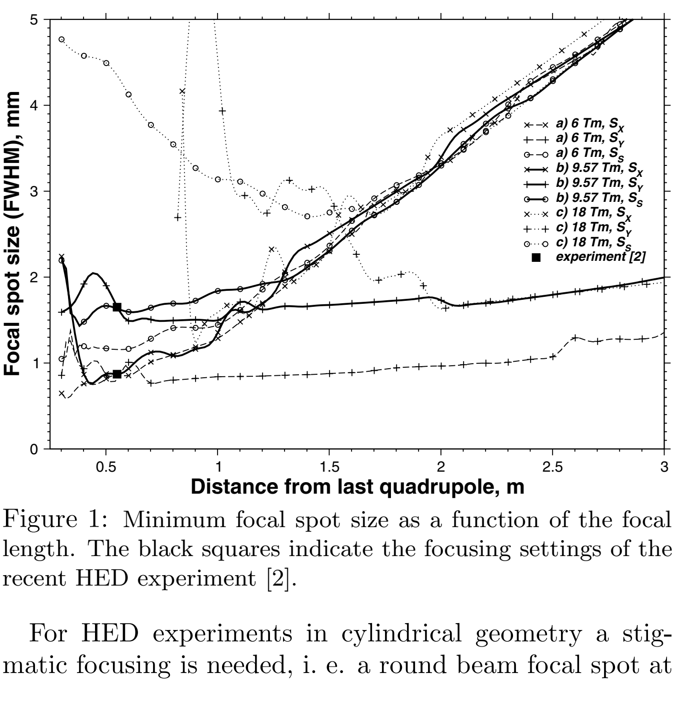

Figure 1: Minimum focal spot size as a function of the focal length. The black squares indicate the focusing settings of the recent HED experiment [2].

For HED experiments in cylindrical geometry a stigmatic focusing is needed, i. e. a round beam focal spot at the target, $S_X = S_Y = S_S$, whereas for experiments in plane geometry [2] an elliptical focal spot ($S_X \neq S_Y$) is preferable. We therefore performed two sets of calculations minimizing the quantities S_S and $\sqrt{S_X S_Y}$, respectively. It is important to note, that the actual apertures of the quadrupole vacuum chambers and the strengths of the magnets have been taken into account. These constrains lead to a highly non-linear dependence of the minimum focal spot size at short focal distances below 1.2–1.6 m. Since the objective function has a very complicated structure with many local minima, a special optimization strategy has been chosen. First, an attempt to approach the global minimum of the objective function is done by varying the settings of the last five quadrupoles and using the Simulated Annealing algorithm in many iterations. After this, the optimization is refined with the last quadrupole triplet using the Simplex minimization algorithm. The results of these calculations are shown in Fig. 1.

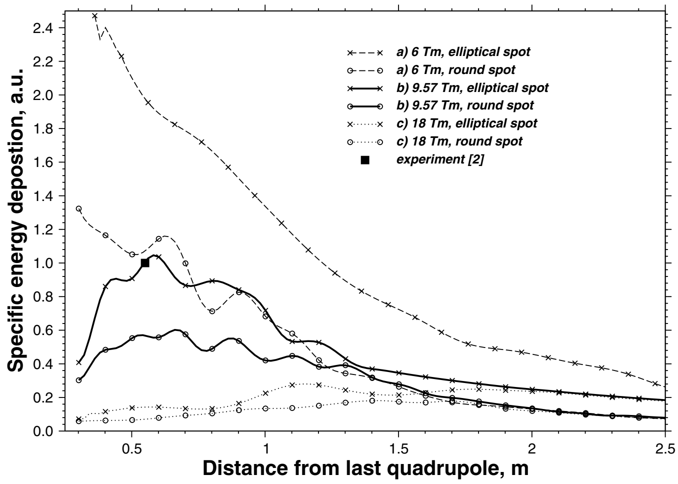

Figure 2: Relative maximum specific energy deposited in a target, recalculated from Fig. 1.

Assuming that the maximum specific energy deposited by the beam in a target material scales with the focal spot size as $E_s \propto S_S^{-2}$ and $E_s \propto (S_X S_Y)^{-1}$, this quantity is plotted in Fig. 2, relative to the value of experiment [2].

In conclusion, for the HED experiments at the HHT using the present final focusing system, a focal length of 40–90 cm and beam magnetic rigidities of 6–10 Tm are preferable. Since the level of energy deposition rapidly drops with increasing rigidity, for $\mathbf{U}^{28+}$ beam a stripper foil before the focusing system should be used. More advanced studies on the final focusing, taking into account high-order aberrations, chromatic effects, influence of the beam emittance and the stripper foil are planned.

References

[1] M. Berz and J. Hoefkens, *COSY INFINITY Version 8.1 Programming Manual,* MSUHEP-20703, Michigan State University, 2002. URL: http://cosy.pa.msu.edu/.

[2] D. Varentsov et al., *Report on December 2003 Beamtime Experiment at HHT: Near-Critical HED States of Lead Generated by Intense Uranium Beam,* in this report.