Optimization of Focal Spot Size and Pulse Length for Heavy Ion Beam Heating of Targets at the SIS-100

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To maximize heating of matter by an ion beam, one should optimize the specific power deposition, P$_s$ which is given by

$$P_s = \frac{E_s}{\tau} \tag{1}$$

where τ is the pulse duration and E_s is the specific energy deposition given by

$$E_s = \frac{\frac{1}{\rho}\frac{dE}{dx}N}{\pi r_b^2} \tag{2}$$

In the above equation, $\frac{1}{\rho}\frac{dE}{dx}$ is the specific energy loss due to a single ion, ρ is the target material density, x is the coordinate along the particle trajectory, N is the total number of particles in the beam and r$_b$ is the beam radius that is the full width at half maximum (FWHM) of the Gaussian distribution.

When the future SIS-100 will work at its full capacity, it will deliver a uranium beam with an N = 2 × 10^{12} and a wide range of particle energy, 400 MeV/u - 2.7 GeV/u will be available. The bunch length corresponding to this energy range will be 90 - 25 ns. It is seen from Eq.(2) that E$_s$ varies as inverse square of r$_b$ and in principle one should be able to substantially increase E$_s$ by improving the beam focusibility. However one should also adjust the bunch length according to the change in the focal spot radius, otherwise the hydrodynamic transit time will not match the pulse duration and significant hydrodynamic expansion of the target will occur during the irradiation. This will lead to a significant reduction in the deposited energy.

In this contribution we report results from two-dimensional hydrodynamic simulations of heating of solid lead cylindrical targets using the SIS-100 beam assuming a particle energy of 1 GeV/u and a pulse duration of 50 ns. The beam target geometry is shown in Fig.1.

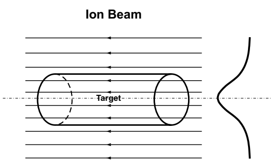

Figure 1: Beam-target geometry.

The target is assumed to have a length, L = 2 mm and three different values for the beam radius (FWHM), namely, 0.5 mm, 1.0 mm and 1.5 mm have been used. Corresponding to these values of FWHM we considered the target radii to be 0.2 mm, 0.4 mm and 0.6 mm respectively. This implies that the target will be uniformly heated along the length as well as along the radial direction.

In Fig.2 we plot density vs radius at L = 1 mm at different times during the irradiation for the case with a FWHM = 0.5 mm. It is seen that the density decreases significantly at t = 20 ns and the target radius becomes 0.4 mm due the hydrodynamic expansion. This leads to a lower energy deposition by the bulk of the ions that come in the later part of the pulse.

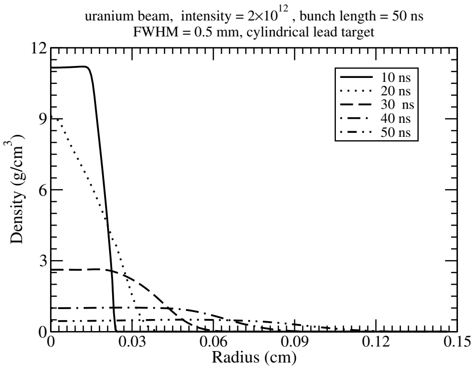

Figure 2: Density vs radius at the cylinder center, N=2 × 10^{12}, FWHM=0.5 mm, τ=50 ns .

In Fig.3 we plot the corresponding temperature profiles. It is seen that a maximum of 23 eV temperature is achieved at t = 20 ns but by the time the pulse delivers its total energy the temperature has been reduced to about 15 eV due to expansion of the material. For such a small focal spot radius it is necessary to have a bunch length of 5 ns that will lead to a high specific energy deposition of 1023 kJ/g which will produce a temperature of the order of 46 eV. However this bunch length will not be achievable at the SIS-100 and therefore this beam spot radius is not suitable.

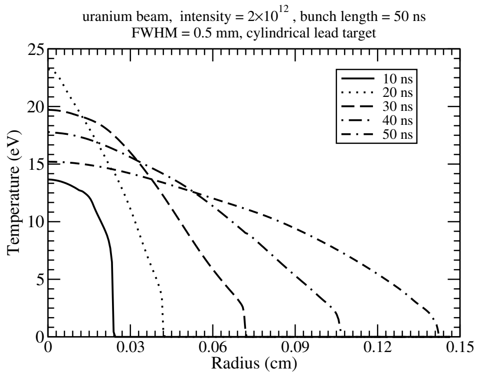

Figure 3: Temperature profiles corresponding to Fig.2

Our calculations show that for a pulse length of 50 ns an r$_b$ of 1 mm and for a pulse length of 100 ns an r$_b$ of 1.5 mm are suitable.