Q&A

Near-field-CTR-based self-focusing in beam-multifoil collisions: towards solid-density beams, extremely-dense gamma-ray pulses, and laserless SFQED

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“What is the (damage) effect on the foil material from the high density electron beam?”

The collisions of beam particles with the foil are negligible due to the low cross section at large CM energies. Inside the conductor dissipation occurs via Ohmic heating. The energy dissipated is

$$Q = \int dt \int d^3x\, \mathbf{E} \cdot \mathbf{J} = \int dt \int d^3x\, \rho \mathbf{J}^2 = \int_0^l dx \int_{-\infty}^{\infty} dt \int_0^{\infty} dr\, 2\pi r \rho \mathbf{J}^2$$

where ρ is the resistivity and the return current inside the foil is such that it neutralizes that of the beam $\mathbf{J} = -\mathbf{J}^b$

$$\mathbf{J}^b = \frac{Nqce^{-(x-ct)^2/(2\sigma_\parallel^2)}e^{-r^2/(2\sigma_\perp^2)}}{(2\pi)^{3/2}\sigma_\parallel \sigma_\perp^2}$$

$$Q = \frac{\rho N^2 q^2 cl}{8\pi^{3/2}\sigma_\parallel \sigma_\perp^2}$$

For the fusion of a foil with uniform density d, thickness l, specific heat C and latent heat for fusion L one needs an energy

$$Q_{fus} = \pi d(C\Delta T + L)R^2 l$$

where ΔT is the difference of temperature from ambient to the temperature of fusion. By setting $Q = Q_{fus}$ one obtains a result independent of l.

By plugging the numbers for a 2 nC, 10 GeV electron beam and $l = 2\mu$m Al foil we obtain $R \approx 9\mu$m for $\sigma_{\parallel} = \sigma_{\perp} = 1\mu$m and $R \approx 0.8\mu$m for $\sigma_{\parallel} = \sigma_{\perp} = 5\mu$m.

In addition, part of the beam electromagnetic energy is deposited at the foil surface. Reflectivity/absorptivity is difficult to calculate in the ultraintense ultrafast regime. We assume 10% of the electromagnetic beam energy is deposited in the foil. The field is

$$\mathbf{E}_{\perp}^{b} = \frac{Nqe^{-(x-ct)^2/(2\sigma_{\parallel}^2)}e^{-r^2/(2\sigma_{\perp}^2)}}{(2\pi)^{3/2}\epsilon_0\sigma_{\parallel}\sigma_{\perp}^2}; \qquad r \lesssim \gamma\sigma_{\parallel}$$

The total energy is obtained by integrating the electromagnetic energy density tensor over the volume.

By plugging the numbers for a 2 nC, 10 GeV electron beam and $l = 2\mu$m Al foil we obtain $R \approx 1$mm for $\sigma_{\parallel} = \sigma_{\perp} = 1\mu$m and $R \approx 0.5$mm for $\sigma_{\parallel} = \sigma_{\perp} = 5\mu$m.

The above estimates are for the beam interacting with one thin foil. In the experiment, a grid will be used together with the stack of foils to absorb part of the heat deposited.

Backup

Approximate chosen values for the estimates

$\rho = 2.65 \times 10^{-8}\,\Omega m$
$C = 920$ J / kg K
$\Delta T = 600$ K
$L = 3.96 \times 10^{5}$ J/kg