Simulation of laser cooling of heavy ion beams at high intensities

L. Eidam[*†1,2] *and O. Boine-Frankenheim*[1,2]
[1]GSI, Darmstadt, Germany; [2]TEMF, TU Darmstadt, Germany

Abstract

In the past the principle of Doppler laser cooling was investigated and verified in low energy storage rings. In the SIS100 laser cooling will be applied to intense ion beams in the high energy regime for the first time. Laser cooling leads to an increase of the longitudinal phase space density and to non-Gaussian bunch distributions. In order to optimize the cooling process and ensure stable operation laser cooling has to studied numerically.

Principle of Laser Cooling

Laser cooling produces very cold beams by intersecting laser light anti parallel with the ion beam. The wavelength of the laser in the particle frame has to fit to an atomic transition with a short lifetime. The absorbed photons always give a kick in the same direction whereas the emitted photons kick the ions in any direction. This results in a net force pointing in the direction of the laser beam. The narrow force only interacts with particles with a momentum deviation of approximately $\Delta p/p \approx 10^{-7}$. The cooling of a hot ion beam is feasible by sweeping the laser frequency to interact with all particles in the bucket [1].

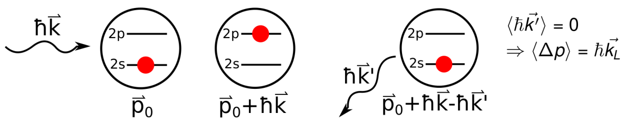

Figure 1: Schematic explanation of directional force for multiple scattering events during the laser cooling process.

Numerical Model

For the studies of the cooling process the simulation considers only the longitudinal phase space because the photon-particle interaction only affects the longitudinal motion. The tracking code contains different RF bucket configurations, intra beam scattering (IBS), space charge (SC) and the laser forces.

The laser forces are modelled statistically to take care of the so called ’random walk’ [2]. This concept clarifies that the probability of absorbing the next photon changes after each scattering event. Therefore the assumption of an averaged force is not valid in general. For the simulation the laser interaction region is divided into slices. For each simulated particle in each slice the probability of a scattering event is calculated and statistically applied. The momentum change of a scattering event is given by:

$$\delta_j' = \hbar\vec{k}_{pf} \cdot (1 + \cos(\pi \cdot U_j)) \qquad (1)$$

where $\hbar\vec{k}_{pf}$ is the momentum of the photon in the particle frame and U_j a random number. The therm $\cos(\pi \cdot U_j)$ describes the projection on the longitudinal axes of the randomly emitted photon. The probability of this momentum change is given by:

$$\rho(S, \Delta v) = \frac{L_{\text{intersec.}}}{n_{\text{slices}}\beta c_0 \gamma} \frac{\Gamma_L}{2} \frac{S}{1 + S + (2\Delta v/\Gamma_L)^2} \qquad (2)$$

where the first factor describes the time interval of each slice and the rest is given by the well known probability of a spontaneous emission of a two level system with the saturation parameter S [2].

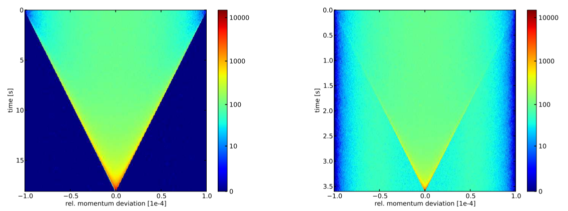

Figure 2: Momentum deviation over time during the cooling process for two different speeds of the laser sweep.

Figure 2 shows the simulated momentum deviation during the cooling process in a regular RF-bucket. In the second plot the sweep of the laser is too fast and some particles get lost behind the laser force and consequently for the cooling process.

Outlook

In the future the laser force and the IBS rates of possible transitions of different ion species will be analysed to find ions for a fast cooling process. Besides different cooling schemes with different RF configurations have to be analysed to optimize the cooling process.

References

[1] M. Bussmann et al, J. Phys.: Conf. Ser. 88, 012043 (2007)

[2] H.J. Metcalf, P. van der Straten, “Laser Cooling and Trapping of Atoms and Ions”, Springer (1999)

* leidam@gsi.de
† Work supported by HGShire

DOI:10.15120/GR-2015-1-FG-SIS100-05