# Ion beam formation and propagation

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The extraction from a plasma source and the propagation of a particle beam (say $H^-$ ions) with finite temperature are governed by the Vlasov equation and the coupled Poisson equation for electric potential $\phi$ (relativistic effect are typically neglected for simplicity since particle speed is small in the source); geometries with $N_d$=2 or $N_d$=3 space dimensions are considered, in stationary regime. While $N_d$-dimensional finite elements are quite suitable for Poisson equation solution, allowing arbitrary shapes of the electrodes, a similar solution of Vlasov equation is widely considered impractical, for the 2*$N_d$ dimensions required and its hyperbolic character. Existing simulation codes samples the solution of Vlasov equation along characteristic lines with the tracing of a few (N) particle trajectories, called rays. Considering practical limitations on N ($<10^4$), typical numerical implementations shows granularity effects and unphysical fluctuation of fields; moreover, while iterating between the solution of Poisson and Vlasov equations, convergence may deteriorate [1] for these fluctuations.

To solve granularity issues, it was proposed to consider the calculated rays as input data to find the motion map, called ray map, which is then interpolated to a continuum of ion initial conditions [2]. This was implemented in $N_d$=2 model with interpolation on the ion position only. Extending the interpolation over the ion initial divergence was not yet implemented, so that sampling over few values is still used. Another approach is to perturbatively treat ion temperature, starting from laminar flow as zero order approximation; the laminar flow is a particular case of ray map, where N may be small (typically 20). In any case, the computational overhead of map calculation in not yet optimized and interpreted programming languages limits N even more strongly than for ray tracing; of course, a large computational speed-up is to be expected in future compiled versions. Typical results of this advanced simulation techniques are shown, as applied to a few extraction systems.

Another issue is the presence of transverse magnetic fields and of many species inside the plasma, some of which are extracted (for example $H^-$ and electrons), some of which are not (for the same example, protons): Electron current is reduced thanks to transverse magnetic fields, and typically comparable to $H^-$ one. In most existing codes, proton density is taken to be proportional to extracted ion density times a maxwellian factor. Some progress in $N_d$=1 models of electron extraction was obtained by adding a collisional term to the Vlasov equation, and representing its solution (via the integration on characteristic lines) with an integral equation for $\phi$. Physically, a plasma-beam interface is formed, with the plasma remaining in a quasi neutral condition; electron deconfinement and extraction is due to collisions; in principle, Poisson-Vlasov-collision system should be solved for all particle species [3]. Parameters of electron emission are critically discussed and compared with existing code assumptions.

## References

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