Energy straggling cross section for antiproton-atom collisions

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Synopsis We present benchmark simulations of the energy straggling cross section for antiprotons colliding with hydrogen and helium. We solve the one- and two-particle Schrödinger equation numerically within the framework of the straight-line impact-parameter approximation. Our results provide first evidence for the convergence of the *ab-initio* simulation toward the classical Bohr straggling cross section proposed a century ago.

One frequently employed key observable characterizing the collisions of charged particles with matter, both in the gas phase and condensed phase, is the stopping power or stopping cross section introduced more than a century ago by N. Bohr and intensely studied ever since. It characterizes the first moment of the energy loss distribution or, in case of atomic collisions, the collisional energy transfer to the target nucleus and the electronic excitation and ionization spectrum. Surprisingly, unlike the stopping cross section, the higher moments of the spectral distribution have not been systematically studied. In particular, *ab-initio* simulations of the straggling cross section characterizing the second moment of the energy loss distribution appear to be still missing.

We present first numerical results for straggling for gas phase collisions of antiproton with hydrogen and helium. Antiproton projectiles are of fundamental interest as they allow to probe the pure Coulomb excitation and ionization spectrum without admixture of the charge transfer channel. The main computational challenge is the accurate coverage of the large spectral width of the ionization spectrum at high impact energies. The ionization cross section peaks near threshold ($\varepsilon \approx 0$) while the binary encounter peak extends to $\varepsilon \approx 20$keV electron energy (e.g., for 10MeV impact energy). The higher moments sensitively depend on the tails of this wide distribution. We employ a straight-line impact parameter approximation for the $\bar{p}$. The time evolution of the electronic wave function is propagated by the split-operator method with a generalized pseudospectral method in the energy representation as described in Ref. [1]. In the present simulation we improve the method by projecting the ionized electron onto the Coulomb continuum wave function at given time intervals Δt which are determined by the fastest components of the electronic wave packet. We have tested the convergence against time step, space grid structure as well as the number of partial waves included. The latter is of particular importance for higher moments of the ionization spectrum. For example, at 5MeV impact energy, the total inelastic cross section converges, within 1% error, with inclusion of 30 partial waves. However, to reach the convergence for energy loss already 90 partial waves and for straggling even 150 partial waves are required. For energy loss cross section (Fig.1), our results are in reasonable agreement with the recent results by Lühr and Saenz [2]. The straggling cross section monotonically increases with impact energy and converges to the classical Bohr straggling cross section σ_{bs} at high energies. Extension to antiproton-helium collisions and the influence of correlations effects will be presented at the conference.

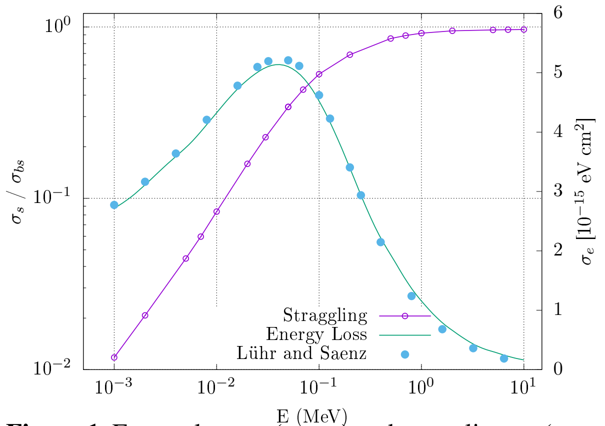

Figure 1. Energy loss σ_e (green) and straggling σ_s (purple) cross sections in units of the Bohr straggling cross section σ_{bs} of antiproton colliding with hydrogen.

References

[1] X. M. Tong *et al.* 2001 *Phys. Rev. A* **64** 022711

[2] A. Lühr and A Saenz, 2009 *Phys. Rev. A* **79** 042901