Electron correlations in the antiproton energy-loss distribution in He

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Synopsis We present two-electron ab-initio calculations of the stopping and straggling cross sections for antiprotons with energies between 3keV and 1MeV interacting with helium. By comparison with mean-field (single active electron) simulations we identify electron correlation effects in both the stopping and straggling cross sections. Most remarkably, we find that straggling exceeds the Bohr straggling limit when correlated shake-up processes are included.

The energy deposition processes during the interaction of charged particles and matter is quantified by the mean energy loss (the first moment of the energy loss distribution) and the energy straggling (the second moment). Their investigation was triggered by the early work by Bohr [1, 2] and continues up to date, however, the fully ab-initio investigation of the many-electron response [3, 5] to charged particle penetration became possible only recently.

We present fully ab-initio simulations of the electronic stopping and straggling cross sections for antiproton scattering at helium atoms. The time-dependent Schrödinger equation describing the quantum dynamics of the two active electrons of the target is solved numerically [4, 5] using the time-dependent close-coupling (TDCC) method. The mean energy loss (stopping) and the energy loss straggling is extracted directly from the time-dependent wave function [5] and alternatively from the ionization spectrum. In order to highlight the electron correlation effects mean-field calculations based on the single active electron approximation [6] are also performed and compared to the TDCC model.

For the straggling cross section (shown on Fig. 1) a good agreement between the single electron contribution of the TDCC model and the mean-field model is observed. With the inclusion of the two-electron contributions in the TDCC model the straggling cross section significantly exceeds the mean-field cross sections and at high projectile energies the Bohr straggling limit.

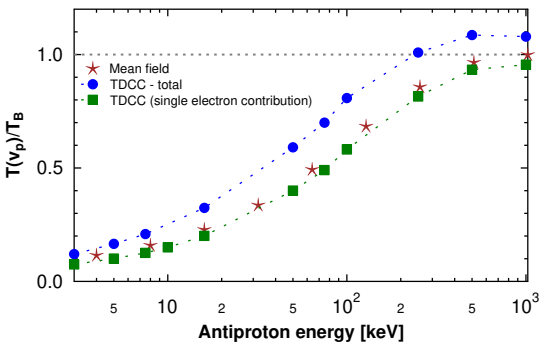

Figure 1. The straggling cross sections for antiprotons colliding with helium for different antiproton impact energies. Mean-field results are compared to two-electron (TDCC) results. The cross sections are expressed in Bohr straggling units ($T_B = 4\pi Z_p^2 Z_t$).

References

[1] N Bohr 1913 *Phil. Mag. Ser. 6* **6** 25.
[2] N Bohr 1915 *Phil. Mag. Ser. 6* **30** 581.
[3] J. J. Bailey *et al* 2015 *Phys. Rev. A* **92** 022707.
[4] S. Borbély *et al* 2014 *Phys. Rev. A* **90** 052706.
[5] S. Borbély *et al* 2018 *Phys. Rev. A* **98** 012707.
[6] X.-M. Tong *et al* 2000 *Phys. Rev. A* **62** 052701.

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