

Nuclear and Particle Physics with Single Atoms in Strong Laser Fields

C. Mueller,¹ T. J. Buervenich,^{1,2} J. Evers,¹ K. Z. Hatsagortsyan,¹ and C. H. Keitel¹

¹*Max-Planck-Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany*

²*Frankfurt Institute for Advanced Studies, Max-von-Laue-Str. 1, 60438 Frankfurt, Germany*

Summary: High-energy reactions resulting from the interaction of a positronium atom with a super-strong laser field are considered. As an example, the process of muon pair creation in laser-driven electron-positron collisions is studied. Further, nuclear excitation by the direct interaction of a nucleus with an intense, high-frequency laser beam is discussed.

Inside the most powerful laser fields available today, electrons acquire ponderomotive energies of order 1 GeV. In principle, such high energies can be exploited to induce elementary particle reactions like heavy lepton-pair creation or hadron production in electron-positron collisions [1,2]. This indicates that there might be a way to merge laser physics with high-energy physics. Similar efforts are being undertaken with respect to laser and nuclear physics [3].

A particular advantage of laser fields is that, apart from the high energies achievable, they can be used to generate coherent particle collisions at microscopic impact parameters [1]. This is demonstrated by considering a strongly laser-driven positronium atom. Employing ultra-intense laser pulses and strong static magnetic fields, the electron and positron acceleration and their head-on-head collision can be united in one stage. The resulting coherent collisions in the GeV regime yield an enormous luminosity enhancement with regard to conventional particle colliders.

As a specific example, we have calculated the rate for muon pair production from laser-driven positronium [2]. The threshold intensity of this process is almost reached by the most powerful present laser systems. For the case of a single driving laser wave of circular polarization, however, the total production rate turns out to be very small due to a destructive interference effect. Therefore, the related process of muon pair creation by the interaction of a super-intense laser beam with an electron-positron plasma is more favorable.

Moreover, we discuss direct interactions of nuclei with super-intense laser fields, where no secondary particles mediating the interaction are involved [3]. We demonstrate that upcoming x-ray laser facilities, especially together with a moderate acceleration of the target nuclei, do allow for resonant laser-nucleus coupling. These direct interactions may be utilized for the optical measurement of nuclear properties such as the transition frequency and the dipole moment, thus opening the field of nuclear quantum optics.

[1] K. Z. Hatsagortsyan, C. Mueller, and C. H. Keitel, physics/0602093.

[2] C. Mueller, K. Z. Hatsagortsyan, and C. H. Keitel, physics/0602106.

[3] T. J. Buervenich, J. Evers, and C. H. Keitel, Phys. Rev. Lett. 96, 142501 (2006).