Lepton spectroscopy at storage rings: from electrons at ESR to positrons at HESR*

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Electron spectroscopy at ESR

In collisions of heavy highly-charged projectile ions with atomic targets, the energy distribution of the emitted electrons is a characteristic observable for the underlying elementary processes. At the experimental storage ring ESR at GSI, a dedicated magnetic electron spectrometer was built downstream from the gas-jet target, which enabled the measurement of high-energetic electrons emitted in ion-atom collisions within a small cone in the forward direction. Using this electron spectrometer in combination with detectors for emitted x rays and charge-exchanged projectiles, the study of the collision system $U^{88+} + N_2$ @ 90 MeV/u revealed three processes resulting in the emission of electrons with a velocity similar to the projectile velocity, i.e., cusp electrons:

(a) The process of **electron loss to continuum** (ELC) corresponds to the ionization of an electron from the projectile into the projectile continuum during the collision with the target,

$$U^{88+} + N_2 \rightarrow U^{89+} + [N_2]^* + e^-.$$

For the ELC the measured spectrum was compared to first-order perturbation theory using fully-relativistic Dirac wavefunctions [1].

(b) The process of **electron capture to continuum** (ECC) corresponds to the capture of a target electron into the projectile continuum, while the excess energy is carried away by the recoil of the generated target ion:

$$U^{88+} + N_2 \rightarrow U^{88+} + \left[N_2^+\right]^* + e^-.$$

For the ECC the measured spectrum was compared to calculations in the impulse approximation using semi-relativistic Sommerfeld-Maue wavefunctions and to calculations the in continuum-distorted-wave approach [2].

(c) The process of **radiative electron capture to continuum** (RECC) corresponds to the capture of a target electron into the projectile continuum, while the excess energy is carried away by a photon:

$$U^{88+} + N_2 \rightarrow U^{88+} + \left[N_2^+\right]^* + e^- + \gamma.$$

This latter process can be seen as the high-energy endpoint of bremsstrahlung studied in inverse kinematics. For the RECC the measured spectra were compared to calculations in the impulse approximation using semi-relativistic Sommerfeld-Maue wavefunctions, and to calculations using fully-relativistic Dirac wavefunctions [3].

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Positron spectroscopy at HESR

Based on the experience gained with the magnet electron spectrometer at the ESR, an experimental concept for positron spectroscopy at the high-energy storage ring HESR at FAIR was developed [4]. The high projectile energy of up to 5 GeV/u accessible at HESR facilitates the study of electron-positron pair production processes through coincidence experiments observing the emitted positron and the singly or doubly charge-exchanged projectile. For the example of collisions U^{92+} + Ar two processes have been contrasted in Ref. [4]:

(a) The process of **bound-free pair production** (BFPP) results in the emission of a positron and a singly charge-exchanged projectile:

$$U^{92+} + \mathrm{Ar} \rightarrow U^{91+} + \mathrm{Ar}^* + e^+.$$

Its theoretical description requires a relativistic two-center approach, since the electron-positron pair is generated in the combined Coulomb field of projectile and target nucleus.

(b) The hitherto unobserved process of **negative-continuum dielectronic recombination** (NCDR) results in the emission of the positron and a doubly charge-exchanged projectile:

$$U^{92+} + \mathrm{Ar} \rightarrow U^{90+} + \left[\mathrm{Ar}^+\right]^* + e^+.$$

Its theoretical description requires a relativistic single-center approach, since the electron-positron pair is generated by the energy released in the recombination of a target electron into a bound state of the projectile ion.

Electron-optical simulations for the design of a positron spectrometer at the HESR derived from the electron spectrometer at the ESR were performed and resulted in the application of BMBF Verbundforschung for developing and building such a positron spectrometer.

References

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