

Single Differential Cross Section $d\sigma/dE_{\text{electron}}$ for Projectile Ionization of U^{28+} Ions at 30-50 AMeV measured in the ESR

S. Hagmann^{1,2}, P.-M. Hillenbrand^{1,3}, W. Chen¹, G. Dalong⁴, Ch. Dimopoulou¹, R. Dörner², R. Dubois⁵, R. Grisenti^{1,2}, A. Gumberidze^{1,6}, Ch. Kozhuharov¹, M. Lestinsky¹, Yu. Litvinov¹, A. Müller³, F. Nolden¹, N. Petridis², S. Sanjari^{1,2}, S. Schippers³, U. Spillmann¹, M. Steck¹, G. Weber⁷, D. F. A. Winter¹, N. Winckler¹, X. L. Yan⁴, and Th. Stöhlker^{1,7,8}

¹GSI Darmstadt, ²Univ. Frankfurt, ³IAMP, Univ. Giessen, ⁴IMP, Lanzhou, China, ⁵Univ. of Missouri, Rolla, USA, ⁶Extreme Matter Inst. EMMI, Darmstadt, ⁷Helmholtz Inst. Jena, ⁸Physikal. Inst., Univ. Jena,

For heavy ion projectiles with specific beam energies from 1 AMeV to beyond 10 AGeV, the overwhelming contribution to beam loss in accelerator facilities at GSI/FAIR is quantitatively described as collisions of the swift projectile (in a charge state q) with quasifree target electrons which are ionized into the continuum.

Remarkably, for non-bare projectiles another contribution to stopping power and beam loss appears; besides the electron continua attributed to target ionization a prominent and strong cusp shaped feature at 0^0 with respect to the projectile direction and with $v_e \approx v_{\text{projectile}}$ is observed and is attributed to electron emission from ionization of a projectile carrying electrons, this cusp is normally labelled as electron loss to continuum (ELC) cusp.

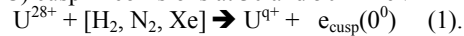
The magnitude of the cross section indicates the relevance this ionization channel has for swift structured projectiles. It so comes as no surprise so see this channel also as the dominant loss rate for multi-electron U^{28+} beams in SIS and ESR and future FAIR facilities [1].

For the future accelerator project FAIR high intensity beams of relativistic high-Z projectiles like Uranium are envisaged. The needed luminosity of the beam –subject to the space charge limit $\sim A/q^2$ -can only be achieved for such ions of high-Z when a low charge state q of the ion to be accelerated keeps the number density at a higher level than the one which would be expected for a higher charge state of the projectile. A technically optimal solution for the existing UNILAC accelerator facilities serving FAIR are Uranium beams with a mean charge state $28+$ (i.e. $4f^{14}5s^25p^2$) accelerated to 7.1 AMeV in the UNILAC and then further in the SIS 18 to 50 AMeV. The SIS18 needs to inject $1.3 \cdot 10^{11}$ ions at 2.6 Hz into the SIS100 synchrotron which then provides beams from 400 AMeV to 2.7 AGeV for experiments.

As the charge state $28+$ of the U beam is nearly over the entire acceleration phase in both synchrotrons far below the average charge state for the near relativistic beam velocity, the dominant beam loss is projectile ionization $U^{28+} + \{A\} \rightarrow U^{(28+n)+} + \{A^{+*}\}$ with $n \geq 1$; a fraction exceeding 40% has been calculated [1] for multiple loss $n \geq 2$ arising from the large number of weakly bound electrons on the projectile ($E_B = 930\text{eV}$ for the ionization potential of U^{28+}). Attempts for first order theoretical description of ionization of U^{28+} in fast collisions ($v_e \ll v_{\text{projectile}}$ for outermost electrons) have surprisingly produced mixed results.

Detailed calculations by A. Voitkiv et al. from the MPI-K [2] incorporate in their *ab initio* theoretical approach the symmetric eikonal model for relativistic ion-atom collisions and provide total ionization cross sections, but also differential projectile ionization cross sections for the ELC cusp. Importantly, the eikonal approximation gives at low collision energies 5 to 10 lower total cross sections than the first order theory [2].

We have embarked on an extensive experimental study to investigate single differential ionization cross sections $d\sigma/dE_{\text{electron}}$ (SDCS) for single and multiple U^{28+} projectiles [3]. Using the imaging forward electron spectrometer in the supersonic target zone of the ESR we have measured SDCS $d\sigma/dE_{\text{electron}}$ for the electron loss to continuum (ELC) cusp in collisions at 30 and 50 AMeV



The preliminary absolute SDCS exhibit strong asymmetries of the (ELC) cusp (see fig. 1), which are at variance with simple first order Born approximation theories. Future experiments with electrons measured in coincidence with the outgoing projectile charge state in order to distinguish SDCS from single and multiple electron loss of the projectile are in preparation.

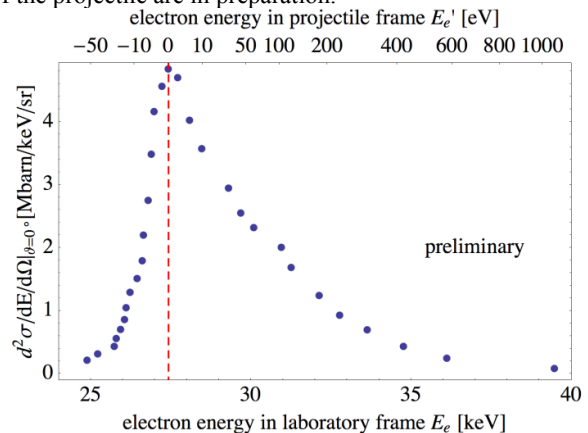


Fig.1 absolute SDCS ($\pm 70\%$) for projectile ionization in 50 AMeV $U^{28+} + Xe$ collisions

References

- [1] M. Song et al., NIM **B267** 2369 (2009)
- [2] A. Voitkiv et al., Phys. Rev. **A82**, 022707 (2010)
- [3] S. Hagmann et al., Proposal E117, GSI (2012).