**Electron emission from projectile ionization of U^{28+} and U^{88+,90+} at moderately relativistic velocities in heavy-ion storage rings**

<table>
<thead>
<tr>
<th>Institution</th>
<th>Authors and Affiliations</th>
</tr>
</thead>
<tbody>
<tr>
<td>GSI- Darmstadt</td>
<td></td>
</tr>
<tr>
<td>CIRIL-Ganil, Caen</td>
<td>H. Rothard, R. Dubois</td>
</tr>
<tr>
<td>INFN Catania, Italy</td>
<td>E. de Filippo, B. Wei, Y. Zou</td>
</tr>
<tr>
<td>Joint.Inst. f. Nuclear Res. Dubna, Russia</td>
<td></td>
</tr>
<tr>
<td>Theoretical support:</td>
<td></td>
</tr>
<tr>
<td>Max Planck Inst. f. Kernphysik, Heidelberg</td>
<td>A. Artiomov, A. Surzhykov, A. Voitkov, B. Najjari, P. N. Lebedev Physical Institute, Moscow, Russia</td>
</tr>
<tr>
<td>FIAS, Frankfurt and Oulu University, Finland</td>
<td></td>
</tr>
<tr>
<td>S. Fritzsch</td>
<td></td>
</tr>
</tbody>
</table>

within the SPARC Community
Outline

1. Motivation

2. Status: experiment/theory

3. Setup for e⁻-loss experiment

4. Beamtime request
Motivation

In ion-atom collisions:

1. For ions with bound electrons a strong electron emission cusp at $0^\circ$ with $v_e \approx v_{proj}$ has puzzled observers with unexpected shapes—what can we learn from electrons at the projectile continuum threshold?

2. $e$-loss cross sections for low-q high-Z ions (like $U^{28+}$) exhibit dependence on $E_{\text{coll}}$ and $Z_{\text{target}}$ not compatible with first order Born theories—differential electron cross sections as benchmarks for new theories with predictive power.
Status: experiment / theory

1st order theories for projectile ionization of U^{28+} exhibit discrepancies with experiment. They may fit beam lifetimes:

but fail $E_{\text{coll}}$ and $Z_{\text{target}}$ dependence:

$1/v_{\text{coll}}$ slope for high $Z_{\text{target}}$

strong higher order/ multiple excitation [+ autoionization(AI)] channel for high $Z_t$ 
produces discrete AI lines in $0^0$ e$^-$ cusp
Even for few–electron systems like $U^{90+}(1s^2)$ 1st order perturbation theory overestimates total loss cross sections for higher $Z_{\text{target}}$:

- Single differential electron emission spectra in projectile frame for $105 \text{ AMeV } U^{90+} + Z_2 \rightarrow U^{91+}(1s) + e(0^0)$

  *coincidence can provide benchmark for test of advanced theories beyond 1st order*
The electron spectrometer permits to reconstruct primordial vector momenta behind momentum slits when it is operated in a telescopic mode, i.e. $|M_x|=|M_y|=1$. 

**Forward Electron Spectrometer at supersonic Jet target**
Electron transfer into projectile continuum for $U^{28+}(5s^25p^2)$

**OPEN CHANNELS** for electron transfer into projectile continuum:

$$U^{28+} + \{\text{He...Xe}\} \rightarrow U^{29+}(5s^25p^1) + \{A^{+*}\} + e^-_{\text{Cusp}(0^0)}$$

**ELC** electron loss to continuum cusp (direct ionization DI-Cusp)

$$\rightarrow U^{28+*}(..nln'\ell') + \{A^{+*}\}$$

**Excitation**

$$\downarrow$$

$$U^{29+}(5s^25p) + e^-_{\text{Al}(0^0)}$$

**Autoionization** (strong discrete lines superimposed on ELC)

**Coincidence**

$E_B(5p)=928$ eV

$E_B(4f)=1060$ eV

Multiple excitation to dense range of unoccupied levels is easy ($\Delta E \approx 100$ to few 100 eV)

at 50 AMeV $E_B$ corresponds to $E_e \approx 27$ keV : $E+A$ is strong.
OPEN CHANNELS for electron transfer into projectile continuum:

\[ U^{88+} + \{\text{He...Xe}\} \rightarrow U^{89+}(1s^22s^1) + \{A^+\} + e^{-}_\text{Cusp}(0^0) \]

**CLOSED CHANNELS**

- \( U^{88+} \rightarrow U^{88+*}(..nln''l'') + \{A^+\} \)
- \( U^{89+}(1s^22s) + e^{-}_\text{AI}(0^0) \)

Excitation

Autoionization

\( E_B(1s) = 129.3 \text{ keV} \)

\( E_B(2s) = 32. \text{ keV} \)

Excitation to dense range of unoccupied levels requires large \( \Delta E \approx \text{few keV to few 10 keV} \)

at 90 AMeV corresponds to \( E_e \approx 50 \text{ keV} \) : E+A is weak
90 AMeV U^{88+} + N_2:
most stringent test of theory is in projectile frame

Projectile electron loss:
0\textsuperscript{0} - Cusp e\textsuperscript{-} coinc with U\textsuperscript{89+}

Radiative electron capture to continuum:
Laboratory 0\textsuperscript{0}-Cusp e\textsuperscript{-} coinc. with $\hbar\omega|_{\text{bremsst.}}$

To be measured for every data point in cusp
We request beam time for single and double ionization (DI) of U^{28+} and for single ionization of U^{88+}. The necessary statistics for DI determines the accumulation time.

- 20 -50 AMeV $U^{28+} + \{H_2, He, N_2 , Xe\}$
  - single and double ionization of $U^{28+}$
  - 16 shifts

- 90 AMeV $U^{88+} + \{H_2, He, N_2 , Xe\}$
  - single ionization of $U^{88+}$
  - 6 shifts

- beam tuning $U^{28+}$ for 2 charge states on detector
  - 1 shift

SUM 23 shifts