Upcoming Studies of Heavy Quasi-molecular Systems at the ESR

R.D. DuBois

ExtreMe Matter Institute
Missouri University of Science and Technology

R.D. DuBois[1,2], F. Bosch[3], R. Grisenti[4], T. Gross[3,6], S. Hagmann[3,4], M. Hegewald[3], P. Indelicato[5], C. Kozhuharov[3], D. Liesen[3], R. Märtin[3,6], R. Reuschl[7], M. Schwemlein3,6, U. Spillmann3, Th. Stöhlker1,3,8, D. Thorn1, M. Trassinelli7, S. Trotsenko[3,8], A. Warczak[9], G. Weber[3,6], D. Winters[3], N. Winters[3]

[1]ExtreMe Matter Institute, EMMI, GSI 64291 Darmstadt, Germany
[2] Missouri University of Science and Technology, Rolla, MO 65409, USA
[3] GSI Helmlotzzentum für Schwerionenforschung, 64291 Darmstadt, Germany
[4] Institut für Kernphysik, Universität Frankfurt, 60325 Frankfurt, Germany
[5] Laboratoire Kastler Brossel, École Normale Supérieure; CNRS; Université Pierre et Marie Curie-Paris 6 Case 74, 4 Place Jussieu, 75005 Paris, France
[6] Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg, Germany
[7] Institut des Nanosciences de Paris, CNRS and Université Pierre et Marie Curie-Paris 6, 75015 Paris, France
[8] Helmholtz-Institut Jena, 07743 Jena, Germany
[9] Uniwersytet Jagielloński, 30-059 Kraków, Poland

Within the SPARC collaboration

First Step in ESR Studies of K-Shell Excitation and Ionization at Small Impact Parameters and in Symmetric Heavy Systems

Overall Goals

Extend ESR studies to new regimes, e.g., to study

- symmetric heavy particle interactions where the combined nuclear charge is >100
- K-shell excitation and ionization processes at small impact parameters
  (much less than K-shell radius, e.g. < 200 fm)
- excitation and ionization of quasi-molecules produced in slow collisions

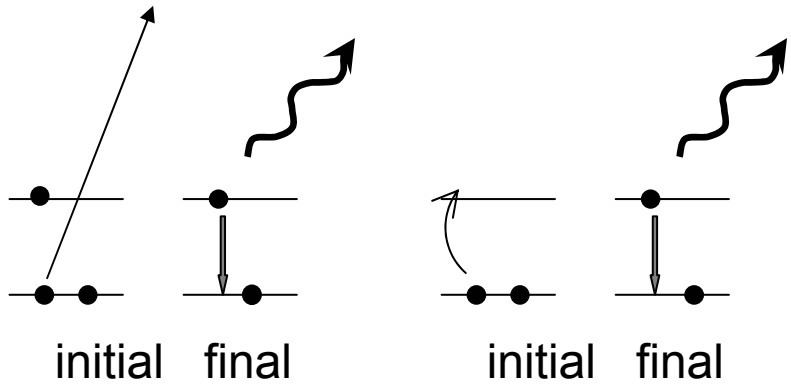
First Step

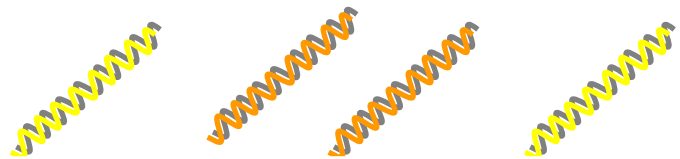
- Measure K-shell excitation at small impact parameters for "symmetric" heavy particle system, e.g., ~~50 MeV/u He-like Cs - Xe~~ .
- Investigate signal rates and backgrounds and use present study as a stepping stone for future impact parameter studies of K-shell ionization, excitation, and radiative electron capture.
- Test possibility of using the ESR and internal gas target to measure MO radiation produced in very heavy quasi-molecules.

Inner Shell Processes in Few-Electron Heavy Ions

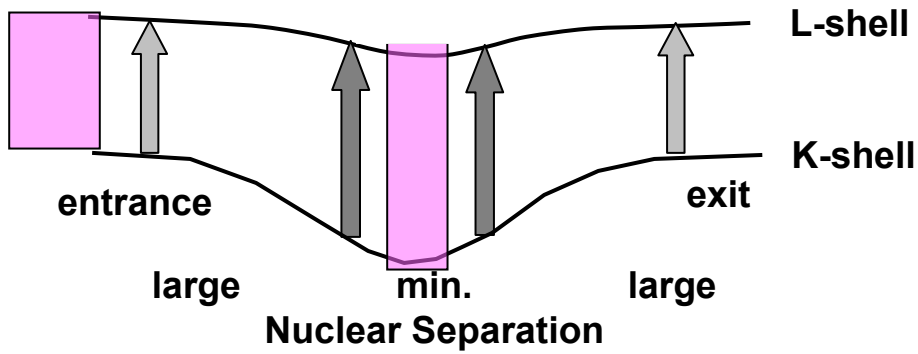
To date:
Fast, asymmetric interactions
(information about
atomic states and transitions)

- Mechanisms
- Strong field effects
- Relativistic and QED effects





Future:
Slow, symmetric interactions
(information about transient quasi-atoms
with very large Z)

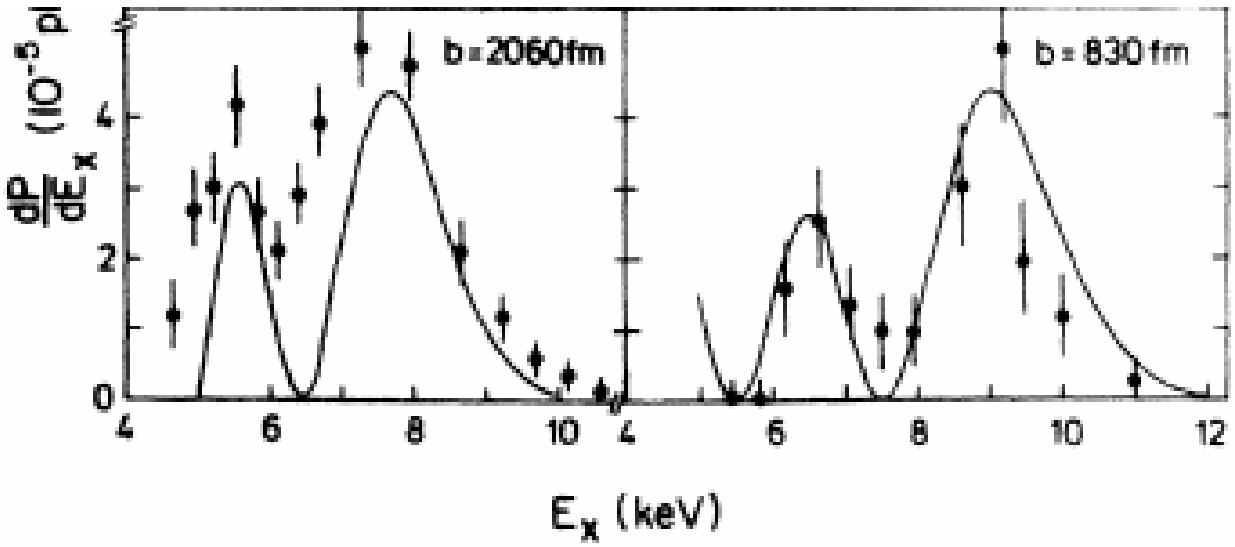


Impact parameter studies

IONIZATION

MO radiation

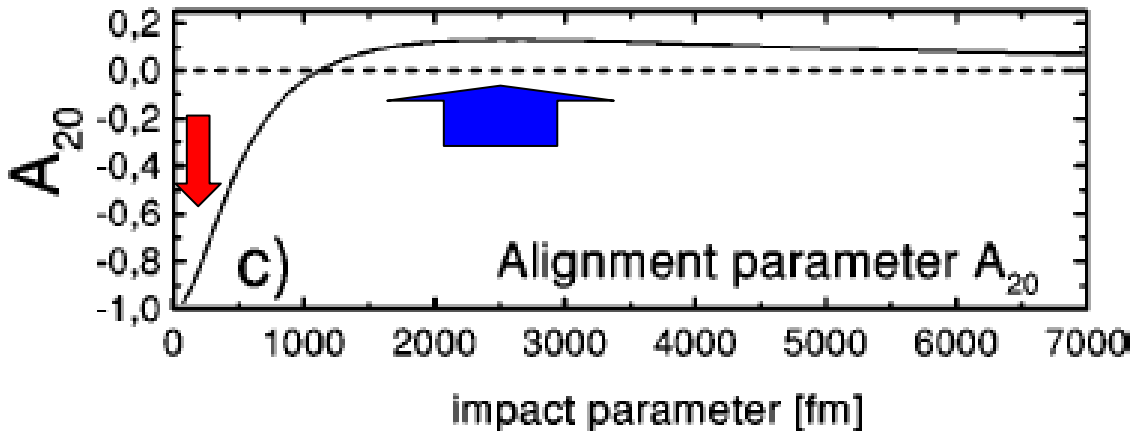
0.07 MeV/u Cl^{16+} - Ar
Schuch et al., PRA 37, (1988)



EXCITATION

Alignment at small and average impact parameters

$2p_{3/2}$ excitation of U^{91+} at 223 MeV/u
Ludziejewski et al. PRA 61 (2000)



Early MO Studies Using Solid Targets
Single-pass experiments

1972: Mokler, Stein and Armbruster, "X Rays from Superheavy Quasiatoms Transiently Formed during Heavy Ion-atom Collisions" PRL 29.

X rays produced by 10- to 60-MeV I-ion bombardment on thick Au, Th, and U targets were analyzed with a high-resolution Si(Li) detector. The spectra can be understood in the framework of diabatic molecular orbitals. Radiative transitions in the quasimolecule formed during the collision are observed. These transitions between transient molecular orbitals may be interpreted as M x rays of superheavy quasiatoms with nuclear charges of $Z = 132$, 143, and 145.

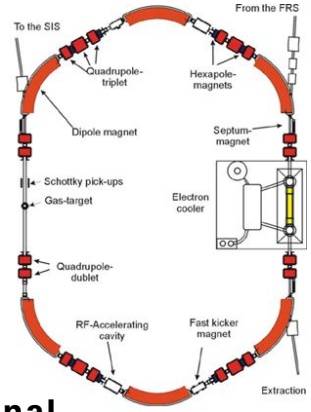
1974: Kraft, Mokler and Stein, "Anisotropic Emission of Noncharacteristic X Rays from Low-Energy I-Au Collisions", PRL 33**.**

1978: Liesen, Armbruster, Behncke, and Hagmann, 4.7 MeV/u Xe-Au impact parameter measurements of K-shell vacancy production, Z. Physik A 288.

1979: Kozhuharov et al., 1.4 GeV U-Pb and Pb-Pb positron production, impact parameter measurements for b<40fm, PRL 42.

1983: Maor, Liesen, Mokler, Rosner, Schmidt-Böcking and Schuch, impact parameter measurements for 1.4 MeV/u Ni-Zr,Ag,Te,Au collisions, PRA 27.

Upcoming ESR Based Studies



Internal Gas-jet Target

UNILAC
11.4 MeV/u
U^{73+}

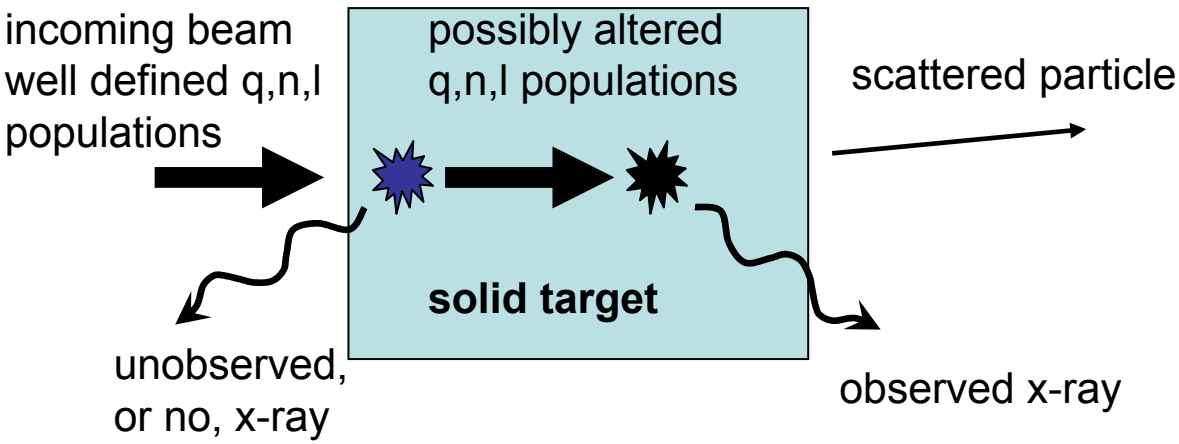
ESR

10 - 500 MeV/u
U^{92+}

SIS

up to 1000 MeV/u
U^{92+}

Advantages and improvements as compared to previous studies



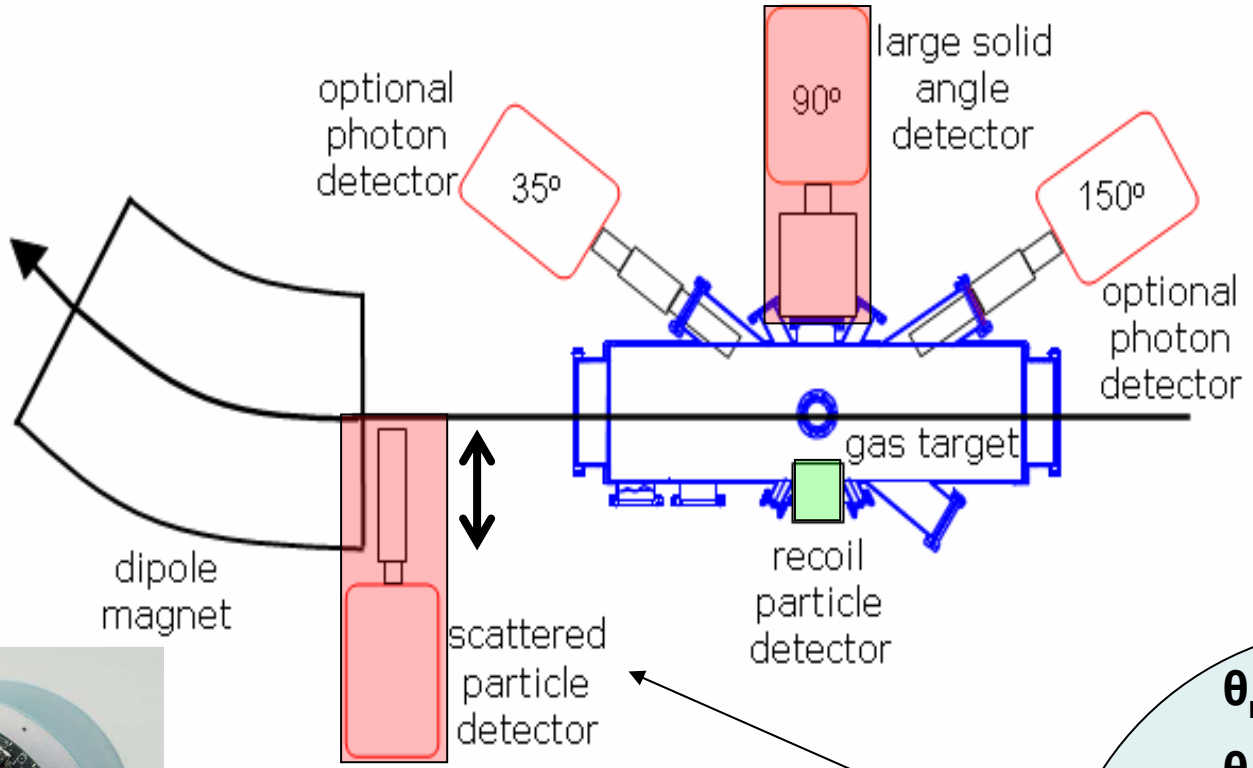
Advantage:
high signal rates,
very high Z_{targ} possible

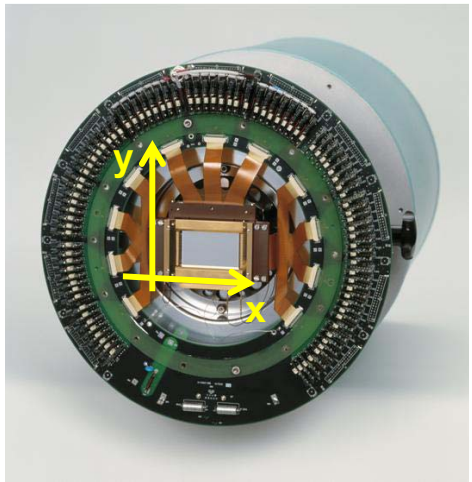
Dissadvantage:
data must account for possible alterations in initial and final q,n,l populations.

Advantages of using the ESR and Internal Gas-jet Target

- incoming ion in a well defined and desirable charge-state
- gas-target: single collision conditions
- outgoing ion charge-state undisturbed

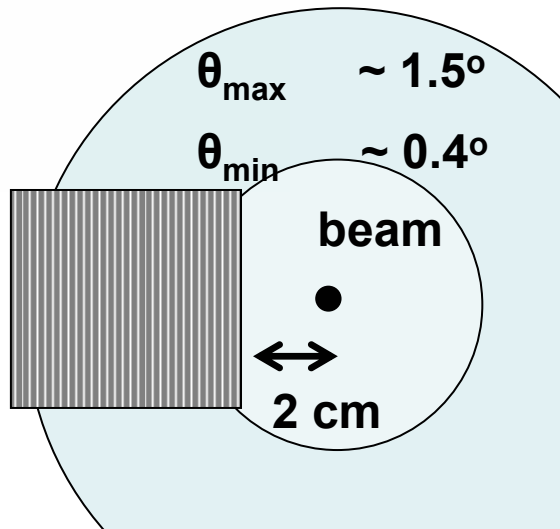
Experimental Method





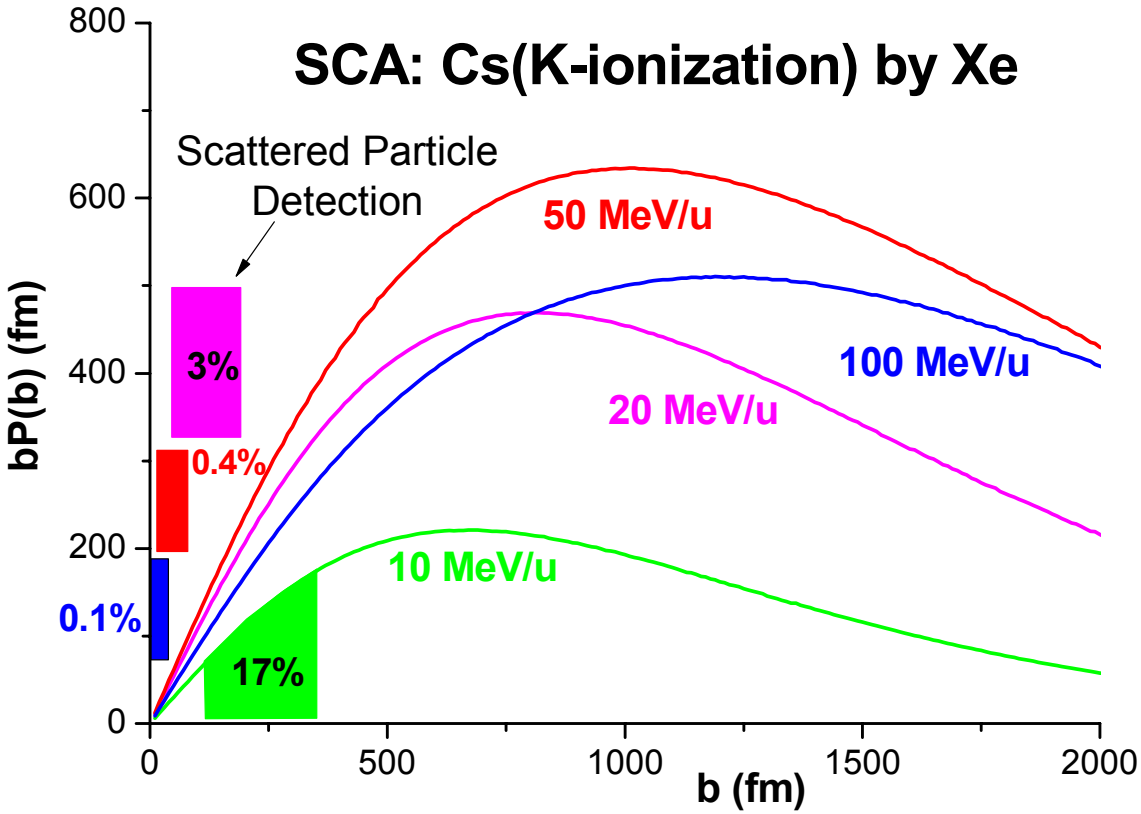
2D μSTRIP
germanium detector
GSI

5 x 5 cm
particle detector
~ 3 m downstream



Rate Estimates for Cs K-shell Ionization and Excitation

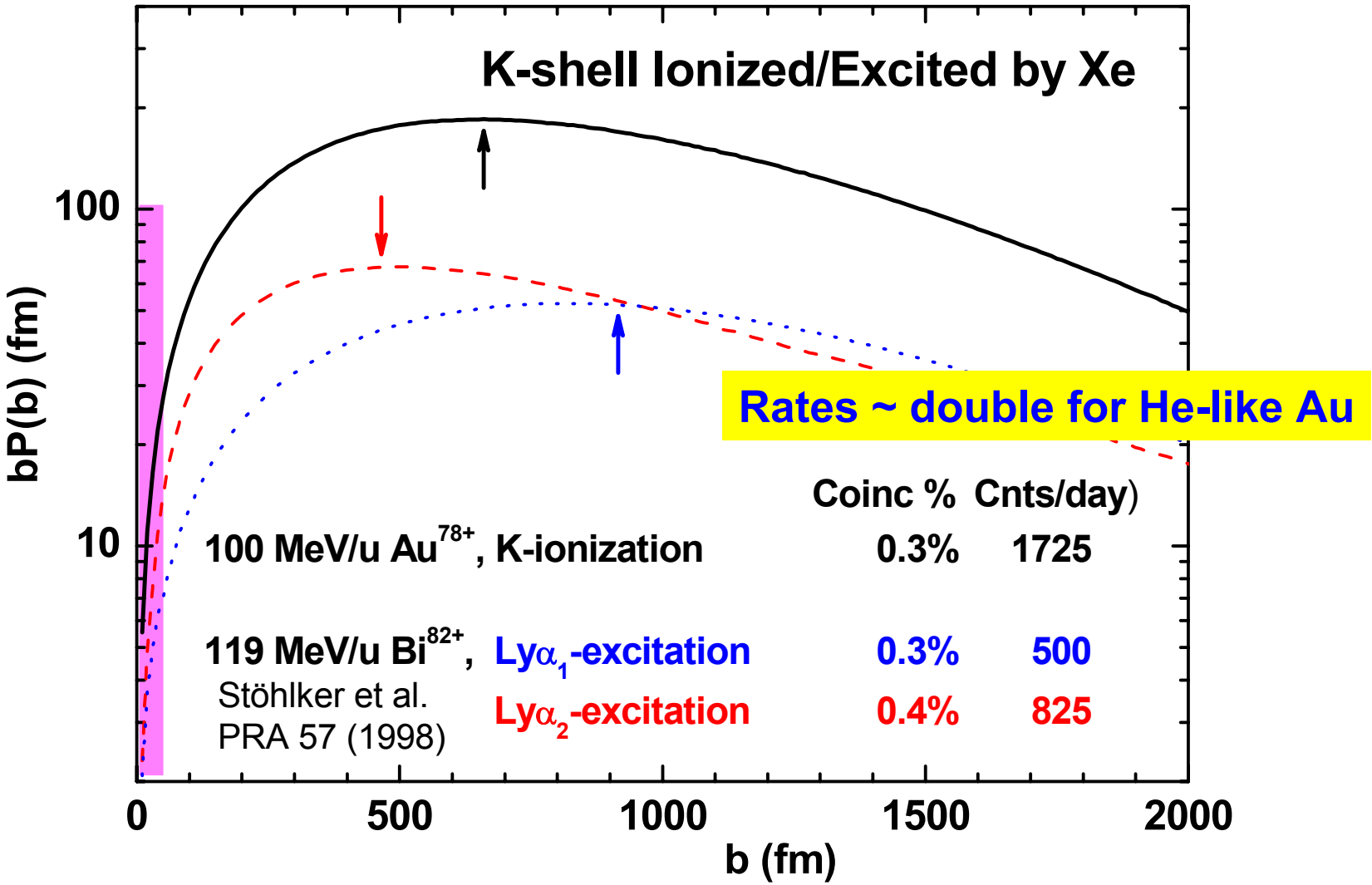
Energy (MeV/u)	1s-2s total cross section in barn	1s-2p	ionization
10	11372	14288	20219
20	14580	32076	53247
50	11956	46656	87694
100	8165	46073	77294



Excitation collected percentage ~10 to 15 smaller (Estimated from 400 MeV/u U^{89+}-N_2 data (Banaś et al.)

IF can bring scattered projectile detector closer to beam, e.g., 1 cm, collected percentage, and rates, increase by factor of 2- 4.

Rate Estimates for Au K-shell Ionization and Excitation



Summary

Outlined a new experimental ESR program based upon a new observable, the impact parameter. This will allow us to study K-shell ionization, excitation, and radiative electron capture in more detail than previously possible.

Described an upcoming experiment which will establish techniques, signal rates, and backgrounds for planning future studies.

Possible Future Studies

- extension to broader range of b and to lower velocities
- test higher-order theories (since Z/v ↑ as v ↓)
- MO interference in high Z quasi-molecules (**extreme/ critical fields**)
- anisotropy and alignment (population of 2p substates) for K excitation
- test theoretical predictions, e.g., new calculations by Prof. V. Shabaev (St. Petersburg State University) and Dr. A. Surzhykov (University of Heidelberg)