Selective population of 1s2s states after K-shell ionization of Li-like heavy ions

Ajay Kumar

GSI, Darmstadt

a.kumar@gsi.de

Collaboration

Th. Stöhlker[1,2], S. Trotsenko[1,3], D. Banas[4], H. Beyer[1], H. Bräuning[1], A. Gumberidze[1], S. Hagmann[1,3], S. Hess[1,3], C. Kozhuharov[1], R. Reuschl[1,3], U. Spillmann[1,2], M. Trassinelli[1], A. Volotka[5,6], G. Weber[1,2] and the ESR-Team

[1]Atomic Physics Group, GSI-Darmstadt, Germany
[2]Physikalisches Insitut, Ruprecht-Karls-Universität Heidelberg, Germany
[3]IKF, University of Frankfurt, Germany
[4]Institute of Physics, Swietokrzyska Academy, Kielce, Poland
[5]Institut für Theoretische Physik, TU Dresden, Germany
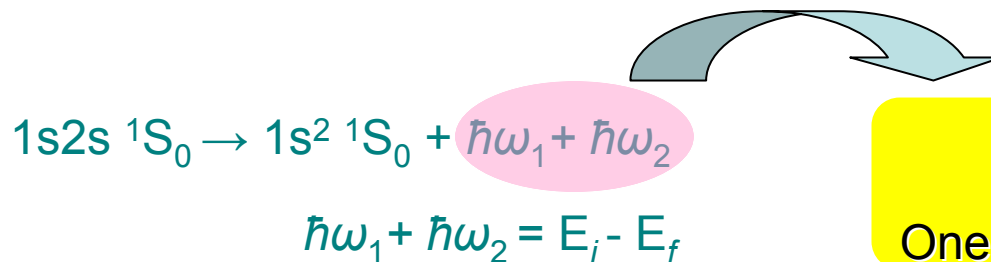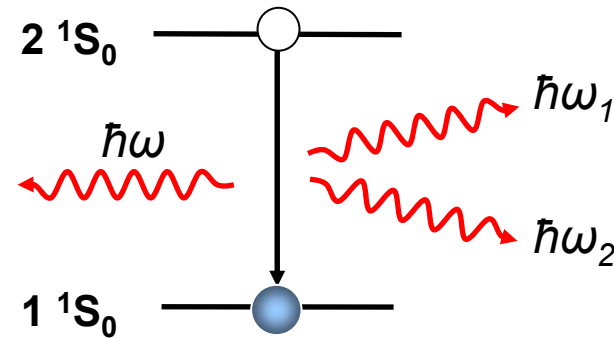[6]Department of Physics, St. Petersburg State Univ., Russia

Outline

❑ Introduction

❑ Experimental details

❑ Results and comparison with theory

❑ Summary

Two photon decay in He-like ions
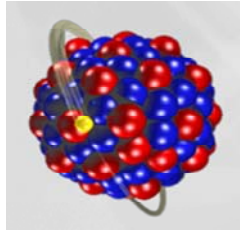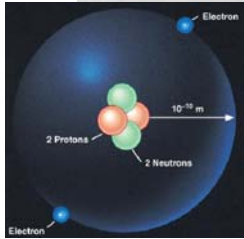
He- and He-like ions

Single photon transition

$1s2s\ ^1S_0 \rightarrow 1s^2\ ^1S_0 + \hbar\omega$

is forbidden $\boxed{J=0 \nrightarrow J=0}$

$2\ ^1S_0$ — $\hbar\omega_1$

$\hbar\omega$ $\hbar\omega_2$

$1\ ^1S_0$

$1s2s\ ^1S_0 \rightarrow 1s^2\ ^1S_0 + \hbar\omega_1 + \hbar\omega_2$
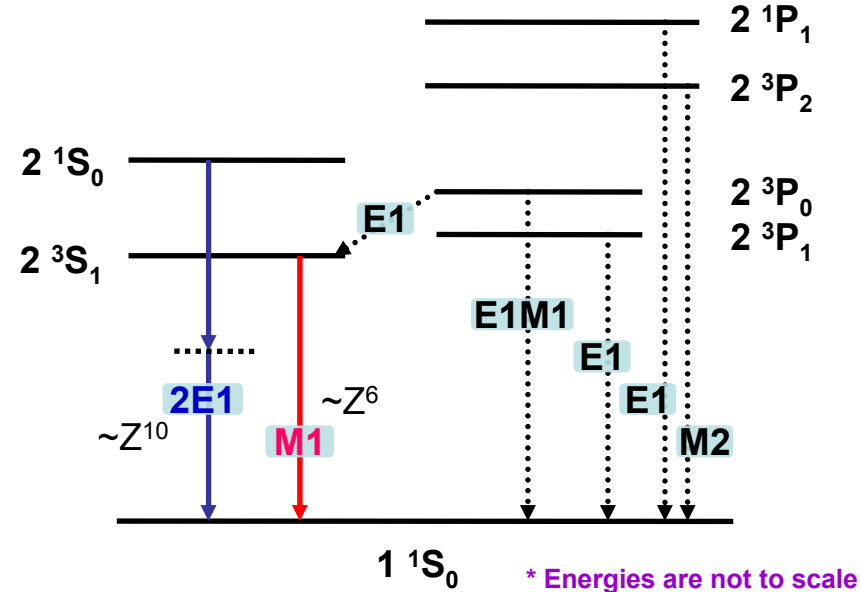
$\hbar\omega_1 + \hbar\omega_2 = E_i - E_f$

**Two photon decay process
or
One electron two photon decay process**

M. Göppert, Naturwissenschaften 17 (1929) 932
M. Göppert-Mayer, Ann, Phys. 9 (1931) 273

Why highly charged high-Z ions ?

Atomic Structure

$2\,^1P_1$
$2\,^3P_2$
$2\,^1S_0$
$2\,^3P_0$
$2\,^3P_1$
$2\,^3S_1$

E1
E1 M1
E1
E1
M2
2E1
$\sim Z^6$
$\sim Z^{10}$
M1
$1\,^1S_0$
* Energies are not to scale

➢ **Change of atomic structure with Z** - influences the two-photon decay rates

➢ **Competing of e-e correlation and relativistic effects**

➢ **Increased probability of forbidden transitions**
decay rate of forbidden transitions (M1,M2,E2,2E1) scales with Z^6-Z^{10}

➢**Spectral shape of two photon emission allows test the whole atomic system**
- probe of relativistic effects in the strong central field in heavy atomic system

➢**Testing of the quantum electrodynamics (QED)**

Lifetime (τ) of 2^1S_0 state of He-like ions

Theory

Phys. Rev. A 56 (1997) 1288
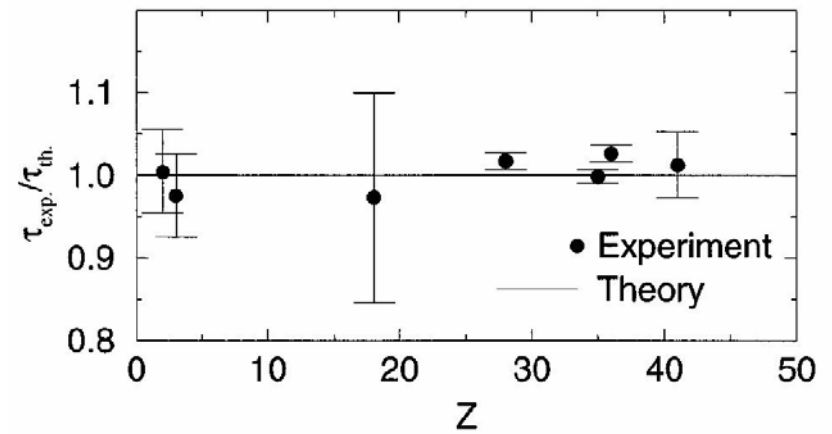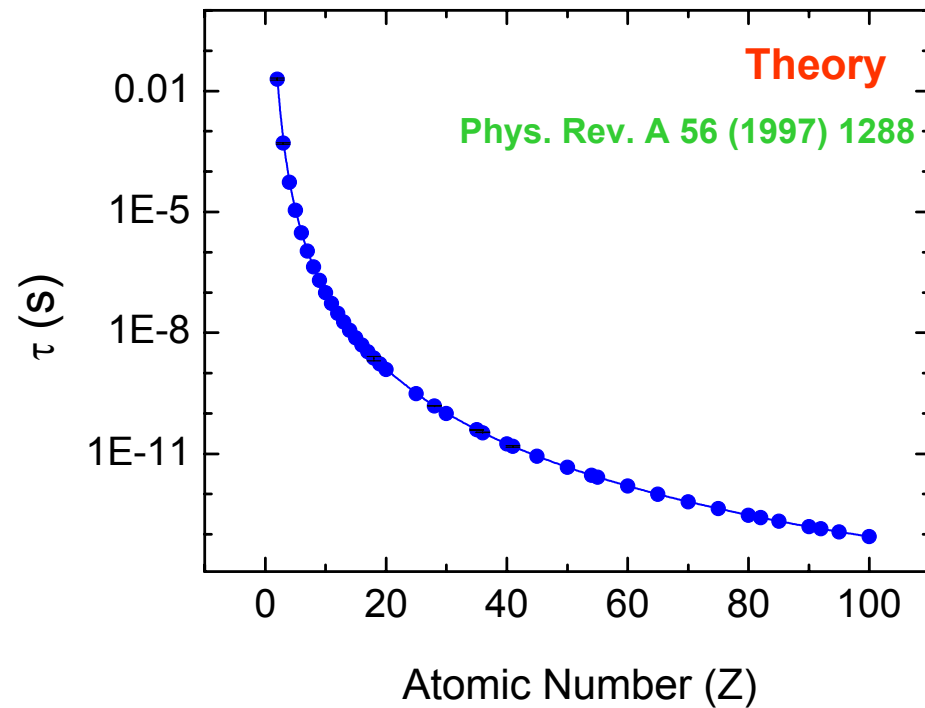
Z	Measured lifetime (s)	Reference
2	1.97 (0.10)E -2	vanDyck et al, Phys. Rev. A 4 (1971) 1327
3	5.03 (0.26)E -4	Prior and Shugart, Phys. Rev. Lett 27 (1971) 902
18	2.30 (0.30)E -9	Marrus and Schmieder, Phys. Rev. A 5 (1972) 1160
28	1.561 (0.016)E -10	Dunford et al, Phys. Rev. A 48 (1993) 2729
35	3.932 (0.032)E -11	Dunford et al, Phys. Rev. A 48 (1993) 1929
36	3.408 (0.034)E -11	Marrus et al, Phys. Rev. Lett. 56 (1986) 1683
41	1.533 (0.060)E -11	Simionovici et al, Phys. Rev. A 48 (1993) 1695
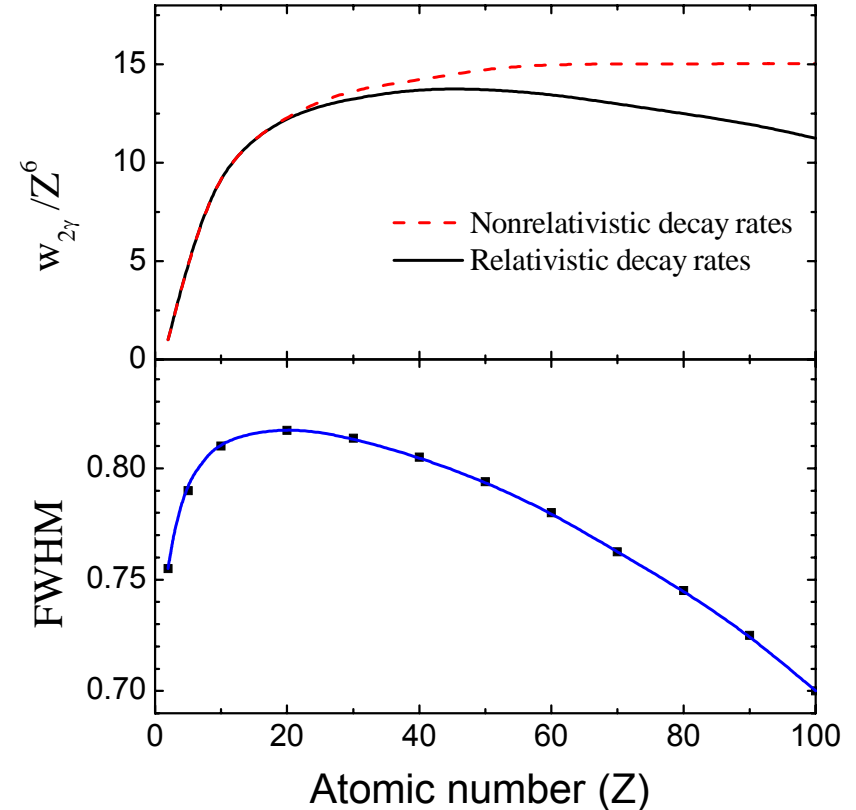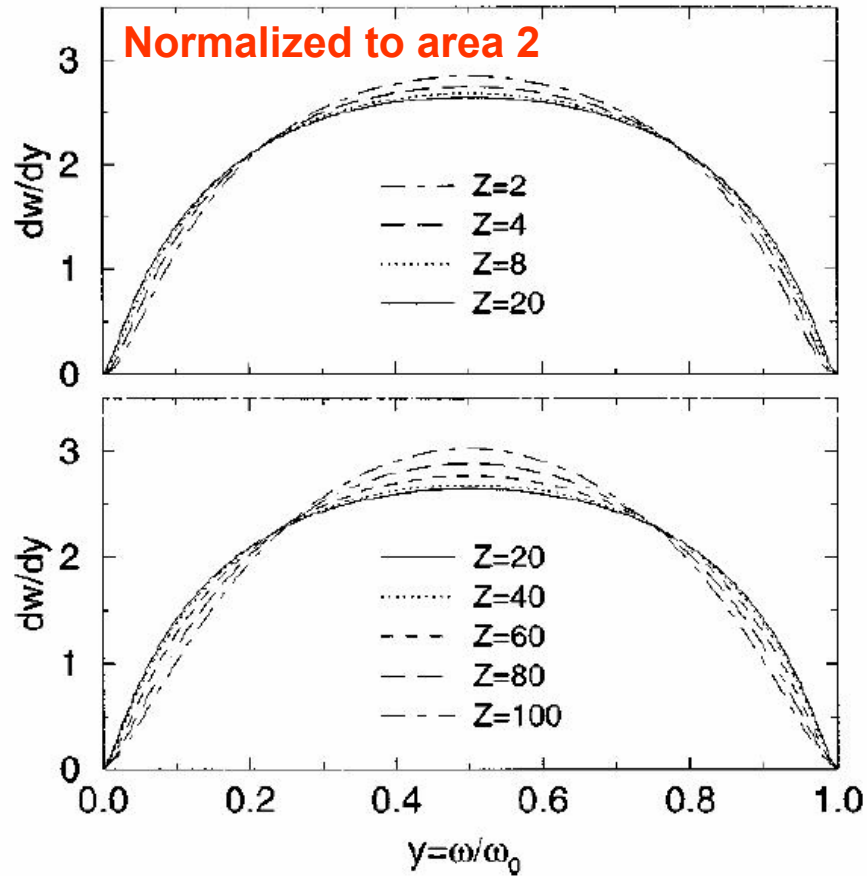
Spectral shape – Z dependence

Derevianko and Johnson, Phys. Rev. A 56 (1997) 1288

Conventional technique for the energy distribution of the two photon decay
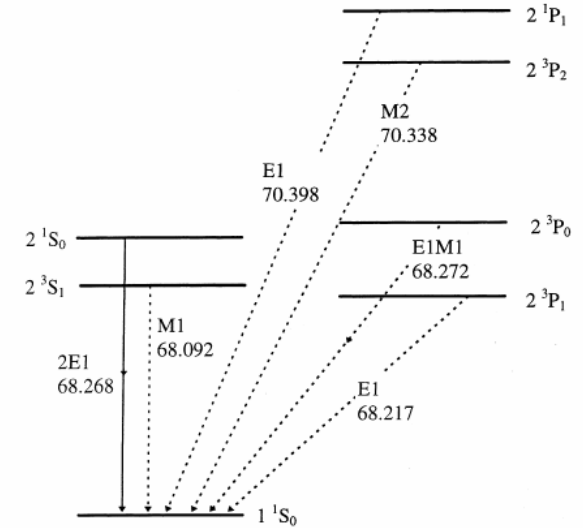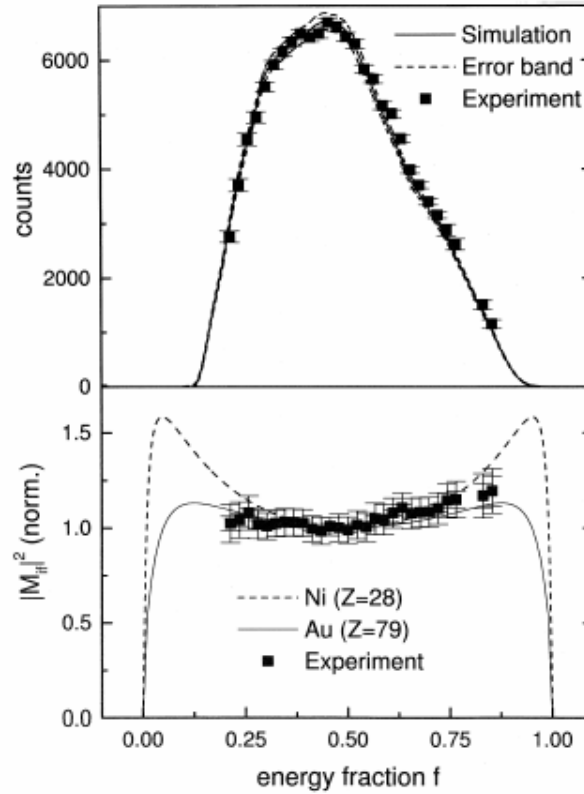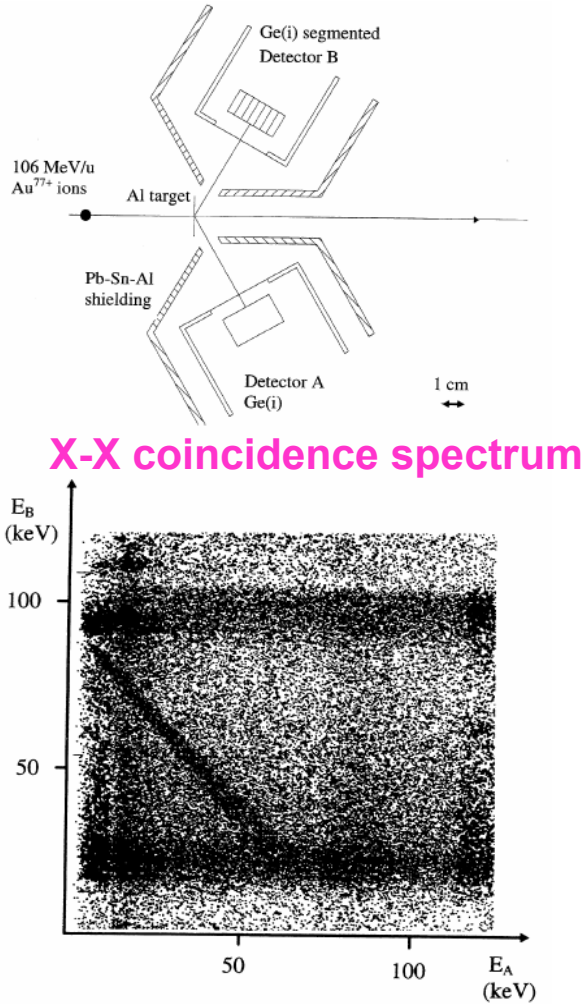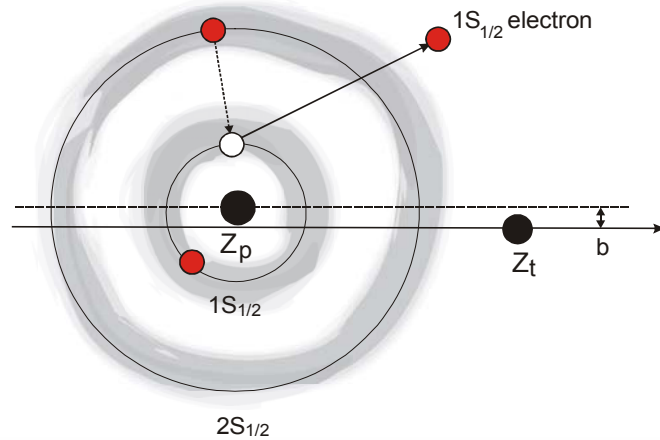
X-X coincidence spectrum

Fig. 1. Level scheme of heliumlike gold including important decay modes. All energies in keV.
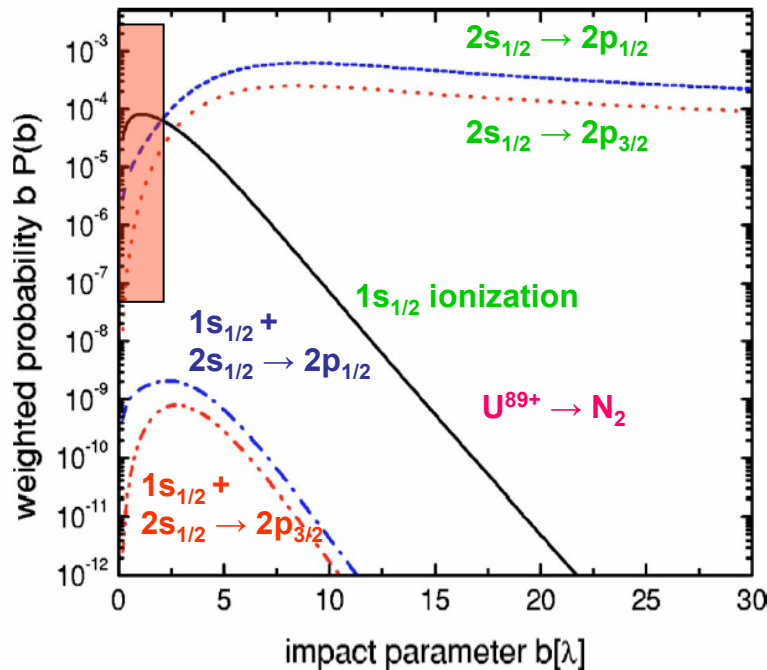
H.W. Schäffer et al. Phys. Lett. A 260 (1999) 489

Several experimental precautions are required

Production of excited states by ionization (gasjet target)

Probability for a simultaneous ionization and excitation:
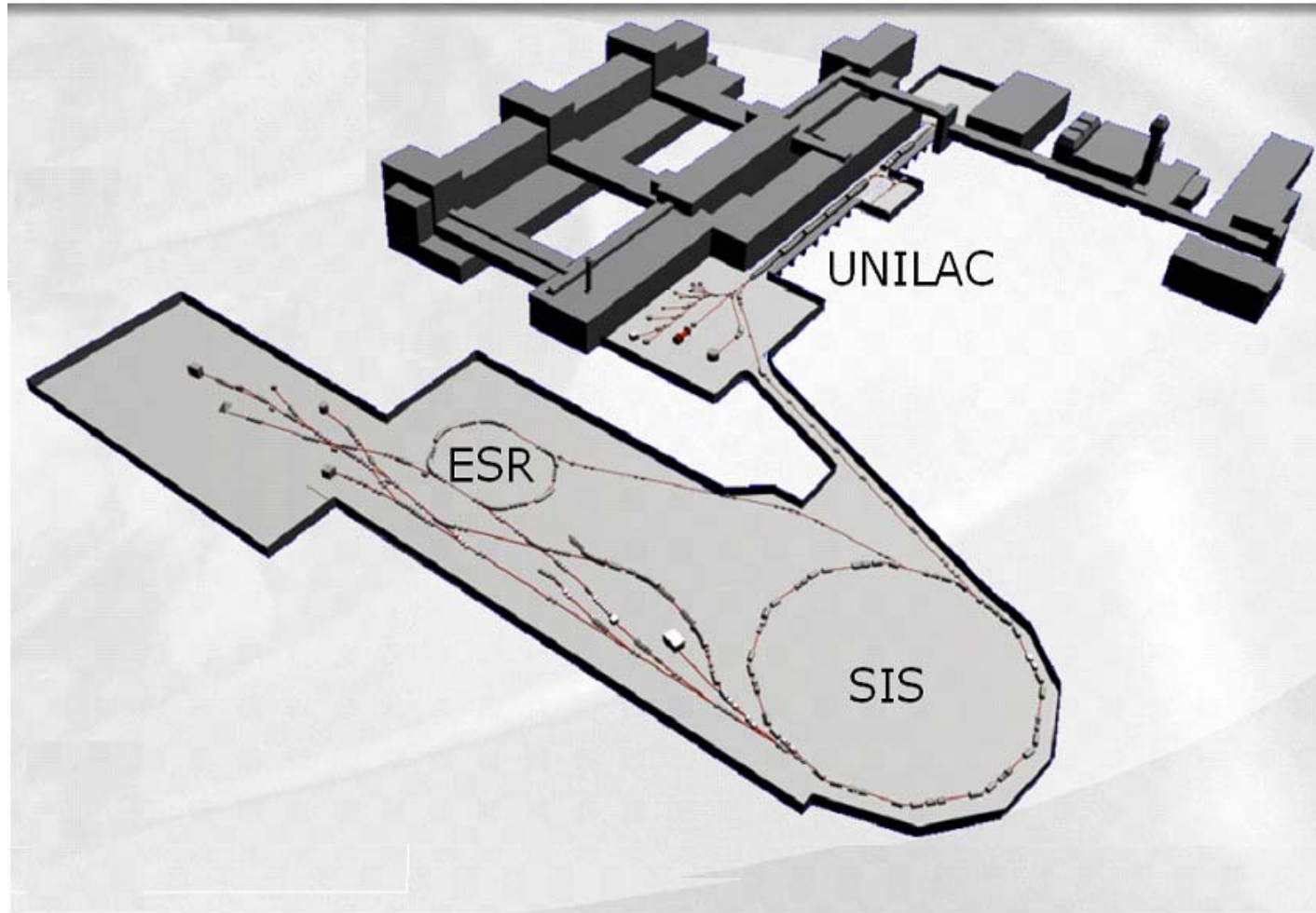
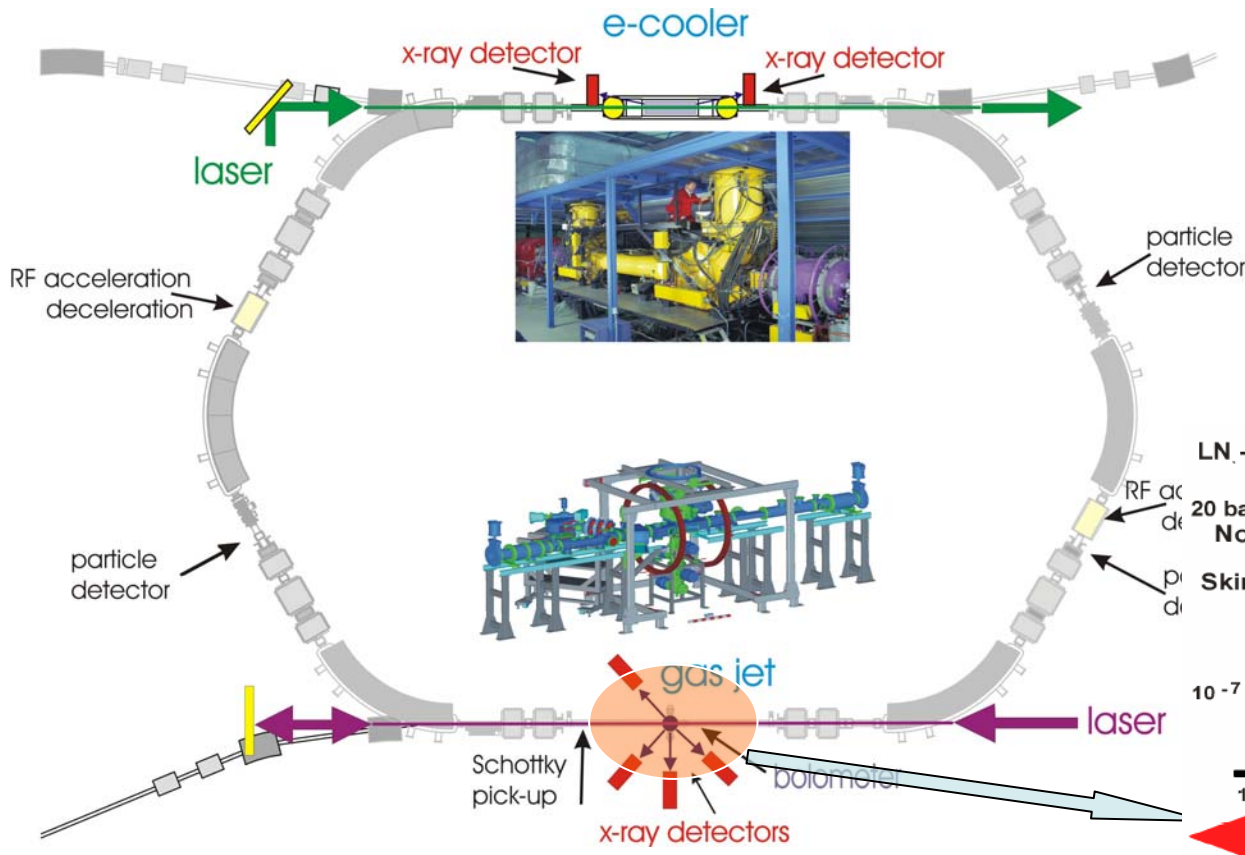$$p_{nlj}^{ion-exc}(b) \approx p^{ion}(b)\, p_{nlj}^{exc}(b)$$

The ionization and/or excitation probabilities as a function of impact parameter 'b' (λ-Compton wavelength)

D.C. Ionescu and Th. Stöhlker, Phys. Rev. A 68 (2003) 022705
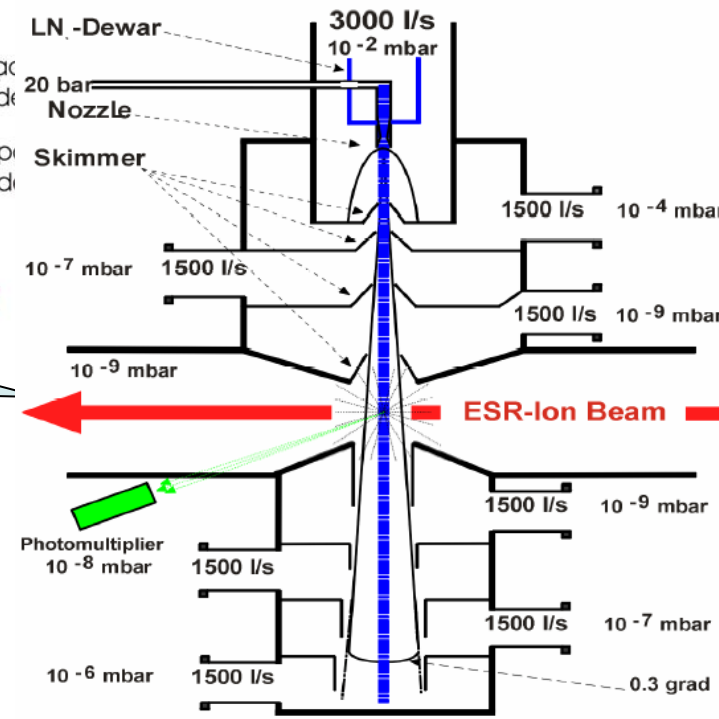
Accelerator Facility @ GSI
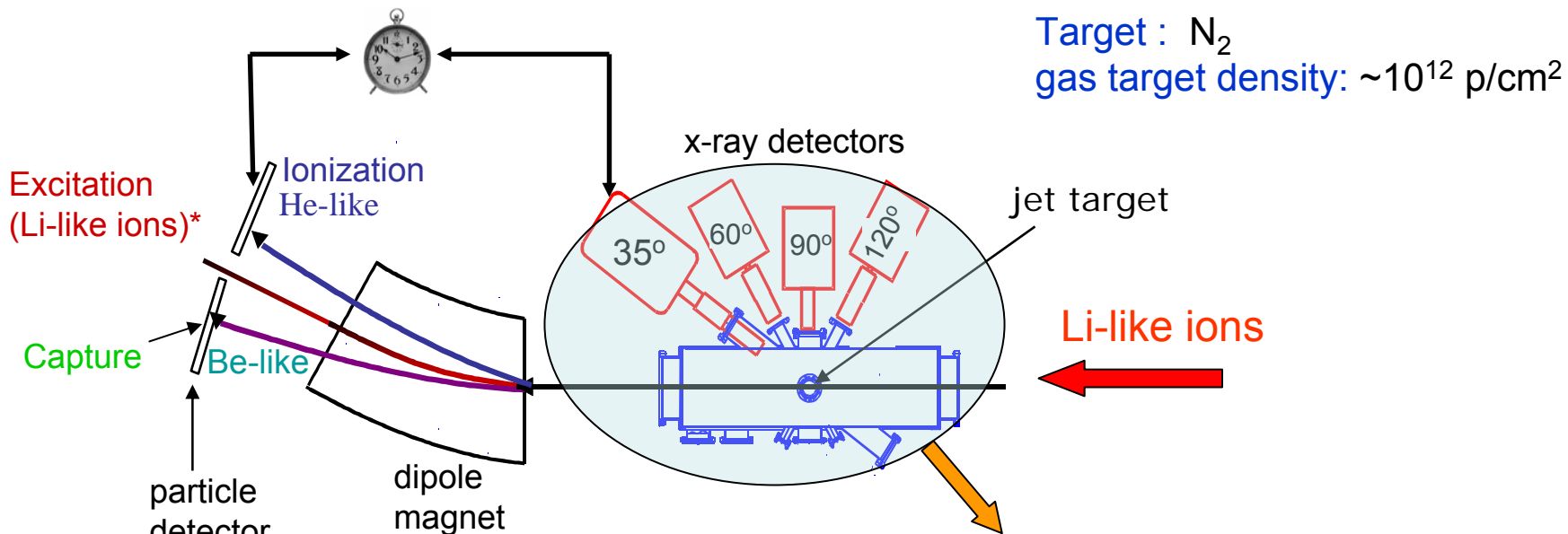
Experimental Storage Ring (ESR)

Circumference : 108 m
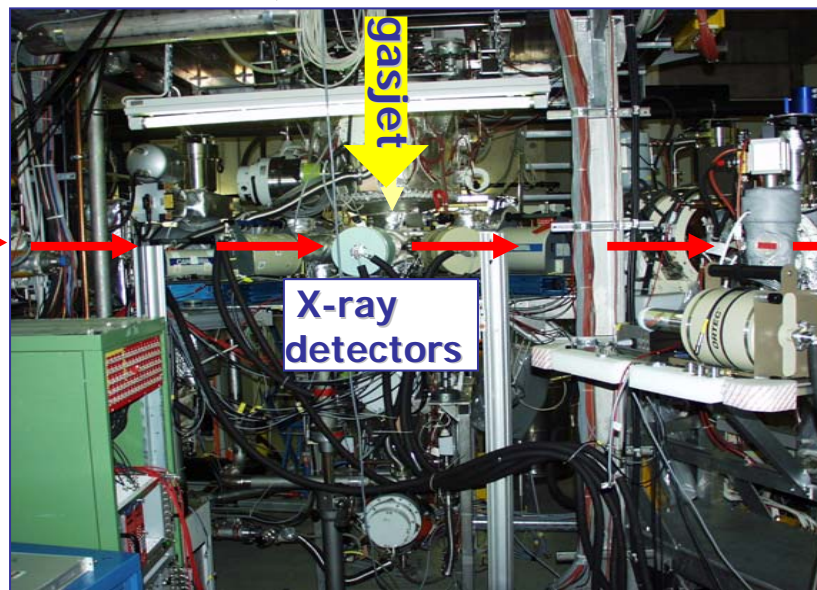**Amount of ions : 10^8**
Frequency : 10^6 1/s

Supersonic gas jet target
Target Density: 10^{12}-10^{14} p/cm^2
Single collision condition

particle - x-ray coincidence

Target : N_2
gas target density: ~10^{12} p/cm^2

x-ray detectors

Excitation
(Li-like ions)*

Ionization
He-like

jet target

35°   60°   90°   120°

Li-like ions

Capture

Be-like

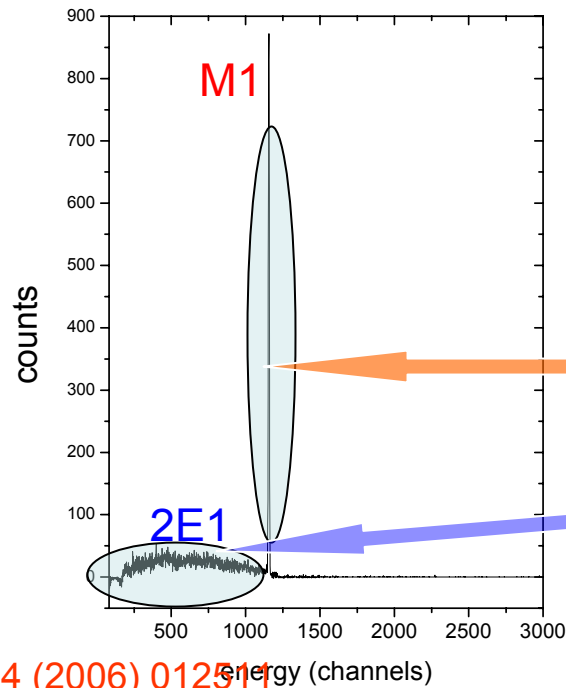particle
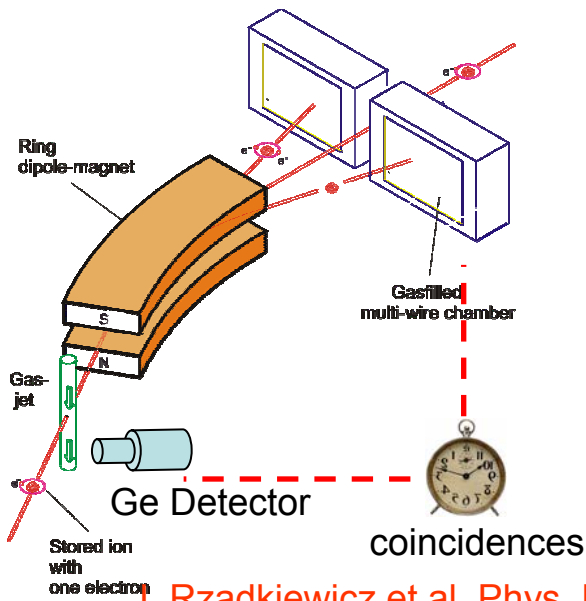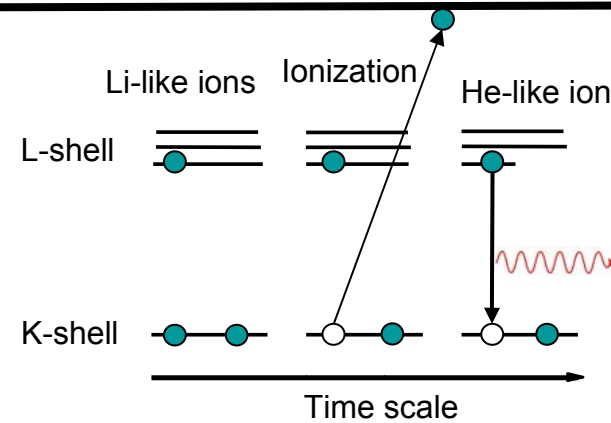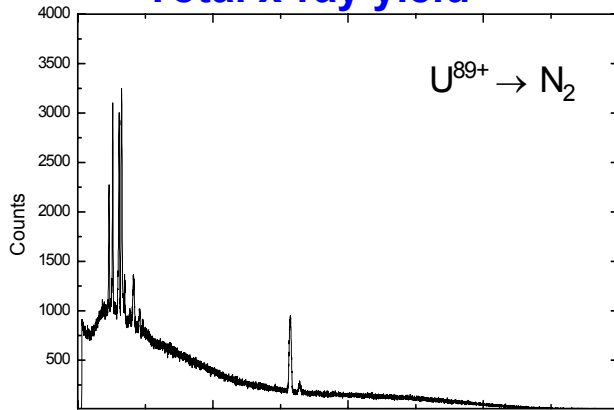detector

dipole
magnet

gasjet

Ion
beam

X-ray
detectors

Particle
detector

up- and down-charged ions were registered by
particle detectors (MWPC) with eff.~100%

x-rays were detected by Ge(i) detectors
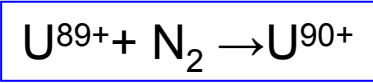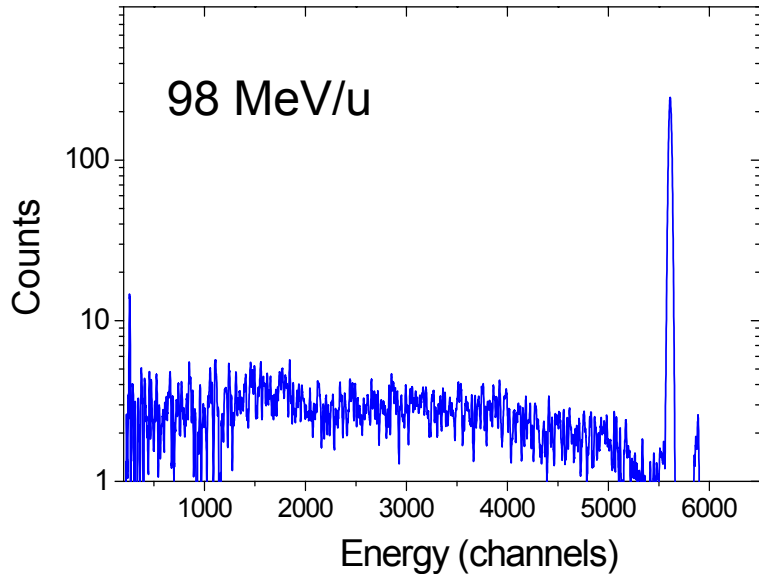(calibrated with use of the radiative sources)

# X-ray spectrum of 400 MeV/u He-like U ions

Total x-ray yield

$U^{89+} \rightarrow N_2$

Counts

Li-like ions   Ionization   He-like ion

L-shell

K-shell

Time scale

Ring dipole-magnet

Gasfilled multi-wire chamber

Gas-jet

Ge Detector

Stored ion with one electron

coincidences

M1

counts

2E1

Energy (channels)

Energy (keV)

2^1P_1
2^3P_2

E1   M2

2^1S_0
2^3S_1

2^3P_0
2^3P_1

E1M1

M1

2E1

E1

1^1S_0

He- like Uranium (U^{90+})
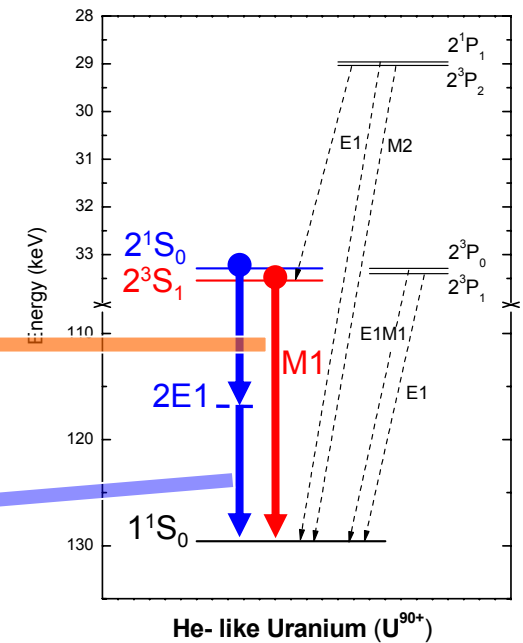
J. Rzadkiewicz et al, Phys. Rev. A 74 (2006) 012511

X-ray spectrum of He-like U ions

$$U^{89+} + N_2 \rightarrow U^{90+}$$

98 MeV/u

Counts — Energy (channels)

- **Presence the 2E1 and M1 x-ray lines only**
- **Absence of the x-ray lines associated with the n=2 P-states**

400 MeV/u

$M1: 2\,^3S_1 \rightarrow 1\,^1S$
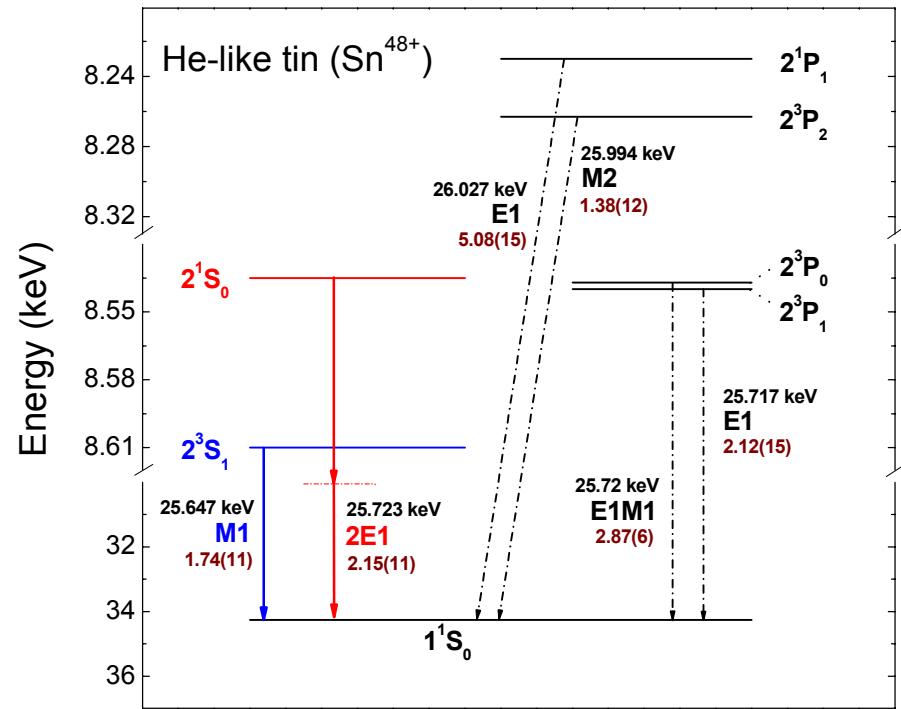
$2E1: 2\,^1S_0 \rightarrow 1\,^1S_0$

Counts — Energy [keV]
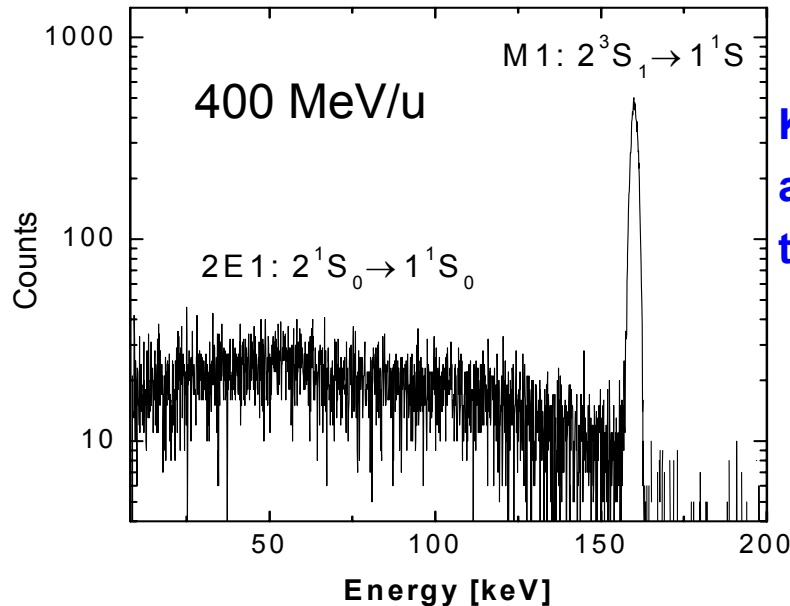
K-shell ionization of the initially Li-like high-Z ions is a highly selective mechanism for the production of the n=2 S-states of He-like systems

J. Rzadkiewicz et al, Phys. Rev. A 74 (2006) 012511

# Typical x-ray spectra of 300 MeV/u He-like Sn
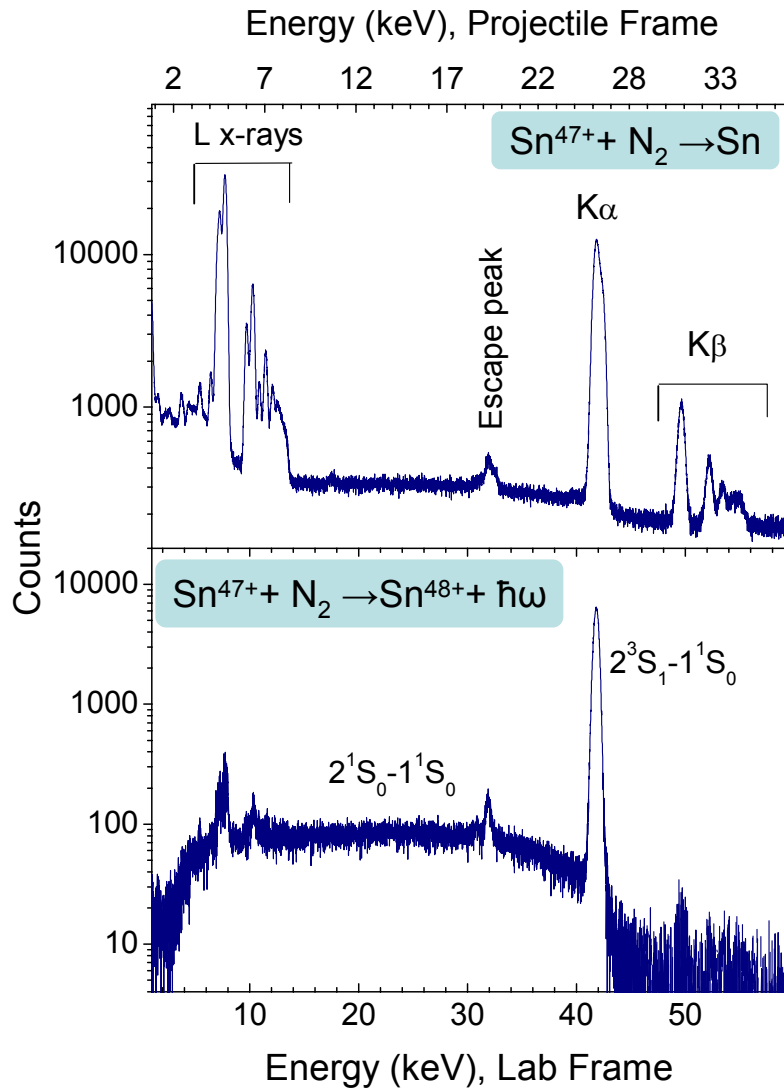
Decay scheme of the excited states of He-like Sn

# Theoretical two photon spectra from He-like ions
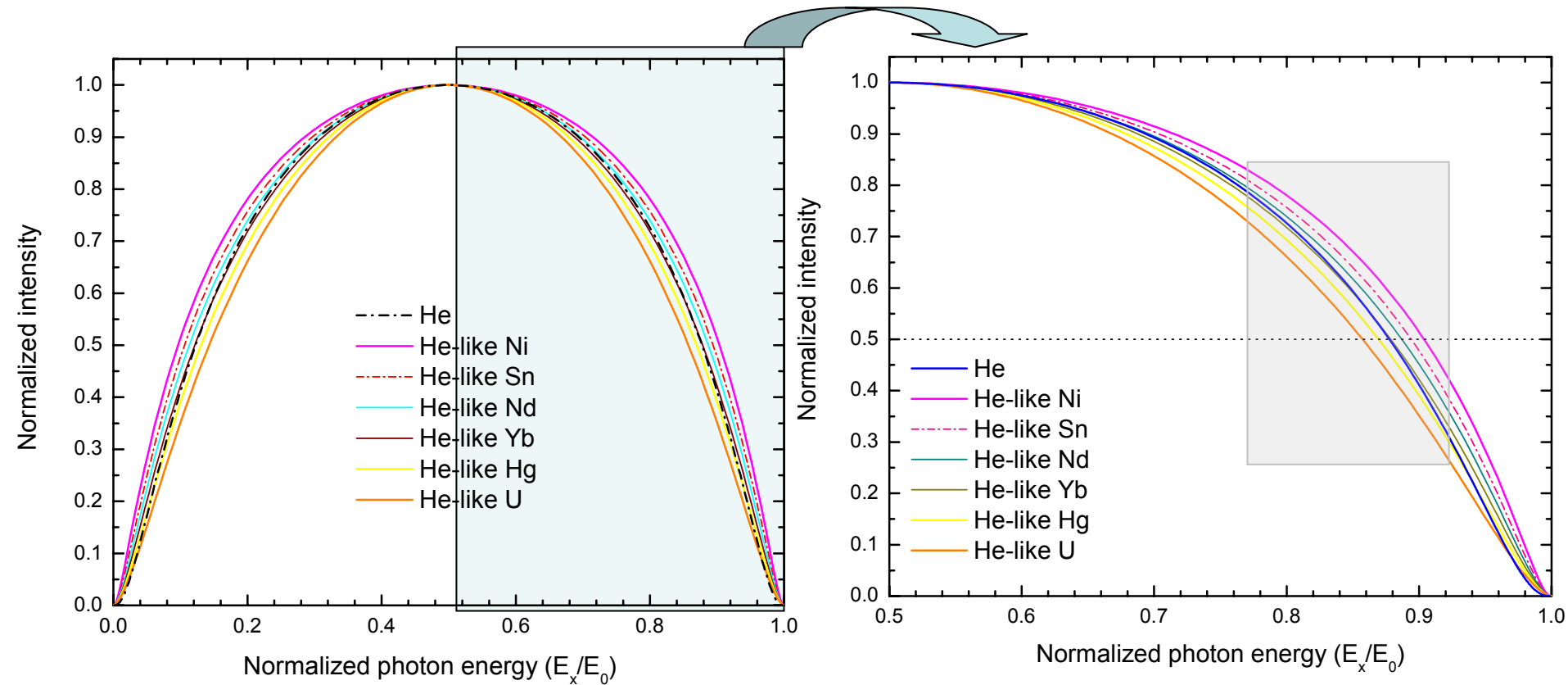
The spectral distribution for the two photon decay was predicted to form a broad continuum with a maximum at half the transition energy which gradually drops to zero at the endpoints.

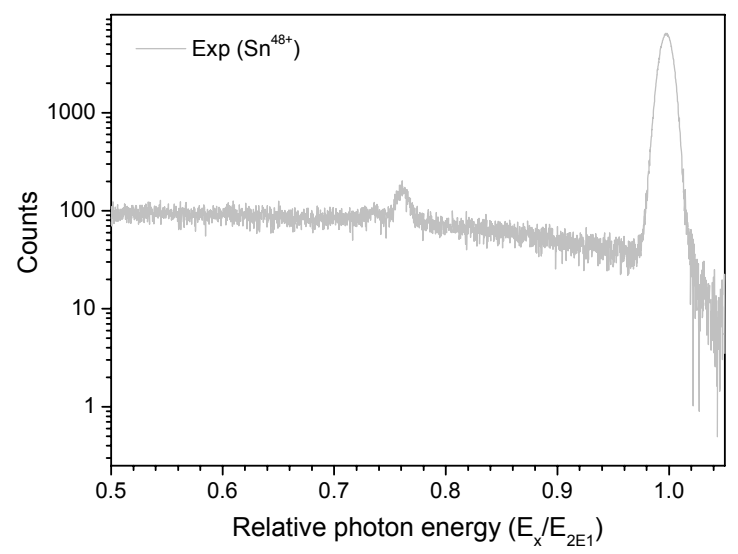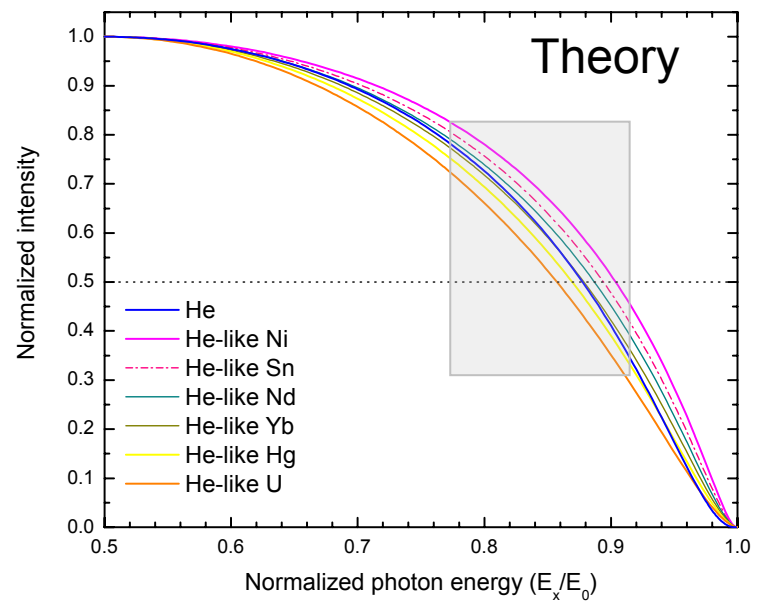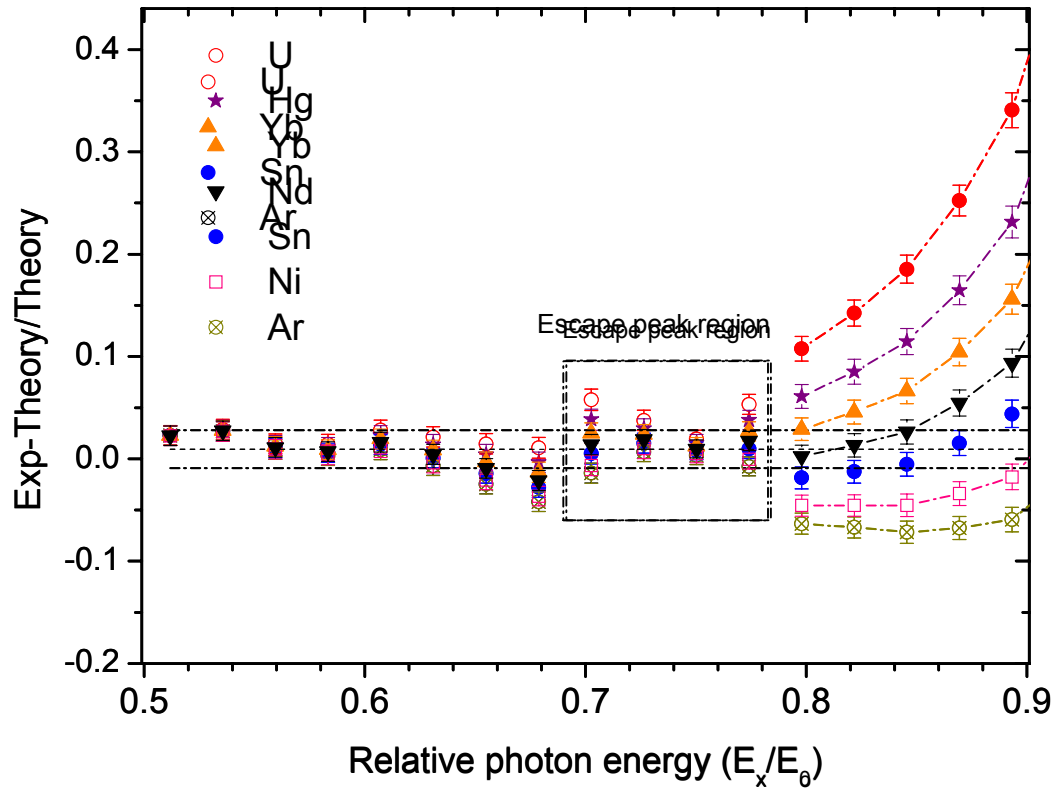**Fully relativistic theoretical calculations: A. Volotka (Private communication)**
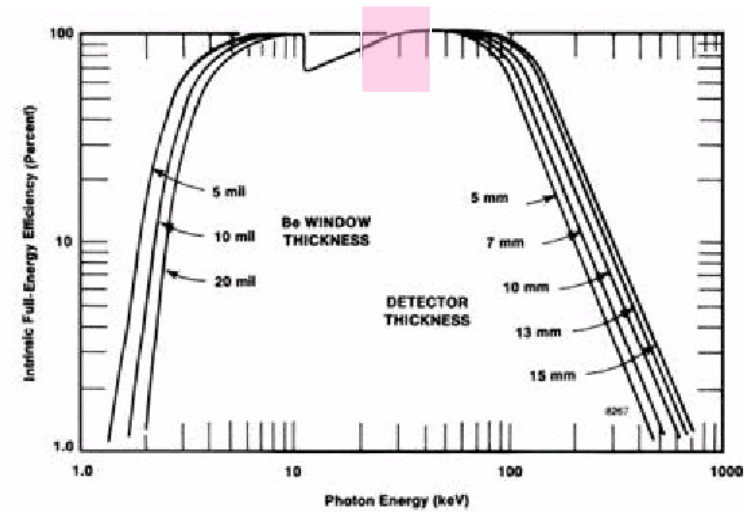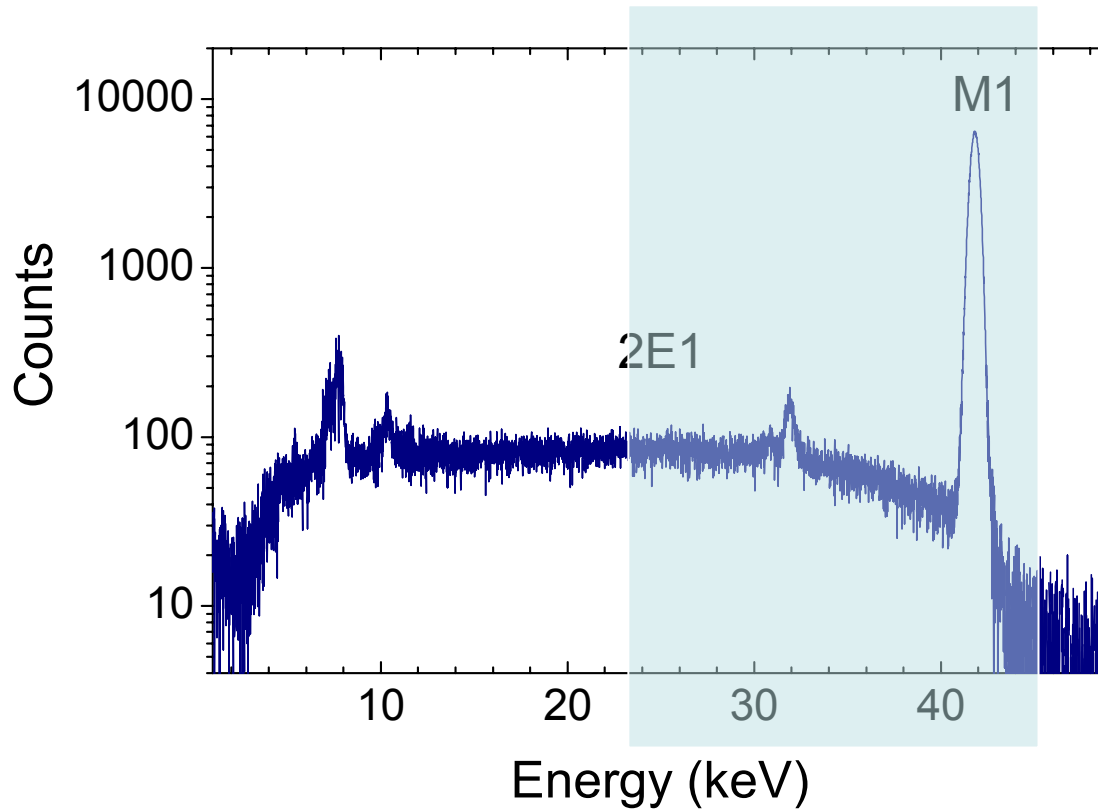
Theoretical efficiency curve of Ge detector

Data analysis and comparision with theory
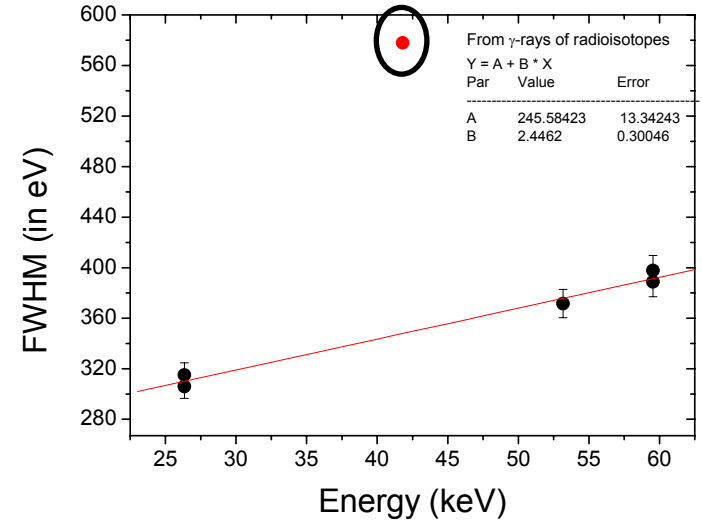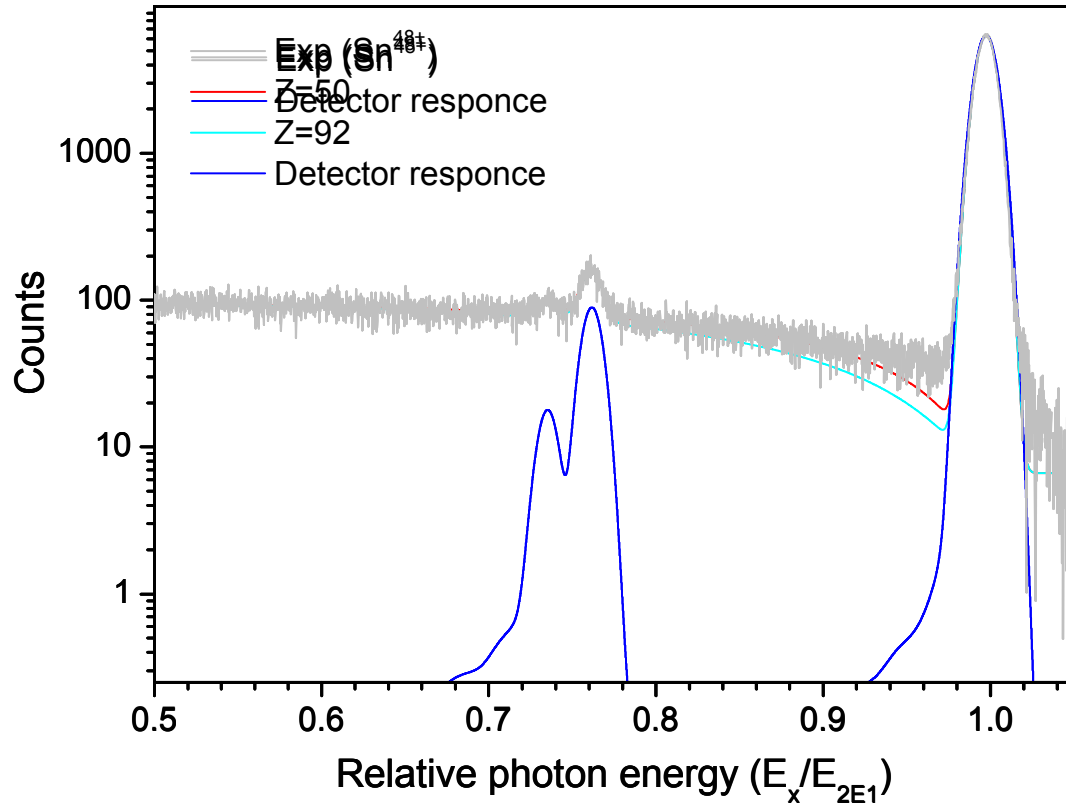
Comparison of measured and theoretical 2E1 Spectral shape

Bin size : 120 channels (1 keV)

Summary

The experimental study of the production of the low-lying excited states in He-like high- and middle-Z ions followed by the K-shell ionization of initially Li-like species has been performed:

➢The technique of a undistorted two-photon transition measurements

➢ Exclusive production of excited states in He-like ions

➢ New approach for investigation of exotic 2E1 decays

➢ Experimental results are in agreement with relativistic theory

➢The spectral shape of 2E1 photons of He-like Sn has been discriminated from other He-like ions (sensitivity : Z = 50 $\pm$ ~5)

Thank you for attention