Spectral shape of two-photon decay from 2S state in He-like tin

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Team

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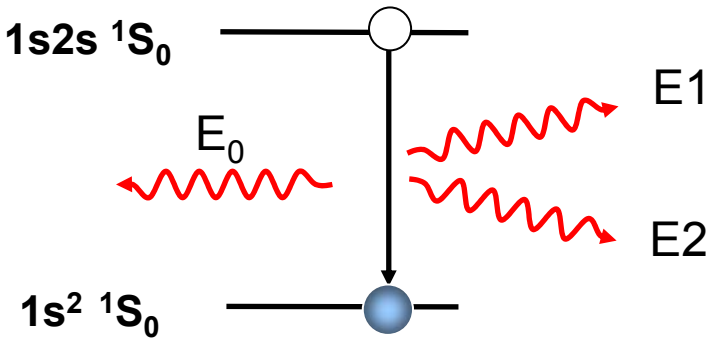
Outline

- Introduction and motivation
- Experimental details
- Data analysis and results
- Summary

Two-photon decay in He-like ions

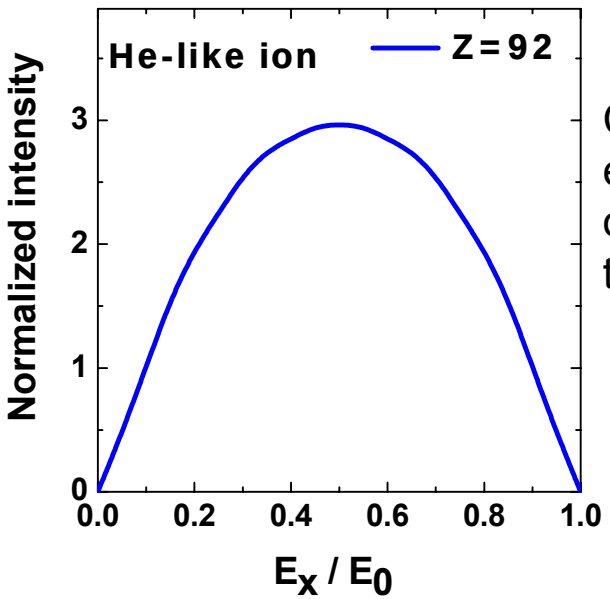
He-isosequence



Single photon transition

~~1s2s $^1S_0$ → 1s^2 $^1S_0$ + E_0~~

is forbidden $J=0 \nrightarrow J=0$



Calculated photon energy distribution of $2\,^1S_0 \rightarrow 1\,^1S_0$ transition

$E_x=E_1/E_0=E_2/E_0$

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

1s2s $^1S_0 \rightarrow$ 1s^2 $^1S_0$ + $E_1 + E_2$

$E_1 + E_2 = E_0 = E_i - E_f$

Two-photon (2E1) decay
or
One-electron two-photon decay

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

Energy differential emission rate of two-photon decay

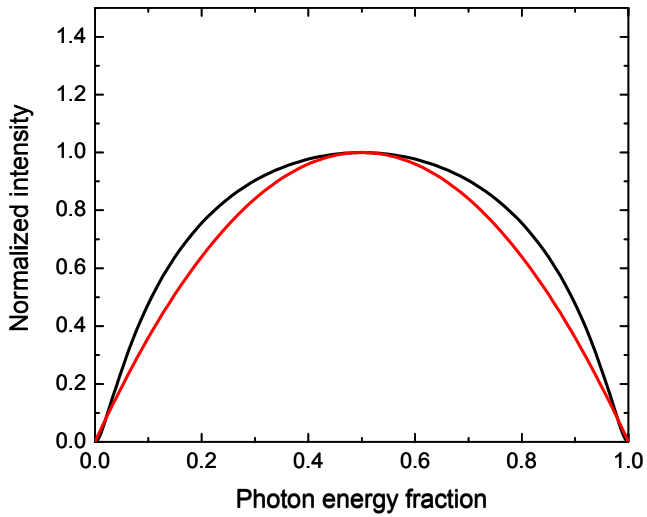
$$A(E_1)dE_1 \propto E_1 E_2 \left|M_{fi}\right|^2 dE_1$$

$$M_{fi} = \sum \left[\frac{< f|D_1|n >< n|D_2|i >}{E_{ni} + E_1} + \frac{< f|D_2|n >< n|D_1|i >}{E_{ni} + E_2} \right]$$

$$f_1 = \frac{E_1}{E_0}; \quad f_2 = \frac{E_2}{E_0} = 1 - f_1$$

$$A(E_1)dE_1 \propto f_1(1-f_1)\left|M_{fi}\right|^2 dE_1$$

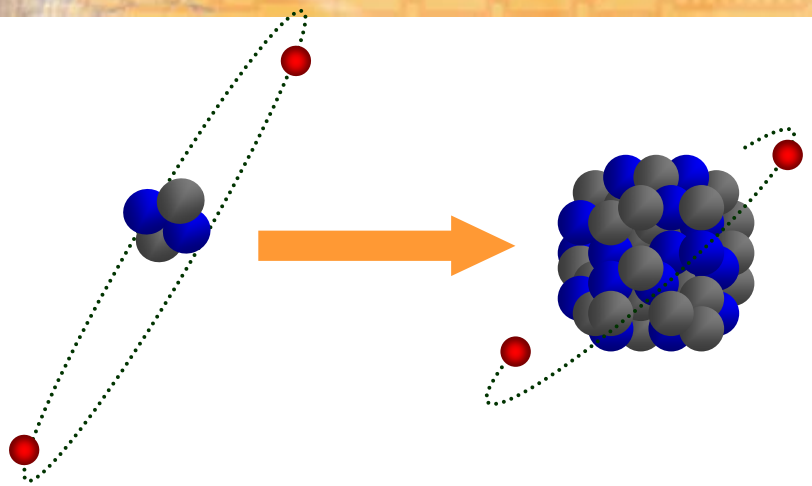
Overall shape of the spectral distribution

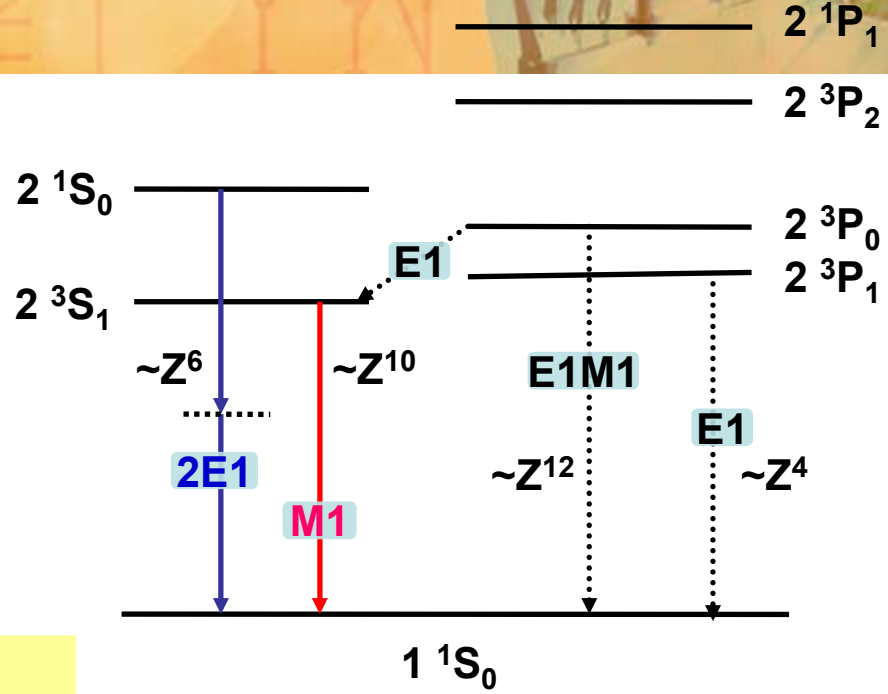


Total emission rates

$$A_T = \frac{1}{2}\int_0^{E_{if}} A(E_1)dE_1$$

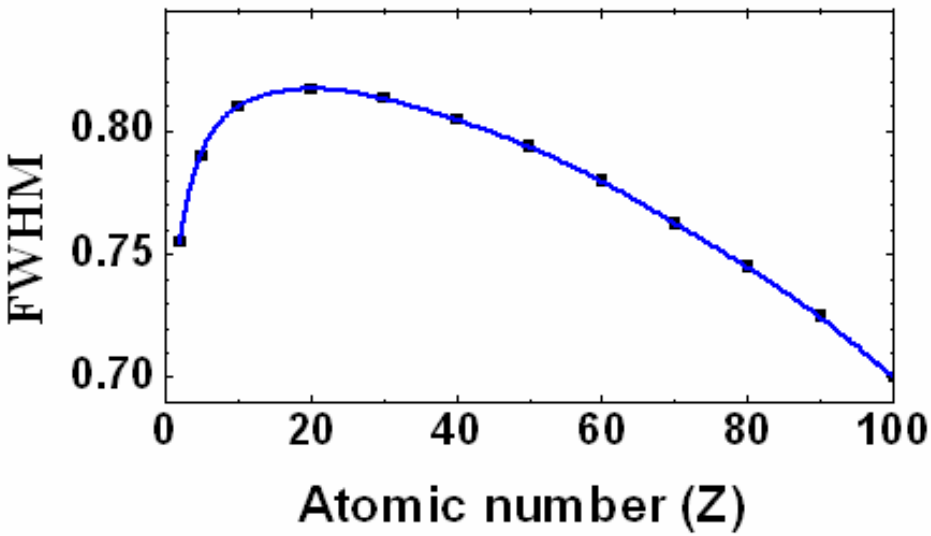
Why going to highly charged high-Z ions ?

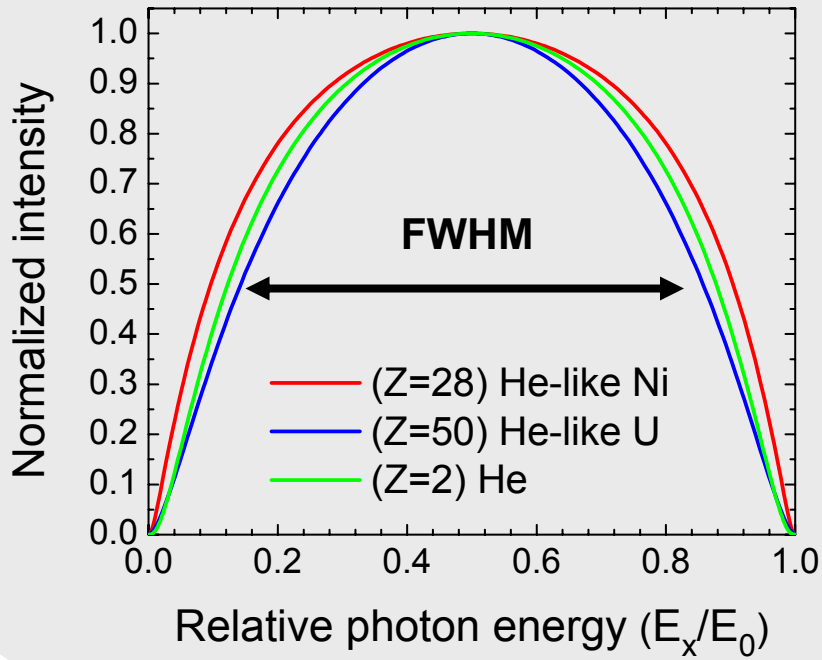




- Increased probability of forbidden transitions
- Competition of e-e correlation and relativistic effects
- He-like ions are the simplest for the two-photon decay measurements.
- Change of atomic structure with Z - - influences the two-photon decay rates
- Spectral shape of two photon emission allows test the whole atomic system
  - probe of relativistic effects in the strong central field in heavy atomic system

Theoretical spectral shape of the 2E1 transition

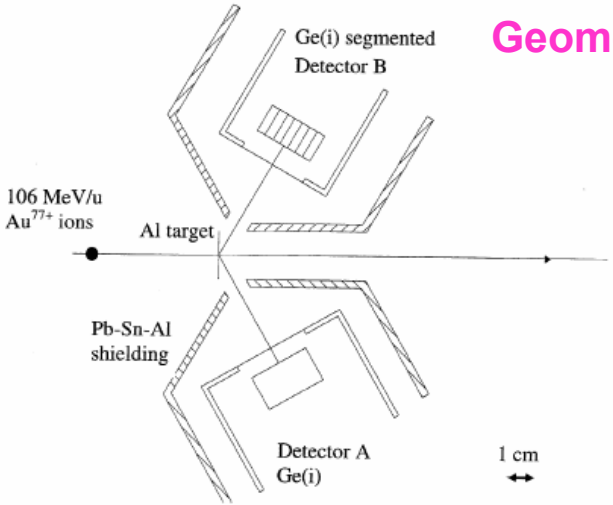




Full width at the half maximum of the two-photon energy distribution of the 2 $^1S_0$ state as function of Z

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

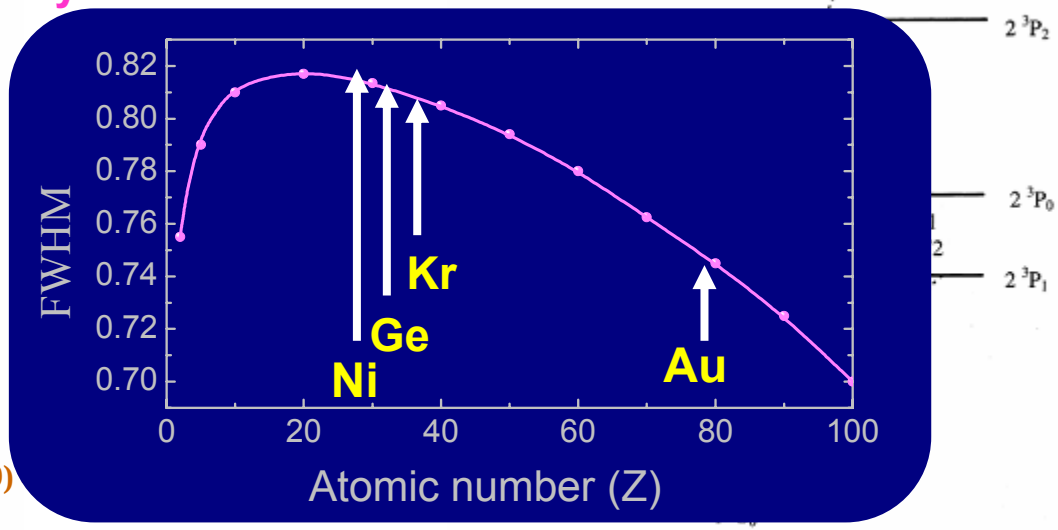
Conventional technique for measuring the energy distribution of the two-photon decay: x-x coincidence



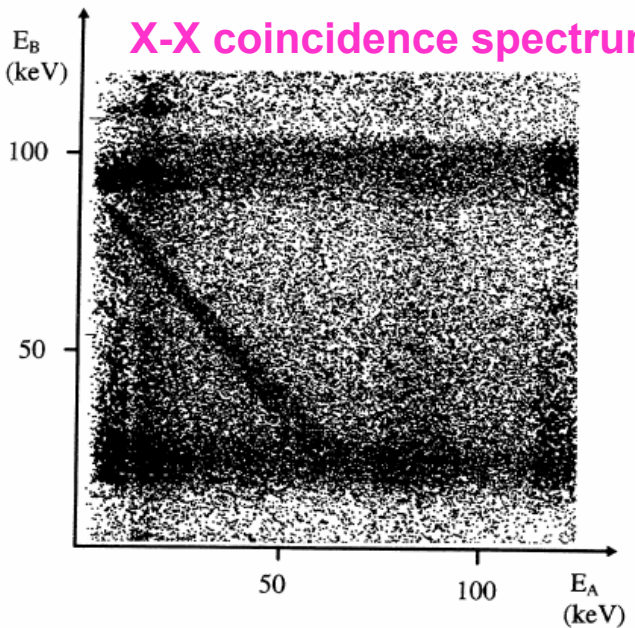
Geometry

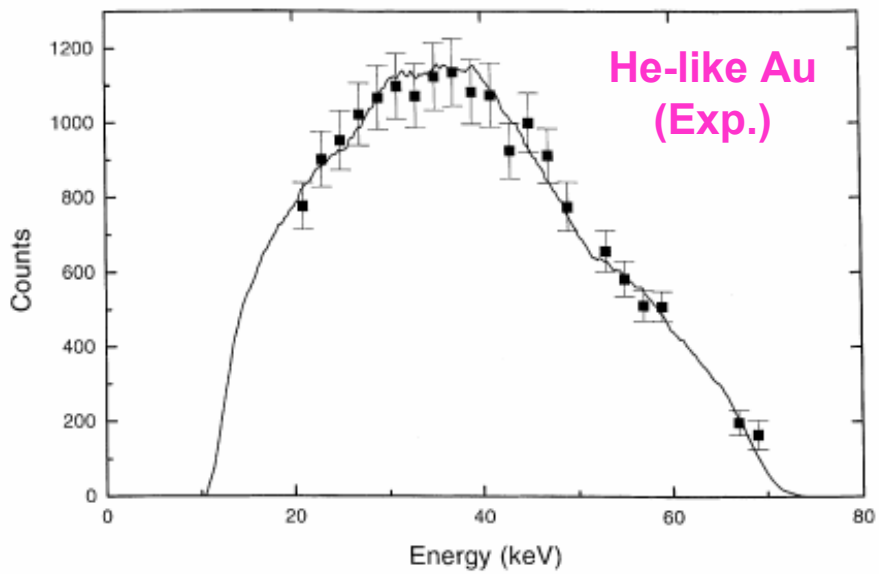
H.W. Schäffer et al. Phys. Lett. A 260 (1999)

He-like Au



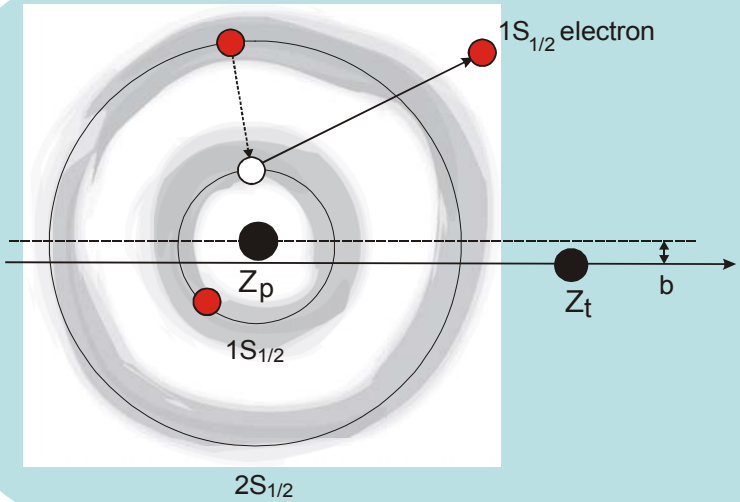
X-X coincidence spectrum





He-like Au (Exp.)

Production of excited states by ionization (gas jet target)



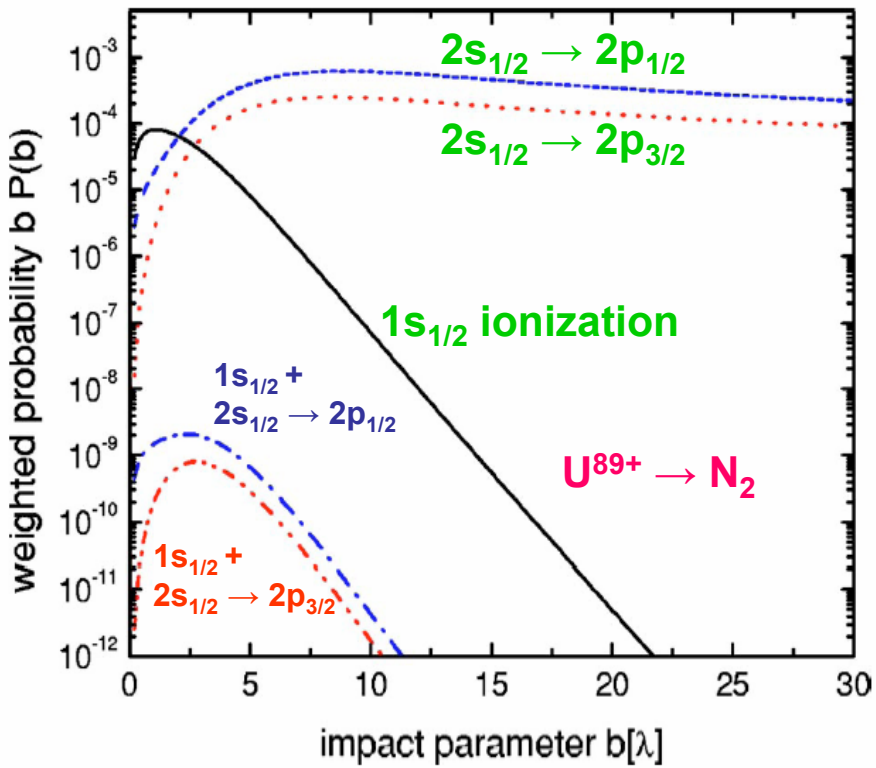
Probability for simultaneous ionization and excitation

$$p_{nlj}^{ion\ \ exc}(b) \approx p^{ion}(b)\, p_{nlj}^{exc}(b)$$

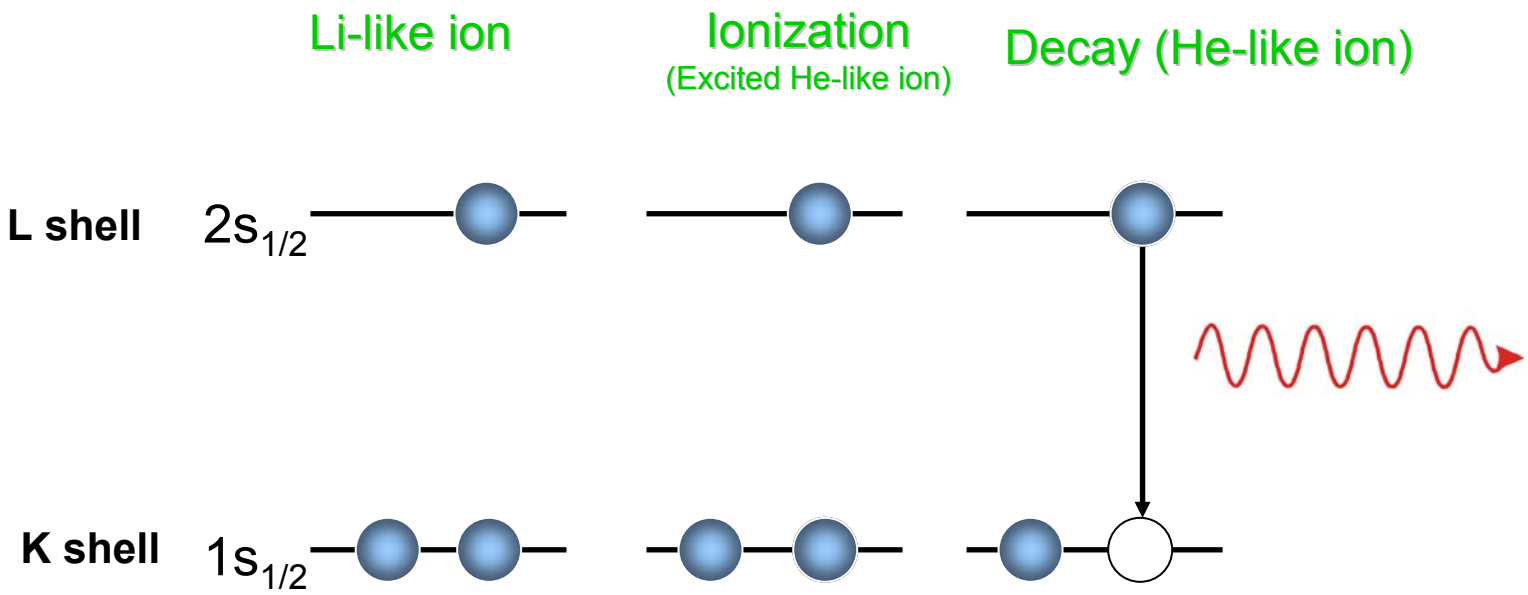
$$\sigma_{nlj}^{ion\ \ exc}(b) = \int p^{ion\ \ exc}(b)\ 2\pi\, b\, db$$

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

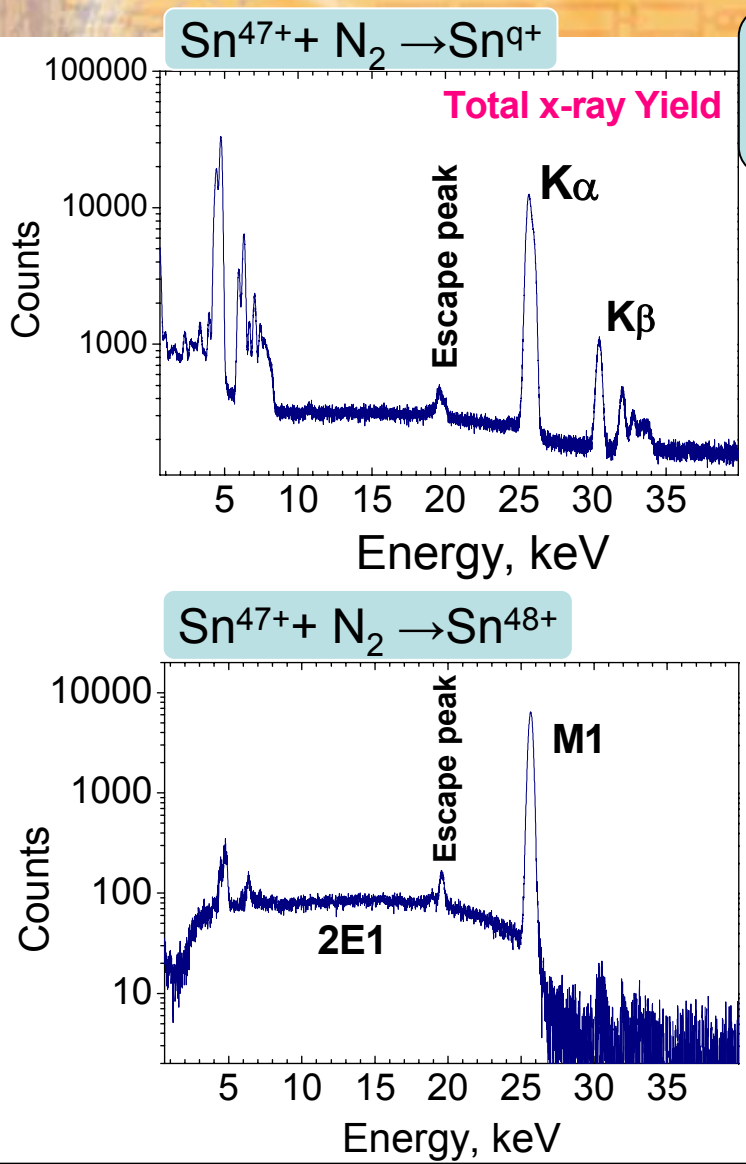
D.C. Ionescu and Th. Stöhlker, Phys. Rev. A 68 (2003) 022705



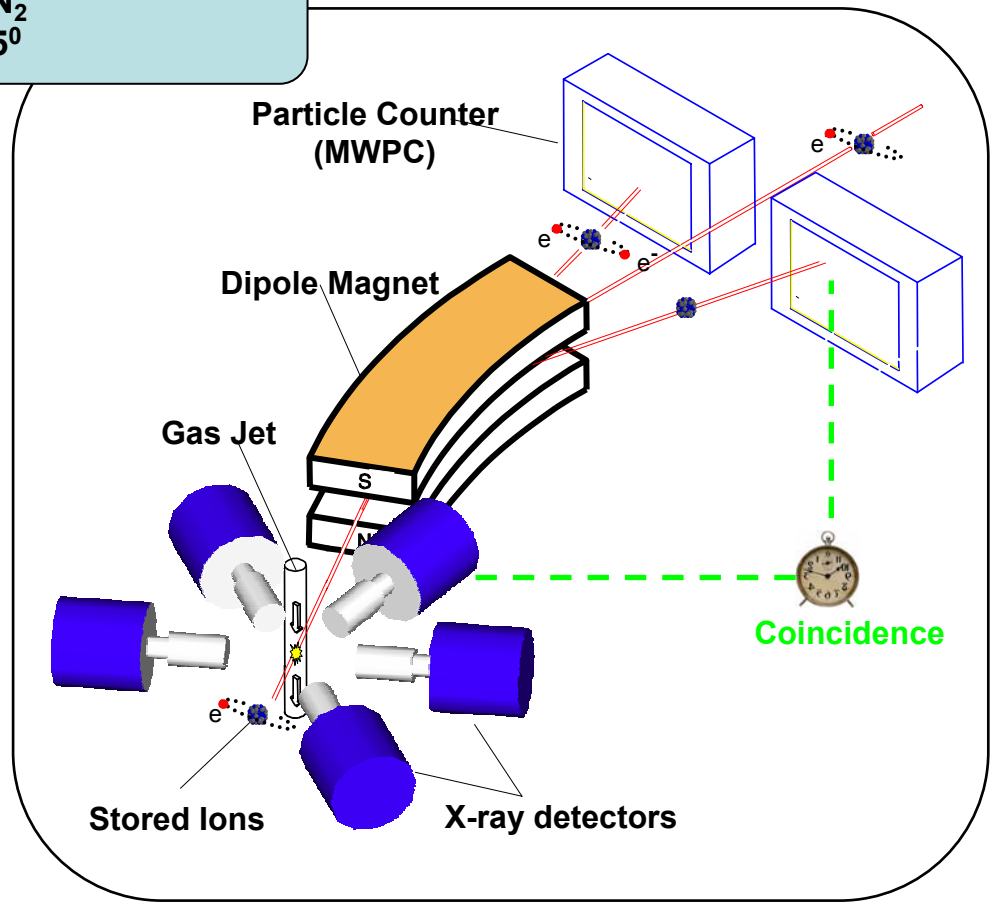
Production of the excited state in He-like ions by selective K-shell ionization of Li-like ions



Typical x-ray spectra of 300 MeV/u He-like Sn

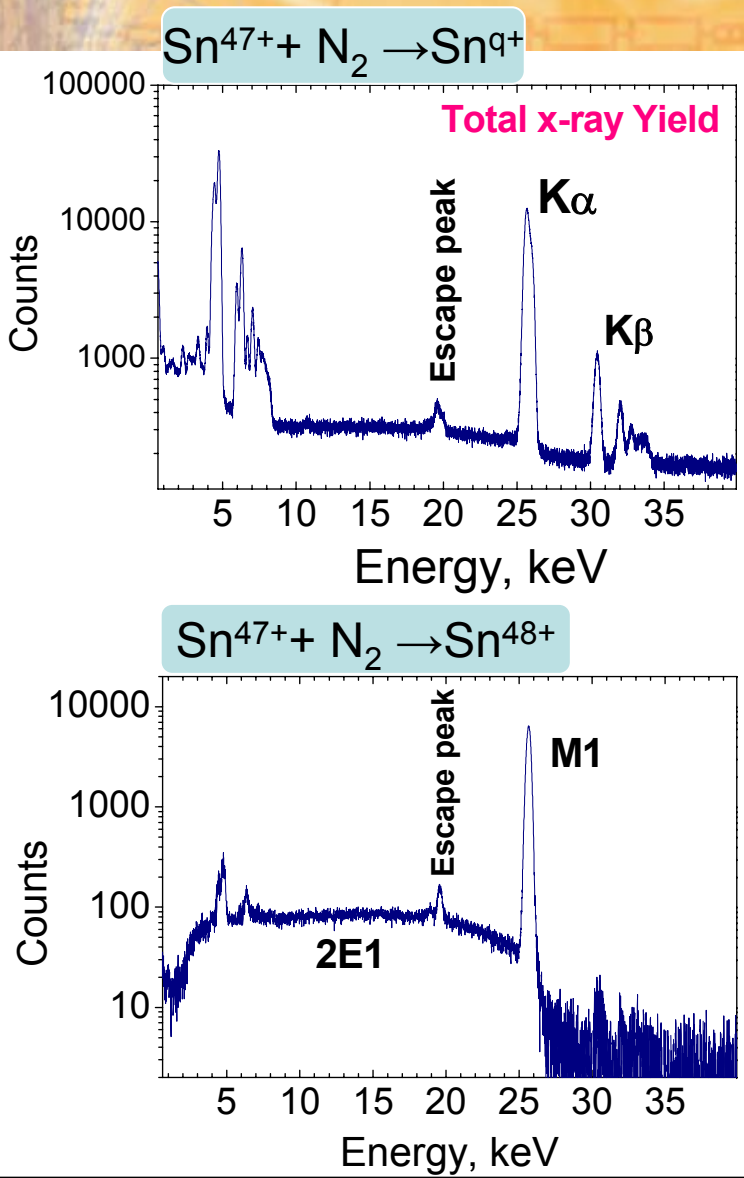


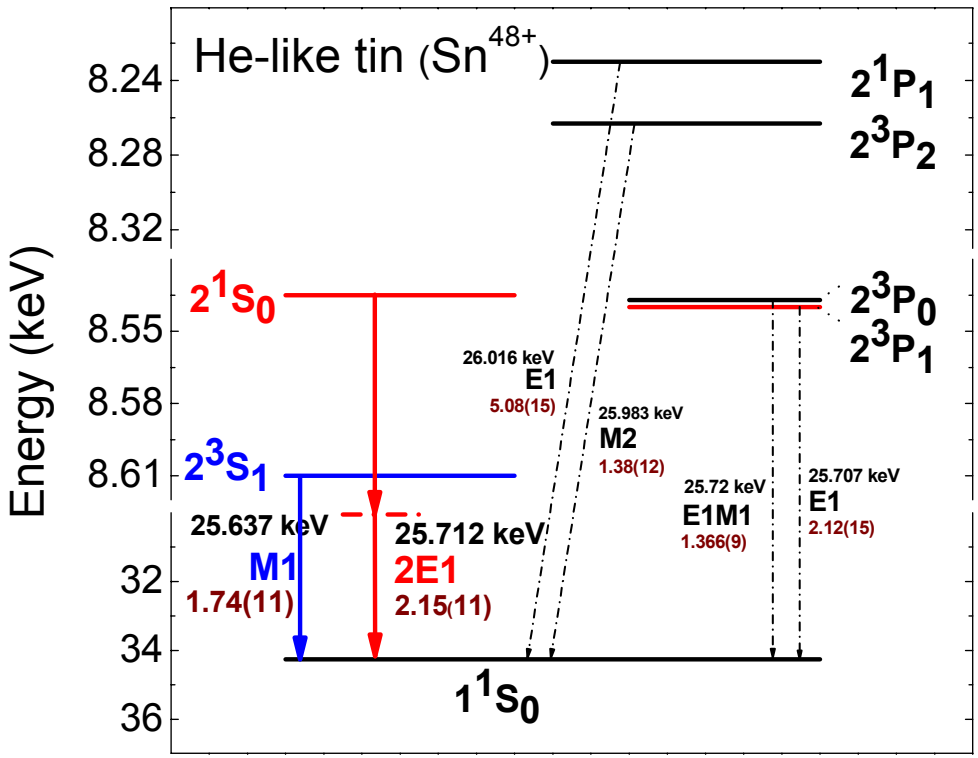
Projectile: Sn^{47+}; 300 MeV/u
Target : N_2
Angle: 35^0



Coincidence registration of x-rays and up charged (He-like) ions

Typical x-ray spectra of 300 MeV/u He-like Sn





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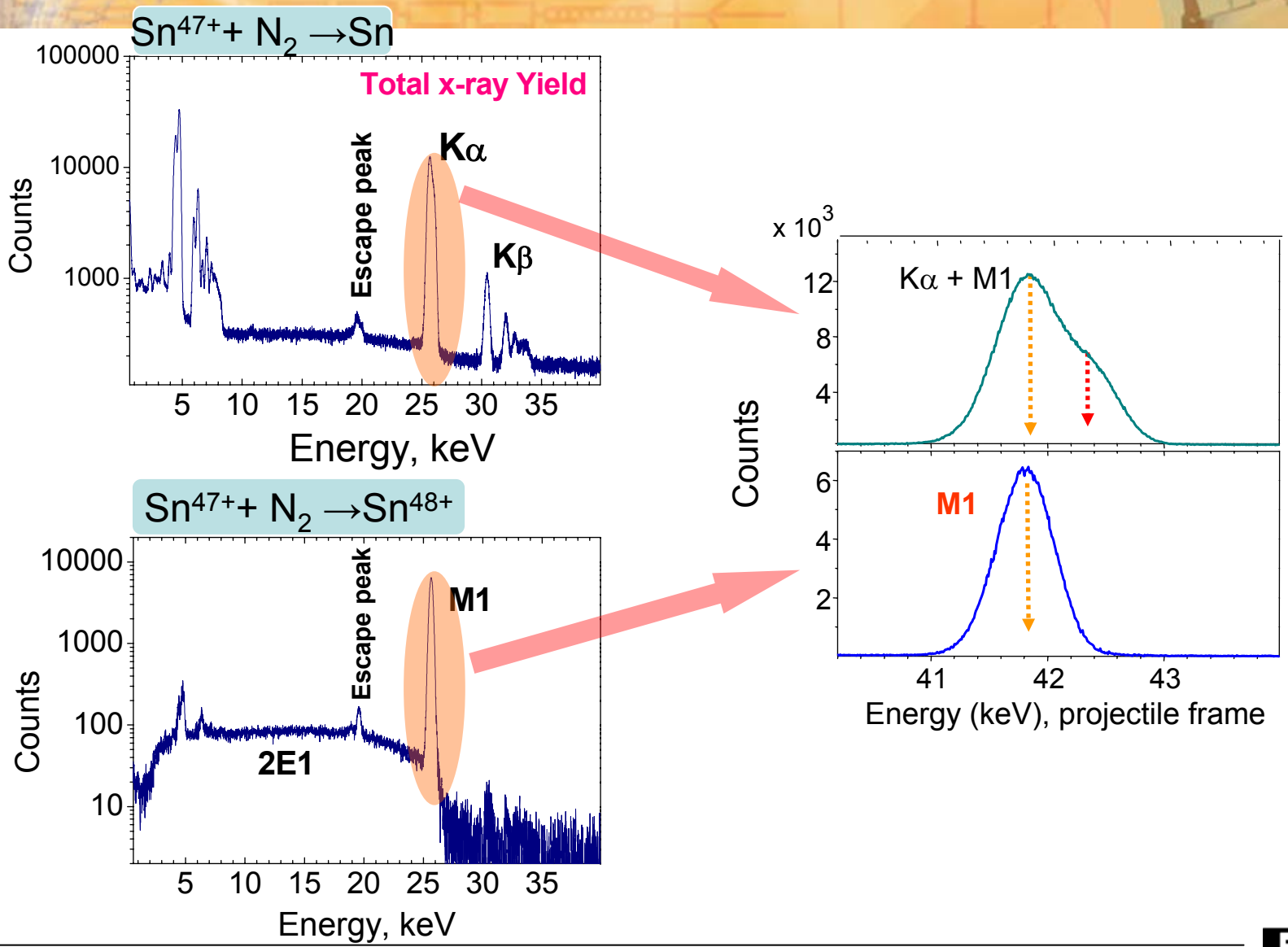
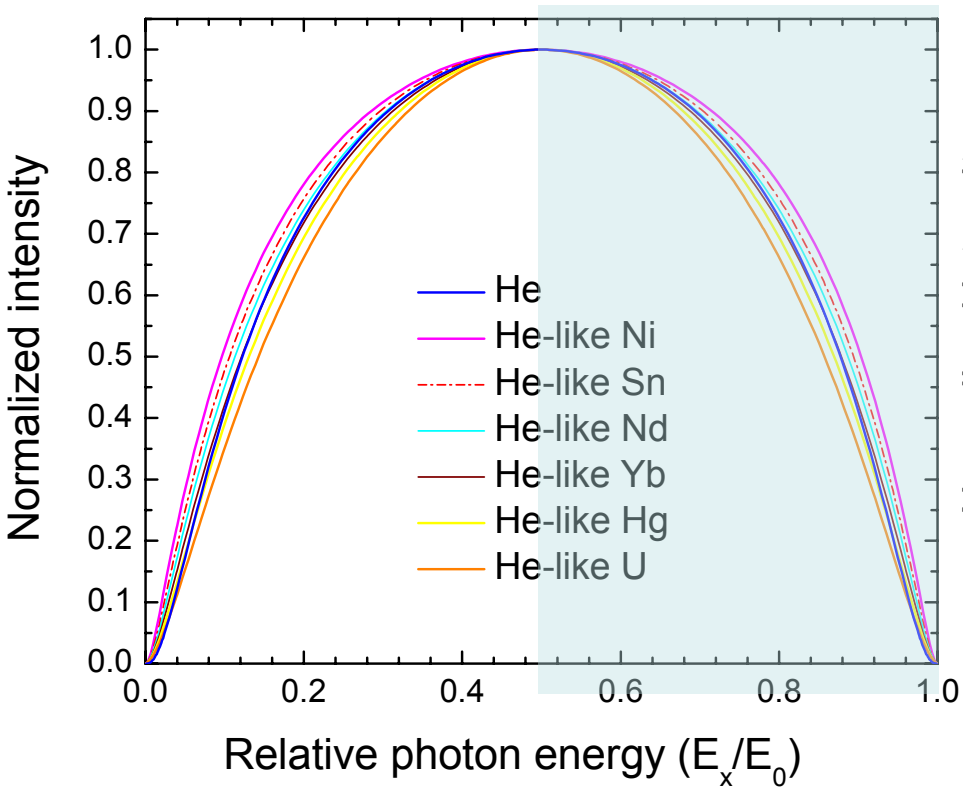
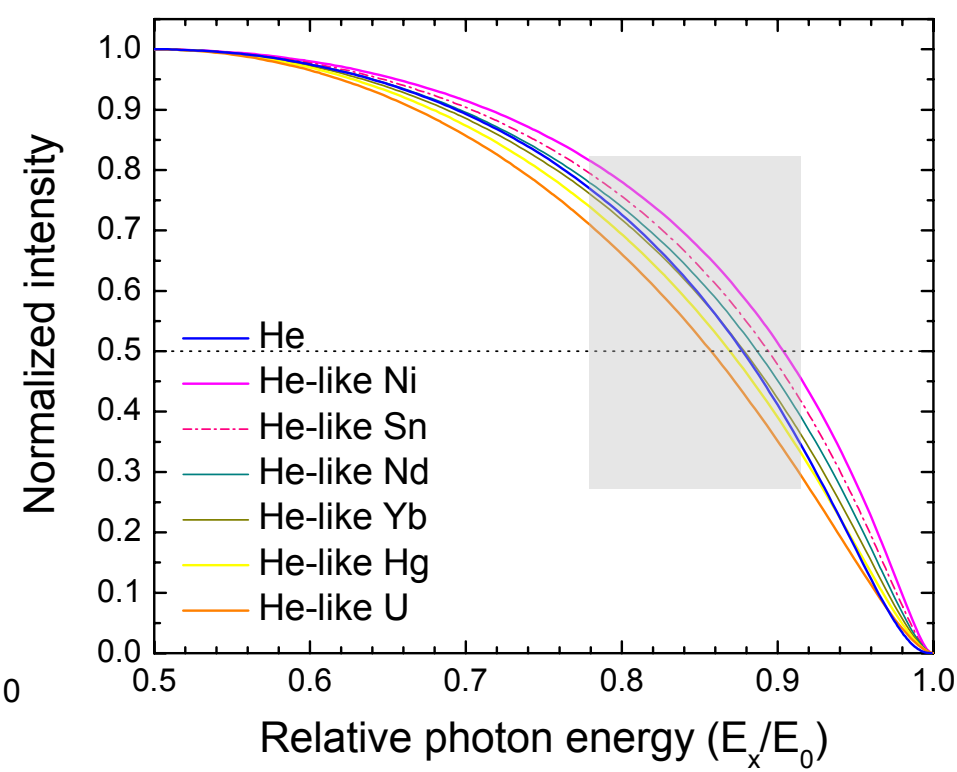


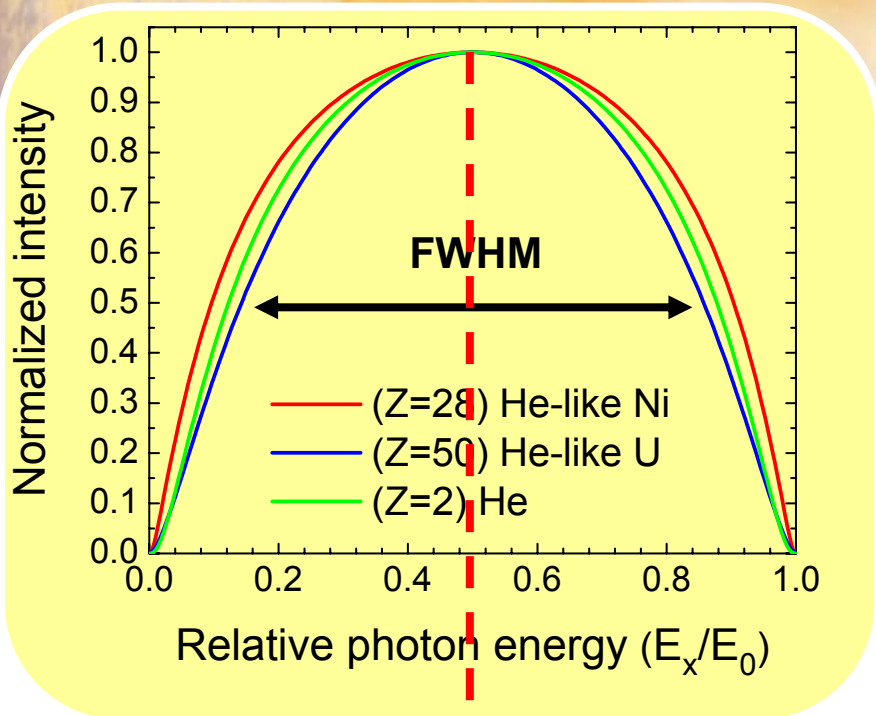
Theoretical 2E1 energy distribution from He-like ions

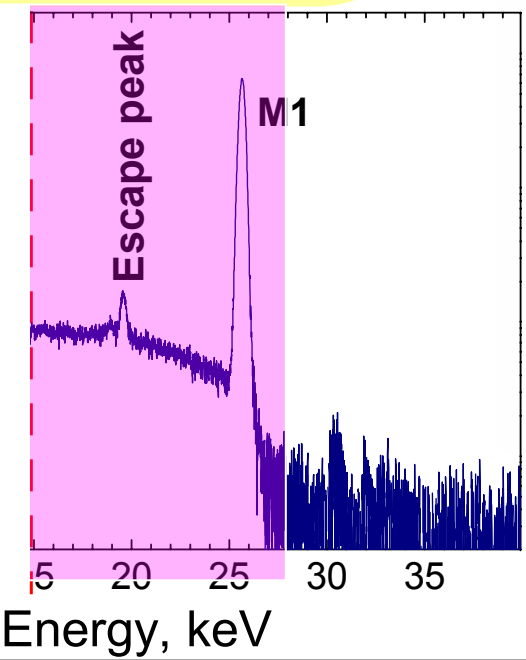




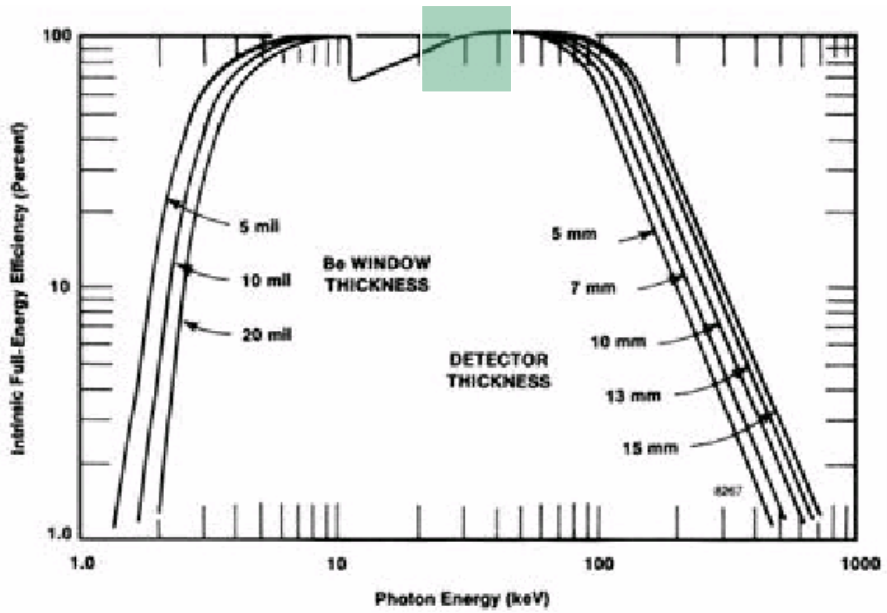
Fully relativistic calculations of the two-photon energy distribution for He-like ions

A. Volotka (Private communication)

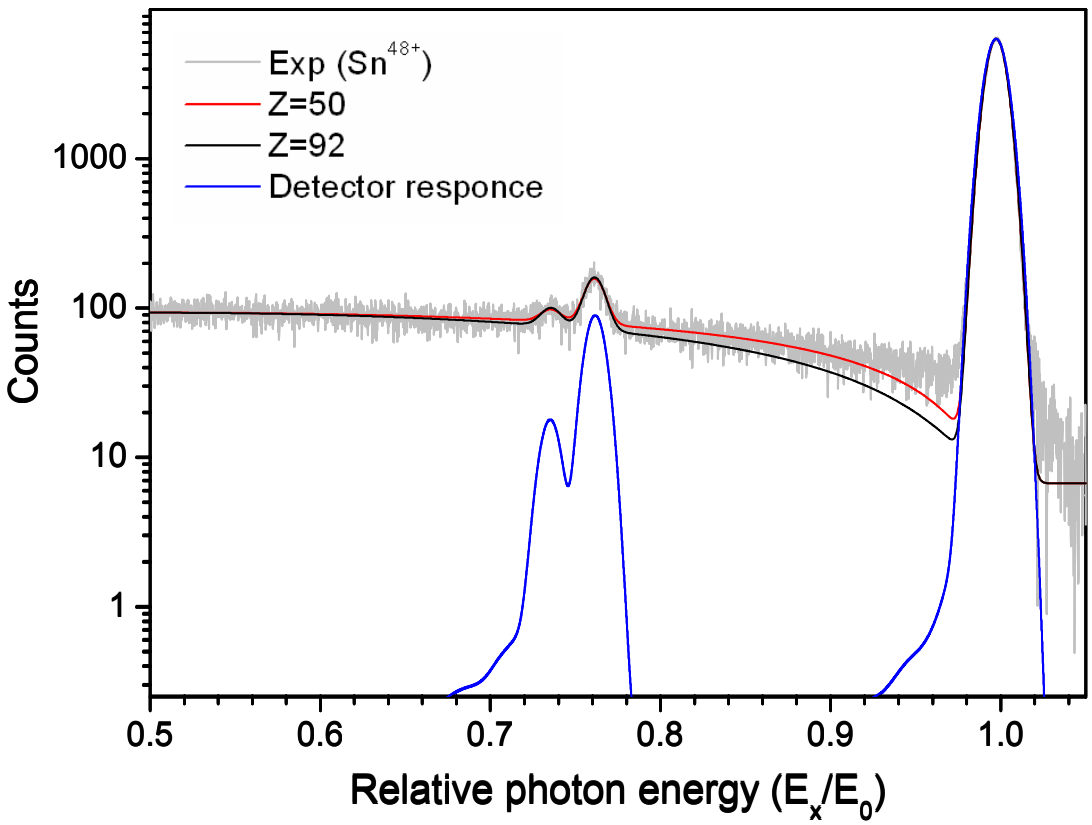


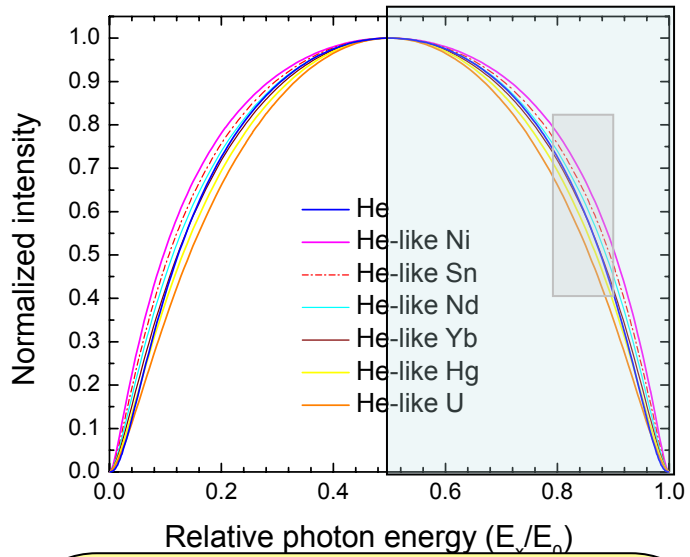


Theoretical efficiency curve of Ge detector



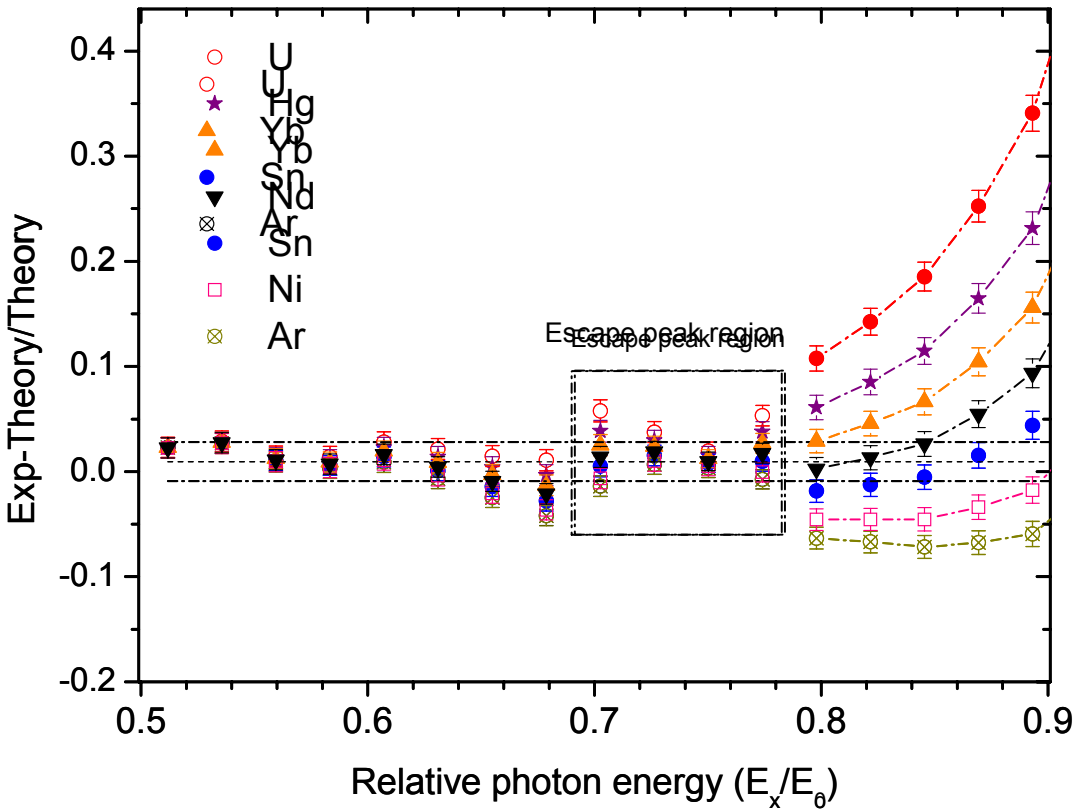
Data analysis and comparision with theory





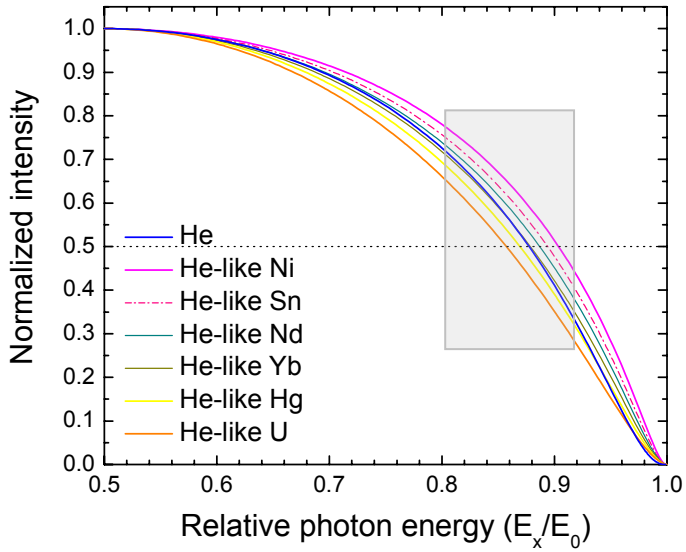
Z	Counts ratio [x=(0.80-0.92)/ x=(0.50-0.68)]	
	Exp.	Theory
28		0.403
50	0.390±0.003	0.386
60		0.374
70		0.366
92		0.324

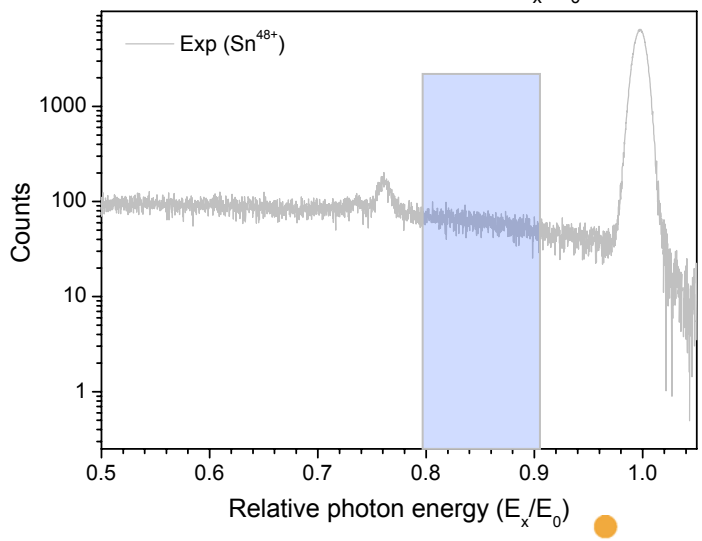
Comparison of measured and theoretical 2E1 Spectral shape



"Experiment-theory/theory" ratio for He-like Ar, Sn, Yb and U theoretical values as a function of relative photon energy. **Bin size : 120 channels (1 keV)**

The spectral shape of 2E1 photons of He-like Sn has been discriminated from other He-like ions





Summary

- New approach is introduced for measuring the spectral distribution of 2E1 decay

- The spectral shape of 2E1 photons of He-like Sn are in agreement with the relativistic calculations

- The experimental results confirm, for the first time, predictions of relativistic theories.

Summary

An 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:

- A technique for background-free two-photon transition measurements has been developed.
- Exclusive production of excited states in He-like ions
- New approach for investigation of exotic 2E1 decays
- The spectral shape of 2E1 photons of He-like Sn has been discriminated from other He-like ions.
- The experimental results confirm, for the first time, predictions of relativistic theories.

Many thanks for your attention