Exclusive production of the n=2 S-states in He-like uranium - two-photon transitions

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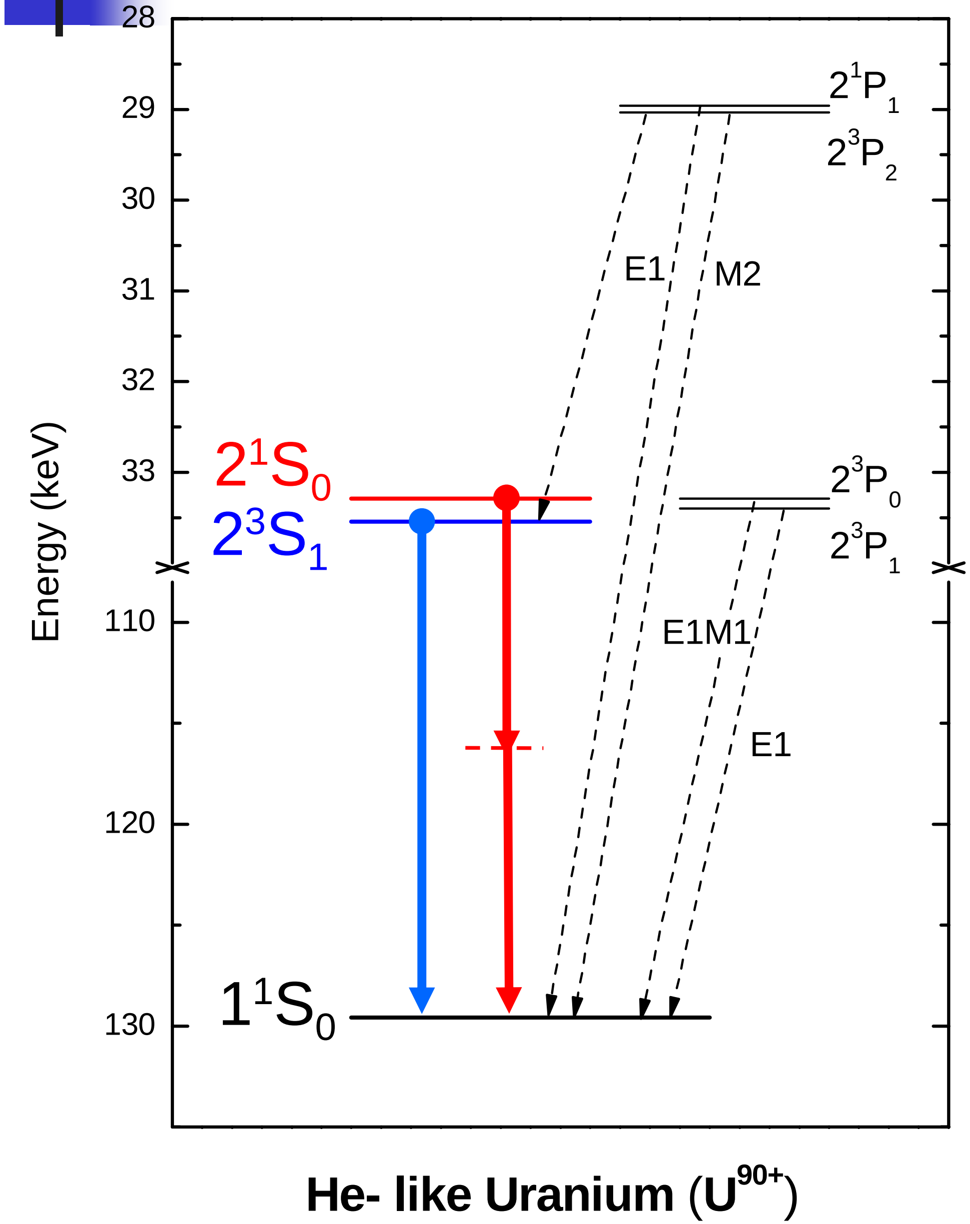
- Experimental scheme and setup
- Why exclusive production of n=2 S-states?
- Results and comparison with theoretical calculation

Decay of He-like uranium

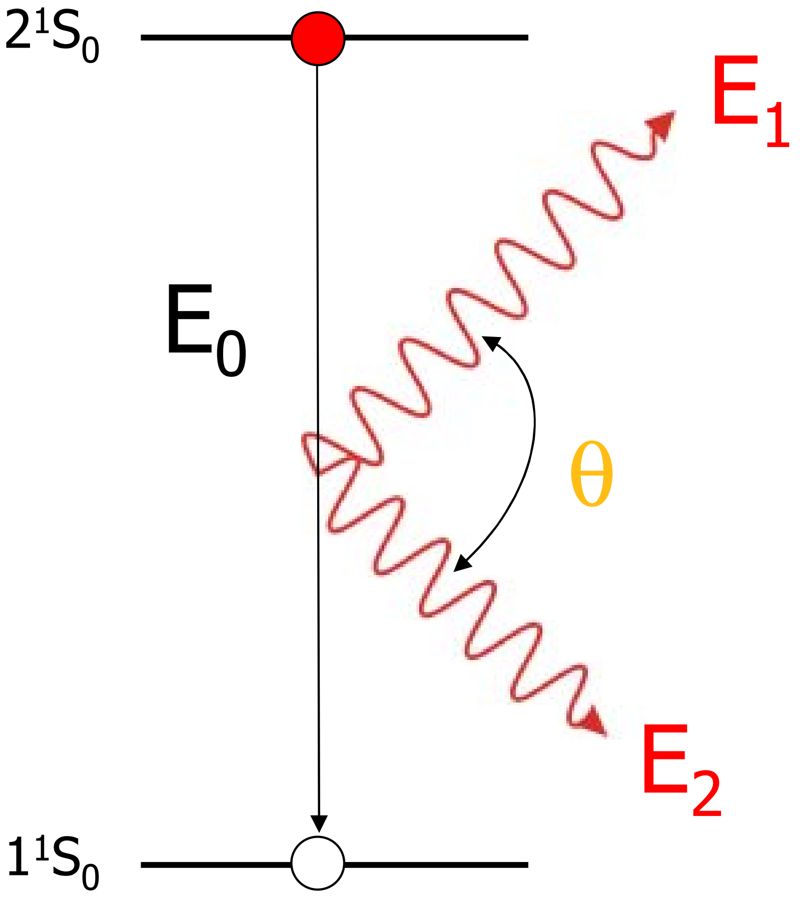


$2S_{1/2}$ state in the He-like ions can only decay to the ground state by two competitive transitions:

M1: ($2^3S_1 \rightarrow 1^1S_0$) – relativistic (is strictly forbidden in nonrelativistic case) magnetic dipole transition

2E1: ($2^1S_0 \rightarrow 1^1S_0$) – transition which, due to the conservation of angular momentum, is only possible by emission of two photons.

Two-photon transition



Energy of emmited photons:

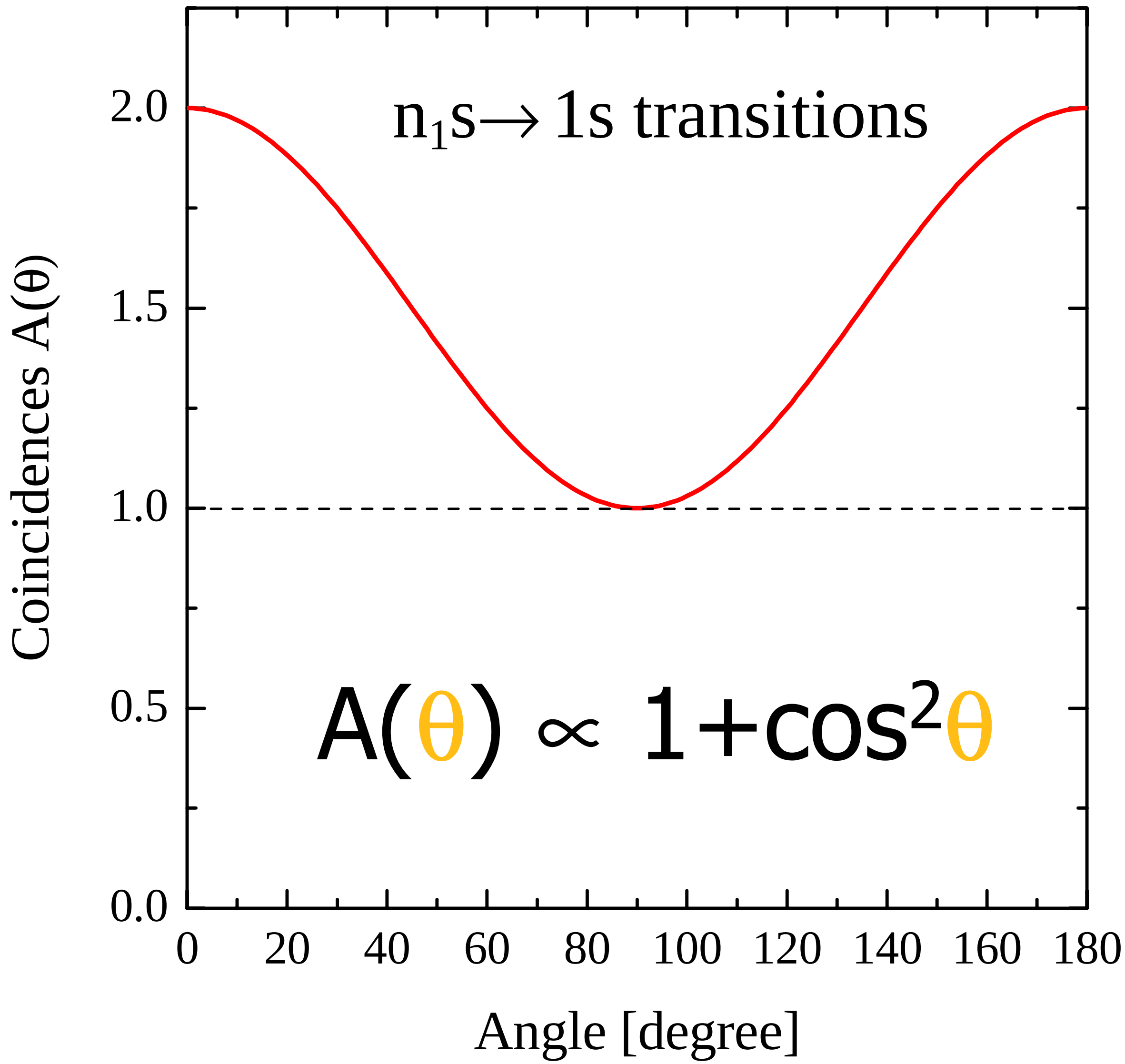
$$E_1 + E_2 = E_0$$

Angular distribution function A as a function of the angle θ between two simultaneously emmited photons:

$$A(\theta) \propto 1 + \alpha \cos^2\theta$$

Reference:
G. W. F. Drake, Phys. Rev. A 34 (1986)

Angular correlation

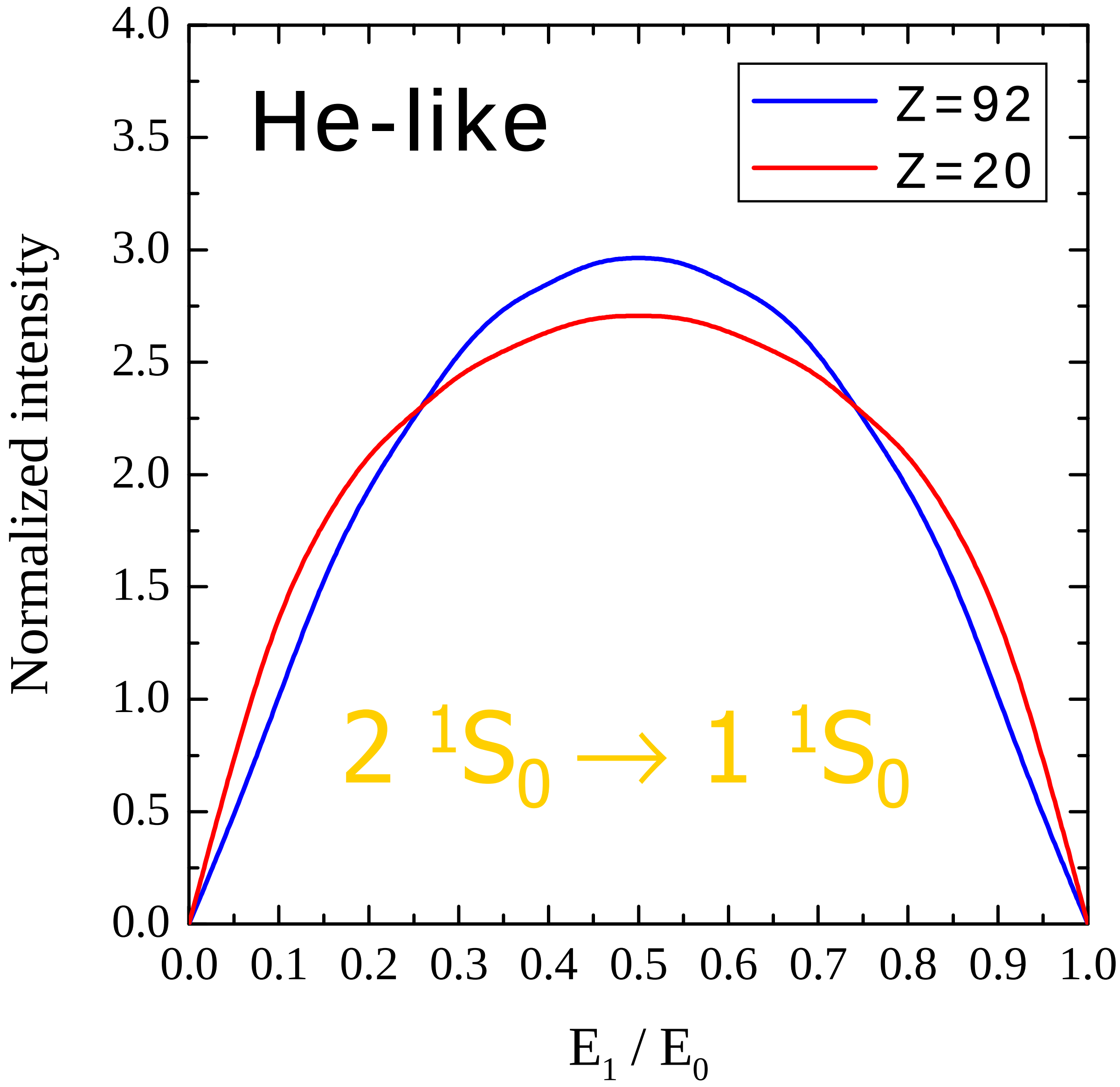


The curve indicates expected coincidence signal between two detectors as a function of angle between them

Note:
for $n_1s \rightarrow 1s$ transitions $\alpha=1$
but for example for:
$n_1d \rightarrow 1s$ transitions $\alpha=1/13$

Reference:
J. H. Tung et al., Phys. Rev. A 30 (1984)

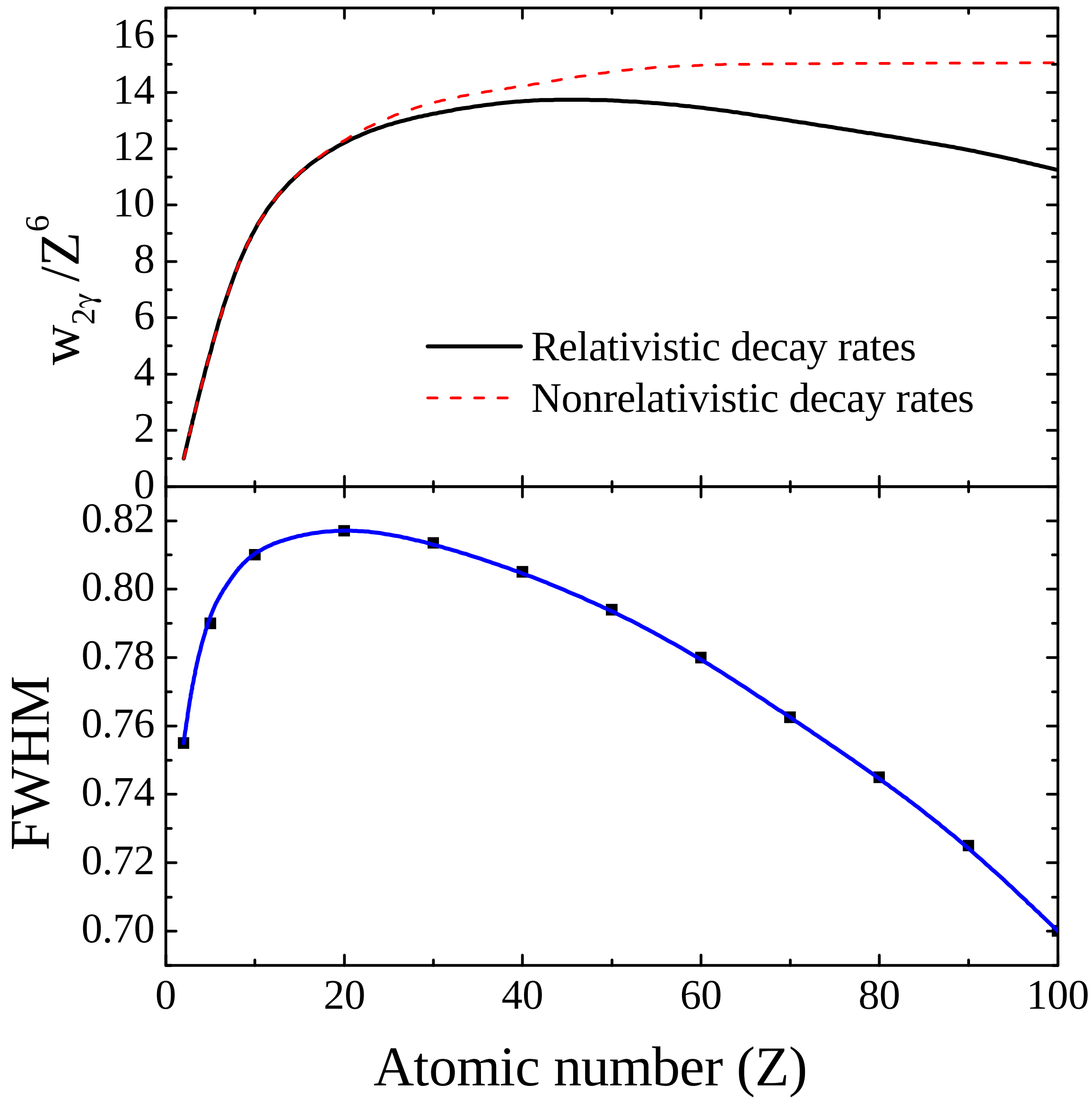
Energy distribution



Comparison of the photon energy distribution of $2\ ^1S_0$ state in He-like ions with Z=20 and Z=92

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

Relativistic effects

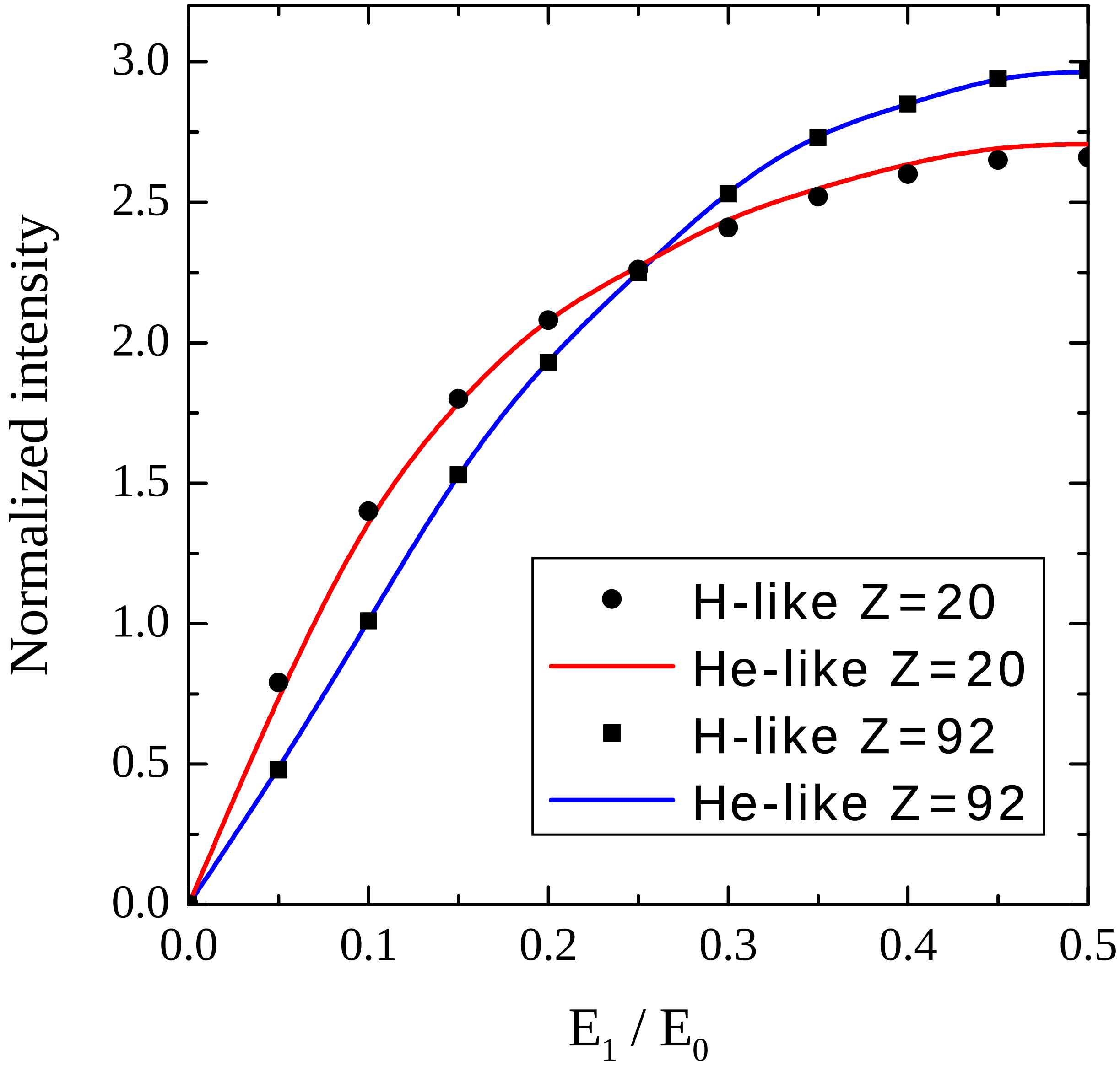


Comparison of the theoretical relativistic and nonrelativistic decay rates of 2 $^1S_0$ state

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

Reference:
Derevianko and Johnson , Phys. Rev. A 56 (1997)
G. W. F. Drake, Phys. Rev. A 34 (1986)

Correlation effects



Comparison of the photon energy distributions of 2 $^1S_0$ state with the corresponding hydrogenic $2s_{1/2} \rightarrow 1s_{1/2}$ energy distributions

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

Decay rates for He-like uranium

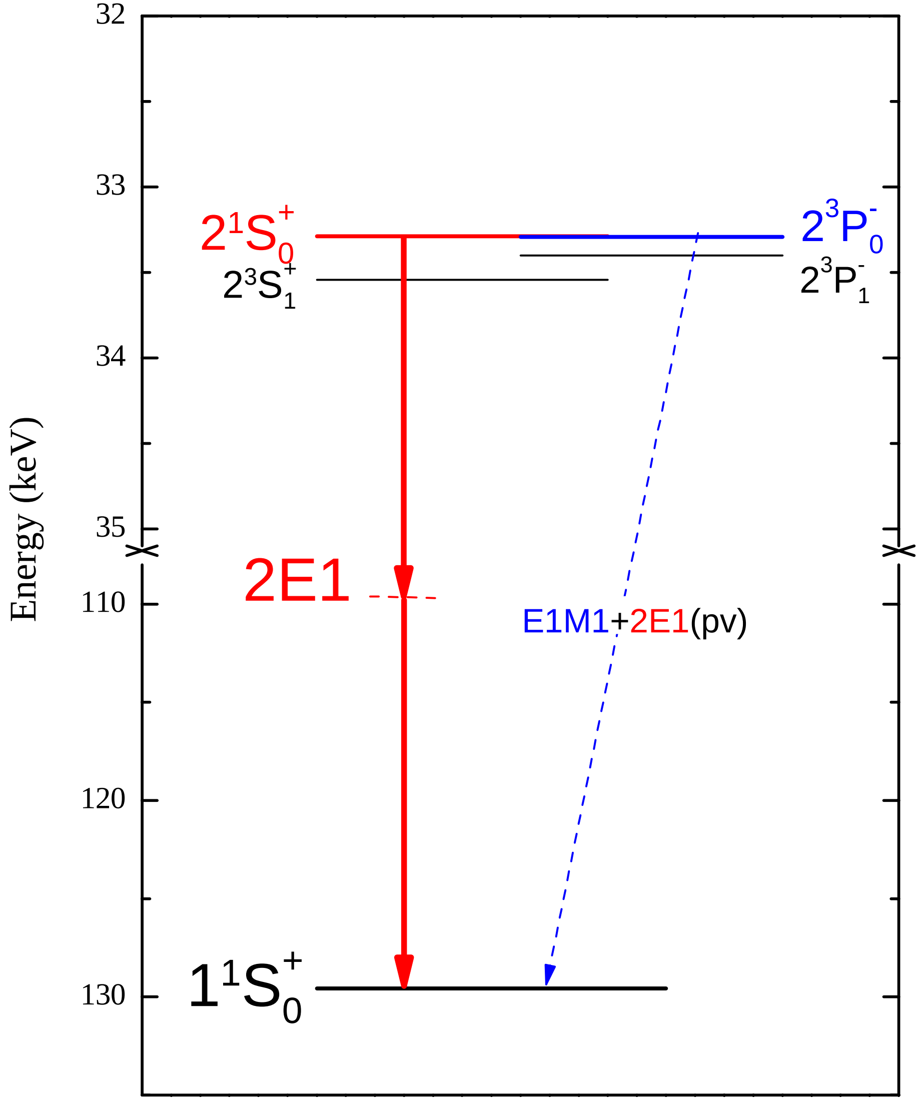
- 2E1 $(2\ ^1S_0 \rightarrow 1\ ^1S_0)$ – $7.26 \cdot 10^{12}\ [s^{-1}]$
- M1 $(2\ ^3S_1 \rightarrow 1\ ^1S_0)$ – $1.21 \cdot 10^{14}\ [s^{-1}]$

- E1 $(2\ ^3P_1 \rightarrow 1\ ^1S_0)$ – $2.99 \cdot 10^{16}\ [s^{-1}]$
- E1M1 $(2\ ^3P_0 \rightarrow 1\ ^1S_0)$ – $5.61 \cdot 10^{9}\ [s^{-1}]$

Why to measure 2E1 distribution?

- For high-Z ions lifetime of the transition is too short for traditionall measurement technics
- 2E1 energy distribution is very sensitive for relativistic effects and allows us to test theoretical calculations

Parity mixing



He- like U^{90+} ions

Degree of PNC:

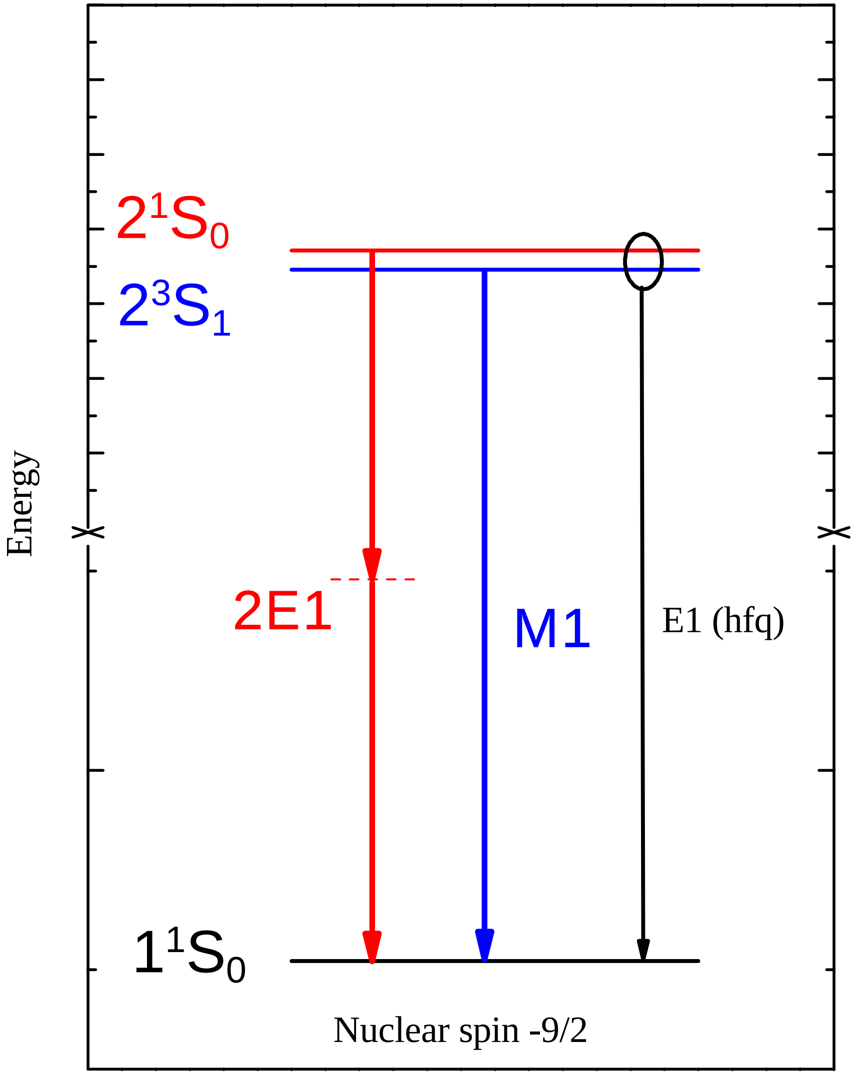
$$P \approx \frac{Z(\alpha Z)^4}{\Delta E} \sqrt{W_1 / W_0}$$

He-like uranium is a very interesting system for searching parity-violation because :

- Overlap of the electron wave functions with nuclear charge distribution is large
- Two states of oposite parity but identical total spin are almost degenerate (separated by about 1 eV)

Proposed prospects of the experiments:
A. Schäfer *et al.* , Phys. Rev. A 40 (1989)
V. V. Karasiev *et al.* , Phys. Lett. A 172 (1992)

Hyperfine quenching



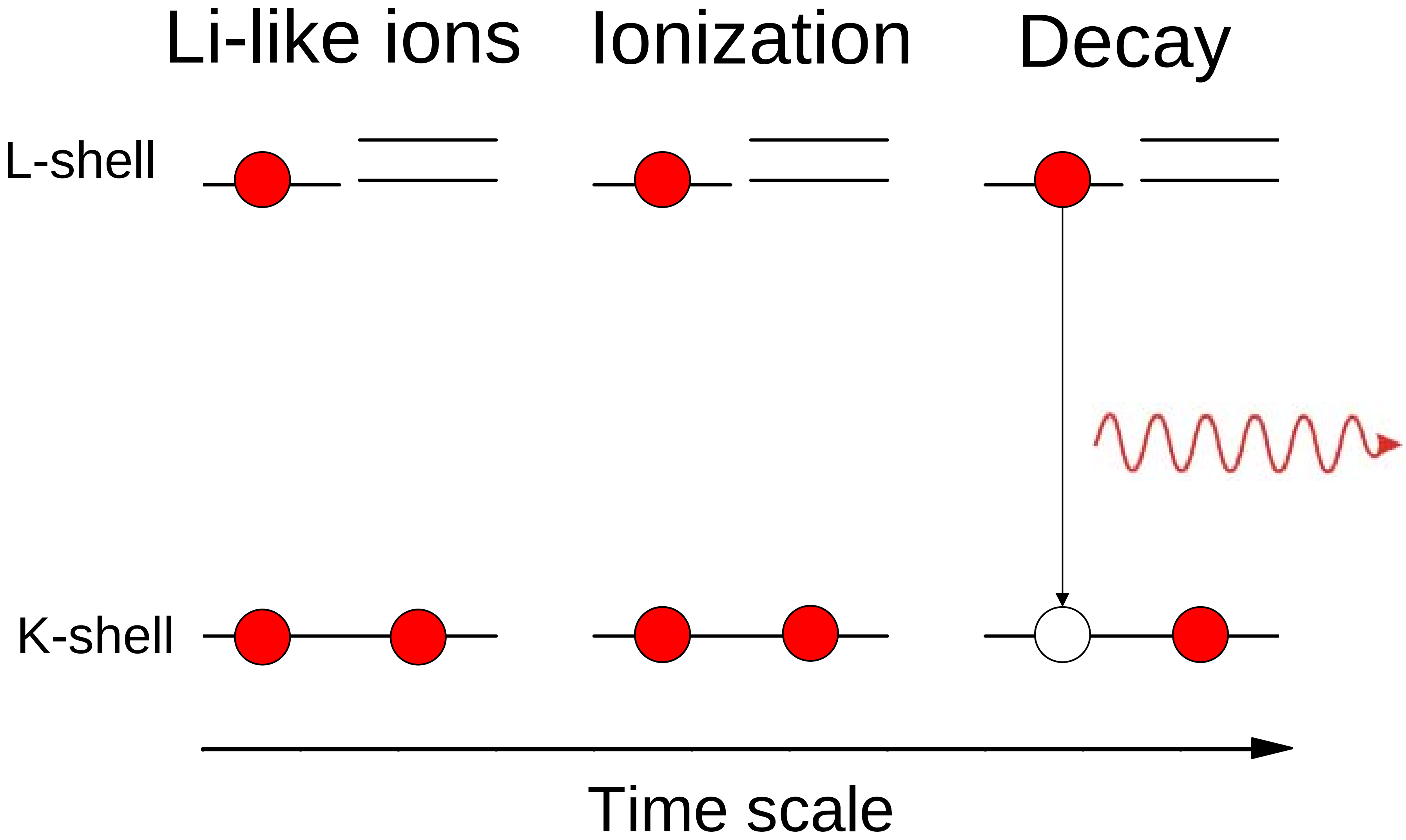
He- like Bismut (Bi^{81+})

How does it work?

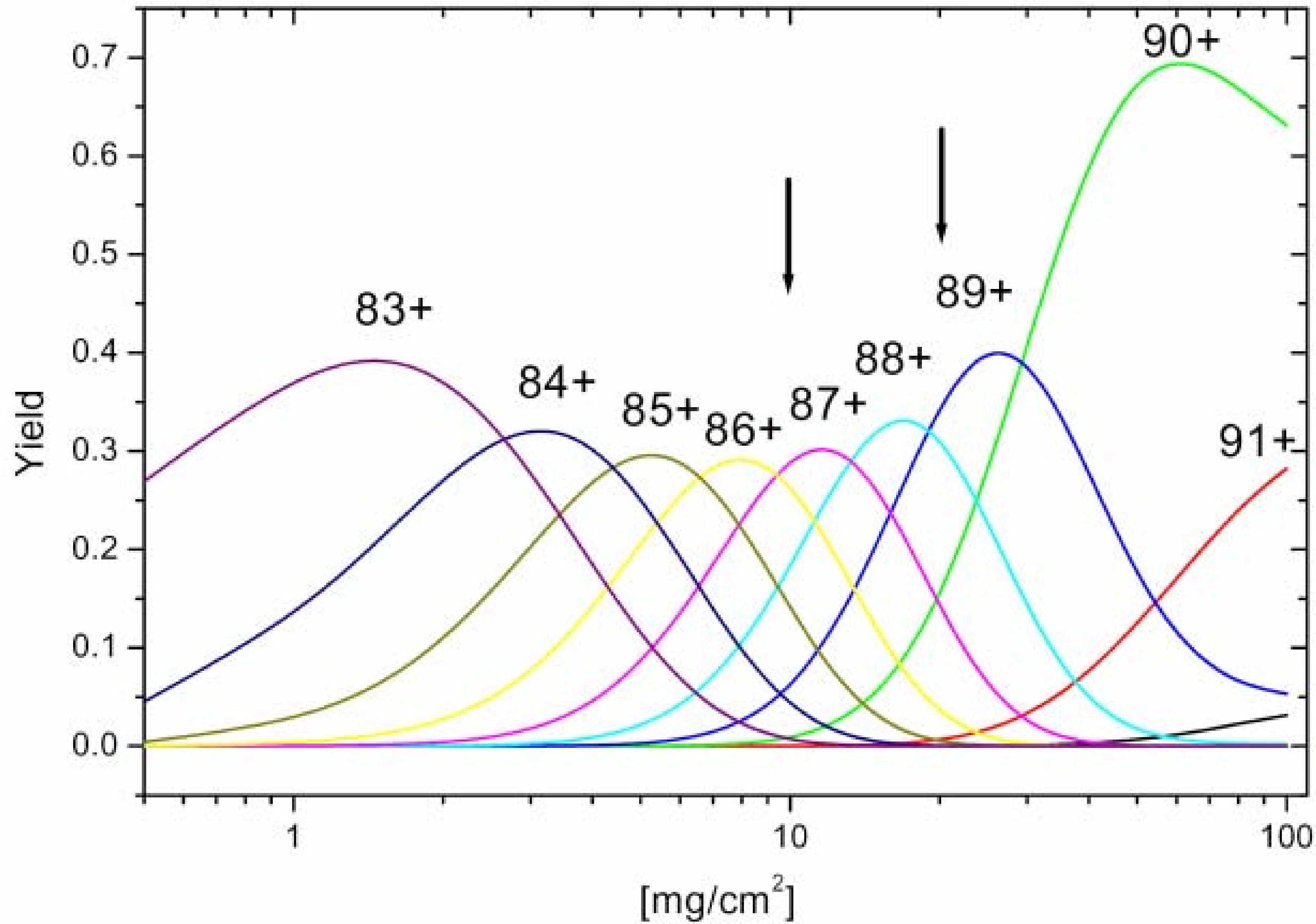
- two nearby levels 0 and 1
- level 0 is metastable (cannot decay to the ground state because strictly forbidden J = 0 → J=0 transition)
- the two levels must have the same parity

Hyperfine quenched transition modifies the 2E1/M1 intensity ratio.

Schematic description

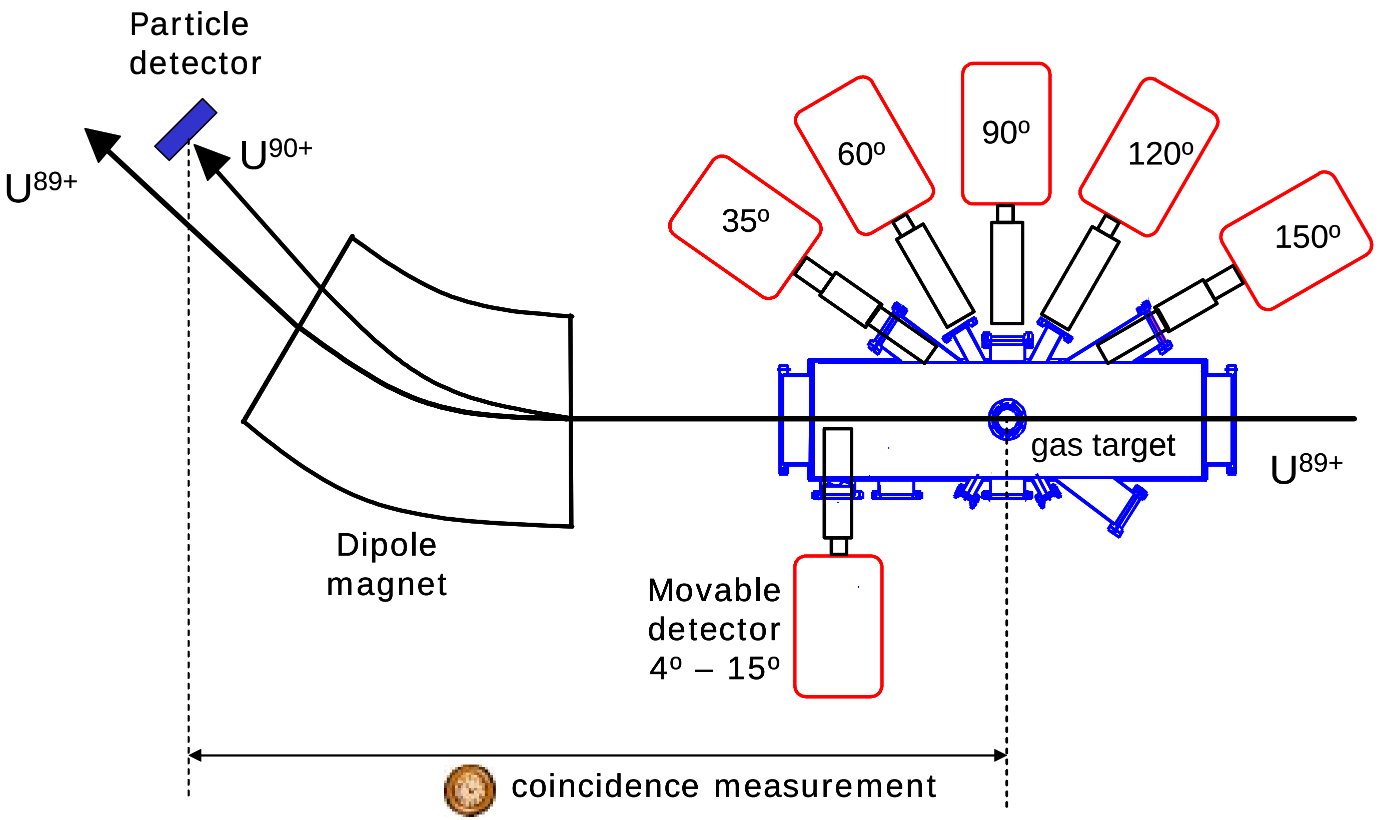


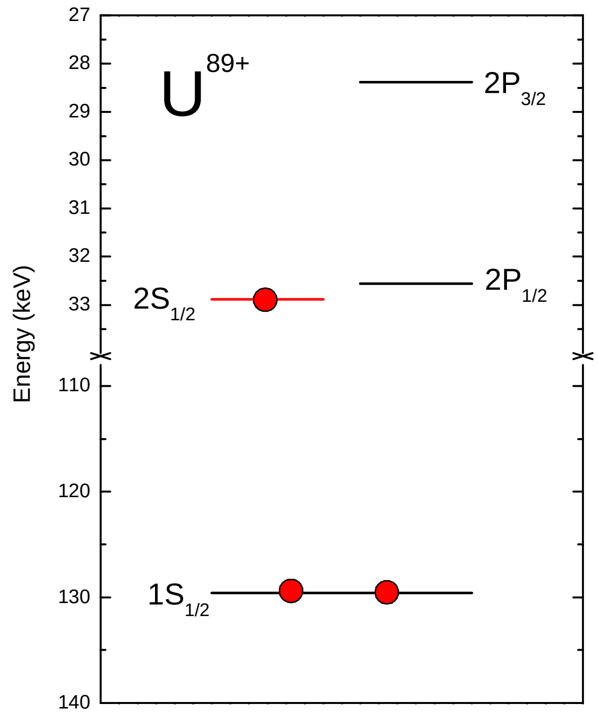
New posibilities of ESR



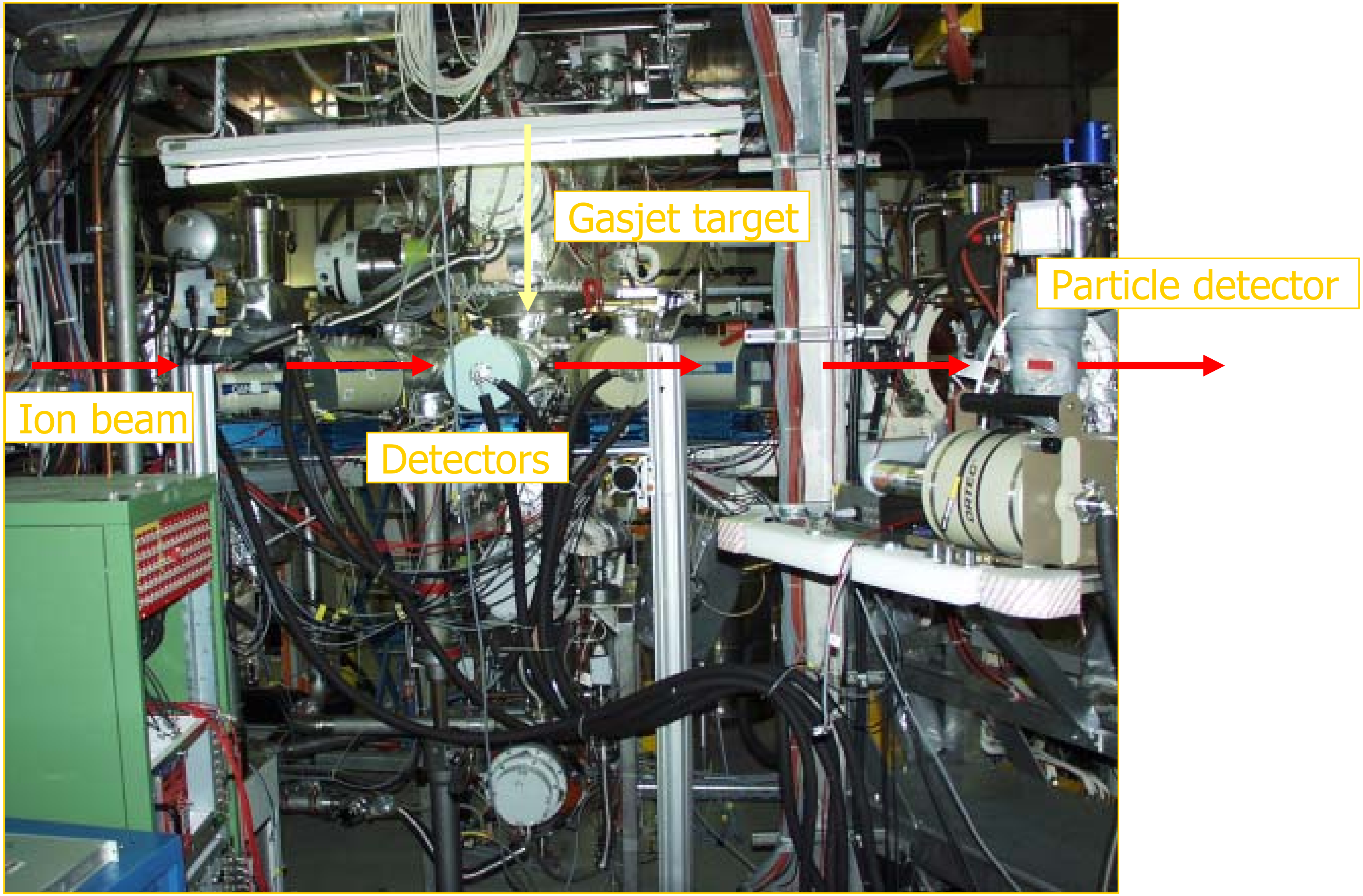
Experimental setup

- Li-like uranium ions at energy 378 MeV/u were stored in ESR storage ring and cooled in electron cooler
- We measured X-rays emitted in collision of the ions with N_2 gaseous target



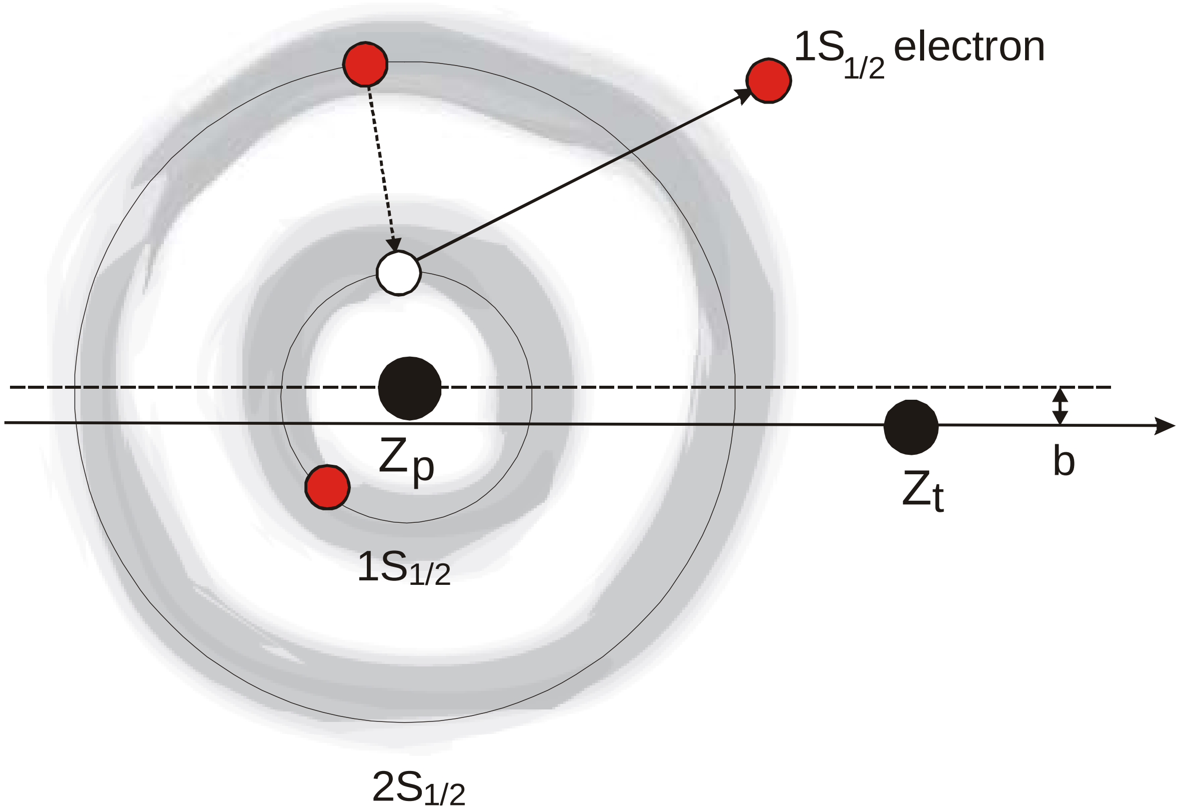


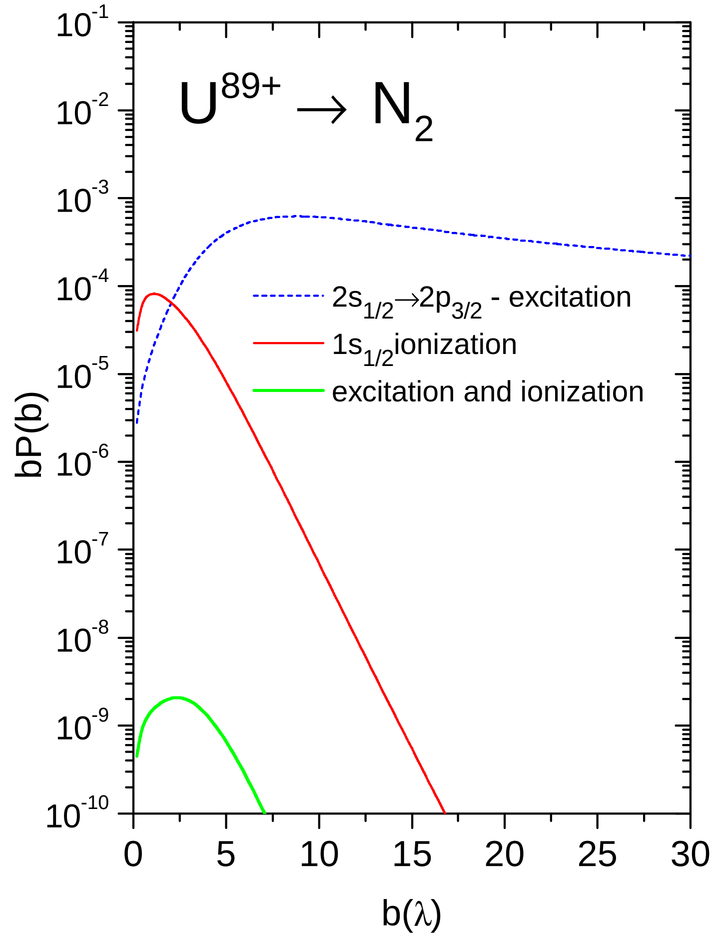
View of experimental setup



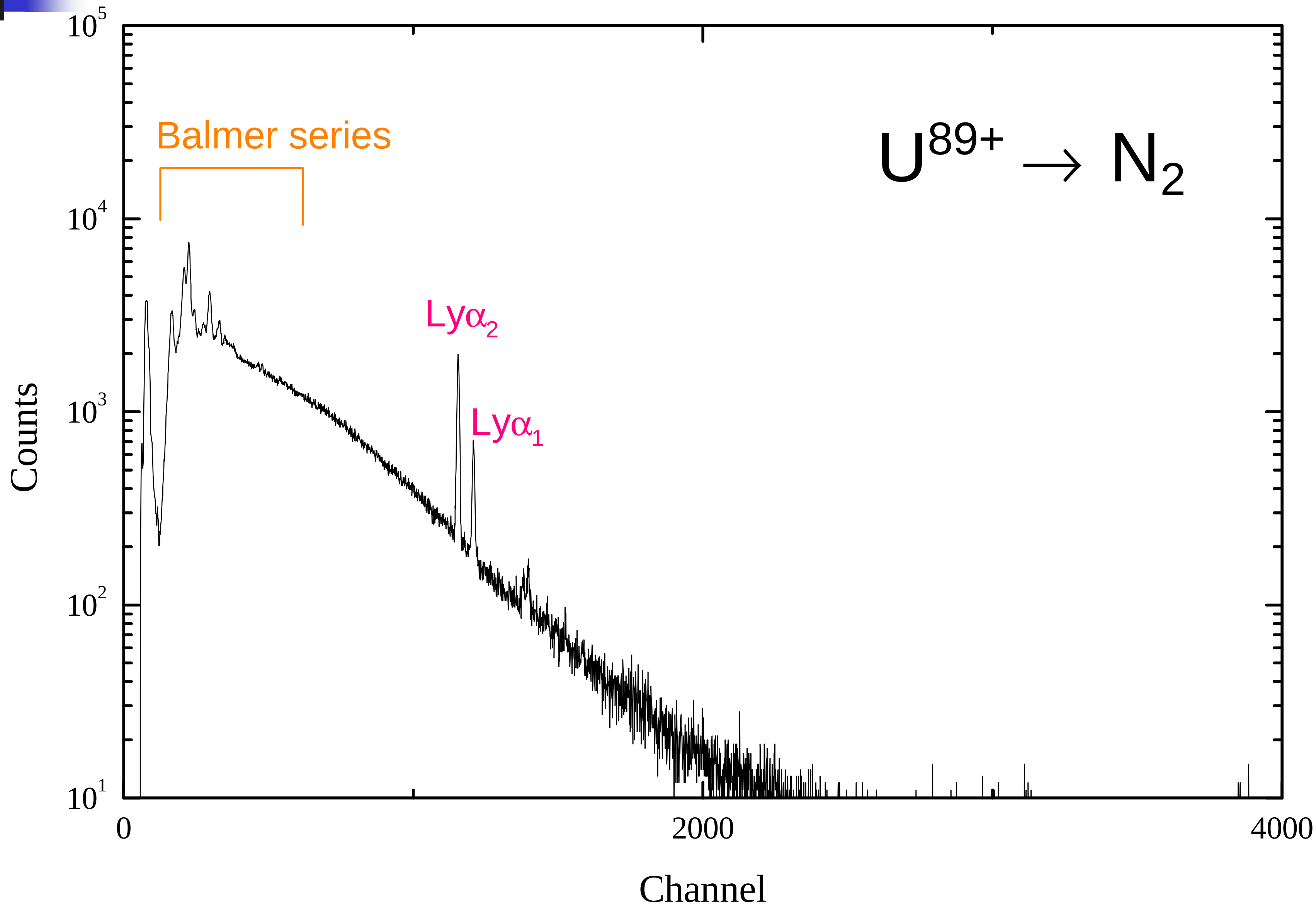
Selective K-shell Ionization

- Ionization of K-shell electron without disturbing of L-shell electron

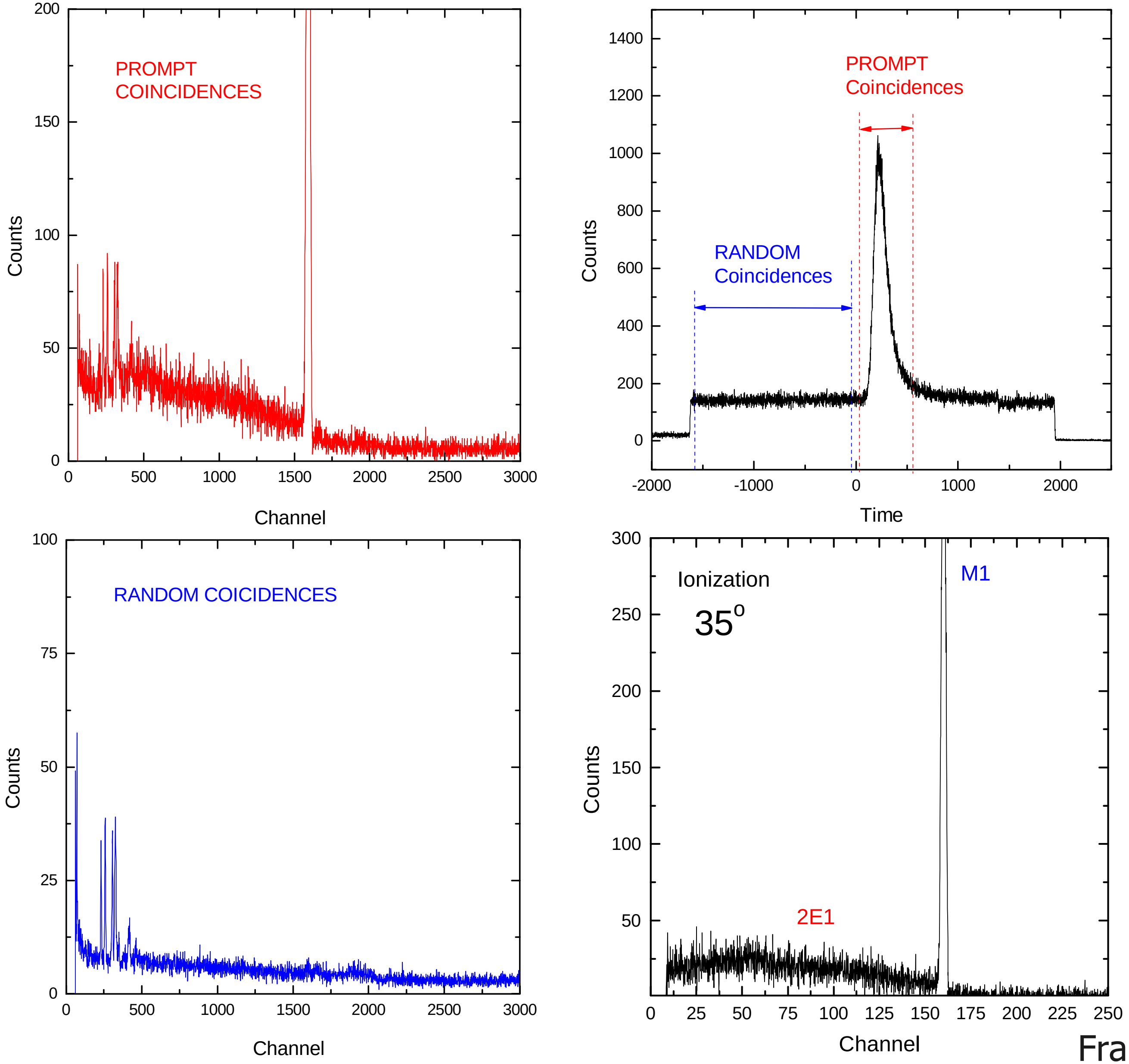




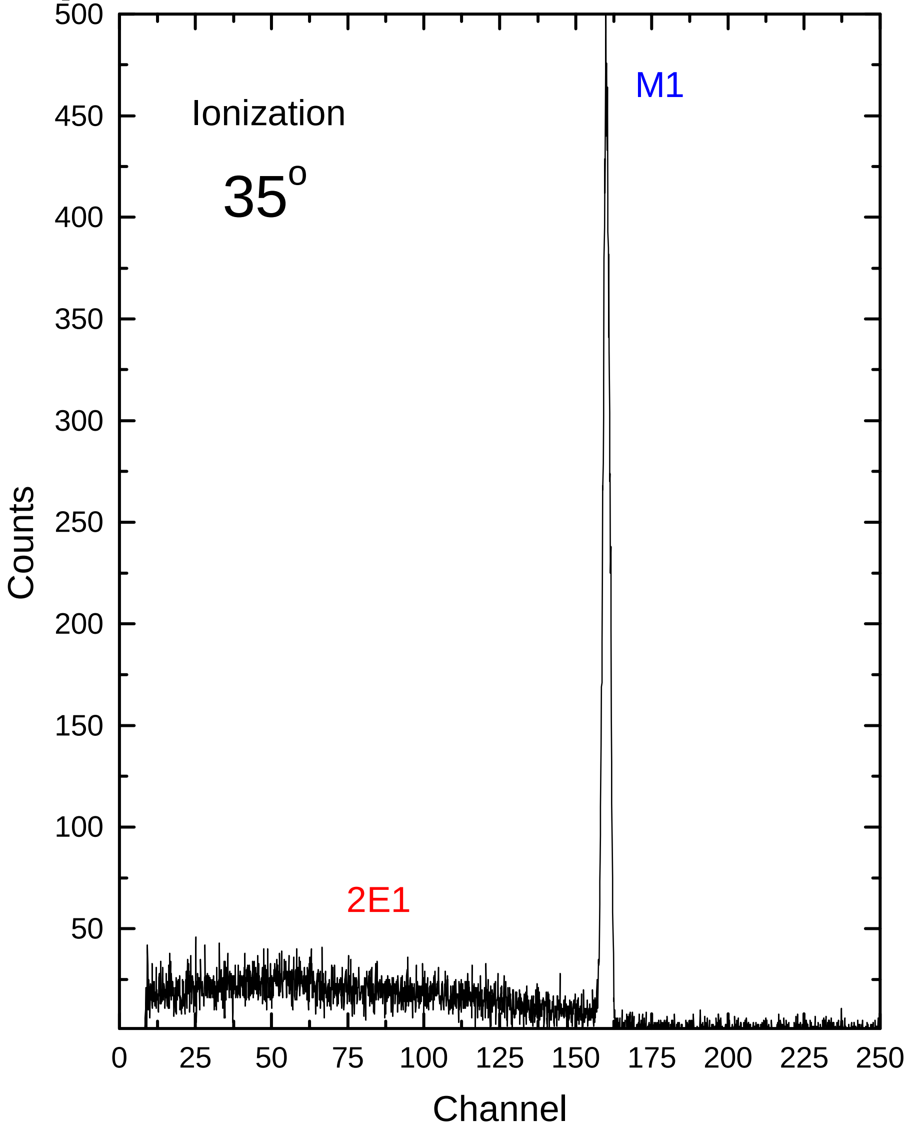
Measured spectra

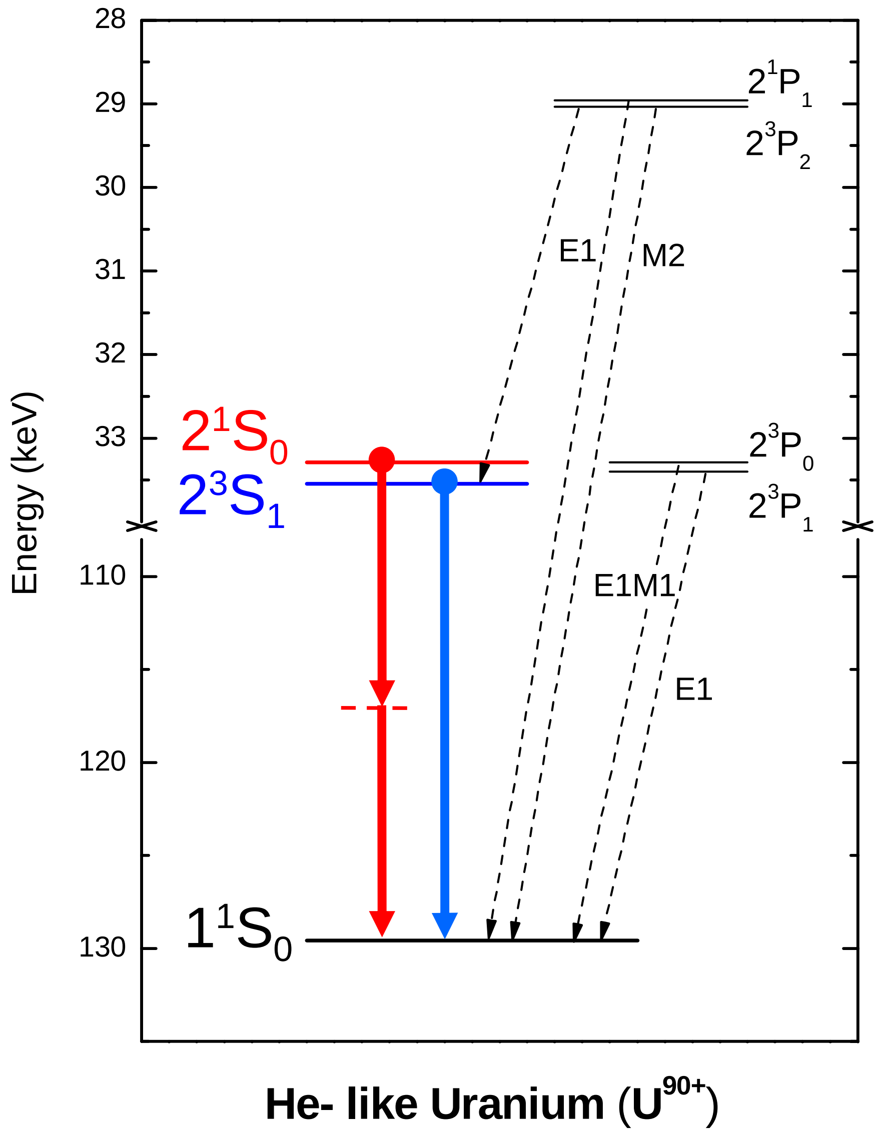


Coincidence technique

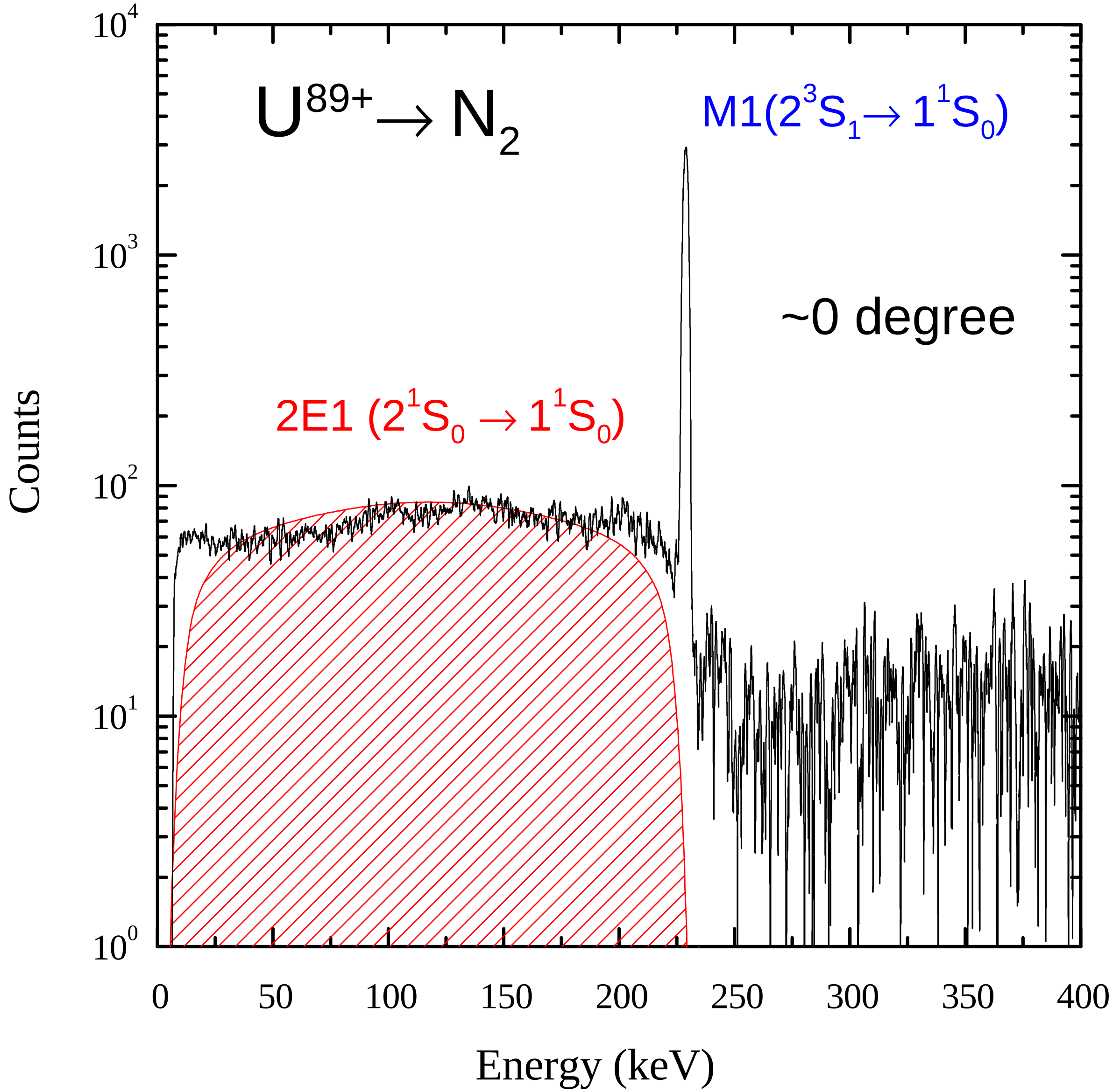


Coincidence spectra



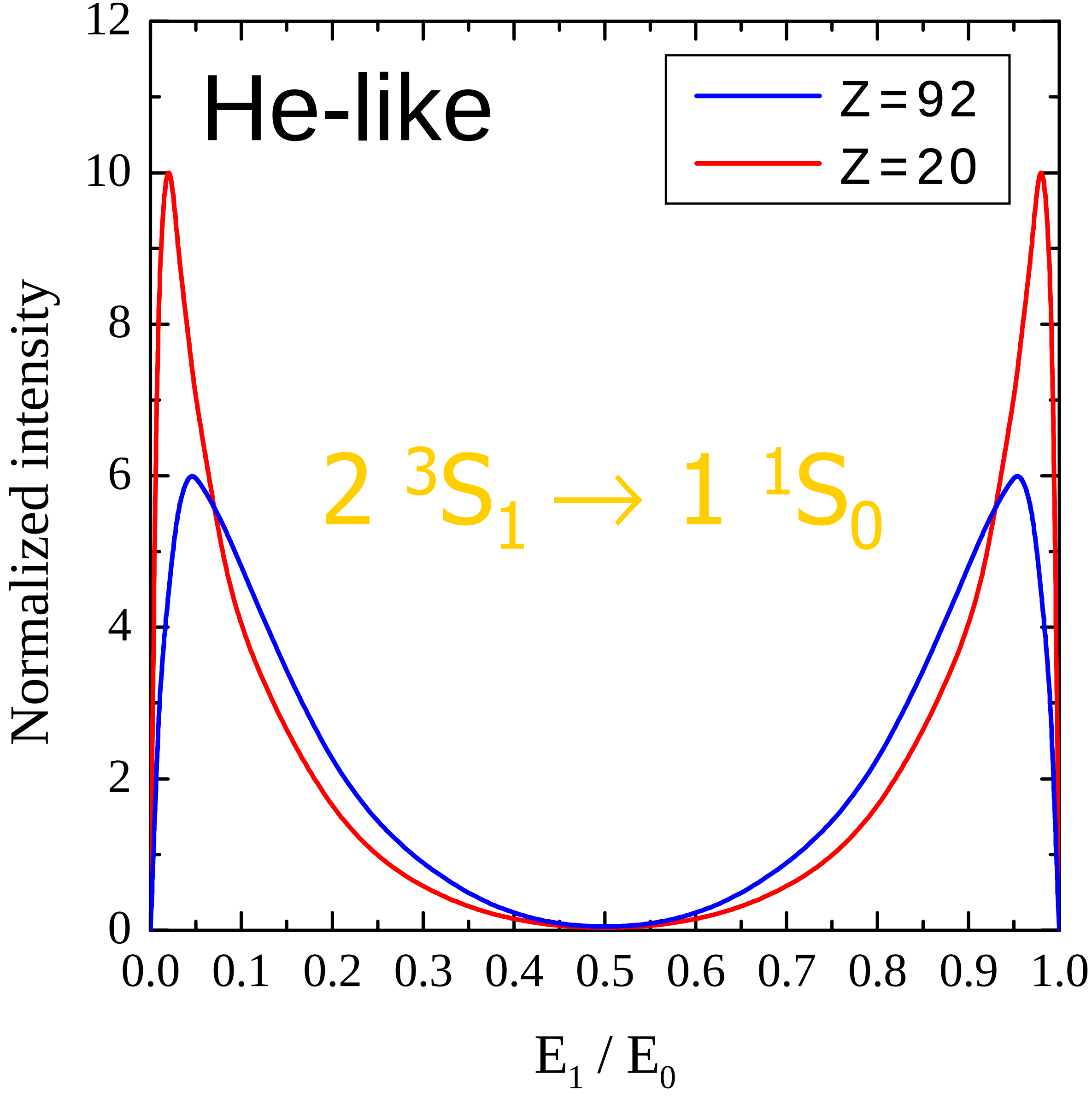


Comparison with theory



Measured spectrum was corrected for efficiency of the detector and for absorbtion in chamber window

$2\ ^3S_1 \rightarrow 1\ ^1S_0$ transition



Comparison of the photon energy distribution of $2\ ^3S_1$ state in He-like ions with Z=20 and Z=92

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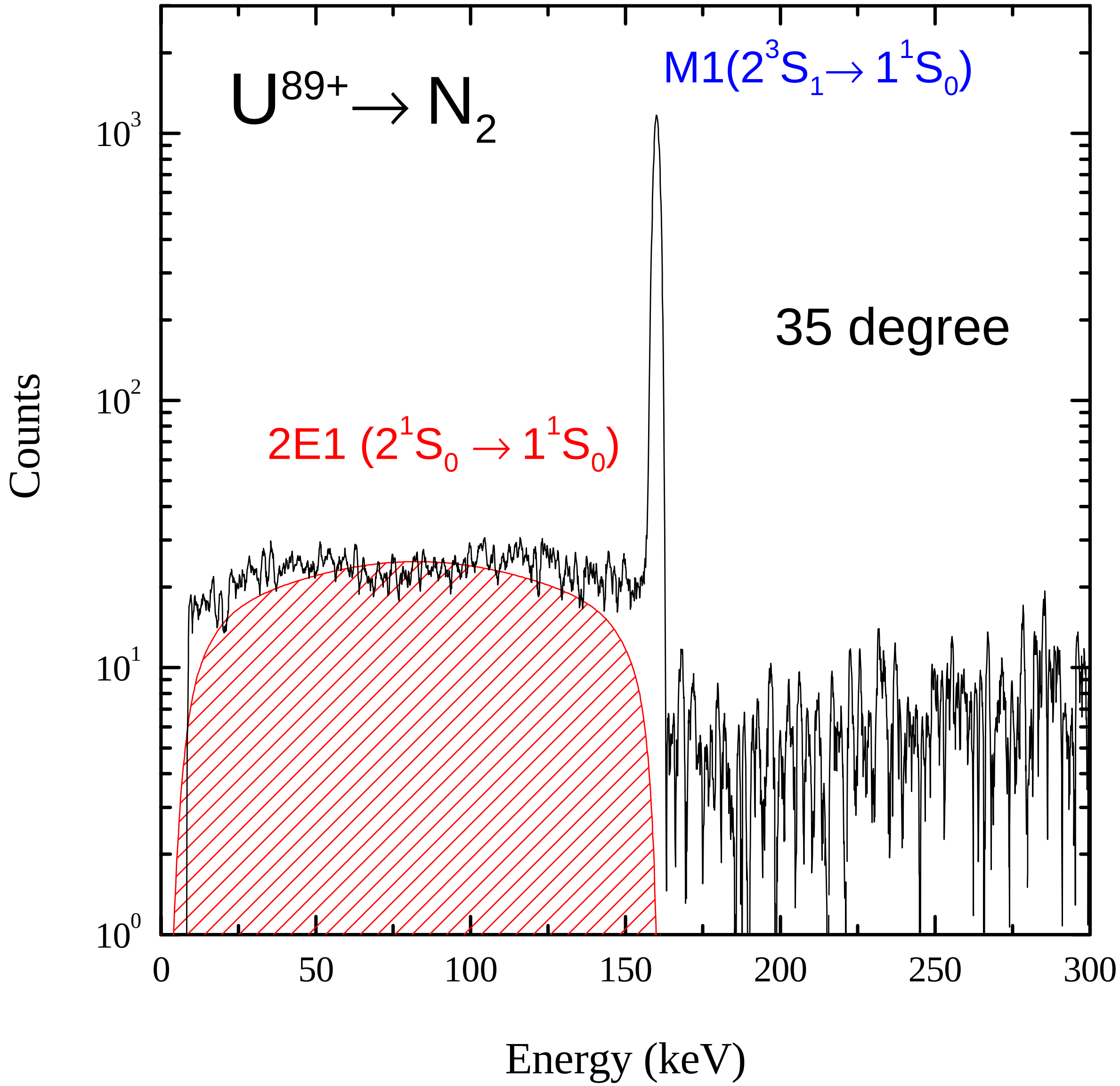
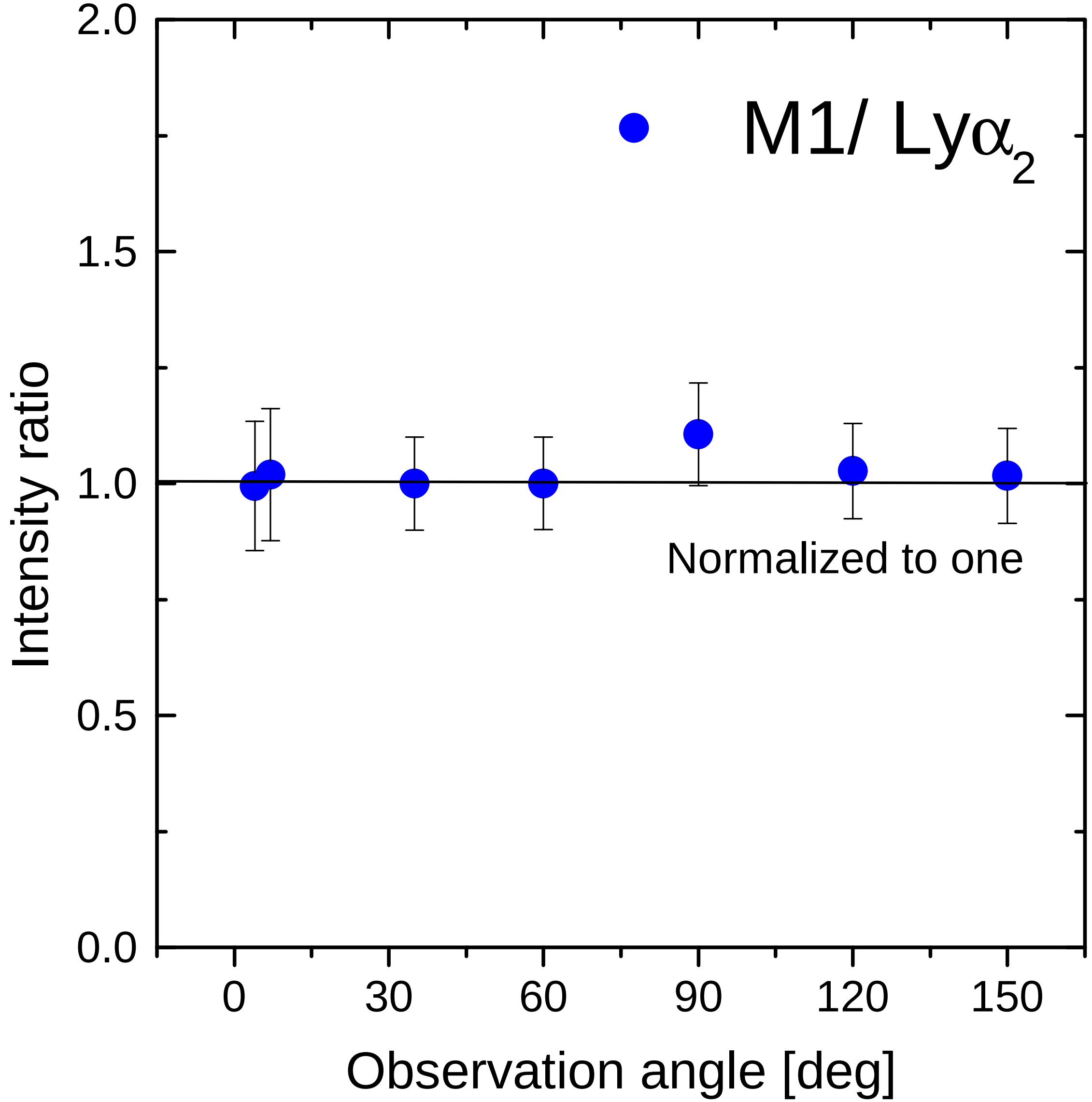
Derevianko and Johnson , Phys. Rev. A 56 (1997)

Comparison with theory



Measured spectrum was corrected for efficiency of the detector and for absorbtion in chamber window

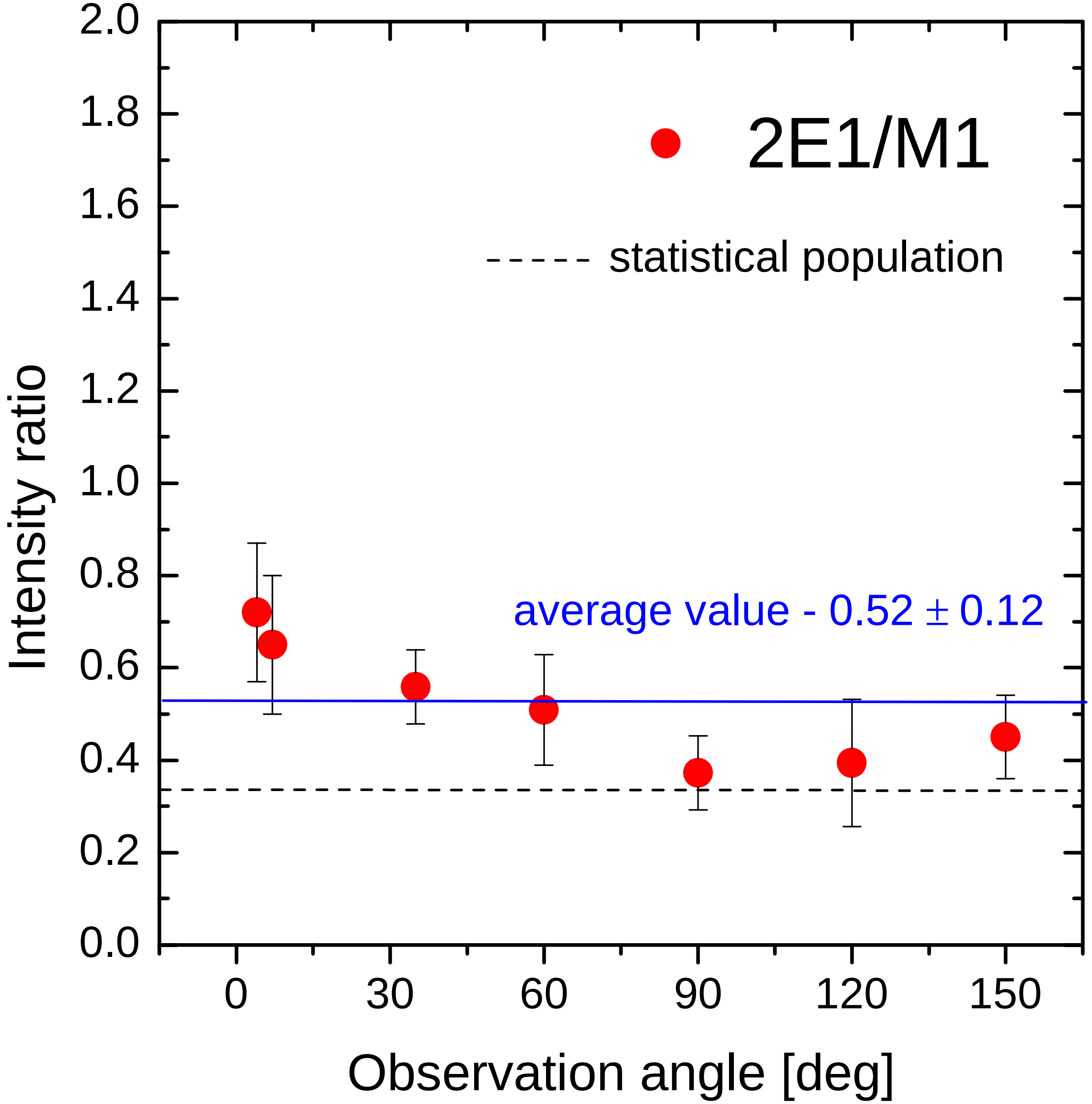
M1/Lα_2 intensity ratio



Measured intensity ratio for **M1** and **Lyα_2** transition which is isotropic in the emitter frame as function of observation angle

- **M1:** produced by K-shell ionization in $U^{89+} \rightarrow N_2$ collision
- **Lyα_2 :** produced by electron capture in $U^{92+} \rightarrow N_2$ collision

2E1/M1 intensity ratio



Measured intensity ratios for the **2E1** and **M1** transitions as function of observation angle

- **2E1:** produced by K-shell ionization in $U^{89+} \rightarrow N_2$ collision
- **M1:** produced by K-shell ionization in $U^{89+} \rightarrow N_2$ collision

Future

- Symulations of the detectors responce functions
- Measurements for Be-like ions and C-like ions
- Searching for hyperfine quenching effects by measurement of the ions with non-zero spin of the nucleus
- Searching for PNC sensitive transition

Summary

- We showed good level selectivity during K-shell ionization of Li-like uranium
- We measured not distorted **M1** and **2E1** transitions from decay of n=2 S-states in He-like uranium
- Theoretically calculated two-photon distribution is in good agreement with measured distribution
- We found that after ionization of K-shell 2S-states are not statistically populated