High-accuracy crystal spectroscopy of He-like Uranium

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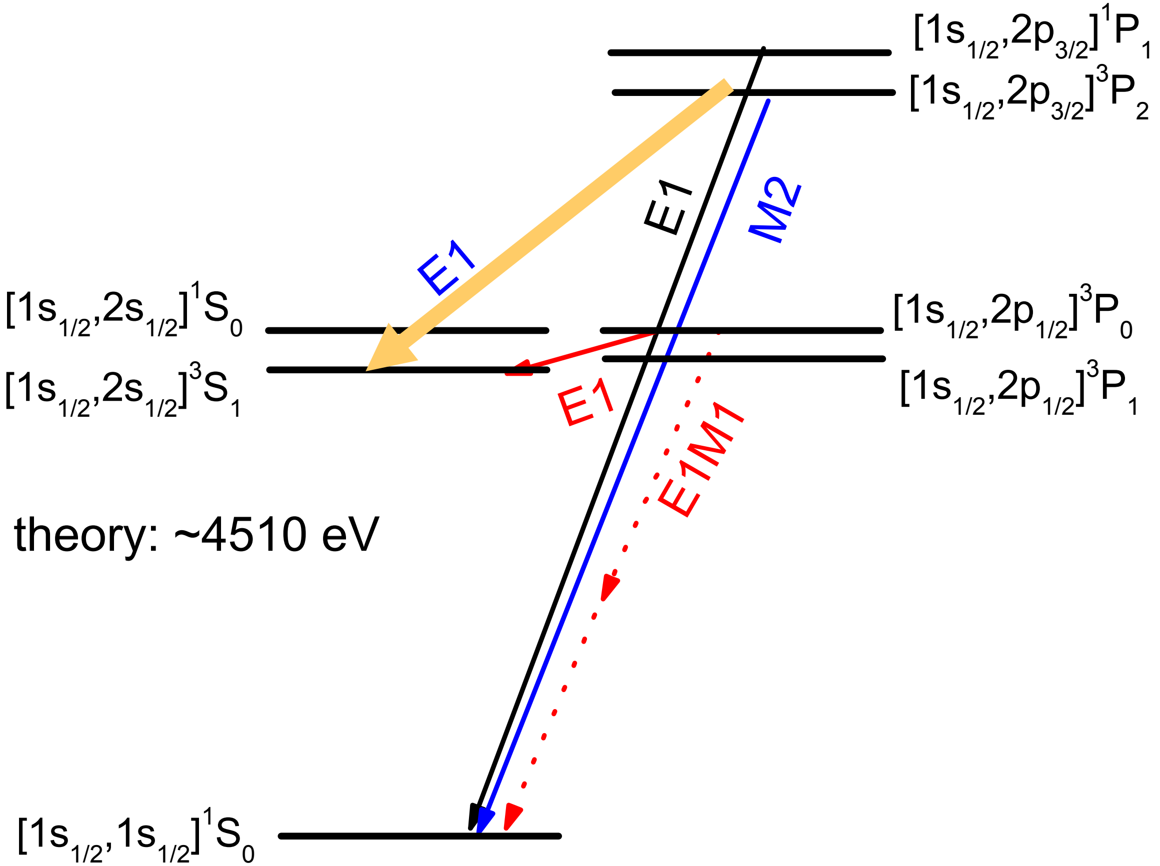
Table of Contents

- Motivation
- Experiment in August 2007
- Crystal Spectrometer
- Results
- Conclusion and Outlook

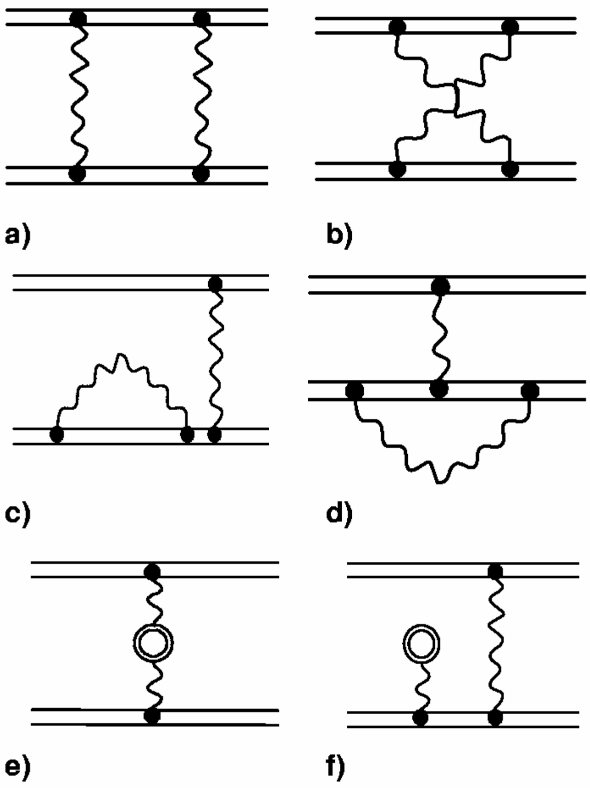
Precise measurement of Δn=0 transition

- Measurement of the $1s2p\,^3P_2 \rightarrow 1s2s\,^3S_1$ transition in He-like Uranium



- Transition energy predicted by theory: ~4510 eV

Motivation



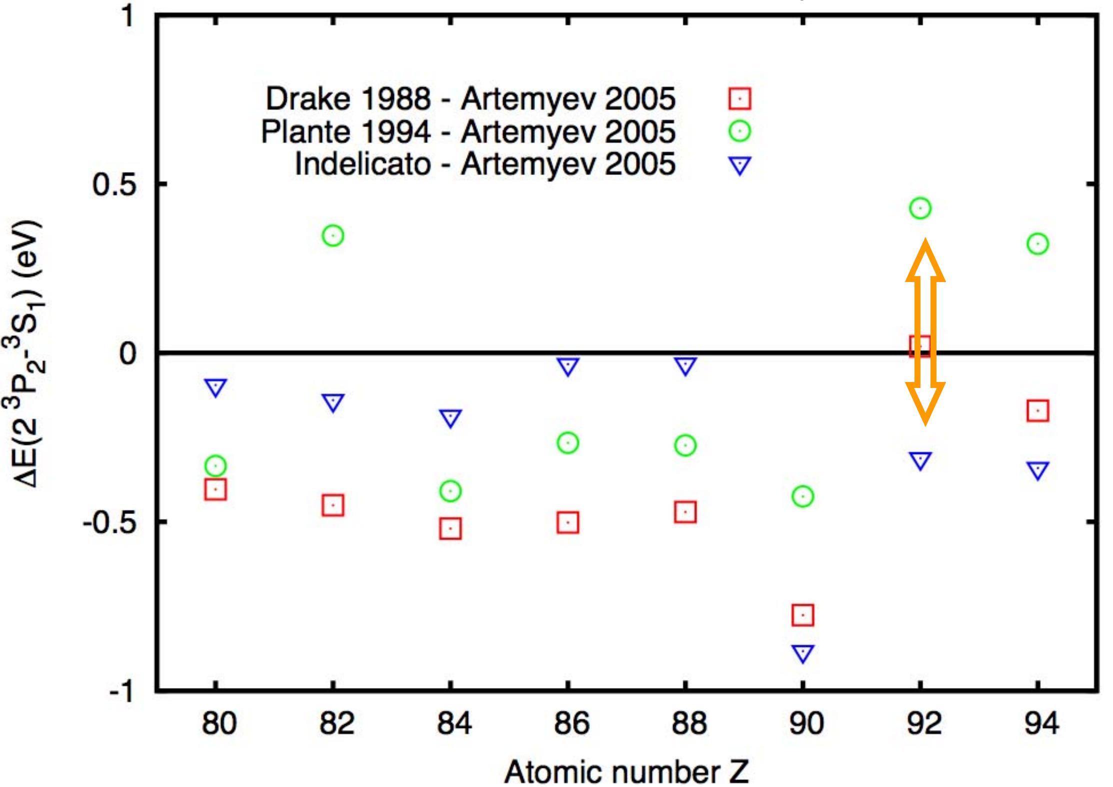
a),b) Non-Radiative QED
c),d) Two-electron Self Energy
e),f) Two-electron Vacuum Polarization

- He-like ions are the simplest many-body systems
- QED corrections in strong Coulomb field
- $\Delta n = 0$ transitions are sensitive to QED effects
- candidate for parity violation
- almost no experimental data for He-like high-Z ions

Precise measurement of Δn=0 transition

Differences in theoretical predictions up to ~1eV

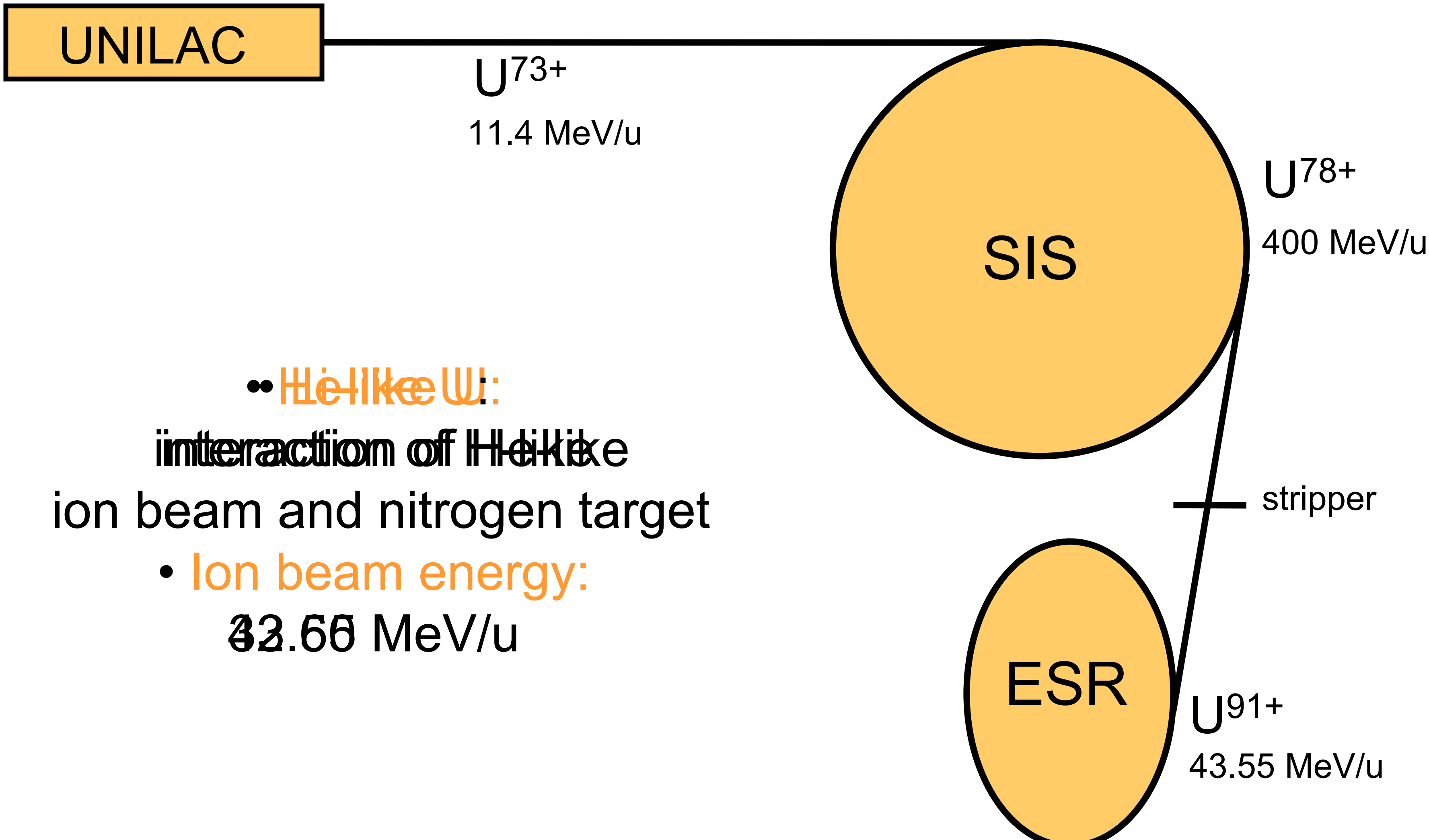
Different theories compared to Artemyev calculations:



[1] G.W.F. Drake, Can. J. Phys. **66**, 586 (1988)
[2] D.R. Plante *et al.*, Phys. Rev. A **49**, 3519 (1994)
[3] A.N. Artemyev *et al.*, Phys. Rev. A **71**, 062104 (2005)
[4] P. Indelicato, private communication

possible experimental achievable accuracy < 1 eV

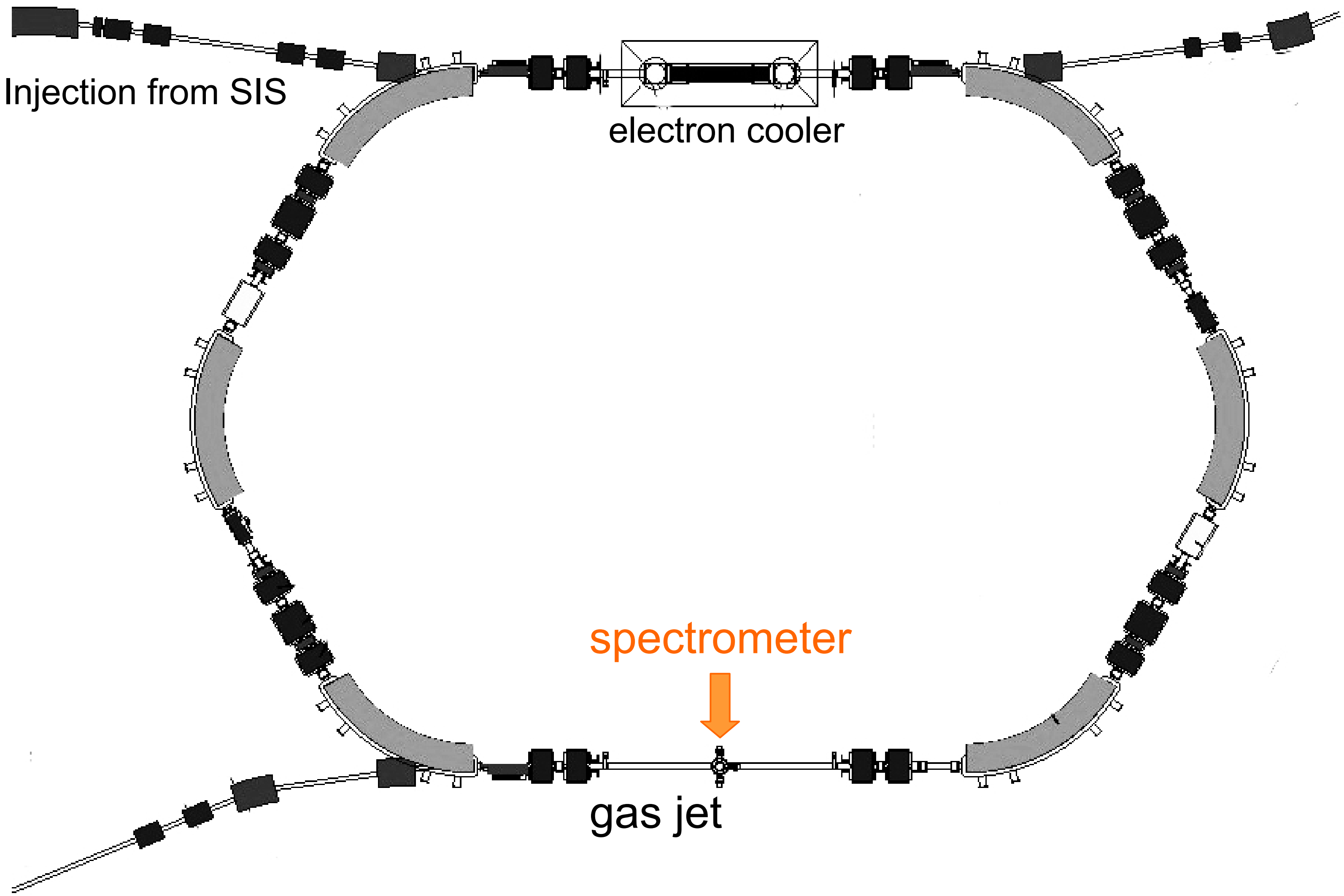
GSI accelerator facility



- Li-like U: interaction of Li-like ion beam and nitrogen target
- Ion beam energy: 43.55 MeV/u

- He-like U: interaction of He-like ion beam and nitrogen target
- Ion beam energy: 32.66 MeV/u

ESR storage ring



Experimental Setup - Beamtime August 2007

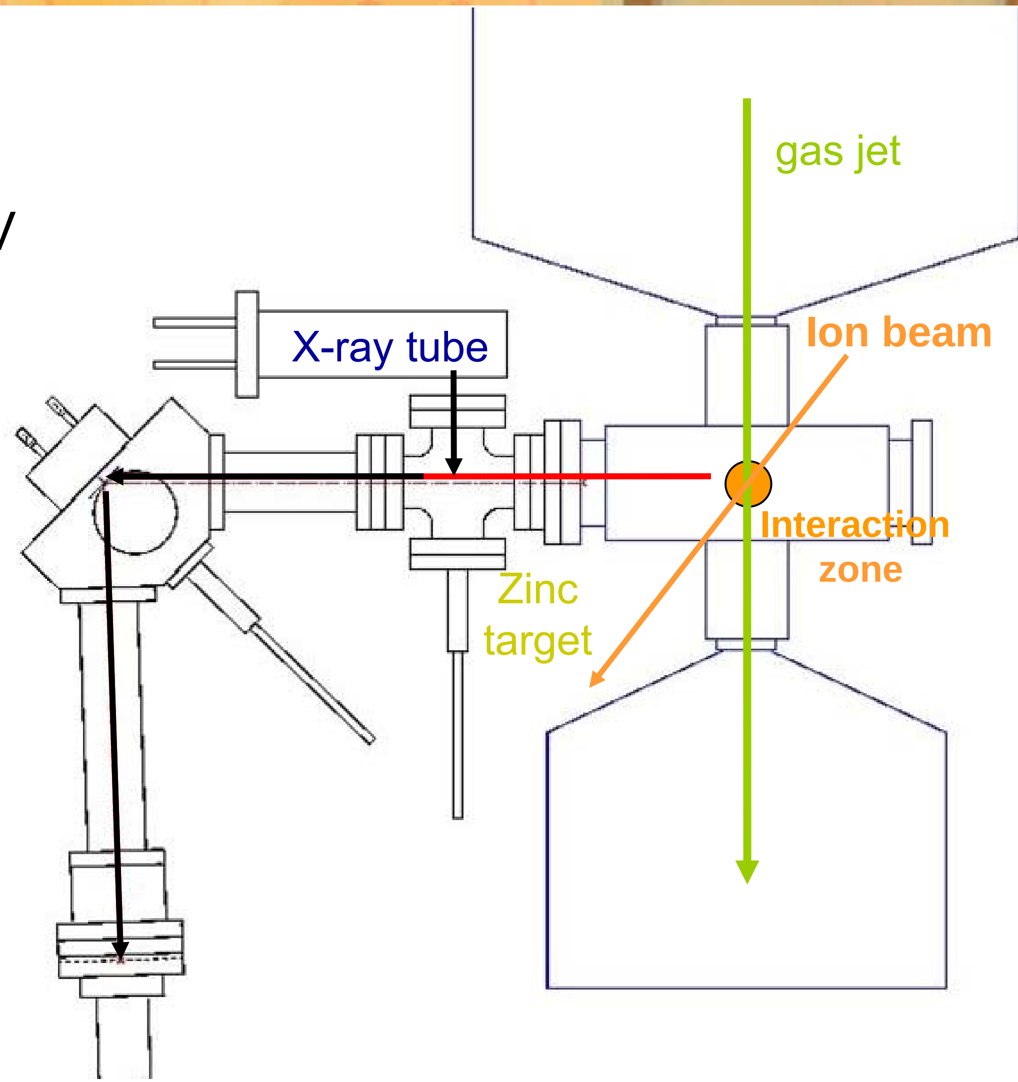
- observation angle of 90°
- energy in laboratory frame ~4.3 keV

$$E_{Proj} = E_{Lab} \cdot \gamma (1 - \beta \cos \theta_{Lab})$$

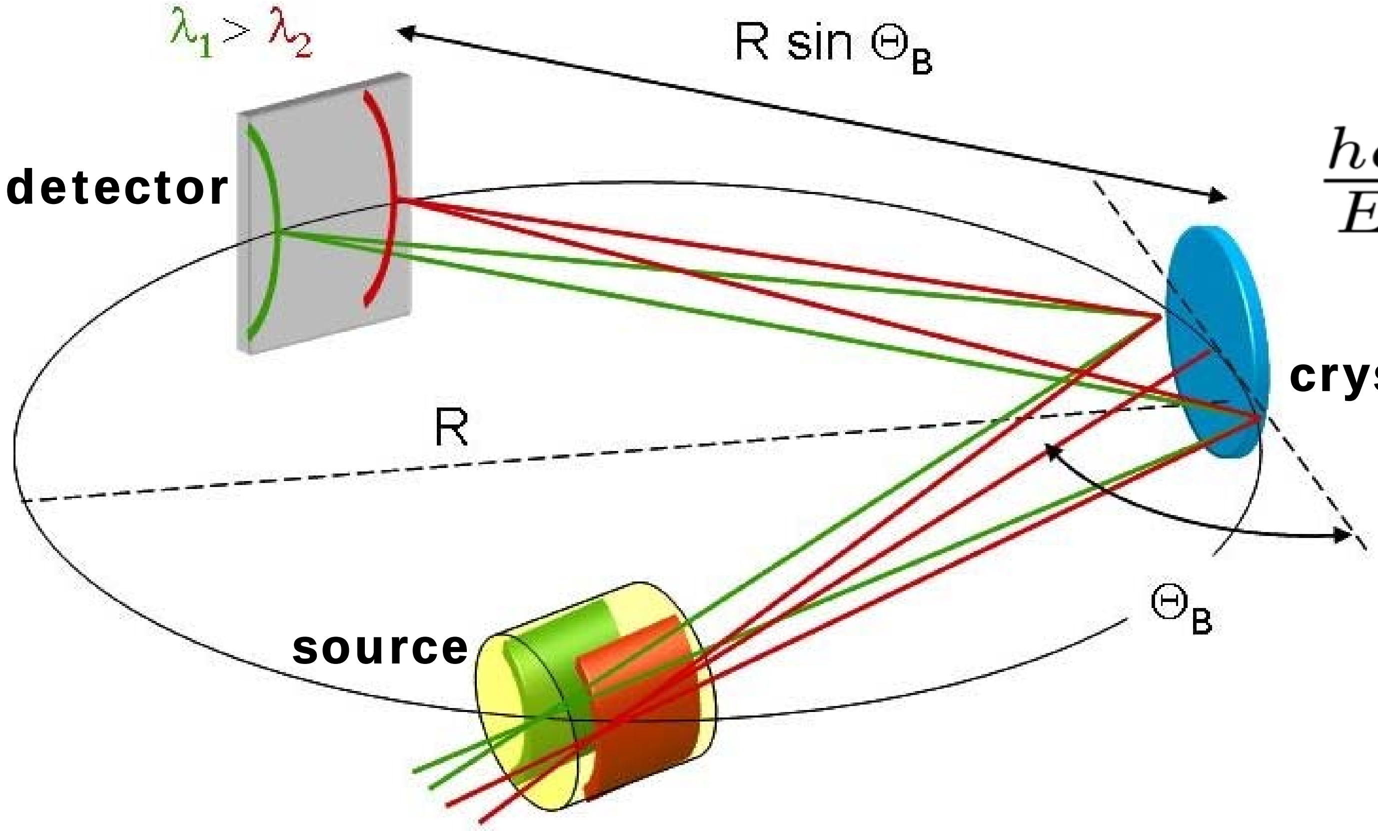
$$\gamma = \frac{1}{\sqrt{1-\beta^2}}$$

E_{proj}: Photon energy in the emitter frame
E_{lab}: energy in the laboratory frame
θ_{Lab}: observation angle
β = v/c

- Ge Crystal (220), Bragg angle of 46°, in 1st order reflection,
- Li-like U transition energy as a reference (calibration)
- Zn K_{α}-lines in 2nd order reflection (external reference)



Bragg Crystal Spectrometer



Bragg´s law:

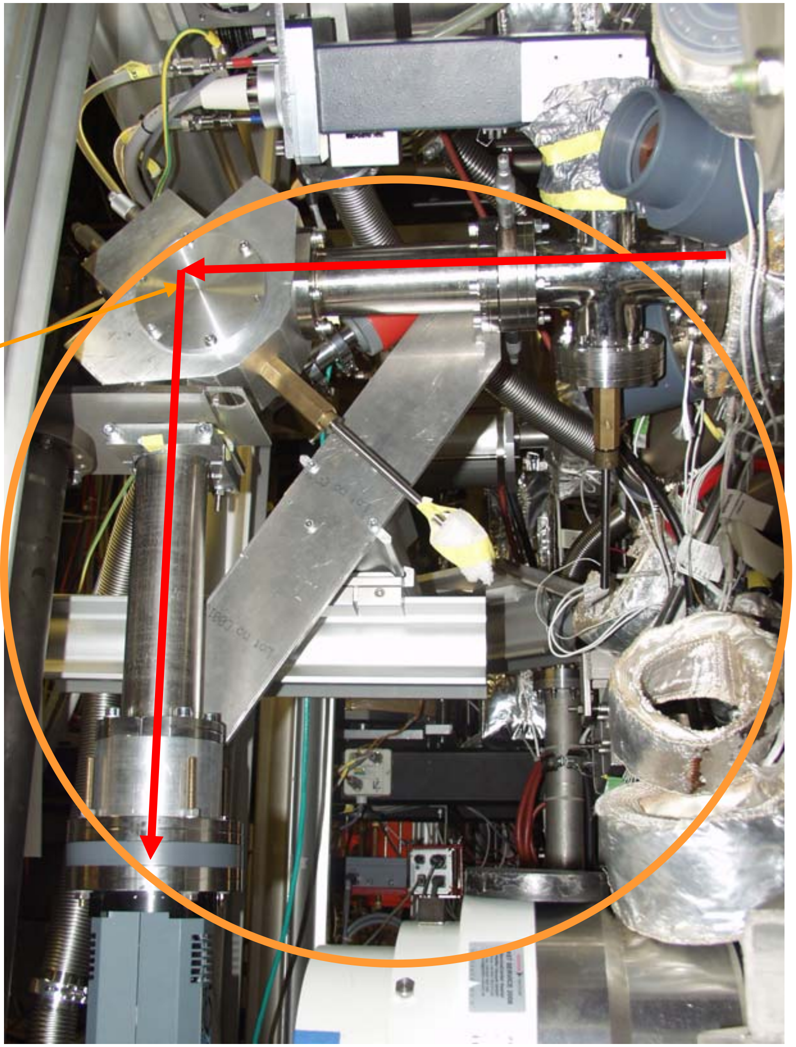
$$\frac{hc}{E} = 2d \sin \theta_B$$

measurement of angles = measurement of energies

Fixed Angle Bragg Crystal Spectrometer

> Johann-type spectrometer:

- Rowland circle diameter: 0.8m
- Cylindrically bent Ge (220) crystal
- energy resolution defined by the crystal intrinsic resolution
- efficiency: ~10^{-6}
- energy range determined by source dimensions and detector size



Fixed Angle Bragg Crystal Spectrometer

Reference Measurement:

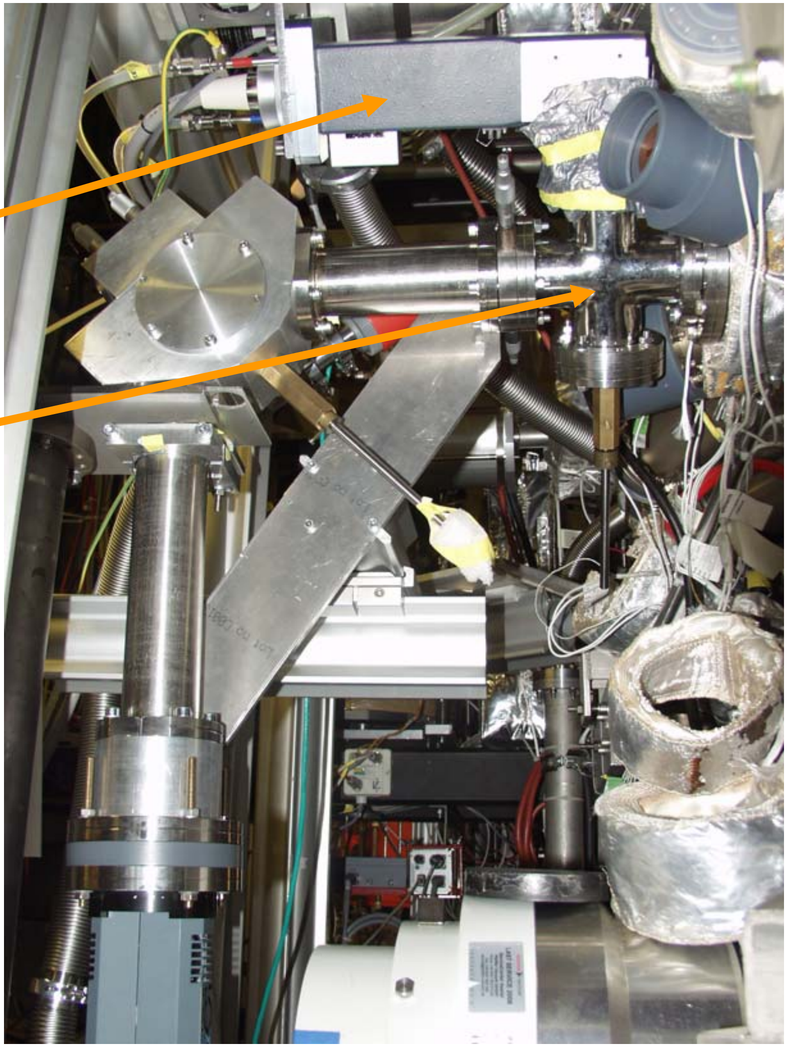
X-ray tube

and

Zinc-target

↓

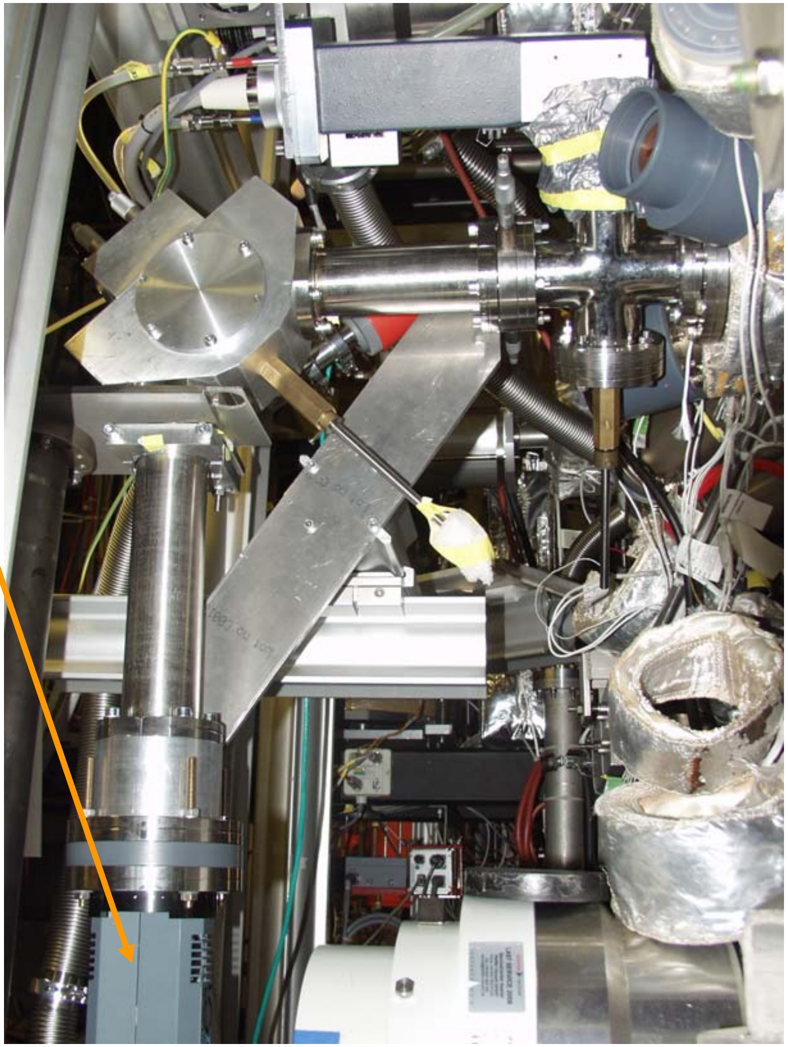
Zinc K_α– doublet



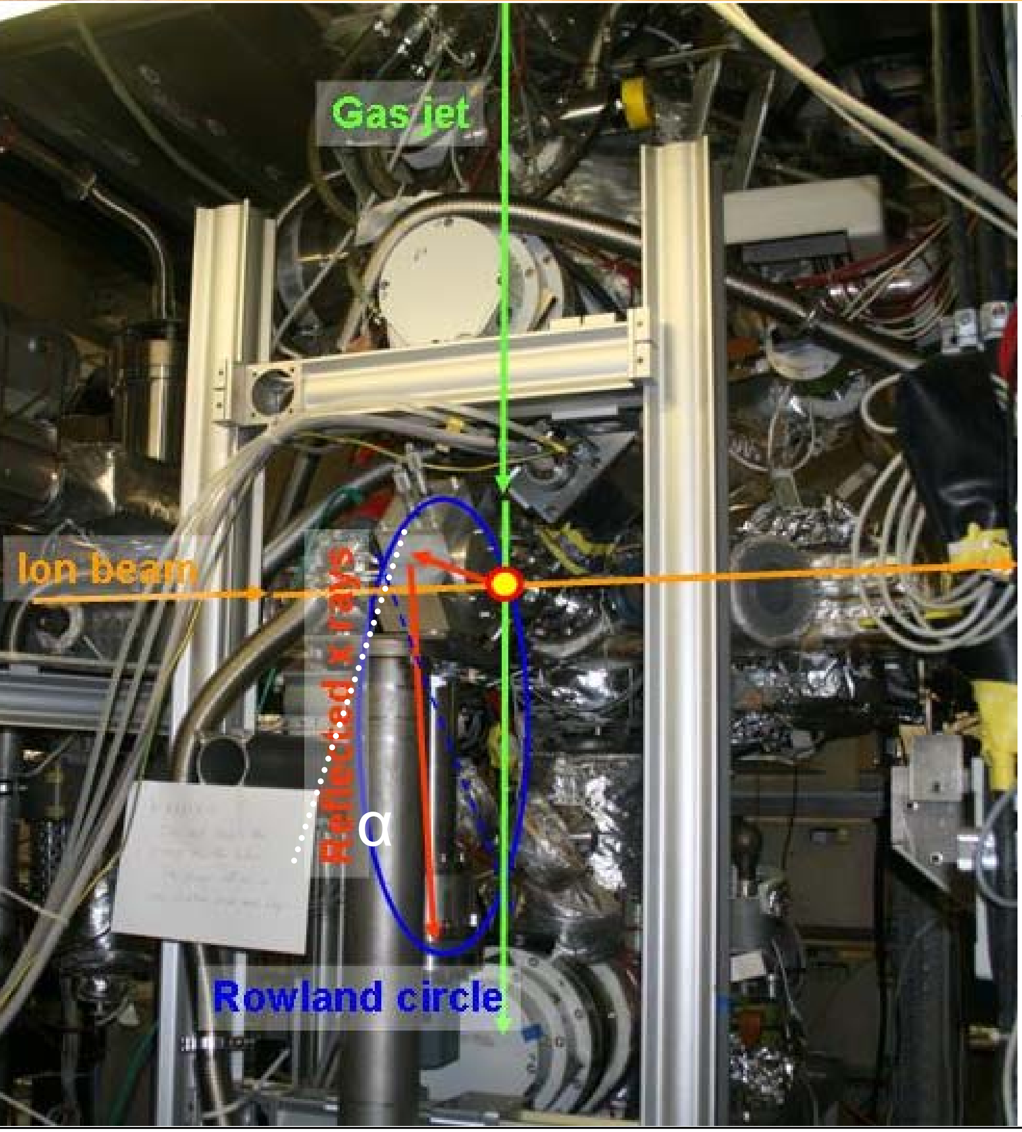
Fixed Angle Bragg Crystal Spectrometer

> position sensitive CCD x-ray detector

- Energy range: 1-10 keV
- Q.E. ~ 90% for 3-4 keV
- 1024 x 256 pixels (each pixel 26 μm^2)
- cluster analysis necessary

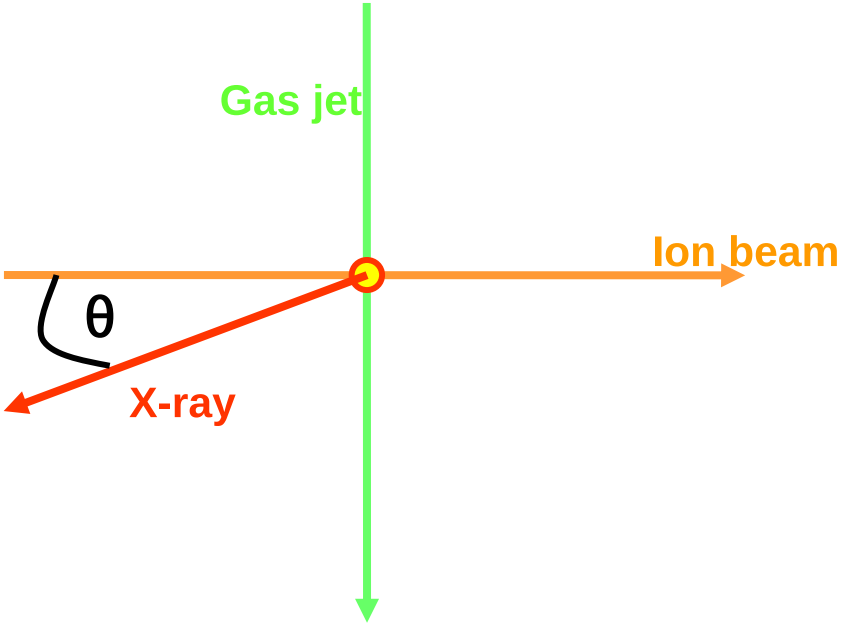


Geometrical uncertainties

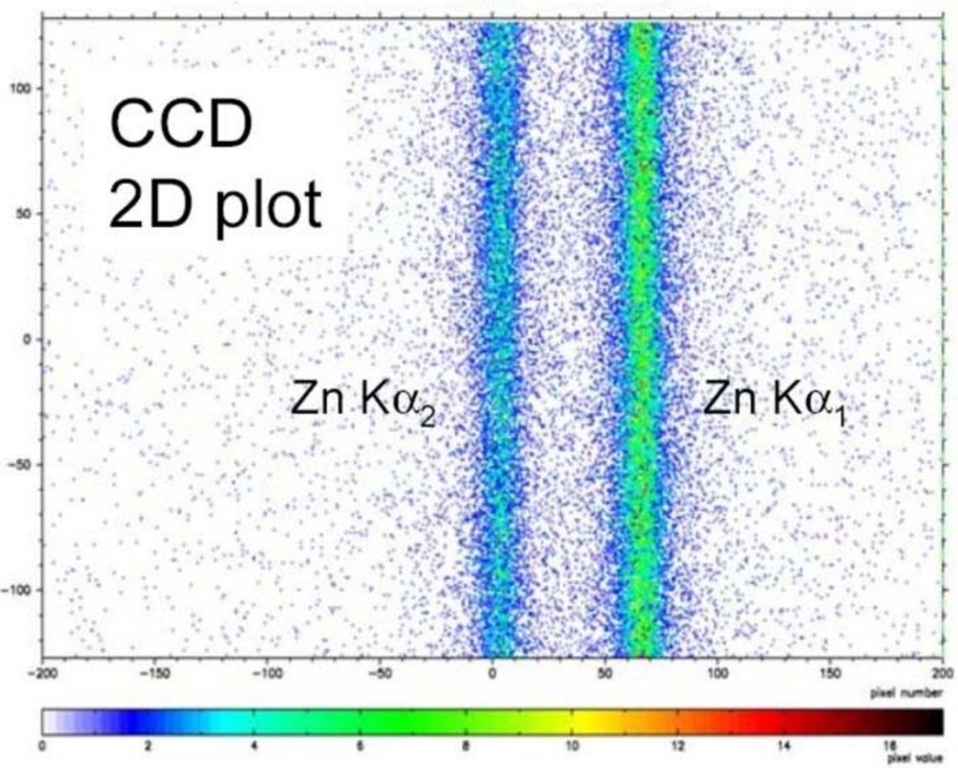


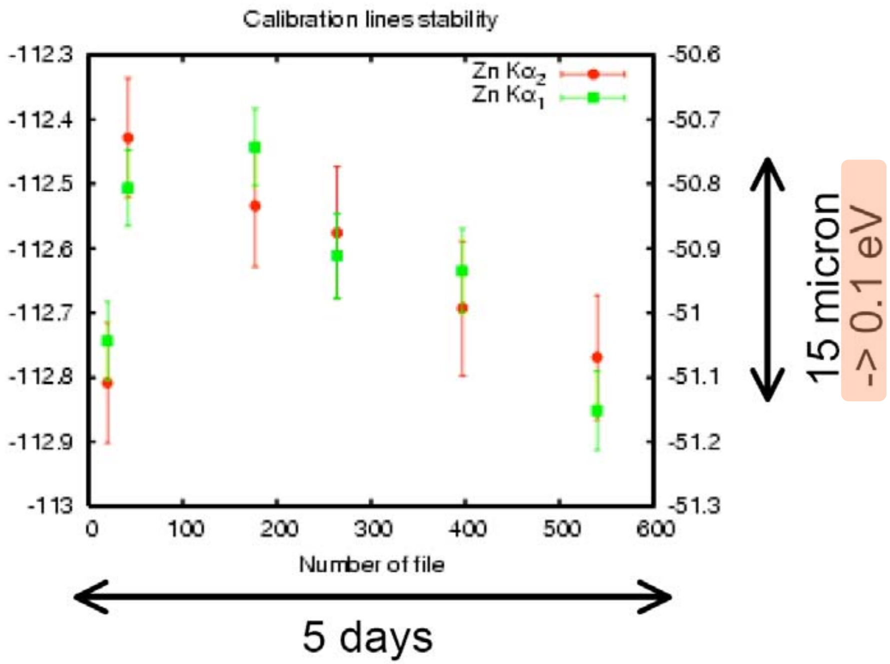
Systematic uncertainty (geometry):

- Observation angle (**θ**): 90 ± 0.05°
- α : 0 ± 1°



Stability test of the spectrometer setup

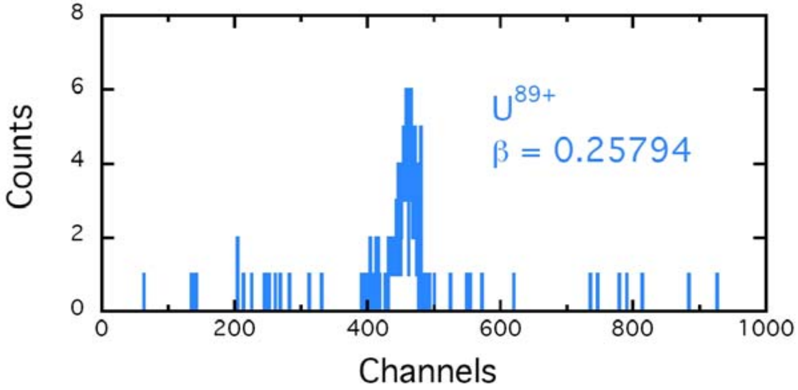




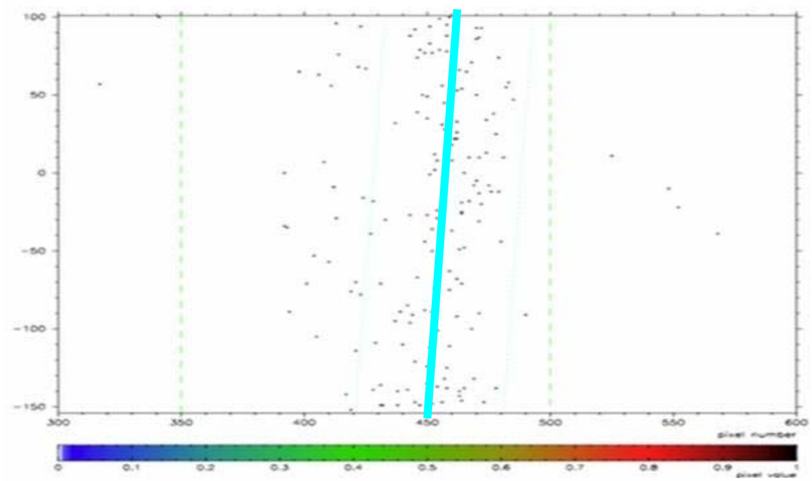
insignificiant variation of the lines

$1s2p\,^3P_2 \rightarrow 1s2s\,^3S_1$ transition in He-like U

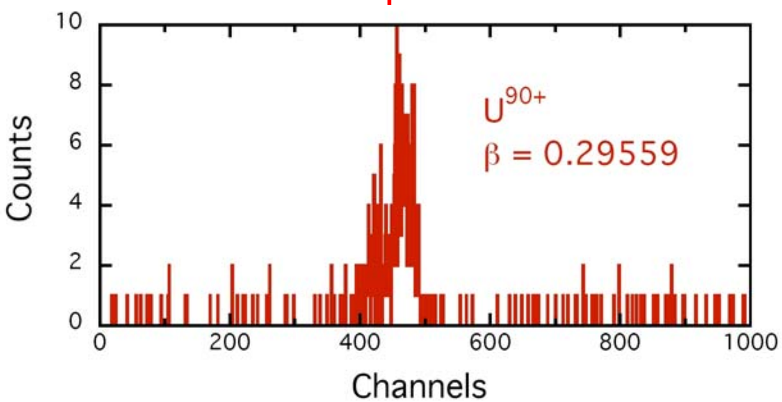
10h acquisition time



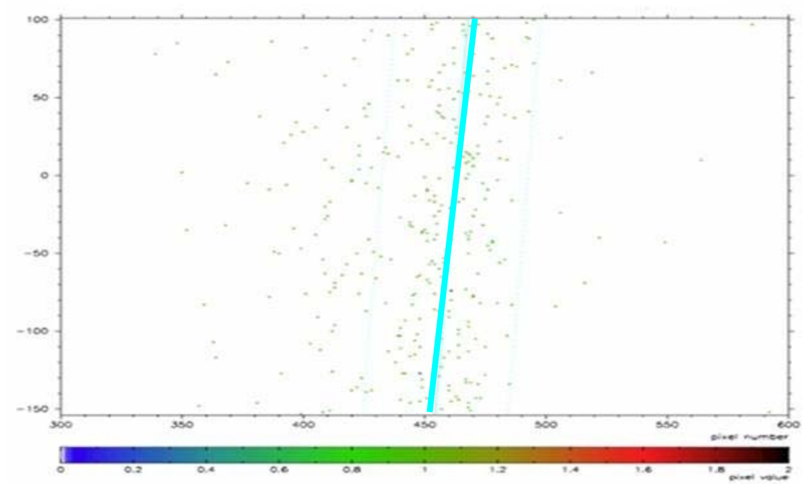
Li



36h acquisition time

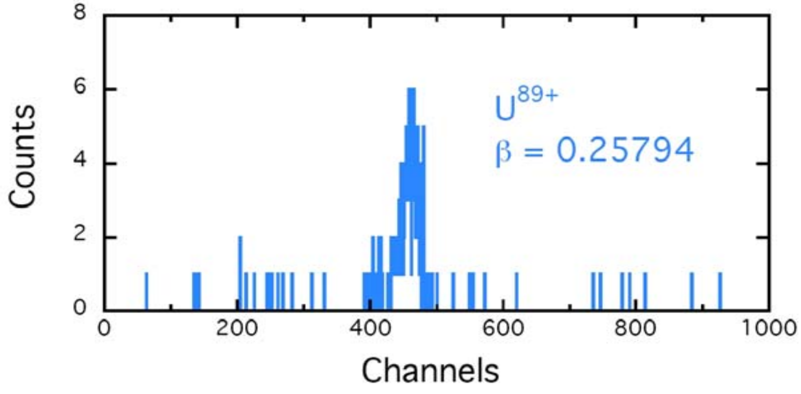


He



$1s2p\,^3P_2 \rightarrow 1s2s\,^3S_1$ transition in He-like U

10h acquisition time



Li

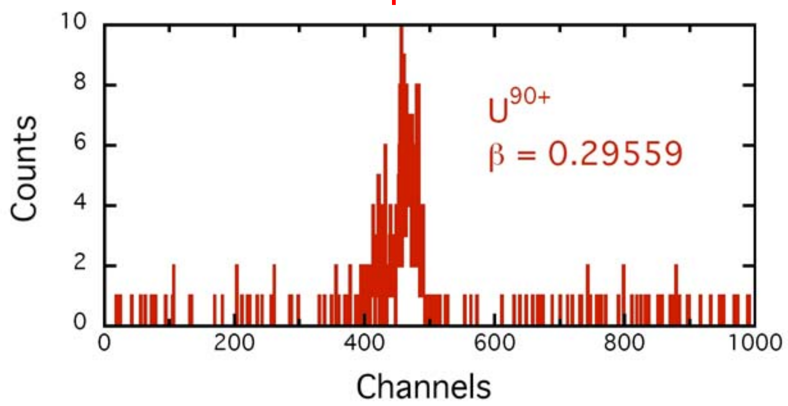
Li-like transition energy
4459.37 ± 0.35 eV

P. Beiersdorfer *et al.*, Phys. Rev. Lett. **71**, 3939 (1993)

$$E_{He} = \left(\frac{\gamma_{He}}{\gamma_{Li}} + \gamma_{He} \frac{\Delta x}{\tan \Theta_B \; D} \right) E_{Li}$$

Δx : relative distance on the CCD
θ_B : Bragg-angle 46˚
D : distance from crystal to CCD

36h acquisition time



He

Very preliminary result

He-like U transition energy:

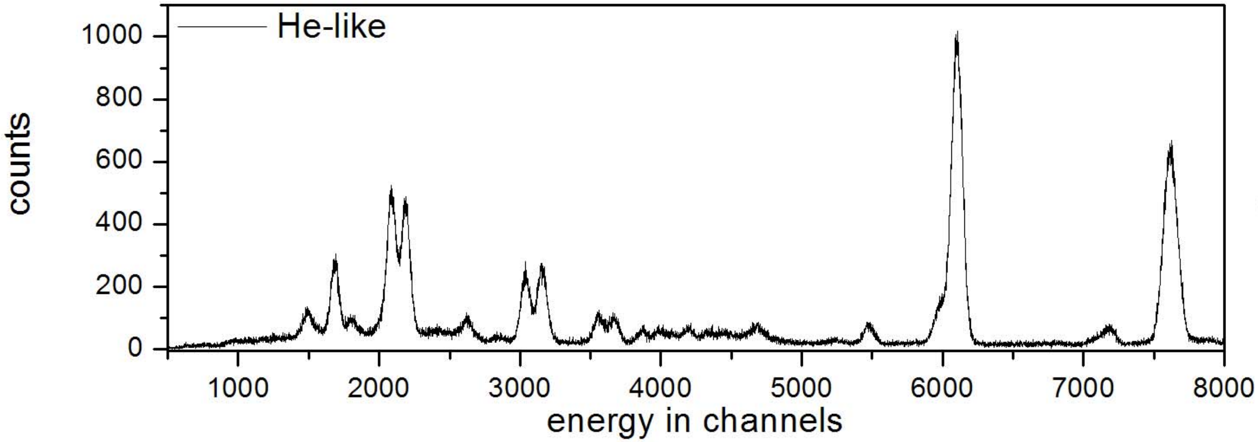
4510.00

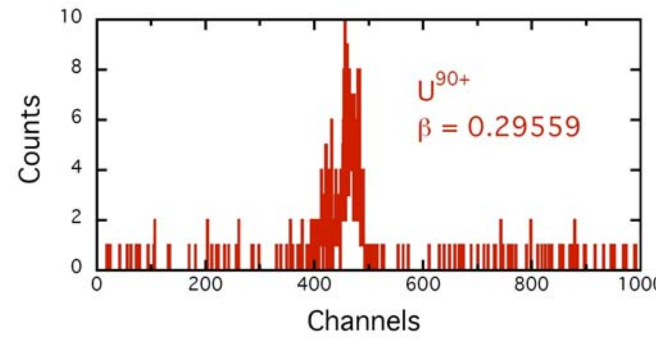
error <1 eV

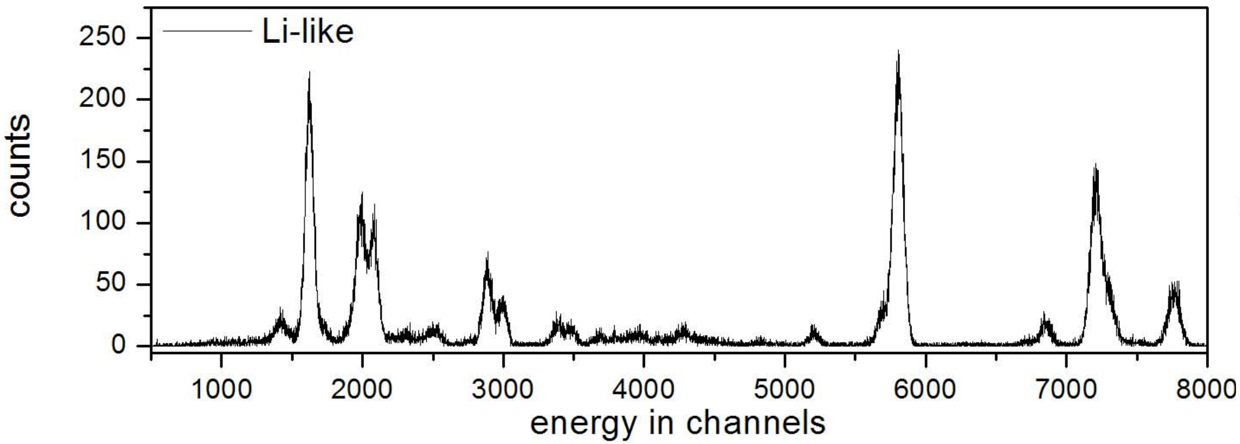
Analysis is still in progress

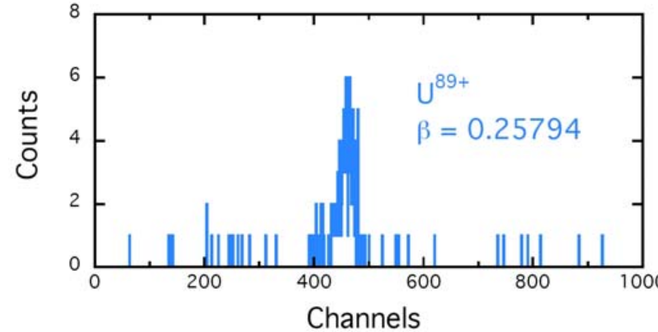
GSI

$1s2p\,^3P_2 \rightarrow 1s2s\,^3S_1$ transition in He-like U



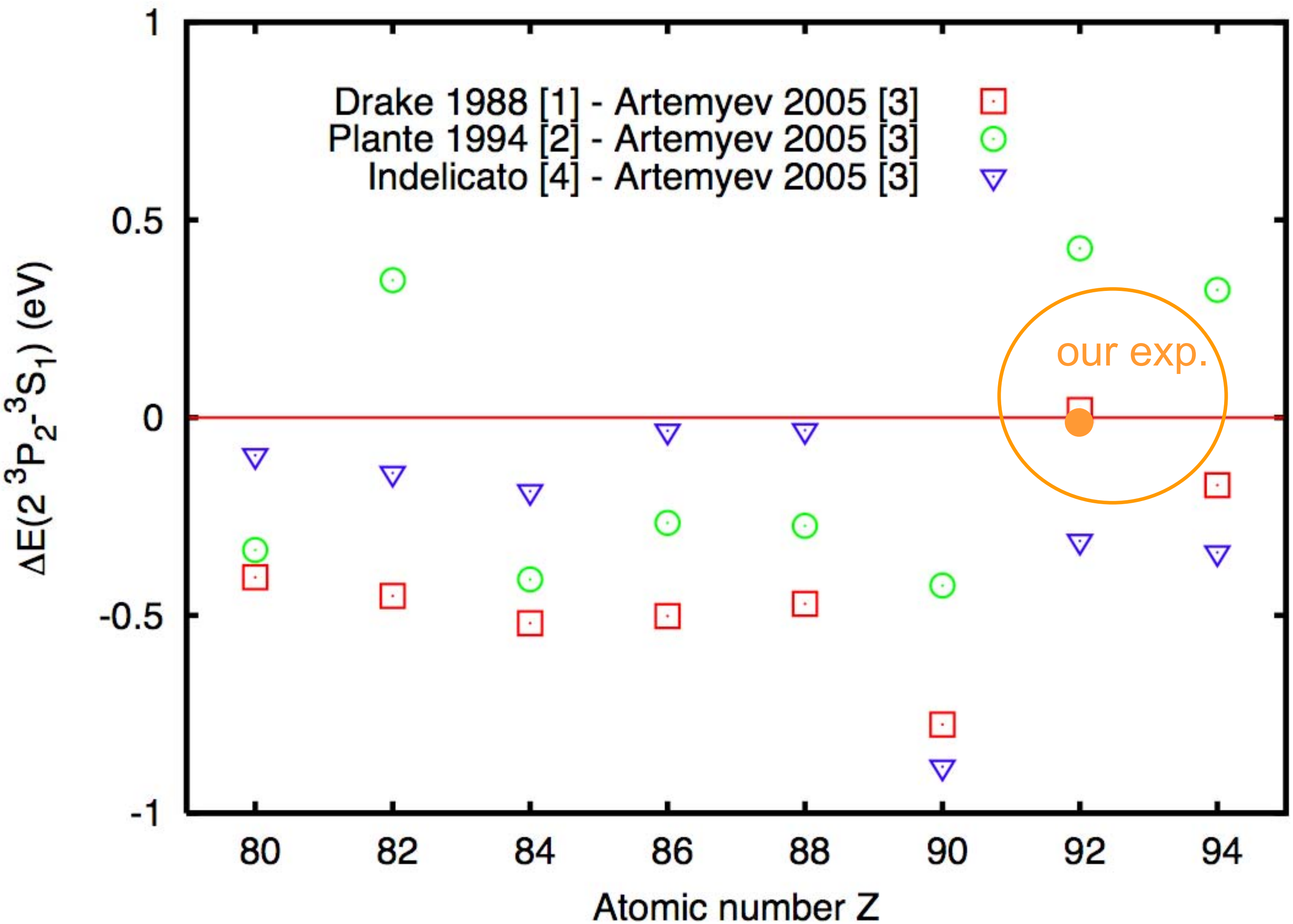




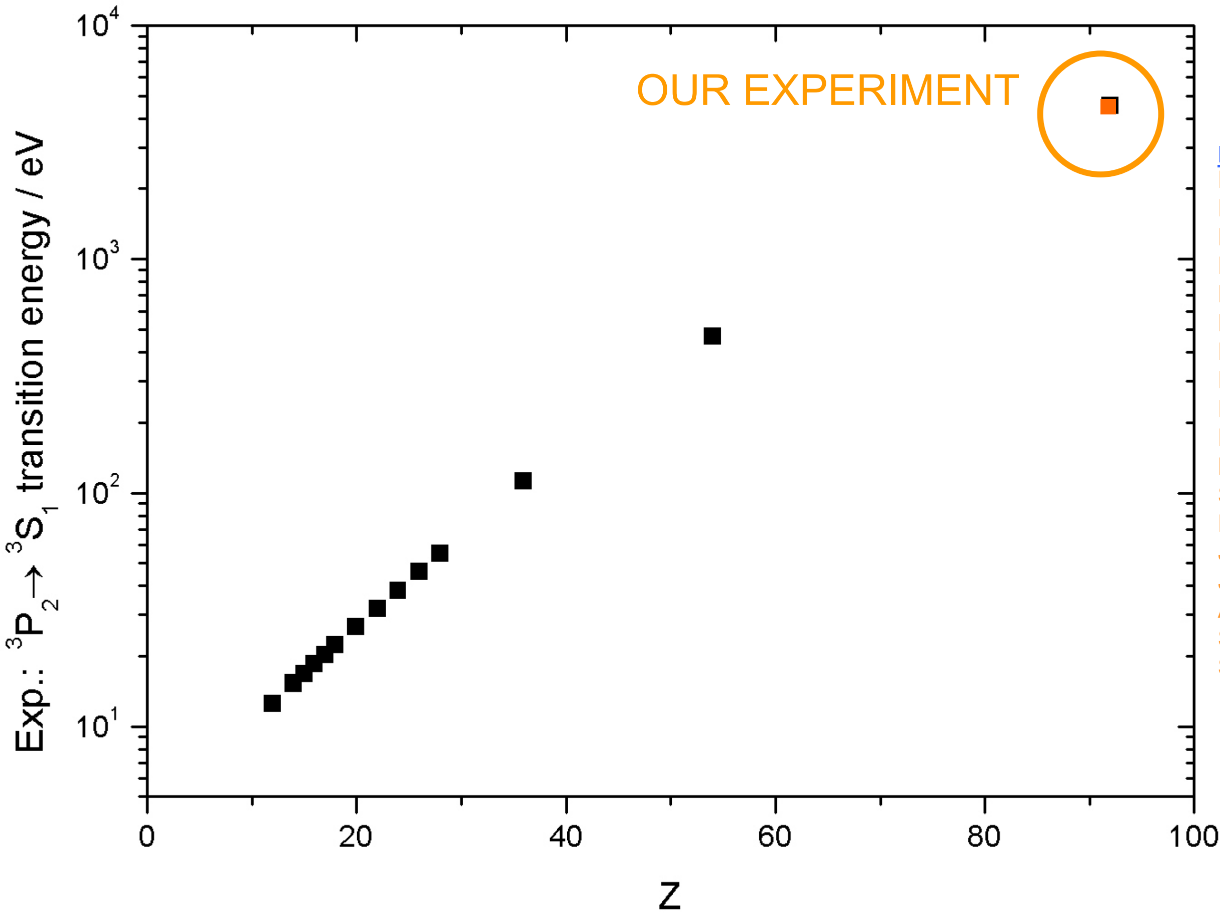


R. Reuschl private communication

Experiment compared to theoretical calculations



Experiment: $1s2p\,^3P_2 \rightarrow 1s2s\,^3S_1$ transition energy



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Conclusion and Outlook

- First high accuracy X-ray spectroscopy measurement of the intra-shell transition $1s2p\,^3P_2 \rightarrow 1s2s\,^3S_1$ in He-like uranium has been successful performed

- expected uncertainty below 1 eV; Analysis is still in progress

- Experiment and theory are of the same order of magnitude

- Proposal for a second beamtime in order to increase the statistics

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