Measurement of the Lamb shift of n=2 excited states in helium-like uranium using crystal spectroscopy methods

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MOTIVATION

Electron - electron correlation and QED correction in strong field

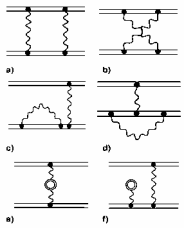
- Relativistic effects ~(Zα) -> electron velocity ~60% of c
- QED effects in electron-electron interaction

Correction for 1s2p $^3P_2$ -> 1s2s $^3S_1$ transition [1]

a,b) Non-Radiative QED
+0.25 eV [U^{90+}]

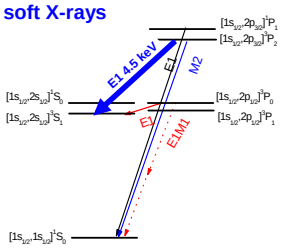
c,d) Two-Electron Self Energy
-0.76 eV [U^{90+}]

e,f) Two-Electro Vacuum Polarization
-0.26 eV [U^{90+}]



High precision measurement of soft X-rays

- Measurement of the n=2 intra-shell transition *1s2p* $^3P_2$ -> *1s2s* $^3S_1$ in He-like uranium
- ΔE = ~ 4.5 keV
- Easy population of the *1s2p* states by electronic capture
- 30% of the *1s2p* $^3P_2$ decays via the M2 transition

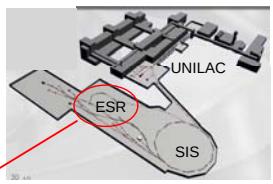


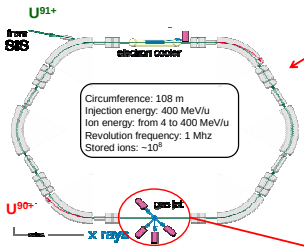
HELIUM-LIKE URANIUM PRODUCTION AND DETECTION

AUGUST 2007 EXPERIMENT

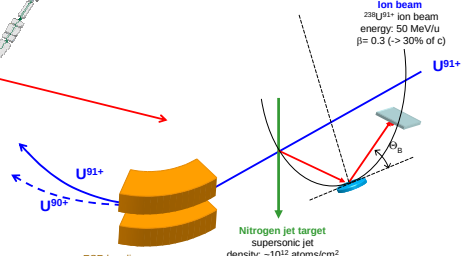
Production of He-like uranium

- Ions stored in the ESR ring
- Decrease of the ion temperature using the electron cooler
- Low temperature crucial for precise energy measurements (relativistic Doppler effect!)

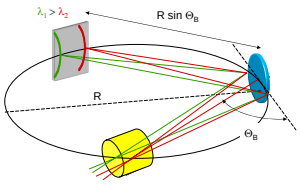




$$E_{Lab} = \frac{E_{Proj}}{\gamma(1-\beta\cos\theta_{Lab})}$$



Crystal spectroscopy at ESR



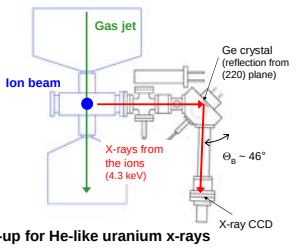
Resolution ~0.4 eV à 2-4 keV

- Bragg reflection: measurement of angles => measurement of energies
- Cylindrically bent crystal in Johann geometry
- High efficiency: ~ 10^{-6}
- Energy range depending on the x-ray source dimension
- Typical resolution <0.5 eV for 4.5 keV x-rays [2]

$$n\frac{hc}{E} = 2d\sin\Theta_{Bragg}$$

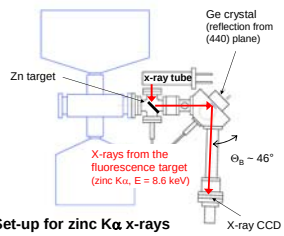
h : Planck constant
c : light velocity
d : crystal planes distance
n : diffraction order

Bragg spectrometer with fixed angle

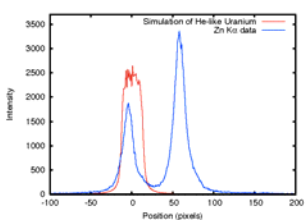


Set-up for He-like uranium x-rays

- Fixed geometry defined by the spectrometer components
- 2nd order diffraction for He-like U x-rays
- 4th order diffraction for the calibration line: Zn Kα
- Relative position measurement -> relative energy measurement



Set-up for zinc Kα x-rays

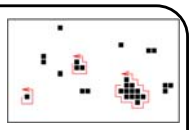


Position of the $Kα_1$ and $Kα_2$ line of zinc (real measurement) and the expected line from intra-shell He-like uranium transition on the CCD detector. Simulation made with MacRay [3-5]

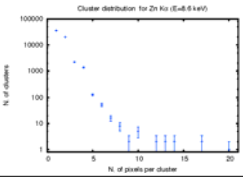
CCD DATA PROCESSING

X-ray CCD camera (Andor DO420)

- Vacuum port
- Back side illuminated
- Energy range = 1-10 keV
- Q.E. ~ 90% at 3-4 keV
- 1024 X 256 pixels
- pixel size = 26 µm X 26 µm

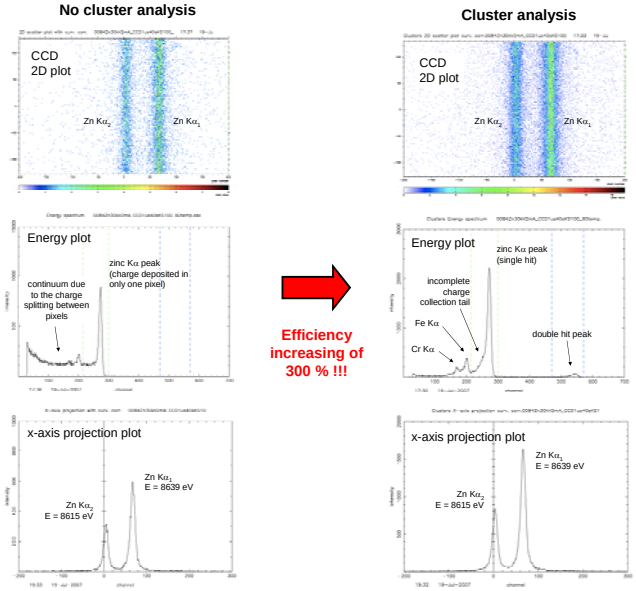


Raw signal from the CCD camera: few keV x-rays (>4-6 keV) absorption produce a charge deposit in several pixels



Cluster analysis required for the correct treatment of the data, particular important for the calibration line at 8.6 keV [5]

Cluster analysis of zinc Kα lines



Resolution of about 2 eV at 8.6 keV

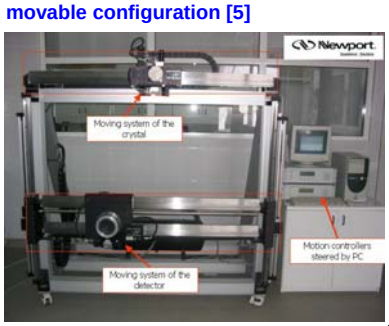
FUTURE: LET'S MOVE!

New crystal spectrometer with movable configuration [5]

Silicon (111) crystal (Zeiss)
Spherically bent
Radius of curvature = 1 m
d-spacing = 0.31 nm
Diameter = 75 mm

Newport Mounting system
2 linear motorized stages (acc.= 1µm)
1 pneumatic linear stage (acc.= 1µm)
2 rotation motorized stages (acc.=0.001º)
1 high precision angular encoder (acc.=0.5")

see also P. Jagodzinski poster !!!



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[3] H.F. Beyer, Nucl. Instrum. Meth. A **400**, 137-148 (1997)
[4] H.F. Beyer *et al.*, Nucl. Instrum. Meth. A **272**, 895-905 (1988)
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[6] F. Zamponi *et al.*, Rev. Sci. Inst. **76**, 116101-3 (2005)

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