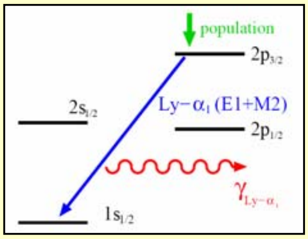
Linear polarization and angular distribution of Ly-α_1 radiation in H-like uranium

G. Weber [a,b], H. Bräuning [a], S. Hess [a,c], U. Spillmann [a], S. Fritzsche [a,d], S. Geyer [a,c], R. Märtin [a,b], R. Reuschl [a,e], A.Surzhykov [a,b], S. Trotsenko [a], D. Winters [a,b], and Th. Stöhlker [a,b]

[a] GSI, Planckstr. 1, 64291 Darmstadt, Germany; [b] University of Heidelberg, Grabengasse 1, 69117 Heidelberg, Germany; [c] University of Frankfurt, Max-von-Laue-Str. 1, 60438 Frankfurt, Germany; [d] Department of Physical Sciences, University of Oulu, Fin-90014 Oulu, Finland; [e] Université Pierre et Marie Curie-UPMC, UMR 7588, INSP, Campus Boucicaut, 140 rue de Lourmel, Paris, 75015 France

Motivation / Experimental Setup

In high-Z ions the Lyman-α_1 line ($2p_{3/2}$ to $1s_{1/2}$) can occur as an E1 or M2 transition.



If the population of the $2p_{3/2}$ magnetic sub-states is non-statistical the Ly-α_1 radiation exhibits an anisotropic emission pattern:

$$W_{2p_{3/2}\rightarrow 1s_{1/2}}(\theta) \approx 1 + \beta_2^{eff} P_2(\cos\theta)$$

The angular distribution of the Ly-α_1 radiation is related to the effective anisotropy parameter β^{eff}_2, see [1] for details.

Using the density matrix theory β^{eff}_2 can be written as a product of two factors [2]:

$$\beta_2^{eff} = \mathcal{A}_2/2 \times f(E1, M2)$$

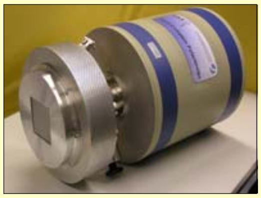
- A_2 depends on the dynamics of the population mechanism, in our case the REC process.
- f(E1,M2) reflects the atomic structure of the ion, namely the E1-M2 mixing.

While it was previously shown that the E1-M2 mixing gives rise to a 28% increase in the anisotropy parameter as compared to the pure E1 transition, calculations predict that the same effect should lead to a significant decrease of the degree of linear polarization of the Ly-α_1 radiation [3,4].

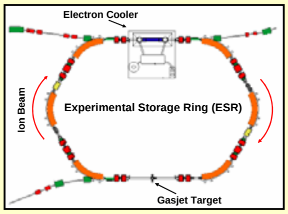
Efficient polarimeters for hard X-rays are now available, allowing for an independent probe of our understanding of the structure of highly charged ions as well as the dynamic processes.

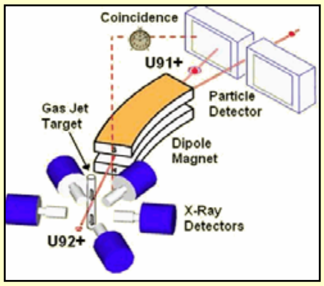
The experiment:

- U^{92+} at 96.6 MeV/u crossing a H_2 gasjet target.
- Standard X-ray detectors at 10°, 35°, 60°, 90°, 120° and 150°.
- Novel-type 2D µ-strip detectors at 35° and 90°.
- Utilizing a coincidence technique to suppress the X-ray background.



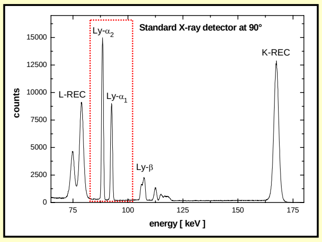
2D µ-strip Si(Li) detector for Compton polarimetry.





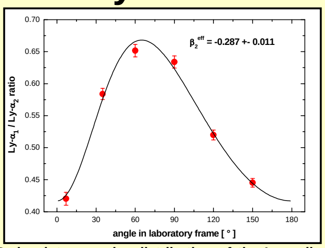
Schematic drawing of the setup used in the present experiment at GSI, Darmstadt.

Preliminary Results



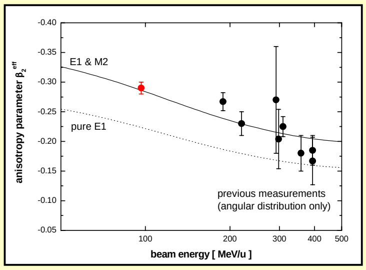
By normalization to the isotropic Ly-α_2 line ...

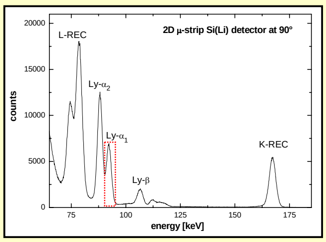
... one obtains angular differential cross sections.



Red points: angular distribution of the Ly-α_1 line; solid line: a least-squares fit to the data with β_2^{eff} as a free parameter.

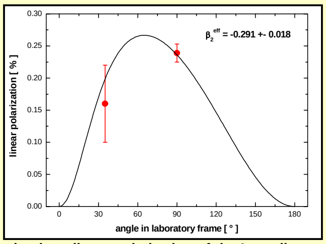
The E1-M2 interference causes a significant shift of the anisotropy parameter β^{eff}_2 (solid line). The dotted line refers to the pure E1 transition (no interference f=1).





Compton Polarimetry:

Analysis of the Compton scattering angular distribution.



Red points: linear polarization of the Ly-α_1 line, every data point lead to an independent determination of β_2^{eff}; solid line: theoretical prediction by A. Surzhykov.

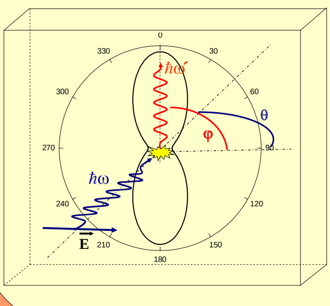
Preliminary Result: At 96.6 MeV/u, the measured Lyman-α_1 anisotropy is consistent with previous results in the high-energy regime.

High accuracy and reliability was achieved by the combination of two independent measurement techniques.

Compton Polarimetry with 2D µ-strip Detectors

Klein-Nishina equation for Compton scattering:

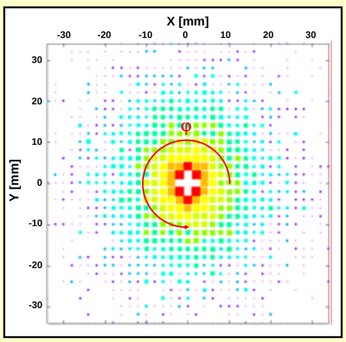
$$\frac{d\sigma}{d\Omega} = \frac{1}{2} r_0^2 \left(\frac{\hbar\omega'}{\hbar\omega}\right)^2 \left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2 \ldots \right)$$



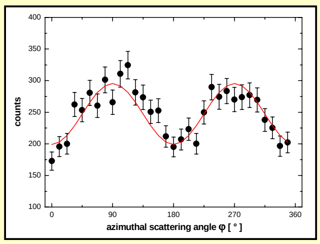
According to the Klein-Nishina equation, emission of the Compton scattered photons perpendicular to the electric field vector of the incident photon is preferred.

Thus, the spatial distribution of the scattered photons allows to determine the degree of linear polarization of the incident photon beam.

In contrast to standard Compton polarimeters consisting of a scatterer and one or more separated detectors for the scattered photons, the 2D detectors applied here act simultaneously as scatterer and scattered photon detector [5].



Position distribution of the Compton scattered photons with respect to the scattering position on the 2D µ-strip X-ray detector at 90°.



Projection on the φ-axis: The red solid line results from a least-squares fit of a modified Klein-Nishina equation to the data with the degree of polarization as a free parameter.

References:

[1] J. Eichler et al., Phys. Rev. A 58, 2128 (1998).
[2] A. Surzhykov et al., Phys. Lett. A 289, 213 (2001).
[3] A. Surzhykov et al., Phys. Rev. Lett. 88, 153001 (2002).
[4] A. Surzhykov et al., Hyperfine Interact. 146-147, 35 (2003).
[5] U. Spillmann et al., Rev. Sci. Instrum. 79, 083101 (2008).