Highly polarized tunable X-ray radiation produced in a storage ring environment by K-REC into Xe^{54+}

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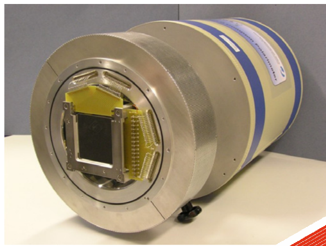
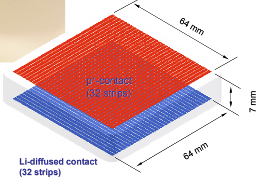
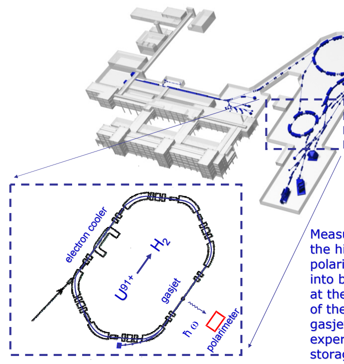
Abstract

Many physical effects like Bremsstrahlung, Synchrotron Radiaton and Radiative Recombination produce polarized X-rays. However for technical purposes only a few facilities like highly specialized Synchrotron light sources are able to deliver tunable high quality beams of almost completely polarized X-ray radiation to the user. In our novel approach, we used Radiative Electron Capture (REC) into the K - shell of bare Xenon to produce tunable and highly polarized X-ray Radiation, even in a storage ring environment. Although former theoretical investigations [1] already showed this potential feature of the REC process, the polarization of X-rays, produced by Capture transitions, could hardly be detected with traditional Polarimeters due to a low efficiency in this energy regime. The recent development of novel 2D semiconductor Compton polarimeters [2,3,4] opens up the low energy regime for efficient polarization measurements for the very first time. In an experiment performed in 2008, we used the internal gasjet target of the ESR to produce the polarized X-ray radiation and a novel 2D Si(Li) type Compton polarimeter to detect the polarization of the radiation.



position sensitive 2D Si(Li) detector
active area: 64 x 64 mm
thickness: 7 mm
number of strips: 32 + 32
pitch: 2mm
corresponding to 1024 pixels





Measurement of the higly polarized K-REC into bare Xenon at the 90° port of the internal gasjet at the experimental storage ring

Highly polarized tunable monoenergetic X-rays produced by REC into Xe^{54+}

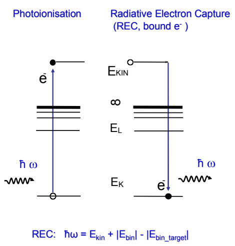
The experiment has been performed using the internal gas jet of the ESR at GSI. The polarimeter has been positioned at 90° with respect to the ion beam. Molecular hydrogen has been chosen as a target for several advantages, such as a very narrow Compton-profile and therefore small REC linewidths.

A modified Klein – Nishina formula for Compton scattering of arbitrarily polarized light can be used to determine the direction and the degree of the polarization of the emitted radiation:

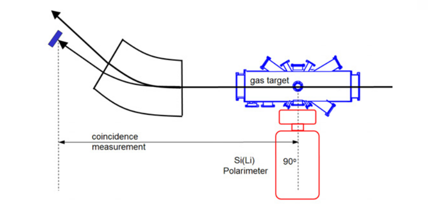
$$\frac{d\sigma}{d\Omega} = \frac{r_e^2}{2}\left(\frac{\hbar\omega'}{\hbar\omega}\right)^2\left(\frac{\hbar\omega'}{\hbar\omega} + \frac{\hbar\omega}{\hbar\omega'} - 2\sin^2\vartheta\cos^2\varphi\right) \qquad (1)$$

Here, the scattered photons are plotted relative to the location of the Compton interaction. For this analysis the scattering angle has been chosen to lie in the range of 90° ± 10° by using the relation:

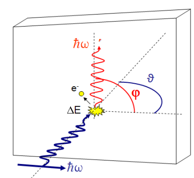
$$\Delta E = \hbar\omega\frac{\frac{\hbar\omega}{mc^2}(1-\cos(\vartheta))}{1+\frac{\hbar\omega}{mc^2}(1-\cos(\vartheta))} \qquad (2)$$



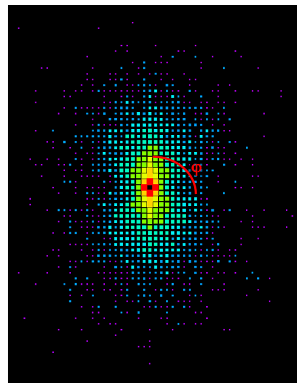
Scheme of the REC process



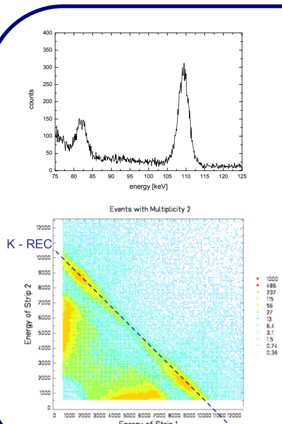
Experimental Setup. The K-REC photons are detected with a 2D Si(Li) Polarimeter in coincidence with the downcharged Xenon ions at a particle detector behind the first dipole magnet



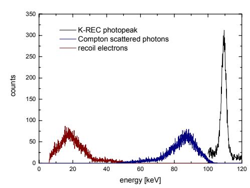
The polarization of the photons has been detected by compton scattering within the detector plane.

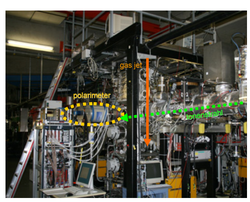


Compton image of K-REC into bare Xenon for a scattering angle of ϑ = 90° ± 10°

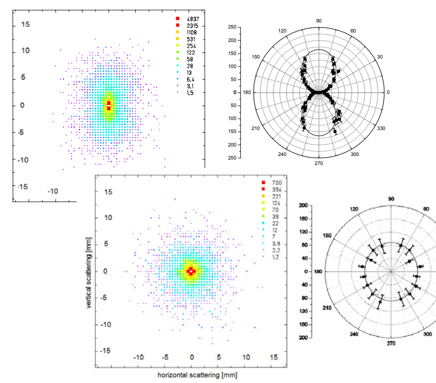


The upper left figure shows an energy spectrum of one of the front-side strips. The investigated K-REC photons have an energy of 109 keV in the laboratory frame, while the L-REC is at 84 keV. The lower left figure shows a correlation plot, where exactly two events in different strips on the same side of the detector were required (multiplicity of 2). The energies of the two strips are plotted versus each other. The energy splitting between the Compton scattered electrons and Compton photons is reflected in the diagonal lines. The plot in the upper right corner shows the energy distributions of the recoil electrons and the scattered photons. The spatial distribution of the scattered photons for K-REC into Xenon and a comparison to the unpolarized $K\alpha_2$ transition after capture into hydrogenlike Uranium are shown in the plots on the right hand side. Here, the scattered photons are plotted relative to the location of the Compton interaction. Events within a radius of 6 to 8 mm around the central pixel are plotted in the figures on the far right. A strong correlation with the Klein - Nishina formula for polarized light can be stated for the K-REC.





experimental setup



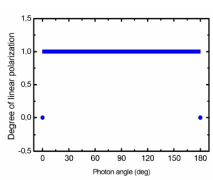
Comparison of the Compton - images and Klein-Nishina fits of the highly polarized Xe^{54+} K-REC transition radiaton with an earlier measurement of unpolarized $K\alpha_2$ radiation after capture into hydrogenlike Uranium

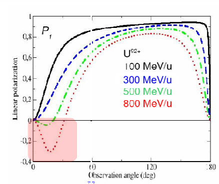
Comparison to the theory

Classically, radiative electron capture is the time-reversed process of photoionisation. Therefore photons are emitted in the capture-plane and are 100% polarized (see figure on the upper right). A consideration of higher multipoles and a relativistic approach lead to a decreased degree of polarization, especially under small emission angles with respect to the ion beam.

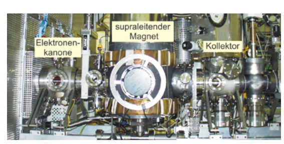
$$M = \int \Psi^*_{n_b j_b \mu_b}(\boldsymbol{r})\ \boldsymbol{\alpha} \underbrace{u_\lambda e^{-i\boldsymbol{kr}}}_{E1+M1+E2+...} \Psi_{pm_s}(\boldsymbol{r})\ d\boldsymbol{r} \qquad (3)$$

On the right hand, this effect is shown for K-REC into bare uranium. In case of the K-REC into bare Xenon and an observation angle of 90° with respect to the the ion beam, the preliminary data analysis shows a polarization of the radiation close to 98%.

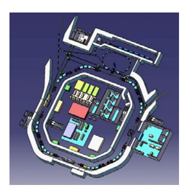




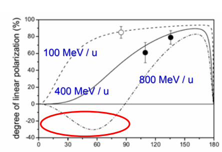
Outlook



Comparison measurements of xenon in the ESR and in the HD EBIT



Spin-polarized ion beams at FAIR
http://www.gsi.de/sparc/



Measurement of the theoretically predicted cross-over at higher beam energies

References:

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