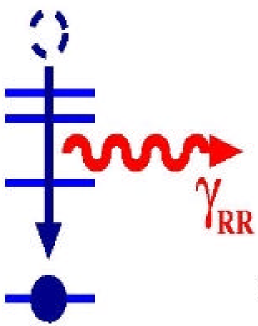
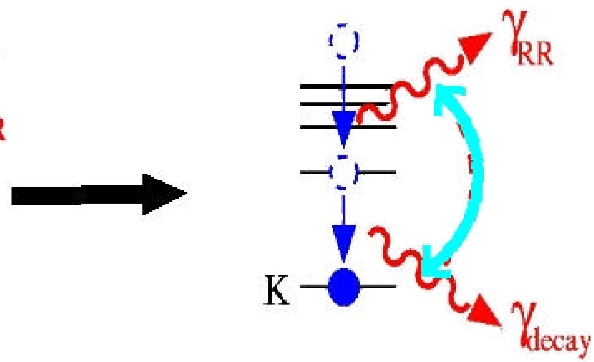
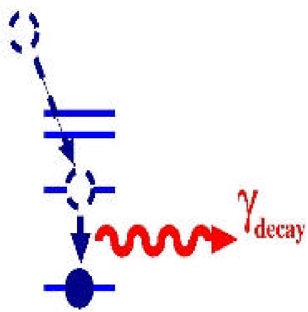
Polarization and correlation studies on the electron capture into highly-charged ions

S. Fritzsche and A. Surzhykov, Universität Kassel



So far, first and second step photons have been observed separately.





Polarization of the ions in the storage ring

Theoretical and experimental polarization and correlation studies:

- Polarization measurements (T. Stöhlker: first experiments in 2001)
- Angle-angle correlations

Aim: Characterization of the ions beams ?

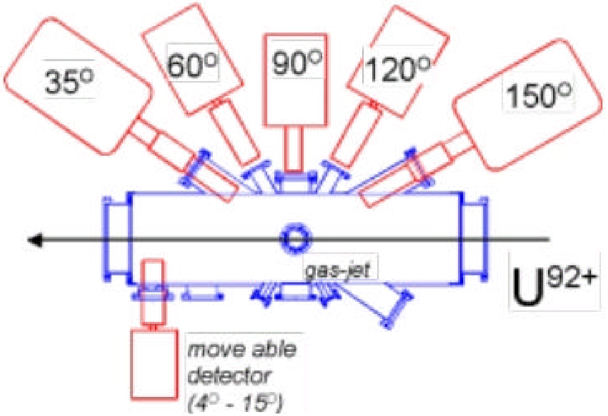
- supression of cascade effects

Outline of this talk

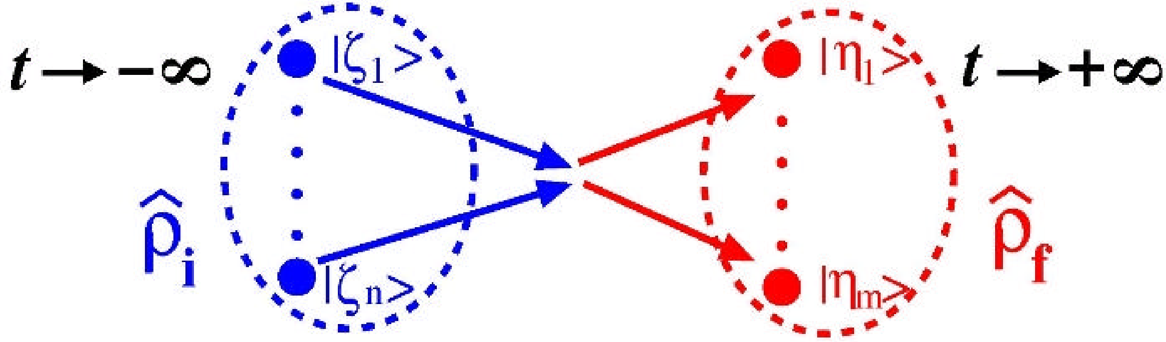
Polarization of the RR photon

Alignment studies

Photon-photon coincidences



Density matrix theory: Time-independent description



$$\hat{\rho}_f = \hat{S}\,\hat{\rho}_i\,\hat{S}^+$$

$\hat{S}$ - scattering operator

Measurement of physical properties:

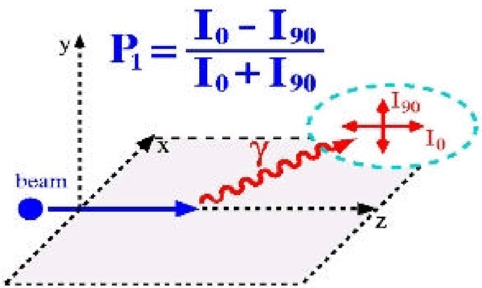
- 'detector operator' describes the experimental setup: $\hat{P} = |\epsilon><\epsilon|$
- probability to get a 'click' at the detectors:

$$W = Tr(\hat{P}\,\hat{\rho}_f) = \sum_{\eta_1 \ldots \eta_m} \langle \eta_1 \ldots \eta_m | \hat{P}\,\hat{\rho}_f | \eta_1 \ldots \eta_m \rangle$$

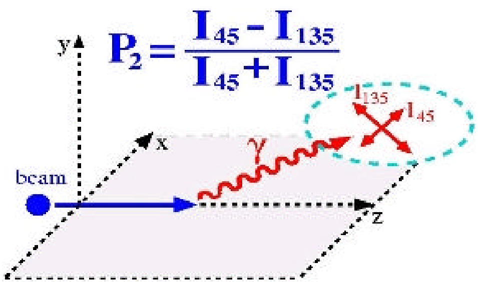
Linear polarization of the radiative recombination (RR) photons

Stokes parameters

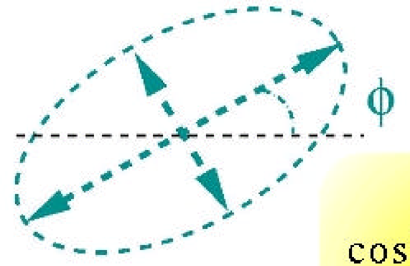
$$P_1 = \frac{I_0 - I_{90}}{I_0 + I_{90}}$$



$$P_2 = \frac{I_{45} - I_{135}}{I_{45} + I_{135}}$$

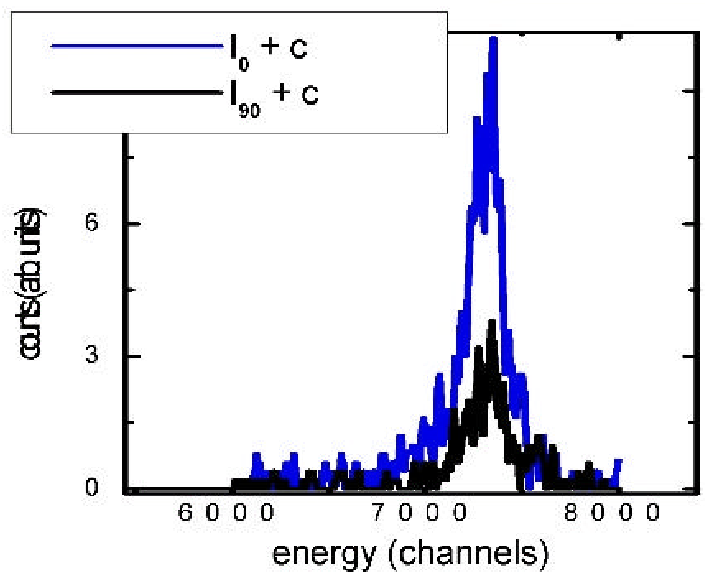


Polarization ellipse



$$\cos(2\varphi) = \frac{P_1}{P_L}$$

$$P_L = \sqrt{P_1^2 + P_2^2}$$

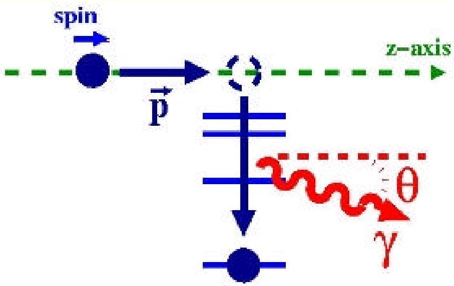


Experiment: GSI, May 2002
(Th. Stöhlker)

So far, only parameter P_1 was measured

Linear polarization of the radiative recombination (RR) photons

-- a route to measure the polarization of ion beams

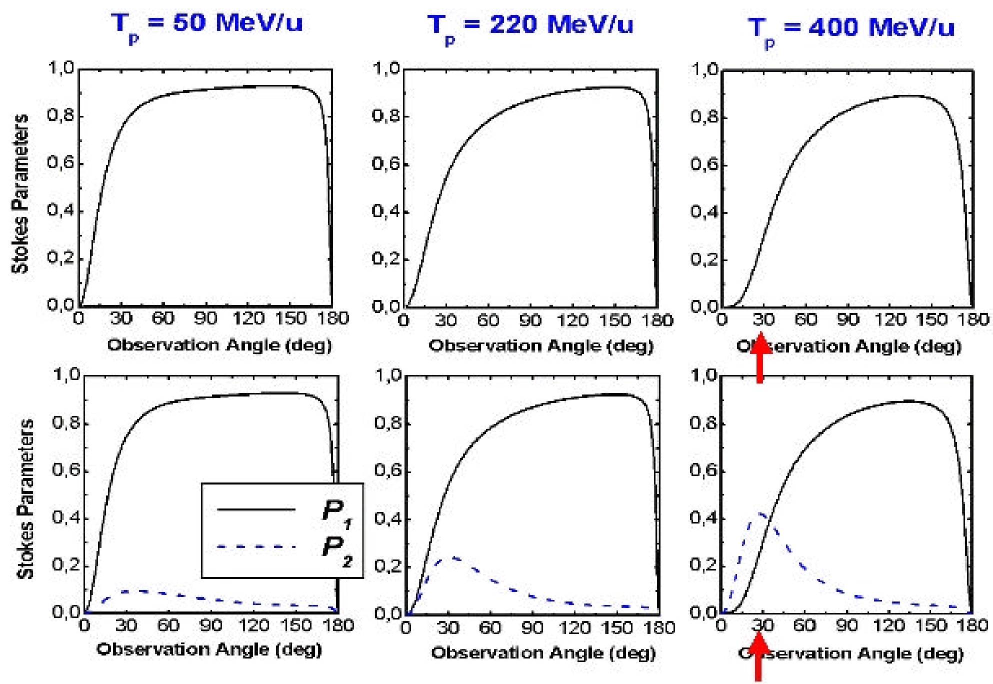


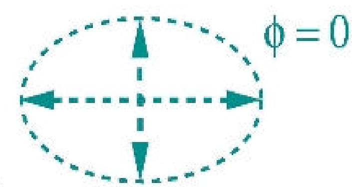
$$\cos(2\varphi) = \frac{P_1}{P_L}$$

$$P_L = \sqrt{P_1^2 + P_2^2}$$

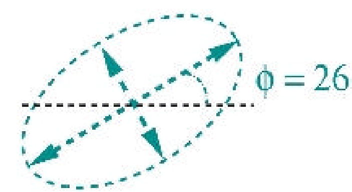
unpolarized electron

polarized electron





$\theta_{RR} = 30$ deg



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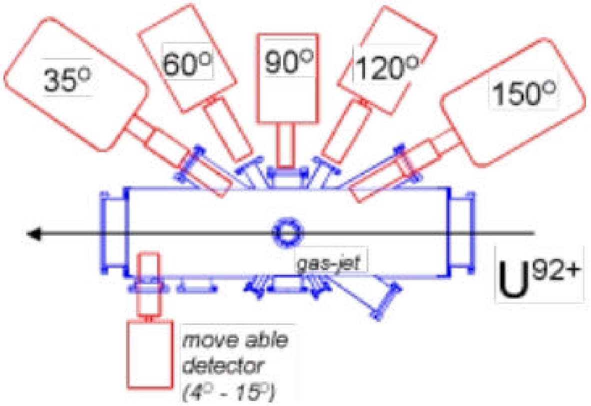
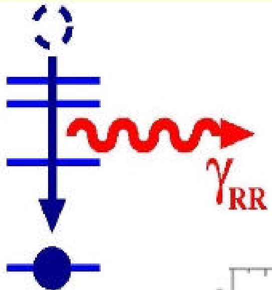
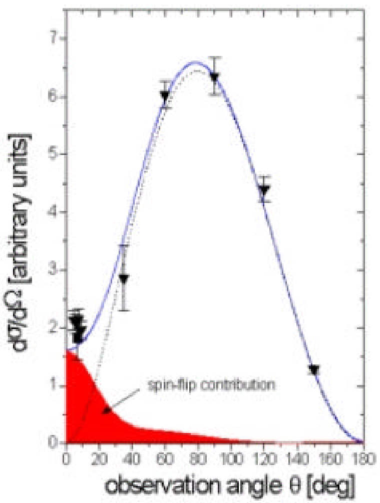


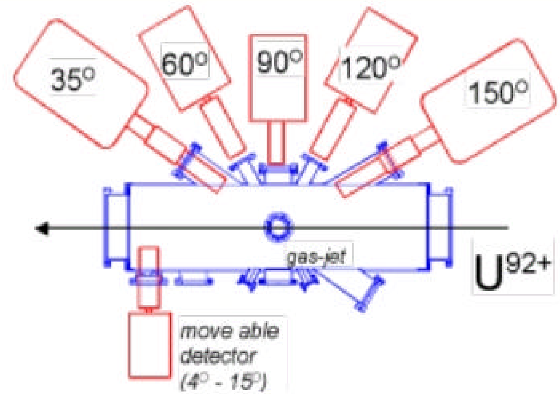
Electron capture into highly-charged ions

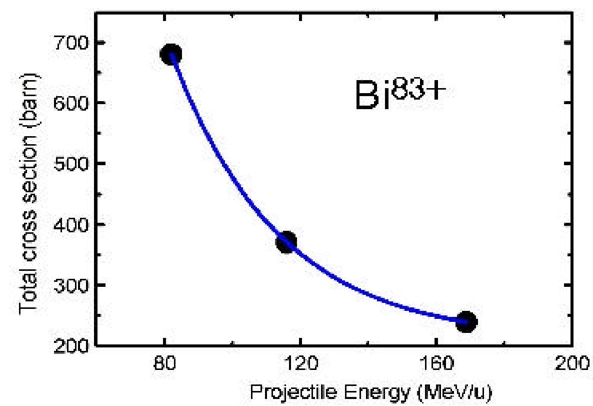


U^{92+} $T_p = 310$ MeV/u



$$W(\theta_{RR}) \propto \left|\langle j_b \mu_b | \alpha u_\lambda e^{-ikr} | p\, m_s \rangle\right|^2$$

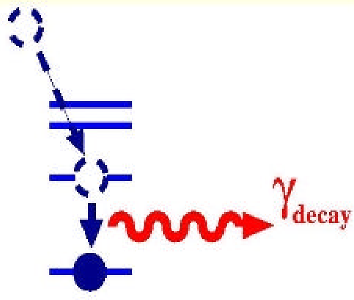




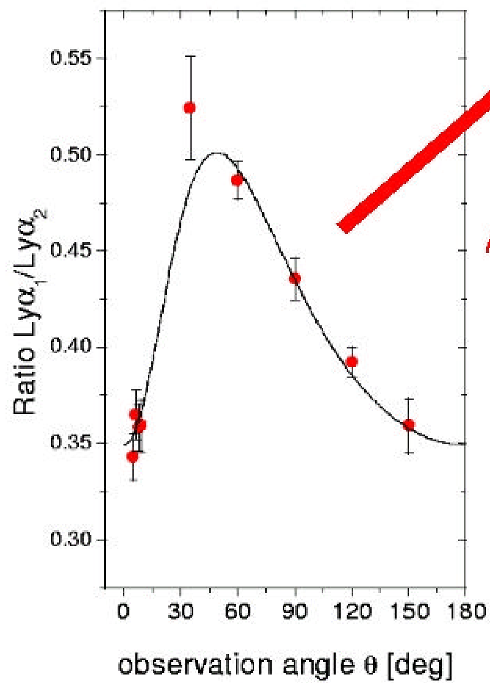
$$\sigma \propto \int d\Omega \; \left|\langle j_b \mu_b | \alpha u_\lambda e^{-ikr} | p\, m_s \rangle\right|^2$$

Theory: Relativistic formulation(Pratt *et al* 1973, Eichler *et al* 1994)

Electron capture into highly-charged ions
.... and their subsequent photon decay

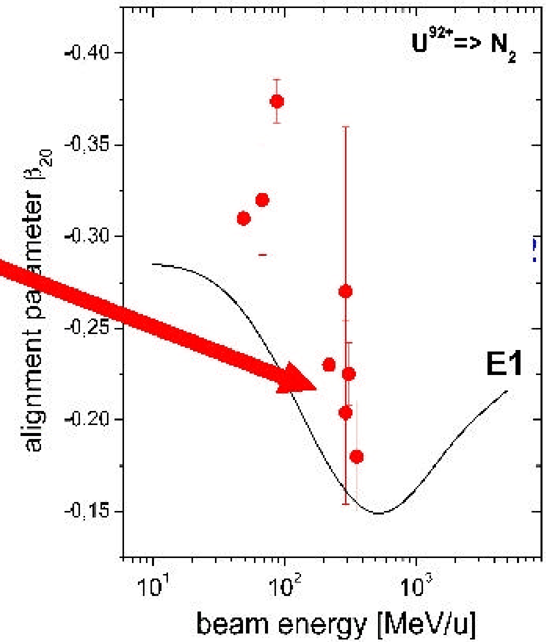


$$w(\theta_{Ly}) \propto 1 + \beta P_2(\cos\theta)$$



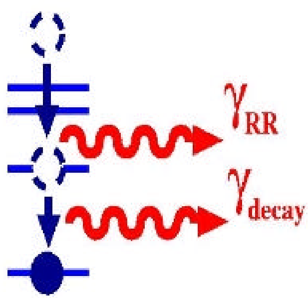
Anisotropy parameter

U^{92+} $T_p = 310$ MeV/u

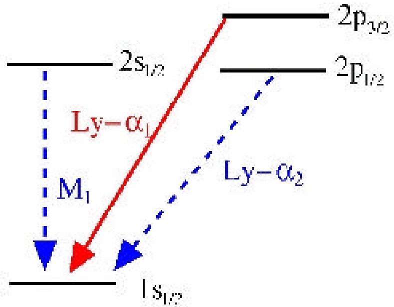


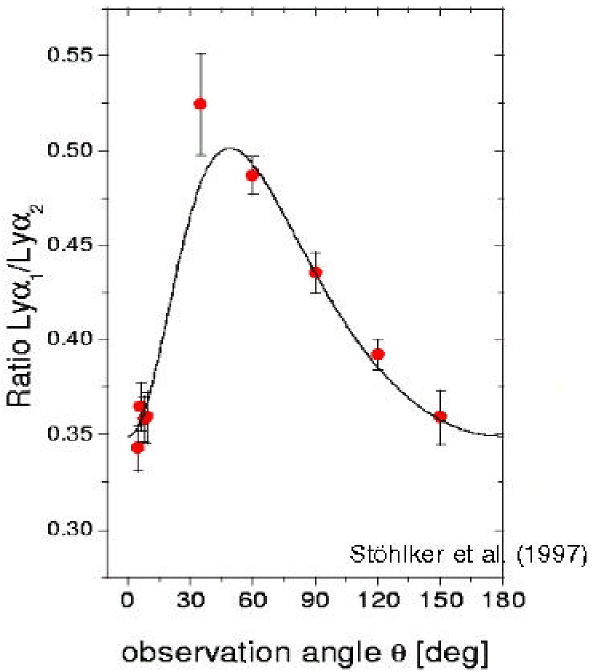
Stöhlker et al. (1997)

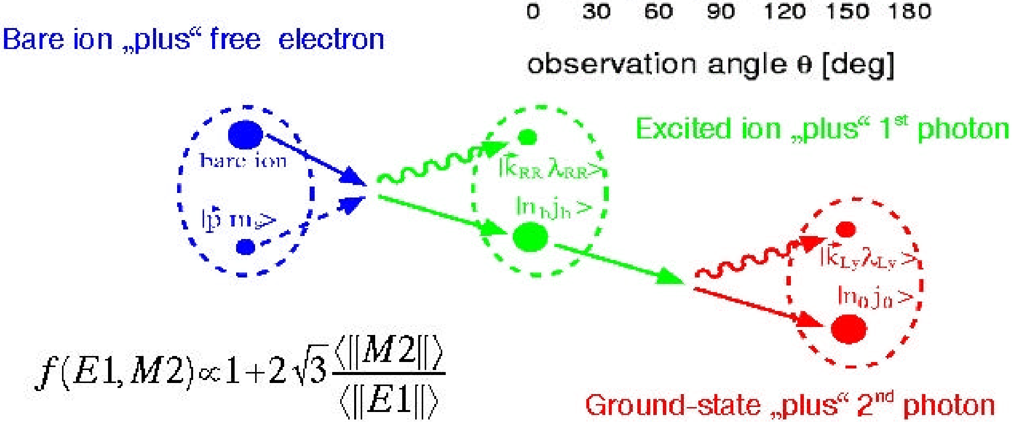
Formation and decay of excited ion states



$$W_{Ly-\alpha_1}(\theta) \propto 1 + \underbrace{\frac{A_2}{2} f(E1, M2)}_{\beta_2^{eff}} P_2(\cos\theta)$$







decays via E1 or M2 multipole transitions

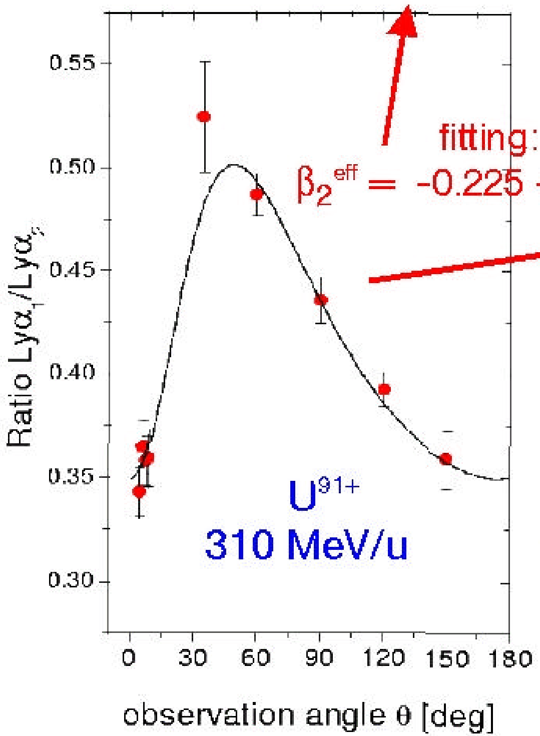
- Lifetime ratio: M2 / E1 ~ 1 %
- $\langle \| M2 \| \rangle / \langle \| E1 \| \rangle \sim 0.1$

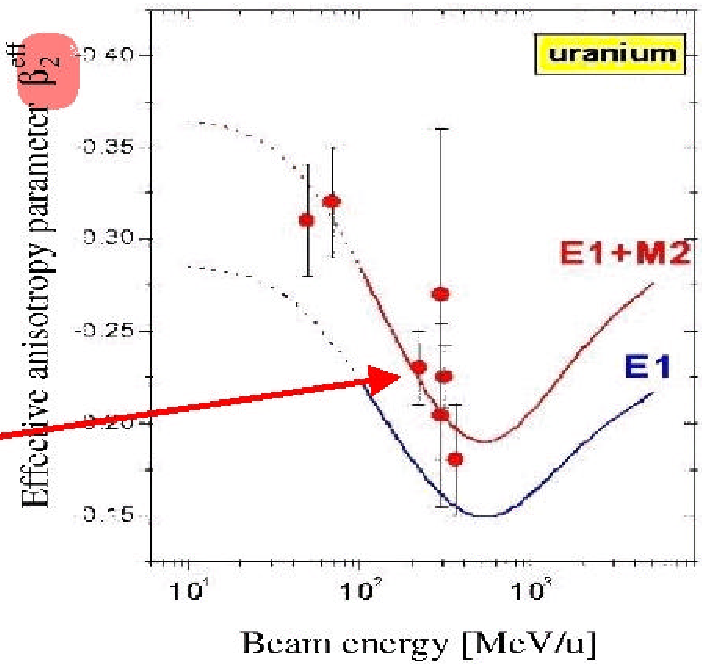
$$f(E1, M2) \propto 1 + 2\sqrt{3}\frac{\langle \| M2 \| \rangle}{\langle \| E1 \| \rangle}$$

A. Surzhykov *et al*, PRL 88 (2002)

Alignment of the $2p_{3/2}$ state following electron capture

$$W_{Ly-\alpha_1}(\theta) \propto 1 + \underbrace{\frac{A_2}{2} f(E1, M2)}_{\beta_2^{eff}} P_2(\cos\theta)$$





Theoretical predictions:

- dipole approximation:

  $\beta_2^{eff} = A_2 / 2$

- both, E1 and M2 transitions:

  $\beta_2^{eff} = f(E1, m) * A_2 /2$

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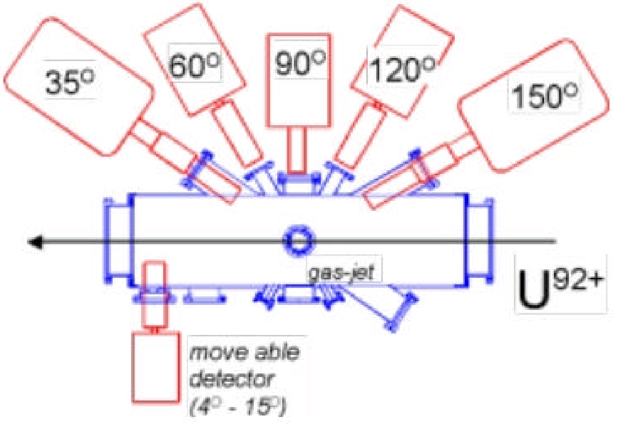
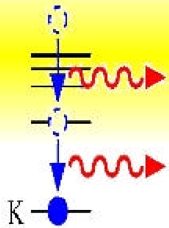
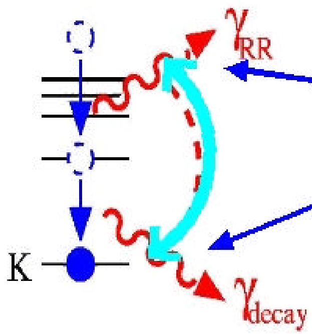




Two-photon coincidence: Angle-angle correlations

„Tool“ to analyze the polarization of either the ion beam and/or the target particles.

Which REC processes provide a clear „signature“ of the ion polarization ?



Linear polarization of the RR photons

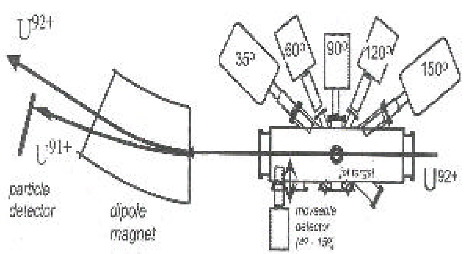
(First measurements at GSI 2002)

Angular distribution of decay photons

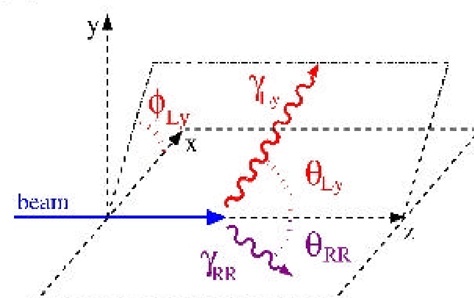
However: Very small effect (< 0.1 %).

$$W\left(\vec{n}_{Ly}, \vec{n}_{RR}\right) = ?$$

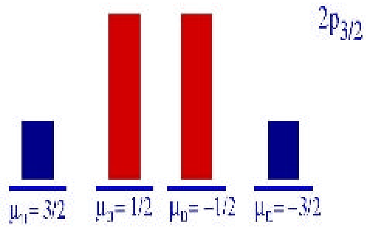
Geometry of the (e,2γ) process



Derivation and analysis of „angular correlation functions“

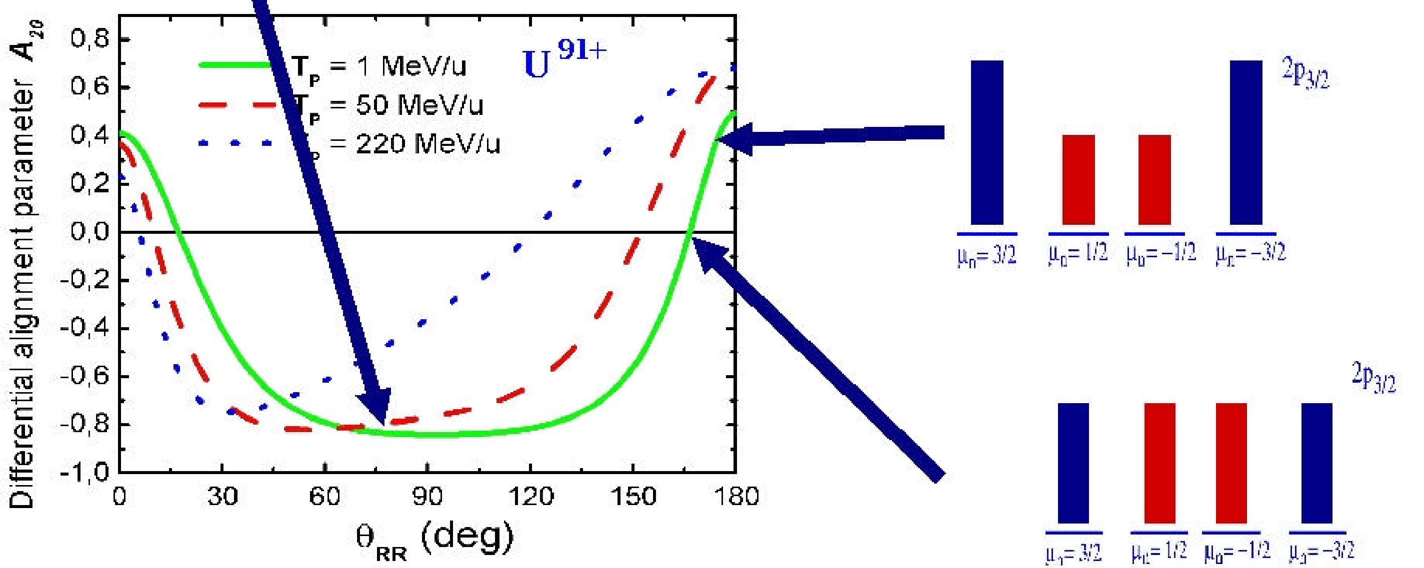


Differential alignment of the $2p_{3/2}$ states



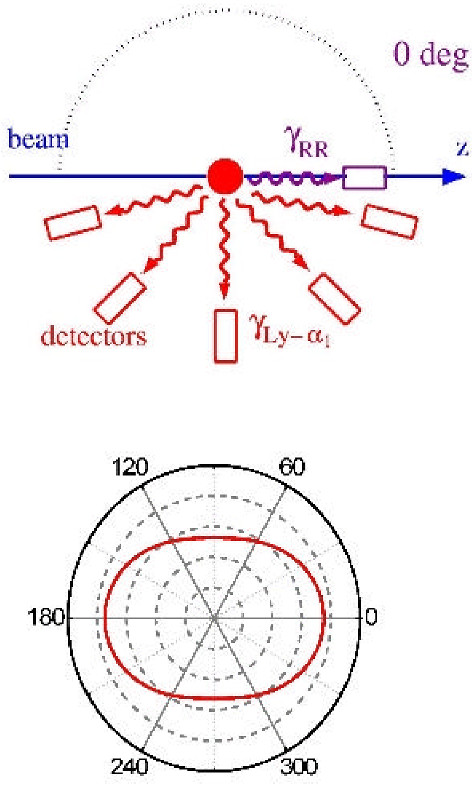
Differential alignment parameter:

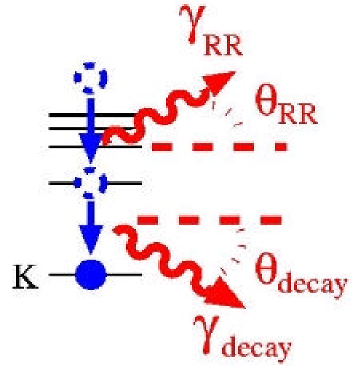
$$A_{20}(\theta_{RR}) = \frac{\frac{d\sigma}{d\Omega}(\mu_n = 3/2) - \frac{d\sigma}{d\Omega}(\mu_n = 1/2)}{\frac{d\sigma}{d\Omega}(\mu_n = 3/2) + \frac{d\sigma}{d\Omega}(\mu_n = 1/2)}$$

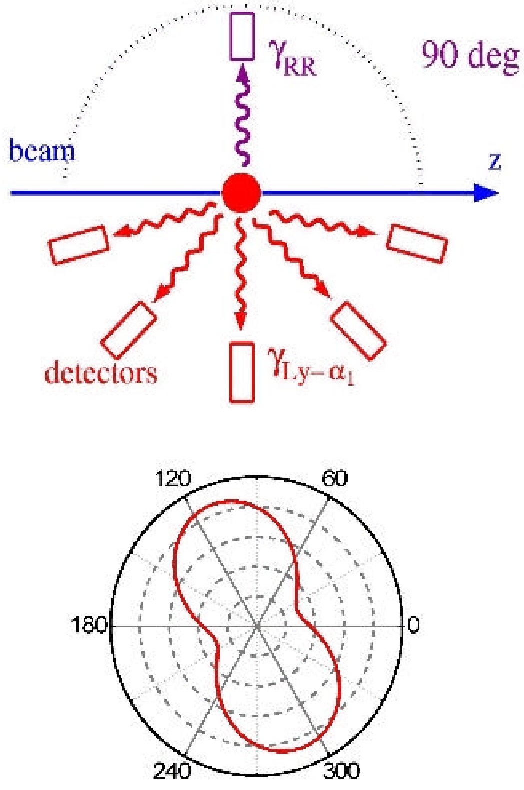


Angle-angle correlation function

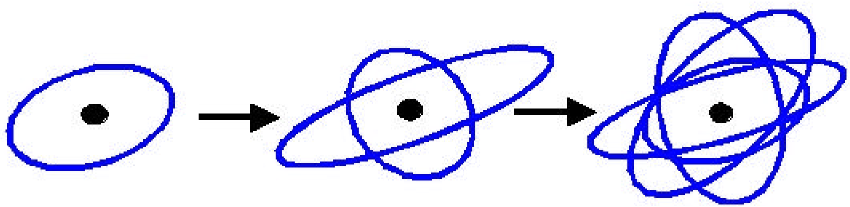
$$W(\vec{n}_{Ly};\vec{n}_{RR}) = 1 + \sqrt{\frac{4\pi}{5}} \sum_{q=-2,2} Y_{2q}(\vec{n}_{Ly}) A_{2q}(\vec{n}_{RR})\ f(E1, M2)$$





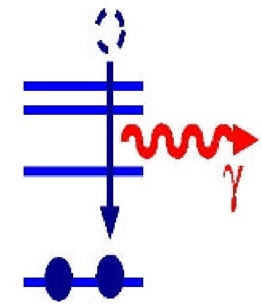


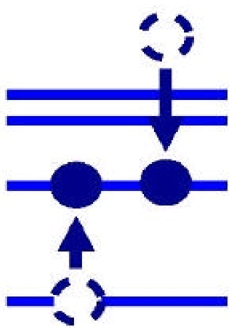
Outlook: Recombination of few-electron ions



→ Few-electron ions

Angular correlation studies provide a very sensitive tool for our understanding of capture, transfer, and collision processes.

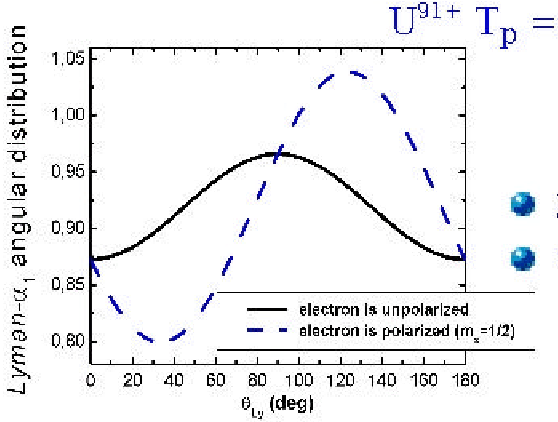




Many-particle character:

- Electron-electron correlations in the bound system and within the continuum
- Influences of external fields

U^{91+} $T_p = 310$ MeV/u



„Physical model“

- Zero nuclear spin ($I = 0$)
- Polarized electrons ($m_s = 1/2$)

Interest: PNC in highly-charged ions, polarized targets, heavy-ion matter, ...