Absolute Efficiency for STIRAP Excitation of Rydberg States

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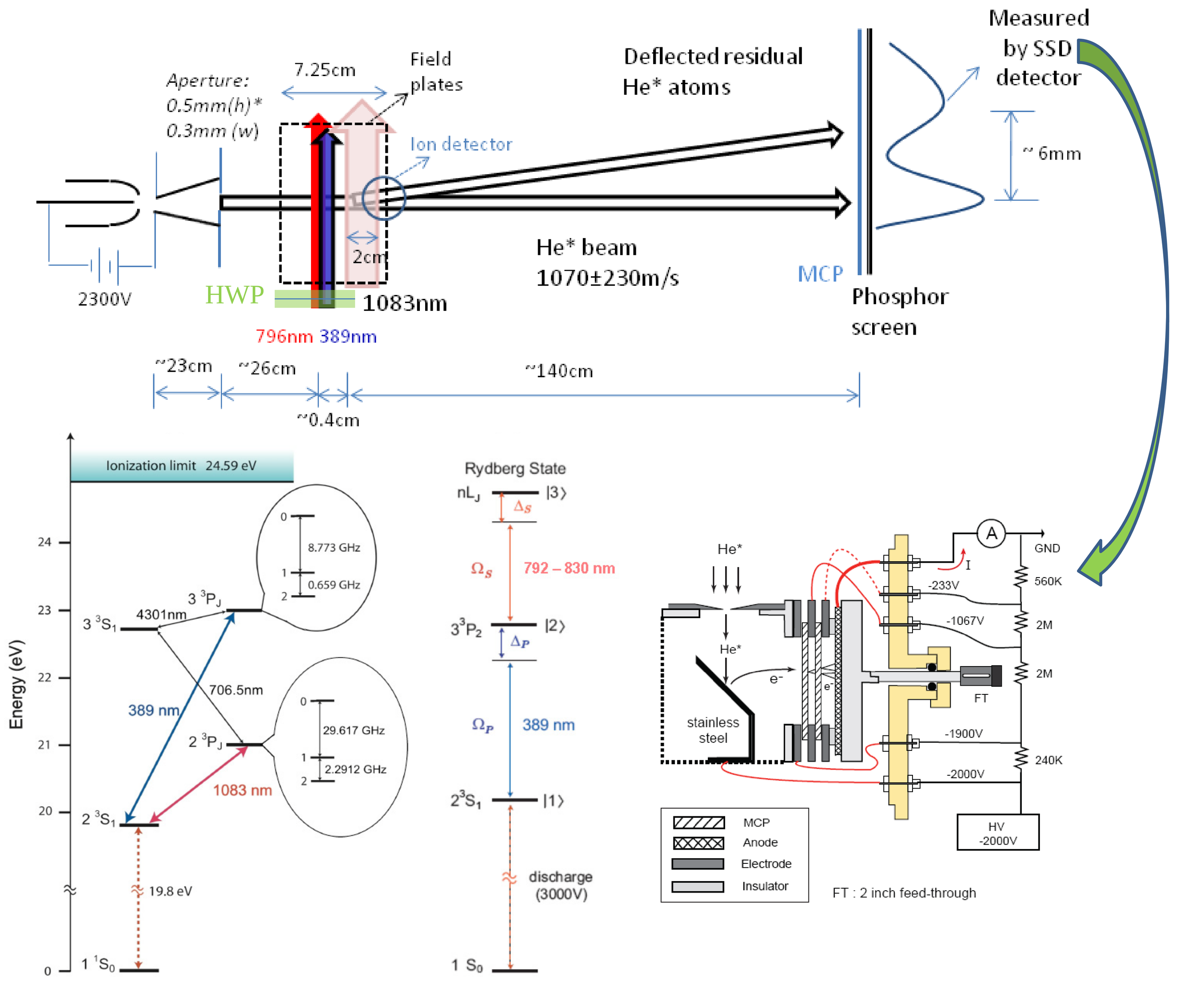
We have set up a STIRAP excitation mechanism for helium from the metastable 2^3S state into Rydberg states, via the intermediate level 3^3P . A uv laser at 389 nm and an ir laser at 780-815nm are used as the pump and Stokes beams respectively. Our purposes is to examine how well STIRAP works to efficiently produce the Rydberg atoms, and also to apply STIRAP for further coherent manipulations of helium. To examine the efficiency of the STIRAP process, we use the state selectivity of the light force on atoms to physically separate atoms with different internal states. We use the bichromatic force on a transition different from those used for Rydberg excitation. We do not measure an excitation efficiency close to the ~100% theoretical optimum but instead only about 50%. To gain more insight into this coherent process, an excitation path interferometer is envisioned that showes the expected interference, via the final population of the Rydberg level.

Experimental setup



STIRAP (in the usual sense)

Adiabatic States:

$$|+\rangle = \sin\theta\sin\varphi|1\rangle + \cos\varphi|2\rangle + \cos\theta\sin\varphi|3\rangle$$

$$|0\rangle = \cos\theta|1\rangle - \sin\theta|3\rangle$$

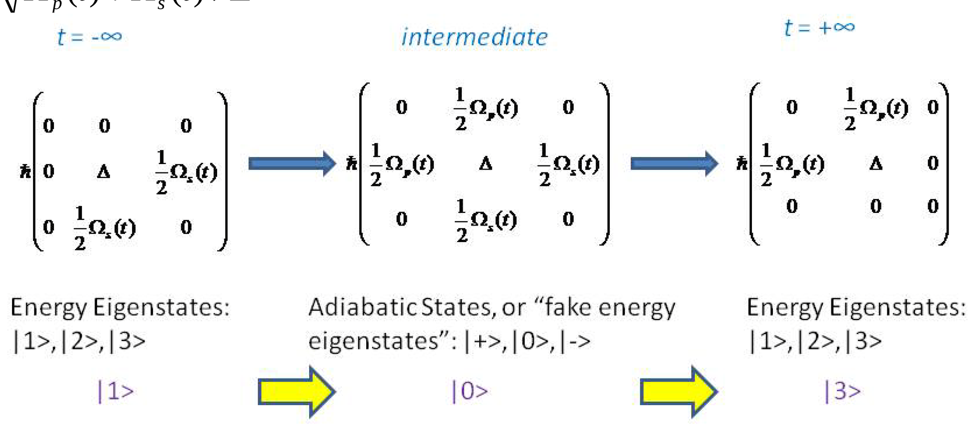
$$|-\rangle = \sin\theta\cos\varphi|1\rangle - \sin\varphi|2\rangle + \cos\theta\sin\varphi|3\rangle$$

$$H = \hbar\begin{pmatrix} 0 & \frac{1}{2}\Omega_p(t) & 0 \\ \frac{1}{2}\Omega_p(t) & \Delta & \frac{1}{2}\Omega_s(t) \\ 0 & \frac{1}{2}\Omega_s(t) & 0 \end{pmatrix}$$

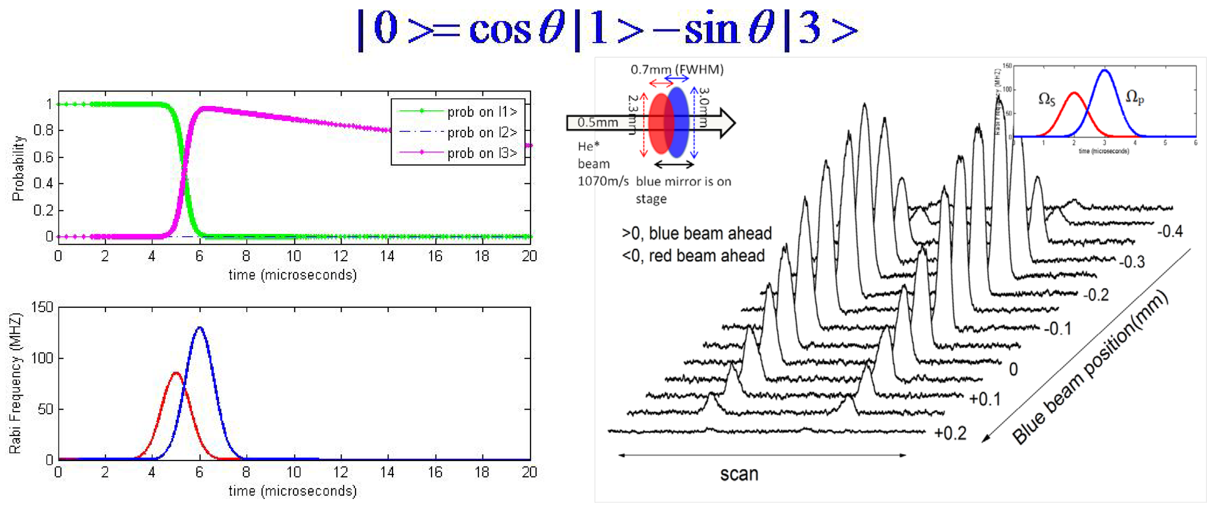
where the mixing angles are:

$$\tan\theta = \Omega_p(t)/\Omega_s(t)$$

$$\tan 2\varphi = \sqrt{\Omega_p^2(t)+\Omega_s^2(t)}/\Delta$$

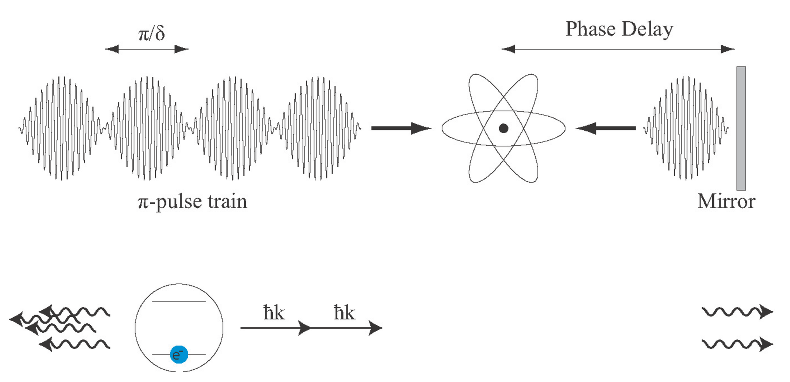


$$|0\rangle = \cos\theta|1\rangle - \sin\theta|3\rangle$$



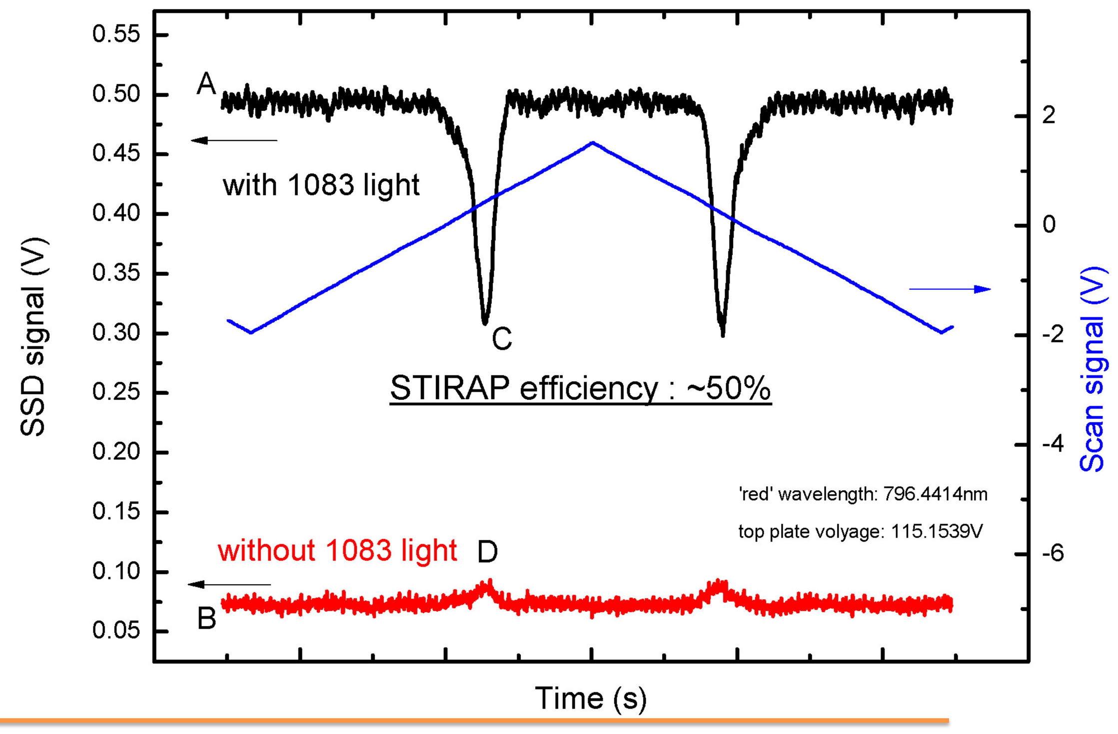
Numerical *Experiment data, from BBR ion signal*

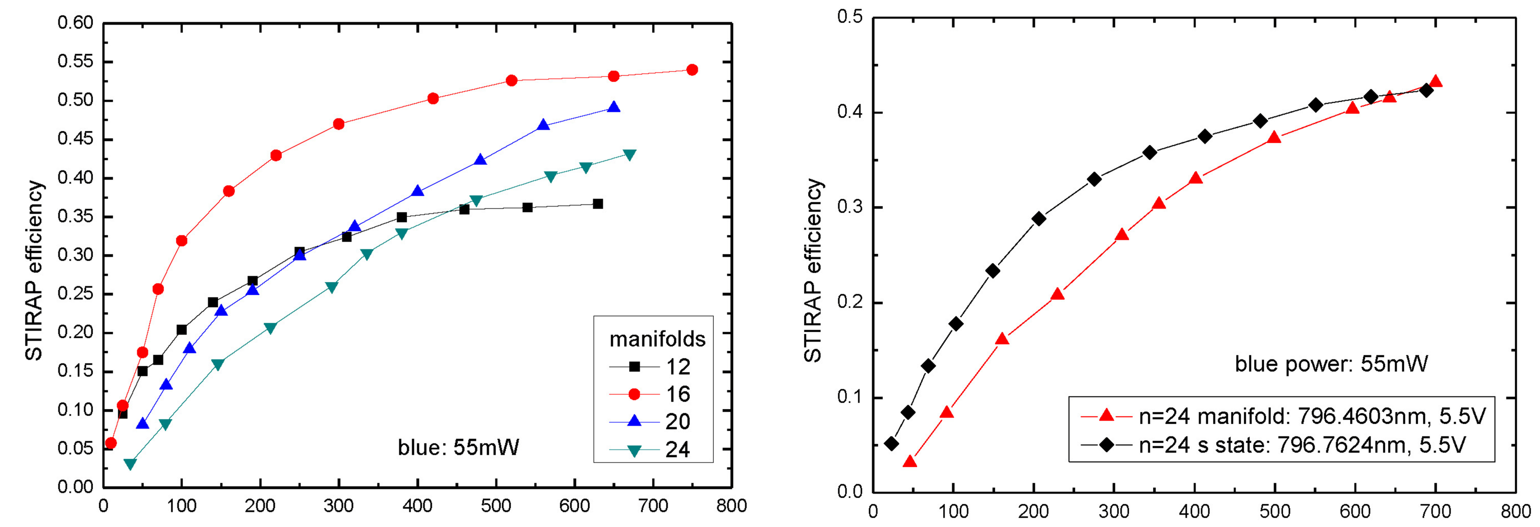
Physical separation: the bichromatic force



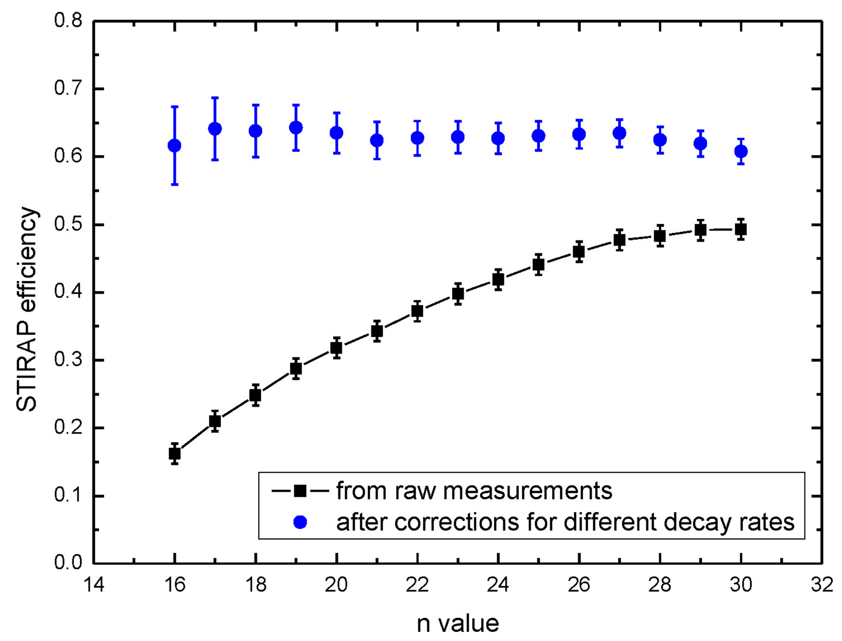
Absolute efficiency measurement results

Typical Data, as shown on oscilloscope





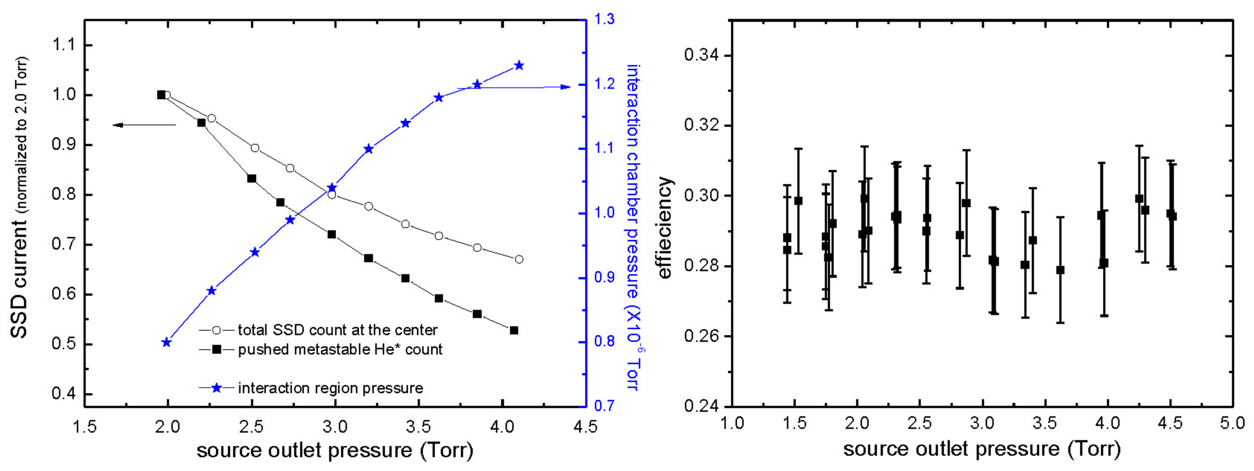
We can always saturate the pump process since we can generate uv laser at a high power to provide a Rabi frequency more than needed. Hence we want to test the relation between the STIRAP efficiency and the ir laser power, for different final states. The horizontal axis of the above graphs is the power of ir laser in mW.

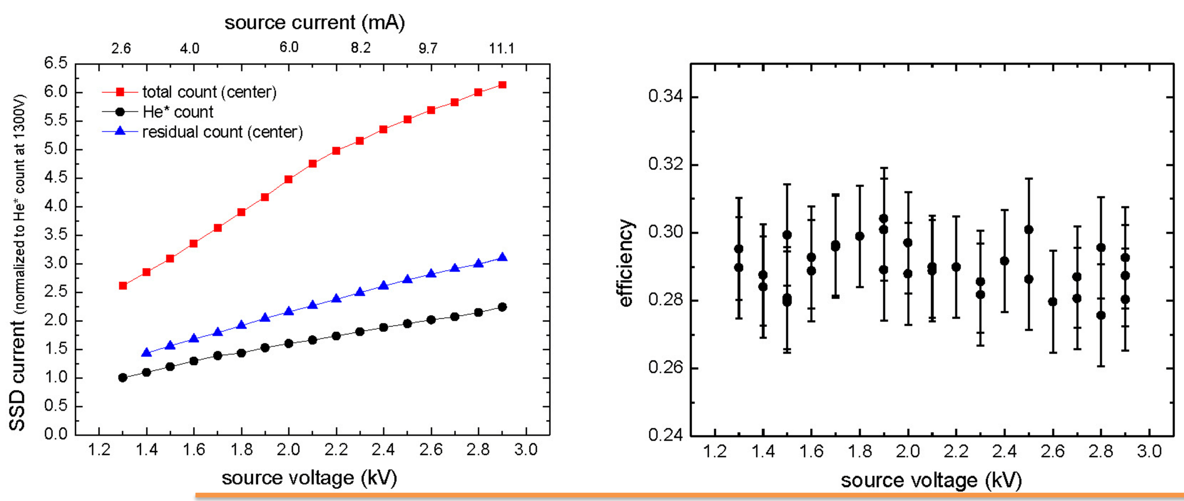


Absolute efficiency measurement for S state, for a series of principle quantum number n. Black dots are the raw data, while the blue dots are corrected for the Rydberg atoms' decay when travelling from the STIRAP interaction point to the bichro beam interaction point.

What's wrong with STIRAP of helium?

Is it a problem from the source, or collision, or other dirt effects?





No!

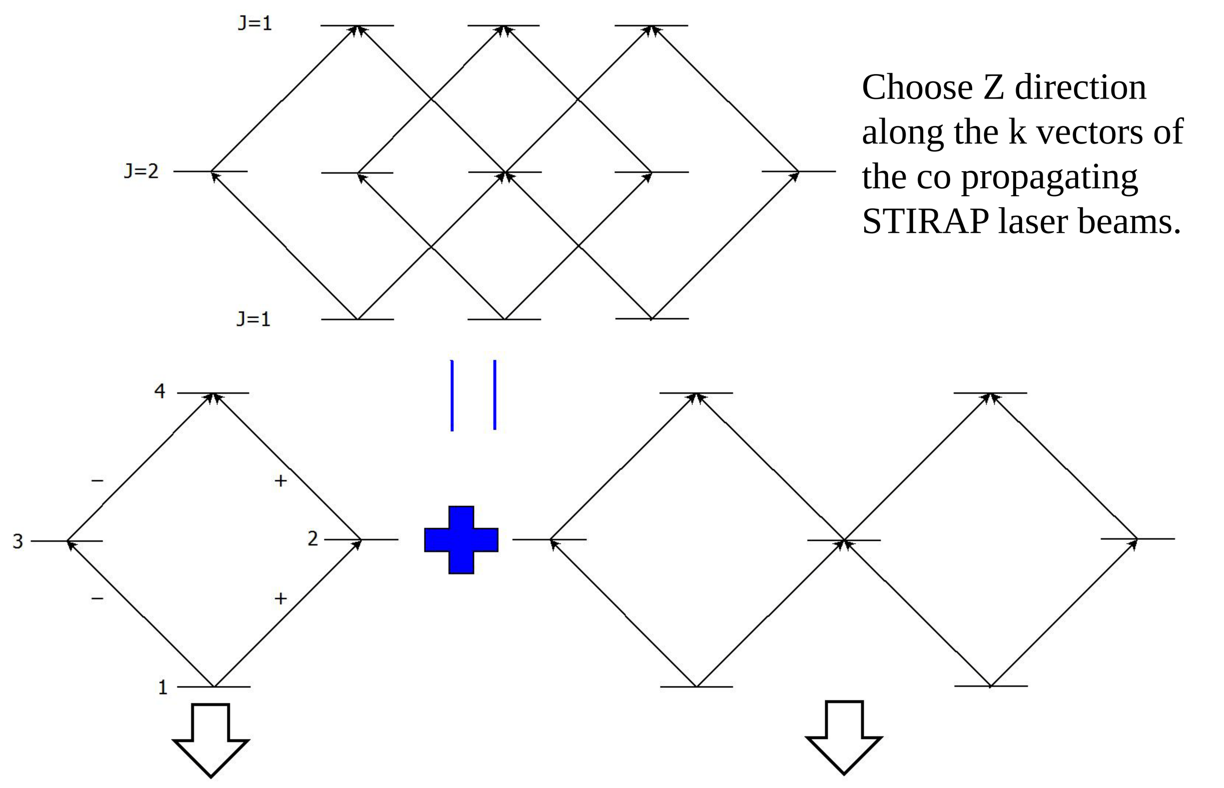
Other possibilities: Beyond the dipole approximation? Magnetic sublevels? Quantum defect of helium?

$$i\hbar\frac{d}{dt}\begin{pmatrix} c_1(t) \\ c_2(t) \\ c_3(t) \end{pmatrix} = \hbar\begin{pmatrix} 0 & \frac{1}{2}\Omega_b(t) & 0 \\ \frac{1}{2}\Omega_b(t) & \Delta_b & \frac{1}{2}\Omega_r(t) \\ 0 & \frac{1}{2}\Omega_r(t) & \Delta_b+\Delta_r+\Lambda(t)+\Gamma(t)\sin(\omega_r t) \end{pmatrix}\begin{pmatrix} c_1(t) \\ c_2(t) \\ c_3(t) \end{pmatrix}$$

$$\hbar\Lambda(t) = \frac{1}{4m}q^2k_r^2\langle 3|y^2|3\rangle\mathcal{A}_r^2(t)$$

$$\hbar\Gamma(t) = q\mathcal{E}_r(t)\langle 3|y\sin(k_r x)|3\rangle$$

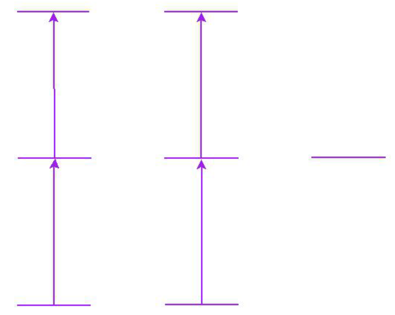
Magnetic sublevels and path interference



Choose Z direction along the k vectors of the co propagating STIRAP laser beams.

Interference!

Caused by polarization direction differences of the two STIRAP lasers



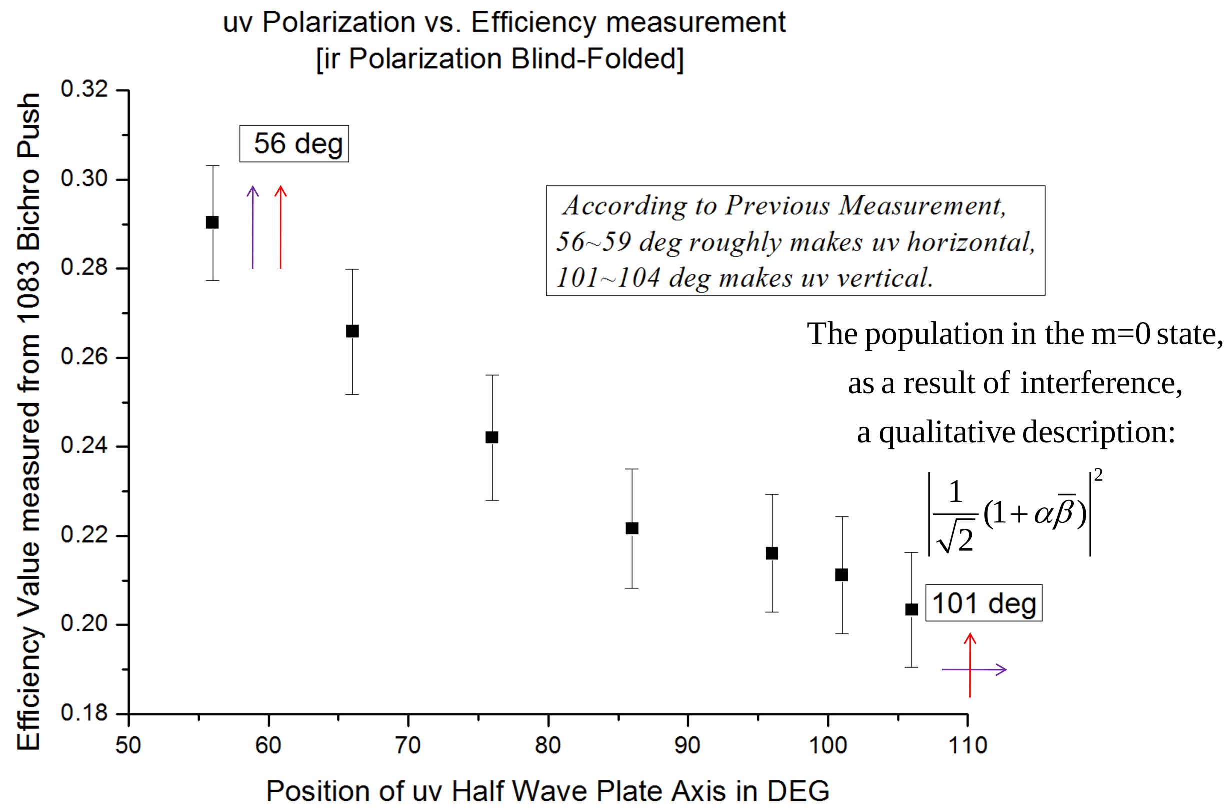
Two states with magnetic number +/-1 in the final Rydberg level aren't affected. The state with magnetic number zero experiences an interference. The simplest model can be given under circular polarization basis.

$$|uv\rangle = \eta_{uv}(|+\rangle + \alpha|-\rangle)$$

$$|ir\rangle = \eta_{ir}(|+\rangle + \beta|-\rangle), |\alpha| = |\beta| = 1$$

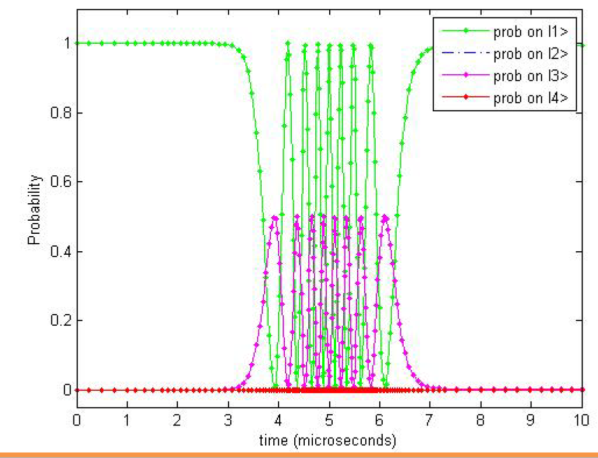
$$i\frac{d}{dt}\begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix} = \begin{bmatrix} & \Omega_p & \alpha\Omega_p & \\ \Omega_p & & & \beta\Omega_s \\ \bar{\alpha}\Omega_p & & & \Omega_s \\ & \bar{\beta}\Omega_s & \Omega_s & \end{bmatrix}\begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix}$$

ONE THIRD of the total Rydberg population is subject to interference!



$$\left|\frac{1}{\sqrt{2}}(1+\alpha\bar{\beta})\right|^2$$

Numerical results on the extreme destructive interference case. The final m=0 state is never populated when the polarizations are orthogonal to each other, hence the Rydbergs we get is automatically polarized!



Conclusion

Physical separation of the Rydberg helium and the metastable ground state helium is achieved by the use of bichromatic force and hence it yields a precise measurement of the STIRAP efficiency of producing Rydberg atoms. The process of spontaneous decay and ionization of Rydberg atoms can be accurately monitored.

References

[1] B.W. Shore et al, Coherent population transfer in multilevel systems with magnetic sublevels.(1995)
[2] K. Bergmann et al. Coherent manipulation of atoms and molecules by sequential laser pulses.
[3]J. R. Morris et al, Reduction of degenerate two-level excitation to independent two-state systems.(1983)

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