Absolute Measurement of STIRAP Efficiency

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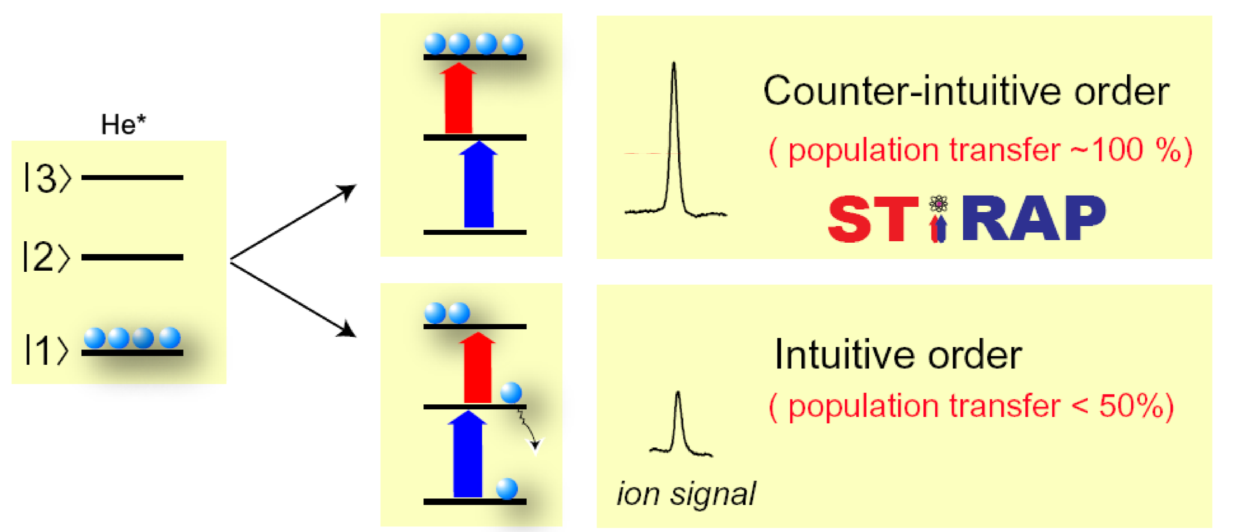
Abstract

Driving atoms from an initial to a final state of the same parity via an intermediate state of opposite parity is most efficiently done using STIRAP[1], because it doesn't populate the intermediate state. We populate Rydberg states of He (n = 24) in a beam of average velocity 1070 m/s by having them cross two laser beams in a tunable dc electric field of ~100 V/cm. By varying the relative position of these beams we can vary the order and overlap encountered by the atoms. We vary the dc field to sweep across several Stark states of the Rydberg manifold. We measure the absolute efficiency using a curved wavefront light beam of 1083nm to deflect residual 2^3S_1 atoms out of the atomic beam, and we measure their flux with and without the STIRAP beams. This uncontaminated measurement has high absolute accuracy.

What is STIRAP?

Stimulated Rapid Adiabatic Passage

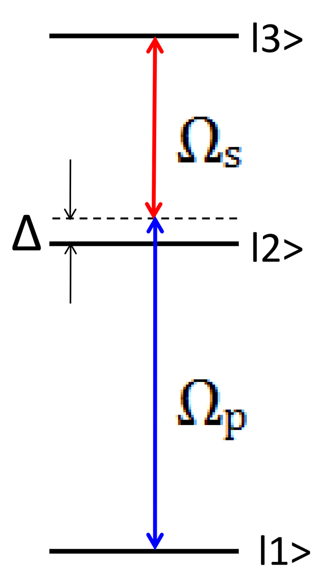


Theory of STIRAP

Hamiltonian [2]

For two-photon resonance $\Delta_p = -\Delta_s = \Delta$

$$H(t) = \frac{\hbar}{2}\begin{bmatrix} 0 & \Omega_p(t) & 0 \\ \Omega_p(t) & 2\Delta - i\Gamma_2 & \Omega_s(t) \\ 0 & \Omega_s(t) & -i\Gamma_3 \end{bmatrix}$$



Solution

Eigenstates for $\Gamma_2 = \Gamma_3 = 0$

(Γ_i : Decay rate of level i)

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

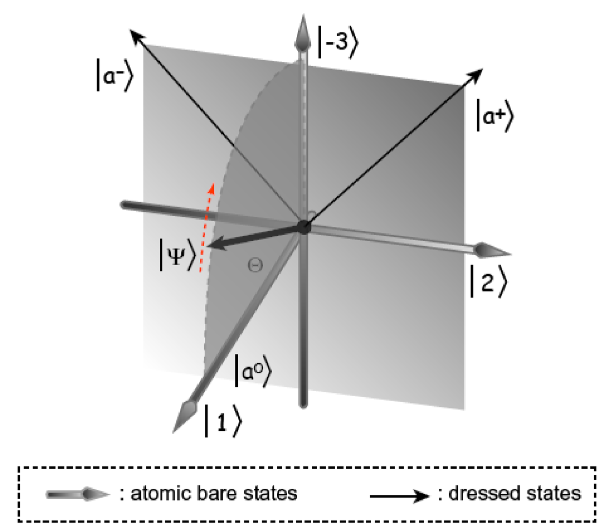
$$|a^0\rangle = \cos\theta|1\rangle - \sin\theta|3\rangle$$

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

Mixing angles

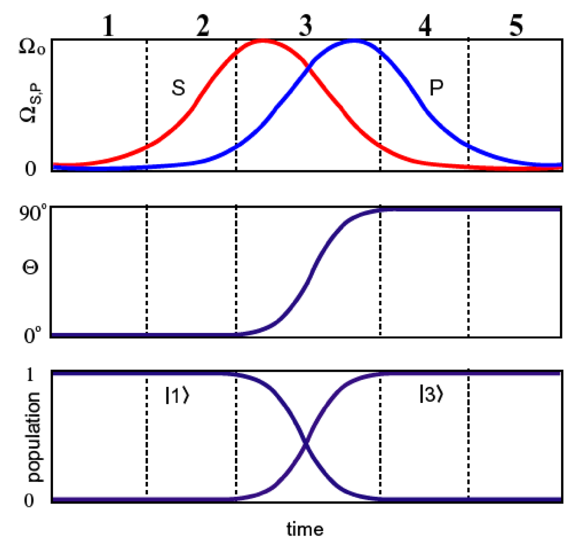
$$\tan\theta(t) = \Omega_P(t)/\Omega_S(t)$$

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



|Ψ⟩ : state vector

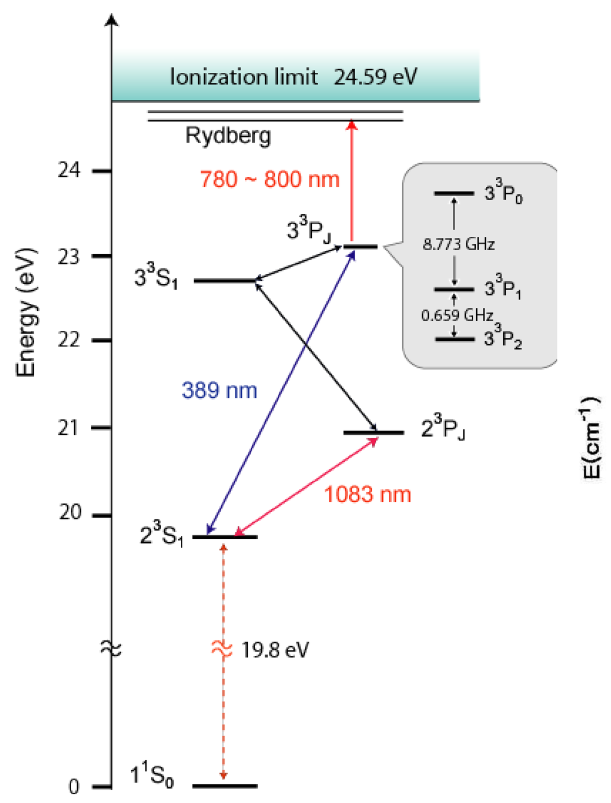
Vector picture of STIRAP [3]



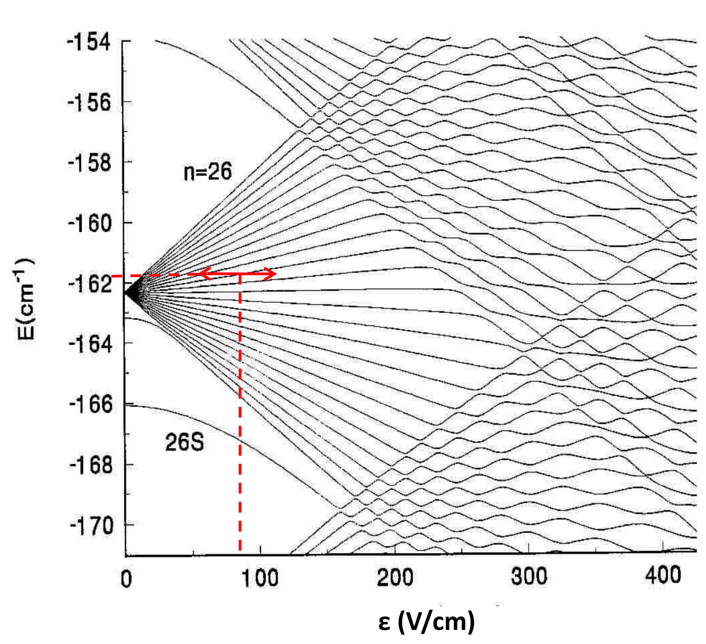
Time dependence of Rabi frequencies (top), mixing angle (middle) and the populations (bottom) [3]

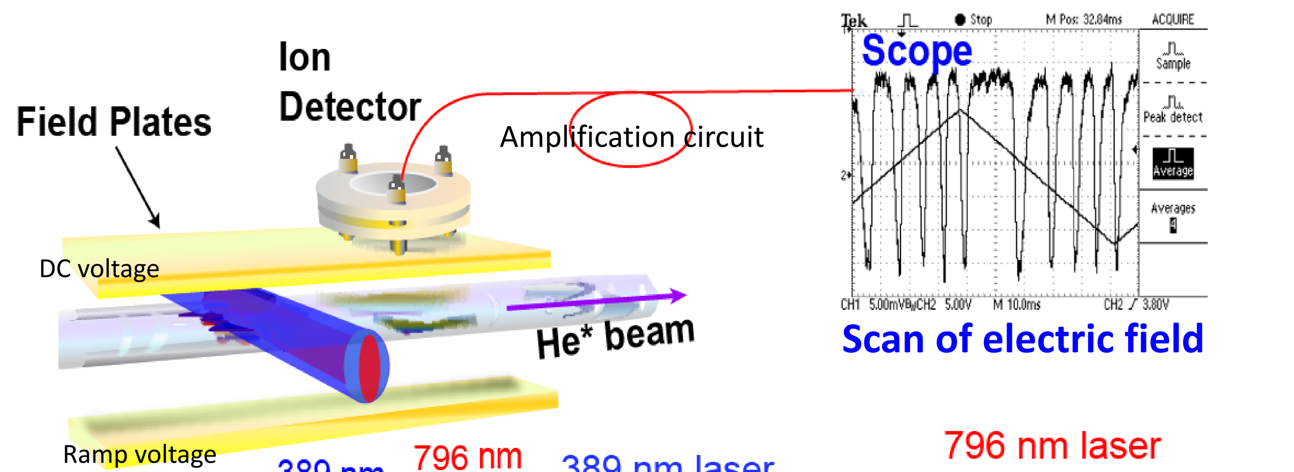
adiabatic condition: $\Omega_{eff}T \gg 1$ (T is the interaction time, $\Omega_{eff} = \sqrt{\Omega_s^2 + \Omega_p^2}$)

Experimental implementation of STIRAP



Energy levels of He Triplet states in an electric field



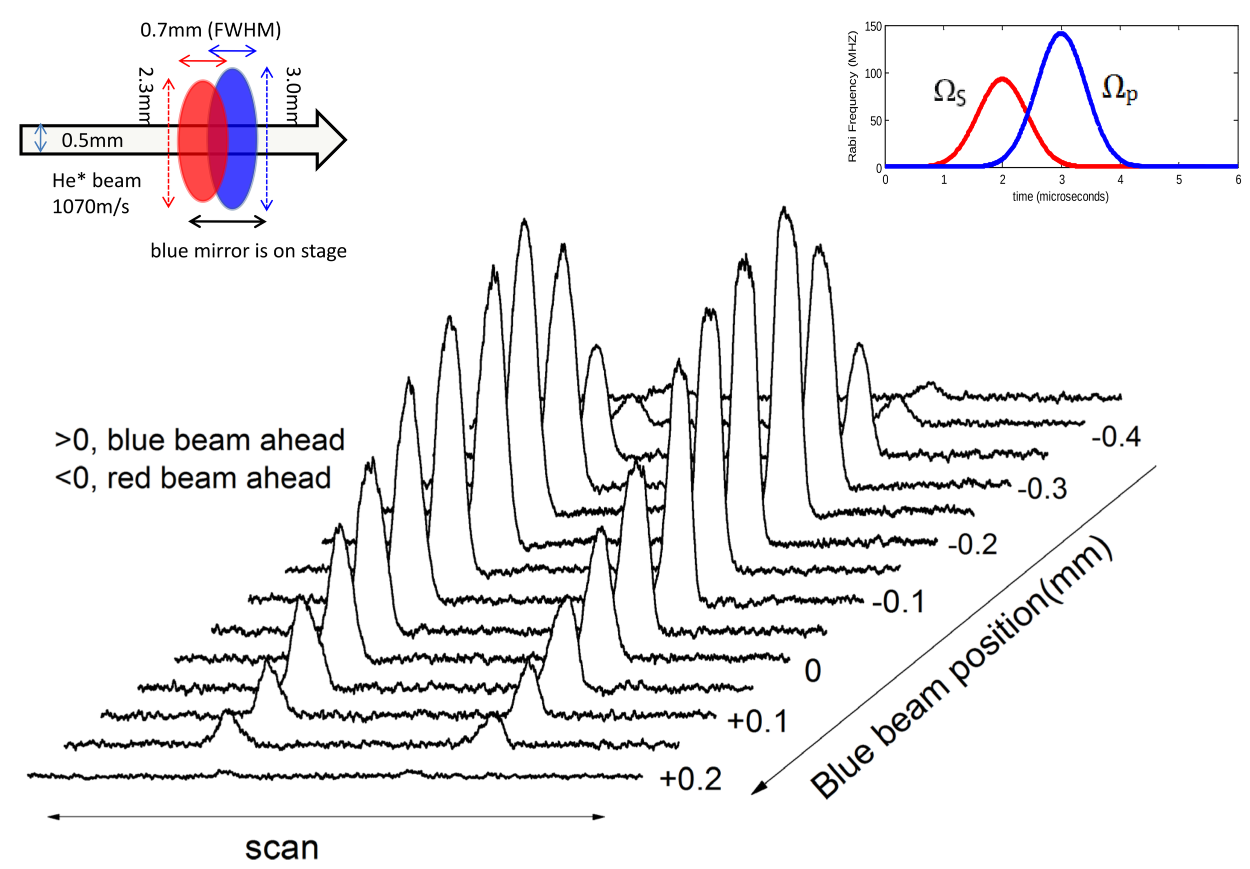


389 nm (Ω_P) 796 nm (Ω_S)

389 nm laser locked to the transition $2^3S_1 \longrightarrow 3^3P_2$

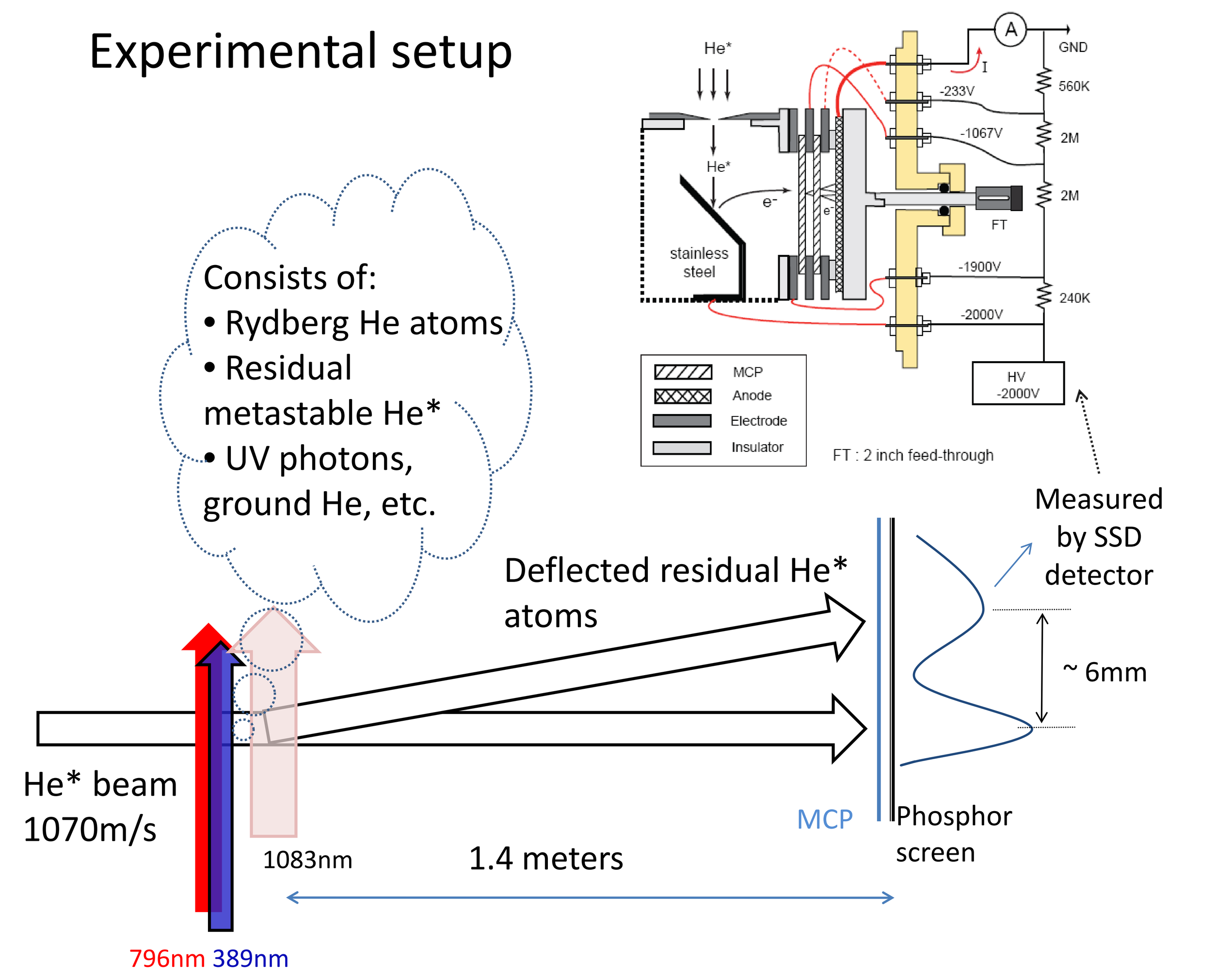
796 nm laser locked to a frequency in the range of $3^3P_2 \longrightarrow$ n=26

STIRAP results

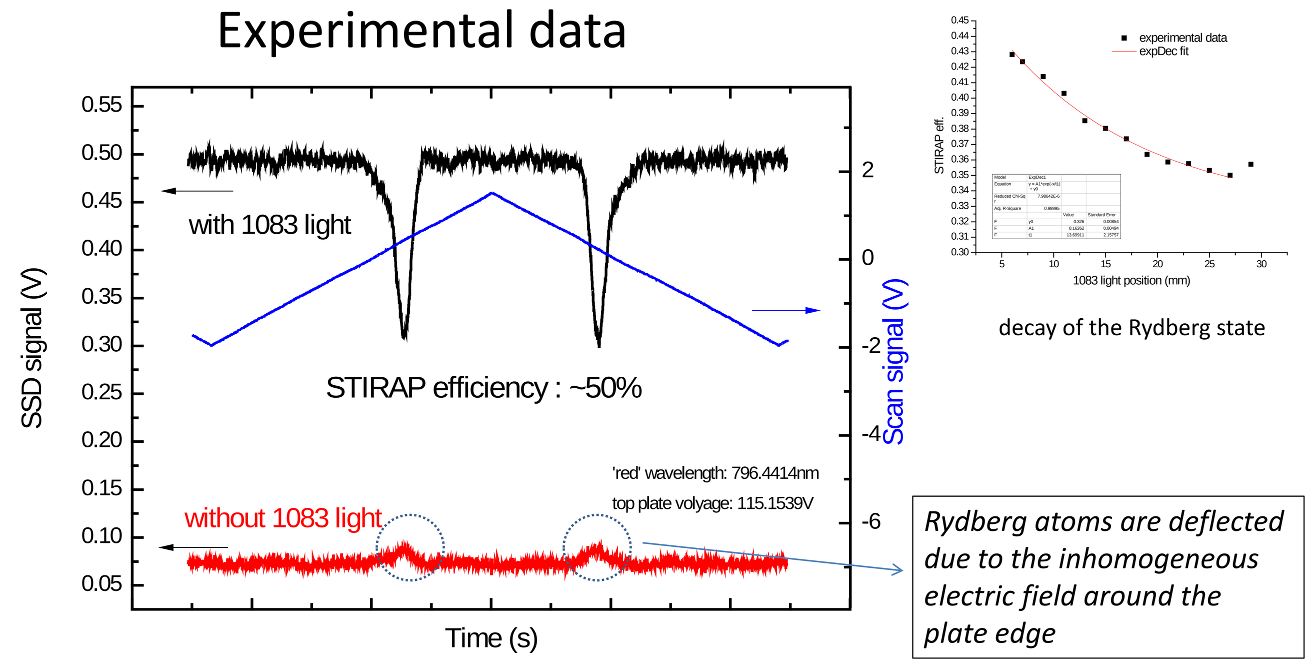


Absolute measurement of efficiency

Experimental setup

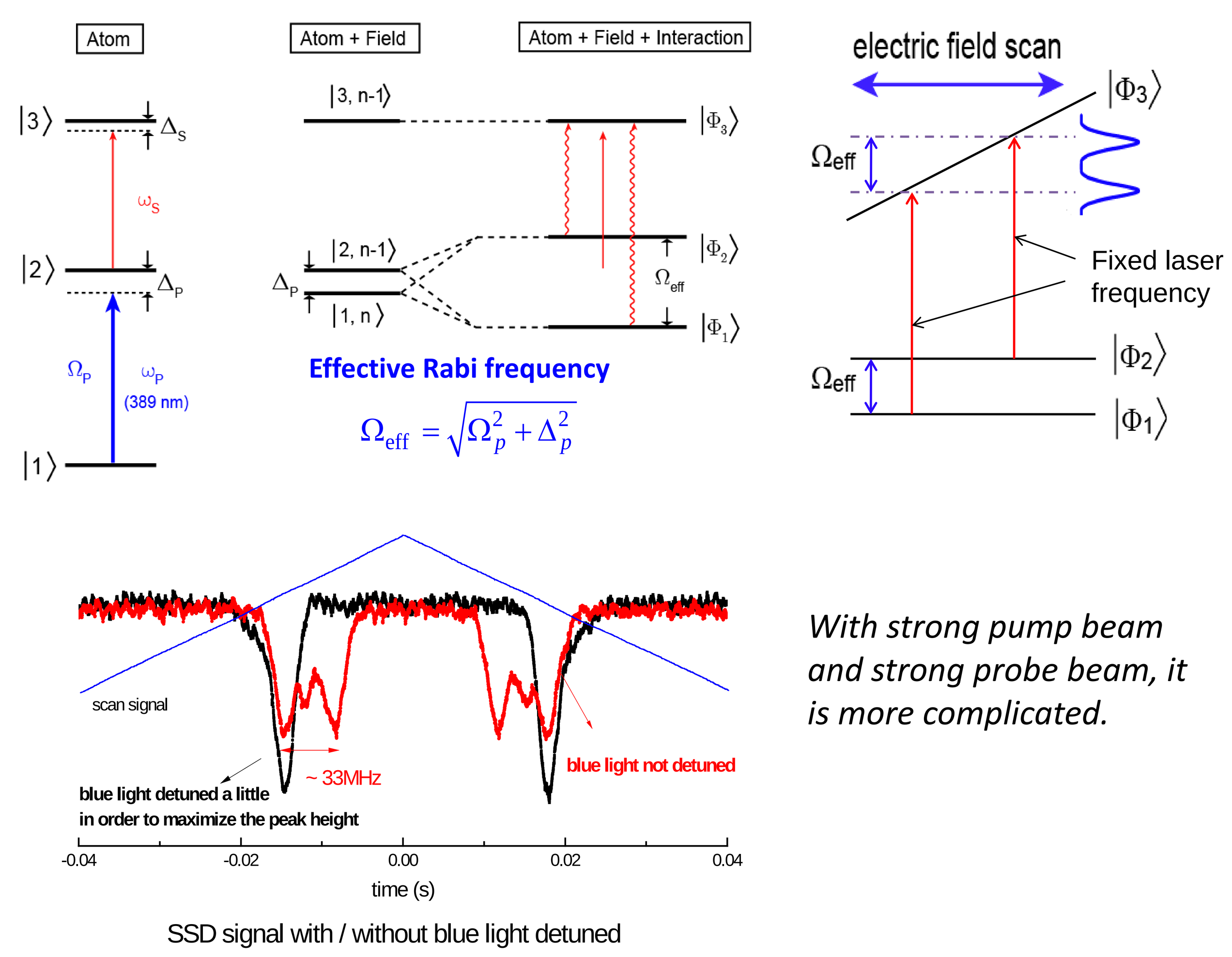


Experimental data



Rydberg atoms are deflected due to the inhomogeneous electric field around the plate edge

Autler-Townes splitting



SSD signal with / without blue light detuned

With strong pump beam and strong probe beam, it is more complicated.

References

[1]. U. Gaubatz et al., *J. Chem. Phys.*, 92, 5363 (1990).
[2]. B. W. Shore, *The Theory of Coherent Atomic Excitation*, Wiley, New York (1990)
[3]. K. Bergmann, et al, *Rev. Mod. Phys.* 70, (1998)

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