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# Phase shift of a weak coherent beam by a single atom

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Thanks to

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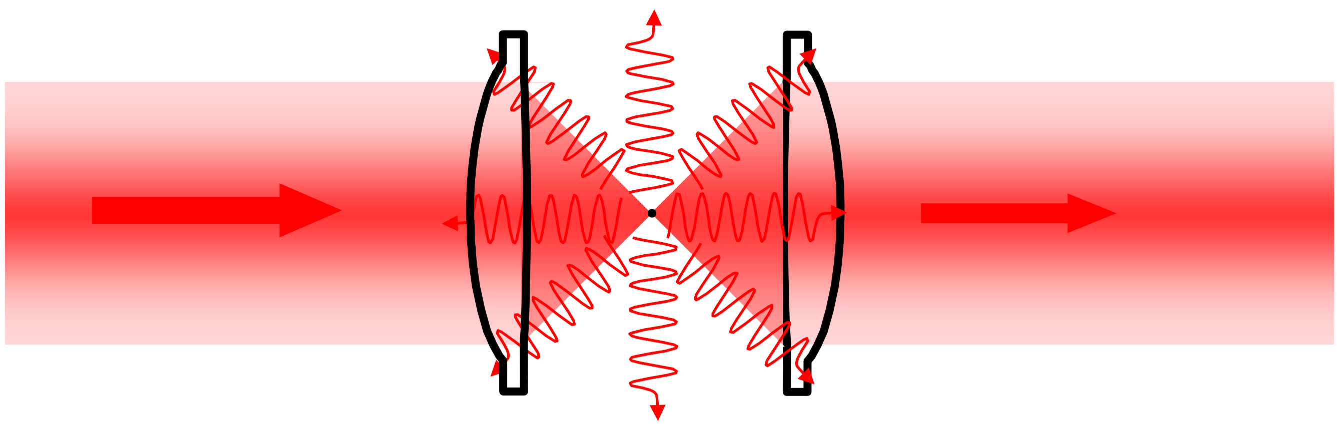
# Brief Outline

- Motivation for the experiment
- Theoretical description
- Experiment and Results

# Motivation



- Quantify interaction of a two-level atom with light
- Strong interaction without a cavity.



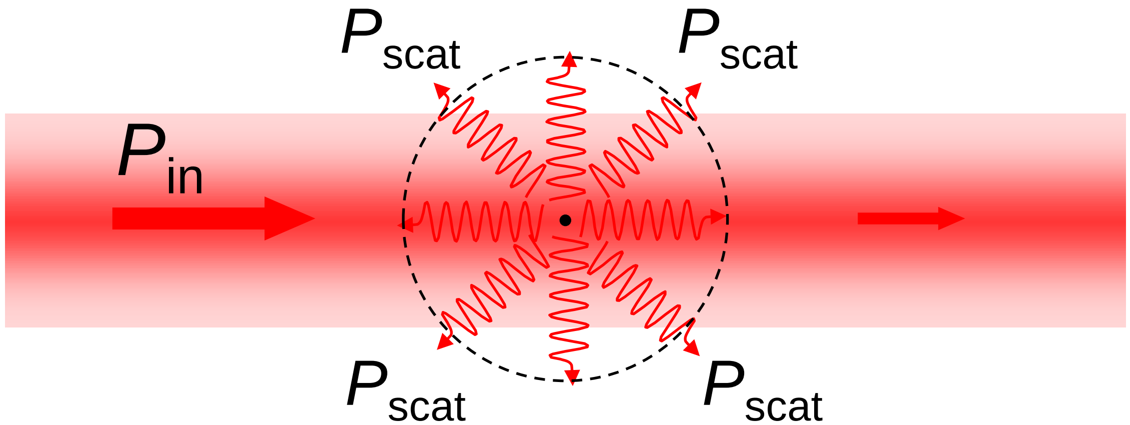
*Tey M.K. et al. Nature Physics* 4, 924 - 927 (Dec 2008)

# Quantifying Interaction



Scattering Ratio

$$R_{\text{scat}} = \frac{P_{\text{scat}}}{P_{\text{in}}}$$



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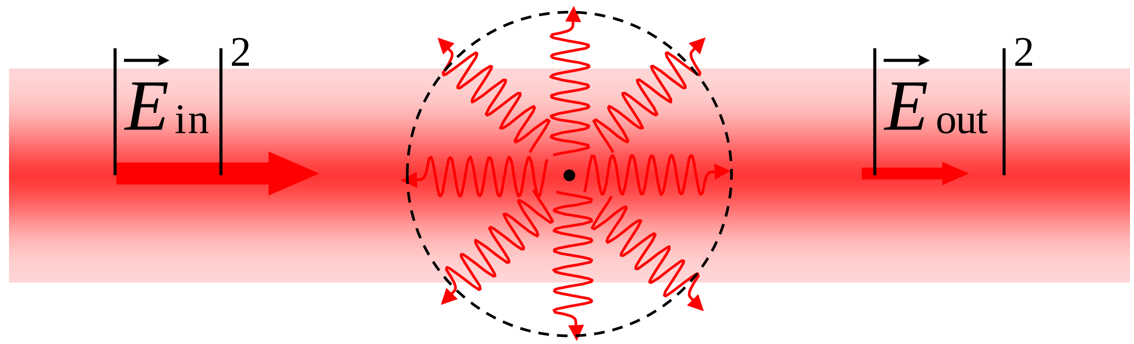



Transmission

$$T = \left|\vec{E}_{\text{out}}\right|^2 \Big/ \left|\vec{E}_{\text{in}}\right|^2$$

Phase shift

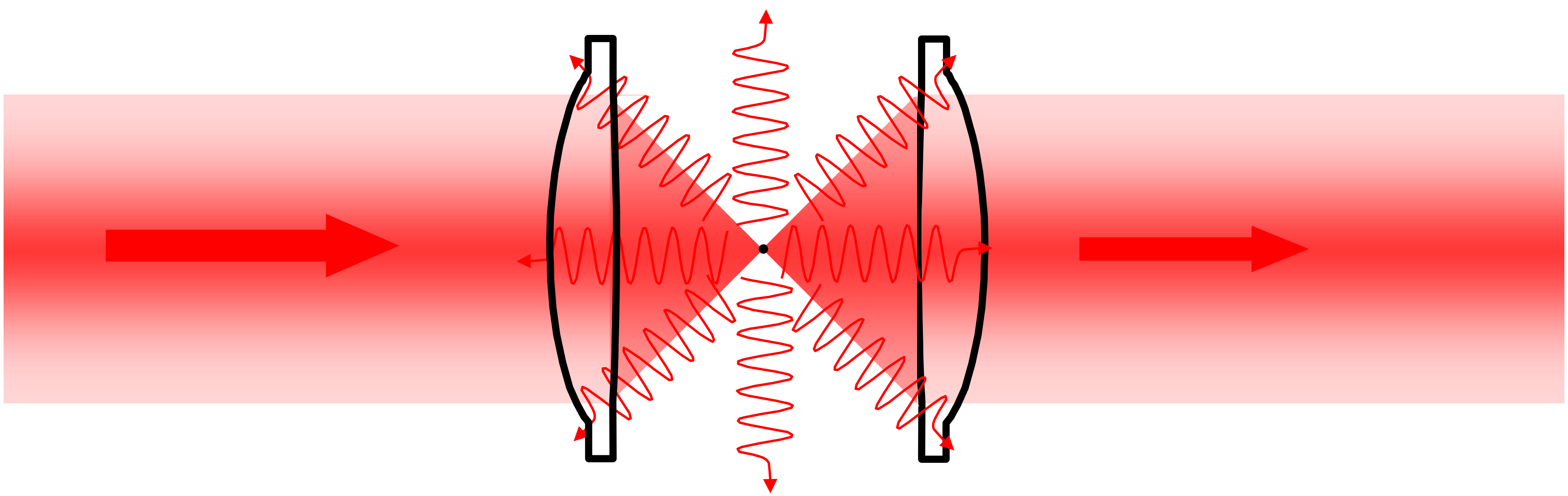
$$\delta\phi = \arg(\vec{E}_{\text{out}} \cdot \vec{E}_{\text{in}}^{\,*})$$

# Atom-Light Interaction



Weak excitation, and on-resonant input light

$$\vec{E}_{\text{out}} = \vec{E}_{\text{in}} + \vec{E}_{\text{scat}}$$



# Atom-Light Interaction



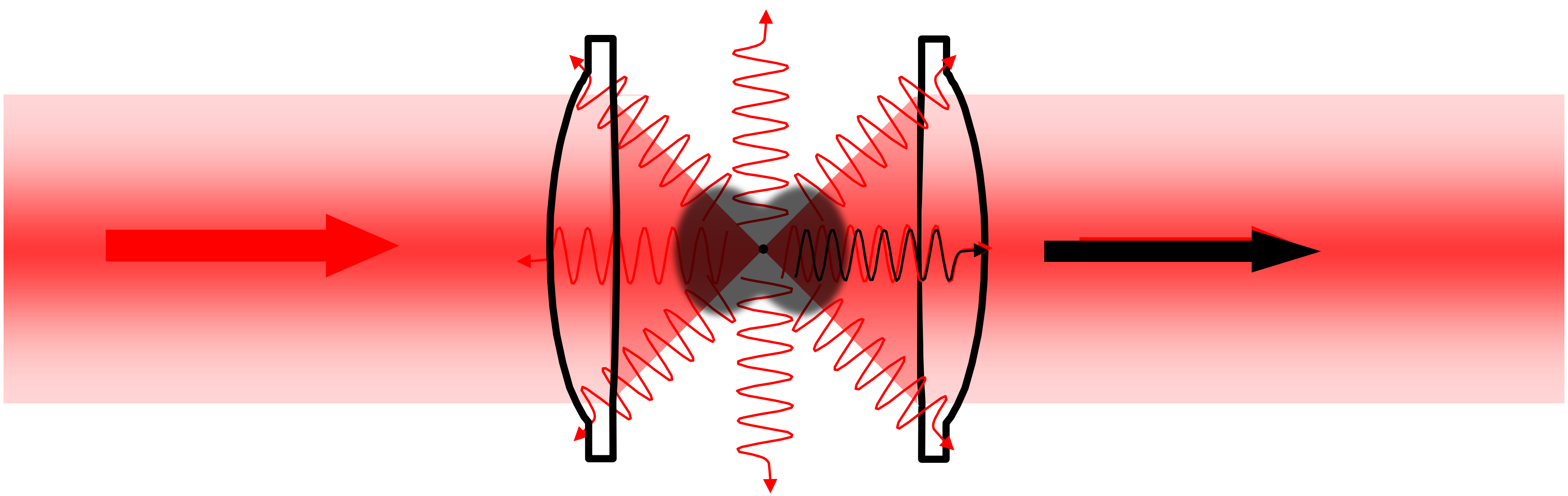
Weak excitation, and on-resonant input light

$$\vec{E}_{out} = \vec{E}_{in} + \vec{E}_{scat}$$

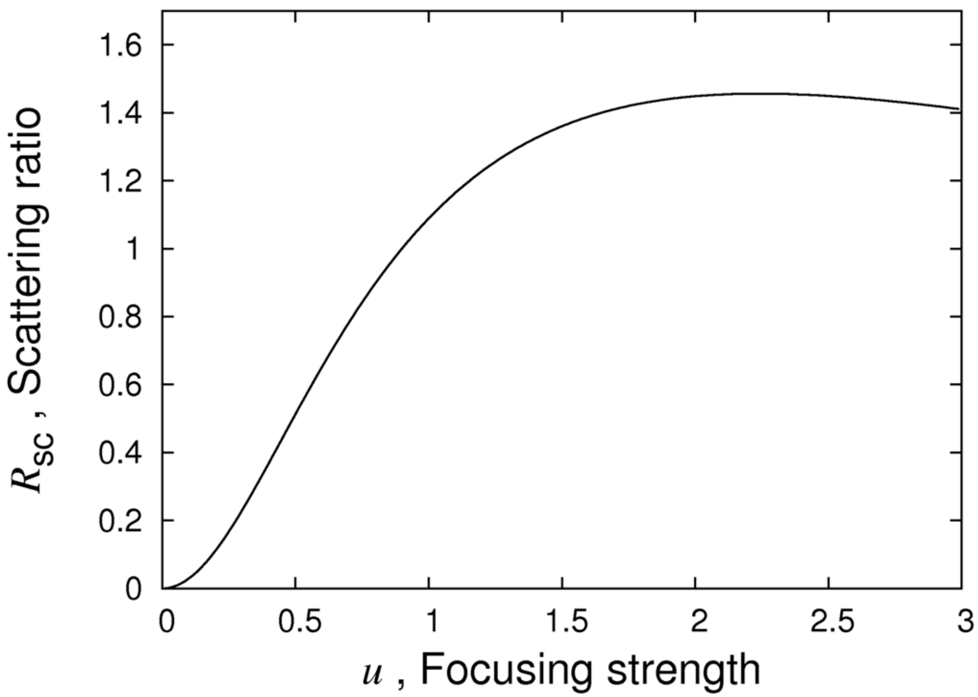
(On axis) $$= \vec{E}_{in}\left(1 - \frac{R_{scat}}{2}\frac{i\Gamma}{2\Delta + i\Gamma}\right)$$

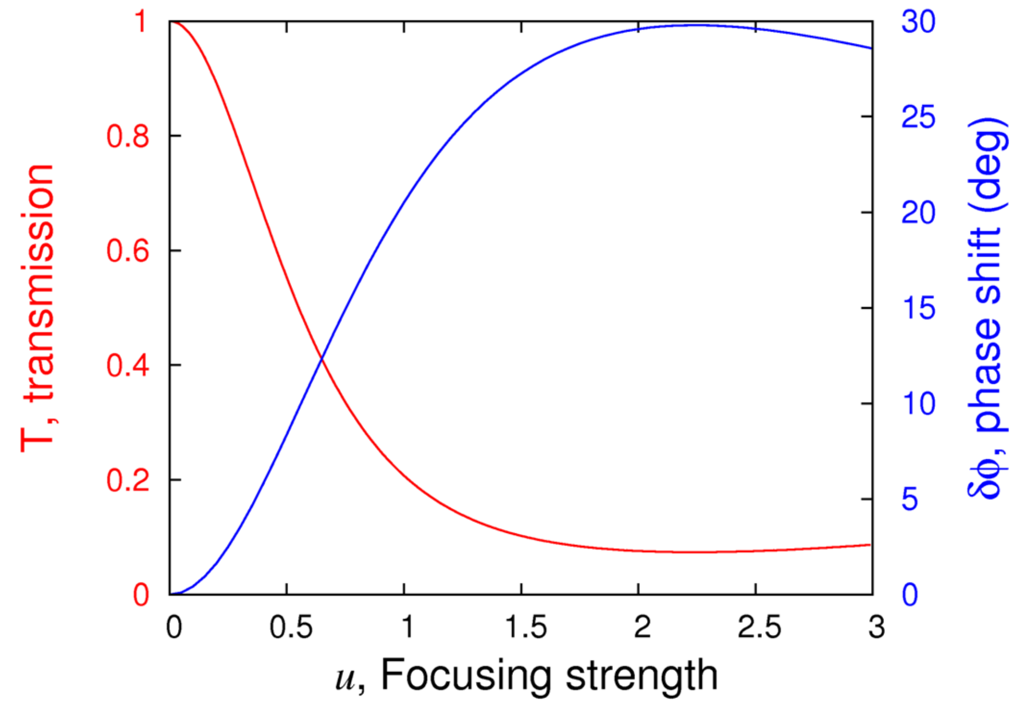
$\Gamma$ : natural linewidth

$\Delta$ : detuning



# Strong Interaction



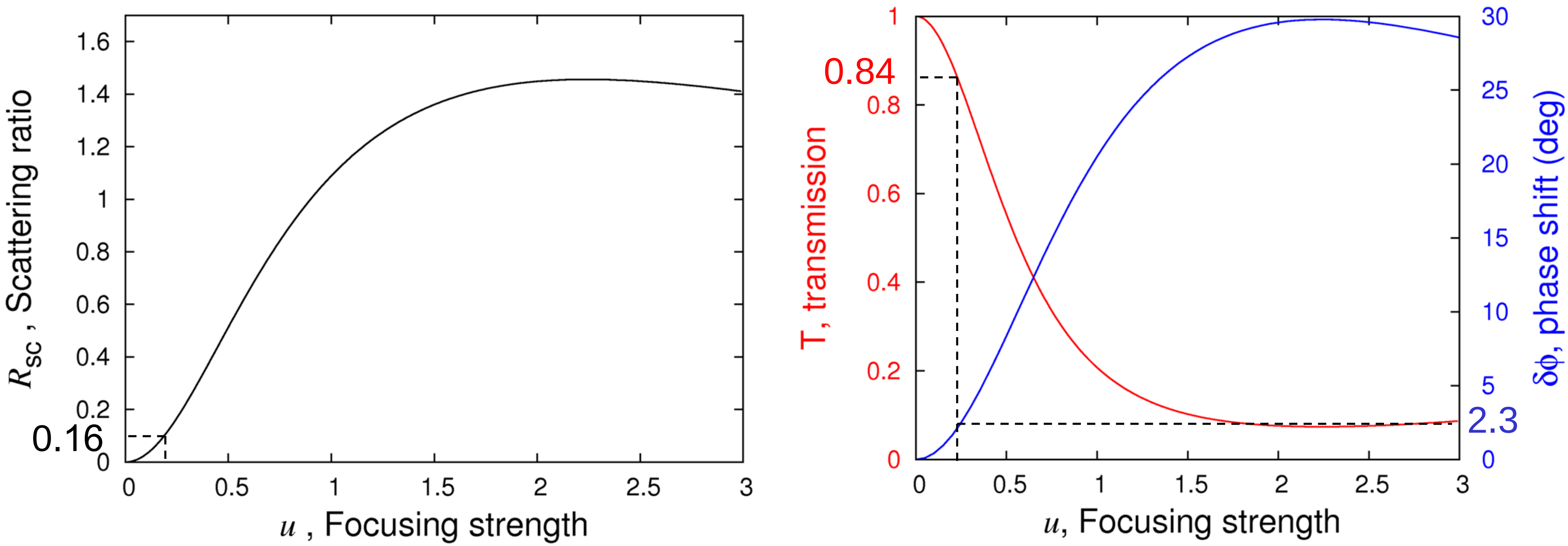

$$R_{sc} = \frac{3}{4u^3} e^{2/u^2} \left[ \Gamma\left(-\frac{1}{4}, \frac{1}{u^2}\right) + u\Gamma\left(\frac{1}{4}, \frac{1}{u^2}\right) \right]^2$$

Closed expression for focused Gaussian beam

M. K. Tey, et. al.
**New J. Phys. 11 (2009) 043011**

G. Zumofen, et. al.,
**Phys. Rev. Lett. 101, 180404 (2008)**

# Strong Interaction

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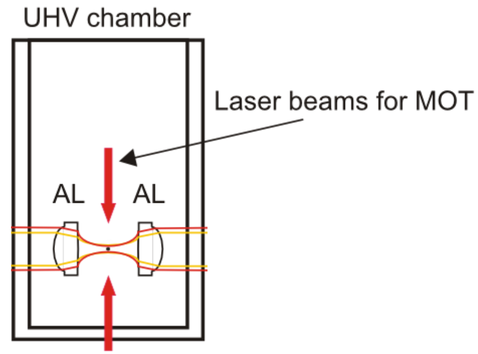
# Experimental Setup



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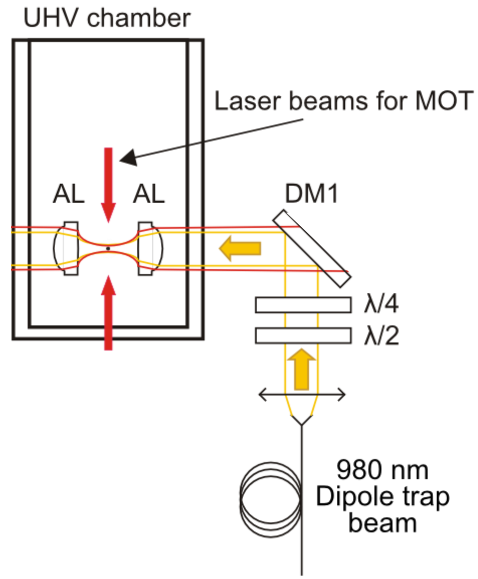

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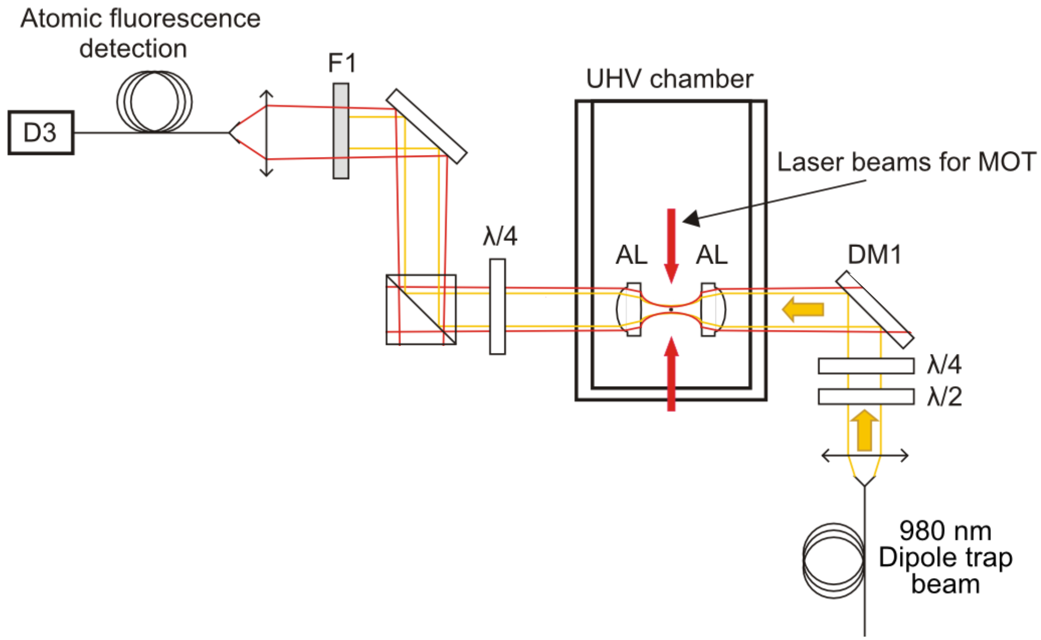

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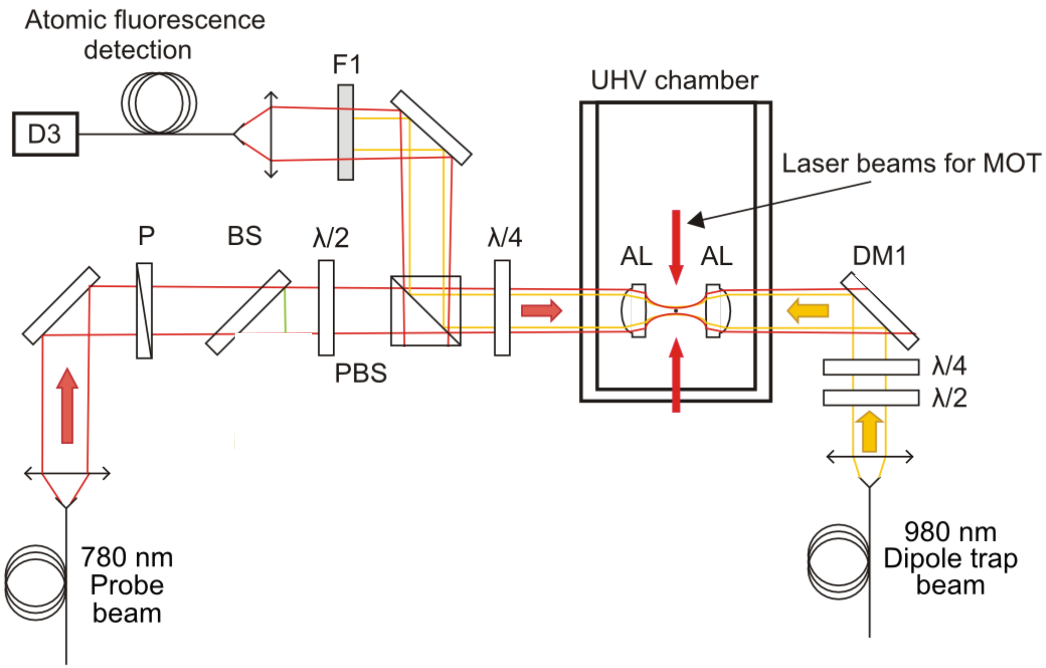

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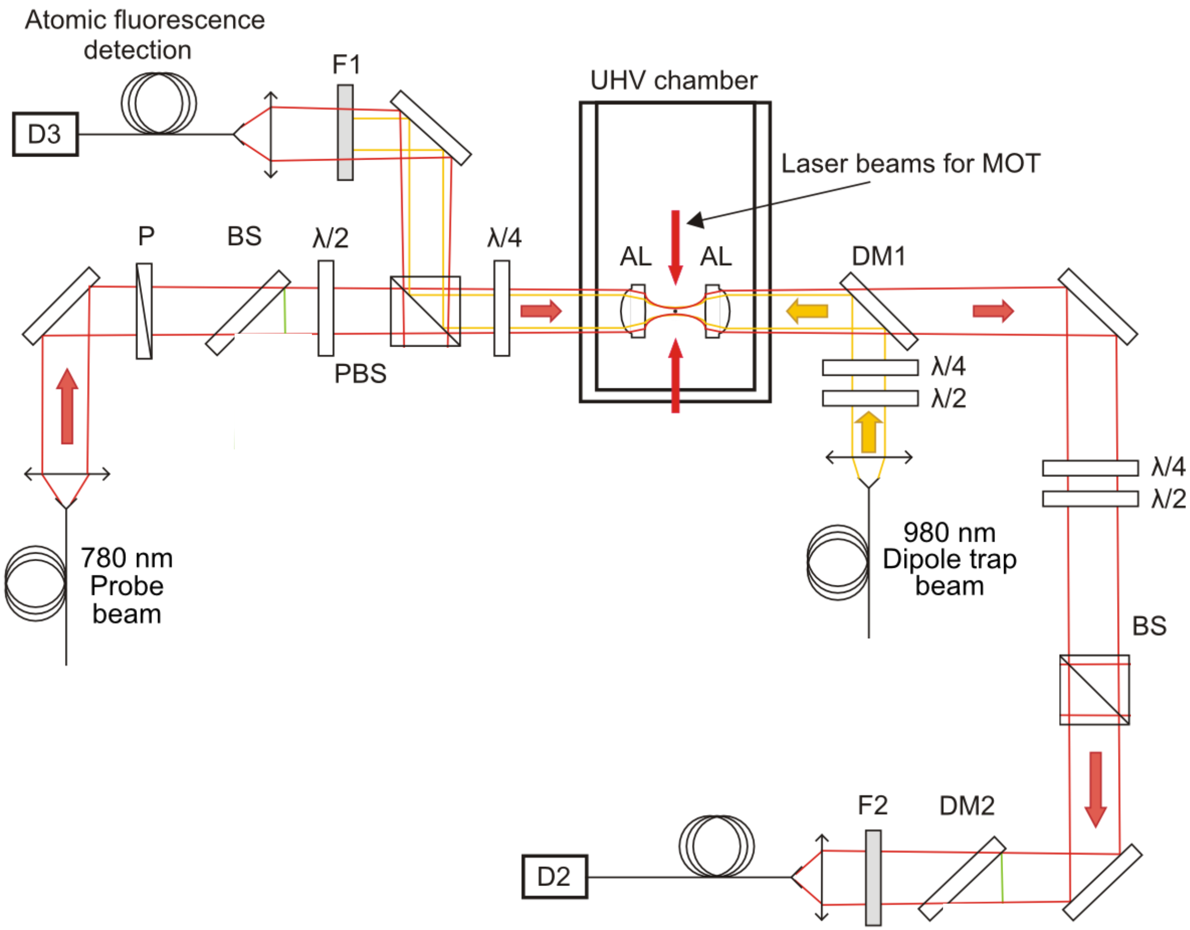

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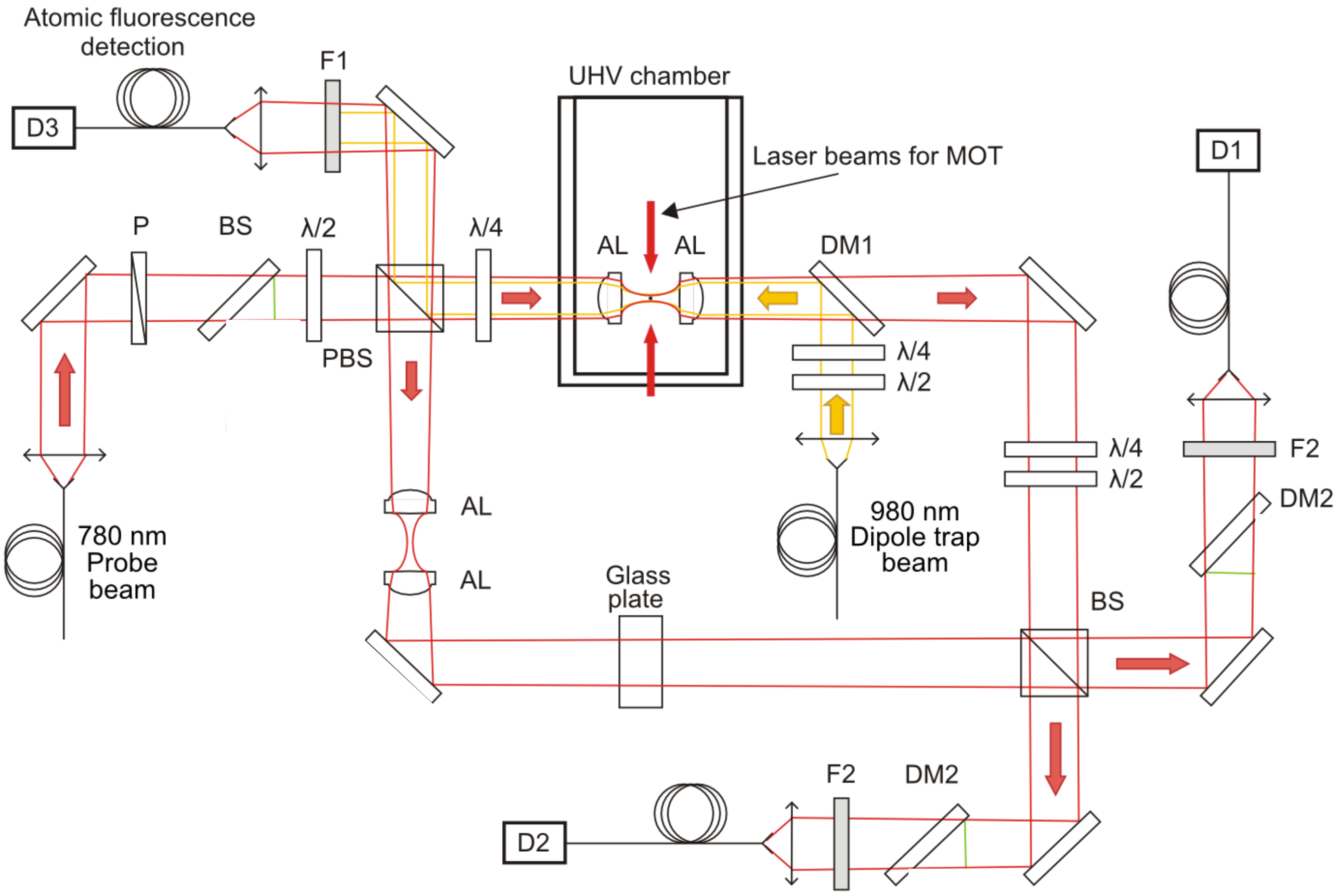

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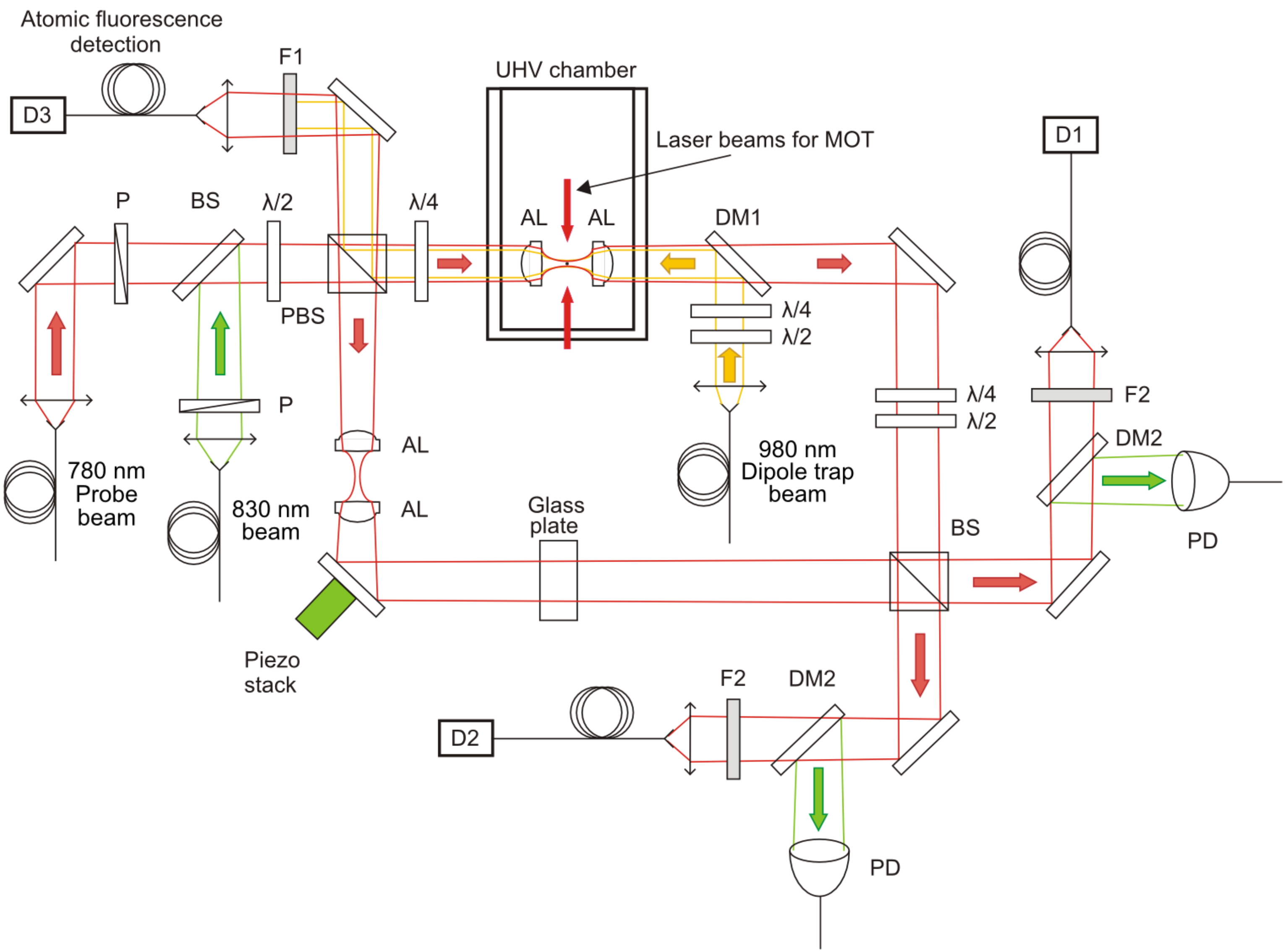

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# Experimental Setup

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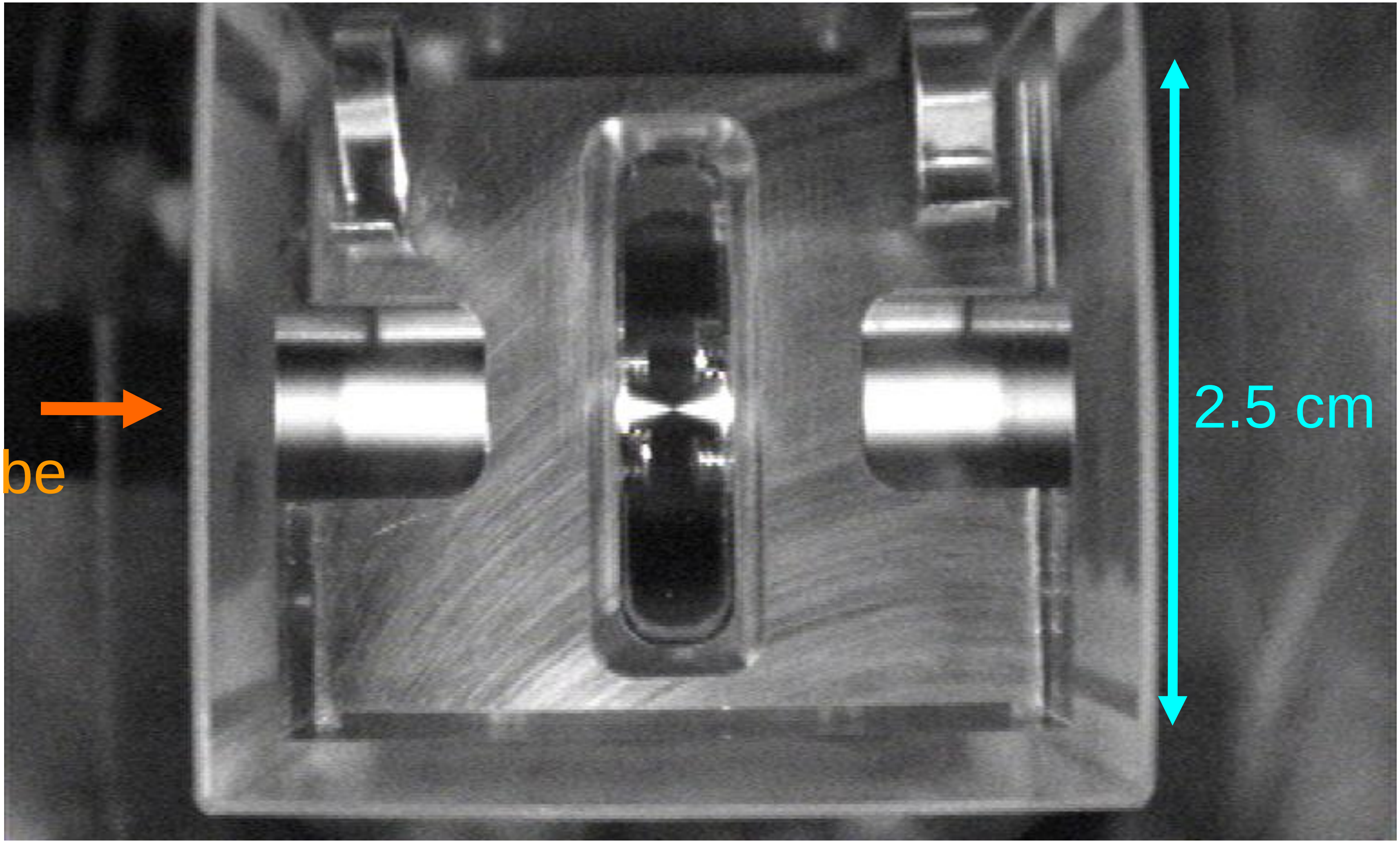
probe

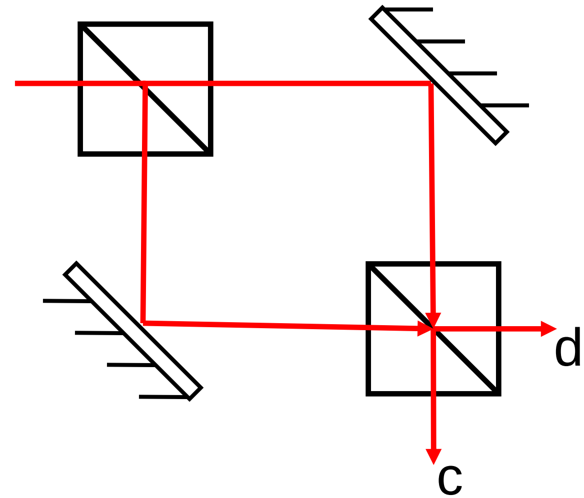


# Phase Measurement



Mach-Zehnder interferometer.

$$\Delta\phi = \arccos\left(\frac{P_c - P_d}{P_c + P_d}\right)$$



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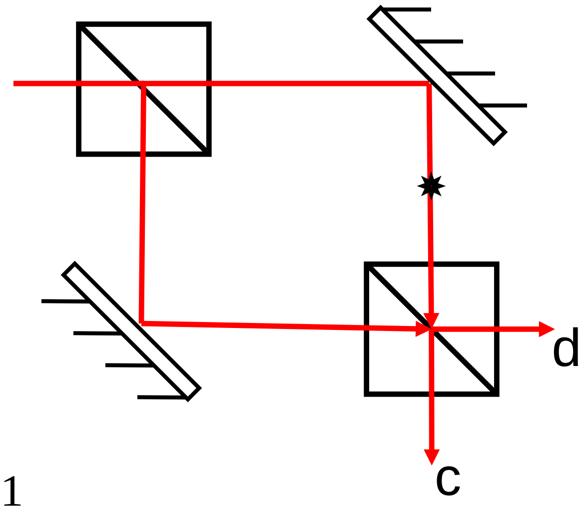


$$\Delta\phi = \arccos\left(\frac{P_c - P_d}{P_c + P_d}\right)$$

$$\Delta\phi' = \arccos\left(\frac{P_{c'} - P_{d'}}{\left(P_c + P_d\right)\sqrt{T}}\right) \quad ; T = \frac{2(P_{c'} + P_{d'})}{\left(P_c + P_d\right)} - 1$$

$$\delta\phi = \Delta\phi' - \Delta\phi$$

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# Results

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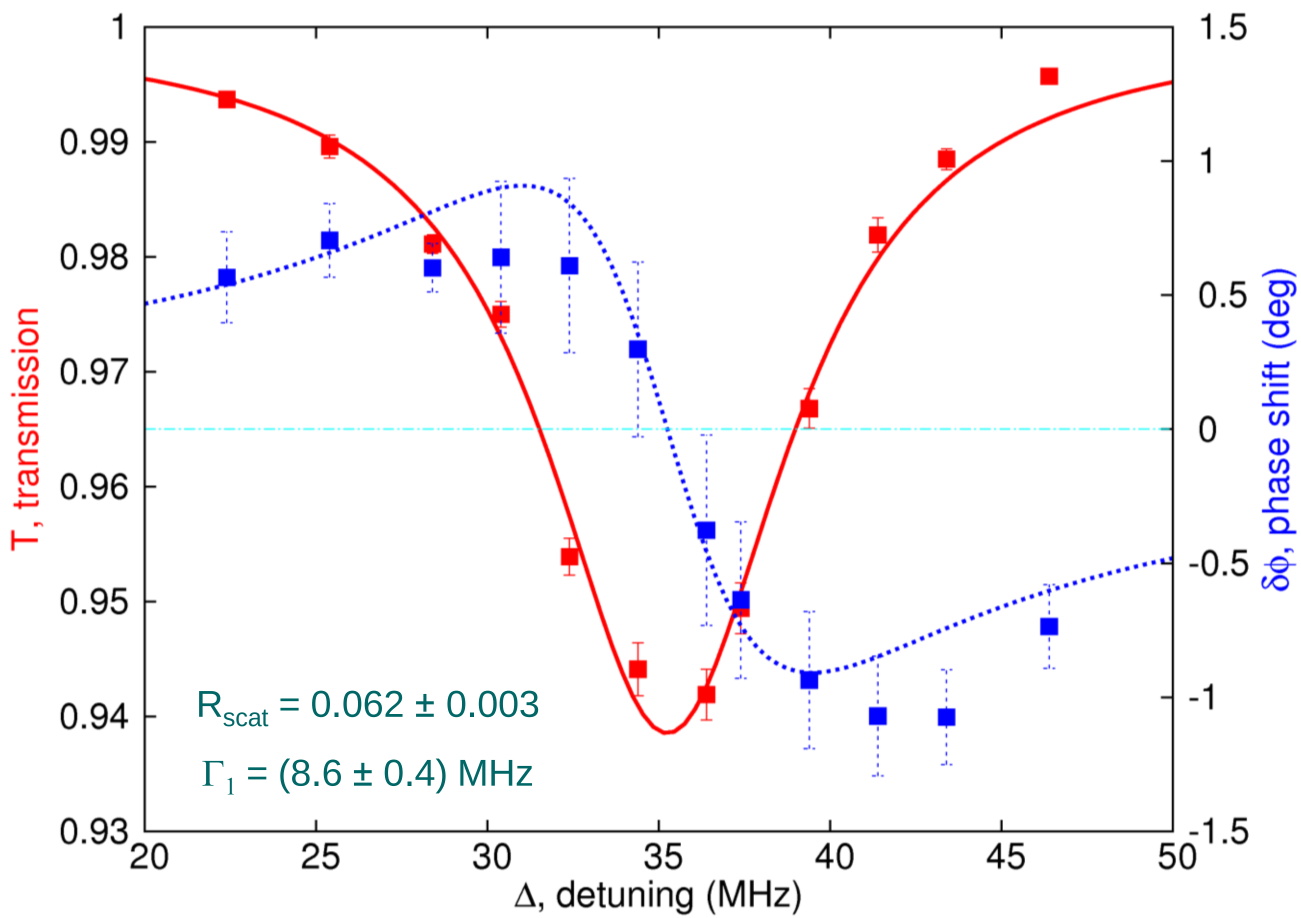


Transmission of

(93.9 ± 0.2)%

Max phase shift of (0.9 ± 0.2) ° at ~Γ/2

<u>Theoretical</u>

Transmission: 84%

max phase shift: 2.3°

$$\delta\phi = \arg(\vec{E}_{\text{out}} \cdot \vec{E}^*_{\text{in}}) = \arg\left(4\Delta^2 + \Gamma^2\left(1 - R_{\text{scat}}/2\right) + iR_{\text{scat}}\Gamma\Delta\right)$$

$$T = \frac{|\vec{E}_{\text{out}}|^2}{|\vec{E}_{\text{in}}|^2} = \frac{4\Delta^2 + \Gamma^2\left(1 - R_{\text{scat}}/2\right)^2}{4\Delta^2 + \Gamma^2}$$

# Conclusion

- Strong interaction of light with a single atom can be observed by simple focusing.
- 0.9° phase shift of a weak coherent beam observed together with 93.9% transmission.

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Thank You & The End

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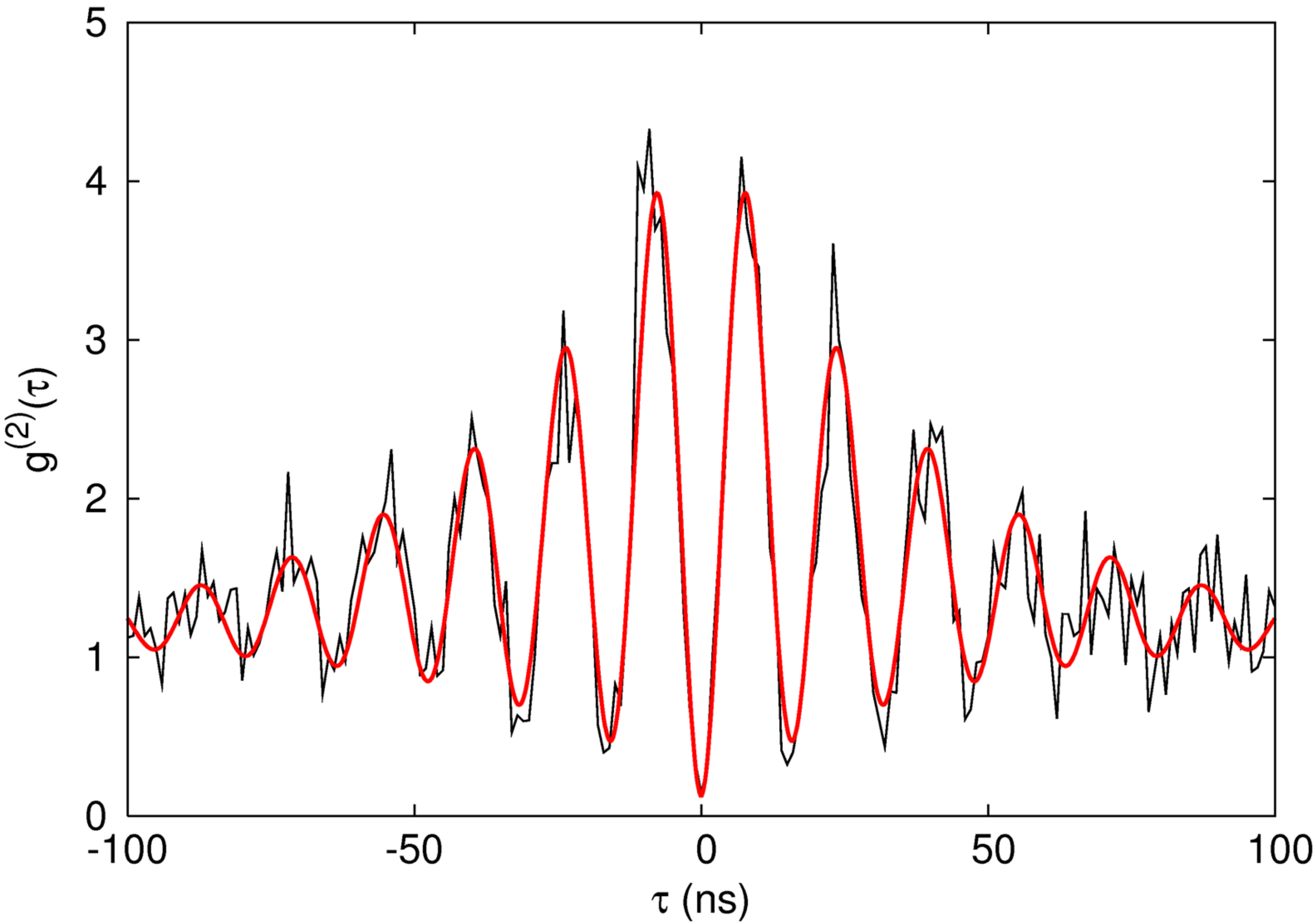
# Antibunching in single atom fluorescence



# Dipole trap laser wavelength: 980 nm