# Molecules Coupled to Dielectric Waveguides: On-Chip Platform for Many-Body Physics

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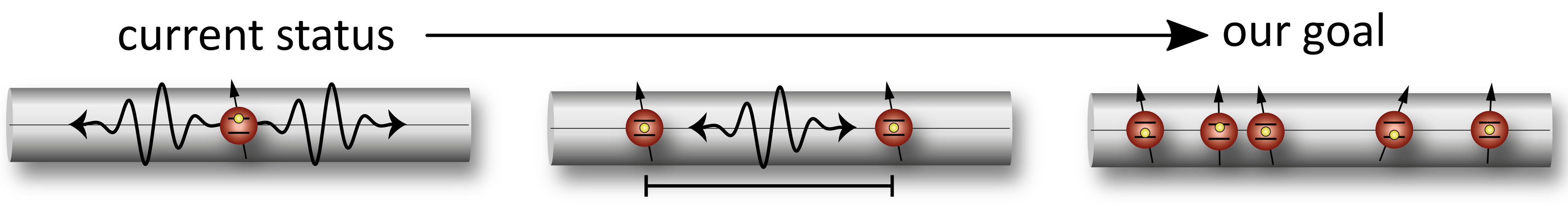
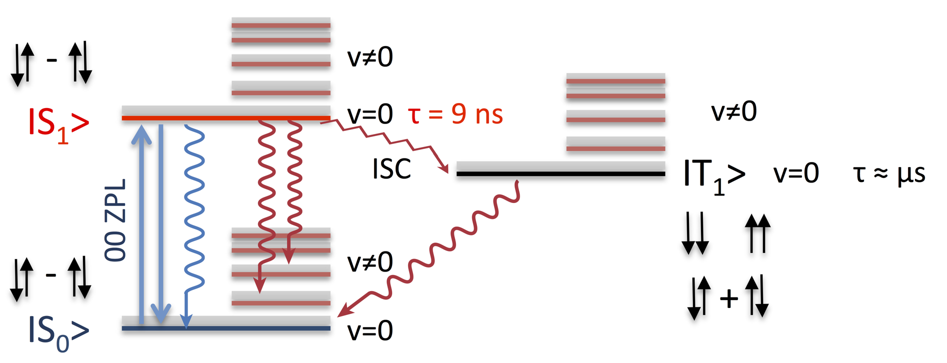
## Introduction

Studies of photons interacting with a well-defined arrangement of single emitters are experimentally challenging either due to lack of spatial or spectral control over the atomic resonances. Dielectric waveguides interfacing solid state emitters as quantum dots, NV-centers or molecules are promising systems with high control over the photonic potential for exploring the rich phenomena of polaritonic behaviour in one dimension [1].



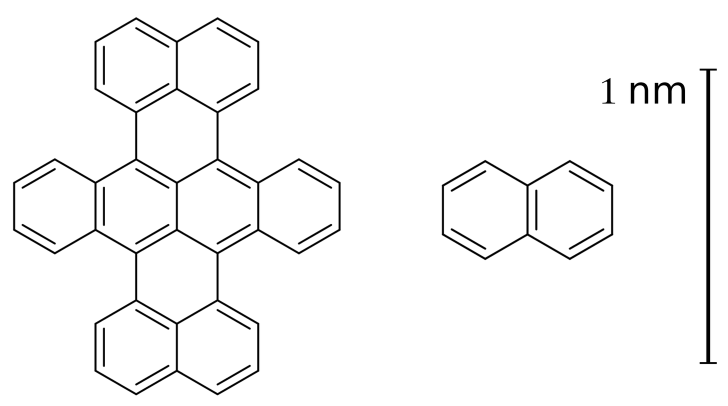

1D light matter interface | far field coupling of two emitters | shared polaritonic excitation

## Quantum Emitter: Dye Molecule

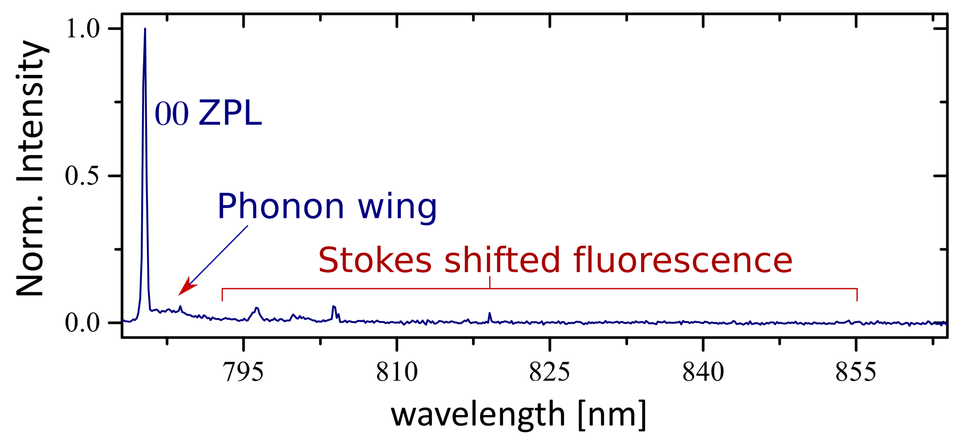



simplified level scheme of dye molecules

host guest system



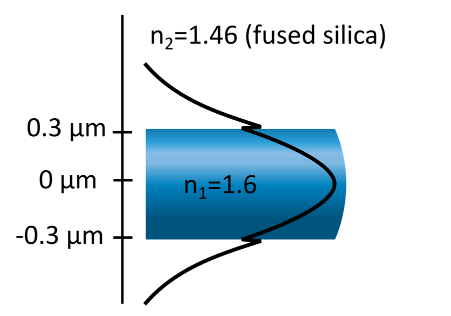

DBT (dye) naphthalene (matrix)



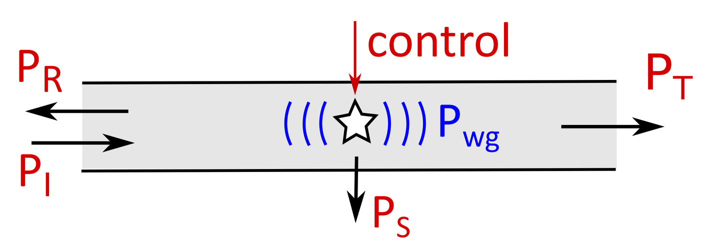

emission spectrum of a single DBT molecule

- lifetime-limited transition at 1.5 K ($\Gamma_0$ = 30 MHz)
- quantum efficiency close to unity
- 50 % emission on 00-ZPL η

## Coherent Interaction in a Nanoguide [2]




power transmission



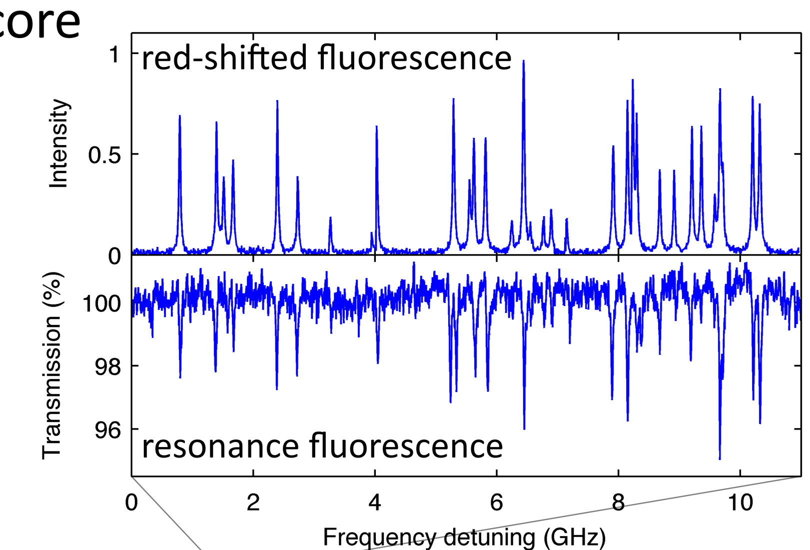

coupling efficiency

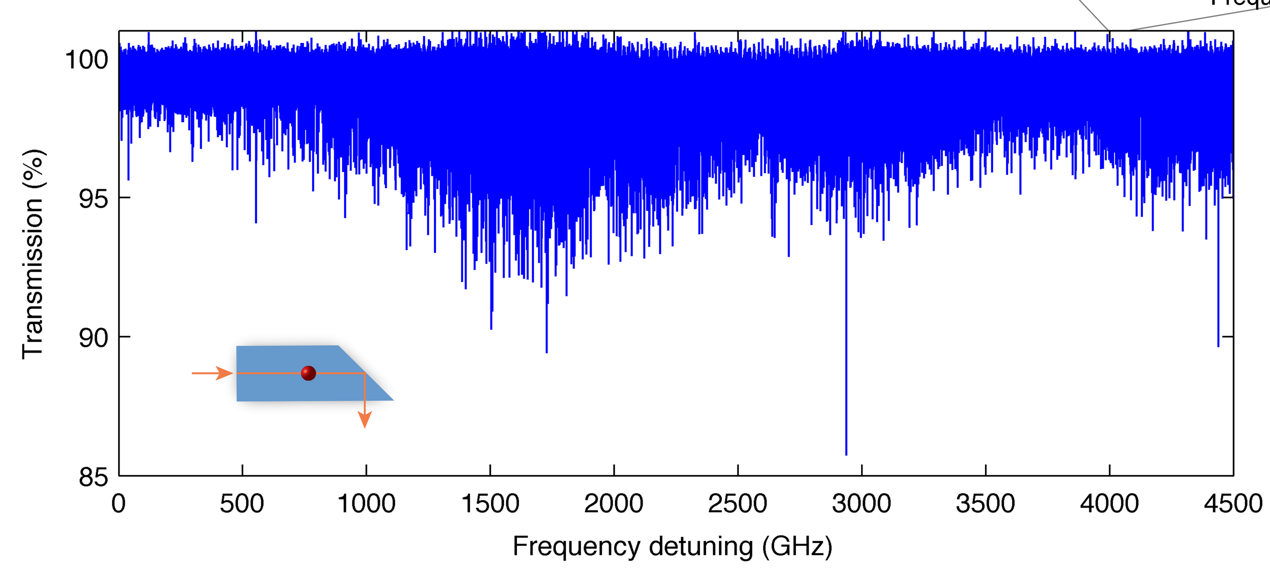
$$\beta = \frac{P_{wg}}{P_{wg} + P_S} = \frac{\Gamma_{wg}}{\Gamma_{tot}}$$

- nano capillary filled with dye doped core
- coupling efficiency up to 18%

reflection $R = \frac{P_R}{2P_I} = (\eta\beta)^2$

transmission $T = \frac{P_T}{P_I} = (1 - \eta\beta)^2$



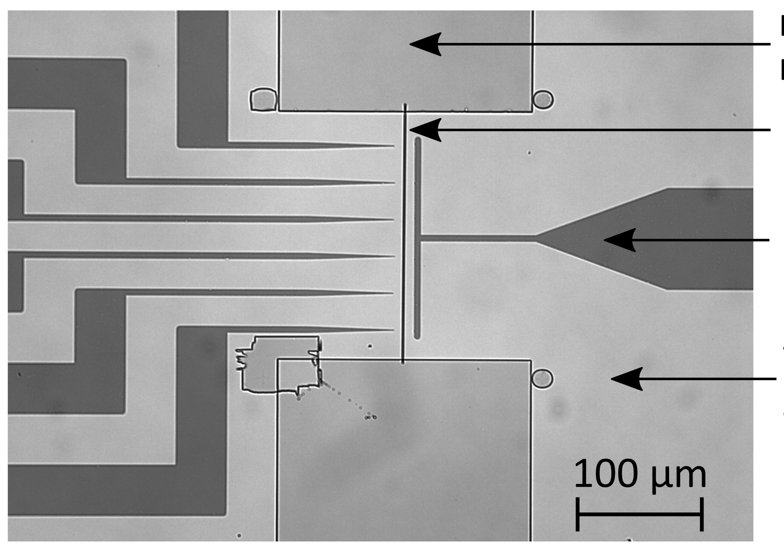

up to 11% extinction for a single molecule due to destructive interference

inhomogeneous broadening: coherent transmission of a nanoguide (5500 molecular resonances)

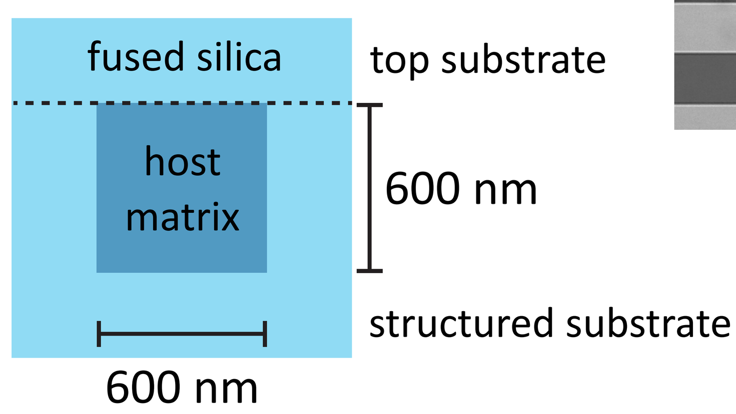
[1] H. Haakh, S. Faez, V. Sandoghdar, arXiv:1510.07979v2 (2015).
[2] S. Faez et al., *Phys. Rev. Lett.* **113**, 213601 (2014).

## Tunability of Molecular Resonances

- burried naphthalene bar waveguides
- integrated ITO micro-electrodes along active waveguide region

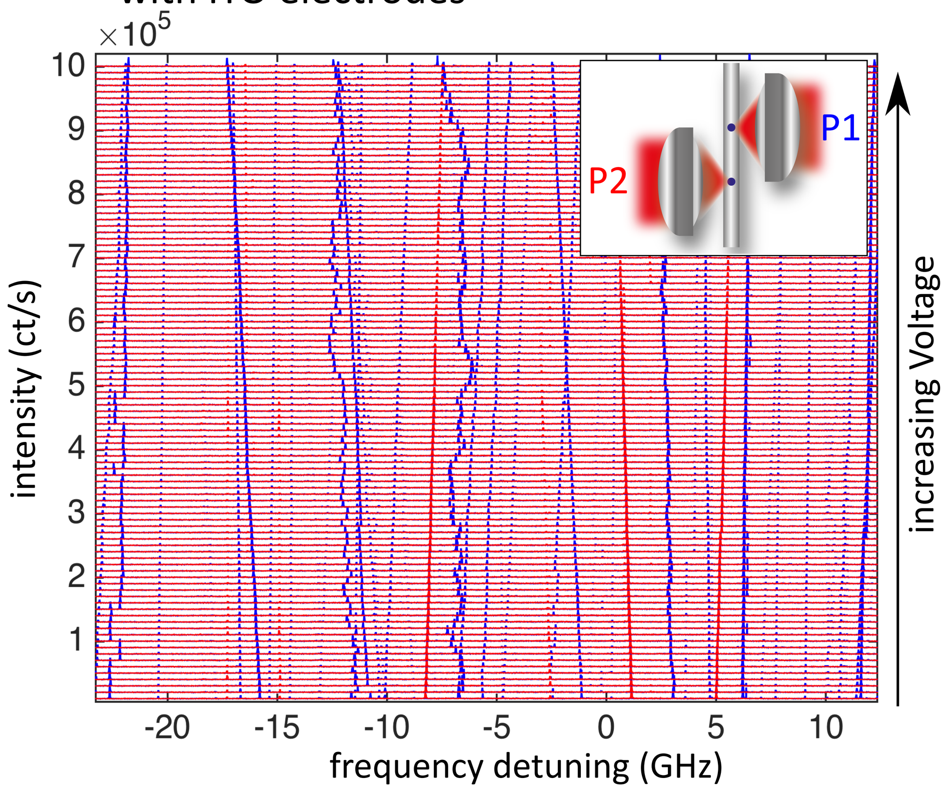



microscope image of waveguide with ITO electrodes




- DC-Stark shift up to 1 GHz/V, tuning range of 100 GHz
- random spatial distribution of emitters

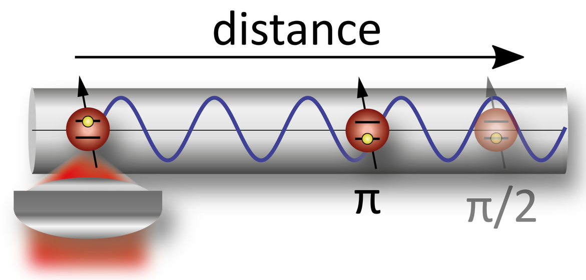
→ **search for crossing pairs**



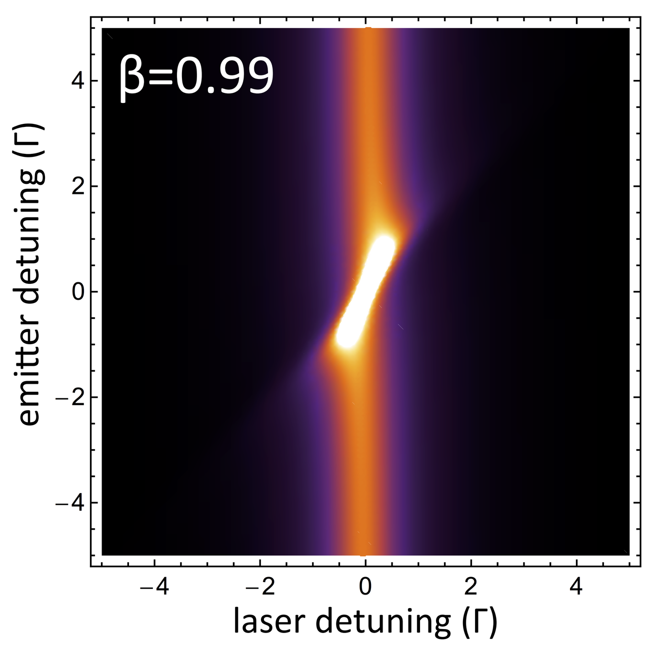

voltage sweeped excitation spectrum at two different positions (P1, P2) along waveguide

## Dipole-Dipole Interaction

phase dependent interaction potential:

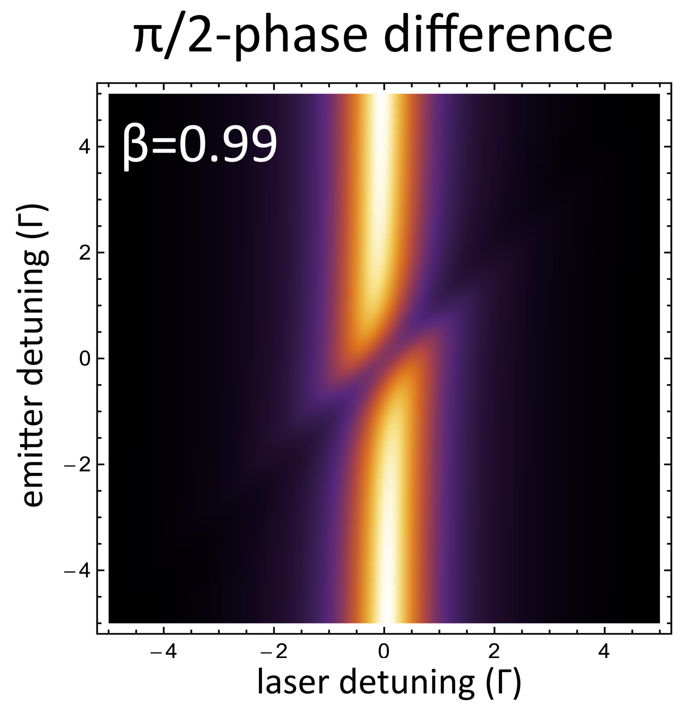



π-phase difference




- bragg resonance
- cavity formation

π/2-phase difference

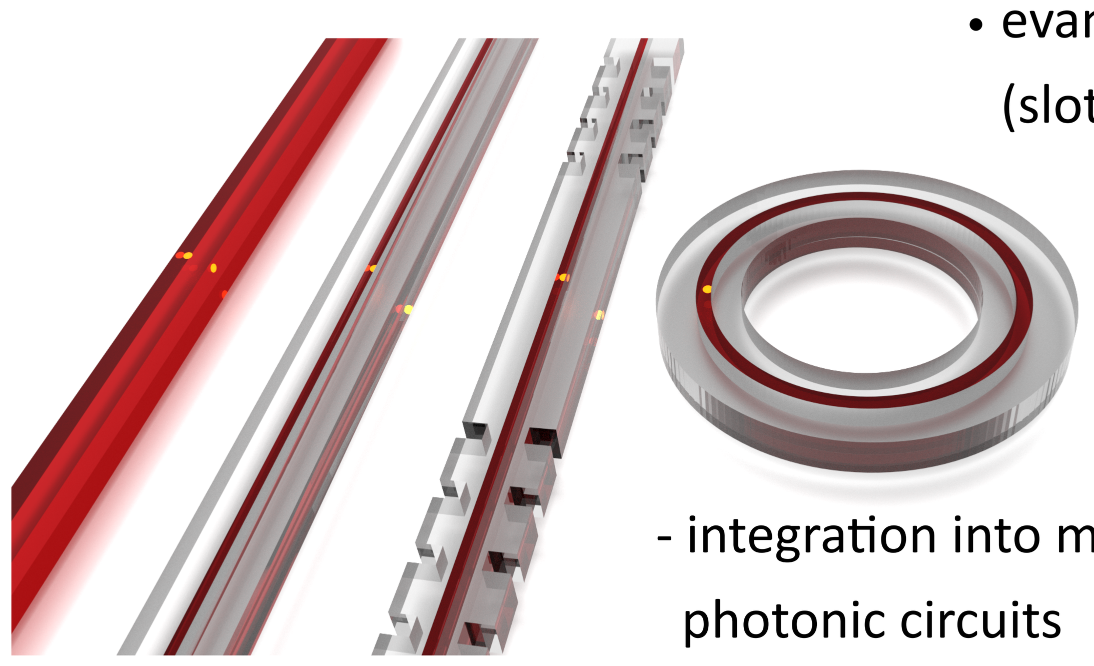



- anti-crossing feature
- coupling strength of β Γ

Spectral features are highly sensitive to relative emitter spacing.

## Future Directions

- exploration of polaritonic behaviour and many-body states
- increased coupling efficiency β:
  - evanescent field enhancement (slot waveguides)
  - resonant feedback (ring resonators, Fabry-Perot cavities)



- integration into more complex photonic circuits