NIST Nanoscale Spectroscopy

SPS Presentation

Modeling the two-quantum coherent spectrum of a semiconductor microcavity

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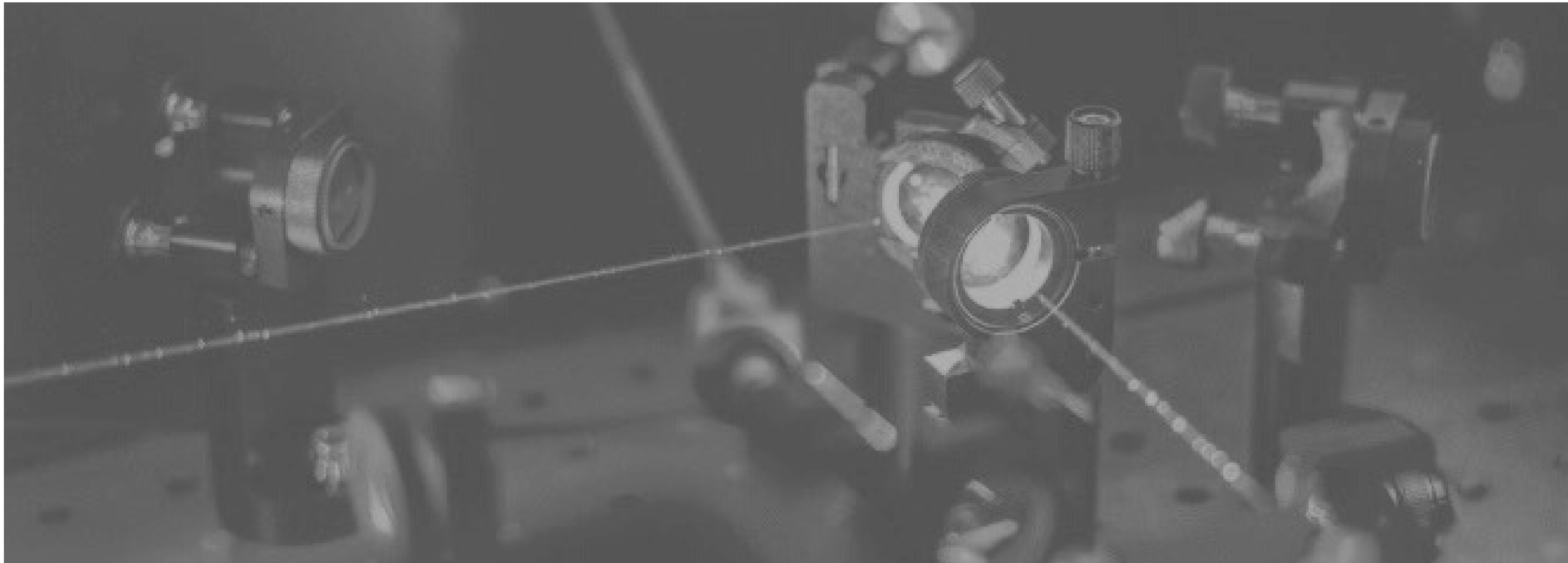
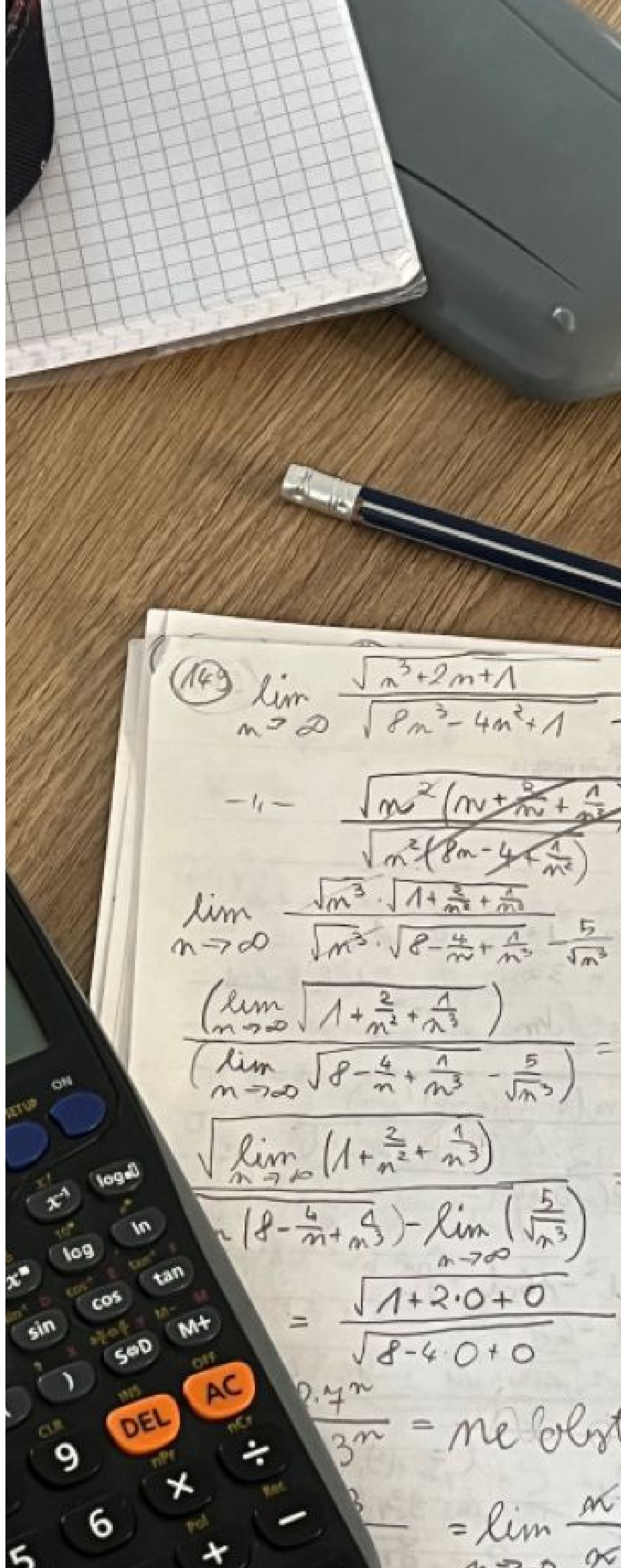
Embry-Riddle Aeronautical University (Prescott)



About Me

- 2023 Graduate
  - B.S. Space Physics, Minor Computer Science
  - ERAU (Prescott)
  - Gravitational Theory
- 2x SPS Intern
  - SOCK
  - NIST Research
- Served on SPS National Council 2 years
  - AZC Zone 16
- NASA Starshade Program
- Love to read

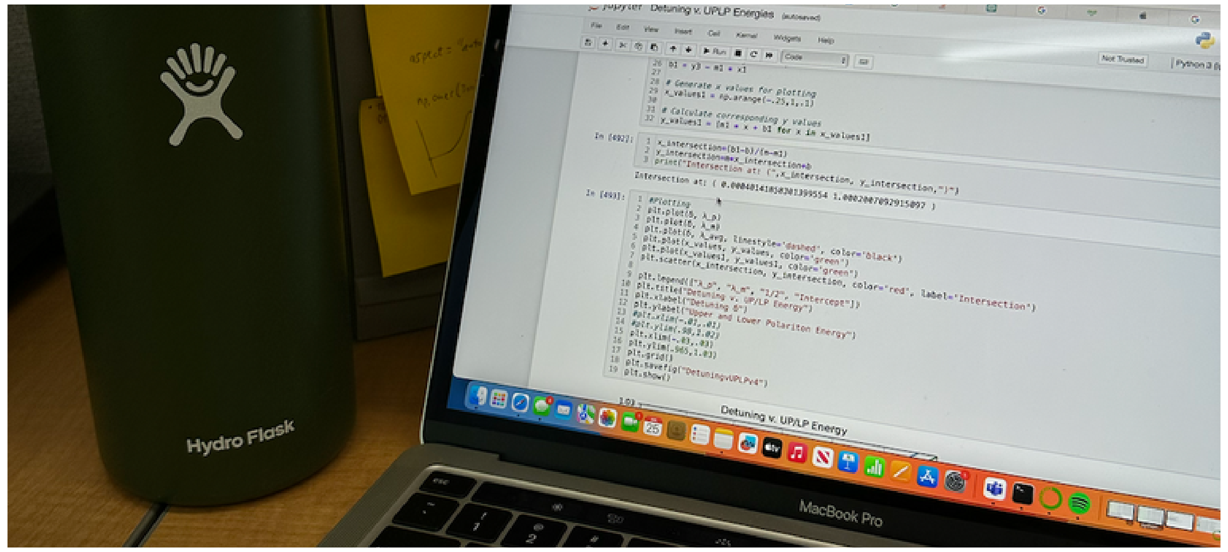


Our Project

- Multidimensional Spectroscopy
  - Light-matter interactions
  - Analyzing excitonic spectra
- Gallium Arsenide Nanostructure Semiconductor
  - Many-body interaction inside cavity

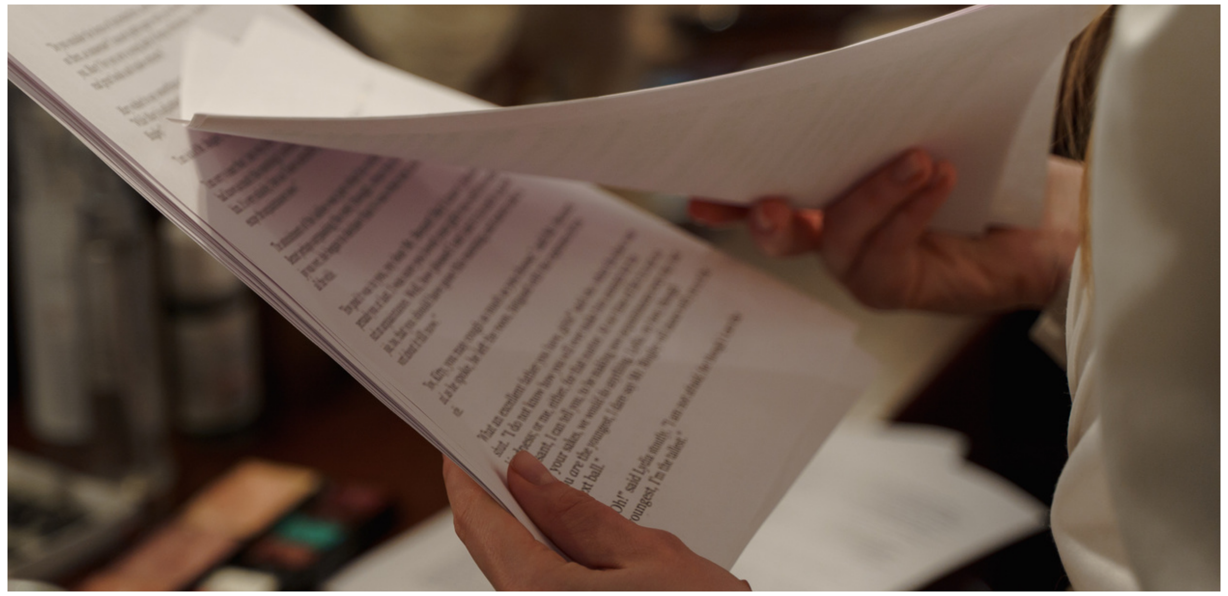
Our Goal

Simulate a 2-Quantum Spectra to compare with Experimental results



Our Approach

- Polariton Basis
  - Double-Sided Feynman Diagrams



The Details

The "-itons"

- Polariton: Combination of a photon and an exciton
- Exciton: Combination of an electron and a hole
- Biexciton: 2 X Exciton

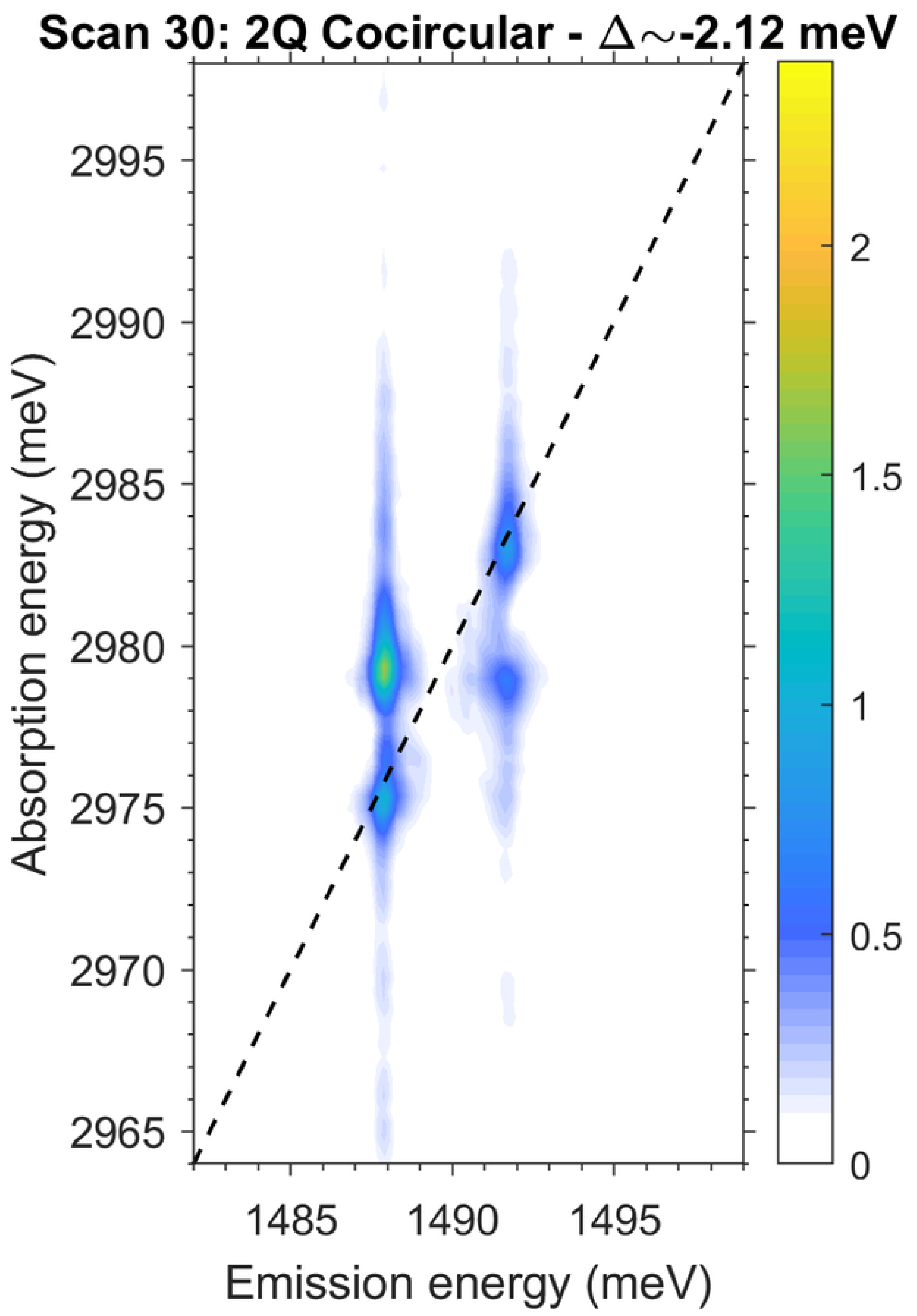
What's happening in the lab?

- Short pulses excite sample
- Set of nested interferometers
- Isolates the nonlinear response
- Multiple time delays -> multiple spectral dimension
- Linear v. Nonlinear

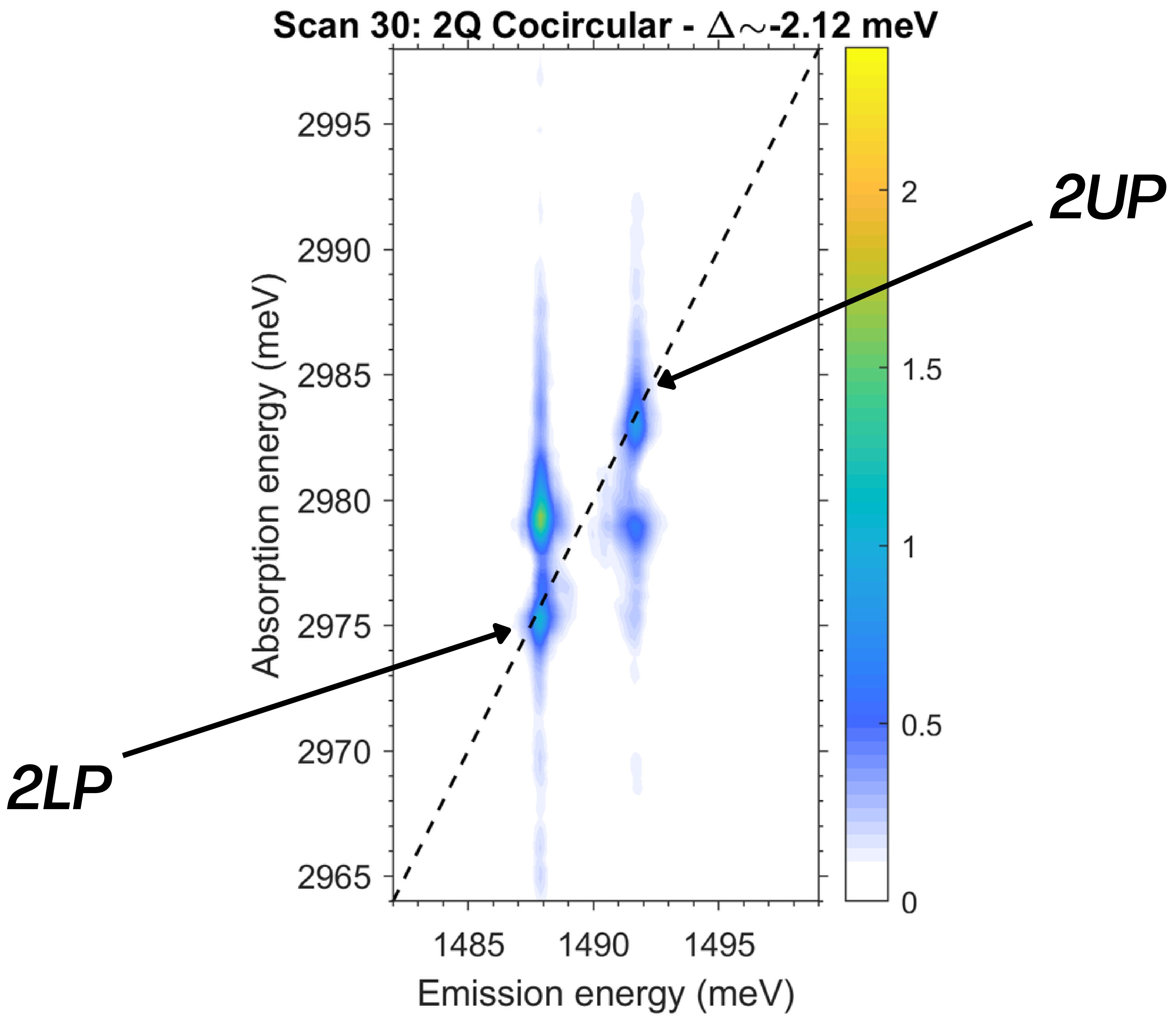
What We Saw

- LP/UP Spectra
- Needed a theoretical model to compare our findings based on various parameters

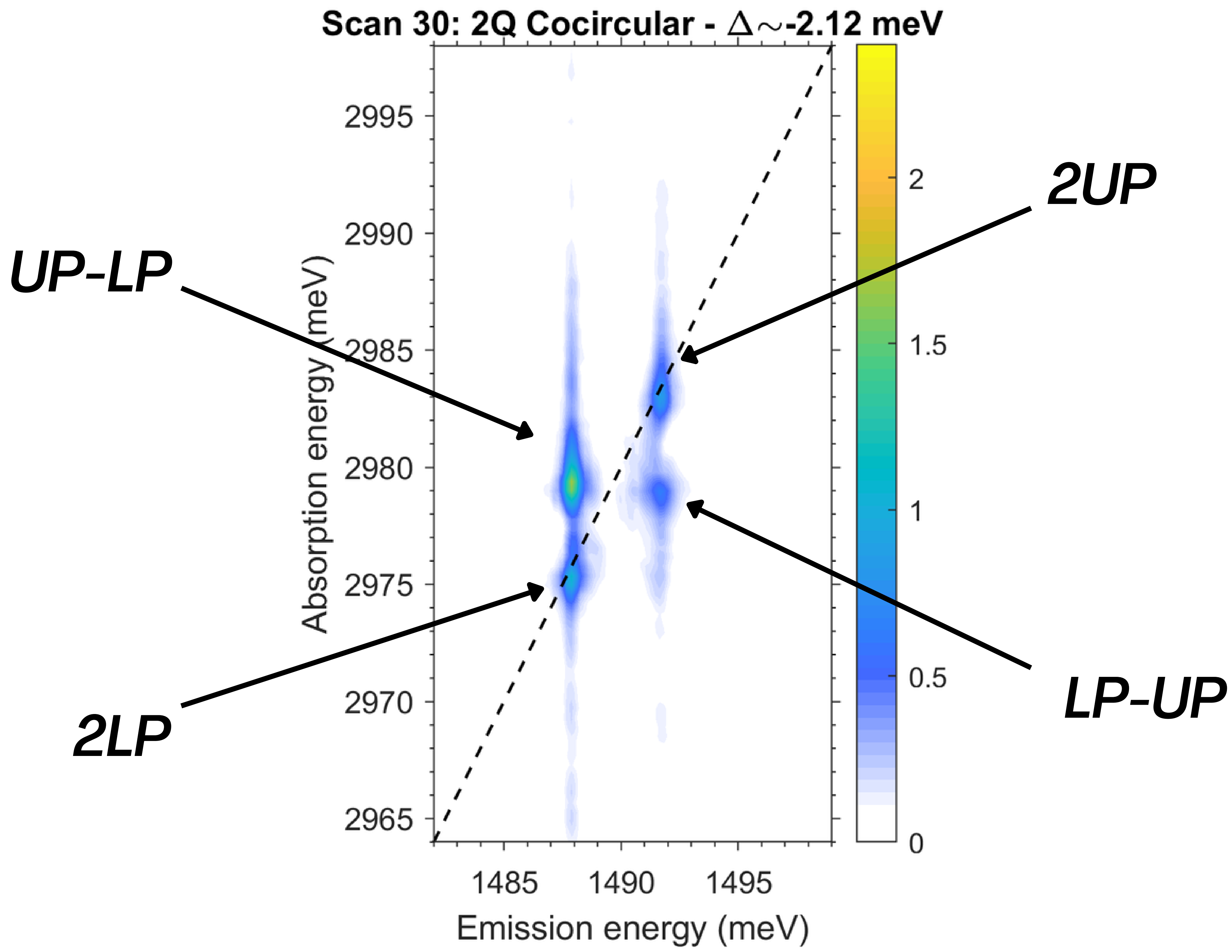
Experimental Spectra



Experimental Spectra



Experimental Spectra



Diagonalization

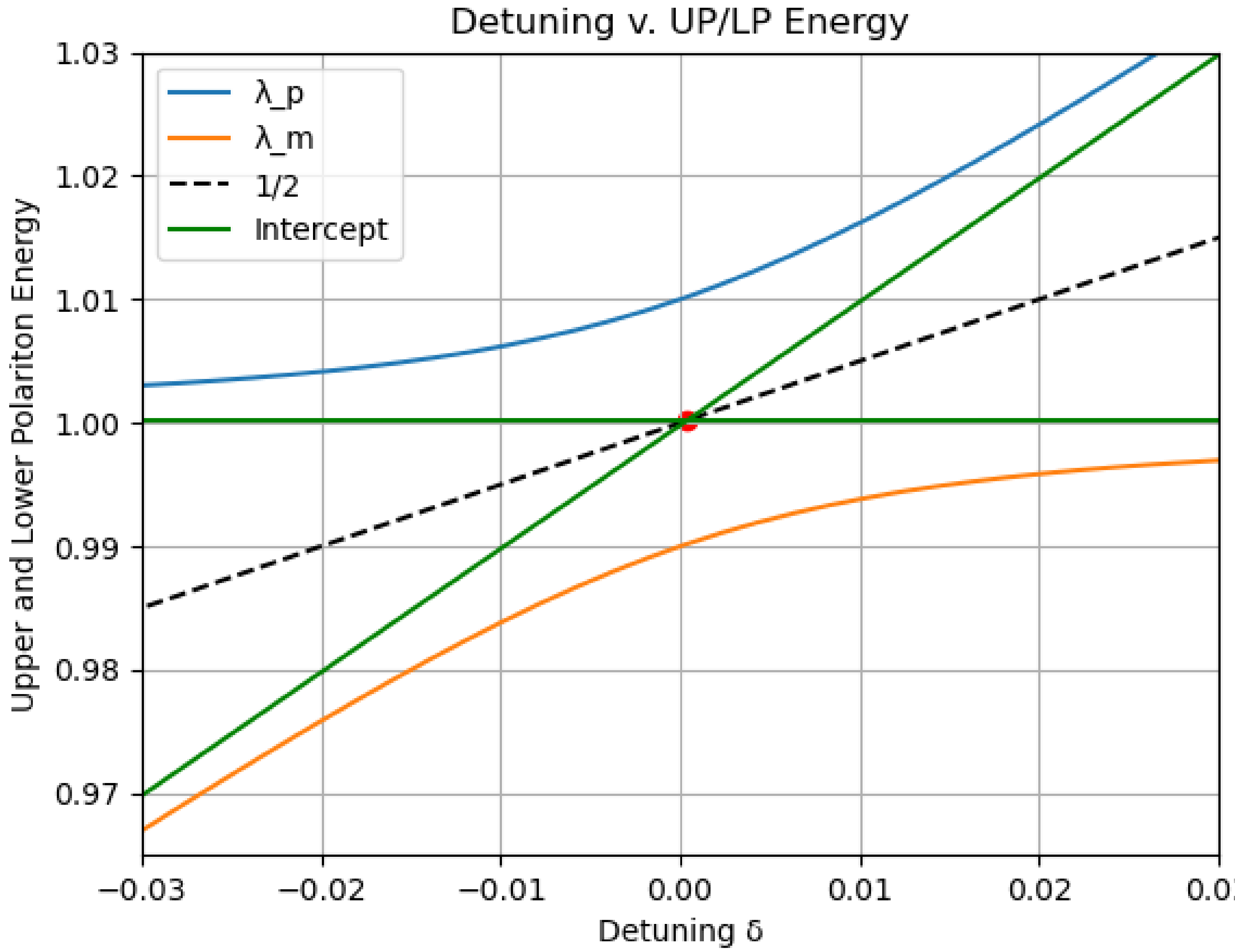
- Diagonalize the Jaynes-Cummings Hamiltonian:

$$\frac{\hat{H}_{JC}}{\hbar} = \tilde{\omega}_a \hat{\sigma^+} \hat{\sigma^-} + \tilde{\omega}_c \hat{a}^\dagger \hat{a} + g_1(\hat{a}^\dagger \hat{\sigma^-} + \hat{a} \hat{\sigma^+})$$

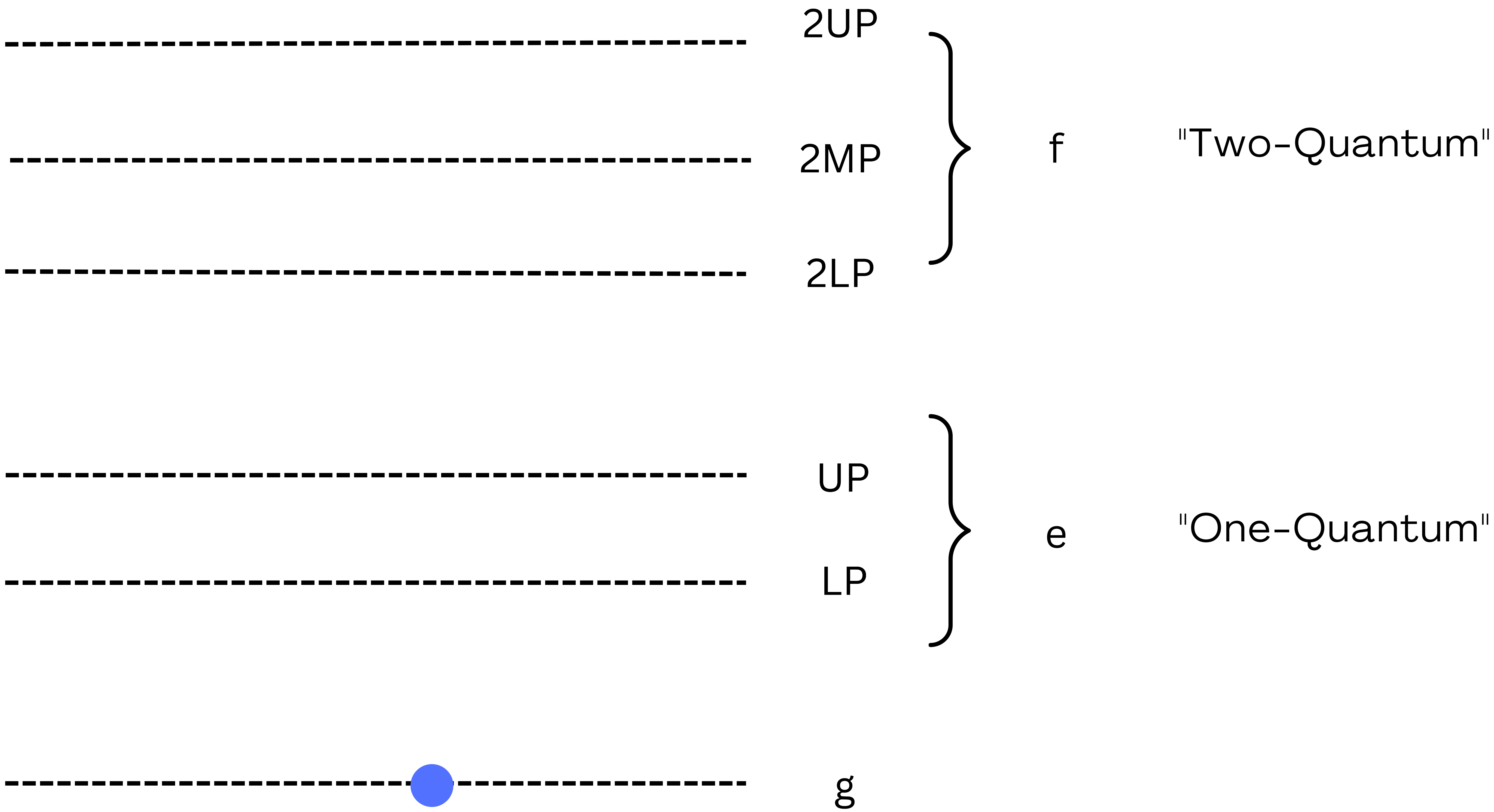
$$\lambda_1, \lambda_2 = \frac{-E_x + E_c \pm \sqrt{(E_x + E_c)^2 - 4(E_c E_x - g^2)}}{2}$$

$$\lambda_1, \lambda_2 = \frac{2E_x + \delta \pm \sqrt{\delta^2 + \Omega}}{2}$$

- Plot λ as a function of δ



Level Scheme Diagram



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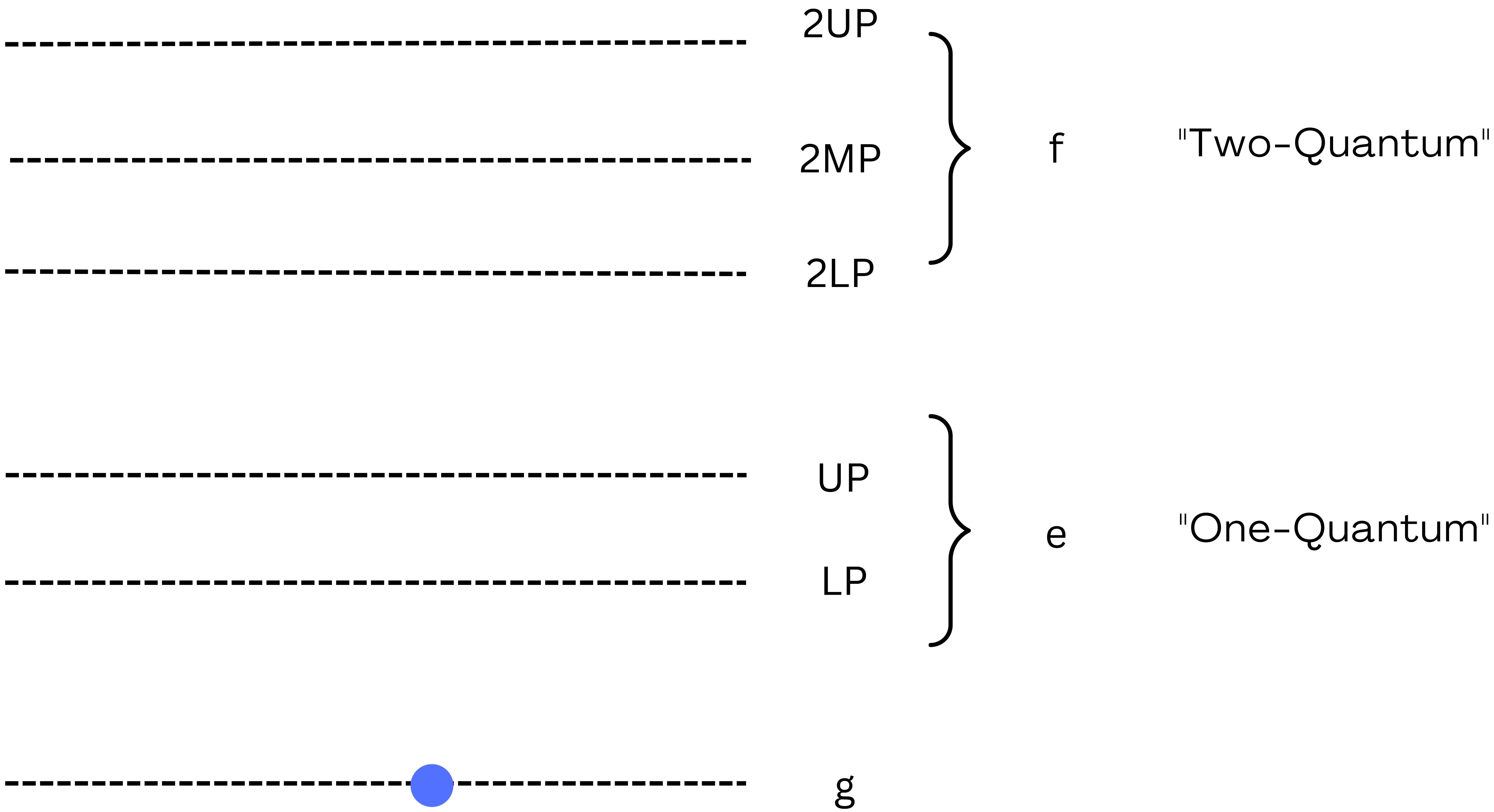
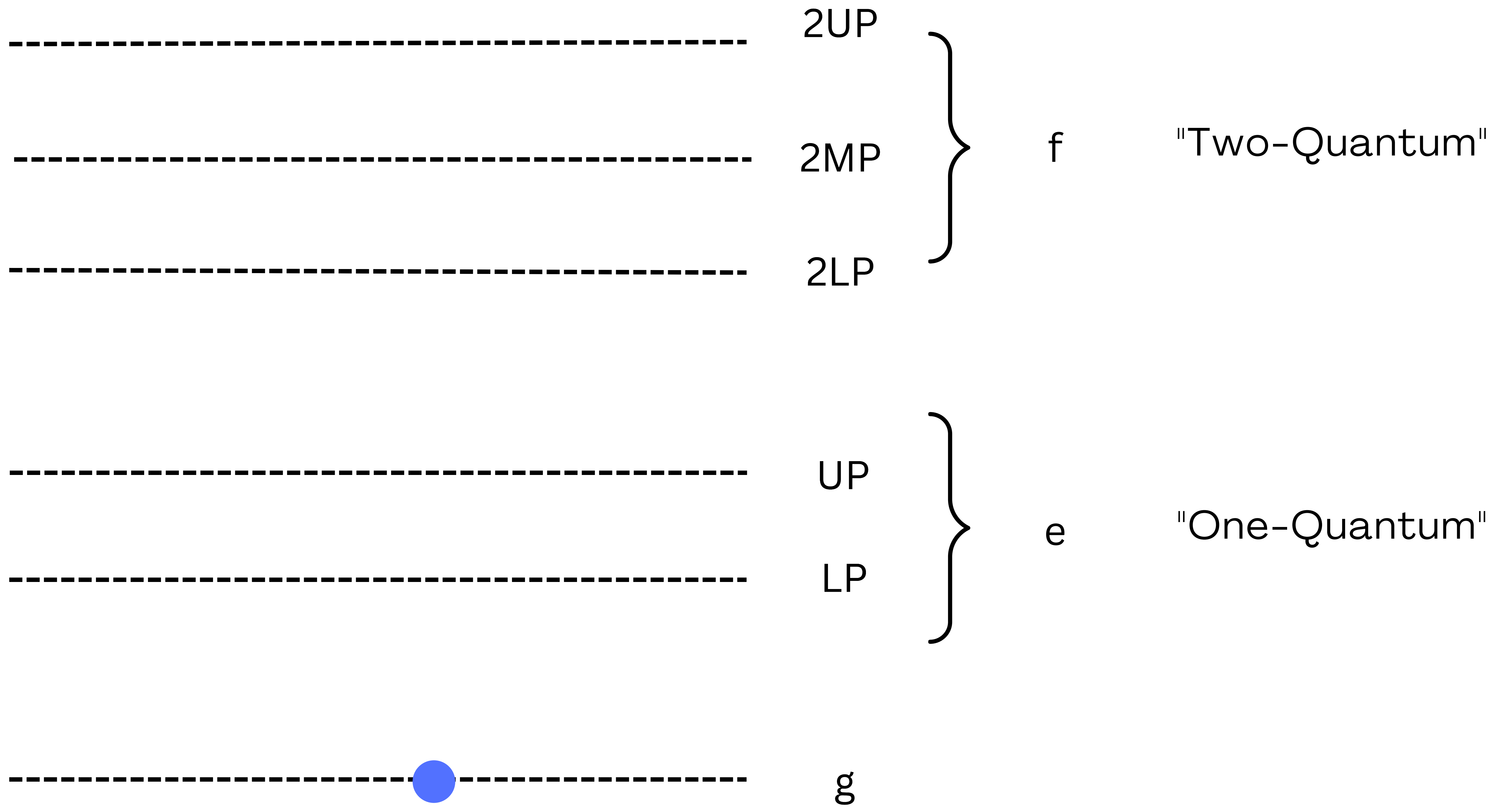
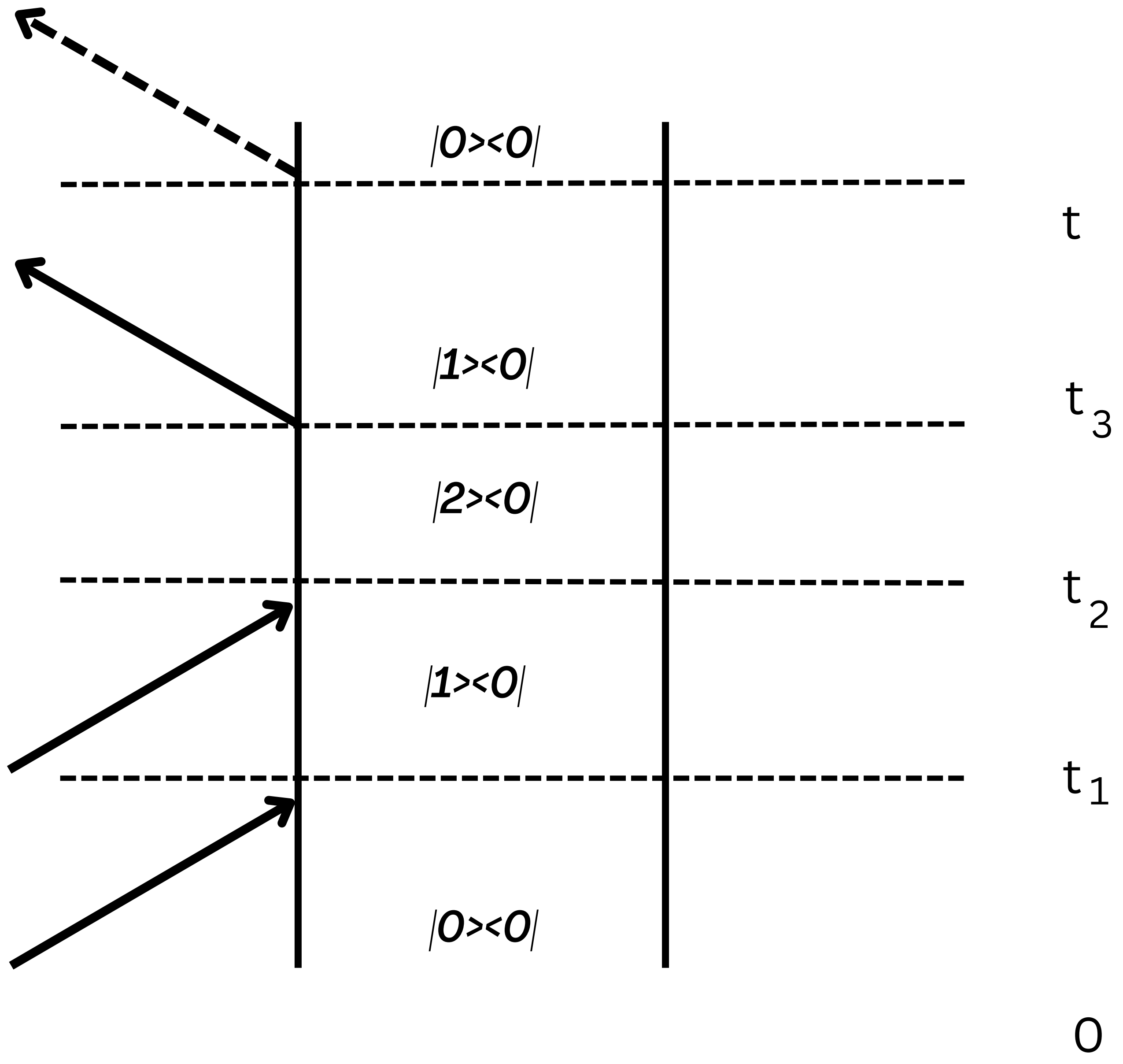


Level Scheme Diagram

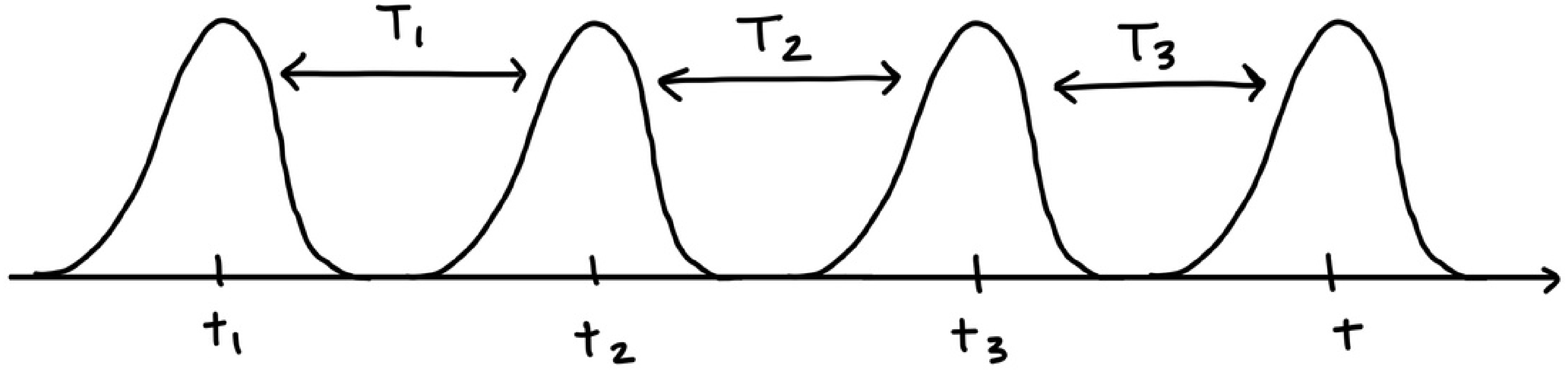


An example (2 quantum):



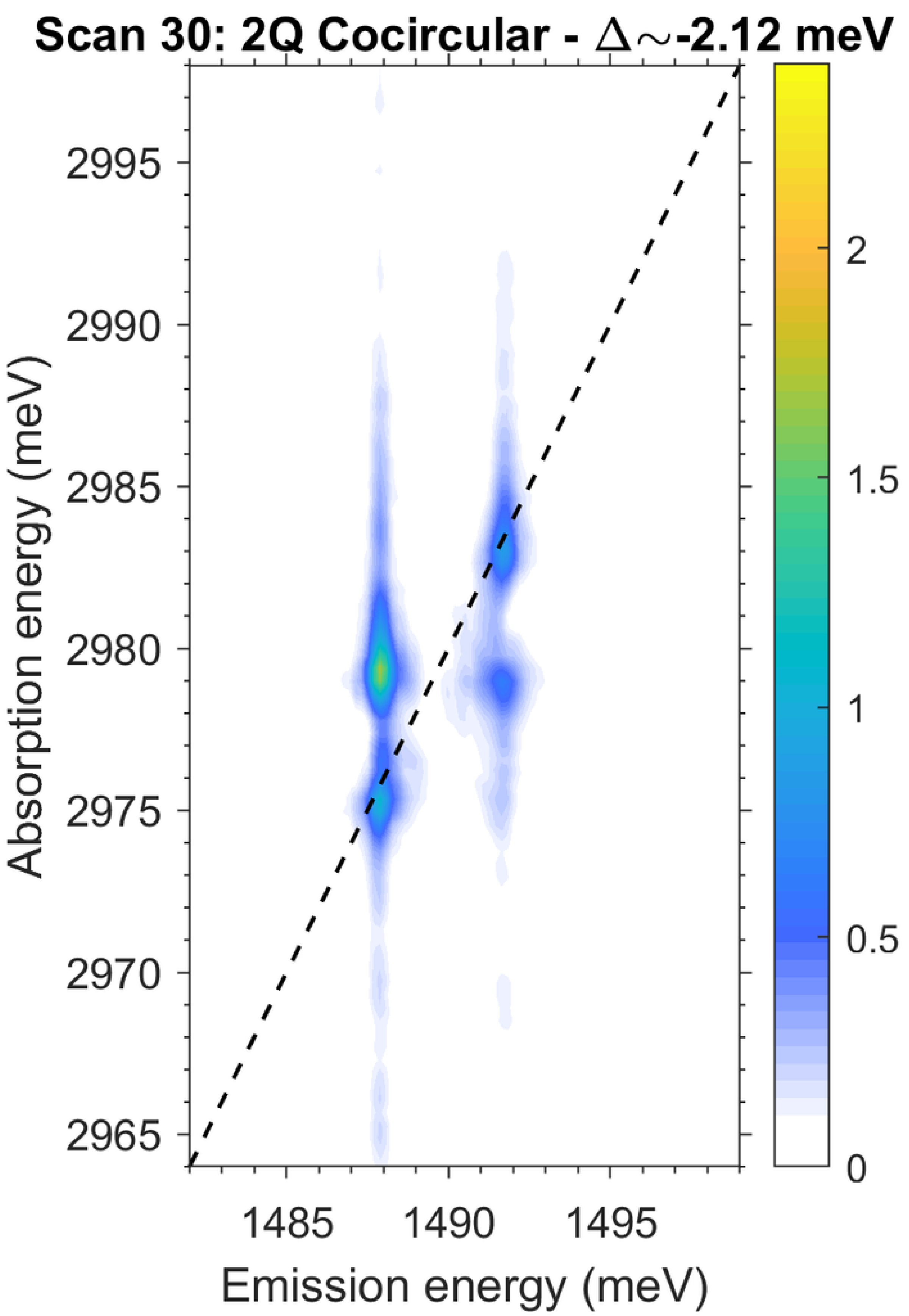
- Each element of the diagram tells us a different part of the equation
- Left Line = ket, Right Line = bra
- After various approximations, you can receive an equation like:

$$P^{(3)}(t) = \mu * (\varepsilon_1 (T_2 - T_1) e^{-i\omega_{eg}(T_2 - T_1)} \\ \varepsilon_2 (T_3 - T_2) e^{-i\omega_{fg}(T_3 - T_2)} \\ \varepsilon_3 (t - T_3) e^{-i\omega_{fe'}(t - T_3)})$$



2 Quantum Spectra

- Materials Needed:
  - Energy of UP/LP (diagonalization)
  - Level Scheme Diagram
  - 2D Fourier Transform of P(3)
  - Patience
- Figure has modified detuning value = -3
  - Detuning: Moves both peaks around



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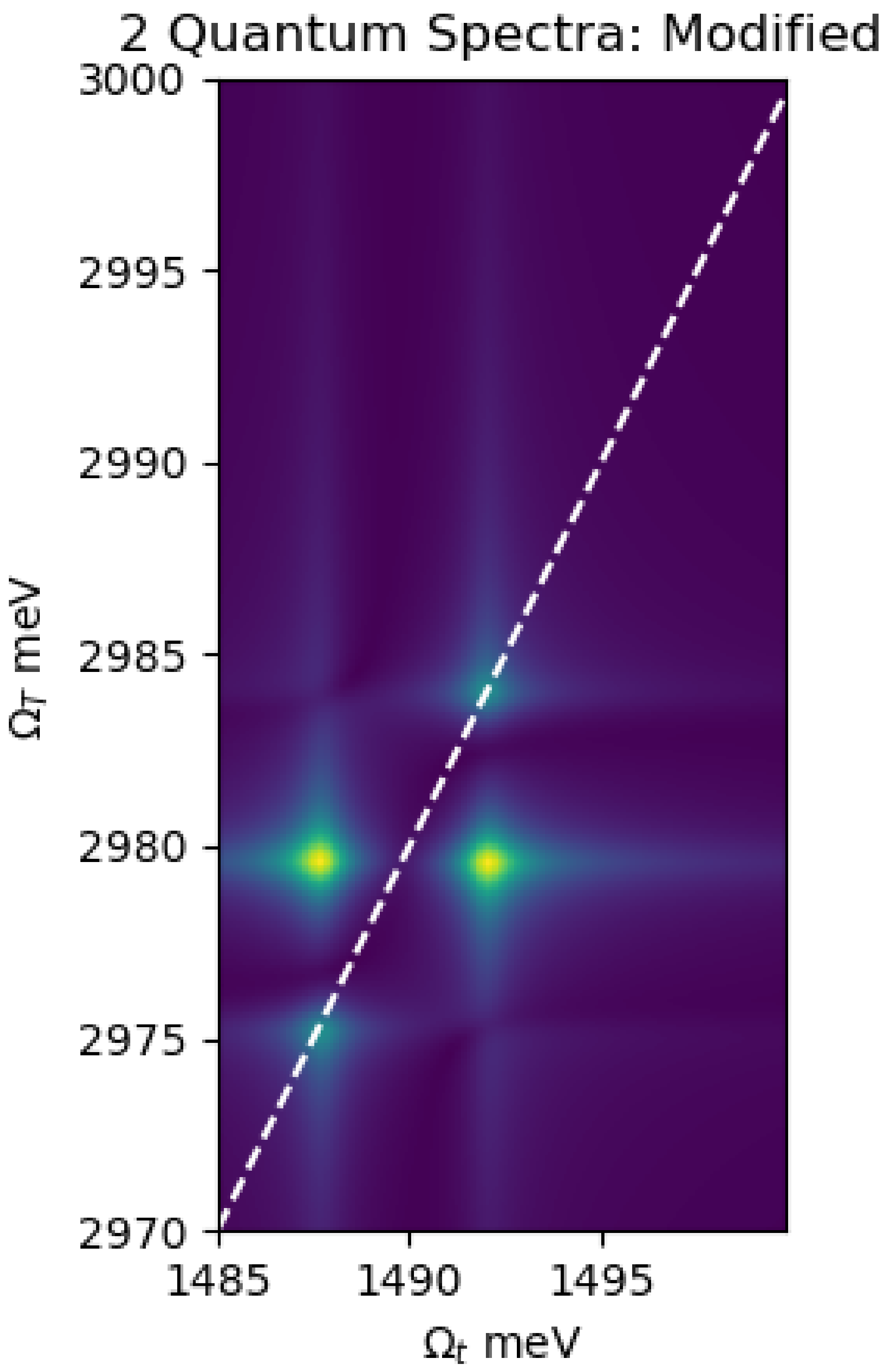

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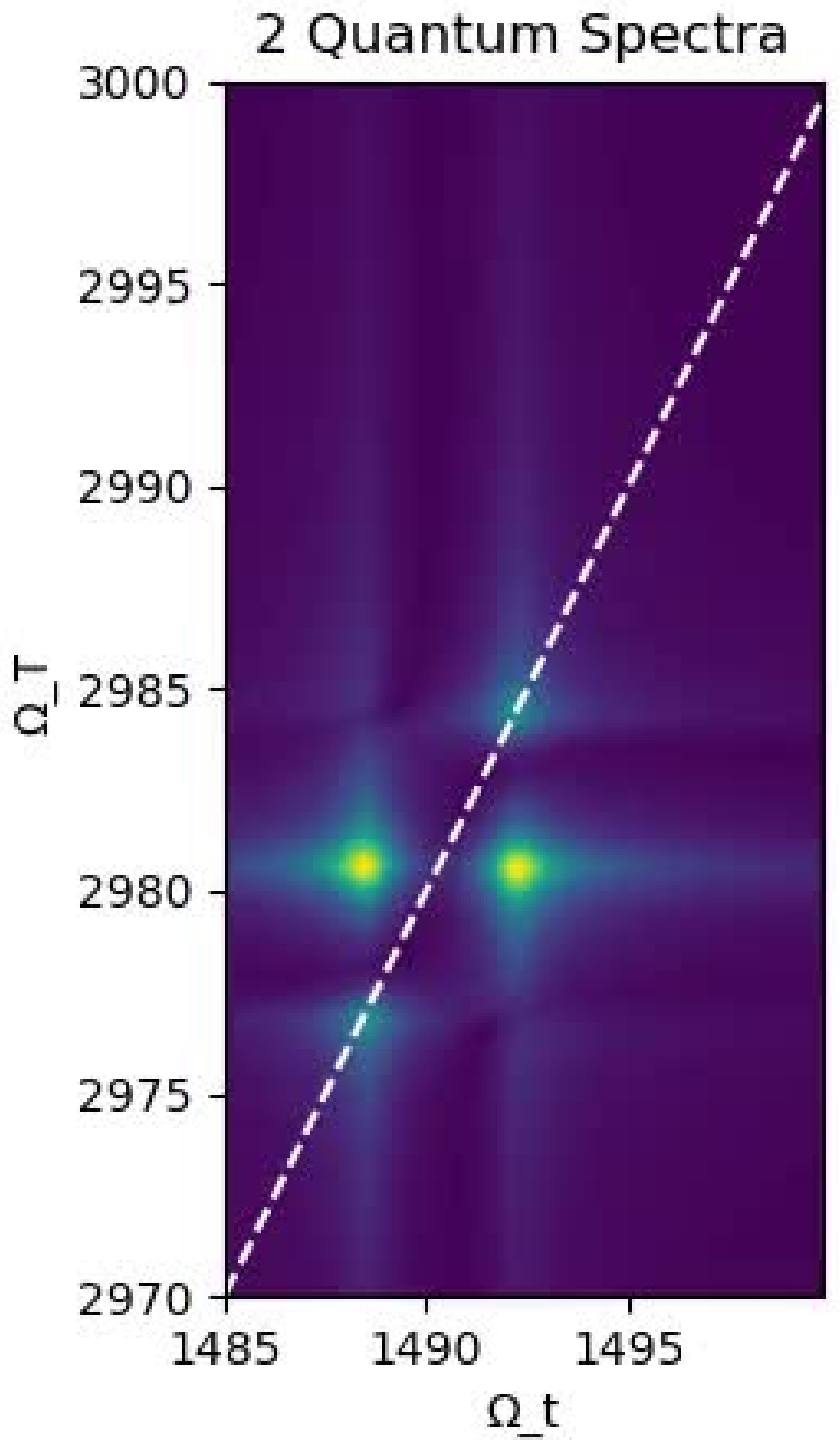
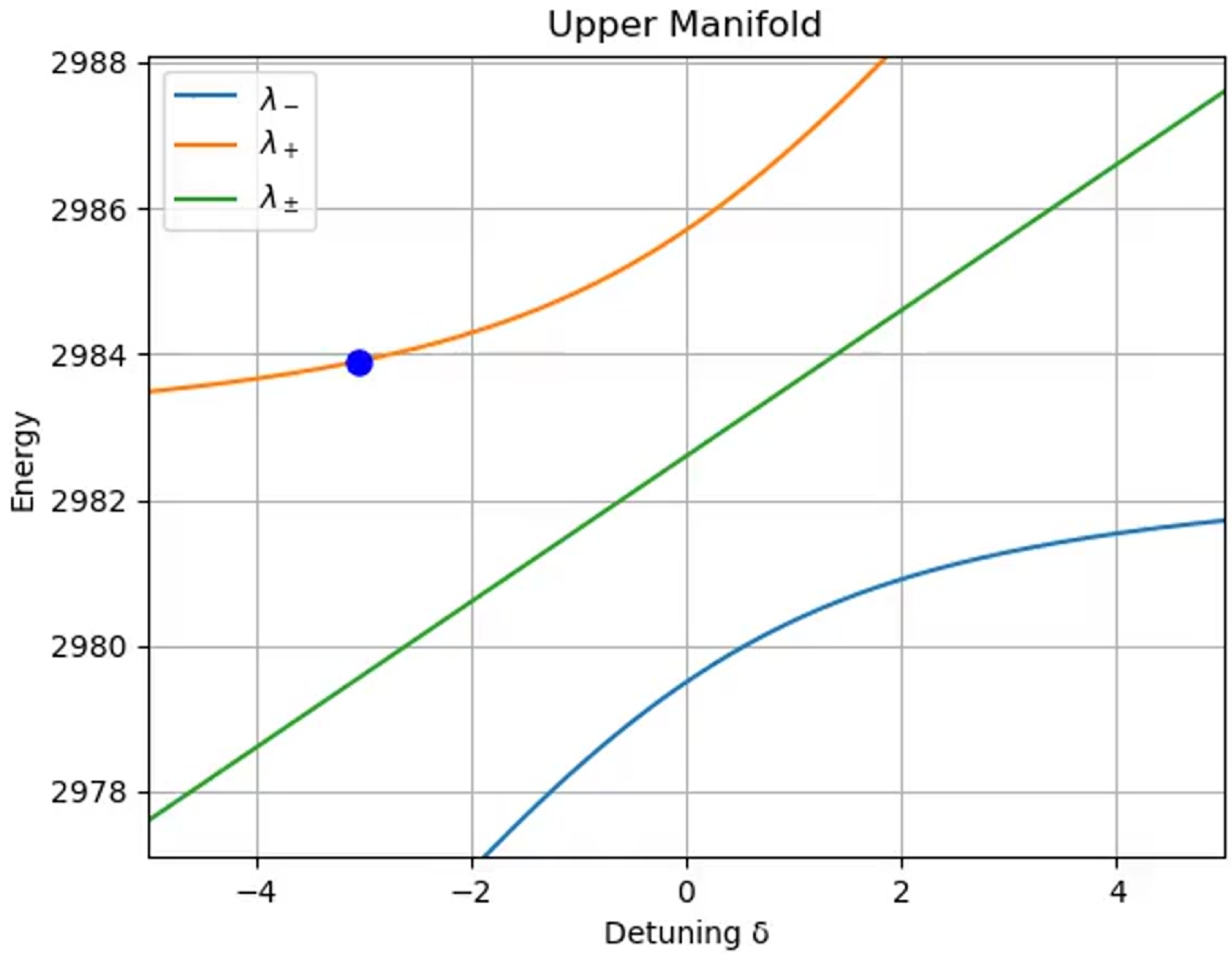
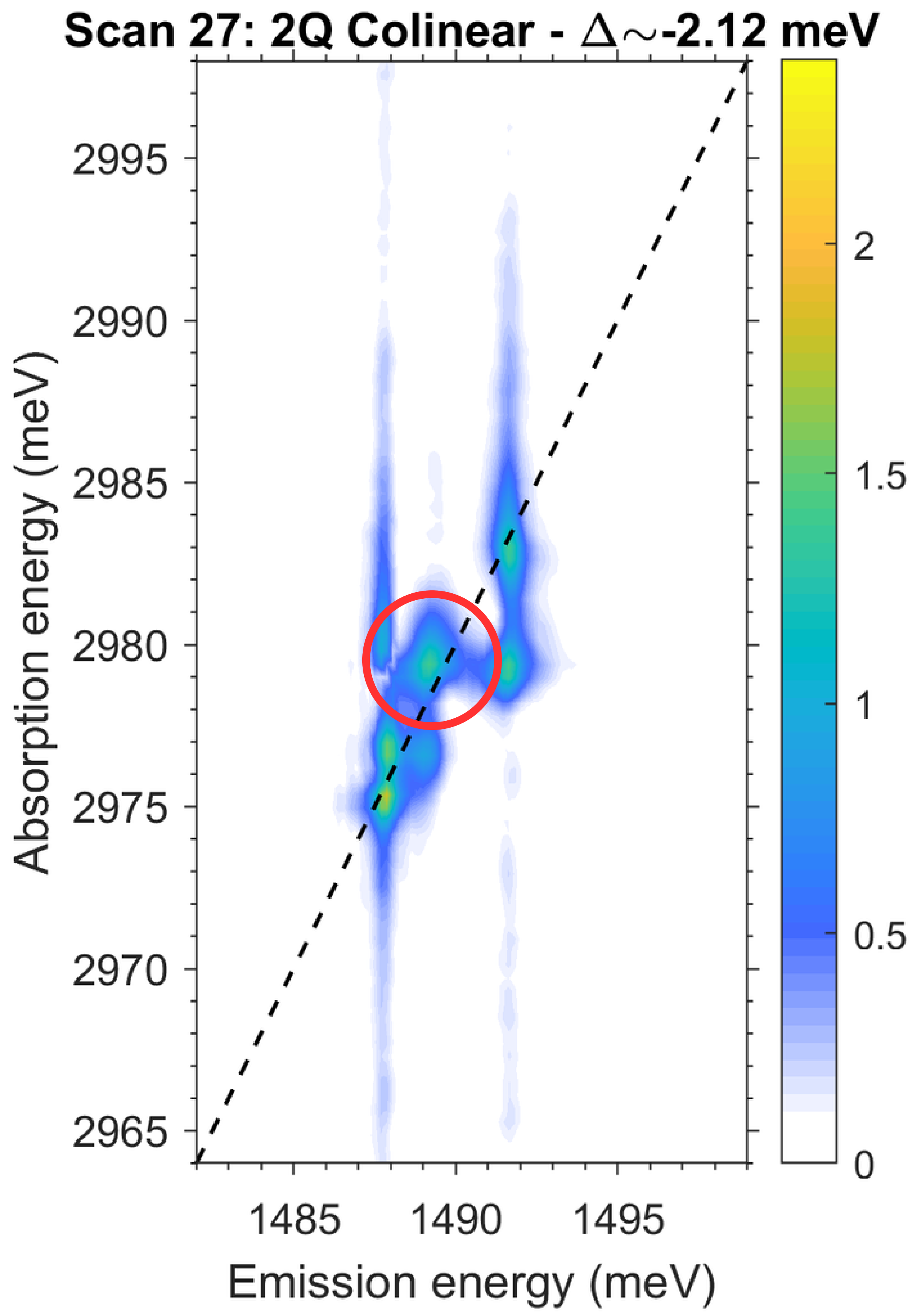

2 Quantum Spectra
3000
2995
2990
2985
2980
2975
2970
Ω_T
1485
1490
1495
Ω_t


Upper Manifold
λ_-
λ_+
$\lambda_\pm$
2988
2986
2984
2982
2980
2978
Energy
−4
−2
0
2
4
Detuning δ

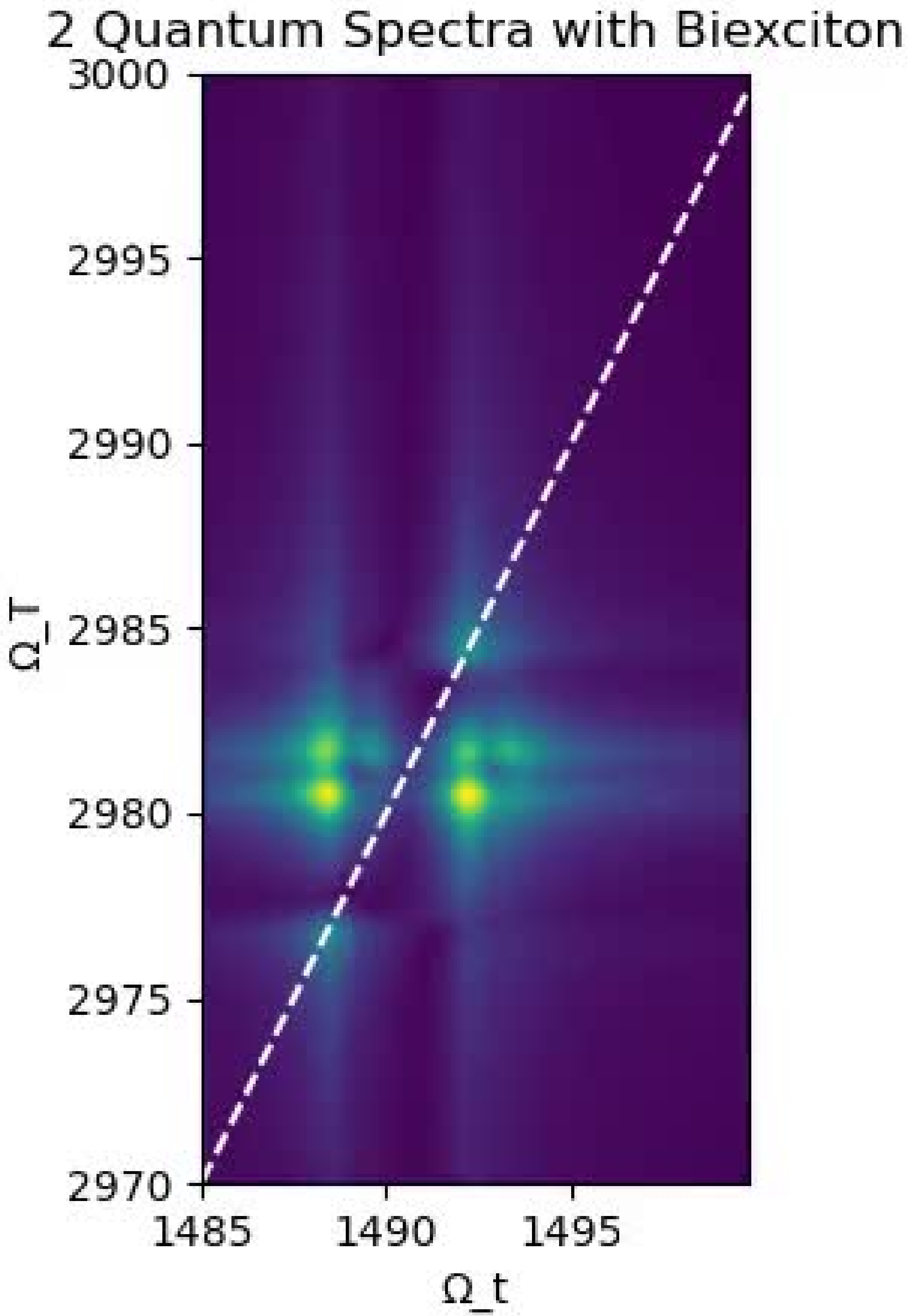
Adding the Biexciton

- Experimental Data including Biexciton
- A "biexciton" can be added to the simulation
  - Has independent energy
  - Another level on the level scheme diagram



Adding the Biexciton

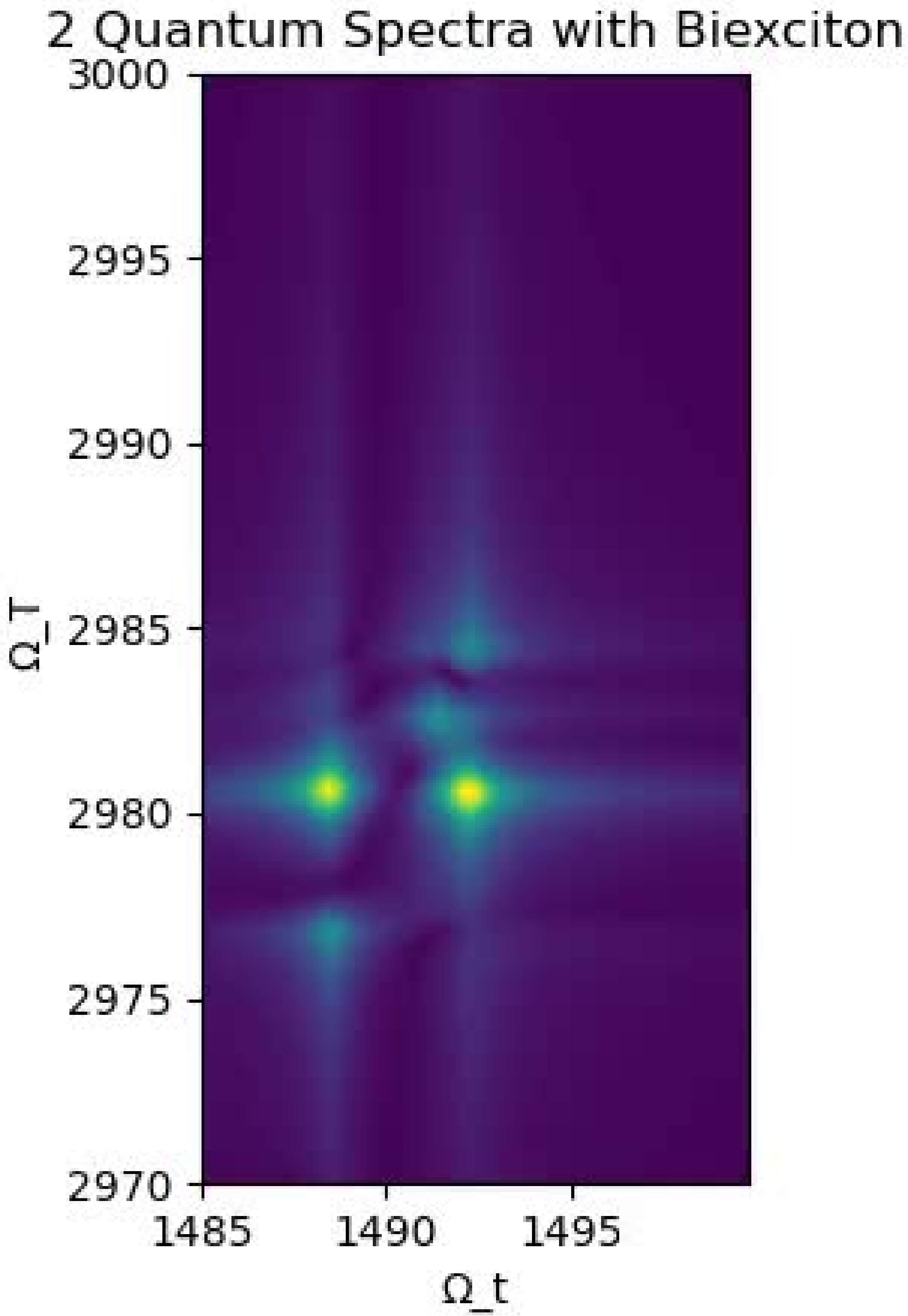
- A "biexciton" can be added to the simulation
  - Has independent energy
  - Another level on the level scheme diagram
    - Filtered level gives this animation -->



Next Steps

- With the biexciton added, we are close to simulating experimental data
  - Vary our matrix to match peak amplitudes
  - Add parameters or other options to explain "biexciton"

This dark state animation has a fixed detuning of -1



Thank You

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