Collective effects in biphoton generation of a four-wave-mixing (FWM) process

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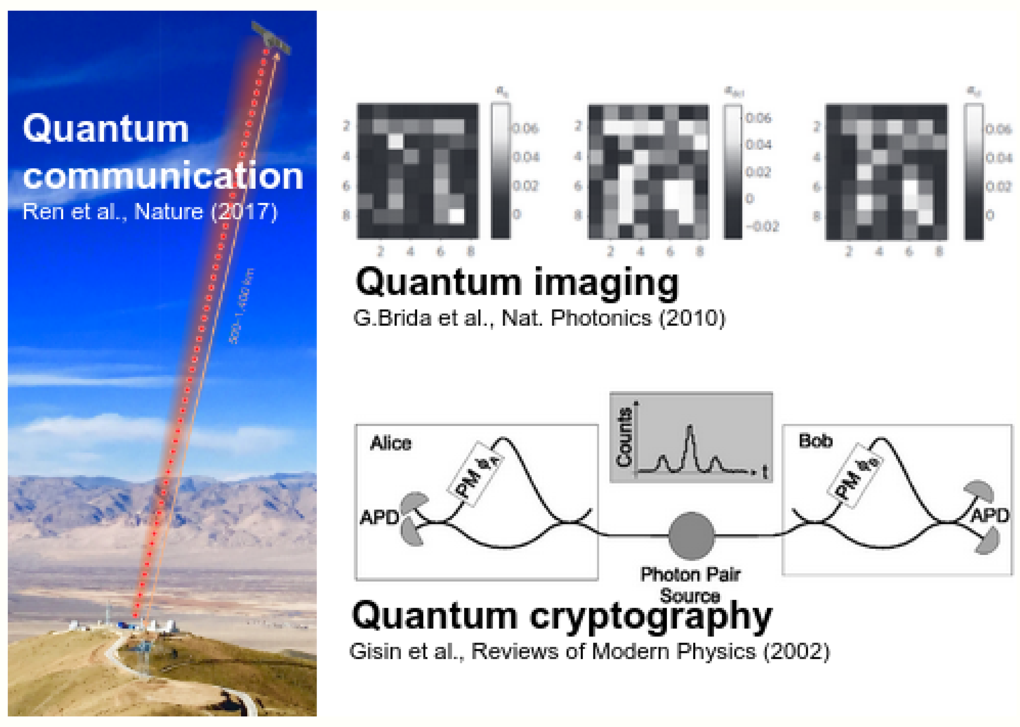
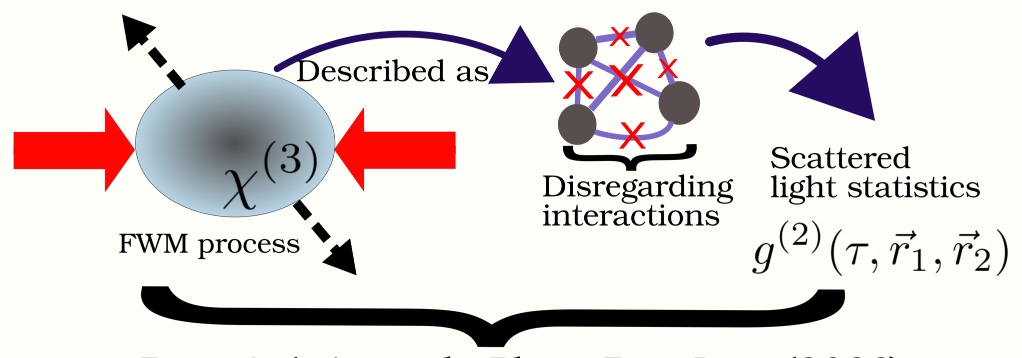
Motivation

- Biphotons can be generated using **FWM**.
- Biphotons are very important for quantum technologies:



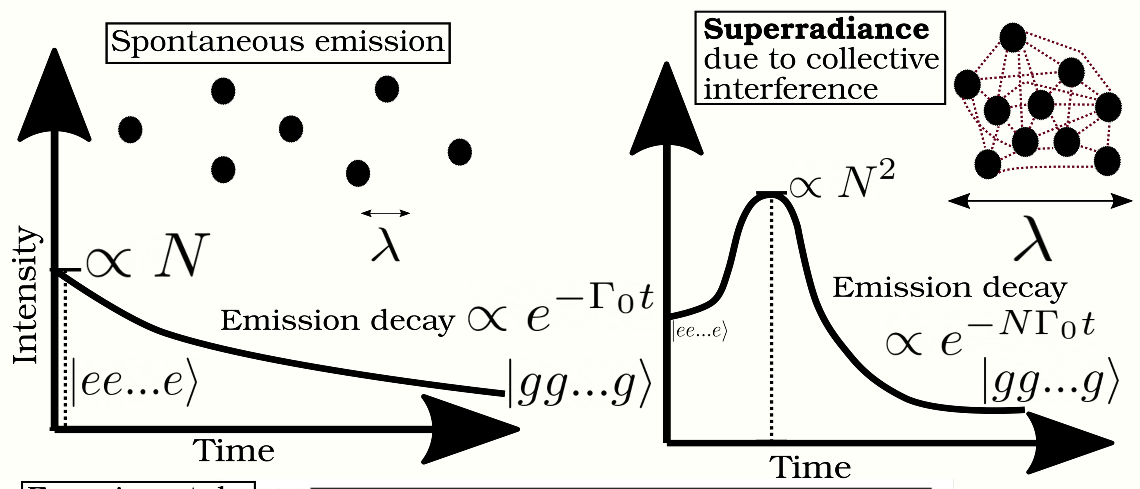
Background

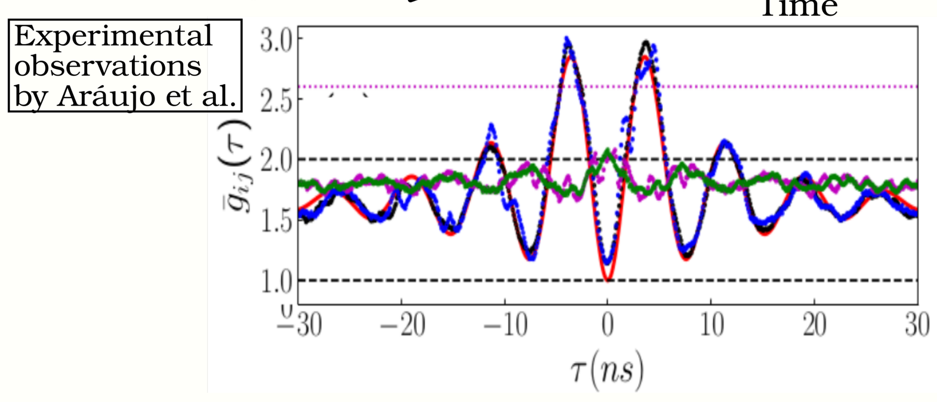
- The typical description for FWM in two-level-systems (TLS) considers **independent** atoms:



But, *Aráujo et al., Phys. Rev. Lett. (2022)* reported evidence of collective behavior.

- Collective effects, suggest the existence of **interactions** between the scatterers:



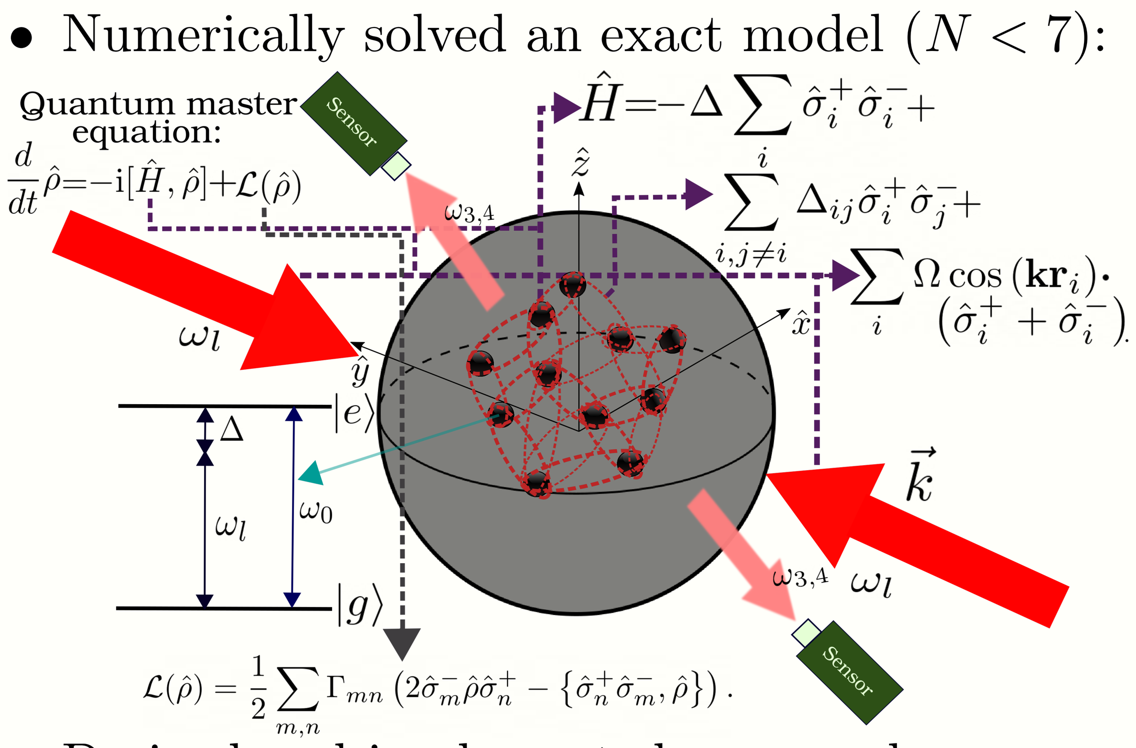


Objective

- Identify and characterize **collective effects in FWM**, considering N two-level atoms **interacting** through **coupled dipoles interaction**.

Methodology and Model

- Numerically solved an exact model ($N < 7$):

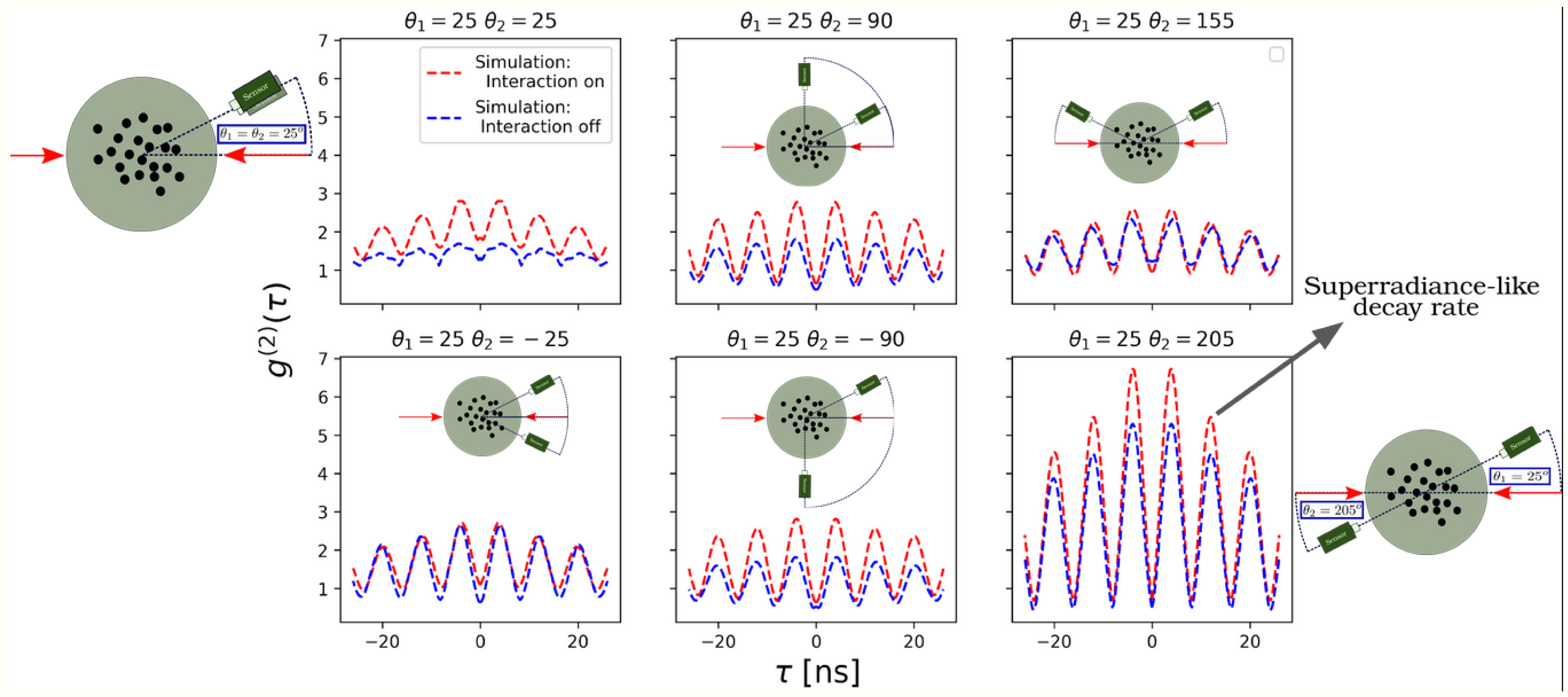


- Derived and implemented a new scheme considering the single and double excitation subspace equations ($N < 100$):

$$|\Psi(t)\rangle = \alpha(t)|0\rangle_a|0\rangle_{\mathbf{k}} + \sum_{j=1}^{N} \beta_j(t)|j\rangle_a|0\rangle_{\mathbf{k}} + \sum_{j,m=1}^{N} \beta_{j,m}(t)|j,m\rangle_a|0\rangle_{\mathbf{k}} + ... + \sum_{\mathbf{k}} \eta_{\mathbf{k}}(t)|0\rangle_a|2\rangle_{\mathbf{k}}$$

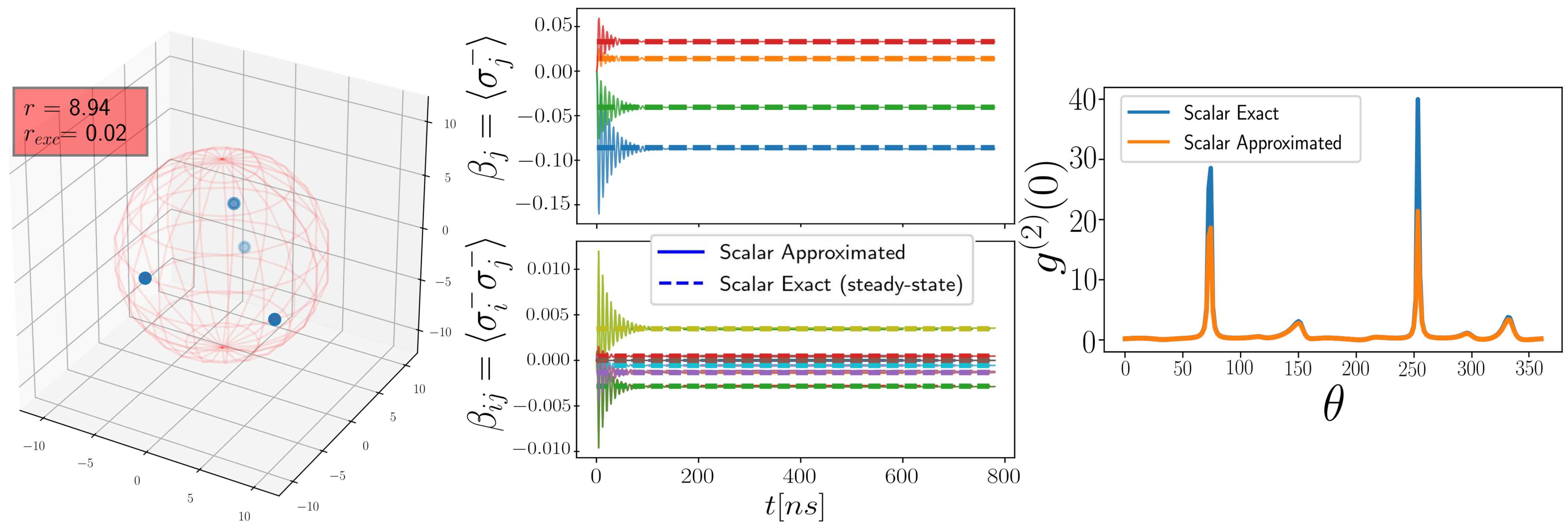
Exact simulations

- We obtain stronger correlations in opposite directions as expected in FWM (for 5 particles in the atomic cloud).

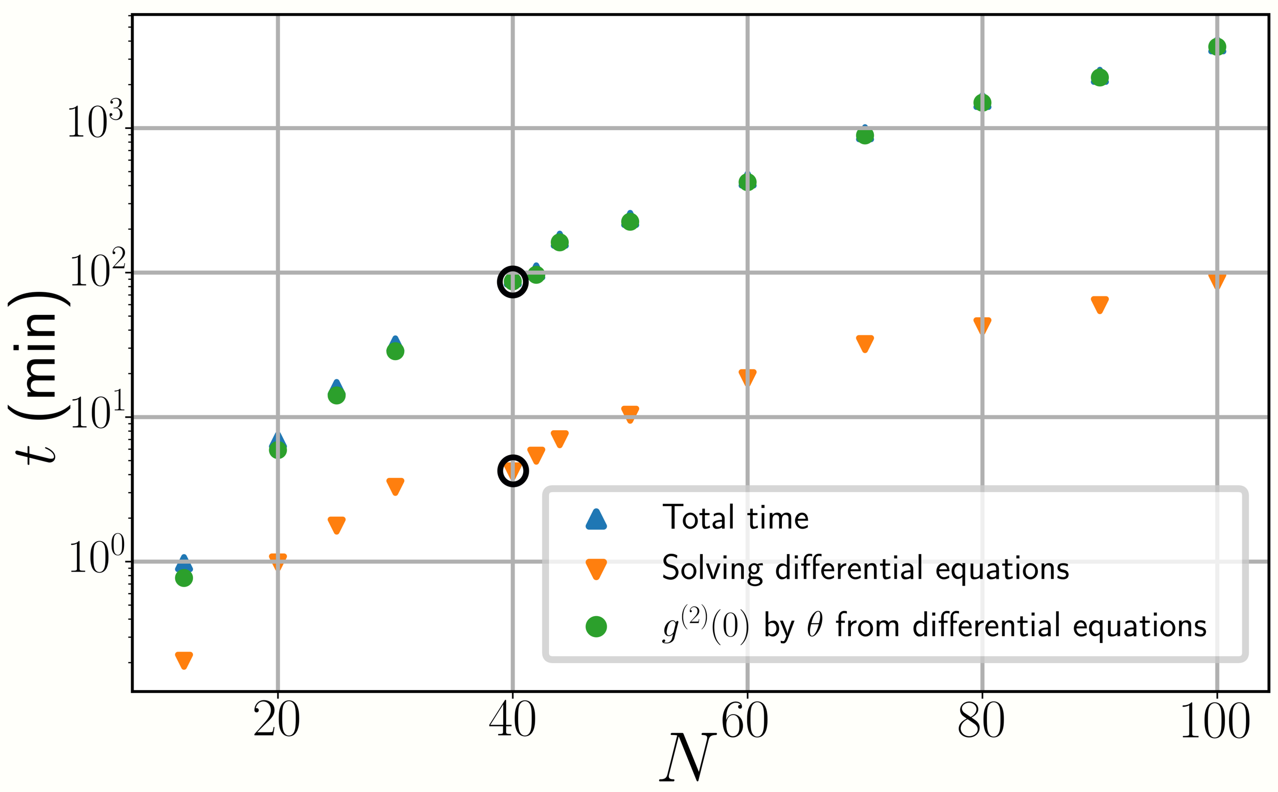


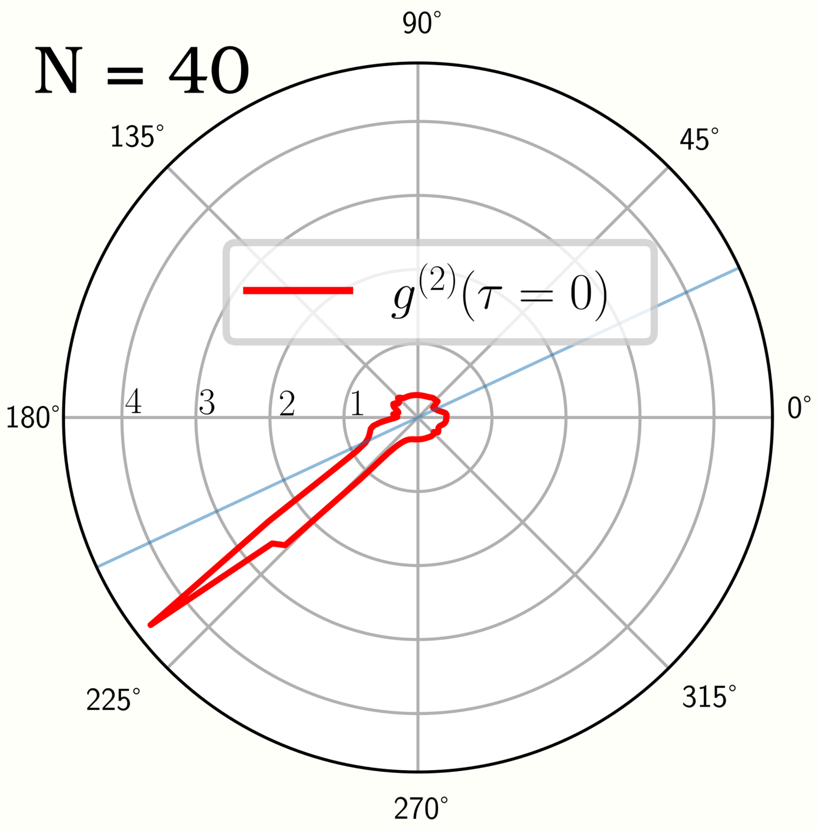
Subspace simulations

- Subspace approximations reproduce exact calculations.



- The method allows us to simulate systems with many atoms.
  - In just a few hours the subspace approximation equations and $g^{(2)}(\tau = 0)$ can be calculated.
  - For $N = 40$, we find again that $g^{(2)}(\tau = 0)$ is stronger for opposite directions.





Conclusion

Considering dipole-dipole interactions in FWM in TLS we obtained results qualitatively consistent with recent experimental measurements, but further characterizations with larger clouds are necessary to fully characterize the collective effects.

Acknowledgements

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