INTERNSHIP PROPOSAL

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Thesis possibility after internship: YES
Funding: YES If YES, which type of funding: PEPR OQULUS

Experimental temporal entanglement in a linear cluster state

Photonics-based quantum networks are fundamental resources for quantum information processing, as quantum states of light enable the efficient distribution and manipulation of information. In this context, we focus on continuous-variable (CV) entangled states, where quantum correlations arise between the quadratures of the electromagnetic field.

The Multimode Quantum Optics group at LKB has been at the forefront of experimental research on the generation of squeezed and continuous-variable entangled states, aimed at implementing advanced quantum information protocols. Such states can be deterministically produced by combining multiple squeezed optical modes through linear-optical operations or, more generally, by performing transformations in the mode basis [1,2]. Our current work investigates experimental implementations based on nonlinear optics in waveguides, fast and frequency-resolved homodyne detection, and tailored non-Gaussian operations achieved via photon counting [4]. The proposed internship will focus on developing an optical setup for generating linear cluster states with entangled macro-nodes distributed in time, where each macronode comprises several entangled spectral components.

This internship will serve as the foundation for a broader PhD project devoted to the experimental realization of continuous-variable resources for quantum information protocols, in alignment with the French National Acceleration Strategy PEPR OQULUS initiative: https://www.pepr-quantique.fr/en/projet/oqulus/.

Potential applications include quantum reservoir computing schemes in the continuous-variable regime, leveraging both Gaussian and non-Gaussian states [5–8].

References

[1]V. Roman-Rodriguez, et al *Multimode squeezed state for reconfigurable quantum networks at telecommunication wavelengths* Physical Review Research 6 (4), 043113 (2024)

[2]T. Kouadou, et al *Spectrally shaped and pulse-by-pulse multiplexed multimode squeezed states of light* APL Photonics 8 (2023)

[3]Y. Cai, et al *Multimode entanglement in reconfigurable graph states using optical frequency combs* Nature communications 8 (1), 15645 (2017)

[4]P. Namdar, et al. *Spectro-temporally tailored Non-Gaussian Quantum Operations in Thin-Film Waveguides*, arXiv:2508.04578 (2025)

[5] J. Nokkala,et al, *Gaussian states of continuous-variable quantum systems provide universal and versatile reservoir computing* Communications Physics 4, Article number: 53 (2021)

[6]J Henaff, et al. *Optical phase encoding in a pulsed approach to reservoir computing* Optics Letters 49, 2097 (2024)

[7] Garcia Beni et al, *Quantum machine learning via continuous-variable cluster states and teleportation* EPJ Quantum Technology volume 12, Article number: 63 (2025)

[8] I. Paparelle, et al *Experimental memory control in continuous variable optical quantum reservoir computing,* *arXiv:2506.07279 (2025)*

Please, indicate which speciality(ies) seem(s) to be more adapted to the subject:

Condensed Matter Physics: NO Soft Matter and Biological Physics: NO
Quantum Physics: YES Theoretical Physics: YES