Quantum Computing with Optical Frequency Combs

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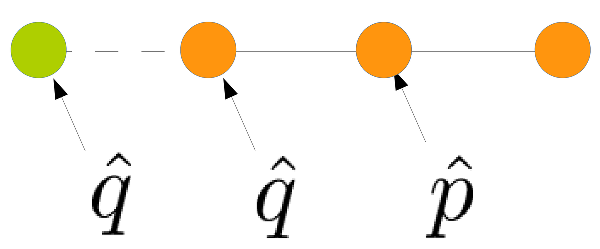
Continuous-Variable Quantum Information Protocols

Quantum computing

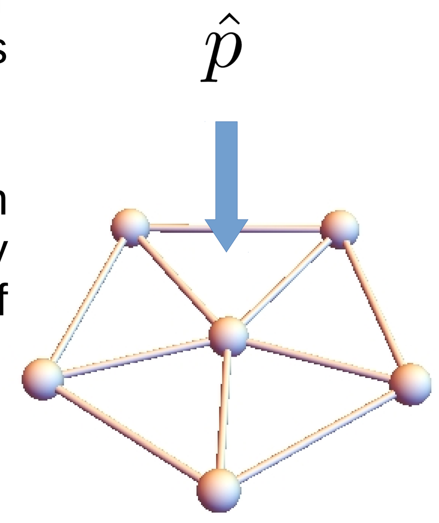


In **measurement-based** quantum computation, information is processed through **local measurements** on an entangled resource state (**cluster state**).

Secret sharing

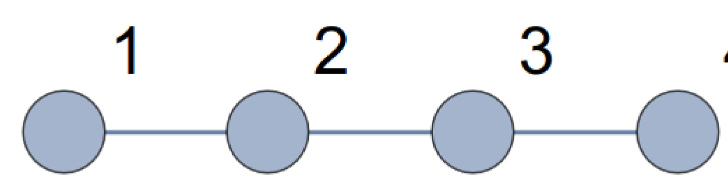
Cluster states are also useful in other quantum information protocols, such as secret-sharing.

In SS, a **dealer** shares information with several **players** in such a way that they can only retrieve the initial message if they **collaborate**.



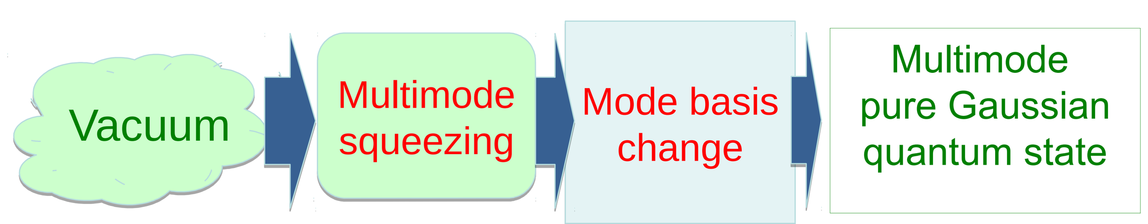
Cluster states

Cluster states can be represented as graphs and are characterized by **nullifier operators**.

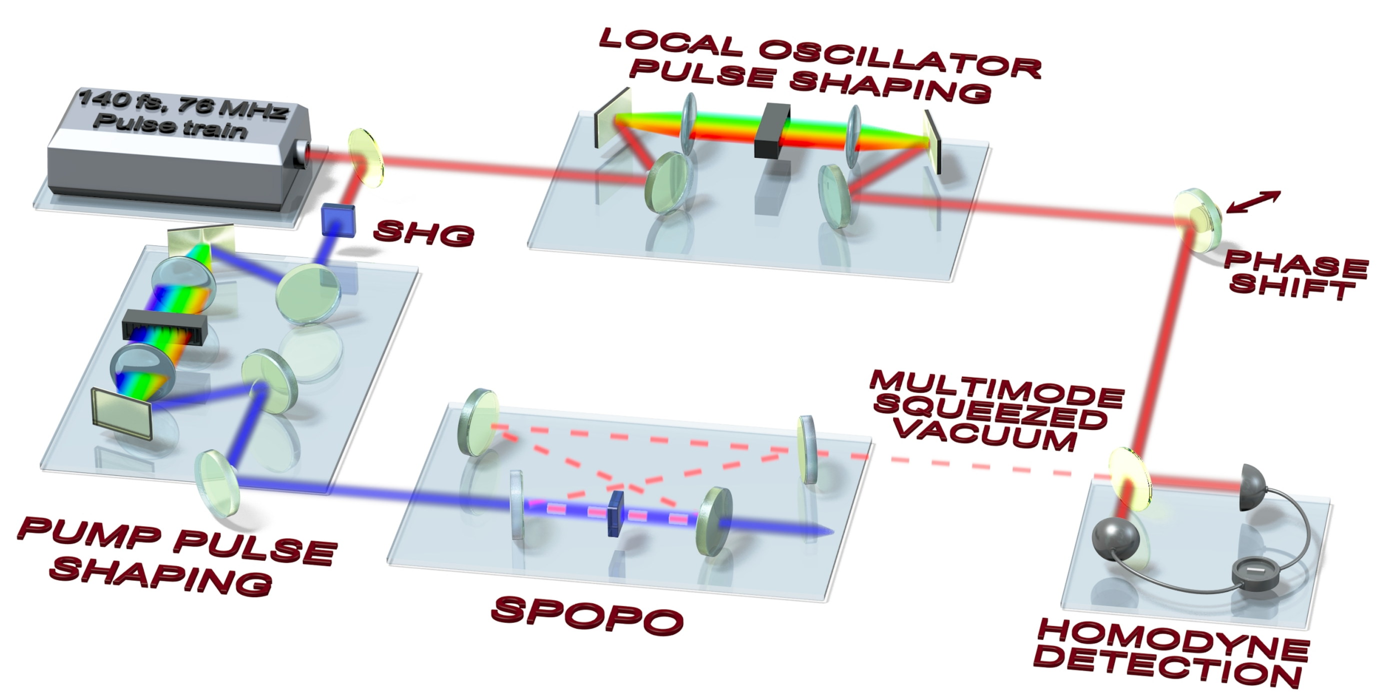


$$\begin{aligned}\hat{\delta}_1 &= \hat{p}_1 - \hat{q}_2\\ \hat{\delta}_2 &= \hat{p}_2 - \hat{q}_1 - \hat{q}_3\\ \hat{\delta}_3 &= \hat{p}_3 - \hat{q}_2 - \hat{q}_4\\ \hat{\delta}_4 &= \hat{p}_4 - \hat{q}_3\end{aligned}$$

$$\exp\left(i\sum_{i>j} V_{ij}\hat{q}_i \otimes \hat{q}_j\right)|0\rangle_p^{\otimes N}$$

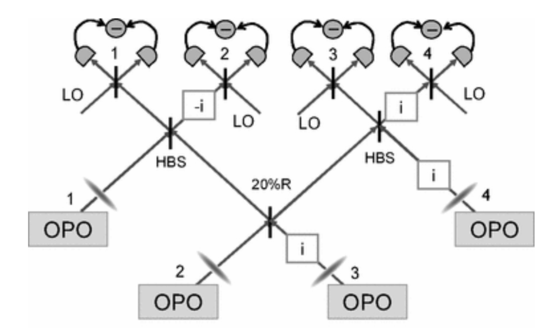


Experimental setup



An **SPOPO** pumped below threshold acts as set of independent squeezers in a basis of modes with a broad spectral profile, called **supermodes**.

Scalable source of entanglement, if compared with



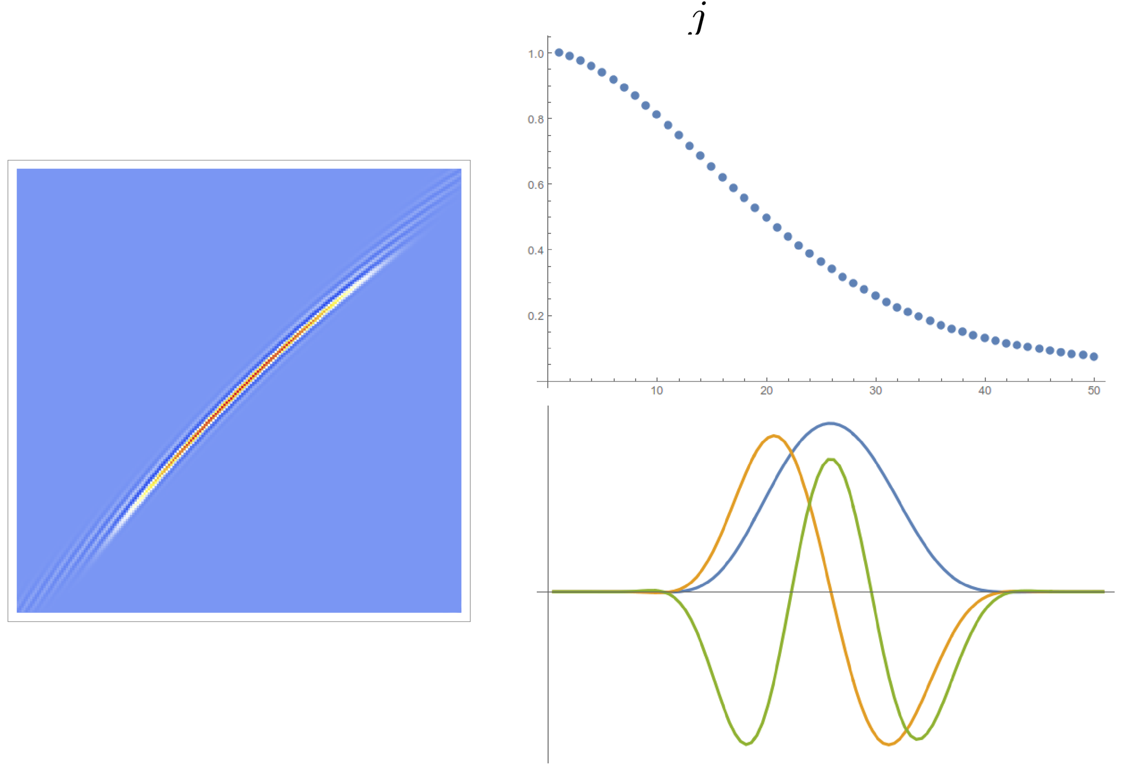
Pump Shaping for State Engineering

Supermodes

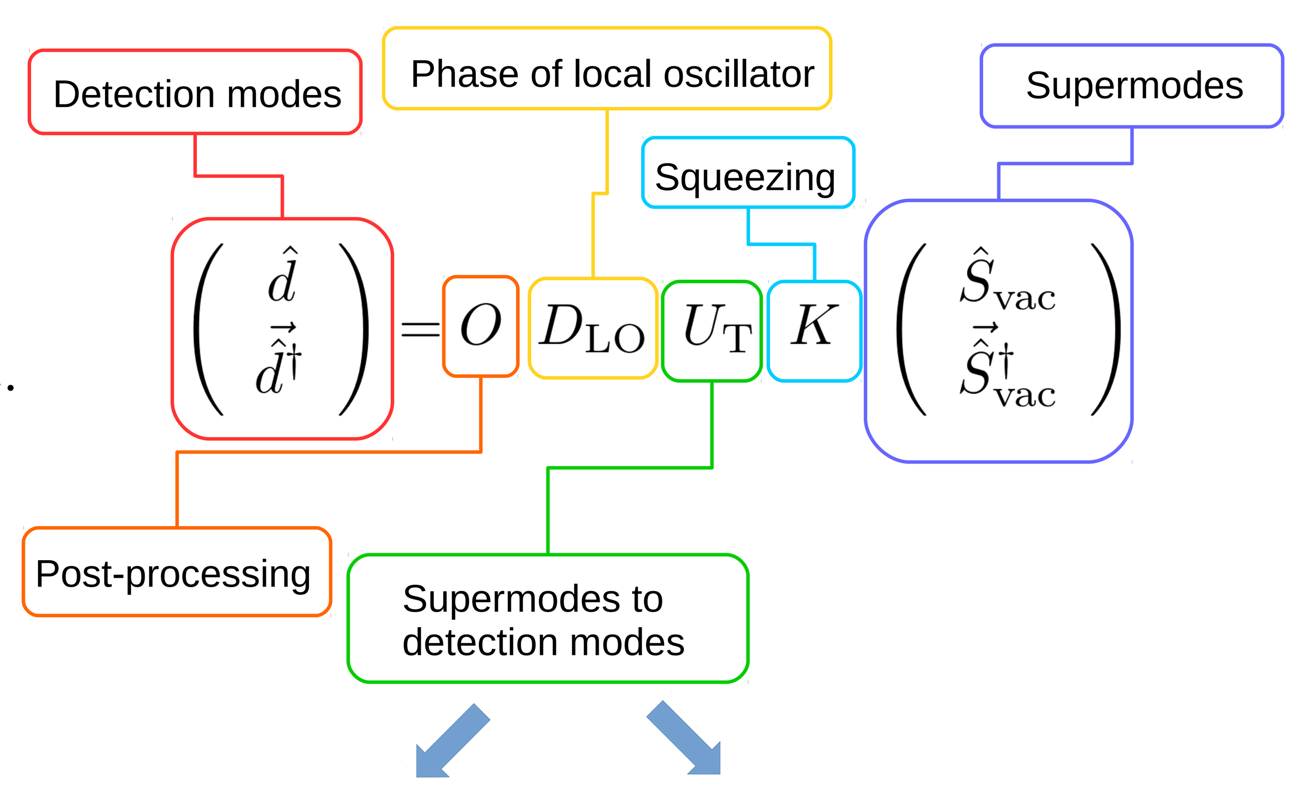
$$\hat{H} = i\frac{\hbar}{2}k\left(\hat{\vec{a}}^\dagger\right)^T \mathcal{L}\hat{\vec{a}}^\dagger + \text{h.c.}$$

$$\mathcal{L}_{mq} = \text{sinc}\left[(k_{p,m+q} - k_{s,m} - k_{s,q})\frac{l}{2}\right]\alpha_{m+q}$$

$$ULU^T = \Lambda \qquad \vec{S} = U\vec{a} \quad \Rightarrow \quad \hat{H} = i\hbar\sum_j \Lambda_{jj}\left(\hat{S}_j^\dagger\right)^2 + \text{h.c.}$$



Tunable parameters



Fixed pump profile / PM
Arbitrary LO shape
Measure one mode at a time
Fixed squeezing spectrum

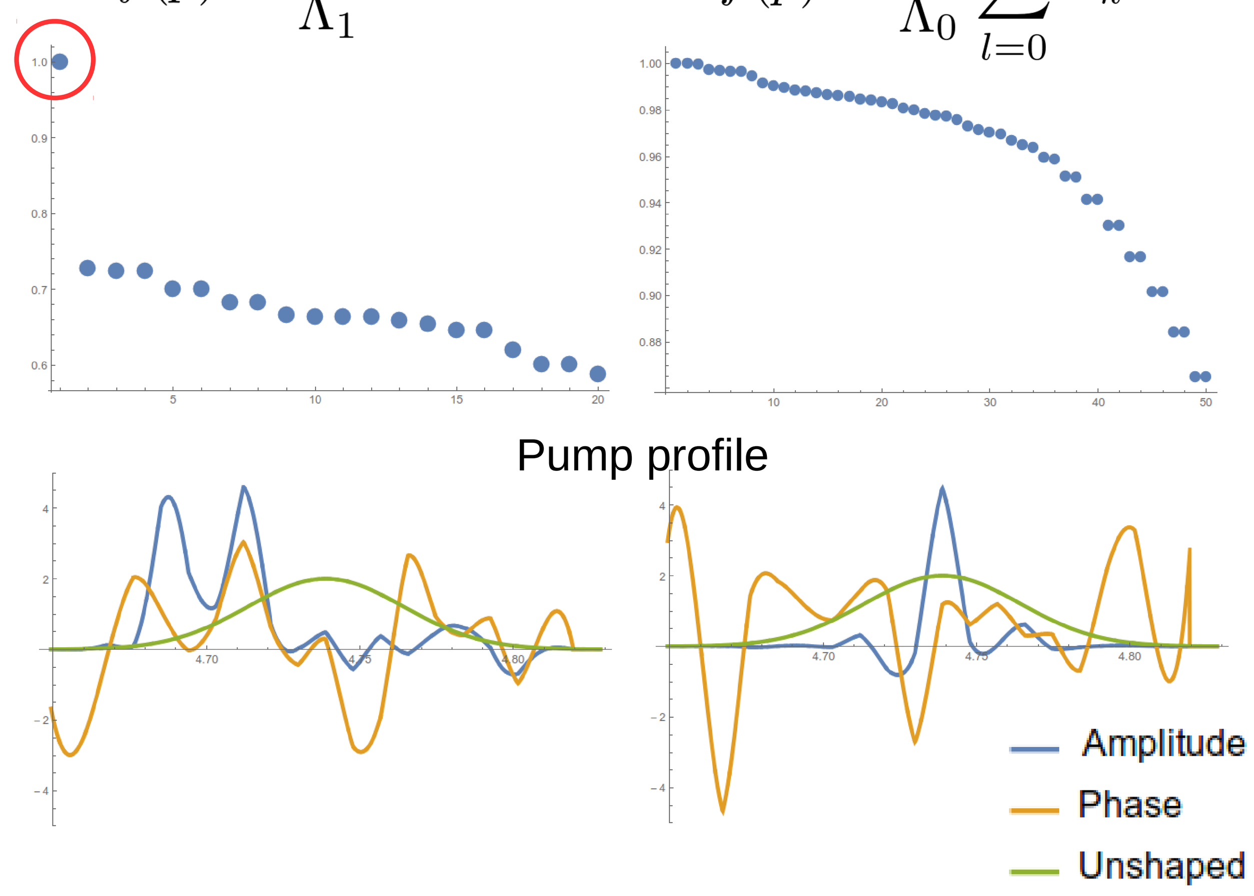
Fix detection modes, shape the pump

Tweaking the squeezing

The shape of the pump can be adjusted to optimize the squeezing spectrum.

An evolutionary algorithm can be used to find the optimal pump shape.

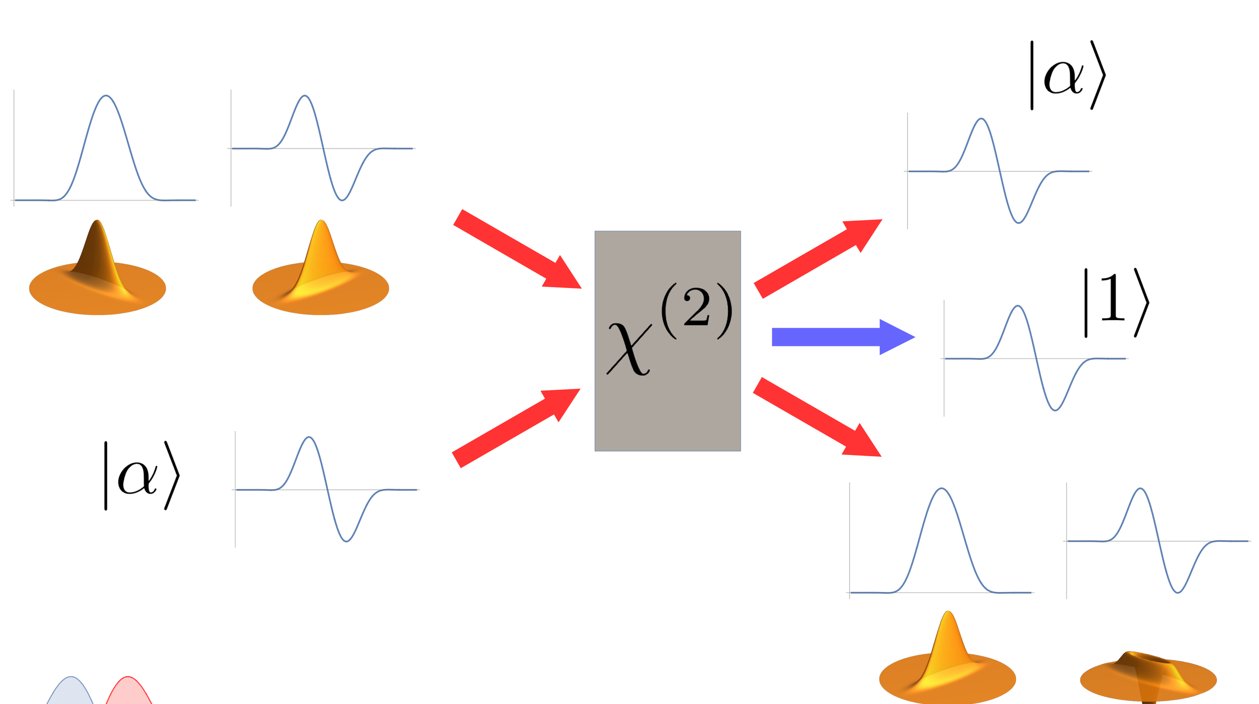
$$f(\vec{p}) = \frac{\Lambda_0}{\Lambda_1} \qquad f(\vec{p}) = \frac{1}{\Lambda_0}\sum_{l=0}^{10}\Lambda_k$$

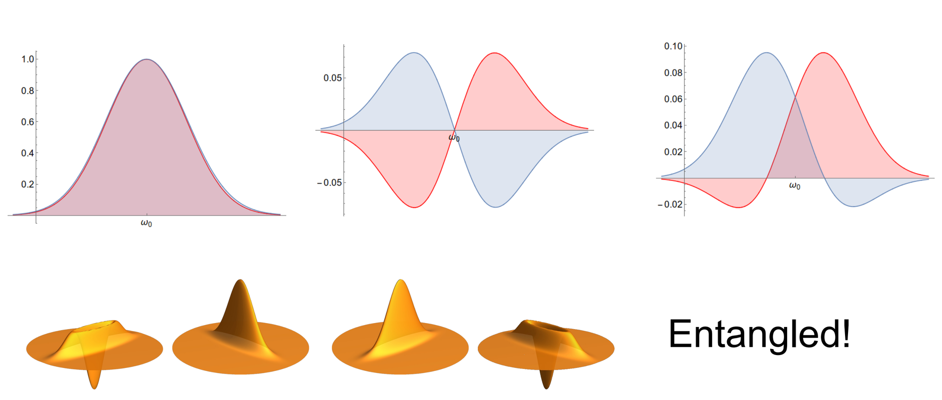


Non-Gaussian Operations

Mode-dependent photon subtraction

Non-Gaussian operations are necessary for **universality** and to obtain any **quantum speed-up**. On-off single photon detectors and photon subtracted states are some of the simplest non-gaussian resources. They can be implemented in our multimode source.



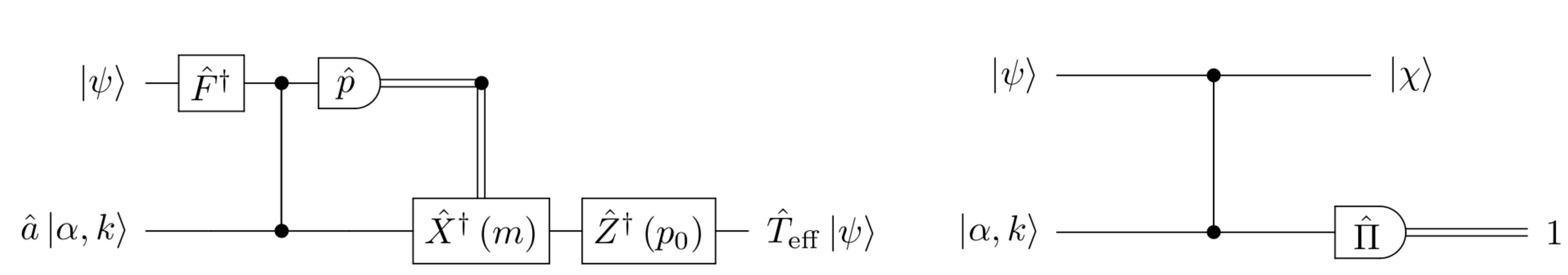


Entangled!

Non-gaussian entangled states can be produced subtracting a photon from a **multimode** squeezed state.

Polynomial Gates

Can **photon subtraction** and other single photon operations be useful for **quantum computation** in continuous variables?



Effective transformation: $|\psi'\rangle = \mathcal{N}\mathcal{G}(\lambda - \hat{q})|\psi\rangle$

$$e^{is\hat{q}^3} \approx 1 + is\hat{q}^3 = (\lambda - \hat{q})(\eta - \hat{q})(\zeta - \hat{q})$$

This allows to approximate any unitary transformation which is a function of the position quadrature.
But fidelity and success probability are state-dependent.

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