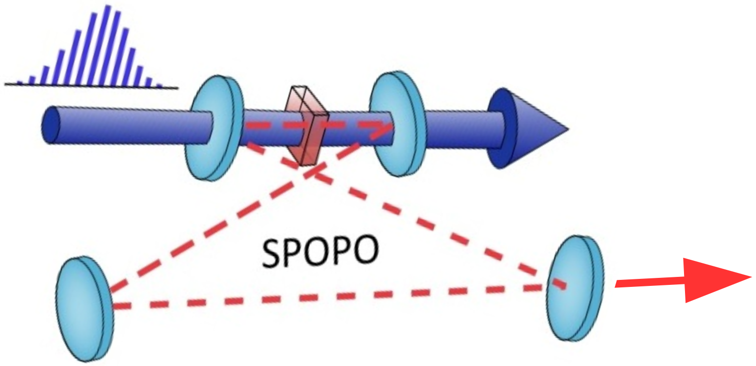
Laboratoire Kastler Brossel
Physique quantique et applications

Shaping the Pump of a Synchronously Pumped Optical Parametric Oscillator for Continous-Variable Quantum Information

Francesco Arzani, Claude Fabre, Nicolas Treps

Motivation: CV cluster states



Multi-mode squeezed vacuum

G. Patera et al, EPJD 56, 123-140 (2010)

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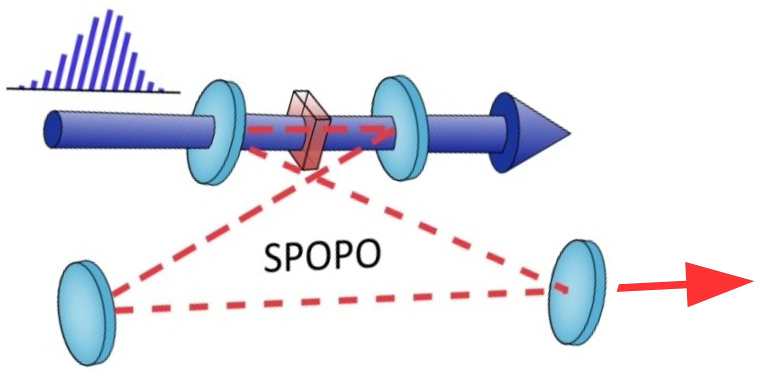

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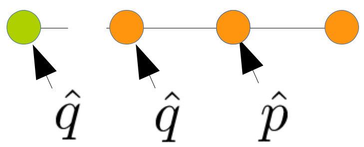
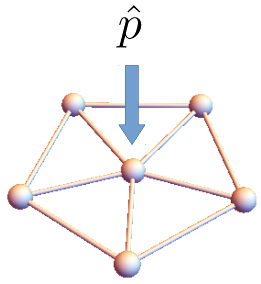


- CV Secret Sharing



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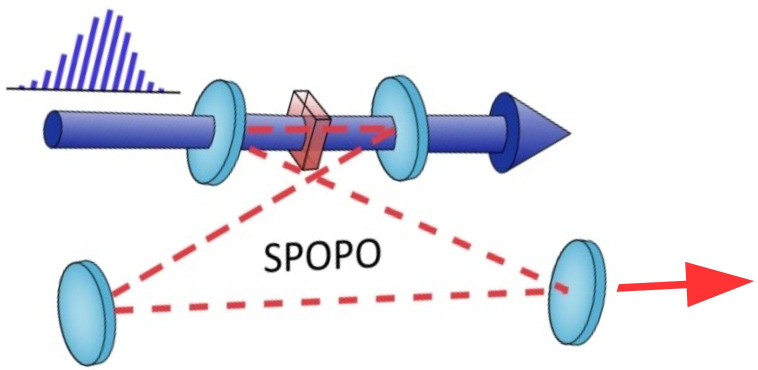

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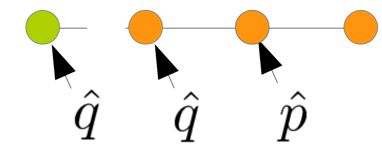

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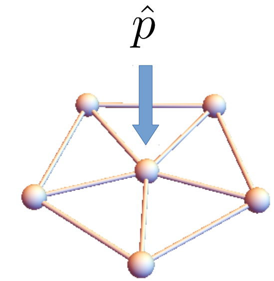

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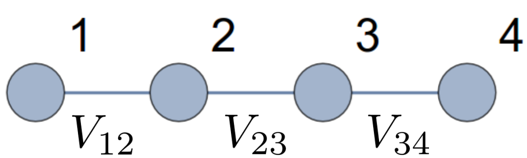
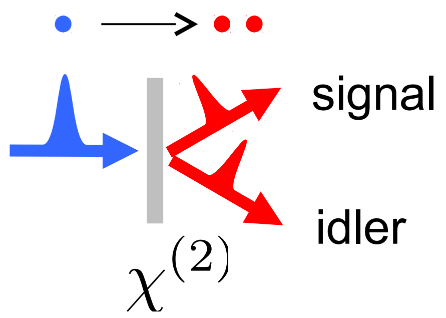


$$\begin{aligned}
\hat{\delta}_1 &= \hat{p}_1 - \hat{q}_2 \\
\hat{\delta}_2 &= \hat{p}_2 - \hat{q}_1 - \hat{q}_3 \\
\hat{\delta}_3 &= \hat{p}_3 - \hat{q}_2 - \hat{q}_4 \\
\hat{\delta}_4 &= \hat{p}_4 - \hat{q}_3
\end{aligned}$$

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

- Can be represented as graphs
- Characterized by **nullifier operators**
- Approximated by Gaussian states

Parametric Interaction



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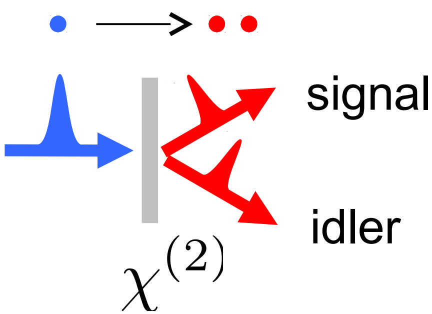

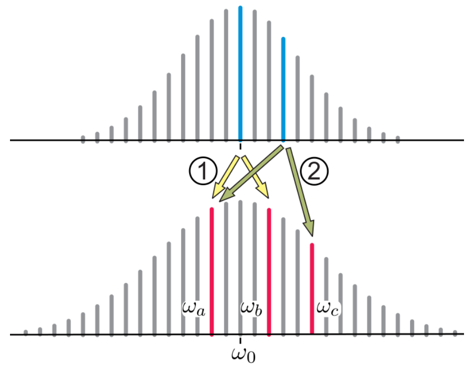

Interaction Hamiltonian

$$H = i \sum_{m,q} \mathcal{L}_{m,q} \hat{a}^{\dagger}_{\omega_m} \hat{a}^{\dagger}_{\omega_q} + \text{h.c.}$$

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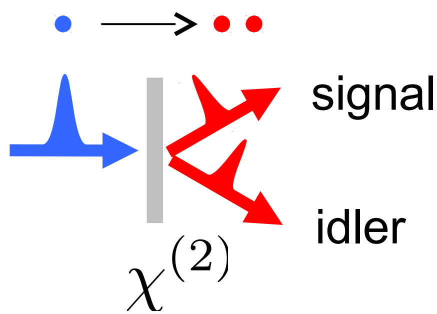

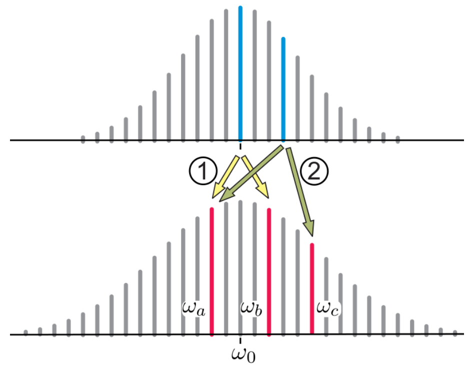

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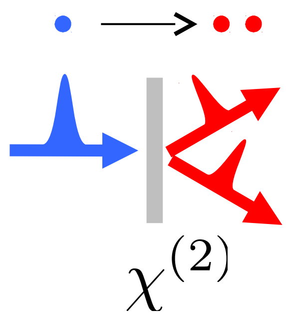
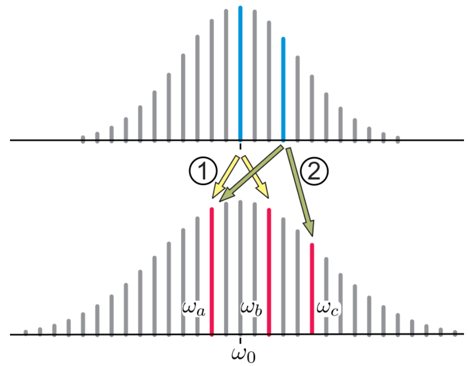
$$\mathcal{L}_{m,q} = \underbrace{\operatorname{sinc}\left(\Delta k_{m,q} \frac{l}{2}\right)}_{\text{Crystal}} \times \underbrace{\alpha\left(\omega_m + \omega_q\right)}_{\text{Pump}}$$

Parametric Interaction





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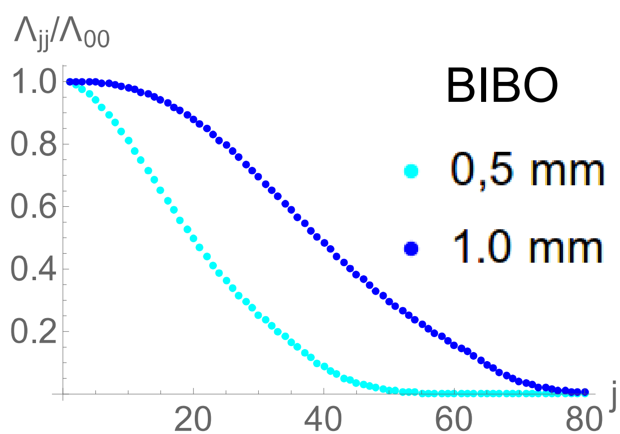
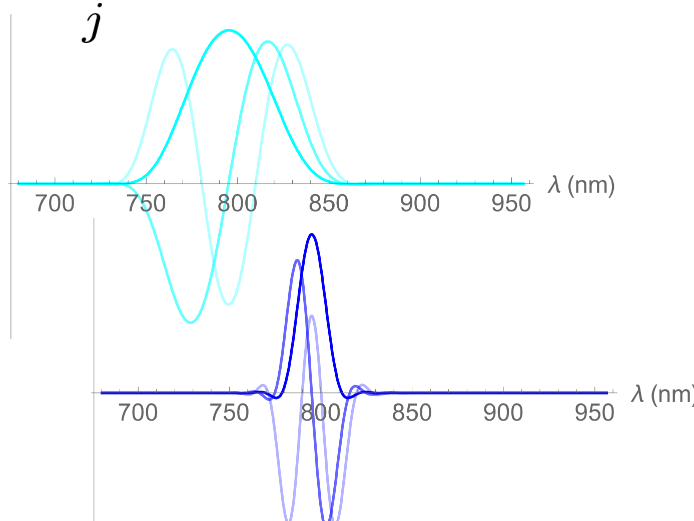
$$U \mathcal{L} U^T = \Lambda$$

Symmetric SVD

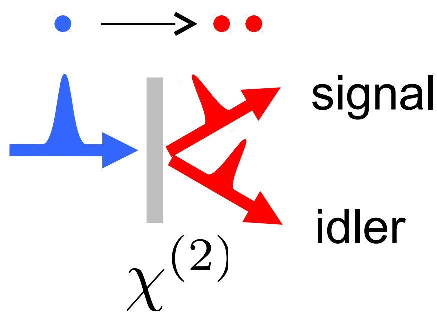
$$H = i \sum_j \Lambda_{jj} \left(\hat{S}_j^\dagger\right)^2 + \text{h.c.}$$

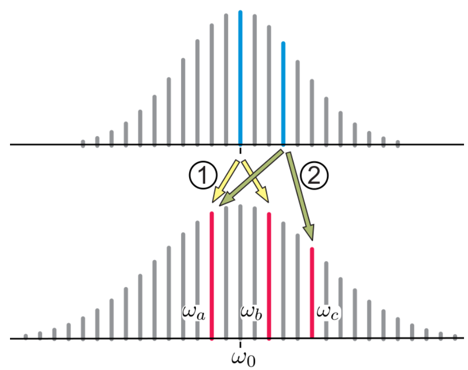




Supermodes: Independently squeezed modes **Any other mode basis: Entanglement**

Parametric Interaction





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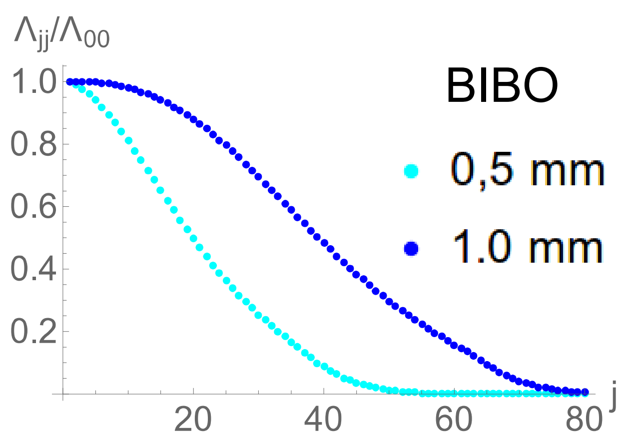

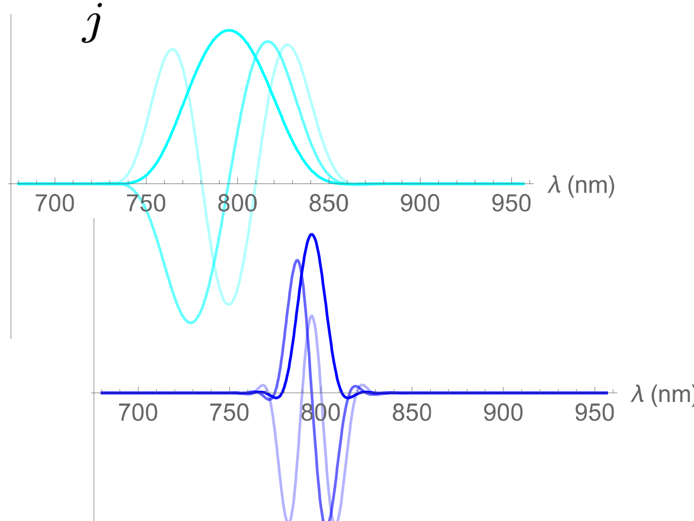

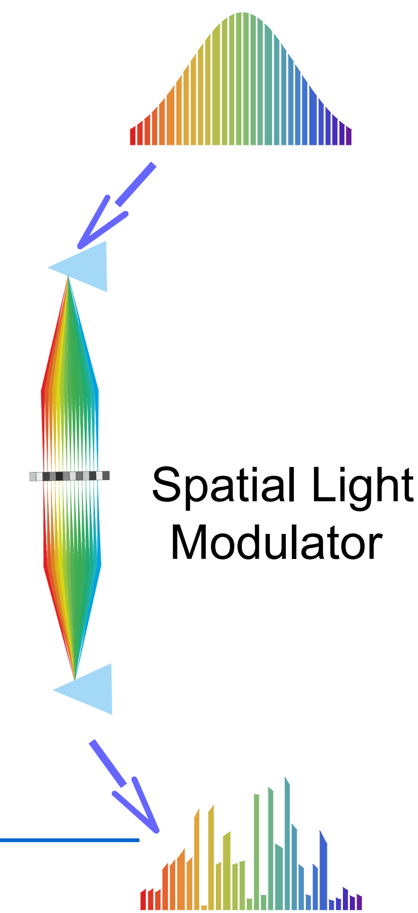

Supermodes: Independently squeezed modes **Any other mode basis: Entanglement**

Tweaking the Squeezing

Complex relation between pump and squeezing/supermodes :

Use **numerical optimization**

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To flatten the squeezing spectrum : $f_{\mathrm{Fl}}\left(\vec{\theta}\right)=\sum_{j=0}^{100}\Lambda_{jj}\left(\vec{\theta}\right)/\Lambda_{00}\left(\vec{\theta}\right)$

To concentrate the squeezing in one mode : $f_{\mathrm{Conc}}\left(\vec{\theta}\right)=\Lambda_{00}\left(\vec{\theta}\right)/\Lambda_{11}\left(\vec{\theta}\right)$

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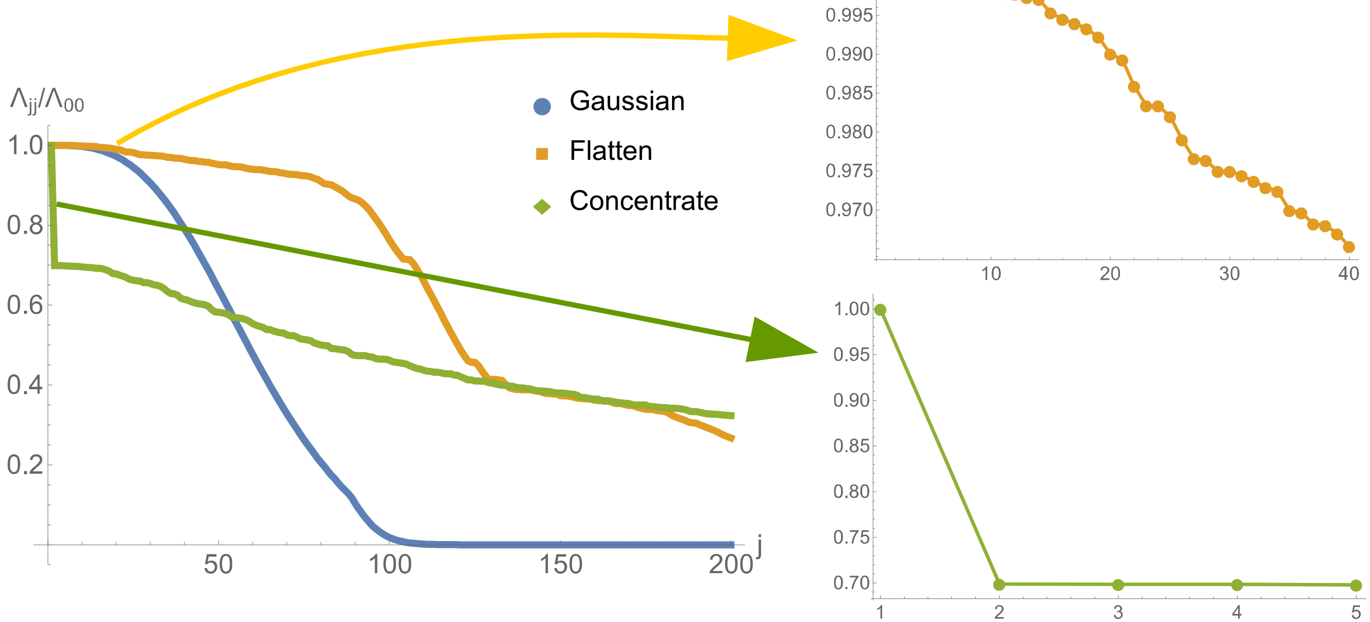
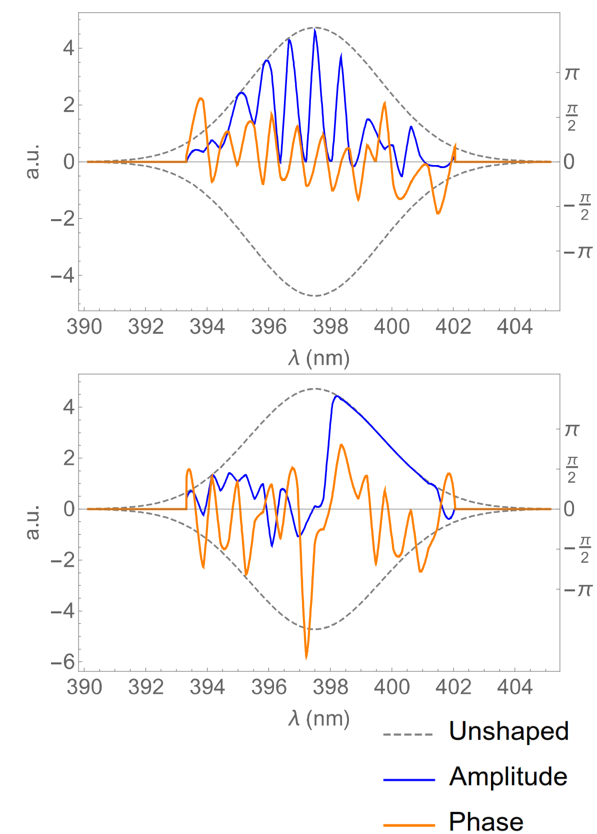
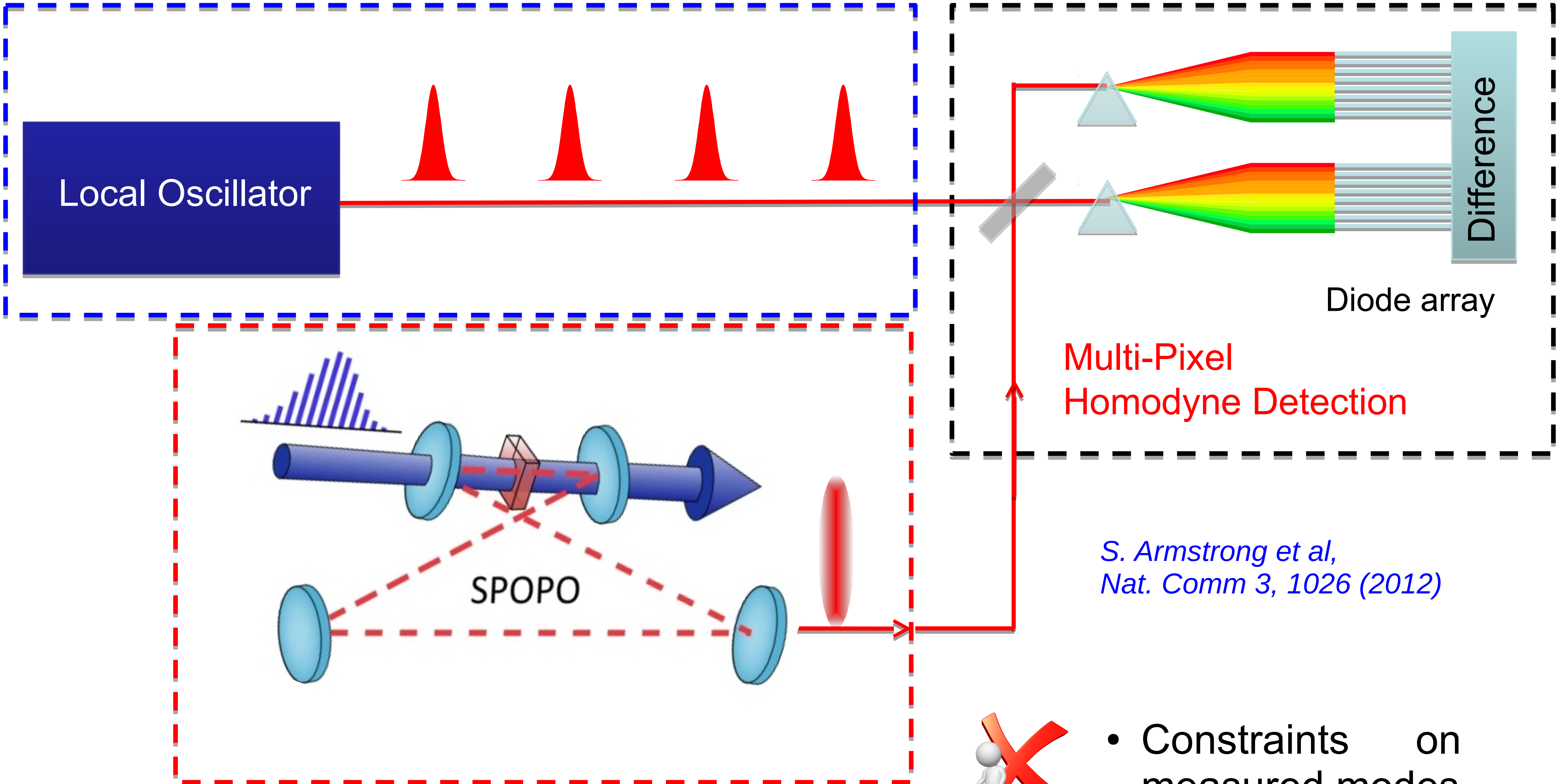


Optimal Pump



Macroscopic effect on the properties of the output !

Multi-pixel Homodyne Detection



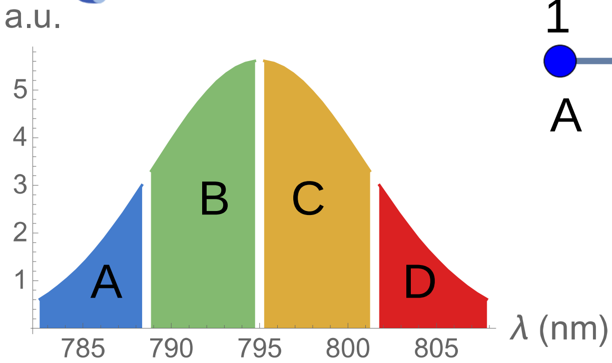
S. Armstrong et al,
Nat. Comm 3, 1026 (2012)

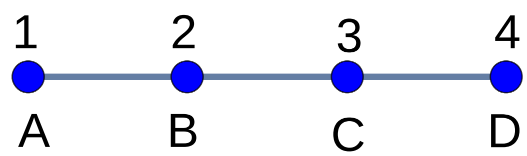
- Constraints on measured modes

- Modes can be separated easily
- Measurement of one mode does not destroy the rest of the system

Can we engineer correlations given such constraints ?

Optimizing CV Cluster States - QC





Mean nullifiers' squeezing :

$\langle \Delta\delta_i \rangle$ = - 0.18 dB

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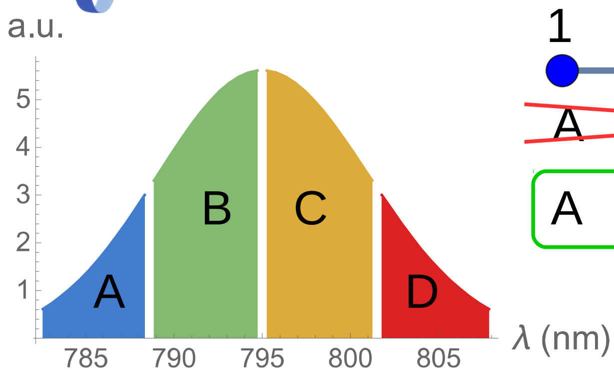

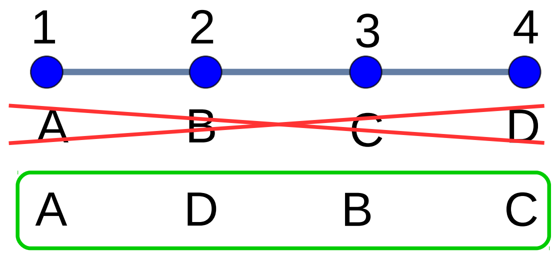

$$\hat{\delta}_1 = \hat{p}_A - \hat{q}_D$$

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$\langle \Delta\delta_i \rangle$ = - 2.31 dB

Fully inseparable (PPT)

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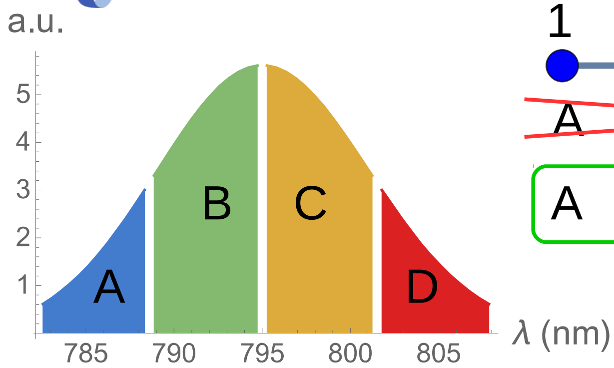

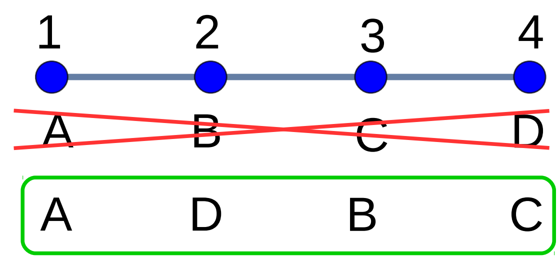

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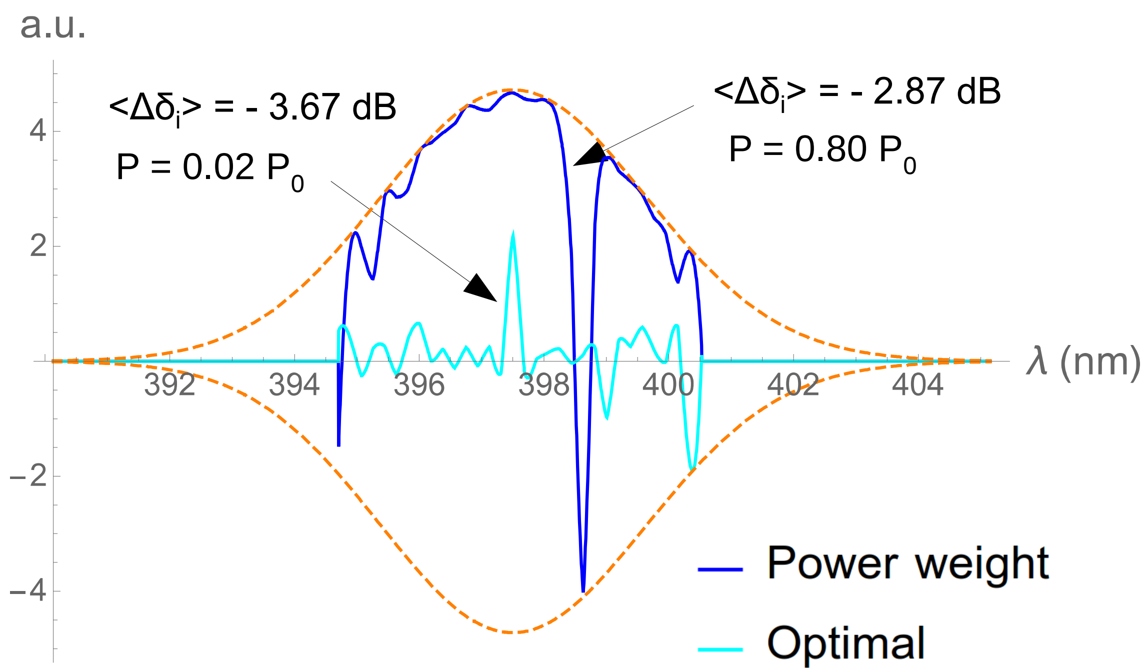
Pump optimizing average nullifiers' noise
(fixed maximum squeezing = 7 dB)



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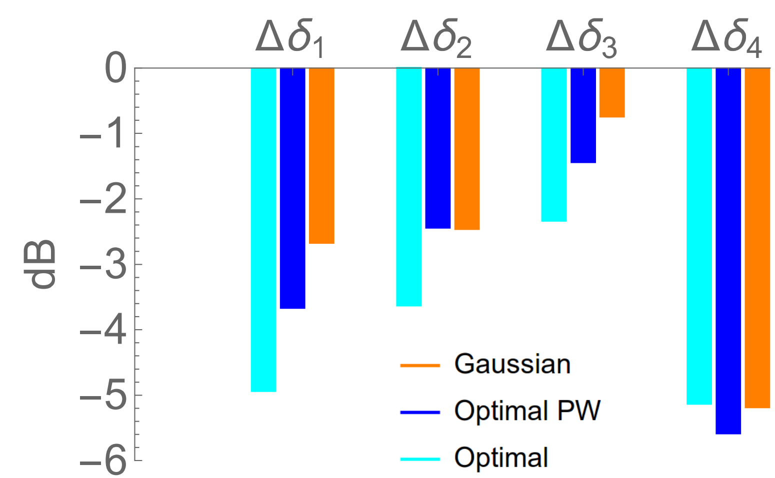
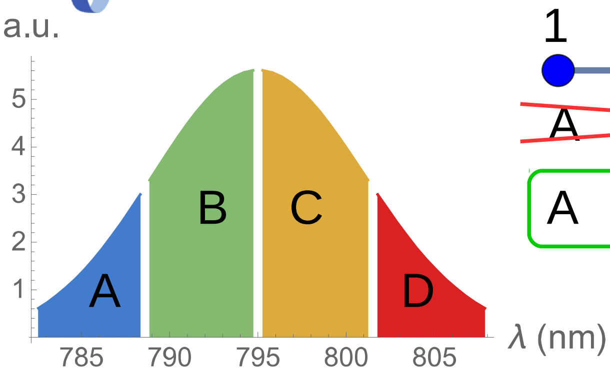
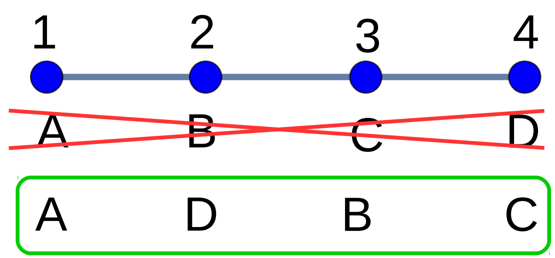


Non trivial spectral phase as well...

Optimizing CV Cluster States - QC





$$\Rightarrow \hat{\delta}_1 = \hat{p}_A - \hat{q}_D$$

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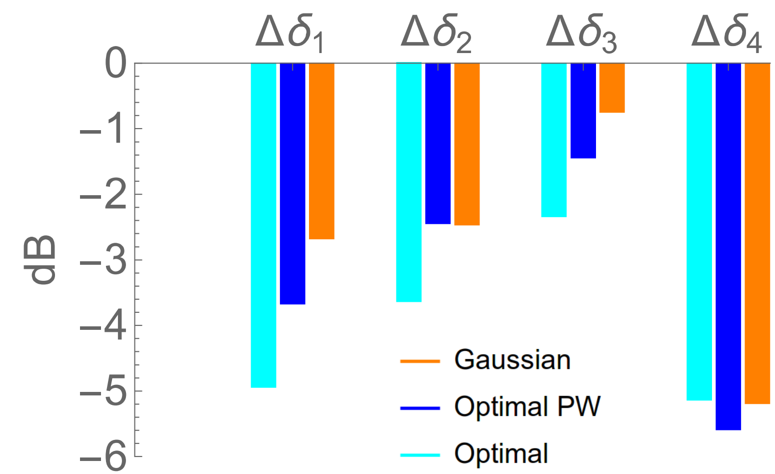

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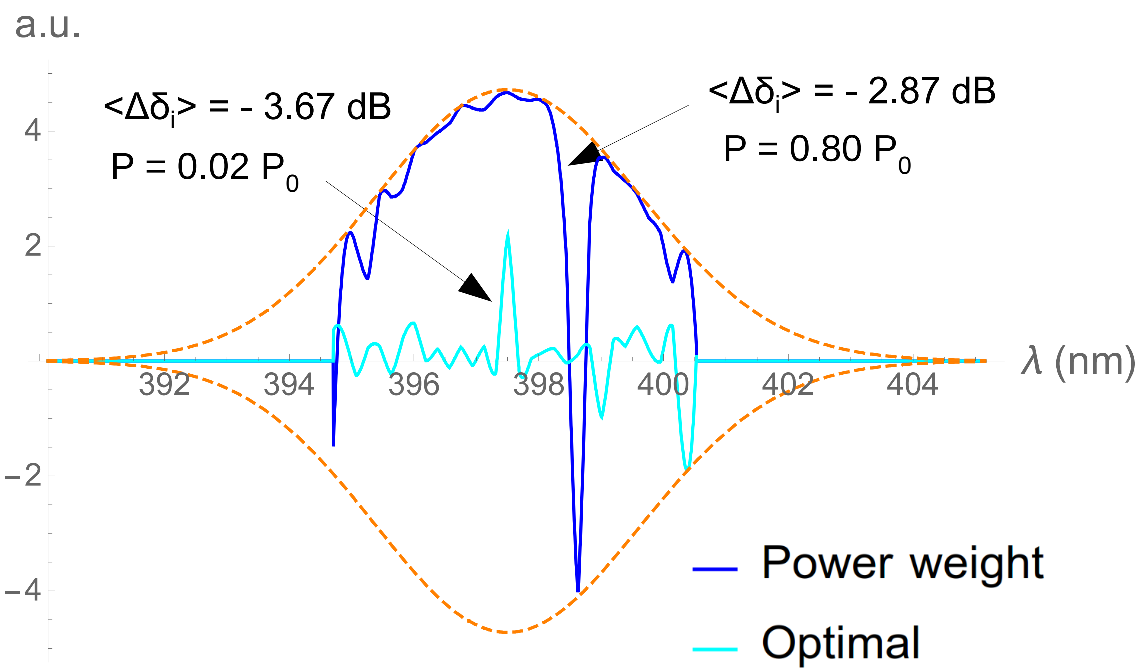
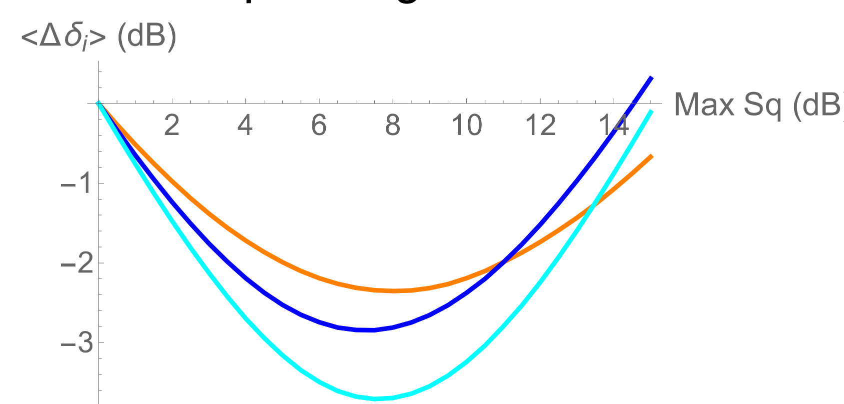


More squeezing ≠ Better nullifiers



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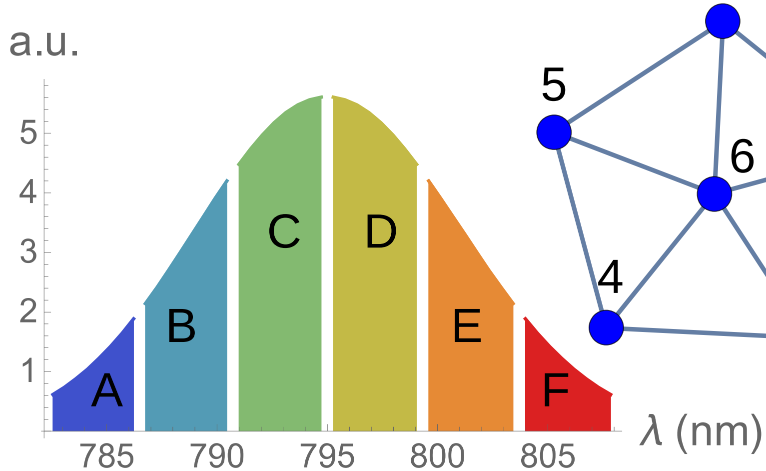

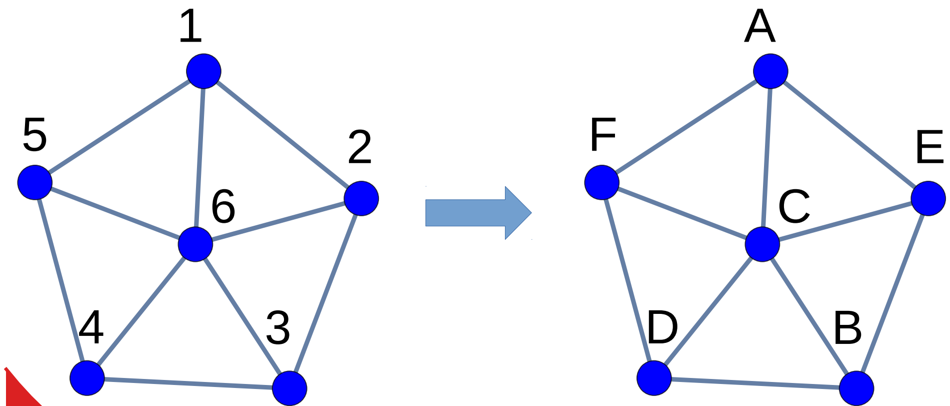

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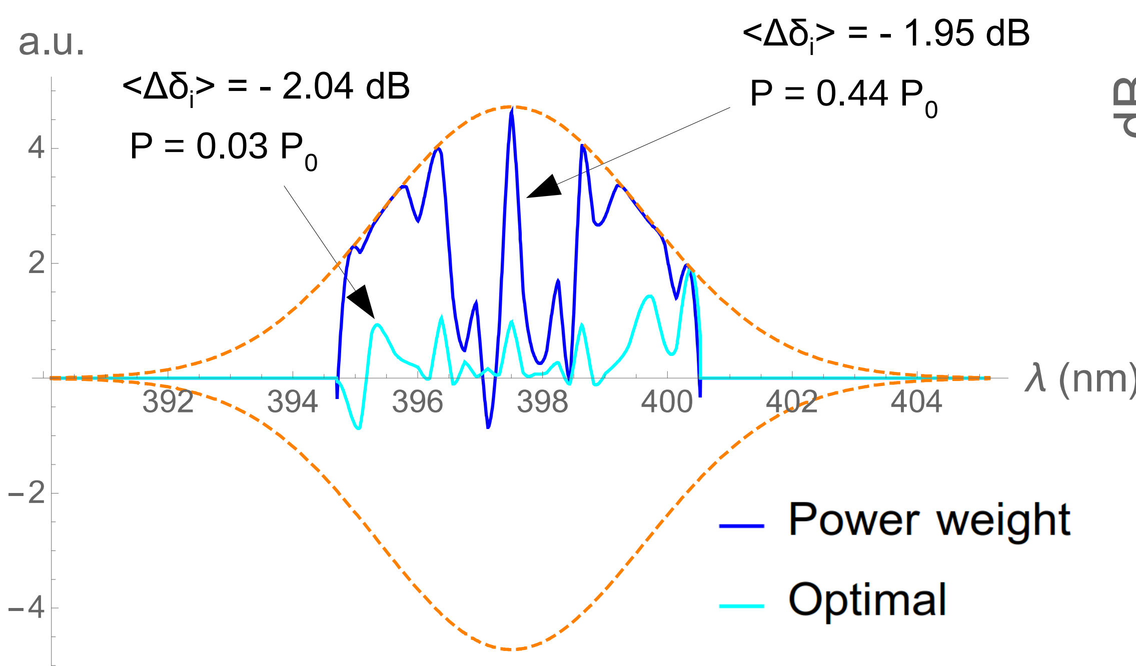

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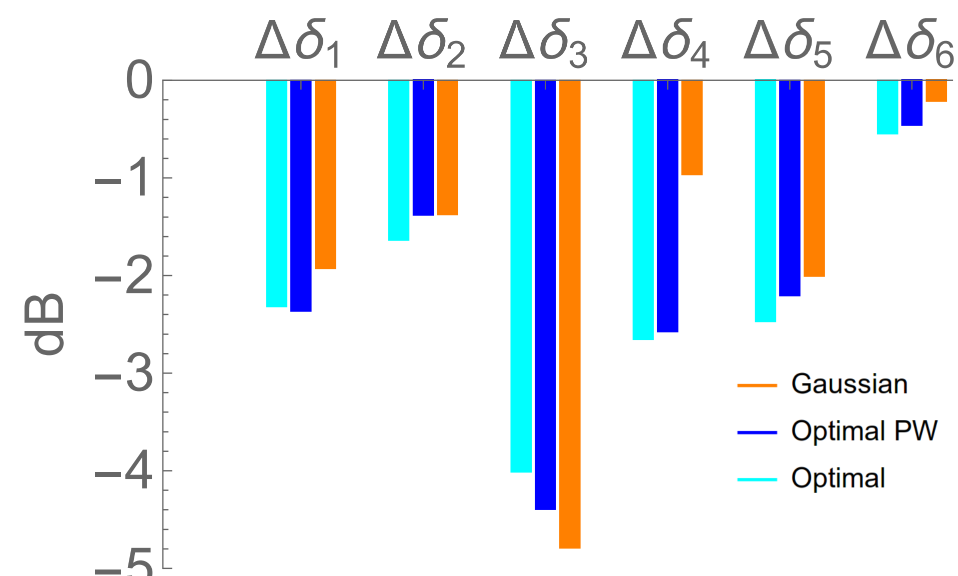

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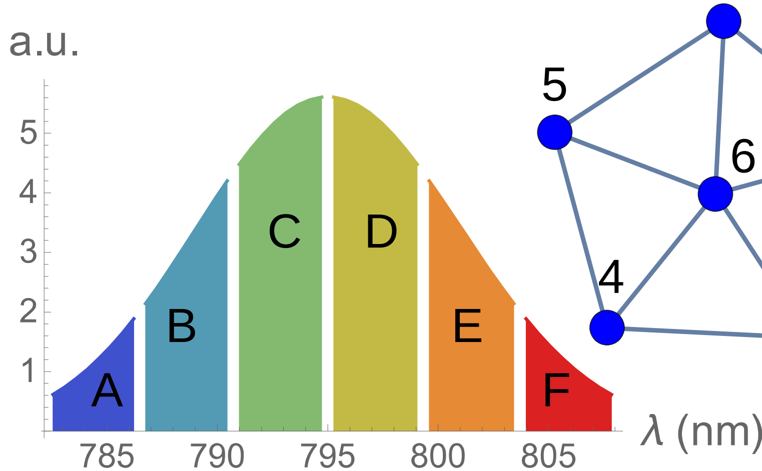

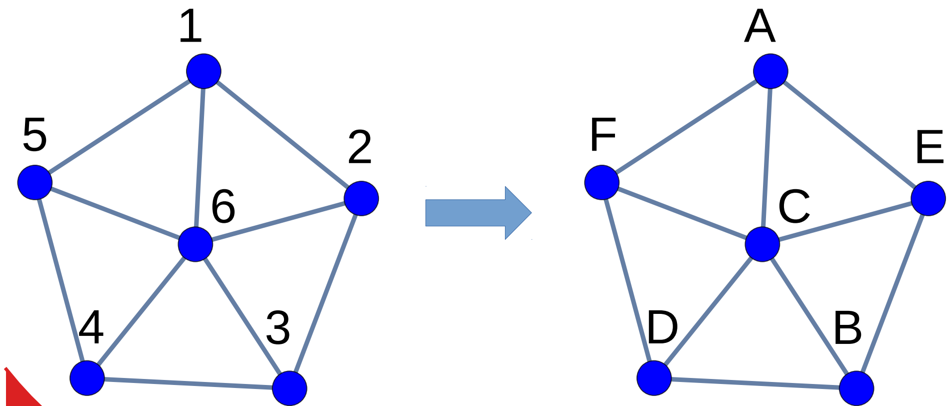

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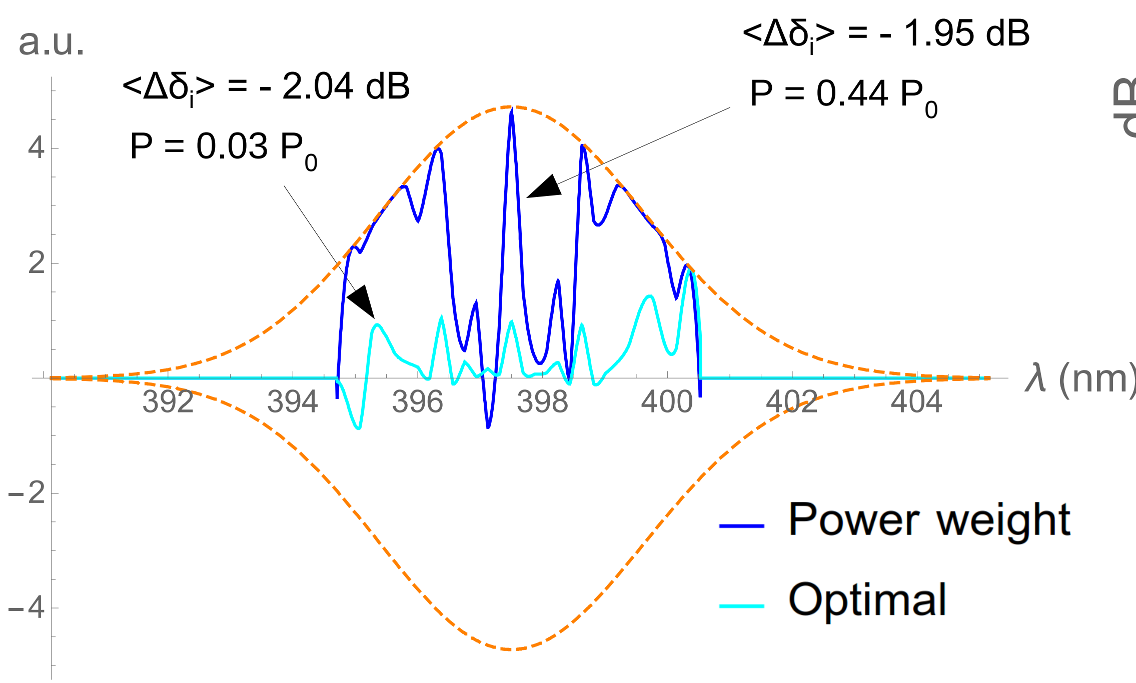

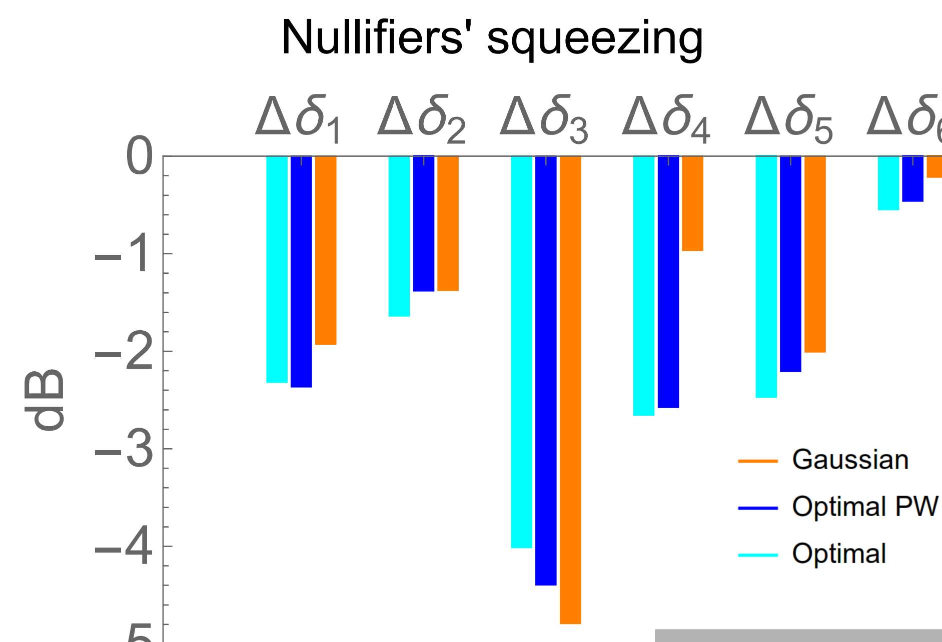

	Purity
Gaussian	0.73
Optimal PW	0.84
Optimal	0.91

Summary

- SPOPOs can generate CV entangled states
- The shape of the pump has a macroscopic effect on the output state
- Numerical optimization can be used effectively to improve the generation of CV cluster states

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Thank you !