Generation of Continuous Variable Quantum Correlations in the Transverse Plane

Quantum Imaging Team

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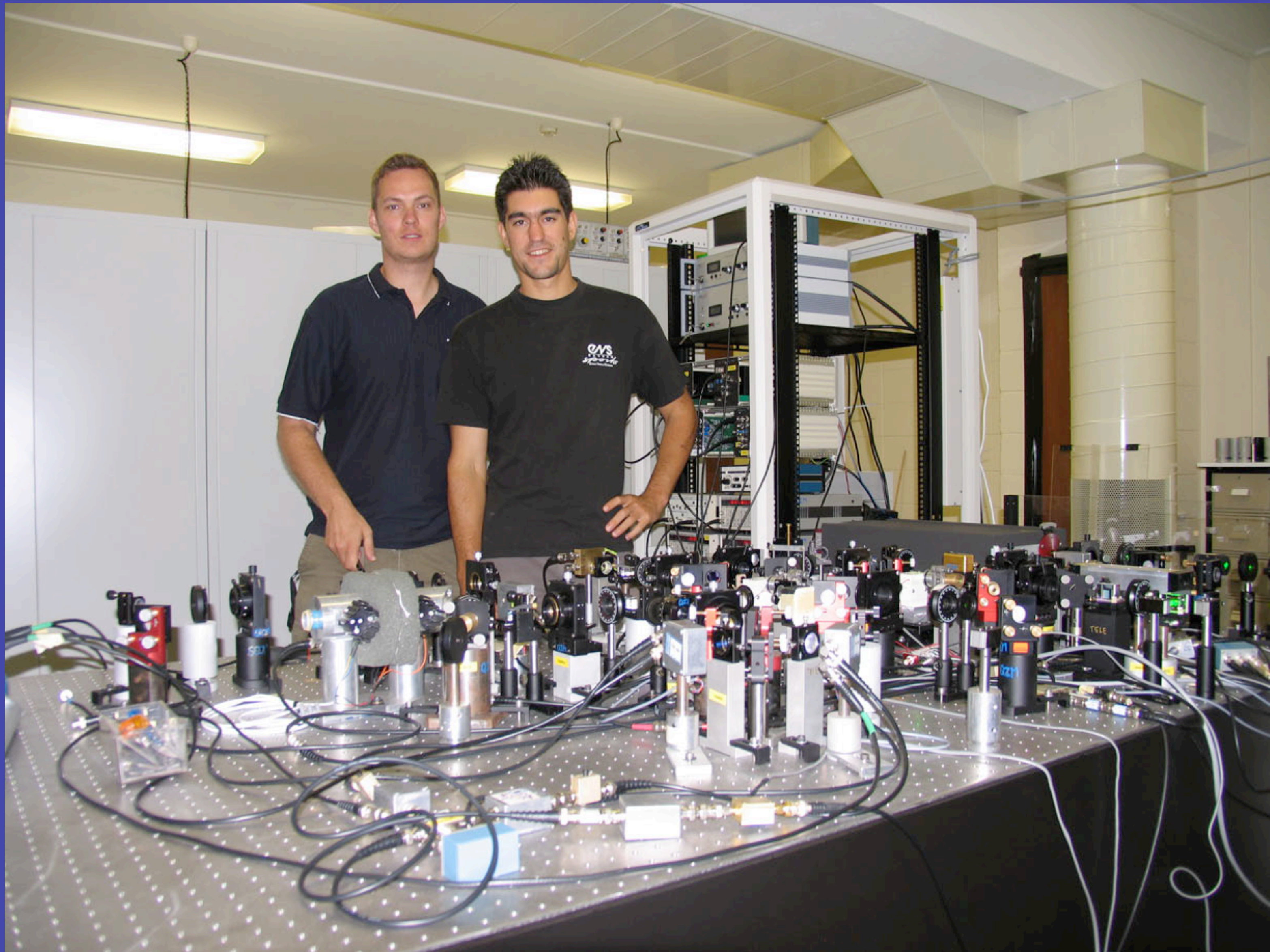

Why higher spatial mode measurements ?

Quantum optics experiments usually consider:

- single mode quantum states of light.

Higher order modes give:

- Additional information about the laser field.

This information does lead to:

- Improved sensitivity for laser tilt / displacement / ROC change and mode squashing.

This information could lead to:

- parallel quantum information processing.

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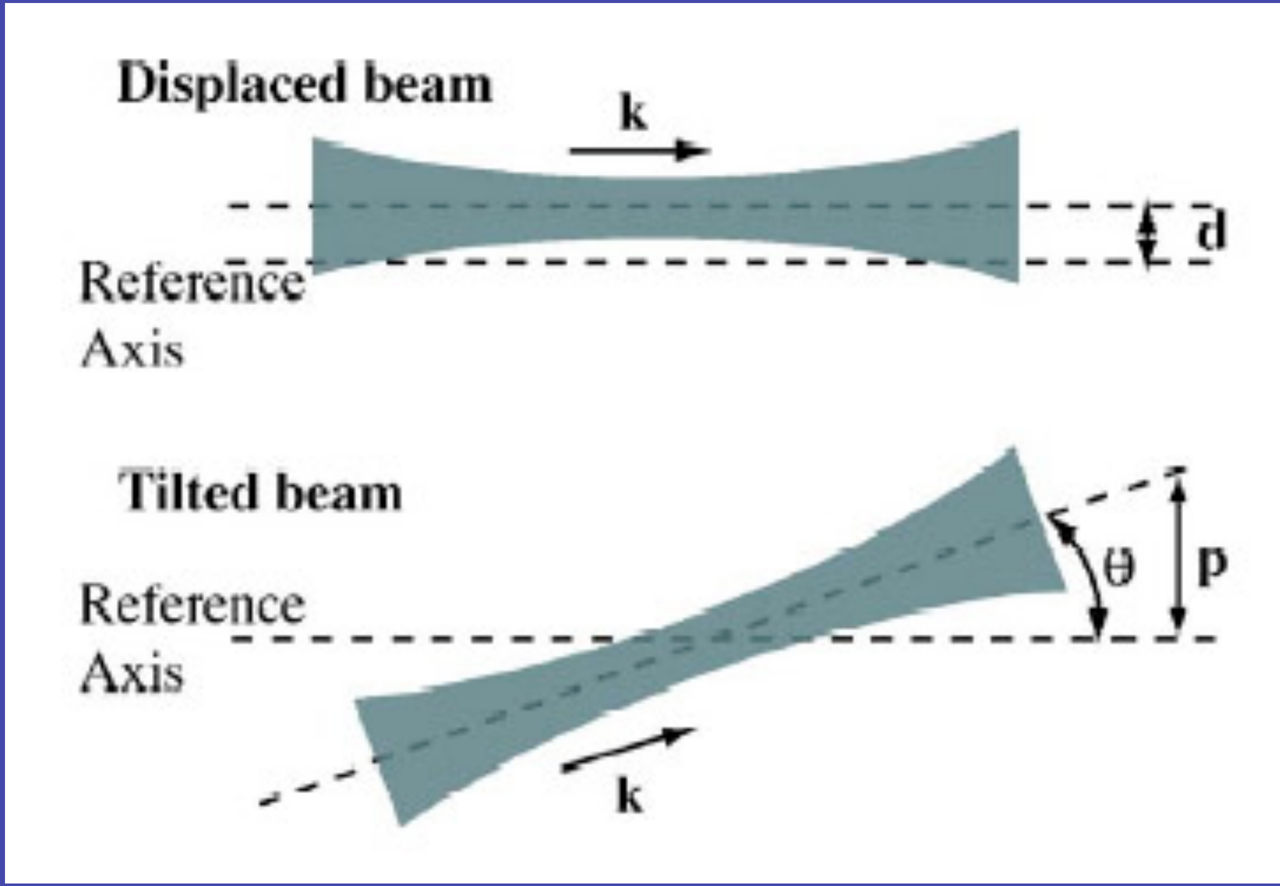
Displacement and Tilt



Small signal expansion

$$TEM_{00}(d) = TEM_{00} + d.\frac{\partial TEM_{00}}{\partial x}$$

1st order (Taylor)

No d dependence   proportional to d

Displacement

$$TEM_{00}(d) = TEM_{00} + \frac{d}{w_0} TEM_{10}$$

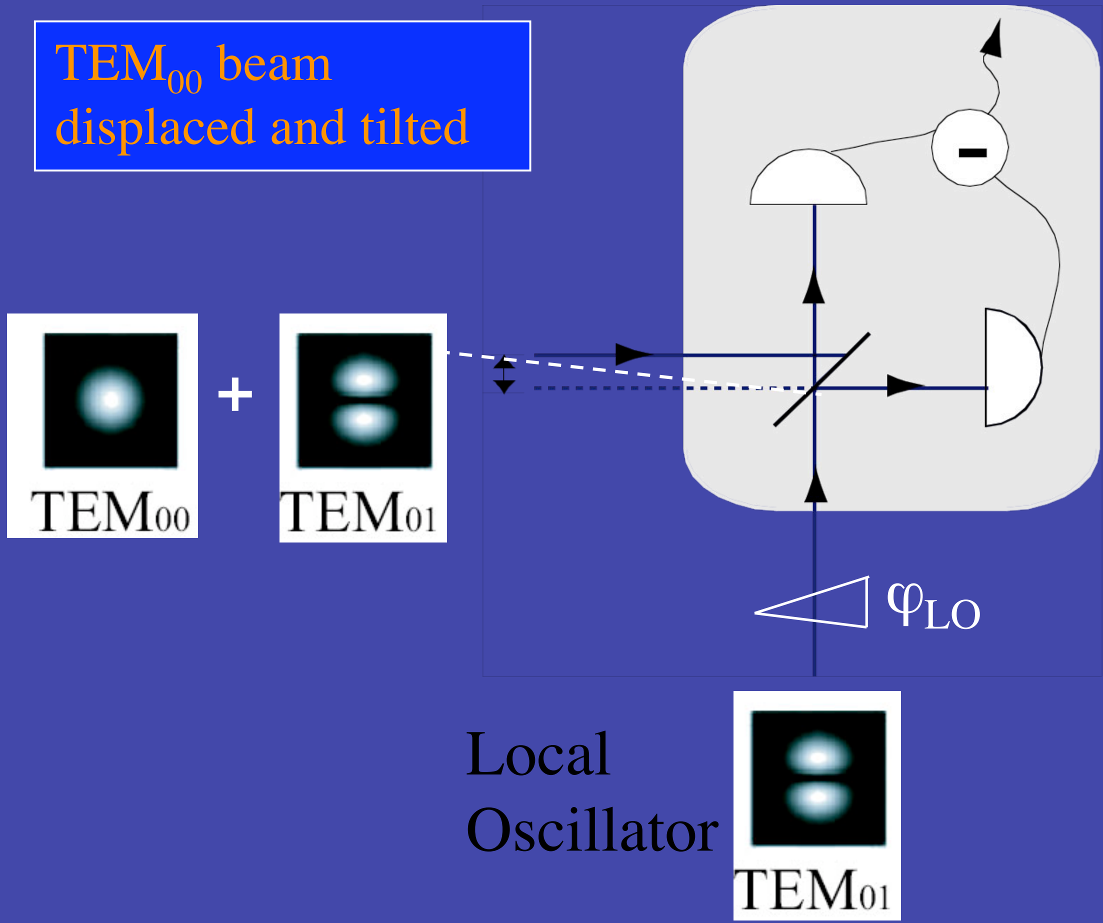
Tilt

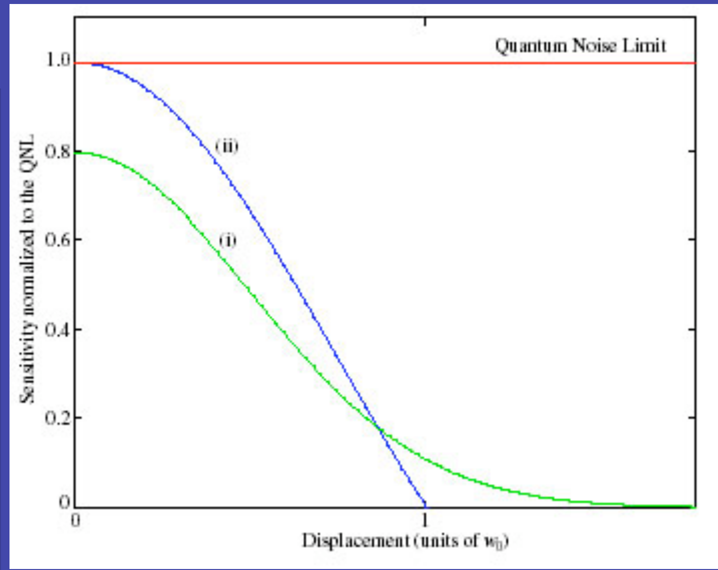
$$TEM_{00}(\theta) = TEM_{00} + i\frac{\pi w_0 \theta}{\lambda} TEM_{10}$$

M.T.L. Hsu et al. Phys. Rev. A 72, 013802 **(2005).**

Optimal T & D measurements

TEM$_{00}$ beam
displaced and tilted

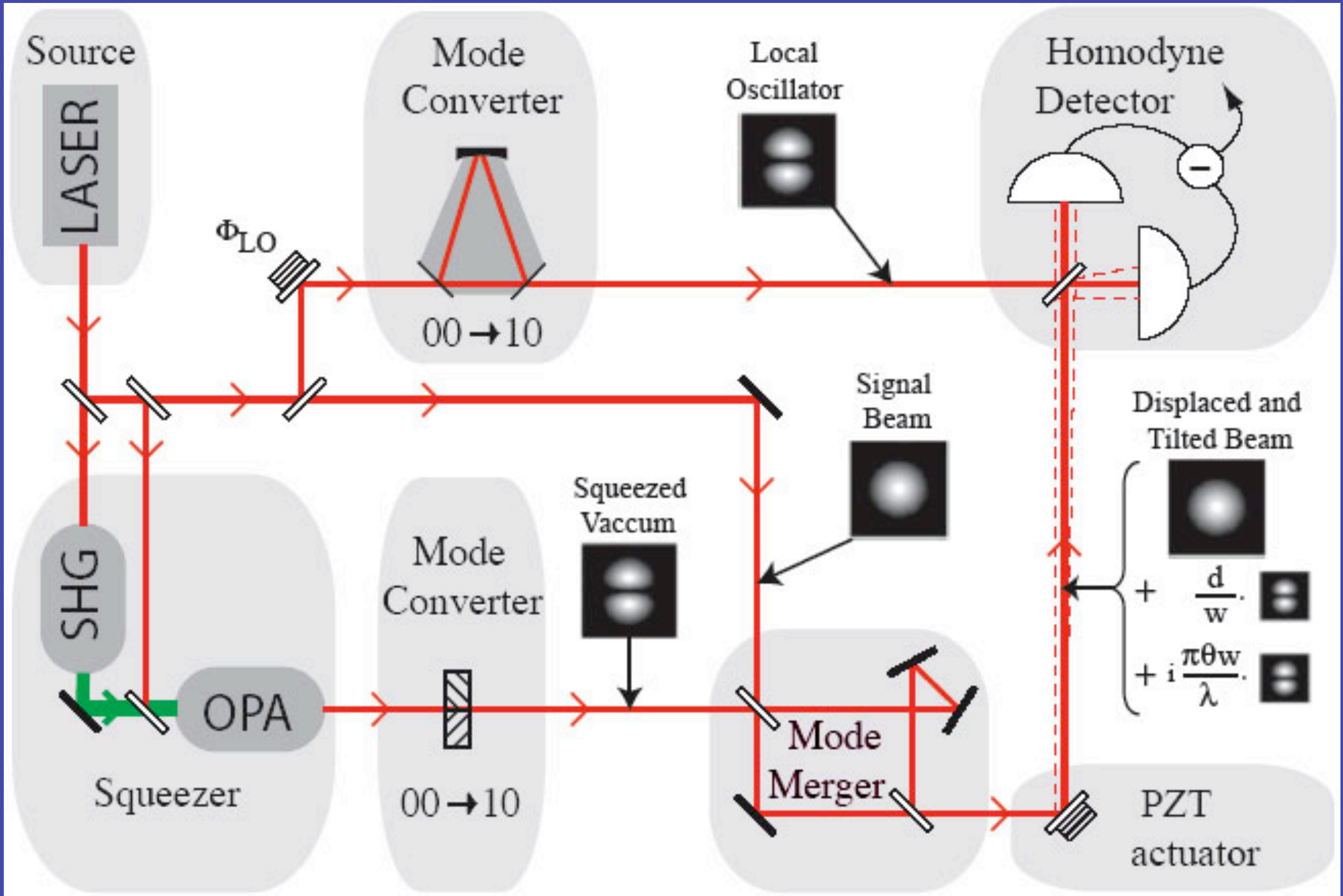




Tilt or displacement
component selection
according to LO phase
➡ 100% efficiency
for small modulations

[1] M.T.L.Hsu, V.Delaubert, P.K.Lam and W.P.Bowen,J.Opt.B, **6**, 495 (2004)

Experiment using flipped mode



Conclusions as of last meeting

- **Results :**

  - demonstration of TEM_{10} Homodyne Detection for displacement and tilt measurements

  - detection of displacement modulation below the QNL using the homodyne scheme

  - 25% efficiency improvement compared to Split Detection

$$\frac{SNR_{\text{split detection}}}{SNR_{\text{homodyne detection}}} = 0.64 \pm 0.07$$

↑ theoretical value !

How do we generate CV quantum correlations in higher spatial modes?

We do this by producing squeezed light fields in modes other than TEM00;

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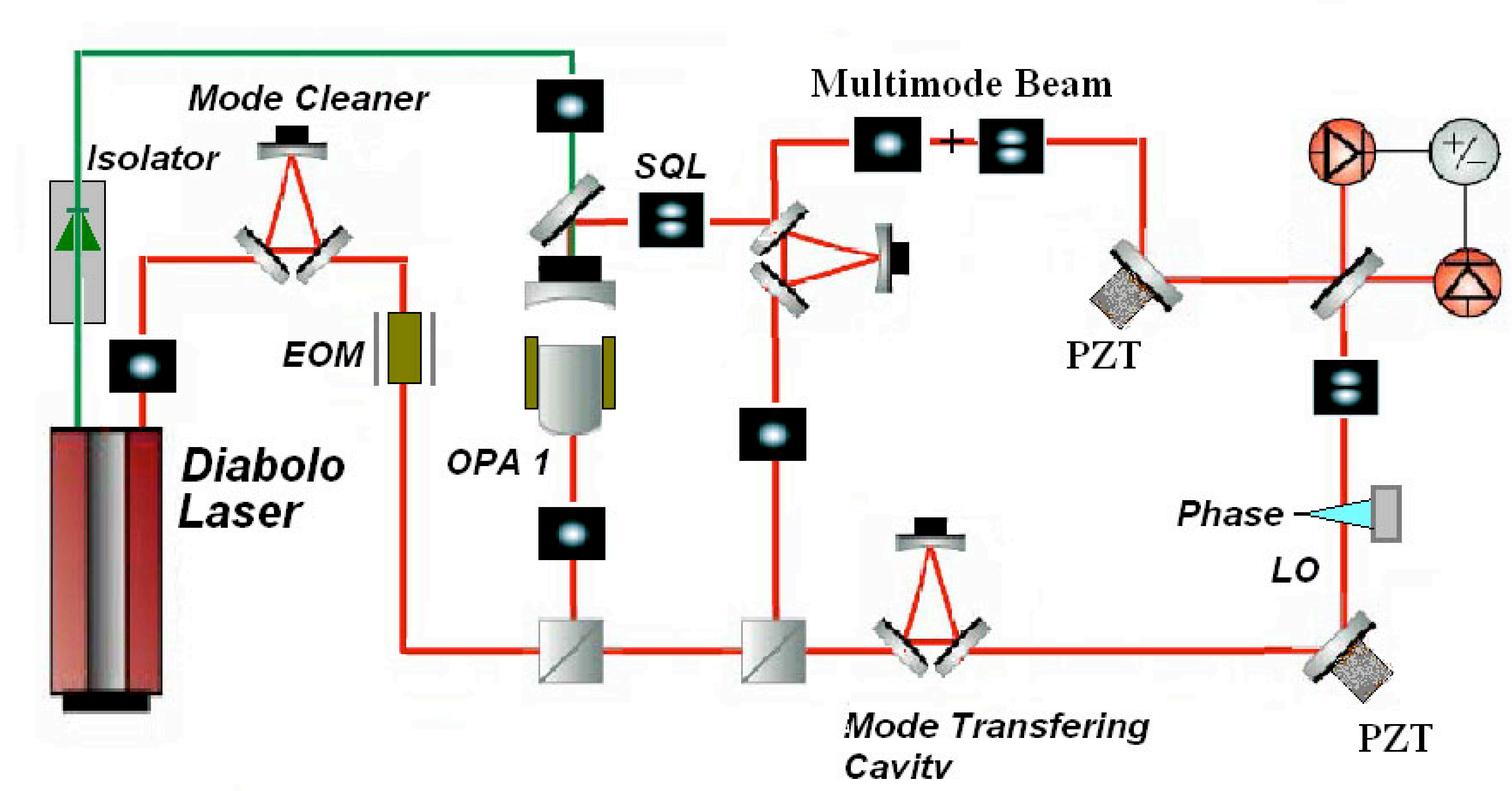
But there is a better way!!

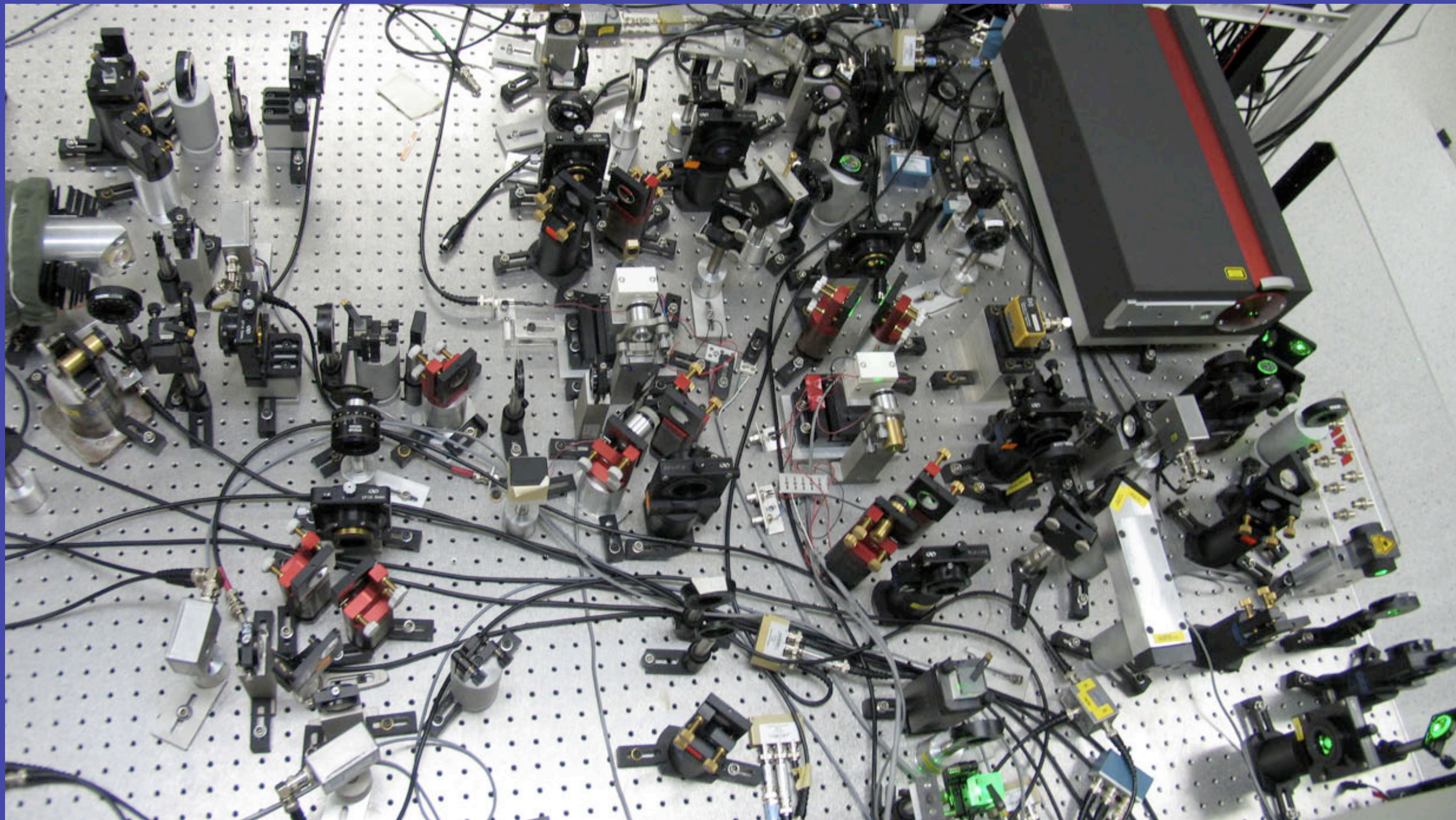
What choices do we have ?

- SHG/OPA configuration;
- Optical Cavity;
- MEMS mirrors;
- Holograms; or
- Computer controlled phase plates.

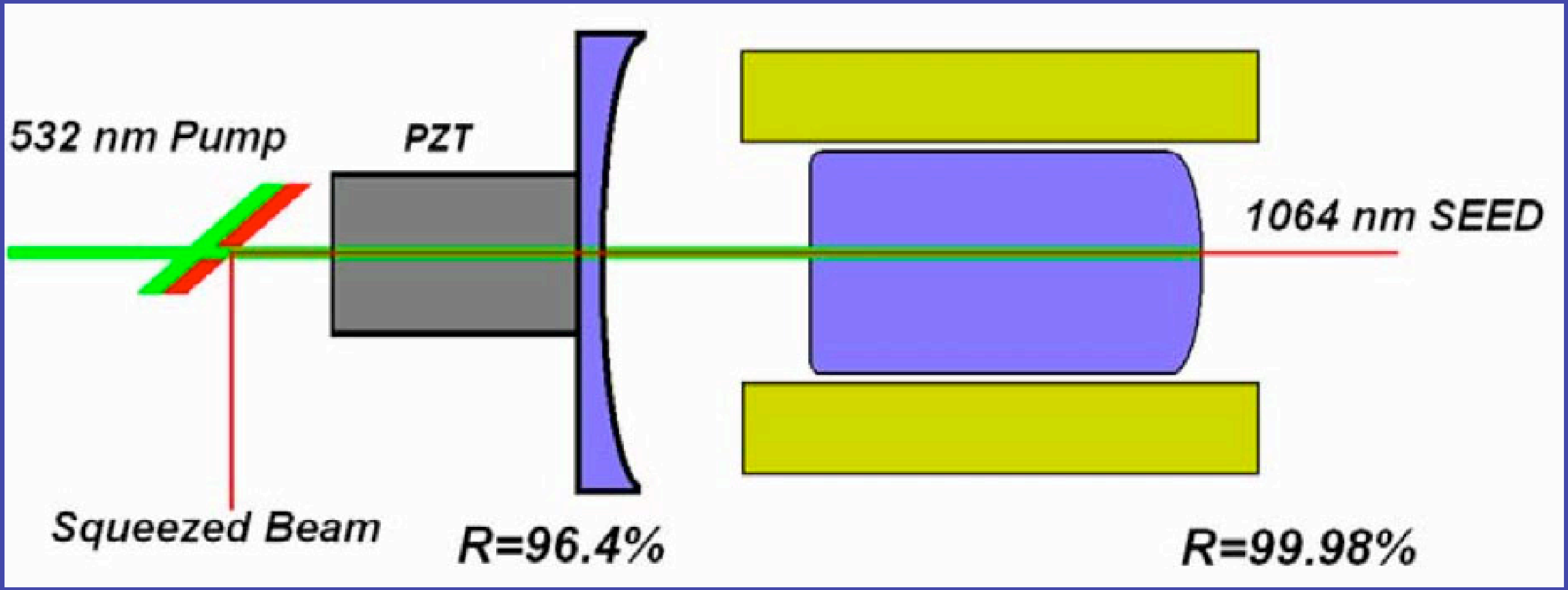
OPA Cavity Creating TEMn0 Squeezing



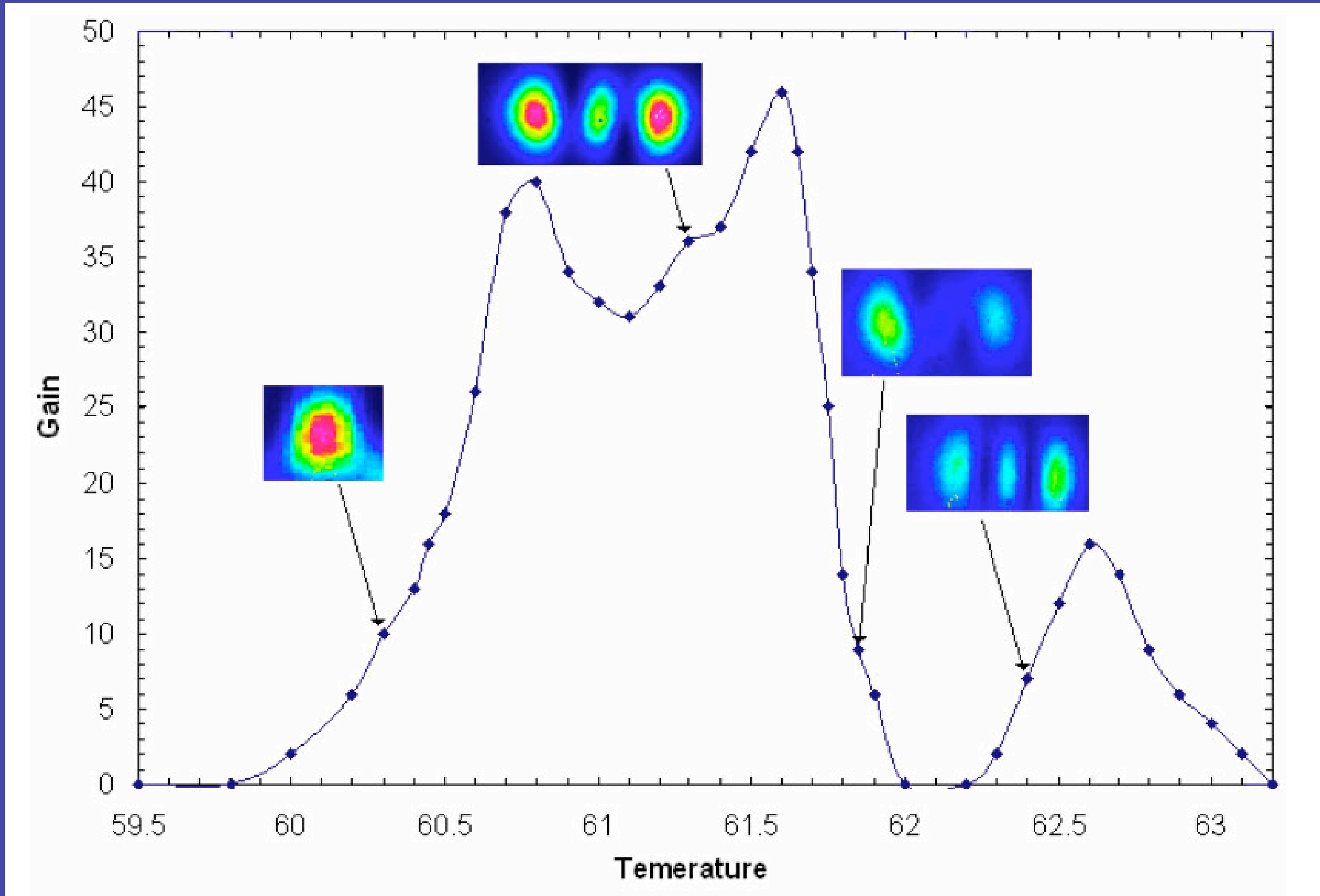
The Experiment



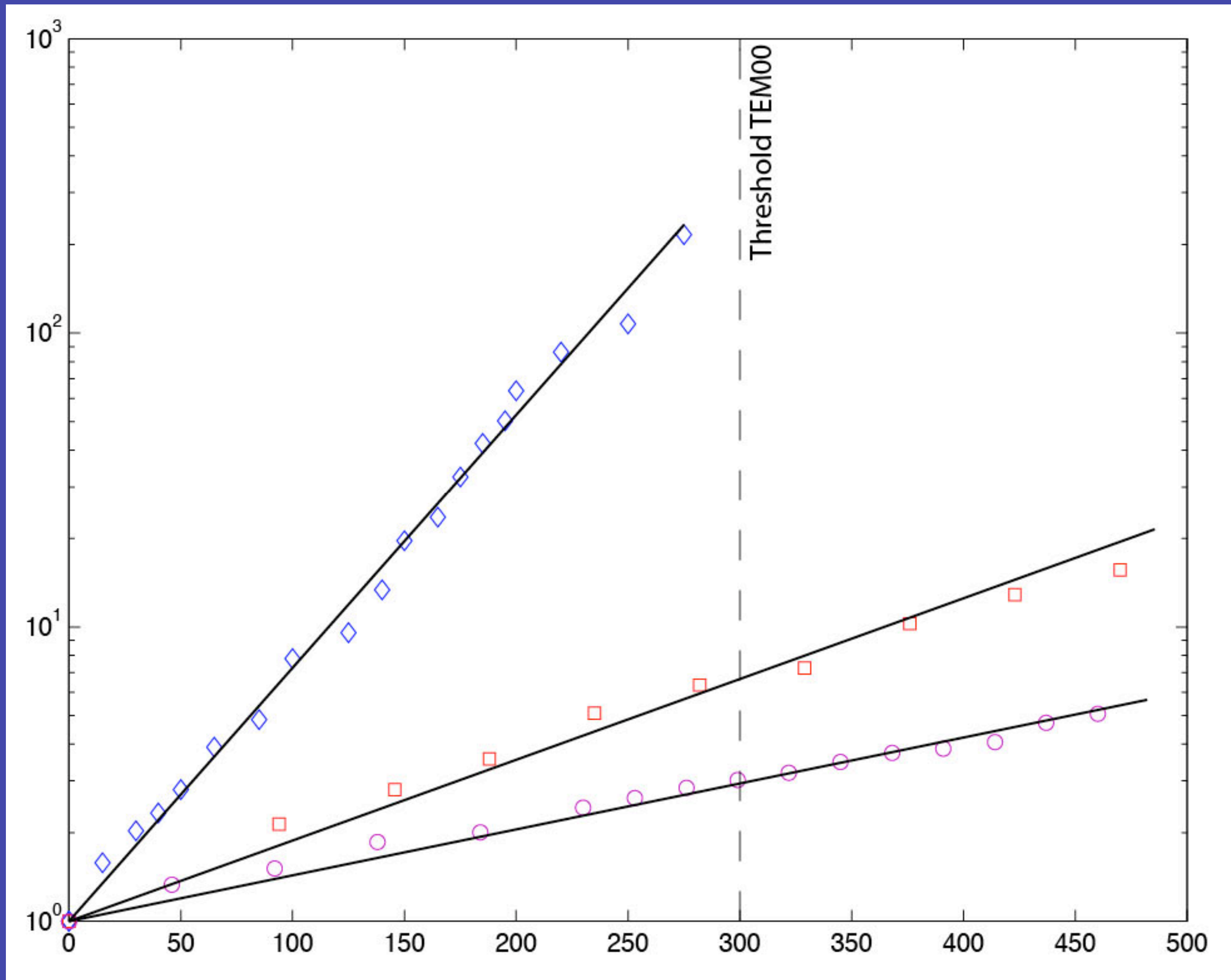
The OPA Cavity



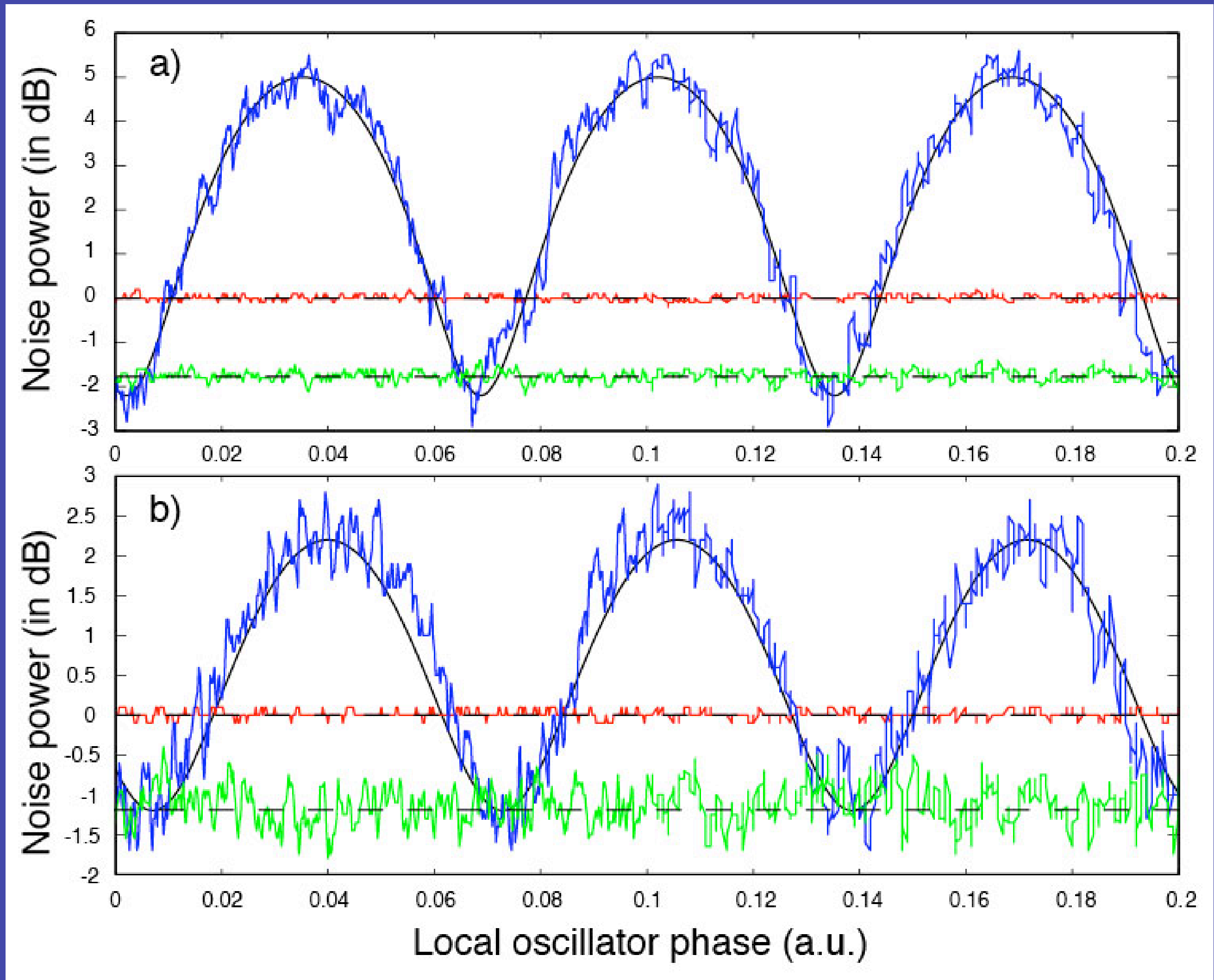
Phase Matching for OPA Cavity



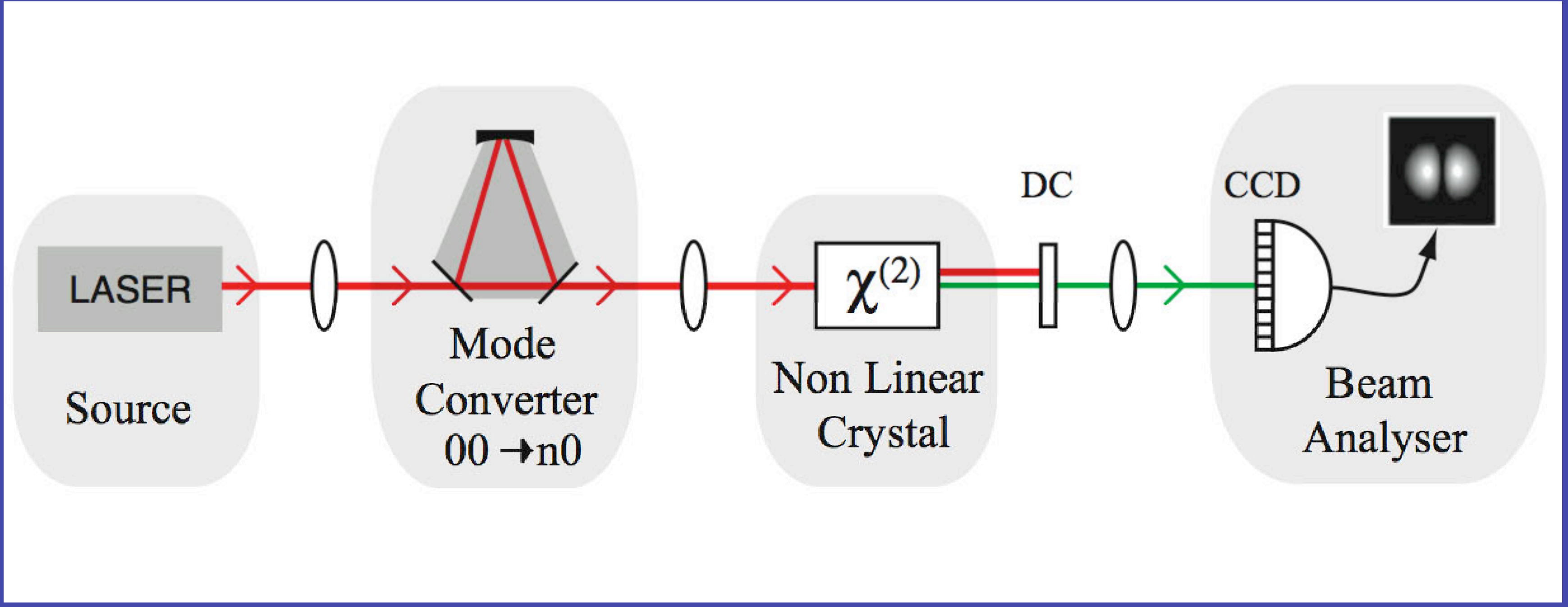
Gain Curves for TEM00, 01, 02



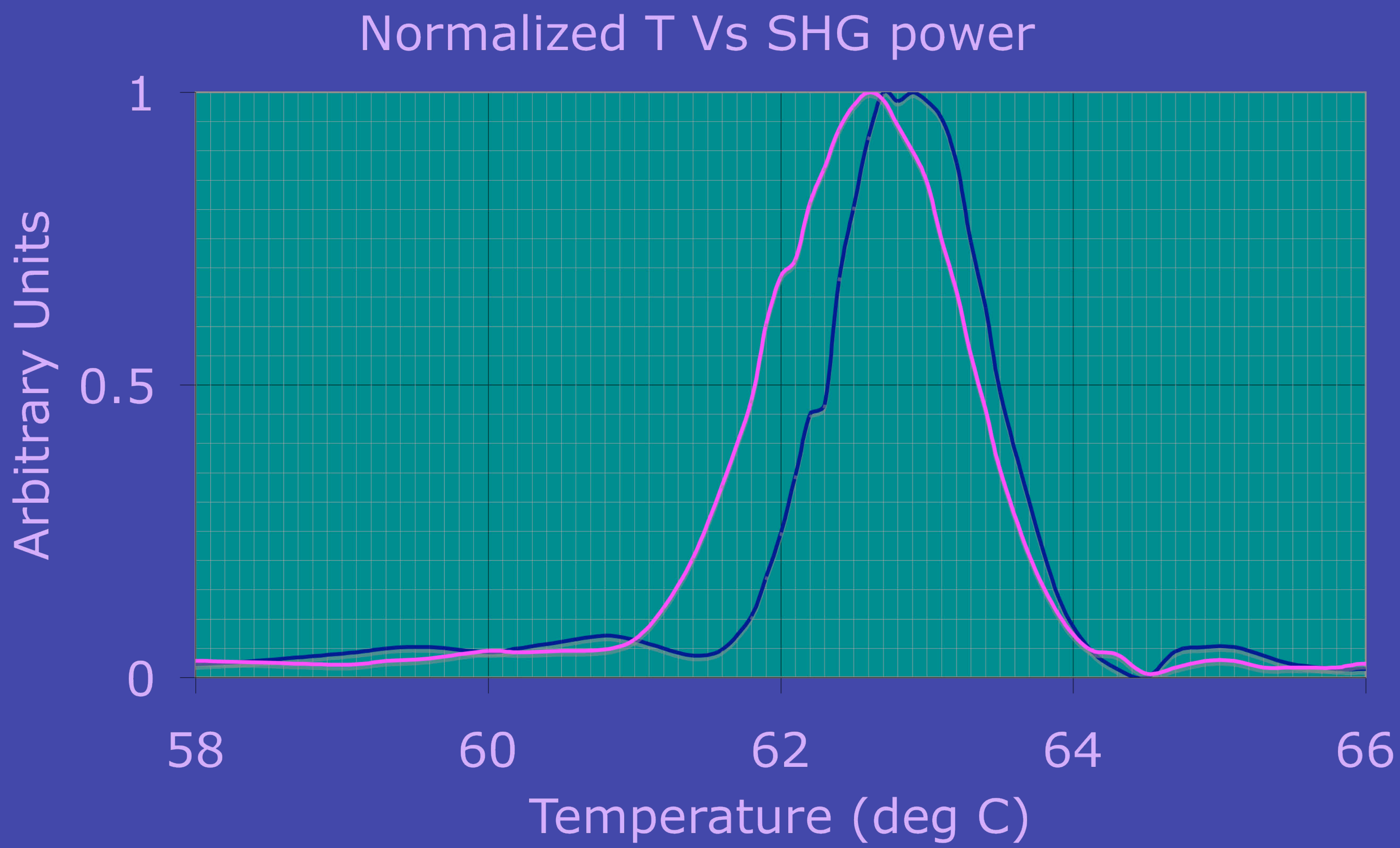
SQZ TEM01 and TEM02



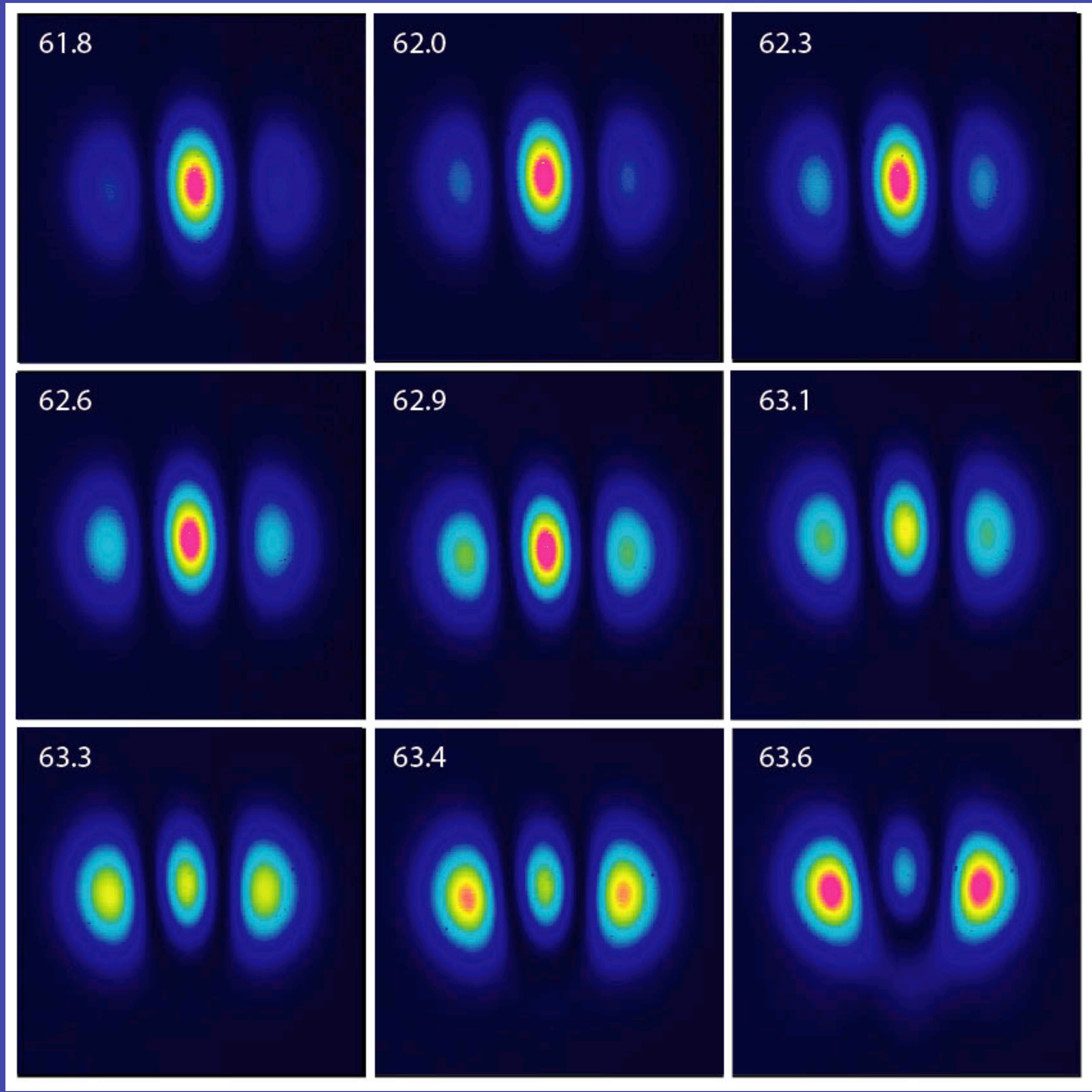
Single Pass Measurements



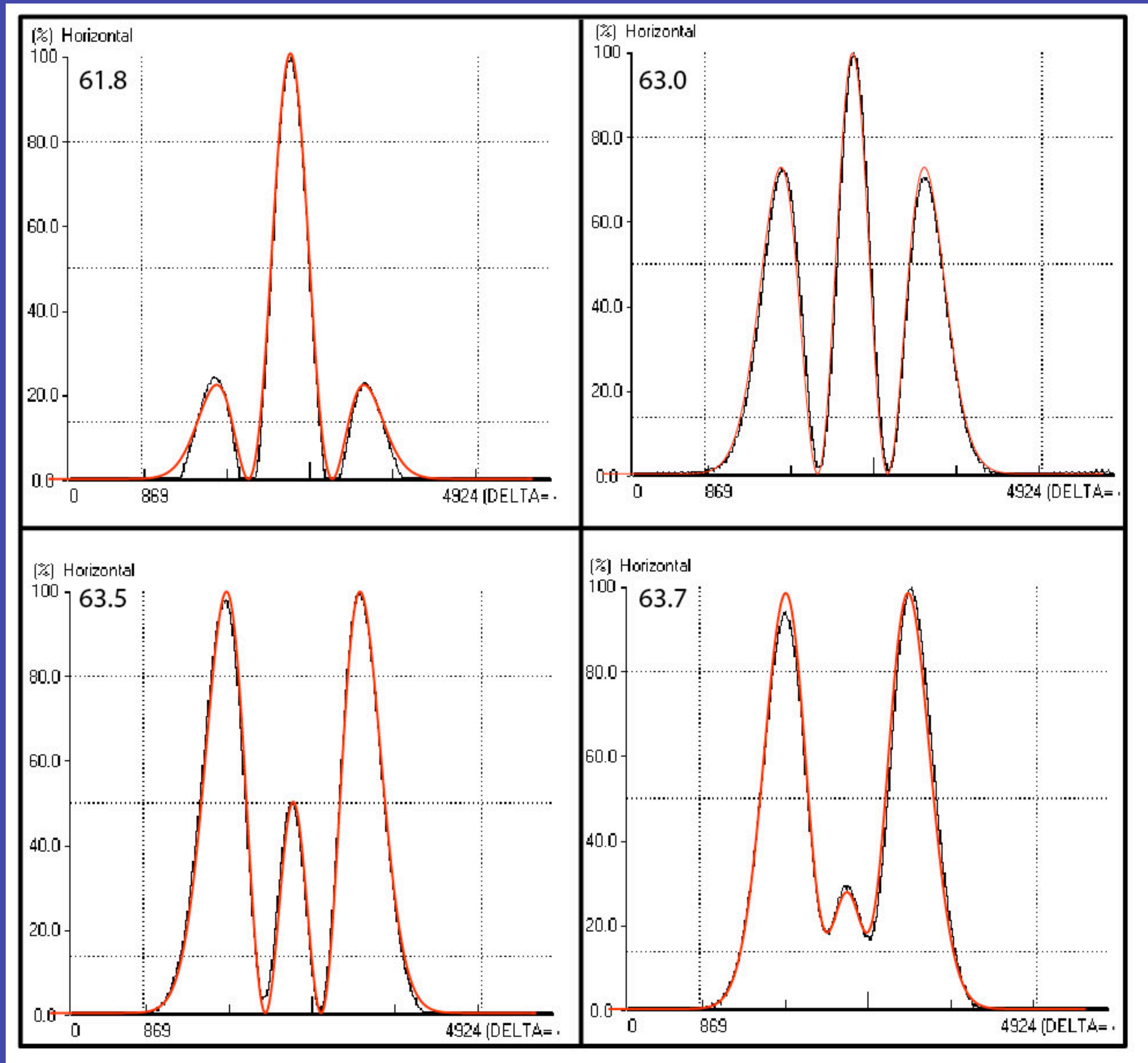
SHG Efficiency



Mode output Vs phase matching Temperature



Energy Transfer



The Physics

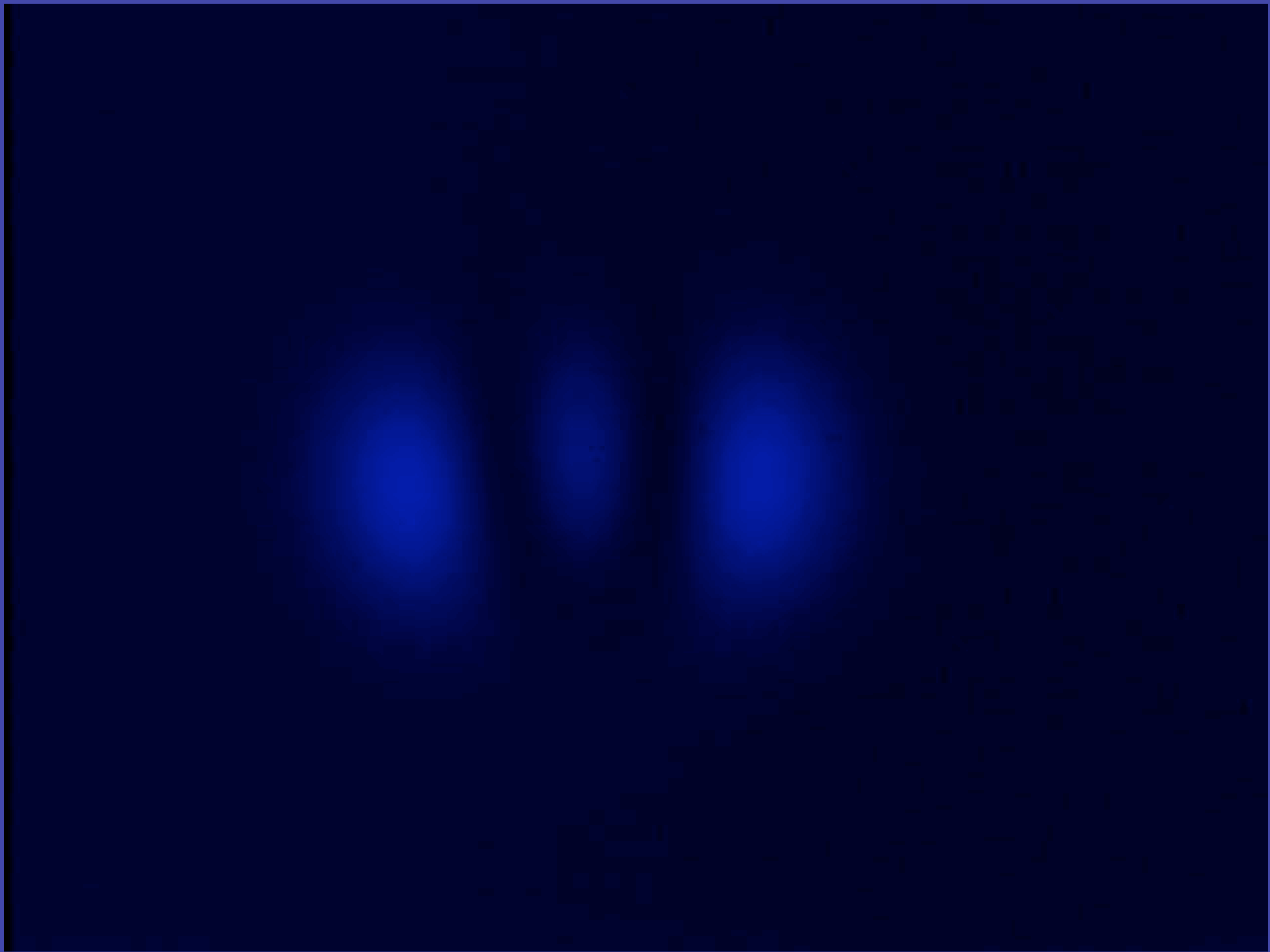
If u represents the IR laser amplitude and v represents the green amplitude then it was previously thought that:

$$u^2 = \alpha_0 v_0 + \alpha_2 v_2 = 0.57 v_0 + 0.82 v_2$$

But it is actually described by:

$$u^2(T) = \alpha_0(T) v_0 + \sqrt{1 - \alpha_2(T)} v_2 e^{i\phi(T)}$$

The Main Feature



The End

Other interesting results

PHYSICAL REVIEW A **73**, 013817 (2006)

Generation of a frequency comb of squeezing in an optical parametric oscillator

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The multimode operation of an optical parametric oscillator (OPO) operating below threshold is calculated. We predict that squeezing can be generated in a comb that is limited only by the phase matching bandwidth of the OPO. Effects of technical noise on the squeezing spectrum are investigated. It is shown that maximal squeezing can be obtained at high frequency even in the presence of seed laser noise and cavity length fluctuations. Furthermore the spectrum obtained by detuning the laser frequency off OPO cavity resonance is calculated.

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