QUANTIM

Quantum Imaging IST-2000-26019

IMEDEA

Palma de Mallorca, Spain

http://www.imedea.uib.es/PhysDept

Image processing with Type I-TW-SHG

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FET-Open scheme

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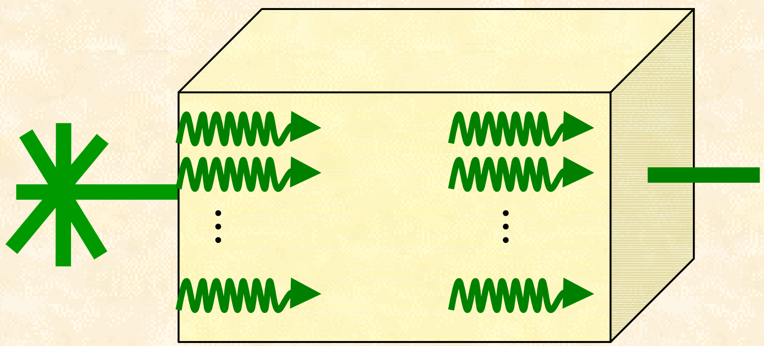
OPA vs. TW-SHG (I)

Propagation of the pump field through the nonlinear crystal

$\chi^{(2)}$ nonlinear crystal pumped with a *strong* monochromatic field at

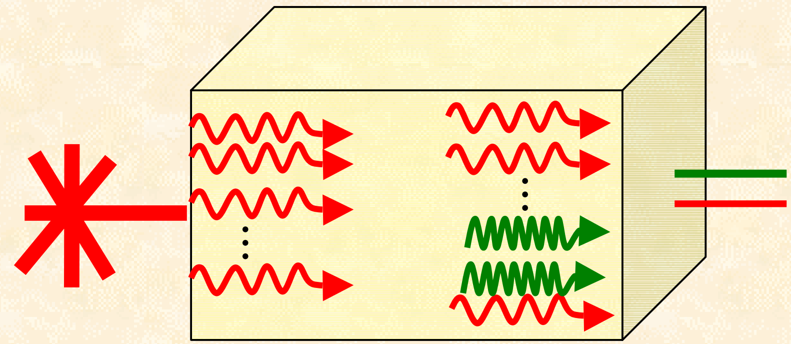
Second Harmonic freq. (OPA)



Pumping at 2ω — **strong** field at 2ω, **weak** field at ω

Generation of Fundamental field only triggered by fluctuations (Spontaneous emission)

Fundamental freq. (TW-SHG)



Pumping at ω — **strong** field at ω, **strong** field at 2ω

SHG: A strong homogeneous field at frequency 2ω develops.

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OPA vs. TW-SHG (II)

Behaviour in presence of an input signal

Three wave interaction:

$$H_{INT} = i\eta\lambda\left(\sum_{K,k}\hat{A}_S^{+}(K)\hat{A}_F(k)\hat{A}_F(K-k)+\sum_{K,k}\hat{A}_S(K)\hat{A}_F^{+}(k)\hat{A}_F^{+}(K-k)\right).$$

Parametric approximation

•Strong homogeneous field at SH frequency: **Twin photon emission**

$$\hat{A}_S(k) \text{ in } H_{INT} \leftarrow \left\langle \hat{A}_S \right\rangle \delta^{(3)}(k) \qquad H_{INT}^{Eff} = i\eta\lambda_{II}\left(\sum_{k}\hat{A}_F(k)\hat{A}_F(-k)+\sum_{k}\hat{A}_F^{+}(k)\hat{A}_F^{+}(-k)\right)$$

OPA

SHG

•Strong homogeneous field at FH frequency: **Frequency conversion**

$$\hat{A}_F(k) \text{ in } H_{INT} \leftarrow \left\langle \hat{A}_F \right\rangle \delta^{(3)}(k) \qquad H_{INT}^{Eff} = i\eta\lambda_{I}\left(\sum_{k}\hat{A}_S^{+}(k)\hat{A}_F(k)+\sum_{k}\hat{A}_S(k)\hat{A}_F^{+}(k)\right)$$

Propagation in a $\chi^{(2)}$ nonlinear crystal

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Quantum operators associated with FH and SH fields

$$\hat{A}_F(z,q,\Omega) = \delta^{(2)}(q)\delta(\Omega)c_F(z) + \hat{a}_F(z,q,\Omega)$$
$$\hat{A}_S(z,q,\Omega) = \delta^{(2)}(q)\delta(\Omega)c_S(z) + \hat{a}_S(z,q,\Omega)$$

q: transverse wave number
Ω: frequency offset

Strong monochr.fields generated by the pump inside the crystal

Quantum operators: (Quantum noise propag. of input signal)

Propagation equations

Classical eq. of nonlinear optics for the strong homogeneous fields

Zeroth order:

$$\partial_z c_F(z) = -2Kc_F^*(z)c_S(z)e^{-i\Delta k.z}$$
$$\partial_z c_S(z) = Kc_F^2(z)e^{i\Delta k.z}$$

$\Delta k = 2k_F - k_S$: Collinear phase mismatch

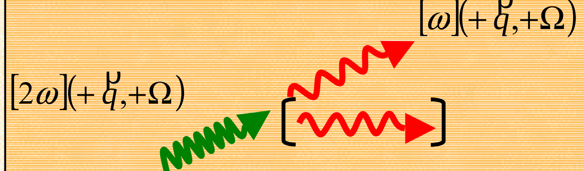
$$\Delta(q,\Omega) = k_F^Z(q,\Omega) + k_F^Z(-q,-\Omega) - k_S^Z(0,0)$$

Propagation eq. for an input signal/quantum fluctuations

First order:

$$\partial_z \hat{a}_F(z,q,\Omega) = -2Kc_S(z)\hat{a}_F^+(z,-q,-\Omega)e^{-i\Delta(q,\Omega)z} - 2Kc_F^*(z)\hat{a}_S(z,q,\Omega)e^{-iD(q,\Omega)z}$$

$$\partial_z \hat{a}_S(z,q,\Omega) = 2Kc_F(z)\hat{a}_F(z,q,\Omega)e^{iD(q,\Omega)z}$$



$$D(q,\Omega) = k_F^Z(q,\Omega) + k_S^Z(0,0) - k_S^Z(q,\Omega)$$

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Formal solution of the propagation equations

INPUT OUTPUT TRANSFORMATION:

$$\hat{a}_{F,out}(q,\Omega) = u_F(q,\Omega)\hat{a}_{F,in}(q,\Omega) + \upsilon_F(q,\Omega)\hat{a}^{+}_{F,in}(-q,-\Omega)$$
$$+ \mu_F(q,\Omega)\hat{a}_{S,in}(q,\Omega) + \nu_F(q,\Omega)\hat{a}^{+}_{S,in}(-q,-\Omega)$$

$$\hat{a}_{S,out}(q,\Omega) = u_S(q,\Omega)\hat{a}_{F,in}(q,\Omega) + \upsilon_S(q,\Omega)\hat{a}^{+}_{F,in}(-q,-\Omega)$$
$$+ \mu_S(q,\Omega)\hat{a}_{S,in}(q,\Omega) + \nu_S(q,\Omega)\hat{a}^{+}_{S,in}(-q,-\Omega)$$

Operators associated with the FH and SH outgoing waves at frequency (q,Ω)

Operators associated with the ingoing waves at frequency (q,Ω) and (-q,-Ω)

TW-SHG in the phase matched case

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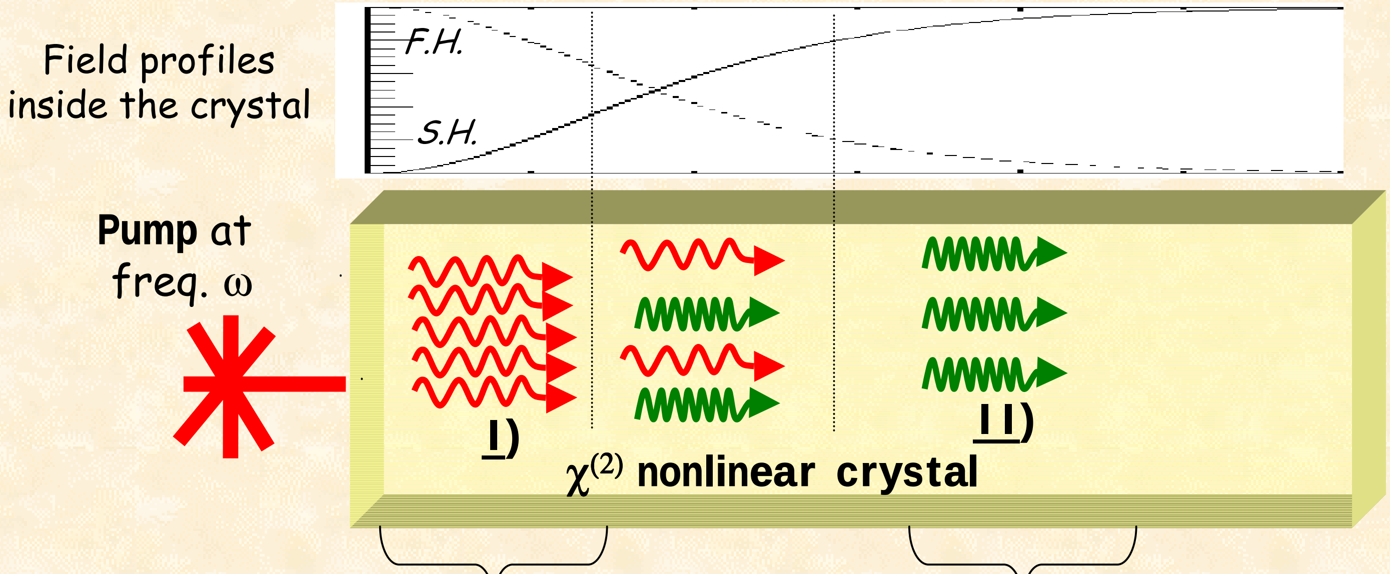
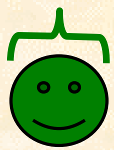
Perfect phase matching: $2k_F = k_S$

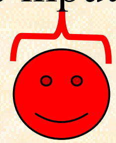


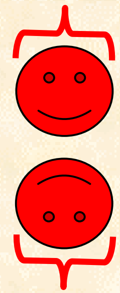
Frequency Converter   OPA

Signal processing

Injection of an image (2ω) → Frequency down converted version of the input image → Amplification and duplication





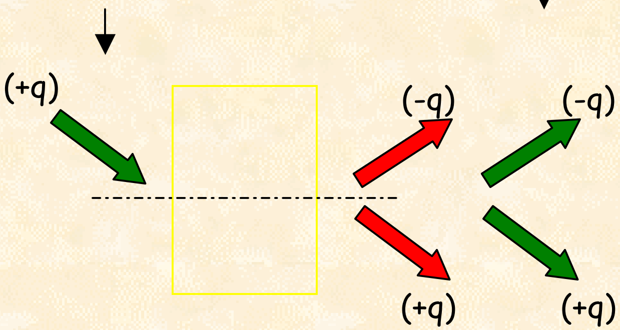


Phase-insensitive configuration:

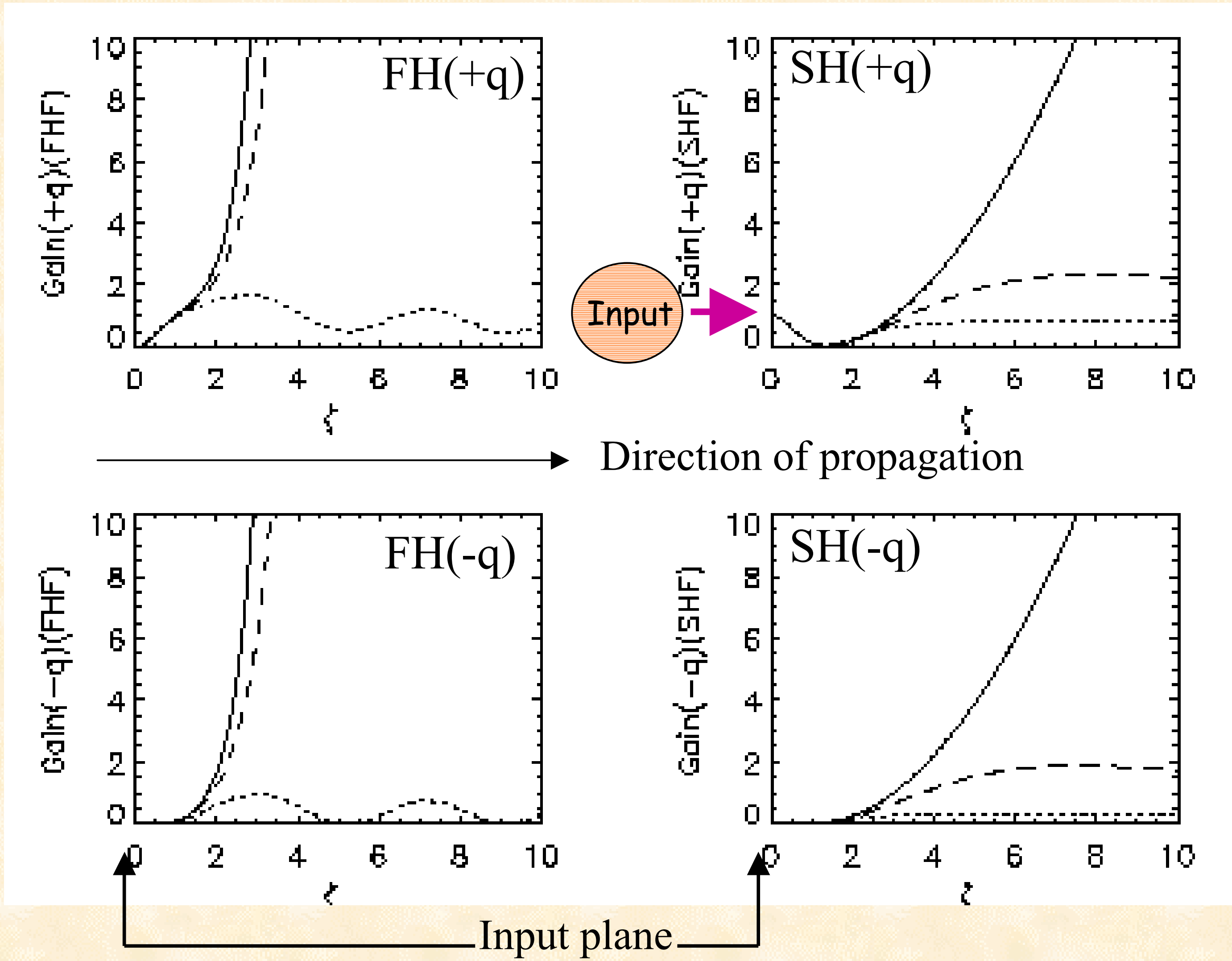
Input signal confined to one half of the input plane

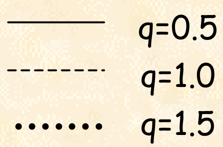
Input signal: a coh. wave at 2ω with transv. wave vector +q

Output



Intensity of each output as a function of the propagation length

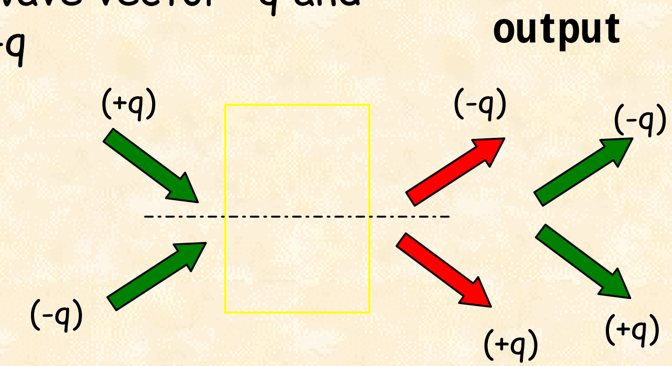




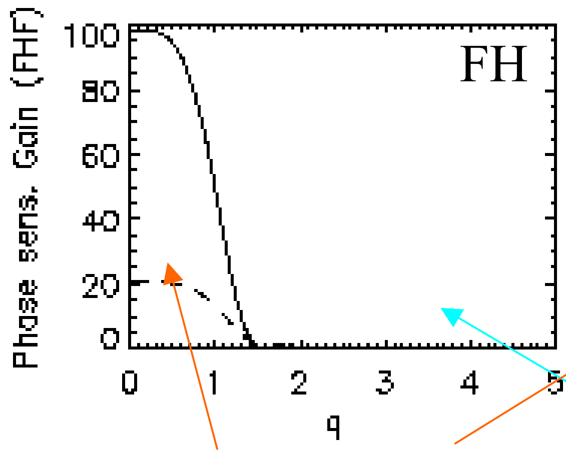
Phase-sensitive configuration:

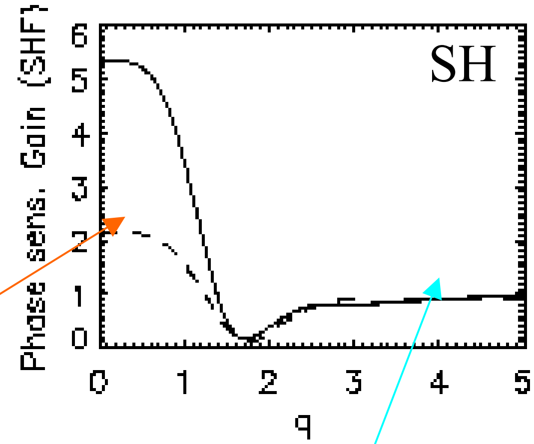
Input signal symmetric /optical axis

Input signal: two coh. waves with wave vector +q and -q



Output intensity / Input intensity

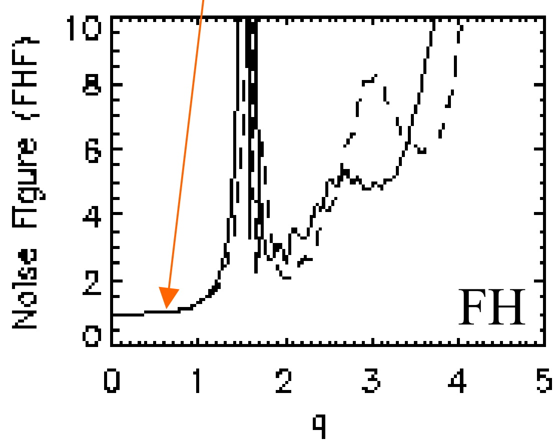


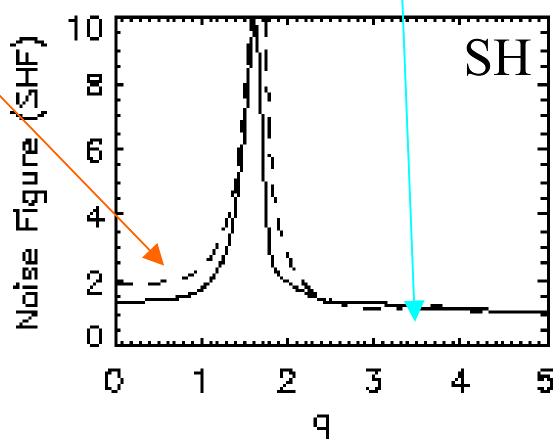


Domain of efficient freq. down conversion and amplification

The signal goes through the optical device without modification

SNR input / SNR output





Work in Progress
Spatial quantum correlations in the SHG fluorescence spectrum

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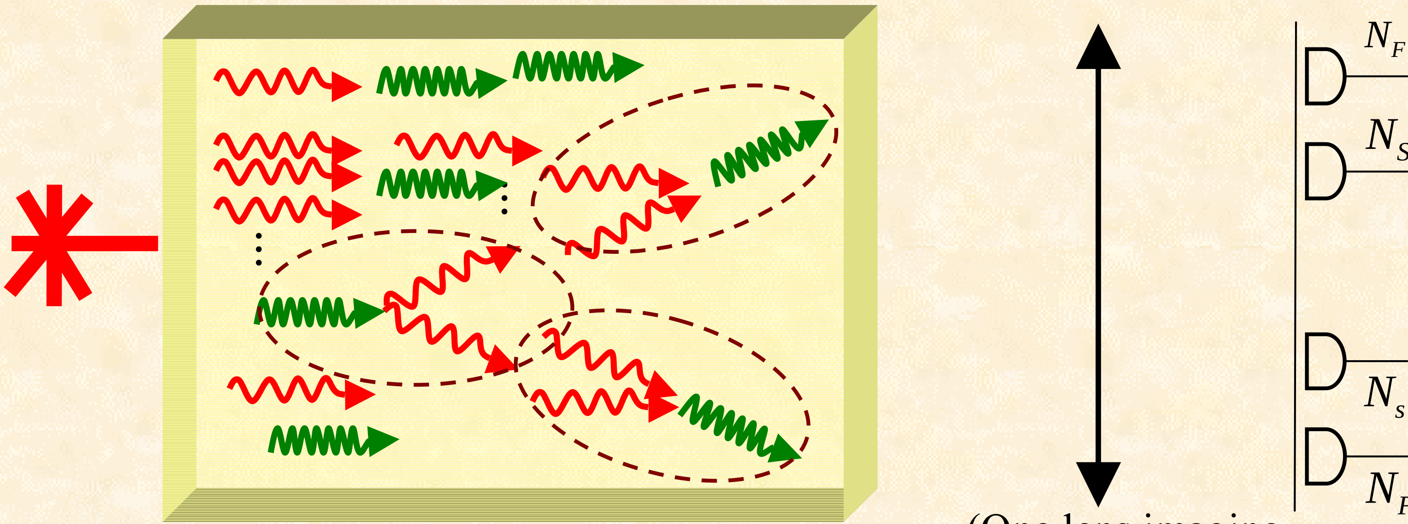
Spontaneous emission: Fluorescence pattern
- at Fundamental
- at Second Harmonic



$$N_F(q) = \int_{-\tau/2}^{+\tau/2} dt \langle e_F^{+}(q,t) e_F(q,t) \rangle$$

Detection of the far field fluorescence patterns

Results:

* Strong (but not perfect) noise reduction in the intensity difference $N_F(q) - N_F(-q)$
* *Sub*poissonian statistics of intensity difference $N_S(q) - N_S(-q)$
* *Super*poissonian statistics of cross intensity differences $N_F(q) - N_S(q)$ and $N_F(q) - N_S(-q)$

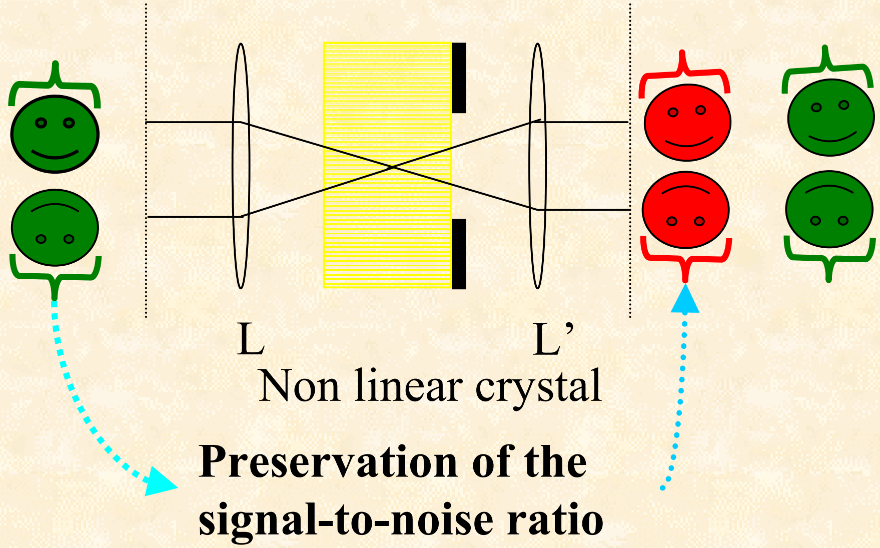
But *Sub*poissonian statistics of $N_F(q) - \lambda N_S(-q)$ for some values of λ

whereas $N_F(q) - \lambda N_S(q)$ at best poissonian

Conclusion

SHG useful for quantum image processing

- allows frequency conversion of an optical signal before amplification
- possibility of noiseless operation



Outlook

Quantum image processing with TW - Type II – SHG

New possibilities due to the polarization degree of freedom.