Aberration Cancellation in Quantum Imaging

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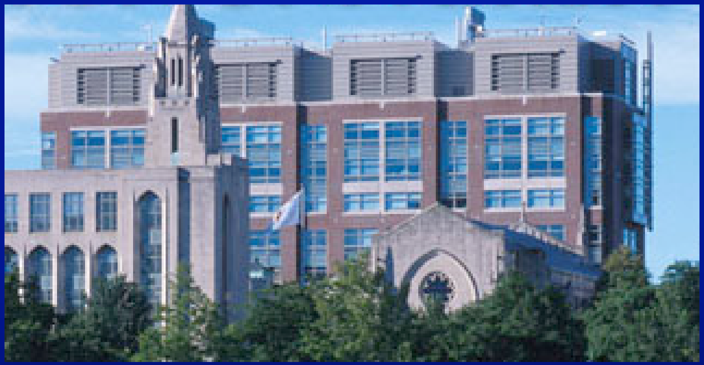

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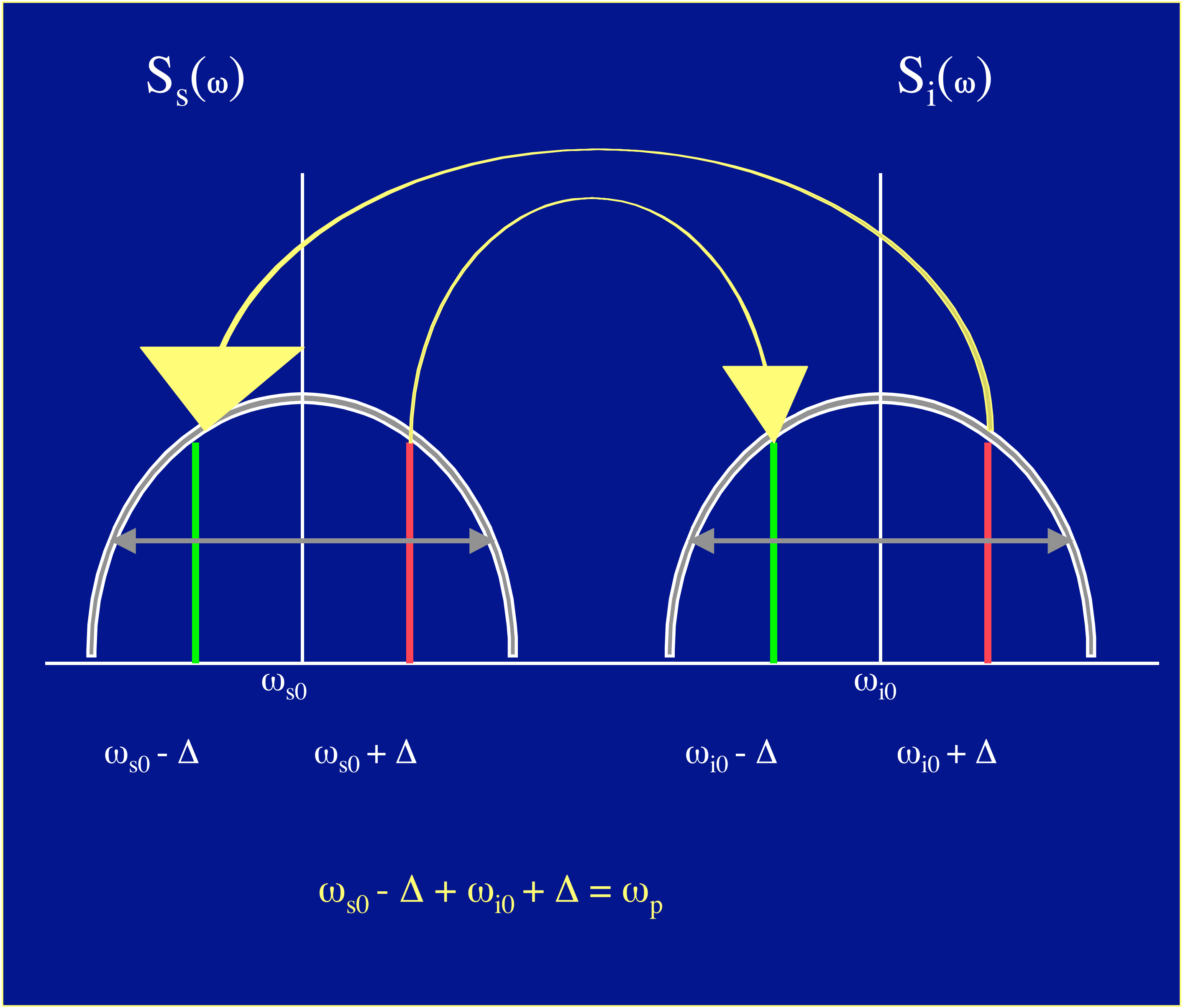
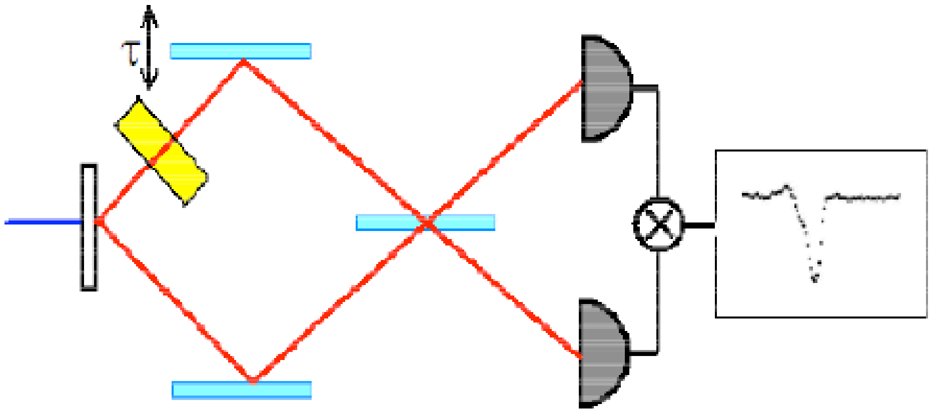
Frequency Entanglement



HOM interferometer



- SPDC produces pairs of photons anticorrelated in frequency

- in a Hong-Ou-Mandel interferometer we observe **even-order dispersion cancellation**: only the odd-order dispersion terms affect the interference pattern

$$|A(\Omega_0+\omega)-A(|\Omega_0-\omega)|^2 \sim |A(\Omega_0+\omega)|^2+|A(\Omega_0-\omega)|^2+A^*(\Omega_0+\omega)A(\Omega_0-\omega)$$

interference term

if we consider the phase:

$$\phi(\Omega_0+\omega)-\phi(\Omega_0-\omega)\sim \cancel{\phi_0}+\phi'\omega+\cancel{\frac{1}{2}\phi''\omega^2}+\frac{1}{6}\phi'''\omega^3$$

$$-(\cancel{\phi_0}-\phi'\omega+\cancel{\frac{1}{2}\phi''\omega^2}-\frac{1}{6}\phi'''\omega^3)$$

J. D. Franson, Phys. Rev. A v. 45, 3126 (1992).
A. M. Steinberg, P. G. Kwiat, and R. Y. Chiao, Phys. Rev. Lett. v.68, 2421 (1992).

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Outline

Multi-parameter entanglement

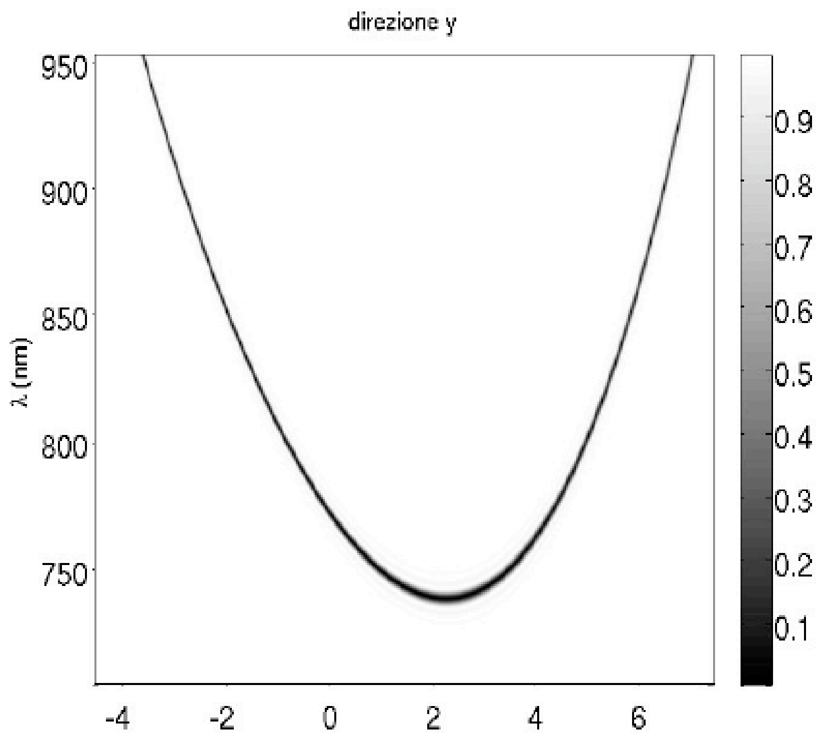
and Spatial aberration cancellation

C. Bonato *et al.*, Phys. Rev. Lett. v.101, 233603 (2008)

Type-II SPDC state

$$|\psi^{(2)}>= \int d\mathbf{q_s} d\mathbf{q_i} d\omega_s d\omega_i \tilde{\Phi}(\mathbf{q_s},\mathbf{q_i};\omega_s,\omega_i)\hat{a}_s^\dagger(\mathbf{q_s},\omega_s)\hat{a}_i^\dagger(\mathbf{q_i},\omega_i)|0>$$

$$\tilde{\Phi}(\mathbf{q_s},\mathbf{q_i};\omega_s,\omega_i) = \delta(\omega_s - \Omega_P + \omega_i)\delta(\mathbf{q_s}+\mathbf{q_i})\int dz\chi(z)e^{i\Delta(\mathbf{q}_s,\omega_s;\mathbf{q}_i,\omega_i)z}$$



phase-matching:

$$\Delta \approx -\nu D + \frac{2|\mathbf{q}|^2}{\tilde{K}_p} + M\mathbf{e}_2 \cdot \mathbf{q}$$

group-delay between the ordinary and extraordinary photons in the crystal

spatial walk-off

M. Atature, G. Di Giuseppe, M. Shaw, A. V. Sergienko, B. E. A. Saleh, and M. C. Teich "Multiparameter Entanglement in Femtosecond Parametric Down Conversion", ***Physical Review A*, v. 65, 023808 (2002)**

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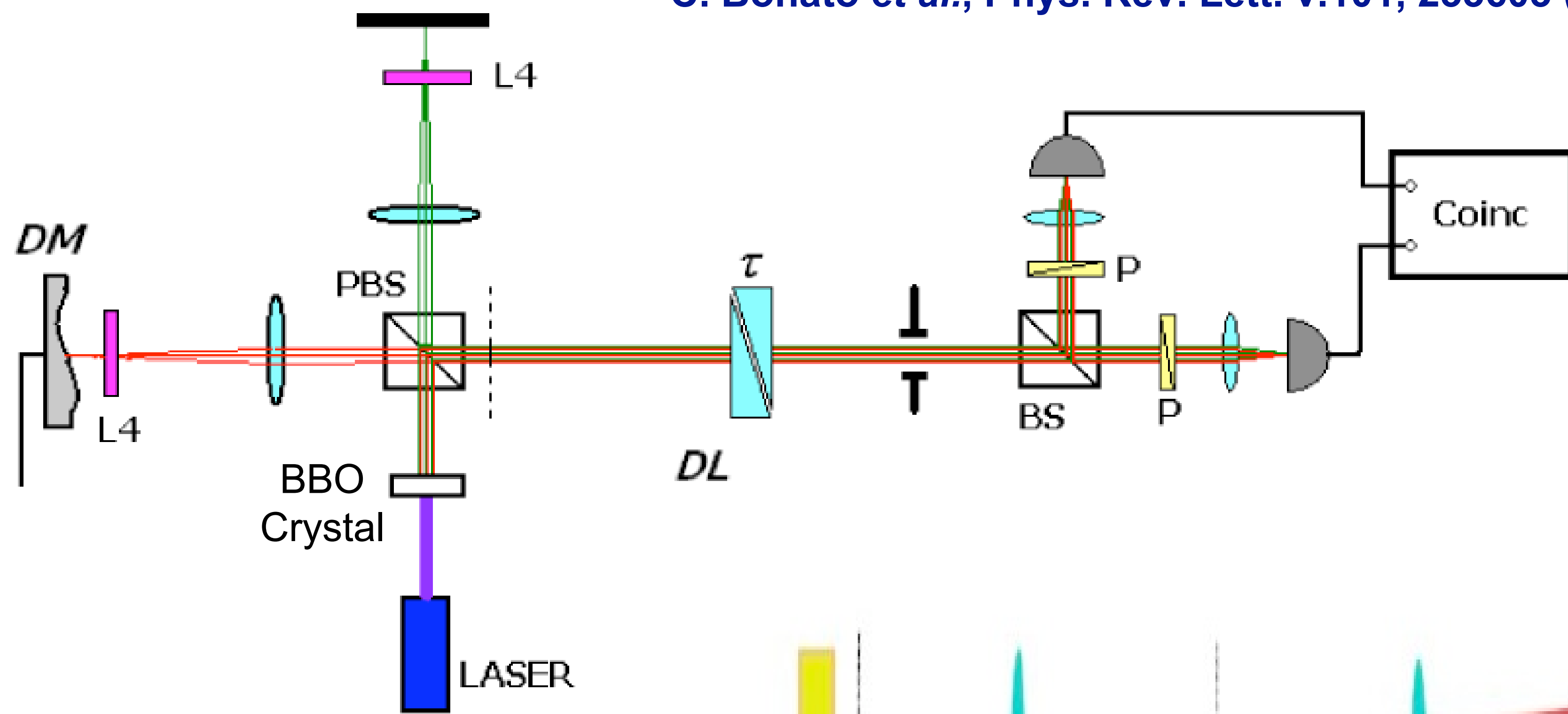
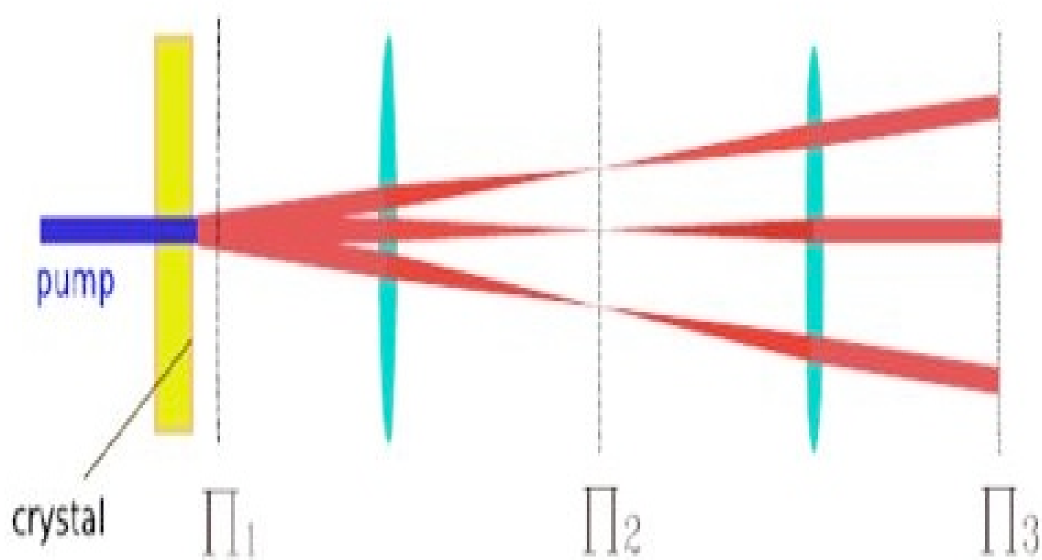
C. Bonato *et al.*, Phys. Rev. Lett. v.101, 233603 (2008)





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Even-order aberration cancellation in quantum interferometry

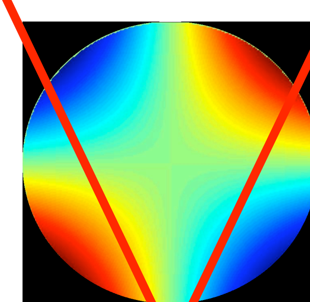
C. Bonato *et al.*, Phys. Rev. Lett. v.101, 233603 (2008)

In the case of a circular aperture we can expand the phase on the Zernike basis:

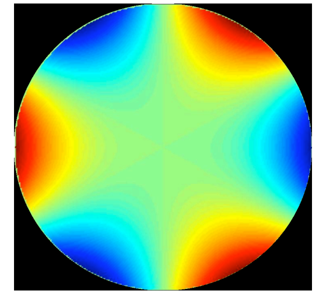
$$\phi(\mathbf{q}) = \sum_n \phi_{nm} \sum_m R_n^m(\rho)\cos(m\theta)$$

m = -n, -n+2, -n+4, …, n

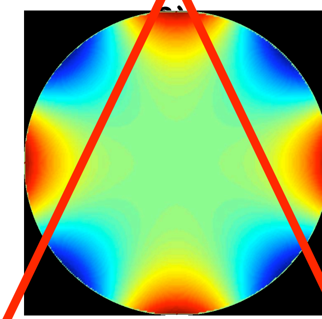
$$\longrightarrow \cos[m(\theta + \square)] \begin{cases} \cos(m\theta) & \text{(m even)} \\ -\cos(m\theta) & \text{(m odd)} \end{cases}$$



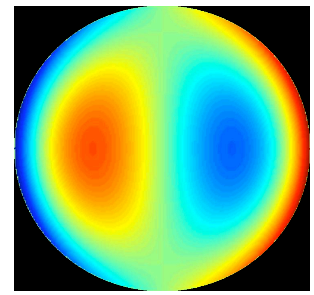
astigmatism (n=2, m=-2)



*trefoil (n=3, m=3)_*



*(n=4, m=4)_*



*coma (n=3, m=1)_*

$$\phi(\mathbf{q}) - \phi(-\mathbf{q}) = \sum_n \left\{ \sum_{\text{m even}} A_{nm} R_n^m(\rho)\cos(m\theta) + \sum_{\text{m odd}} A_{nm} R_n^m(\rho)\cos(m\theta) \right\} -$$

$$- \sum_n \left\{ \sum_{\text{m even}} A_{nm} R_n^m(\rho)\cos(m\theta) - \sum_{\text{m odd}} A_{nm} R_n^m(\rho)\cos(m\theta) \right\}$$

only odd-order aberrations contribute!!

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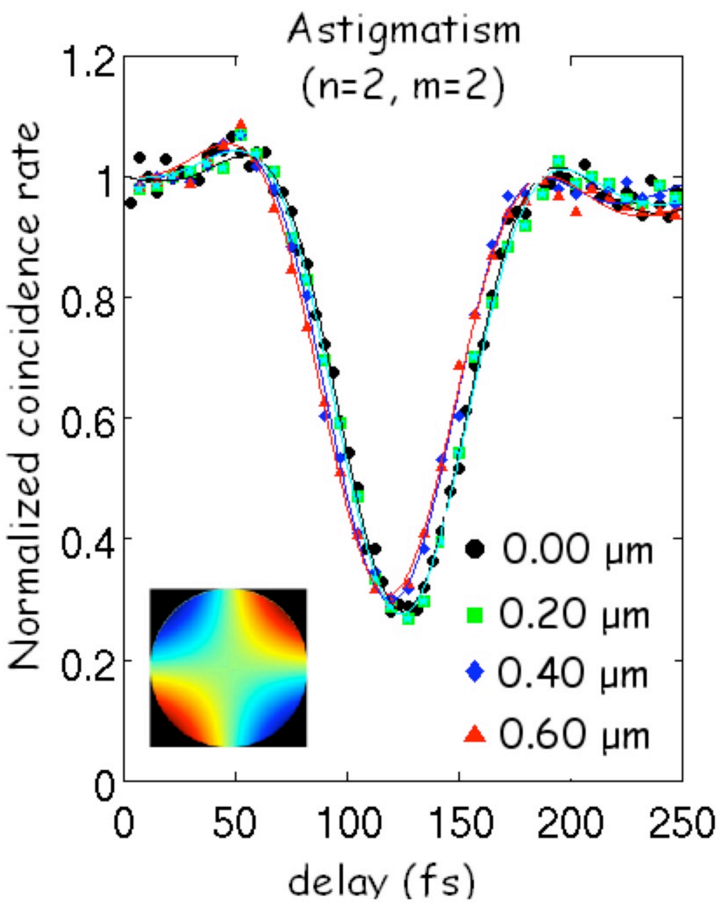
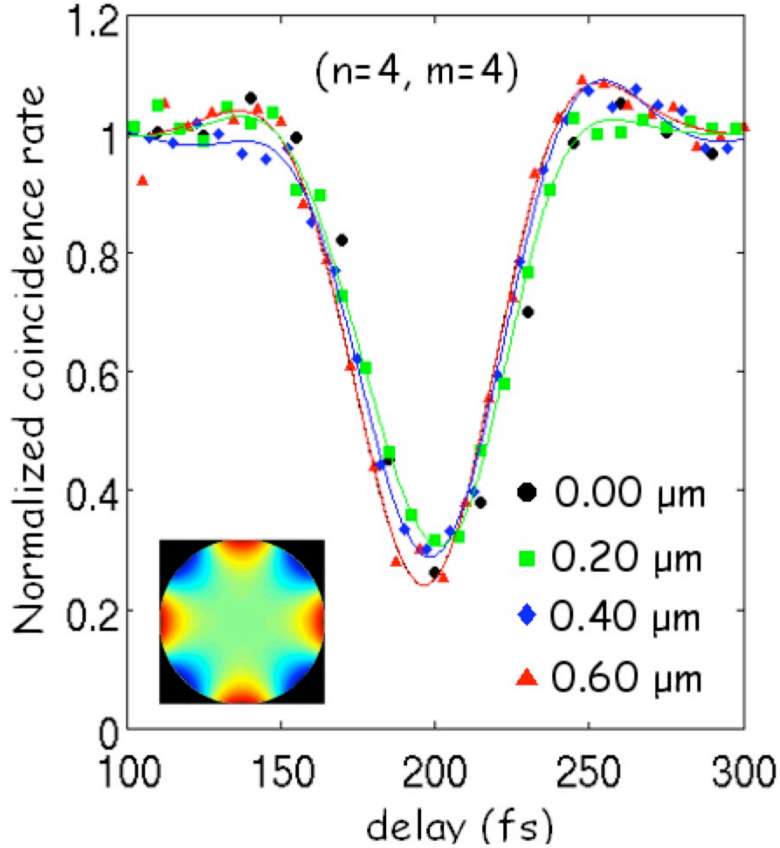
Insensitive to Astigmatism





C. Bonato *et al.*, Phys. Rev. Lett. v.101, 233603 (2008)

C. Bonato *et al.*, Phys. Rev. A v. 79, 062304 (2009)

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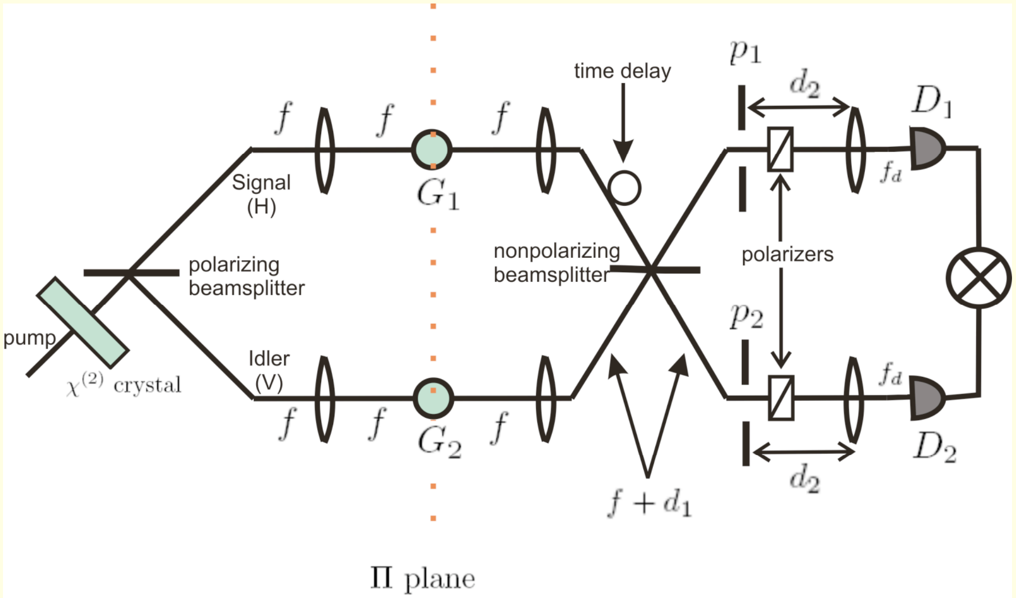
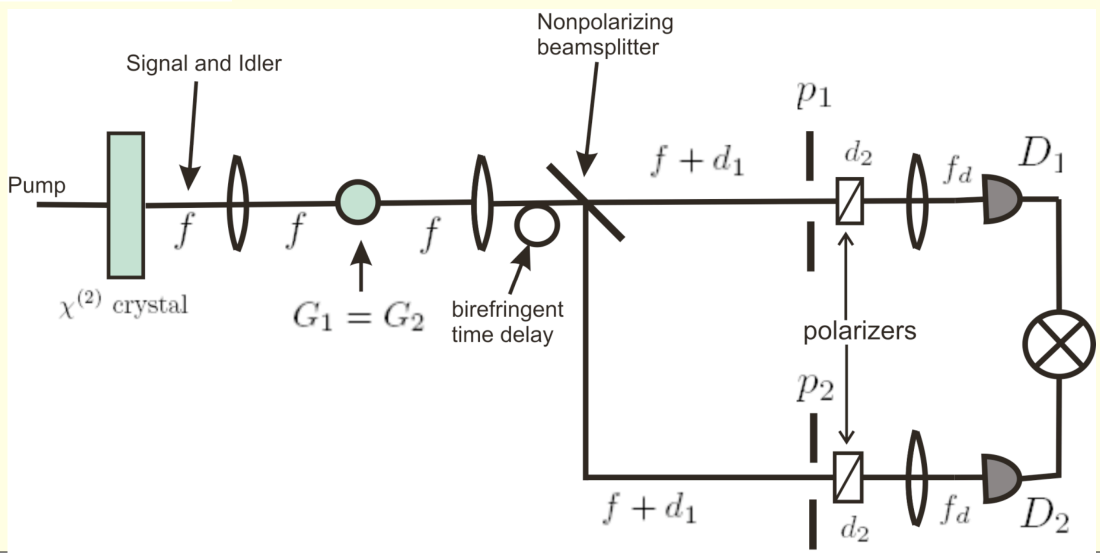
Physics of Aberration Cancellation

D. S. Simon and A. V. Sergienko, **Phys. Rev. A v.80, 053813 (2009)**



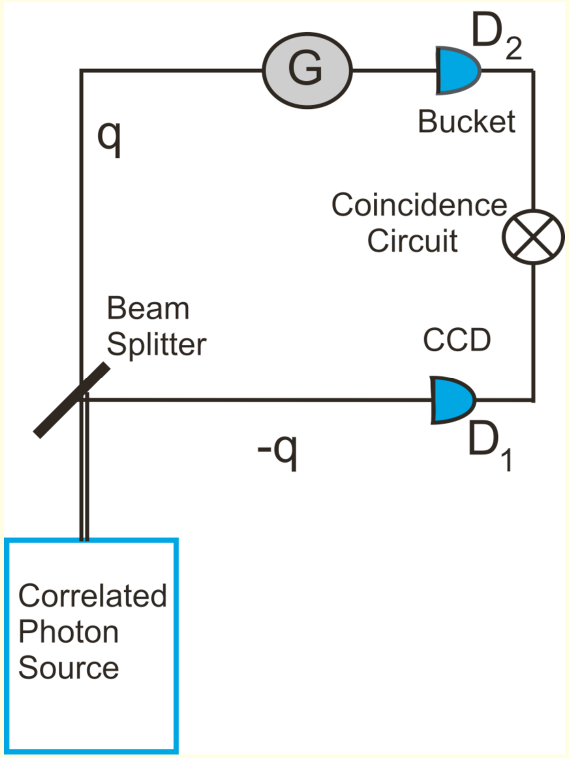
Even-order aberration cancellation

$$G_j(x) = t_j e^{i\varphi_j(x)}$$

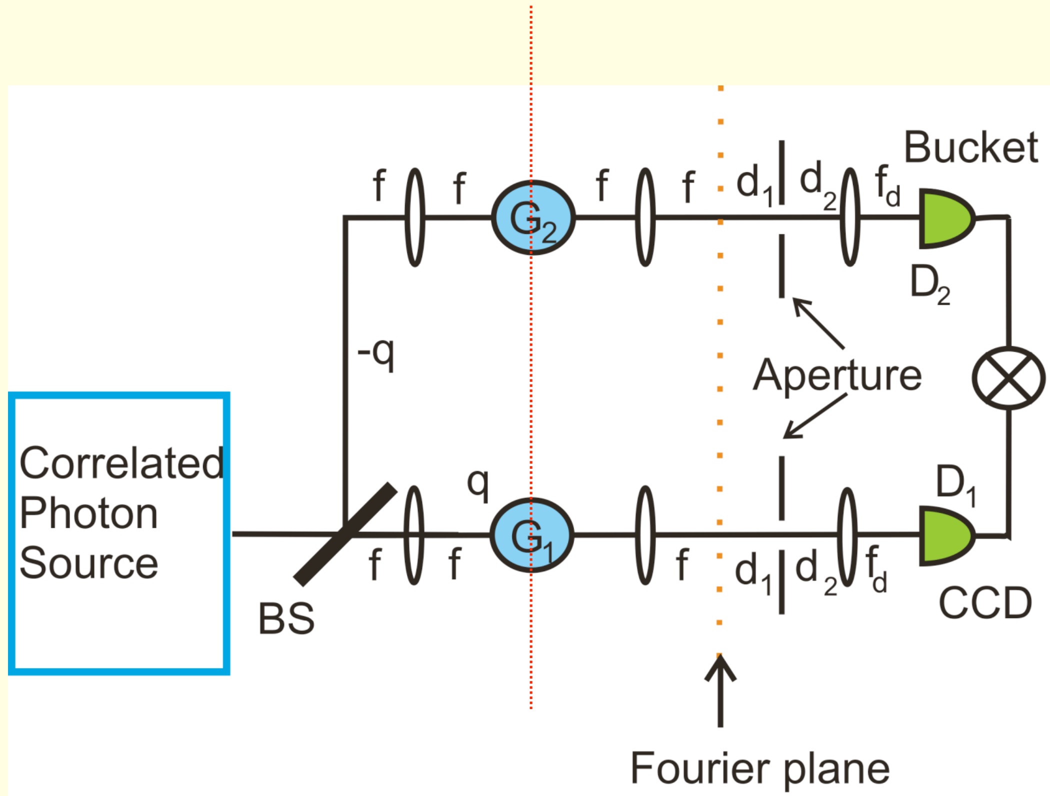


All-order aberration cancellation (G_1=G_2)

Future of Aberration Cancellation



Traditional "Ghost" imaging since 1982



"Ghost" Imaging with All-Order Aberration Cancellation

D. S. Simon and A. V. Sergienko

arXiv:0911.3056 [quant-ph] (2009)

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Summary and Future

The Boston University photonics center

➲ Aberration cancellation in quantum interferometry --- Eliminate sample-induced aberration in confocal microscope; enhancements in temporal correlation-based methods such as dynamical light scattering or fluorescence correlation spectroscopy.

➲ Aberration-free "ghost" imaging --- better imaging and microscopy in biophotonics and life sciences.

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Support

The Boston University photonics center

- *U. S. Army Research Office (ARO) Multidisciplinary University Research Initiative (MURI) Grant;*

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- ***Publications:***

D. S. Simon and A. V. Sergienko, arXiv:0911.3056 [quant-ph] (2009)
D. S. Simon and A. V. Sergienko, Phys. Rev. A v. 80, 053813 (2009)
C. Bonato *et al.,* Phys. Rev. A v. 79, 062304 (2009)
C. Bonato *et al.*, Phys. Rev. Lett. v. 101, 233603 (2008)

2 Patent disclosures