Aberration Cancellation in Quantum Interferometry

Alexander V. Sergienko[1, 2],
(AlexSerg@bu.edu)
C. Bonato[1, 4], B.E.A. Saleh,[1] D. S. Simon [1], S. Bonora [4], and P. Villoresi [4]

[1] Dept. of Electrical & Computer Engineering, Boston University, Boston, Massachusetts 02215
[2] Dept. of Physics, Boston University, Boston, Massachusetts 02215
[4] CNR-INFM LUXOR, Department of Information Engineering, University of Padova, Padova (Italy)

Outline

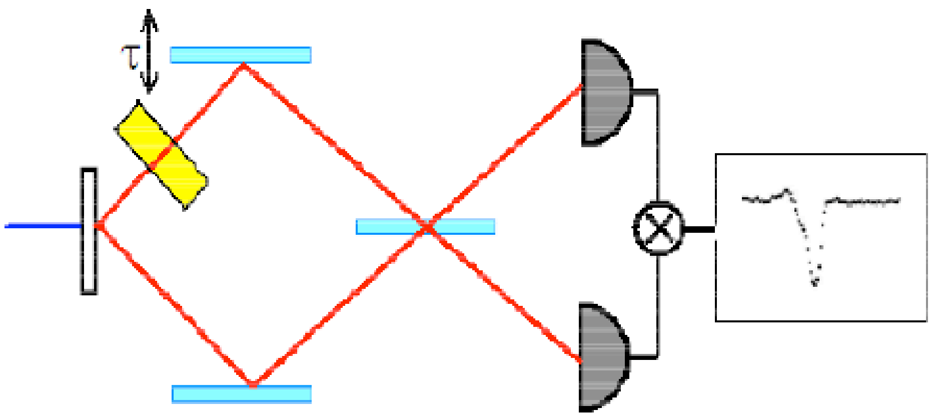
- **Introduction:**

a) Dispersion cancellation

b) Multi-parameter entanglement and spatial aberration cancellation

- **Experimental results**
- **Future**

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:

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

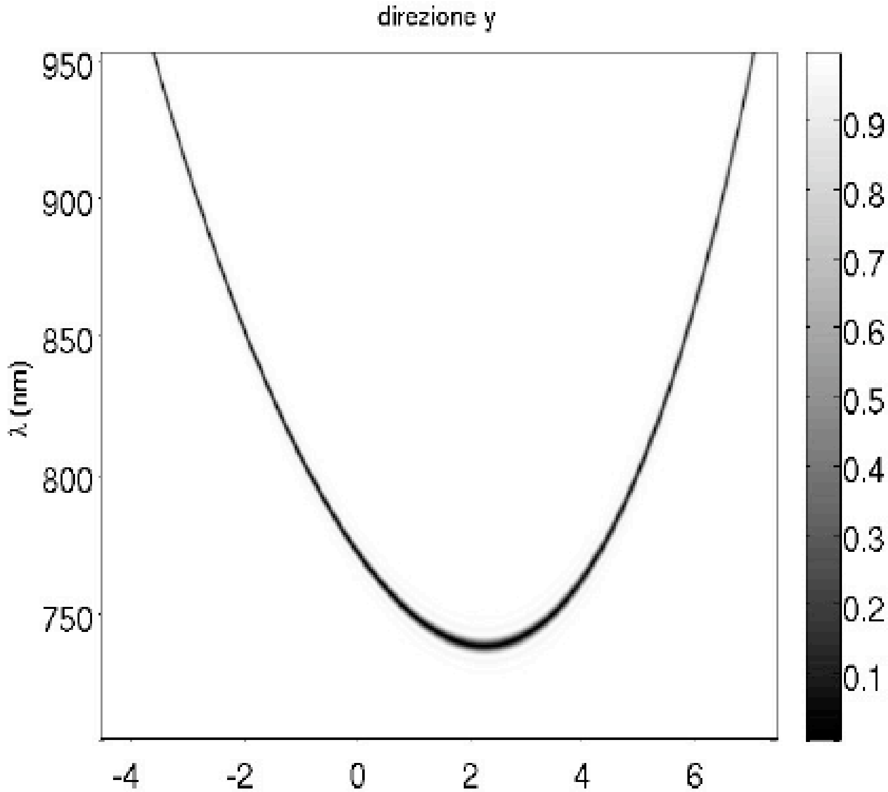
$$-(\phi_0-\phi'\omega+\frac{1}{2}\phi''\omega^2-\frac{1}{6}\phi'''\omega^3)$$

BOSTON UNIVERSITY

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:

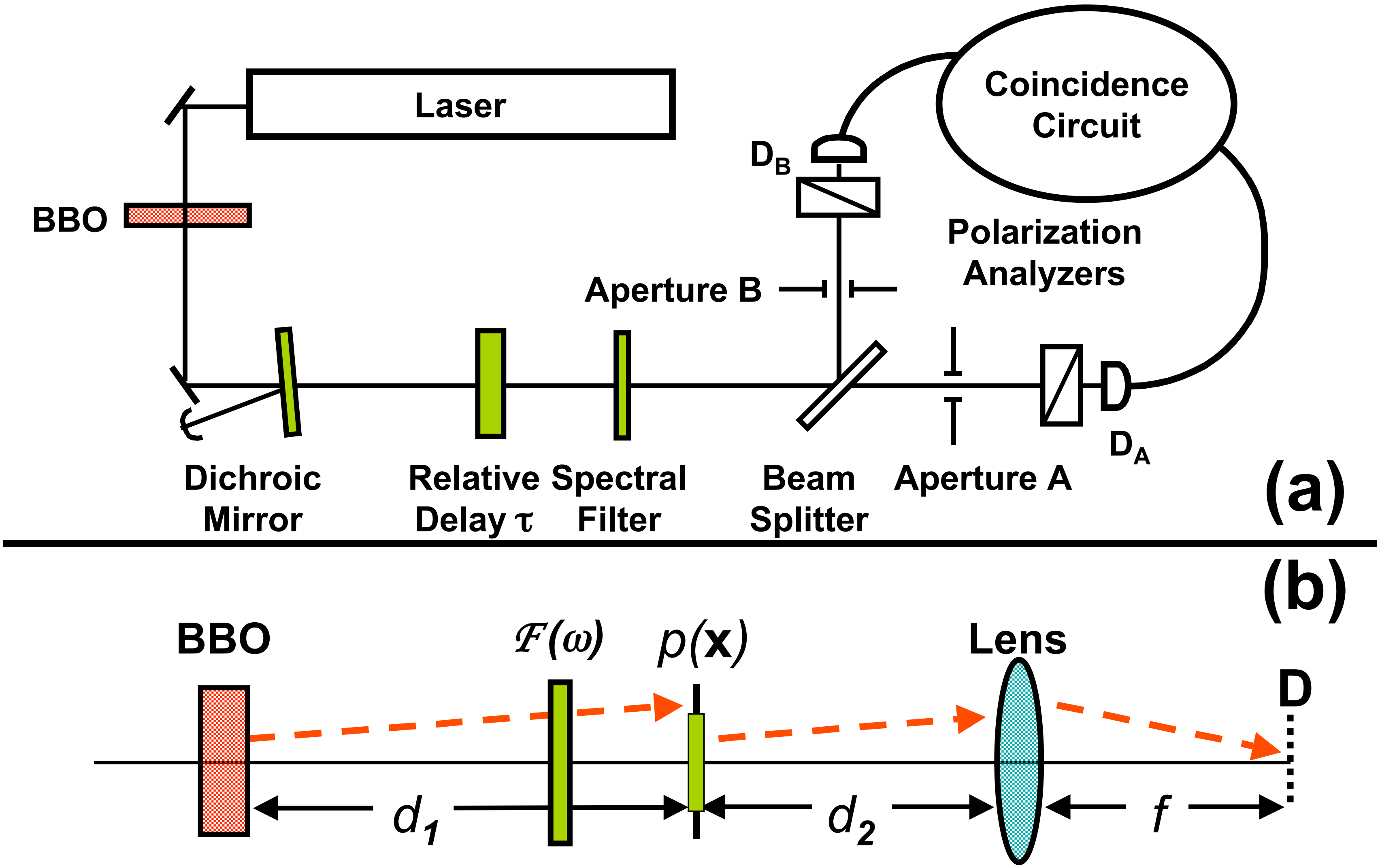
$$\Delta \approx -\nu D + \frac{2|\mathbf{q}|^2}{\tilde{K}_p} + M\mathbf{e}_2\cdot\mathbf{q}$$

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

spatial walk-off

BOSTON UNIVERSITY

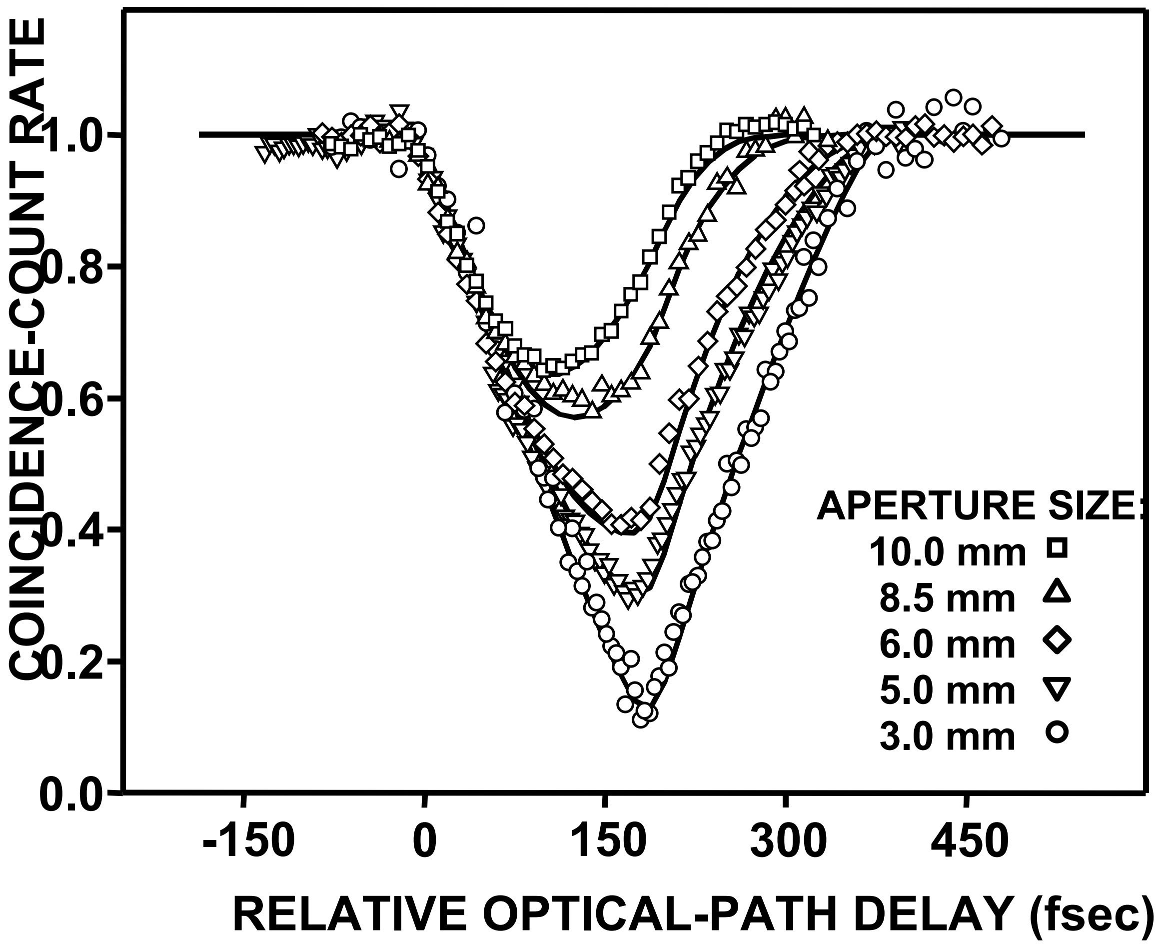
Hyperentanglement and Quantum State Engineering

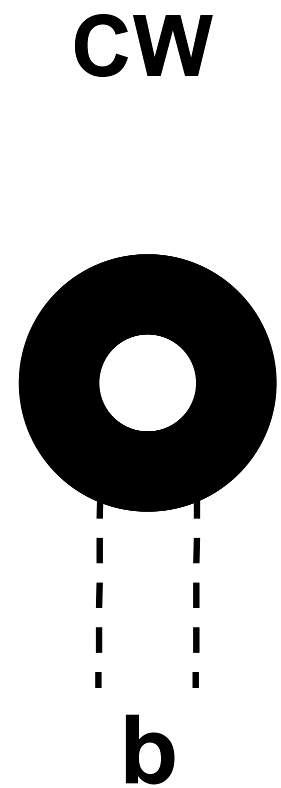


M. Atature, G. Di Giuseppe, M. Shaw, A. V. Sergienko, B. E. A. Saleh, and M. C. Teich "Multiparameter Entanglement in Femtosecond Parametric Down Conversion", *Physical Review A*, v. **65**, 023808 (2002).

BOSTON UNIVERSITY

Effect of Circular Apertures

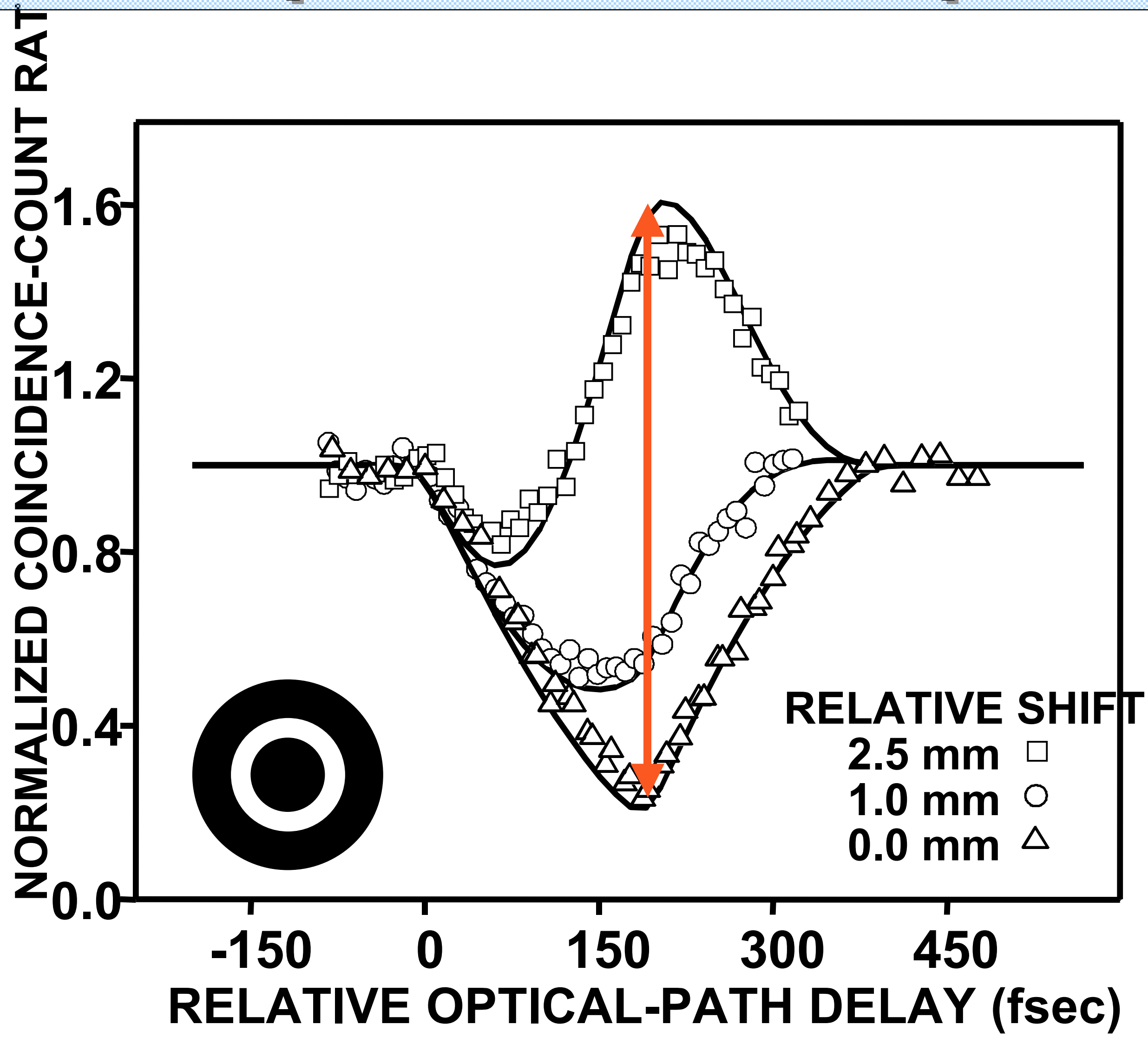




M. Atature, G. Di Giuseppe, M. Shaw, A. V. Sergienko, B. E. A. Saleh, and M. C. Teich "Multiparameter Entanglement in Femtosecond Parametric Down Conversion", *Physical Review A*, v. **65**, 023808 (2002).

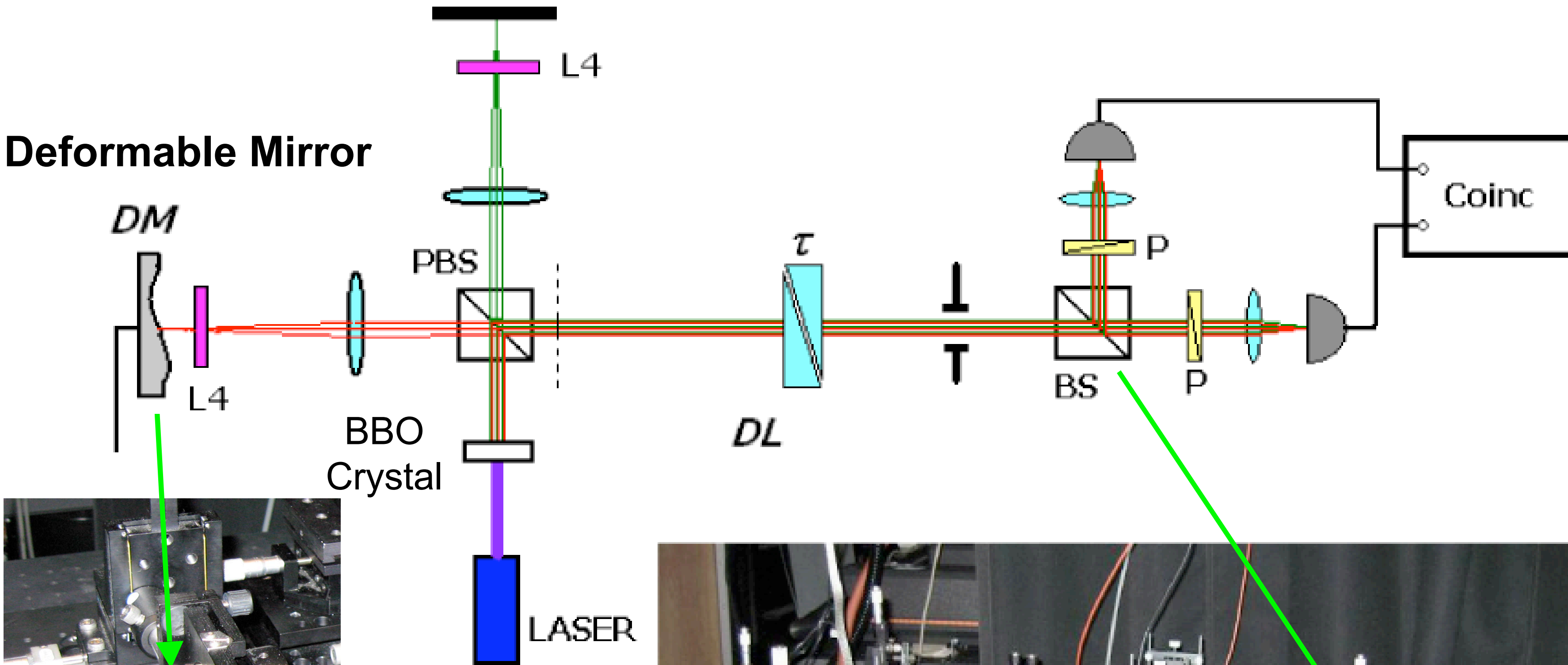
BOSTON UNIVERSITY

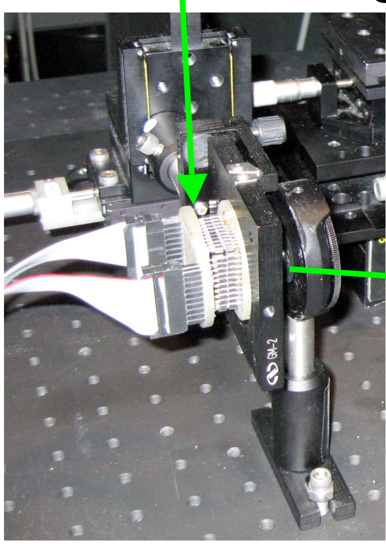
Multi-parameter entanglement: spatial manipulation modulates polarization

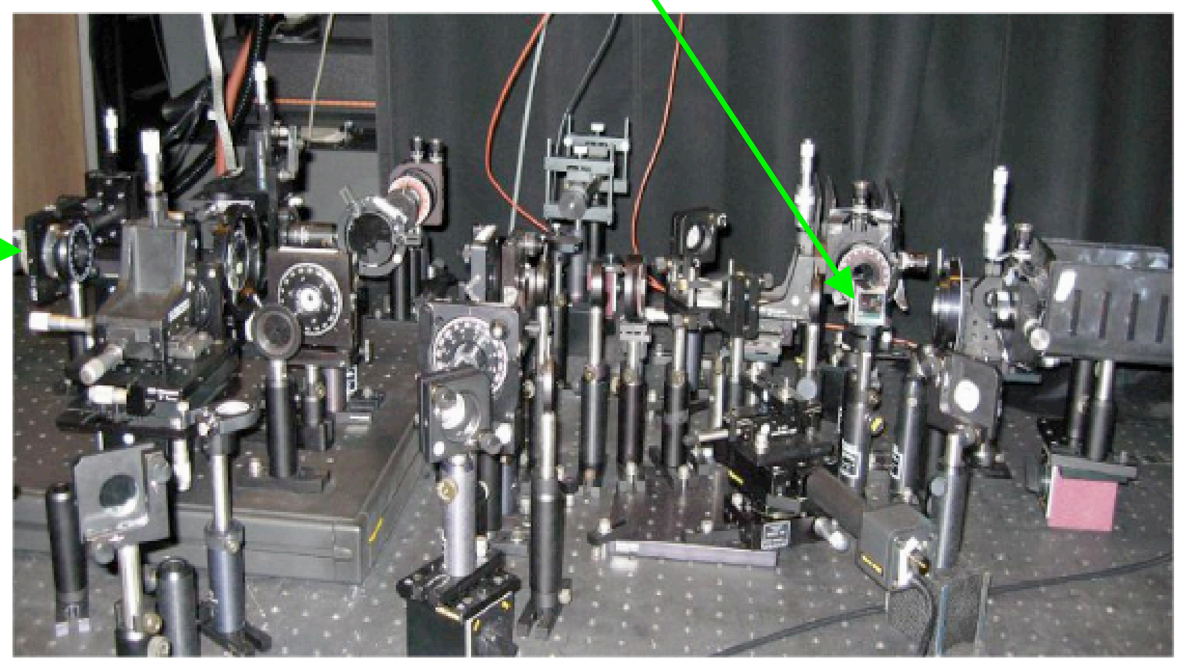


M. Atature, G. Di Giuseppe, M. Shaw, A. V. Sergienko, B. E. A. Saleh, and M. C. Teich "Multiparameter Entanglement in Femtosecond Parametric Down Conversion",
Physical Review A, v. **65**, 023808 (2002).

BOSTON UNIVERSITY

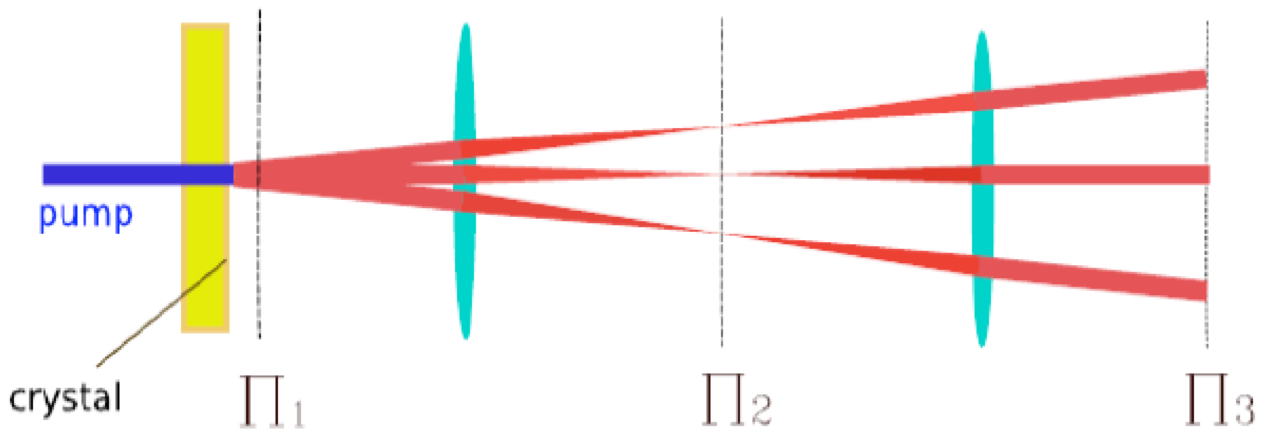




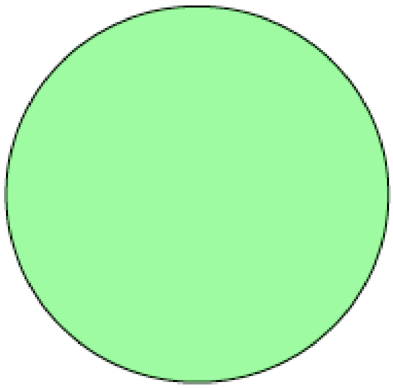


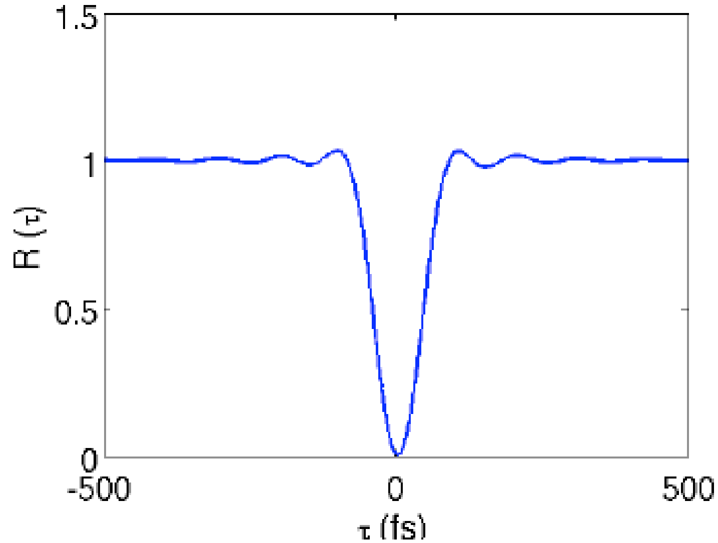
BOSTON UNIVERSITY

Wave-vector modulation:

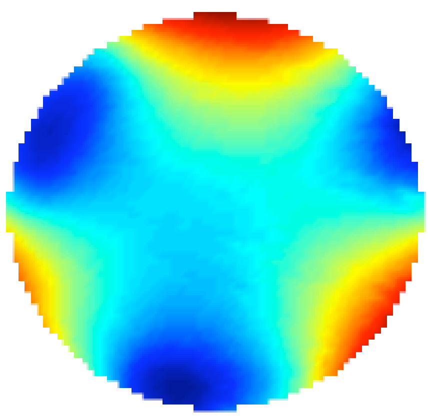


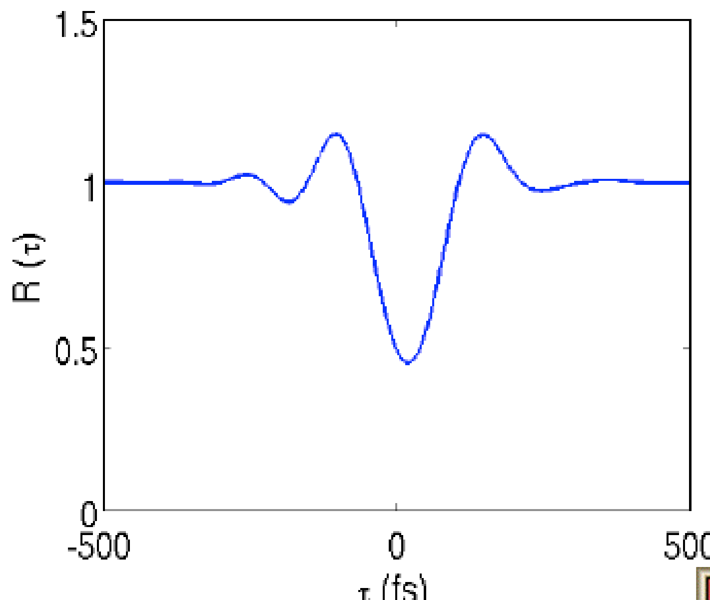
flat mirror



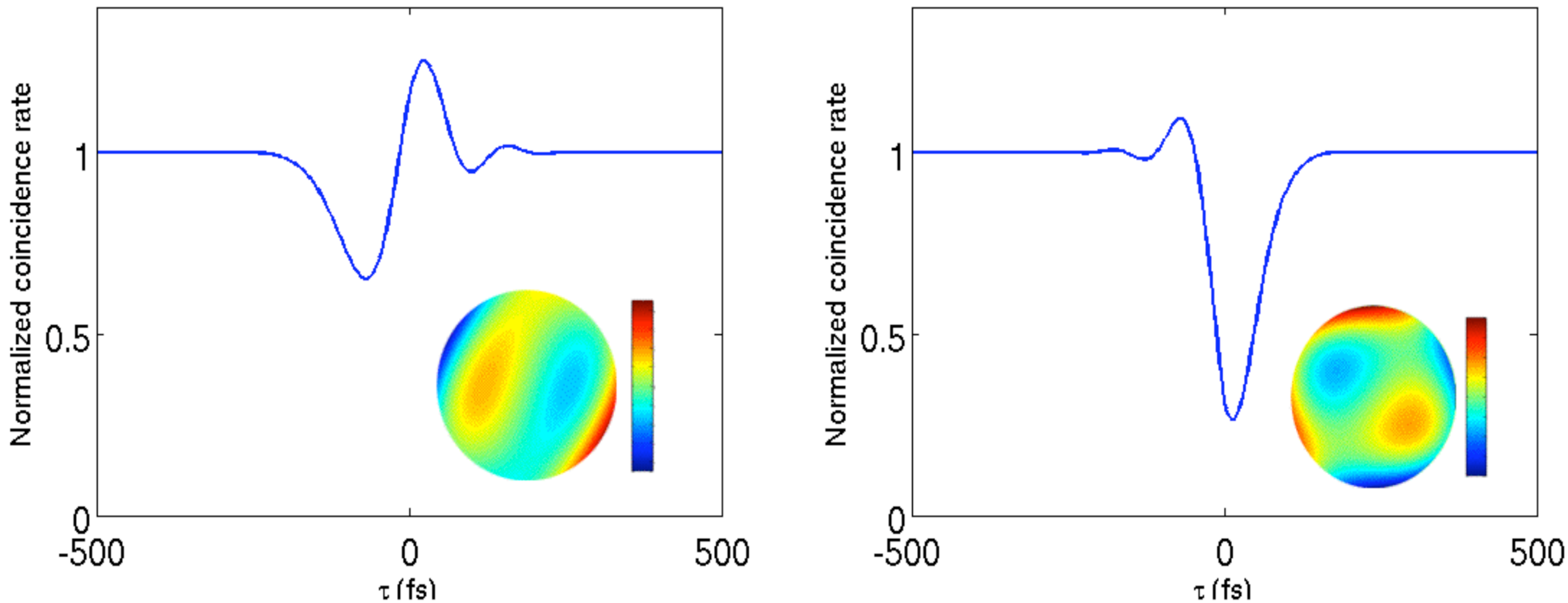


trefoil aberration





BOSTON UNIVERSITY

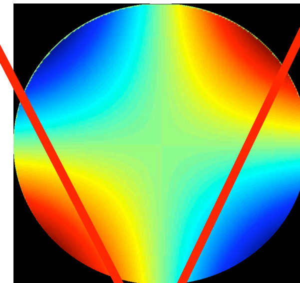

Normalized coincidence rate
1
0.5
0
-500
0
500
τ (fs)
Normalized coincidence rate
1
0.5
0
-500
0
500
τ (fs)

Even-order aberration cancellation in quantum interferometry

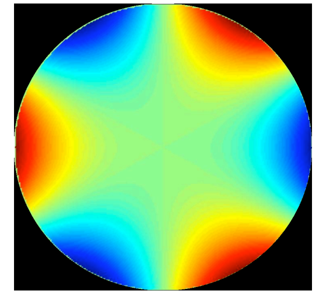
In the case of a circular aperture we can expand the phase on the Zernike basis:

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

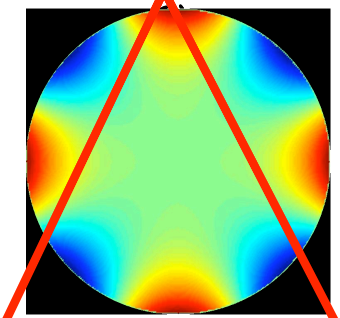
m = -n, -n+2, -n+4, ..., n



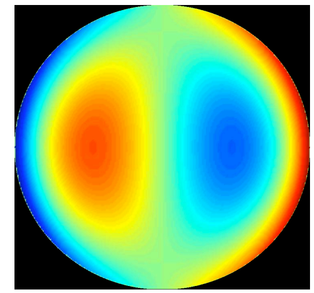
astigmatism (n=2, m=-



trefoil (n=3, m=3)_



(n=4, m=4)_



coma (n=3, m=1)_

→ cos [m(θ +π)] → cos (mθ) (m even)
→ - cos (m θ) (m odd)

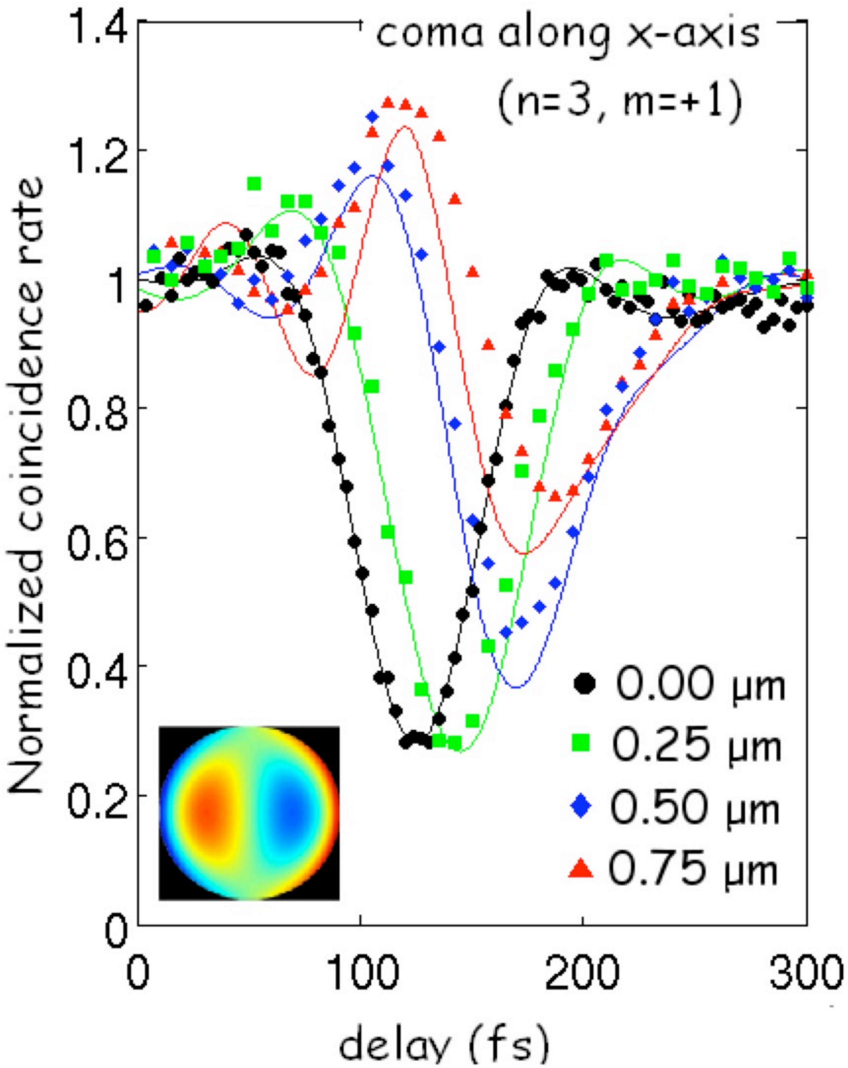
$$\phi(\mathbf{q}) - \phi(-\mathbf{q}) = \sum_n \left\{ \sum_{\text{m even}} A_{nm} R_n^m(\rho)\cos(m\theta) + \sum_{\text{m odd}} A_{nm} R_n^m(\rho)\cos(m\theta) \right\} -$$

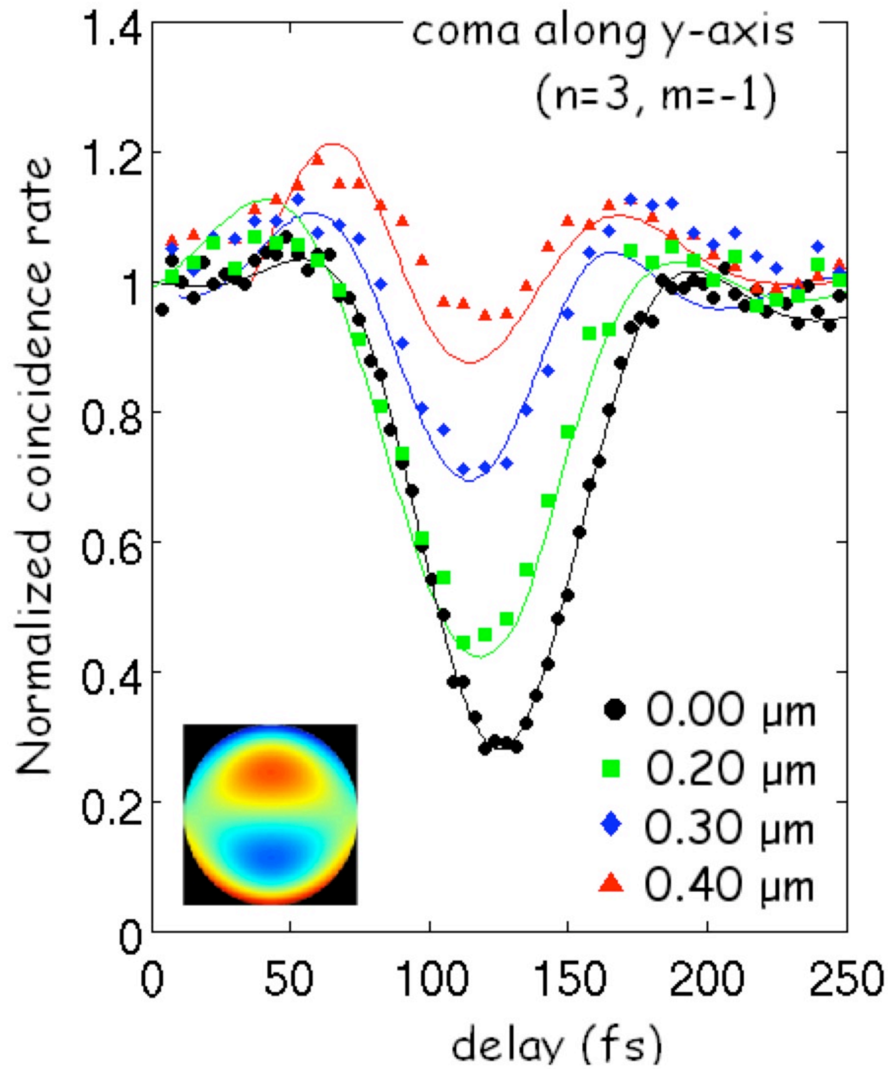
$$- \sum_n \left\{ \sum_{\text{m even}} A_{nm} R_n^m(\rho)\cos(m\theta) - \sum_{\text{m odd}} A_{nm} R_n^m(\rho)\cos(m\theta) \right\}$$

only odd-order aberrations contribute!!

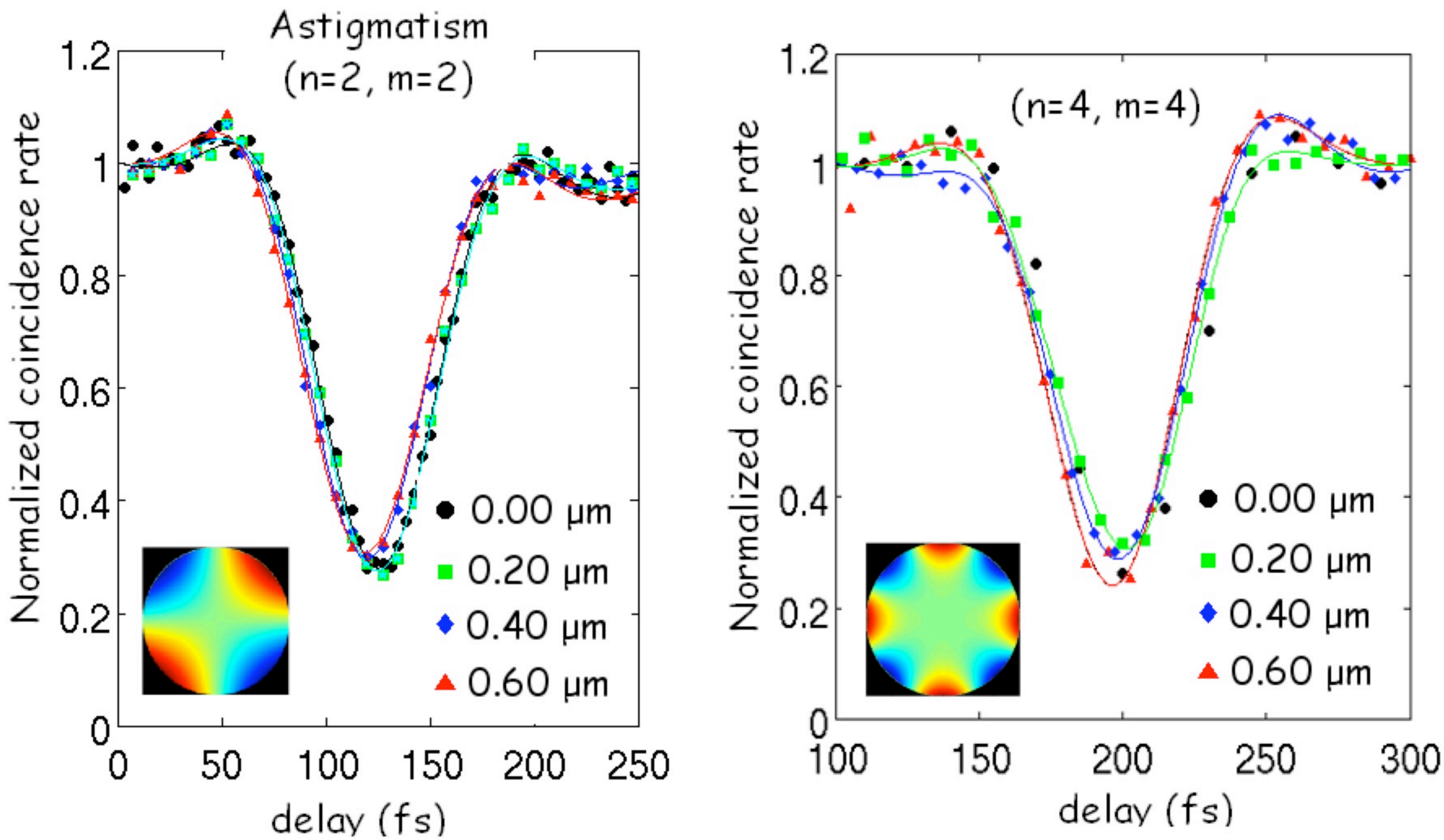
BOSTON UNIVERSITY

Even-order aberration cancellation in quantum interferometry





Aberration cancellation



C. Bonato, A. V. Sergienko, B. E. A. Saleh, S. Bonora, and P. Villoresi, "Aberration Cancellation in Quantum Interferometry" arXiv:0807.2909 [quant-ph]

(To appear in PRL)

BOSTON UNIVERSITY

Conclusions and Future

The Boston University photonics center

Conclusions:

✓ New effect of aberration cancellation has been observed.

Future:

From demonstrating quantum effects to developing practical applications.

➲ Designing classical analogues of quantum-optical effects that combine the best of quantum features with the ease of manipulation and detection of intense optical fields.

➲ Developing practical schemes for aberration-free imaging and microscopy.

BOSTON UNIVERSITY

The Boston University photonics center

Support:

- ***U. S. Army Research Office (ARO) Multidisciplinary University Research Initiative (MURI) Grant;***
- ***The Bernard M. Gordon Center for Subsurface Sensing and Imaging Systems (CenSSIS), an NSF Engineering Research Center;***
- ***Intelligence Advanced Research Projects Activity (IARPA) and ARO through Grant No. W911NF-07-1-0629.***

Relevant Publications:

1) **C. Bonato, A. V. Sergienko, B. E. A. Saleh, S. Bonora, and P. Villoresi, "Aberration Cancellation in Quantum Interferometry" (To appear in PRL)**
2) **O. Minaeva, C. Bonato, B. E. A. Saleh, D. S. Simon, and A. V. Sergienko, "Simultaneous Odd- and Even-Order Dispersion Cancellation in Quantum Interferometry", (Submitted to PRL)**
3) **D. S. Simon, A. V. Sergienko, and T. B. Bahder, "Dispersion and Fidelity in Quantum Interferometry", (To appear in Physical Review A).**