S-H tomography of partially coherent beams

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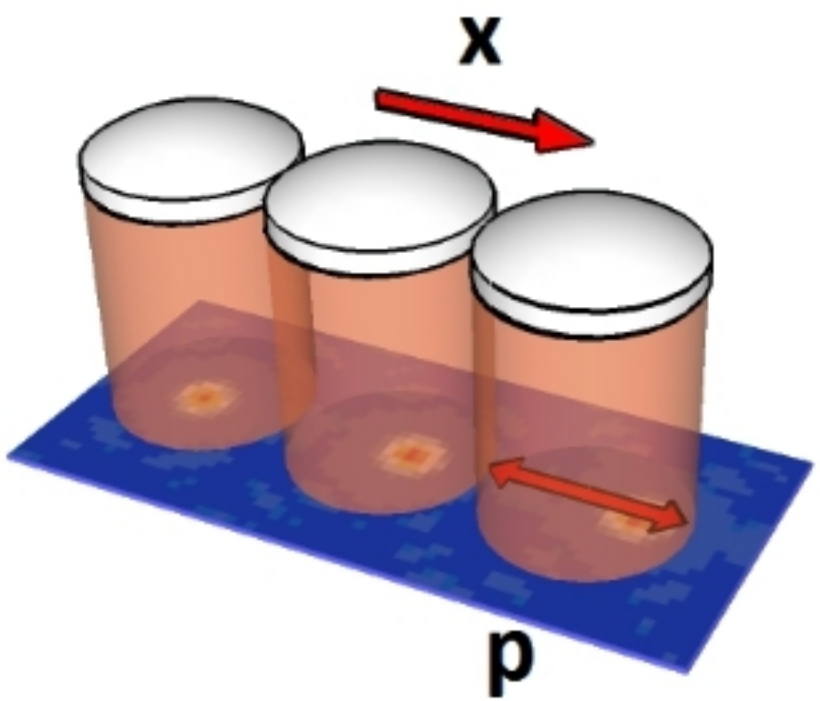
Shack-Hartmann detection

standard S-H detection

- local wavefront tilts are measured
- wavefront is reconstructed
- what if there is no well-defined wavefront?



SH-detection: detailed picture

system

- external degrees of freedom of light
- described by coherence matrix ρ
- notice that $\rho \geq 0$ ⟹ QIP

measurement

- simultaneous position and momentum measurement
- projections $|k\,l\rangle = U(\Delta x_k)\,U(\Delta p_l)|a\rangle, \quad P(a) = \langle x|a\rangle$
- example: Gaussian aperture ⟹ Q-function

Z.Hradil, J.R., L.L.Sanchez-Soto, Phys. Rev. Lett. ***105****, 010401 (2010)*

Quantum interpretation

system

- suitable choice of reconstruction basis (e.g. LG modes)
- space truncation makes the scheme info-complete

reconstruction

$$I_{kl} = \mathrm{Tr}\left(\rho |k\,l\rangle\langle k\,l|\right) = \sum_n c_{kl,n} r_n$$

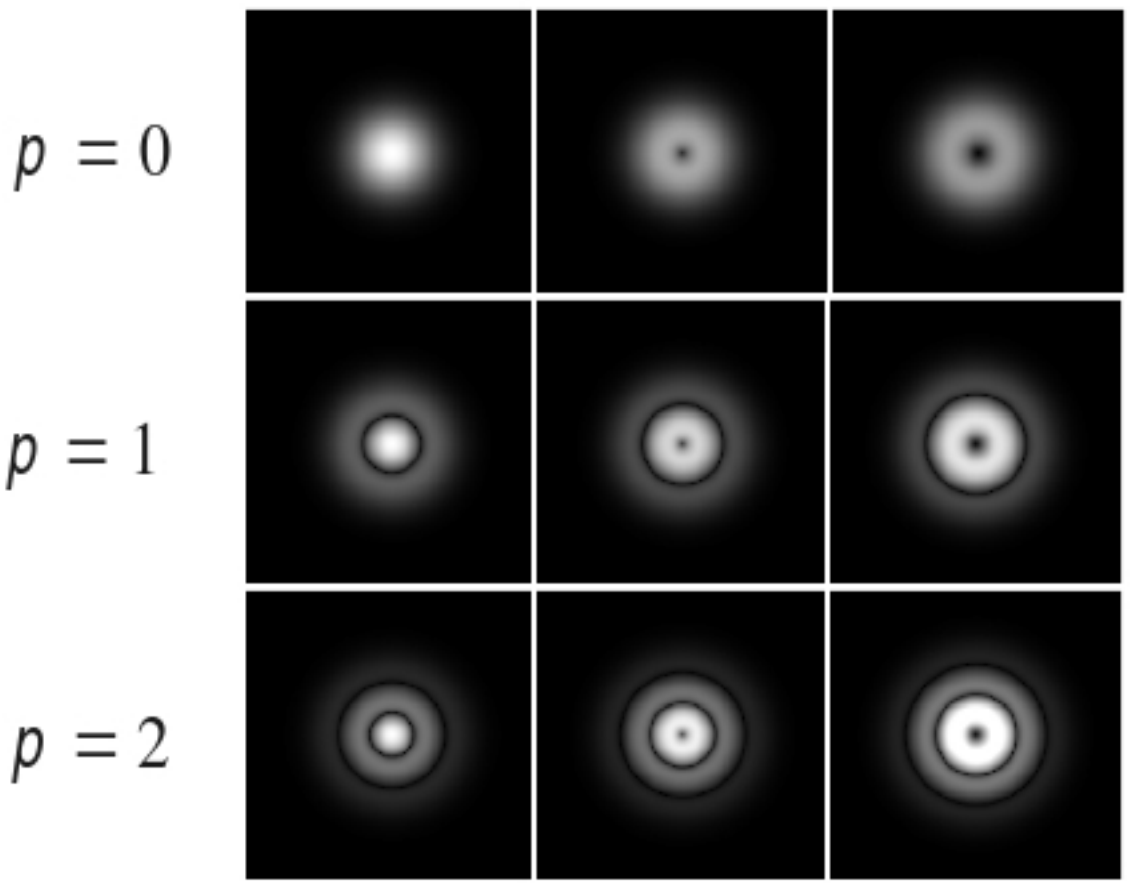
- quantum-state estimation techniques
- method of choice: MaxLik possibly combined with MaxEnt

Y.S.Teo, H.Zhu, B.-G.Englert, J.R., Z.Hradil, Phys. Rev. Lett. ***107****, 020404 (2011)*

Characterization of vortex beams

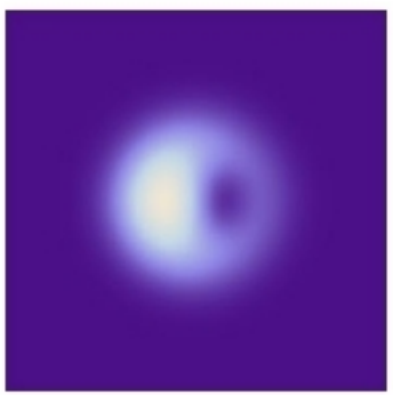
- Laguerre-Gaussian beams

$$LG_p^l(x,y) = \langle x\, y | l\, p \rangle \propto r^{|l|} L_p^{|l|}(2r^2) e^{-r^2} e^{il\varphi}$$

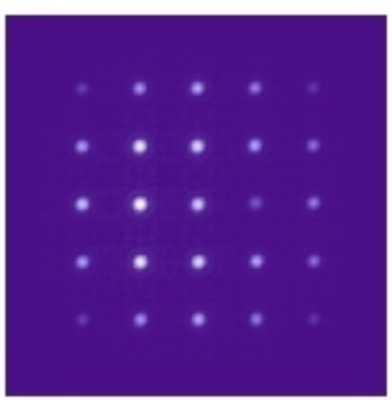


Characterization ...

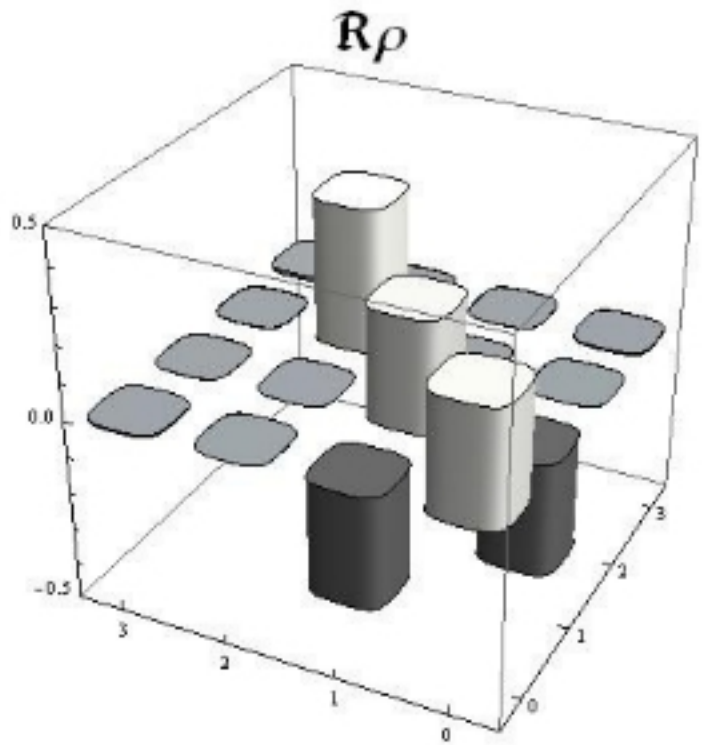
$$\rho_{\text{true}} = \frac{3}{5}\left|LG_0^0 - LG_0^1\right\rangle\left\langle LG_0^0 - LG_0^1\right| + \frac{2}{5}\left|LG_0^2\right\rangle\left\langle LG_0^2\right|$$

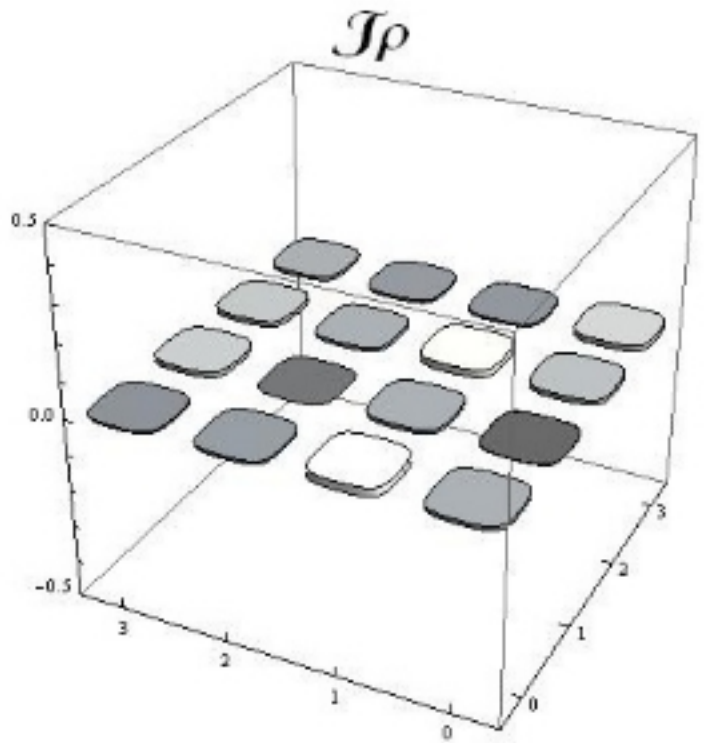


intensity



SH data





reconstruction from simulated data (5% noise)

Propagation of optical vortices

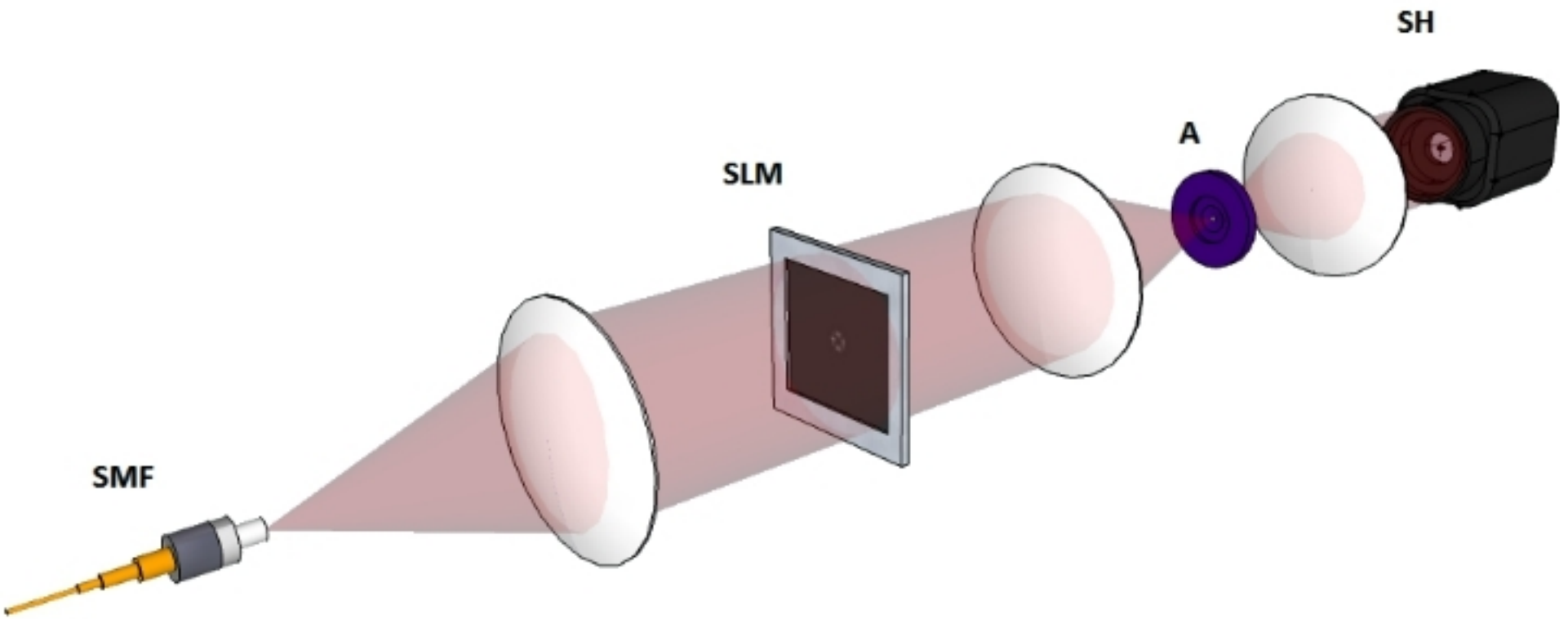
propagation of light

$$I(x) = \int_{-\infty}^{\infty} h(x, x') h^{*}(x, x'') G(x', x'') \, dx' \, dx''$$

mutual intensity $G(x', x'') = \langle x' | \rho | x'' \rangle$

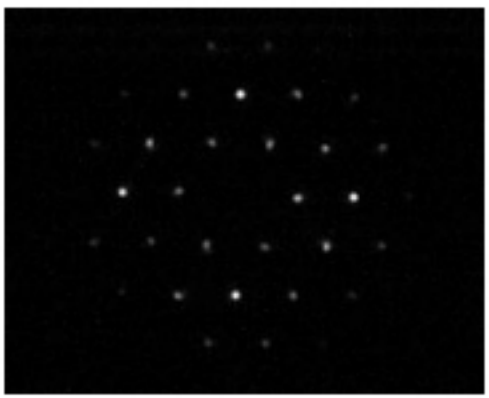
- knowledge of second-order coherence properties is required for digital propagation/focusing etc.

Propagation … experiment

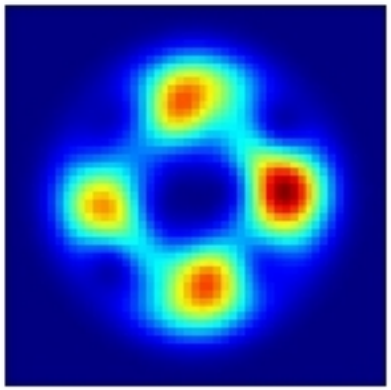


Propagation ...

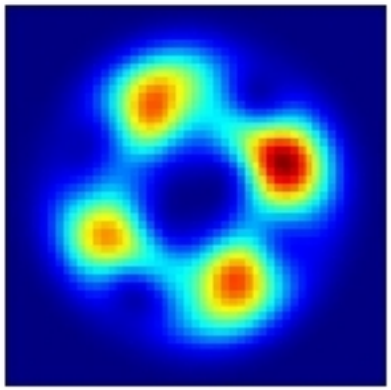
- target state $|LG_0^4\rangle + |LG_0^8\rangle$

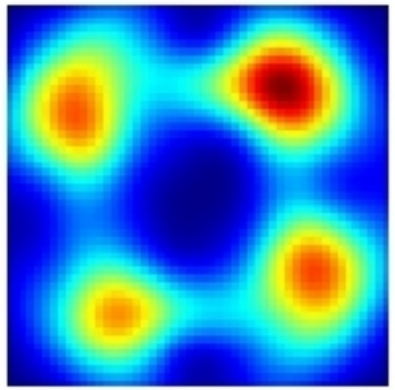


SH data



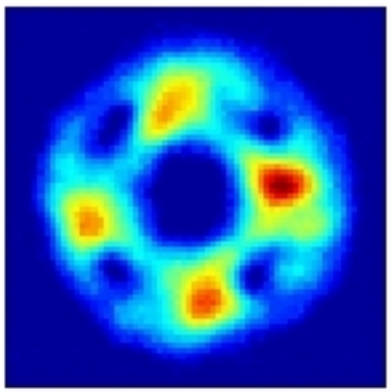
tomography



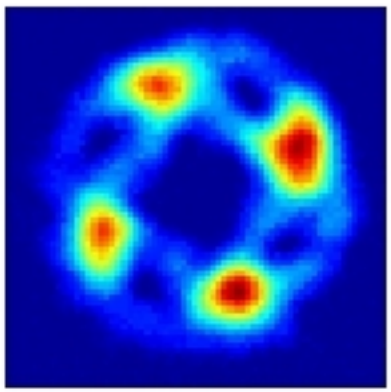


digital propagation

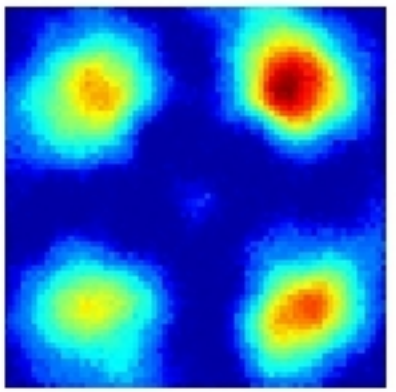
CCD



0 cm

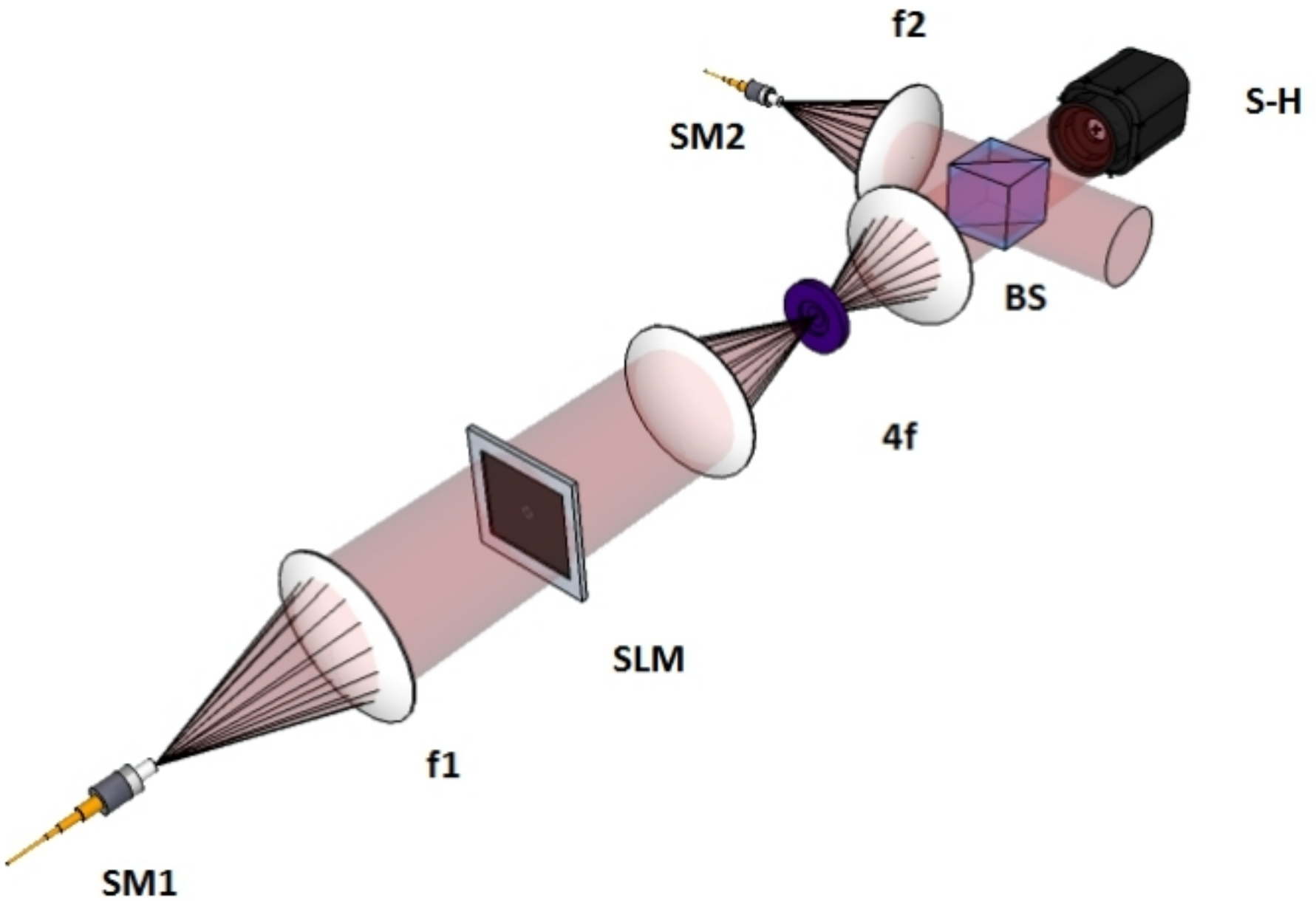


17 cm



62 cm

Plane waves – controlled coherence



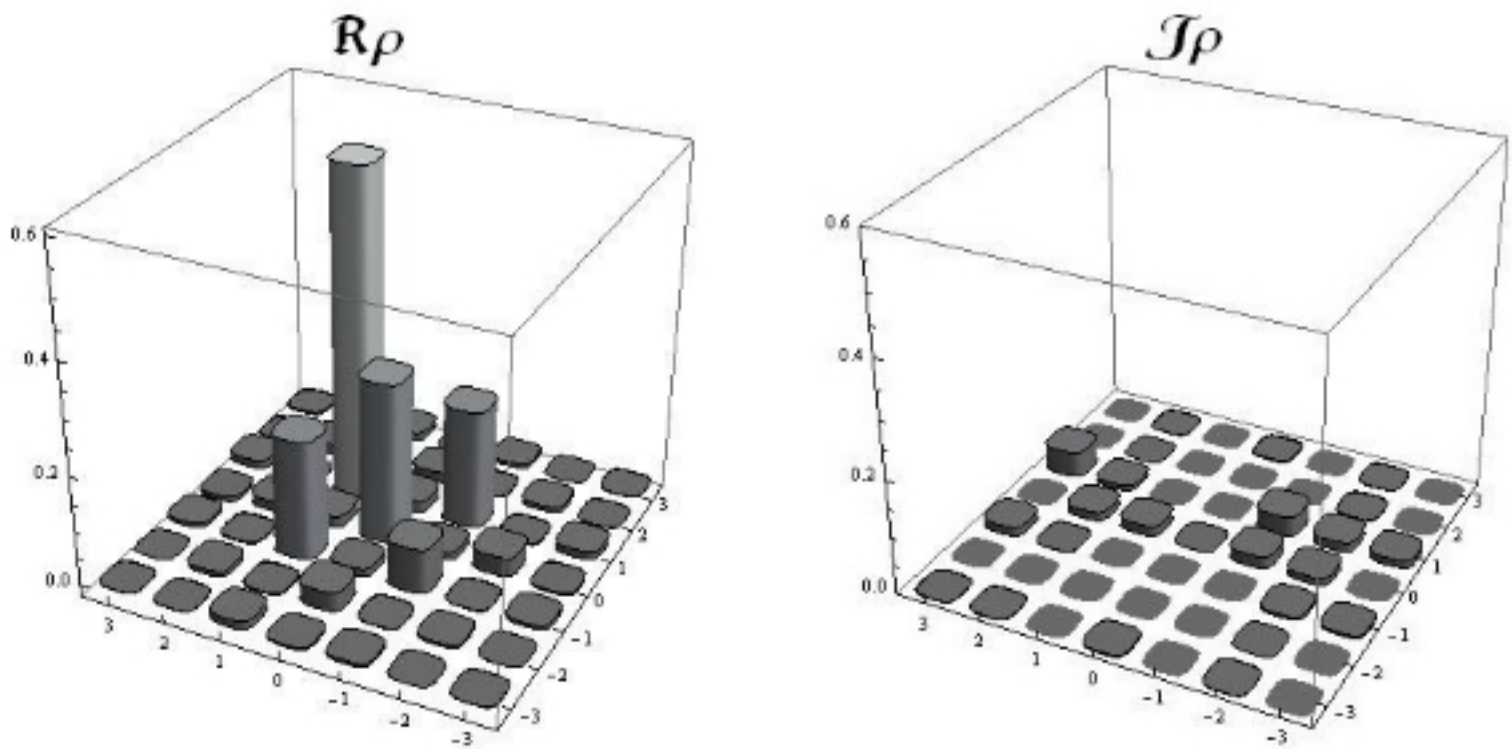
Plane waves ...

- target state

$$\rho = |\Psi\rangle\langle\Psi| + \alpha\,|0\rangle\langle 0| \quad , \quad |\Psi\rangle = |-1\rangle + \beta\,|1\rangle$$

angle w.r.t. optical axis

- reconstruction



Conclusions

- realistic theory of S-H detection presented
- applications discussed:
  - characterization of vortex fields
  - digital propagation and 3D imaging
- possible extensions
  - optimization
  - alternative inversion methods

D.Sych, J.R., Z.Hradil, G.Leuchs, L.L.Sanchez-Soto, Phys. Rev. A ***86****, 052123 (2012)*

J.R., D.Mogilevtsev, Z.Hradil, Phys. Rev. Lett. ***105****, 010402 (2010)*