Title: Polarisation tomography of macro- and mesoscopic quantum states of light

Date: Aug 29, 2008 09:30 AM

URL: http://pirsa.org/08080053

Abstract: We report an experiment on reconstructing the quantum state of bright (macroscopic) polarization-squeezed light generated in a birefringent (polarization-maintaining) fibre due to the Kerr nonlinearity. The nonlinearity acts on both H and V polarization components, producing quadrature squeezing; by controlling the phase shift between the H and V components one can make the state squeezed in any Stokes observable. The tomography is performed by measuring histograms for a series of Stokes observables, and the resulting histograms (tomograms) are processed in a way similar to the classical 3D Radon transformation. At the output, we obtain the polarization Q-function, which in the case of large photon numbers coincides with the polarization W-function. An interesting extension of the performed experiment will be going down to lower photon numbers (mesoscopic quantum states), and we expect a different behaviour of polarization W and Q functions in this case. An experiment on producing such states is discussed.

POLARIZATION TOMOGRAPHY OF MACRO- AND MESOSCOPIC STATES OF LIGHT

Christoph Marquardt[1], Joel Heersink[1], Ruifang Dong[1], Maria V. Chekhova[1,2], Andrei B. Klimov[3], Luis L. Sánchez-Soto[4], Ulrik L. Andersen[1], Gerd Leuchs[1]

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[2] Department of Physics, M.V. Lomonosov Moscow State University
[3] Departamento de Fisica, Universidad de Guadalajara
[4] Departamento de Optica, Facultad de Fisica, Universidad Complutense Madrid

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Department of Physics, M.V. Lomonosov Moscow State University

OUTLINE

Polarization of light: quantum and classical description

Polarization tomography

Experiment made: polarization tomography of Kerr-squeezed light with bright polarized component

Experiment planned: polarization tomography of bright *squeezed* vacuum

PRL 99, 220401 (2007) PHYSICAL REVIEW LETTERS week ending 30 NOVEMBER 2007

Quantum Reconstruction of an Intense Polarization Squeezed Optical State

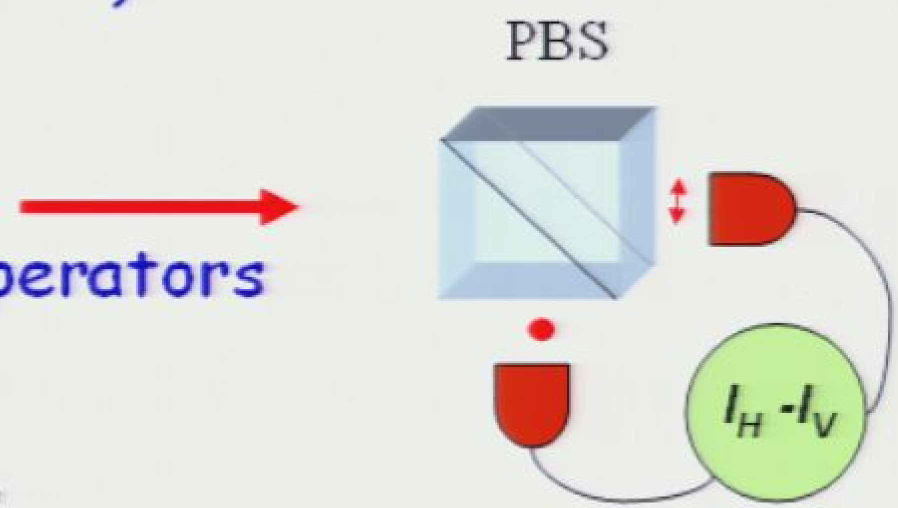
Ch. Marquardt,[1] J. Heersink,[1] R. Dong,[1] M. V. Chekhova,[2] A. B. Klimov,[3] L. L. Sánchez-Soto,[1] U. L. Andersen,[1,4] and G. Leuchs[1]

POLARIZATION OF LIGHT

Classical Stokes parameters (1852)

$$S_0 \equiv I_H + I_V, \quad S_1 \equiv I_H - I_V,$$

$$S_2 \equiv I_{45} - I_{-45}, \quad S_3 \equiv I_R - I_L$$



Quantum description: Stokes operators

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$$\vec{\hat{S}} \equiv \{\hat{S}_1, \hat{S}_2, \hat{S}_3\}, \ \vec{n} \equiv \{\cos\vartheta, \sin\vartheta\cos\varphi, \sin\vartheta\sin\varphi\}$$

$$\hat{S}(\vartheta, \varphi) = \vec{\hat{S}} \cdot \vec{n}$$

'Stokes space', not a sphere

$$[\hat{S}_i, \hat{S}_j] = 2i\hat{S}_k \Rightarrow \Delta^2 S_i \Delta^2 S_j \geq \left|\langle S_k \rangle\right|^2$$

$$i, j, k = 1,2,3$$

$\Delta^2 S_i < \left|\langle S_k \rangle\right| < \Delta^2 S_j$ polarization squeezing

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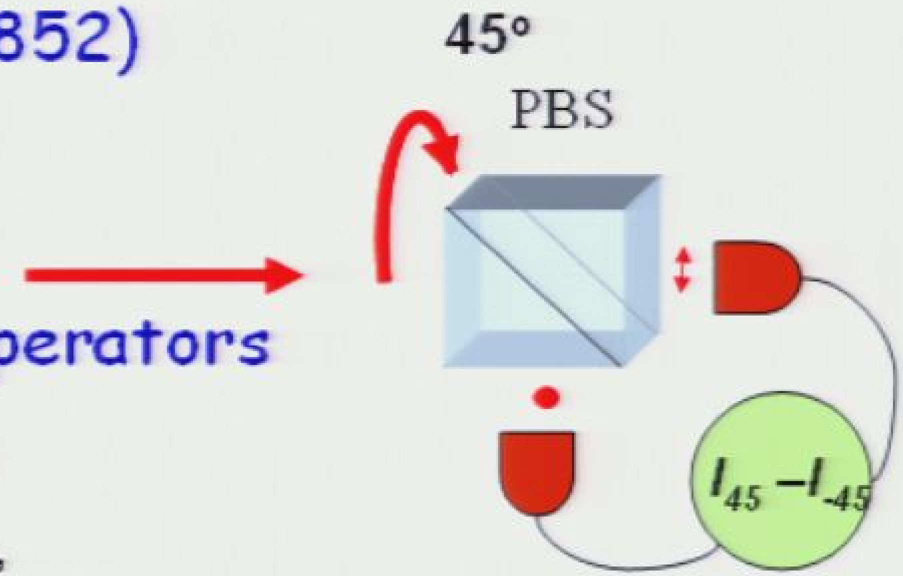

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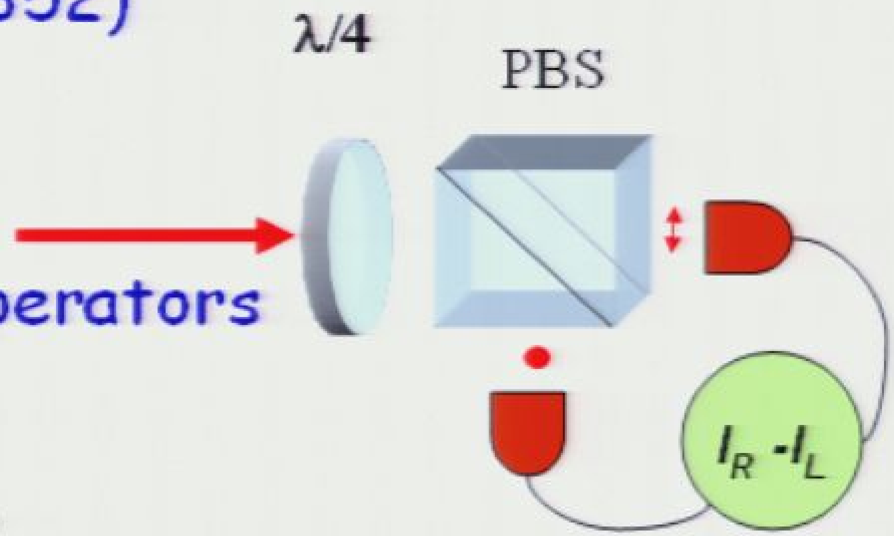

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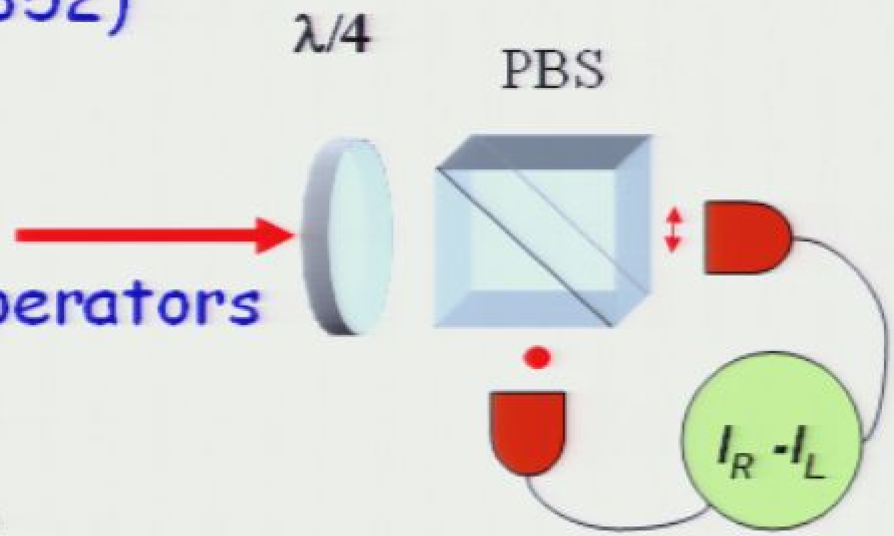

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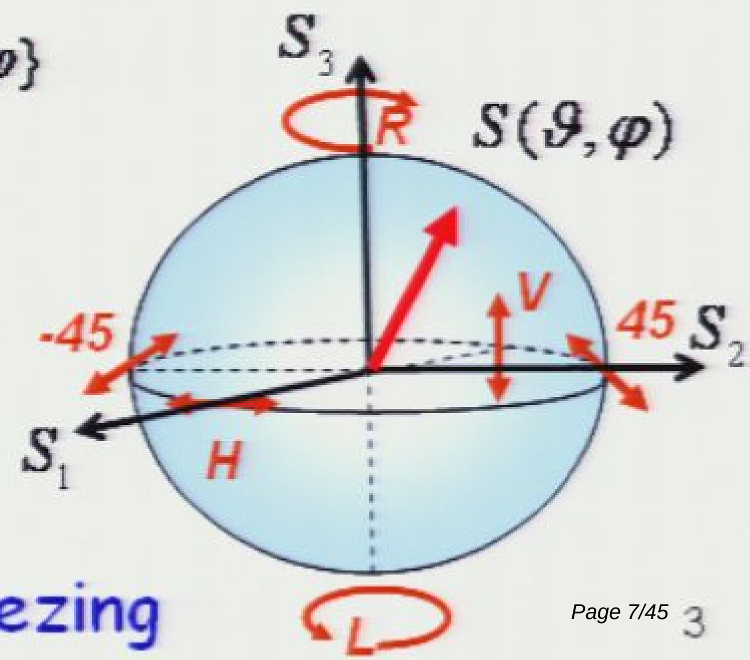

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3

CAN WE MEASURE MORE THAN THE STOKES PARAMETERS AND THEIR VARIANCES?

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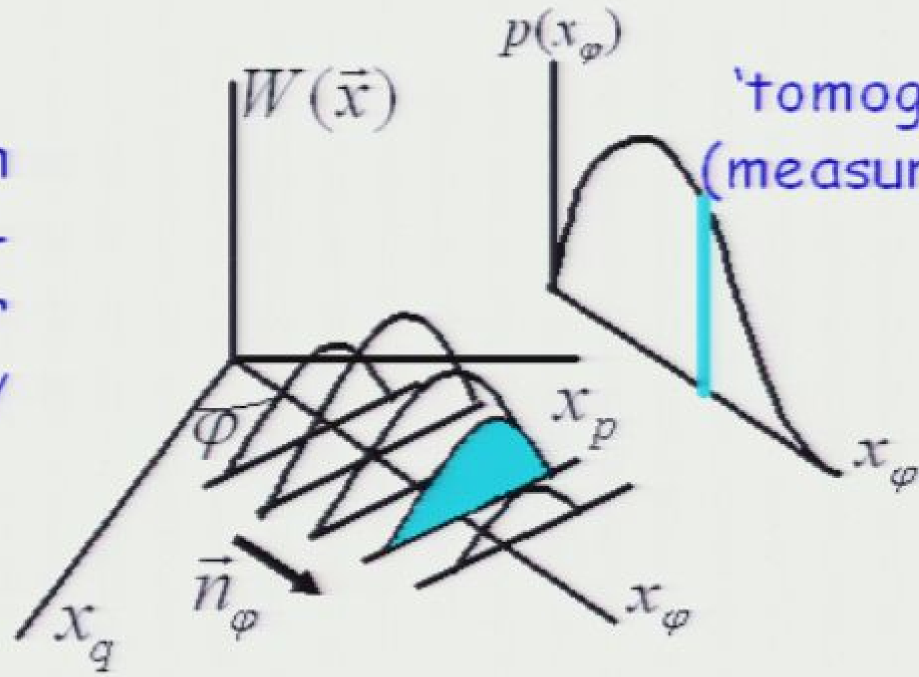
QUANTUM TOMOGRAPHY

'Traditional' quantum tomography, or Wigner-function tomography, or homodyne tomography

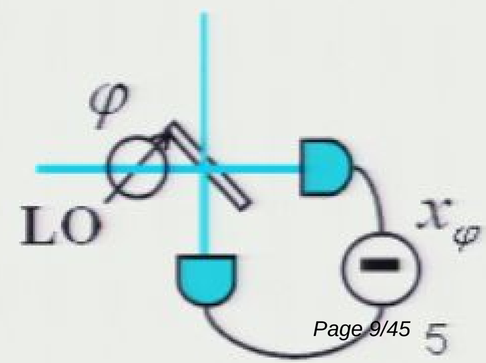
D.T.Smithey, M.Beck, M.Raymer, and A.Faridani, PRL 70, 1244 (1993)



$$\vec{x} \equiv \{x_q, x_p\}$$

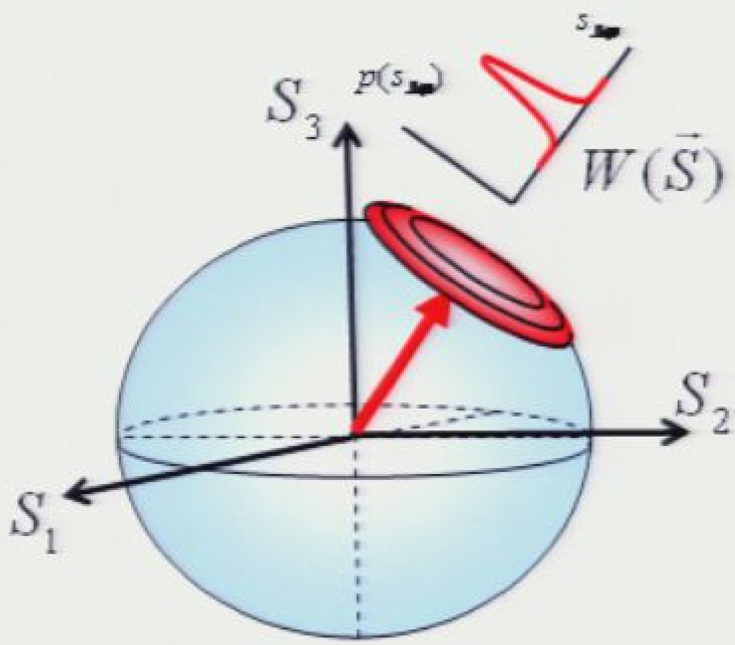
Direct Radon transform: $p(x_\varphi) = \int W(\vec{x})\delta(\vec{x}\cdot\vec{n}_\varphi - x_\varphi)d^2\vec{x}$

Inverse Radon transform: $p(x_\varphi) \rightarrow W(\vec{x})$



Can we do this for polarization variables?

POLARIZATION TOMOGRAPHY



$W(\vec{S})$ (some quasiprobability function in the Stokes space)

$$\vec{n} \equiv \{\cos\vartheta, \sin\vartheta\cos\varphi, \sin\vartheta\sin\varphi\}$$

$$p(s_{\vartheta\varphi}) = \int W(\vec{S})\delta(\vec{S}\cdot\vec{n} - s_{\vartheta\varphi})d^3\vec{S}$$

tomogram of a Stokes measurement

P.A.Bushev, V.P.Karassiov, A.V.Masalov, and A.A.Putilin, Optics and Spectroscopy 91, 526 (2001)

Reconstruction: $p(s_{\vartheta\varphi}) \rightarrow W(\vec{S})$

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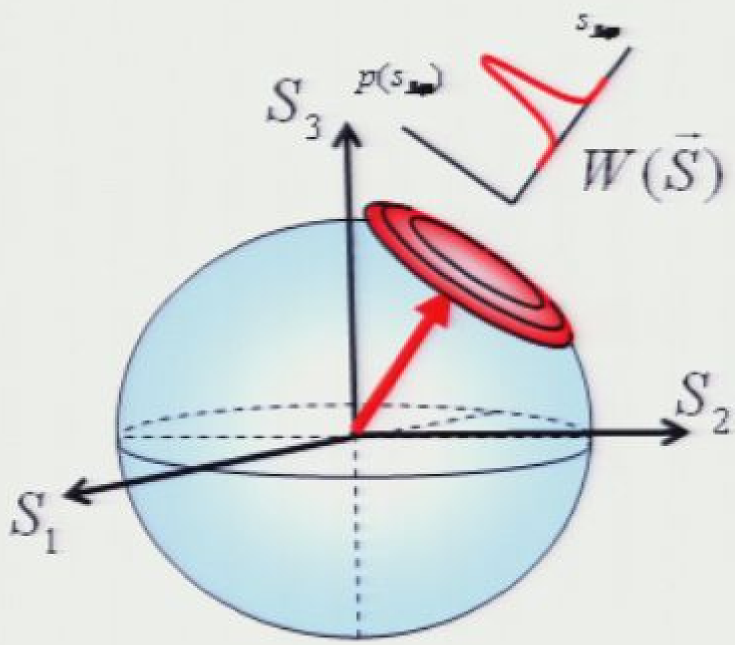

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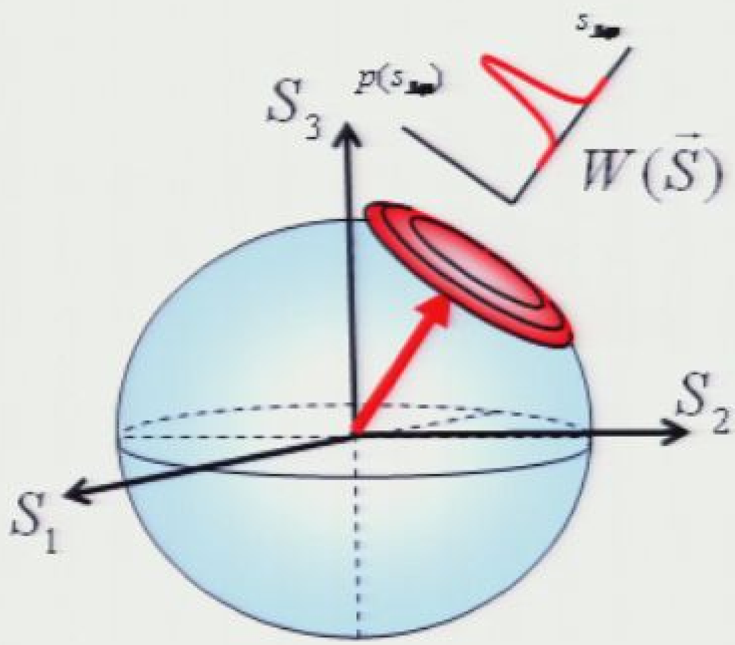

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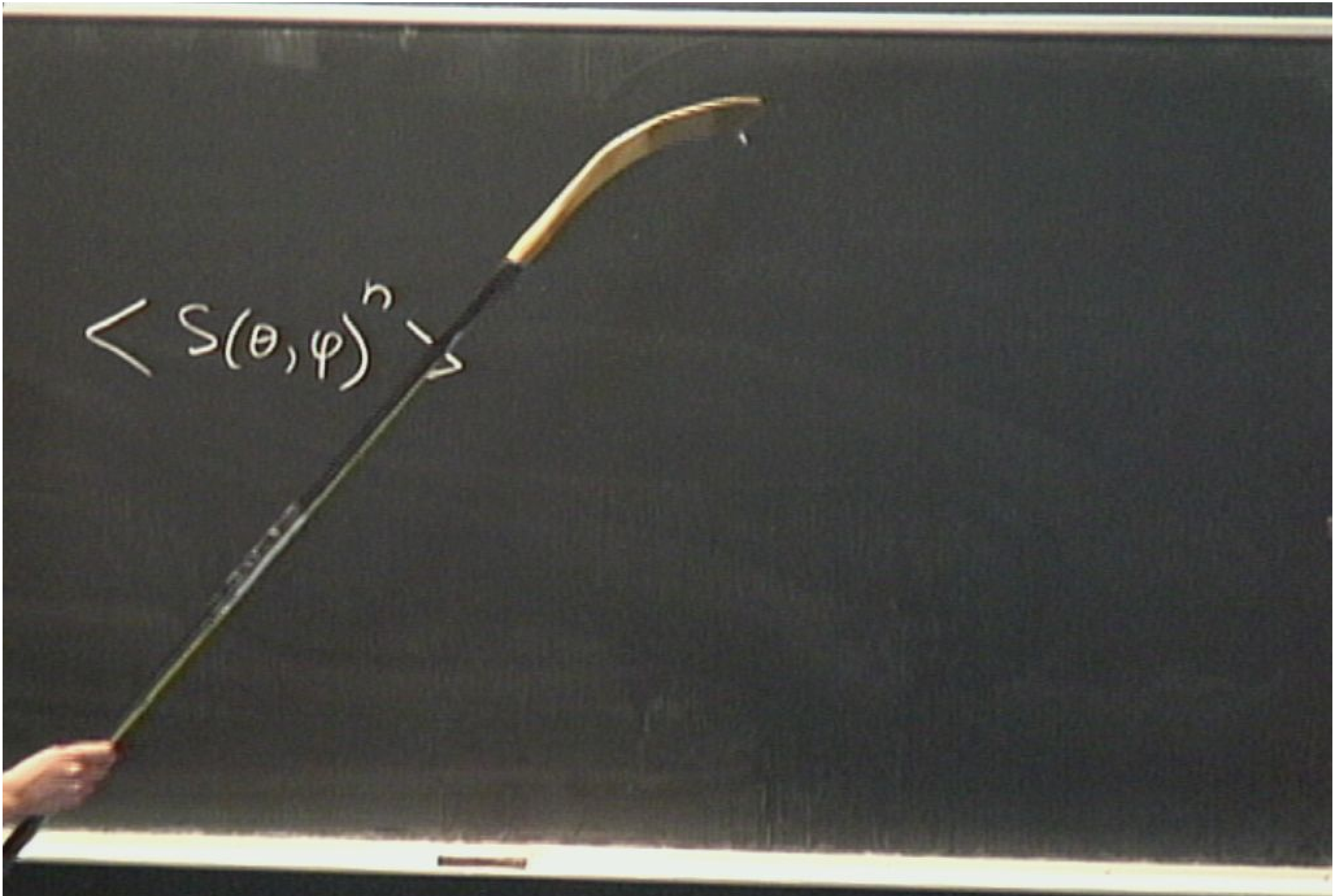
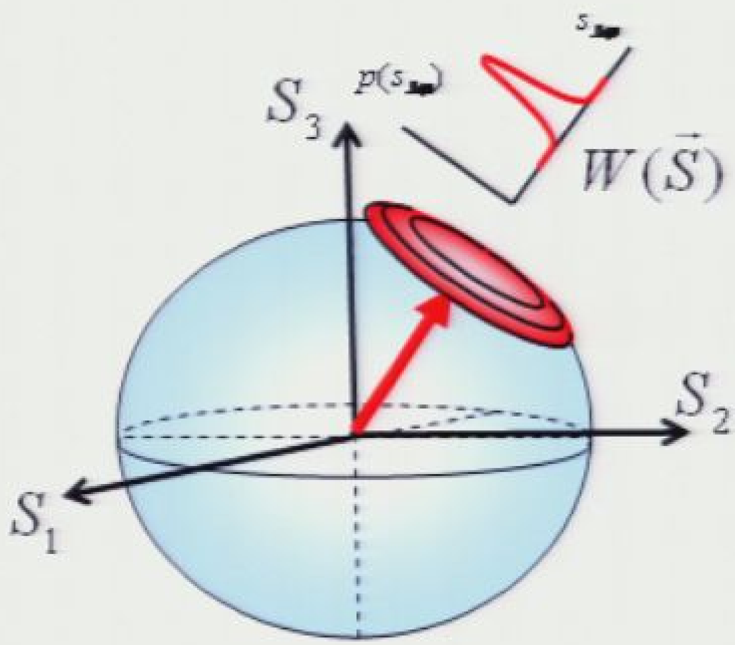

$\langle S(\theta,\varphi)^n \rangle$

POLARIZATION TOMOGRAPHY



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RECONSTRUCTION OF QUASIPROBABILITY FUNCTIONS

W-function $$W(\vec{S}) \equiv \int_{R^3} \frac{d^3\vec{\omega}}{(2\pi)^3} \chi(\vec{\omega}) e^{-i\vec{\omega}\vec{S}}, \quad \chi(\vec{\omega}) \equiv \left\langle e^{i\vec{\omega}\hat{\vec{S}}} \right\rangle$$

Reconstruction (for $S_0 >> 1$) $$W(\vec{S}) \propto \int_{-\infty}^{\infty} ds_{\vartheta\varphi} \int_{S_2} d^2\vec{n} \frac{d^2 p(s_{\vartheta\varphi})}{ds_{\vartheta\varphi}^{\;2}} \delta(s_{\vartheta\varphi} - \vec{S}\cdot\vec{n})$$

K.B. Wolf, Opt. Commun. 132, 343 (1996);
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Q-function $Q(S_0, \vec{n}) = \left\langle S_0, \vec{n} \middle| \hat{\rho}_{S_0} \middle| S_0, \vec{n} \right\rangle$

Reconstruction for S_0>>1: $Q(S_0, \vec{n}) \propto (2S_0 + 1) \int_{-\infty}^{\infty} ds_{\vartheta\varphi} \int_{S_2} d^2\vec{n} \frac{d^2 p(s_{\vartheta\varphi})}{ds_{\vartheta\varphi}^{\ 2}} \delta(s_{\vartheta\varphi} - \vec{S}\cdot\vec{n})$

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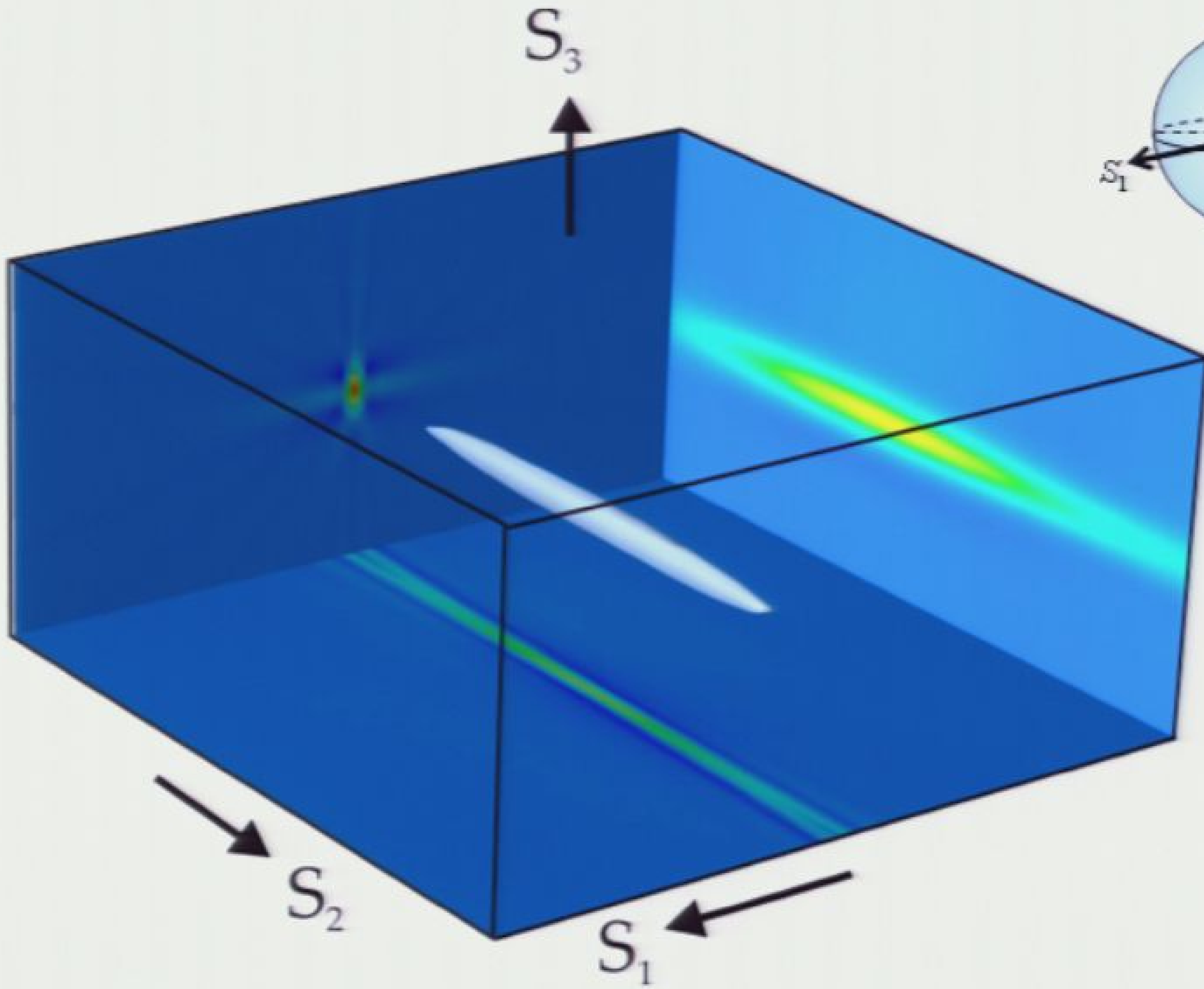
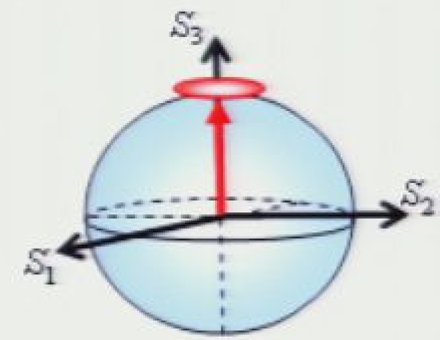
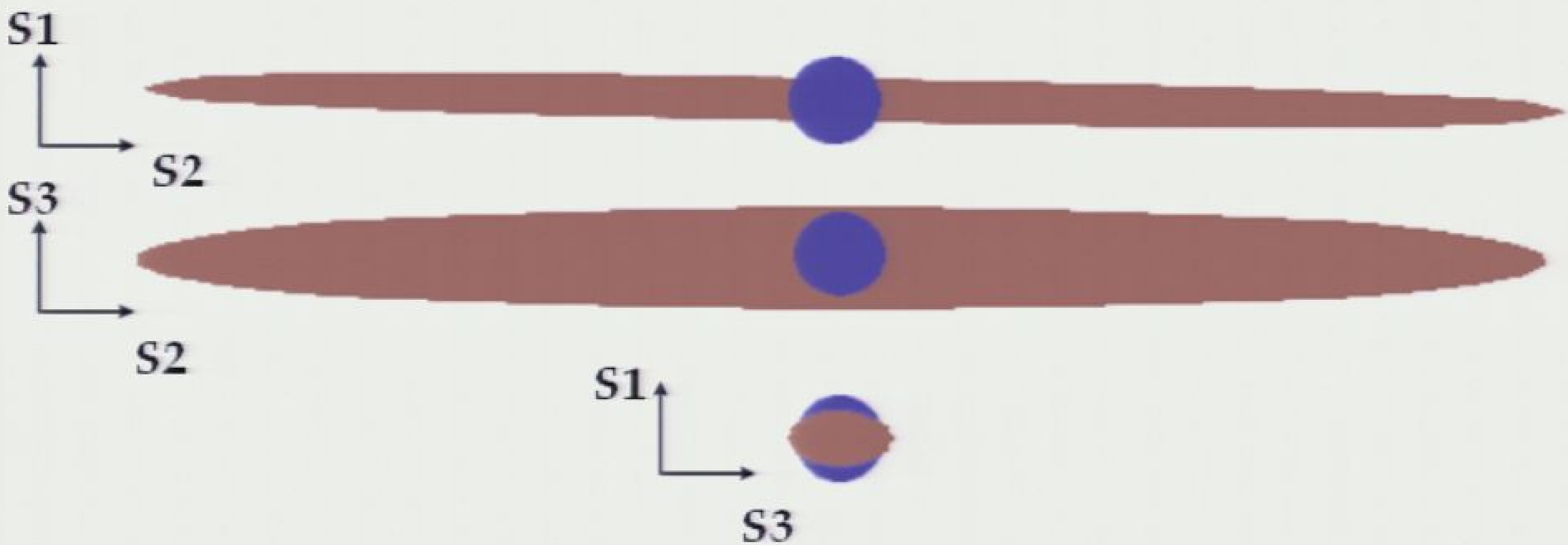
$S_0 = N \sim 10^7 \Rightarrow$ W-reconstruction ~ Q-reconstruction ~ classical 3D inverse Radon transformation

RESULTS: Q-FUNCTION RECONSTRUCTION





RESULTS: COMPARISON WITH A COHERENT STATE



6.2 dB squeezing almost along S_1

Much larger anti-squeezing, due to phase noise

Slightly above shot noise along S_3

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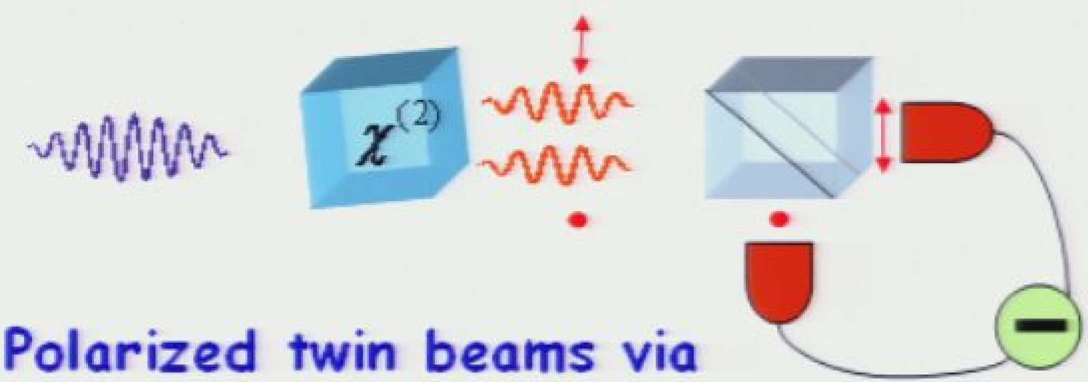
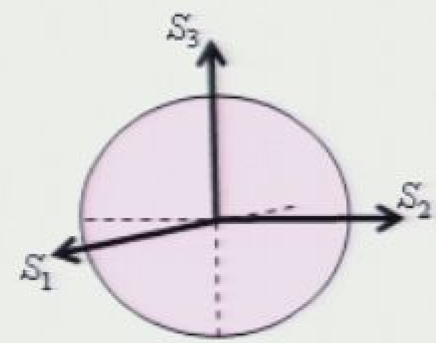
FROM MACROSCOPIC TO MESOSCOPIC SCALE

Further questions:

1. What happens if S_0 reduces, so that $Var(S_i)$ gets closer to S_0?
2. What happens if the classical polarized component reduces, $Var(S_i)$ gets closer to S_3?
3. Can we prepare arbitrary shapes of $Q(S)$ and how can we use them?





Polarized twin beams via travelling-wave OPA

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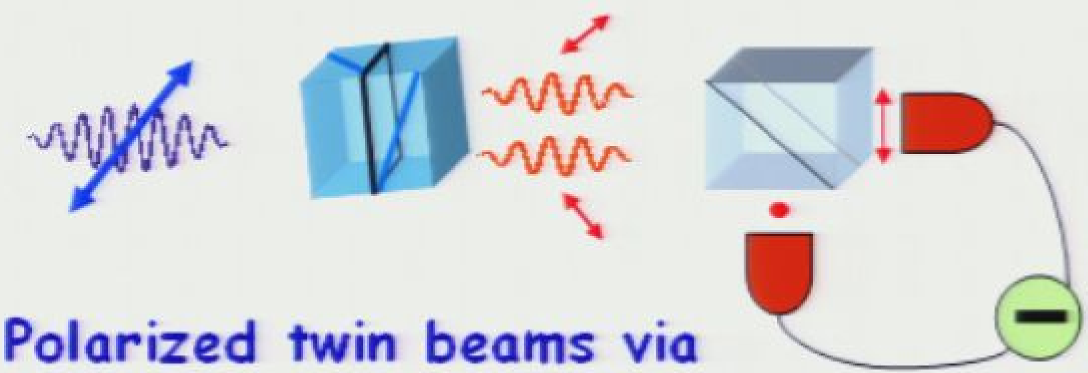

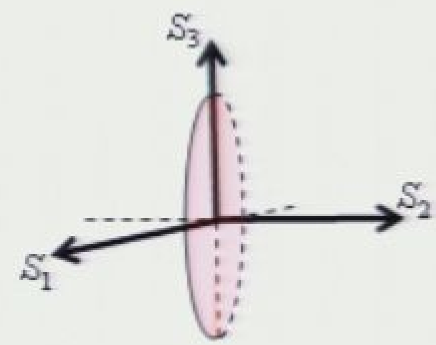

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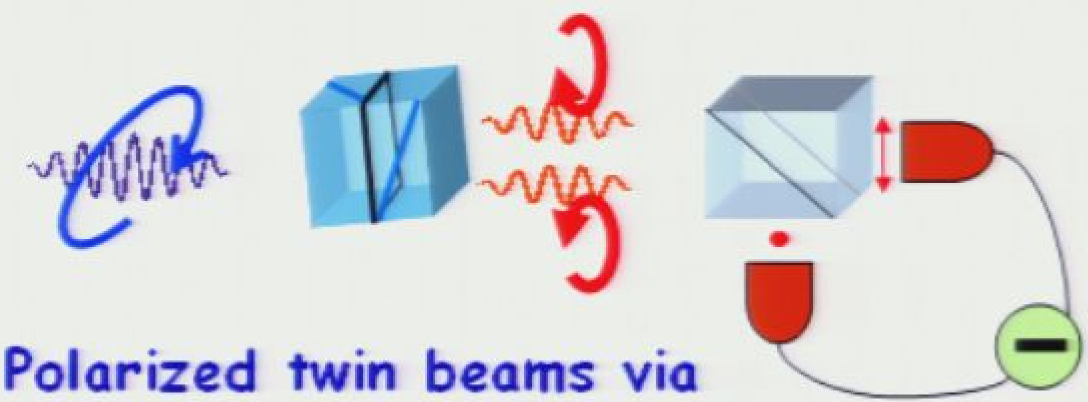

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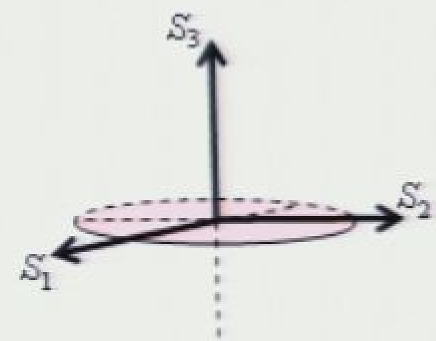

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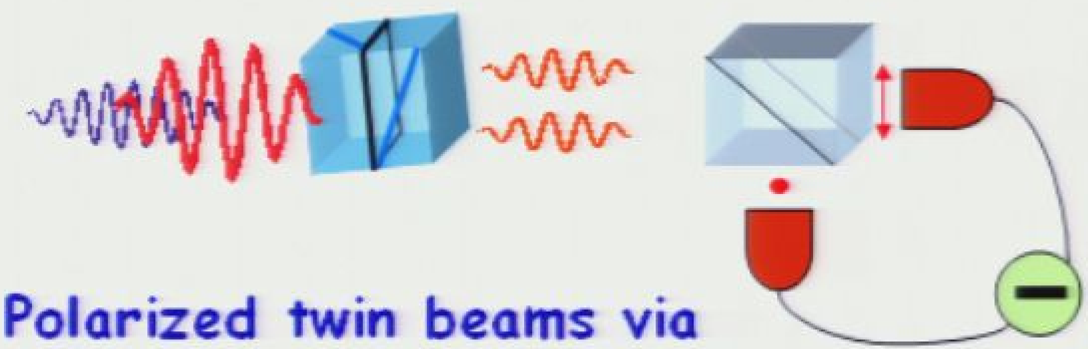

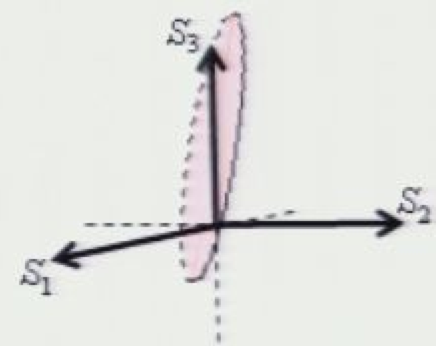

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LATEST NEWS

from Zdenek Hradil and Jaroslav Rehacek (Palacky University, Olomouc, Czekh Republic)

Problem: negative 'ripples' created by the inverse Radon transformation in the Q-function (also in W-function)

Solution: Maximum-likelihood approach eliminates the Q-function negativities

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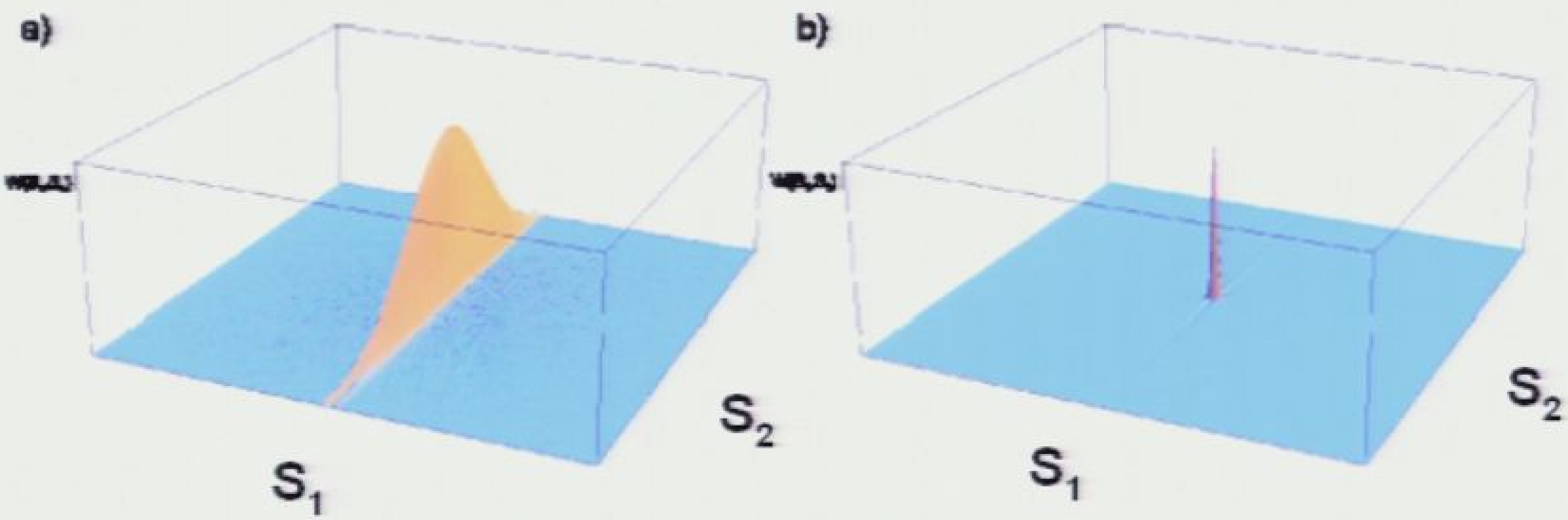
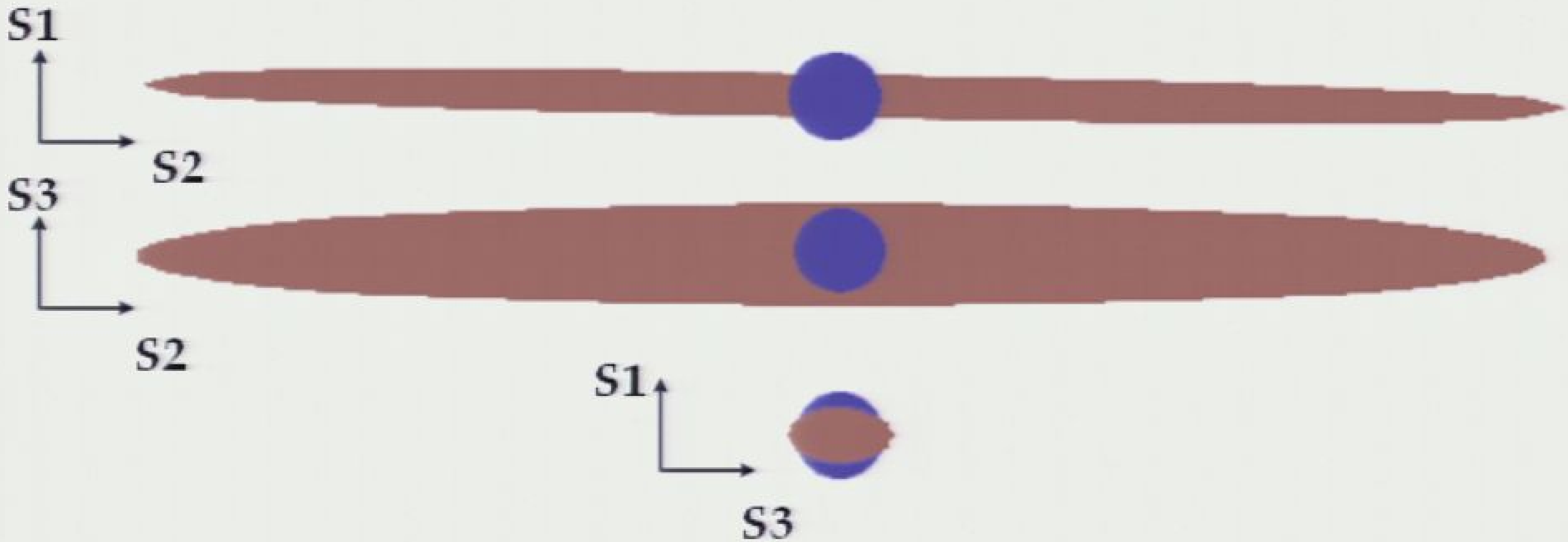
Universität Erlangen-Nürnberg

RADON-TRANSFORMATION RESULTS



RESULTS: COMPARISON WITH A COHERENT STATE

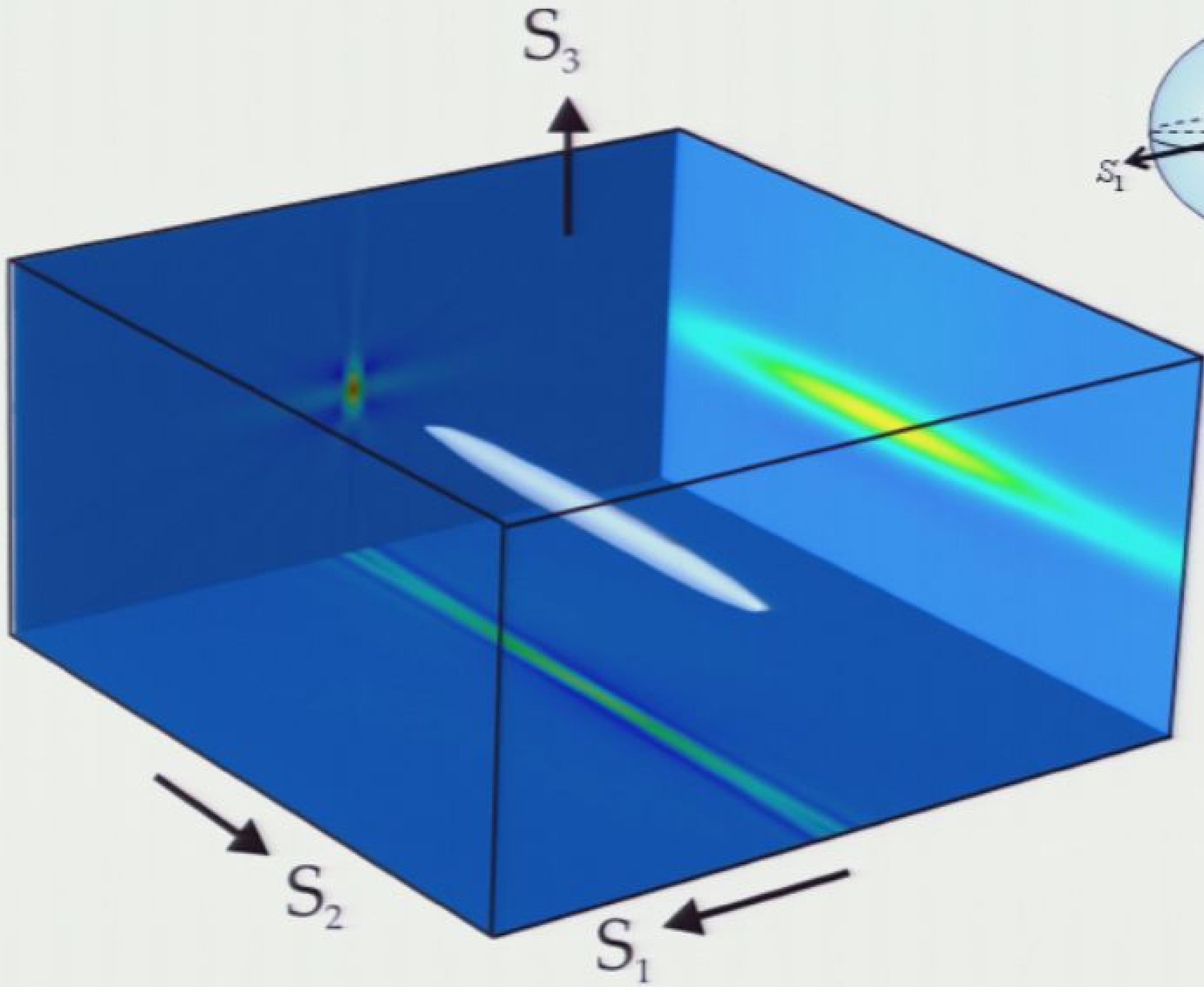


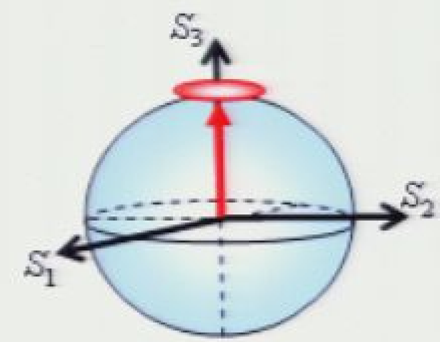
6.2 dB squeezing almost along S_1

Much larger anti-squeezing, due to phase noise

Slightly above shot noise along S_3

RESULTS: Q-FUNCTION RECONSTRUCTION

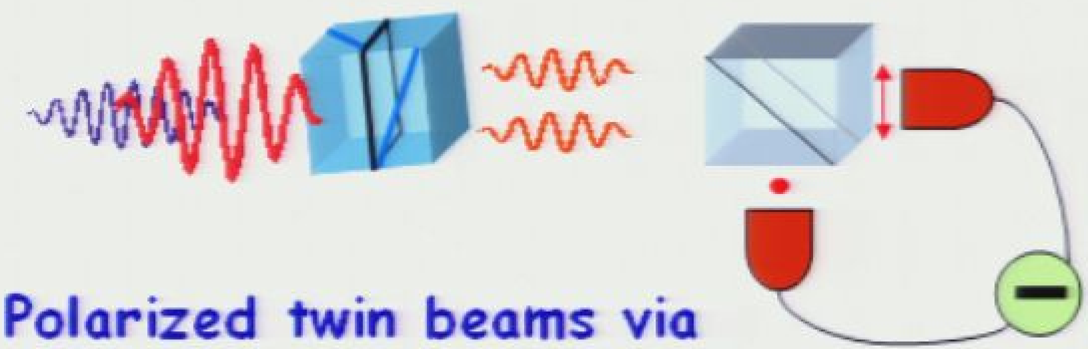




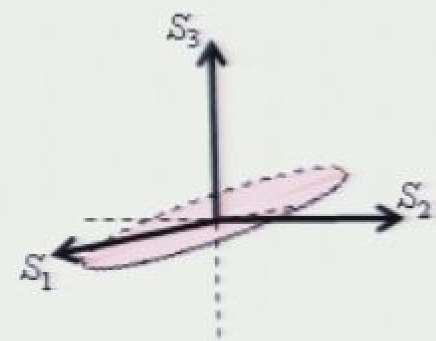
FROM MACROSCOPIC TO MESOSCOPIC SCALE

Further questions:

1. What happens if S_0 reduces, so that $Var(S_i)$ gets closer to S_0?
2. What happens if the classical polarized component reduces, $Var(S_i)$ gets closer to S_3?
3. Can we prepare arbitrary shapes of Q(S) and how can we use them?



Polarized twin beams via travelling-wave OPA



LATEST NEWS

from Zdenek Hradil and Jaroslav Rehacek (Palacky University, Olomouc, Czekh Republic)

Problem: negative 'ripples' created by the inverse Radon transformation in the Q-function (also in W-function)

Solution: Maximum-likelihood approach eliminates the Q-function negativities

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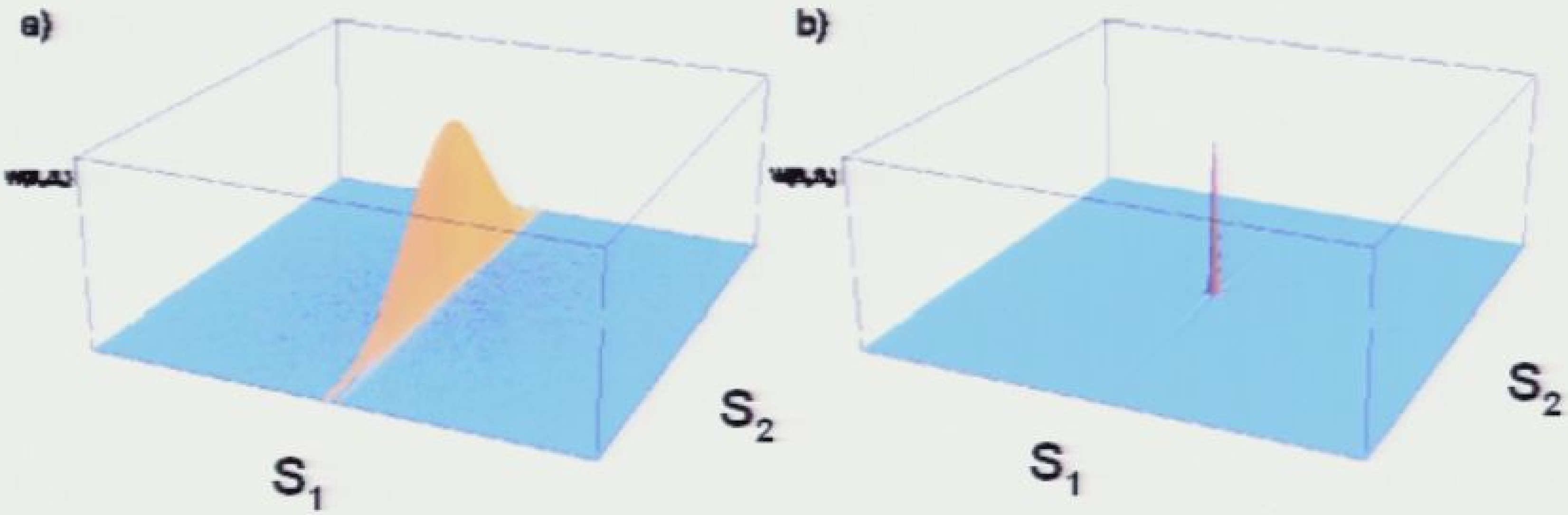
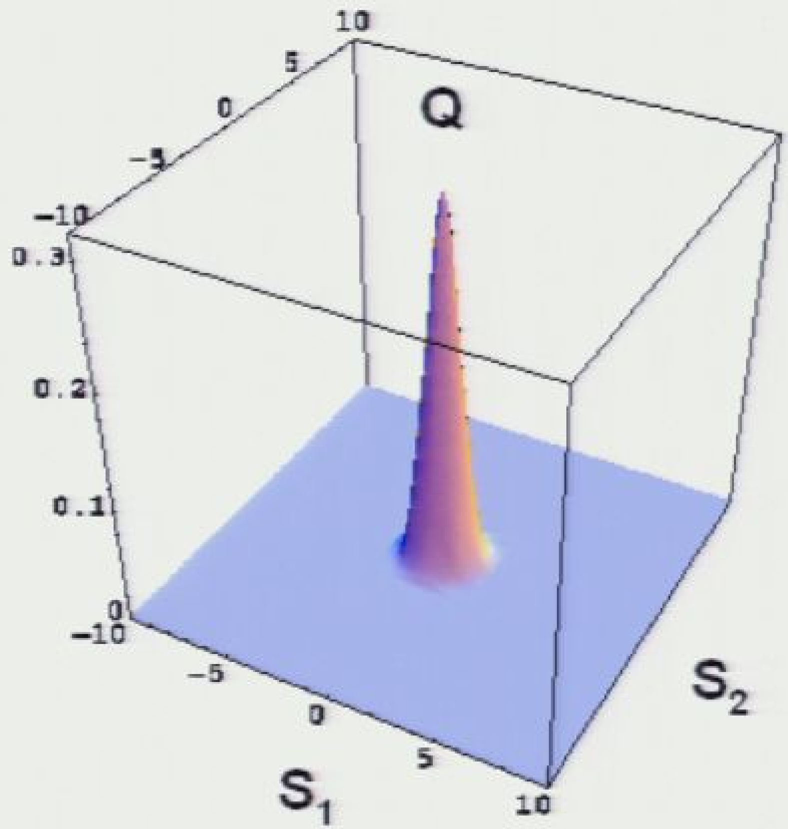


'DARK-PLANE TOMOGRAPHY': COHERENT STATE



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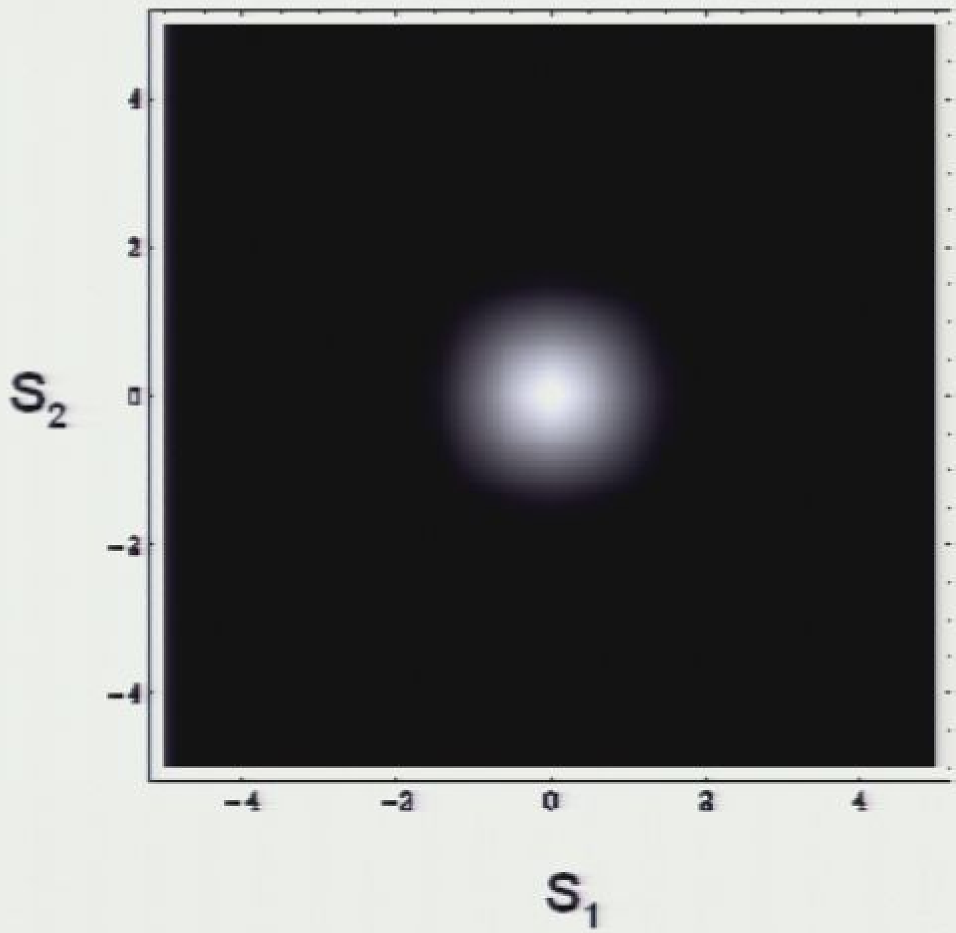
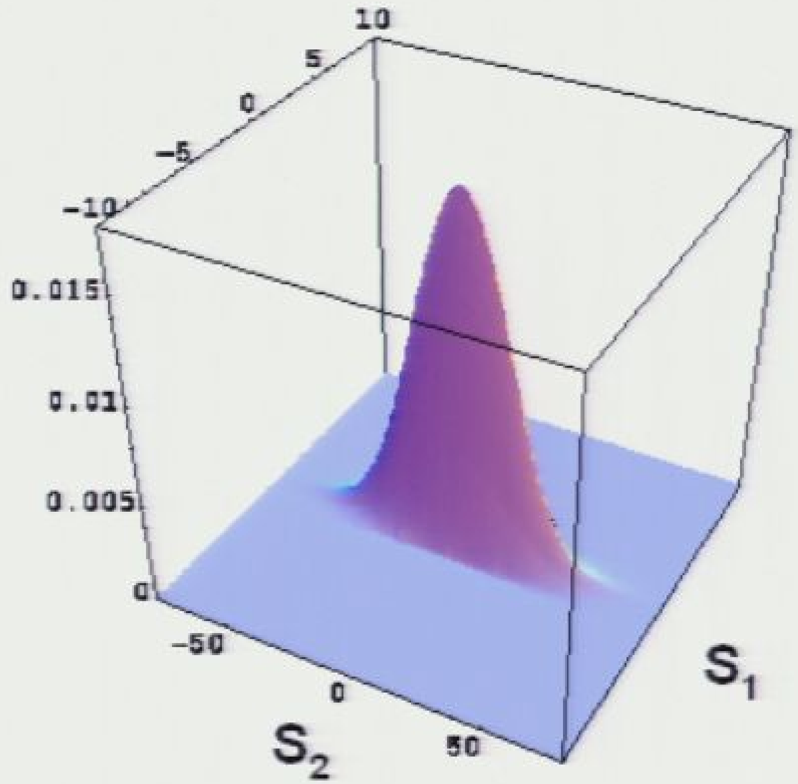


'DARK-PLANE TOMOGRAPHY': SQUEEZED STATE



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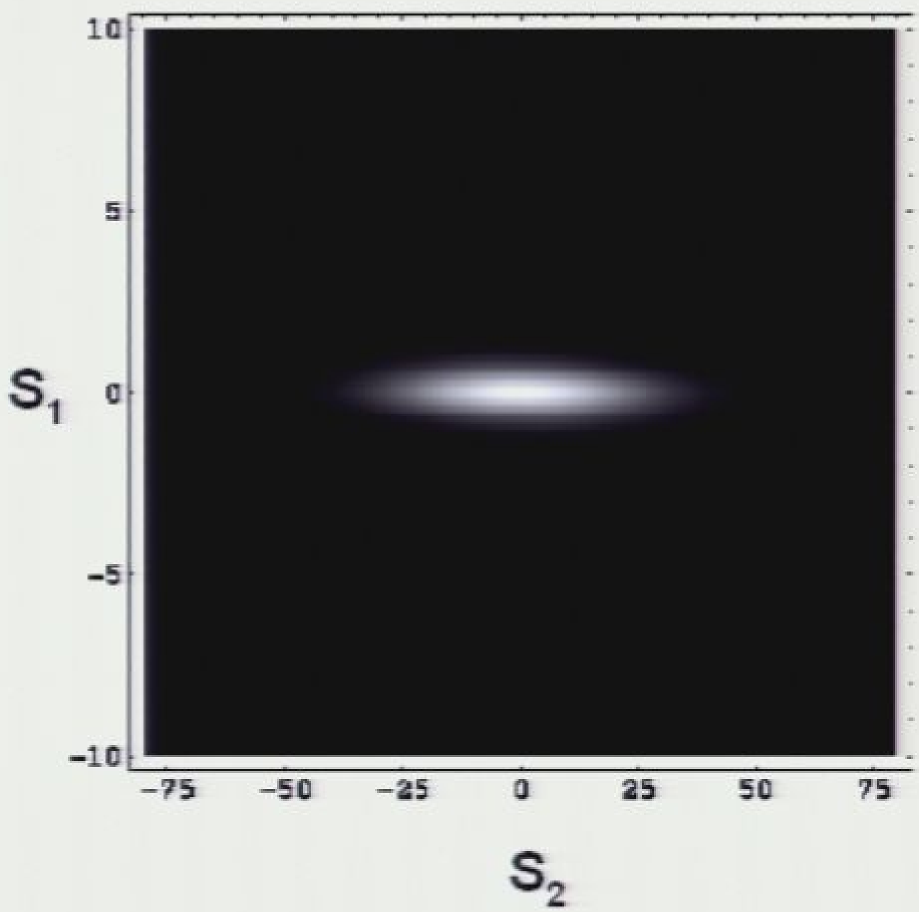


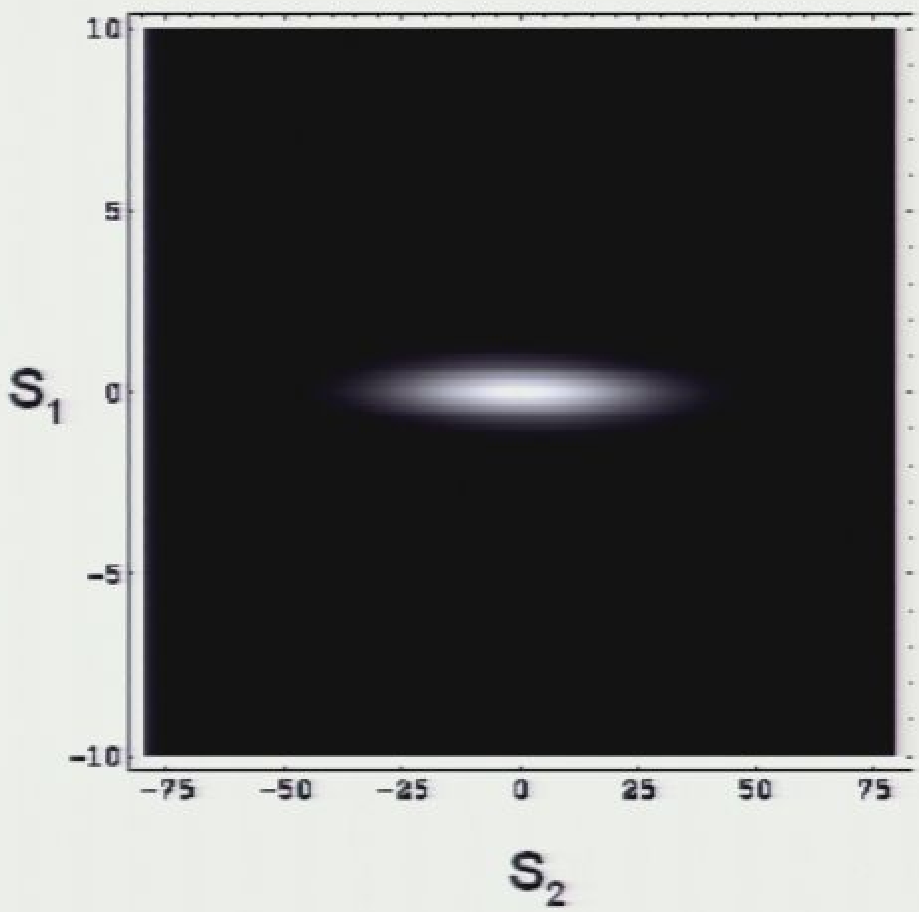
CONCLUSIONS

1. Performed: full polarization tomography of an intense squeezed state generated via third-order nonlinearity in an optical fibre. In the 'macroscopic' limit, reconstruction of W- and Q-quasiprobability functions is similar and coincides with the classical 3D inverse Radon transform. We now have a tool for polarization state reconstruction.

2. Planned: generation and full polarization tomography of 'mesoscopic' states of polarization-squeezed vacum with and without polarized coherent component.

THANK YOU FOR YOUR ATTENTION!

'DARK-PLANE TOMOGRAPHY': SQUEEZED STATE



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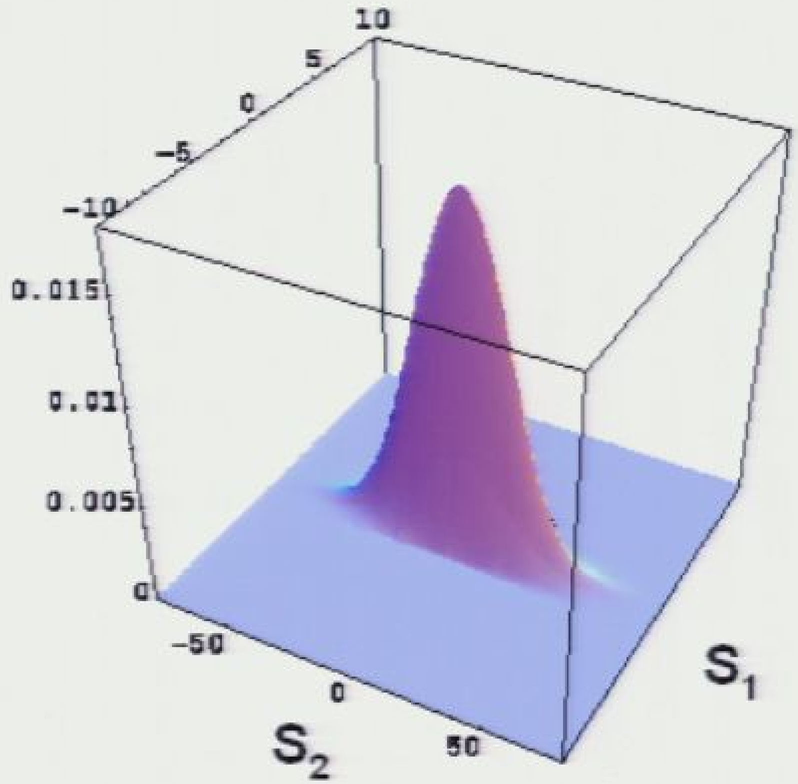

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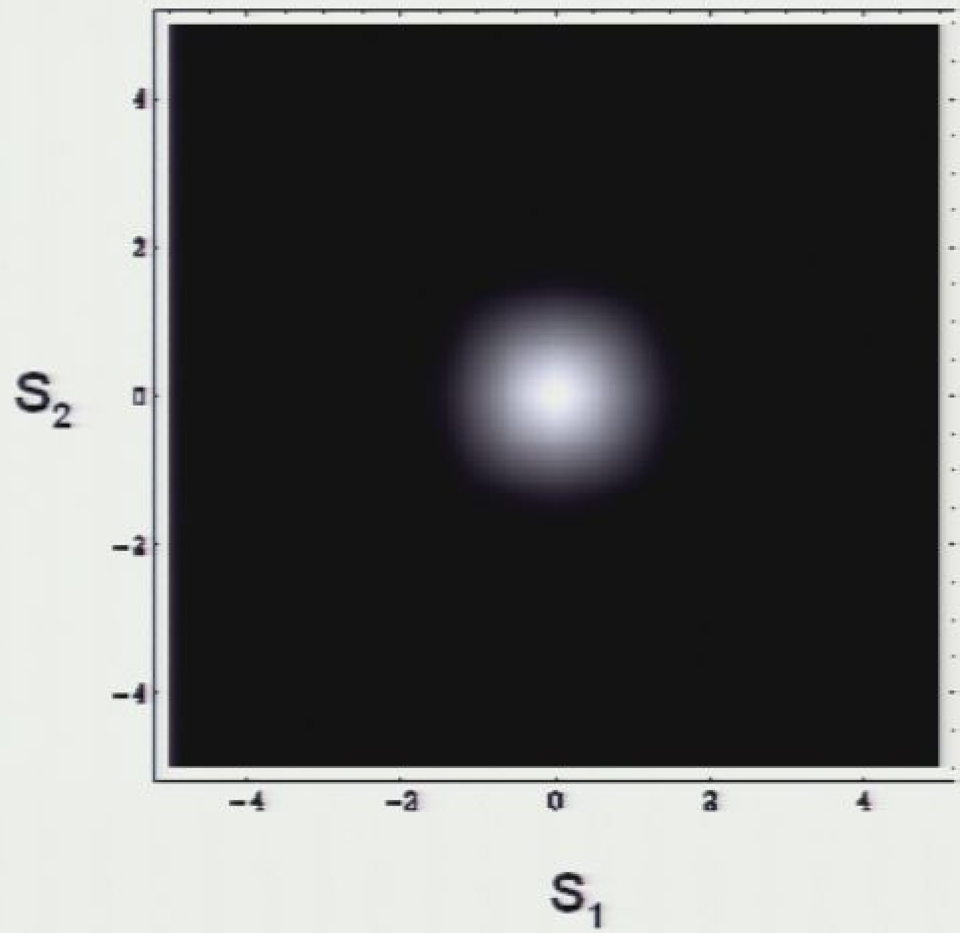

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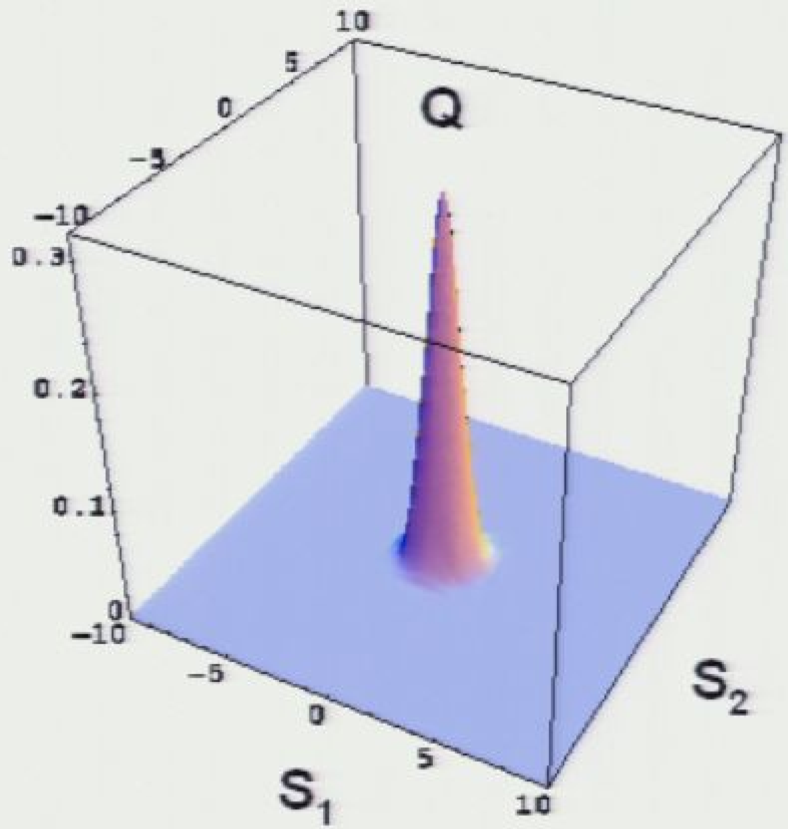

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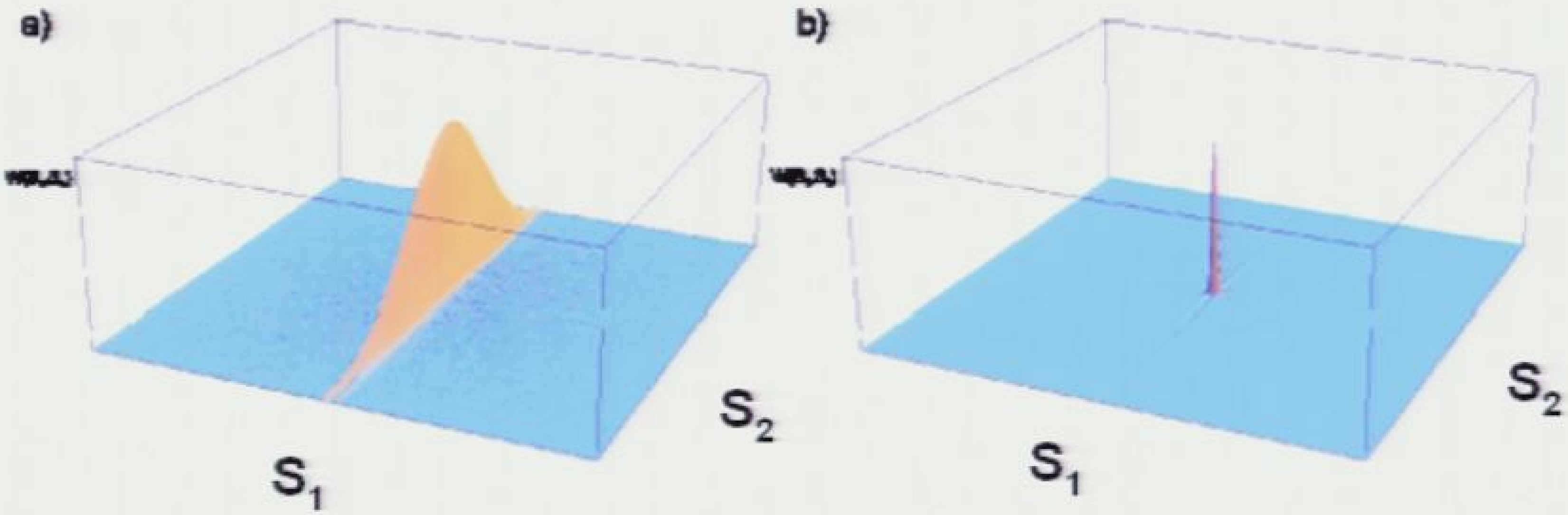

X-PLANCK-FORSCHUNGSGRUPPE
Institut für Optik,
Information und Photonik
Universität Erlangen-Nürnberg

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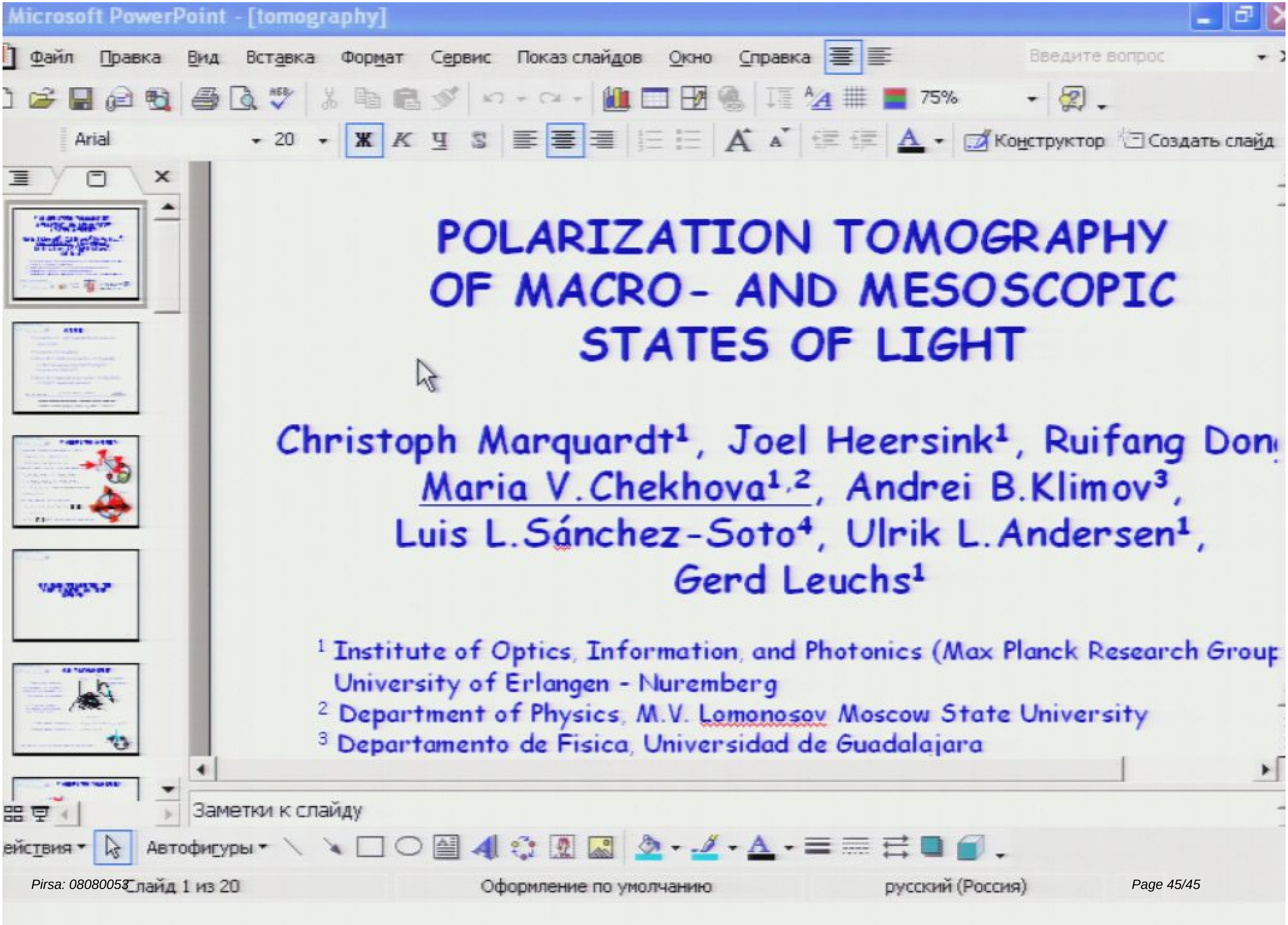
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Maria V.Chekhova[1,2], Andrei B.Klimov[3],
Luis L.Sánchez-Soto[4], Ulrik L.Andersen[1],
Gerd Leuchs[1]
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University of Erlangen - Nuremberg
[2] Department of Physics, M.V. Lomonosov Moscow State University
[3] Departamento de Fisica, Universidad de Guadalajara
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