A method based on classical entangled polarization modes and imaging to determine the Mueller matrix associated to transparent birefringent samples using a single incident beam.

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ABSTRACT

The experimental determination of the Mueller matrix of a transparent birefringent sample is presented. The novelty of this procedure is associated to the use of a single incident classically entangled polarized light (azimuthal unconventional polarization) and the presentation of results as spatially-resolved polarization responses (images). This work shows the contributions of the spatial and polarizations degrees of freedom and the procedure to separate them from its localized, classical entanglement. Therefore, the independent manipulation of the spatial and polarization distributions of the beam, once it has interacted with the sample, allows the determination of the Mueller matrix with just one incident beam, contrary to the traditional polarimetric method, which needs to prepare at least 4 incident polarization states to interact with the sample. Results are compared with the traditional polarimetric method, showing the potential advantages associated to the method proposed here.

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INTRODUCTION

We talk about **unconventional polarization** when the beam is characterized for have associated different electric field vectors whose amplitude and phase are dependent on their position across the transversal section[1]. We have a **classically entangled state** when "we need two coordinate-independent Jones vectors and two independent scalar fields (modes) to represent the electric field", [2].

The **Mueller matrix (MM)** represents the linear responses associated to optical materials and it contains all the available polarimetric information. Usually, it can be determined by using at least 4 incident conventional polarization states. In this work, we obtain the same information using a single incident unconventional polarization: an **azimuthally polarized beam of light**.

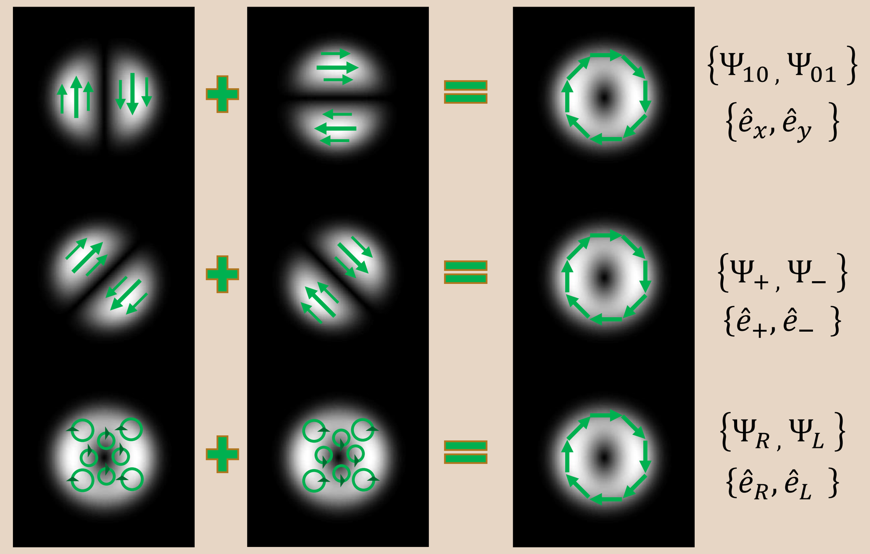


Fig. 1. Azimuthally polarized beam represented as a combination of Hermite-Gaussian ($\Psi_{10}, \Psi_{01}, \Psi_+, \Psi_-$) or Laguerre-Gaussian (Ψ_R, Ψ_L) modes with the appropriate conventional polarization distributions.

STATE OF THE ART

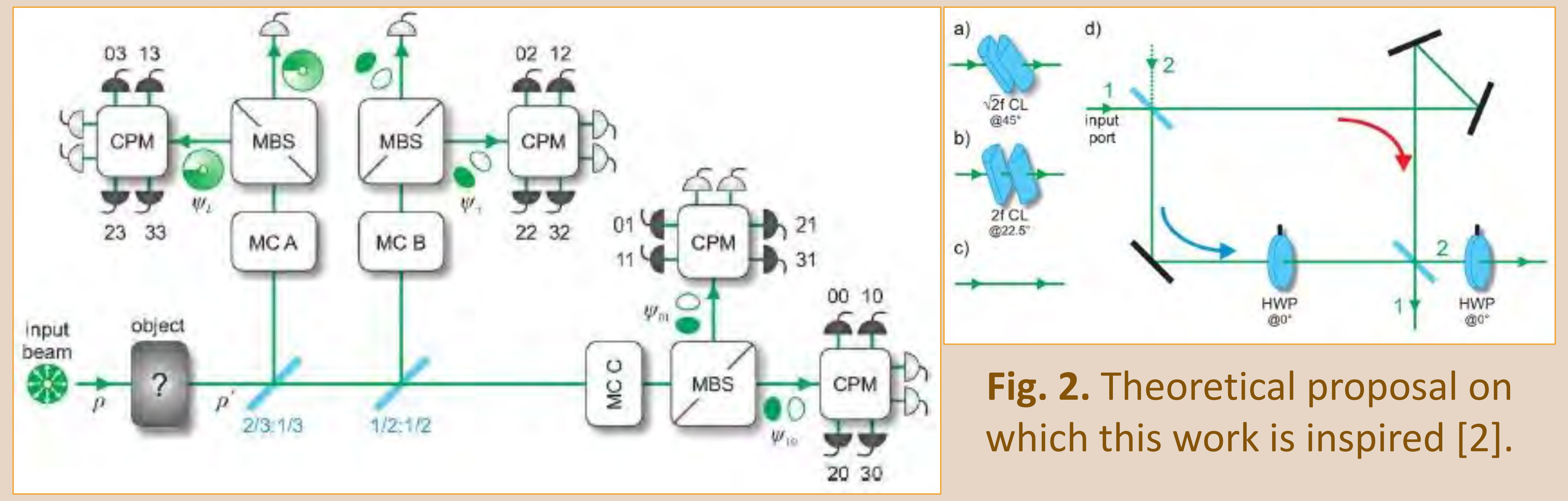
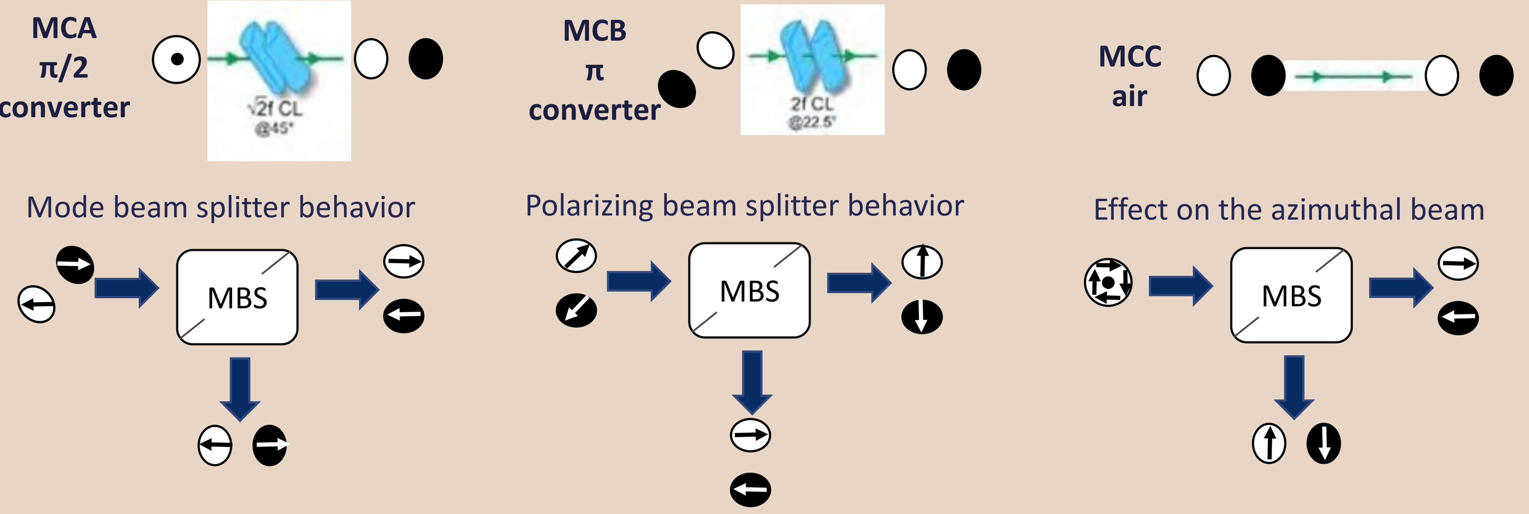


Fig. 2. Theoretical proposal on which this work is inspired [2].



OUR EXPERIMENTAL IMPLEMENTATION

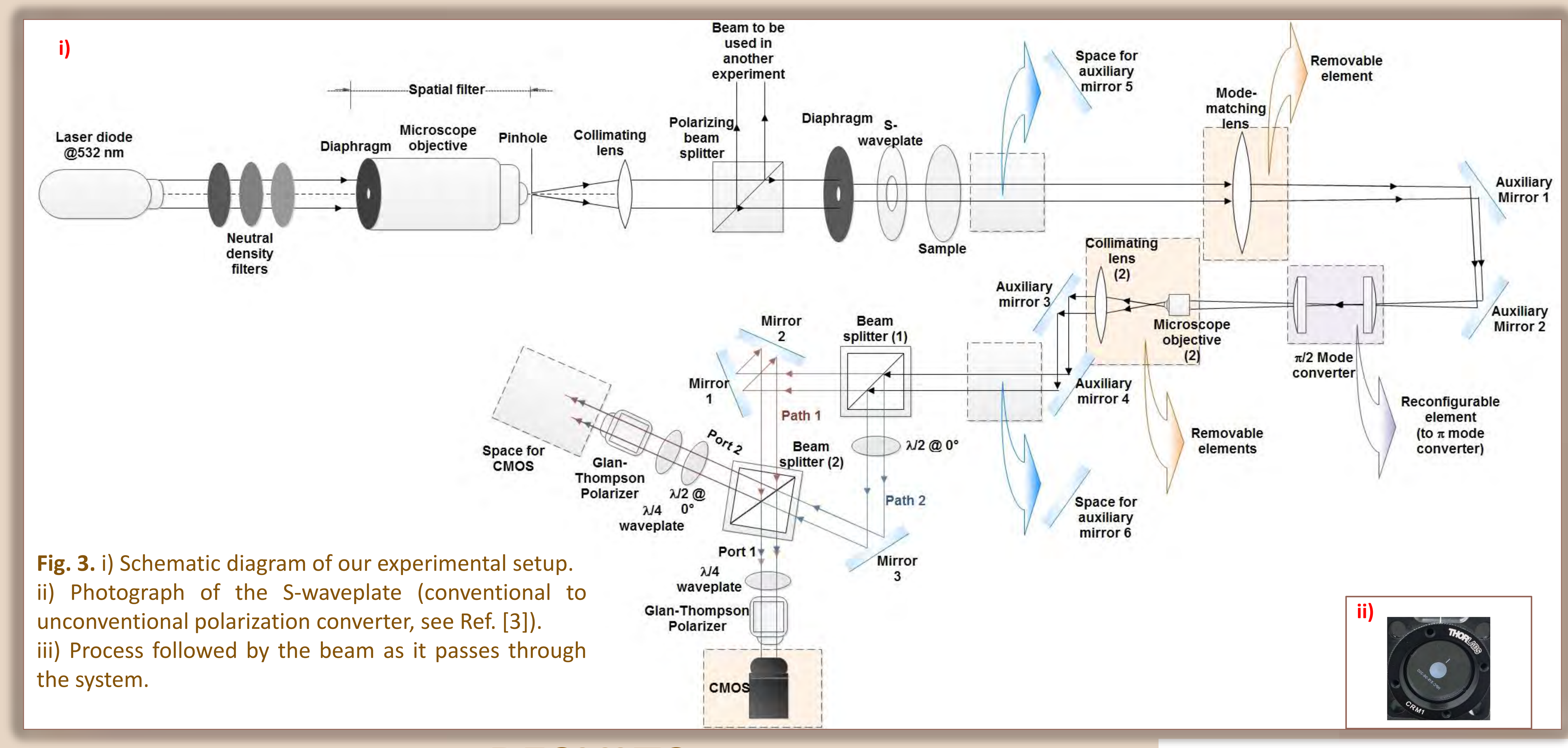
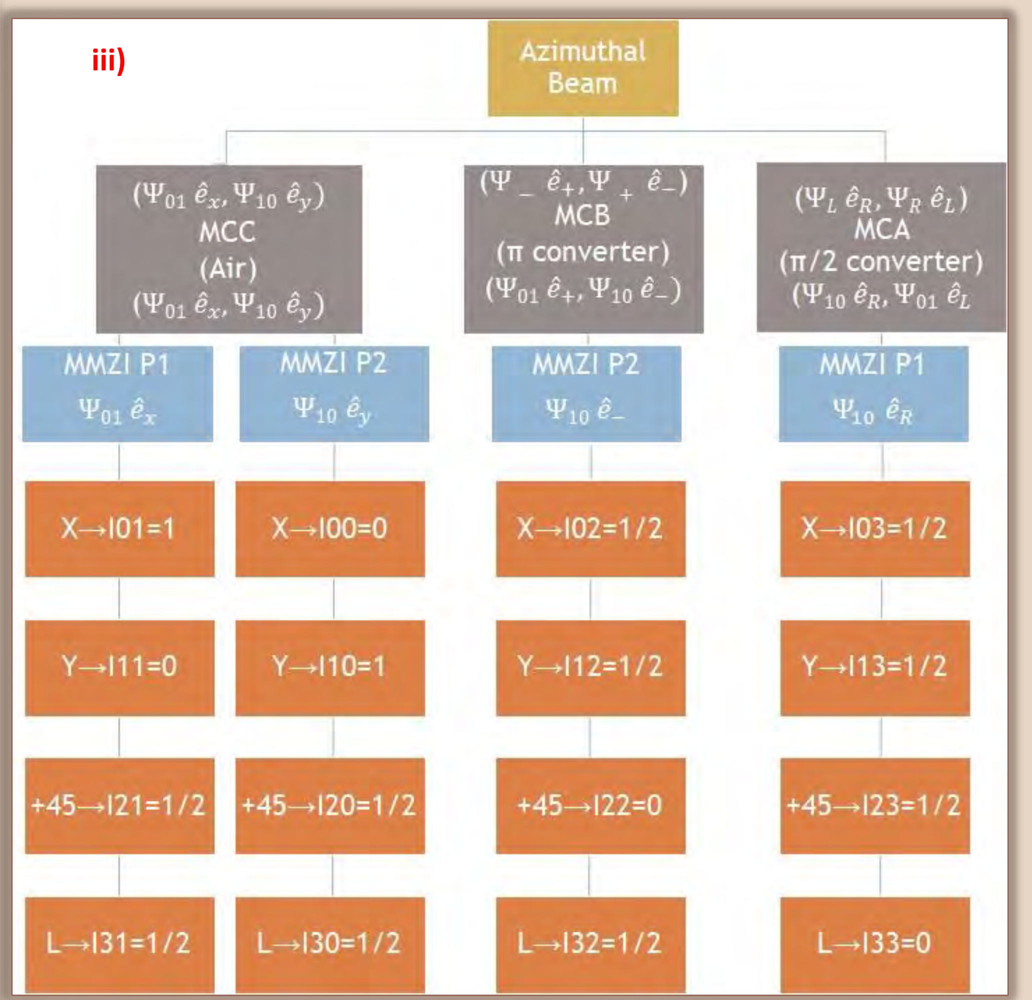


Fig. 3. i) Schematic diagram of our experimental setup. ii) Photograph of the S-waveplate (conventional to unconventional polarization converter, see Ref. [3]). iii) Process followed by the beam as it passes through the system.

OPERATIONAL ALGORITHM



RESULTS

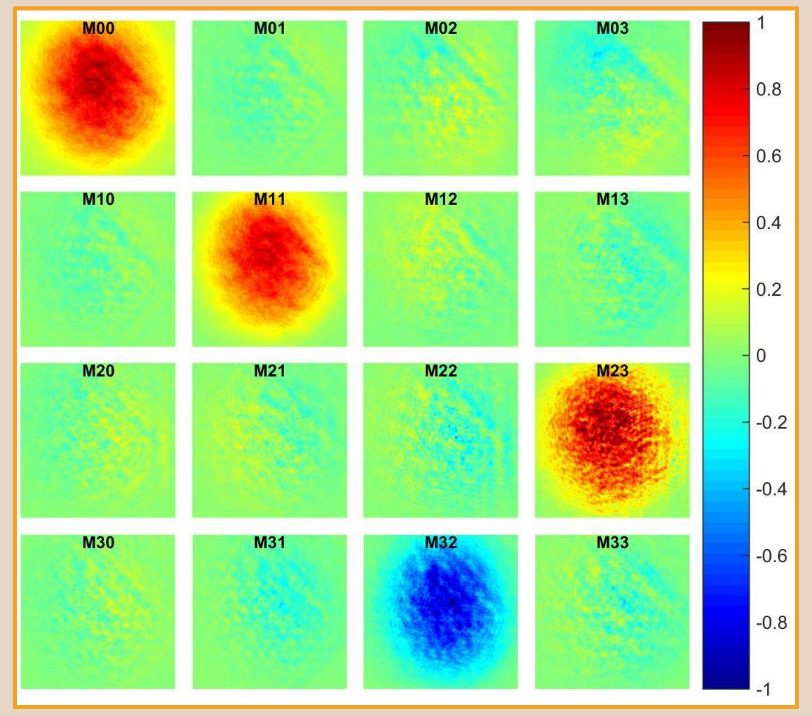


Fig. 4a). Experimental MM for a λ/4 WP, fast axis at 0°, obtained when applying the expressions of Ref. [4] (conventional polarization, IPA method).

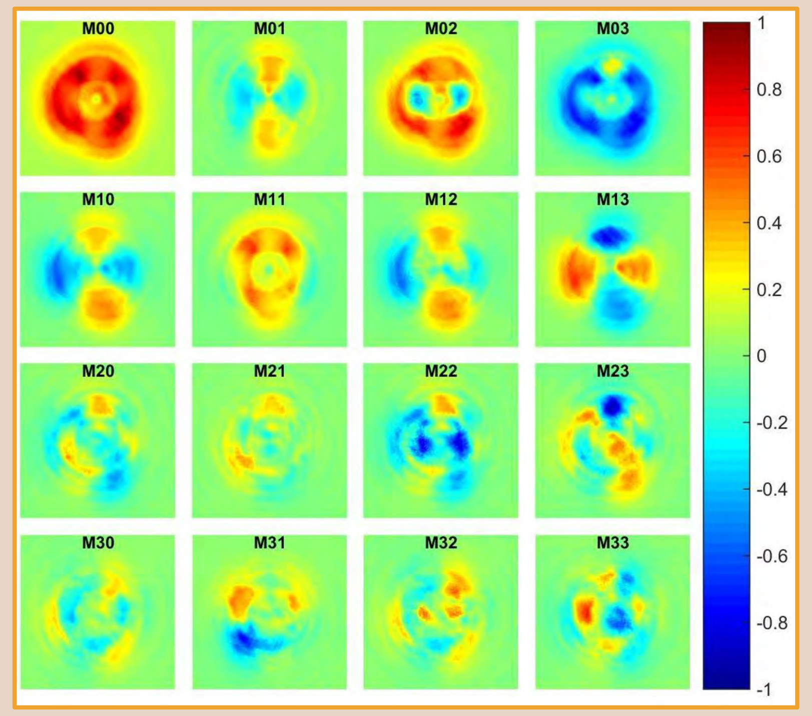


Fig. 4b). Experimental MM for a λ/4 WP, fast axis at 0°, obtained when applying the relationships of Ref. [2] (unconventional/classical entangled polarization).

$$M_{IPA}^{\lambda/4} = \begin{bmatrix} 1.0000 & -0.0477 & 0.0268 & -0.0538 \\ -0.0349 & 0.8218 & 0.0334 & -0.0961 \\ 0.0128 & 0.0114 & -0.0840 & 0.9101 \\ -0.0061 & 0.1317 & -0.8264 & -0.0777 \end{bmatrix} \quad M_{Unc}^{\lambda/4} = \begin{bmatrix} 1.0000 & 0.0861 & 0.5362 & -0.6111 \\ -0.0392 & 0.2967 & 0.0175 & 0.0123 \\ -0.0690 & 0.0893 & -0.2179 & 0.0306 \\ 0.0430 & 0.0186 & 0.0983 & -0.0626 \end{bmatrix}$$

DISCUSSION

1. The MM obtained using conventional polarization shows a concordance with the expected results for the sample under study.
2. Results for classical entangled polarization show that important source of errors arise due to the difference on intensity losses intrinsic to each mode converter (M02 and M03, Fig. 4b, directly affected) and due to the imperfection of the polarizing behavior of the MBS, which causes a normalized intensity considerably lower to the expected value 1 (M23 and M32, Fig. 4b, directly affected). This implies that, in order to achieve high precision values experimentally, it is necessary to have the interferometer exhibiting an almost perfect polarizing and mode beam splitter behaviors, which entirely depend on the phase difference between the arms and the symmetry of the entrance modes.
3. The system is extremely sensitive to any changes and therefore it is suitable for obtaining measurements of high accuracy and also has the potential to be used to obtain the MM of a sample in a single shot once all the modules are assembled at the same time.

CONCLUSIONS

We determined the Mueller matrix of a birefringent, transparent sample using both, conventional (IPA method [4]) and classical entangled polarization (a special case of unconventional polarizations). To the best of our knowledge, this is the first approach for the experimental implementation of the theoretical proposal of Töppel et al. [2], which allows to determine the MM of a sample using only a single incident beam of light. Our work also shows which are the main difficulties to overcome in order to get the complete arrangement working as presented theoretically.

REFERENCES

1. Zhan, Q., **Vectorial Optical Fields, Fundamentals and Application**. World Scientific (2014).
2. Töppel, F., Aiello, A. and Marquardt, C., **Classical entanglement in polarization metrology**. New Journal of Physics, **16**, 073019 (2014). DOI: 10.1088/1367-2630/16/7/073019
3. Altechna. S-waveplate, at http://www.altechna.com/product_details.php?id=1048&product_name=S-waveplate+%28Radial+Polarization+Converter%29.
4. Atondo-Rubio, G., Espinosa-Luna, R. and Mendoza-Suárez, A. **Mueller matrix determination for one dimensional rough surfaces with a reduced number of measurements**. Optics Communications, **244**, 7-13 (2005). DOI: 10.1016/j.optcom.2004.09.027.

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